

# **FCC Week 2016**

Sunday, April 10, 2016 - Friday, April 15, 2016

Italy

## **Book of Abstracts**



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## Opening, study status and physics perspectives / 2

### Welcome

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## Opening, study status and physics perspectives / 3

### Study Status & Parameter Update

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## Status Experiments and Detectors / 4

### FCC-hh Progress on physics and experiment studies

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## Status Machines / 5

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**Opening, study status and physics perspectives / 7**

## **Keynote: FCC and the Physics Landscape**

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**Strategy Roadmaps / 11**

## **CERN roadmap and FCC**

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**Strategy Roadmaps / 12**

## **Italian & INFN activities towards future colliders**

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**Summaries Machines and Technologies / 14**

## **Summary of parallel FCC-hh sessions**

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**Summaries Machines and Technologies / 15**

## **Summary of parallel FCC-ee sessions**

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**Summaries Machines and Technologies / 16**

## **Summary of parallel I&O sessions**

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**Summaries Machines and Technologies / 17**

## **Summary of parallel Magnets sessions**

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**Summaries Machines and Technologies / 18**

## **Summary of parallel RF sessions**

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**Summaries Physics and Experiments / 19**

## **Summary of parallel Physics & Phenomenology sessions**

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**Summaries Physics and Experiments / 20**

## **Summary of parallel FCC-hh Experiments & Detectors sessions**

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**Summaries Physics and Experiments / 21****Summary of parallel FCC-ee Experiments & Detectors sessions**

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**Summaries Physics and Experiments / 22****Closing remarks**

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**Conductor Development: Industry contribution I / 23****Development of Nb<sub>3</sub>Sn conductors in Japan**

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A research program to develop high Jc Nb<sub>3</sub>Sn conductors are started in Japan in corroboration with CERN. The presentation report the research plan as well as the current status of Japanese Nb<sub>3</sub>Sn conductor development.

**Beam Energy Deposition & Machine Protection / 24****Simulations of Hydrodynamic Tunneling of FCC Proton Beam in Solid Cu Target and its Implications on Machine Protection**

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Hydrodynamic tunneling of ultra-relativistic protons and their shower through matter is an extremely important phenomenon for high-energy, high-intensity proton accelerators with significant implication to machine protection [1,2]. Therefore, full hydrodynamic simulations of the impact of one FCC beam on solid targets were performed. We carried out simulations of FCC beam interaction with solid copper target using the energy deposition code, FLUKA and a 2D hydrodynamic code, BIG2, iteratively. Our calculations show that although the range of a single FCC proton and its shower is about 1.5 m in solid copper, the full 8000 FCC bunches and their shower will penetrate up to about 250 m in solid copper due to the hydrodynamic tunneling effect. Moreover, a substantial part of the target including the beam heated region is melted or even evaporated, thus causing irreversible damage to the material and possibly pollution of the accelerator environment and other equipment.

References:

[1] N.A. Tahir et al., Phys. Rev. Special Topics Accel. Beams 15 (2012) 051003.

[2] R. Schmidt et al., Phys. Plasmas 21 (2014) 080701. Hydrodynamic tunneling of ultra

Poster session / 25

## Double Higgs Production with a Jet Substructure Analysis to Probe Large Extra Dimensions

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In this paper, we perform a comprehensive study to probe the effects of large extra dimensions through double Higgs production in proton-proton collisions at the center-of-mass energies of 14, 33, and 100 TeV. We concentrate on the channel in which both Higgs bosons decay into the  $b\bar{b}$  pair and take into account the main background contributions through realistic Monte Carlo simulations. In order to achieve an efficient event reconstruction and a good background rejection, jet substructure techniques are used to efficiently capture the boosted Higgs bosons in the final state. The expected limits on the model parameters are obtained based on the invariant mass and the angular properties of the final state objects. Depending on the number of extra dimensions, bounds up to 6.1, 12.5, and 28.1 TeV are set on the model parameter at proton-proton collisions with the center-of-mass energies of 14, 33, and 100 TeV, respectively. [Phys. Rev. D 92, 073013].

FCC-hh Experiments and Detectors, 2nd session / 26

## Minimum time integration calorimetry

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We present the results of the studies of the electromagnetic and hadronic shower developments with the goal to determine minimum charge integration window to preserve both the energy calibration

and the resolution of a calorimeter. Integration time of only a few ns appears to be enough for the hadronic showers detection and even shorter times are adequate for the electromagnetic showers detection. These results are important for the design of the calorimeters for very high energy and high luminosity colliders as well as for the optimization of the accelerator bunch spacing.

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## Tracking detector for muon systems at very high energy colliders

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Tracking detectors for the muon system at high energy colliders have to fulfill many specifications including high coordinate and time resolutions while keeping reasonable cost for the areas of 1000's of square meters. In the talk we will present major specifications for the muon detectors parameters as well as the results of the studies of the scintillating plastic extruded strips with WLS fibers and SiPMs readout which is an excellent candidate to serve as a muon system tracking detector. Time resolution of such a detector is a fraction of ns and position resolution (along the strip) can reach a few cm reducing complexity of the muon system design, construction and operation.

### Manufacturing & Test Infrastructures / 28

## FCC Synergy's with Industry and the Impact on the Future Superconducting Magnet Technologies

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CERN's Future Circular Collider (FCC) will result in a big push in the state of the art of High-Field Superconducting magnets. The performance of superconducting materials such as Nb3Sn will be developed to yield higher performance at lower costs, construction materials and techniques will be advanced. Industry on the other hand, is experiencing a renewed interest in the field of industrial superconductivity for which FCC should contribute with the development of materials and technologies.

Considering the social impact of the investment that is foreseen as part of the FCC project, a Working Group on Future Superconducting Magnet Technology (FuSuMaTech) was set up by CERN and CEA. The working group will explore the large spectrum of possible synergies with industry, and will propose a set of relevant practical R&D projects to be conducted jointly between the National labs, universities and industry to be implemented before the end of the decade.

FuSuMaTech aims to establish a strong and sustainable R&D set of networks that will strengthen the field of superconductivity and associated industrial applications.

This paper summarizes the first year report, presents initial R&D axis, and the roadmap foreseen to germinate the proposed collaborative developments.

**Injection, Extraction, Transfer Lines / 29**

## Dynamic Aperture studies at Injection

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In the hadron machine option, proposed in the context of the Future Circular Colliders (FCC) study, the dipoles field quality is expected to play an important role, as in the LHC. A preliminary evaluation of the field quality of dipoles, based on the Nb3Sn technology, has been provided by magnets designers. The effect of these field imperfections on the dynamic aperture, using the present lattice design, is presented and first tolerances on the main multipole components are evaluated.

**Technologies R&D: Beam transfer, Magnet & Instrumentation / 30**

## Septum concepts, technologies and prototyping for FCC-hh injection and extraction

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Due to their limitations, existing hardware solutions of the extraction septa will not be sufficient to achieve the required performance for the extraction from the FCC-hh ring. A few concepts will be reviewed and a new solution is proposed to use a passive superconducting shield and persistent eddy currents to create a field-free region within a strong magnetic field. A project to study, design and construct a prototype device in collaboration with Wigner Research Centre for Physics (Budapest) will be presented.

**16T dipole development: EuroCirCol / 31**

## CA program and 20 T design

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IHEP (Beijing, China) is pursuing R&D of high field accelerator magnet technology for recently proposed CEPC-SPPC project, which will need thousands of 20-T level accelerator magnets in 20 years. A long term plan has been made aiming to realize the 20-T magnets in 15 years. The conceptual design study has been ongoing from 2014 based on the current Jc level of superconductors. As both Nb3Sn and HTS superconducting materials are strain-sensitive, the common coil configuration has been chosen as the first option for the design study of the 20-T dipoles, to simplify the coil structure, raise the bending radius and lower the strain level in superconducting coils. The magnetic analysis, mechanical analysis, preliminary design study of the straight section and the coil ends have been completed for a 20-T common coil dipole magnet. The main characteristics and challenges of this design concept and R&D steps will be discussed.

**FCC-hh Beam Dynamics / 33**

## Alignment and Tolerances

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The FCC-hh (Future Hadron-Hadron Circular Collider) is one of the three options considered for the next generation accelerator in high-energy physics as recommended by the European Strategy Group, and the natural evolution of existing LHC. Preliminary studies have started to estimate the design parameters of this option.

One of these studies is the calculation of the residual orbit in the arcs of the collider. This is very important for the evaluation of the alignment tolerances of the quadrupoles used in the arcs, the correctors dimensioning and the electron screening. Moreover it has an impact on the dynamic aperture of the ring and the field tolerances of the arcs multipoles. To perform the simulations, the beam transport code MADX has been used. Systematic studies of the residual orbit and of the correctors strength dependance on the magnets misalignment are presented, and different correction schemes are compared.

**FCC-hh Experiments and Detectors, 2nd session / 34**

## Simulation of a high-granular hadronic calorimeter for multi-TeV physics

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The emerging technology of high-granularity calorimeters help advance the identification and reconstruction of highly-boosted particles at the TeV scale, such as tau leptons, top quarks, Higgs and W/Z bosons. The performance of high-granularity calorimetry can be studied using fast and full detector simulations. This talk describes a software setup to perform such simulations, as well as preliminary physics performance results on reconstruction of boosted W bosons and tau leptons at the TeV-scale using a full GEANT4 detector simulation.

**Technologies R&D / 35**

## Simulation of the Evolution of the Residual Gas Particle Density – an Analytical Approach

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Ultrahigh vacuum is a basic requirement for the Future Circular Colliders (FCC). The size of the vacuum chambers and the high energy of the circulating particles will make this requirement challenging. Simulations that predict the pressure distribution due to thermal outgassing as well as beam induced effects will allow to evaluate different designs and to choose an optimal pumping solution.

The mathematical model behind the simulations will be presented. Four coupled differential equations describe the mass conservation of the residual gas particles in the beam pipe. The model includes both distributed and local pumping, and take into account gas sources generated by synchrotron radiation, electron and ion-induced desorption.

The equation system is solved by an analytical method. This requires a transformation to first order equations for which a general valid solution exists. Adding a particular solution and the inclusion of appropriate boundary conditions define the solution function. The big advantage here is that an analytical simulation delivers fast results over large systems.

The model has been implemented in a Python environment. It has been cross checked with VASCO [1] and MolFlow [2]. Data obtained from the Large Hadron Collider's (LHC) pressure gauges were successfully compared to the simulation outputs. These encouraging results give trust to produce accurate vacuum forecasts for the FCC.

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[1] Rossi A.; VASCO (VACuum Stability Code); Multi-gas Code to Calculate Gas Density Profile in UHV System. Geneva: CERN; 2004. LHC-Project-Note-341.

[2] Kersevan R., Ady M.; MolFlow - A test-particle Monte-Carlo simulator for ultra-high-vacuum systems. Geneva: CERN; 2009. <https://test-molflow.web.cern.ch/>

**Injection, Extraction, Transfer Lines / 36**

## Hadron Injectors, injection and TLs

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There are several candidates for the injector for FCC-hh. A modified LHC with a faster ramp is the baseline, but High Energy Boosters in the SPS or FCC tunnel are also under consideration. The

present state of the machine designs will be presented for each case and their respective merits and difficulties will be discussed. Main magnet technology and feasibility, collective effects, power consumption, filling times and transfer will be among the figures discussed.

#### Poster session / 37

### Prospects for laser triggering of large arrays of semiconductor switches

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In pulsed power technology, high voltage triggering circuits are one of the most critical components that will determine the global performance of a system. In the systems of the future, the role of trigger systems are even more critical as they trigger more components and produce the shaped-pulses by independent timing of individual switches or switch groups.

The prospect was aimed at determining whether high power lasers could command semiconductor switches arrays in high-power accelerator systems such as Future Circular Collider (FCC) beam dump. Among the traditional triggering techniques like passive, active and optical there is none that satisfies entirely the request.

The state of the art in pulse power lasers will by needed, we need to understand what laser capabilities are currently available, what capabilities are desired for the future, and what R&D activities are needed to bridge the gap. In the near future, we want construct a pulse-power facility to allow us to test laser triggering of a new high voltage semiconductor device for high power electronics applications.

#### Italian contributions / 38

### Toward an Italian HFM/Technology program for FCC

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#### Italian contributions / 39

### Italian view on HEP beyond LHC

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#### Italian contributions / 40

### The socio-economic impact of large-scale science projects



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FCC-ee Optics / 41

## Arc optics, global Q' correction and emittance variation

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Layout and lattice of FCC-ee are being optimised for precision studies and rare decay event observations in the range of 90 to 350 GeV center of mass energy. To reach luminosities in the order of  $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  extremely small vertical beta functions of 1 - 2 mm are required at the two interaction points. The strong focusing by the final doublet quadrupoles drives the absolute value of the chromaticity to more than 2000 units, which is far beyond the values that have been achieved in previous storage rings. As a consequence a pure linear chromaticity compensation scheme will not be sufficient to obtain the required  $\pm 2\%$  energy acceptance. A state of the art multi-family sextupole scheme in the arcs will have to be combined with a local chromaticity correction scheme.

This talk will present last year's results of systematic studies of the sextupole scheme in the arcs and the status of the arc lattice, optimised for highest momentum acceptance, that will be combined to the local sextupole scheme in order to gain highest chromaticity performance.

Poster session / 43

## Tapering options for the FCC-ee collider

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FCC-ee is being optimised for operation at four different collision energies in the range of 90 GeV to 350 GeV. At these high energies, vast synchrotron radiation losses cause orbit offsets, creating the so-called sawtooth effect and optics distortions due to focusing errors.

In order to achieve the foreseen beam emittances, strong constraints are inflicted onto the design of the arc lattice as well as the beam orbit and high beam stability and performance are needed. To ensure a high level of stability, there is the idea of adjusting dipole magnets to the local beam energy, effectively suppressing the sawtooth-effect and decreasing orbit distortions by two orders of magnitude. This process is called dipole tapering. It can be shown, that the residual optics distortion in the form of beta- and dispersion beat, which before tapering is hardly manageable, after dipole tapering can easily be corrected solely by rematching the quadrupoles in the dispersion suppressors and matching sections.

The talk will present different dipole magnet tapering scenarios and compare them in terms of effectiveness, feasibility and cost.

**FCC-hh Collimation System / 44****Simulation of the FCC-hh collimation system**

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The current status of the FCC-hh beam halo cleaning system will be presented. Simulations of the collimation system have been performed with the codes Sixtrack and Merlin for collision energy (50 TeV). The relative performance of different collimation system designs will be shown. Critical loss locations will be identified and suggestions for appropriate design changes will be given.

**FCC-ee Lattice corrections & performance / 45****Tolerance studies and coupling correction for FCC-ee**

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The FCC-ee project is foreseen for precision studies and rare decay observations in the range of 90 to 350 GeV center of mass energy with luminosities in the order of  $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ . In order to reach such performances, an extreme focusing of the beam is required in the interaction regions with a low vertical beta function of 2mm at the IP. Moreover, the FCC-ee physics program requires also very low emittance never achieved in a collider with 2nm for  $\text{eps}_x$  and 2pm for  $\text{eps}_y$ , bringing down the coupling ratio to 1/1000. With such requirements, any field errors and source of coupling introduce spurious vertical dispersion which degrades the emittances, limiting the luminosity of the machine. This study aims to describe the tolerance of the emittances to the misalignments of the magnets and how beam position monitor reading errors will affect the vertical emittance. In order to preserve the FCC-ee performances, in particular  $\text{eps}_y$ , a challenging correction scheme is proposed to keep the coupling and the vertical emittance as low as possible.

**FCC-hh Machine Detector Interface / 46****Beta\* reach studies**

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The current design of the FCC-hh detector features a forward spectrometer with an integrated magnetic field of 10 Tm. The effect of this dipole field on the beam requires compensation via strong

orbit correctors and has implications for the geometry, performance and radiation protection of the Interaction Region (IR). In the talk, aspects of the Machine-Detector Interface, the consequences for the IR design and radiation studies will be presented.

**FCC-ee Single-beam collective effects / 47**

## **Beam Heating due to Coherent Synchrotron Radiation**

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We discuss the fine structure of the field dynamics of coherent synchrotron radiation (CSR). The details of the time-domain field distributions have been investigated using a recently developed method for the numerical solution of Maxwell's equations for a very short bunch moving in a magnetic field. We have discovered a transverse variation of the particle energy loss in a bunch due to CSR fields. It explains the slice emittance growth in bending magnets of the bunch compressors and transverse decoherence in undulators. This effect could be very important for the future ultra-short high power FEL designs. It can also play the same role as the effect of quantum fluctuations of synchrotron radiation in damping rings. It can limit the minimum achievable emittance in the synchrotron light sources for short bunches.

**16T dipole development: Protection / 49**

## **Development of 60-mm aperture Nb3Sn dipole demonstrator for FCC at Fermilab**

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A 100 TeV scale Hadron Collider (HC) with a nominal operation field of 16 T is being considered for the post-LHC era, which requires using the Nb3Sn technology. Practical demonstration of this field level in an accelerator-quality magnet and substantial reduction of the magnet costs are important requirements for realization of such a machine. Fermilab has started the development of a 15-T-class Nb3Sn dipole demonstrator for a Future Circular Collider (FCC). The magnet design is based on optimized 60-mm aperture 4-layer shell-type coils, graded between the inner and outer layers to maximize the performance and reduce the cost. This paper describes magnetic and structural designs and parameters of the 15 T Nb3Sn dipole demonstrator. Coil magnetization and iron saturation effects as well as magnet quench protection are presented. Magnet cost reduction strategy is also discussed.

**Poster session / 50**

## **Strand and Cable Development for 16 T Magnets for FCC**

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A 100 TeV center of mass energy machine in a 100 km tunnel requires dipoles with a nominal operation field of 15-16 T and appropriate operation margins, which can presently be obtained only with the Nb<sub>3</sub>Sn technology. A practical demonstration of this field in accelerator-quality magnets and reduction of magnet costs are key conditions for the realization of such a machine. A decade-long investment in the Nb<sub>3</sub>Sn technology produced at FNAL the first series of 10 to 12 T accelerator-quality dipoles and quadrupoles, as well as their scale-up. Such advanced technology can now be pushed up to its limits by improving Nb<sub>3</sub>Sn strands and cables, and developing innovative design approaches. For cost-effective 15 T accelerator magnets, the critical current density  $J_c(15T,4.2K)$  of commercial Nb<sub>3</sub>Sn composite wires has to be pushed to  $\sim 2000$  A/mm<sup>2</sup>. In addition, wider cables are required to reduce the number of coil layers and decrease the number of turns. FNAL has started the development of a 15-16 T Nb<sub>3</sub>Sn dipole demonstrator for a 100 TeV scale HC based on the optimized "cos-theta" coil. A 4-layer graded coil design is foreseen to achieve the necessary coil width. The cable in the two innermost layers has 28 strands 1.0 mm in diameter and the cable in the two outermost layers has 40 strands 0.7 mm in diameter, same nominal width of 14.7 mm and keystone angle of 0.79 degree, and both use state-of-the-art RRP® wires. This presentation summarizes the results obtained in the strand and cable studies, and shows how an innovative Nb<sub>3</sub>Sn thin film technique under US patent application could help to test flux pinning properties of additional elements in Nb<sub>3</sub>Sn inexpensively and with fast turnaround before implementation in actual billets.

**Poster session / 51**

## On the Physical Readability of Beam Fields in a Realistic (Finite Thickness and Conductivity) Beam Pipe

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Readable asymptotic forms of the Electromagnetic Fields produced by a bunched beam in a realistic pipe are described and the applicability to actual machines is discussed.

**Poster session / 52**

## HTS solutions for FCC magnets and power infrastructure

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The SuperOx group of companies is a supplier of customised 2G HTS wire. At present, the wire is manufactured jointly by SuperOx in Moscow and SuperOx Japan LLC in Tokyo.

Ultimately, independent full production cycles will be established at both locations.

SuperOx 2G HTS wire has successfully qualified for high current operation at 4.2 K in 20 T magnetic

field, as targeted by CERN's magnet development programme. An internal R&D effort is under way at SuperOx, to improve further in-field performance of the wire.

Going beyond the material production, SuperOx has been integrating 2G HTS wire into HTS devices. Particularly relevant to the FCC magnets and power infrastructure safety and efficiency are our HTS cable and fault current limiter development activities.

We have established production capabilities for HTS Roebel cables, the conductors of choice to wind HTS inserts into 21 T dipole magnets. We have implemented the advanced "Punch-and-Coat" approach to making Roebel cables, resulting in much more mechanically stable cables than the conventional HTS Roebel cables. In the novel approach, Roebel cable strands are punched from silver-coated 2G HTS wire and subsequently electroplated with a surround copper stabilising layer. As a result, the wire architecture, along the entire strand, is fully encased in copper and is thus protected from delamination. The copper coating, added after punching, smoothens the punching burr on the substrate, making it no hazard for the adjacent strands.

In consortium with Russian Cable R&D Institute (VNIIEP), an ITER supplier, SuperOx is bidding to supply both the 2G HTS and MgB<sub>2</sub> sections of the superconducting link cables for the LHC upgrade. Similar cables are seen as an important part of the FCC energy infrastructure.

SuperOx has been developing and marketing low-, medium- and high-voltage superconducting fault current limiters, and is offering these to contribute to the energy efficiency and safety of FCC.

## FCC-hh Experiments and Detectors, 3rd session / 53

### Study of hh production in the WWbb channel at the FCC-hh

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With the Higgs boson discovery all particles expected from the Standard Model of Particle Physics have been found. From now on the main target of the field is to look for signatures of new physics. The Higgs field potential sector is up to now unexplored and predicts the presence of a self-interaction coupling among Higgs bosons.

Being almost unconstrained from the present precision observables, it is one of the best place to look for beyond standard model contribution.

The Higgs self-coupling measurement is extremely challenging: even the High Luminosity - LHC could be not enough to produce a good estimate of its magnitude.

It is therefore the main duty of future projects, like FCC, to determine their potentiality to its measurement.

The Higgs self-coupling can be extracted from the double Higgs production cross section measurement.

The two Higgs bosons can decay in a multitude of final states, in this study we show the sensitivity to the Higgs self-coupling measurement that can be reached at a future pp collider at 100 TeV, using the  $hh \rightarrow W(-\rightarrow l\nu) W(-\rightarrow jj) + b\bar{b}$  decay channel.

Efficient b-jets tagging and good jets and Missing Transverse Energy (MET) resolution are crucial ingredients to discriminate the signal from the main background from top pair production. In this study we will show the effect of different detector parameters affecting jet and MET reconstruction at different pile-up conditions, providing a preliminary detector optimization.

**Status Machines / 54**

## **Infrastructure & Operation overview**

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**Status Technologies and Infrastructure / 56**

## **Special Technologies Overview**

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**Status Experiments and Detectors / 57**

## **Design study for experiment magnets**

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**Strategy Roadmaps / 58**

## **ACFA view and Asian activities on future colliders**

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**Status Machines / 59**

## **Civil engineering**

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**16T dipole development: Overview / 75**

## **Preliminary design of a 16T $\cos\theta$ dipole for the Future Circular Collider**

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After LHC will be turned off, a new machine will be needed in order to explore unknown high-energy physics regions. For this reason, the project FCC (Future Circular Collider) has started, with the target of studying the feasibility of a very large hadron collider with 50 TeV proton beams in a 100 km circumference.

The EuroCirCol project is part of the FCC study under European Community leadership. It has the goal of developing a conceptual design of the FCC within 2019. One of the main targets is designing the superconducting main dipole needed for the collider, able to reach 16 T in order to bend the beams, complying with tight dimensional and operational constraints and requirements. This magnetic field can be achieved using Nb<sub>3</sub>Sn conductors at their highest performances.

The Milan and Genova INFN groups are responsible to explore the  $\cos\theta$  dipole configuration and here we present the preliminary conceptual designs. The configurations presented here have been designed in order to have 10 % margin on the load-line at 4.2 K, taking care of using less conductor as possible. Field quality, quench protection and mechanical properties have been studied in order to ensure the feasibility of the designs.

**Conductor Development II / 76**

## **Increasing the High-Field Performance of Nb<sub>3</sub>Sn Wires by Pinning Landscape Modification**

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While Nb<sub>3</sub>Sn is certainly a very promising candidate for the superconductor to be used in the FCC's magnet system, the highly demanding performance requirements of the project call for significant advances in the fabrication of this material. In particular, relative to currently available Nb<sub>3</sub>Sn wires an increase of the critical current density  $J_c$  by roughly 50% in a background field of 16 T will be required.

We present data obtained from the hitherto most extensive neutron irradiation study on Nb<sub>3</sub>Sn wires. Samples of five state-of-the-art industrial wires were subjected to sequential irradiation up to a fast neutron fluence of more than  $3 \cdot 10^{22} \text{ m}^{-2}$ . Changes in the superconducting parameters caused by the irradiation were assessed by means of SQUID magnetometry in a wide temperature range after each irradiation step. By means of pinning force analyses we were able to show that fast neutron irradiation leads to the introduction of material defects which act as point-like pinning centers. This pinning landscape modification significantly changes both the magnitude and the functional dependence of the volume pinning force, leading to a large  $J_c$  enhancement at high magnetic fields.

These results fuel our hopes that the ambitious  $J_c$  requirements for the FCC magnets can be met by designing a new generation of Nb<sub>3</sub>Sn wires with an improved pinning landscape. This may be accomplished for instance by introducing normal-conducting nano-particles whose size should be approximately equal to that of the irradiation induced defects.

**FCC-hh Experiments and Detectors, 1st session / 77**

## Detector radiation studies

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In view of a new 100 km long hadron collider, which is expected to operate at a centre-of-mass energy of 100 TeV and to accumulate up to  $30 \text{ ab}^{-1}$ , with a peak instantaneous luminosity up to  $30 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ , the evaluation of the radiation load on the detector is a key ingredient for the choice of materials and technologies.

The first concept of the detector foresees the presence of central and forward sub-detectors to study physics up to  $|\eta|=6$  and of a magnetic field generated by the combination of a central solenoid and a forward dipole. This layout has been modelled and relevant fluence distributions have been calculated using the FLUKA Monte Carlo code.

In this contribution the detector model will be first discussed. Distributions of fluence rates will be then shown separately for different type of particles, like charged particles, charged hadrons, neutrons and photons. Dose distributions and 1 MeV neutron equivalent fluence, for the accumulated integrated luminosity, will be presented. The peak values of these quantities in the different sub-detectors will be highlighted, in order to allow to compare them to the limit of the material and technologies presently used in the LHC detectors. The effect of the magnetic field will be discussed.

Based on the first results obtained, a shielding has been conceived to minimise the background in the muon chambers, due to particles coming from the forward part of the detector. Its tentative design will be shown and its effectiveness will be discussed in term of neutron, photon and charged particles fluence rate reduction.

**16T dipole development: Protection / 78**



## Analysis of the requirements for the quench protection in the 16 T Nb<sub>3</sub>Sn dipole designs

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The EuroCirCol collaboration is designing a 16 T Nb<sub>3</sub>Sn dipole that can be used as the main bending magnet in a 100 km long 100 TeV hadron collider. For economic reasons, the magnets need to be as compact as possible, requiring optimization of the cable cross section in different magnetic field regions. This leads to very high stored energy density in the coil and poses serious challenges for the magnet protection in case of a quench, i.e., sudden loss of superconductivity in the winding. The magnet design therefore must account for the limitations set by quench protection from the earliest stages of the design.

In this paper we describe how the aspect of quench protection has been accounted in the process of developing different options for the 16 T dipole designs. We discuss how the various magnet design parameters were analyzed, their impact to the estimated maximum temperature after a quench, as well as the assumptions for the efficiency of possible quench protection systems. Finally we summarize the requirements that the quench protection system must have in order to reliably protect the designed magnets.

**Common Detector Technologies / 80**

## Multi-Gigabit Wireless Data Transmission

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Wireless techniques have developed extremely fast the last decade, and using them in particle physics detectors for data transfer is not science fiction any more.

Tremendous advances in silicon technologies have made possible to build high performance transceivers operating in the mm band, where the 57-66 GHz band is situated. The use in the HEP environment has been triggered by the high data transfer rate that can be achieved in this license free 9 GHz band and its unique energy propagation characteristic.

It has a free space loss of 68 dB over 1m, a high penetration loss, measured to be about -50dB for a fully equipped SCT (ATLAS) detector module, and an oxygen absorption of about 15 dB/Km. The last effect is of less importance in this case, since a typical data transmission distance in HEP detectors is from a few cm to about a few meters where attenuation of about 0.1 dB are expected. Operating at 60 GHz frequency results in a more focused antenna with a narrower beam width for a fixed antenna size, that minimizes the possibility of interference and the risk that the transmission can be intercepted. Also the use of high carrier frequency provides low form factor, which will reduce the material budget. These features, the high path loss, high material penetration loss, narrow beamwidth, Line-Of-Sight (LOS), and operation in a controlled environment, makes the 60 GHz band optimal for short range operation. This provides an extremely desirable frequency-reuse that can handle a large number of transceivers in a small area as in the HEP detectors and other detector facilities. Also, the fact that we can provide higher data transfer by using higher frequencies to transmit the data, makes this spectrum feasible as replacement or supplement to fiber optics.

In this talk I will present the latest developments of the 60 GHz transceiver at University of Heidelberg as well as the development at CEA Leti, and antenna development at University of Uppsala.

**Safety, Availability, Controls / 81**

## Controls architecture challenges for beam dump kickers

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The FCC Beam Dump architecture will be a configuration with a high amount of kicker magnets, even though a final FCC Beam Dump architecture has not yet been decided upon. One of the concepts being studied is the use of 300 kicker magnets to safely extract and dilute the beam onto an external absorber block. Independently of the exact extraction scheme and geometry, it is already clear that the existing kicker controls architecture used at CERN has to be revised in order to cover the FCC's challenging technical and operational requirements.

Based on a proposed magnetic field rise-time of around 1  $\mu$ s and on the prerequisite that a spontaneous firing of one generator should not result in immediate beam loss, the extraction kicker design has yielded to a magnet length of around 35 cm which needs to be pulsed with 7kA. The stringent field rise time and magnet impedance parameters will constrain the length of the transmission line and this will possibly entail a higher radiation dose for the power pulse generator and its control electronics. Additionally the short magnet length and the need to fit all magnets in a 120 m long straight section requires more compact and integrated solutions. Full redundancy, high availability and maintainability will be critical parameters because of the limited accessibility to the equipment during operation. Controls architectures taking into account the main challenges, being triggering, retriggering, integration, reliability and availability, will be discussed in this paper.

**Technologies R&D: Beam transfer, Magnet & Instrumentation / 82**

## FCC-hh injection and extraction kicker topologies and solid state generators

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One of the major challenges for the FCC proton collider will be reliable and safe beam transfer. This contribution outlines recent progress on the conceptual design of the injection and extraction kicker systems. For injection the preliminary system requirements and a novel idea to employ a solid state pulse generator, based on the inductive adder principle, will be presented together with first considerations for the kicker magnets.

The conceptual design for the beam dump system includes kickers for both extraction and beam dilution, for each beam: these systems must reliably abort proton beams with stored energies in the range of 8 Gigajoule. The preliminary kicker system requirements will be presented together with first concepts for the extraction kicker magnets and generators as well as for the dilution kicker system. Their feasibility for an abort gap in the 1  $\mu$ s range is discussed and the advantages and challenges for a highly segmented extraction system are outlined.

### 16T dipole development: Protection / 83

## Comparison of magnet designs from a circuit protection point of view

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Several designs for the 16 T main dipole magnets are currently under study for the FCC, which can be classified in three categories: cosine-theta, block coils, and common coils designs. Presently, the performance of these different designs is evaluated considering technical features related to single magnets, e.g. margin on the load line, coil windability, quench protection requirements, etc. However, as for the LHC, these magnets have to be powered in long strings, resulting in large stored energy in the circuit and large voltages during a fast power abort.

Safe powering such a long string of high-field high-current dipole magnets, and especially discharging the magnet energy in case of a quench or equipment failure, is very challenging. Sophisticated and highly reliable detection and protection systems are therefore required. Magnet designs with different operating currents and inductances may have a large impact on the required circuit configuration, protection, and cost. It is therefore important to ensure, right from the design phase, that magnets emerging from different design options can be properly powered and protected once being part of a string of magnets.

In this paper, we present the advantages and disadvantages of the different design options with respect to the main circuit characteristics, such as ramp time, voltage to ground during powering and discharge, and the required voltage and power of the power converter. We focus as well on the voltage oscillations during a fast power abort, which can cause false triggers of the quench detection system. The outcome of this study could be included in the performance evaluation phase for a fair comparison among the different magnet designs.

**Poster session / 85****Preliminary quench protection analysis for the FCC 16 T dipole magnets****Author:** Marco Prioli<sup>1</sup>**Co-authors:** Antti Aleksis Stenvall<sup>1</sup>; Arjan Verweij<sup>1</sup>; Bernhard Auchmann<sup>1</sup>; Lorenzo Bortot<sup>1</sup>; Michal Maciejewski<sup>2</sup>; Tiina Salmi<sup>3</sup><sup>1</sup> CERN<sup>2</sup> Technical University of Lodz(PL)<sup>3</sup> Tampere University of Technology, Finland**Corresponding Author:** marco.prioli@cern.ch

High-field, high-current superconducting dipole magnets are currently under study for the FCC project. Within the EuroCirCol collaboration, many efforts are dedicated to the optimization of the design of the 16 T dipole magnets. In general terms, cost-efficiency and, hence, compactness, are key criteria in the design optimization. This means that an optimal design is characterized by a low copper-to-superconductor ratio of the cables and a high energy density in the coils. Both these aspects represent potential criticalities from a magnet protection point of view, since they always imply higher hot-spot temperatures in case of quenches. In order to keep the hot spot temperatures lower than a safe limit, detection times and current decay times have to be minimized. This requires that a large fraction of the coil volume must be made to quench within milliseconds after the detection of the resistive transition.

In this paper, we present the hot spot temperatures and thermal gradients during a quench event for two different available quench protection technologies. The first technology is based on traditional quench heaters and the second one on the Coupling-Loss Induced Quench (CLIQ) system, a new technology developed at CERN that relies on inter-filament and inter-strand coupling currents to quickly spread the normal zone after a quench. Finally, also a hybrid scenario is discussed in which a combination of heaters and CLIQ is used to protect the magnet. A recently developed multiphysics simulation setting is used to accurately simulate the different physical phenomena involved in a quench event.

**Other Magnets / 86****Design studies for a fast ramped high field superconducting septa****Author:** Egbert Fischer<sup>1</sup>**Co-authors:** Kei SUGITA<sup>1</sup>; Pierre Schnizer<sup>1</sup><sup>1</sup> GSI Darmstadt**Corresponding Author:** e.fischer@gsi.de

The conceptual design for the SIS300 extraction septum magnet of the FAIR project was used as start point to further the development to significant higher fields. The curved, truncated cos theta septa uses an iron yoke mirror and induces 3.65 T over the effective length of 4 m. This design can be adapted up to 10 T using conventional low temperature superconductors. We present feasibility studies for a 5 T septum magnet with a single layer coil as well as for a 9.5 T double layer coil version based on the results of 2D magnetic field optimisations for both septa.

**FCC-hh Machine Detector Interface / 87**

## Developments on IR baseline design

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Previously, optics design studies were conducted for the interaction region for FCC-hh with an L of 36m and 61m. In the continuation of exploring possible lengths of the L, we will present the status of a new study with L\*=45m.

**FCC-hh Beam dump concept / 89**

## Dump system concepts, dilution and comparison of options

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The FCC-hh beam dump system must provide a safe and reliable extraction and dilution of the beam when being sent on the dump absorber. Energy deposition studies show that damage limits of presently used absorbers are already approached for single bunches at 50 TeV. A fast field rise of the extraction kicker is required in order to separate swept single bunches far enough on the extraction absorbers in case of an asynchronous beam dump. In line with this demand is the proposal of a highly segmented extraction kicker system. This could allow for the possibility of accepting a single kicker switch erratic and thus significantly reduce the probability of an asynchronous beam dump. In order to dump a full train of about 10000 bunches, in the dump line a dilution kicker system with varying frequency is proposed. Over-focussing quadrupoles are studied in order to reduce the aperture and strength requirements on the dilution kicker system.

**Poster session / 90**

## Beam dump for the FCC-ee collider

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The conceptual design of a beam dump for the future electron positron linear collider is presented. The critical components of the beam dump are the absorbers. We have investigated several materials for the absorbers taking into account the properties of thermal conductivity, melting temperature etc. Monte Carlo simulations were done to find the optimal absorber and its dimensions.

**FCC-hh Beam dump concept / 91**

## Absorbers for beam dumping

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The FCC proton beams pose a severe challenge for the robustness of the beam dump and protection devices. Depending on the local  $\beta$ -function, already a single 50 TeV bunch can induce damage in typical absorber materials presently used at the LHC (e.g. Graphite or carbon composites). In order to safely absorb the FCC beams in a LHC-like dump, the beams need to be sufficiently diluted across the dump front face. In this study, we assess dilution kicker requirements and derive energy densities and temperatures in the dump core for different dilution patterns; in particular, we quantify the effect of overlapping shower tails from neighbouring bunches and neighbouring branches in the sweep pattern. In addition, we present first considerations on the energy deposition in protection devices in case of an asynchronous beam dump.

### FCC-hh Machine Detector Interface / 92

## Collision debris

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The FCC-hh experimental insertion design poses as a major challenge the impact of the proton-proton collision debris on the final focus quadrupoles. Both instantaneous power load and accumulated dose have to be reliably quantified and brought down to an acceptable level through suitable mitigation strategies, in order to allow accelerator operation according to the desired luminosity goals.

Based on the LHC and HL-LHC design experience, dedicated energy deposition studies have been carried forward in an iterative process exploring various optics solutions. In particular, a promising crossing angle gymnastics has been evaluated and the effect of the detector spectrometer has been investigated.

### FCC-hh Collimation System / 93

## Collimation System Optics

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The very high stored energy in FCC-hh beams is a source of concern for machine protection when even small fraction of the beam could represent a potential danger in case of losses. In order to ensure machine protection by beam cleaning for both betatronic and synchrotronic movements, collimation sections are inserted in FCC-hh lattice. Optics of these sections, designed and optimised for FCC-hh, are presented here. Lattice sequences, including collimators layout have been optimised for both betatron and momentum collimation, according to different options under study for Long Straight Sections layout.

**FCC-hh Beam dump concept / 94**

## Surviving an asynchronous beam dump

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A single FCC proton bunch at 50 TeV carries almost 1 MJ of energy, with a transverse beam sigma of typically 0.1 mm. The transverse energy density is around a factor 20 above the HL-LHC design values, which themselves already pose a serious engineering and beam physics challenge when designing protection systems to prevent damage to the accelerator in the event of an asynchronous firing of the LHC beam dump kickers. In this paper the specific challenges are explored for designing the FCC-hh beam dump system to enable an asynchronous beam dump to be survived. Possible approaches are outlined and the most interesting new directions for study and simulation are discussed in the context of the required performance aspects.

**Poster session / 95**

## Doubly charged Higgs bosons at the FCC-hh

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Discovery of the Higgs particle at the LHC confirmed the mechanism of mass generation in the Standard Model. But that still does not eliminate the possibility of existence of models with extended scalar sectors. Those models can be constructed just by introduction of additional scalar multiplets, with or without extension of the gauge group. Among the non-standard Higgs particles could appear also doubly charged scalars. This kind of particles couples to leptons and can contribute to the processes violating the lepton number. The possibility of observation of these scalars is considered in context of Left-Right Symmetric Models which contain additional scalar triplets.

**Physics/Pheno / 96**

## Characteristic signals of right-handed currents at future colliders

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The perspectives on the detection of right-handed currents at future experiments will be discussed. We shall focus on processes with 2 or 4 leptons and jets in the final state. Such processes are expected to give important insight into the structure of couplings of heavy gauge bosons to leptons, including heavy neutrinos, and into the Higgs sector of the BSM model under consideration. We show how important for the experimental signal analysis is to carefully take into account interference effects. We also estimate the background for the discussed processes and confront presented setups with low-energy constraints.

**Material, cavities and cryomodules R&D / 97**

## **Innovative Nb<sub>3</sub>Sn Thin Film Approaches and their Potential for Research and Applications**

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Two different electro-chemical deposition techniques, both under US Patent Application No. 62/190,199, to produce Nb<sub>3</sub>Sn coatings have been studied in the last few years by FNAL in collaboration with Politecnico di Milano.

In the first technique, the Nb<sub>3</sub>Sn phase is obtained by electrodeposition from aqueous solutions of Sn layers and Cu intermediate layers onto Nb substrates followed by high temperature diffusion in inert atmosphere. Subsequent thermal treatments are realized at 700°C to obtain the Nb<sub>3</sub>Sn superconducting phase. The thickness of the Nb<sub>3</sub>Sn phase was between 5.7 and 8.0 μm for the different types of samples. All samples showed superconducting transport behavior, with a maximum obtained T<sub>c</sub> of 17.68 K and B<sub>c20</sub> ranging between 22.5 T and 23.8 T.

In the second technique, the synthesis of Nb-Sn coatings was carried out on Cu substrates by direct electrodeposition from 1-Butyl-3-methylimidazolium chloride (BMIC) ionic liquids at 130°C containing SnCl<sub>2</sub> and NbCl<sub>5</sub>. No heat treatment whatsoever is necessary in this technique. The electrodeposited coatings showed a cubic Nb<sub>3</sub>Sn phase with (211) preferred orientation, a disordered orthorhombic NbSn<sub>2</sub> phase and Sn-Cu phases. Film thickness was 200 to 750 nm in direct current mode and 500 to 1600 nm in pulsed current mode.

Both methods should be cost-effectively scalable to 3D shapes, as typical of electrochemical techniques. Whereas the second technique still requires research to optimize film homogeneity, the first can already be applied for superconducting Nb<sub>3</sub>Sn wires, i.e. use thin films to test flux pinning properties of additional elements inexpensively and with fast turnaround. Coating of SRF cavities will also be tested in the near future. The second technique, which carries great money-saving potential for future accelerators, is under active R&D.

**Recent design and progress / 98**

## **First Results of SRF Cavity Fabrication by Electro-Hydraulic Forming at CERN**



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Superconducting RF (SRF) structures are traditionally fabricated from sheet metal forming. An alternative technique to traditional shaping methods, such as deep-drawing and spinning, is Electro-Hydraulic Forming (EHF). In EHF, cavities are obtained through ultra-high-speed deformation of blank sheets, using shockwaves induced in water by a pulsed electrical discharge. With respect to traditional methods, such highly dynamic process can yield interesting results in terms of effectiveness, repeatability, final shape precision, higher formability and reduced spring-back. In this paper, the first results of EHF on copper prototypes and ongoing developments for niobium are presented and discussed. The simulations performed in order to master the embedded multi-physics phenomena and to steer process parameters are also presented.

FCC-hh Overall Design / 99

## SPPC Study Progress

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This presentation gives an overview on what we have carried out on the preliminary concept design and identification of technical challenges of the SPPC accelerators, including the collider and the injector chain. With the emphasis on the parameters optimization, lattice design, and collimation design, the accelerator physics studies also include injector chain concepts, luminosity leveling, instabilities and injection-extraction, and longitudinal dynamics. The main technical challenges are believed to be high-fields superconducting magnets and cryogenic beam screen, but other technical issues have also been surveyed.

Poster session / 100

## SRF Cavities High Q Development for CW Accelerators

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Nitrogen doping is the innovative high Q SRF technology pioneered at FNAL and currently implemented by the LCLS-II project at SLAC. In order to fulfill the high quality factor requirement of this continuous wave free electron laser, the nitrogen doping R&D at Fermilab has been further intensified with aim to deeply understand how ultra-high Q-factors can be maintained throughout all the production chain, from the cavity vertical test to the cryomodule operation. Results will be presented from vertical to horizontal to cryomodule tests.

Cavity horizontal operation introduces a major issue: even after the optimization of the magnetic shielding, some level of remnant magnetic field will always be present during the cool down through the critical temperature. Magnetic field studies performed at Fermilab showed that in cryomodule

environments the cavity experiences remnant magnetic field during the cooldown of the order of 5 mGauss, even with advanced shielding techniques. Research is ongoing on how to further reduce these remnant field levels.

We will present studies to address such issues, via efficient cooling and optimization of shielding design. We will show progress on ideal cooling procedures to minimize the magnetic flux trapped at the cavity RF surface. In addition, fundamental studies allowed us to define the best nitrogen doping treatment in order to maximize the cavity quality factor even in presence of trapped magnetic field (via lowering the sensitivity to trapped flux), and then to preserve high quality factors to the cryomodule operation.

We will also show that the nitrogen doping technology is suitable also for future accelerators as PIP-II at Fermilab or FCC, as we have made progress developing N doping at different frequencies like 650 MHz and 3.9 GHz.

## Material, cavities and cryomodules R&D / 101

### Bulk based technologies

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Recent years have seen a tremendous progress in fundamental understanding of physical mechanisms limiting the performance of superconducting radio frequency (SRF) cavities, enabled by implementation of new research techniques, and exploring new materials such as Nb3Sn.

Accelerating gradient limit of SRF cavities both of Nb and Nb3Sn was shown to be higher than Hc1, providing a tantalizing outlook for the upcoming years. Fermilab's Nb3Sn program has been started and is proceeding forward at the fast pace.

Components of surface resistance (which determines the value of Q0) and their RF field dependence for niobium cavities prepared by different state-of-the-art techniques have been measured and thoroughly analyzed within the context of BCS-based theory in an unprecedented range from milliVolts/m to > 30 MV/m, shedding light on all the so-called Q-slopes.

Fundamental materials science uncovered previously unknown contributors to both the surface resistance and achievable gradients, such as nanoscale niobium nanohydrides, which gain superconductivity only by proximity effect.

In this contribution I will review these recent breakthroughs and outline a possible stream of further advancements stemming from them, which may happen on the timescale of relevance to FCC, and may shape the emerging research program in this area.

## Beam Induced Effect / 102

### Radiation Hardness of Electronics in the FCC

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FCC will need a significant amount of electronic components and systems in the accelerator tunnel, the Particle Detectors and the side galleries in order to control and monitor the various infrastructures and systems such as power converters, vacuum, cryogenics, RF systems, etc. The radiation assurance procedure will be driven by the high availability requirements of the systems and the highly challenging radiation levels.

Therefore, two complementary approaches will be implemented in the context of the FCC activities in R2E (Radiation to Electronics) in order to provide the targeted availability: the reduction of the radiation levels received by the electronic systems through shielding and optimized location and the development of electronics and equipment which is radiation resistant for FCC levels. The second point is tightly linked to the Radiation Hardness Assurance (RHA) procedure, which consists of all activities undertaken to ensure that electronics and materials developed for FCC perform to their design specifications after exposure to the FCC radiation environment, therefore involving (i) the radiation environment definition (ii) the electronic component selection (iii) the part testing and (iv) radiation tolerant design.

Concerning the radiation environment definition, the baseline approach will be that of implementing models of the FCC geometry in a Monte Carlo transport code context (i.e. FLUKA) and perform simulations in order to retrieve the relevant radiation levels. In addition, it will be important to identify the existing and foreseen radiation test facilities suitable for the characterization of FCC components and systems. Finally and in combination with the simulations, it will be essential to monitor the radiation levels in the relevant FCC locations as the latter will have a very strong impact on the radiation hardness assurance methodology.

**FCC-hh Experiments and Detectors, 3rd session / 103**

## **US activities and plans for physics and detector studies for FCC-hh**

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There is considerable expertise and a growing interest in the US hadron collider community to help understand and develop the physics case for a future, higher-energy hadron collider beyond the LHC. This interest extends from developing BSM models that can address the big, open questions in the standard model, to performing simulated analyses to quantify the sensitivity of benchmark models for a 100 TeV pp collider, to understanding the detector requirements. We will present a summary of collaborative activities occurring in the US in these directions, as well as near-term plans.

**Physics/Pheno / 104**

## **The search for sterile neutrinos at the FCC-ee**

**Author:** Oliver Fischer<sup>1</sup>

**Co-authors:** Eros Cazzato<sup>2</sup>; Stefan Antusch<sup>2</sup>

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Sterile neutrinos are among the most attractive (but also hardest to test) extensions of the SM to generate the light neutrino masses observed in neutrino oscillation experiments. When the sterile (heavy) neutrinos have masses around the electroweak scale, they can be efficiently searched for at the FCC-ee. In this talk I review the most efficient search channels, present updated estimates for future sensitivities and compare those with the present bounds from existing experiments. Particular emphasis is put on the connection between sterile neutrinos and the Higgs sector.

**Physics/Pheno / 105**

## Testable SUSY spectrum from GUTs at the FCC-hh

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Grand Unified Theories (GUTs) are attractive candidates for more fundamental elementary particle theories. They can not only unify the Standard Model (SM) interactions but also different types of SM fermions, in particular quarks and leptons, in joint representations of the GUT gauge group. We discuss how comparing predictive supersymmetric GUT models with the experimental results for quark and charged lepton masses leads to constraints on the SUSY spectrum. We show an example from a recent analysis where the resulting superpartner masses were found just beyond the reach of LHC run 1, but fully within the reach of a 100 TeV pp collider like the FCC-hh.

**FCC-ee Optics / 106**

## Update on CEPC pretzel scheme design

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CEPC was proposed as an electron and positron collider ring with a circumference of 50-100km to study the Higgs boson. Since the proposal was made, the lattice design for CEPC has been carried out and a preliminary conceptual design report has been written at the end of 2014. In this paper, we will describe the principles of pretzel scheme, which is one of most important issues in CEPC lattice design. Then, we will show the modification of the lattice based on the lattice design shown in the Pre-CDR. The latest pretzel orbit design result and the dynamic aperture optimization result will be shown.

**Physics of FCC-eh, and of HI collisions at FCC-hh / 109**

## Geometry and space-time extent of pion emission region at FCC energies

**Author:** Vitalii Okorokov<sup>1</sup>

<sup>1</sup> *National Research Nuclear University MEPhI (RU)*

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The energy dependence is investigated for a wide set of space-time characteristics derived from Bose–Einstein correlations (BEC) of secondary pion pairs produced in proton-proton and nucleus-nucleus interactions. There is no sharp changing of femtoscopic parameter values at intermediate and high energies. Analytic functions suggested for smooth approximations of energy dependence of emission region parameters demonstrate reasonable agreement with most of experimental data at collision energies above 5 GeV. Estimations of some femtoscopic observables are obtained for energies of both the proton-proton and the nucleus-nucleus mode for the Future Circular Collider (FCC) project based on the smooth approximations. The space particle densities at freeze-out are derived also from estimations for volume of emission region and for total multiplicity at FCC energies.

**FCC-eh Accelerator/Detector / 110**

## **FCC Based Lepton-Hadron and Photon-Hadron Colliders: Luminosity and Physics**

**Author:** Saleh Sultansoy<sup>1</sup>

<sup>1</sup> *TOBB ETU*

Construction of linear electron-positron collider (or special/dedicated linac) and muon collider tangential to FCC will give opportunity to achieve highest center of mass energy in lepton-hadron and photon-hadron collisions. Luminosities of the FCC based e-p, mu-p, e-A, mu-A, gamma-p, gamma-A and FEL gamma-A colliders are estimated. Physics search potentials of these machines are summarized.

**FCC-ee Optics / 111**

## **CEPC partial double ring scheme and crab-waist parameters**

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In order to avoid the pretzel orbit, CEPC is proposed to use partial double ring scheme in CDR. In this paper, a general method of how to make a consistent machine parameter design of CEPC with crab waist by using analytical expression of maximum beam-beam tune shift and beamstrahlung beam lifetime started from given IP vertical beta, beam power and other technical limitations was developed. Based on crab waist scheme, we hope to either increase the luminosity with same beam power as Pre-CDR, or reduce the beam power while keeping the same luminosity in Pre-CDR. FFS with crab sextupoles will be developed and the arc lattice will be redesigned to achieve the lower emittance for crab waist scheme.

**FCC-ee Injector / 112**

## **Preliminary injector linac design**

**Author:** Sergey Polozov<sup>1</sup>

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MEPhI have the grate and successful experience in particle accelerators both for science and industry. We collaborate with leading accelerator centers as CERN, JINR, DESY, ANL, KEK and other in fields of electron and ion linac and they components development and construction including beam dynamics and instabilities study, RF components R&D, accelerating structures testing and commissioning. We can to propose the following items for FCC design: e-linac development and construction, beam dynamics simulation and optimization in rings, RF cavities, loads development including HOM and multipac studies. All these propositions will discuss in report.

**Poster session / 114**

## Quench Mechanism in Nitrogen-Doped Cavities

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**Co-authors:** Alexander Romanenko <sup>2</sup>; Anna Grassellino ; Dmitri Sergatskov <sup>3</sup>; Martina Martinello <sup>1</sup>; Melnychuk Oleksandr <sup>3</sup>; Sam Posen <sup>3</sup>

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Nitrogen doping was demonstrated to be a feasible superconducting radio frequency technology in order to achieve high quality factors. The possibility of building accelerating machines operating in continuous wave or high duty factor for medium field applications, such as LCLS-II, are therefore now affordable. Still, cavities treated in such a way are usually limited to lower gradients excluding high accelerating field machines form their range of application. Studies performed till now suggest that the origin of such gradient limitations is magnetic, meaning that the field of first penetration of magnetic flux in the superconductor is somehow lowered from the doping treatment. The work presented is addressed to the understanding of the dependence of the maximum accelerating field with the doping concentration, with the final scope of tweaking the state-of-the-art treatment in order to increase the quench field.

**Poster session / 115**

## Quench-Induced Quality Factor Degradation in Superconducting Resonators

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**Co-authors:** Alexander Romanenko <sup>2</sup>; Anna Grassellino ; Dmitri Sergatskov <sup>3</sup>; Martina Martinello <sup>1</sup>; Melnychuk Oleksandr <sup>3</sup>; Sam Posen <sup>3</sup>

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Quench of superconductivity is a well-known phenomenon causing an increase in the microwave surface resistance of superconducting cavities. In this paper we investigate the nature of these quench-induced losses and present the proof that ambient magnetic field trapped at the quench spot is the single cause. We uncover the effect of different ambient field orientation and also show how the quality factor can be fully recovered after it was highly deteriorated by quenching several times in the presence of the external magnetic field. We also demonstrate that above a certain ambient magnetic field value the cavity quality factor cannot be fully recovered anymore, which we attribute to the migration of the magnetic flux driven by synergistic action of magnetic tension acting on the field lines and the heating caused by the dissipation introduced by the trapped flux itself.

**Physics of FCC-ee / 119**

## QED effects in muon charge asymmetry near Z peak

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Analysing the size and theoretical uncertainty of both interference and non-interference effects in angular distribution on muon pair produced near Z resonance for the purpose of measurement of  $\alpha_{QED}(M_Z)$ . Estimating theoretical (h.o.) uncertainties limiting the precision of this measurement.

**Physics at 100 TeV (SM,Higgs, BSM) / 120**

## Prospects for the measurement of the Higgs Potential at FCC

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I will discuss about the theoretical perspective of measuring Higgs potential at FCC, which is one of the major goals. I will first talk about a phenomenological study of triple-Higgs production in which we estimate the prospects for measuring the form of the Higgs potential at FCC, focusing on the sensitivity on the Higgs cubic and quartic self-interactions. I will discuss possible luminosity goals for future 100 TeV collider projects that would allow for a measurement of the Higgs potential and its possible departures from the Standard Model expectation.

Lastly, I will discuss about a class of models where the electroweak symmetry is broken by strong dynamics with Higgs boson appears near a quantum critical point. I will show that measuring the Higgs potential is a way to test the possible non-mean-field behavior.

**Poster session / 121****Additive Manufacturing for Accelerators Components****Author:** Romain Gerard<sup>1</sup>**Co-authors:** Alexej Grudiev<sup>1</sup>; Francesco Bertinelli<sup>1</sup>; Gilles Favre<sup>1</sup>; Ignacio Aviles Santillana<sup>2</sup>; Konrad Eiler<sup>1</sup>; Thomas Sahner<sup>1</sup><sup>1</sup> CERN<sup>2</sup> University Carlos III (ES)**Corresponding Author:** romain.gerard@cern.ch

Accelerator components are traditionally fabricated using a wide range and combination of techniques: sheet metal forming, machining, vacuum brazing and welding. An alternative technique could be metal additive manufacturing (AM). AM process allows the fabrication of complex geometries with functional characteristics. AM is particularly relevant for prototypes or small series of parts, and for geometries difficult to fabricate with conventional processes. Currently, the most popular AM materials include stainless steel, aluminium, nickel and titanium alloys. RF components require the use of high-quality Oxygen Free Electronic (OFE) copper and/or pure niobium, neither of which is common within the AM industry. This paper introduces the relevance of AM for accelerator components and describes CERN's intentions in the additive domain considering also the qualification of AM for CERN's applications. Additionally, this paper presents the RF characterisation of AM waveguides in titanium alloy, together with the first developments of pure copper manufactured by the Electron Beam Welding process, in collaboration with Industry.

**Physics of FCC-ee / 122****Electroweak precision observables in the Standard Model and beyond: present and future****Authors:** Enrico Franco<sup>1</sup>; Jorge de Blas Mateo<sup>2</sup>; Laura Reina<sup>3</sup>; Luca Silvestrini<sup>4</sup>; Marco Ciuchini<sup>5</sup>; Maurizio Pierini<sup>6</sup>; Satoshi Mishima<sup>7</sup><sup>1</sup> INFN (Istituto Nazionale Fisica Nucleare)<sup>2</sup> INFN - National Institute for Nuclear Physics<sup>3</sup> Florida State University (US)<sup>4</sup> INFN Rome<sup>5</sup> INFN Sezione di Roma Tre<sup>6</sup> CERN<sup>7</sup> KEK**Corresponding Authors:** jorge.deblasmateo@roma1.infn.it, luca.silvestrini@roma1.infn.it

We discuss the perspectives for the global fit to electroweak precision observables at FCC-ee. We consider the Standard Model fit and several generalizations: oblique parameters (STU and  $\delta\epsilon_{1,2,3,b}$ ), modified  $Zb\bar{b}$  couplings, modified Higgs couplings to vector bosons, and dimension 6 gauge-invariant operators built with Standard Model fields.

We compare with the current results and discuss the impact on New Physics searches.

**Physics at 100 TeV (SM,Higgs, BSM) / 123****(Mostly) Model-Independent Searches for New Physics in Vector-Boson Scattering**



**Author:** Jürgen Reuter<sup>1</sup>

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The discovery of a light Higgs boson has all but strengthened the case of weak vector boson scattering (VBS) at hadron colliders as a search vehicle for new physics, as deviations in the Higgs saturation of the unitarization in that channel provide a huge lever arm for searches. The very highest-energy nature of those events with large diboson invariant masses notoriously plagues effective-field theory descriptions aiming for model-independent approaches. We show how to accommodate this problem by a unitarization prescription that allows to get meaningful limits from data. This prescription saturates vector boson scattering amplitudes to their maximal values allowed by unitarity at high energies, and can accommodate both weakly and strongly interacting models. Beyond the (unitarized) EFT ansatz we also discuss generic scalar and tensor resonances in VBS with special emphasis on the theoretical treatment of the high-energy behavior of tensor resonances.

**Poster session / 124**

## **The phenomena of spin rotation and depolarization of high-energy particles in bent and straight crystals at FCC energies and the possibility to measure the anomalous magnetic moments of short-lived particles (charm and beauty baryons)**

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The analysis shows that the phenomena of spin rotation and depolarization of high-energy particles in crystals at energies that will be available at FCC can be used to measure the anomalous magnetic moments of short-lived particles at such energies. It has also been demonstrated that for negatively-charged particles (e.g., beauty baryons), the phenomenon of spin depolarization in crystals is a promising tool allowing the anomalous magnetic moment measurements. Moreover it has been noted that the spin depolarization effect occurs for neutral particles incident at small angles to crystal axes (planes), and this opens the potential for magnetic moment measurements of such short-lived particles. Channeling of particles in either straight or bent crystals with polarized nuclei could be used for polarization or polarization analysis of high-energy particles, including neutral particles. Depolarization and spin rotation of that fraction of neutral particles which moves in the region of high concentration of nuclei can be defined by particle reactions in the crystal: if at a certain point the particle is scattered at a large angle, this means that it has undergone a collision, and hence it was in the vicinity of the nuclei. At high energies, particles move along a straight line. Particles moving between the planes do not undergo collisions, while those moving along the axis or a plane do.

**Poster session / 125**

## **Crystal collimator systems for high energy frontier**

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The advantages of crystal collimators over amorphous ones increase with particle energy increasing, as the coherent scattering effects are enhanced at smaller particle incidence angles with respect to crystal planes and strings typical of higher particle energies. The crystal-assisted collimation approach explored up to the present relies on particle channeling and volume reflection effects in the field of crystal planes. This scheme suffers both a limited probability of particle capture into channeling regime and a small volume reflection angle. We suggest promote particle capture into channeling regime by fabricating of a cut (an empty plane layer) beneath the crystal surface [1]. However channeling imposes quite extreme requirements on crystal quality, alignment and radiation hardness at high energies. Therefore we also suggest increase a particle deflection angle fivefold or even more by applying the effect of multiple volume reflection (MVR) in a single-piece crystal [2], which can be additionally promoted by joint use with channeling in the field of some skew crystal plane [3]. The MVR effect can be also used to reduce the leakage from secondary collimators. Also particle scattering enhancement by atomic strings, which can be used in both correlated and uncorrelated modes, become quite promising as the typical particle deflection angles decrease with their energy. Both the MVR and particle scattering by atomic strings ease the requirements on both crystal alignment and quality.

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**FCC-ee Energy Calibration & Polarisation / 126**

## Polarization study for CEPC

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Transversely polarized e<sup>+</sup>/e<sup>-</sup> beams for precision energy calibration and (possibly) longitudinally polarized colliding e<sup>+</sup>/e<sup>-</sup> beams are critical topics for CEPC operation at lower energy ranges (Z pole and possibly WW threshold). A preliminary study of these aspects is presented in this paper, mostly based on extrapolation of LEP experiences. In addition, some Monte Carlo simulation results of a model ring lattice with relevant parameters will also be reported.

**Poster session / 127**

## Superconducting sputtered Nb<sub>3</sub>Sn films for SRF applications

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A solution to reduce the cost of superconducting radiofrequency cavities is represented by superconducting thin film coated copper substrates. This technology has shown its potential within LEP, LHC and HIE-ISOLDE machines. In all those machines the superconducting thin film was made of *Nb*. Among the most promising future coating materials *Nb<sub>3</sub>Sn* stands as one of the best candidates. Combined to the copper substrate it would offer important benefits with respect to the bulk *Nb* cavities: significantly higher stability against quenching, due to the high thermal conductivity of copper and lower Bardeen-Cooper-Schrieffer (BCS) surface resistance  $R_{BCS}$  and therefore higher quality factor  $Q_0$ , owing to the high critical temperature of *Nb<sub>3</sub>Sn* (~18.2K).

This work is devoted to the investigation of *Nb<sub>3</sub>Sn* thin films with the aim to produce low-loss surfaces. The synthesis of *Nb<sub>3</sub>Sn* coatings was carried out on copper substrates using DC magnetron sputtering. Three different post-coating annealing temperatures were applied in order to achieve a stable A15 phase. The influence of the deposition and annealing parameters on the grain formation and superconducting properties of the system were studied.

## FCC-hh Beam Dynamics / 128

### Octupole for Landau Damping

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Dedicated octupole magnets should be employed in the FCC as a cure against transverse collective instabilities, in addition to the transverse feedback system. In the LHC, the Landau octupoles are routinely combined with the chromaticity and the transverse feedback system in order to ensure the bunch stability through the cycle. We estimate the stability provided by an octupole scheme in FCC using the stability diagrams for the resulting two-dimensional betatron frequency spread. Using the estimations for the impedance-driven tune shifts, and comparisons with the LHC experience, we try to provide suggestions for the adequate octupole scheme in the FCC.

## Material, cavities and cryomodules R&D / 129

### Beyond bulk Nb

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With the development of energetic vacuum deposition techniques, high quality Nb films have been produced supporting the promise of high RF performance. A Nb/Cu thin film deposited by ECR (electron cyclotron resonance) plasma has shown a significantly improved Q-slope, at 4 K and 400 MHz, compared to magnetron sputtered Nb films. Another category of ECR Nb films show first flux penetration at 180 mT, close to bulk Nb Hc1. In energetic condensation, the controlled incoming ion energy enables a number of processes such as desorption of adsorbed species, enhanced mobility of surface atoms and sub-implantation of impinging ions, thus producing improved film structures at lower process temperatures. All these processes along with the quality of the underlying substrate have an important influence on the nucleation and subsequent growth of the Nb film, creating a favorable template for growing the final surface exposed to SRF fields. Each phase in the film growth can be tailored in order to optimize the final RF response of the Nb film. This contribution shows how the ion energy and thermal energy provided to the substrate influence the nucleation, structure and defect density, and quality of the final RF surface for ECR Nb films.

**Recent design and progress / 130**

## RF systems for the Jefferson Lab Electron Ion Collider

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We present recent updates and overall system parameters for the RF systems for the Jlab EIC study. Overall system stability limits and requirement and options for HOM damping in the storage rings and bunched-beam electron cooler ERL will be presented. Major technical challenges and ongoing R&D to address them will be described.

**Physics/Pheno / 132**

## High Energy Jets at 100 TeV

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The production of multiple hard jets in hadronic collisions takes on a different character as the centre-of-mass energy increases. The importance of higher-order terms in the perturbative series (and therefore of higher multiplicity events in inclusive samples) is enhanced both because of the massive increase in phase space and due to the large logarithmic corrections at all orders. The High Energy Jets (HEJ) framework combines hard-scattering matrix elements with a systematic resummation of the leading logarithms in  $s/t$  at all orders in  $\alpha_s$ . The approach has currently been applied to the production of dijets, Higgs-plus-dijets, W-plus-dijets and Z-plus-dijets and it has already been seen in LHC Run I data that the inclusion of these logarithms is important to give a correct description of data in challenging regions of phase space. In a recent ATLAS W-plus-dijet study for example, the HEJ predictions gave a good description in the region of large invariant mass (where the logs in  $s/t$  are large) where other standard descriptions struggled. This has clear implications for the accurate description of multi-jet processes within VBF cuts in Higgs analyses.

In this talk, I will outline the High Energy Jets framework and the existing evidence from LHC Run I that we are already sensitive to the logarithms uniquely included in HEJ. Motivated by this, I will

go on to explore the impact of these corrections in 100 TeV collisions in inclusive jet rates, inclusive distributions including invariant mass and rapidity distributions before and after VBF cuts and also the average number of jets as a function of rapidity and  $H_t$ .

**FCC-ee Single-beam collective effects / 133**

## Collective Effects in Low-Emittance Rings: Projection for FCC

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A comparative analysis of collective effects has been done for a dozen of operating low-emittance storage rings. The beam energy is in the range from 1.5 to 8 GeV, horizontal emittance - from 0.3 to 7 nm. Both single-bunch and multi-bunch effects have been analyzed including beam lifetime, collective instabilities, current-dependent bunch lengthening and betatron tune shifts. For the machines in operation, measured data have been compared with the predictions based on impedance budgets. Some extrapolations for FCC-ee have been done using design parameters. The results of the analysis are presented, general trends of collective effects behavior are discussed.

**Poster session / 136**

## Trapped Flux Dissipation in SRF Cavities

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**Co-authors:** Alexander Romanenko <sup>2</sup>; Anna Grassellino ; Mattia Checchin <sup>3</sup>; Olexander Melnychuck <sup>2</sup>; Posen Sam <sup>2</sup>; Sergatskov Dmitri <sup>2</sup>

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Quality factor of superconducting radio-frequency (SRF) cavities is degraded whenever magnetic flux is trapped in the cavity walls during the cooldown. Indeed, one of the main contribution at the surface resistance of SRF cavities is the trapped flux surface resistance. In this contribution we study how the trapped flux sensitivity, defined as the trapped flux surface resistance normalized for the amount of flux trapped, depends on the cavity surface treatments, i.e. on the mean free path. A variety of 1.3 GHz cavities with different surface treatments (EP, BCP, 120C bake and different level of N-doping) were studied in order to cover the largest range of mean free path nowadays achievable, from few to thousands of nanometers. A bell shaped trend appears for the range of mean free path studied. Over doped cavities falls at the maximum of trapped flux sensitivity, while lighter doped cavities show sensitivity closer to EP cavity. It was also found that the trapped flux sensitivity has a field dependence which also depends on the surface treatment. EP cavities seems to have the larger field dependence leading to values of sensitivity comparable of N-doped cavities at high field.

**Poster session / 137**

## Magnetic Flux Expulsion Studies of Horizontally Cooled Single Cell Cavity

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The cooldown of a superconducting cavity through its critical temperature is a crucial step in which external magnetic field might be trapped in the cavity surface, improving the radio-frequency (RF) surface losses. In particular, fast and slow cooldowns determine considerable differences in terms of trapped magnetic flux and RF cavity performance.

In order to understand the nature of these differences, the temperature all around the cavity is monitored with a T-map system during different cooldown. The study is performed placing a single cell 1.3 GHz elliptical cavity perpendicularly to the helium cooling flow, which is representative of how SRF cavities are cooled in the cryomodules of particle accelerators.

In addition, the cooldown details of the cavity horizontally cooled are analyzed in order to fully understand the differences with the vertical cooldown configuration. The study involves the analysis of the trapped magnetic flux as a function of both different cooldown details and different directions of external magnetic field.

Experimental data proves that under established condition, flux lines are concentrated at the top of the equatorial region, leading to localize temperature rise.

**Poster session / 139**

## Coherent interactions in crystals as a tool for manipulation of ultrarelativistic electron and positron beams

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Coherent interactions of charged particles in crystals are known since the 60s and are exploited for material analysis by ion channeling and for the generation of polarized gamma-beams through coherent bremsstrahlung in the periodical crystal structure.

In the field of hadron accelerators, a collimation scheme based on channeling in bent crystals has been investigated at the CERN-SPS and, recently, at the LHC by UA9 experiment. Moreover, the CRYSBREAM project is currently studying the feasibility of a crystal-based extraction for the LHC.

In the case of future electron/positron colliders, e.g., FCC-ee or ILC, a possible application of coherent effects in crystals could be the generation of intense positron beams through axial channeling [1].

Moreover, for linear colliders it has been suggested to improve the beam collimation by exploiting volume reflection in bent crystals [2]. Here, we present an investigation on this possibility carried

out on the H4 extracted line of SPS by using a 120 GeV/c e- beam interacting with a 2 mm-long bent Si crystal [3]. The beam was deflected by the crystal at an angle of 11  $\mu$ rad and 40  $\mu$ rad through single and multiple volume reflection, respectively. The energy loss by electrons inside the crystal was far more intense with respect to the case of an amorphous medium. The loss enhancement was more pronounced under multiple volume reflection, for which the stronger axial potential plays the main role [3].

By combining the deflecting power with a large energy loss, coherent interactions in bent crystals can be envisaged as good candidates for manipulation of hundreds-GeV beams in future electron/positron colliders, as already proposed for the ILC collimation [2,3].

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## FCC-hh Beam Dynamics / 140

### FCC-hh impedances

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This contribution summarizes the impedance and single beam instability studies performed within EuroCirCol WP 2.4 (single beam current limitations). Numerical results for the beam pipe impedance will be presented together with the resulting growth rates for coupled bunch instabilities. The effect of different coatings will be estimated as well as the threshold for transverse mode coupling instabilities resulting from different broadband impedance sources.

## Poster session / 141

### Advances in Low SEY Engineered Surface for Electron Cloud Eradication

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Developing a surface with low Secondary Electron Yield (SEY) is one of the principal methods of mitigating the beam-induced electron multipacting and electron cloud in high-energy charged particle

accelerators [1]. Since the wall material, surface chemistry, topography and electron energy are the parameters that influence the SEY, common mitigation mechanisms are based on engineering the above parameters. Recently ASTeC has demonstrated that nano- and microstructures engineered on Cu, Al and Stainless steel surface reduces SEY to less than 1 [2]. Further development led to laser engineered surfaces with SEY<0.8 on as-received surfaces of aluminium, stainless steel and copper. Furthermore these surfaces are compatible with accelerators beampipe requirements, providing low surface resistance, low outgassing, low photon and electron stimulated desorption. Such structures can be readily produced by nano- and sub-nanosecond pulsed laser. SEY can be further reduced to an even lower value by bake-out and/or photon and/or electron bombardment. A systematic analysis of surface composition and chemistry (using XPS), the surface topography (using SEM), and SEY measurements with primary electron energies ranging from 50 to 1000 eV is reported and correlated to the laser treatment conditions. A test liner was prepared by ASTeC for a first machine test of such new anti-e-cloud technique. The liner has been installed at SPS for testing in the LHC-like beam conditions.

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## Poster session / 142

### NEG Coating developing in ASTeC

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The ASTeC Vacuum Science Group has an ongoing study to improve the non-evaporable getter (NEG) coating which is currently used in many accelerators around the world. The main advantages of using NEG coatings are, an evenly distributed pumping speed, low thermal outgassing rates and low photon and electron stimulated gas desorption (PSD and ESD). The gas density along the accelerator vacuum chamber is proportional to desorption yield and is decreasing with sticking probability. Previously we reported that by vacuum firing prior to NEG deposition, the level of ESD of hydrogen reduced by an order of magnitude [1]. This depicted the dependence of ESD of hydrogen to the amount of hydrogen stored in the vacuum walls. In addition, the dense NEG coating provides lower than one ESD from the columnar film, but its pumping properties are reduced [2]. Our experiments demonstrated that a dual layer of NEG, where the dense layer acts as a barrier for hydrogen diffusion into the columnar layer, is further reducing the ESD of hydrogen and providing better pumping properties. An alloy target of Ti-Zr-Hf-V was used to deposit dense NEG followed by ~1 um of columnar structure of NEG onto the inner surface of a 50-cm long stainless steel tube. The composition and structure of the dual layer were determined by Energy Dispersive X-ray spectroscopy (EDX) and Scanning Electron Microscopy (SEM) respectively. NEG coating ESD and pumping properties were measured on a dedicated in-house designed facility demonstrating improved properties of dual NEG coating layer.

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**Physics/Pheno / 143**

## Imprints of compositeness in Higgs and Top sectors at the FCC-ee

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Future e+e- colliders have a great potential for the Higgs and the Top-quark physics, not only as a test of the SM but also for New Physics (NP) indication.

Theoretical arguments supporting the importance of sub-percent Higgs coupling precision measurements continue to grow, especially to find hints for non-SM Higgs: how can we decide if it is the elementary SM Higgs or a composite state from a strong dynamics? The attractive idea is that new interactions at the TeV scale bind the Higgs constituents and are responsible for EWSB. This is compatible with a Higgs light and weakly coupled if the Higgs is a pseudo-Goldstone Boson. Compositeness of the Higgs can bring compositeness of the Top quark and the prediction of new particles. If nothing is seen, or, better, if the LHC will give some evidence, future e+e- machines will have a great potential in testing indirectly the salient features of composite Higgs models (CHMs). Realistic scenarios can be built and analyzed with the full spectrum: the 4DCHM (De Curtis,Redi,Tesi,JHEP1204,042(2012)) embeds the main characteristics of CHMs with a partially composite Top quark, new spin-1 and spin-1/2 resonances. We use this general parameterization to test the power of the FCC-ee to exclude the CHMs or to fully characterize their properties. In particular the observables from Top pair production offer a unique possibility to determine the left- and right-handed couplings of the Top quark to the photon and the Z. The sensitivity could be pushed down to less than 1% (HL-LHC cannot be competitive). The precise determination of these couplings is crucial to distinguish among various NP scenarios but, the very important outcome of the analysis, is that the FCC-ee will be sensible to finite mass effects from new particle exchanges. In fact the unequalled precision in extracting the Top form factors allows to find imprints of the interference effects of new Z', and to make quantitative estimations of their mass and couplings.

**FCC-ee Machine Detector Interface / 144**

## Backgrounds in the FCC-ee detector and consequences for the trigger and DAQ

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The very high luminosities anticipated at FCC-ee may pose constraints to the trigger system and to the data acquisition of the experiment. At the Z peak, the rate of physics events to be recorded can reach 100 kHz. Together with the high granularity of the detector, the high rates can lead to a very large volume of data to be sent to the acquisition system, and to be written to disk. The amount of machine-induced and beam-induced backgrounds largely determines this volume. This talk will report on ongoing detector simulations of background processes, and on their consequences for the trigger system.

**Poster session / 145**

## Preliminary hydraulic layout of the beam screen cooling system for the FCC-hh

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The proton beams accelerated, bent and focussed in the FCC-hh will reach a centre of mass energy up to 100 TeV. During circulation each beam will emit synchrotron radiation and generate an image current, causing a heat transfer of about 31.4 W/m to each beam screen, which has to be extracted within a narrow temperature range (40 K – 60 K). Additionally the beam screen cooling system is supposed to shield the FCC thermally. The technical segmentation of the collider foresees continuously cooled sections of up to 10.4 km; throughout the entire section length, more than 700 kW of heat has to be discharged at low temperature level. A cryogenic system of this size not only has to work dependably, but also calls for a high efficiency design to enable the operation economically. The reliable and efficient cooling of the FCC-hh beam screen in all possible operational modes requires a solid basic design as well as well-matched components in the final arrangement without unreasonably high investment costs and controlling effort. This poster presents the preliminary conceptual design of the FCC-hh beam screen cooling system based on exergetic, technical and economic considerations.

**FCC-ee Beam-Beam & Luminosity / 146**

## Beam-beam simulations of FCC-ee with Lifetrac

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Beam-beam effects for FCC-ee in the energy range from 45 to 175 GeV will be discussed. An important role at such high energies plays beamstrahlung which may limit the beam lifetime and causes the bunch lengthening, the latter may enhance flip-flop instability. To perform the parameters optimization and evaluation of achievable luminosity, we used quasi-strong-strong beam-beam simulations.

**Other Magnets / 147**

## JINR experience in SC magnets

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Work on design of superconducting proton and ion synchrotrons is continuing at the Laboratory of High Energy Physics since 1970. Several options of superconducting magnets covering the parameters range of  $B = (1.5 - 4.5 \text{ T})$ ,  $dB/dt = (1 - 4 \text{ T/s})$  and pulse repetition rate  $f = 0.5 - 5 \text{ Hz}$  were

proposed and studied. The 6 AGeV proton and ion synchrotron, Nuclotron, based on a fast cycled superferric magnets was constructed and put into operation in March 1993. The Nuclotron magnetic system is based on several technological now-how that was further accepted for the SIS100 of FAIR project at GSI. We analyze the solutions that have been used and discuss their possible development for application in the FCC, in particular: design of a curved 5-6 T dipoles ramped at least at 1 T/s, consideration of a 1-2 TeV proton bunch extraction schemes, some aspects of a beam transportation to the main ring, work in polarized proton mode etc.

## FCC-hh Experiments and Detectors, 1st session / 148

### Magnet systems

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As part of the conceptual design of the Future Circular Collider for hadron-hadron collisions (FCC-hh), new detector magnet designs are required. Due to the need to provide a magnetic field of 5-6 T over a very large volume, these detector magnets have stored magnetic energies as high as 50 GJ. The two main designs currently under consideration are the 'Minimum Yoke Solenoid' and the 'Twin Solenoid' designs.

Key questions in the design of these magnets are which materials should be used and how this impacts the mechanical and thermal behavior of the magnet. In this investigation the feasibility of using copper, a combination of copper and stainless steel, and aluminum are evaluated. These material options are compared to see how a given choice in materials, weight and volume affects the stress and strain in the coils. Subsequently, the implications for quench protection are given in terms of hot-spot temperature and energy extraction under regular and fault conditions.

Given the very large size and weight of the detector magnets needed to meet the needs of the Future Circular Collider, a detailed stocktaking of the mechanical and thermal properties resulting from material choices is an important step towards finding a suitable design.

## Poster session / 149

### Funnel-shaped end-cap solenoids: A possible alternative for the solenoid & dipoles combination

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As part of the conceptual design phase of the Future Circular Collider for hadron-hadron collisions, new detector magnet designs with stored energies on the order of 50 GJ are being developed that provide sufficient bending power to track particle products resulting from 100 TeV collisions. The main designs currently under consideration feature both solenoids and dipoles, where bending power for

low-eta (i.e. low pseudorapidity) particles is provided by the former and bending power for high-eta particles is provided by the latter. The combination of solenoids and dipoles in close vicinity results in very large forces and torques, which is a challenge and an important design consideration.

As an alternative to combining solenoids and dipoles, an investigation is performed in which the twin solenoid is combined with end-cap solenoids to augment the bending power for high-eta particles and thus reduce the need for dipoles. Two variants are proposed: The first variant involves a funnel-shaped end-cap solenoid with an inner free bore that is much smaller than that of the twin solenoid. The advantage of this variant is a significant enhancement in field homogeneity, but this variant comes with the disadvantage of a large (over 100 MN) net force towards the twin solenoid. The second variant involves two concentric funnel-shaped coils in which the outer cancels the stray field generated by the inner. Like the first variant, this variant has enhanced field homogeneity, but also net force neutrality, superior stray field reduction and a more suitable field orientation and amplitude for muon tracking, at the cost of greater complexity.

The two variants are compared to the previously published twin solenoid & dipoles option and discussed in terms of complexity, volume, mass, and field integrals, to determine whether these options may be suitable alternatives to the solenoid & dipoles combination.

**Poster session / 151**

## **A report on the CBMM-JLab SRF science & technology of ingot niobium summary workshop\***

**Author:** Ganapati Myneni<sup>1</sup>

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CBMM North America and Jefferson Lab entered into a Cooperative Research And Development Agreement to develop ingot niobium technology for efficient and economic SRF linacs in 2004. The final ingot niobium summary workshop, a third in the series, was recently hosted at Jefferson Lab Dec 4, 2015 in collaboration with CBMM(1). In this presentation I will give a brief summary of the workshop. In addition I will review the specifications of niobium for SRF cavities, discuss the role of thermal diffusivity of niobium in the performance limitation of the present SRF cavities and propose new process-procedures for producing improved SRF cavities efficiently & economically.

(1)<https://www.jlab.org/conferences/ingot/index.html>

International Symposium On Hydrogen In Matter (ISOHIM), Yorktown, Virginia, USA

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**Poster session / 152**

## **Developments in detector and beam technologies at INP BSU**

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Fast physical phenomena of radiation interaction with matter that allowed capturing ionization process in scintillators with the definition about 10 ps were researched. It is shown that in e.g. lead tungstate (PWO) scintillation crystal it is possible to distinguish start of scintillation and start of electromagnetic shower by the measurements of non-linear optical absorption of femtosecond laser pulses.

Classes of non-organic materials, including scintillating, that have minor damage of their properties by protons with energies higher than 1 GeV and fluxes up to  $5 \times 10^{14} \text{ cm}^{-2}$  are specified. These materials are prospective for application in detectors intended for installation in proximity to the beam interaction points.

INP BSU manages and takes part in design and production of 1.3 GHz superconductive niobium resonators for future accelerators. Three prototypes of the resonators have been tested in liquid He cryostat and demonstrated superconducting operation and quality factor  $Q \sim 2.8 \times 10^9$  at the top boundary of the measurement region. At present the resonators are suppressed by additional polishing and the measurement technique is being refined to reach the best possible results.

INP BSU has solid expertise for development of custom integrated circuits (IC) for many years. Two custom monolithic 8-channel ICs transimpedance amplifiers Ampl-8.3 and fast comparators DEisc-8.3 have been developed and produced for 50 thousand channels of the Forward Muon System of the Dzero experiment (Fermilab), 8 thousand channels for Muon System of the COMPASS (CERN), one thousand channels in the PiBeta (PSI), and 3200 channels with straw-tubes of SVD-2 (IHEP, Protvino). Now we engineer 8-channel custom low-impedance amplifier for the muon system of the PANDA project (GSI) and 9-channel amplifier for electromagnetic calorimeters of the NICA experiment setups.

**FCC-ee Single-beam collective effects / 153**

## Feedback systems for FCC-ee

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In this presentation some preliminary considerations on the feedback systems for FCC-ee are developed. Bunch-by-bunch feedback systems have been designed in the last years for other e+/e-collider like PEP-II, KEKB, DAFNE, SuperB and SuperKEKB. In all these cases, similar approaches have been implemented, even if some design variations have been suitable or necessary for different reasons. Generally speaking all these feedback systems are based on the concept that the barycenter of each bunch move with harmonic motion around the equilibrium point in three planes (L,H,V). The feedback cope with the forcing excitations by producing damping correction for each individual bunch. This is possible managing every single bunch by a dedicated processing channel in real time. For FCC-ee the very high number of stored bunches requests for the feedback systems much more power in term of processing capability. Also the ring length (80-100 Km) should be considered and could ask for a more effective strategy for the feedback system design.

**16T dipole development: EuroCirCol / 155**

## Review and Potential of 16 T (or more) Common Coil Dipole

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High field and lower cost dipoles are desired for future high energy hadron colliders. This presentation will discuss the progress in the design of a 50 mm aperture, 16 T, 2-in-1 dipole based on the common coil geometry using Nb<sub>3</sub>Sn superconductor.

The common coil design is a conductor friendly design based on simple racetrack (mostly flat) coils with large bend radii. The common coil design is attractive for high field magnets as the coil modules move as a whole under large Lorentz forces, causing much smaller stress/strain on the conductor in the end region. Therefore, there is the potential to significantly reduce the amount of expensive support structure as the common coil design may be able to tolerate much larger deflections than those acceptable in conventional designs. One major goal of the high field magnet R&D program is to develop designs that can produce lower cost magnets in industry. The common coil design is expected to produce lower cost high field magnets since the number of coils required is half (because they are shared between two apertures), since it requires less structure (because large deflections may be allowed) and since it allows lower cost production techniques (because of simpler geometry). The common coil design is also expected to produce magnets with better performance due to less strain on the conductor.

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## Cost Model / 156

### Cost drivers for very high energy p-p collider magnet conductors

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VHEPP collider magnets are envisioned to be constructed from a baseline Nb<sub>3</sub>Sn conductor and a possible extension using high-temperature superconductors (HTS) Bi-2212, Bi-2223, or REBCO. In this presentation, we build upon past analyses of cost in view of recent procurement experience and university research. Real production conditions compel the procurement of about 70% more Nb<sub>3</sub>Sn conductor than given by the mass of conductor in magnets, with the chief drivers being:

- (1) thermal margins of magnets;
- (2) long cable unit lengths and associated mapping losses;
- (3) production statistics and associated process control limits.

We argue that research into cost saving should therefore address thermal margin and protection, take into consideration cables with short or mixed unit lengths as well as novel winding ideas, and assess how the lower process control limits can be improved. While conductor R&D should result in gains in critical current at fixed field, the value of such gains are diminished when considered along the magnet load line, and any concomitant changes to temperature margin, piece length statistics, and performance statistics must also be weighed. This is especially important for emerging ideas that might replace the present RRP® and PIT mainstays. An additional impediment to Nb<sub>3</sub>Sn conductor cost reduction stems from the lack of a large commercial end-use market, which implies that scale-up must be pulled directly by science projects. Cost trade-offs also lie at basic levels to Nb<sub>3</sub>Sn conductor design, where metallurgical limits of materials impede reduction of sub-element diameter, and might require costly special conditioning to overcome. The impact of transformative improvements in HTS magnet conductors over the next decade could be more far-reaching for a VHEPP collider.

## Technologies R&D / 157

## Magnetic refrigeration down to 1.6 K for FCC-ee

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High-field superconducting RF cavities of the FCC-ee require a kW-range superfluid helium refrigeration down to 1.6 K. A magnetic refrigeration working below 4.2 K can be an alternative to the present compression/expansion helium refrigeration. The significant difference between this application and previous magnetic refrigerator studies is its large cooling power, even 1000 times larger than the other designs. Principles of magnetic refrigeration will be recalled and preliminary designs will be compared for a kW-range magnetic refrigerator down to 1.6 K.

**Cryogenics / 158**

## Cryogenics overview

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The conceptual design of the FCC cryogenics systems has made significant progresses. Different magnet cooling schemes have been studied in superfluid and normal helium. The impact on the size and on the operation cost of the cryogenic system has been studied for different magnet operating temperature. A cryogenic architecture has been defined and the main hardware location at ground, service cavern or tunnel levels has been optimized.

**Cryogenics / 159**

## Ne-He cycle refrigeration above 40 K

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The Nelium concept is an approach for highly efficient refrigeration in the temperature range from 25 K to 65K, making it a promising candidate for the cooling of the FCC-hh beam screens in the range from 40 K to 60K. The concept uses a cycle with turbo compressors, which have higher efficiencies compared to classical screw compressors. The mixing of helium and neon reduces the number of stages needed to compress the light gas in a turbo compressor, but comes at the expense of decreased heat exchanger performance. The overall concept and possible cycle configurations were presented during last year's FCC workshop. In this presentation, the critical components compressor and heat exchangers are specified in detail. Emphasis is given on the influence of the mixture composition, which is one of the main optimization parameters.

**Cryogenics / 160**

## Innovative He cycle

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Large unit-capacity cryogenic plants are required to cool at helium temperature high-field superconducting magnets of FCC-hh, high-gradient superconducting RF cavities of FCC-ee as well as for the cooling above 40 K of heavy-loaded FCC-hh beam screens, thermal shields and the HTS current leads. The cooling requirements are challenging with a very large refrigeration capacity up to 3 to 4 times larger than the present state-of-the-art (FCC-hh) and a non-conventional thermal load distribution with very large synchrotron radiation to the beam screens (FCC-hh). The FCC cryogenic system has also to fulfil high-efficiency and high-reliability criteria to minimise the operation cost and to increase the overall availability of the future accelerator complex. Based on the present reference architecture of the FCC cryogenic system and on existing large-capacity cryogenic plants, a preliminary set of specifications for He cycle will be detailed and possible innovations will be outlined.

**Cryogenics / 161**

## Cool-down and warm-up studies of a FCC sector

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The development of FCC poses great challenges in cryogenic process equipment and to future cryogenic facilities. Specifically, as compared to the Large Hadron Collider (LHC), cooling a magnet lattice of about 186000 tons over an equivalent period of time, requires three times of the current available cooling power. Hence, exploring the potential impact of the cooling power on the cooling and warmup timescales of a FCC sector is of utmost importance.

A mathematical formulation based on the preliminary magnet design was used to estimate the cooldown and warmup timescales of the arrangement of quadrupole and dipole magnets that occurs periodically along the magnetic lattice, i.e. magnet string. The results show: 1) it is possible to cooldown a FCC sector within 11.9 days in normal operation and, 2) warmup a FCC sector in about 12.1 days. Additionally, for a cooling power of 2.5 MW, the nitrogen quantity needed is of about 60 Ml (equivalent to 6 CERN Globes). The results give a relevant input for simplification of the future cryogenic facilities and, respective, modular cryogenic distribution line elements.

**Cryogenics / 162**

## Impact of high design pressures on heat inleaks

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FCC accelerator will require helium distribution system exceeding the presently exploited transfer lines by almost order of magnitude. The helium transfer line will contain 5 process pipes protected



against heat leaks by a common thermal shield. The design pressure of the FCC process pipe with supercritical helium will be equal to 50 bar, significantly exceeding the 20 bar value in present state-of-art transfer lines. The increase of design pressure requires construction changes in the support system, vacuum barriers and compensation bellows. This will influence heat fluxes to the helium. The paper analyses the impact of design pressure increase on the heat flux. It seems from the preliminary scaling analysis that the increase of heat flux may scale with a square root of pressure increase, with basic design features of the transfer line unchanged. The design modifications of the compensation system including stainless steel replacements with invar, aimed at mitigation of the pressure increase will be discussed. Alternative designs of the FCC transfer lines will be compared on the basis of Second Law analysis.

**Poster session / 163**

## Advanced Hybrid Current Leads

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Hybrid current leads consisting of a warm copper heat exchanger and a cold HTS sections have greatly reduced the refrigeration needs of many applications of superconductors. We have investigated whether it is possible to improve the presently used hybrid current leads. In our opinion improvements are possible by

- using 2nd generation superconductors produced by thin film deposition
- increasing the overlapping length between superconductor and copper for a more efficient use of the refrigerant
- optimizing the geometry of the heat exchanger of the copper section to obtain a maximum heat transfer with a minimum of pressure drop of the coolant
- using a coolant for the refrigerator, which is efficient in the region between 300 K and 70 K -
- avoiding internal section joining surfaces by introduction of appropriate design and manufacturing technologies.

Considering the proposed improvements, first estimations show a potential for remarkable reductions of the thermodynamic losses in the range of about 20 %.

**Implementation, Electricity, Cooling and Ventilation / 165**

## FCC Civil Engineering – Tunnel Optimisation

**Author:** John Andrew Osborne<sup>1</sup>

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This presentation describes how CERN's civil engineering team are investigating the optimal position for the FCC underground structures in the Geneva area.

A 3D geological model contained within bespoke web-based systems has enabled the position of the FCC underground structures to be narrowed down to two options. The feasibility of these alternative locations has been assessed from a civil engineering perspective and a comparison has been made. A description of this study is given and the results of the comparison are presented.

**Implementation, Electricity, Cooling and Ventilation / 166**

## Design considerations for the FCC electrical network architecture

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This paper discusses various design aspects of a large scale electrical network infrastructure for the Future Linear Collider (FCC), a 100 km long circular accelerator, under feasibility evaluation. The key requirements are very reliable, redundant and operable electrical networks granting the highest accelerator availability. Firstly, the required types of electrical networks are identified and characterised. Then, a first estimate of the power requirements in each geographical location along the accelerator is presented per type of network. Based on the available point of interconnection to the European high voltage transport grid, different network architectures and power line routing layouts are presented. Finally, the feasibility of the proposed architectures are examined in the aim of identifying at the conceptual design phase any specific requirements on the civil engineering infrastructure and defining the prerequisites for the underground integration of the network components.

**Implementation, Electricity, Cooling and Ventilation / 167**

## Large Scale Metrology

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**Co-author:** Nerea Ibarrola Subiza<sup>1</sup>

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The Large Scale Metrology work plan established for the FCC CDR will be presented. Our studies are concentrated on those aspects which present new challenges. The resources required to prepare the CDR, and the progress to date, as well as an overview of the survey activities for a new project of this type will be presented.

The Survey team is implicated in all stages of the assembly and installation of accelerator beamline and experiment detector components for any new project. We should be involved early on in all discussions regarding the components and assemblies; ensure that appropriate fiducials are in place for all metrology, measurement and alignment work; and participate in developing systems for positioning and orienting them correctly. We establish appropriate geodetic and local, reference and coordinate systems in which objects can be defined; provide the metrology and dimensional control of all large elements; and undertake as-built measurements for integration analysis.

**Poster session / 168****Analysis and Evaluation of the CERN Geodetic Reference System****Author:** Nerea Ibarrola Subiza<sup>1</sup>**Co-author:** Mark Jones<sup>1</sup><sup>1</sup> CERN**Corresponding Author:** nerea.ibarrola.subiza@cern.ch

Using the currently available data a new set of topocentric datum parameters have been determined to re-establish the CERN Geodetic Reference Frame (CGRF). A new set of transformation parameters linking the CGRF to the ITRF97 (epoch 98.5) have also been established, minimizing any misalignments between them. This work will be presented, together with the additional steps that will be required to refine these parameters, and to develop a CERN geoid model, for the FCC.

Measurements carried out to link the CERN reference systems to a global network for the CNGS project identified misalignments in the CGRF with respect to a global International Terrestrial Reference Frame. My new studies have also shown misalignments between the CERN geoid model CG2000 and the Swiss geoid model CHGEO98 from which it is derived. The FCC will cover an area more than 10 times larger than the current installations, and the current reference systems would have to be extended. The differences caused by such misalignments will therefore become more significant across the new FCC site.

**Implementation, Electricity, Cooling and Ventilation / 169****FCC electrical power requirements – Methodology for data collection and geographical mapping****Author:** Davide Bozzini<sup>1</sup>**Co-author:** Maria Mylona<sup>1</sup><sup>1</sup> CERN**Corresponding Author:** maria.mylona@cern.ch

The design of the electrical network for the supply of the Future Linear Collider (FCC), a 100 km long circular accelerator under feasibility evaluation, relies on the identification, classification and geographical location of the electrical power requirements. This paper presents a methodology for the data collection and geographical mapping of the power requirements. First, the systems of the accelerator requiring electrical power are identified. Then, for each system a classification of the power requirements is done by considering the system consumption during each phase of the accelerator operational cycle. Finally, the locations where the electrical power shall be delivered to each individual system are identified and mapped. The methodology will allow to compare the proposed versions of the individual systems power requirements and to quantify average and peak power requirements of all studied accelerator configurations.

**Safety, Availability, Controls / 170****FCC collaboration “Fire Safety”****Author:** Saverio La Mendola<sup>1</sup>

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A collaboration on fire safety matters was launched in 2015 among five laboratories and a university. Three workshops have already taken place and a fourth one is scheduled for May 2016. Differently from ordinary buildings, fire safety objectives for peculiar facilities such as the FCC are validated through performance-based fire risk assessments. The work packages (WP) defined are: fire statistics, fire detection and extinguishing, fire propagation and its limitation, evacuation as well as conclusions and recommendations. The collaboration, its deliverables and organization in WPs as well as a preliminary status report will be presented.

**Safety, Availability, Controls / 171**

## Conventional Safety

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The Future Circular Collider (FCC) will face conventional safety challenges throughout its life-cycle, from fire prevention in an unprecedented large underground facility to environmental protection. The general safety studies for the underground areas progressed in line with the advancement on the baseline tunnel layout as well as advanced concepts in different fields of the FCC study. The status of the fire safety and air management concepts for the protection of occupants and environment, as well as new studies linked to the underground infrastructure for evacuation and fresh air will be presented.

**Safety, Availability, Controls / 172**

## Radiation Protection

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The ideas and concepts for the Future Circular Collider have further progressed in 2015. Baseline parameters for the FCC are known and ideas in different fields are converging to viable options. Radiation Protection studies accompany the discussions on civil engineering layout, HVAC aspects and material optimisation in the different parts of the FCC study.

The talk will provide the current status of the studies performed and recommendations given on various radiation protection aspects. It will address the crucial challenges and raise awareness of accelerator and experiment designers for optimal access and working conditions for personnel and the importance for material optimisation at this stage of the project.

**Implementation, Electricity, Cooling and Ventilation / 173**

## Cooling and ventilation plants

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Although several options are still open for the general layout of the FCC, a proposal for the future configuration of the cooling and ventilation plants can be made. Some of the specificities of the FCC such as the underground depth of the tunnel leads to additional constraints for the construction and design of the systems. The ventilation system has to comply with the technical and safety requirements but has also a not negligible impact on the definition of the civil engineering layout in the underground to solve issues such as for the helium release scenario, the smoke extraction, the presence of safe areas, etc. Similarly, the cooling network, given the length of the sectors, the flowrates concerned as well as the constraints imposed to allow accessibility to the pipework, has a major impact on the cross section of the tunnel. In most cases, the experience gained in the operation of the LHC has been driven the choice among different options in order to optimize the operability of the plants. The author shall present the overall proposed layout and configuration for the main cooling and ventilation systems for the underground premises and the reasons that led to this choice, including some simulations with a CFD tool to assess the solutions retained. Specificities with respect to standard solutions used at CERN will also be highlighted.

**FCC-ee Beam-Beam & Luminosity / 174**

## **Interplay of the beam-beam effect and the lattice nonlinearity**

**Author:** Demin ZHOU<sup>1</sup>

<sup>1</sup> *KEK*

In this talk, I will first give a brief overview of observed interplay of beam-beam effect and the lattice nonlinearity in collider rings, and then I will present our recent work on this subject for FCC-ee. Efforts for better understanding the behind mechanism and possible compensation schemes will be discussed.

**RF concepts and directions for R&D / 175**

## **RF system parameters for Z, W, H and tt**

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The FCC-ee RF system must handle beams at different energies and beam intensities ranging from the high energy case of a few mA at 175 GeV to the heavily beam loaded situation at 1.45 A and 45.5 GeV. Higher order mode power will be a major issue at the highest beam intensities. A conceptual design of the FCC RF system is proposed along with staging schemes and highlights of specific R&D topics to reach the design performance. Challenges related to RF structure design, RF powering and higher order modes are addressed. Optimum configurations and synergies between the different collider modes and the hadron collider are identified.

**FCC-ee Optics / 176**

## FCC-ee IR optics solutions

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**Co-authors:** Dmitry Shatilov<sup>1</sup>; Evgeny Levichev<sup>1</sup>; Ivan Okunev<sup>1</sup>; Katsunobu Oide<sup>2</sup>; Pavel Piminov<sup>1</sup>; Sergey Sinyatkin<sup>1</sup>

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The part of the ongoing study of the future circular collider (FCC) is an electron positron machine with center of mass energy from 90 to 350 GeV. Crab waist collision scheme and small (1 mm) vertical beta function at the interaction point (IP) provide superior luminosity. At the top energy, radiation in the field of the opposite bunch (beamstrahlung) limits the beam lifetime and therefore achievable luminosity. Beamstrahlung influence depends on momentum acceptance of the lattice, the value of 2% provides acceptable lifetime. The small value of vertical beta function enhances effects of nonlinear chromaticity. Synchrotron radiation at top energy creates high background in vicinity of the interaction point. The work describes two crossing angle and one head-on optical solutions, discusses pros and cons of the variants.

### FCC-ee Energy Calibration & Polarisation / 177

## Self polarization in the collider

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The use of resonant depolarization has been suggested for precise beam energy measurements in the FCC-ee for Z and WW physics at 90 and 160 GeV CM energy respectively. In addition longitudinal beam polarization would benefit the Z peak physics program.

The large time constant of self-polarization (Sokolov-Ternov effect) in such a large ring can be greatly reduced by inserting proper wigglers in the machine lattice. The resulting large beam energy spread however may destroy polarization in presence of unavoidable magnet misalignments. This calls for precise machine alignment and careful orbit correction.

In this paper the possibility of self-polarization in the FCC-ee at 45 and 80 GeV beam energy in presence of wigglers is investigated. Simulations with quadrupole misalignment and orbit correction are presented.

### Poster session / 179

## A-15 Inhomogeneity in Nb<sub>3</sub>Sn Wires: A Potential Leverage Point for Conductor Improvement

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A recently established collaboration between CERN and TU Wien aims at increasing the critical current density of Nb3Sn wires under the envisaged operating conditions of the Future Circular Collider by roughly 50% relative to currently available products. One of the leverage points for Nb3Sn wire optimization is the inhomogeneity of the A-15 phase, which manifests in the form of Sn concentration gradients and a grain morphology transition in PIT-type wires.

We have devised a fast method for obtaining the global Sn concentration gradient in PIT Nb3Sn wires from AC susceptibility measurements. We present the measurement and evaluation procedure, and compare our initial results to data obtained from high-resolution Sn concentration measurements by means of EDX / EELS as well as to critical temperature distribution data obtained from calorimetry. In addition, we present scanning Hall-probe microscopy examinations of thin wire slices, from which the spatial current distribution can be inferred. This measurement technique complements the AC susceptibility examinations by providing data regarding the spatial variation of the critical current density.

**FCC-ee Energy Calibration & Polarisation / 180**

## Accelerating and Injecting Polarized Beams

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Polarized electron and positron beams are needed for precise energy calibration in storage rings of FCC-ee collider. Such beams will be produced in special low-energy damping rings using superconducting wigglers and Sokolov-Ternov self-polarization mechanism. Next step assumes acceleration of polarized bunches in sequence of synchrotrons up to 45 - 120 GeV. The solenoid type spin rotators will ensure the preservation of beam polarization during the energy ramp. The resonant depolarization technique and, alternatively, the free spin precession approach shall provide the extremely accurate energy determination of beams in future FCC-ee collider. All these topics are briefly discussed in the report.

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## High-precision $\alpha_s$ from W decays at FCC-ee

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The hadronic branching ratio of the W boson  $BR_{had}$ , computed today at next-to-next-to-leading order (NNLO) accuracy, can be used to determine the QCD coupling  $\alpha_s$  using the experimental data to be collected in  $e^+e^- \rightarrow W^+W^-$  processes at the FCC-ee. By exploiting the huge data sample of  $5 \times 10^8$  W bosons (a thousand times more than the  $5 \times 10^5$  W's collected at LEP), the statistical uncertainty on  $BR_{had}$  can be reduced to around 0.005%. By combining the measurement of  $BR_{had}$  and  $(1 - BR_{lep})$ ,  $\alpha_s$  can be extracted with a state-of-the-art experimental uncertainty of order

0.2\%. The associated parametric and theoretical uncertainties of such an  $\alpha_s$  determination will be also discussed.

#### FCC-ee Machine Detector Interface / 182

### FCC-ee Interaction Region Layout

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The Interaction Region of the FCC-ee is an interesting part of the accelerator. The design has to span beam energies from 45 GeV (Z running) to 175 GeV (top running). The beam currents range from 6.6 mA at the top mass to 1.45 A at the Z. Synchrotron radiation from the beam is both a detector background as well as being capable of damaging and even destroying machine and detector components. I present here a very preliminary IR design that attempts to span the entire range of beam energies and currents with emphasis on SR issues. There are many open questions in this design and we list some of them in the summary that need further attention. The attempt here is to generate discussion about an IR design and to get further input from both the detector and machine groups concerning necessary constraints as well as needs.

#### FCC-hh Collimation System / 183

### Betatron collimation efficiency

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We present a first design of a collimation system for FCC-hh. The baseline collimation layout is based on the scaling of the present LHC collimation system to the FCC-hh energy. It includes dedicated betatron and momentum cleaning insertions as well as collimators in the experimental insertions to protect the inner triplets. Optics are scaled from the LHC ones that were optimised for a multi-stage collimation system. An aperture model for the FCC-hh is defined and the geometrical acceptance is calculated element by element at injection and top energy taking into account mechanical and optics imperfections. Based on these studies the collimator settings needed to protect the machine are defined. The performance of the collimation system is then assessed with particle tracking simulation tools. The efficiency of the betatron cleaning is evaluated by studying the longitudinal distribution of losses. Possibility for optimisations of the system are described.

#### Manufacturing & Test Infrastructures / 184

### SC strand and cable test demands and infrastructures (ITER experience)

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In large projects, the effective test of the components prior to final assembly is a key step to secure the final success. For superconducting magnets, beside the mandatory tests of the structural and insulation components, the cryogenic test of the superconducting strands and cables call for attention.

The approach to cryogenic tests in other large projects with superconducting magnets is summarized and the analogies/differences with the FCC are highlighted.

A sound justification must be the driver for the expensive, cryogenic tests. In the R&D phase the validation of the design and of the manufacturing approach and the exploration of novel operating conditions require a fast and accurate test of prototypes. No saving, but also no duplication, is recommended for cryogenic test in the R&D phase.

Once the design of the magnet is frozen and the prototype magnet has achieved the target performance, the cryogenic tests aim at integrating the overall database and quality control activities. Here, the perception of needs for the cryogenic test varies substantially according to the attitude and professional background of the project managers.

A tentative list of cryogenic test infrastructure of potential interest for FCC is given.

**Common experiment software / 185**

## Tracking SW developments

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The ATS (a tracking software) package, which is an experiment independent common tracking software toolkit will be used for tracking in the FCC software. The ATS package contains the existing and well tested ATLAS tracking software decoupled from ATLAS specific components. Furthermore the software was updated to new coding standards and prepared for possible concurrent use in the future. A common introduction to the ATS package, its status and development will be given.

In concrete the integration of the ATS package into the FCC software suite, containing its automatic geometry conversion and smooth embedding into the FCC simulation framework will be shown.

A first standalone demonstrator of the Tracking package including geometry, fast simulation, truth tracking and tracking fitting is foreseen, as well as its usage in the FCC environment using a FCC-like inner detector directly translated from the FCC detector description.

**Conductor Development: Industry contribution I / 186**

## Development of higher performance Nb<sub>3</sub>Sn conductors for the FCC

**Author:** Jeff A. Parrell<sup>1</sup>

<sup>1</sup> Oxford Superconducting Technology

Many concepts for advanced accelerator magnets such as those for the Future Circular Collider include superconducting materials beyond the state of the art. To realize the technical goals for such magnets, Nb<sub>3</sub>Sn strands will at least need to have smaller filaments and higher critical current density values than are available today. However, achievement of such high performance may not be sufficient to enable the launch of a new very large accelerator project; such a decision may hinge on cost due to the tremendous scales involved. Thus, while the cost of superconductors has always been important for accelerator projects, more than ever the economics of conductor designs needs to be

a focus for materials developers. In our presentation we will review potential pathways to improve the strand performance, and discuss the cost benefits and limitations of high volume production of Nb3Sn strands, starting from the situation today with strands in production for the HL-LHC upgrade.

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## US program

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The US DOE Office of High Energy Physics has launched the creation of a national Magnet Development Program (MDP). The newly established organization will coordinate the magnet and material R&D efforts of US laboratories and universities in the development of enabling magnet technologies that further the mission of US HEP. The organization, mission and goals of the MDP will be presented.

**Technologies R&D: Beam transfer, Magnet & Instrumentation / 188**

## Perspectives for beam-beam- compensation and collimation using electron beams for FCC-hh

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High intensity low energy electron beams have been suggested at the Tevatron as actuator on the hadron beams (being called electron lenses). At FNAL these lenses have been used for various machine experiment and they served regularly during Tevatron operation for abort gap cleaning. CERN is presently studying the usage of such lenses for Halo diffusion of the LHC beams and for the compensation of long range beam beam forces.

The presentation will describe the hardware of such lenses, the present state of preparation at CERN for the above applications and it will suggest steps to evaluate the potential for FCC-pp.

**FCC-hh Beam dump concept / 189**

## History and lessons from existing and studied high energy hadron machines (SSC, VLHC, Tevatron, LHC)

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A review of various beam dump and protection schemes for very high energy hadron colliders both studied and realized, with specific emphasis on the Tevatron, the Superconducting Super Collider design, the Very Large Hadron Collider design, and the Large Hadron Collider.

**Injection, Extraction, Transfer Lines / 190**

## **Faster ramping of LHC as FCC-hh injector**

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We examine the feasibility of ramping the LHC magnets faster than present operation, in view of a reuse in a FCC-hh booster.

**Technologies R&D: Beam transfer, Magnet & Instrumentation / 191**

## **FCC-ee warm magnets design**

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We present a first conceptual design of the main magnets for the FCC-ee arcs.

**FCC-ee Injector / 192**

## **CEPC injector-ring design**

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In the CEPC program, a booster is needed to accelerate electrons from Linac to high energy of 120 GeV. A preliminary design of the booster has been given. After that, some new requirements have shown, mainly about the dynamic aperture of the booster. Efforts have been taken to improve this booster design to fulfill these requirements. Some new results are presented here.

**Material, cavities and cryomodules R&D / 193**

## **SRF Material Options for FCC**

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In contrast to bulk niobium, the use of niobium on copper coated SRF cavities allows operation at 4.5 K due to the lower BCS resistance and the high thermal stability of the copper substrate. Moreover, Nb/Cu technology lowers significantly production cost for cavities as well as the cryo modules as coated cavities do not require magnetic shielding. This talk will present the latest advances in the niobium thin film development with the focus on energetic condensation techniques.

**FCC-ee Lattice corrections & performance / 194**

## Dynamic aperture

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The estimation of dynamic aperture (DA) is one of the most important tasks to be conducted in the design of an accelerator, allowing the evaluation of its performance. In order to compute the DA, a numerical approach can be followed, in which particle tracking simulations are performed. The main limitation of this approach is the time needed involved in the process. An automation routine for particle tracking with MAD-X and PTC has been developed to overcome this issue. We apply this tool to the latest FCC-ee lattices, and the results are presented and discussed. Plans for the improvement of this tool are also proposed.

**FCC-ee Beam-Beam & Luminosity / 195**

## A new beam-beam effect in collisions with crossing angle

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During beam collisions with a crossing angle particles get horizontal deflection with opposite direction in the head and the tail of the bunch (like does crab cavity but more nonlinear). Due to the transverse kick bunch slices (and particles) undergo betatron oscillation in the ring and come again to the IP with additional horizontal spread which (for FCC-ee) may exceed the natural beam size. This effect causes several problems which need careful analyses.

**Beam Energy Deposition & Machine Protection / 196**

## FCC beam dump septum requirements and suitability of different septa technologies and topologies

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**Co-authors:** Alejandro Sanz Ull<sup>2</sup>; Anton Lechner<sup>1</sup>; Daniel Barna<sup>3</sup>; Jan Borburgh<sup>1</sup>; Linda Susanne Stoel<sup>4</sup>; Wolfgang Bartmann<sup>1</sup>

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This article will describe the how the baseline design for the beam dump system septa is derived and provide further insight into the consequences of the septum technology choice for the extraction protection equipment (absorbers), for the dump kickers and for the required space in the lattice. Subsequently an inventory of potential septa topologies will be considered and their relative merits will be discussed. Finally an initial cross section of two septa will be proposed and their robustness described to allow a feasibility study of the extraction protection elements, which are needed to protect the septa in case of an asynchronous beam dump.

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## Public Event: Macchine per scoprire: dal bosone di Higgs alla nuova fisica

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FCC-hh Experiments and Detectors, 3rd session / 198

## EMCAL performance studies

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This talk will explore the options for electromagnetic calorimetry for FCC-hh experiments. The requirements and key parameters for electromagnetic calorimetry in the FCC environment will be reviewed and discussed. Special emphasis will be given to the similarities to the LHC experiments and what could be learned from them, but also the expected differences with respect to LHC will be elaborated. Possible technology options will be presented and compared.

The status of the implementation of the EMCAL into the FCC software will be described and further plans presented. Planned studies of EMCAL performance with the FCC software will be outlined.

Poster session / 199

## Multiphysics Modeling of Superconducting Canted-Cosine-Theta Dipoles

**Author:** Lucas Brouwer<sup>1</sup>

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The Superconducting Magnet Group at Lawrence Berkeley National Laboratory is building a series of Canted-Cosine-Theta (CCT) dipoles to test the performance of the CCT design at high field. The modeling techniques which have been developed for the design and analysis of these magnets will be

presented. An integrated approach using ANSYS software will be shown which allows for magnetic, electric, mechanical, and thermal modeling using a single finite element mesh. The results of this modeling will be compared to strain gauge and electric measurements taken during recent tests of both NbTi and Nb<sub>3</sub>Sn CCT dipole magnets.

**Poster session / 200**

## **Quench Protection of a 20 T Dipole Magnet with HTS Insert**

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The design of a 20 T dipole magnet constituted by an LTS outer coil and a HTS insert is analyzed from a quench protection standpoint.

Protection of such a magnet in the case of a quench brings several challenges. The very high stored energy density requires an effective mean to quickly discharge the transport current and homogeneously distribute the magnet's energy in the winding pack after a quench. The different characteristics of the superconductors used in the insert and outsert coils, in particular their current densities and their energy-margins to quench, make it even more difficult to achieve a uniform ohmic heating in the cross-section. The voltages induced by the magnetic coupling between the insert and outsert coils and the different resistance per unit length in their conductors can generate an unbalanced voltage distribution in the magnet.

Several options for the protection of this outsert-insert magnet system based on quench heaters, CLIQ (Coupling-Loss Induced Quench), or combinations of these are investigated. The electromagnetic and thermal transient occurring during the magnet discharge is simulated with a model developed using the software TALEs (Transient Analysis with Lumped-Elements of Superconductors).

Goal of the design study is the development of an effective quench protection scheme which allows maintaining the coil's hot-spot temperature and the peak internal voltages within acceptable limits. Key parameters of the analyzed protection systems are identified and their impact on the quench performance are assessed.

This study is also relevant for future test facilities where high-field inserts are tested in the background field of a large aperture LTS dipole.

**Status Technologies and Infrastructure / 206**

## **Development towards higher efficiency of RF systems**

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**Status Technologies and Infrastructure / 207**

## **The steps towards 16T FCC magnets**

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**Status Technologies and Infrastructure / 208**

## **Design, Prototyping and Tests of the FCC Vacuum Beam Screen**

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**Strategy Roadmaps / 209**

## **HEPAP view and American activities on future colliders**

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## **FCC-hh Beam impact: Energy deposition challenges**

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**Beam Energy Deposition & Machine Protection / 217**

## **Concepts for magnet circuit powering and protection**

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**Technologies R&D / 219**

## **FCC-hh Beam screen studies and beam screen cooling scenarios**

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**Technologies R&D / 220**

## **FCC-ee Vacuum Effects and Simulations**

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**Technologies R&D / 222**

## **Concept of in situ repair using laser based additive manufacturing techniques**

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**Beam Induced Effect / 223**

## **The LHC RF transverse system and perspectives for FCC-hh**

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**Beam Induced Effect / 224**

## **FCC-hh Beam impedance mitigation at injection: Status report on HTS coating study**

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**Beam Induced Effect / 225**

## **FCC-hh Synchrotron Radiation Effects: The new ANKA facility for desorption measurement**

**Author:** Sara Casalbuoni<sup>1</sup>



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**RF concepts and directions for R&D / 228**

## **Beam dynamics: RF requirements for the FCC-hh and FCC-ee options**

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**RF concepts and directions for R&D / 229**

## **Perspective on future challenges for very high energy hadron colliders**

**Author:** Vladimir Litvinenko<sup>1</sup>

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**RF concepts and directions for R&D / 230**

## **Experience gained with the LHC LLRF system and challenges for FCC-hh**

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**Recent design and progress / 231**

## **Present status of the SRF systems for the ILC**

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**Recent design and progress / 232**

## **Cavity Design and Construction Experiences**

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**Material, cavities and cryomodules R&D / 236**

## **Advances on seamless cavities and Nb/Cu coatings**

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**RF efficiency optimization / 240**

## **Energy Efficiency of Particle Accelerators**

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**RF efficiency optimization / 241**

## **Advances and results towards super-efficient klystrons**

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**RF efficiency optimization / 242**

## **Kladistron – the klystron with adiabatic bunching**

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**RF efficiency optimization / 243**

## **Recent developments and perspectives**

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**Physics at 100 TeV (SM,Higgs, BSM) / 244**

## **BSM physics at FCC-hh**

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**Physics at 100 TeV (SM,Higgs, BSM) / 245**

## **Higgs physics at FCC-hh**

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**Physics of FCC-eh, and of HI collisions at FCC-hh / 248**

## **PDFs and QCD at FCC-eh**

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**Physics of FCC-eh, and of HI collisions at FCC-hh / 249**

## **BSM Higgs Physics at FCC-eh**

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In this talk, I will argue that high energy lepton-hadron colliders are suited to studying a wide class of important, well-motivated exotic Higgs decay processes (especially those which suffer from large backgrounds and pile-up at concurrent hadron-hadron colliders). Invisible Higgs decay at the LHeC is taken as an example to illustrate this point. I will emphasize from a more general perspective the important role expected to be played by future lepton-hadron colliders in precision Higgs physics and precision study of new resonances discovered in hadron-hadron collisions.

**Physics of FCC-eh, and of HI collisions at FCC-hh / 250**

## Electron-Ion Physics at FCC-eh

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In this talk we will present a review on the possibilities for nuclear studies at the FCC-he. We will show an update on the possibilities for a precise determination of nuclear PDFs, and their complete unfolding, in a kinematic region never explored before in DIS. We will also discuss diffractive and exclusive observables and the possibilities which these offer for constraining nuclear GPDs and for disentangling the relevance of non-linear dynamics in nuclei. Finally, we will show prospects for jet physics and for studies of QCD radiation in the nuclear medium, of relevance for ultra-relativistic heavy-ion collisions.

**Physics of FCC-ee / 253**

## Precision EW calculations

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**Physics of FCC-ee / 254**

## Flavor studies at FCC-ee/FCNC

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**Physics of FCC-ee / 255**

## Conclusions

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Physics/Pheno / 258

## Effective electromagnetic coupling

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We propose a measurement of the effective electromagnetic coupling in the space-like region extracted from Bhabha scattering data. We argue that this new method may become feasible at present and future lepton colliders resulting in an alternative determination potentially competitive with the accuracy of the present methods.

Conductor Development I / 262

## FCC Conductor development plans

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Conductor Development I / 263

## Report from LTHFSW

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Conductor Development I / 264

## The CERN LHC procurement experience

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**Conductor Development II / 265****Potential for  $J_c$  improvement**

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**Conductor Development: Industry contribution II / 270****Nb3SN developments in Russia**

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**Conductor Development: Industry contribution II / 271****HTS - status and potentials**

**Author:** Soren Prestemon<sup>1</sup>

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**16T dipole development: Overview / 272****EU/CERN program**

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**16T dipole development: Overview / 276****EuroCirCol - blocks**

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In the frame of the high field accelerator magnet design work package of EuroCirCol design study, three different layouts for double-aperture dipole magnets made of Nb<sub>3</sub>Sn conductors and providing a field of 16 T in a 50-mm aperture are being considered: block-coils, common-coils and cosine-theta. All options are being explored and will be compared based on the same assumptions, in particular in what regards the conductor performance, operating temperature and margin. This presentation concerns the block-option under development at CEA. After an exploratory phase of various block-coils possibilities (cable dimensions, number of layers, cable grading) the design converged to a four layer magnet. An internal grading, driven by a conductor saving and consisting in both a high and low field cables, is required. An electromagnetic analysis of the magnet cross-section in a 2-in-1 configuration is performed, coupled to a protection investigation. Preliminary results of the mechanical study ongoing are also presented.

**16T dipole development: EuroCirCol / 277**

## **EuroCirCol - common coils**

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**16T dipole development: Protection / 279**

## **development of CCT Nb<sub>3</sub>Sn dipole**

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**Manufacturing & Test Infrastructures / 283**

## **Production and manufacturing infrastructure**

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**Manufacturing & Test Infrastructures / 284**

## **Magnet test demands and infrastructure**

**Author:** Andrzej Siemko<sup>1</sup>

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**Other Magnets / 286**

## **Field quality, correctors and filling factor in the arcs**

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**Other Magnets / 287**

## **MQ design**

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**Cost Model / 290**

## **Magnet cost model and targets**

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In the frame of the EuroCirCol, a conceptual design study for a post-LHC research infrastructure based on an energy-frontier 100 TeV circular hadron collider, a cost model for the dipole arc magnets is being developed. This talk presents an first analysis of the different cost drivers for these magnets, in particular for what concerns magnet aperture, field amplitude, margin and operating temperature.

**Cost Model / 291**

## **Round table on R&D and cost reduction**

**FCC-hh Overall Design / 294**

## **Considerations on injection energy**



**Author:** Oliver Bruning<sup>1</sup>

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**FCC-hh Overall Design / 296**

## **Beam-beam study strategy**

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**FCC-hh Collimation System / 297**

## **Collimation System study overview and plans**

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**FCC-hh Beam Dynamics / 302**

## **Beam-beam Effects and Compensation Techniques**

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**FCC-hh Beam Dynamics / 305**

## **Electron Cloud Studies**

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**FCC-hh Machine Detector Interface / 307**

## Experimental Insertion Design

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**FCC-hh Machine Detector Interface / 309**

## Collision debris into the arcs

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**Injection, Extraction, Transfer Lines / 319**

## Turn-around cycle

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The calculation of the turn-around cycle time (defined as the time spent between the end of stable beams and the start of the next stable beams period) of a collider is of fundamental importance. On one side it is a crucial ingredient for the computation of the optimal time in luminosity production, which defines the integrated luminosity per fill or store. On the other side, combined with the availability and reliability of the machine, it allows to perform a detailed breakdown of the operational performance of the collider over an operational season, i.e. percentage of time in stable beams and beam in the machine with respect to down time. This paper presents a preliminary operational cycle definition for the hadron-hadron Future Circular Collider, as a base line for estimating the corresponding turn-around time. The cycle definition is based on the Large Hadron Collider (LHC) operational cycle. Two turn-around times are presented, the theoretical one and a more realistic one based on the LHC experience.

**FCC-hh Experiments and Detectors, 1st session / 320**

## Overview

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**FCC-hh Experiments and Detectors, 1st session / 323**

## Tracker design

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A 100TeV hadron collider is the core aspect of the Future Circular Collider (FCC) studies. An integral part of such studies is a conceptual design study of a detector system. This talk will discuss a tracker design study for such a detector with focus on geometry, expected detector performance, estimated particle occupancy and data rates.

**FCC-hh Experiments and Detectors, 2nd session / 327**

## Summary of CPAD detector workshop

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**Common experiment software / 331**

## Status and Plans for the FCC SW Project

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**Common experiment software / 333**

## Geant 4 full and fast simulation framework

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Geant4 is the most common framework for the full simulation studies in HEP. It has been integrated with the FCCSW, in order to provide the users the possibility to perform the simulation within the common software framework.

The full simulation takes into account all the physics processes the particles may encounter, being very detailed thus time and CPU consuming. At the early stage of the detector design and for different physics cases such accuracy is not needed, making the fast simulation better suited. Geant4 provides the tools to define the parametrisation, where the overall response of the detector is simulated in a parametric way.

The parametrisation may come from either external sources, or from the full simulation. The detector resolutions may originate from our knowledge of the existing detectors as well as from the external tools, for instance those used in the tracker performance studies. One of such tools is tkLayout. The more sophisticated approach involves the semi-automatic procedure of obtaining the resolutions within FCCSW from a sample of full simulations of single-particle events. Such resolutions are unique for tested detectors, hence they may be used for parametrisation with a better accuracy. Implementation of this approach is still in progress. The parametrisation for the tracking detectors is performed by smearing the particle space-momentum coordinates, while for the calorimeters - by reproducing the particle showers. For instance, GFlash library, implemented in Geant4, parametrises the calorimeter longitudinal and radial profiles.

The fast simulation in FCCSW can be applied to any type of particles in any region of the detector. Possibility to run both full and fast simulation in Geant4 creates a chance for an interplay, performing the CPU-consuming full simulation only for the regions and particles of interest.

This presentation will show the current status of the Geant4 full and fast simulation in the FCC common software framework.

**Common experiment software / 334**

## **Parametrized simulation and analysis**

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**Common Detector Technologies / 335**

## **Future monolithic pixel developments**

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Recently monolithic silicon sensors integrating sensor and readout in one chip fabricated in standard CMOS technologies have been selected for STAR and ALICE where they offer low mass, high granularity, low cost and low power density. Major requirements for monolithic CMOS sensors to be adopted in more aggressive applications like FCC, are increased radiation tolerance and speed maintaining low power consumption. The key challenge here is to fully deplete the sensitive layer maintaining a low capacitance collection electrode. Wafer-scale integration would also be desirable to cover large areas and is in principle accessible through stitching. These challenges will be discussed as well as some promising developments and ideas to meet these requirements.

**Common Detector Technologies / 336**

## **Future Trigger and DAQ developments**

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**FCC-ee Beam-Beam & Luminosity / 340**

## **Beam-beam simulations and ecloud in e+ ring**

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**FCC-ee Single-beam collective effects / 343**

## **Single-beam collective effects in FCC-ee**

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**FCC-ee Optics / 351**

## **Lattice for a Higgs factory**

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**FCC-ee Lattice corrections & performance / 358**

## **SR-based emittance diagnostics**

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**FCC-ee Lattice corrections & performance / 359**

## **SuperKEKB injector experience**

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**FCC-ee Injector / 360**

## **FCC-ee injector complex incl. Booster**

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**FCC-ee Injector / 362**

## **Design of the booster ring optics**

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**FCC-ee Injector / 364**

## **Top-up injection schemes**

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**FCC-ee Machine Detector Interface / 365**

## **Challenges for FCC-ee MDI**

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FCC-ee Machine Detector Interface / 366

## Synchrotron radiation background

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FCC-ee Experiments I / 369

## $\alpha_s$ measurement from the hadronic and leptonic partial widths of the W at FCC-ee

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FCC-ee Experiments I / 370

## Luminosity measurements at FCC-ee

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FCC-ee Experiments I / 371

## Measurements of $\alpha_{\text{QED}}$ around the Z pole

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FCC-ee Experiments I / 372

## Detector implications for FCNC searches at the Z pole

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FCC-ee Experiments II / 373

## Detector implications for Higgs invisible width and DM portal models

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**Physics of FCC-eh, and of HI collisions at FCC-hh / 374****Heavy-ion physics studies for the Future Circular Collider****Author:** Andrea Dainese<sup>1</sup><sup>1</sup> *INFN - Padova (IT)***Corresponding Author:** andrea.dainese@pd.infn.it

This presentation will give an update on the projected accelerator performance and on the physics studies for a heavy-ion programme at FCC-hh. Operating FCC-hh with heavy-ion beams would provide Pb-Pb and p-Pb collisions at centre-of-mass energies of 39 and 63 TeV, respectively, per nucleon-nucleon collisions. Updated estimates indicate that a luminosity of about 30/nb could be integrated during a one-month Pb-Pb run, that is more than one order of magnitude above the maximum projections for the LHC. The large increase in centre-of-mass energy and luminosity opens interesting physics opportunities.

The Quark-Gluon Plasma (QGP) state produced in Pb-Pb collisions at 39 TeV is expected to have initial temperature and energy density substantially larger than at LHC energy, a stronger flow field and freeze-out volume twice as large. The larger temperature could entail novel features, like changes in the quarkonium spectrum and abundant in-medium production of charm quarks. The latter could determine an increase in the number of degrees of freedom of the QGP (from 3 to 4 quark flavours) and provide a new tool to study its temperature evolution. New, rarer, hard probes would be available, like boosted top quarks, which could give access to the time-evolution of the medium properties, e.g. of its opacity. The physics of high-density gluon densities at small Bjorken- $x$  and the onset of saturation can be studied using high-energy p-A and A-A collisions, as well as the gamma-A interactions produced in ultra-peripheral (electromagnetic) collisions of nuclei. At FCC-hh, the increase in centre-of-mass energy of a factor seven with respect to the LHC will extend the kinematic coverage in  $x$  and  $Q^2$ , providing access to the region down to  $x < 10^{-6}$  with perturbative probes like heavy quarks and quarkonia and down to  $x < 10^{-4}$  with W, Z and top.

**Common Detector Technologies / 375****Tracker mechanics****Author:** Georg Viehhauser<sup>1</sup><sup>1</sup> *University of Oxford (GB)***Corresponding Author:** georg.viehhauser@physics.ox.ac.uk

In this presentation I will first discuss the requirements for the mechanics and cooling of the tracking system of a FCC-hadron experiment. I will then explore possible approaches, building on solutions developed for the LHC experiments and their upgrades, to satisfy these requirements.

**Poster session / 376****Study of superconducting Tl(1223) coatings for beam impedance mitigation in the FCC****Author:** Emilio Bellingeri<sup>1</sup><sup>1</sup> *SPIN CNR***Corresponding Author:** emilio.bellingeri@spin.cnr.it

Among the high-temperature superconductors (HTS) Tl-cuprates stand out due to their very high critical temperatures and upper critical fields. In particular TlSr<sub>2</sub>Ca<sub>2</sub>Cu<sub>3</sub>O<sub>x</sub> (Tl(1223)) with a T<sub>c</sub> of about 120 K, very high H<sub>c2</sub> and H<sub>irr</sub>, and moderate anisotropy is a promising material for the realization of a low surface resistance coating for the FCC beam screen. The main function of the beam screen is of intercepting the synchrotron radiation emitted by the beam where the SC coating should shield the AC field generated by the bundles of charged particles moving through the accelerator. Due to considerations related to vacuum stability and thermal effectiveness, the screen has to be kept at a temperature around 50 K, and it is exposed to the dipole magnetic field of 16 T. Among the known HTS, the extensively studied YBCO can work under these conditions, but the deposition require complex processes and performing it on the inside of a tube would require significant modifications of the fabrication process. Tl(1223) can be grown textured on pure silver by much simpler and cheaper techniques, and has the additional advantage of a potentially lower surface resistance (since  $RS \propto R_S \propto \sqrt{H/H_{c2}}$ ). The feasibility of using this material for coatings suitable for the FCC beam screen is currently being explored by CNR-SPIN, TU Wien, and CERN in a joint project.

**Safety, Availability, Controls / 377**

## First results from availability studies

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Reaching the challenging integrated luminosity production goals of a future circular hadron collider (FCC-hh) and High-Luminosity LHC (HL-LHC) requires careful design for high machine availability. However, the identification of the key factors that impact availability and cost is far from obvious due to the unparalleled complexity of such machines. A dedicated activity has been launched in the frame of the Future Circular Collider study to develop models to study possible ways to optimize accelerator availability. This contribution presents a probabilistic approach for Monte Carlo simulation of the machine operational cycle, schedule and availability for physics. The approach has similarities to common risk analysis methods. It relies on failure rates and repair times to model failure probabilities and consequences. The main source of information is therefore coming from operational maintenance data. The recent improvements in LHC failure tracking has enabled the accurate modelling of LHC operations. The model accuracy is discussed by comparing obtained results with past LHC operational data. Furthermore, the prerequisites for making predictions for FCC-hh operations are discussed, focusing on the differences between FCC and LHC, related to size and complexity, beam parameters, operational constraints (e.g. beam injection process) and technological progress.

**FCC-ee Energy Calibration & Polarisation / 378**

## Energy calibration - a look back at LEP

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One of the principal accomplishments of the LEP programme was the precise measurement of the mass and width of the Z boson. This achievement required excellent understanding of the collision energy of the accelerator, which was obtained through instantaneous calibrations of the beam energy with the technique of resonant polarisation, and then the application of a model to transport these calibrations in time and space to the individual interaction points during physics operation.



A similar challenge was encountered when measuring the  $W$  mass during the LEP 2 era, with the additional difficulty that resonant depolarisation could not be performed in the energy regime of  $W$ -pair production. This measurement programme will be reviewed, and lessons drawn for similar studies at the FCC-ee.

#### FCC-hh Collimation System / 379

### Collimation system study plans in the US

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A review of possible studies for energy deposition and collimation system designs from the US will be presented.

#### FCC-hh Experiments and Detectors, 2nd session / 380

### Flavour tagging performance studies and geometry optimisation for the vertex detector at FCC-hh

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This contribution describes the status of an ongoing effort to study the flavour tagging performance and optimise the vertex detector geometry of the FCC-hh detector. The beauty and charm tagging performances in proton-proton events are estimated using a full detector simulation based on Geant4. The simulation and reconstruction software chain used for this study was developed for linear colliders. The performances of different vertex detector geometries are compared for jets in a wide energy range. First, the arrangement of layers in the barrel part is varied. The geometry of the forward region is addressed in a second step.

#### FCC-hh Overall Design / 381

### Luminosity Evolution in a Run

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The evolution of the beam parameters during luminosity production in the FCC-hh is described based on basic models of the effect of synchrotron radiations, intra-beam scattering, luminosity burn-off and beam-beam limitations. The model allows for an estimation of the luminosity performance in different running scenarios and of the tolerances on the intensity lifetime and emittance growth

rate. It is shown that a large variations of the beam parameters is expected during a cycle. Potential operational schemes adapting to these variations are considered.

**Conductor Development: Industry contribution I / 382**

## **PIT Nb<sub>3</sub>Sn conductor for FCC: potentials and challenges**

**Author:** Klaus SCHLENGA<sup>1</sup>

<sup>1</sup> *BRUKER*

Nb<sub>3</sub>Sn conductor manufacturing is a mature technology. The world wide large scale fabrication effort by various approaches for ITER has proven this. Nevertheless, the magnets that are currently discussed for FCC require much higher performance levels and quantities. Up to now, no Nb<sub>3</sub>Sn conductor exists that satisfy the challenging targets. Bruker supplies Nb<sub>3</sub>Sn conductors manufactured by the Powder-In-Tube- (PIT-) approach. Conductors like these have the potential to fulfill the demanding target specification, but need dedicated R&D. The talk will summarize the performance status of its PIT-Nb<sub>3</sub>Sn conductors and give an outlook on required R&D for further improvement.

**Status Experiments and Detectors / 383**

## **FCC-ee Progress on physics and experiment studies**

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**Status Experiments and Detectors / 384**

## **FCC-eh Progress on physics and experiment studies**

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**Summaries Machines and Technologies / 385**

## **Summary of parallel Technologies sessions**

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**Summaries Physics and Experiments / 386**

## **Summary of parallel sessions on FCC-eh**

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**FCC-eh Accelerator/Detector / 387**

## **Status of the LHeC Development**

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**FCC-eh Accelerator/Detector / 388**

## **FCC-eh Parameters**

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**FCC-eh Accelerator/Detector / 389**

## **Detector Development**

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**FCC-eh Physics / 391**

## **Civil Engineering Study**

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**FCC-eh Physics / 392**

## **Low x Physics**

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**FCC-eh Physics / 393**

## **Top and BSM Physics**

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FCC-eh Physics / 394

## **Discussion on Higgs Analyses**

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FCC-ee Experiments II / 395

## **Measurement of W mass and width at the FCC-ee**

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FCC-ee Experiments II / 396

## **Top physics at the FCC-ee**

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FCC-ee Experiments II / 397

## **Asymmetry measurements at the FCC-ee: is longitudinal polarisation needed?**

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**Conductor Development: Industry contribution II / 398**

## **Nb3Sn developments in Korea**

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**Conductor Development: Industry contribution II / 399****What happened with the Nb<sub>3</sub>Sn Bronze Route?****Author:** Rene Louis Jacques Flukiger<sup>1</sup><sup>1</sup> *Universite de Geneve***Corresponding Author:** rene.louis.jacques.flukiger@cern.ch**Poster session / 400****Basic comparison of hydraulic schemes for the FCC-hh cold mass cooling with supercritical helium****Author:** Claudio Kotnig<sup>1</sup><sup>1</sup> *Graz University of Technology (AT)***Corresponding Author:** claudio.kotnig@cern.ch

The possible operation of the FCC-hh cold mass cooling system with supercritical helium at a temperature of 4 K – 4.5 K is currently under investigation at CERN. The completely different thermodynamic and flow-mechanical properties of supercritical helium compared to pressurized superfluid helium at 1.8 K used in the LHC requires a cryogenic system based on a different concept for cooling the superconducting material. In several particle accelerators cold mass cooling systems working with supercritical helium are realized and serve as a basis for the development of a possible refrigeration scheme for the FCC-hh at a cold mass temperature of about 4 K. Dependent on the final magnet design and the possible installation of piping and auxiliary equipment for cryogenic applications in the cryostat, a probate cooling scheme to extract the heat load of 1.5 W/m reliably can be designed. A basic analysis of different concepts adapted to the specifications of the FCC-hh in advance is important to enable the development of well-matching machinery systems. This poster compares various hydraulic schemes for a cold mass cooling system based on a supercritical helium cycle with respect to the feasibility, the exergetic efficiency and the technical requirements.

**Poster session / 402****Superconducting Cavity Design for FCC-ee****Author:** Shahnam Gorgi Zadeh<sup>1</sup>**Co-authors:** Frank Gerigk<sup>2</sup>; Rama Calaga<sup>2</sup>; Ursula Helga Van Rienen<sup>1</sup> *Universitaet Rostock (DE)*<sup>2</sup> *CERN***Corresponding Author:** shahnam.gorgi.zadeh@cern.ch

As a part of the Future Circular Collider (FCC) study, the FCC-ee design is considered as a potential intermediate step towards the 100 TeV hadron collider. The Superconducting RF (SRF) system of the FCC-ee shall serve for electron-positron collision at different beam energies ranging from 45.5 GeV to 175 GeV. Challenges for the SRF cavity design result from operating at four different voltages and currents. The two limiting cases are the Z-pole characterized by low voltage and a current exceeding 1 A, and tt-nominal for requiring high voltage of 10 GV. The SRF requirements for each case would optimally necessitate different cavity designs. Nevertheless, no more than one or two designs shall be found that can serve for all four scenarios. This poster will address some design aspects of SRF

cavities mainly covering the requirements of the FCC-ee with high accelerating gradient and high current in the same machine.

**HTS Collaboration meeting / 403**

## **EASITrain**

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**Poster session / 404**

## **Low-emittance muon collider from positrons on target**

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**Poster session / 405**

## **An innovative computational design approach to decision optimisation of large infrastructure civil engineering projects: The FCC case**

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## **Increasing the High-Field Performance of Nb<sub>3</sub>Sn Wires by Pinning Landscape Modification**

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**Poster session / 407**

## **Particle shower studies to tackle the FCC challenges**

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The demanding goals of the FCC project require to address various aspects related to the impact of radiation on accelerators and detectors. For the FCC-hh machine, different sources have to be investigated: the 100 TeV cms proton collision debris, determining the radiation field in the experimental caverns and affecting the interaction region elements, in particular the final focus quadrupoles; the beam losses on absorbers, dumps and collimators, implying issues of protection effectiveness and robustness; the beam interaction with the residual gas along the beam line. On the other hand, in

the lepton ring the synchrotron radiation represents a critical by-product in several respects. An overview of studies carried out along these lines is given, together with a summary of the main results and first conceptual solutions, which look extremely encouraging, especially as far as shielding from the luminosity debris is concerned, opening to feasibility for effective detector and machine operation.

**Poster session / 408**

## Slot 3 AN

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**FCC-hh Experiments and Detectors, 3rd session / 409**

## Performance & potential of an HCAL Tile concept readout by si-PMTs

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The particles produced at the future hadron Circular Collider (FCC-hh) with  $\sqrt{s} = 100$  TeV are of unprecedented energies. We present preliminary studies that motivate a  $12\lambda$  calorimeter in order to contain at 98% level TeV single hadron showers and multi-TeV jets and keep a needed pion energy resolution constant term of 3%, the dominant contribution to the total energy resolution at the TeV energies. The hadronic shower containment and resolution parametrizations shown are based on Geant4 simulations and are compared with test-beam data from the ATLAS Tile hadronic calorimeter. Other requirements such as the transversal granularity and acceptance improvements with respect to LHC calorimetry are also addressed using FCC physics benchmarks. We also present the potential of the ATLAS-Tile hadron calorimeter mechanics/optics concept read out by silicon photomultipliers, allowing big flexibility to achieve the needed transversal and longitudinal granularity, while keeping the overall good performance, hermeticity, and complexity at reasonable levels.

**FCC-ee Experiments II / 410**

## Performance estimate of a FCC-ee-based muon collider

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**Poster session / 411**

## Marx Generator Solid-State Pulse Modulator Application to Kicker Systems of the Future Circular Collider

**Author:** Mike Barnes<sup>1</sup>

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The Future Circular Collider (FCC) will require extremely reliable kicker systems to ensure safe injection and extraction of beam. Most existing kicker systems at CERN rely on long-established technologies which include thyatron switches and pulse-forming networks/lines (PFN/PFL). However thyatrons are susceptible to untriggered (erratic) turn-on which negatively impacts system reliability. In addition long-term commercial availability of thyatrons is a real concern. In mitigation an alternative fast-switch technology, based on high power semiconductor devices, such as the Marx generator is being actively pursued. A Marx generator topology would also potentially resolve problems which are associated with the pulse forming: PFNs are complex devices built of many discrete components, difficult to adjust for optimisation of pulse-shapes, and PFLs rely on difficult-to-source cable for the highest voltage (~80 kV) kicker systems. This contribution discusses the application of solid-state Marx generators to the injection and extraction kicker systems of FCC.

**Poster session / 412**

## **Inductive Adder Type Solid-State Pulse Modulator Development for Kicker Systems of the Future Circular Collider**

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**Conductor Development II / 413**

## **LARP / US Hi Lumi magnet conductor and relevance to FCC**

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**FCC-eh Physics / 414**

## **FCC-eh Interaction Region**

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**Poster session / 415****FCC dump pattern studies****Author:** Daniel Barna<sup>1</sup><sup>1</sup> *University of Tokyo (JP)***Corresponding Author:** daniel.barna@cern.ch

In order to avoid the damage of the dump target, the extracted beam of the FCC will be swept over its surface using dilution kickers. The optimal sweep pattern will be derived, and its basic parameters will be presented. A possible scheme to synthesize the required kicker waveforms will be shown.

**Poster session / 416****High field normal conducting septum magnets****Author:** Alejandro Sanz Ull<sup>1</sup>**Co-authors:** Jan Borburgh<sup>2</sup>; Miroslav Georgiev Atanasov<sup>2</sup>; Wolfgang Bartmann<sup>2</sup><sup>1</sup> *Eindhoven Technical University (NL)*<sup>2</sup> *CERN***Corresponding Authors:** alejandro.sanz.ull@cern.ch, miro.atanasov@cern.ch, wolfgang.bartmann@cern.ch, jan.borburgh@cern.ch

For the FCC challenging requirements are set for the extraction septa magnets. A scaled up LHC-like beam dump system architecture poses many difficulties in terms of space reservation, power consumption and dissipation. To address these challenges whilst maintaining the reliability and availability of the insertion, the study will first explore steel dominated Lambertson type septum magnets with a minimum target field of 2 T. The study focuses on field quality, maximum obtainable field, the leak field limits and the effective shielding of the circulating beams. The use of high-saturation magnetic materials and the space reserved for the coil will also be taken into account in the context of the possible implementation of a cryostat for a superferric solution.

**Gender Equality Working Group / 417****Forming a Gender Equality Group****Author:** Kristin Kaltenhauser<sup>1</sup>**Co-author:** Genevieve Guinot<sup>1</sup><sup>1</sup> *CERN***Corresponding Authors:** kristin.kaltenhauser@cern.ch, genevieve.guinot@cern.ch

Status report – First achievements - Challenges

**Gender Equality Working Group / 418**

## **Gender Equality at INFN / EU Funded GENERA project**

**Gender Equality Working Group / 419**

### **Making the gender equality effort sustainable**

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Why and how should a scientific international collaboration like FCC embed gender equality issues from the start?

The working group will engage the participants in a discussion on the optimal modus operandi to embed gender equality and more generally diversity issues in a large collaboration like FCC.