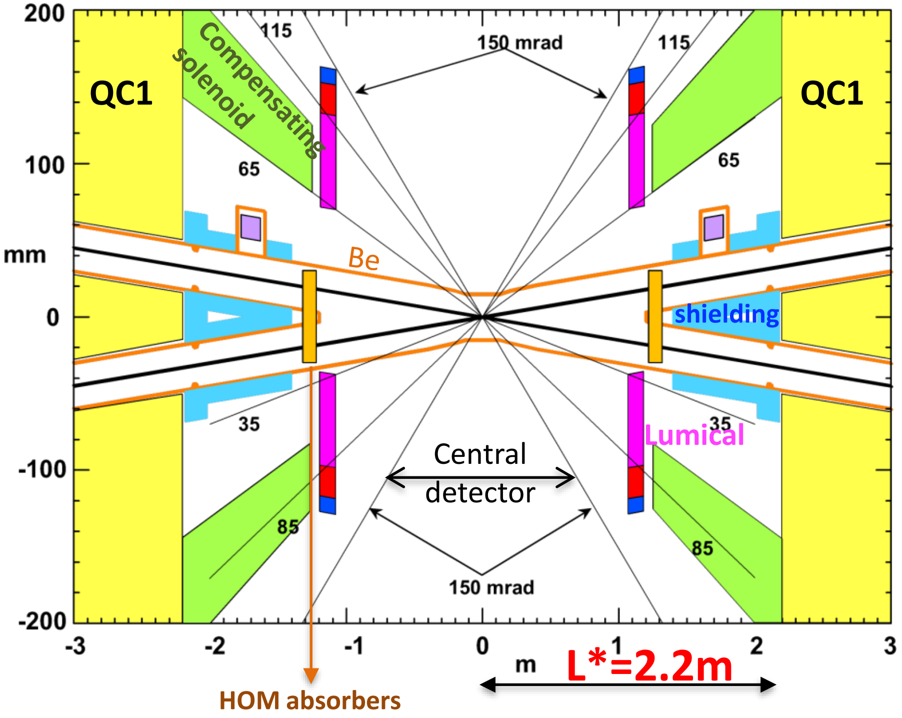
MDI status

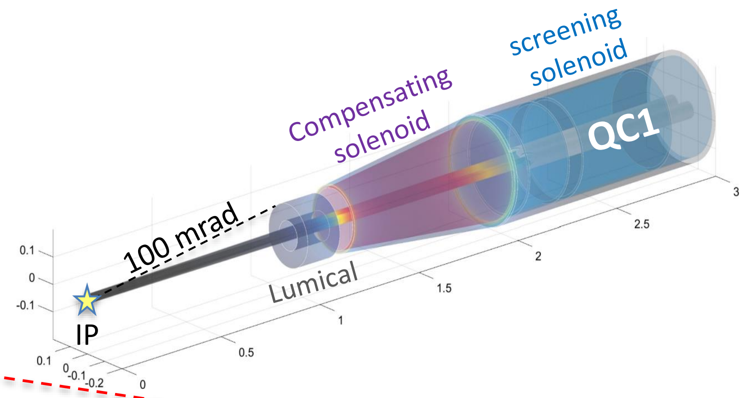
Manuela Boscolo

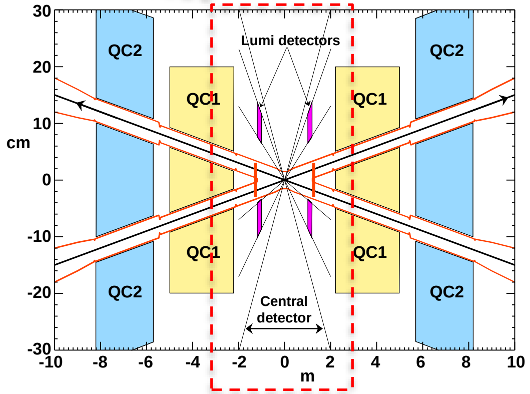
CERN, 10/9/2019

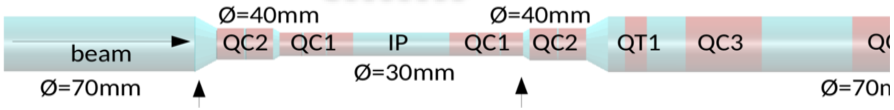
Interaction Region Layout

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

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

FCC-ee 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

Machine Detector Interface design

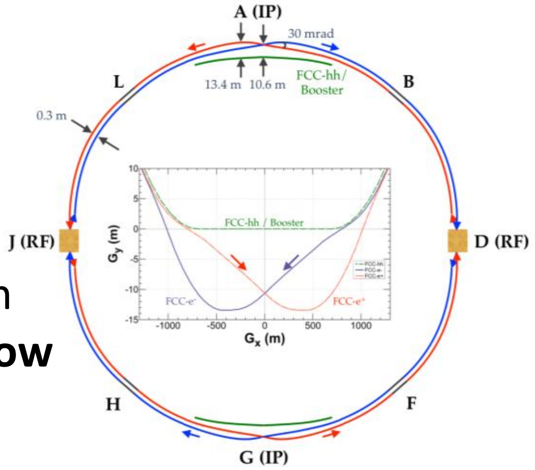
The next steps can be subdivided in the following macro-areas, all inter-connected:

1. **Beam physics (optics, beam dynamics, collective effects)**
2. **Experimental environment & luminometer**
3. **Software**
4. **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 finalize them for the TDR phase.

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

MDI & Beam physics issues



- **Goal is to optimize the design with 4 IPs:** beam-beam optimization implies an evolution of beam parameters, and **MDI layout will follow the optics updates that will come** also for other beam dynamics studies that may come

- FCC-hh footprint is not a constraint anymore
- Optimization of beam pipe aperture, studied the reduction of the central Be pipe

presented at the FCCWEEK19

- **Synchrotron Radiation** (SR) **at the IR**, major issue for the MDI design, well under control as reported in CDR, on-going study

- **Beam backgrounds simulations: single beam and IP processes**
  - Beam losses from all main processes (beam-gas, thermal photons, ...)
  - Collimation system for betatron and momentum cleaning (possibly outside the MDI area, but useful to control losses in the experiments)
- **Heat load** evaluation from RW impedance and SR at IR (strictly connected with engineering issues)
- **Collective effects at IR**

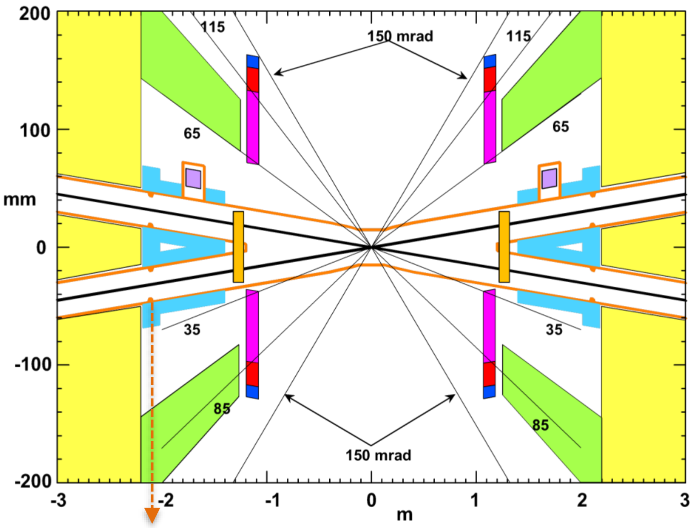
Synchrotron Radiation in the IR

- To fulfil the requirement that **$E_{critical}$ from dipoles is < 100 keV** from ~ 500m from IP, special optics has been developed
  [ref. : 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

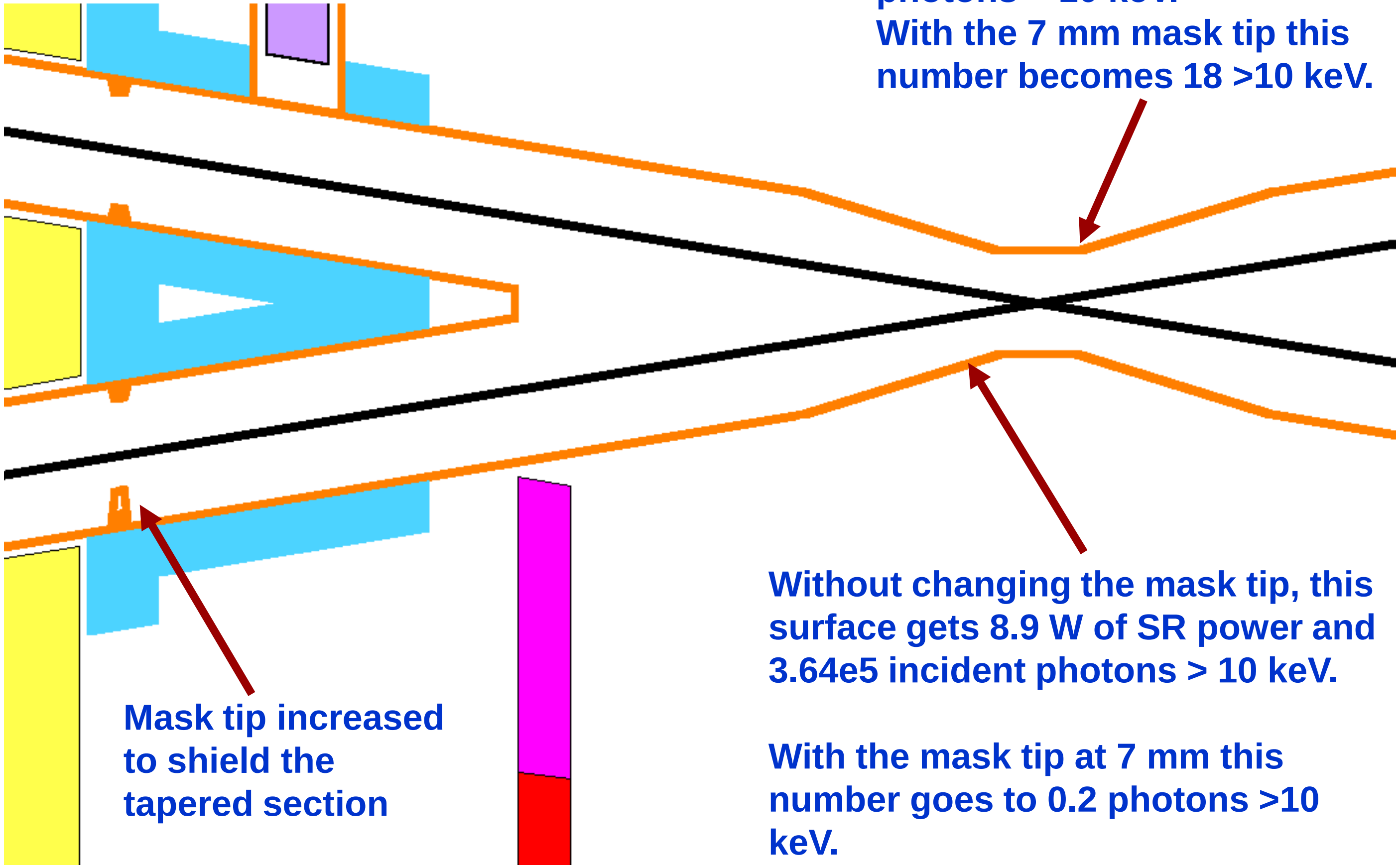


mask tips prevent FF quad radiation from striking nearby beam pipe elements

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

New beam pipe – Z case

- 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



FF SR strikes here with 903 photons > 10 keV.
With the 7 mm mask tip this number becomes 18 >10 keV.

Mask tip increased to shield the tapered section

Without changing the mask tip, this surface gets 8.9 W of SR power and 3.64e5 incident photons > 10 keV.

With the mask tip at 7 mm this number goes to 0.2 photons >10 keV.

Summary

- 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 can not be totally masked away even with a 5 mm radius mask at -2.1 m

Synchrotron Radiation in the IR

Still a lot of work to be done:

- **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

Beam induced backgrounds

Two main classes:

- **Synchrotron Radiation**
- **Beam particles effects (e^+, e^-, e^+e^-)**
  - Beamstrahlung
    - Incoherent/ Coherent e^+e^- Pair Creation
    - $\gamma\gamma$ to hadrons
  - beam-gas elastic and inelastic
  - Thermal photon Compton scattering
  - Radiative Bhabha

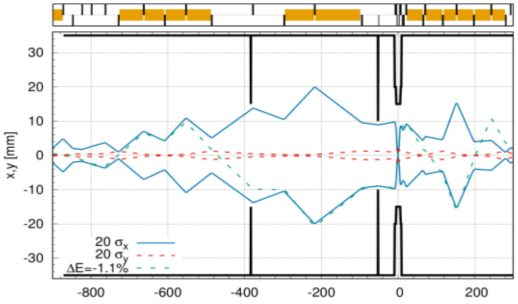
PURPLE: collision induced backgrounds

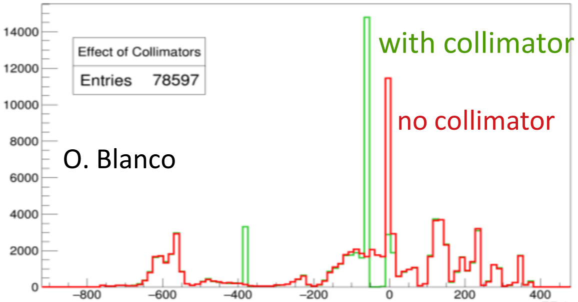
GREEN: single beam backgrounds

Impact of backgrounds studied in detector designs CLD & IDEA

Single Beam induced backgrounds

aperture reduced to 10 mm (20 σ_x)





example of
off-momentum collimator

- **Inelastic beam-gas** simulation performed with MDISim (MADX+GEANT4) and scattered particles tracked into the lumical -> negligible background source

- Particle tracking code that reads MADX matrix elements and tracks particles according to the process to be studied -> first results next Wedn. 18/9 (by A. Ciarma, LNF) for
- **Elastic beam-gas** scattering
- **Radiative Bhabha loss map next** (Oide-san will show results with BBBrem+SAD on Thurs. 12/9)
- **Touschek IR lossess**

- **Touschek** scattering: expected not to be relevant but check of IR beam losses planned
  Touschek lifetime ~15/30 hrs at Z, evaluated with MADX and SAD

- **Thermal photons** backgrounds being studied by H. Burkhardt (see talk on 18/9)

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

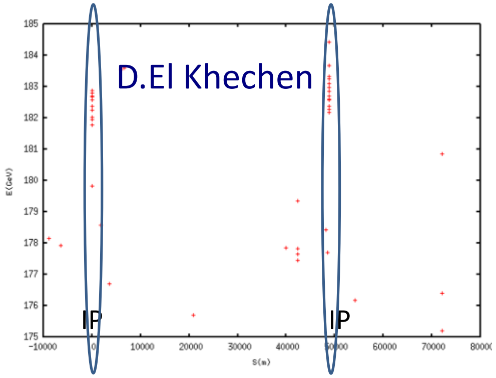
Impact of backgrounds evaluated in detectors CLD & IDEA

- **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

IP backgrounds: $\gamma\gamma$ to hadrons

- Direct production of hadrons, or indirect, where one or both photons interact hadronically
- Simulation with a combination of Guinea Pig and Phythia
- The effect of this background source is confirmed to be small

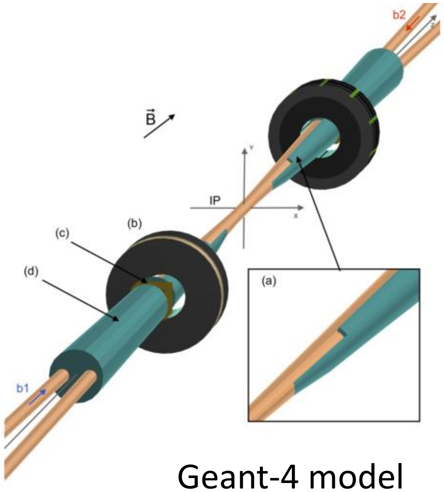

D.El Khechen

- **Beamstrahlung** loss map through the ring to be continued
- Beamstrahlung photons produced at IR

- **Radiative Bhabha** loss map: Oide-san will show results with BBBrem+SAD on Thursday 12/9, plan is to study it also with BBBrem+MADX

Experimental environment & luminometer

- **Keep refining the studies** on the impact of the various backgrounds on the detector performance and impact on the luminometer, for example:
    - detector performance with smaller beam pipe
    - **collimation system to minimize SR**
    - **track particles in detector from all backgrounds processes**



Geant-4 model

All of above is dynamic as the detector description becomes more refined and the engineering of the IR progresses

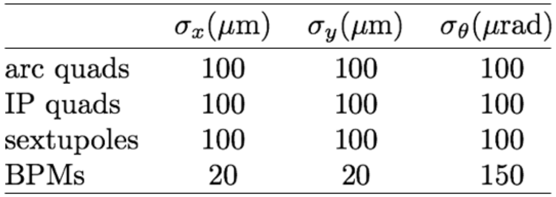
Software

- Essential part of FCC studies is using, interfacing and further developing standard programs of general interest , in particular MAD-X, ROOT, GEANT4 (combined in MDISim) and SAD
- This activity is strictly connected with the beam backgrounds simulations and with the tracking into the detector and luminometer
- We need to close the loop between MDISim and the Geant4 detector model
- … Gerardo Ganis will tell us (18/9) about his plan with his team for the FCC Software

Engineering: toward the TDR

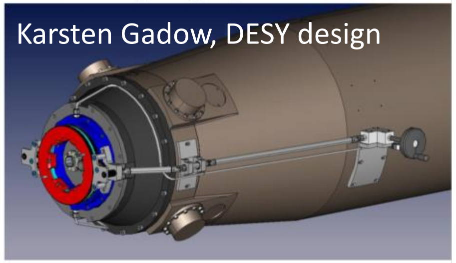
- Mechanical design and integration
- IR magnets: Final focus quads and anti-solenoids
- Engineered design of IR components like: diagnostics (BPM), flanges, bellows to be included in the mechanical design
- HOM absorbers
- Beam pipe cooling system
- Cryostat support and remote vacuum connection
- Lumical support and alignment
- Vibration control

alignment tolerances



	$\sigma_x(\mu\mathrm{m})$	$\sigma_y(\mu\mathrm{m})$	$\sigma_\theta(\mu\mathrm{rad})$
arc quads	100	100	100
IP quads	100	100	100
sextupoles	100	100	100
BPMs	20	20	150

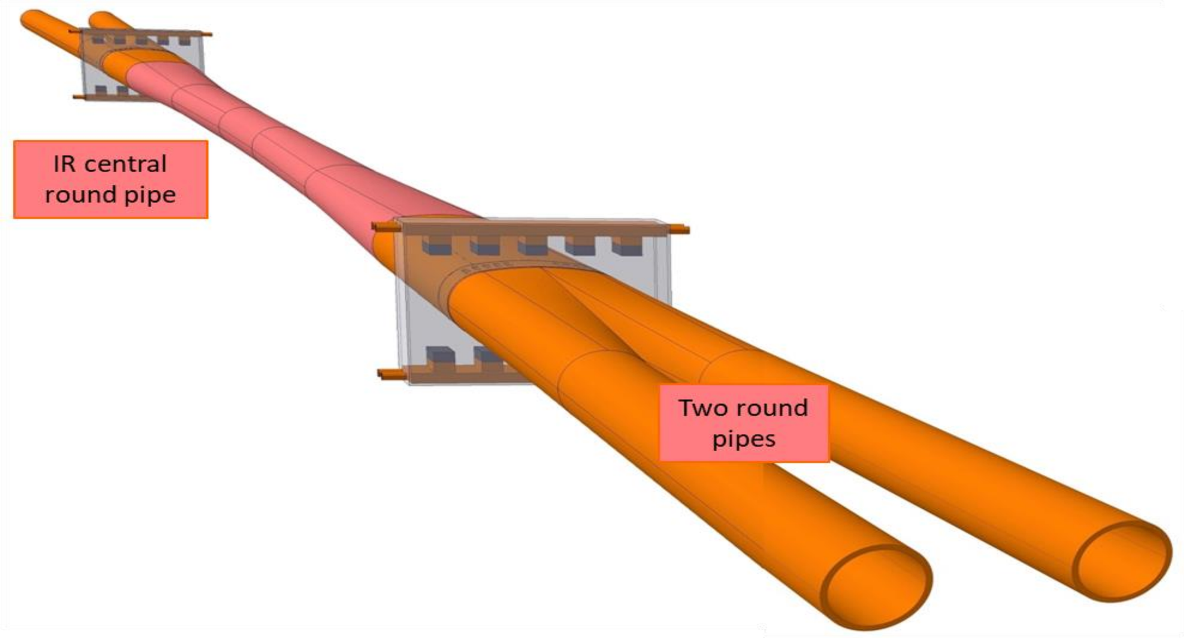
Remote flange and gears, rods on the cryostat



Karsten Gadow, DESY design

Some are standard features, other require a custom study

The choice of the IR beam pipe



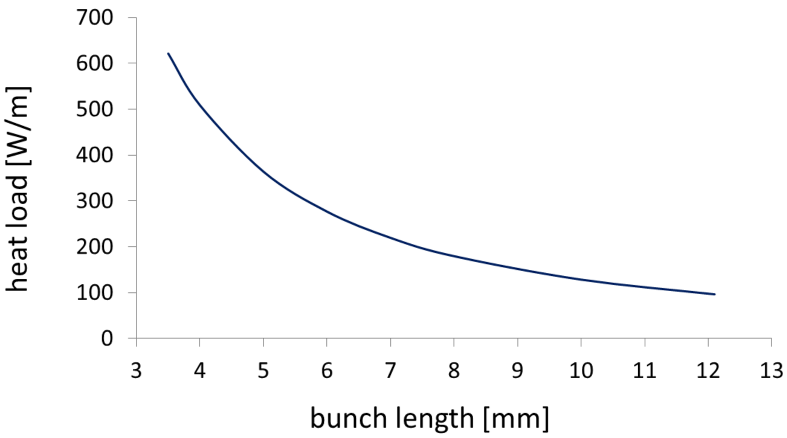
In the design we tried to achieve the minimum of the electromagnetic interaction of the colliding beams with metal walls of the IR beam pipe.

We developed a special smooth transition from two beam pipes to a common central pipe.

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%



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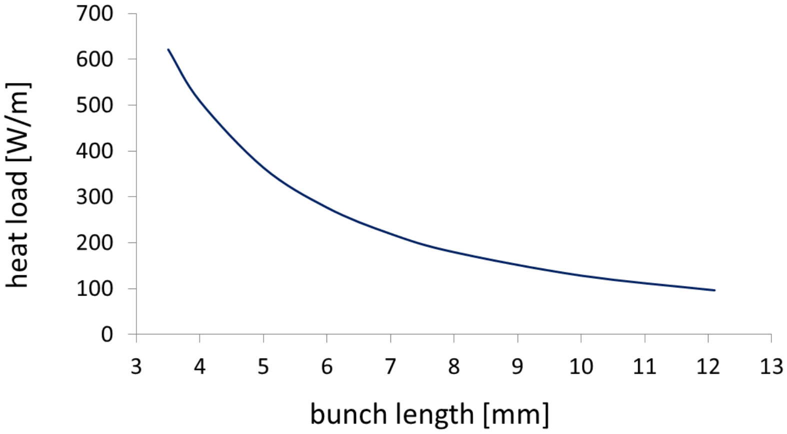


Summary

- Examining the IR beam pipe carefully, we found a way to reduce the impedance of the trapped mode. This progress shows how important each element of the beam pipe surface is.
- However, HOM absorber is still needed.
- Analyses of the smaller central beam pipe shows that geometrical wake field do not change much.
- However, the heat load coming from the resistive – wall wake fields becomes more important.
- The central beryllium tube requires increasing cooling with decreasing the beam pipe diameter.
- First estimates show that this problem can be technically solved.

Some concerns on the assembly

- Remote vacuum connection
- Central chamber support
- Cooling pipe space for central detectors
- Space for lumical, cryostat, NEG pump, HOM absorbers, shielding

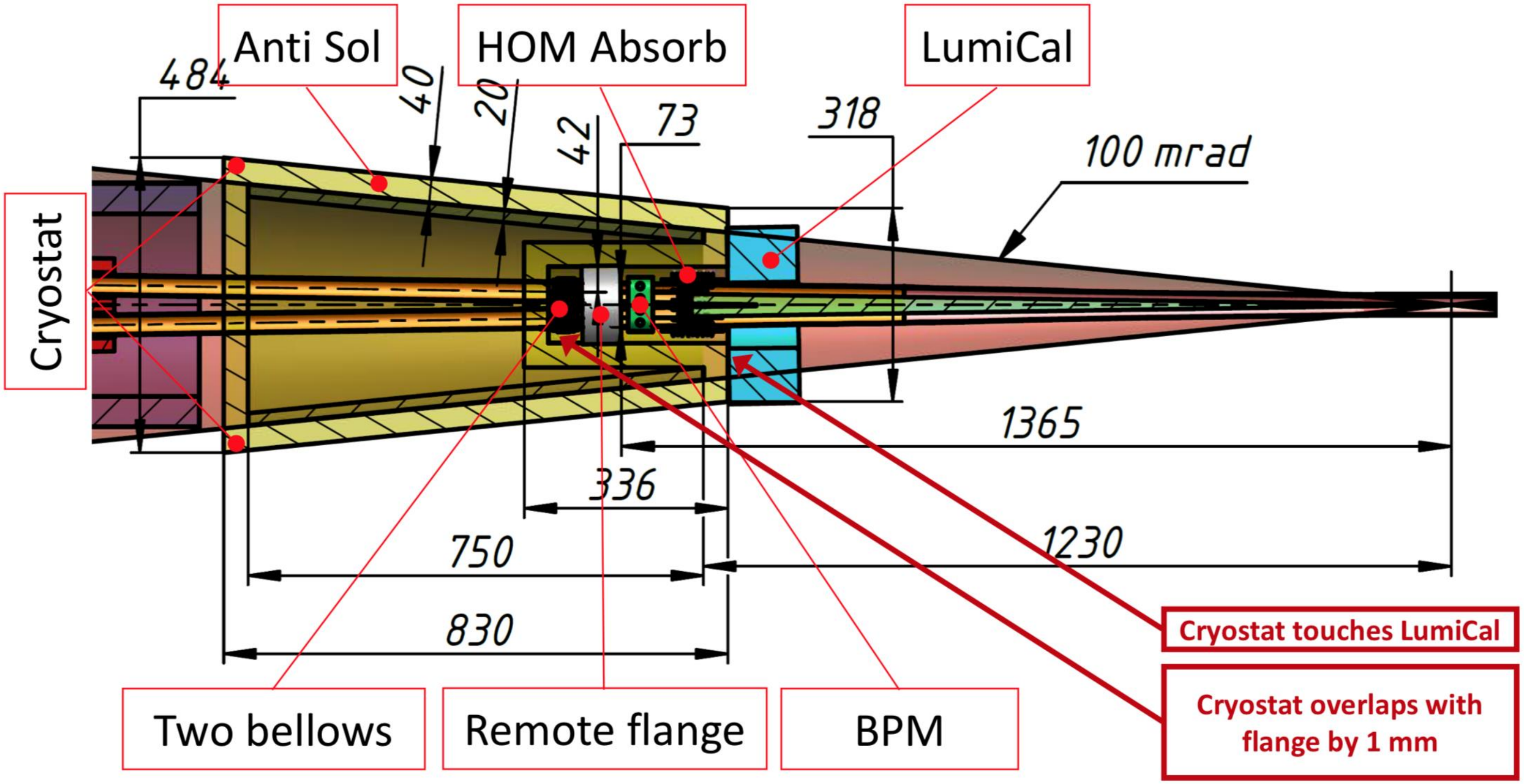
Mechanical design & integration

Goal:

- Try to converge on a design of the IR with sufficient details to constitute a **real engineering baseline**
- Understand **installation procedures**, mechanical detector interfaces, detector and machine elements accessibility for maintenance/upgrades
- **Mechanical stability** and **position precisions** of some detector elements (i.e. Lumical) is a relevant element to consider in the design
- Better define the general strategy for **services** in and out of the detector

E. Levichev, fcc week 2019

Baseline (with M. Koratzinos' dimensions)



Anti Sol

HOM Absorb

LumiCal

Cryostat

Two bellows

Remote flange

BPM

Cryostat touches LumiCal

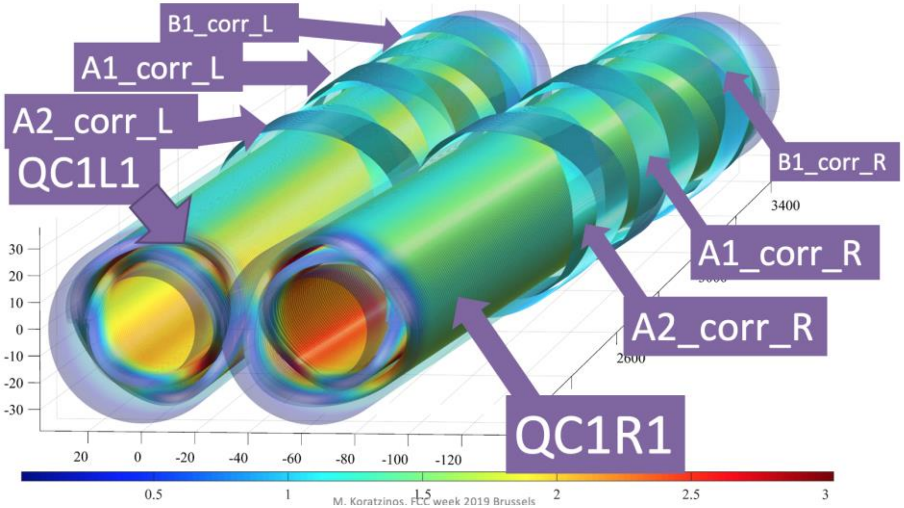
Cryostat overlaps with flange by 1 mm

Conclusion

IR/MDI is very critical system for the FCC-ee performance. To be sure in the IR/MDI mechanical design, we need

- 3D magnetic field map
- 3D force map
- Collect requirements for the MDI area from accelerator/detector experts
- Design separately all the systems/components (magnets, vacuum, cryo, …)
- Integrate all the components is the blocks
- Integrate the accelerator blocks in the detector

Final Focus quadrupole: CCT project



M. Koratzinos, FCC week 2019 Brussels

What has been achieved so far:

- Conceptual design
- Final magnetic design
- Final mechanical design
- Manufacturing
- Set up of the winding table (motorized)

To be performed:

- Winding of the magnet
- Test at warm
- Test at cold
- impregnation
- Test at cold of impregnated magnet

Timescales:

The timescale of the project critically depends firstly on the manufacturing of the test (rotating) probe and secondly on the availability of a small cryostat for cold testing

- Winding of the magnet July 2019 – one week
- Test at warm: starting when testing probe would be ready – one week
- Test at cold: starting when cryostat would be ready – one week
- Impregnation: one week
- Test at cold of impregnated magnet: starting at next available slot of cryostat

Summary

- A CAD design of the MDI area would be as a starting point toward the next phase after the CDR.

- With a mechanical design of the MDI area we will understand its feasibility.
- We need to pass the informations we have to the experts that are ready to start working on a CAD model.

- All other topics related to MDI go on in parallel, are progressing (i.e. beam dynamics, beam losses from main processes, collimators, SR, ...)

Back-up

Some related references

- **CDR**
- MDI meetings: https://indico.cern.ch/category/5665/
- 1st MDI workshop http://indico.cern.ch/event/596695
- 2nd MDI workshop https://indico.cern.ch/event/694811
- K. Oide et al, *Design of beam optics for the future circular e+e- collider rings*, PR-AB 19, 111005 (2016) link:
- M. Boscolo, H. Burkhardt, M. Sullivan, *Machine detector interface studies: Layout and synchrotron radiation estimate in the future circular collider interaction region*, PR-AB 20, 011008 (2017) link
- A. Novokhatski, M. Sullivan, E. Belli, M.G. Costa, R. Kersevan, *Unavoidable trapped mode in the interaction region of colliding beams*, PR-AB 20, 111005 (2017) link
- E. Belli et al, PR-AB 21, 111002 (2018) link
- H Burkhardt and M Boscolo, *Tools for flexible optimisation of IR designs with application to FCC*, IPAC15-TUPTY031 (2015)
- M Boscolo, O R Blanco-Garcia, H Burkhardt, F Collamati, R Kersavn, M Lueckhof, *Beam-gas background characterization in the FCC-ee IR, Phys.: Conf. Ser.* **1067** 022012 (2018) link
- M Boscolo et al, *Machine detector interface for the e+e- future circular collider*, 62th ICFA ABDW on high luminosity circular e+e- colliders, eeFACT18, Hong Kong (2019) link

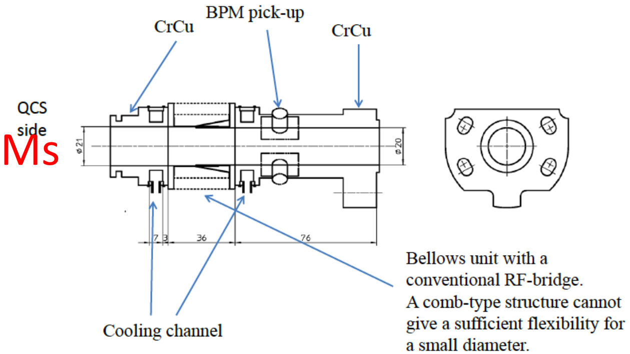
BPM

- 3 BPMs in the IR:
  - 1 before QC1
  - 1 between first and second section of QC1
  - 1 between QC1 and QC2
- **Special BMPs** in IR needed due to space constraint: smaller than standard ones (~1 cm long instead of 4-5cm)

Phase 2 hardware

BPM-bellows tube between IP chamber and QCS

Superkekb BPMs



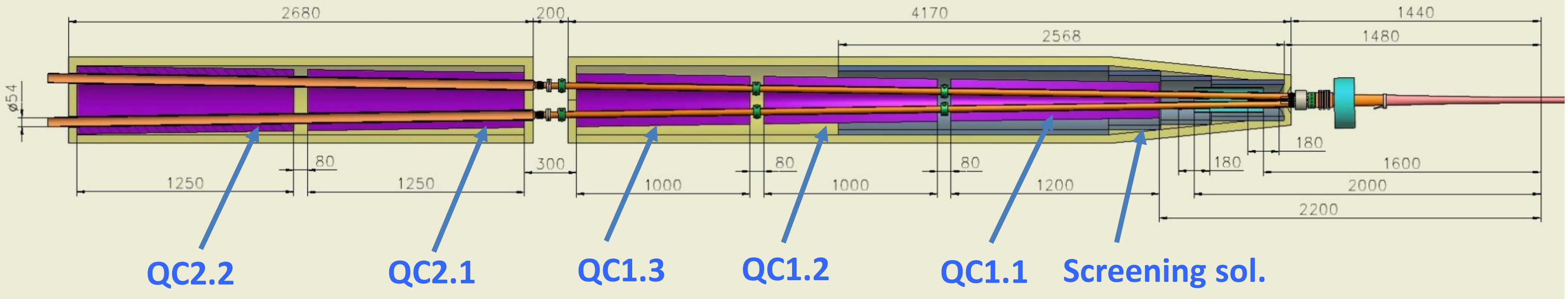
Bellows unit with a conventional RF-bridge. A comb-type structure cannot give a sufficient flexibility for a small diameter.

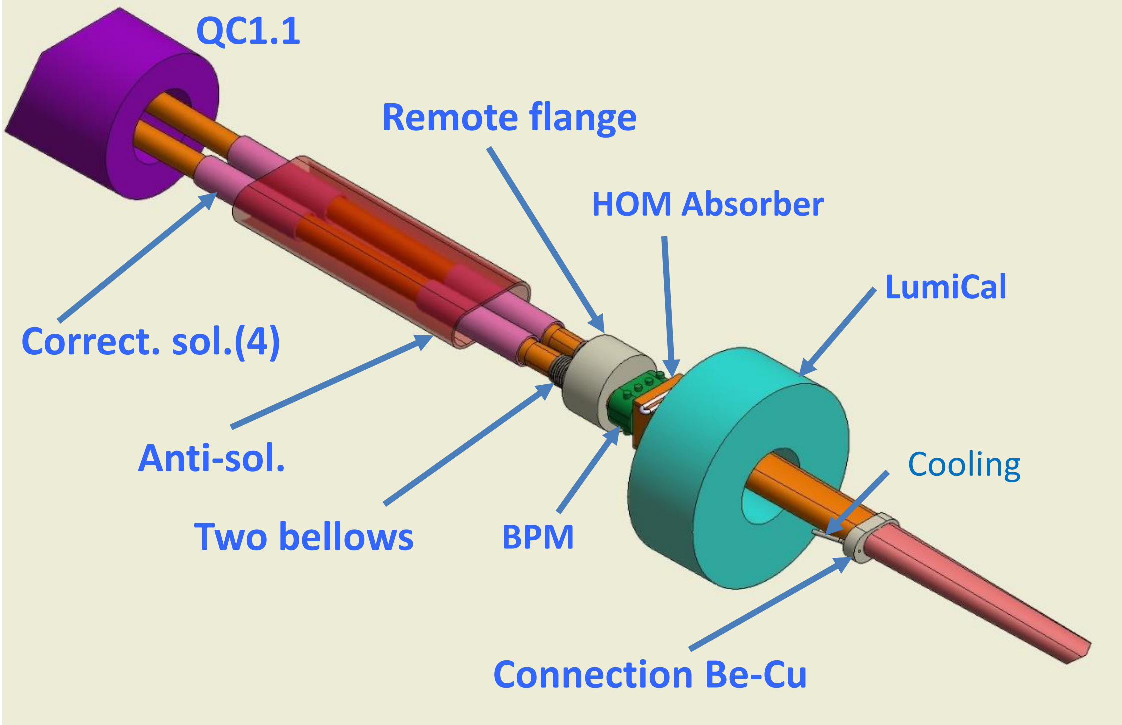
transversely fixed to the beam pipe, but longitudinally free to move with temperature variations

BPM-bellows tube

3D conceptual design Interaction Region.

BINP





Cryostat "walls" thickness.

Outer SS wall 10 mm

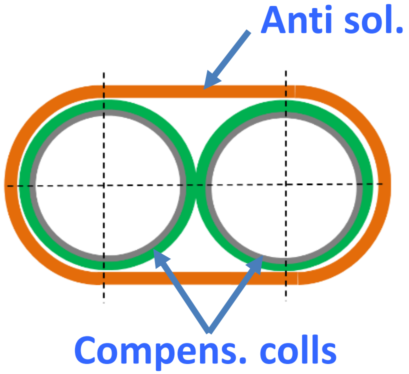
10 mm vacuumn

Thermal shield 3 mm

10 mm vacuum

Inner wall 6 mm

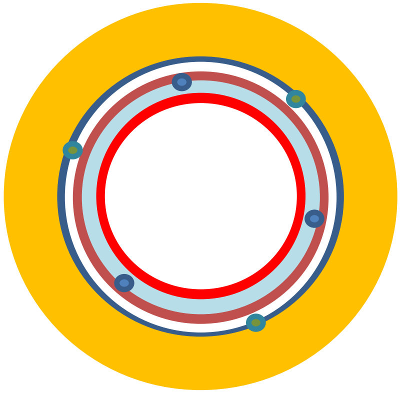
In total: ~40…45 mm



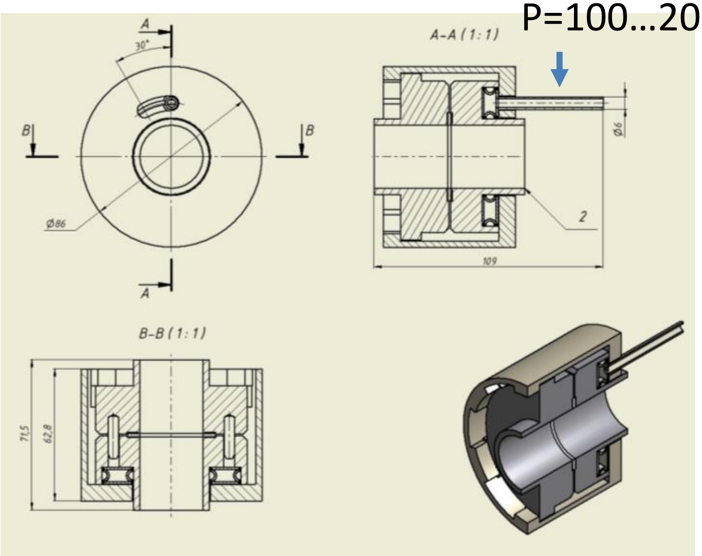
BINP

Vacuum chamber inside the cryostat

Rough estimation shows for the SCTF MDI vacuum chamber ~100 W/m thermal load due to HOMs and image currents. The task is to develop, produce and test a prototype for the multilayer vacuum chamber inside the cryostat providing tolerable heating of FF magnets.

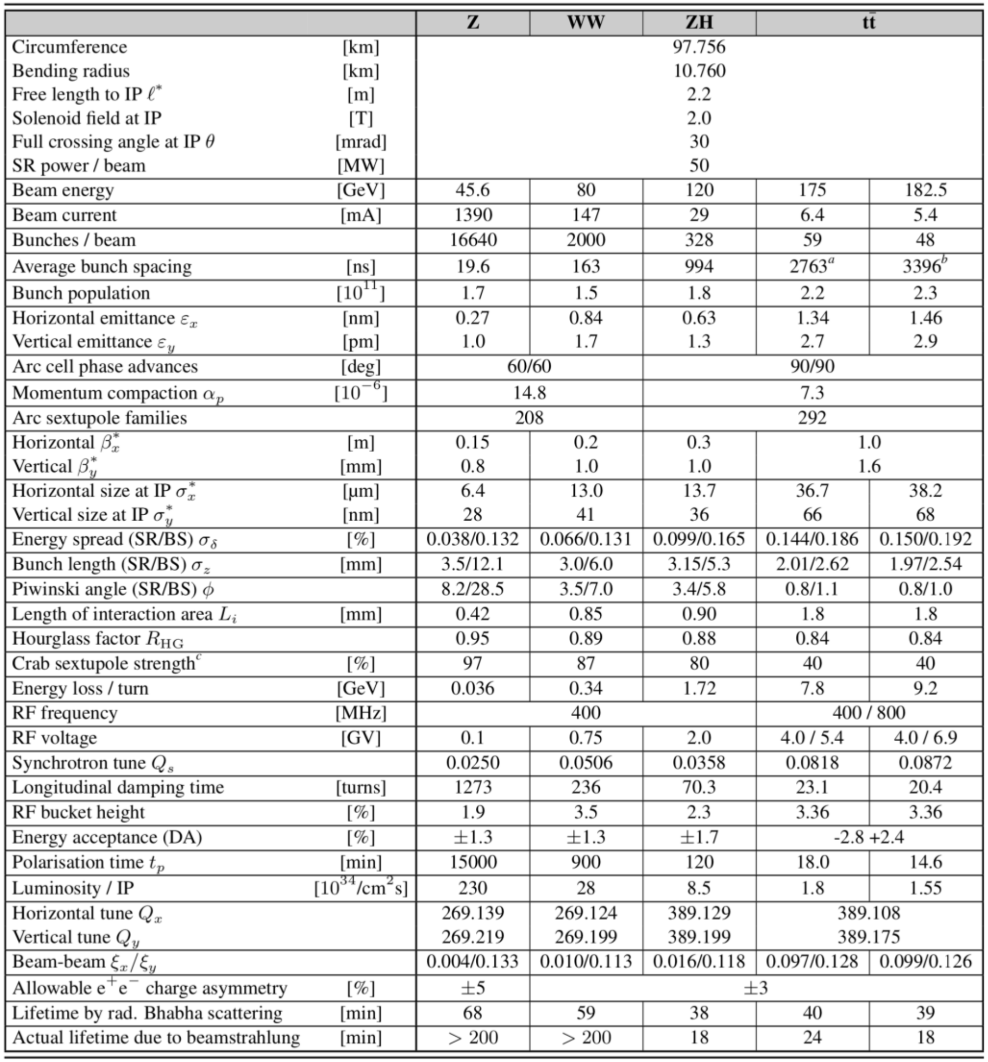


- 🟥 Inner vessel 0.7 mm thick with copper coating, T=300K
- ▣ 0.7 mm cooling water gap against HOM & IC
- 🟥 Vacuum tube 0.7 mm with mirror-like coating (Cu or Au), T=300K
- ☐ 0.9 mm vacuum gap
- ■ Outer 1 mm vessel coated by Cu, T=4.2K
- 🟨 Superconducting coil on a mandrel



P=100…200 bar

Remote flange prototype



		Z	**WW**	**ZH**	**$t\bar{t}$**	
Circumference	[km]	97.756				
Bending radius	[km]	10.760				
Free length to IP ℓ^*	[m]	2.2				
Solenoid field at IP	[T]	2.0				
Full crossing angle at IP θ	[mrad]	30				
SR power / beam	[MW]	50				
Beam energy	[GeV]	45.6	80	120	175	182.5
Beam current	[mA]	1390	147	29	6.4	5.4
Bunches / beam		16640	2000	328	59	48
Average bunch spacing	[ns]	19.6	163	994	2763[a]	3396[b]
Bunch population	[10^{11}]	1.7	1.5	1.8	2.2	2.3
Horizontal emittance ε_x	[nm]	0.27	0.84	0.63	1.34	1.46
Vertical emittance ε_y	[pm]	1.0	1.7	1.3	2.7	2.9
Arc cell phase advances	[deg]	60/60		90/90		
Momentum compaction α_p	[10^{-6}]	14.8		7.3		
Arc sextupole families		208		292		
Horizontal β_x^*	[m]	0.15	0.2	0.3	1.0	
Vertical β_y^*	[mm]	0.8	1.0	1.0	1.6	
Horizontal size at IP σ_x^*	[µm]	6.4	13.0	13.7	36.7	38.2
Vertical size at IP σ_y^*	[nm]	28	41	36	66	68
Energy spread (SR/BS) σ_δ	[%]	0.038/0.132	0.066/0.131	0.099/0.165	0.144/0.186	0.150/0.192
Bunch length (SR/BS) σ_z	[mm]	3.5/12.1	3.0/6.0	3.15/5.3	2.01/2.62	1.97/2.54
Piwinski angle (SR/BS) ϕ		8.2/28.5	3.5/7.0	3.4/5.8	0.8/1.1	0.8/1.0
Length of interaction area L_i	[mm]	0.42	0.85	0.90	1.8	1.8
Hourglass factor R_{HG}		0.95	0.89	0.88	0.84	0.84
Crab sextupole strength[c]	[%]	97	87	80	40	40
Energy loss / turn	[GeV]	0.036	0.34	1.72	7.8	9.2
RF frequency	[MHz]	400			400 / 800	
RF voltage	[GV]	0.1	0.75	2.0	4.0 / 5.4	4.0 / 6.9
Synchrotron tune Q_s		0.0250	0.0506	0.0358	0.0818	0.0872
Longitudinal damping time	[turns]	1273	236	70.3	23.1	20.4
RF bucket height	[%]	1.9	3.5	2.3	3.36	3.36
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.4	
Polarisation time t_p	[min]	15000	900	120	18.0	14.6
Luminosity / IP	[10^{34}/cm^{2}s]	230	28	8.5	1.8	1.55
Horizontal tune Q_x		269.139	269.124	389.129	389.108	
Vertical tune Q_y		269.219	269.199	389.199	389.175	
Beam-beam ξ_x/ξ_y		0.004/0.133	0.010/0.113	0.016/0.118	0.097/0.128	0.099/0.126
Allowable e^+e^- charge asymmetry	[%]	±5	±3			
Lifetime by rad. Bhabha scattering	[min]	68	59	38	40	39
Actual lifetime due to beamstrahlung	[min]	> 200	> 200	18	24	18

[CDR]

Comparison of Site Vibration

Presented by R. Deng (SINAP)@GM2017@IHEP

M. Masuzawa , “Superkekb vibration measurement and collision feedback’ 2nd MDI workshop 2018

	Peak to Peak distribution		without highest 5%		Selected Data	
Location	**Maximum pp (nm)**	**FWHM (nm)**	**Average RMS (nm)**	**SD σ (nm)**	**Quiet RMS (nm)**	**Noisy RMS (nm)**
1 Seismic Station Moxa	7	17	0.6	0.1	0.5	0.9
2 Salt Mine Asse	12	35	0.5	0.1	0.5	0.7
3 CERN LHC Tunnel	21	53	1.8	0.8	0.9	2.9
4 Spring-8 Harima	22	40	2.0	0.4	1.8	2.5
5 FNAL Batavia	23	49	2.9	0.9	2.2	4.0
6 LAPP Annecy	35	59	3.3	1.6	1.9	7.0
7 IHEP Beijing	49	18	8.4	0.5	8.1	9.0
8 SLAC Menlo Park	60	105	4.8	1.2	4.1	7.4
9 APS Argonne	68	56	10.5	1.0	9.8	11.0
10 ALBA Cerdanyola	87	125	18.3	9.5	9.1	42.0
11 DESY TESLA	104	160	17.4	8.4	9.3	35.9
12 DESY XFEL Osdorf	150	195	28.9	11.9	19.5	48.4
13 DESY Zeuthen	105	235	64.0	40.4	88.5	75.6
14 ESRF Grenoble	155	175	71.6	34.9	40.2	137.2
15 DESY XFEL Schenefeld	180	245	38.7	16.6	35.1	70.0
16 DESY HERA	170	200	51.8	18.9	34.8	77.0
17 KEK Tsukuba	170	210	78.0	36.0	38.0	125.1
18 BESSY Berlin	245	160	72.8	28.1	53.1	140.7
19 SSRF Shanghai	550	1000	292	164	102	444

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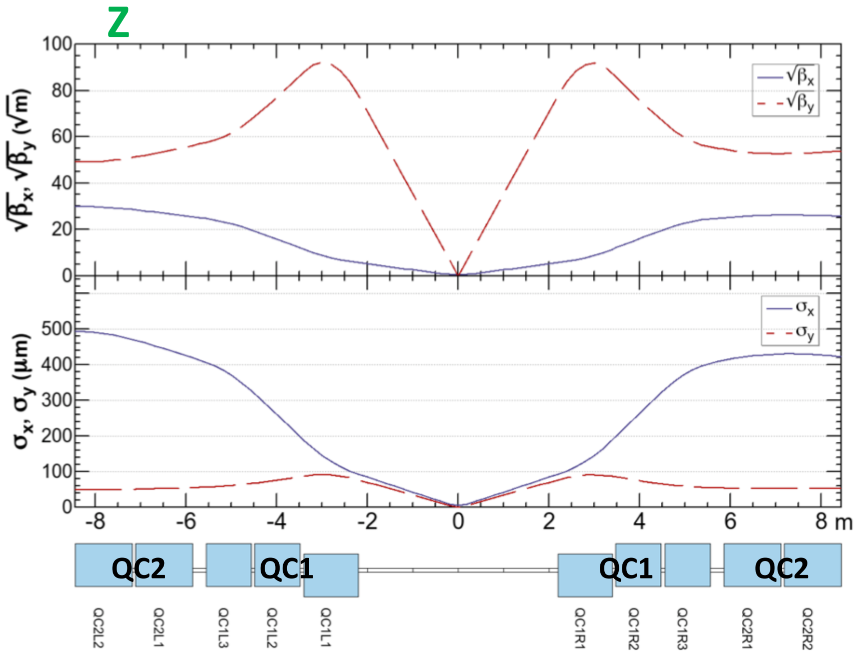
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

Courtesy of H. Ehrlichmann

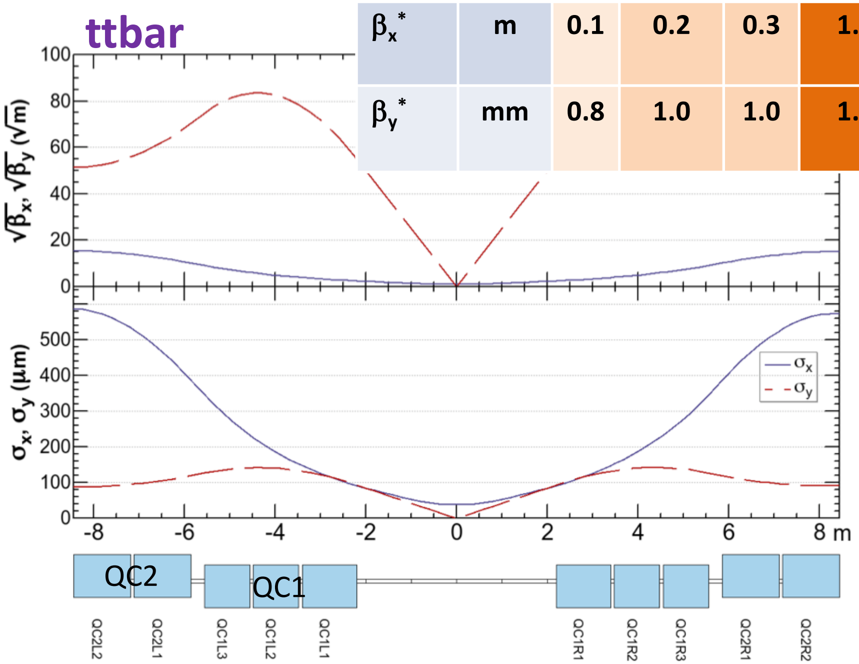
GM2017

Final Focus optics

		Z	W^+W^-	ZH	ttbar
β_x^*	m	0.1	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

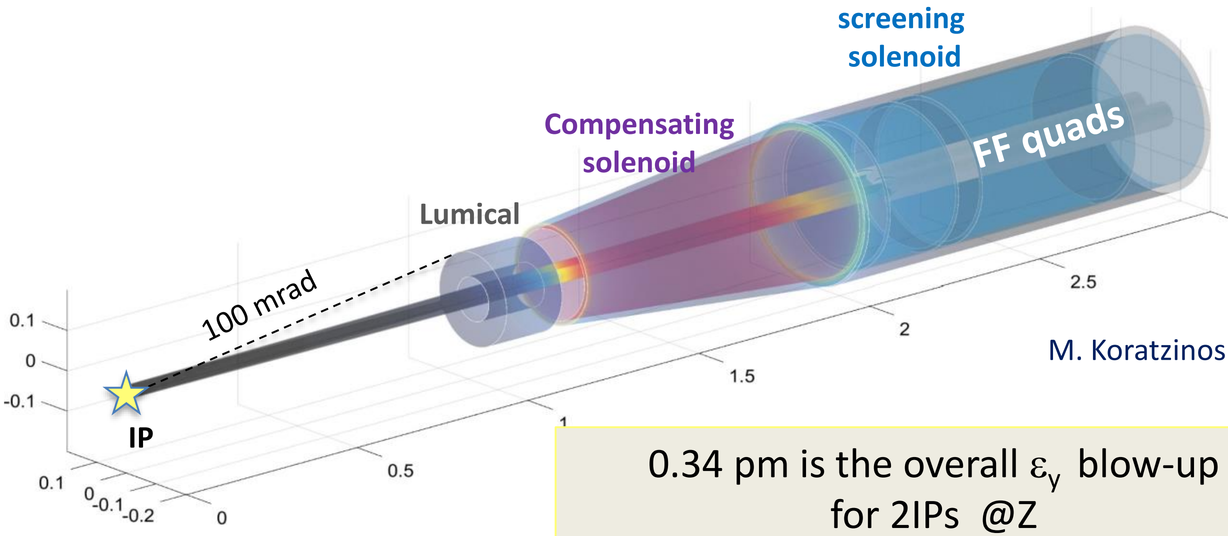


All 3 slices of QC1 are defocusing horizontally

- 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

Baseline for 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

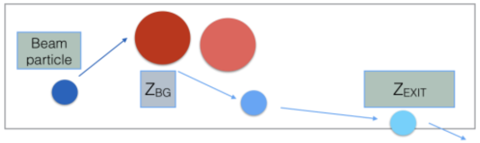
The discussion on the mechanical integration is actually bringing to improvements of this scheme, due to space constraints

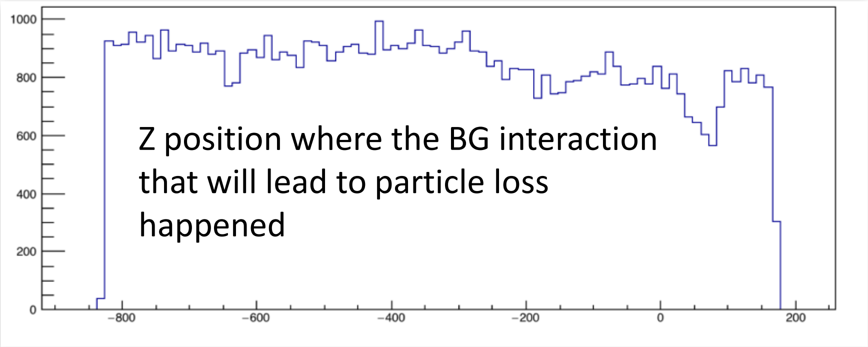
0.34 pm is the overall ε_y blow-up for 2IPs @Z

detector solenoid dimensions 3.76m (inner radius) (outer radius 3.818m) × **4m** (half-length)
drift chamber at z=2m with 150 mrad opening angle (IDEA design)

Inelastic Beam Gas scattering in the IR

- MDISim was used to import in Geant4 beam pipe geometry + magnetic elements + beam characteristics

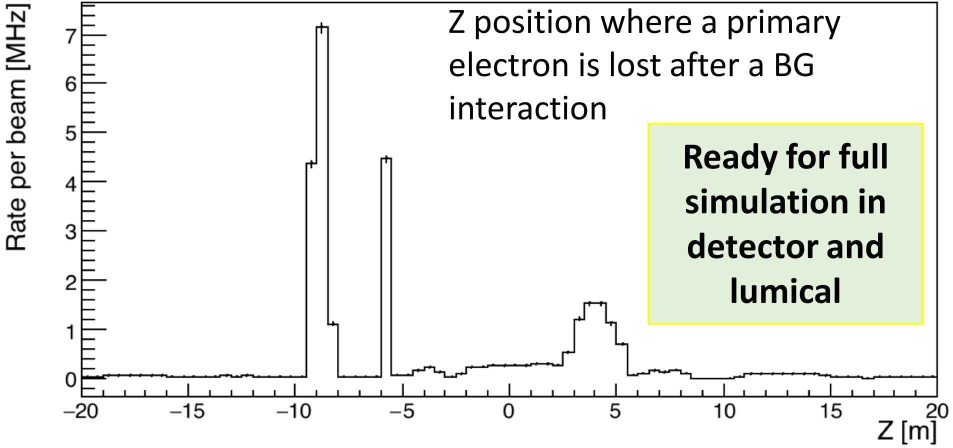




Z position where the BG interaction that will lead to particle loss happened

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

IR Loss map



Z position where a primary electron is lost after a BG interaction

Ready for full simulation in detector and lumical