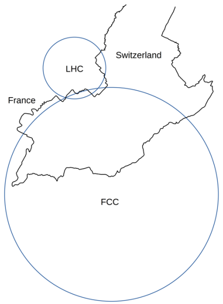
Istituto Nazionale di Fisica Nucleare

INTRODUCTION TO THE MACHINE DETECTOR INTERFACE WG



Manuela Boscolo (INFN-LNF)

for the MDI group

6th FCC Physics Workshop
Krakow, 23-27 January 2023

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.

FUTURE CIRCULAR COLLIDER
Innovation Study

Agenda MDI sessions

Tuesday 24/1 (MDI/Detector Joint)	
Mechanical model of the FCC-ee MDI	Francesco Fransesini (INFN-LNF)
Detectors integration in the MDI area	Franco Bedeschi (INFN-Pisa)
Status and Perspectives for FCC-ee Detector Backgrounds Studies	Andrea Ciarma (CERN)
FCC-hh detector concept	Anna Zaborowska (CERN)

Wednesday 25/1	
Summary of review for FCC Experimental sites	Mogens Dam (NBI)
Lesson learnt from CMS IR mock-ups	Andrea Gaddi (CERN)
IR beam losses	Andrey Abramov (CERN)
FCC-ee synchrotron radiation collimators and masks	Kevin Andre (CERN)
Detector Stray Magnetic Fields	Nikkie Deelen (CERN)

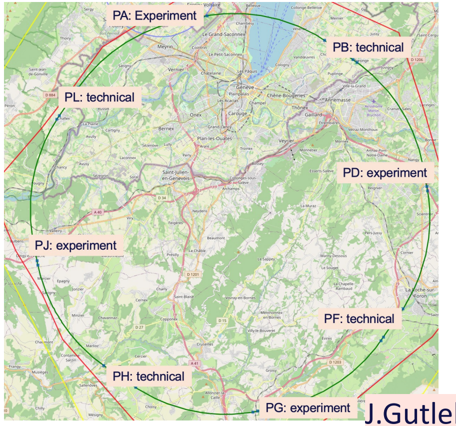
Since the last physics workshop

- New placement and layout → optics with smaller circumference (C=90.6 km) and 4IPs
- Progress on the **mechanical model** of the MDI area, with a focus on the central region $\pm$1.5 m from IP
  - beam pipe with the cooling system and its support
  - IR bellows
  - integration of the lumical
  - integration of the vertex and outer tracker detectors

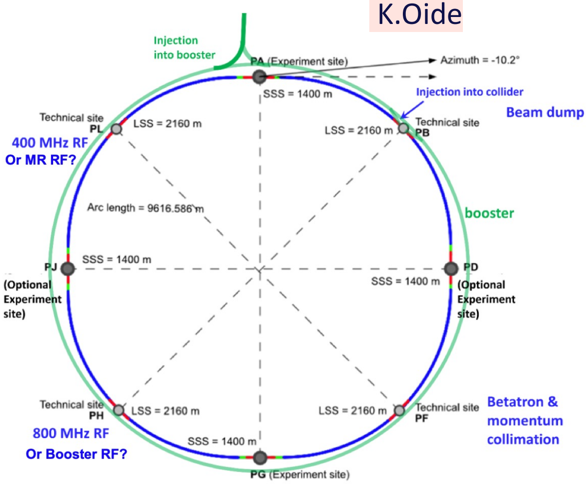
  + assembly
- Progress on the **backgrounds** studies:
  - **beam losses** in the MDI: collimation scheme and first loss maps
  - **synchrotron radiation** in the MDI: SR collimators and SR source on the MDI
  - **Detector backgrounds**: primary beam losses and photons tracked with Key4HEP on CLD
- **Beamstrahlung** Photons dump:
  - optimal location at around 400-500 m from IP, impact on the civil engineering addressed
  - characterization of the BS & radiation studies

Optimized placement and 4IPs Layout – Accelerator Design Status

- New ~90 km circumference placement with 8 access points
- Layout with 4IPs that is consistent with upgrade to FCC-hh
- Optimizing allocation of straight sections
- New FCC-ee optics to optimize beam-beam
- 400 MHz and 800 MHz RF systems
- Tunnel integration studies for RF and Arc sections
- Full energy booster that will fit in FCC tunnel for top-up injection
- e+/e- injector to fill booster



J.Gutleber, K.Oide



Parameters (19 Jan 2023)

FUTURE CIRCULAR COLLIDER

Table 1: FCC-ee collider parameters as of Jan. 19, 2023

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-3.0			
# of IPs		4			
Circumference	[km]	90.658816			
Bending radius of arc dipole	[km]	9.936			
Energy loss / turn	[GeV]	0.0394	0.370	1.89	10.1
SR power / beam	[MW]	50			
Beam current	[mA]	1270	134	26.7	4.94
Bunches / beam		9200	688	260	40
Bunch population	[10^{11}]	2.60	3.68	2.04	2.33
Horizontal emittance ε_x	[nm]	0.71	2.16	0.67	1.55
Vertical emittance ε_y	[pm]	1.42	4.32	1.34	3.10
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.6		7.34	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.565 / 53.595		100.556 / 98.590	
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.143	0.069 / 0.176	0.103 / 0.179	0.157 / 0.220
Bunch length (SR/BS) σ_z	[mm]	4.37 / 15.9	3.55 / 9.09	3.34 / 5.78	1.89 / 2.66
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.1 / 0	2.1 / 9.4
Harmonic number for 400 MHz		121200			
RF freuqeuncy (400 MHz)	MHz	400.786684			
Synchrotron tune Q_s		0.0370	0.0800	0.0327	0.0881
Long. damping time	[turns]	1158	215	63.8	18.3
RF acceptance	[%]	1.6	3.3	1.9	3.1
Energy acceptance (DA)	[%]	±0.8	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y[a]		0.0023 / 0.139	0.011 / 0.139	0.014 / 0.126	0.093 / 0.136
Luminosity / IP	[10^{34}/cm^{2}s]	186	21.4	6.94	1.20
Lifetime (q + BS + lattice)	[sec]	1120	–	< 1660	< 4170
Lifetime (lum)[b]	[sec]	980	960	620	750

[a]incl. hourglass.
[b]only the energy acceptance is taken into account for the cross section

K. Oide, Jan. 19, 2023 6

Layout in the Interaction Region

Both IPs of FCC-ee and FCC-hh now completely overlap.

- The IP transversely deviates from the layout line by about 10.5 m outward.
  Beams always enter the IP from inside of the ring.

- The **placement of the booster** has not been perfectly determined yet.
  The booster must be at least 8 m from the IP, to bypass the detector

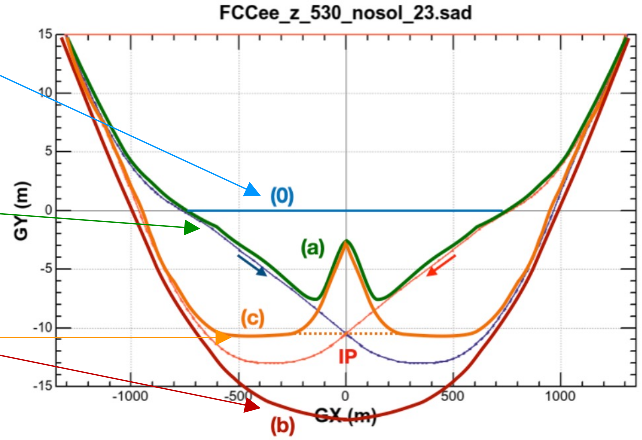
(0) Layout line

Possibilities for location of booster

(a) stay inside of the inner collider ring with a bypass chicane within about ±200 m of the IP.

(b) going outside of the detector

(c) follow the FCC-hh beam line with a bypass chicane.



The choice depends on the size of the tunnel, synchrotron radiation toward the detector

A side issue: Position of the booster ring

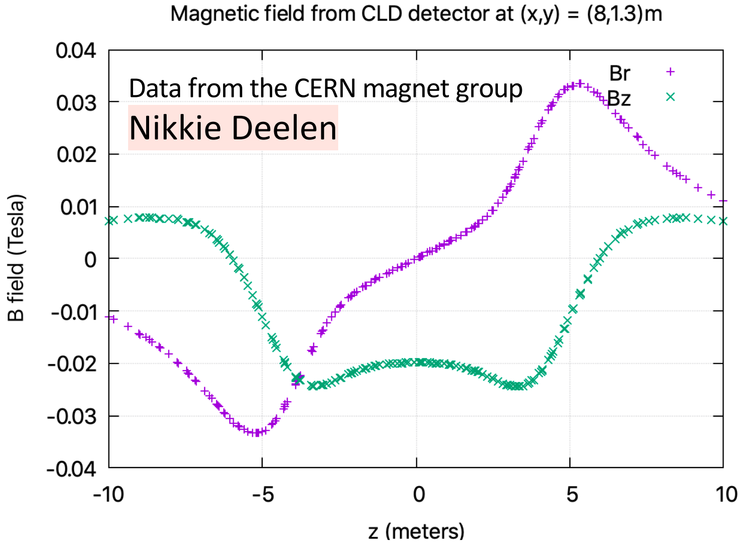
more details by M. Dam

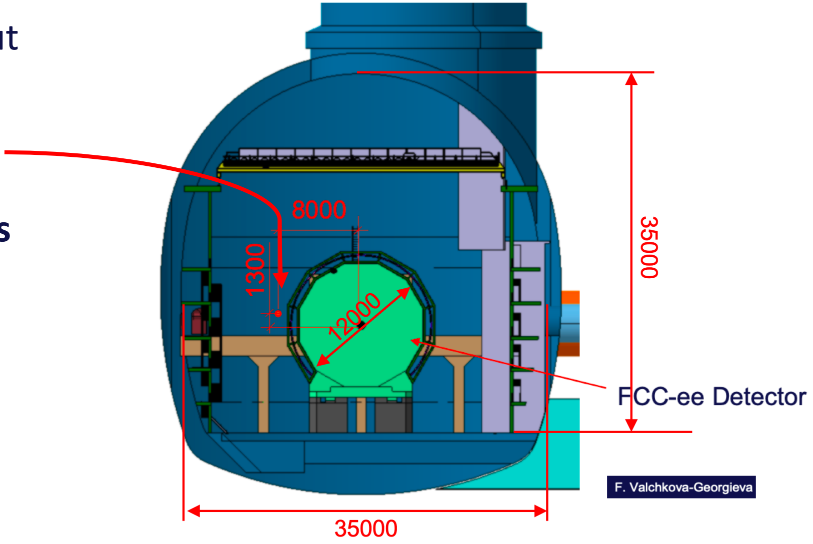
Booster position may have consequences on the tunnel layout around the IP

For this study, booster ring passes through cavern outside detector volume at [x, y]= [8.0, 1.3]m

Detector stray field at the booster location is up to ten times stronger than the 3 mT dipole field strength at injection

- Needs to be corrected for

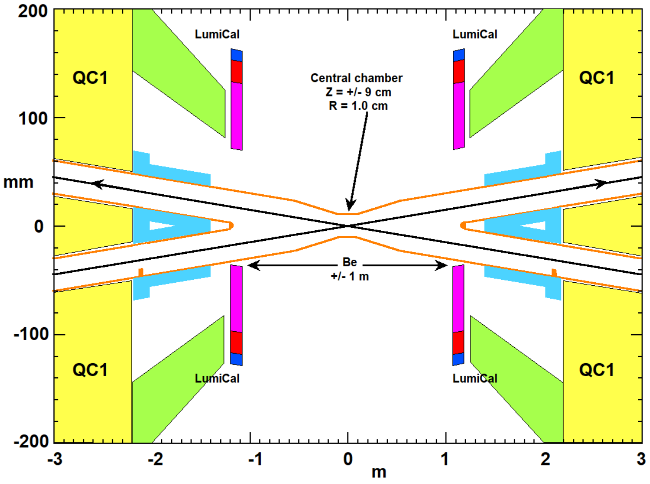




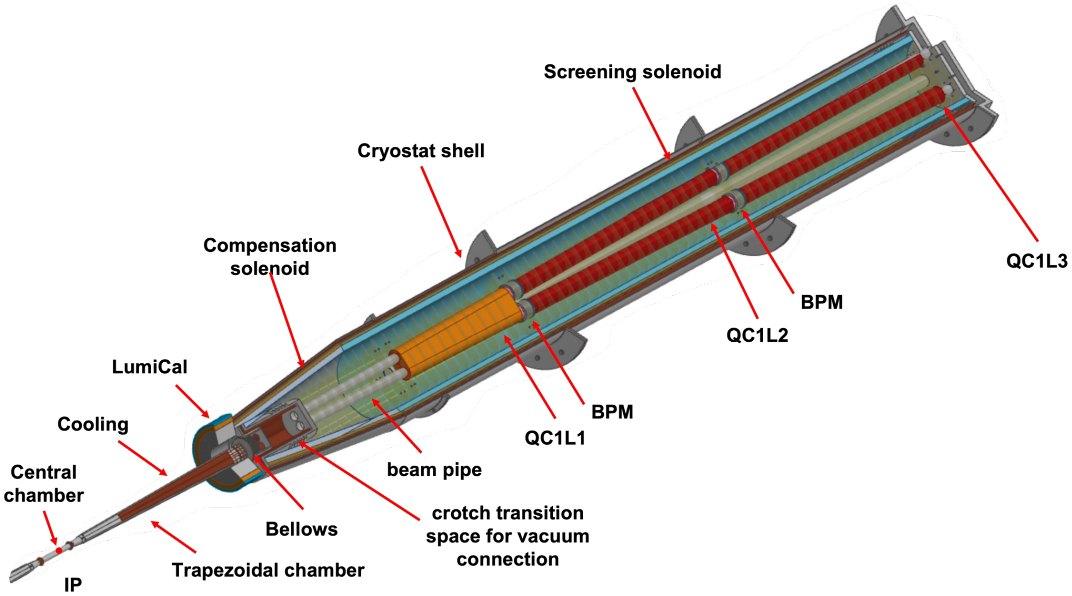
A solution for shielding and/or correction has to be developed

- The booster location must be such that there is at least 1 m free space around the detector envelope with the shielding/compensation in place
- The shielding/compensation must not sizeably affect the magnetic field of the detector.

FCC-ee Interaction Region



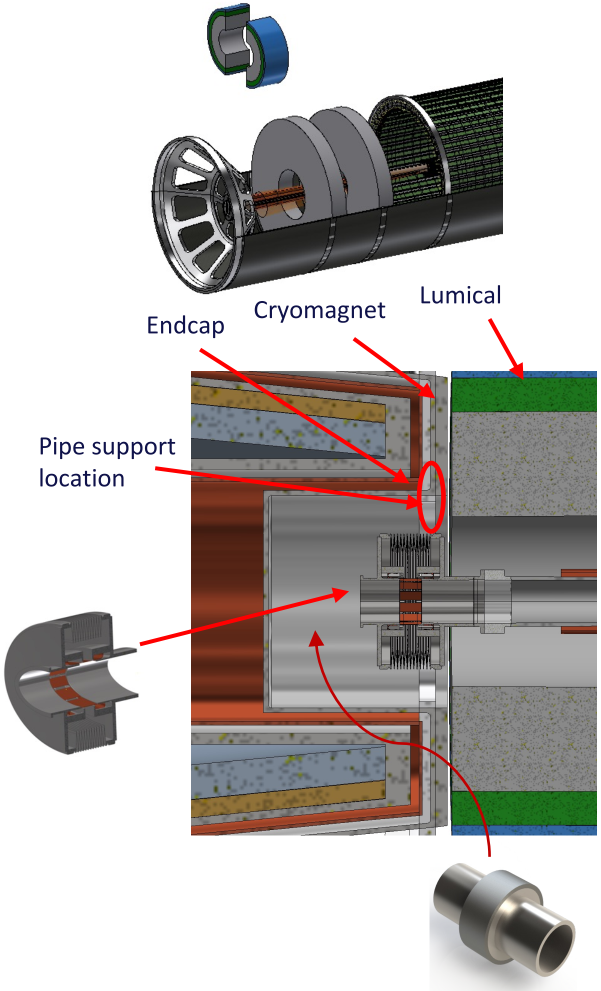
FCC-ee IR layout. The face of the first final focus quadrupole QC1, and the free length from the IP, L*, is 2.2 m. The 10 mm central radius is foreseen for ± 9 cm from the IP, and the two symmetric beam pipes with radius of 15 mm are merged at 1.2 m from the IP.



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

This will be inside the detector, being the half-length of the detector almost 6 m and the end QC1 at about 8.4 m.

Follow-up from MDI October workshop (link): some open questions on the mechanical design



Lumical

- Can we avoid the splitting of the lumical in two halves for the assembly?

Bellows

- Bellows cannot be attached to LumiCal and it will also support the beam pipe.
- Interference with magnet

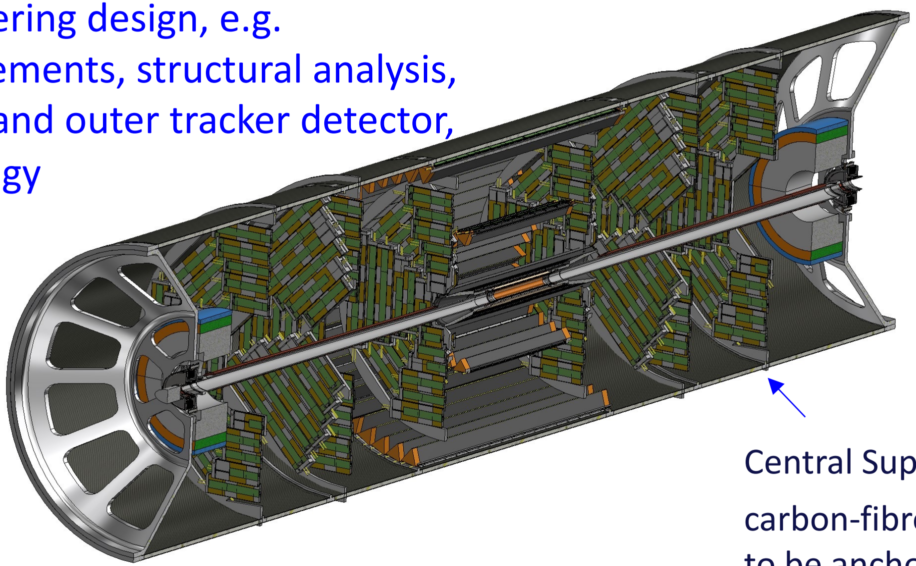
Remote Flange for the Vacuum Connection

- Special shape memory alloy couplers should be studied with the remote connection and compared with the solution developed by DESY for SuperKEKB

MDI central region $\pm$1.5 m from the IP

more details by
F. Fransesini, F. Bedeschi

Progress with the engineering design, e.g.
details of the different elements, structural analysis,
integration of the vertex and outer tracker detector,
supports, assembly strategy



Central Support tube with endcaps

carbon-fibre lightweight rigid structure,
to be anchored to the detector

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

Once the structure is assembled it is slided inside the rest of the detector

Collimation studies & IR loss maps

- Using newly-developed simulation tools to study collimation for the FCC-ee

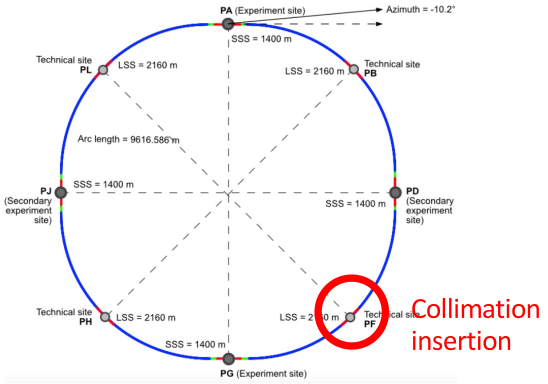
pyAT, Xtrack — Particle tracking

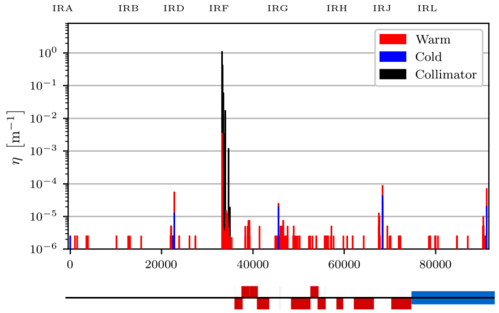
BDSIM — Collimator interactions

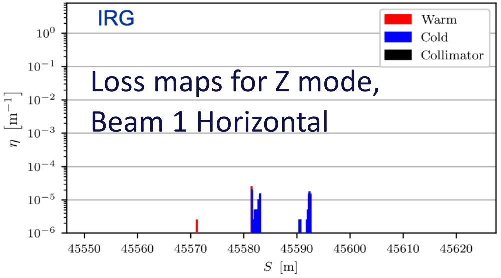
Particle transfer at every collimator pass

- First collimation scheme
- Currently focussing on beam halo losses with a workflow similar to LHC studies

- Various beam loss scenarios are being considered →
- → The beam loss maps are used to evaluate the impact to the detector using Key4HEP





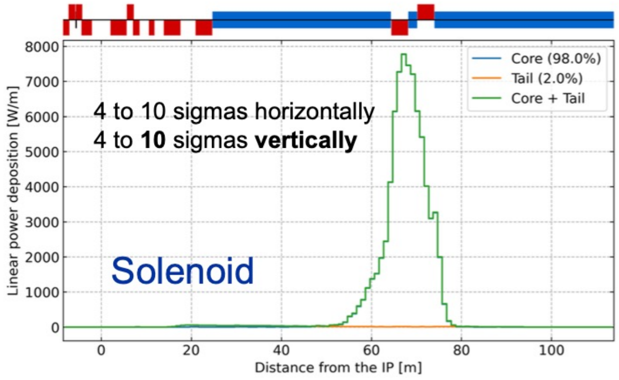


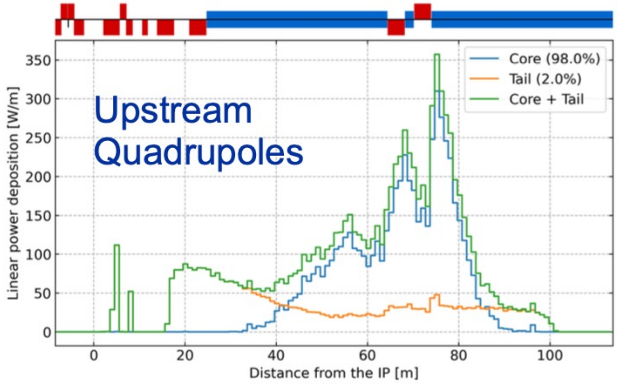
Synchrotron Radiation backgrounds

- Interaction region lattices for the 4 operation modes implemented in BDSIM
- Dipole, solenoid and quadrupole radiation evaluated
- Radiation from last bend reaches the IP
- SR photons from solenoid do not hit near the IP
- SR from FF quadrupoles leads to losses near the IP, in particular when beam tails are considered

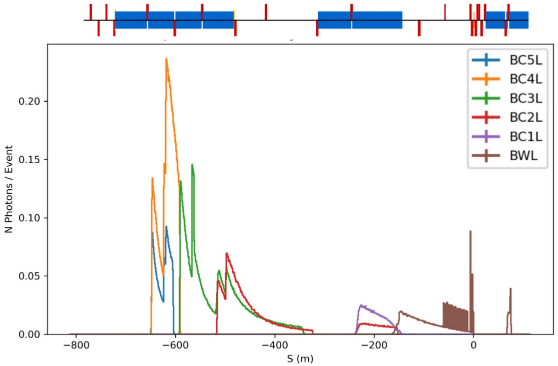
- injection backgrounds simulations with study of the SR produced by the injected beam, possibly impacting the detector ->

giving the constraints to the injection scheme





SR from beam tails in quads and solenoid for Z



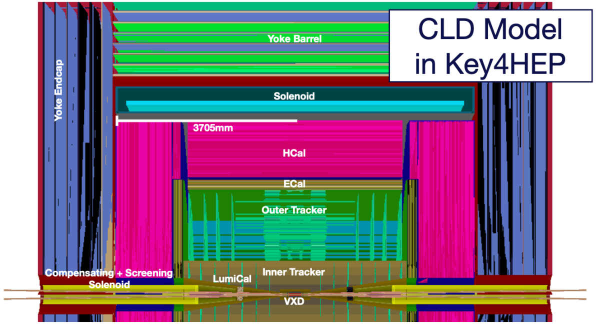
SR from dipoles

Photons tracks impacting the beam pipe are tracked with Key4HEP into the CLD detector, to evaluate occupancy

Detector Backgrounds

- CLD detector and MDI model in Geant4 adapted to 10 mm beampipe
- Solenoid field map imported in key4hep
- Collision products, beam, and photon losses are now studied

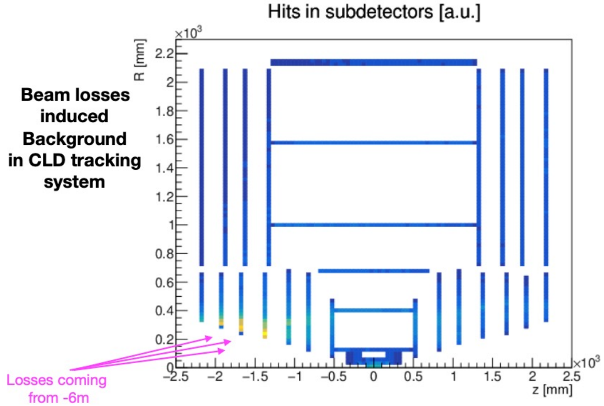
- Occupancy from incoherent pair production tolerable
- Occupancy from beam halo losses only concerning at ttbar, for beam loss scenarios considered until now



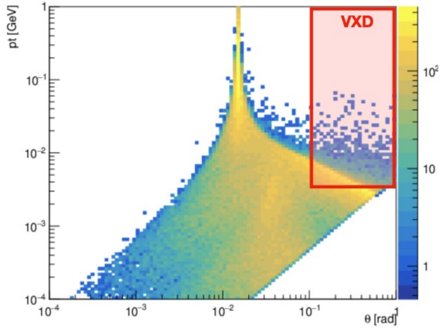
CLD Model in Key4HEP

	Z	WW	ZH	Top
Pairs/BX	1300	1800	2700	3300
Max occup. VXDB	70e-6	280e-6	410e-6	1150e-6
Max occup. VXDE	22.5e-6	95e-6	140e-6	220e-6
Max occup. TRKB	9e-6	20e-6	38e-6	40e-6
Max occup. TRKE	110e-6	150e-6	230e-6	290e-6

Beam losses induced Background in CLD tracking system



- Preliminary studies show little quench risk for the FF quads due to halo losses.
- Preliminary studies show photon losses absorbed or deflected by mask

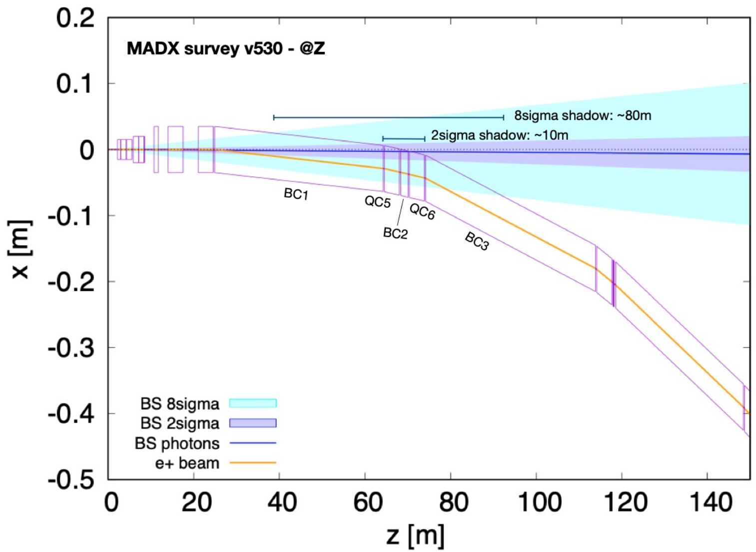


Incoherent pair creation

Beamstrahlung Photon Dump

Radiation from the colliding beams is very intense 370 kW at Z

Synchrotron Radiation from the fringe solenoid and anti-solenoid is ~ 77 kW



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

GuineaPig++

A. Ciarma

This BS radiation exits the vacuum chamber around the first bending magnet BC1 downstream the IP

Next MDI meeting 6 February: https://indico.cern.ch/event/1241377/
the study on the magnets aperture for the extraction of the BS radiation will be presented

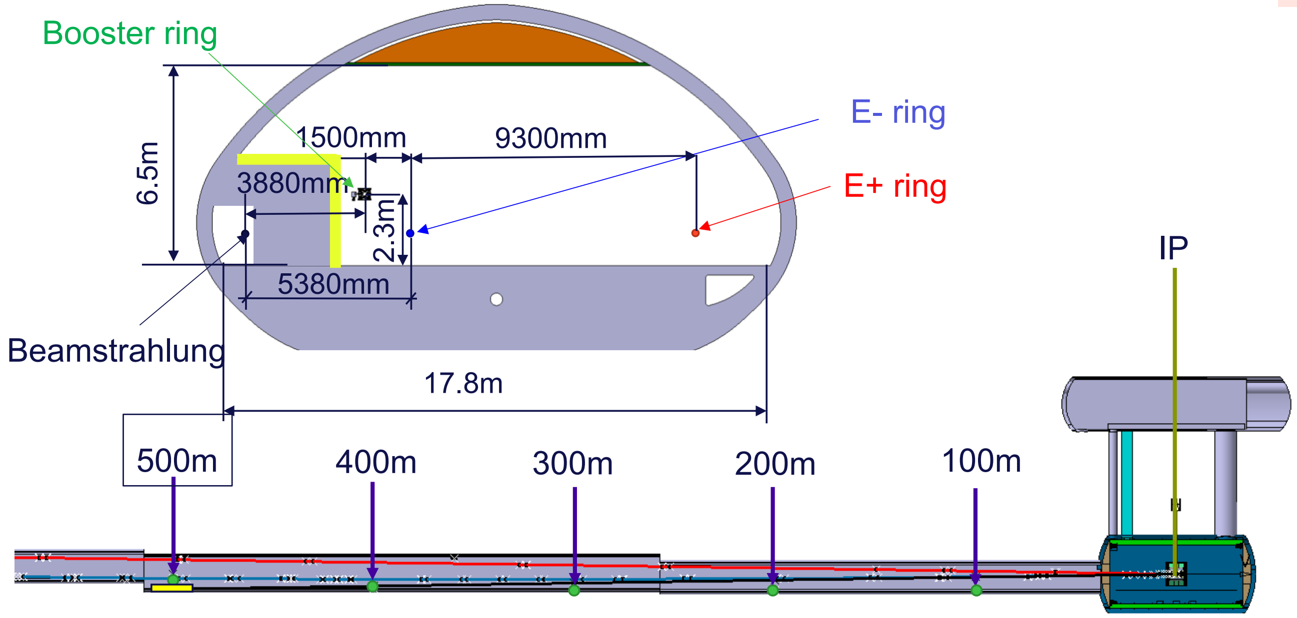
High-power beam dump needed to dispose of these BS photons + all the radiation from IP

- Dump absorber material non defined yet, liquid lead is a possibility
- Shielding needed for equipment and personnel protection

Handling of Beamstrahlung

Fani Valchkova:
link talk MDI Oct. workshop

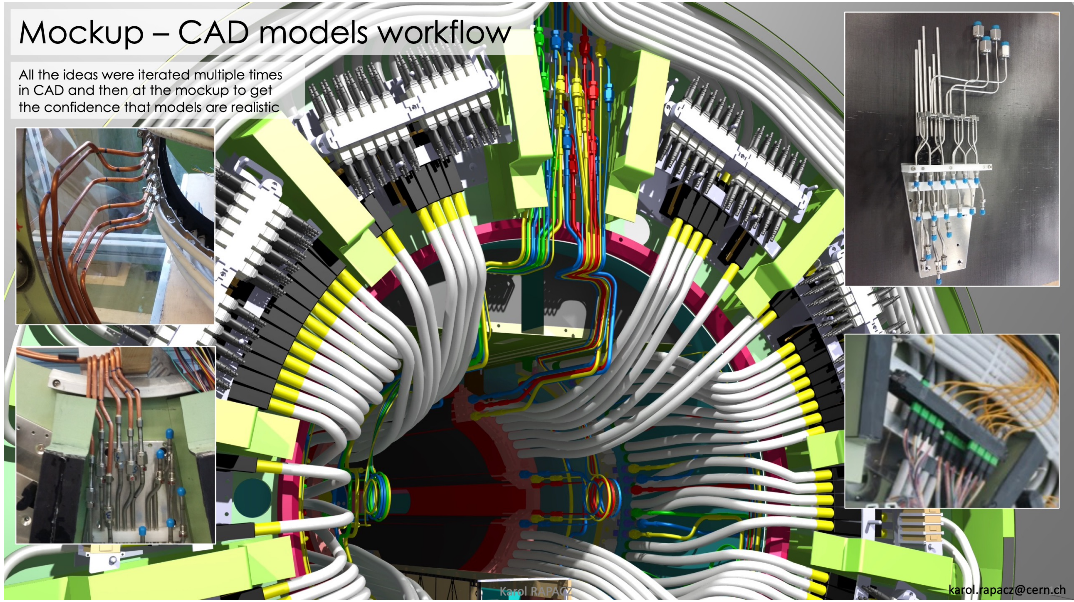
FCC-ee beamstrahlung dump integration at point A



Integration in the tunnel:
External dump @400/500m from IP preferrable option

IR Mock-up

- We propose to add to the CAD model of the MDI a **complementary R&D activity consisting in a full-scale IR mock-up to be realised at Frascati**. We need to conclude with FCC addendum.
- It will allow to test technological solutions with prototypes and to address the main issues related to the assembly.
- The IR mock-up will eventually be available for further studies on stability, alignment and vibrations, to be conducted by other interested international partners.



Example of CMS IR mock-up, tomorrow A. Gaddi

IR magnet system

- **Progress on the overall IR magnets design including solenoids and correctors is essential to progress with the overall mechanical design, integration and assembly of the MDI.**

- Review April 2022 on IR magnets design with cryostat, challenges identified - tapering, corrector design, accessibility and serviceability- **we need to move to the next level of the design.** There are pending details on the mechanical support, cryogenics, thermal heat loads, alignment, services which need resourcing to move forward.
- TE Magnet group identified two main work packages as potential collaboration to be discussed with FCC.
  - IR final focus magnets with solenoids, interest of BNL to collaborate, collaboration CERN-BNL under discussion.
  - Crab high field sextupole on FCC-ee are under evaluation for conduction cooled options, optics sensitivity requested and magnetic design. Resourcing subject to pending collaboration with TE.

Conclusion

The MDI study has made great progress in many areas, mechanical model, backgrounds study, beamstrahlung dump. More will come in the next months.

For the mid-term review we aim at developing a

- feasible MDI design that includes a sustainable detector backgrounds rate
- cost estimate of the MDI

Join our MDI meetings ! https://indico.cern.ch/category/5665/