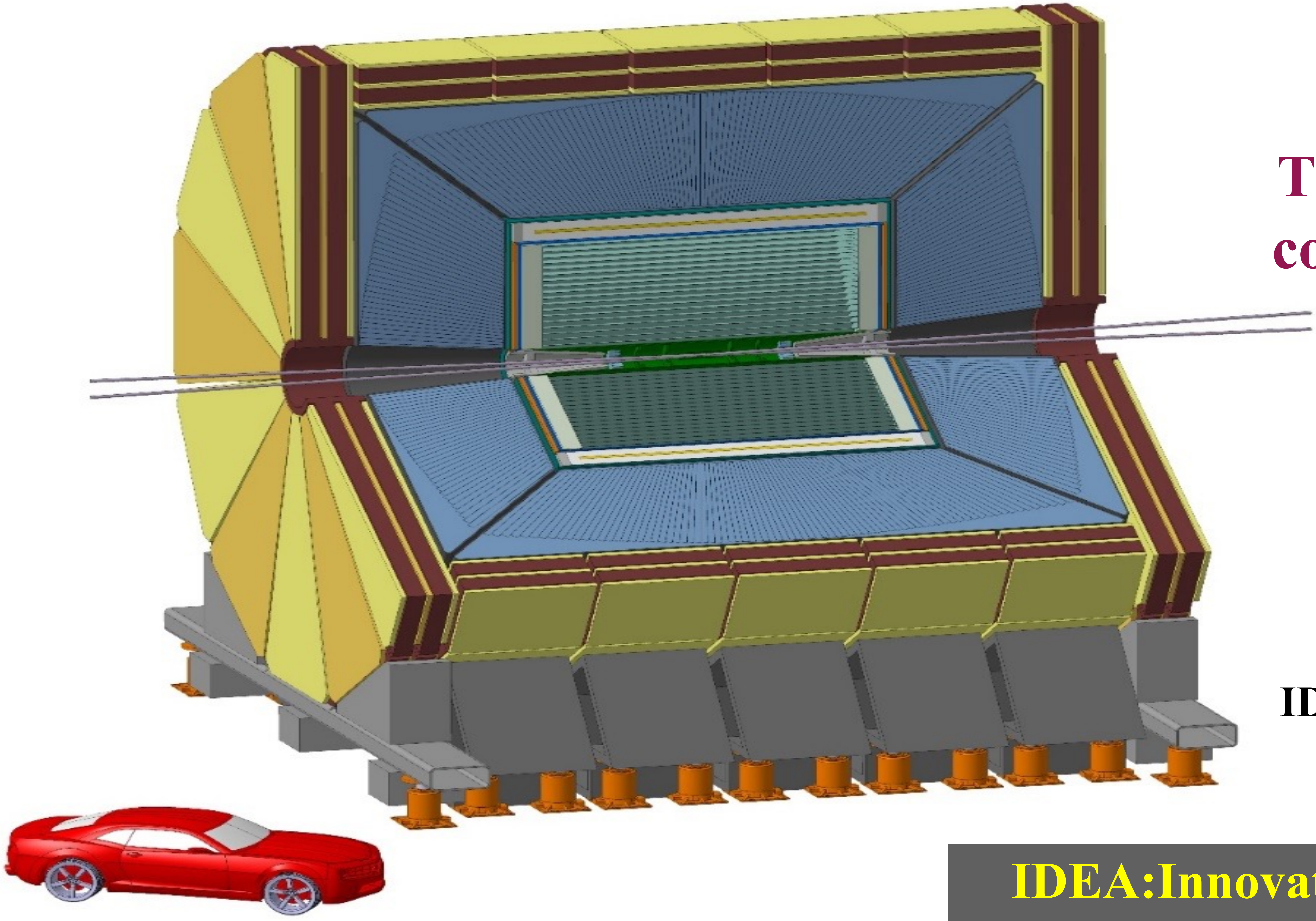


The IDEA detector concept for FCC-ee and CepC

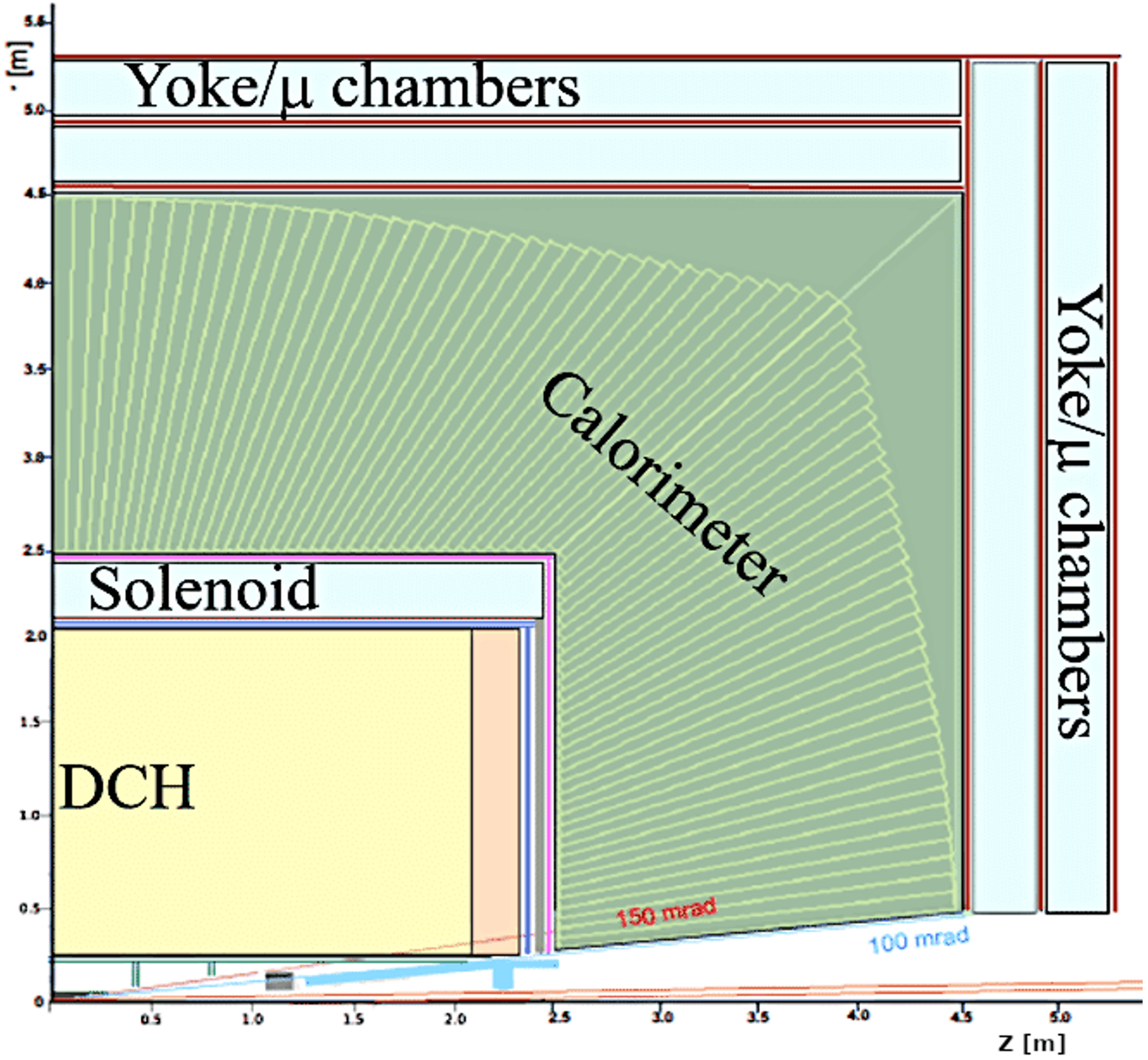
G. Gaudio
(INFN Pavia)

on behalf of the
IDEA proto-collaboration

IDEA:Innovative Detector for e^+e^- Accelerator

IDEA concept

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



FCC-ee/CepC General requirements

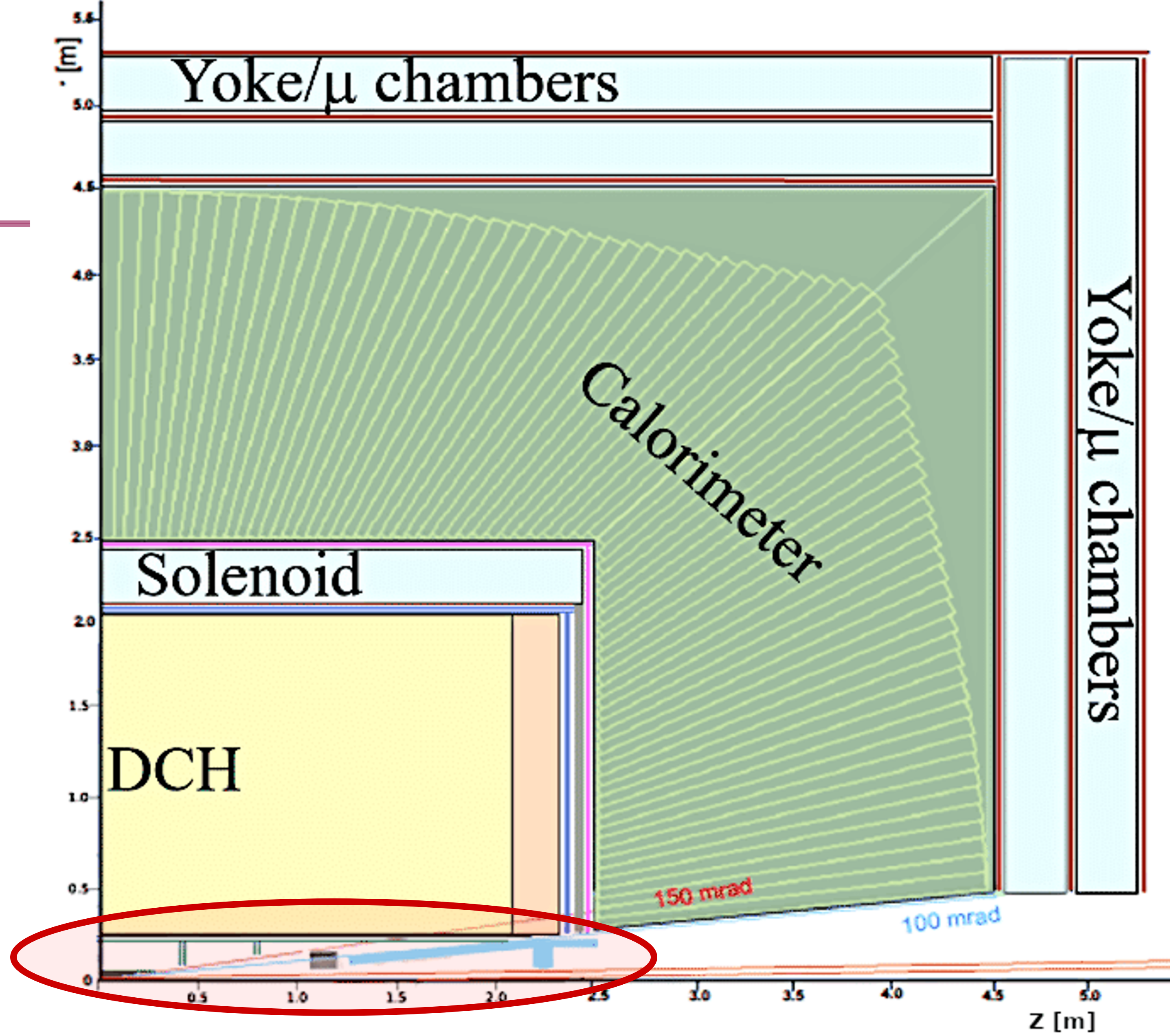
- $\Delta(1/p_T)$
  - high precision measurement at the end of tracker
- $\sigma_{r\Phi}$
  - finely segmented vertex detector
- Challenging requirements for detector materials

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

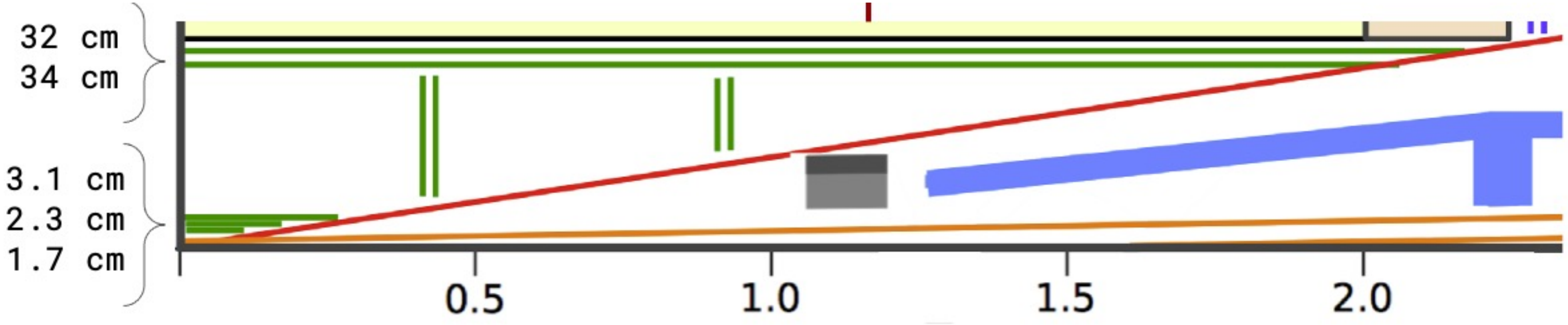
Requirements

- Fast readout
- Low power **< 20 mW/cm^2**
- Low material ~ **0.15 X_0**
- Spatial resolution ~ **3 μm**
- Efficiency ~**100%**
- Extremely low fake rate

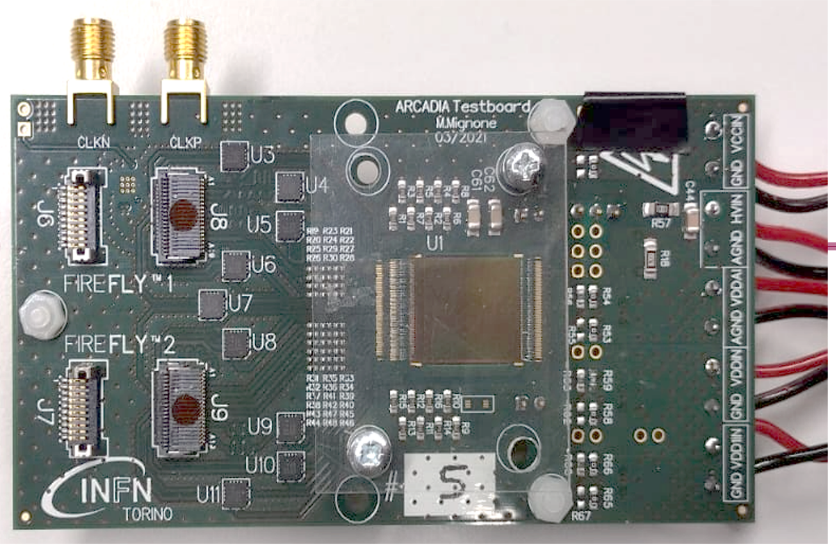


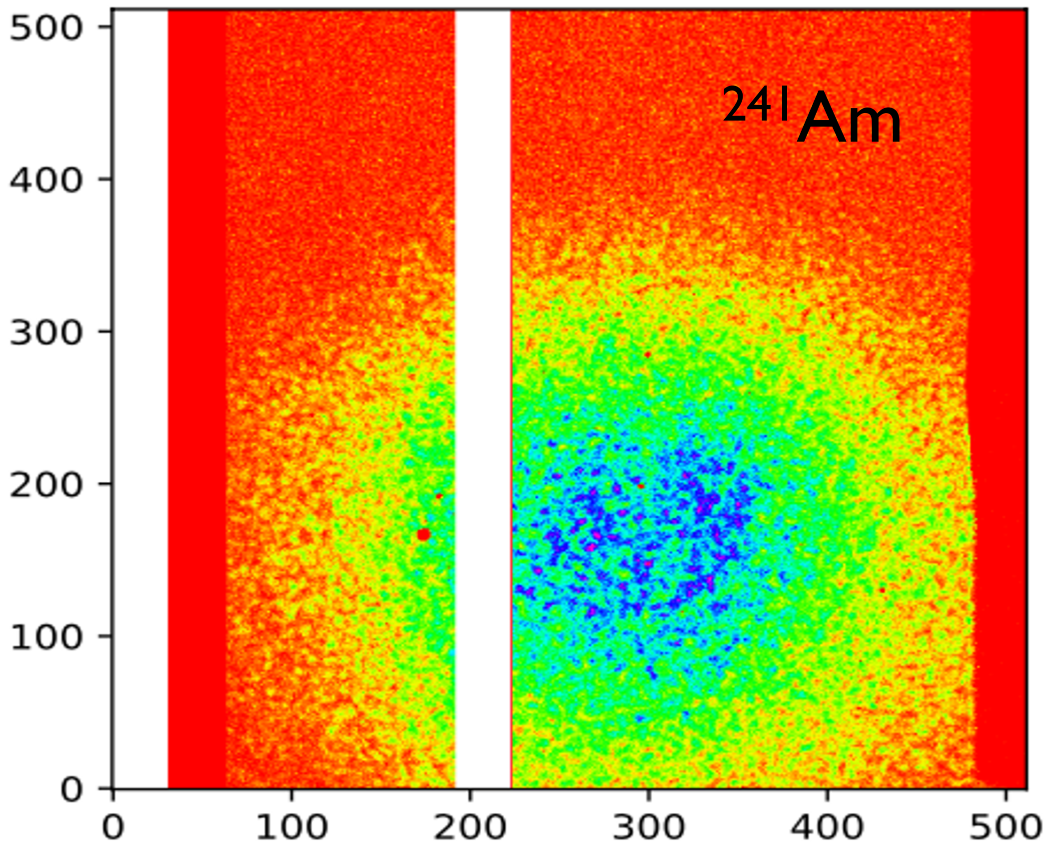
Inspired by ALICE ITS based on MAPS technology,

exploiting progress in the ARCADIA R&D program

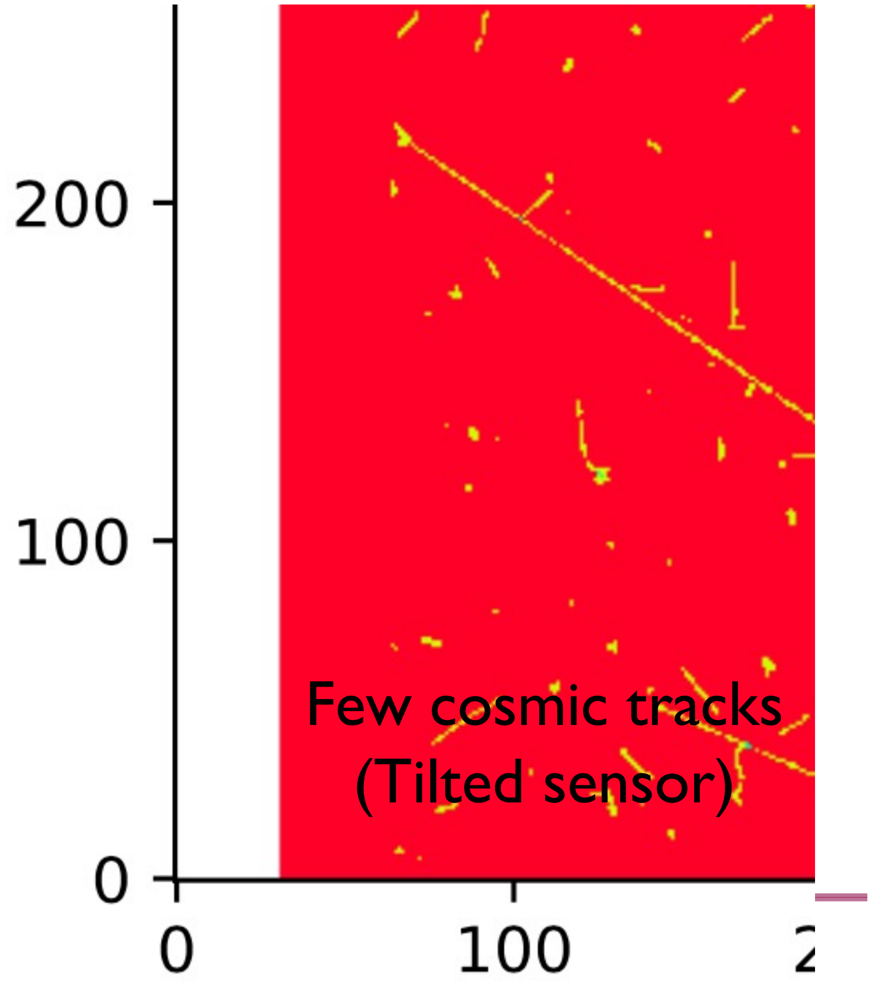


Arcadia project



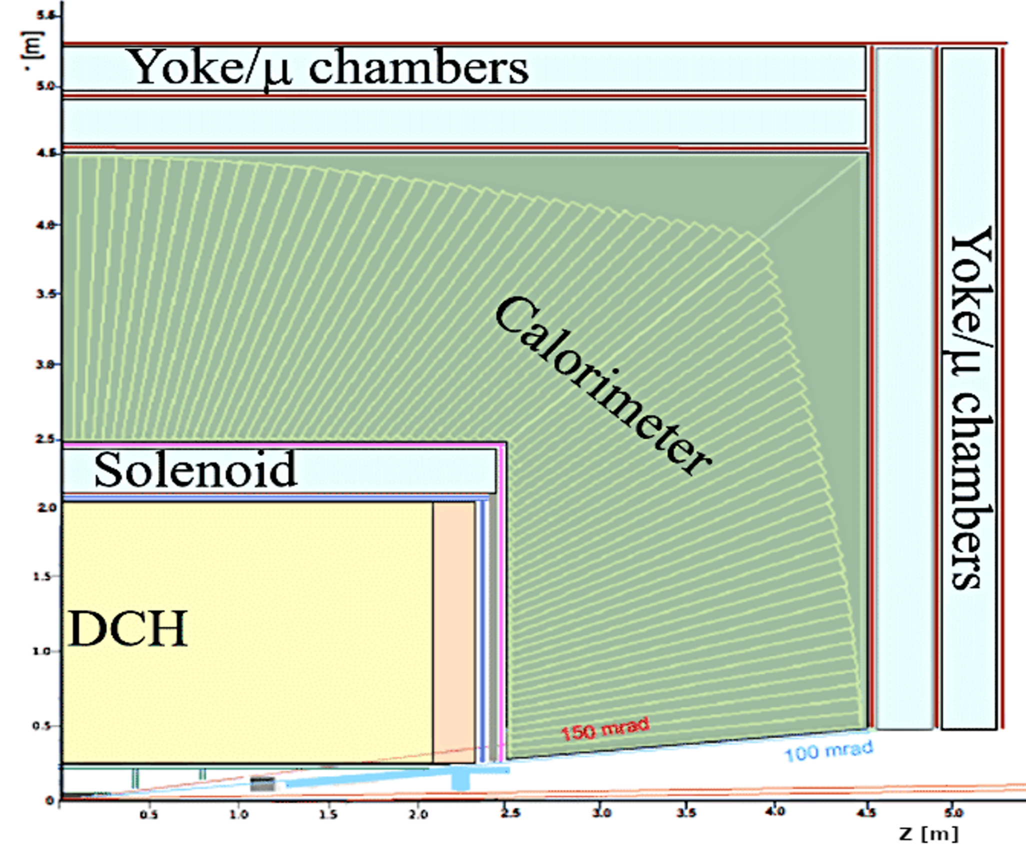


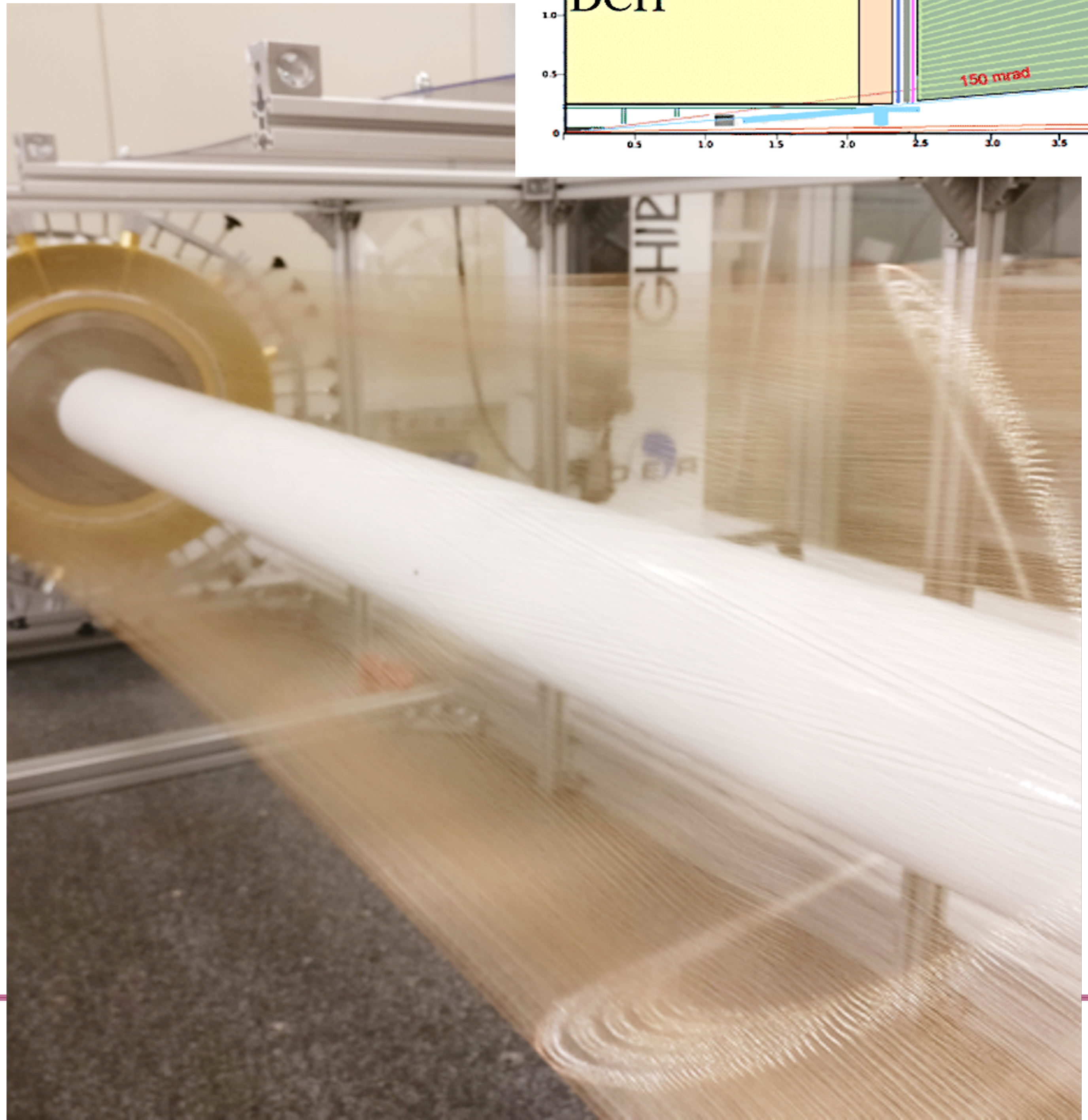
- ✦ CMOS DMAPs Platform
  - INFN project, w/ CH and China
  - Project within EU AIDAInnova
- ✦ ARCADIA-MD1: pixels 25×25 μm^2
  - tested sensor and back-side processing
  - readout architecture charact. ongoing
  - 110 nm CMOS CIS technology, high-resistivity bulk, operated in full depletion mode
  - Matrix = 512 x 512 pixels
  - Thickness = 200 μm
- ✦ ARCADIA-MD2 submitted in summer '21
  - design and architecture improvements targeting power reduction, scalability



Drift CHamber

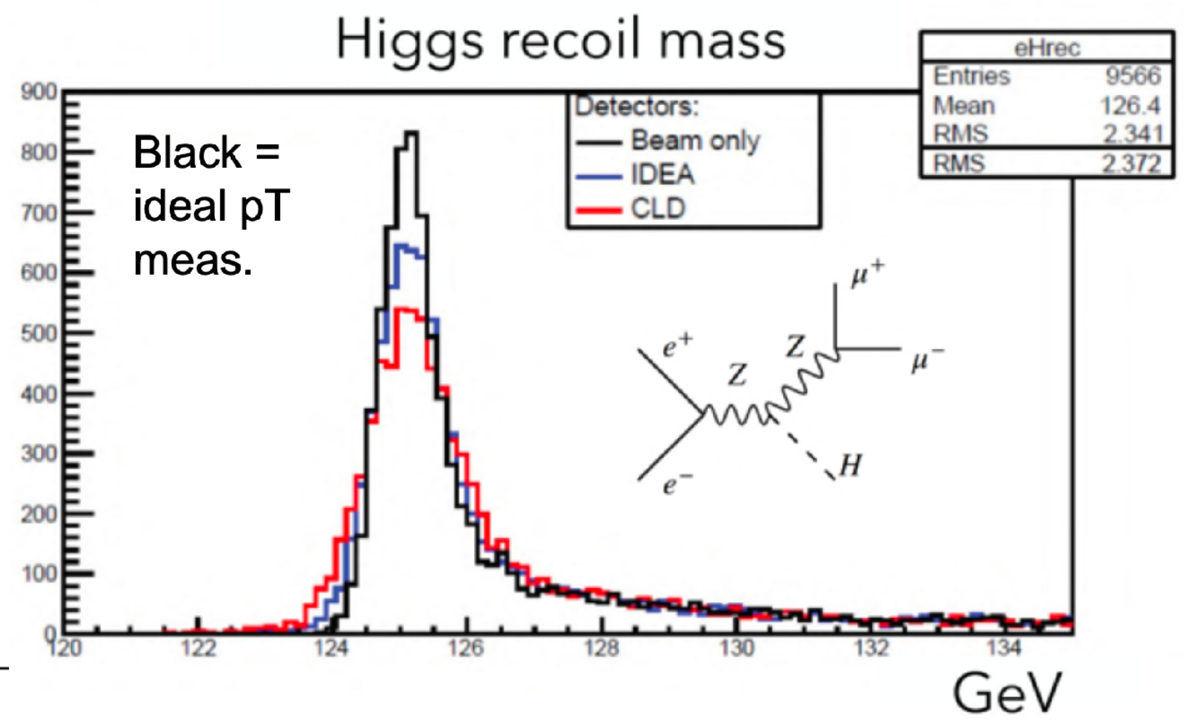
- Compromise between granularity and transparency
  - High momentum resolution
  - Ultra light detector
  - Assisted by Si wrappers
- Dimensions
  - L = 400 mm
  - R = 35 ÷ 200 cm
  - Total thickness: 1.6% of X_0 at 90°
    - Tungsten wires dominant contribution
  - 112 layers for each 15° azimuthal sector
- Inherit from previous DCHs
  - KLOE and MEG II

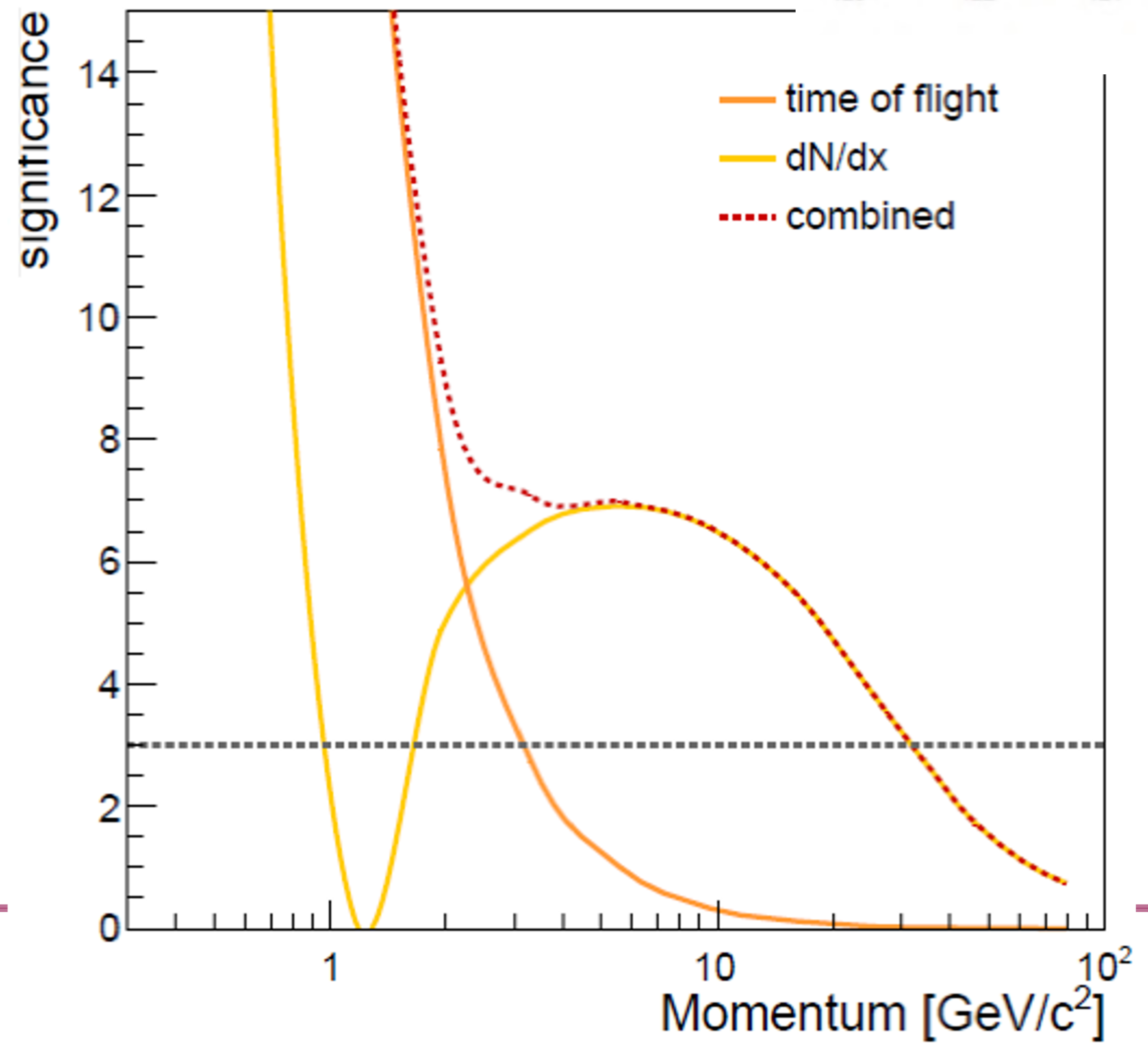




DCH: Particle ID with cluster counting

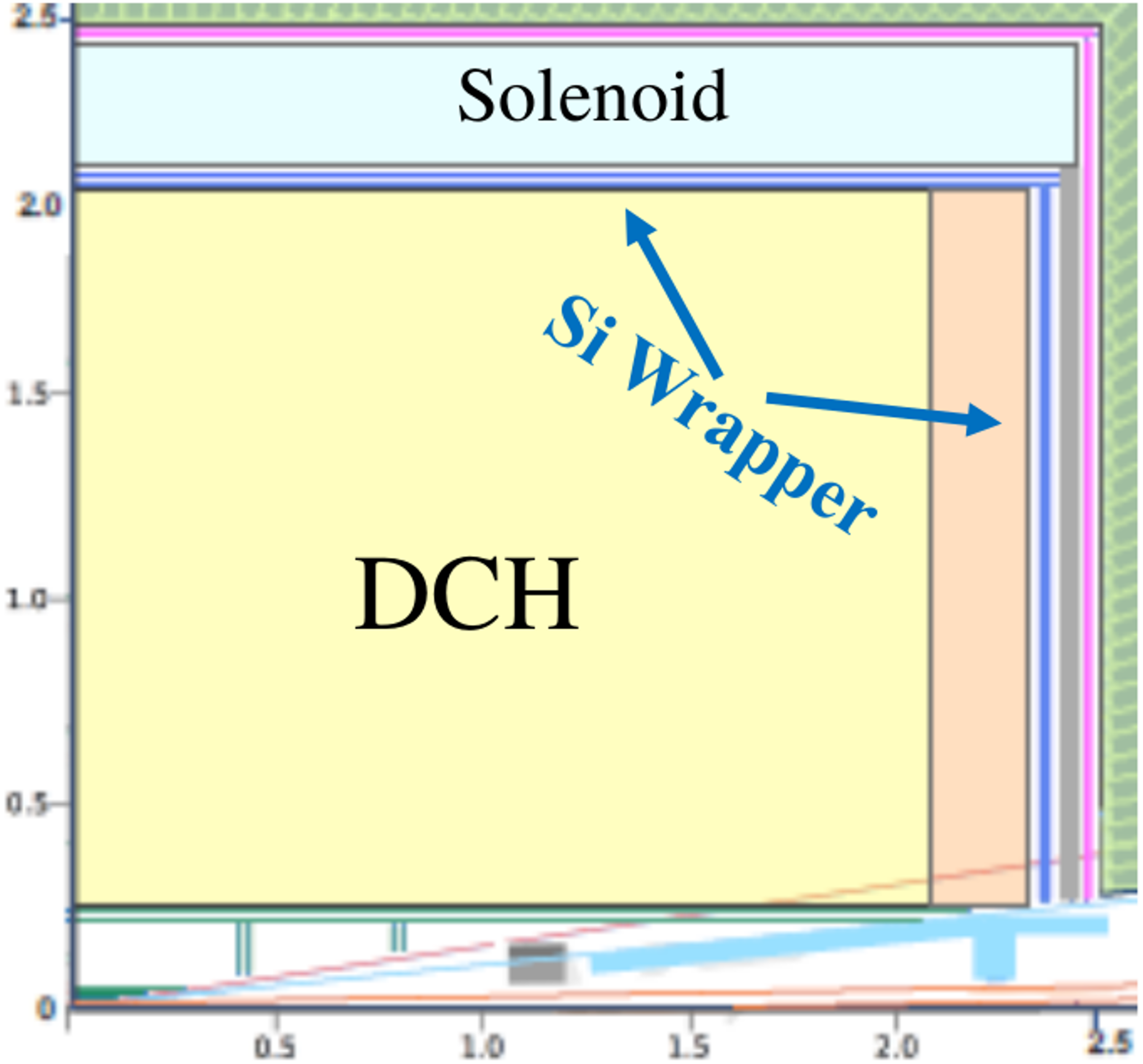
- Tracks have rather low momenta ($p_T \lesssim 50$ GeV)
  - Transparency more relevant than asymptotic resolution
- He based gas mixtures (90% He – 10% iC_4H_{10})
  - ionization signals last few ns
  - max drift time: 350 ns
- Fast readout (~GHz sampling)
- PID counting dN_{cl}/dx
  - # of ionization acts per unit length
  - PID w/ better resolution than dE/dx
- 0.75 < p < 1.05 gap recoverable with timing layer
  - 100 ps enough for 3σ K/p





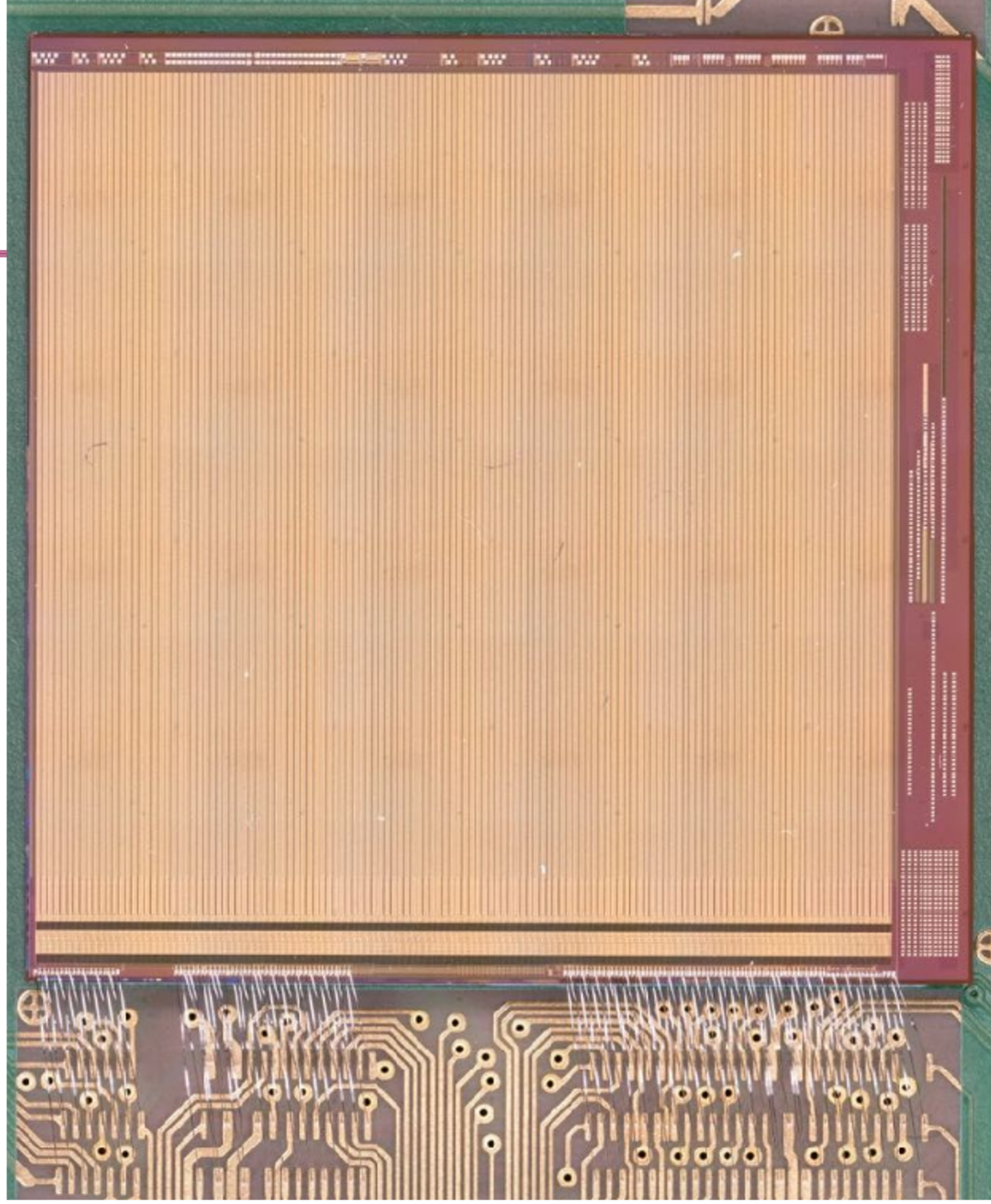
Si wrappers

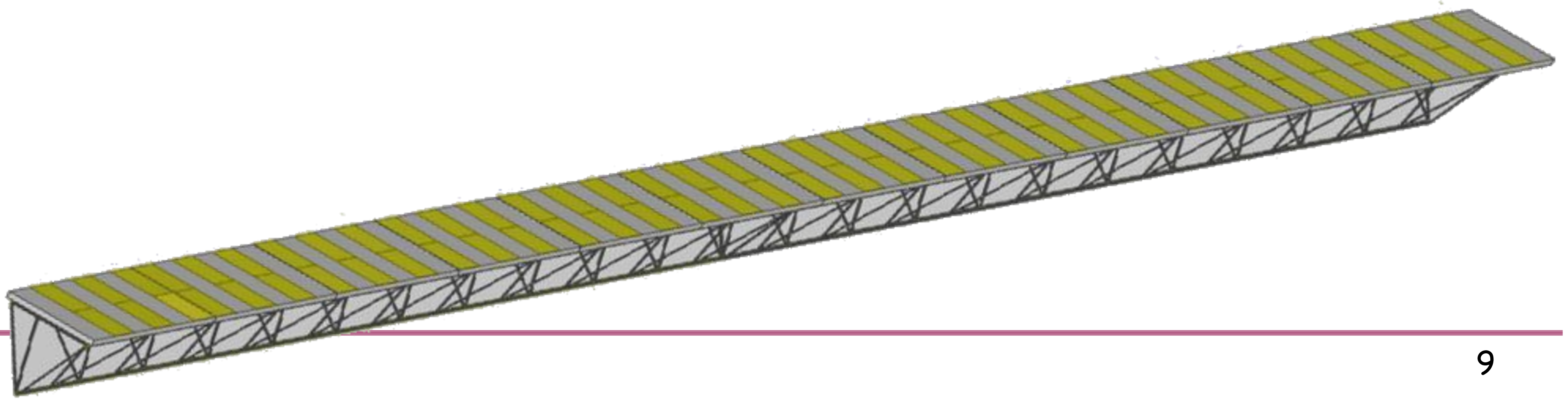
- Precision Si layer around DCH
  - momentum resolution
  - extend tracking coverage in the forward/backward region
  - precise and stable ruler for acceptance definition
- Suitable technologies
  - microstrips (2 layers)
  - DMAPS, e.g.: ATLASPIX3



Si wrappers: ATLASPIX3

- pixel size 50×150 μm^2
  - 150 mW/cm^2
  - both triggerless and triggered readout
  - First 2 multi-chip modules has been operated successfully
- Target: build few mini-staves of an outer tracker for FCCee/CepC
  - 2022: realization of prototypes and thermo-mechanical characterization

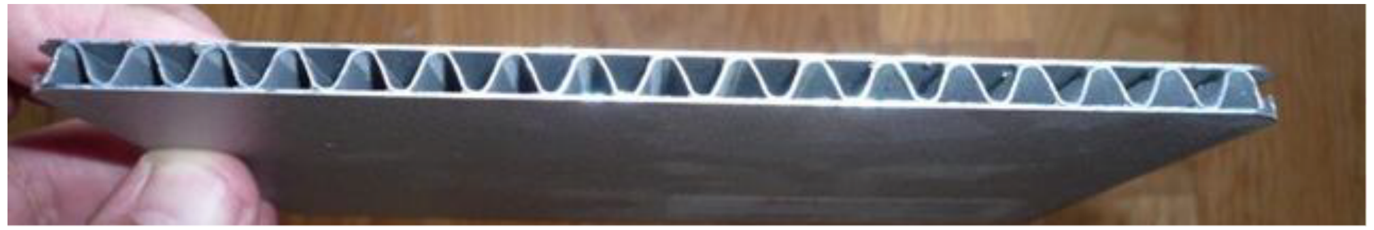


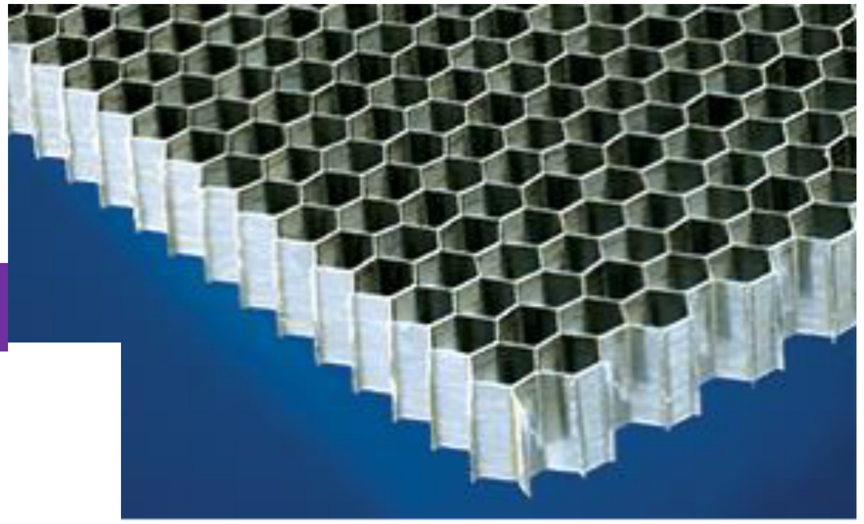


Superconducting solenoid

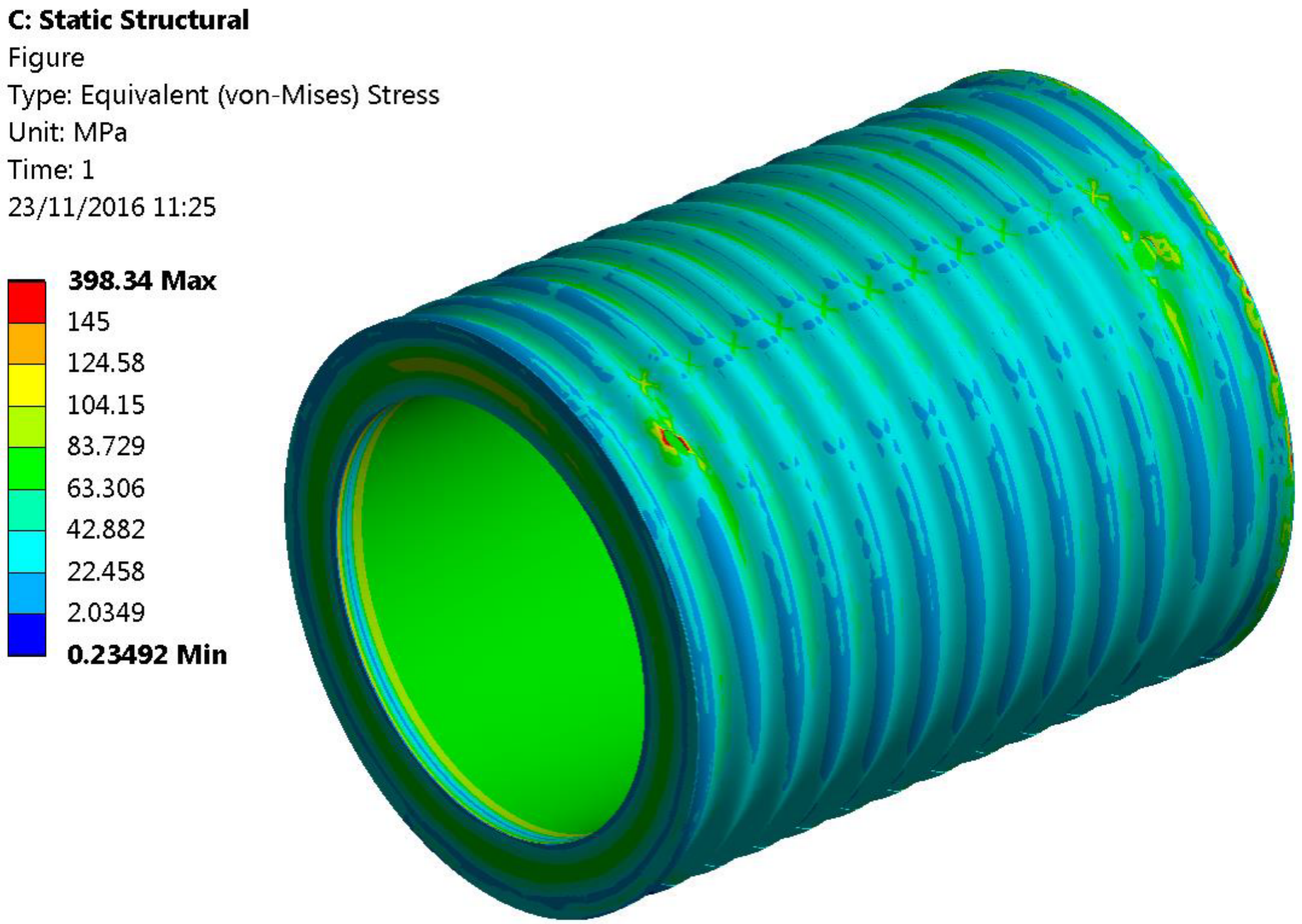
Ultra light 2 T solenoid:

- Radial envelope 30 cm
- Single layer self-supporting winding (20 kA)
  - Cold mass: $X_0 = 0.46$, $\lambda = 0.09$
- Vacuum vessel (25 mm Al): $X_0 = 0.28$
  - Can improve with new technology
    - Corrugated plate: $X_0 = 0.11$
    - Honeycomb: $X_0 = 0.04$





Courtesy of H. TenKate



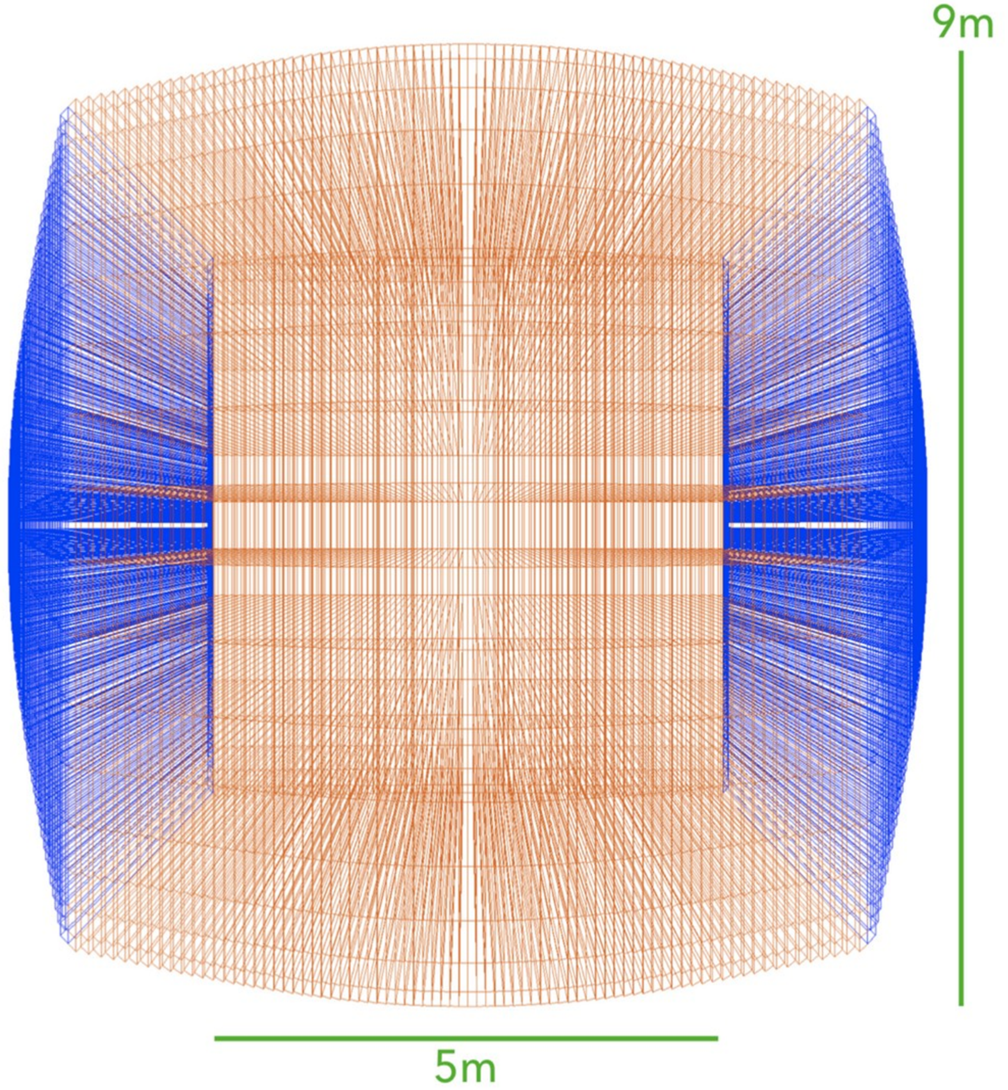
Fcc-ee/CepC general requirements

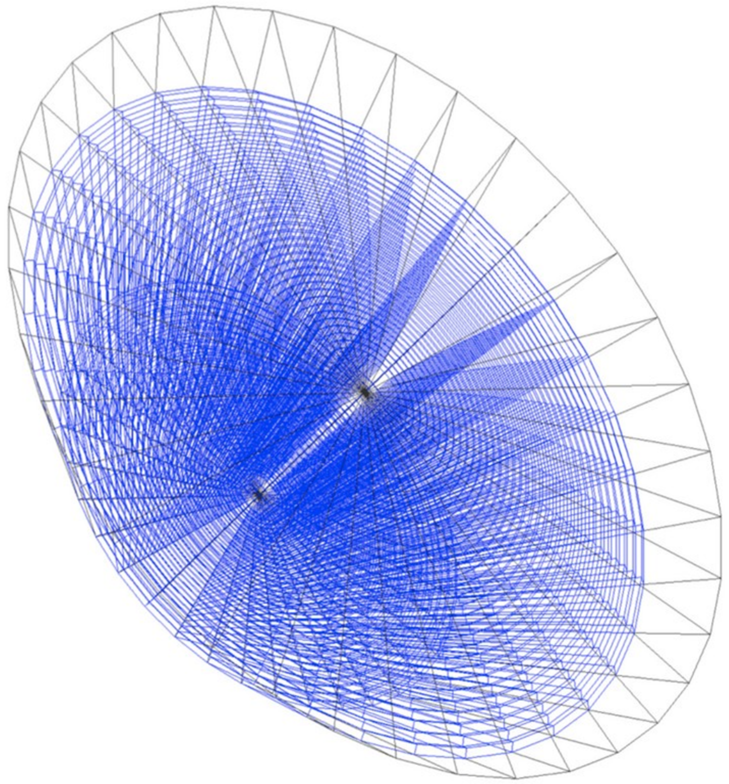
- Fair $\sigma_{EM} \sim$ 10-20% /√E sufficient for Higgs physics
- $\sigma_{jets} \sim$ 30-40% /√E to clearly identify W, Z, H in 2 jets decays
- Transverse granularity < 1 cm for π_0 from τ and HF
- It could be satisfied by
  - a dual readout fiber calorimeter w/ SiPM readout
  - a combined dual readout crystal/fiber calorimeter

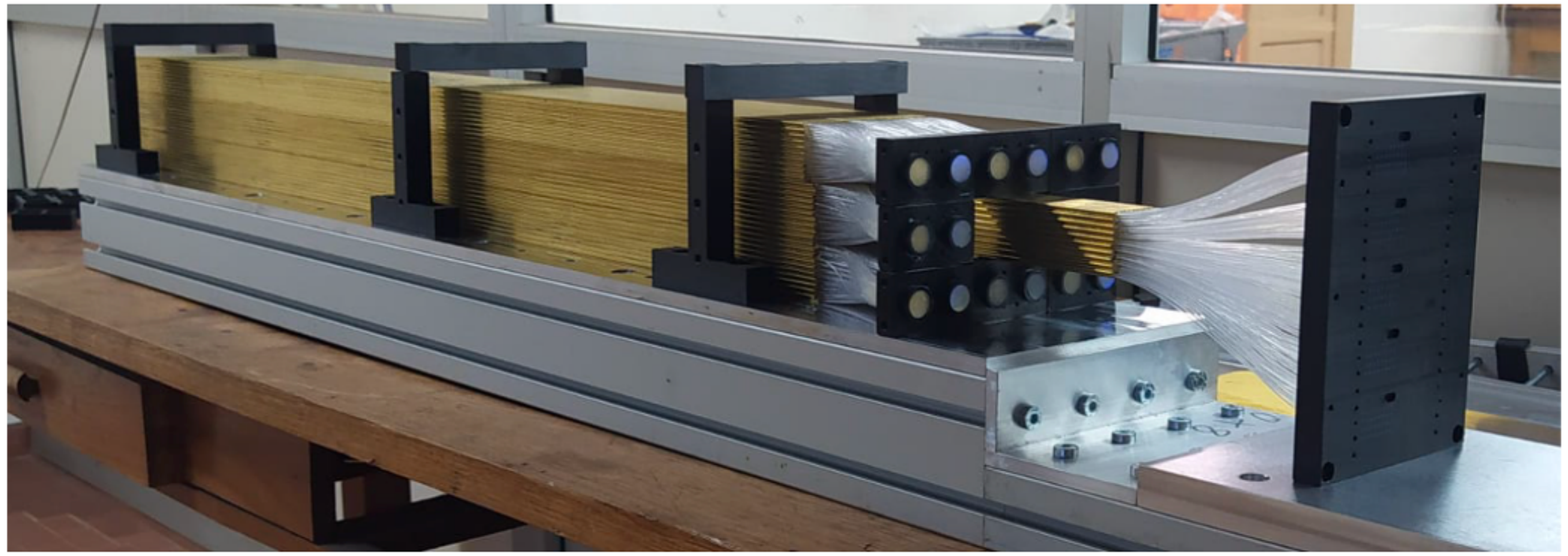
Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	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	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

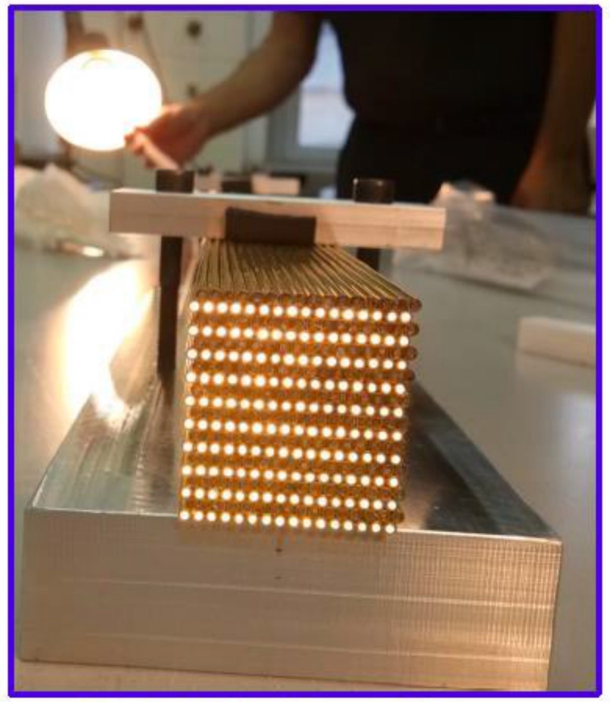
All-fiber DR calo option

- DR fiber calorimeter
  - ~ 130 M fibers
    - 1 mm ⌀, 1.5 mm pitch
  - Copper absorber
  - 75 projective towers x 36 slices
    - $\Delta\vartheta = 1.125°$, $\Delta\varphi = 10.0°$
    - ϑ coverage: ~0.100 rad
- G4 simulation available
  - Tuned to RD52 TB data

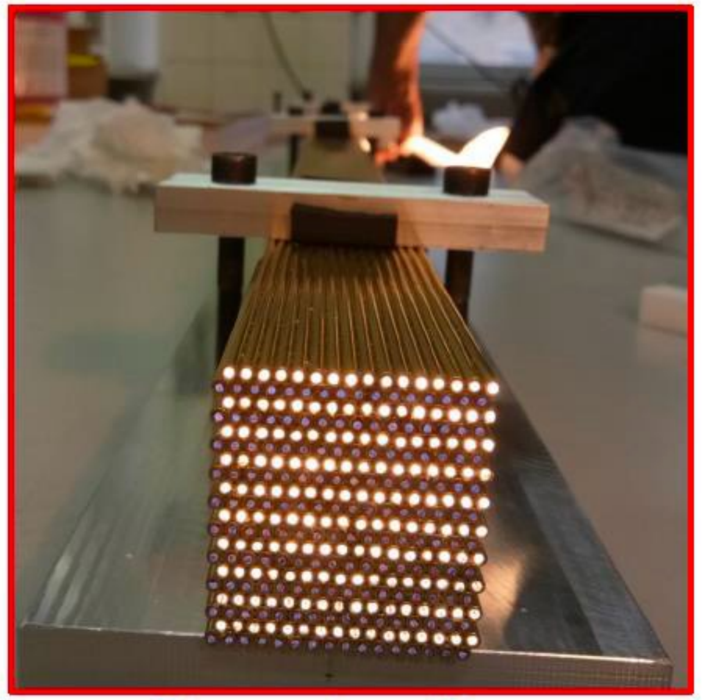








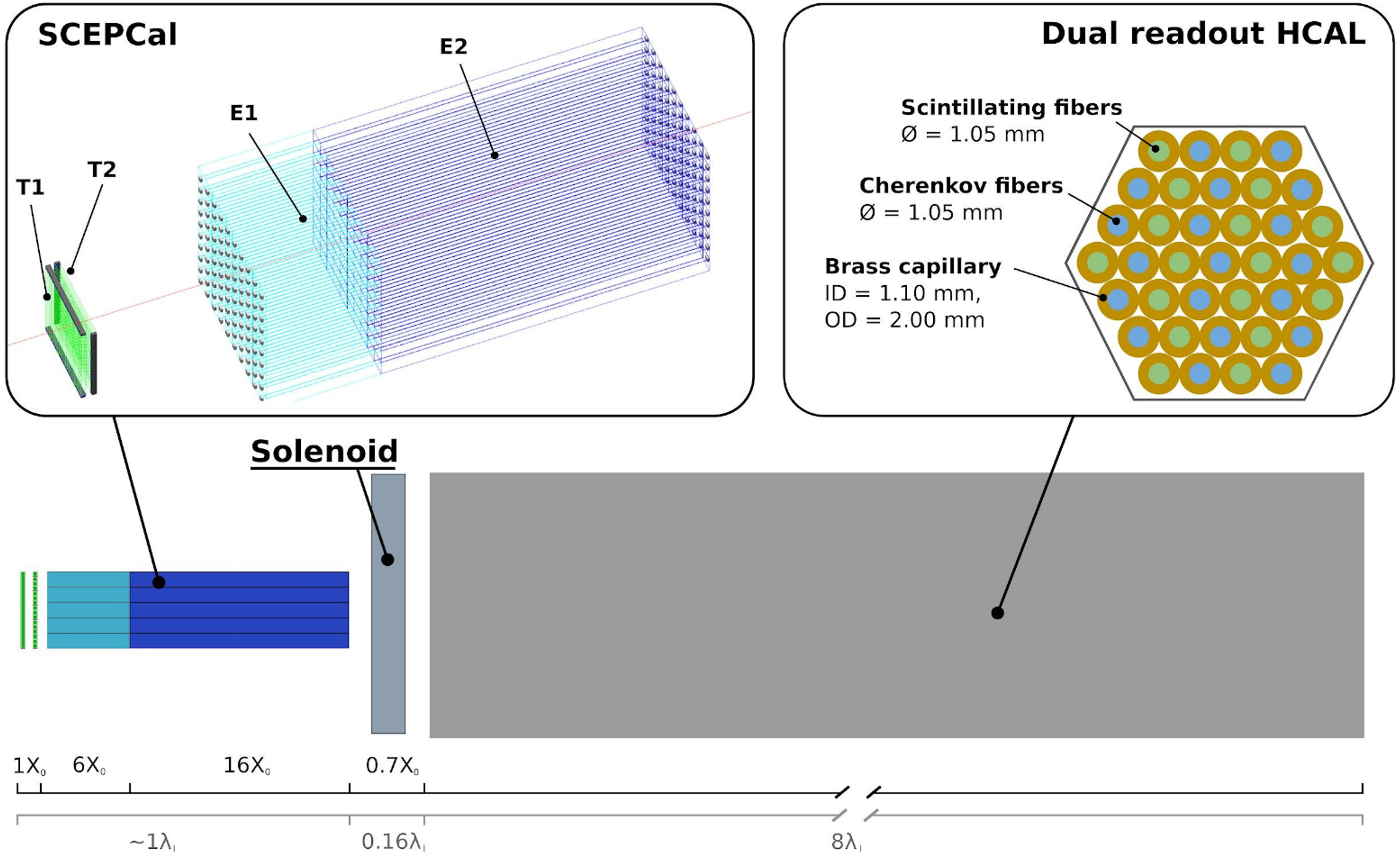
Scintillation fibers



Cherenkov fibers

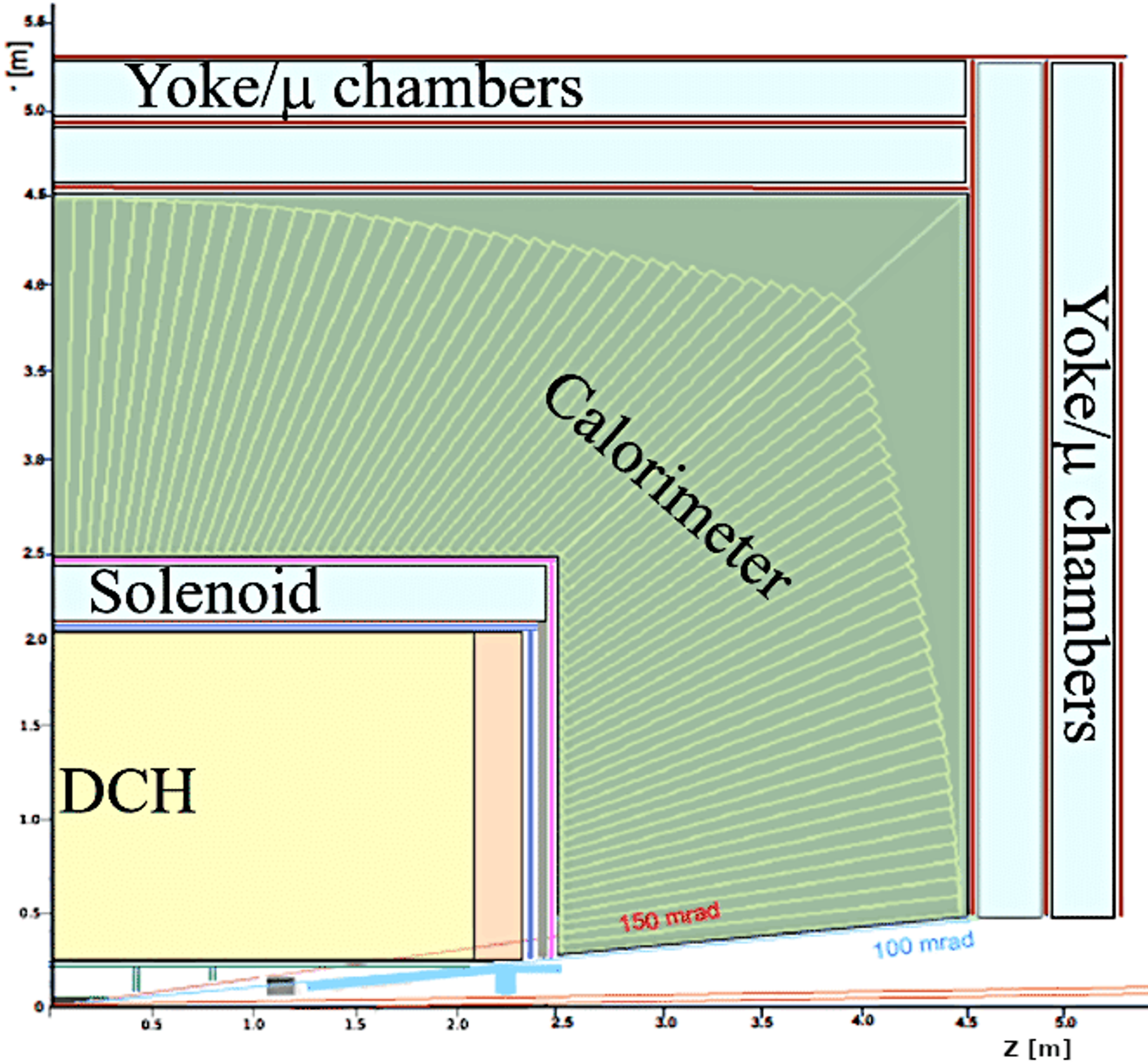
Crystal option

- 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
  - $\sigma_t \sim 20$ ps
- HCAL layer
  - $\sigma_{HAD}/E \sim 26\%/\sqrt{E}$



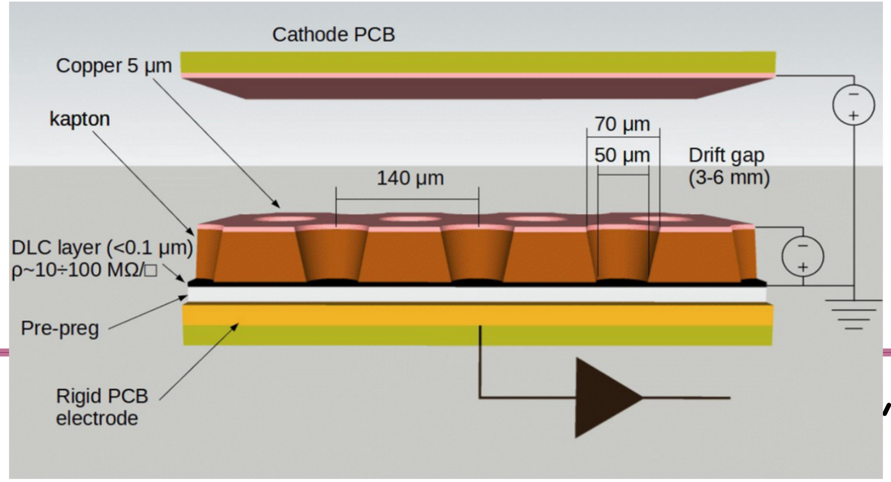
Preshower and muon detector

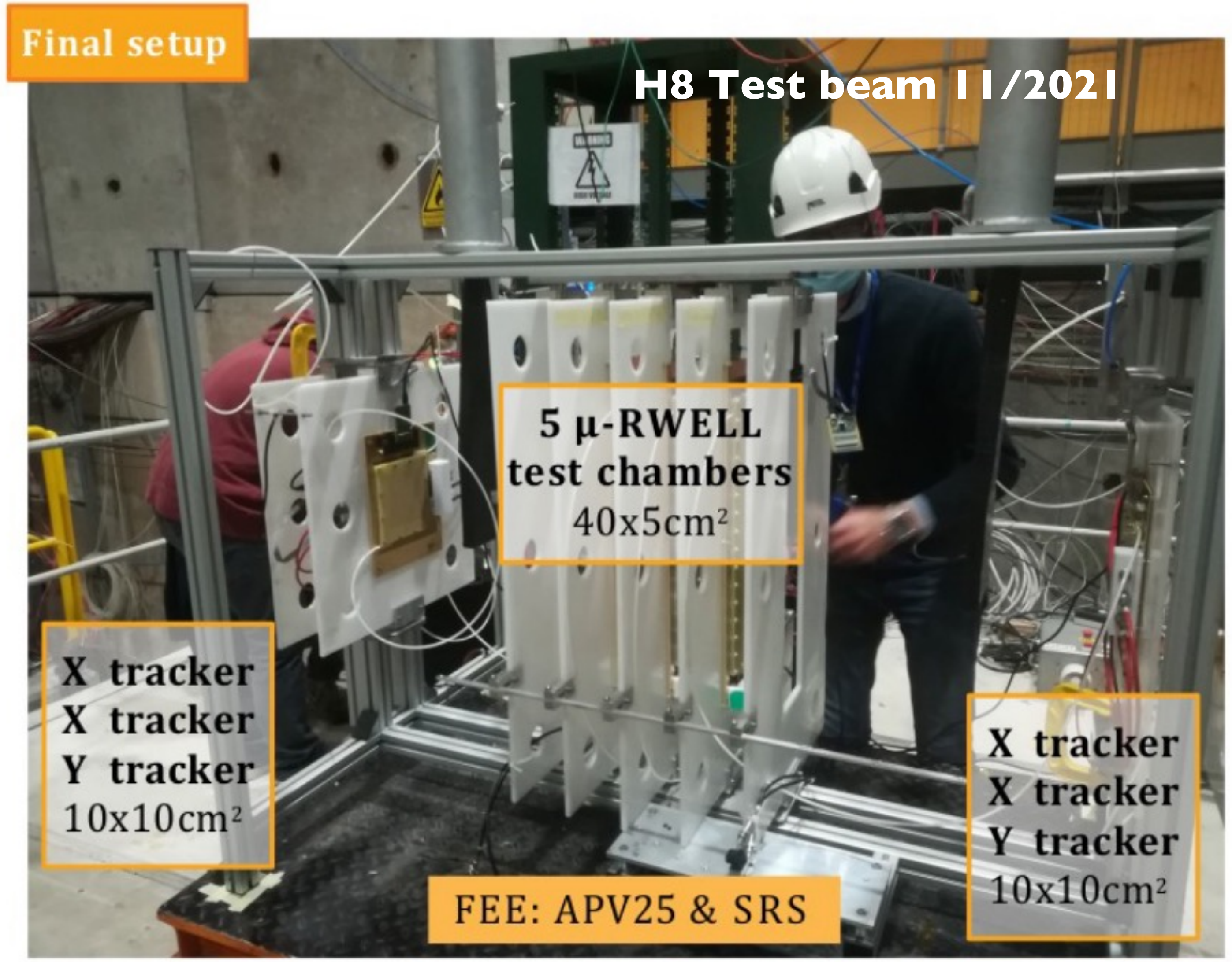
- Preshower Detector
  - High resolution space points before the calorimeter to improve cluster reconstruction
- Muon detector
  - Identify μ and search for LLPs
  - 3 layers in the return joke
- Both based on tha same technology: μ-RWELL
  - Efficiency > 98%
  - Mass production
  - Optimization of FEE channels/cost



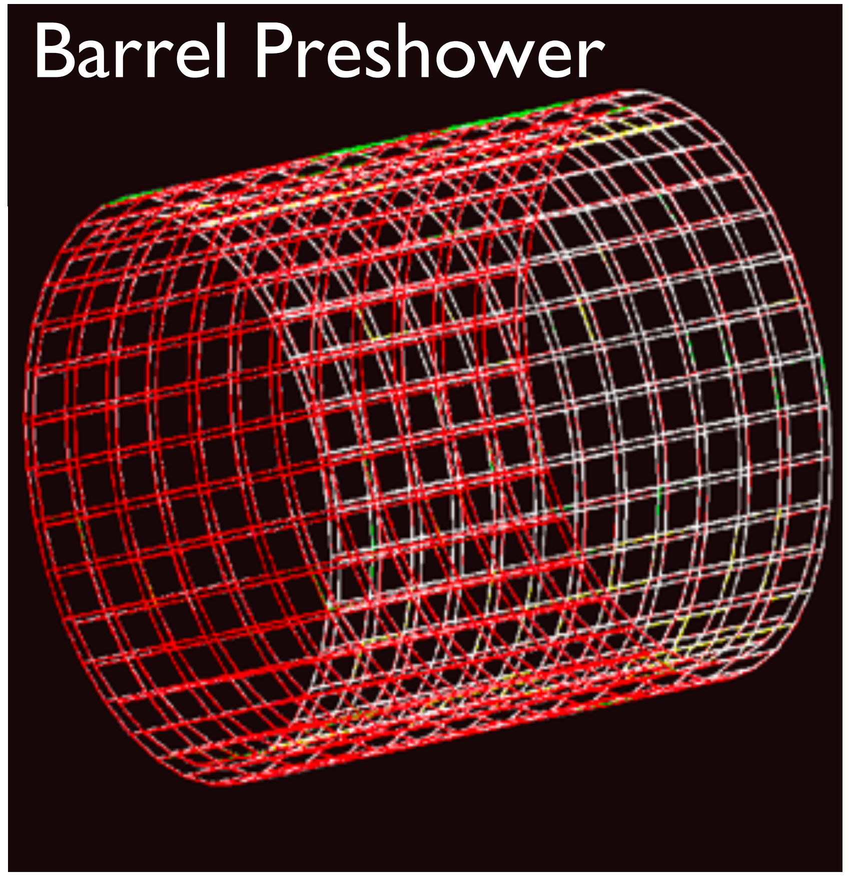
Preshower and muon detector

- ✦ **Preshower Detector**
  - ✦ Pitch 0.4 mm
  - ✦ Resolution < 100 μm
  - ✦ 1.5M channels
- ✦ **Muon detector**
  - ✦ Pitch 1.5 mm
  - ✦ Resolution < 400 μm
  - ✦ 5M channels
- ✦ **50x50 cm^2 2D tiles**
  - ✦ to cover more than 4330 m^2

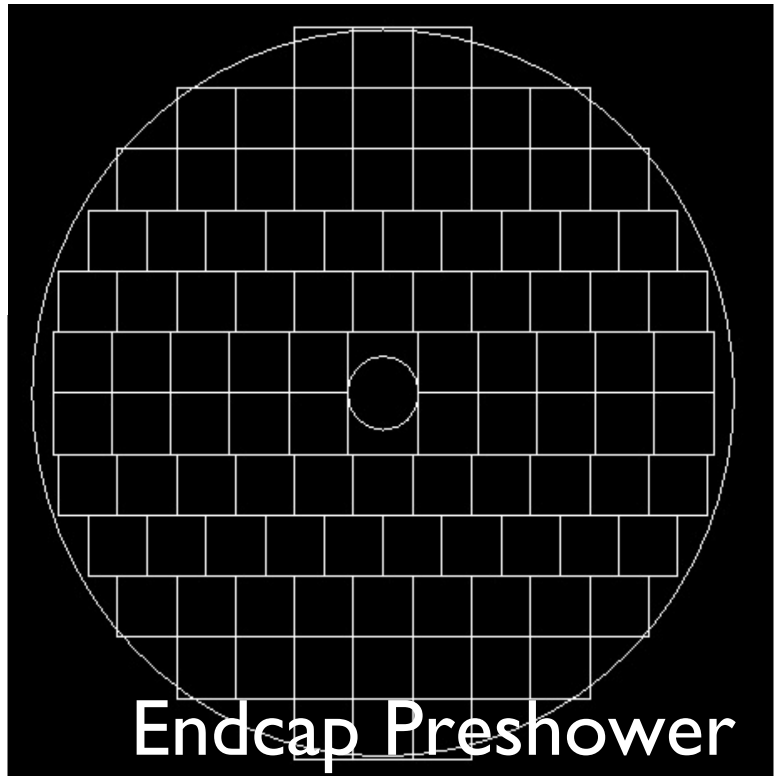




7 μ-RWELL prototypes with resistivity varying between 10 and 80 MOhm/□ will allow to define best resistivity for final 50x50 cm^2 detector



Similar design for the Muon detector



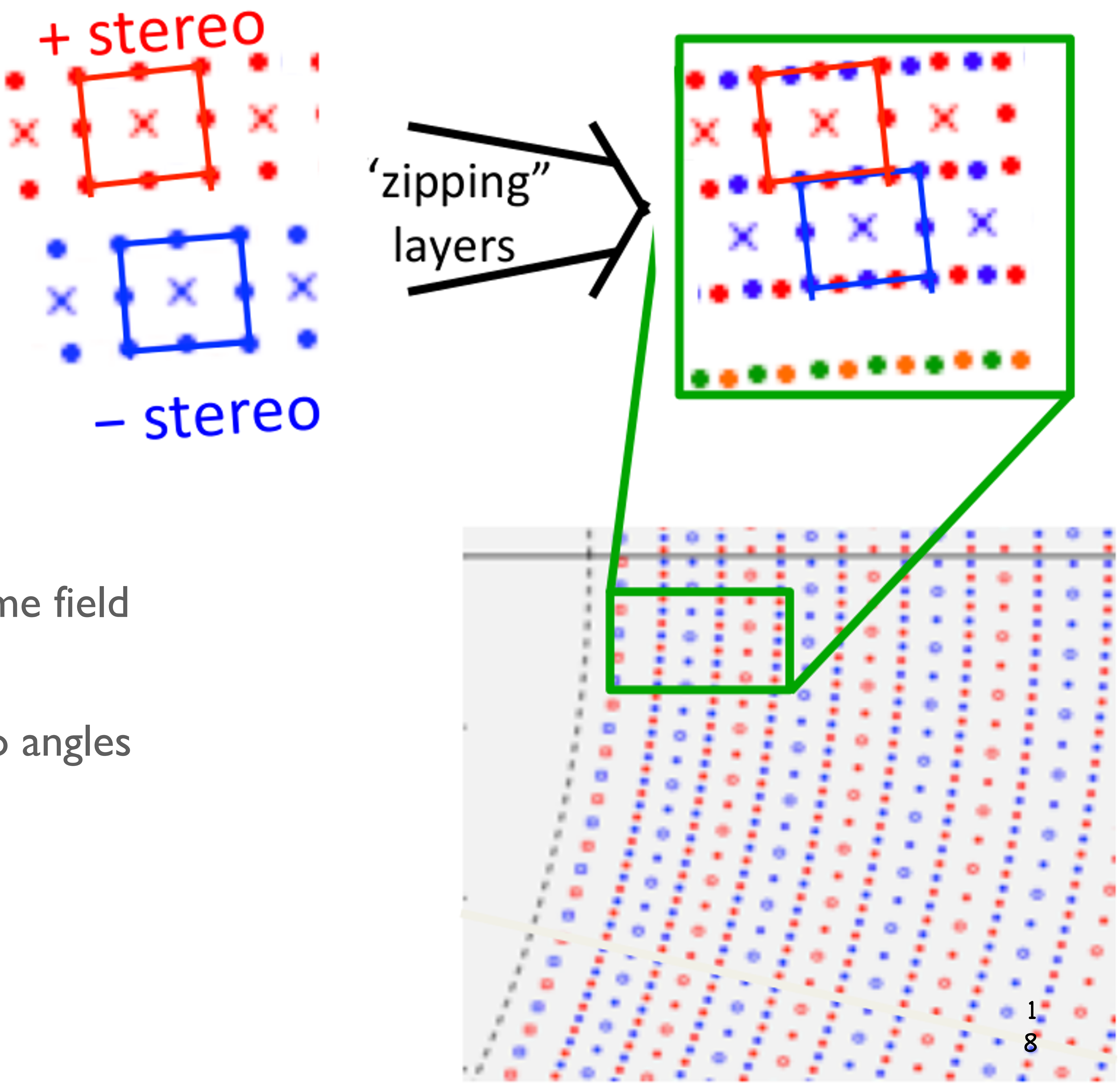
Conclusions: a lot R&Ds in each area

- Vertex detector w/ DMAPs for best momentum resolution
  - Work in progress. E.g. Arcadia
- Silicon wrapper R&D starting from the ATLASPIX3 chips
  - also for the outer layers of the vertex
- Wire chamber R&D ongoing on many aspects
  - Lot of work to demonstrate the cluster counting performances
- Dual readout: project for full containment prototype
  - EM Crystal option, w/ DR
- Preshower and muon system based μ-RWELL technology
  - R&D on DLC resistive, long strips, 2-D sensors, custom ASIC

Backup

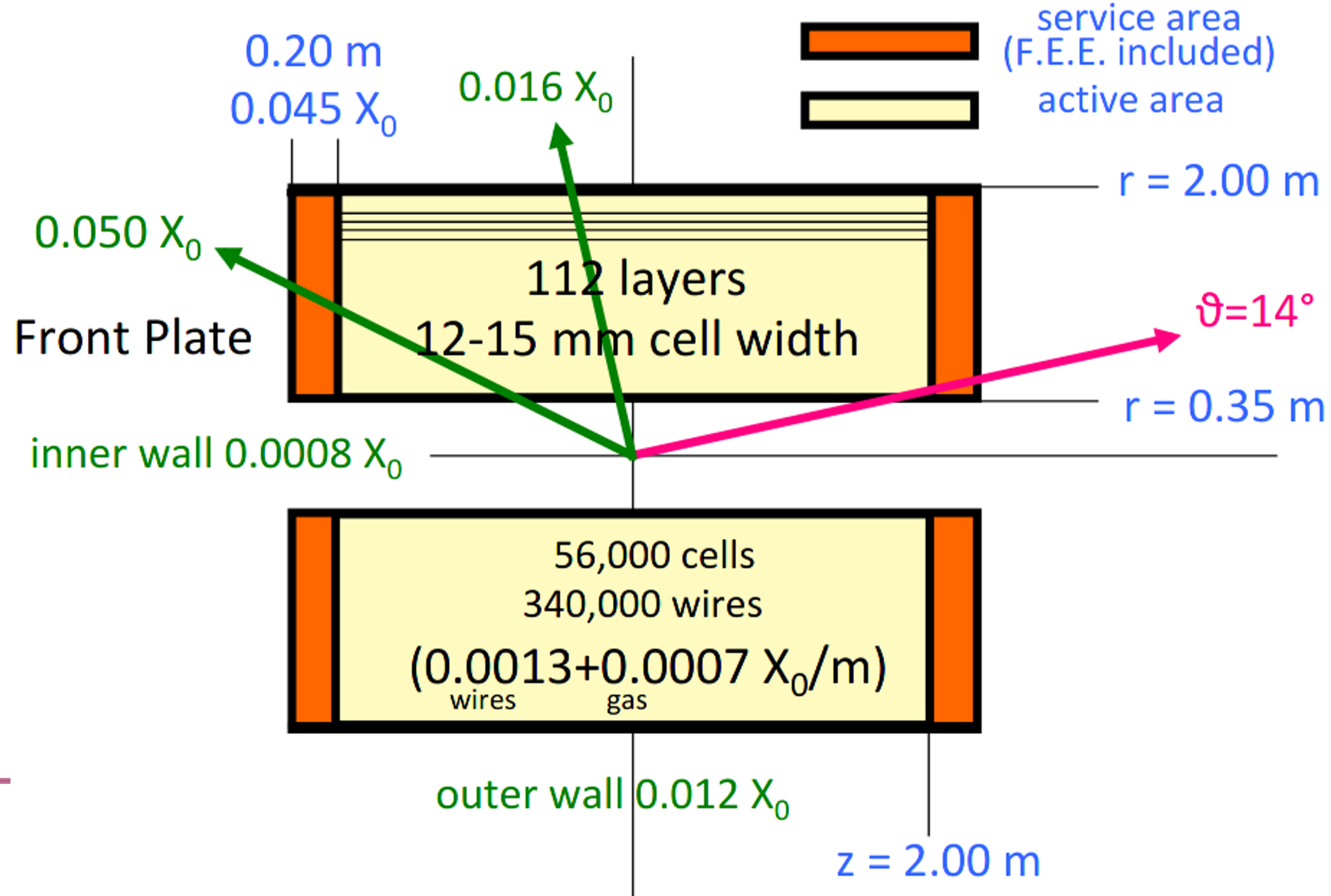
Drift CHamber

- 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
  - in 24 azimuthal 15° sectors

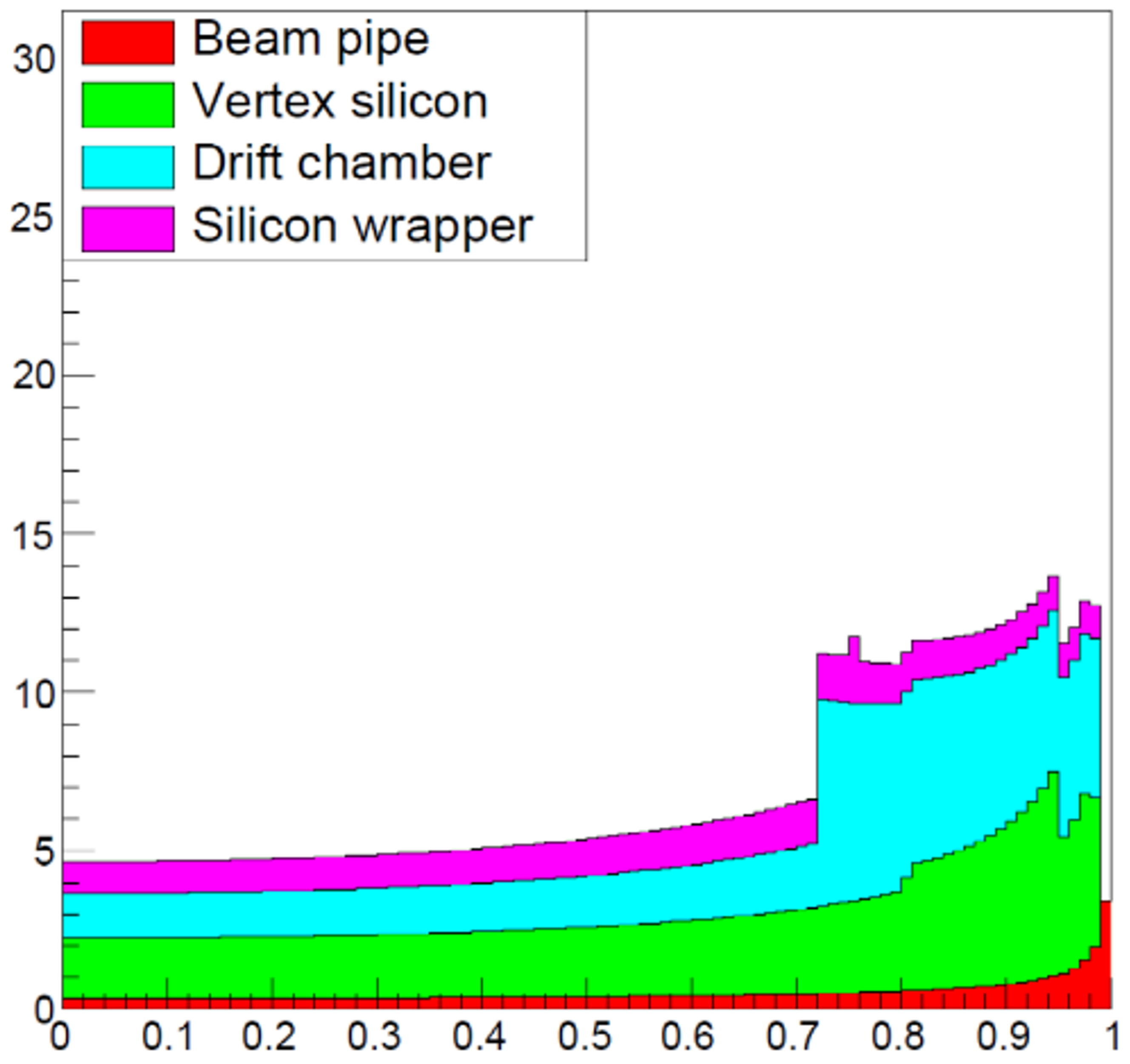


Drift CHamber: transparency

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

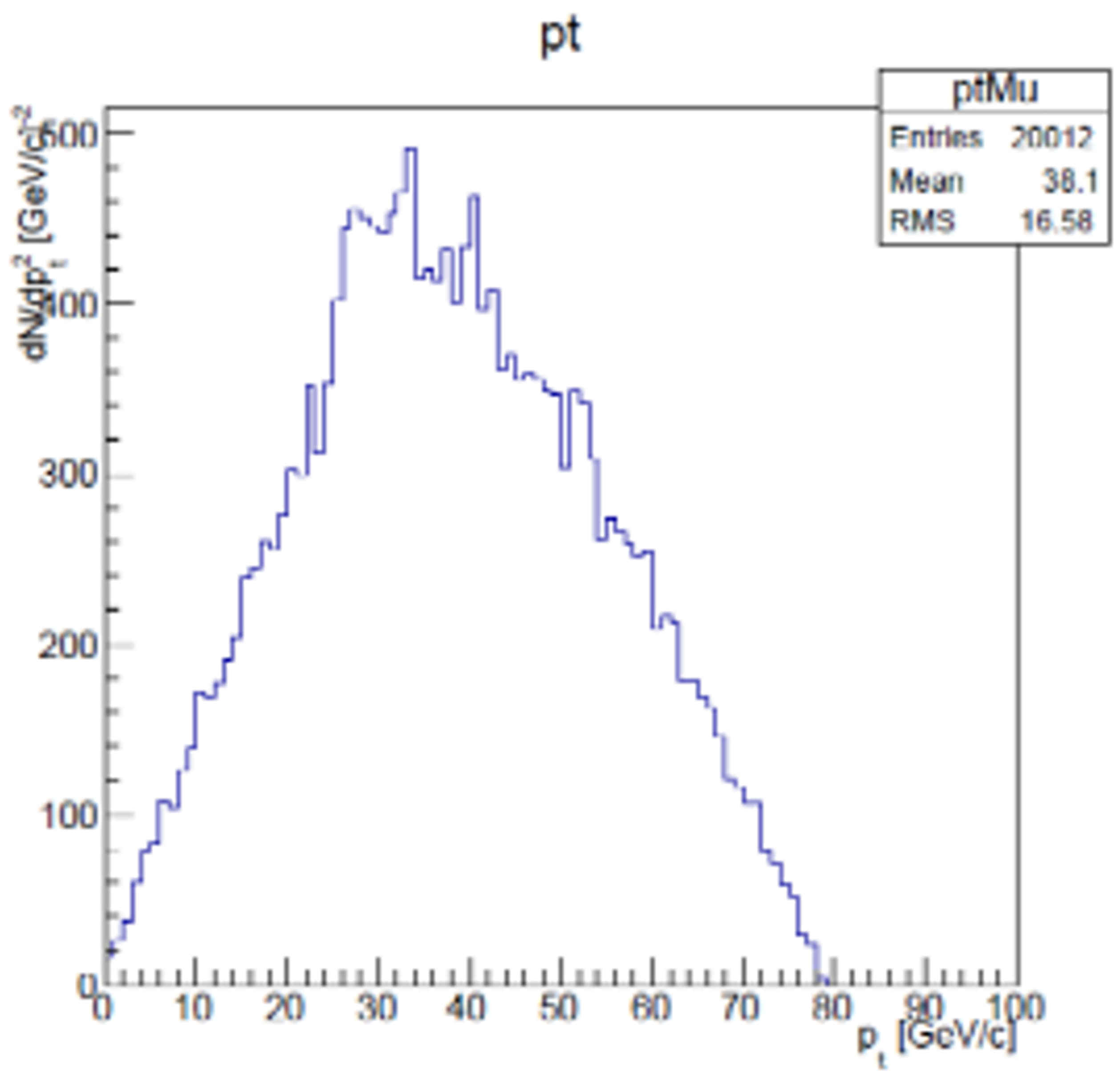


IDEA: Material vs. cos(θ)



Additional requirements

- Excellent **acceptance** and luminosity control
  - E.g. ECAL inner radius known at 15 μm
- B ~ 2T for beam emittance preservation
  - Maximize **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 small p_T
  - **Transparency** more relevant than asymptotic resolution

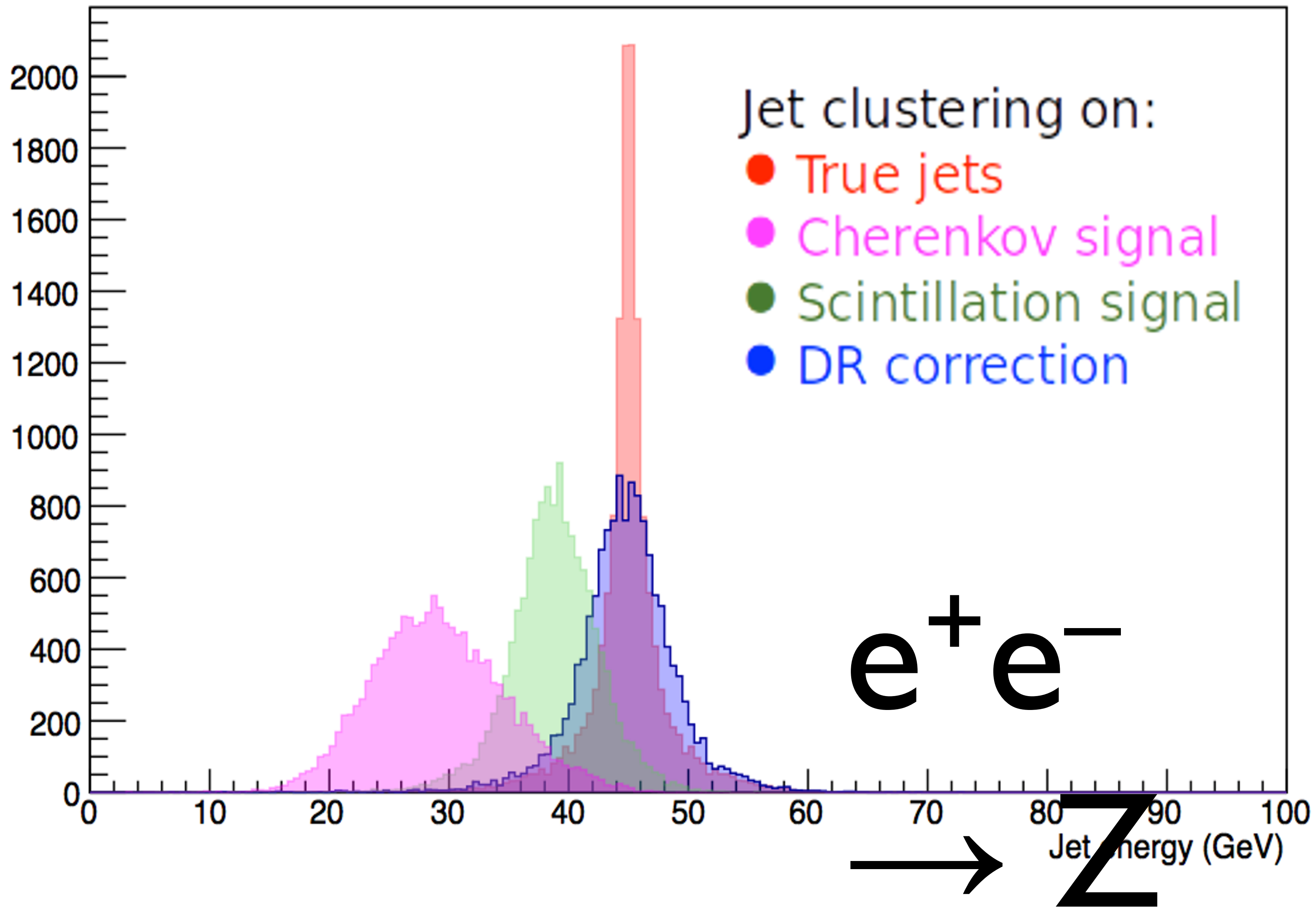


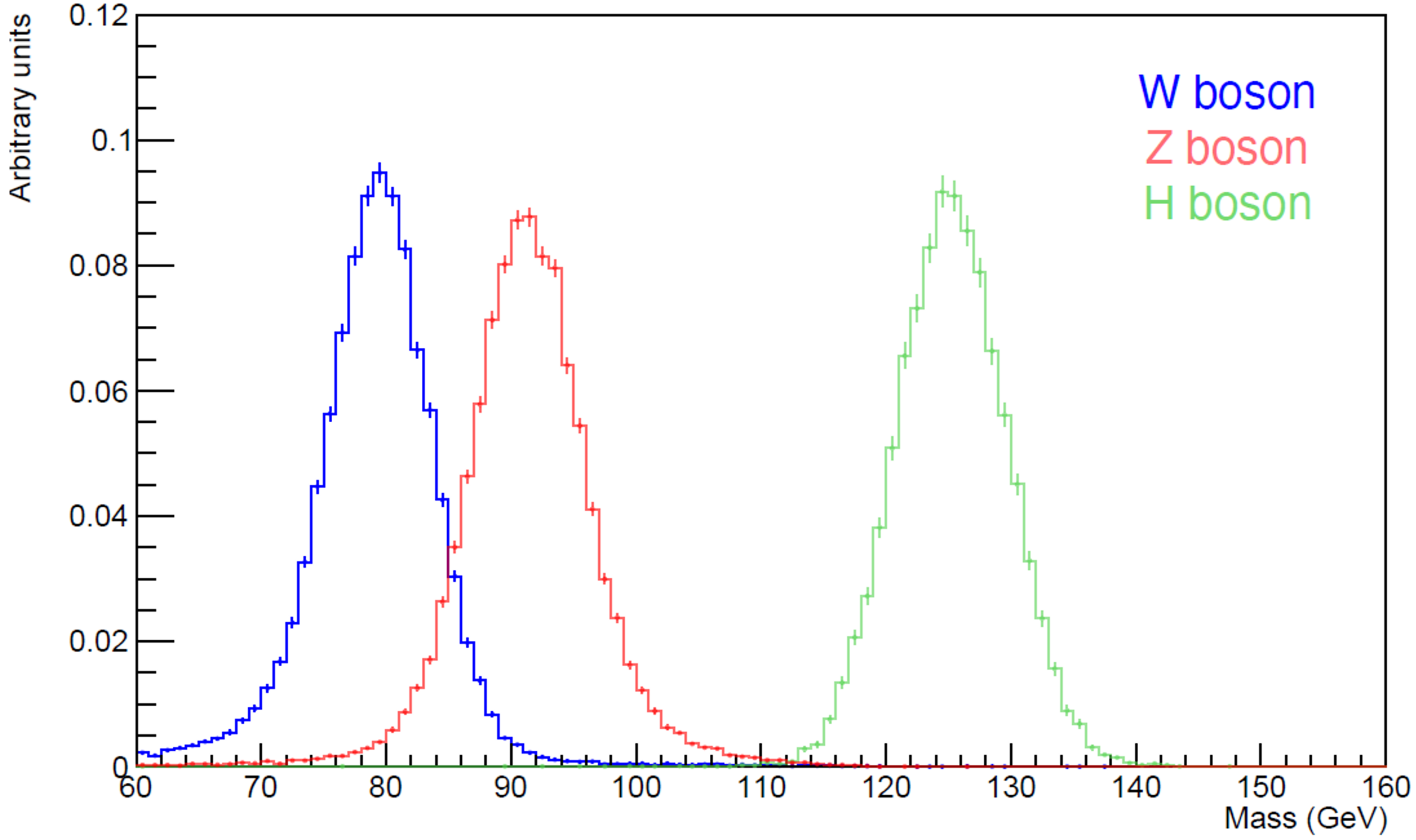
ZH (Z→μμ)

Geant 4 simulation

INFN
Istituto Nazionale di Fisica Nucleare

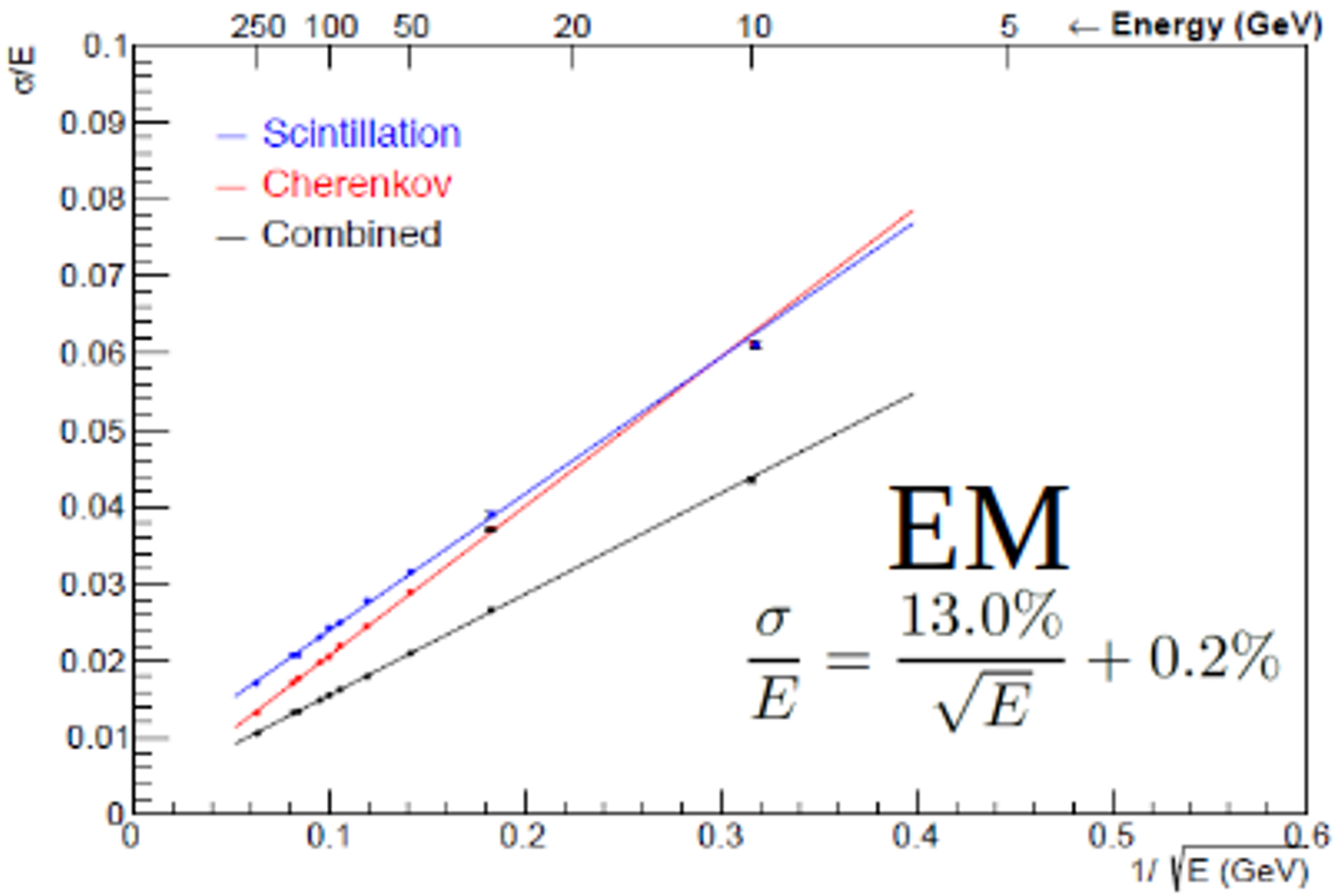
- Gaussian resolution
- Adequate separation of W/Z/H

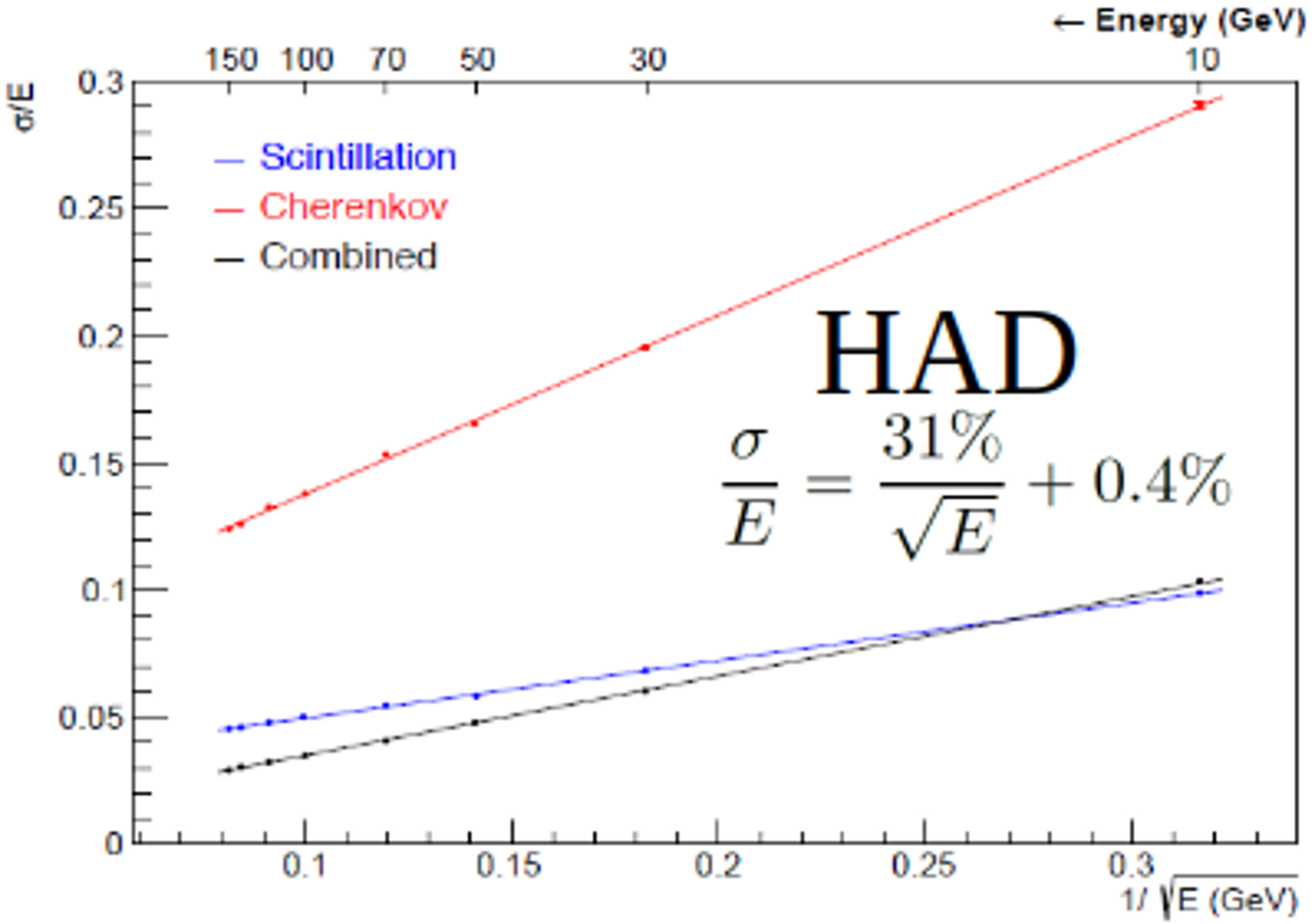




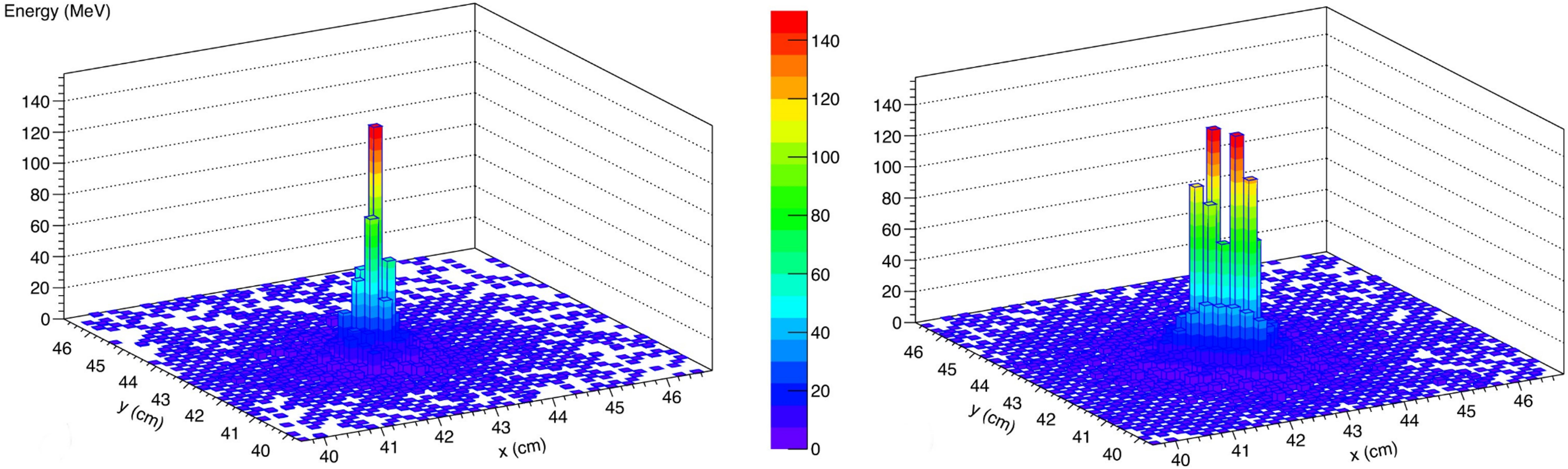
Geant 4 simulation

- Good resolutions averaged over eta and phi





Event displays

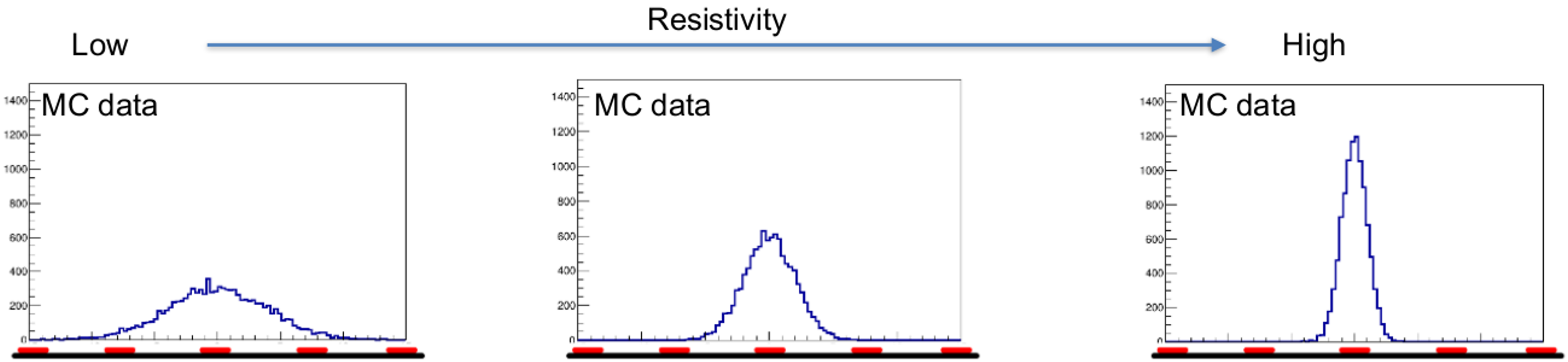


50 GeV e^-

100 GeV π^0

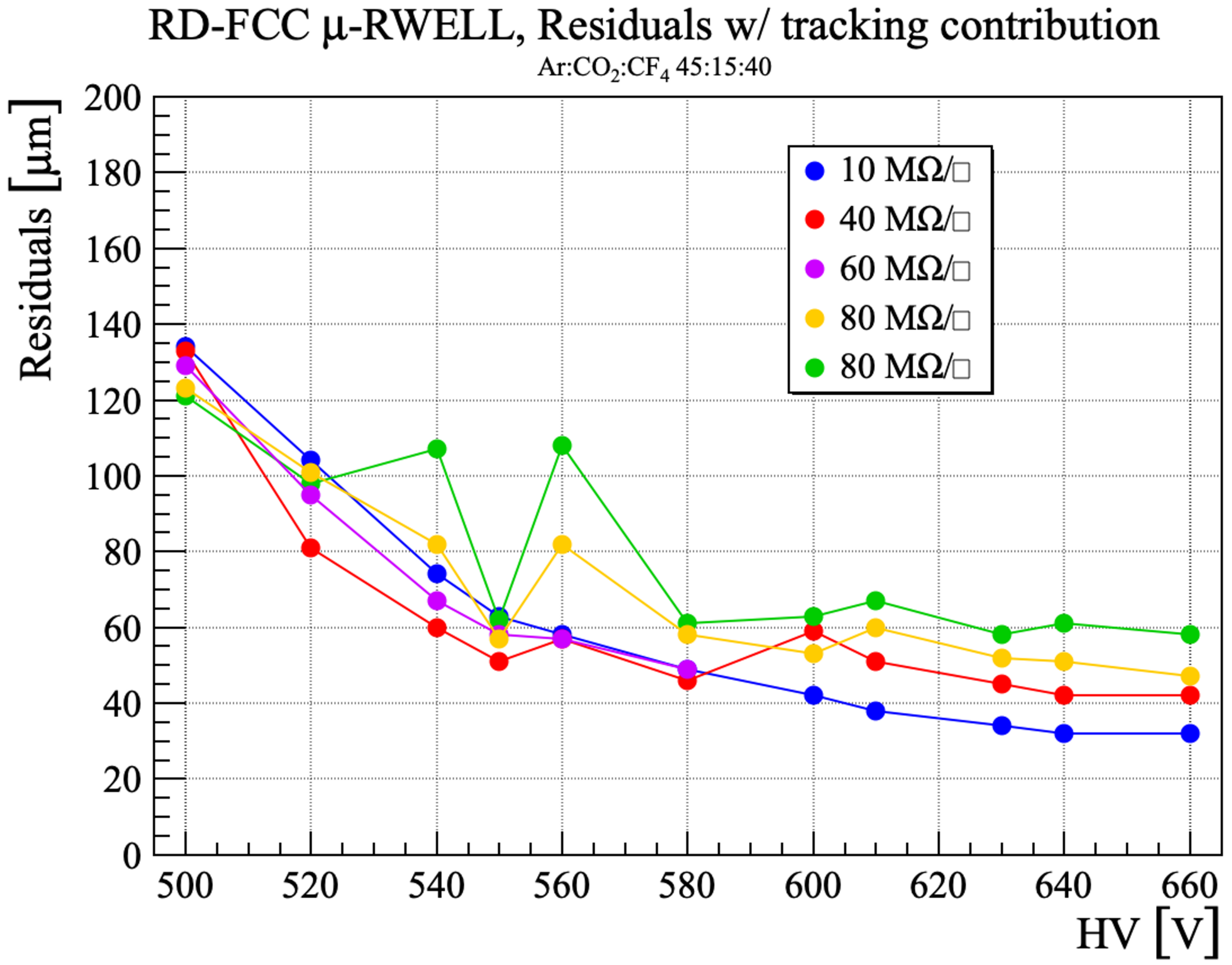
test beam: resistivity validation

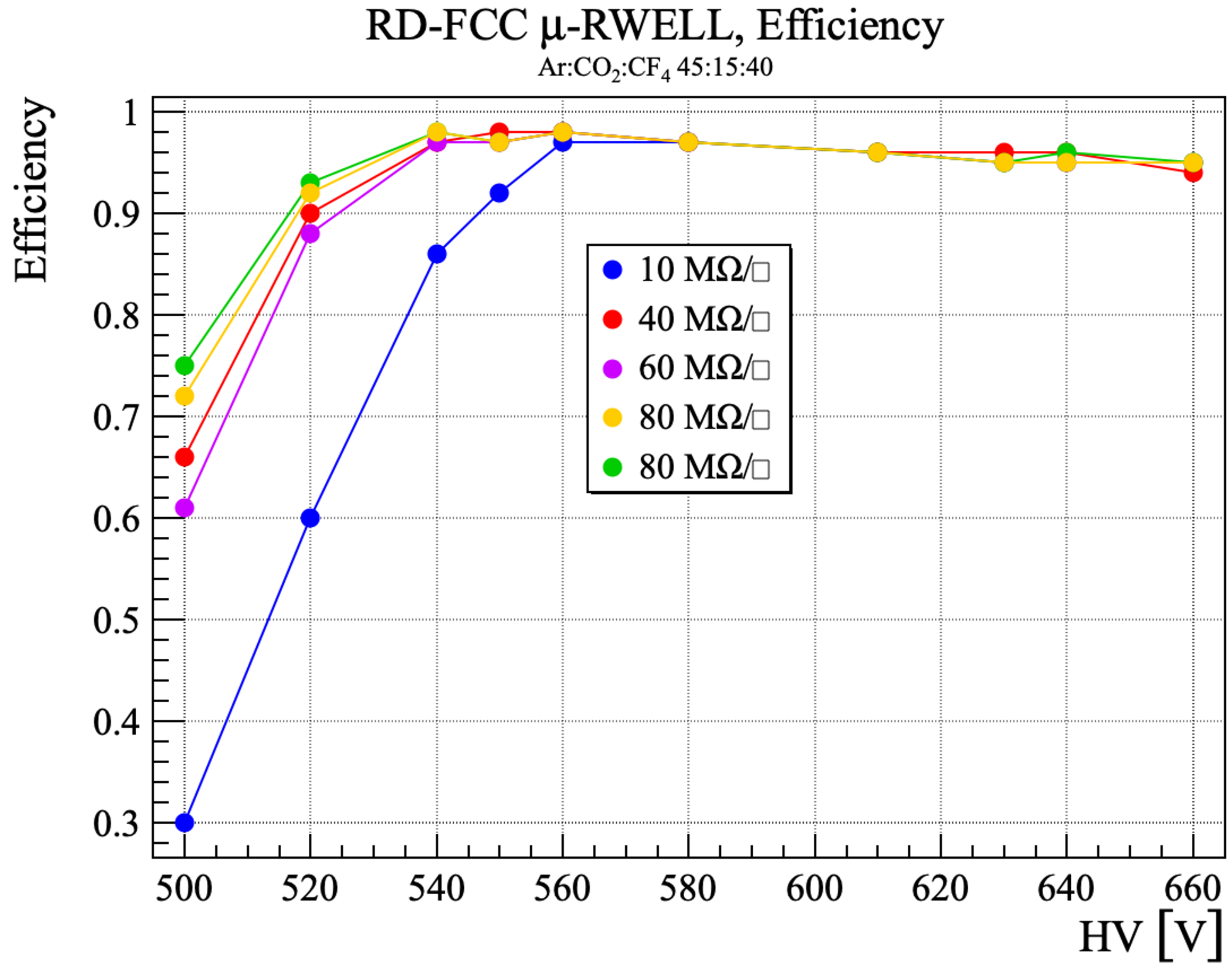
- R&D: optimal DLC resistivity by studying spatial performance
  - Preshower: 10, 30, 50, 70, > 100-200 MOhm/square
  - Muon: 15, 35 MOhm/square
- Eg: effect of resistivity on charge spread



test beam results

✦ Residuals and efficiency for different resistivities





2D µ-RWELL ideas

µ-RWELL w/ 2D anode readout

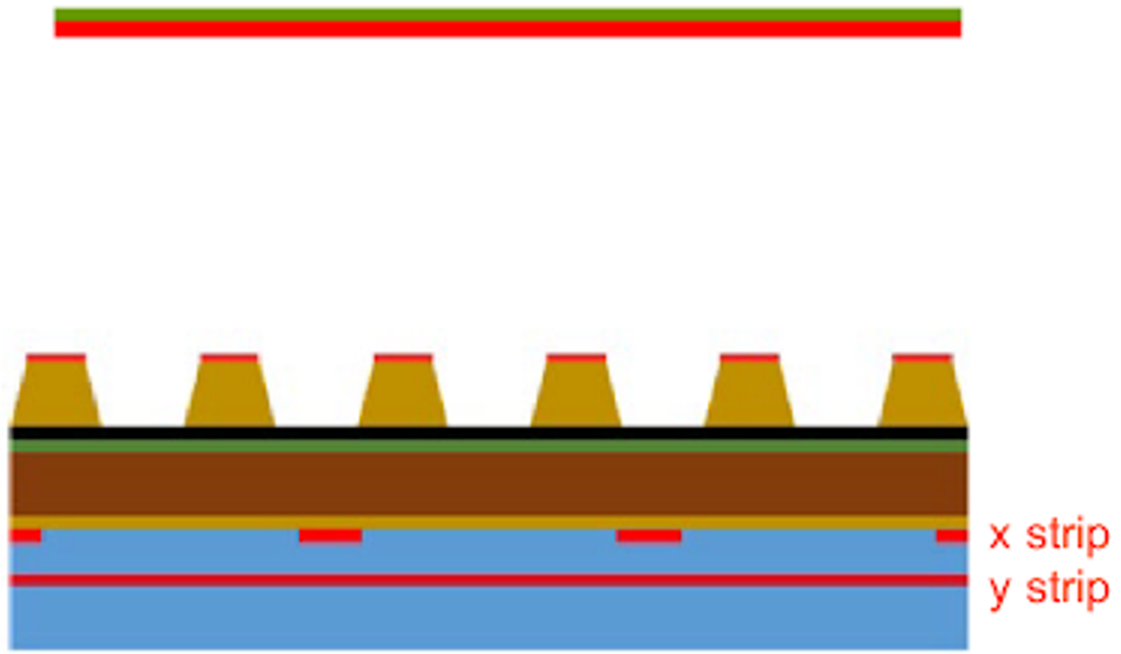
- Good performance but need higher gain wrt. to 1D
- More complex PCB construction

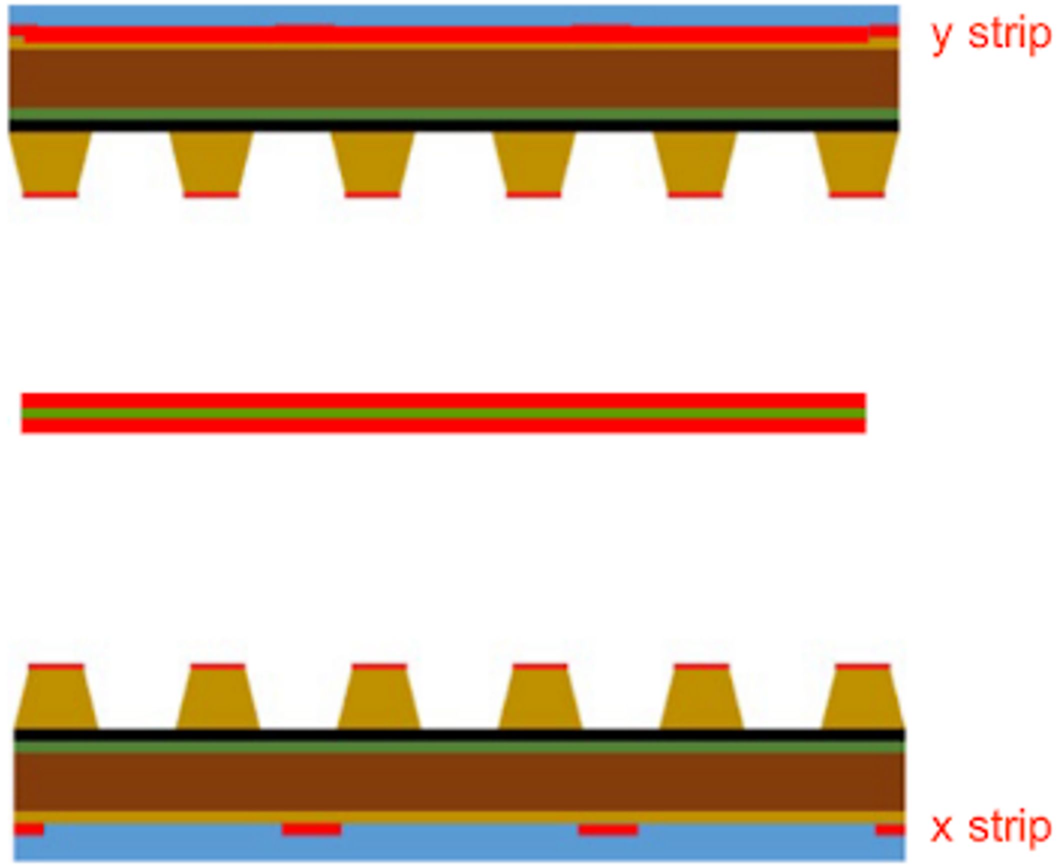
2 stacked 1D µ-RWELL

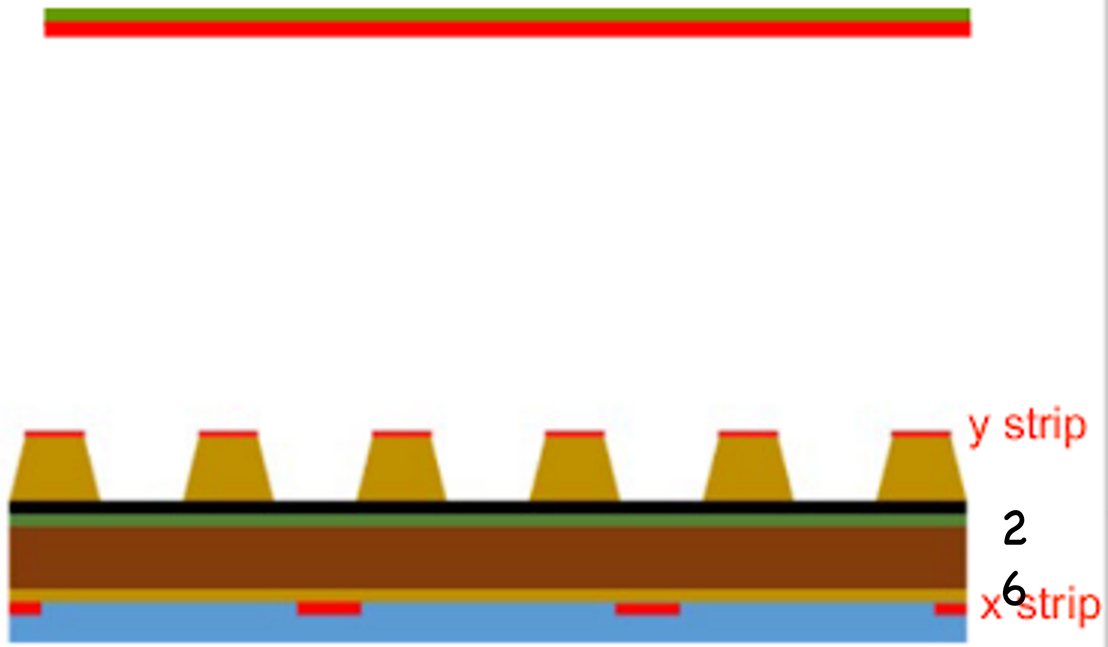
- 1 view per µ-RWELL
- easy PCB construction
- 2D performance to be measured

µ-RWELL with strips on top and anode

- HV on DLC
- TOP to ground
- 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