MDI SUMMARY AND HIGHLIGHTS

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7th FCC Physics workshop
Annecy (France)
29 January – 2 February 2024

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

Agenda MDI sessions

Tuesday 30/1 9H00-10H30 Joint Session: Detector & MDI	
Fabrizio Palla (INFN-Pisa)	Vertex Detector
C. Turrioni (INFN-Perugia)	Progress on air cooling of the vertex detector
Armin Ilg (Univ. Zurich)	Vertex detector and silicon wrapper simulation and material budget
Andrea Gaddi (CERN)	First studies on detector integration in the beamline

Wedn. 31/1 11H00-12H30 MDI II	
R. Kersevan (CERN)	Vacuum system and requirements in the IR
K. Andre (CERN)	Synchrotron Radiation Background
A. Abramov (CERN)	IR Beam losses and collimation system
A. Frasca (CERN)	Results and prospects of radiation level studies in the FCC Interaction Region

Wedn. 31/1 9H00-10H30 MDI I	
F. Fransesini (INFN)	Progress on the MDI mechanical design
J. Seeman (SLAC)	Status of the IR magnet system design
A. Ciarma (INFN)	Solenoid Coupling compensation scheme

Wedn. 31/1 17H45-18H45 MDI III	
P. Raimondi (FERMILAB)	LCCO Final Focus beam dynamics studies
Peter Kicsiny (EPFL)	Status of the beam-beam studies
E. Montbarbon (LAPP)	An FCC-ee vibrations study for its MDI

Excellent work and progress

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

Good participation, but too few detector experts joined

VERTEX DETECTOR AND GENERAL INTEGRATION

Vertex: services integration and going low mass

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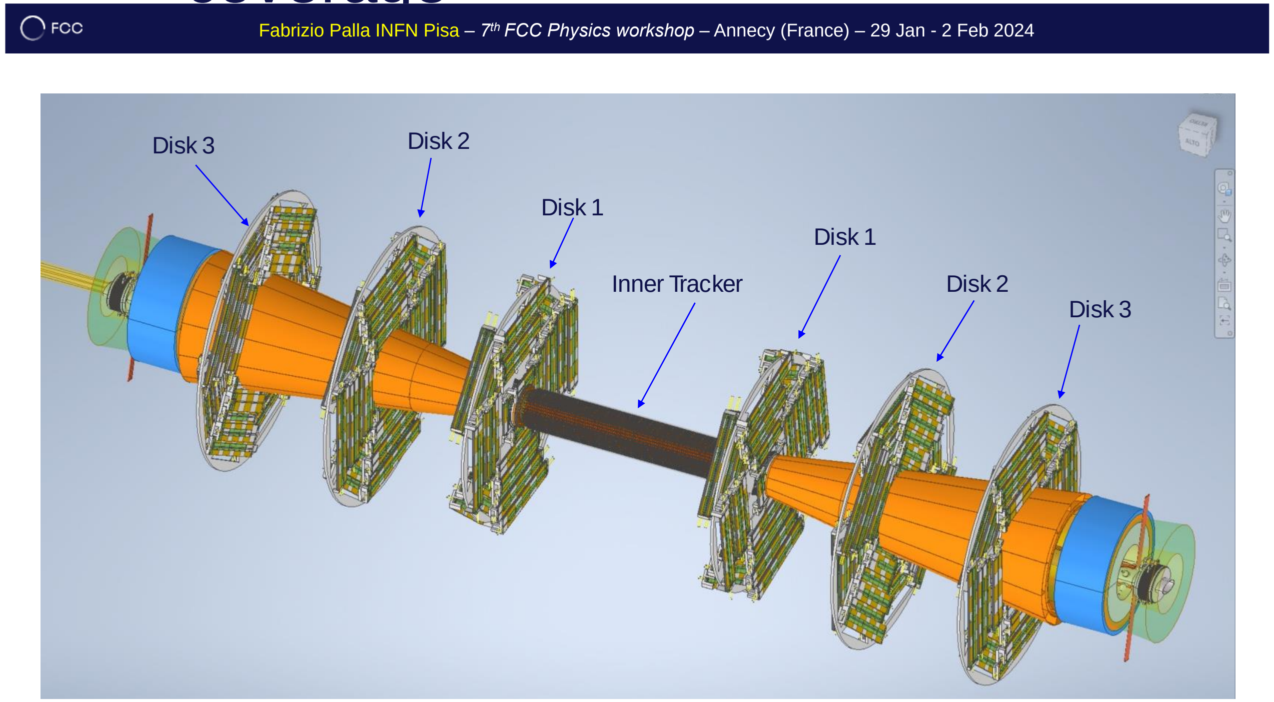
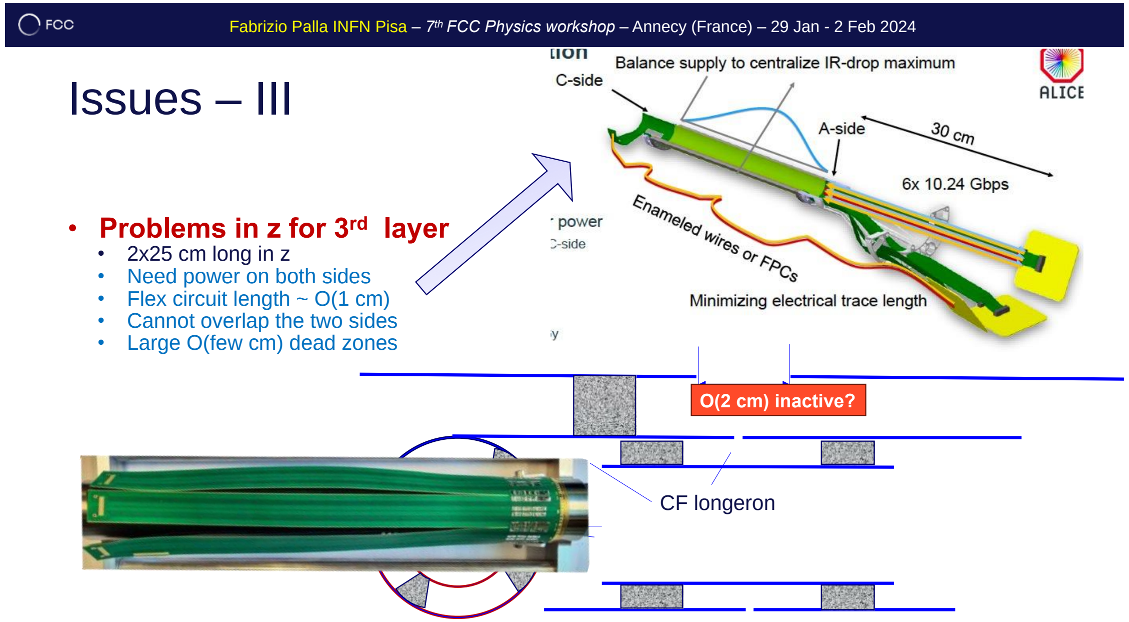
F. Palla

- Inner vertex cooling and cables supports defined and integrated
- Can lower material budget to ~0.2% X/X0
- Need to evaluate the impact on physics of a reduced (95%) active pixel area
- Need to solve integration of long barrel layers to allow for full angular coverage





Vertex thermal and stress simulations

- **A CFD model for the evaluation of thermal performance of layer 3 has been made.**
- **Cooling with air is doable**
- **Better performance with Helium cooling (lower mass flow)**

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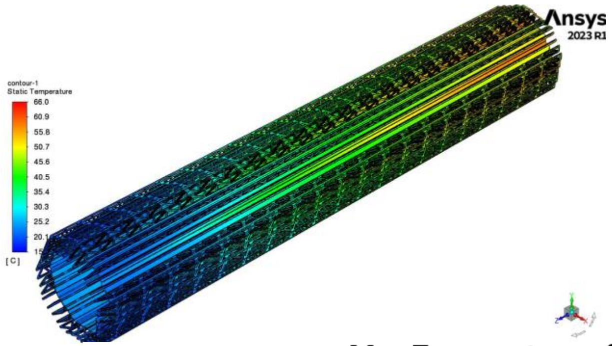
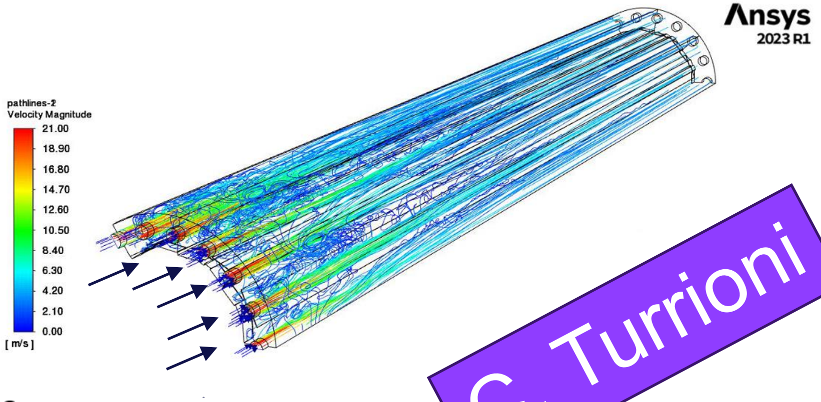
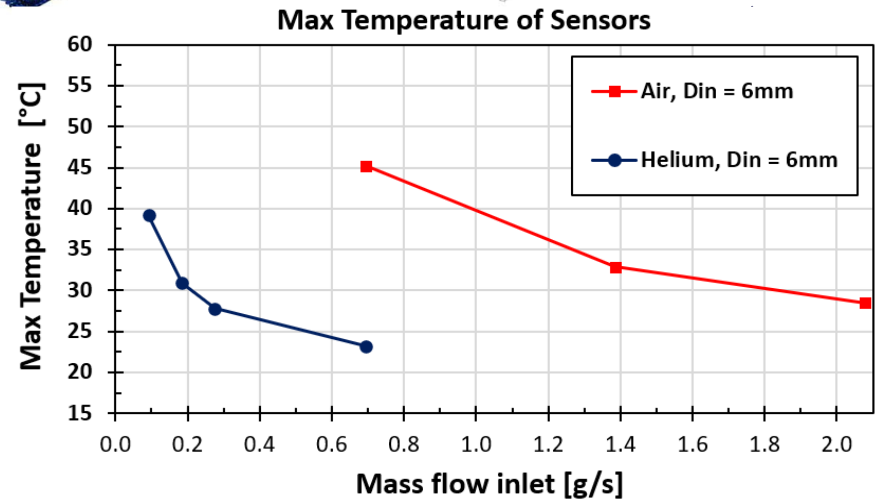
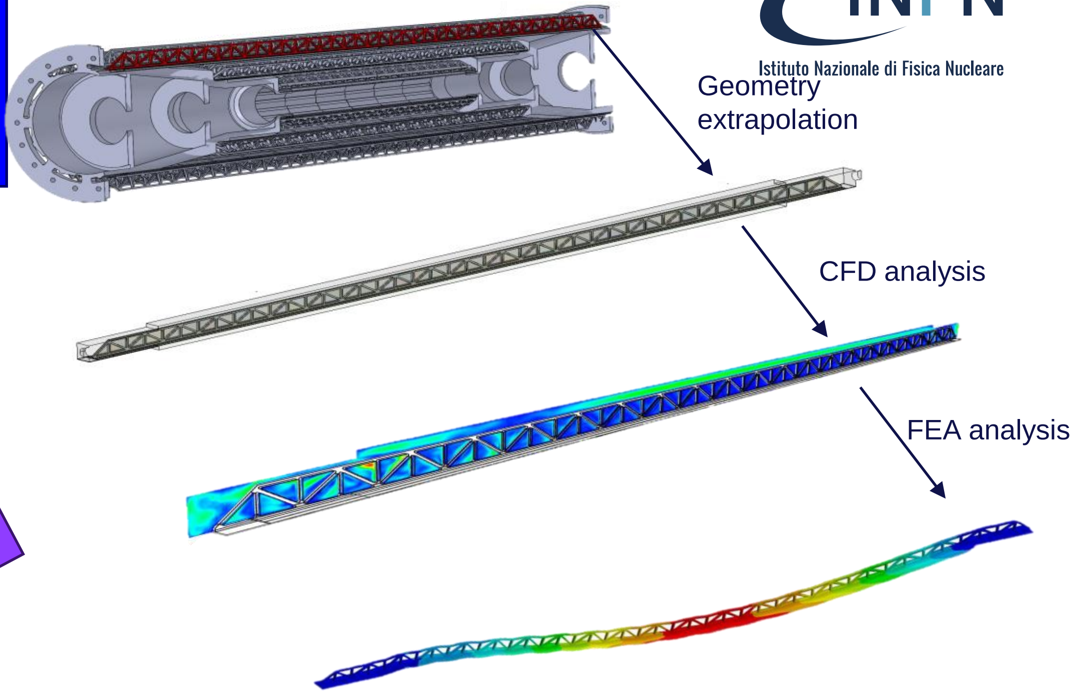






C. Turrioni



- **A CFD and FEA workbench has started to evaluate the effects of air flow induced vibrations on the structure**

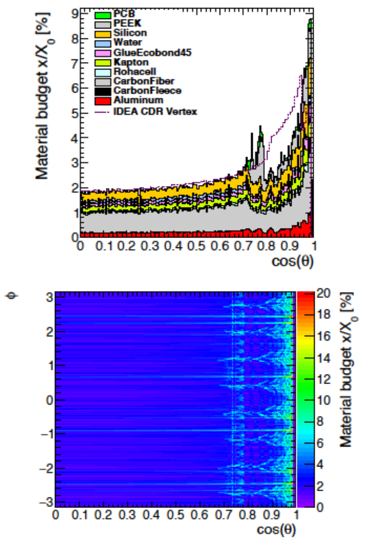
Vertex and Silicon Wrapper simulation

A. Ilg

- Vertex detector and Silicon Wrapper geometries implemented
- Material budget estimation done
- Need to define integration of the Silicon Wrapper wrt the other detector elements
- Low mass (see previous) vertex detector implementation started

Complete system

University of Zurich

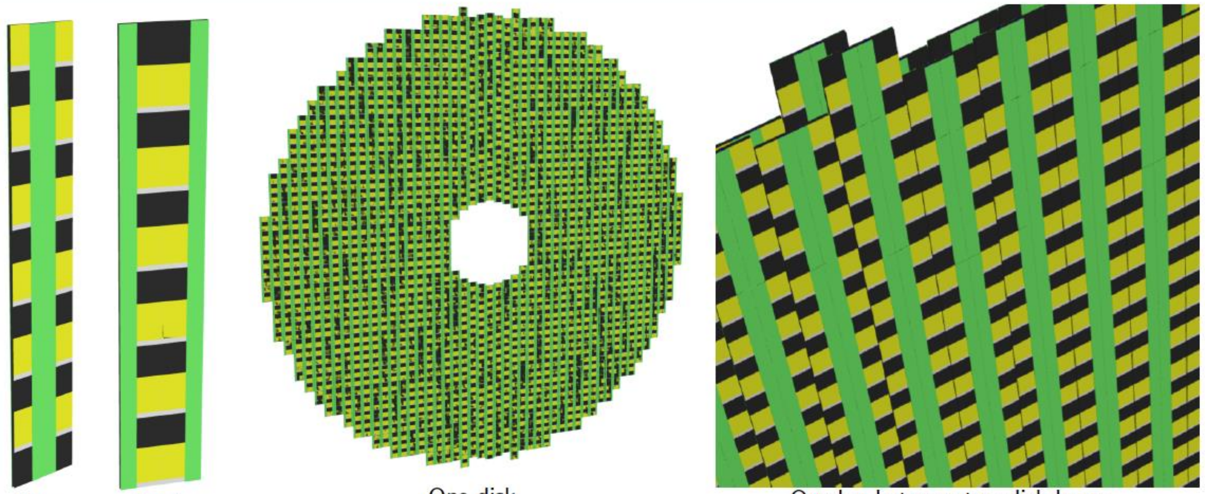


Complete vertex system

- Material budget comparable with CDR estimate
- First working version on k4geo, update imminent with some fixes (getting rid of last overlaps)
- Use it, let me know if you find problems!
- Plan to include last missing volumes using DDCAD (and find a way their material budget is seen using k4SimGeant4 script)
- Look at all material budget evaluations as a lower limit, there's always gonna be more added! (e.g off-detector cabling)

IDEA Silicon wrapper disks

University of Zurich



Front Back One disk Overlap between two disk layers

Only inactive area at side of tile

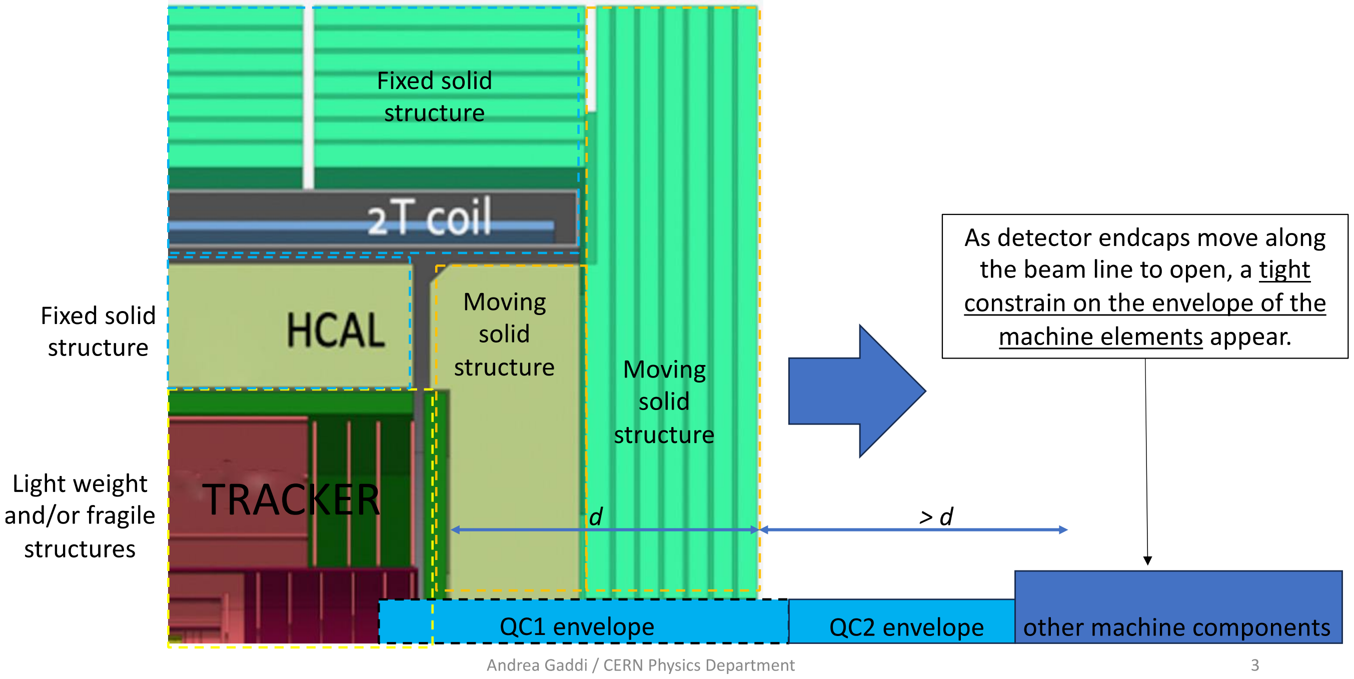
- Tiling the disks with tiles of 6, 12 and 24 modules
- Total of 30432 modules, 51 m^2 of Si

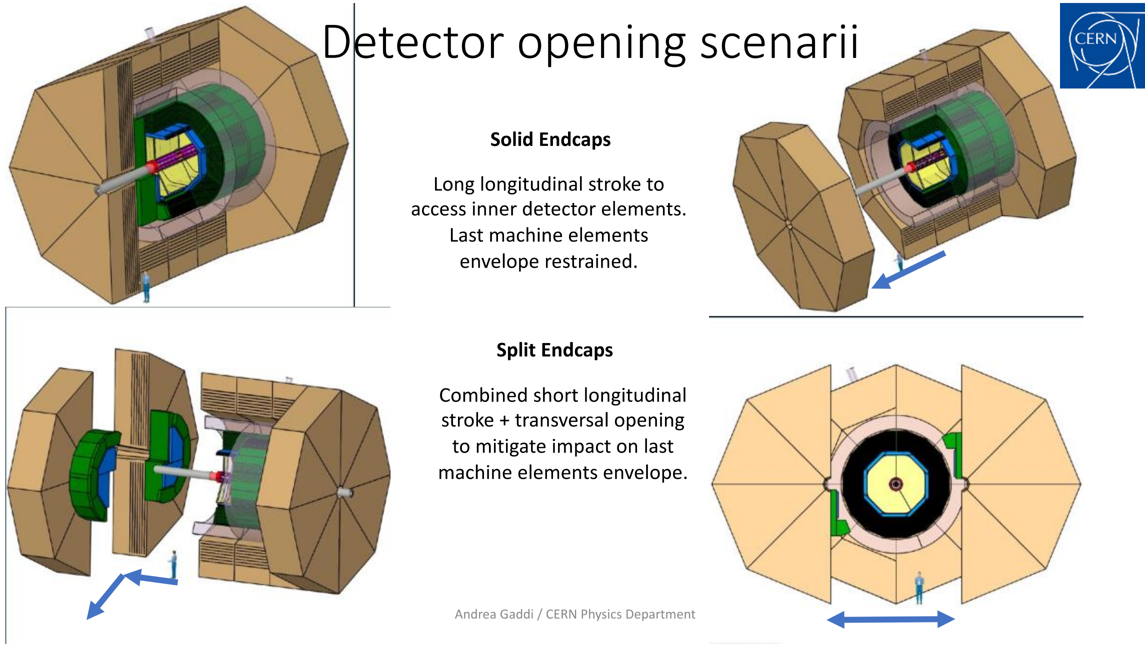
General detector integration issues

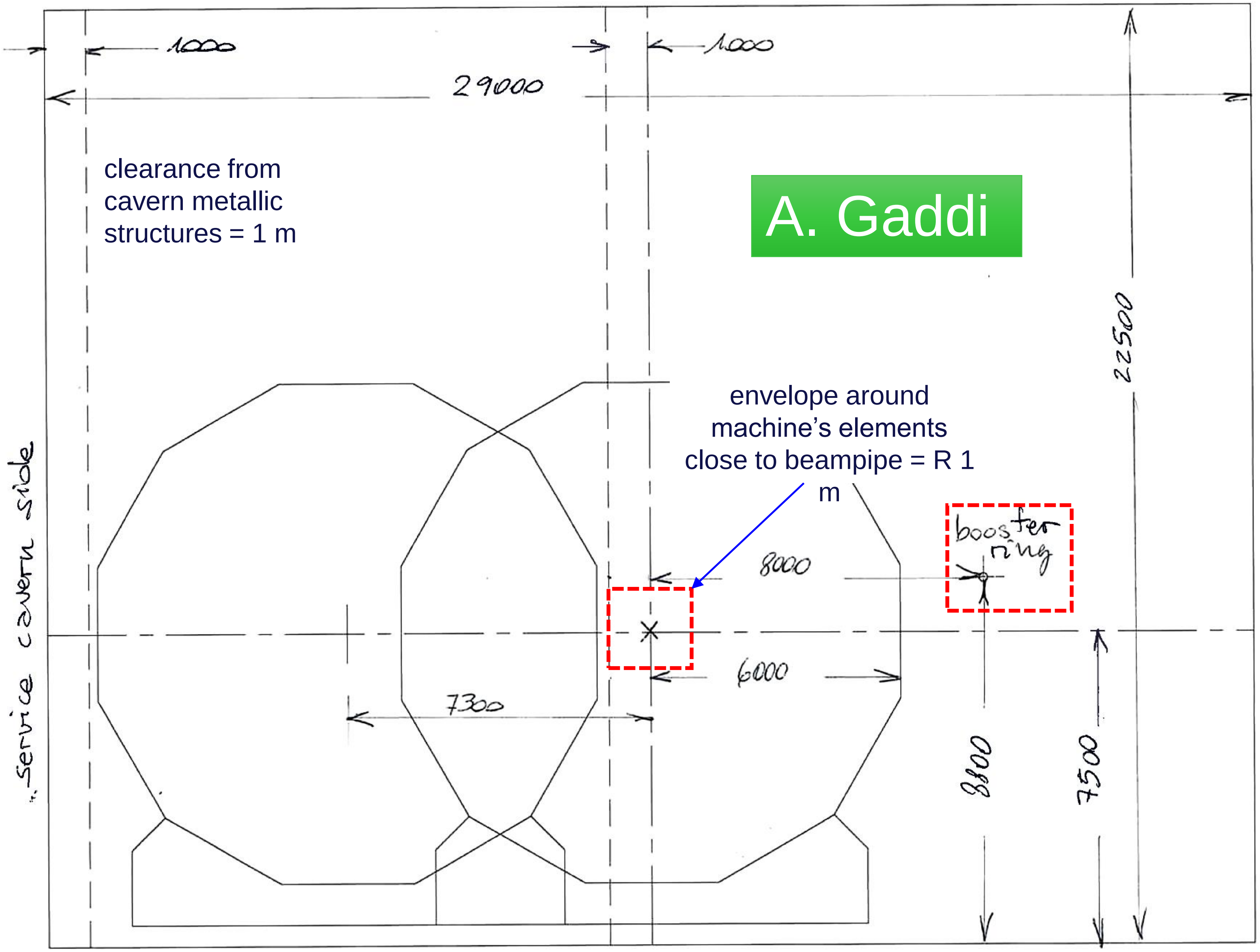
- Considering how to access the detector elements taking care of the machine elements (QC)

A. Gaddi

Typical detector structure.







There is enough clearance to envisage the scenario to move the detector aside the beamline and get full access to the detector's inner parts

INTERACTION REGION DESIGN

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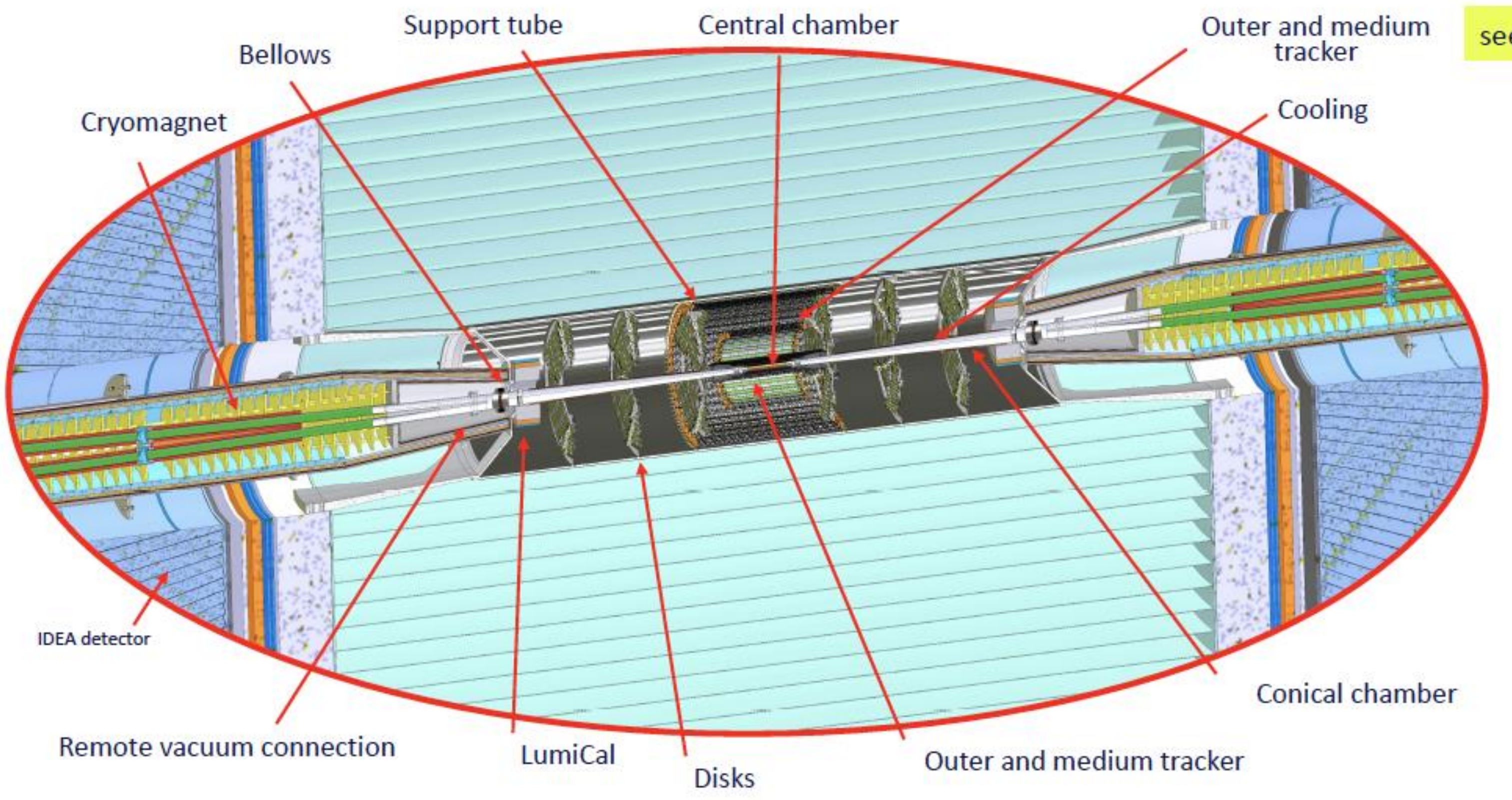
FCC-ee engineered Central Interaction Region

see talk by F. Fransesini

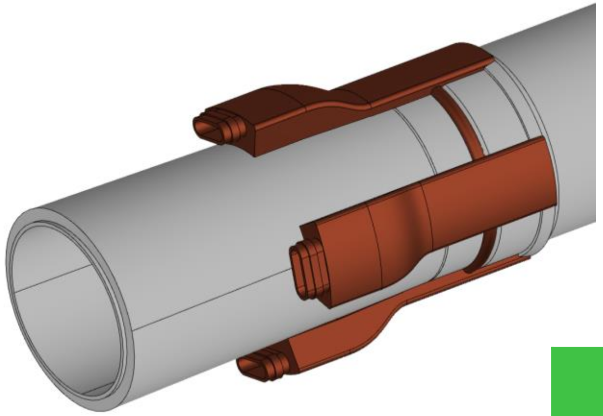


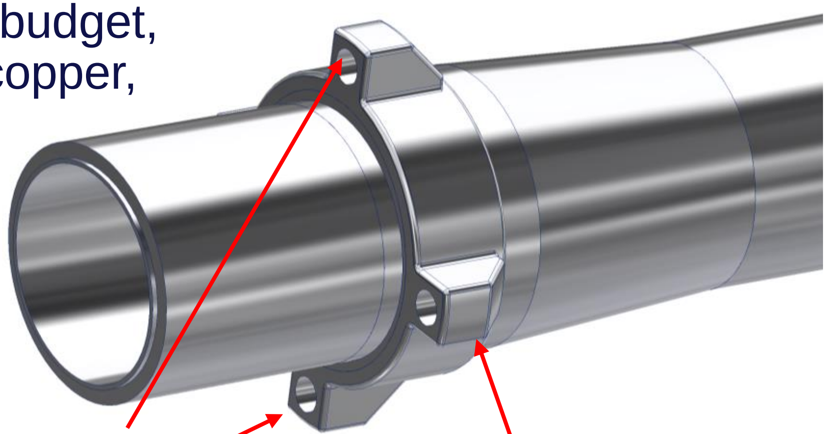
Ref: M. Boscolo, F. Palla, et al., *Mechanical model for the FCC-ee MDI,* EPJ+ Techn. and Instr., https://doi.org/10.1140/epjti/s40485-023-00103-7

Interaction region mechanical layout progress

Change in central beam pipe inlet and outlet material

- Reduction of the material budget, avoiding any manifold in copper, especially in LumiCal





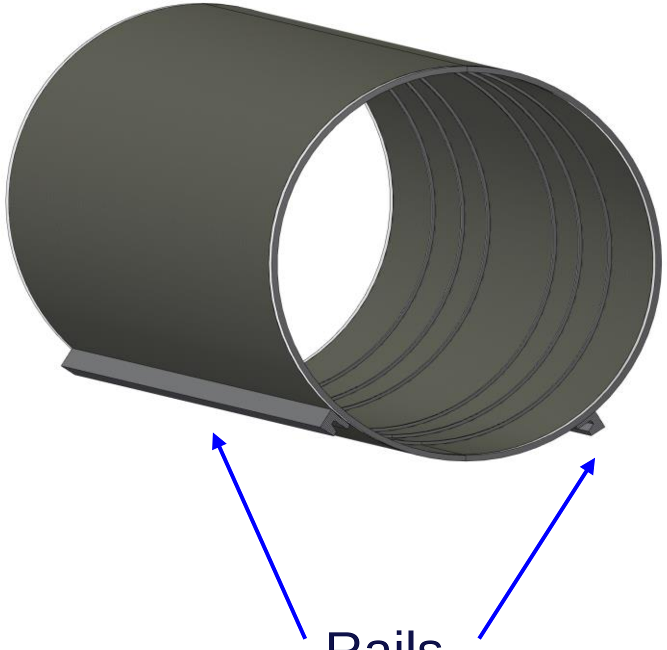
Inlet/outlet for paraffin cooling (AlBeMet)

Value of L/X0		
	Previous design	Current design
Minimum	0.06	0.07
Maximum	1.8	0.52
Average	0.2	0.16

F. Fransesini

New idea for the support tube insertion

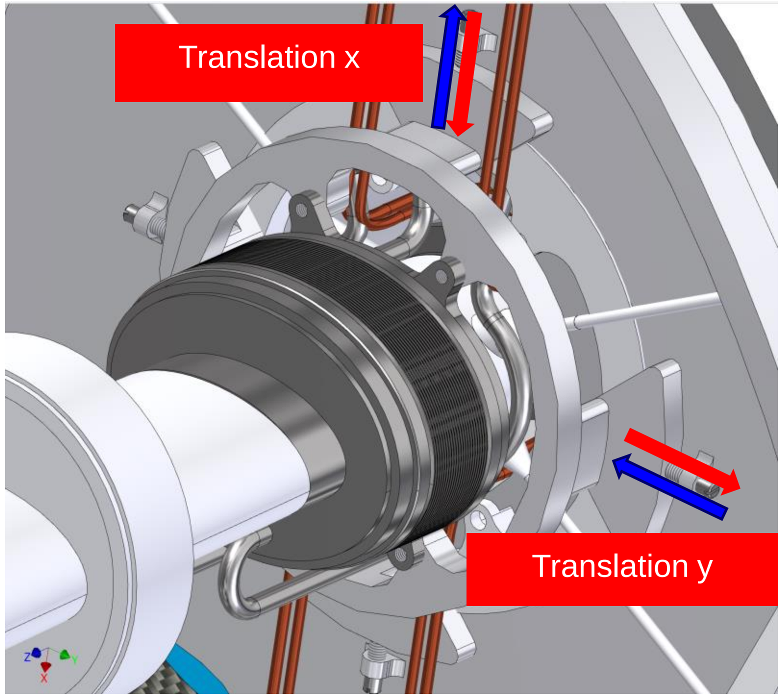
- Carbon Fiber rail embedded on the support tube, sliding on special rails on the detector *(need to define which one)*



Interaction region mechanical layout progress

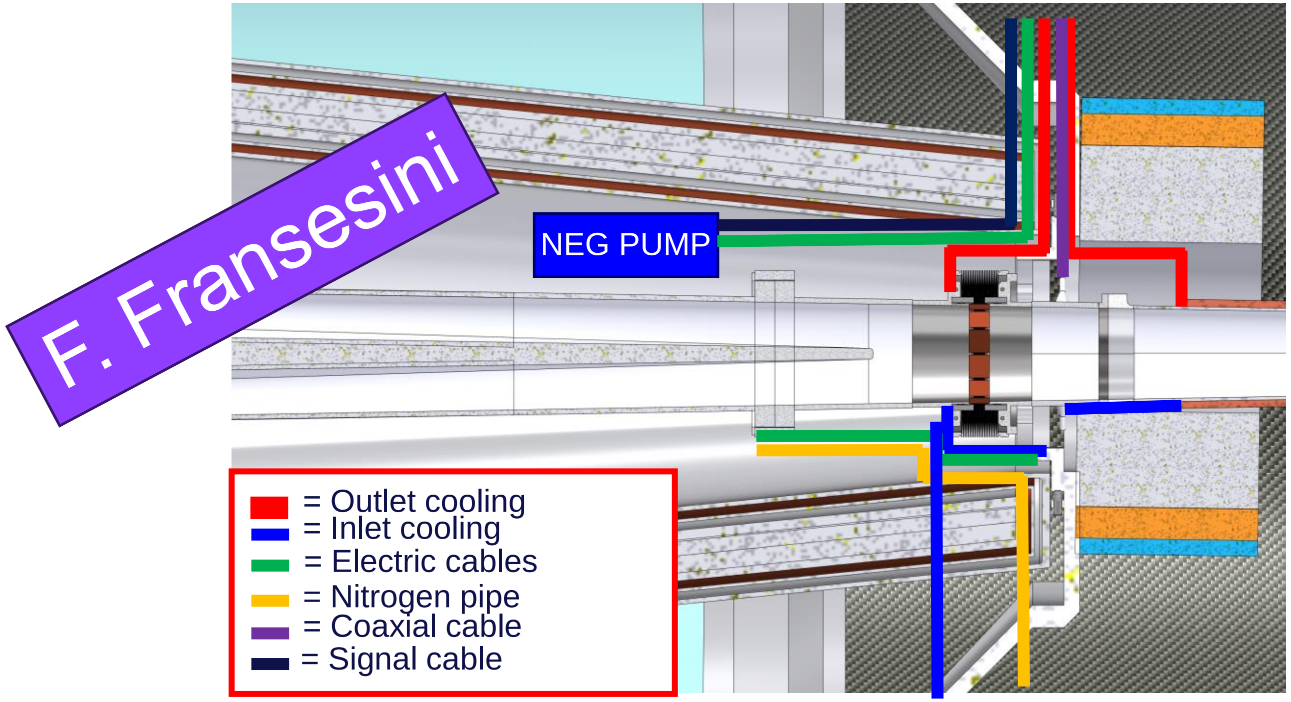
Interface between the bellows and the Support Tube

- A preliminary design has been proposed; this interface is important for the alignment and support system of the whole chamber.



List of services

- The services (cables, pipes) are important in terms of space and integration; therefore, it has been necessary to start this study that will continue in parallel with the other studies.



General summary for MDI IR Magnets (J. Seeman…)

SLAC

FCCee QC1 CCT magnet was successfully tested cold in Fall 2023 (M. Koratzinos …). Analysis of field harmonics is ongoing.

IR magnet cryostat is understudy, looking at needed cryogenic layers, cryogen flows, magnet leads, magnetic forces, vibration, cantilever supports, heat shields, support struts, detector shielding layers …

New lattice is under review (P. Raimondi …) could change, a little, the IR magnet strengths and locations.

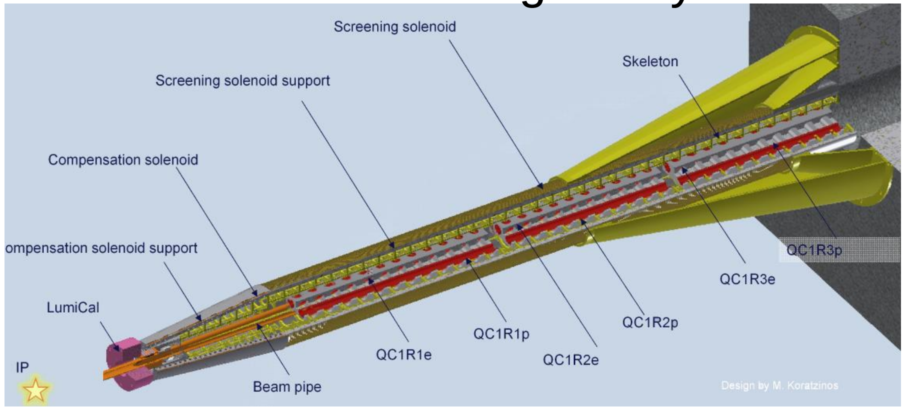
Correction schemes for field cross-talk (side-by-side) between quadrupoles need testing.

Cryo-plant and cryogen distribution to the IR magnets is understudy, investigating e.g. 1.9 K versus 4.5 K and flow rates.

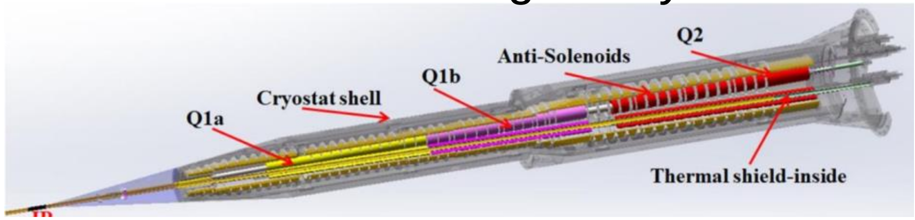
The separation angle between detector and FCCee accelerator needs a refreshed look.

CEPC TDR was released in December 2023 including designs for the IR magnets and cryostat. Compare.

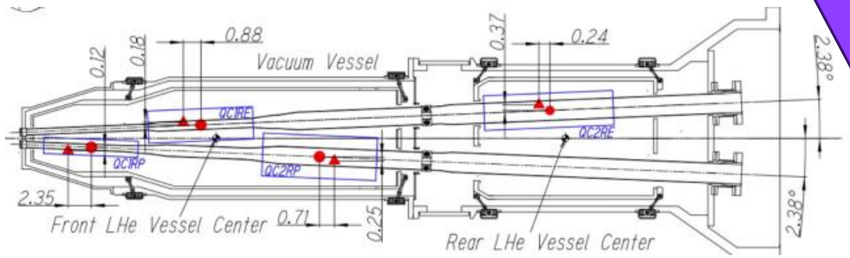
FCCee IR magnet cryostat



CEPC IR magnet cryostat



SuperKEKB IR magnet cryostat



J. Seeman

Suggested technical goals for FCCee MDI IR magnets for 2024 (Seeman …)

SLAC

1) Full list of magnet, vacuum, and cryogenic specifications
2) Make initial cryostat design (4 or 7 m) by cryogenic/mechanical engineer(s)
3) Make initial layout of magnet/cryogenic splice box
4) Resolve Raimondi's new IR lattice vs present
5) Converge on Q1 to Q2 longitudinal separation
6) Construct a left+right CCT magnet pair for QC1
7) Carry out warm test of CCT quadrupole for reduced left-right field cross-talk
8) Answer if IR magnets need higher-order trim coils
9) Design remote vacuum flanges (need 6 flanges with 2 designs)
10) Converge on background mask geometry
11) Confirm 100 mrad detector-accelerator cone angle
12) Decide on a W, Ta, or Cu background shield around cryostat (1 cm?)

J. Seeman

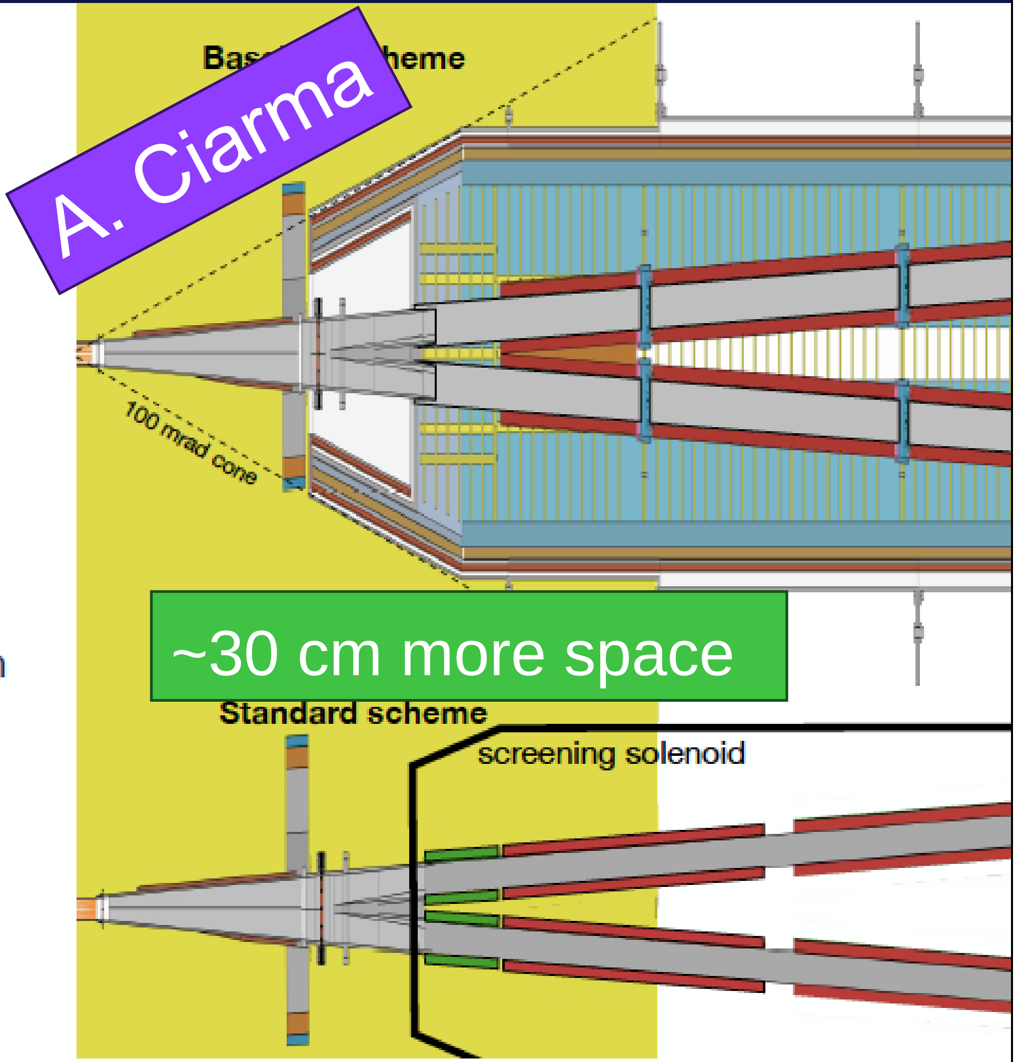
Standard Solenoid Compensation Scheme

A compensation scheme similar to that used in DAΦNE would allow for the **removal of the -5T Compensating Solenoid**

- reduced Synchrotron Radiation (now 80kW)
- avoid R&D challenges of a 5T magnet
- overall simplification of hardware requirements

Compensation is mainly achieved by **weak correctors** in the IR and **skew components** winded around the Final Focus quadrupoles.

The **Screening Solenoid** is preserved and will start as close as possible to the IP, according to mechanical constraints (bellows, flanges, acceptance, …)



Vertical emittance growth $\varepsilon_y = 0.039\ pm\ rad$ (compared to ~0.3 of the baseline)

BEAM DYNAMICS, BACKGROUNDS AND OPTICS

Background overview

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M. Boscolo Monday plenary

IP backgrounds

Mostly unavoidable and proportional to the luminosity, only the multiturn losses can be mitigated with collimators

Radiative Bhabha *BBBrem/GuineaPig & SAD/MADX*

- multiturn tracking of spent beam
- characterization of photons produced at IP

First studied with SAD (CDR), ongoing effort to implement it in Xsuite.
Partial results also with baseline lattice

Beamstrahlung *GuineaPig /BBWS & SAD/MADX*

- multiturn tracking of spent beam
- characterization of photons
  - collinear with the core beam→ BS photon dump

Ongoing effort to implement it in Xsuite
Studied with baseline lattice

see talks by P. Kicsiny & A. Abramov

- e^+e^- **pairs** *GuineaPig, G4 into detector (CDR & baseline lattice)*
  - **Coherent** Pairs Creation: **Negligible**
    Photon interaction with the collective field of the opposite bunch, strongly focused on the forward direction
  - **Incoherent** Pairs Creation: **Dominant** (real or virtual photon scattering)
- **γγ to hadrons** combination of *GuineaPig and Phythia, G4*
  Small effect (Direct production of hadrons, or indirect, where one or both photons interact hadronically)

Study performed for the CDR & with baseline lattice

Being synchronous with the interaction, can be discriminated a

Single Beam particles effects

- Synchrotron Radiation
  - main driver of the IR design, studied with various tools, approaches, for all the optics
  - SR collimators and masks implemented, effect of non-Gaussian tails on the mask tip & effect during top-up injection studied
- Inelastic/ Elastic beam-gas scattering
  - Only first studies done for the CDR.
  - Pressure maps (all ring and MDI region) now available for the baseline lattice.
  - Ongoing effort to implement it in Xsuite for multiturn tracking and loss maps, and eventually determine collimators in the upstream MDI regions.
  - Beam-gas background produced in the IR and its impact to detector: planned with Fluka, now working on the MDI model
- Thermal photons
  - Only first studies done for the CDR
  - Ongoing effort to implement it in Xsuite for multiturn tracking and loss maps, and determine collimators in the upstream MDI regions.
- Touschek
  - Expected not to be relevant due to high beam energy, but to be studied, especially at the Z-pole, due to the dense beam (high bunch current and low emittance)

see talk A. Abramov
see talk K. Andre
see talk R. Kersevan
see talk A. Frasca

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Ongoing effort to implement it in Xsuite

Studied with baseline lattice

see talks by P. Kicsiny & A. Abramov

  - e^+e^- pairs *GuineaPig, G4 into detector (CDR & baseline lattice)*
    - **Coherent** Pairs Creation: **Negligible** Photon interaction with the collective field of the opposite bunch, strongly focused on the forward direction
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  - **$\gamma\gamma$ to hadrons** combination of *GuineaPig and Phythia, G4* **Small effect** (Direct production of hadrons, or indirect, where one or both photons interact hadronically)

Study performed for the CDR & with baseline lattice

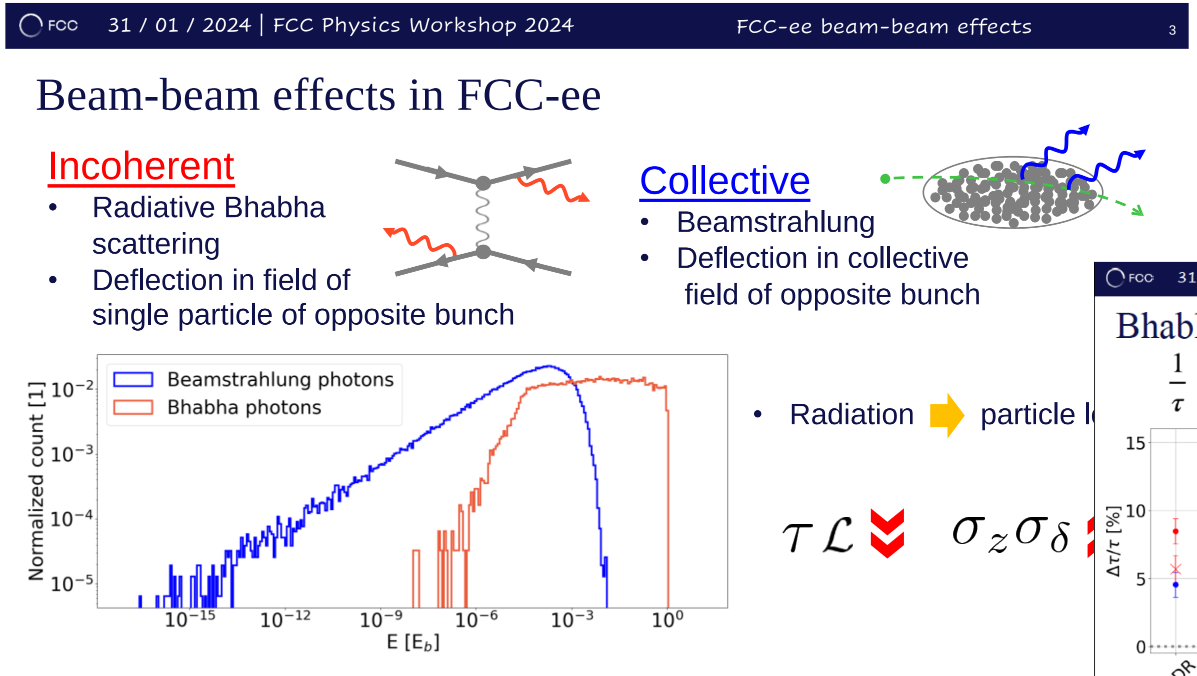
Being synchronous with the interaction, can be discriminated at trigger level

Beam-beam simulation

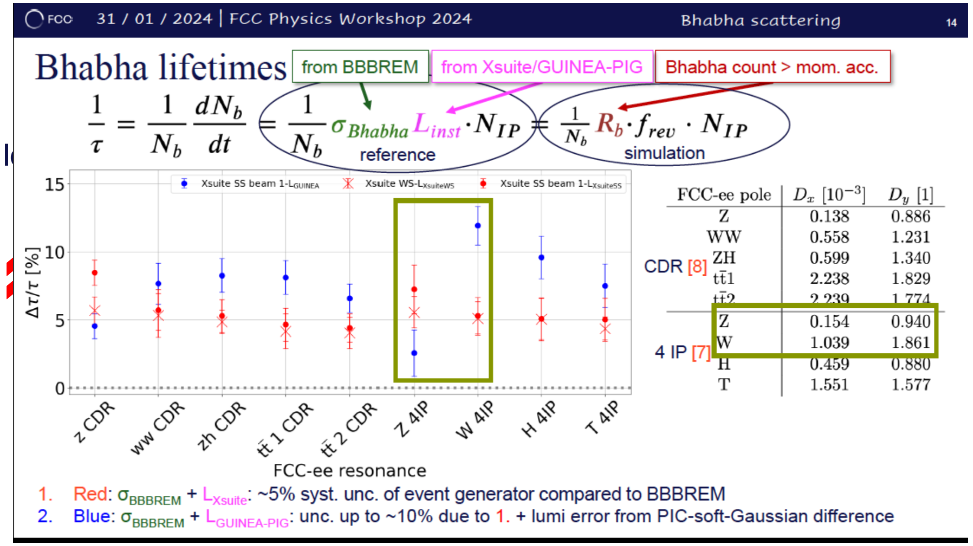
Beam—beam interaction is now ported in Xsuite (code)

- Reproduced the so-called “flip-flop” beam instability observed in other colliders
- Reproduced beam lifetime

- The code can be used now for other studies related to backgrounds and collimation studies



P. Kicsiny

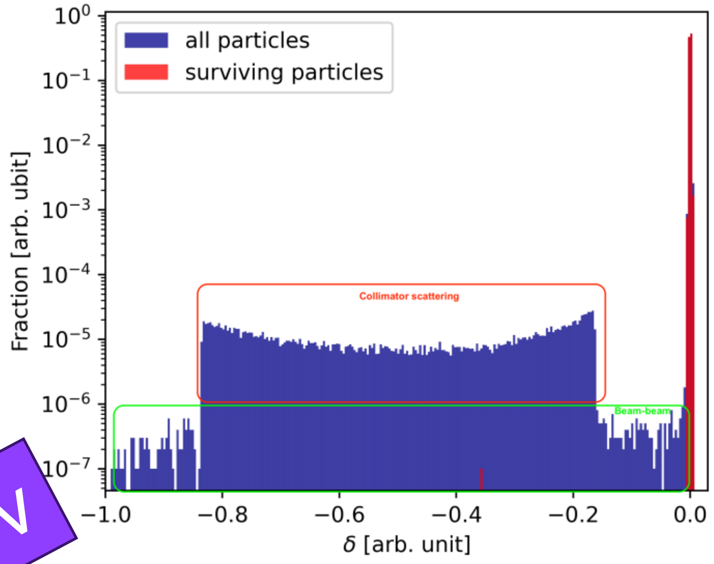


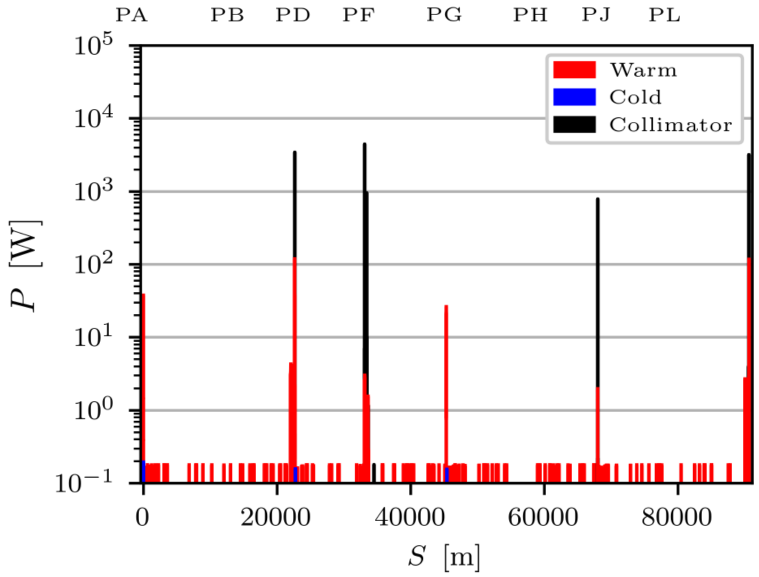
FCC-ee Z-mode spent beam losses

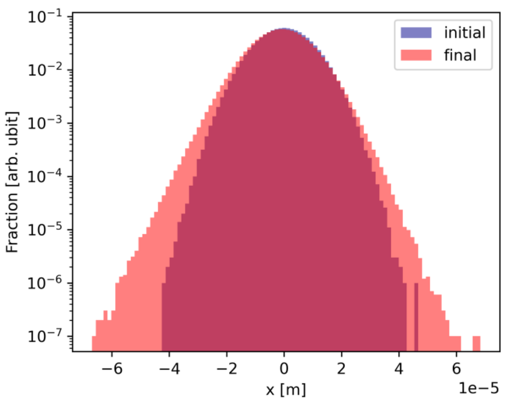
- **Study for the first time collimation with beam-beam integrated**
  - Full non-linear lattice, crab-waist, detailed aperture and collimator models, radiation and tapering, weak-strong beam-beam, Beamstrahlung, and Bhabha scattering in 4 IPs

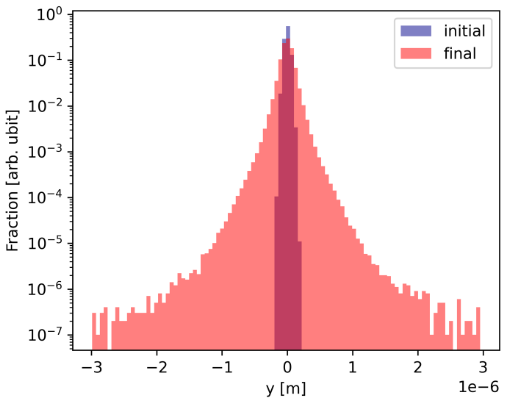
- **Initial run carried out:**
  - High losses on SR collimators observed due to an unexpected vertical blow-up
  - Detailed investigation ongoing
  - Demonstrated the technical feasibility of integrated studies

A. Abramov









FCC-ee collimation summary

- **Studies of IR beam losses and collimation for the FCC-ee**
  - The collimation system design is available, including beam halo and SR collimators
    - Adapted to the latest layout and lattice baseline, new collimation optics implemented
  - Crucial beam loss scenarios identified, with studies ongoing:
    - Beam halo losses studied for the most critical *Z* mode, no show-stoppers identified
      - Improved collimation performance with respect to the previous baseline
      - Ongoing collaboration with the MDI, impedance, engineering, FLUKA studies team
    - First integrated beam-beam and collimation studies
      - Preliminary results available, but further studies are required

A. Abramov

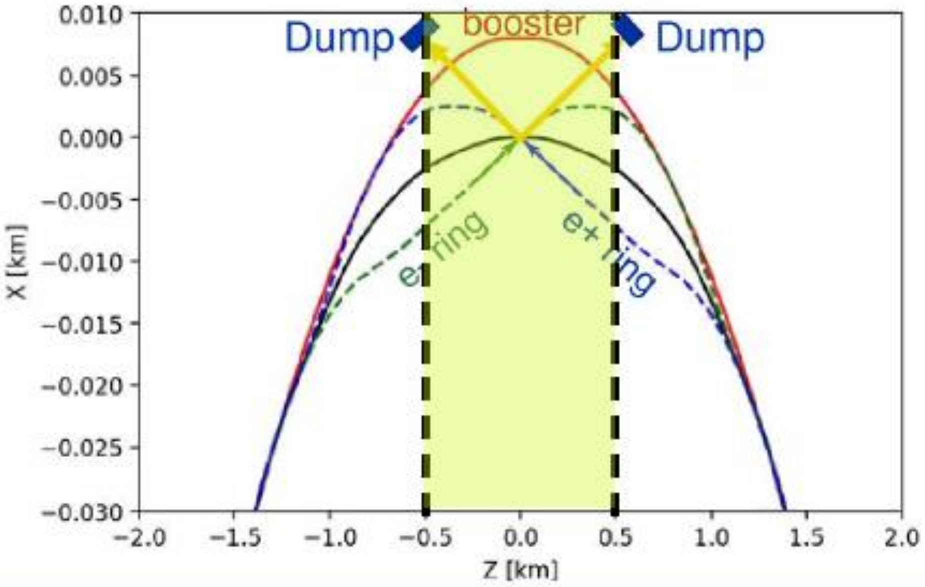
- **Next steps**
  - Study other beam loss scenarios – top-up injection, beam-gas, failure scenarios
  - Obtain input for the equipment loss tolerances – superconducting magnets, collimators, other
    - Energy deposition studies required for magnets, collimators, and mas[k]s
    - Tolerance of the detectors to backgrounds required ← Need input from PED experts
  - Study all beam modes

Results and prospects of FLUKA studies of the FCC-ee IR

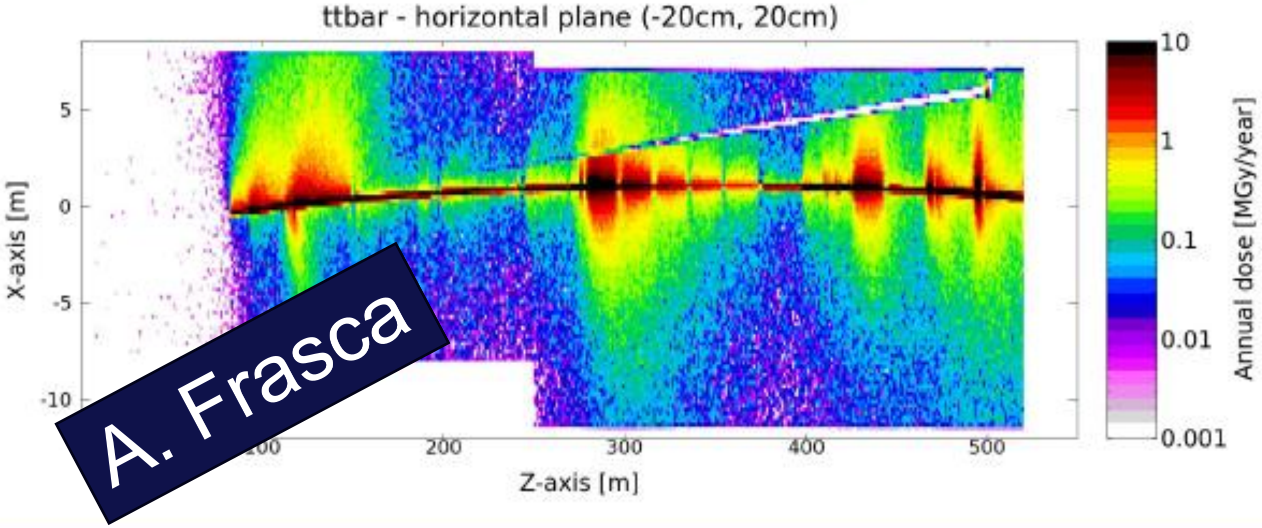
RESULTS

FLUKA model to estimate the **power deposition** and **radiation levels** in the tunnel within ±500 m from the IP

- beamstrahlung dump
- synchrotron radiation outgoing from the IP (no SR absorbers included)



ANNUAL DOSE FROM SR @ttbar



PROSPECTS

Focus on final focusing quadrupoles and on detector (±10 m from the IP):

- power deposition and dose in FFQ
- radiation damage to the detector through dose and 1 MeV neutron-equivalent fluence in Si

Low Chromatic Correction arc and FF (P. Raimondi – K. Andrè)

Alternative to the baseline optics

Main benefits:
- Larger dynamic aperture
- Largest beam stay clear and lower losses
- No need for super conducting crab sextupoles
- See S. Liuzzo plenary talk for testing the robustness against baseline

Summary (1)

SLAC

- The LCCO beam dynamics is extremely well understood and optimized
- The understanding of the quads SR on beam dynamics has lead to unprecedented means to mitigate the related DA deterioration. This will be potentially even more beneficial to the higher energies operation.
- DA/MA exceeds the baseline.
- There is only one very well identified aberrations that makes the CS detrimental to the DA. The reduction of this effect seems possible.
- Hardware requirements for LCCO are much less demanding and are being assessed (as requested by G. Roy)

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Summary (2)

SLAC

- LCCO includes all the know-how and experience acquired in designing, building, commissioning and operating most of the high-energy and high-luminosity linear and circular colliders that have been operating in the past 30 years.
- Many innovative solutions developed in the very active (and forefront) Synchrotron Radiation Accelerator community are utilized as well
- LCCO hardware requirements are in line with standard (and cheap) solutions adopted for most of the colliders built so far
- LCCO is an invaluable opportunity to further progress in Accelerator Physics and push forward the frontier of High Energy Science

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Vibration studies

Define vibration tolerances of magnets in the MDI

- Model implemented
- First studies with plane ground wave
- Next studies with realistic wave models

First conclusions and outlook

- Investigation of the effect of a plane ground wave on the whole FCC-ee accelerator
  - Photography of the misalignments taken, no tracking yet
- MAD-X simulations and the analytical method are giving the same results
  - Checks done to establish the reliability of the method
- The analytical method can be used as a fast scanner
- Flexible, adaptable and tunable study, to highlight:
  - The Machine Detector Interface
  - But as well, other parts of the accelerator, such as the arc-cells

Perspectives:

- Parametric study to test the influence of all definition parameters (inclination, phase advance)
- Comparison with other FCC-ee lattices (V23, LCCO)
- Towards more realistic waves models:
  - Injection of coherence measurements made at other accelerators (SuperKEKB,…)
  - Wave speed(s) definition

Summary

K. Andrè

- The BDSIM model features a Ø60mm beam pipe with horizontal wing[illegible]e the final focus region, impacts the SR flux reaching the SR collimators and masks.
- Simulations with beam core and transverse tail have been performed **at Z and tt energies** for the **V23-baseline and LCCO lattices** with equivalent power deposition in the vicinity of the particle detector,
  - **LCCO-V23** shows better results regarding the SR from the transverse tail but needs more collimation to mitigate the SR from the beam core **(especially in the mask)**
  - **Baseline-V23** shows better results regarding the SR from the beam core because the SR collimation is more effective (and mature) but the SR from the transverse tail causes more power deposition close to the IP.

Future plans:

➢ Investigate the x-ray reflection in the GEANT4 model see details in [5],

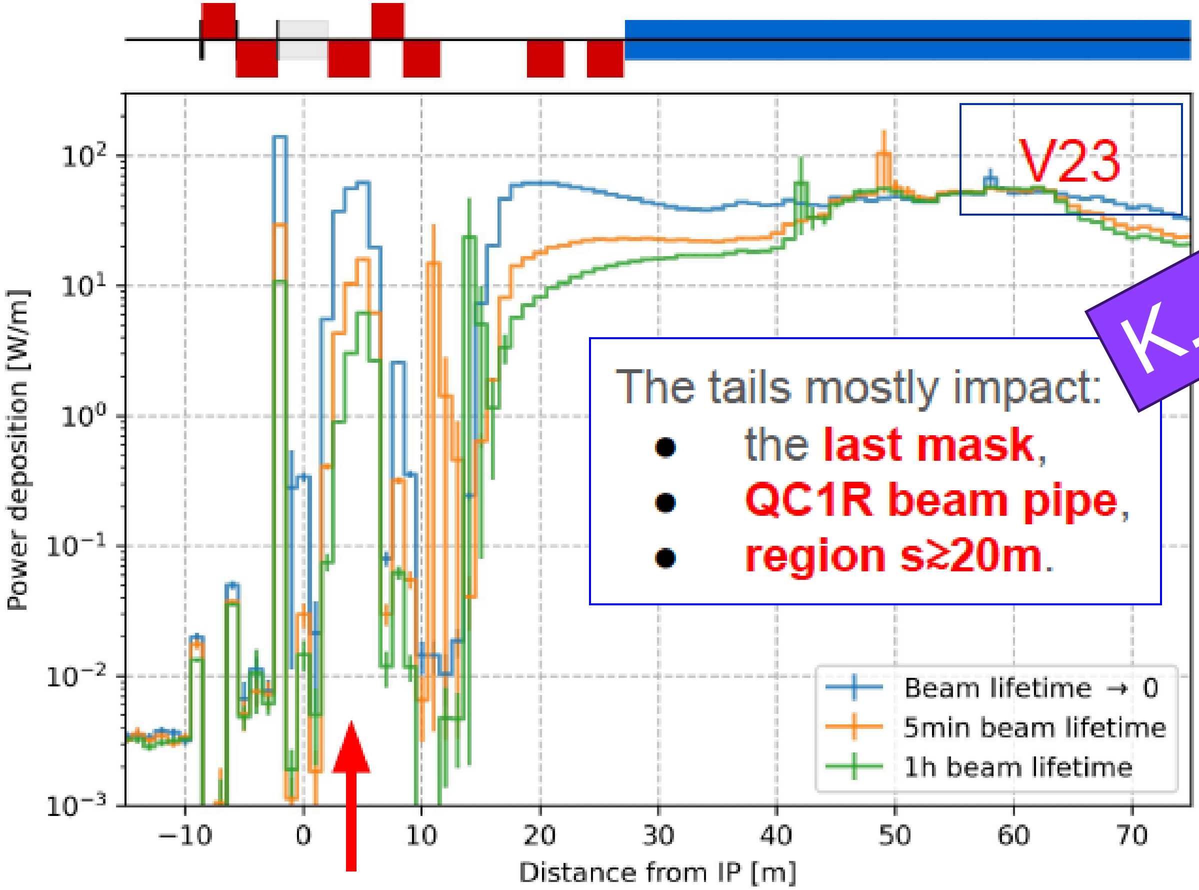
➢ Compare the two solenoid compensation schemes, see A. Ciarma's slide.

➢ Top-up injection must be studied for the V23 lattice and optics design, investigate the effects of some imperfections such as optics mismatch, emittance blowup, etc..

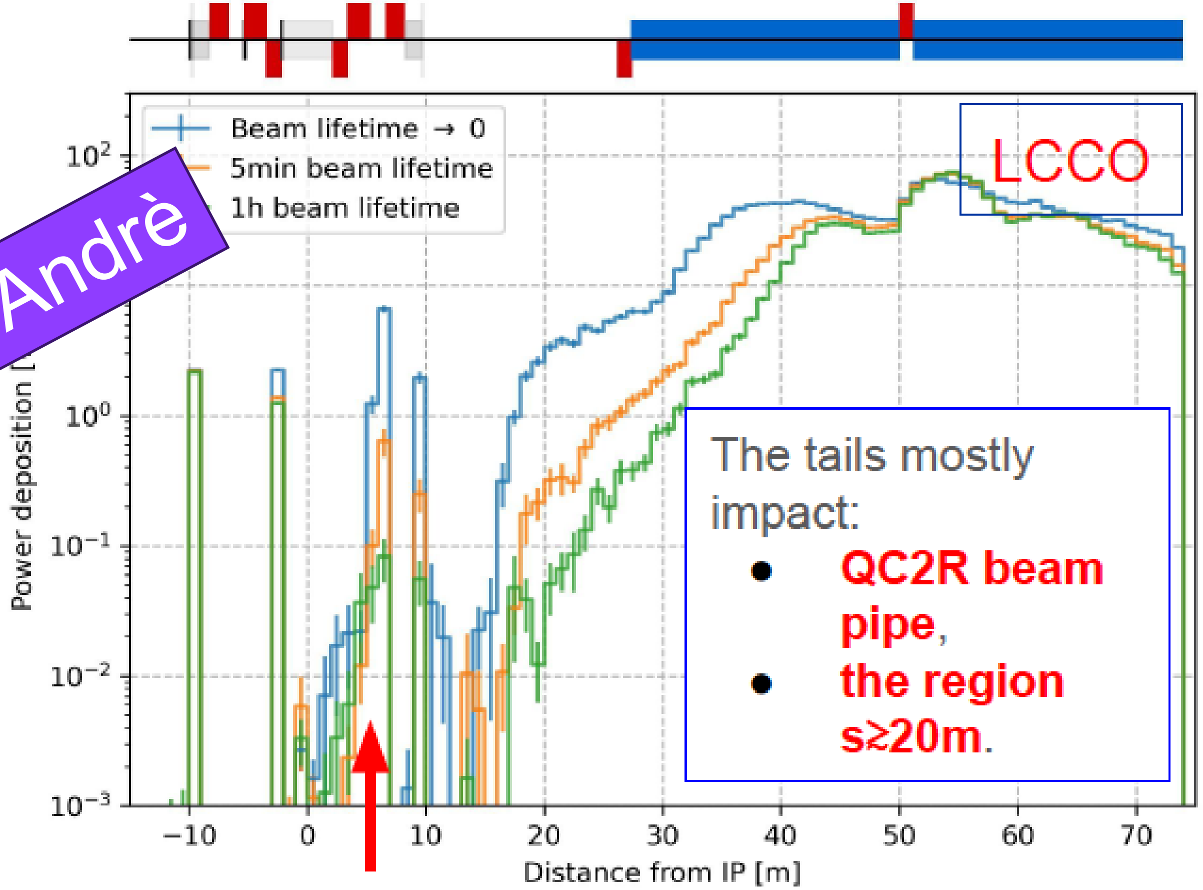
Transverse halo impact with beam lifetime @ Z energy

The transverse tails extend until the primary collimator apertures: 11σ /65σ. The "beam lifetime → 0" correspo[...]ne "5min beam lifetime" is considered in the collimation studies, see A. Abramov's slides. 1h beam lifetime is given as point of comparison.

Better performance for LCCO due to lower tails

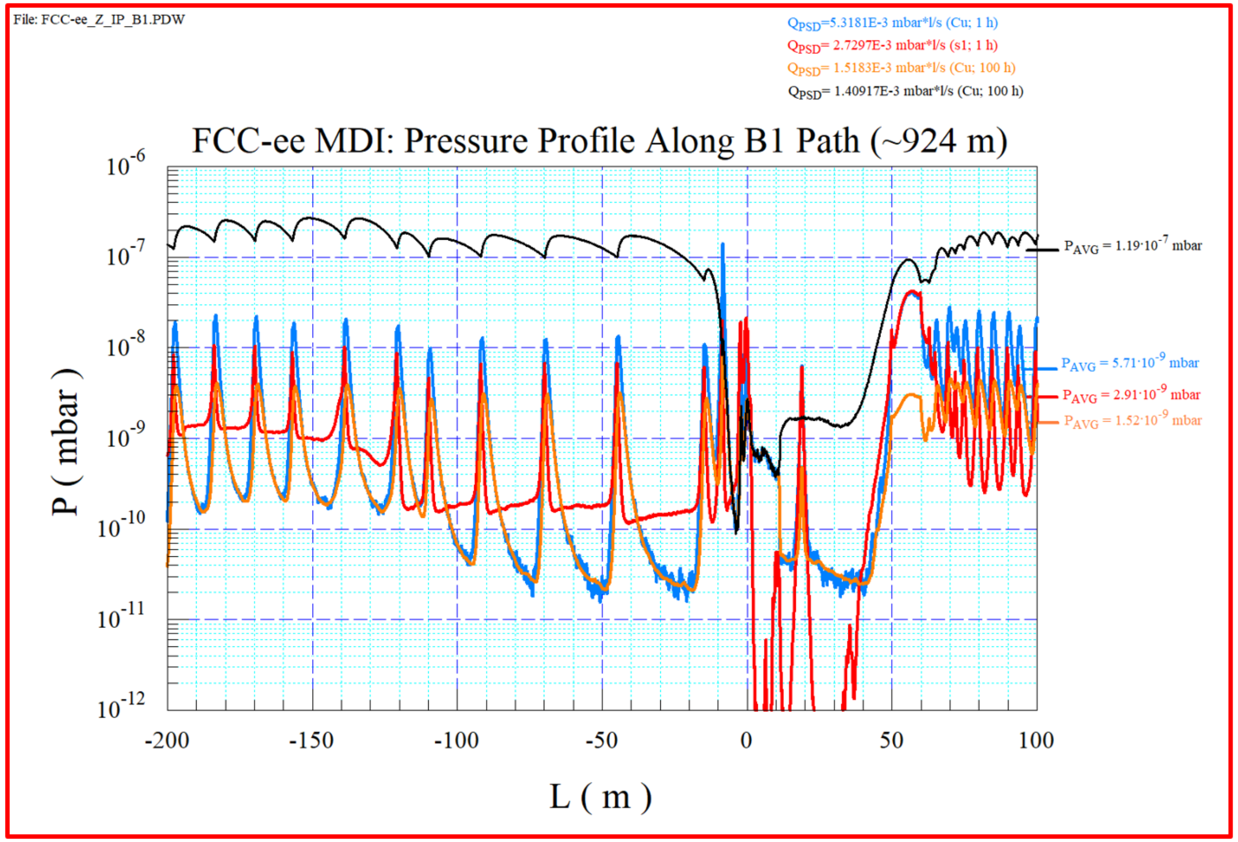


K. Andrè



Vacuum system

R. Kersevan



end up, namely the photon beam dump downstream of the IP, for each of the two beams;

- One conclusion is that we need to have NEG-coated chambers in the IP area too, not just in the arcs (see slide p.47);
- **Outstanding vacuum issues:**
  1. identification of (possibly) two areas where lumped NEG pumps could be placed, as close as possible to the IP: right now there is no space for them, due to space constraints in addition to luminometer no-go areas (keeping high-Z materials outside of the luminomenter collection cones);
  2. Analysis/simulation of the possible saturation of the NEG-coating in the IP chambers, due to 2-beams in the same chamber and high beam currents (esp. at Z energy), with reference to no.1.

We have a plan ...

Conclusion -- Progress & plans on key aspects of the MDI design

- IR magnet system & Cryostats
  - FF Quads & Correctors
  - Solenoid comp. scheme & anti-solenoid design
- IR Mechanical model, including vertex and lumical integration, and assembly concept
  - Services (i.e. air & water cooling for vertex and vacuum chambers) and cables
  - Anchoring to the detector
  - Accessibility & Maintenance
  - Vacuum connection
  - IR BPMs
  - Integrate in the design an alignment system
- Beam induced backgrounds
  - The MDI region is now improved as more realistic, and software model developed.
  - Single beam effects being implemented in Xsuite, and additional collimators might be needed. Halo beam collimators have been added.
  - SR backgrounds studied in different conditions and beasline/LCCO optics compare
  - Study of IR radiation level & fluences started (Fluka)
  - Optimization of shielding will follow
  - Beamstrahlung dump with radiation levels
- Heat Loads from wakefields in IR region
  - In progress

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THANKS FOR YOUR ATTENTION