INFN LNF
Istituto Nazionale di Fisica Nucleare

FUTURE CIRCULAR COLLIDER
Innovation Study

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.

MDI SUMMARY

Manuela Boscolo (INFN-LNF)

FCC WEEK 2023
London, 5-9 June 2023

FCC WEEK 2023 – MDI sessions

https://indico.cern.ch/event/1202105/

3 sessions

Tue. 6 + Wed. 7

90 min. each

Mechanical model, vertex integration, vibration studies

Backgrounds, losses, SR, beamstrahlung

IR magnets, IR BPMs, alignment

Version: 0.25 Date: 27.04.2023

Day / Time	Sunday	Monday	Tue Parallel 1	Tue Parallel 2	Tue Parallel 3	Tue Parallel 4	Tue Governance	Wed Parallel 1	Wed Parallel 2	Wed Parallel 3	Wed Parallel 4	Wed Governance	Thu Parallel 1	Thu Parallel 2	Thu Parallel 3	Thu Parallel 4	Thu Governance	Friday Plenary
	Registration desk	Plenary																
08:30-09:00		Opening	Baseline design	Physics Case + Theoretical calculations (I)	FCCIS WP3 Integrate Europe (I)	Industry day (tbc)		Optics correction	Detector requirements from Physics (I)	Technologies	FCC local communication activities		Injector (II)	EPOL (II)	Electricity and Energy Management	SRF Technology (I)		Summaries
09:00-09:30		Perspectives										Governance						
09:30-10:00																		
10:00-10:30		FCC FS Status	Coffee Break					Coffee Break					Coffee Break					
10:30-11:00		Coffee break	Collimation & collective effects	Physics Case + Theoretical calculations (II)	FCCIS WP3 Integrate Europe (II)	Industry day (tbc)		Injector (I)	Detector requirements from Physics (II)	Future magnet developments	FCC global communication activities		FCC-hh	Detectors technology (I)	Safety, Transport & Survey	SRF Technology (II)		
11:00-11:30		Baseline scenario & Host States																
11:30-12:00		Civil Engineering																
12:00-12:30			Lunch break				Scientific Advisory Committee	Lunch break					Lunch break					
12:30-13:00		Lunch break																
13:00-13:30																		END
13:30-14:00			Machine Detector Interface (I)	RF Points for FCC-ee	FCCIS WP4 Impact & Sustainability (I)	Industry day (tbc)		EPOL (I)	Civil Engineering	Directions for R&D	Machine Detector Interface (III)	Scientific writing	Code development	Software/Detector	Technologies	FCC-eh	Scientific Advisory Committee	
14:00-14:30		FCC Accelerator					FS Steering Committee											
14:30-15:00																		
15:00-15:30	Registration	Technical Infrastructure	Coffee Break					Coffee Break					Coffee Break					
15:30-16:00		Break	Machine Detector Interface (II)	Integration and Cooling	FCCIS WP4 Impact & Sustainability (II)	Industry day (tbc)		Plenary: UK Session					Alternative FCC-ee Optics Development	Detectors technology (II)	Technologies	Early Career Researchers		
16:00-16:30		Physics, Experiments, Detectors																
16:30-17:00																		
17:00-17:30												Governance session	Plenary: **poster session + wine & cheese** (Sentosa suite)					
17:30-18:00				International Collaboration Board					FCC - local institutes satellite session									
18:00-18:30		**Welcome reception**																
18:30-19:00																		
19:00-19:30													**Public event** (Royal Society)					
19:30-20:00																		
20:00-20:30								**Conference dinner**										
20:30-21:00																		
21:00-21:30																		
21:30 -22:00																		

Agenda 3 MDI Sessions

15 talks

MDI (I)	Convener: John Seeman (SLAC)
M. Boscolo	MDI overview
F. Palla	Mechanical integration of the IDEA detector in the IR
A. Ing	IDEA VXD implementation in full simulation
F. Fransesini	Mechanical model of the MDI
L. Brunetti	Towards mechanics and optics evaluation of the vibration effects for the MDI

MDI (II)	Convener: Manuela Boscolo (INFN-LNF)
Hiroyuki Nakayama	SuperKEKB MDI lessons
Giacomo Broggi	Beam Losses in the MDI
Kevin Andre	Synchrotron radiation background studies
Andrea Ciarma	Detector background simulations
Alessandro Frasca	Beamstrahlung dump and radiation levels in the experiment IRs

MDI (III)	Convener: Kathleen Amm (BNL)
Brett Parker (BNL)	SC IR magnets system
Carl J Eriksson (CERN)	Magnet design for beamstrahlung photons extraction line
Arnaud Foussat (CERN)	Preliminary design study of interaction region crab sextupole for FCC-ee collider
Leonard Watrelot (CNAM)	Alignment systems propositions to face the FCC-ee MDI challenges
Manfred Wendt (CERN)	Challenges for the IR BPMs

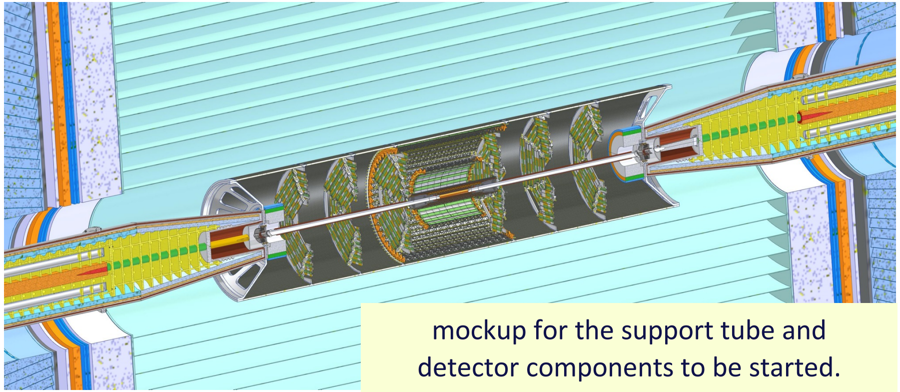
Progress since the last FCC WEEK 2022

- New placement and layout → optics with smaller circumference and **4IPs**
- **Mechanical model**
  - **engineering of beam pipe with cooling system**, and its support, up to the IR magnets
  - **vertex detector** designed, integrated in MDI, its software description implemented
  - integration of the **lumical**
  - **assembly** concept
- **Backgrounds** simulations
  - **beam losses** in the MDI: halo collimation scheme and first loss maps in the MDI
  - **synchrotron radiation** in the MDI: SR collimators and masking, constraints to the top-up injection
  - **detector backgrounds** simulations with refined and more realistic software model
- **Heat load** from wakefields, SR, and beam losses
- **Beamstrahlung** Photon dump
  - optimal location at 500 m from IP, study on the magnet aperture yoke to allow an extraction line
  - radiation studies with Fluka started
- And also : **IR magnets, IR BPMs**, feedback
- **Non-local solenoid compensation** – pros & cons under evaluation

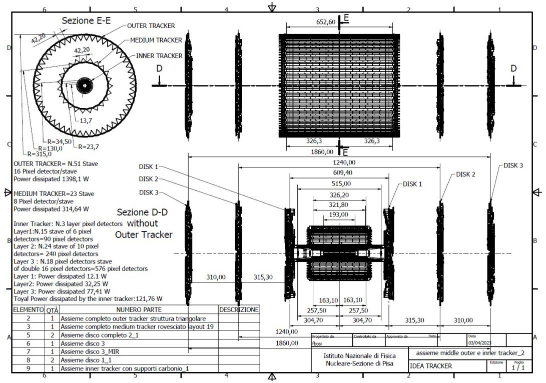
Fabrizio Palla (INFN-Pisa) & Francesco Fransesini (INFN-LNF)

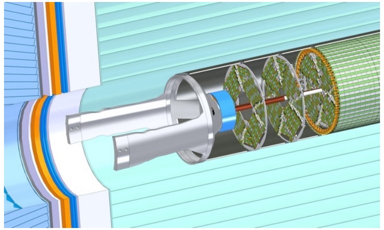
Mechanical integration of the IDEA VXD and Lumical

Ref: M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, *Mechanical model for the FCC-ee MDI,* EPJ+ Techn. and Instr., in publication



mockup for the support tube and detector components to be started.

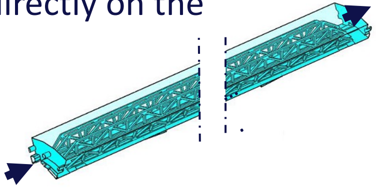




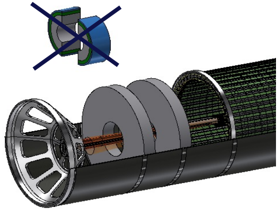
Fully engineered design of the Vertex:

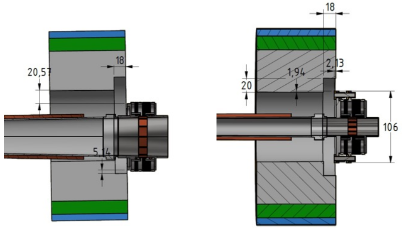
- 3 inner layers supported by the conical chamber and mounted with the beam pipe and Lumical to the support tube
- 2 outer layers and 6 disks mounted directly on the support tube.

Services design and routings in progress.



Study of the air cooling of the inner vertex ongoing (INFN-Perugia)

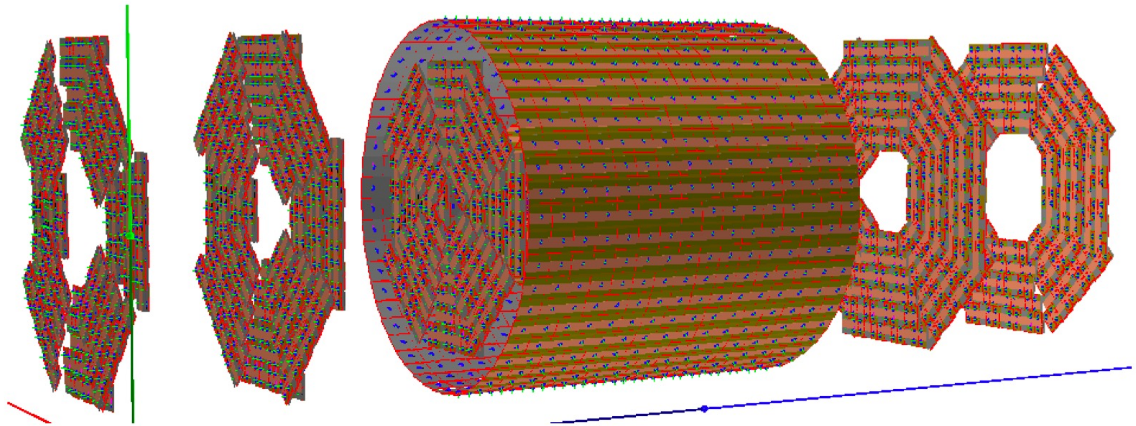




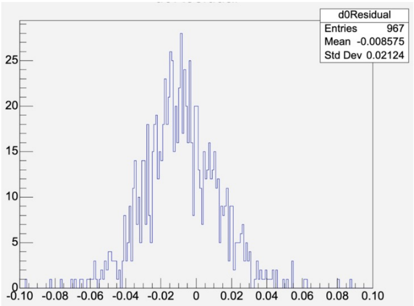
slight modification to allow assembly (<1% loss on energy)

Engineering of the lumical awaited

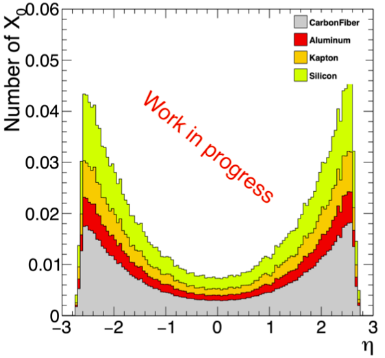
IDEA VXD implementation in key4hep full simulation



Complete geometry in IDEA vertex implementation in DD4hep



D_0 resolution in mm.



Vertex inner barrel

Material budget estimation of IDEA vertex in DD4hep in nice agreement with engineering estimates

Next steps

- Complex services and support structures, reassess material budget
- Accurate sensor periphery description in barrels (done in disks already)
- Add digitisation inside Key4hep
- Implement silicon wrapper, aim to have complete IDEA description in DD4hep

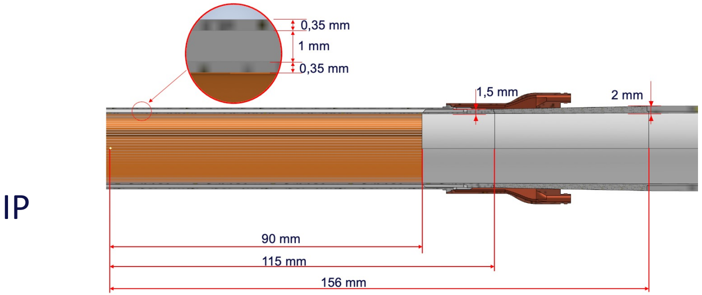
Done

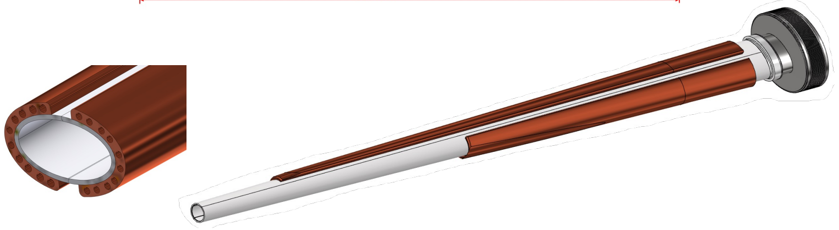
- First implementation of the IDEA vertex detector in DD4hep → Can get vertex simHits for other studies
- Track+vertex reconstruction using iLCSoft with k4MarlinWrapper → It's working!
- Preliminary material budget estimation

Francesco Fransesini (INFN-LNF)

Mechanical model of the MDI

Engineering of vacuum chambers from IP to 1.2 m done.

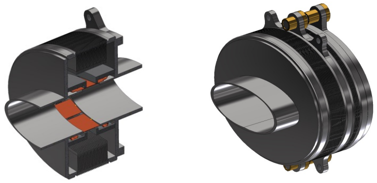




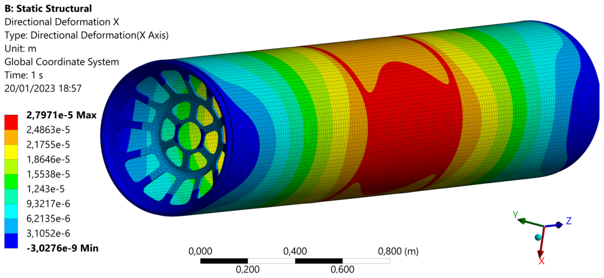
Asymmetric cooling channels due to the LumiCal acceptance requirements.

Thermo-structural analysis of chambers

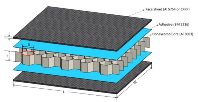
The **design of IR bellows is in progress,** together with impedance and wakefields calculations



ANSYS structural analysis of the support tube



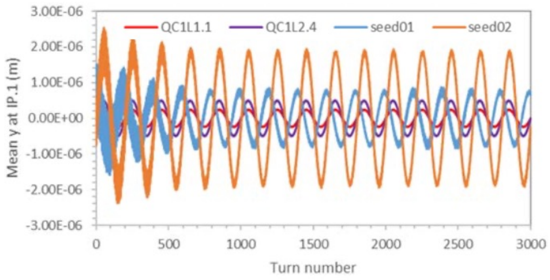
Lightweight carbon fiber& honeycomb tube walls



prototyping and mockup of chambers, bellows, and support tube to be started.

Towards mechanics and optics evaluation of the vibration effects for the MDI

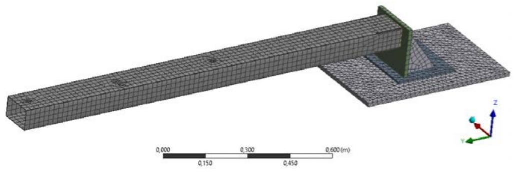
Optics: beam tracking studies



Setup tracking simulation:

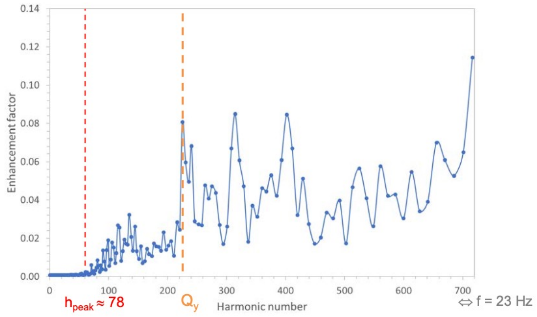
- sinusoidal vibration of all FFQs at 15 Hz with 1 µm of amplitude (first mode of vibration for SuperKEKB)
- Each FFQ contributes to the mean vertical offset at the IP.

Mechanics



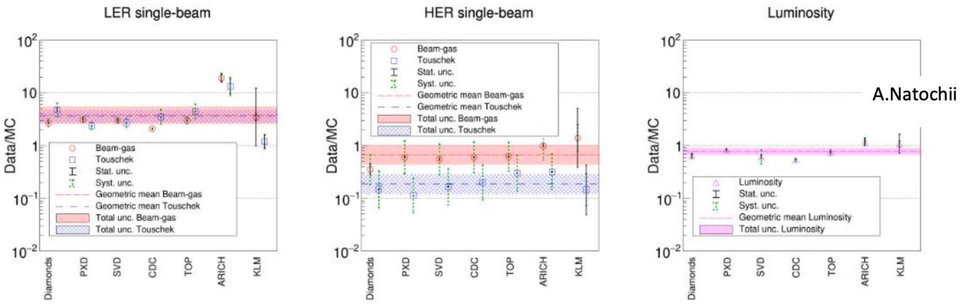
validation of the method on a cantilever beam prototype

Effect of plane ground waves on the closed orbit

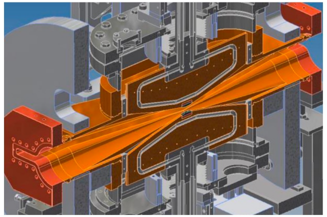


study performed with MADX, each quad of the ring is assumed with a vertical misalignment

SuperKEKB MDI Lessons

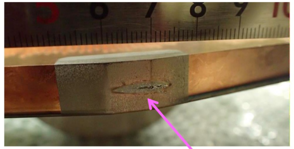


SuperKEKB-type vertical collimator



- Tungsten (or Tantalum) jaws were severely damaged and replaced several times.
- Low-Z head tip (carbon) was installed in 2020 but its impedance was found out to be too large (beam size blow-up due to TMC instability was observed)
- more robust heads are considered (MoGr, Ti, Ta+Gr)

Collimator head damaged by severe beam loss



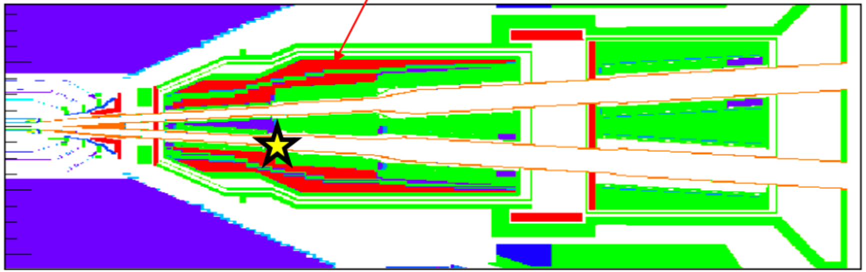
Scar along the beam line

- Data/MC ratio is now within one order of magnitude from unity (with improved simulation)
- Good understandings on beam loss processes

Sudden beam loss cause still remains unknown

Final design

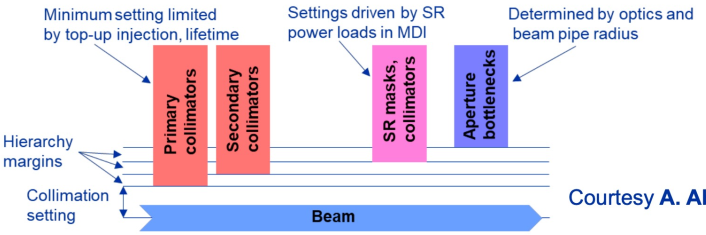
thick tungsten layers



Reserve space for the BG shields between detectors and beam pipes

Giacomo Broggi (CERN & Sapienza & INFN-LNF)

Beam Losses in the MDI

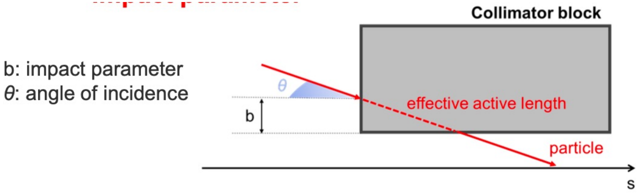


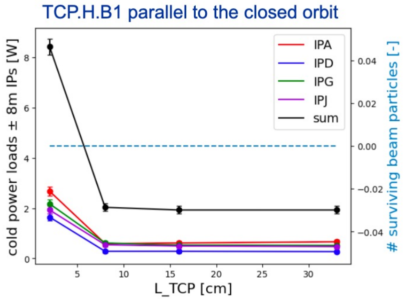
Courtesy **A. Abramov**

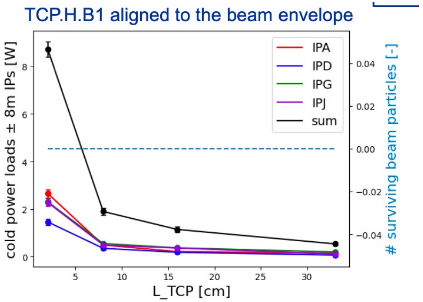
Evaluation of the halo collimation system performance

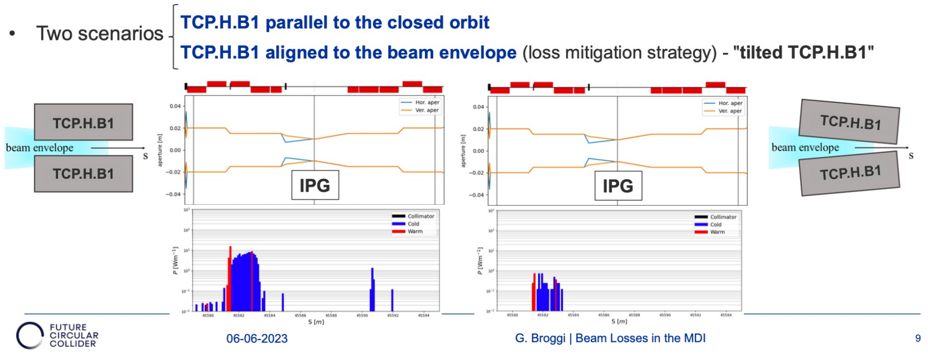
MDI beam losses (Xtrack-BDSIM)

- **Parametric scan of the primary collimator length** indicates 25-30 cm TCP (Two radiation-length primary collimators)
- **Impact parameter scan** study









Synchrotron Radiation backgrounds

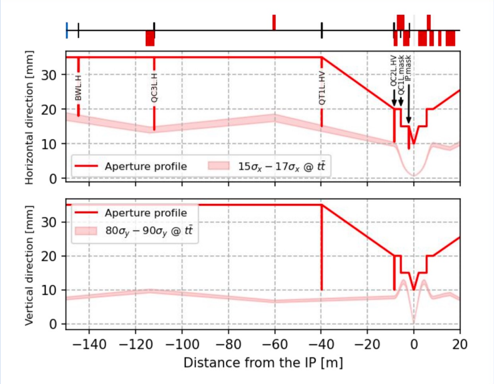
SR collimation scheme and symmetric masking designed
BDSIM (GEANT4) simulation, Gaussian core beam and tails

Synchrotron radiation collimation scheme

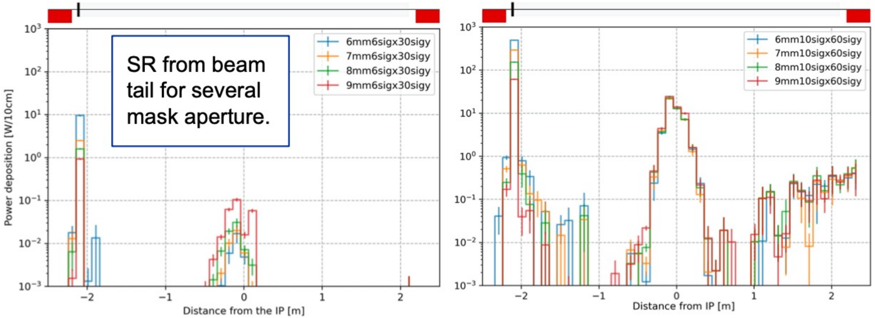
Name	s [m]	half-gap [m]	plane
BWL.H	-144.69	0.018	H
QC3L.H	-112.05	0.014	H
QT1L.H	-39.75	0.015	H
PQC2LE.H	-8.64	0.011	H
MSK.QC2L	-5.56	R = 0.015	H&V
MSK.QC1L	-2.12	0.007	H

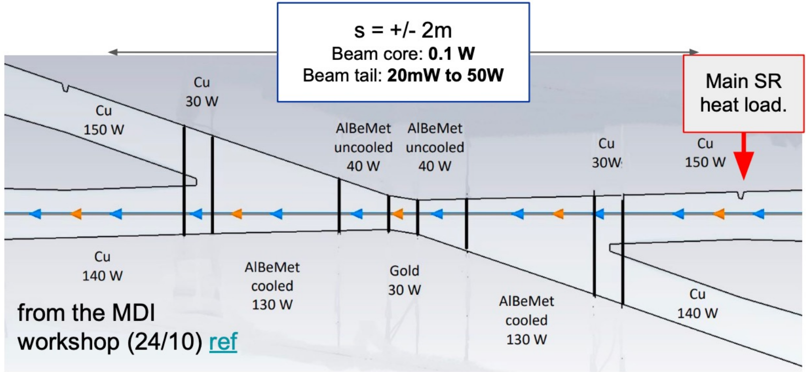
15 σ_x corresponds to the aperture of the **primary** collimators, **17 σ_x** corresponds to the aperture of the **secondary** collimators.

→ See A. Abramov talk for more details.



Heat Load from Synchrotron Radiation





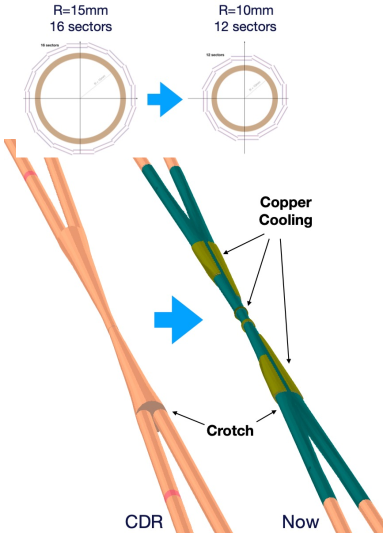
Off-axis top-up injection requires symmetric masks, heat load is low thanks to the damping

Heat Load from wakefields

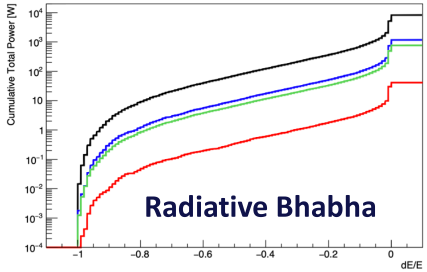
Detector background simulations

More realistic MDI software model implemented in key4hep:

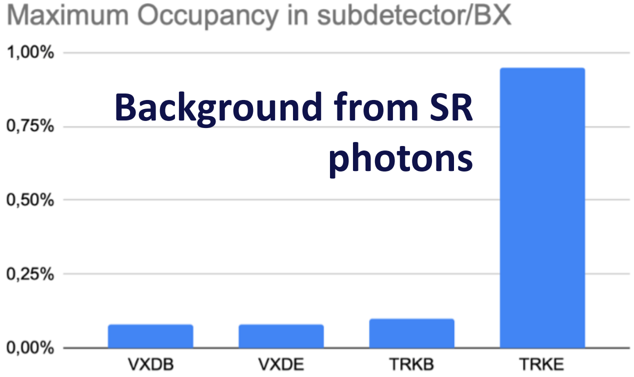
- CAD beam pipe
- lumical
- IR magnet and cryostat hollow shell
- CLD VXD adapted to the smaller 10mm radius beam pipe



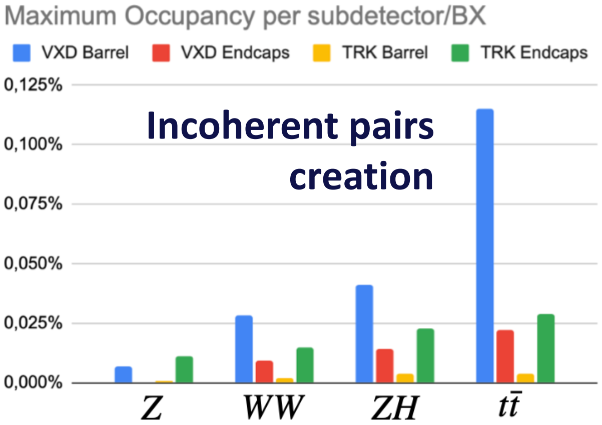
Energy Radiated [dE/E]		>2%	>10%	>50%
Power Carried by spent beam [W]	Z	1500	650	70
	WW	200	100	10
	ZH	150	60	6
	tt	8	3	0.3



from beam tails hitting SR mask tips

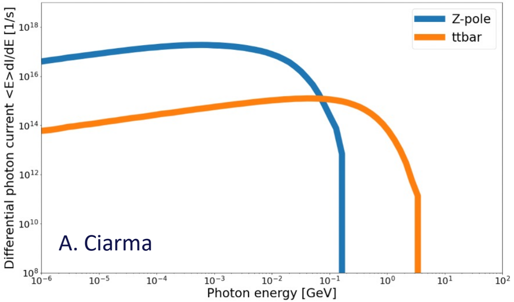


($t\bar{t}$ threshold - CDR beam parameters CLD detector - NO shieldings)



Beamstrahlung dump and radiation levels in the experiment IRs

- **Very intense beamstrahlung Radiation from the colliding beams**
- BS dump **external to the beamline at 500 m** after the IP
- Dump core under study with FLUKA (choice under discussion)
  - **graphite** (1.8 g/cm^3), cylindrical (3m long, 35 cm radius)
  - **liquid lead** (10.678 g/ cm^3), cylindrical (0.2 m long, 35 cm

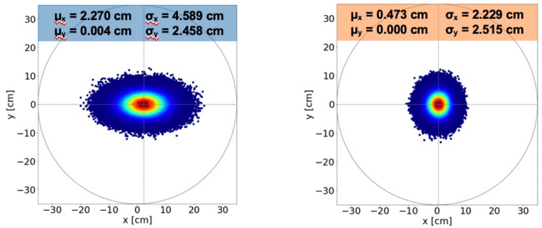


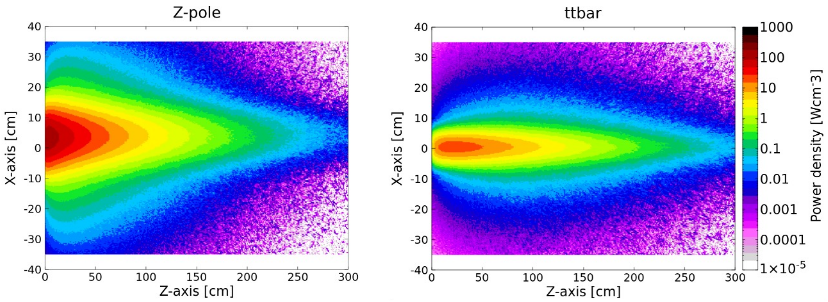
power radiated by each beam

- Z-pole: 369 kW
- ttbar: 76 kW

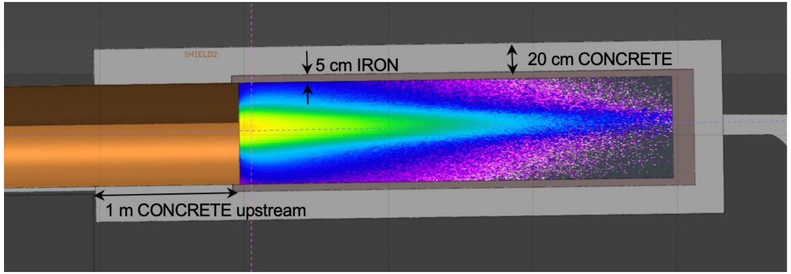
Z-pole **ttbar**

photons on dump





2D FLUKA plot of power density in the graphite dump at beam height (y=0)

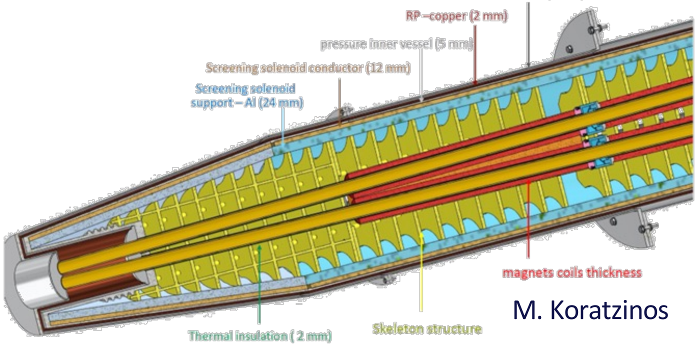


Simple Shielding model to evaluate the effectiveness:
Total Ionising Dose (TID) and High Energy Hadron-eq fluence in the tunnel

Superconducting IR magnet system

IR MDI is complex but feasible. Approach of the talk: motivate securing adequate IR study project resources to implement improvements, as there are a few MDI concerns whose impact on the IR magnet design that should be addressed.

Side-by-side quadrupole coils designed with field crosstalk (local) compensation. Has both an **anti-solenoid** plus a **screening** solenoid



M. Koratzinos

→**30 Ton longitudinal force**

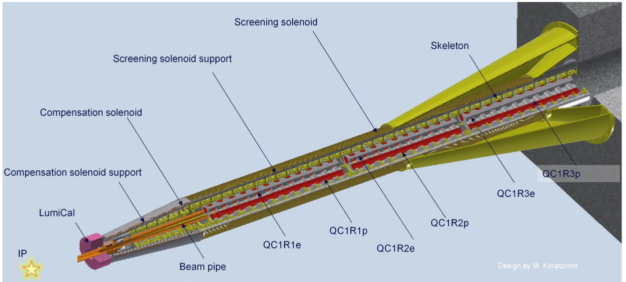
NbTi as superconductor, requires **1.9 K He-II superfluid** cooling but with warm beam pipes

→ need more space for heat shields

→ no access to warm BPMs

- 2 mm radial space for insulating vacuum inside the coils → thicker maybe needed
- Larger inner QC1 radius would increase the coil peak field, but it might be difficult because the coil ends are nearly touching
- Direct wind coil technology could fit the corrector coils

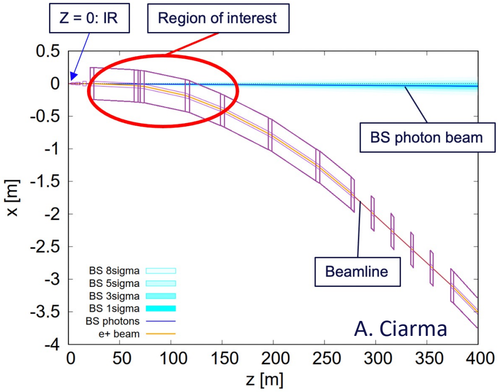
Envisage for quick access for detector maintenance, and working assumptions on the detector endcap interface to be assessed.



If the cryostat is attached to the detector endcap, it is not viable to open the detector by transversely splitting/separating the endcap.

Magnet design for beamstrahlung photons extraction line

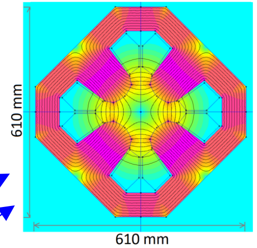
8σ BS envelope assumed



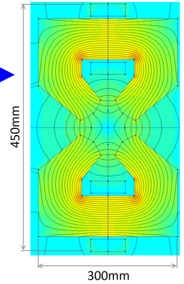
Magnet-BS conflict along lattice

- BS envelope within beam aperture
- BS envelope intersects beam aperture edge
- BS envelope intersects magnet poles
- BS envelope intersects magnet back-leg
- BS envelope fully separated from magnet cross-section

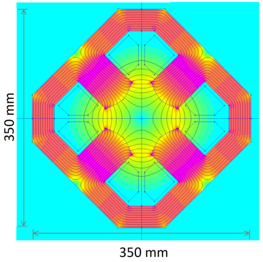
Name	L [m]	S [m]	BS status	Comment
QC4.1	3.50	24.55		BS envelope within beam aperture for all magnets before and up to this point.
BC1.1	39.39	64.25		BS envelope intersects beam aperture edge, enlarged vacuum chamber (VC) needed.
QC5.1	3.50	68.05		Magnet aperture radius needs to be enlarged significantly.
BC2.1	1.70	70.05		BS envelope intersects beam aperture edge, enlarged VC needed.
QC6.1	3.50	73.85		Magnet aperture radius needs to be enlarged significantly.
BC3.1	39.66	113.81		C-shape cross-section required.
QC7.1	3.50	117.61		Figure-of-eight cross-section required.
SY1R.1	0.15	118.06		Superconducting; not investigated.
SY1R.2	0.15	118.21		Superconducting; not investigated.
BC4.1	29.92	148.43		C-shape cross-section required.
QY2.1	3.50	152.23		BS envelope outside of magnet cross-section.
BC5.1	42.45	194.98		BS envelope outside of magnet cross-section, no conflicts foreseen beyond this point.



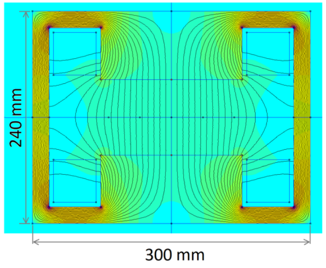
QC5.1 & 6.1 – Enlarged aperture

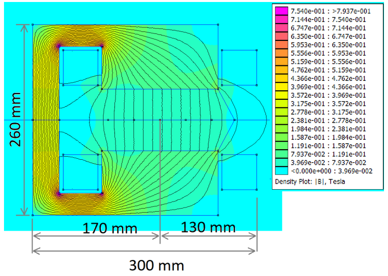


QC7.1 – Figure-of-eight



BS extraction line is feasible,
larger aperture yokes can be designed.



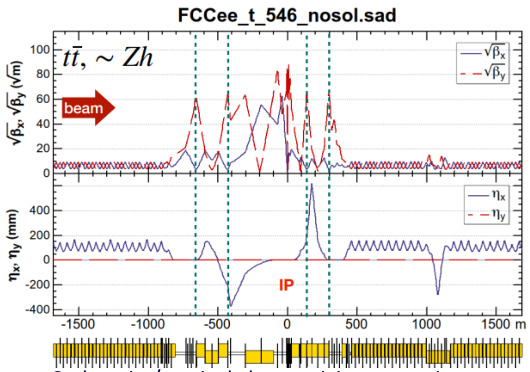


C-shaped cross-section – BC3.1 & 4.1

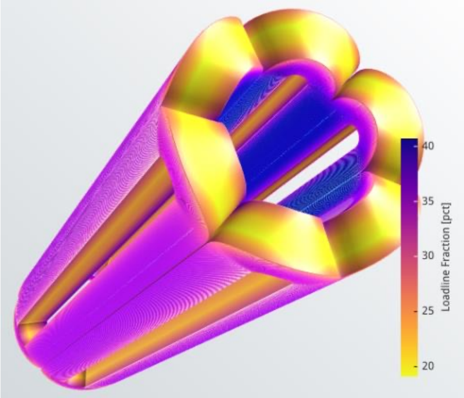
Next

- SC sextupoles to be investigated
- BS envelope with latest optics.
- SR from IR envelope to be added.

Preliminary design study of SC IR crab sextupoles



Crab waist/vertical chromaticity correction sextupoles located at the vertical dashed lines.



3D magnetic model of sextupole saddle HTS coils

- Two layers wound, 12 mm wide tape, 100 turns, wc = 24 mm, Top = 10 K, 900 A / tape
- min T_{margin} = 59 K, (41%.ISS), peak Bp = 5.9 T (Bo = 4.7 T at bore radius Ro = 35 mm)

- 4.1 T magnetic bore field at 35 mm
- Liquid helium impractical, 10-20 K attractive solution

Beamstrahlung radiation and synchrotron radiation envelopes to be studied at the IR crab sextupoles

Case 1: LTS Nb3Sn sextupole at 4 K and 10 K

requires heat treatment and impregnation dedicated tools

Case 2: HTS ReBCO sextupole design at 10K

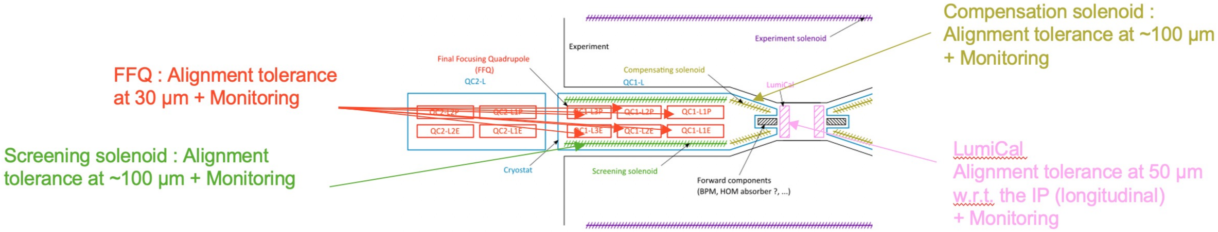
Design based on HTS ReBCO (ReBCO, RE : rare earth)

Next steps; launch detail engineering on **mechanical structure including conduction cooled interfaces, beam losses. Protection scheme and field quality study.**

Leonard Watrelot (CNAM)

MDI Alignment and monitoring system

- Monitoring of the interface at the end of **QC1**
- Monitor the alignment **between QC1 and QC2.**
- Monitor the alignment **between the inner components and the experiment solenoid**.
- Monitor the alignment **between the two sides of the experiment**.
- Monitor the alignment of the **lumical**.

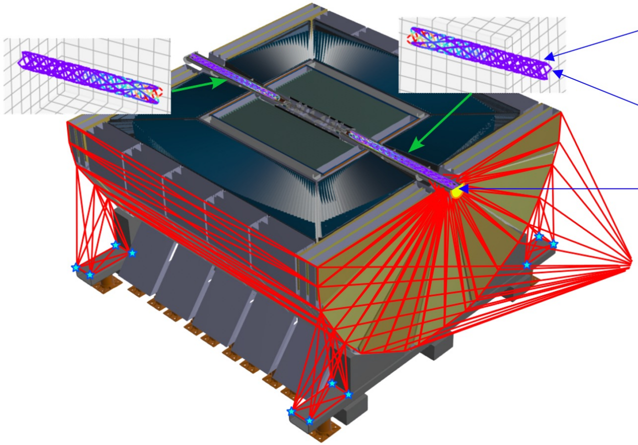


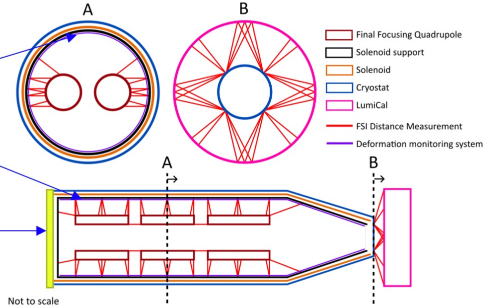
Permanent network of interferometric distance measurements based on Frequency Scanning Interferometry (FSI).

https://iopscience.iop.org/article/10.1088/1361-6501/acc6e3

Internal alignment using optical fibers and deformation monitoring.

Simulations shown **micrometric accuracy** for the alignment between final focusing quadrupoles on both sides.





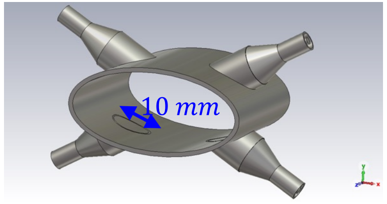
Challenges for the IR BPMs

Special beam position monitors (BPM) are required to be placed **near the lumical** as well as **next to the SC FFQ** and **attached to the warm beam pipe**. The former are supported independently from these magnets. The small space available in this area sets strict constraints on the BPM design.

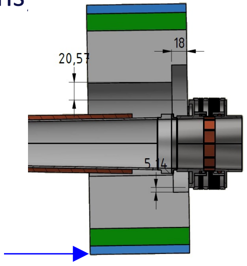
- IR BPMS need to be **reliable** after final assembly, no access for maintenance or repair.
- Avoid cable connectors between button electrodes and cables.
- Mount on non tapered chamber.

Lumical BPM

Elliptical chamber
At least **10 cm longitudinal**
BPM with four skewed buttons, $\sim\mathbf{10}\ \boldsymbol{mm}$ diameter
Integrated shape memory alloy (SMA) button assembly
(no flange-mount UHV feedthroughs)



IP

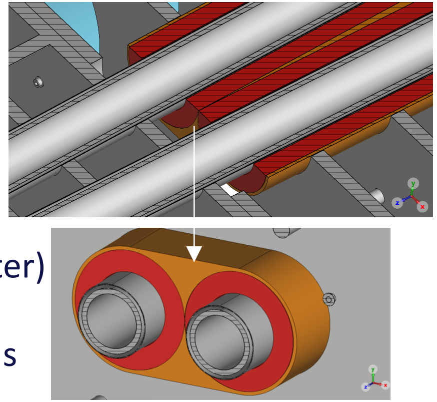


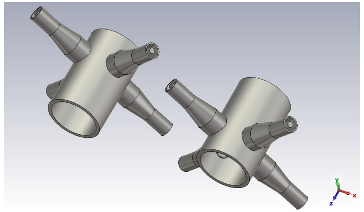
FFQ **(QC1L1) BPM**

Separate chambers with
circular cross-section ($\mathbf{20}\ \boldsymbol{mm}$ diameter)

BPM pickups with four skewed buttons
($\mathbf{6}\ \boldsymbol{mm}$ diameter)

Staggered by $12.5\ mm$ to accommodate the signal cables





Summary

- **Significant progress on all key aspects of the MDI design:**
  - Mechanical model, including vertex and lumical integration, and assembly concept
  - Backgrounds, halo beam collimators, IR beam losses
  - Synchrotron radiation, SR collimators and masking, impact on top-up injection
  - Heat Loads from wakefields, synchrotron radiation, and beam losses
  - Beamstrahlung photon bump with first radiation levels
  - Alignment and monitoring
  - IR magnets, ongoing work to progress on a complete design of magnets, cryostat, correctors, and diagnostics

- **Lots of activities on route for the end of the feasibility study**.

- **All the activites are (being) documented in several papers and a draft of the MDI section for the mid-term review report has been released.**