The FCC-ee IR and ILD: Status and Future Developments

ILD Group Meeting

04.02.2025

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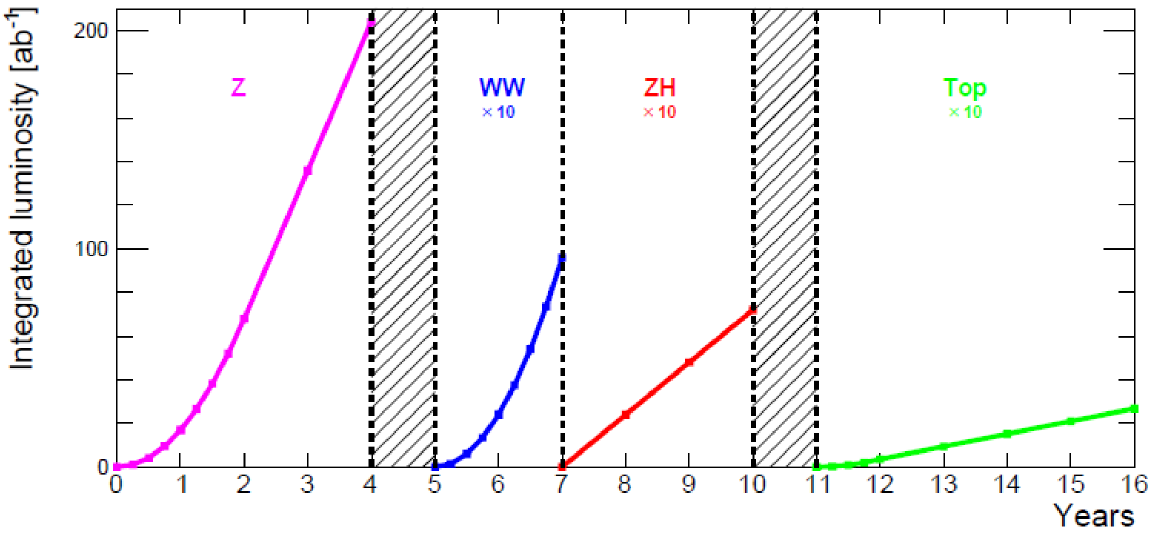
Developments since MTR: flexibility in running order

Status at time of MTR: different RF configuration required for Z and (WW+ZH) meaning that hard choices needed to be made about which runs came first.

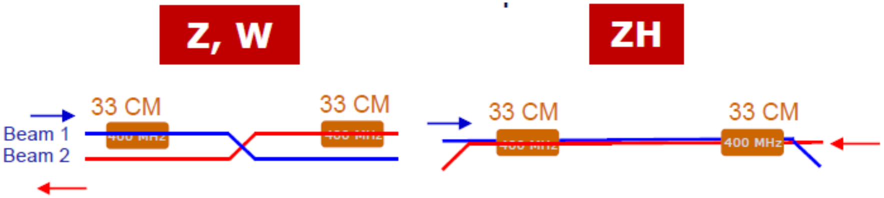


Also. a year's shutdown required to switch from one to the other. Ugh !

Developments since MTR: flexibility in running order

New RF strategy for Z, WW and ZH:

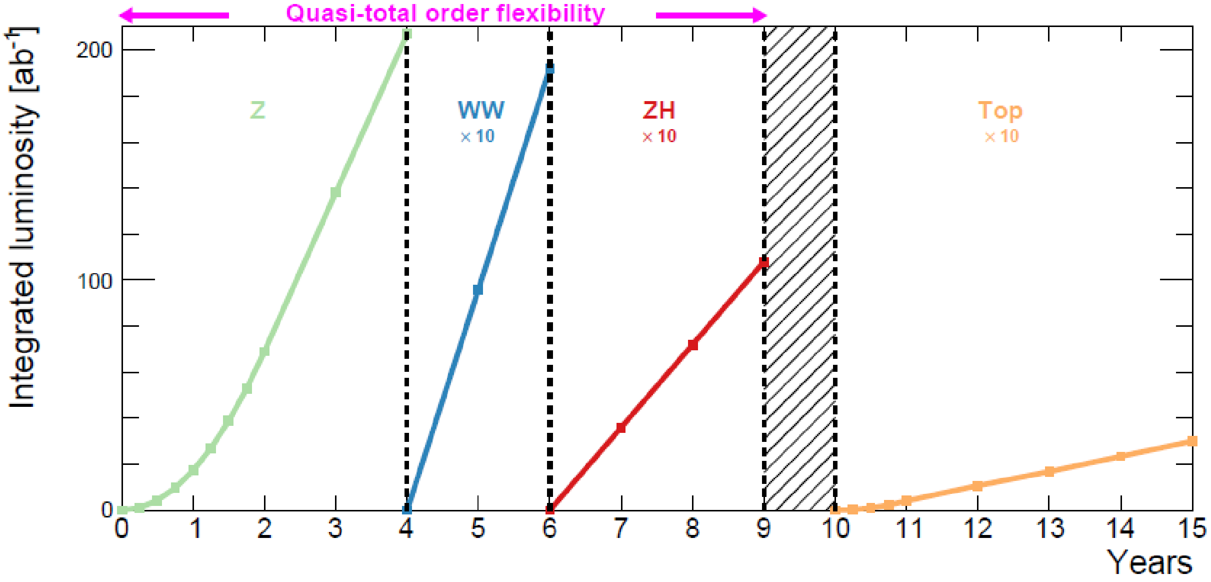
- Two-cell 400 MHz cavities for all three working points;
- Reverse phase operation;
- Separators for switching beams in and out of cavities.



Allows for high flexibility in switching between operation energies.

Developments since MTR: flexibility in running order

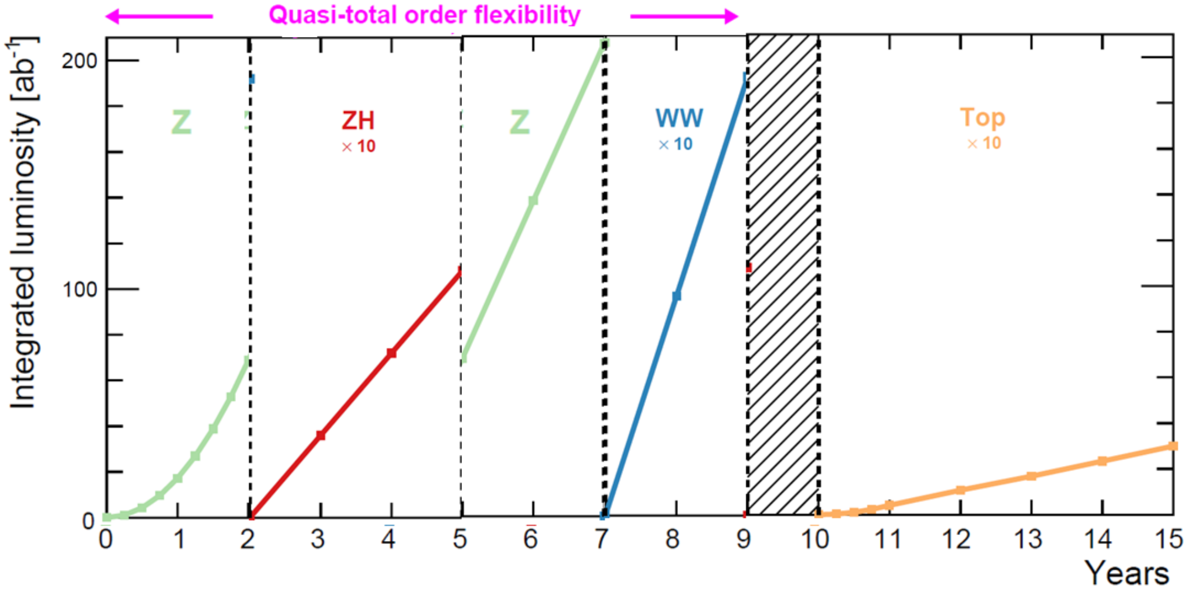
This is the figure in the Final Report.



But scheduling all the Z running in the first four years would be most unwise, as this encompasses the most demanding measurements, which require the best possible understanding of both the detectors and the accelerator.

Developments since MTR: flexibility in running order

Something like this might be more optimal.



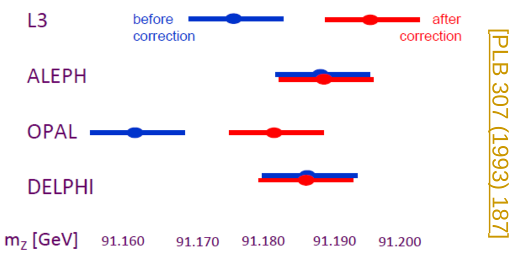
This also has the advantage of not postponing the excitement of the Higgs running until late in the schedule. With hew RF scheme most things are possible !

Developments since MTR: four interaction points

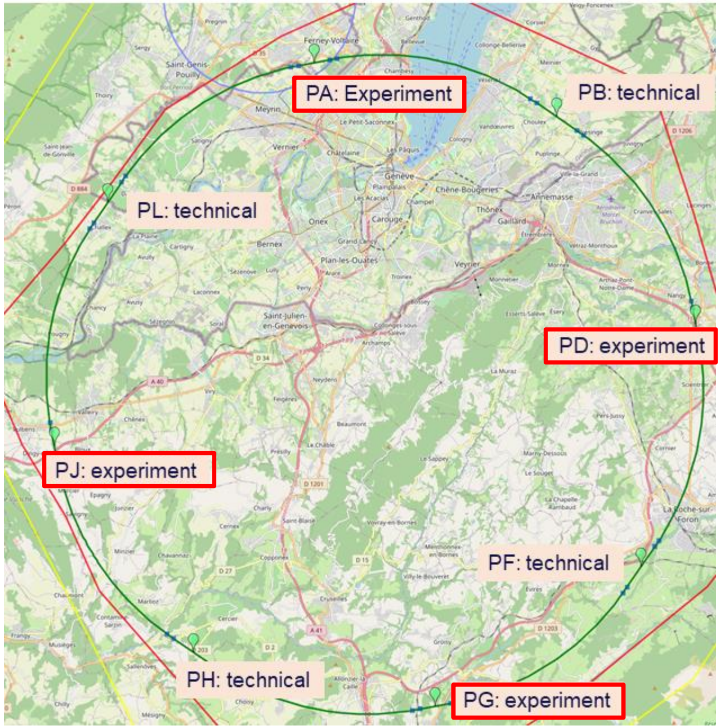
Decision to go from 2 to 4 interaction points is an important step forward:

- Increases integrated luminosity by (almost) same factor;
- Provides systematic robustness;

Lessons from LEP – discovery of impact of `RF sawtooth' on Z mass



- Allows for different detector solutions, which will ensure full coverage of the physics goals.

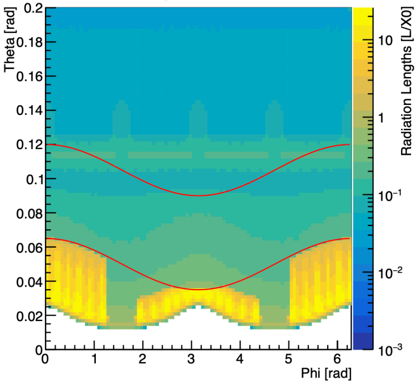


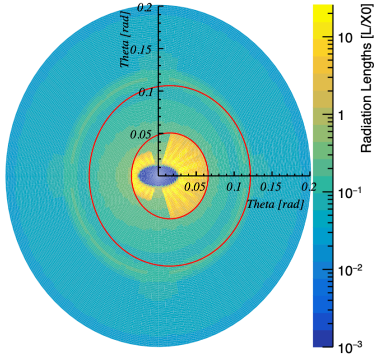
MDI

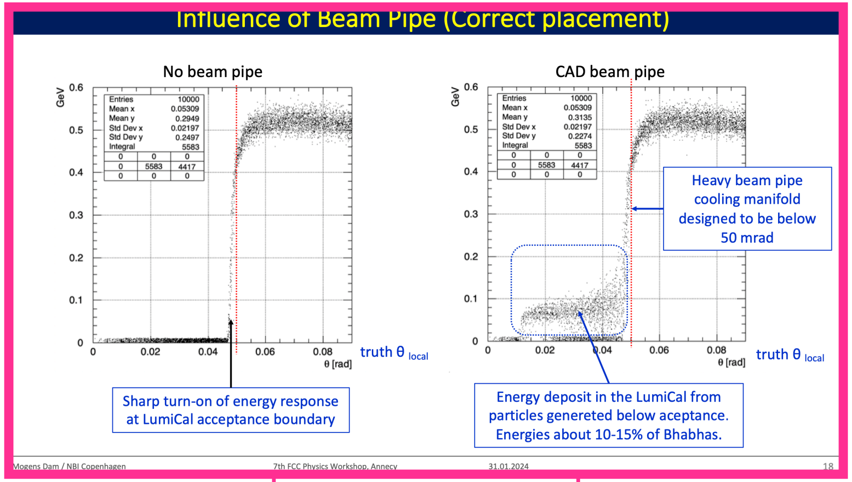
Previous studies

In the previous engineered design of IR beam pipe, two asymmetric **copper cooling manifolds** were foreseen. Their size was **tapered** to fit the LumiCal **angular acceptance.**

However, first **tracking studies** showed an **energy deposit** coming from the beam pipe, probably caused by **secondary showers** off the high-X0 copper just below the LumiCal acceptance.







M. Dam - FCCPW2024

Tuesday MDI session 14 Jan @16.30

Interaction region layout

- **Beam pipes in AlBeMet (68% Al, 32% Be)**
- **Central beam pipe 1 cm internal radius**
  - Internally 5µm gold coated to reduce impedence 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 acc.: (mostly 7% X_0, few regions up to 50% of X_0). Shaped to minimise showers off manifolds

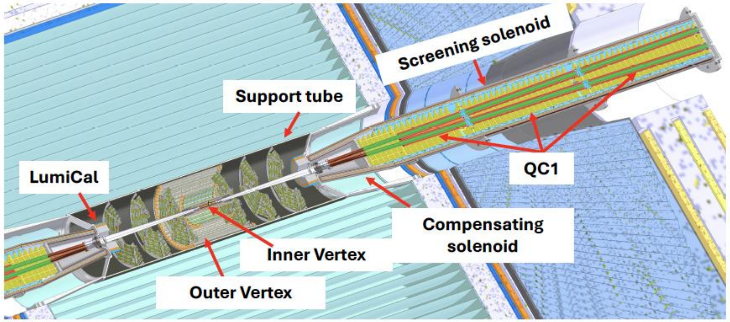


Fig. 47: Interaction Region overall layout. The support tube allows to integrate the luminosity calorimeter (LumiCal) and the vertex detector. Also shown the three segments of the final focus quadrupoles (QC1) together with the screening and compensating solenoids.

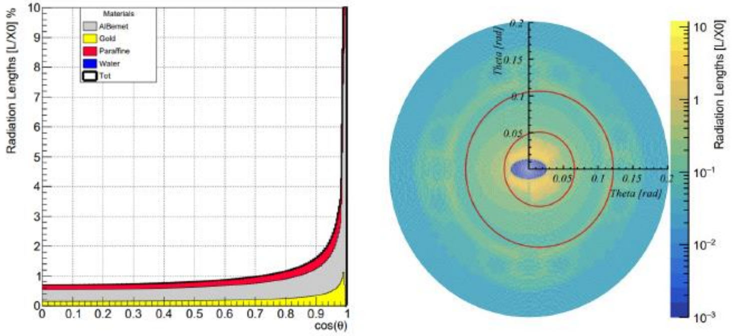


Fig. 50: Material budget of the beam pipe as a function of the polar angle (left) and in front of the LumiCal (right) in the region $\theta \in [0, 0.2]$ rad. The red lines represent the LumiCal acceptance, i.e. the 50 mrad and 105 mrad cones.

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

Fig. 49: Ellipto-conical vacuum chamber.

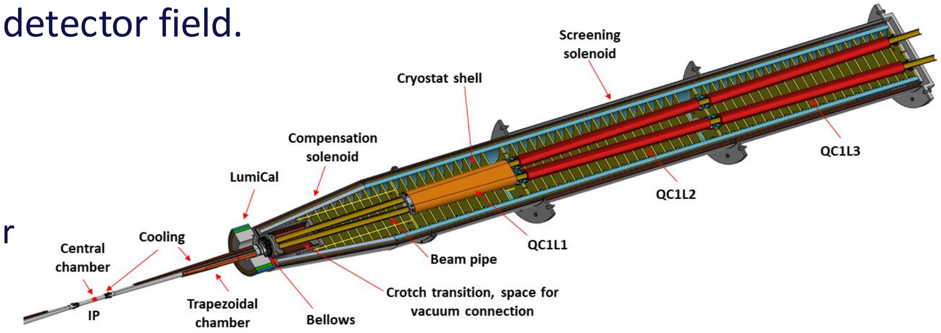
Summary^2 of MDI: IR Design + BIB at FCC Physics Week

IR Optics – Solenoid compensation scheme

Katsunobu Oide

Helmut Burkhardt

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

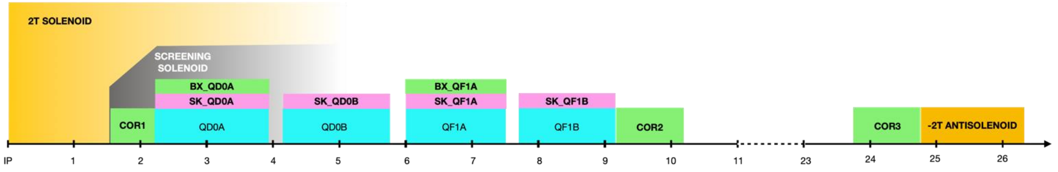


***Local* solenoid compensation scheme (Baseline design)**

- 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

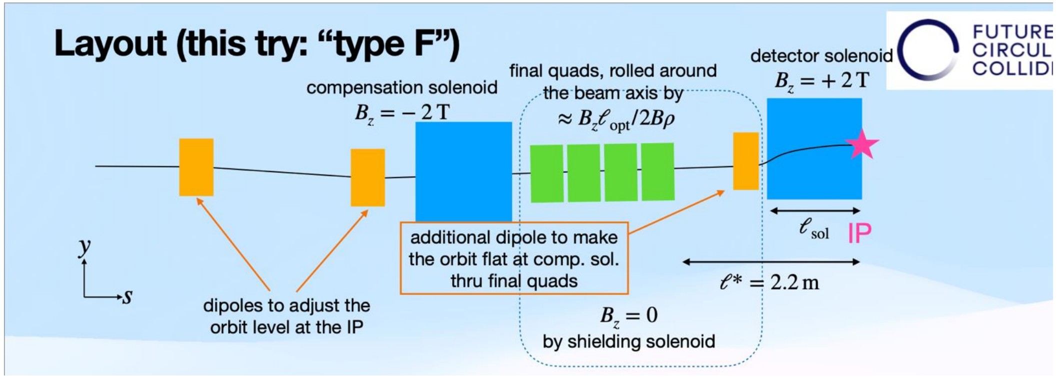
Main Advantages with non-local scheme: Higher detector field is possible, some margin to increase the crossing angle, removal of -5T magnet inside the detector with a factor of 2 lower SR at the IR, better coupling compensation

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

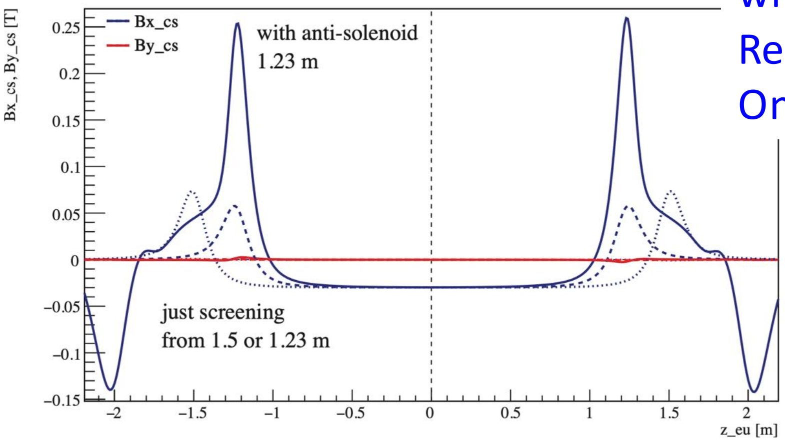
Helmut Burkhardt

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 $(3/2)^2 = 2.25$

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

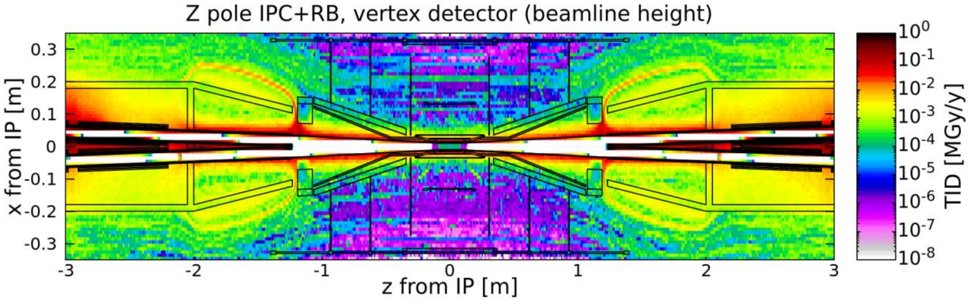
- Optimization of collimators scheme

Alessandro Frasca

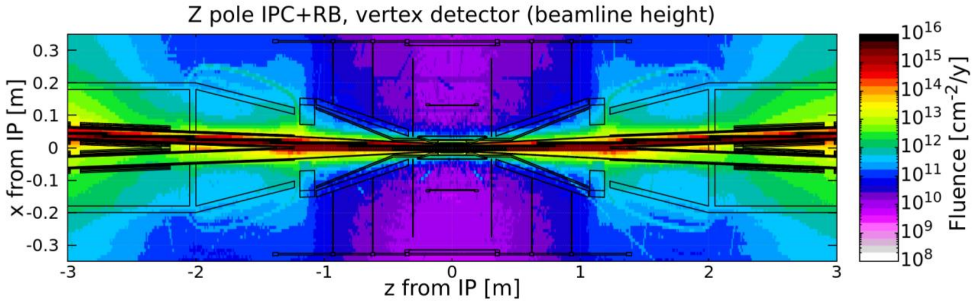
Vertex radiation levels (RB + IPC)

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

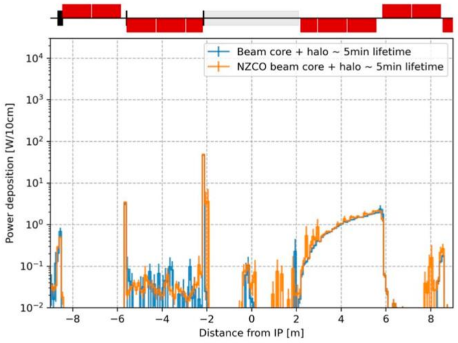
Fresh news !

Kevin Andrè

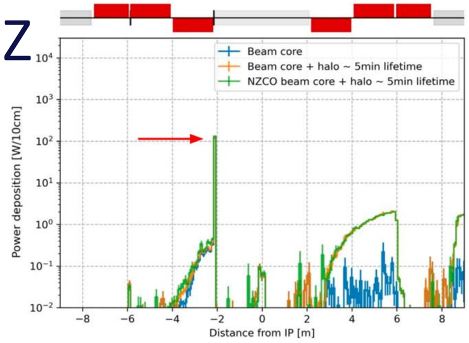
Synchrotron Radiation Backgrounds

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

Z

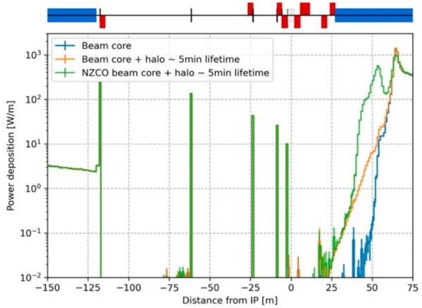


GHC - SR power deposition summary, 1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).



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).

tt



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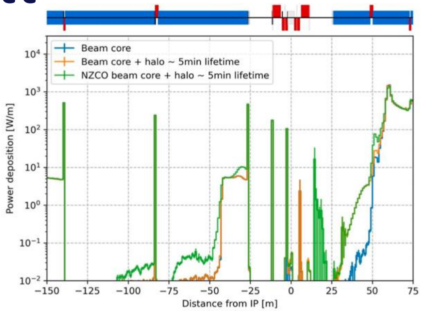
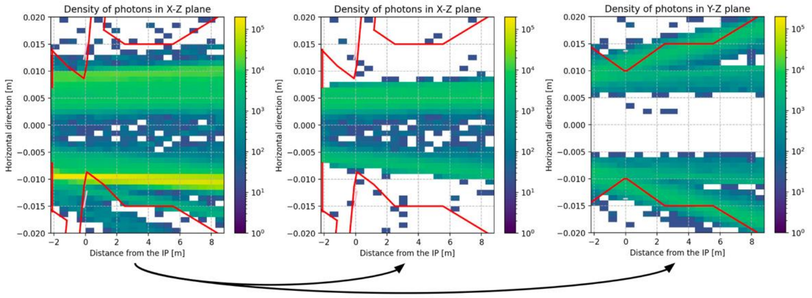
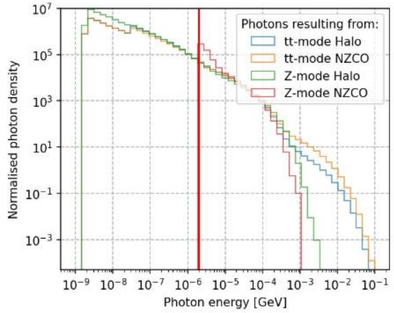


LCC - SR power deposition summary, 1% of the particles in the tails, with beam lifetime equivalent to 5 min, and 100 um std in X&Y and 6 urad std in PX&PY applied to the beam core (NZCO).

Already able to be tracked inside the detector



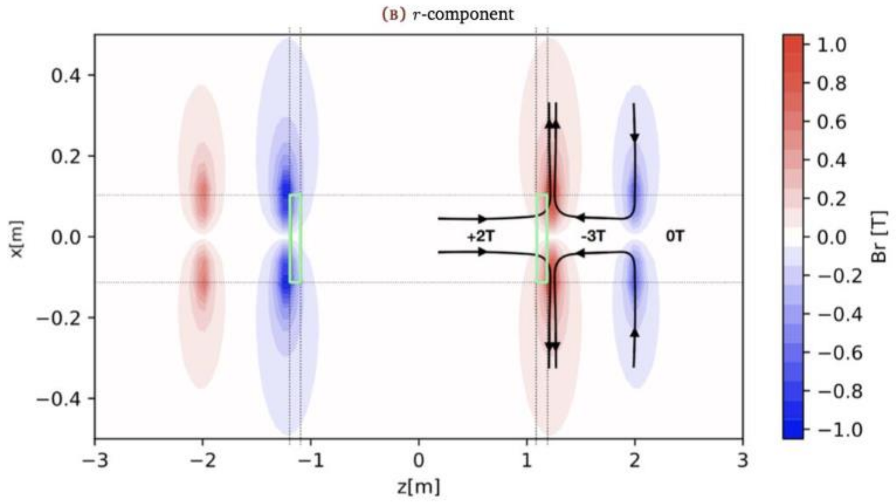
Including the mask aperture x>7mm

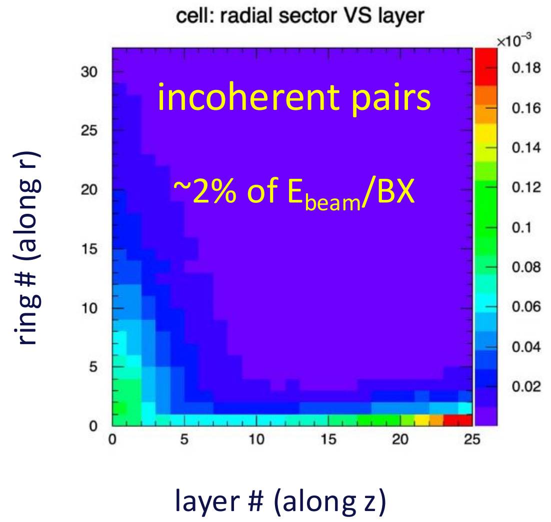


Photons with energy below 2 keV are unlikely to cross the beam pipe.

Mogens Dam

Background signal from Incoherent Pairs in LumiCal





Field configuration creates a hot spot at the rear of LumiCal

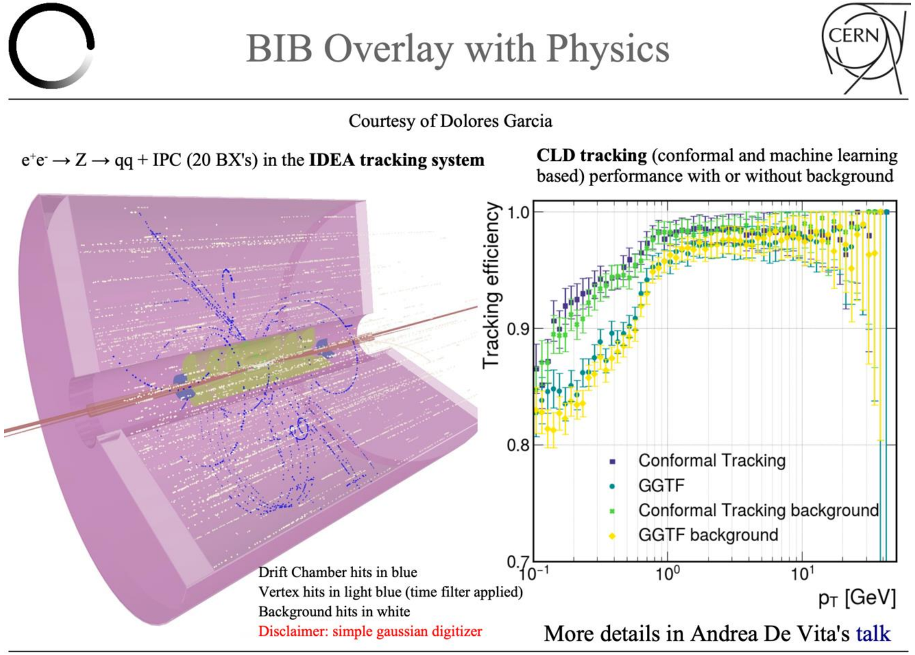
Energy deposited by radiative Bhabha ($e^+e^- \to e^+e^-\gamma$) about 20 times lower than incoherent pairs (0.1% E_{beam}/BX @ the Z)

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!

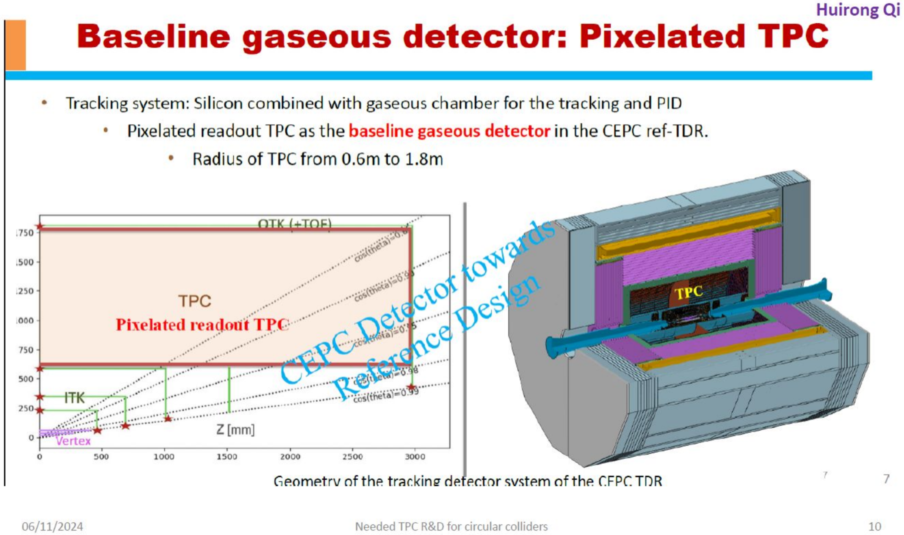


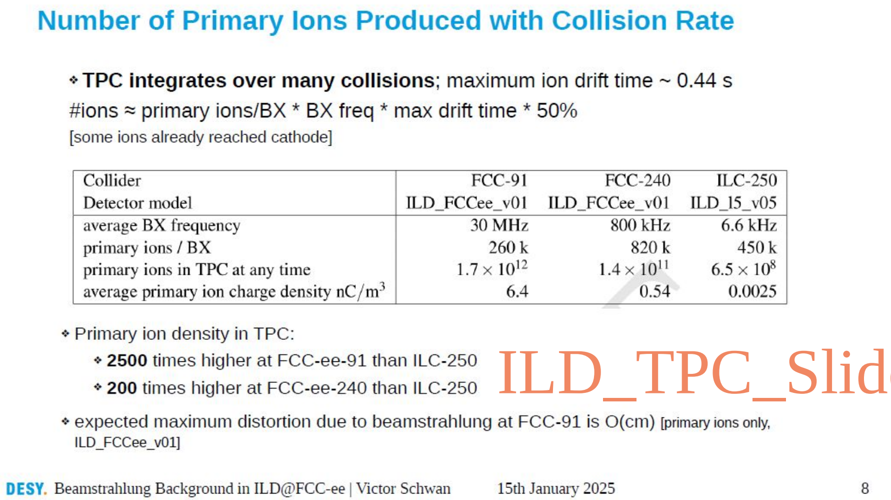
Machine experts will continue with BIB studies by following optics evolution, collimator settings, MDI magnetic configurations, injection options, etc.
Machine and detector experts need to keep in synch the SW tools.

Detector Session

Time Projection Chamber

[Paul Colas](#)
[Victor Schwan](#)





Number of Primary Ions Produced with Collision Rate

- **TPC integrates over many collisions**; maximum ion drift time ~ 0.44 s
  #ions ≈ primary ions/BX * BX freq * max drift time * 50%
  [some ions already reached cathode]

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.4	0.54	0.0025

- Primary ion density in TPC:
  - **2500** times higher at FCC-ee-91 than ILC-250
  - **200** times higher at FCC-ee-240 than ILC-250
- expected maximum distortion due to beamstrahlung at FCC-91 is O(cm) [primary ions only, ILD_FCCee_v01]

DESY. Beamstrahlung Background in ILD@FCC-ee | Victor Schwan 15th January 2025 8

ILD_TPC_Slides

CEPC Reference Detector usesTPC for high energy running (10 years of HZ + 6 years of top)

Large (cm!) distortions from ion space charge when running at Z pole - operability at FCC-ee luminosities is being actively investigated (MDI mods, corrections)

Brookhaven National Laboratory

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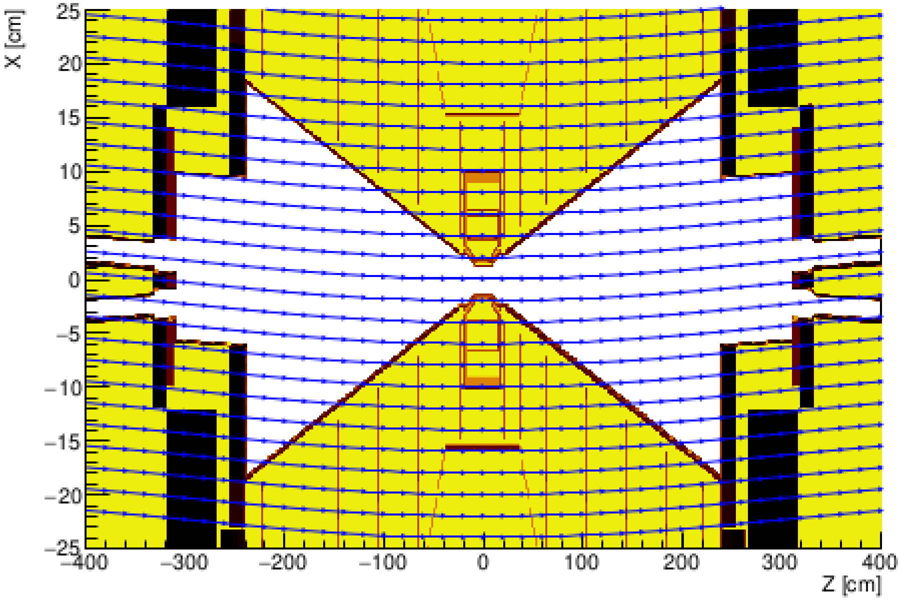
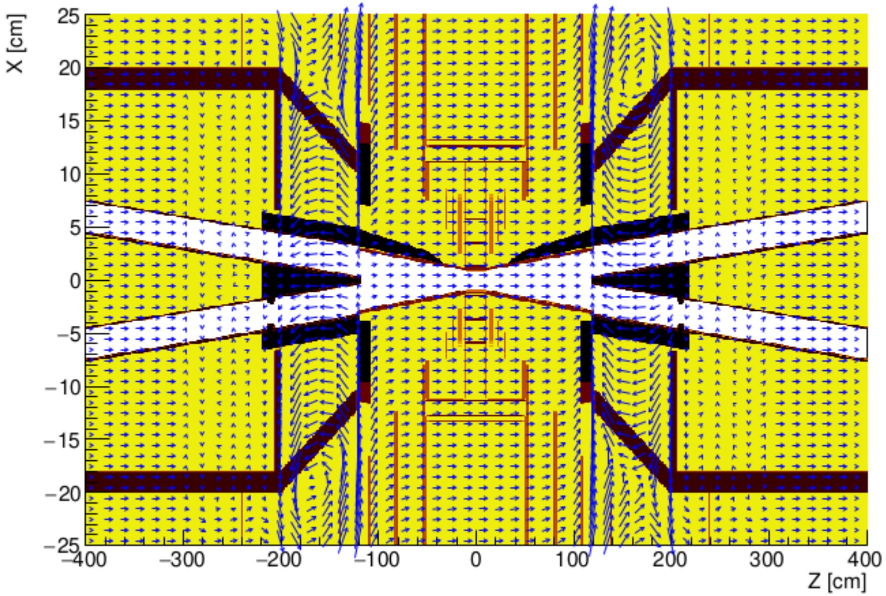
Anti-DID Not Feasible at Circular Collider



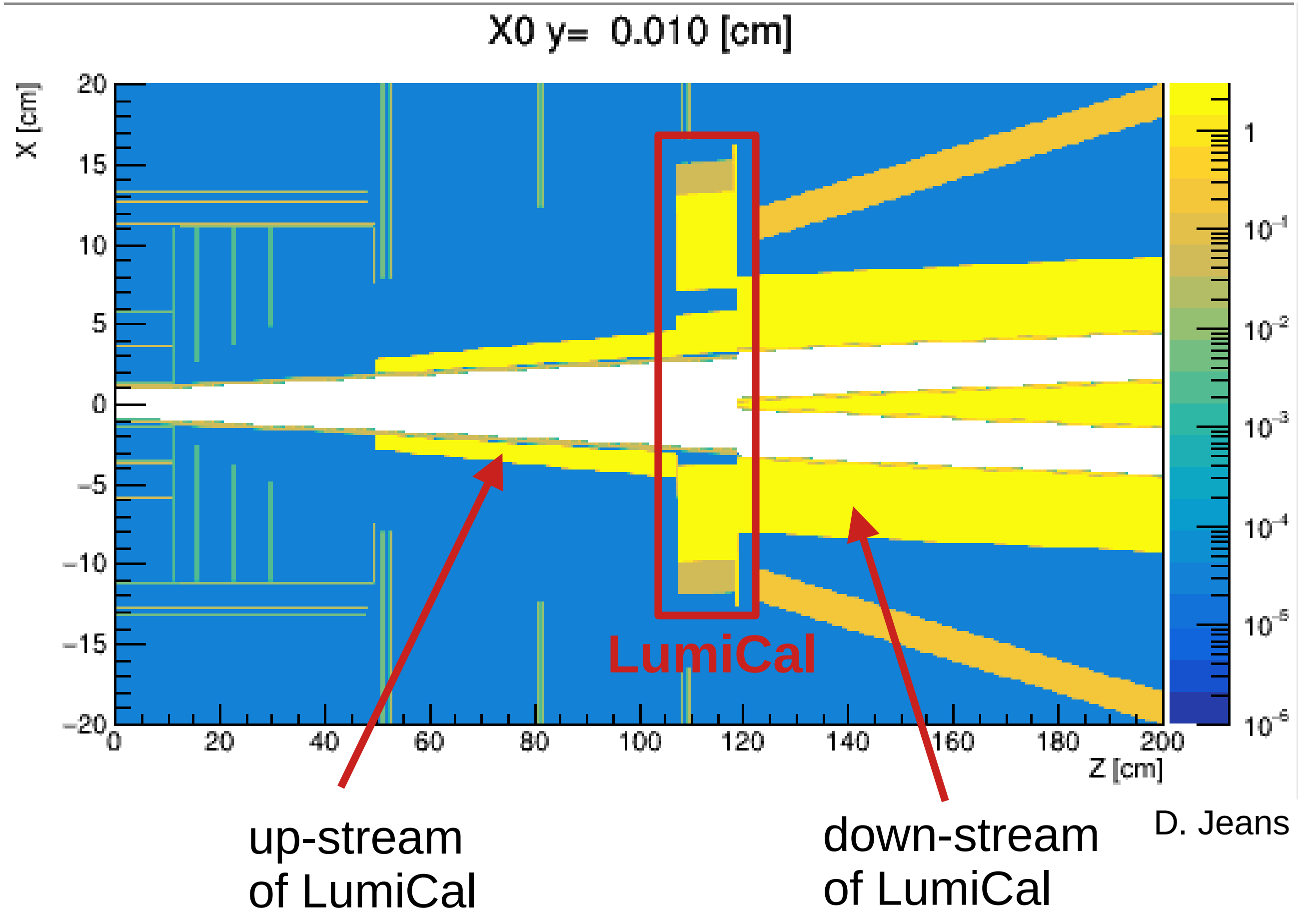
ILC with anti-DID



FCC-ee with compensating and screening fields (old MDI)

- Beamstrahlung ⇒ many, very low p_T e+e- created in bunch collisions
- Anti-DID (detector-integrated dipole) field guides low p_T particles into the outgoing beampipes

No Space for Additional Shielding Available



Switching to new MDIv0 1 strongly recommended

Conclusions

- IR under active development, significant changes possible/expected
- Preliminary samples of (some) background processes available, e.g. synchrotron radiation
- Occupancy numbers are more or less a matter of running the code
- MDI is moving target → wait for a more settled MDI design?

- Focus on reconstruction issues for now: consistent cellIDs, track merging...

Back up

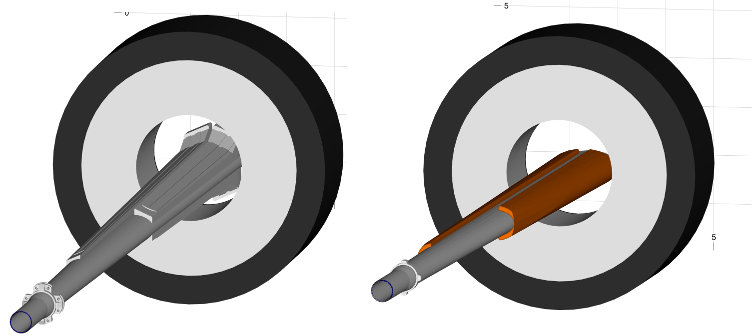
Old MDI – Energy Deposit in LumiCal

Very Brief Recent History of MDI Design

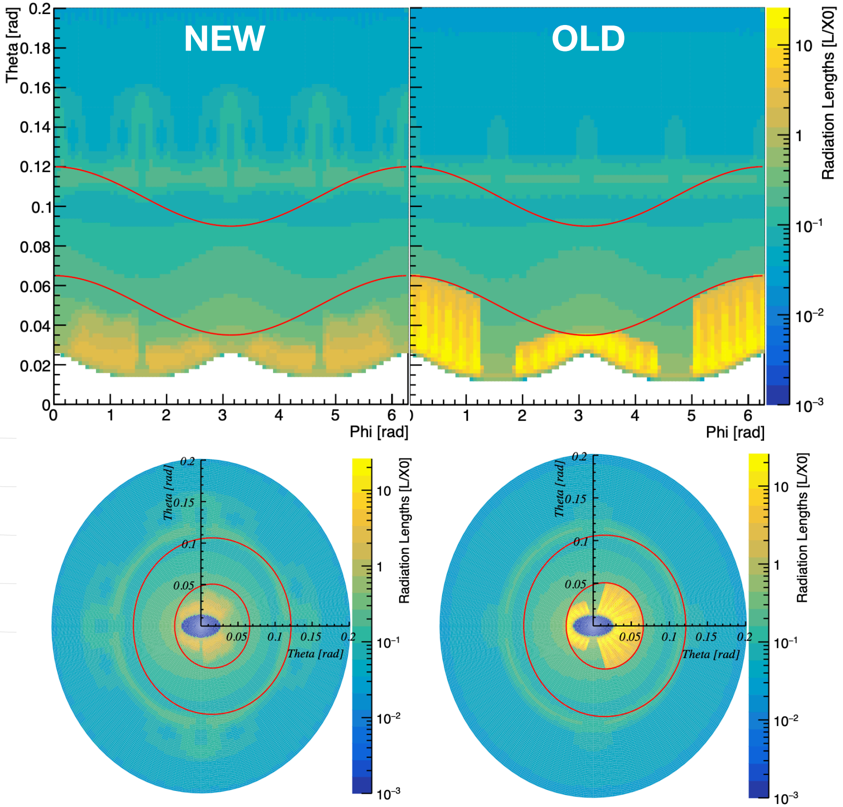
FCC MDI Meeting #53 - 13/05/2024 Andrea Ciarma INFN LNF 3

New beam pipe and cooling

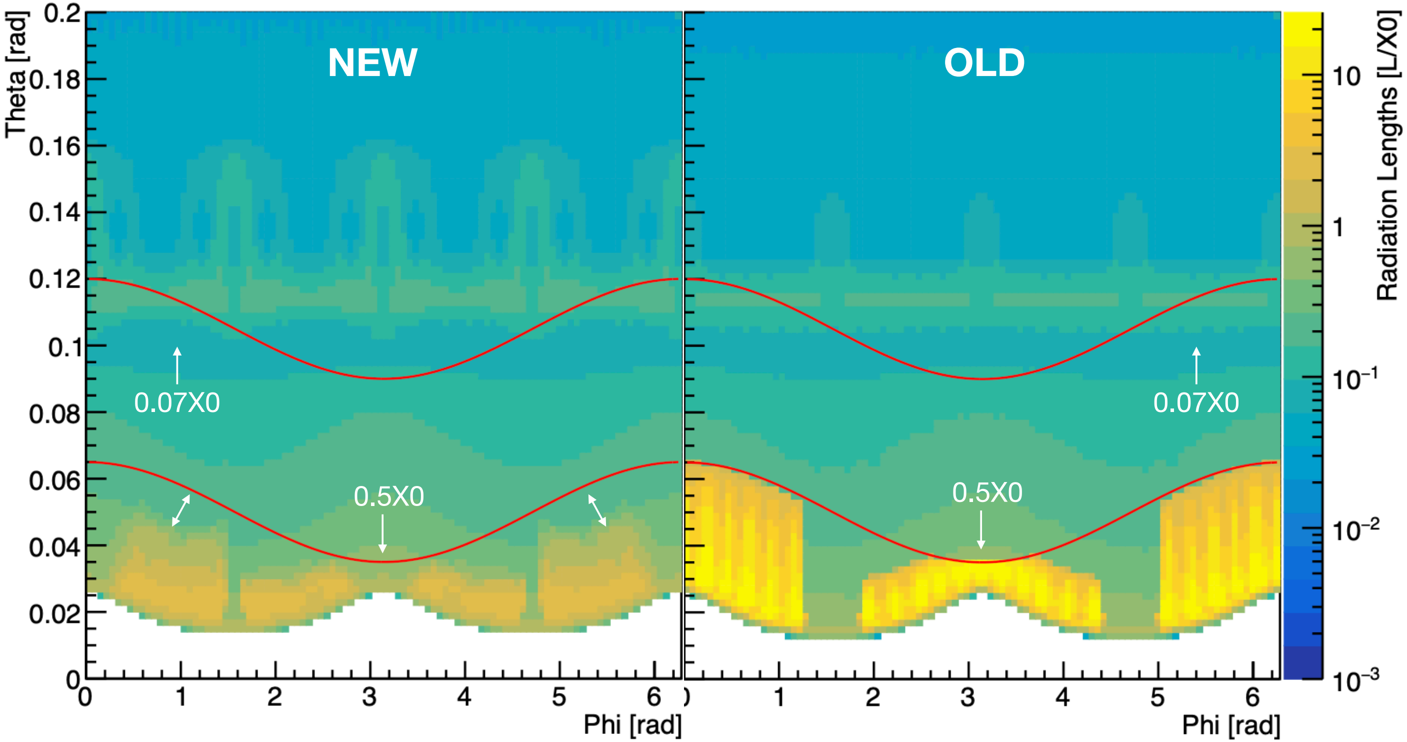
After this feedback, a new solution for the trapezoidal chamber cooling was found. Cooling manifolds are now **all in AlBeMet162** and are placed at **safety margin from the LumiCal acceptance**.



New Old

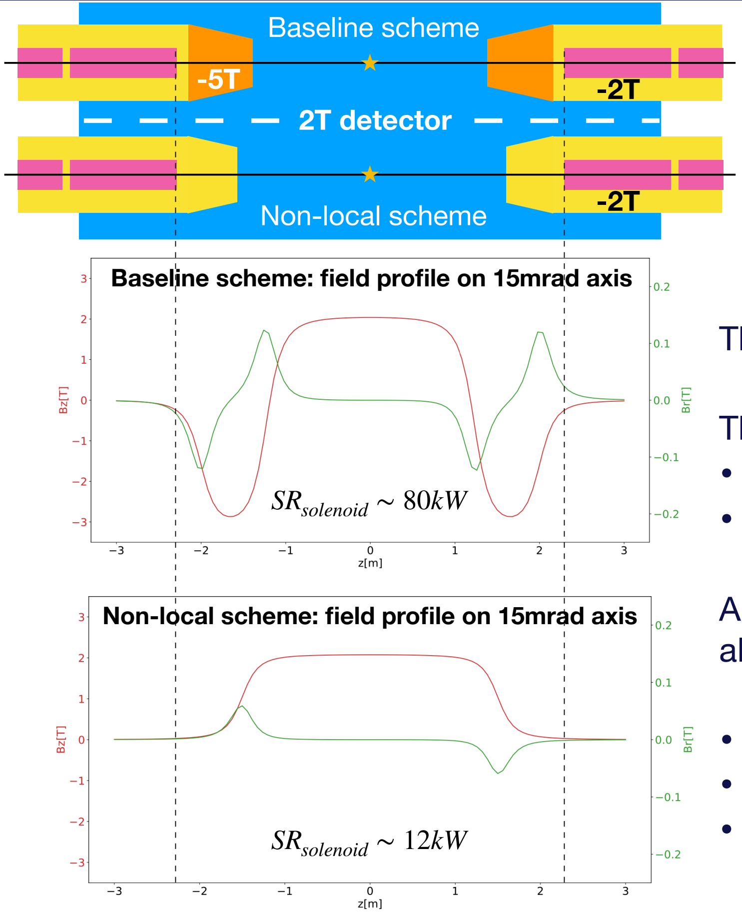


- New MDI is a tessellated shape based on the CAD model
- It has holes; to be fixed
- Technical prerequisites for using new MDI as baseline in k4geo are currently being implemented
- Old = MDI_o1_v00
- New = MDI_o1_v01
- See https://github.com/key4hep/k4geo/tree/main/FCCee/MDI/compact



- Same trapezoidal chamber: max = 0.5X0 , min = 0.07X0 within LC acceptance
- Larger paraffine inlet/outlet: very small impact
- Water cooling manifolds in AlBeMet162: much lighter (2.5X0 vs 20X0) and distance from 50mrad cone

Non-local Compensation Scheme



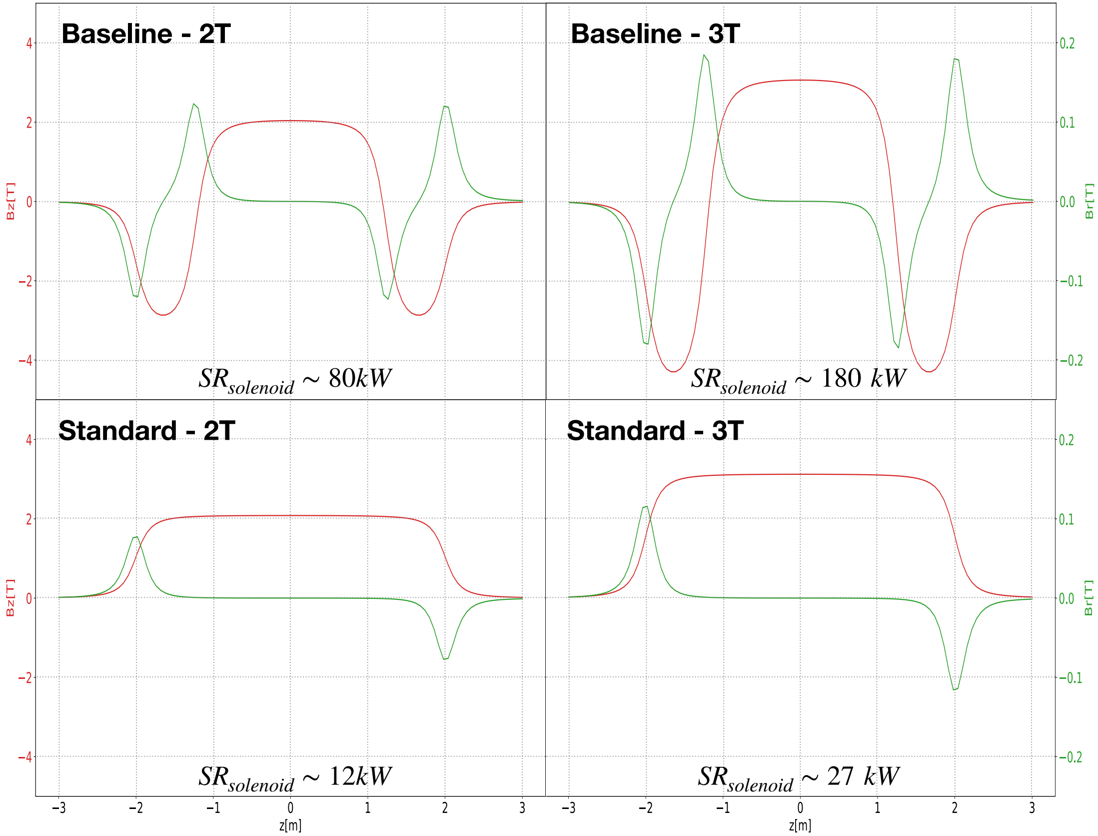
Coupling Correction Scheme at FCC-ee

The **2T detector solenoids** induce coupling in the FCCee 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** proposed by P. Raimondi would allow to move the **compensating solenoids** outside the IR.

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



Can we go to 3T?

Synchrotron radiation is emitted from the **fringes** between regions of different magnetic fields.

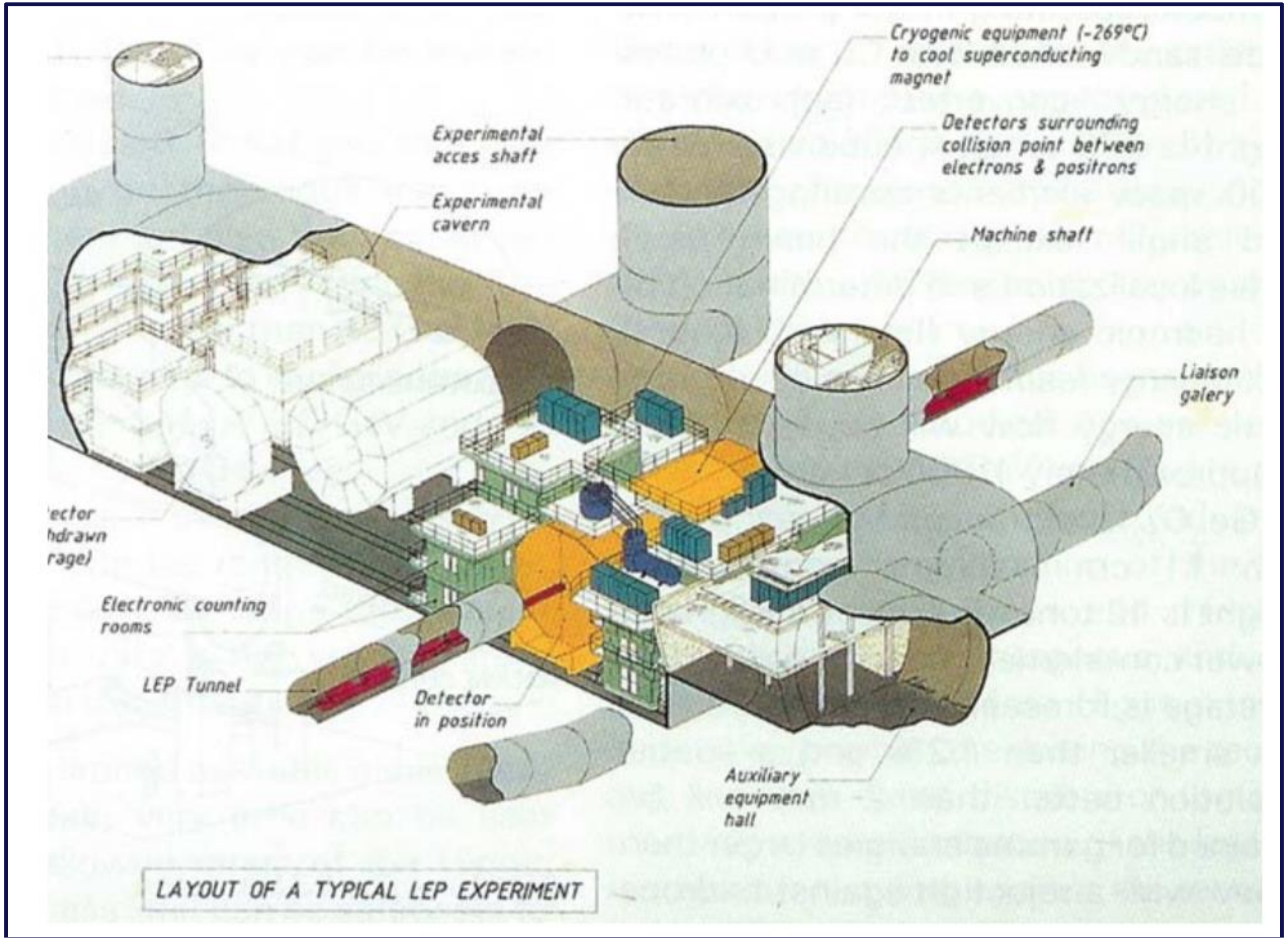
Scaling everything up from **2T to 3T** we can expect an increase of a factor:

$$P_{SR} = \frac{2}{3}\frac{e^2 c}{4\pi\epsilon_0}\frac{\beta^4\gamma^4}{\rho^2} \propto B^2$$

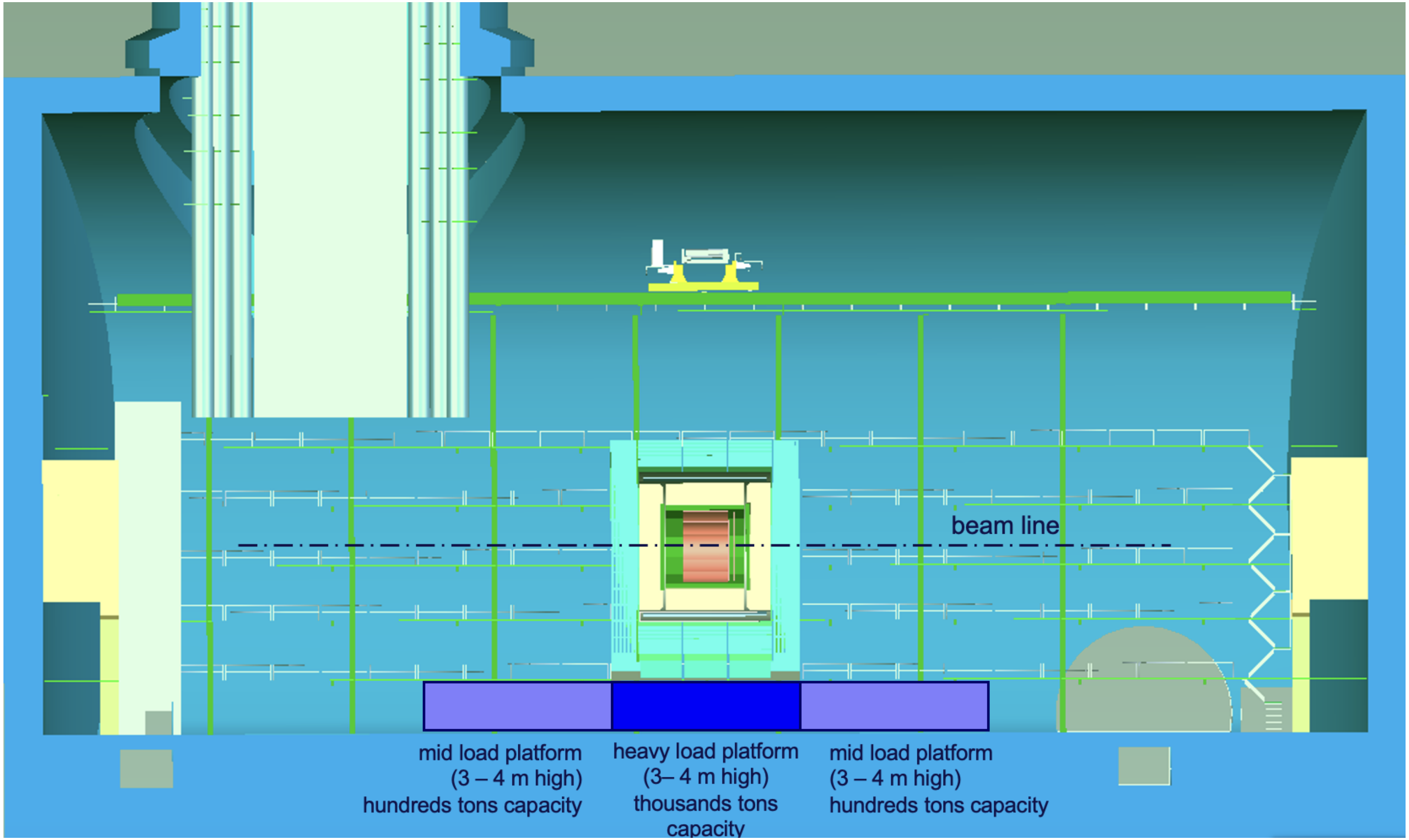
$$\frac{P_{SR}^{3T}}{P_{SR}^{2T}} = \frac{3T^2}{2T^2} = 2.25$$

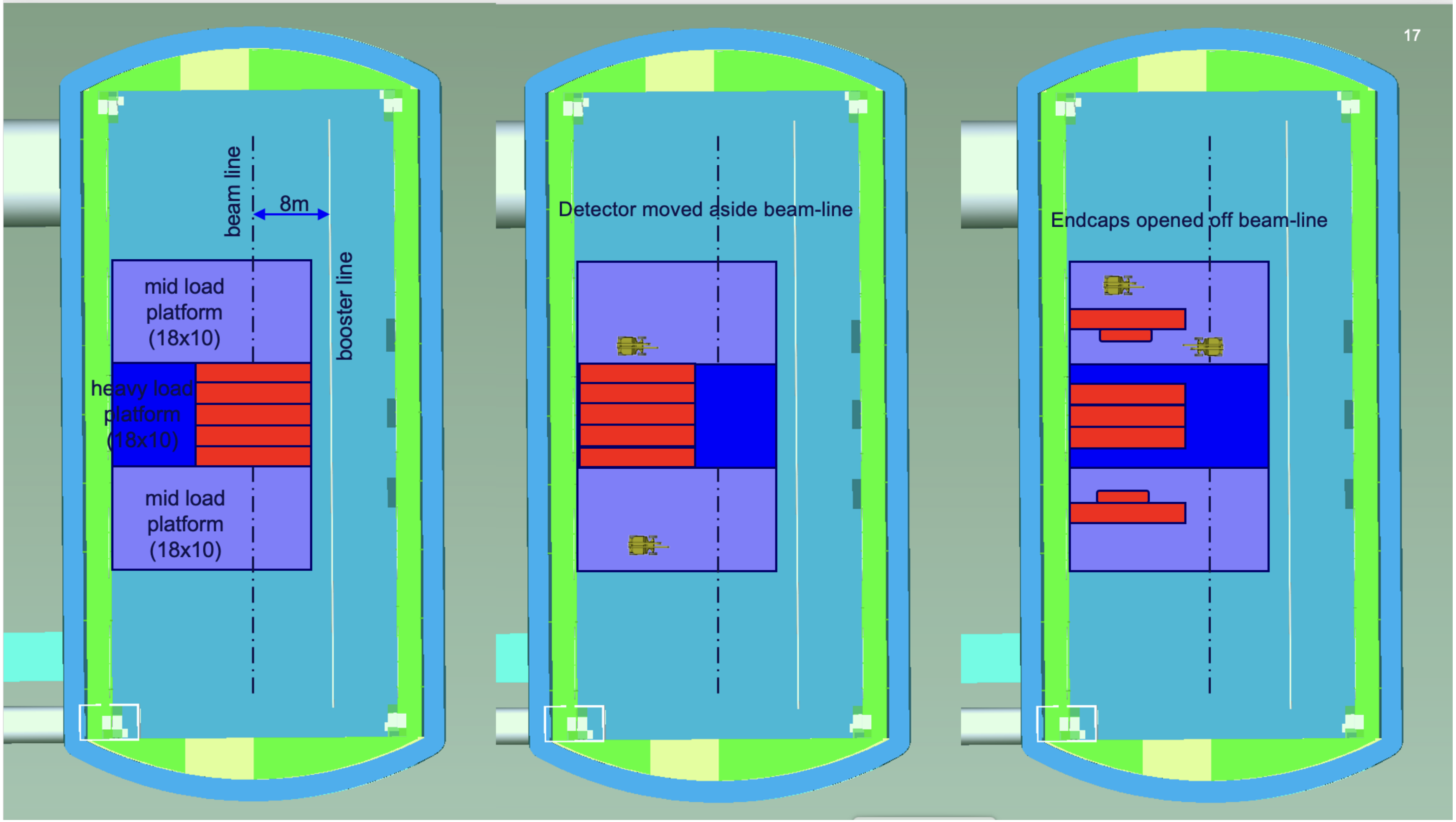
The power in the 3T standard scheme would still be **x3 lower than the baseline 2T scheme.**

Maintenance Scenarii

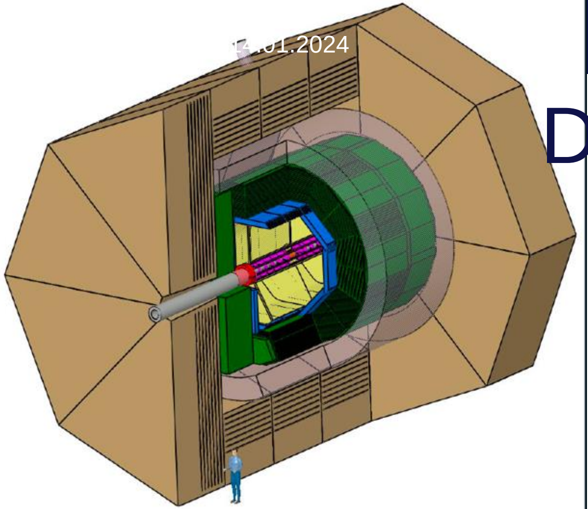


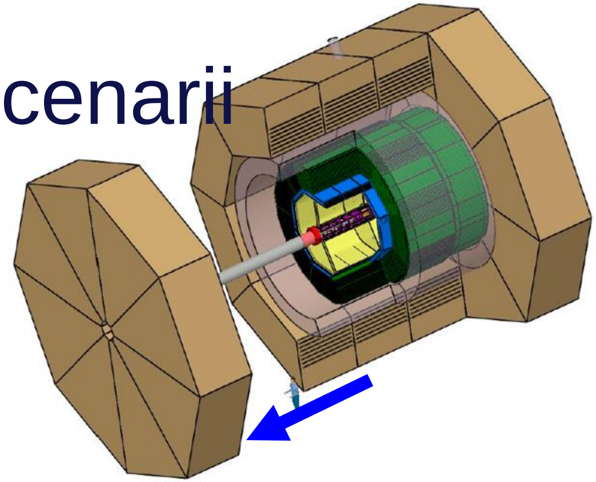
LEP time:
experiment cavern trasversal to beam axis. Three shafts (!)
Note the detector in parking position for maintenance.


beam line
mid load platform
(3 – 4 m high)
hundreds tons capacity
heavy load platform
(3– 4 m high)
thousands tons
capacity
mid load platform
(3 – 4 m high)
hundreds tons capacity


17
beam line
8m
booster line
mid load platform (18x10)
heavy load platform (18x10)
mid load platform (18x10)
Detector moved aside beam-line
Endcaps opened off beam-line

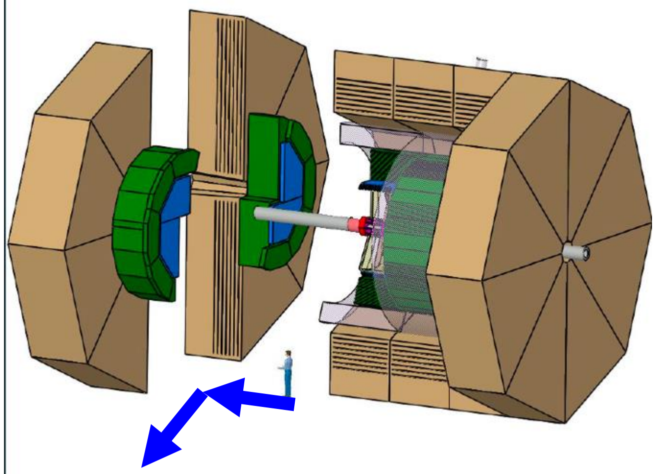
Detector opening scenarii

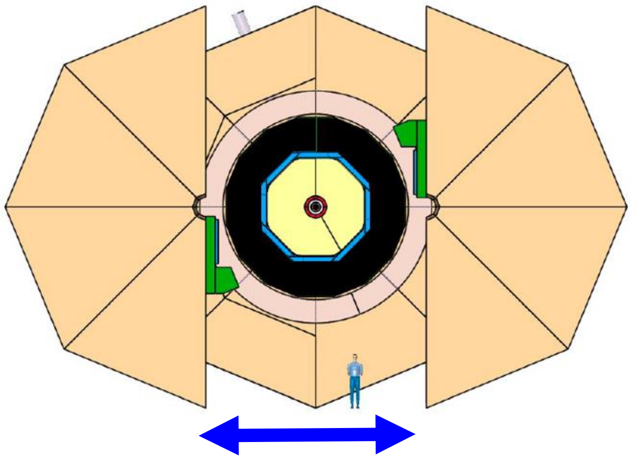




Solid Endcaps

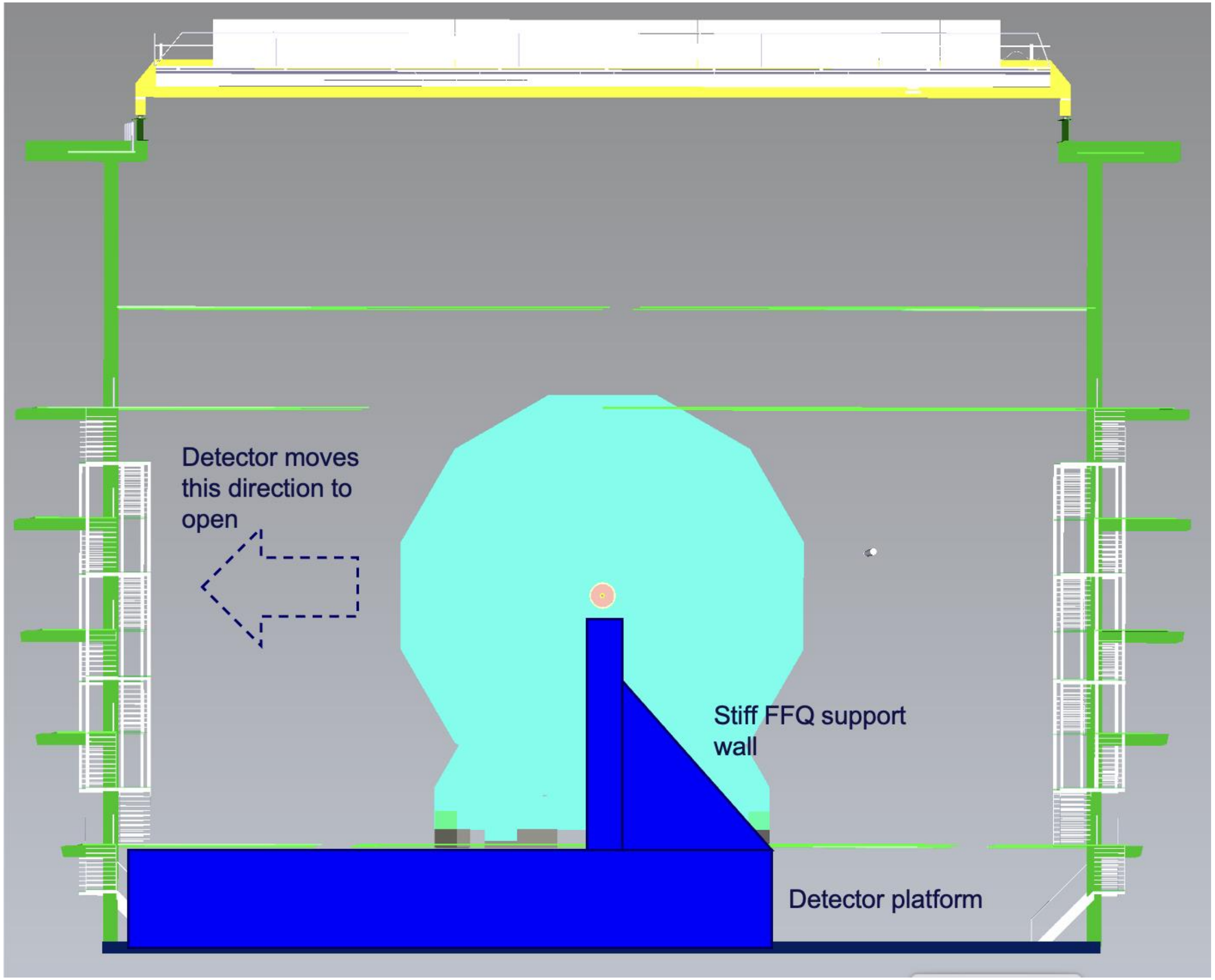
Long longitudinal stroke to access inner detector elements. Last machine elements cantilevered & removed for opening.





Split Endcaps

Combined short longitudinal stroke + transversal opening to mitigate impact on last machine elements envelope. Detector acceptance seriously compromised in the forward region.



Scenario #3

In large experiment sites A & G there is enough clearance to envisage to move the detector aside the beamline and get full access to the detector's inner parts.

The FFQ can either be removed before the translation or move with the detector and then be removed from the garage position.

In small experiment sites D & J this scenario is only possible by adding an alcove (approx.10x25m) on the near side of the ring.