FCC-ee Machine Detector Interface (WP2)
Status report & Plans

Manuela Boscolo (LNF), N. Bacchetta (Pd)

Meeting with RD_FCC - CSN1 referees
3 giugno 2021

INFN LNF
Istituto Nazionale di Fisica Nucleare

FCC-ee MDI study

Overview of main areas of activity

- **Engineering design** and **mechanical layout with integration**
- **Software tools development** for beam induced backgrounds and optimization of the design
- **Backgrounds study** (SR, single and IP bkgs, sustainability by the detector, shieldings, top-up injection bkg,..)
  - → Related to the MDI layout design: **masks, shieldings, collimators**
  - → Related to optics design, with requirements especially to dynamic aperture, energy acceptance
  - → Beam-beam and beamstrahlung stability
- Beam physics & beam dynamics with IR heat load assessment
- Luminosity measurement
- First final focus quadrupole R&D in progress
- IR beam diagnostics and IP detectors
- Alignment system
- Vibration mitigation system

New activities started, team is enlarging

MDI/IR engineering design and mechanical layout with integration

Luigi Pellegrino (resp. servizio progettazione meccanica Div. Acc. LNF),
Francesco Fransesini (INFN-LNF) – AdT con fondi FCC-IS

This activity is part of Task 2.3 FCC-IS

- **Beam pipe design**
- **Magnet integration including el.-magn/ forces**
- **Cryostat integration**
- **Shielding against hard synchrotron radiation & collision debris**
- **IP detectors integration (luminosity calorimeter, vertex detector) support & alignment**
- **Vacuum system integration**
- **Supporting structures**
- **Thermal simulations**
- **Manageament of electrical and hydraulic connection/routing**
- **Mechanical IR assembly, disassembling & repair procedures**

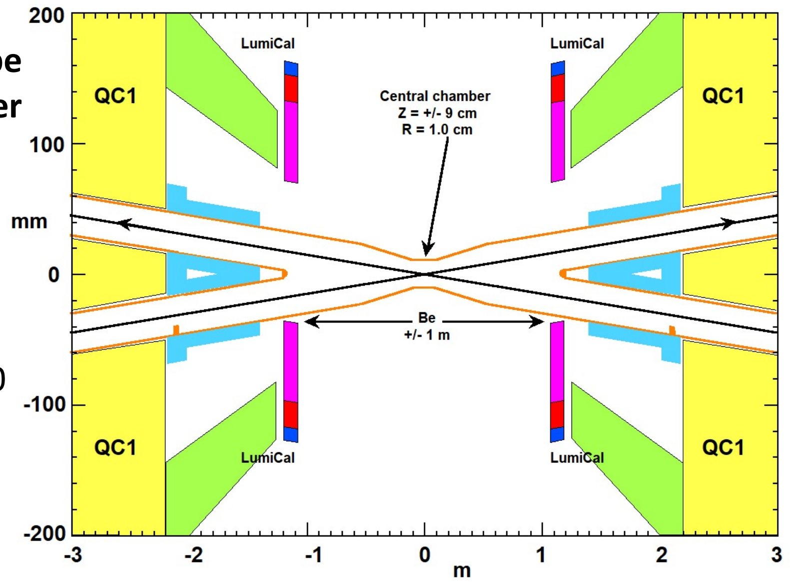
Key deliverables: 3D CAD model of whole IR ; Preliminary structure design ; Thermal and mechanical simulations; Civil engineering requirements; Prototypes (IR vacuum chamber, alignment devices)

Interaction Region Layout

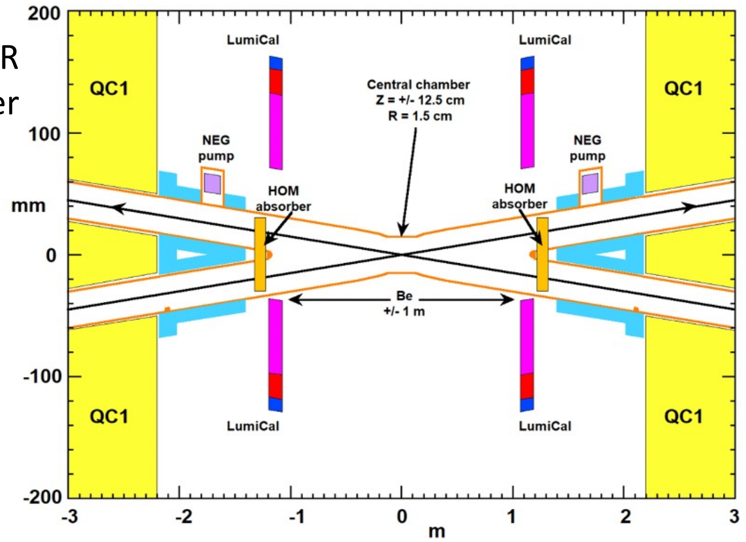
L*=2.2 m B=2 T

- Abbiamo un nuovo disegno della beampipe con un’impedenza piu’ piccola, che quindi genera minor *heating power*, che evita la necessità degli *HOM (Higher Order Modes) absorbers.*
- La beampipe centrale ha raggio = 1 cm, spessore:
  - 5 mu m Au (X/X0 = 0.15%)
  - 0.35 mm AlBeMet (X/X0 = 0.14%)
  - 1 mm paraffin X/X0 = 0.18% for PF200
  - 0.3 mm AlBeMet ((X/X0 = 0.12%)
- L’impatto della radiazione di sincrotone sulla zona centrale della pipe (e quindi sul vertex detector) è stato studiato, trovando che è necessario aumentare la *mask tip* all’uscita di QC1 per bloccare parte dei fotoni che altrimenti illuminerebbero la pipe centrale.
- È in corso uno studio di performance del vertex detector per diverse dimensioni della pipe.
- È iniziato lo studio ingegneristico della pipe per l’analisi strutturale della camera insieme al disegno meccanico della MDI (INFN-LNF)

new (post-CDR) low impedance beam pipe
1 cm radius central chamber



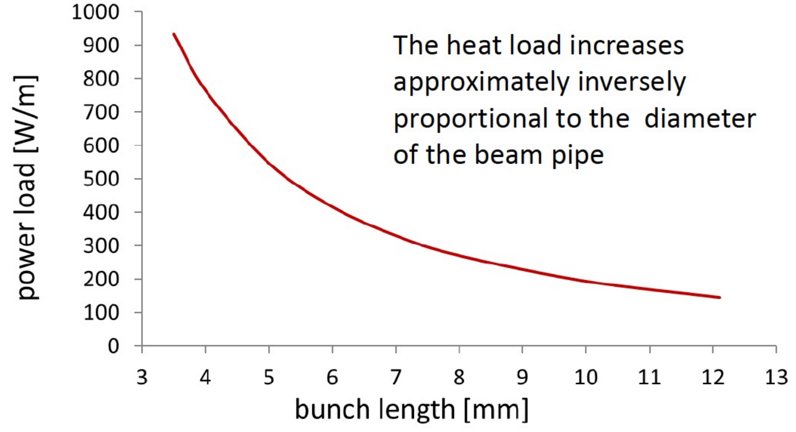
Baseline, CDR
1.5 cm radius central chamber



New FCC-ee central beam pipe with low impedance

Smaller central beam pipe 20 mm diameter

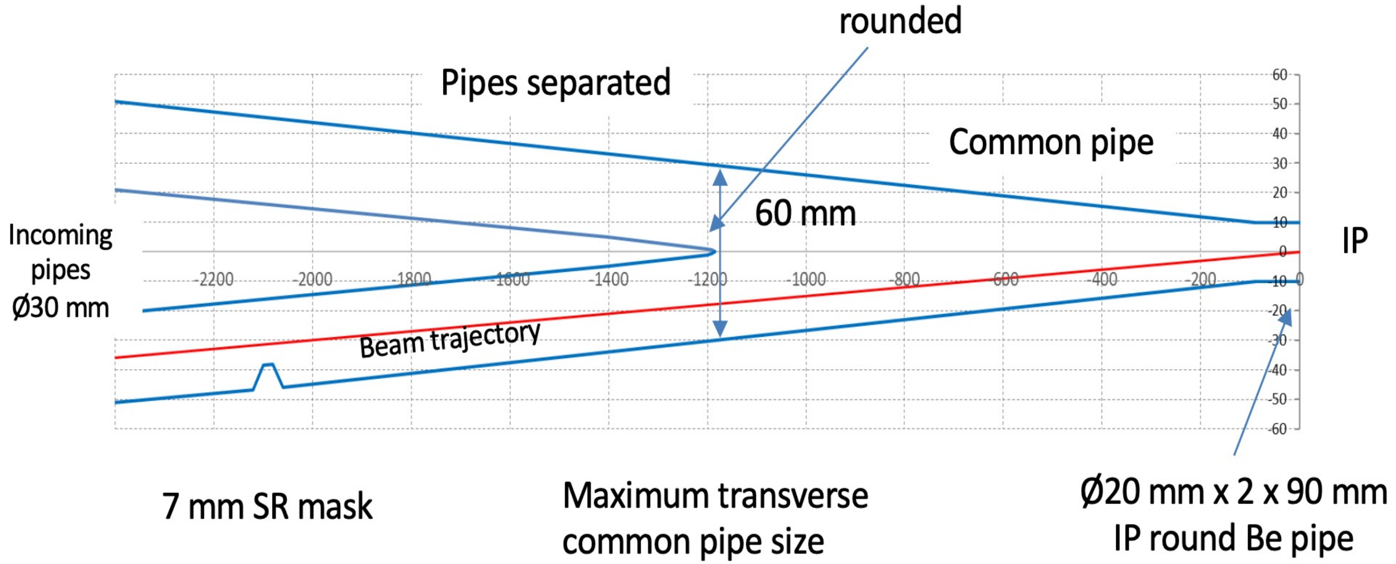
The double effect of smoothing the geometry and a smaller central pipe reduces the local heating power by a factor ten wrt the CDR design.

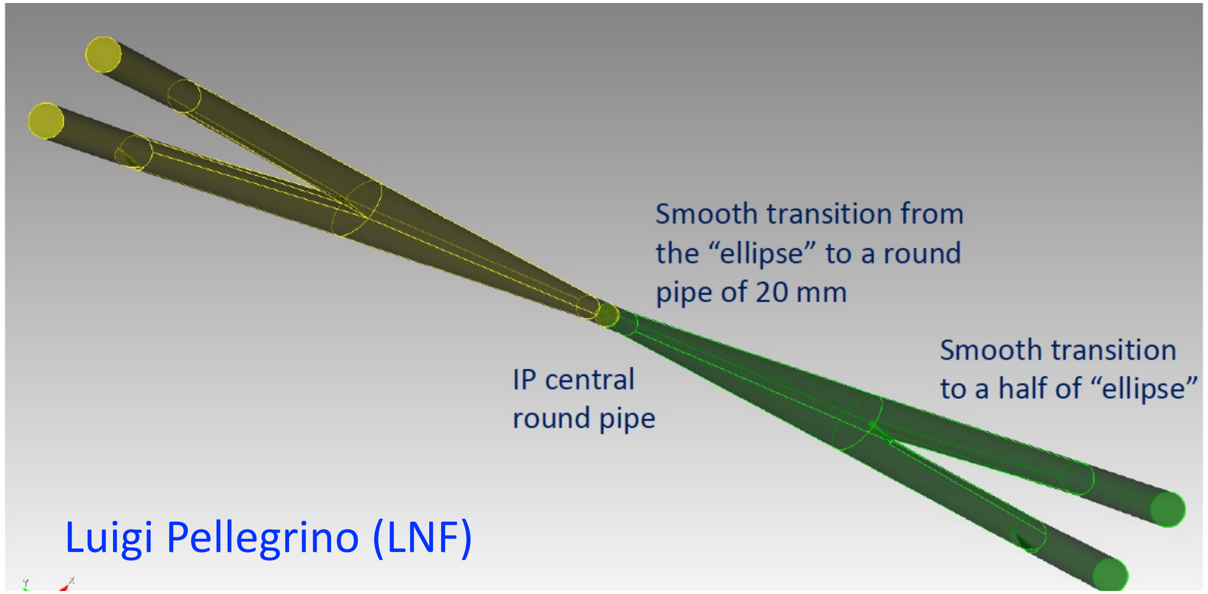


Heat load due to resistive wakefields vs bunch length for a r=1cm Be central beam pipe.

σ_z=12 mm in collision at Z

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



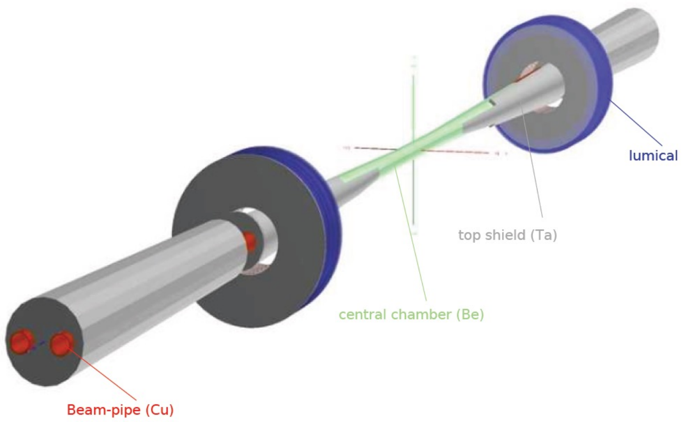


MDI CODES and detector software

- MDI induced detector backgrounds estimation study restarted to deepen the studies presented in the CDR
- The objectives
  - Get full control of the relevant tools for detector background estimation, provide a unified vision and simplified –and well documented- access.
  - Investigate the impact of the debris in the MDI, in particular the amount of shielding.
  - A complete and flexible description of the geometry of the relevant components is required (in DD4hep format)
  - A solution for interplay with CAD based formats is required.

Andrea Ciarma (adesso junior fellow al CERN) lavora sullo sviluppo del software comune per MDI.

- First case-study GuineaPig++ performed
  - used to practice integration in common software
- Geometry consistency issue being investigated
  - realistic target is to have unique connection between different tools



FCC-IS & MDI

FCC-IS it is an EU-H2020 –INFRADEV design study, 4-years project
it has started last November 2020 with the kick-off meeting at the FCC WEEK 2020

FCC-IS is part of CSN1 (synergic with RD_FCC), only LNF involved

Resp. scientifico per INFN: M. Boscolo

FCC-IS organized in 5 WPs:

- WP1: study management
- WP2: collider design →
- WP3: integrate Europe
- WP4: impact & sustainability
- WP5: leverage & engage

Task 2.3: Interaction region and machine detector interface design
(lead: INFN, participants: CERN, CNRS, DESY, partners BINP and UOXF)

FCCIS Work Packages

WP1: study management

WP2: collider design

Deliver a performance optimised machine design, integrated with the territorial requirements and constraints, considering cost, long-term sustainability, operational efficiency and design-for- socio-economic impact generation.

WP3: integrate Europe

Develop a feasible project scenario compatible with local – territorial constraints while guaranteeing the required physic performance.

WP4: impact & sustainability

Develop the financial roadmap of the infrastructure project, including the analysis of socio-economic impacts.

WP5: leverage & engage

Engage stakeholders in the preparation of a new research infrastructure. Communicate the project rationale, objectives and progress. Create lasting impact by building theoretical and experimental physics communities, creating awareness of the technical feasibility and financial sustainability, forging a project preparation plan with the host states (France, Switzerland).

Conclusion

Activity progressing well

- dal modello meccanico allo sviluppo di software comuni integrati in key4hep per lo studio dei fondi nel detector, ma anche beam dynamics, ottica, collimation scheme, misalignments, vibration mitigation

Publication plan:

- EPJ+ Special Issue on FCC-ee challenges (in Part II) contains contribution on the MDI challenges
- EPJ+ Software Development and Computational Challenges (in Part IV) Review and outlook of accelerator-related codes and their interplay with the experiments software
- MDI activity presented at IPAC21 https://arxiv.org/abs/2105.09698 (21 May 2021):

Some relevant Talks:

- FCC week 2020, 2021
- Task Force 8 Integration Symposium, ECFA Det. R&D, "Machine Detector integration" (M.B.), 31/3/21

Back-up

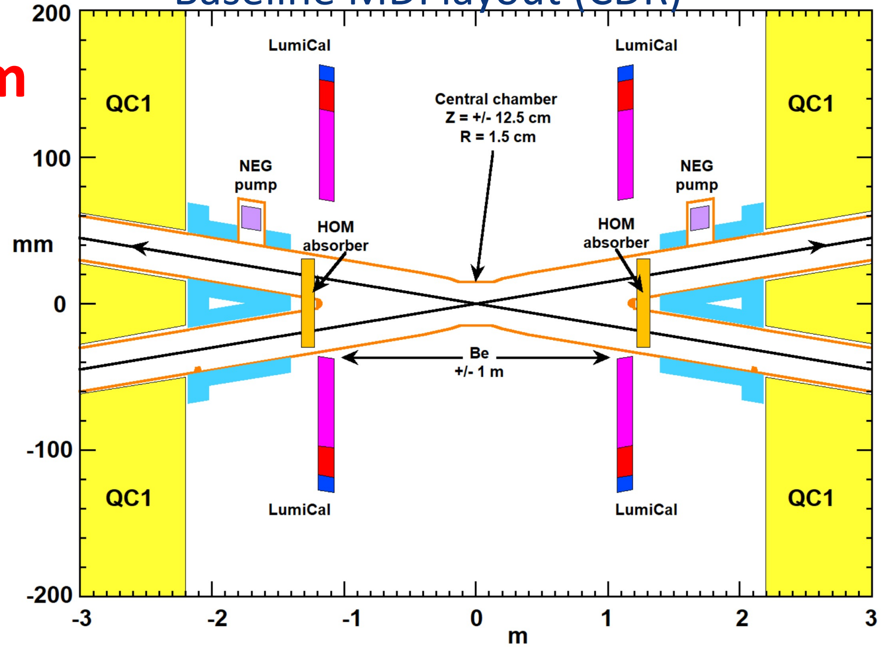
FCC-ee Interaction region & MDI – Integration challenge

- Requirement: **flexible** design, one IR at all energies
- **Very compact IR**, many magnets and devices inside detector
- **Very squeezed beams at IP** →
  - stringent quality of FF quads, and solenoid compensation
  - beam stabilization at IP: vibrations suppression, beam orbit and $\mathcal{L}$ feedback, tight alignment tolerances
- **High beam current at Z** (I=1.39 A) →
  - Heat load, cooling of beam pipe, HOM absorbers
  - Vacuum requirement, NEG coating, beam screens

L*=2.2 m

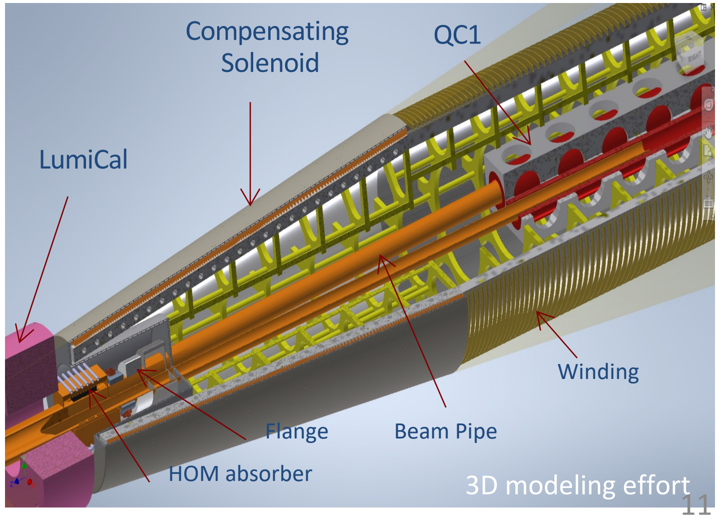
B=2 T

Baseline MDI layout (CDR)



- **Solenoid compensation scheme** to preserve $\varepsilon_y \approx$ pm
- **Luminosity detector** @Z: absolute meas. to 10^{-4} (low angle Bhabha), acceptance to 1 μm level, tight requirements on alignement

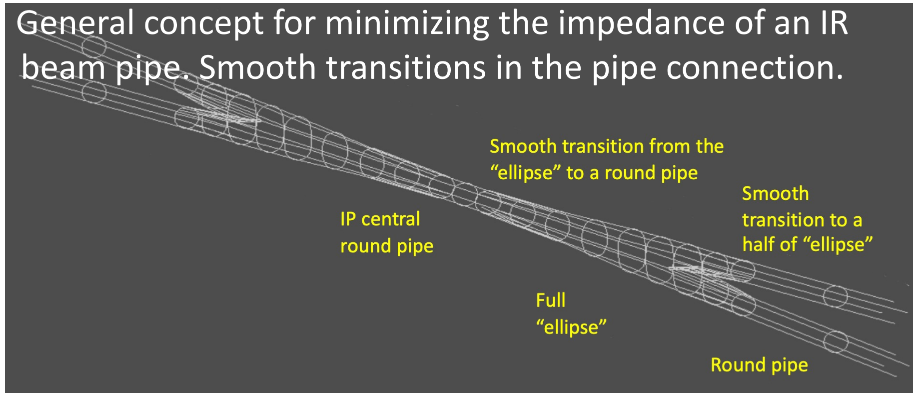
- **Synchrotron radiation**: detector sustainability top priority
- **Robustness against machine bkgs, occupancy**
- **Optimization of the central beam pipe design, material, thickness**
- Keep **low material budget**: minimise mass of electronics, cables, cooling



FCC-ee central beam pipe

Baseline design (CDR):

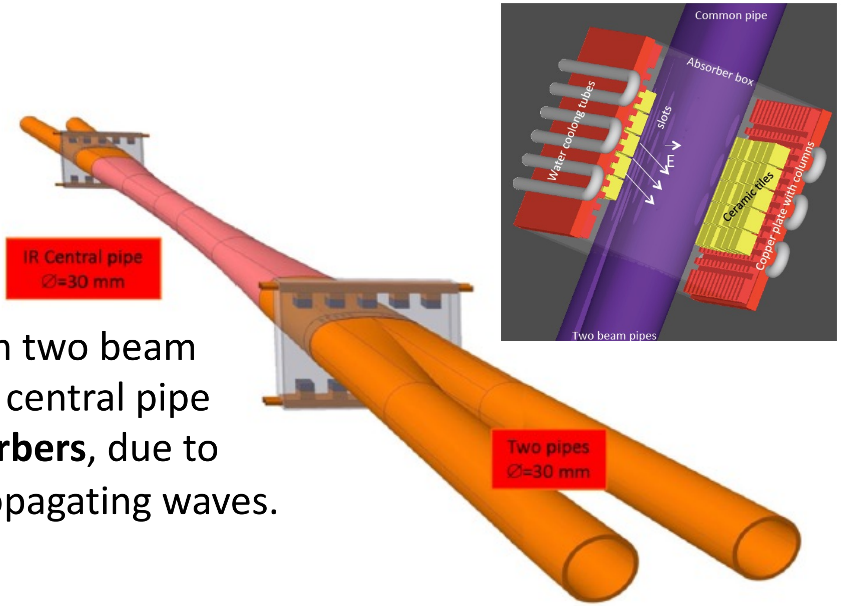
- **Warm pipe**
- Incoming and central beam pipes have a **constant diameter of 30 mm**
- Central part in Beryllium (in the lumical window acceptance)
- Shape determines low impedance
- Very good vacuum, low bkgs: SR masks, coating
- Remote vacuum connection (same concept as SuperKEKB)



General concept for minimizing the impedance of an IR beam pipe. Smooth transitions in the pipe connection.

HOM absorber
(from PEP-II experience)

[A. Novokhatski et al. PRAB 20, 111005 (2017)]



The transition from two beam pipes to a common central pipe requires **HOM absorbers**, due to trapped modes and propagating waves.

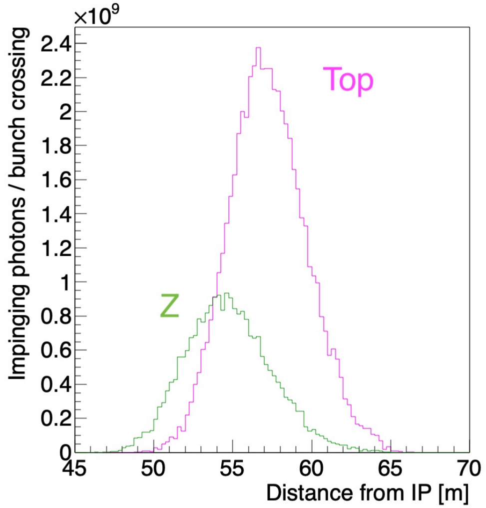
Liquid cooling needed due to the beam heat load, needed also in the central pipe (as for SuperKEKB).
few μm Au coating required in the central pipe (it can decrease the heat load by 30% but also for the low conductivity of Be)
-> one compromise to assure the best possible physics could be to foresee a different pipe for the Z and ttbar runs
(for SR shielding at ttbar, for heating from image currents at Z)

Software MDI & backgrounds simulations

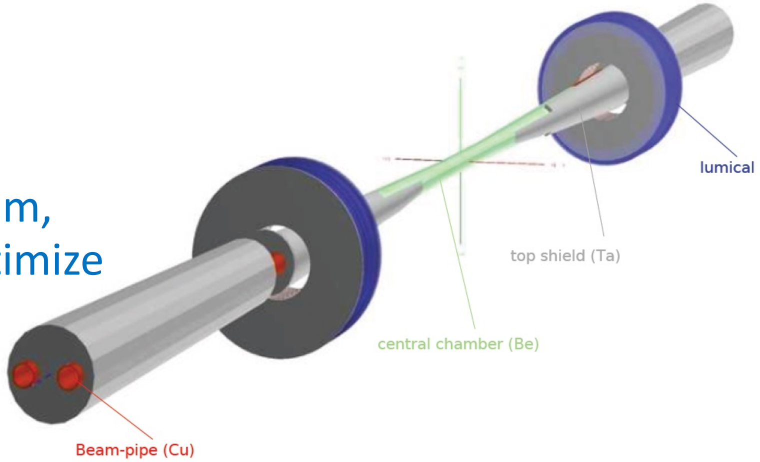
- Insieme al *software team* di FCC-ee stiamo lavorando all'interfaccia tra i codici di simulazione dei fondi macchina dell'acceleratore e Key4hep.
- GuineaPig++ é stato implementato in Key4hep
- Implementazione di BBBrem in corso
- L'idea e' di valutare facilmente la variazione dei backgrounds nel detector al variare di diverse configuarazioni di macchina, di geometria, raccordando i codici.
- In corso e' anche un'interfaccia che permetta non solo di leggere i files CAD negli xml di DD4hep e Geant4, ma anche il viceversa (da xml a CAD).

Andrea Ciarma (adesso junior fellow al CERN) lavora sullo sviluppo del software comune per MDI.

Con GuineaPig++ abbiamo studiato la radiazione di Beamstrahlung che colpisce la beam pipe a ~60 m dopo l'IP
(Potenza di radiazione molto alta: 387 kW alla Z e 89 kW al ttbar)



FCC-ee Background studies



- **Synchrotron radiation background**
  - different codes used on the accelerator side for collimation and masking (MDISim, Synch_bkg, SynRad+) and impact on detector (Geant4) -> effort on-going to optimize beam pipe, masks, shielding
- **Generation of background sources**
  - IP backgrounds
  - Single beam backgrounds:
- **Tracking beam scattered particles**
  - **to produce IR loss map → and track into detectors** (CLD and IDEA)
  - **to produce loss maps around the ring → for collimation study**
  - Multiturn tracking for IP and single beam bkgs to be continued and strenghtened with more details, especially with non-ideal lattice (energy tapering with radiation, imperfections)
  - Collimation scheme
  - Beam tail

Backgrounds are found maneagable in detector as documented in the CDR, it is essential to continue and refine these studies for more and more realistic simulations