



Status of the MDI for FCC-ee

Manuela Boscolo

INFN Laboratori Nazionali di Frascati, Italy

Fourth US FCC meeting

SLAC

8 - 11 September 2026

Outline

- New MDI organisation for the RDP
- IR optics highlights
- Beam backgrounds highlights
- Technological Systems
- Alignment
- Integration
- Outlook

New MDI organisation for the RDP

To align with the overall FCC Reference Design Phase organisation, the MDI activities are **thematically grouped into five Work Packages**. This new organisation will facilitate broader international participation, optimise CERN's contribution, and ensure the timely delivery of the highest-priority Reference Design Phase objectives by the end of 2027:

- Consolidation of the project baselines
- Demonstration of design compliance with the project performance requirements
- Increase of the maturity level for the various designs from feasibility study and reduction of the technical and financial risks
- Potential impact on civil engineering for underground caverns and surface sites.

The work of the five thematic Work Packages will be coordinated by dedicated Leaders under the guidance of the MDI Coordinators. The WP Leaders will ensure the overall coherence of the programme, foster harmonisation across the transversal MDI activity, and minimise duplication of effort.

New MDI organisational structure

Will interface with, and report progress also to

MDI Coordination

*Manuela Boscolo,
Fabrizio Palla, and a
technical coordinator
from CERN*

WP 1

IR optics and Beam dynamics

Collider and booster design pillar

WP 2

Detectors and beam induced backgrounds

PED & Collider and booster design pillars

WP 3

Accelerator technical systems

Accelerator Technical systems pillar

WP 4

Metrology, Alignment and adjustment strategy

Accelerator Technical systems & System
Engineering Project Integration pillars

WP 5

Global integration studies for MDI, Detectors and
Experimental caverns

System Engineering Project Integration & PED
& Technical Infrastructure

MDI coordination of 5 work packages

WP1 – IR Optics and Beam Dynamics

- Optimise the IR optics for the minimisation of the synchrotron radiation levels in the interaction region and detector environment. Definition of the final-focus quadrupole systems
- Define baseline detector-field compensation scheme. Validate the detector magnetic field.
- Specify the optics correction elements.
- Definition of permissible field errors, alignment tolerances and stability requirements to ensure achievement of design luminosity
- Optics correction. Develop a beam-based alignment procedure for the IR quadrupoles
- Requirements and specifications of fast IP collision feedback
- Evaluate the various sources of IR heat loads

WP2 – Detectors and beam induced background

- Inner Detectors
 - Integration concepts for inner detectors and vacuum chamber
 - R&D plan
- Beam-Induced Backgrounds and Shielding
 - Accelerator-to-detector simulation workflow
 - Consolidate realistic MDI geometry models
 - Single beam losses and synchrotron radiation, and transport into detector systems
 - Beam-beam backgrounds and transport into detector systems
 - Optimise IR collimators, shielding, masking, and beampipe radius
 - Following detector background estimates of collision debris, determine shielding requirements for IR magnets.
 - Evaluate TID and fluence for detectors and accelerator systems

WP3 – Accelerator technical systems

- Design of final focus superconducting magnets
- Design of the cryogenic systems
- Design of the beam vacuum systems
- Design of the beam instrumentation
- Beamstrahlung monitor
- Radiation studies and conceptual Radiation shielding design
- R&D plan

WP4 – Metrology, alignment and adjustment strategy

- Alignment strategy
- Characterization of the various sources of instability
- Structural analysis methodology
- Support structures, positioning systems
- R&D plan

WP5 – Global integration studies for MDI, Detectors and Experimental cavern including infrastructure

- MDI systems static and dynamic envelopes
- Global experimental cavern integration
- MDI and detector assembly/disassembly scenario
- Assessment of removal/installation of cavern vacuum chambers
- Proof of concepts of MDI Far End vacuum supporting structures

Organisation, key roles of MDI coordinators

- Establish and confirm **Requirements, Parameters, Deliverables, Schedule and Work Package Descriptions (incl. resource estimates)** in collaboration with the FCC pillar leaders concerned.
- Together with Pillar coordinators concerned, **setup the work packages, including integration of external contributors to MDI.**
- **Coordination and guidance of technical work** executed through the 5 WPs to assure harmonized advancement and solution of incompatibilities, optimisation of parameters and choice.
- **Steering of the work** must be done **ALWAYS** via MDI coordinators.
- MDI WP Leaders nominations in progress.

WP1 IR Optics and Beam Dynamics

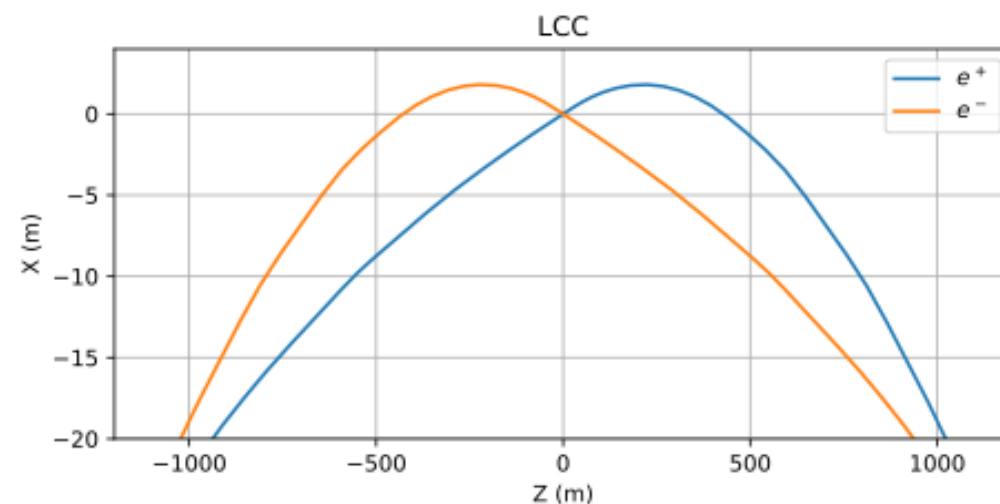
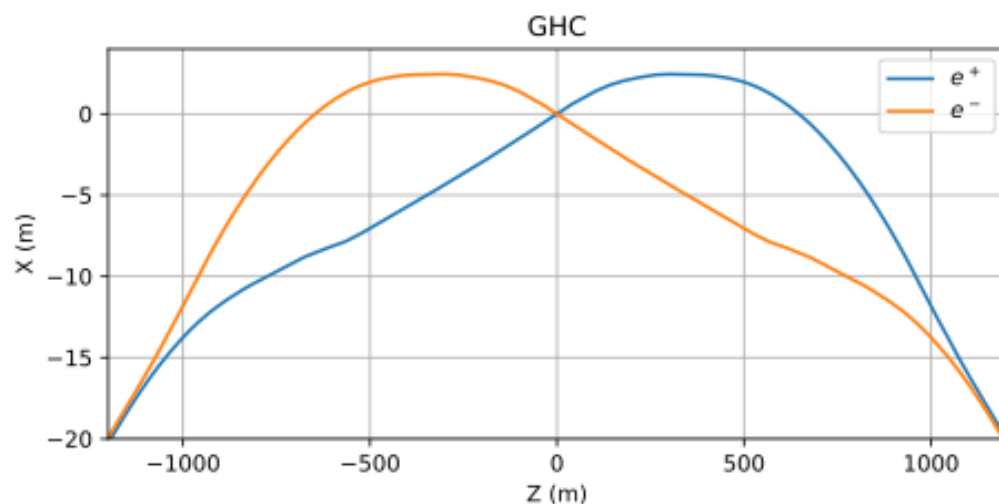
IR optics highlights

- In March 2026 the **FCC-ee Optics Evaluation review** established the **LCC Optics** (by P. Raimondi) as the new baseline.
- **L^*** was increased from 2.2 to **2.4 m** following the requirements of the MDI integration studies to allow for more radial space at the entrance of QC1, as required by the cryostat layers.
- As a drawback for the L^* increase and with the adoption of LCC, **SR backgrounds have greatly increased**; investigations are ongoing to optimise the IR optics (L^* , physical aperture, FFQ strength, ...).
- **Detector-field compensation scheme** is essential to define the IR magnet system and validate the allowable detector magnetic field strength.

Next slides will give a glance of the main updates and status of the study

Final Focus Matching Section with LCC Optics

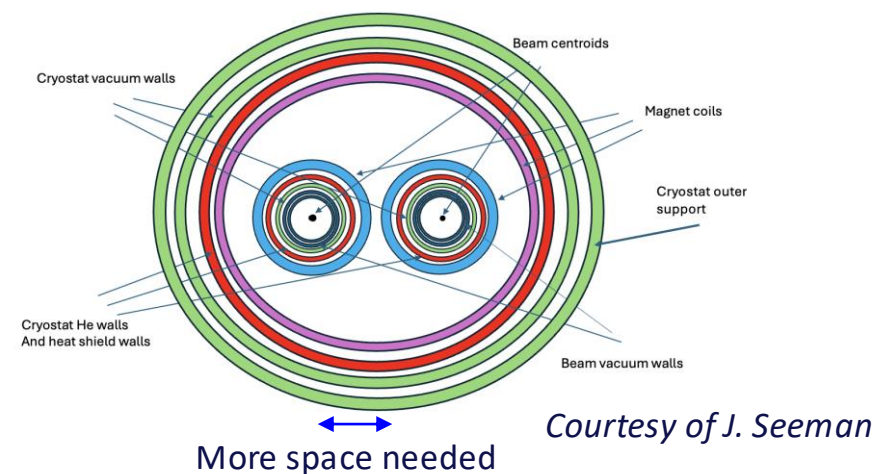
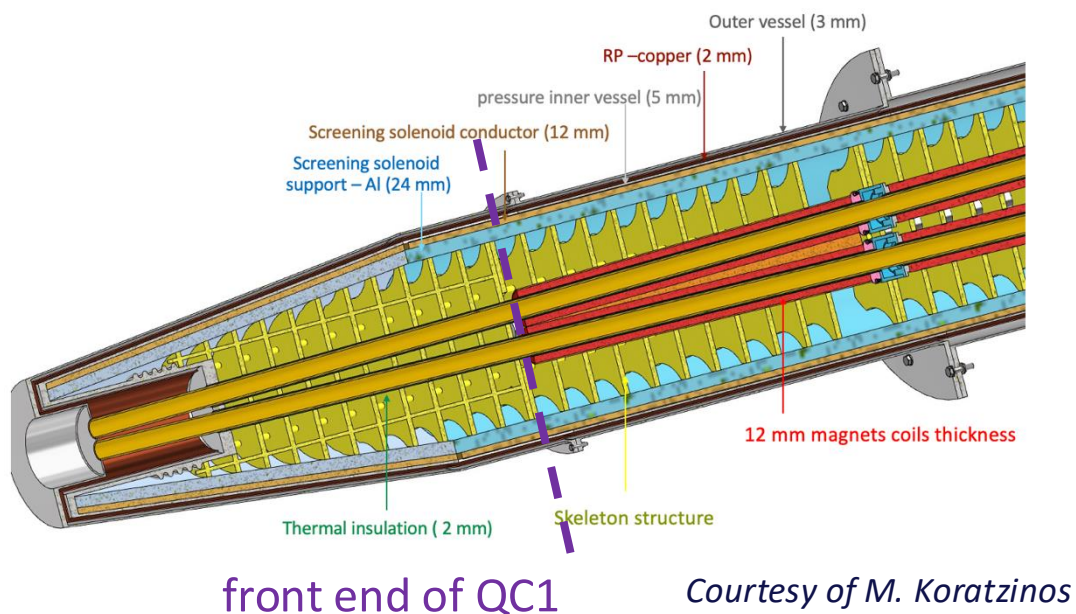
- 30 mrad beam crossing angle at IP is obtained in both optics by strongly bending the outgoing beam trajectories from the IP so that the beam can merge back close to the opposite beam at ~ 1 km from the IP.
- This final focus matching section is different for GHC and LCC**
 - GHC includes reverse bends; LCC does not**



- Different footprints** require different tunnel layouts $\rightarrow$ Implication on civil engineering presently under study
- Different dipole configuration $\rightarrow$ **higher SR backgrounds from upstream dipoles**
different photon dump location (~ 300 m instead of ~ 500 m as for GHC)

L* Choice

- SLAC (John Seeman) started reviewing the **radial buildup layers of the FFQ cryostat** → the result was a requirement of more space needed at first segment of FFQ (QC1, now named QD0).
- Radial space is needed for the layers of the cryostat, for corrector and skew quad windings, and for radiation shielding due to radiative Bhabha events → **L* increased from 2.2 to 2.4 m**

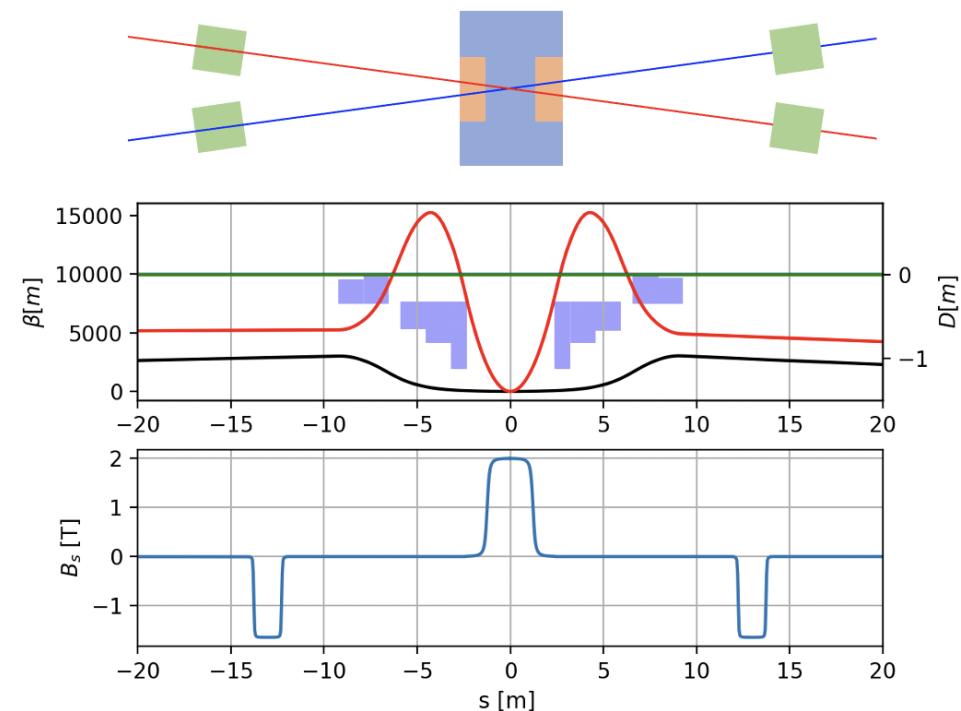


SLAC is studying the cryostat radial buildup, envelope, integration to progress with a more realistic design.

- The increase in L* has increased the SR power deposited on the central chamber, for geometrical reasons. (see later slides)
- The IR optics is being optimised according to all the different requirements

Detector-solenoid Compensation scheme

- Until the Feasibility Study phase the “*local* compensation scheme” was the baseline. However, to let the detector solenoid field increase and lower the SR, we have now switched to the “*semi-local* compensation scheme” as default.
- At each IP:
 - **Detector solenoid (2 T)**
 - **Screening solenoids to cancel the field at the FFQ**
 - **Compensation solenoids to have zero net integrated field**
- First studies of semi-local scheme with MAD-X ([Link NIM A](#))
- **Xsuite** simulations are ongoing to determine the maximum allowable detector field value with the optimal magnet configuration (e.g. starting position of anti-solenoids and correctors)
- The experiments would like to increase the solenoid field to **3 T**, but this increase brings a higher vertical emittance, and, in turn, luminosity degradation.
- Update of this study will be presented at #81 MDI meeting, 14 September: <https://indico.cern.ch/event/1719205/>
- Q4-2026: baseline detector-field compensation scheme defined. Validate detector magnetic field



Courtesy of G. Iadarola

WP2 Detectors and beam induced backgrounds

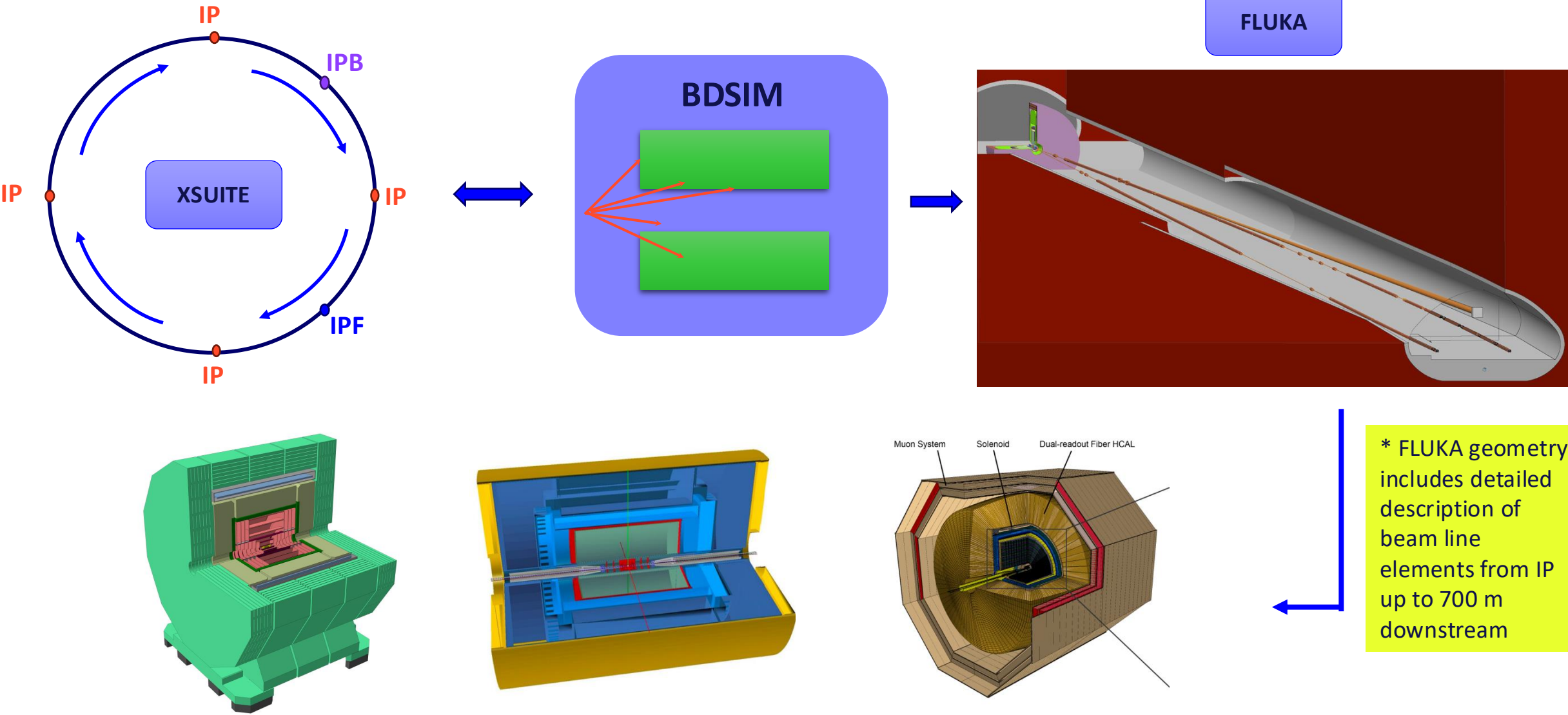
Detector and beam-induced backgrounds

- Accelerator-to-detector workflow and repository is in place.
- Single beam and IP backgrounds studied,
 - Collimation system very efficient with LCC optics, IR losses are well reduced wrt GHC
- **SR** is presently the **dominant background source**, **produced by the beam tails in the FFQs**.
 - SR masks are under study to mitigate the effect, also IR optics modifications are being proposed.
- **IPC** is also relevant background source, impact on various detectors is being studied.
- **Injection background** with top-injection may be dangerous, its effect on detectors has not yet been studied thoroughly. Injected beam produces additional SR backgrounds that may be dangerous for vertex detectors especially.
- Beam-gas and thermal photons with LCC optics not performed yet.

Next slides will give a glance of the main updates and status of the study

More info [here](#).

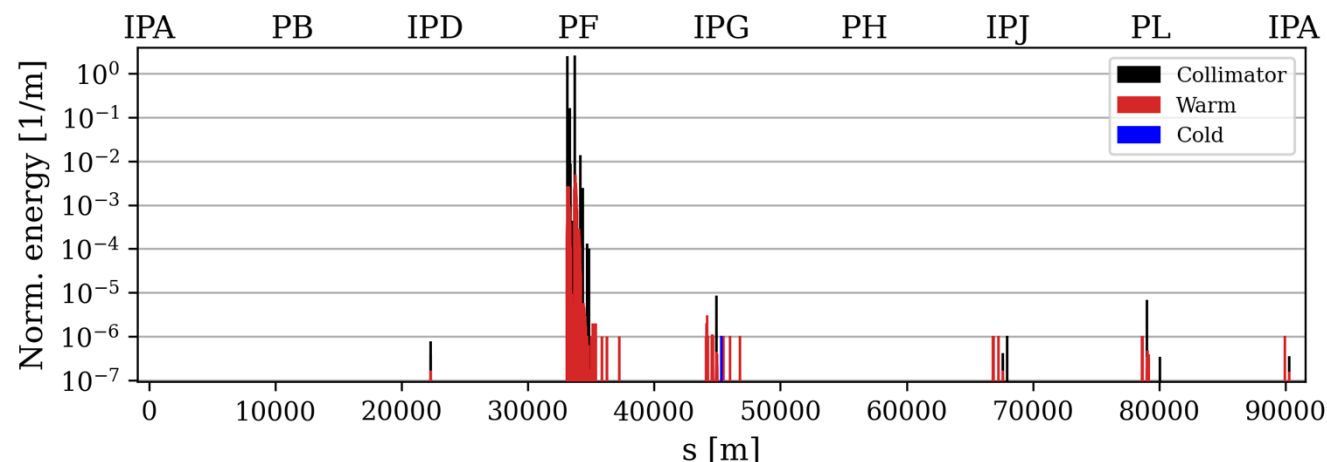
BIB simulation workflow



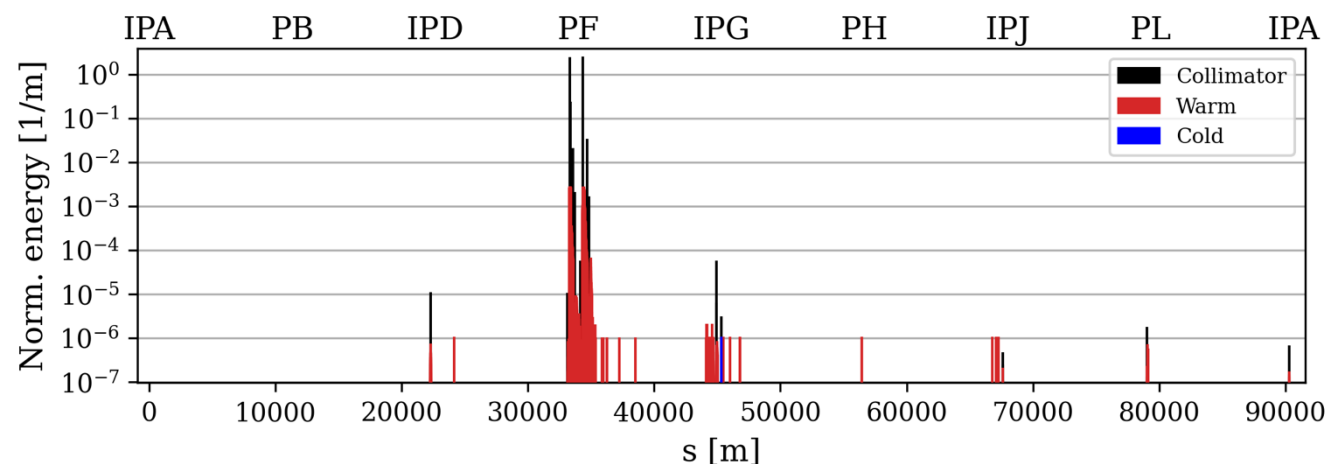
FCC-ee betatron collimation performance LCC optics

- **Betatron collimation system in the PF achieves excellent cleaning performance in both planes**
 - Losses reaching the IR collimators suppressed by several orders of magnitude
 - **>5 orders of magnitude** suppression for horizontal betatron losses
 - **>4 orders of magnitude** suppression for vertical betatron losses
- The FCC-ee LCC V106.2 lattice delivers the **best betatron cleaning performance** ever recorded in such studies to date

Horizontal betatron collimation



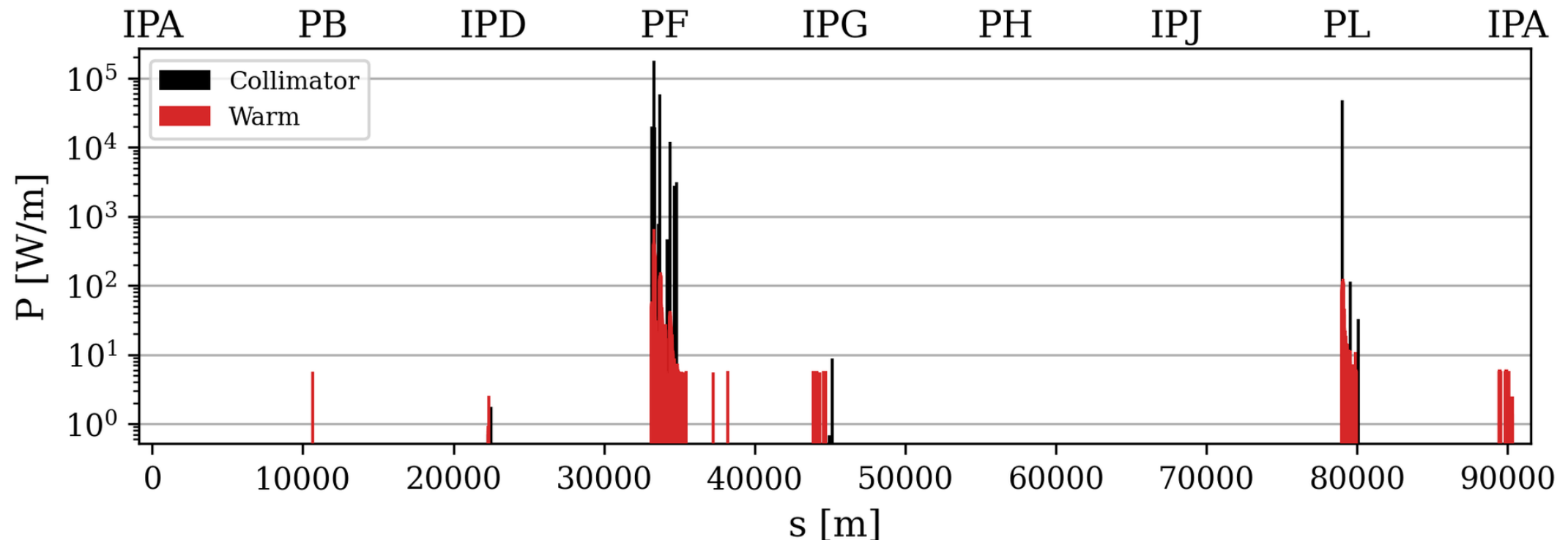
Vertical betatron collimation



LCC Injection performance

Hybrid scheme $\delta_{off} = -1.02\%$

- **Injection efficiency ~86%**, includes collimation, SR, and beam-beam, like GHC.
- **Losses localized in collimation insertions**, both betatron and momentum.
- Negligible leakage to IR $\rightarrow$ **injection background significantly suppressed**.
 - Step 2 and 3 not performed for LCC.
- **Overall, very good performance w.r.t. GHC!**

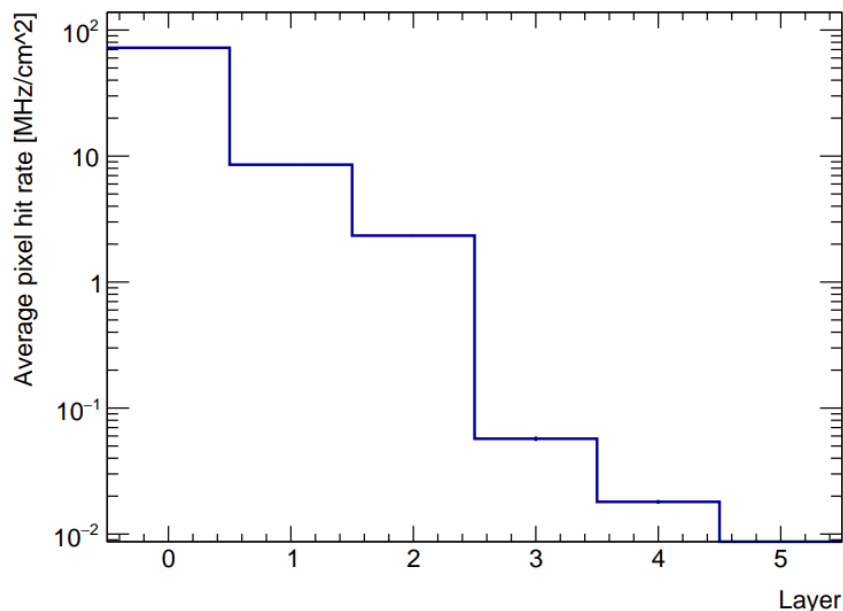


Beam-induced backgrounds in vertex detector

A. Ilg FCC WEEK 2026

Incoherent Pair Creation (IPC)

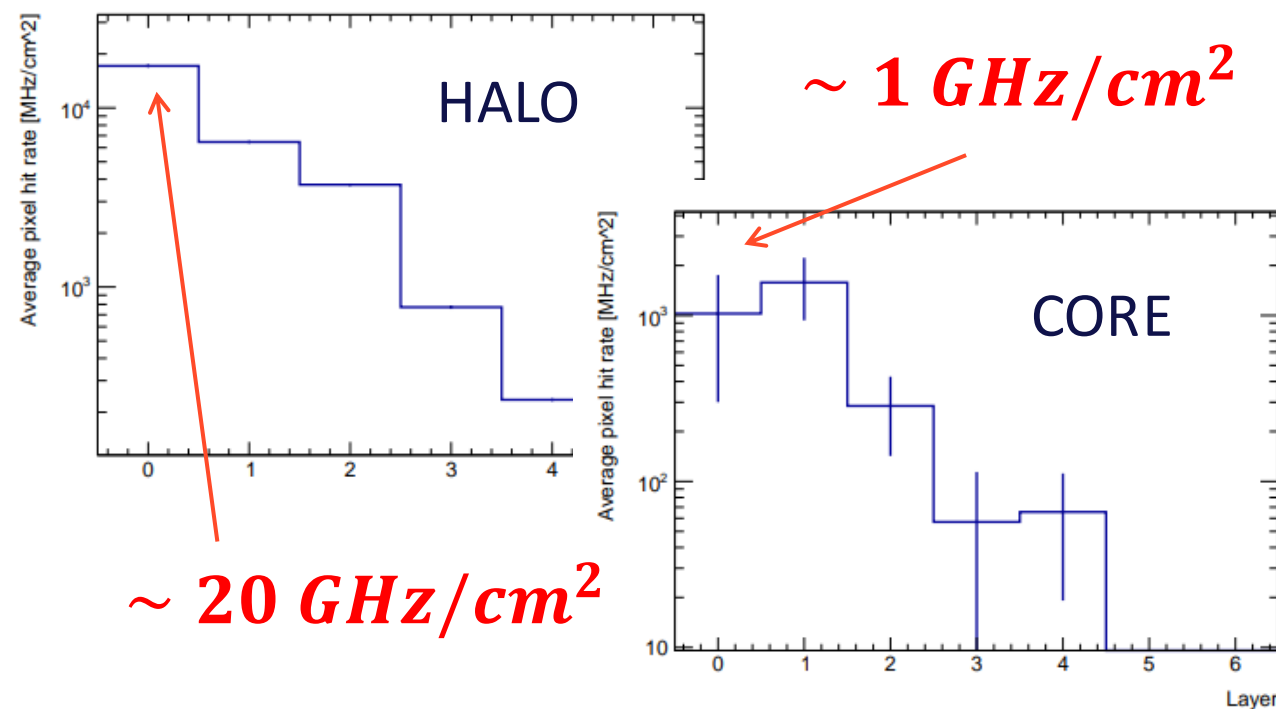
- Average pixel hit rate $\sim 70 \text{ MHz cm}^{-2}$ in first vertex barrel layer
- One order of magnitude less in vertex disks and silicon wrapper



- With a realistic LUT-based digitizer (J. Dilg) → $42\text{--}71 \text{ MHz cm}^{-2}$ in 1st layer

Synchrotron Radiation (SR)

- Much larger samples allow for the first time
- Way higher than IPC → Not good!
- Lower (but still very high) hit rates in VXD disks and silicon wrapper
- Work on IR optics and shielding needed.

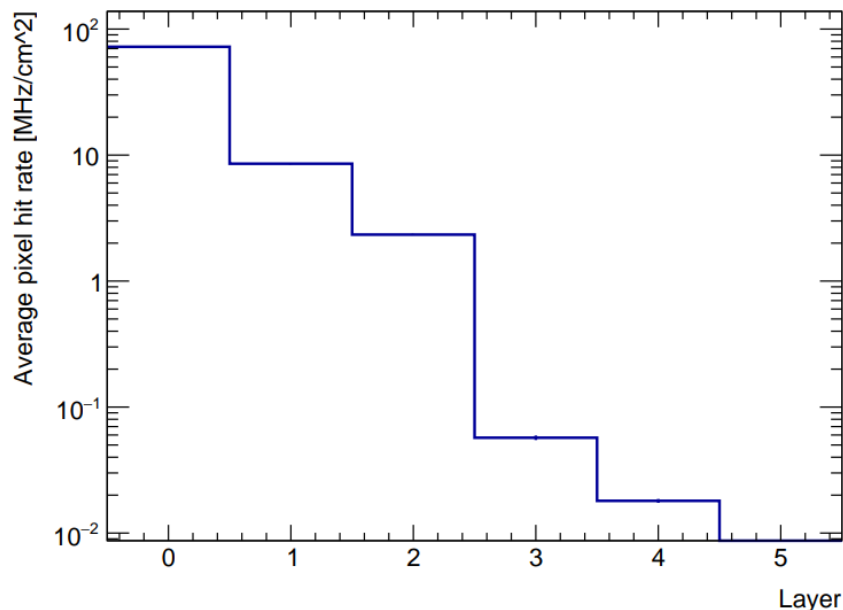


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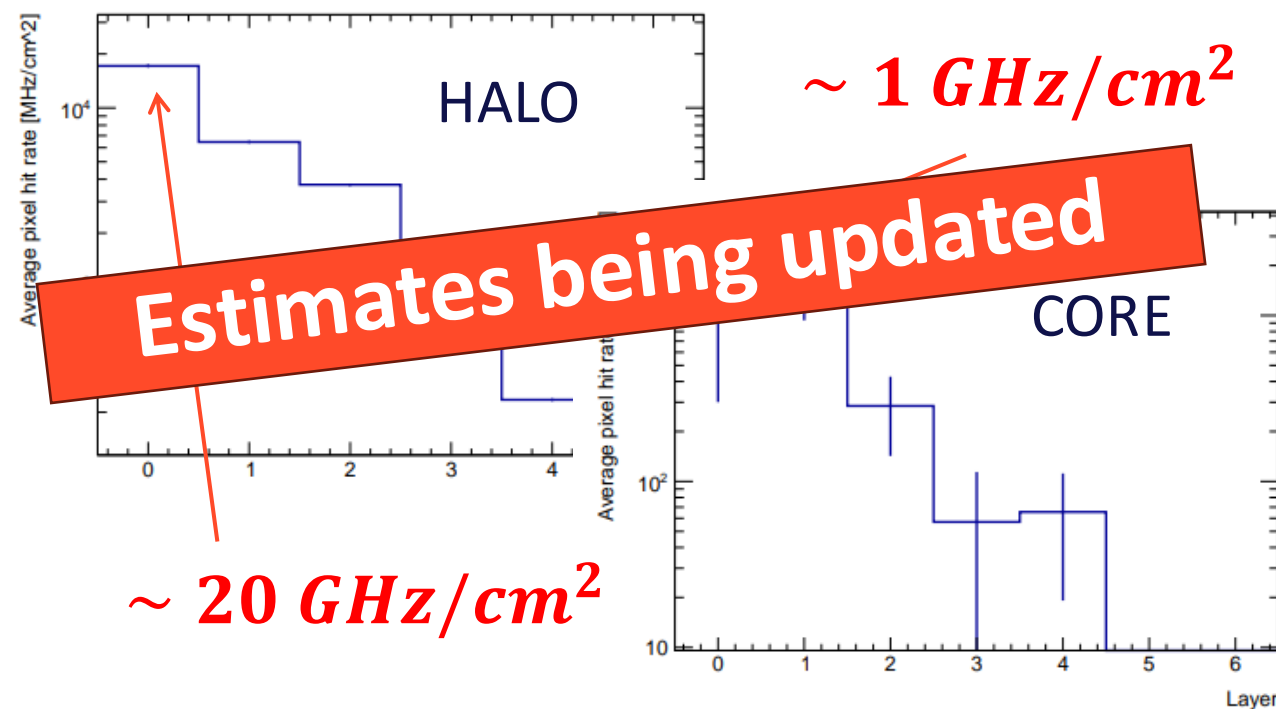
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$\sim 20 \text{ GHz/cm}^2$

$\sim 1 \text{ GHz/cm}^2$

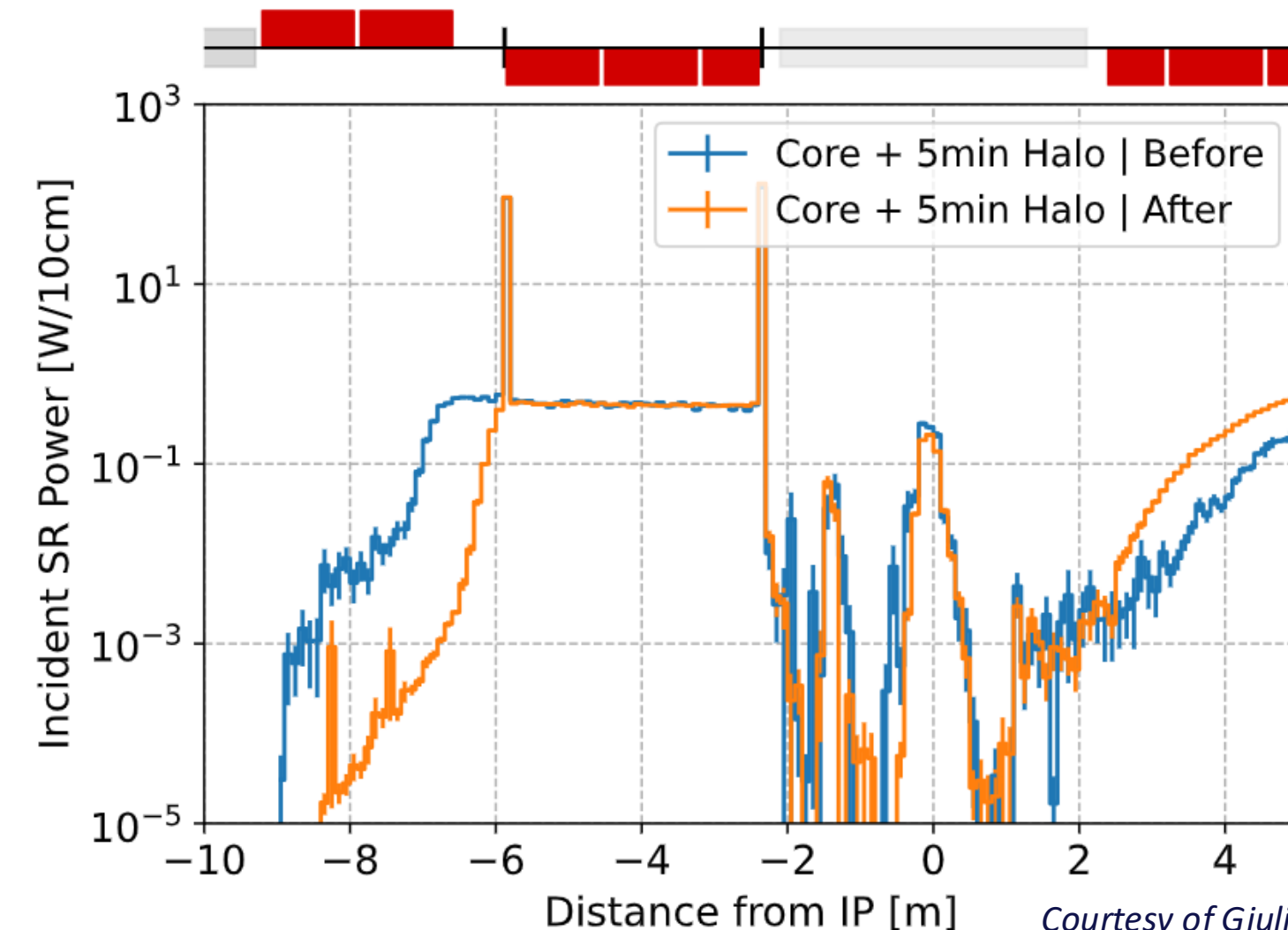
Estimates being updated

Synchrotron Radiation mitigation task force highlights

- A feature was discovered in the **angular spectra approximation** of the SR photons in **GEANT** giving a higher beam core radiation compared to Synrad and Fluka.
- Now this is fixed and the **SR from the core is reduced about 2 orders of magnitude** wrt FCC WEEK 26, but this was anyway sub-leading.
- We are studying an **additional SR mask** closer to IP, just after the Y-pipe **at about 1.2 m** from IP, to mitigate the SR from the beam tails at FFQs.
 - High power, it might need cooling
 - Secondary showers to be investigated
 - Comparison with sawtooth ridged beam pipe like at SuperKEKB started
- **IR optics modification** to mitigate SR is also under study
 - Lower L^*
 - increase space between QD0 and QF1
 - Modify strength and length of QD0

SR from beam halo: update since FCC WEEK 2026

corrected SR angular distribution in Geant (yellow)



Courtesy of Giulia Nigrelli

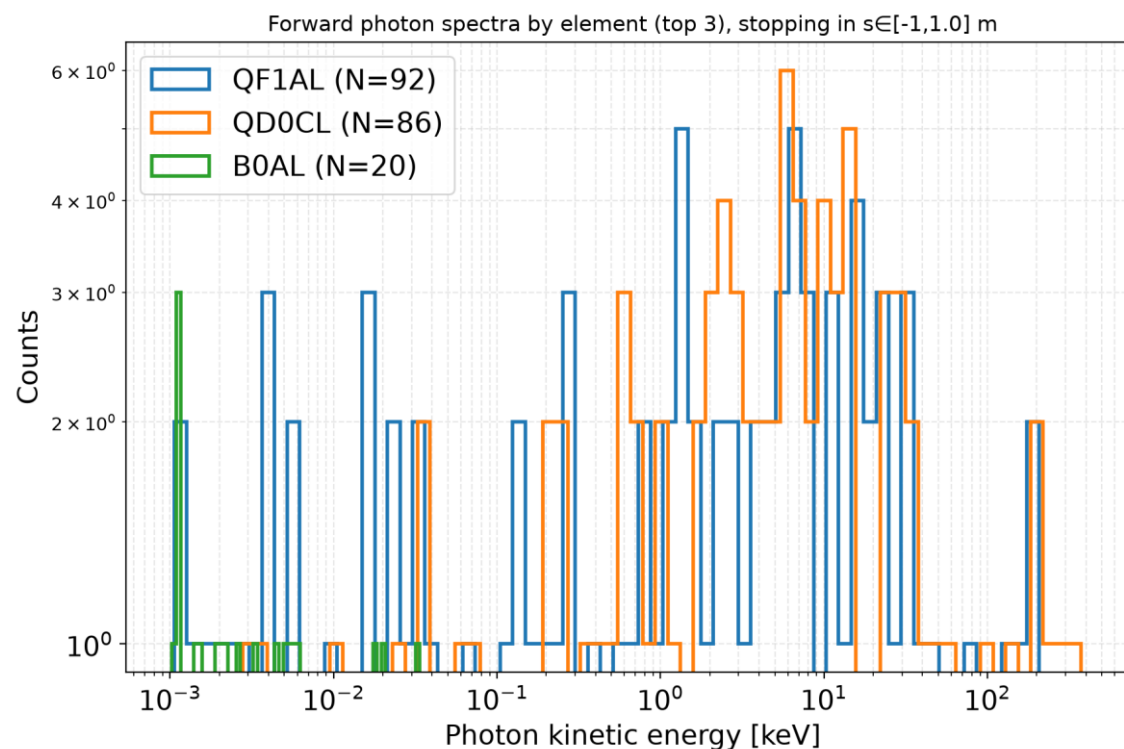
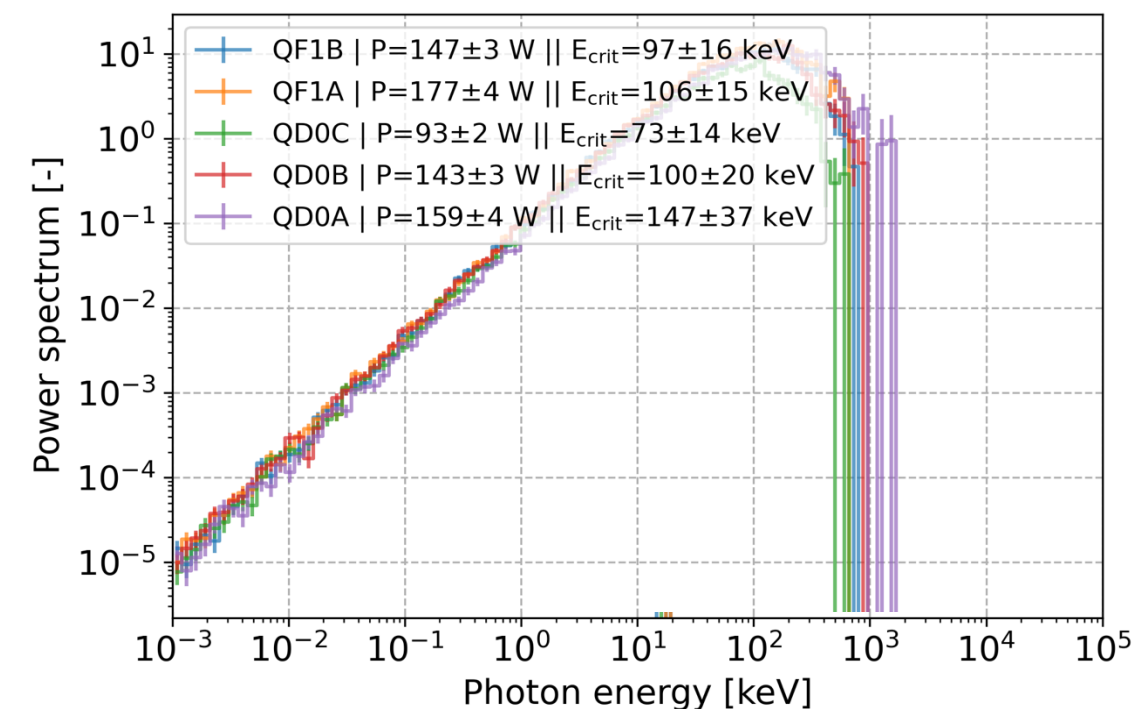
- As expected, no significant changes observed.
- Most of the **SR** is produces at the **FFQ**
- **SR at IP increased by 2 orders of magnitude** by halo-5min lifetime
 - Versus the previous factor 3
- Difference at IP is less than a factor 2 with the new angular sampling.

Energy Spectra at IP

- Halo-SR produced at QF1:
 - **Critical energy up to 150 keV**
 - **Spectra up to 1 MeV**
- **SR intercepting beam pipe mostly with energy >10 keV**

- **Photons won't be absorbed by the beam pipe.**
- With the new angular sampling the contribution from B0AL is negligible.

Courtesy of Giulia Nigrelli



WP3 Accelerator technical systems

MDI coordination of 5 work packages

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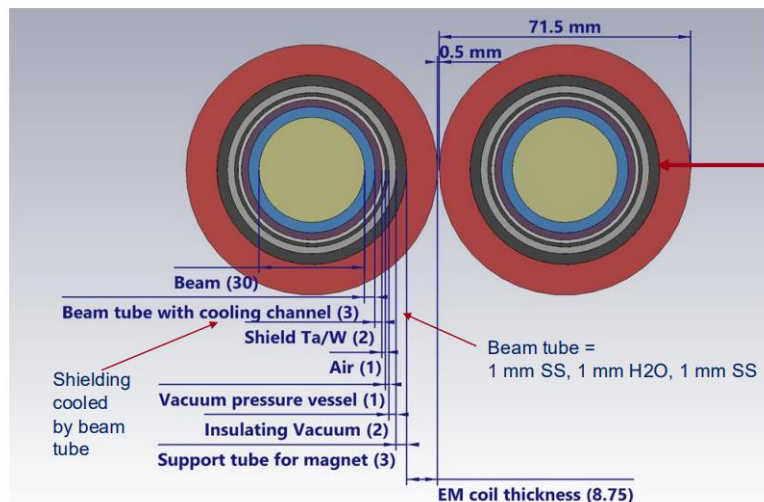
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FFQs and cryostat design

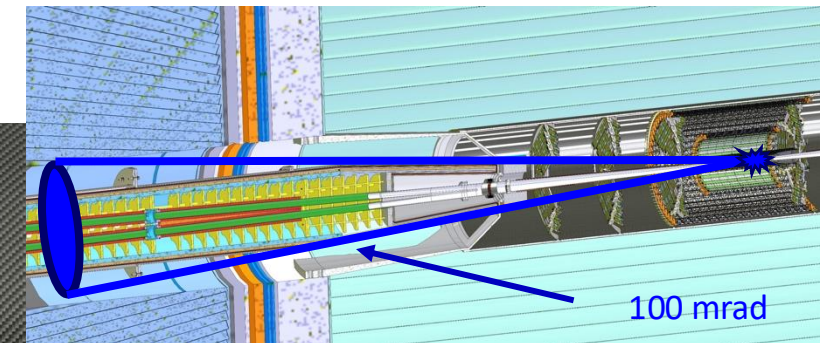
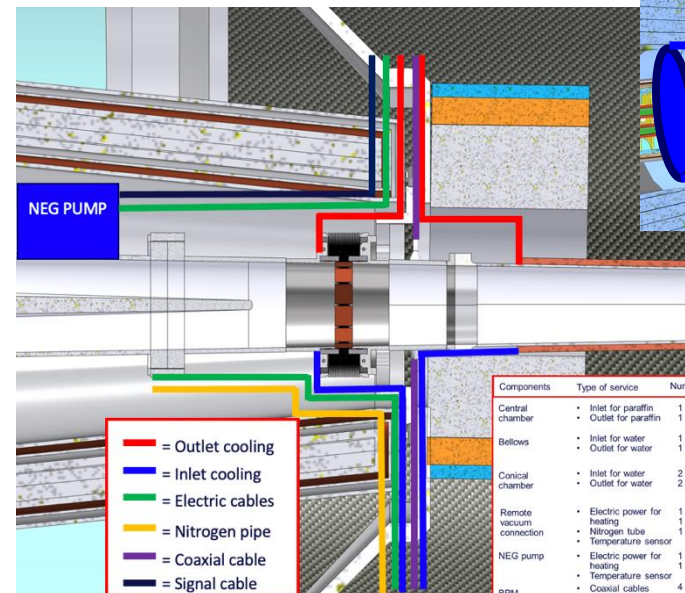
- **FFQs design:** technology to be chosen according to the specifications and requirements given by the solenoid compensation scheme, alignment tolerances for optics tuning, radiation coming from backgrounds studies.
- **Cryostat design:** technology, envelope, internal layered structure, integration
 - Requirement from the physics to let machine stay within 100 mrad cone



Here the magnet coil mandrel is, also, the helium vessel

Now all layers fit due to
a) $L^* = 2.4$ m
b) Direct wind SC magnets on helium vessel.

Courtesy of J. Seeman

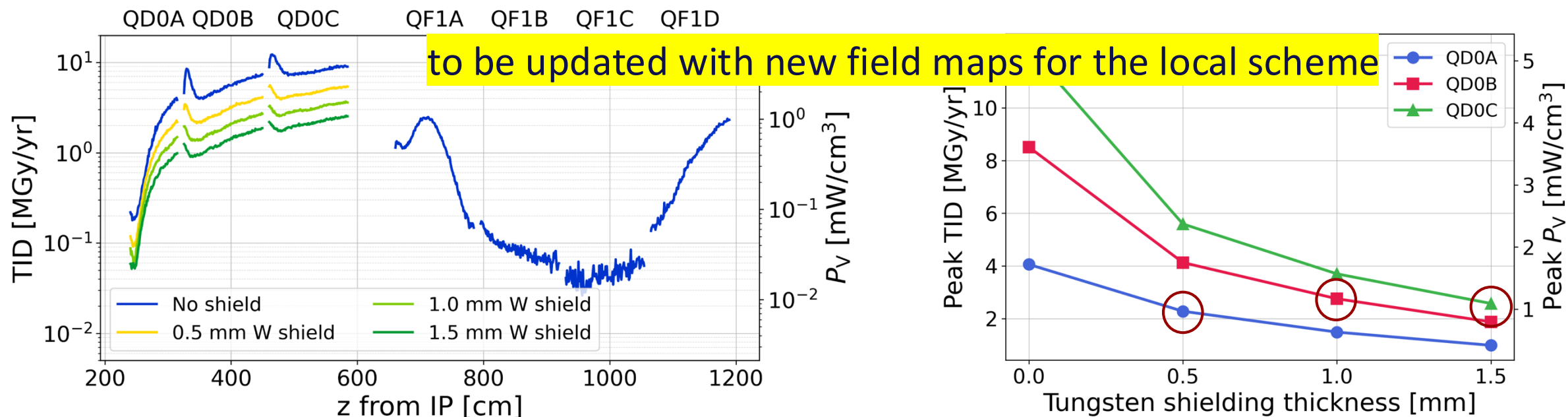


Courtesy of F. Franesini

FFQ shielding: how much tungsten is needed?

A. Frasca, FCC WEEK 2026

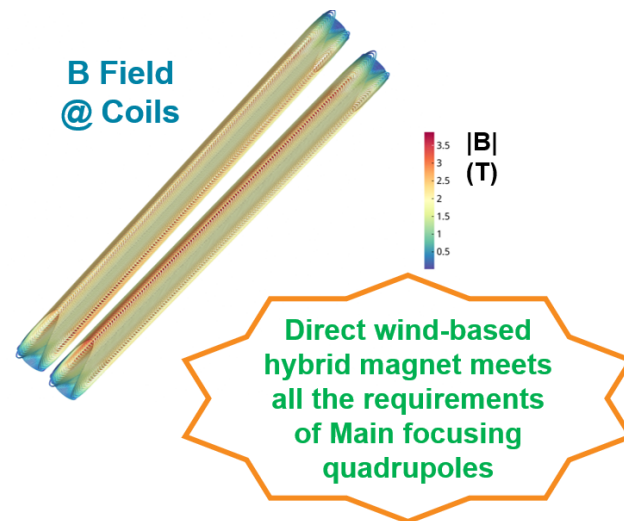
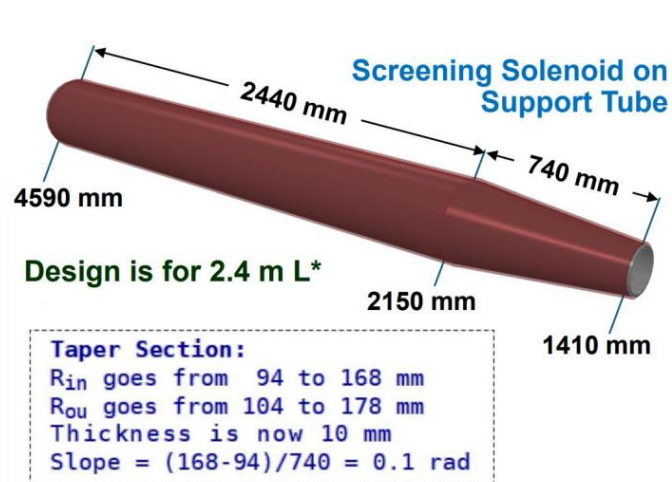
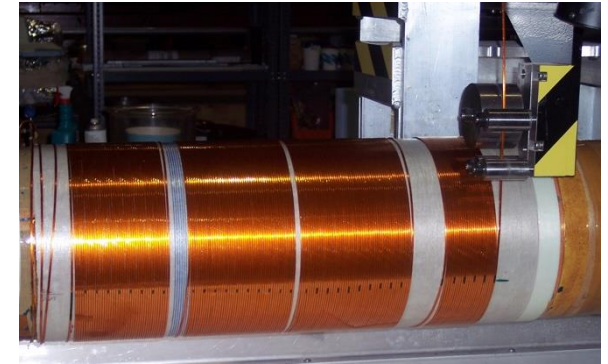
Impact of a tungsten layer around the QD0 beam pipe on peak TID and P_V in the SC coils



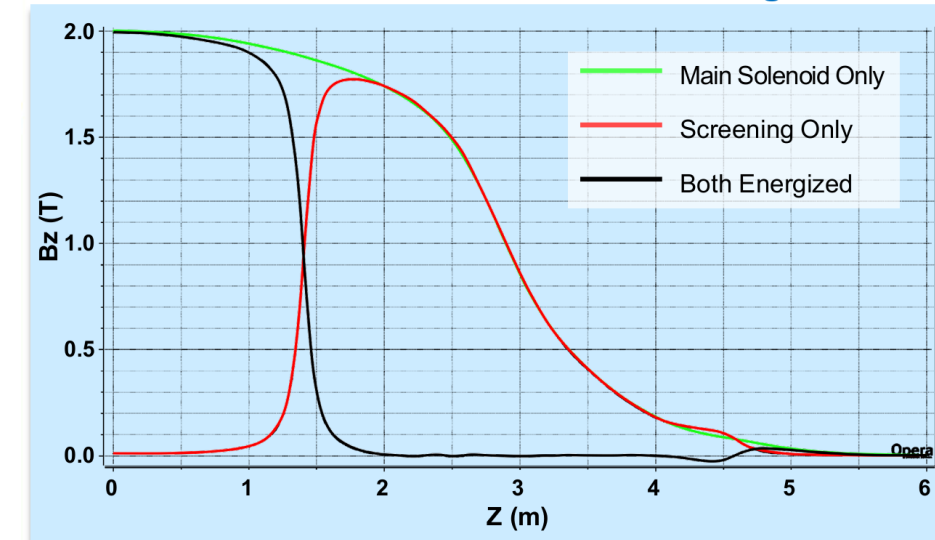
- 0.5 mm W layer already enough to reduce P_V below ~ 2.5 mW/cm³ for QD0C (and less for A/B) → shielding requirements driven by TID
- **New recommendation: 0.5mm for QD0A, 1.0mm for QD0B, 1.5mm for QD0C** ensuring that TID from RB never peaks beyond 3 MGy/yr at Z pole → 4 years of Z well below the limit, while minimizing the W thickness in QD0A where space constraints are most significant

IR magnet system

- B. Parker and Vikas Teotia (BNL) propose a **direct wind technology** for the FFQs, in addition to the skew quads and correction coils to add around the quads, with the advantage of saving space
- BNL is also interested to design the screening solenoids for IDEA
- No engineering design started yet, but field maps provided for background studies and compensations scheme study



Field Profile for IDEA Detector & Screening Solenoid



WP4 Metrology, alignment and adjustment strategy

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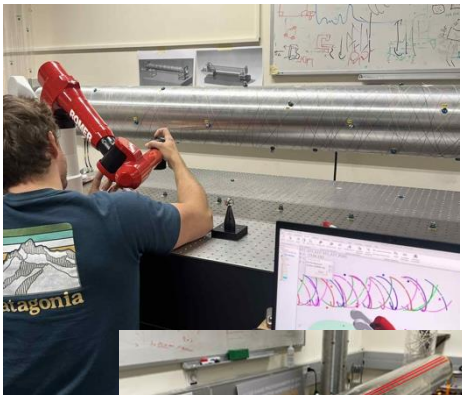
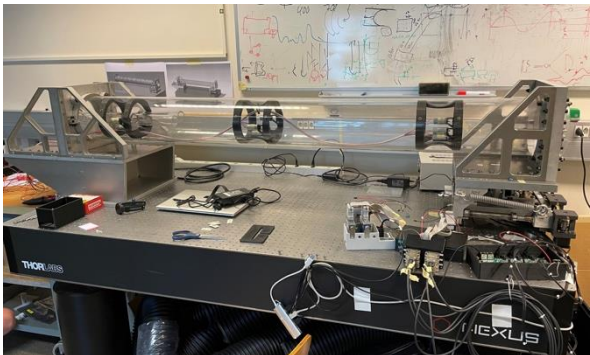
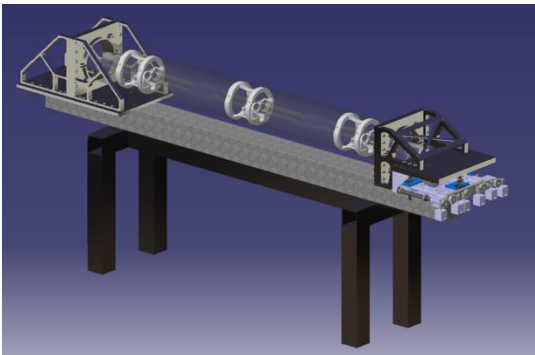
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Metrology, alignment and adjustment strategy

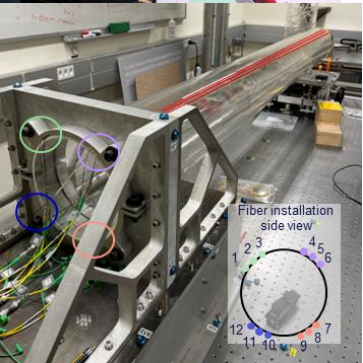
- A strategy needs to be studied for the **FFQs re-alignment after detector openings** for maintenance
 - longitudinal opening is baseline, a strategy and estimate of the time needed to realign to specs the cryostat is yet to be started, it is planned for the RDP
- **Survey of LumiCal and FFQs**
 - **Monitoring system** is under study at CERN by the BE-GM group
- Vibration suppression system (passive, and active?) after the **characterization of instabilities**
 - Just started with the CERN expertise

MDI alignment prototyping status

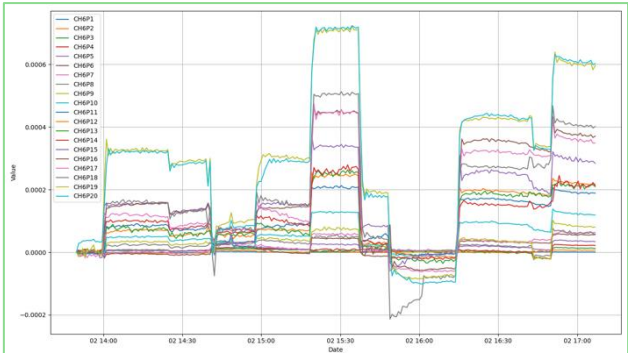
Received almost all the elements for the MDI alignment mockup



- Checking the geometry “as-built” of the helices engraved in an aluminium tube
- Training on plastic tubes before preparing the aluminium one.
- **First “real-size” deformation measurements from the plastic tubes.**

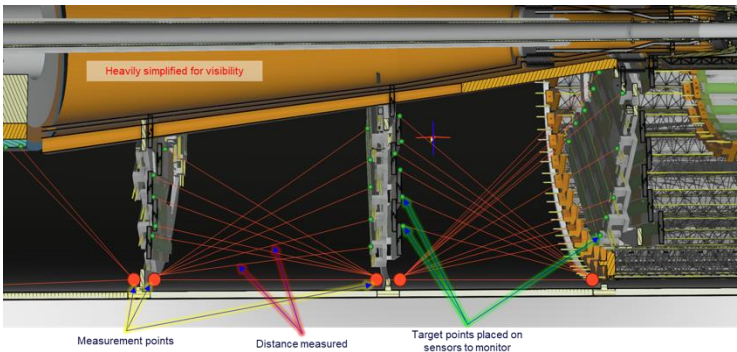


FSI measurements



L. Watrelot FCC WEEK 26

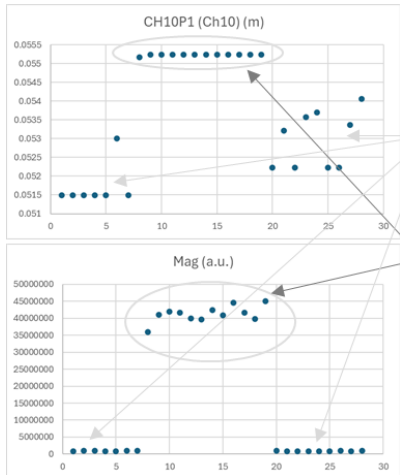
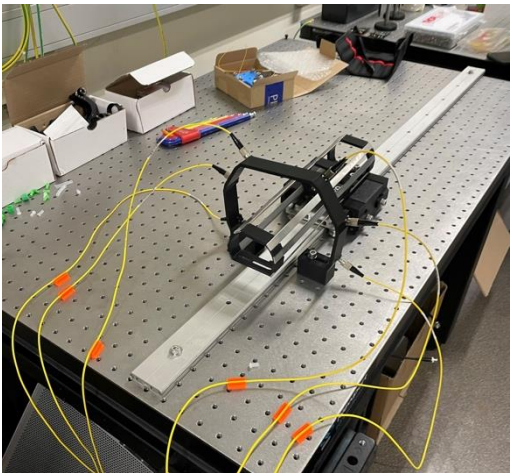
Vertex Detector study



Careful study of the requirements (weak modes, link between subsystems ...) before doing a second run of simulations.

Parallel R&D: LHCb and CMS

Useful for speeding up the detector opening/closing



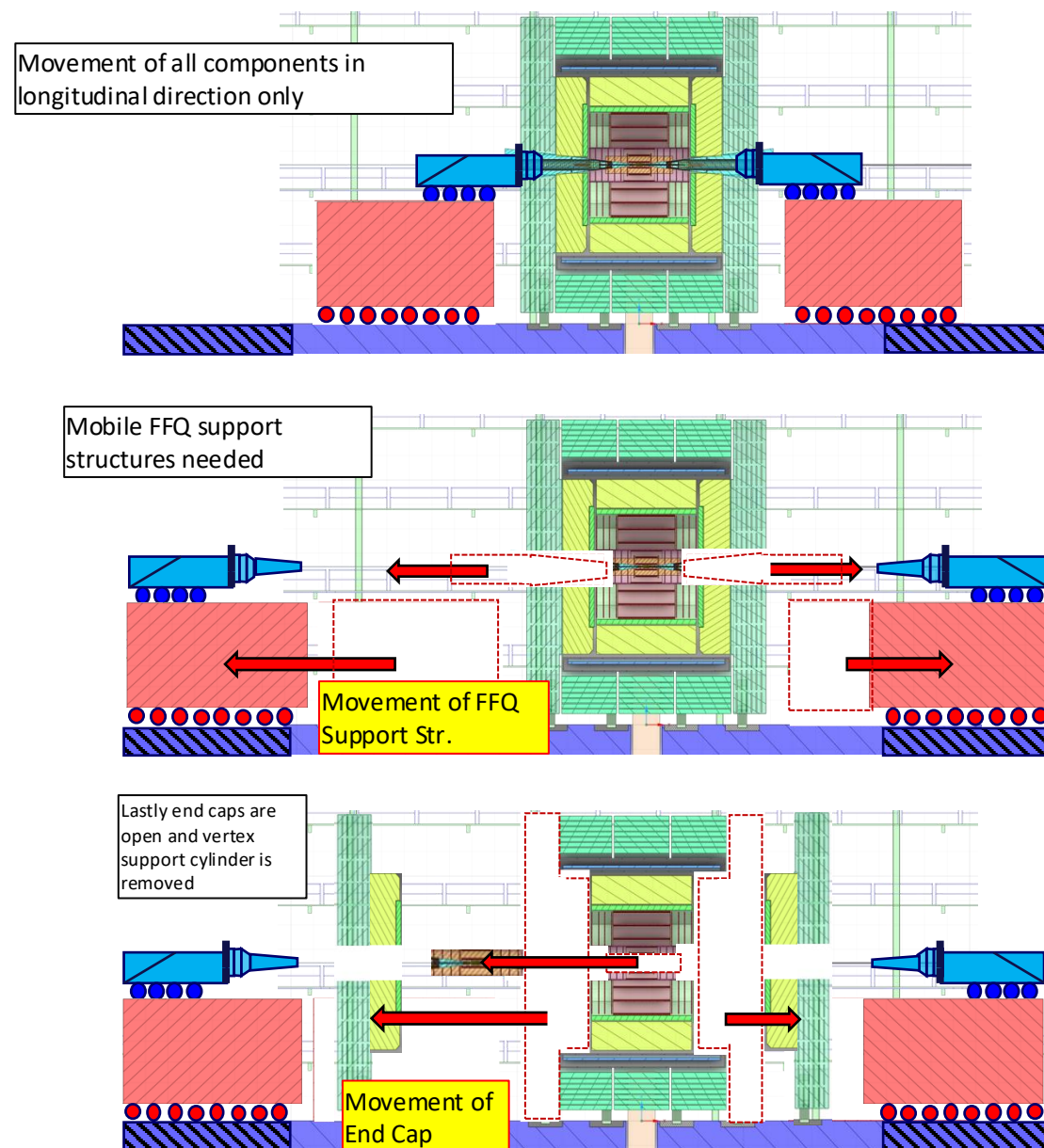
Element not in the portal (no peak in the FSI data)

Element inside the portal, in the line of sight of the FSI

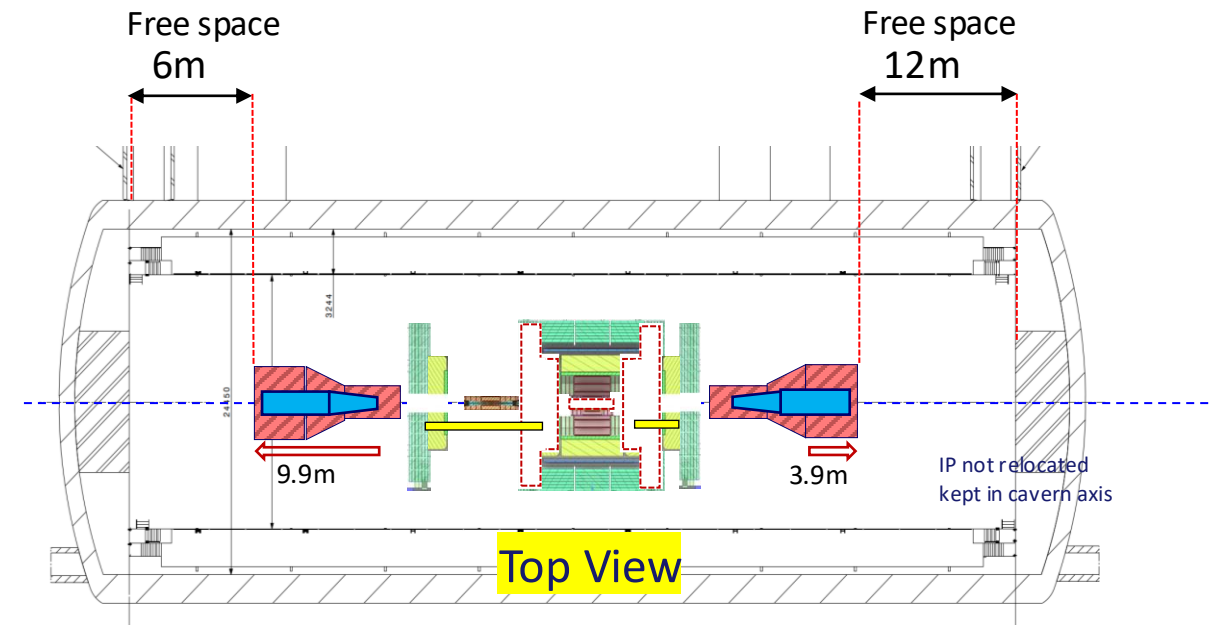
WP5 Global integration studies for MDI, Detectors and Experimental cavern including infrastructure

WP5 – Global integration studies for MDI, Detectors and Experimental cavern including infrastructure

- MDI systems static and dynamic envelopes
- Global experimental cavern integration
- MDI and detector assembly/disassembly scenario
- Assessment of removal/installation of cavern vacuum chambers
- Proof of concepts of MDI Far End vacuum supporting structures



- Major movement required after opening/maintenance:
 - FFQ mobile support structure – **longitudinal**.
 - FFQ mobile base – **longitudinal**.
 - End caps – **longitudinal**.
- No cavern and shaft modifications required – no impact on cost.
- Detectors barrel is stationary – flexible chain (services) only needed for end-caps.
- Installation of the detector and the accelerator parts can be done in parallel – no expected time impact.
- More flexibility for the Booster location – on the inner side of the Experimental Cavern).

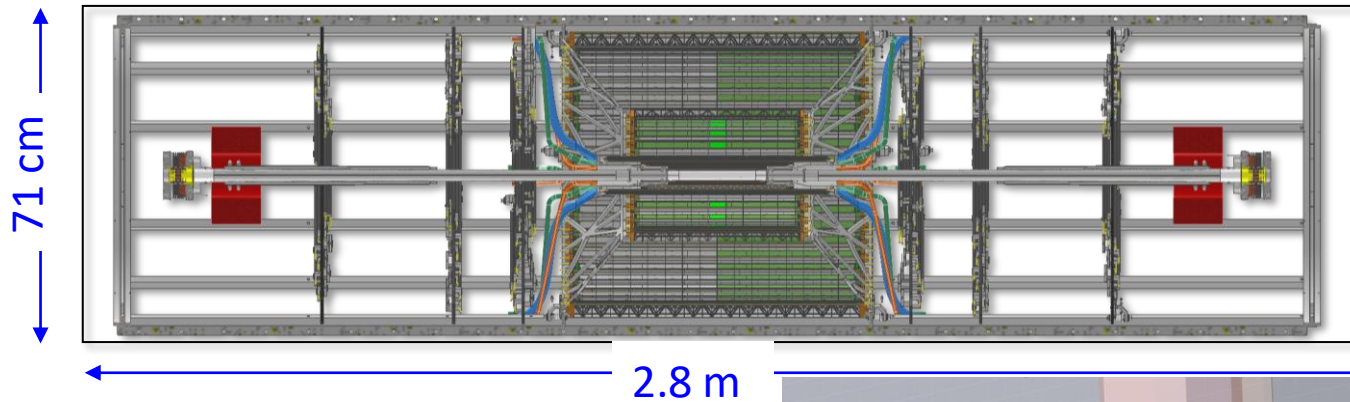


Full-scale IR mock-up at Frascati

Co-funded INFN & CERN project



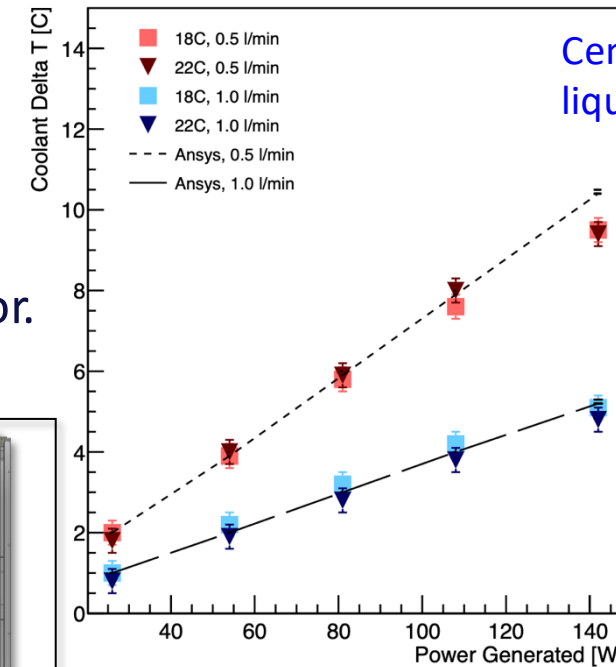
Study the MDI integration of all detectors.
integration started with IDEA/ALLEGRO planar vertex detector.
Possibly study also curved variant (FCC-SEED) one.



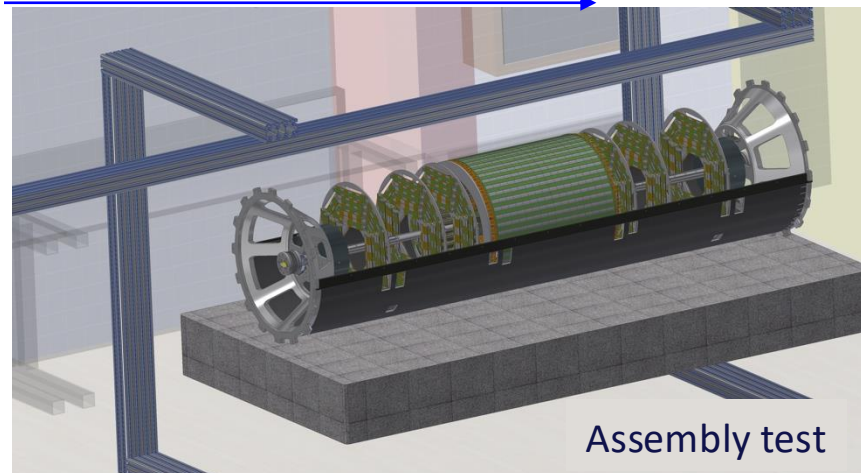
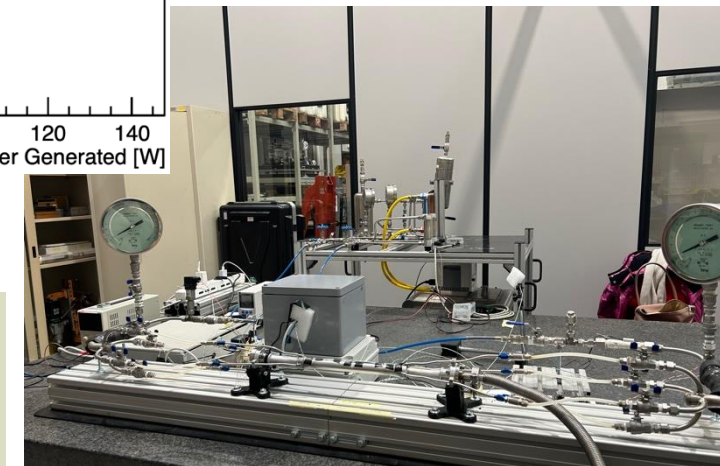
Validated:

- beam-pipe fabrication (in aluminium)
- beam-pipe liquid-cooling system
- inner vertex air-cooling system
- support tube design

Next to be validated:
assembly sequence



Central beampipe
liquid paraffin tests



Assembly test



Outlook

MDI monthly meetings e-group: fcc-ee-MDI@cern.ch

- Split of the work in 5 WP will allow focused design for each system for the RDP
- Overall MDI coordination will ensure a coherent finalization of settings to accommodate detectors and machine requirements

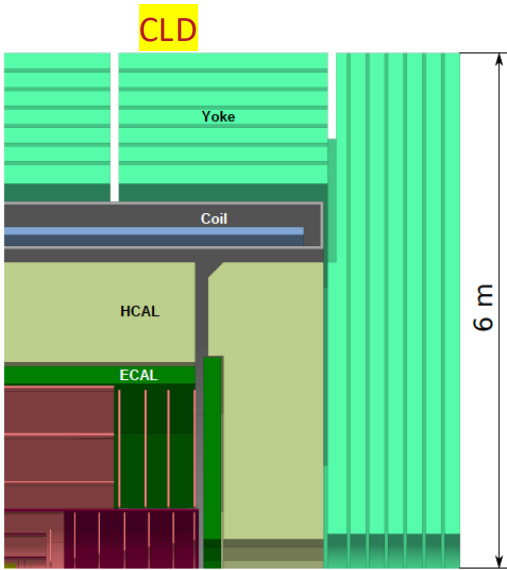
Key points to address:

- Definition of IR magnets for the semi-local compensation scheme, progress in their design, assess detector stay clear and detector envelope
- Design of the FFQ cryostat
- Synchrotron Radiation background mitigation and improved design of beam pipes
- Estimate of other background sources (thermal photons...)
- Integration of IR in different detectors, understand opening scenarios conditions and impact of re-alignment on performance (instantaneous and integrated luminosity)
- FFQ alignment needs and stabilisation strategy



Thank you
for your attention

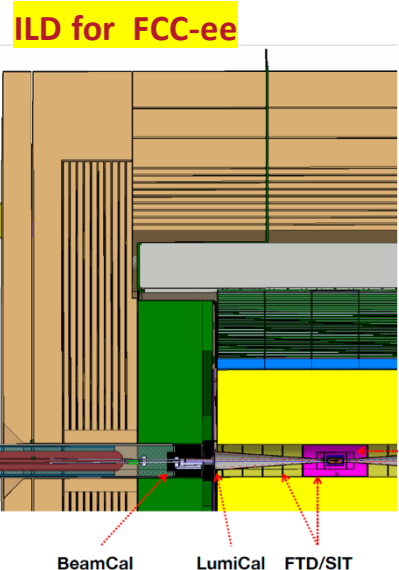
Detectors for FCC-ee



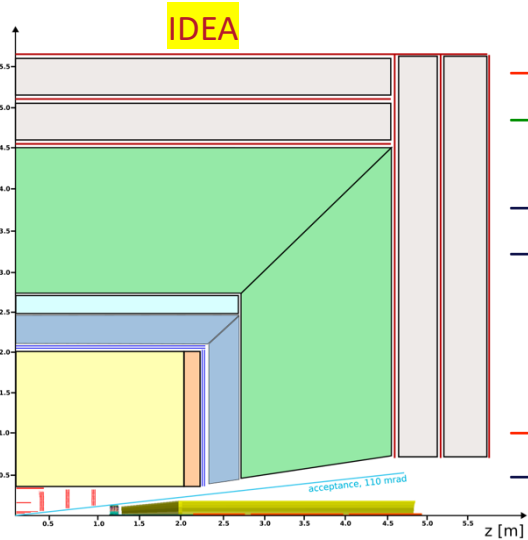
- VTX MAPS
- Main Tracker: Silicon
- Very high granularity (CALICE) inside the Solenoid
 - ECAL Si+W
 - HCAL Fe+scintillator
- PID: RICH and TOF
- Muons ID with RPC



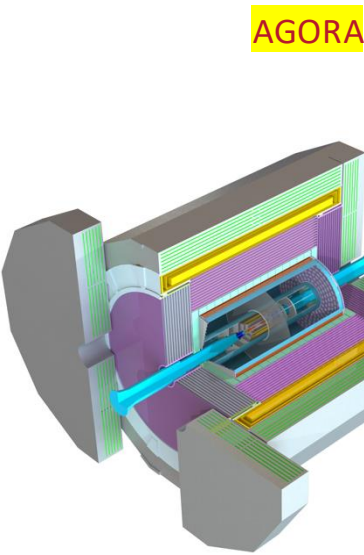
- VTX MAPS
- Main Tracker:
 - Drift Chamber/Straw/Si
- Si/LGAD wrapper (TOF)
- ECAL: Pb+L-Ar/W-L-Kr
- HCAL: Fe+scintillator outside the Solenoid
- PID: RICH (in case of Silicon main tracker)
- Muons with RPC



- VTX MAPS
- Main Tracker: TPC
- Very high granularity (CALICE) inside the Solenoid
 - HCAL Fe+scintillator
 - ECAL Si-W
- Muons with scintillator



- VTX MAPS
- Main Tracker:
 - He+Isob drift chambe
- Si/LGAD wrapper (TOF)
- DR calorimetry (fibres):
 - ECAL: Crystals
 - HCAL: Iron outside the Solenoid
- HTS Solenoid (up to 3T)
- Muon ID: μ -RWELL



Sub-system	Technologies
Beam pipe	Beryllium, ϕ 20 mm
LumiCal	Silicon tracker + LYSO crystals
Vertex	Si Pixels: CMOS MAPS+stitching
Inner tracker (ITK)	Si Pixels: CMOS MAPS 55-nm
Gas detector	TPC with high granularity
Outer tracker (OTK)	AC-LGAD $\rightarrow$ TOF
ECAL	4D transverse crystal bars
HCAL	Glass scintillator, SiPM + Fe
Magnet	LTS Solenoid
Muon	Plastic scintillator bars, SiPM

Semi-local Compensation scheme

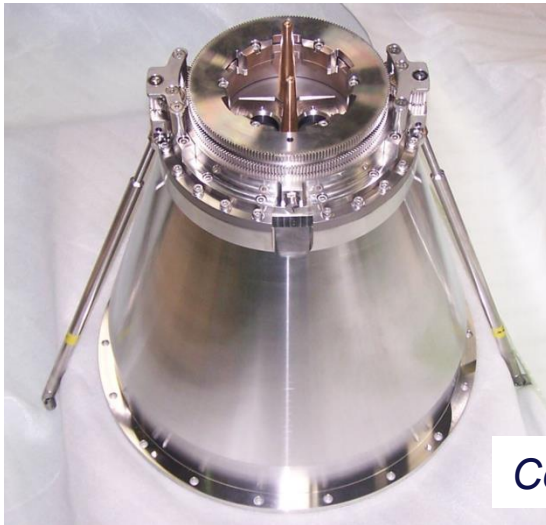
- **Due to the crossing angle** the beams go through the transverse fields **introduced by solenoid fringes**
- These generate **closed orbit distortion and dispersion** (mostly in vertical)
- Use **dipole correctors (H & V) per side to preserve low emittance**
 - 1 nested in the screening solenoid
 - 4 nested in the final doublets
 - 1 in front of the compensation solenoids
- The main solenoid introduces a **tilt of the beam plane** (→ linear coupling)
- This is **compensated by**:
 - **Skew quadrupole coils nested in the final focus quads**
 - The two **compensation solenoids**
- **Linear coupling remains local**

Ongoing work at optics simulation level to assess the maximum allowable detector field, checking the vertical emittance increase and its correspondent luminosity degradation.

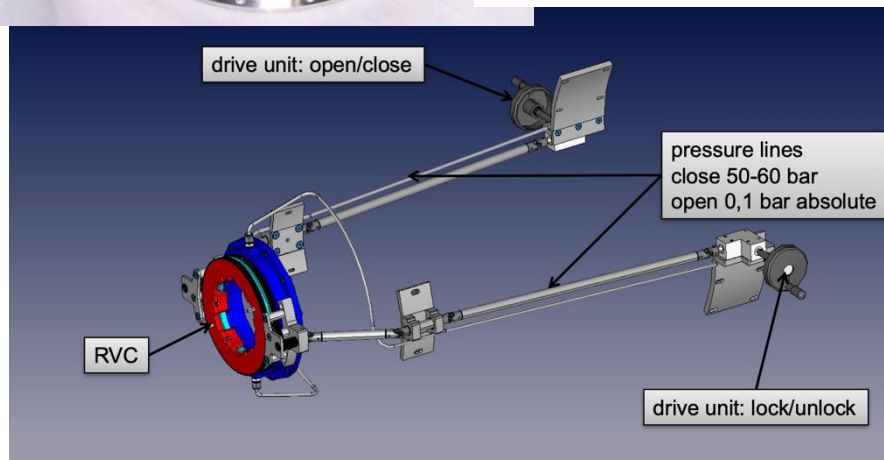
Challenge is to find the space for all these IR SC magnets, to design a robust system in terms of quench risks, stability, alignment, that fulfils all requirements.

Remote Vacuum Connection: two alternative approaches

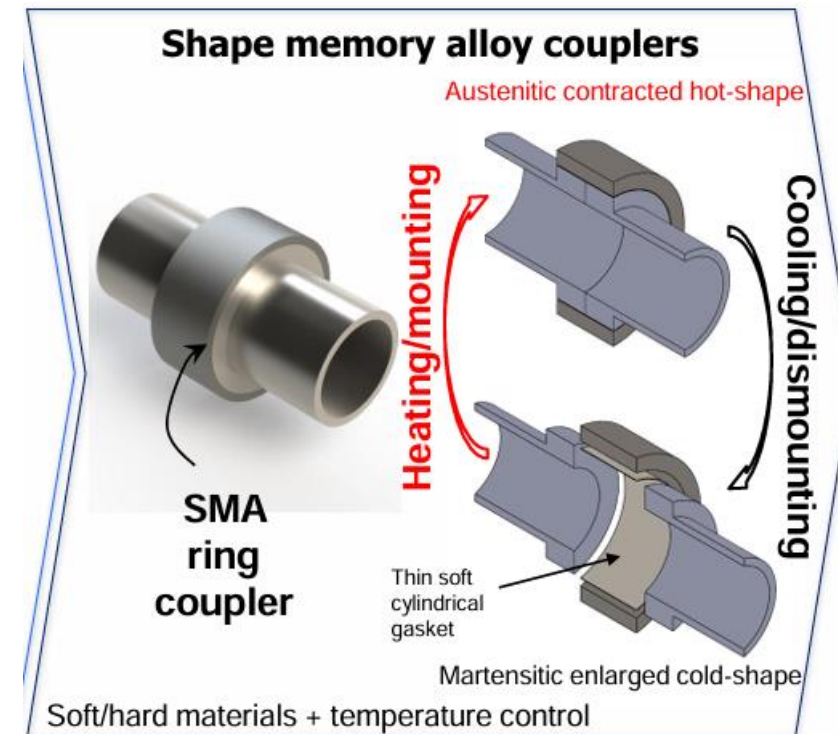
RVC fitting on to the SuperKEKB final QCSR cap



Courtesy Karsten Gadow



Shape Memory Alloy
Needs operations between -40°C and 100°C



F. Niccoli, F. Fransesini