FUTURE CIRCULAR COLLIDER
Innovation Study

FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

MDI OVERVIEW

Manuela Boscolo (INFN-LNF)

on behalf of the MDI group

FCC WEEK Conference 2024
10 - 14 June 2024
San Francisco, USA

INFN
Istituto Nazionale di Fisica Nucleare

Outline

- Interaction region layout optimization
- Progress on the MDI engineering design
- Beam induced Backgrounds studies
- Outlook

FCC WEEK 2024 – MDI sessions

2 sessions

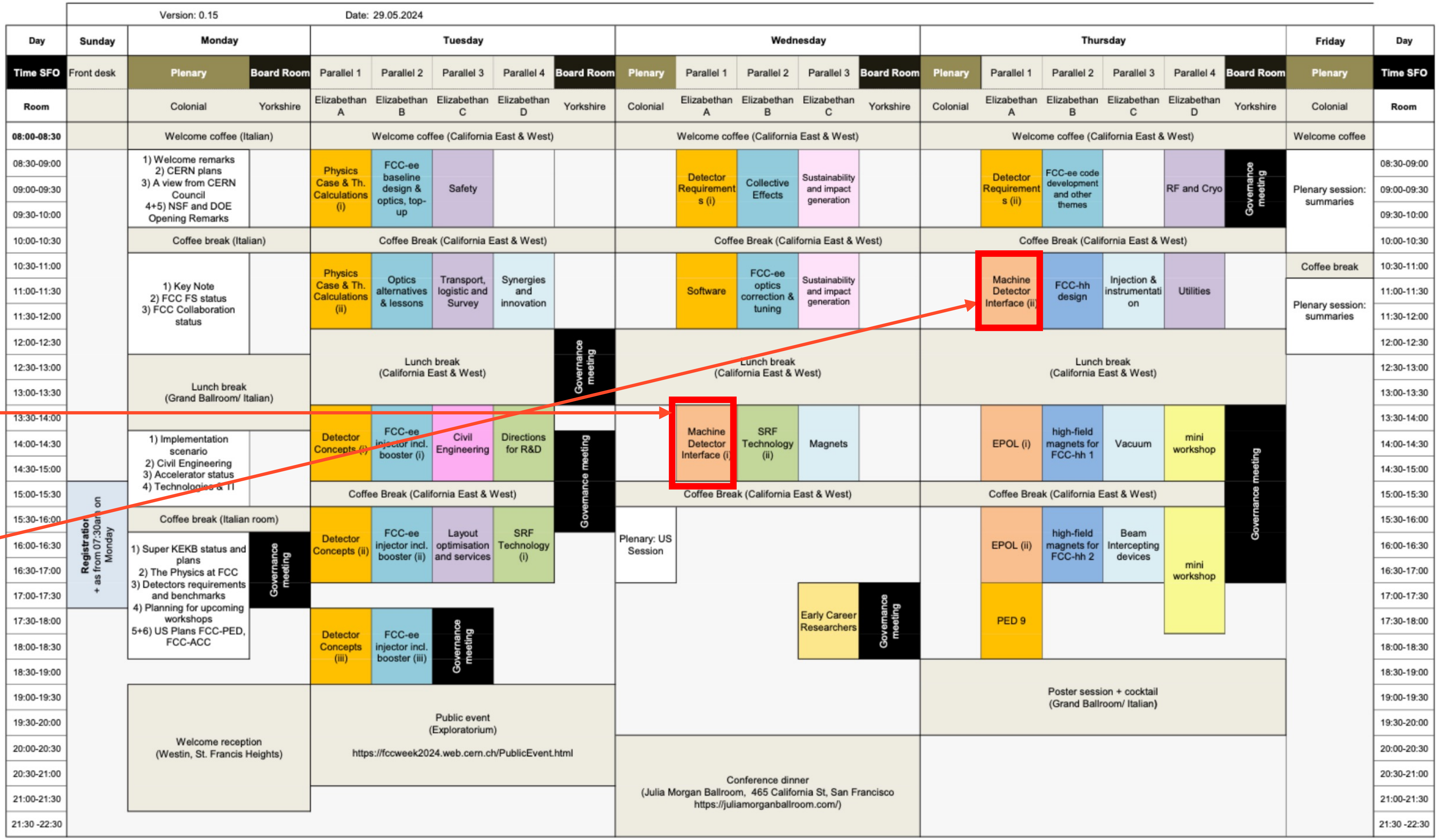
Wed 12

Thu 13

90 min. each

MDI-1

MDI-2



Agenda

MDI (I)	Convener: Fabrizio Palla
Manuela Boscolo (INFN-LNF)	MDI overview
Francesco Fransesini (INFN-LNF)	Mechanical model of the MDI
Alexander Novokhatski (SLAC)	Optimization of the FCC-ee IR beam pipe elements for minimum of the wake field energy loss responsible for the heat load
John T. Seeman (SLAC)	IR magnet system
Alessandro Frasca (CERN & Uni Liv.)	Radiation dose from Fluka simulation in the MDI area

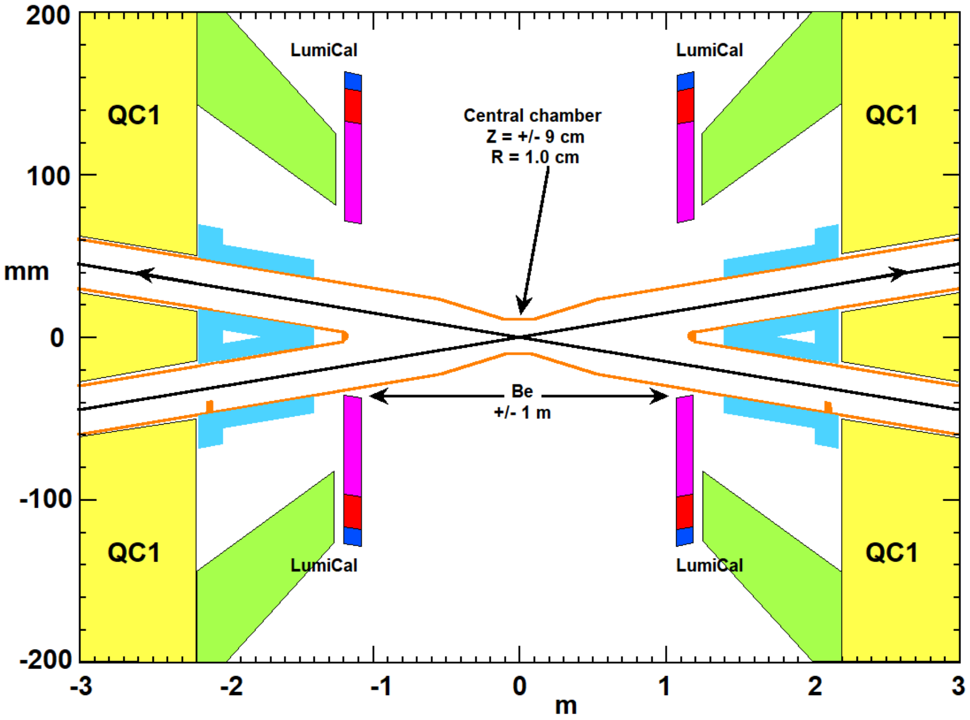
MDI (II)	Convener: Manuela Boscolo
Fabrizio Palla (INFN-Pisa & CERN)	Vertex detector design and integration
Andrea Ciarma (INFN-LNF)	Status and Perspectives for FCC-ee Detector Background Studies
Kevin Andrè (CERN)	Synchrotron Radiation background studies
Giacomo Broggi (CERN, INFN-LNF, Uni. Sapienza)	Beam-gas beam losses and MDI collimators
Andrii Natochii (BNL)	A new framework for synchrotron radiation studies in the EIC experiment

Since the last FCC WEEK 2023

Mid-term review accomplished

- Two **optics** with different final focus region design: GHC (Global Hybrid Correction), LCC (Local Chromaticity Correction)
- **Solenoid compensation scheme**
- Progress on the **mechanical model**
  - integration of the lumical, lighter cooling manifolds
  - engineered vertex detector and inner vertex services, i.e. air cooling and cables
  - optimization of the material budget
  - IR bellows design, SR masks, collimators
- Progress on the **backgrounds** simulations:
  - **beam losses** in the MDI: halo collimation and first beam-gas loss maps
  - **synchrotron radiation** in the MDI: SR collimators and masking
  - **Interface between accelerator and detector** to track showers from the accelerator to the detectors
- Fluka **radiation studies** started
- MDI **vacuum**
- **Beamstrahlung dump**
  - Liquid Pb target to absorb intense radiation produced at the IP, ~ 500 kW, at about 500 m from IP
- Progress on the **IR heat load** from wakefields and trapped modes, from synchrotron radiation, and from beam losses
- **IR magnet system**
  - cold test on CCT final focus quad segment prototype performed
  - studies of assembly, cryogenic lines, operation, vibration, supports

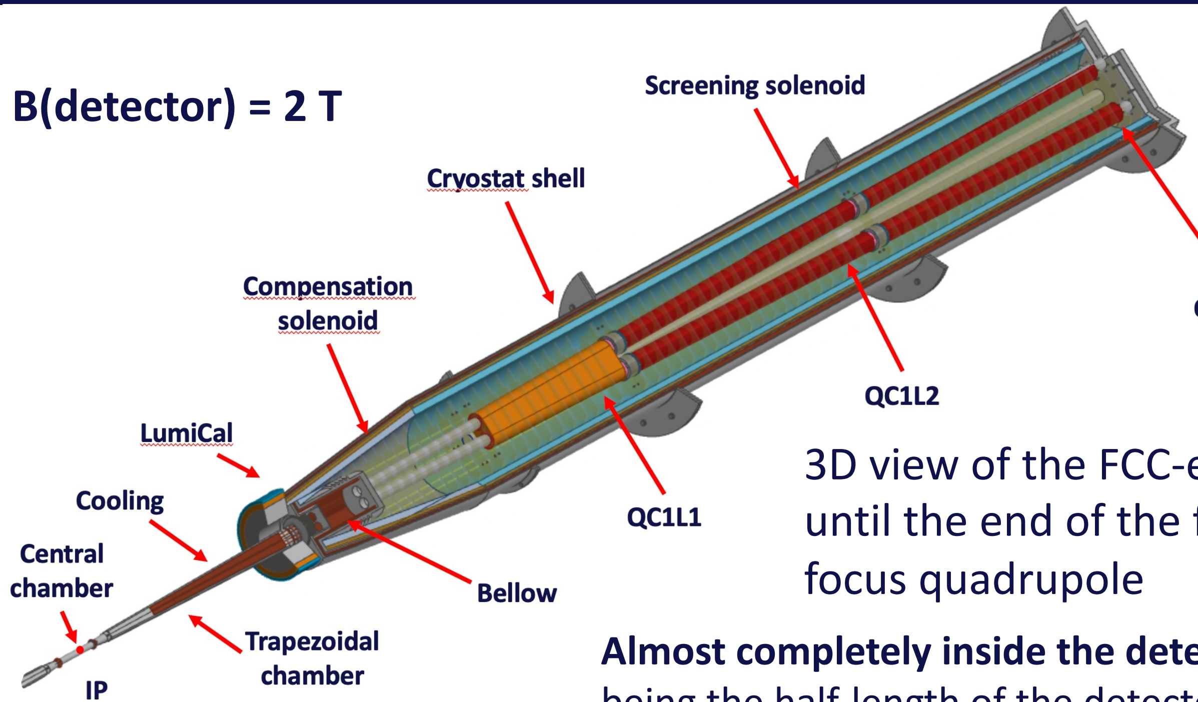
FCC-ee Interaction Region



FCC-ee IR layout.

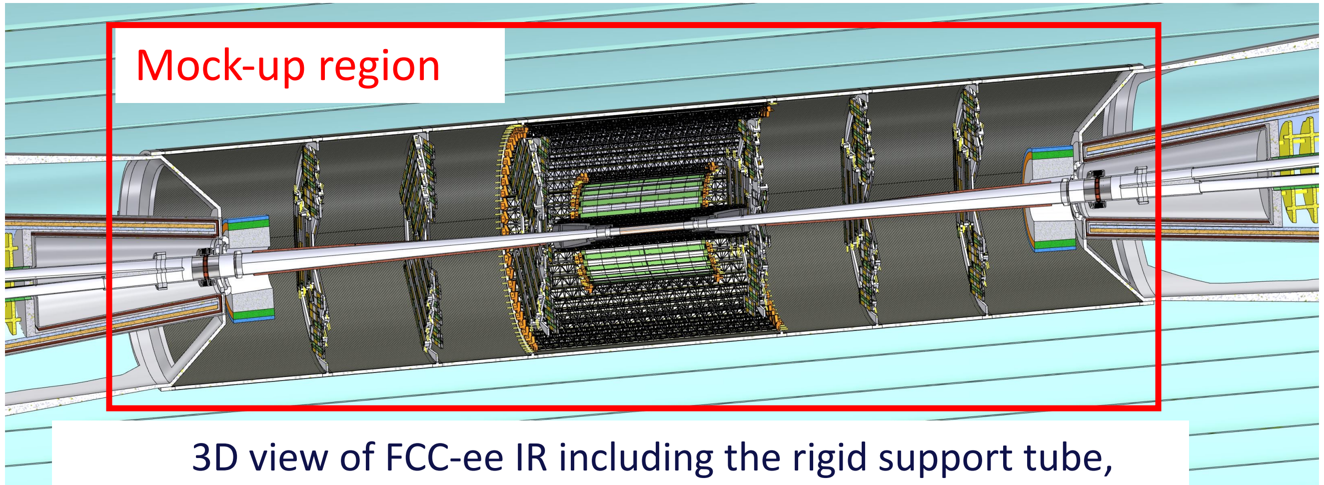
L*, is 2.2 m. The 10 mm central radius is foreseen for ± 9 cm from the IP, and the two symmetric beam pipes with radius of 15 mm are merged at 1.2 m from the IP.

B(detector) = 2 T



3D view of the FCC-ee IR until the end of the first final focus quadrupole

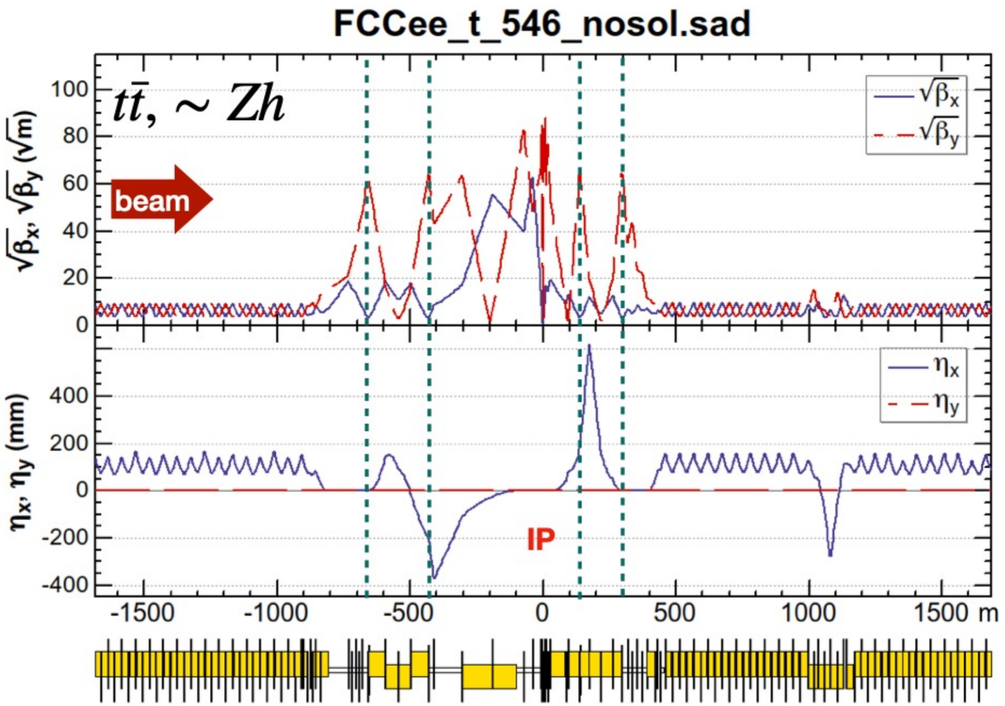
Almost completely inside the detector, being the half-length of the detector about 5.2 m and the end of QC1L3 at about 5.6 m.



3D view of FCC-ee IR including the rigid support tube, vertex detector and outer trackers.

GHC optics (baseline)

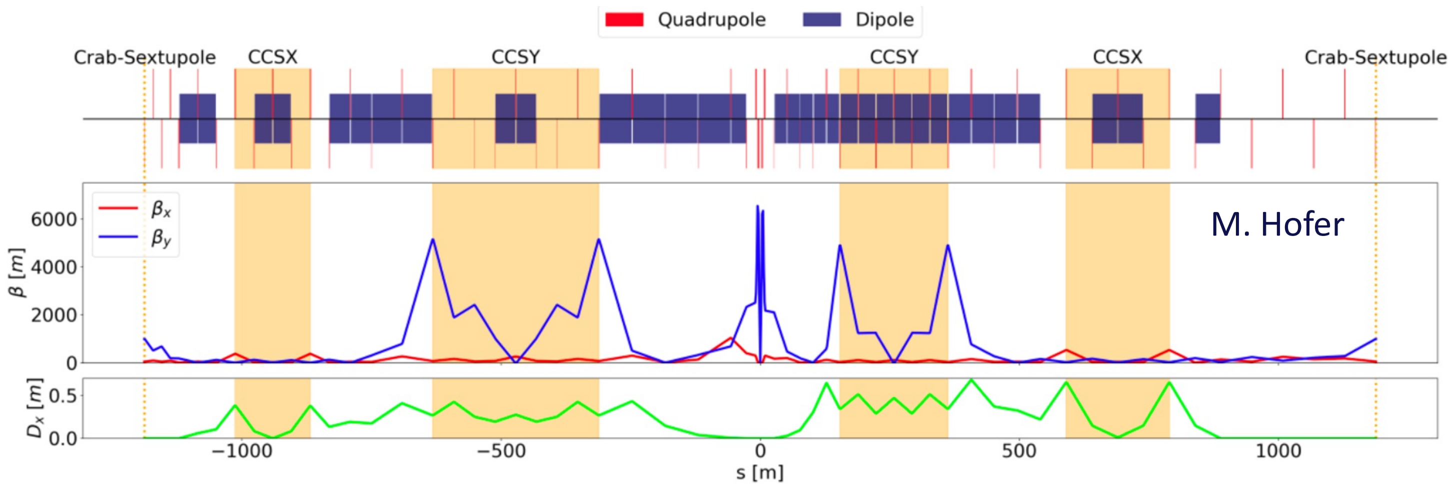
K. Oide



LCCO Optics

P. Raimondi

ttbar



LCCO: Local Chromatic Correction Optics

- IR Horizontal chromaticity corrected in arcs
- Crab sextupoles are “virtual” by detuning one sextupole of the chromaticity correction pair

- Chromaticity correction is local in the Interaction Regions
- Dedicated sections for crab sextupoles

- **The beam optics are asymmetric between upstream/downstream due to crossing angle & suppression of the SR upstream to the IP.**
- **The two final focus optics impact differently the MDI design, we heard the details in the optics session on Tuesday morning 11/6.**

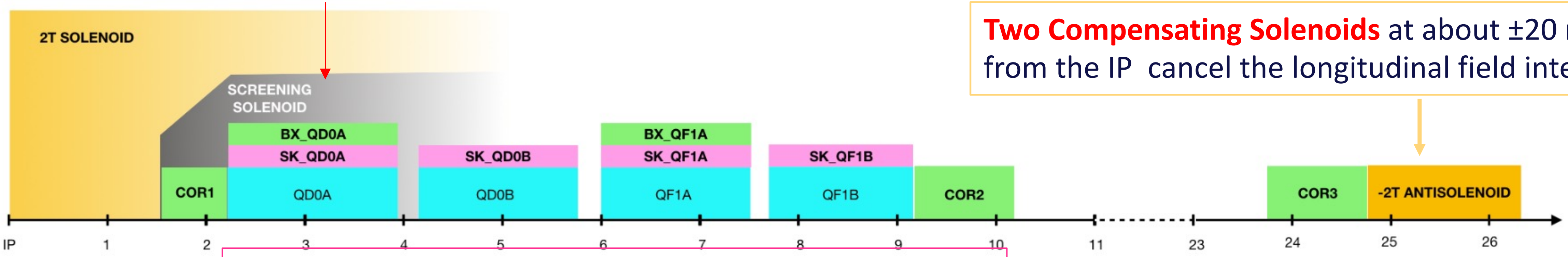
Alternative Solenoid Compensation Scheme

Poster session: A. Ciarma (INFN-LNF)

Details in: IPAC2024- TUPC68, "Alternative Solenoid Compensation Scheme for the FCC-ee Interaction region", A. Ciarma, M.B., H. Burkhardt, P. Raimondi: link

A **Screening Solenoid** shields the Final Focus Quads

Two Compensating Solenoids at about ±20 m from the IP cancel the longitudinal field integral



Skew quadrupolar components in the FFQs align the magnet axis to the rotated reference frame of the beam

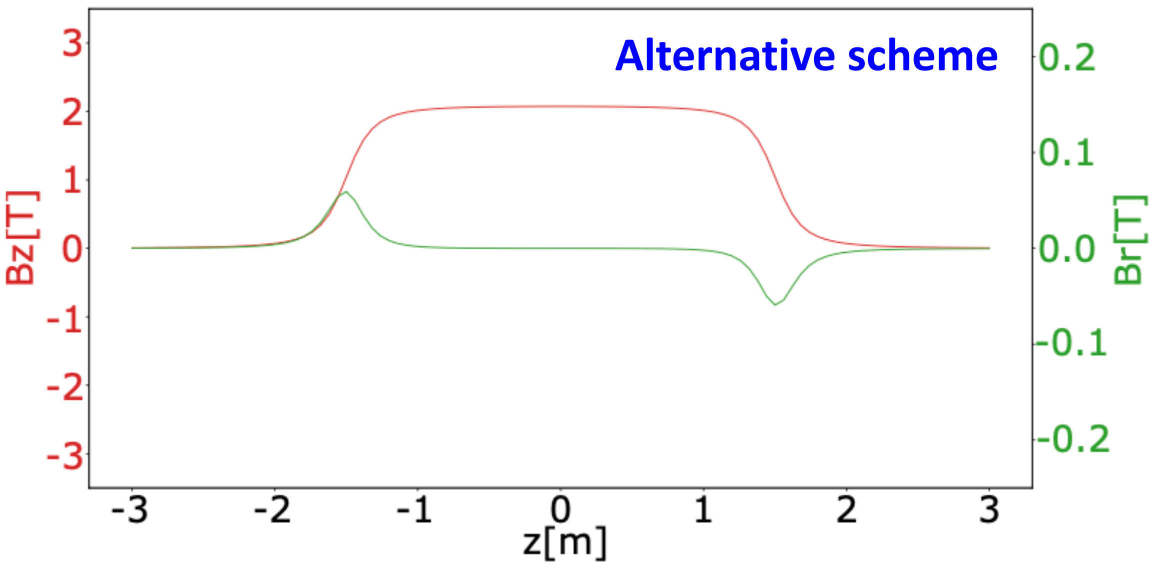
Correctors right after the beam pipe separation and around the FFQs compensate the orbit distortion generated by the horizontal crossing angle in the detector field

- **This solution is optics independent.**
- **The tuning knobs -correctors and skews- are needed for orbit and coupling correction for all optics.**

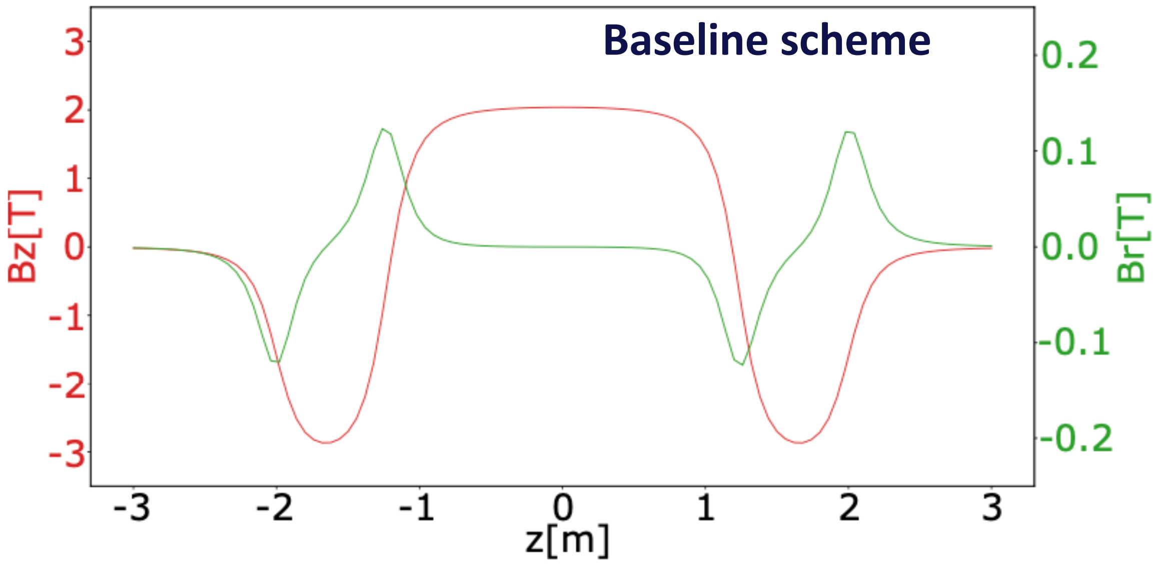
https://doi.org/10.18429/JACoW-IPAC2024-TUPC68

Solenoid Coupling Compensation Scheme

Longitudinal and radial magnetic fields along the 15 mrad axis



Synchrotron radiation power 12 kW

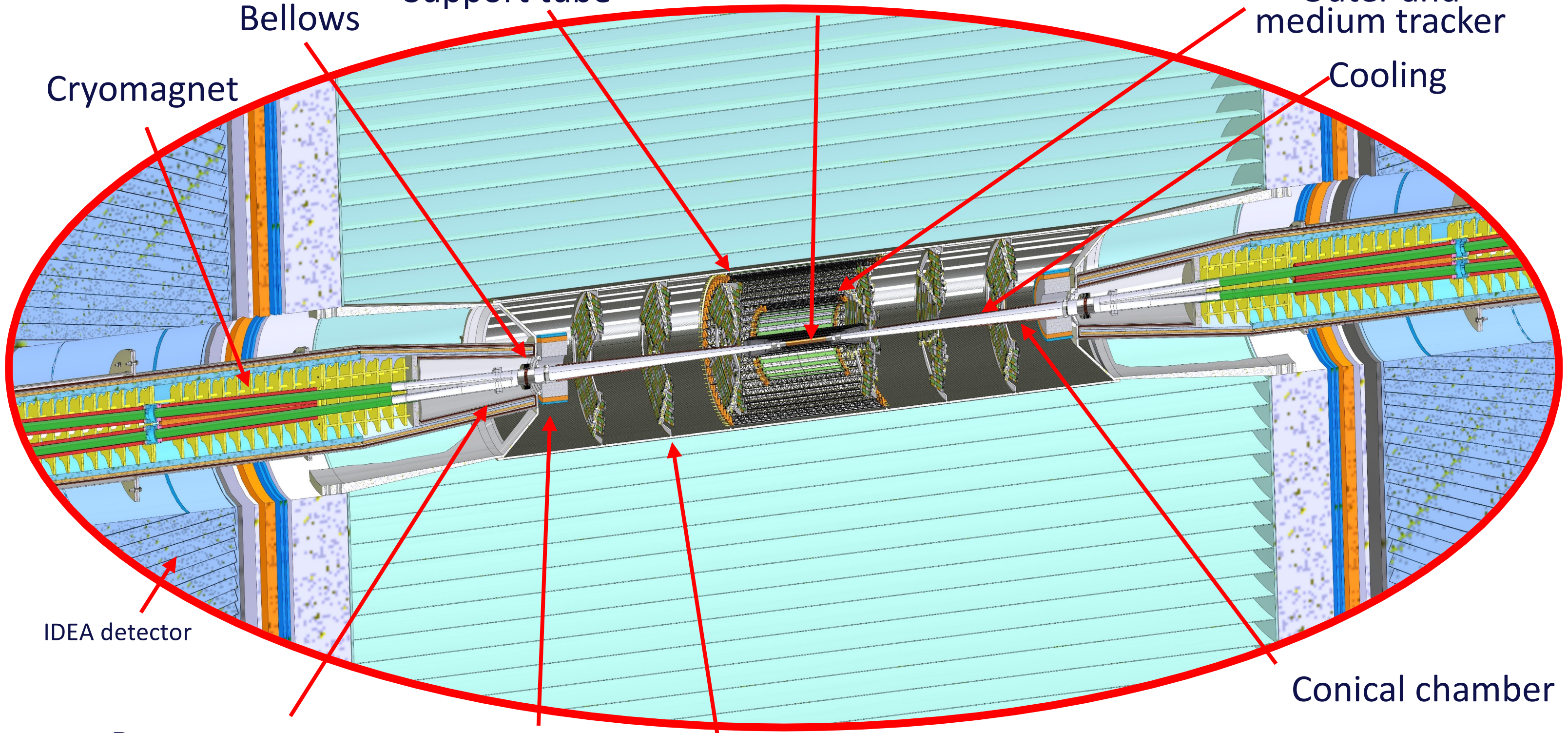


Synchrotron radiation power 80 kW

Alternative scheme:

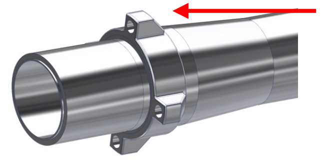
- Vertical emittance increase is only 0.2% of the nominal value of 1 pm.
- Chromatic behavior of the vertical emittance increase small in the range of dE/E = ±4%.

FCC-ee engineered Interaction Region



Design in continuous optimization:

- vacuum chamber copper cooling manifolds replaced by AlBeMet to minimize showers in the LumiCal

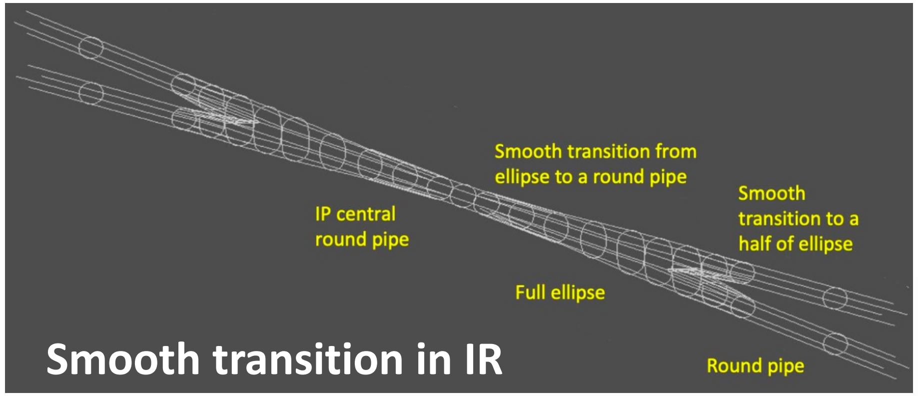


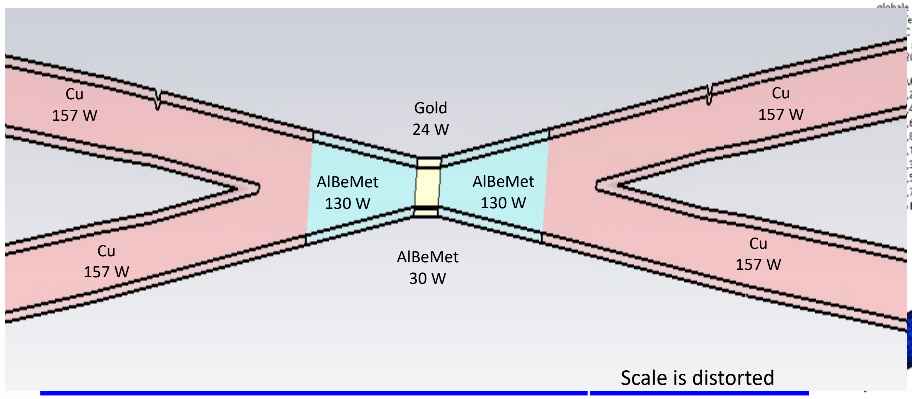
- More advanced and detailed studies on vertex detector integration
- IR magnet system to be integrated
- Remote vacuum connection to be designed

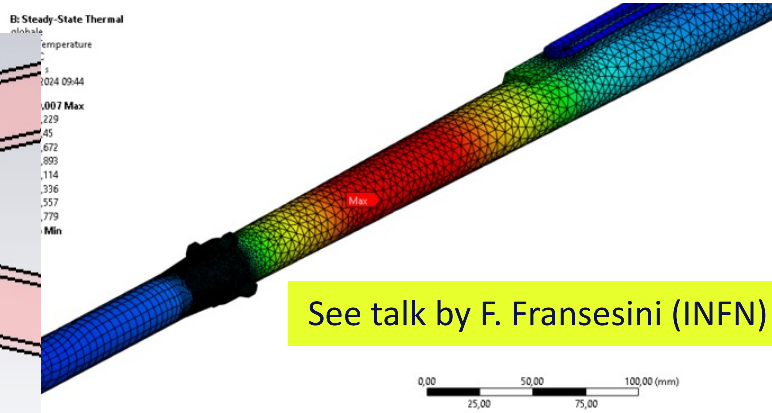
- Crucial area: a full-scale mockup assembly has started

Ref: M. Boscolo, F. Palla, et al., *Mechanical model for the FCC-ee MDI,* EPJ+ Techn. and Instr., https://doi.org/10.1140/epjti/s40485-023-00103-7

Low-impedance IR vacuum chamber





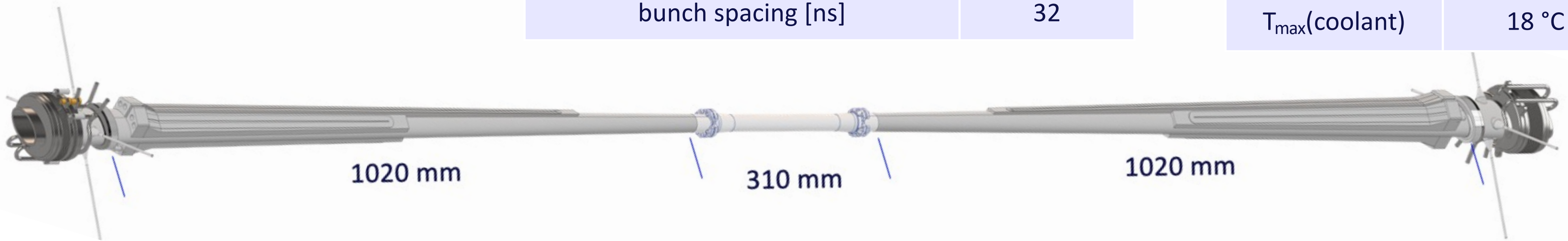


See talk by F. Fransesini (INFN)

See talk by A. Novokhatski (SLAC)

beam energy [GeV]	45
beam current [mA]	1280
number bunches/beam	1000
rms bunch length with SR / BS [mm]	4.38 / 14.5
bunch spacing [ns]	32

	conical chamber	central chamber
coolant	water	paraffin
T_{max} (chamber)	50°C	29°C
T_{max}(coolant)	18 °C	20 °C

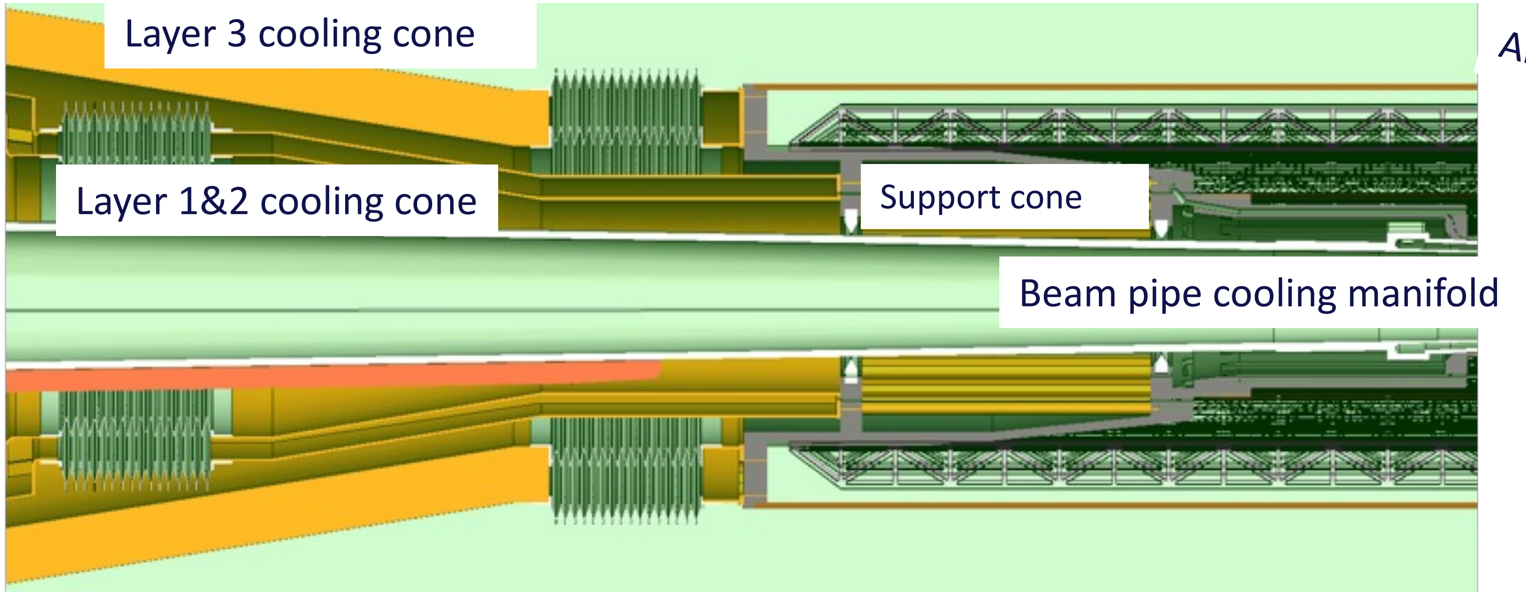


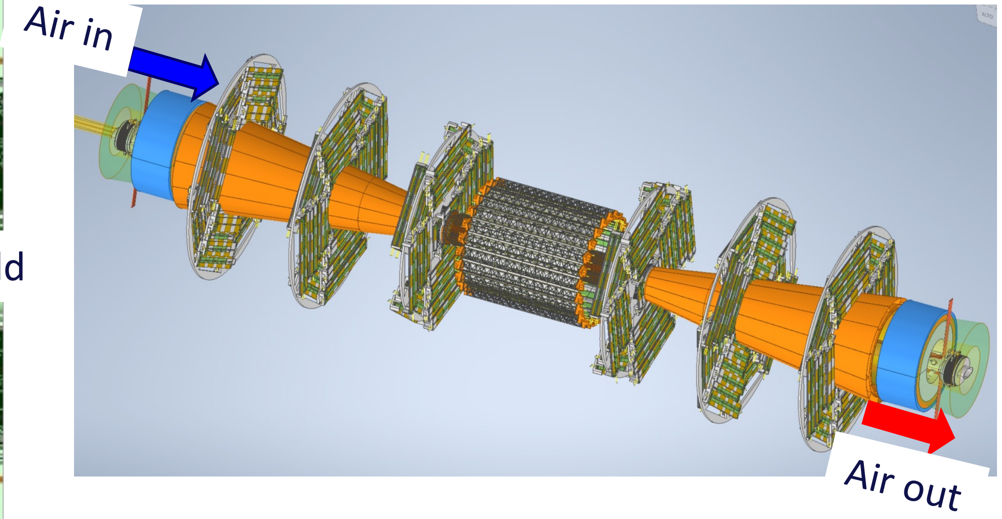
Study and optimization of the material budget for the beam pipe has been performed and is in progress.
LumiCal requirements and material budget minimization considered, also comparing Be with AlbeMet.

See poster by Giulia Nigrelli (INFN-LNF & Sapienza)

Inner vertex support and cooling cones

see talk by F. Palla





Engineering study to design and integrate the vertex in the IR

Cooling (vertex and beam pipe) and cables engineered integration ongoing

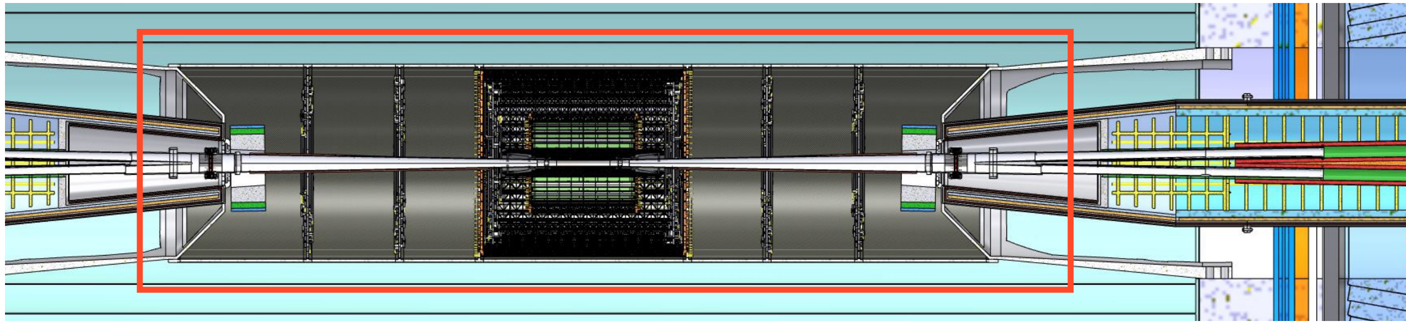
Progress on the air cooling simulation studies for the vertex see poster by G. Baldinelli (INFN-Perugia)

IR mockup

The mockup project has received a great deal of interest within the FCC community

- **primarily for technology validation of the MDI design for the Feasibility Study**
- **Integrating vertex and chambers "on paper" has been proven to be difficult, more surprises expected with a real mock-up!**
- **Global assembly sequence to be studied**

central region $\pm$1.2 m



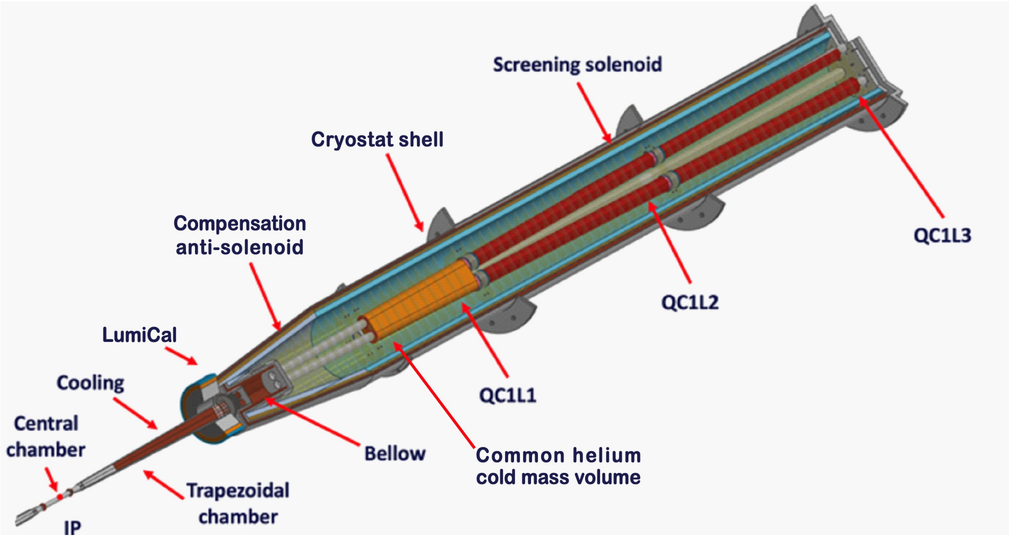
IR based on the crab-waist scheme, compact and crowded with tight constraints and many technical challenges → **mockup being built** for R&D in Frascati to prove state-of-the-art technological solutions and test its feasibility

LNF, CERN and INFN-Pisa collaboration (LNF-CERN MoU)

Main components

- ✓ Central vacuum chamber with paraffin cooling system
- ✓ Lateral vacuum chamber with water cooling system
- IR Bellows
- Support tube – carbon fibre + honeycomb
- Inner vertex detector with air cooling system + outer tracker and services routings
- Luminosity calorimeter and services routings

FCC-ee IR Magnets



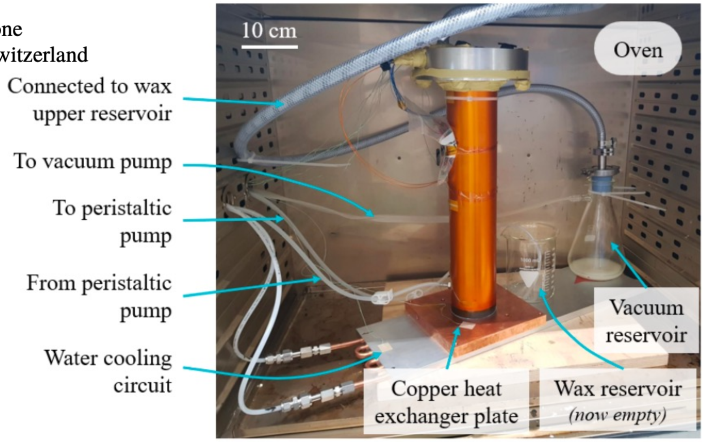
Cold tests on first segment prototype of QC1L1: IPAC24-WEPS65

15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS65

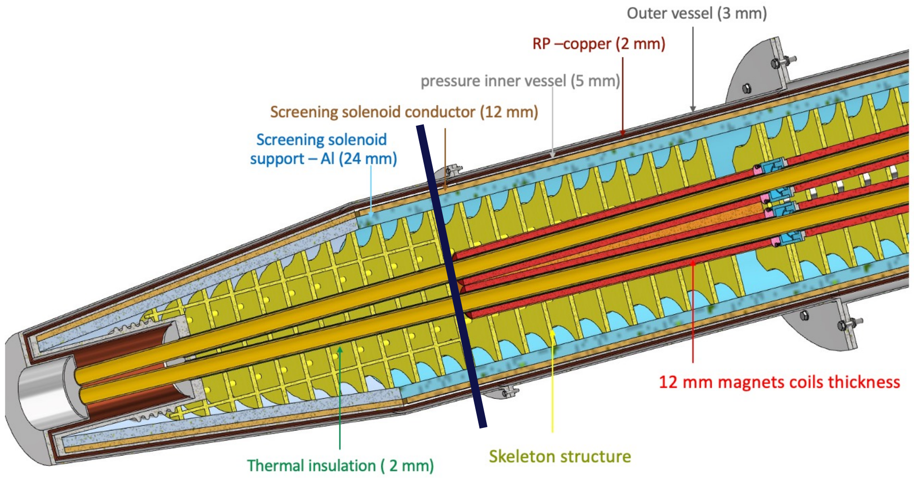
THE FIRST SUPERCONDUCTING FINAL FOCUS QUADRUPOLE PROTOTYPE OF THE FCC-ee STUDY

A. Thabuis, M. Koratzinos, G. Kirby, M. Liebsch, C. Petrone
European Organization for Nuclear Research (CERN), Geneva, Switzerland

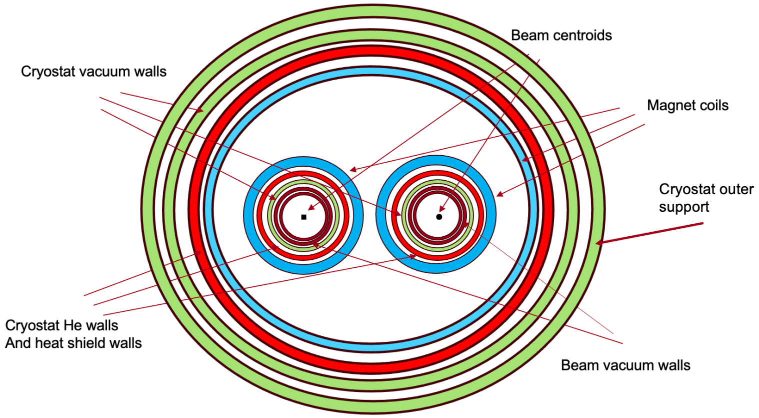
see talk by M. Koratzinos



Integration of complete cryostat with magnets, correctors, and diagnostics is required. Study has started.



IR Magnet Cross Section View (front and end of each magnet)



J. Seeman Nov 4, 2023

IR QC1 and QC2 in different cryostats but one integrated raft seems the best solution

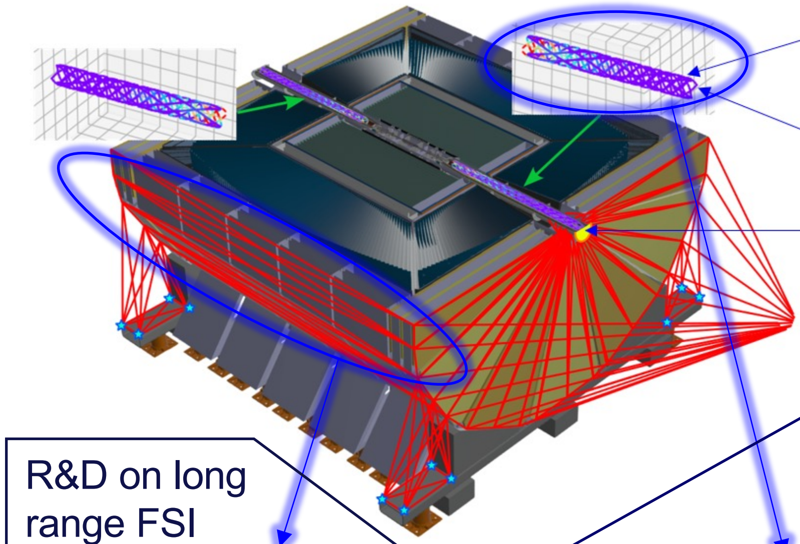
see talk by J. Seeman

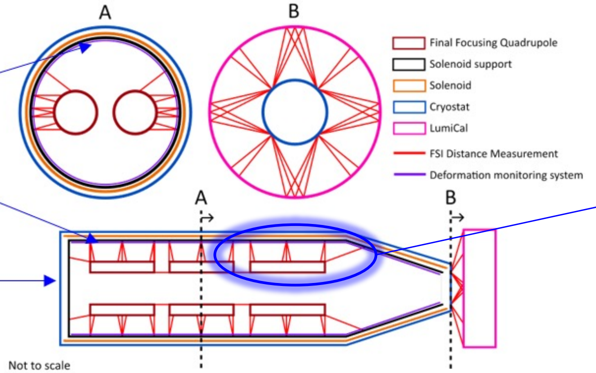
FCC-ee MDI alignment

see talk by Léonard Watrelot (CERN)

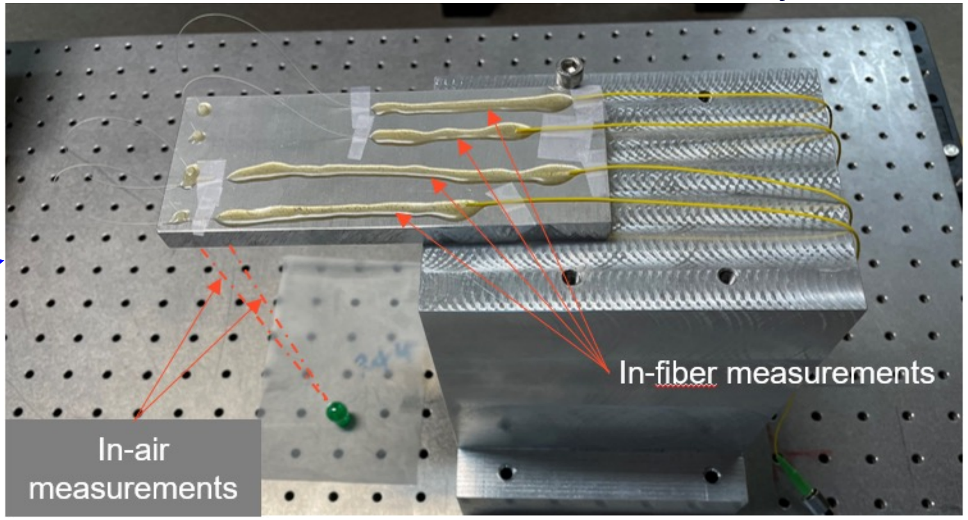
Thesis
Article

MDI alignment monitoring strategy

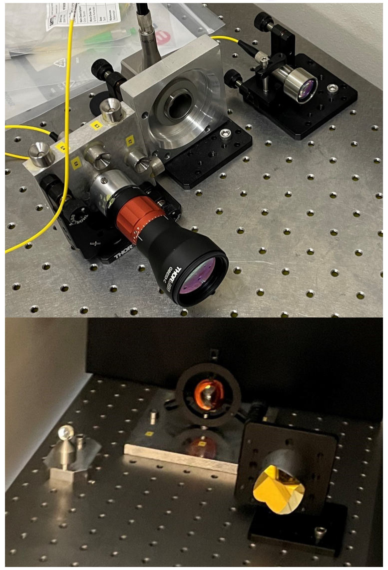




R&D for measurement of inside the assembly

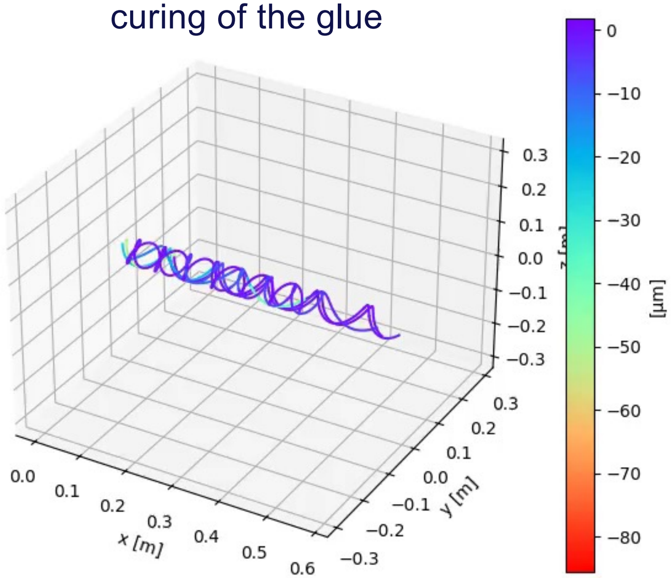


R&D on long range FSI

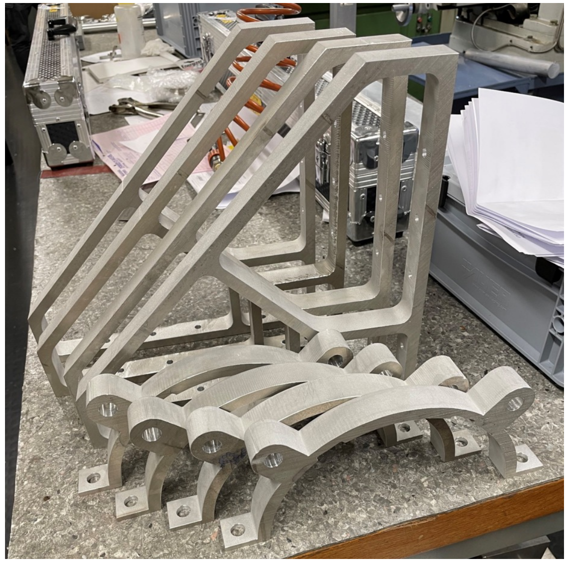


R&D on deformation monitoring system (IMD-FSI)

Timelapse of an 8 hours measurement
Shrinkage of the fibres due to the curing of the glue



Parts getting ready for a 2m long tube deformation study



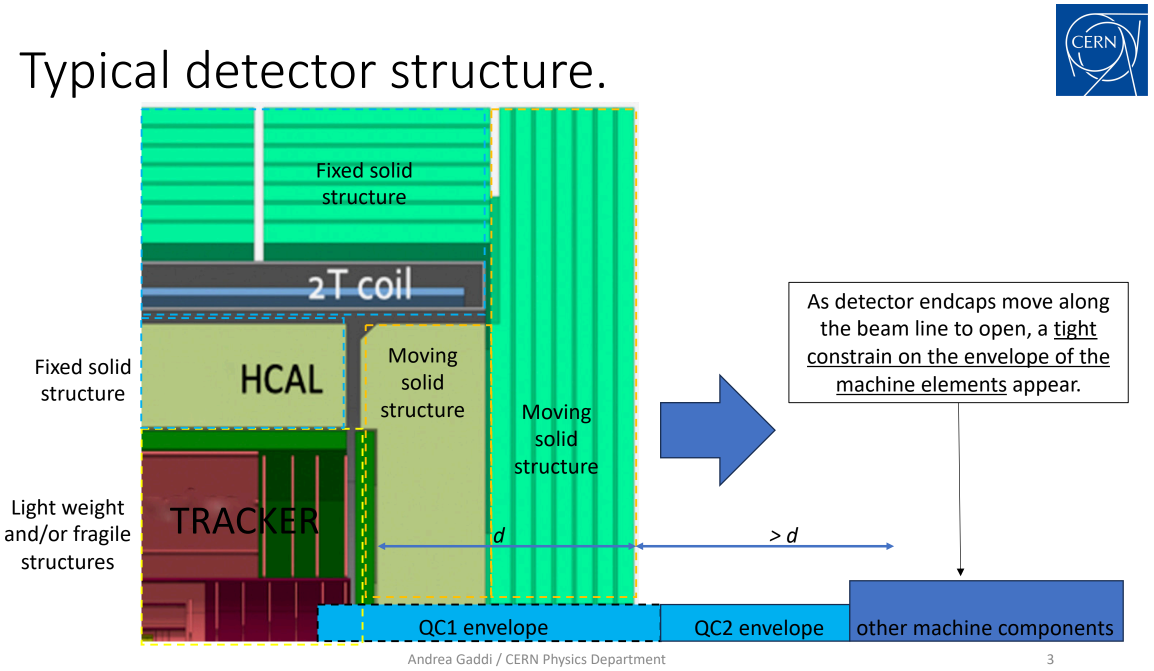
A. Gaddi, FCC Physics Week , Annecy

General detector integration issues

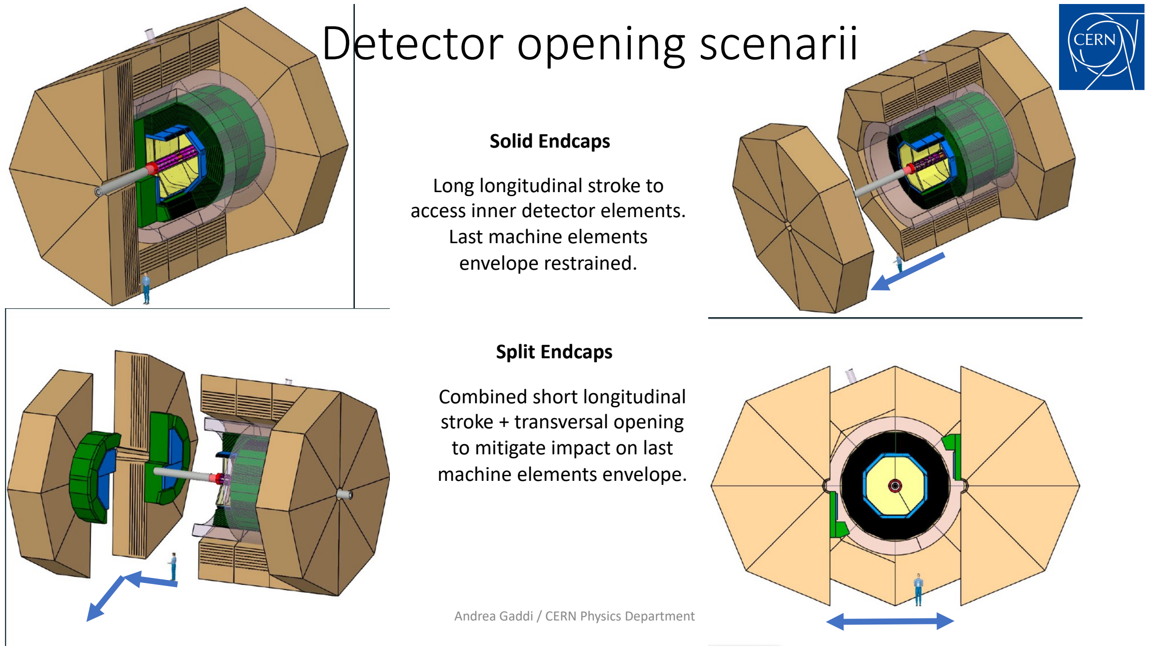
Considering how to access the detector elements taking care of the final focus superconducting quads

There is enough clearance to envisage the scenario to move the detector aside the beamline and get full access to the detector's inner parts

Typical detector structure.



Detector opening scenarii



Beam induced Backgrounds

Luminosity backgrounds

Radiative Bhabha
Beamstrahlung: photons and spent beam
Incoherent/ Coherent e^+e^- Pair Creation
$\gamma\gamma$ to hadrons

Synchronous with the collisions, can be discriminated at trigger level

Single Beam effects

Synchrotron Radiation
Beam-gas
Thermal photons
Touschek

Mostly can be mitigated with collimators & shieldings except for those produced just next to and in the IR

Halo beam backgrounds
Injection backgrounds

A collimation region has been implemented for halo beam

Fluences, radiation levels, Ionization doses

Luminosity backgrounds

Source generated with GuineaPig, BBBREM, Phythia
Products tracked directly into the detectors

Incoherent pairs production tracked into

- vertex
- calorimeter
- drift chamber

First results!

see talk by A. Ciarma

Single beam effects

Each background source requires dedicated study to evaluate and to mitigate as much as possible the effects, before providing detector experts the background events for estimating occupancy, data rates, to evaluate the effects on reconstruction.

Synchrotron Radiation

- BDSIM (Geant4 based)
- SR collimators and masks in the MDI region upstream the IR have been determined.
- SR can be provided to detector experts.

see talk by K. Andrè

Beam-gas

- X-suite – implementation was required first, done
- Beam losses along the ring due to beam-gas scattering evaluated
- MDI beam-gas planned
- Thermal photon on MDI planned

First results!

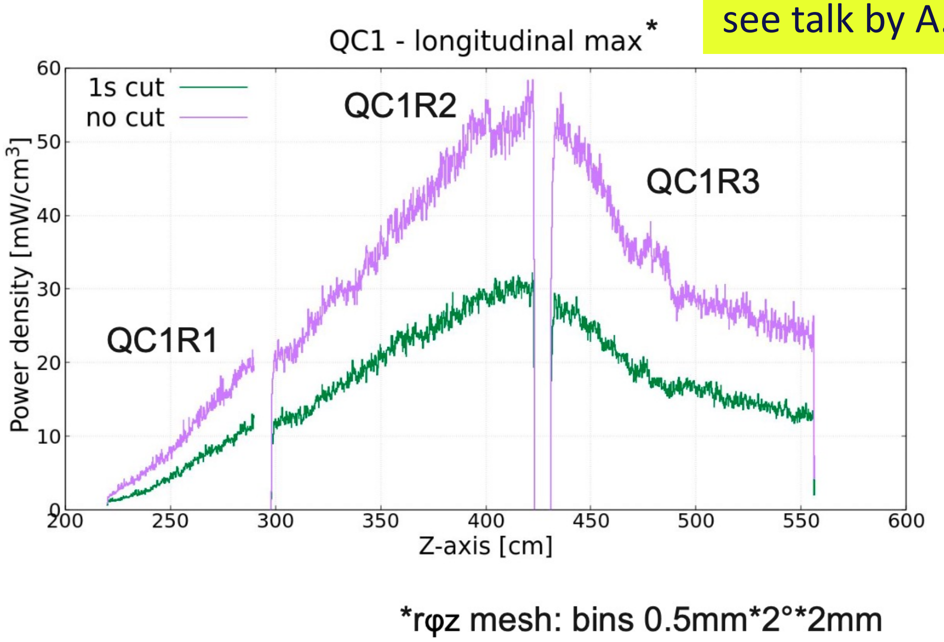
see talk by G. Broggi

Ongoing simulations on various background sources, few examples of recent updates in next slide

Beam losses, Backgrounds & Radiation

Fluka studies of Radiative Bhabhas

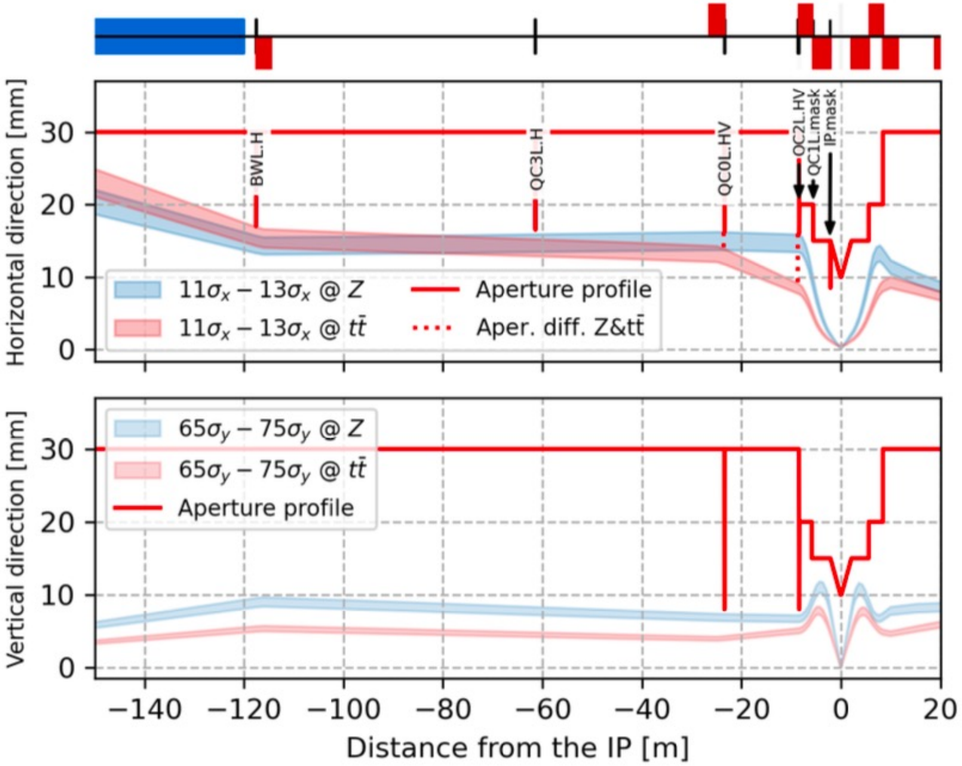
see talk by A. Frasca



- Estimated power deposition **~10 mW/cm³**
- Estimated dose **~10 MGy/y** inside the superconducting FFQs
- **Internal shielding must be developed to avoid quenches**

Synchrotron Radiation studies

see talk by K. Andre



Synchrotron radiation horizontal and vertical collimators, and masks.

more details in IPAC24-WEPR09

MDI Vacuum

Courtesy from R. Kersevan

- Several simulations of the synchrotron radiation (SR) fans generated along the MDI area and corresponding pressure profiles have been already provided by the CERN vacuum group (VSC) (see C. Garion, https://indico.cern.ch/event/1298458/contributions/5978899/; M. Morrone, https://indico.cern.ch/event/1298458/contributions/5978901/).
- The use of extruded copper chambers with "winglets" hosting ad-hoc placed SR absorbers, as contemplated for the FCC-ee arcs, has been implemented in the MDI models.
- Basically all SR generated upstream of the IP can be blocked by such absorbers: only a small fraction goes inside the opening of the final focus quadrupoles, and is dealt with by different absorbers built into the final focus chamber (see F. Fransesini https://indico.cern.ch/event/1298458/contributions/5977812/).
- The intense SR generated by many sources at the IP have been modeled too, in order to give a first thought of the vacuum design of the challenging photon beam dump, together with residual gas pressure profiles for collimator location studies (see G. Broggi https://indico.cern.ch/event/1298458/contributions/5977817/).
- Pressure profiles for the ~600 m upstream and ~500 m downstream of the IP have been computed: it has been found that adopting a fully NEG-coated vacuum chamber with additional lumped NEG pumps at strategic locations (near SR absorbers) would allow obtaining a pressure in the **10^{-10} mbar range after ~100 Ah of integrated beam dose (for the Z-machine**). **Starting the FCC-ee at higher energies (e.g. H) would therefore need a longer time to condition**, since the beam current is much lower compared to the Z case (~50x lower). **The final solution cannot be given until the MDI optics is not finalized.**
- In order to make a more precise vacuum commissioning scenario **it is important to use the real beam energy commissioning scenario**, the ideal case being starting at the Z energy since it has a much higher SR photon flux, and therefore accelerated decrease of the dynamic pressure.
- All technologies presently being prototyped by the VSC for the arc vacuum are going to be valid for the MDI as well.
- MDI-specific vacuum issues, e.g. gold- and NEG-coating of the IP chambers will be tackled as soon as the design of the MDI IP area is frozen. **The VSC group can help in developing custom solutions for coating**.

Not exhaustive!

Plans on key aspects of the MDI design

IR magnet system & Cryostats

- FF Quads & Correctors
- Solenoid comp. scheme & anti-solenoid design

IR Mechanical model, including vertex and lumical integration, and assembly concept

- Services (i.e. air & water cooling for vertex and vacuum chambers) and cables
- Anchoring to the detector
- Accessibility & Maintenance
- Vacuum connection
- IR BPMs
- Integrate in the design an alignment system

Heat Loads from wakefields in IR region

- In progress

Beam induced backgrounds

- Activity on the software and MDI model level, great effort done, to be continued in the next months.
  - Halo beam collimators implemented.
  - IP backgrounds evaluated.
  - Single beam effects (e.g. beam-gas, thermal photons, Touschek) being implemented in Xsuite.
  - SR backgrounds studied in different conditions and baseline/LCCO optics was compared.
  - Injection backgrounds
  - Study of IR radiation level & fluences started (Fluka)
- Results to be used by the detectors to estimate their backgrounds, and feedbacks to MDI to optimize shieldings, masks and collimators.
- Beamstrahlung dump with radiation levels

Steps towards the FS final report: MDI note written for the midterm report will be updated with the improvements made so far, and it will be expanded with new studies by September 2024.

And thanks to many people for inputs!

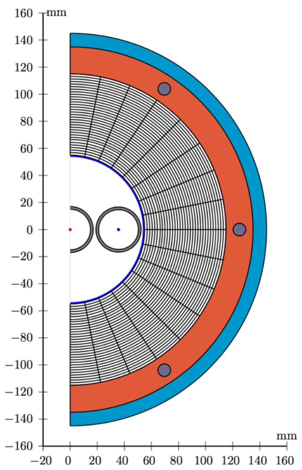
Backup

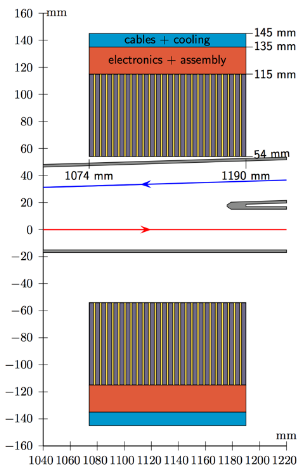
LumiCal constraints & requirements

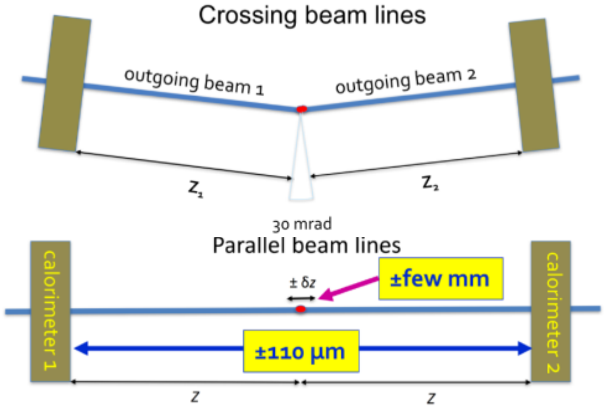
Goal: absolute luminosity measurement 10^{-4} at the Z

Standard process Bhabha scattering

- Bhabha cross section 12 nb at Z-pole with acceptance **62-88 mrad** wrt the outgoing pipe
- Requires **50-120 mrad clearance to avoid spoiling the measurement**
- The LumiCals are centered on the outgoing beamlines with their faces perpendicular to the beamlines
- Requirements for alignment
  - few hundred μm in radial direction
  - few mm in longitudinal direction

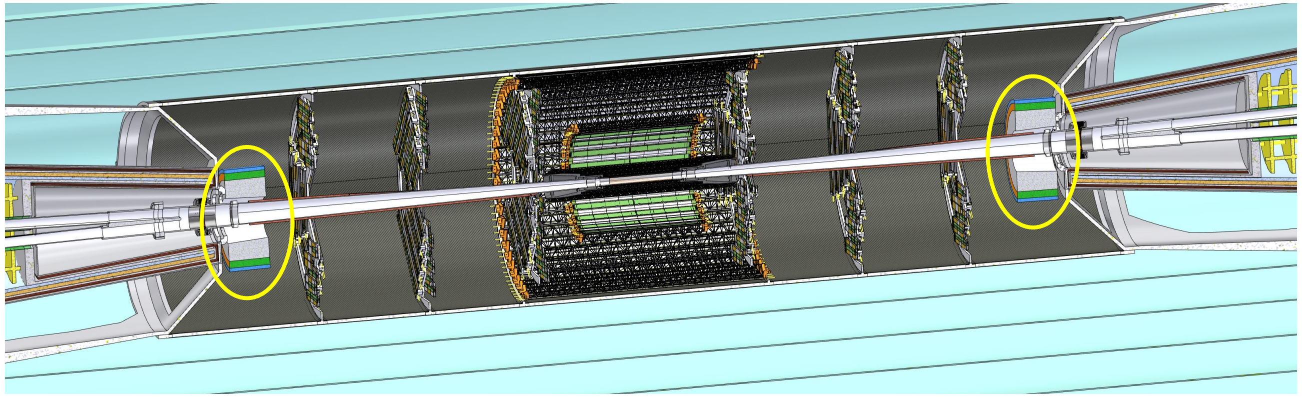






Lumical integration:

- **Asymmetrical cooling system** in conical pipe to provide angular acceptance to lumical
- **LumiCal held by a mechanical support structure**



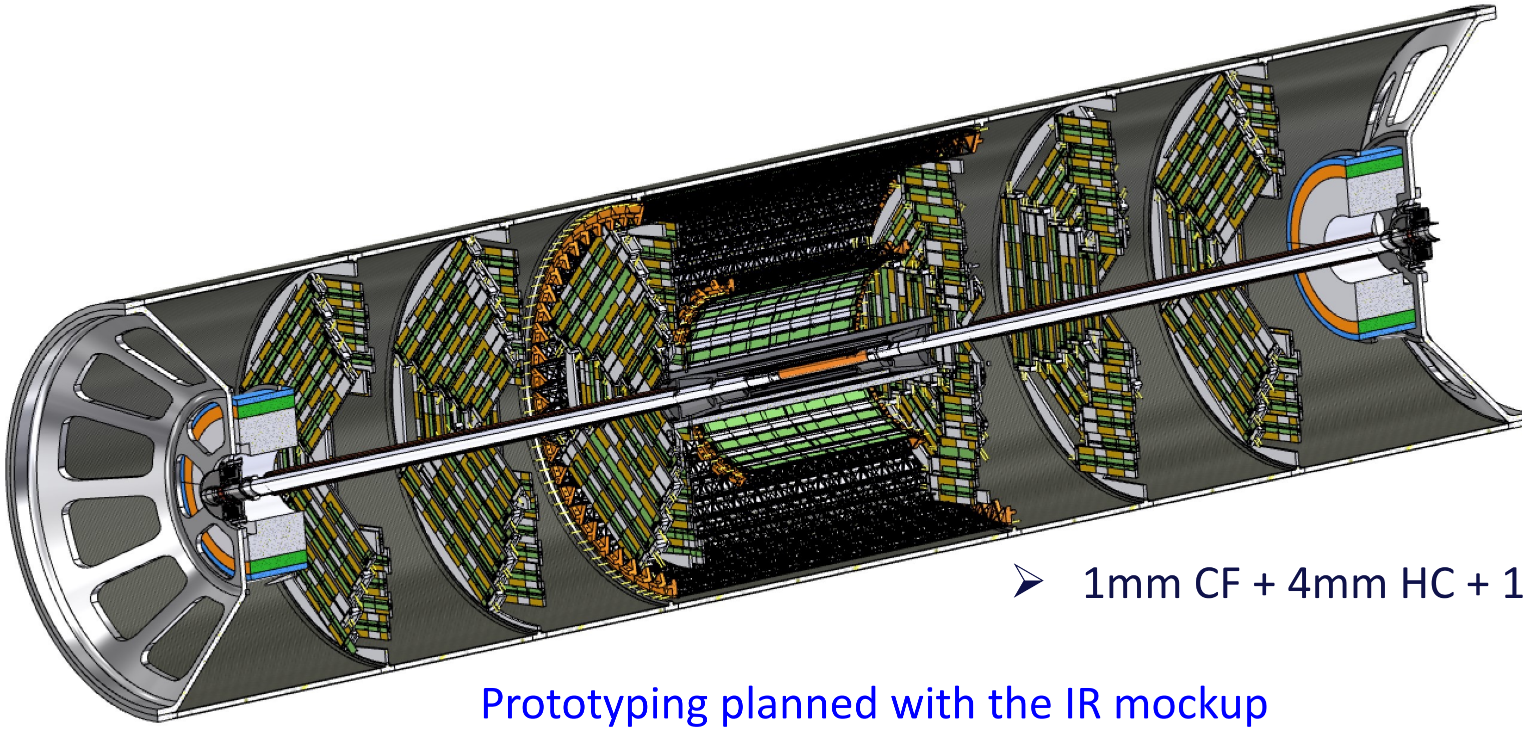
Support cylinder

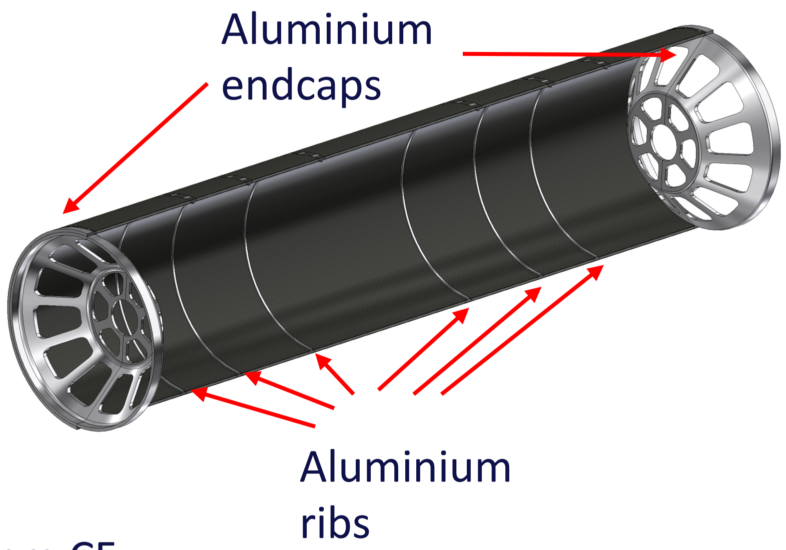
INFN Istituto Nazionale di Fisica Nucleare

All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

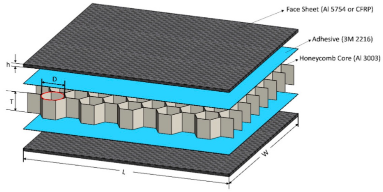
- Provides a cantilevered support for the pipe
- Avoids loads on thin-walled central chamber during assembly or due to its own weight

- Once the structure is assembled it is slided inside the rest of the detector
- Studies on-going where to anchor it





- 1mm CF + 4mm HC + 1mm CF



Prototyping planned with the IR mockup