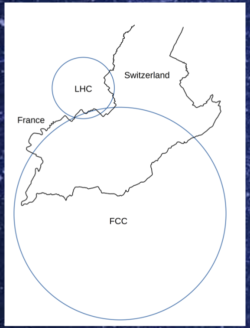
OVERVIEW OF THE FCC-EE MDI REGION

Manuela Boscolo



Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022
23-25 May 2022

Outline

The design of the interaction region must comply with various important constraints, imposed by high beam energy, high luminosity, need for polarization, and crossing scheme.

An **overview of the MDI design** with recent results and ongoing studies

- Progress on Beam optics & parameters
- Collimation scheme and aperture model -> IR beam losses to be tracked in detector
- Synchrotron Radiation collimators
- Beamstrahlung radiation
- Mechanical model of the IR vacuum chamber

Conceptual Design & input to ESPPU ‘19/20

FCC-Conceptual Design Reports (end 2018):

- **Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC**
- CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4) [Springer]**

EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 , EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

EPJ is a merger and continuation of *Acta Physica Hungarica, Anales de Fisica, Czechoslovak Journal of Physics, Fizika A, Il Nuovo Cimento, Journal de Physique, Portugaliae Physica* and *Zeitschrift für Physik*. 25 European Physical Societies are represented in EPJ, including the DPG.

Summary documents input to EPPSU 2019/20

- **FCC-integral, FCC-ee, FCC-hh, HE-LHC**, at http://fcc-cdr.web.cern.ch/

FCC-ee basic design choices

Double ring e+ e- collider

Common footprint with FCC-hh, except around IPs

Asymmetric IR layout and optics to limit synchrotron radiation towards the detector

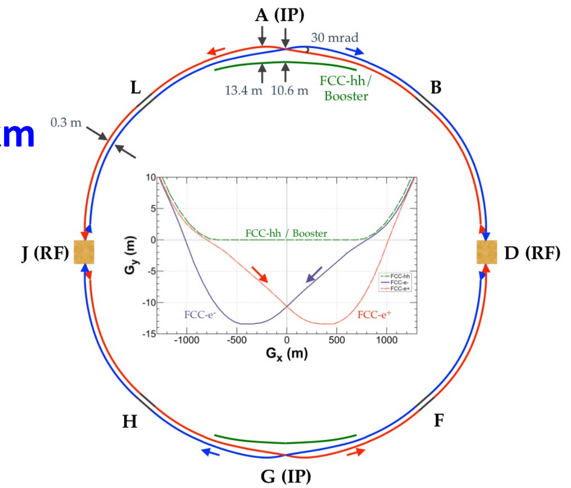
2 IPs (or 4IPs) large horizontal crossing angle 30 mrad, **crab-waist** collision optics

Synchrotron radiation power **50 MW/beam** at all beam energies

Top-up injection scheme for high luminosity requires booster synchrotron in collider tunnel

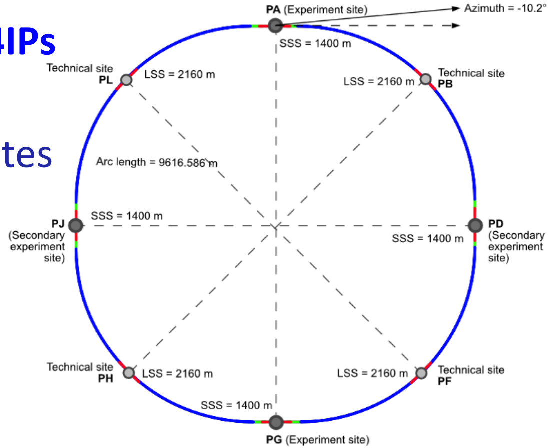
"**Tapering**" of magnets along the ring to compensate the sawtooth effect

CDR
C=97 km



evolution 4IPs
C=91 km

8 surface sites



FCC-ee Interaction Region

Crab-waist scheme, based on two ingredients:
- concept of **nano-beam scheme** (vertical squeeze of the beam at IP and horizontal crossing angle increased, reducing the instantanous overlap area, allowing for a lower β_y*)
- **crab-waist sextupoles**

Smaller beams at IP → higher luminosity & higher backgrounds
(IP bkgs and beam losses in the final focus quads due to the very high β-function)

- Squeezed beams at IP, tens of nm in σ_y* (vertical emittance ε_y =1 pm at 45.6 GeV)
- This scheme, with the goal luminosity of 10^{36}cm^{-2}s^{-1} at 45 GeV sets the constraint to:
  - L* (distance between IP and first quad)
  - the strength of the final focus doublet
  - the solenoidal detector field (e.g. $\varepsilon_y \propto B_z{}^5$)

L*=2.2 m
B(detector) = 2 T

⬇

Tight and packed interaction region with first final focus quadrupole QC1 inside detector, different QC1 for each beam, and two anti-solenoids inside the detector, as well.

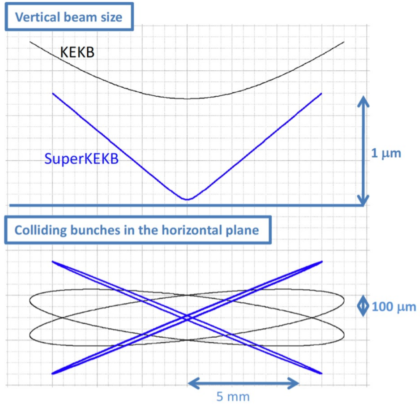


Figure 2: Schematic view of the nanobeam collision scheme.

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

FCC-ee Interaction Region

- Requirement for the CDR: **Flexible design, one common IR for all energies**, from 45 to 182.5 GeV
- IR magnets will be superconducting
- At 45.6 GeV it will be a high intensity run (issues related on residual gas, collective effects)
- At 182.5 GeV it will be high energy run (issues related to synchrotron radiation)
- First circular collider dominated by Beamstrahlung
    - at the Z-pole bunch length is increased by 2.5 times, forcing top-up injection with few percent of current drop
    - above the ttbar threshold lifetime is dominated by BS
- Synchrotron radiation is a driver of the design

FCC-ee IR optics design

K. Oide

driven by synchrotron radiation:

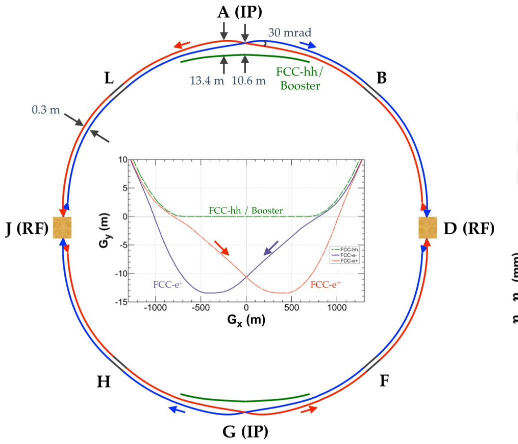
$E_{critical}$ <100 keV from 450 m from the IP

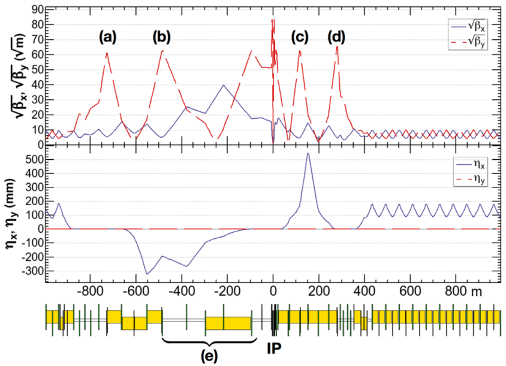
(from LEP experience)

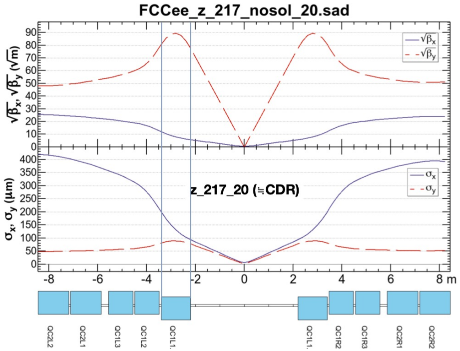
-> Very Asymmetric IR optics

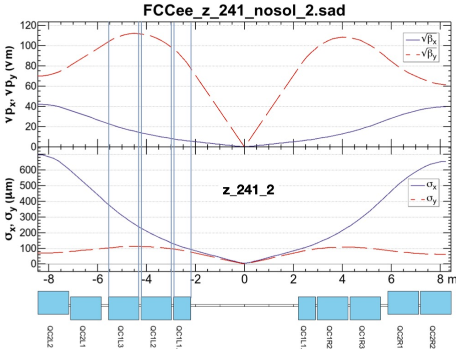
IR parameters table		Z	W^+W^-	ZH	ttbar	
β_x^*	m	0.15	0.2	0.3	1.0	
β_y^*	mm	0.8	1.0	1.0	1.6	
σ_x^*	µm	6.4	13	13.7	38.2	
σ_y^*	nm	28	41	36	68	
σ_z	mm	12.1	6	5.3	2.54	in collision
z^*_{int}	mm	0.42	0.85	0.9	1.8	interaction length

- β_x^* at the Z-pole has been recently reduced to **0.1 m** (according to simulations of coherent beam-beam instabilities including longitudinal impedances).
- Beam parameters are being optimized also according to beamstrahlung simulations that include machine errors.
- Distance between IP and booster is under discussion for determining its optimal value.





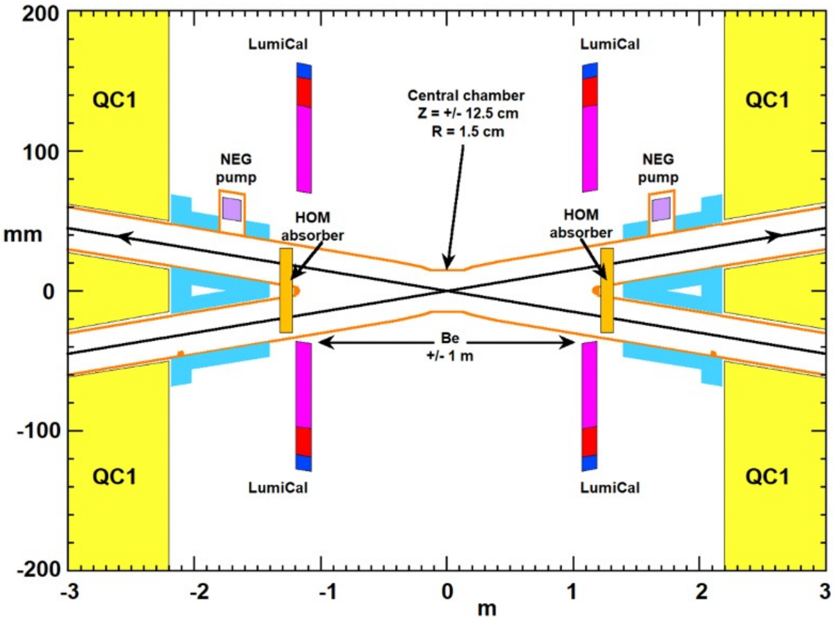




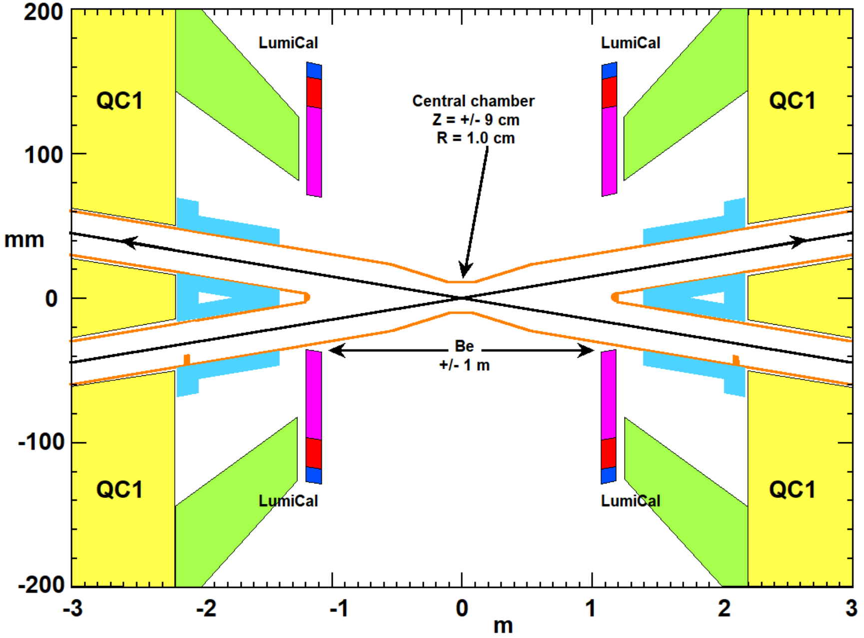
Flexible design with final focus doublet
in slices to adapt for the different beam energies

IR layout

CDR
1.5 cm radius central chamber

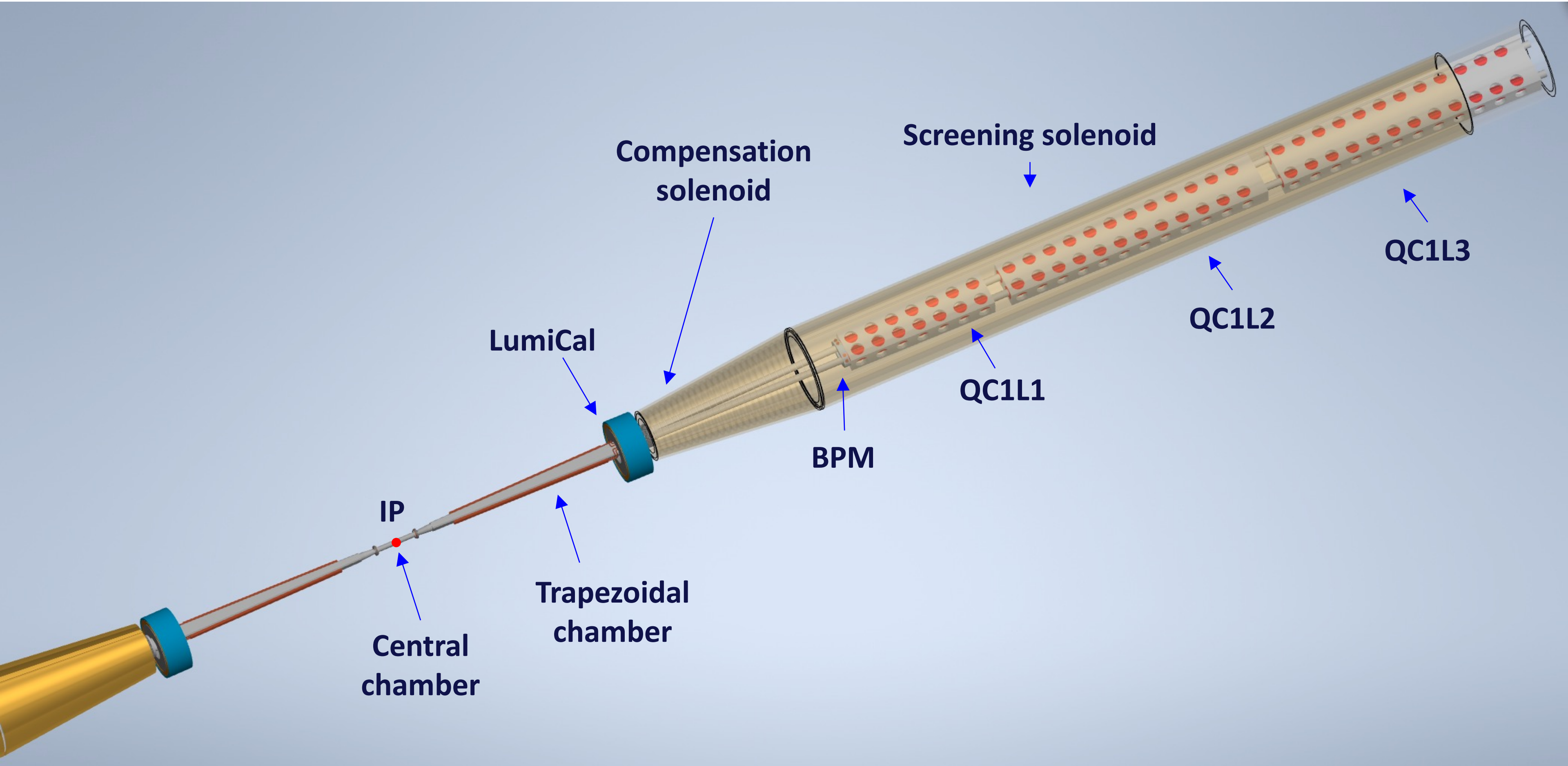


present low impedance beam pipe
1 cm radius central chamber

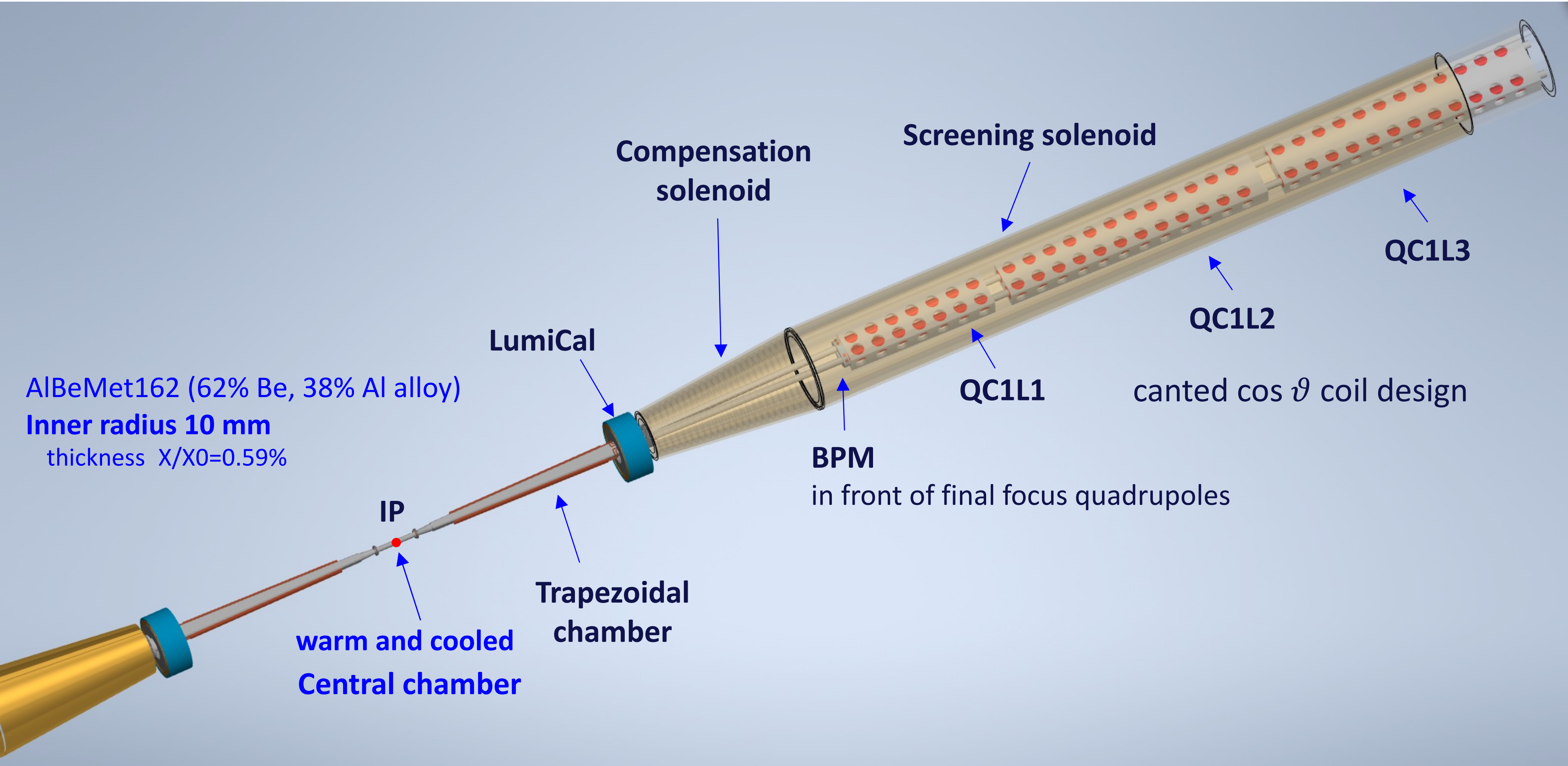


a smaller central vacuum chamber allows for a smaller radius of the innermost vertex detector layer

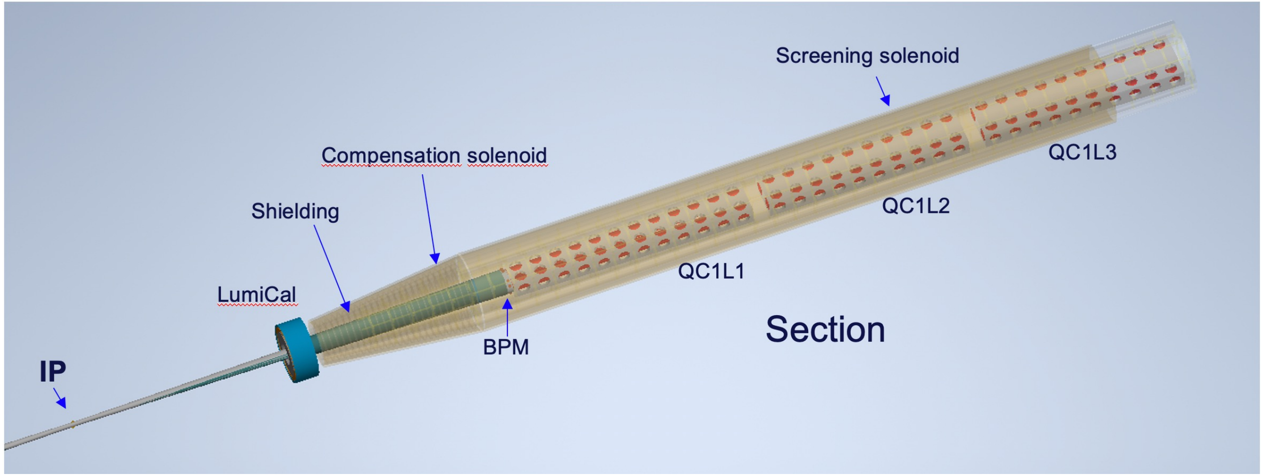
3D view of IR


Screening solenoid
Compensation solenoid
QC1L3
QC1L2
LumiCal
QC1L1
BPM
IP
Trapezoidal chamber
Central chamber

3D view of IR


Compensation solenoid
Screening solenoid
QC1L3
QC1L2
LumiCal
QC1L1
canted cos ϑ coil design
AlBeMet162 (62% Be, 38% Al alloy)
Inner radius 10 mm
thickness X/X0=0.59%
BPM
in front of final focus quadrupoles
IP
Trapezoidal chamber
warm and cooled
Central chamber

Solenoid compensation scheme



two anti-solenoids

- **compensating solenoid** in front of the first quad, as close as possible to IP, to reduce the ε_y blow-up (integral BL~0)
- **screening solenoid** shields the detector field inside the quads (in the FF quad net solenoidal field=0)

Requirements for the IR and MDI region

- **Luminosity** at Z-pole at 10^{36} $cm^{-2}s^{-1}$ level: it drives L*, beam size at IP, emittance, anti-solenoids, IR quads values, beam stabilization with orbit tuning, vibration suppression, alignment control, among others.

- **Solenoid compensation** scheme
  vertical emittance blow-up as small as possible: nominal value **1 pm,** 30% increase is considered acceptable, it increases at each IP and it is proportional with fifth power of detector solenoid field: this has set the detector field to **2 T**
  Two anti-solenoids inside the detector are needed to compensate the detector field

- Synchrotron radiation control in the IR
- Heat load on the beam pipe from wakefields and from beam losses has to be properly managed.

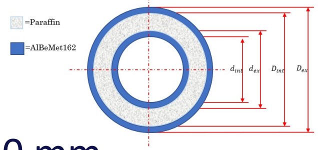
Some detector requirements for the MDI design

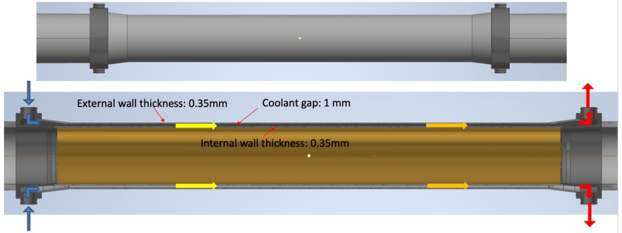
- **100 mrad physics cone:** all accelerator components required to stay within <100 mrad
  - trade-off between accelerator/detector needs, refinement of this value to be expected
- Luminosity monitor @Z: absolute measurement to 10^{-4} with low angle Bhabhas:
  - window acceptance of the lumical
  - alignment constraints
  - independent support from the beam pipe
- Low X/X0 central chamber, keep low material budget
  - constraint to vacuum chamber model with cooling
- SR critical energy below 100 keV from last bendings upstream the IR
  - constraint to the FF optics, asymmetrical bendings
- Background suppression and radiation shielding
  - Robustness against machine bkgs, radiation hardness
  - Detector occupancy below 0.1%-1%
  - Impact to the collimation scheme and shielding around the beam pipe
- Accessibility of inner detectors (Lumical and vertex) for maintenance and repair

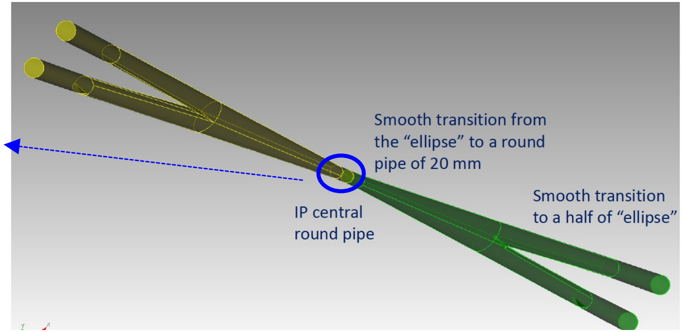
Low impedance central chamber

The double effect of smoothing the geometry and a smaller central pipe reduces the local heating power by a factor ten wrt the CDR design.

warm and cooled central beam pipe







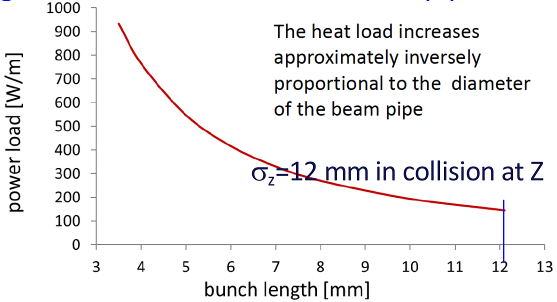
Inner radius 10 mm

Material	thickness
AlBeMet162 (62% Be and 38% Al alloy)	0.35 mm
Paraffin (PF200)	1 mm
AlBeMet162	0.3 mm
Au	5 µm

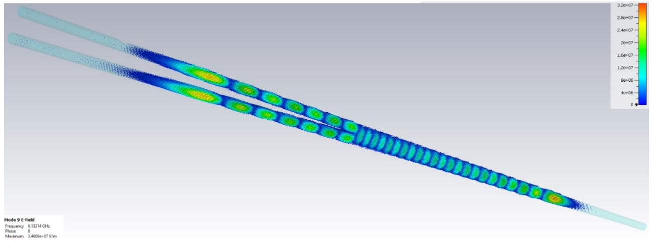
Thickness 1.7mm (X/X0=0.59%)

CDR: inner radius 15 mm for X/X0=0.47%

Heat load due to resistive wakefields vs bunch length for a r=1cm Be central beam pipe.



CST wake-field simulation (A. Novokhatski, SLAC)

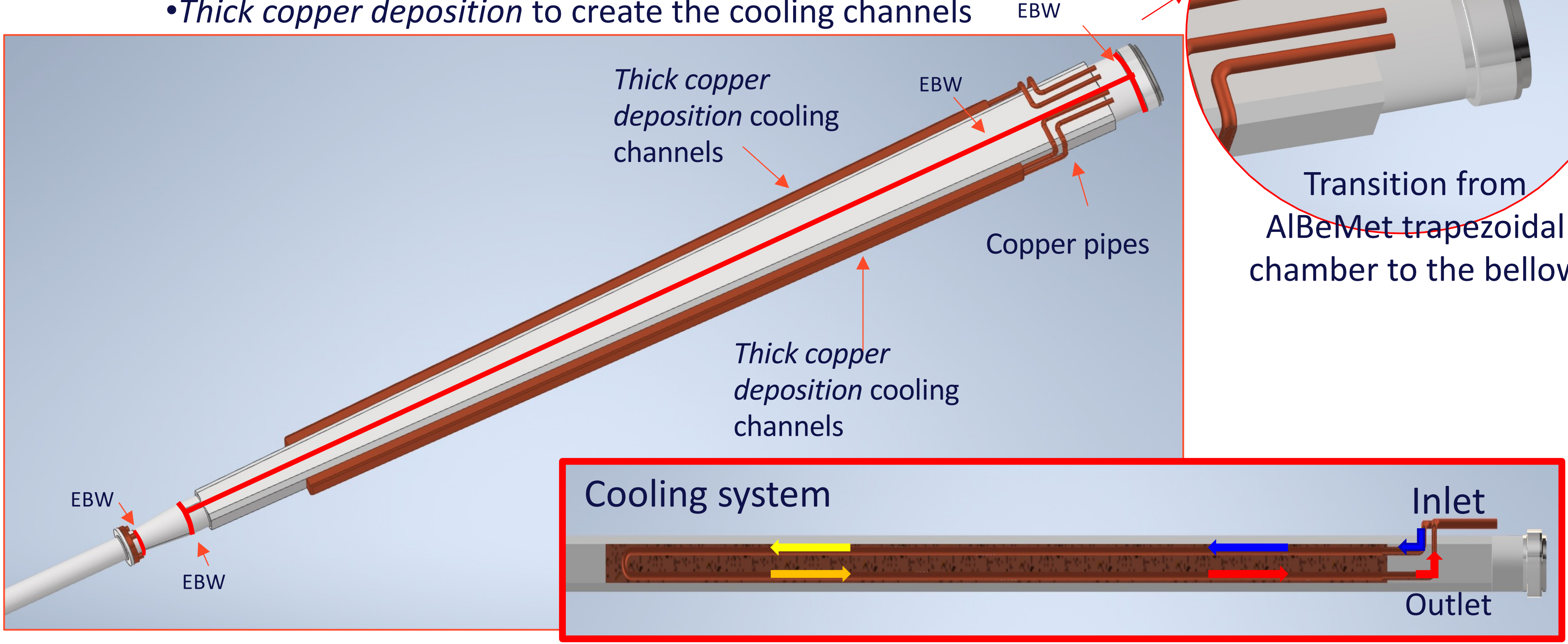


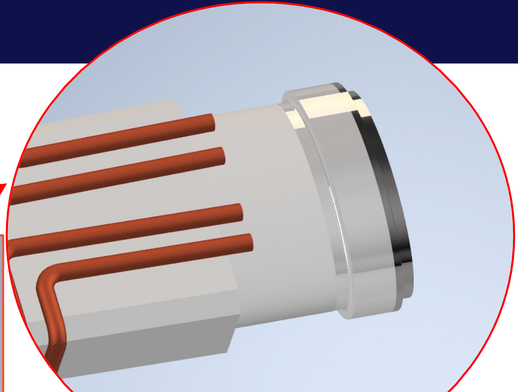
Heating power is 260 W for the two beams, most of this power will travel out away from the IP

These results have been recently confirmed with the latest mechanical model of the central AlBeMet chamber and latest beam parameters (higher beam density), we confirm that no HOM absorbers are required.

Trapezoidal chamber with cooling system

- Two Electron Beam welded shells
- *Thick copper deposition* to create the cooling channels





Transition from AlBeMet trapezoidal chamber to the bellow

The cooling channel is created using the "*thick copper deposition*", this technique allows to create complex geometry during the deposition.

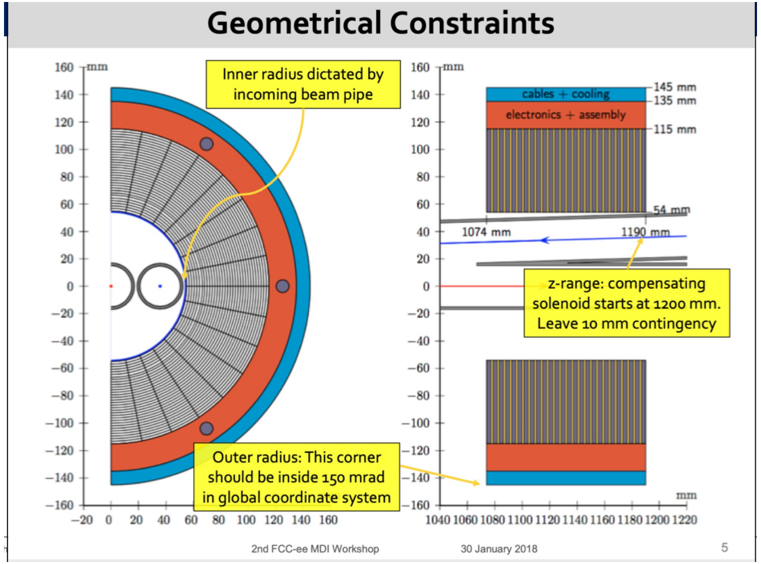
Luminosity monitor

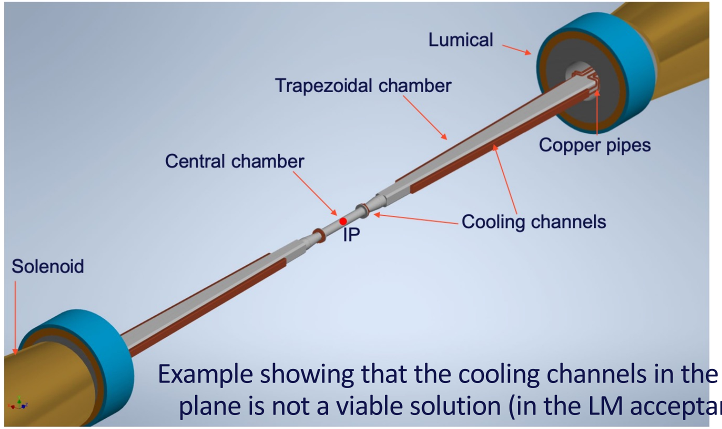
M. Dam

Basics of the design:
small angle Bhabha scattering σ = 14 nb;
wide acceptance 62-88 mrad,
96 mrad average coverage

LM sits in the outgoing beamline system, while the large detector is symmetrical in the average beamline coordinate system.

- Discussion in progress about the requirements on the angular acceptance and trade-off with the vacuum chamber including the cooling system
- Geant4 study would help to define the requirements, studying secondary interactions with the beampipe and cooling system





Example showing that the cooling channels in the horiz. plane is not a viable solution (in the LM acceptance)

M. Koratzinos

Final Focus quadrupoles

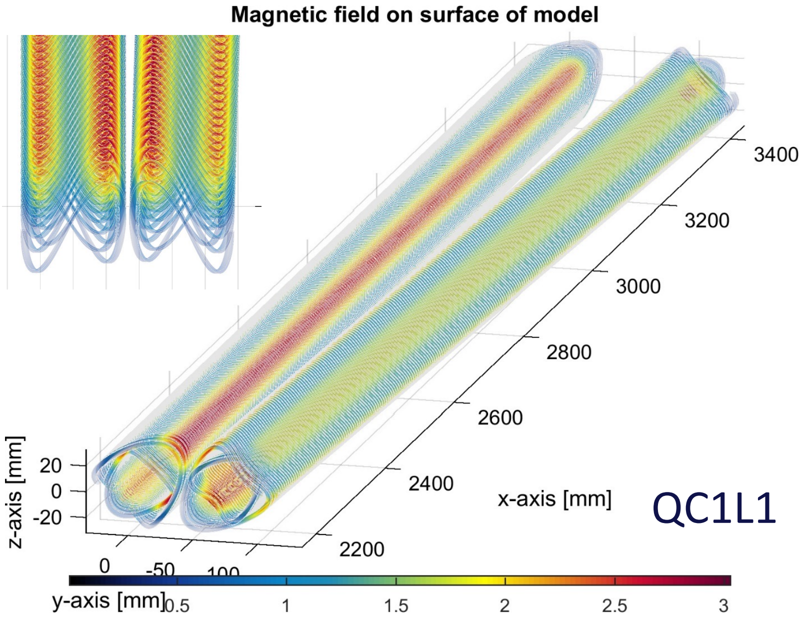
Canted Cosine theta (CCT) design

Quadrupole with embedded local edges correction and crosstalk correction

Pros:

- Excellent field quality
- The design can have embedded correctors
- Strengths up to 150T/m possible

The beam pipe inner radius in QC1 is 15 mm, the quadrupole aperture radius is 20 mm.
66mm between the two beams at QC1L1, very small distance.
Quads are at an angle so crosstalk varies along the length
The beam pipe is warm, so we need vacuum insulation and cooling/heating for the beam pipe

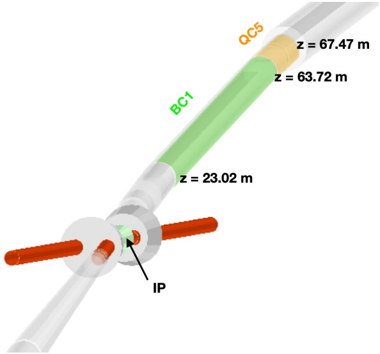


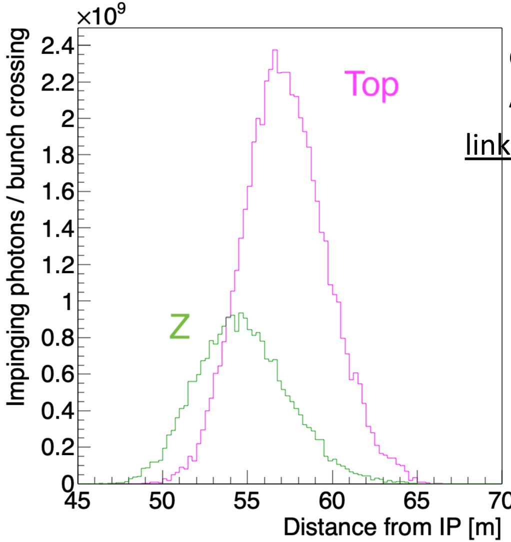
Some of the open questions related to the IR magnets design:
Required field stability, field quality, cross-talk compensation, required IR correction coils thickness for the shielding for magnet protection and for beam losses, supports, …

Beamstrahlung Radiation generated at the IP

- A significant flux of photons is generated at the IP in the very forward direction by Beamstrahlung, radiative Bhabha, and solenoidal and quadrupolar magnetic fields.
- **Beamstrahlung** interactions produce an **intense source of locally lost beam power**
- The impinging angle of the **Beamstrahlung** photons with the pipe is about 1 mrad for both beam energies.

	Beam energy	Beamstrahlung Radiation power
$\langle E\gamma \rangle = 2$ MeV	45.6 GeV	387 kW
$\langle E\gamma \rangle = 67$ MeV	182.5 GeV	89 kW





GuineaPig++
A. Ciarma
link: IPAC21 MDI

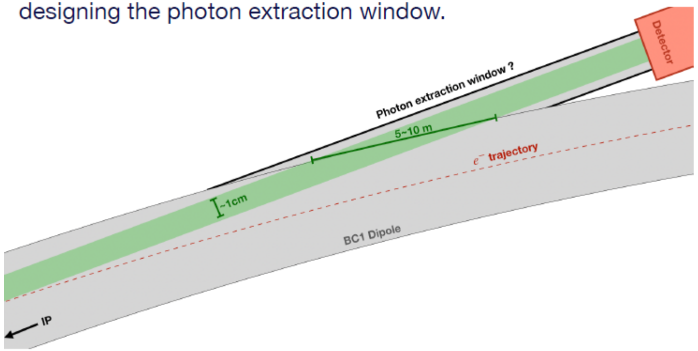
Beamstrahlung photons tracked up to their loss points, at about 50-60 m after the IP

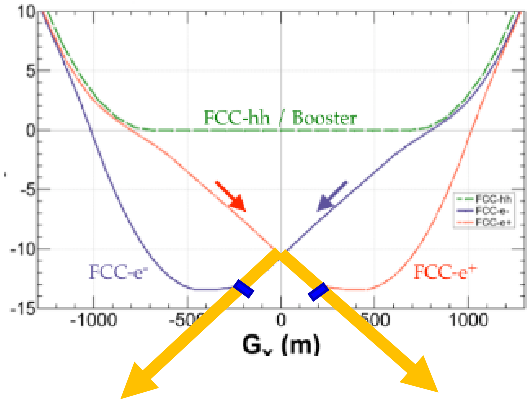
Requires special beam pipe extraction line and alcove: Beamstrahlung instrumented photon dump

Beamstrahlung monitor

-radiation from the colliding beams is intense (380 kW over cm^2 section!)
- potentially very precise monitoring of collision offsets in both x and y.
  - -- operations
  - -- centre-of-mass energy control
- basically un instrumented beam dump.   proposed by A. Blondel

While the spot size is ~1x1cm^2, due to the very small impinging angle on the beam pipe wall (~1mrad) the region hit by the photons is **several meters long** on the longitudinal dimension, so this should be taken in consideration when designing the photon extraction window.





detect photons at exit from bending magnet in a detector system that is all to be designed!

Synchrotron Radiation background

K. André

- New independent simulations performed with BDSIM from about 1.2 km from the IP with CDR lattice.
- Comparison with previous studies performed with MDISim have shown very good agreement.
- Only the last dipole upstream the IP, and the quadrupoles QC3L, QT1L, QC1L produce SR that propagates until or traverses the IP.
- New results for the latest V22 lattice with 4IPs is in progress.

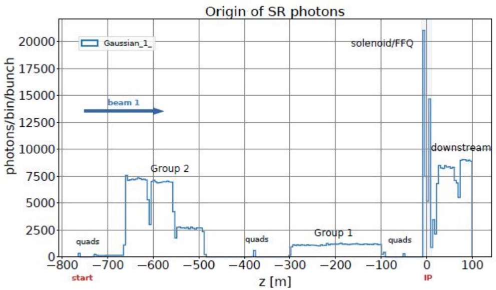
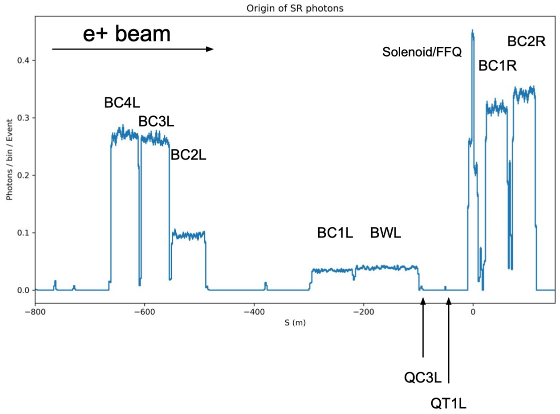


Figure 7.18: Photon emission spectrum along the beam trajectory. Two groups of upstream dipole magnets can clearly be identified, as well as the quadrupoles upstream. The final-focus doublet (FFQ) can be distinguished as well, very close to the Interaction Point (IP).



M. Lückof

Summary

The Interaction Region is a complicated and vital part of the FCCee machine and detector design

Central vacuum chamber design in progress, prototyping foreseen.
Progress on the IR magnets design will help to progress with supports, and general assembly.
Lumical key device in the MDI area, compatibility with its requirements to mechanical model are under study.

Preliminary collimation scheme with beam loss map is in progress.
First loss maps are being tracked into the detector.
Effects of beam backgrounds in the detector will allow to optimize the necessary shieldings foreseen around the beam pipe and behind the lumical.

More at the FCC WEEK 2022 !

In Paris 30 May to 3 June 2022

Hybrid event !

https://indico.cern.ch/event/1064327/