FUTURE CIRCULAR COLLIDER
Innovation Study

MDI OVERVIEW

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IDEA collaboration meeting
19 November 2024
zoom

Outline

- Interaction region layout
- MDI engineering design
- Beam induced Backgrounds studies
- Outlook

Disclaimer: The IR and MDI is the same for all 4 IPs.

The integration of the vertex presented here is the one of IDEA.

High-level Requirements for the IR and MDI region -1

- **One common IR for all energies, flexible design** with a constant detector field of **2 T**
  - This has been a requirement since the CDR: **we have the same IR and MDI for all energies and all of the four IPs.**

- **At Z pole a Luminosity of ~ 10^{36} $cm^{-2}s^{-1}$ is required**
  - This luminosity can be obtained with the **crab-waist scheme** (nano-beams & large crossing angle).
  - **Continuous top-up injection** is required **with few percent of current drop** to keep a constant luminosity, lifetime is ~15 min (as defined to decrease the beam intensity by 1/e, without any injection).

- **Cone angle of 100 mrad between accelerator/detector** required from the physics
  - **Presently not realistic:** first look at the cryostat dimension with thermal shielding thickness show larger angles necessary.
- **Solenoid coupling compensation**
  - The integral $\int B_z ds = 0$ to avoid vertical emittance blow-up.
  - **Local compensation scheme (Baseline):** Two compensating solenoids 5 T each in front of the first final focus quads, all inside the detector, vertical emittance growth ~ 30-40%, so B=2 T detector solenoid field required.
  - **Non-local compensation scheme**: Compensating solenoids outside the detector at ~20 m from the IP, vertical emittance growth only 0.2% of the nominal value, so 3T detector field becomes possible, study ongoing.

High-level Requirements for the IR and MDI region -2

- **Luminosity monitor** @Z: absolute measurement to 10^{-4} with low angle Bhabhas
  Acceptance of the lumical sets constraints to the central vacuum chamber design and material budget

- **Minimization of the Synchrotron Radiation impacting on the IR**
  Optics design constraint: weak bends upstream the IR (and strong ones downstream, to produce the horizontal crossing angle), having an asymmetric optics wrt IP
  Critical energy below 100 keV produced by the last bending magnets upstream the IR: required from the LEP2 experience

Critical energy: $E_c = \frac{3}{2}\hbar c \frac{\gamma^3}{\rho}$

Half of the synchrotron radiation is radiated below, and the other half above the critical frequency.

The mean photon energy is about 30% of the critical energy $< E_\gamma >= \frac{8}{15\sqrt{3}} E_c = \frac{4}{5\sqrt{3}} \hbar c \frac{\gamma^3}{\rho}$

FCC-ee Interaction Region rationale: crab-waist

Crab-waist scheme, based on two ingredients:

- concept of **nano-beam scheme:**
  - vertical squeeze of the beam at IP and large horizontal crossing angle
  - large ratio σ_z/σ_x reducing the instantanous overlap area, allowing for a lower β_y^*
- concept of **crab-waist sextupoles:**
  - placed at a proper phase advance they suppress the hourglass effect by inducing a constant β_y along the larger coordinate of the beams overlap.

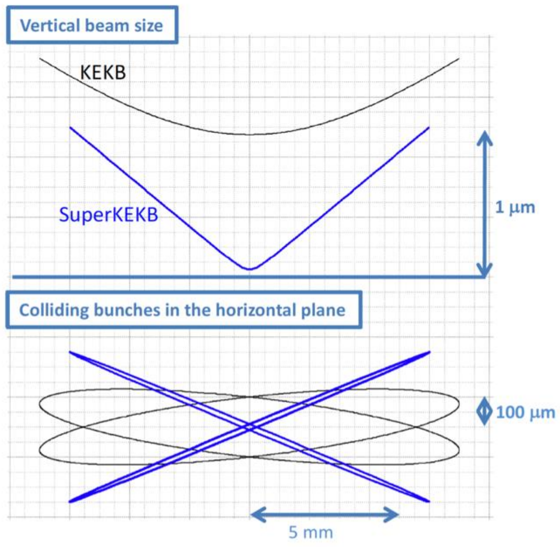
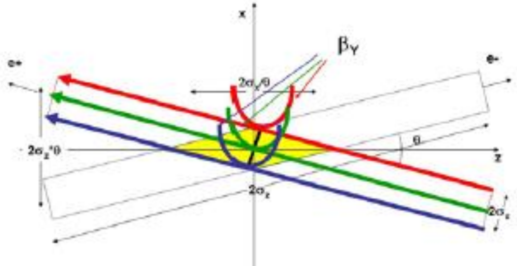
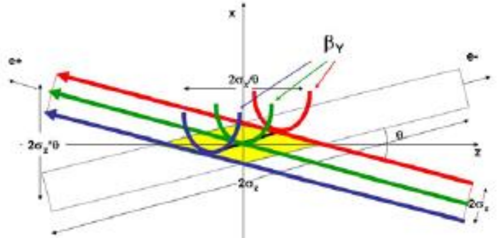


Figure 2: Schematic view of the nanobeam collision scheme.

SuperKEKB https://arxiv.org/pdf/1809.01958.pdf

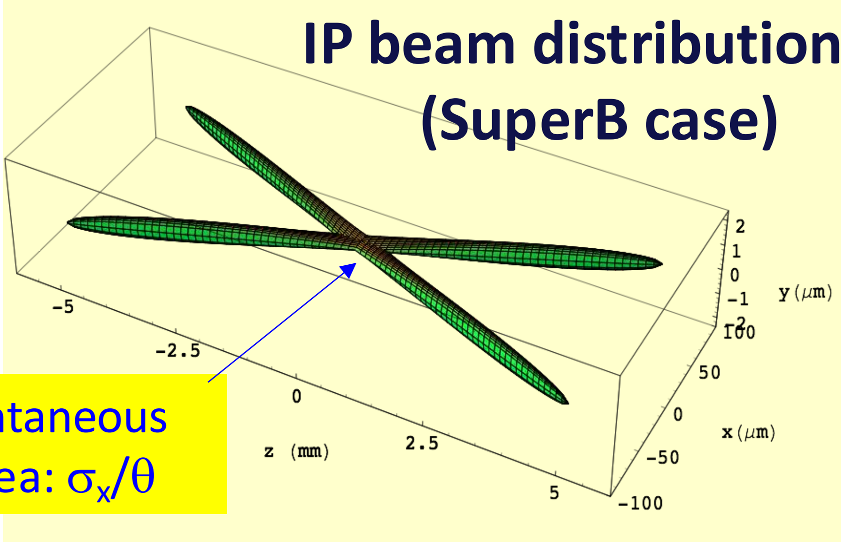


crab sextupoles off



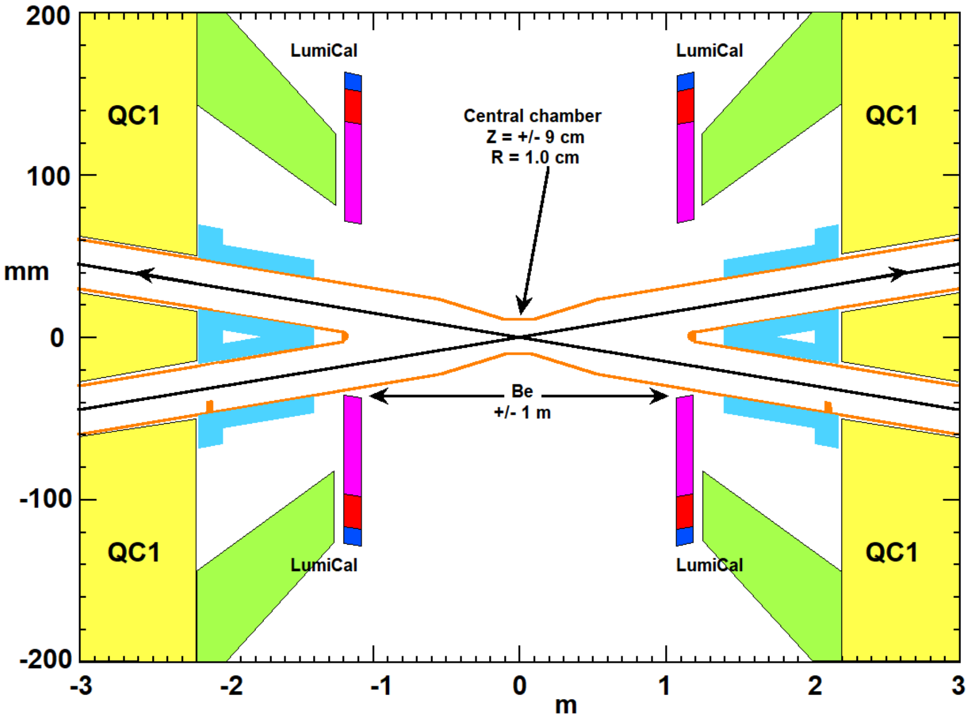
crab sextupoles on

DAFNE, PRL 104, 174801 (2010)



Small instantaneous collision area: σ_x/θ

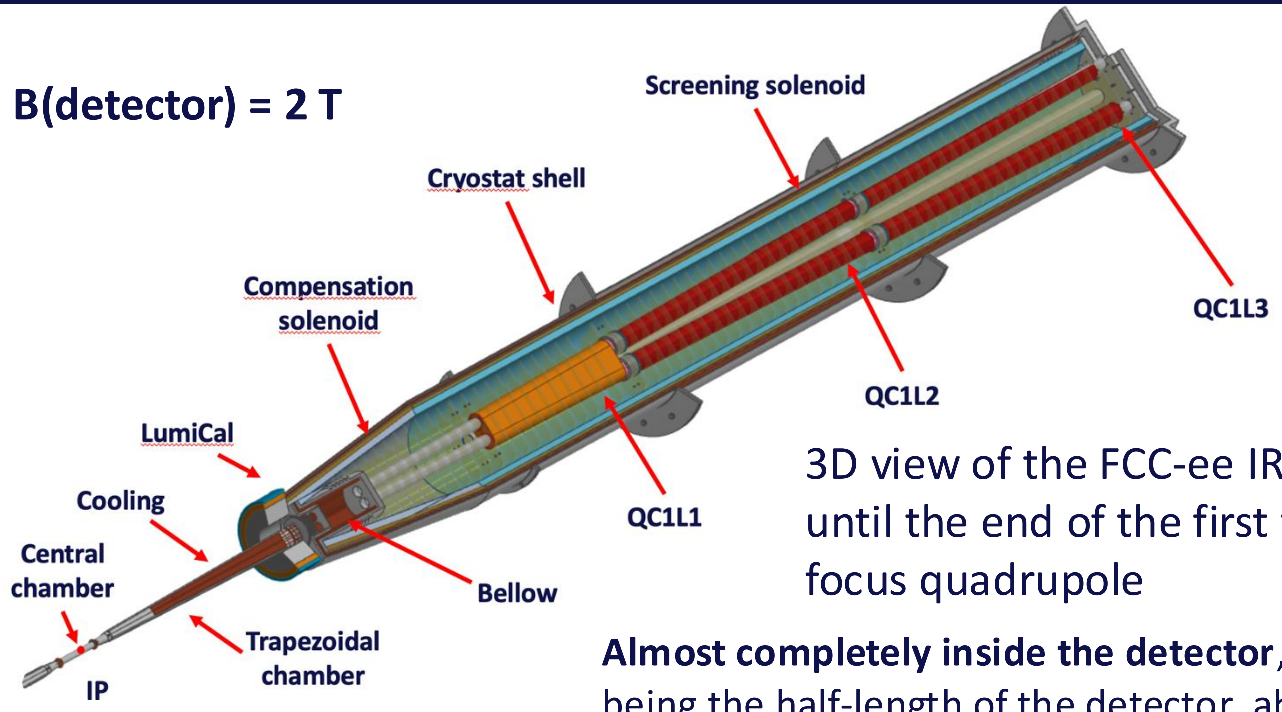
FCC-ee Interaction Region



FCC-ee IR layout.

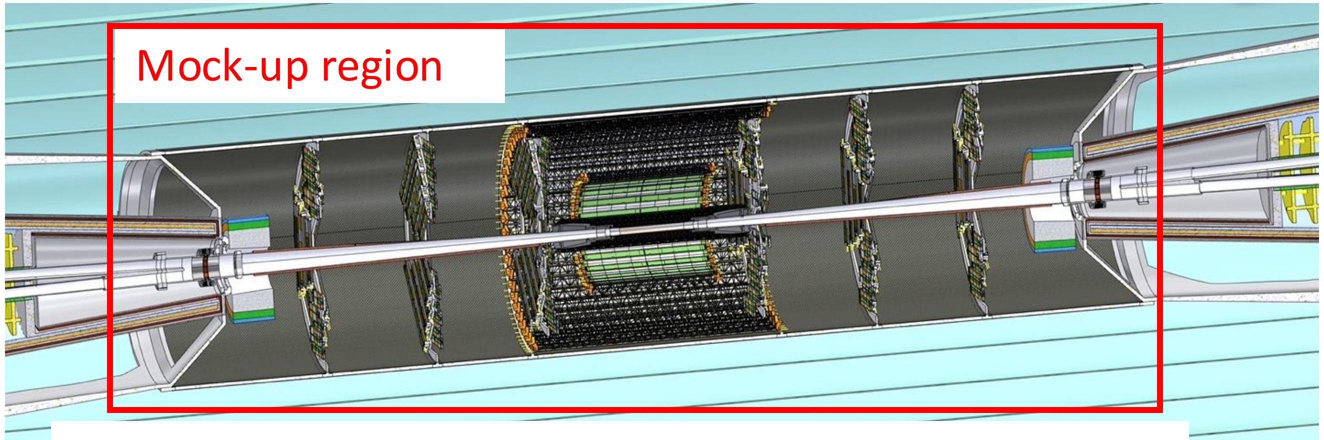
L*, is 2.2 m. The 10 mm central radius is foreseen for ± 9 cm from the IP, and the two symmetric beam pipes with radius of 15 mm are merged at 1.2 m from the IP.

B(detector) = 2 T



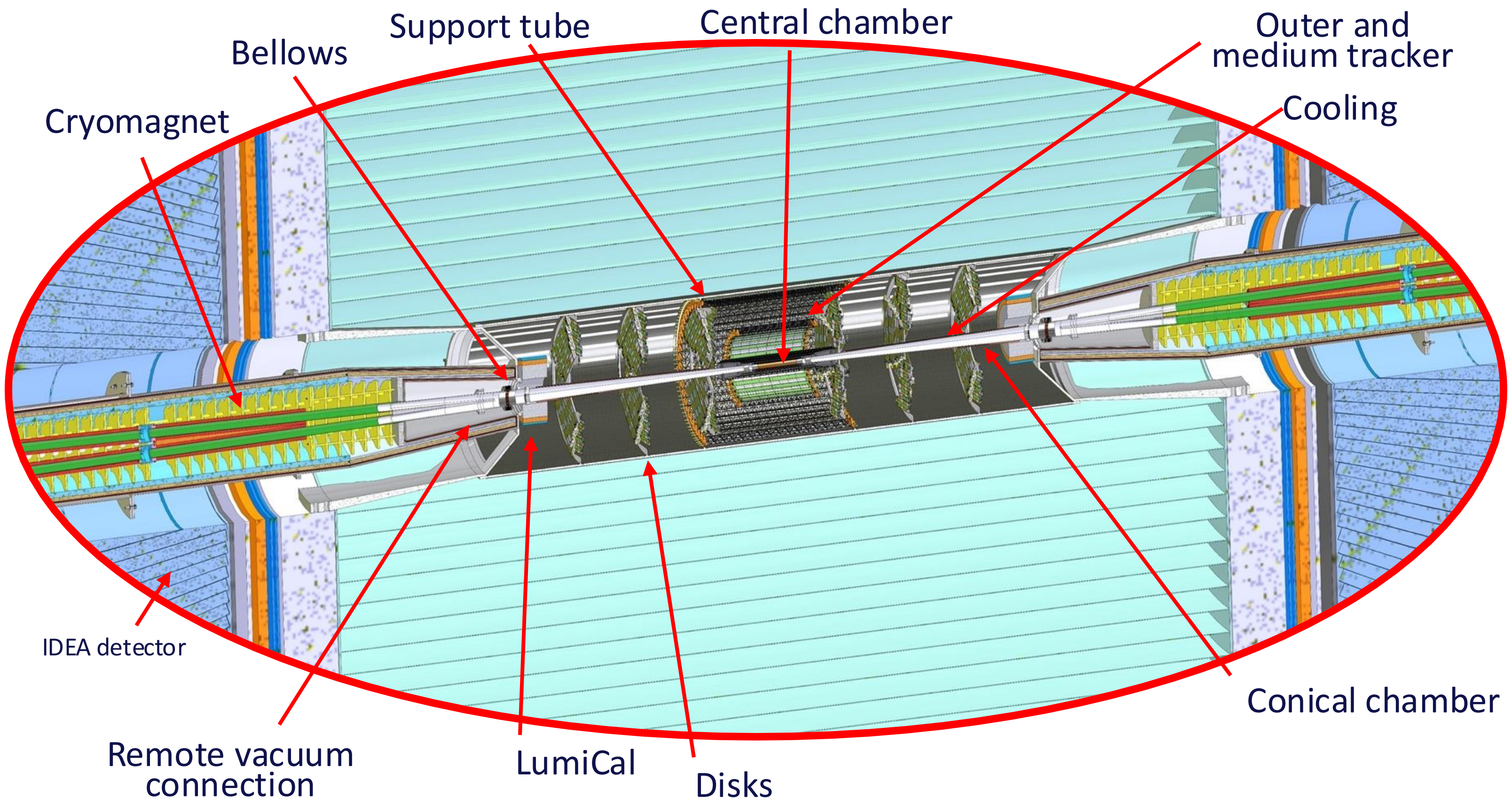
3D view of the FCC-ee IR until the end of the first final focus quadrupole

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.

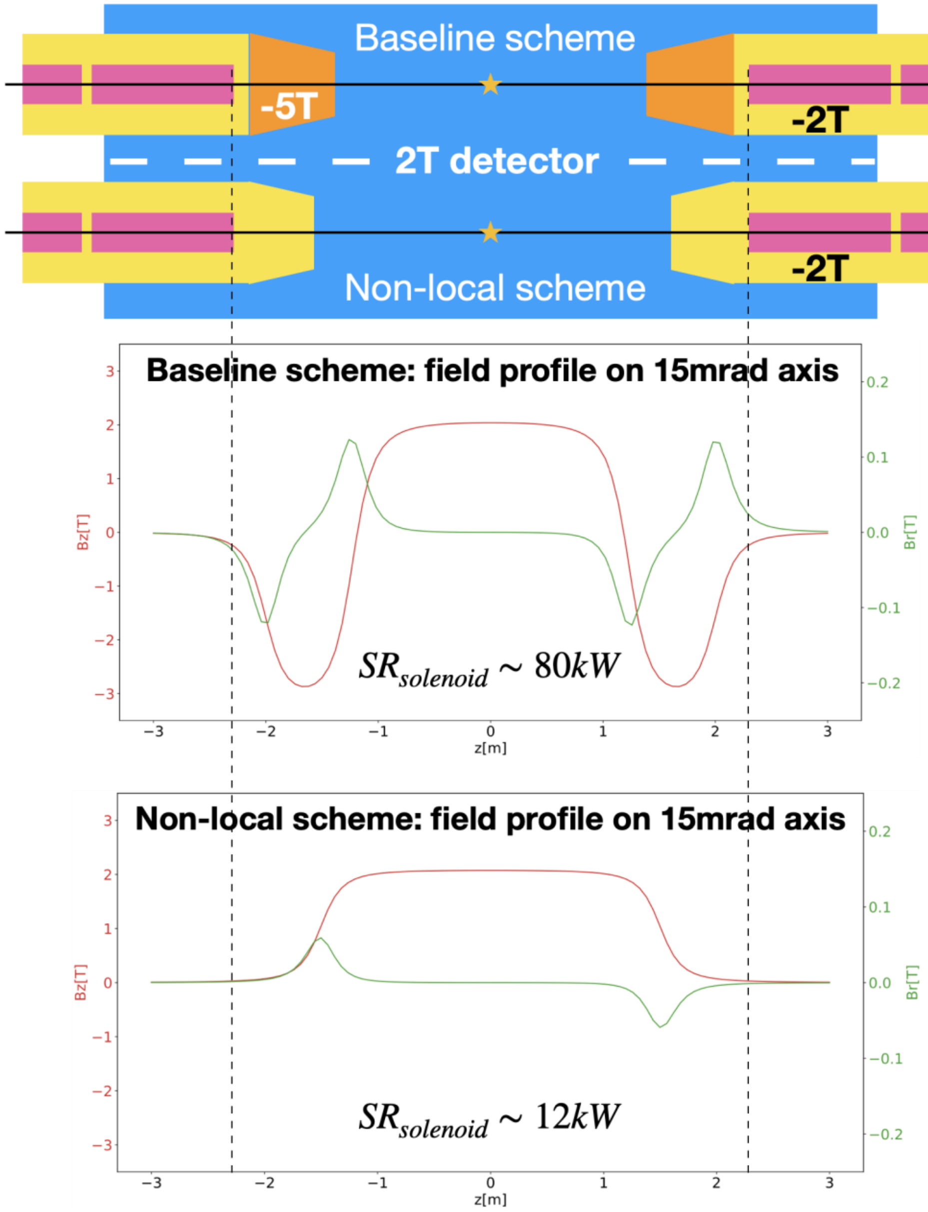
FCC-ee engineered Interaction Region



- Studies on vertex detector integration have been performed, it is the IDEA VXD, same to the Allegro VXD.
- IR magnet system design and integration not engineered yet, study on-going.
- MDI is a crucial area: a full-scale IR mockup has started in collaboration with CERN

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

Coupling Correction Scheme at FCC-ee



The **2T detector solenoids** induce coupling in the FCCee lattice.

The current correction scheme uses:

- **-5T compensating solenoids** to cancel the magnetic field integral
- **-2T screening solenoids** to shield the **FFQs** from the detector field

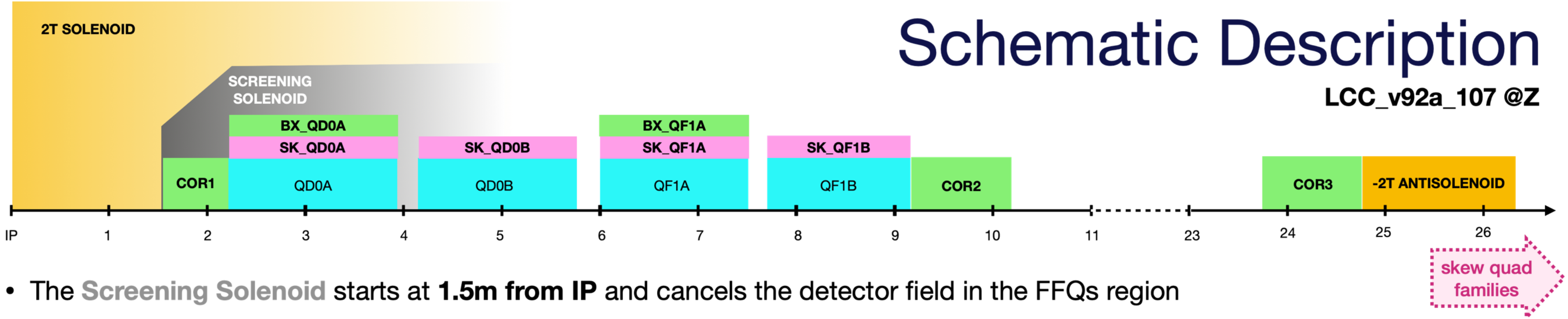
A **non-local correction scheme** proposed by P. Raimondi would allow to move the **compensating solenoids** outside the IR.

- relaxed mechanical constraints in the IR
- no technical R&D of a -5T compact magnet
- **Synchrotron Radiation** from B-field transition region (~80kW).

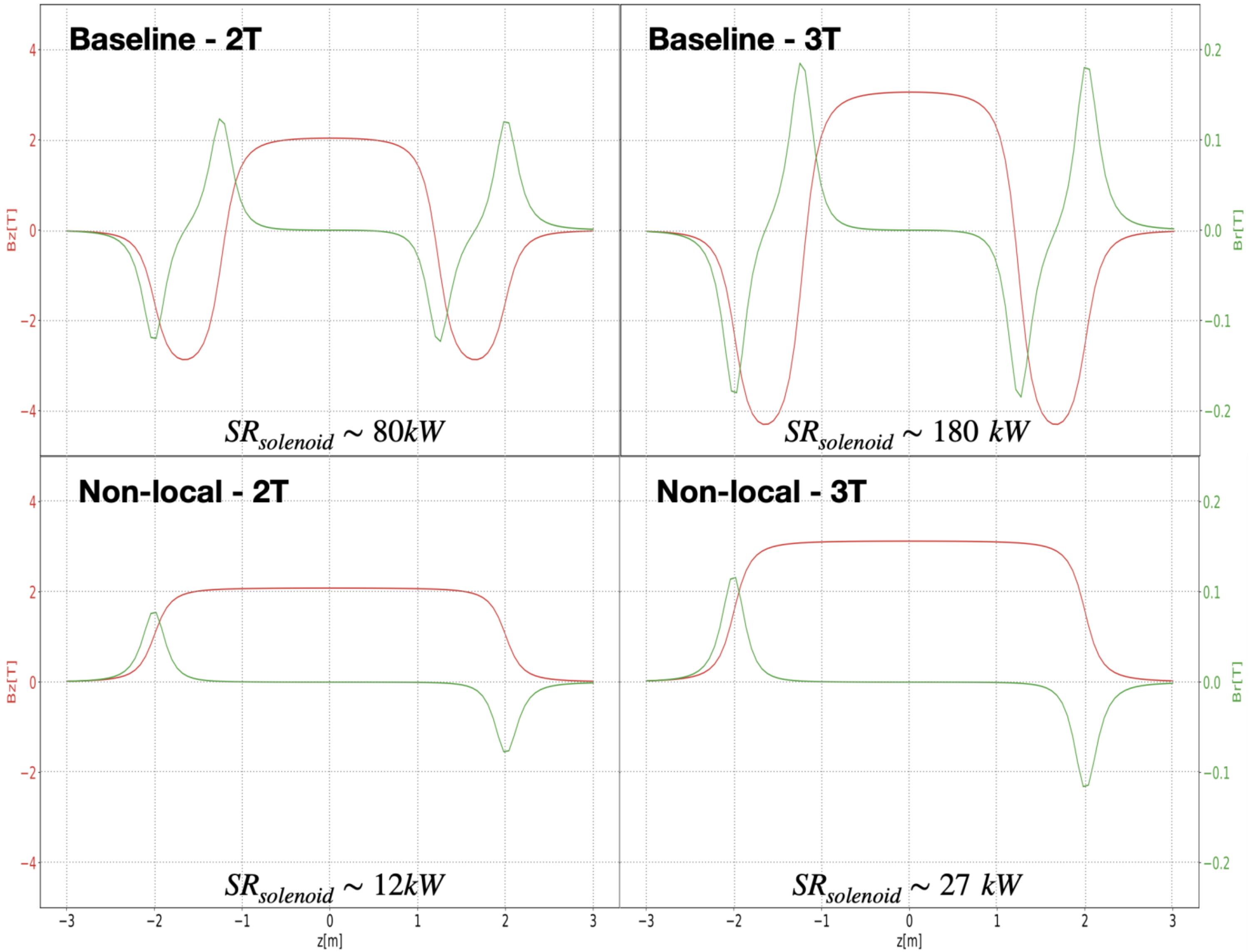
IPAC proceeding: A. Ciarma, M. Boscolo, H. Burkhardt, P. Raimondi, “Alternative solenoid compensation scheme for the FCC-ee interaction region” - 10.18429/JACoW-IPAC2024-TUPC68

Schematic Description

LCC_v92a_107 @Z



- The Screening Solenoid starts at **1.5m from IP** and cancels the detector field in the FFQs region
  - may be **conical or cylindrical** according to detector angular acceptance and magnet radius
  - **starting point** can be varied for mechanical constraints
  - outer part will be **tapered** to match main solenoid fringe fields
- The antisolenoid moved outside the IR (before the first dipole) to cancel $\int B_z ds = 6.25\,Tm$ => **longer, weaker magnet**
- Skew components winded around the FFQs correct coupling due to beam rotation under Bs $K_{1s} = K_1 \ sin(2\theta) \sim 0.02K_1$
- 3 H/V correctors (COR1, COR2, COR3) are used to close the orbit bumps due to tilted solenoid Bx
  - Orbit correctors are **needed regardless of correction scheme**, these are not additional elements
- 3 families of skew quadrupoles placed at several hundred meters from IP to match vertical dispersion and coupling
- Bx components are winded around QD0A and QF1A to control emittance growth, orbit bump and dispersion bump



Going to 3T

Synchrotron radiation is emitted from the **fringes** between regions of different magnetic fields.
Orbit and Dy bumps remain small.

Scaling from **2T to 3T**:

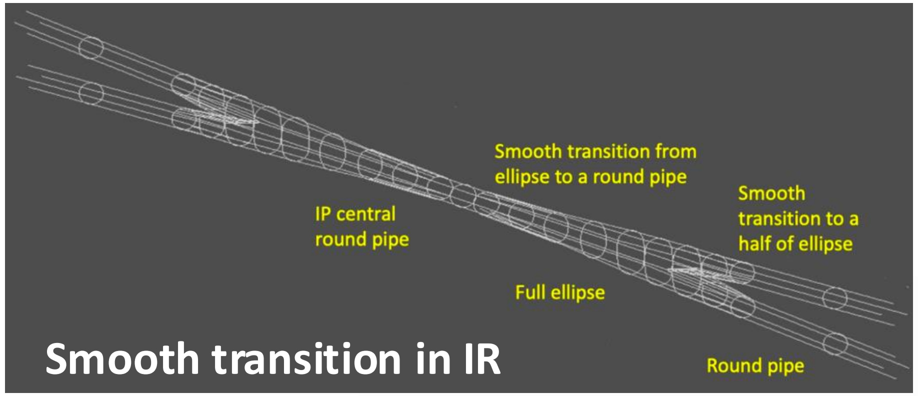
$$P_{SR} = \frac{2}{3}\frac{e^2 c}{4\pi\epsilon_0}\frac{\beta^4\gamma^4}{\rho^2} \propto B^2$$

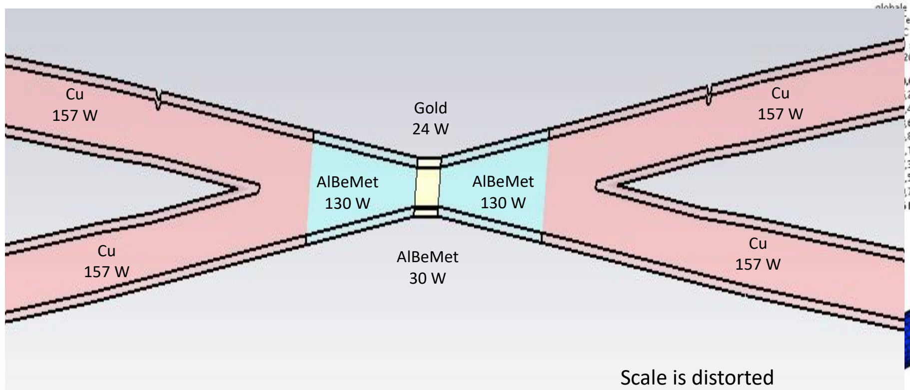
$$\Rightarrow \frac{P_{SR}^{3T}}{P_{SR}^{2T}} = \frac{3T^2}{2T^2} = 2.25$$

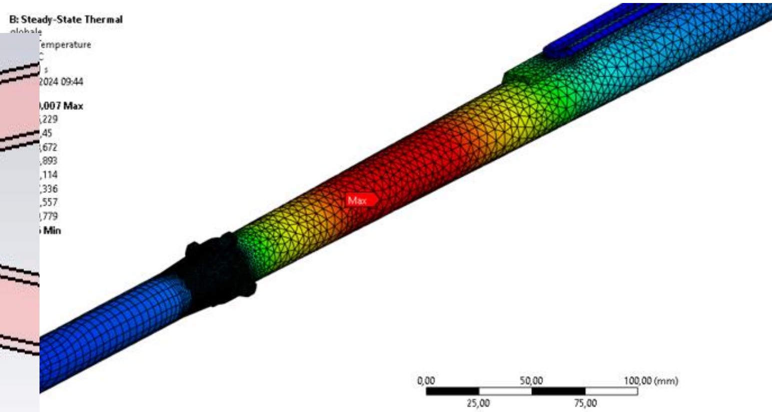
The power in the 3T standard scheme would still be **x3 lower than the baseline 2T scheme.**

3T HTS solenoid for IDEA
see talk by S. Mariotti

Low-impedance IR vacuum chamber

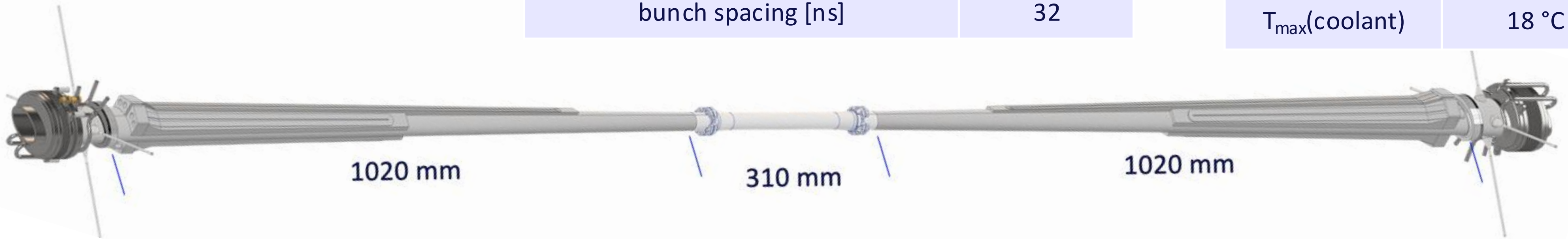






beam energy [GeV]	45
beam current [mA]	1280
number bunches/beam	1000
rms bunch length with SR / BS [mm]	4.38 / 14.5
bunch spacing [ns]	32

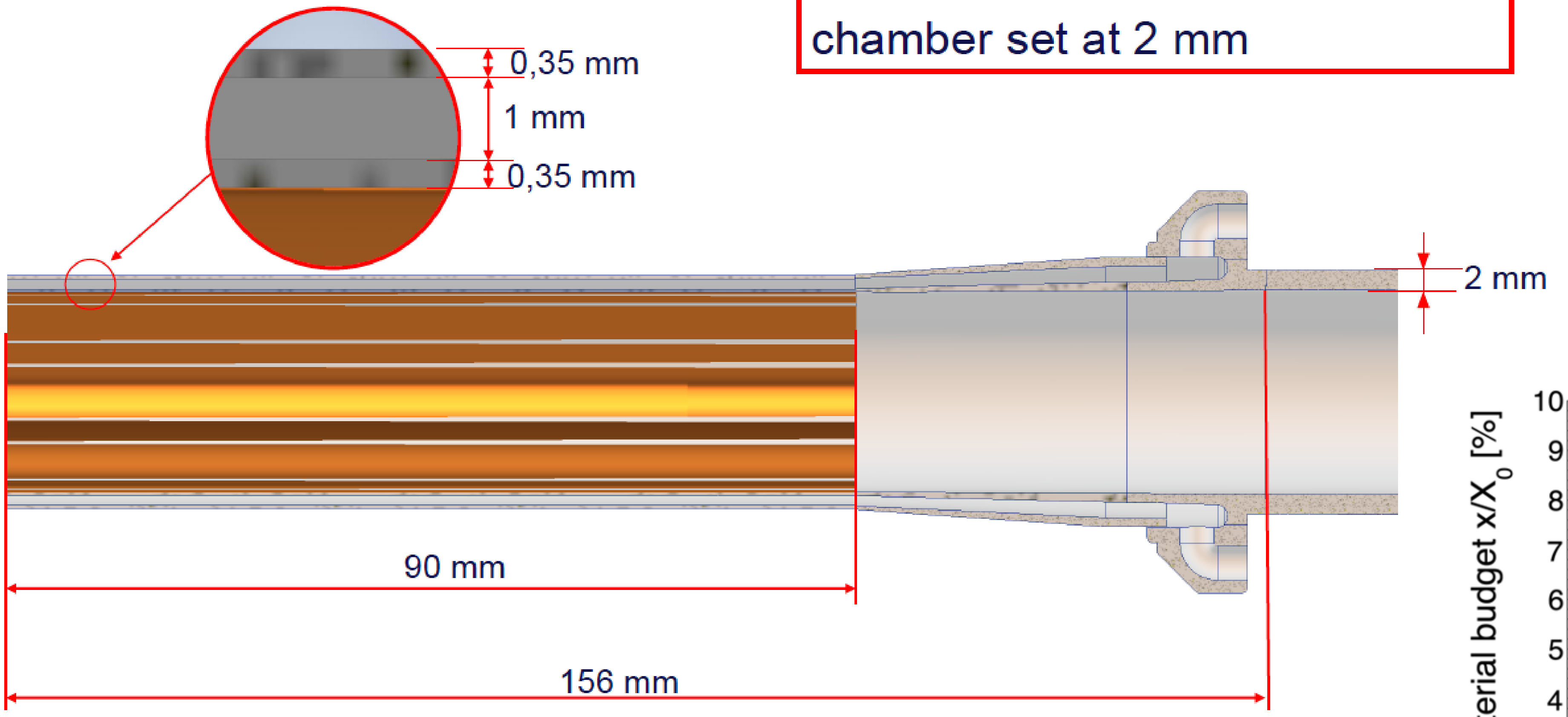
	conical chamber	central chamber
coolant	water	paraffin
T_{max} (chamber)	50°C	29°C
T_{max}(coolant)	18 °C	20 °C

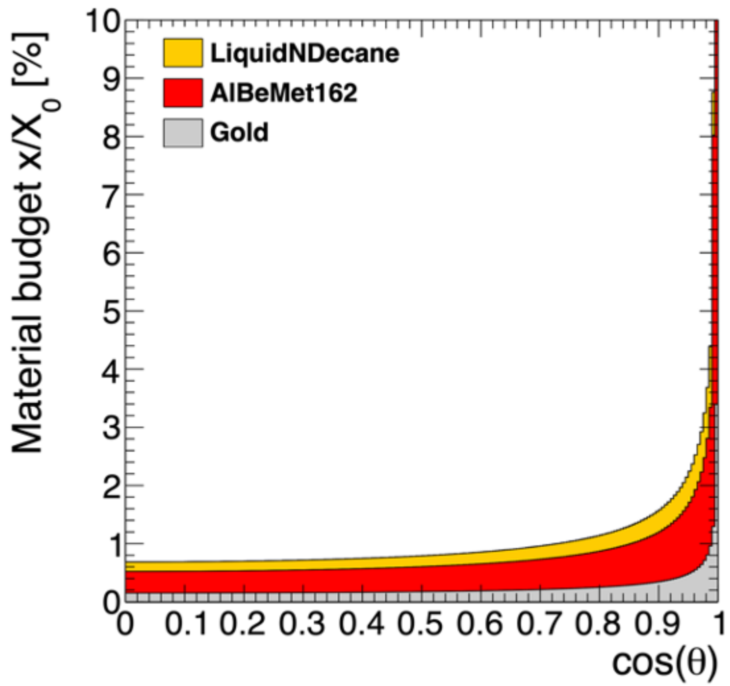


Study and optimization of the material budget for the beam pipe has been performed and is in progress. LumiCal requirements and material budget minimization considered, also comparing Be with AlbeMet.

Thickness of the chamber

Uniform thickness of the conical chamber set at 2 mm



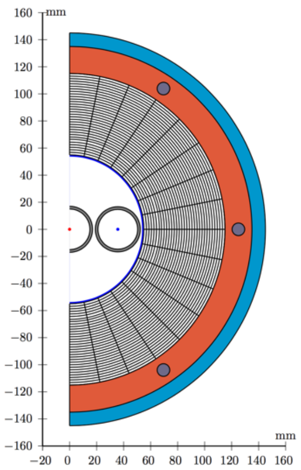


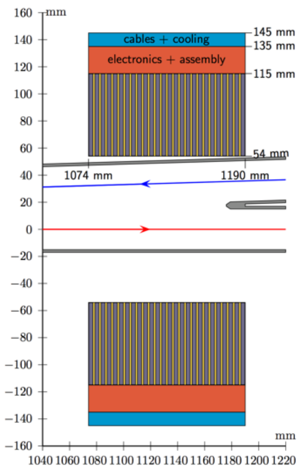
LumiCal constraints & requirements

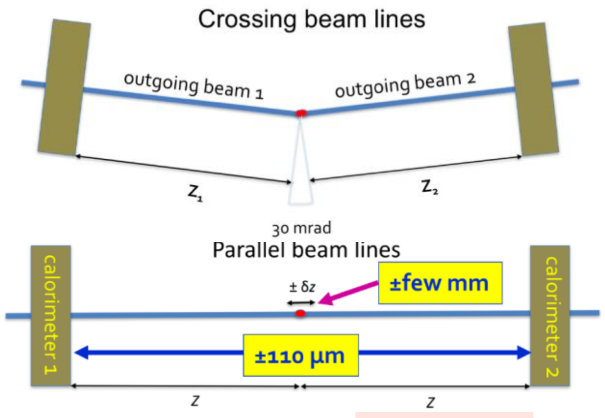
Goal: absolute luminosity measurement 10^{-4} at the Z

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



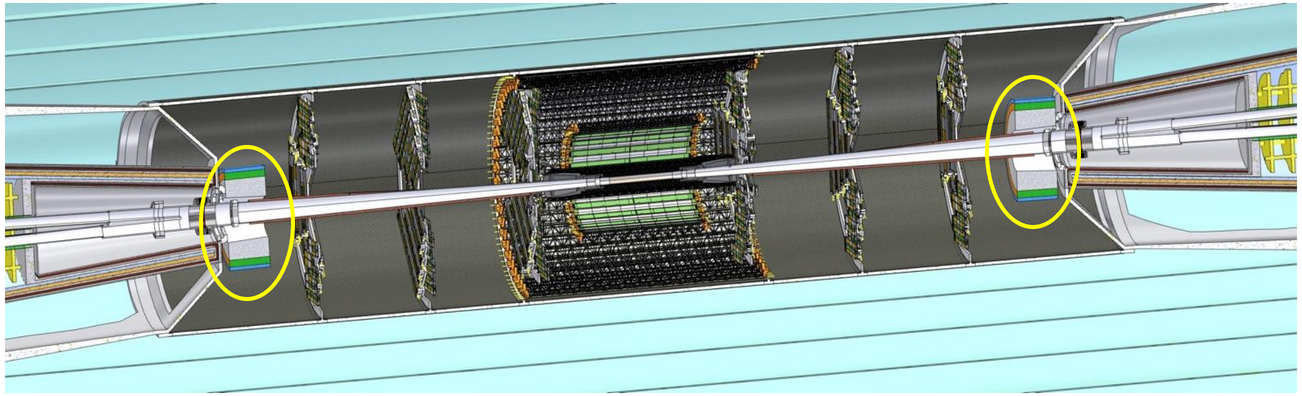




M. Dam

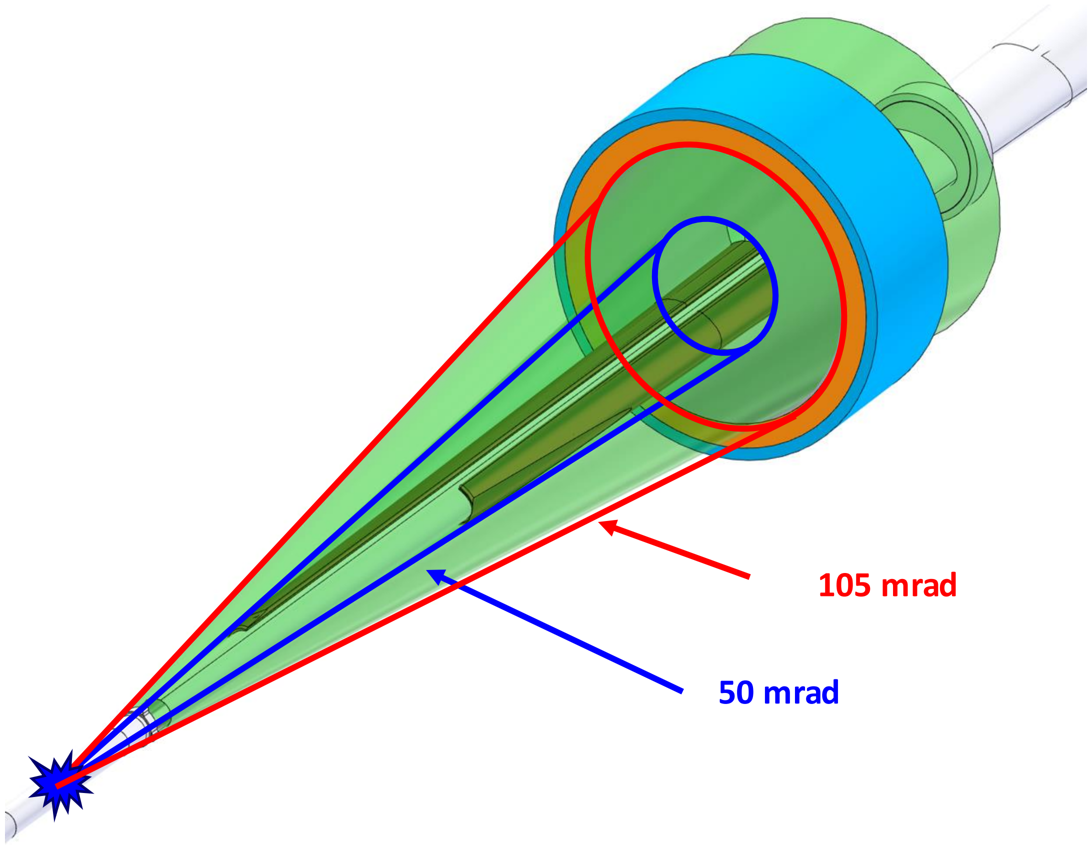
Lumical integration:

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

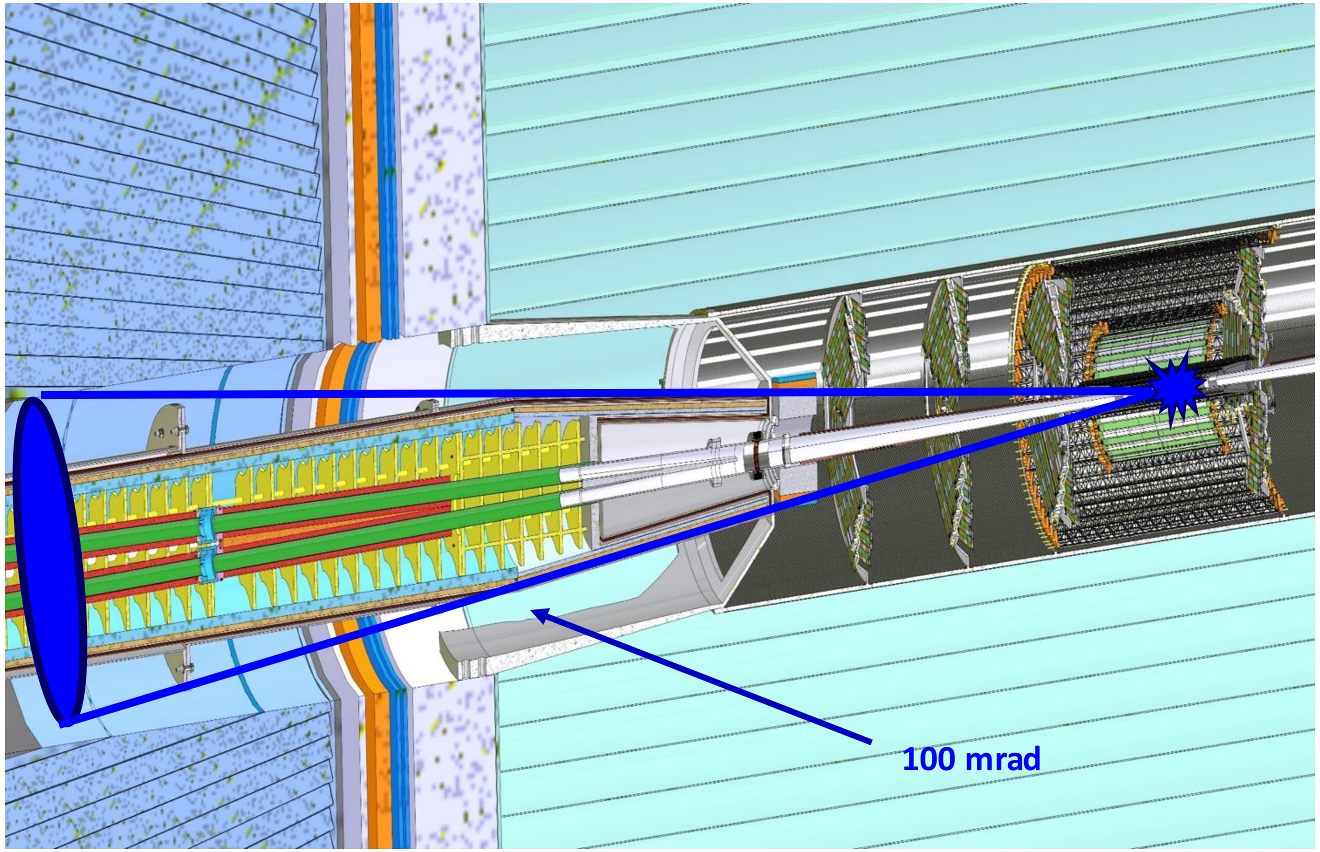


Spatial constraints

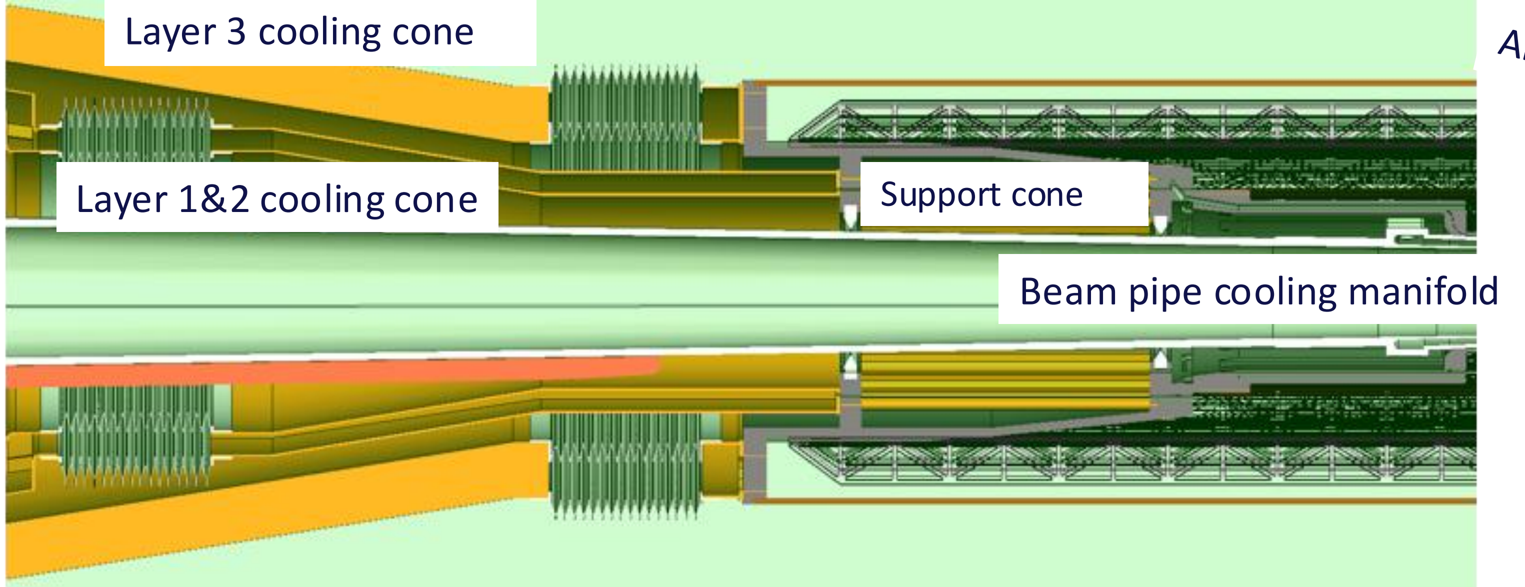
To achieve the required performance, it is necessary to have **low material budget** within the LumiCal acceptance (between **50 mrad** and **105 mrad** centered on the outgoing beam pipe).

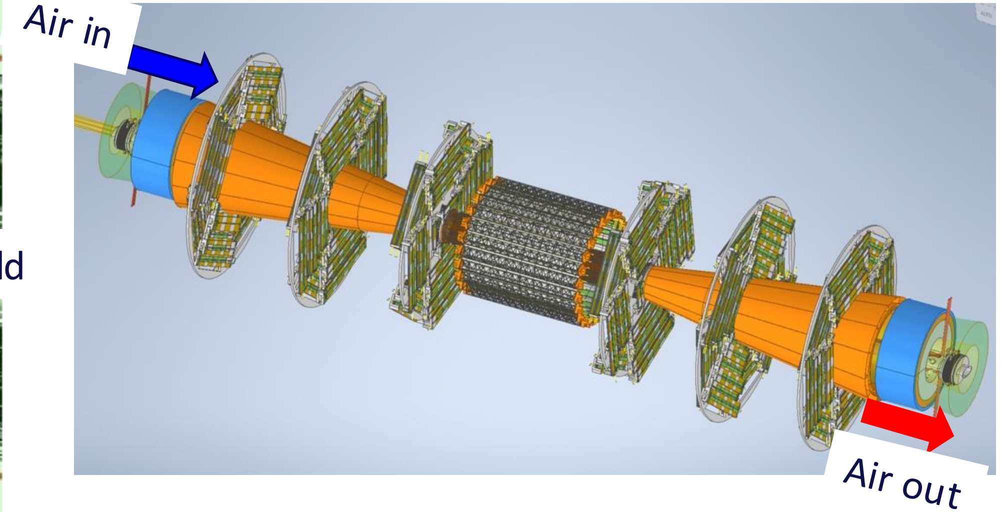


Every component of the MDI must stay inside the **100 mrad detector acceptance** cone.



Inner vertex support and cooling cones





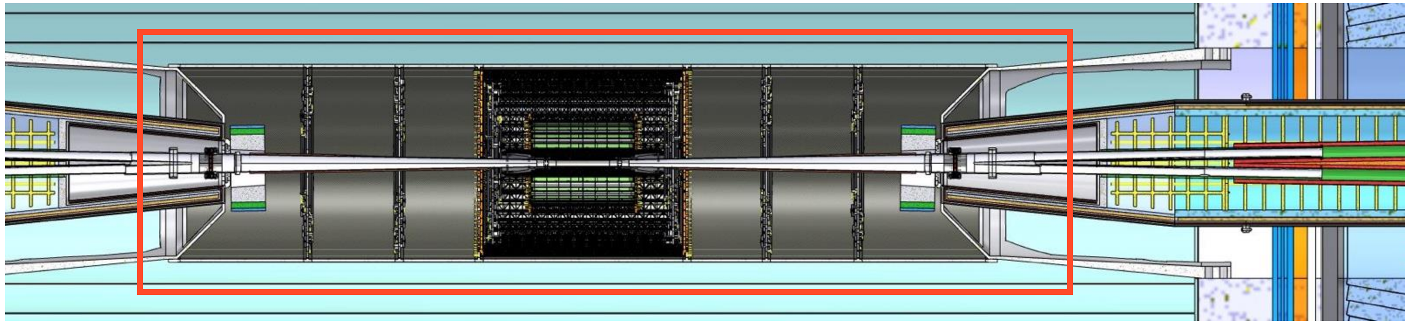
Engineering study to design and integrate the vertex in the IR

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

Air cooling simulation studies for the vertex

IR mockup

central region ±1.2 m



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**

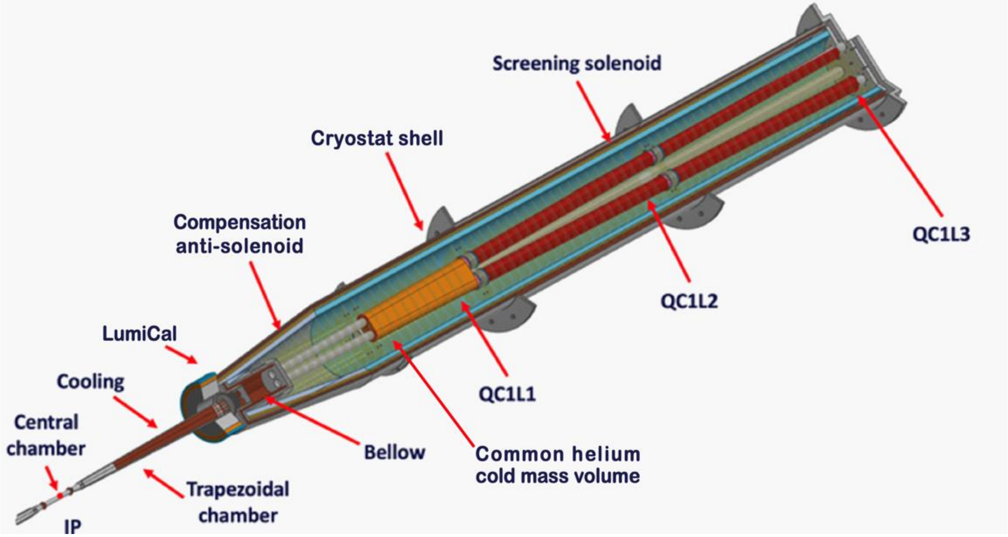
IR based on the crab-waist scheme, compact and crowded with tight constraints and many technical challenges → **mockup being built** for R&D in Frascati to prove state-of-the-art technological solutions and test its feasibility

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

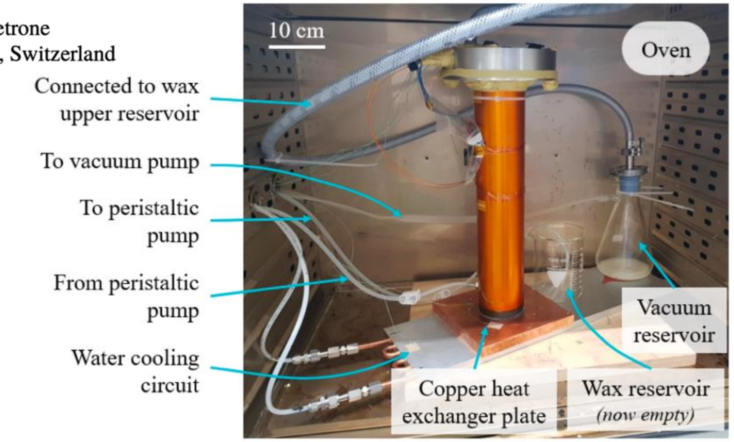


Cold tests on first segment prototype of QC1L1: IPAC24-WEPS65

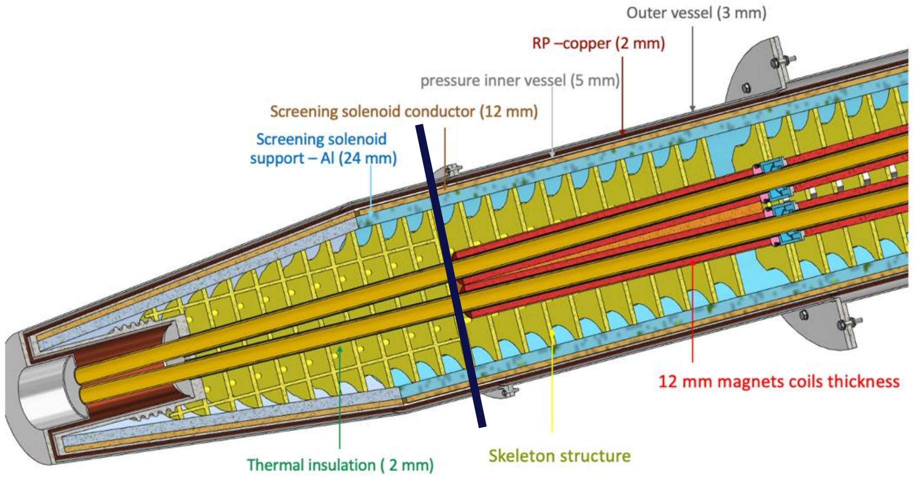
15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPS65

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

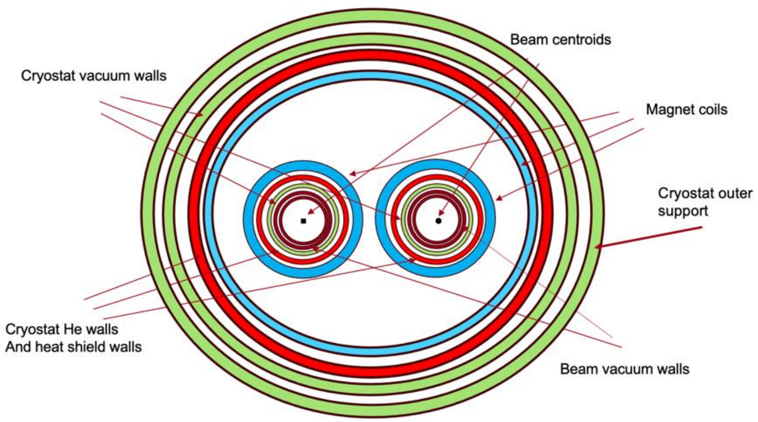
A. Thabuis, M. Koratzinos, G. Kirby, M. Liebsch, C. Petrone
European Organization for Nuclear Research (CERN), Geneva, Switzerland



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

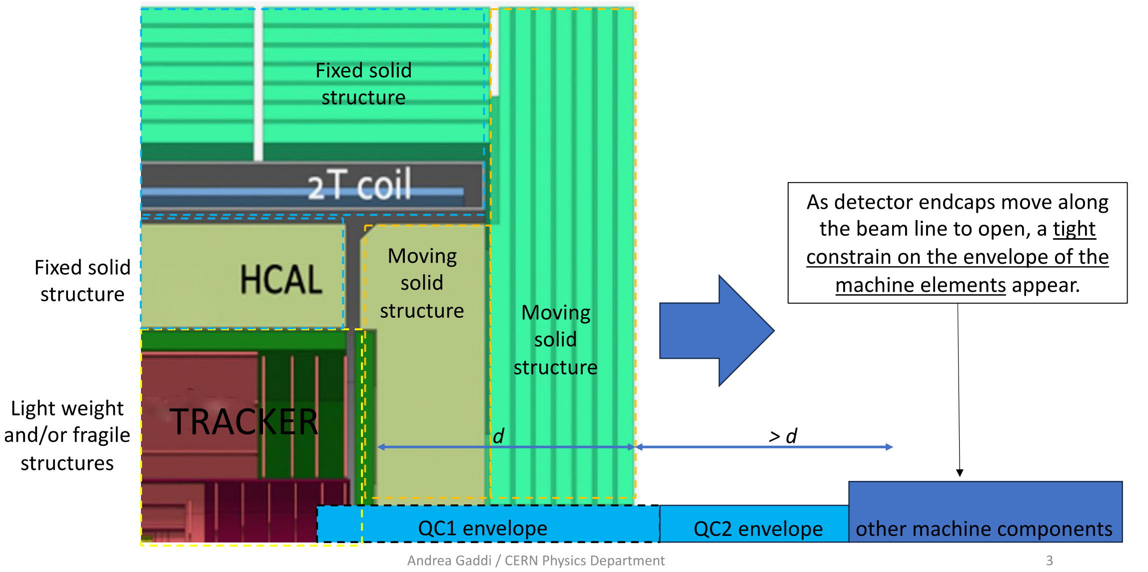
IR QC1 and QC2 in different cryostats but one integrated raft seems the best solution

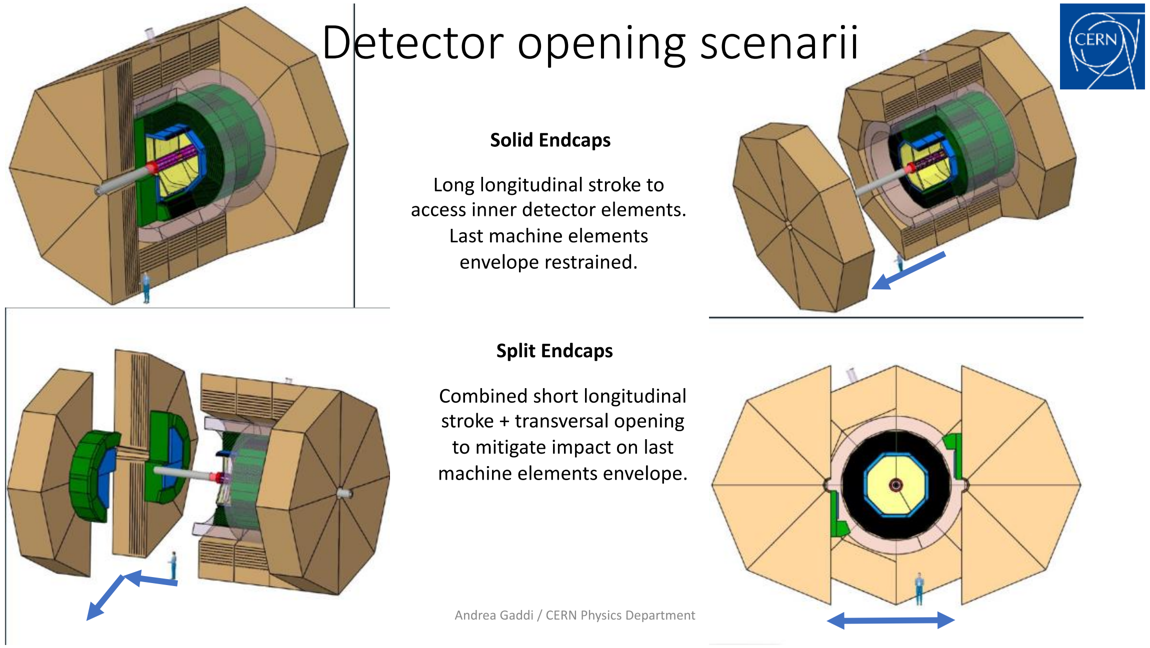
General detector integration issues

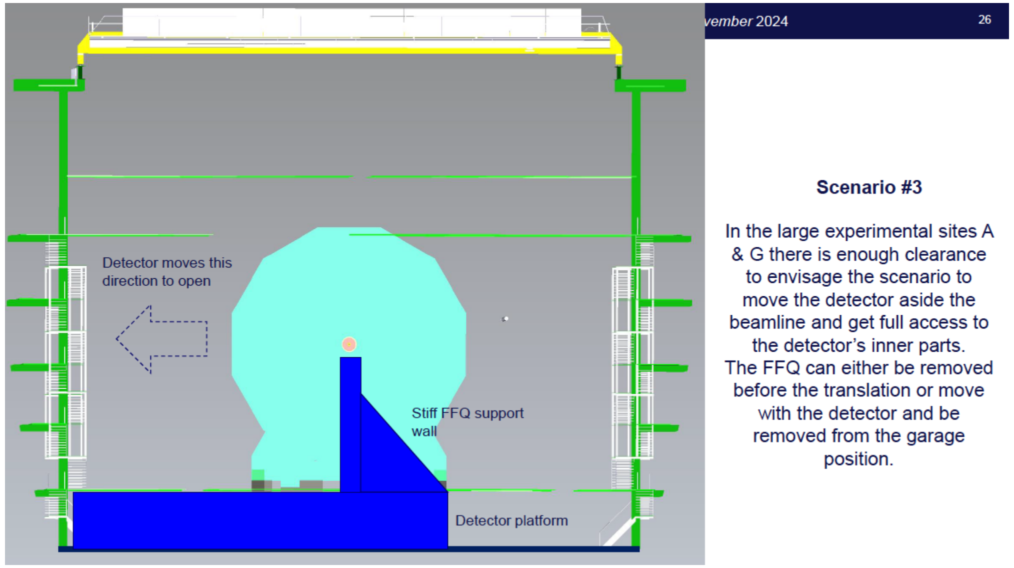
Considering how to access the detector elements taking care of the final focus superconducting quads

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.







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

Background assesment at FCC-ee

Estimation of beam induced backgrounds is a **driver element** for the design of detectors and MDI region.

A **streamlined procedure** for occupancy calculation in each subdetector is a key feature under development in the FCCSW framework:

- **repository** with primary particles for each **background source** at the four FCCee energies
- **detector description** for the three experiments and common **MDI elements**
- particle tracking in the detectors performed using **key4hep**

Key aspects:

- MDI modelization (pipe, cooling, supports, fields, etc)
- identification of appropriate event generators

X-Suite/Fluka/key4hep interface
see G. Nigrelli talk

Detector Background Studies

First occupancy calculations from Incoherent pairs in

- IDEA Vertex detector
- IDEA drift chamber
- Allegro ECAL

Please consider to contribute!

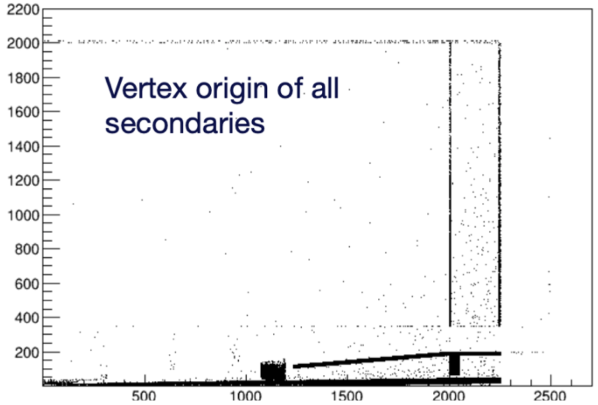
- Add more subdetectors
- Evaluate more background sources

IDEA-VTX

	linear layout	curved layout
Occupancy	$\sim 20\times10^{-6}$	$\sim 30\times10^{-6}$
Hit rate	$170\ MHz/cm^2$	$250\ MHz/cm^2$

data rates of
O(10 Gb/s) per module.

IDEA-DCH



SIM hit occupancy of ~7.5% over **400ns**

ALLEGRO ECAL

Average occupancy per BX (over 1000 BXs):

	NO CUTS	20% MIP CUT	30% MIP CUT
Endcaps	0.1% ~ 0.6%	0.02% ~ 0.2%	0.01% ~ 0.15%
Barrel	< 0.45%	< 0.03%	< 0.01%

occupancy per layer **up to ~0.5%/BX**

Radiative Bhabha: beam losses in IR

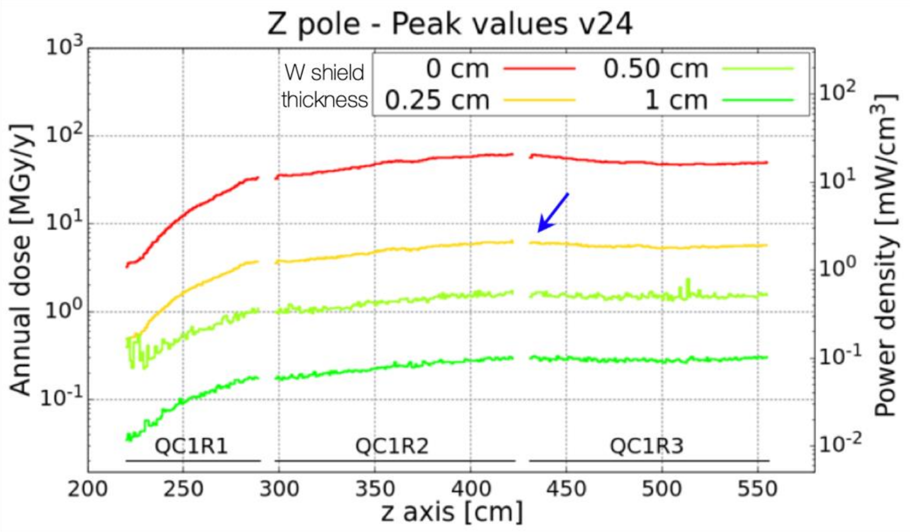
During bunch crossing beam particles can **lose energy** via photon emission, and exit the lattice **energy acceptance**.

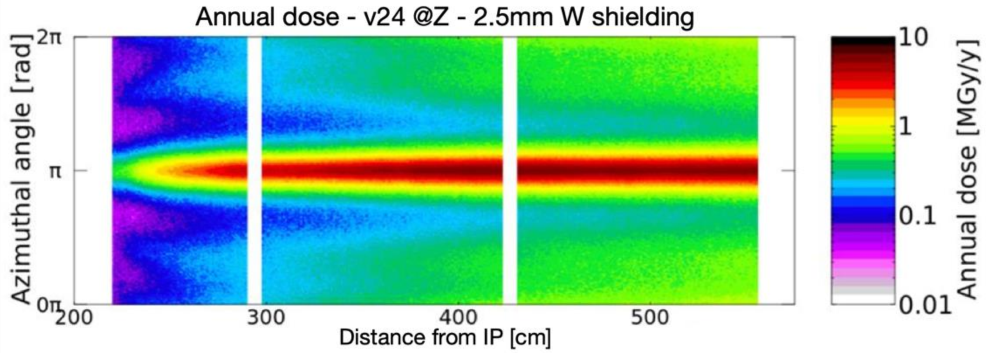
Particles produced using **BBBrem**[1] and **GuineaPig++**.

Off-energy particles are tracked downstream to estimate the **power deposited** on the SC final focus quadrupoles.

FLUKA simulations show that a **thin tungsten shielding** between the magnets and the pipe efficiently reduces the total dose below O(10MGy/y).

Integration of this shielding is an important part of the magnets final design.



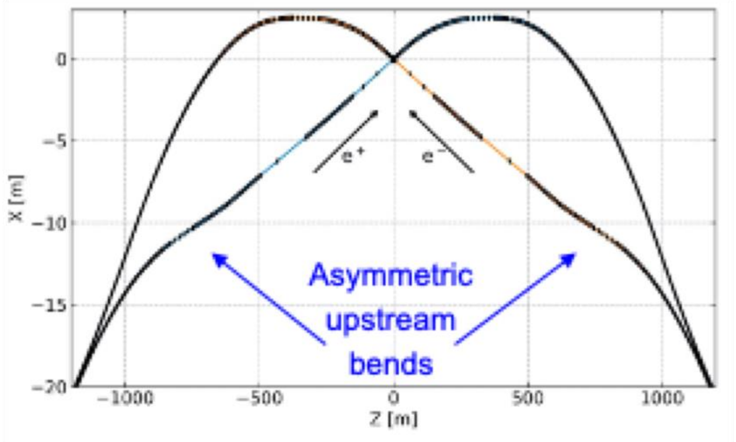


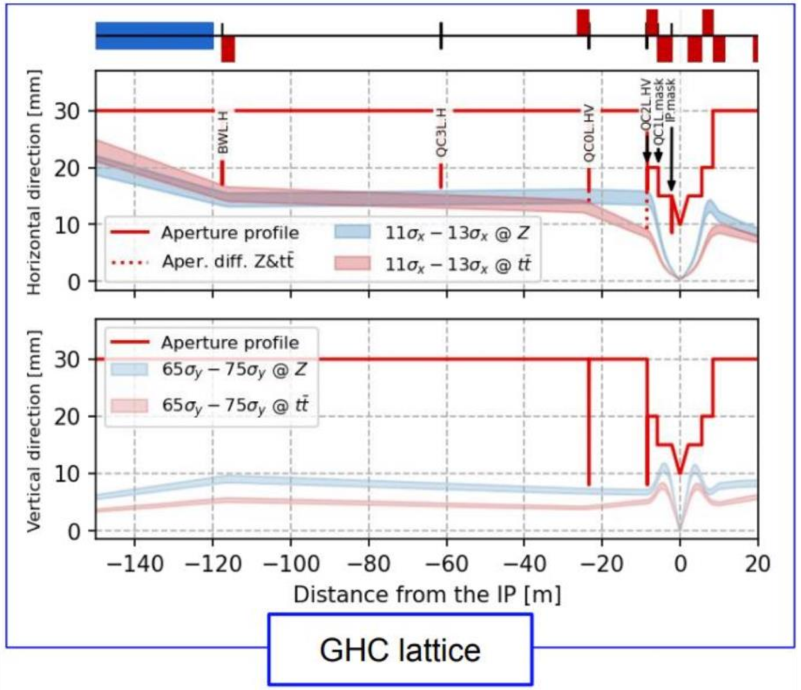
[1] BBBREM – Monte Carlo simulation of radiative Bhabha scattering in the very forward direction, R. Kleiss, H. Burkhardt

Synchrotron Radiation

SR is the **main driver** for FCC-ee MDI and lattice design

- **Asymmetric bend** to mitigate SR coming from upstream magnets
- Characterization of the radiation using **G4 based tool BDSim**
- Tungsten **SR collimators and masks** to protect the IR





SR Background coming from the **beam core** particles is **shielded** thanks to the **tungsten masks.** Other contributions currently under study are:

- **beam halo** particles
- top-up **injection**

Characterization of background is essential for **dedicated shielding** design.

First tracking in key4hep ongoing for **occupancy calculation**.

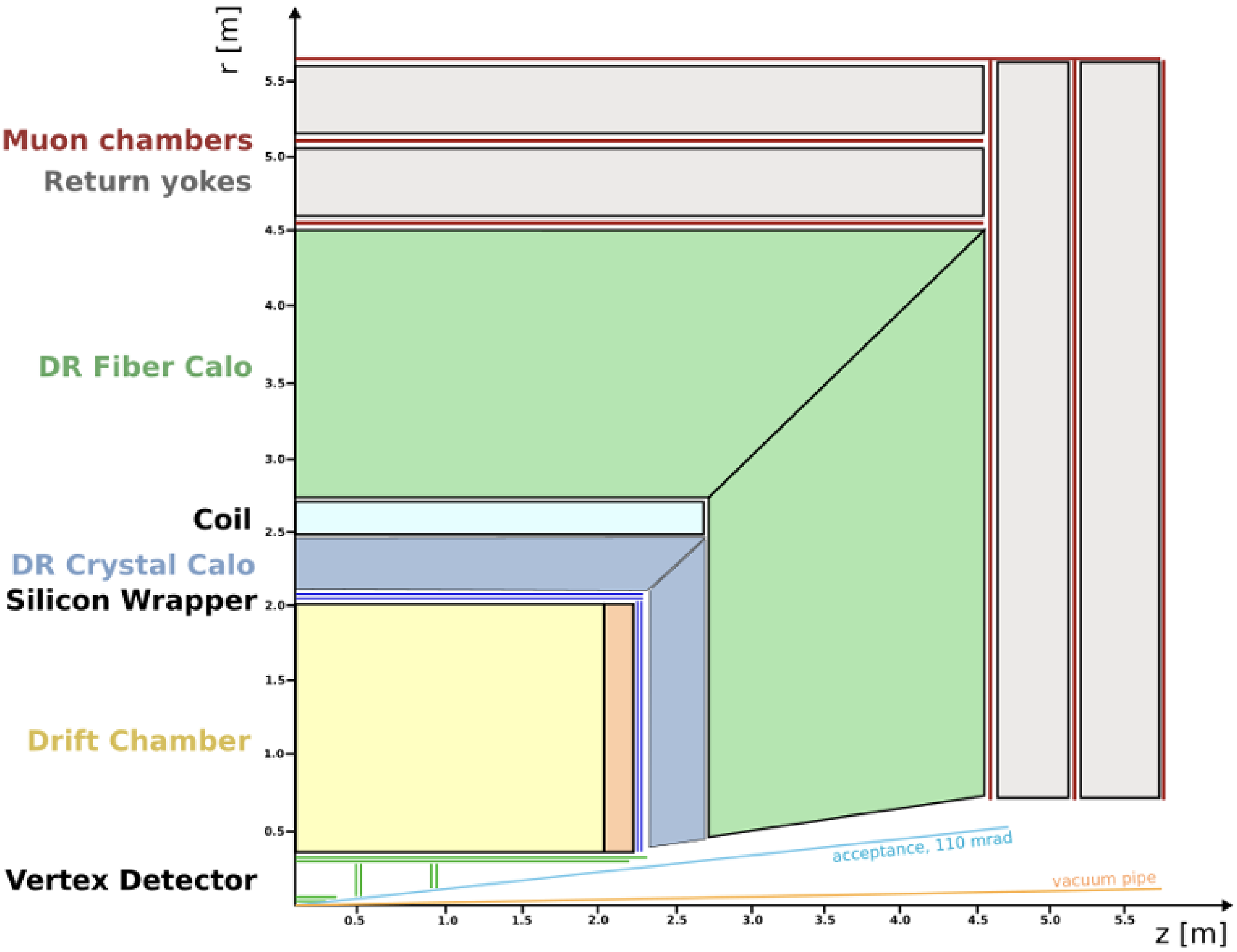
Plans on key aspects of the MDI design

Help needed!

- 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

And thanks to many people for inputs!

Backup

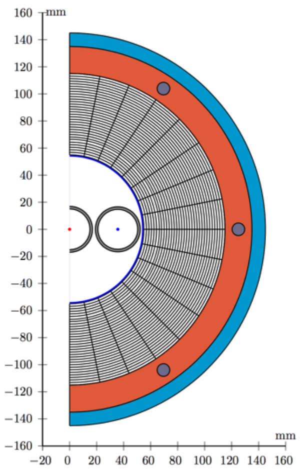

r [m]
Muon chambers
Return yokes
DR Fiber Calo
Coil
DR Crystal Calo
Silicon Wrapper
Drift Chamber
Vertex Detector
acceptance, 110 mrad
vacuum pipe
z [m]
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5

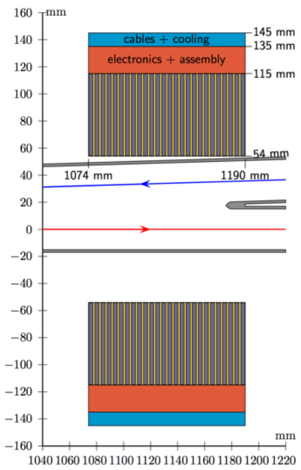
LumiCal constraints & requirements

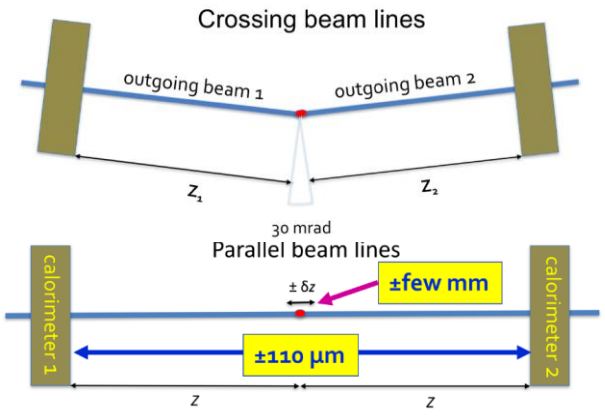
Goal: absolute luminosity measurement 10^{-4} at the Z

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

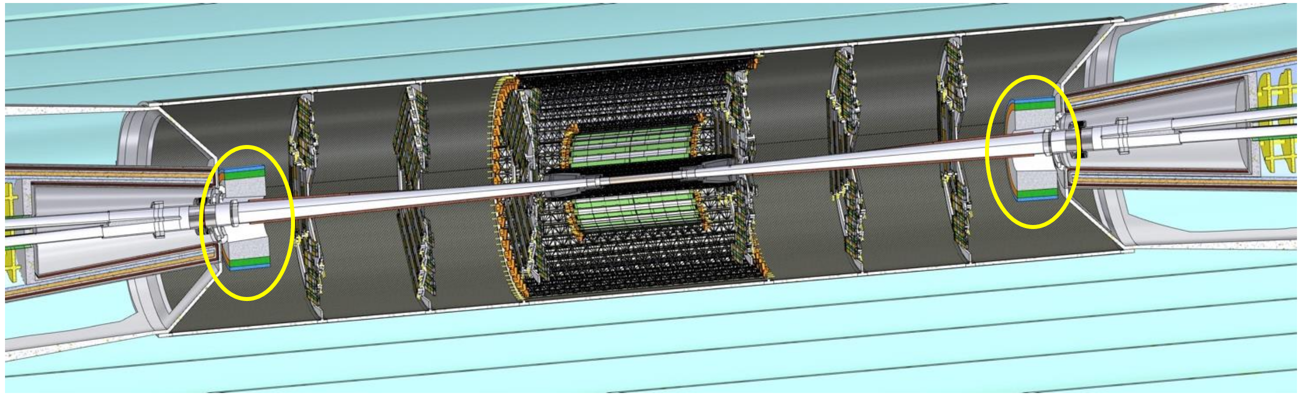






Lumical integration:

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

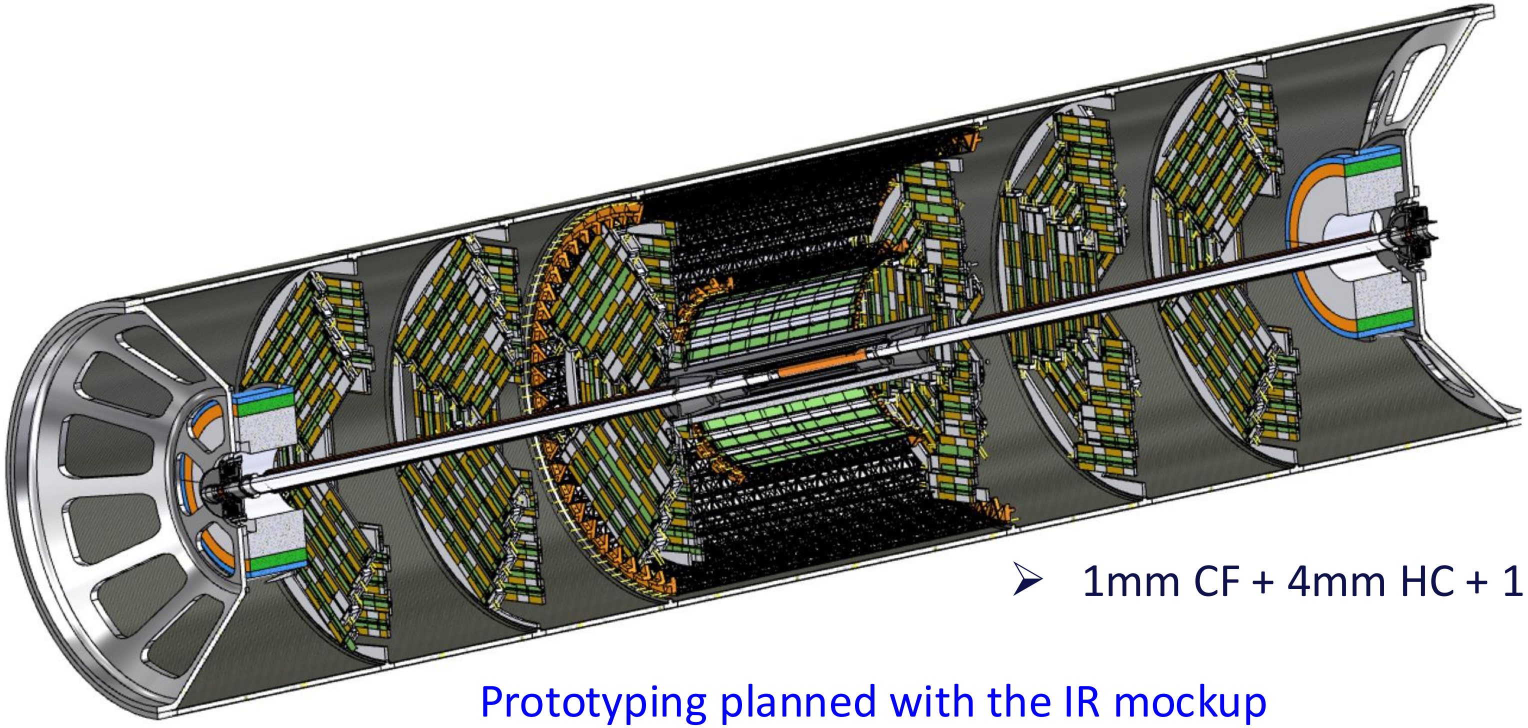


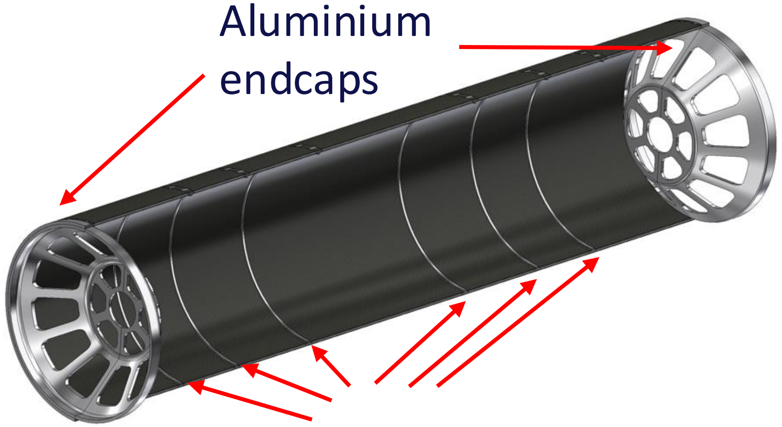
Support cylinder

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

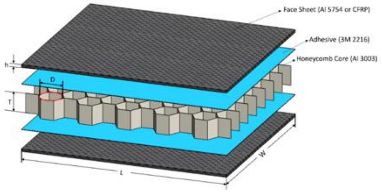
- Provides a cantilevered support for the pipe
- Avoids loads on thin-walled central chamber during assembly or due to its own weight

- 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