Special Technologies Work Package

FCC Special Technologies
Mandate

- Study the special technologies: this includes the conceptual aspects required for the FCC accelerator as well as the identification of the possible design and performance limitations.
- Identify the challenges and the opportunities for technological breakthroughs and define the R&D program:
- Set up collaborations to address standard FCC issues and R&D opportunities
  - Understand impacts of technologies
  - Prioritize R&D topics
  - Define scope, schedule, cost guidelines
  - Report on Specific Technologies R&D Programs

- The R&D activities will be followed up in the framework of the Accelerator R&D Work Package which is sub-divided in three Sub-Work Packages:
  - High field Magnet Program
  - Superconducting RF Program
  - Special Technology Program (except Magnet and RF)

FCC Special Technologies
Organisational matters

- Two follow-up meetings will be organized:
  - The Special Technologies Conceptual Design WP Meeting
    - Chairman*: José Miguel JIMENEZ (CERN, TE Department)
    - Deputy Chairman*: Daniel Schulte (CERN, BE Department)
    - Expected frequency: every 2 months
  - The Special Technologies R&D WP Meeting
    - Chairman*: José Miguel JIMENEZ (CERN, TE Department)
    - Deputy Chairman*: Olivier Brunner (CERN, BE Department)
    - Expected frequency: every month

*in the framework of the pre-study phase

FCC Special Technologies
List of technical systems for FCC-hh and FCC-ee

- Technologies that require R&D
- Beam diagnostics requirements and conceptual design
- Beam transfer elements requirements and conceptual design
- Collimation systems and absorber requirements and conceptual design
- Control system requirements
- Dump and stopper requirements and conceptual design
- Element support, survey and alignment requirements and concepts
- Machine detector interface system needs and conceptual design
- Machine protection system requirements and conceptual design
- Normal magnet requirements and element conceptual design
- Power converter requirements and conceptual design
- Quench protection and stored energy management requirements and concepts
- RF system requirements and conceptual design
- Superconducting magnet and cryostat requirements and conceptual design
- Proximity cryogenics for superconducting magnets and RF
- Vacuum system requirements and conceptual design
- Shielding

FCC Special Technologies
Proposed Action Plan

- WP Administrative and Collaboration aspects
  - Contact CERN Groups
    - Miguel or Olivier will meet Group Leaders / Representatives (Deadline: April'14)
  - Complete / modify the detailed scope of each WU (including milestones and deliverables)
    - Deadline: April'14
  - Identify potential contributors:
    - From CERN (please name the link person)
      - Deadline: Mid-May'14
    - From external institutes
      - Send emails with proposals: May'14
      - Try to get answers: Mid-July'14
  - Iteration with Project Management and CERN participants
    - Report to Accelerator Coordination meeting
  - Define the resources for the WU's
    - Fellows, TS, Docs by September'14
- Special Technology Work Package meeting
  - Kick-off meeting in May'14
- Special Technology R&D meeting
  - Kick-off meeting in May'14

FCC Special Technologies
Work Units details (1)

- Technologies that require R&D
  - Identify all the technologies that require specific R&D (e.g. RF system (beam power, high gradients, klystron efficiency) and superconducting magnets)
  - Identify breakthrough technologies and show-stoppers.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Beam diagnostics requirements and conceptual design
  - Explore the beam instrumentation and diagnostics requirements and identify critical issues. Estimate the required number of components (e.g. BPMs) and their performance in terms of resolution and dynamic range.
  - Design study of machine protection components (e.g. beam loss monitors).
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Beam transfer elements requirements and conceptual design
  - Define the requirements and parameters for the beam transfer elements (injection and dump kickers, electrostatic separators). Provide design studies of the critical elements.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

* issues only linked to FCC-hh or FCC-ee shall be differentiated.

FCC Special Technologies
Work Units details (2)

- Collimation systems and absorber requirements and conceptual design
  - Define the number of components and the power loads for collimators.
  - Explore potential materials for collimators and define mechanical requirements for collimators.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Control system requirements
  - Define the needs in terms of network, data transfer rates and logging volumes.
  - Define requirements for synchronization.
  - WU contact Person: (J. Gutleber)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Dump and stopper requirements and conceptual design
  - Define the requirements in terms of energy/power deposition on the dumps and other beam stopper devices. Explore possible designs of dumps and absorbers.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

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FCC Special Technologies
Work Units details (3)

- Element support, survey and alignment requirements and concepts
  - Define the requirements in terms of alignment for beam line elements and experiments. Define needs for active alignment and stabilization.
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Machine detector interface system needs and conceptual design
  - Define the technical requirements of the elements needed at the machine-detector interfaces (e.g. synchrotron radiation masks, vacuum pumping).
  - Address the maintenance and safety aspects.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Machine protection system requirements and conceptual design
  - Define requirements and explore the design of the machine protection elements.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

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FCC Special Technologies
Work Units details (4)

- Quench protection and stored energy management: requirements and concepts
  - Define the requirements for the quench protection system of the super-conducting magnets for the low-beta insertions.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Normal magnet requirements and element conceptual design
  - Define the requirements in terms of peak fields or peak gradients and length of the normal conducting magnets. Explore the design of the main magnets, in particular for the arc sections and long straight sections.
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Power converter requirements and conceptual design
  - Define requirements in terms of current, voltage and stability of the power converters for the collider and the booster ring.
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

* issues only linked to FCC-hh or FCC-ee shall be differentiated.

FCC Special Technologies
Work Units details (5)

- Proximity cryogenics for superconducting magnets and RF
  - Define the requirements off the cryogenic system for the RF systems, the low-beta quadrupoles and the cryomagnets.
  - Address the possible impact of the beam screen operating temperature and the required stability.
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Vacuum system requirements and conceptual design
  - Define the requirements and explore the design of the vacuum system for the arcs and the straight sections. The design must take into account the large amount of synchrotron radiation and the possible shielding of the vacuum chamber as protection of tunnel equipment. It has also to mitigate beam-induced dynamic effects (pressure blow-up, electron and ion clouds).
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Shielding
  - Define and explore the design of static shielding for synchrotron radiation inside and outside of the vacuum chamber.
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

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FCC Special Technologies
Work Units details (6)

- RF system requirements and conceptual design
  - *"missing description of the scope of the conceptual design part"*
  - WU contact Person: (O. Brunner)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*
- Superconducting magnet and cryostat requirements and conceptual design
  - *"missing description of the scope of the conceptual design part"*
  - WU contact Person: (J.M. Jimenez)
    - *CERN contact Person:*
    - *CERN Participants:*
    - *Potential collaborations:*

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Challenges and expected Breakthroughs
Cryogenics

- Challenges
  - Study and development of larger cryoplants:
    - New type of cycle compressors ? (centrifugal vs screw)
    - New refrigeration cycle ? (higher HP pressure)
  - Study and development of larger cold-compressor systems (10 kW range):
    - Larger cold compressors development ?
    - Operation with parallel cold compressor trains ?
  - Management of He inventory and He losses, in particular helium release during magnet resistive transitions and cold buffering
  - Higher availability of cryo-systems
- Breakthroughs
  - The beam screen cooling:
    - High heat deposition: up to 44 W/m per aperture
    - Integration of the cooling circuits in a narrow space.
    - Control of the 40-60 K temperature level with high dynamic range (up to 10) alternative cooling method (with neon…)

- *Please refer to the talk given by Laurent TAVIAN Friday morning Session*

Challenges and expected Breakthroughs

Radioprotection and Radiation

- Requirements
  - Radioprotection
- Challenges
  - Radioprotection has to be considered in early stages of the design due to implications of normative regulations
    - Limit number of access pits / Hard-wire cabling of safety signals / Radiation access veto / …
  - Remote Handling and Telemanipulation: here we need a giant leap in both technology and culture.
    - The machine should be designed such that most of the standard maintenance can be performed with cots robots. All machine components shall have to be designed to be maintained/repaired/removed remotely.
- Breakthroughs
  - Material developments to find low-activation alternatives
  - Combine machine protection (BLM) with dose rate instrumentation…

Challenges and expected Breakthroughs
Resistive Magnets

- Requirements
  - Decide which operating mode is used since having huge implications on magnets (and power converters)
    - Continuous, cycled, pulsed, fixed or variable energy
    - Just dedicated to fill the FCC or also for other purposes…
- Challenges
  - Energy efficiency vs flexibility of the machine vs cost optimisation
- Breakthroughs
  - Increase the radiation hardness of the coil insulation
    - A gain of a factor 10 in radiation hardness (from 20 MGy to at least 200 MGy) appears on reach, for example by using mica + cyanate esther systems or other alternatives…
    - Local shielding included at the design stage…
  - Need a proper technological development in particular in the processing/manufacturing techniques and in the experimental validation of the radiation hardness.

Challenges and expected Breakthroughs
Beam Instrumentation

- Challenges
  - BPMs and BLMs
    - Thousands of them needed all along the ring with an order of magnitude to be gained in resolution, reliability and availability
    - Operational constraints
- Breakthroughs
  - Non-invasive emittance measurements are already a challenge in the LHC it will be even more so for FCC.
    - Synchrotron light: will have to go for X-ray imaging (diffraction already limited in the visible at 7TeV)
    - Gas targets: being investigated in the LHC (ionisation profile monitors and the beam gas vertex detector) but concerns with vacuum compatibility (radiation)
  - Maintenance, electromagnetic compatibility (EMI), radiation hardness
    - Minimal tunnel electronics with regrouping them at surface with an extensive use of fibre optics.

Challenges and expected Breakthroughs
Beam Transfer Elements *(1/2)*

- Requirements
  - Facing 3+ TeV p+ extraction/injection and TLs, 50 TeV beam dump, top-up lepton injection, injection and dump kicker protection systems, … are challenges much higher than ever reached.
  - Scaling from the existing technology will require an improvement in reliability by more than an order of magnitude… a real challenge!
- Challenges
  - Scaling of existing technologies would imply an improvement by more than one order of magnitude of the reliability / availability…
- Breakthroughs
  - Injection / Extraction insertions
    - Special injection/extraction insertion magnet concepts with split quadrupole/dipole, coil/yoke beam passages, superconducting (massless?) septa, very slim quadrupole cold-mass and cryostats, very large aperture quadrupoles, opposite-field septa, ...);
  - High current semiconductor switches
    - Design and construction of very fast high-current semiconductor switches (sub-us turn on, >20 kA, x15 voltage range, reliability, radiation resistance, ...);
  - Beam absorbers
    - Shall go for sacrificial beam absorbers with optimised materials, failure modes, exchange methodology, vacuum, absorption, diagnostics, …

Challenges and expected Breakthroughs
Beam Transfer Elements *(2/2)*

- Less “breakthrough” but still appearing as showstoppers…
  - Kickers
    - Impedance shielding (thin films, wires, active current elements, geometry, ...)
    - Ferrite cooling technologies (solid-state, thermal design, surface emissivity, ...)
    - Electron cloud (SEY) and UFOs
  - High saturation, high temperature ferrite materials
  - Ultra-high reliability system design (redundancy, failsafe modes, diagnostics, testing, QC, ...)
  - Thermomechanical design and fatigue mitigation for fast-repetition rate, high field pulsed magnets
  - Burst-mode bunch-to-bucket transfer systems (CLIC inductive adder concept...)
  - Diluter materials and designs for dumps and transfer line collimators (low density, high robustness, magnetised, optics insertions, ...)
  - Thermal, mechanical, electrical design for high-strength in-vacuum pulsed magnets (impedance, e-cloud suppression, heating mitigation, beam losses, ..)

Challenges and expected Breakthroughs

Vacuum – for Beams *(1/2)*

- Challenges
  - Vacuum compatibility of beam equipment (collimators, beam instrumentation,…)
  - UFOs at design stage and during installation in the tunnel: cleanroom” type installation
  - Definition of the Operating temperature of the beam screen
    - Hydrogen pumping, beam lifetime, HOM, Impedance, dB/dt,…
- Breakthroughs
  - New beam screen approach compatible with:
    - Beam-induced dynamic effects
      - Electron and ion clouds, pressure bursts, …
    - Temperature transients during the ramp in energy…

Challenges and expected Breakthroughs
Vacuum – for thermal insulation *(2/2)*

- Challenges
  - Leak tightness: reliability issues since about 4 times more sealing and welding "length"…for the same reliability!
    - 500 km of welds!
    - 100 km of elastomer seals!
  - Mechanical design and compatibility with superfluid helium
    - Interconnection bellows, flexible links and bellows
      - Multiplies technology to be optimised!
- Breakthroughs
  - Sealing technologies, reliable and compatible with radiation
  - Helium pumping (trapping) to mitigate leaks appearing during operation.

Technical Challenges and Breakthroughs for the FCC-hh

Radiation to Electronics (R2E)

- Challenges
  - Radiation levels will roughly scale with energy
    - Shielding issues in particular integration
      - To reduce by a factor ten one needs approximately 80 cm of concrete plus 40 cm of iron
  - Finding the right balance between number of alcoves for controls and power electronics, and massive development of rad hard electronics.
- Breakthroughs
  - Electronics to remain in the tunnel improved by at least a couple of order of magnitudes.
  - Radiation hardness of miniaturized electronics, which normally would have an increased sensitivity.

Technical Challenges and Breakthroughs for the FCC-hh
Collimation Systems *(1/2)*

- Challenges
  - New optics concepts and IR layouts to be developed in order to achieve at least 20x better cleaning with larger collimator gaps
    - Reduced impedance and operational tolerances
    - We might need more than 2 collimation IRs…!
  - Inter-alignment: if the hierarchy of different collimators depend on micrometer or submicrometer alignment from collimator to collimator is necessary, it will be necessary to further develop position measurement and control solutions based on new technologies (piezo, optical, etc…)
  - Assuming that one can clean the primary halo, stopping the secondary halo will be a challenge. Optics and collimation shall have to check that one can safely clean the beam from secondaries, or invent a new strategy.
  - Operational aspects: how often will we have to change the collimators? Radiation issues? Remote handling? disposable collimators should be developed (quick and fully automated collimator replacement)
  - FLUKA models are already reliable for most purposes related to the design of the machine. Will need some scaling and integration of new models derived from data published by LHC experiments (this work actually already started).

Technical Challenges and Breakthroughs for the FCC-hh

Collimation Systems *(2/2)*

- Breakthroughs
  - New collimator design to withstand much larger energy loads with reasonable transient deformation and no permanent damage.
  - Associated to that, some breakthrough is most likely needed in collimator material science
    - Compatible with Impedance and Vacuum requirements
    - Explore new collimation concepts like crystal collimation. Crystal collimation will however push even further the material challenge.
  - Manufacturing tolerances: micrometer or submicrometer planarity will be required. Knowing that the present 20 micron planarity is already at the edge of what is available in industry, it will probably be necessary to develop a special temperature and vibration controlled machine for flattening all the surfaces facing the beams and provide it to the companies that will build collimators

Challenges and expected Breakthroughs

Major issues not necessarily expected: Survey

- Requirements
  - Determination of a new reference system which will be used to transfer the coordinates calculated by the physicists in a Cartesian XYZ system into an XYH coordinates system taking into account the shape of the earth
    - Is the actual ellipsoid chosen to represent the shape of the earth accurate enough ?
    - And the deviation of the vertical generated by the lake and the mountains (Jura, Salève, Vuache)…
- Challenges
  - Geodesy and Survey in a 100 km ring passing under a lake and/or mountains needs to be worked out… where is our reference?!
- Breakthroughs
  - Learn from major civil engineering projects… and integrate accelerator specificities:
    - Operational aspects : regular realignments, accessibility of components, time constraints, radiation issues and associated shielding, …

Special Technologies – Challenges

Special Technologies R&D
HORIZON 2020 Long Listing

- Beam Vacuum
  - Topic 1: New beam screen approaches compatible with beam-induced dynamic effects (electron and ion clouds, pressure bursts, …), beam screen shielding and heat load evacuation and temperature transients during the ramp in energy.

Special Technologies R&D
Long Listing (1)

- Radioprotection
  - Topic 1: Development and qualification of a radiation monitoring system for very high energy, mixed radiation fields (= development of detectors) for very large accelerators (= safe alarm and data transmission with minimum of hardwiring).
  - Topic 2: Development of a method for full radiological characterization of material at the exit of the radiation area (only dose rates are presently measured at the exit of the radiation areas – in future, a system should allow to determine the complete inventory of all nuclei (isotopes and activity)
- Cryogenics
  - Topic 1: R&D on large refrigeration capacity. Development of a refrigeration cycle using new refrigerant based on Nelium (mixing of Helium and Neon) for the cooling of the beam screens and HTS leads. New types of cycle compressors can be used improving the overall efficiency of the process.
  - Topic 2: R&D on large helium refrigerator (50 - 100 kW @ 4.5 K). Probably in collaboration with Air Liquide and Linde.
  - Topic 3: R&D on large superfluid helium refrigeration (~10 kW @ 1.8 K). Development of larger cold compressors and or study of operation with parallel cold-compressor trains.
  - Topic 4: R&D on improvement of cryoplant reliability and availability (from 99.4 to 99.8 %)
  - Topic 5: R&D on beam screen cooling with Neon or Nelium.
  - Topic 6: R&D on large cooldown and warm-up units (3 MW @ 80 K).
  - Comments: du CEA Grenoble et le WUT qui sont intéressés à collaborer à cette étude mais si possible dans le cadre de H2020
- Warm magnets
  - Topic 1: Increase the radiation hardness of the coil insulation with the objective to gain at least a factor 10 in radiation hardness in an aggressive environment with ozone.

Special Technologies R&D
Long Listing (2)

- Beam instrumentation
  - Topic 1: Non-invasive emittance measurements using Synchrotron light in the X-ray imaging and gas targets.
  - Study the feasibility of using radiation hard electronic sensors coupled with fibre optic lines.
- Beam Vacuum
  - Topic 1: New beam screen approaches compatible with beam-induced dynamic effects (electron and ion clouds, pressure bursts, …), beam screen shielding and heat load evacuation and temperature transients during the ramp in energy.
  - Topic 2: Research of alternative materials with a better radiation activation "signature" and similar mechanical / thermal / electrical performances and alternatives for Beryllium beampipes and windows.
  - Topic 3: Pressure sensors with radiation hard electronic converters coupled with fibre optic lines.

Annexes

FCC R&D on Special Technologies
High Field Magnets (very preliminary)

- 16 T Superconducting Magnet Program
  - Accelerator magnet design study for hadron collider
  - Nb3Sn material R&D
  - 16 T short model construction
  - 16 T support technologies
  - Magnet/collider integration studies
  - 20 T Superconducting Magnet Program
  - 5 T HTS insert
  - HTS Material R&D
  - 20 T magnet design
- Injector/Booster Magnet Program
  - Superferric HTS magnet
  - Superferric HTS short model
- Performance of ramped SC magnets

FCC R&D on Special Technologies
100 MW RF Program (very preliminary)

- Cavity design
- Optimisation of cryogenic power consumption
- Multi-beam klystron demonstrator
- Klystron working point for optimum efficiency
- Cryo-module and ancillary systems design
- Specific Technologies Program
- More efficient, compact and higher capacity helium cryo-plants
- Non conventional cryogen mixtures for efficient refrigeration below 100 K

FCC R&D on Special Technologies
Special Technologies (except RF & High Field Magnets)

- Cryogenics
  - More efficient, compact and higher capacity helium cryo-plants
  - Non conventional cryogen mixtures for efficient refrigeration below 100 K