…looking at two infinities should not prevent us from working together.

FCC Special Technologies

Dr. José Miguel JIMENEZ
Dr. Olivier BRUNNER
FCC Special Technologies

Mandate

- Study the **special technologies** at conceptual aspects required for the FCC accelerator and identify the possible design and performance limitations for the accelerator.

- Identify challenges, **opportunities for technological breakthroughs** and set the R&D program.
  - Understand impacts of technologies
  - Prioritize R&D topics
  - Define scope, schedule, cost guidelines
  - Reporting on Specific Technologies R&D Programs

- Set up **Collaborations** to address standard FCC issues and R&D opportunities

- The R&D activities will then be followed in the frame of the **Accelerator R&D** which includes:
  - High field Magnet Program
  - Superconducting RF Program
  - Special Technology Program (all except Magnets and RF)
Beam vacuum induced dynamic effects [WP9]

CryoPlants efficiency [WP2]

Cryomagnet insulation vacuum [WP10]

Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]

Manufacturing technologies [WP4]

Transverse feedback [WP6]

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Surface-Vacuum parameters for beam-induced effects [WP13]

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Francis Perez ([ALBA (ES)]) & Paolo Chiggiato [CERN]
Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [WP1]

Work Package objectives

- Develop an overall, integrated design for the cryogenic beam vacuum system consisting of:
  - beam screen;
  - proximity cryogenics;
  - magnet cold bore;
  - vacuum system.
- Study synchrotron radiation heat load distribution and mitigation.
- Study gas density distribution.
- Consider novel mitigation techniques for electron cloud.
- Design, manufacture, and test at ANKA prototypes of beam screens.
Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [WP1]

Major achievements

- 3D massive model
- Heat deposition field based on SynRad simulation

Localised temperature increase
(reflector tip and ribs)
Screen temperature less than 4 K higher than the He temperature

Investigation includes:
Installation completed in ANKA
Ready to take photons

Francis Perez [(ALBA (ES)] & Paolo Chiggiato [CERN]
Beam vacuum – Magnet Cold Bore (Eurocircle WP4) [WP1]

On the way to the CDR contribution

<table>
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<th>Next steps</th>
<th>Cryogenic beam characteristics</th>
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<td>• Conditioning of the testing set-up.</td>
<td>• Gas density requirements.</td>
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<td>• Measurement of temperature distribution.</td>
<td>• Photon flux characteristics.</td>
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<td>• Photoelectron current measurement.</td>
<td>• Beam screen characteristics.</td>
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<tr>
<td>• Desorption yield measurement.</td>
<td>• Mechanical aspects.</td>
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<td>• Gas adsorption-desorption on laser treated surfaces.</td>
<td>• Thermal aspects.</td>
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<td>• SEY on laser treated surfaces at cryogenic temperatures.</td>
<td>• Laser treated surfaces as multipacting mitigation.</td>
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<td>• Proposal for localised photon absorbers.</td>
<td>• Photon absorption at dipole extremities.</td>
</tr>
<tr>
<td>• Proposal for interfaces at the cold-warm transitions.</td>
<td>• Gas density simulation and vacuum stability.</td>
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<td>• Indicative nr of pages: 30</td>
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</table>

Francis Pérez ((ALBA (ES)) & Paolo Chiggiato [CERN]

FCC Week 2017
Berlin (DE)

29 May’17
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CryoPlants

Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]

Radiation Hardness of Electronics [WP11]
CryoPlants efficiency [WP2]
Scope, resources & contributions

- Scope: Identify the challenges, the showstoppers and look towards opportunities for technology breakthroughs related to:
  - **5 kW magnetic refrigeration** allowing reaching temperature down to 1.6 K for FCC-ee RF cavity cooling.
  - **Proximity cryogenics** for the superconducting magnets and the beam screen for FCC-hh

- Resource

- External contributions:
  - **CEA-INAC-SBT** collaboration (magnetic refrigeration) → 0.25 FTE.y
  - **Graz University** of Technology: PhD contribution
## CryoPlants efficiency [WP2]

*On the way to the CDR contribution*

<table>
<thead>
<tr>
<th>Next steps</th>
<th>Cryogenic challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic refrigeration at 1.6 K for FCC-ee:</td>
<td>• Overview</td>
</tr>
<tr>
<td>• Task completed</td>
<td>• Temperature levels</td>
</tr>
<tr>
<td>Proximity cryogenics of FCC-hh:</td>
<td>• Cooling scheme</td>
</tr>
<tr>
<td>• Beam screens cooling:</td>
<td>• Operating modes</td>
</tr>
<tr>
<td>Reference cooling scheme proposed Transient operation addressed.</td>
<td>• Cryogenic distribution</td>
</tr>
<tr>
<td>• Cold mass cooling:</td>
<td>• Refrigeration plants</td>
</tr>
<tr>
<td>Operating temperature defined (2 K) Reference cooling scheme proposed.</td>
<td>• Instrumentation and controls</td>
</tr>
<tr>
<td>• Cryogenic distribution:</td>
<td>• Storage</td>
</tr>
<tr>
<td>Sizing of the main headers done</td>
<td></td>
</tr>
<tr>
<td>• Next milestones</td>
<td></td>
</tr>
<tr>
<td>Transients during magnet current ramp-up and fast ramp-down</td>
<td></td>
</tr>
<tr>
<td>Transients during resistive transitions of SC magnets</td>
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Beam vacuum
induced dynamic
effects
[WP9]
Cryomagnet insulation vacuum [WP10]

Scope

Study the feasibility of an alternative/complementary pumping in the insulation vacuum of the FCC-hh, for example pumping by cryosorption.

The problem

Pumping in LHC insulation vacuum:

\[ \approx 200 \text{ m} \]

For FCC-hh: \( \approx 80 \text{ km of arcs.} \):

Not desirable to adopt the same pumping scheme as in the LHC would require 400 turbomolecular pumps:

- Impressive costs for pumps, controllers, cables, and maintenance!
- No means to detect He leaks before appearance of thermal insulation failure
Cryomagnet insulation vacuum [WP10]

On the way to the CDR contribution

Integration of He/H$_2$ local adsorber in the dipole magnets, possibly in thermal contact with the C’ line (cold-mass support cooling) at 4.5 K.

First proposal: sheets made of compressed carbon material.

Collaboration agreement with Universities to be set up. **Looking for Partners!**
Beam vacuum induced dynamic effects [WP9]

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Beam vacuum Magnet Cold Bore (Eurocircle WP4) [WP1]
Beam transfer devices [WP3]

Work Package objectives

Key parameters and new technologies for the FCC injection and extraction kickers and septum magnets are being studied. Technologies under study include:

- **Solid state switch** technology for FCC kicker pulse generators for reasons of high reliability, modularity, cost and maintainability:
  - Switch topology
  - Critical components for high reliability and performance
- Studies and development of existing and novel methods of shielding the kicker magnet yoke from the FCC beam
- Studies and development of a compact, or massless, septum system to provide flexibility in the design of the injection and extraction insertions, and economies in power consumption, installation cost and complexity
- Development of ultra-high-reliability triggering and synchronisation concepts for highly segmented dump systems
- Development of novel methodologies to analyse vast amounts of measurement data in order to increase system availability and reliability.
Beam transfer devices [WP3]

Status report

- **WU 3.1: Kicker Generator with Solid State Switch Technology:**
  - Testing of solid state switches and critical components – ongoing for both Marx Generator (2TUP49) and Inductive Adder (Wed. Talk).
  - Preliminary designs exist for both Marx and Inductive Adder

- **WU 3.2: Kicker Magnet R&D**
  - Preliminary calculations demonstrate need for beam screen.

- **WU 3.3: Septum Magnet R&D**
  - Lambertson based solution studied (presented FCC week 2016)
  - Massless septa and Superferric solution studies ongoing;
  - Superconducting Shield (SuShi) – in collaboration with the Wigner Institute (HU) ongoing

- **WU 3.4: Fast Electronics, Triggering and Switch Controls**
  - Studies of laser triggered thyristors ongoing
  - Development of an Artificial Intelligence prototype ongoing
Beam transfer devices [WP3]

On the way to the CDR contribution

Beam transfer challenges

- **Solid State Switch Technology for Injection Kicker Systems (6 pages)**
  - Characterization and choice of critical components
  - Marx Generator including topology for reliability
  - Inductive Adder

- **Injection Kicker Magnets (3 pages)**
  - Beam coupling impedance considerations

- **Septa topology potential and limitations (6 pages)**
  - LHC-like Lambertson solution in new extraction layout
  - RF leak field compensation
  - Massless septa study
  - Superconducting septa variants

- **Septa proposed for the FCC (4 pages)**
  - Injection
  - Extraction

- **Fast Electronic, Triggering and Switch Controls (5 pages)**
  - Technological considerations for dump switch firing
  - Machine learning for improved diagnostics and prediction
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Normal conducting magnets [WP5]

Status report

• Improved understanding of the radiation dose levels in the betatron and momentum cleaning insertions thanks to radiation monitoring carried out in 2015-2016 LHC Run and intensive modelling campaign. Two independent experimental set of data (BLM and RPL) were correlated via numerical modelling.

• Local shielding of the coils of the most exposed magnets has been designed and partly implemented during LS1, the work will be completed during LS2. High efficiency capable to reduce dose to 35%.

• Manufacturing of radiation resistant coils for LHC quadrupoles with new technology could however still be explored because it would:
  • Provide more freedom in the operation of the collimation scheme;
  • Keep safety margins in case the reality of operation will give higher radiation doses than expected from an extrapolation of the present operation;
  • Investment in know how for the future, not only the FCC but also magnets for highly radiation exposed locations as for example the target areas.
Normal conducting magnets [WP5]

FCC-ee twin design

The proposed main dipoles and quadrupoles for FCC-ee are twin designs, to provide a cost effective solution.

free field in one aperture 50% power saving
Normal conducting magnets [WP5]
On the way to the CDR contribution

NC magnet challenges

• Plan the **construction of prototypes** for several reasons, in particular:
  
  o To prove experimentally the twin configuration.

  o To assess the field quality with respect to beam physics targets, considering the low field and very elongated pole (for the dipole) and the unconventional asymmetries (for the quadrupole).

  o To push forward the integration with the vacuum chamber and its peculiar geometry.

  o As a starting point for a further optimization, in view of a series production of thousands of units.

• **Learn from the on-going studies made in the frame of HL-LHC** for the radiation resistance of coils.
Beam vacuum-induced dynamic effects [WP9]

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Beam instrumentation [WP8]

Simone Gilardoni [CERN]
Beam dumps [WP7]

Work package objectives

3 work packages:
• 7.1 Energy deposition/interaction in materials up 50 TeV
• 7.2 Thermomechanical feasibility of the FCC-hh beam dump and other critical protection devices in the extraction line
• 7.3 Research and development of a new class of materials (such as very low density carbon foams or graphite or graphite powder)

Scope:
• Engineering and conceptual design of beam dumps
• Simulation of the interaction between particle beams and matter up to 50 TeV proton beam energy (applicable also to HE-LHC)
• Research and development of advanced materials for beam intercepting devices, starting from characterization of exiting or non-conventional materials with also beam tests.
Beam dump challenges

- Introduction about challenges of dumping FCC beam
- Existing beam dump design and known operational constraints (integrity and safety aspects)
- Design choices: possible options
- FLUKA and thermo-mechanical calculations on more promising conceptual design
- Future developments:
  - Innovative designs (different dumps configurations, different absorbing material segmentations)
  - Innovative materials (low graphite, carbon foam, powders, etc.)
- Options
Beam instrumentation [WP8]

Status report

- BPMs:
  - Electronics prototype in order to measure the resolution for turn by turn measurements (single bunch) for signals levels corresponding to $5 \times 10^8$ protons measured with a 30 mm button.
  - Paper study for a BPM with 4+N sensors for interlocked BPMs.

- Transverse profiles:
  - Development from a gasjet sheet monitor to a gasjet scanner. Simulations and construction of a prototype.
  - Theoretical & experimental studies to improve halo diagnostics from a contrast ratio $10^{-4}$ to $10^{-6}$ including apodization and a semitransparent cover for the central beam. Studies of parasitic light sources and their mitigation.
  - X-ray interferometry for proton profile evaluations.

- Versatile communication link (rad-hard) based on HEP chips and fibre optics.
Beam instrumentation [WP8]

Already existing collaborations

KEK & Australian Synchrotron Collaboration:
- SR monitor collaboration for FCC-ee and FCC-hh
  - Provide the optimum technique & configuration for FCC-hh & FCC-ee SR monitors
- Design of an X-ray interferometer for measurement of small vertical beam size in FCC-ee
  - Identify beam and photon parameters at the source point for the FCC-ee
  - Characterize spectrum and angular divergence of the synchrotron radiation
  - Devise an extraction system for the synchrotron radiation
  - Optimize parameters of the X-ray interferometer
  - Develop a K-edge filter to obtain a quasi-monochromatic x-ray beam
  - Study x-ray polarization and background subtraction
  - Construction of an X-ray interferometer prototype and its testing at the Australian Synchrotron
  - Design & construction of an X-ray interferometer for proof-of-concept testing at the Australian Synchrotron

Goethe Universität Frankfurt am Main / Institut für Angewandte Physik:
- Electron beam profile monitors
  - Document parameters and performance of electron profile monitor and identify possible applications within the FCC complex
  - Design and build electron profile monitors
  - Test monitor with ion beam and quantify performance
Dr. José Miguel Jiménez (Coordinator)
CERN, Technology Department
Dr. Olivier Brunner (Deputy Coordinator)
CERN, Beams Department

Beam vacuum
Magnet Cold Bore (Eurocircle WP4) [WP1]

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Francesco Bertinelli & Cédric Garion [CERN]
Manufacturing technologies [WP4]

Scope

2 workpackages:
- 4.1: Additive Manufacturing for accelerator components
- 4.2: Additive Manufacturing for vacuum systems

Scope:
- Introduce AM as a qualified, referenced alternative for the production of accelerator components throughout laboratories world-wide,
- New materials: copper and niobium parts manufactured by Selective Laser Melting (SLM) or Electron Beam Melting (EBM) for SRF,
- Thick and leak tight coatings, joining of dissimilar metals.

External contributors:
- AIDIMME (ES): EBM copper
- Danish Technological Institute (DK): SLM copper
- Mines Paris Tech (FR)
- Suppliers of powders and AM
### Manufacturing technologies [WP4]

**Status, results and milestones**

**WP4.1: Additive Manufacturing for accelerator components**
- Benchmarking and characterisation of powders (Cu and Nb) finished
- Identified suitable suppliers of powders
- Ongoing in-depth characterisation of **EBM copper**
- Ongoing Material development for Copper
- First dissemination papers published.

**WP4.2: Additive manufacturing for vacuum systems**
- **Leak tightness** of stainless steel, titanium, aluminium and copper samples
- **Thermal outgassing** of stainless steel, titanium and aluminium samples

Next expected milestones:
- Development of **Nb** in MME AM workshop at CERN
- **Vacuum and RF** characterisation of EBM copper
- Material characterisation and optimisation of the process for SLM copper

**Next expected milestones:**
- Vacuum characterisation of **cold sprayed coatings**
- **Redesign** of a vacuum component to include AM technology

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<table>
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<tr>
<th>Pressure [mbar]</th>
<th>Time [h]</th>
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<tr>
<td>$10^{2}$</td>
<td>10</td>
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</tbody>
</table>

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![Spherical Nb powder suitable for AM process.](image-url)

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**CERN (EN-MME / TE-VSC)**

Francesco Bertinelli  
Cedric Garion

Romain Gerard  
Gilles Favre

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**FCC Week 2017**

Berlin (DE)
## Manufacturing technologies [WP4]

**Status, results and milestones**

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<th>WP4.2: Additive manufacturing for vacuum systems</th>
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<td>1. Introduction</td>
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<td>2. Powder Characterisation and benchmarking results</td>
<td>2. Vacuum performance</td>
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<td>a. SLM niobium</td>
<td>a) Leak tightness</td>
</tr>
<tr>
<td>b. SLM copper</td>
<td>b) Thermal outgassing for baked and unbaked</td>
</tr>
<tr>
<td>c. EBM copper</td>
<td>materials</td>
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<tr>
<td>4. Topics of interest for AM for accelerator components</td>
<td>3. Material development in cold spray coating</td>
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<tr>
<td>• Copper plating of AM materials</td>
<td>a. Intrinsic properties of aluminium coating</td>
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<td>• Innovative surface finish technologies</td>
<td>b. Coating on different materials</td>
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<td>• Design considerations and topology optimisation</td>
<td>4. Design of vacuum components</td>
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<tr>
<td>5. Conclusions</td>
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**Expected length:** 20 pages

**Expected length:** 15 pages

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Dr. José Miguel JIMENEZ (Coordinator)
CERN, Technology Department
Dr. Olivier BRUNNER (Deputy Coordinator)
CERN, Beams Department
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Transverse feedback system [WP6]

Scope

FCC different types of transverse feedback systems are studied in simulation:

- **FCChh**
  - **Transverse coupled bunch feedback** with options for 5 ns and 25 ns bunch spacing.
  - Based on experience from the LHC transverse feedback system (ADT) extending existing technology.
  - **Intra-bunch feedback (wide-band).**
  - Leveraging on collaboration with John Fox, SLAC-Stanford and US-LARP with prototyping for LIU SPS developments: **kicker development and signal processing.**

- **FCCee**
  - **Coupled bunch feedback, extremely fast growth rates**
  - Based on technology and experience from B-factories
Transverse feedback system [WP6]

Simulations: results achieved

- Design of feedback systems relies on macro-particle simulations that integrate beam dynamics and feedback action.
- Simulation environment developed to treat coupled bunch and intra-bunch feedbacks.
- Input: FCC impedance model.
Transverse feedback system [WP6]

Perspectives: kicker design

- R&D for SPS *intra-bunch feedback* (LIU and US-LARP supported)
  - *Faltin type kicker being built*
    (strip-line with slotted shield to beam pipe)
- Applicable to FCC intra-bunch feedback for up to 4 GHz

SPS prototyping:
J. Cesaratto et al. (SLAC), IPAC’2013
M. Wendt (CERN), IPAC’2017
Transverse feedback system [WP6]

FCCee transverse feedback

- Impedance and **Instability** estimates done
  M. Migliorati, E. Belli, Univ. Roma La Sapienza
- Strong coupled bunch feedback needed
  - **Fast rise-times of 6 turns** at operation on Z peak (45.5 GeV)
  - Extension of existing technology from B-factories
  - **Feedback design and technologies** presented at last meeting in Rome (A. Drago, LNF-INFN, Frascati)

Impedance spectrum driving resistive wall instability in FCCee
M. Migliorati et al. IPAC’17
Transverse feedback system [WP6]

On the way to the CDR contribution

<table>
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<tr>
<td>• Simulation Results with feedback for FCChh</td>
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<tr>
<td>• Kicker Design Options</td>
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<td>• Signal Processing</td>
</tr>
<tr>
<td>• Injection Damping for FCChh</td>
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<tr>
<td>• Instability mitigation</td>
</tr>
<tr>
<td>o Transverse coupled bunch instabilities for FCChh and FCCee, with fast growth rates</td>
</tr>
<tr>
<td>o Intra-bunch Feedback for FCChh: Electron Cloud and TMC feedback</td>
</tr>
<tr>
<td>• Need for continued and increased collaboration with experts in the field</td>
</tr>
<tr>
<td>o Leveraging on experience at SLAC and B-factories world-wide (LNF-IFNF Frascati, KEK)</td>
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Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]

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CERN, Technology Department
Dr. Olivier BRUNNER (Deputy Coordinator)
CERN, Beams Department

29 May'17
FCC Week 2017
Berlin (DE)
Beam vacuum - induced dynamic effects [WP9]

Scope

- WP 9.2: Find out the best vacuum system for the **FCC-ee arcs and experimental regions** in terms of performance, feasibility, and costs.

- WP 9.3: **TI-based superconducting** coatings for the FCC-hh.

- WP 9.4: **HTS coated conductors** for the FCC-hh beam screen.
Beam vacuum - induced dynamic effects [WP9]

Dr. José Miguel JIMENEZ (Coordinator)
CERN, Technology Department
Dr. Olivier BRUNNER (Deputy Coordinator)
CERN, Beams Department

WP 9.2: Vacuum system for the FCC-ee arcs and experimental regions

WP 9.3: First Deliverables achieved
- Laboratory for preparation of Ti-based
data processing and analysis
- First samples of Ti-HTS are being procured
- New large-area high-resolution Hall-probes are being manufactured
- Next Deliverable: report on precursor materials

WP 9.4: Collaboration signed, first Deliverables achieved
- Selected REBCO tapes undergoing transport measurements, including nano-engineered tapes for better pinning (higher depinning frequency)
- Development of tensile test machine started, for qualification of assembly process
- First SEY results at room temperature and cryogenic temperature
- RF test device for samples being commissioned (in partnership with Universitat Politècnica de Catalunya · BarcelonaTech)
- Next Deliverable: full definition of RF test system for small samples at 9 T

Paolo Chiggiato, Sergio Calatroni & Roberto Kersevan [CERN]
Beam vacuum - induced dynamic effects [WP9]

Next milestones

<table>
<thead>
<tr>
<th>Beam vacuum challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Update the 3D models</strong> and re-run the ray-tracing montecarlo codes for SR and molecular flow (SYNRAD+ and Molflow+, respectively), in order to obtain results consistent with those of other WPs;</td>
</tr>
<tr>
<td>• <strong>Collaboration with the MDI working group</strong> in terms of beam-impedance and also special vacuum chamber design in the vicinity of the detectors;</td>
</tr>
<tr>
<td>• Start another round of discussions with the working group dealing with <strong>FLUKA analysis</strong>, in order to get updated results for the new lattice configurations;</td>
</tr>
<tr>
<td>• Collaboration for the design of beam instrumentation is also to be started: so far no actual design neither of the thousands of BPM blocks, nor of the very delicate areas where the superconducting RF cavities will be installed has been carried out;</td>
</tr>
<tr>
<td>• Follow any special design for polarization wigglers and their attendant high-power SR fans, which were responsible for a rather large number of vacuum leaks in LEP…</td>
</tr>
</tbody>
</table>
Beam vacuum - induced dynamic effects [WP9]

On the way to the CDR contribution

Beam vacuum challenges

- Introduction (with Machine Physics issues related to vacuum)
- Synchrotron Radiation Issues
  - Power density / Photon Flux / Special areas
- Synchrotron Radiation-Induced Gas Loads
  - Distributed absorbers / Lumped absorbers
- Vacuum Chamber Cross-section and Materials: Different Options and Choice
  - Materials: Al, Cu, SS: pros and cons
  - Thin-films: NEG, TiN, amorphous carbon (α-C)
  - Clearing electrodes
- Vacuum Pumping System: Different Options and Choice
  - Distributed pumps (multi-NEG strip, SuperKEKB-like) / Lumped pumps
- Pressure Profiles
- Vacuum Components
  - Low-loss flanges / Low-loss gate valves
  - Special components: masking absorbers for SC cavities; masking for BPM blocks; masking for special components and IR area.
## Radiation Hardness Assurance [WP11]

### Scope & deliverables

<table>
<thead>
<tr>
<th>FCC Task 11</th>
<th>Deliverables</th>
<th>Month</th>
<th>By end of</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TASK 1</strong> Field conditions and radiation levels at FCC</td>
<td>D1-1. Evaluation of FLUKA models’ needs</td>
<td>M6</td>
<td>Mar’16</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>D1-2. FLUKA tuning for FCC</td>
<td>M12</td>
<td>Sep’16</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>D1-3. Agreement on FCC target radiation field/levels</td>
<td>M14</td>
<td>Nov’16</td>
<td>✓</td>
</tr>
<tr>
<td><strong>TASK 2</strong> FCC Qualification Protocols</td>
<td>D2-1. Define overall FCC qualification requirements for RHA</td>
<td>M12</td>
<td>Sep’16</td>
<td>ongoing</td>
</tr>
<tr>
<td></td>
<td>D2-2. Evaluation of current irradiation facilities and testing infrastructure</td>
<td>M20</td>
<td>May’17</td>
<td>ongoing</td>
</tr>
<tr>
<td><strong>TASK 3</strong> Equipment needs for the accelerator, detectors, service systems</td>
<td>D3-1. Identification of technologies used at FCC with their expected radiation levels</td>
<td>M14</td>
<td>Nov’16</td>
<td>ongoing</td>
</tr>
<tr>
<td></td>
<td>D3-2. Catalogue of critical equipment (technology, supplier, function, etc.)</td>
<td>M18</td>
<td>Mar’17</td>
<td>starting</td>
</tr>
<tr>
<td><strong>TASK 4</strong> Development efforts on radhard components for HL-LHC</td>
<td>D4.1 Evaluate HL-LHC VS FCC needs of rad hard components</td>
<td>M20</td>
<td>May’17</td>
<td>ongoing</td>
</tr>
<tr>
<td><strong>TASK 5</strong> New Technologies</td>
<td>D5.1 Prototype status and definition of developments linked to technologies</td>
<td>M20</td>
<td>May’17</td>
<td>ongoing</td>
</tr>
<tr>
<td></td>
<td>D5.2 Radiation tester of advanced components/systems</td>
<td>M36</td>
<td>Sep’18</td>
<td>ongoing</td>
</tr>
<tr>
<td></td>
<td>D5.3 Radiation sensor</td>
<td>M40</td>
<td>Jan’19</td>
<td>ongoing</td>
</tr>
</tbody>
</table>
Radiation Hardness Assurance [WP11]

Radiation Levels in the FCC Tunnel & Alcove

FCC FLUKA model:
- Full arc cell: 12 dipoles + 2 quadrupoles
- Latest layout of tunnel & alcove infrastructure
- Up-to-date tentative gas-density profile
- Latest design of the main dipole
- Source: Beam-gas interactions @ 50 TeV/c
- Full particle transport

Main achievements:
- Strong interaction across many areas of expertise
- Design: FLUKA simulation used for finalising the design of the tunnel and alcove infrastructure.
- R2E: assessment of the radiation levels in critical areas for electronics:
  - Dose (long term effects): below the magnet (power converter) factor ~200 LHC
  - High Energy Hadrons (Single Event Effects):
    - Tunnel: below the magnet (power converter) factor ~500 LHC
    - Alcove: Fluence ≤ RRs alcove in LHC Point IP 1/5
- Qualification requirements already beyond current availability
Deep submicron CMOS technologies (F.Faccio, G.Borghello)

CMOS transistors in sub-250nm nodes have a very thin gate oxide, almost insensitive to radiation effects (Total Ionizing Dose). However the thick lateral (STI) and spacer oxides are still prone to defect buildup that, at very large TID levels, affects the performance of short- and narrow-channel transistors.

The complex physical mechanisms of radiation effects in the STI and spacer oxides have been studied in detail in the 65nm technology chosen for HL-LHC upgrades.

Radiation-induced degradation of the on-current in transistors with sizes commonly used in digital design in 65 and 28nm CMOS technologies.

First measurements of 28nm transistors evidence a different response to TID, and an overall larger tolerance. Several 40nm and 28nm CMOS processes will be studied to extract possible trends and select the best option for ASIC design.
Radiation Hardness Assurance [WP11]
On the way to the CDR contribution

Favor a unique chapter summarizing all RHA for FCC

1. Field conditions and radiation levels at FCC (5p)
   • Documentation of Fluka models, tunnel layout and corresponding radiation maps/levels, assessment of radiation levels on critical areas for electronics.

2. Equipment needs and RHA strategies for the accelerator, particle detectors and service systems. (5-7p)
   • Catalog of technologies used at FCC and radiation levels they will be exposed to.
   • Strategies for RHA taking into account maintenance, equipment availability and reliability and remote operation.

3. Qualification Protocols (5p)
   • Definition of qualification requirements (safety factors, sample size, procedures) for components and systems, including particle detectors and FE electronics. Limitations of COTS-based designs.
   • Limitations of current irradiation facilities and testing infrastructure at CERN and available worldwide; proposal of upgrade programs for facilities at CERN.

4. Rad-hard technology trends (5-8p)
   • Communication technologies: ethernet-based, fiber optic-based and wireless solutions.
   • Miniaturization, compactness, Deep submicron CMOS technologies, On-chip optical/electrical.
   • MGy dosimetry.

5. Final summary for identified showstoppers and long-term R&D requirements (beyond CDR) (3p)
Beam vacuum
Magnet Cold Bore
(Eurocircle WP4) [WP1]

CryoPlants
efficiency [WP2]

Cryomagnet
insulation vacuum [WP10]

Beam transfer
devices [WP3]

Normal conducting
magnets [WP5]

Beam dumps [WP7]

Beam instrumentation [WP8]

Robotics [WP14]

Architecture for magnets & machine protection [WP12]

Manufacturing technologies [WP4]

Transverse feedback [WP6]

Surface-Vacuum parameters for beam-induced effects [WP13]

Radiation Hardness of Electronics [WP11]

CryoPlants induced dynamic effects [WP9]

Beam vacuum
Magnet Cold Bore
(Eurocircle WP4) [WP1]

CryoPlants
efficiency [WP2]

Cryomagnet
insulation vacuum [WP10]
Architecture for magnets & machine protection & interlocks [WP12]

Powering and protection architecture for high field circuits

Studies of the layout of main dipole circuits

Proposal for FCC Powering Sectors (PS)

Study of possible circuit layouts to reduce the stored energy and limit the voltage to ground during the fast power abort
Ongoing studies on Machine Protection of the FCC-hh - execution time for a beam dump

Studies on Beam Impact & Machine Protection of the FCC-hh

Top critical equipment failure modes (to be continued)
Beam size $\sigma_{x,y} = 0.2$ mm, beam energy from 50 MeV to 50 TeV.

For each energy, another two typical beam sizes were studied, in addition to 0.2 mm.

The integral study provides a reference for quick assessment of beam impacts on ‘targets’ in FCC-hh and its injector chain.
Beam vacuum induced dynamic effects [WP9]

Manufacturing technologies [WP4]

Transverse feedback [WP6]

Radiation Hardness of Electronics [WP11]

Surface-Vacuum parameters for beam-induced effects [WP13]

Architecture for magnets & machine protection [WP12]

Robotics [WP14]

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Cryomagnet insulation vacuum [WP10]

Beam transfer devices [WP3]

Normal conducting magnets [WP5]

Beam dumps [WP7]

Beam instrumentation [WP8]

Machine tunnels + bypass galleries

Detector caverns + shafts

Service caverns + access shafts

Electrical arcoves

Connection tunnels
Surface-Vacuum parameters for beam-induced effects [WP13]

On the way to the CDR contribution

<table>
<thead>
<tr>
<th>Scope</th>
<th>Surface-Vacuum parameters challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Designs of beam pipes and their vacuum systems are based on simulations on the thermal, mechanical, gas density, electron cloud and impedance behaviours.</td>
<td></td>
</tr>
<tr>
<td>• Simulations need precise inputs and surface characteristics are those known with the lowest degree of precision with respect to thermal and mechanical properties.</td>
<td></td>
</tr>
<tr>
<td>• Desorption properties: Electron, ion, and photon induced desorption at different temperatures and gas adsorption loads.</td>
<td></td>
</tr>
<tr>
<td>• Thermal properties: Emissivity and photon interaction (reflection and absorption)</td>
<td></td>
</tr>
<tr>
<td>• Electron cloud: photoelectron yield and secondary electron yield as a function of surface temperature, gas load, electron dose and applied magnetic field; and SE energy distribution.</td>
<td></td>
</tr>
<tr>
<td>• Evaluation of set-up at CERN and propose internal investment or external collaboration to cover the whole spectrum of measurements.</td>
<td></td>
</tr>
<tr>
<td>• Select the materials and surface treatments of importance for the FCC-hh.</td>
<td></td>
</tr>
<tr>
<td>• Identification of key simulation parameters and analysis of impacts for the outcome of their simulations.</td>
<td></td>
</tr>
<tr>
<td>• Induce desorption at different temperature (whenever possible and relevant) for the selected materials.</td>
<td></td>
</tr>
<tr>
<td>• Reflectivity of FCC-hh synchrotron radiation.</td>
<td></td>
</tr>
<tr>
<td>• PEY and SEY, possibly angle resolved, at variable temperature, magnetic field, gas load and electron dose.</td>
<td></td>
</tr>
</tbody>
</table>
Beam vacuum
Magnet Cold Bore
(Eurocircle WP4)
[WP1]

CryoPlants
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[WP12]

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[WP11]

Normal conducting magnets
[WP5]

Beam transfer devices
[WP3]

Beam dumps
[WP7]

Beam instrumentation
[WP8]

Robotics
[WP14]
Remote handling impact on Accelerator design & infrastructures [WP14]

Scope and resources

3 work packages:
• 14.1 Integration study for the remote handling/manipulation
• 14.2 Development of the remote handling concepts
• 14.3 Dissemination of guidelines for best practice on mechanical design and process optimizations compatible with robotic tele-manipulation

Scope:
• Evaluate the compatibility of the LHC integration with remote handling and propose a new concept of acceleration-infrastructure interface which will ease this remote handling.
• Analyze the methods and the procedures to be used in the design of new equipment or preparation of dismantling and installation of new devices in order to optimize their dismantling, installation, maintenance, and operation, including exchange, handling and transport activities with respect to individual and collective dose to personnel.
• Definition of guidelines for the design of novel devices and procedures will be focused on the compatibility with future robotic and remote handling solutions for tele-operation

Timeline
• 2018: review of existing experience on accelerator complex. Definition of work plan for following years.
• 2019: Guidelines definition for generic HW design. Simulation of most representative cases for Robotic interventions FCC specific.
• Beyond 2019: Technology revision, R&D. By 2025 technology should be defined to follow installation.
Remote handling impact on Accelerator design & infrastructures [WP14]

On the way to the CDR contribution

<table>
<thead>
<tr>
<th>Next steps</th>
<th>Remote handling challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 1:</strong> Development of the remote handling concept, including:</td>
<td>• Robotics for interventions in harsh environment</td>
</tr>
<tr>
<td>• Identification of possible robotic solutions compatible with the needs</td>
<td>• Existing applications, technologies handling technologies in accelerator domain</td>
</tr>
<tr>
<td>of future remote handling needs in FCC. These solutions will be</td>
<td>• FCC specific case: robotic systems for 100 km machine</td>
</tr>
<tr>
<td>then customized for each common needs, i.e. design of specific tools,</td>
<td>• Guidelines for HW design for robotic installation and maintenance</td>
</tr>
<tr>
<td>integration of the robotic solutions for the specific interventions.</td>
<td>• Which robotic technologies</td>
</tr>
<tr>
<td><strong>Task 2:</strong> Integration study for the remote handling/manipulation</td>
<td>• RP and geological/geometers survey</td>
</tr>
<tr>
<td>• Integrate the remote handling/telemanipulators in the tunnel cross</td>
<td>• Safety aspects, availability and reliability</td>
</tr>
<tr>
<td>section to reserve space.</td>
<td>• Future of robotics</td>
</tr>
<tr>
<td><strong>Task 3:</strong> Dissemination of guidelines:</td>
<td>• Robotic support for Fire-Brigades/Safety related interventions</td>
</tr>
<tr>
<td>• Dissemination of guidelines for best practice on mechanical design and</td>
<td>• Robotics for reconnaissance</td>
</tr>
<tr>
<td>process optimizations compatible with robotic tele-manipulation</td>
<td>• interventions and human guidance</td>
</tr>
<tr>
<td></td>
<td>• human health monitoring at distance</td>
</tr>
</tbody>
</table>
Closing remarks

- Progress made towards identification of critical items…
  - It’s an iterative process… decided to add *Surface-Vacuum* and *Robotics* work packages

- Scope, deliverables and milestones were compiled…
  - and *adjusted for Berlin WS in view of the CDR*.

- CERN Resource impact evaluated…
  - and *commitments have been confirmed*.

- Scenario “à la carte“ is favoured, come and talk with us… never too late !
  - for once, Technologies allow *conceptual dreams*.

- Same dynamic observed with Partners…
Dream the next generation of Accelerator Components… take off!

Join us in Technologies! …we’re Special!

FCC Special Technologies
Work Package

Dr. José Miguel JIMENEZ
Dr. Olivier BRUNNER

Thanks to all contributors…