

The IDEEA detector for a future large circular e^+e^- collider



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- FCC-ee (CEPC) Physics requirements
 - Detector requirements
 - A detector concept for an electron circular collider: IDEA
- Conclusions

Disclaimer

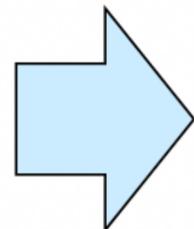
To prepare these slides I used content from many friends and colleagues, whom I wholeheartedly wish to thank. Any mistake or misinterpretation is entirely my fault!



This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511.

Higgs Factory Programme

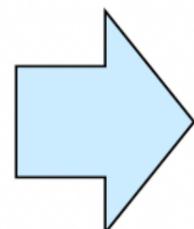
- At $\sqrt{s}=240$ and $\sqrt{s}=365$ GeV collect 2.6M HZ and 150k WW \rightarrow H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling ($\sim 4 \sigma$) via loop diagrams
- Unique possibility: s-channel $e^+e^- \rightarrow H$ at 125 GeV



- **Momentum resolution $\sigma(p_T)/p_T \simeq 10^{-3}$ @ $p_T \sim 50$ GeV**
 - $\sigma(p)/p$ limited by multiple scattering \rightarrow minimise material
- **Jet $\sigma(E)/E \simeq 3-4\%$ in multijet events for Z/W/H separation**
- **Superior impact parameter resolution for b, c tagging**
- **Hadron PID for s tagging**

Precision EW and QCD Programme

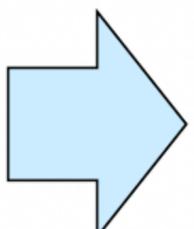
- 6×10^{12} Z and 2×10^8 WW events
- $\times 500$ improvement of statistical precision on EWPO: $m_Z, \Gamma_Z, \Gamma_{inv}, \sin^2\theta_W, R_b, m_W, \Gamma_W, \dots$
- 2×10^8 tt events: $m_{top}, \Gamma_{top},$ EW couplings
- Indirect sensitivity to new physics up to tens of TeV



- **Absolute normalisation of luminosity to 10^{-4}**
- **Relative normalisation to $\lesssim 10^{-5}$ (e.g. Γ_{had}/Γ_ℓ)**
 - Acceptance definition to $\mathcal{O}(10 \mu\text{m})$
- **Track angular resolution < 0.1 mrad**
- **Stability of B field to 10^{-6}**

Heavy Flavour Programme

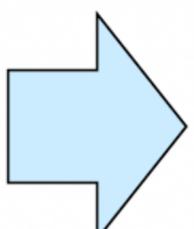
- 10^{12} bb, cc, 2×10^{12} $\tau\tau$ (clean and boosted): $10 \times$ Belle II
- CKM matrix, CP measurements
- rare decays, CLFV searches, lepton universality



- **Superior impact parameter resolution**
- **Precise identification and measurement of secondary vertices**
- **ECAL resolution at few %/VE**
- **Excellent π^0/γ separation for τ decay-mode identification**
- **PID: K/ π separation over wide p range \rightarrow dN/dx, RICH, 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-lifetime LLPs



- **Sensitivity to (significantly) detached vertices (mm \rightarrow m)**
 - tracking: more layers, "continuous" tracking
 - calorimetry: granularity, tracking capabilities
- **Precise timing**
- **Hermeticity**

M. Dam

Table 13: Summary of detector requirements.

	Aggressive	Conservative	Comments
Beampipe	$X/X_0 < 0.5\%$	$X/X_0 < 1\%$	$B \rightarrow K^* \tau \tau$
Vertex	$\sigma(d_0) = 3 \oplus 15 / (p \sin^{3/2} \theta) \mu\text{m}$ $X/X_0 < 1\%$	–	$B \rightarrow K^* \tau \tau$ R_c
	$\delta L = 5 \text{ ppm}$	–	$\delta \tau_\tau < 10 \text{ ppm}$
Tracking	$\sigma_p/p < 0.1\%$ for $\mathcal{O}(50)$ GeV tracks	$\sigma_p/p < 0.2\%$ for $\mathcal{O}(50)$ GeV tracks	$\delta M_H = 4 \text{ MeV}$ $\delta \Gamma_Z = 15 \text{ keV}$ $Z \rightarrow \tau \mu$
	t.b.d.	$\sigma_\theta < 0.1 \text{ mrad}$	$\delta \Gamma_Z(\text{BES}) < 10 \text{ keV}$
ECAL	$\sigma_E/E = 3\%/\sqrt{E}$	$\sigma_E/E = 10\%/\sqrt{E}$	$Z \rightarrow \nu_e \bar{\nu}_e$ coupling, B physics, ALPs
	$\Delta x \times \Delta y =$ $2 \times 2 \text{ mm}^2$	$\Delta x \times \Delta y =$ $5 \times 5 \text{ mm}^2$	τ polarisation boosted π^0 decays bremsstrahlung recovery
	$\delta z = 100 \mu\text{m},$ $\delta R_{\min} = 10 \mu\text{m} (\theta = 20^\circ)$	In-situ constraint with dilepton/diphoton events	alignment tolerance for $\delta \mathcal{L} = 10^{-5}$ with $\gamma \gamma$ events
HCAL	$\sigma_E/E = 30\%/\sqrt{E}$	$\sigma_E/E = 50\%/\sqrt{E}$	$H \rightarrow s\bar{s}, c\bar{c}, gg, \text{invisible}$ HNLs
	$\Delta x \times \Delta y =$ $2 \times 2 \text{ mm}^2$	$\Delta x \times \Delta y =$ $20 \times 20 \text{ mm}^2$	$H \rightarrow s\bar{s}, c\bar{c}, gg$
Muons	low momentum ($p < 1 \text{ GeV}$) ID	–	$B_s \rightarrow \nu \bar{\nu}$
Particle ID	$3 \sigma K/\pi$ $p < 40 \text{ GeV}$	$3 \sigma K/\pi$ $p < 30 \text{ GeV}$	$H \rightarrow s\bar{s}$ $b \rightarrow s \nu \bar{\nu}, \dots$
LumiCal	tolerance $\delta z = 100 \mu\text{m}, \delta R_{\min} = 1 \mu\text{m}$ acceptance 50–100 mrad	–	$\delta \mathcal{L} = 10^{-4}$ target (Bhabha)

4 experimental areas

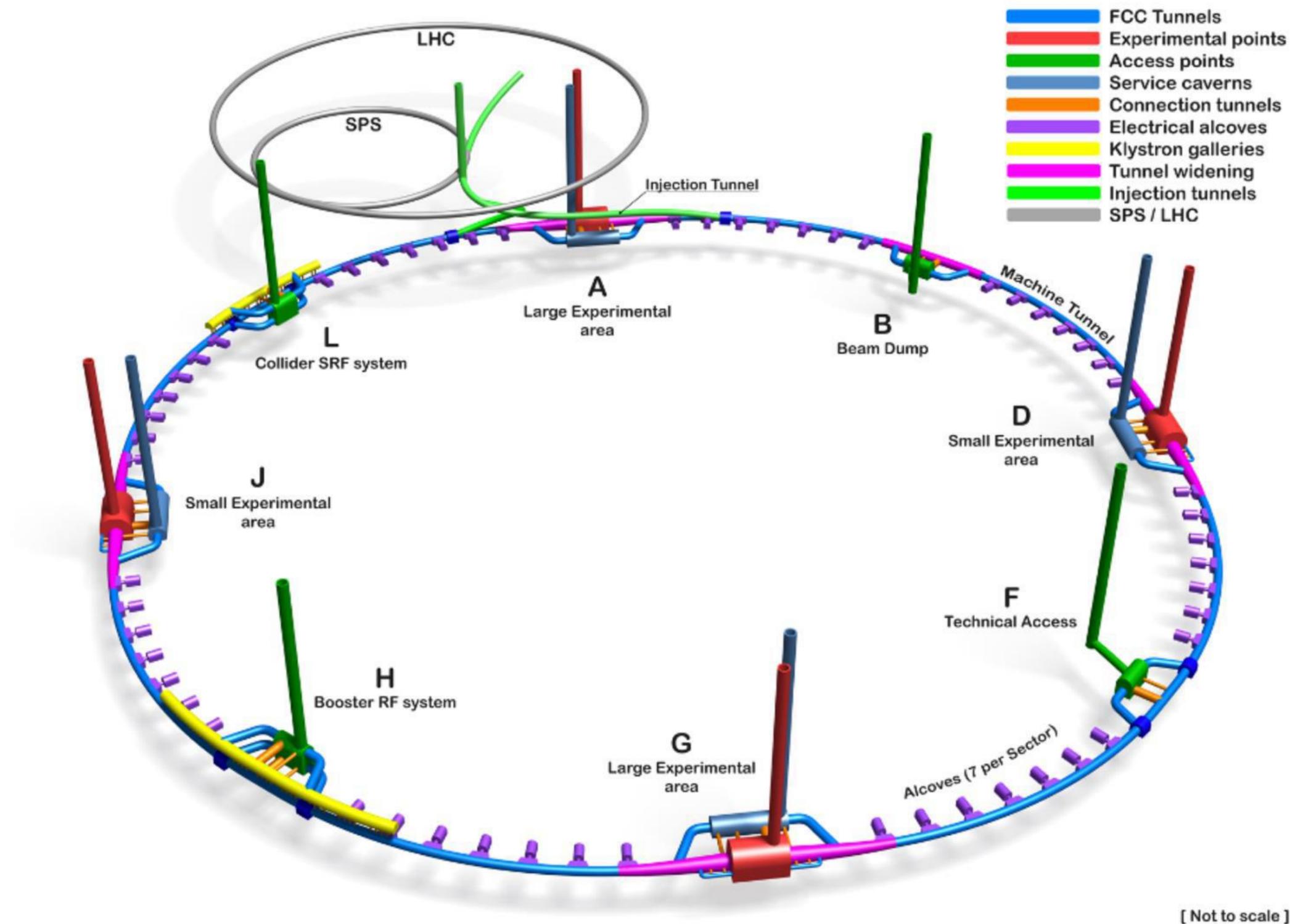
(4 experiments)

Point A

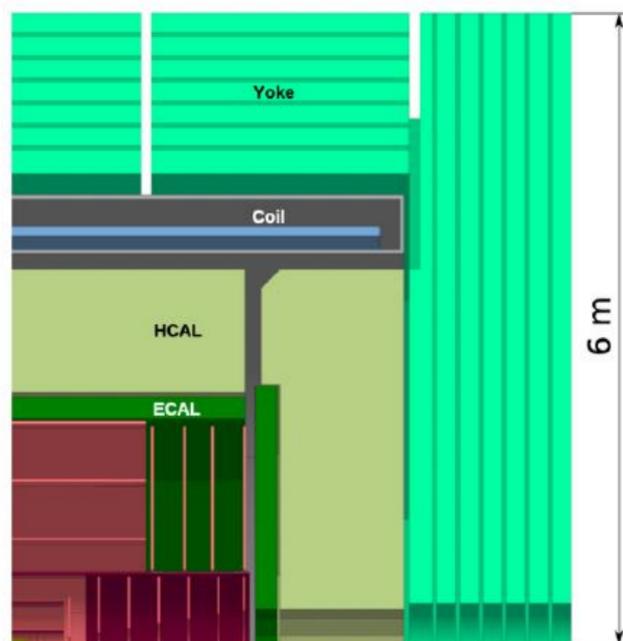
Point D

Point G

Point J



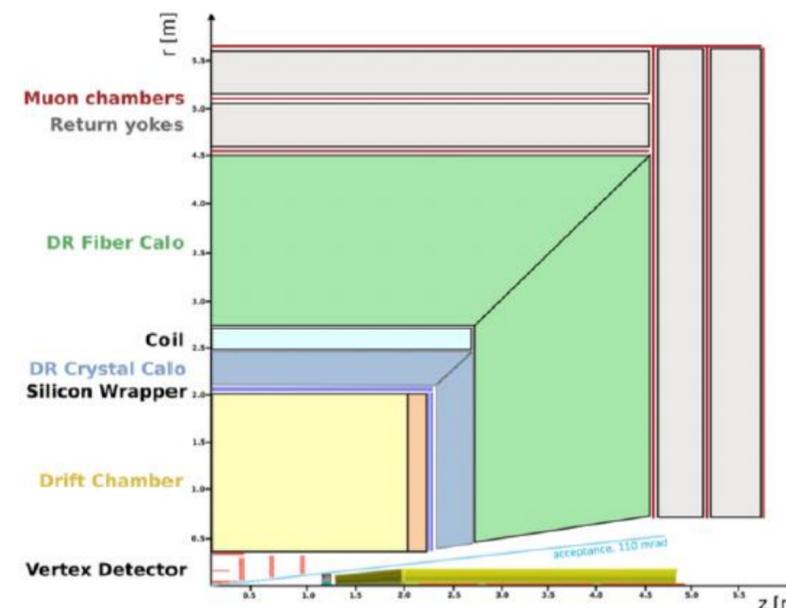
CLD



- Well established design
 - ILC → CLIC detector → CLD
- Full Si VXD + tracker
- CALICE-like calorimetry – very high granularity
- Coil outside calorimetry, muon system
- Possible detector optimizations
 - Improved σ_p/p , σ_E/E
 - PID: precise timing and RICH

[arXiv:1911.12230](https://arxiv.org/abs/1911.12230)

IDEA



- Design developed specifically for FCC-ee and CEPC
- Si VXD; ultra-light drift chamber with powerful PID
- Crystal ECAL w. dual readout
- Compact, light coil;
- Dual readout fibre calorimeter
- Muon system

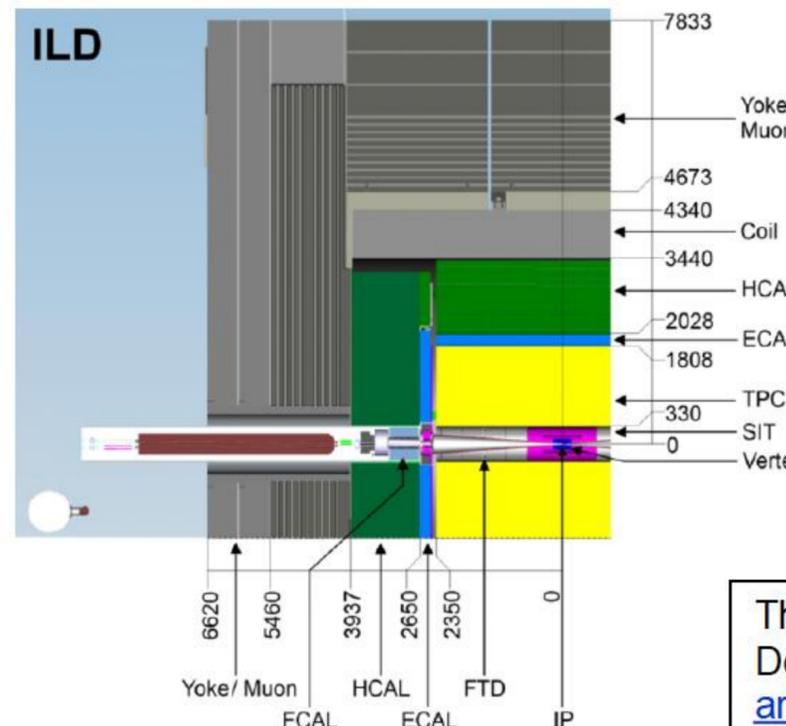
<https://doi.org/10.48550/arXiv.2502.21223>

Allegro



- Still in early design phase
- Design centred around High granularity **Noble Liquid ECAL**
 - Pb+LAr (or denser W+LKr)
- Si VXD
- Tracker: Drift chamber, straws, or Si
- Steel-scintillator HCAL
- Coil outside ECAL in same cryostat
- Muon system

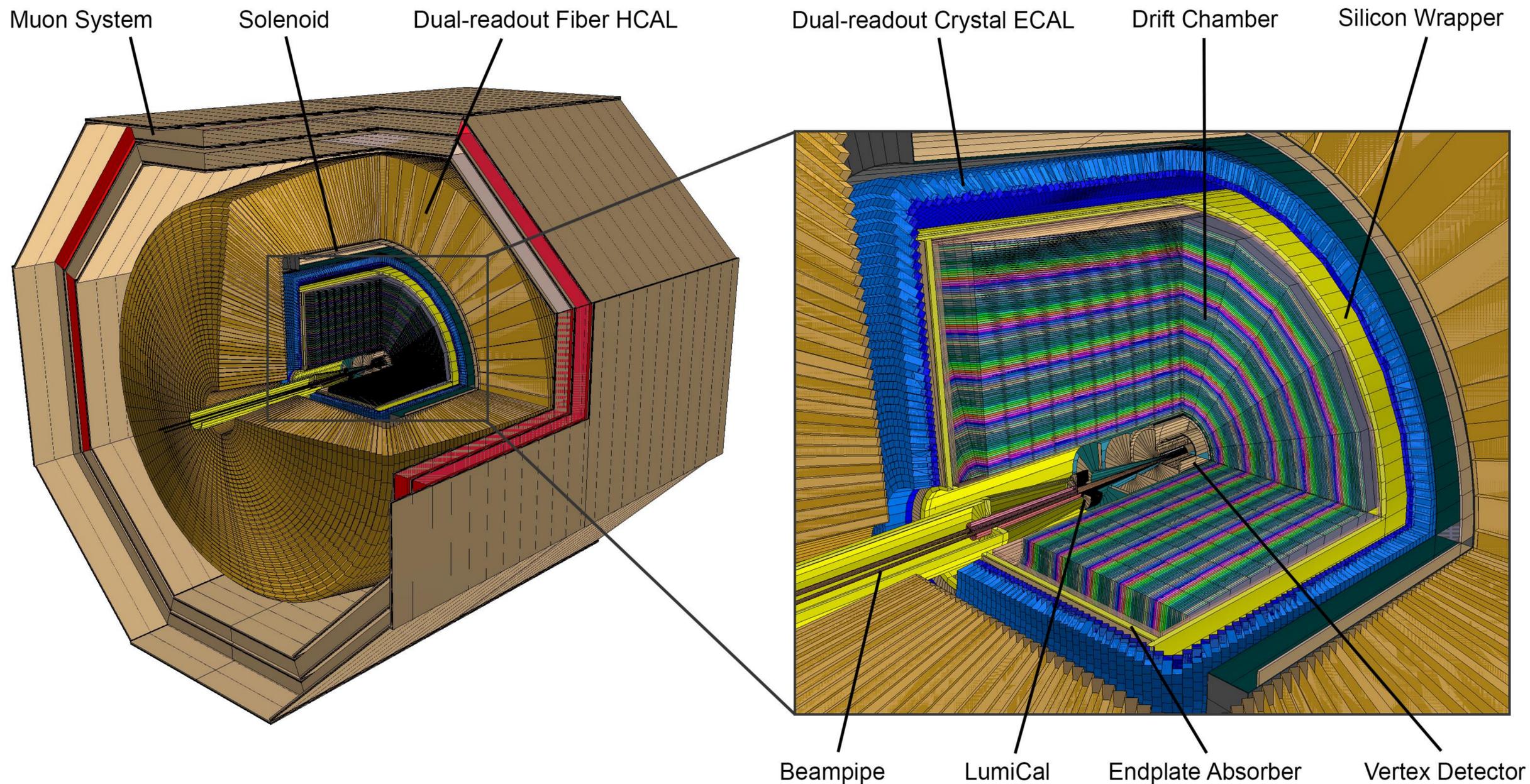
[Eur.Phys.J.Plus 136 \(2021\) 10, 1066, arXiv:2109.00391](https://arxiv.org/abs/2109.00391)



- Designed originally for operation at the ILC
- Together with SiD, ancestor of CLD.
- Main difference and signature element:
 - Large-volume time projection chamber (TPC)

The International Linear Collider Technical Design Report - Volume 4: Detectors
[arXiv:1306.6329](https://arxiv.org/abs/1306.6329)

IDEA was proposed quite some years ago by several INFN researchers. It was the first detector conceived specifically for FCC-ee. Several International collaborators have joined in the past years. It is probably the most ambitious of all 4 detector concepts.



Beam pipe: $R \sim 1.0$ cm

Vertex:

5 MAPS layers
 $R = 1.37-31.5$ cm

Drift Chamber: 112 layers
 4 m long, $R = 35-200$ cm

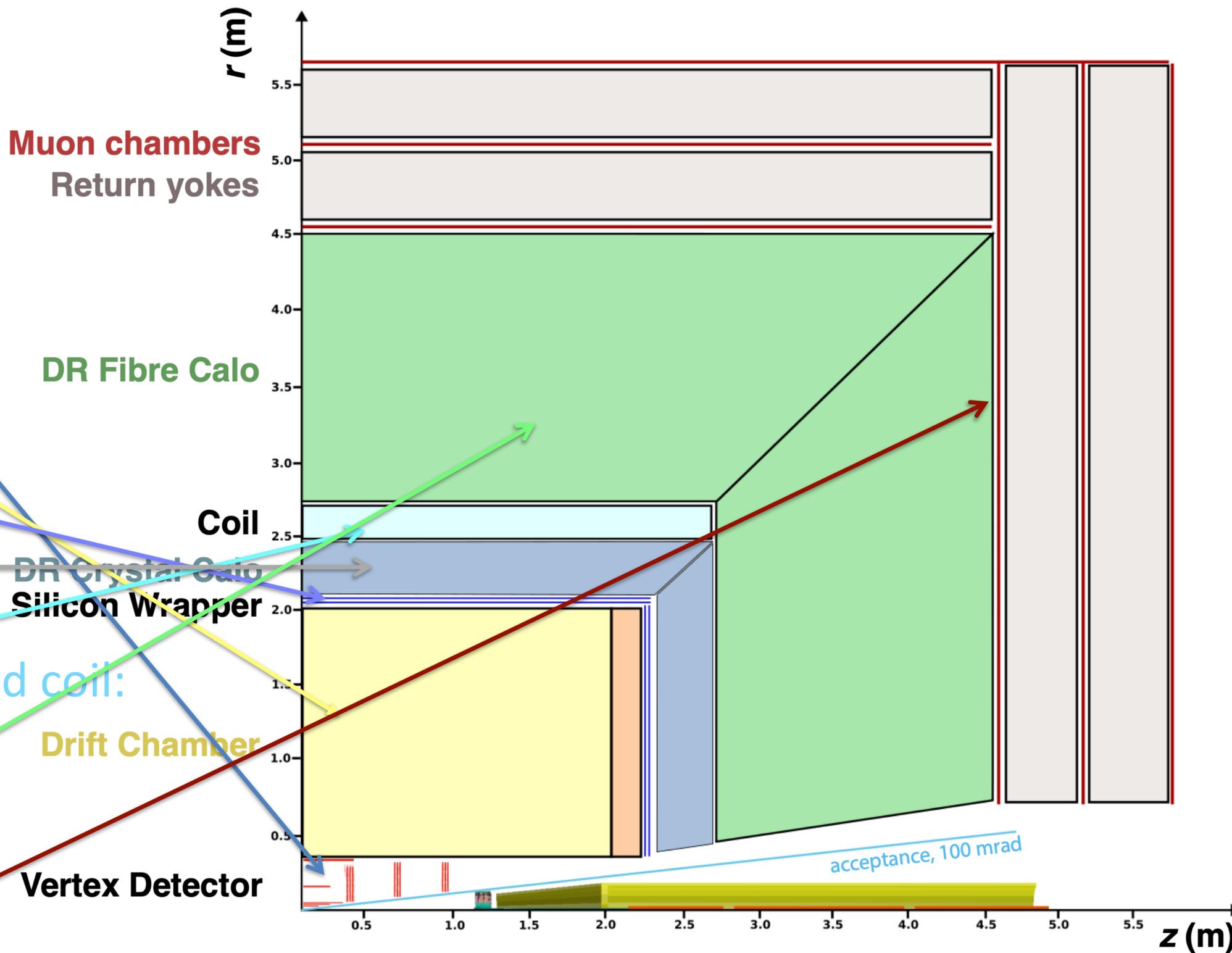
Outer Silicon wrapper:
 $R = 200-215$ cm

DR crystal ecal: $\sim 22 X_0$
 $R = 215-250$ cm

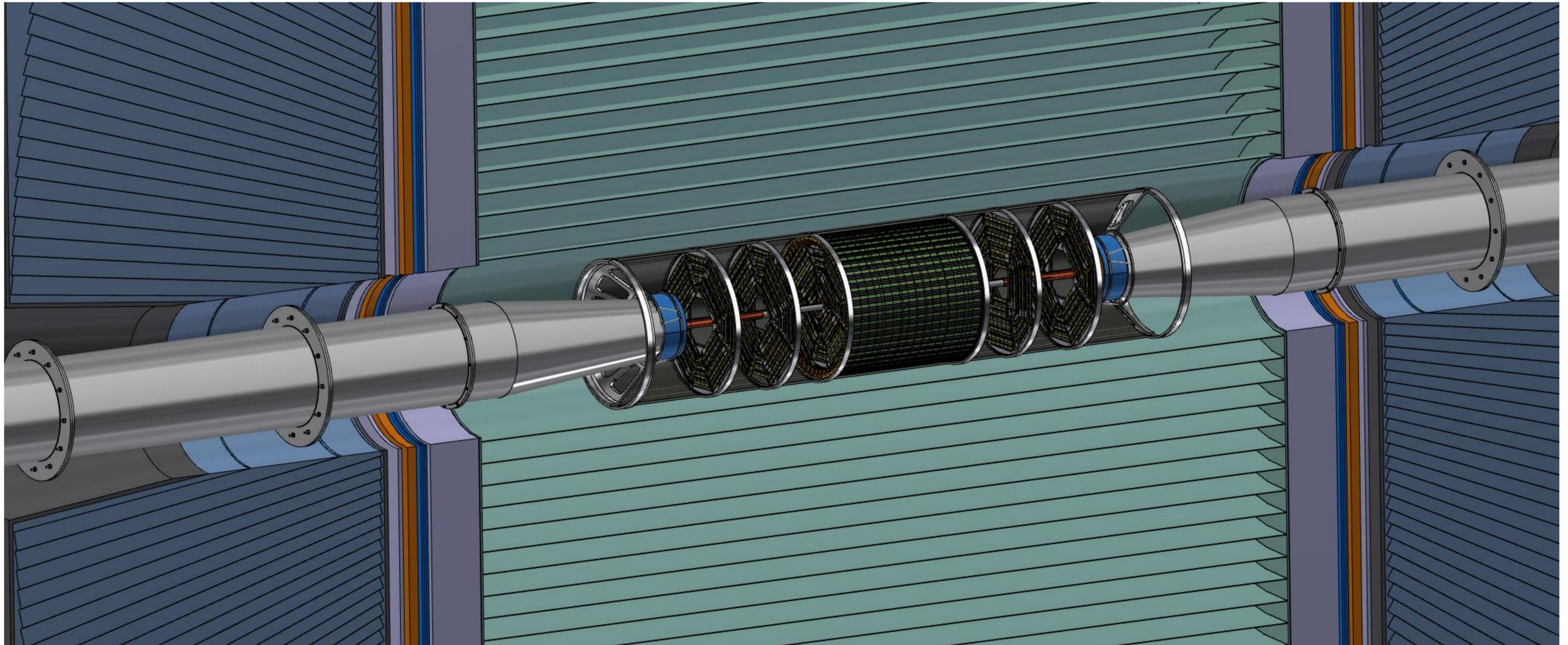
Superconducting solenoid coil:
 3 T, $R \sim 2.5-2.8$ m

Dual-Readout Calorimeter:
 $R = 280-460$ cm

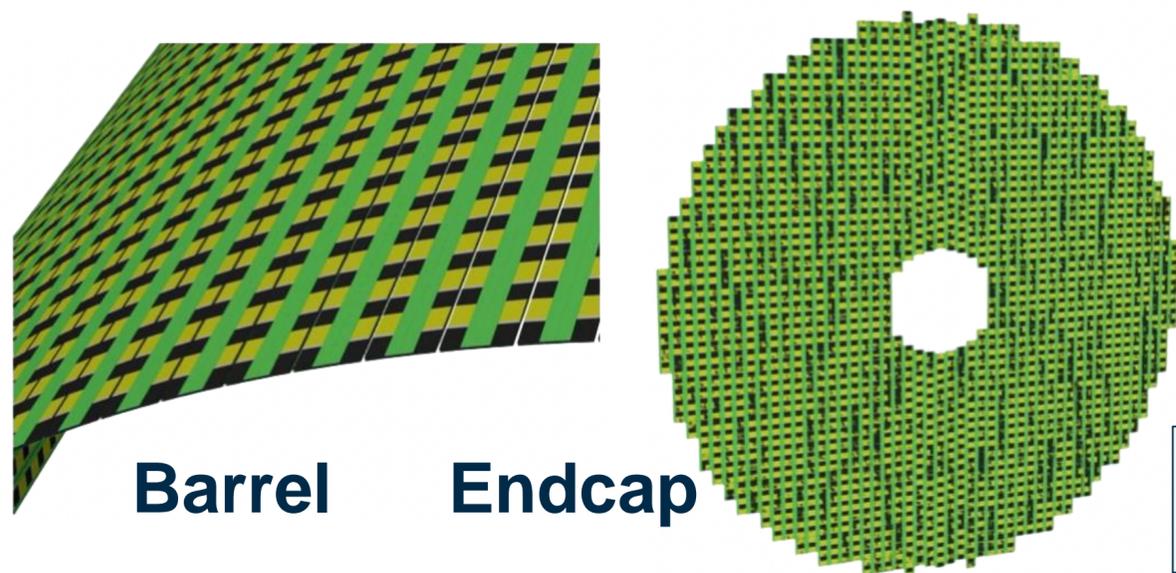
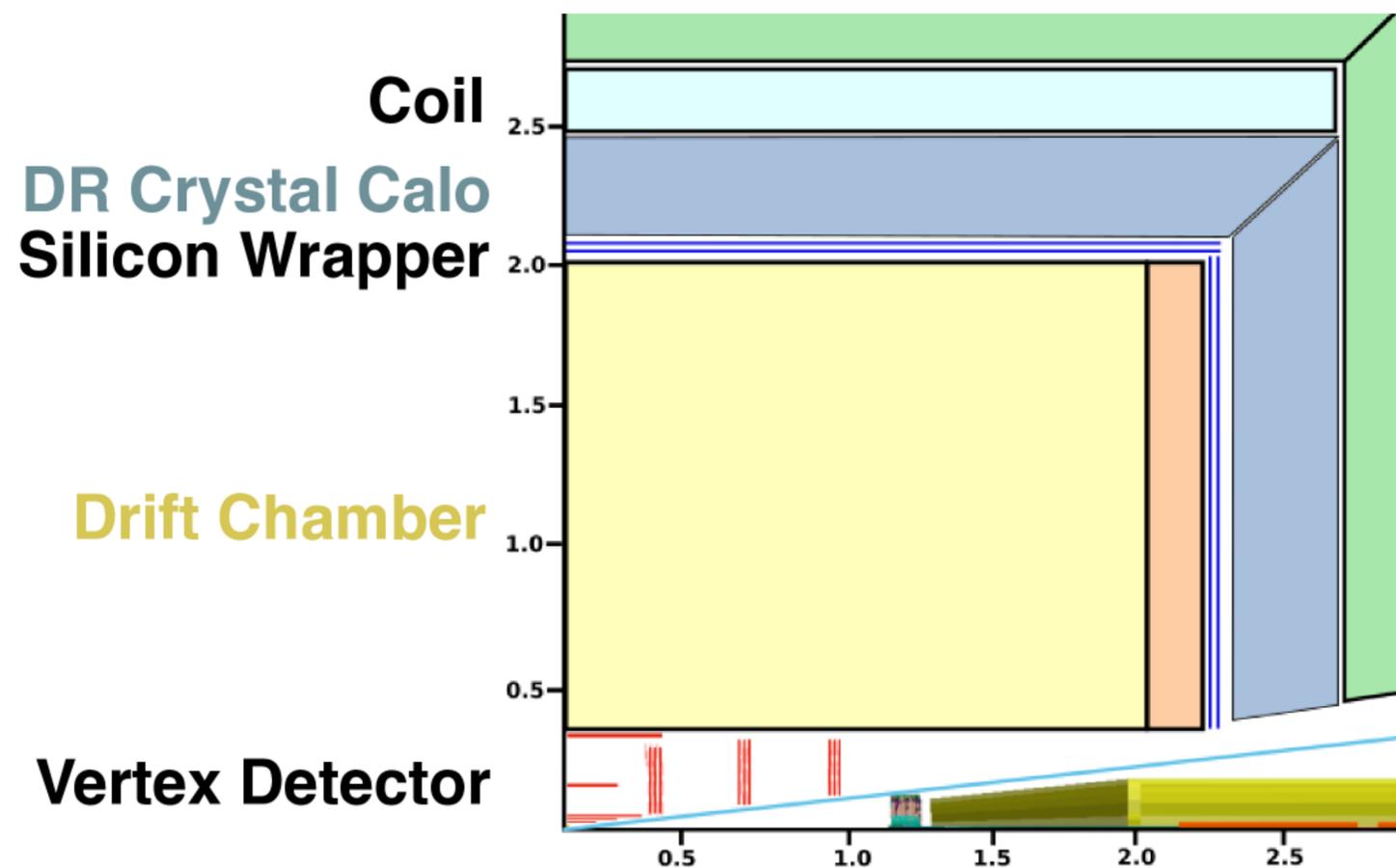
Yoke + Muon chambers
 $R = 460-570$ cm



General integration



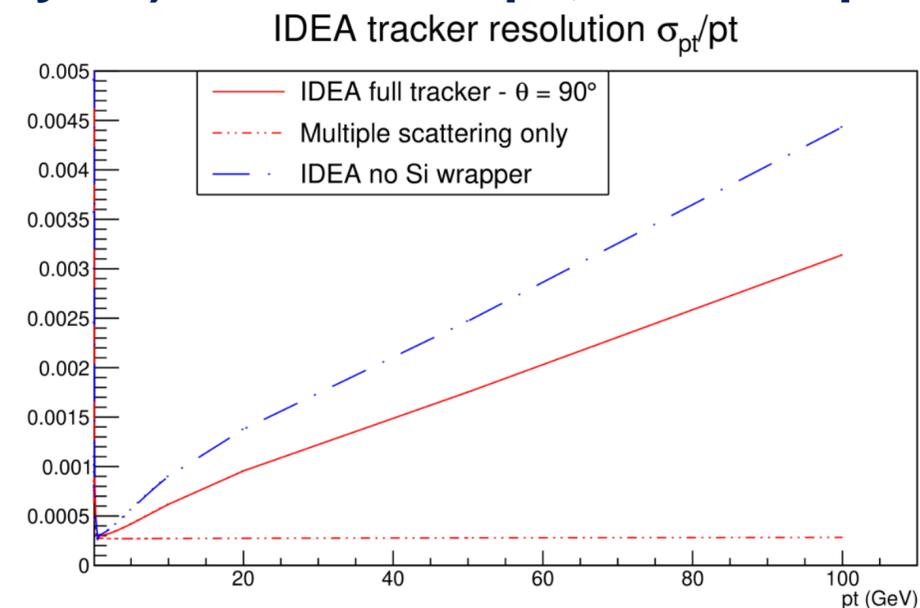
F. Palla

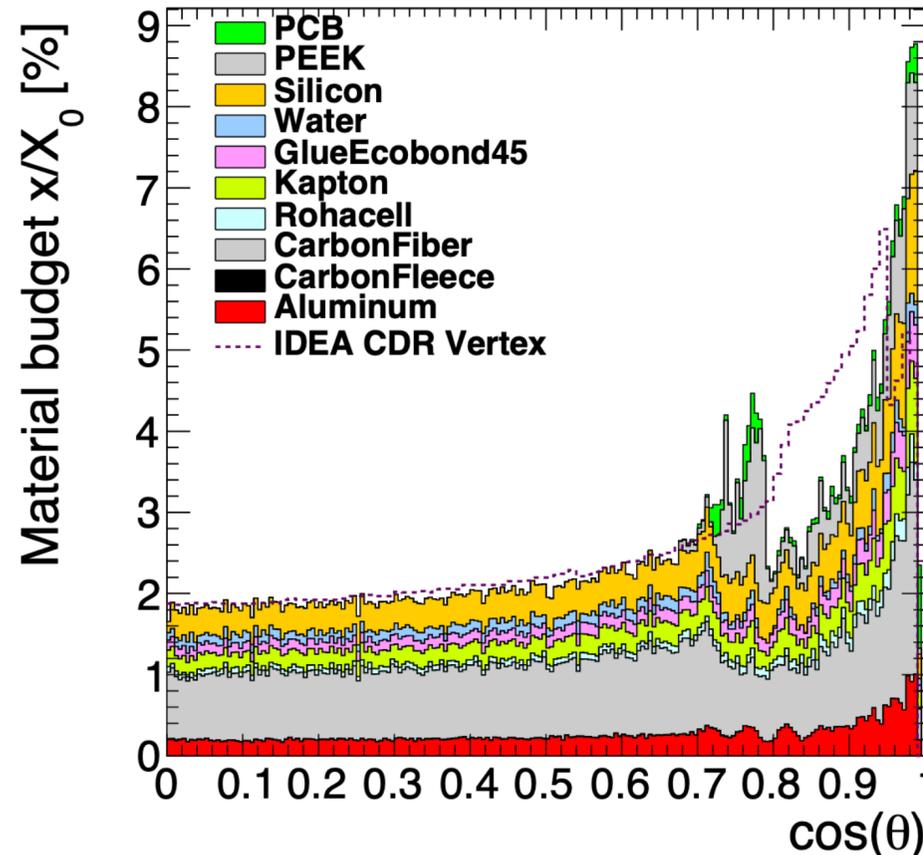
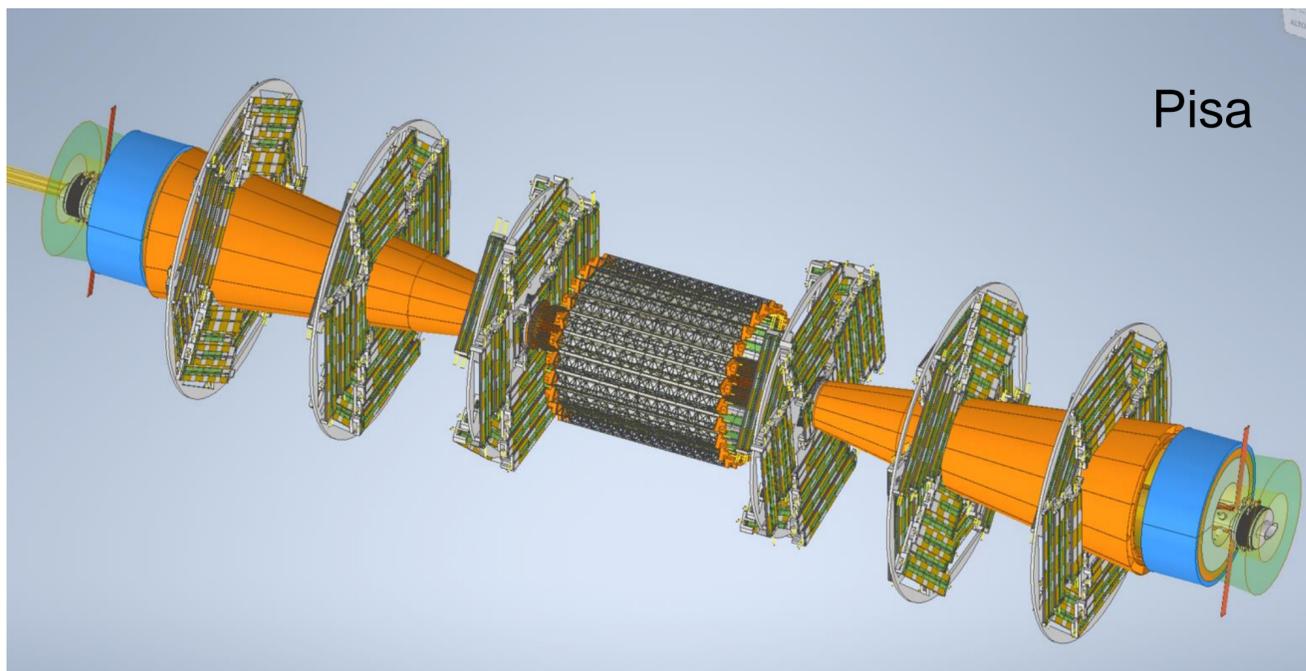


The IDEA detector concept for FCC-ee
[arXiv:2502.21223](https://arxiv.org/abs/2502.21223)

Silicon tracking in different regions (IDEA concept shown here, but general considerations are valid for all layouts)

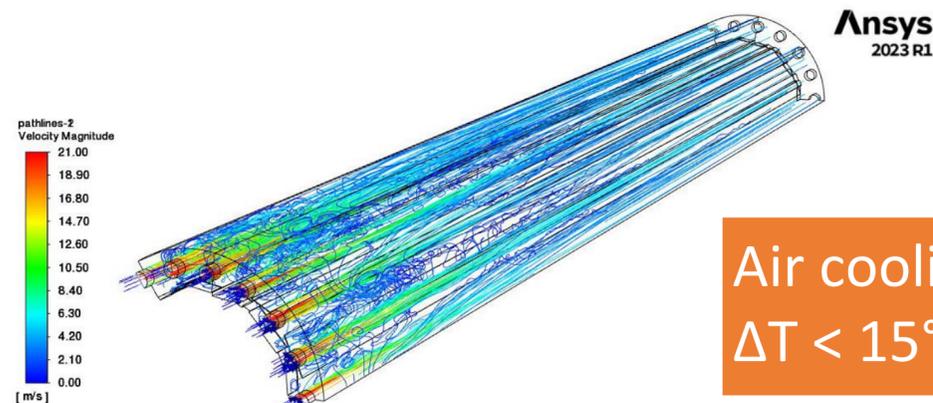
- **inner vertex detector (R=1.4-3.3 cm)**
 - 3-5 μm resolution, O(200 MHz/cm²), very low material
- **outer vertex detector (R=13-31 cm)**
 - ~7 μm resolution, 32 ns timestamp, O(40-100 kHz/cm²)
 - material is a concern
- **silicon wrapper/TOF (R/z = 200 cm)**
 - ~7 μm resolution, 32 ns timestamp
 - 100 m² (2 layers): ~2.5 10^5 chips, ~100 kW power



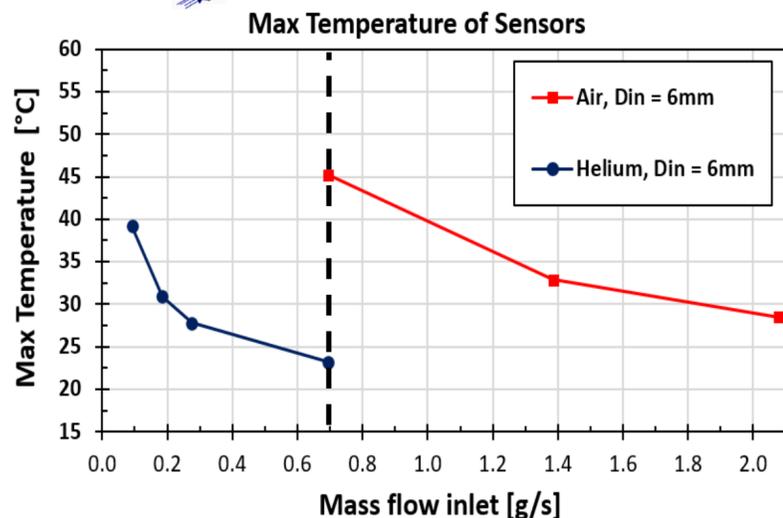


Outer vertex tracker:
ATLASPix3 based (Milano)
Modules of $50 \times 150 \mu\text{m}^2$ pixel

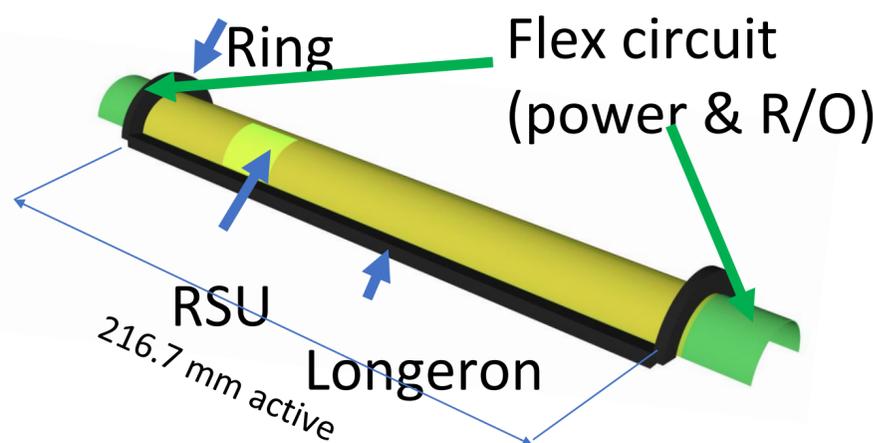
Inner Vertex detector:
ARCADIA based (Torino, Milano, Padova, Pisa, Perugia)
Modules of $25 \times 25 \mu\text{m}^2$ pixel size



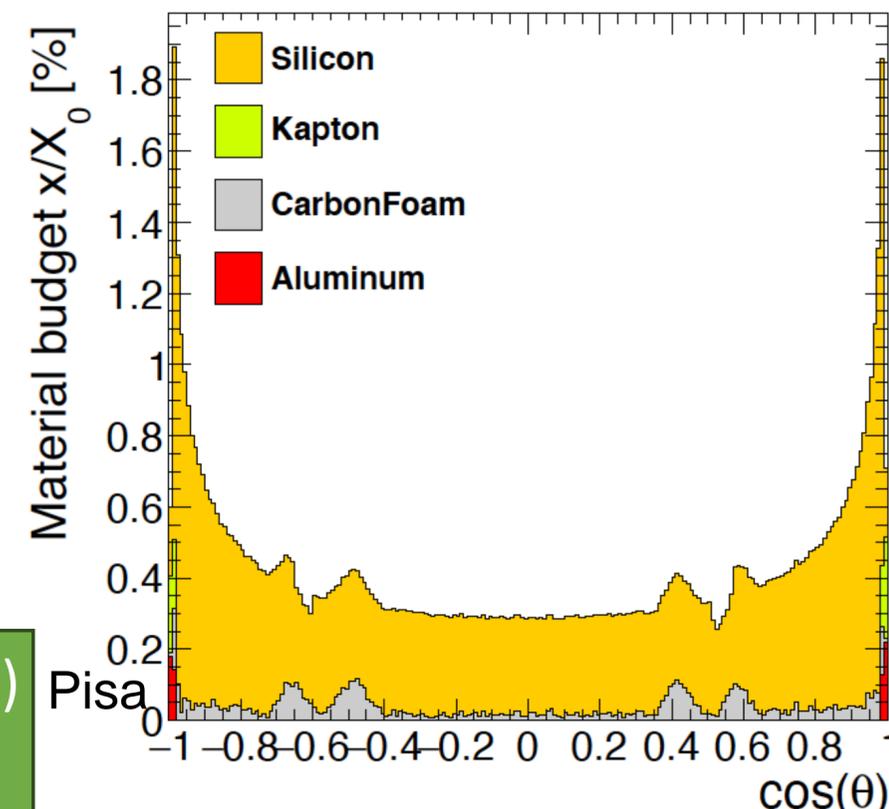
Air cooling studies:
 $\Delta T < 15^\circ\text{C}$



Perugia

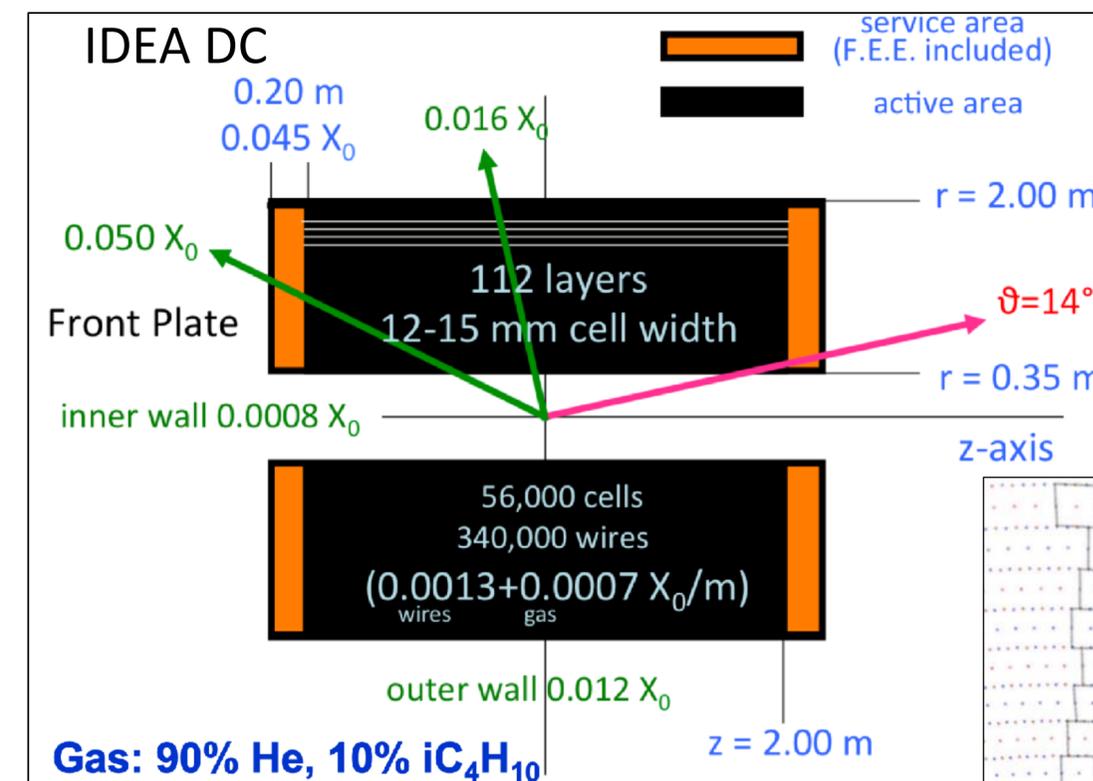
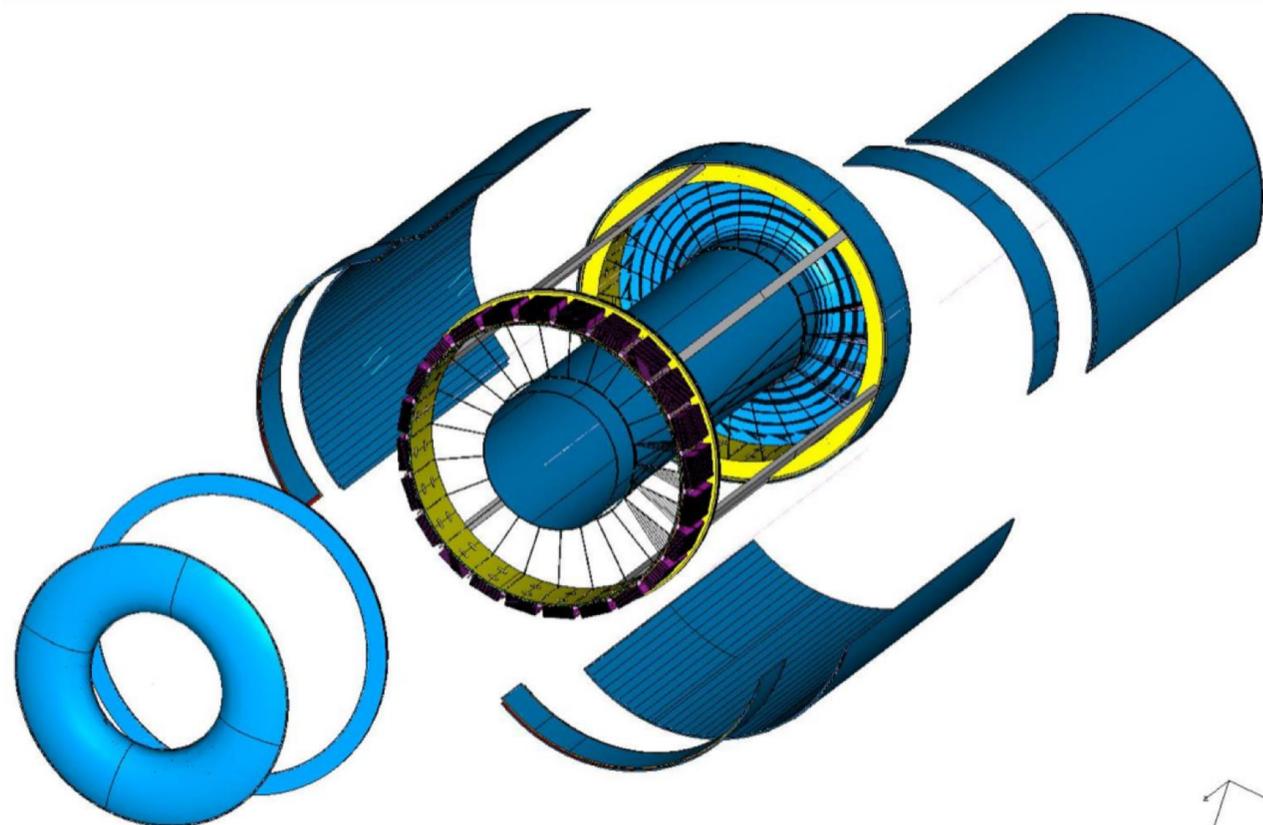
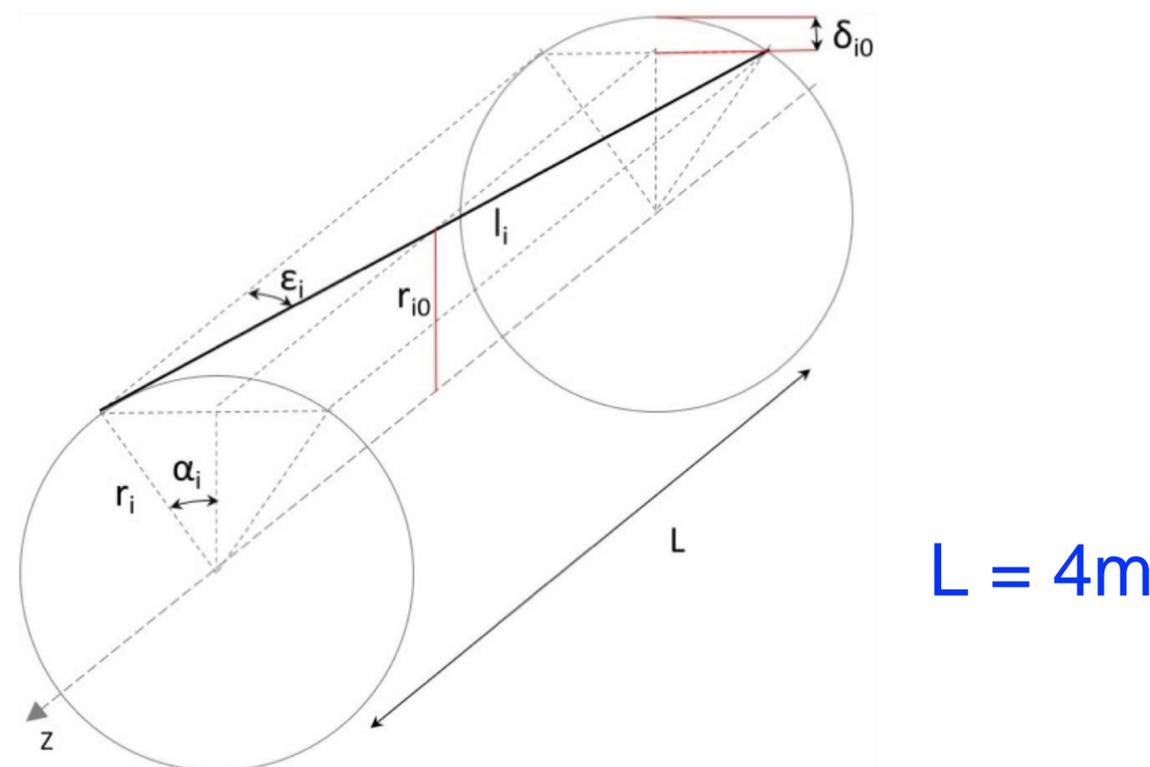


Also studying curved Silicon layout (ITS3 like)
~4 smaller material budget for inner vertex



◆ IDEA: Extremely transparent Drift Chamber

- Gas: 90% He – 10% iC_4H_{10}
- Radius 0.35 – 2.00 m
- Total thickness: 1.6% of X_0 at 90°
- All stereo wires (56448 cells, 343968 wires)
 - ◆ Tungsten wires dominant contribution
- 112 layers for each 15° azimuthal sector
- max drift time: 350 ns

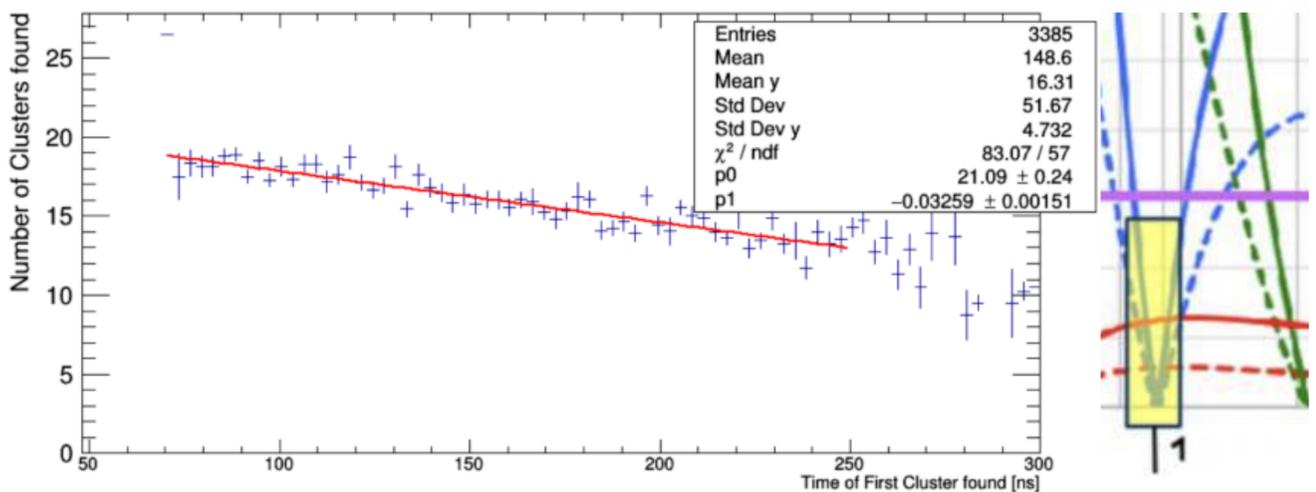


2022 test-beam data

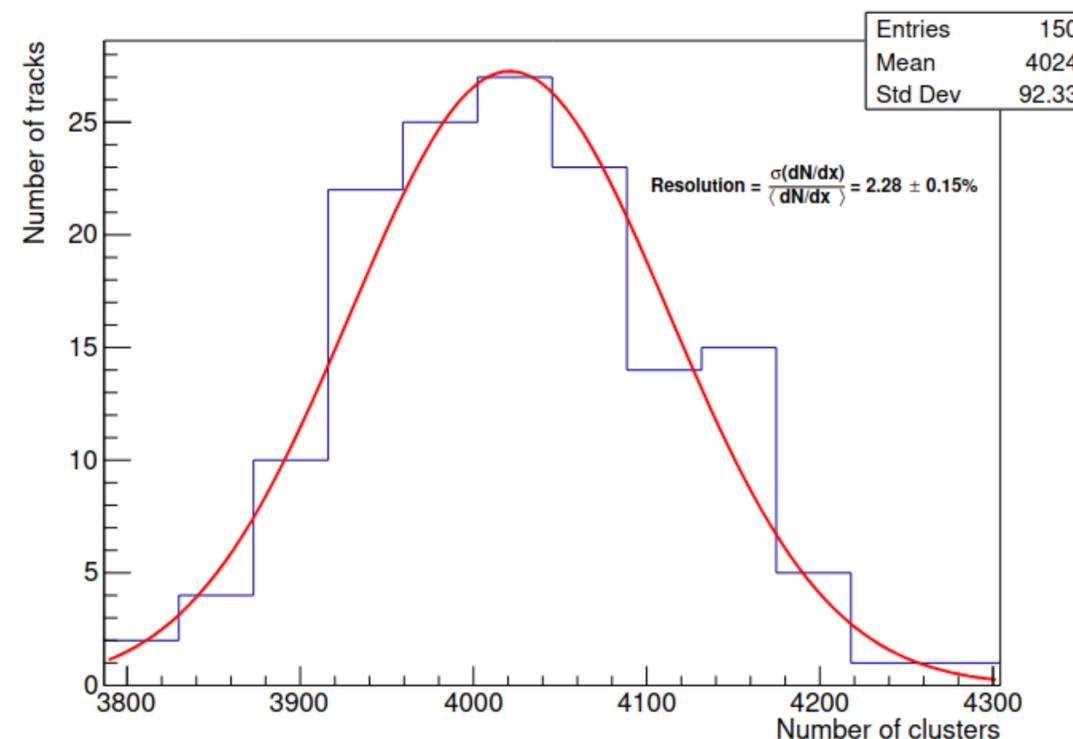
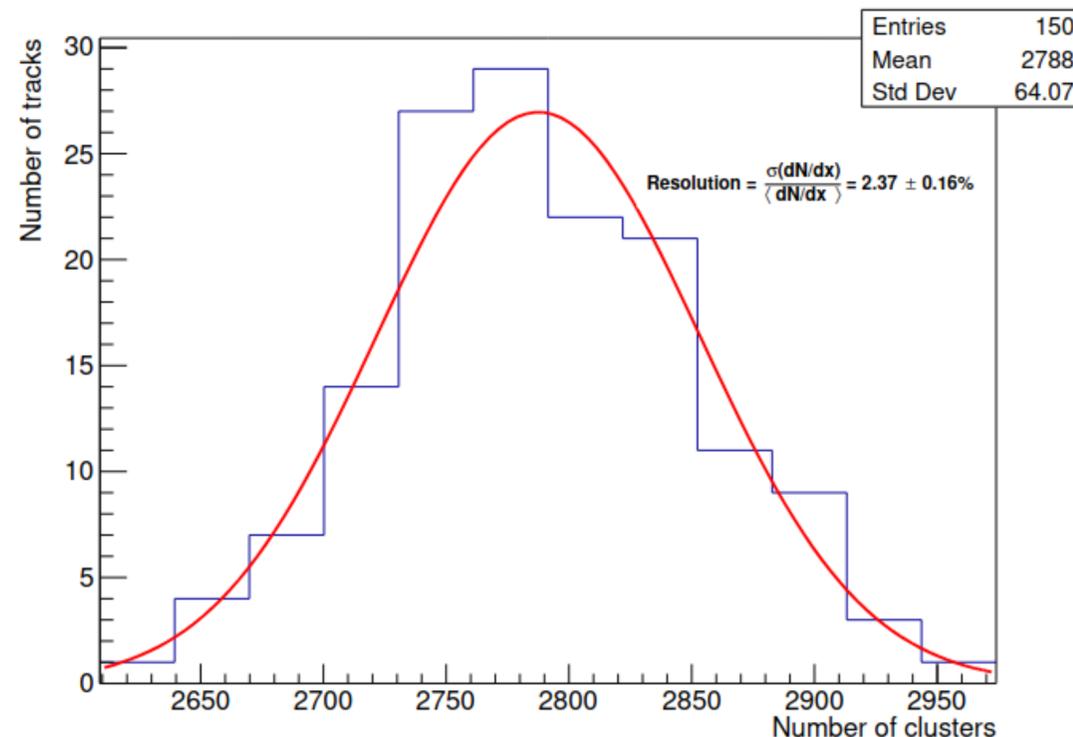
[JINST 20 P11019](#)

Improved dN/dx resolution:

- better event cleaning**
 - time span of clusters
 - rejecting abnormally wide and noisy waveforms
- mitigation of recombination and attachment effect**
 electrons can possibly recombine with the positive ions reducing the cluster count (*more impactful with more drifting*)



dN/dx shows a better resolution of $2.28 \pm 0.16\%$



Measured resolution

3.01%

More tight event cleaning

2.37%

Recom. & attachment correction

2.28%

Instrumented surface:

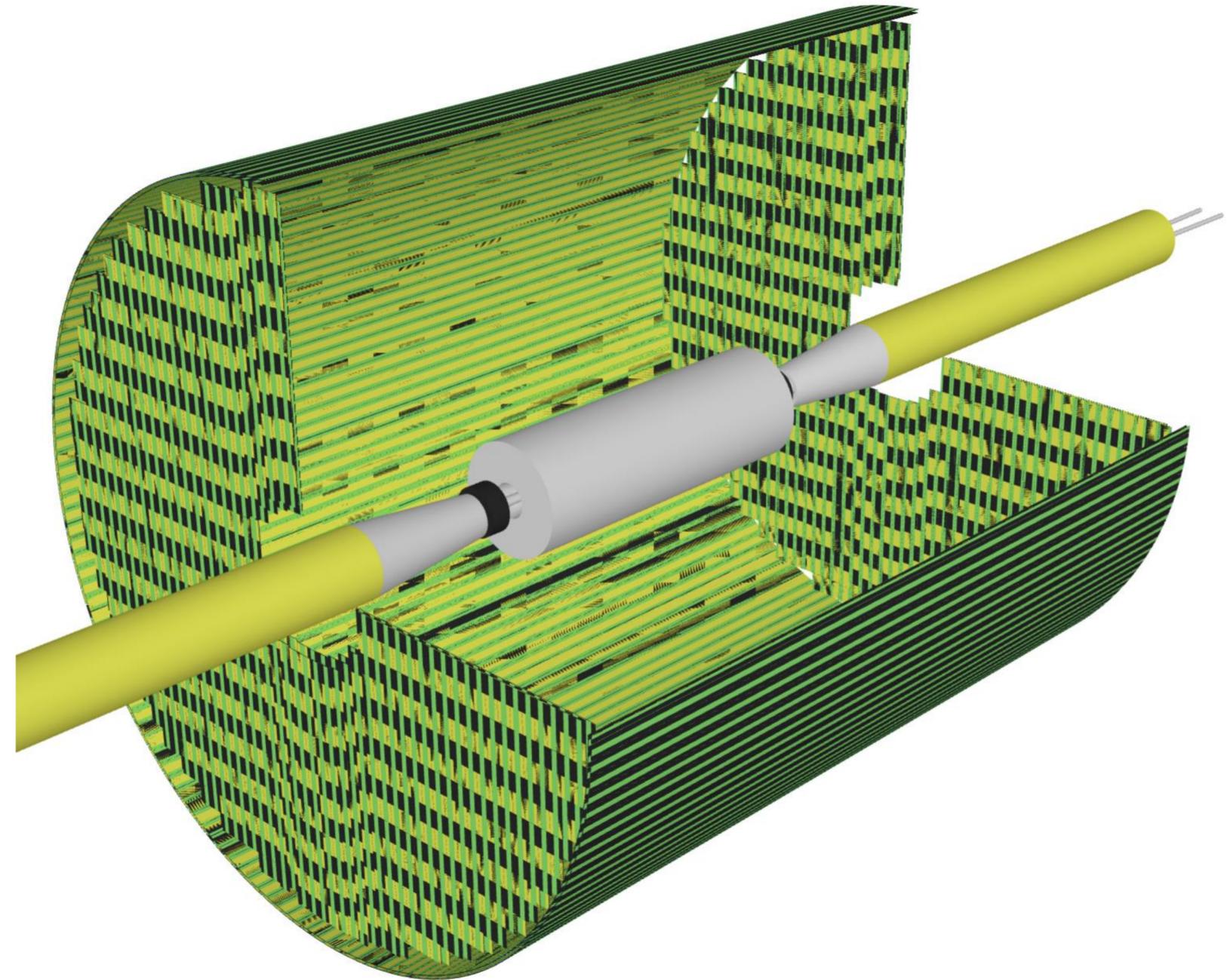
- $r = 2\text{m}$;
- $|z| < 2.4\text{ m}$;
- $|\eta| < 2.6$

⇒ Total area for a single layer: $\sim 90\text{ m}^2$

Baseline design uses same MAPS detectors as original vertex detector design:

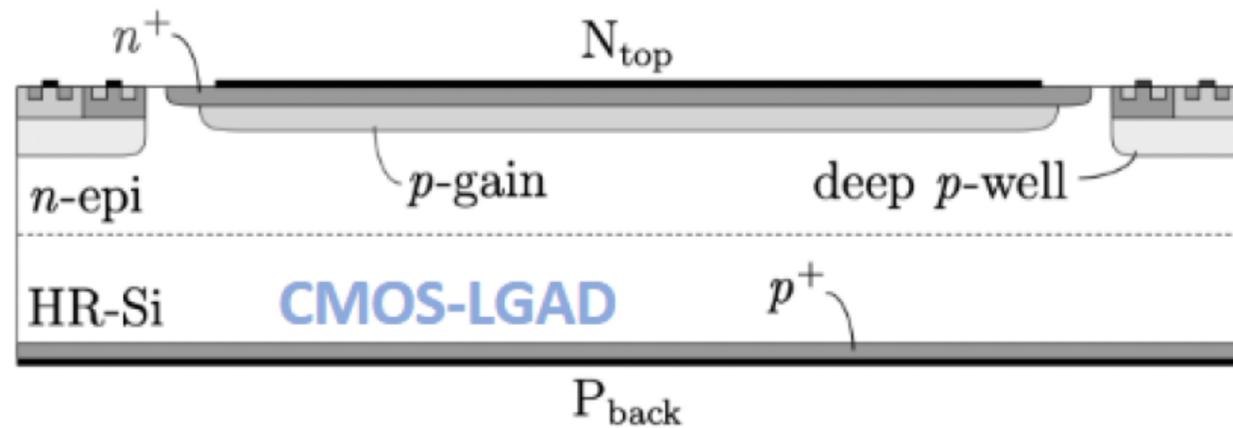
- $25\text{ }\mu\text{m} \times 25\text{ }\mu\text{m}$ pixel size $\rightarrow 7\text{ }\mu\text{m}$ resolution in both coordinates

⇒ Total number of channels: $\sim 150 \times 10^9$



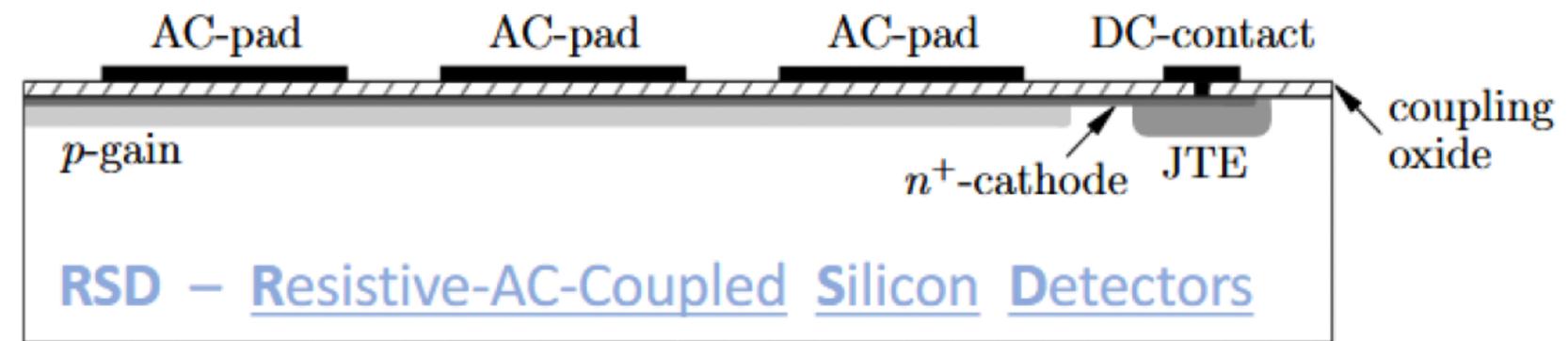
M. Mandurrino
FCC-ee Tracking WS

CMOS integration of the LGAD technology
already demonstrated (in LF11is)



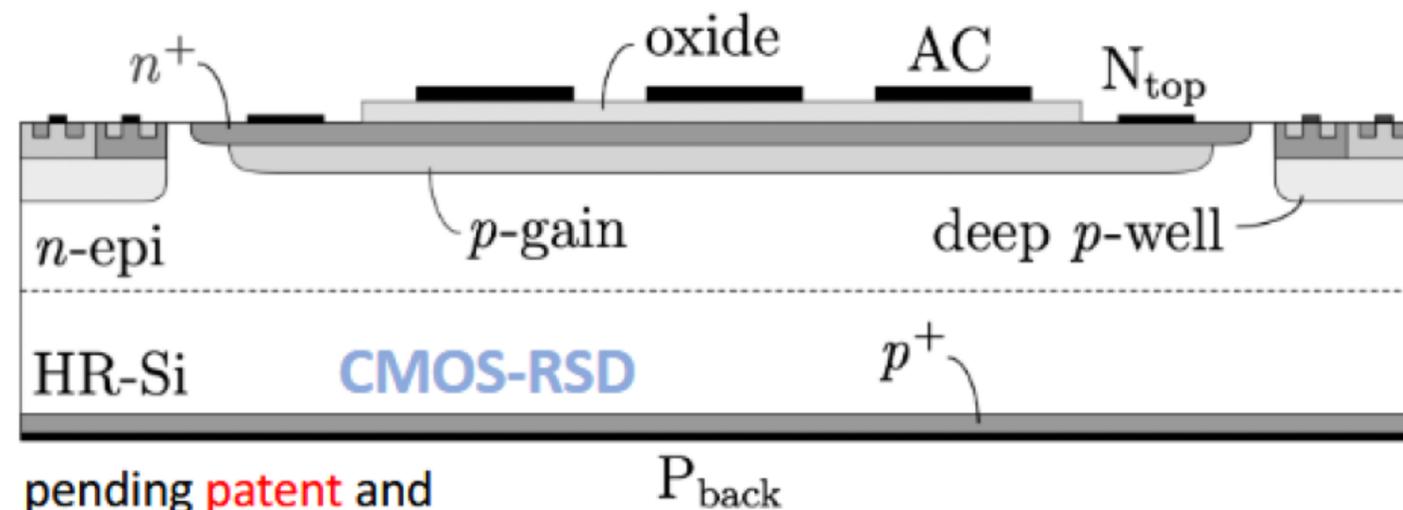
Spatial resolution $\sim 3\%$ of sensor pitch
(allowing to relax the channel density)

Time resolution similar to standard
LGADs: **30-40 ps**



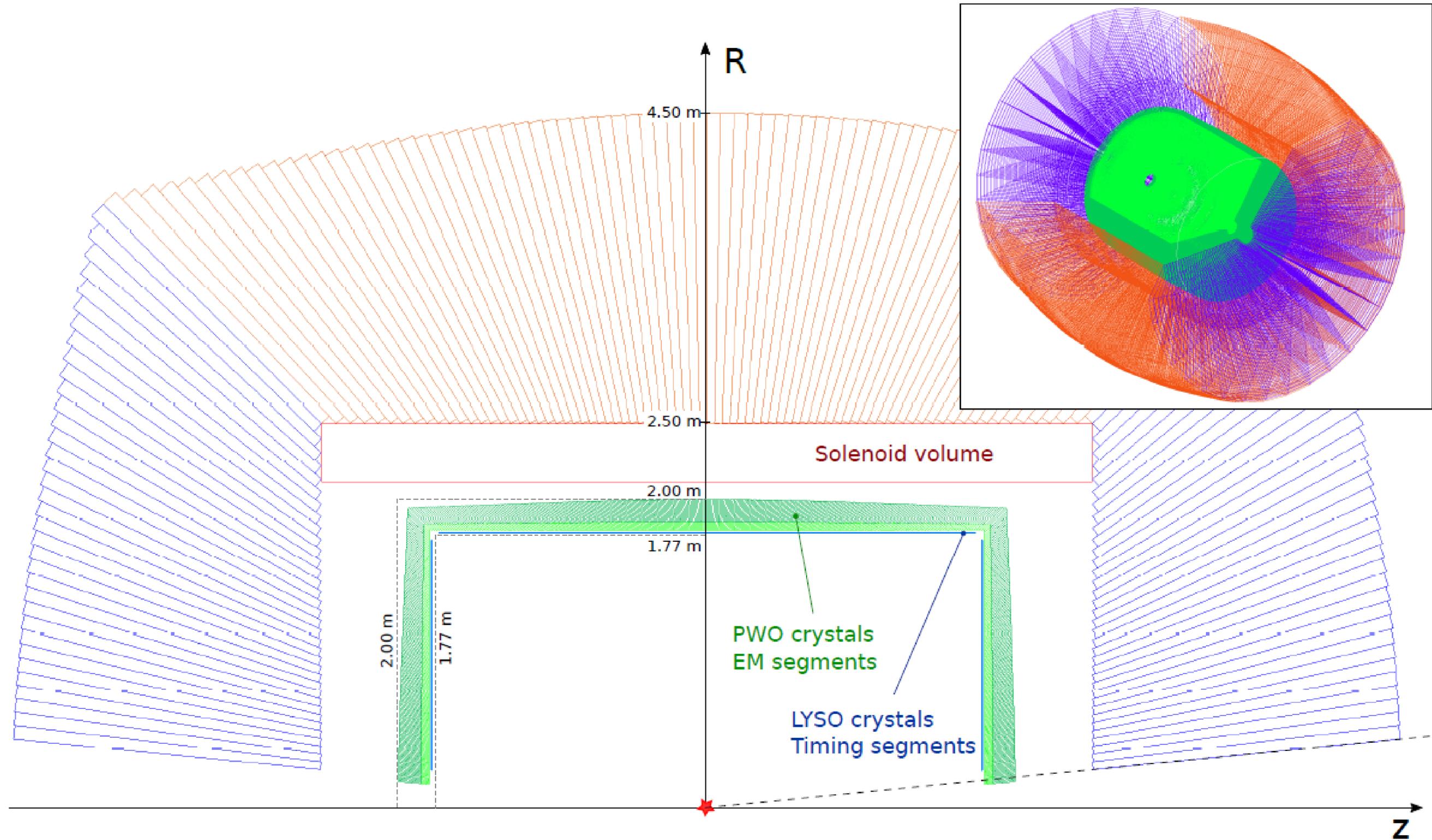
Plausible concurrent targets:

- $\sigma_t = 10-20$ ps
- $\mu\text{m-level } \sigma_x$
- 100% FF



pending patent and
extent of protection

Detector layout and
process flow design
activities are ongoing
First prototypes in next
silicon production runs
(std. CMOS process)

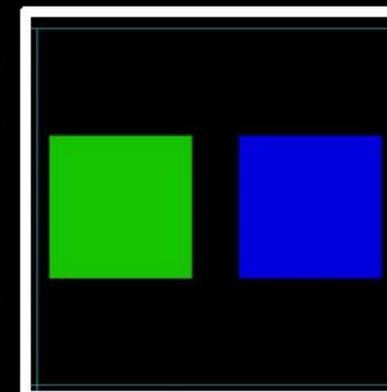


Prototype design

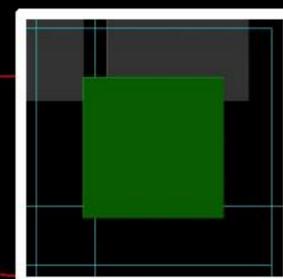
- Building a full containment EM prototype
 - **Optimized** through simulation: minimum crystal volume required for full containment of EM shower
 - **Versatility**: possibility to exchange central 3x3 core with BG(S)O crystals and waveform digitization
- Targeting test on beam in **Sept 2025**

One 6x6 mm² SiPM
(15 um cell size, no filter)

One 6x6 mm² SiPM
(50 um cell size, w/ K24 filter)



One 6x6 mm² SiPM
(15 um cell size, no filter)



10x10x50 mm³ crystals

14x14x160 mm³ crystals

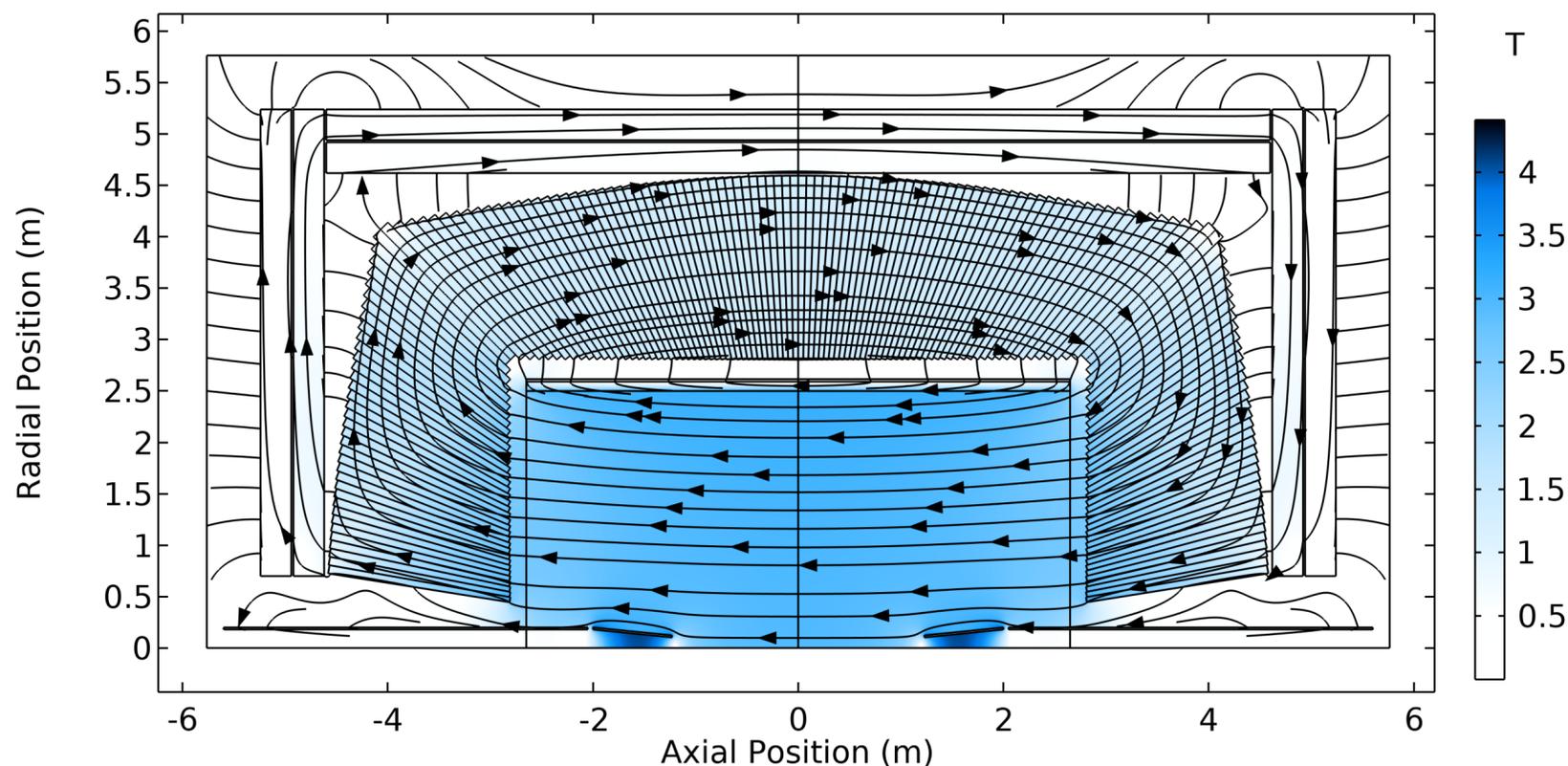
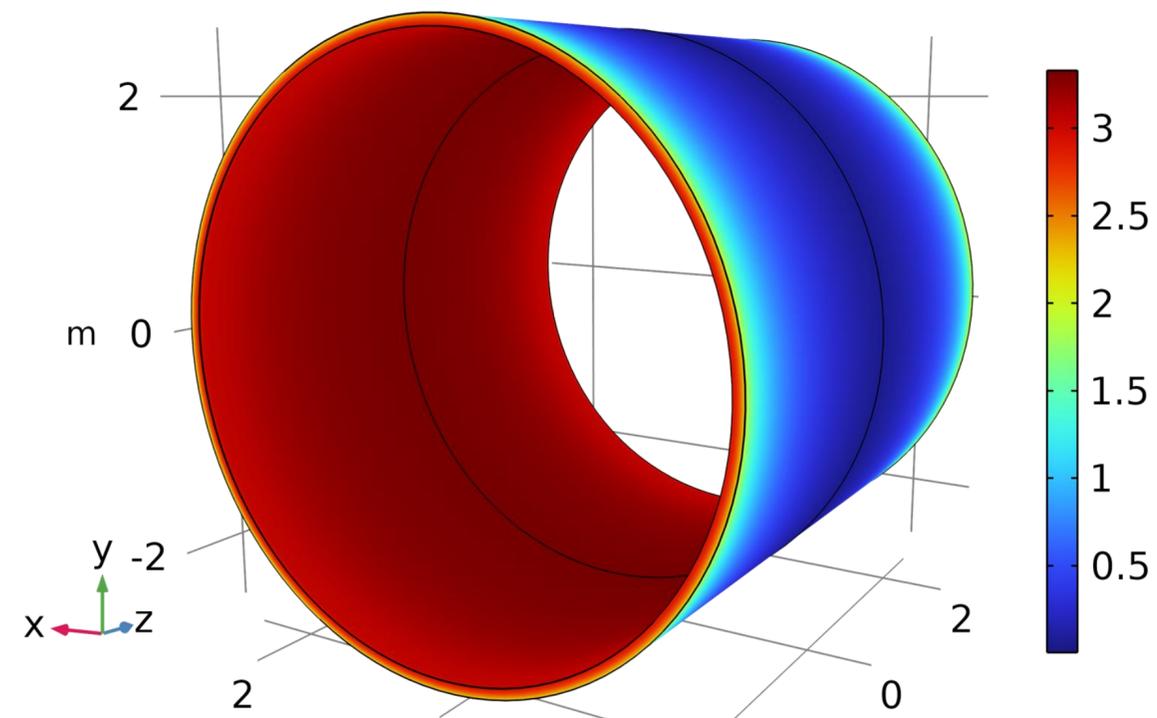
From analytical evaluations:

- $B = 3 \text{ T}$, $R_i = 2.5 \text{ m}$ e $L = 6 \text{ m} \rightarrow$ **18.65 MA-turns**

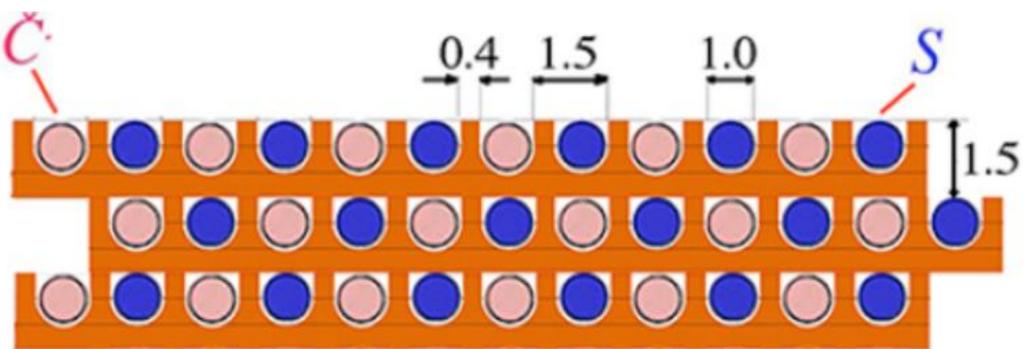
Peak field on the conductor equal to **3.37 T**

2D Rotational Symmetry Simulation in COMSOL

- Internal radius increased to allow for EM Calorimeter
- Coil thickness limited stress on conductor (100 MPa)
- Dual readout ferromagnetic HCal **implemented in the computation model!**

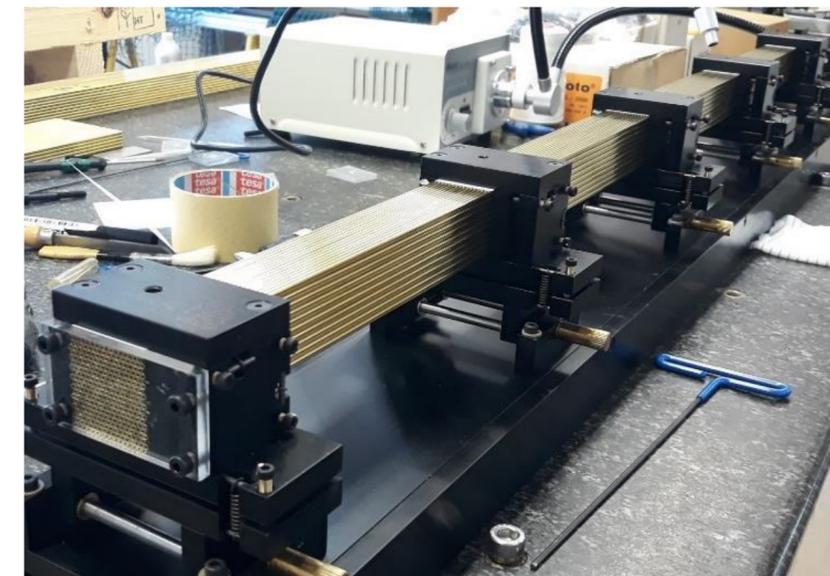


Parameter	Value
Bore Field	3 [T]
	8068 [A]
Coil Thickness	91.7 [mm]
Turns	1760 (220x8)
Inductance	12.4 [H]
Stored Energy	402 [MJ] 19.41 [kJ/kg]
Operating Temperature	20 [K]



Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



- ❖ Measure simultaneously:
 - Scintillation signal (S)
 - Cherenkov signal (Q)
- ❖ Calibrate both signals with e^-
- ❖ Unfold event by event f_{em} to obtain corrected energy

Newer DR calorimeter
(bucatini calorimeter)

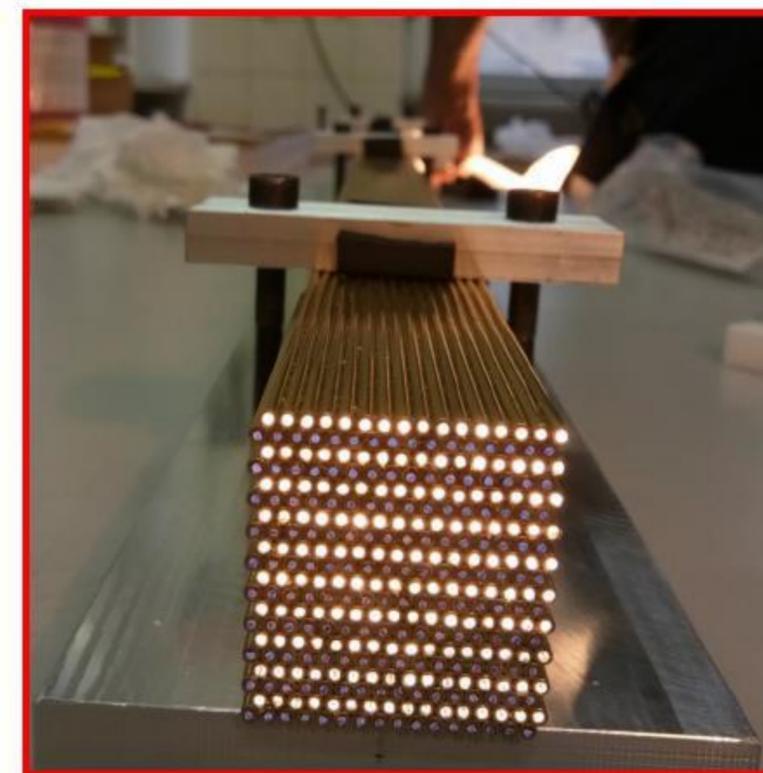
$$S = E[f_{em} + (h/e)_s(1 - f_{em})]$$

$$C = E[f_{em} + (h/e)_c(1 - f_{em})]$$

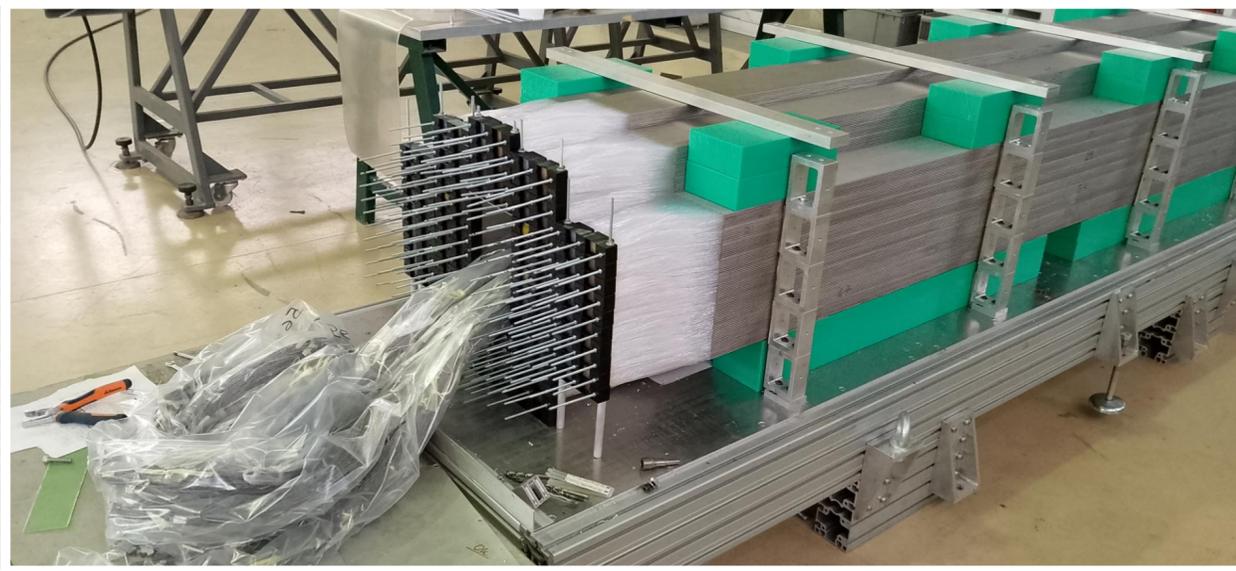
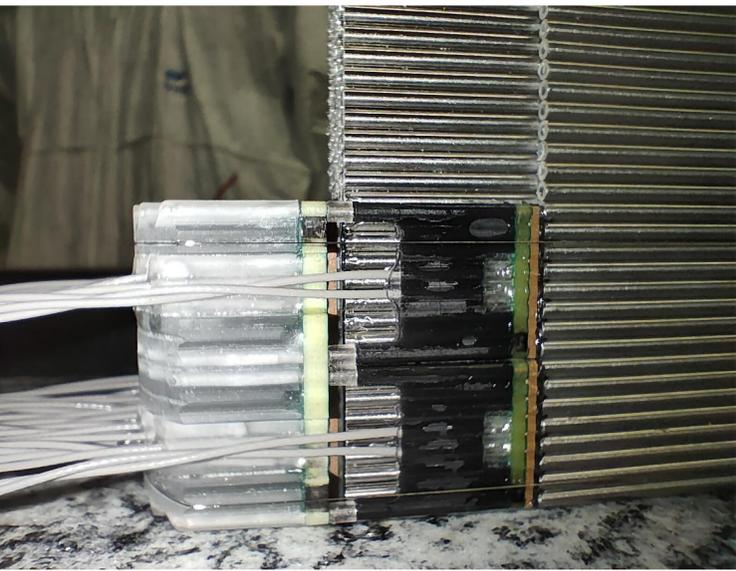
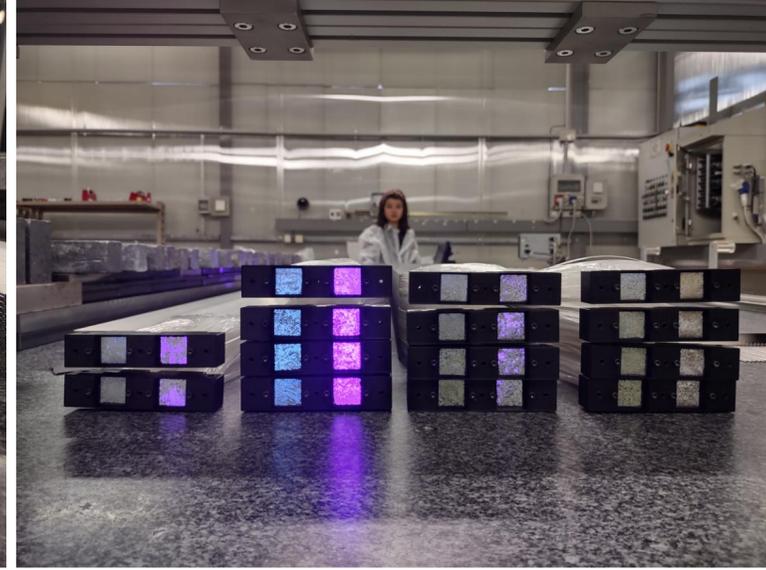
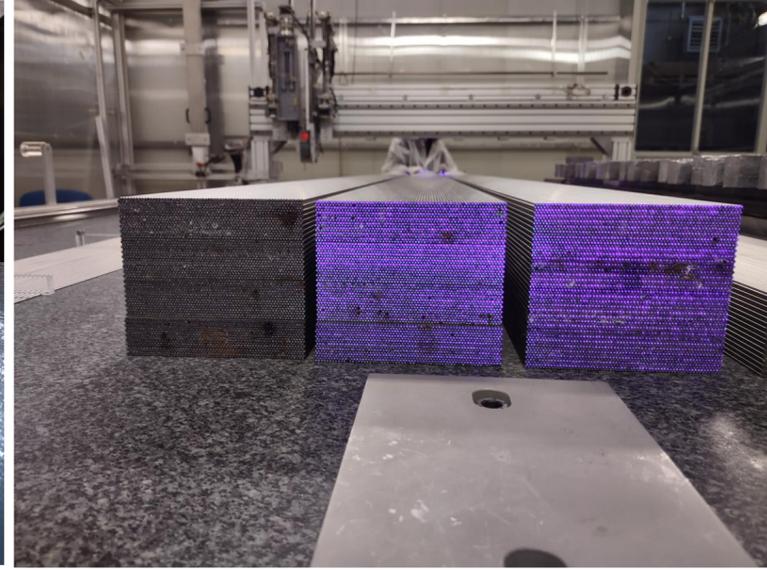
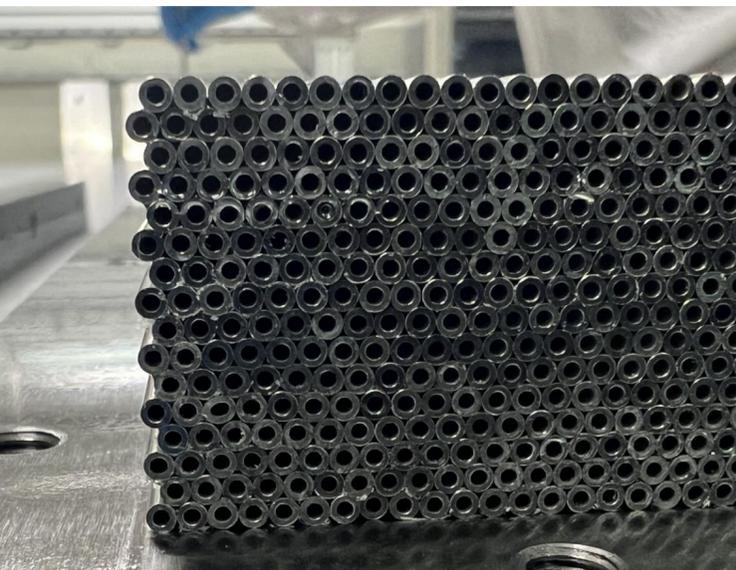
$$E = \frac{S - \chi C}{1 - \chi} \quad \text{with: } \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}$$



Scintillation fibers

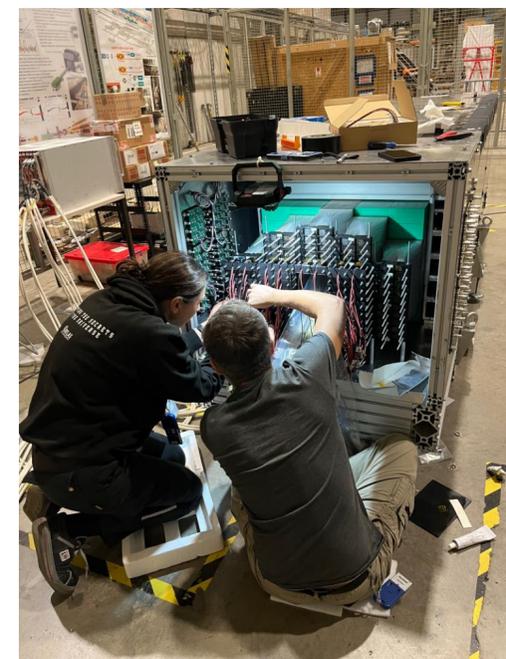
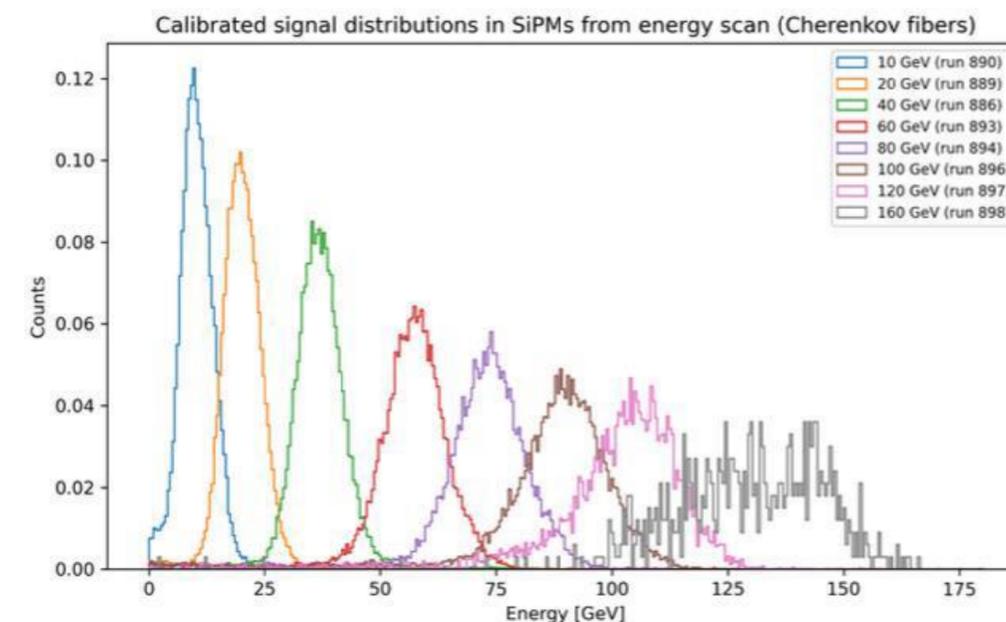
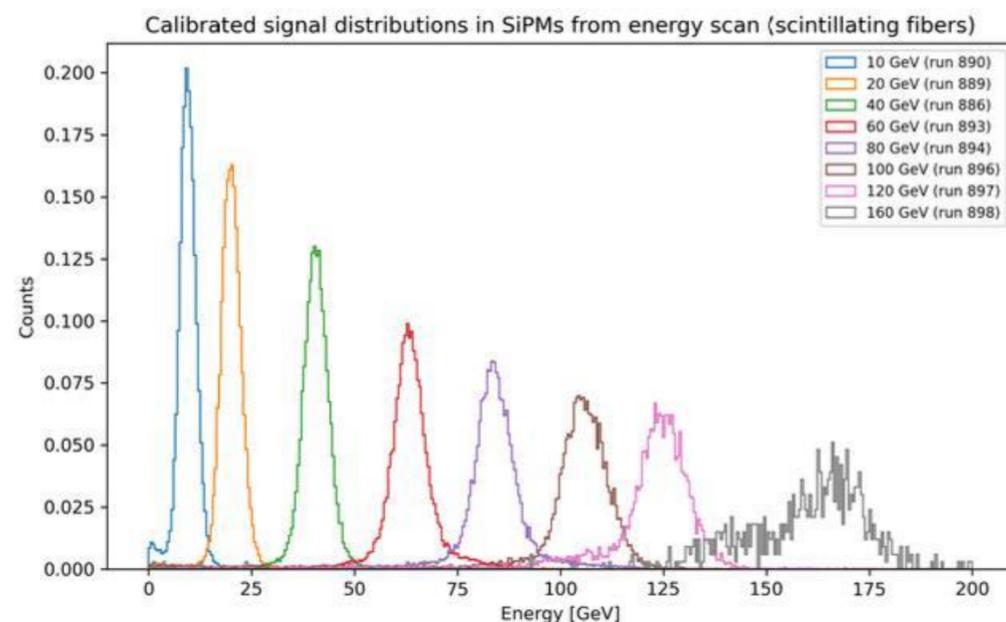
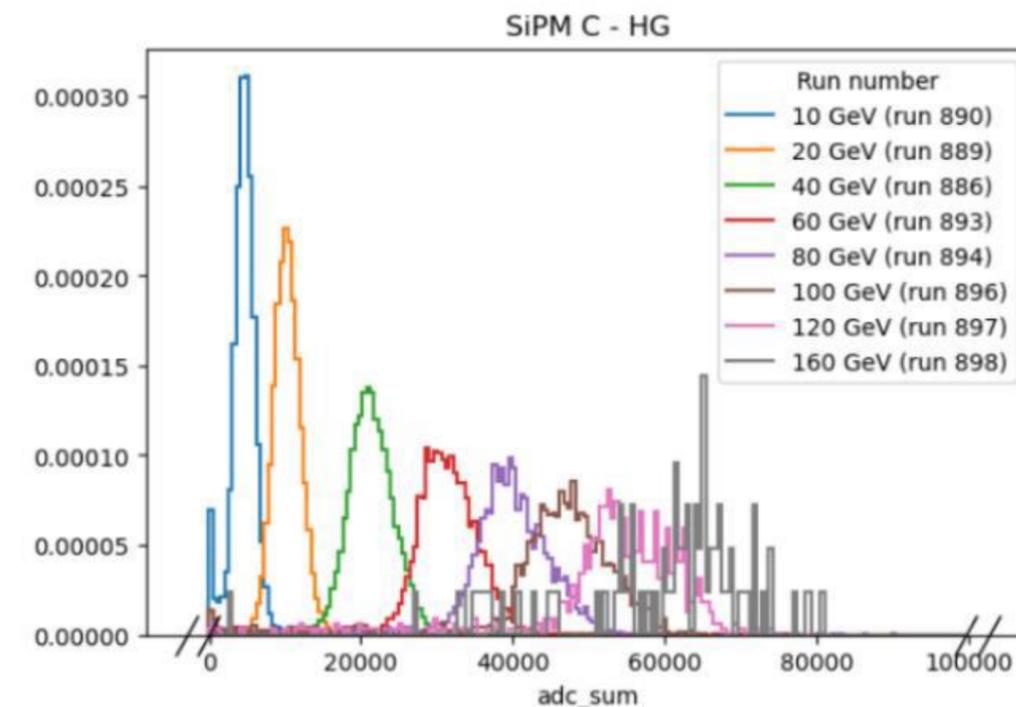
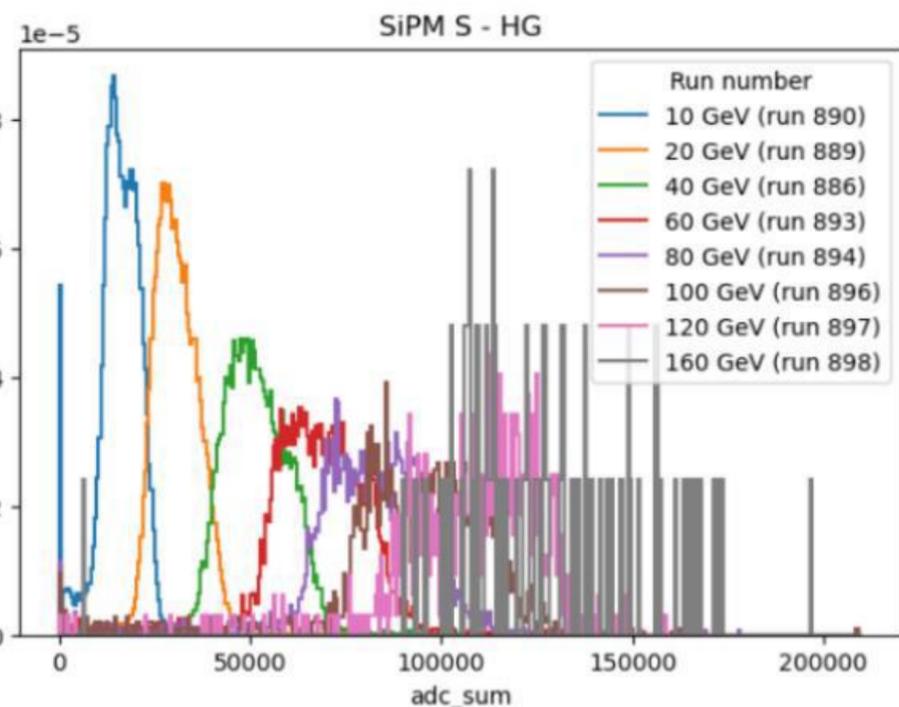


Cherenkov fibers



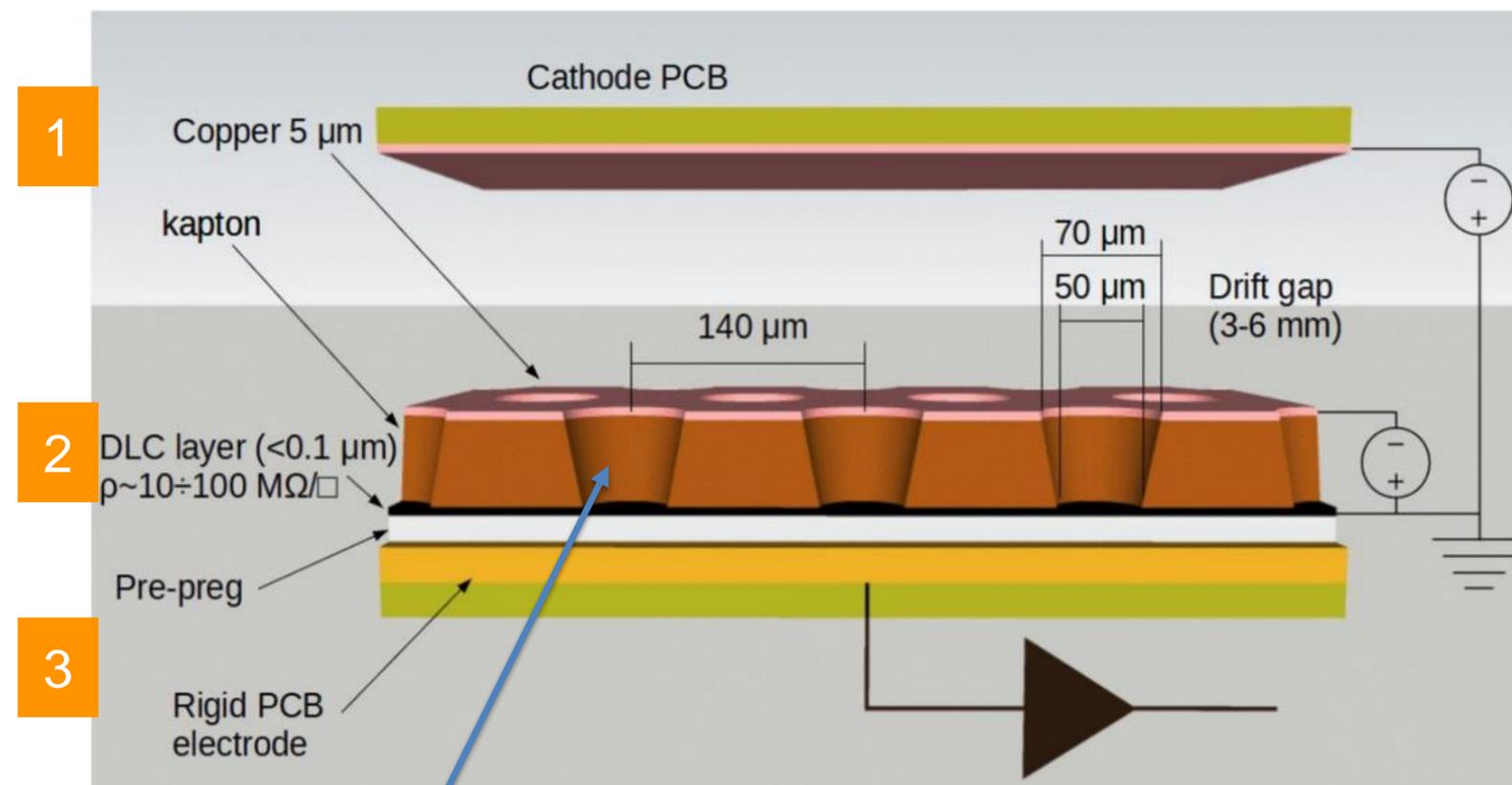
Electron test beam with energies varying from 10 to 160 GeV.

Analysis still ongoing, linearity and resolution plots will come soon

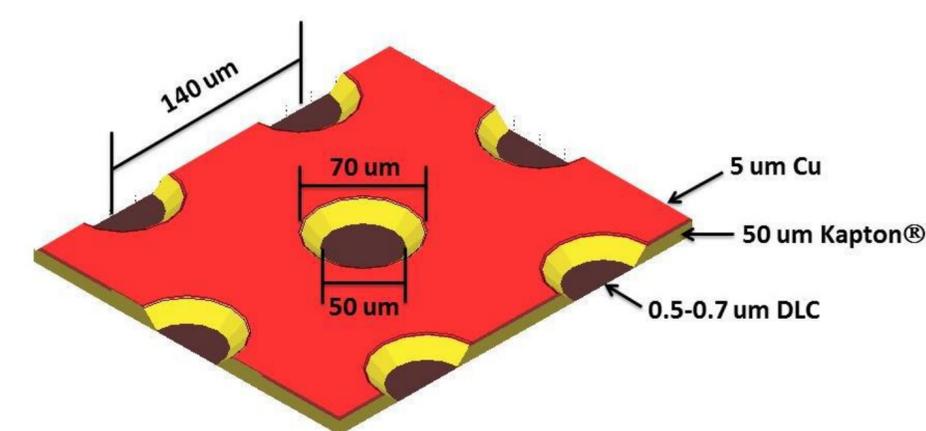
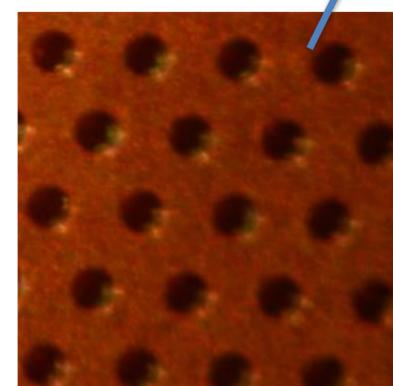


The μ -RWELL is a MPGD composed of two elements: the μ -RWELL PCB and the cathode. The core is the μ -RWELL PCB realised by coupling three elements:

- 1 a **WELL** patterned kapton foil acting as **amplification stage** (GEM-like)
- 2 a **resistive DLC layer**^(*) (Diamond Like Carbon) for discharge suppression w/surface resistivity $\sim 50 \div 100 \text{ M}\Omega/\square$
- 3 a standard readout PCB

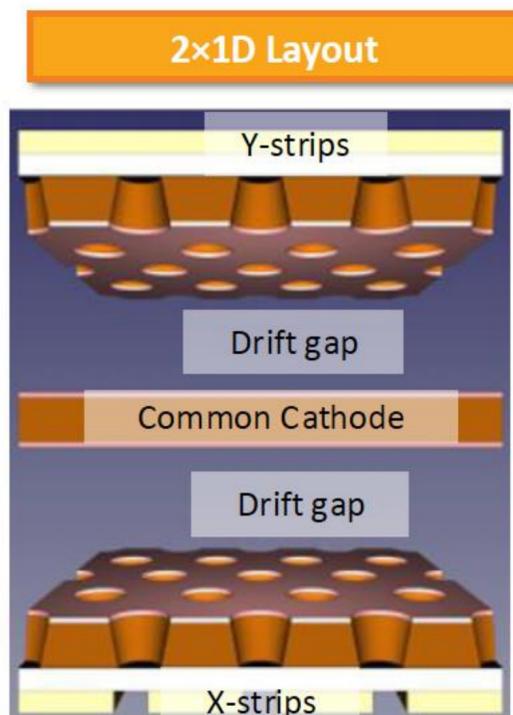


For the IDEA muon detector use a very modular assembly with a large array of $50 \times 50 \text{ cm}^2$ 2D μ -RWELL detectors (tiles)

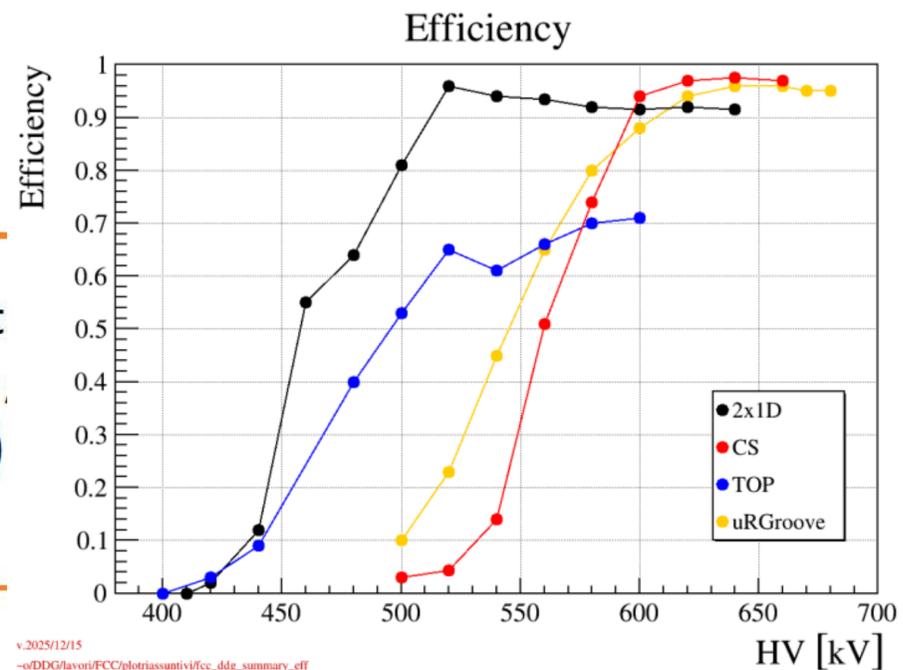


(*) G. Bencivenni et al., "The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD", 2015_JINST_10_P02008)

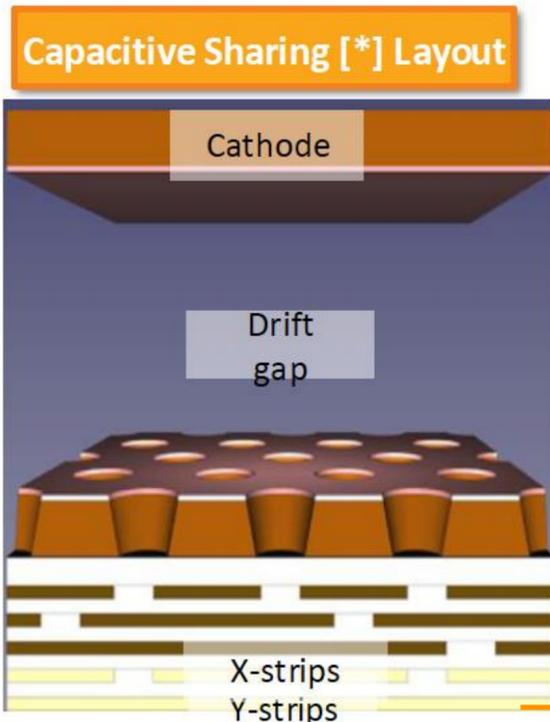
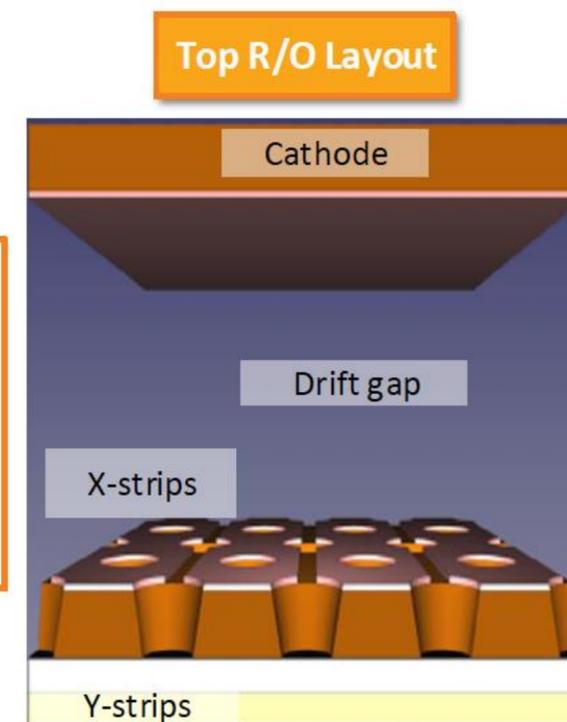
[20] R. Farinelli et al 2025 JINST 20 C06064



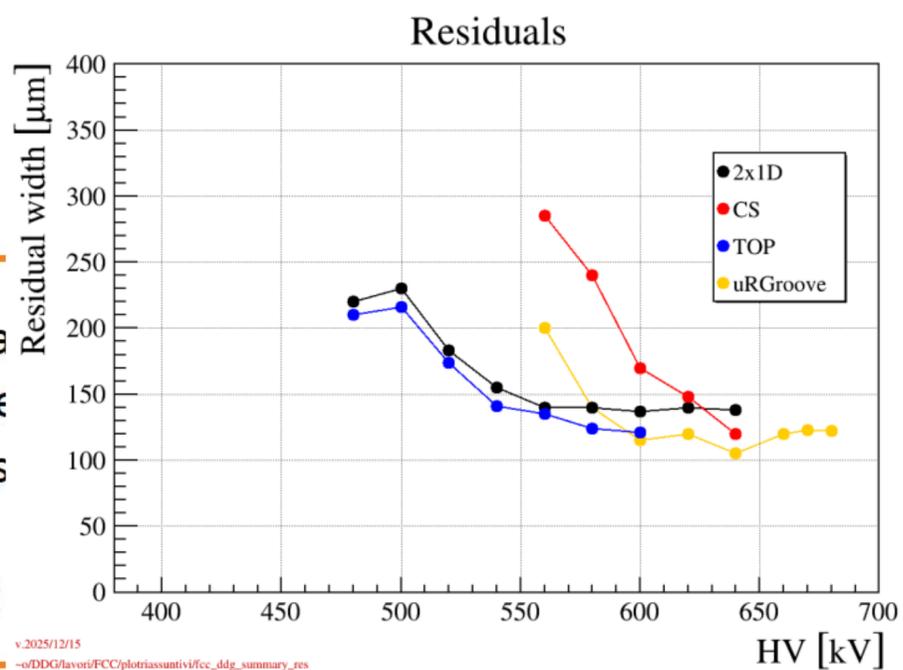
Lower gas gain w.r.t "COMPASS R/O" (X sharing any charge)
Pitch strip: 0.8 mm



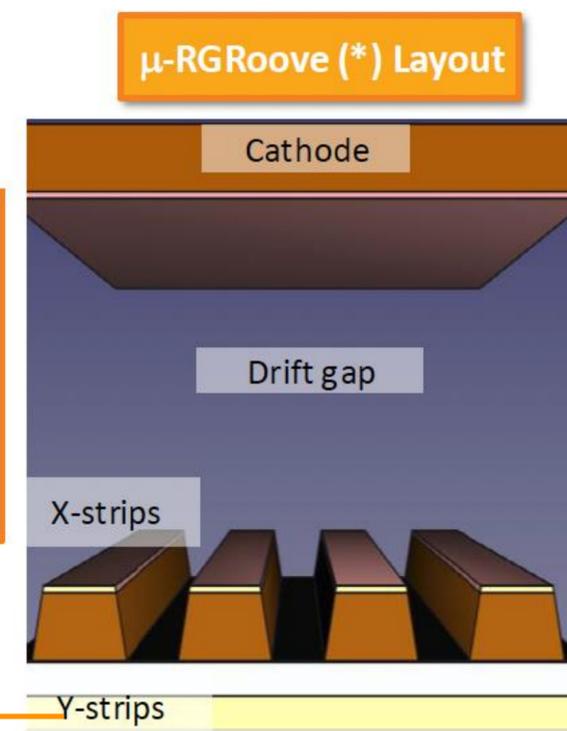
The "COMPASS (sharing any charge) introduces dead area



Reduce the FEE charge
The charge is divided and Y → Higher gas required w.r.t. 1D
Pitch strip: 1.2 mm



The "COMPASS (sharing any charge) is Top R/O layout



- A Future large Circular Collider provides a fantastic scientific program for particle physics for the next 60-70 years
 - In a first phase, **FCC-ee (CEPC)**, electron-positron collisions will be studied
 - In a second phase, **FCC-hh (SppC)**, proton-proton collisions up to 100 TeV will be available
 - The **IDEA detector concept** will be an excellent choice for an FCC-ee (CEPC) IP
- We are living in **very interesting times**, especially for our young collaborators
- **Lots of possibilities for new International collaborators to join IDEA and contribute to all these developments!!**