Detector Summary

A Personal Selection

2nd US FCC Workshop, MIT

March 25-27

Felix Sefkow*

* Put all the blame here.

Menu

Sequence of Courses

Introductory remarks

Detector systems and technologies

- Vtx
- Tracker
- Calorimeters

Detector concepts

- ALLEGRO, CLD, IDEA
- MDI
- TDAQ

Many thanks for the invitation

- personal bias
- all mistakes and mis-understandings are mine

Panel Discussion

My personal re-collection

Main question was about how to get involved

- how to get involved - in particular at low level?
  - how to balance with ongoing experiments and obligations
    - cross-fertilisation
- deal with ILC FCC ambiguity?
  - common software framework
- relate to which detector concept?
  - all

Concrete suggestions in many talks

- see in particular André, Paolo, Nicolas

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

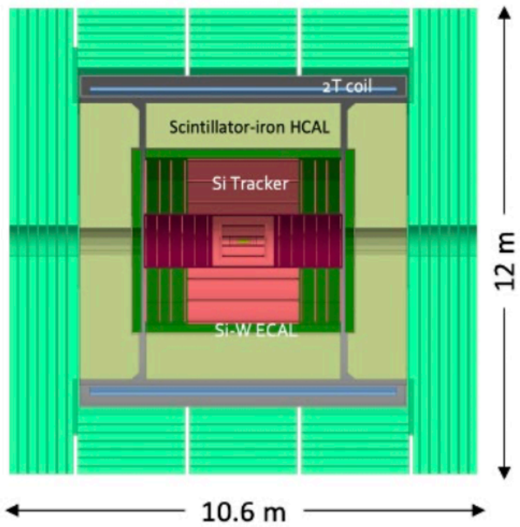
Two main ingredients:

- 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

FCCee Detector Concepts

Defined by Calorimetry

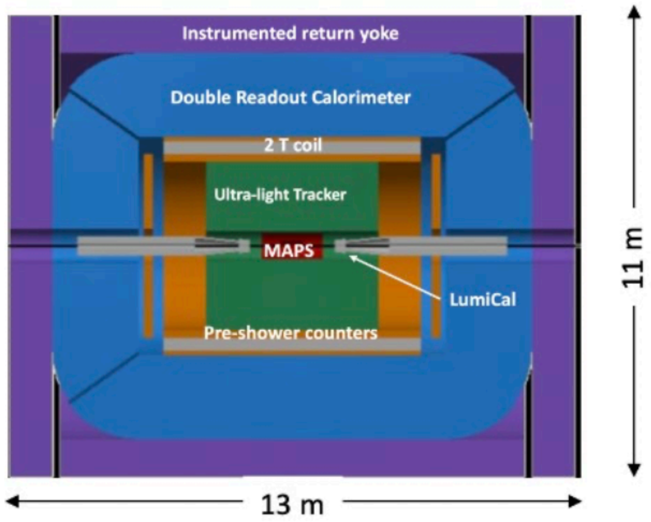
CLD



- 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)?

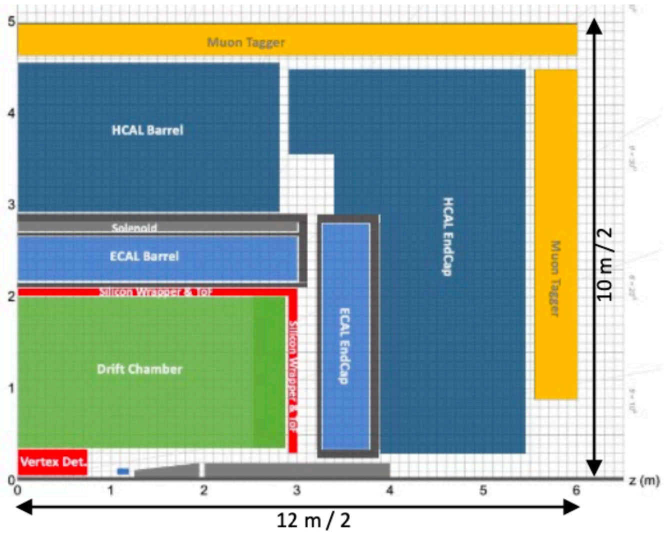
CDR

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

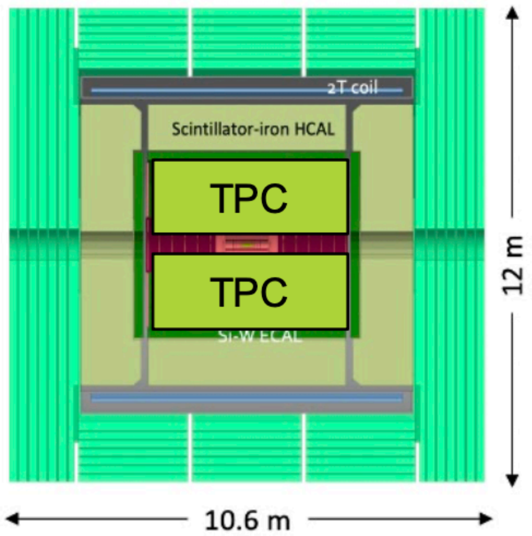


- The "new kid on the block"
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout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

FCCee Detector Concepts

Defined by Calorimetry

CLD/ILD'



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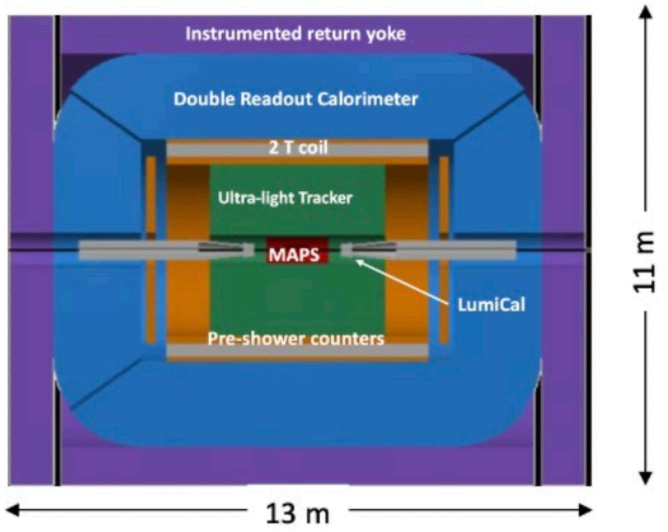

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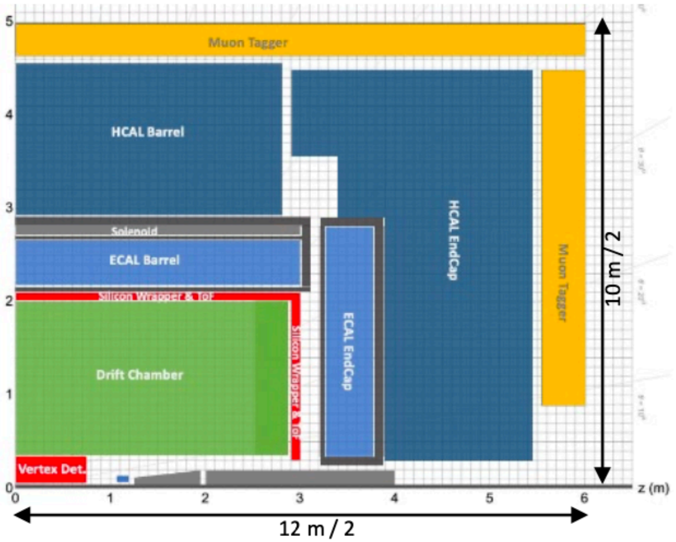

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FCCee Detector Concepts

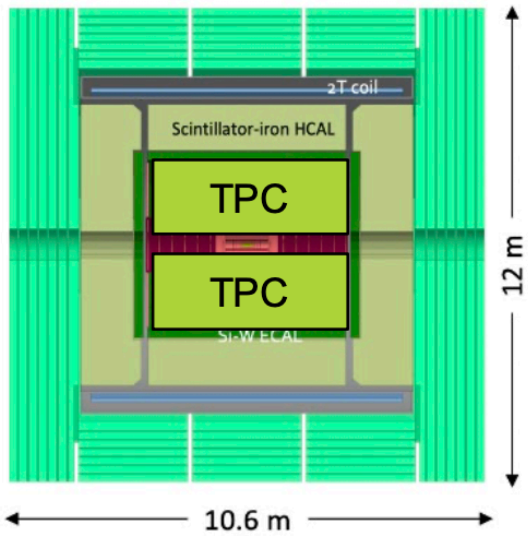
Defined by Calorimetry

Don't panic! (Patrick)
- 3 calorimeters
- 1-2 gaseous trackers
- 0-1 silicon tracker
- 1 vertex detector

US everywhere

CDR

CLD/ILD'



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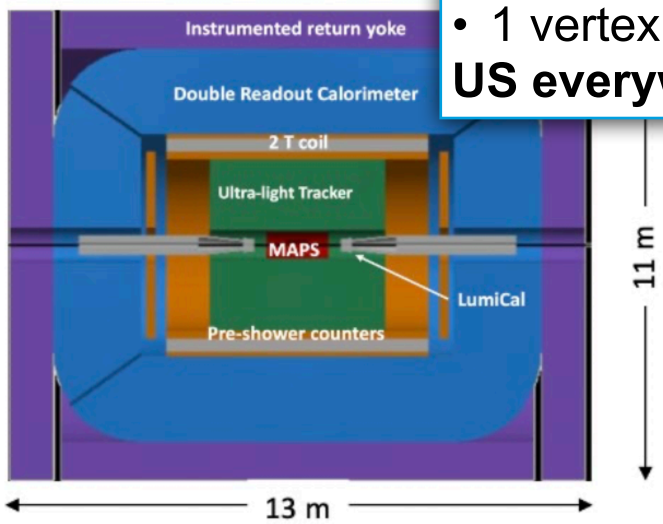

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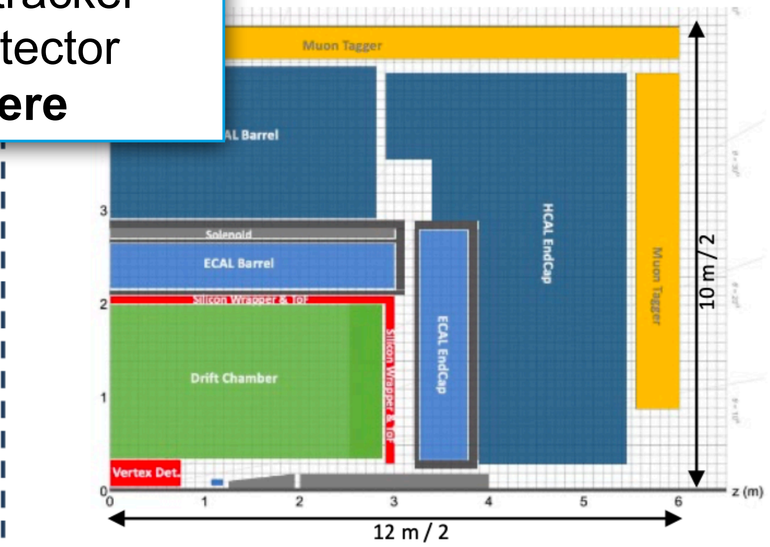

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From Linear to Circular e+e- Detectors

Conceptual Adaptations

see also:
Discussion of synergies by Caterina:
FCC has many common challenges with ILC
plus significant additional ones

Lower energy jets and particles, less collimated jets:

- reduced calorimeter depth
- shift imaging vs. energy resolution balance towards the latter
  - jet assignment ambiguities: added value of $\pi^0 \rightarrow \gamma\gamma$ mass reconstruction
- tracking even more multiple-scattering dominated: increased pressure on material budget of vertex detector and main tracker
  - fresh air to gaseous tracking

Limitations on solenoidal field B < 2T, to preserve luminosity:

- recover momentum resolution with tracker radius
- on the other hand larger magnetic volume also more easily affordable (coil and yoke)

Main difference: no bunch trains; collisions every 20 ns (~ at LHC)

- no power pulsing, more data bandwidth: both imply larger powering and cooling needs
- adds material to the trackers and compromises calorimeter compactness - or reduce granularity, timing, speed
- implications strongly technology-dependent, interesting optimisation challenges
- **Trigger and DAQ re-enter the stage**

Detector R&D Collaborations

T.Bergauer

Fully Approved
- Gaseous Detectors (DRD1) [ex RD51]
- Liquid Detectors (DRD2)
- Photodetectors & Particle ID (DRD4)
- Calorimetry (DRD6)

Conditionally approved
- Semiconductor Detectors (DRD3) [ex RD50, RD42,..]

Full proposals submitted last week for review
- Quantum Sensors (DRD5)
- Electronics (DRD7)

Letter of Intent submitted
- Integration (DRD8)

2nd Meeting of the DRD Committee
March 4, 2024
Talks by all approved DRDs
https://indico.cern.ch/event/1356910/
and references therein

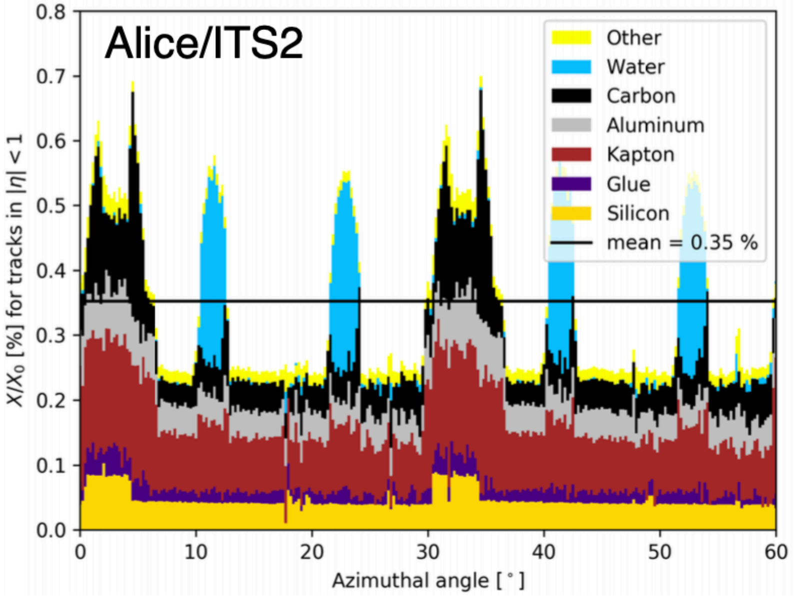
Detector subsystems and technologies

Sensors technology requirements for Vertex Detector

Several technologies are being studied to meet the physics performance

- Sensor's contribution to the total material budget is 15-30%
  - Services cables + cooling + support make up most of the detector mass
- Sensors will have to be less than 75 μm thick with at least 3-5 μm hit resolution (17-25 μm pitch) and low power consumption
- Beam-background suppression
  - ILC/C^3 - evolve time stamping towards O(1-100) ns (bunch-tagging)
  - FCC, continuous r/o integrated over ~10μs with O(1) ns timing resolution for beam background suppression

CERN-LHCC-2019-018



Physics driven requirements		Running constraints	Sensor specifications	
σ	$< 3\ \mu m$		Small Pixel	~15μm
Material budget	$0.1\% X_0$/layer		Thinning to	50 μm
		Cooling	Low Power	20-50 mW/cm^2
r of the Inner most layer	12-14 mm	Beam-background	Fast Readout	~1-10 μs
		Radiation damage	Radiation Tolerance	10 MRad, $10^{14}\ n_{eq}$ / /cm^2

Time resolution vs. power

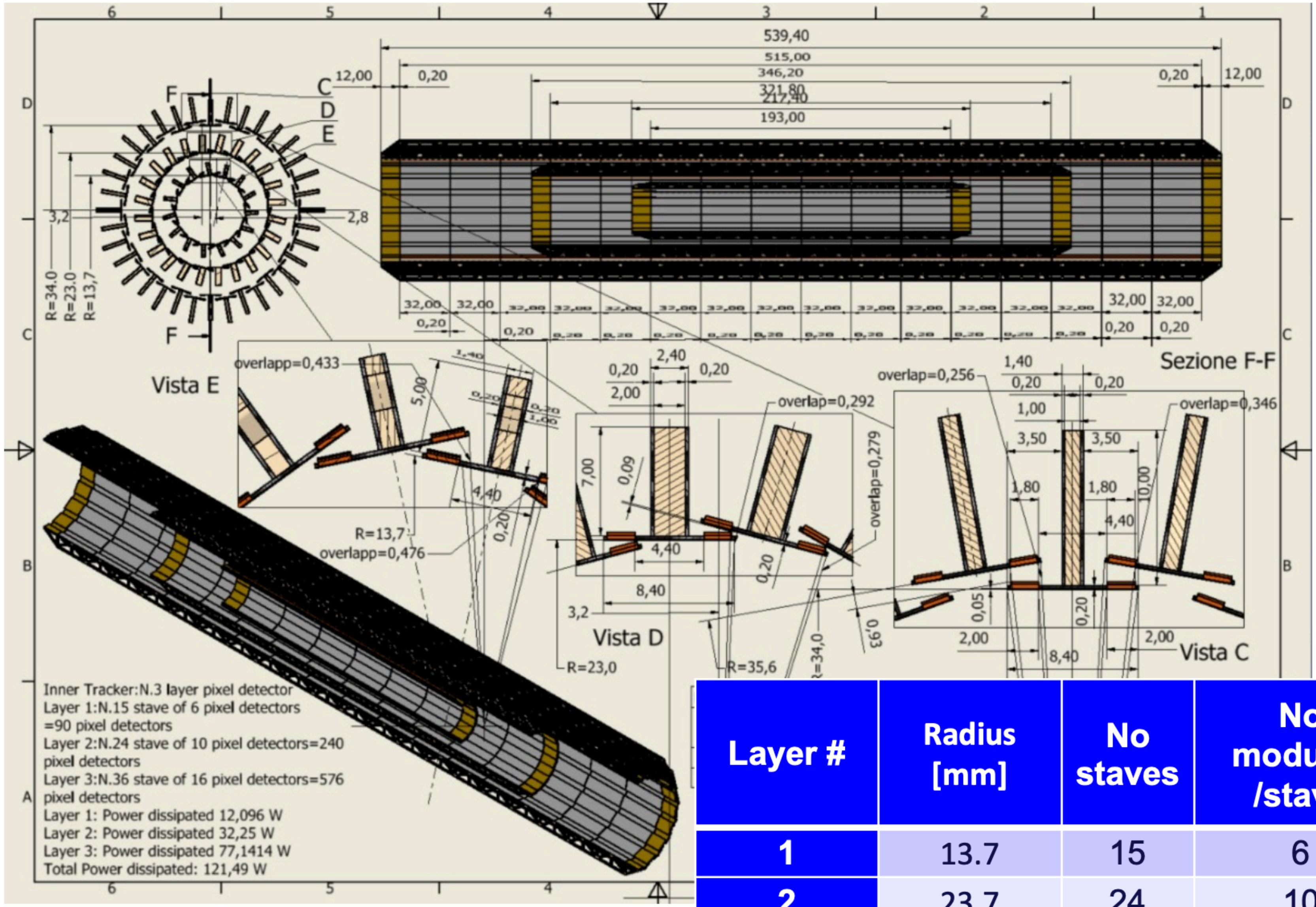
O(ns) time resolution for beam-background suppression requires dedicated optimizations

Current designs that can achieve ns or sub-ns time resolutions compensate with higher power consumption

- Target power consumption is less than 20 mW/cm^2

Chip name	Experiment	Subsystem	Technology	Pixel pitch [μm]	Time resolution [ns]	Power Density [mW/cm^2]
ALPIDE	ALICE-ITS2	Vtx, Trk	Tower 180 nm	28	< 2000	5
Mosaic	ALICE-ITS3	Vtx	Tower 65 nm	25x100	100-2000	<40
FastPix	HL-LHC		Tower 180 nm	10 - 20	0.122 – 0.135	>1500
DPTS	ALICE-ITS3		Tower 65 nm	15	6.3	112
NAPA	SiD	Trk, Calo	Tower 65 nm	25x100	<1	< 20
Cactus	FCC/EIC	Timing	LF 150 nm	1000	0.1-0.5	145
MiniCactus	FCC/EIC	Timing	LF 150 nm	1000	0.088	300
Monolith	FCC/Idea	Trk	IHP SiGe 130 nm	100	0.077 – 0.02	40 - 2700
Arcadia	FCC/Idea	Trk	LF 110 nm	25	-	30

Dedicated ongoing effort to target O(ns) resolution with MAPS (slides)
First prototype (Napa-p1) produced in TJ 65 nm process 5x5 mm^2, 25 μm pitch



INFN
Istituto Nazionale di Fisica Nucleare

Total thickness per layer 0.25% X/X0

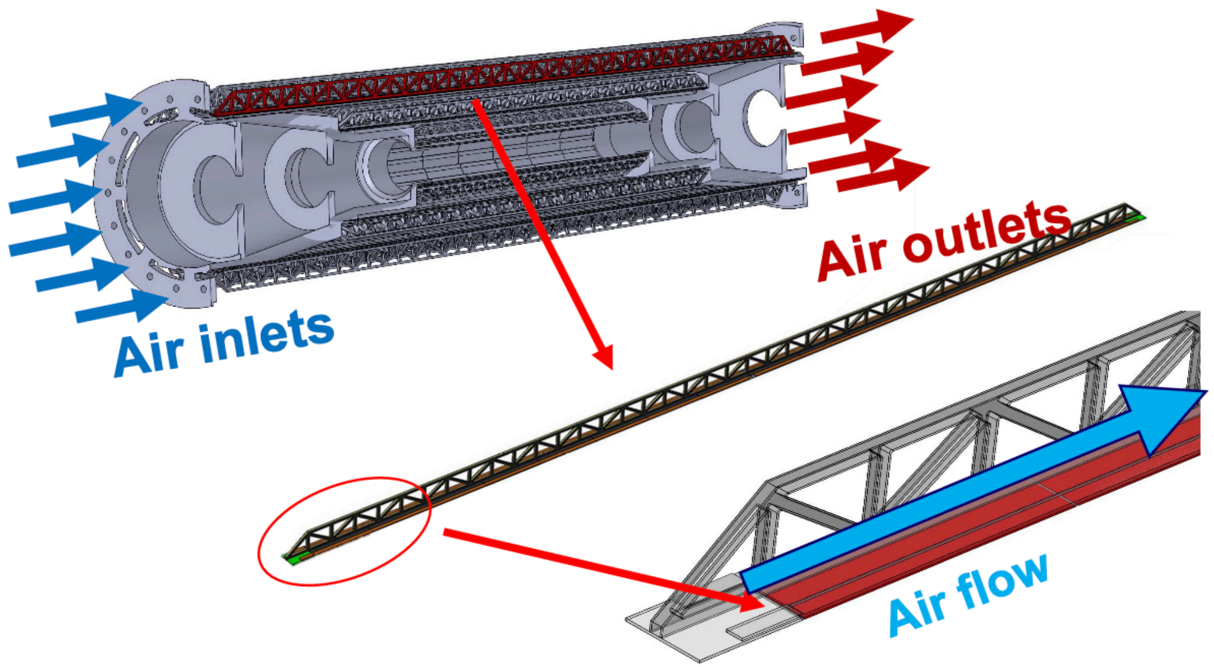
Carbon Fibre ~60 %

Silicon: ~20%

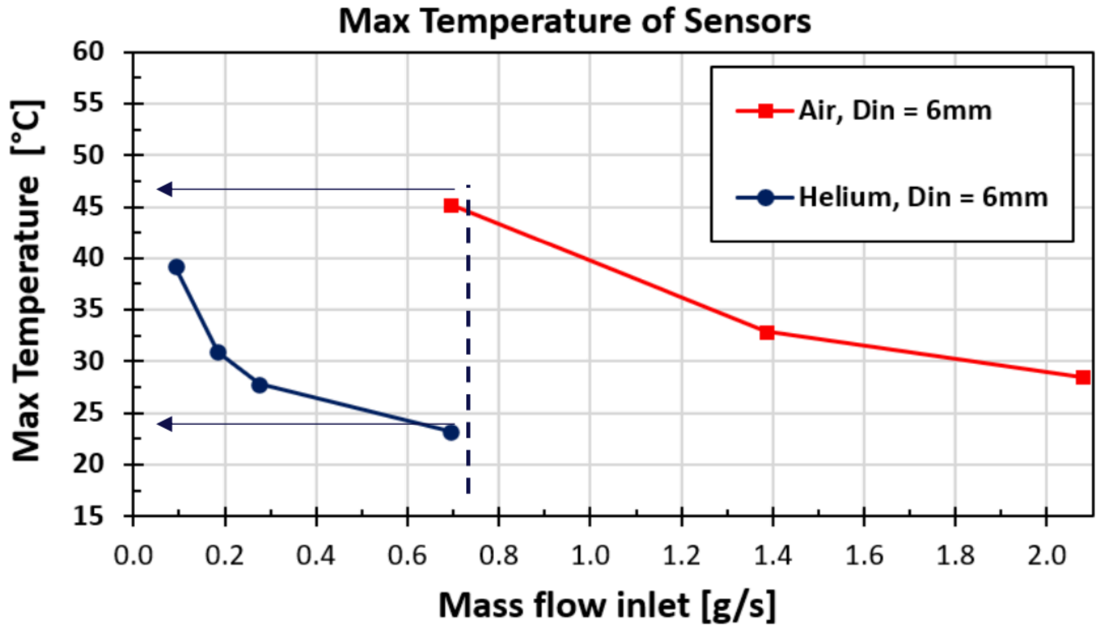
Power and readout bus: ~20%

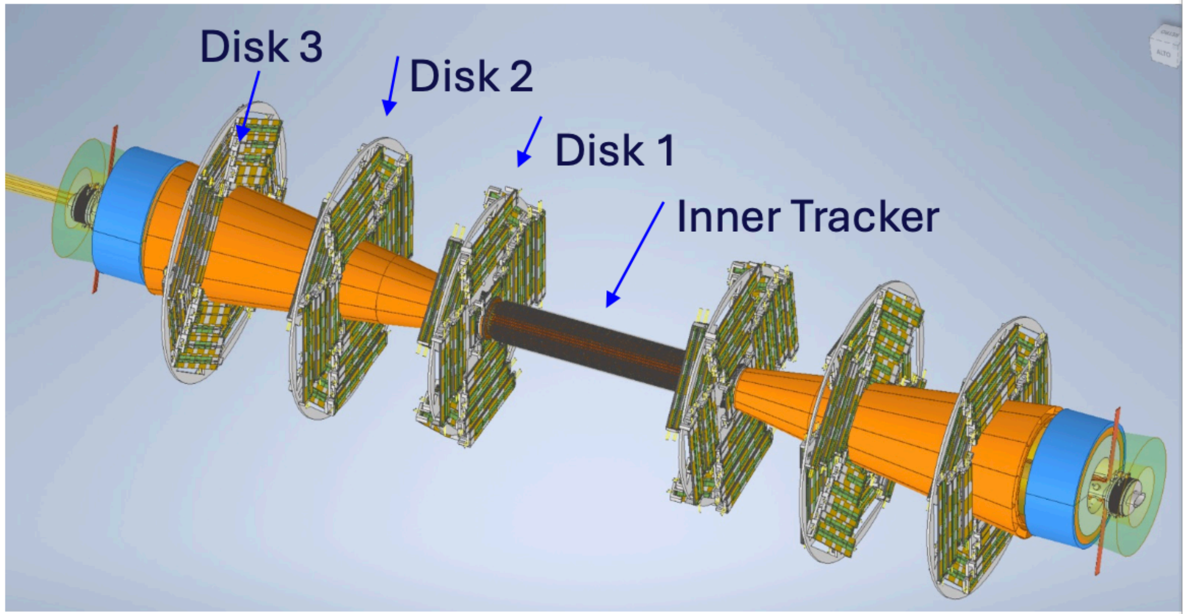
Layer #	Radius [mm]	No staves	No modules /stave	Total Length [mm]	Active Area [cm²]	Power [W]
1	13.7	15	6	217.40	241.92	12
2	23.7	24	10	346.20	645.12	32
3	34 & 35.60	36	16	539.40	1548.29	77

Air cooling (simulations)



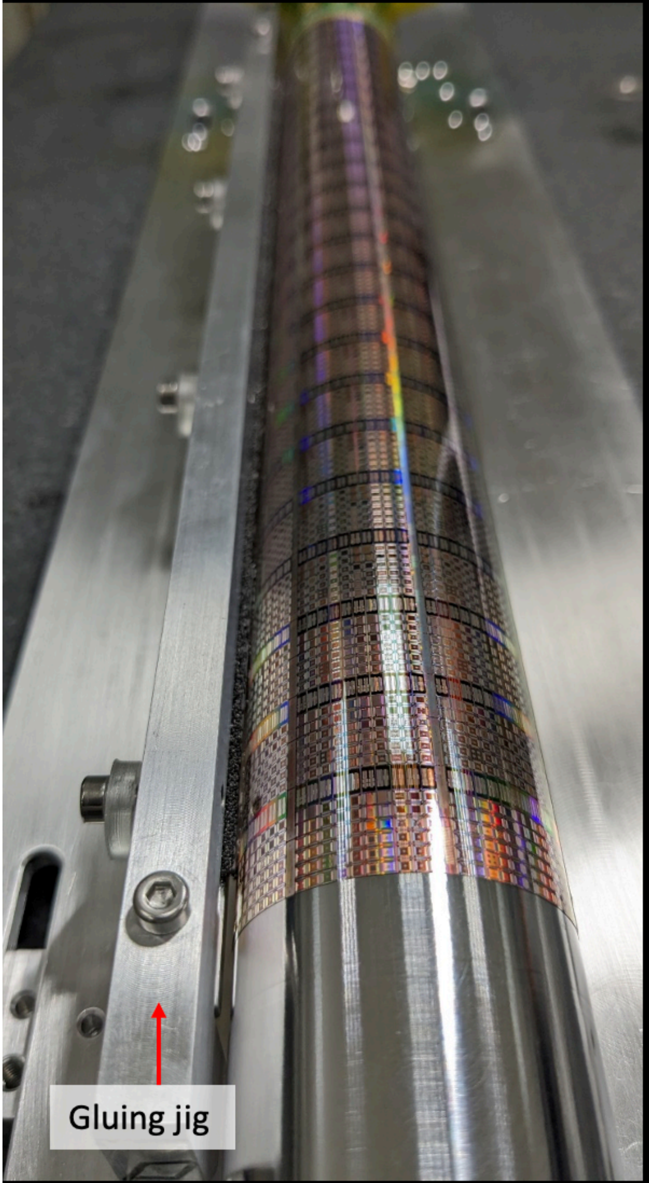
- Cooling with air/He flow along the detector.
  - Air temperature: T_{air} = 15°C
  - Max sensor temp on layer 3 (hottest one) ~25/30 ºC with He/Air.
  - Vibrations studies ongoing

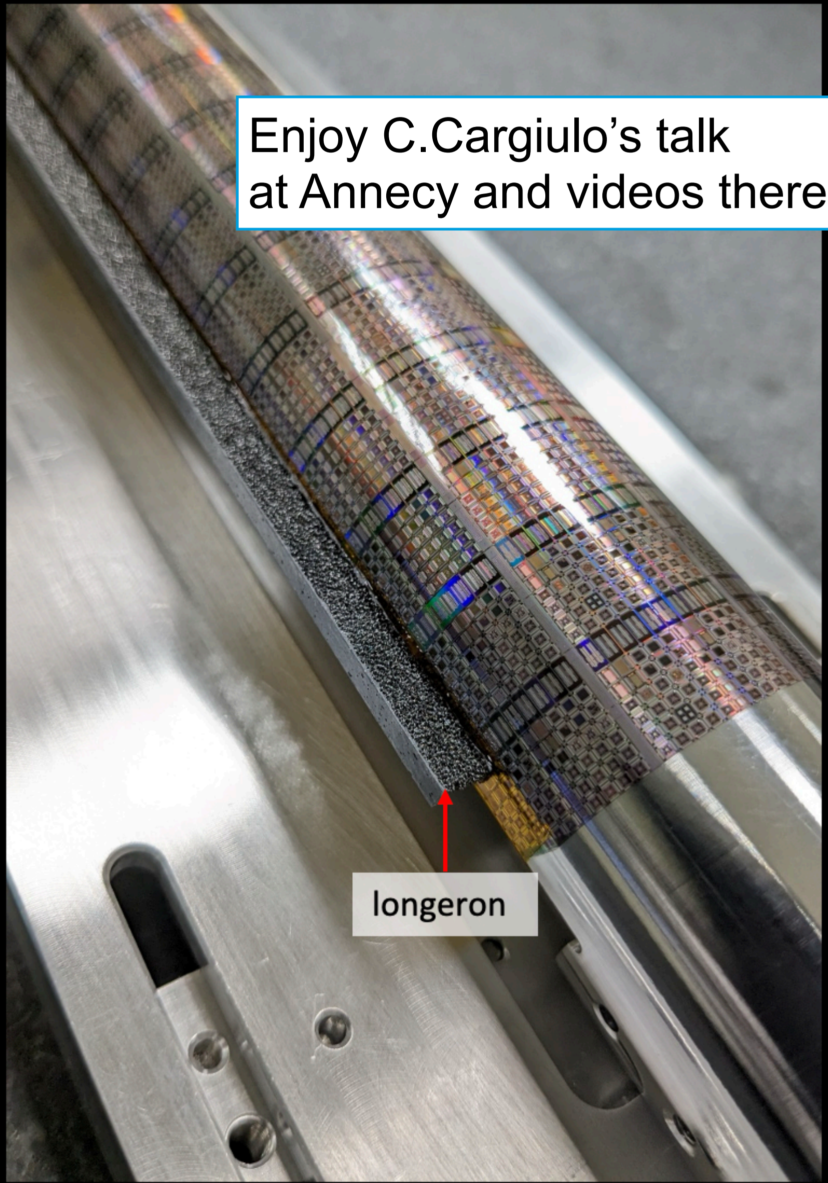




Assembly of a half-layer

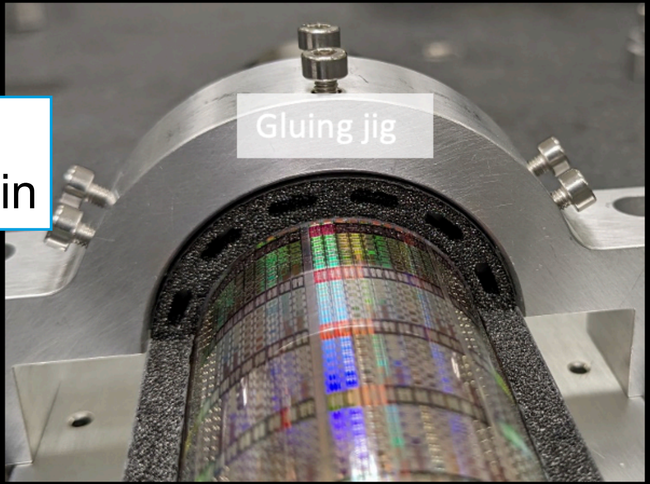
Gluing of the longerons

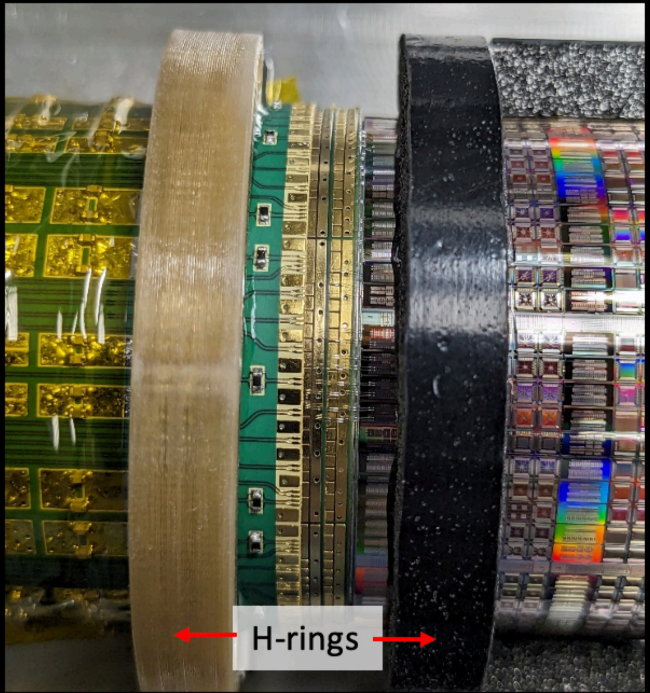


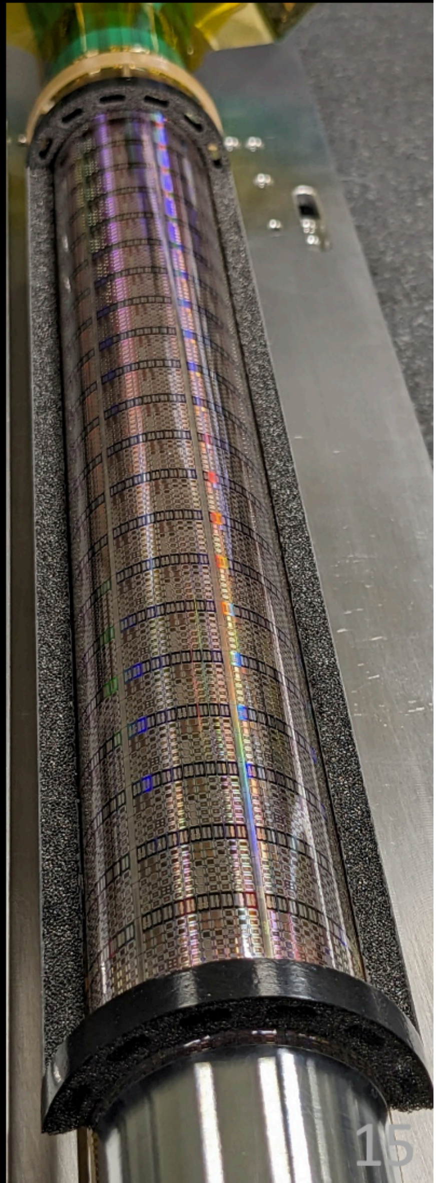


Enjoy C.Cargiulo's talk
at Annecy and videos therein

Gluing of the H-rings







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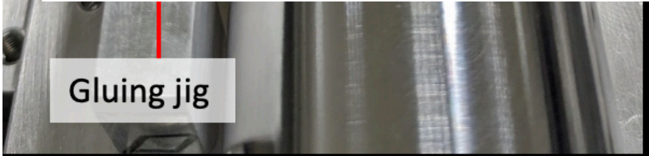

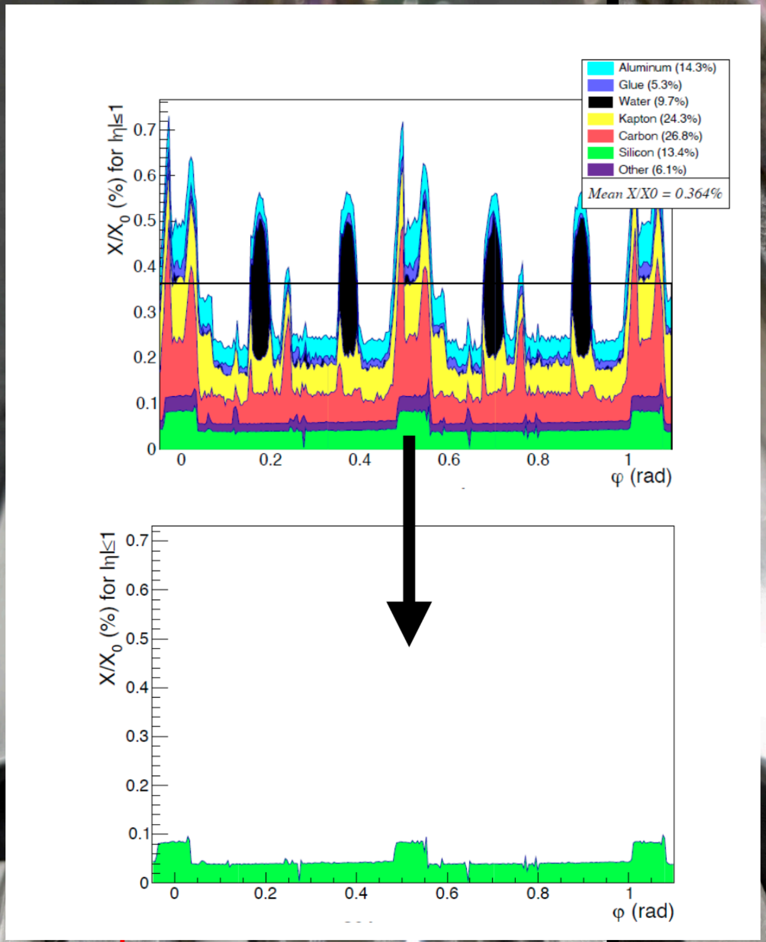

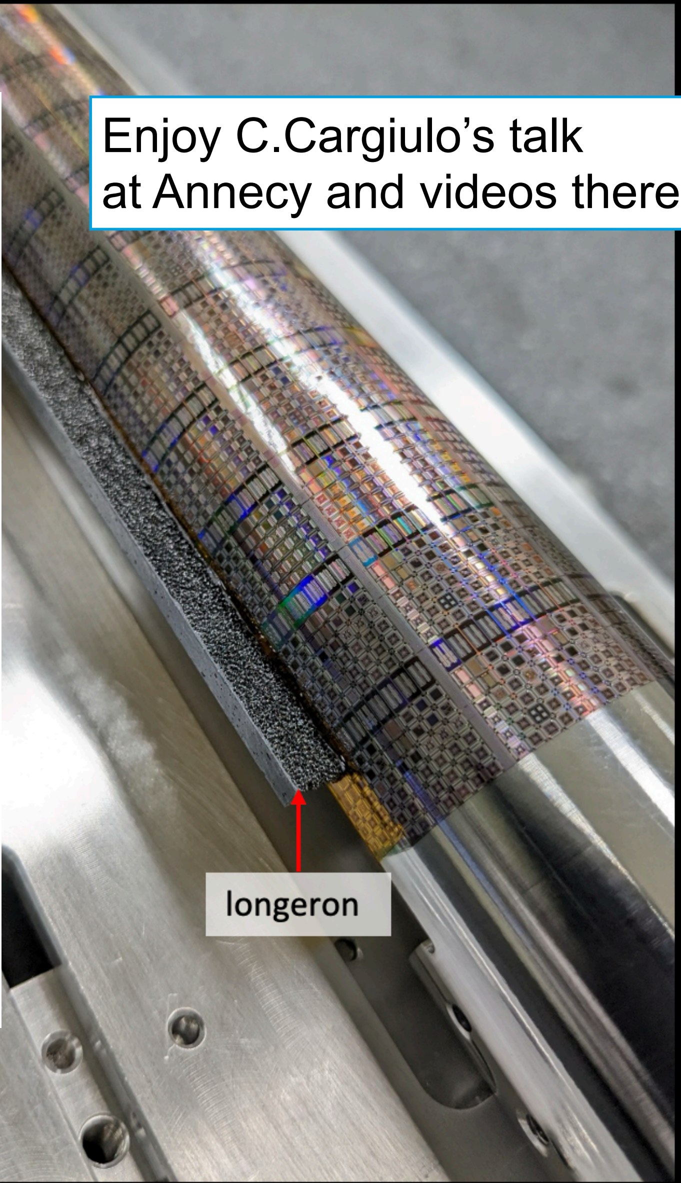

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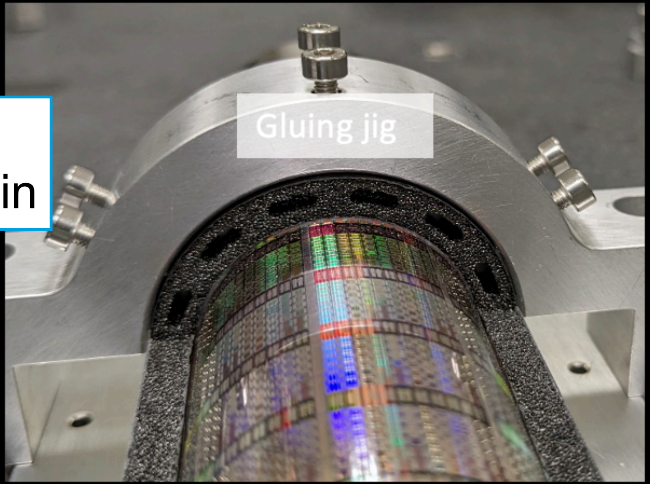
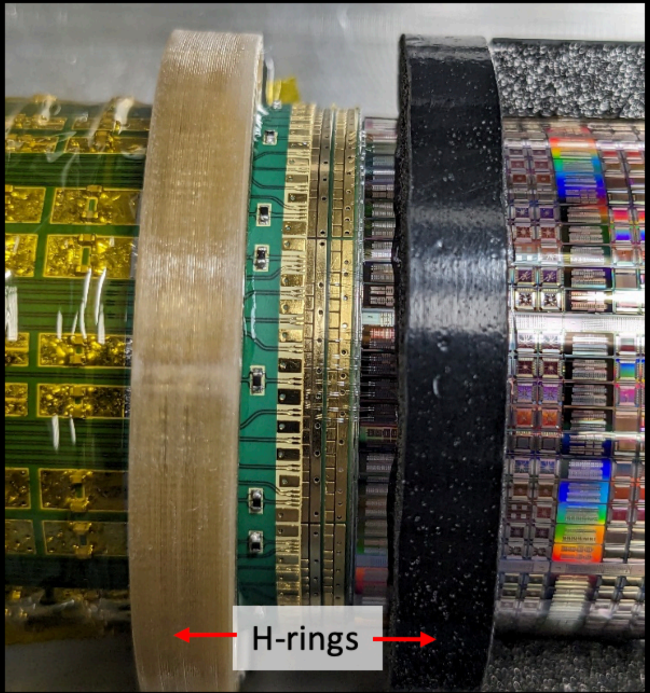
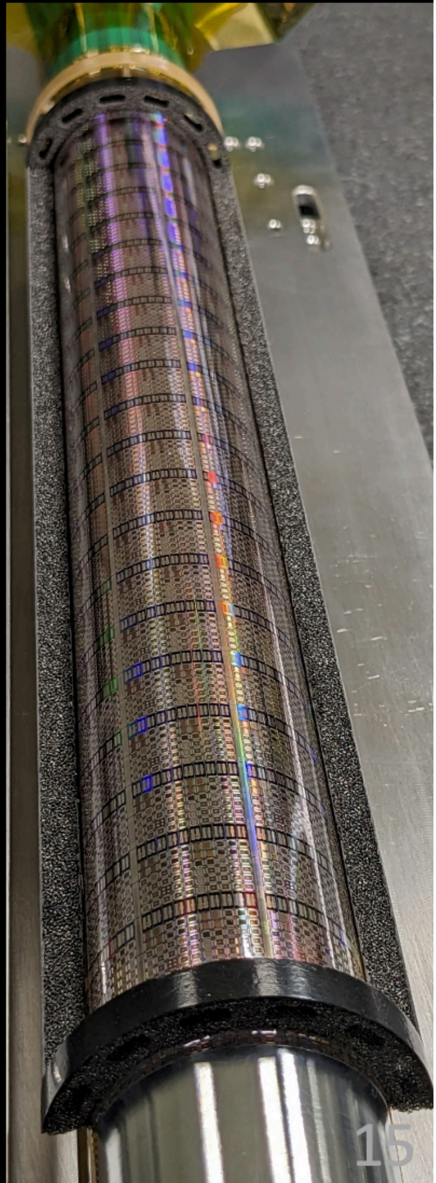
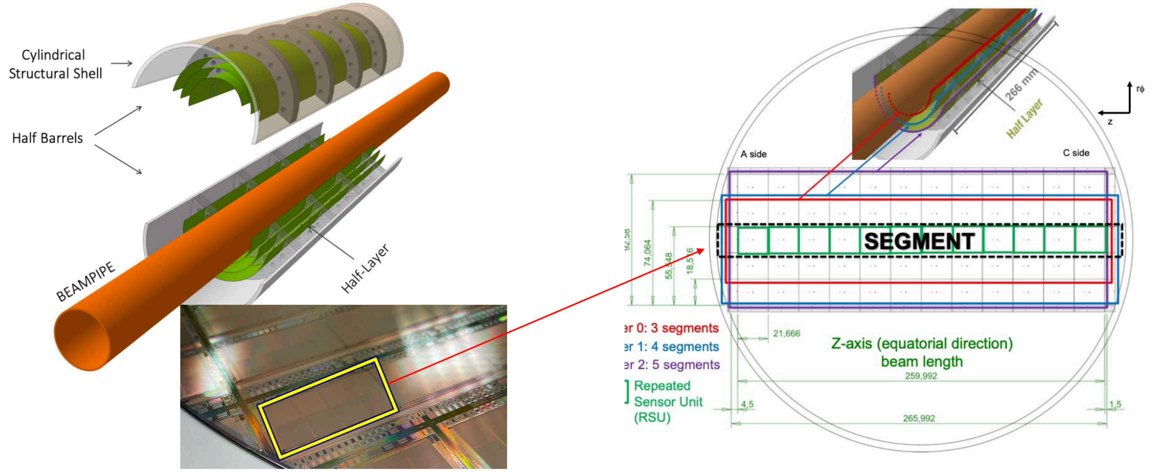






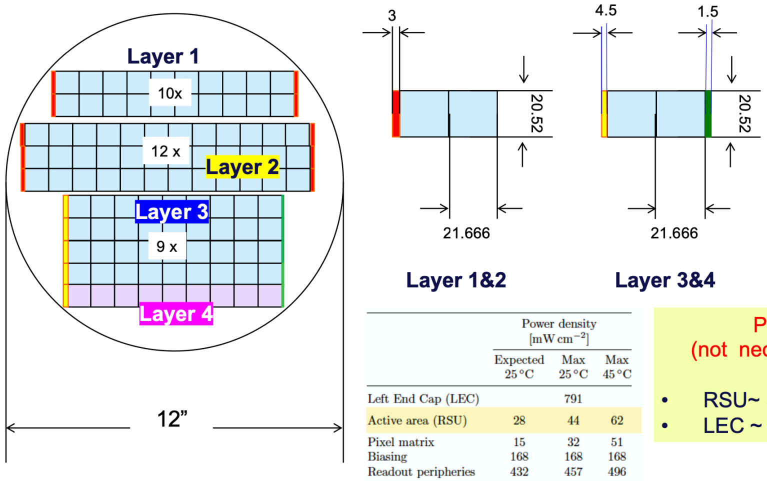


Proposed layout using an ALICE ITS3 inspired design

(~0.05 % X/X_0 *material budget per layer – 5 times less than the Mid-Term one)*

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

Same reticle for all layers



Layer	Radius (mm)
1	13.7
2	20.23
3	26.76
4	33.3

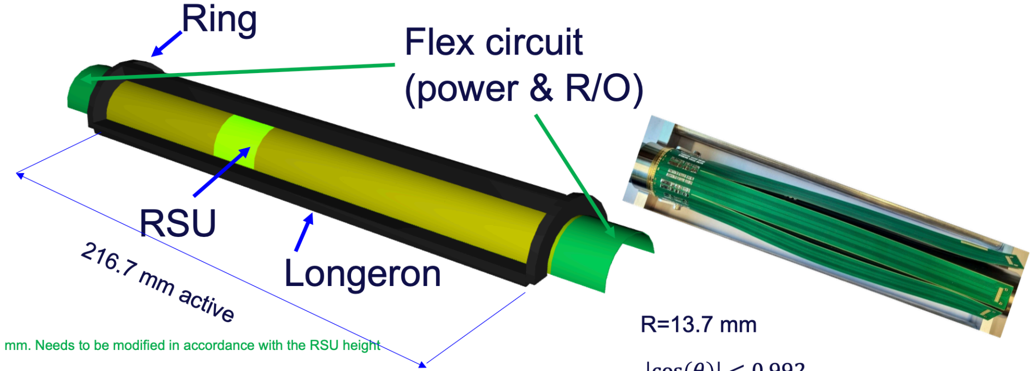
	Power density [mW cm^{-2}]		
	Expected 25 °C	Max 25 °C	Max 45 °C
Left End Cap (LEC)		791	
Active area (RSU)	28	44	62
Pixel matrix	15	32	51
Biasing	168	168	168
Readout peripheries	432	457	496
Data backbone	719	719	719

Power dissipation in ITS3
(not necessarily the same for FCC-ee)

- RSU~ 50 mW/cm^2 (depends on Temp.)
- LEC ~ 700 mW/cm^2

Layer 1

- 10 RSU + 2 EC (same size) long per half layer
  - Readout and power from both sides (reduces transmission off-detector and limits power dissipation in the endcaps)
- Leaves two ~2 mm* insensitive gaps in R-phi, to account for assembly tolerances

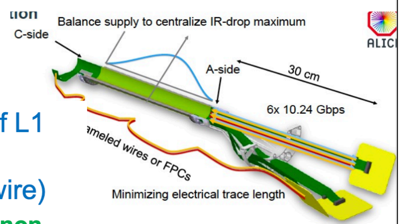


R=13.7 mm

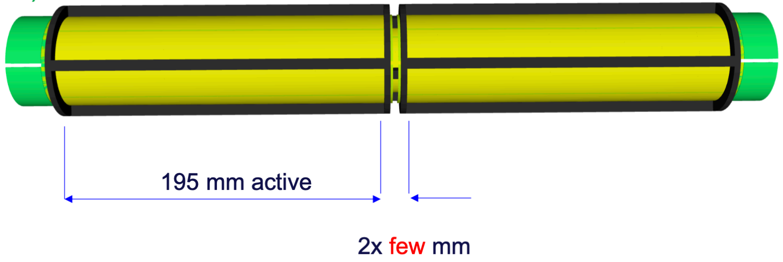
$|\cos(\theta)| < 0.992$

* In ITS3 is 1 mm. Needs to be modified in accordance with the RSU height

Layers 3 & 4



- Four "quarter" layers of 9 RSU to allow same angular coverage of L1
- Layer 4 has the same length of Layer 3 but higher radius
- Quarter readout only on one side. The other side only for power (wire)
  - Gap of ~ 2xO(10 mm) at z=0: can be mitigated by having **quarters with non-symmetric layout** (e.g. left quarter with 10 RSU and right one with 8 RSU, and swapped for L4) **or with (slightly) twisted wrap** (complicated wire bonding of the flex circuit)

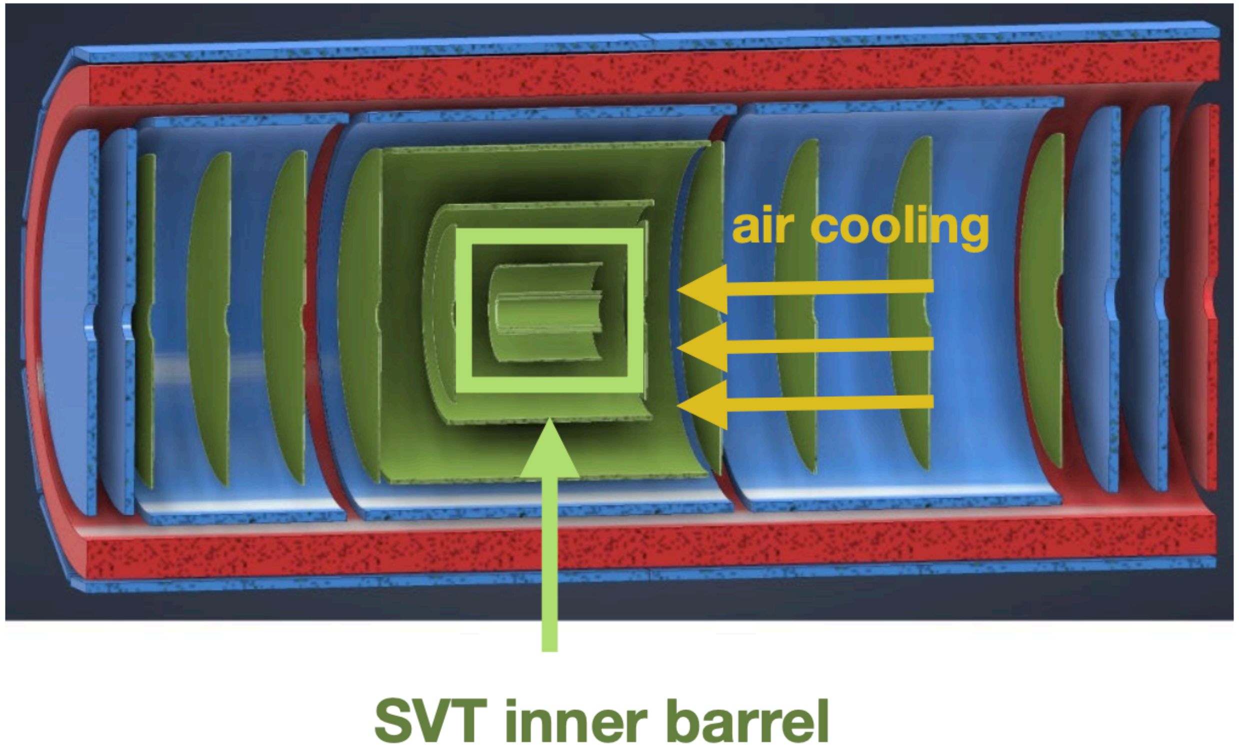


Layer 3
R=26.76 mm
$|\cos(\theta)| < 0.992$

Layer 4
R=33.3 mm
$|\cos(\theta)| < 0.987$

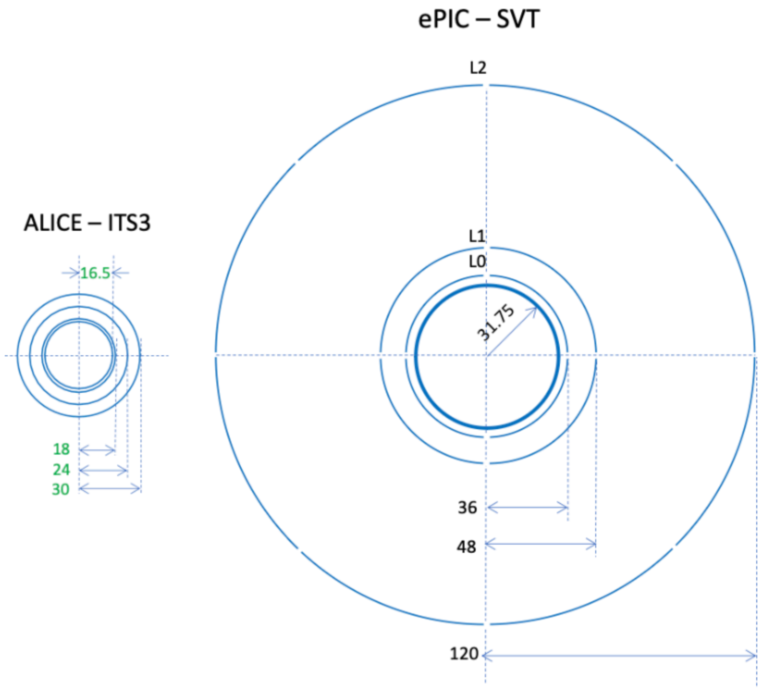
The SVT inner barrel ("bent" layers 0, 1, 2)

Innocenti



- built with **bent ITS3 wafer-size sensors**
- minimal support structure (carbon foam)
- air cooling (~ few m/s)

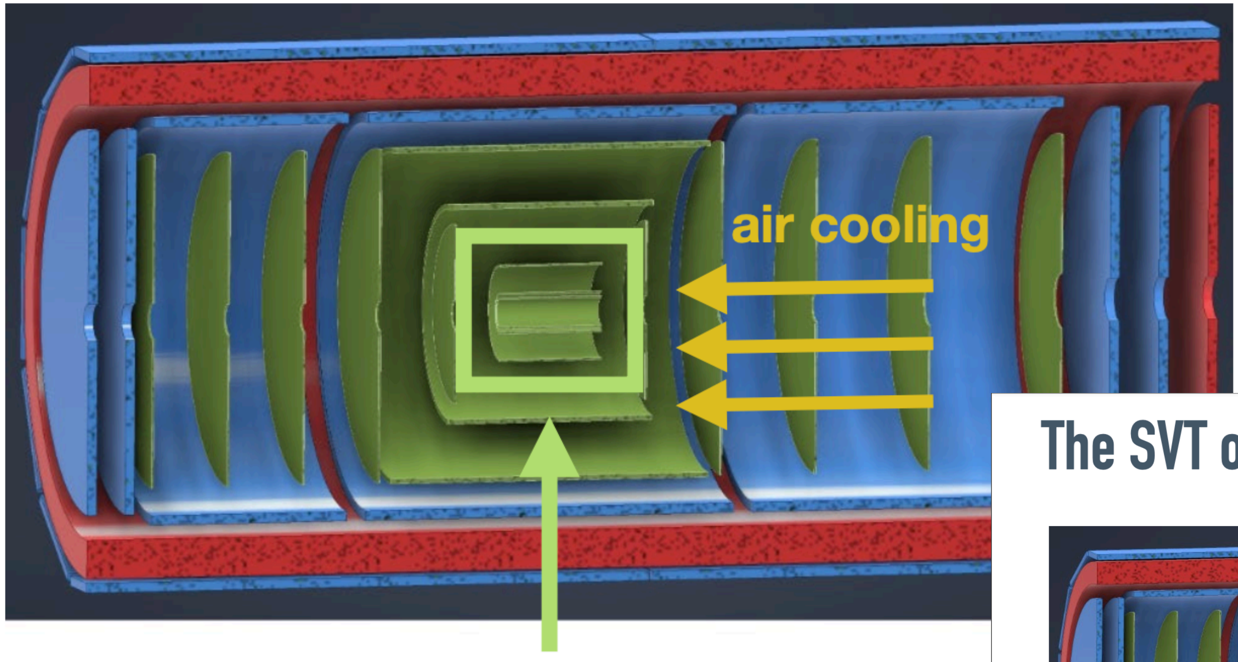
- **Radii = 3.6, 4.8, 12 cm**
- **Lengths = 27 cm**



ePIC specific needs:
- reduce services at forward/backward
- mechanical stability in the presence of a R=12 cm layer (R_{ITS3}^{max} is < 4 cm!)
- air cooling strategy is more challenging due to the presence of the disks

The SVT inner barrel ("bent" layers 0, 1, 2)

Innocenti



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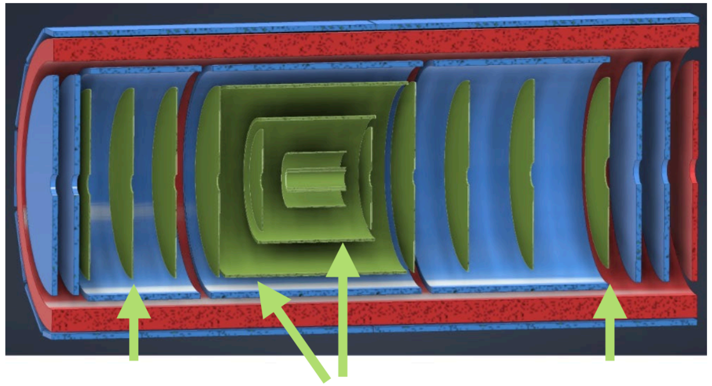
The SVT outer barrel (layers 3, 4) and disks

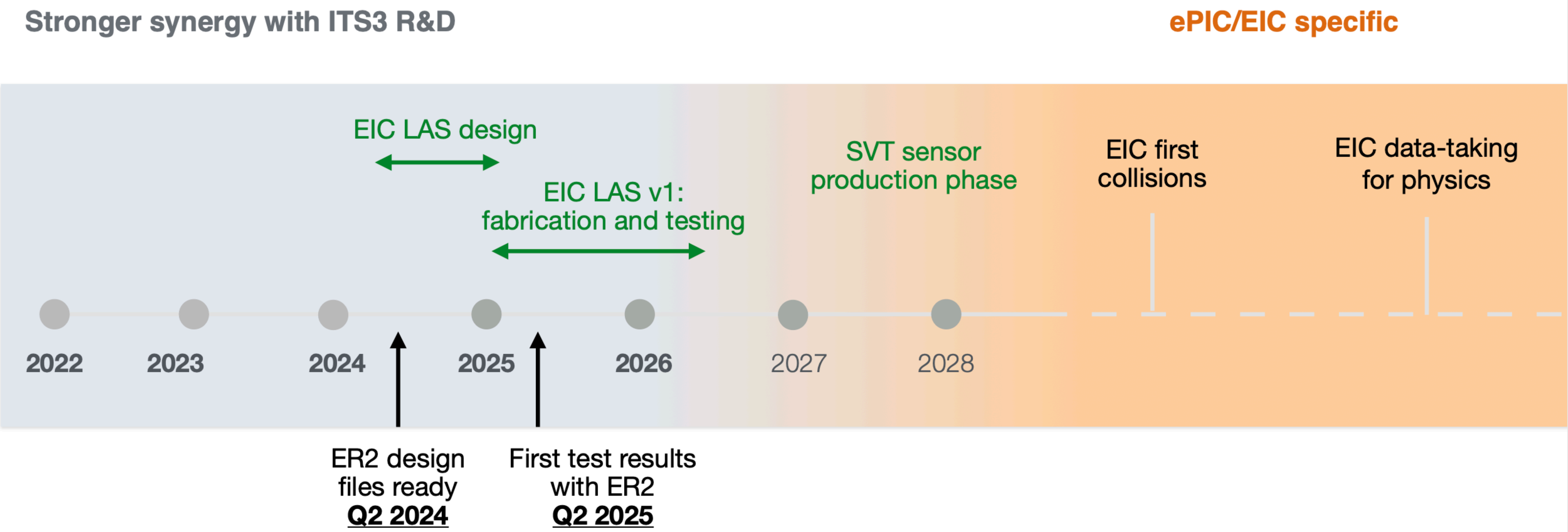


"Flat" Large Area Sensors (LASs) derived from ITS3 optimised for covering large surfaces
- **traditional staved** structure (not bent)
- carbon fibre support
- integrated cooling (liquid or air)

Challenges:
- preserve the low material budget in the presence of carbon fiber supports and services
- disk geometry can obstruct air cooling for the inner barrel

→ **SVT for ePIC** as the most advanced application of stitched MAPS sensors for large-area wide-acceptance detectors
→ **unique benchmark for a future MAPS-based FCC tracker**

SVT at the ePIC: timescale and synergies with the ITS3 project



Key strategy of MIT PixELphi lab for the SVT project:

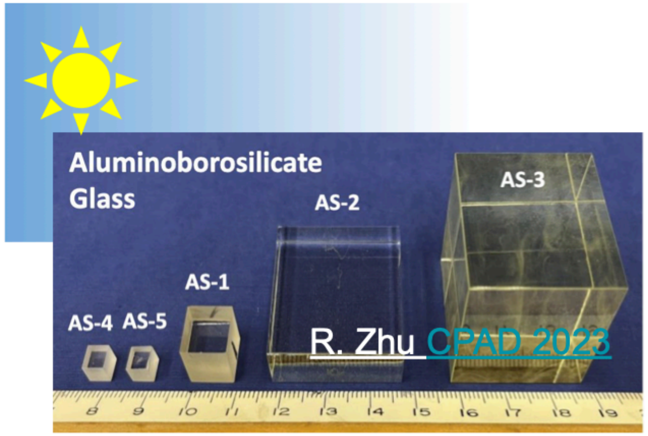
- build a CERN-based MIT pixel lab to maximize synergies with the R&D for ALICE ITS3 for ER2/ER3
- specific R&D for SVT detector (focus on data and service reduction)

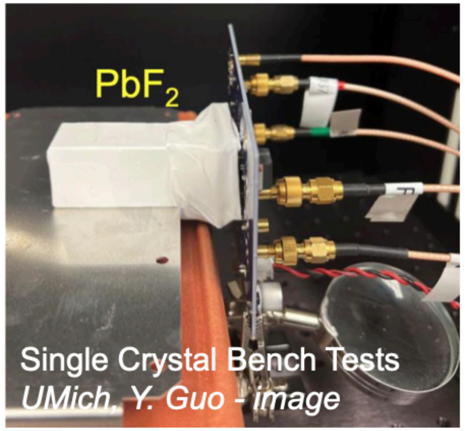
Heavy Glasses for
DR Fiber HCAL
Homogenous HCAL

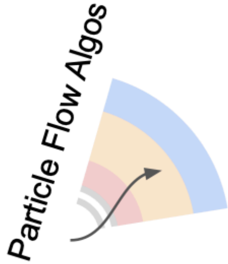
CalVision - Overview

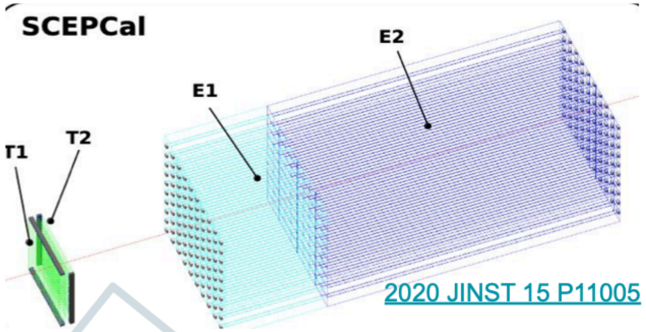
Joined w/ MaxiCC!

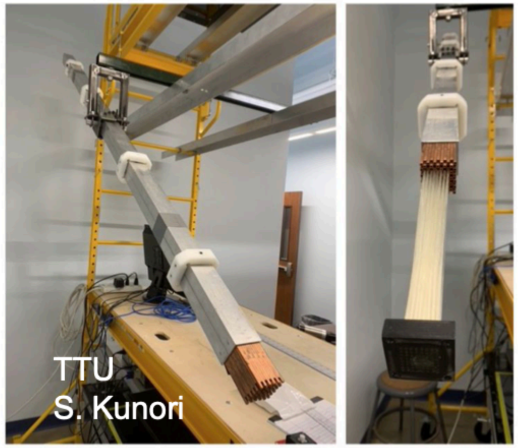
Technologies → Detector Implementation

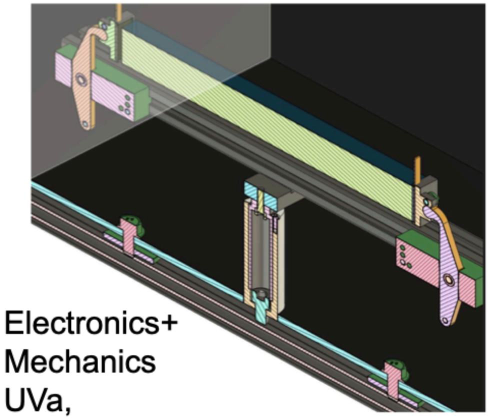




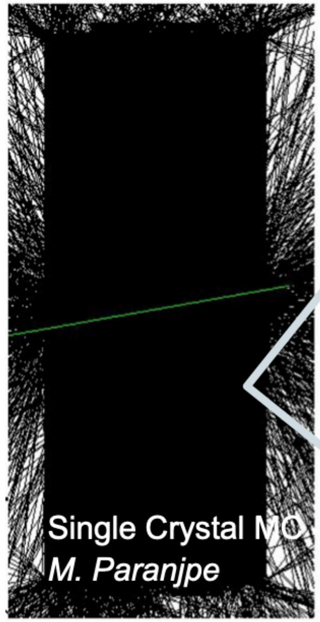




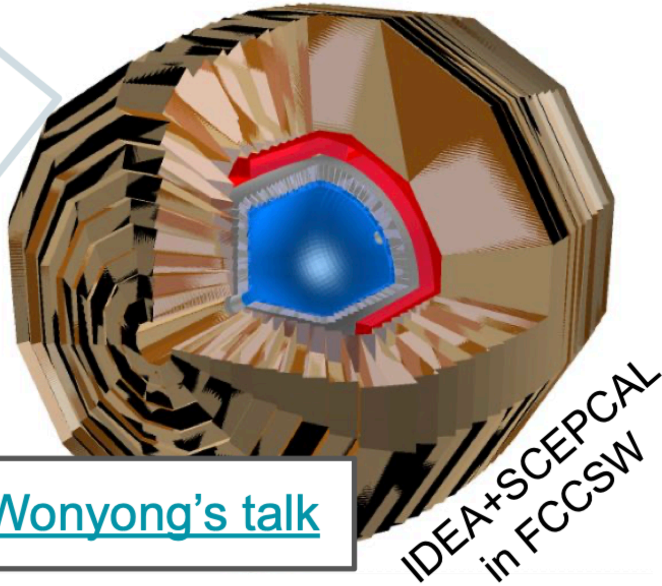




Electronics+
Mechanics
UVa,
E. Fernandez- image



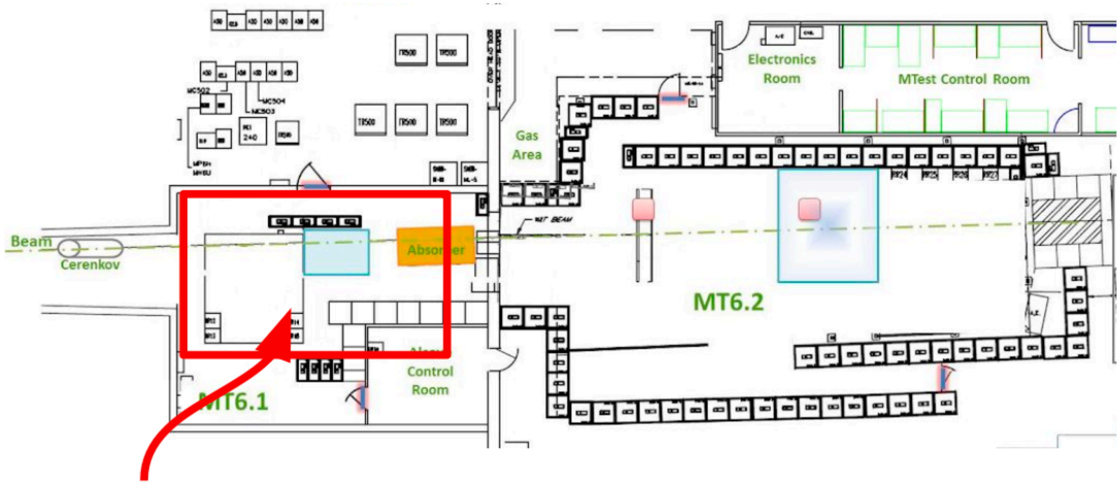
Simulation Fundamentals-
See Sergei's talk



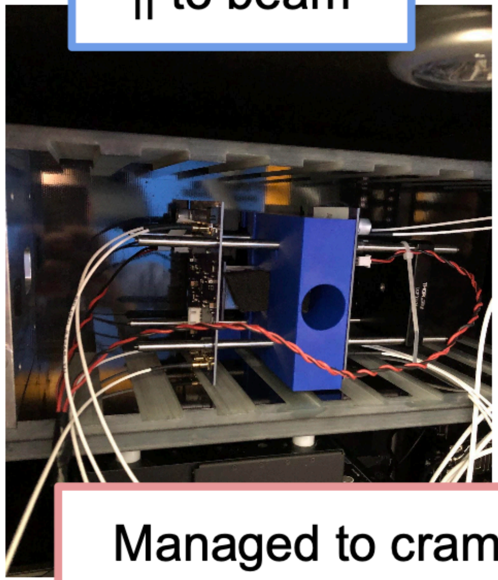
See Wonyong's talk

April '23 Test Beam

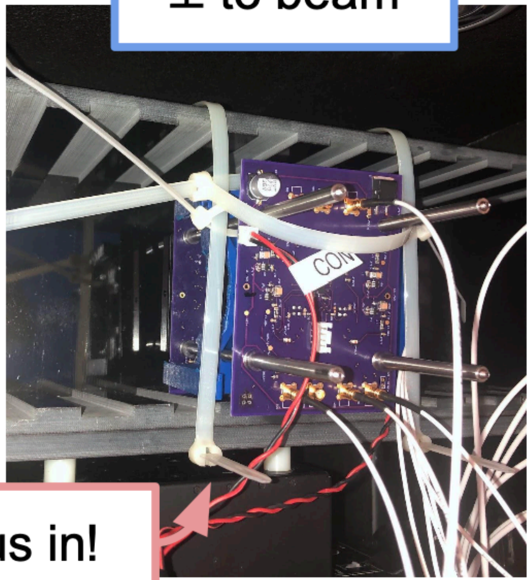
- Partnered with CMS Endcap Timing Layer
  - Thanks to C. Madrid + A. Apresyan
  - Used there DAQ + MCP+ box
  - 8 channel LeCroy scope readout
    - 7 SiPM readout + MCP for trigger
- 120 GeV Protons
  - Fermilab Test Beam Facility
  - 4s spills, 1 spill a minute
  - ~60,000 events per spill
  - 3 cm x 3 cm beam spot
  - pixel telescope for position
- 1.5 days of data ~30 hours of work



|| to beam



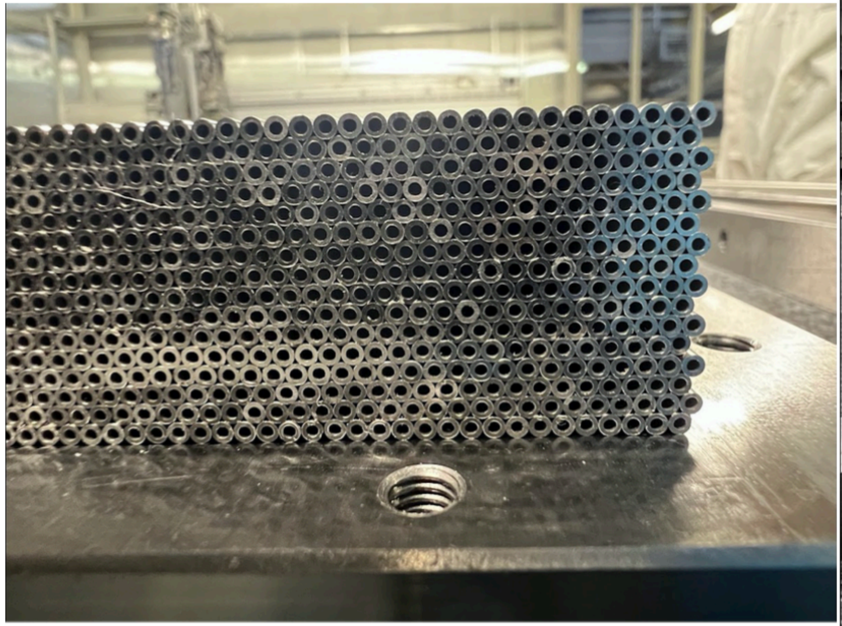
⊥ to beam

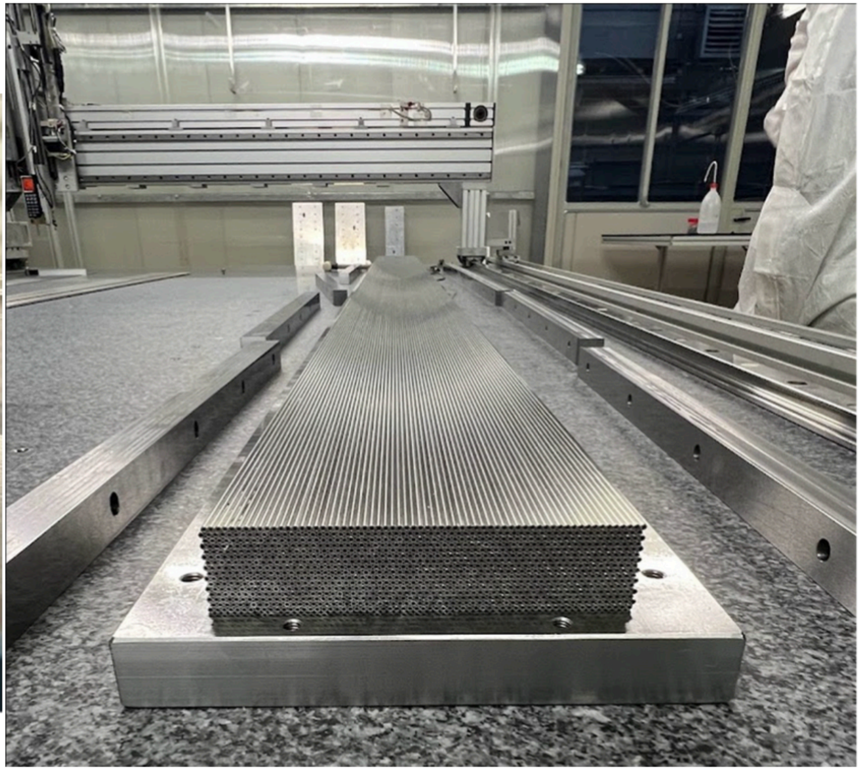


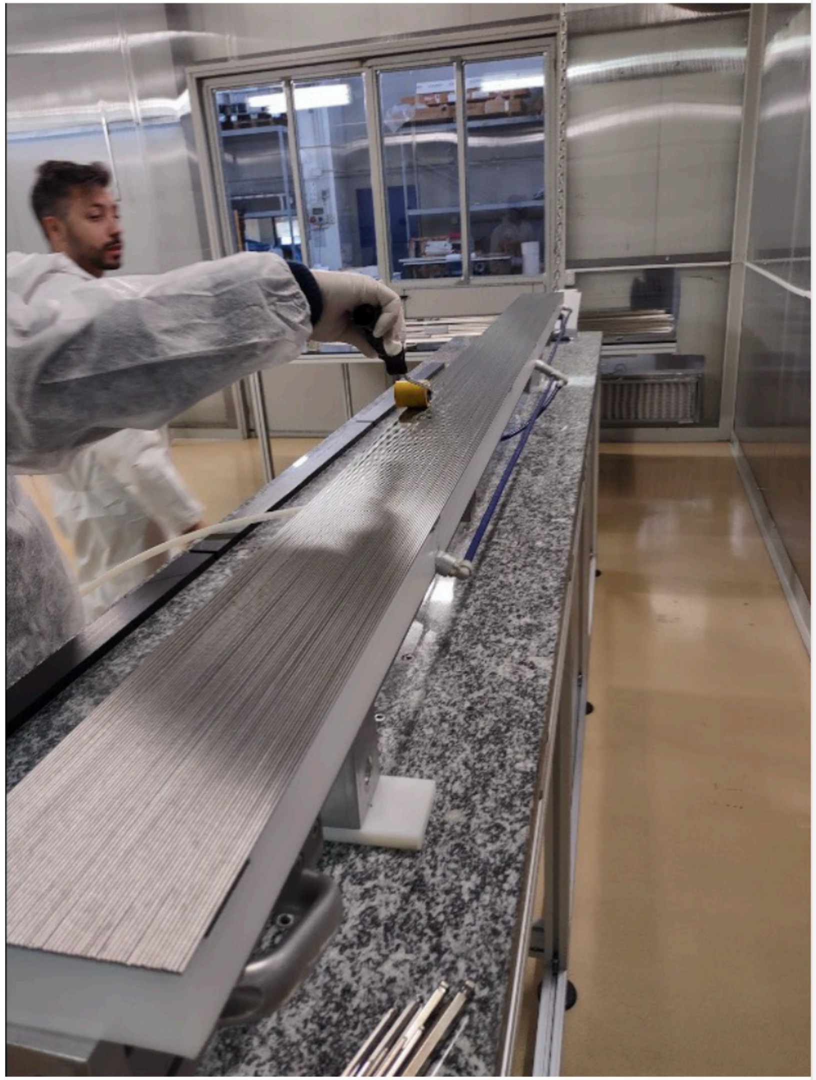
Managed to cram us in!

DR calorimeter

- Full containment hadronic prototype in progress
  - Hidra2 call INFN CSN5

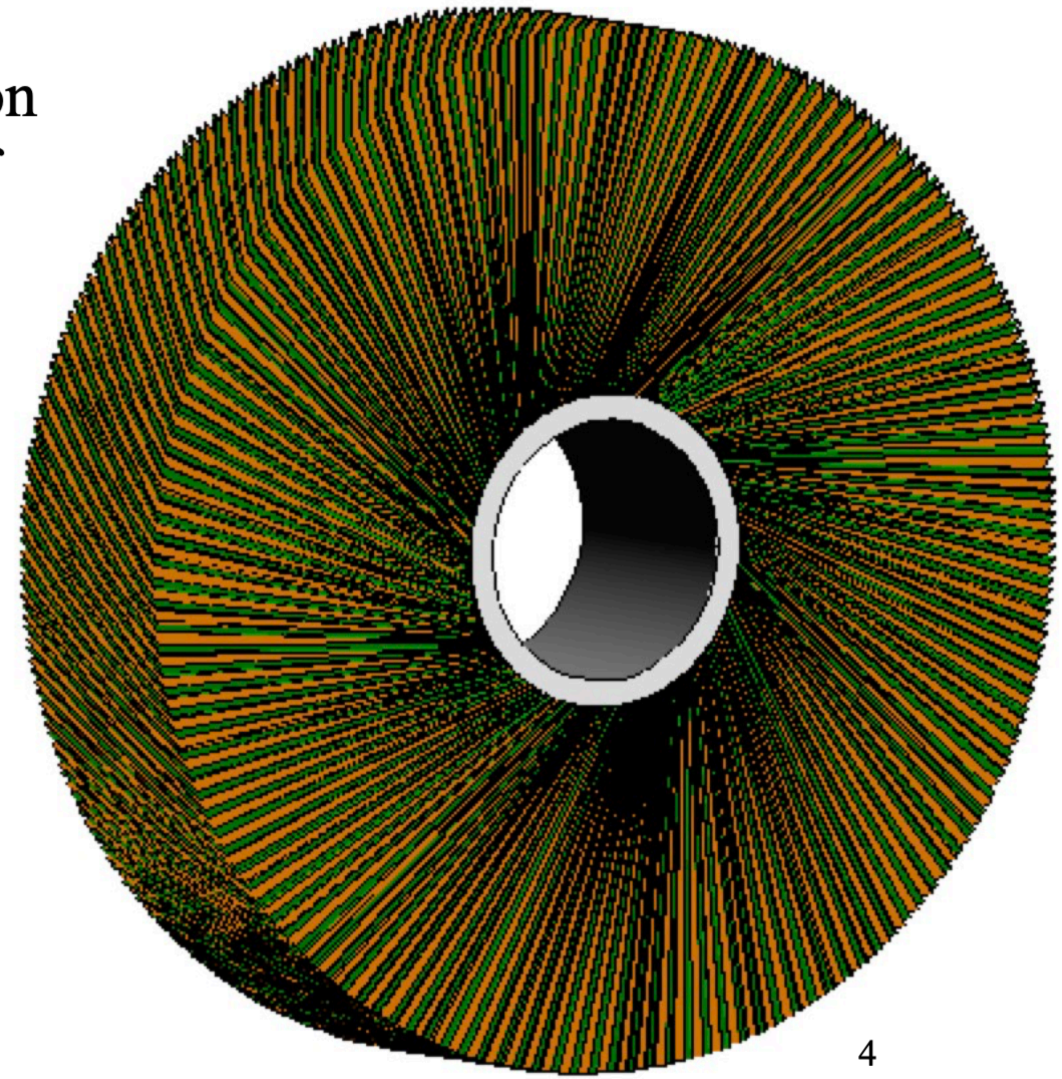






Turbine Concept

- Inner radius portion with the full set of absorbers and electrodes (~240 of each):



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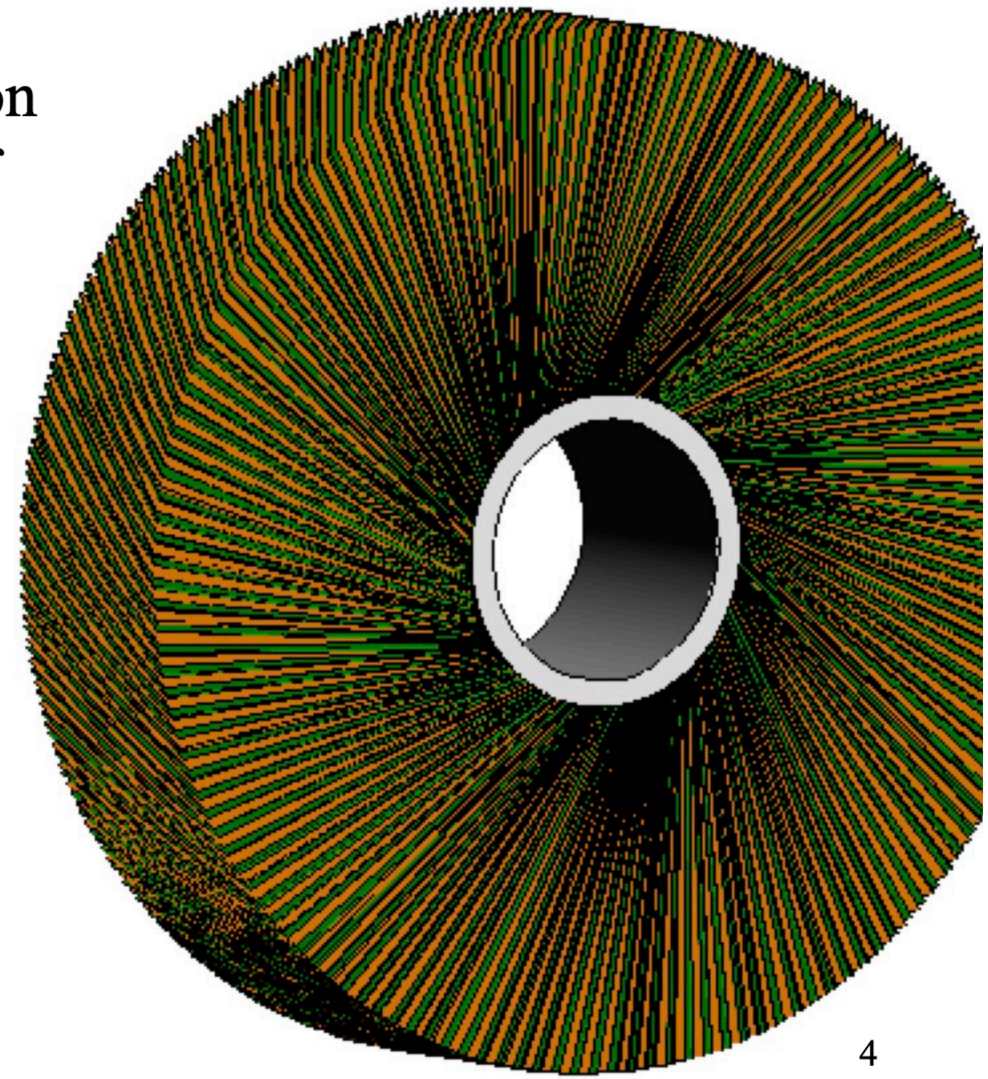
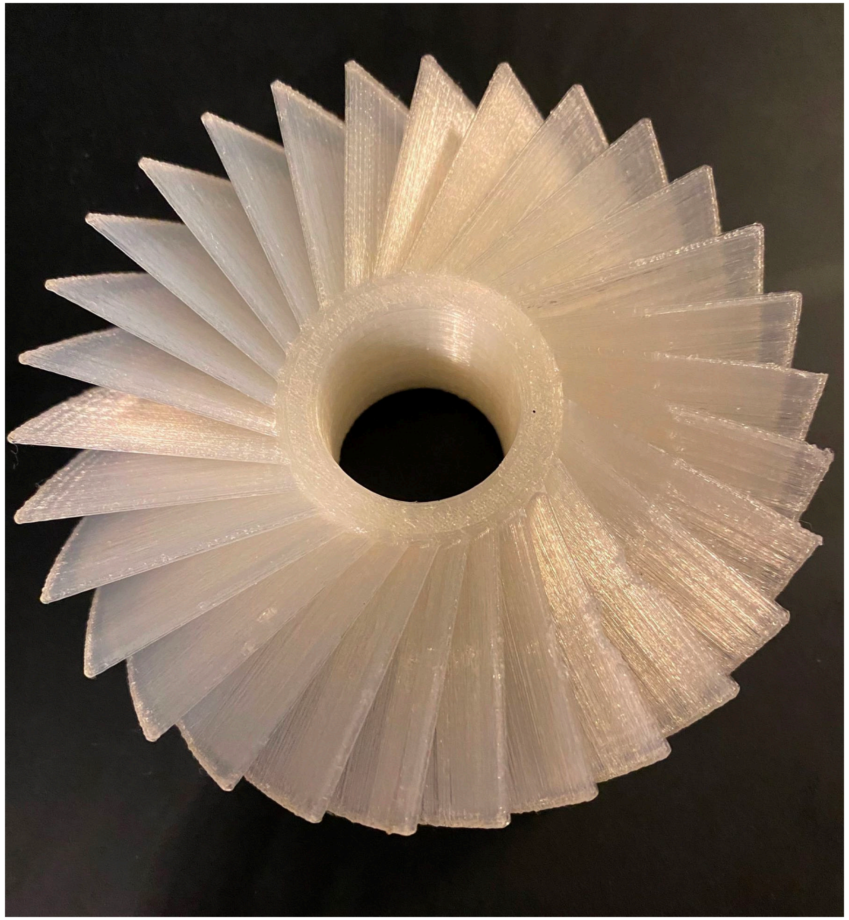
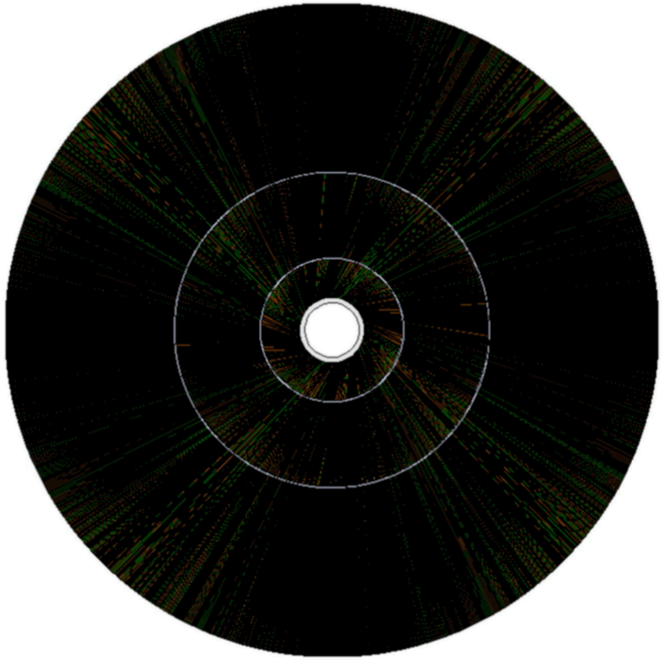


Simplified model from 3D printer

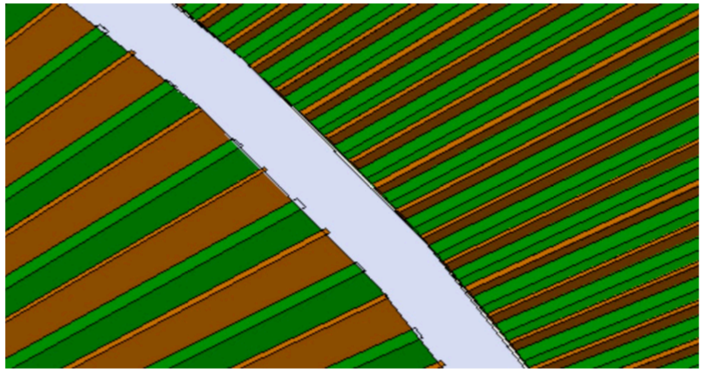


- One consideration is the variation of the gap with radius
  - means that response is very different at the inner and outer radii (42 cm and 275 cm)
- To mitigate this, the detector can be subdivided into a set of nested cylinders:



Tradeoff between minimizing variation in gap width vs. minimizing transitions/dead areas

In this example, each cylinder has $r_o/r_i \approx 1.9$



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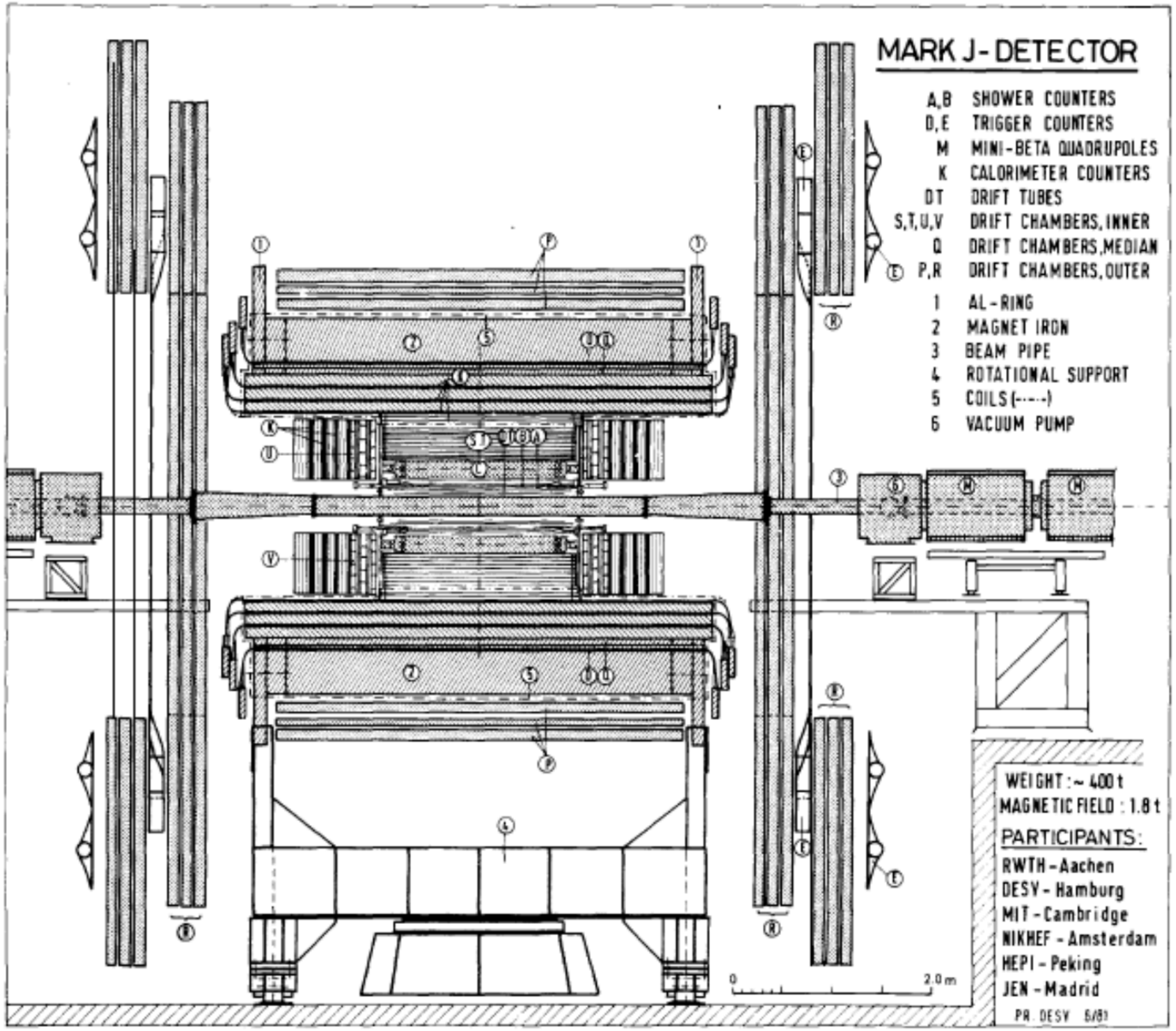
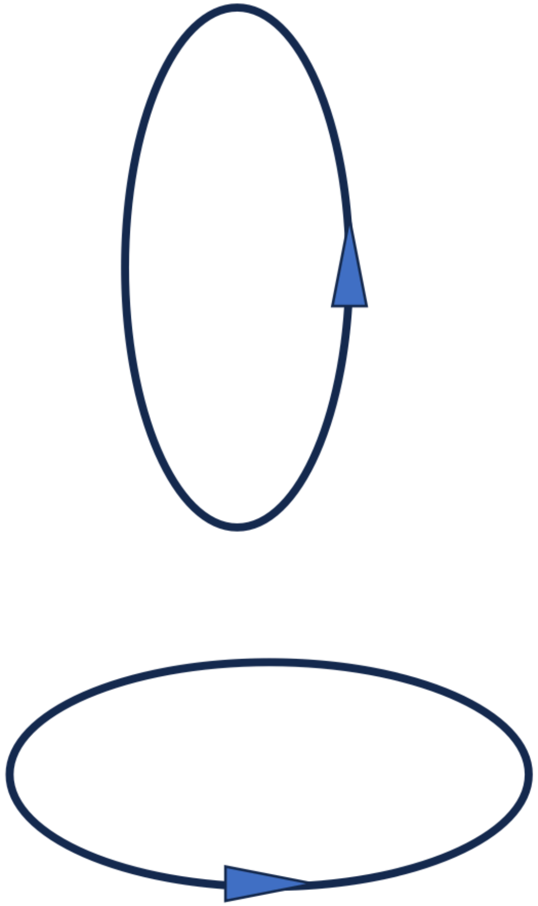


Example of a detector design with built in control of systematics



Haber

Wither systematic errors at Tera-Z?

- With 10^{12} Z's produced at Tera-Z, statistical errors will be so small that measurements can become systematics dominated
- Ignore here the major systematics from energy and luminosity. These will be addressed by other "specialists"
- Orthodoxy – systematic errors also improve by sqrt(N)? So no problem???
- Actually, the need to reduce systematic errors may create new technical challenges to detector builders
- We will need to understand alignment, positioning, stability, tagging, efficiencies and acceptances with unprecedented accuracy
- These may be more challenging than meeting the regular physics performance specs like X_o, P_t resolution, ip_res, timing, etc.
- What does this mean in practice? Does it lead to new types of specifications and/or detector features, systems?

Haber

lots of room for toy studies
redundancy is key

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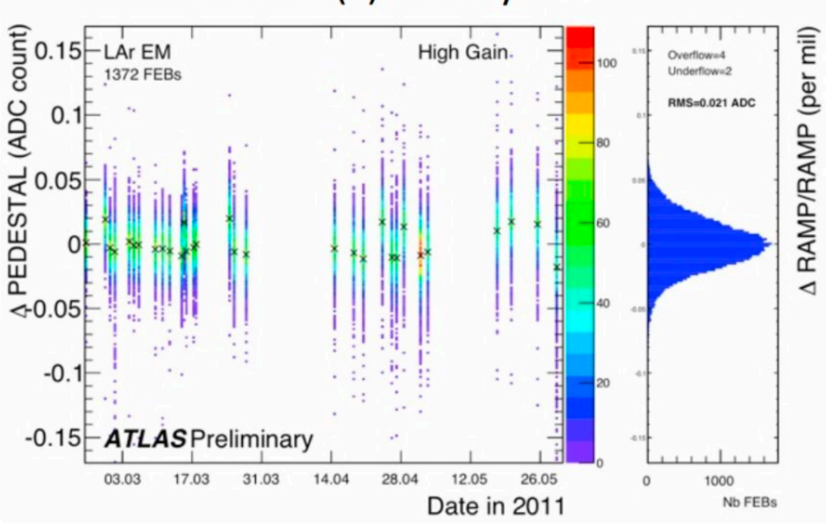
- What does this mean in practice? Does it lead to new types of specifications and/or detector features, systems?

Example: Stability of ATLAS LAr Energy Scale

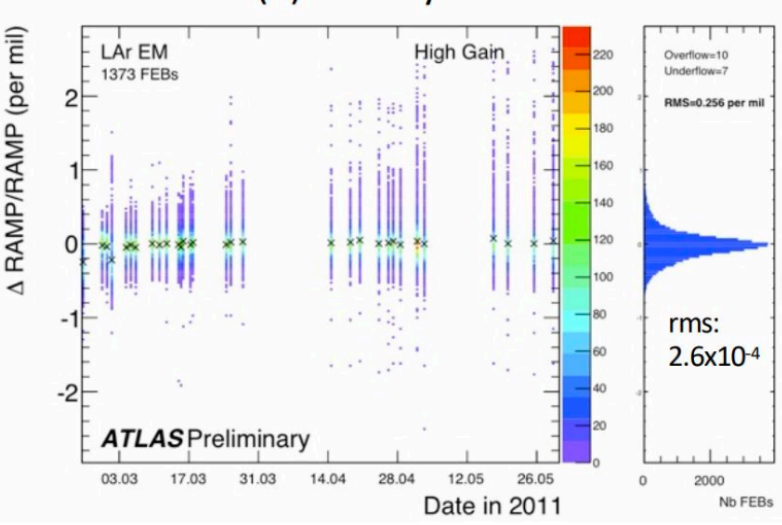
Noble-liquid calorimetry: High intrinsic stability

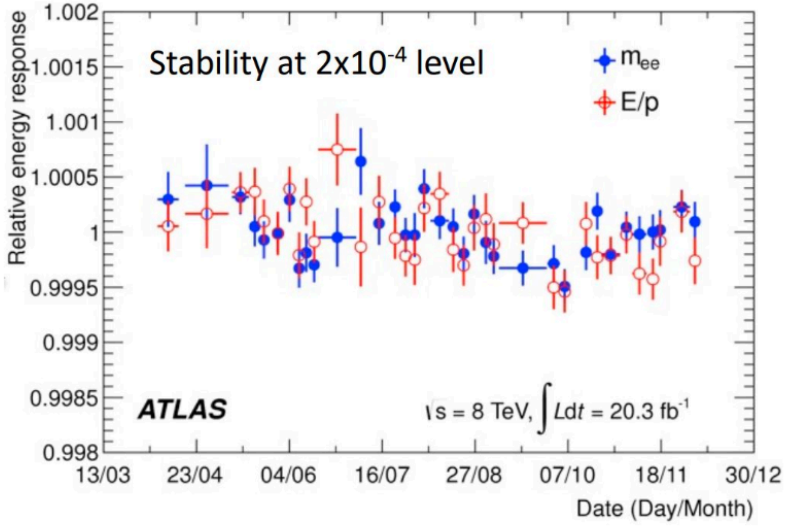
- Pedestal stability < 100 keV
- Gain stability 2.6×10^{-4}
- Parameters monitored in daily calibration runs
  - Changes in constants needed only about 1 / month
- ➢ Stability of the energy scale of 2×10^{-4}
  - Visible on Z→ee invariant mass and E/p

Pedestal (P) stability



Gain (R) stability

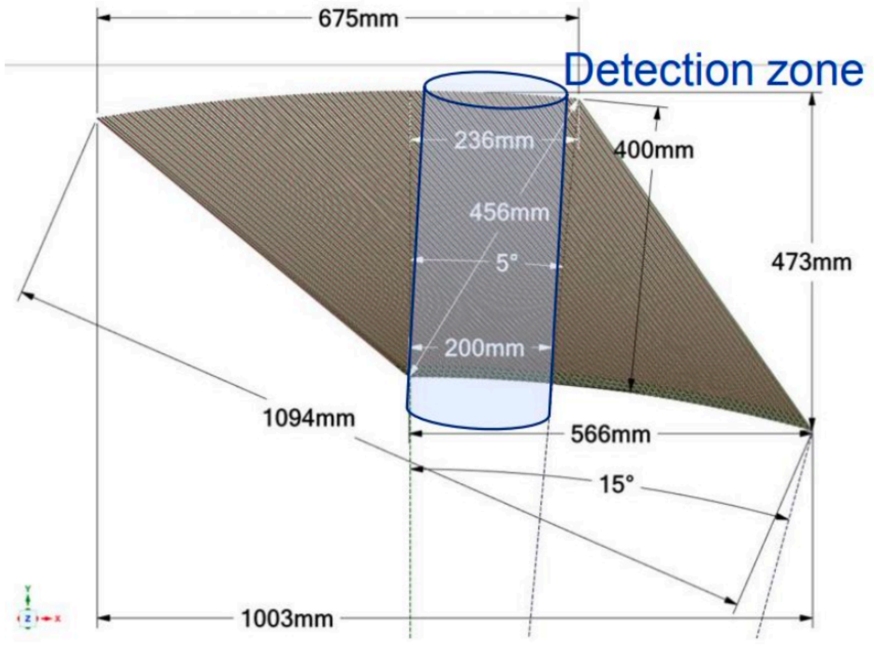




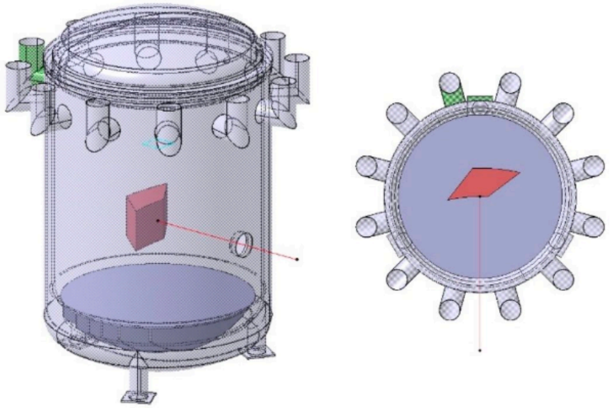
Towards a testbeam module

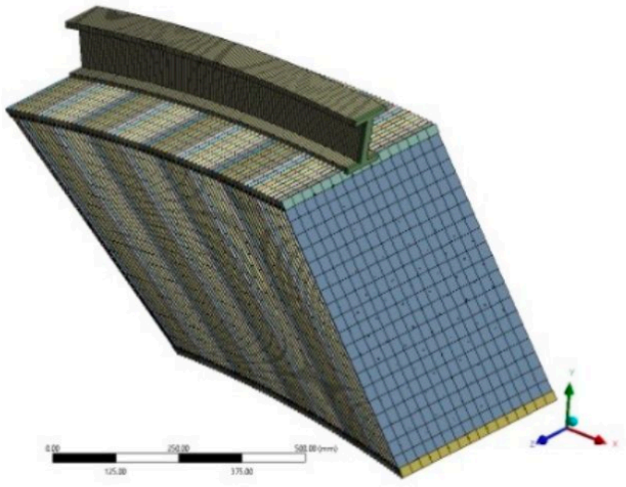
Plan to produce testmodule in the next four years

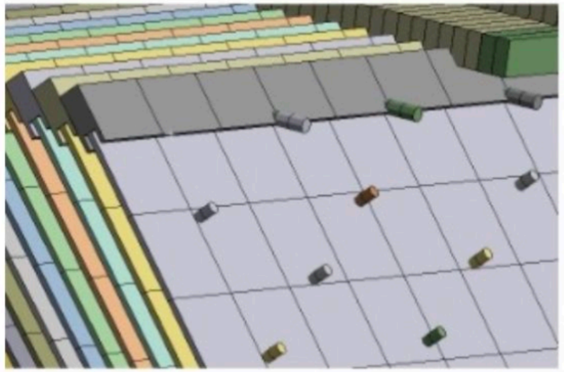
- Mechanical design of module (64 absorbers) has started
  - First finite element calculations performed
- Work on finding / adapting testbeam cryostat
- Common tools (e.g EUDAQ) should facilitate integration in testbeam facility



The cryostat available to make the test beam is the CRRP-00563.







Towards a testbeam module

prototypes are small experiments!

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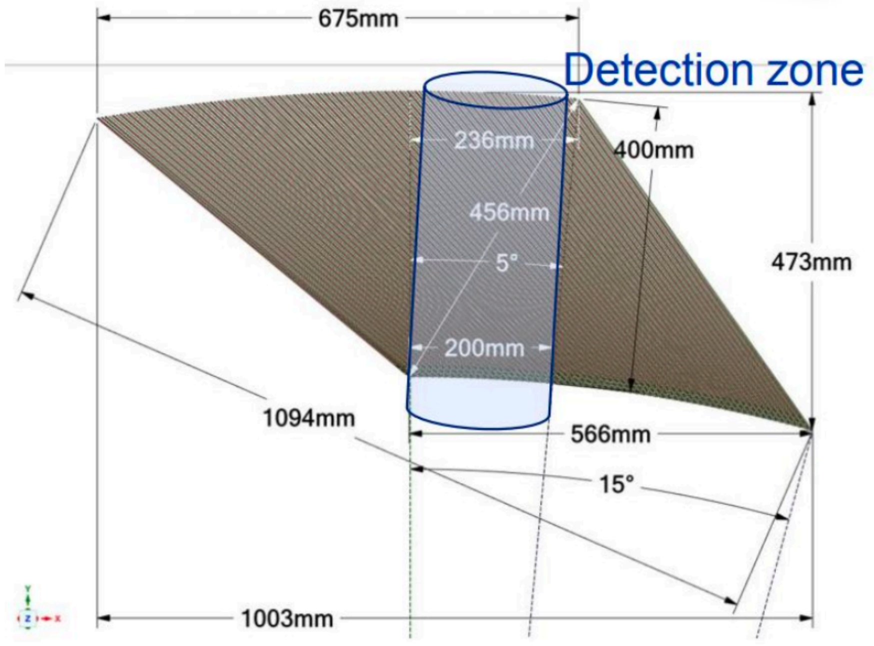

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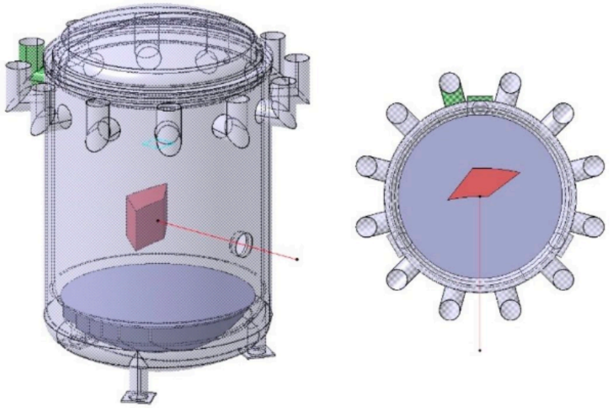
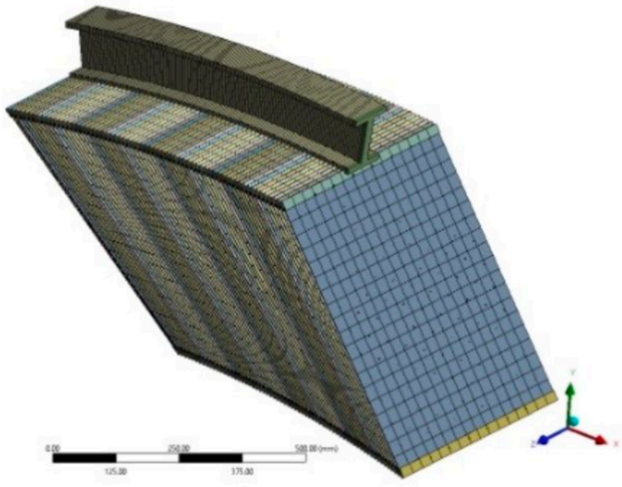
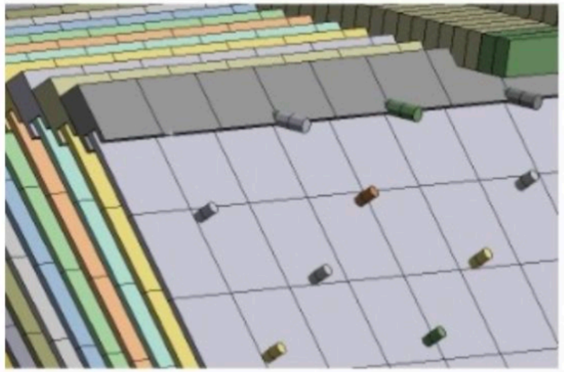


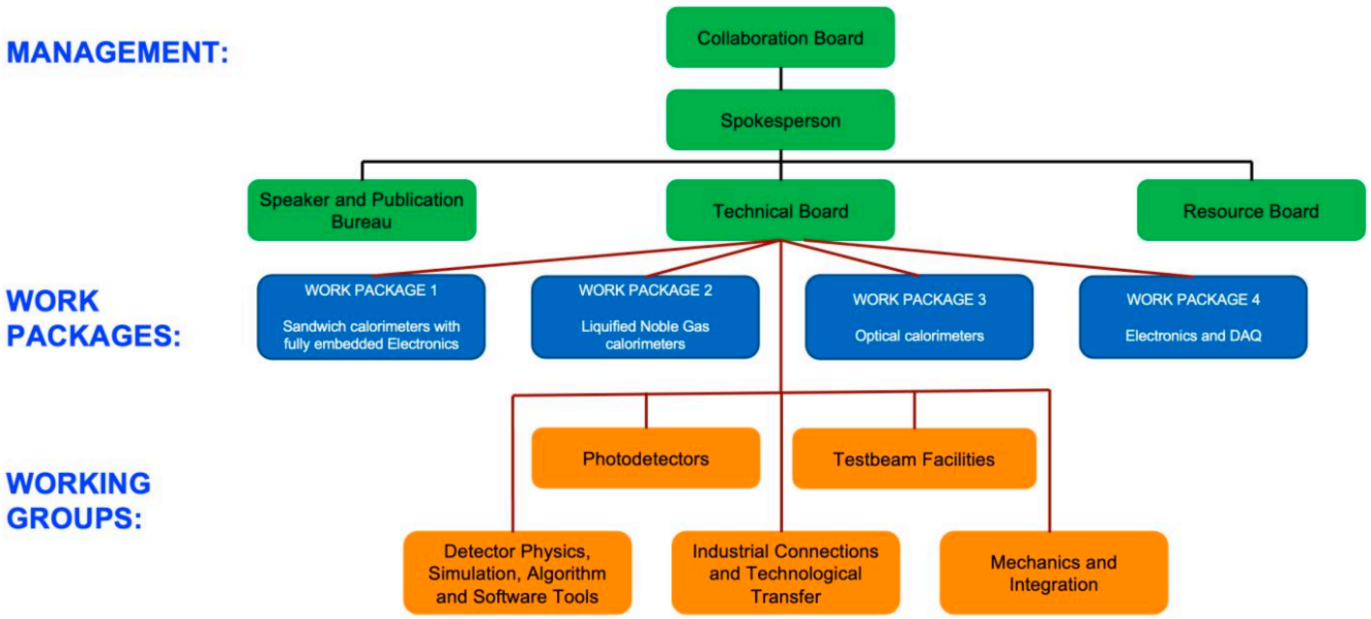




The Allegro Ecal team in DRD6

Detector R&D (DRD) collaborations implement the ECFA Detector R&D Roadmap

- DRD6 on Calorimetry with 4 work packages and several transversal activities (TB, Materials, SW, …)
  - First Collaboration meeting: April 9-11 at CERN
- Noble liquid calo is the WP2
  - 20 institutes from 7 countries
    - Of which **7 US institutes** !
- 4 main goals
  - Performance studies and optimisation
  - Study of readout electrodes
  - Development of readout electronics
  - Mechanical studies of a full calo, and for a testbeam module



Concepts

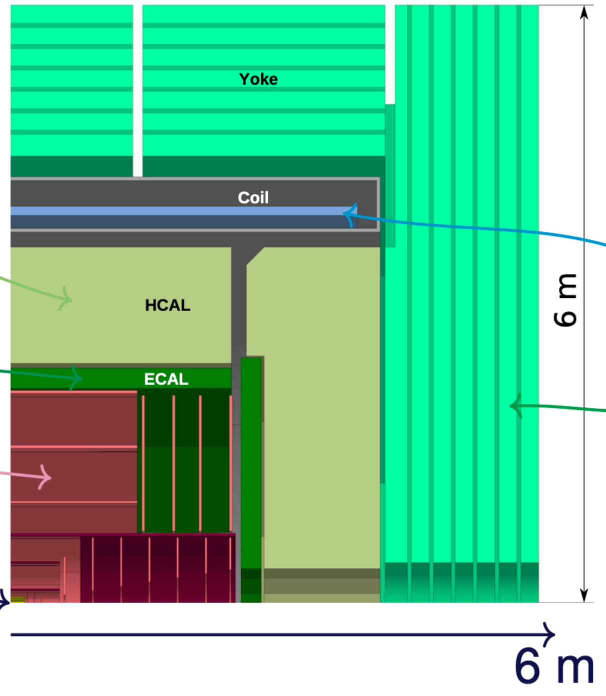
The CLD Geometry

Sailer

Detector for FCCee

General purpose detector for Particle Flow reconstruction [1]

- Steel–Scintillator HCal with 3 cm cell-size
- Silicon–Tungsten ECal with 5 mm cell-size
- Silicon Tracker, mostly 50 µm pitch strips
- Vertex Detector with 25 µm pixels



- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs Muon ID

Sailer

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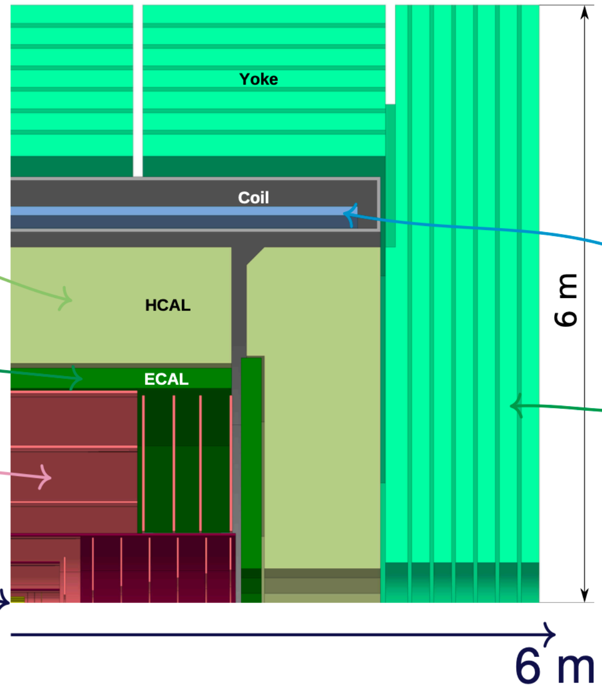

- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs Muon ID

result of simulation-based optimisation

Key4hep Software

- Software for CLD part of the Key4hep software stack
- Available on CVMFS: `/cvmfs/sw.hsf.org/key4hep/setup.sh`
- Documentation: **https://key4hep.web.cern.ch**
- See also the **full sim demonstration by B. Francois**

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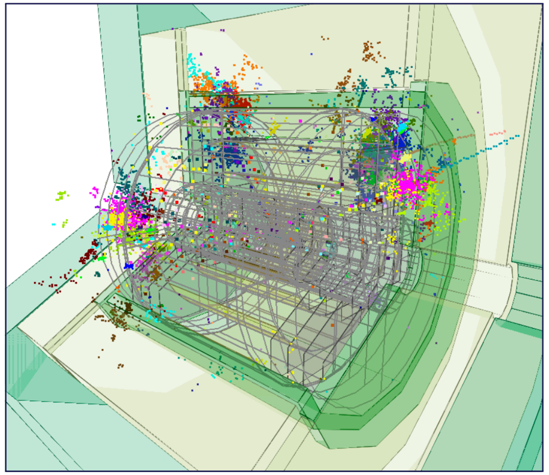
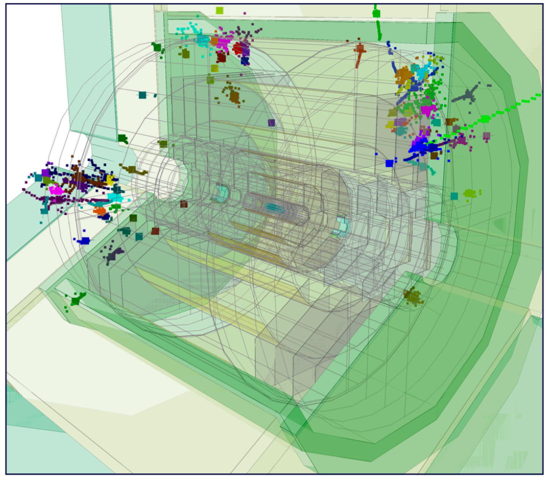
Event Displays





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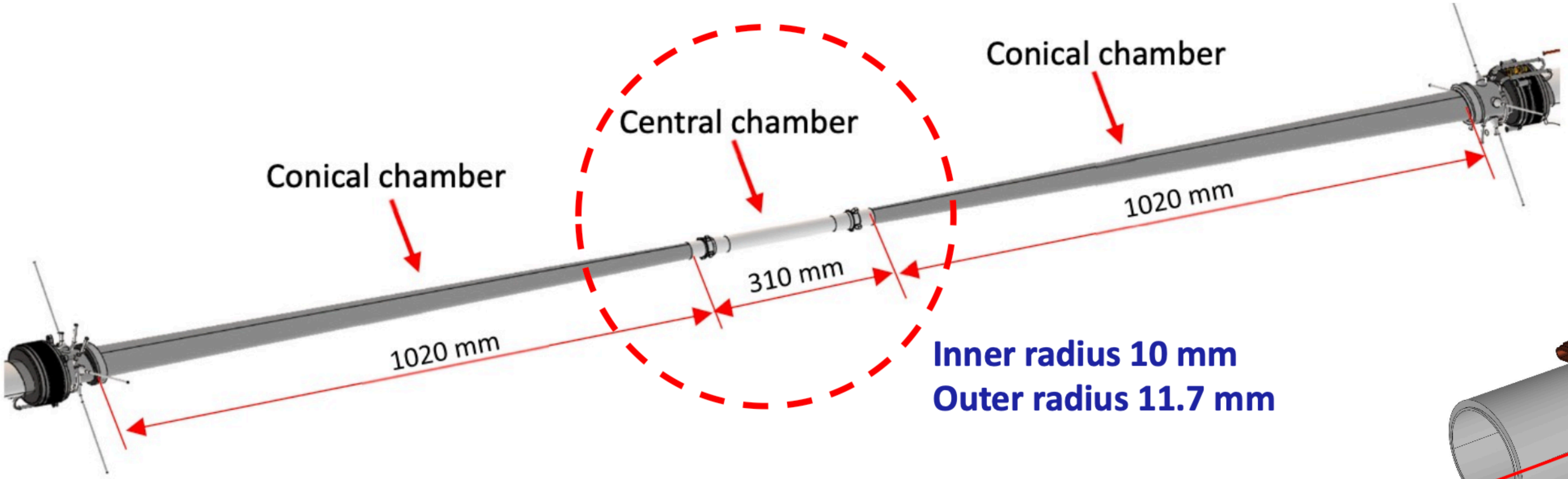
Full Simulation with DDSim

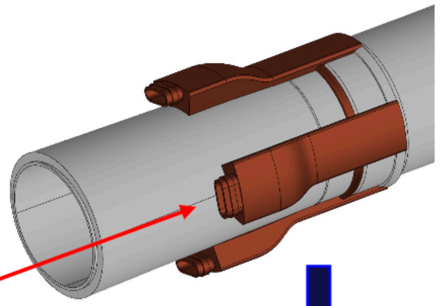
- Using `ddsim` and the CLD specific steering file
  - 30 mrad crossing angle
  - configuration of sensitive detectors, particularly Scintillator HCal (Birks' Law), and silicon tracking sensors
  - Physics list, simulation parameters (e.g., stepper, range cut), additional particles

```
source /cvmfs/sw.hsf.org/key4hep/setup.sh
git clone https://github.com/Key4hep/CLDConfig
cd CLDConfig/
ddsim --compactFile $K4GEO/FCCee/CLD/compact/CLD_o2_v05/CLD_o2_v05.xml \
      --inputFiles ../test/yyxyev_000.stdhep \
      --numberOfEvents 3 \
      --steeringFile cld_steer.py \
      --outputFile tops_edm4hep.root
```

AlBemet Central Vacuum Chamber design



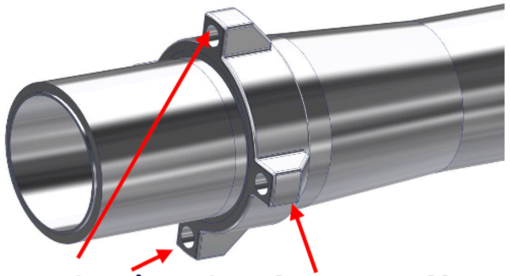
Inner radius 10 mm
Outer radius 11.7 mm



NOW

Inlet and outlet manifolds for the paraffin cooling system: copper removed

material budget is reduced especially in LumiCal



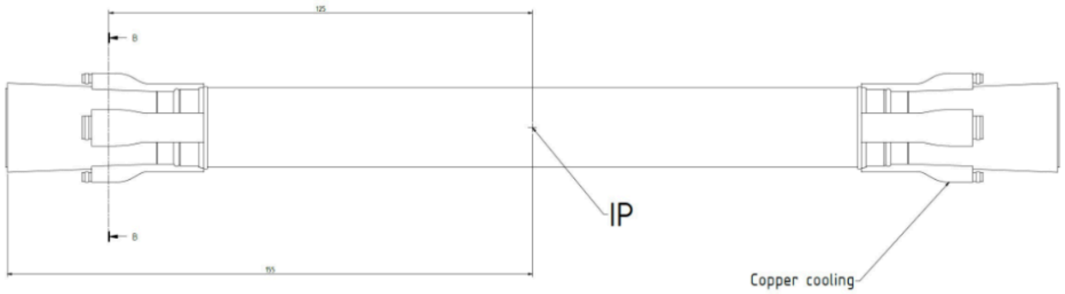
Inlet/outlet for paraffin cooling (AlBeMet)

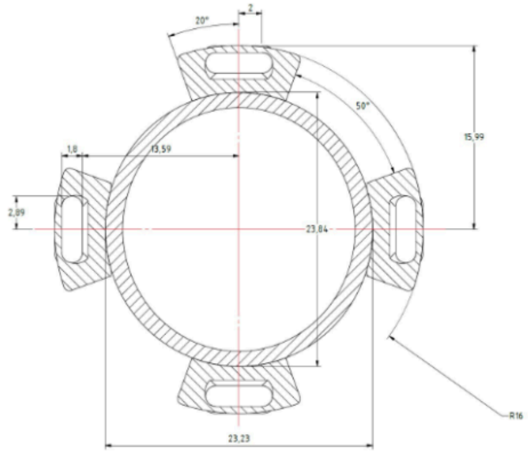
[AlBeMet: 62% Be and 38% Al alloy]

New Beampipe

- New beam pipe design **(cf. MDI session)**. Figures from [7]
- Only using primitive volumes available in Geant4 and TGeo, no CAD created pieces here
  - Conical chamber is conical, no circular to ellipse volume

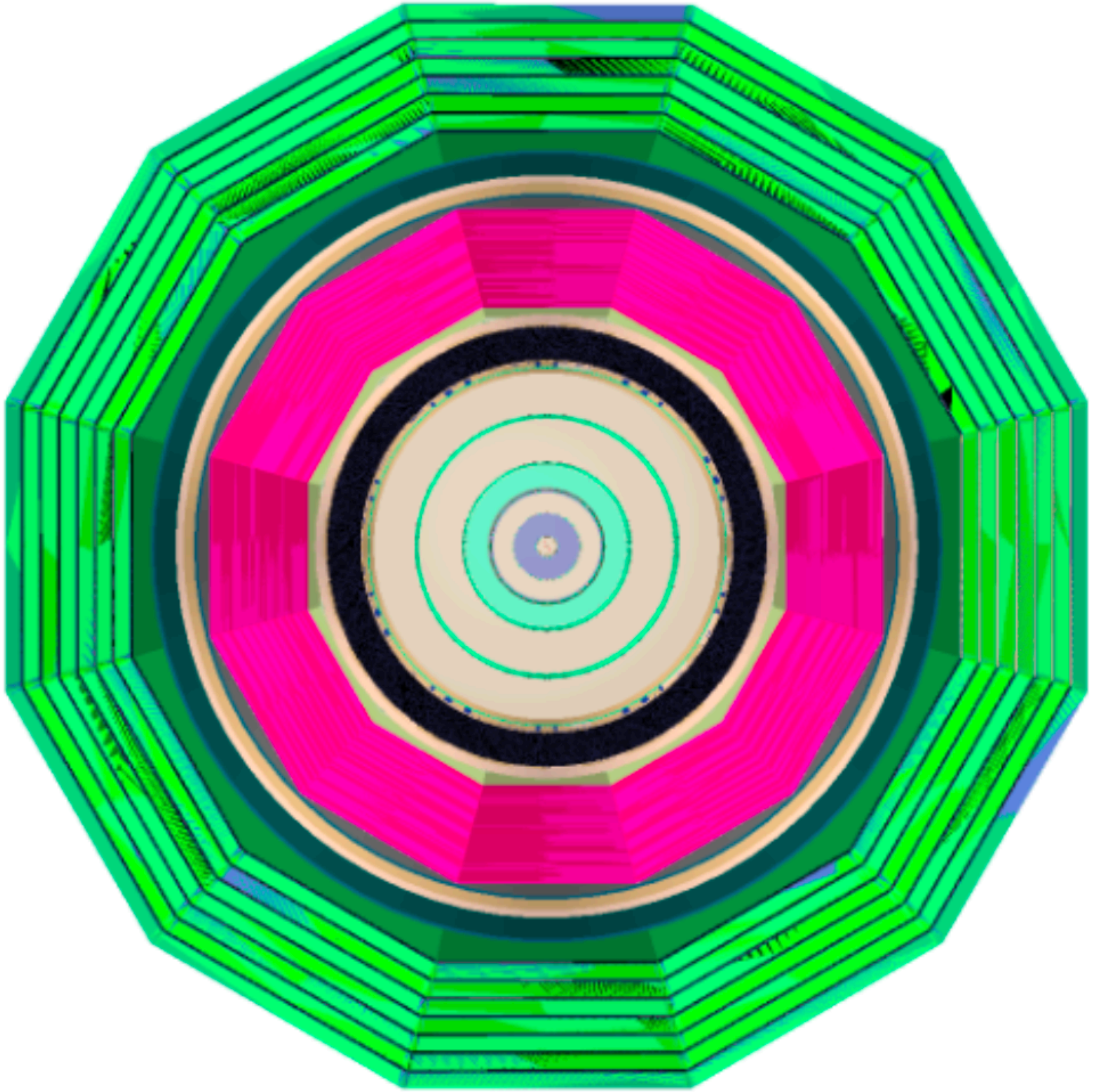
[mm]	Cyl R_{min}	Cyl R_{max}	Cyl L	Cone R_{min}
v02	10	11.2	125	11
v05	**10**	**11.7**	**90**	**12**

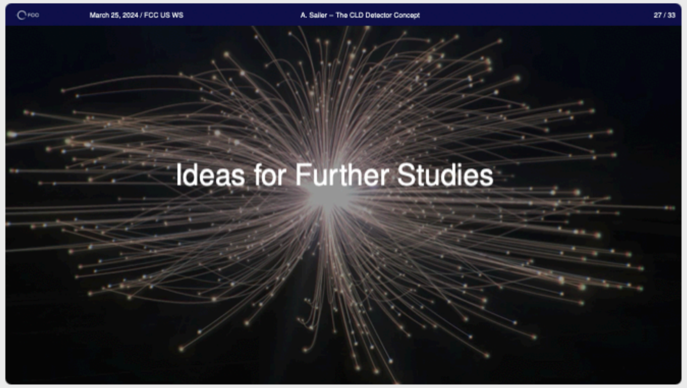




CLD_o4_v05

- Same as CLD_02_v05, except
- ECal Barrel replaced by LAr
- HCal, Solenoid, Yoke moved outwards by ≈40 cm
- Testing PandoraPFA for LAr, making interfaces more generic

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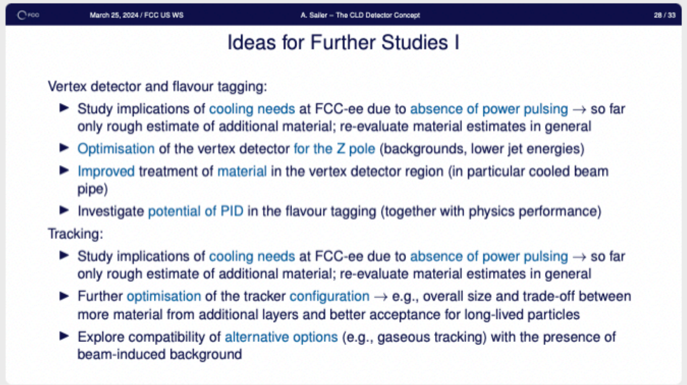
Ideas for Further Studies

27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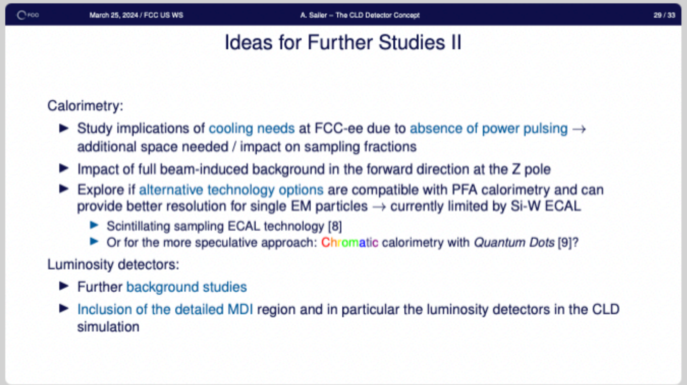
Ideas for Further Studies I
Vertex detector and flavour tagging:
Study implications of cooling needs at FCC-ee due to absence of power pulsing → so far only rough estimate of additional material; re-evaluate material estimates in general
Optimisation of the vertex detector for the Z pole (backgrounds, lower jet energies)
Improved treatment of material in the vertex detector region (in particular cooled beam pipe)
Investigate potential of PID in the flavour tagging (together with physics performance)
Tracking:
Study implications of cooling needs at FCC-ee due to absence of power pulsing → so far only rough estimate of additional material; re-evaluate material estimates in general
Further optimisation of the tracker configuration → e.g., overall size and trade-off between more material from additional layers and better acceptance for long-lived particles
Explore compatibility of alternative options (e.g., gaseous tracking) with the presence of beam-induced background

28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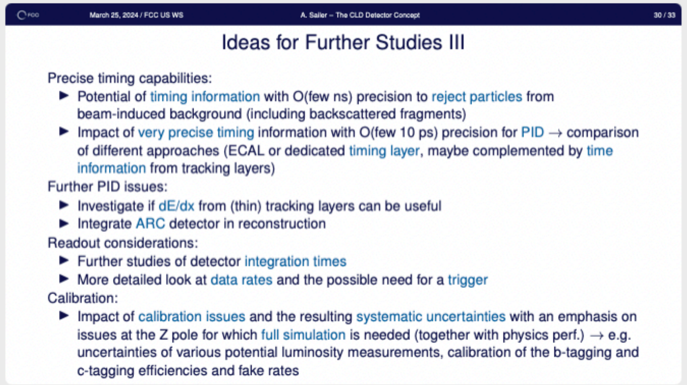
Ideas for Further Studies II
Calorimetry:
Study implications of cooling needs at FCC-ee due to absence of power pulsing → additional space needed / impact on sampling fractions
Impact of full beam-induced background in the forward direction at the Z pole
Explore if alternative technology options are compatible with PFA calorimetry and can provide better resolution for single EM particles → currently limited by Si-W ECAL
Scintillating sampling ECAL technology [8]
Or for the more speculative approach: Chromatic calorimetry with Quantum Dots [9]?
Luminosity detectors:
Further background studies
Inclusion of the detailed MDI region and in particular the luminosity detectors in the CLD simulation

29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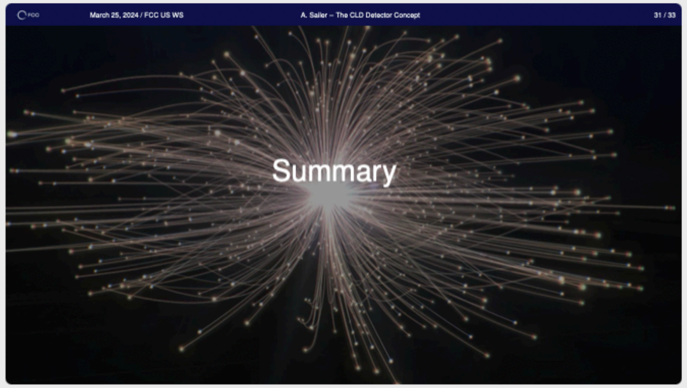
Ideas for Further Studies III
Precise timing capabilities:
Potential of timing information with O(few ns) precision to reject particles from beam-induced background (including backscattered fragments)
Impact of very precise timing information with O(few 10 ps) precision for PID → comparison of different approaches (ECAL or dedicated timing layer, maybe complemented by time information from tracking layers)
Further PID issues:
Investigate if dE/dx from (thin) tracking layers can be useful
Integrate ARC detector in reconstruction
Readout considerations:
Further studies of detector integration times
More detailed look at data rates and the possible need for a trigger
Calibration:
Impact of calibration issues and the resulting systematic uncertainties with an emphasis on issues at the Z pole for which full simulation is needed (together with physics perf.) → e.g. uncertainties of various potential luminosity measurements, calibration of the b-tagging and c-tagging efficiencies and fake rates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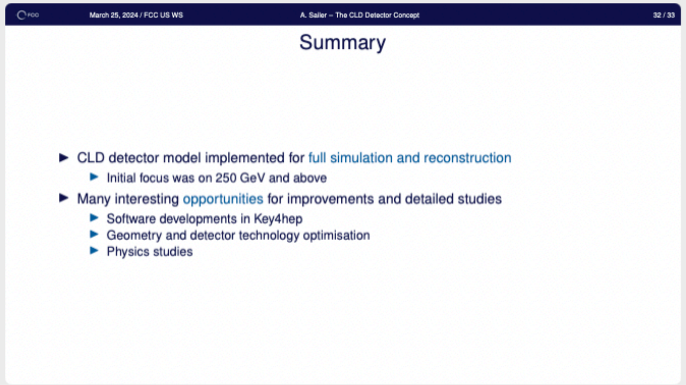
Summary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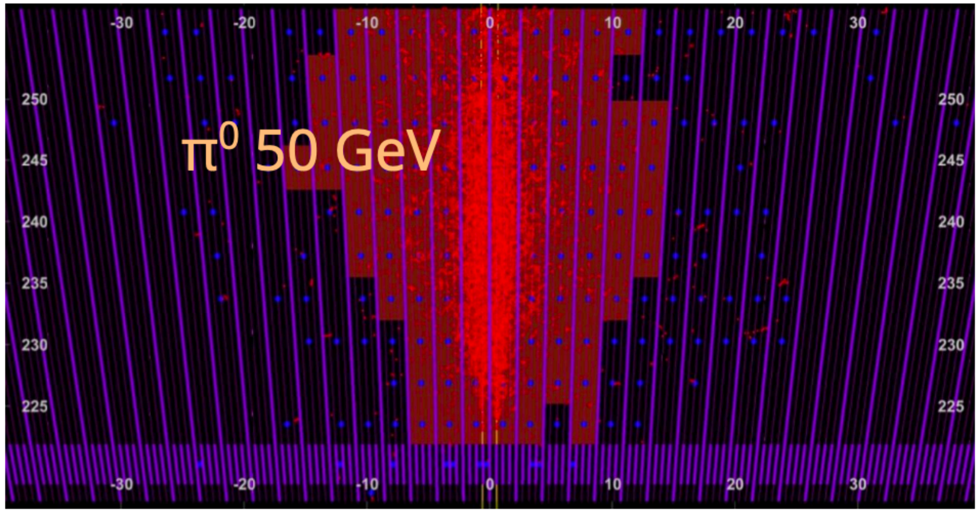
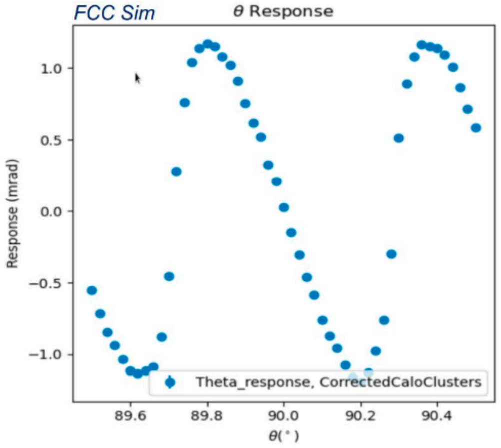
Summary
CLD detector model implemented for full simulation and reconstruction
Initial focus was on 250 GeV and above
Many interesting opportunities for improvements and detailed studies
Software developments in Key4hep
Geometry and detector technology optimisation
Physics studies

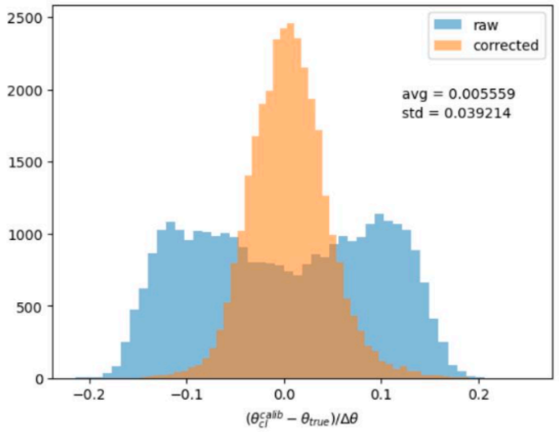
PID/PFlow: granularity optimisation

2023: important groundwork. ⇒ 2024: granularity optimisation studies possible

- Flexible geometry implemented in Full sim
  - Can study EM shower shapes
  - Benchmark: photon / π^0 separation
  - Ongoing: implementation of cross-talk effects
- Calibrations of reconstruction
  - Simple MVA energy regression of EM clusters
  - Cluster position calibration per layer
    - Allows pointing studies (⇒ ALPs)
- Particle Flow on its way
  - Using Pandora toolbox
  - For technical reasons, pioneered in detector sim with Allegro Ecal + CLD Tracker
  - Hope for first results in 2024 !





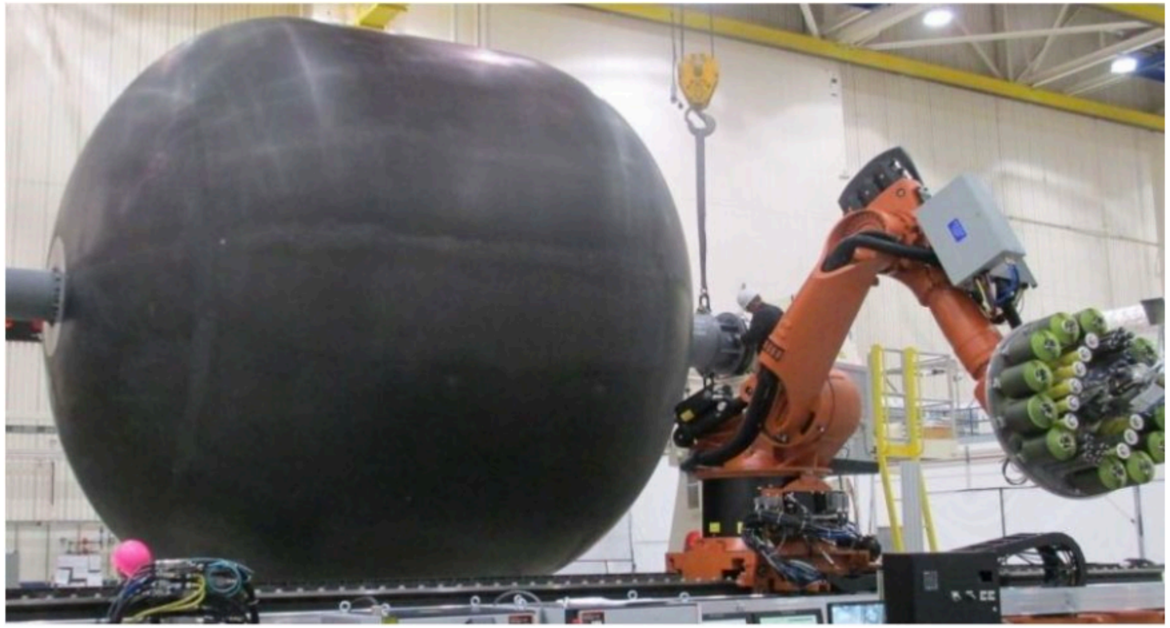


PID/PFlow: granularity optimisation

2023: important groundwork. ⇒ 2024: gra

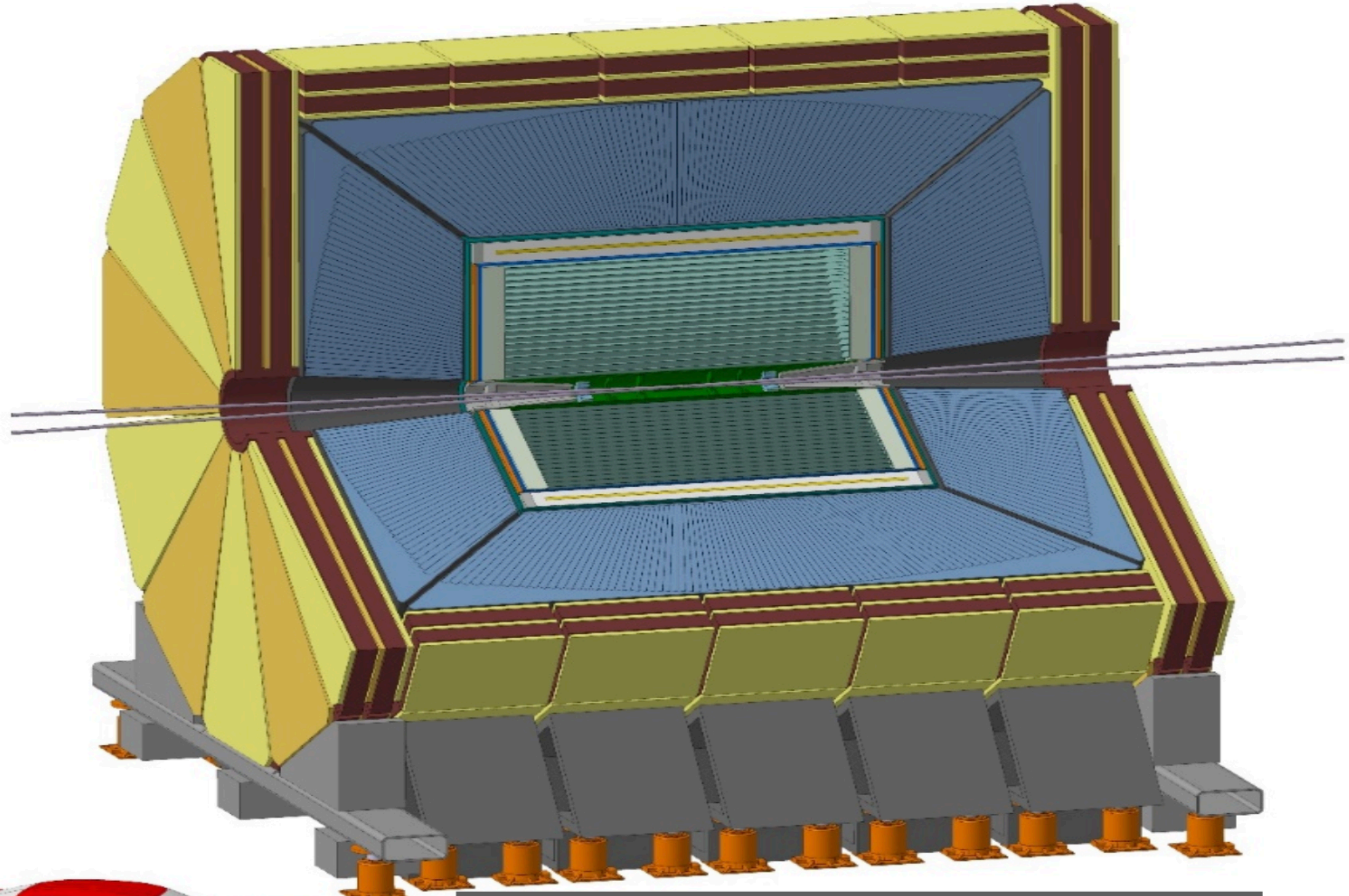
- Flexible geometry implemented in I
  - Can study EM shower shapes
  - Benchmark: photon / π^0 separation
  - Ongoing: implementation of cross-ta
- Calibrations of reconstruction
  - Simple MVA energy regression of EM
  - Cluster position calibration per layer
    - Allows pointing studies (⇒ ALPs)
- Particle Flow on its way
  - Using Pandora toolbox
  - For technical reasons, pioneered in c sim with Allegro Ecal + CLD Tracker
  - Hope for first results in 2024 !

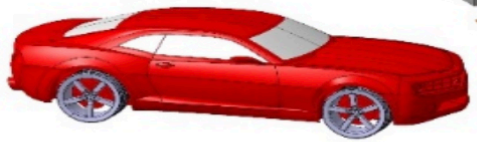
- CERN R&D: address CFRP/Metal interfaces
- Promises for **"transparent" cryostats**: few % of X_0 !



NASA's lineless cryotank

The IDEA detector concept





IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

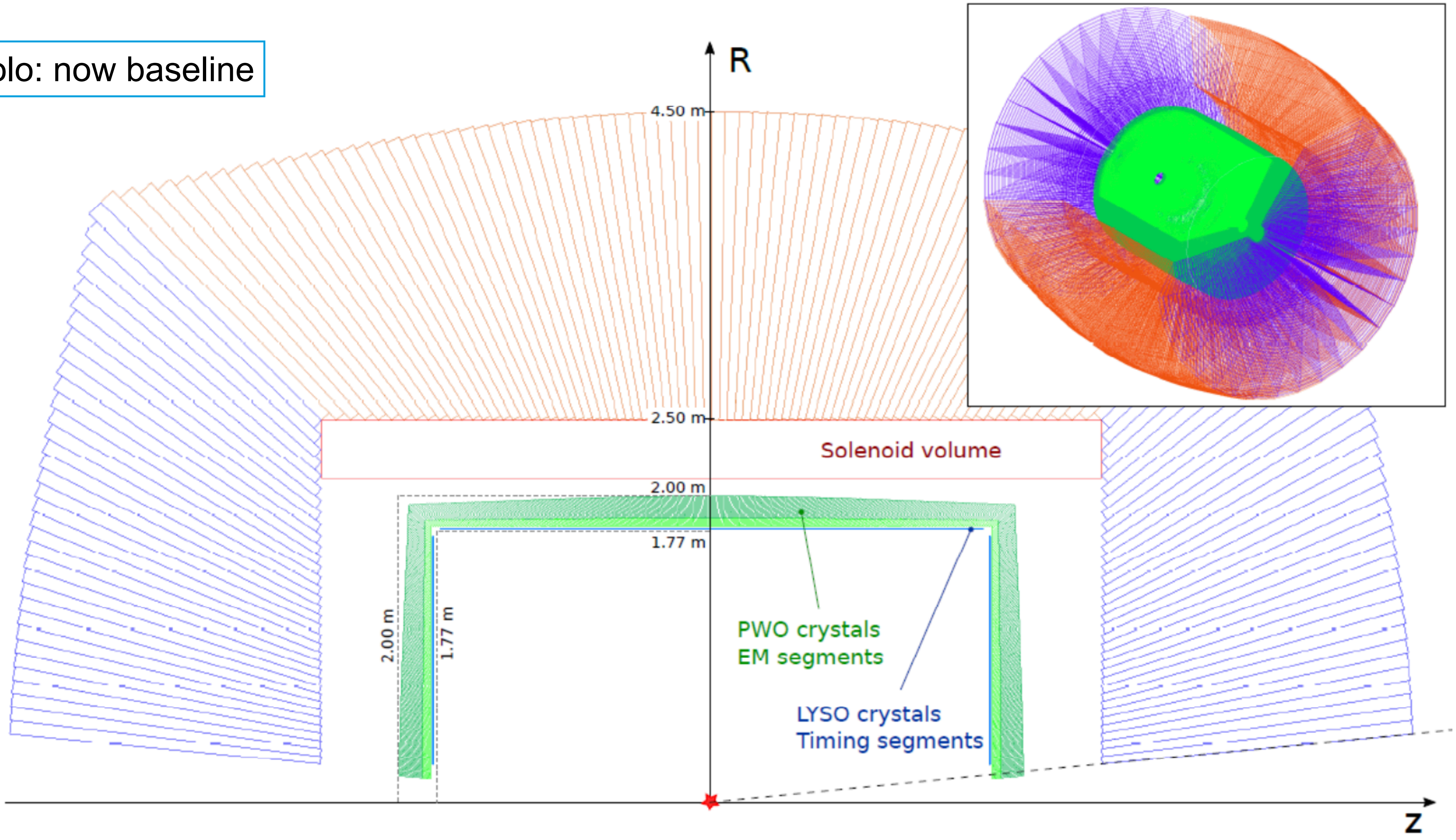
- **New, innovative, possibly more cost-effective concept**
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil *inside* calorimeter system
    - Small magnet ⇒ small yoke
  - Muon system made of 3 layers of μ-RWELL detectors in the return yoke

https://pos.sissa.it/390/

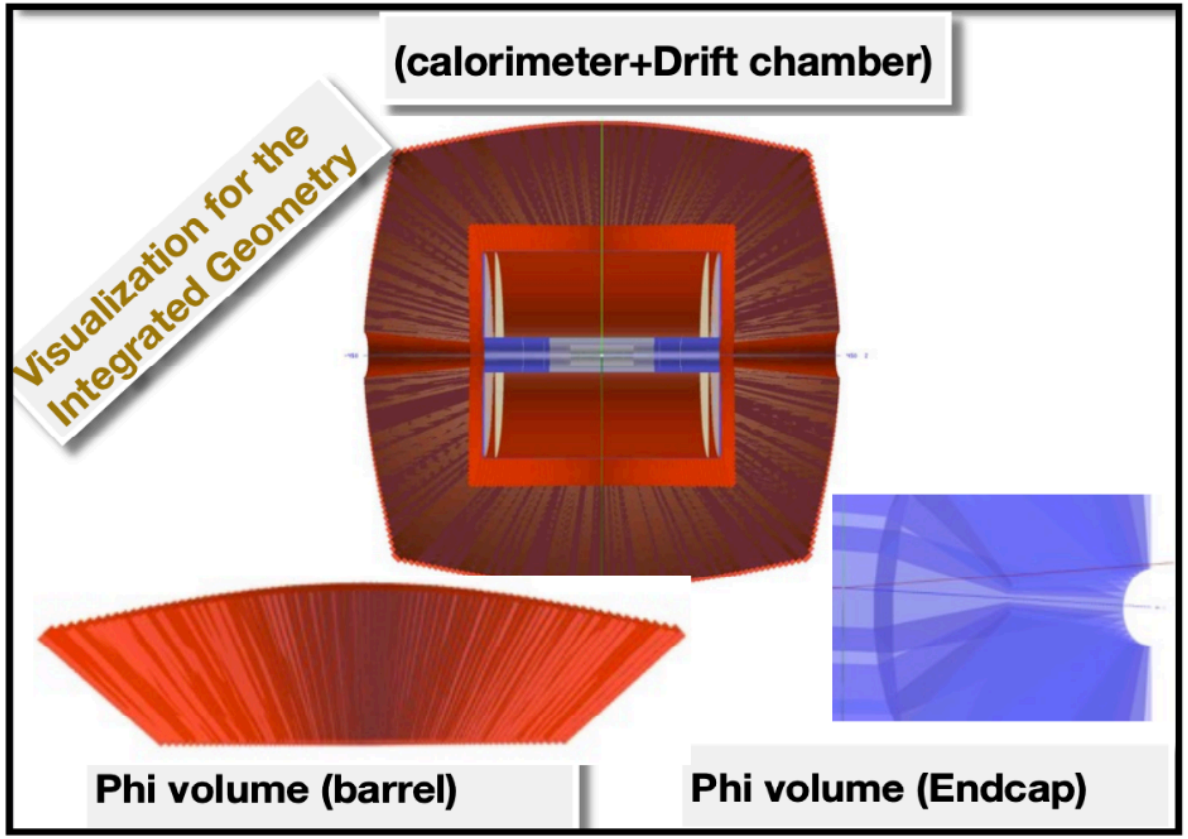
Acknowledgments
I need to thank many colleagues, in particular:
F. Bedeschi

Crystal option

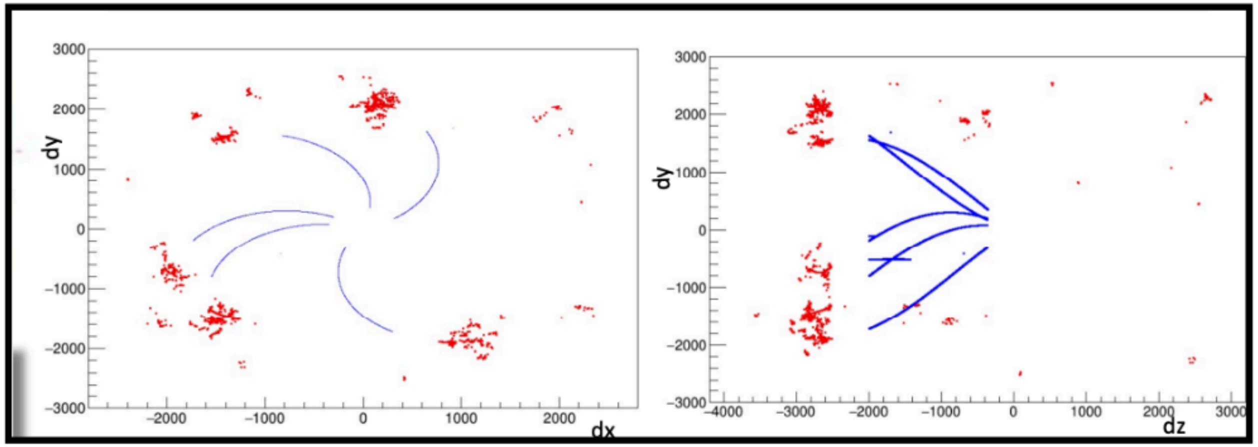
Paolo: now baseline



Status of Simulation of IDEA concept

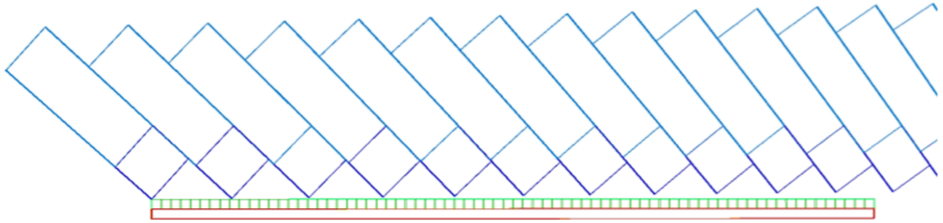


FASTSIM Delphes IDEA card used for performance studies FCCSW
Very sophisticated compared to default.
Latest additions: Vertexing, LLP, PID, dN/dx, dE/dx



FULLSIM: standalone GEANT4 description

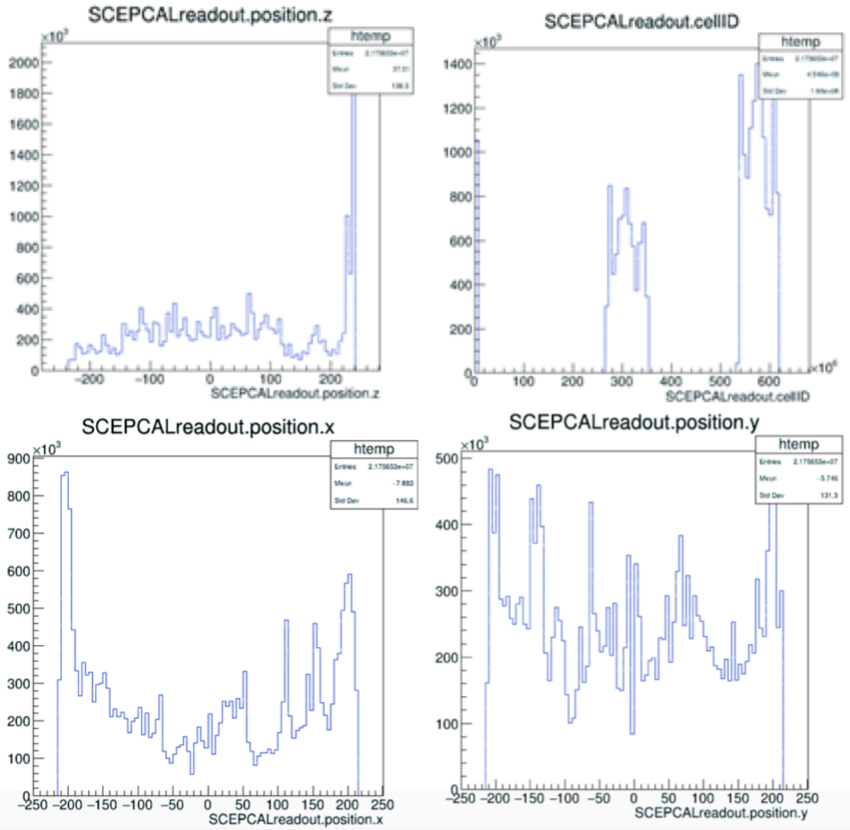
- **Fully integrated geometry**
- **Output hits and reco tracks converted to EDM4HEP**
- **Ready for PFlow development and other reconstruction frameworks/algorithms (ACTS, Pandora etc) in FCCSW**



Let’s get it

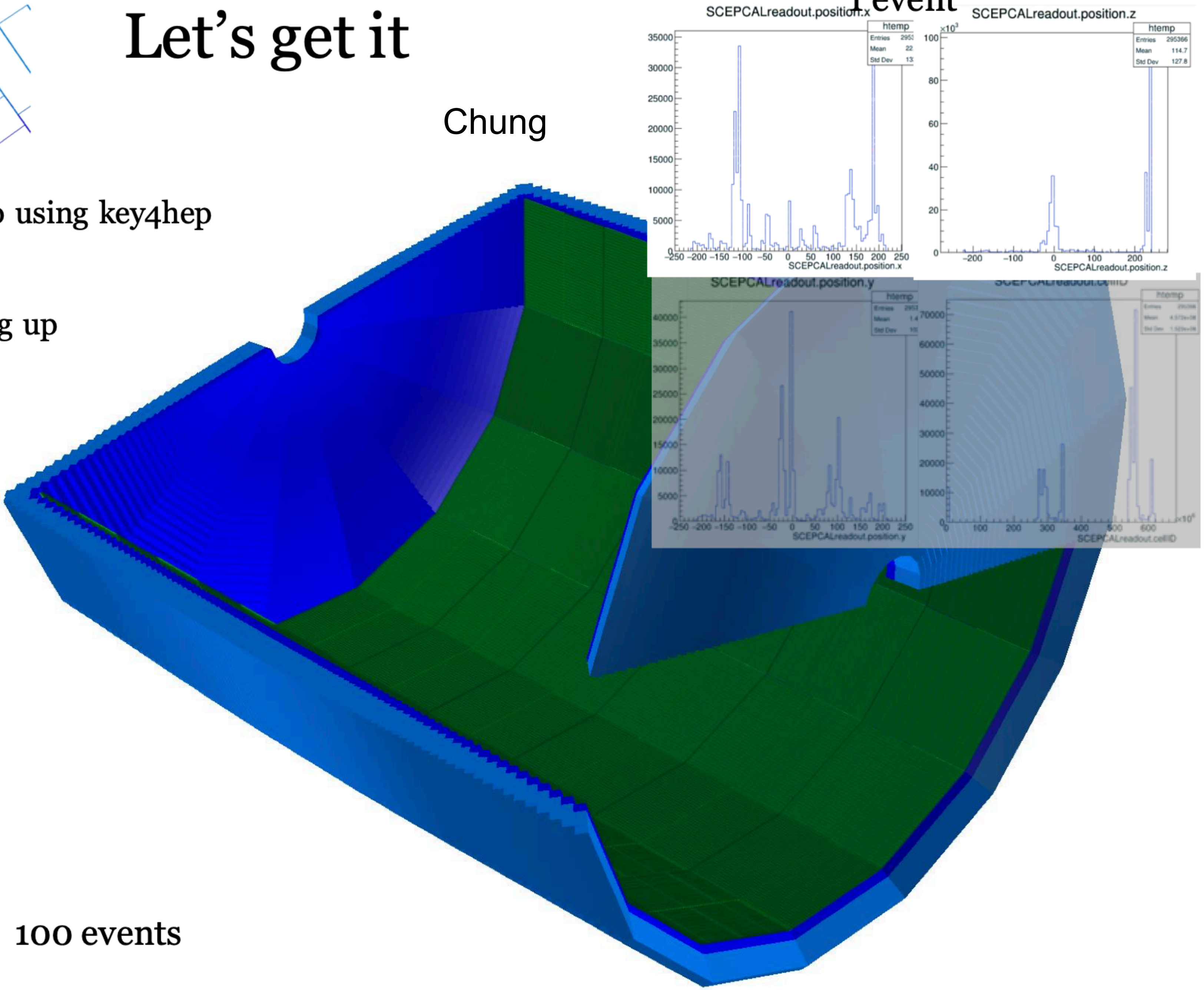
Chung

- New detector fully implemented in dd4hep using key4hep
- Runs FCC-ee events and outputs Calo hits
- Plots - ***wzp6_ee_ZZ_test_ecm240***
- First full simulation ML/PF studies coming up
- https://github.com/SCEPCAL/SCEPCAL



100 events

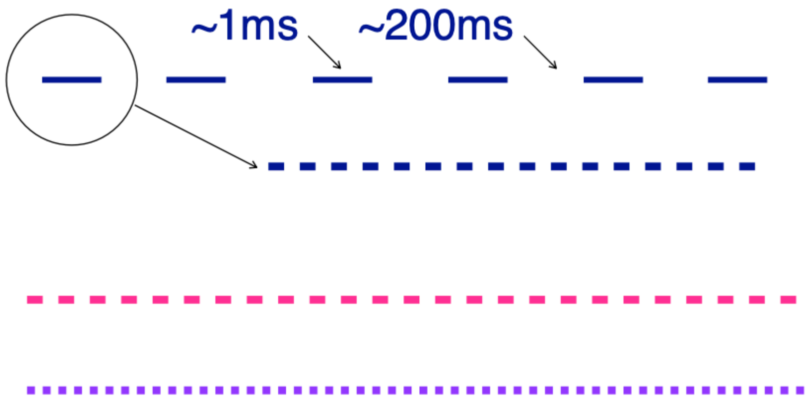
1 event



Concept common issues

[arXiv:2003.01116](#)
[FCC Mid Term Report](#)

Beam Format and Detector Design Requirements



ILC Trains at 5Hz, 1 train 1312 bunches
Bunches are 369 ns apart

FCC@ZH Bunches 1 μs apart

FCC@Z Bunches 20 ns apart

- Very low duty cycle at LC (0.5% ILC, 0.03% C^3) allows for trigger-less readout and power pulsing
  - Factor of 100 power saving for front-end analog power
  - **O(1-100) ns bunch identification capabilities**
- Impact of beam-induced background to be mitigated through MDI and detector design
  - Timing resolution of O(ns) can further suppress beam-backgrounds and keep occupancy low
  - **O(1-10) ns for beam background rejection and/or trigger decision before reading out the detector**
  - Tracking detectors need to achieve good resolution while mitigating power consumption

D. Ntounis (2023)
G. Marchiori (2023)
TDAQ@Annecy2024

Current status of beam-background studies

Same tools and methodology between ILC & FCC within Key4HEP

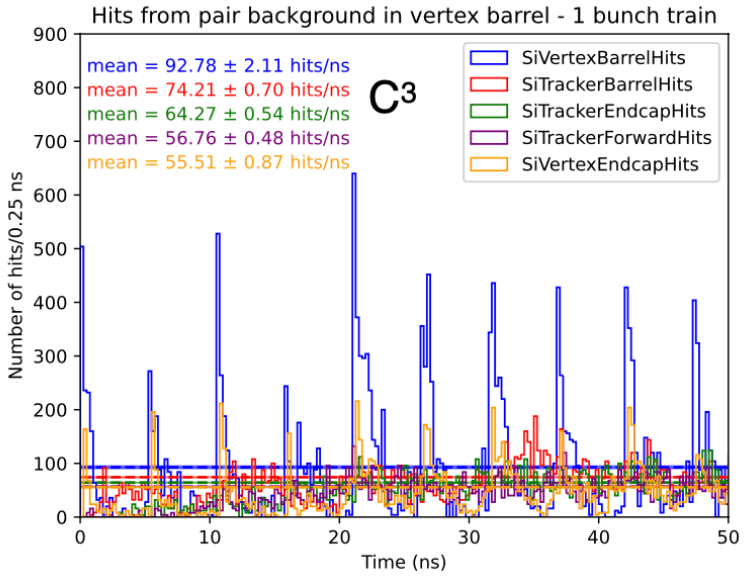
- ILC physics studies are based on full simulation data and some have been recently repeated for C^3
  - Time distribution of hits per unit time and area on 1st layer ~ $4.4 \cdot 10^{-3}$ hits/(ns·mm²) ≃ 0.03 hits/mm² /BX
- CLD detailed studies @FCC show an overall occupancy of 2-3% in the vertex detector at the Z pole
  - assuming 10μs integration time

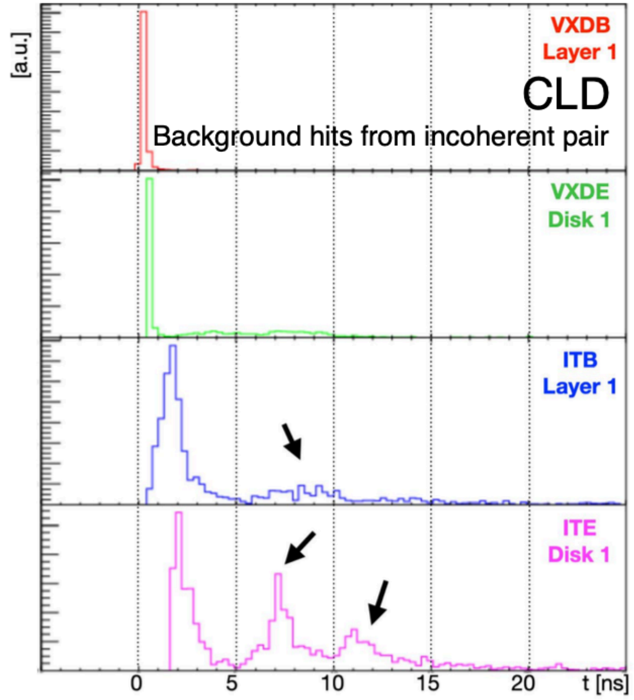
$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \qquad safety = 3$$

	Z	WW	ZH	Top
Bunch spacing [ns]	30	345	1225	7598
Max VXD occ. 1us	2.33e-3	0.81e-3	0.047e-3	0.18e-3
Max VXD occ.10us	23.3e-3	8.12e-3	3.34e-3	1.51e-3
Max TRK occ. 1us	3.66e-3	0.43e-3	0.12e-3	0.13e-3
Max TRK occ.10us	36.6e-3	4.35e-3	1.88e-3	0.38e-6

Occupancy in readout window (10μs)





Beam induced backgrounds impact on detectors

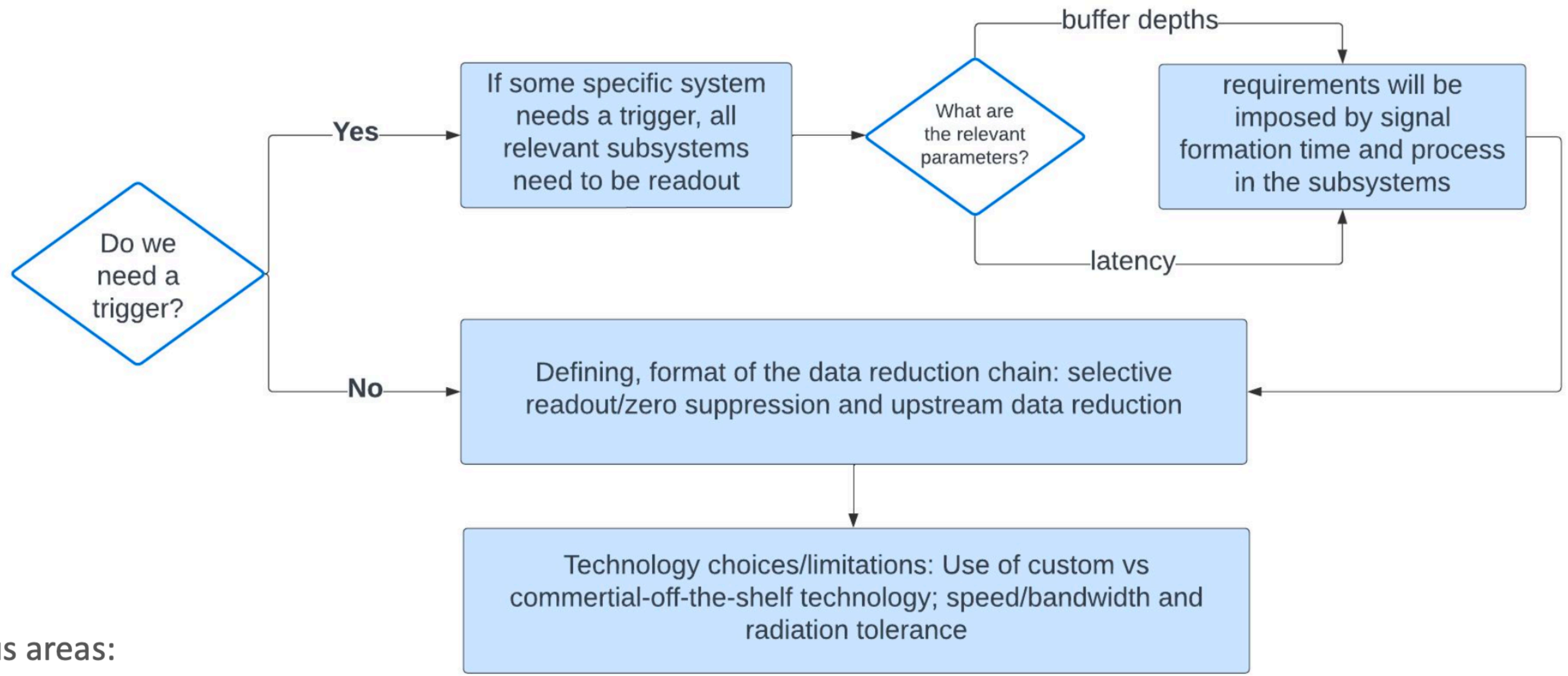
- Machine backgrounds were evaluated during FS with **limited impact** on detector design, **except for IPC backgrounds** revealing constraints on vertex detector.
- The main limitation for completing these studies is twofold:
    - **lack of digitizers** (describing the readout electronics) for some sub-detectors
    - not all single beam induced backgrounds simulations, such as beam-gas, were ready. Complication is that these backgrounds build up with time or originate far from the IP and necessitate an interface plane with the detector.
- Efforts underway to standardize simulation of machine-induced backgrounds, akin to LHC methods, aiming to provide detector experts with background events for estimating occupancy, data rates, to evaluate the effects on reconstruction.

Data rates issues *(see F. Bedeschi talk at 7th FCC Workshop)*

- **Largest data rates occur at the Z energy**
- **Expected data rates per BX/module [cluster size 5]**
  - From machine backgrounds (Incoherent pair creation – safety factor of 3) ~ 19 hits/BX/module
  - From collisions (200 kHz) ~ average ~<1 hit/BX/module
- **Inner layer ~400 MHz/cm^2 → ~25 Gb/s per module**
  - might be reduced if cluster size is only 2 – as measured for many MAPS
  - *ALICE3 hit rate ~100 MHz/cm^2 (pixel size 10μm x 10μm)*
  - 2nd layer ~10x less data volume
- **Triggered readout**: for 200 kHz the data bandwidth per module, rate is only 150 Mb/s
  - Impact on physics?

- **All these depend on pixel pitch, thickness, R/O architecture, bias voltage.**
  - For a review see M. Winter talk at March 11 meeting

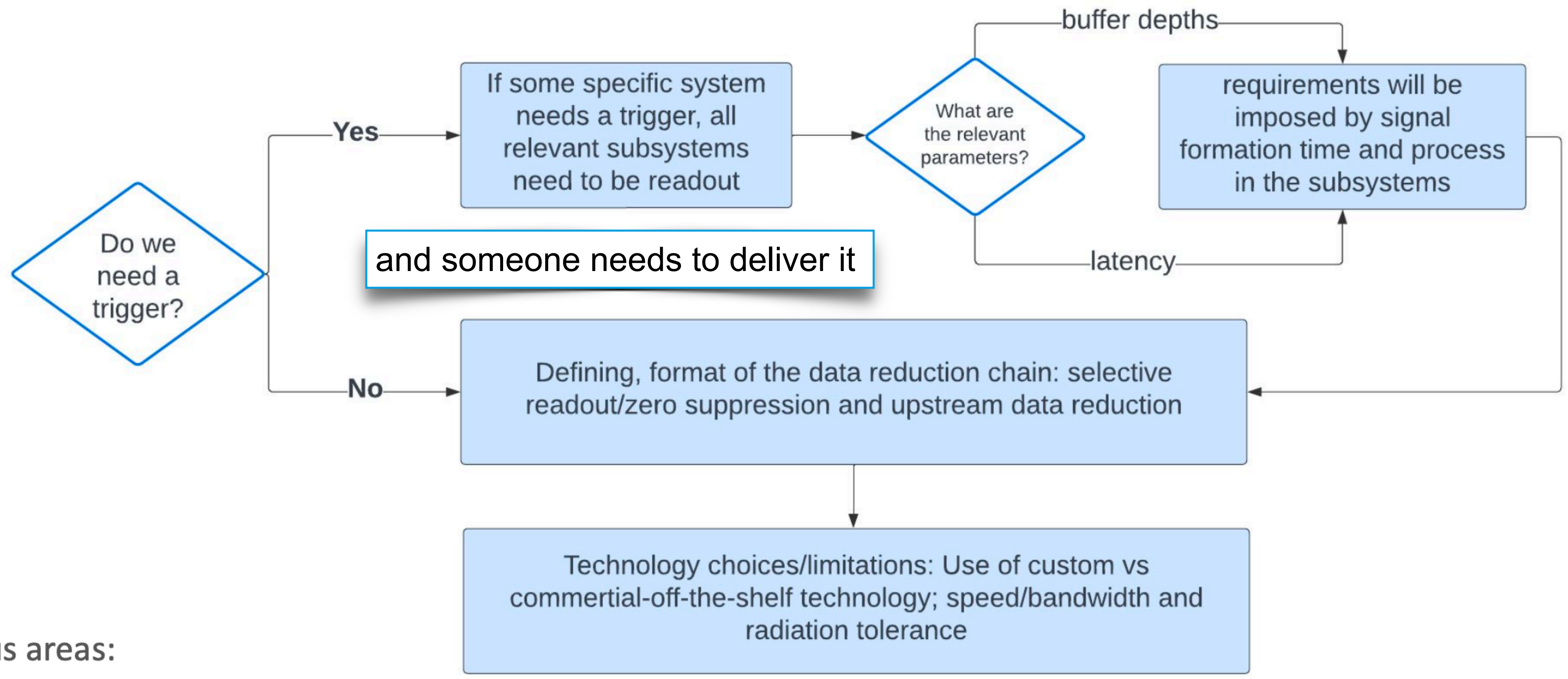
Fundamental Concepts to Address: Do we need a trigger?



Focus areas:

- Intelligence on detector: advance data reduction (ML/AI, etc)
- High performance sampling and timing (4D readout, etc)
- Levering emerging technologies (high-speed optical link, etc)

Fundamental Concepts to Address: Do we need a trigger?



Focus areas:

- Intelligence on detector: advance data reduction (ML/AI, etc)
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Summary

Take-home

FCCee detectors represent real challenges

- radiation tolerance generally not an issue - but rate capability is, and in tension with ILC-like ambitions for material budget and compactness

There is time and room for new ideas, concepts and technologies

- radiation tolerance generally not an issue - but rate capability is, and in tension with ILC-like ambitions for material budget and compactness
- try them out: demonstrators are collider-agnostic
- but real (scalable) prototypes will soon have to meet TDAQ electronics specs and will require some engineering

Software: common ILC FCC framework

- full simulations nearing completion - less true at the reconstruction frontier

After dinner: “starts to look like a real project”

- Lots of opportunities to get involved at smaller and larger levels - now!

Back-up

PICOSEC Micromegas

Studies on alternative gas mixtures

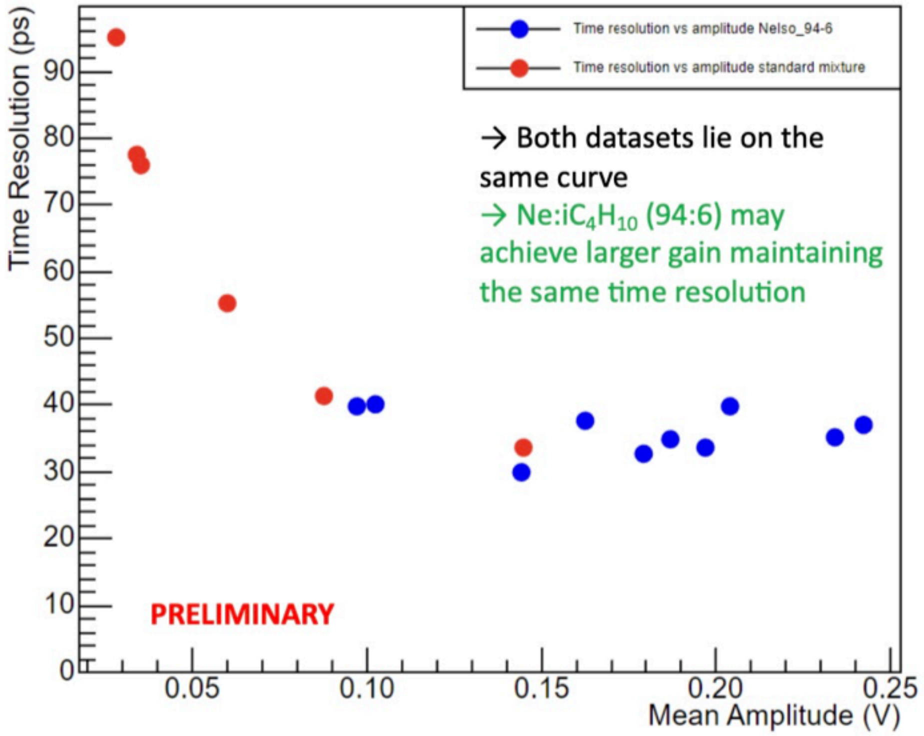
Alternative gas mixture studies But recall volume tiny!

- **PICOSEC standard gas mixture:** Ne:CF_4:C_2H_6 (80:10:10) → high gain, quenching, drift velocity, but expensive, **not eco-friendly**, flammable
- **Alternative gas mixture:** Ne:iC_4H_{10} → CF_4 dropped, iC_4H_{10} as a replacement of C_2H_6 → low GWP (0.2 instead of 740), good quenching

Promising results with Ne:iC_4H_{10}, further studies on the alternative gas mixtures to be performed

Ne:iC_4H_{10} (94:6)

CERN Chamber – 160 μm drift gap – rMM 82 MΩ/□ – CsI 18 nm



→ Both datasets lie on the same curve

→ Ne:iC_4H_{10} (94:6) may achieve larger gain maintaining the same time resolution

Ar-based gas mixtures:
→ Ar:CO_2 (93:7)
→ Ar:CO_2:iC_4H_{10} (93:5:2)
also tested but showed unstable operation

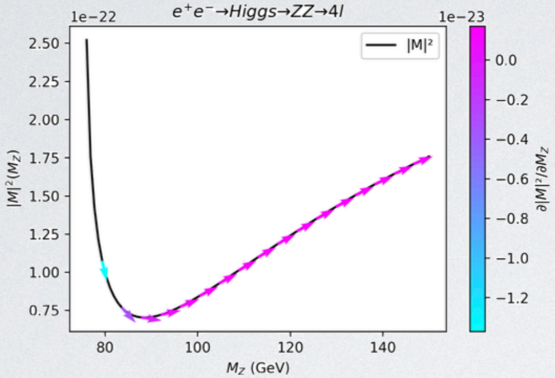
Details: D. Fiorina, INFN Pavia, FAST2023: link

AUTO-DIFFERENTIATION

- Keep track of gradients at each step → repeated chain rule*

MadJax (Differentiable MadGraph)

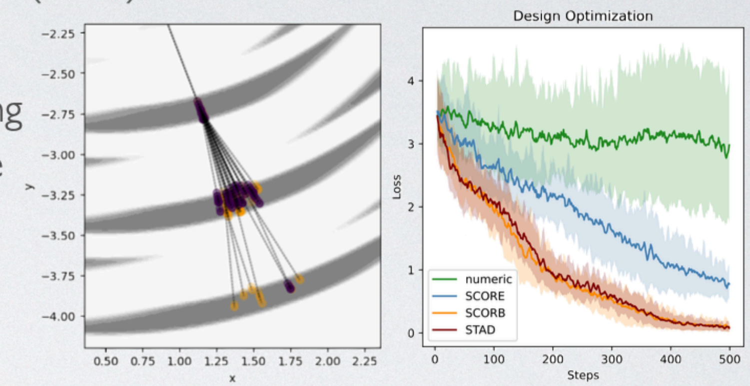
L. Heinrich and M. Kagan (2023)



Derivatives of discrete and random processes

L. Heinrich and M. Kagan (2023)

- Estimating gradients using stochastic AD and score
- Optimizing for toy detector inner radius



neos: Optimizing directly for p-values / FoMs

N. Simpson and L. Heinrich (2023)

- Tested on 2D toy problem with uncertainties