MDI SUMMARY AND PROSPECTS

Manuela Boscolo[1] and Fabrizio Palla[2,3]

[1]INFN Laboratori Nazionali di Frascati, Italy

[2]INFN Sezione di Pisa, Italy

[3]CERN, Switzerland

8th FCC Physics workshop
CERN
13-17 January 2025

1. **Jt MDI & Det session:**
   - Vertex det
   - LumiCal
   - Integration
2. **Jt MDI & Det & SW session:**
   - Beam background
3. **MDI session**
   - Mechanical layout & integration
4. **MDI session**
   - IR optics and beam dynamics

8th FCC Physics Workshop
CERN, Jan. 13-16, 2025 + Satelite meeting Jan. 17
indico agenda: https://indico.cern.ch/event/1439509/timetable

	Monday 13.01		Wednesday 15.01	Thursday 16.01	Friday 17.01
0-9:30 0-10:00 00-10:30		-- Parallel Sessions -- 1. **Phys. Prog.** (General) Council Chamber (503/1-001) 2. **Jt MDI & Detectors** (beam pipe, vertex detector, LumiCal) Filtration plant ()222/R-001) 3. **Jt SW & Phys. Perf.** (analysis) TH conference room (4/3-006)	-- Parallel Sessions -- 1. **Phys. Prog. & Perf.** (QCD+Flavour) Council Chamber (503/1-001) 2. **MDI** (IR optics layout and beam dynamics) TH conference room (4/3-006) 3. **SW** (Key4HEP, LEP@E4H, resources) Main auditorium (500/1-001)	-- Parallel Sessions -- 1. **Phys. Prog.** (Higgs/EW) Council Chamber (503/1-001) 2. **Jt SW & Phys. Perf. & Detectors** (digitization/reconstruction) TH conference room (4/3-006)	-- Satelite meeting -- 1. **Planning for ESPP submissions and future steps** TH conference room (4/3-006) 2. **Detector EoIs** Filtration plant (222/R-001)
30-11:00	-- Early Career Researcher Session -- BE Auditorium (6/2-024)	Coffee break	Coffee break	Coffee break	Coffee break
11:00-11:30 11:30-12:00		-- Parallel Sessions -- 1. **Phys. Prog. & Perf.** (Higgs/EW) Council Chamber (503/1-001) 2. **EPOL** TH conference room (4/3-006) 3. **Jt MDI & SW & Detectors** (beam background) Filtration plant ()222/R-001)	-- Parallel Sessions -- 1. **Phys. Prog. & Perf.** (BSM) Council Chamber (503/1-001) 2. **Detectors** (detector concepts, large-scale structures and cryostats) TH conference room (4/3-006)	-- Parallel Sessions -- 1. **Phys. Prog.** (FCC-hh) Council Chamber (503/1-001) 2. **EPOL** Main auditorium (500/1-001) 3. **Joint Software, Phys. Perf. & Detectors** (reconstruction) TH conference room (4/3-006)	-- Satelite meeting -- 1. **Planning for ESPP submissions and future steps** TH conference room (4/3-006) 2. **Detector EoIs** Filtration plant (222/R-001)
13:00-13:30	Lunch	Lunch	Lunch	Lunch	Lunch
13:30-14:00 14:00-14:30	-- General FCC Meeting -- **Plenary talks** Main auditorim (500/1-001)	-- Parallel Sessions -- 1. **Jt Phys. Prog. & Perf.** (top/EW) Council Chamber (503/1-001) 2. **Detectors** (tracking and vertexing) TH conference room (4/3-006)	-- Parallel Sessions -- 1. **Phys. Prog. & Perf.** (QCD+Flavour) Council Chamber (503/1-001) 2. **Jt Detectors & SW** (simulations, progress towards full-sim) TH conference room (4/3-006)	-- Summaries/Highlights -- Main auditorium (500/1-001)	
	Coffee break	Coffee break	Coffee break	Coffee break	
16:30-17:00 17:00-17:30 17:30-18:00	-- PED Feasibility Study -- **Plenary talks** Main auditorim (500/1-001)	-- Parallel Sessions -- 1. **Phys. Prog.** (BSM) Council Chamber (503/1-001) 2. **MDI** (assembly and integration) TH conference room (4/3-006)	-- Parallel Sessions -- 1. **Phys. Prog. & Perf.** (QCD+Flavour) Council Chamber (503/1-001) 2. **Detectors** (PID, Calorimetry) TH conference room (4/3-006)	-- Summaries/Highlights -- Main auditorium, 500/1-001	
18:00-18:30	Welcome reception Salle des pas perdus, 61/1-201		Poster session Cocktail Salle des pas perdus (61/1-201)		
20:00-20:30					

16 talks on parallel sessions
1 talk in plenary (+this one)

Tuesday 14 January

09:00 → 10:30 **Joint MDI and detectors: Vertex detector, LumiCal, and Integration**
Convener: Fabrizio Palla

- 09:00 **Vertex Detector Cooling simulations** — Speaker: Dr Giorgio Baldinelli (University of Perugia)
- 09:20 **Lumical - residual B field effects and bkgs** — Speaker: Mogens Dam (University of Copenhagen (DK))
- 09:40 **Curved VDX layout, performance and constraints** — Speaker: Armin Ilg (University of Zurich)
- 10:00 **Detector integration and maintenance** — Speaker: Andrea Gaddi (CERN)

11:00 → 12:30 **Joint MDI and Software and Detectors: Beam backgrounds**
Convener: Helmut Burkhardt (University of Freiburg (DE))

- 11:00 **Backgrounds on detectors** — Speaker: Andrea Ciarma (INFN e Laboratori Nazionali di Frascati (IT))
- 11:15 **Simulation interface of accelerator backgrounds in the detectors** — Speaker: Brieuc Francois (CERN)
- 11:30 **Synchrotron Radiation bkgs** — Speaker: Kevin Daniel Joel Andre (CERN)
- 11:50 **Beam losses in the IR** — Speaker: Giacomo Broggi (CERN, Sapienza Università di Roma e INFN Laboratori Nazionali di Fra
- 12:10 **FLUKA results on fluences, doses and backgrounds on the detector** — Speaker: Alessandro Frasca (University of Liverpool (GB))

16:30 → 18:30 **MDI: IR Mechanical layout and Integration**

- 16:30 **IR corrector magnets design** — Speaker: Brett Parker (Brookhaven National Laboratory (US))
- 16:50 **IR Beam pipes** — Speaker: Francesco Fransesini (INFN e Laboratori Nazionali di Frascati (IT))
- 17:10 **3D integration models for experimental areas** — Speaker: Fani Valchkova-Georgieva (Bulgarian Academy of Sciences (BG))
- 17:30 **MDI Alignment** — Speaker: Leonard Watrelot

Wednesday 15 January

09:00 → 10:30 **MDI: IR optics layout and beam dynamics**
Convener: Manuela Boscolo (INFN e Laboratori Nazionali di Frascati (IT))

- 09:00 **IR optics** — Speaker: Dr Katsunobu Oide (Universite de Geneve (CH)) — IPOptics_Oide_2501...
- 09:30 **IR correction optics** — Speaker: Helmut Burkhardt (University of Freiburg (DE))
- 09:50 **Beam losses from fast instability** — Speaker: Giulia Nigrelli (Sapienza Universita, INFN-LNF, CERN)
- 10:10 **IR heat load** — Speaker: Alexander Novokhatski (SLAC National Accelerator Laboratory (US))

Excellent work and progress

- Vertex and detector integration
- Interaction region layout optimization
- Machine backgrounds studies
- Optics and beam dynamics

Very good participation and discussions.

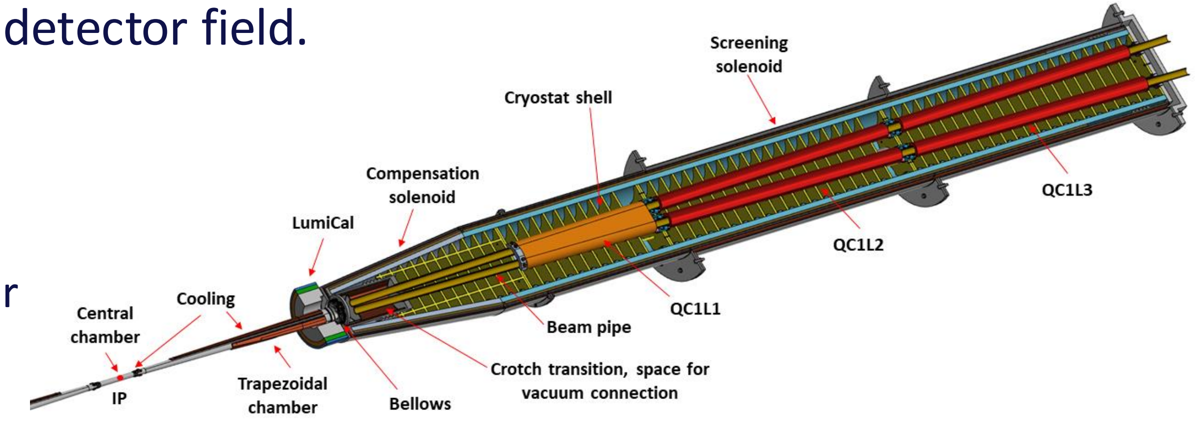
INTERACTION REGION DESIGN

IR Optics – Solenoid compensation scheme

Katsunobu Oide

Helmut Burkhardt

Two schemes to compensate the coupling induced by the detector field.

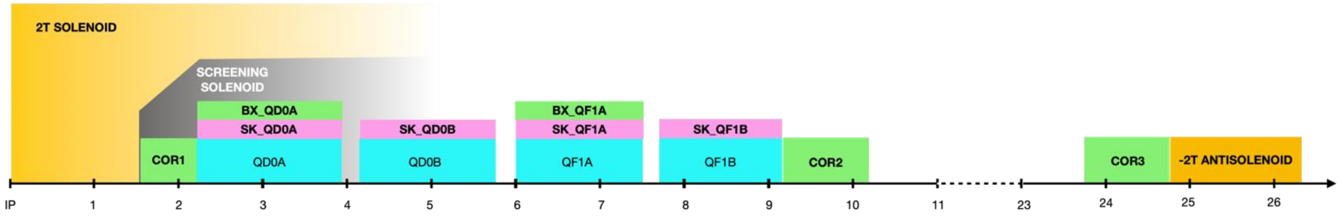


***Local* solenoid compensation scheme (Baseline design)**

- 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)
- screening solenoid around portion of QC1 inside the detector
- Weak corrector dipoles
- Skew quads windings around FFQs



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

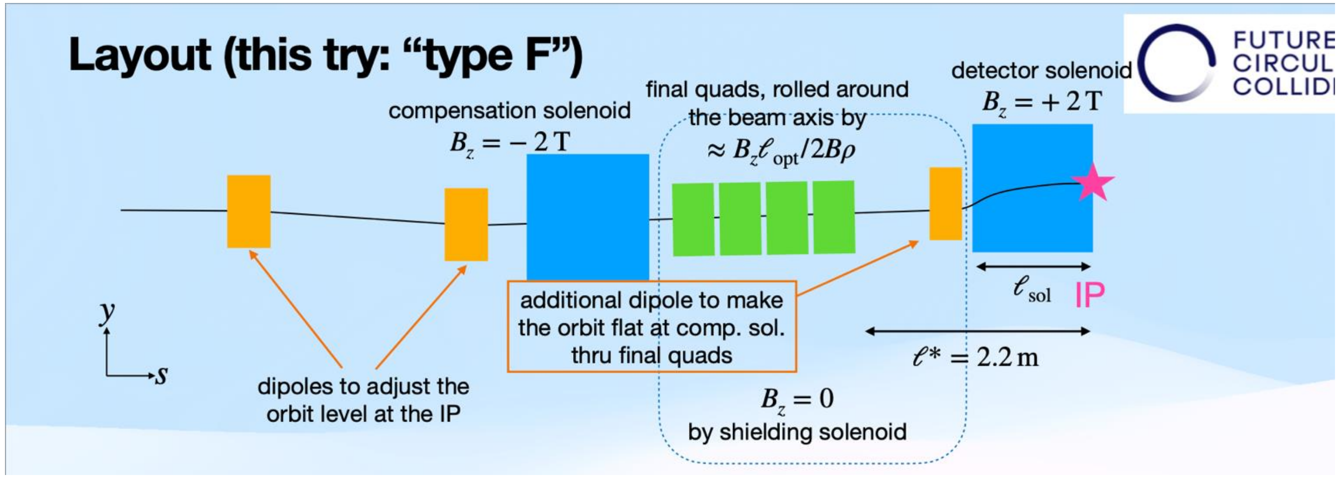
Main Advantages with non-local scheme: Higher detector field is possible, some margin to increase the crossing angle, removal of -5T magnet inside the detector with a factor of 2 lower SR at the IR, better coupling compensation

Disadvantage (study ongoing) : depolarisation → solvable

- This solution is optics independent (in terms of final focus quads)
- The tuning knobs -correctors and skews- are needed for orbit and coupling correction for all optics.

Katsunobu Oide

Non-local Solenoid Compensation Scheme



Depolarisation is weak for the local scheme, stronger with the non-local scheme,
Polarisation bump tuning as at LEP will be necessary, promising on-going study. Anyway solvable with e+e- polarised injector.

Allows to **increase detector B field up to 2.5 T** or **crossing angle up to 40 mrad**, but not simultaneously (see tables below) contrary the local scheme

$\theta_x = \pm 15$ mrad

B_z (T)	ε_y (pm)	$\varepsilon_{y,sol}$ (pm)
2	0.24	0.11
2.5	0.61	0.20
3	1.29	0.30
3.5	2.31	0.61

$B_z = 2$ T

θ_x (mrad)	ε_y (pm)	$\varepsilon_{y,sol}$ (pm)
±15	0.24	0.11
±20	0.79	0.43
±25	2.17	1.50
±30	5.13	3.71

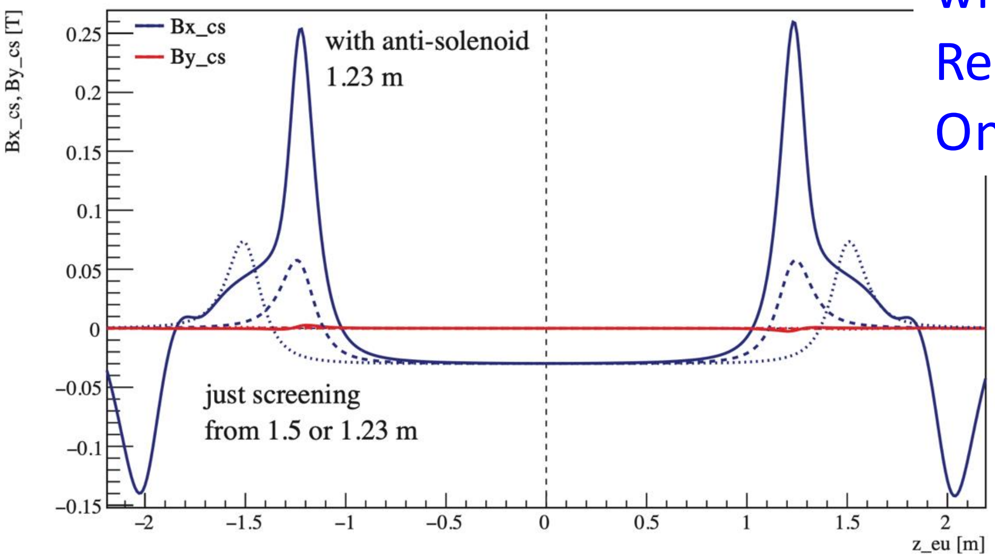
Helmut Burkhardt

IR correction optics

Solenoid fields seen by beams, without correction

crossing angle, 15 mrad tilt in x
major effect, mostly from fields,
with anti solenoid ~ 80 kW power per beam and IP

transverse fields seen by beam
Bx = 0.26 Tesla 16× arc bends



with the *non-local* scheme:
Reduction of synchrotron radiation power from 80 kW to 40 kW
Only 3 weak correctors needed, in spite of anti-solenoid

We upgraded our tools to handle nested orbit correctors

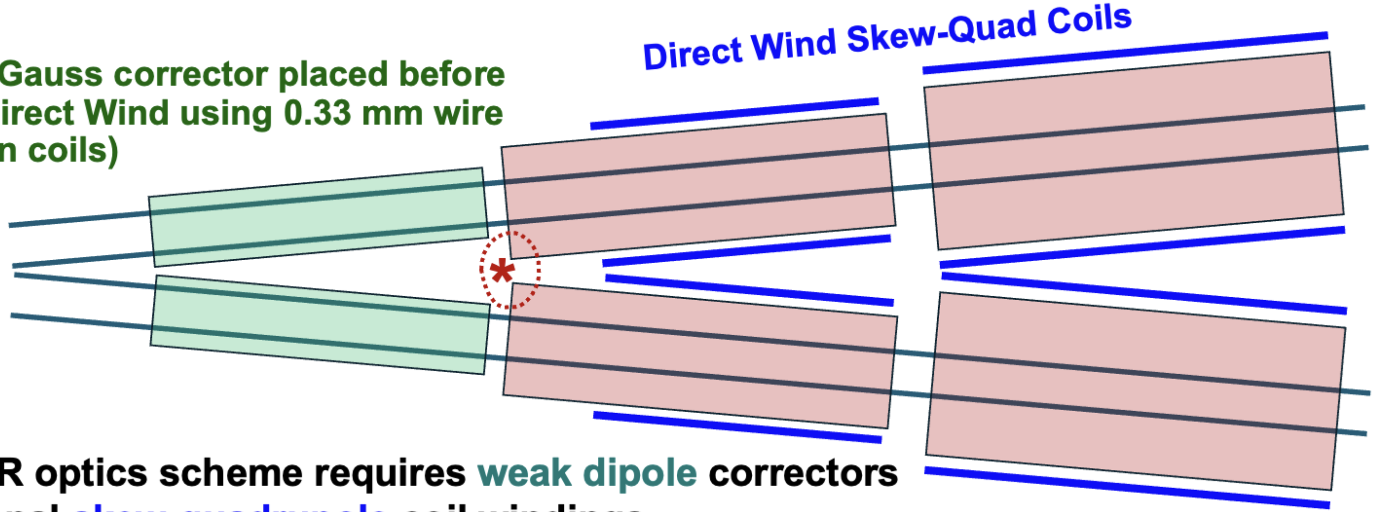
With 3 rather weak correctors (per plane and side)
we can close the bump and correct for the effects of the main solenoid on the beams at the IR without need for a local anti-solenoid

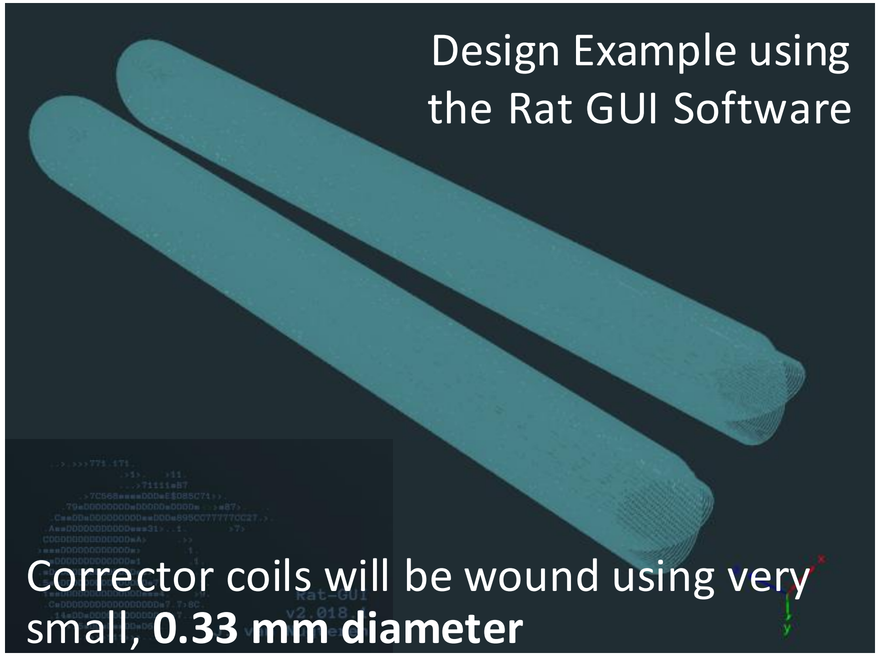
The SR power radiated in the IR system including radiation in quadrupoles and correctors is ~ 2× reduced compared to the power with a local anti-solenoid
Increasing the fields from 2 to 3 T may become more realistic
It would increase the power by $(3/2)^2 = 2.25$

Brett Parker

IR compensation scheme and corrector magnets

Wind ≈ 600 Gauss corrector placed before quads via Direct Wind using 0.33 mm wire (for very thin coils)





Non-local IR optics scheme requires weak dipole correctors and additional skew-quadrupole coil windings.

It is very challenging to add corrector coils around the first QC1 section; would it be ok if this corrector, e.g. the first skew-quad, did not cover the full length?

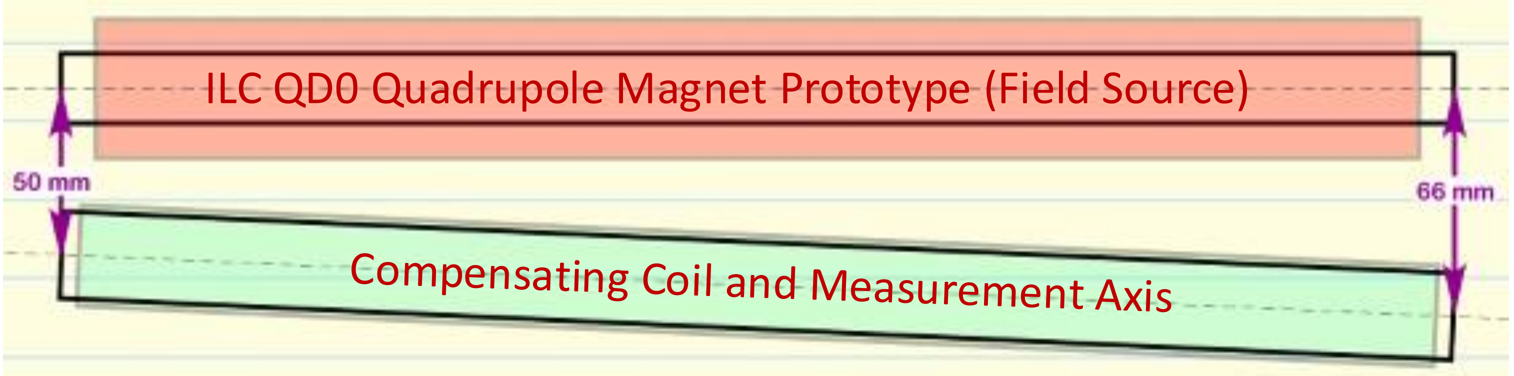
***First NbTi quad coils nearly touch at IP end; HTS-tape based version is worse due to non-circular cross section.**

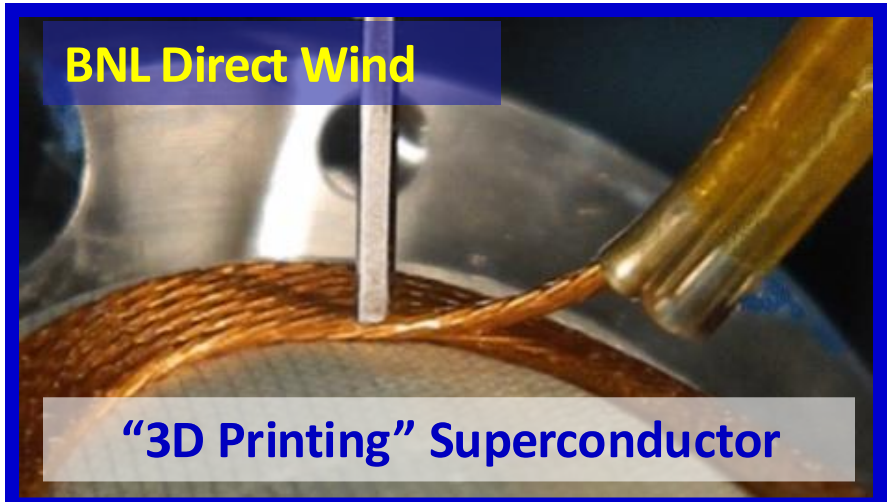
BNL got funded to make and test a corrector that will compensate the coil external field

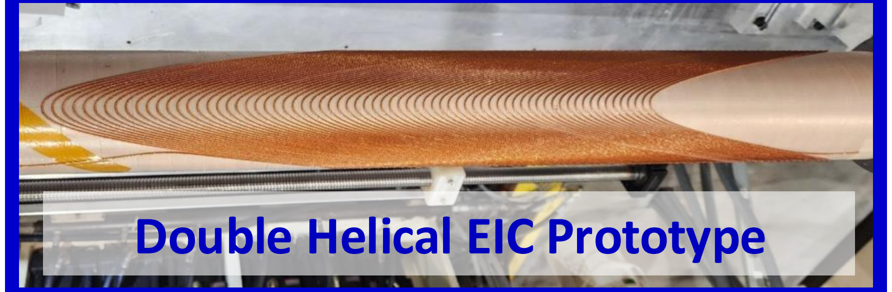
Brett Parker

FCC-ee IR Corrector Magnet Design Considerations

- FCC-ee IRs fundamentally need corrector coils.
- Main coil like “grooves” are not useful for correctors.
- So, build up nested correctors via BNL Direct Wind.
- Use Double Helical (CCT) to handle field crosstalk.
- Will test coil optimization principles by fabricating and measuring a coil to buck out external field of an existing ILC QD0 prototype magnet.







BEAM BACKGROUNDS

Andrea Ciarma

Beam backgrounds

Realistic description of MDI elements in simulations

- CAD description for IR beam pipe and magnetic fields for experiments and machine elements

Occupancy calculations for IPCs

- Test and establish workflow in Key4hep, first results and mitigation strategies

Radiative Bhabha

- Annual dose in magnets and detectors

Synchrotron Radiation

- Masks efficiently shield photons from beam core, other effects currently under study

Halo losses and single beam background source

- Optimization of collimators scheme

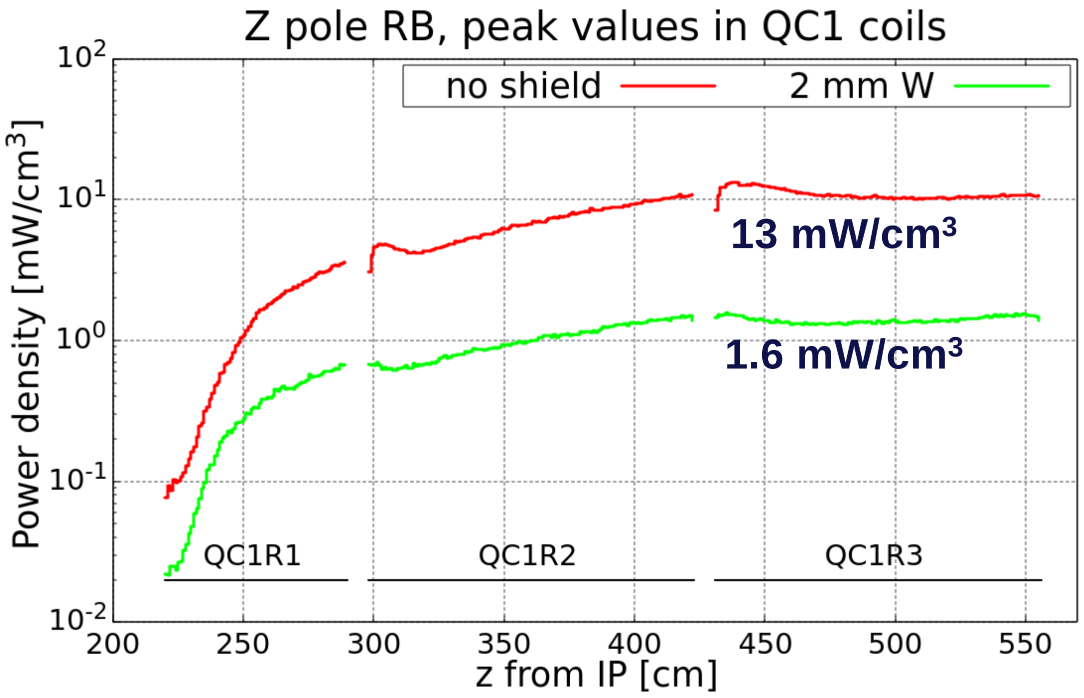
Alessandro Frasca

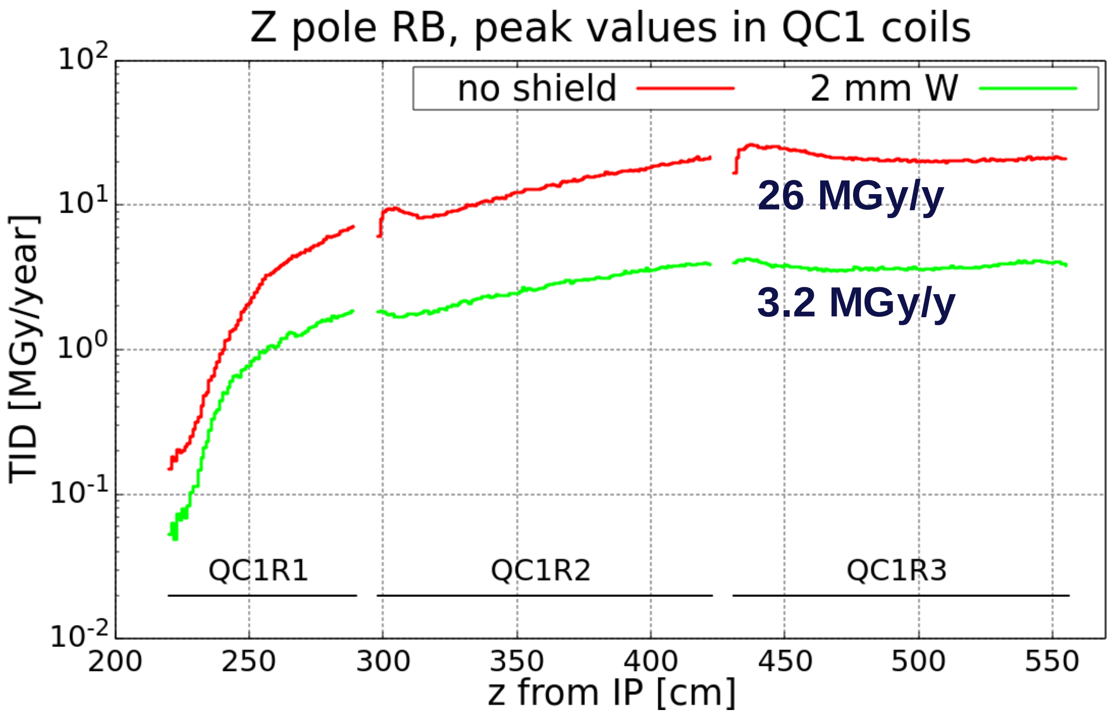
Radiative Bhabha impact on realistic FFQs

Simulated a more realistic FFQ geometry

- water-cooled beam pipe in SS
- magnets modelled as layers of Al and coils (NbTi+Al+Cu mixture)

Estimates based on BBBrem+GuineaPig





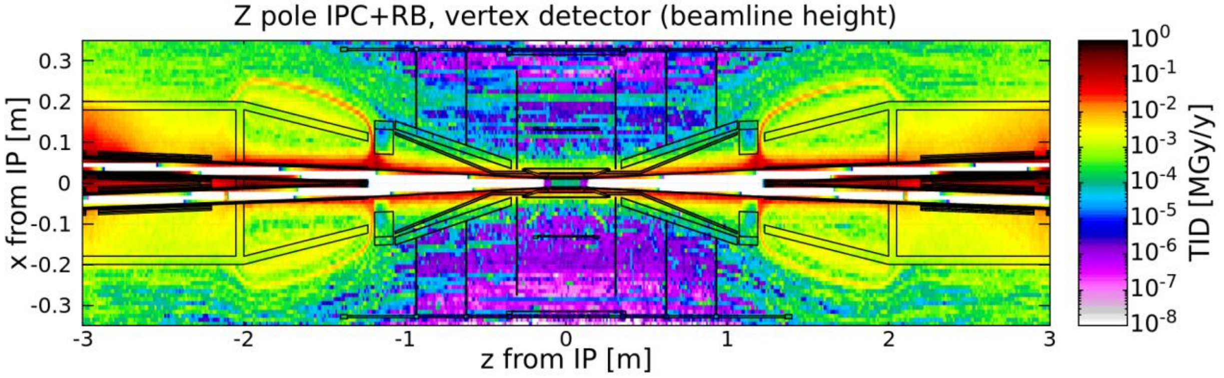
Fresh NEW !

Alessandro Frasca

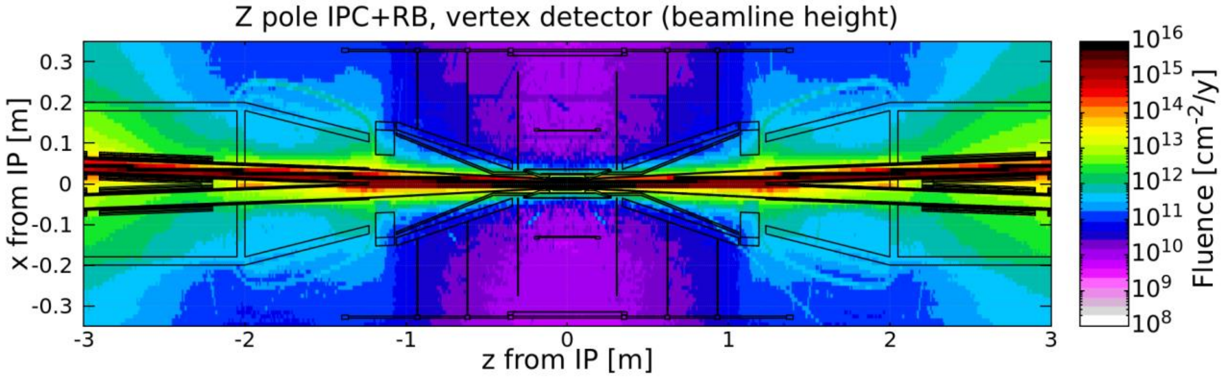
Vertex radiation levels (RB + IPC)

1 operational year = 10^7 s

Dose



Fluence



- Peak TID on 1st vertex layer of few tens of kGy/year
- Peak fluence on 1st vertex layer ~2 10^{13} cm^{-2}/year

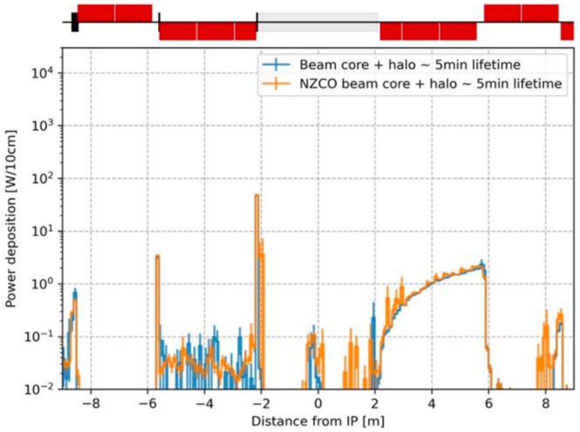
Fresh news !

Kevin Andrè

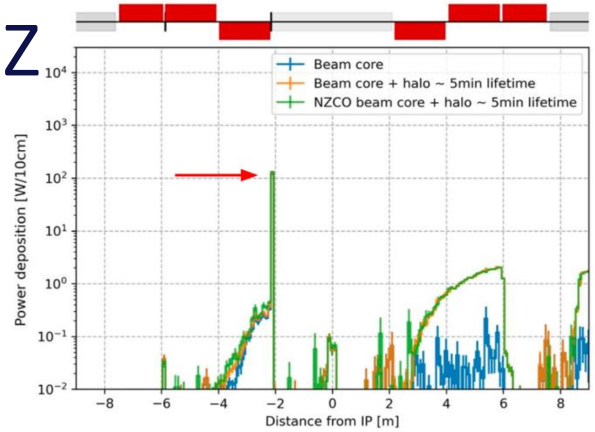
Synchrotron Radiation Backgrounds

- SR simulations performed with BDSIM (Geant4 based) including X-ray reflection
- SR collimator and masks implemented at optimised positions
- Realistic conditions studied

Z



GHC - SR power deposition summary, 1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).



LCC - SR power deposition summary, 1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).

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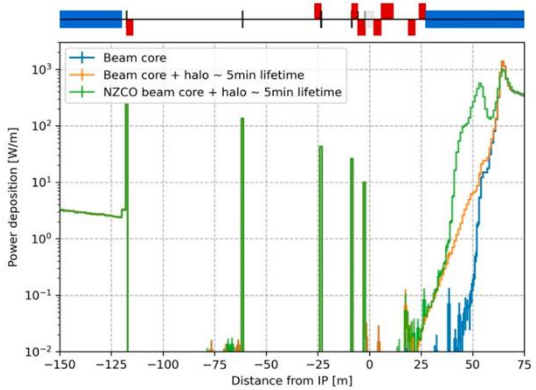

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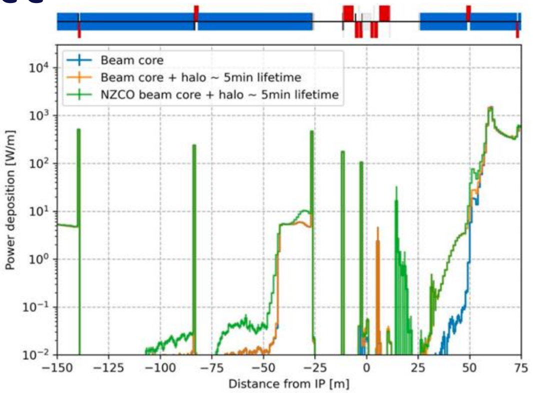

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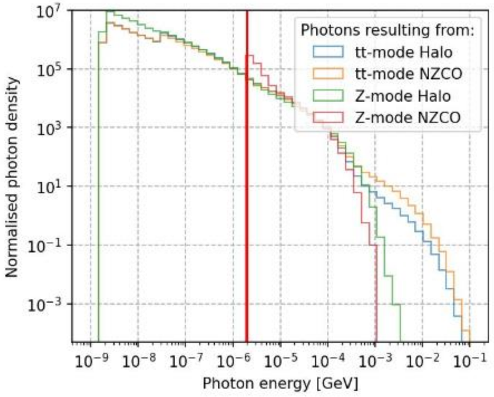
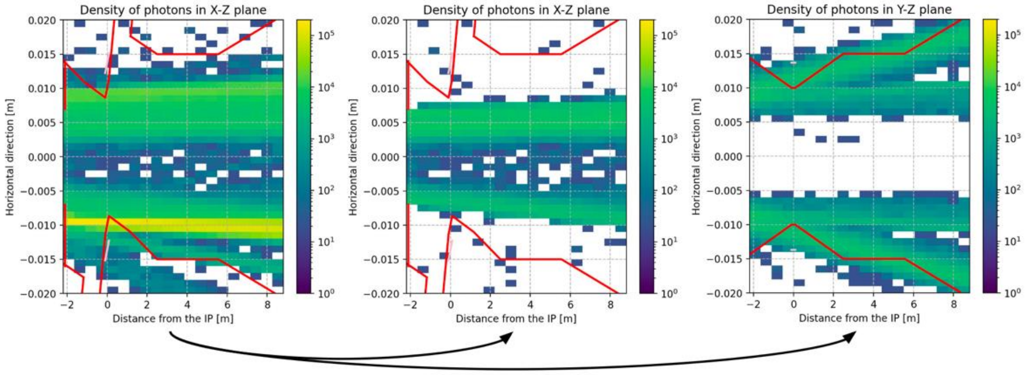


Photons with energy below 2 keV are unlikely to cross the beam pipe.

Already able to be tracked inside the detector



Including the mask aperture x>7mm

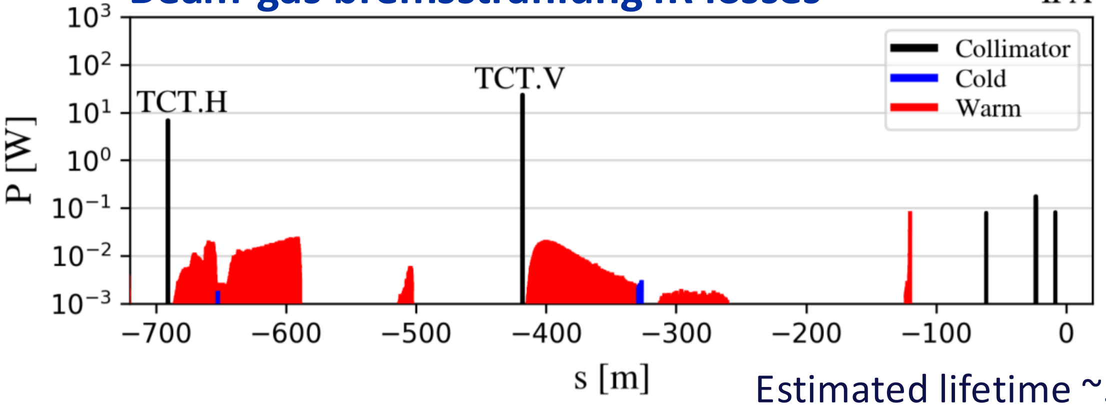
Giacomo Broggi

Beam losses in the IR

*1h beam conditioning at full nominal current (1.27 A): pressure is expected to condition down further (up to a factor ~100) over time

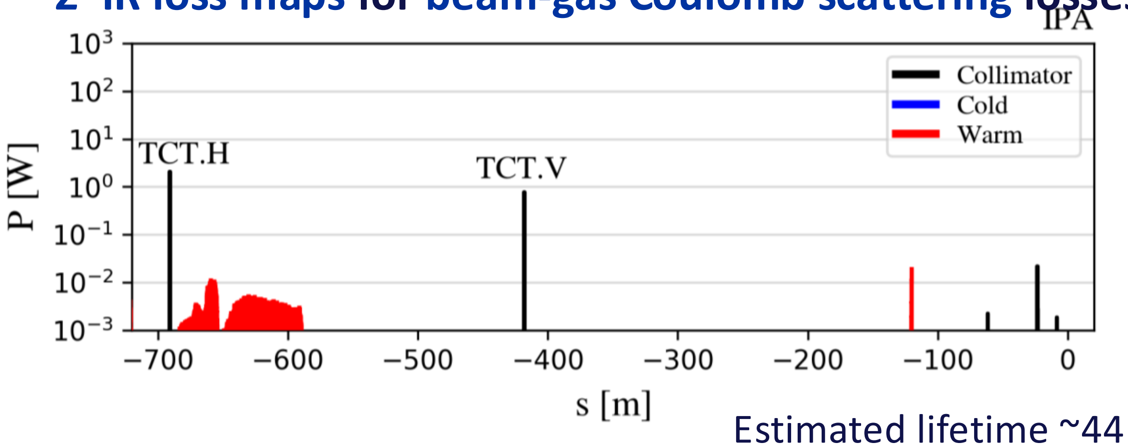
- Beam halo losses studied at the Z
- Beam-gas bremsstrahlung and Coulomb losses

Beam-gas bremsstrahlung IR losses



Estimated lifetime ~5 h*

***Z* IR loss maps for beam-gas Coulomb scattering losses:**



Estimated lifetime ~44 h*

Losses to be tracked in the detectors:

Multi-turn collimation tracking (Xsuite-BDSIM, Xsuite-FLUKA, …)
Beam loss distributions impacting IR collimators and aperture
Step1

→ IR model (FLUKA) →

Dedicated shower simulations (FLUKA)
Particle showers reaching the detectors
Step2

→ Detector model (DDSim) →

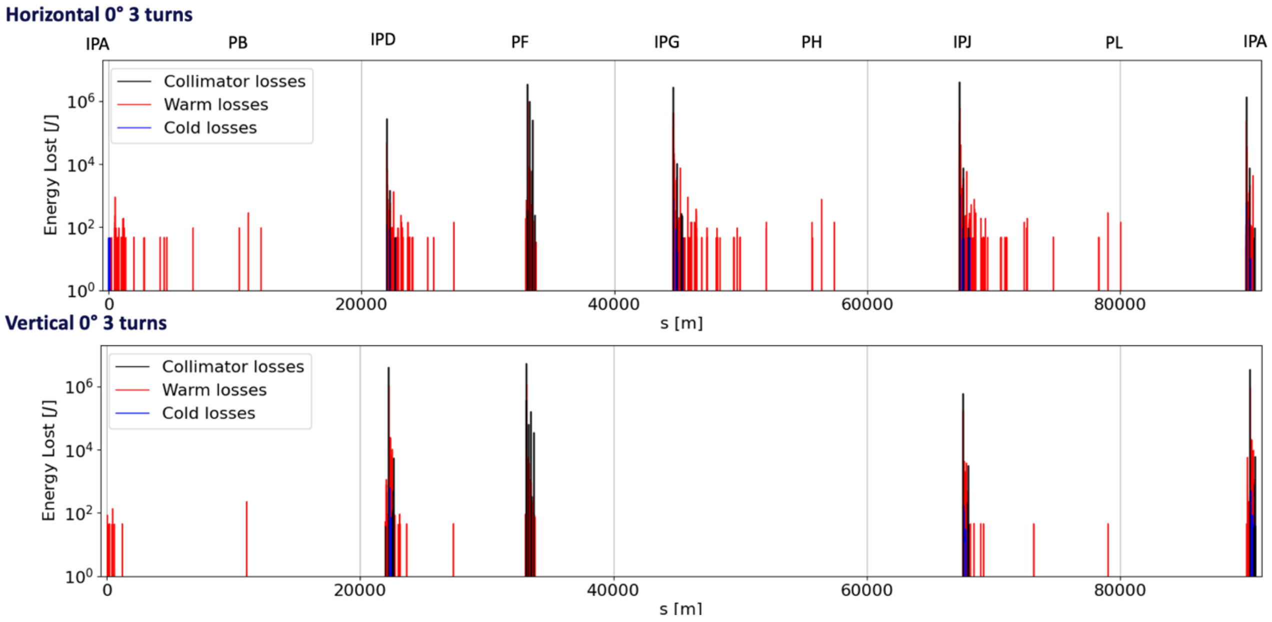
Detector simulations (DDSim)
Background assessment
Step3

Giulia Nigrelli

Beam losses from Fast Instability

- The ring impedance can generate an instability that leads the **beam to oscillate coherently with an exponentially growing amplitude, potentially losing the beam within few turns**.
- A feedback system is under development to damp the instability.
- Collimation system must protect the machine/detectors.

Integrated lossmaps over all turns H vs V

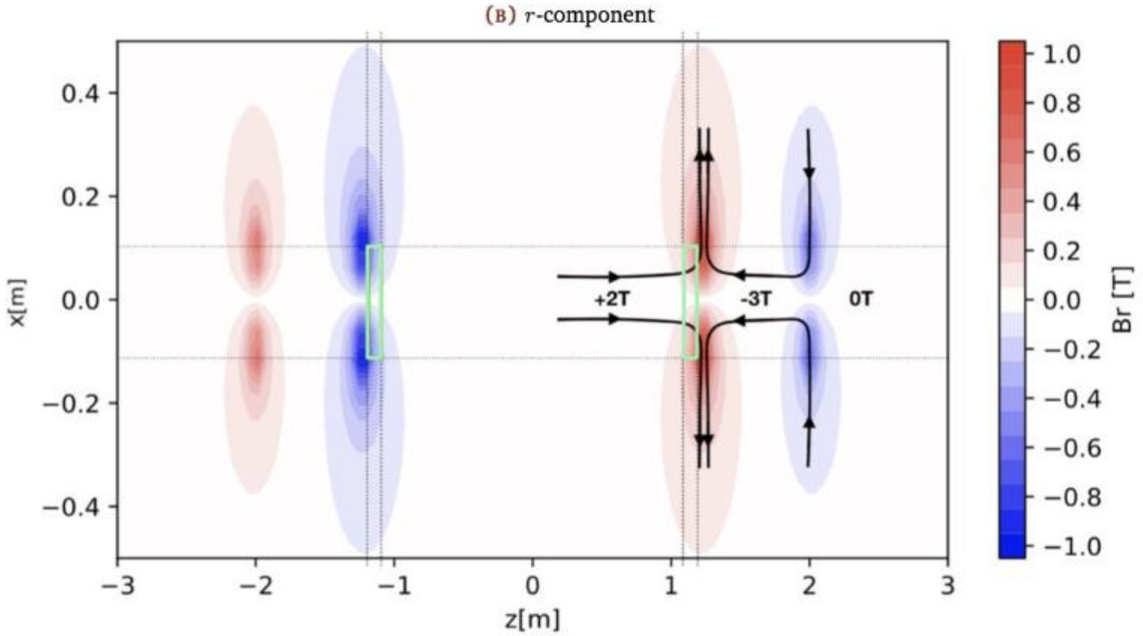


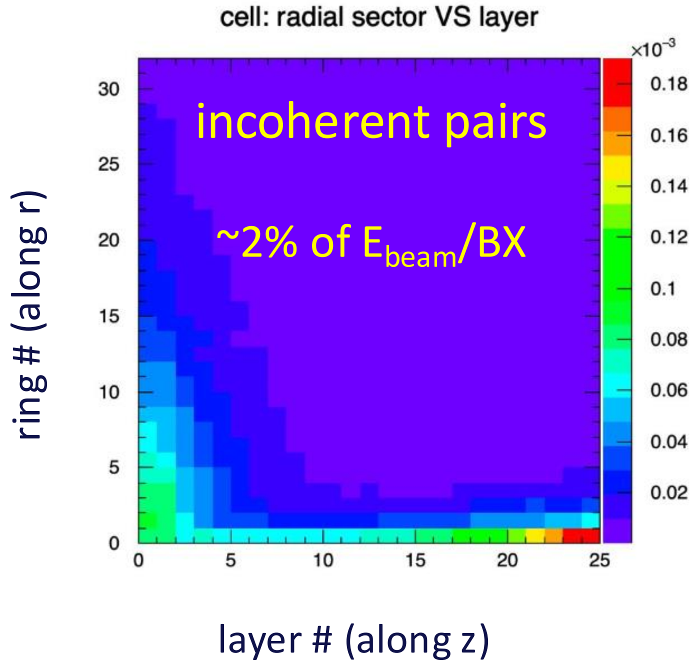
- The **fast instability could be disruptive** if the feedback system fails.
  - Full beam potentially lost within few turns.
  - Almost 50% of beam energy lost in one turn, losses of order of MJ in the collimator can be expected.
  - The effects depend also on the phase advance.
  - High losses in tertiary collimators hence nearby experiments.

Study very important for the design of the machine protection.

Mogens Dam

Background signal from Incoherent Pairs in LumiCal





Field configuration creates a hot spot at the rear of LumiCal

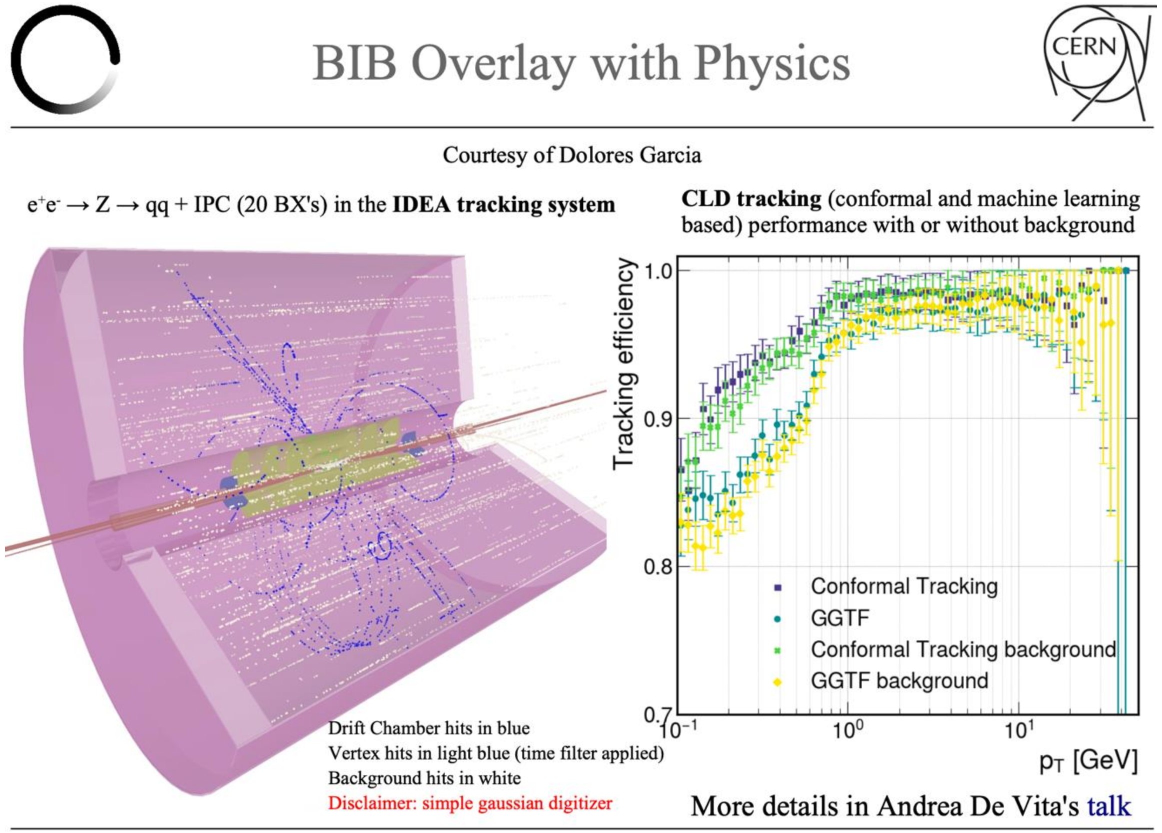
Energy deposited by radiative Bhabha ($e^+e^- \rightarrow e^+e^-\gamma$) about 20 times lower than incoherent pairs (0.1% E_{beam}/BX @ the Z)

Brieuc Francois

Simulation interface of accelerator backgrounds in the detectors

- Finally managed to treat machine background events similarly to "physics generators" ones
- Detector experts can now compute detector backgrounds, data rates, and occupancies now that digitizers start to appear

Framework now in place to study BIB!



Machine experts will continue with BIB studies by following optics evolution, collimator settings, MDI magnetic configurations, injection options, etc.
Machine and detector experts need to keep in synch the SW tools.

VERTEX DETECTOR, BEAM PIPES AND GENERAL INTEGRATION

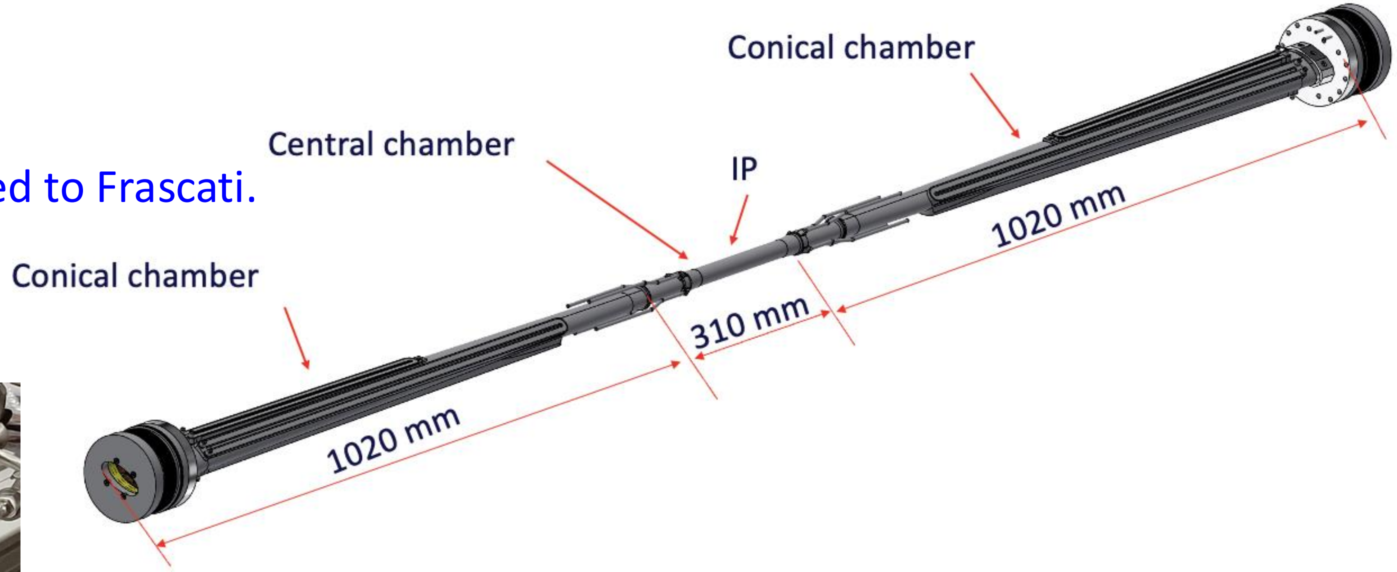
Francesco Fransesini

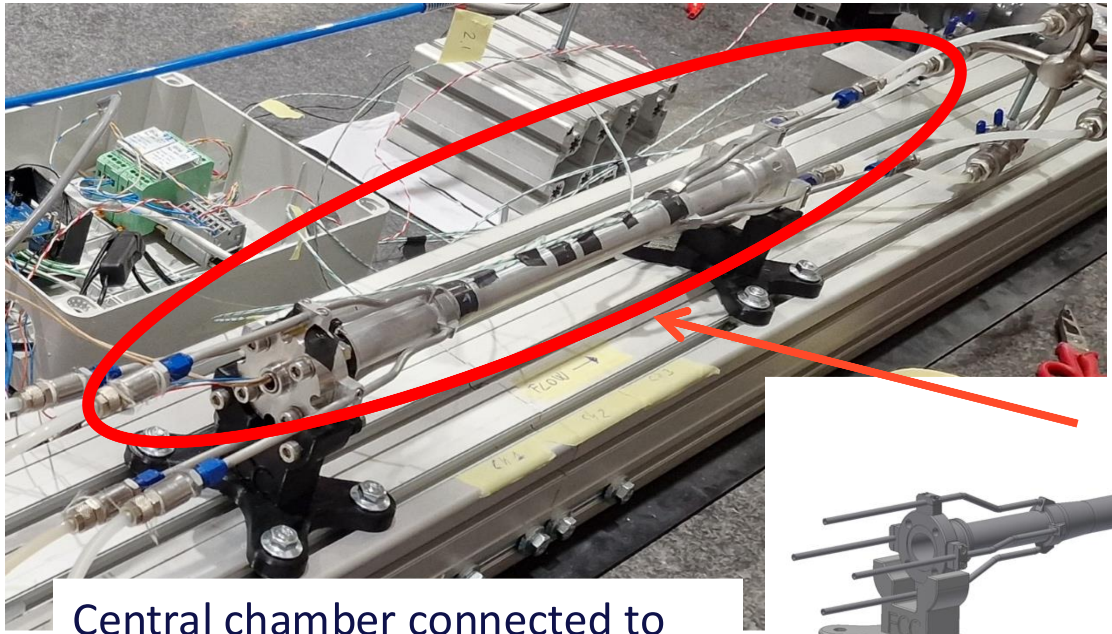
IR beam pipes

- AlBeMet central and ellipto-conical chambers have been engineered.
- We want to do experimental validations.

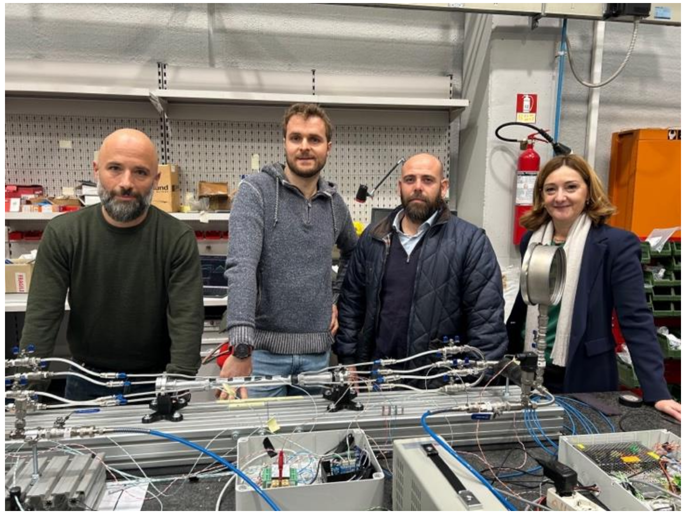
IR Mock-up in Frascati

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



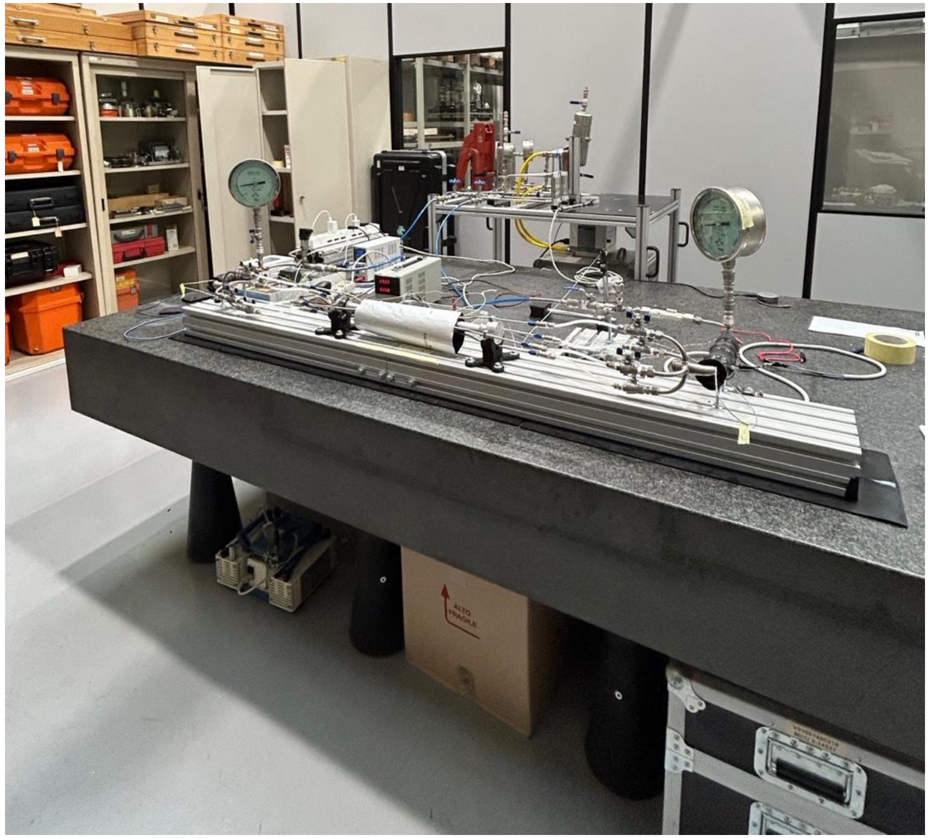


Central chamber connected to the hydraulic circuit



Francesco Fransesini

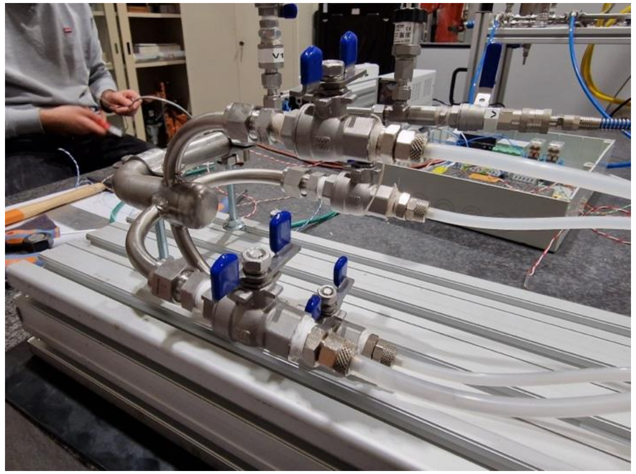
First tests on the central chamber

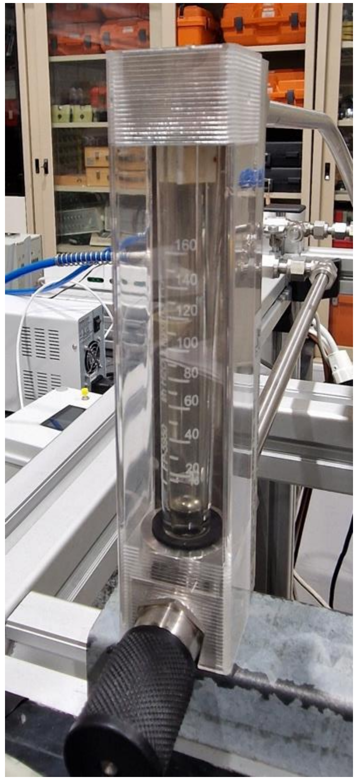


To verify efficiency of the cooling system we measure:

- temperature
- flow rate
- coolant pressure

in the inlet and outlet





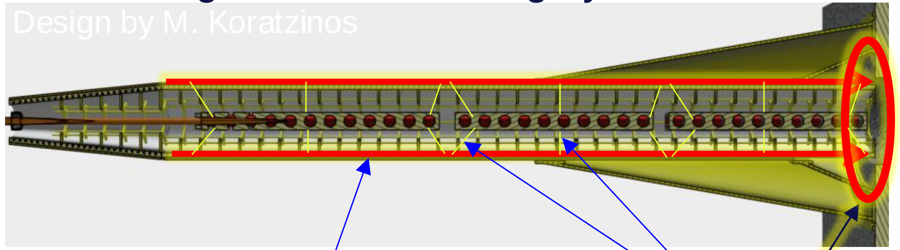
An electrical heater inside the central chamber simulates the beam heat load, a variable power supply controls the power.

Clear plan to progress with the IR mockup.
Order of the ellipto-conical chambers prototypes placed.

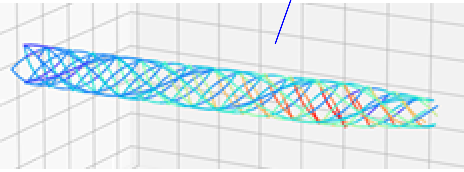
Leonard Watrelot

MDI Alignment

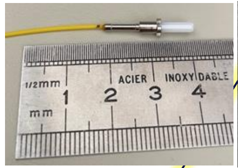
Internal alignment monitoring system

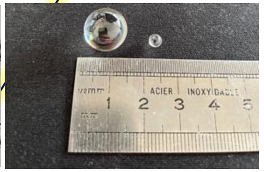


Impact of deformation on a network of fibers



Laser emitting ferrule





Glass beads

Interface to extract the information

Epoxy glued optical fiber

Brazed interface

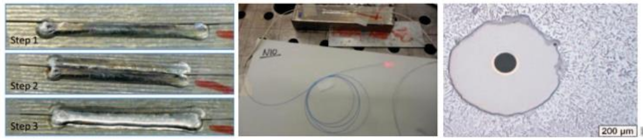
(a) Ceramic washer brazed into the EO-BPM body

(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)

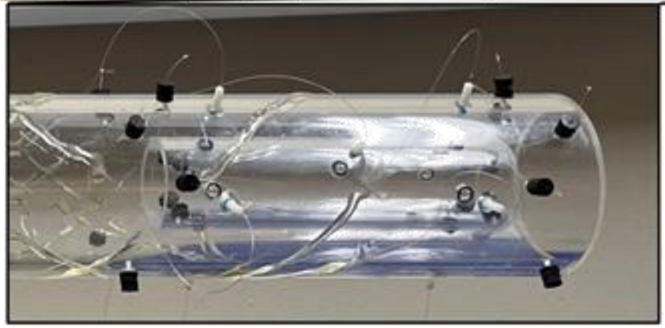
Figure 2. (a) Optimized 3-step embedding technique with laser brazing, (b) setup with red light fault detector for coarse tuning of the embedding technique and (c) cross section cut of the embedded optical fiber in metal using laser brazing.

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

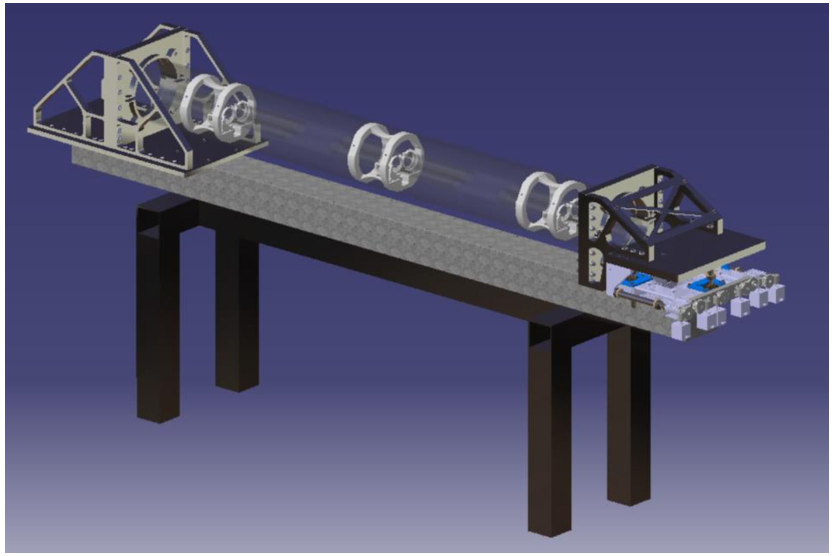
Bosman, M. Z. C., et al. "DESIGN AND DEPLOYMENT OF AN IN-VACUUM ELECTRO-OPTIC BPM AT THE CERN SPS."

Prototypes

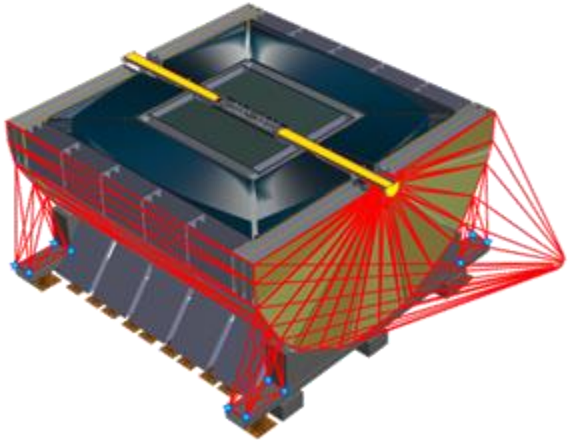
Last prototype



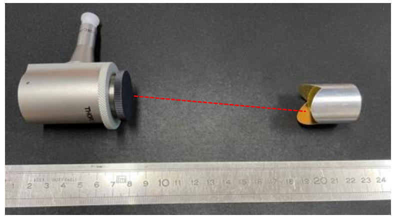
½ scale prototype currently being built



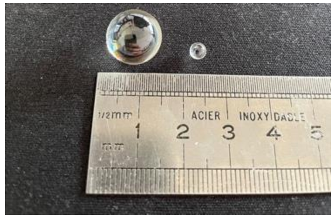
External alignment system



Laser delivery and reflection

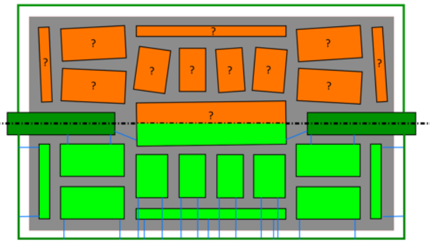


Collimator and Corner Cube retroreflector



Glass beads

Glass bead supports



Question to link this system with subdetector alignment systems

Giorgio Baldinelli

IDEA Vertex detector air-cooling simulations

Inner Vertex (ARCADIA based):

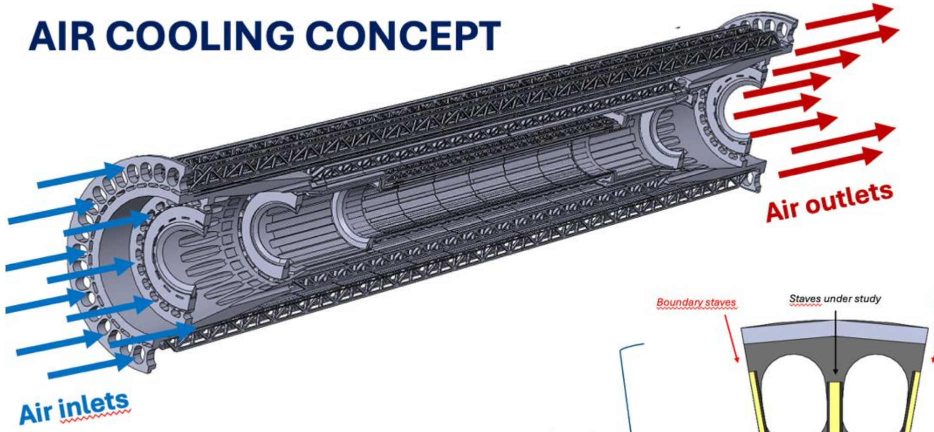
- Lfoundry 110 nm process
- *50 μm thick*
- Module Dimensions: $8.4 \times 32\ mm^2$
- Power density $50\ mW/cm^2$
- **100 MHz/cm²**

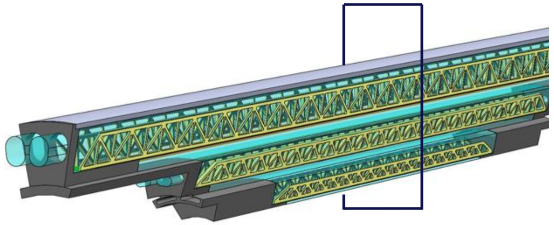
Estimation for sensors power dissipation:

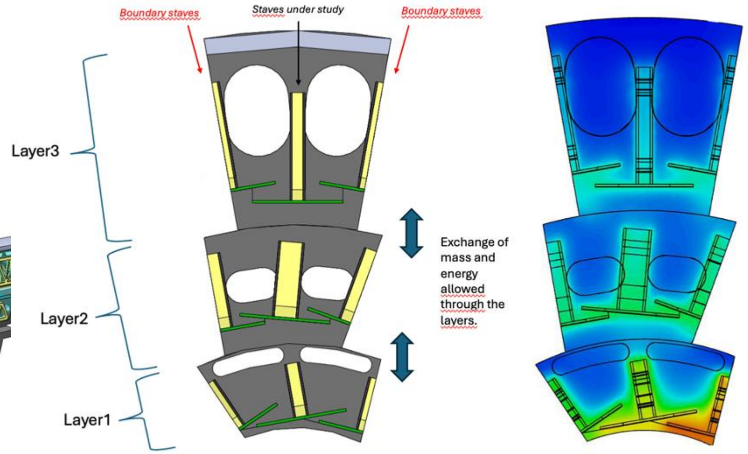
Layer 3: $\dot{Q}$ **~ 77 W** (total)

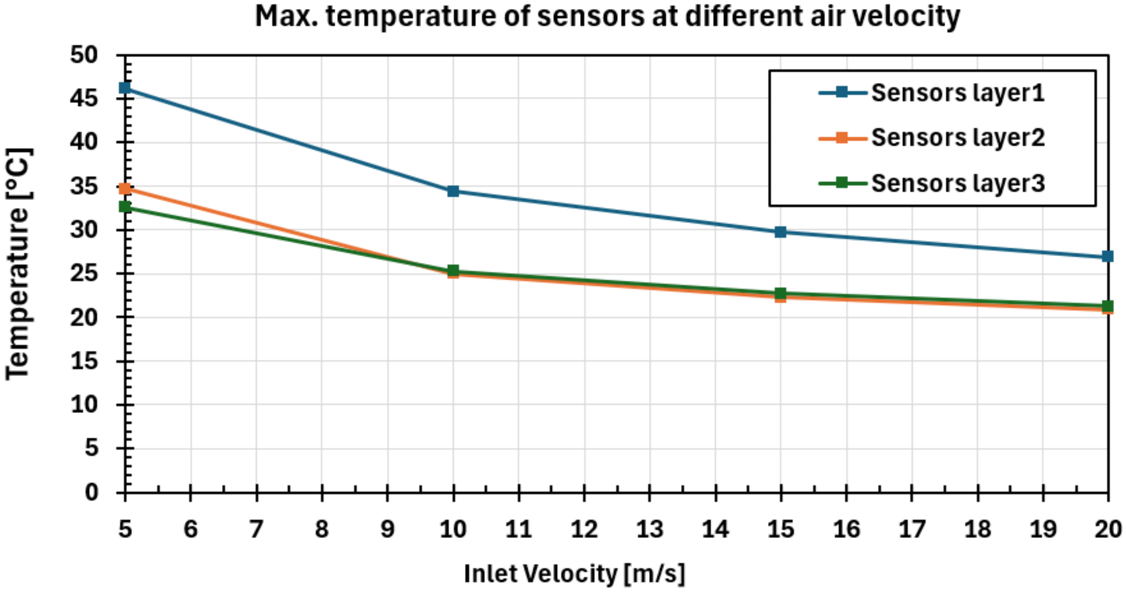
Layer 2: $\dot{Q}$ **~ 32 W** (total)

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







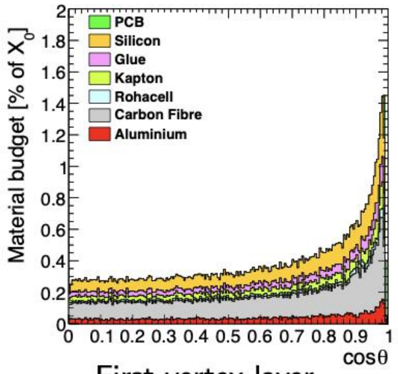


- **The air has the potential to cool the vertex, however some optimisation is needed for the 1st layer**
  - **hole size and fluid-dynamical (adding splitters …)**
- **Experimental validation ongoing R&D in INFN-Pisa**

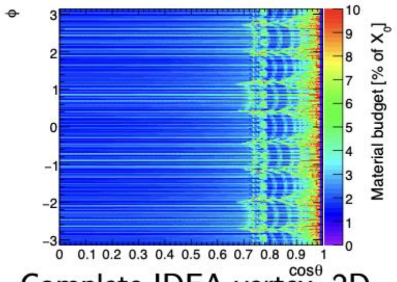
Armin Ilg

Curved Vertex layout

Baseline (flat)



First vertex layer



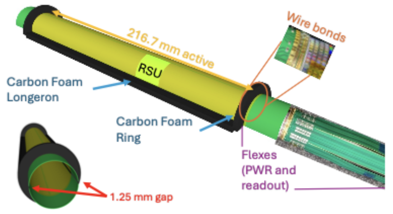
Complete IDEA vertex, 2D

Ultra-light inner vertex concept for FCC-ee

University of Zurich

Layer 1 and 2: $r = 13.7, 20.35$ mm

- 10 and 13 repeated sensor units long → $|\cos(\theta)| < 0.992/0.99$
- Peripheries, gap between half-barrels → Rotation in ϕ to fill gaps
- Readout and power from both sides

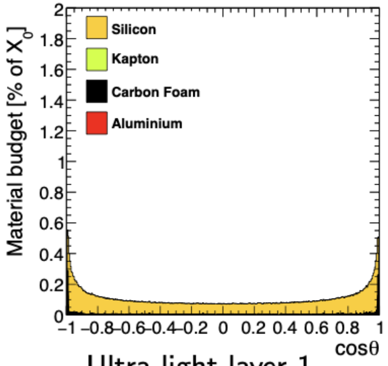


Layer 1 layout

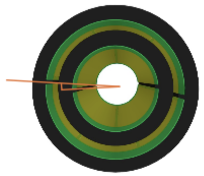
Layer 3 and 4: $r = 27, 33.65$ mm

- Two sensors per side, readout only on sides, power on sides and centre (power wire)
- 8 (10) RSUs on +z (-z) side for layer 3, inverted for layer 4 → $|\cos(\theta)| < 0.991/0.986$

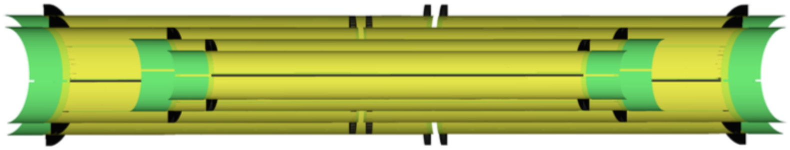
Assume 50 μm of Si + 16 μm of Si-equivalent (metal layer along sensor)



Ultra-light layer 1



Layer 1+2 front



Longitudinal cross section of all four layers

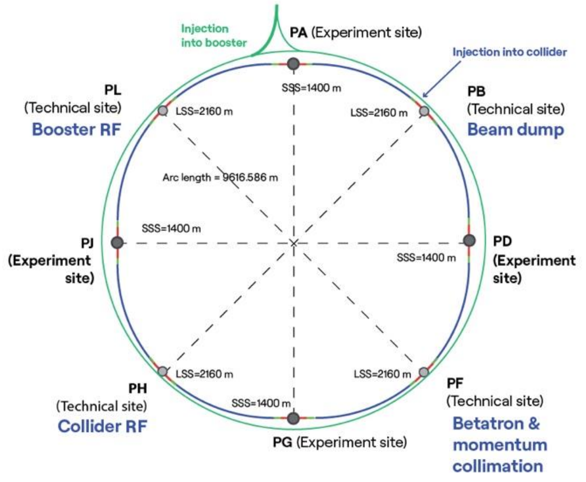
0.075% X_0 at $\cos(\theta) = 0$

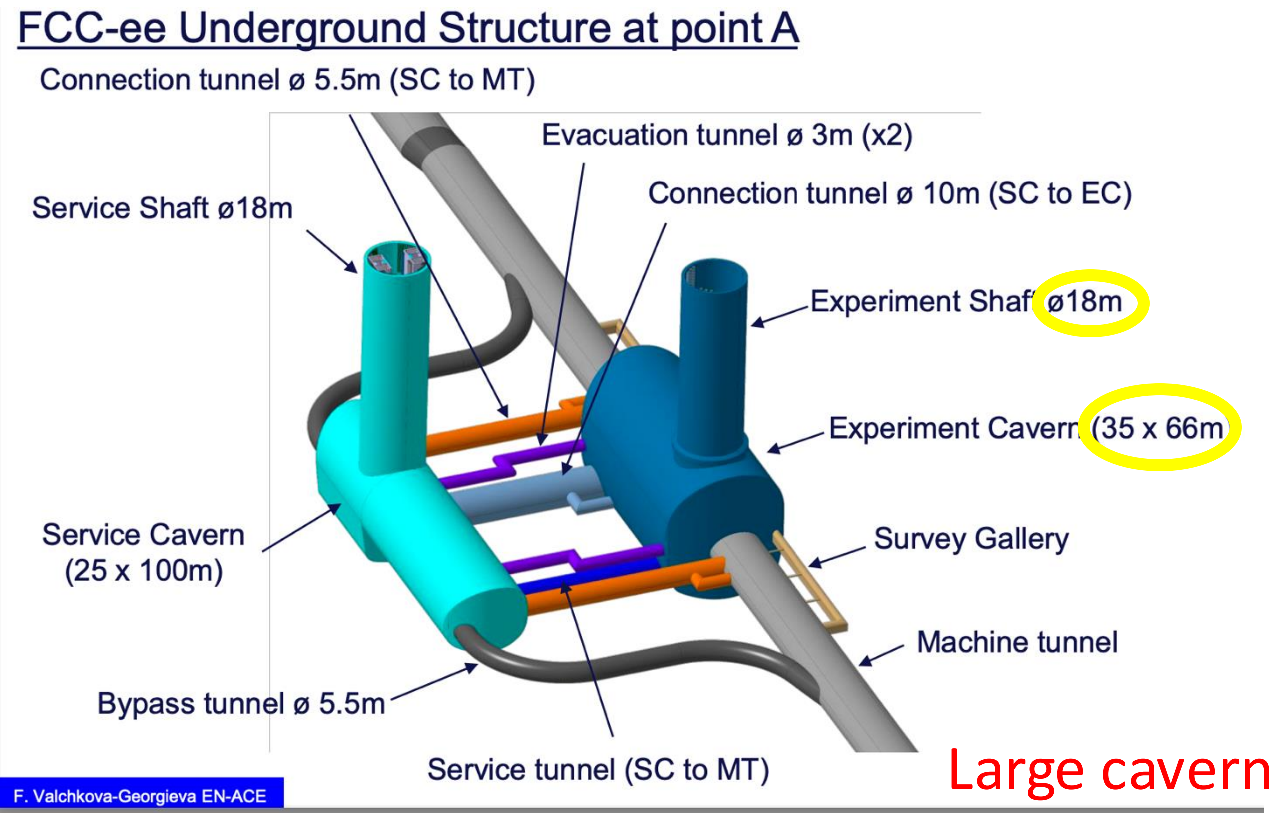
→ More than ×3 improve-

- Conceptual design based on ALICE ITS3 to FCC-ee
- Compromise hermeticity (or radius of first hit) with reduced material budget
- Evaluate performance similarly to IDEA vertex, optimise design in forward region

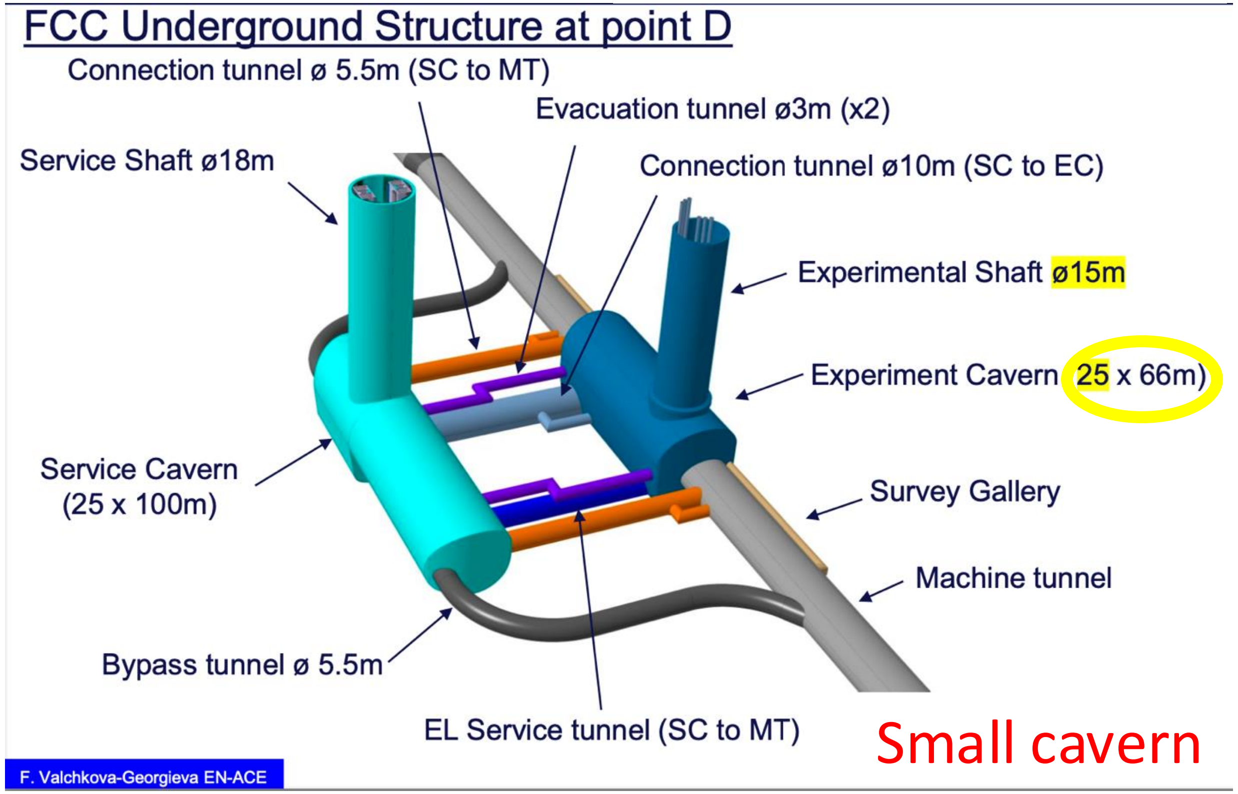
Fani Valchkova-Georgieva

3D Integration model for Experimental Areas





Large cavern

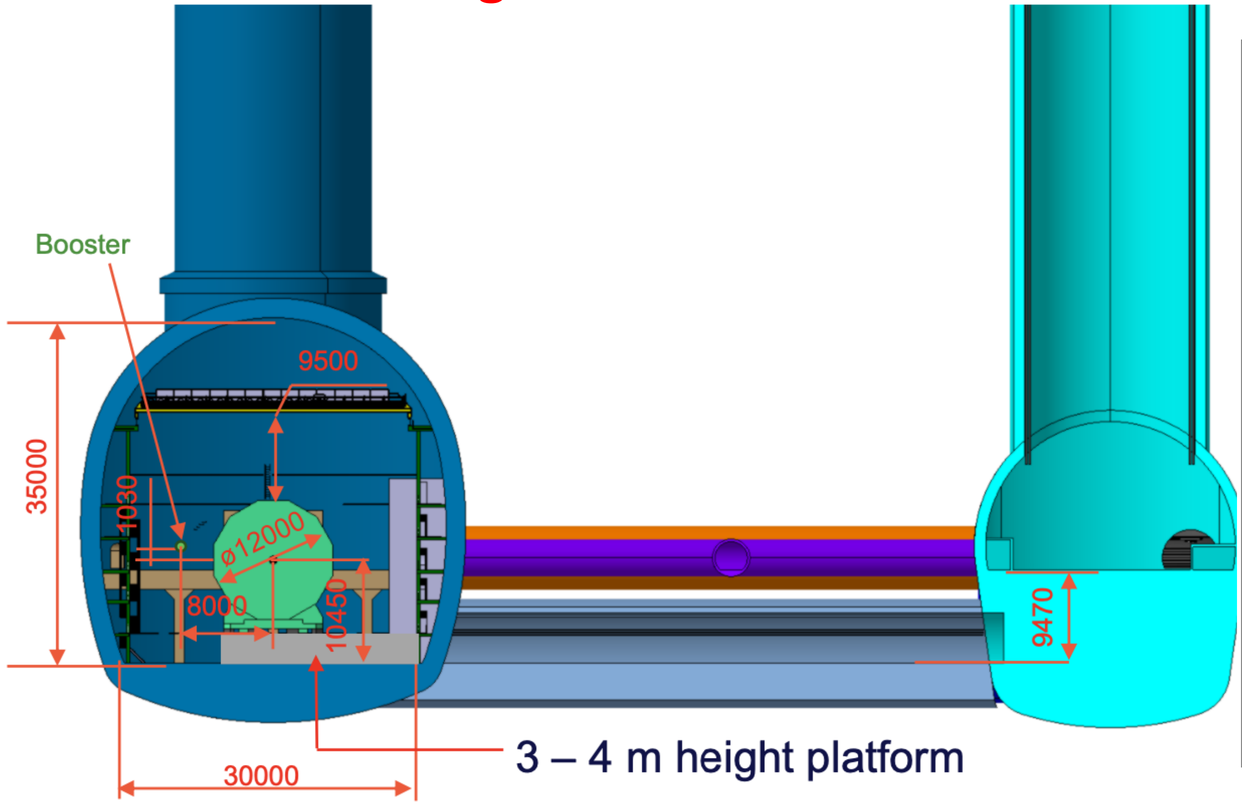


Small cavern

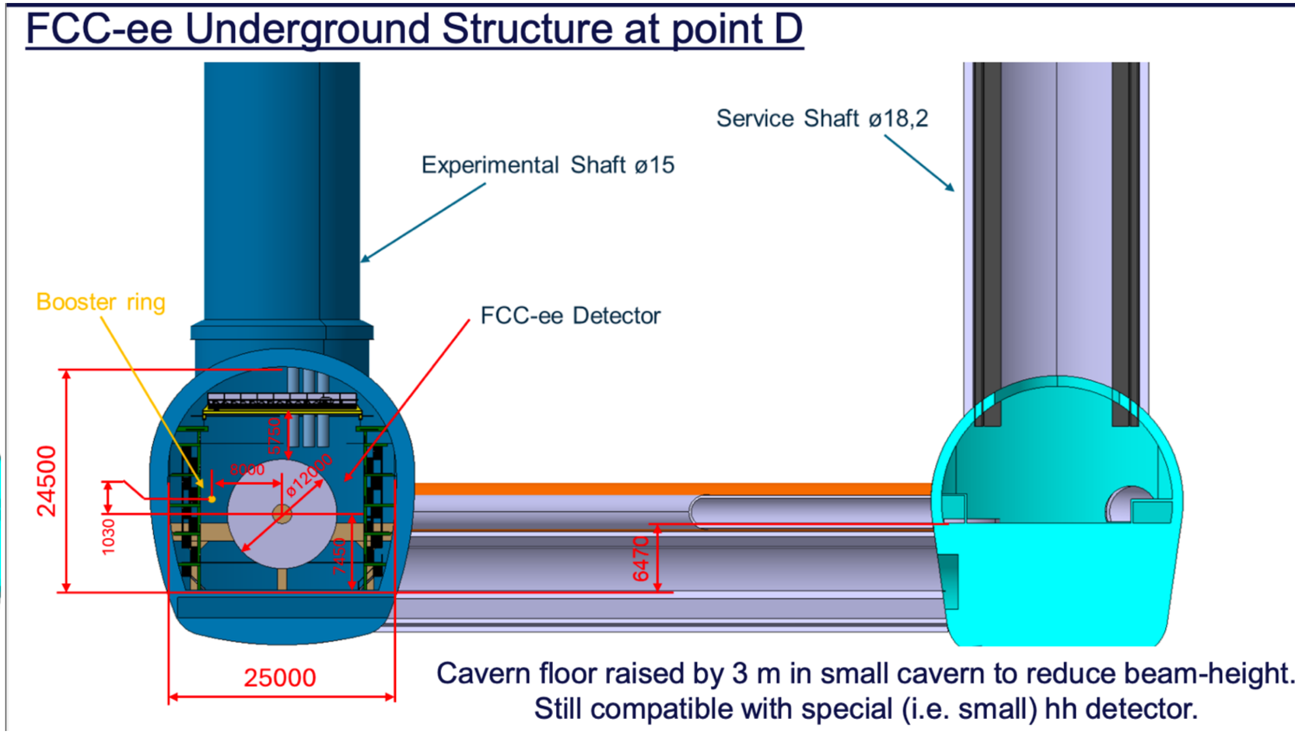
Fani Valchkova-Georgieva

3D Integration model for Experimental Areas

Point A Large cavern



Point D Small cavern



17 m available width for detector

At least for the small cavern a small alcove for parking the detector would be necessary (see next)

Andrea Gaddi

Detector (and machine) integration and maintenance

We aim at same detector size for the 4 IPs, even in the two smaller caverns.

FFQ is very close to the detector and impede its easy opening:

A. **Longitudinal shift** can be done only by breaking the vacuum and removing the FFQs, realignment needed

B. **longitudinal + transverse shift:** split endcaps (deteriorates detector precision), vacuum and FFQ alignment maintained

C. **(preferred) Transversal shift (parking position)** of the full detector and the FFQ assembly, then extraction of the FFQ and full longitudinal opening of the detector endcaps. *Caverns dimensions are limiting this option*

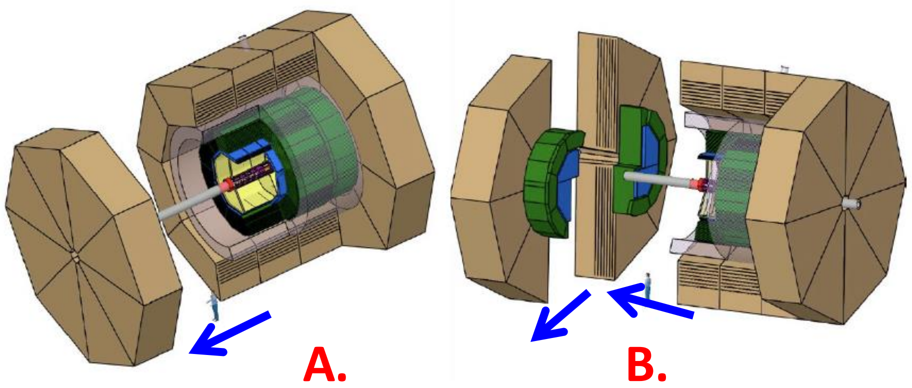
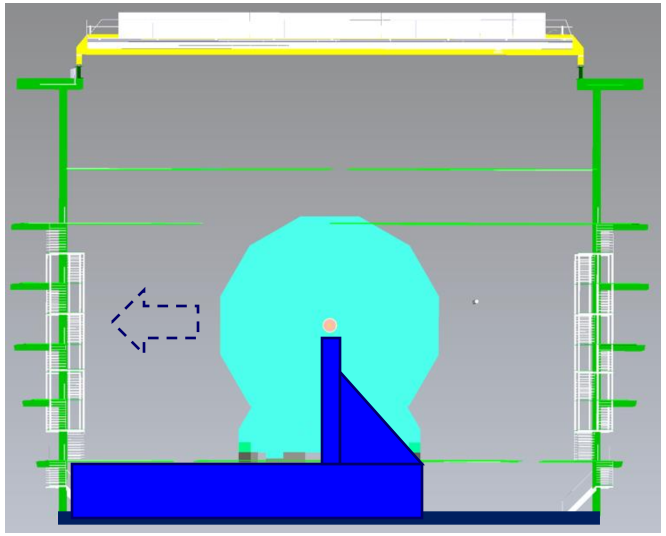


Fig. 54: Longitudinal (left) and short longitudinal plus transversal endcap (right) detector opening

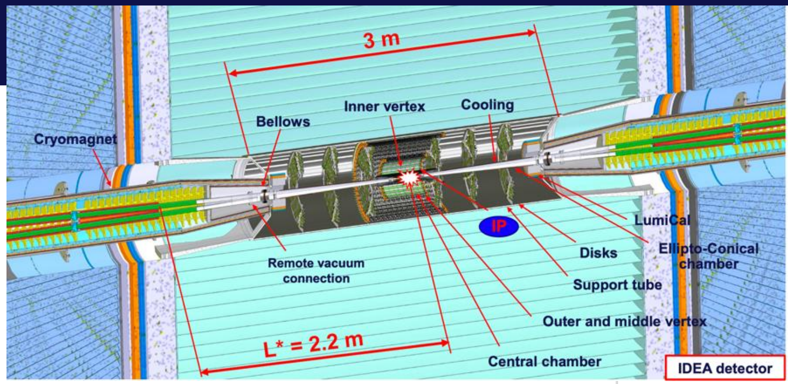


C.

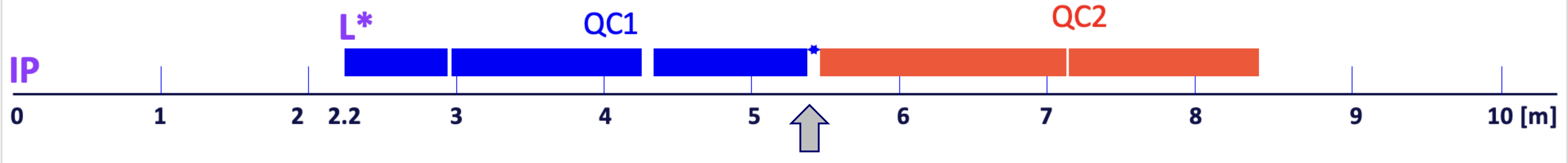
Prospects & Plans

- Consolidate studies performed so far with new optics
- QC1 cryostat design and temperature of the cryomodule
  - 1.9-2.1 K in pressured He II; or 4.5 K for supercritical He, or 1—20 K He gas forced flow
  - Investigate clearance angle 100 mrad, and crossing angle
- Solenoid coupling compensation scheme: local and non-local scheme
- IR magnet system:
  - Anti-solenoids and correctors design and prototyping, and detector solenoid
- Beam backgrounds studies:
  - Add Injection backgrounds, thermal photons, etc.
  - Impact on the sub-detectors
  - Shielding to protect the detector and the FFQs
- Detector maintenance, machine and detector integration
  - Study machine elements and detector assembly and opening in the caverns

Thank you for your attention!

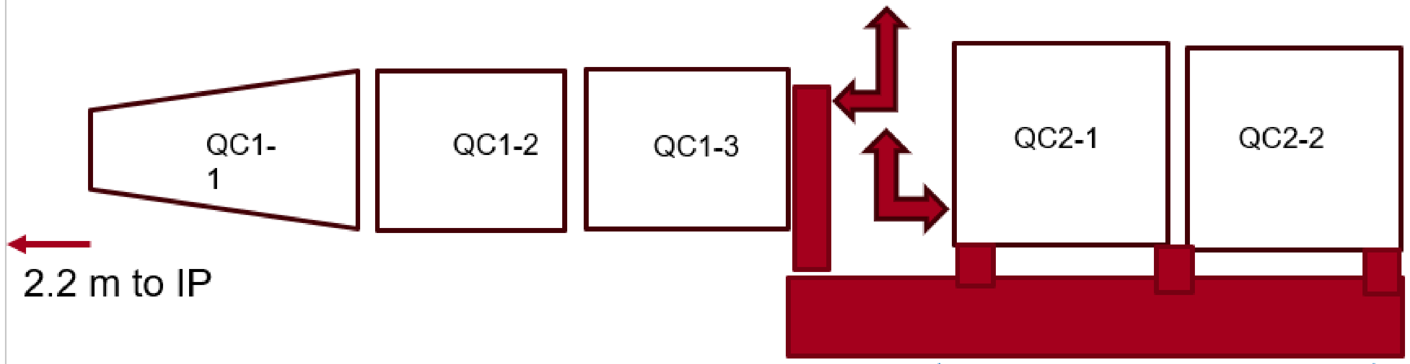


We need two separate cryostats for QC1 & QC2



IR QC1 and QC2 in different cryostats but one integrated raft (not to scale)

Need to make space for cryogens, leads, and cantilever supports.



Layout from J. Seeman

We need more space between QC1 and QC2 for stable support structure (alignment / vibration) and other connections (cryogenics, current leads, vacuum, diagnostics and more).