FCC-ee
MACHINE DETECTOR INTERFACE

Manuela Boscolo

INFN Laboratori Nazionali di Frascati, Italy

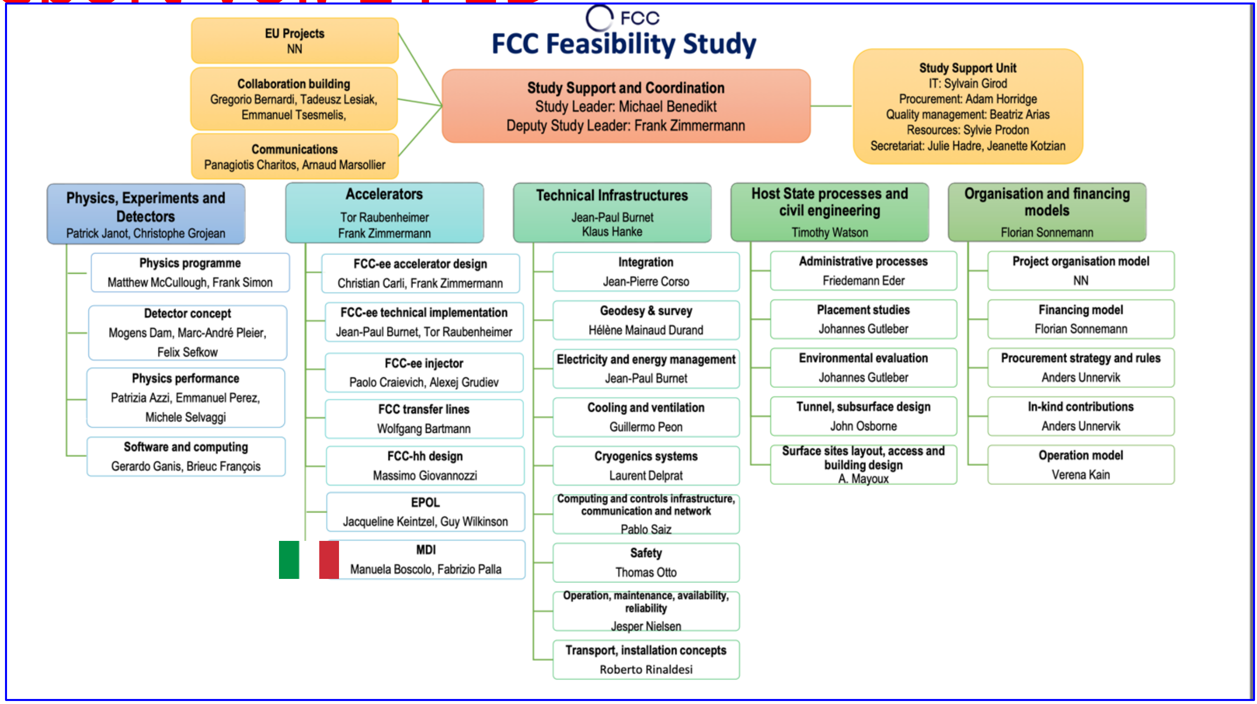
on behalf of the MDI group

Workshop on FCC-ee and Lepton Colliders 2025
Frascati
22 - 24 January 2025

Overview of the Feasibility Study Report Vol. 1 PED

A big effort by a lot of people!

(see contributors on the final slide)

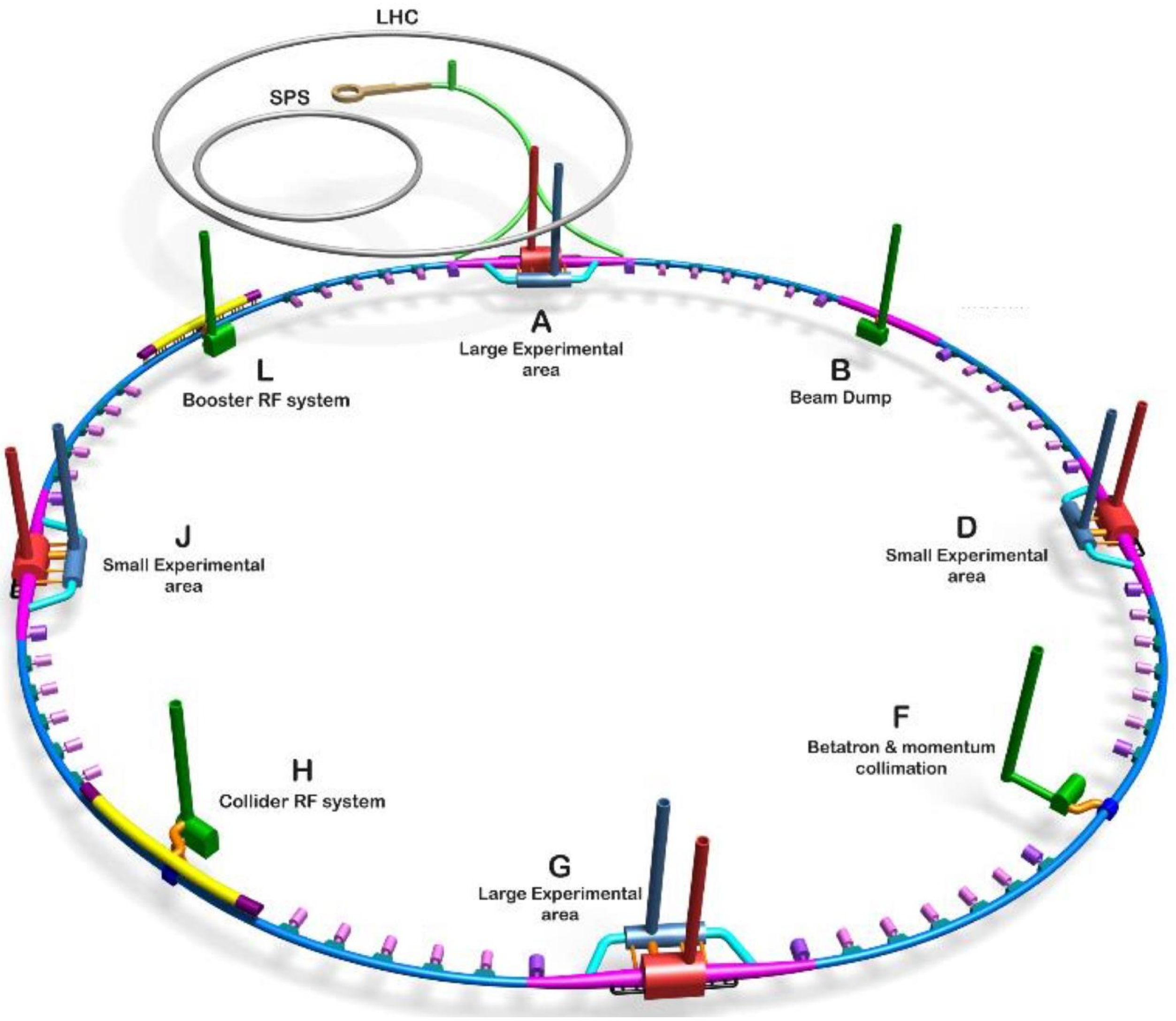


- Chapter 4 of the Feasibility Study Report in Volume 1:
  - 9 ¼ pages
  - 10 Figures
  - 1 Table

MDI Chapter also in Vol. 2 Accelerator

FCC-ee layout

- Double ring e+e- collider with 91 km circumference
- Common footprint with FCC-hh, except around IPs
- 4 Experimental interaction points (IP)
- Large horizontal crossing angle 30 mrad, crab-waist collision optics
- Synchrotron radiation power 50 MW/beam at all beam energies
- Continuous top-up injection scheme for high luminosity
- Requires booster synchrotron in collider tunnel and 20 GeV e+/e- source and linac



Main parameters

Table 12: Key parameters of FCC-ee IR for scenarios with 4 IPs.

	Z	W	H	ttbar
Beam energy (GeV)	45.6	80	120	182.5
Luminosity/IP ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	145	20	7.5	1.41
beam current (mA)	1294	135	26.8	5.1
bunch number /beam (#)	11200	1852	300	64
bunch spacing (ns)	27	163	1008	4725
σ_x^* (μm)	9.5	21.8	12.6	36.9
σ_y^* (nm)	40.1	44.7	31.6	43.6
bunch length by SR /BS (mm) σ_z	4.7/14.6	3.46/5.28	3.26/5.59	1.91/2.33
energy spread by SR /BS (%) σ_δ	0.039 / 0.121	0.069 / 0.105	0.102 / 0.176	0.151 / 0.184

- Beam crossing angle of 30 mrad in x-z
  - Allows to reach high luminosity
  - Determines the luminous region size in x and z
- Beam power limited to 50 MW (due to synchrotron radiation) by design
  - determines maximum beam current per each c.o.m. energy and therefore limits the available instantaneous luminosity
  - In turn determines the no. of bunches → interaction frequency
  - Also determines the size of the beam in z together with the beamstrahlung
- Final focus superconducting quadrupoles inside the detector (L*=2.2 m)
  - Determines the luminosity and the beam size in y
- Maximum detector B-field at 2 T not to decrease luminosity

Interaction region layout

- **Beam pipes in AlBeMet (68% Al, 32% Be)**
- **Central beam pipe 1 cm internal radius**
  - Internally 5µm gold coated to reduce impedance and shield of sync. rad. photons.
- **Actively cooled**
  - Liquid paraffin for the central one (60 W) and water for the lateral ones (130 W).
- **Minimised material budget**
  - Central beam pipe double wall AlBeMet, paraffin and Au (0.68% X_0)
  - Lateral beam pipes minimised within LumiCal acceptance: (mostly 7% X_0, few regions up to 50% of X_0). Shaped to minimise showers off manifolds

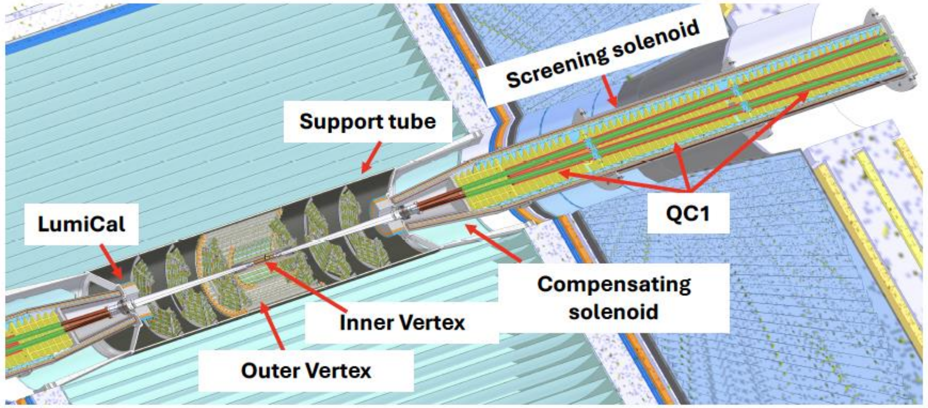


Fig. 47: Interaction Region overall layout. The support tube allows to integrate the luminosity calorimeter (LumiCal) and the vertex detector. Also shown the three segments of the final focus quadrupoles (QC1) together with the screening and compensating solenoids.

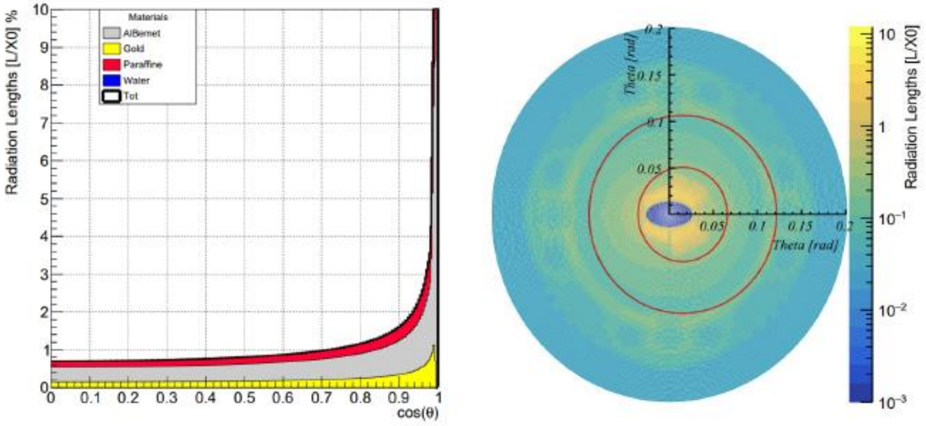


Fig. 50: Material budget of the beam pipe as a function of the polar angle (left) and in front of the LumiCal (right) in the region $\theta \in [0, 0.2]$ rad. The red lines represent the LumiCal acceptance, i.e. the 50 mrad and 105 mrad cones.

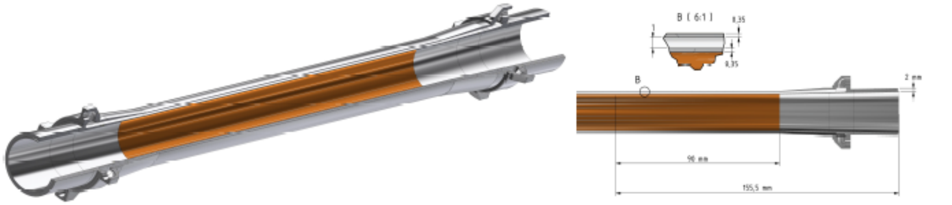
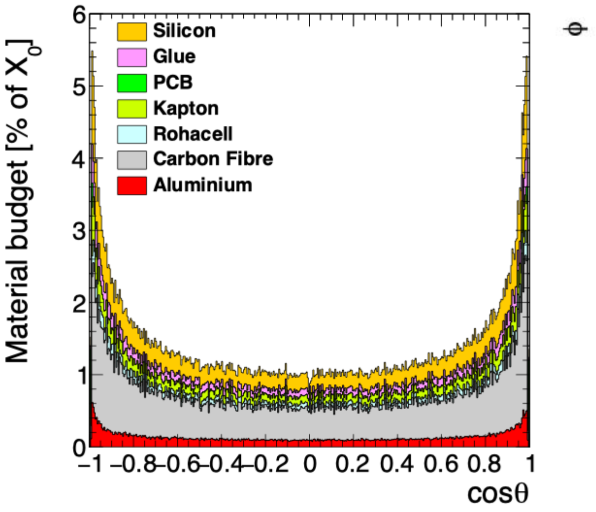


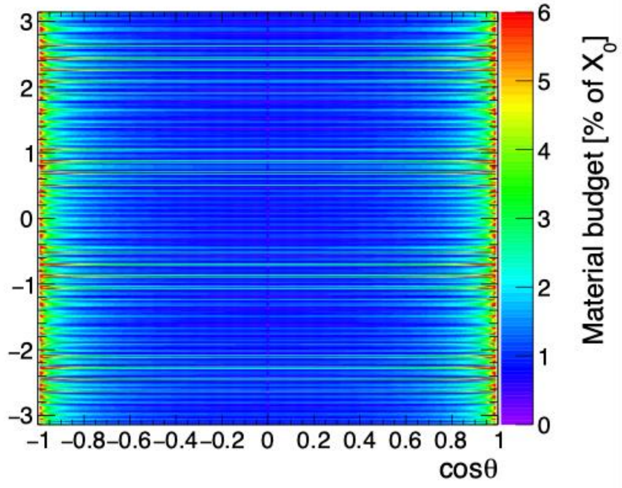
Fig. 48: Central chamber in AlBeMet162 including cooling inlets and outlets (left); cross-section view and zoom of the structure of the cooling channel for the paraffin flow.

Fig. 49: Ellipto-conical vacuum chamber.

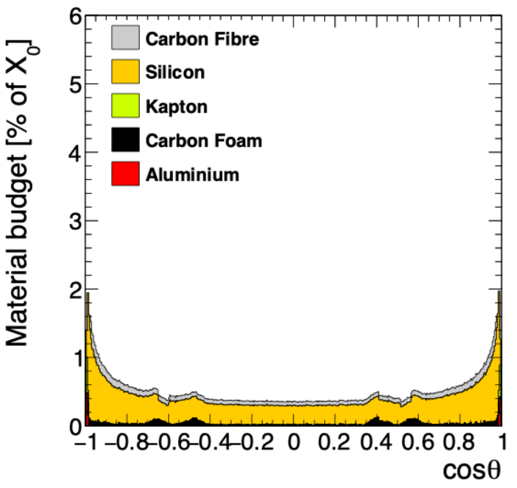
Vertex material budget and impact parameter resolution

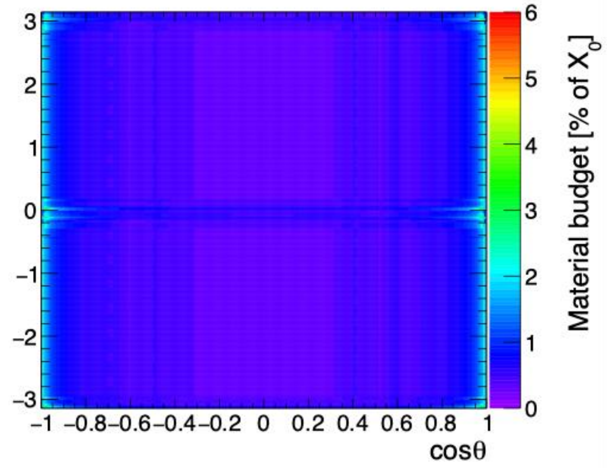
Baseline Inner vertex

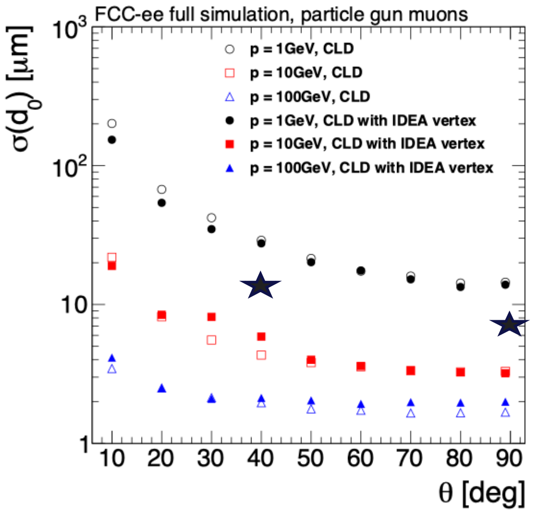




Ultralight Inner vertex

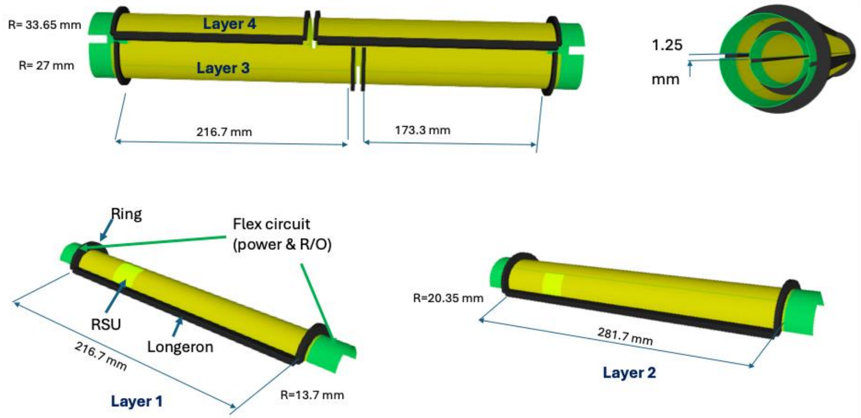






baseline:
beam pipe inner radius = 1 cm
beam pipe outer radius = 1.17 cm
1st vertex inner layer = 1.37 cm

★ p=1 GeV ultralight



Vertex and LumiCal integration

Support tube provides integration of beam pipes, vertex and LumiCal

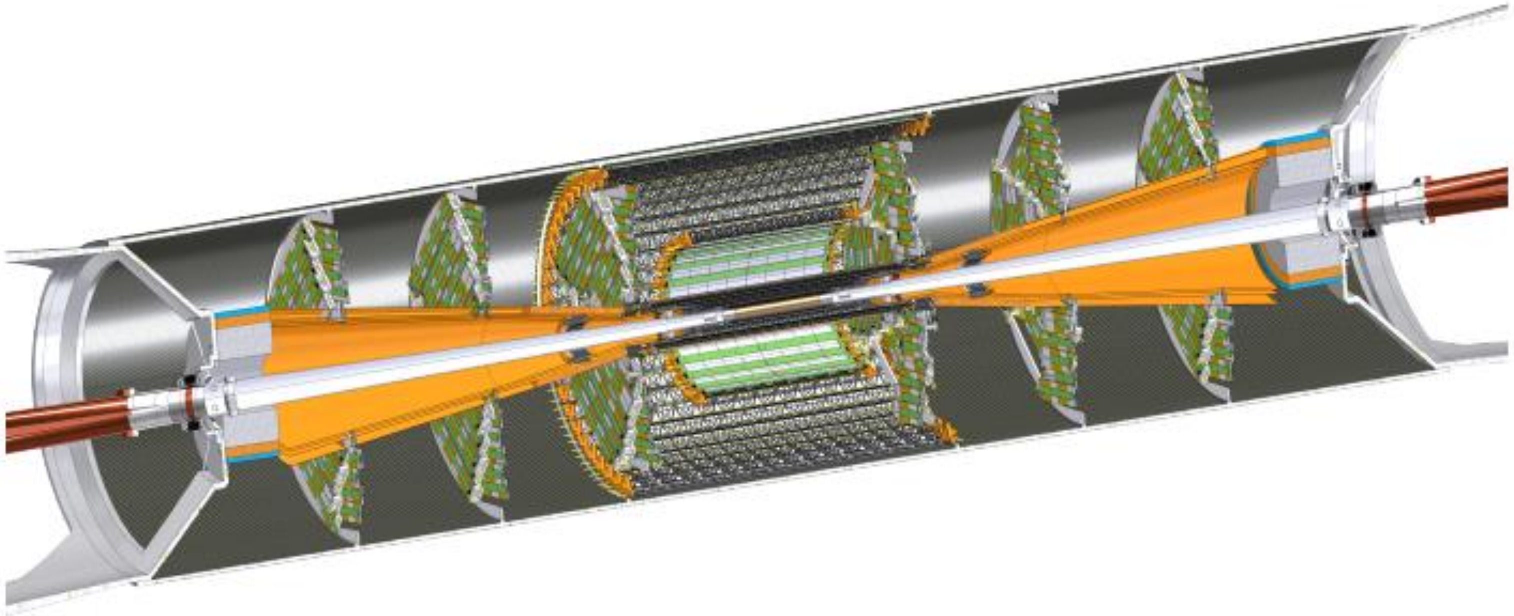


Fig. 53: Support tube showing the supported beam pipes and bellows, the vertex detector with air-cooling cones, luminosity detector, and at the edges, in brown, the vacuum chambers internal to the cryostat (not shown).

Vertex and LumiCal integration

- **Inner vertex detector anchored to the lateral beam pipe and air(or He)-cooled:**
  - maximum $\Delta T < 15^{o}C$ and maximum vibration 1.5 μm radial (reported in the detector chapter).
- **Integration with central beam pipe services and cooling cones has been engineered**

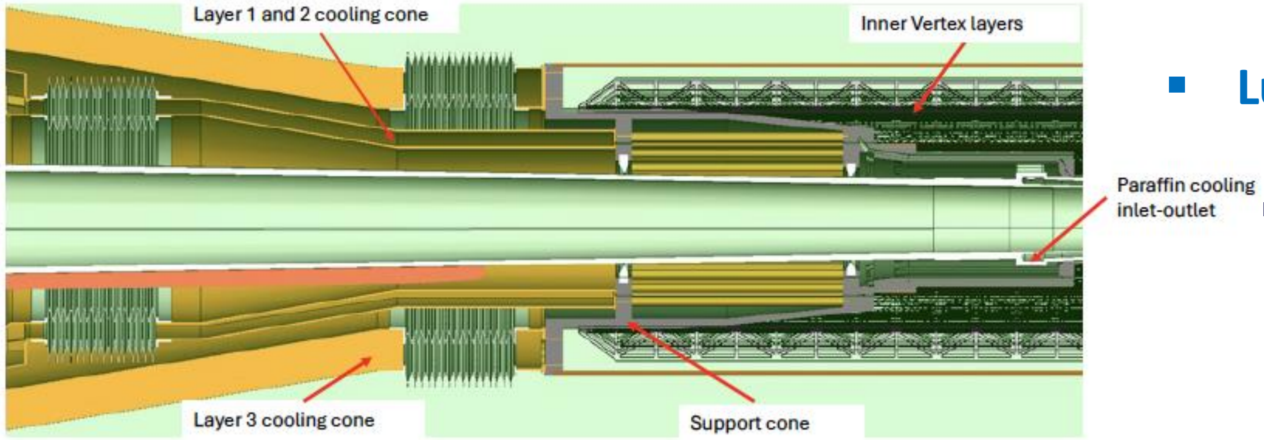


Fig. 52: Longitudinal section of the beam pipe and the inner vertex. The dark gray object is the conical support of the vertex detector, which is supported by the conical beam pipe. At the edge of the support cone, the inlet/outlet paraffine of the central chamber cooling manifolds are visible. The orange structures show the cooling cones.

- **LumiCal integrity has been preserved**
  - Important for energy resolution
  - Mounted sliding it through the beam pipe and bellows

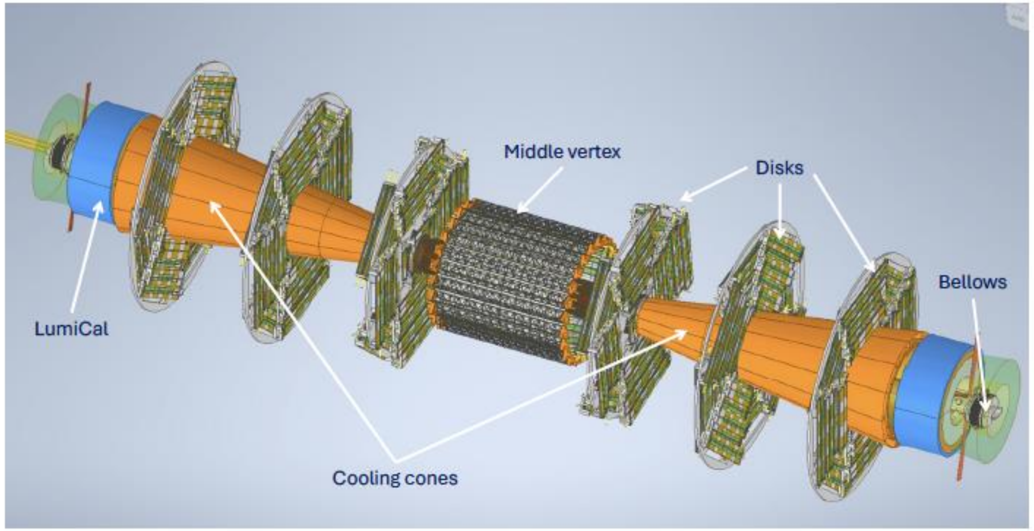


Fig. 51: Layout of the vertex detector cooling cones assembly, together with the main elements to be integrated around.

IDEA Vertex detector air-cooling simulations

Inner Vertex (ARCADIA based):

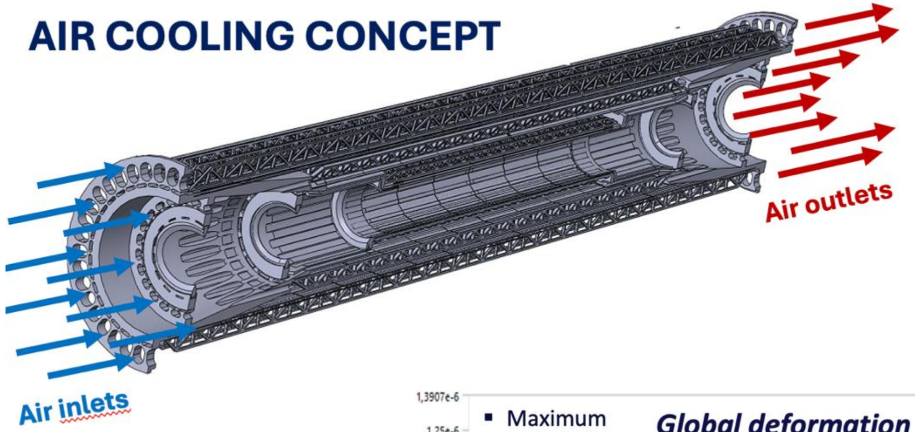
- Lfoundry 110 nm process
- *50 μm thick*
- Module Dimensions: $8.4 \times 32\ mm^2$
- Power density 50 mW/cm^2
- **100 MHz/cm²**

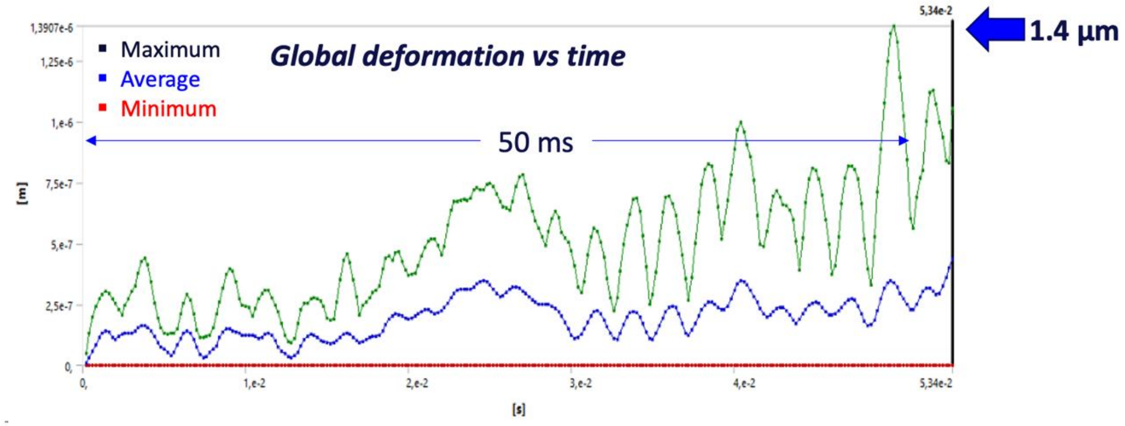
Estimation for sensors power dissipation:

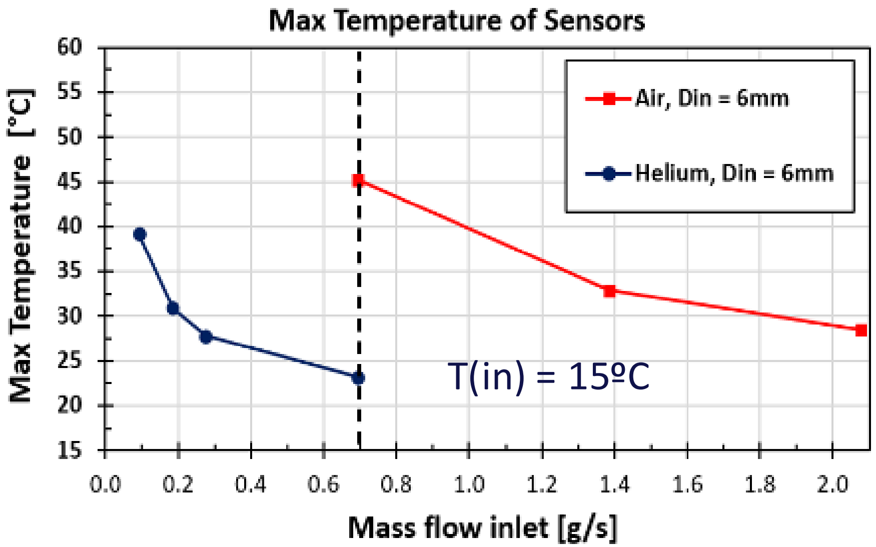
Layer 3: $\dot{Q}$ **~ 77 W** (total)

Layer 2: $\dot{Q}$ **~ 32 W** (total)

Layer 1: $\dot{Q}$ **~ 12 W** (total)





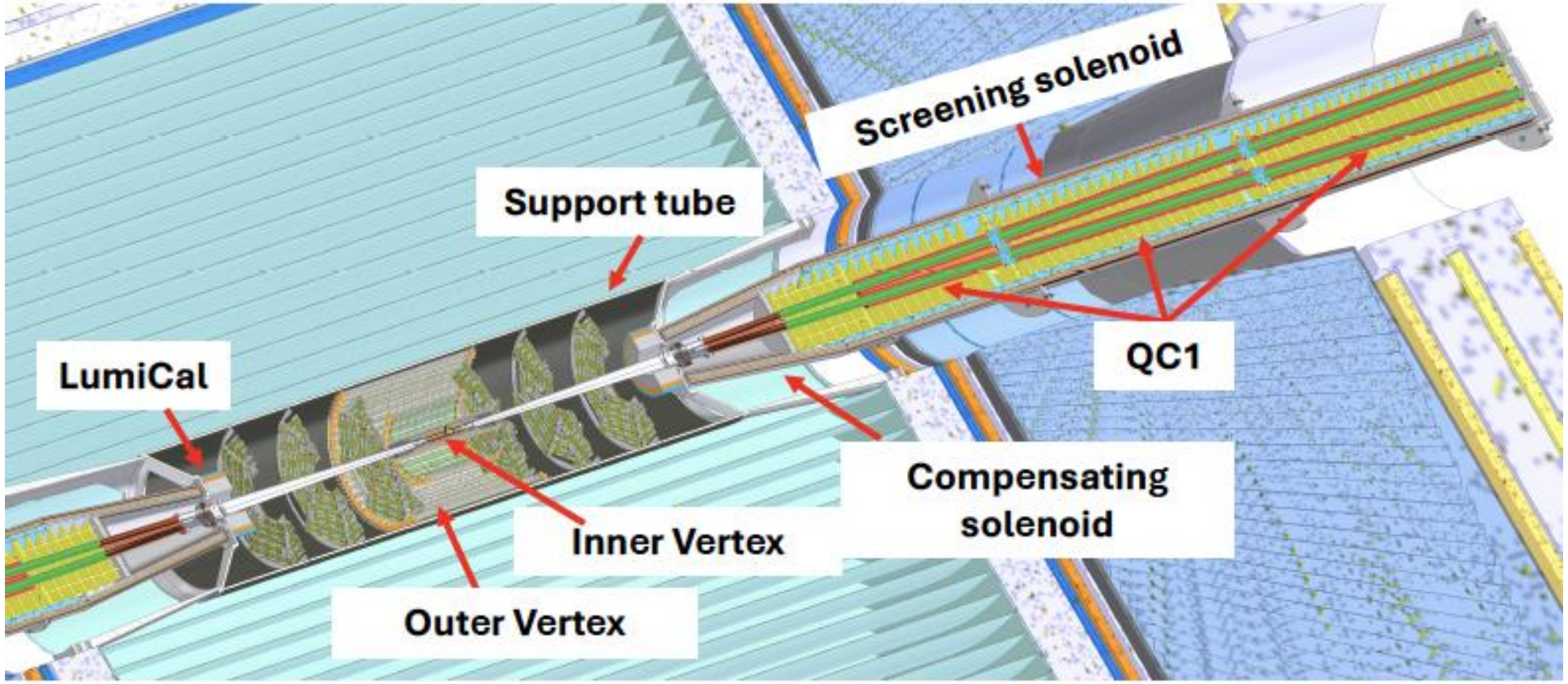


Simulations by INFN-Perugia show the feasibility of air/He cooling
Experimental validation ongoing R&D in INFN Pisa

IR magnet system integration

IR magnet system inside the detector and is all cryogenic

- Compensating solenoid
- Final focus quadrupole QC1
- Screening solenoid

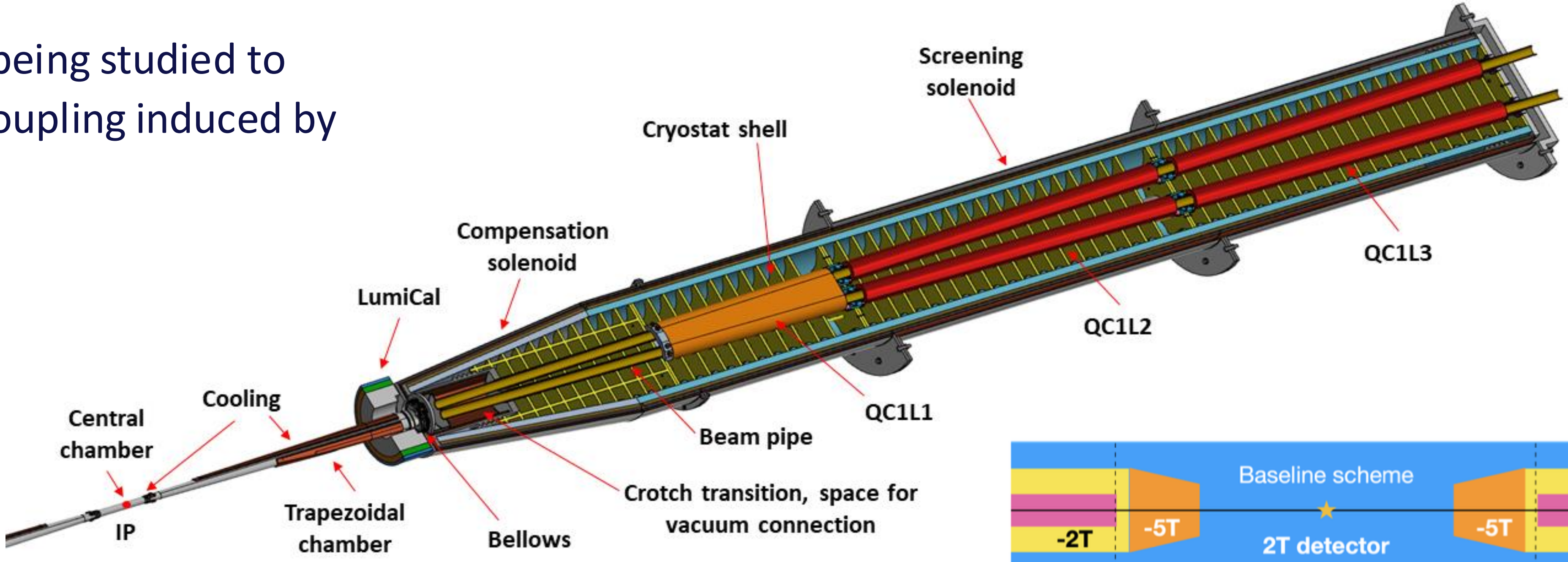


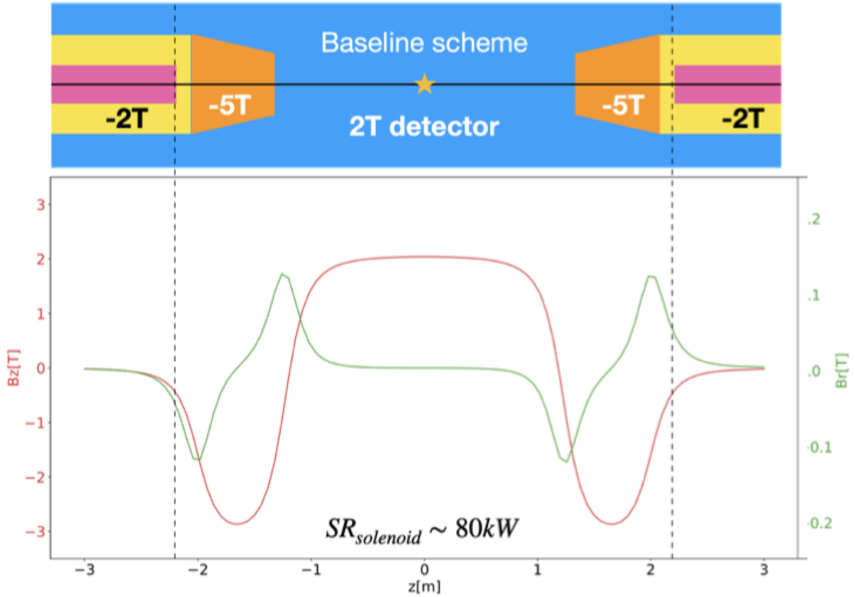
Space budget is critical, especially for the first segment of QC1, due to the close proximity of the exterior of the two beam pipes because of their size and crossing angle.

Design will be performed in the next pre-TDR phase

Local Solenoid compensation scheme - Baseline

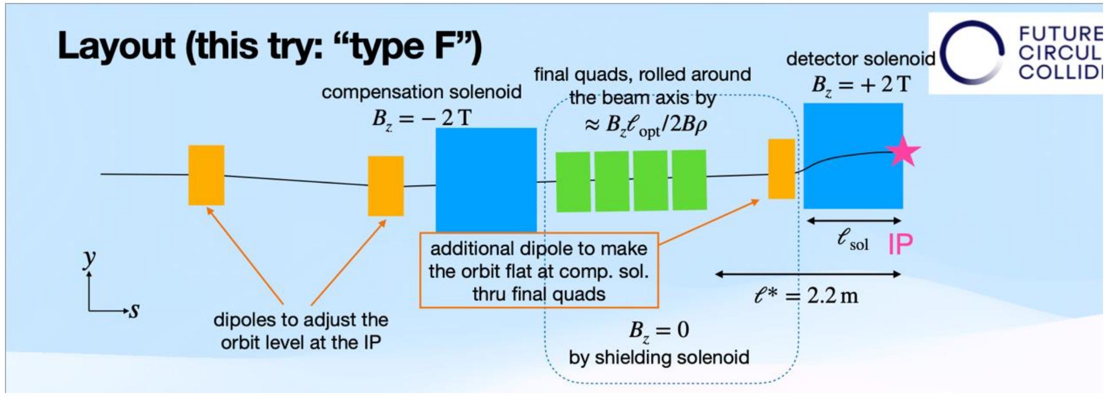
Two schemes are being studied to compensate the coupling induced by the detector field.





- Strong anti-solenoid (-5 T) in front of QC1
- screening solenoid around portion of QC1 inside the detector

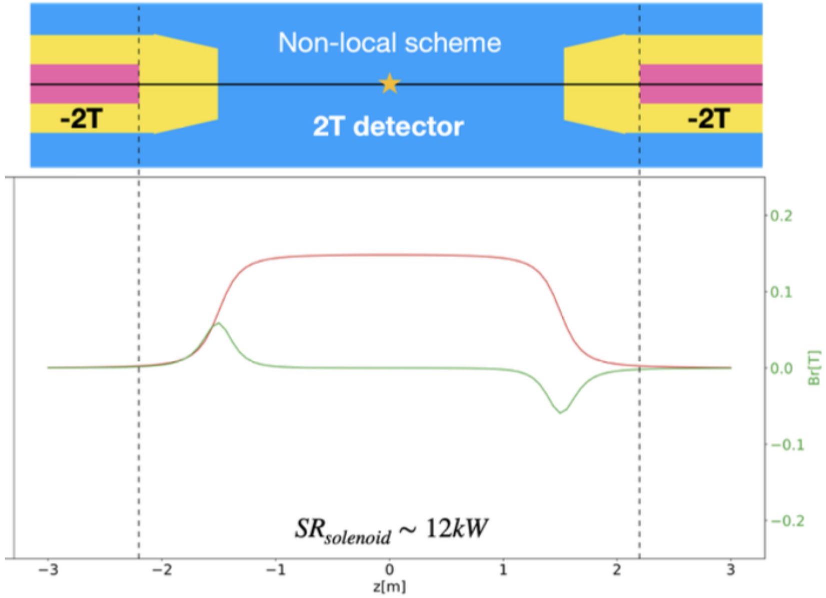
Non-local Solenoid Compensation Scheme



- Anti-solenoid outside (10/20 m from the IP)
- Weak corrector dipoles
- Skew quads windings around FFQs
- screening solenoid around portion of QC1 inside the detector

https://doi.org/10.18429/JACoW-IPAC2024-TUPC68

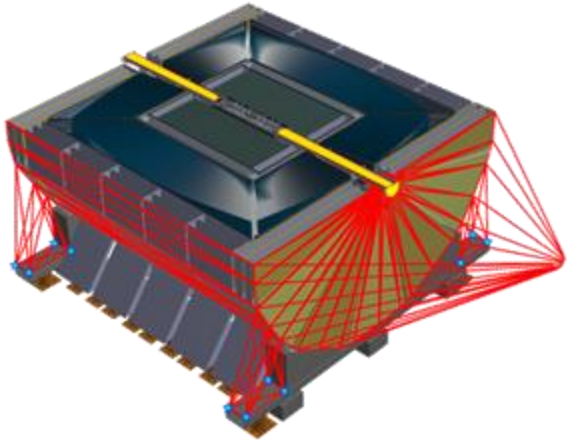
- Allows to **increase detector B field up to 2.5 T** contrary the local scheme (due to a better coupling compensation)
- **Going from 2T to 2.5T detector solenoidal field improved the pt resolution by 20 %**
- **Factor of 2 lower SR at the IR**
- **Polarization build-up: e+ e- polarised injector under study**

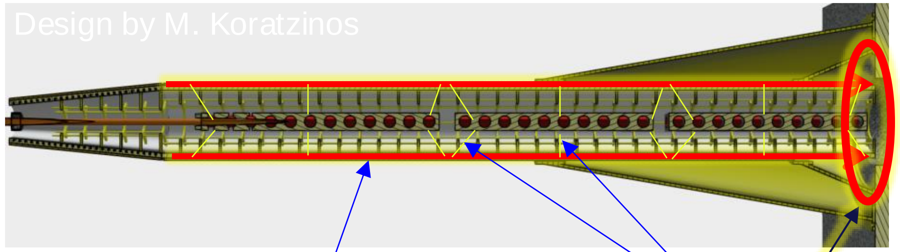


Alignment

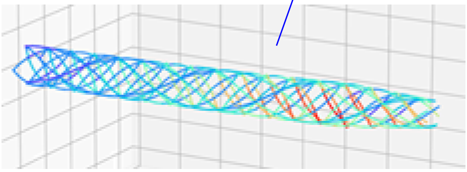
- **Aligment system based on three levels**
  - A deformation monitoring system of the shape of the screening solenoid with laser and fibres interferometric system (IMD-FSI)
  - A short-distance monitoring system, targeting QC1, LumiCal, etc, similar to FSI and HL-LHC MDI
  - A long-range FSI system joining the two sided of the detector

External alignment system





Impact of deformation on a network of fibers



Laser emitting ferrule

Glass beads

Interface to extract the information

Epoxy glued optical fiber

Brazed interface

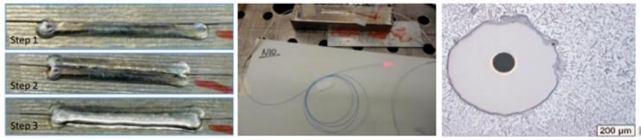
(a) Ceramic washer brazed into the EO-BPM body

(b) EO-BPM button assembly, mating view

(c) EO-BPM button assembled onto the body

Figure 3: Photos showing detail of the ceramic washer brazed to the EO-BPM body, mating interface to the button assembly and button assembled onto the body.

Brazed optical fiber



(a) (b) (c)

Figure 2. (a) Optimized 3-step embedding technique with laser brazing, (b) setup with red light fault detector for coarse tuning of the embedding technique and (c) cross section cut of the embedded optical fiber in metal using laser brazing.

Grandal, Tania, et al. "Laser brazing metallic embedding technique for fiber optic sensors." 2017 25th Optical Fiber Sensors Conference (OFS). IEEE, 2017.

Maintenance and accessibility of the detectors

Three options for opening the detector in the caverns

1. longitudinal shift
   - FFQ and other machine elements beyond detector endcaps shall be removed (with their supports). BP vacuum broken also in cold pipes. Realignment of the machine needed.
2. longitudinal + transverse shift
   - Split endcaps significantly deteriorate detector precision measurements. BP vacuum stay (or Ne flushing), no realignment needed.
3. Transversal shift of the full detector and the FFQ assembly (parking position), then extraction of the FFQ and full longitudinal opening of the detector endcaps
   - Optimal detector acceptance. FFQ assembly stays inside the detector, temporarily supported by the detector's endcaps. Machine elements beyond detector endcaps also stay in place. BP vacuum broken for detector beampipe. Realignment needed
   - Can only be done for large caverns

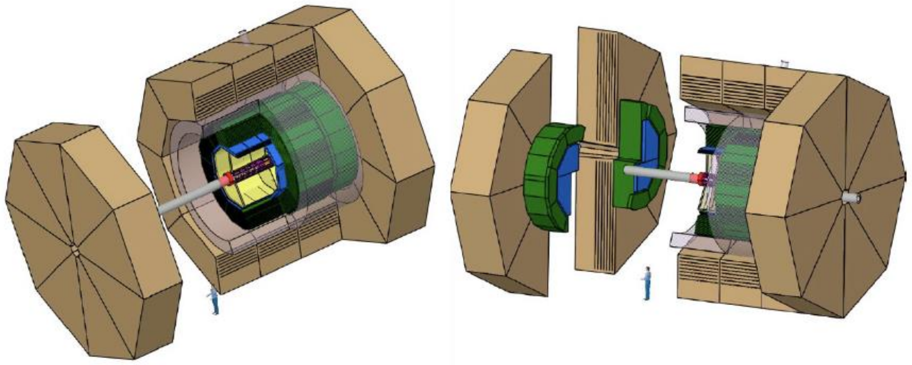
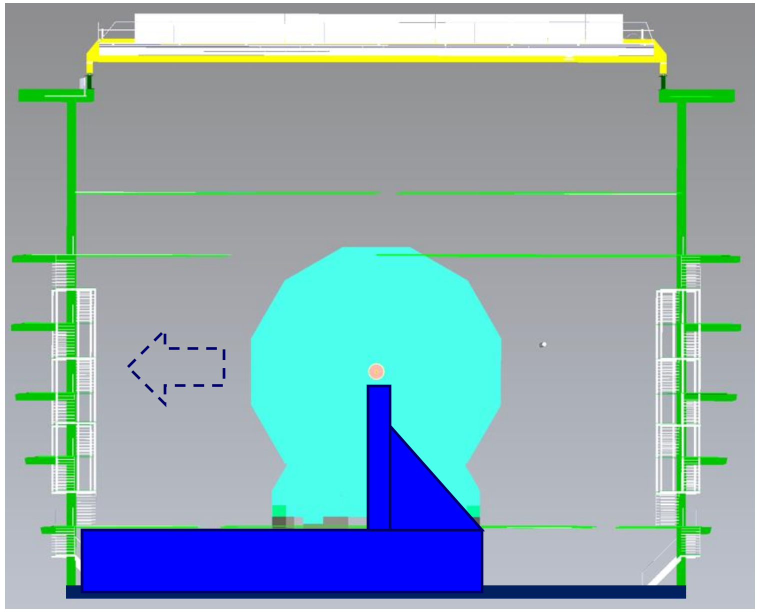


Fig. 54: Longitudinal (left) and short longitudinal plus transversal endcap (right) detector opening



Beam induced backgrounds

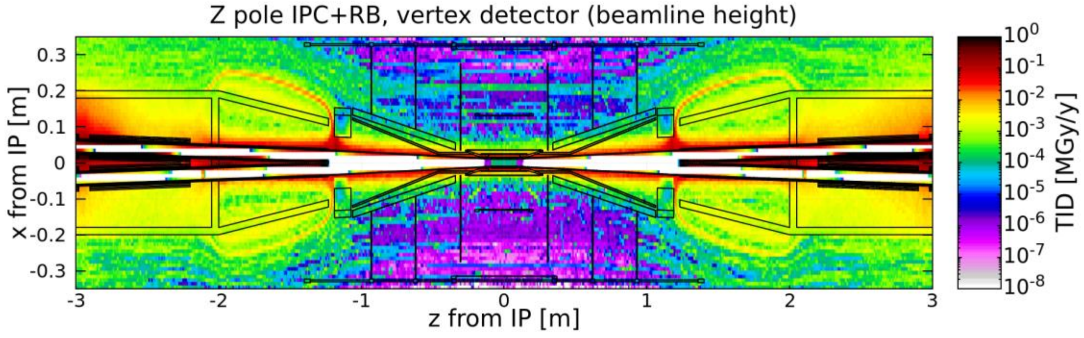
Two classes of backgrounds: single beam and colliding beams induced

- **Single beam induced:**
  - Beam halo losses, due to beam instabilities, interaction with residual gas, intra-beam scattering, magnet misalignments, and magnetic field errors are 'cleaned' by the collimator system
  - Beam-gas causes negligible losses in the detector and FFQ
  - Synchrotron radiation caused by imperfections and beam tails are being studied
- **Colliding beams induced:**
  - Incoherent Pair Creation (IPC)
    - 200 MHz/cm^2 in the innermost layer of VDET, 7% occupancy in Drift chamber, 0.2% in ECAL
  - Radiative Bhabha $e^+e^- \to e^+e^-\gamma$, where one particle hits the FFQ or detector elements have a large cross-section and simulated with BBBREM and GuineaPig
    - Energy deposits in QC1 needs about 2 mm tungsten shielding

Total Ionisation Dose and Fluence

Studied with FLUKA

At the moment only two major sources: IPC and radiative Bhabha. Beam gas at least one order of magnitude smaller



- Largest dose and fluence occurs at the Z pole
  - 1st layer of the vertex detector
    - Few tens of kGy/year
    - 10^{13} /cm^2 1 MeV n_{eq}.

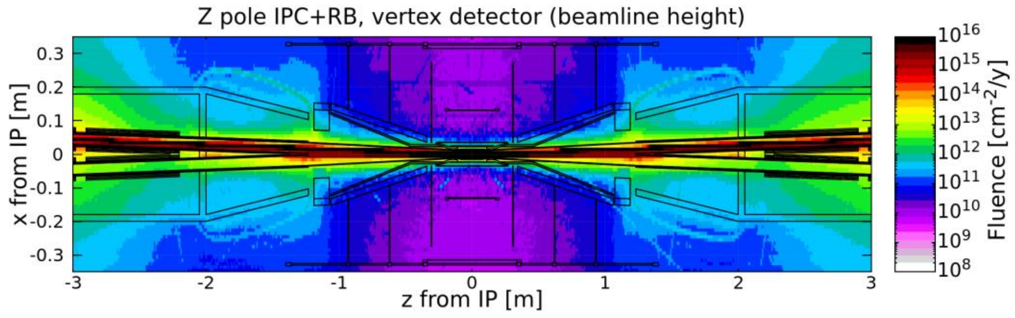
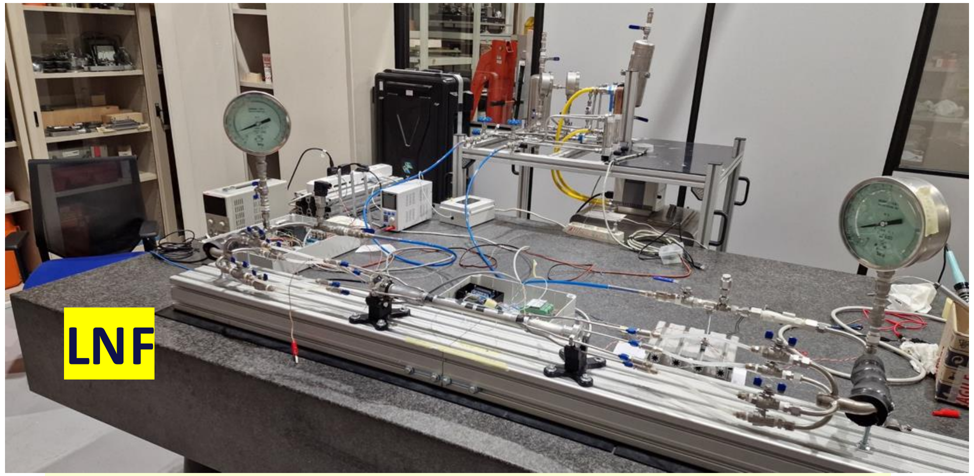


Fig. 56: Total Ionisation Dose (top) and 1MeVn_{eq} fluence (bottom) in the interaction region of the IDEA detector concept.

Experimental activities

Ongoing activities

- INFN + CERN (co-funded): IR full scale mockup in Frascati –
  - Linked to the DRD8 WP1.1
- CERN: Alignment system of the FFQ 1:2 mock-up

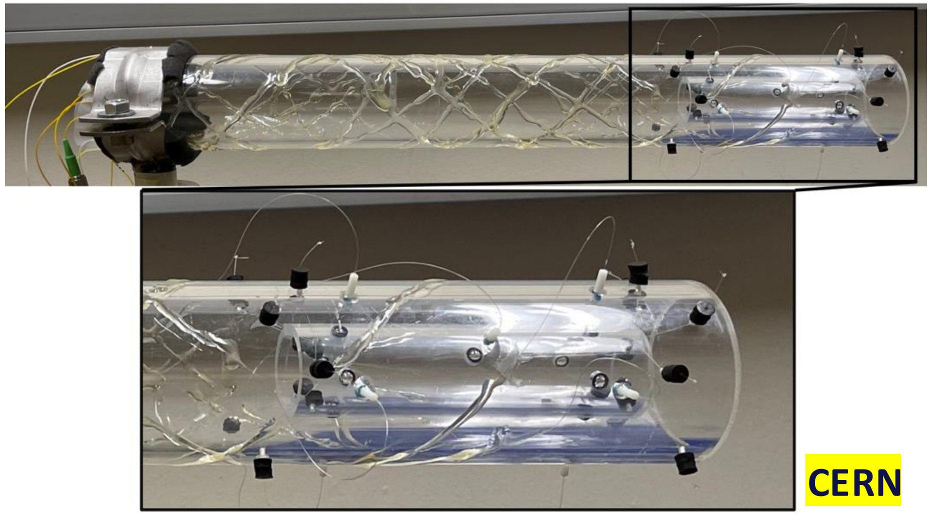


LNF

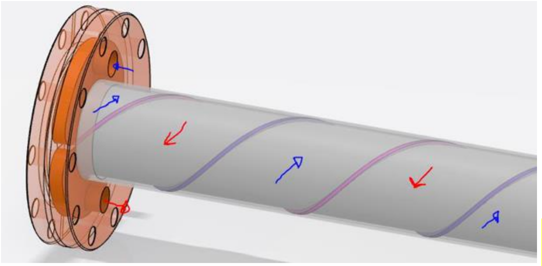
Friday 12h30-13h30 Visit
Please contact Enrico.DiPasquale@lnf.infn.it if you are interested and would like to see it before Friday.

Proposed activities

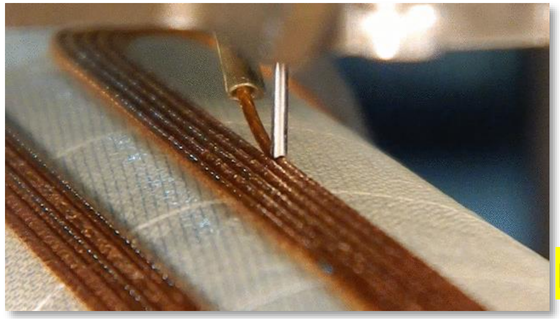
- BNL: QC1 prototypes using direct winding technique
- LAPP: HTS magnet for QC1, and its integration with the water-cooled beam-pipe.



CERN



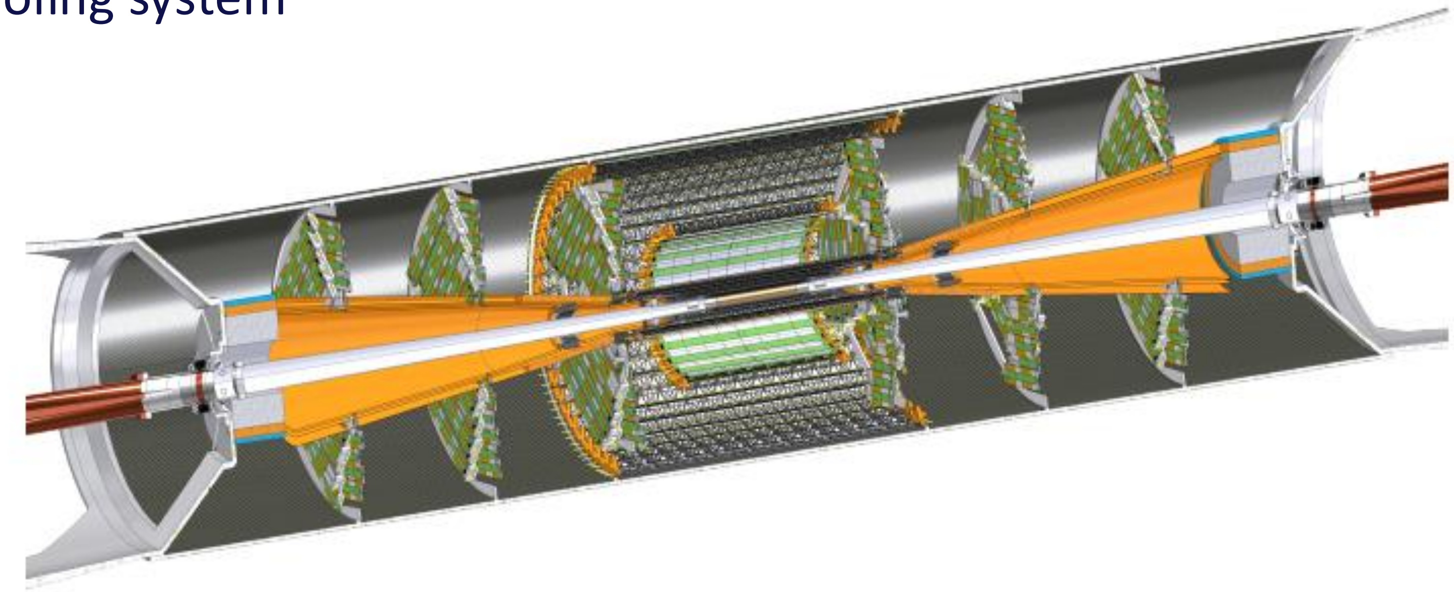
LAPP



BNL

Main Components of the IR Mock-up

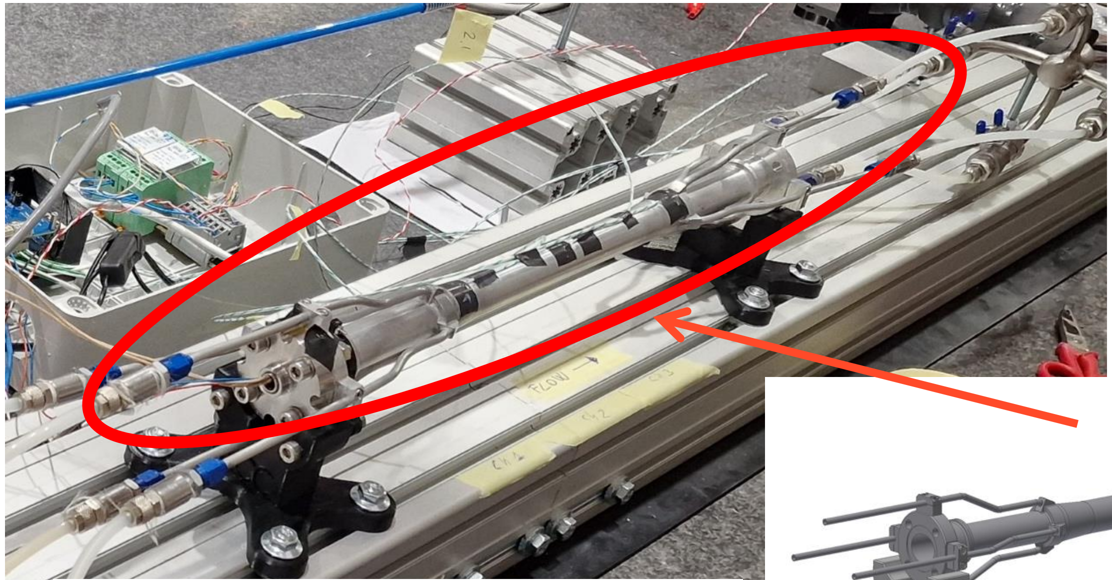
- Central vacuum chamber with cooling system
- Conical vacuum chamber with cooling system
- Bellows
- Inner vertex detector with air cooling system
- Outer tracker
- Support tube
- Luminosity calorimeter



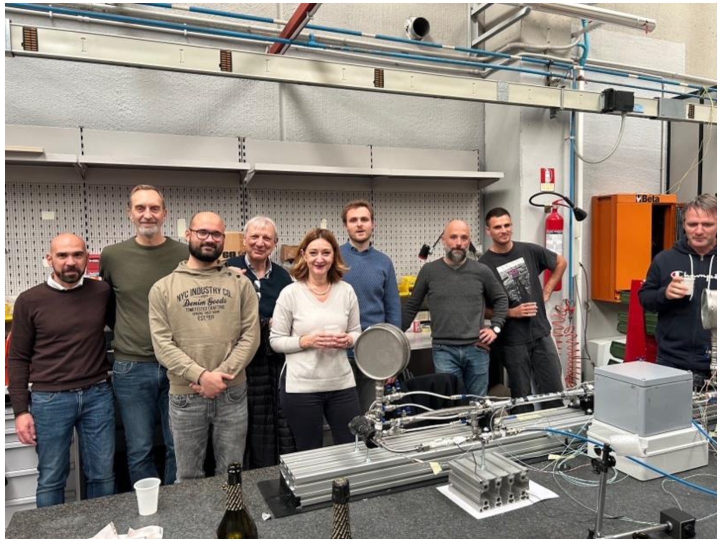
IR mock-up

- Experimental validation of the IR beam pipes manufacturing and cooling system, vertex and LumiCal integration, vertex cooling, services and routings, and assembly.

- Central beam pipe prototype in aluminium delivered to Frascati.
- First measurements started.



Central chamber connected to the hydraulic circuit



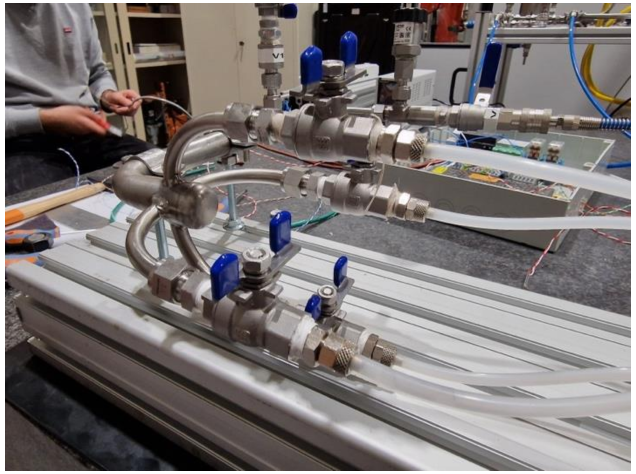
S. Cantarella, A. Ciarma, E. Di Pasquale, F. Fransesini, S. Lauciani G. Luminati, G. Sensolini, M. B.

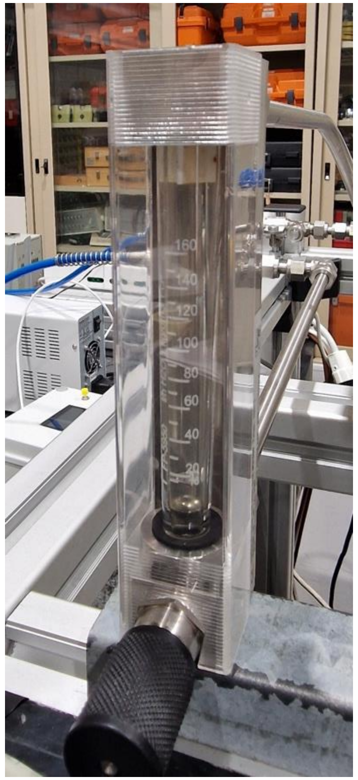
First tests on the central chamber

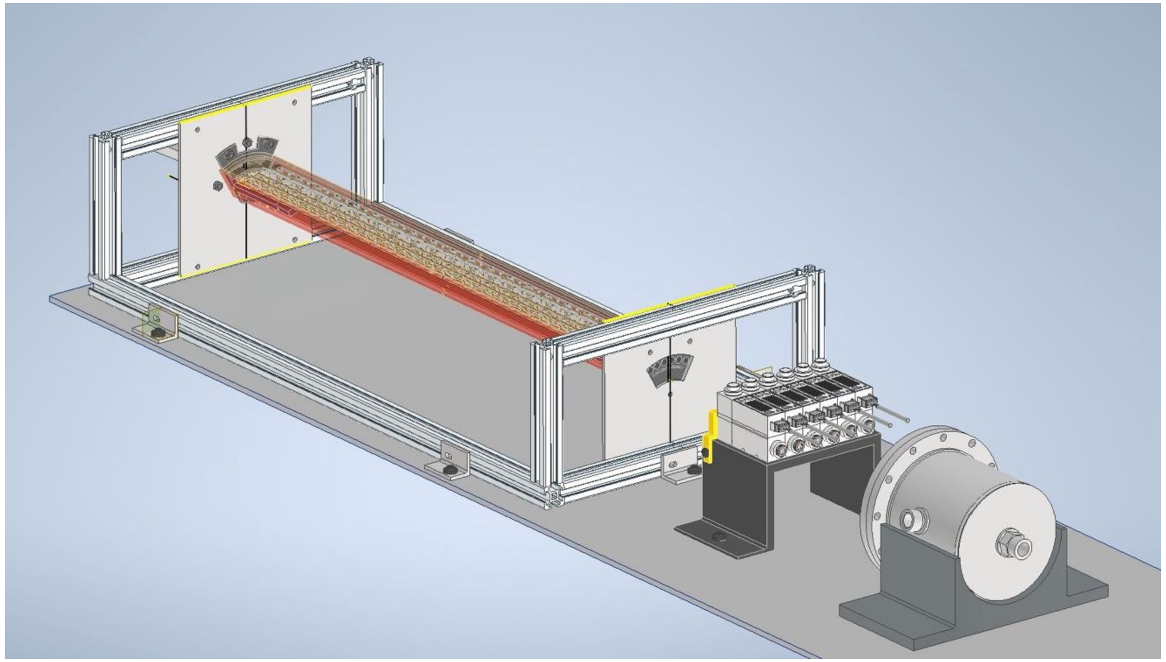
To verify efficiency of the cooling system we measure:

- temperature
- flow rate
- coolant pressure

in the inlet and outlet







Sketch of open circuit wind tunnel for vertex cooling, R&D ongoing in Pisa.

An electrical heater inside the central chamber simulates the beam heat load, a variable power supply controls the power.

Order of the ellipto-conical chambers prototypes and bellows placed.

Prospects & Plans during pre-TDR (2025-2027)

- Outstanding design optimisations:
  - QC1 cryostat design and temperature of the cryomodule
  - Decide the solenoid coupling compensation scheme
  - IR magnet system design and prototyping
  - Detector maintenance, machine and detector integration
- Validate design through experimental mockup activities
- International Expression of Interest to be submitted to ESPPU

List of contributors to the MDI chapter in Vol. 1

M. Boscolo and F. Palla editors

INFN: G. Baldinelli, F. Bosi, G. Broggi, A. Ciarma, F. Fransesini, S. Lauciani, G. Nigrelli, C. Turrioni
CERN: K. Andre, R. Bruce, H. Burkhardt, B. Francois, A. Gaddi, A. Lechner, G. Lerner, F. Valchkova-Georgieva, L. Watrelot
SLAC: A. Novokhatski, J. Seeman
BNL: B. Parker
NBI: M. Dam
Liverpool Univ.: A. Frasca
Uni. Zurich: A. Ilg
UNIGE: K. Oide
FNAL: P. Raimondi

Thank you for your attention.

FCC-ee Interaction Region rationale: crab-waist

Crab-waist scheme, based on two ingredients:

- concept of **nano-beam scheme:**
  - vertical squeeze of the beam at IP and large horizontal crossing angle
  - large ratio σ_z/σ_x reducing the instantanous overlap area, allowing for a lower β_y^*
- concept of **crab-waist sextupoles:**
  - placed at a proper phase advance they suppress the hourglass effect by inducing a constant β_y along the larger coordinate of the beams overlap.

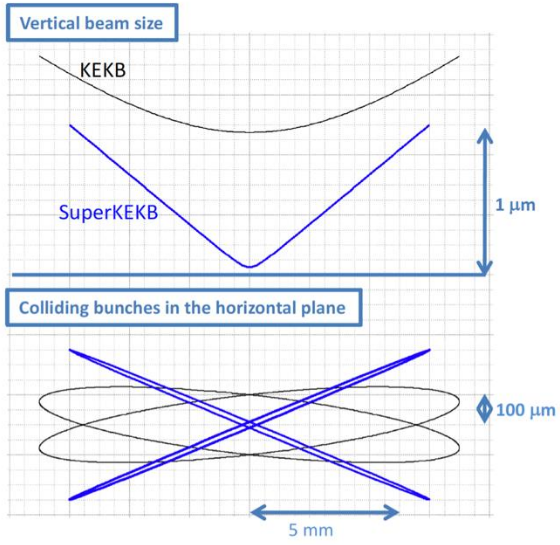
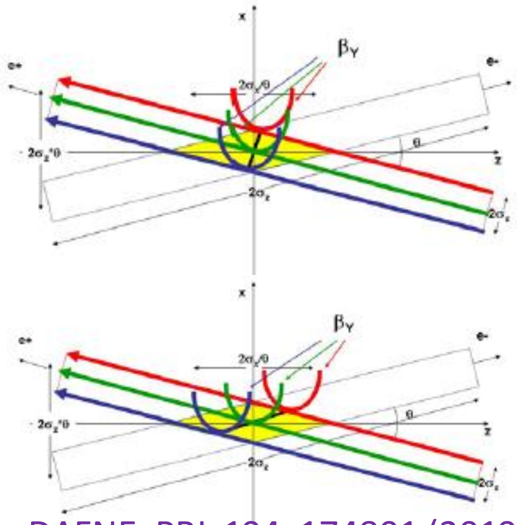
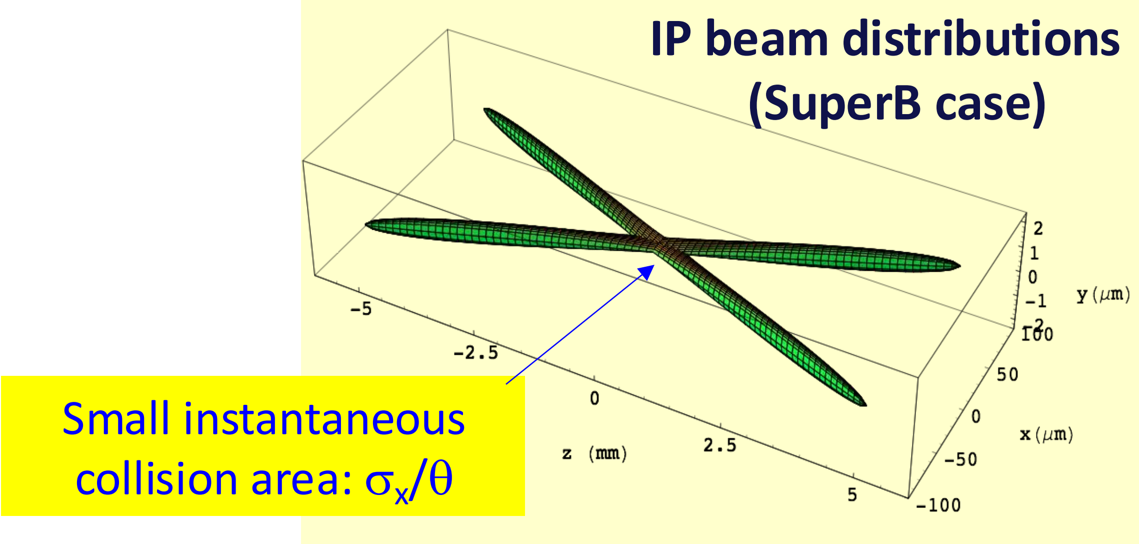


Figure 2: Schematic view of the nanobeam collision scheme.

SuperKEKB https://arxiv.org/pdf/1809.01958.pdf



DAFNE, PRL 104, 174801 (2010)



FCC Innovation Study (FCC-IS) 2020-2024

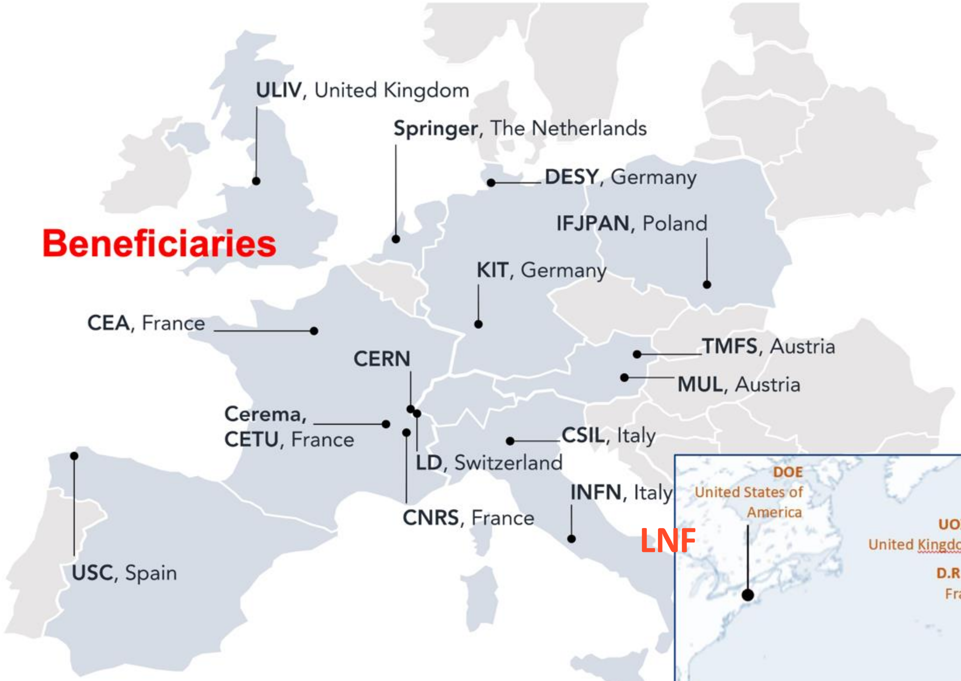
Strategic project for funding the Feasibility Study phase: grants to the beneficiaries and building a global collaboration

Beneficial for INFN to be part of the European Project:

- **Many post-doc contracts for young researchers and engineers at the LNF**
- **LNF leading institute of the MDI working package, in collaboration with CERN, CNRS, UOXF, DESY**
- **LNF deliverable: the 3D CAD proof-of-principle engineered mechanical design of the interface between the accelerator and detector components in the IR**

European Commission | Horizon 2020 European Union funding for Research & Innovation

Topic	**INFRADEV-01-2019-2020**
Grant Agreement	FCCIS 951754
Duration	48 months
From-to	2 Nov 2020 – 1 Nov 2024
Project cost	**7 435 865 €**
EU contribution	**2 999 850 €**
Beneficiaries	16
Partners	6



European Circular Collider (EuroCirCol) 2015-2019

European Commission | Horizon 2020 European Union funding for Research & Innovation

Strategic project for funding the Feasibility Study phase: grants to the beneficiaries and building a global collaboration

Beneficial for INFN to be part of the European Project:

- **Many post-doc contracts for young researchers and engineers at the LNF, Genova, Milano**
- **All of them have been hired permanently (thanks to their very high-level profiles!) and are now involved in the various future colliders studies (not only FCC, also Muon Collider)**

INFN Involvement in:

- **FCC-hh MDI** (LNF)
- **Cryogenic beam vacuum system** (LNF)
- **High Field Magnet** (Genova, Milano)

  Exploration of different design options for the16T Nb_3Sn dipoles

Essential for the CDR of FCC-hh

A relevant outcome of EuroCirCol is to have initiated the research activity for the HFM program.