Detector Concept Highlights

A Personal Selection

7. FCC PED Week Annecy

Jan 29 - Feb 2, 2024

Mogens Dam, Marc-André Pleier, Felix Sefkow*

* Put all the blame here.

Menu

Sequence of Courses

2 Mixed Sessions:

- with MDI
- with Software
- some overlap inevitable and actually intended

3 Detector-Detector sessions:

- Calorimeters
- Tracking and vertexing
- TDAQ

Menu:

- Concepts
- TDAQ
- Tracking
- Calo

Detector Concepts

In a Nutshell

Detector concepts form the link between performance requirements and technological capabilities

- thus **guide the R&D** and give **feedback on performance** impact of technical solutions

Two main ingredients:

- a full **simulation** model
  - enable validation of single particle performance with prototypes
  - realistic prediction of full-event performance: will also need higher-level reconstruction tools
- overall **engineering**
  - to act and respond in the design of the MDI
  - to guide the optimisation of the global structure and parameters

Detector R&D Collaborations

News

4.12. First Meeting of the Detector R&D Committee

- Chair Thomas Bergauer
- Reviewed proposals for strategic detector R&D

DRD 1: Gas Detectors approved, but proposals being further reviewed

DRD 2: Liquid Detectors approved, but proposals being further reviewed

DRD 3: Solid Detectors preliminarily approved, to be reviewed again in March 2024

DRD 4: Photon Detectors and Particle ID approved

DRD 6: Calorimeters approved (mainly Higgs factory targeted)

DRD 5 (Quantum), DRD 7 (electronics) and DRD 8 (Integration) come later

Approved proposals are public, e.g. DRD6: **http://cds.cern.ch/record/2886494**

First collaboration kick-off meetings have taken place or have been announced

Next step: preparation of MoU to plan deliverable contributions & funding

Link of DRDs to Future Collider projects important and will be followed up by (DRDC and) EDP

- Chair Didier Contardo

Detector R&D Collaborations

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D. Contardo, Jan 24

- MoUs will be updated every 3 years
  - based on R&D success reviewed by the DRDC and with the ECFA Detector Panel (EDP) providing input on the evolution of specifications and timelines given by the project concept groups
    - with this purpose concept group liaisons can be formally identified*
    - a first light iteration of inputs could happen on the timescale of initial MoUs
    - with a second deeper update by the following DRD programme cycle and the next ESPP update
      - simulation in project concept groups are essential to identify most critical R&D parameters
    - the ECFA WG3 on detector R&D could provide the forum to discuss these inputs in the community

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Link of DRDs to Future Collider projects important and will be followed up by (DRDC and) EDP

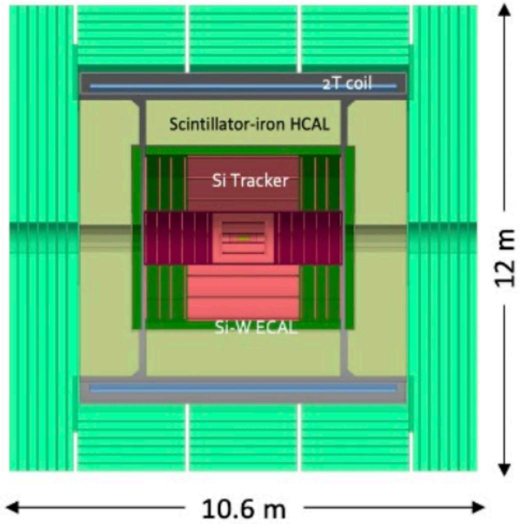
- Chair Didier Contardo

Concepts

FCCee Detector Concepts

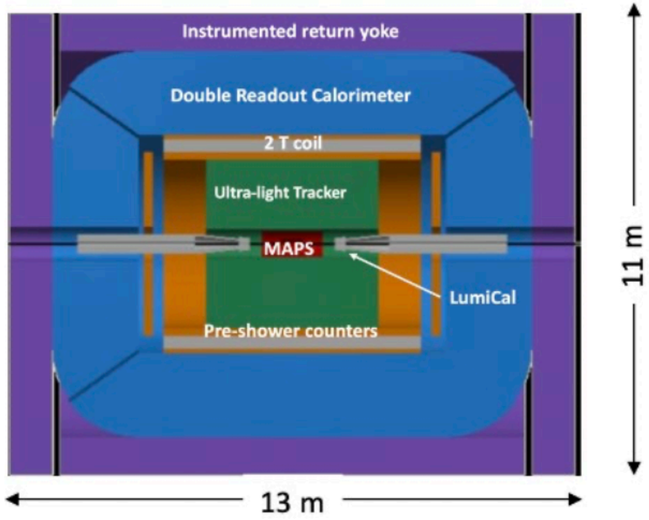
Defined by Calorimetry

CLD



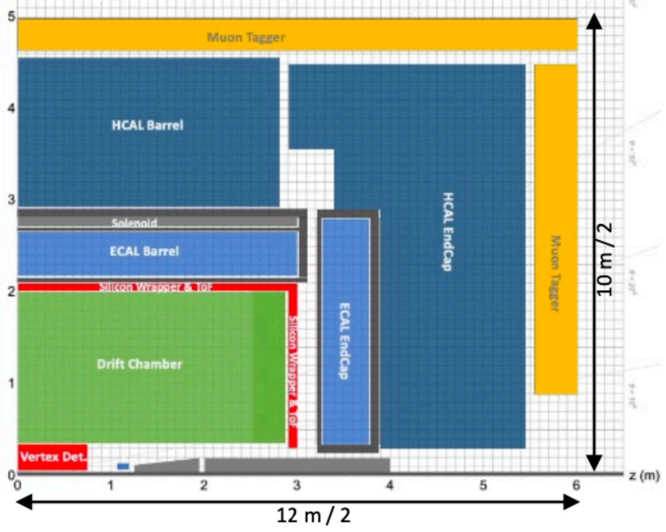
- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?

IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber with powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

ALLEGRO

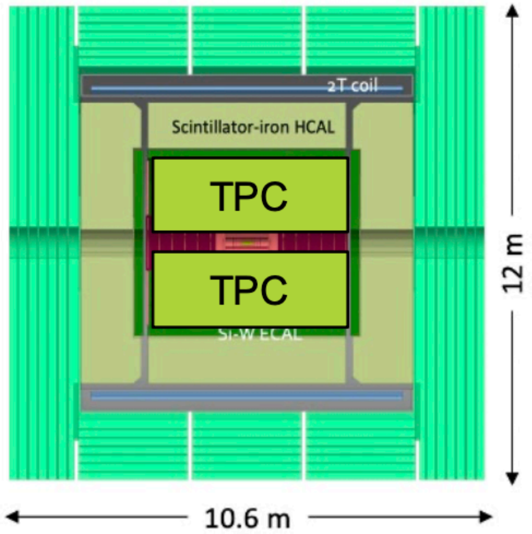


- The "new kid on the block"
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

FCCee Detector Concepts

Defined by Calorimetry

CLD/ILD’



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker, study TPC option viability
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
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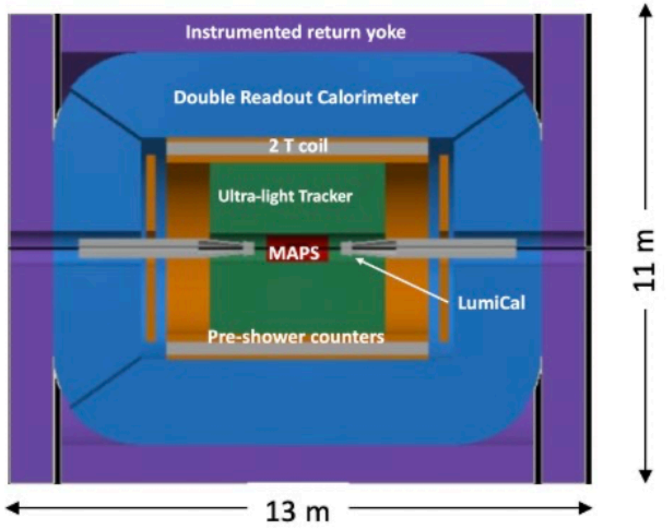

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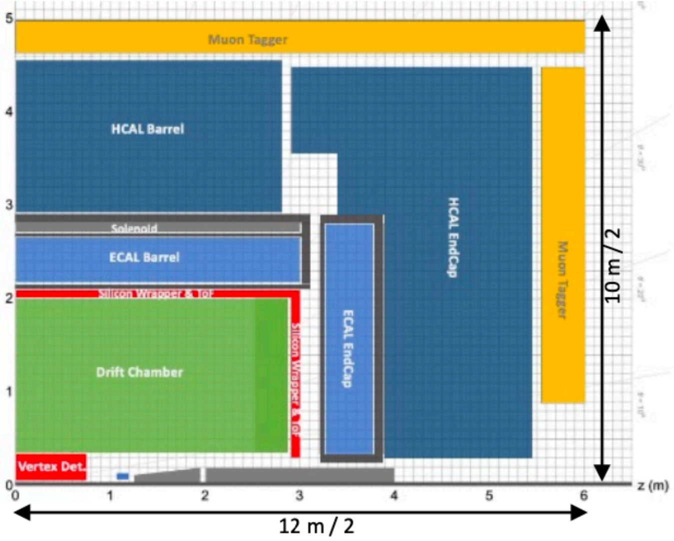

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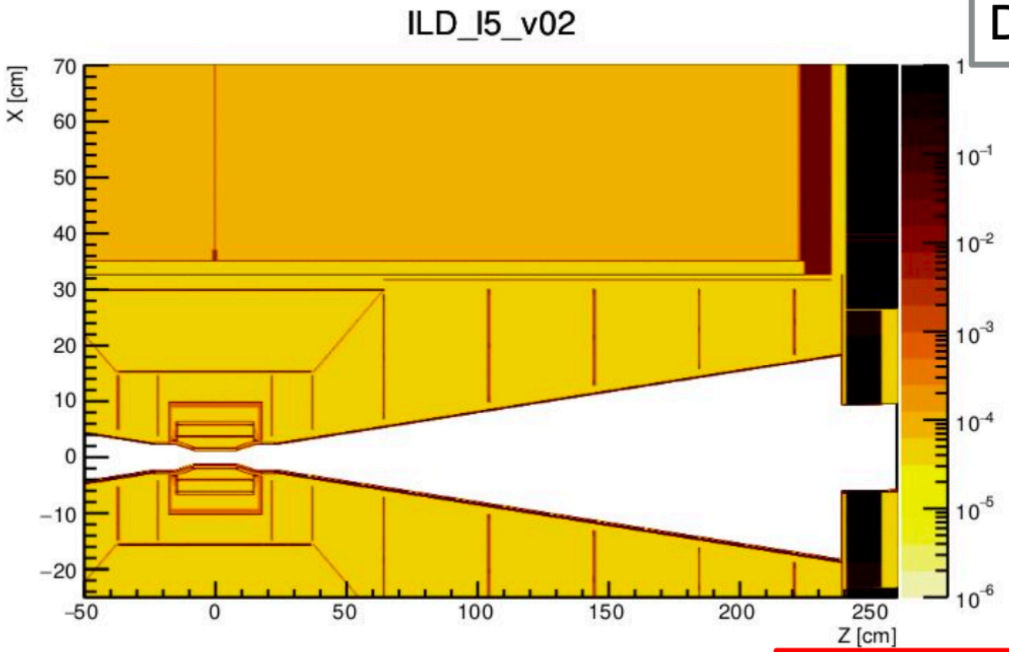
ILD and FCCee MDI

Reconfiguring ILD

	ILC	FCCee
crossing angle	14 mrad	30 mrad
L*	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional fields / components	anti-DID (proposed)	compensating, screening

- Take FCCee MDI from CLD
- Take CLD inner Si tracker layout
  - Squeeze / stretch to fit into available space
- Lower field strength affects backgrounds in VTX and TPC resolution
- **No re-optimization of this configuration yet**
  - Forward tracking, endcap calorimeters, …
  - Review of subdetector layout, material, …

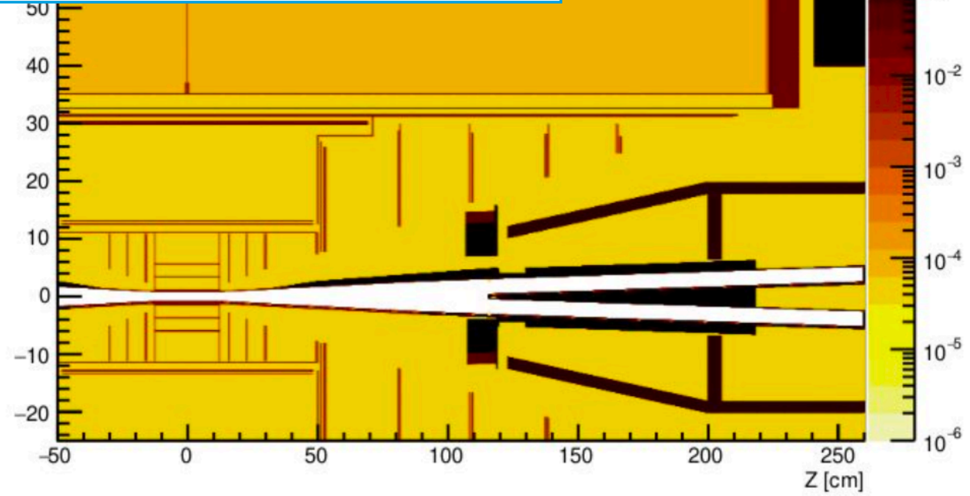
Daniel Jeans



- ILC MDI
- ILD inner tracker

available in k4geo!

CLD inner tracker and MDI
ILD outer tracker
CLD/ILD Calorimeter



- FCCee MDI
- CLD inner tracker

Primary ion density in the TPC

Daniel Jeans

Backgrounds

- GuineaPig for simulating beamstrahlung pairs
  - ILC-250 (ILD/M. Berggren)
  - FCCee-91, FCCee-240 (A. Ciarma)
- Full simulation of different ILD models via ddsim
  - Vary MDI and magnetic fields
  - Special config to correctly track low p_T particles
- Estimate number of **primary ions produced in TPC per BX**
- Estimate **number of primary ions in TPC volume at any time**
  - primary ions/BX * BX freq * max drift time * 0.5
    (some primary ions already @cathode)

PRELIMINARY RESULTS!

model	B-field [T]	MDI	FCCee-91	FCCee-240	ILC-250
			thousand ions / bunch crossing mean ± RMS		
ILD_l5_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300
ILD_l5_v03	3.5 (map)	ILC	5.7 ± 7.9	14 ± 11	1100 ± 200
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6 ± 1.5	3.7 ± 9.7	450 ± 110
ILD_l5_v11β	2.0 (uniform)	FCCee	390 ± 120	1000 ± 170	110000 ± 2400
ILD_l5_v11γ	2.0 (map)	FCCee	270 ± 100	800 ± 140	100000 ± 1900

ILC and FCCee similar: O(100k) - O(1M) primary ions / BX

Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	1.8×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.8	0.54	0.0025

primary ion density in TPC (wrt ILC): x2500 @FCCee-91
x200 @FCCee-240

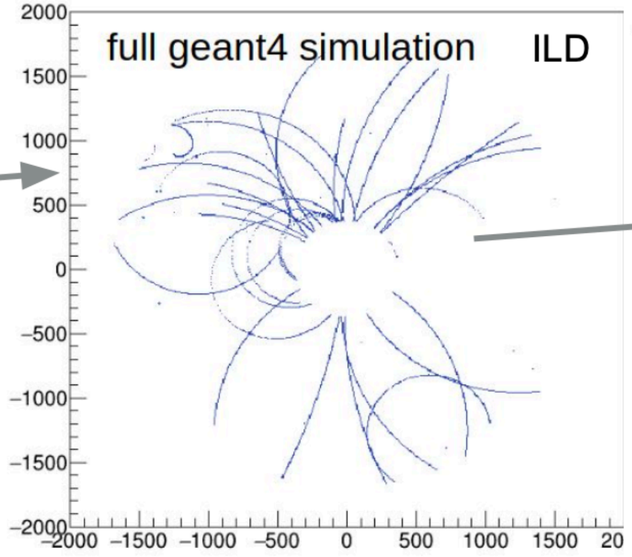
Estimating distortions in the TPC

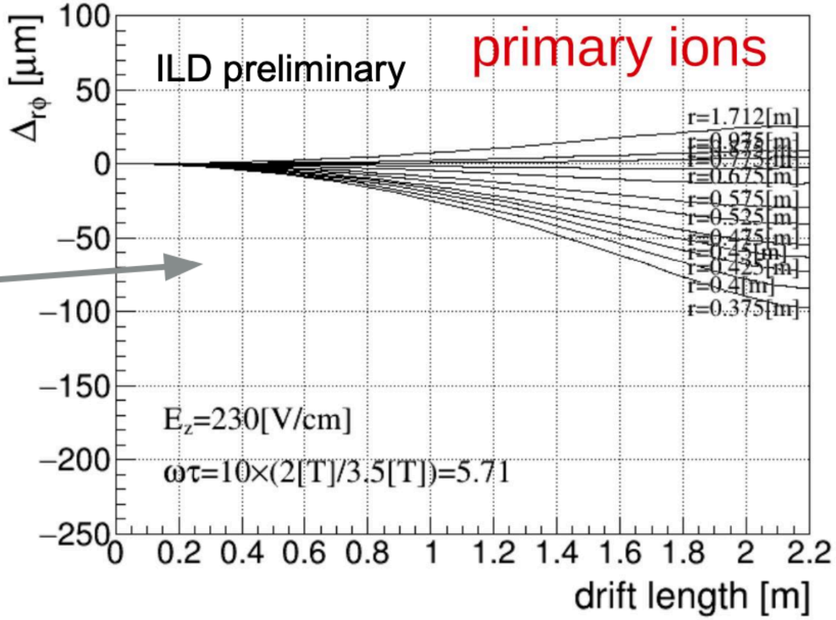
PRELIMINARY RESULTS!

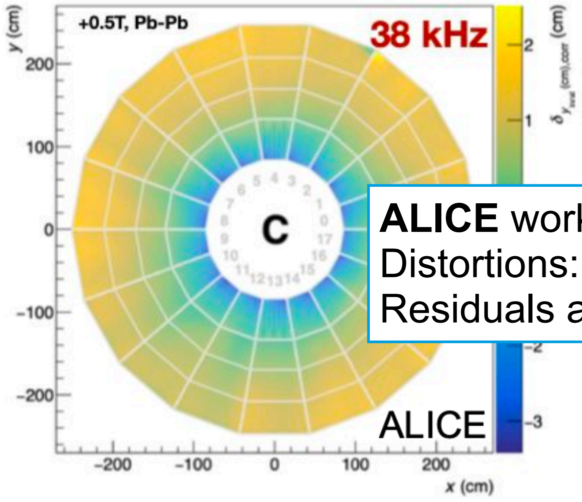
Daniel Jeans

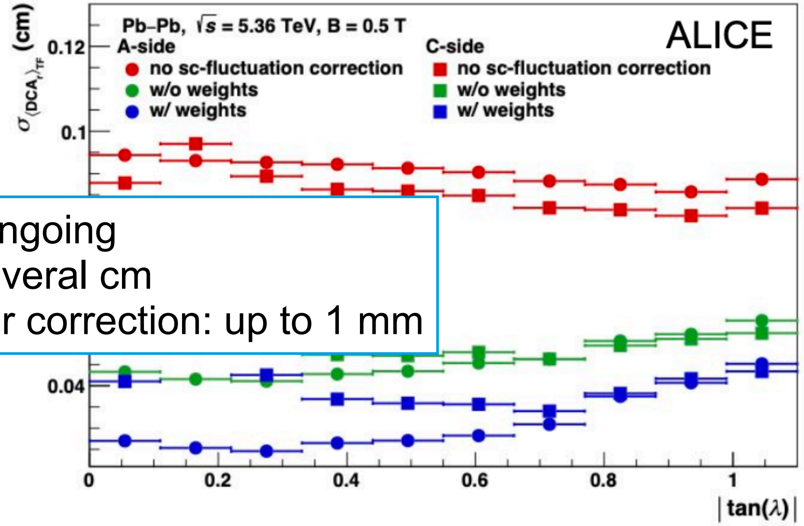
Preliminary studies

- Physics events with high activity:
  ee → qq @91 GeV
  - ~1M primary ions / event
  - ~10^{10} primary ions from physics in TPC at any time (c.f. 2×10^{12} from beamstrahlung)
- Primary ions with drift distortions in rφ of ~100 μm (physics only)
  - Naive scaling: expect max distortions ~20 mm
- ALICE TPC (Run3):
  - 20-120 fC/cm^3 → cm-level distortions
  - Consistent with our "first principles" estimate
- **Data driven corrections are possible but achievable performance needs studies**
  - Uncertainties after corrections?









ALICE work ongoing
Distortions: several cm
Residuals after correction: up to 1 mm

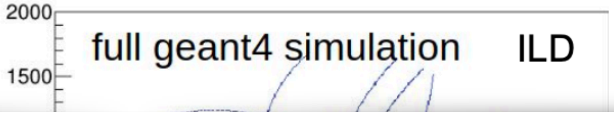
Matthias Kleiner - Goethe-Universität Frankfurt

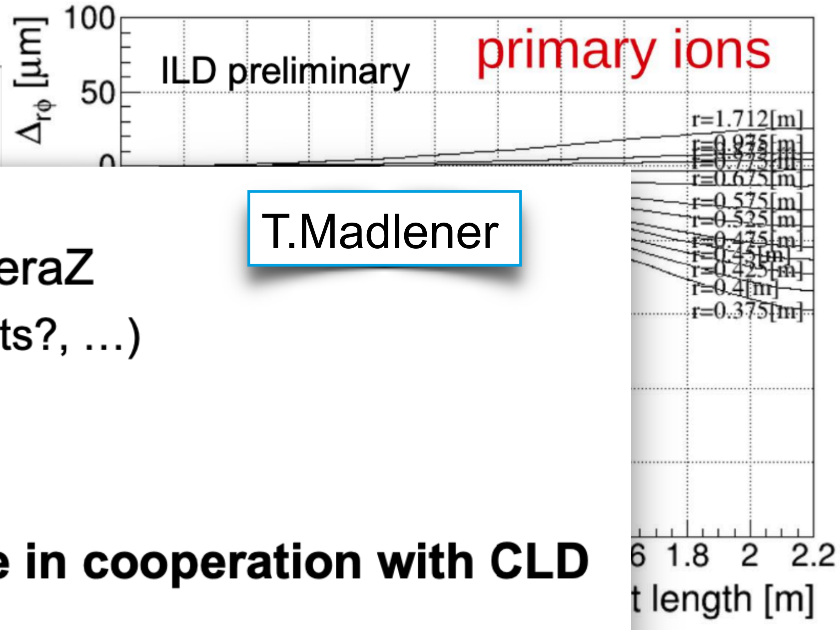
Estimating distortions in the TPC

PRELIMINARY RESULTS!

Daniel Jeans

Preliminary studies





Future plans

T.Madlener

- Optimize and study in more detail the possibilities of a TPC also at TeraZ
  - Mitigation strategies for drift distortions (corrections, redesign MDI elements?, …)
  - Stability of distortions wrt time, operating conditions, …
  - Effect on overall tracking performance (including inner Si tracker)
- **Further studies towards a particle flow driven detector at FCCee in cooperation with CLD**
  - Gas or silicon tracking

- ALICE TPC (Run3):
  - 20-120 fC/cm^3 → cm-level distortions
  - Consistent with our "first principles" estimate
- **Data driven corrections are possible but achievable performance needs studies**
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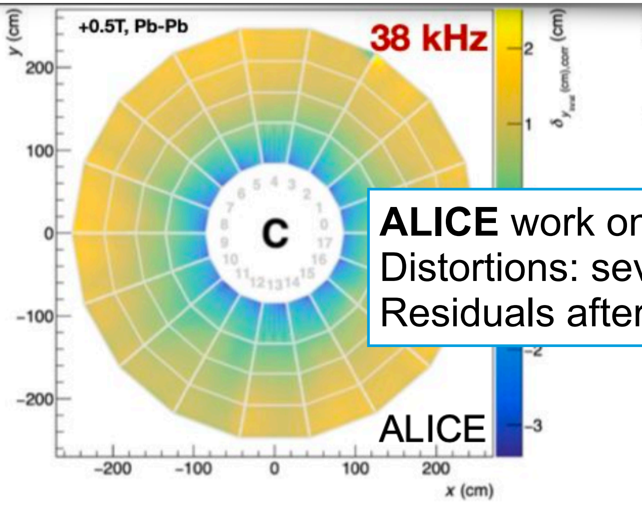

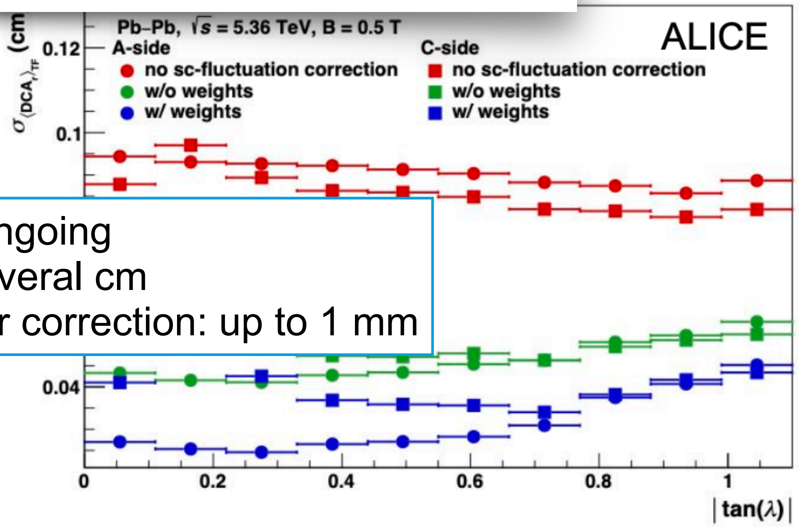

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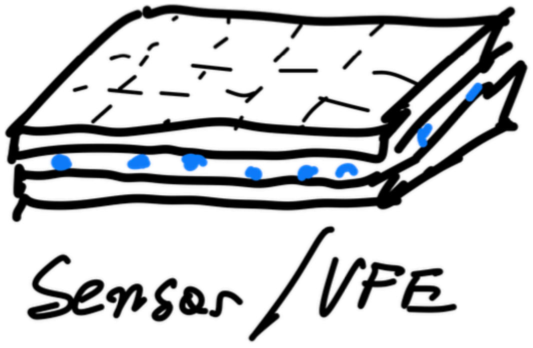
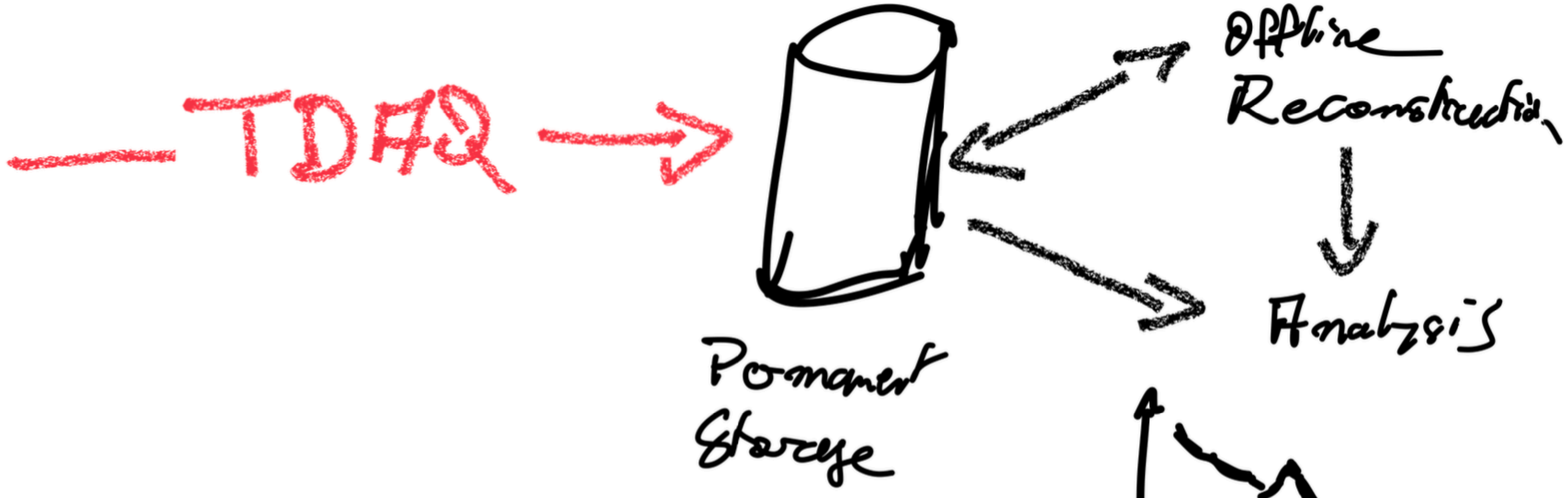
Concepts: TDAQ

Detector Readout

In Perspective





Why care?

Electronics specs drive many aspects of detector design

- data bandwidth and data concentration, power and cooling needs
- space requirements, material budgets, compactness

Pivotal role in overall system design!

A better readout system gives you better physics reach: Statistics, precision, …

Readout Concept & Technology

Fundamental for overall Experiment Design

- Important to address central items early:

  Do we need a trigger?

  - If some detectors need an explicit trigger all relevant systems have to be read out with sufficient speed, processing with sufficiently low latency is required, and specific trigger data paths have to be foreseen.
    - What buffer depths / latencies are required / acceptable?
      Requirements imposed by signal formation time in subsystems?

  What form will the online data reduction chain (trigger in a wider sense, selective readout) take?

  - The need and appetite for upstream data reduction.

  Where can commercial-off-the-shelf components be used?

  - Where does it make sense to use them - where not?
  - What level of radiation tolerance is required where in the system?

  Which new technologies will be adopted?

  - 4D / 5D readout,…
  - Is fundamental R&D required, or should the focus be on scale and implementation?
  - What can new COTS hardware provide? Think FPGAs with integrated AI, …

Introduction: how to compute expected rates ?

rate(r, Θ, detector) = Σ (process rate × occupancy × data/cell)

- Physics events (Z)
- Backgrounds
  - IP backgrounds
  - Single beam effects

Physics process	Rate (kHz)
Z decays	100
$\gamma\gamma \rightarrow$ hadrons	30
Bhabha	50
Beam background	20
Total	~ 200

2111.04168

- Need full simulation
  - Including precise description of MDI
- Integration time of detectors
- Reasonable choice of zero-suppression thresholds

- Number of bytes needed
  - Very detector-dependent

Silicon data volume

- Pixels to read out for ARCADIA L1 (15 staves x 6 modules x **2 chips x 640 x256 pixels**)

Z	WW	ZH	tt		
7.6	2.7	1.1	0.5	$x10^3$	in 10 μsec window/2-chip module
23.2	91.8	133.5	380.6		per bunch crossing/2-chip modeule

- Assuming 32 bits/pixel including time stamp/2-chip module

24.4	8.5	3.5	1.6	Gbit/s	Not triggered	
149	N/A	N/A	N/A	Mbit/s	triggered	**200 kHz trigger rate**

  - Total layer 1:
    - 2.2 Tbit/sec (NoTrigger) → 13.4 Gbit/sec (Triggered) at Z pole → port card transmission needs 1.1 Tbit or 7 Gbit/s/side
- Other layers and disks have lower data volumes
  - Layer 2 has ~10x less data volume

Current ARCADIA

- Max readout speed achievable on chip **100** - 200 MHz x 32 bits? → **3.2** - 6.4 Gbit/sec

Untriggered operation looks difficult

DR calorimeter DCR

- Assumptions:
  - 200 kHz DCR /SiPM
  - 250 nsec integration time
  - Mean number of counts/SiPM $\mu = 0.05$
    - Prob. >= 1 pe = $1-\exp(-\mu)$ = 4.9 % → 6.4 M/ev x 100 kHz x 16 = 10.2 TB/s
    - Prob. >= 2 pe = $1-\exp(-\mu)(1+\mu)$ = 0.12 % → 156 k/ev « = 250 GB/s
    - Prob. >= 3 pe = $1-\exp(-\mu)(1+\mu+\mu^2/2)$ = 0.002 % → 2.6 k/ev « = 4.2 GB/s
    - Threshold at 2.5 pe used during recent test beams
- Dark count could be a problem
  - Thresholds and additional suppressions to be optmized (e.g. isolation, timing, ….)

TDAQ Next Steps

Detector Concepts and DRD7

Triggered (!) a lot of interest

- a lot to be learnt from present or near-term planned experiments

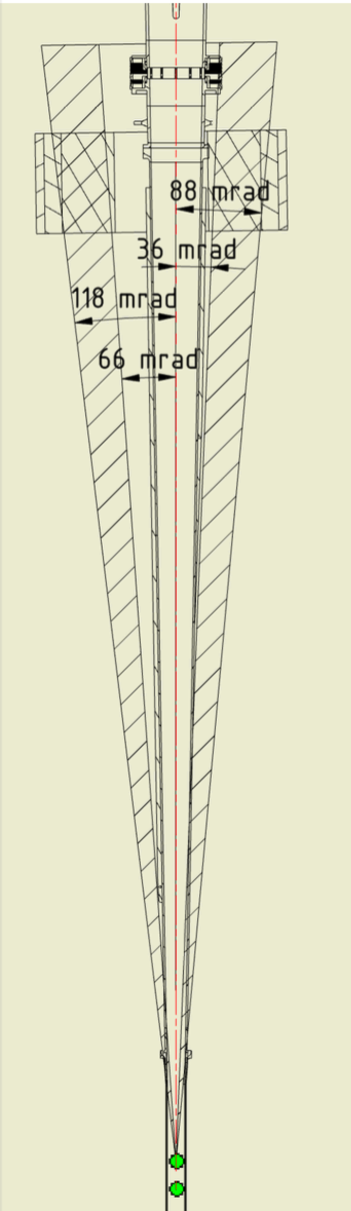
Follow up

- complete the picture for triggered and untriggered read-out scenarios
- many things look well feasible in relation to LHC capabilities
- translate bandwidth needs into power, cooling, material, space requirements
  - study impact on design and performance
- take a closer look on “role models” and their limitations
  - Belle, LHCb, ALICE

LumiCal

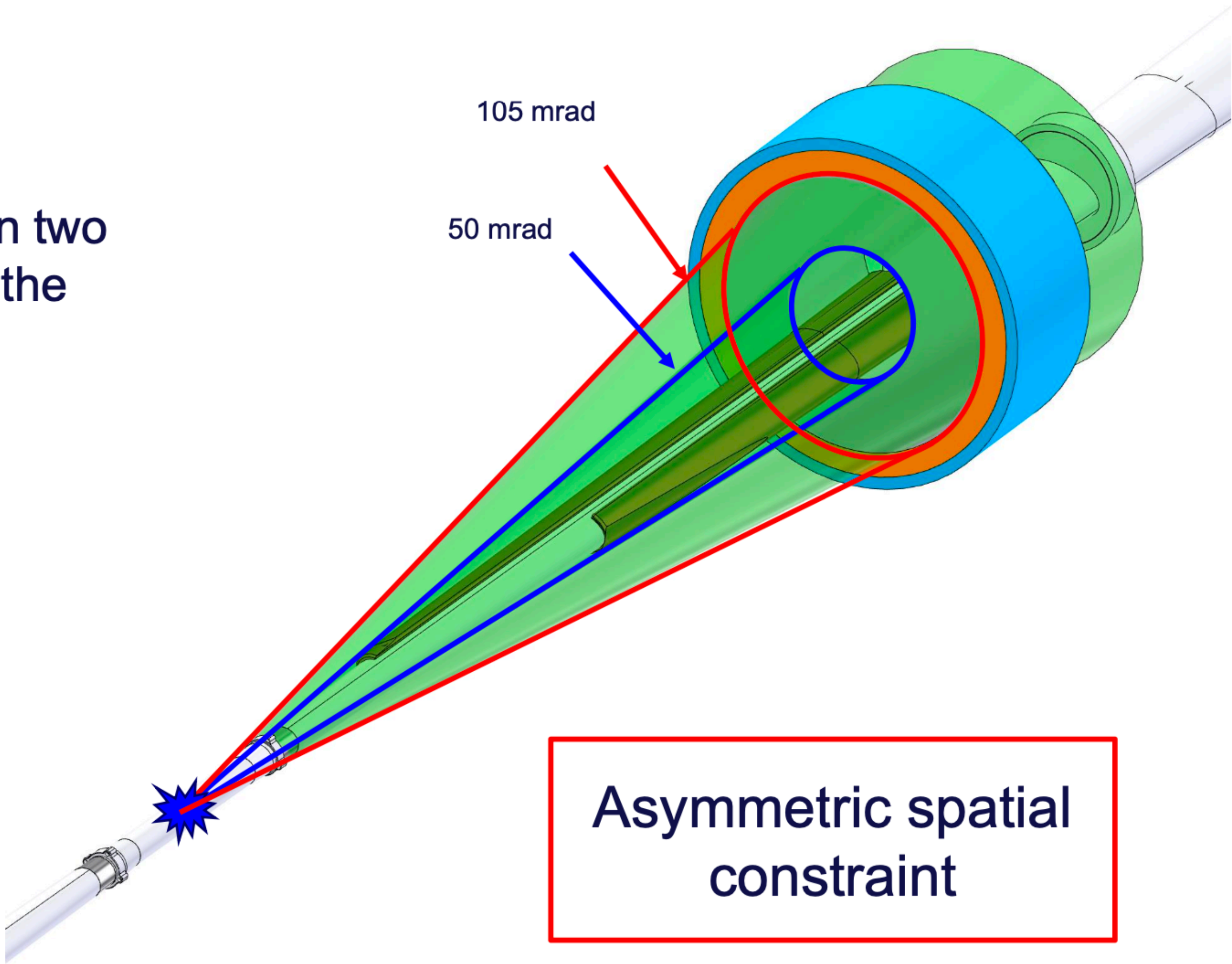
Spatial constraints - LumiCal Cones

Francesco Fransesini



The Lumical is centred on the outgoing beam pipe.
The device to perform properly needs an empty space between two cones, the 50 mrad cones and the 105 mrad cone.

The components integration and each component (i.e. the conical chamber) have been designed to keep everything out of this range, or the thickness has been optimized to achieve the maximum transparency possible.



Asymmetric spatial constraint

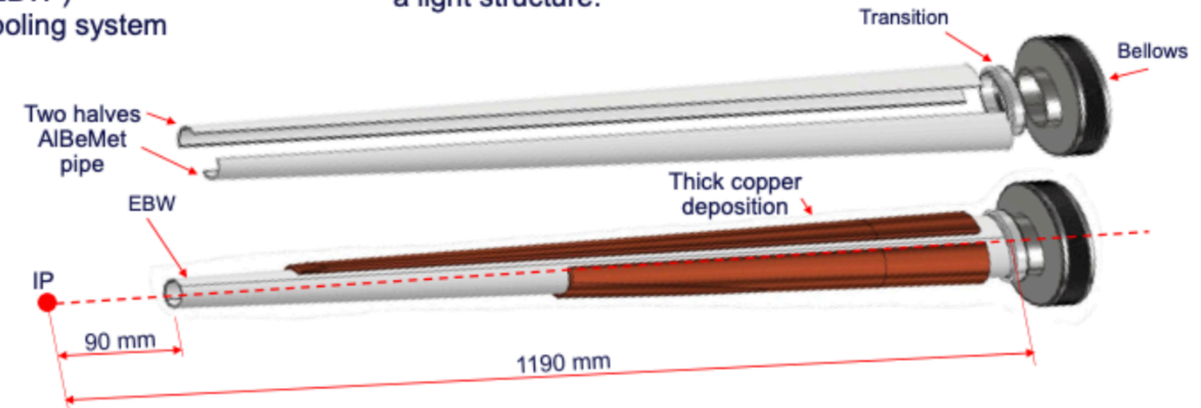
Beam Pipe and Cooling Manifold

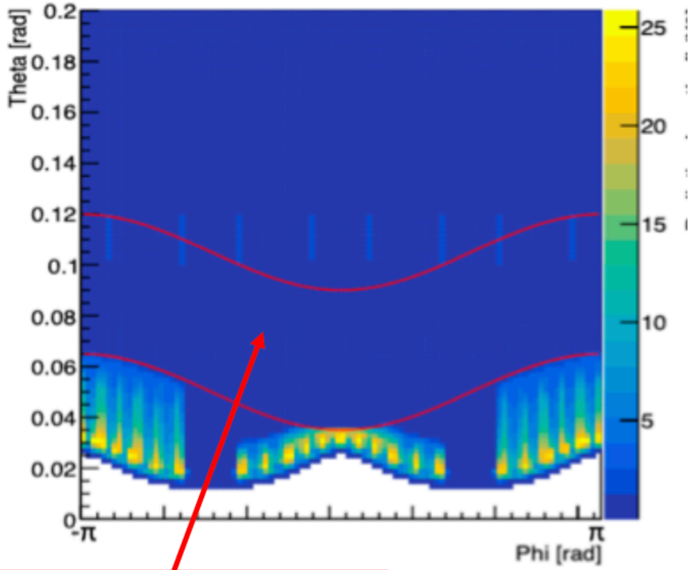
Conical chamber

link

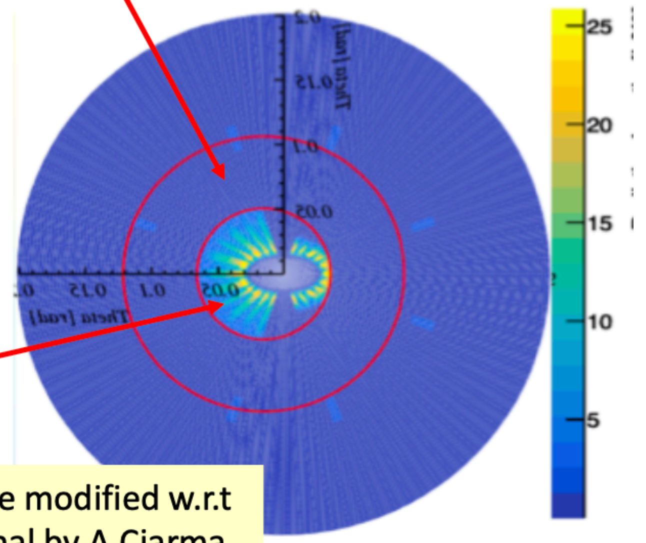
Main characteristics:
- Starting from 90 mm to 1190 mm from IP
- AlBeMet162 as main material
- Chamber in two halves and assembled using electron beam welding (EBW)
- Copper cooling system

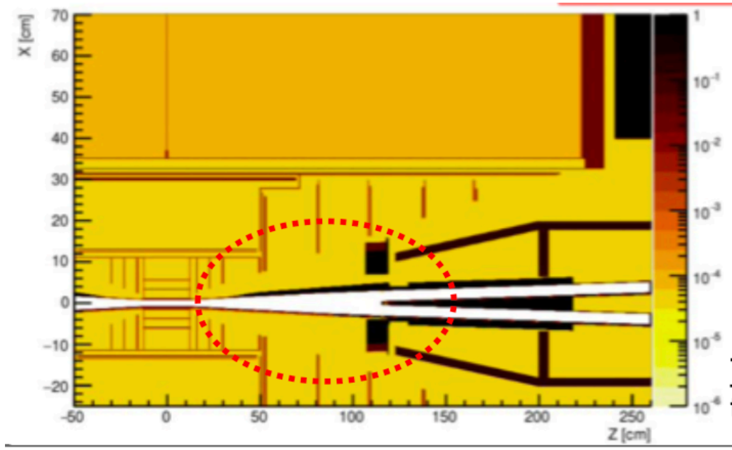
- The cooling is based on an **asymmetric solution**, using the 50 mrad cone as the cutting profile, to assure the respect of the spatial constraint due to the **LumiCal requirement**.
- To reduce the cooling material, the design provides **five channels** for each side; in this way is possible to use the needed quantity of coolant and reduce the material, creating a light structure.





LumiCal acceptance





- FCCee MDI
- CLD inner tracker

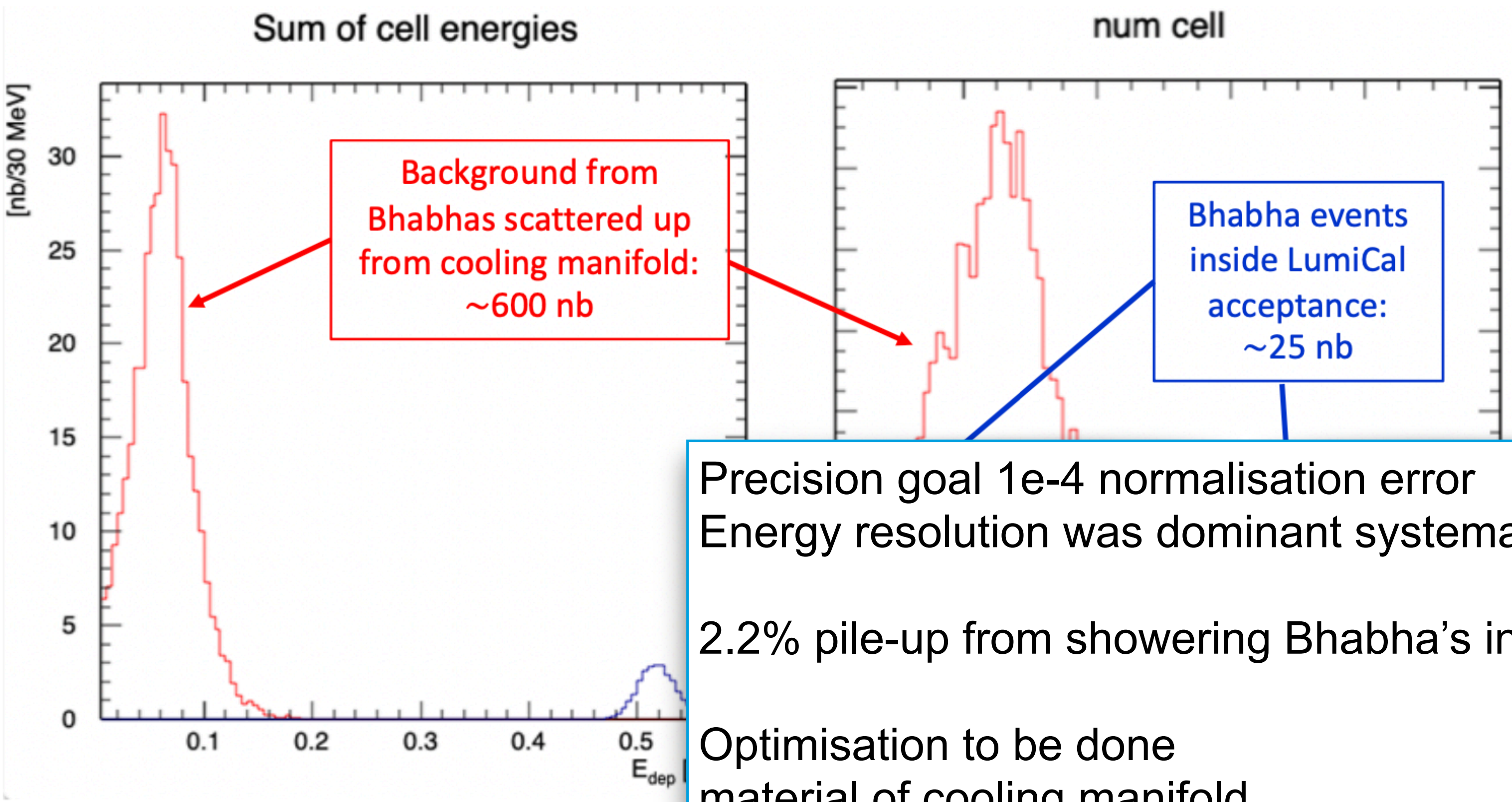
Up to 20 X_0 just below LumiCal accepance

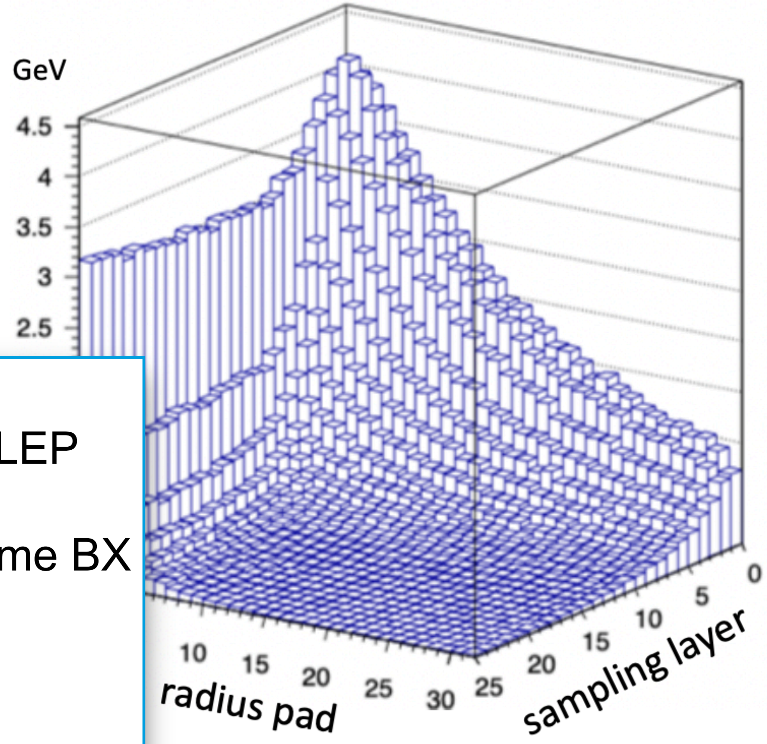
Talk by Thomas Madlener this morning

Figure modified w.r.t original by A.Ciarma

Bhabha background scattered from Cooling Manifold

Full simulation study





Precision goal 1e-4 normalisation error
Energy resolution was dominant systematics at LEP

2.2% pile-up from showering Bhabha's in the same BX

Optimisation to be done
material of cooling manifold
cooling geometry vs beam pipe thickness
pile-up rejection at analysis level

- B
- Background energy 5-15% of Bhabha
- Background event enerdy can be spread over a sizeable number of cells
- Energy deposited primarily at low radius and/or early in calorimeter (first half)

Tracking and Vertexing (partially with MDI)

Vertex Detector & Interaction Region

Detailed Engineering

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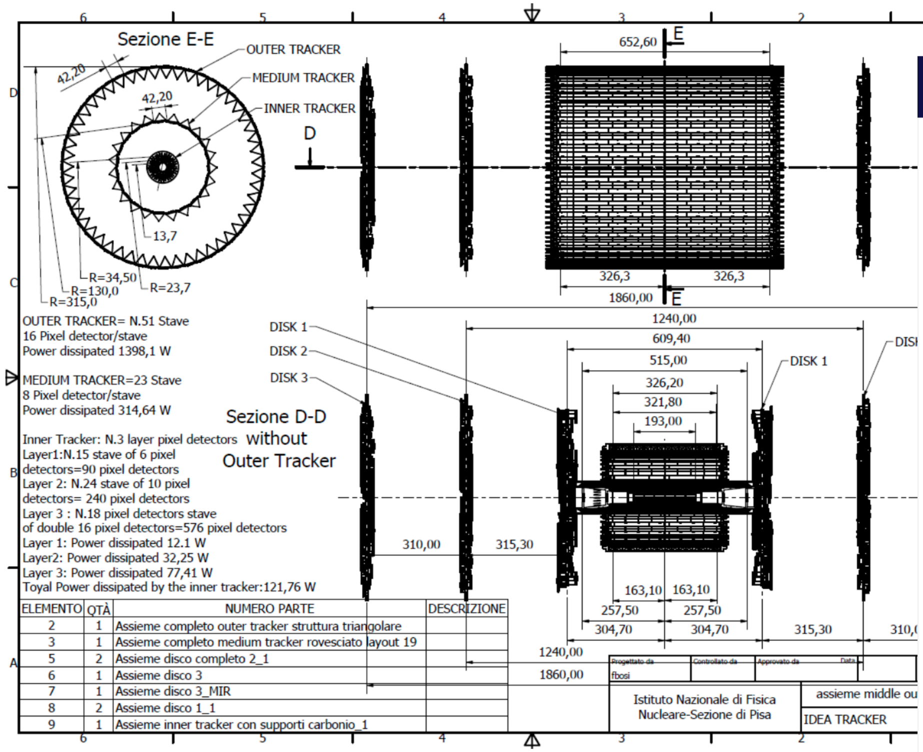
Mid-term review vertex detector overall layout



ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
2	1	Assieme completo outer tracker struttura triangolare	
3	1	Assieme completo medium tracker rovesciato layout 19	
5	2	Assieme disco completo 2_1	
6	1	Assieme disco 3	
7	1	Assieme disco 3_MIR	
8	2	Assieme disco 1_1	
9	1	Assieme inner tracker con supporti carbonio_1	

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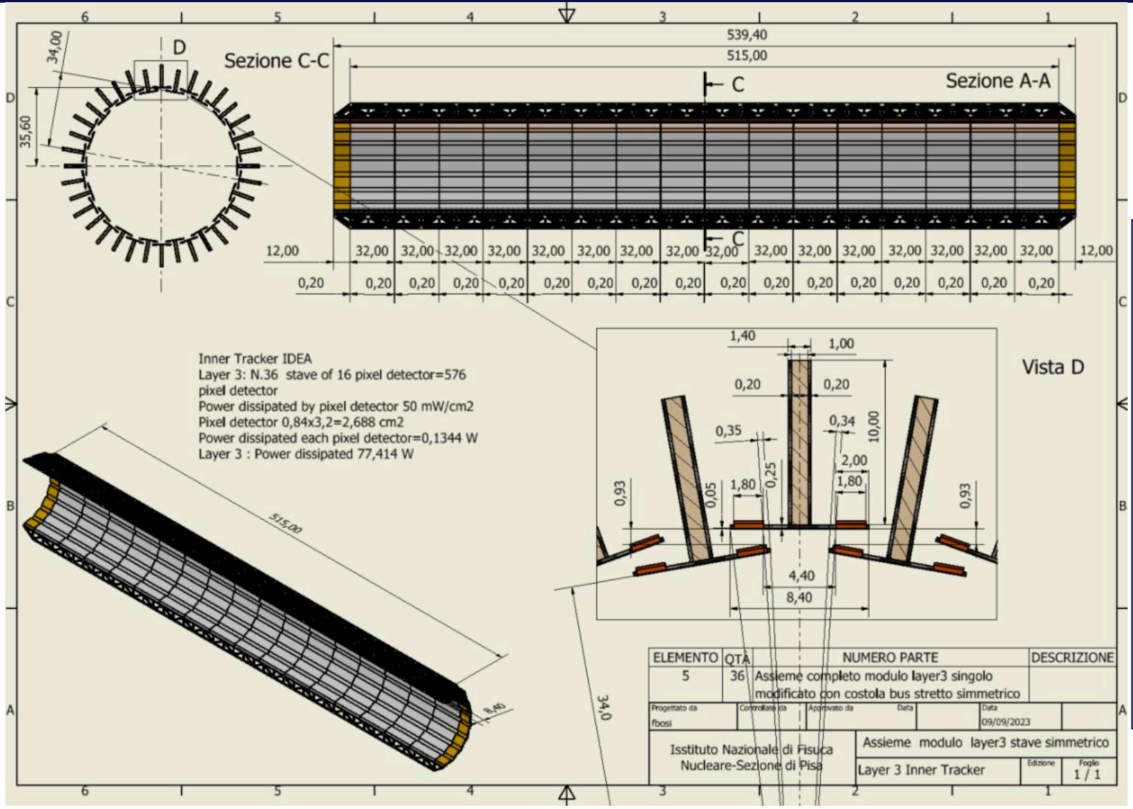


ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
5	36	Assieme completo modulo layer3 singolo modificato con costola bus stretto simmetrico	

NEW

Layer 3
36 staves of 16 modules each

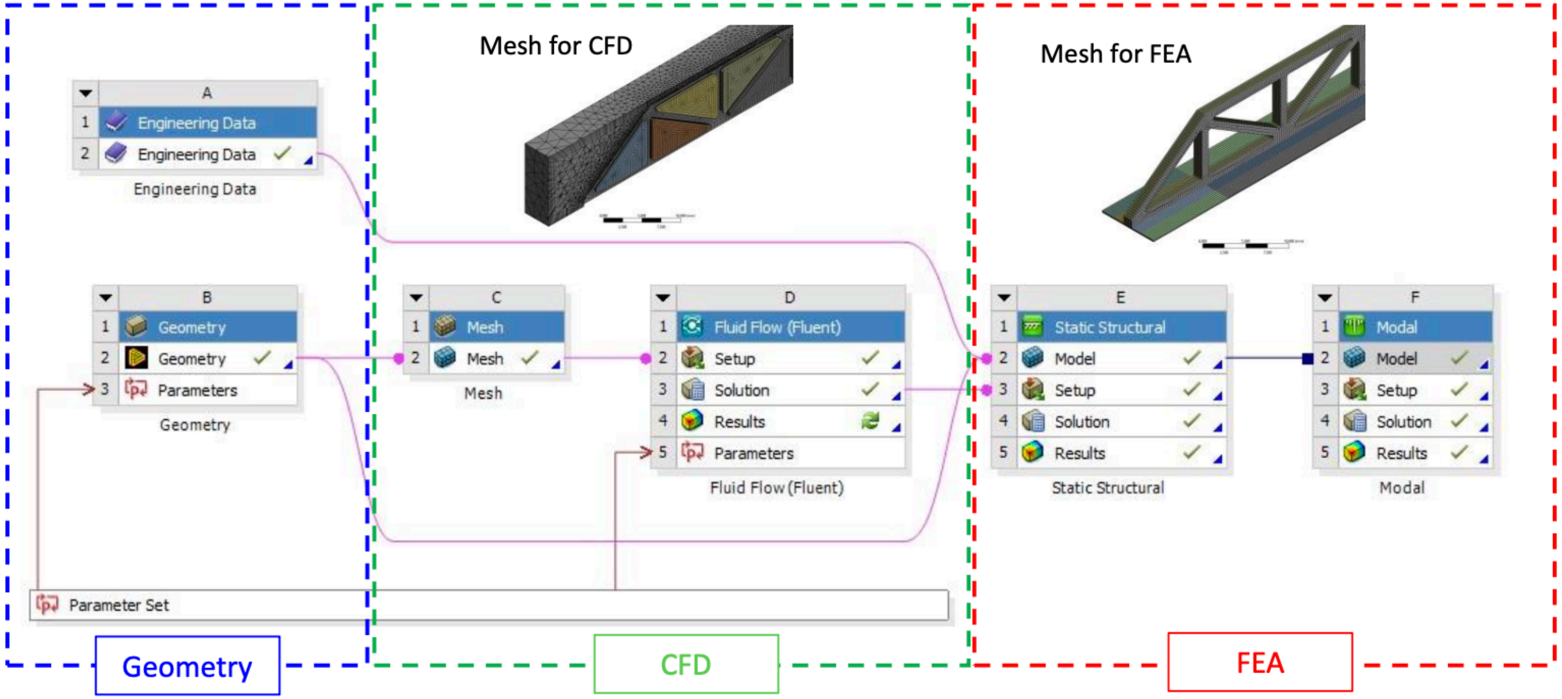
Lampshade geometry.
Charge symmetric track reconstruction

Total weight ~150 grams

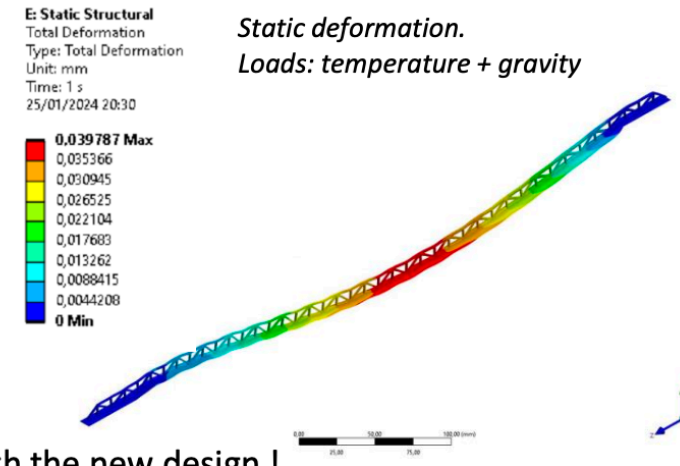
Total thickness 0.25% X_0

Power budget ~77 W

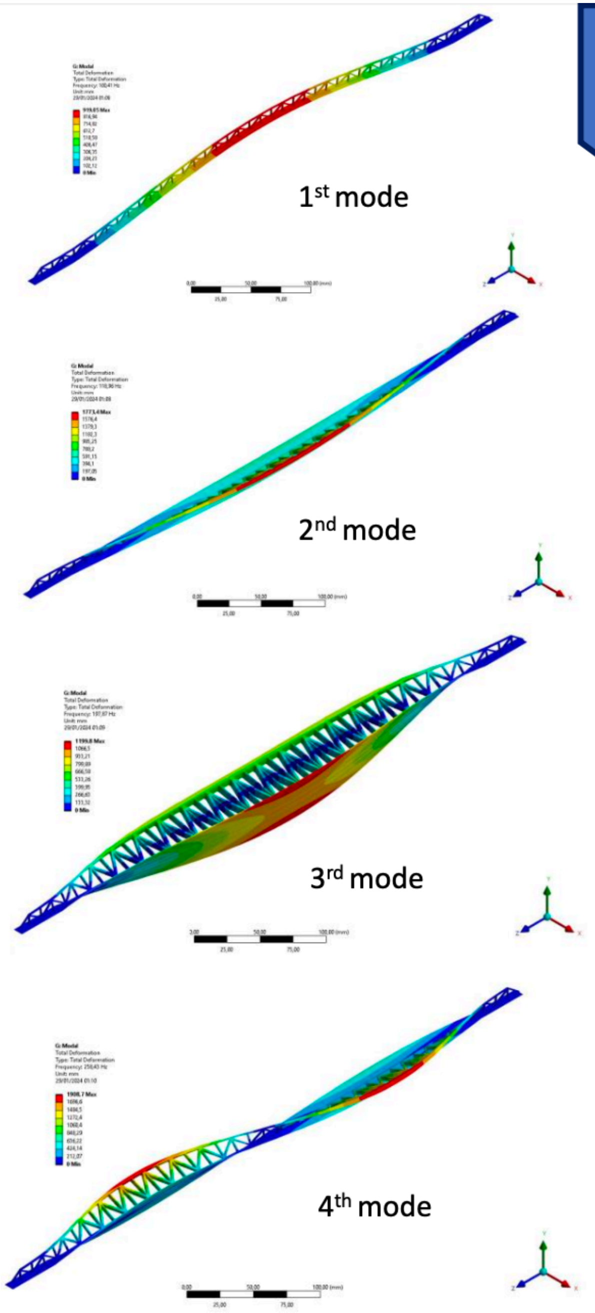
FEA SIMULATIONS



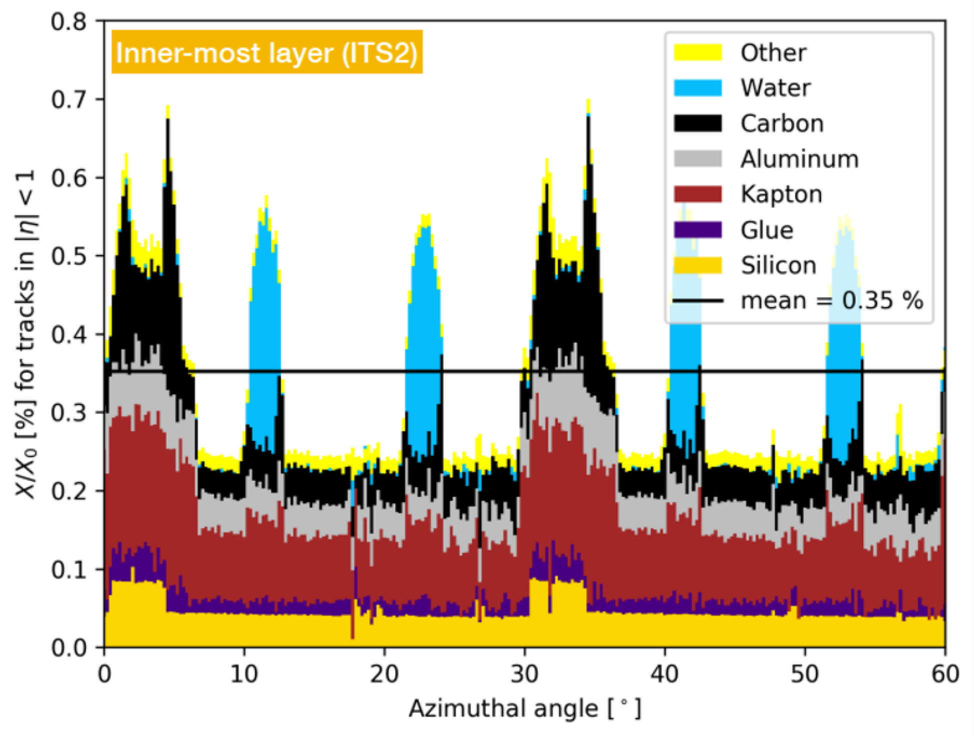
- Workflow of data through Ansys Workbench platform.
- Static analysis already set.
- Model is still work-in progress:
  - Implementing fluid pressures in dynamic regime.
- Building an experimental mockup for validating results is crucial.
- Modal analysis executed on the old geometry: to be updated with the new design !



Static deformation.
Loads: temperature + gravity



Material budget (LHC RUN3)



Si only 1/7 of total material

Non uniformity due to overlaps+ support/cooling

Remove water cooling

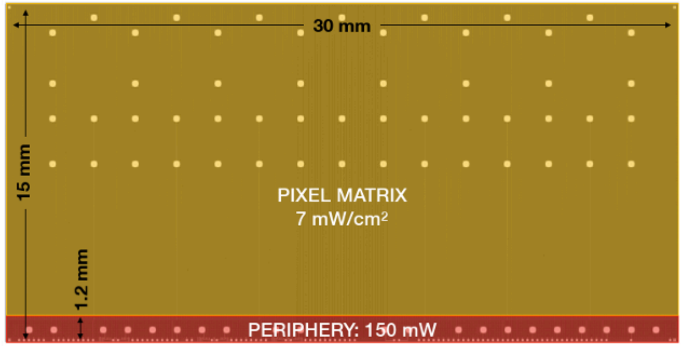
Possible by reducing power consumption in fiducial volume to ~30mW/cm^2

Remove external data lines+ power distribution

Possible to make a single large chip and use that for distribution

Remove mechanical support inside acceptance

Benefits from increased stiffness by rolling Si wafer

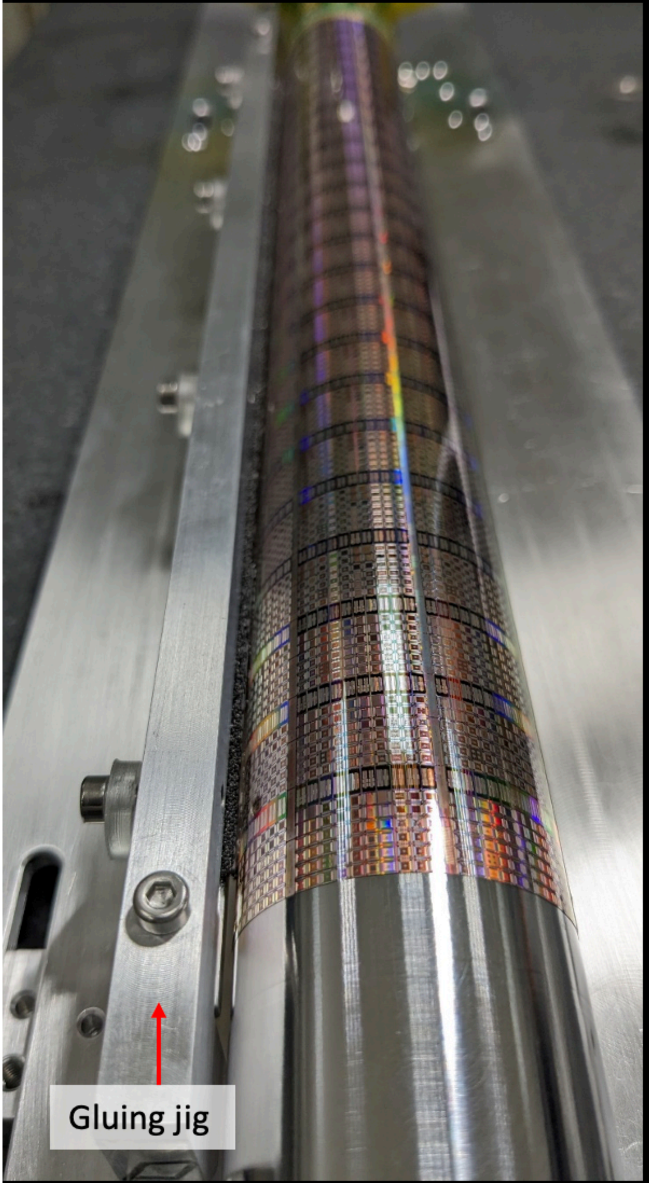


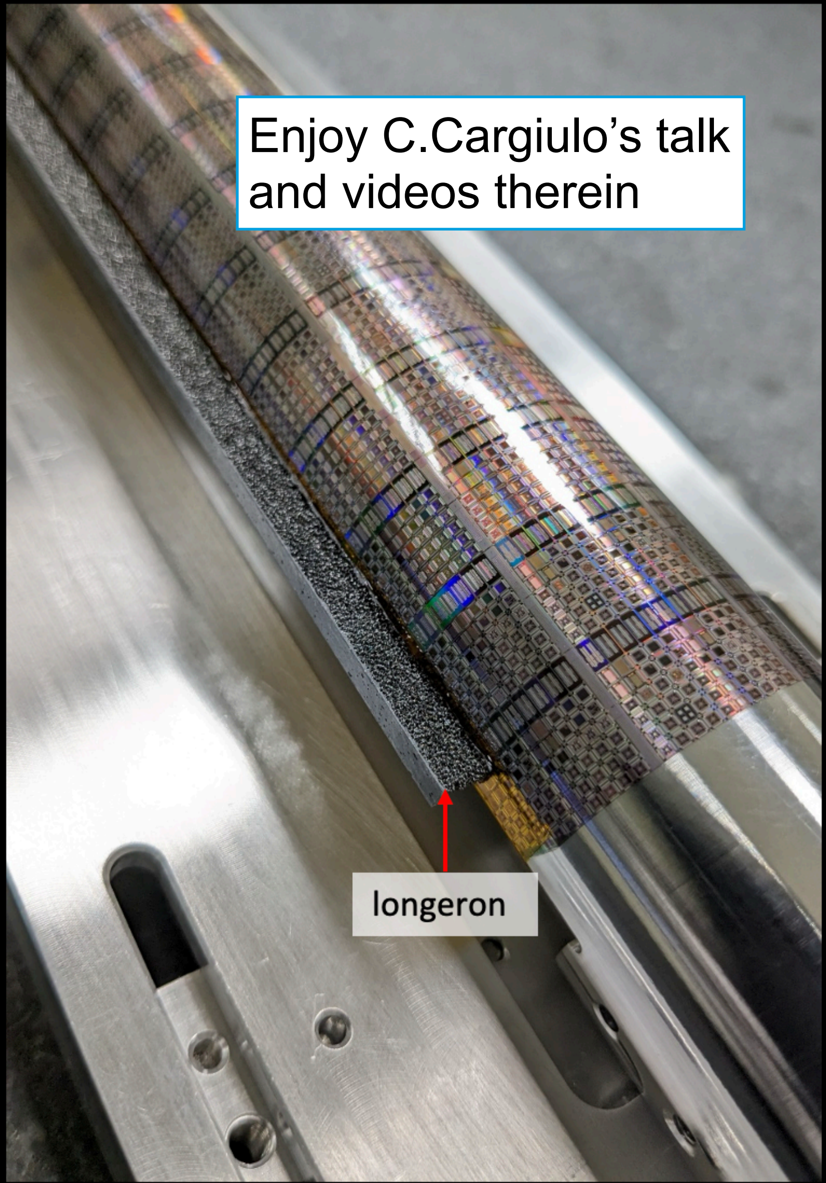
ALPIDE already close: ~40 mW/cm2

Main challenge for the mechanics is to disappear

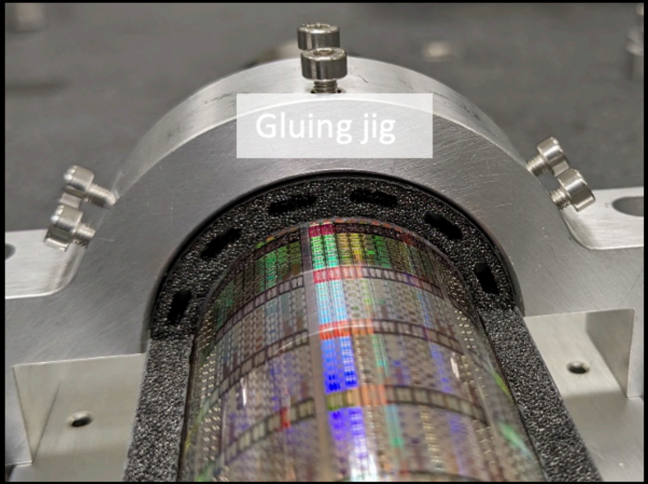
Assembly of a half-layer

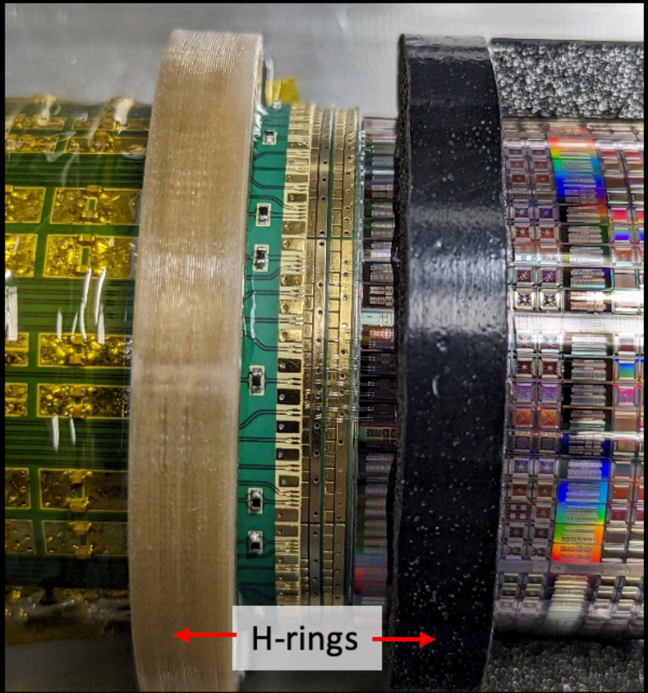
Gluing of the longerons

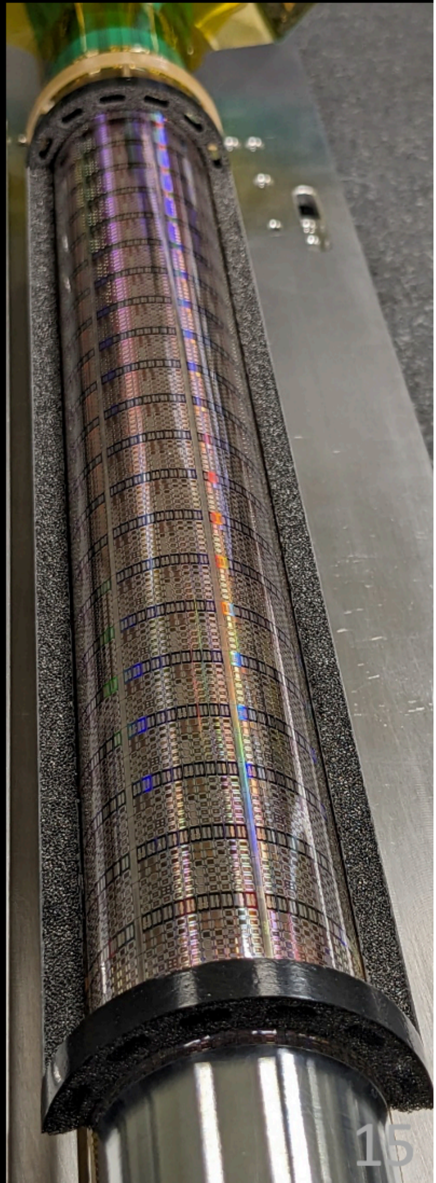




Gluing of the H-rings





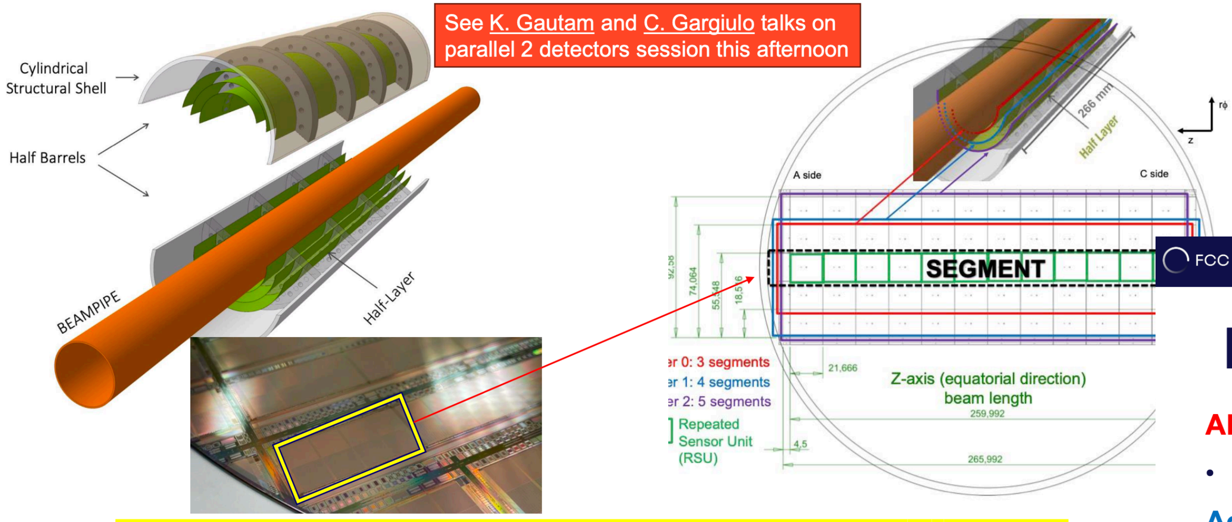


Just Implement ALICE ITS3?

Additional challenges

FCC Fabrizio Palla INFN Pisa – 7th FCC Physics workshop – Annecy (France) – 29 Jan - 2 Feb 2024

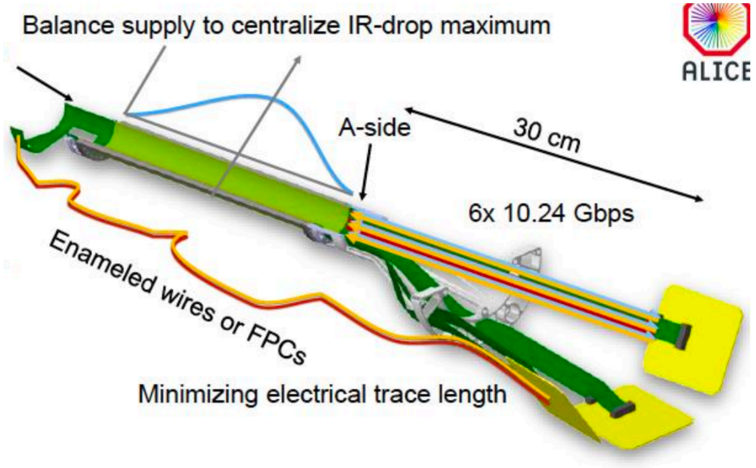
See K. Gautam and C. Gargiulo talks on parallel 2 detectors session this afternoon



ALICE ITS3 inner vertex inspired design – issues

(0.2 % X/X_0 *material budget – 5 times less than the Mid-Term one)*

After fruitful discussions with ***C. Gargiulo, A. Junique, G. Aglieri Rinella, W. Snoeys***



FCC Fabrizio Palla INFN Pisa – 7th FCC Physics workshop – Annecy (France) – 29 Jan - 2 Feb 2024

Issues – I

ALICE smaller radius will be 18 mm (beam pipe 16 mm)

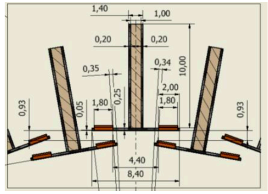
- **Needs to demonstrate bent MAPS with 13.5 mm radius works electrically – mechanically OK**

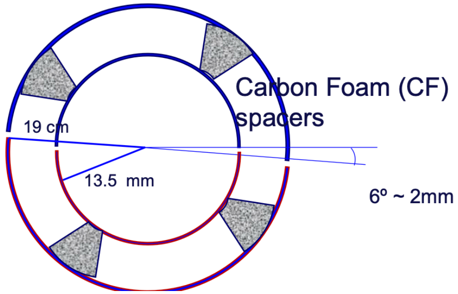
Active pixels 95% of covered area (chip service zones)

- **Which impact has on physics?**
- **Cannot overlap sensors as in "traditional" layouts in same layer**
- **Can be recovered in ϕ by rotating two layers at different radii**

If same angular coverage for all layers is seeked

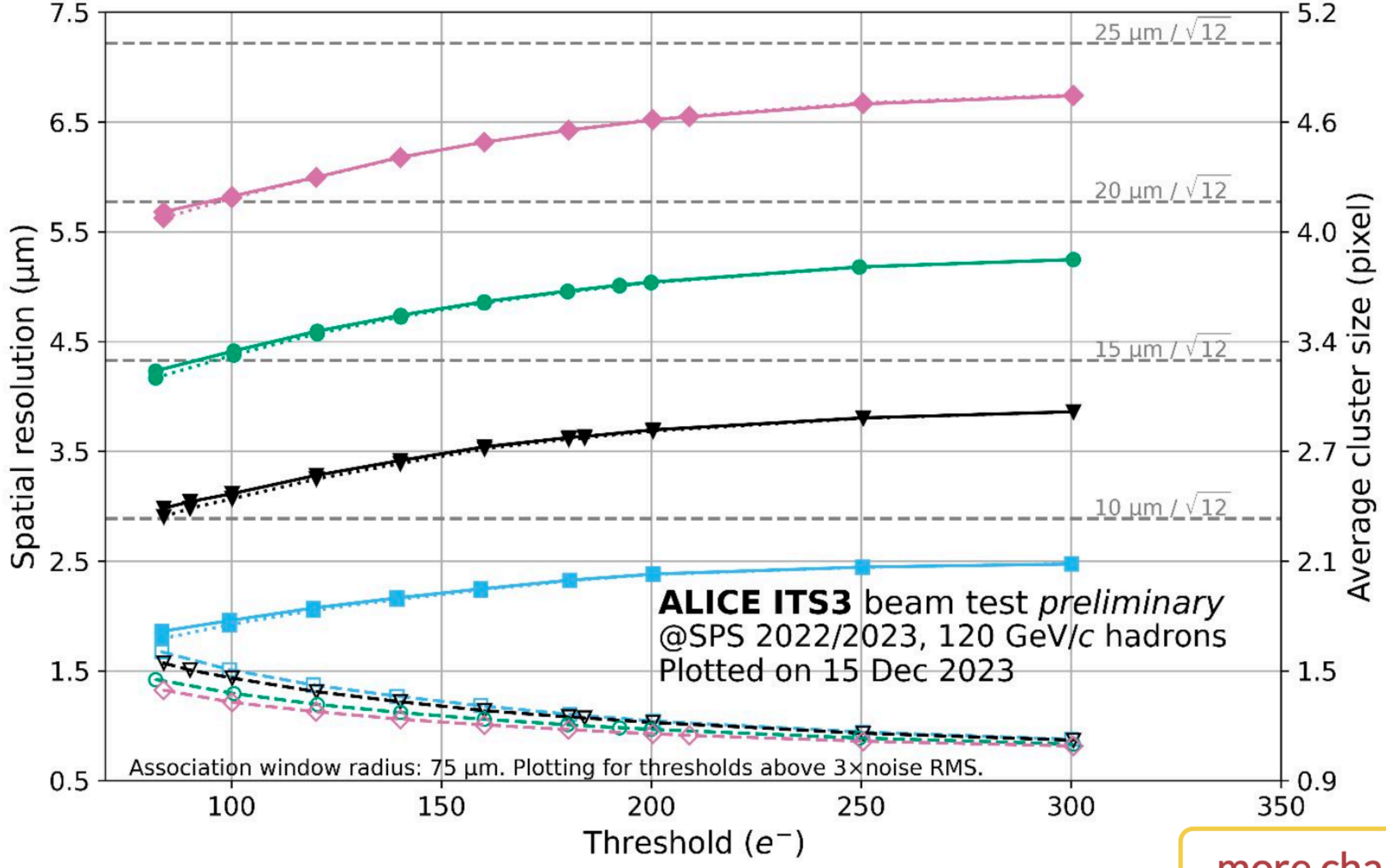
- **Then needs to 2 stitched structures in z for outer layers**



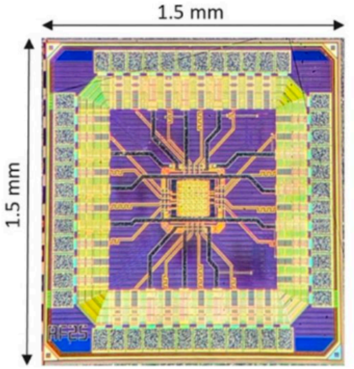


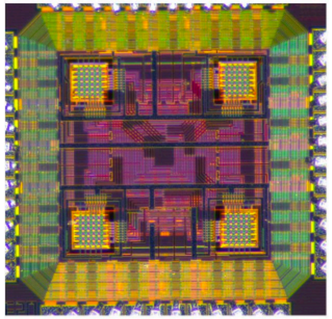
There are no wafers larger than 12 inches!

Spatial Resolution (APTS)



APTS SF
type: modified with gap
split: 4
Non-irradiated
I_{reset} = 100 pA
I_{biasn} = 5 μA
I_{biasp} = 0.5 μA
I_{bias4} = 150 μA
I_{bias3} = 200 μA
V_{reset} = 500 mV
V_{pwell} = V_{sub} = -1.2 V
T = 15 °C

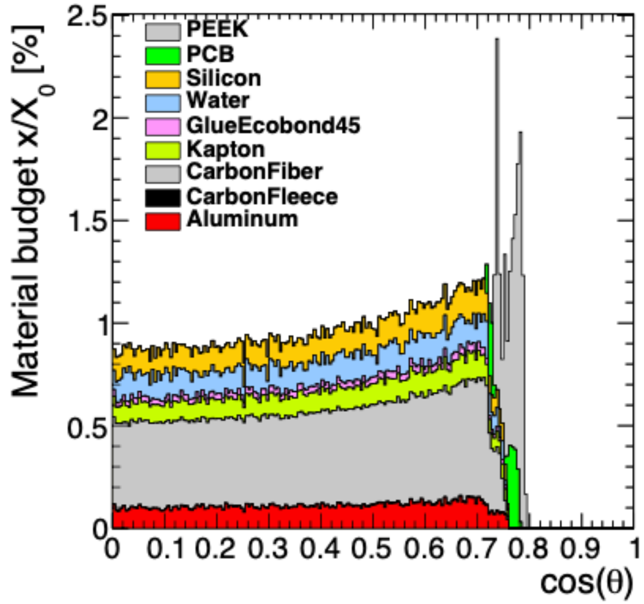


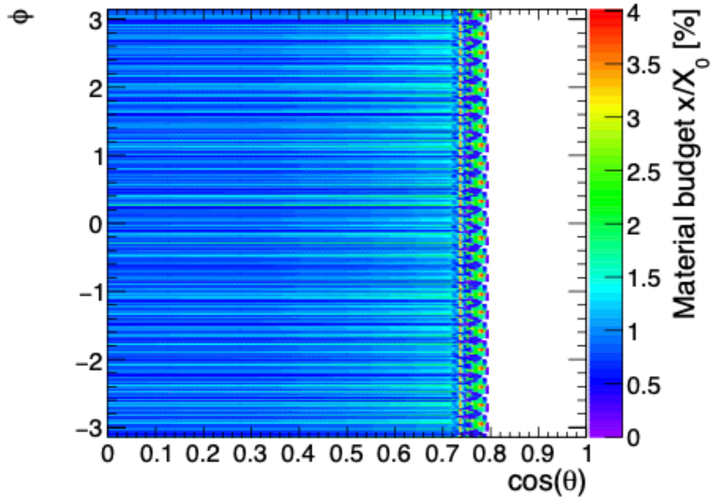


more charge sharing ⇨ improved resolution

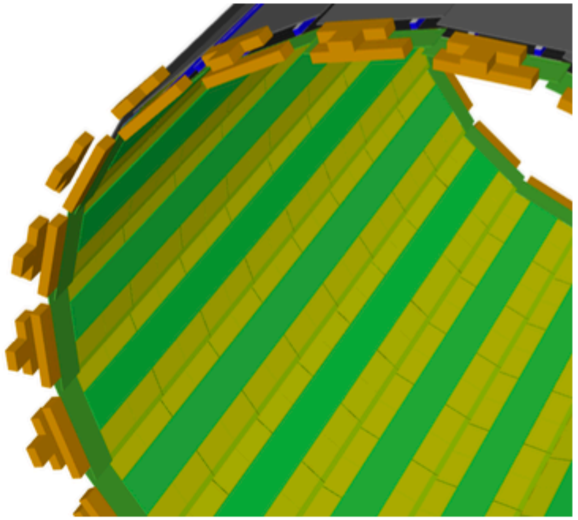
University of Zurich[UZH]

- Proxy volumes for truss structure and cooling pipes
- Proxy volume for end-of-stave holder (material budget contribution optimised with F. Palla)
- Still significant contribution from PEEK stave holder

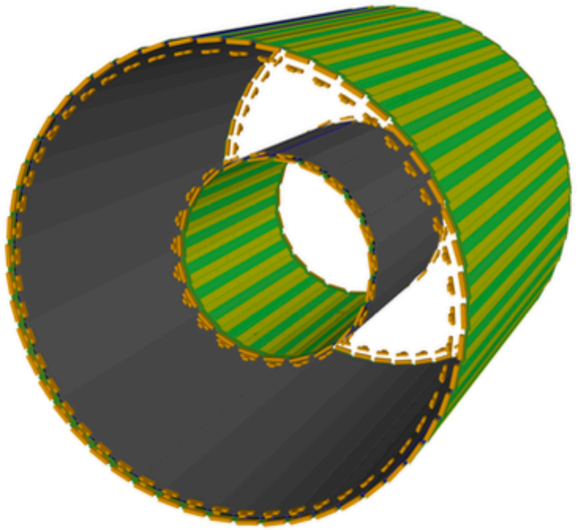




Complete outer barrel

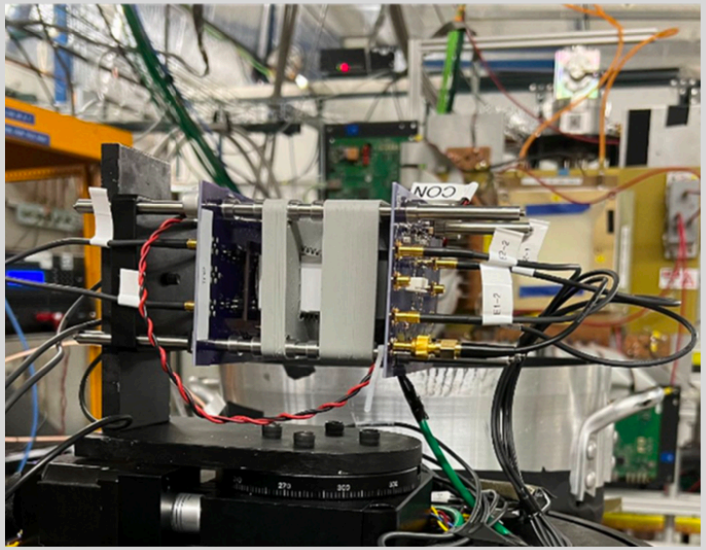


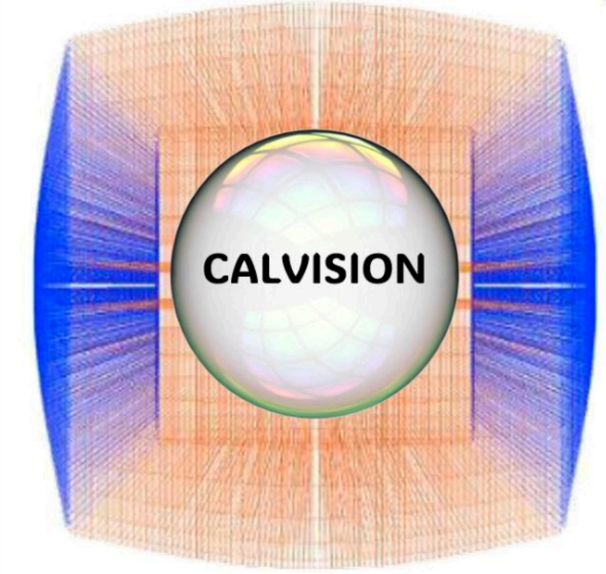
Middle tracker

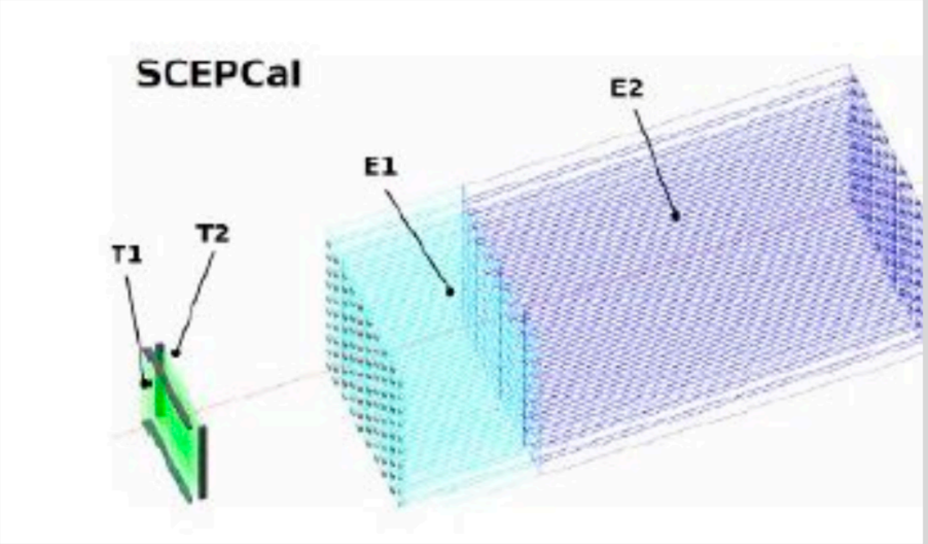


Complete vertex outer barrel system

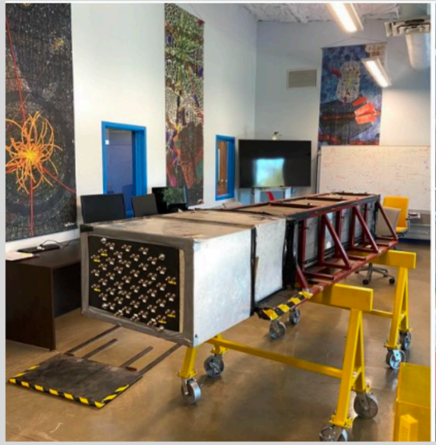
Calorimetry and Muons

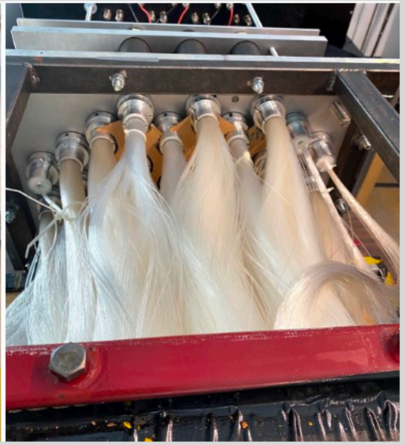




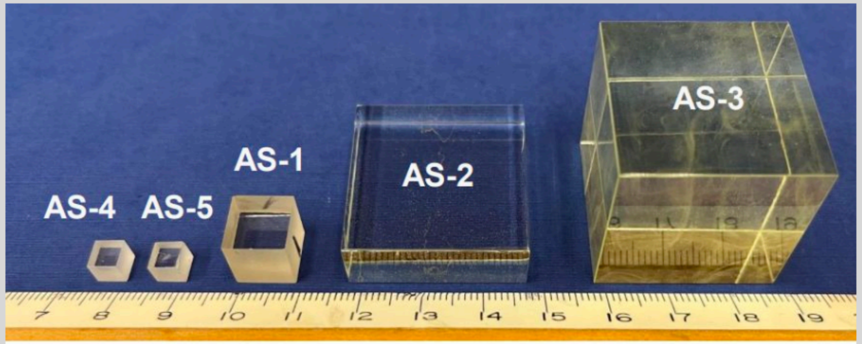


First results from CalVision



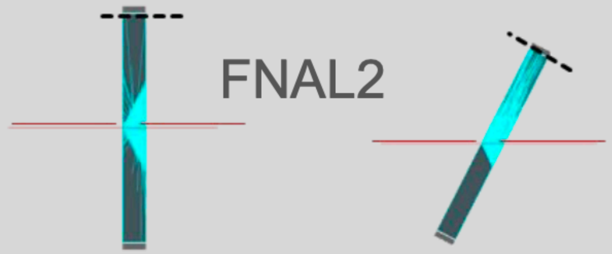


Sarah Eno
U. Maryland



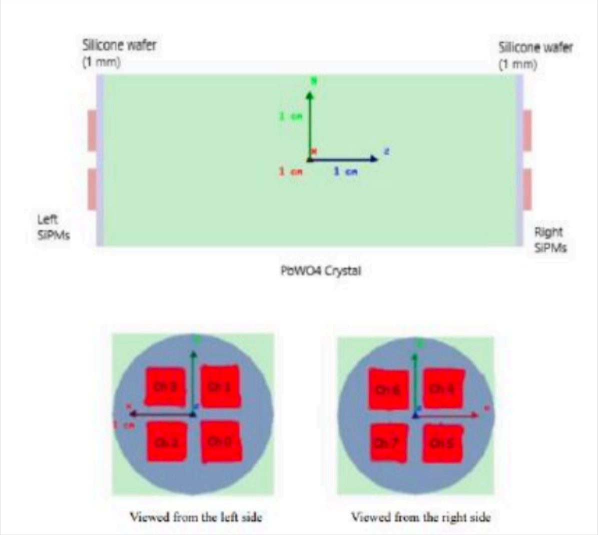
Test beams

Using Hamamatsu SiPM S14160-6050HS



Have completed three test beams studying single crystals PbWO4, PbF2, BGO

- Notre Dame radiation lab 8 MeV electrons
- FNAL1 120 GeV protons
- FNAL2 120 GeV protons



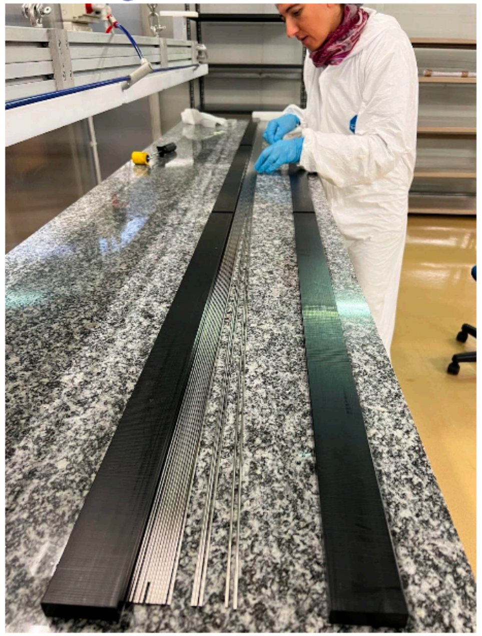
Have two upcoming planned

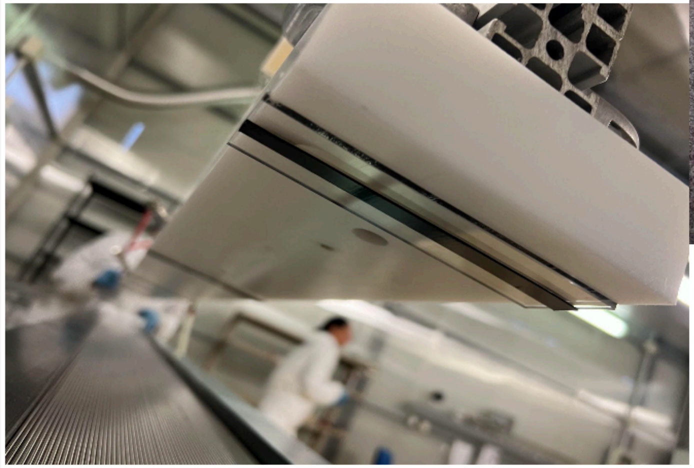
- DESY electrons April 2024
- CERN SPS H8 late July?

Module construction

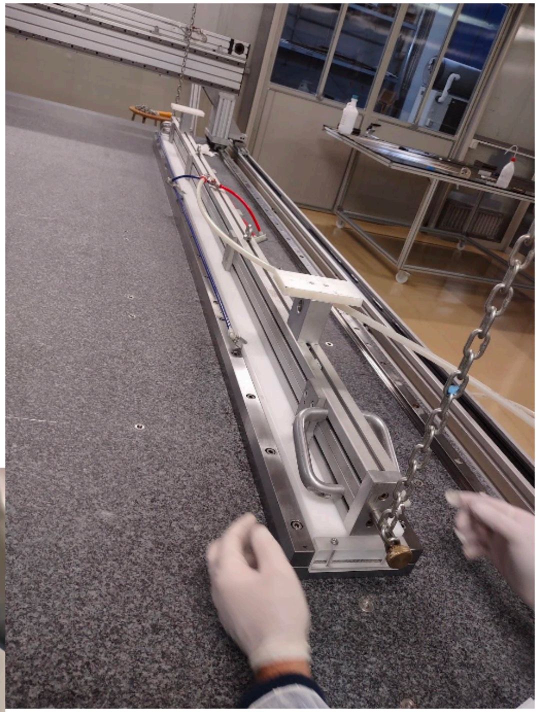
Definition of constructing technique and quality assessment on the modules geometry

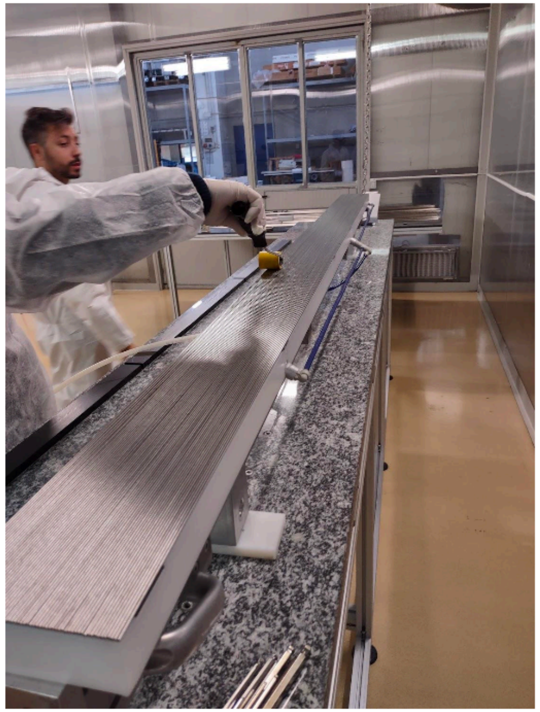
Tube aligned in a reference tool

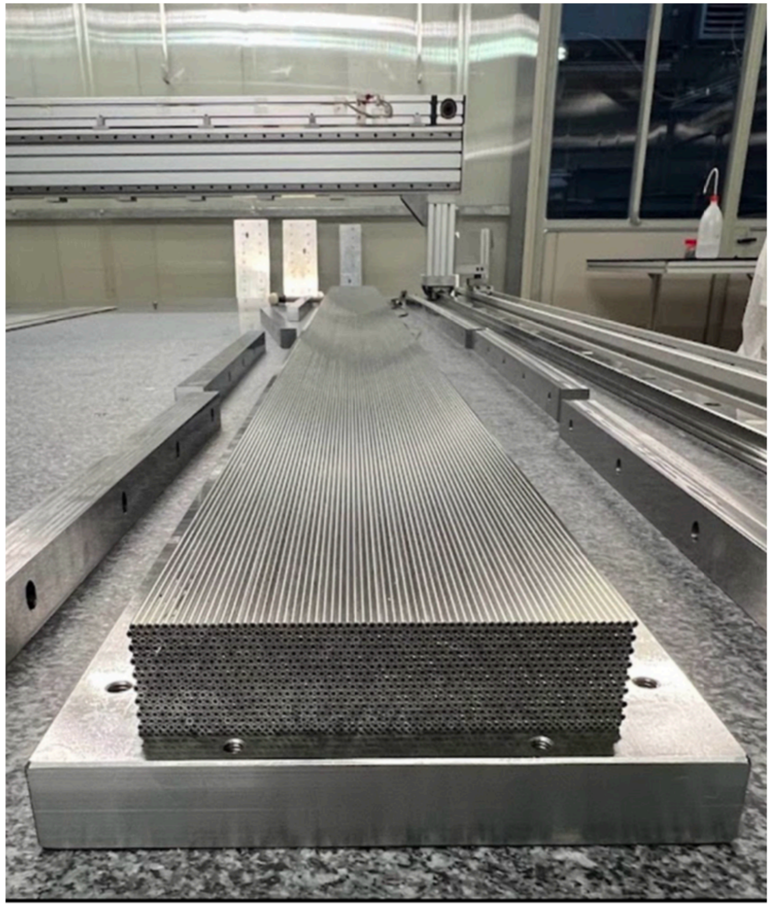




Stiffback-like technique for tube handling, gluing and positioning in the assembly tool





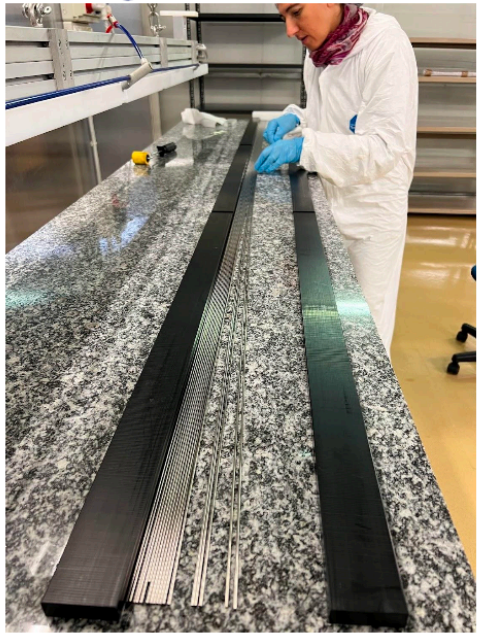


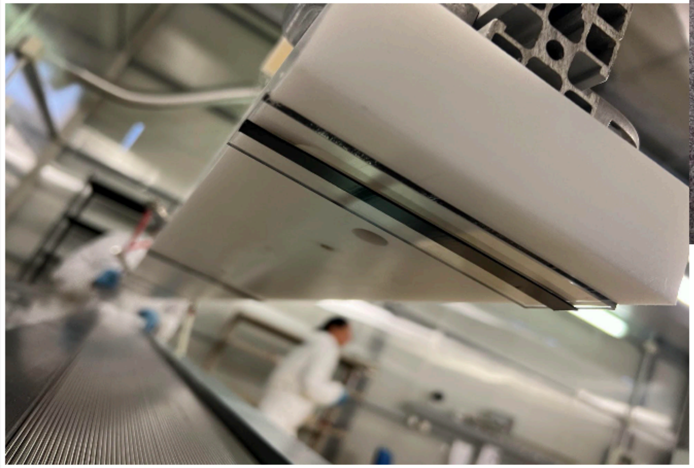
Vacuum + double-sided tape for tube handling

Module construction

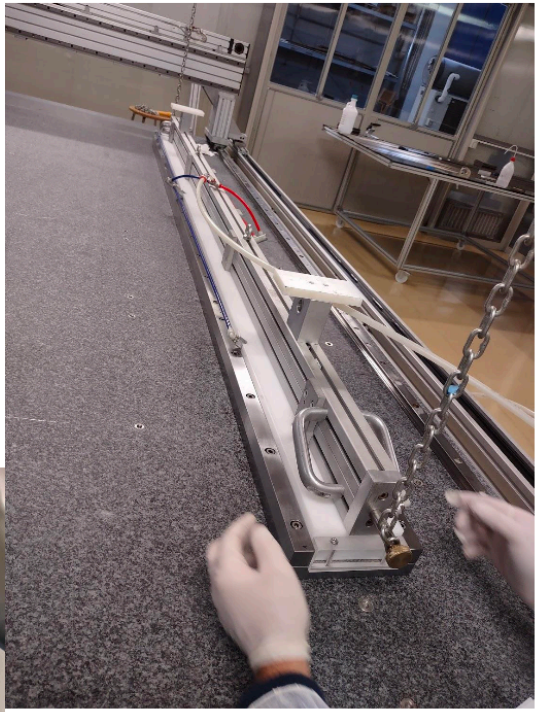
Definition of constructing technique and quality assessment on the modules geometry

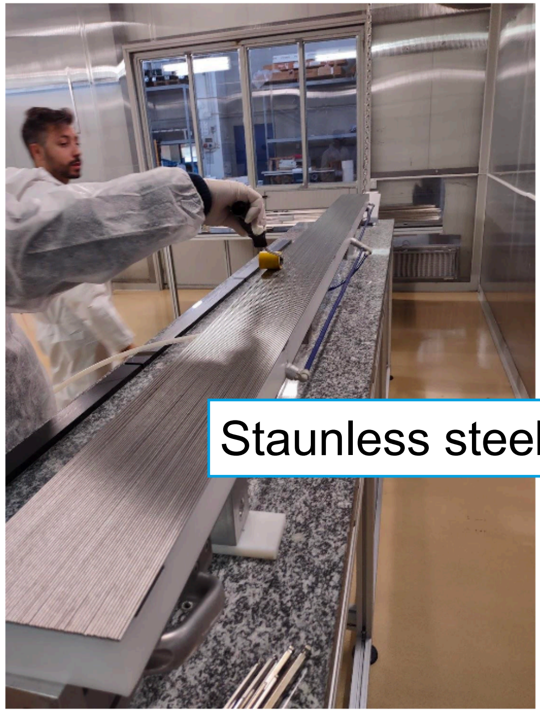
Tube aligned in a reference tool



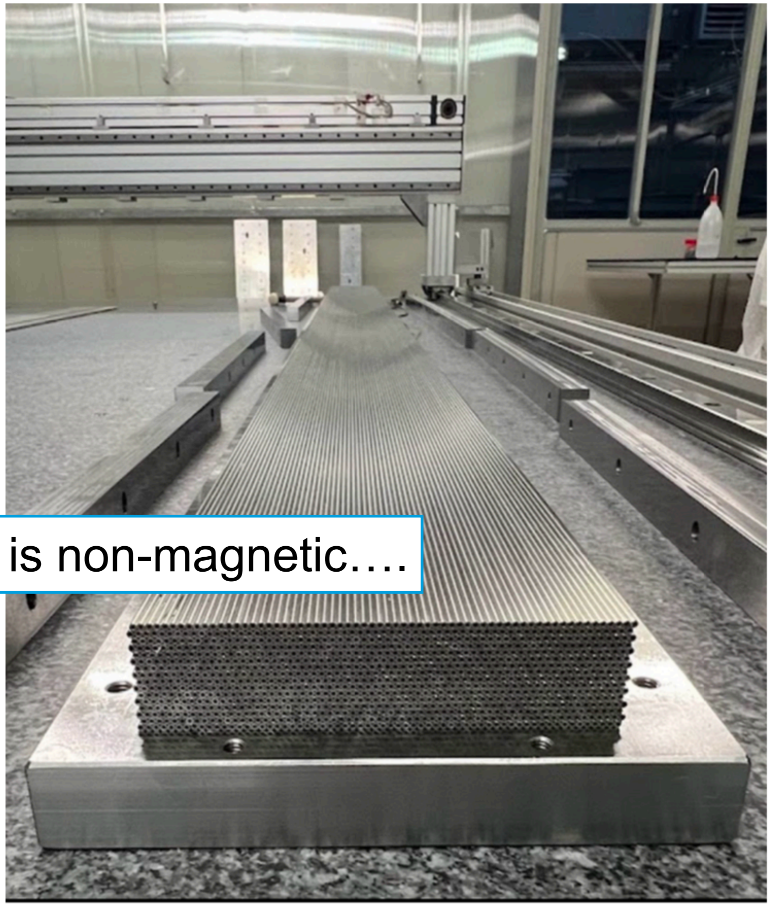


Stiffback-like technique for tube handling, gluing and positioning in the assembly tool



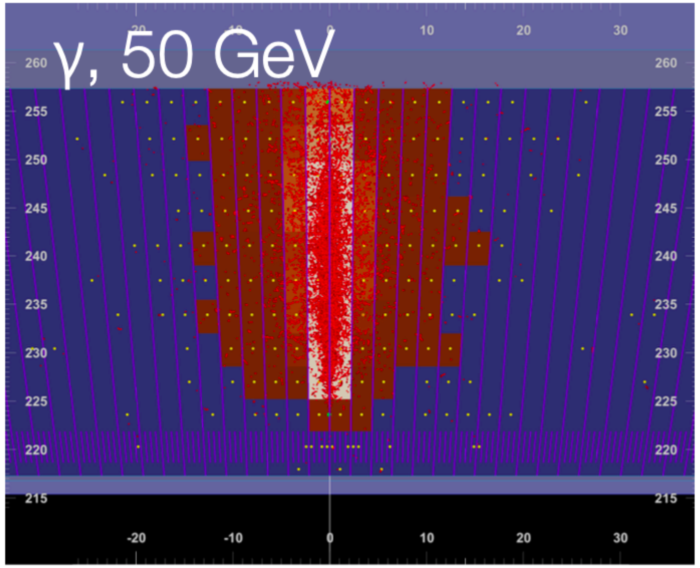


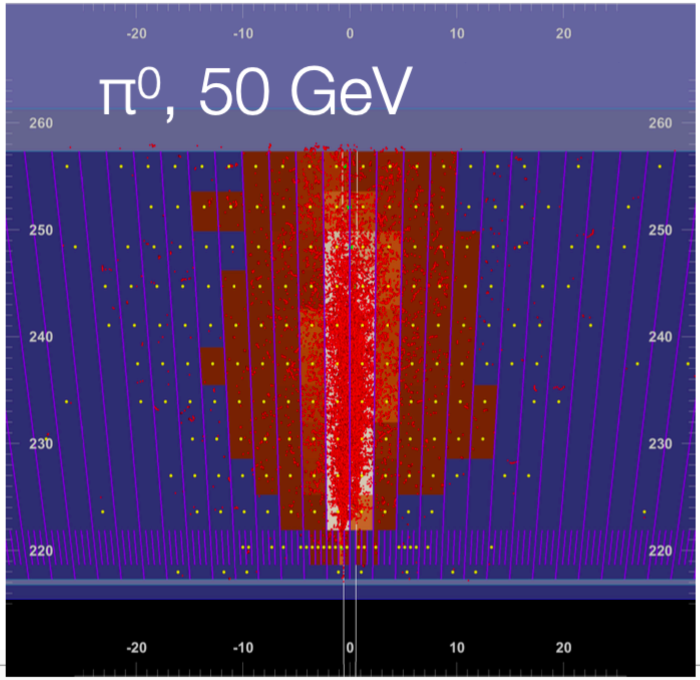
Staunless steel is non-magnetic….

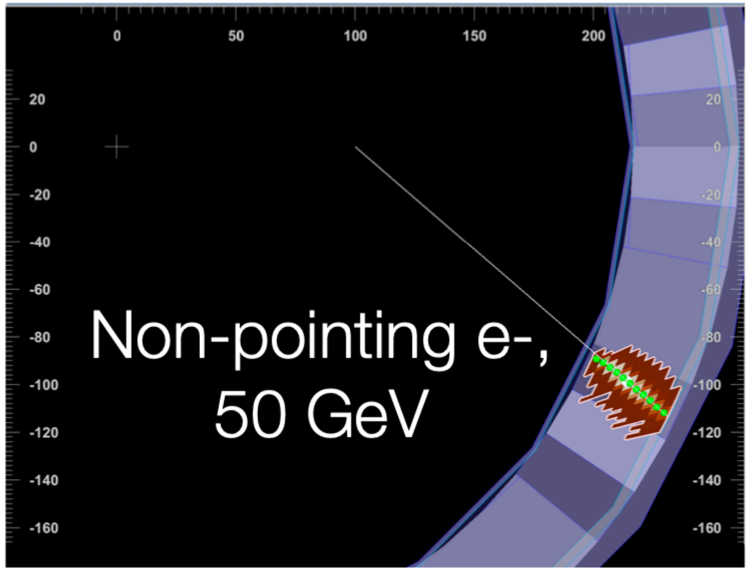


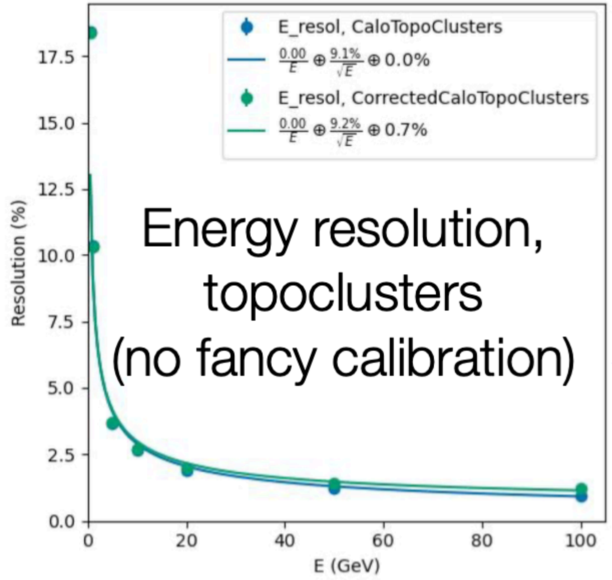
Vacuum + double-sided tape for tube handling

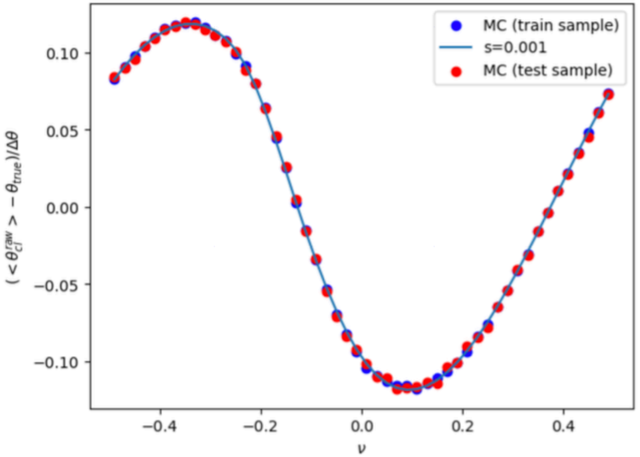
ECAL barrel simulation

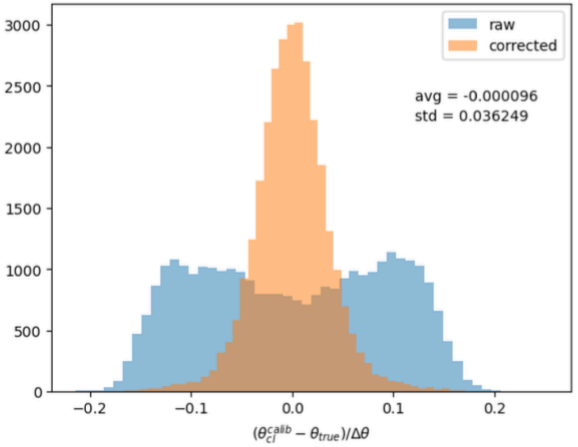








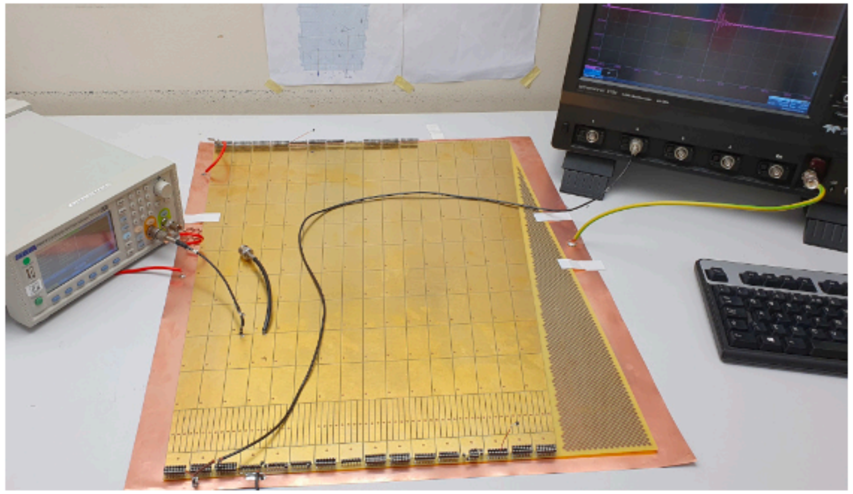


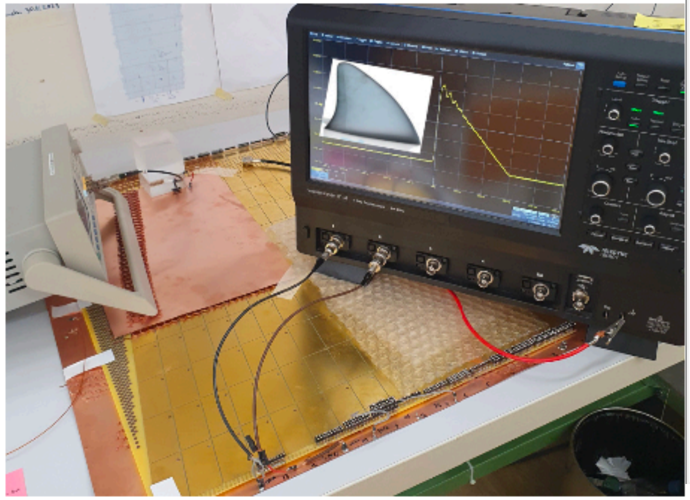


Position/direction reconstruction: S-curve
θ correction and resolution

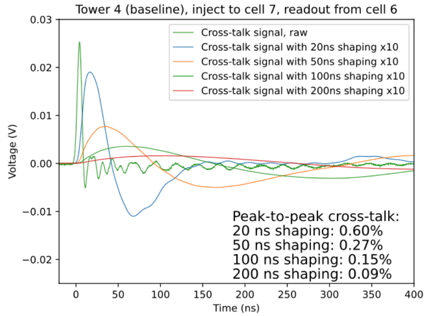
PCB measurement setup

- Electrical properties measured with a table-top setup
- Copper sheet as grouding and "absorber" above and below
- Function generator used for injecting shark-fin signal
  - 300 ns wide 1 V peak at 5 ms intervals
- Signal read with oscilloscope and analyzed offline
- Extra care needed for good quality measurements
  - Short cables, thorough grounding, impedance matching





Cross-talk and shaping time

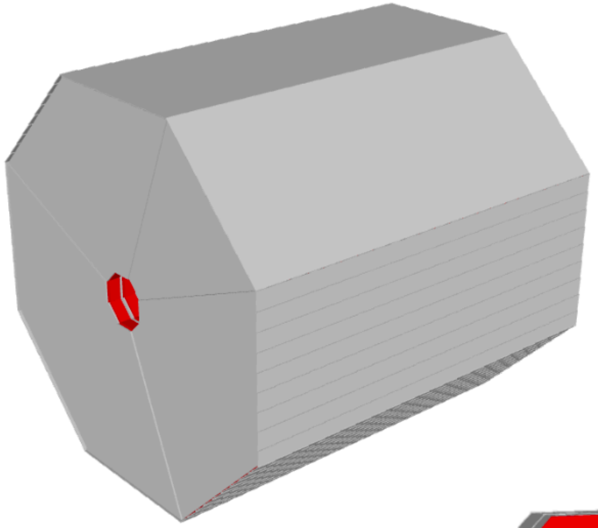


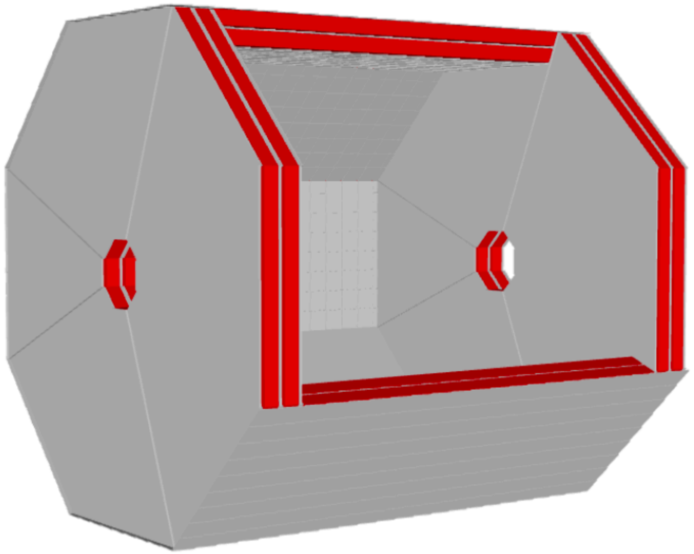
- Longer shaping time gives lower x-talk
  - At LHC long shaping times not good due to pileup, but an option in e^+e^- colliders
- X-talk down to 0.1% and less with long shaping time
- Low x-talk seen also in other shielding configurations

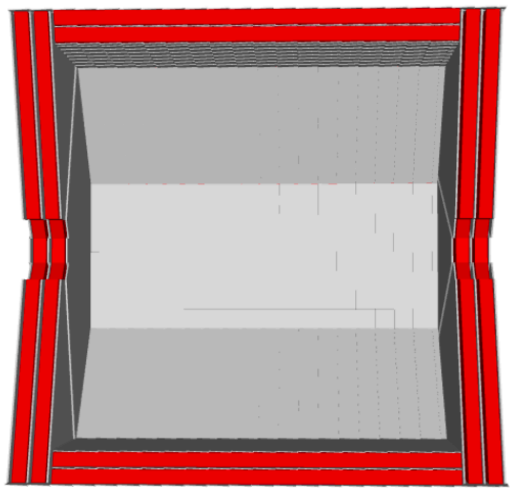
Full-Sim of the muon system

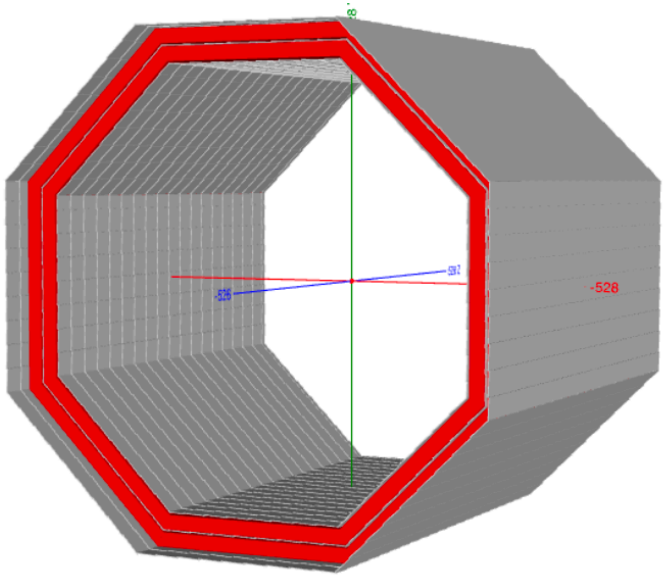
FULL MUON SYSTEM GEOMETRY

- A first draft of the **detailed version of the muon system** geometry implementation is ready.

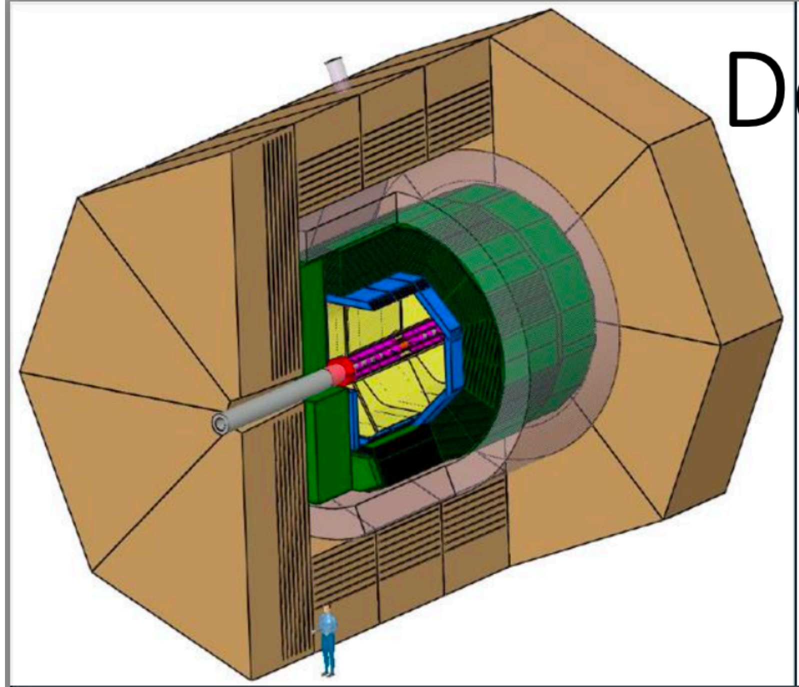


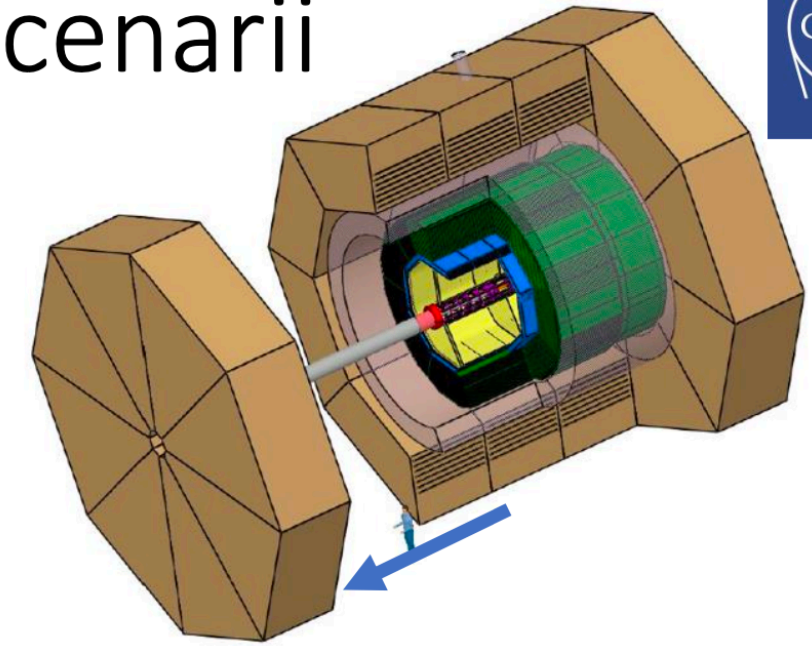






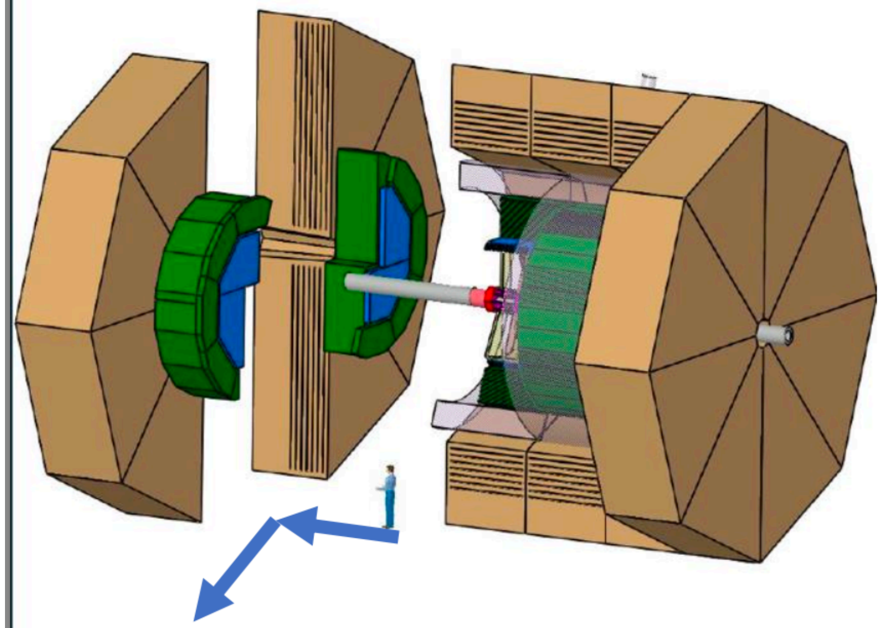
Detector opening scenarii

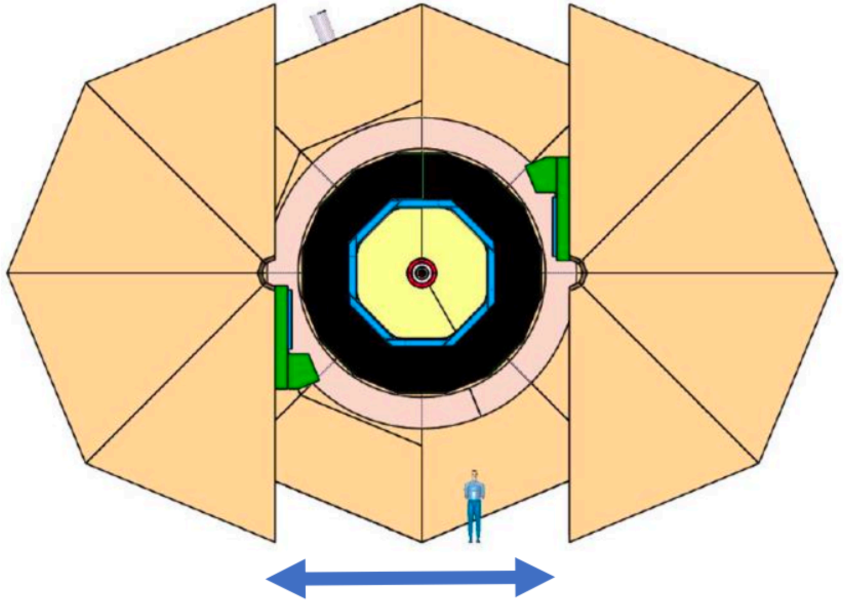




Solid Endcaps

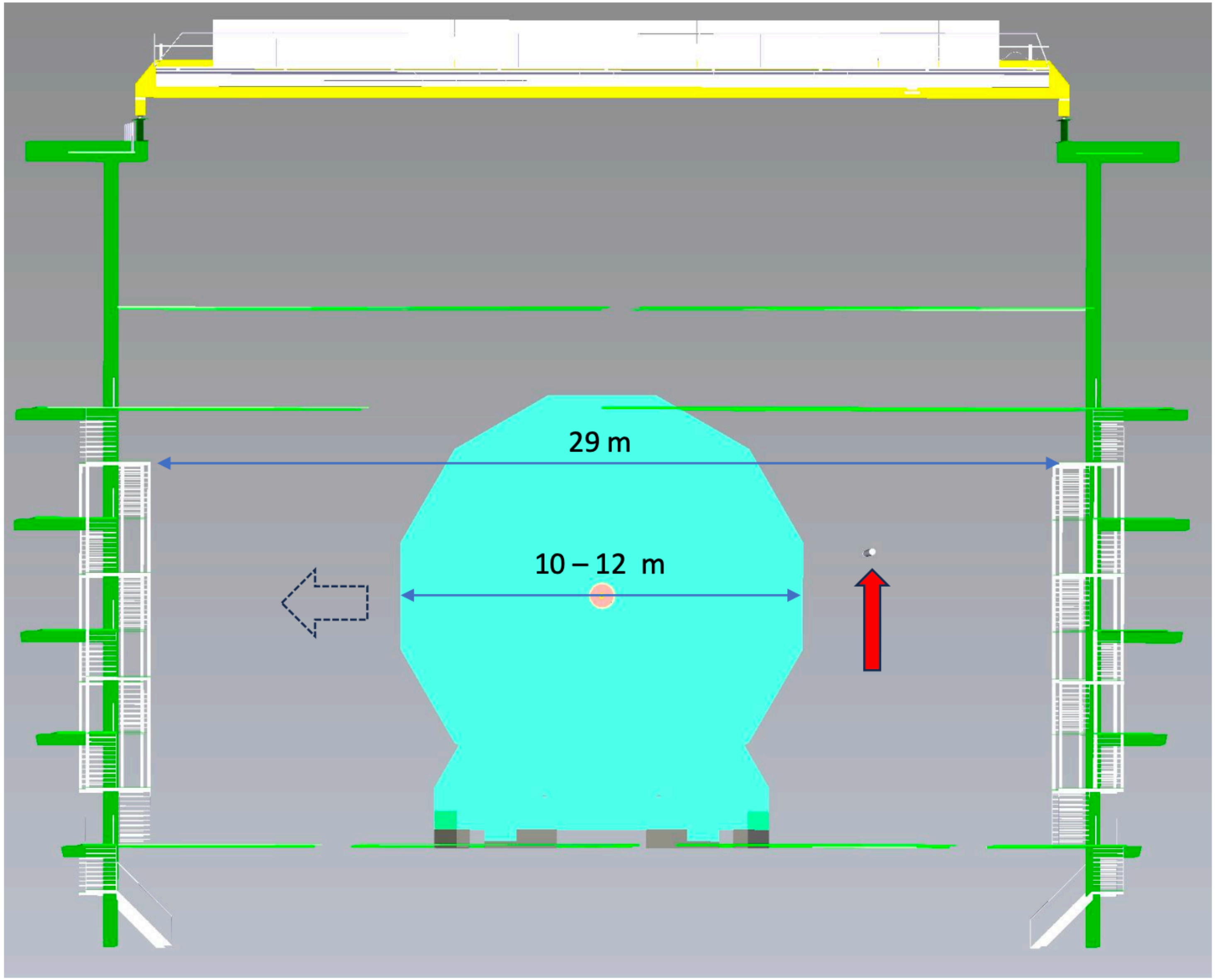
Long longitudinal stroke to access inner detector elements. Last machine elements envelope restrained.





Split Endcaps

Combined short longitudinal stroke + transversal opening to mitigate impact on last machine elements envelope.



A typical FCC-ee detector sits comfortably inside the experiment cavern (but note the presence of the booster ring floating in the air without shielding or compensator…).

Is the cavern large enough to eventually allow for moving the detector aside the beamline, in a parking position where the access to the inner components would be simplified?

OK for access to inner detector but not a safe garage position

by F. Valchkova / CERN

Summary

Take-home

Many exciting activities in the detector area

- increasingly bringing in realism - getting serious is fun!

Excellent progress in full simulation (see Gerry's talk)

- enables new topics to be addressed
- soon ready for detailed optimisation studies

Vertex Region as an example

- engineering, prototyping, simulation
- more of this!
- in all areas!

Feasibility study will soon provide an excellent starting point for the next phase

Back-up