Technical Challenges and Breakthroughs for the FCC-hh (mostly valid for FCC-ee and FCC-he)

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Main topics

- Introduction
- Items included in "Special Technologies"
- Challenges and expected Breakthroughs
- Setting Collaborations…

Many thanks to CERN Colleagues and to the Coordination Committee for the input.

Introduction

- Special technologies are fundamental for this study

  Need to identify the challenges, the showstoppers…

  …and the opportunities for technology breakthroughs.

  This last point will complement perfectly the Physic Cases to get an approval for the next step…

  …and these are the domains where we need your help.

Items included in "Special Technologies"

Using the preliminary WBS structure as guidelines…

Technical systems
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 and alignment requirements and conceptual design
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 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

Items included in "Special Technologies"
…with some more details… *(1/3)*

- Technologies that require R&D
  - Identify all the technologies that require specific R&D. Already identified the RF system (beam power, high gradient and klystron efficiency) and superconducting magnets.
  - Special technologies could also require R&D when looking forward to breakthrough or identified as show-stopping.
- Beam diagnostics
  - Define the needs for the core beam instrumentation. Estimate the required number of components (for example BPMs) and their performance in terms of resolution and dynamic range. Consider including machine protection components like beam loss monitors.
- Beam transfer elements
  - Define the requirements and parameters for beam transfer elements (injection and dump kickers, electrostatic separators). Study the design of those elements.
- Collimation requirements
  - Define the number of components and the power loads for collimators. Explore potential materials for collimators. Define mechanical requirements for collimators.
- Control system requirements
  - Define the needs in terms of network, data transfer rates and logging volumes. Define requirements for synchronization.
- Dump and stopper requirements
  - Define the requirements in terms of energy/power deposition on the dumps and other beam stopper devices. Explore possible designs of dumps and absorbers.

Items included in "Special Technologies"

…with some more details… *(2/3)*

- Element support and alignment requirements
  - Define the requirements in terms of alignment for beam line elements and experiments. Define needs for active alignment and stabilization.
- Machine detector integration
  - Define technical requirements for elements that are required at the interface of machine and detector, like synchrotron radiation masks, vacuum pumping and maintenance safety aspects.
- Machine protection
  - Define requirements and explore the design of the machine protection elements.
- Normal magnet requirements
  - Define the requirements in terms of peak fields or peak gradients and length of the normal conducting magnets. Explore the design the main magnets, in particular for the arc section and long straight sections.
- Power converter requirements
  - Define requirements in terms of current, voltage and stability of the power converters for the collider and the booster ring.

Items included in “Special Technologies”
…with some more details… *(3/3)*

- Quench protection
  - Define the requirements for quench protection of the super-conducting magnets for the low-beta insertions.
- Cryogenics
  - Define the requirements on the cryogenic system for the RF, the low-beta quadrupoles and cryomagnets. Impact of beam screens operating temperature and required stability.
- Vacuum system
  - 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).
- Shielding
  - Define and explore the design of static shielding for synchrotron radiation inside and outside of the vacuum chamber.

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

- 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 (>16’000?) 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 (8GJ beams) and dump kicker protection systems,… are much higher than ever reached.
- Challenges
  - Scaling from the existing technology will require an improvement in reliability / availability by more than an order of magnitude… a real challenge!
- 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, kickers, beam absorbers,…
  - 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, …
    - Beam screen shielding and heat load evacuation…
    - Temperature transients during the ramp in energy…
  - Alternative materials (or alloys) with a better radiation activation "signature" and similar mechanical / thermal / electrical performances… including Beryllium beampipes ad windows.

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?
  - Pressure sensors with radiation hard converters and fibre optics…
    - Multiplexing of signal?

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 *(1/3)*

- 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… 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.

Technical Challenges and Breakthroughs for the FCC-hh

Collimation Systems *(2/3)*

- Challenges (cont.)
  - 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 *(3/3)*

- 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?!

Setting Collaborations…

- Range of technologies to be covered is wide

and

- We need be on time within 3 years with the CDR…

- Thus, we would like to focus on:
  - Identified showstoppers.
  - Required technological breakthroughs.

…an evaluation will quickly be made to address and assess the required R&D levels.

We need you on-board!

Willing to take part to the FCC Conceptual Design Report…

Interested by Technologies, please send an email with details or questions to…

- FCC-technologies-hh for the FCC hh
- FCC-technologies-ee for the FCC ee
- FCC-technologies-he for the FCC he

…we'll then come back to you with answers / clarifications

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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, …