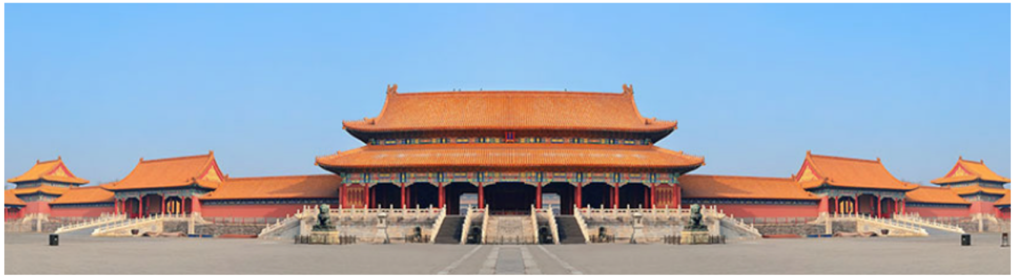


Overview of the FCC-ee Interaction Region Design

M. Boscolo (INFN-LNF)

for the MDI group

The 2019 International workshop on the high energy Circular Electron Positron Collider

IHEP, Beijin, China, 18-20 November 2019

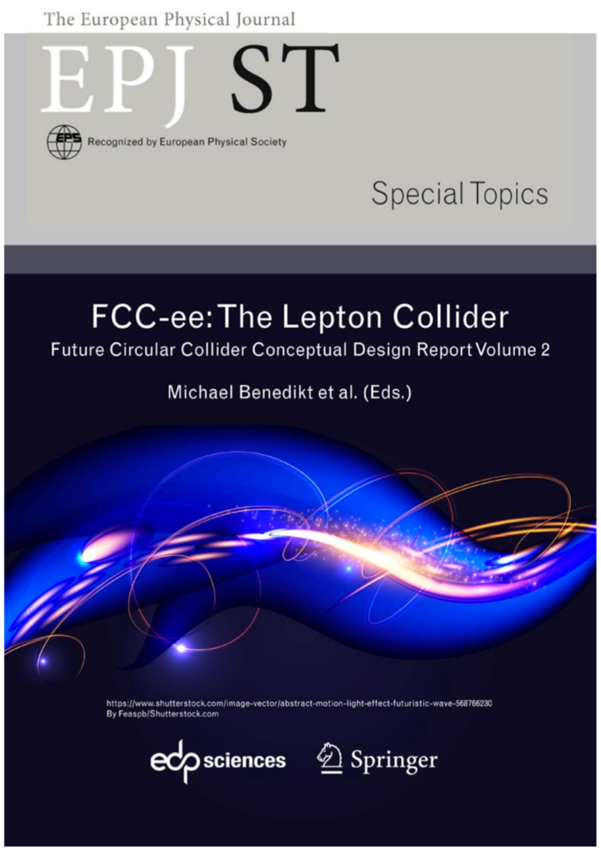
Outline

- MDI layout
- Mechanical design and integration
- Impact of a smaller central beampipe
  - Synchrotron Radiation
  - HOM
- IP backgrounds
- Beam backgrounds
- SR in the IR: characterization and mitigation
- Alignment, vibration and stabilisation
- Conclusion

Present status: CDR completed

[https://fcc-cdr.web.cern.ch/ - FCCEE](https://fcc-cdr.web.cern.ch/)

FCC-ee Conceptual Design Report



Eur. Phys. J. Special Topics **228**, 261–623 (2019)

https://doi.org/10.1140/epjst/e2019-900045-4

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Regular Article

FCC-ee: The Lepton Collider

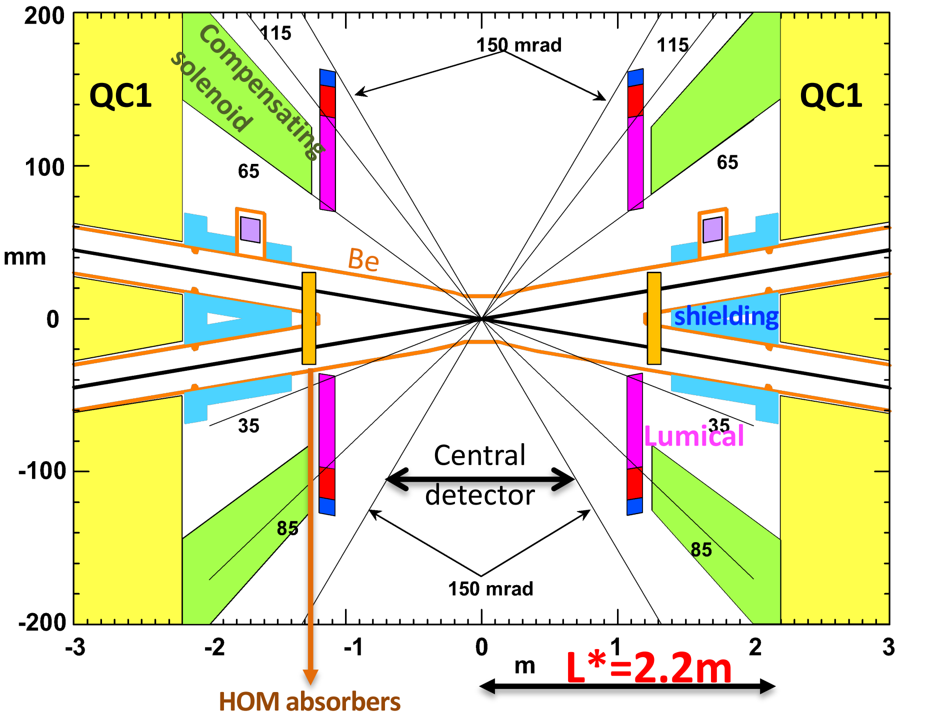
Future Circular Collider Conceptual Design Report Volume 2

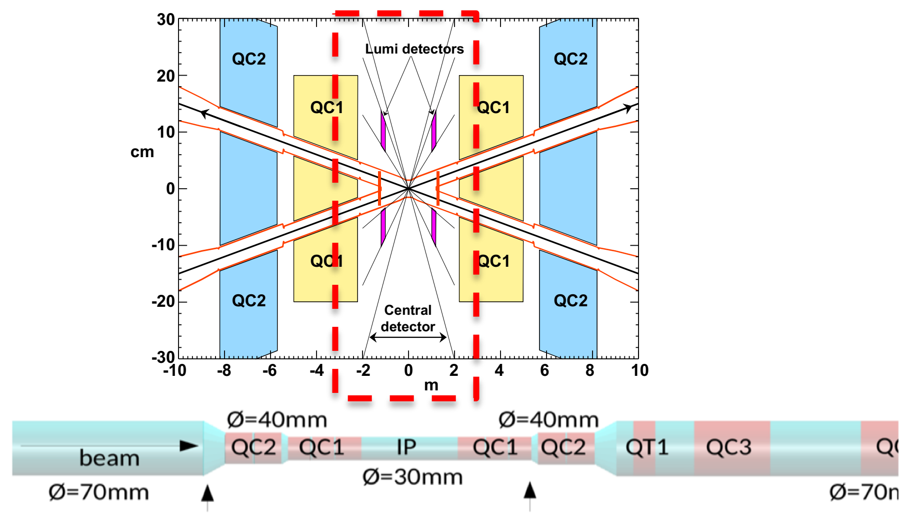
A. Abada[32], M. Abbrescia[117,257], S.S. AbdusSalam[218], I. Abdyukhanov[16], J. Abelleira Fernandez[142], A. Abramov[204], M. Aburaia[284], A.O. Acar[238], P.R. Adzic[287], P. Agrawal[79], J.A. Aguilar-Saavedra[46], J.J. Aguilera-Verdugo[106], M. Aiba[191], I. Aichinger[64], G. Aielli[134,272], A. Akay[238], A. Akhundov[45], H. Aksakal[145], J.L. Albacete[46], S. Albergo[120,260], A. Alekou[311], M. Aleksa[64], R. Aleksan[39], R.M. Alemany Fernandez[64], Y. Alexahin[70], R.G. Alía[64], S. Alioli[126], N. Alipour Tehrani[64], B.C. Allanach[298], P.P. Allport[290], M. Altınlı[112,62], W. Altmannshofer[297], G. Ambrosio[70], D. Amorim[64], O. Amstutz[161], L. Anderlini[123,262], A. Andreazza[127,266], M. Andreini[64], A. Andriatis[167], C. Andris[165], A. Andronic[344], M. Angelucci[115], F. Antinori[129,267], S.A. Antipov[64], M. Antonelli[115], M. Antonello[127,264], P. Antonioli[118], S. Antusch[286], F. Anulli[133,271], L. Apolinário[158], G. Apollinari[70], A. Apollonio[64], D. Appelö[350], R.B. Appleby[311,301], A. Apyan[70], A. Apyan[1], [illegible] A. Arbuzov[17], G. Arduini[64], V. Arı[9], S. Arias[66,309], [illegible] R. Arnaldi[136,274], S.A. Arsenyev[64], M. Arzeo[64], [illegible] E. Aslanides[31], R.W. Aßmann[49], D. Astapovych[228], [illegible] S. Atieh[64], D. [illegible] B. Auchmann[64], A. Audurier[119,259], [illegible] S. Aumon[64], [illegible] G. Avrillaud[83], [illegible] O. Azzolini[116], [illegible] N. Bacchetta[129,267], [illegible] Bacchiocchi[266], H. Bachacou[39], [illegible] S. Baird[64], M.J. Baker[333], M.J. Baldwin[167], A.H. Ball[64], [illegible] S. Banerjee[54], D.P. Barber[49,316], D. Barducci[214,137], [illegible] G.G. Barnaföldi[172], M.J. Barnes[64], A. Barr[190], [illegible] J. Barreiro Guimarães da Costa[97], W. Bartmann[64], [illegible] Baryshevsky[95], E. Barzi[70], S.A. Bass[53], A. Bastianin[266], B. Baudouy[39], F. Bauer[39], M. Bauer[54], T. Baumgartner[232], I. Bautista-Guzmán[15], C. Bayındır[82,19], F. Beaudette[32], F. Bedeschi[132,215], M. Béguin[64], I. Bellafont[6], L. Bellagamba[118,258], N. Bellegarde[64], E. Belli[133,271,208], E. Bellingeri[43], F. Bellini[64], G. Bellomo[127,266], S. Belomestnykh[70], G. Bencivenni[115], M. Benedikt[64,a], G. Bernardi[32], J. Bernardi[232], C. Bernet[32,335], J.M. Bernhardt[3], C. Bernini[43], C. Berriaud[39], A. Bertarelli[64], S. Bertolucci[118,258], M.I. Besana[191], M. Besançon[39], O. Beznosov[316], P. Bhat[70], C. Bhat[70], M.E. Biagini[115], J.-L. Biarrotte[32], A. Bibet Chevalier[27], E.R. Bielert[304], M. Biglietti[135,273], G.M. Bilei[131,270], B. Bilki[305], C. Biscari[6], F. Bishara[49,190], O.R. Blanco-García[115], F.R. Blánquez[64], F. Blekman[340], A. Blondel[303], J. Blümlein[49], T. Boccali[132,215], R. Boels[84], S.A. Bogacz[237], A. Bogomyagkov[23], O. Boine-Frankenheim[228], M.J. Boland[321], S. Bologna[291], O. Bolukbasi[112], M. Bomben[32], S. Bondarenko[17], M. Bonvini[133,271], E. Boos[221], B. Bordini[64], F. Bordry[64], G. Borghello[64,275], L. Borgonovi[118,258], S. Borowka[64], D. Bortoletto[190], D. Boscherini[118,258], M. Boscolo[115], S. Boselli[130,269], R.R. Bosley[290], F. Bossu[32], C. Botta[64], L. Bottura[64], R. Boughezal[11], D. Boutin[39], G. Bovone[43], I. Božović Jelisavčić[339], A. Bozbey[238], C. Bozzi[122,261], D. Bozzini[64], V. Braccini[43], S. Braibant-Giacomelli[118,258], J. Bramante[200,193], P. Braun-Munzinger[77], J.A. Briffa[310], D. Britzger[169], S.J. Brodsky[225], J.J. Brooke[291], R. Bruce[64],

1364 contributors
from 351 institutes

Interaction Region Layout

2D-top view with expanded x-coordinate





1.5 cm radius z ± 12.5 cm

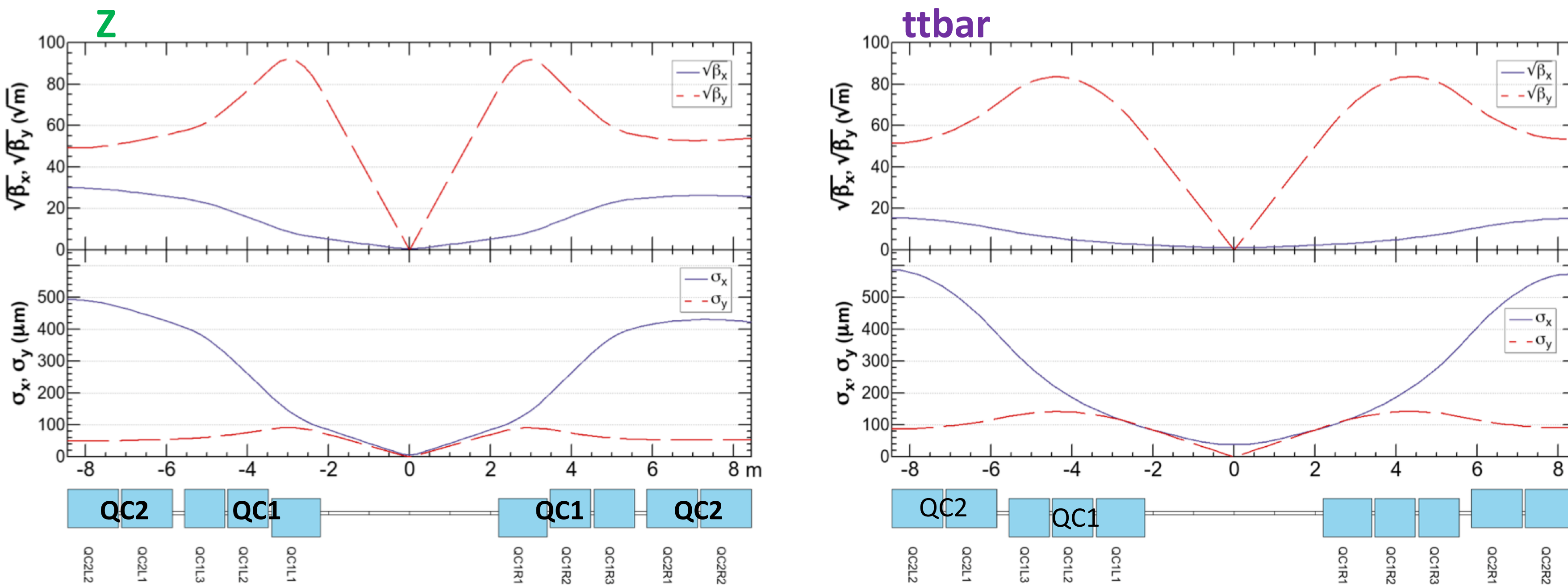
L* = 2.2 m distance from IP to first quadrupole

2 T detector

we considered a smaller central pipe:
1.0 cm for z ± 9 cm
(with taper starting at z ± 40 cm from IP)

Final Focus optics

		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



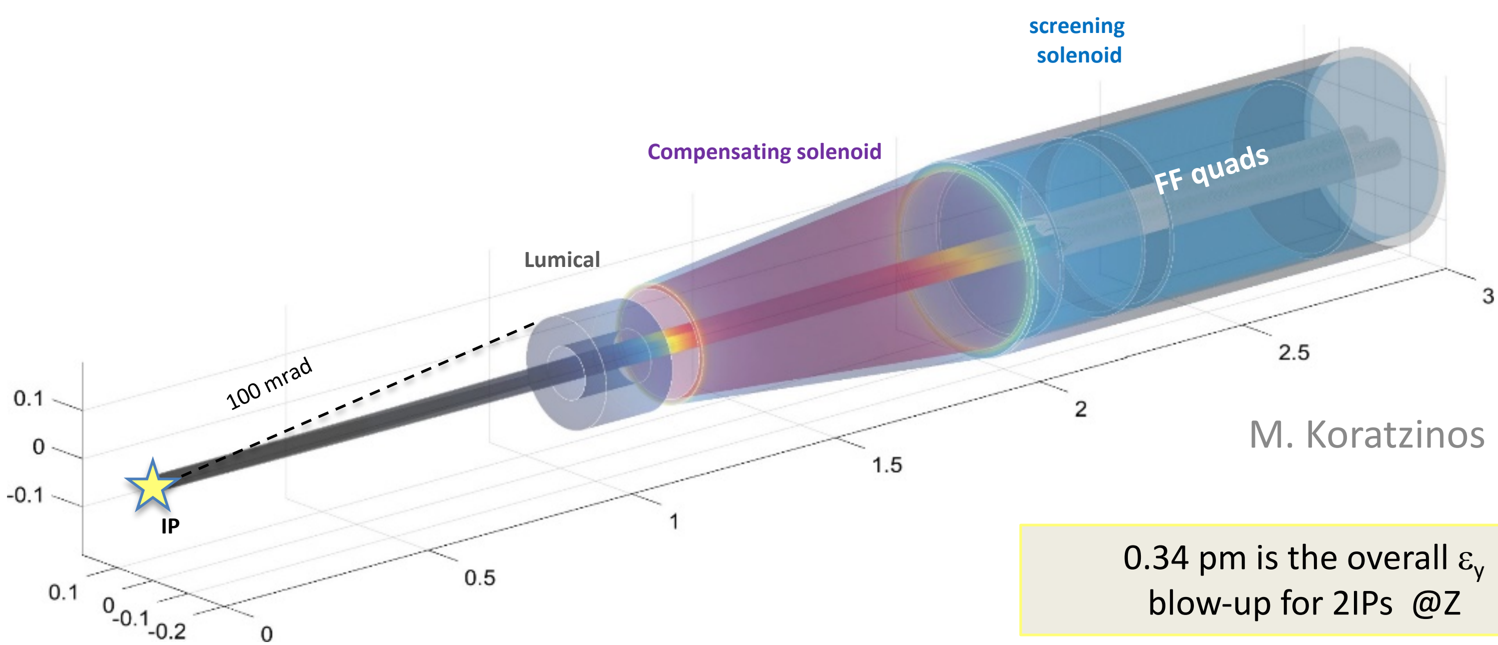
Only 1st slice of QC1 is defocusing horizontally **All 3 slices of QC1 are defocusing horizontally**

- Flexible optics design: final focus quadrupoles are longitudinally split into three slices
  At the Z chromaticity is reduced for the smaller β^*, smaller beam size

K. Oide

Baseline for FCC-ee Solenoid Compensation Scheme

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

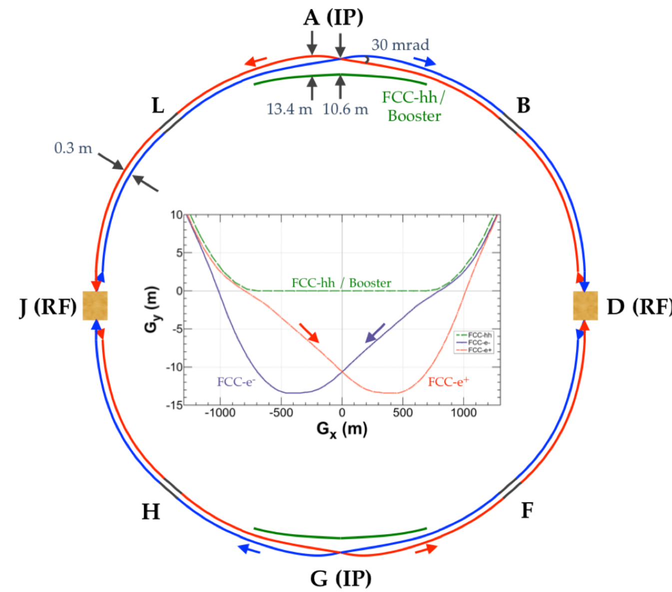


M. Koratzinos

0.34 pm is the overall ε_y blow-up for 2IPs @Z

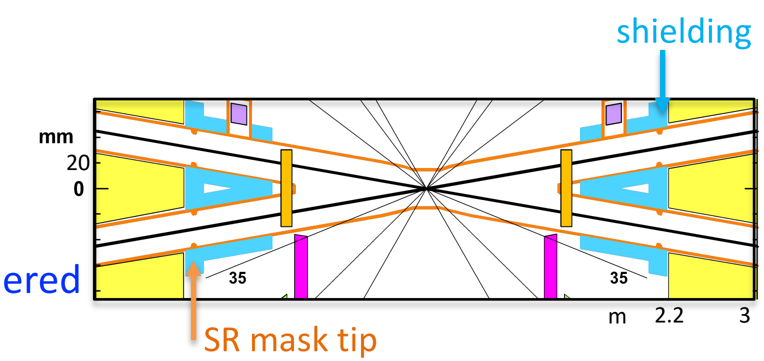
Key parameters

- **Double ring** e^+e^- collider ~**100 km** with constraint to follow the footprint of FCC-hh, except for around the IPs
- **2 IPs** with **crab-waist scheme->** large horizontal crossing angle: **30 mrad**
- **Flexible design:**
  - **common lattice for all energies,** except for a small rearrangement in the RF section



- Crab-waist has large impact in the design,

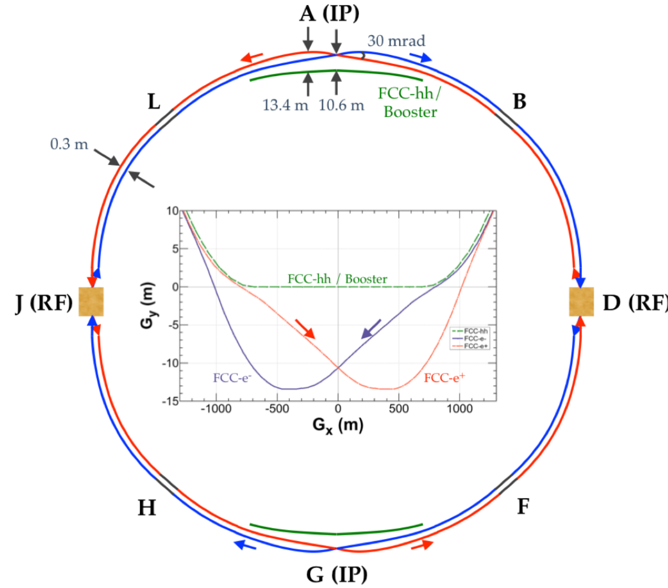
  for instance for the FCC infrastructure: separated tunnel +/- 1.3 km needed
- **Synchrotron radiation** (SR) at such high energies is one of the main drivers of the MDI design
  - Optics with asymmetric dipoles in the IR
  - SR mask tips to intercept SR photon fans
  - high-Z shielding (W) outside vacuum chamber
  - sawtooth ridged chamber inside FF quad being considered
  - absorbers and/or SR collimators



Key parameters

CDR phase:

- **Double ring** e^+e^- collider ~**100 km** with constraint to follow the footprint of FCC-hh, except for around the IPs
- **2 IPs** with **crab-waist scheme->** large horizontal crossing angle: **30 mrad**
- **Flexible design:**
  - **common lattice for all energies,** except for a small rearrangement in the RF section

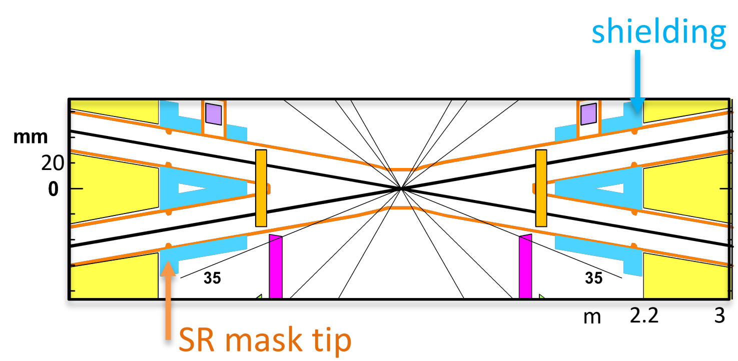


Presently:

- **FCC-hh is not a constraint**
- **4IPs** with crab-waist is under study

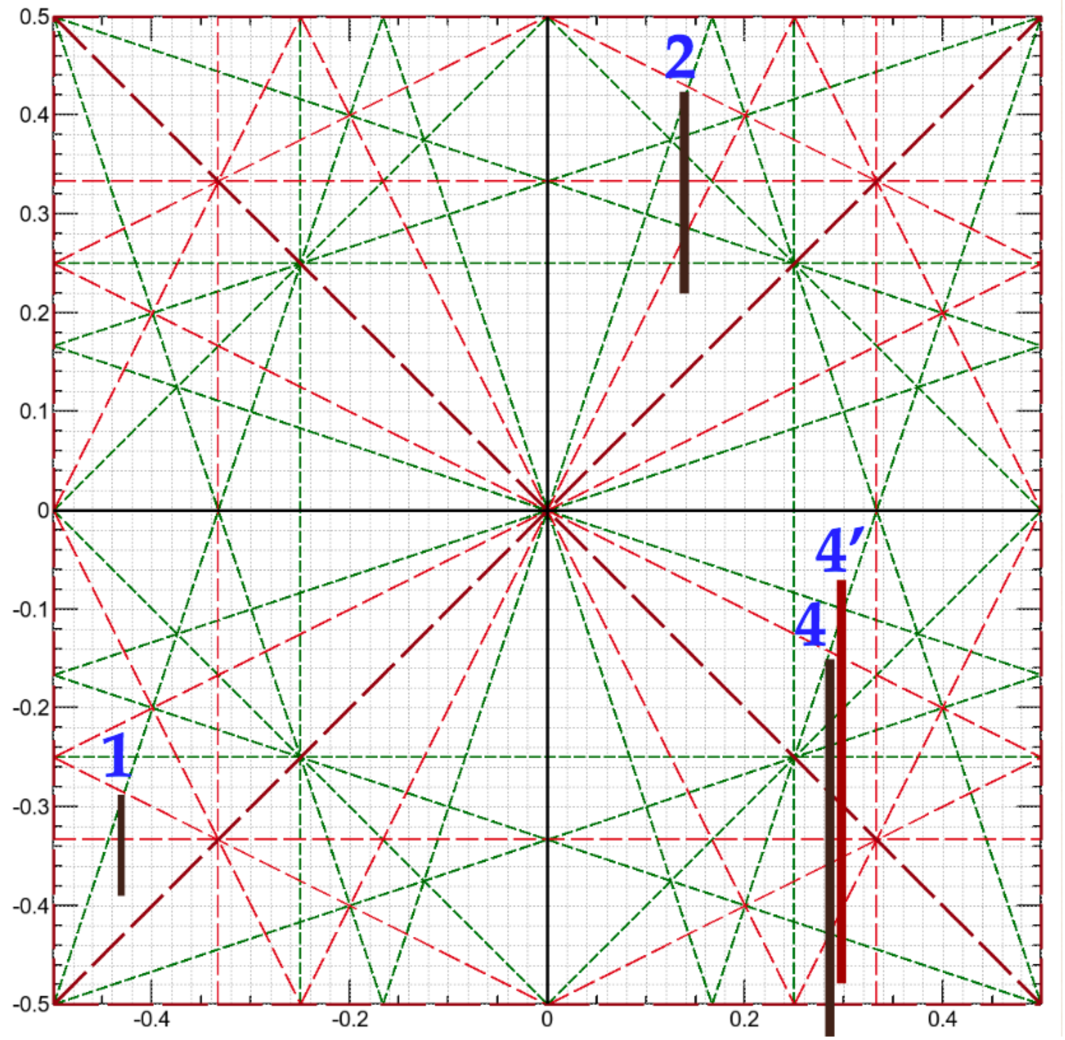
Progress in

- SR studies
- IP backgrounds
- Single beam backgrounds
- Mechanical design



Optics with 4 IPs

- Issues with the large tune footprint for 4 IPs
- If the periodicity is violated due to machine errors such as by β-beat and x-y couplings, the effective footprints become larger for 2 IP and even more for 4 IP.
- Some mitigation is possible (see 4' avoiding vertical tune ν_y = -0.5 resonance). Still many other resonances are crossed, the strength of which depends on the errors and corrections of the lattice.



Oide, Shatilov

- More studies are needed in order to understand the relevance of such an issue, especially looking at β-beats and x-y couplings as well as vertical emittance.
- **Too early to consider 4 IPs as baseline at this moment.**

FCC-ee parameters

CDR parameters

FCC-ee parameters		Z	W^+W^-	ZH	ttbar	
Beam energy	**GeV**	**45.6**	**80**	**120**	**175**	**182.5**
Luminosity / IP	**10^{34} cm^{-2} s^{-1}**	**230**	**28**	**8.5**	**1.8**	**1.55**
Beam current	mA	1390	147	29	6.4	5.4
Bunches per beam	#	16640	2000	328	59	48
Average bunch spacing	ns	19.6	163	994	2763	3396
Bunch population	10^{11}	1.7	1.5	1.8	2.2	2.3
Horizontal emittance ε_x Vertical emittance ε_y	nm pm	0.27 1.0	0.84 1.7	0.63 1.3	1.34 2.7	1.46 2.9
β_x^* / β_y^*	**m / mm**	**0.15 / 0.8**	**0.2 / 1.0**	**0.3 / 1.0**	**1.0 / 1.6**	
beam size at IP: σ_x^* / σ_y^*	**µm / nm**	**6.4 / 28**	13 / 41	13.7 / 36	36.7 / 66	38.2/68
Energy spread: SR / total (w BS)	%	0.038 / 0.132	0.066 / 0.131	0.099 / 0.165	0.144 / 0.196	0.15 / 0.192
Bunch length: SR / total	mm	3.5 / 12.1	3 / 6.0	3.15 / 5.3	2.75 / 3.82	1.97 / 2.54
Energy loss per turn	**GeV**	**0.036**	**0.34**	**1.72**	**7.8**	**9.2**
RF Voltage /station	GV	0.1	0.75	2.0	4/5.4	4/6.9
Longitudinal damping time	turns	1273	236	70.3	23.1	20.4
Acceptance RF / energy (DA)	%	1.9 / ±1.3	2.3 / ±1.3	2.3 / ±1.7	3.5/ (-2.8; +2.4)	3.36 / (-2.8; +2.4)
Rad. Bhabha/ actual Beamstr. Lifetime	min	68 / > 200	59 / >200	38 / 18	37/ 24	40 / 18
Beam-beam parameter ξ_x / ξ_y		0.004 / 0.133	0.01 / 0.141	0.016 / 0.118	0.088 / 0.148	0.099 / 0.126
Interaction region length	mm	0.42	0.85	0.9	1.8	1.8

MDI Design

We are trying to concentrate our efforts in 4 main areas:

- Beam physics (optics, beam dynamics, collective effects)
- Experimental environment, beam induced backgrounds & luminosity measurement
- Software for simulation tools
- Engineering (mechanical, magnets, diagnostics, vacuum, cooling, ...)

- Input and strong collaboration from all areas of expertize are crucial to optimize the promising studies presented in the CDR and proceed to the next steps.

- Our goal is to have a feasible and well engineered design that meets the requirements of optics, beam dynamics and high current, foresees tolerable radiation and meets as well the mechanical requirements in terms of integration, stability, assembly.

IR and its mechanical interface with detector

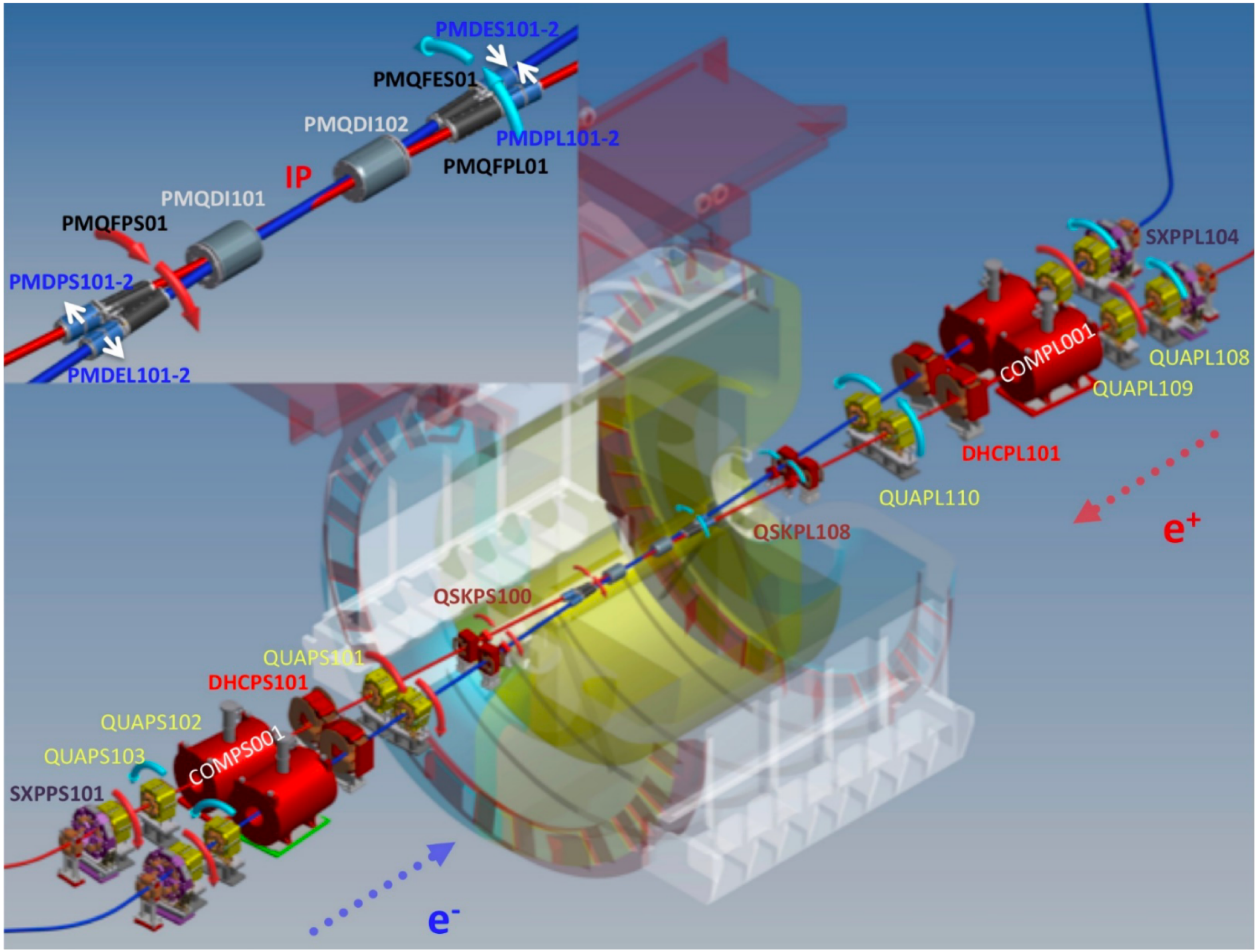
We have been discussing two approaches:

1. Confine all IR and detector elements (with their services) within a certain radius from the beamline in a mechanically compact **cylinder** whose connections in Z are accessible outside the detector (DAΦNE for example)

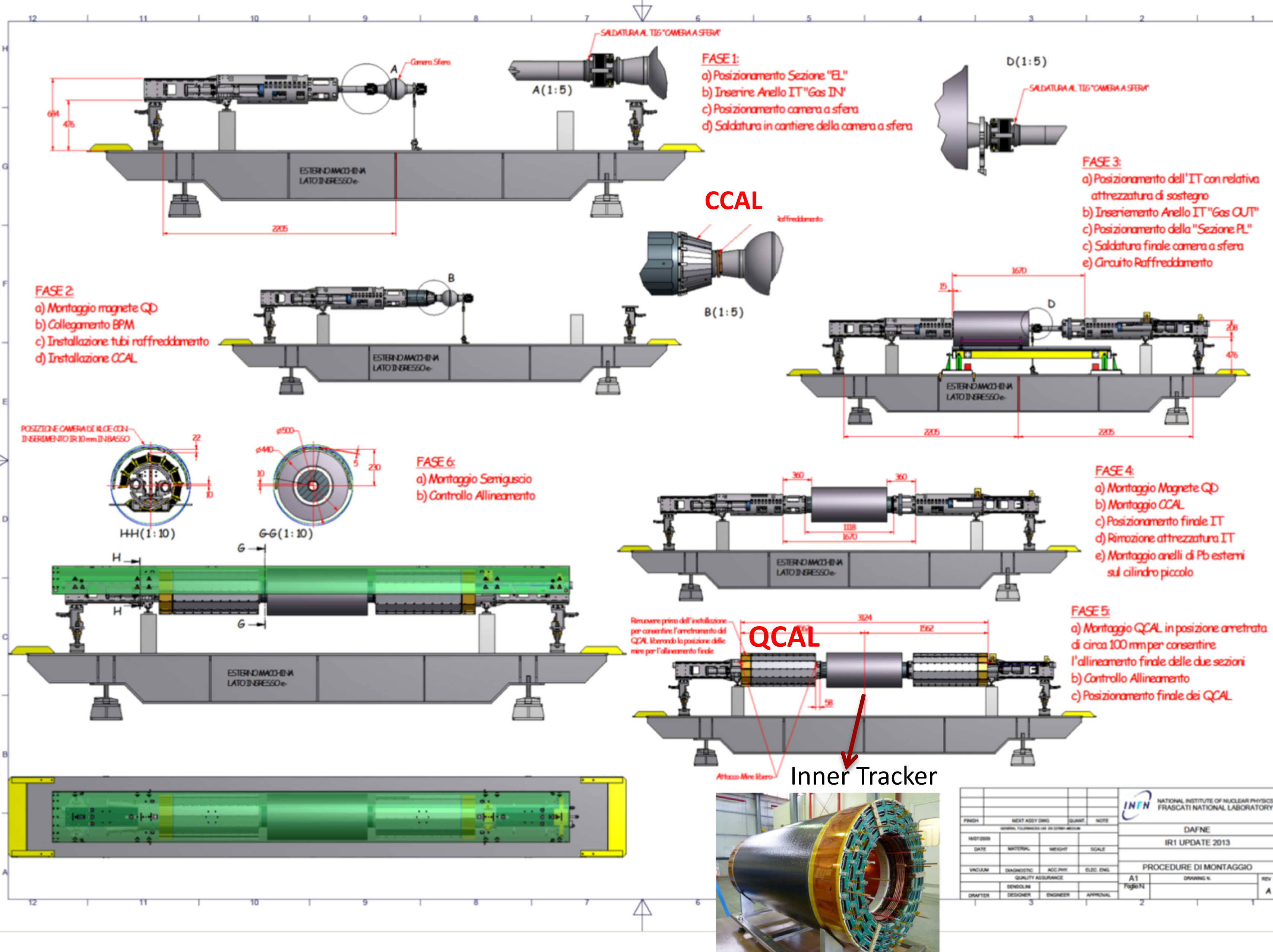
2. Confine the IR elements in a **conical** structure supported at each end separately and move them in from both sides with remote controlled flanges (KEKB for example)

- From a detector point of view both cases should be analyzed starting from a 3D drawing of the IR region combined with the detector.
- Choice should be driven by optimizing accessibility, ease of installation, sufficient space for services (cables, cooling etc.) mechanical stability and maintenance issues
- From the detector point of view it seems attractive to be mechanically independent from machine elements (quenching, heating, vibration of cryostat etc.). Feasible ?

DAFNE IR with KLOE: MDI magnetic elements

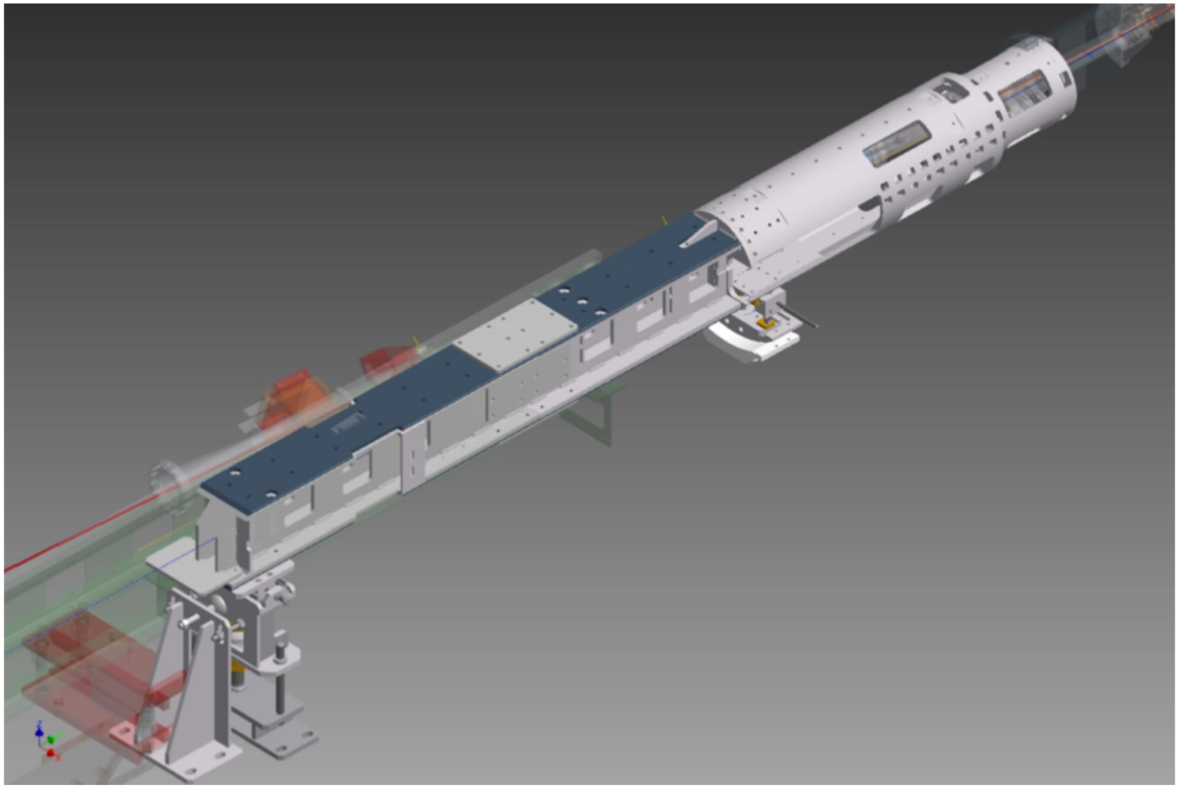


DAFNE Interaction Region offline assembly

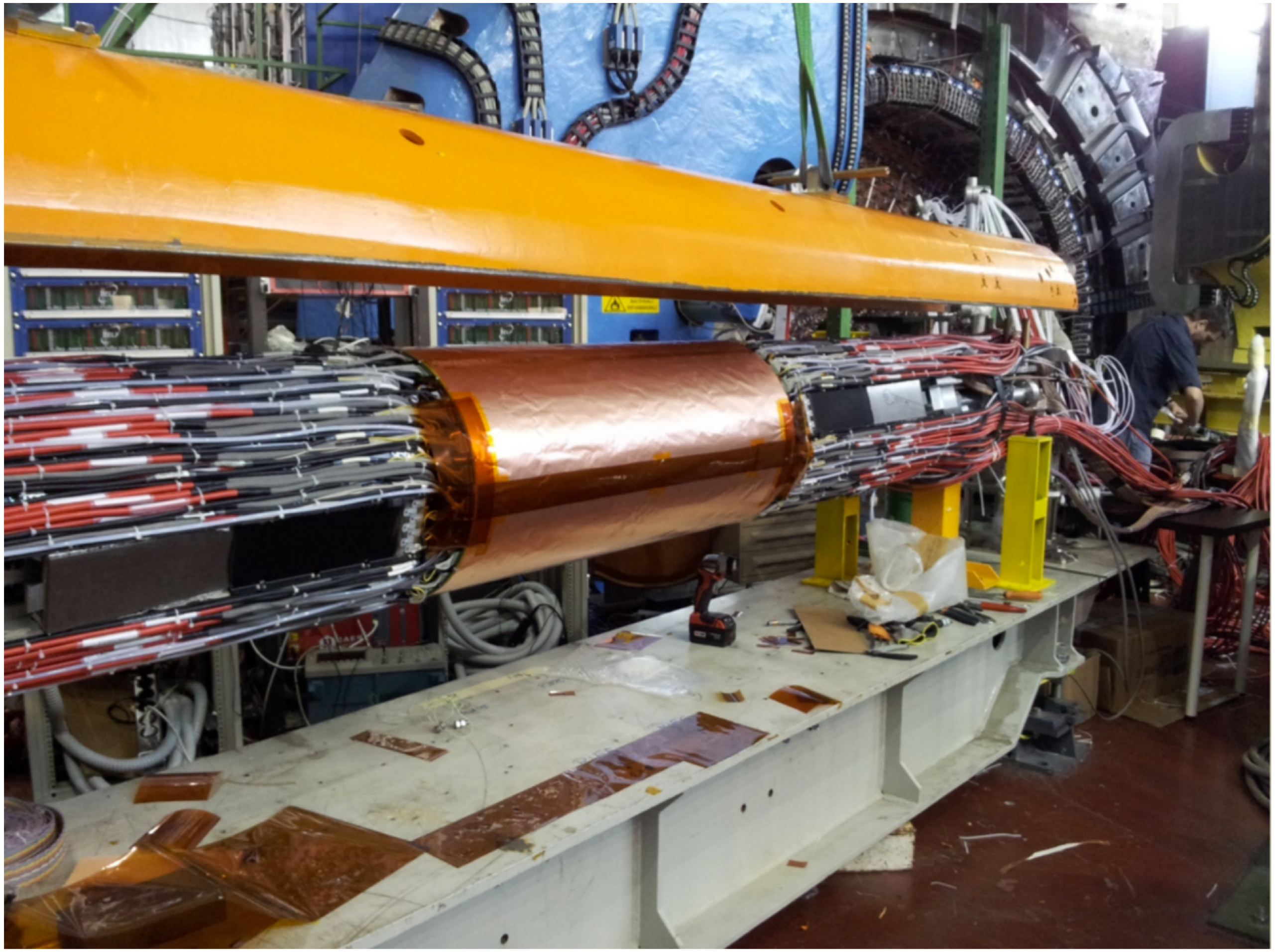


Inner Tracker

DAFNE IR support half 1

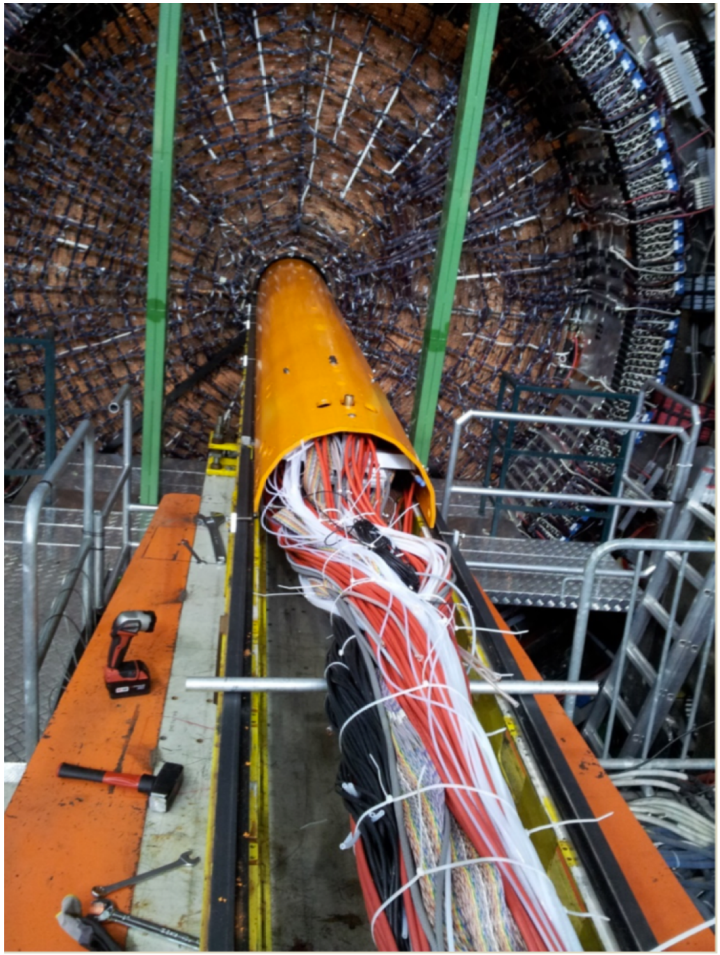


Mounting of the half shell into the DAFNE IR assembly

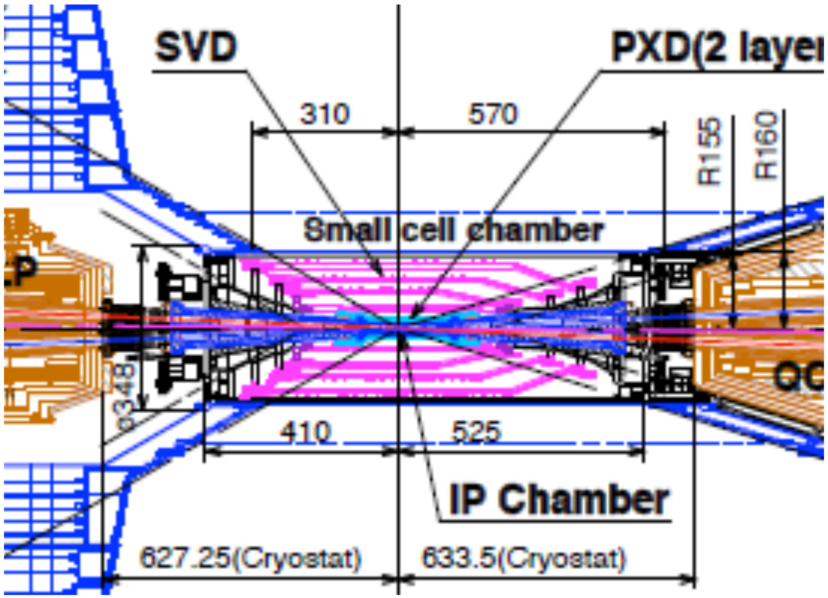


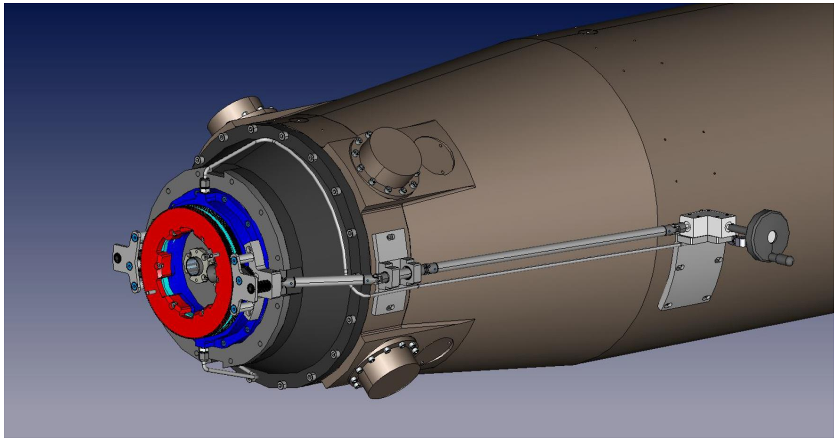
DAFNE IR assembly ready to be inserted

DAFNE IR: during the insertion



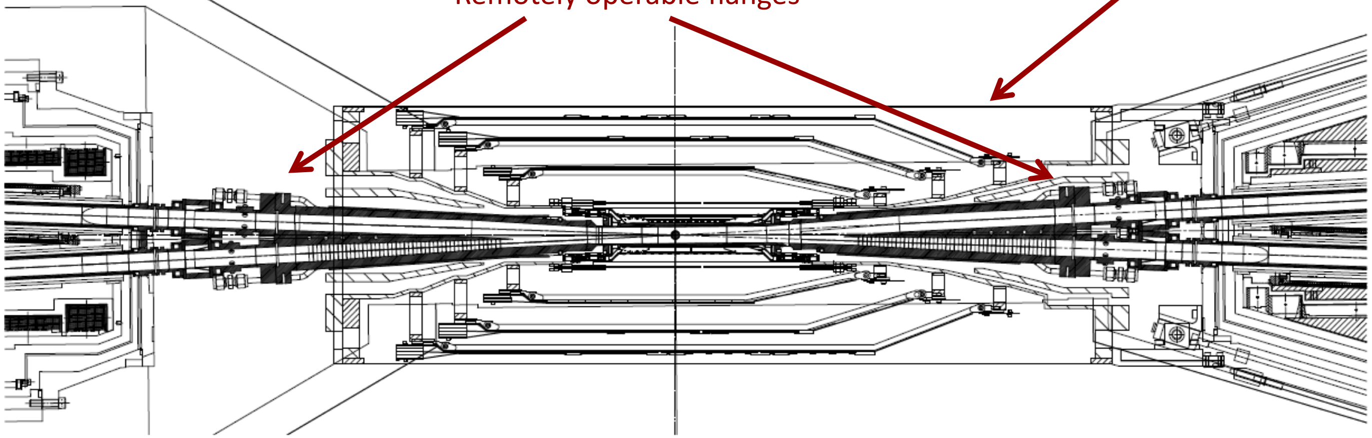
IR and its mechanical interface with detector (BelleII)



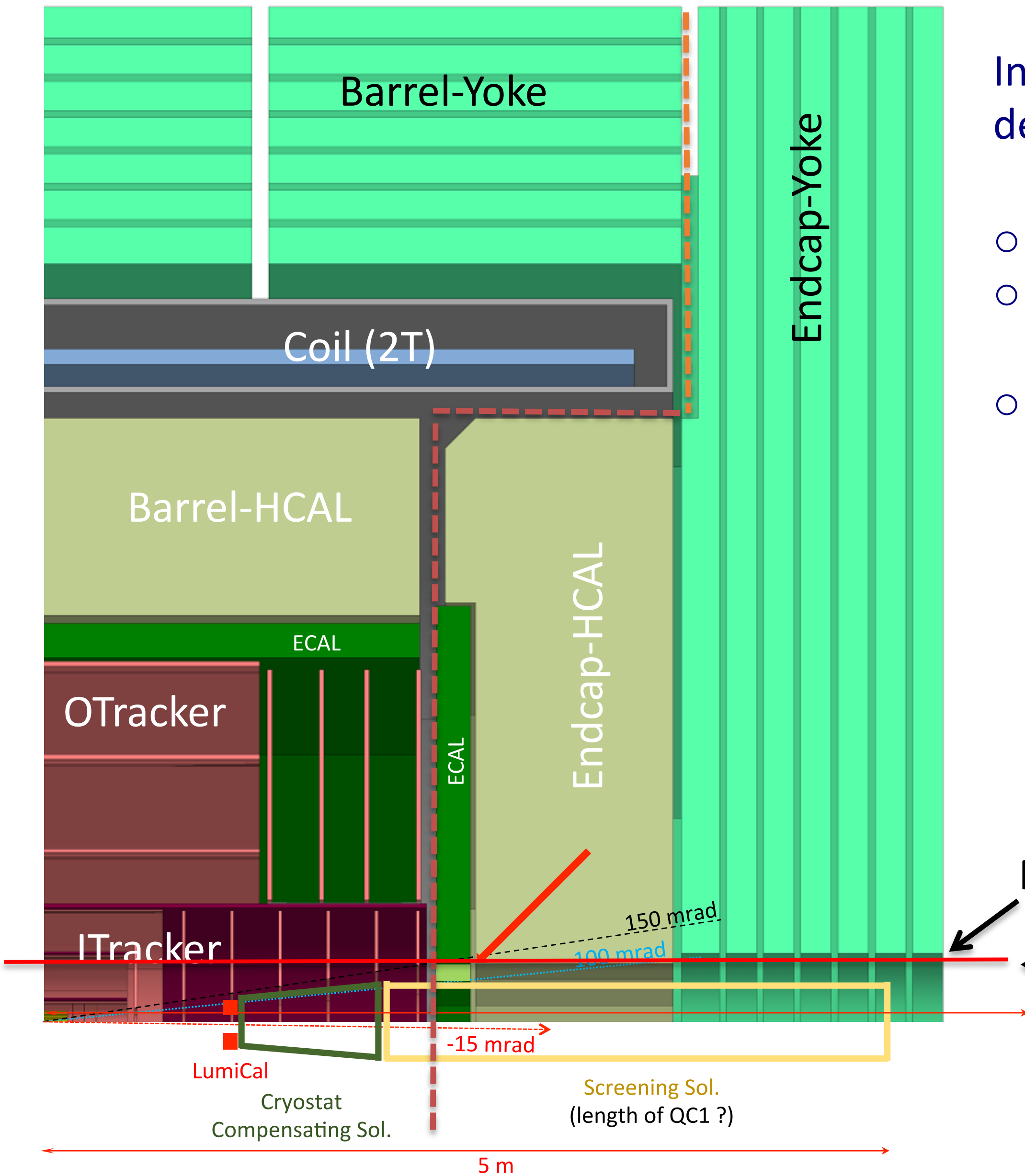


Central part supported by the Detector ?

Remotely operable flanges



IR and its mechanical interface with detector (CLD)



In case of a cylindrical IR + Inner detector assembly:

- Inner tracker to be re-designed
- Close the gap between 100mrad and 150mrad?
- Boundary between endcap and barrel to be re-optimized ?

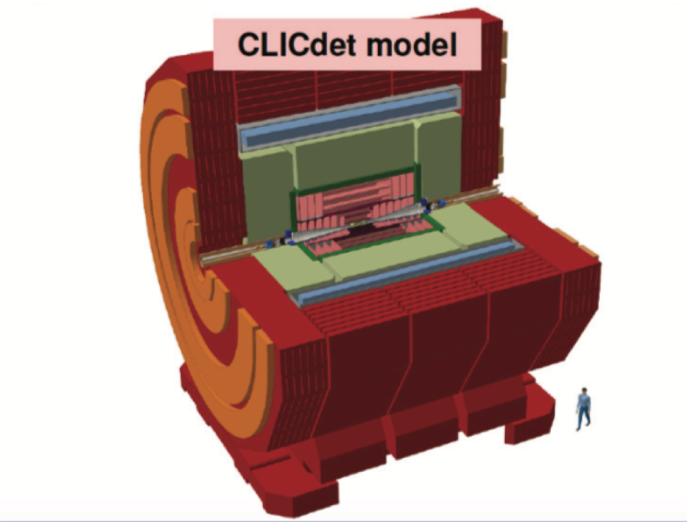
Possible inner bore opening ?

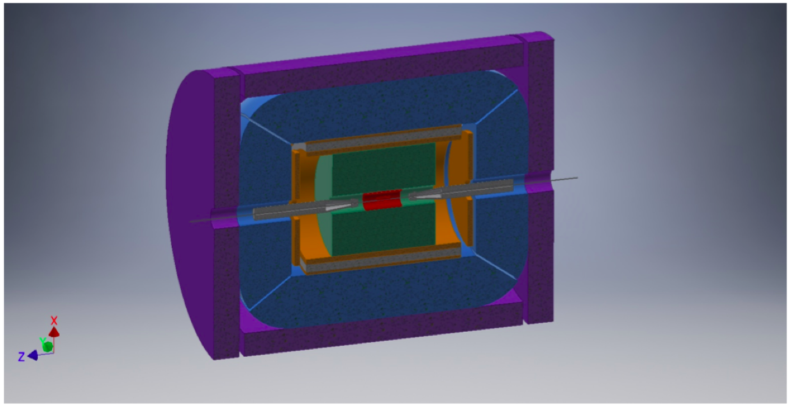
Necessary gap for:

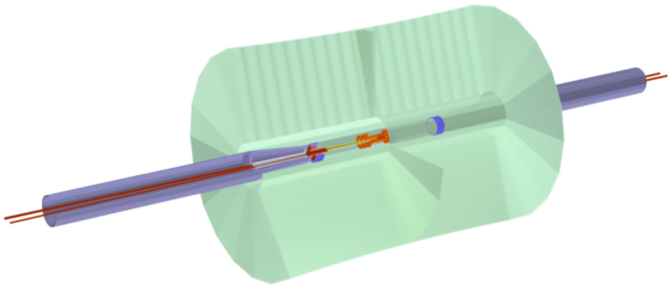
1. mechanical supports
2. Clearances
3. All services of IR+inner detectors

CLD Detector

IDEA detector

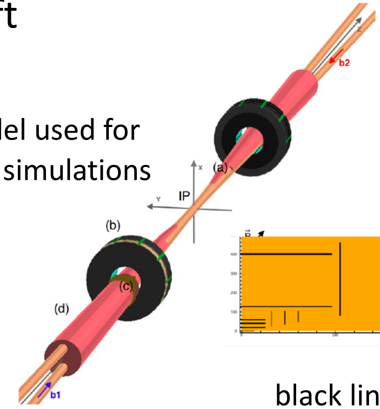




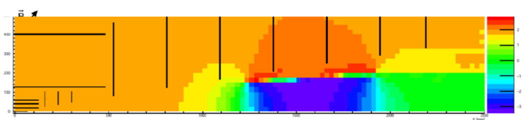


- adaptation of the CLIC detector model
- Silicon-based vertex and tracking detectors
- ILCSoft

Geant4 model used for backgrounds simulations



Field map x-z



B field map: Rz slice
black lines are VXD/tracker layers

IDEA DCH

- Material budget $< 1\% X_0$
- Resolution $\sigma_{xy} < 100 \mu m$, $\sigma_z < 1$mm
- ~ 100 *ns* integration time
- dE/dX $\sim 4\%$, dN/dX $\sim 2\%$
- Implemented in DD4hep
  - Analysis performed with FCC software

Few highlights of the on-going discussion

3D integration - useful experience from various DAFNE IR upgrades, INFN experts ready to work on this topic, BINP also involved

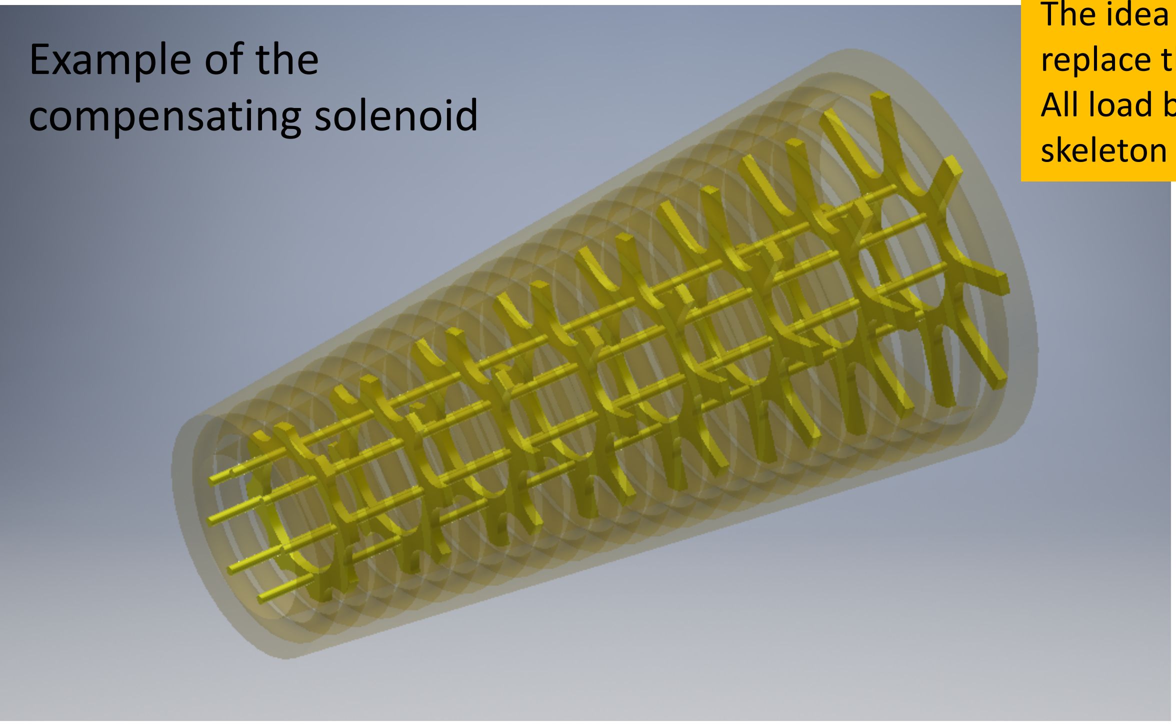
cryostat specification needed – likely to compromise angular acceptance: wall thickness, separation of wall functions (helium containment, stability, shielding)?, helium safety valves?
→ cryo/cryostat expert (CERN)

alignment specification, need for active positioning systems, and **space inside detector for surveying** equipment?

A *two weeks working meeting* with the MDI core team was held on 9-20 September 2019 at CERN: many topics addressed and discussed, progress toward the next *CDR2* phase, with a work plan.

Perhaps we can reduce the space for the solenoids by rely on a stiff internal skeleton

The idea is to use a stiff skeleton which will replace the very heavy cryostat.
All load bearing capability will rely on this skeleton

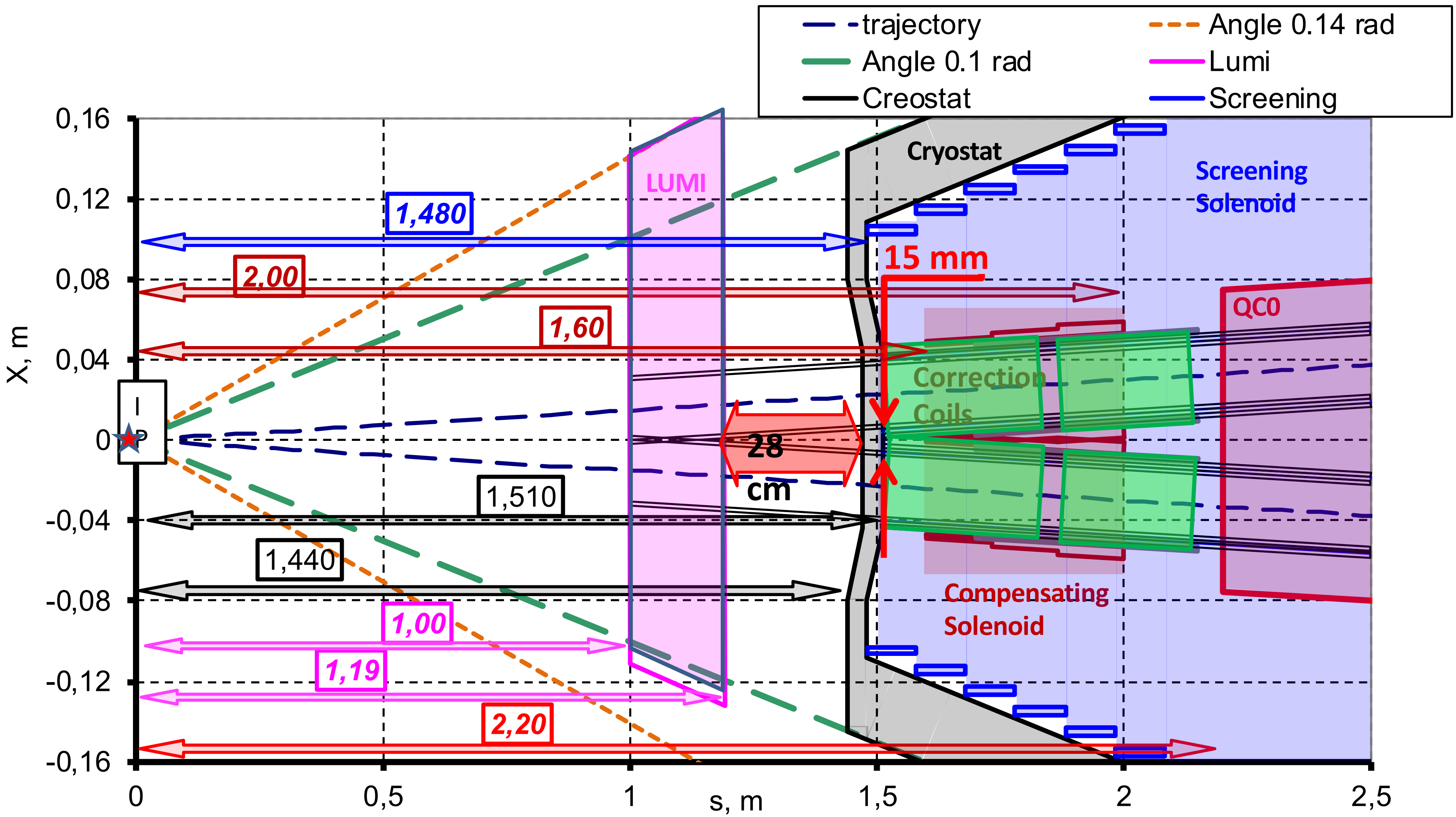


- Forces: 30 tons on compensating solenoid, 8 tons on screening solenoid
- Torque: 1000 Nm on screening solenoid
- Misalignment: 10mm on both solenoids, plus 100mrad twist of compensating solenoid: 1300 Nm on screening solenoid

- FCC-ee FF quad prototype using CCT technology is progressing smoothly
- Forces and twists of the magnet system have been calculated
- A (possible) mechanical design using an (endo)skeleton has been presented

M. Koratzinos

Alternative design for the cryostat



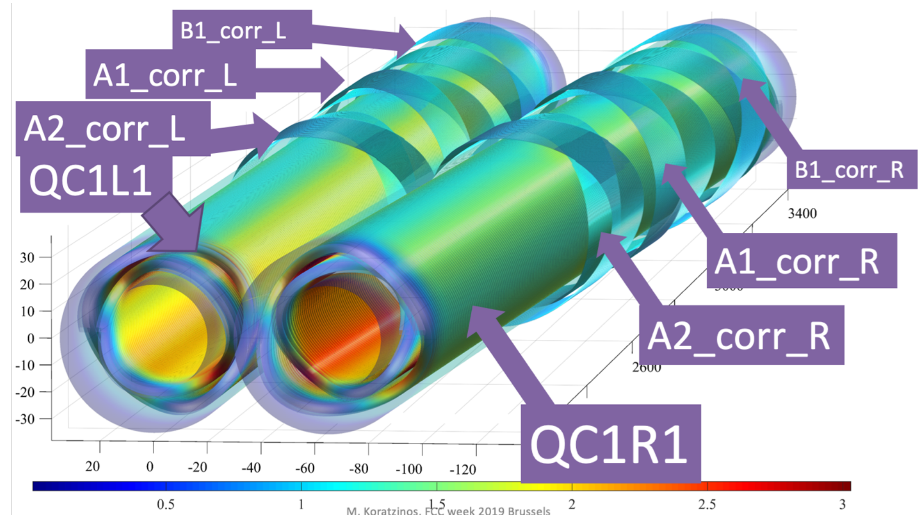
Screening solenoid is extended to 1.5 m and the compensating solenoid moves inside the screening solenoid

S. Sinyatkin

IR magnets

CCT final focus quadrupole

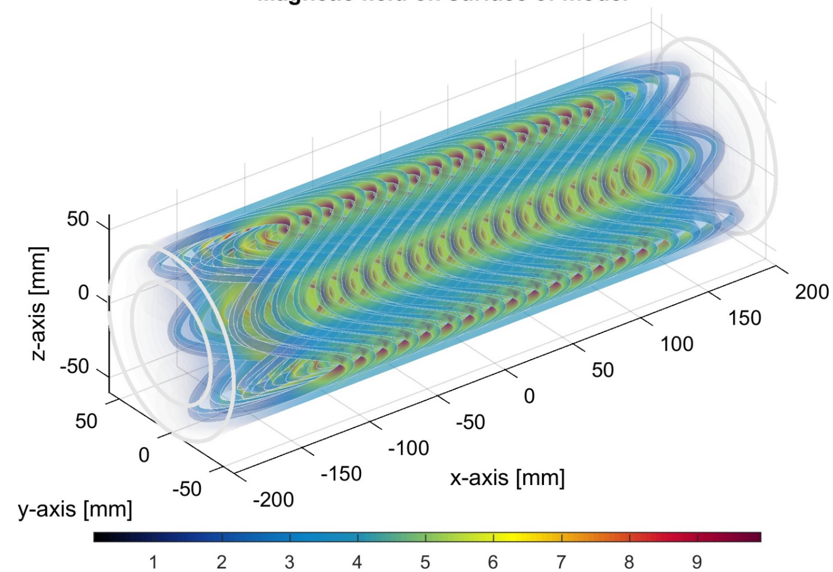
prototype realized, under test



crab waist sextupole

Unique to FCC-ee, is a set of four strong sextupoles in the vicinity of the IP

- ~60mm aperture, single aperture
- Very short (30cm)
- Very high field (10-11T on the conductor)
- CCT is ideally suited – correctors can go on top as extra rings saving space

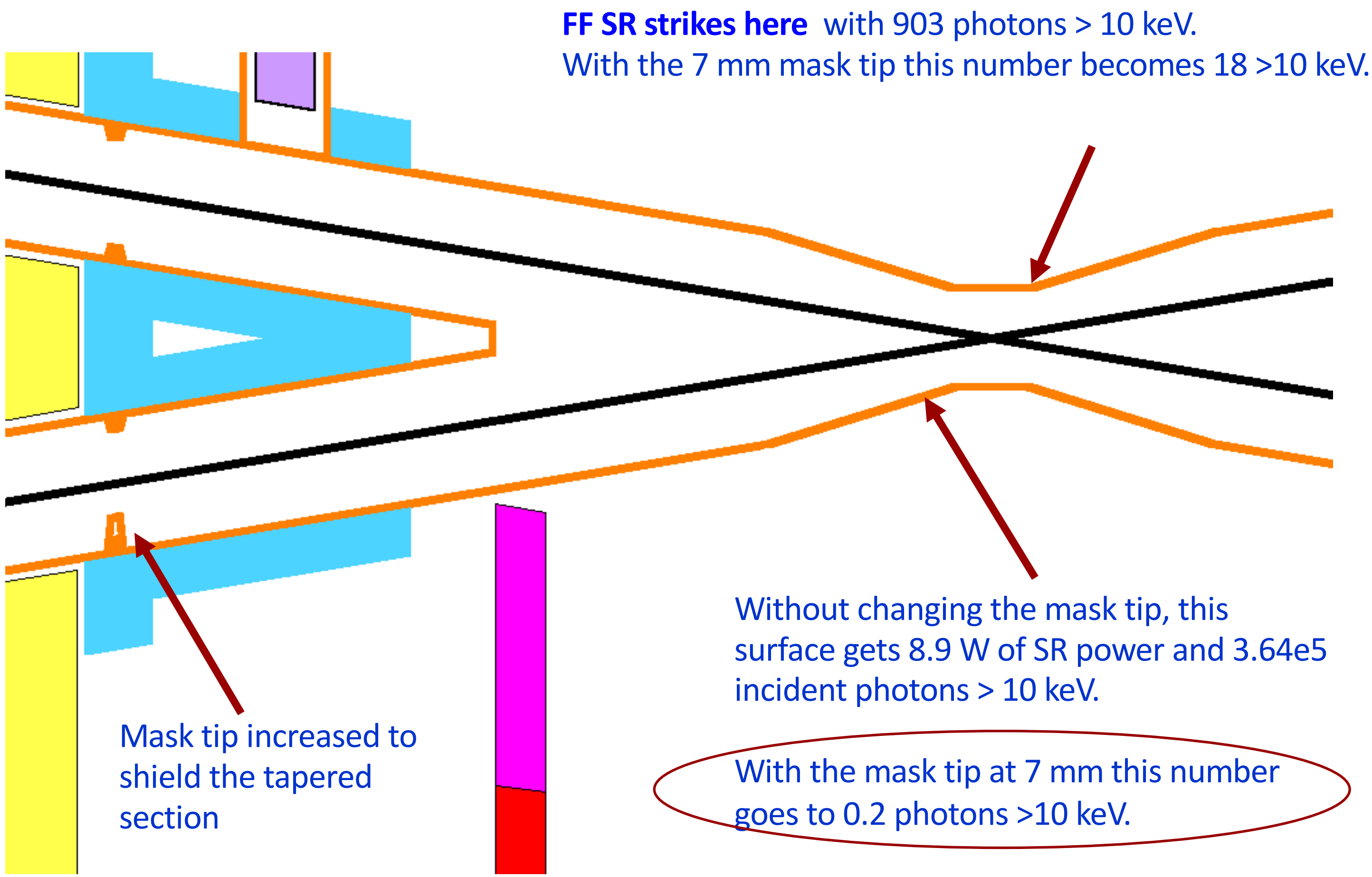


M. Koratzinos

Smaller central beam pipe – Z case

Central pipe with 20mm diameter and cylindrical length shorten from 25 cm to 18 cm

- The **SR fan from the last bend magnet** misses the central chamber only if we increase the **mask tip** from 10 mm **to 7 mm** from the beam line
- The central chamber is then shadowed by the larger mask tip
- There some quadrupole radiation from the FF quads now striking the downstream part of the central chamber



M. Sullivan

Summary of SR in the IR with smaller central chamber

- We have looked at **changing the central beam pipe radius from 15 mm to 10 mm** and shortening the Z length from 25 cm to 18 cm
- The **new beam pipe now intercepts SR from the FF quadrupoles and also intercepts bend radiation** from the last soft bend before the IP
- The bend radiation can be masked away by reducing the mask radius at -2.1 m from 10 mm to 7 mm
- The quadrupole radiation cannot be totally masked away even with a 5 mm radius mask at -2.1 m

- A smaller beam pipe for the Z running looks possible
- A 1 cm radius beam pipe for the ZH running is more problematic but with careful design work should be possible
  - The detector occupancy will be higher – may be still OK?
  - The IR design becomes more sensitive to the high sigma beam tail distributions
  - This also means that the IR design is more sensitive to β^* changes in the machine lattice

The concept of the HOM absorber

Based on the property of the trapped mode we have designed a special HOM absorber.

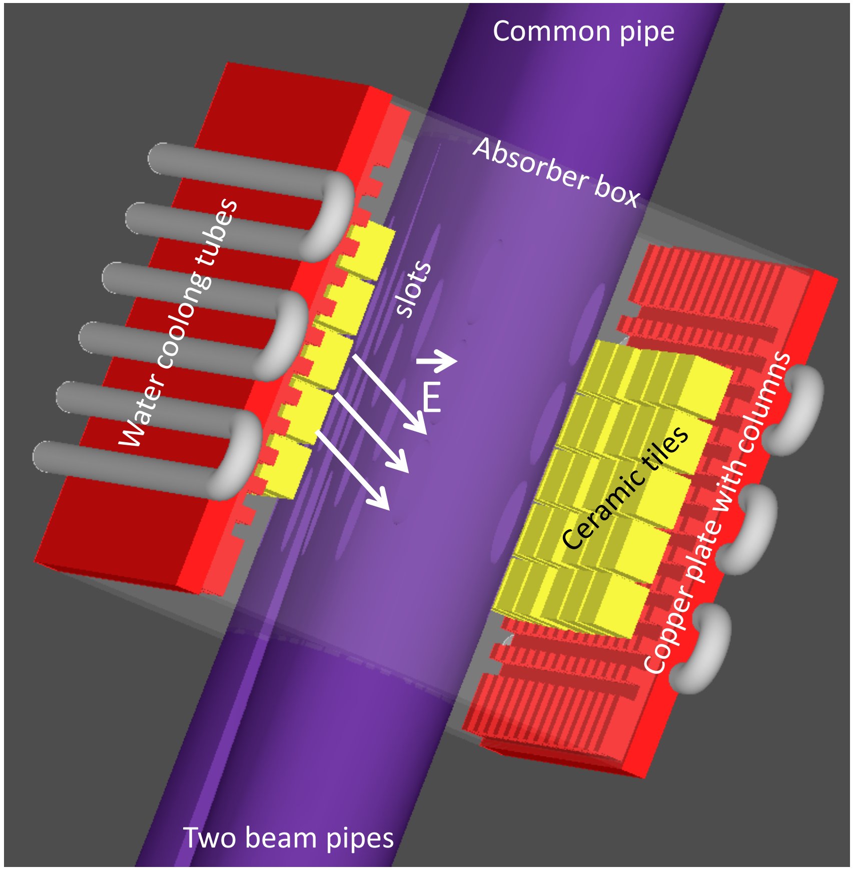
The absorber vacuum box is placed around the beam pipe connection. Inside the box we have ceramic absorbing tiles and copper corrugated plates .

The beam pipe in this place has **longitudinal slots**, which connect the beam pipe and the absorber box. Outside the box we have stainless steel water-cooling tubes, braised to the copper plates.

The **HOM fields**, which are generating by the beam in the Interaction Region **pass through the longitudinal slots into the absorber box**.

Inside the absorber box these fields are **absorbed by ceramic tiles**, because they have high value of the loss tangent.

The **heat from ceramic tiles** is transported through the copper plates **to water cooling tubes**.

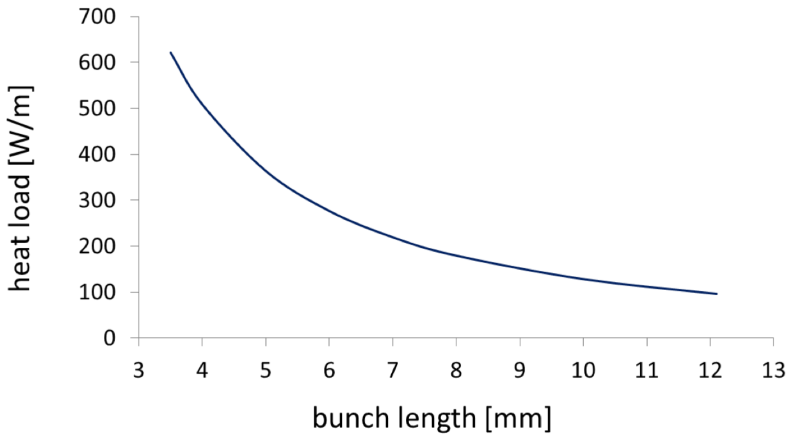


A. Novokhatski

Heat load for 30 mm beam pipe

bunch length [mm]	HEAT LOAD Two beams [W/m]				current [A]	Bunch spacing [ns]	
					2 x 1.39	19.50	
12.10	63.45	69.18	81.68	96.57	125.23	349.64	1473.91
Material	Cu	Au	Al	Be	Ni	SS	NEG

- Beryllium pipe takes 100 W/m for a 12 mm bunch but strongly increasing with shortening the bunch length.
- A gold coating can decrease the heat load by 30%



A. Novokhatski

Comparison of resistive heat loads (Be pipe) and temperatures

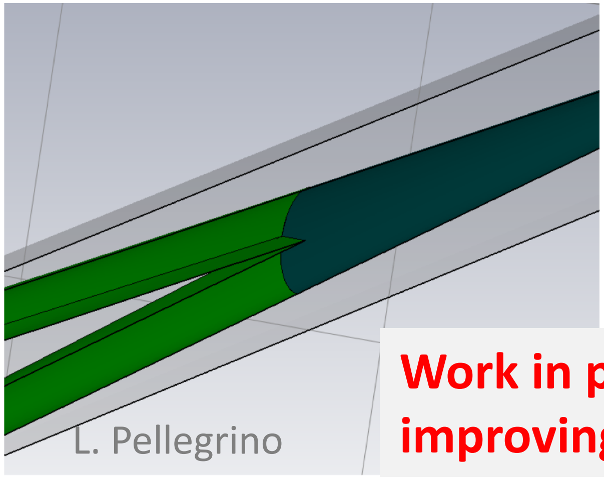
Beam pipe diameter [mm]	Heat load [W/m]	Max Temp. [K] without cooling
30	97	88
20	145	198
10	290	792

The central beryllium tube requires increasing cooling with decreasing the beam pipe diameter.
First estimates show that this problem can be technically solved.

Max temperature
was calculated by formula:

$$\Delta T_{[K^\circ]} = \frac{P_{[W]} * L_{[m]}}{\kappa_{[W/(K^\circ m)]} * 2\pi R_{[m]} \Delta r_{[m]}}$$

For the pipe length L of 125 mm
(half of the Be pipe)
with **thickness** Δr of **1 mm** and
Be thermo- conductivity of 182 W/m/K



Work in progress with an improving beam pipe model

IP backgrounds

Radiative Bhabha *BBBrem/GuineaPig & SAD/MADX*

- beam loss map through the ring
- characterization of photons produced at IP

Beamstrahlung *GuineaPig /BBWS & SAD/MADX*

- beam loss map through the ring
- characterization of photons produced at IP

e^+e^- pairs *GuineaPig, G4 into detector*

- **Coherent** Pairs Creation: **Negligible**
  Photon interaction with the collective field of the opposite bunch, strongly focused on the forward direction
- **Incoherent** Pairs Creation**: Dominant** (real or virtual photon scattering)

$\gamma\gamma$ to hadrons combination of *GuineaPig and Phythia, G4*

- **Small effect**
- Direct production of hadrons, or indirect, where one or both photons interact hadronically

Radiative Bhabha

- BBBrem has been implemented in **SAD**
- Beam loss due to radiative Bhabha for FCC-ee at the Z:
  - **4 kW** by **400 m downstream** the **IP**
  - **150 W** within the first quad **QC1**
- The effect of beam-beam is about 20% on the loss at QC1.
- The result is neither sensitive to the misalignment of aperture at QC1, nor to the IP solenoid field.

- The tolerance of the final quadrupole for such amount of beam loss must be examined.
- Cross check with other method is necessary and in progress.

K. Oide

Beamstrahlung

H. Burkhardt

- SR in field of opposing beam, estimated at the Z with **Guinea-Pig**
- The IR will generate **a very significant flux and power of hard X-rays lost mostly in the first downstream bend** (49-55 m from IP)

Classical SR and Guinea-Pig	<Nγ>	<Eγ> keV	Power KW	
IP magnets (quad, solenoid)	1.3	24	43 kW	(also without collisions)
Beamstrahlung	0.15	2000	**417 kW**	photon energies extend into the GDR region

- **~460 kW hitting in a narrow ~5 m wide region**
- wall power / length of order 100 kW/m

some MW / IP with spectrum extending into tenths of MeV

strongly varying with bb-parameters and residual separation

Beamstrahlung

- well cooled absorbers in the critical region
- study impact of radiation: neutron flux (GDR), activation

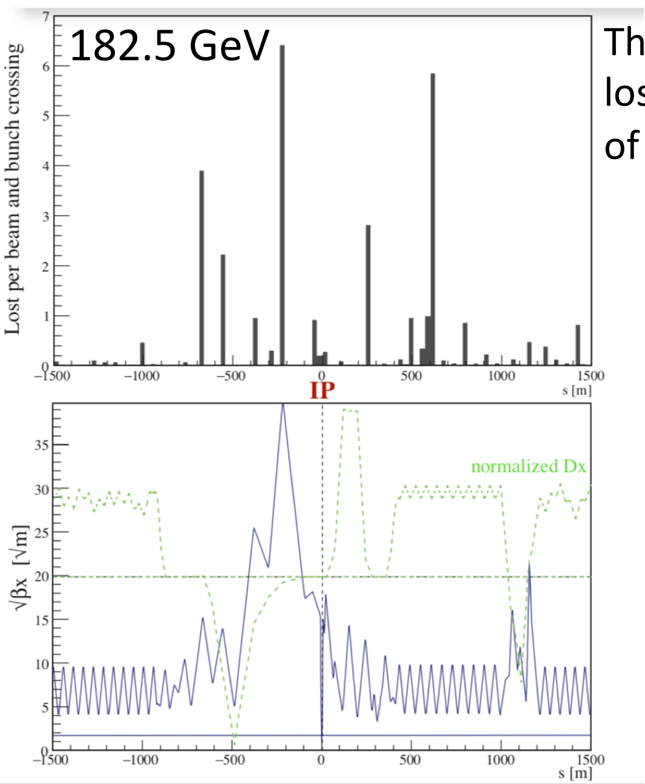
- understanding / tools to deal with the beam dynamics in the FCC-ee with SR by the combined effect of
  - detailed IR fields with solenoid, fringe, overlap
  - beam distribution with realistic tails & crab-waist
  - em-fields of colliding beams

Thermal photon scattering

First described in 1987 by V. Telnov , main single beam lifetime limitation in LEP, well measured and simulated using the algorithm described in SL/Note 93-73

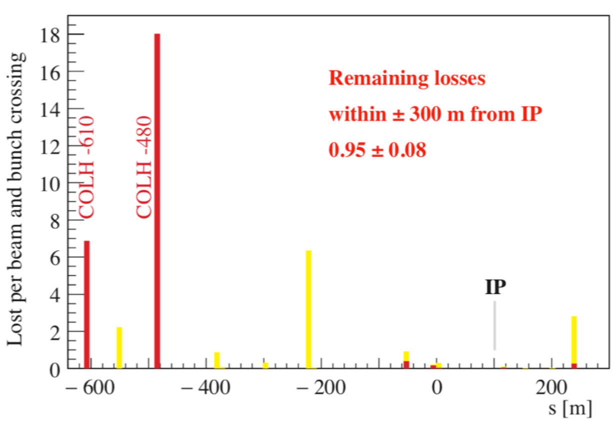
now done using C++ with multithreading, 10^9 events in few min

Normalized loss distribution +/- 1.5 km around IP



Thermal γ 31.2 $\pm$ 0.5 |s|<1.5 km from IP lost/beam/crossing
of which 11.1 $\pm$ 0.3 |s|< 300 m

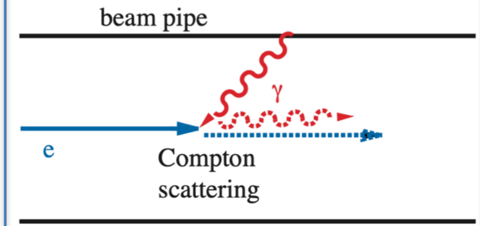
Losses now concentrated at these collimators



mitigation by off-momentum collimators

photon density

$\rho_\gamma = 5.3\times10^{14}$ m^{-3}



very roughly

0.07 eV thermal photons

boosted by γ^2 to GeV

energy loss from beam

H. Burkhardt

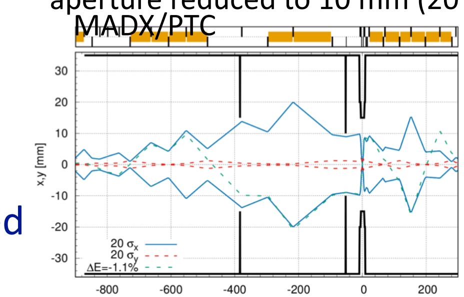
Single beam backgrounds

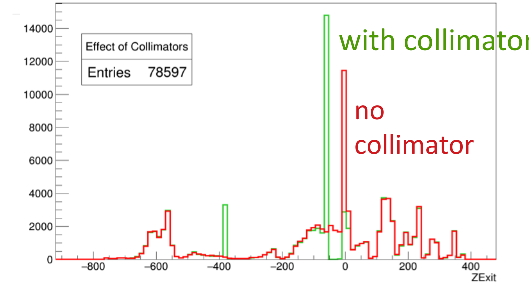
- **New simulation tool** being developed, Monte Carlo technique for multiturn 6D through the ring
- Particle tracking interfaced with MADX/PTC
- Record 6D coordinates of the lost particles (ROOT)
- Interfaced with Geant4 for tracking into detector
- Goal is to simulate:
  – Elastic beam-gas scattering
  – Touschek scattered beam particles

    Touschek lifetime ~15/30 hrs at Z (MADX and SAD)
    Touschek losses: not expected to be relevant, but at IR check needed

  – radiative Bhabha
  – Beamstrahlung

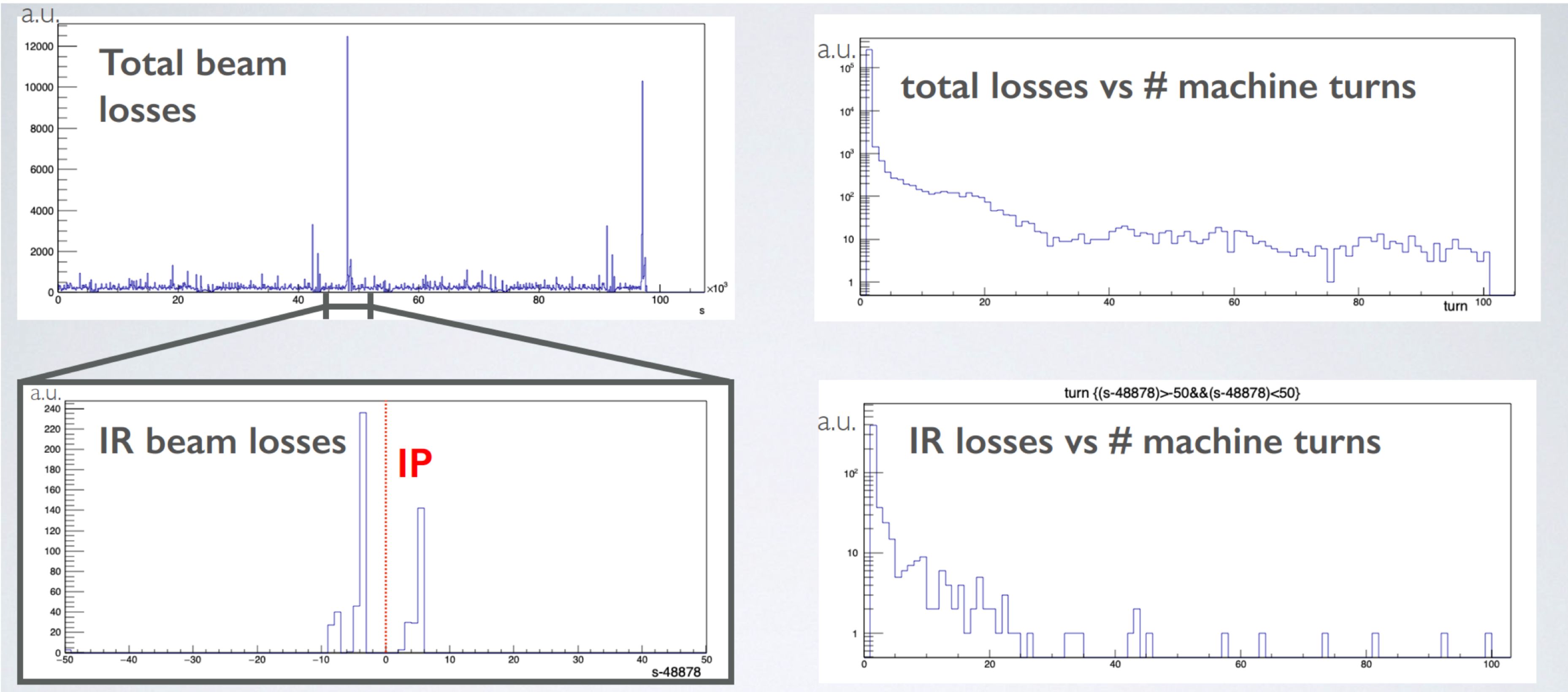
aperture reduced to 10 mm (20 σ_x)





example of
off-momentum collimators

First results Elastic beam-gas scattering



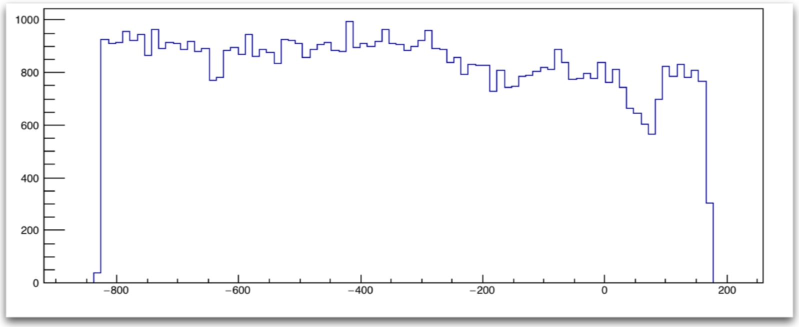
- Most of the **particles are lost close to the IR final focus quadrupoles**, where the physical aperture gets smaller
- Most of particles are lost at the first turn

A. Ciarma (LNF)

Inelastic Beam Gas scattering in the IR

MDISim used to import in Geant4

Z origin of beam gas interactions that will lead to particle loss

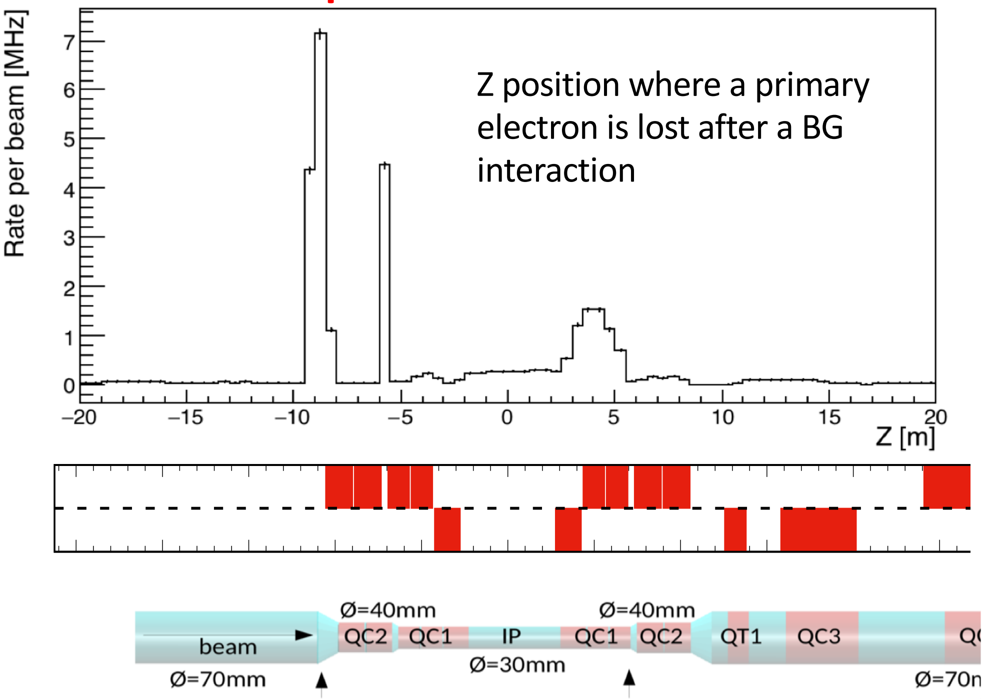


N_2 and 10^{-7} Pa, 300 K

FCC-ee energy	Loss Rate +/-20m from IP [MHz]
Z	147
W	16
H	3
t	0.5

tracked into lumical showing negligible backgrounds rates

IR Loss map



MOPMF085, IPAC18

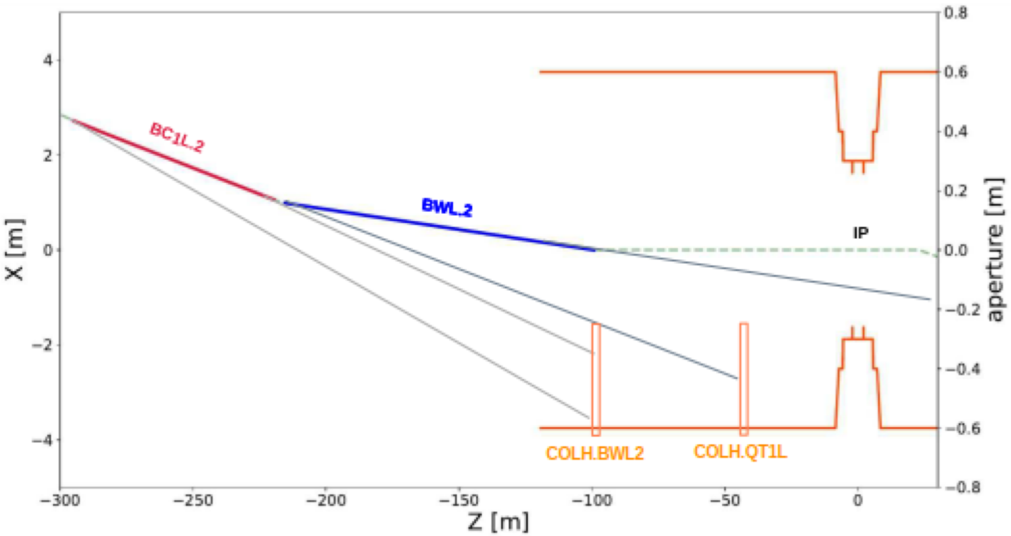
Synchrotron Radiation at the IR - in progress

- **Refine simulations** (also following the optics changes)
- **More detailed studies** with improvements on the simulation level:
  - tracking in IR with beams tilted in solenoid
  - fringe fields overlapping with quads
  - X-ray reflection not yet included in Geant4 (and check for giant dipole resonance)
- Add **SR collimators** upstream the IR
- Neutron production from high-energy tails in FF quads: study has to continue
- Carefully evaluate the **SR from final focus quadrupoles** especially at the top energy: hard photons are produced, lost at ~50/60 m downstream the IP
- Primaries under control, **secondary sources** to be simulated more carefully

- First handle to control SR is OPTICS: to fulfil the requirement that **$E_{critical}$ from dipoles is < 100 keV** from ~ 500m from IP, special optics has been developed
  [K. Oide et al, PRAB 19, 111005 (2016)]
- SR studied with **SYNC_BKG, MDISim** (MADX/ROOT/Geant4) and **SYNRAD+**

SR study with MDISim

Adding upstream IR collimators



SR cones and IR apertures

[MDISim](#): Powerful simulation tool for very detailed analysis

Interfaces

MADX/ROOT/GEANT4

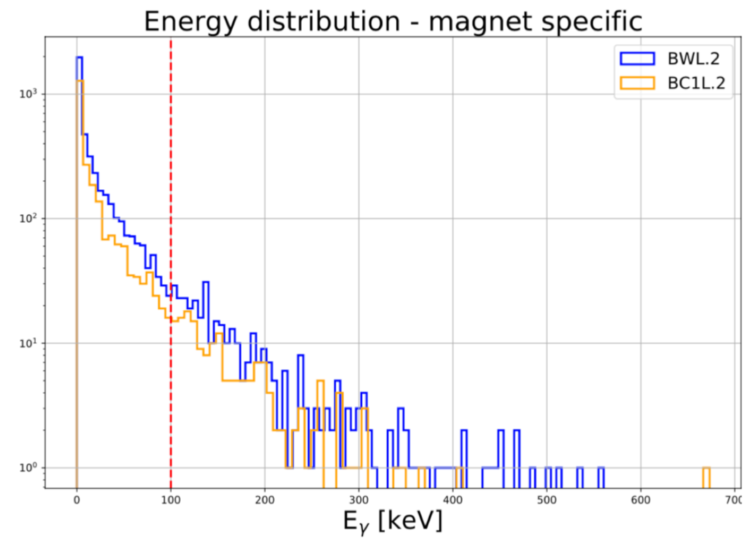
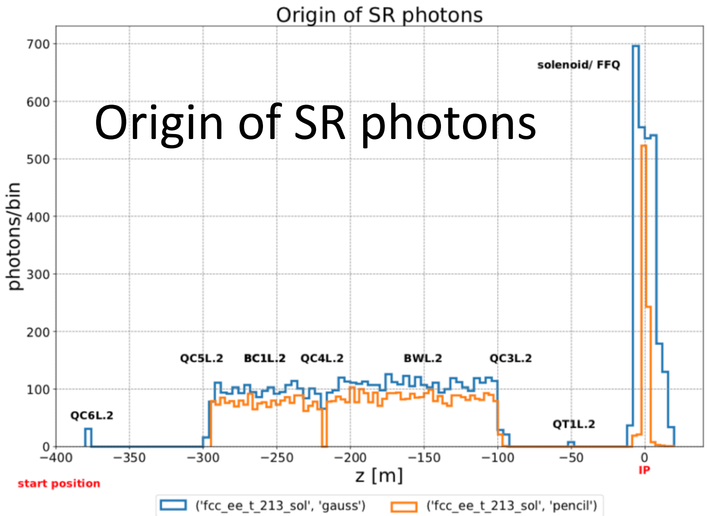
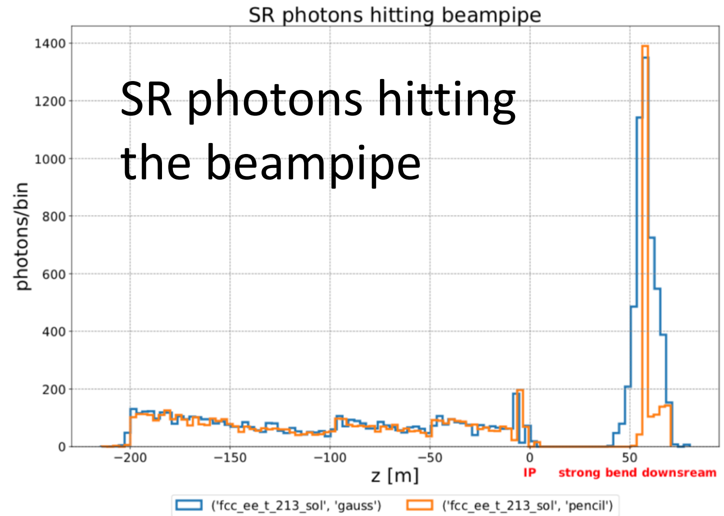


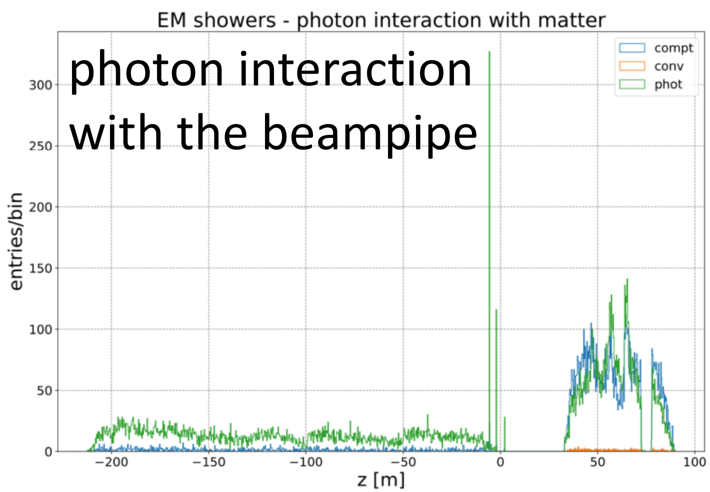
Figure: Energy spectrum last two upstream dipoles.

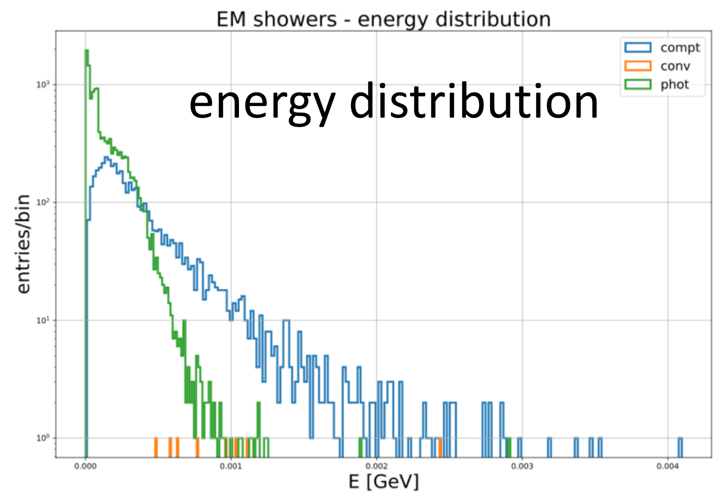
M. Luckhof

Analysis of the SR upstream and into the IR using MDISim





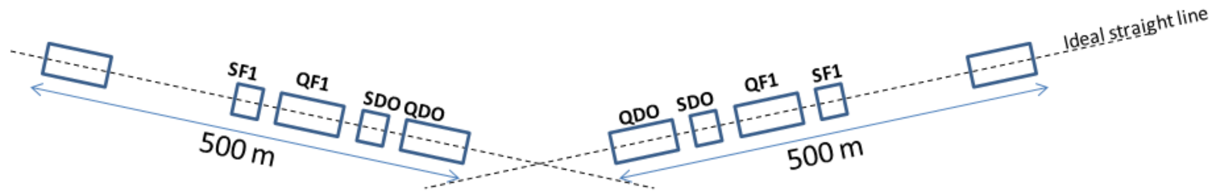




M. Luckhof

FCC-ee Position Monitoring & Alignment

MDI: left side wrt right side



Requirements:

- Position of the **zero of QD0 wrt ideal straight line** of the 500 last meters of BDS: **± 10 µm rms** (including fiducialisation)
- **Longitudinal relative position between QD0 and QF1: ± 20 µm rms** (CLIC)

Experience based on HL-LHC, CLIC and ILC development work

- **Few tents of microns relative alignment of FF quads possible**
- Solution Requires:
  - ✓ Additional space inside the experiment
  - ✓ Sensors, lines-of-sight, position adjustment system
  - ✓ Strong position and orientation links between accelerator elements in the cavern and those in the tunnels
  - ✓ Internal metrology for "encapsulated" elements inside cryostats, or detectors

- The application, adaptation, and integration of alignment and internal metrology components into a single system needs to be studied

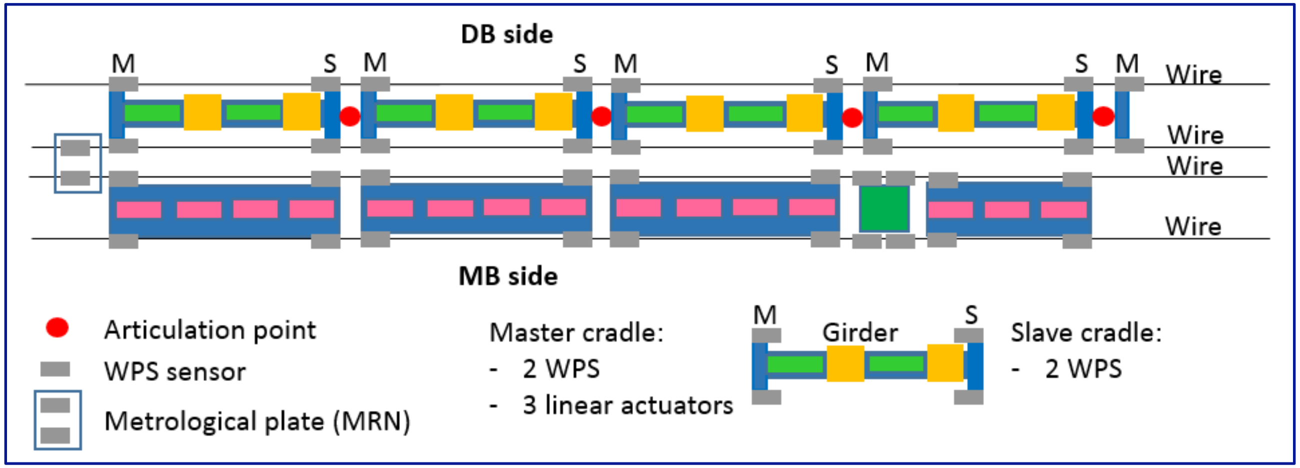
M. Jones

FCC-ee Position Monitoring & Alignment

- Concept based on design for CLIC
  - Full Remote Position Monitoring and Alignment System
  - Wire Position sensors
  - Hydrostatic Levelling sensors
  - Motorised positioning system

continuous position and orientation determination

Design for CLIC



M. Jones

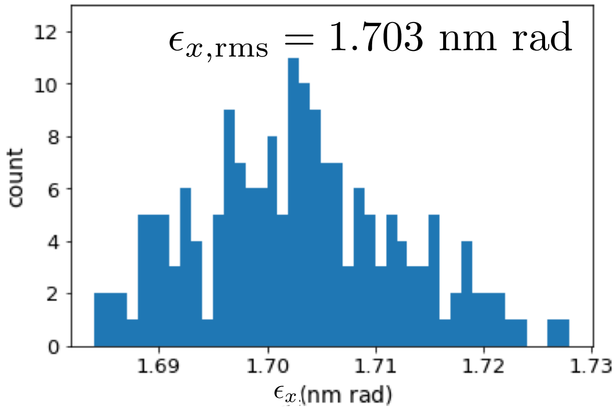
Preliminary corrected **4 IPs** lattices, ttbar

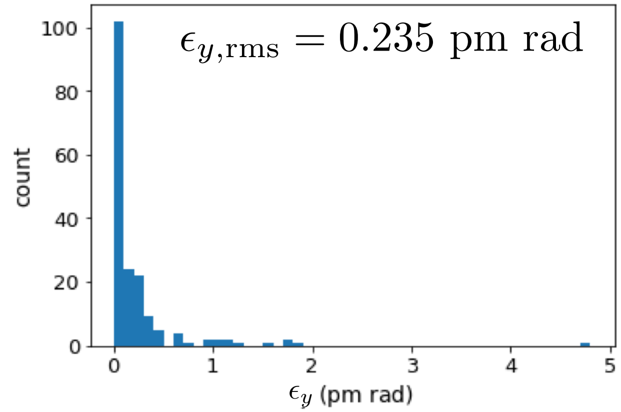
Using the misalignments and roll angles:

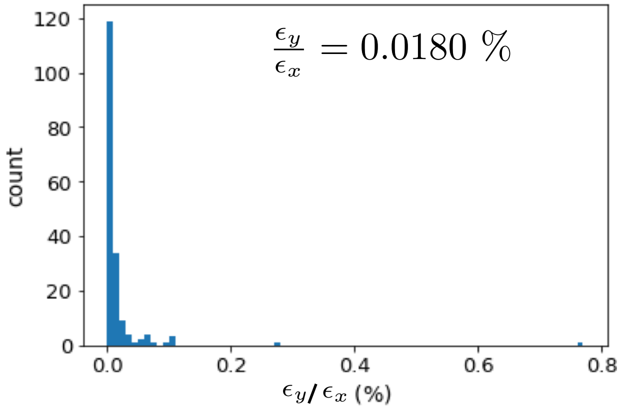
96% of seeds successful.

	$\sigma_x(\mu\mathrm{m})$	$\sigma_y(\mu\mathrm{m})$	$\sigma_\theta(\mu\mathrm{rad})$
arc quads	100	100	100
IP quads	100	100	100
sextupoles	100	100	100
dipoles	100	100	100

After correction:







presently even better than 2 IP solution

T. Charles

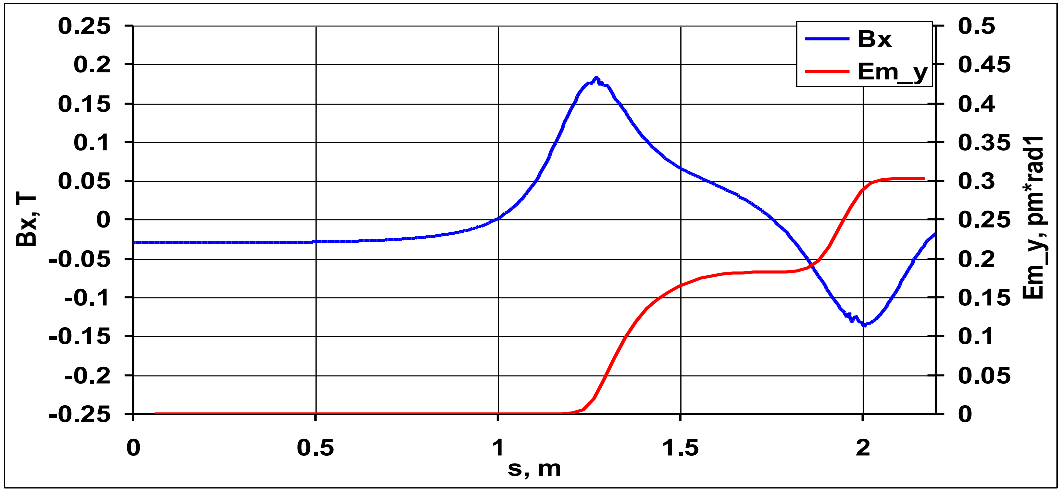
Conclusion

- At the beginning of this year 2019 the CDR was released.
- More refined and detailed studies are in progress, starting the new **CDR2 phase**.

  To plan progress for this new CDR2 phase a two weeks working meeting took place at CERN in 9-20 September, a work plan was developed.
- **Background** simulations: development of new tools, detailed simulation especially for Beamstrahlung and radiative bhabha are in progress, together with mitigation actions.
- **Mechanical design** is a key step to proceed further to more detailed study, it has started.

Back-up

Vertical emittance calculation for baseline



For 2 IPs I_2 = 5.65*10^{-4} m^{-1} β_y^* = 1 mm

$$I_{5y} = h_y^3 \oint \mathrm{H}_y(s)ds = 6.00 \cdot 10^{-14} \ m^{-1}$$

$$\varepsilon_y = 3.83 \cdot 10^{-13} \cdot \frac{\gamma^2}{J_y} \cdot \frac{I_{5y}}{I_2} = 0.3 \ pm * rad$$

$$I_{5y} \sim B_x^5 \sim B_s^5 \qquad \varepsilon_y \sim B_x^5 \sim B_s^5$$

Energy = 45 GeV

βy = 0.8 mm

Ɛy = 0.38 pm*rad

S. Sinyatkin

necessary ingredients for IR CAD design

- **Cryostat dimension** definition
- **Lumical – cryostat separation**
- Update **2d mechanical design started by S. Pivovarov** taking into account workshop discussions
- **Weight budgets**: solenoids, quadrupoles, cryostats, lumical,...
- **Thermal power budget** in the IR (HOM, RW, e-cloud, SR, beam loss)
- **3d magnetic field calculation**
- **Common repository**

M. Boscolo, L. Pellegrino

mechanical design tasks

- Simple **beampipe model** for A. Novokhatski
- Evaluate **the effect of the em static forces** from magnet interaction
- **Pre-dimensioning of the support structures** (important also for space allocation in the MDI area)
- **Pre-dimensioning of the cooling system**
- **First draft of 3D CAD model**
- Verification of the space to be allocated for MDI in **negotiation with detector experts**

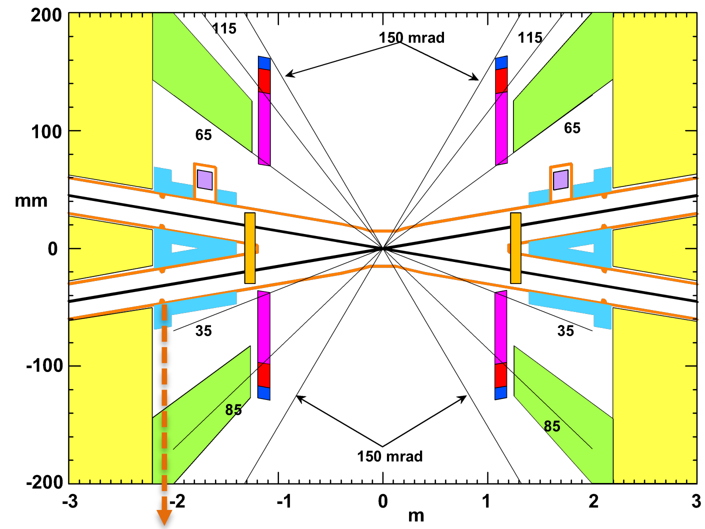
Synchrotron Radiation in the IR

- To fulfil the requirement that $E_{critical}$ **from dipoles is < 100 keV** from ~ 500m from IP, special optics has been developed
  [K. Oide et al, PRAB 19, 111005 (2016)]
- SR studied with **SYNC_BKG, MDISim** (MADX/ROOT/Geant4) and **SYNRAD+**
- Different **countermeasures** undertaken to protect IR & detector
  - SR mask tips in front of QC1 and QC2
  - 1 cm Tantalum shielding
  - 5 μm Gold coating in the central chamber

Countermeasures are effective:

- **No SR from dipoles or from quads hits directly the central beam pipe**
- **SR impact on Vertex detector (VXD) and Tracker barrel (TB) small**

On-axis beam, non-Gaussian beam tails to 20 σ_x and 60σ_y



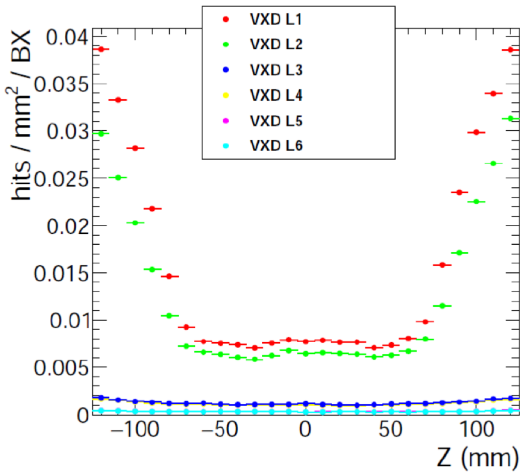
mask tips prevent FF quad radiation from striking nearby beam pipe elements

SR bkg comes only from the last soft bend radiation striking the mask tips

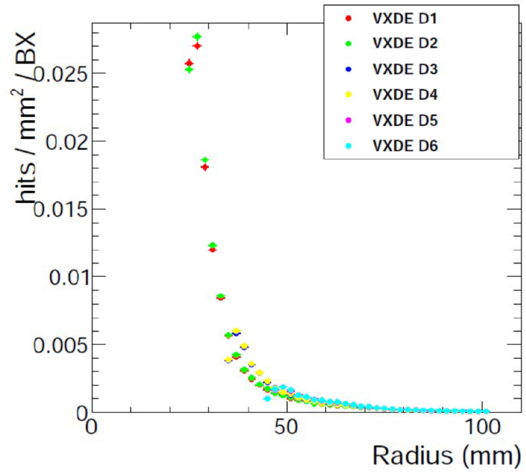
Hit densities @ 365 GeV, from IPC

CLD detector

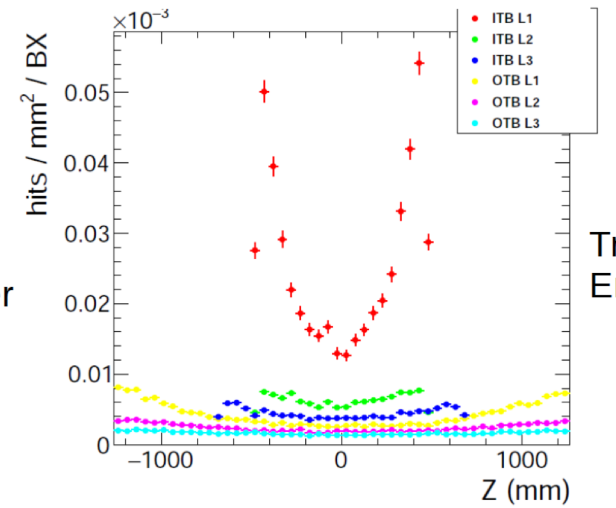
VXD Barrel



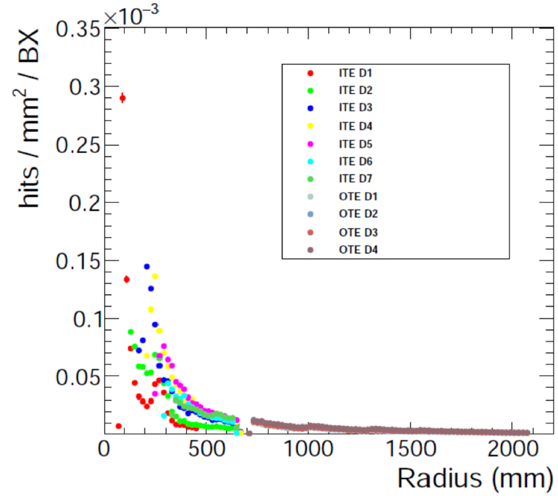
VXD Endcap



Tracker Barrel



Tracker Endcap



Peak occupancy IPC / subdetector

	E_{cm} = 91.2 GeV	E_{cm} = 365 GeV
VXDB	$\sim 10^{-5}$	$\sim 4 \times 10^{-4}$
VXDE	$\sim 3.8 \times 10^{-6}$	$\sim 2.8 \times 10^{-4}$
TE	$\sim 1.8 \times 10^{-5}$	$\sim 1.1 \times 10^{-4}$

Occupancy calculated with the following assumptions:

- Cluster multiplicity = 5 for pixels and = 2.5 for strips
- Pixel pitch 25x25 μm^2 for VXD
- Strip size = 1 x 0.05 mm^2
- We present the estimated occupancy / BX
- Applying a safety factor equal to 3

The table presents max occupancy / subdetector

The presented occupancy / BX is rather low, and pattern recognition is expected to cope with it w/o problems

Bunch spacing at the Z peak is 20ns

- Might be that we have to integrate over several Bxs

However still with a sensor featuring a time resolution of 1μs (it integrates over 50BXs) the occupancy will stay $< 6 \times 10^{-4}$

- Pattern recognition should be able to cope with such value still w/o problems

Summary of background impact in detector

peak occupancies from SR and IPC in CLD VTD and Tracker for E_{cm}=365 GeV

	SR	IPC
VXDB	~0.5×10^{-4}	~4×10^{-4}
VXDE	~1.1×10^{-4}	~2.8×10^{-4}
TB	~4×10^{-5}	~2×10^{-5}
TE	~0.5×10^{-4}	~1.1×10^{-4}

IDEA drift chamber average occupancy

Background	Average occupancy	
	E_{cm} = 91.2 GeV	E_{cm} = 365 GeV
e^+e^- pair background	1.1%	2.9%
$\gamma\gamma \to$ hadrons	0.001%	0.035%
Synchrotron radiation	-	0.2%

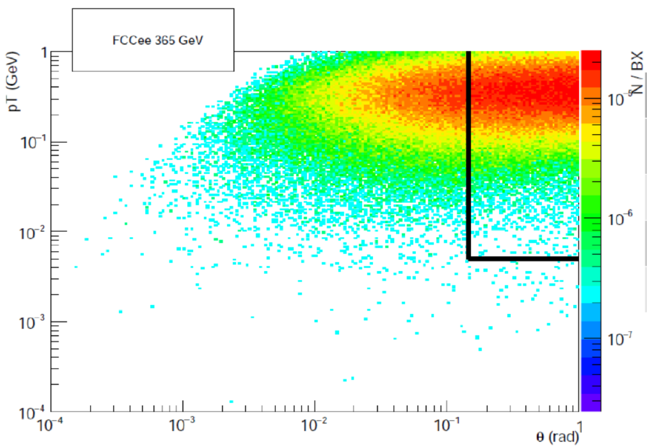
γγ to hadrons

Direct production of hadrons, or indirect, where one or both photons interact hadronically

Simulation with a combination of Guinea Pig and Pythia

- GP: energy spectrum of interacting photons
- Pythia: produces & fragments the partons

2 GeV threshold on E_{cm} of the 2 photons for hadron production applied in our simulation



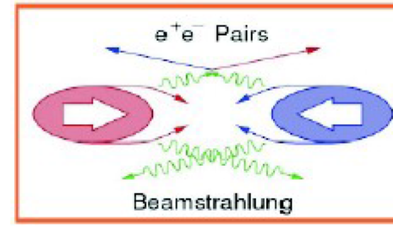
P_T vs θ of hadrons after pythia fragmentation in detector frame

Hadronic events per BX		
$\sqrt{\hat{s}}_{min}$ (GeV)	Z	Top
>2	0.00063	0.0078
>5	0.00029	0.0043
>10	0.00015	0.0027

The effect of this background is expected to be small

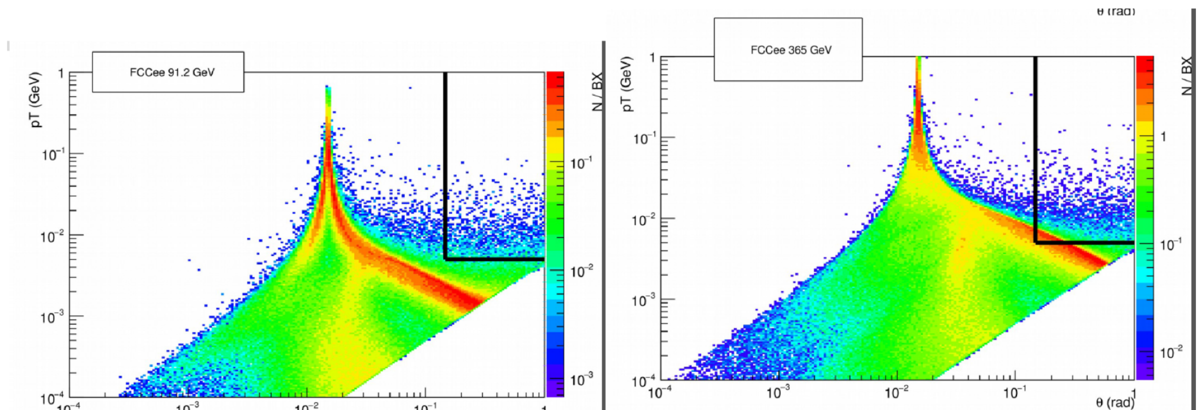
IP backgrounds: e^+e^- pairs simulation with GuineaPig

- **Coherent Pairs Creation** (**CPC**): Photon interaction with the collective field of the opposite bunch
    - **Negligible** for FCC-ee: strongly focused on the forward direction



- **Incoherent Pairs Creation** (**IPC**): real or virtual photon scattering
    - **Dominant** effect: virtual γ scattering

	Z	Top
Total particles	~800	~6200
P_T>5MeV && $\theta > 8^0$	~6	~292
Total E (TeV)	~0.5	~9.3



P_T vs θ for IPC in detector frame. Only the particles within the top right corner will reach a typical VXD in a 2T field.

3