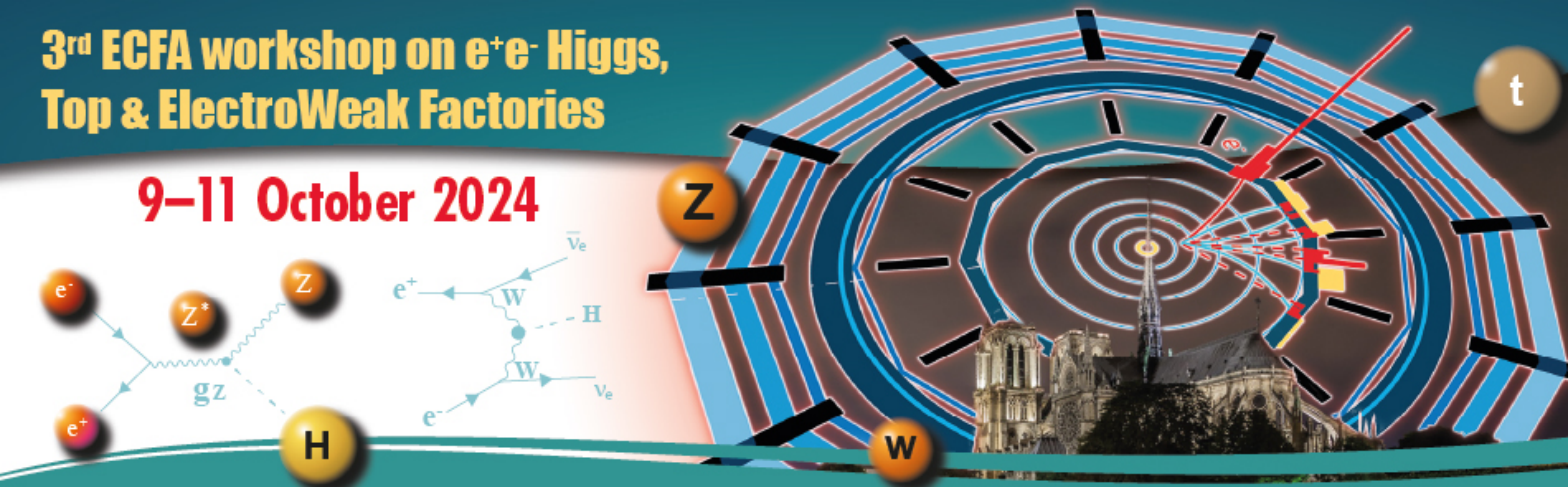


The Higgs-EWK-top Factory Challenge for Detectors

Paris, October 10, 2024

Felix Sefkow

Menu

Sequence of Courses

Detector Requirements

Detector concepts

- linear and circular colliders

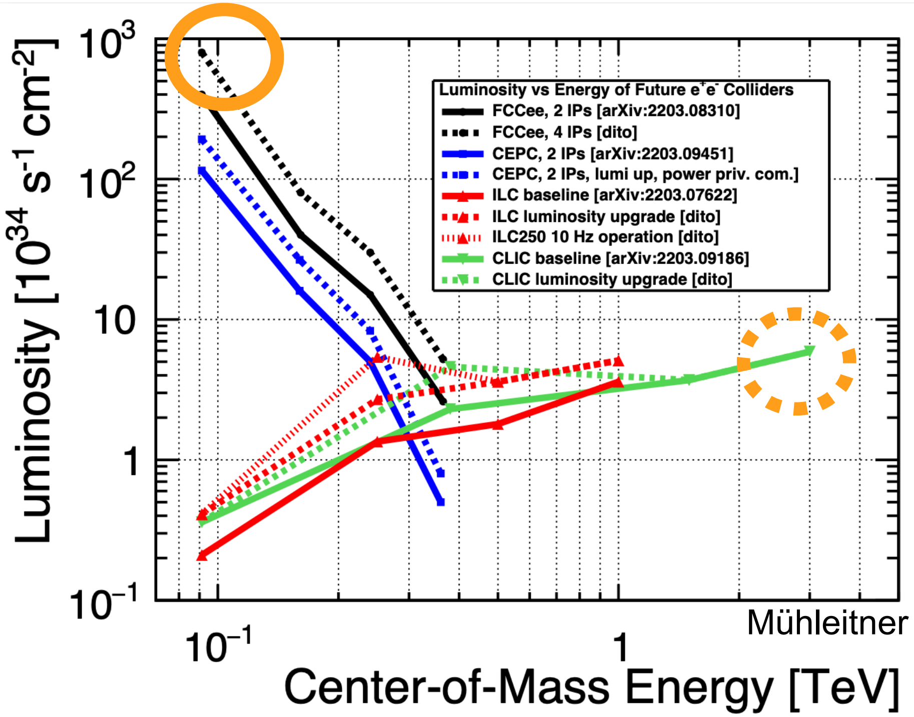
Detector systems and technologies

- Silicon Vtx and Tracker
- Gasous tracking
- Calorimeters
- no time to cover lumi system, muons and coil

Selected impressions from on-going work

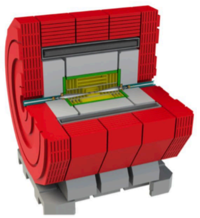
Higgs Factory Energies, Luminosities, Experiments

And Detector Requirements

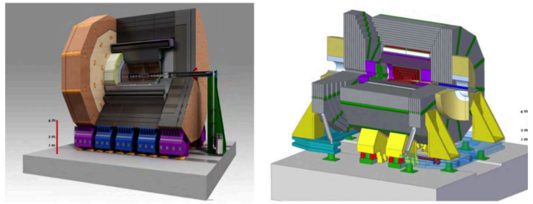


Mühleitner

Linear

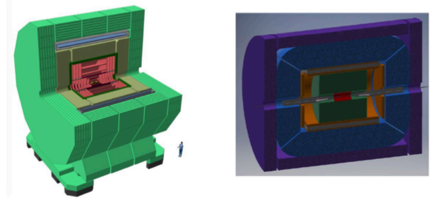


CLIC => **CLICdet**,
√s: 380 GeV, 1.5 TeV, 3 TeV



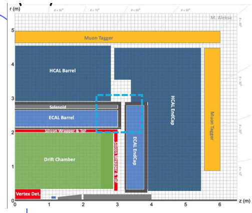
ILC => **ILD** and **SiD**:
√s: 250 – 500 GeV (1 TeV)

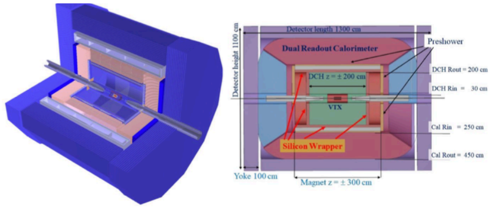
Circular



FCC-ee => **CLD** and **IDEA**
√s: 90 - 365 GeV

and **ALLEGRO**





CEPC => **baseline** and **low-B**
√s: 90-240 GeV

Marchiori

Particle and jet energies vary only logarithmically with collider energy

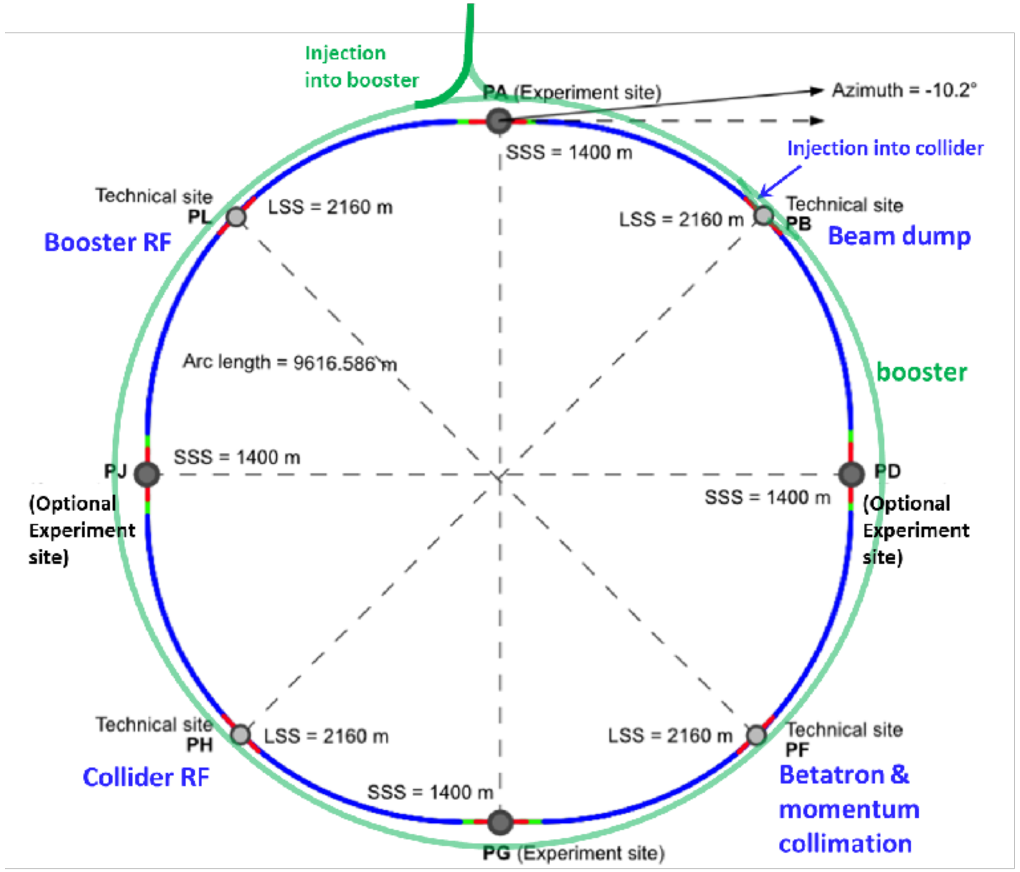
- detector concepts have been evolving adiabatically from one collider to the other

Two extreme points:

- CLICdet at high energy extensively studied 2010-2020: 0.5 ns pile-up of hadronic γγ background manageable
- **Tera-Z at FCCee poses most extreme challenges still to be tackled**

FCCee Parameters and Program

Challenges



FCC-ee parameters		Z	W⁺W⁻	ZH	ttbar
√s	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	143	20	7.5	1.38
Bunch spacing	ns	25	160	680	5000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section	pb	70,000	30	10	8
Event rate	Hz	100,000	6	0.5	0.1
"Pile up" parameter [μ]	10^{-6}	2,500	1	1	1

Z peak	$\sqrt{s}$ ~ 88, 91, 94 GeV	4 yrs	~200 ab^{-1}	6.10^{12} $e^+e^- \to Z$
WW threshold	$\sqrt{s}$ ~ 157.5, 162.5 GeV	2 yrs	~10 ab^{-1}	10^{8} $e^+e^- \to WW$
ZH maximum	$\sqrt{s}$ ~ 240 GeV	3 yrs	~10 ab^{-1}	2.10^{6} $e^+e^- \to ZH$
[s-channel H option	*$\sqrt{s}$ ~ 125 GeV*	*5? yrs*		*~5000 $e^+e^- \to H$*
Top threshold	$\sqrt{s}$ ~ 345 – 365 GeV	5 yrs	~3 ab^{-1}	2.10^{6} $e^+e^- \to tt$

per IP

Detector Requirements from Physics

Ambitious

Higgs Factory Program

- 2M ZH events at vs = 240 GeV
- 75k WW→H events at $\sqrt{s}$ = 365 GeV
- Higgs Couplings
- Higgs self-couplings (2-4σ) via loop diagrams
- Unique: e+e- →H at $\sqrt{s}$ = 125 GeV

- **Momentum** Resolution $\frac{\sigma_{pT}}{p_T} \simeq 10^{-3}\ at\ p_T \sim 50\ \mathrm{GeV}.$
- Jet **energy** resolution of 3-4% in multi-jet environment for Z/W separation
- **Impact** parameter resolution for *b, c* tagging

Precision EW and QCD Program

- 6 x 10^{12} Z and 10^8 WW events
  - m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W$, m_W, Γ_W, …
- 2 x 10^6 tt events
  - m_{top}, Γ_{top}, EW couplings
- Indirect sensitivity to new physics

- Absolute normalisation of **luminosity** to 10^{-4}.
- Relative normalisation to 10^{-5} (eg Γ_{had}/Γ_l)
- Momentum resolution, limited by **multiple scattering** → minimise material.
- Track angular resolution < 0.1 mrad
- Stability of **B-field** to 10^{-6}

Detector Requirements from Physics

Ambitious

Heavy Flavor Program

- 10^{12} bb, cc; 1.7 x 10^{11} $\tau\tau$ produced in a clean environment (10x Belle)
  - CKM matrix, CP measurements,
  - rare decays, CLFV searches, lepton universality

- Superior impact parameter resolution
  - Precisely dentify secondary vertices and measure **lifetimes**
- **ECAL** resolution at few $\%/\sqrt{E}$
- Excellent π^0/γ separation for **tau identification**
- **Particle ID**: K/π separation over a wide momentum range → e.g. by precision timing

Feebly coupled particles Beyond SM

- Opportunity to directly observe new feebly interacting particles with masses below m_Z
- Axion-like particles, dark photons, Heavy neutral leptons
- Long lifetimes LLPs

- Sensitivity to **far detached vertices**
  - Tracking: more layers, “continuous" tracking
  - Calorimeter: granularity, tracking capability
- Large decay length → extended decay volume
- Precise **timing**
- **Heremeticity**

From Linear to Circular e+e- Detectors

Conceptual Adaptations

Lower energy jets and particles, less collimated jets:

- reduced calorimeter depth
- shift imaging vs. energy resolution balance towards the latter
  - jet assignment ambiguities matter: 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 reduces granularity, timing, speed
- implications strongly technology-dependent, interesting optimisation challenges
- **DAQ (and possibly trigger) re-enter the stage, trigger-less read-out challenged**

From Linear to Circular e+e- Detectors

Conceptual Adaptations

FCCee 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 matter: 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 reduces granularity, timing, speed
- implications strongly technology-dependent, interesting optimisation challenges
- **DAQ (and possibly trigger) re-enter the stage, trigger-less read-out challenged**

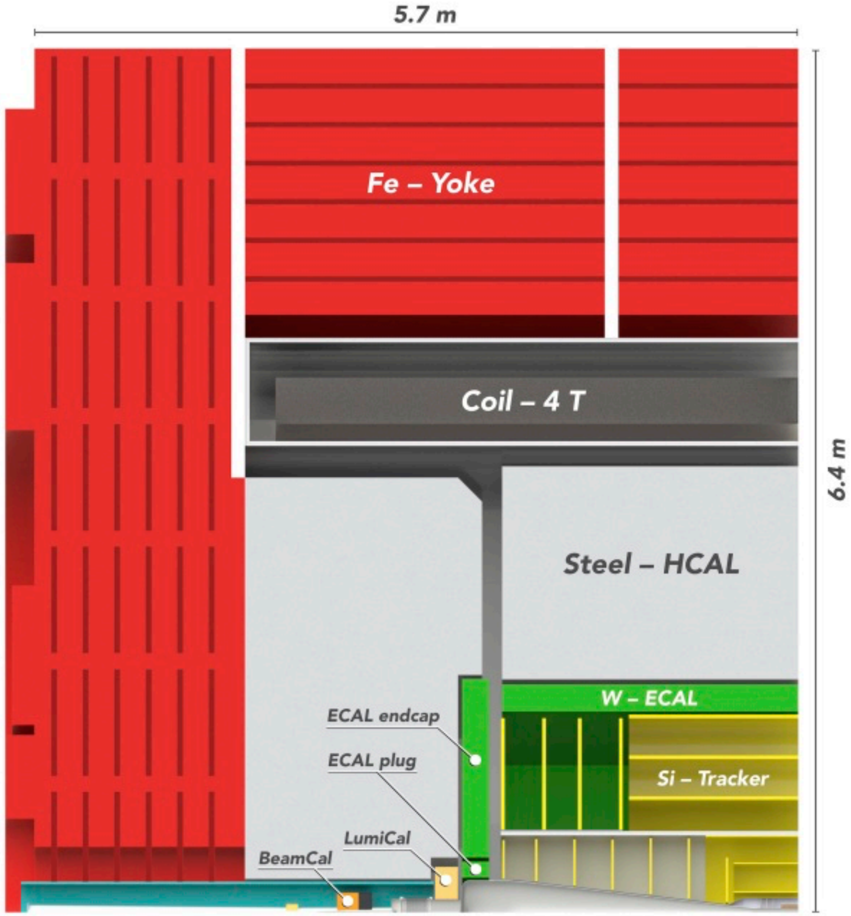
Detector Concepts

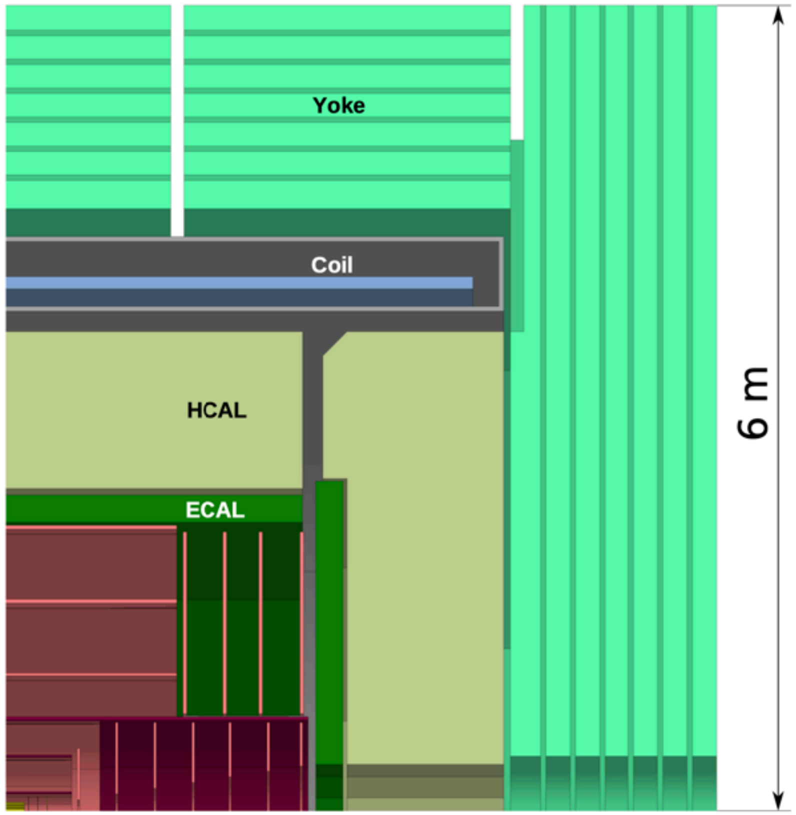
From LCs to FCCee

From CLICdet to CLD

CLICdet = CLIC-SiD CLIC-ILD merger

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD



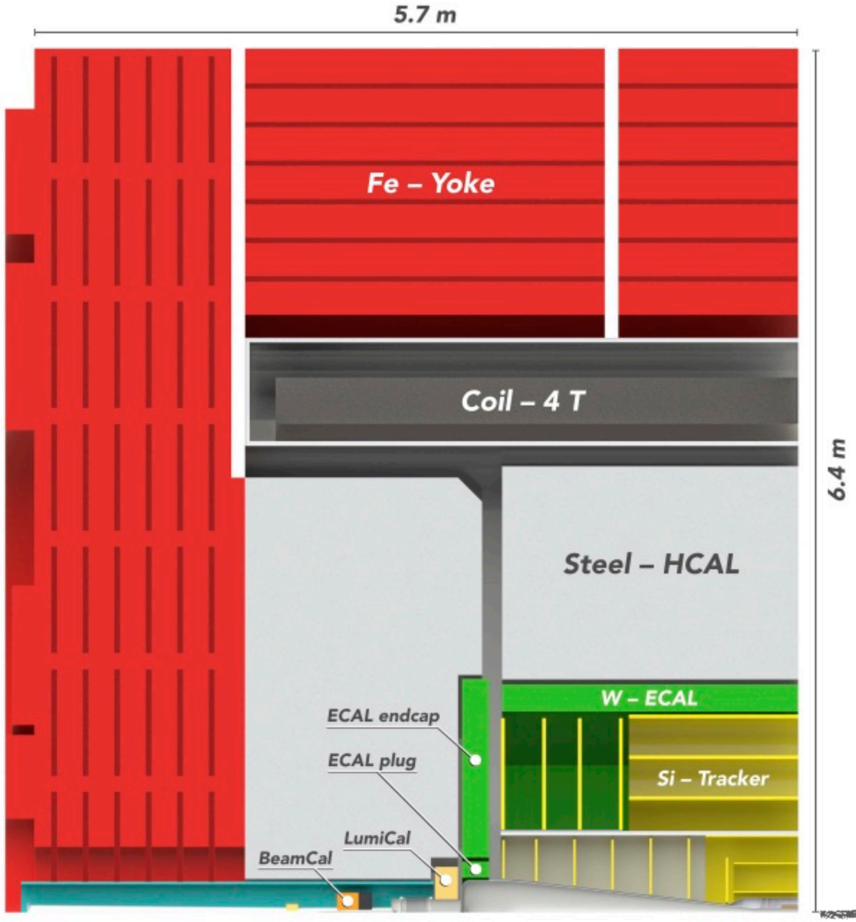


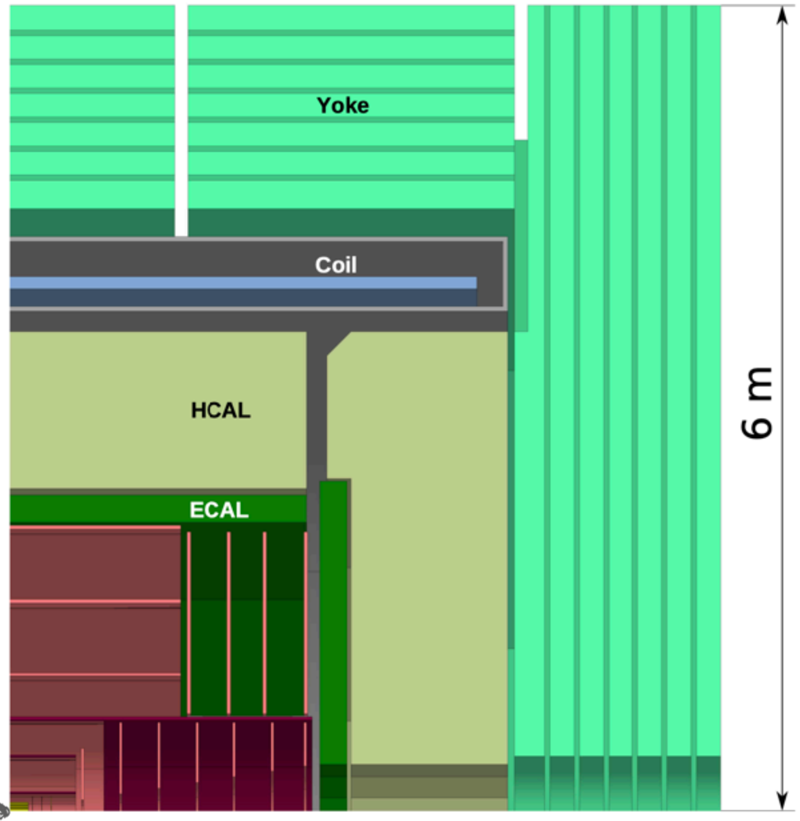
From LCs to FCCee

From CLICdet to CLD

CLICdet = CLIC-SiD CLIC-ILD merger

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD





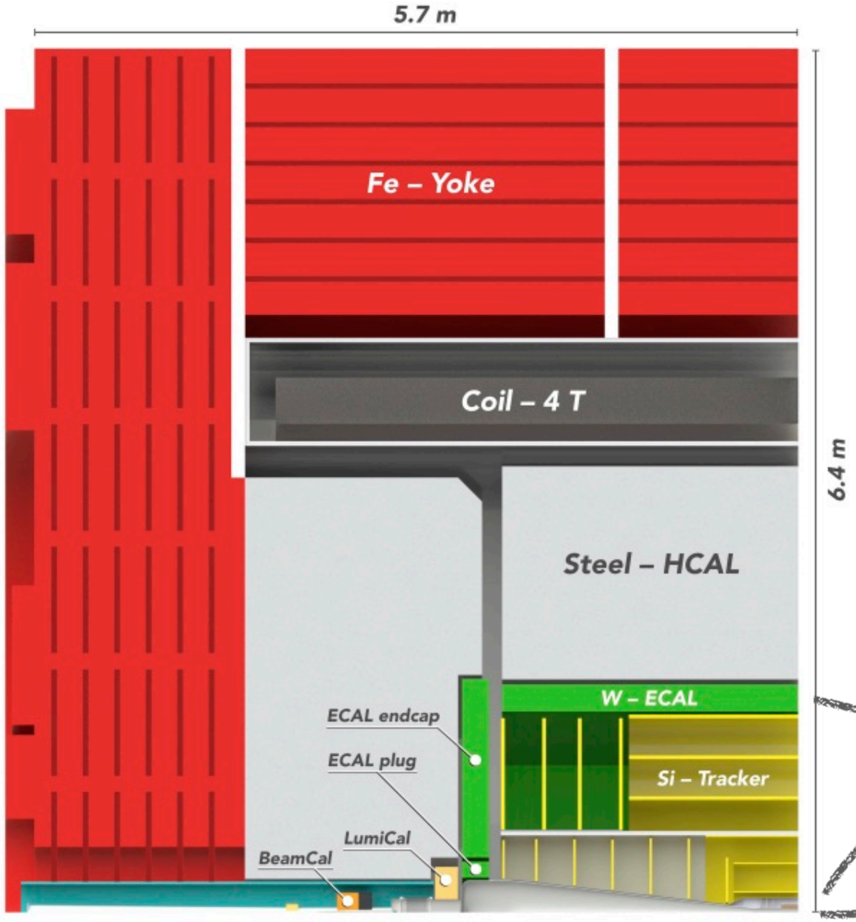
smaller VTX radius: profit from lower backgrounds, compensate material

From LCs to FCCee

From CLICdet to CLD

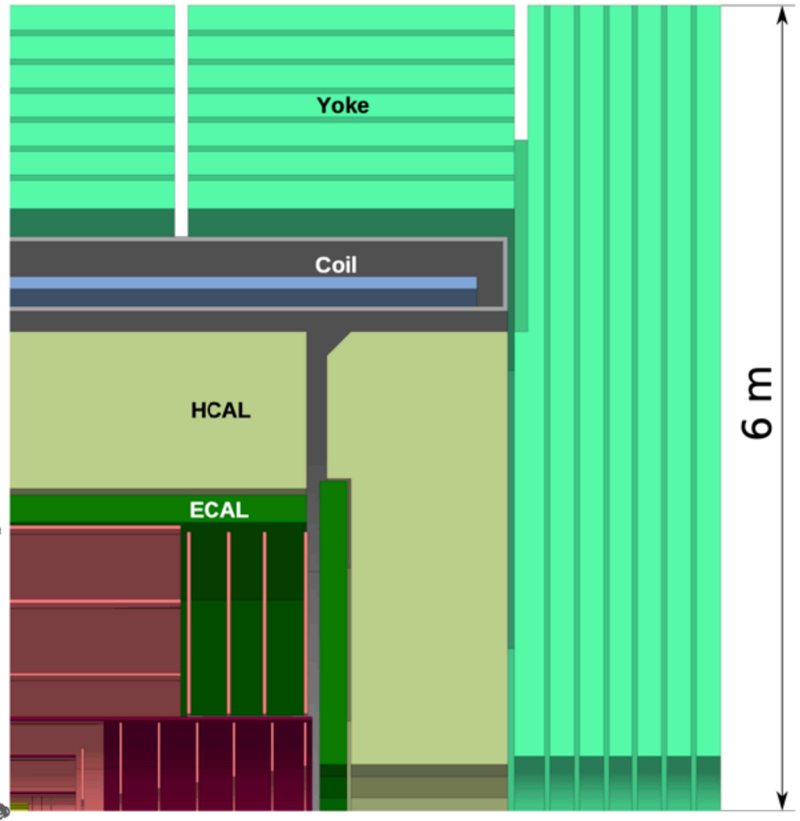
CLICdet = CLIC-SiD CLIC-ILD merger

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD



increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material



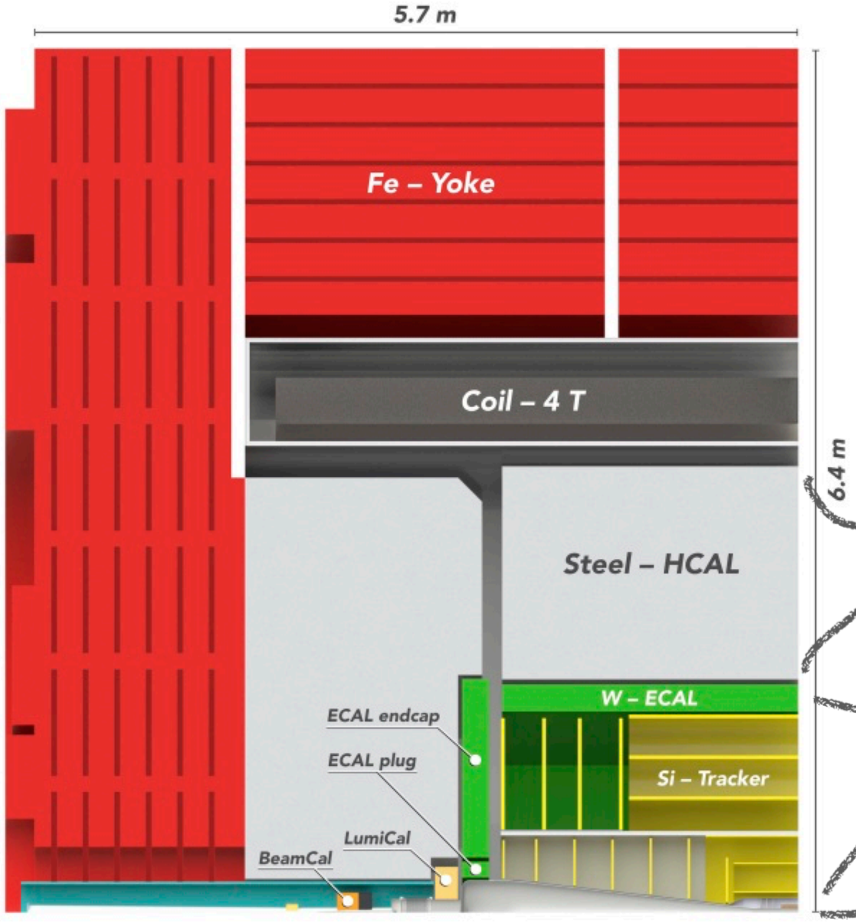
Frank Simon (fsimon@mpp.mpg.de)

From LCs to FCCee

From CLICdet to CLD

CLICdet = CLIC-SiD CLIC-ILD merger

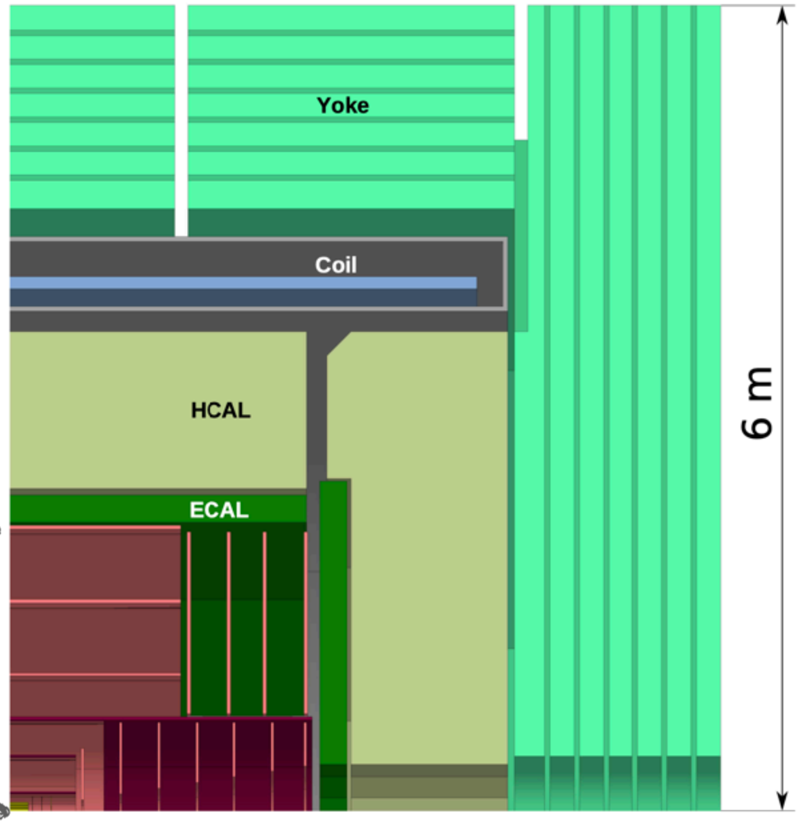
- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD



reduced HCAL thickness: enabled by lower energy

increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material



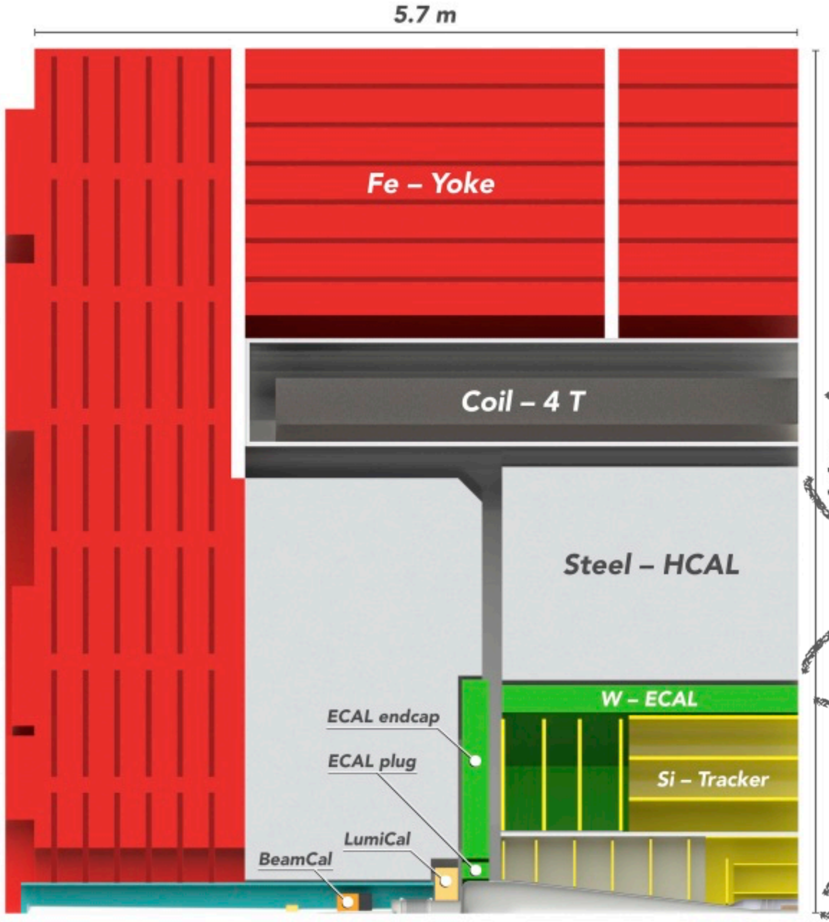
Frank Simon (fsimon@mpp.mpg.de)

From LCs to FCCee

From CLICdet to CLD

CLICdet = CLIC-SiD CLIC-ILD merger

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD

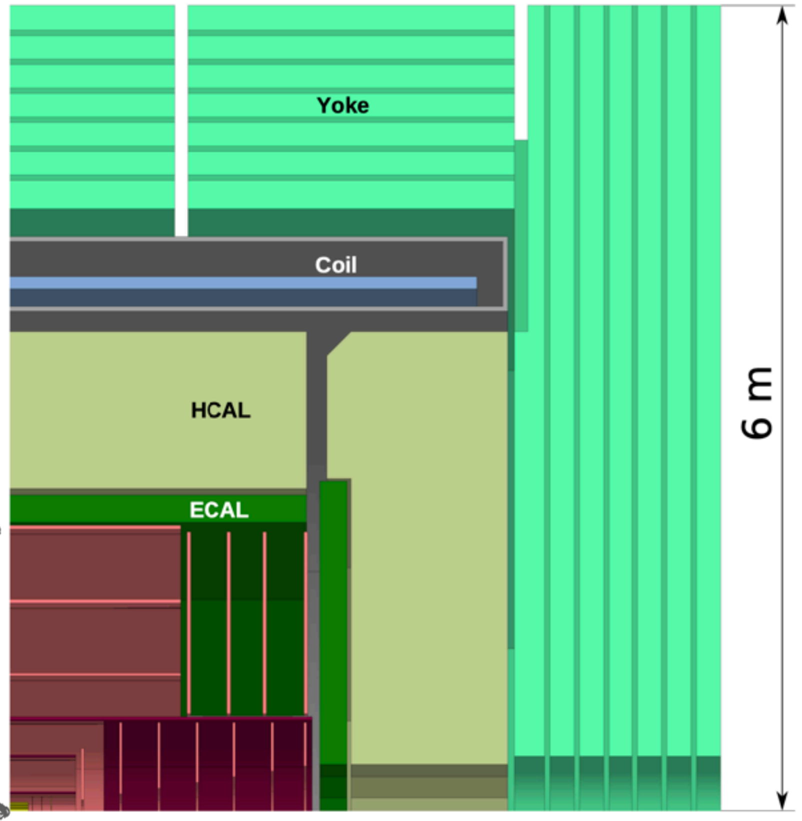


lower field: enable high luminosity in circular collider

reduced HCAL thickness: enabled by lower energy

increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material

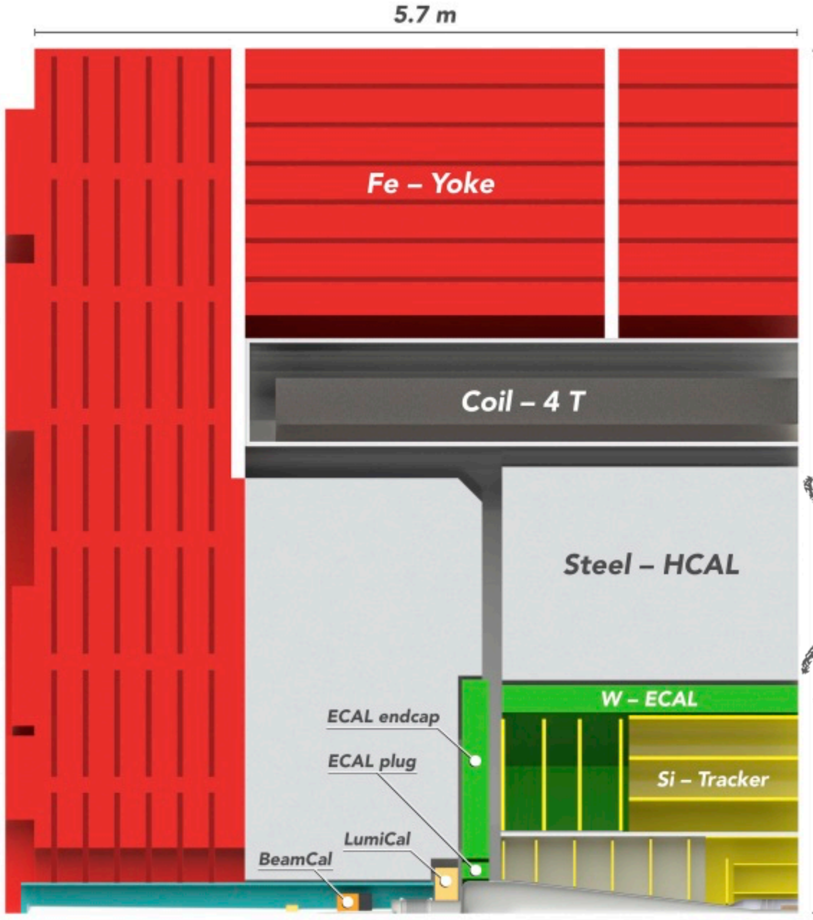


From LCs to FCCee

From CLICdet to CLD

CLICdet = CLIC-SiD CLIC-ILD merger

- A LC-inspired FCCee detector concept - retaining key performance parameters
  Evolving from CLICdet to CLD



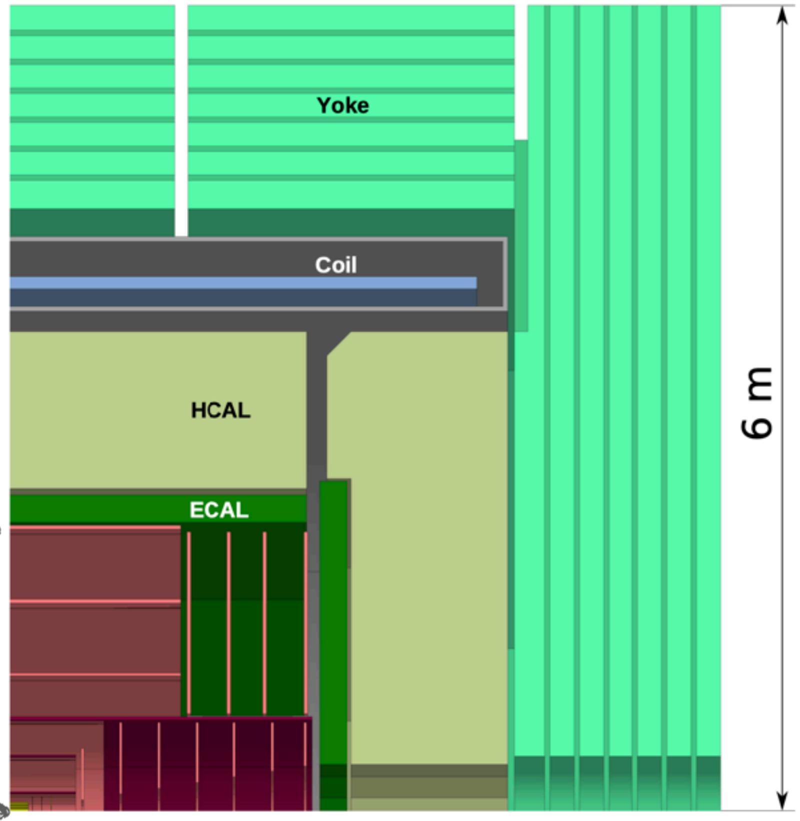
less steel: lower field allows reduced yoke thickness

lower field: enable high luminosity in circular collider

reduced HCAL thickness: enabled by lower energy

increase in tracker radius: retain p resolution

smaller VTX radius: profit from lower backgrounds, compensate material

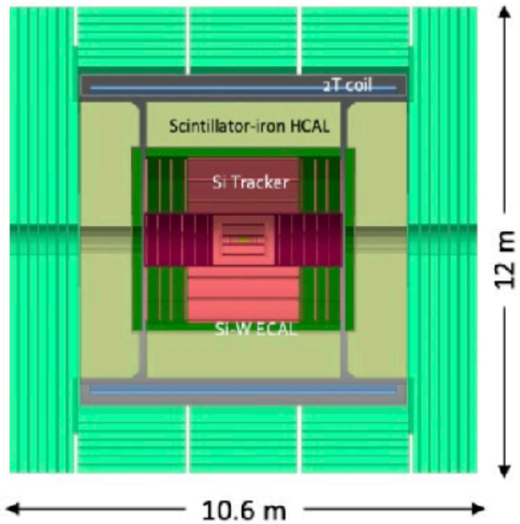


Frank Simon (fsimon@mpp.mpg.de)

FCCee Detector Concepts

Strawman Detector Benchmarks

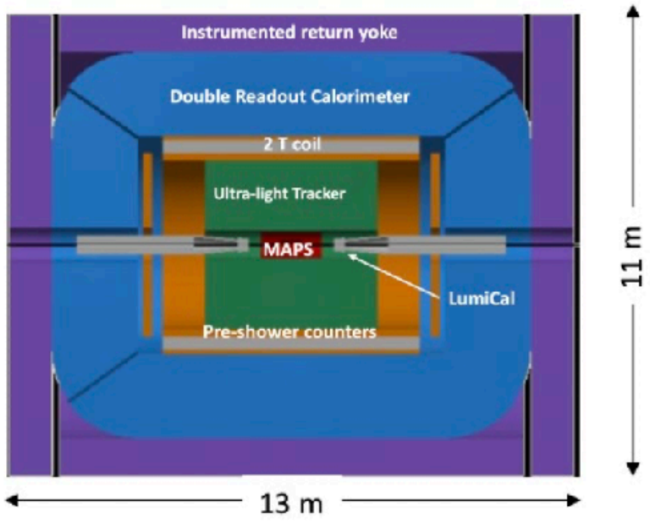
CLD



- 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)?

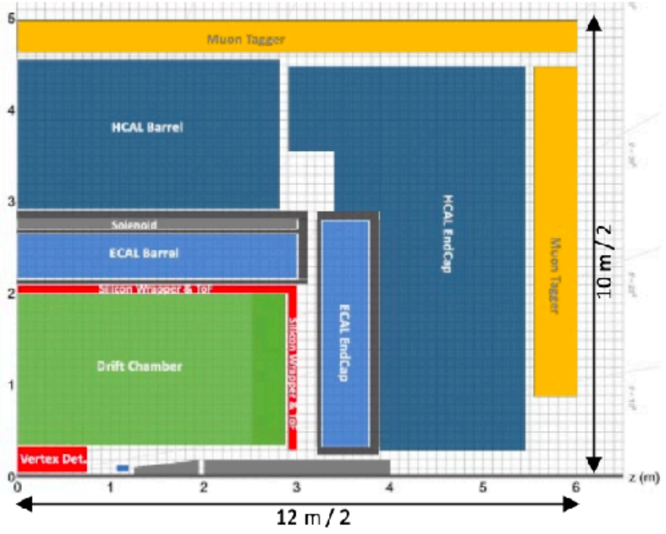
CDR

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

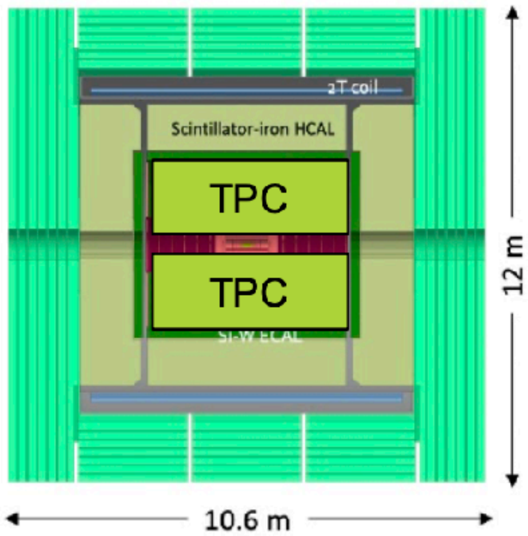


- The "new kid on the block"
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout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

FCCee Detector Concepts

Strawman Detector Benchmarks

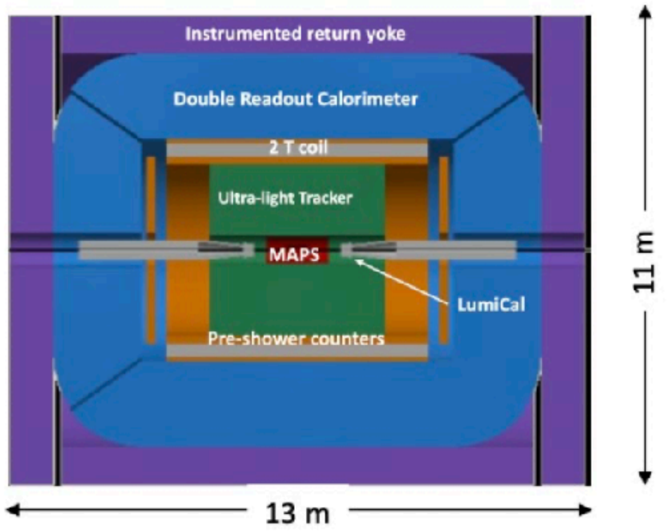
CLD/ILD’



- 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
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?

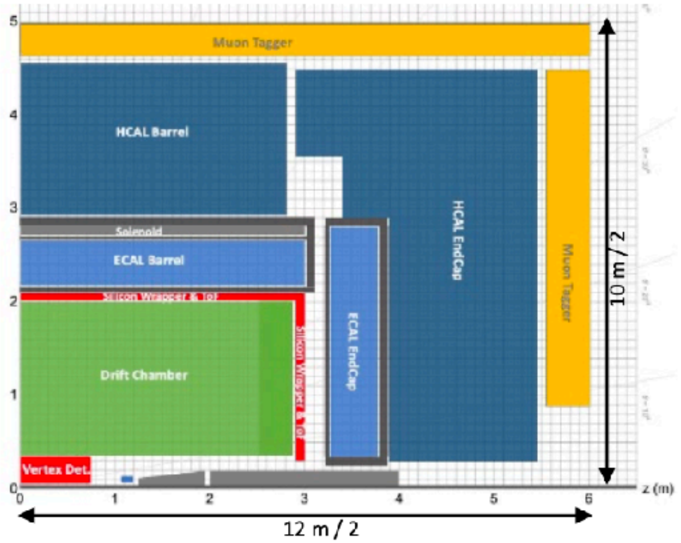
CDR

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



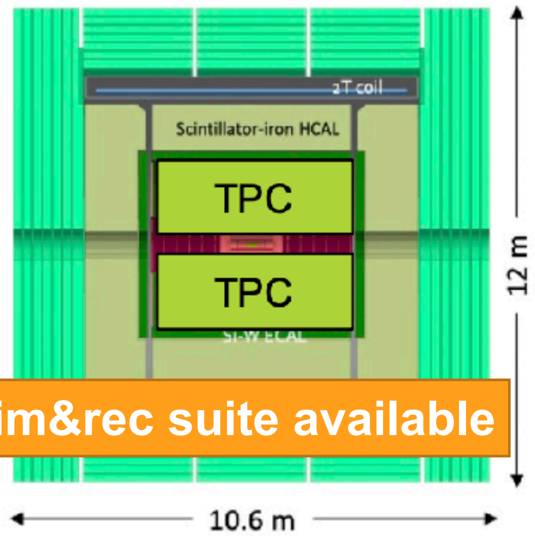
- The “new kid on the block”
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout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

FCCee Detector Concepts

Strawman Detector Benchmarks

CDR

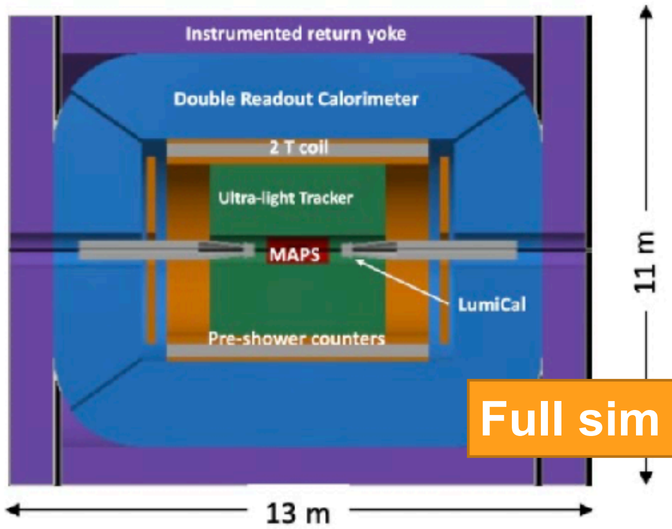
CLD/ILD’



Full sim&rec suite available

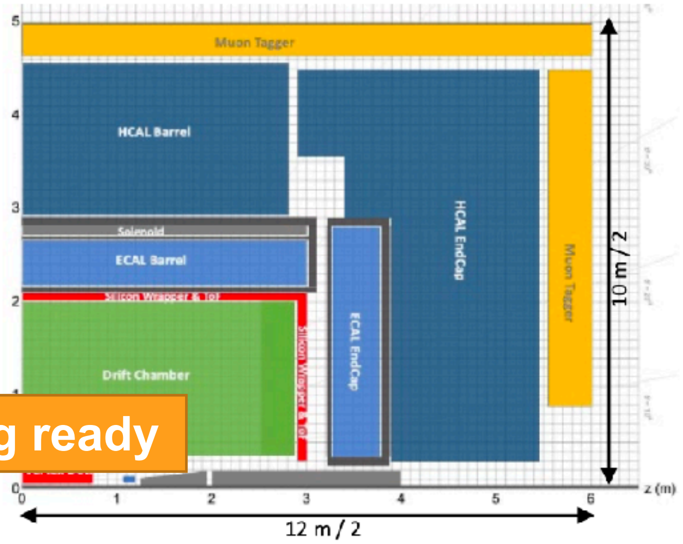
- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker, study TPC option viability
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector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

ALLEGRO



Full sim getting ready

- 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

- CLD: https://arxiv.org/abs/1911.12230
- IDEA: https://pos.sissa.it/390/819
- ALLEGRO: Eur.Phys.J.Plus 136 (2021) 10, 1066, https://arxiv.org/abs/2109.00391

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:

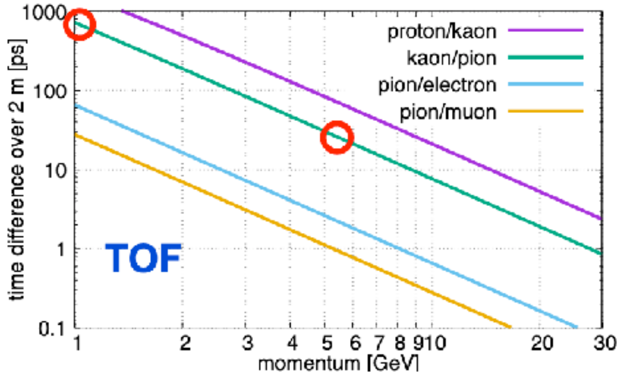
- a full **simulation** model
  - enable validation of single particle performance with prototypes
  - realistic prediction of full-event performance: will also need higher-level reconstruction tools
- overall **engineering**
  - to act and respond in the design of the MDI
  - to guide the optimisation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

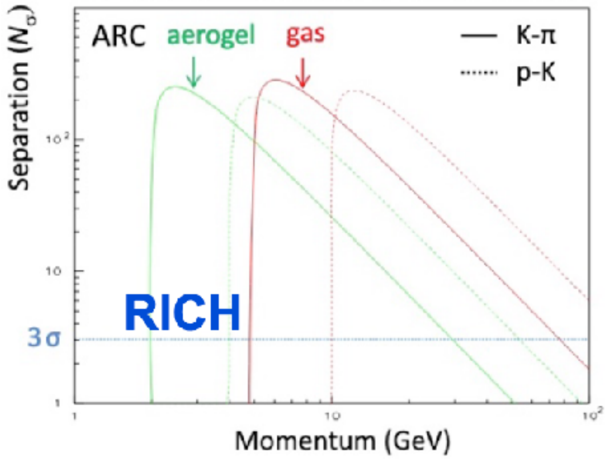
Collaboration forming at a later stage

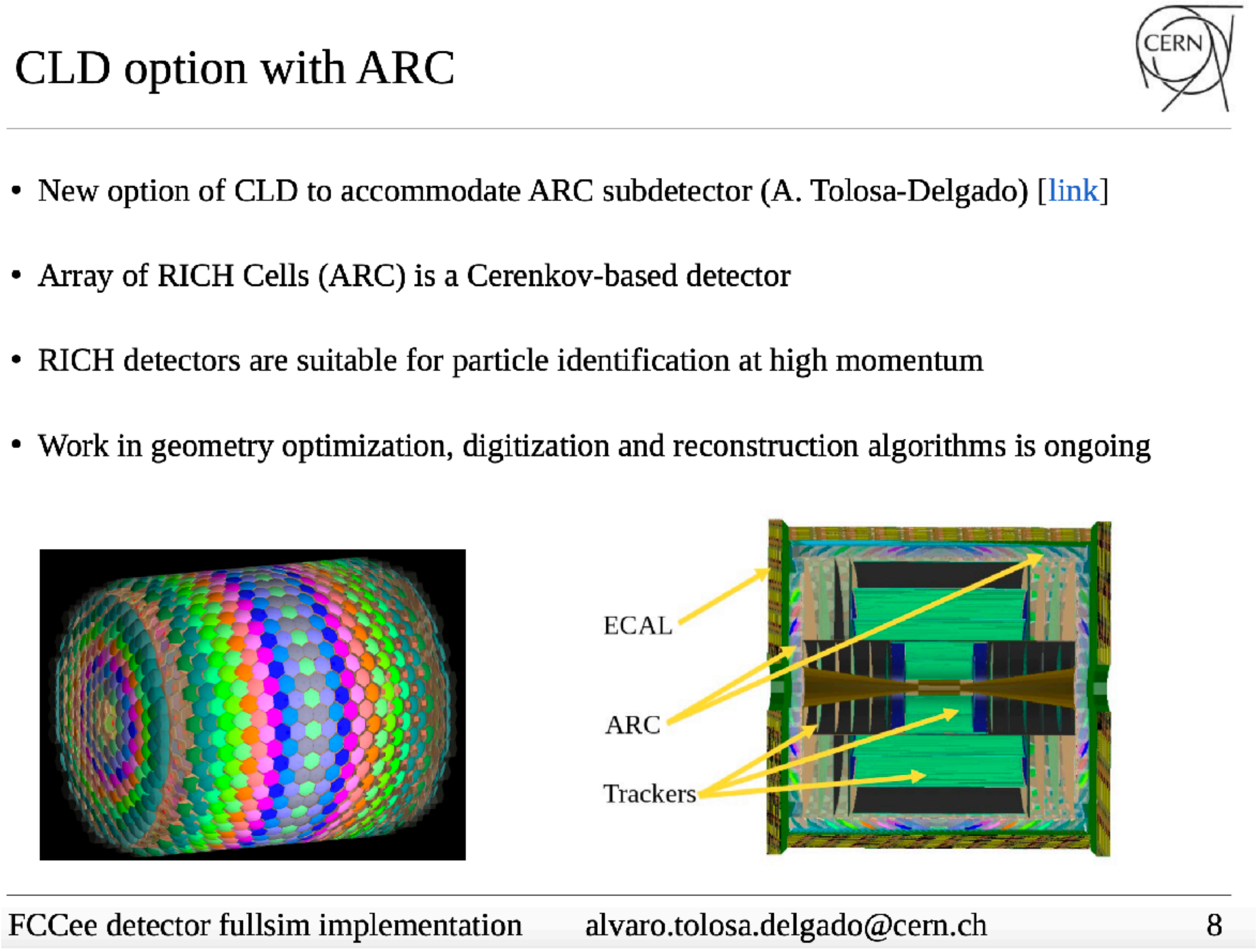
- maintain freedom to combine, e.g. tracking and calorimeter technologies (“plug & play”)

CLD with RICH-based Particle ID

Up to high momenta







CLD option with ARC

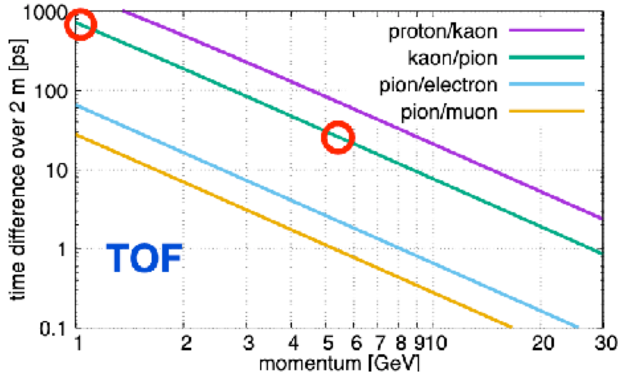
- New option of CLD to accommodate ARC subdetector (A. Tolosa-Delgado) [link]
- Array of RICH Cells (ARC) is a Cerenkov-based detector
- RICH detectors are suitable for particle identification at high momentum
- Work in geometry optimization, digitization and reconstruction algorithms is ongoing

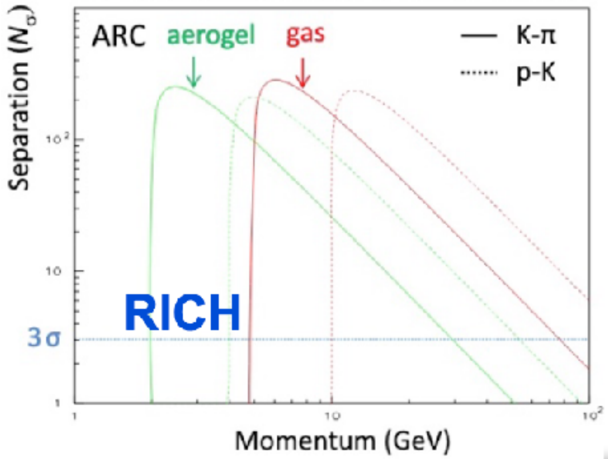
FCCee detector fullsim implementation alvaro.tolosa.delgado@cern.ch 8

CLD with RICH-based Particle ID

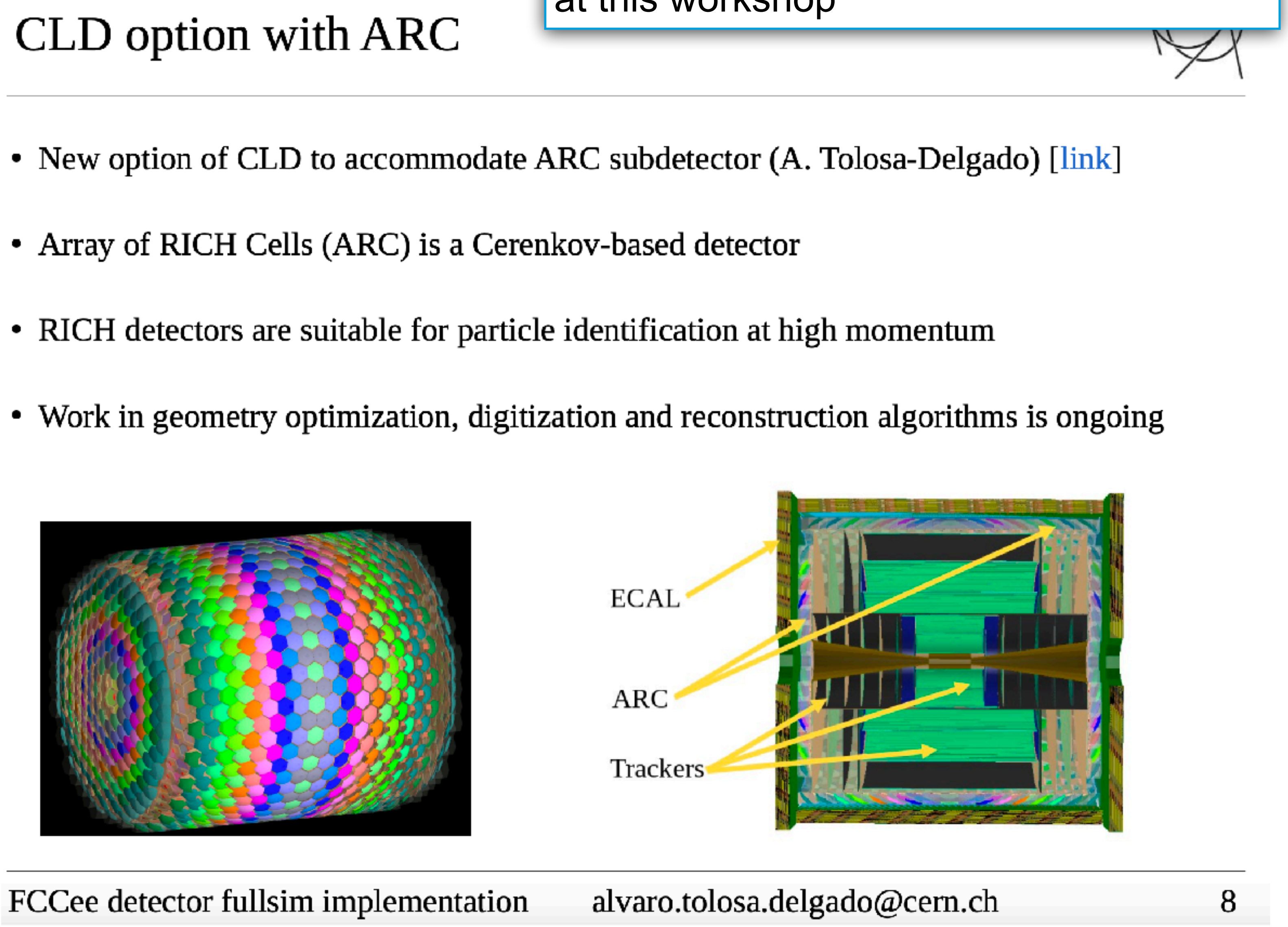
Up to high momenta

Tracker optimisation by Gaelle Sadowski,
ARC status by Serena Pezzulo
at this workshop





Tracking re-optimised
Particle flow to be studied next



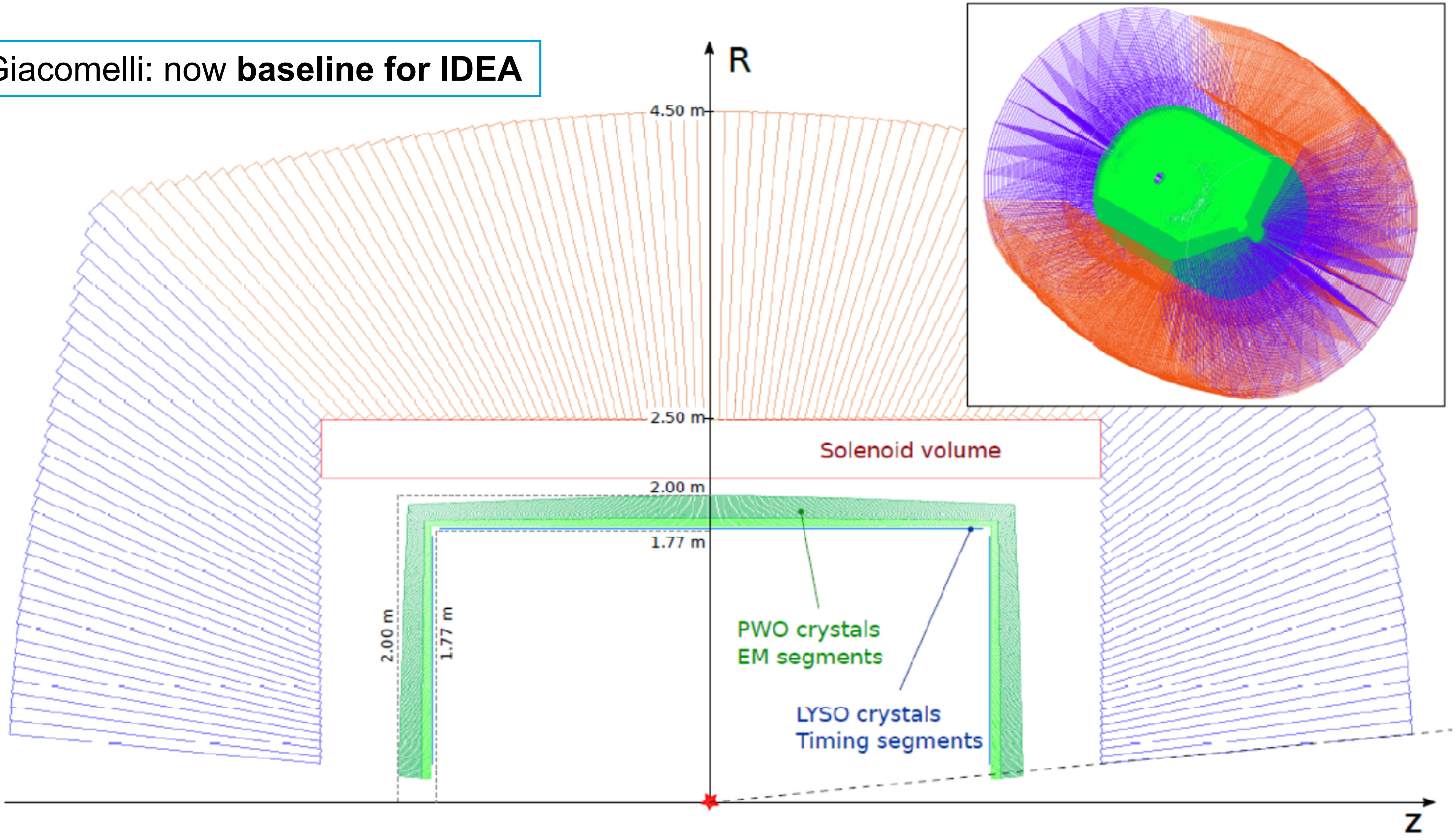
CLD option with ARC

- New option of CLD to accommodate ARC subdetector (A. Tolosa-Delgado) [link]
- Array of RICH Cells (ARC) is a Cerenkov-based detector
- RICH detectors are suitable for particle identification at high momentum
- Work in geometry optimization, digitization and reconstruction algorithms is ongoing

FCCee detector fullsim implementation alvaro.tolosa.delgado@cern.ch 8

Crystal option

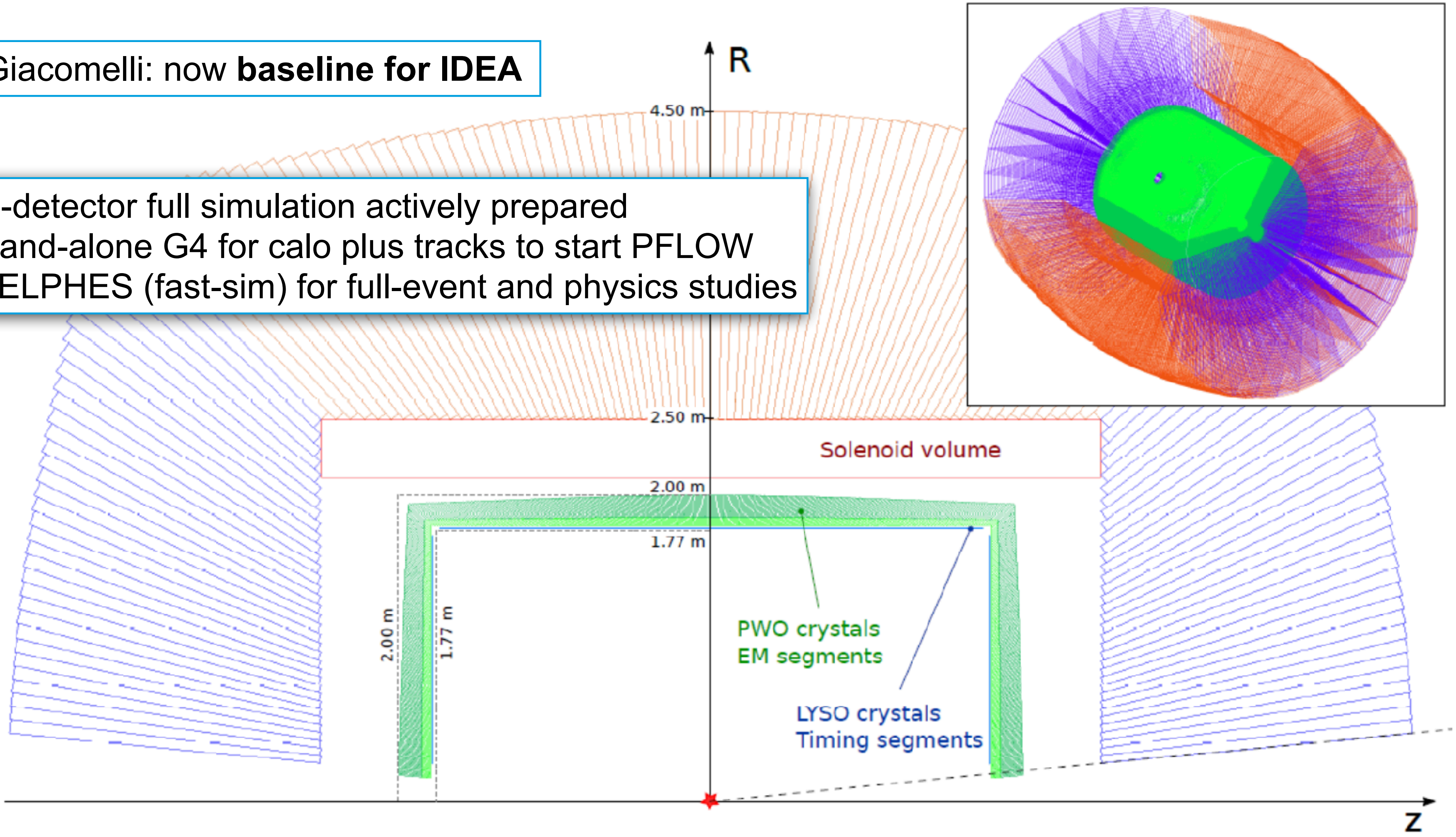
P. Giacomelli: now **baseline for IDEA**



Crystal option

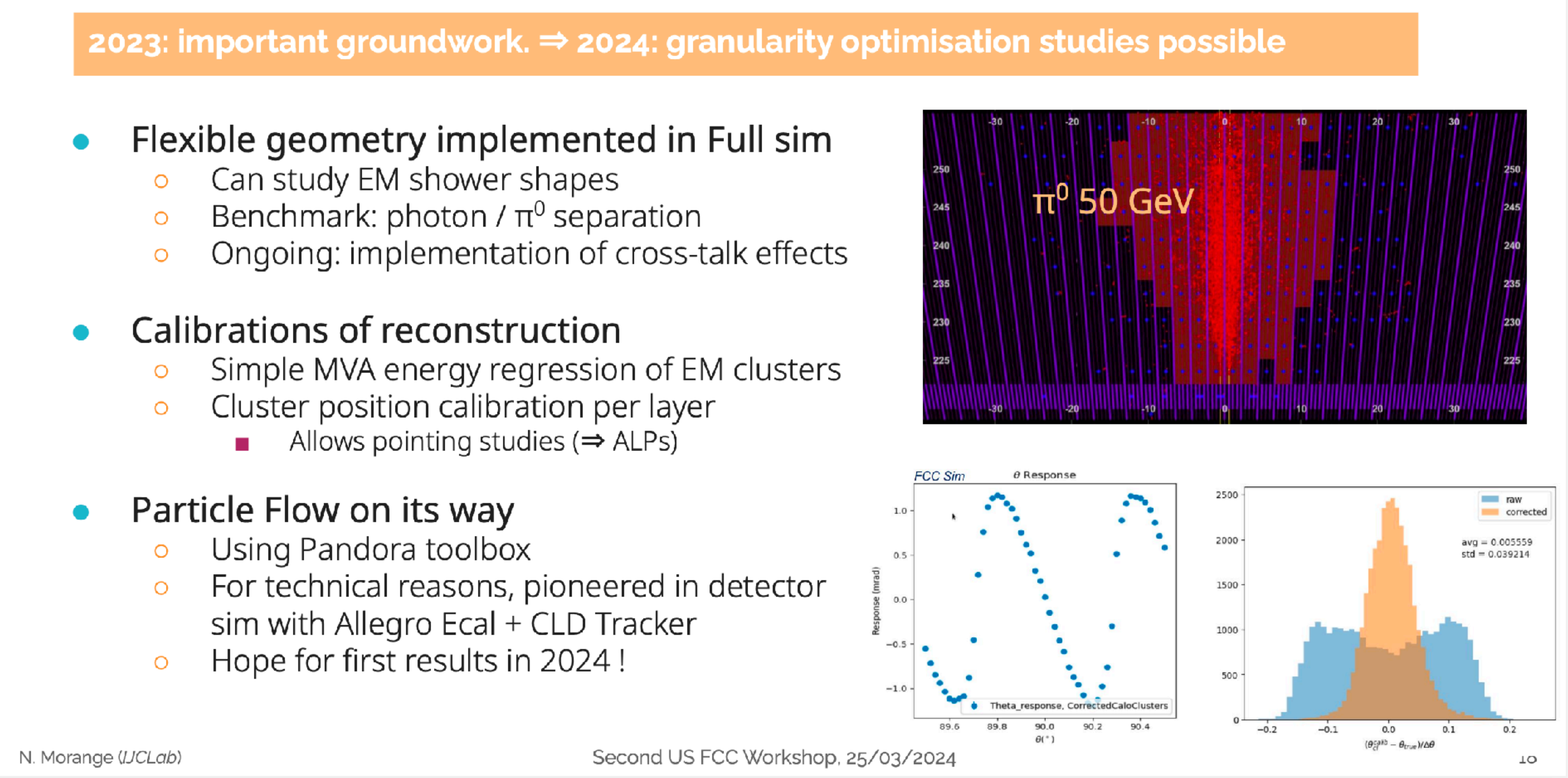
P. Giacomelli: now **baseline for IDEA**

Full-detector full simulation actively prepared
- stand-alone G4 for calo plus tracks to start PFLOW
- DELPHES (fast-sim) for full-event and physics studies



Status of ALLEGRO / LAr Simulations

Active Development in Key4HEP



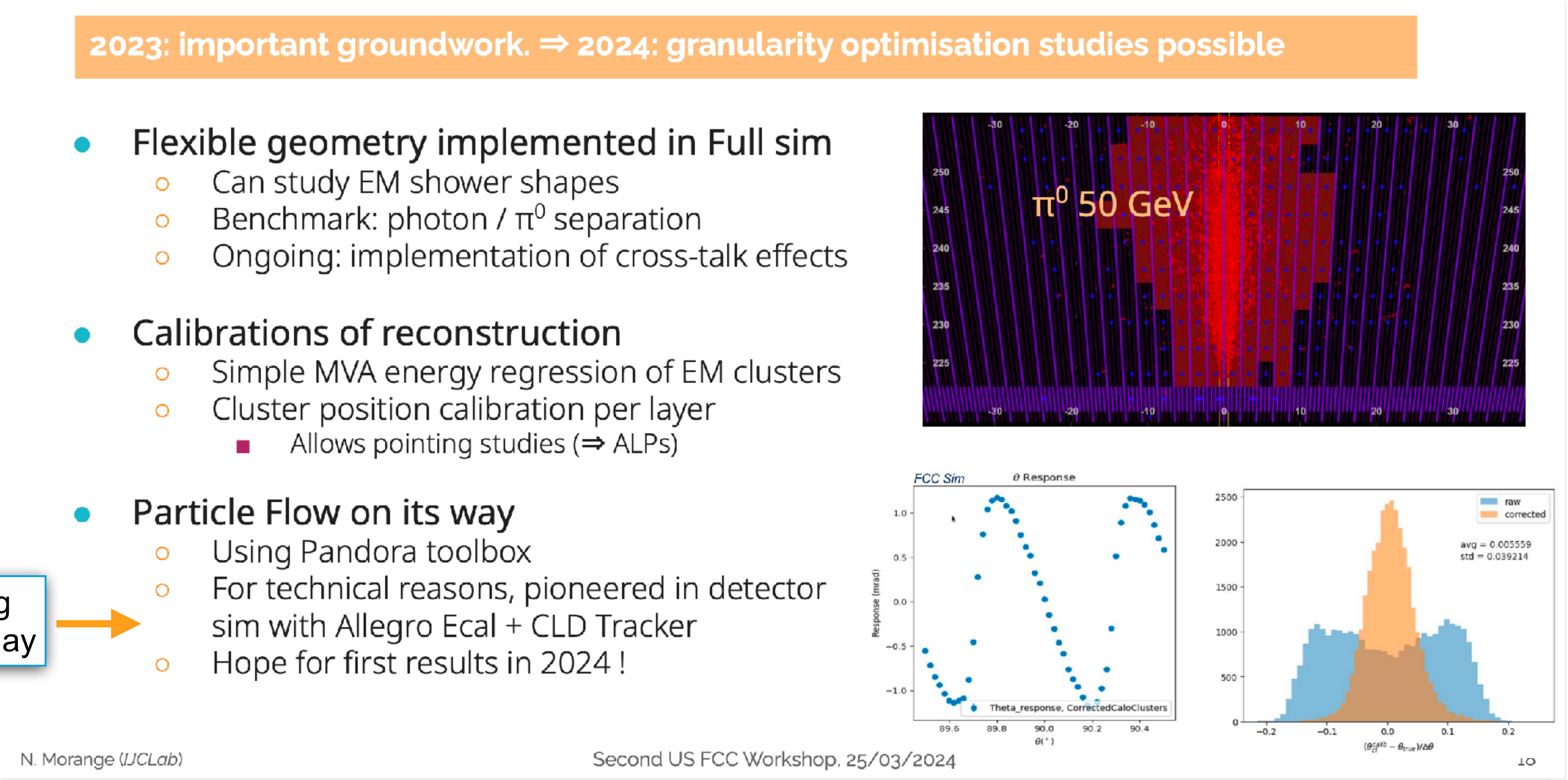
2023: important groundwork. ⇒ 2024: granularity optimisation studies possible

- 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 !

N. Morange (IJCLab)   Second US FCC Workshop, 25/03/2024

Status of ALLEGRO / LAr Simulations

Active Development in Key4HEP



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 !

N. Morange (IJCLab)

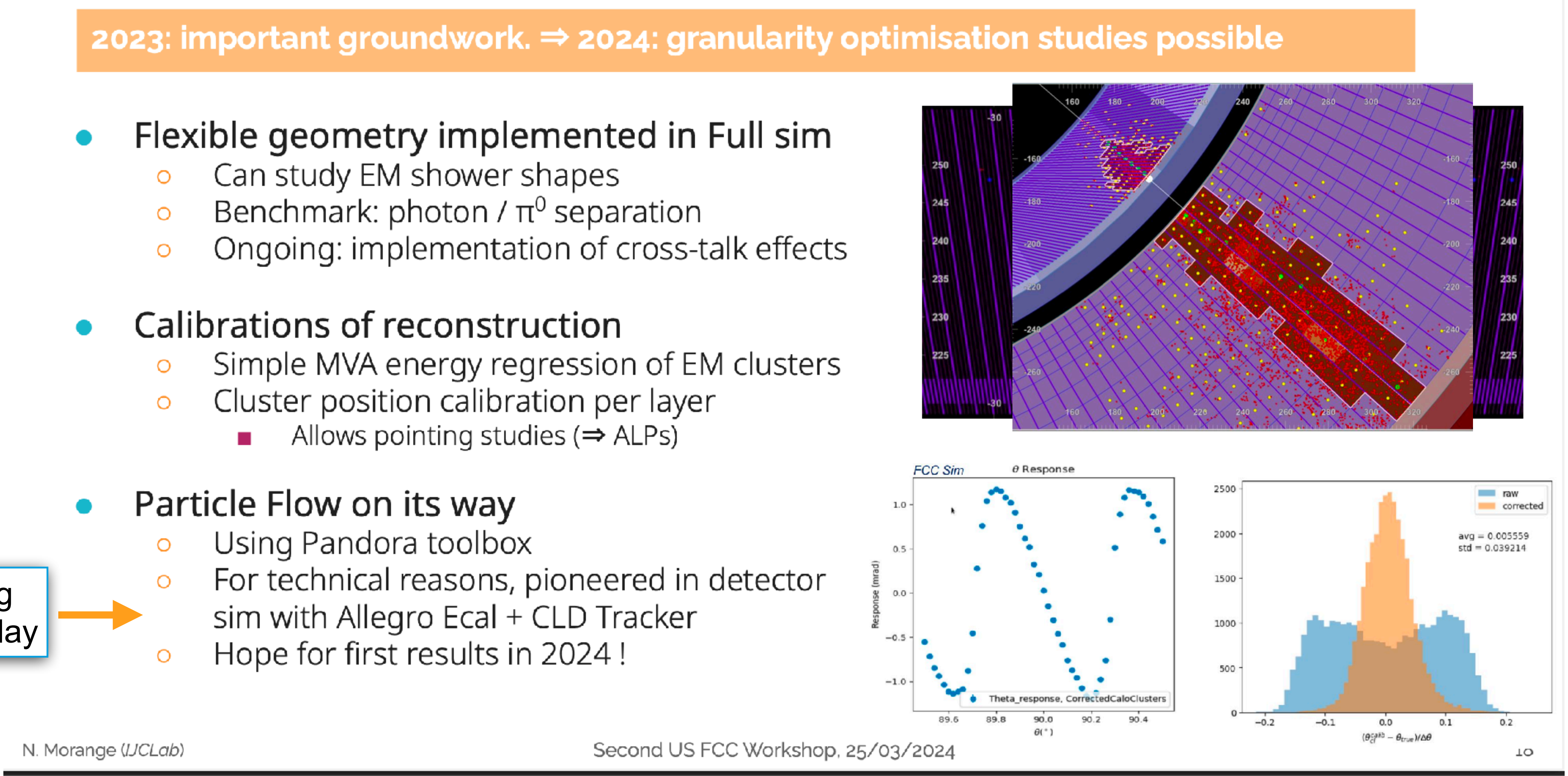
Second US FCC Workshop, 25/03/2024

Plug & play

Status of ALLEGRO / LAr Simulations

Active Development in Key4HEP

update by Michaela Mlynarikova at this workshop



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 !

N. Morange (IJCLab) Second US FCC Workshop, 25/03/2024 16

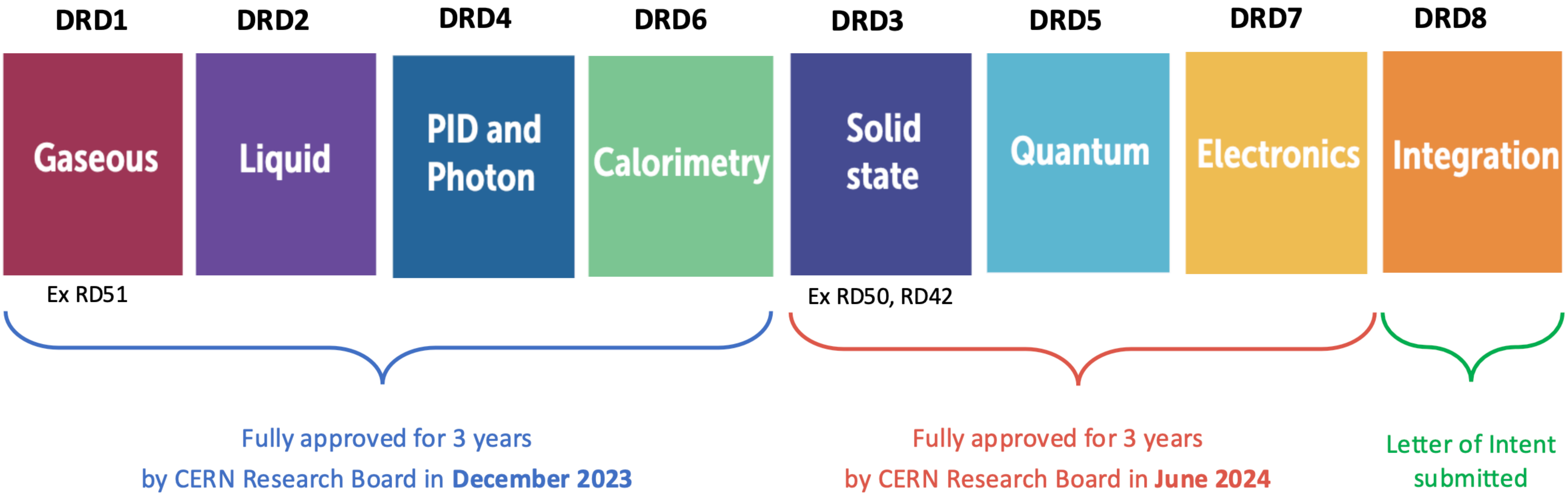
Plug & play

Detector Subsystems and Technologies

Status of DRD collaborations

DRD Meetings:
https://indico.cern.ch/category/6805/

Proposals (search for DRDC public)
https://cds.cern.ch/?ln=en



Fully approved for 3 years
by CERN Research Board in **December 2023**

Fully approved for 3 years
by CERN Research Board in **June 2024**

Letter of Intent
submitted

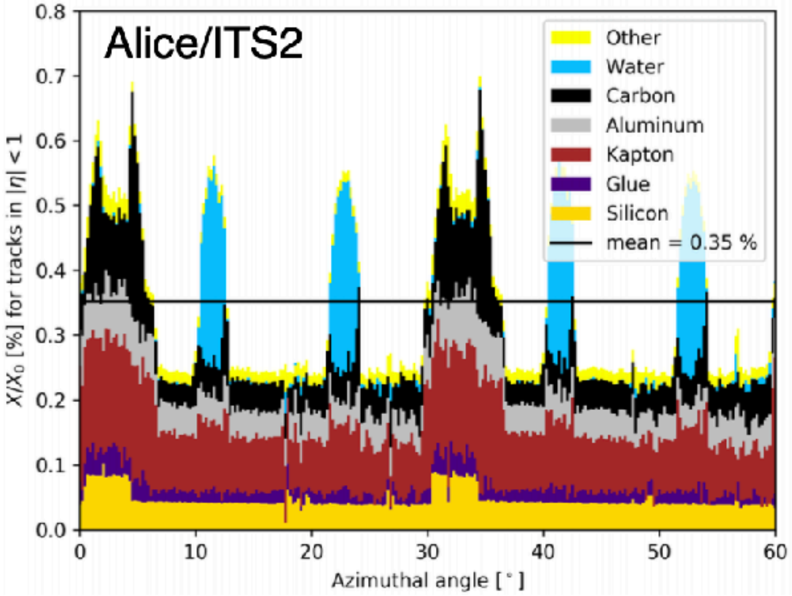
Silicon Vertex Detector and Main Tracker

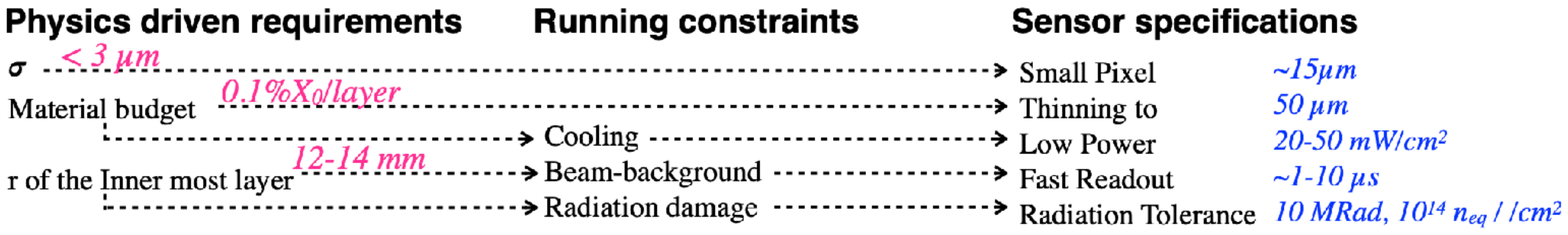
Sensors technology requirements for Vertex Detector

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





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

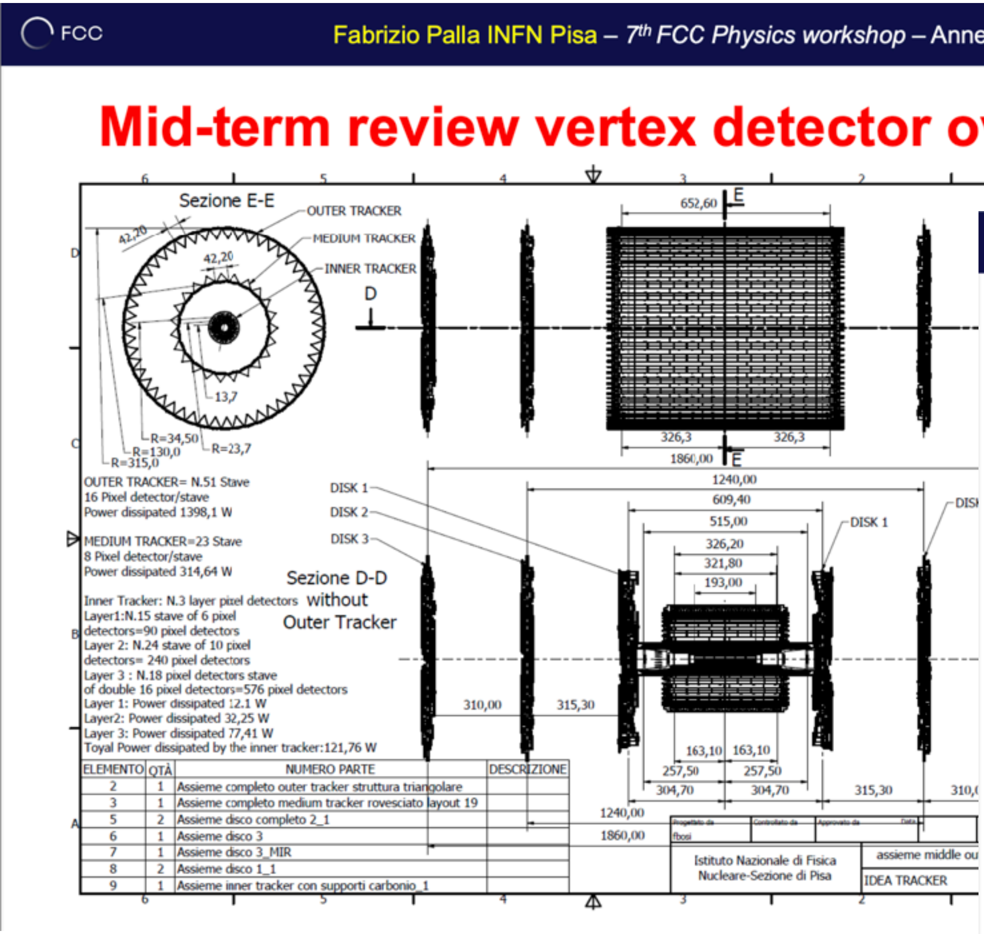
Chip name	Experiment	Subsystem	Technology	Pixel pitch [μm]	Time resolution [ns]	Power Density [mW/cm^2]
ALPIDE	ALICE-ITS2	Vtx, Trk	Tower 180 nm	28	< 2000	5
Mosaic	ALICE-ITS3	Vtx	Tower 65 nm	25x100	100-2000	<40
FastPix	HL-LHC		Tower 180 nm	10 - 20	0.122 – 0.135	>1500
DPTS	ALICE-ITS3		Tower 65 nm	15	6.3	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

Vertex Detector & Interaction Region

Detailed Engineering



FCC Fabrizio Palla INFN Pisa – 7th *FCC Physics workshop* – Annecy (France) – 29 Jan - 2 Feb 2024 4

Mid-term review vertex detector overall layout

OUTER TRACKER= N.51 Stave
16 Pixel detector/stave
Power dissipated 1398,1 W

MEDIUM TRACKER=23 Stave
8 Pixel detector/stave
Power dissipated 314,64 W

Inner Tracker: N.3 layer pixel detectors
Layer1:N.15 stave of 6 pixel detectors=90 pixel detectors
Layer 2: N.24 stave of 10 pixel detectors= 240 pixel detectors
Layer 3 : N.18 pixel detectors stave of double 16 pixel detectors=576 pixel detectors
Layer 1: Power dissipated 12.1 W
Layer2: Power dissipated 32,25 W
Layer 3: Power dissipated 77,41 W
Toyal Power dissipated by the inner tracker:121,76 W

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	

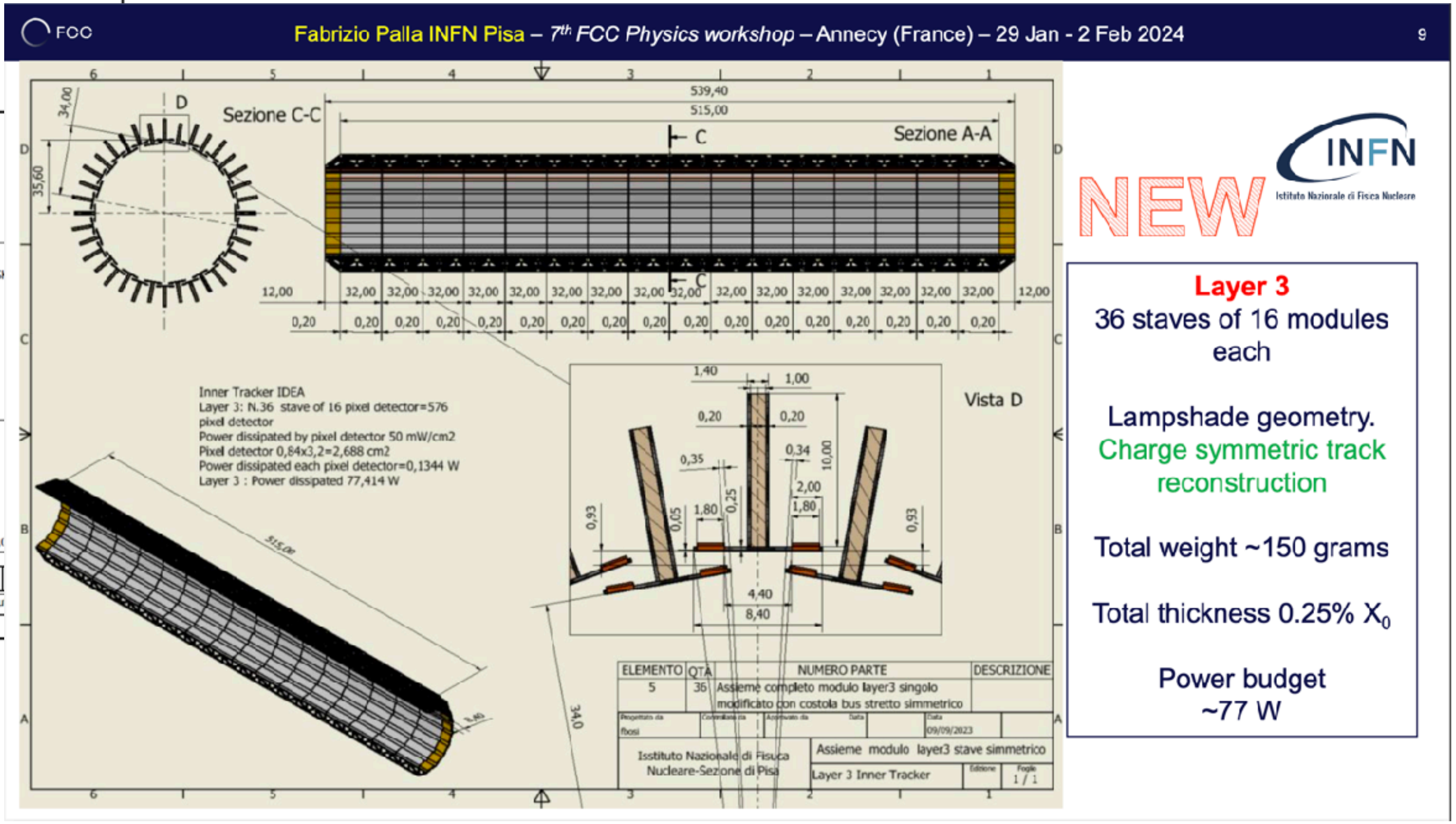
Progettato da fbosi | Controllato da | Approvato da | Data

Istituto Nazionale di Fisica Nucleare-Sezione di Pisa

assieme middle ou

IDEA TRACKER

INFN



FCC Fabrizio Palla INFN Pisa – 7th *FCC Physics workshop* – Annecy (France) – 29 Jan - 2 Feb 2024 9

Inner Tracker IDEA
Layer 3: N.36 stave of 16 pixel detector=576 pixel detector
Power dissipated by pixel detector 50 mW/cm2
Pixel detector 0,84x3,2=2,688 cm2
Power dissipated each pixel detector=0,1344 W
Layer 3 : Power dissipated 77,414 W

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

Progettato da fbosi | Controllato da | Approvato da | Data 09/09/2023

Isstituto Nazionale di Fisuca Nucleare-Sezione di Pisa

Assieme modulo layer3 stave simmetrico

Layer 3 Inner Tracker | Edizione | Foglio 1 / 1

NEW

INFN Istituto Nazionale di Fisica Nucleare

Layer 3
36 staves of 16 modules each

Lampshade geometry.
Charge symmetric track reconstruction

Total weight ~150 grams

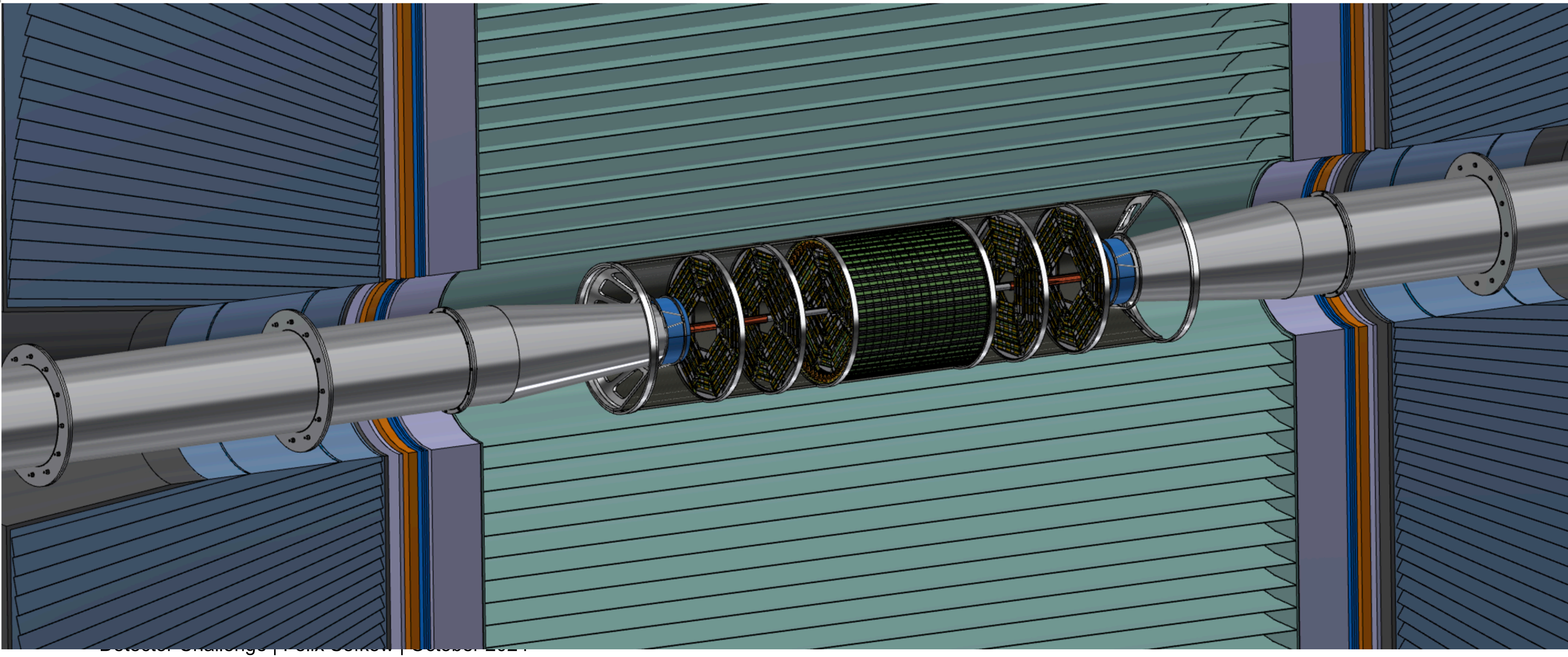
Total thickness 0.25% X_0

Power budget ~77 W

Vertex Detector & Interaction Region

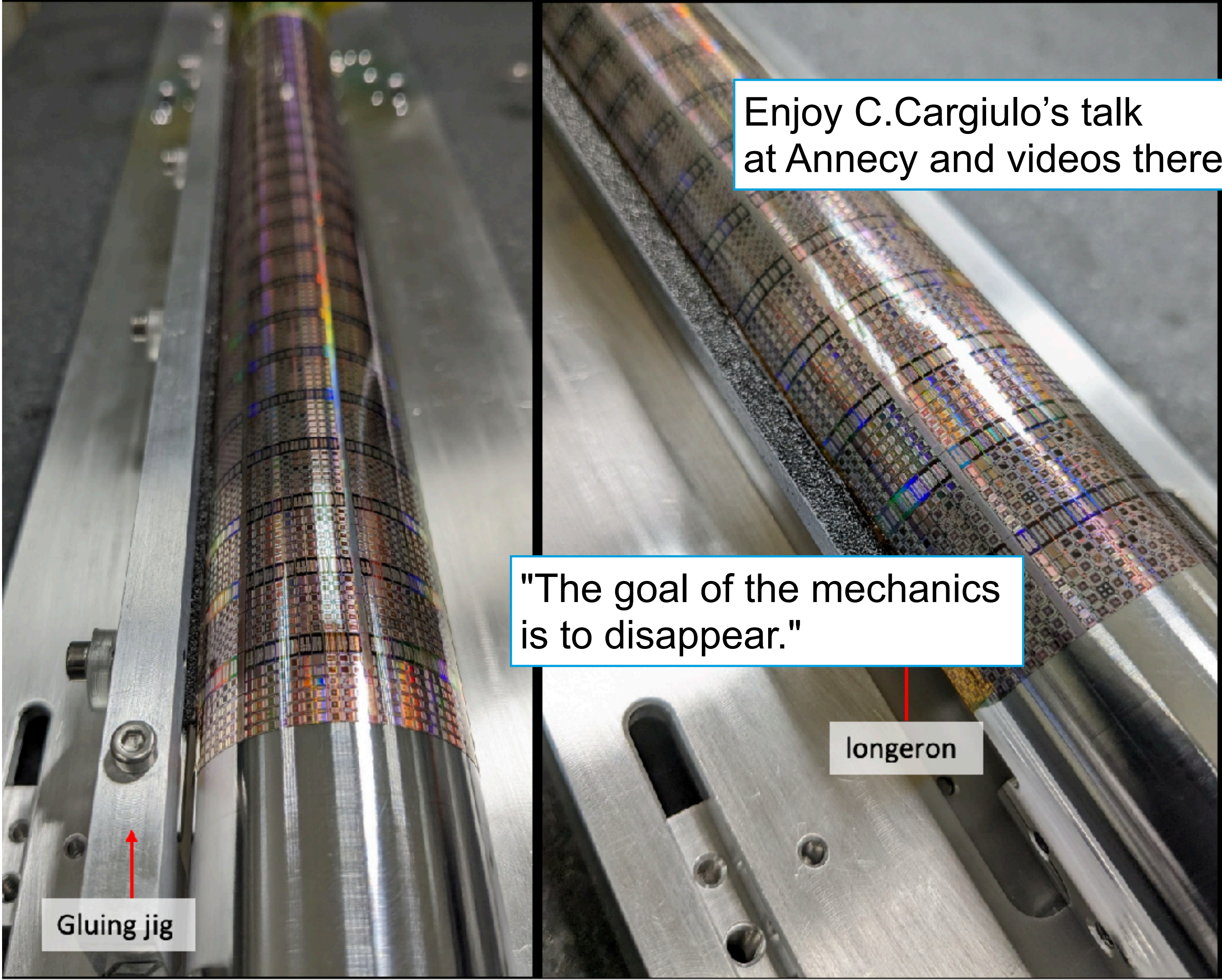
Detailed Engineering

FCC Fabrizio Palla INFN Pisa – 7th *FCC Physics workshop* – Annecy (France) – 29 Jan - 2 Feb 2024 4



Assembly of a half-layer

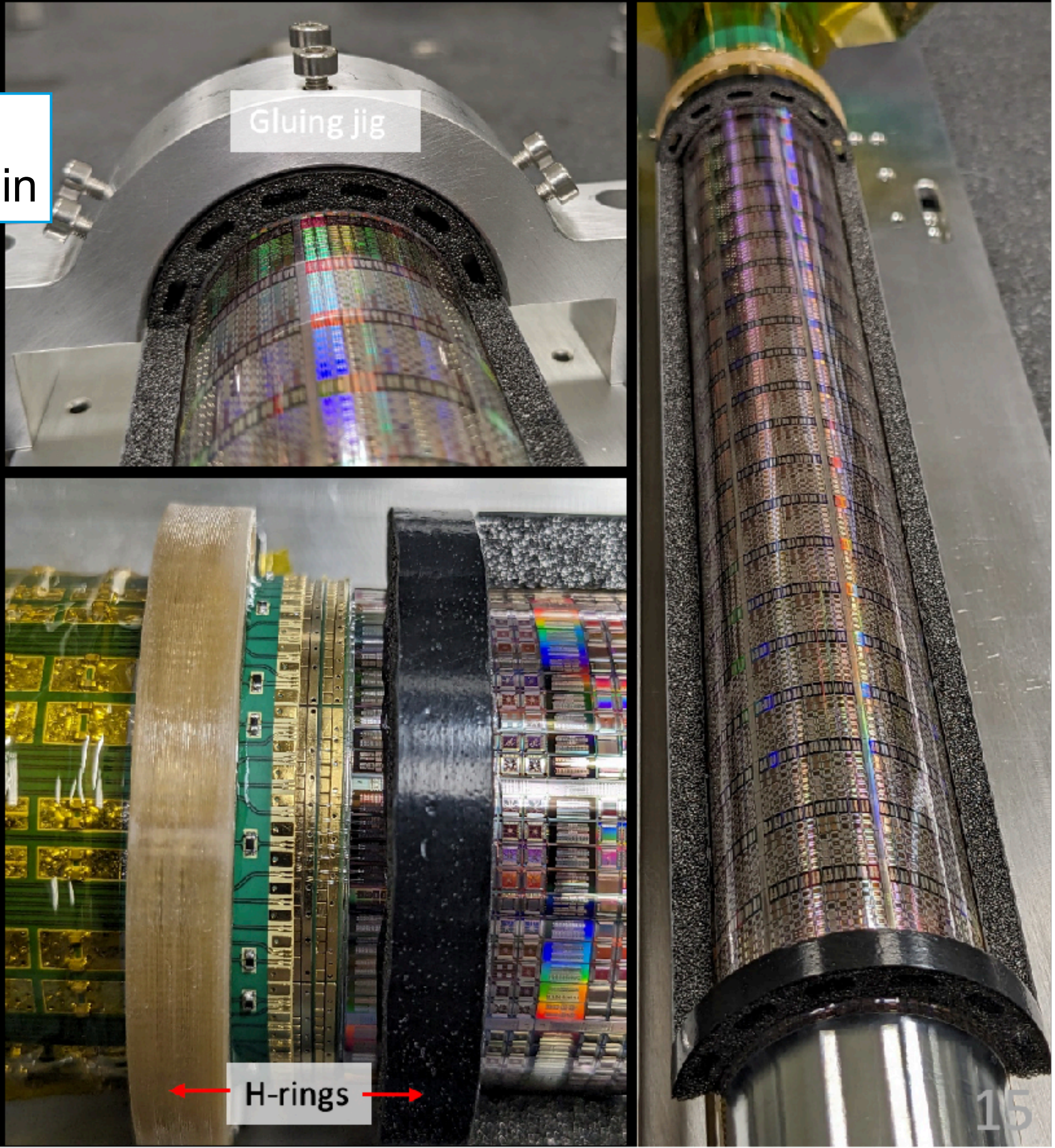
Gluing of the longerons



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

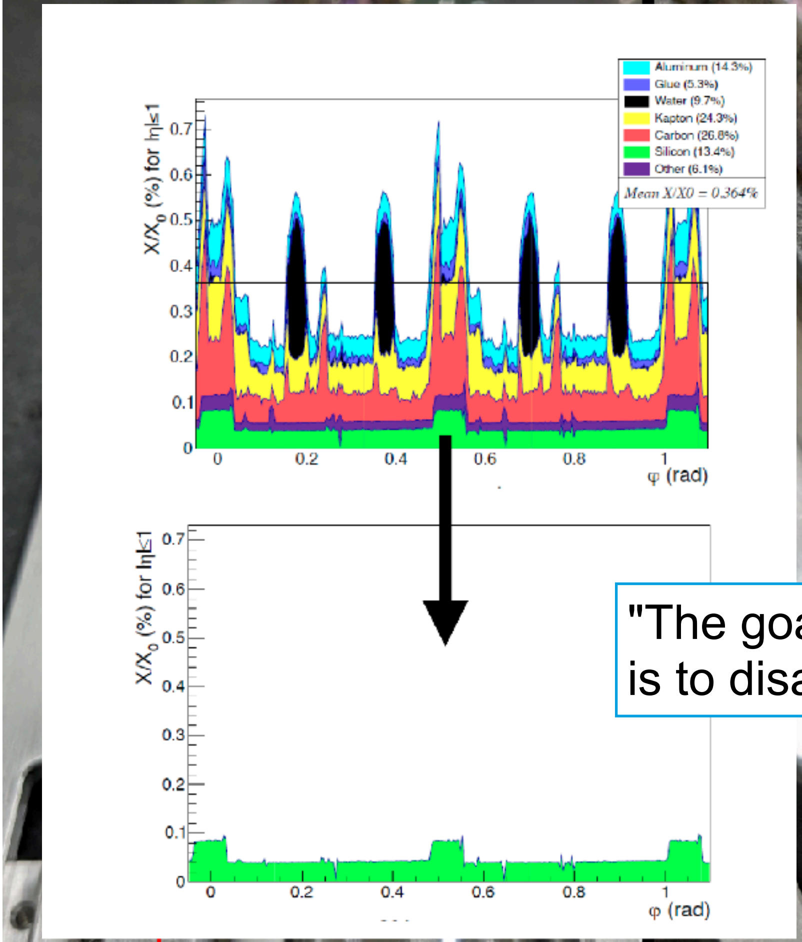
"The goal of the mechanics
is to disappear."

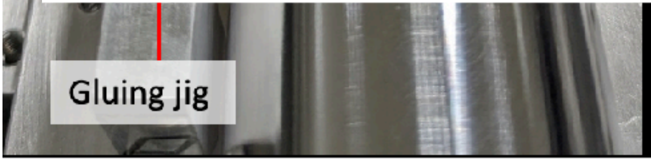
Gluing of the H-rings



Assembly of a half-layer

Gluing of the longerons

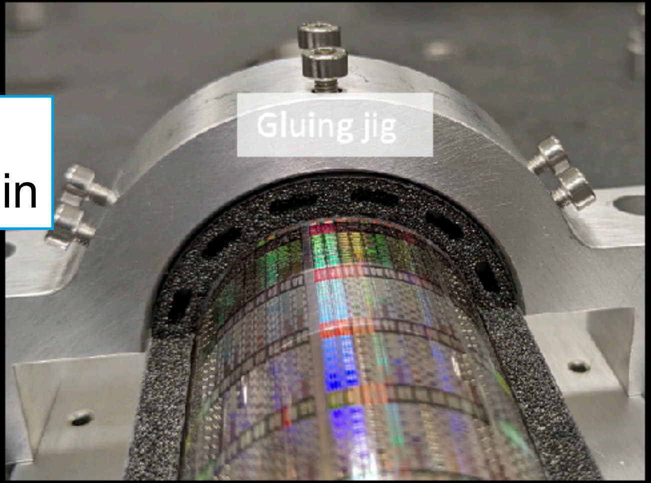


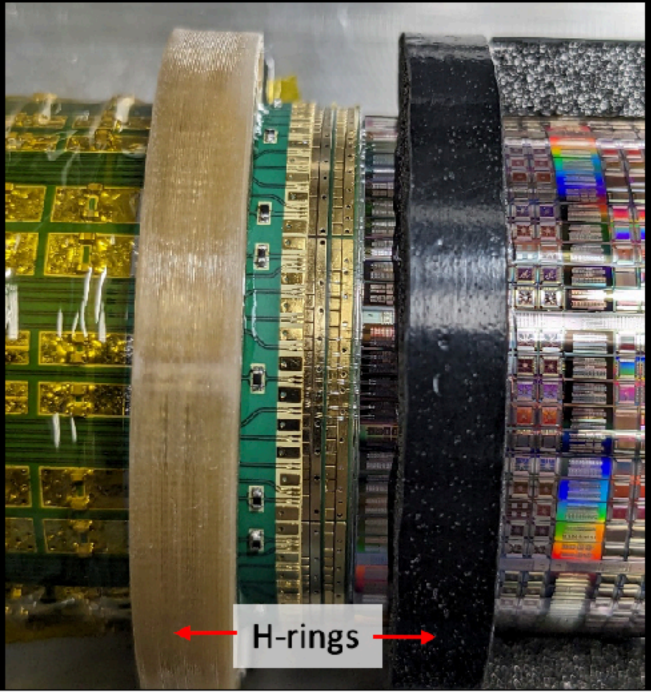


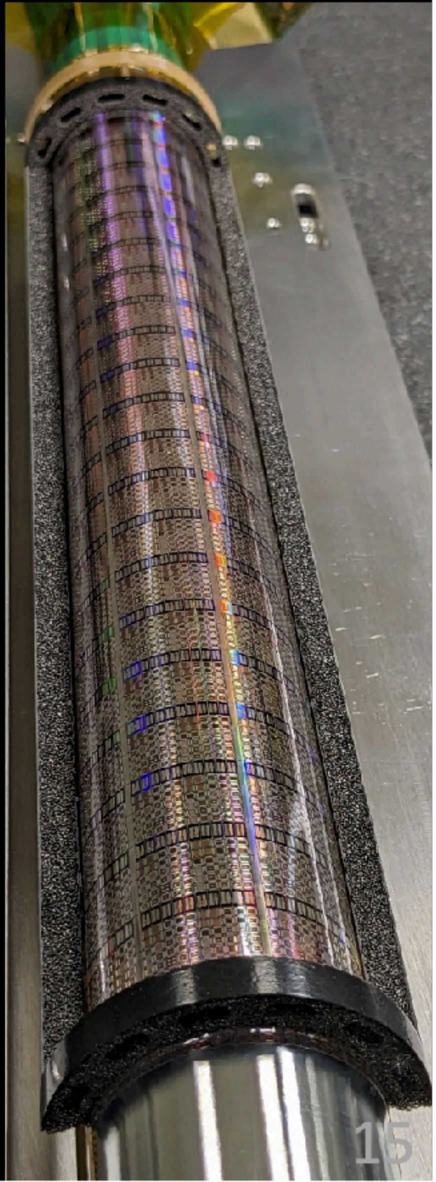
Enjoy C.Cargiulo's talk
at Annecy and videos therein

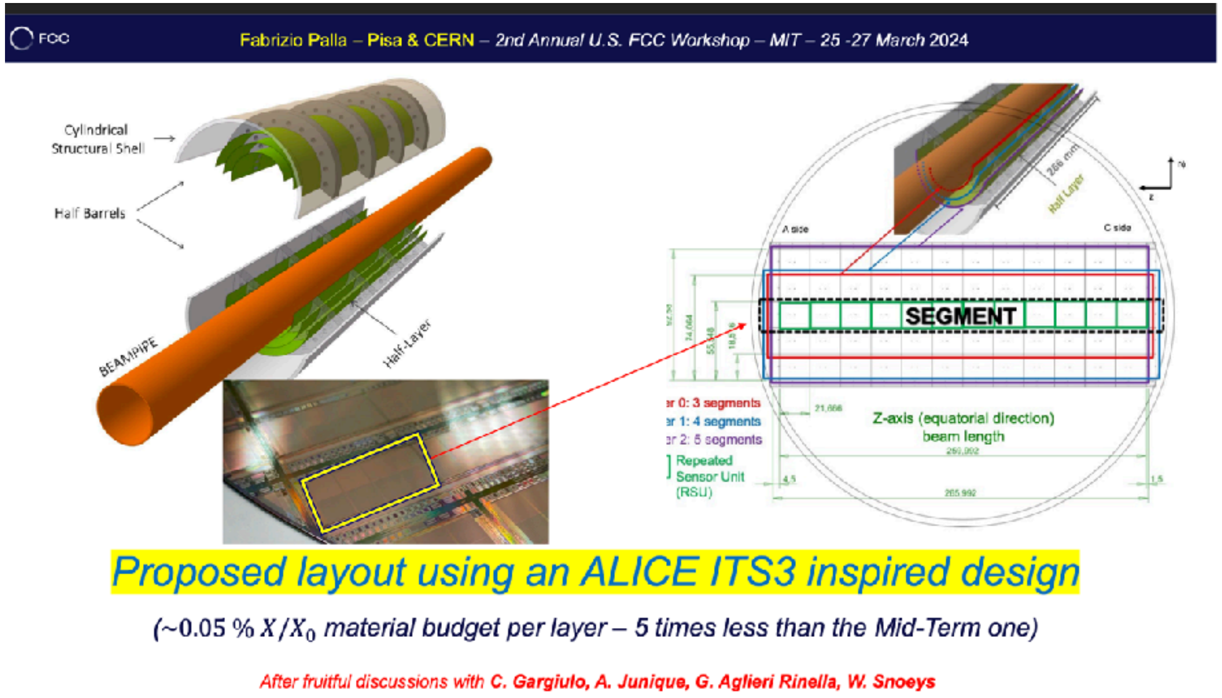
"The goal of the mechanics
is to disappear."

Gluing of the H-rings





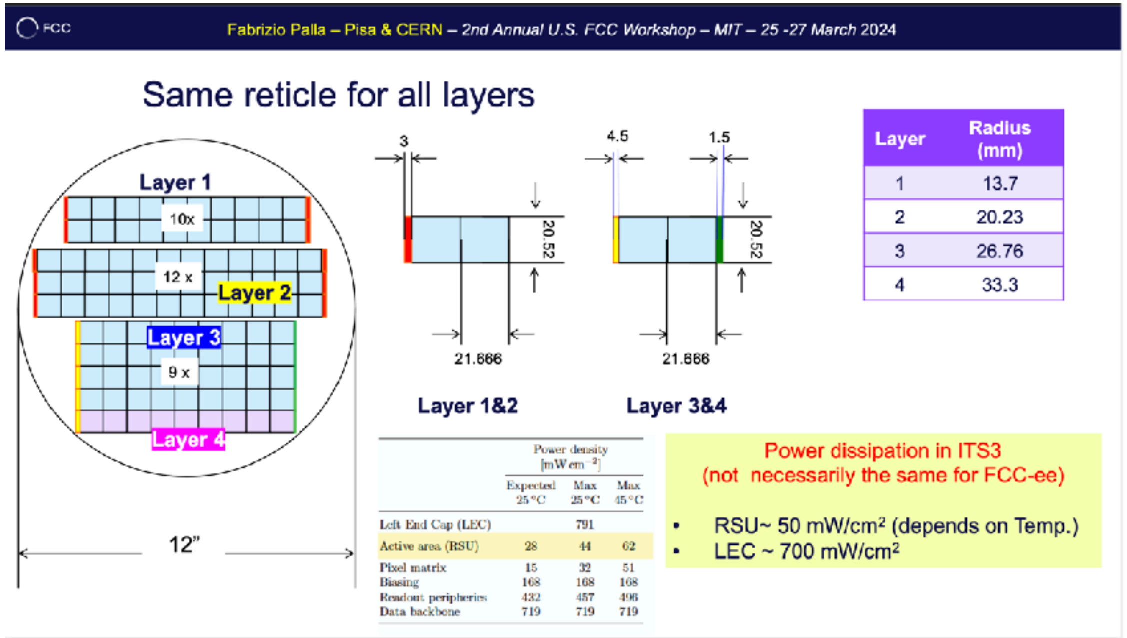




Proposed layout using an ALICE ITS3 inspired design

(~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***



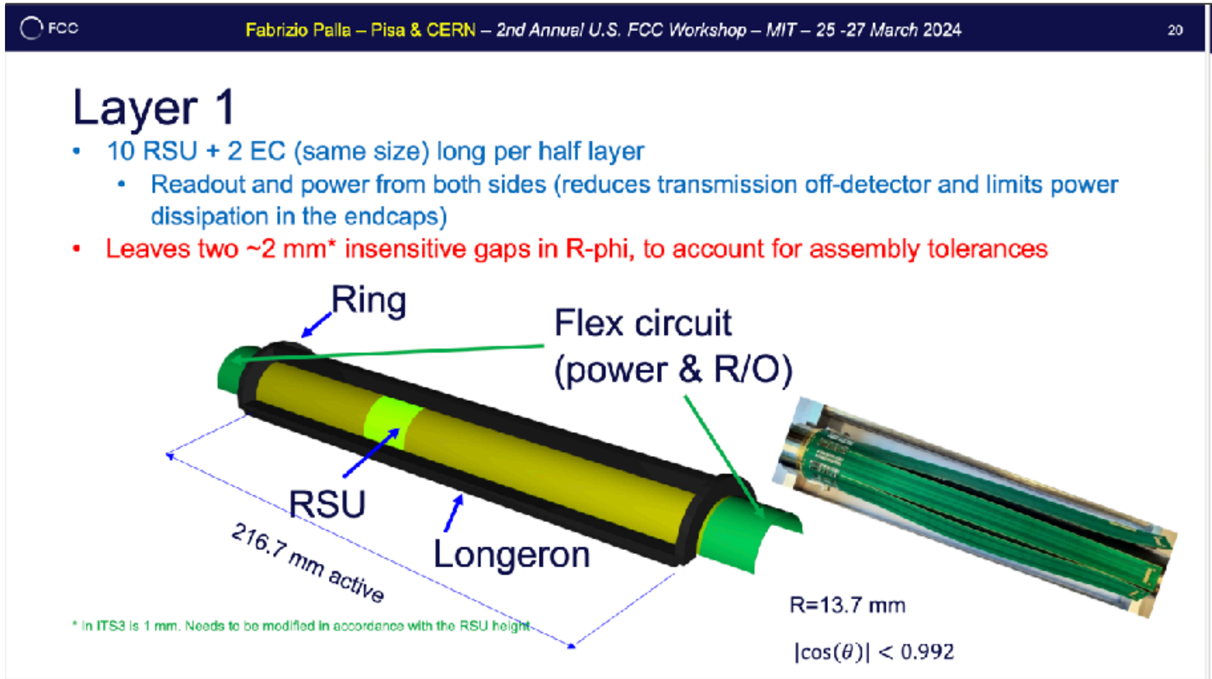
Same reticle for all layers

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/cm² (depends on Temp.)
- LEC ~ 700 mW/cm²



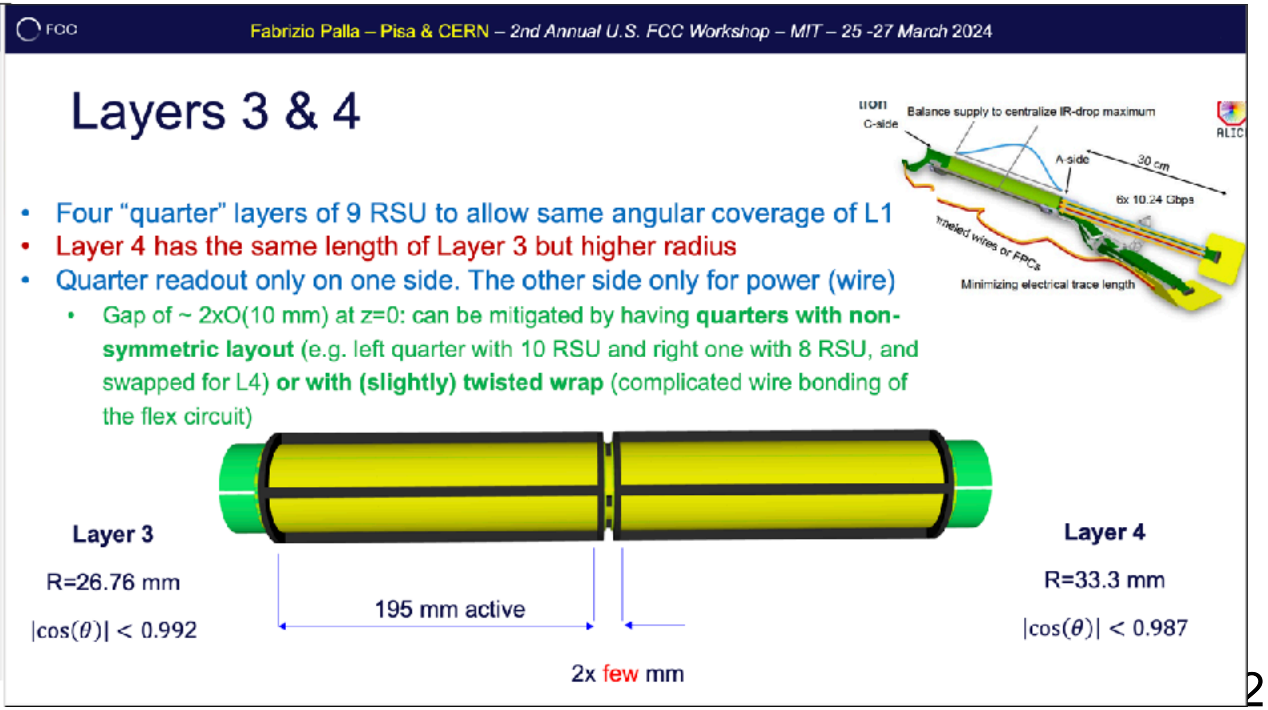
Layer 1

- 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

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

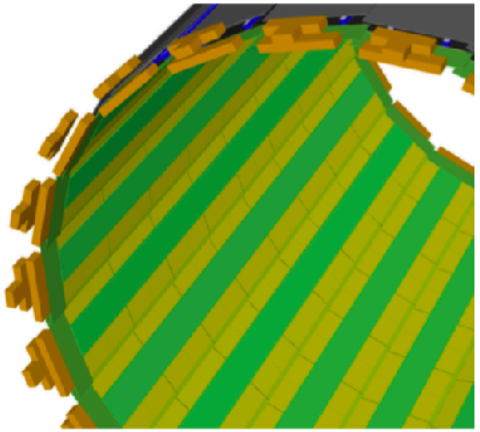
Layer 4

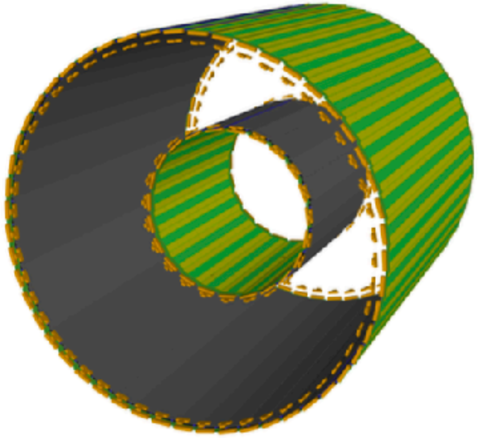
R=33.3 mm

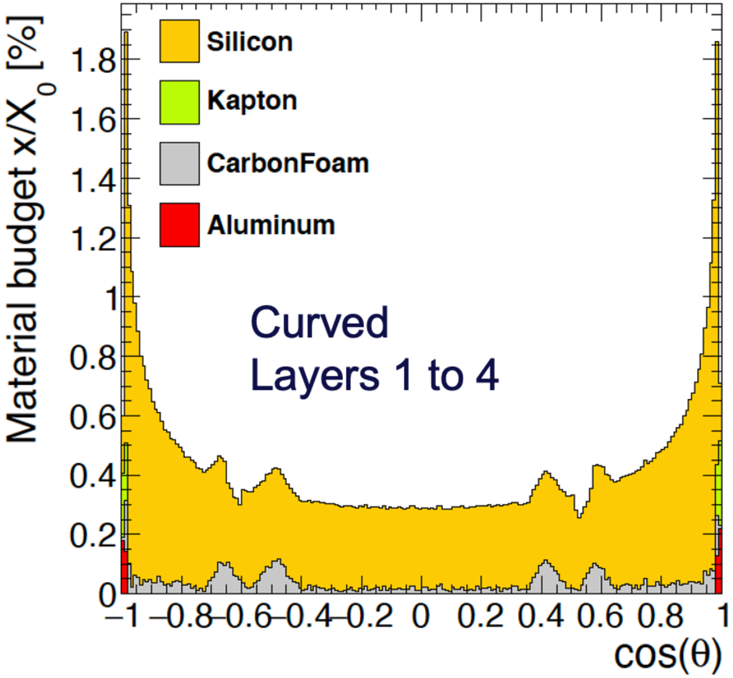
$|\cos(\theta)| < 0.987$

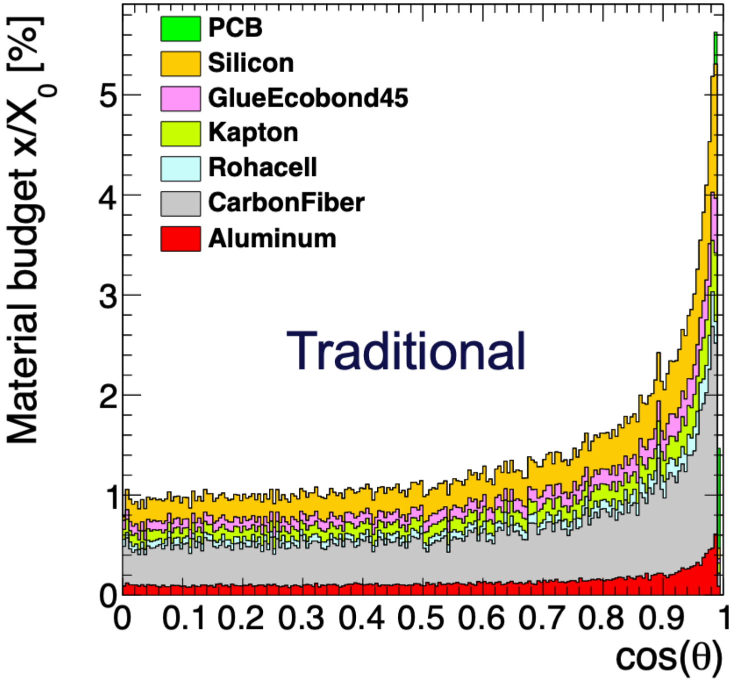
Detailed Full Simulations

Realistic Material Budgets


Middle tracker

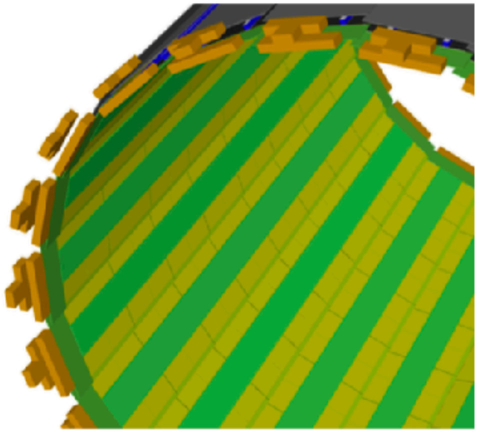

Complete vertex outer barrel system



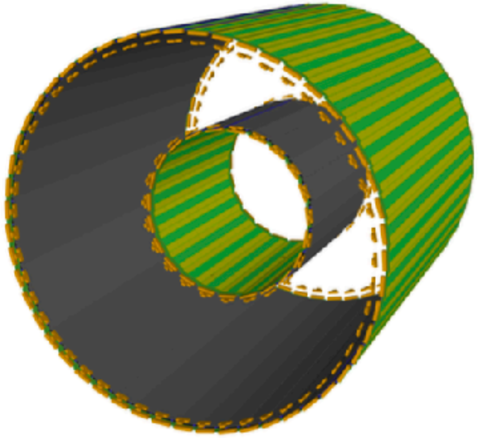


Detailed Full Simulations

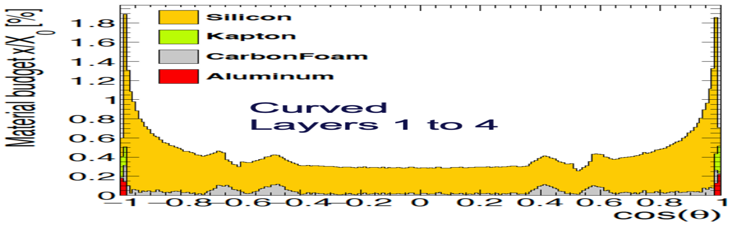
Realistic Material Budgets

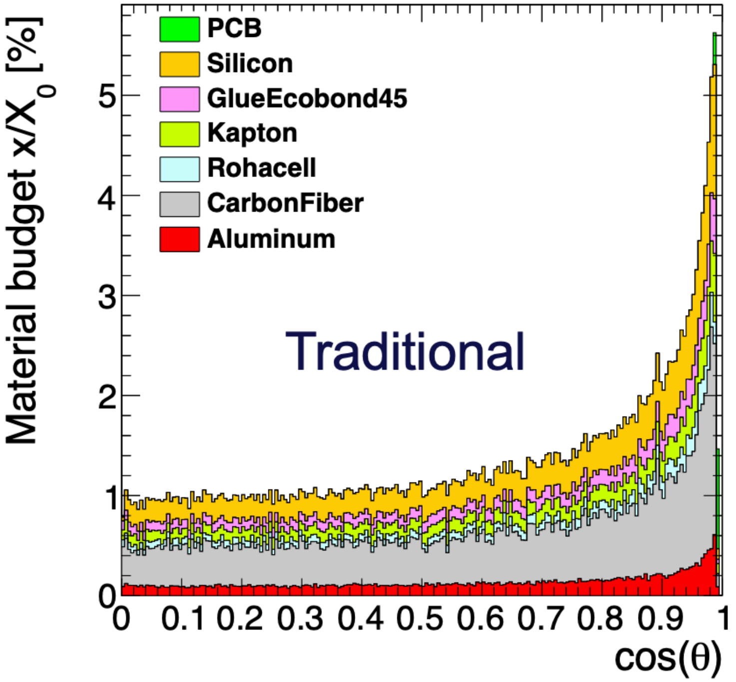


Middle tracker



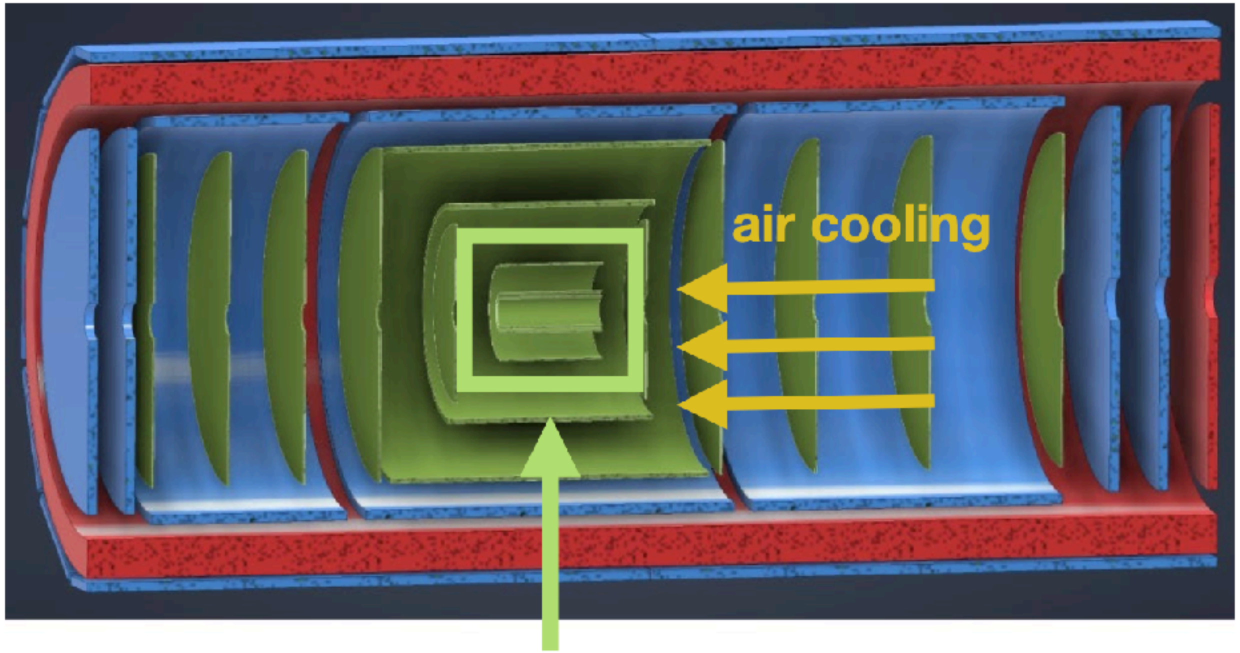
Complete vertex outer barrel system





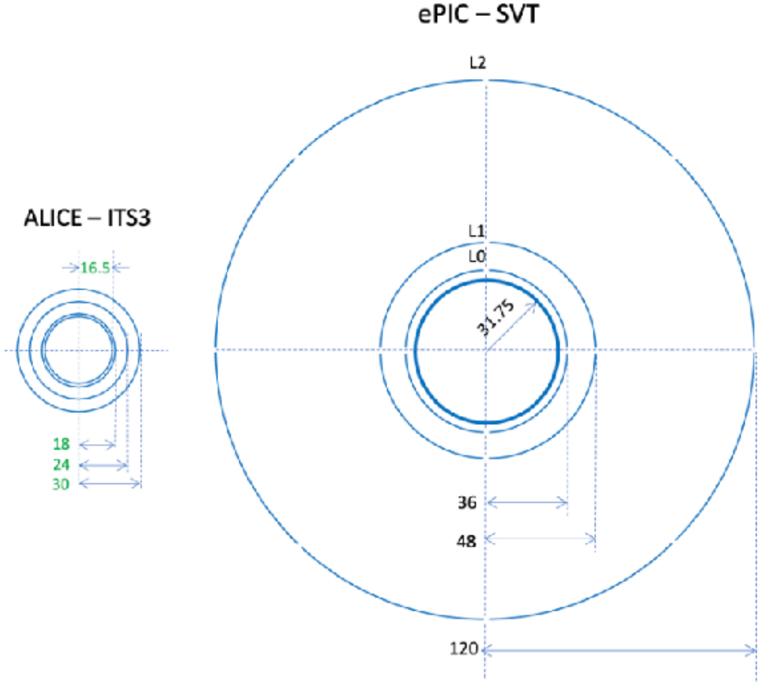
The SVT inner barrel ("bent" layers 0, 1, 2)

Innocenti
https://indico.mit.edu/event/876/contributions/2981/attachments/1070/1762/20240326_SVTInnocenti.pdf



- 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**

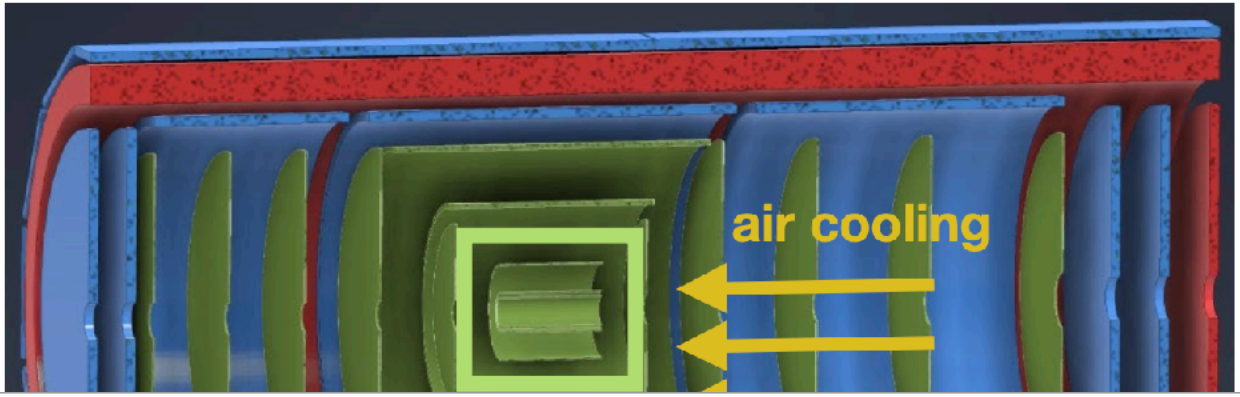


ePIC specific needs:

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

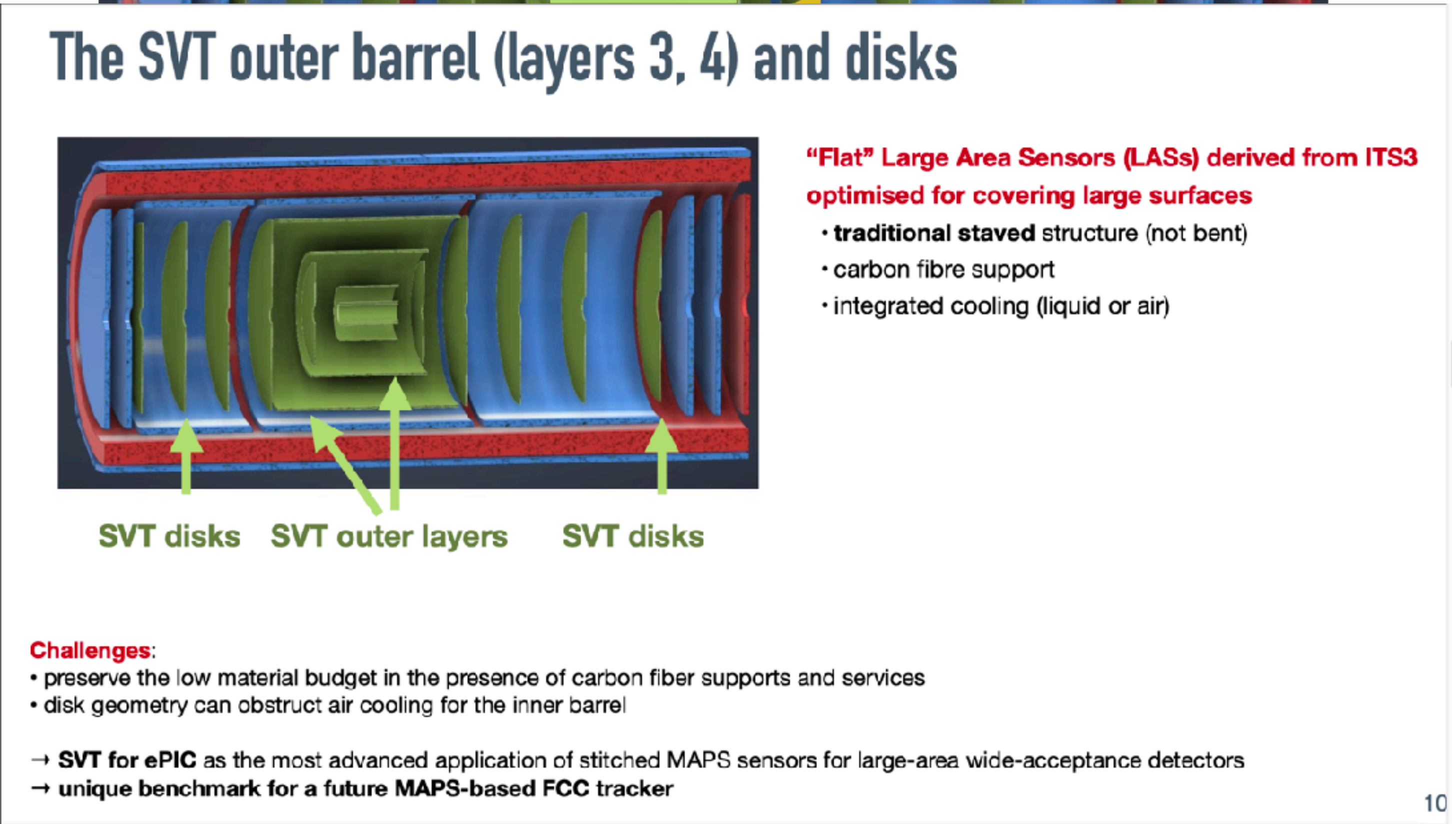
The SVT inner barrel ("bent" layers 0, 1, 2)

Innocenti
https://indico.mit.edu/event/876/contributions/2981/attachments/1070/1762/20240326_SVTInnocenti.pdf



- 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**

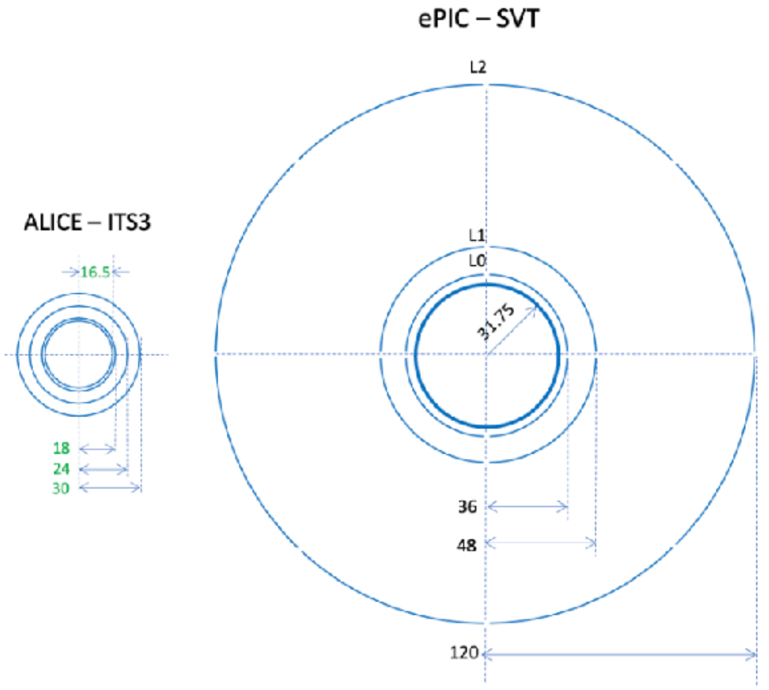


The SVT outer barrel (layers 3, 4) and disks

"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**



Gaseous Tracking

Gaseous Main Trackers

Strong Case

Transparency wins over single point resolution

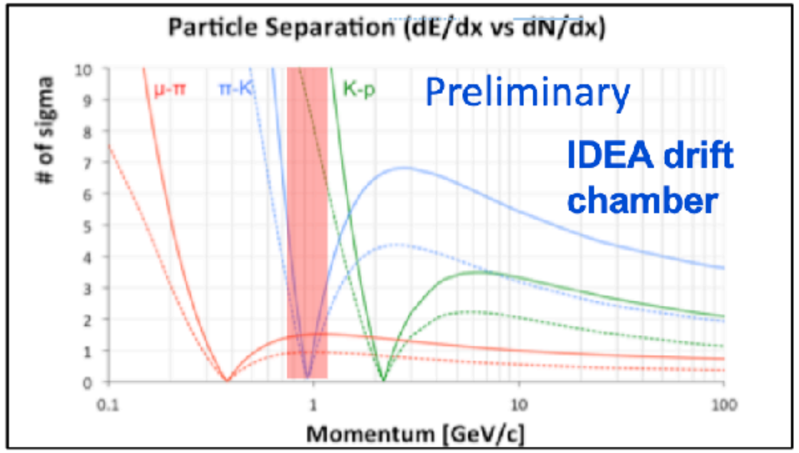
- over most of relevant momentum range

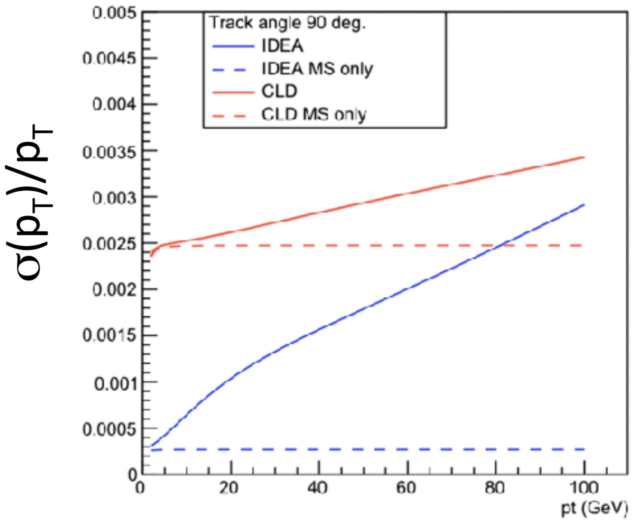
Particle ID via dcdx or dN/dx (cluster counting)

- complement ToF

Continuous tracking

- for long-lived particle vertices



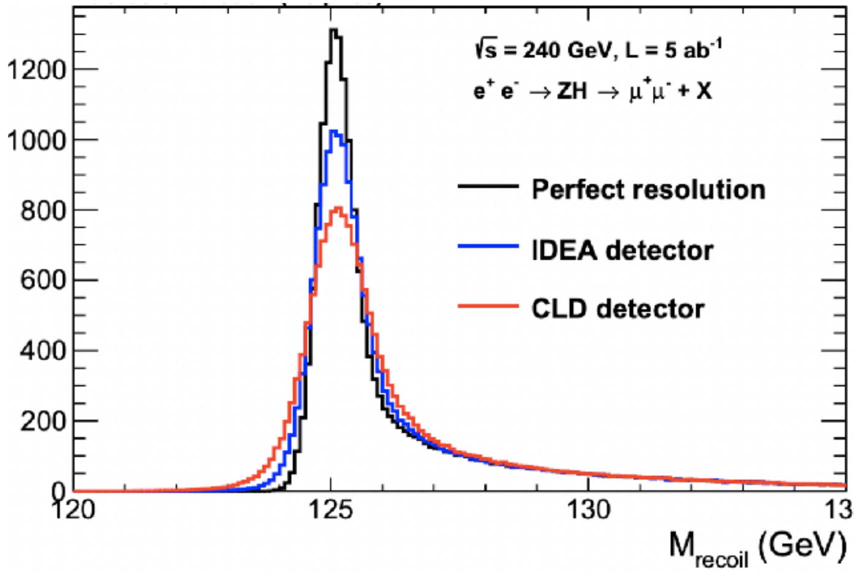


CLID

- All Si Tracker
- total material budget 11%

IDEA

- Drift Chamber
- Material budget is < 2%



Gaseous Main Trackers

Strong Case

Transparency wins over single point resolution

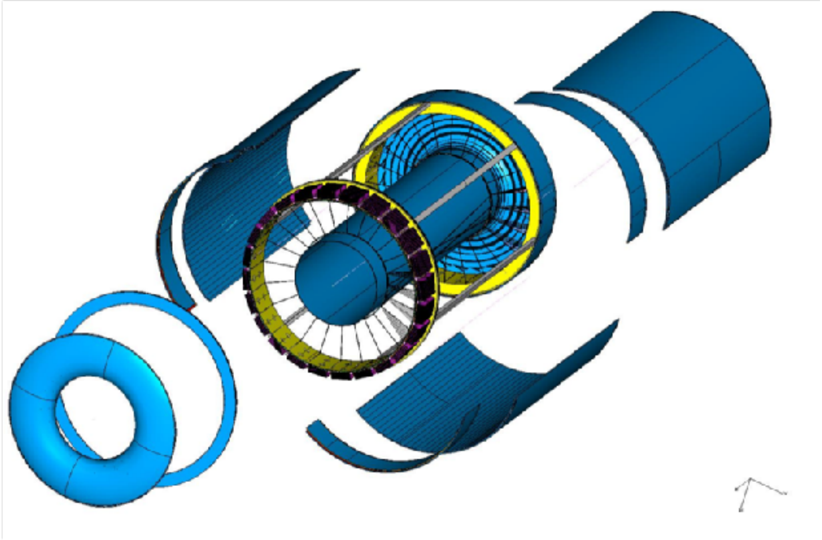
- over most of relevant momentum range

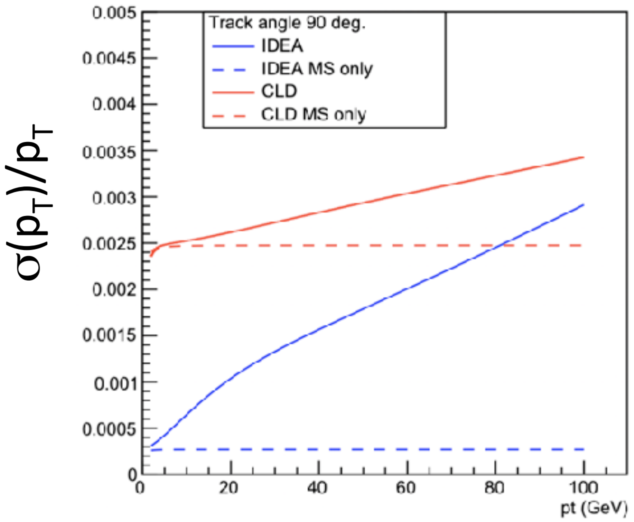
Particle ID via dcdx or dN/dx (cluster counting)

- complement ToF

Continuous tracking

- for long-lived particle vertices



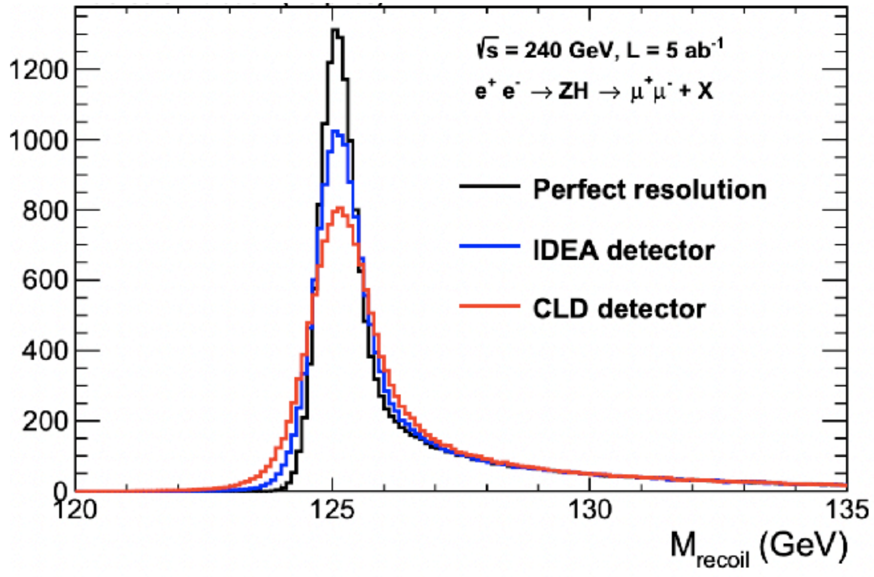


CLID

- All Si Tracker
- total material budget 11%

IDEA

- Drift Chamber
- Material budget is < 2%



Gaseous Main Trackers

Strong Case

Transparency wins over single point resolution

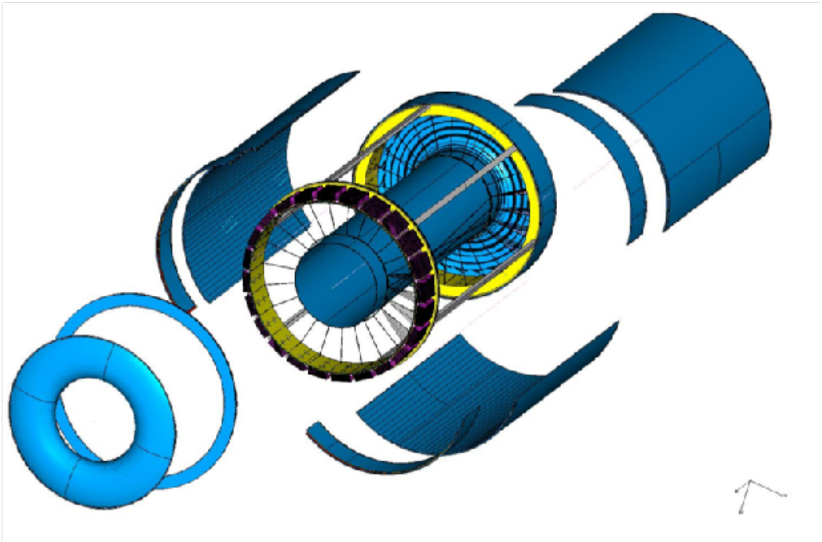
- over most of relevant momentum range

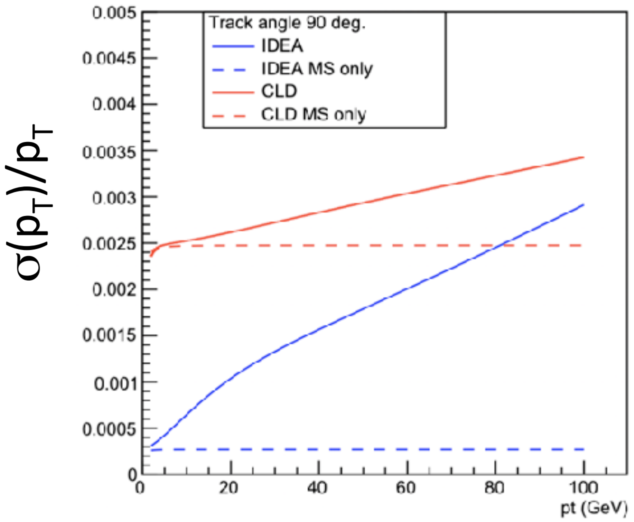
Particle ID via dcdx or dN/dx (cluster counting)

- complement ToF

Continuous tracking

- for long-lived particle vertices





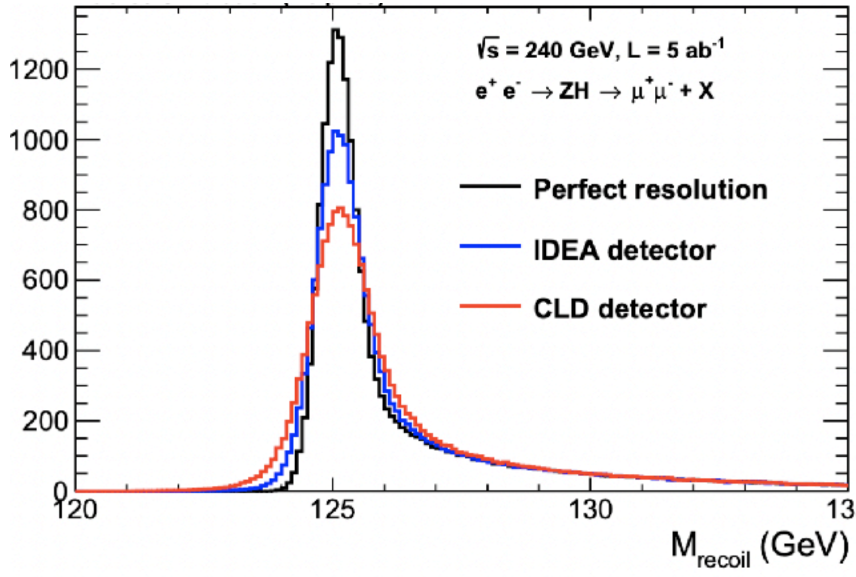
CLID

- All Si Tracker
- total material budget 11%

IDEA

- Drift Chamber
- Material budget is < 2%

this will evolve!



Estimate Distortions in a TPC

Full simulation study in ILD

Combine ILD and CLD elements

- ILD geometry and TPC
- CLD: MDI and inner Si tracker
- lower B field

Primary ions (no backflow)

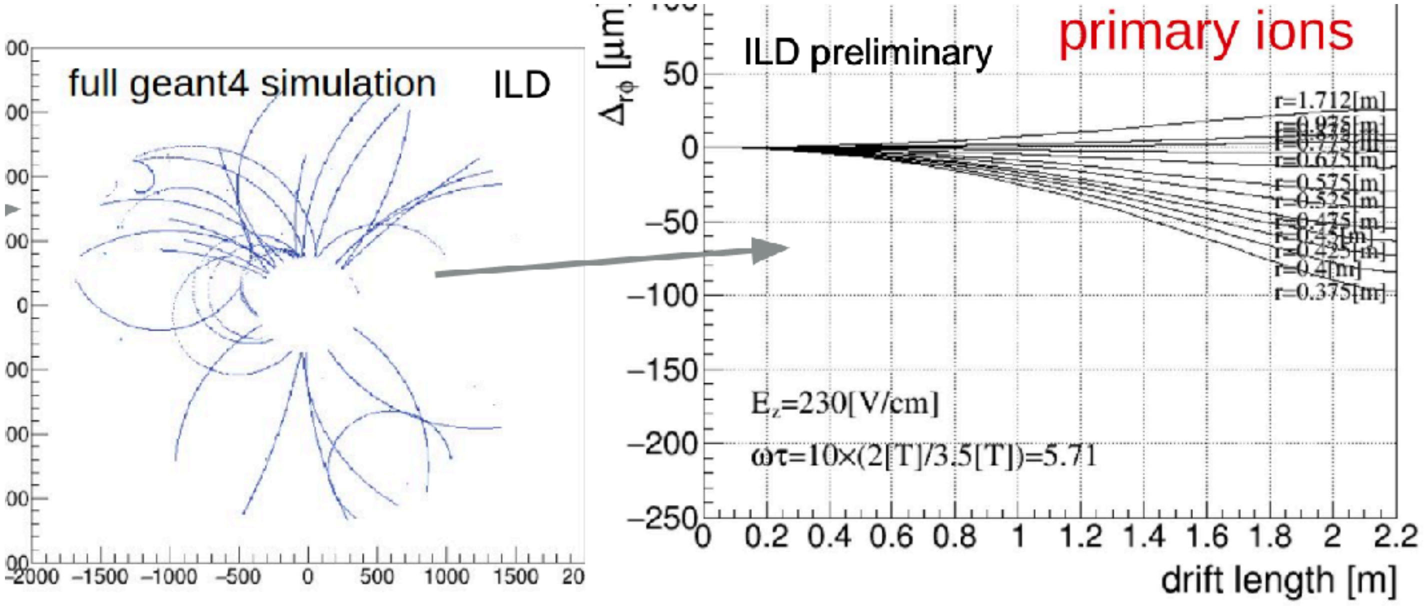
- 1e10 from physics,
- 1e12 from background

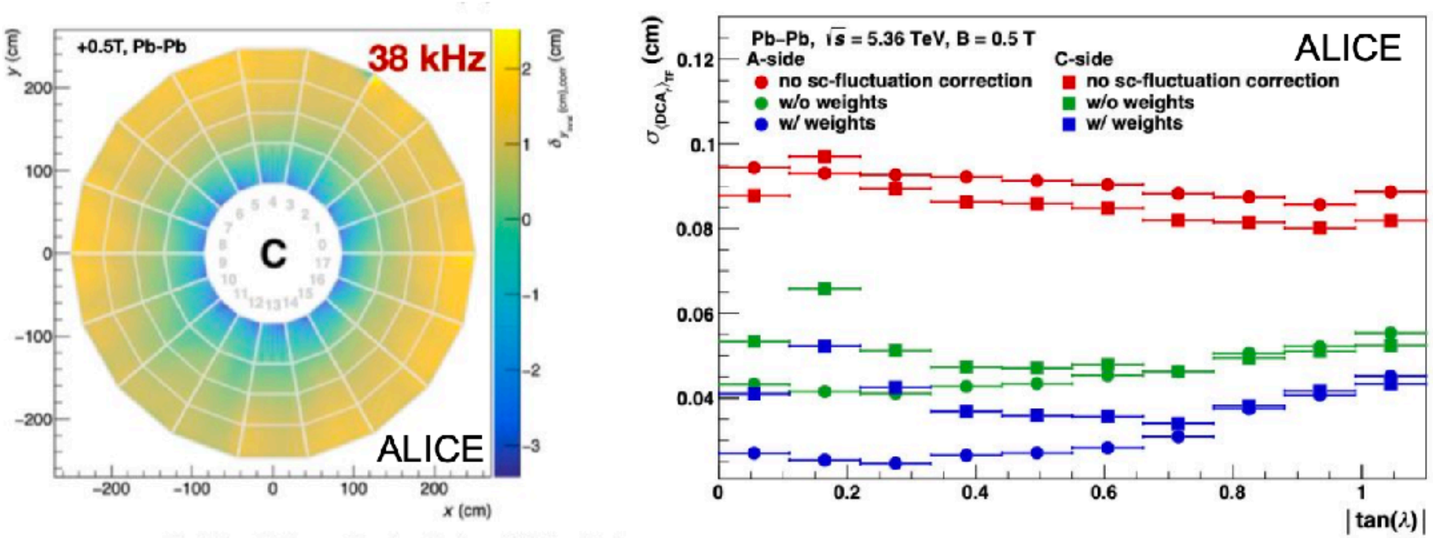
Distortions up to 20 mm

- comparable to ALICE TPC

ALICE: data-driven corrections

- comparable to ALICE TPC
- residuals after correction up to 0.6mm
- work ongoing





Matthias Kleiner - Goethe-Universität Frankfurt

Calorimetry

Calorimeter Technologies

Already Introduced

All concepts aim at Particle Flow reconstruction

- with different emphasis on granularity, energy resolution, stability

Liquid Argon + tiles

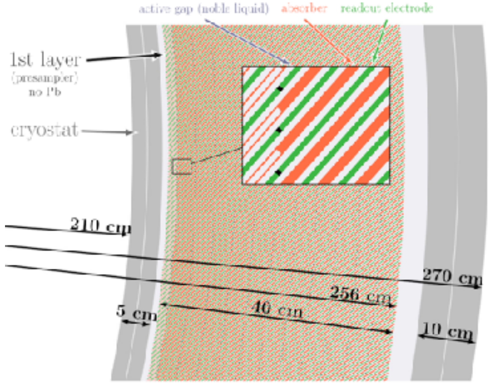
- finer longitudinal sampling wrt ATLAS (4→12)
- warm or cold electronics
- CALICE or ATLAS style scintillator tile HCAL

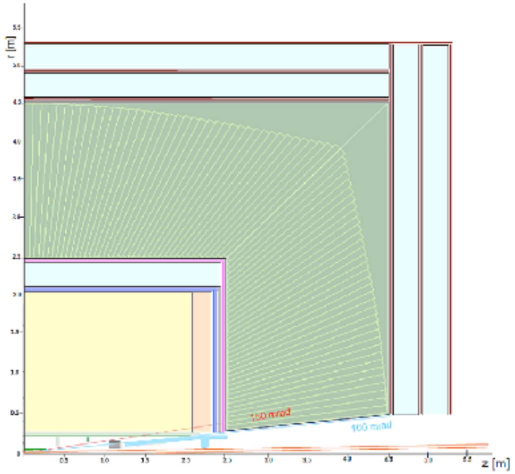
Fibre-based Dual Read-out with crystals in front

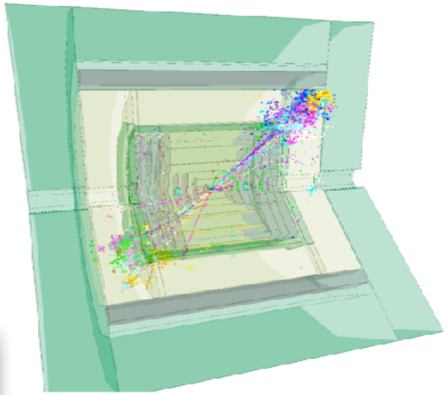
- copper or steel matrix, Cherenkov and scintillating fibres, SiPMs
- pointing geometry, superior PID
- longitudinal segmentation via timing

CALICE-style sandwich with embedded front-end electronics

- silicon (pads or MAPS) ECAL, SiPM-on-Tile HCAL
  - alternatives: strip ECAL, gas HCAL
- LC technology to be re-invented: no power-pulsing
- synergies with CMS HGCAL upgrade





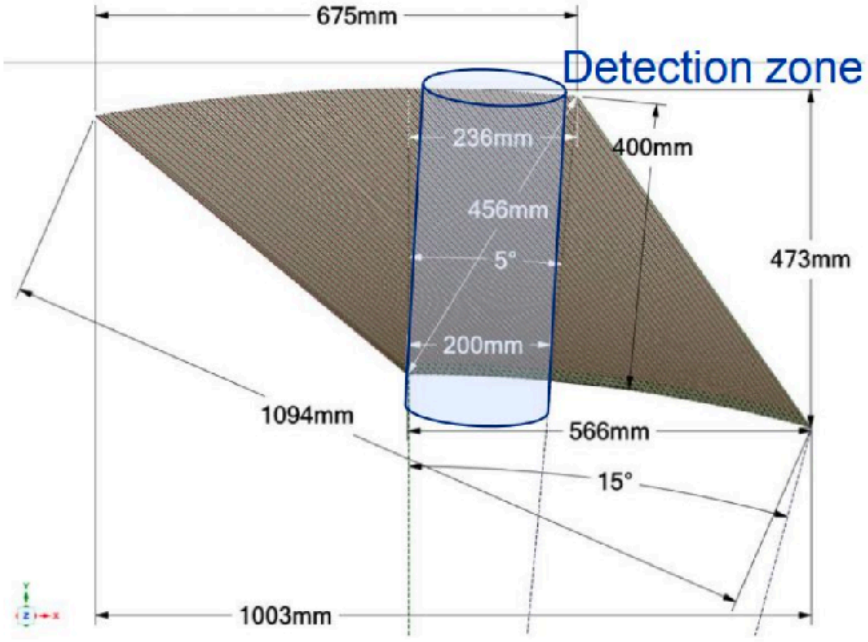


- Eur.Phys.J.Plus 136 (2021) 10, 1066, https://arxiv.org/abs/2109.00391

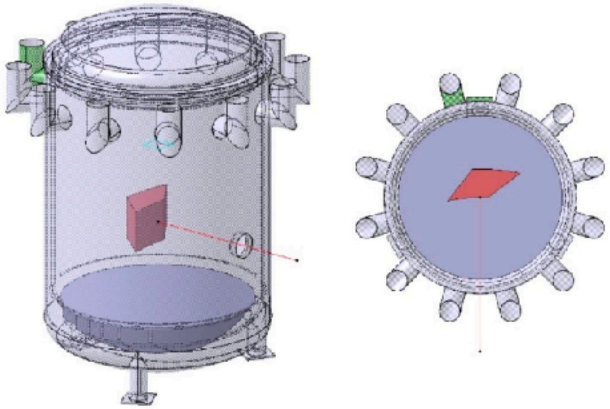
Towards a testbeam module

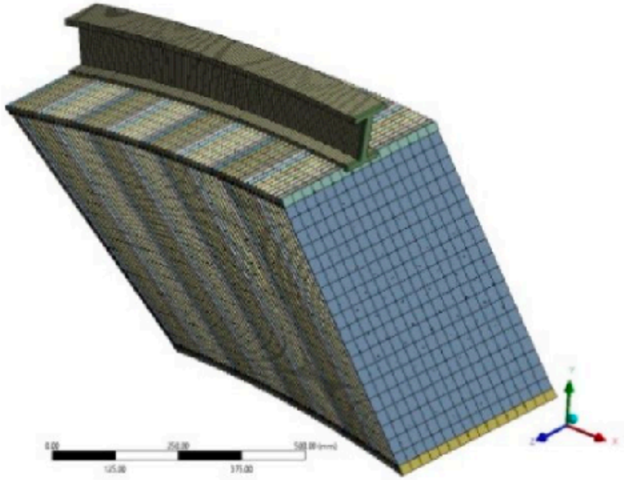
Plan to produce testmodule in the next four years

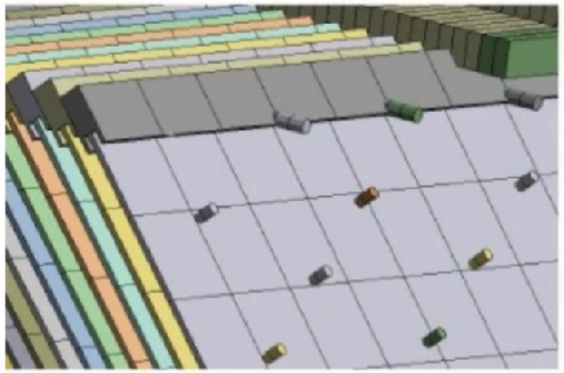
- Mechanical design of module (64 absorbers) has started
    - First finite element calculations performed
- Work on finding / adapting testbeam cryostat
- Common tools (e.g EUDAQ) should facilitate integration in testbeam facility



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







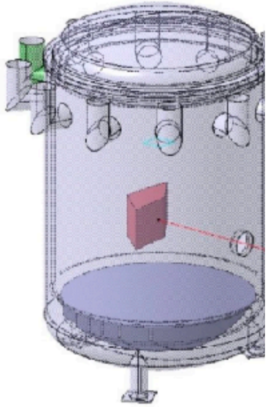
Towards a testbeam module

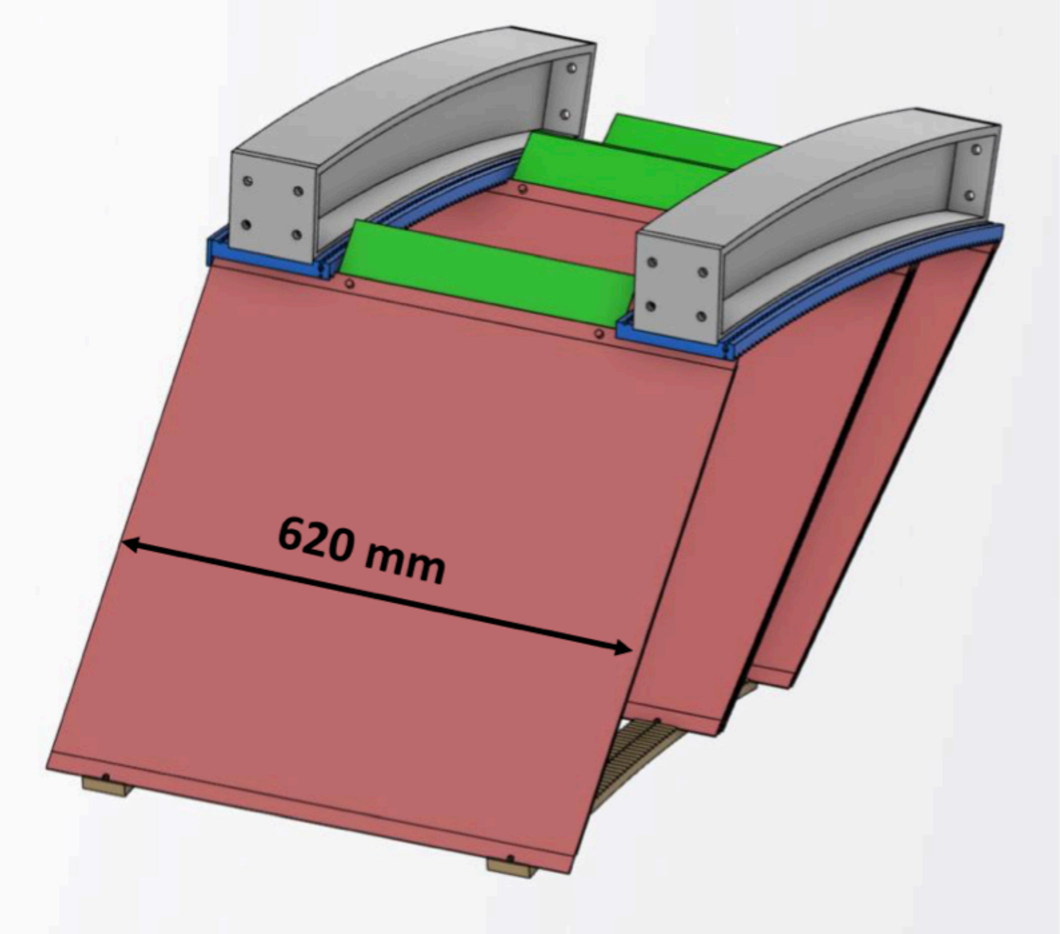
prototypes are small experiments!
update at this workshop

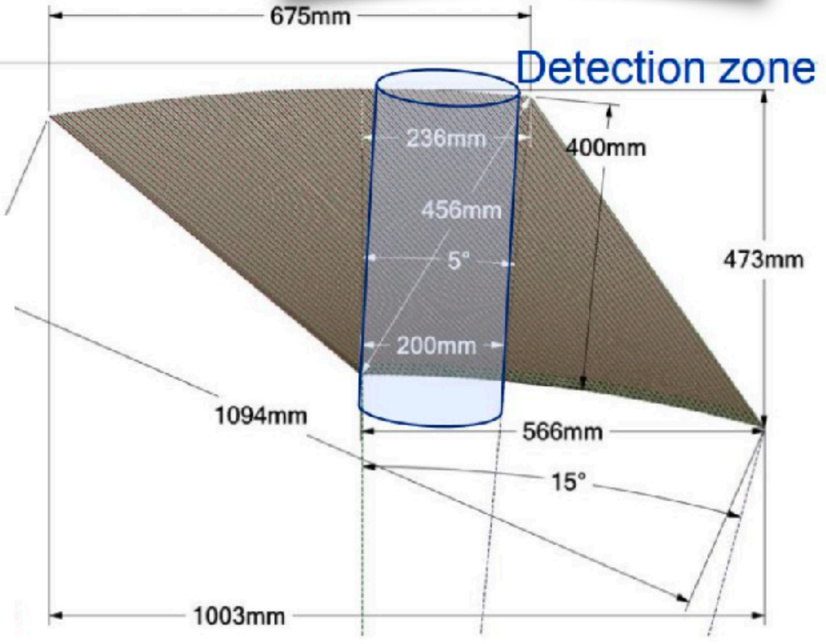
Plan to produce testmodule in the next four years

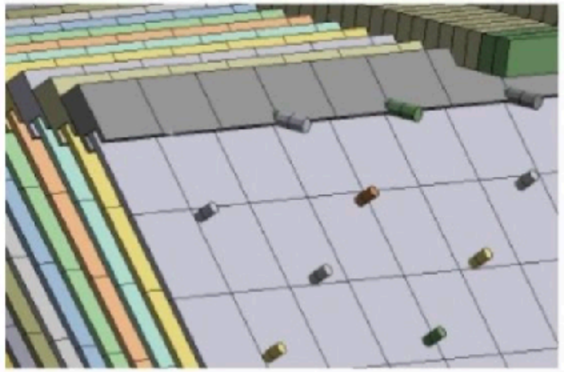
- Mechanical design of module (64 absorbers) has starte
  - First f
- Work on f
- Common integratic

The cryostat available t
is the CRRP-00563.



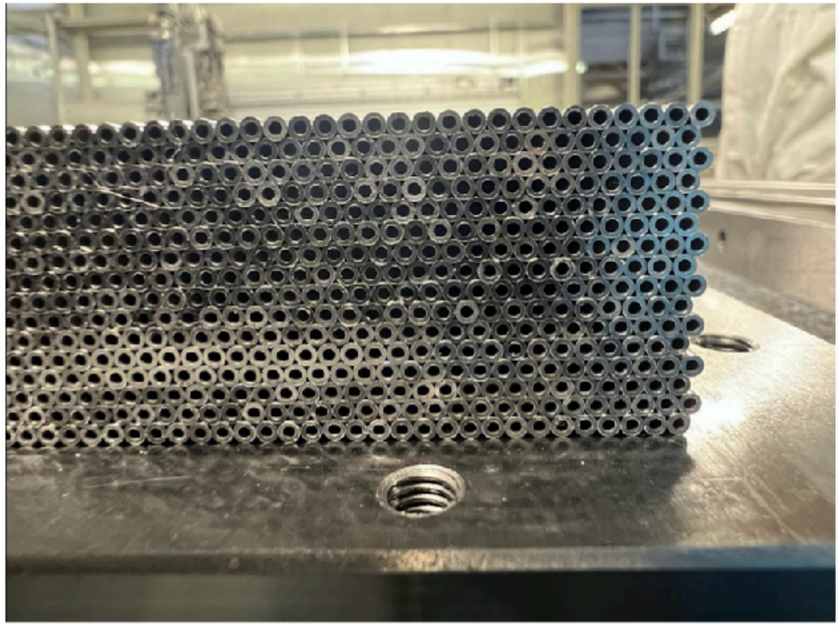
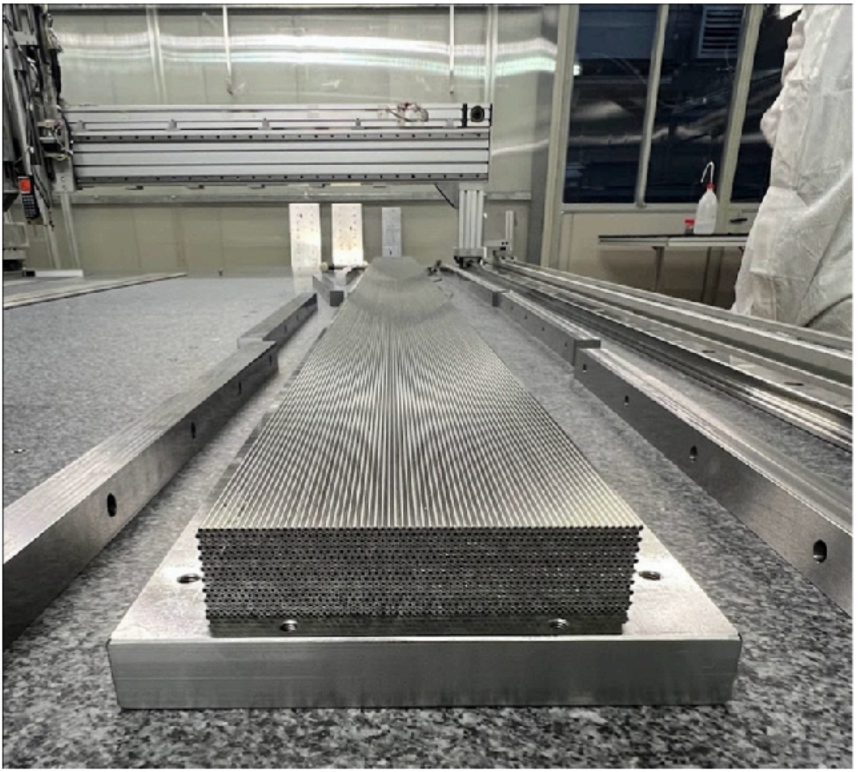
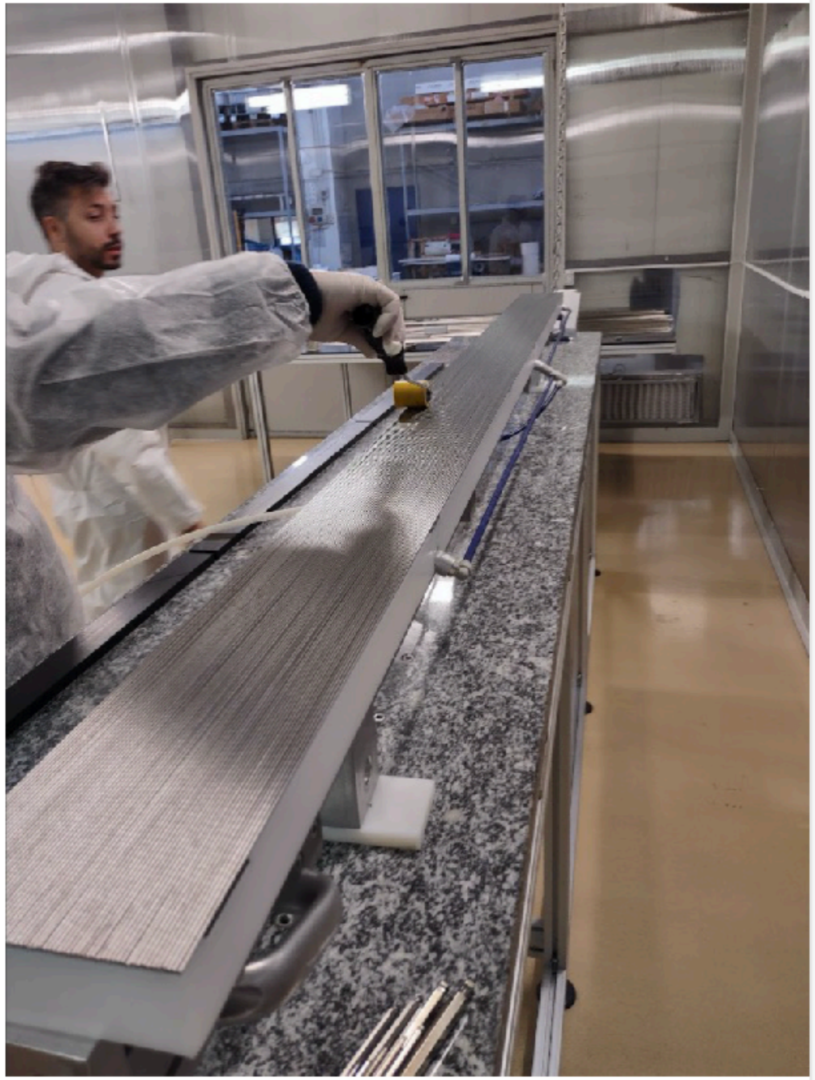






DR calorimeter

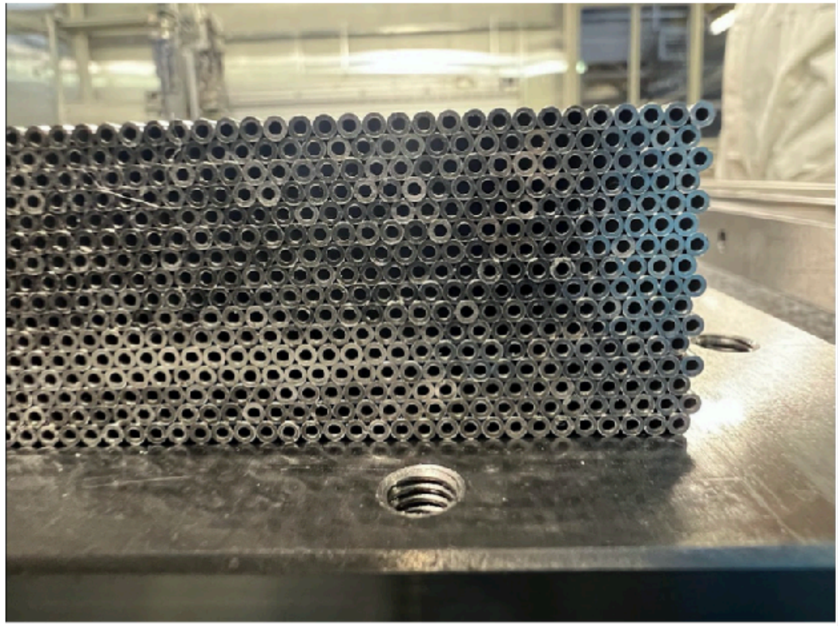
- Full containment hadronic prototype in progress
  - Hidra2 call INFN CSN5

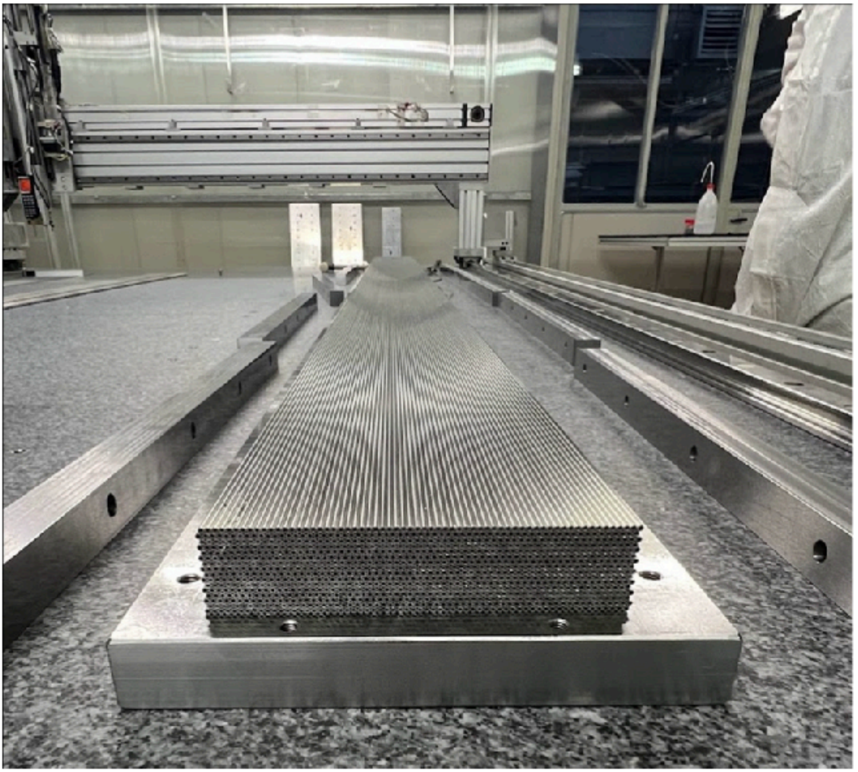




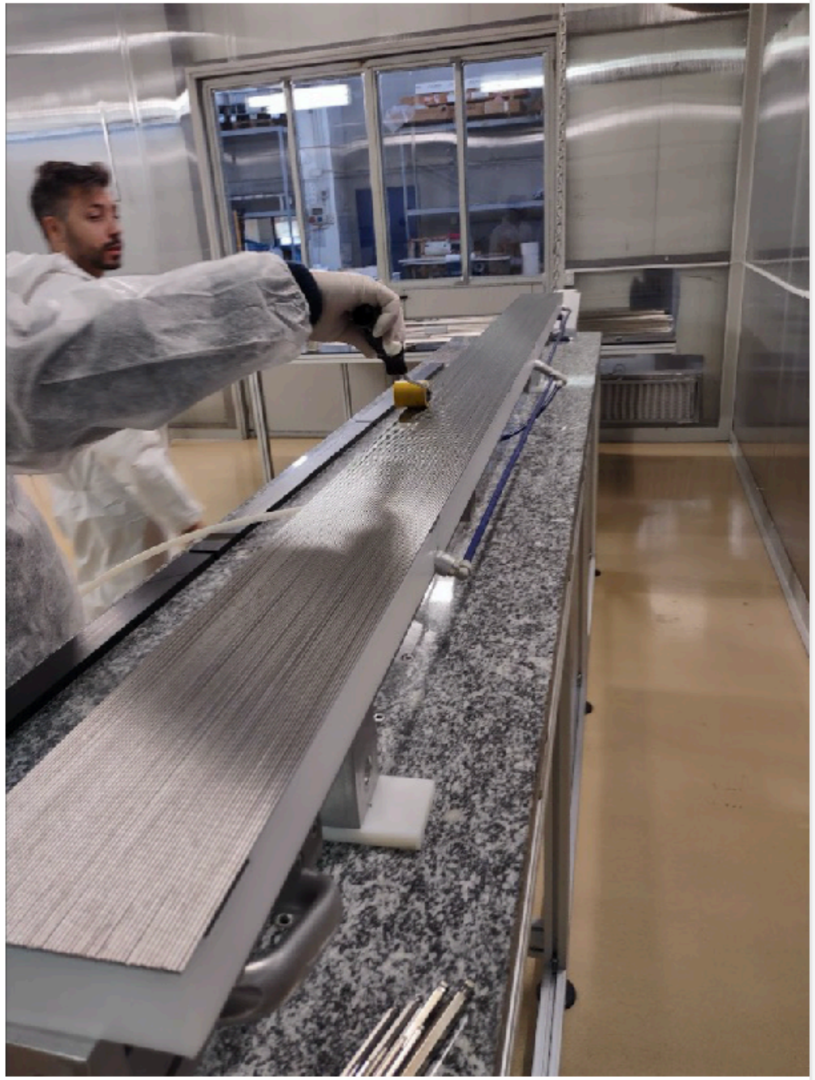
DR calorimeter

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

first DR prototype
with containment





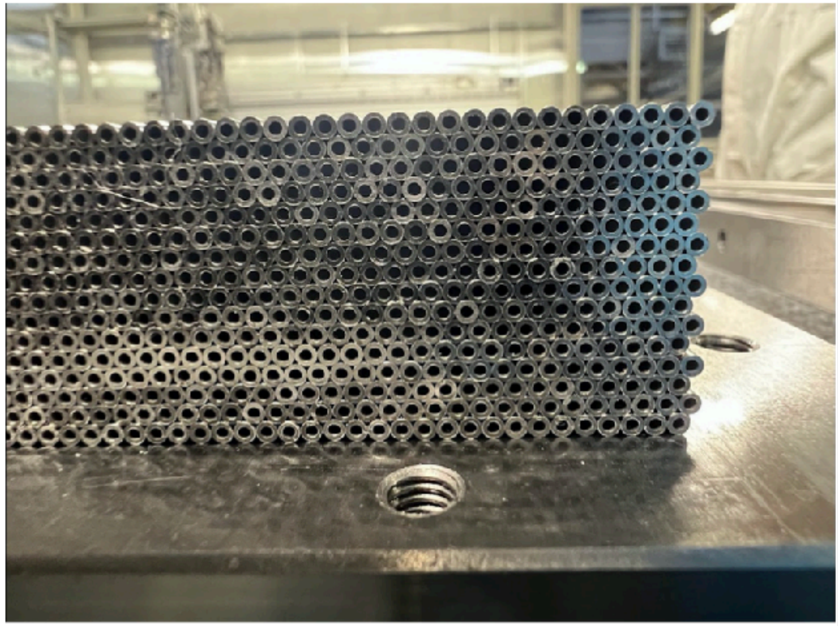


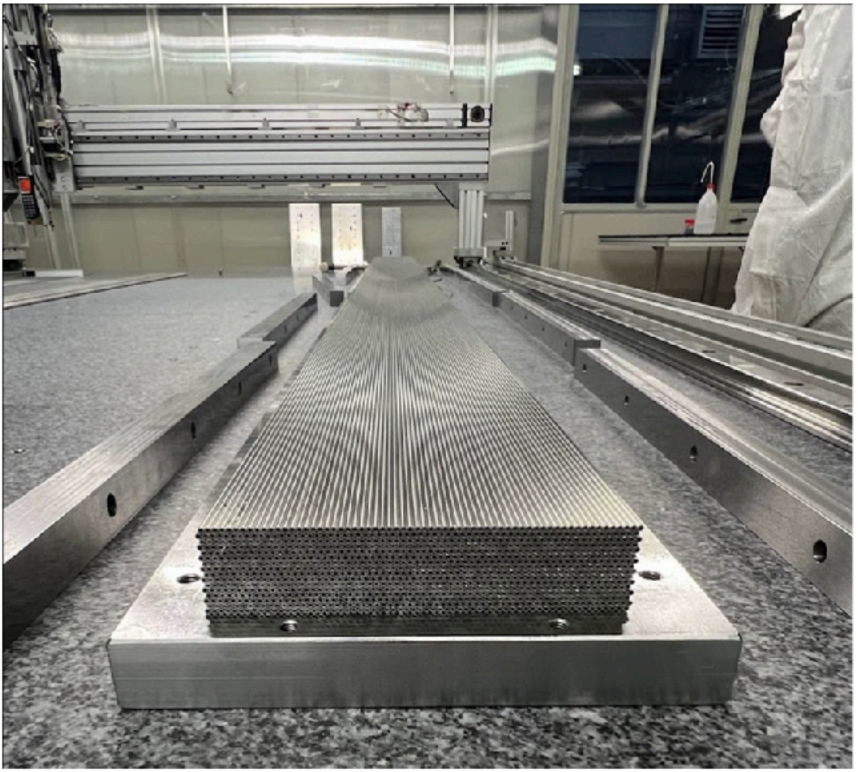
DR calorimeter

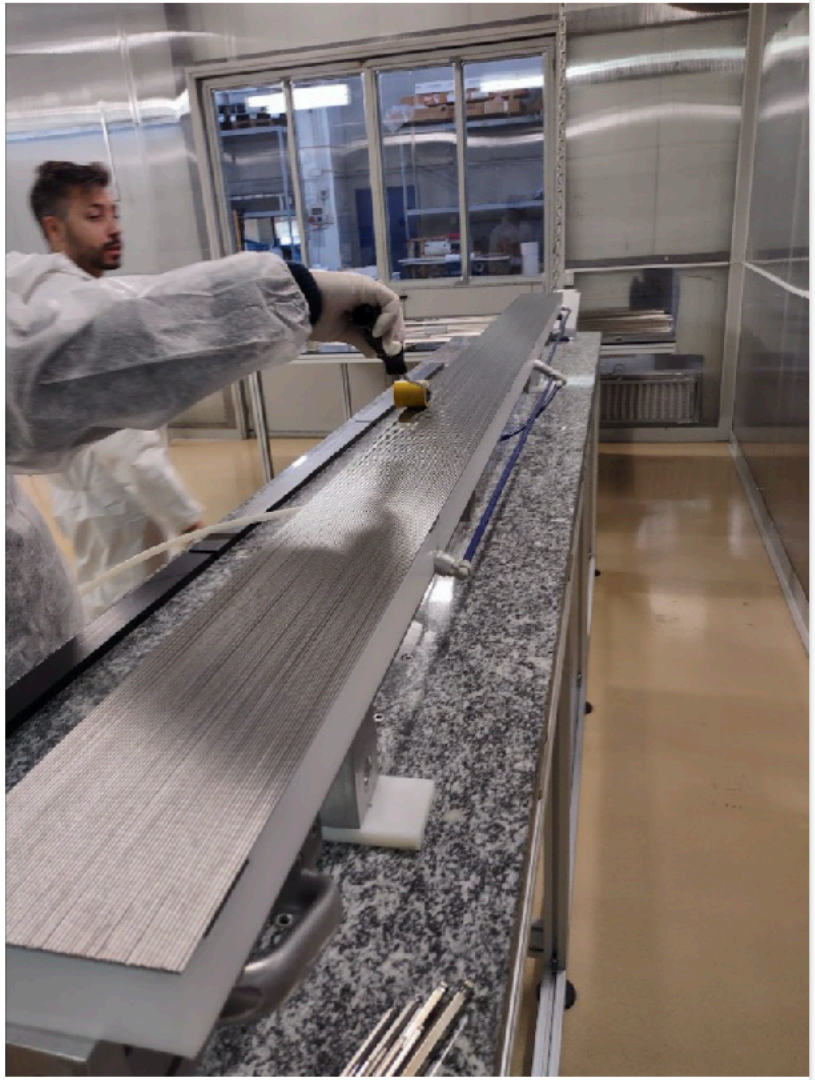
- Full containment hadronic prototype in progress
  - Hidra2 call INFN CSN5

first DR prototype with containment

stainless steel is non-magnetic







Scaling up - Step by Step

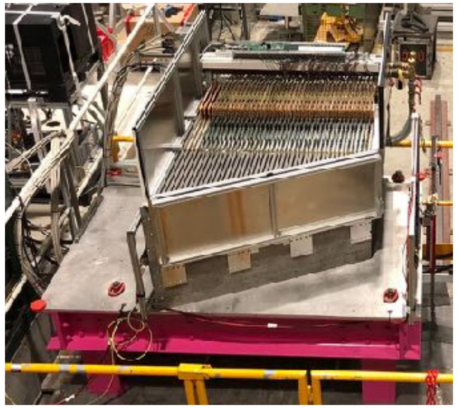
Orders of Magnitude

High channel count of highly granular calorimeters remains a challenge on all levels

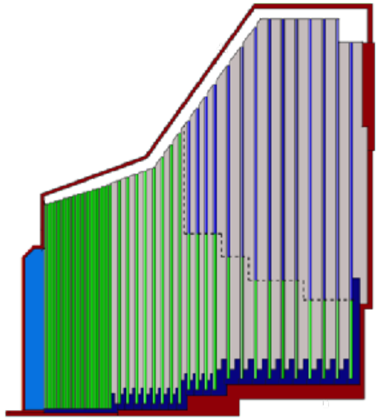
- production, test, calibration, software, management
- each step in size requires higher degrees of automation
  - e.g. mega-tiles

Full imaging power requires both ECAL and HCAL inside the solenoid

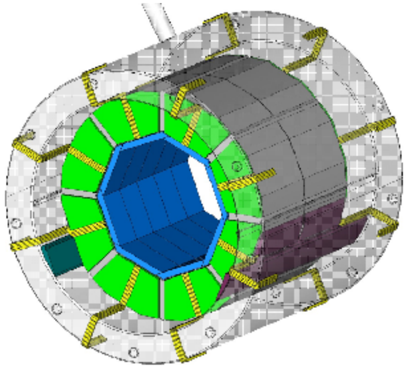
- much higher demands on compactness than in the CMS endcap
- re-optimisation of sampling including cooling and services / dead spaces
- NB: all alternatives have peripheral electronics



CALICE AHCAL prototype
22’000 SiPMs



CMS HGCAL (2 end-caps)
280'000 SiPMs



CLD / ILD HCAL barrel only
4’000’000 SiPMs

Scaling up - Step by Step

Orders of Magnitude

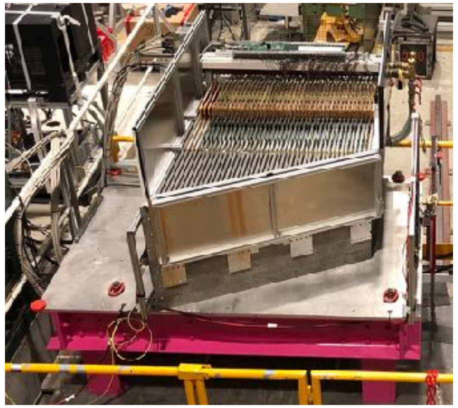
High channel count of highly granular calorimeters remains a challenge on all levels

- production, test, calibration, software, management
- each step in size requires higher degrees of automation
  - e.g. mega-tiles

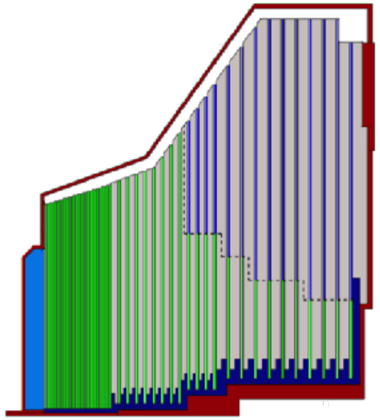
Full imaging power requires both ECAL and HCAL inside the solenoid

- much higher demands on compactness than in the CMS endcap
- re-optimisation of sampling including cooling and services / dead spaces
- NB: all alternatives have peripheral electronics

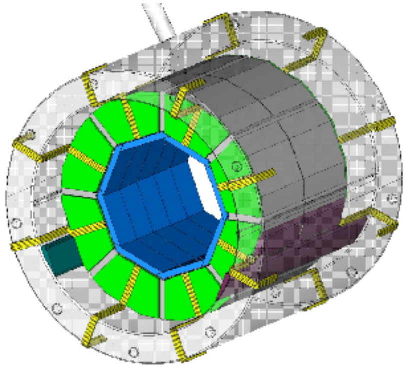
see talk by V.Boudry at this workshop



CALICE AHCAL prototype
22’000 SiPMs



CMS HGCAL
(2 end-caps)
280'000 SiPMs

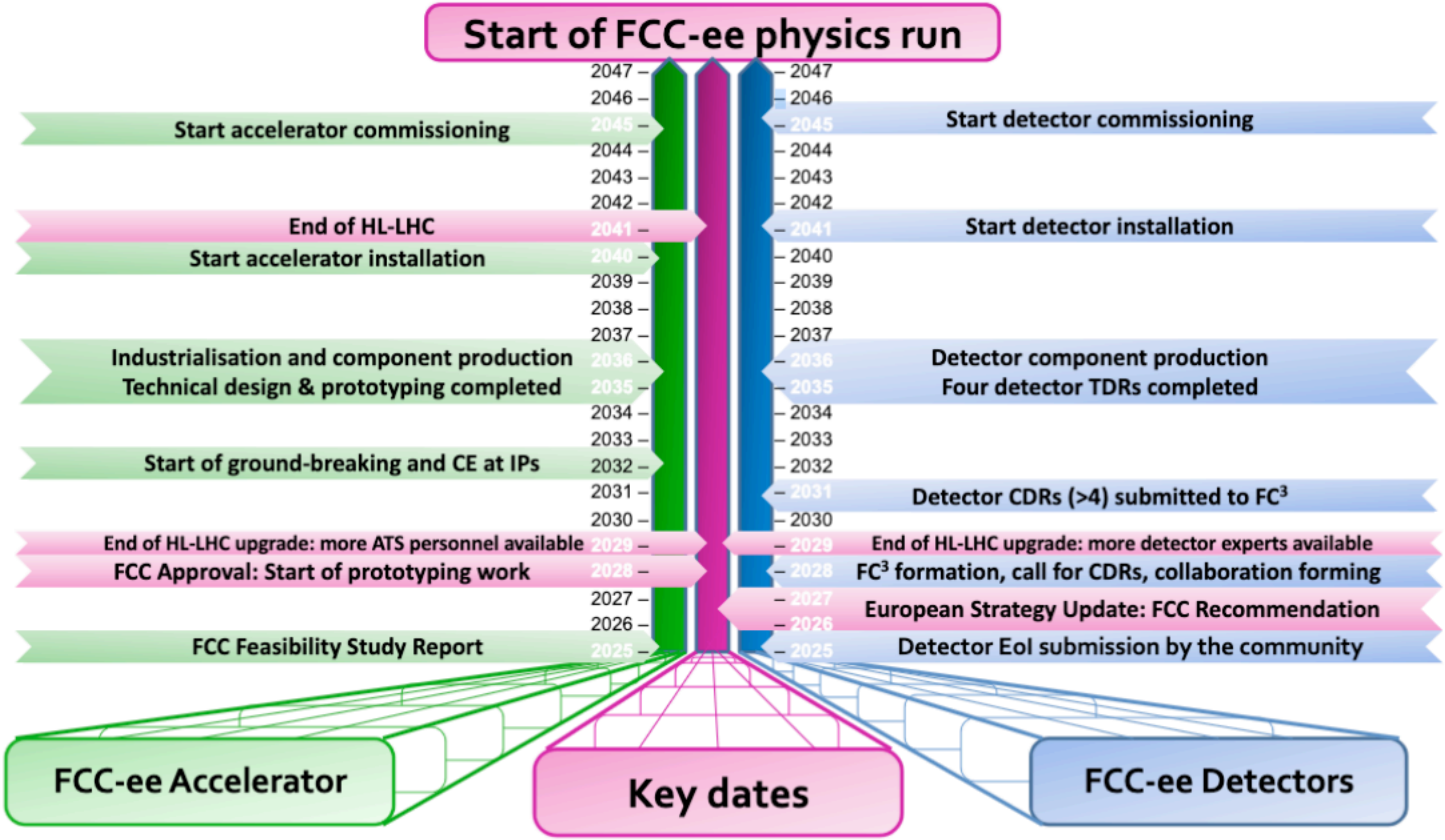


CLD / ILD HCAL
barrel only
4’000’000 SiPMs

Timeline for the FCCee

Working Hypothesis

all HF projects similar,
except maybe CEPC



Start of FCC-ee physics run

Start accelerator commissioning

Start detector commissioning

End of HL-LHC

Start detector installation

Start accelerator installation

Industrialisation and component production

Technical design & prototyping completed

Detector component production

Four detector TDRs completed

Start of ground-breaking and CE at IPs

Detector CDRs (>4) submitted to FC³

End of HL-LHC upgrade: more ATS personnel available

End of HL-LHC upgrade: more detector experts available

FCC Approval: Start of prototyping work

FC³ formation, call for CDRs, collaboration forming

European Strategy Update: FCC Recommendation

FCC Feasibility Study Report

Detector EoI submission by the community

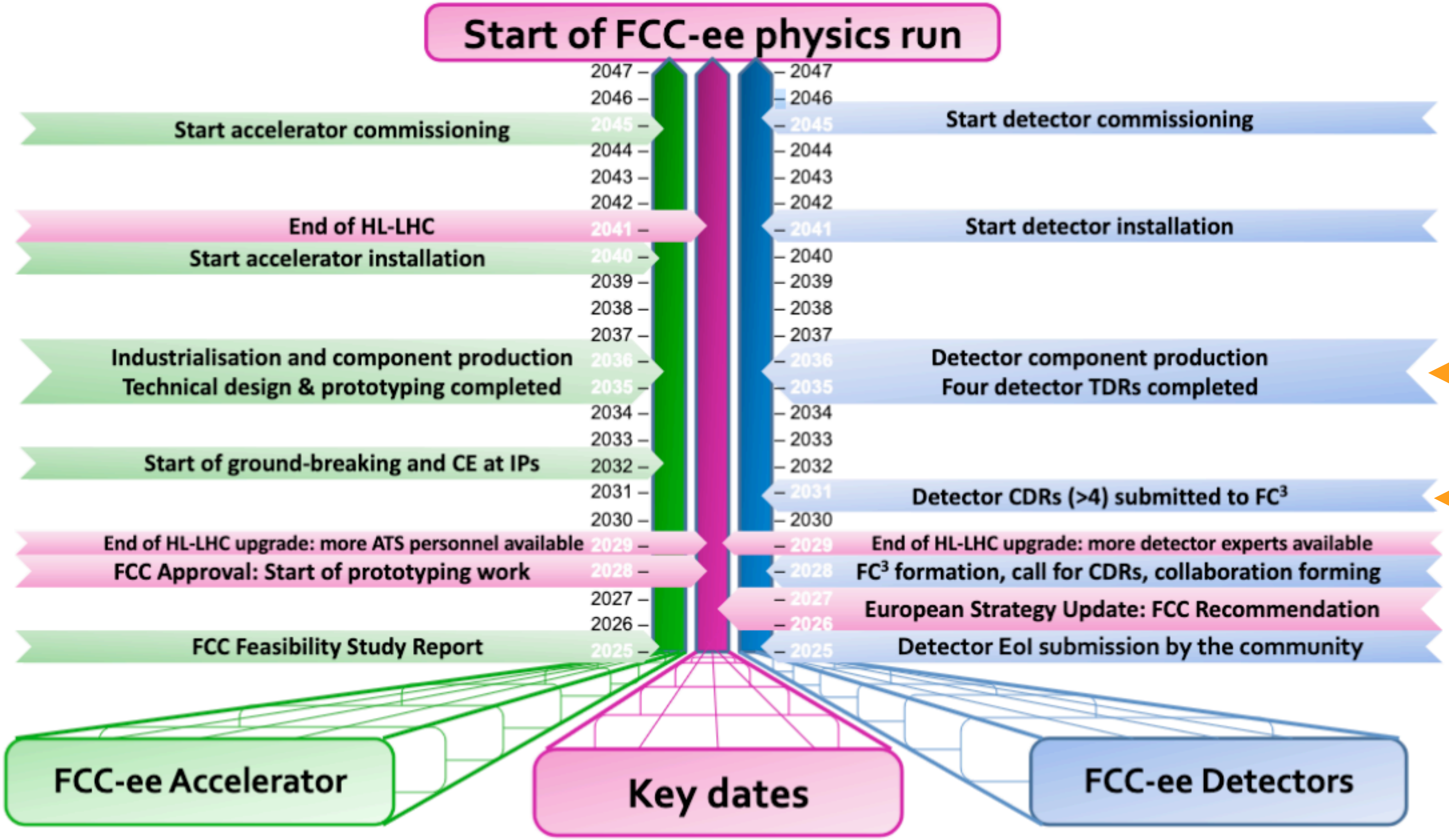
FCC-ee Accelerator

Key dates

FCC-ee Detectors

Timeline for the FCCee

Working Hypothesis



Start of FCC-ee physics run

Start accelerator commissioning

Start detector commissioning

End of HL-LHC

Start detector installation

Start accelerator installation

Industrialisation and component production
Technical design & prototyping completed

Detector component production
Four detector TDRs completed

Start of ground-breaking and CE at IPs

Detector CDRs (>4) submitted to FC³

End of HL-LHC upgrade: more ATS personnel available

End of HL-LHC upgrade: more detector experts available

FCC Approval: Start of prototyping work

FC³ formation, call for CDRs, collaboration forming

European Strategy Update: FCC Recommendation

FCC Feasibility Study Report

Detector EoI submission by the community

FCC-ee Accelerator

Key dates

FCC-ee Detectors

all HF projects similar, except maybe CEPC

2030-33
- scalable prototypes

2027-30
- system demonstrators

2024-27
- optimisation
- component R&D

Summary

Take-home

FCCee detectors represent exciting 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 - see this workshop!

- try them out: demonstrators are largely collider-agnostic

Gradual and moderate ramp-up in resources in some places (only)

- but real (scalable) prototypes will soon have to meet TDAQ electronics specs and will require some engineering - to address system aspects from the beginning

FCC PED is inviting sub-detector groups to form

Back-up