Istituto Nazionale di Fisica Nucleare

Status and Progress of the IDEA Detector Concept

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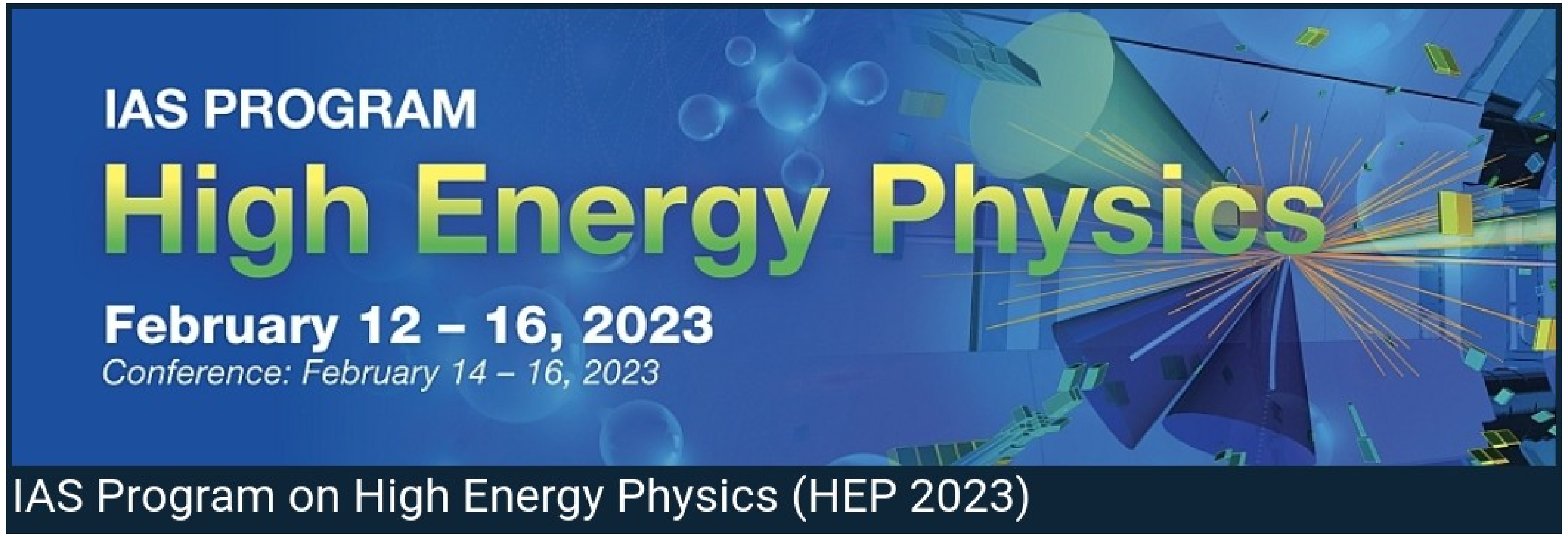
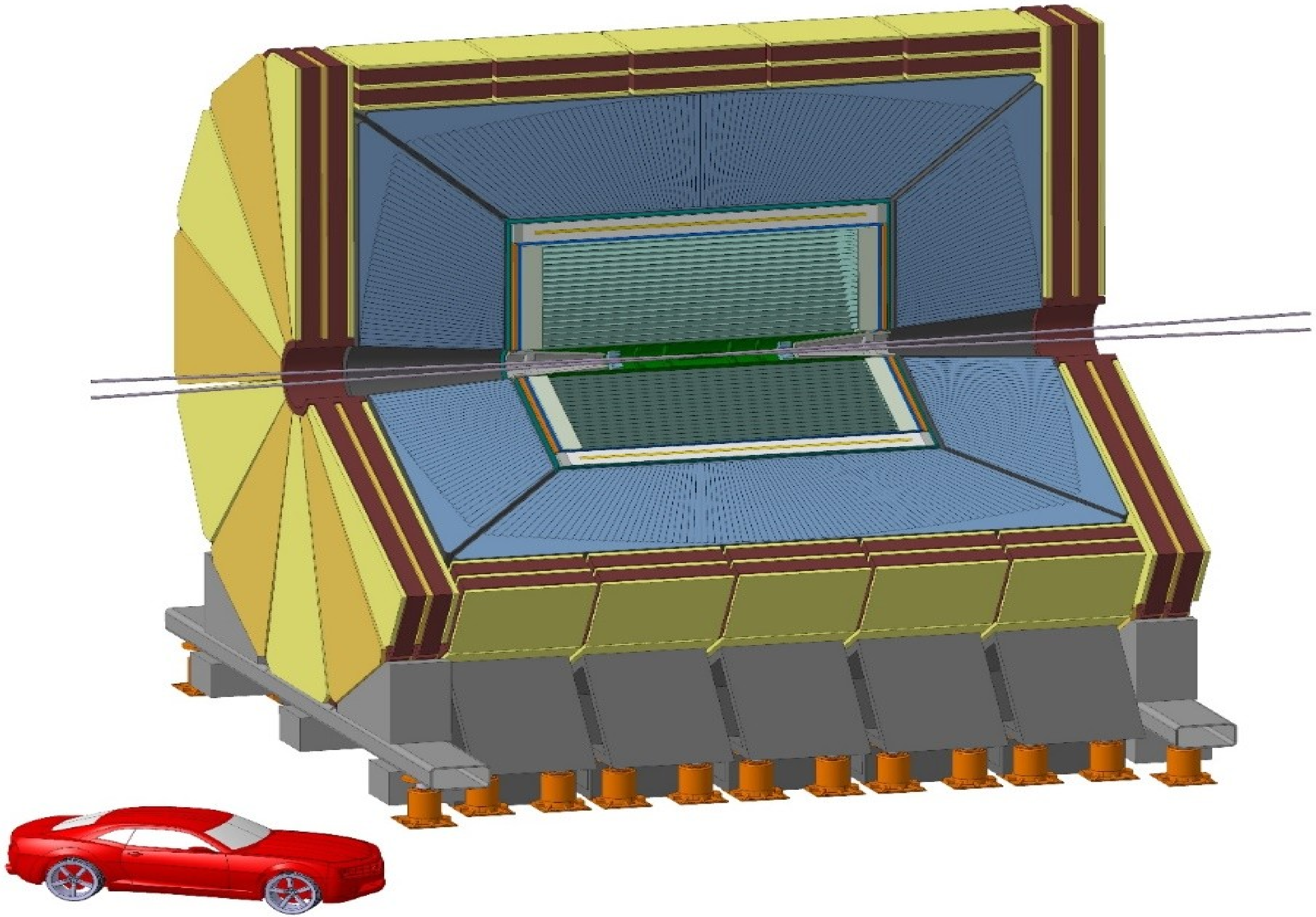
on behalf of the IDEA proto-collaboration

Mini Workshop: Experiment and Detector
Hong Kong 13.02.2023

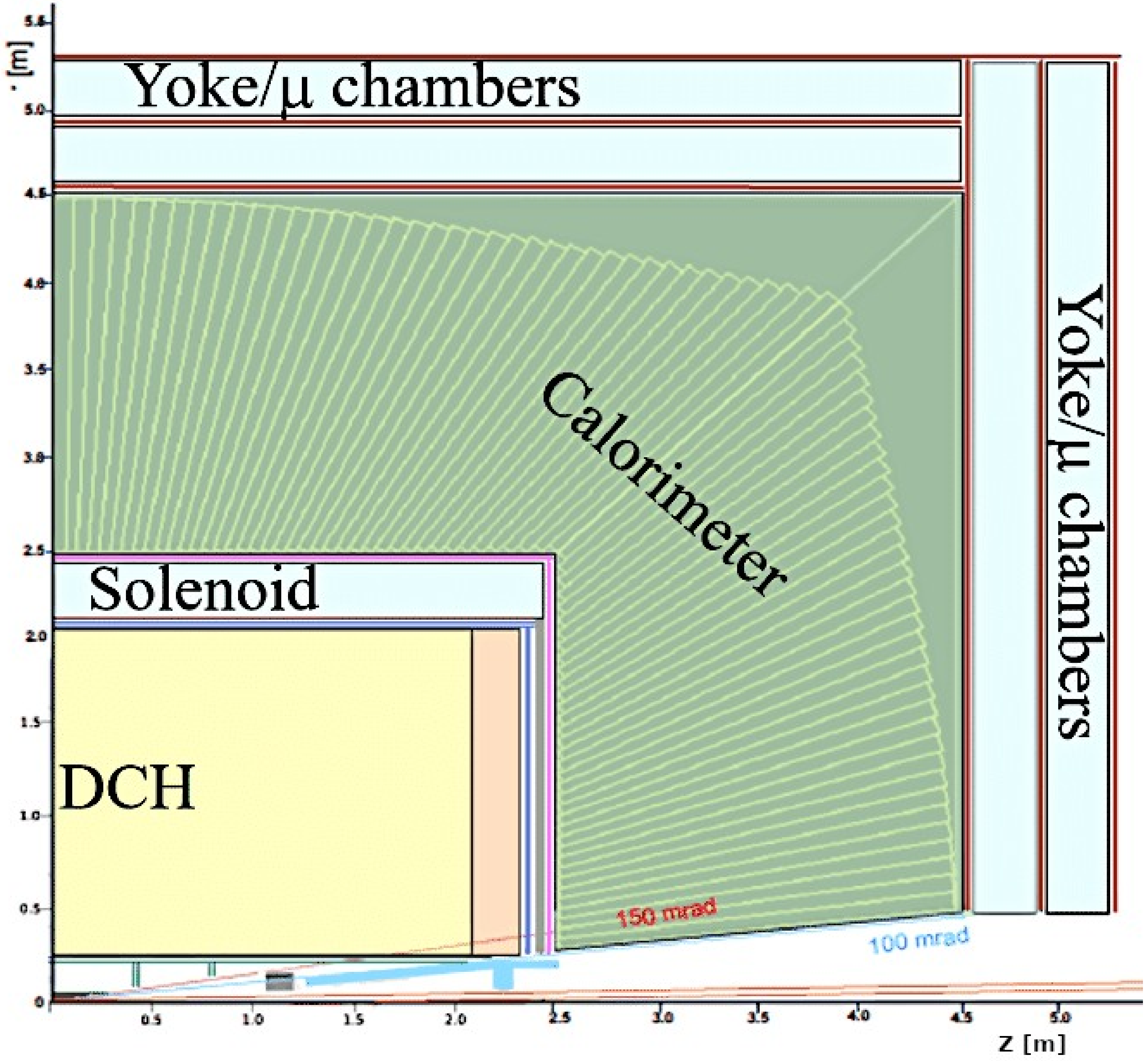


IDEA: Innovative Detector for e+e- Accelerator



IDEA concept

- Muon chambers
  - μ-RWELL in return yoke
- Dual-readout calorimetry 2 m / 7 λ_{int}
  - μ-RWELL preshower
- Thin superconducting solenoid
  - 2 T, 30 cm, ~ 0.7 X_0 , 0.16 λ_{int} @ 90°
- Transparency for tracking
  - Si pixel vertex detector
  - Drift Chamber
  - Si wrappers (strips)
- Beam pipe: r ~ 1.5 cm



FCC-ee / CepC general requirements

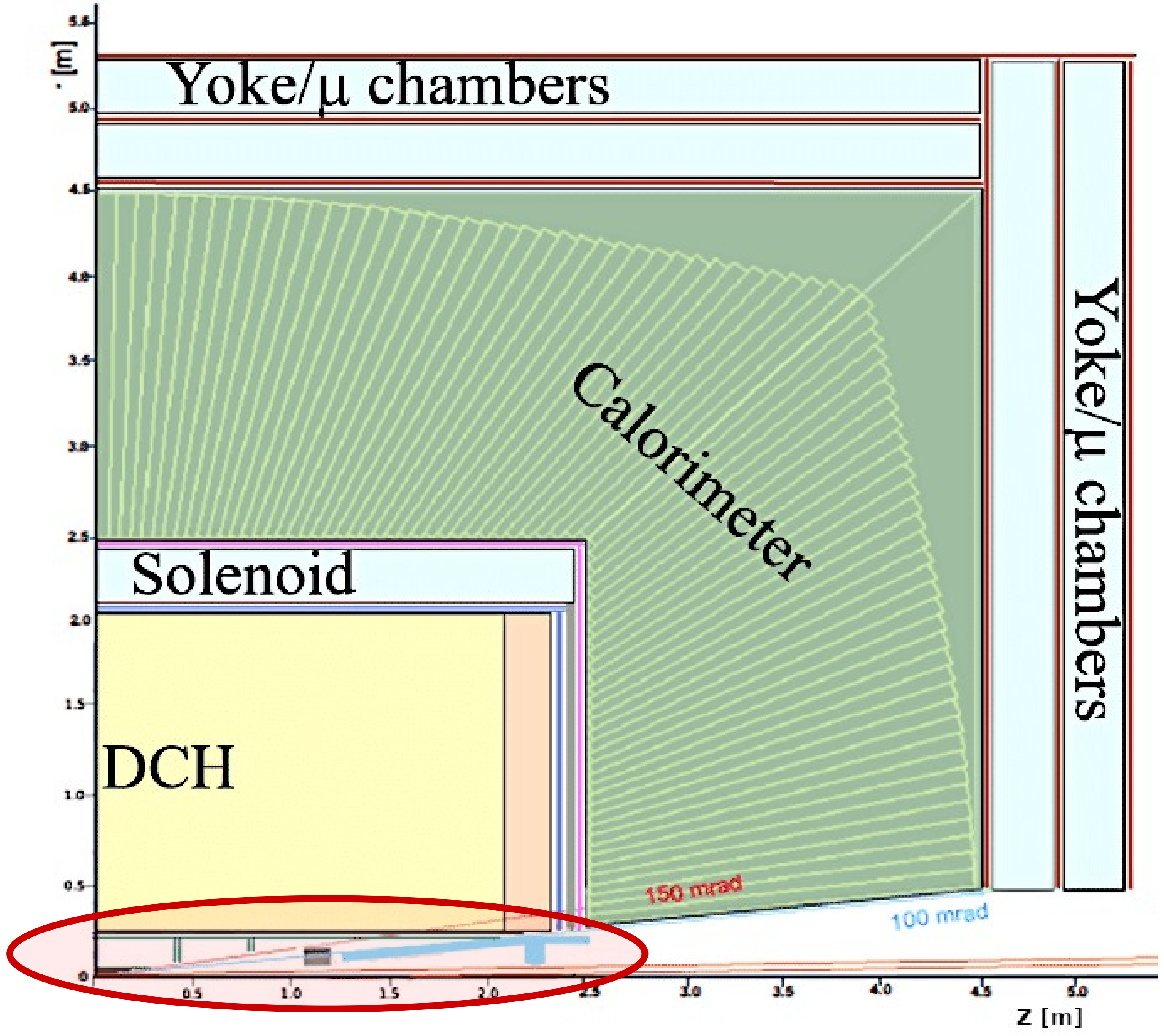
- $\Delta(1/p_T)$
  - high precision measurement at end of tracker
- $\sigma_{r\Phi}$
  - finely segmented vertex detector
- Challenging requirements for detector materials

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

Vertex detector

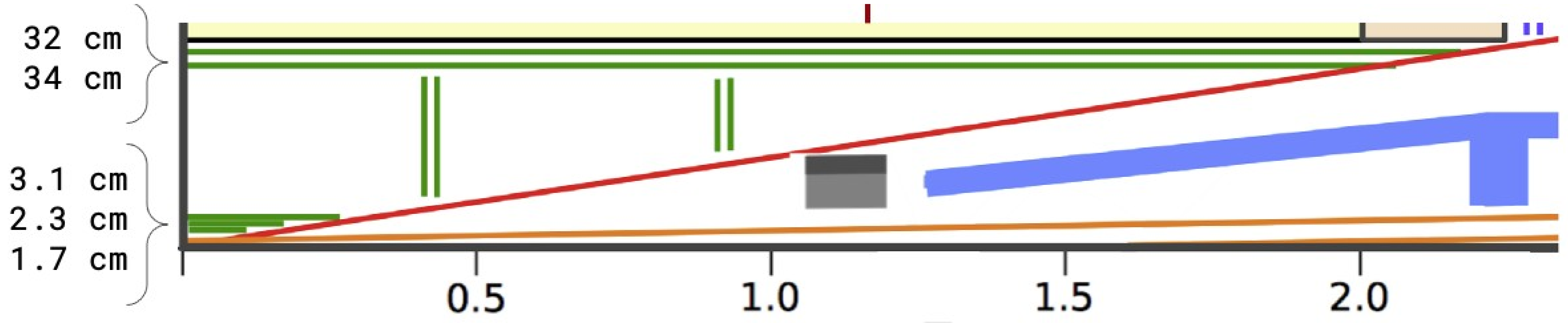
Requirements

- Fast readout
- Low power < 20 mW/cm²
- Low material ~ 0.15 X_0
- Spatial resolution ~ 3 µm
- Efficiency ~100%
- Extremely low fake rate



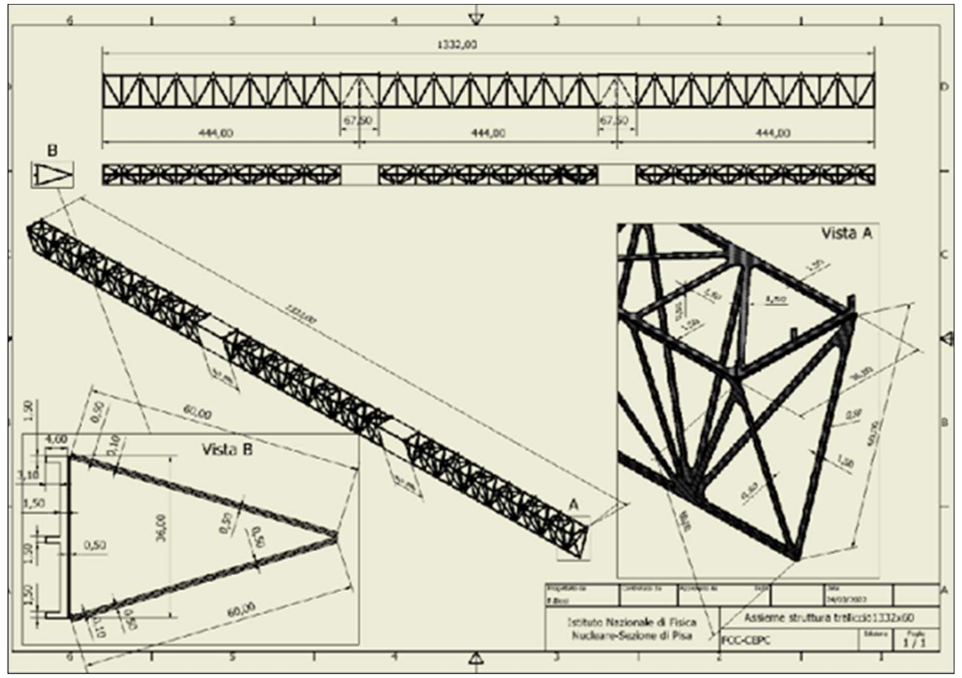
Based on MAPS technology (inspired by ALICE ITS3)

Exploiting progress in ARCADIA R&D program

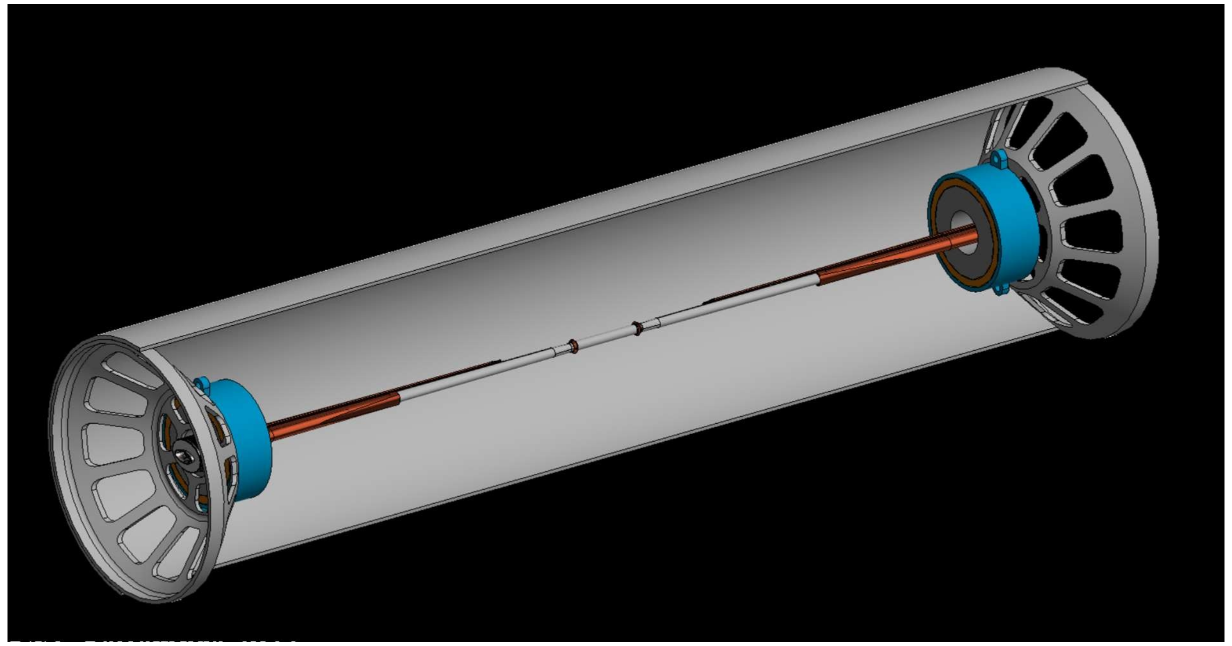


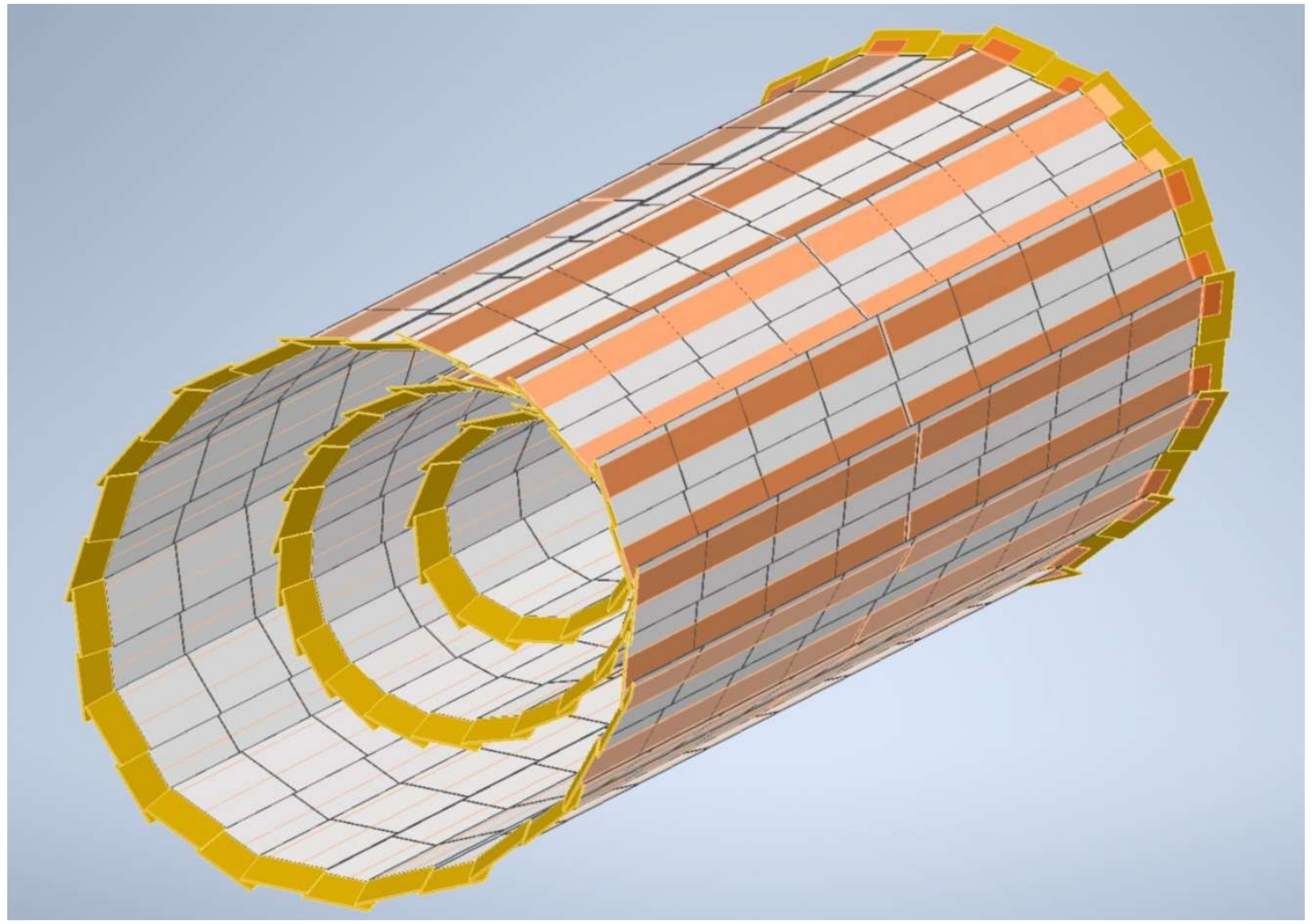
Vertex detector

1) Stave prototype realised with innovative techniques



2) MDI integration: engineered design for pipe and vertex support





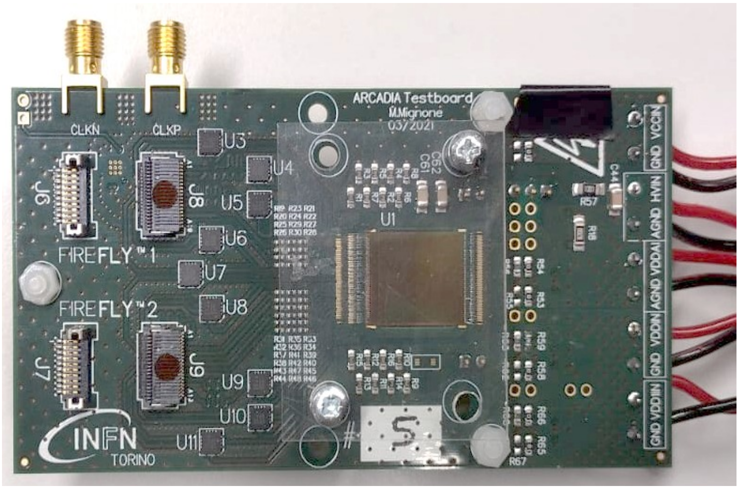
3) Vertex detector design based on ARCADIA

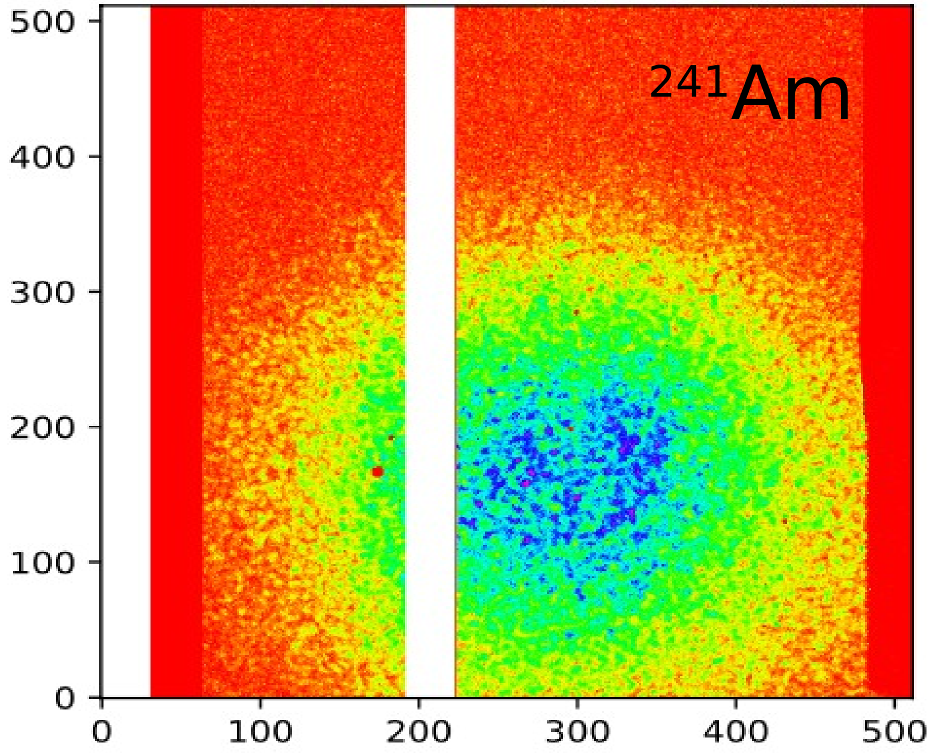
Arcadia project

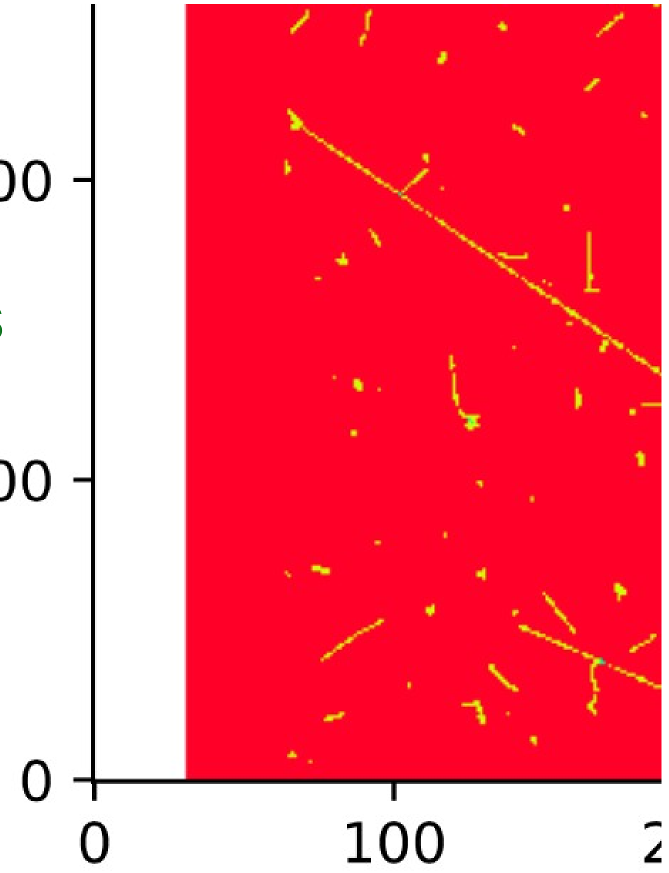
- CMOS DMAPS Platform
  - INFN project, w/ CH and China
  - Part of EU AIDAInnova project

- ARCADIA-MD1: 25×25 μm^2 pixels
  - Tested sensor and back-side processing
  - Readout architecture charact. ongoing
  - 110 nm CMOS CIS technology
  - High-resistivity bulk, operated in full depletion mode
  - Matrix = 512×512 pixels
  - Thickness = 200 μm

- ARCADIA-MD2 submitted in summer 2021
  - design and architecture improvements targeting power reduction and scalability



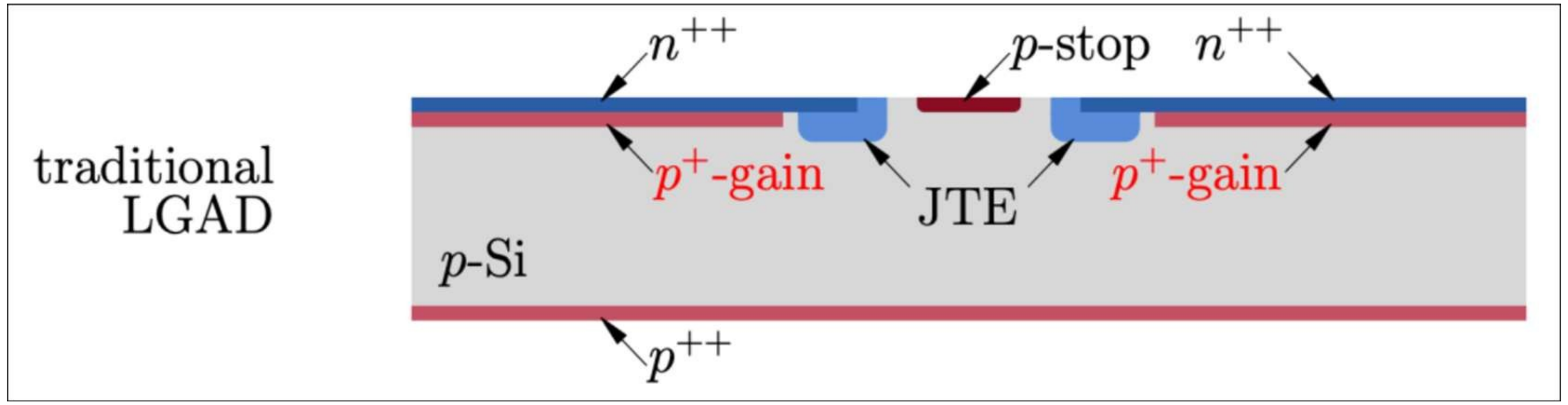


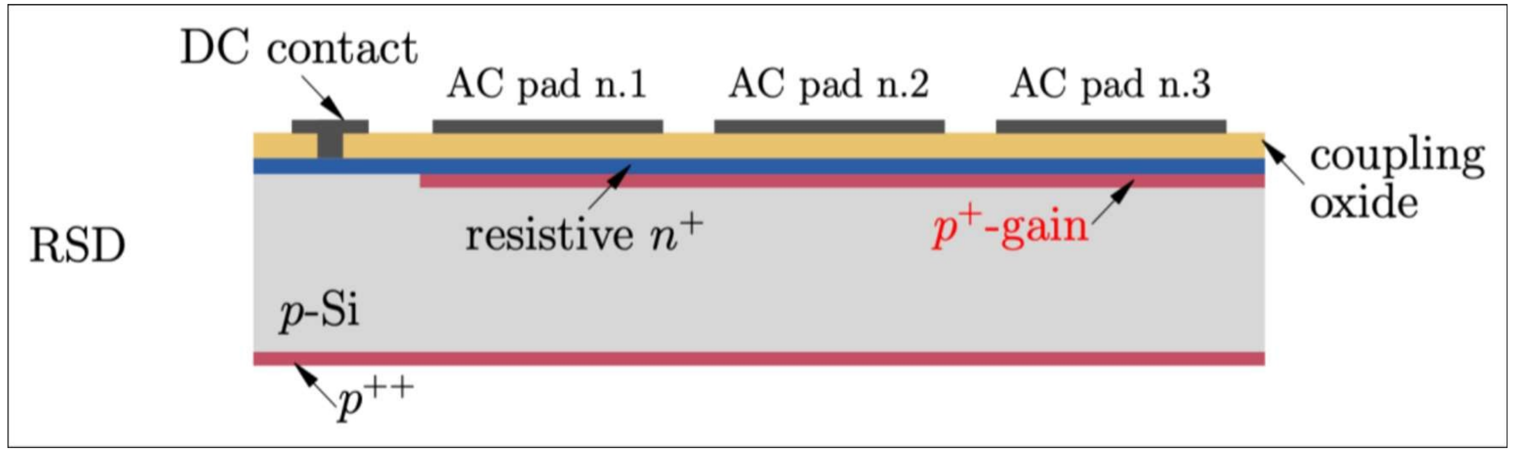


Few cosmic tracks
(tilted sensor)

Vertex detector – LGAD RSD

New activity on LGAD Resistive Silicon Detector: high segmentation, excellent position and time resolution





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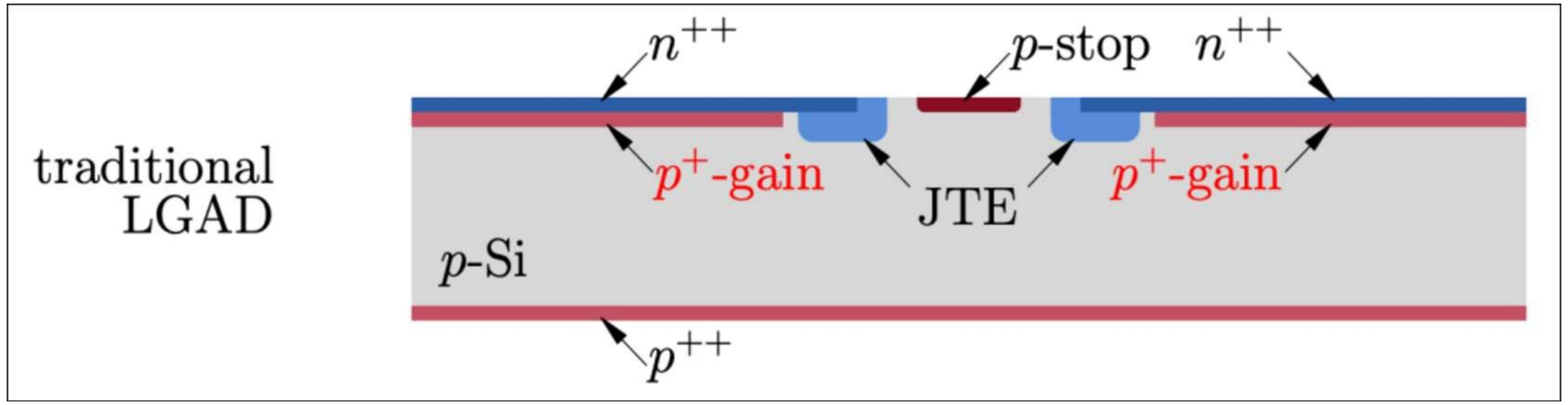
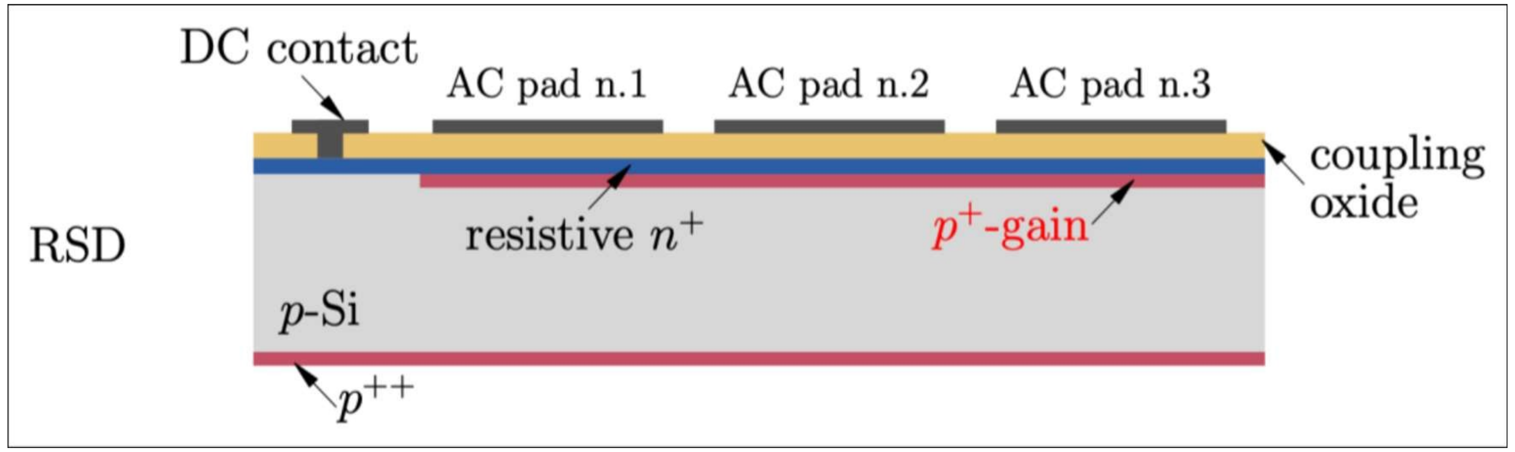
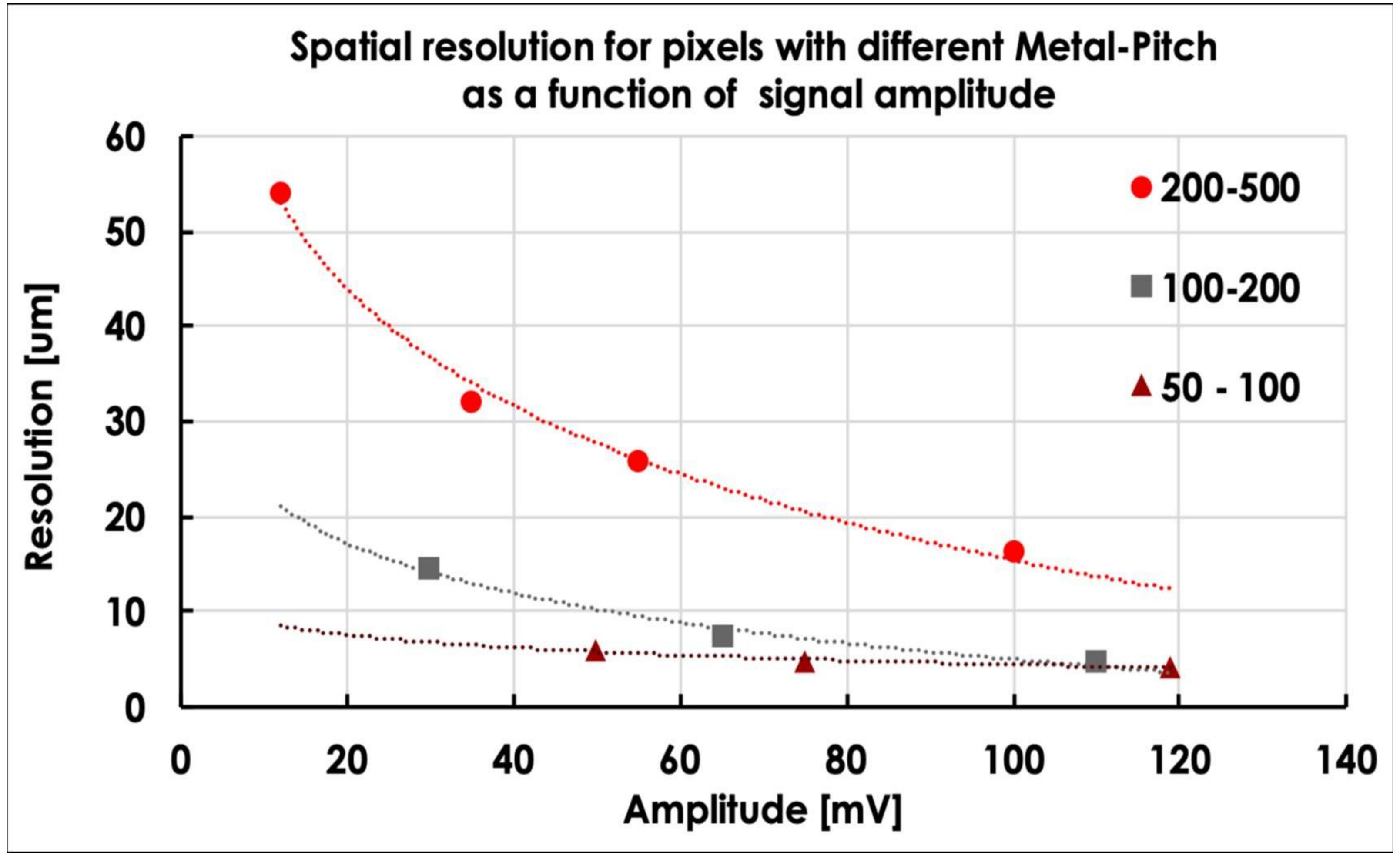
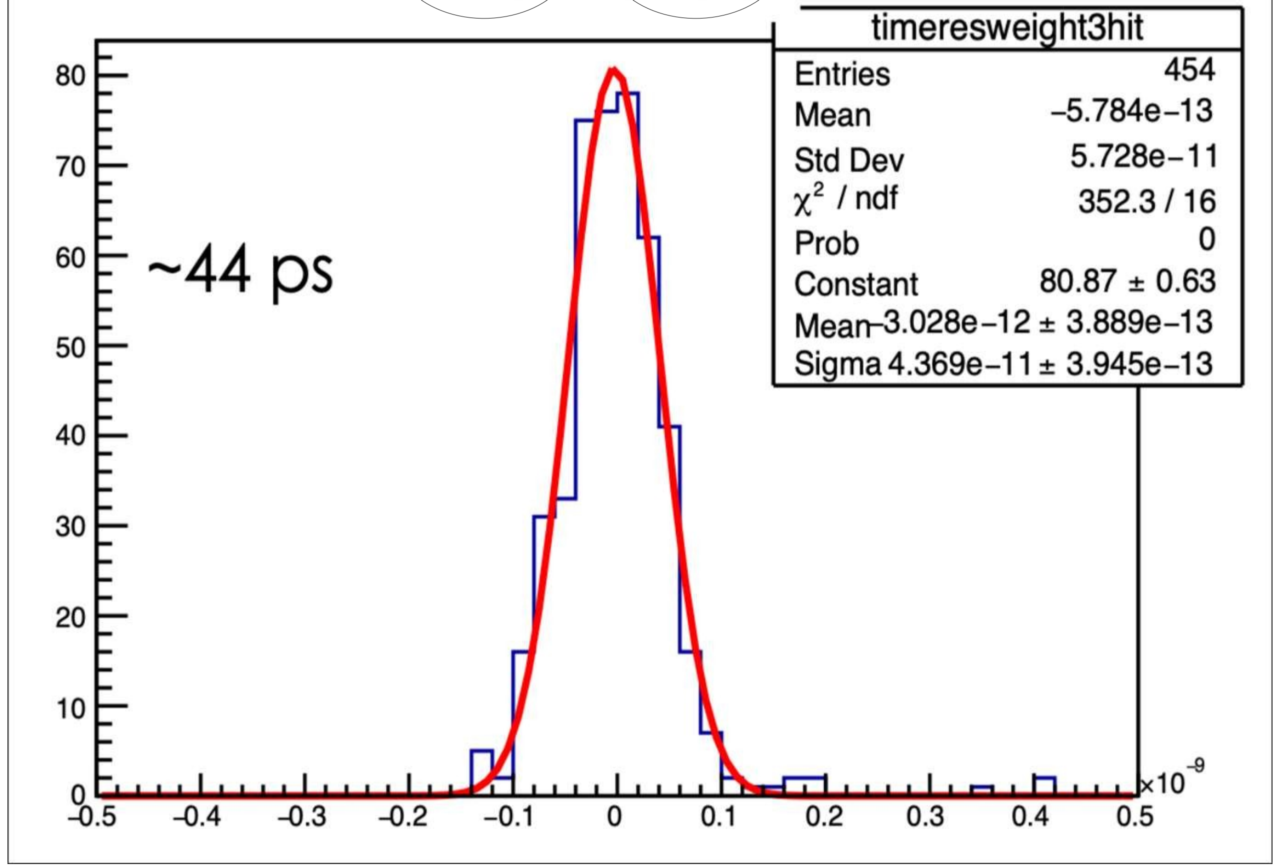






metal pad width → 100 - 200 ← metal pad pitch

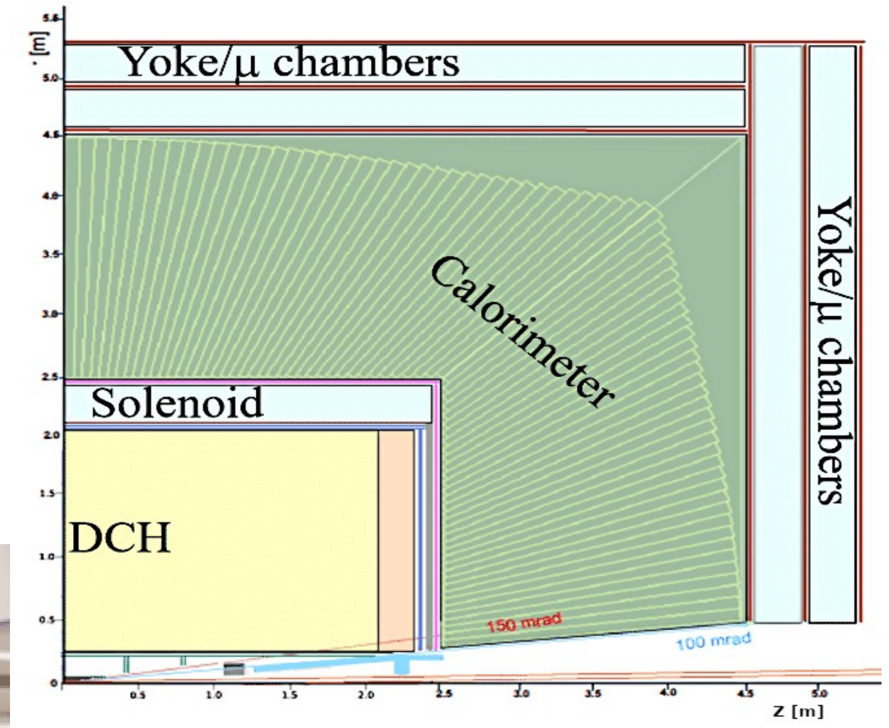


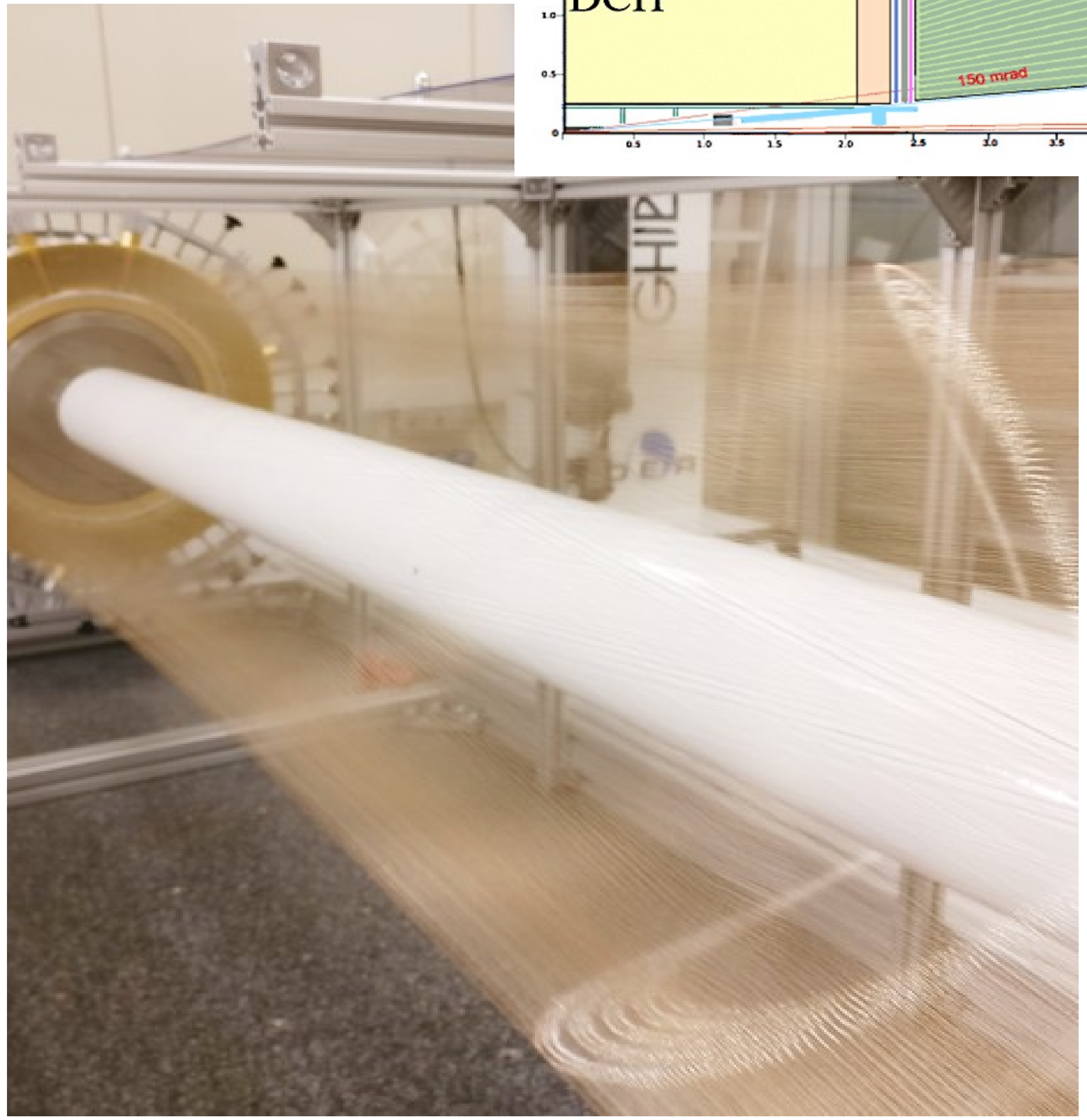
Drift chamber

- Compromise between granularity and transparency
  - High momentum resolution
  - Ultra light detector
  - Assisted by Si wrappers

- Dimensions
  - L = 400 mm
  - R = 35 ÷ 200 cm
  - Total thickness: 1.6% X_0 at 90°
    - Tungsten wires dominant contribution
  - 112 layers for each 15° azimuthal sector

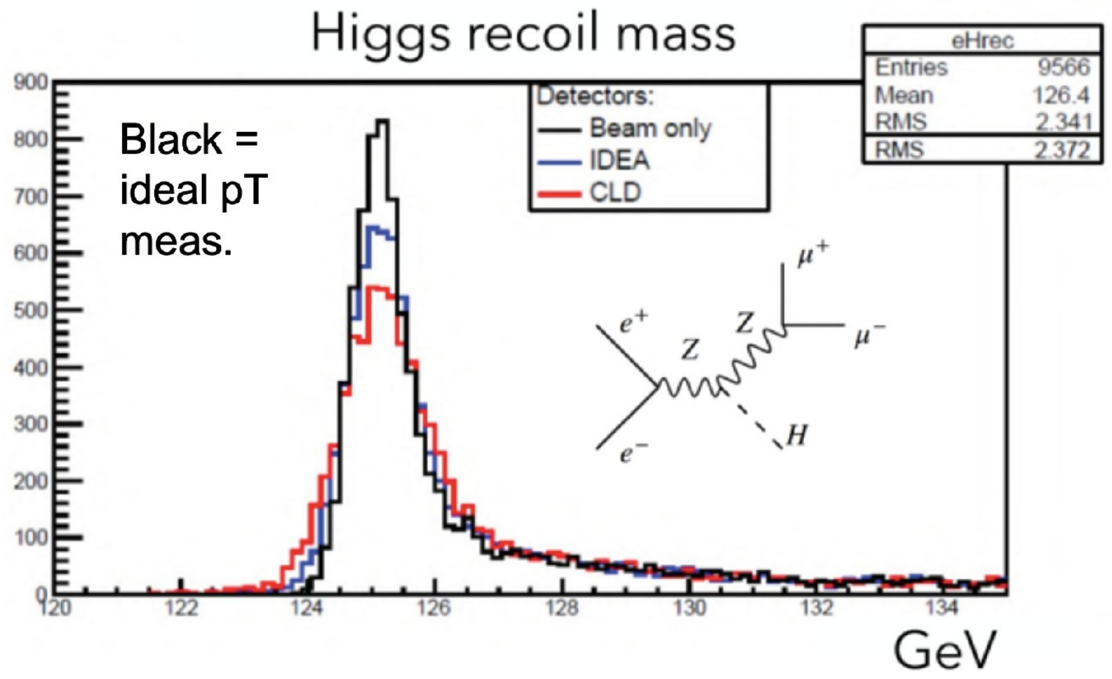
- Inherits from previous DCHs
  - KLOE and MEG II





Drift chamber: Particle ID with cluster counting

- Tracks w/ rather low momenta ($p_T \lesssim 50$ GeV)
  - Transparency more relevant than asymptotic resolution

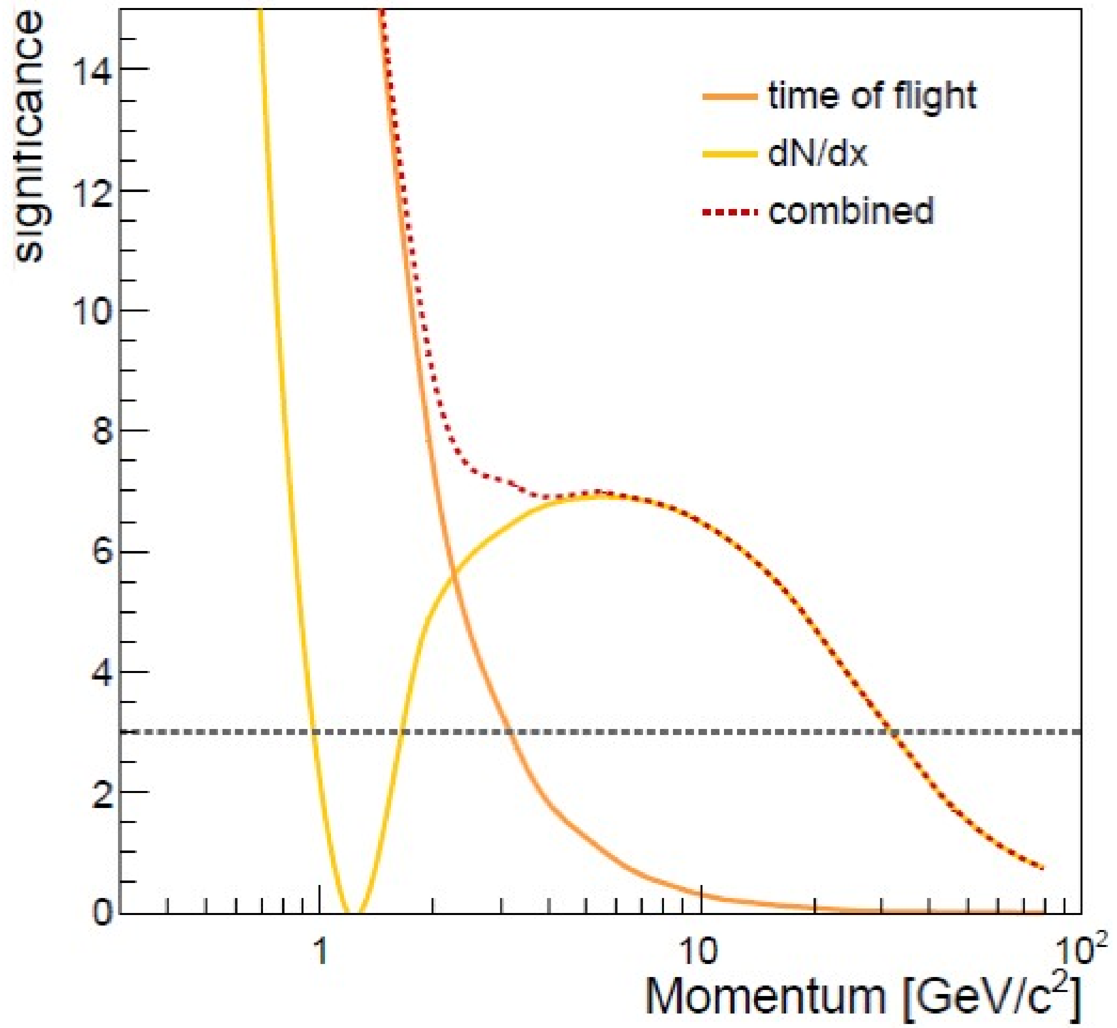


- He based gas mixtures (He / iC_4H_{10} = 90 / 10)
  - ionisation signals last few ns
  - max drift time: 350 ns

- Fast readout (~GHz sampling)

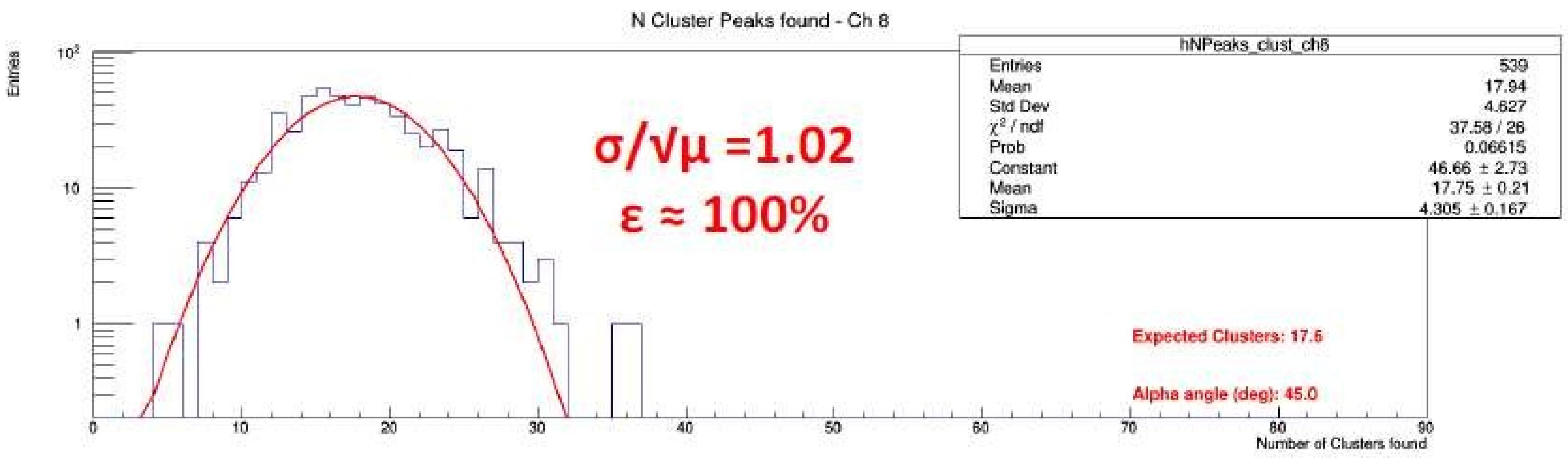
- PID by counting dN_{cl}/dx
  - # of ionisation acts per unit length
  - better PID resolution than dE/dx

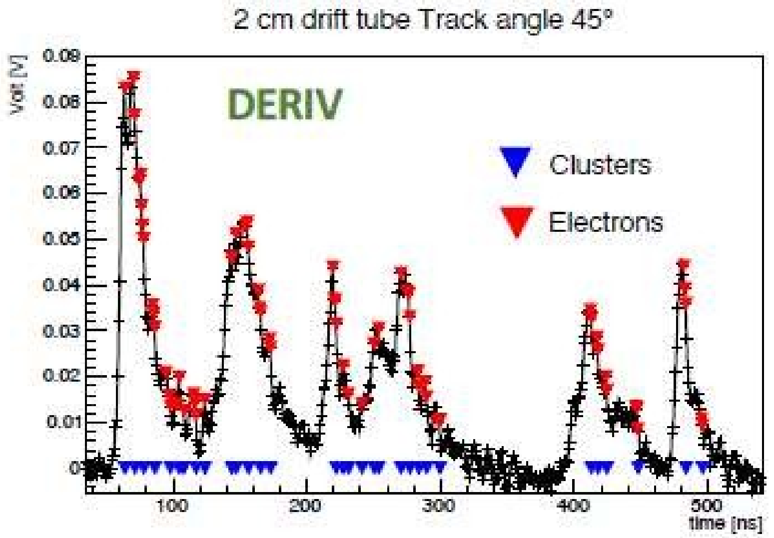
- 0.75 < p < 1.05 gap recoverable with timing layer
  - 100 ps sufficient for 3σ K/p

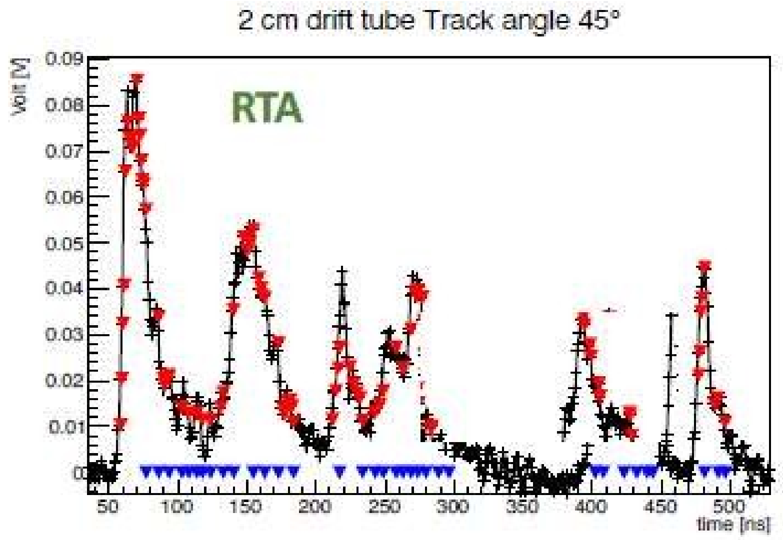


Drift chamber: results on cluster counting

- Successful beam test in July 2022
  - cluster counting works → analysis ongoing
  - collaboration with Chinese groups on algorithm development

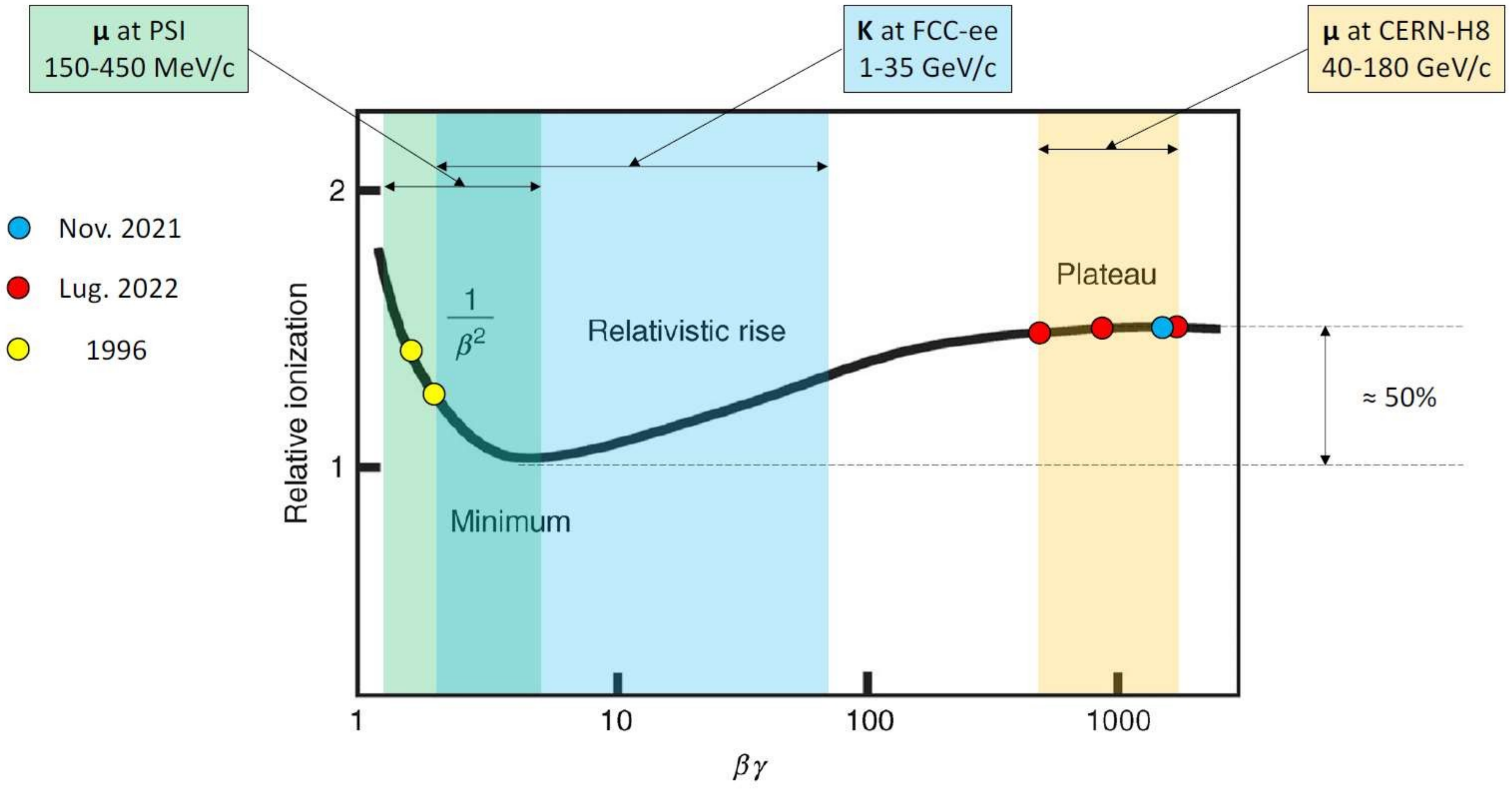


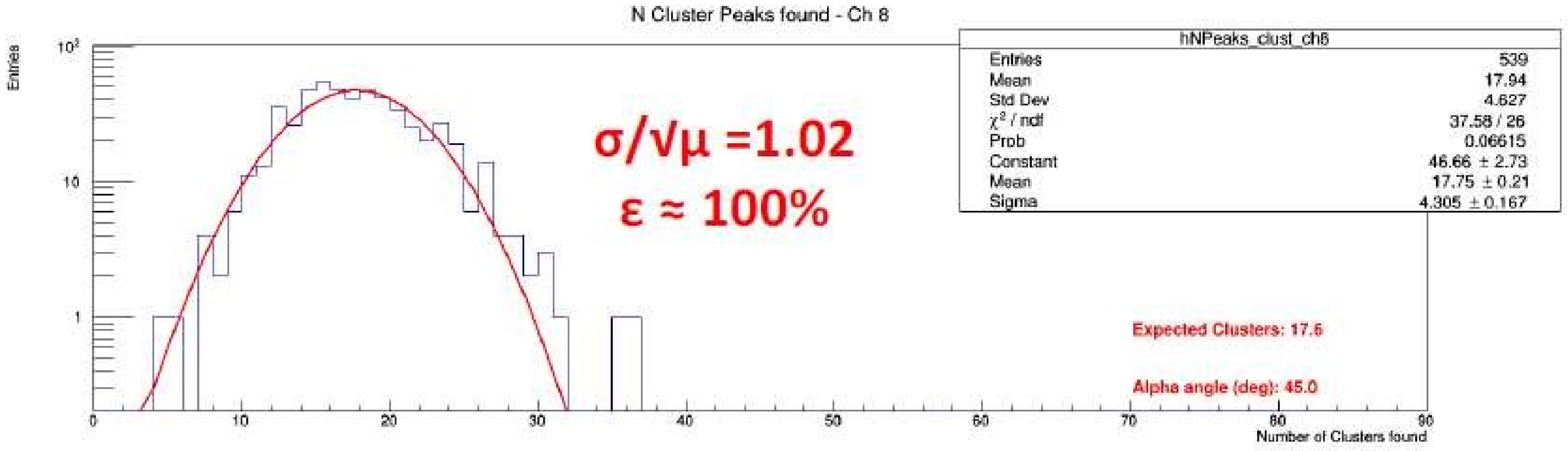


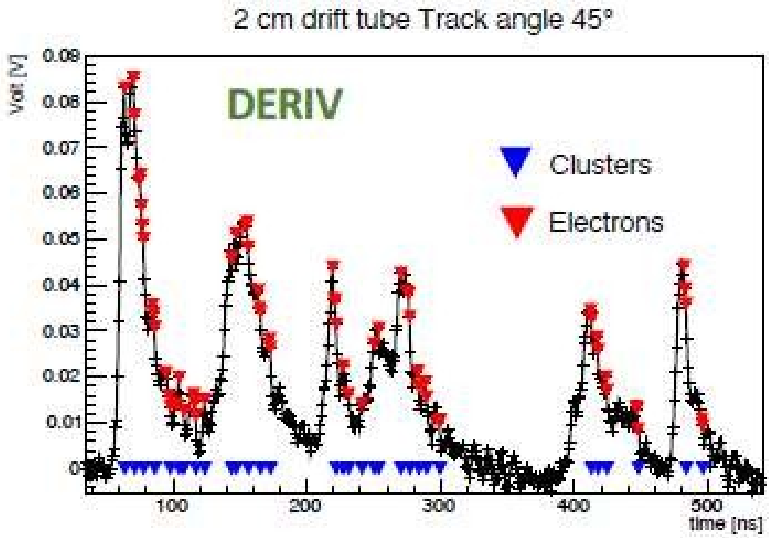


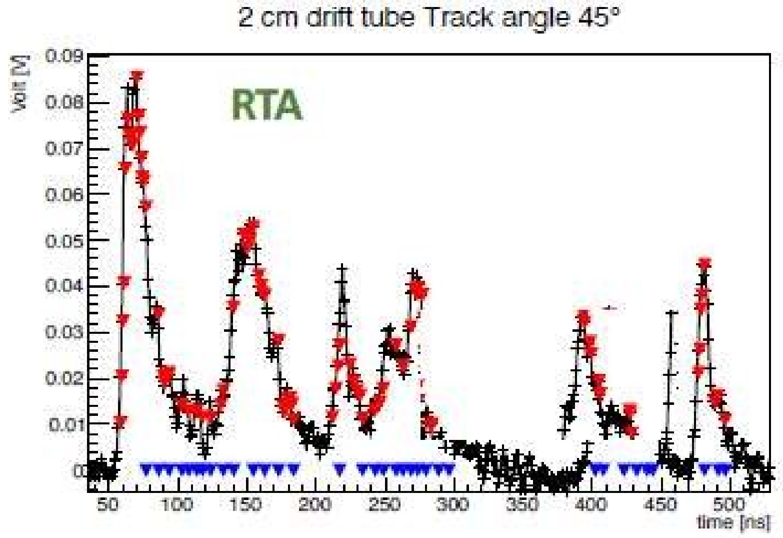
Drift chamber: results on cluster counting

- ✦ Successful beam test in July 2022
  - ✦ cluster counting works → analysis ongoing
  - ✦ collaboration with Chinese groups on algorithm development
- ✦ Searching best place for addressing in 2023 relativistic rise region





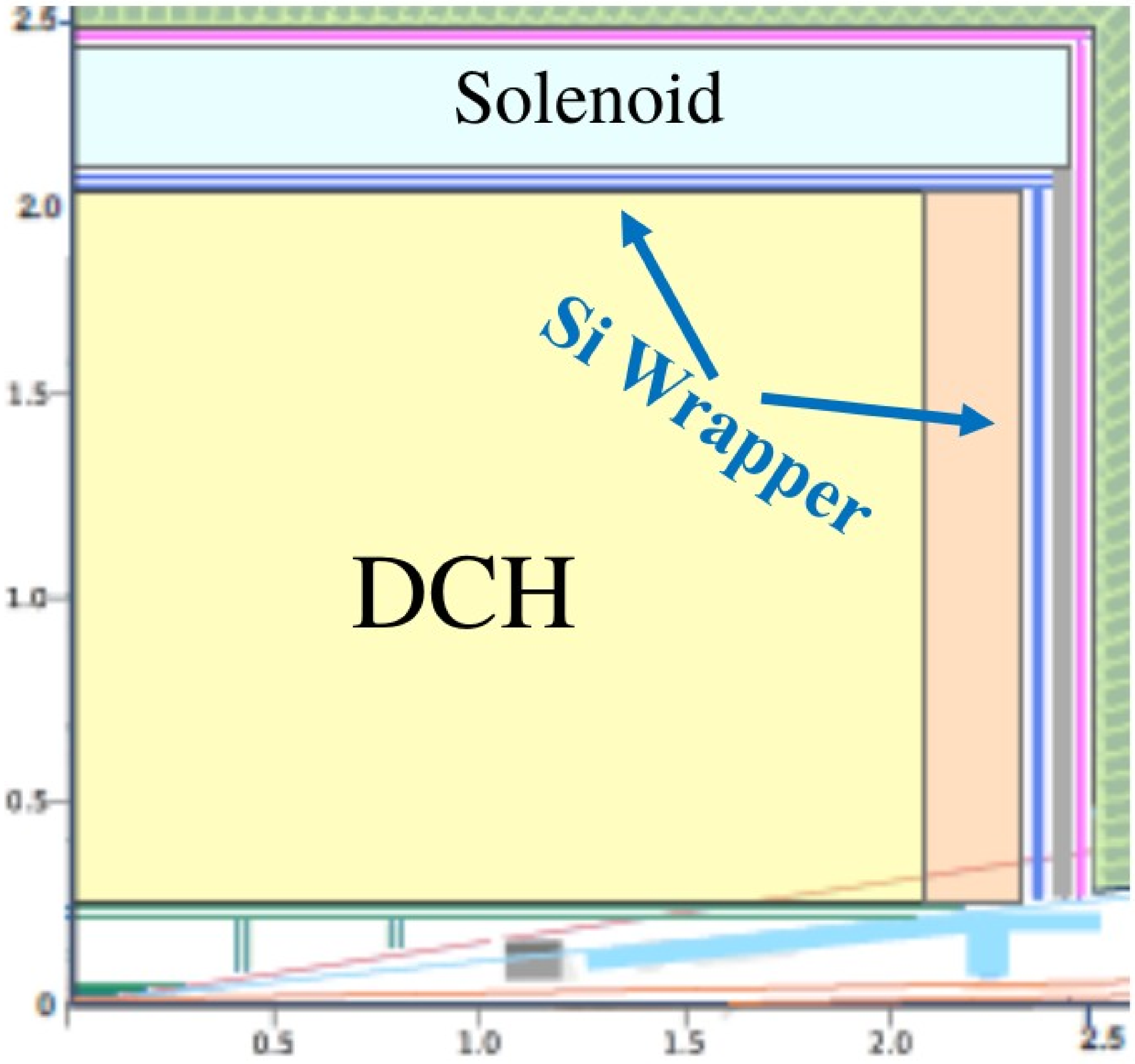




Si wrappers

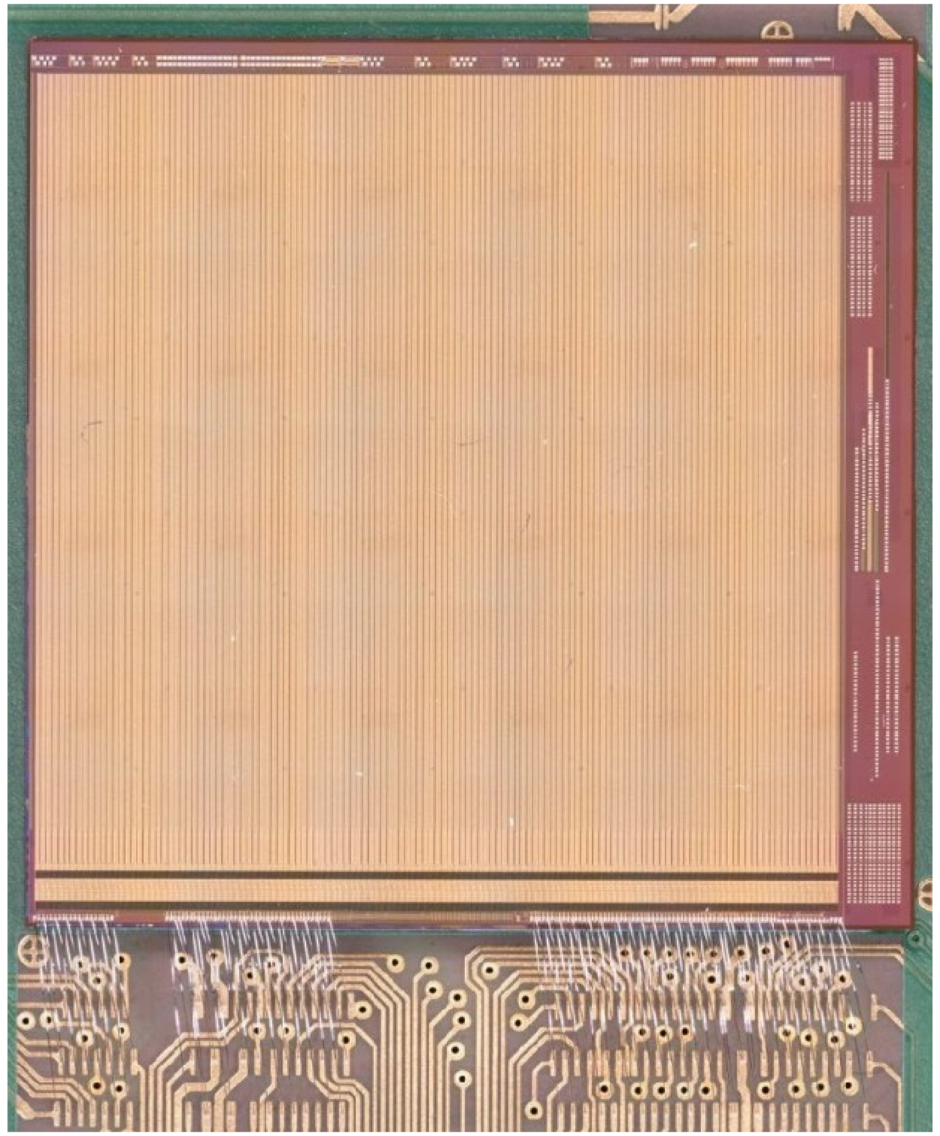
- Precision Si layer around DCH
  - momentum resolution
  - extend tracking coverage in F/B regions
  - precise and stable ruler for acceptance definition

- Suitable technologies
  - microstrips (2 layers)
  - DMAPS, e.g.: ATLASpix3

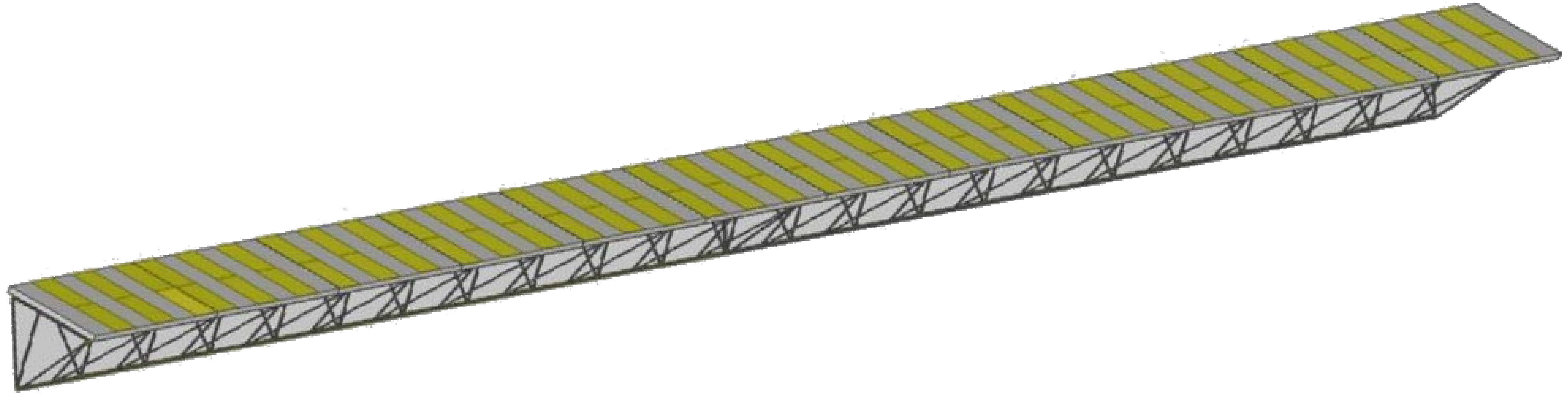


Si wrappers: ATLASpix3

- Pixel size: 50×150 μm^2
  - 150 mW/cm^2
  - both triggerless and triggered readout
  - first 2 multi-chip modules successfully operated



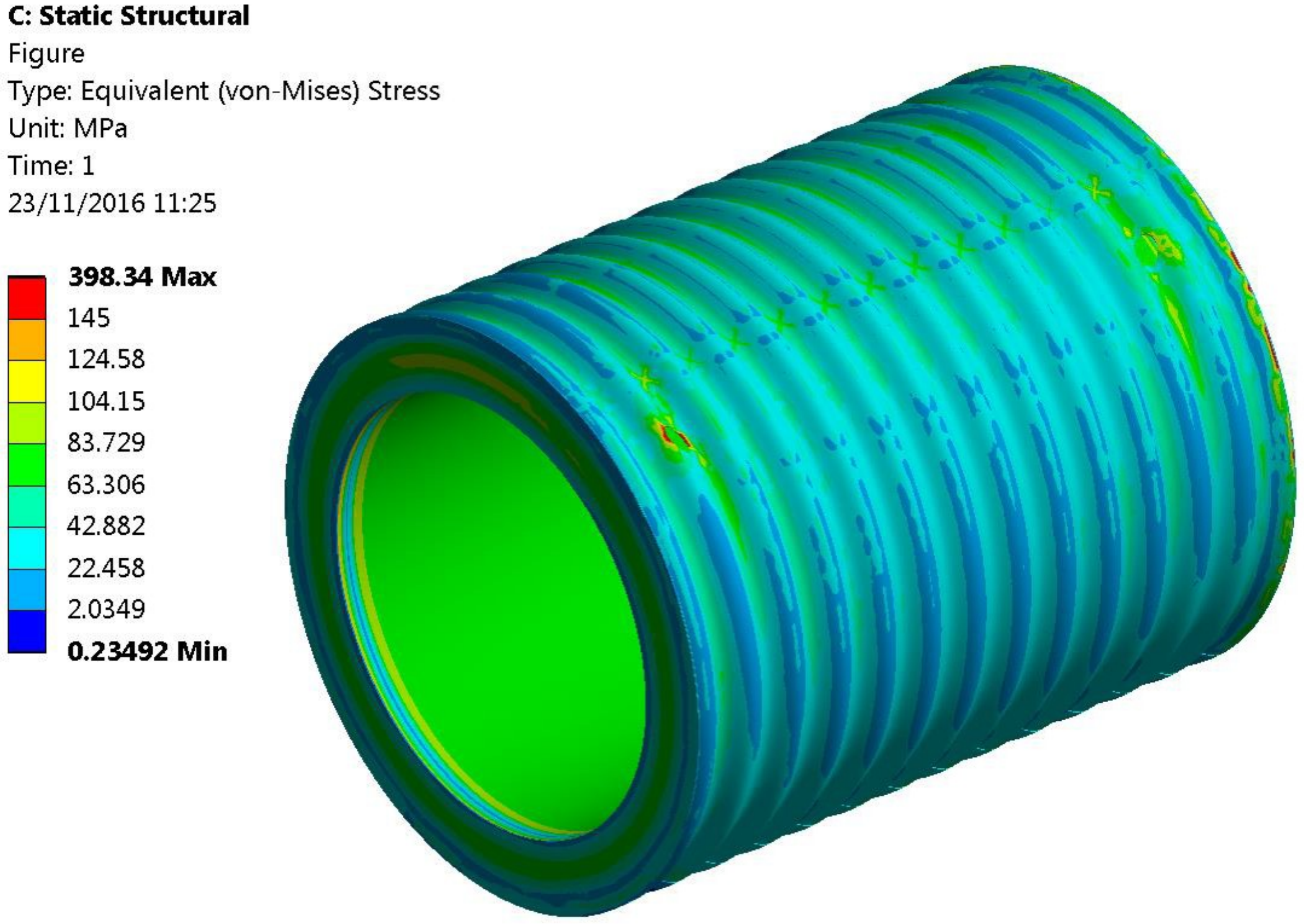
- Target: build few mini-staves of outer tracker for FCC-ee/CepC
  - 2022: realisation of prototypes and thermo-mechanical characterisation

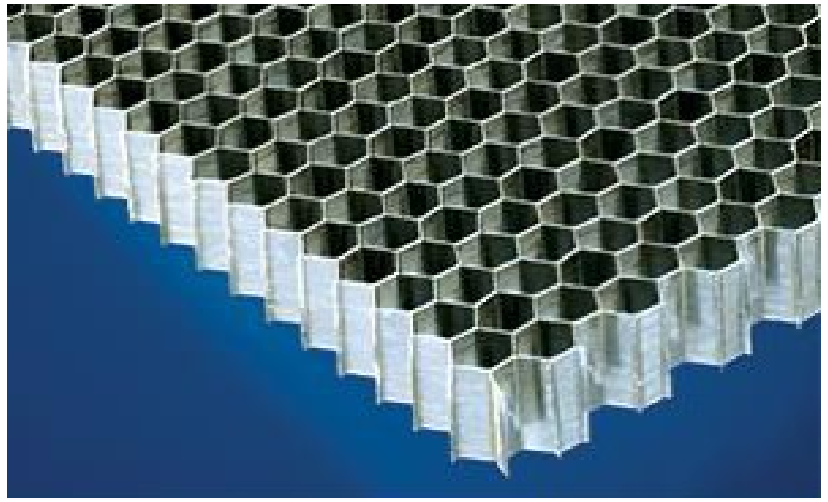


Superconducting solenoid

Courtesy of H. TenKate

- Ultra light 2 T solenoid:
  - 30 cm radial envelope
  - single-layer self supporting winding (20 kA)
    - cold mass: 0.46 X_0, 0.09 λ_{int}
  - Vacuum vessel (25 mm Al): 0.28 X_0
    - can improve with new technology
      - corrugated plates: 0.11 X_0
      - honeycomb: 0.04 X_0





FCC-ee / CepC general requirements

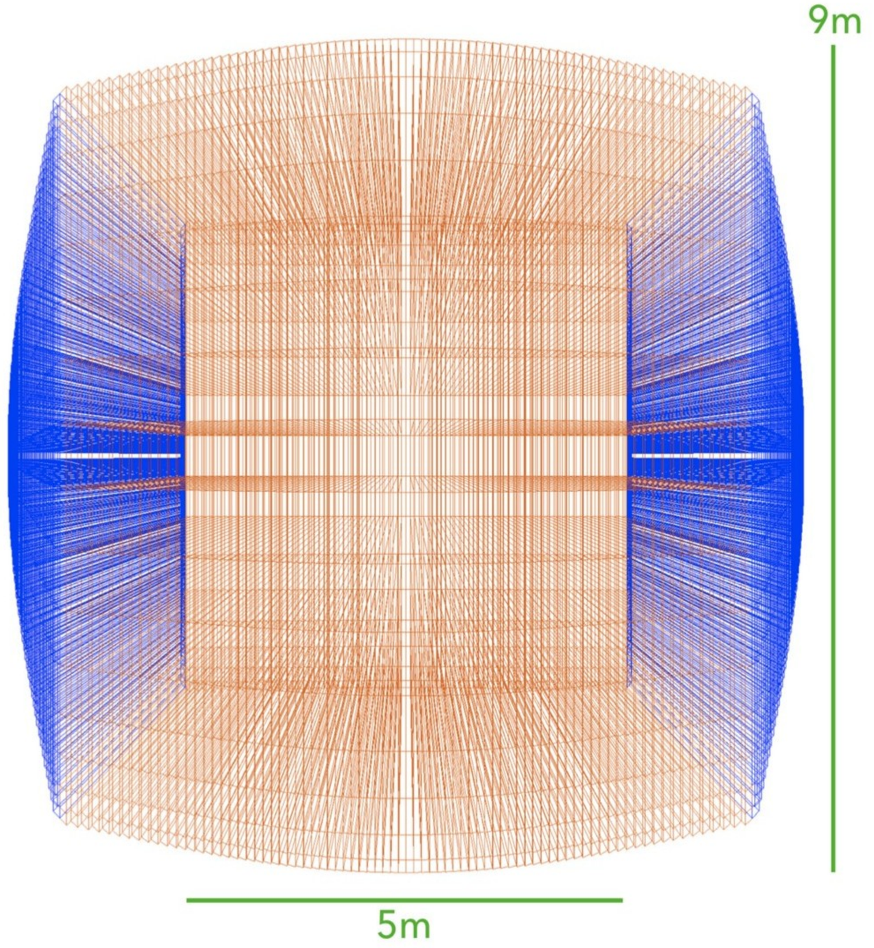
- fair σ_{EM} ~ 10-20% /√E sufficient for Higgs physics
- σ_{jets} ~ 30-40% /√E to clearly identify W, Z, H in 2 jets decays
- transverse granularity < 1 cm for π_0 from τ and HF
- could be satisfied by:
  - high-granularity dual-readout fibre calorimeter → SiPM readout
  - combined dual-readout crystal/fibre calorimeter

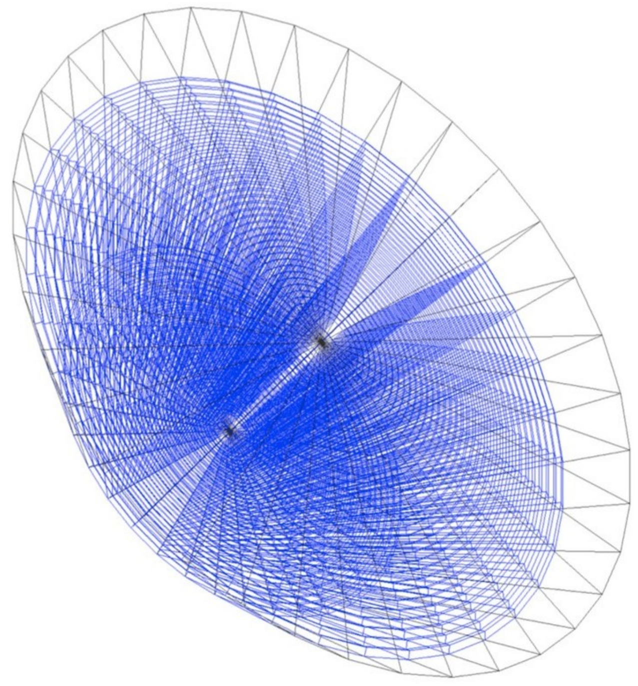
Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

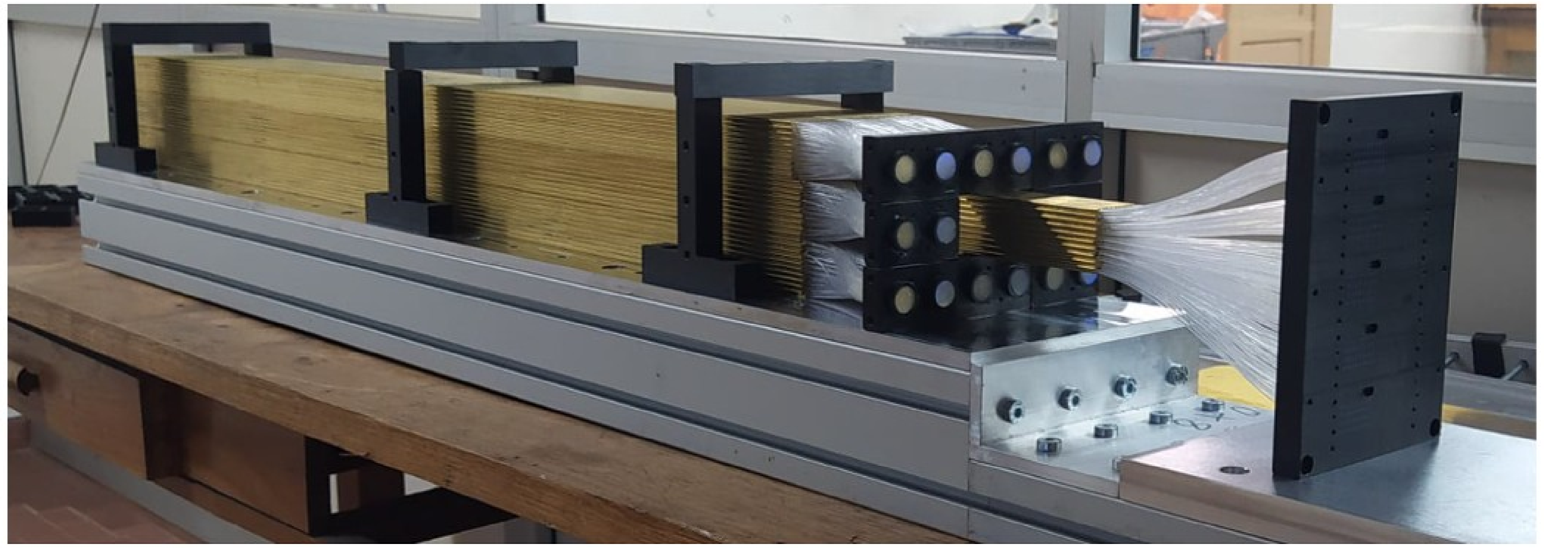
All-fibre DR calorimeter option

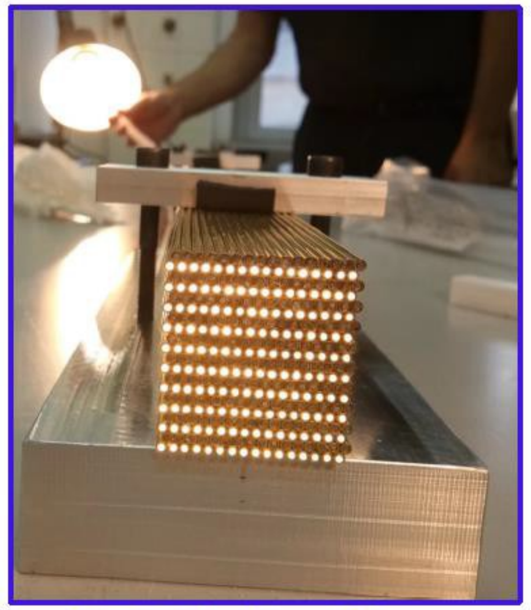
- DR fibre calorimeter
  - ~ 130 M fibres
    - 1 mm ⌀, 1.5 mm pitch
  - copper absorber
  - 75 projective towers × 36 slices
    - $\Delta\vartheta = 1.125°$, $\Delta\phi = 10.0°$
    - ϑ coverage: down to ∼100 mrad

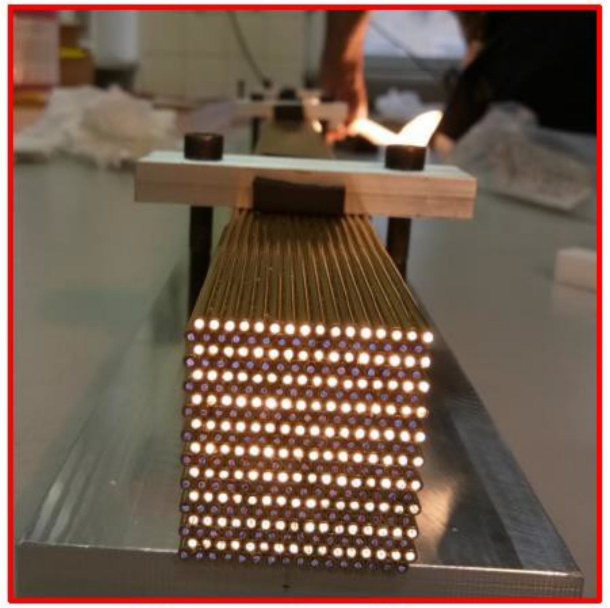
- G4 simulation available
  - tuned to RD52 TB data



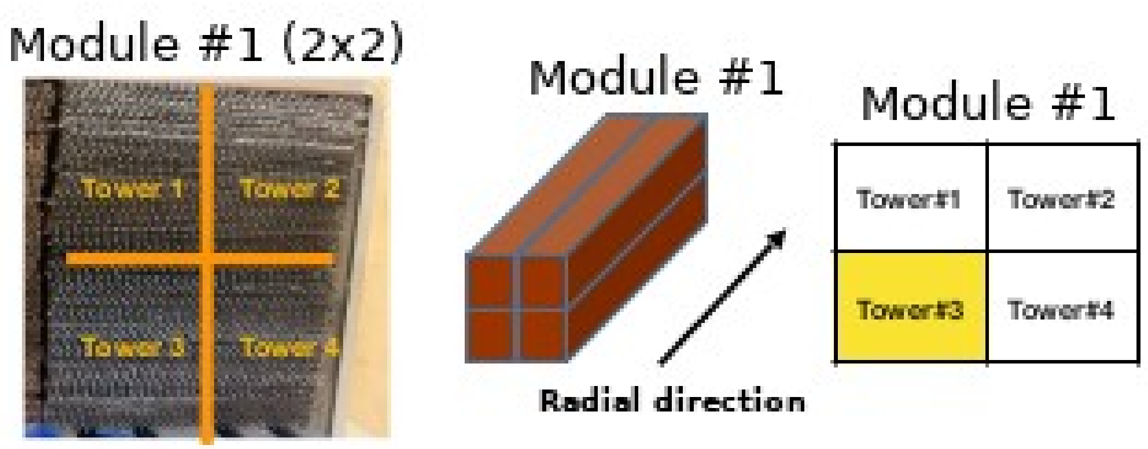


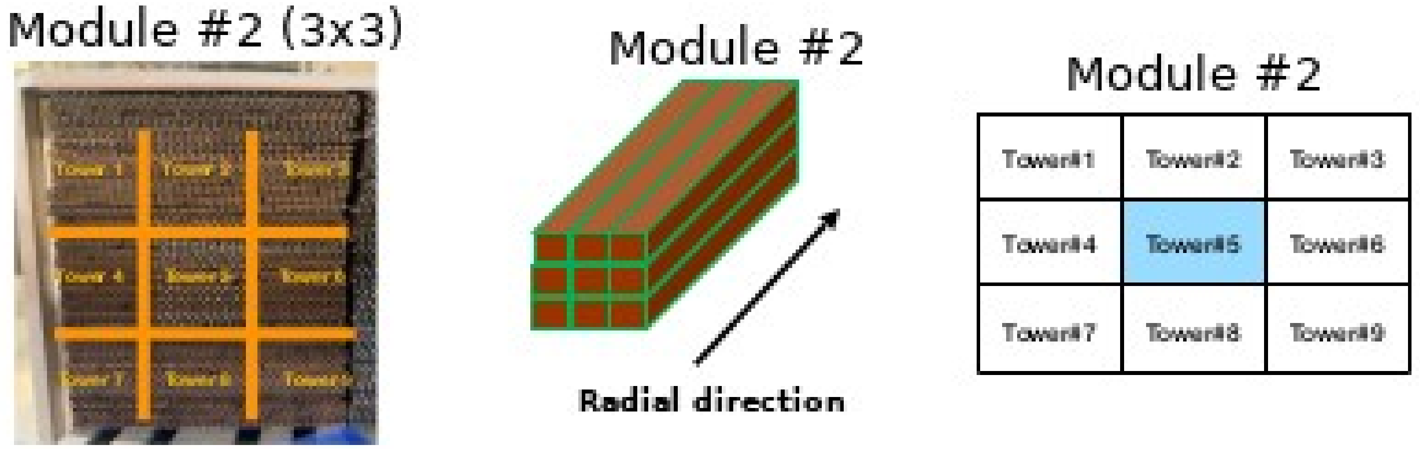



Scintillation fibers

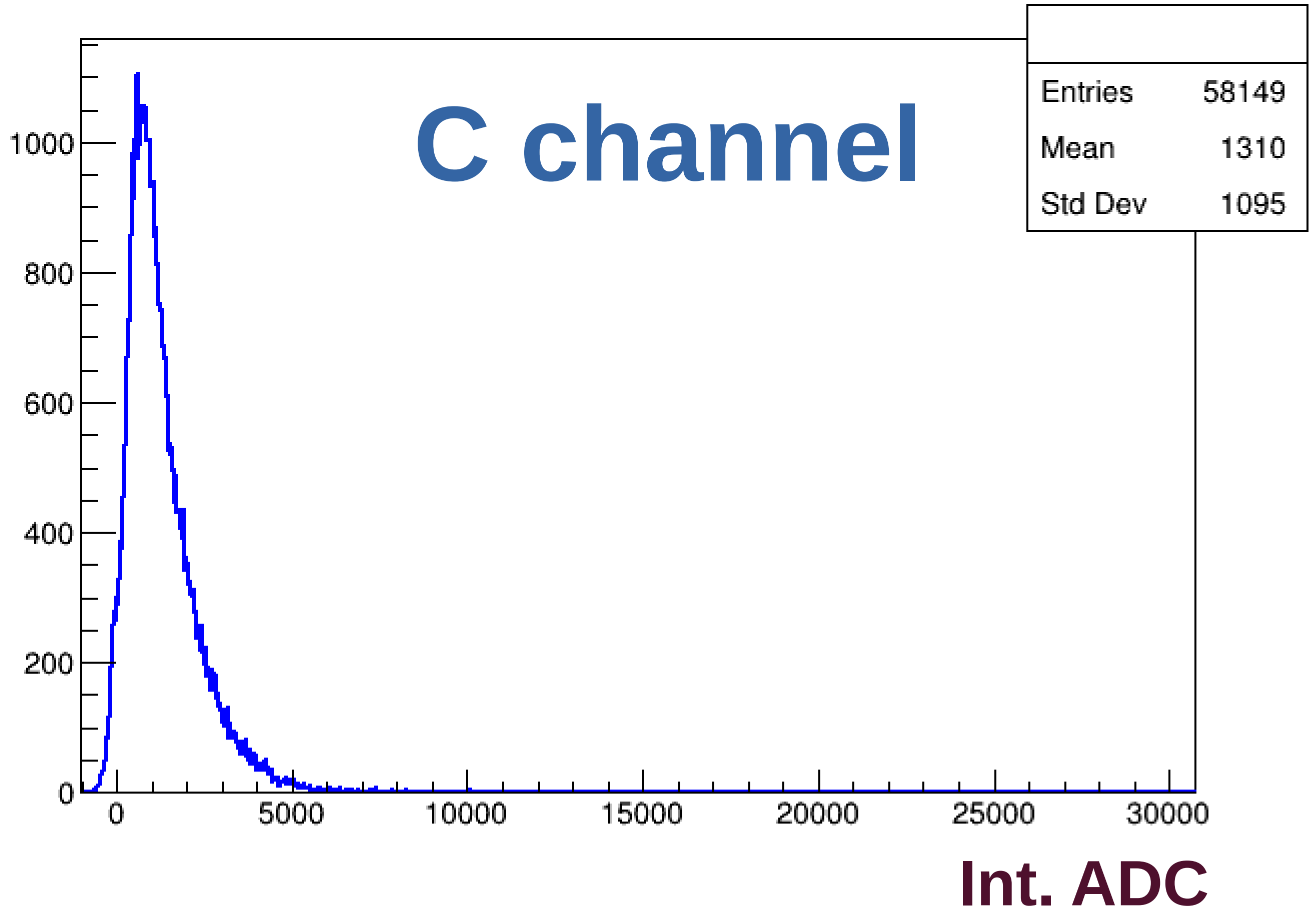

Cherenkov fibers

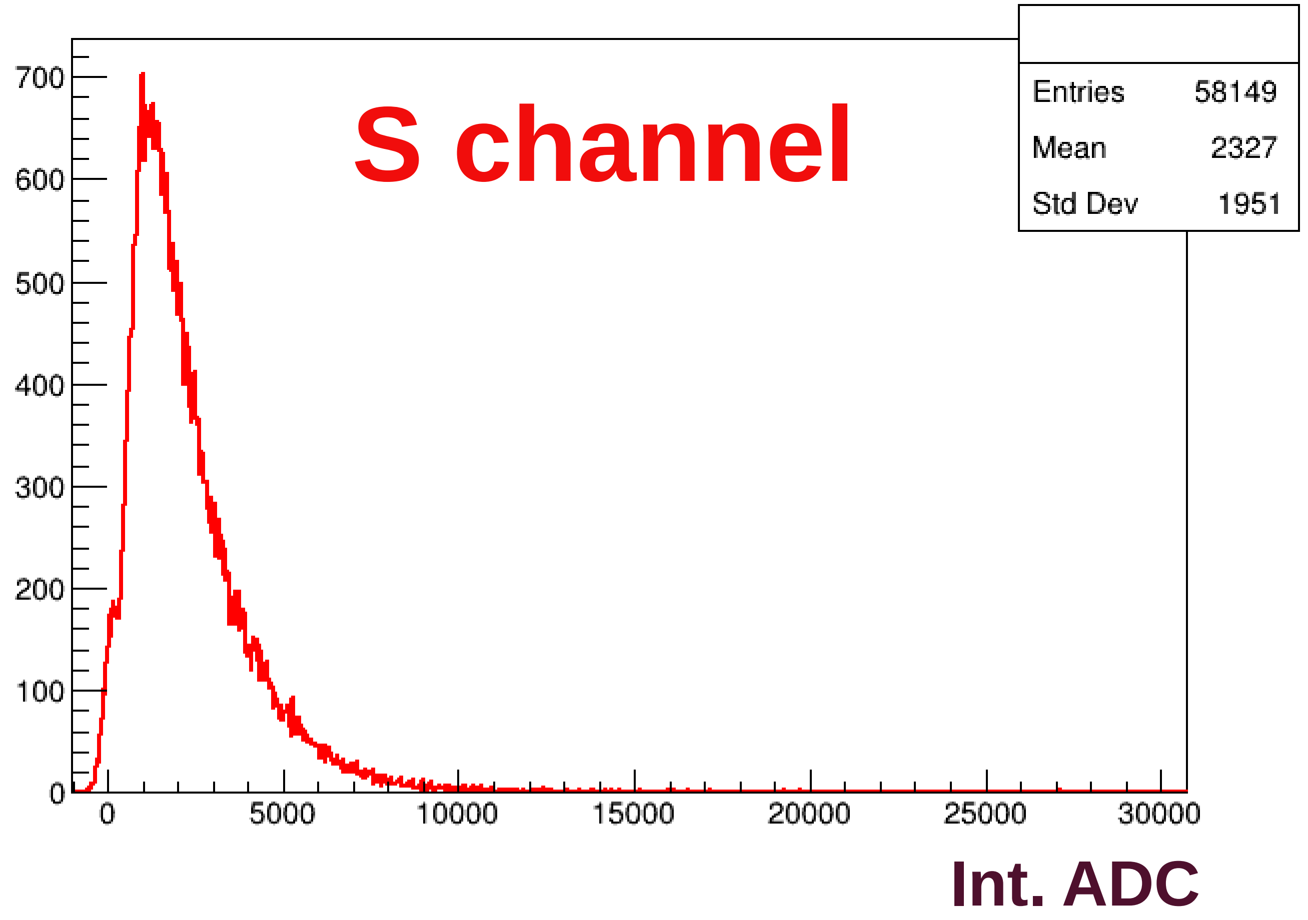
2022 Korean-prototype beam test





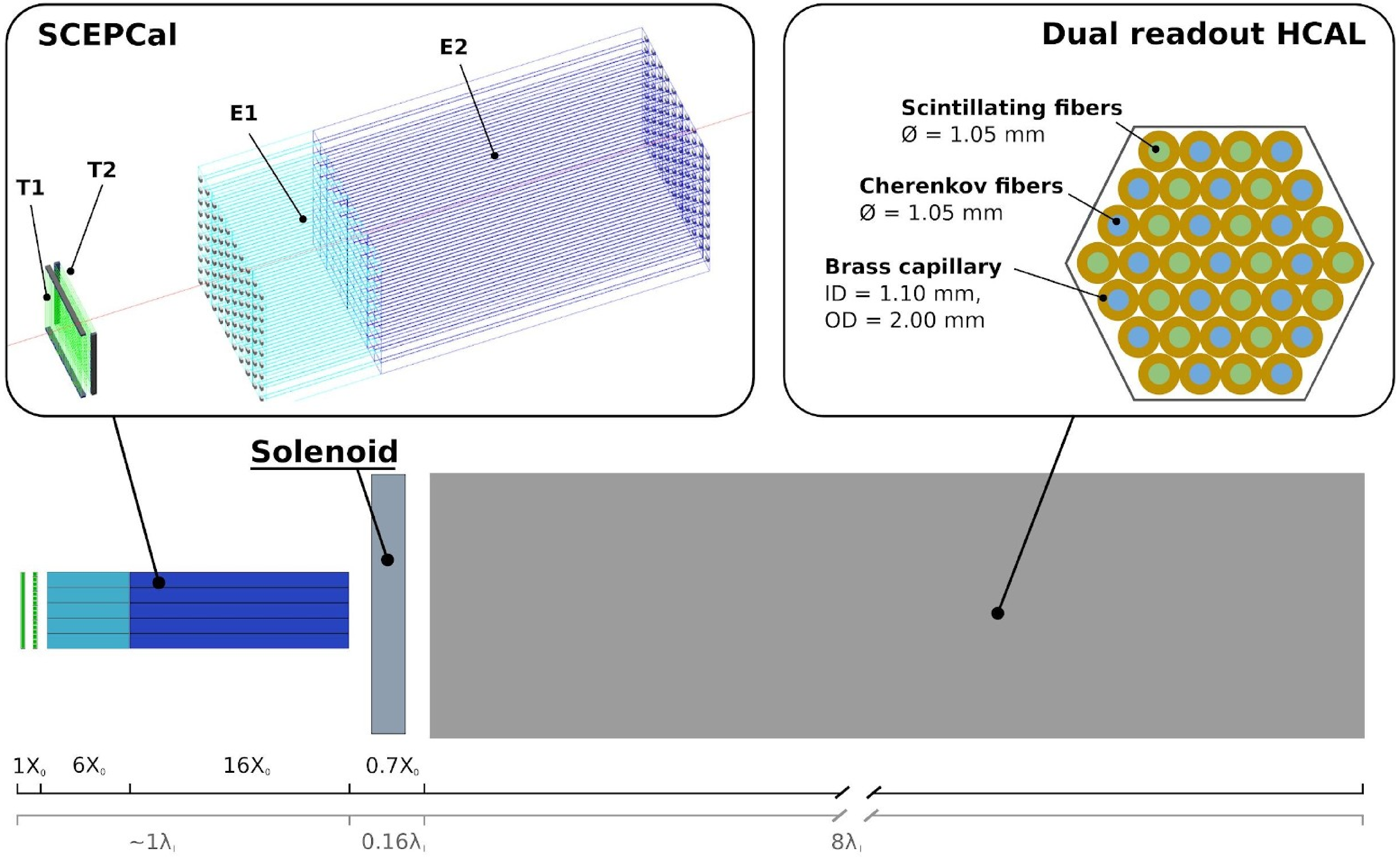
- Data analysis in progress





Crystal option (IDEA++)

- ECAL ~20 cm $PbWO_4$
  - 2 layers: 6+16 X_0
  - DR with filters
  - $\sigma_{EM} \approx 3\% /\sqrt{E}$
- timing layer
  - LYSO:Ce crystals
  - σ_t ~ 20 ps
- HCAL layer
  - $\sigma_{HAD}/E \sim 26\%/\sqrt{E}$



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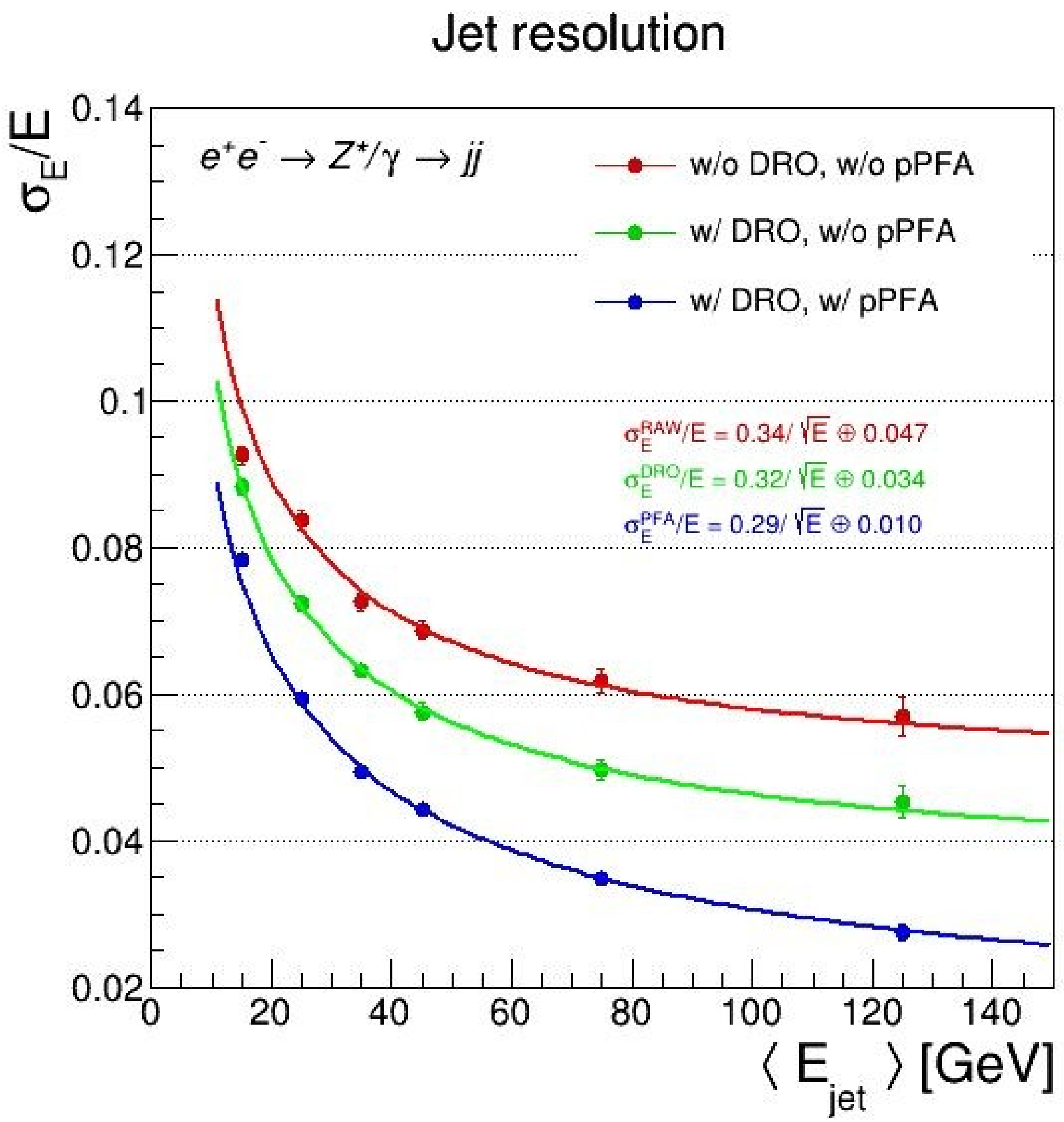
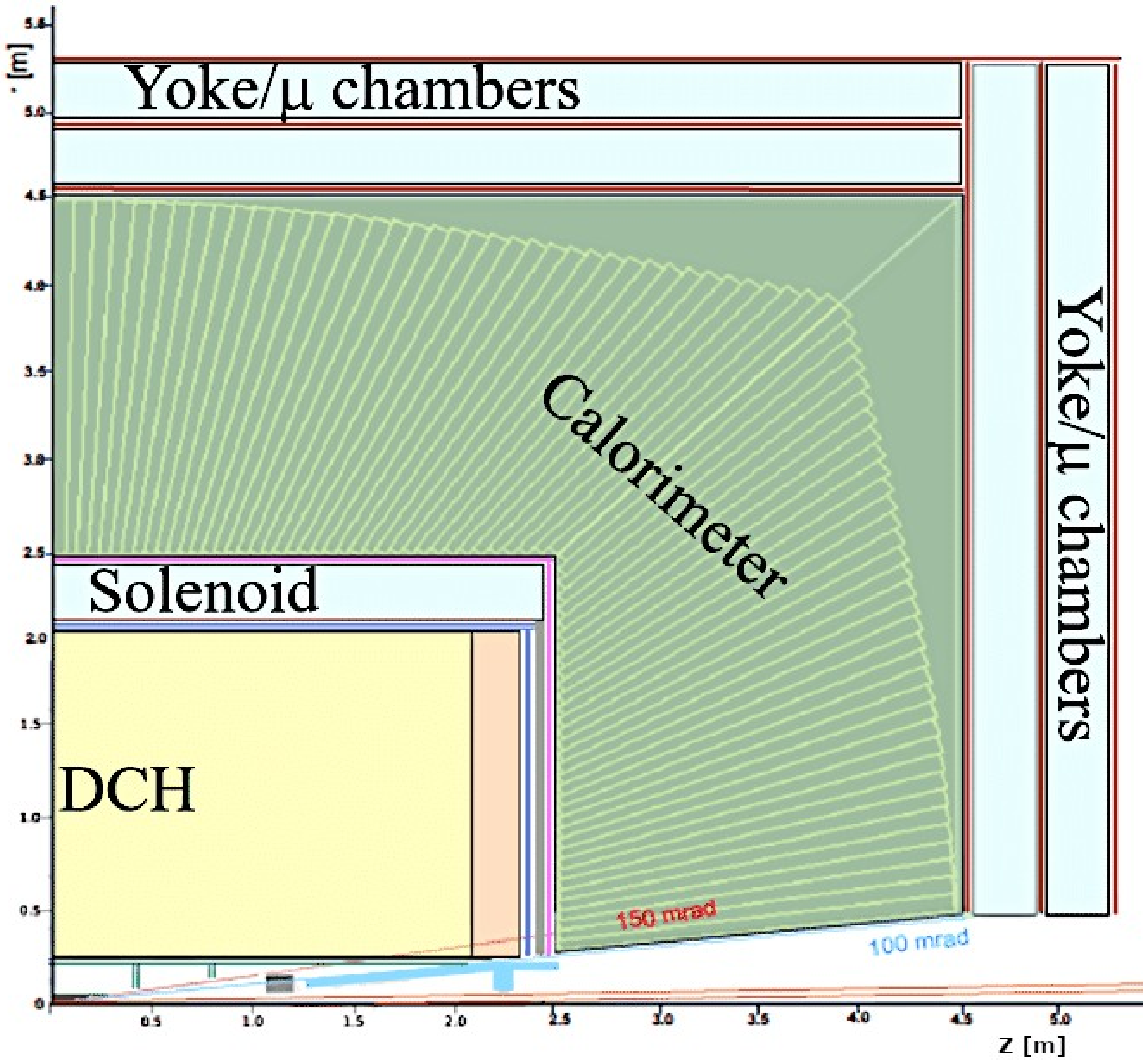


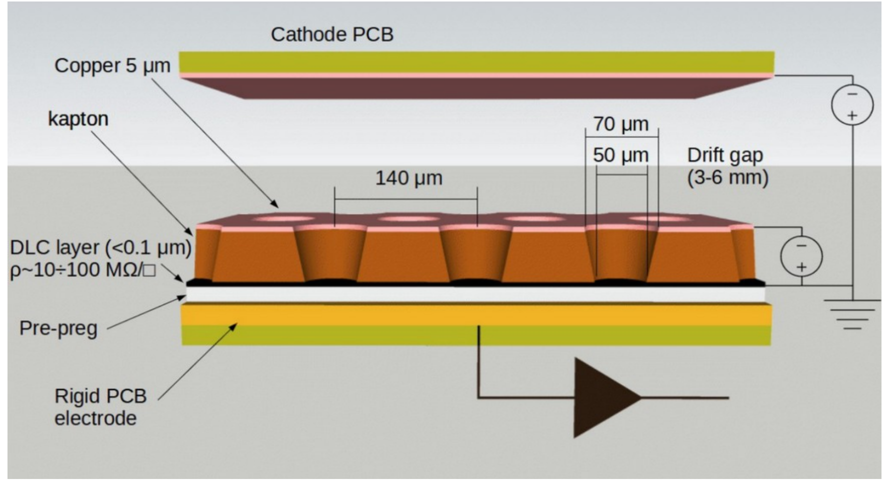
Preshower and muon detector

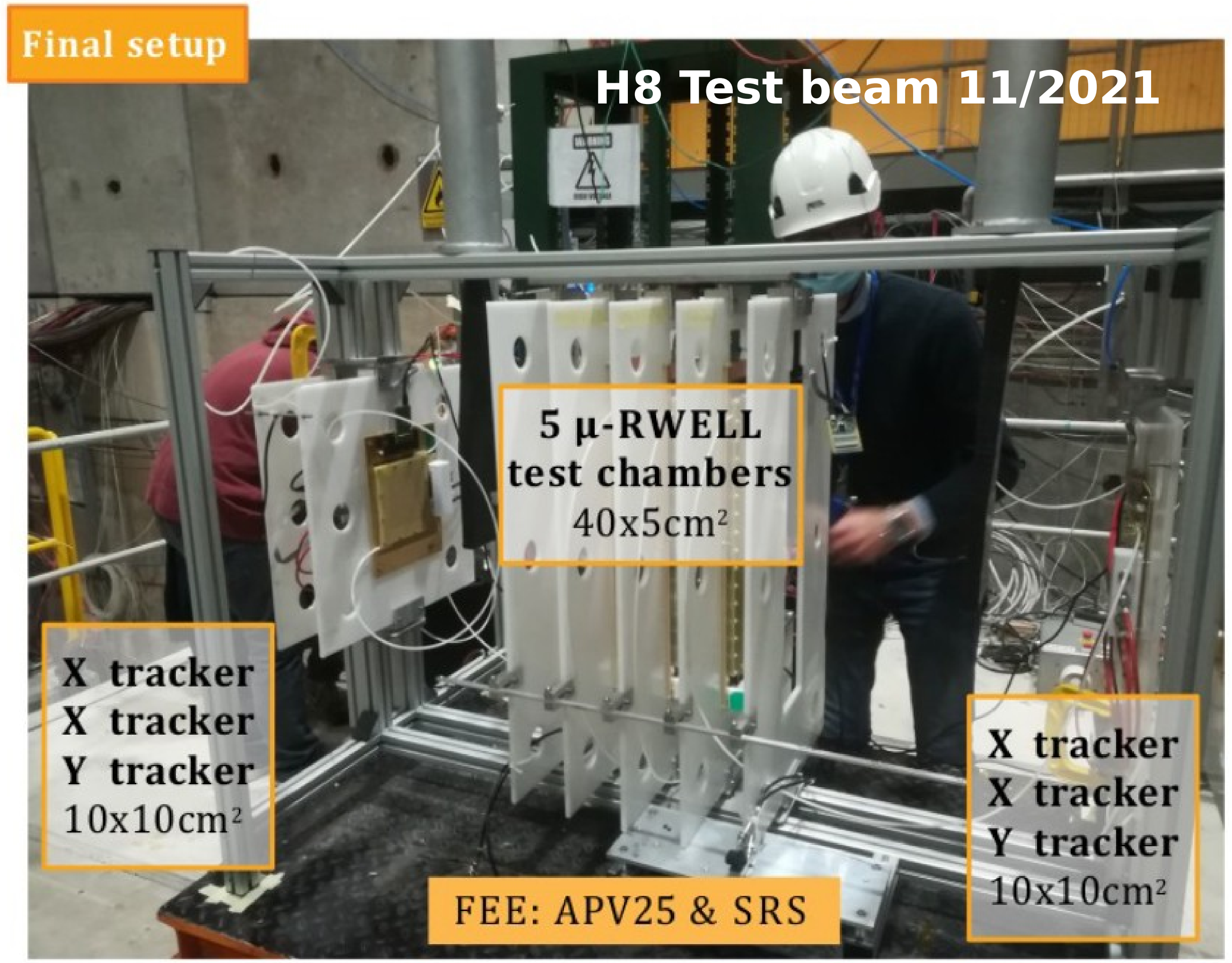
- Preshower detector
  - high-resolution space points before calorimeter to improve cluster reconstruction
- Muon detector
  - identify μ and search for LLPs
  - 3 layers in return joke
- Both based on tha same technology: μ-RWELL
  - efficiency > 98%
  - mass production
  - optimisation of FEE channels/cost



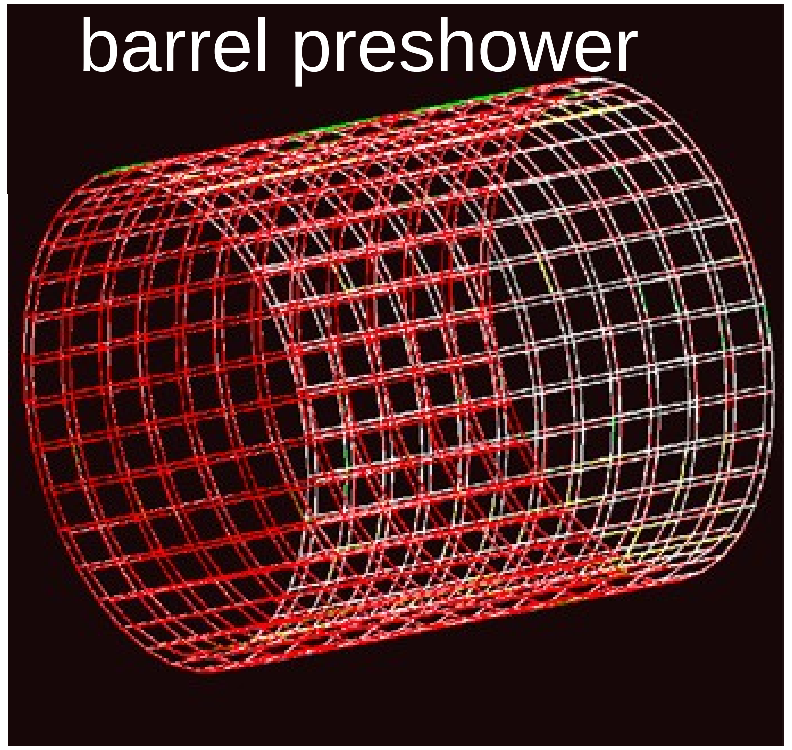
Preshower and muon detector

- Preshower detector
  - pitch 0.4 mm
  - resolution < 100 µm
  - 1.5 M channels
- Muon detector
  - pitch 1.5 mm
  - resolution < 400 µm
  - 5 M channels
- 50×50 cm^2 2D tiles
  - to cover > 4330 m^2

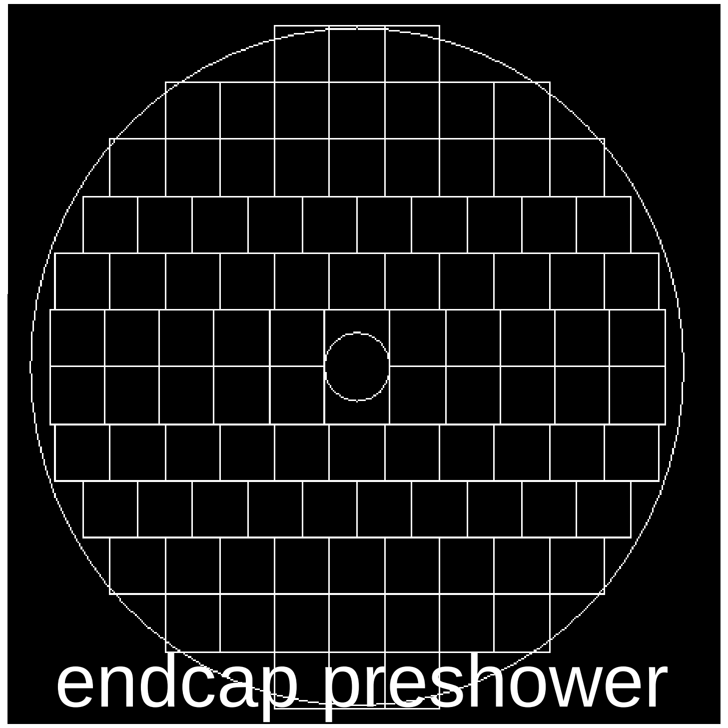




7 µ-RWELL prototypes, with resistivity from 10 to 80 MΩ/□, will allow to define final (50×50 cm^2) detector resistivity



similar design for muon detector



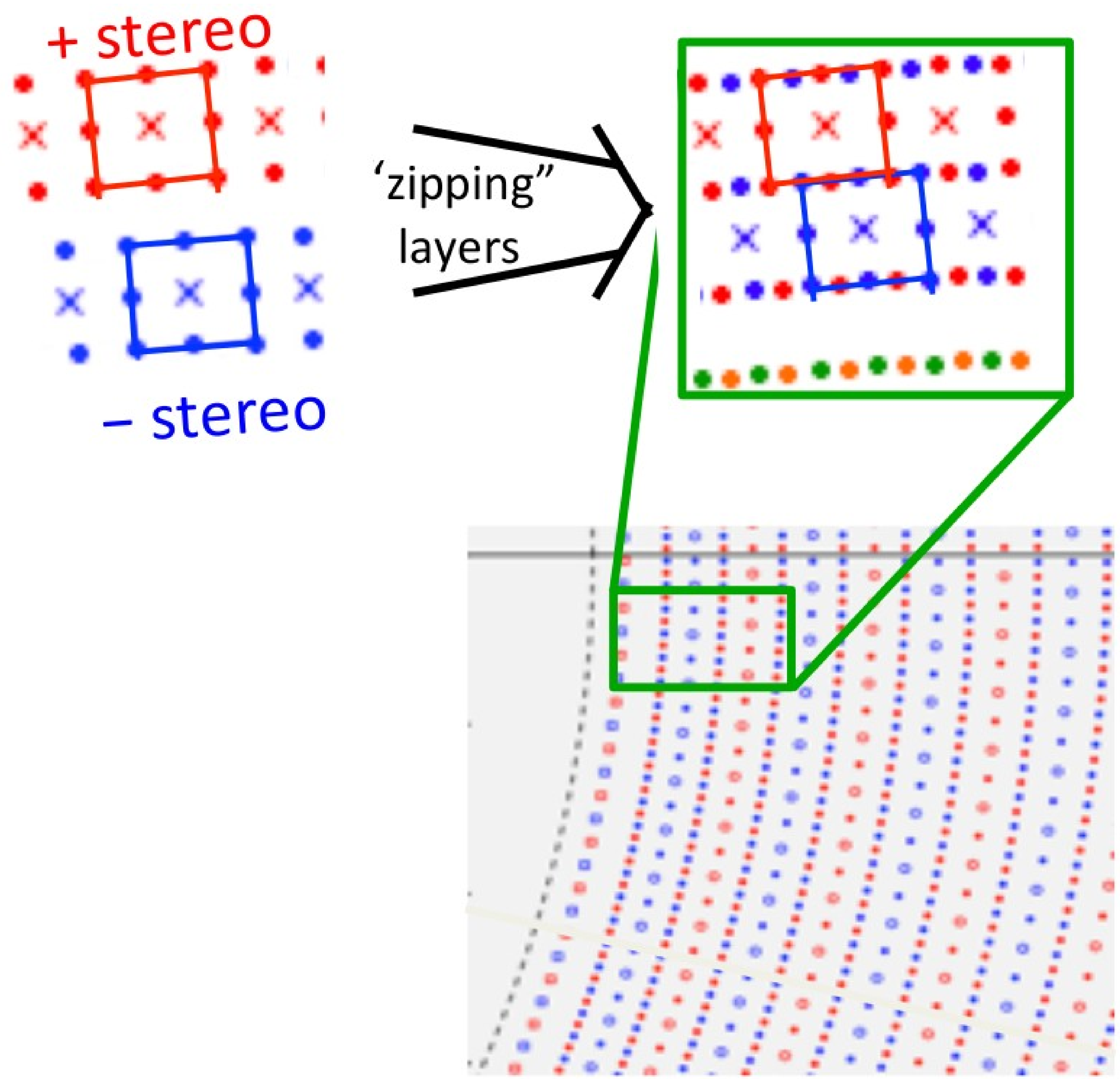
Conclusions: lot of R&D in each area

- Vertex detector w/ DMAPs for best momentum resolution
  - work in progress, i.e. Arcadia
- Silicon wrapper R&D starting from ATLASpix3 chips
  - also for outer layers of vertex detector
- Wire chamber R&D ongoing on many aspects
  - Lot of work to demonstrate cluster-counting performances
- Dual readout: project for full containment prototype(s)
  - EM crystal option w/ DR
- Preshower and muon system based on μ-RWELL technology
  - R&D on resistive, long, DLC strips, 2D sensors, custom ASIC

Backup

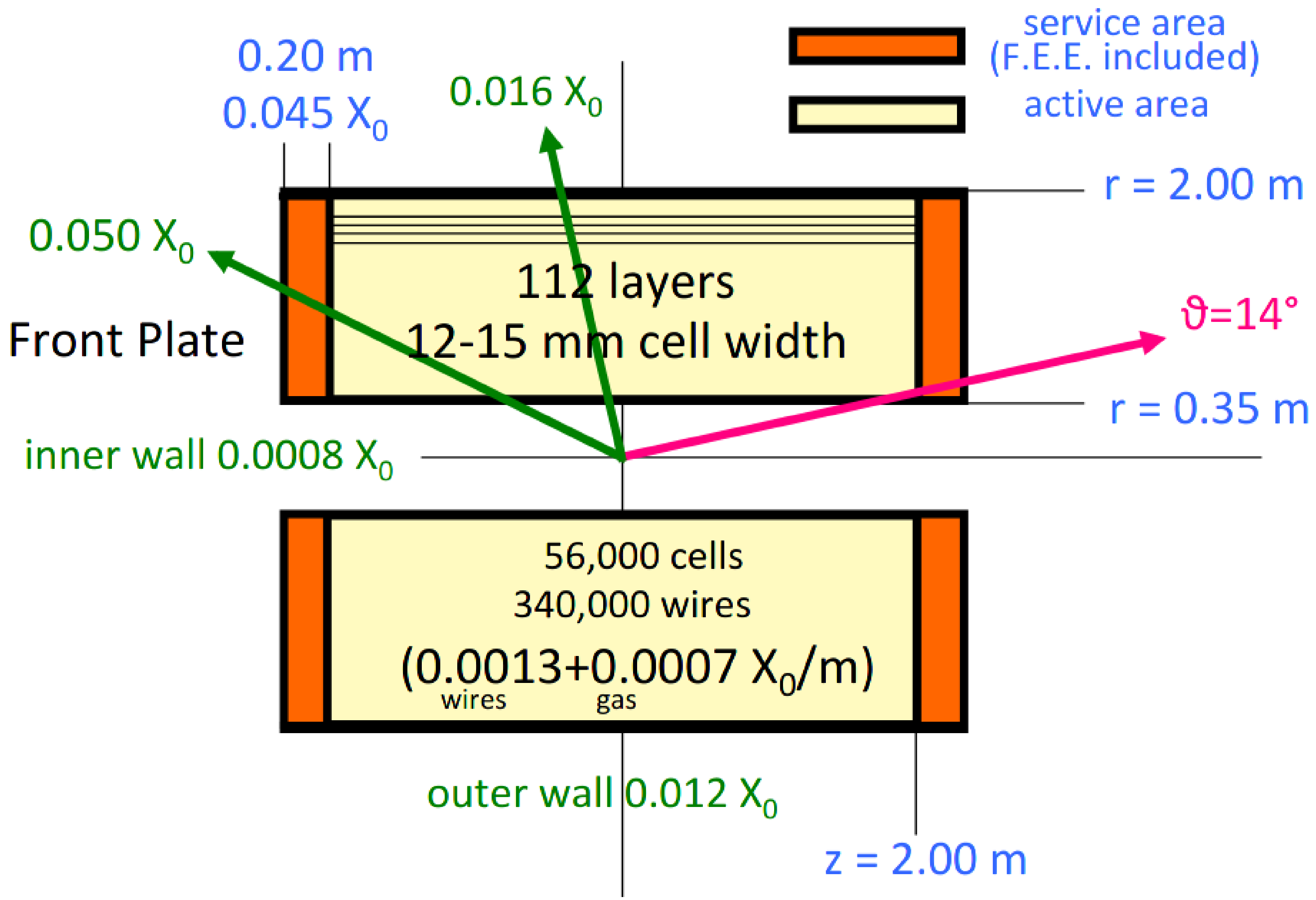
Drift chamber

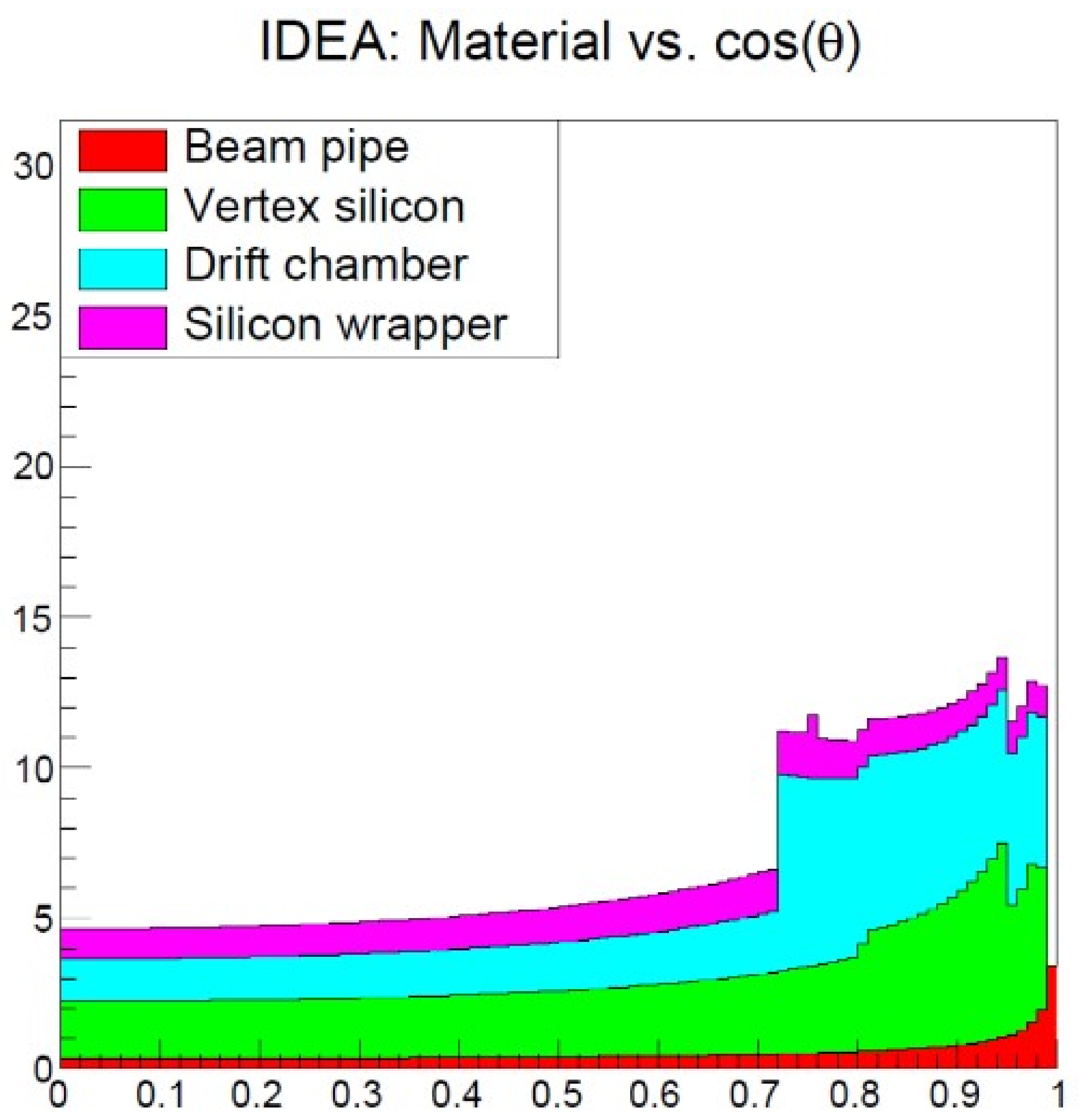
- Thin wires
  - 20 µm sense W(Au)
  - 40 µm field Al(Ag)
- 56448 square cells
  - 12 to 15.5 mm wide
  - 360 ns drift time
  - zipped layers → more uniforme field
- 14 coaxial super-layers
  - 8 layers alternating-sign stereo angles
  - 24 azimuthal 15° sectors



Drift chamber: transparency

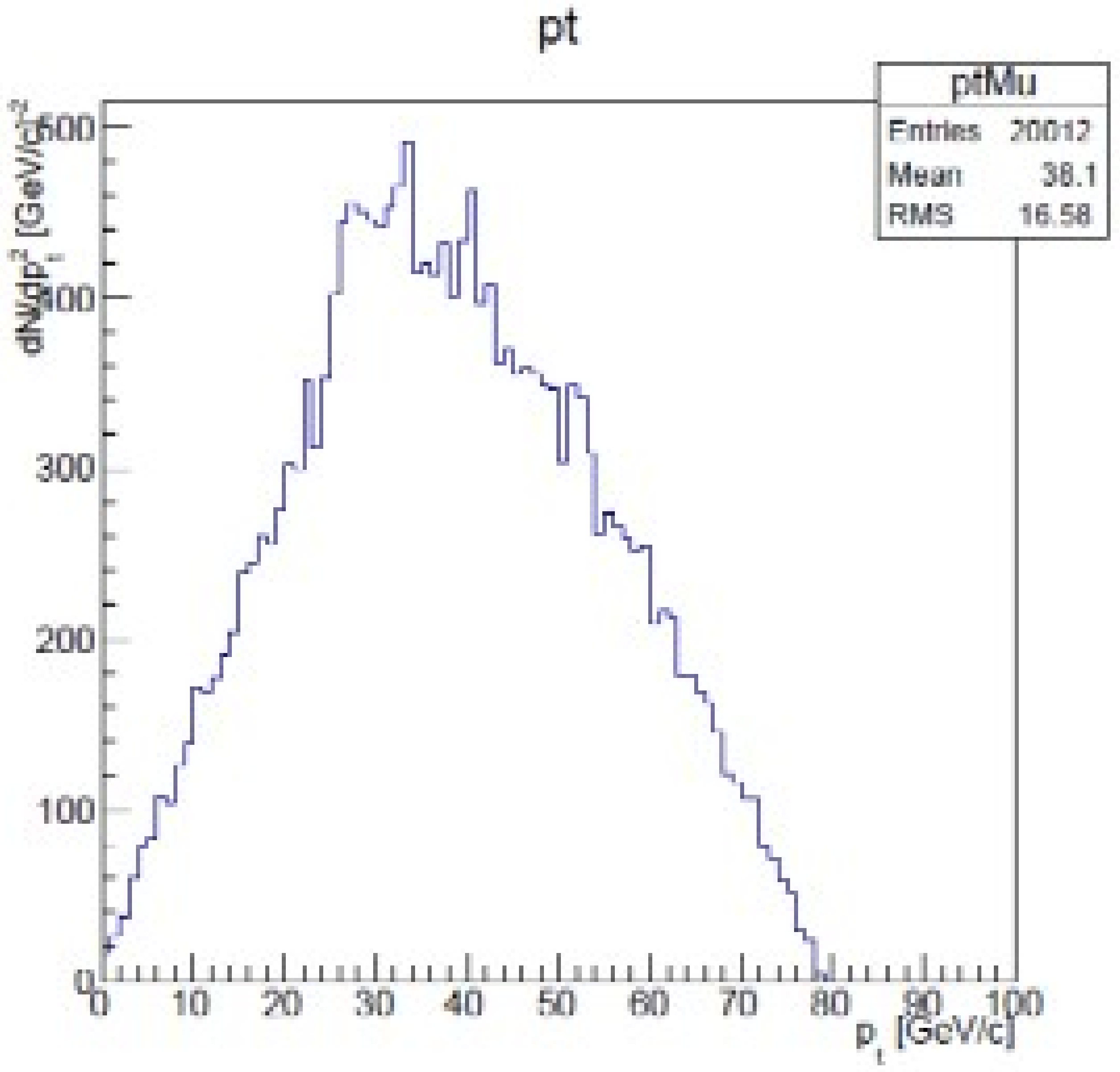
- 0.016 (0.050) X_0 to barrel (end-cap) calorimeter
  - Acceptance θ > 14° (260 mrad)





Additional requirements

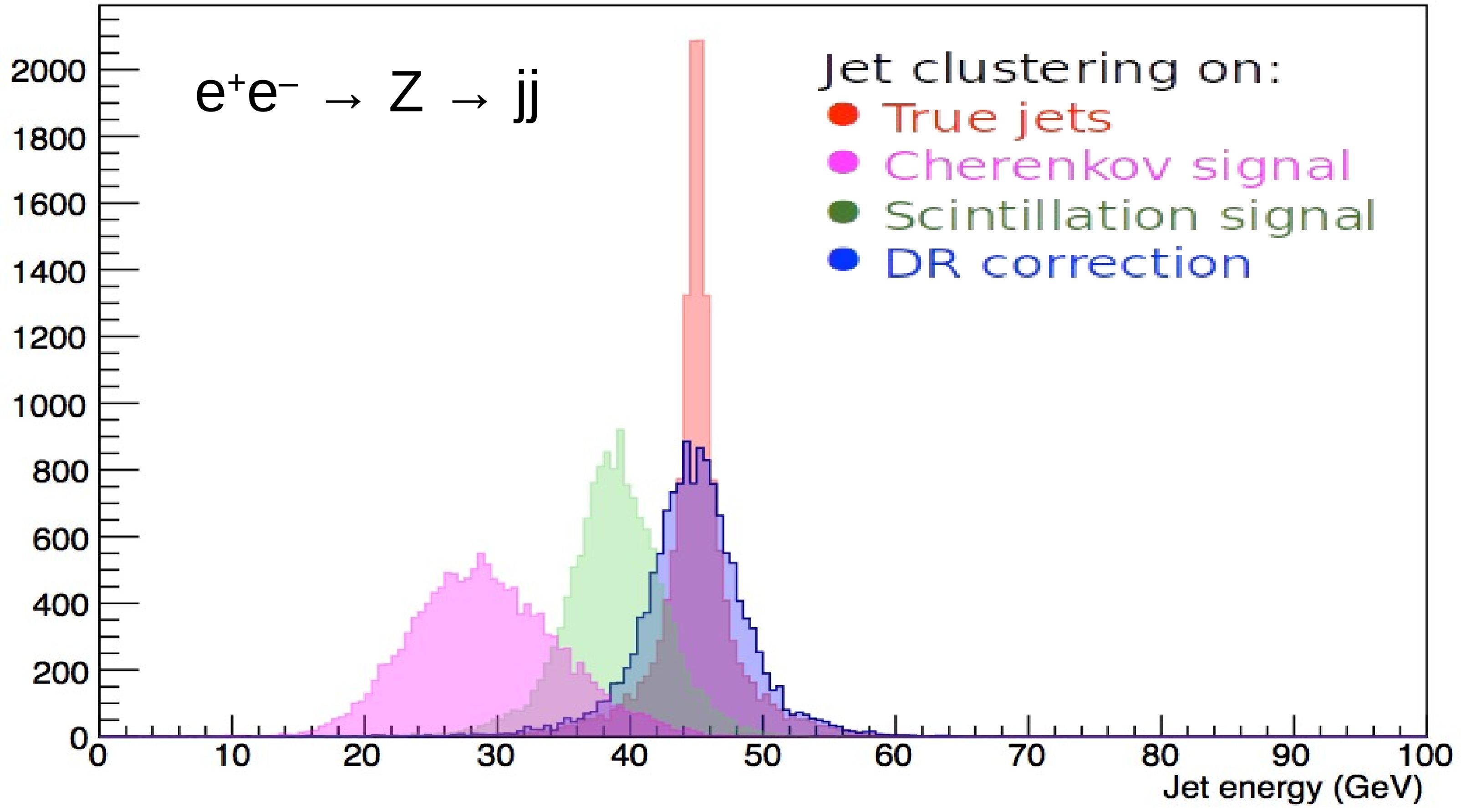
- Excellent acceptance and luminosity control
  - e.g. ECAL inner radius known at 15 μm
- B ~ 2T for beam emittance preservation
  - Maximise tracking volume
- Bunch spacing at Z pole ~ 25 ns
  - Limited drift time
- PID & π_0 ID for HF/τ physics
  - dE/dx or TOF
- Muons in ZH events have rather low p_T
  - Transparency more relevant than asymptotic resolution

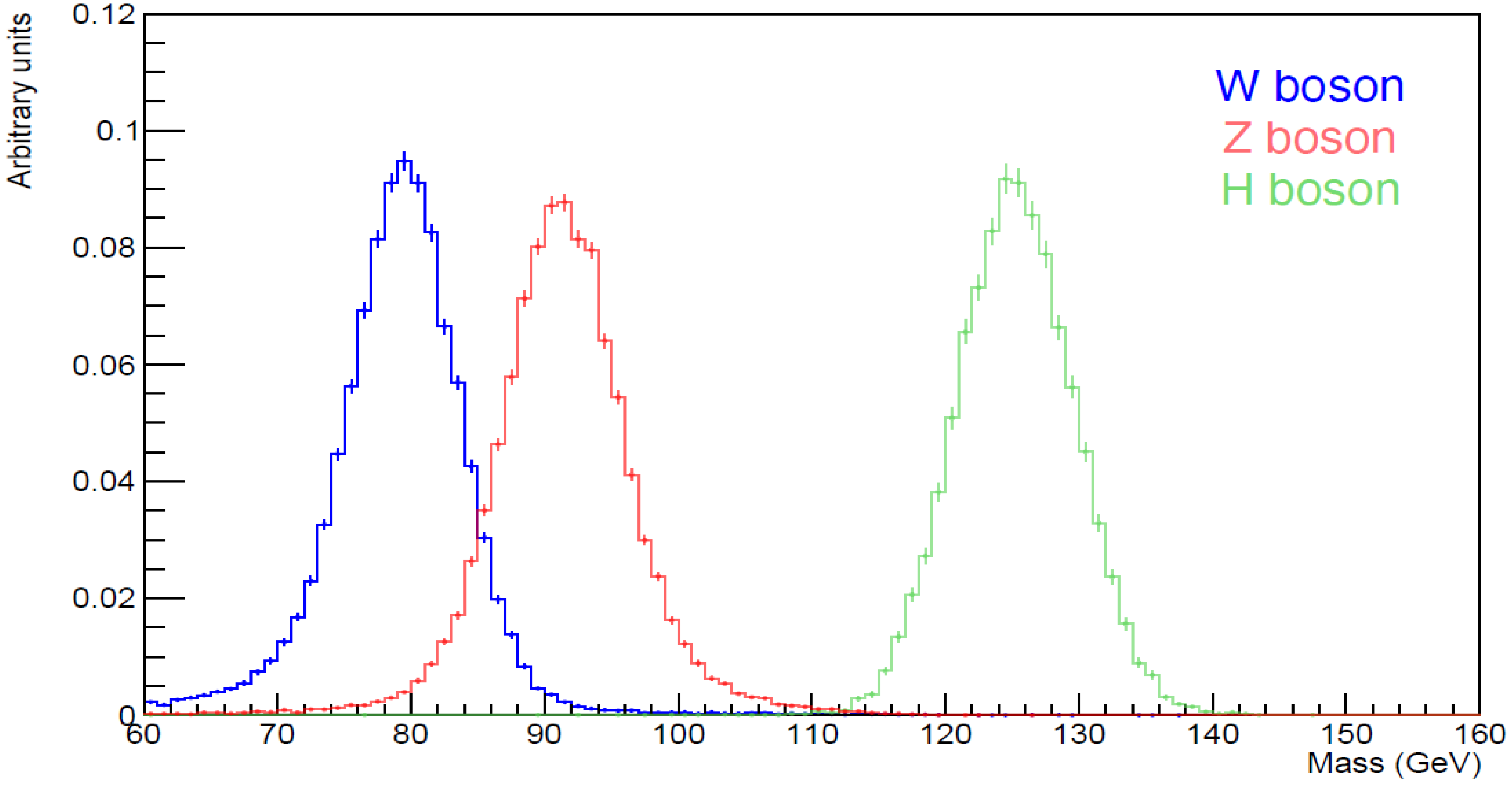


ZH ($Z \rightarrow \mu\mu$)

Geant4 simulation

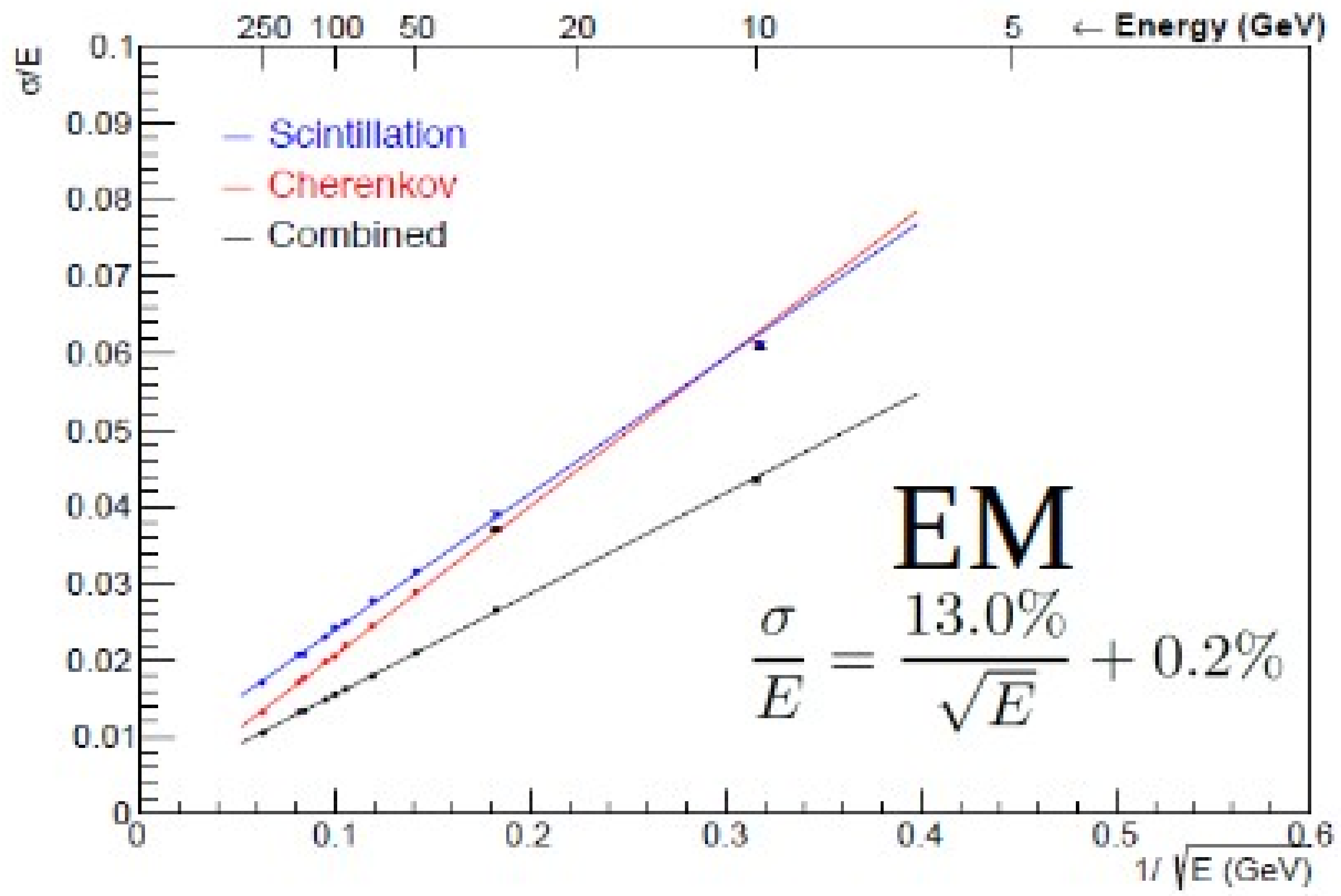
- Gaussian resolution
- Adequate separation of W / Z / H

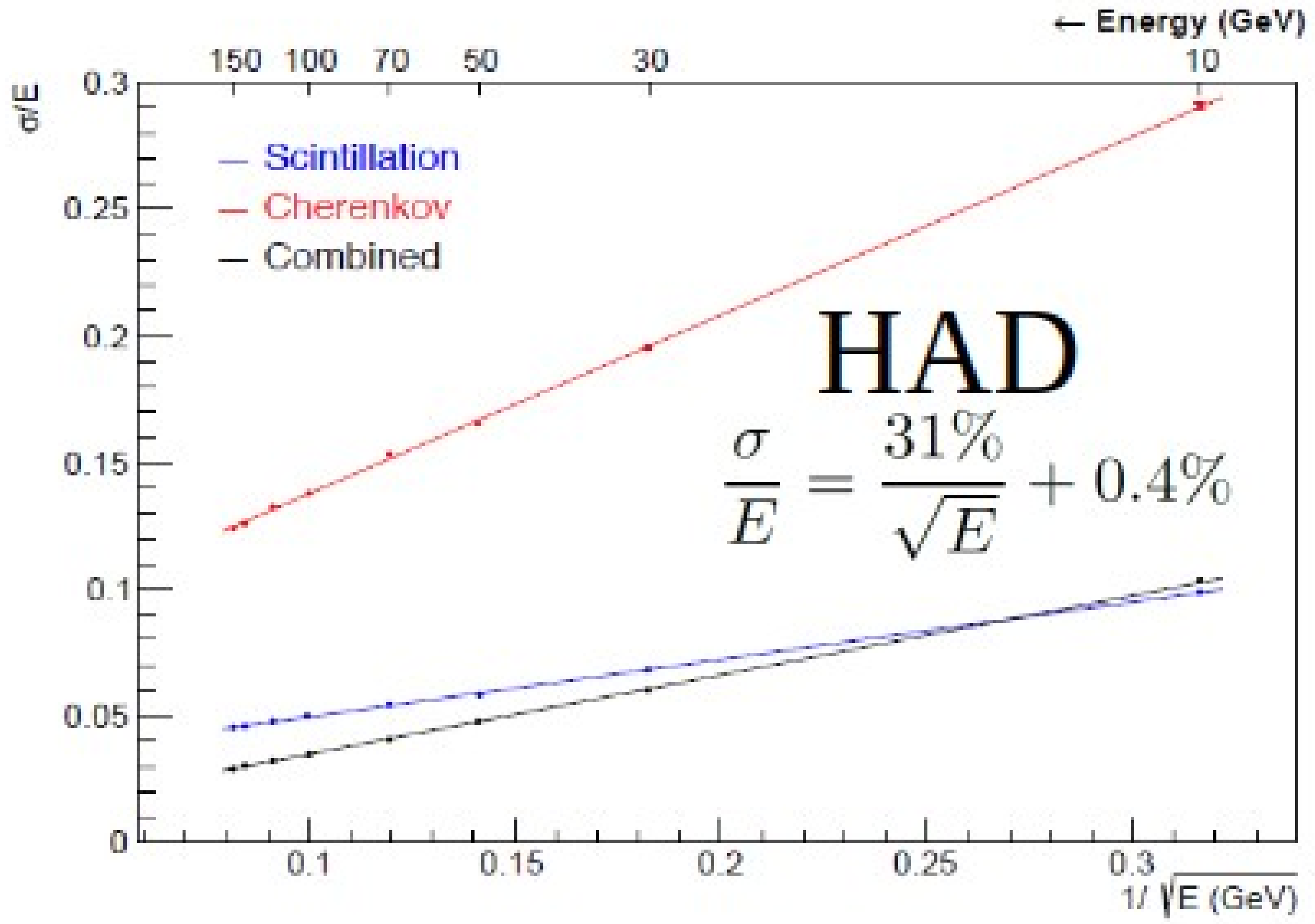




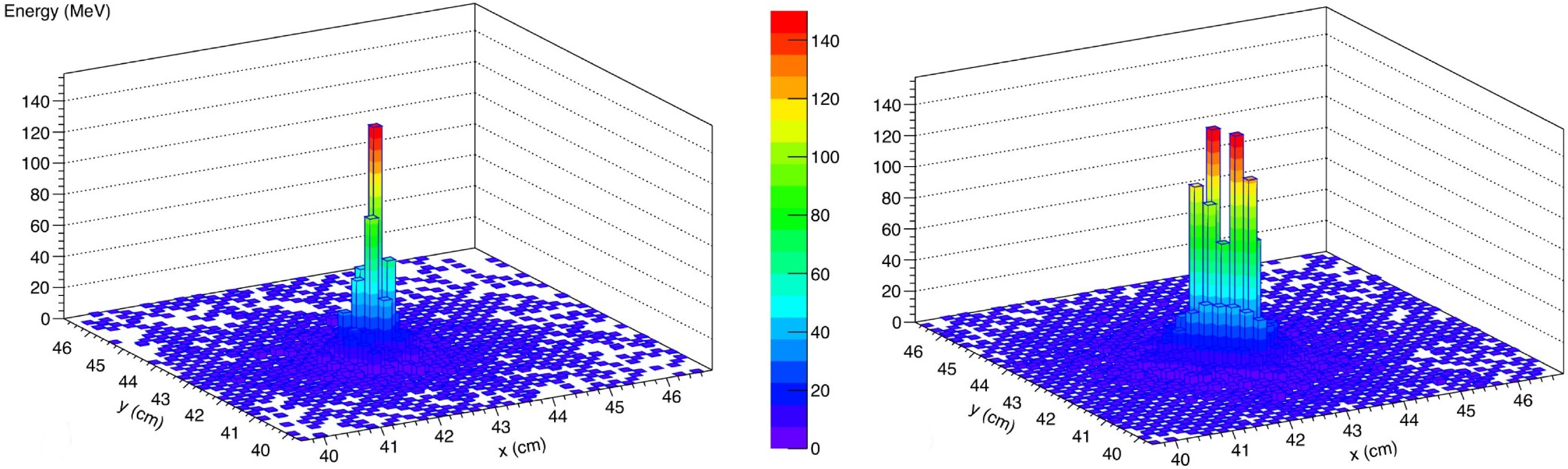
Geant4 simulation

- Good resolutions averaged over eta and phi





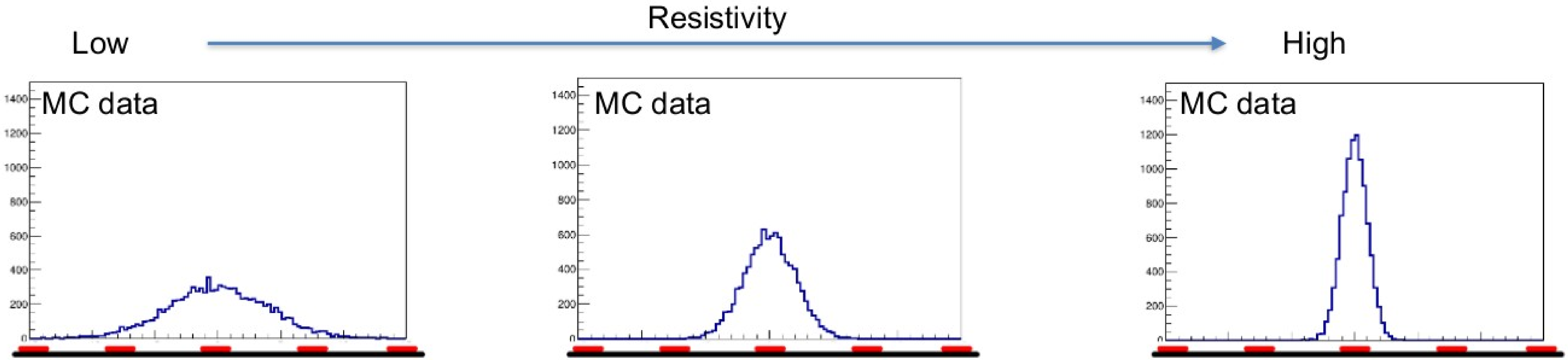
Event displays



50 GeV e^- 100 GeV π^0

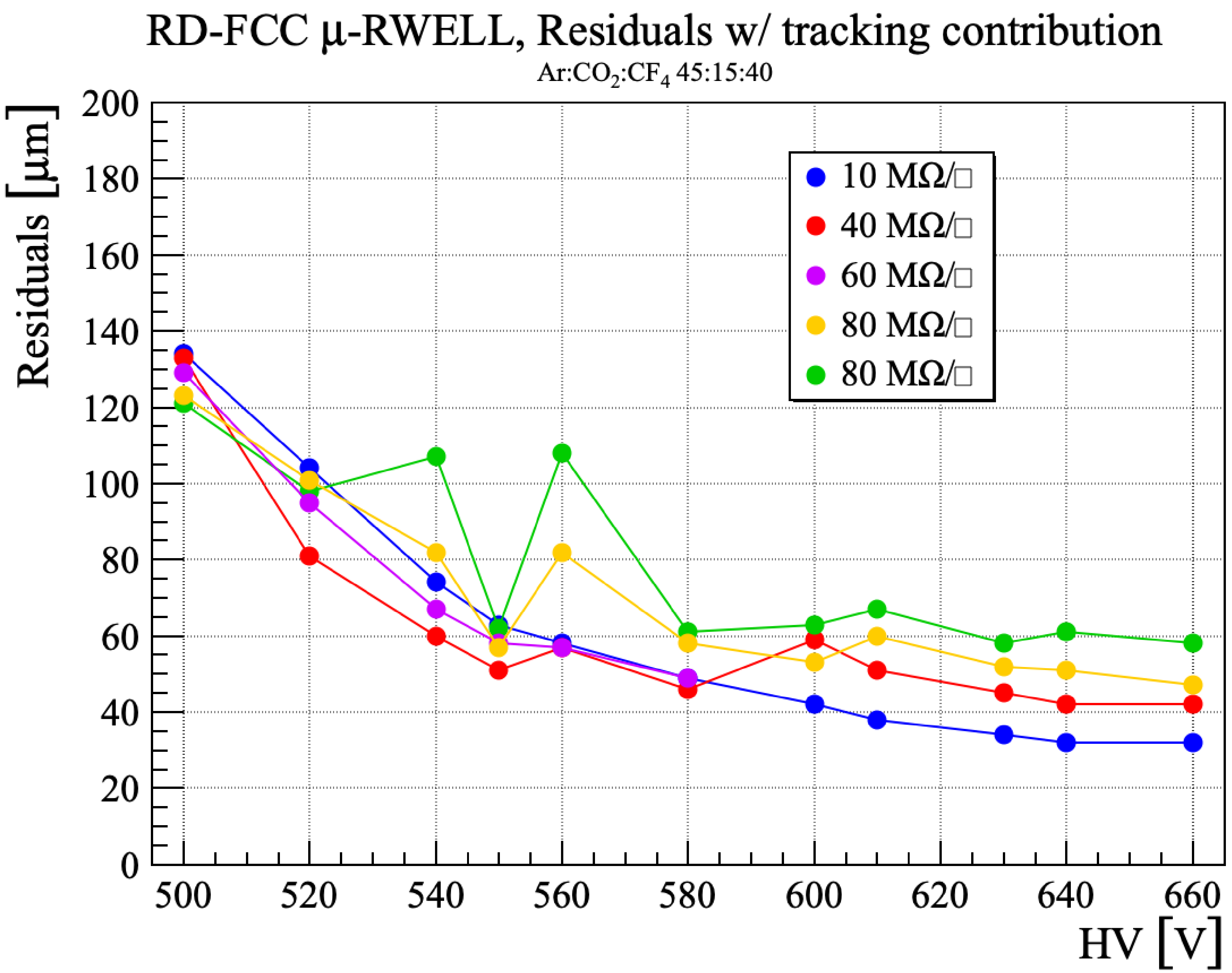
Beam test: resistivity validation

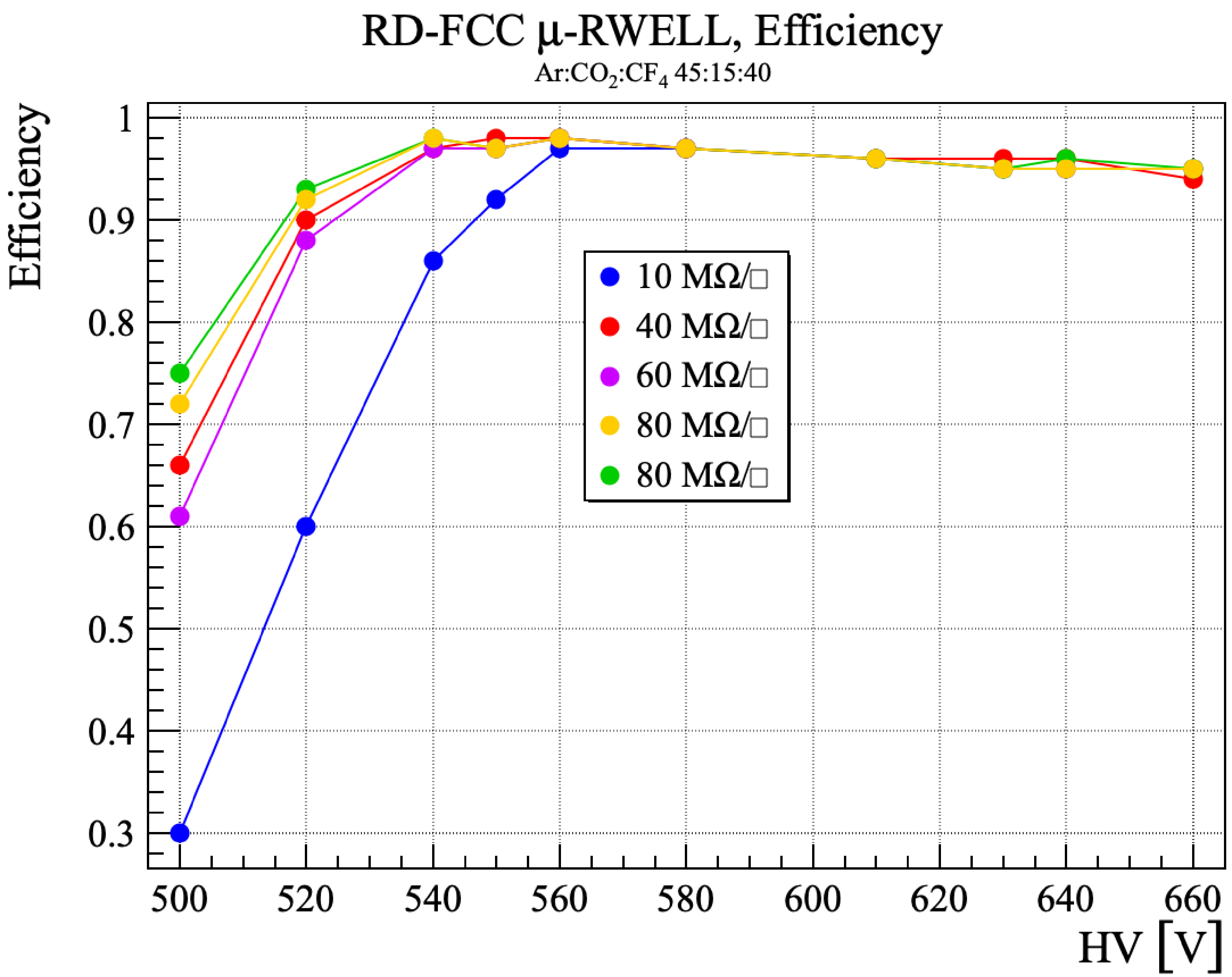
- R&D: optimal DLC resistivity by studying spatial performance
  - Preshower: 10, 30, 50, 70, > 100-200 MΩ/□
  - Muon: 15, 35 MΩ/□
- e.g.: effect of resistivity on charge spread



Beam-test results

✦ Residuals and efficiency for different resistivities





2D μ-RWELL ideas

μ-RWELL w/ 2D anode readout

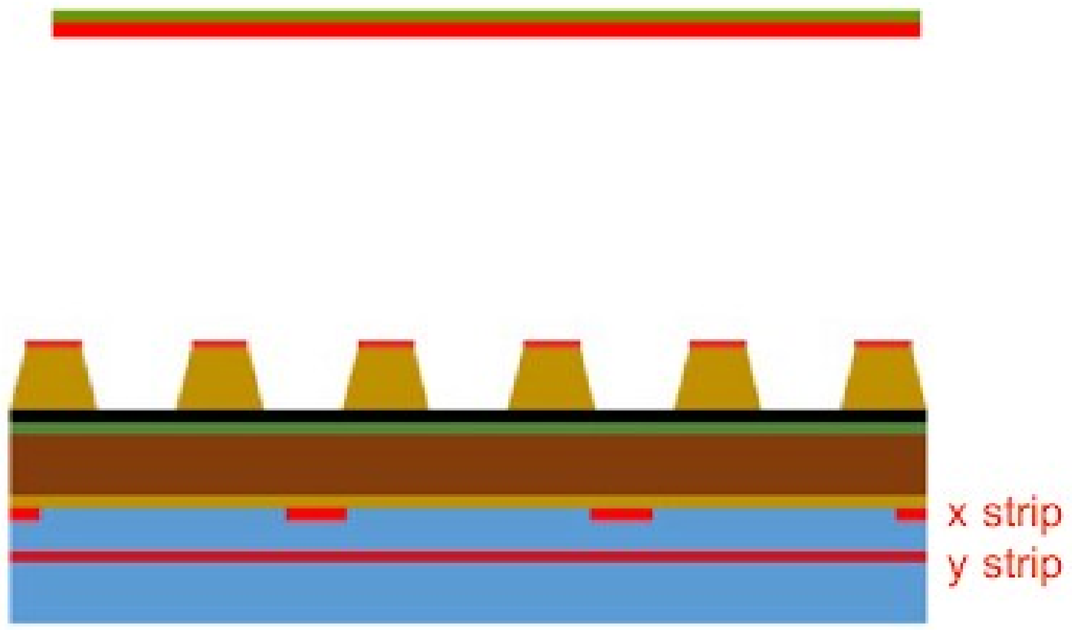
- Good performance but need higher gain wrt. 1D
- More complex PCB construction

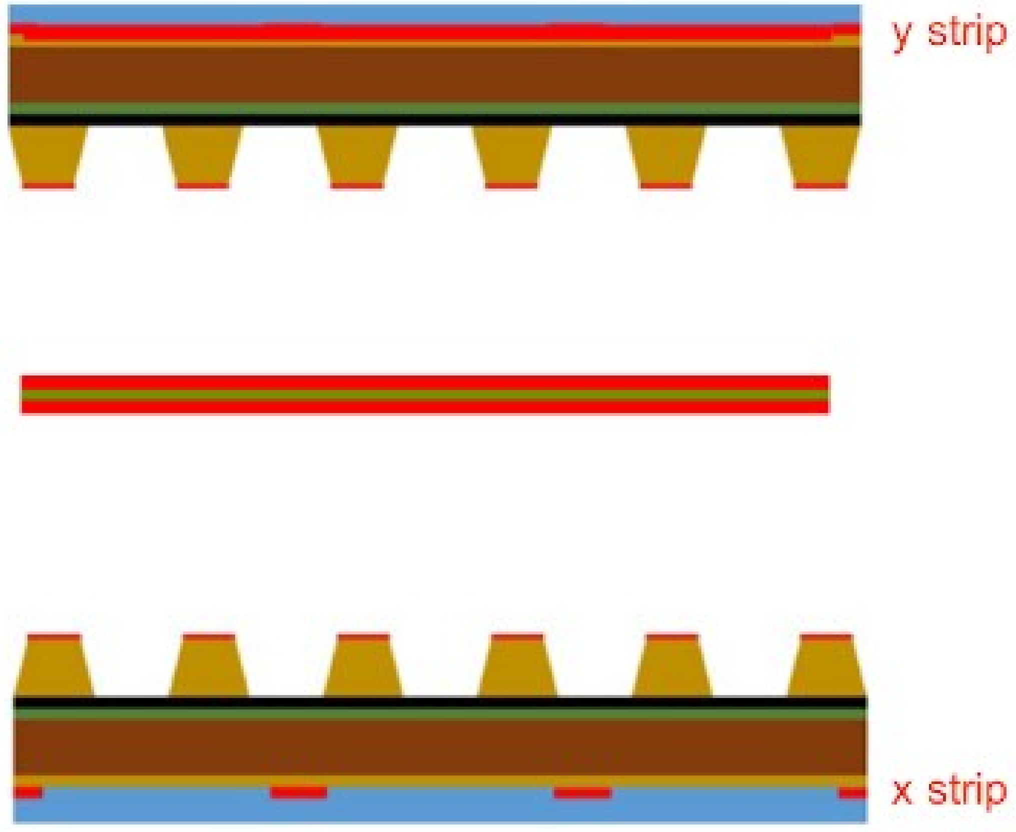
μ-RWELL with strips on top and anode

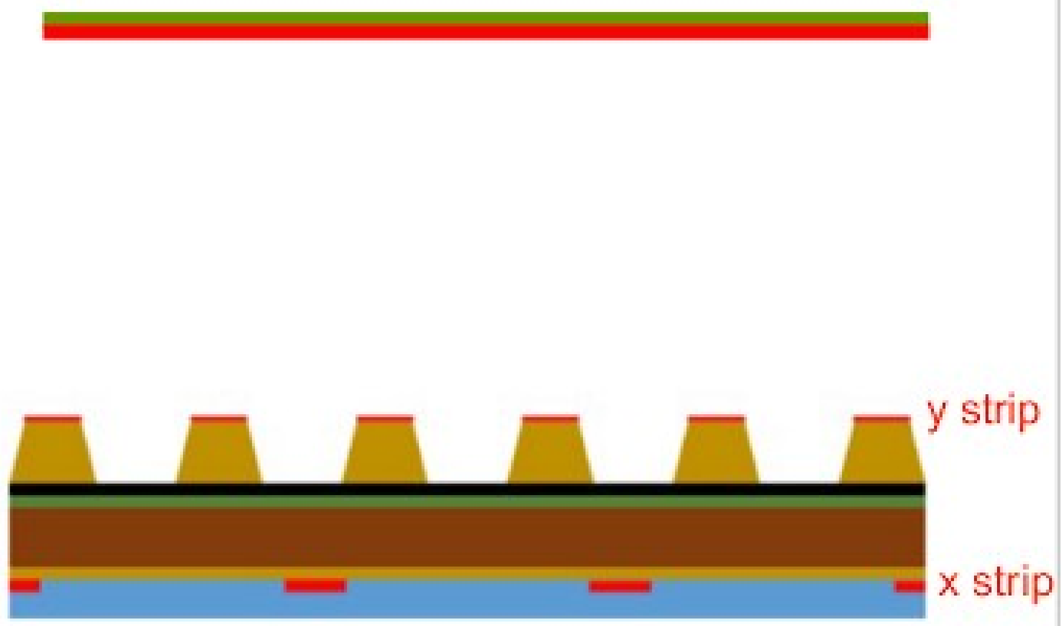
- HV on DLC
- TOP to ground
- 2D performance to be measured

2 stacked 1D μ-RWELL

- 1 view per μ-RWELL
- easy PCB construction
- 2D performance to be measured



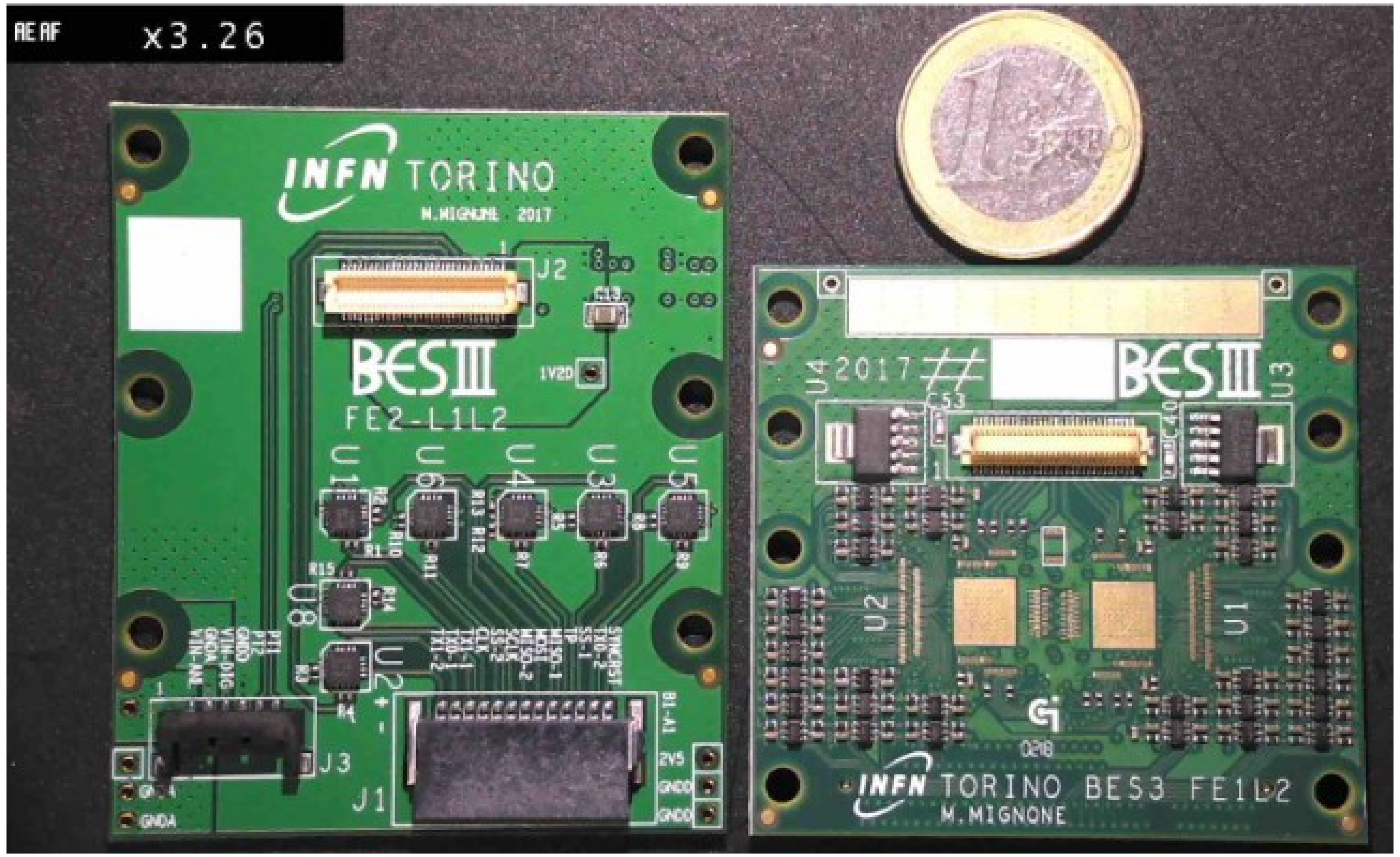




µ-RWELL ASIC

- Test with TIGER ASIC
  - developed for BESIII CGEM-IT

- Prepare new readout card based on System On Modules
  - aim: develop dedicated ASIC for µ-RWELL



Measured performance TIGER ASIC

Parameters	Values
Input charge	5-55 fC
TDC resolution	30 ps RMS
Time-walk (5-55 fC range)	12 ns
Average gain	10.75 mV/fC
Nonlinearity (5-55 fC range)	0.5%
RMS gain dispersion	3.5%
Noise floor (ENC)	1500 e^-
Noise slope	10 e^-/pF
Maximum power consumption	12 mW/ch