RD_FCC @ LNF

Andrea Ciarma

Thanks to: M. Boscolo, G. Nigrelli, M. Poli Lener

RD_FCC

Responsabile Nazionale: P. Giacomelli (BO)

Work packages conveners:

WP1: Physics and Simulation
- P. Azzi (PD), N. De Filippis (BA)

WP2: Accelerators
- **M. Boscolo (LNF)**

WP3: Si Vertex Detectors
- F. Palla (PI), A. Andreazza (MI)

WP4: Drift Chamber
- M. Primavera (LE), N. De Filippis (BA)

WP5: MPGD for muon/preshower
- **M. Poli Lener (LNF)**

WP6: Dual Readout Calorimetry
- R. Ferrari (PV), M. Lucchini (MIB)

WP7: Magnet
- L. Rossi (MI)

Sezione	FTE FCC	FTE altro	FTE tot
BA	5.80	0.00	5.80
BO	4.80	0.40	5.20
CT.DTZ	1.40	0.00	1.40
FE	2.30	0.00	2.30
GE.DTZ	1.05	0.80	1.85
LE	2.40	0.00	2.40
LNF	5.80	0.00	5.80
LNL	2.00	1.15	3.15
MI	3.40	11.95	15.35
MIB.DTZ	0.25	0.25	0.50
NA	4.65	0.00	4.65
PD	2.50	0.75	3.25
PG	2.40	1.00	3.40
PI	3.55	1.05	4.60
PV	1.95	1.80	3.75
RM1.DTZ	1.20	0.00	1.20
RM2.DTZ	0.70	0.00	0.70
RM3	2.00	0.00	2.00
TO.DTZ	2.40	0.00	2.40
UD	2.90	0.00	2.90
Totali	**53.45**	**19.15**	**72.60**

- 2024: 19 sezioni
  - 9 sigle RD_FCC locali
  - R/T: 186 persone
  - FTE: 27.20+13.10=40.30
- 2025: 19 sezioni
  - 13 sigle RD_FCC locali
  - R/T: 214 persone
  - FTE: 42.90+11.30=54.20
- 2026: 20 sezioni
  - Continua crescita!
  - 14 sigle RD_FCC locali
  - R/T: 272 persone
  - FTE: 53.45+19.15=72.60

RD_FCC @LNF

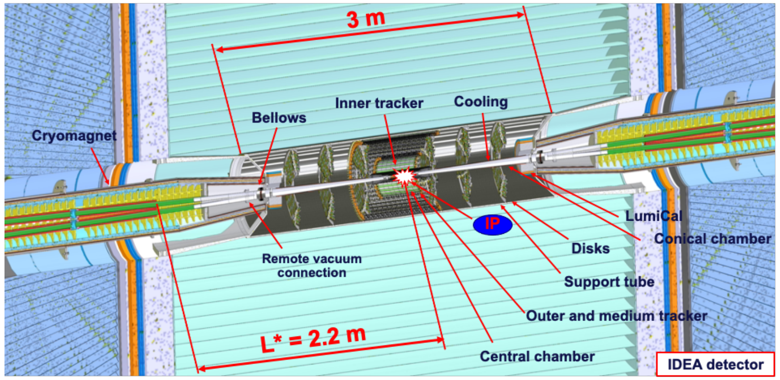
Responsabile Locale: A. Ciarma da Luglio 2025
(M. Boscolo fino a Giugno 2025)

WP1: Physics and Simulations
- B-physics

WP2: Accelerators (Convener: M. Boscolo)
- Engineering Design of Interaction Region
- IR Optics
- Backgrounds and Radiation Sources
- Collective Effects

WP5: MPGD for muon/preshower (Convener: M. Poli Lener)
- µ-RWELL Technology
- Application in IDEA Detector Concept

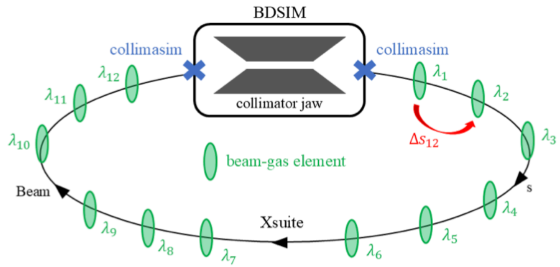
Cognome e Nome	FTE
Bencivenni Giovanni	0.30
Bertani Monica	0.10
Boscolo Manuela	*****
Broggi Giacomo	1.00
Cantarella Sergio	0.10
Cianfrini Marta	0.10
Ciarma Andrea	1.00
De Lucia Erika	0.10
Domenici Danilo	0.05
Fransesini Francesco	1.00
Morello Gianfranco	0.30
Nigrelli Giulia	1.00
Poli Lener Marco	0.30
Ricci Ruggero	0.05
Rotondo Marcello	0.10
Zobov Mikhail	0.30
Totale FTE	5.80

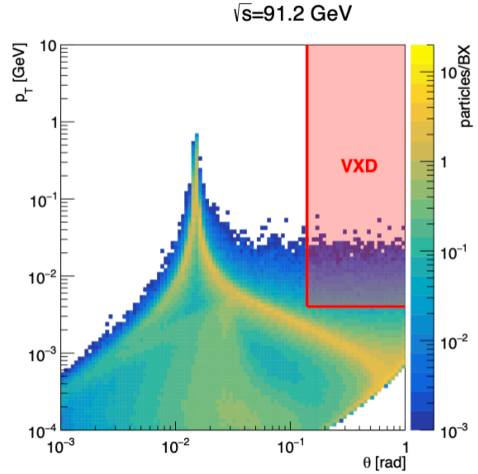


WP2 - FCC-ee MDI activities

IR Mechanical Model

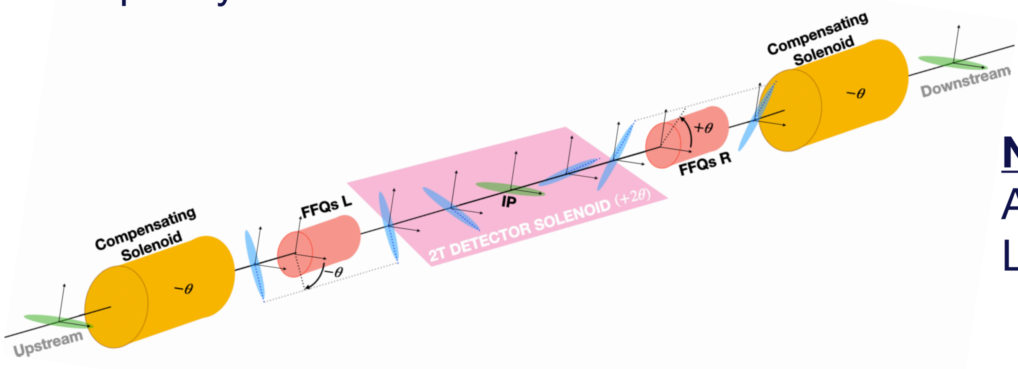
Engineered design of beam pipe, cooling system and support
Material budget and structural optimization
Assembly strategy for innermost detectors





Background Simulations

Estimation of beam losses in the MDI region
Halo collimation scheme and SR maskings
Beam-gas and Touschek scattering
Dedicated interface tool for single beam background studies
Occupancy calculation in the subdetectors



Non-local Solenoid Compensation Scheme

Alternative scheme inspired by DAFNE rotating frame method
Lower SR and coupling, easier spatial constraints

Expression of Interest for

FCC-ee Machine-Detector-Interface (MDI) Integration

Involved Laboratories

Italy: INFN Laboratori Nazionali di Frascati, Pisa

United States of America: BNL, FNAL, JLAB, SLAC

Manuela Boscolo (INFN-LNF)[1], Spencer Gessner (SLAC), Lindsey Gray (FNAL), Brett Parker (BNL), Fabrizio Palla (INFN-Pisa), John Seeman (SLAC), Andrei Seryi (JLAB), Caterina Vernieri (SLAC), Teotia Vikas (BNL)

February 16, 2025

Scientific Context and Objectives

The FCC-ee Interaction Region (IR) is compact and complex accommodating both the detector and accelerator, aimed to reach the highest luminosities at all centre-of-mass energies, from the Z pole to the t-tbar threshold [1,2]. Its layout, based on the crab-waist scheme, must integrate accelerator components such as lightweight and actively cooled beampipes, superconducting (SC) IR-magnets, expansion bellows, remote vacuum connections, beam and detector diagnostics, vertex and luminosity detectors. The SC final quadrupoles (FFQ), around which will be placed windings for high order correctors, screening solenoids, and shielding for backgrounds, will reside inside a cryo-module well inside the detector.

The concept of the Machine Detector Interface (MDI) of FCC-ee mostly close to the detector aspects is based on some of the following design parameters, which are the result of a compromise between the accelerator and detector needs:

- the free space between IP and face of final quadrupole of L*=2.2 m;
- the angular size of the cryostat, as seen from the IP, 100 mrad;
- a beam crossing angle, in the horizontal plane, +/- 30 mrad;
- a central beam pipe of 10 mm inner radius and 18 cm long, with thin wall, actively cooled;
- a lightweight carbon fibre tube supporting the beam pipe, vertex and LumiCal detectors;
- the SC final focus quadrupoles magnetic strength of about 100 T/m;
- Two flat beams with nominal vertical emittances of about 1-pm at the Z-pole.

The above design parameters require pushing the technologies to their current limits, and at the same time guarantee the largest system robustness.

This EoI collaboration endeavors to concentrate on work for the MDI issues of FCC-ee over the next five years. The collaboration will pursue a "complete design" of the interaction region for accelerator and detector components that synergistically share common space, equipment routings, and are affected by the same backgrounds.

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EPJ.org
EPJ Techniques and Instrumentation
RESEARCH ARTICLE Open Access

Check for updates

Status of the FCC-ee interaction region design

Manuela Boscolo[1*], Fabrizio Palla[2*], Gherardo Ammirabile[2], Kevin D.J. Andre[3], Giorgio Baldinelli[4], Patricia Borges de Sousa[3], Filippo Bosi[2], Giacomo Broggi[1,3,5], Roderik Bruce[3], Helmut Burkhardt[3,6], Marco Calviani[3], Silvio Candido[3], Andrea Ciarma[1], Mogens Dam[7], Brieuc Francois[3], Rui Franqueira Ximenes[3], Francesco Fransesini[1], Alessandro Frasca[3,8], Andrea Gaddi[3], Armin Ilg[9], Robert Kieffer[3], Michael Koratzinos[10], Stefano Lauciani[1], Anton Lechner[3], Giuseppe Lerner[3], Giulia Nigrelli[1,3,5], Alexander Novokhatski[1], Katsunobu Oide[12], Antonio Perillo Marcone[3], Brett Parker[13], Pantaleo Raimondi[14], John T. Seeman[11], Cristiano Turrioni[4], Leonard Watrelot[3] and Frank Zimmermann[3]

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[1]INFN, Laboratori Nazionali di Frascati, Frascati, Italy
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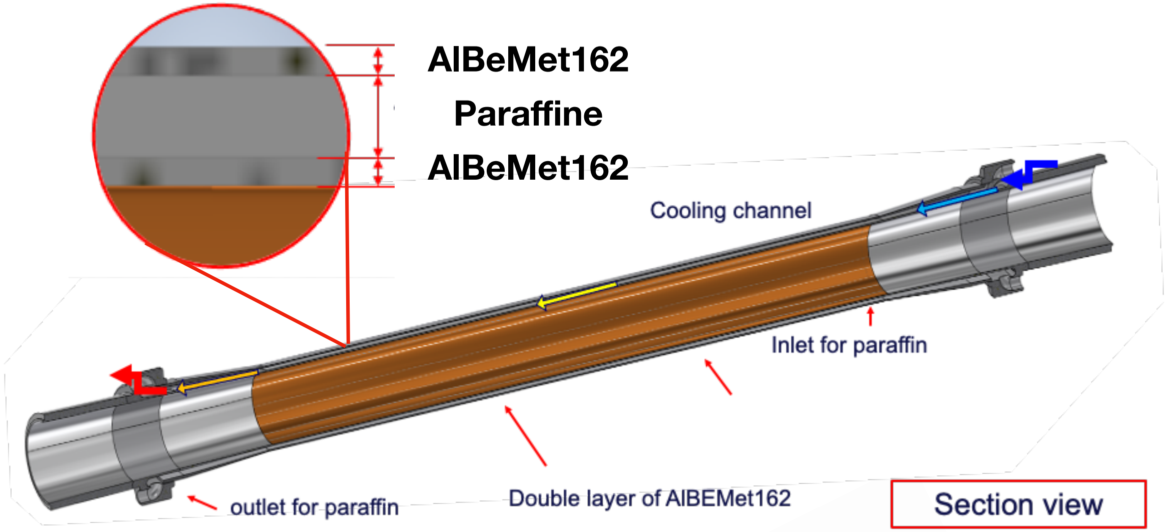
Full list of author information is available at the end of the article

Abstract
This paper presents a comprehensive overview of the Machine Detector Interface (MDI) design developed for the FCC-ee Feasibility Study. It highlights novel studies related to the lightweight interaction region, including a mechanical model of the vacuum chambers, integration of the vertex detector, the MDI alignment system, and assessments of machine-induced backgrounds. The small beam pipe radius and thickness, as well as the high power to be dissipated, require state-of-the-art mechanical design. The integration of all mechanical elements and detectors is challenging, necessitating careful studies to allow fulfilling conflicting requirements. The optimisation of the machine detector interface against formidable backgrounds is presented.

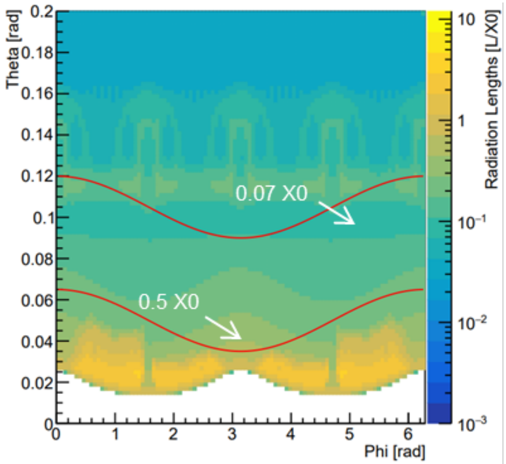
Keywords: Electron-positron collider; Machine-detector interface; Beam-induced backgrounds; Mechanics; Tracking and vertex detectors; Calorimeters

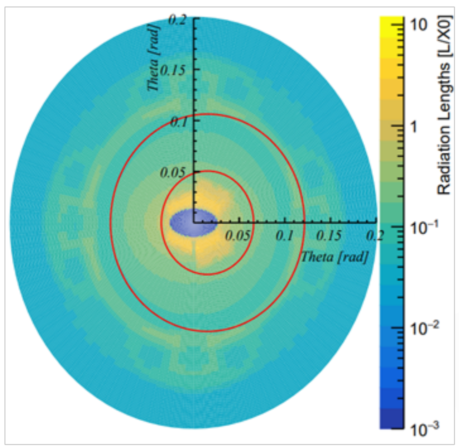
IR beam pipe design



Central Chamber

- Extending ±90mm from the IP
- Double layered **AlBeMet162** pipe
  - 1mm **Paraffine cooling**
- Geometry studied to integrate central chamber with vertex detector





Elliptoconical Chamber

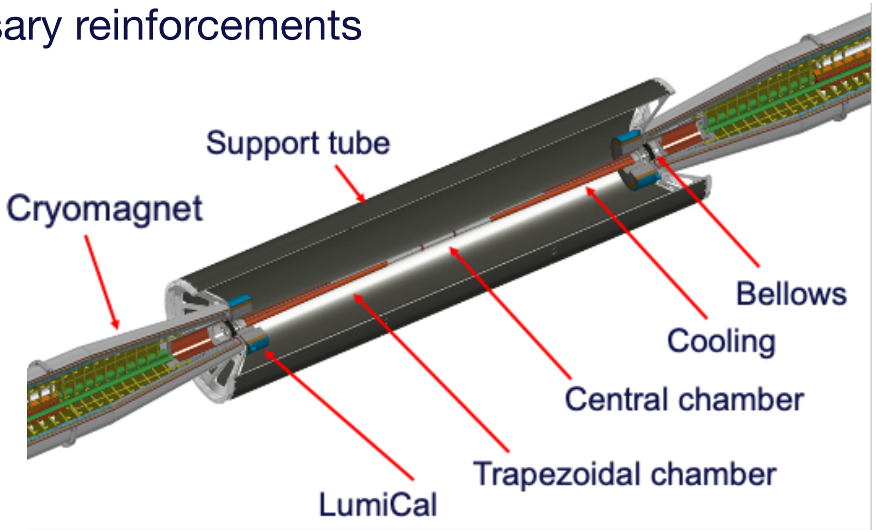
- Two AlBeMet162 chambers from 90mm to 190mm
- Assembled using **Electron-Beam Welding.**
- **Asymmetric water cooling** manifolds to **minimise material budget** in the LumiCal angular acceptance.

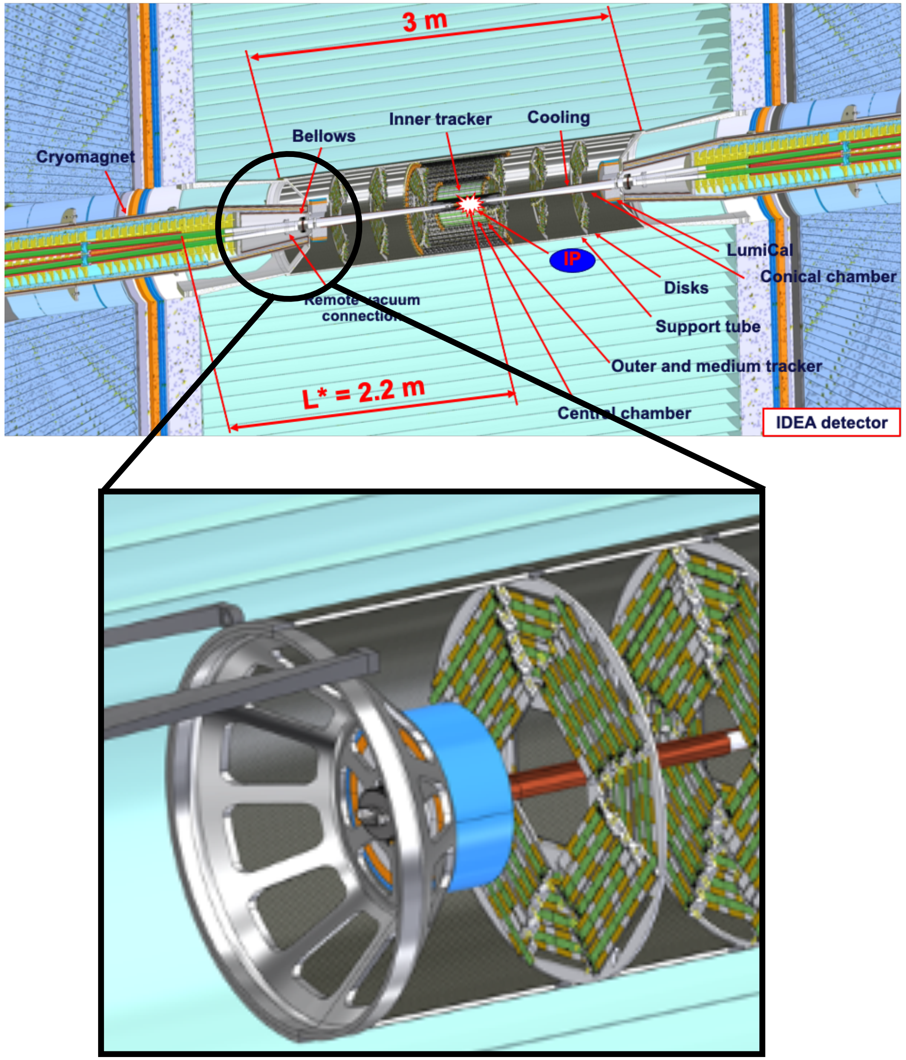
Support Tube for Vertex Detector and LumiCal Integration

Carbon Fibre support tube + Aluminum endcaps for IR integration

- **Cantilevered support** for the beam pipe
- Ease **assembly procedure** for thin-walled central chamber
- Provide support for LumiCal and Vertex Detector

ANSYS structural analysis performed to optimise thickness and necessary reinforcements





Sources of Background in the MDI area

Luminosity backgrounds

- **Incoherent Pairs Creation (IPC)**: Secondary e^-e^+ pairs produced via the interaction of the beamstrahlung photons with real or virtual photons during bunch crossing.
- **Radiative Bhabha:** beam particles which lose energy at bunch crossing and exit the dynamic aperture

Single beam induced backgrounds:

- **Beam halo losses:** high rate of beam losses in the IR coming from halo (transverse or longitudinal) being diffused by the collimators after lifetime drop
- **Synchrotron Radiation:** photons escaping the tip of the upstream SR mask at large angles
- **Beam-gas scattering** (elastic, inelastic) and **Touschek scattering** implemented in X-Suite for multiturn studies, benchmarked with SuperKEKB
- **Injection backgrounds** currently under study

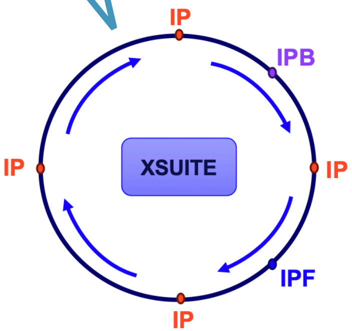
G. Nigrelli - 10.18429/JACoW-IPAC25-MOPM032
G. Broggi - 10.18429/JACoW-IPAC25-MOPM035
G. Broggi - 10.18429/JACoW-IPAC25-MOPM036

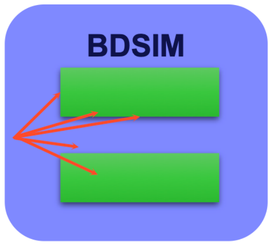
Single beam backgrounds simulation workflow

G. Nigrelli

Dedicated workflow for single beam backgrounds to accurately account for upstream material in the tunnel.

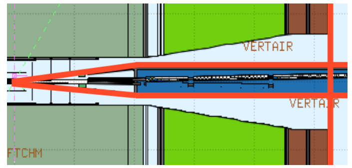
1) Multi-turn XSUITE tracking with realistic apertures and collimation system to produce loss maps

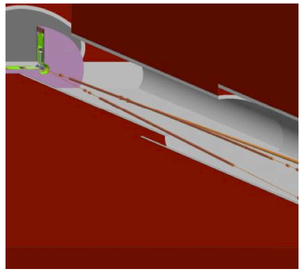


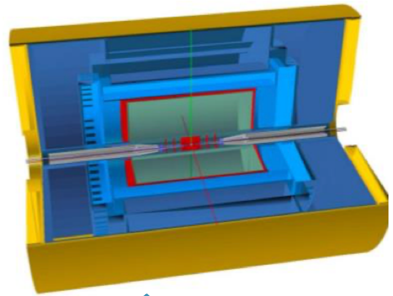


2) Particles hitting collimators are processed in BDSIM (G4 libs) to simulate interaction with material

3) Particles propagated from the tertiary collimators (upstream IP) using FLUKA until dedicated “MDI interface surface”

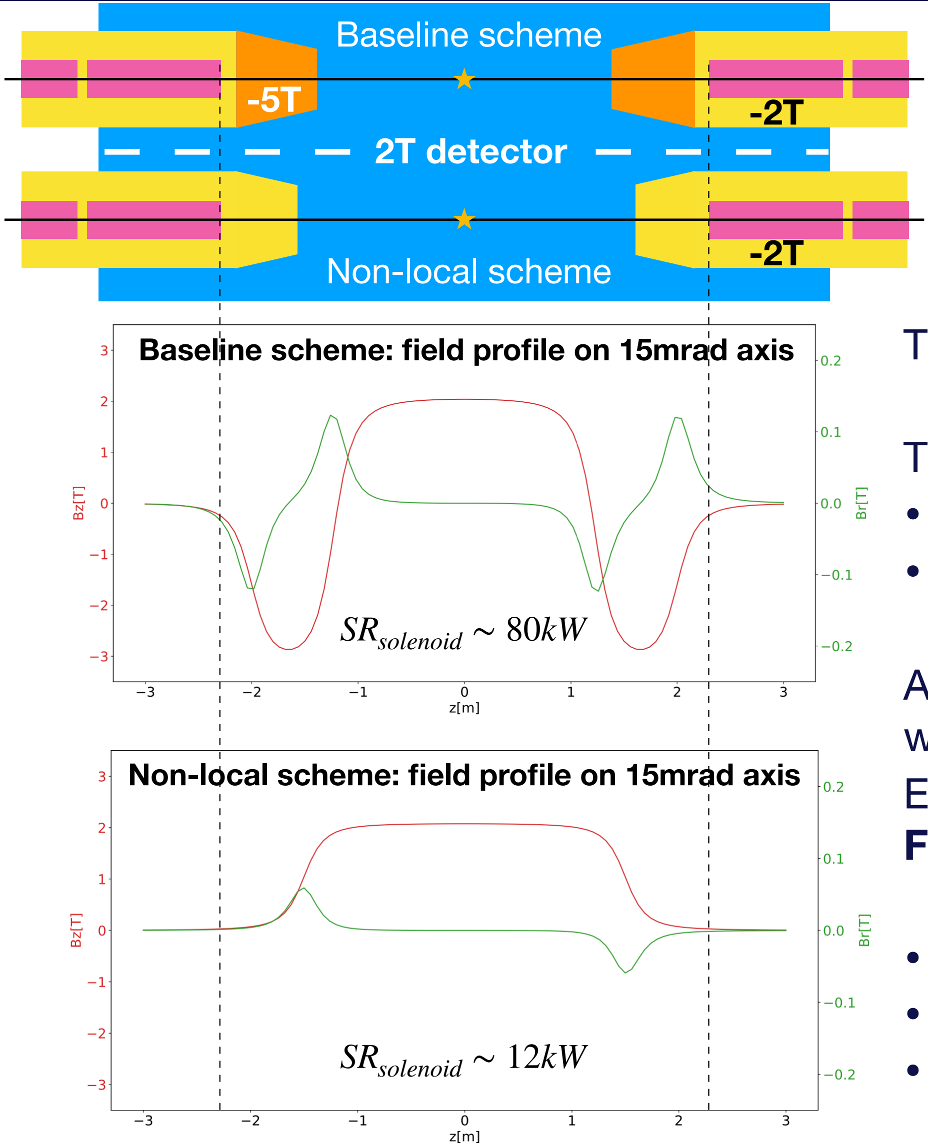






4) Tracking of background particles in the detectors using DD4HEP for occupancy estimate

Coupling Correction Scheme at FCC-ee



The **2T detector solenoids** induce coupling in the FCC-ee lattice.

The current correction scheme uses:

- **-5T compensating solenoids** to cancel the magnetic field integral
- **-2T screening solenoids** to shield the **FFQs** from the detector field

A **non-local correction scheme** inspired by DAFNE (KLOE run) would allow to move the **compensating solenoids** outside the IR. Emittance degradation mitigated via weak **skew components on FFQs** (equivalent to a small rotation) and dedicated orbit correctors.

- relaxed mechanical constraints in the IR
- technical R&D of a -5T compact magnet
- **Synchrotron Radiation** from B-field transition region (~80kW).

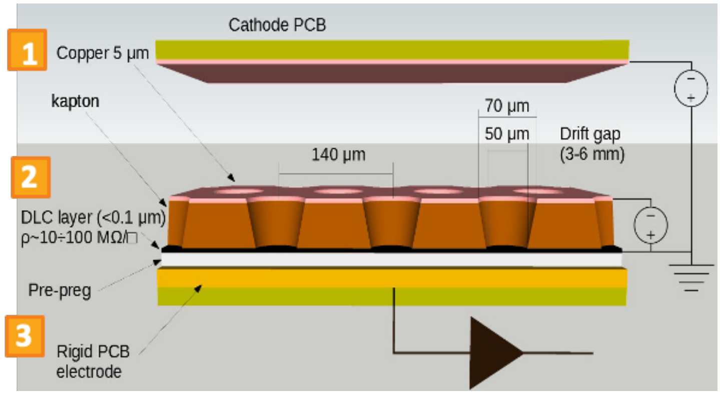
WP5 - The IDEA Muon System with µ-RWELL

Gaseous detectors have historically been favoured for muon detection at colliders like LEP and LHC due to their **cost-effectiveness** for **large areas**, **high time and position resolution and robustness.**

µ-RWELL are an innovative type of **Micro-Pattern Gaseous Detectors (MPGDs)**, expected to have significantly improved capabilities in high-rate intensity environments such as in **LHCb Phase II**.

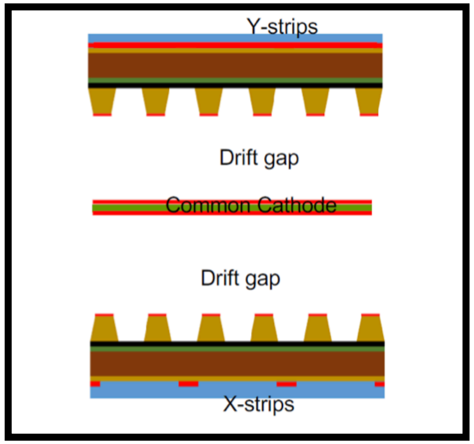
Muon requirements:

- Tiles: 50x50 cm^2 with X-Y readout
- Efficiency ≥ 98%
- Space resolution ≤ 200 µm
- Particle Flux < 1kHz/cm^2
- Instrumented Surface/FEE: 1500 m^2 (6000 det.), ~5×10^6 ch.
- Mass production → Technology Transfer to Industry
- FEE Cost reduction → custom made ASIC (based on TIGER or the new TORA CHIP)



1. **A WELL** patterned Kapton foil acting as **amplification stage** (GEM-like)
2. a **resisitive DLC** layer (Diamond Like Carbon) for discharge suppression w/surface resistivity ~100 MΩ/□
3. a standard readout PCB

2D layouts performance with APV25

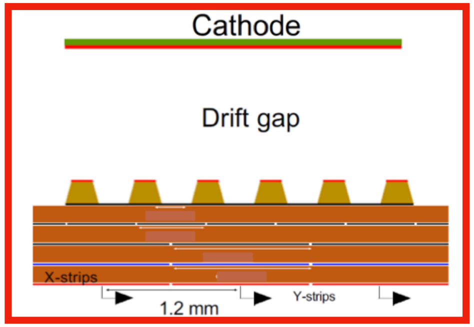


2x1D layout (2 u-RWELL with a 1D readout):

σ_x < 200um (pitch 0.8 mm), ϵ ≥98%

low gain operating point 700 (HV~520V)

- High Costs

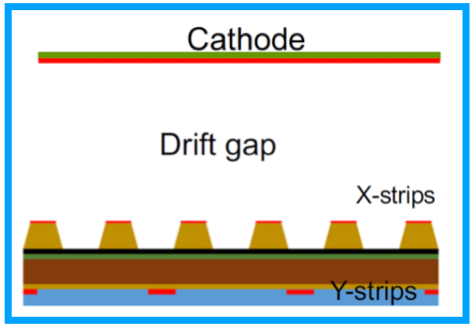


CS layout (1 u-RWELL with 2D Charge Sharing readout):

σ_x < 200um (with pitch 1.2 mm), ϵ ≥98%

high gain operating point 4000 (HV≥ 600V)

- Stability Operation at Limit

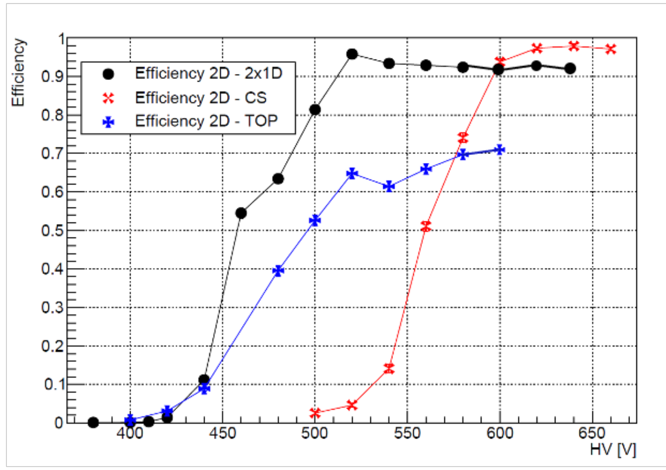


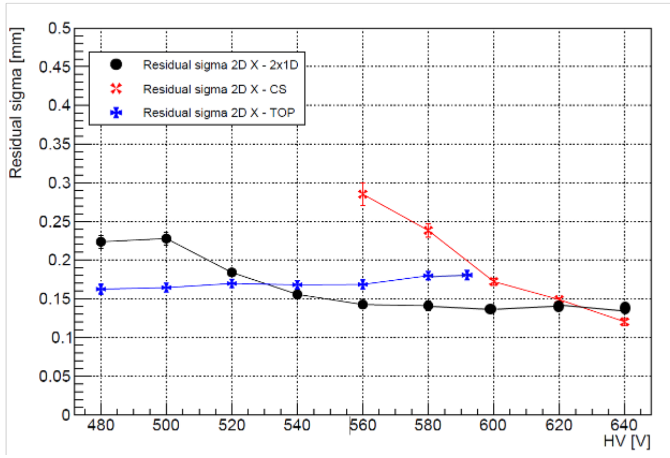
Top layout (1 u-RWELL 1D readout and segmented top amplification for second coordinate):

σ_x < 200um (pitch 0.8 mm), ϵ ≥70% (dead zones)

low voltage operating point ~520V

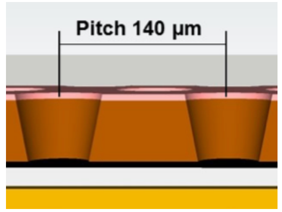
- Limited Efficiency





Solutions under study to increase detector stability:

μ-RWELL well optimization: well pitch from 140 μm to 90 μm with x2 gain increase.
Protos cleaned @CERN, ready to be tested with X-ray



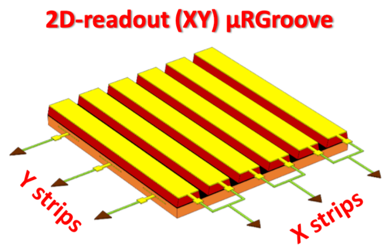
New layouts under study for Muon systems:

GEM + CS μ-RWELL: GEM pre-amplification to lower operating point, greatly improving stability and maintaining high spatial performance with millimetric pitches.

- **10x10 cm2** and **50x50 cm2** prototypes ready at LNF for characterization

DOUBLE DLC FOIL μ-RWELL: new idea of layout, where the first DLC foil will be used as standard resistive layer (100 MΩ/square), while the second one (1 MΩ/square) to spread the charge on the readout.

μ-RGROOVE 10x10 CM2 → amplification based not on **wells but on grooves.**
Easier realization of the **top readout strips**, without introducing dead-zones.
Protos cleaned @CERN, ready to be tested with X-ray



The FCC Feasibility Study

2020 Update of European Strategy for Particle Physics prompted the launch of the **FCC Feasibility study**:

*"Europe, together with its international partners, should investigate technical and financial feasibility of a **future hadron collider at CERN** with a centre-of-mass energy of at least 100 TeV and with **an electron-positron Higgs and electroweak factory as a possible first stage**."*

- **geological, technical, environmental and administrative** (with Host States) feasibility of the tunnel
- surface areas and optimisation of **tunnel placement**
- **cost estimate** and **funding models** for technical design completion, implementation and operation
- identification of **external resources** for first stage (tunnel + FCC-ee)
- **collider design optimisation**, injector chains, R&D to develop needed key technologies
- consolidation of the **physics case** and **detector concepts** for both colliders

Feasibility Study Report has been published on 31 March 2025 and submitted as input for the next ESPPU2026

***Vol. 1:** Physics, Experiments and Detectors*

***Vol. 2:** Accelerators, Technical Infrastructures, Safety Concepts*

***Vol. 3:** Civil Engineering, Implementation & Sustainability*

News from the world

16/07/2025 - European Commission presents the proposal for the Multiannual Financial Framework 2028-2034

"Investing in the European Organization for Nuclear Research's (CERN) Future Circular Collider, alongside other CERN's participating countries. The objective is to maintain Europe's leadership in particle physics research. The funding (up to 20% of the overall cost) could come from Horizon Europe."

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025PC0543

FCC integrated project is the most advanced in terms of readiness and is considered the **flagship option** for Europe, with a completed feasibility study, no identified technical showstoppers, and broad community support.

Overwhelming support in favour of the integrated FCC programme by CERN member states (21 out of 24). No strongly preferred plan B for now (LC, muon, LEP3, …)

Mini-workshop: Highlights from the Future Circular Collider Design with Path to Construction, and theory aspects of the upcoming precision physics program (ACC+TH)

Monday 13 Oct 2025, 14:25 → 21:05 Europe/Rome

Aula Salvini (Laboratori Nazionali di Frascati)

14:25 → 14:30 **Introduction** 5m

Speaker: Manuela Boscolo (Istituto Nazionale di Fisica Nucleare)

14:30 → 15:30 **Highlights from the Future Circular Collider Design and Path to Construction** 1h

The proposed Future Circular Collider (FCC) integrated programme consists of two stages: An electron–positron collider serving as a highest luminosity Higgs-boson, electroweak and top-quark factory, followed by proton–proton collider with a collision energy around 100 TeV.

In 2021, the CERN Council launched the FCC Feasibility Study. This study covered, inter alia, physics objectives and potential, geology, civil engineering, technical infrastructure, territorial implementation,environmental aspects, R&D needs for the accelerators and detectors, socio-economic benefits, and cost.

The Feasibility Study was completed on 31 March 2025. The subsequent European Strategy Symposium has singled out the FCC as the by-far preferred future collider option for CERN. We present a few study highlights, the status, and the next steps.

Speakers: Frank Zimmermann (CERN), Michael Benedikt (CERN)

15:30 → 15:45 **Coffee break** 15m

15:45 → 15:50 **Introduction** 5m

Speaker: Emanuele Angelo Bagnaschi (INFN LNF)

15:50 → 16:50 **Gearing up for the precision frontier: theory challenges at HL-LHC and FCC** 1h

As the High-Luminosity LHC prepares to deliver an order of magnitude more data, and the planning of future colliders such as the FCC gains momentum, the collider physics programme for the upcoming decades relies critically on the precision of theoretical predictions for scattering observables.

Delivering predictions with the necessary accuracy and flexibility is paramount to enhance the discovery potential of future experiments as well as to stress test the Standard Model and explore its complex structure.
Meeting this challenge requires a collective effort and entails a multitude of obstacles in several areas of theoretical calculations.

In this talk, I will discuss the road ahead and highlight some of the key opportunities and the conceptual and technical challenges that must be tackled in the upcoming years.

Speaker: Pier Francesco Monni (CERN)

In this mini-workshop we will focus first on the FCC-ee, and then more broadly on the role of the upcoming precision physics program.

The first presentation will be from **Frank Zimmermann** and **Michael Benedikt** from CERN, who will discuss the technical aspects related to the construction of the FCC-ee collider.

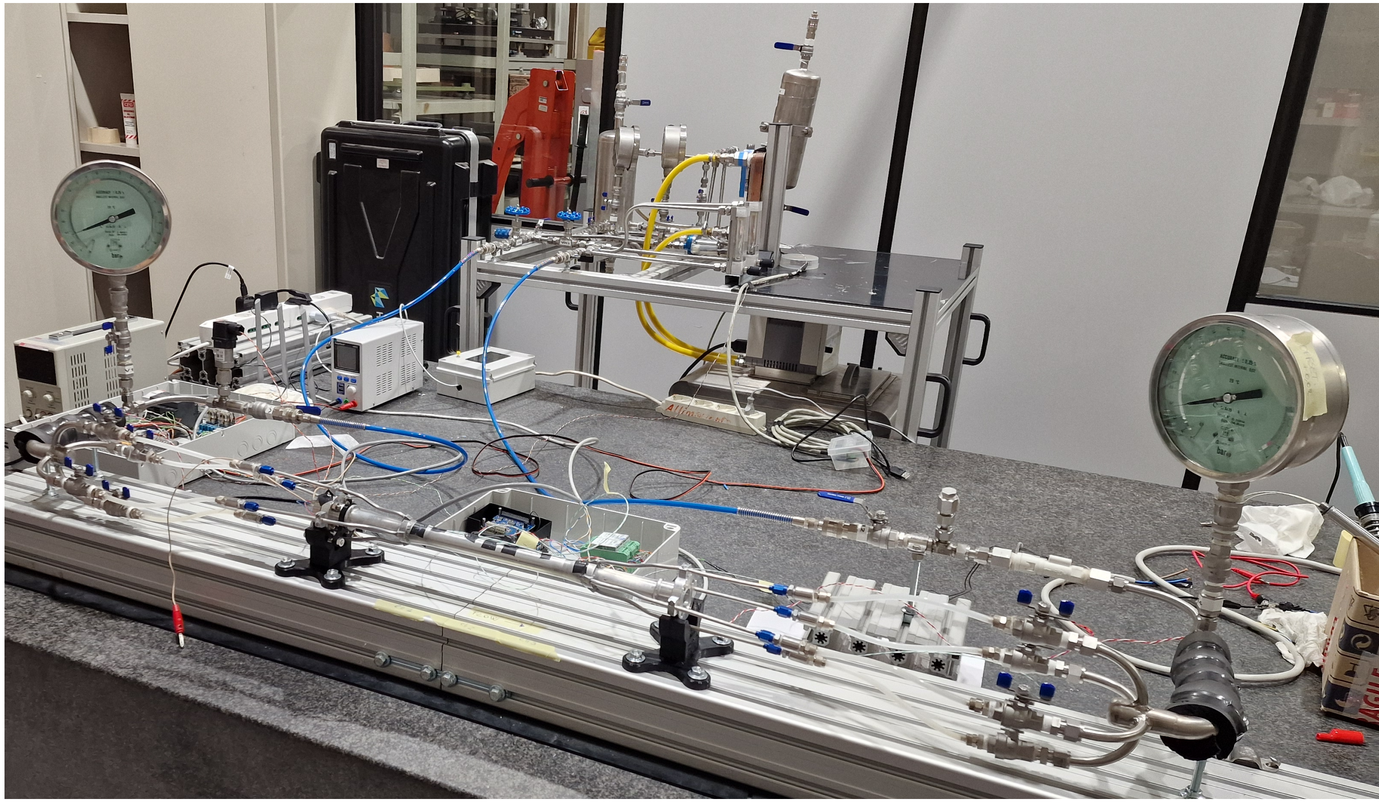
The second contribution will be from **Pier Monni**, also from CERN, who will discuss the role (and the challenges) of the precision physics program at the FCC, as well as at the HL-LHC.

BACKUPS

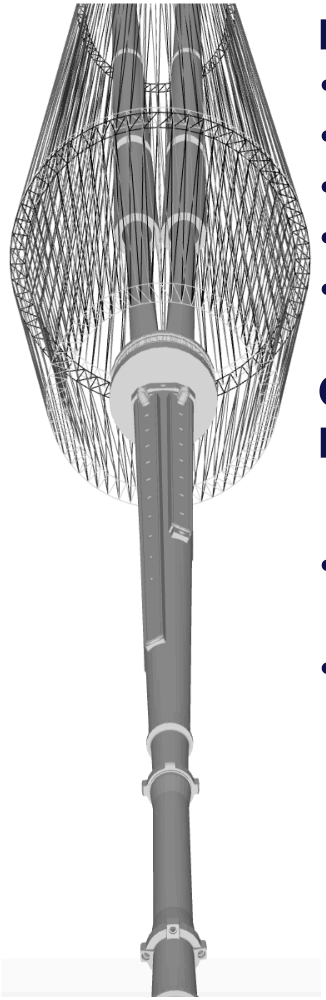
FCC-ee IR Mockup @INFN-LNF

- 1:1 Aluminium model of the Central Chamber (double layered)
- Hydraulic characterization of the cooling manifolds
- Thermal tests of the cooling system
  - exp. power loads 54W (CST)
  - PT1000 sensors
- Elliptoconical chambers in final stage of manifacture
- VXD integration tests with INFN-Pisa

Funded with ESPP_A_FCCMDI
See M. Boscolo next

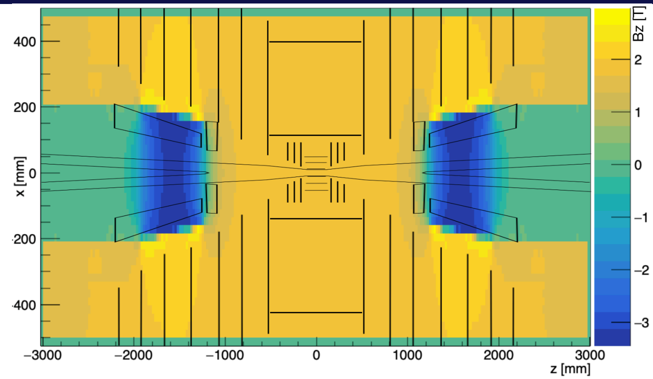


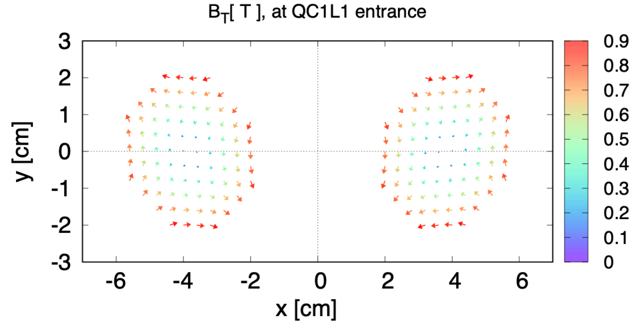
Key4hep MDI modelization



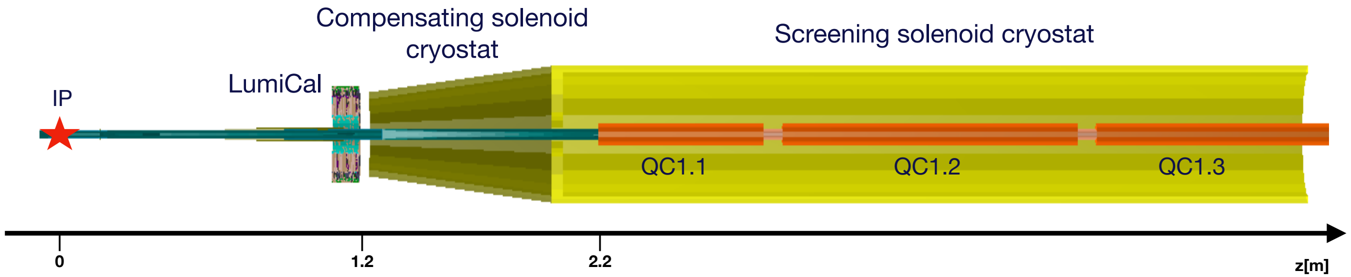
Engineered CAD model of IR beam pipe imported in **Key4hep.**
- Double-layered central section for paraffine cooling
- **Cooling manifolds** for ellipto-conical chambers implemented
- Bellows
- Beam pipe **separation region**
- Tungsten **SR masks** after final focus

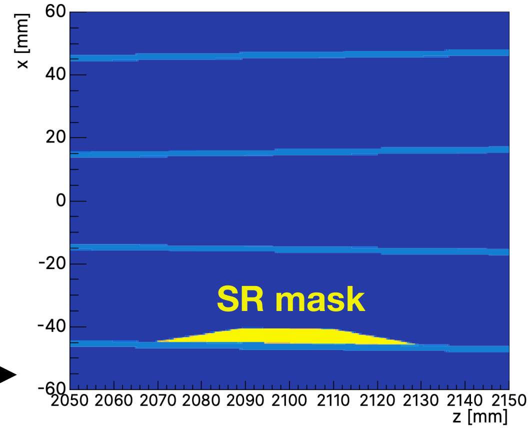
Compensating and Screening solenoid cryostats
Final Focus Quadrupoles simple equivalent material model



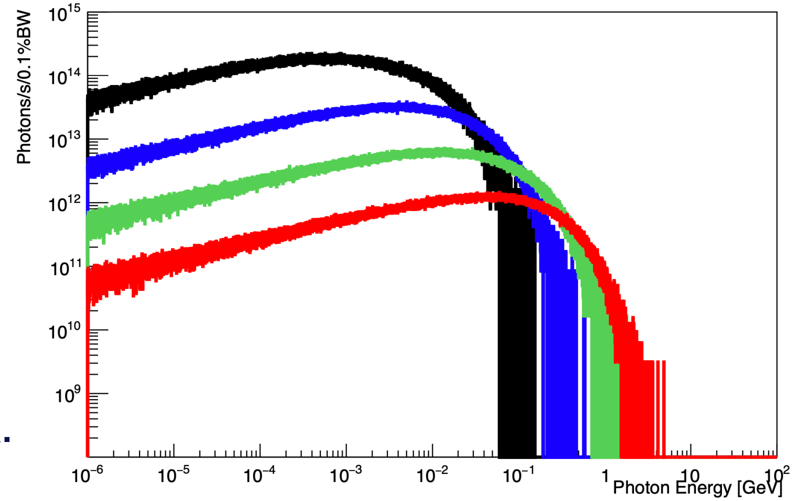


- Field coming from the **anti-solenoids** (screening-S, compensating-S) imported via **field map** to account for fringe effects
- Implementation of **FF quadrupole fields** in the Key4hep geometry





Beamstrahlung radiation

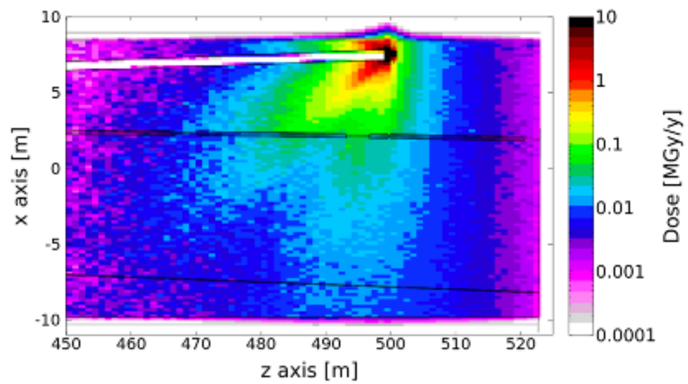


Extremely intense radiation **O(100kW)** produced by the deflection of a beam under the EM field of the other at the IP. The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick.

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

A **dedicated extraction line** collects the intense radiation to a photon beam dump. The downstream **magnets** need to be **redesigned** to allow the passage of the extraction line.

Integration with the tunnel show that a possible location of the beamstrahlung dump is **500m from the IP**. First FLUKA studies to determine **power absorption** in the dump and tunnel ongoing.



M. Boscolo and A. Ciarma, “Characterization of the beamstrahlung radiation at the future high-energy circular collider” Phys. Rev. Accel. Beams **26**, 111002

Muon physics

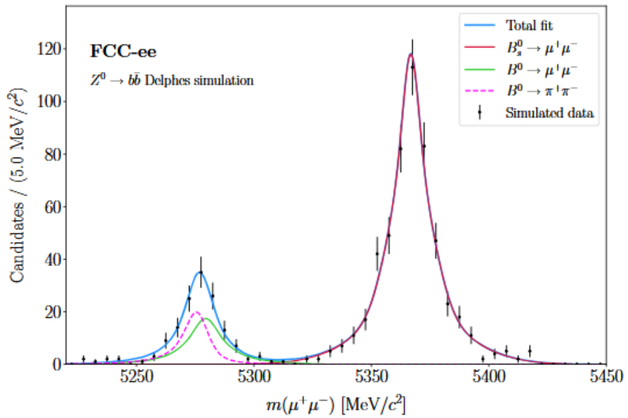
Flavour and rare decays

Beauty and charm hadron production at **the Z^0 pole** enables flavour-physics studies beyond **Belle II** and complementary to the **LHC**.
Rare flavour-changing neutral currents sensitive to **new physics**

Mass resolution and **muon identification** → crucial for separating close-in-mass states like

B^0s → $\mu^+ \mu^-$ (5366 MeV/c2)
B^0 → $\mu^+ \mu^-$(5279 MeV/c2)

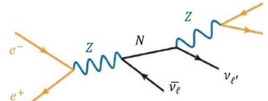
with their branching fractions → powerful test of minimal flavour viol

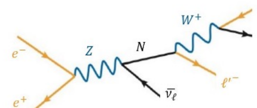


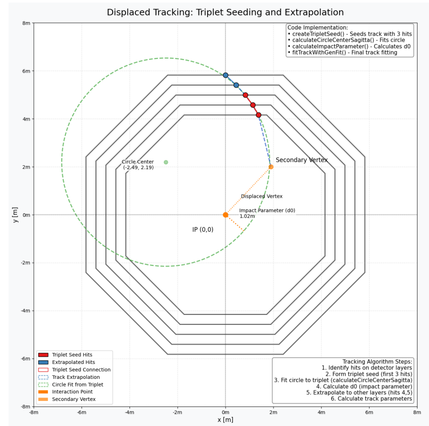
Heavy Neutral Lepton searches

Detecting HNLs at FCC_ee vs LHC:
LLP signature discrimination due a **clean background**
Reconstruction displaced decays with **precise tracking/vertixing**
Sensitive to **low-mass HNLs** (5 ÷ 85 GeV) via rare Z or W decays

- **Fully leptonic** decay $\mu\ \mu\ \nu_\mu$
- **Semi-leptonic** decay into **μj j'** where j and j' are jets from q q' pairs coming from the charged vector boson coupling with HNL and muon







[1] LHCb collaboration, Phys. Rev. Lett. 118, 191801 (2017) [1703.05747]
[2] ATLAS collaboration, JHEP 04, 098 (2019) [1812.03017]
[3] CMS collaboration, JHEP 04, 188 (2020) [1910.12127]
[4] M. Beneke, C. Bobeth, R. Szafron, JHEP 10, 232 (2019)
[5] S. Monteil and G. Wilkinson, Eur. Phys. J. Plus (2021) 136:837
[6] L. Bellagamba et al., arXiv:2503.19464 [hep-ex]