OVERVIEW OF THE FCC-EE MDI REGION

Manuela Boscolo
for the MDI team

FCC WEEK 2022 Conference,
Sorbonne Université, Paris, 30 May – 3 June 2022

Outline

- An **overview of the MDI design** with recent results and ongoing studies
  - Progress on Beam optics & parameters with 4IPs
  - Collimation scheme and aperture model
  - Detector backgrounds evaluation
  - Synchrotron Radiation collimators with 4IPs lattice
  - Beamstrahlung radiation
  - Mechanical model of MDI, e.g. vacuum chamber with cooling system, bellow
  - Alignment system for the MDI
  - Tilted solenoid modeling for optics and beam dynamics simulations

- Next steps

Agenda

MDI session 1 Thu 2/6 11:00 – 12:30	
M. Boscolo (INFN)	MDI overview
M. Dam (NBI)	Luminosity monitor
F. Fransesini (INFN)	IR chamber & MDI assembly
S. Grabon (LAPP)	Modelling process for vibrations estimations
L. Watrelot (CNAM)	MDI alignment system update and challenges

MDI session 2 Thu 2/6 14:00 – 15:30	
M. Koratzinos (MIT)	IR magnet concepts
J. Seeman (SLAC)	IR magnet review
A. Ciarma (CERN)	Machine induced backgrounds in the MDI region and beamstrahlung radiation
K. Andre (CERN)	Synchrotron radiation background studies
M. Calviani (CERN)	Challenges for instrumented beamstrahlung dump

FCC-ee collider

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

4 IPs

large horizontal crossing angle 30 mrad,

crab-waist collision optics

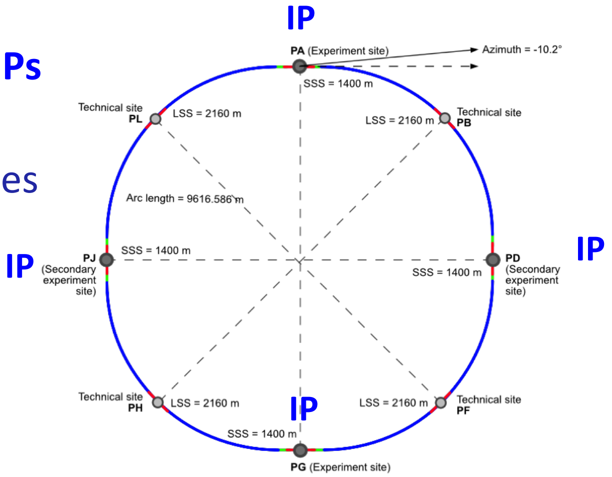
Synchrotron radiation power **50 MW/beam** at all beam energies

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

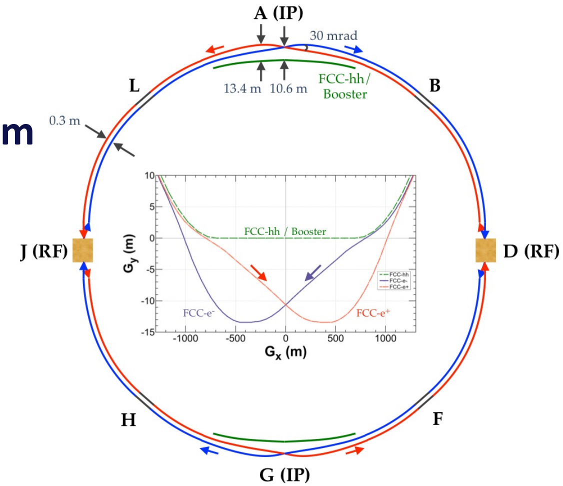
“**Tapering**” of magnets along the ring to compensate the sawtooth effect

evolution 4IPs
C=91 km

8 surface sites



CDR
C=97 km



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)

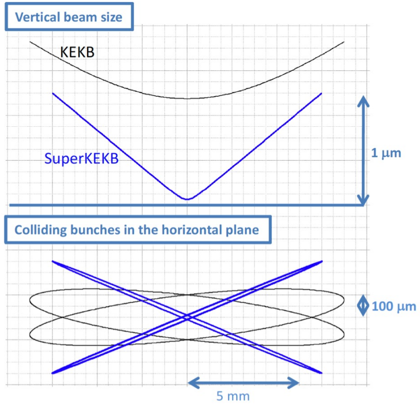


Figure 2: Schematic view of the nanobeam collision scheme.

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

- 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.

High-level Requirements for the IR and MDI region

- **One common IR for all energies, flexible design** from 45 to 182.5 GeV with a constant detector field of **2 T**

  At Z pole: Luminosity ~ 10^{36} $cm^{-2}s^{-1}$ requires crab-waist scheme, nano-beams & large crossing angle.

  Top-up injection required with few percent of current drop.

  Bunch length is increased by 2.5 times by beamstrahlung

  At **ttbar threshold**: synchrotron radiation, and beamstrahlung dominated the lifetime

- **Solenoid compensation** scheme

  Two anti-solenoids inside the detector are needed to compensate the detector field

- **Synchrotron radiation** control in the IR

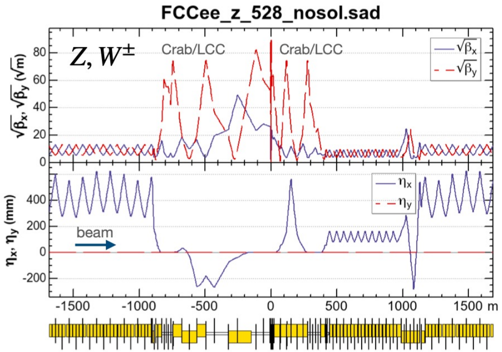
High-level Detector requirements for the MDI design

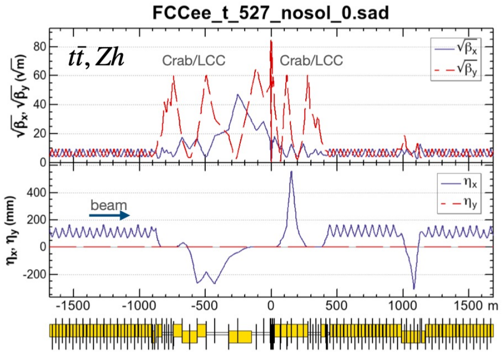
- 100 mrad of physics cone
  - trade-off between accelerator/detector needs expected
- Luminosity monitor @Z: absolute measurement to 10^{-4} with low angle Bhabhas
  - window acceptance of the lumical, alignment and stabilization constraints
- Low X/X0 vacuum chamber with cooling system, keep low material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

FCC-ee IR optics design

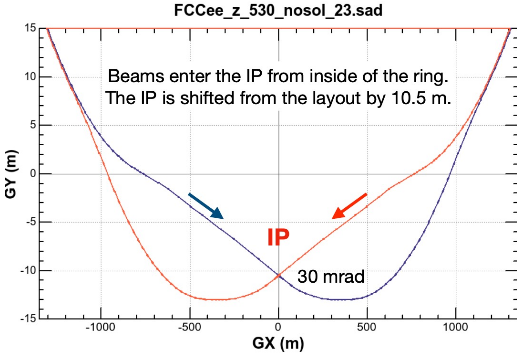
Driven by synchrotron radiation:

$E_{critical}$ <100 keV from 450 m from the IP at ttbar (detector requirement from LEP experience)
→ Very Asymmetric IR optics





Beams enter the IP from inside of the ring

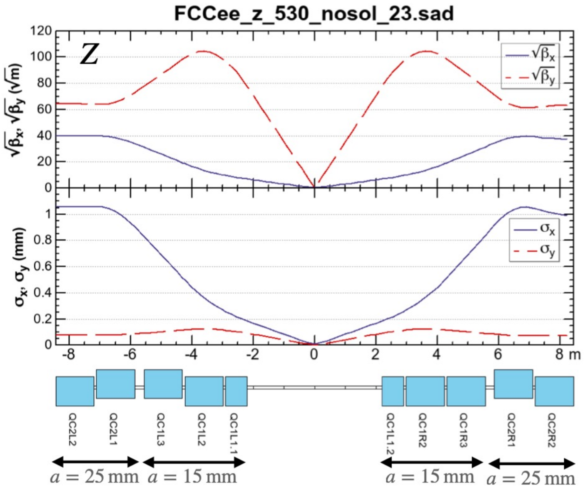


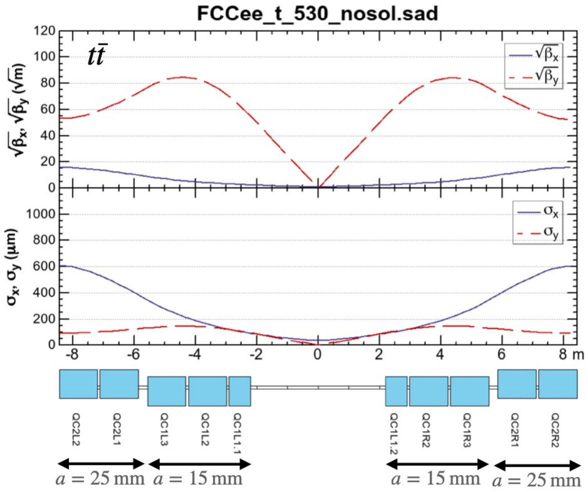
Beams enter the IP from inside of the ring.
The IP is shifted from the layout by 10.5 m.

K. Oide

FCC-ee IR optics design

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





Horizontal aperture
15 mm ≅ 18.7 σ_x at QC1
25 mm ≅ 23.6 σ_x at QC2
(potential issue at Z but larger than dynamic aperture)

K. Oide

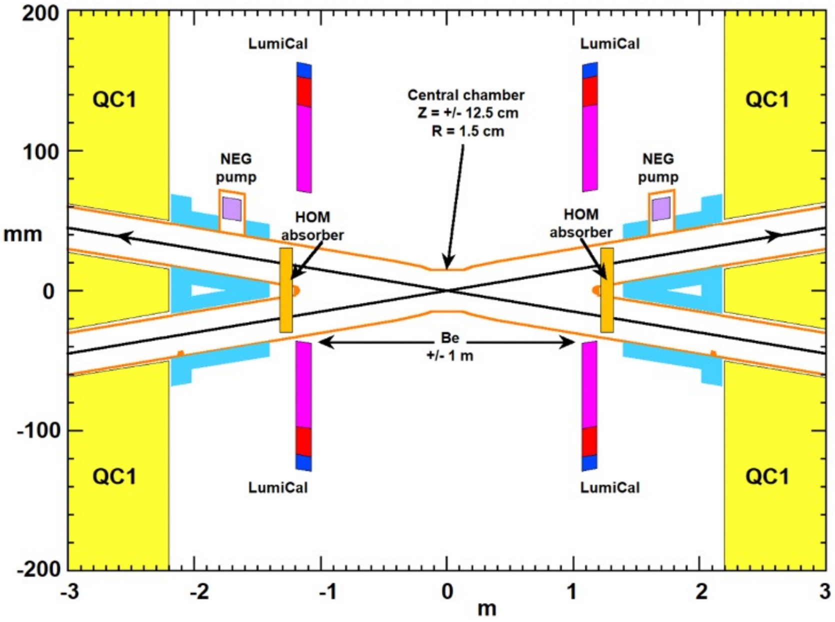
Latest Beam parameters 4IPs

		Z	W^+W^-	ZH	ttbar
Luminosity per IP	cm^2s^{-1}	1.82×10^{36}	1.94×10^{35}	7.26×10^{34}	1.25×10^{34}
β_x^*	m	0.1	0.2	0.3	1.0
β_y^*	mm	0.8	1.0	1.0	1.6
σ_x^*	µm	8	21	14	39
σ_y^*	nm	34	66	36	69
σ_z (with SR / with BS)	mm	4.38 / 14.5	3.55 / 8.01	3.34 / 6.0	1.95 / 2.8
σ_δ (BS)	%	0.132	0.154	0.185	0.219
N_{bunch}	10^{11}	2.43	2.91	2.04	2.37
bunches/beam		10000	880	248	40
bunch spacing	ns	30			

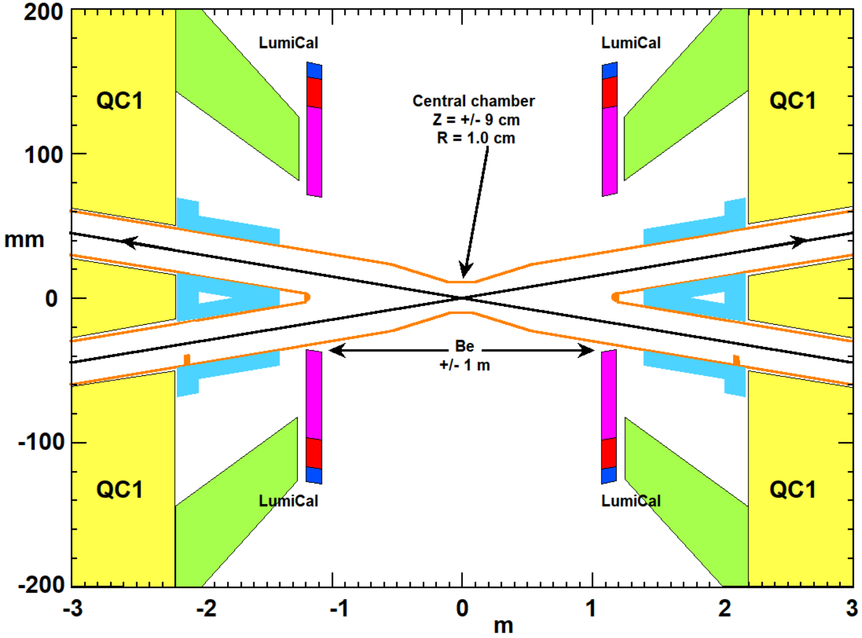
- β_x^* at the Z-pole has been recently reduced to **0.1 m** (according to simulations of coherent beam-beam instabilities including longitudinal impedances).
- Beam parameters are being optimized also according to beamstrahlung simulations that include machine errors.

IR layout

CDR
1.5 cm radius central chamber



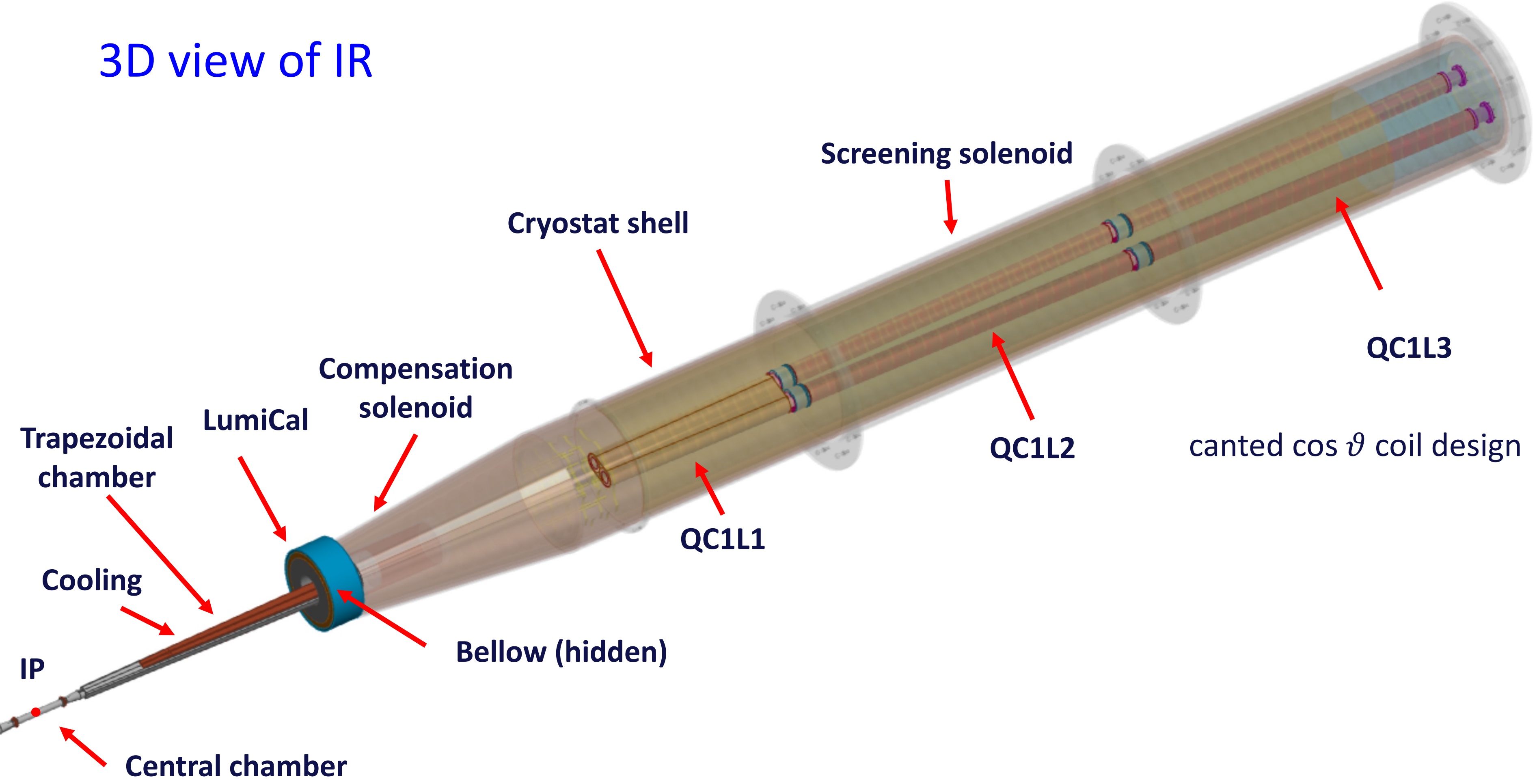
present low impedance beam pipe
1 cm radius central chamber



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

F. Fransesini

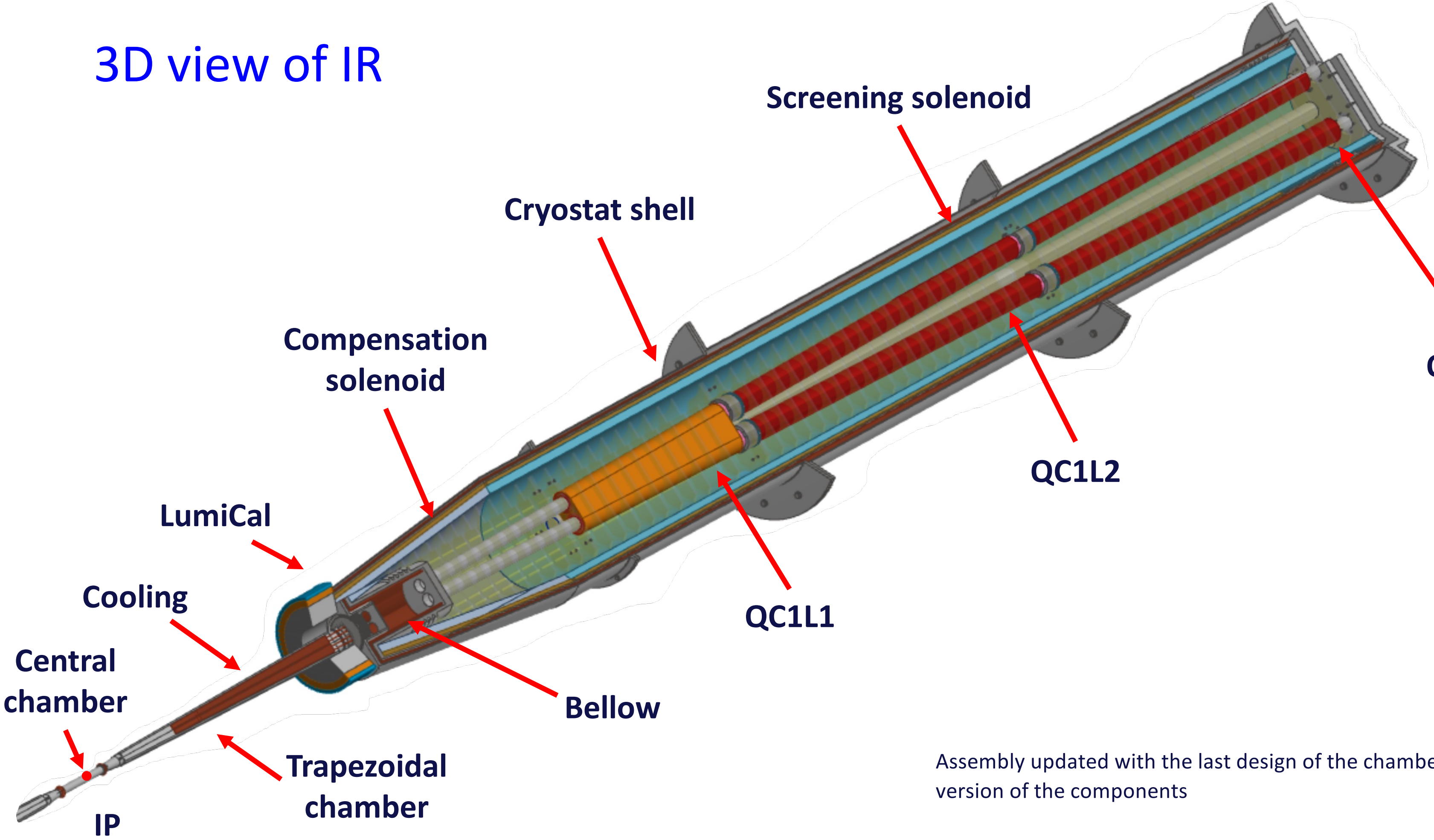
3D view of IR



canted cos ϑ coil design

F. Fransesini

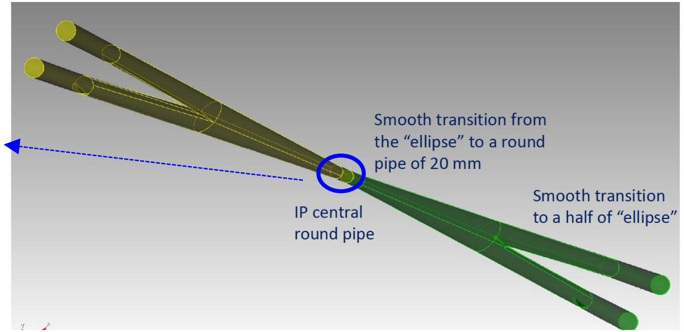
3D view of IR



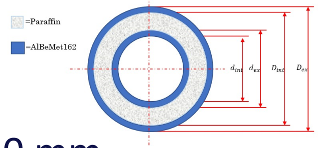
Assembly updated with the last design of the chamber and the last version of the components

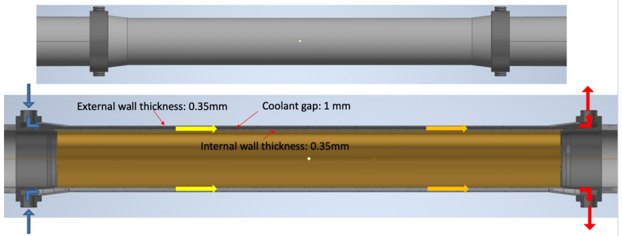
Low impedance central chamber

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





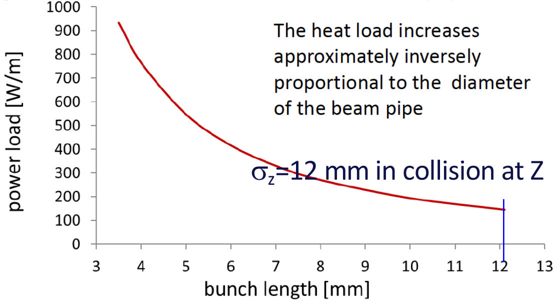
Inner radius 10 mm

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%

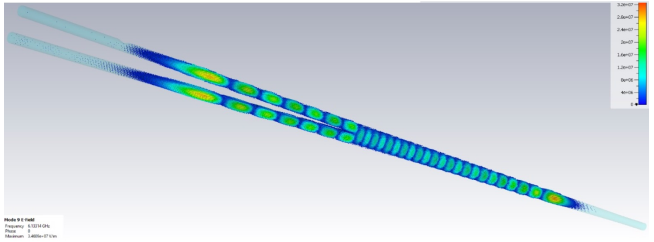
Heat load due to resistive wakefields vs bunch length for a r=1cm Be central beam pipe.



The heat load increases approximately inversely proportional to the diameter of the beam pipe

σ_z=12 mm in collision at Z

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

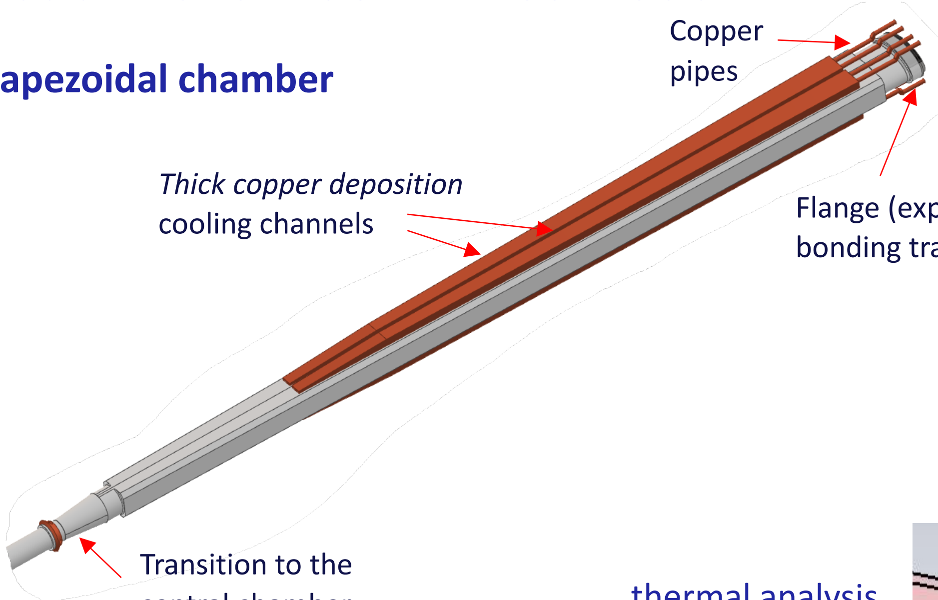


Heating power is 260 W for the two beams, most of this power will travel out away from the IP

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

Vacuum chamber & Heat load

Trapezoidal chamber

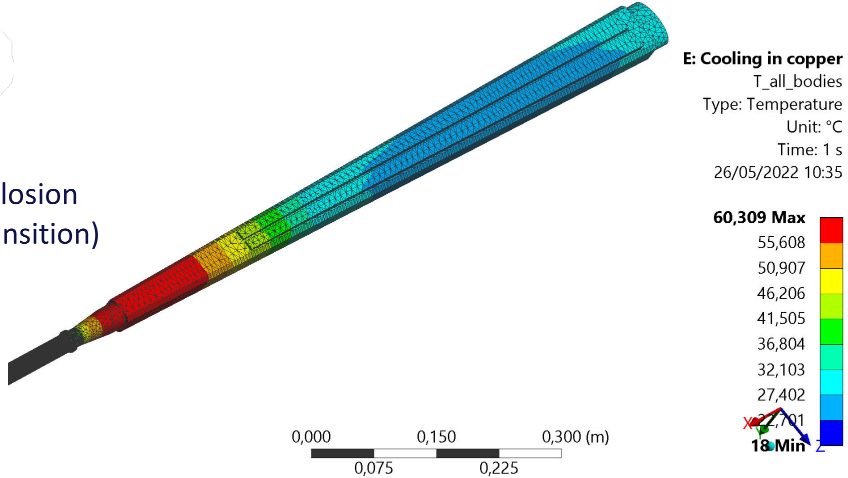


Copper pipes

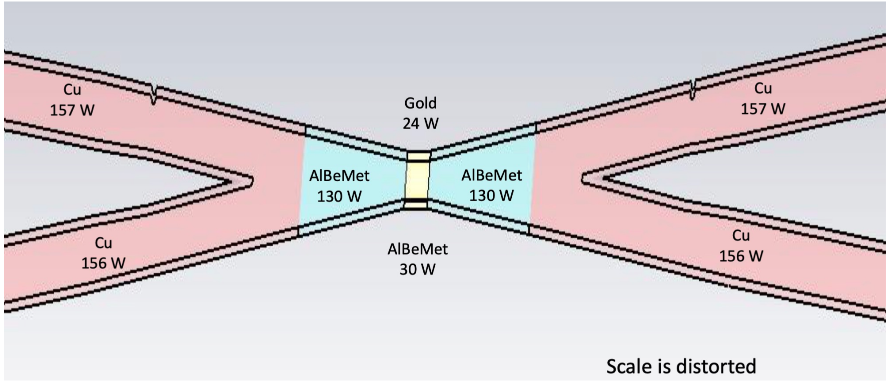
Thick copper deposition cooling channels

Flange (explosion bonding transition)

Transition to the central chamber



thermal analysis, A. Novokhatski



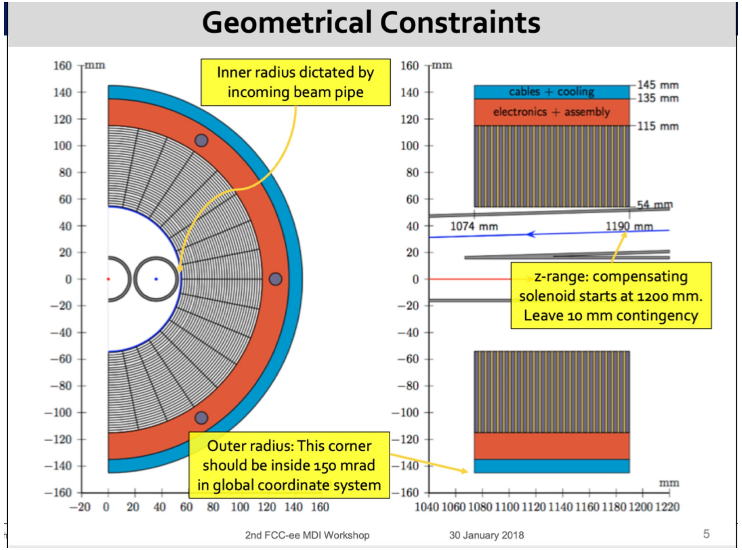
- **54 W central**
- **130 W AlBeMet162 for each part**

no trapped modes

Luminosity monitor

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.

Geant4 study would help to define the requirements



Geometrical Constraints

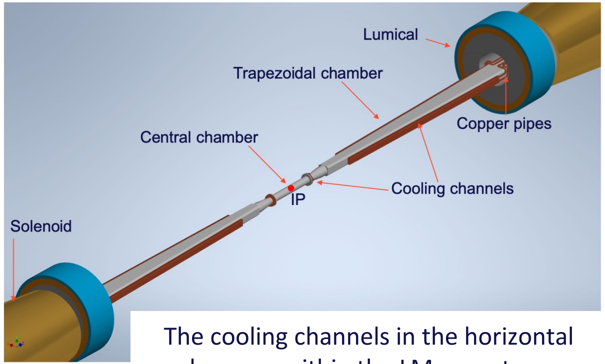
Inner radius dictated by incoming beam pipe

Outer radius: This corner should be inside 150 mrad in global coordinate system

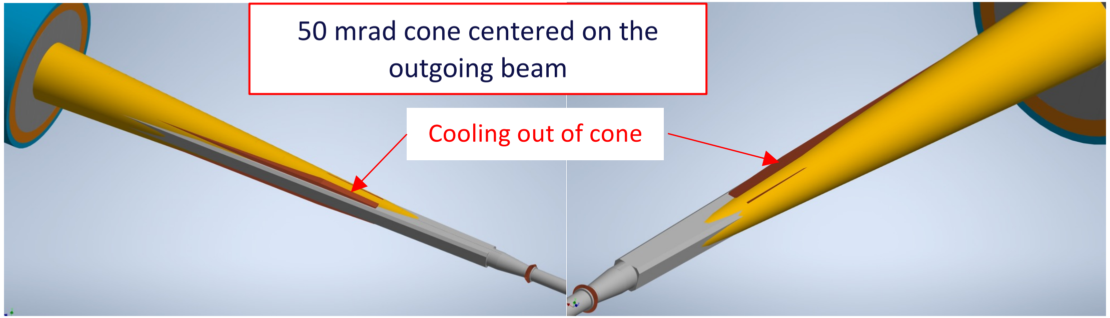
z-range: compensating solenoid starts at 1200 mm. Leave 10 mm contingency

2nd FCC-ee MDI Workshop 30 January 2018 5

Compatibility between LM angular acceptance and the cooling system of the beam pipe



The cooling channels in the horizontal plane are within the LM acceptance



50 mrad cone centered on the outgoing beam

Cooling out of cone

There is an asymmetric interference between the cooling channels in the vertical plane and the cone that defines the LM angular acceptance.

M. Koratzinos

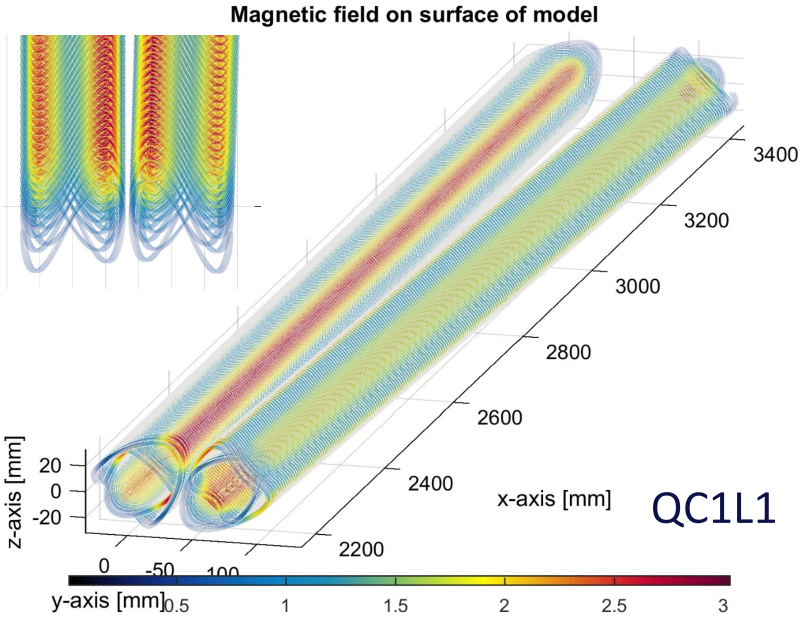
SC Final Focus quadrupole QC1

Canted Cosine theta (CCT) design

Quadrupole with embedded local edges correction and crosstalk correction

Pros:

- Excellent field quality
- The design can have embedded correctors



NbTi, radius aperture 20 mm

Some of the open questions related to the IR magnets design:

Required field stability, field quality, cross-talk compensation, required IR correction coils required shielding for magnet protection and for beam losses, magnet and vacuum chamber supports.

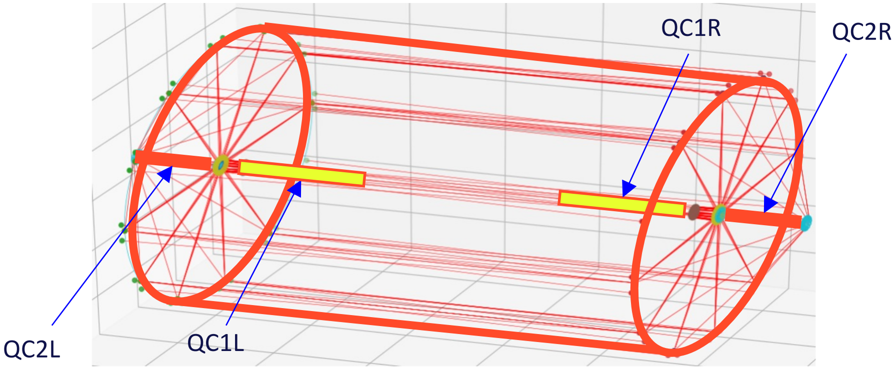
List of requirements for the overall IR magnets will help to move to the next level of design.

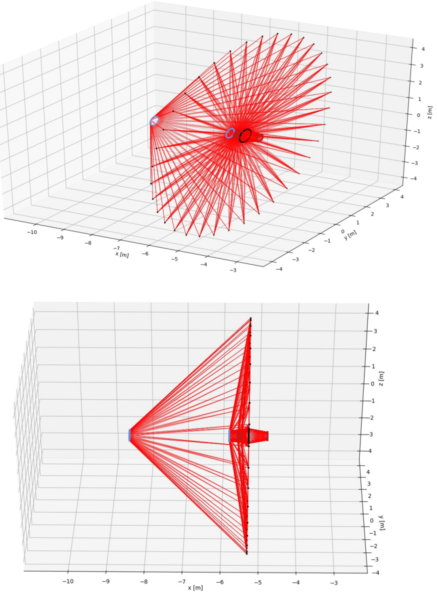
FCC-ee MDI alignment strategy

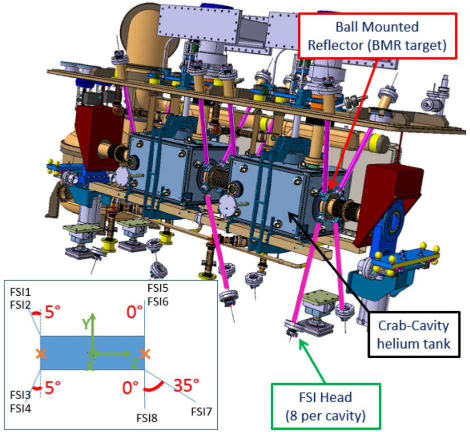
Currently, there’s no alignment system that can be implemented in the FCC-ee MDI, due to space constraints, harsh conditions and tight requirements.

This is underlined by the fact that CLIC and ILC didn’t found any solution for the alignment of their MDI.

<u>But,</u> we have a strategy and simulations ongoing for a **new sensor**, results will follow.







Sosin, Mateusz, et al. Position monitoring system for HL-LHC crab cavities. No. CERN-ACC-2016-197. 2016.

To be continued …

K. André

Synchrotron Radiation (SR) background

- New independent simulations performed with **BDSIM** from about 1.2 km from the IP with CDR lattice (very good agreement with previous studies with MDISim)
- **Only the last dipole upstream the IP, and the quadrupoles QC3L, QT1L, QC1L produce SR that propagates until or traverses the IP.**
- New simulations with 4IPs optics
- SR collimators will be added to the beam collimators
- **SR from last bend intercepted by the mask will be tracked through the present beam pipe to the detector**

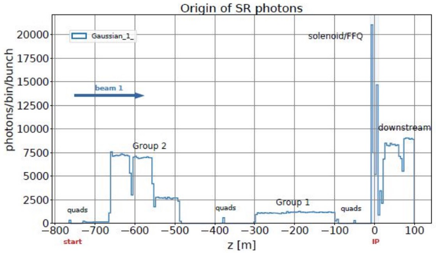
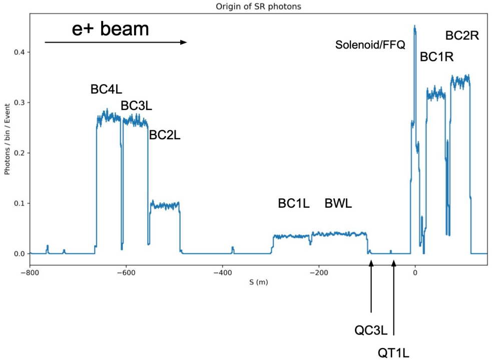


Figure 7.18: Photon emission spectrum along the beam trajectory. Two groups of upstream dipole magnets can clearly be identified, as well as the quadrupoles upstream. The final-focus doublet (FFQ) can be distinguished as well, very close to the Interaction Point (IP).



CDR study, MDISim, M. Lückof

A. Abramov, code development session

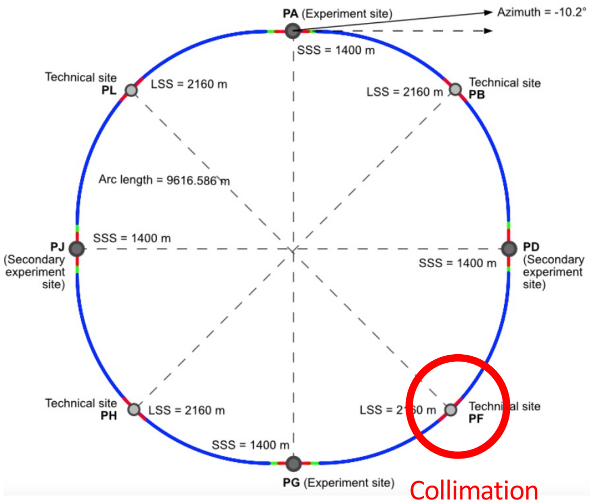
FCC-ee collimation studies

Motivation:

- The FCC-ee will have up to 2 orders of magnitude larger stored energy than other lepton colliders
- A halo collimation system must be implemented to protect the machine from beam losses
- The first design of a halo collimation system is ongoing

Studies involved:

- Aperture studies, including tolerances, definition of aperture model
- Design of layout and optics in collimation insertion
- Definition of collimator settings, materials, needed active lengths
- Studies of protection during regular and irregular beam loss scenarios
- Performance evaluation, including particles out-scattered from
- collimators and residual loss patters around the ring
- Development of simulation tools for collimation simulations



Collimation insertion

A. Abramov, code development session

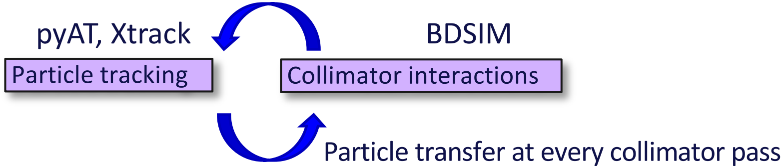
FCC-ee collimation studies

Simulation software development:

- Simulation studies are an important aspect of collimation system design
- For the FCC-ee collimation, need multi-turn tracking with synchrotron radiation and optics tapering, and particle-matter interactions in the collimators
- No simulation readily frameworks available that fit all the requirements

Status:

- Focused on coupling between a tracking code and a Monte Carlo physical interaction code.
- Developed a coupling between **pyAT** / **Xtrack** and **BDSIM** (Geant4).
  - Benchmarked with and without radiation and tapering
  - Used to study CDR layout and new 4 IP layout



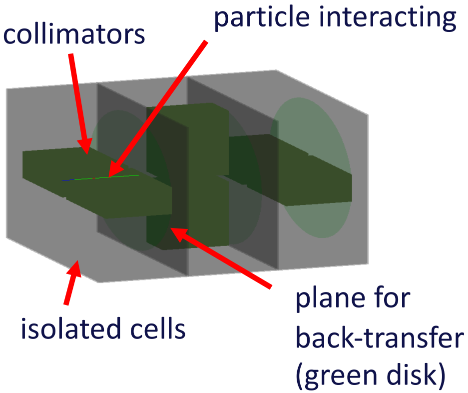
pyAT, Xtrack

Particle tracking

BDSIM

Collimator interactions

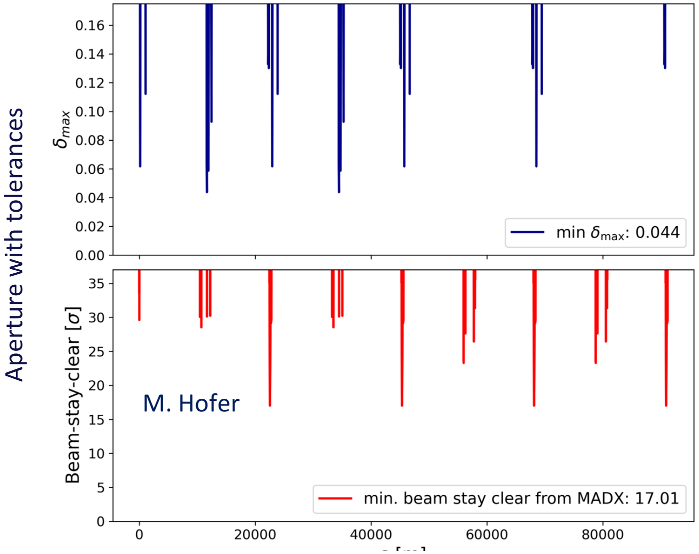
Particle transfer at every collimator pass

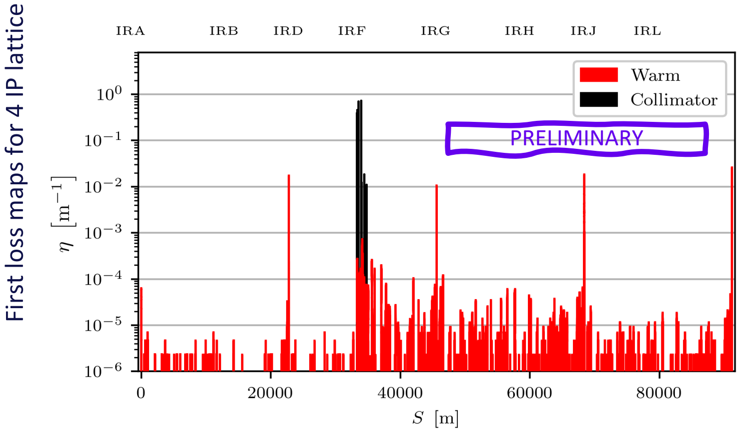


A. Abramov, code development session

FCC-ee collimation studies

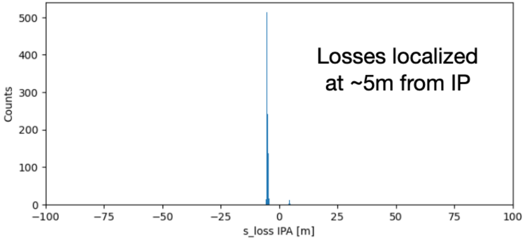
- **Current status (see FCC week talk):**
  - Studies of the latest 4 IP configuration ongoing
  - Significant changes from the previous configuration:
    - Ring layout and optics
    - Collimation insertion with a split betatron and off-momentum collimation
    - New aperture model, including a 10 mm inner beam pipe
    - First guess for new collimator design parameters
- **Next steps**:
  - Include the synchrotron radiation collimators
  - Evaluate the collimation system performance, using:
    - Beam loss scenarios
    - Equipment loss tolerances – quench limits, detector backgrounds
  - Study all beam modes





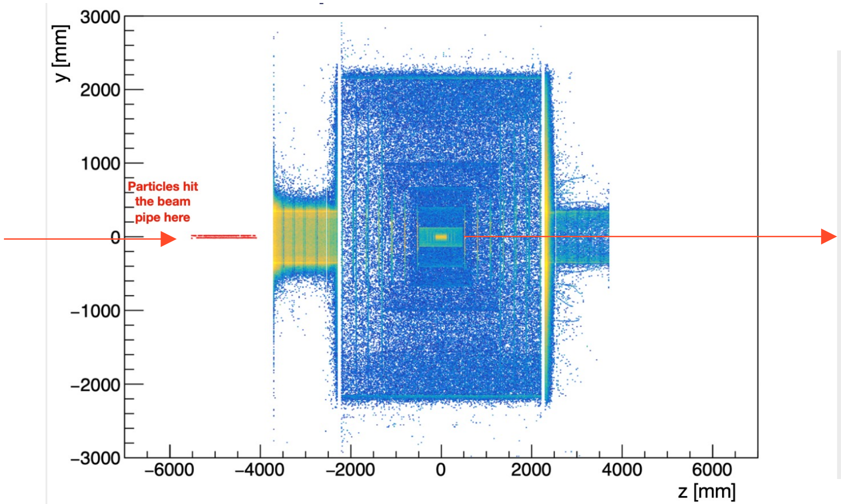
A. Ciarma

First Tracking of IR beam losses to the CLD detector

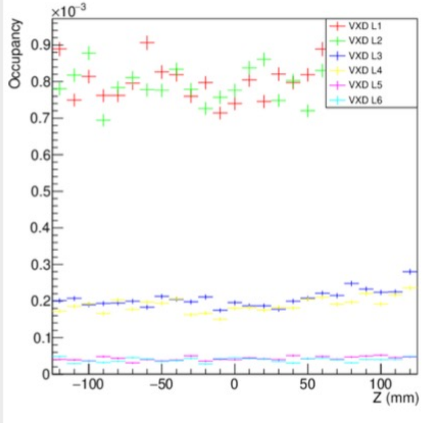


(from the collimation team)

CDR optics, ttbar



VXD occupancy



- Occupancy can get up to 1% in vertex detector –*<u>note:</u>* this is just the first simulation
- Next step will be to refine and update the model of the MDI area

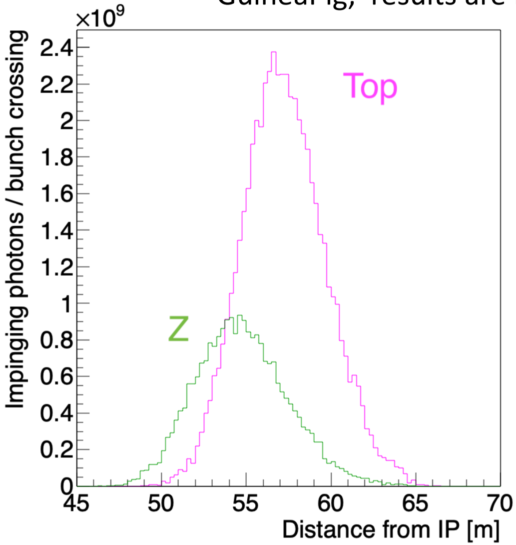
(presently it includes the compensating solenoid, heavy *and not-realistic* SR shielding, not the QC1

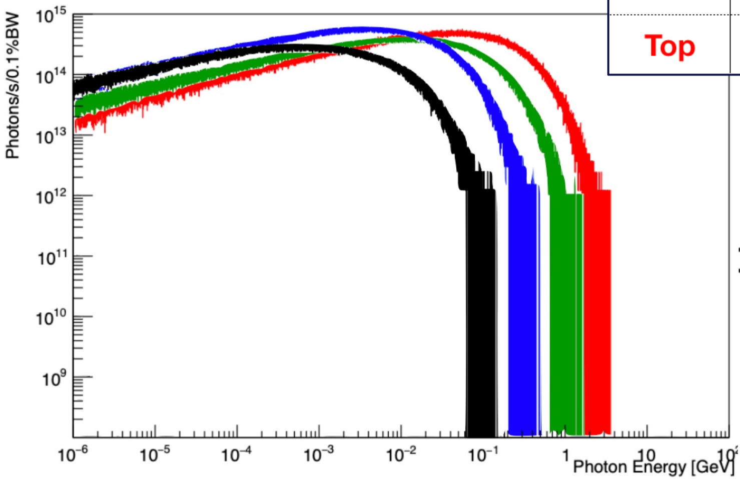
Beamstrahlung Radiation generated at the IP

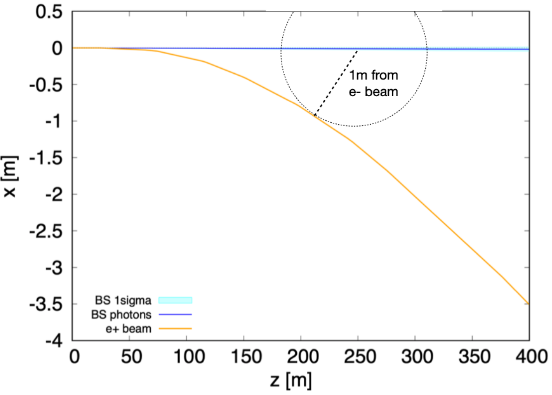
Radiation from the colliding beams is very intense (370 kW over cm^2 section!)

GuineaPig, results are in agreement with D. Shatilov's results

	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3







Beamstrahlung radiation hits the vacuum chamber at the first bend downstream the IP

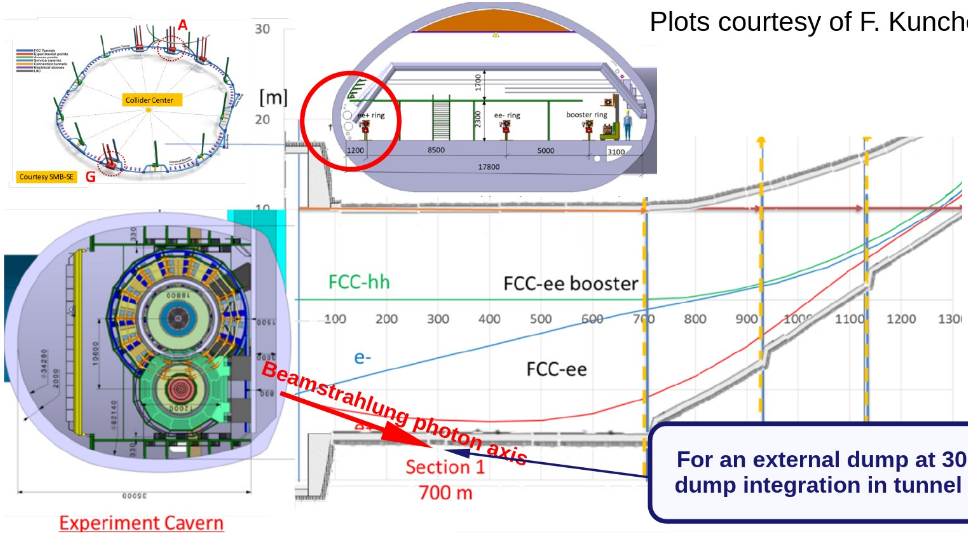
Requires special beam pipe extraction line and alcove -> Beamstrahlung instrumented photon dump

M. Calviani

Challenge for a Beamstrahlung instrumented dump

- High energy and power densities (several kW/cm^3)
- High average deposited power (hundreds of kW)
- Radiation damage and TID (hence shielding) in neighbouring areas
- Internal / external dumps
- Integration in the tunnel

Plots courtesy of F. Kuncheva-Valchkova



For an external dump at 300+ m from IP, dump integration in tunnel to be studied

Proposal for mock-up of the IR

step1

- Central IP vacuum chamber
  - test the cooling system and the vacuum system
- AlBeMet162 – steel transition
  - study the shape of the transition, EBW process
- Bellow
  - vacuum and thermal tests
- Welding
  - EBW for elliptical geometry

step2

- Trapezoidal vacuum chamber with remote vacuum connection
- QC1
- cryostat
- beam pipe and quadrupole and cryostat support
- vibration and alignment sensors

Summary

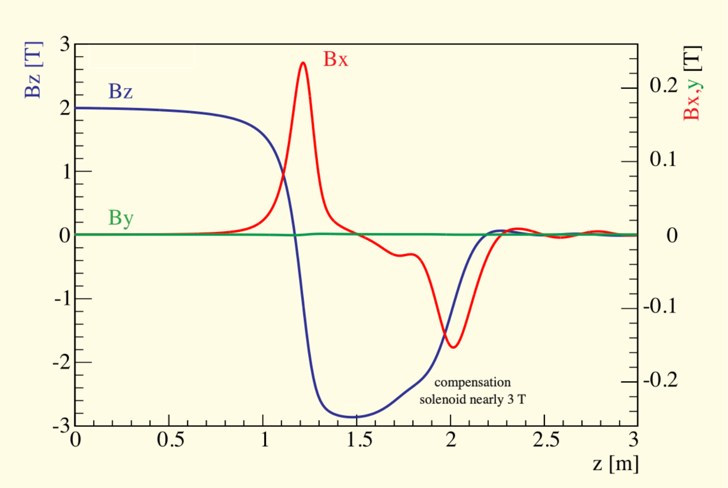
- Progress on various key aspects of the MDI design.
  - Vacuum chamber with thermal analysis and cooling system and bellow, compatibility with the lumi. monitor
  - Collimation scheme with beam loss including the MDI region started by the collimation team
  - Very first loss map tracked in the MDI area through detector
  - New tracking of SR photons to the IR, this radiation will be tracked to the detectors, so to optimize the heavy shielding around the masks added in the model for the CDR studies.
  - Beamstrahlung radiation, challenging photon bump possibly also measuring device

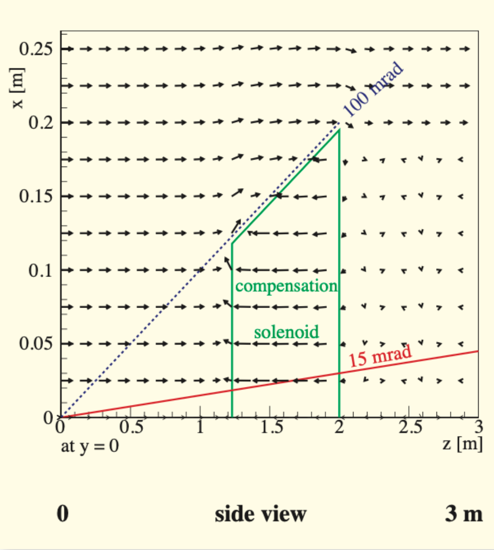
Next steps

- Progress on the **overall IR magnets design including solenoids and correctors** will help with the **cryostat design, supports**, and the overall general **assembly and integration**.
- **List of requirements** for IR magnets, detector, luminosity monitor, MDI key elements.
- **Deliverables** for the mid-term review , **cost estimate update**

Solenoid modeling for the FCC-ee IR

3D map includes compensating and detector solenoid M. Koratzinos





Tilted solenoid modeling for MAD-X