PARIS, France
Venue: Campus des Cordeliers
Sorbonne Université
https://cern.ch/fccweek2022

30 May - 03 June

FCC WEEK 2022

FUTURE CIRCULAR COLLIDER

The IDEA detector concept

Paolo Giacomelli
INFN Bologna

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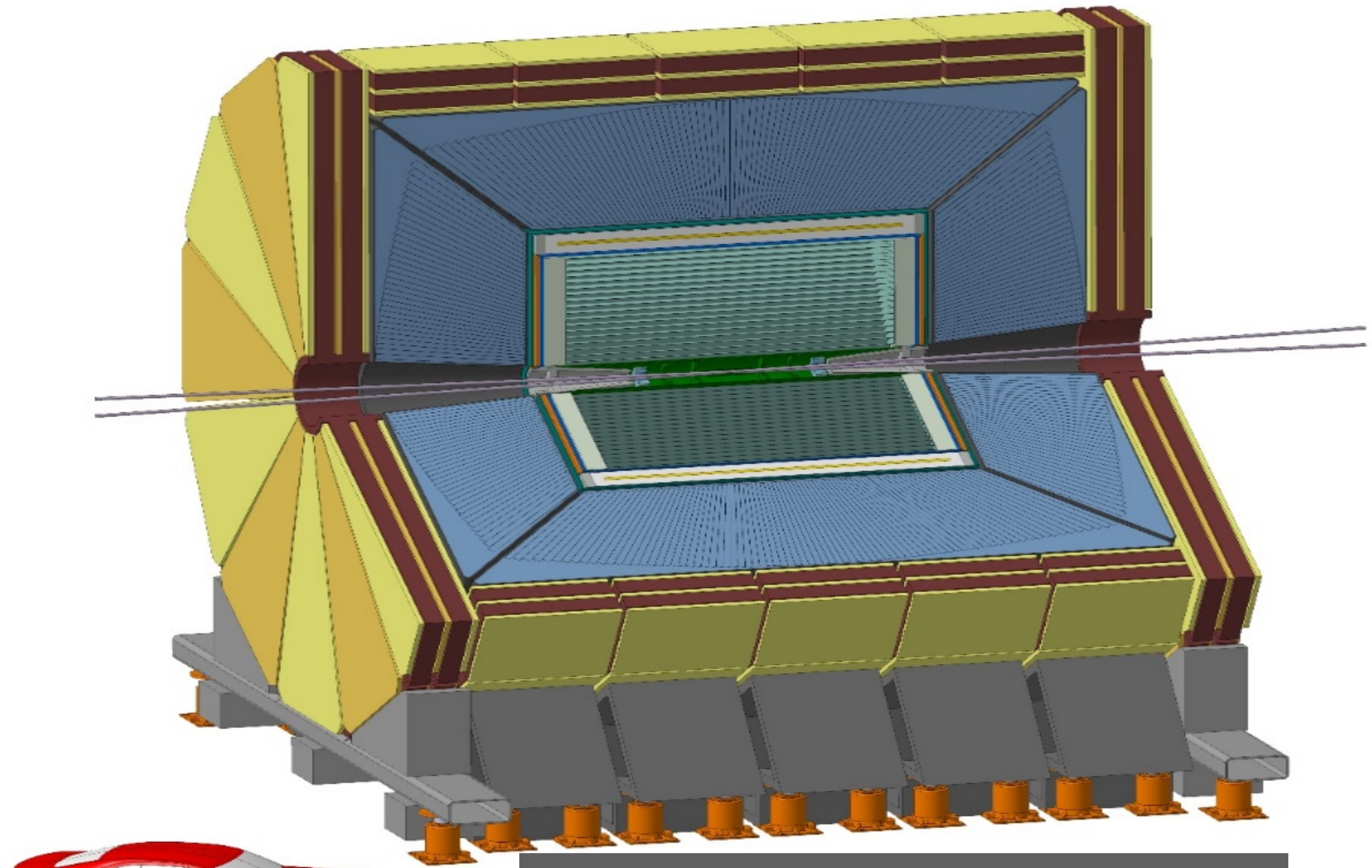
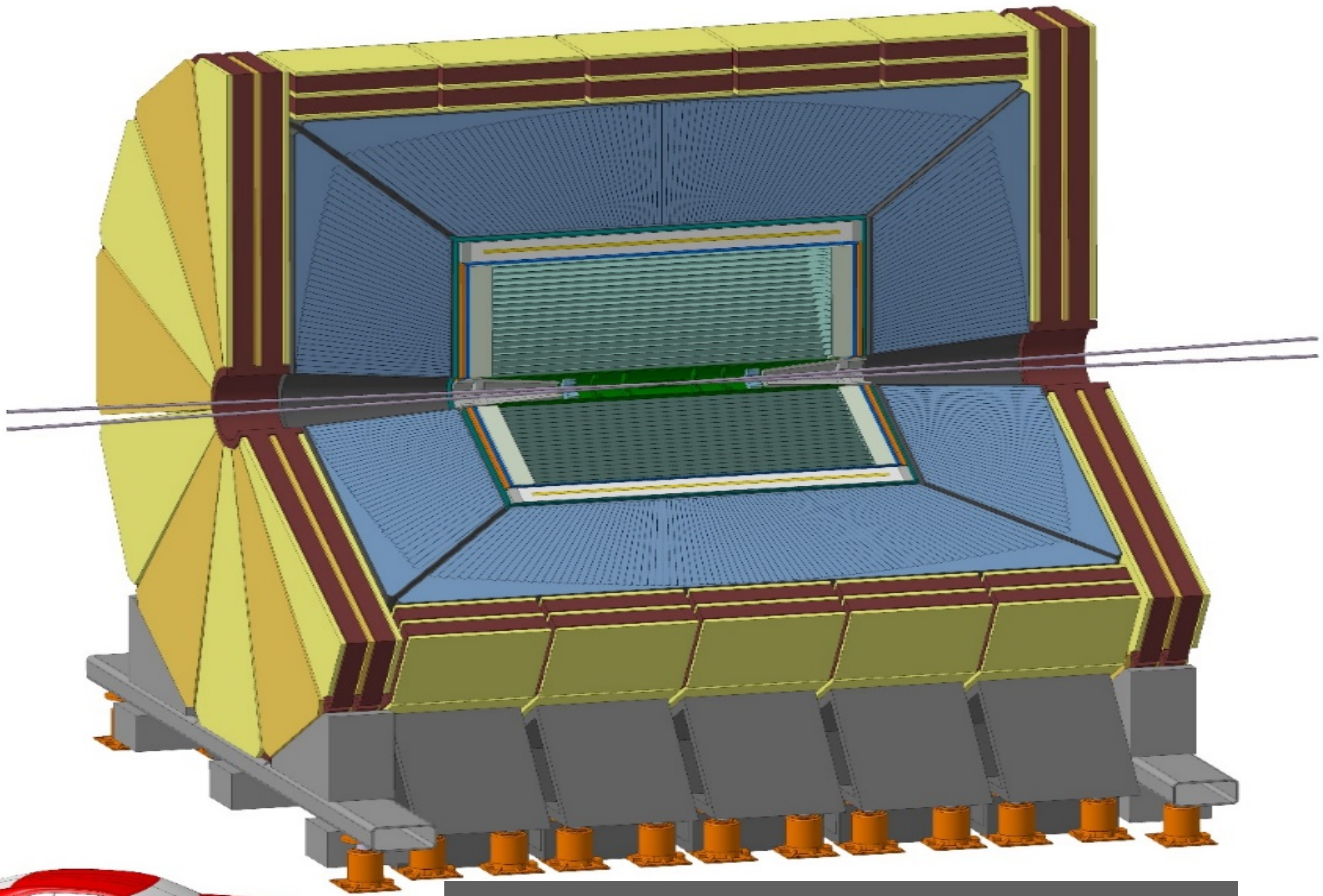


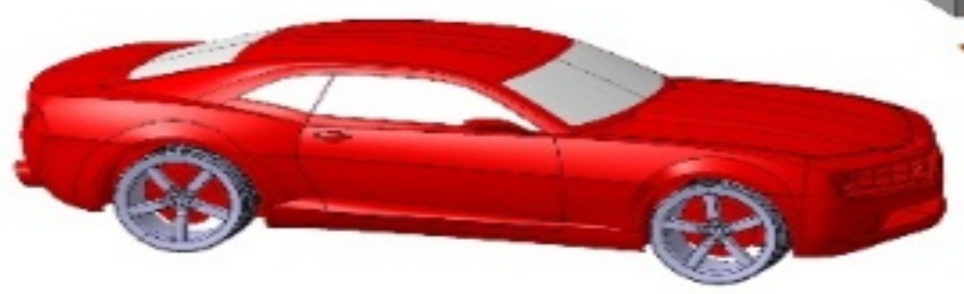
IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

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

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

The IDEA detector concept





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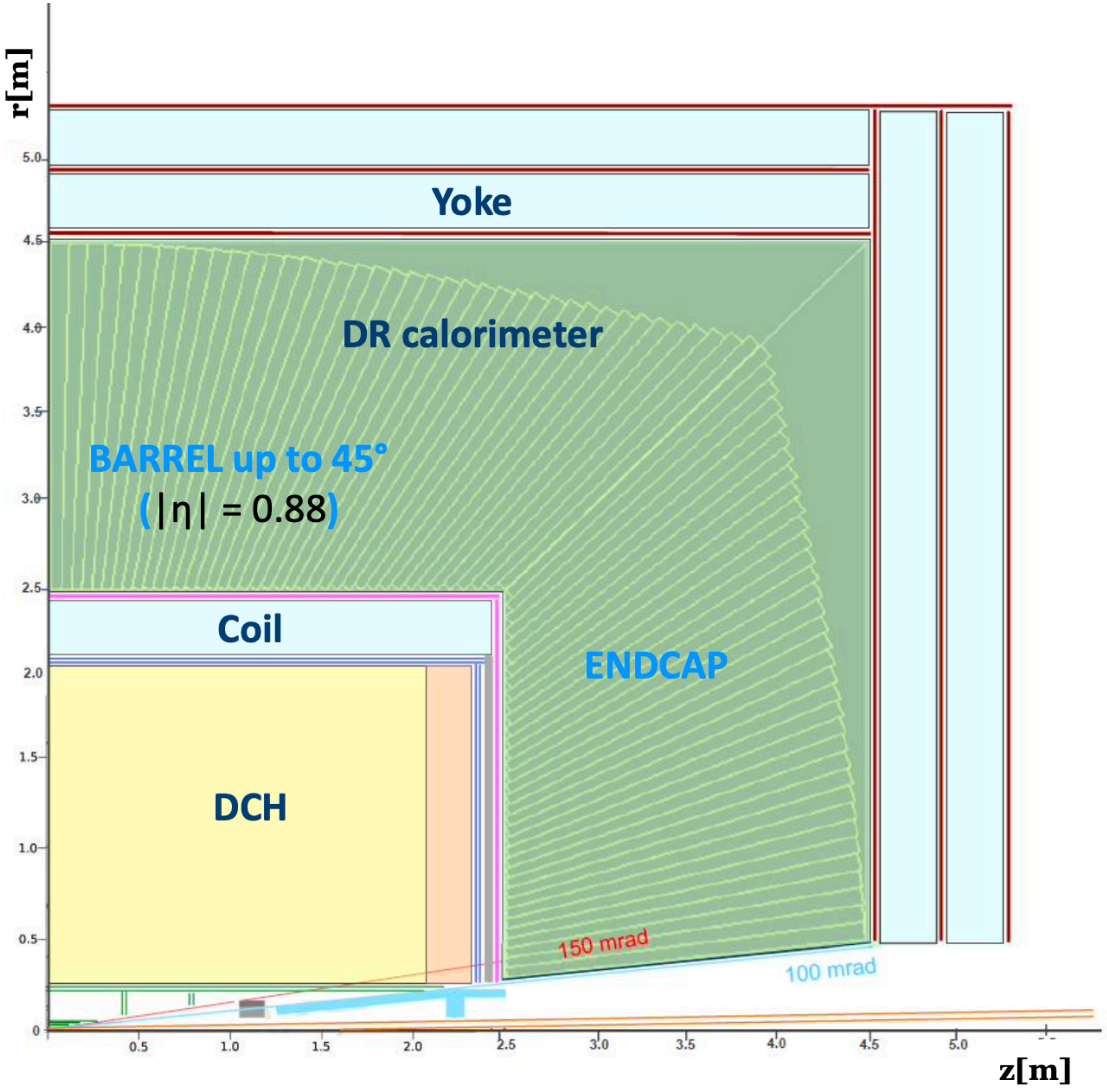
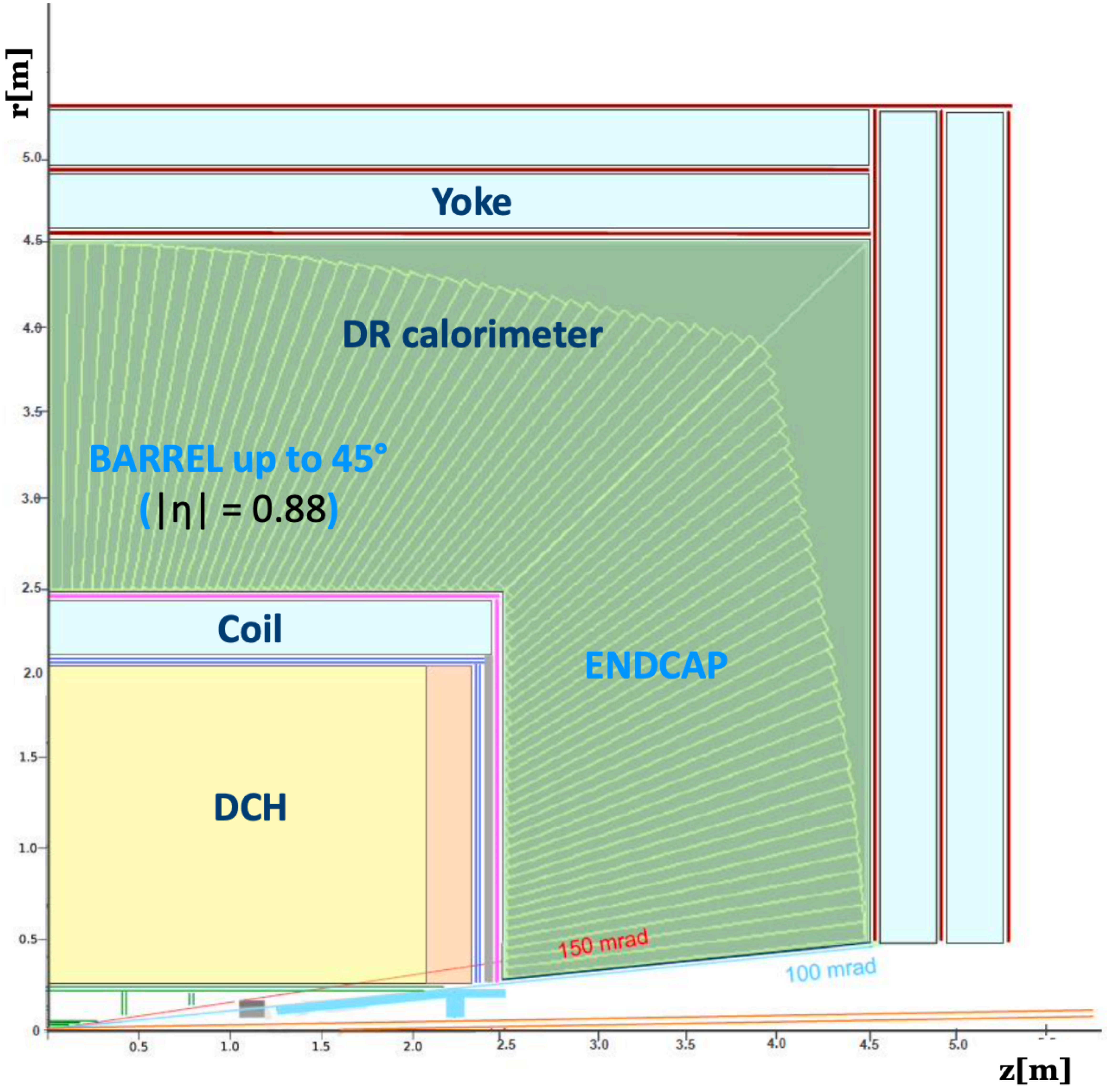
Acknowledgments
I need to thank many colleagues, in particular:
P. Azzi, F. Bedeschi, and R. Santoro

IDEA detector layout



IDEA detector layout

Beam pipe: R~1.5 cm



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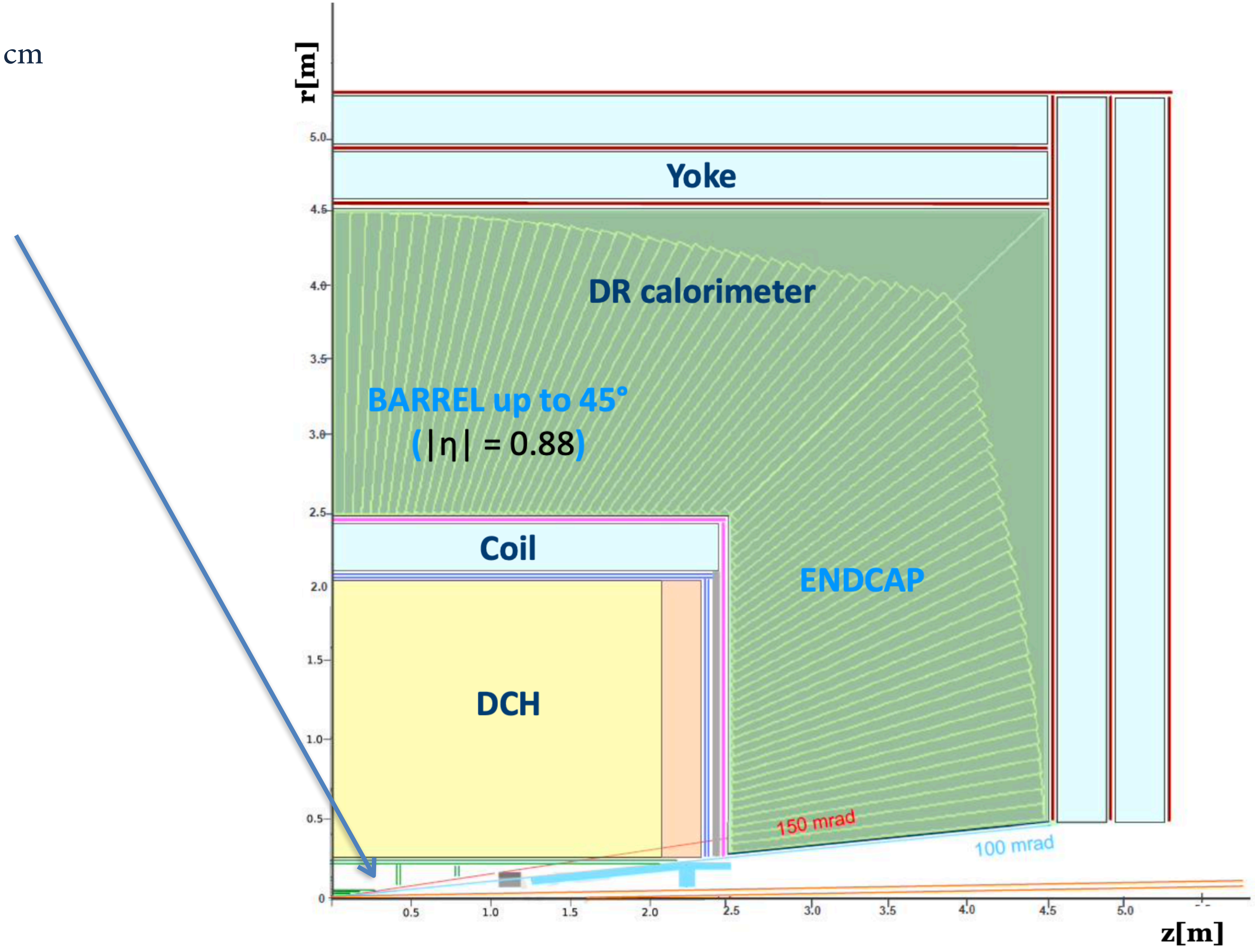
5 MAPS layers

R = 1.7-34 cm



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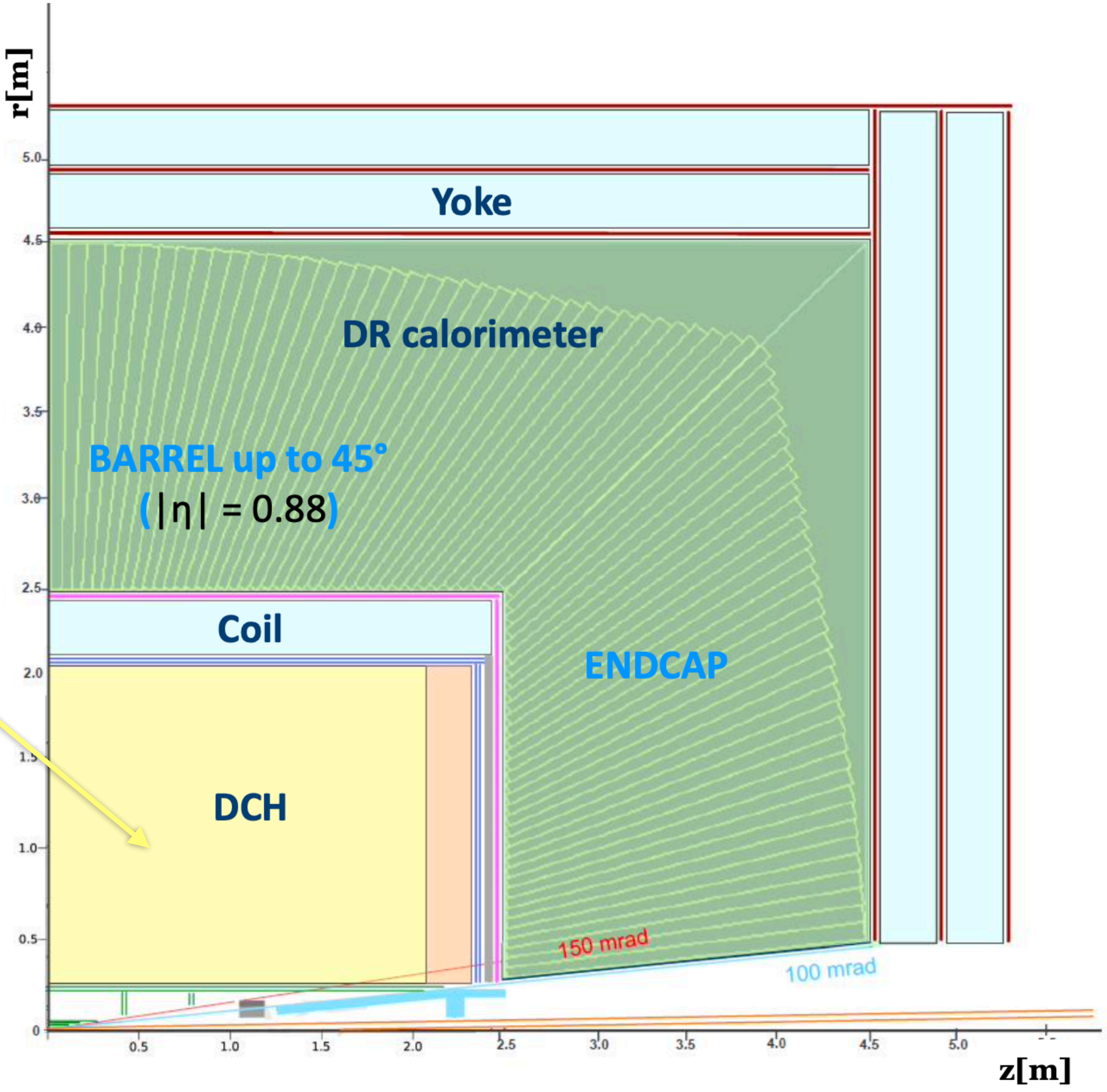
Drift Chamber: 112 layers

4 m long, R = 35-200 cm



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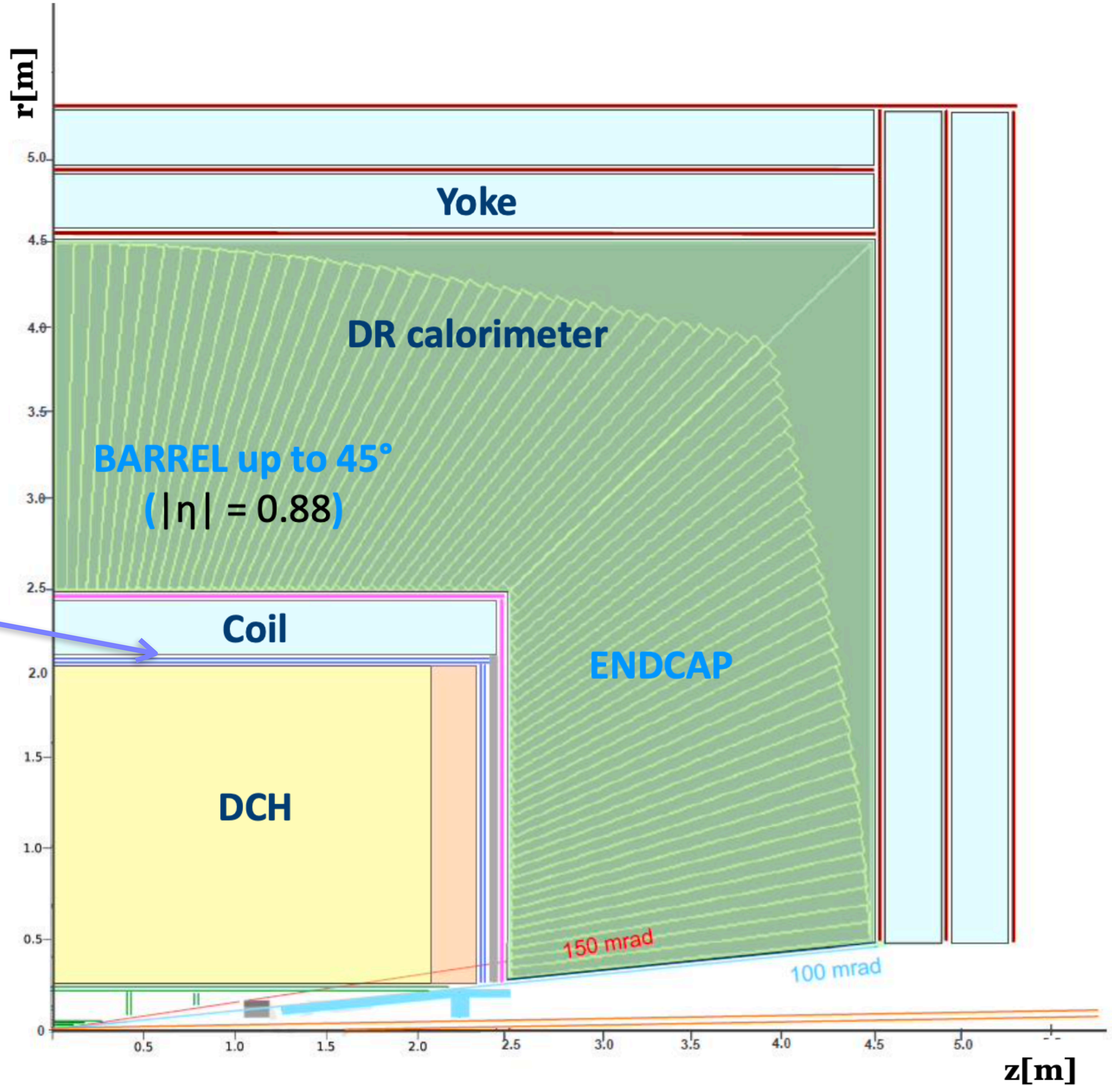

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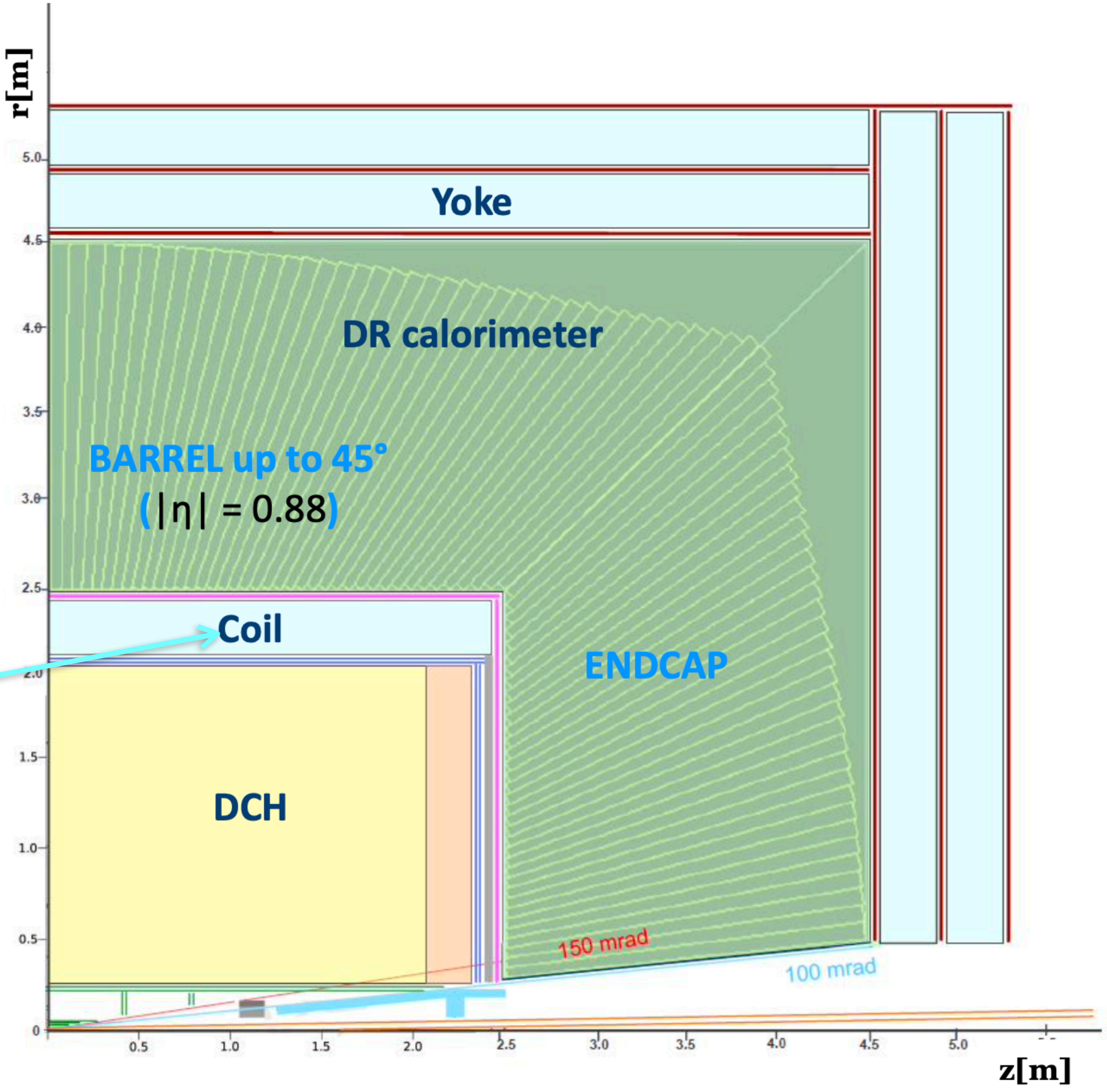
2 T, R ~ 2.1-2.4 m

0.74 X_0, 0.16 λ @ 90°



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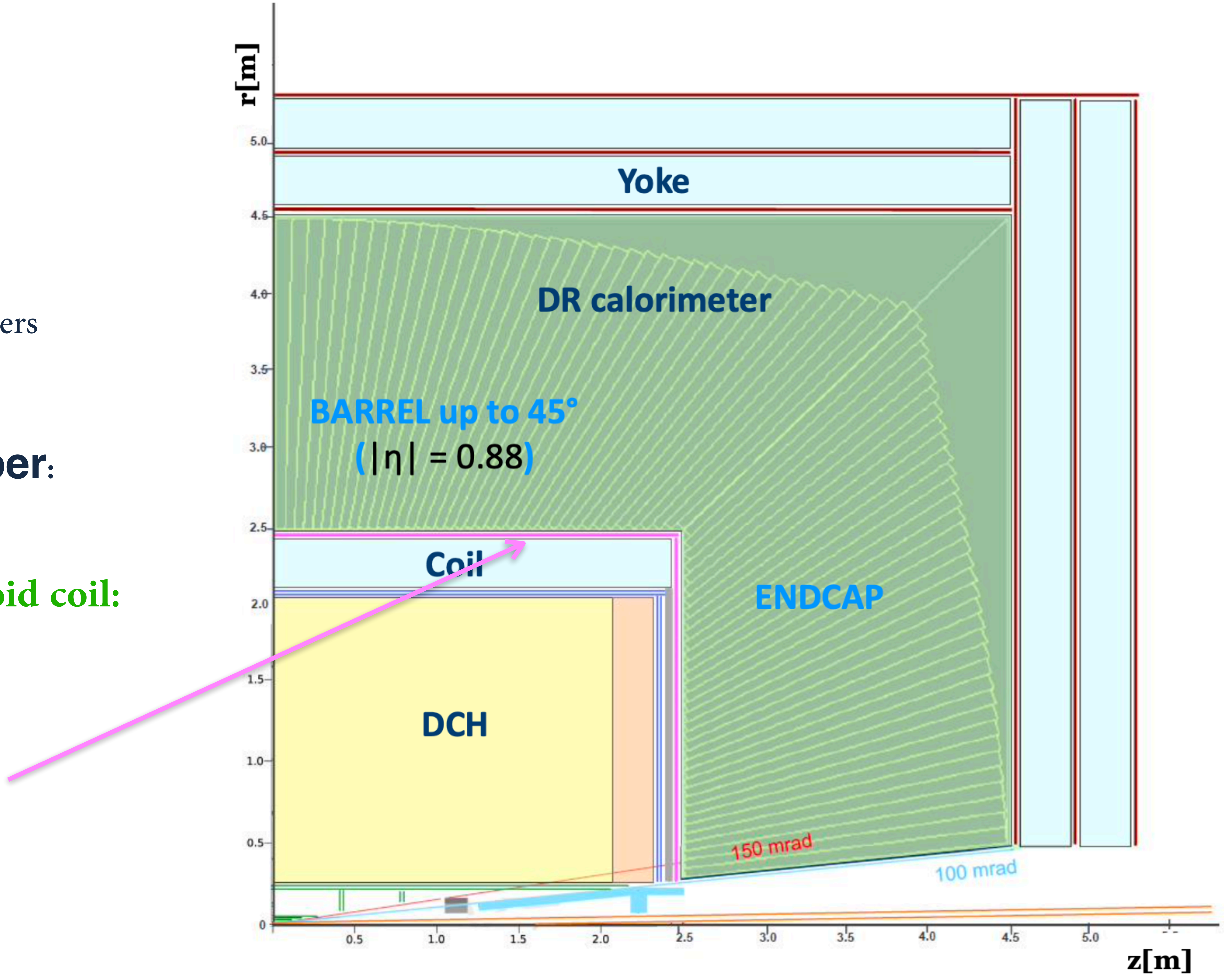

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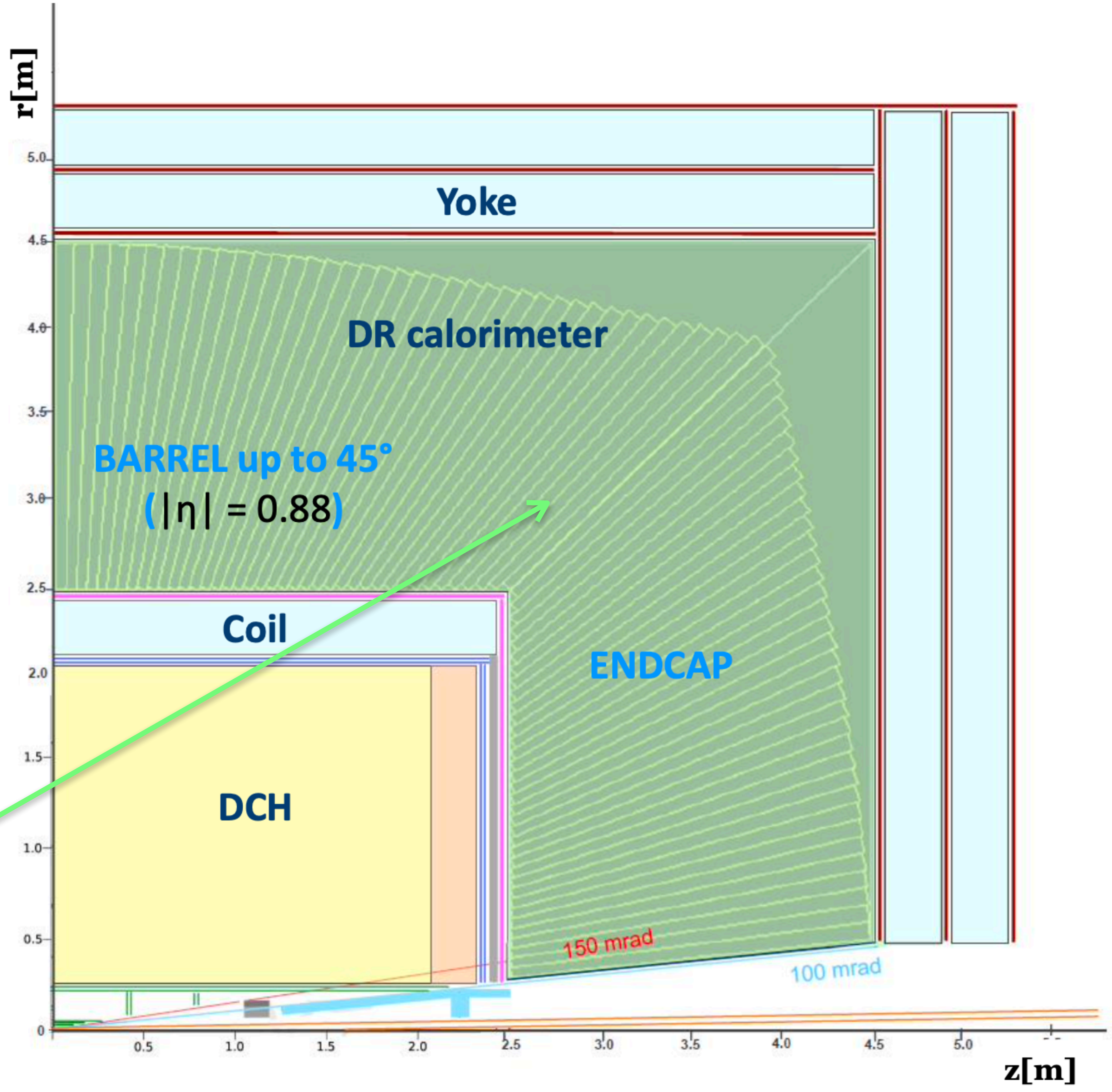
Dual-Readout Calorimeter:

2m / 7 λ_{int}



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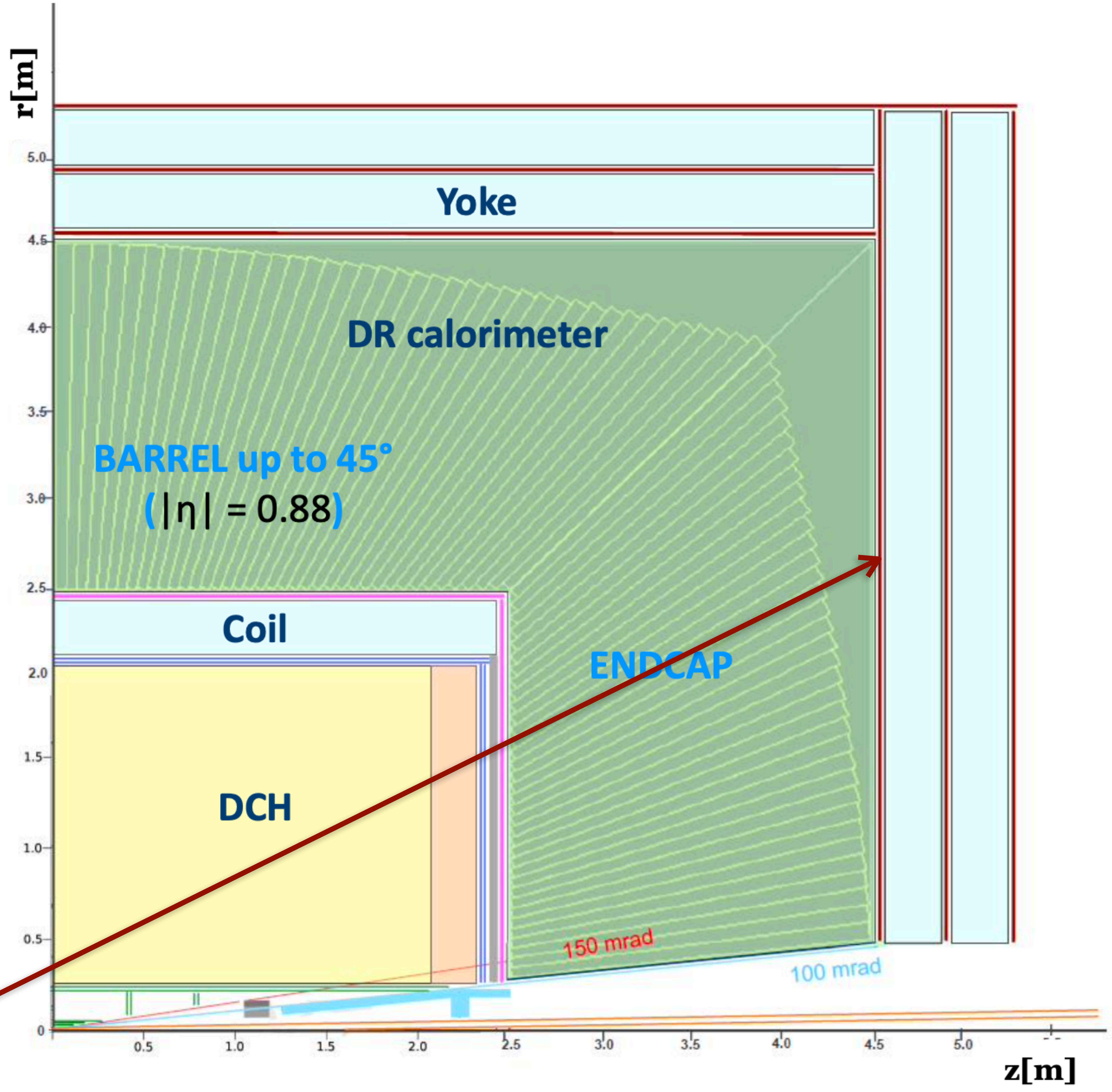
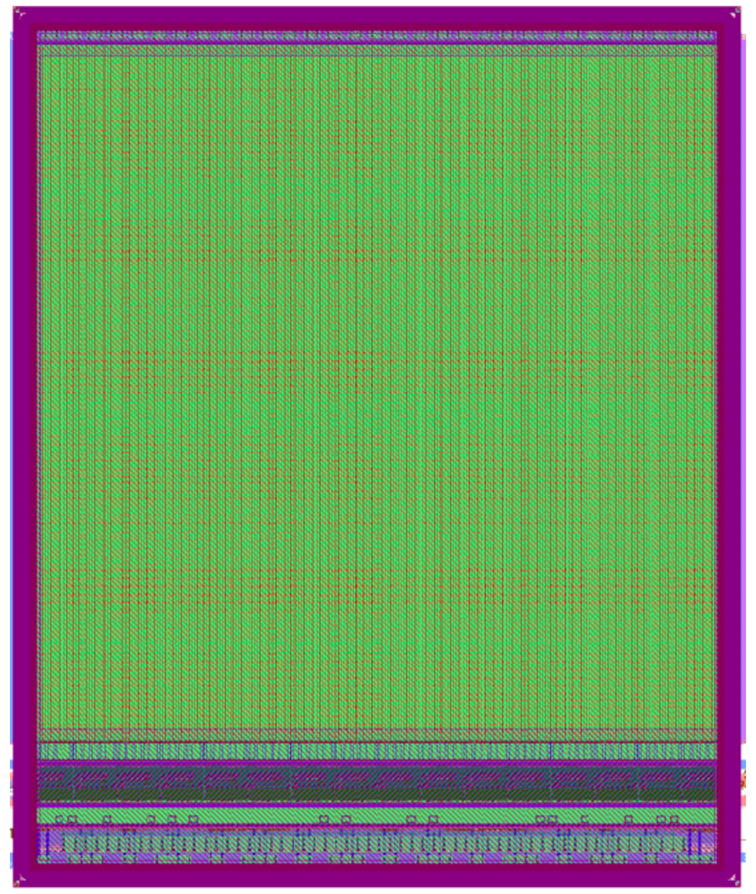
Yoke + Muon chambers



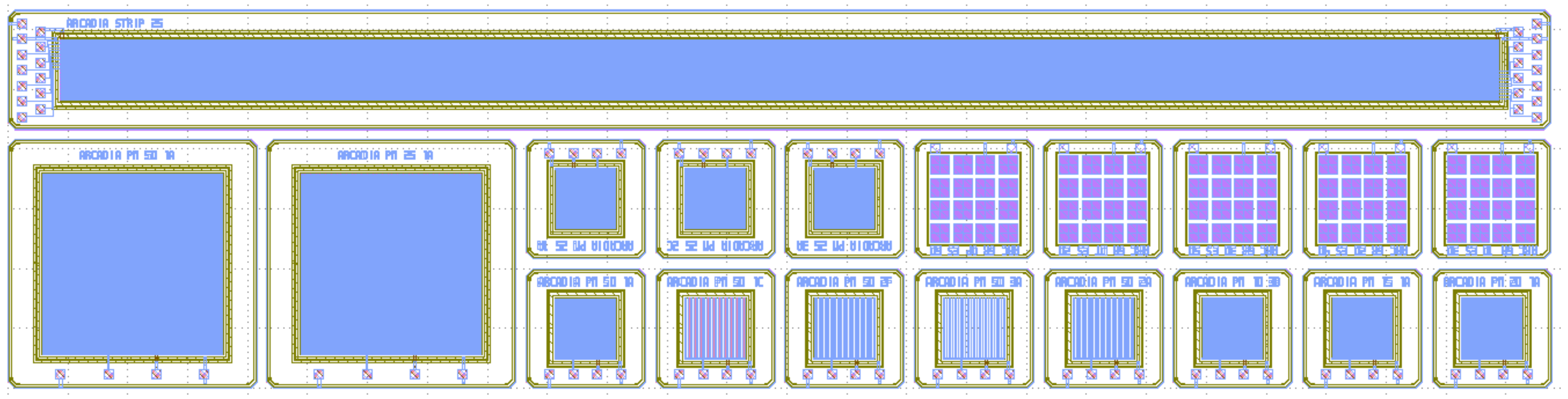
Vertex detector: IDEA



Inspired by ALICE ITS based on MAPS technology, using the ARCADIA R&D program

- ❑ Pixels 20 × 20 μm^2

- Light
  - ❑ Inner layers: 0.3% of X_0 / layer
  - ❑ Outer layers: 1% of X_0 / layer
- Performance:
  - ❑ Point resolution of ~3 μm
  - ❑ Efficiency of ~100%
  - ❑ Extremely low fake rate hit rate



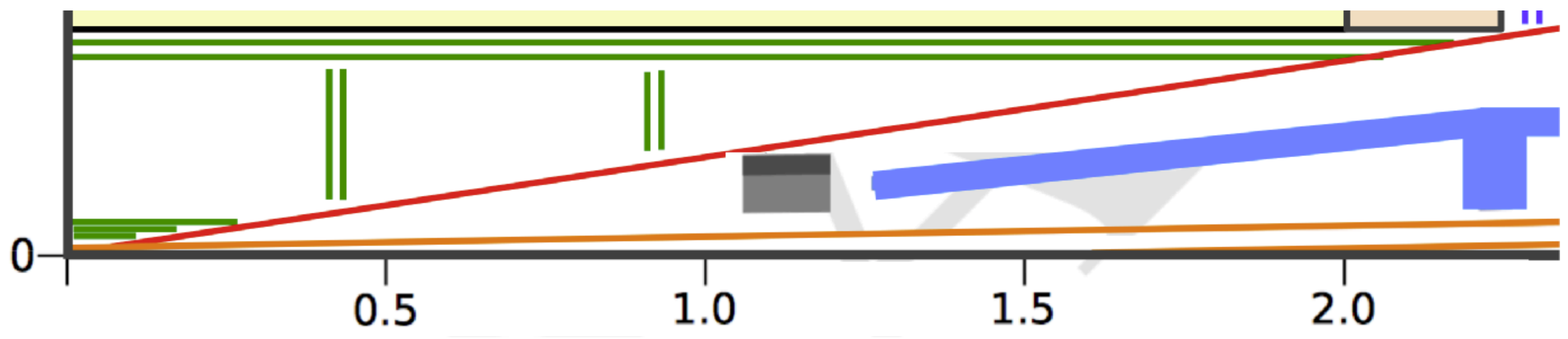
5 MAPS layers:

R = 1.7 - 2.3 - 3.1 cm

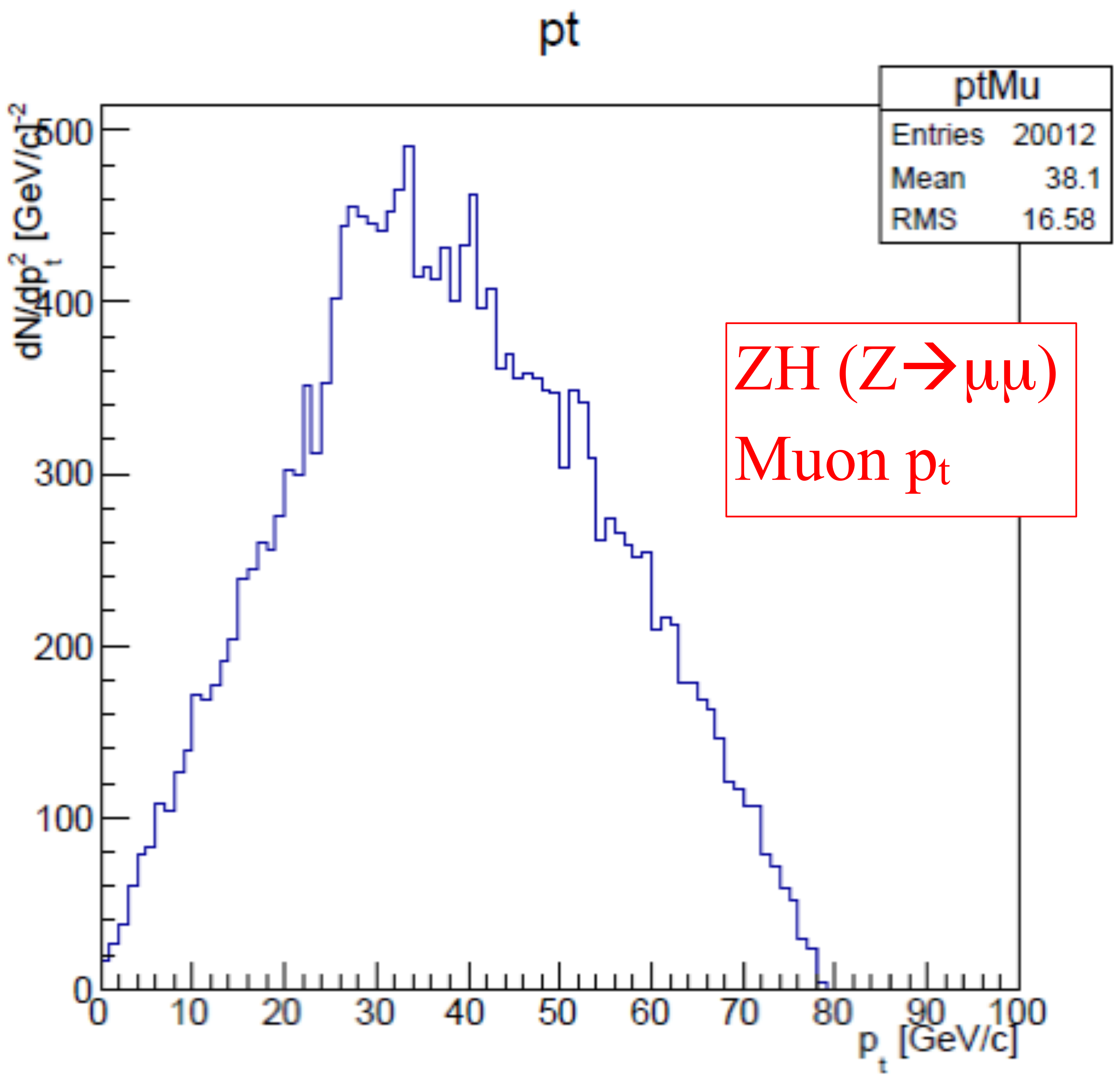
Pixel size: 20 x 20 μm^2

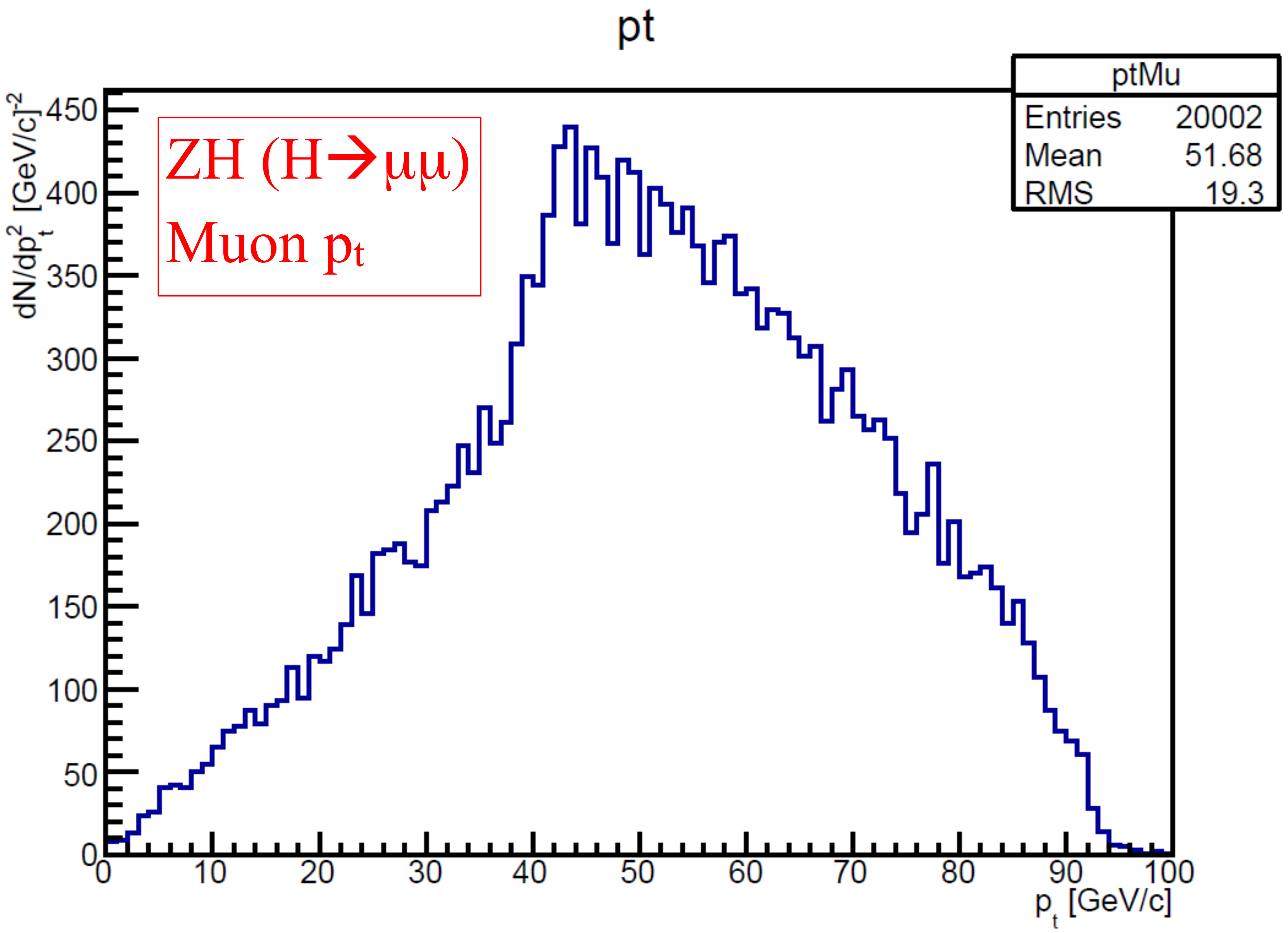
R = 32 - 34 cm

Pixel size: 50 x 100 μm^2



Momentum measurement

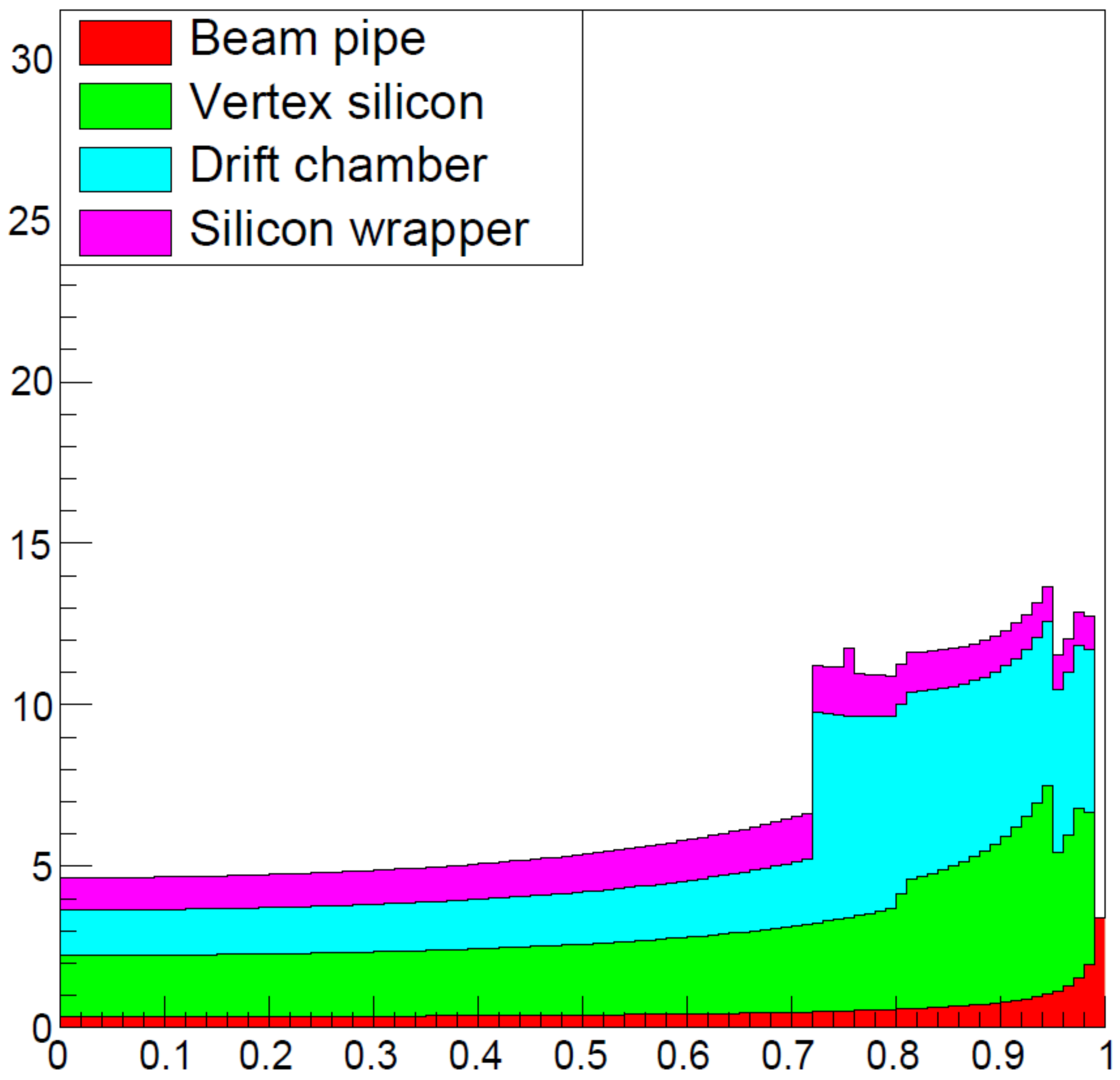




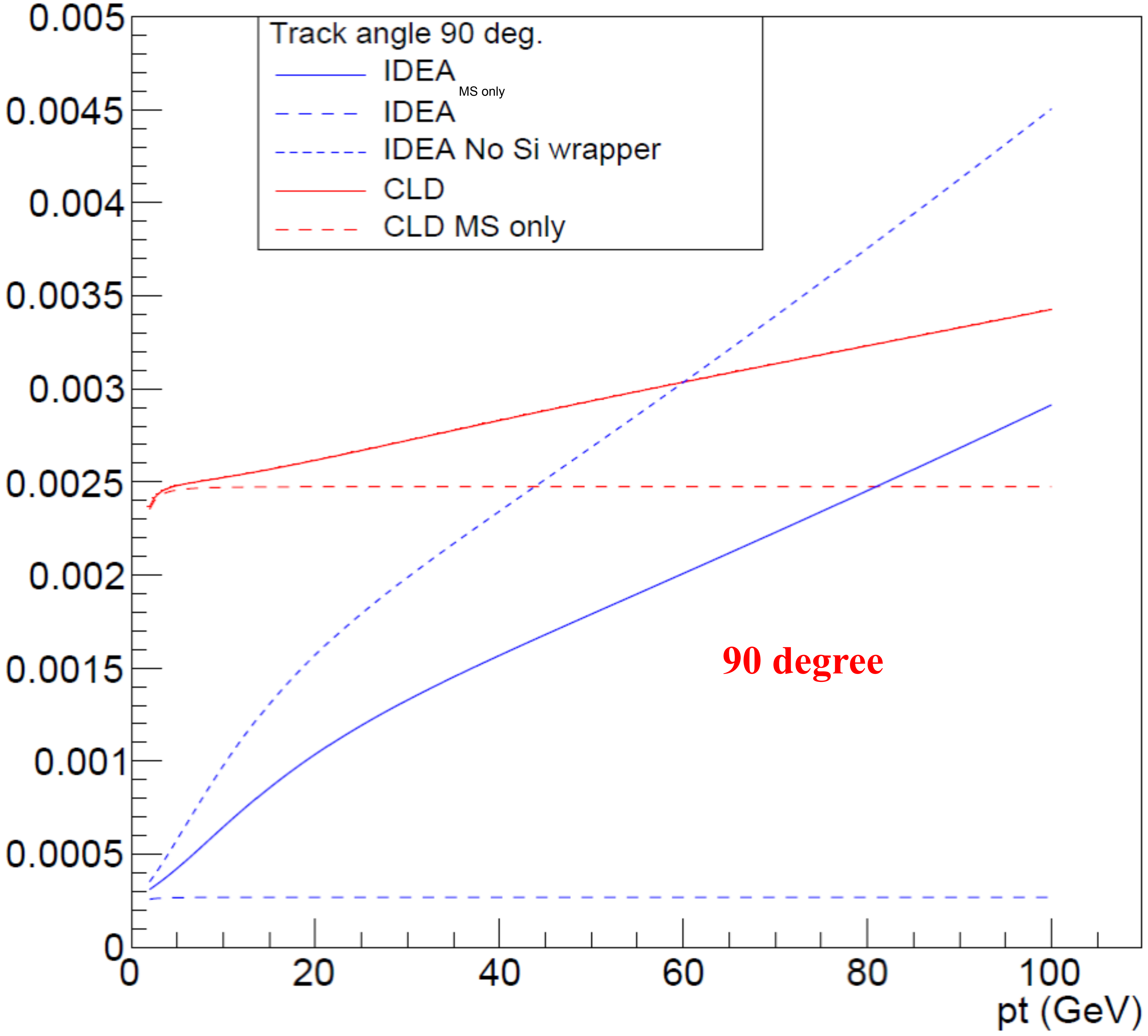
Momentum measurement

- Z or H decay muons in ZH events have rather low p_t
  - Transparency more important than asymptotic resolution

IDEA: Material vs. cos(θ)

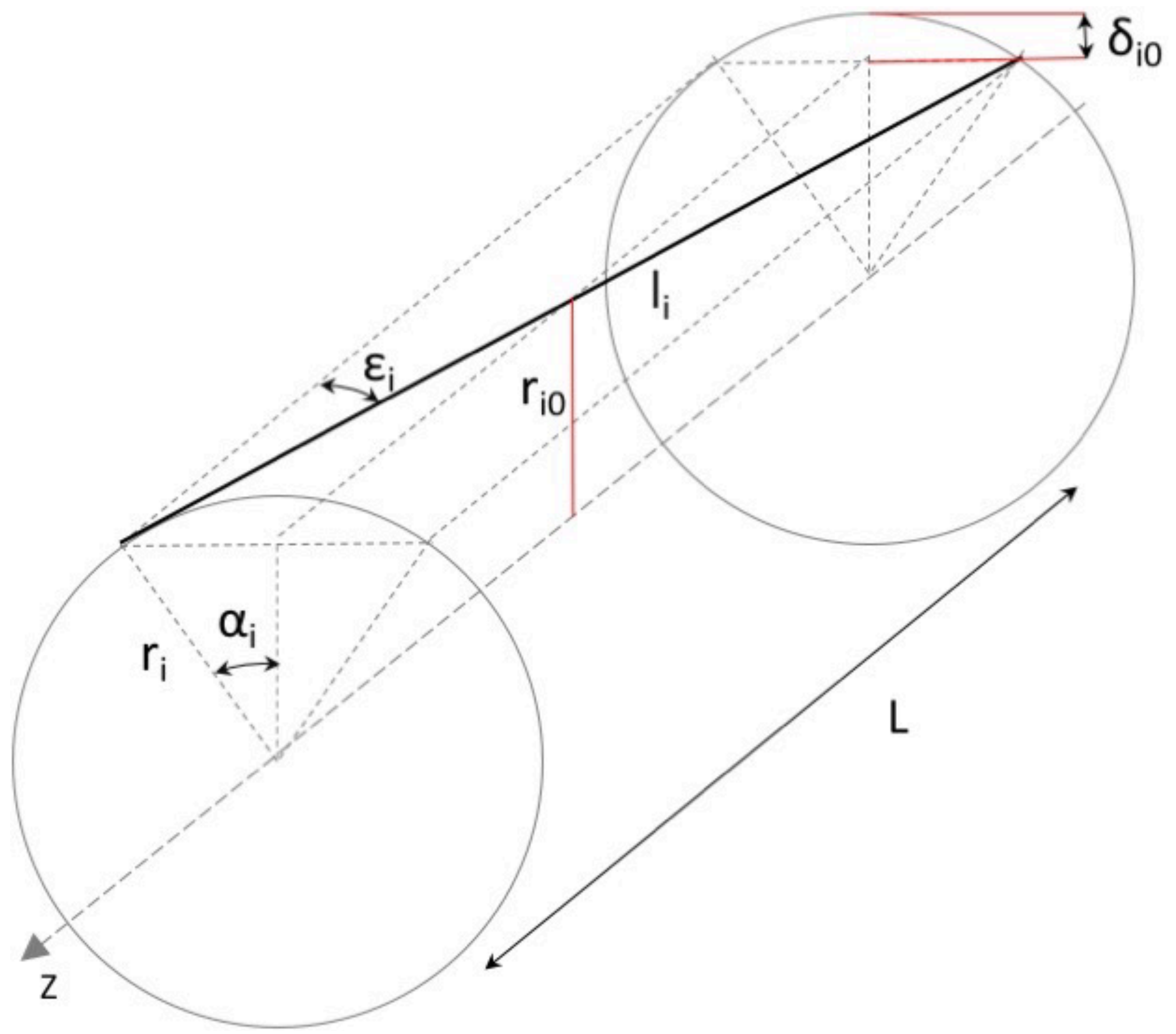


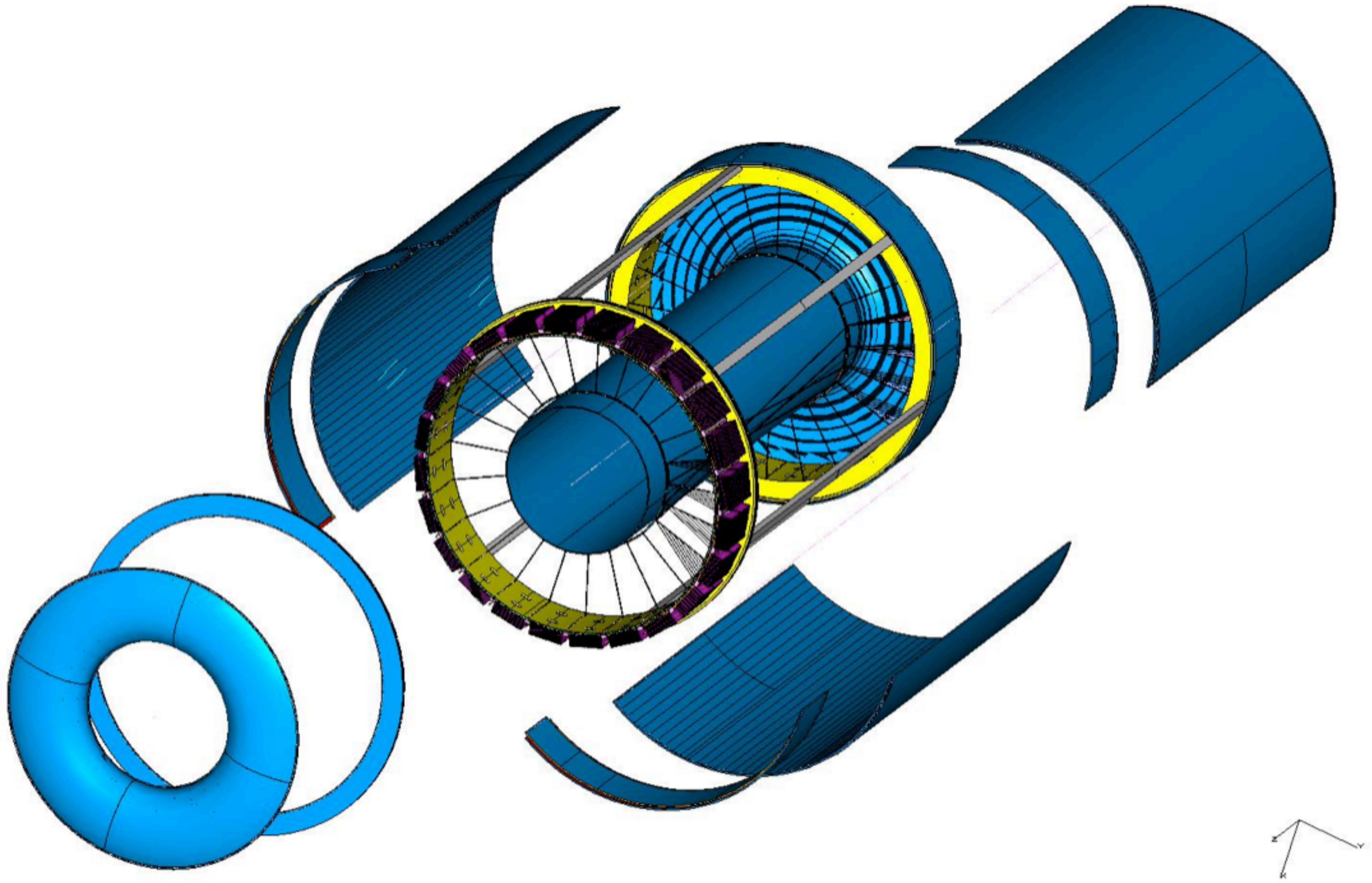
σ_{pt}/pt

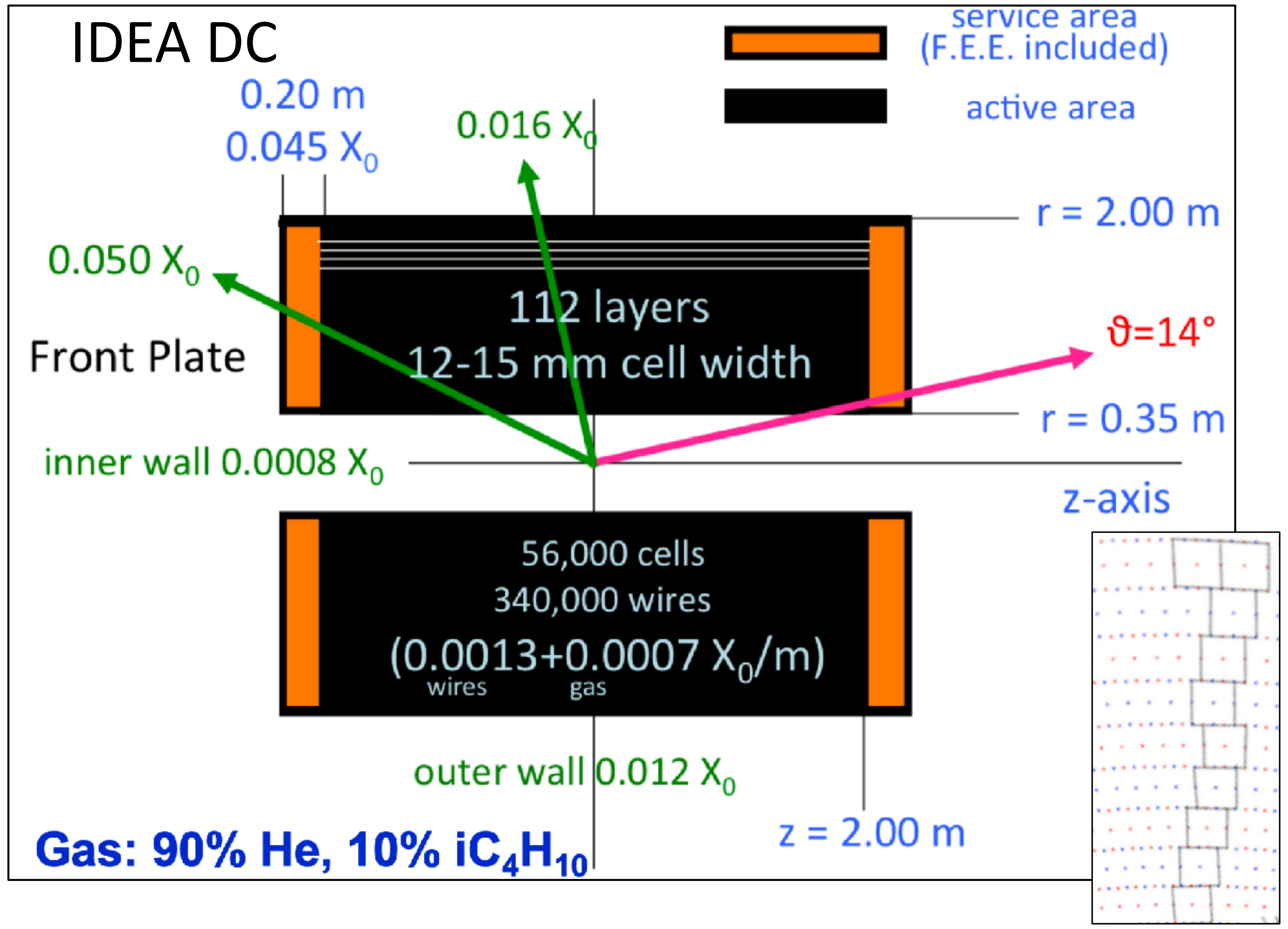


Drift chamber

- 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 90º
    - Tungsten wires dominant contribution
  - 112 layers for each 15º azimuthal sector
  - max drift time: 350 ns



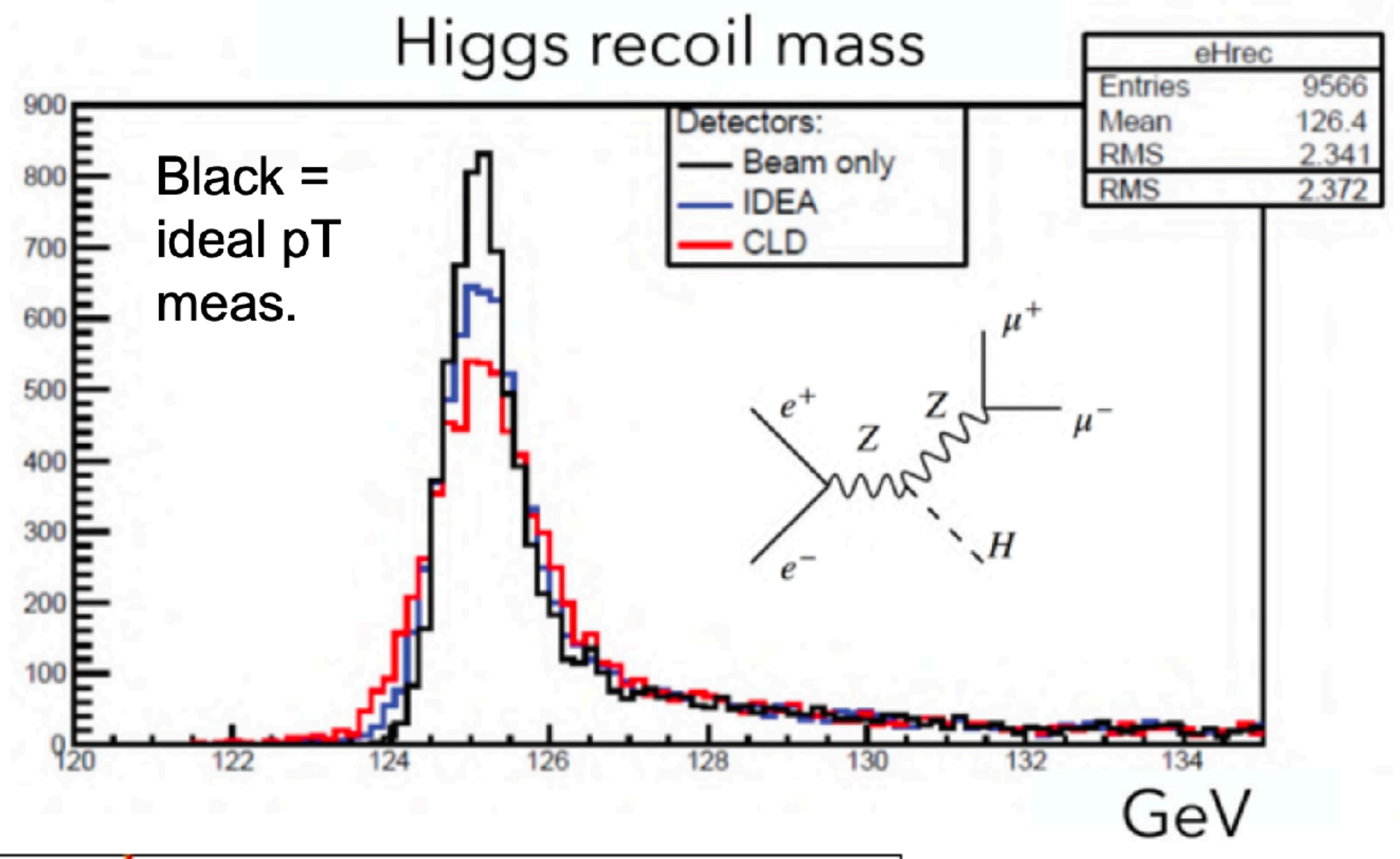


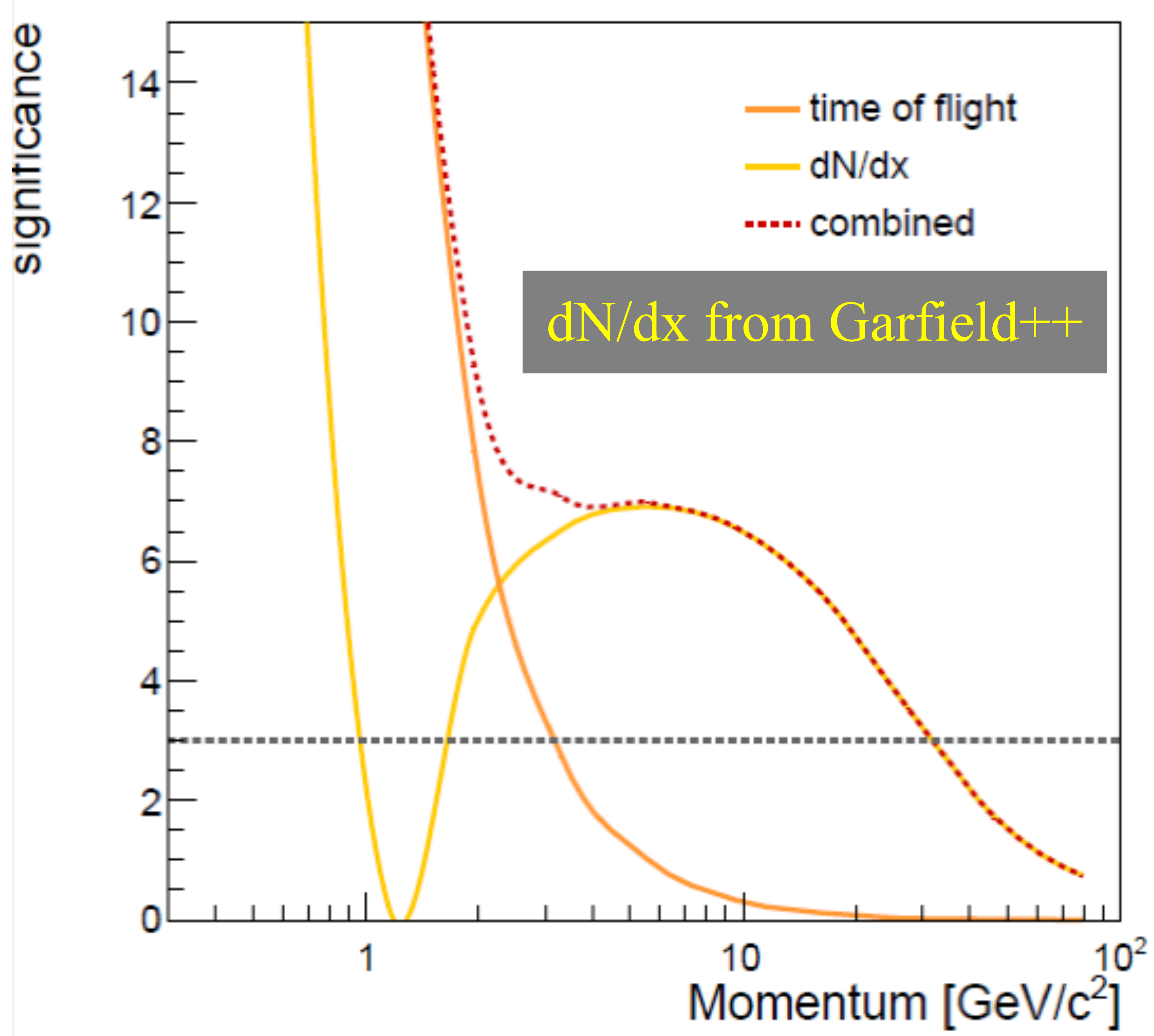


Drift chamber

- In general, tracks have rather low momenta ($p_T \lesssim 50$ GeV)
  - Transparency more relevant than asymptotic resolution

- Drift chamber (gaseous tracker) advantages:
  - Continuous tracking: reconstruction of far-detached vertices (K^0_S, Λ, BSM, LLPs)
  - Outstanding particle separation via cluster counting (dN/dx) or dE/dx
    - >3σ K/π separation up to ~35 GeV

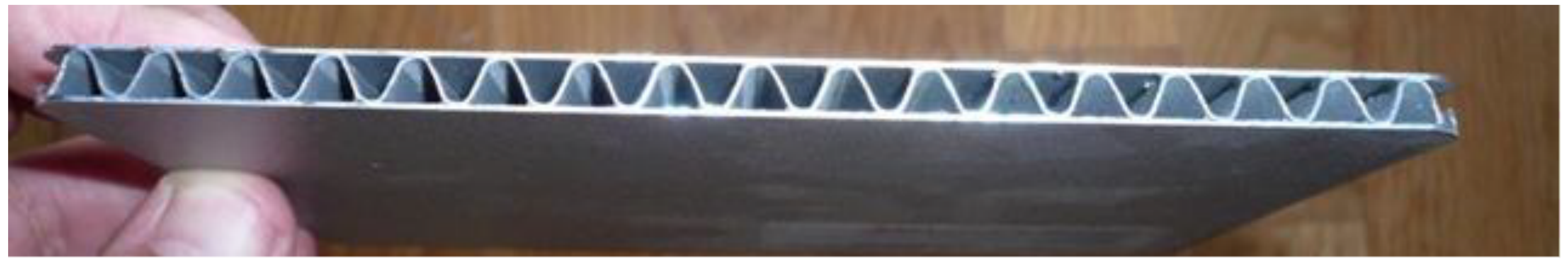


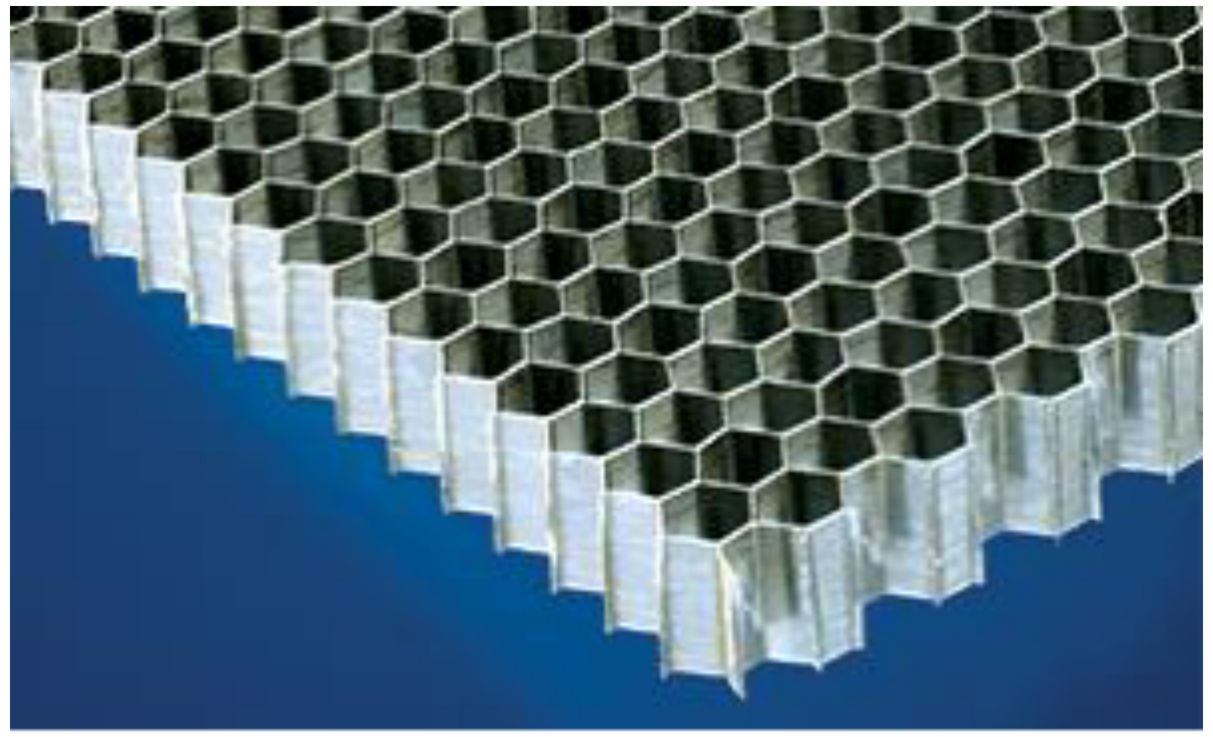


Superconducting solenoid

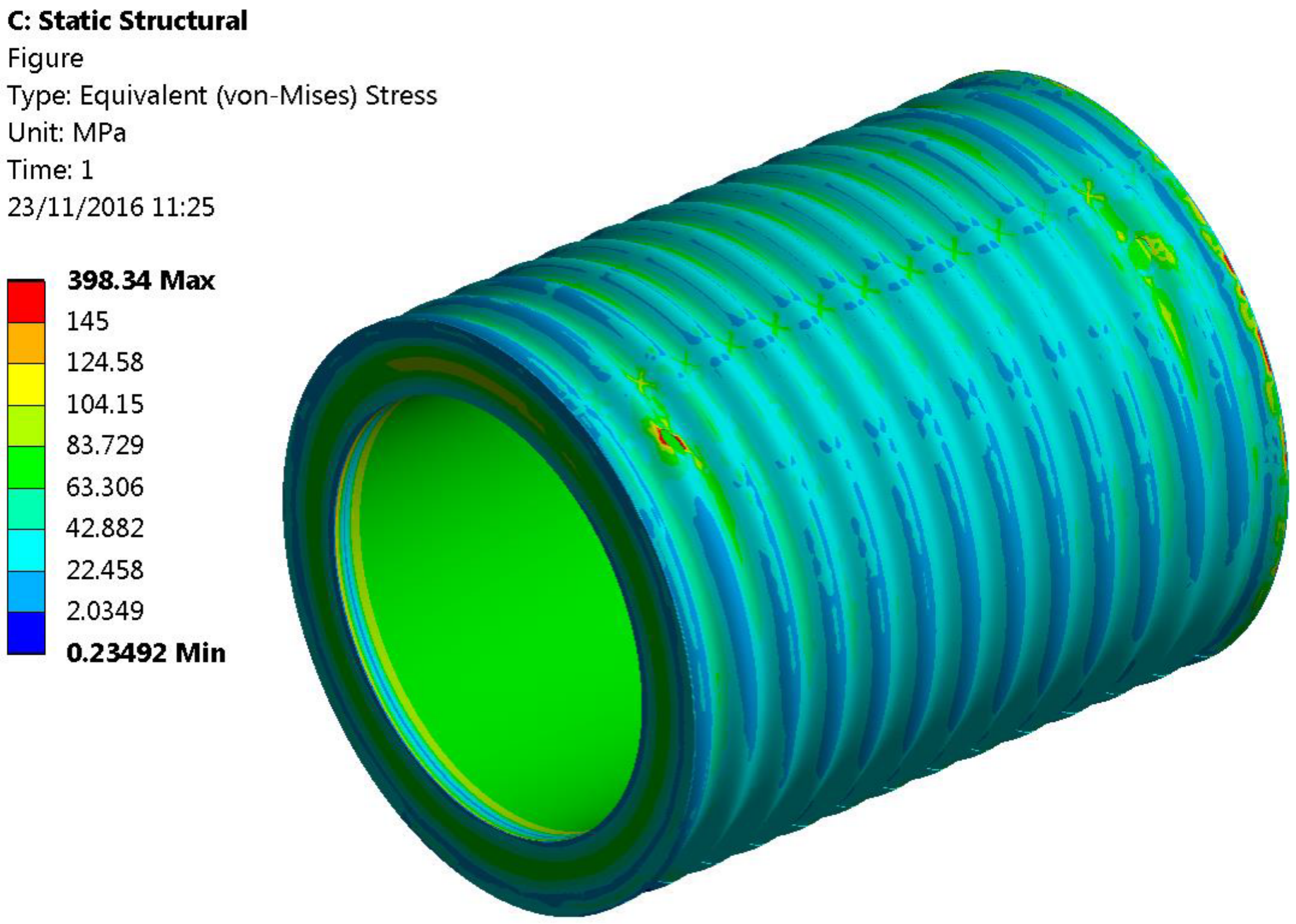
❖ Ultra light 2 T solenoid:

- ➢ 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: $X_0 = 0.04$

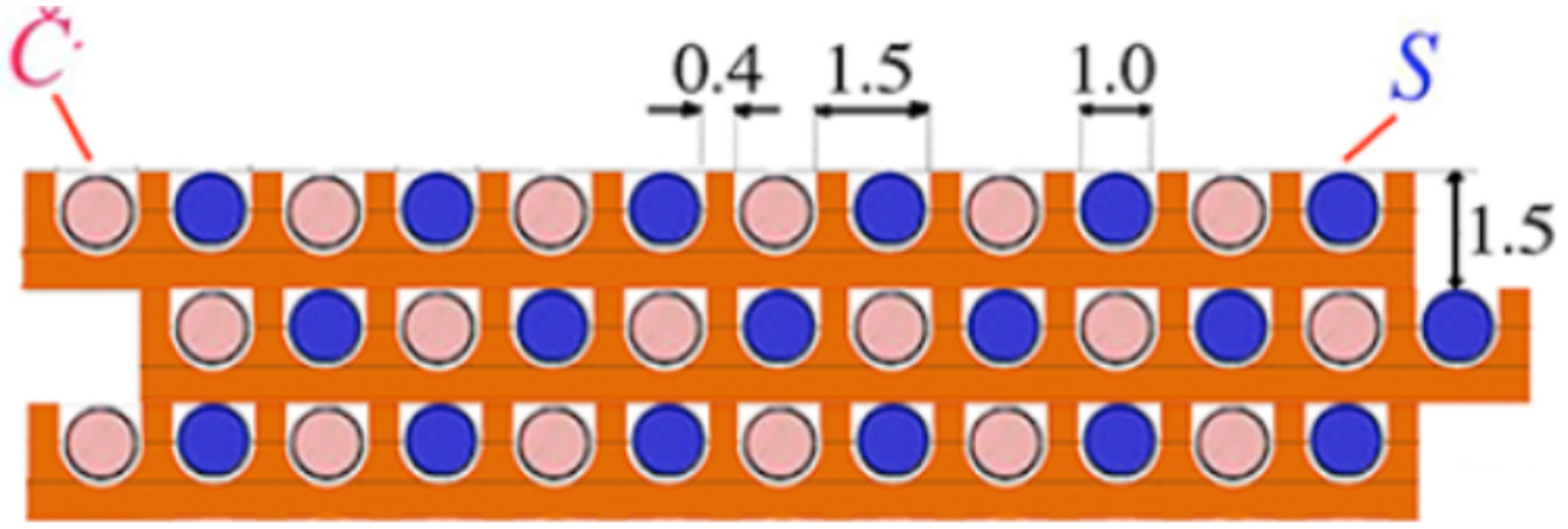




Courtesy of H. TenKate

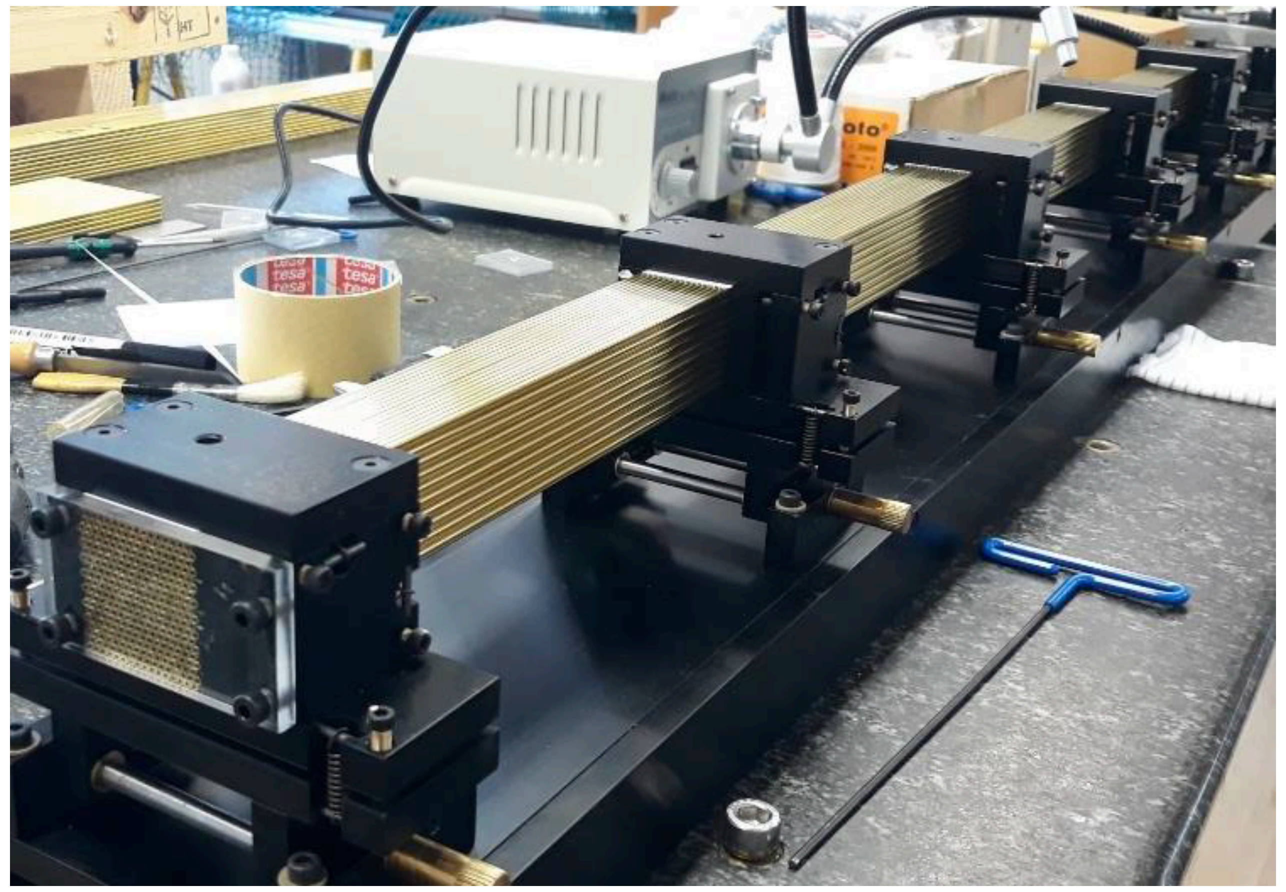


Dual Readout Calorimetry



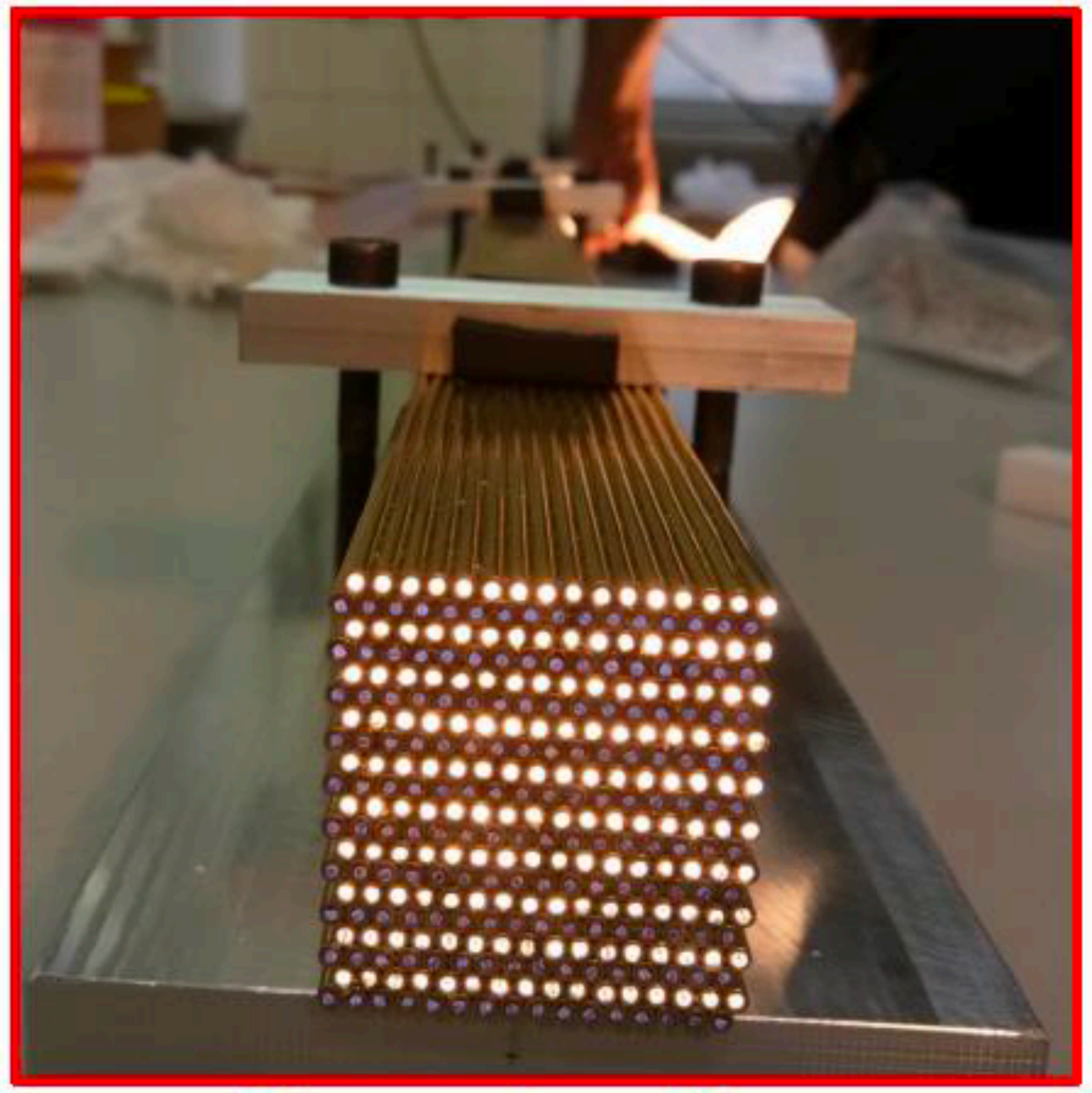
Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers



Cherenkov fibers

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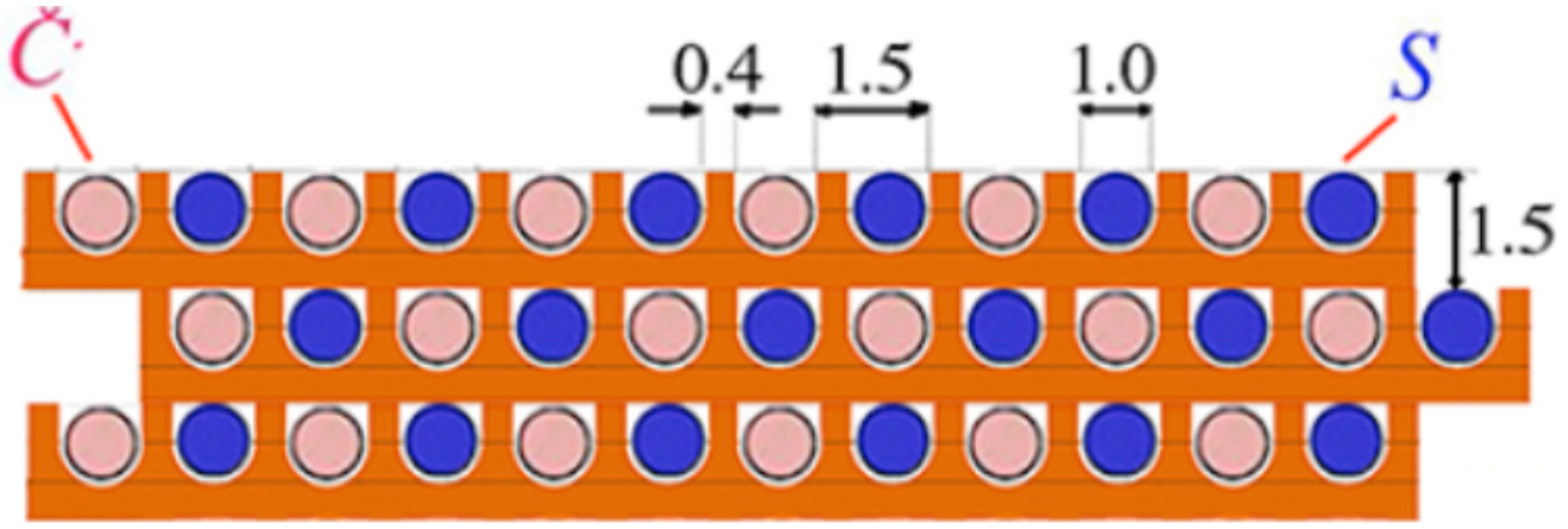

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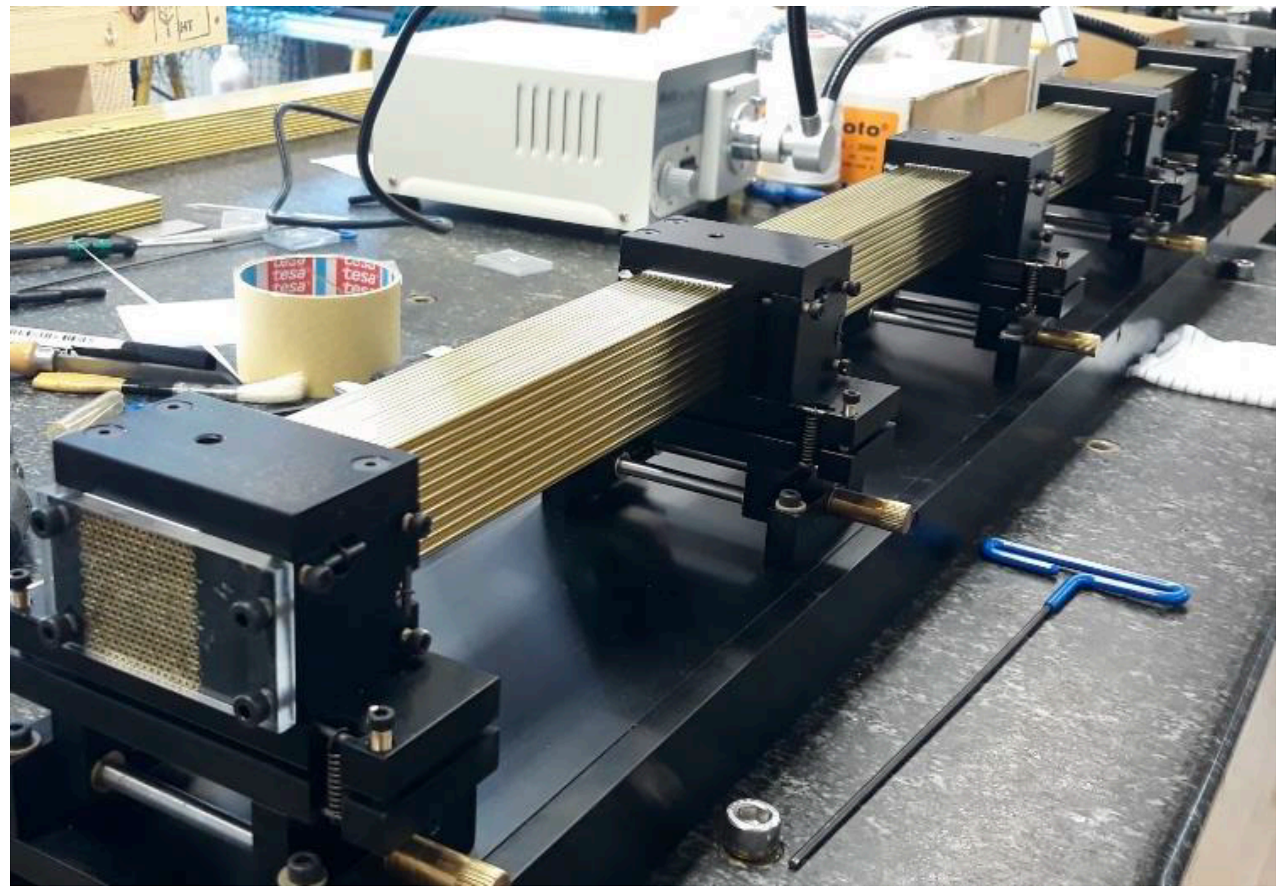

- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)

Newer DR calorimeter
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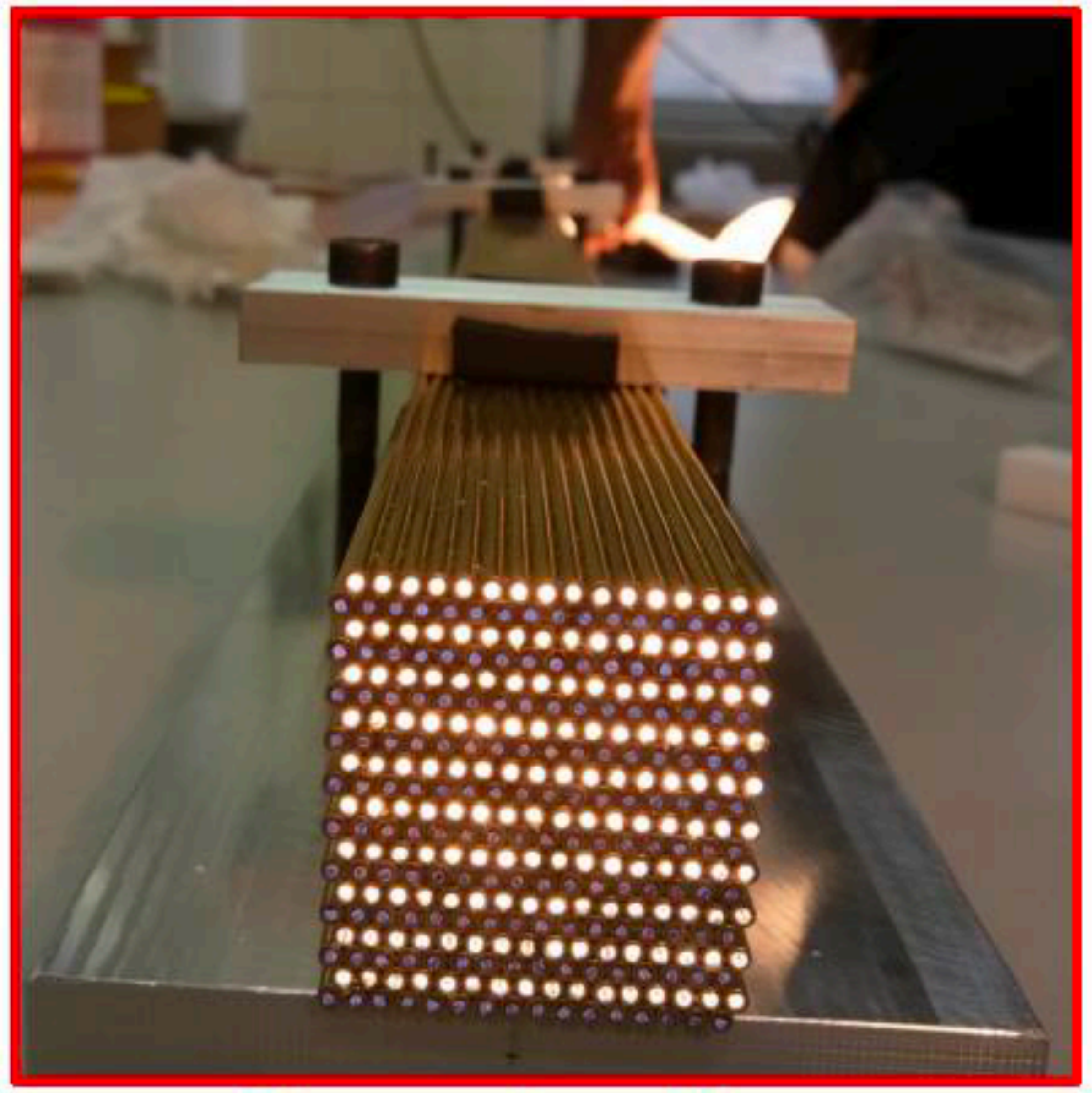

Cherenkov fibers

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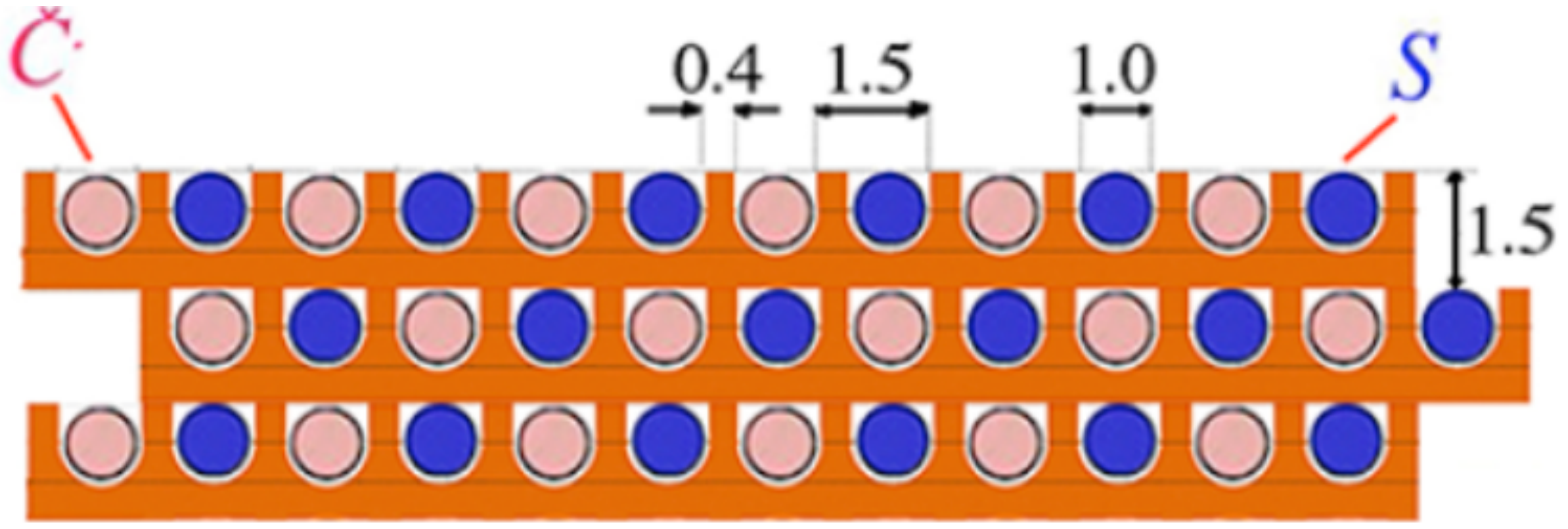

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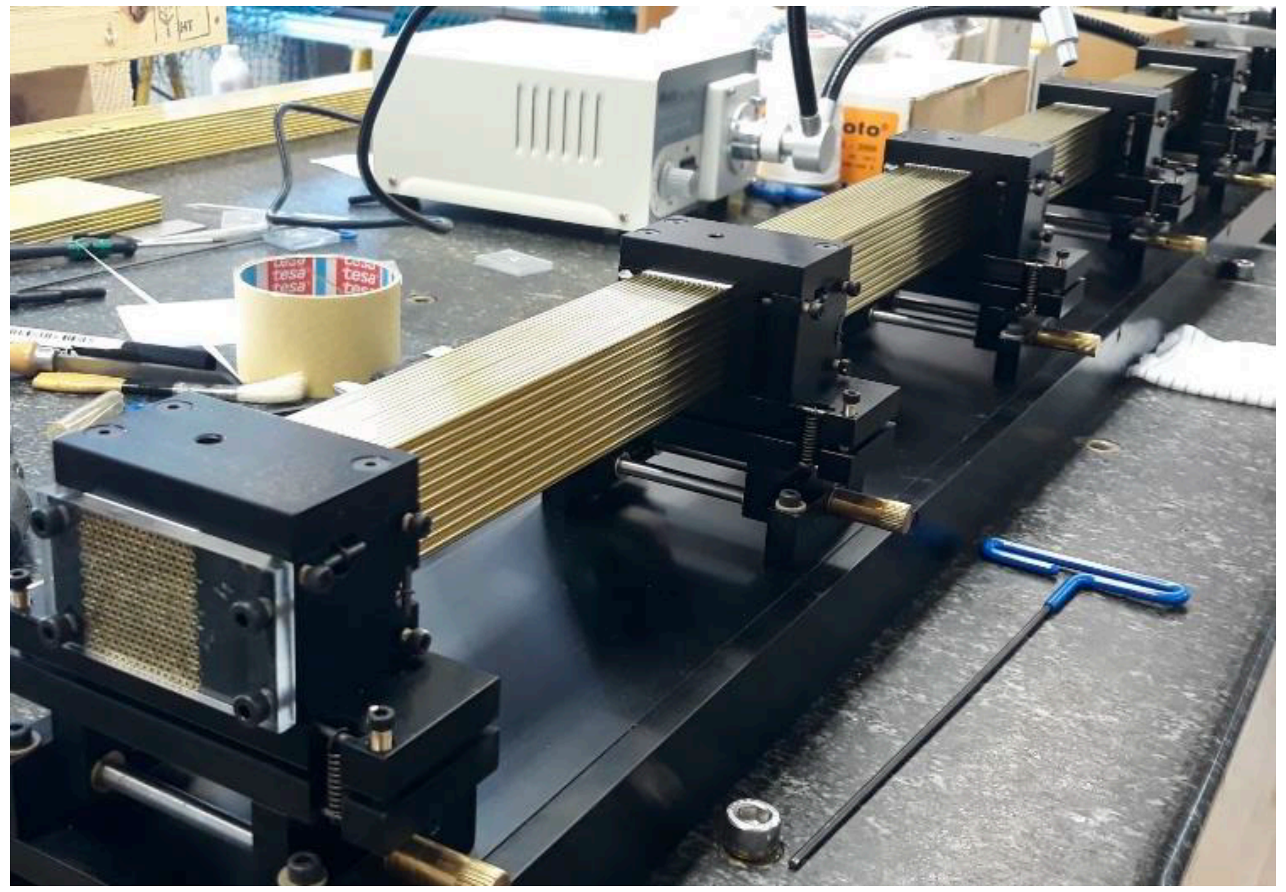

- ❖ Measure simultaneously:
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- ❖ Calibrate both signals with e-

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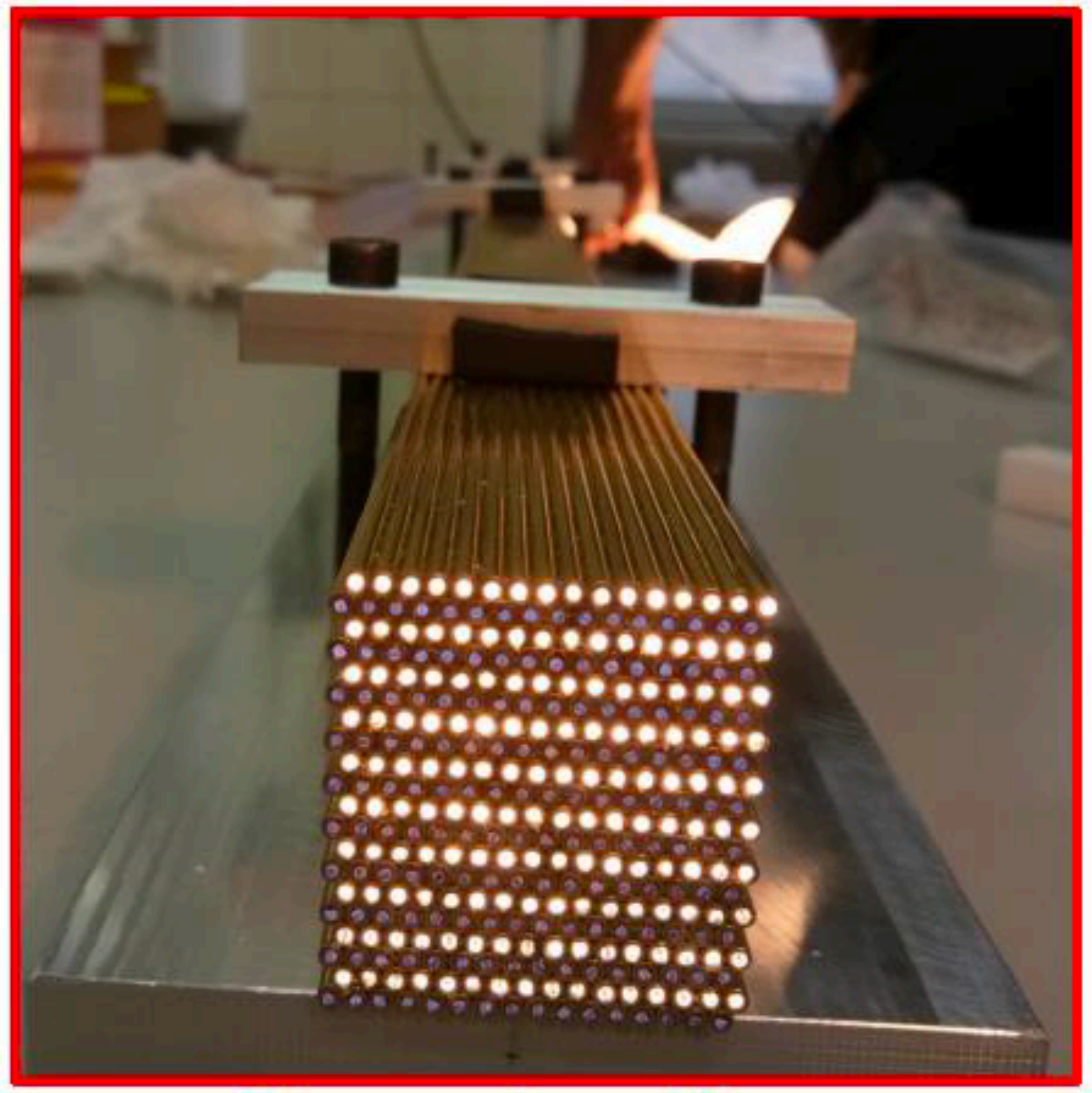

Scintillation fibers

Cherenkov fibers

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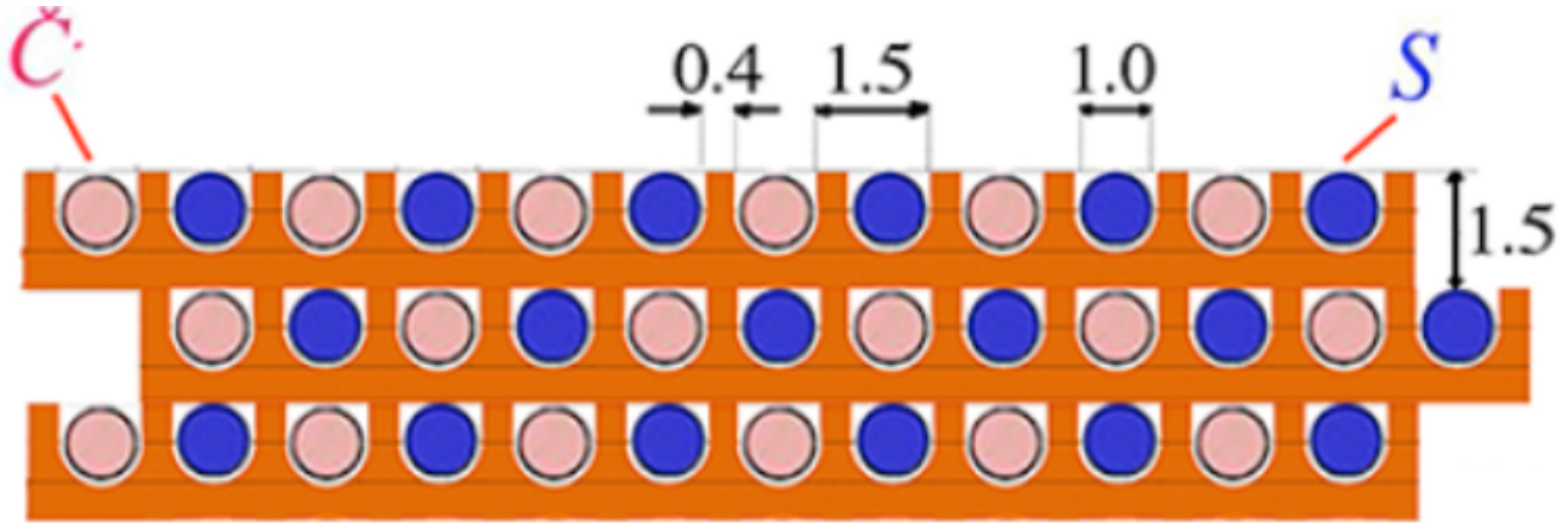

Alternate

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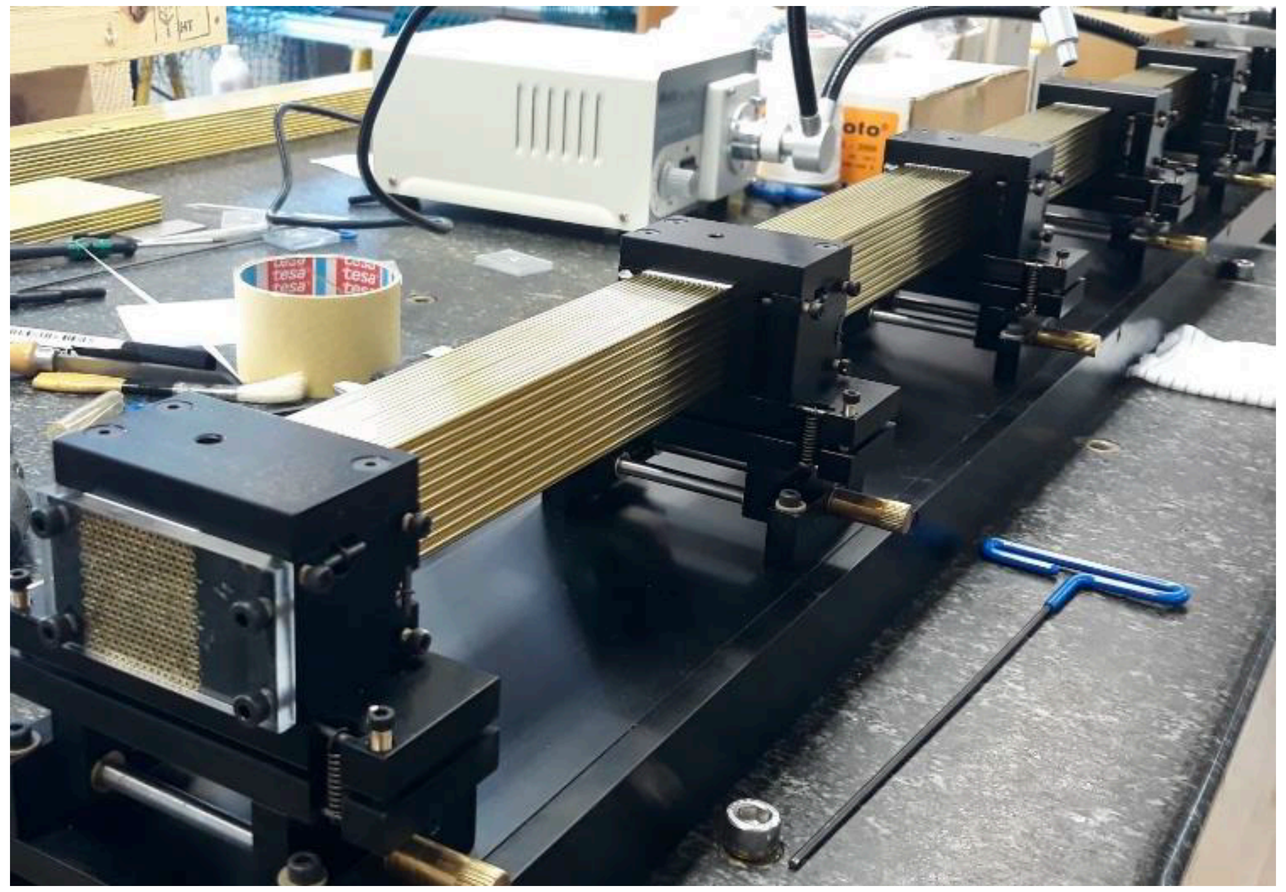
Scintillating fibers

~2m long capillaries



- Measure simultaneously:
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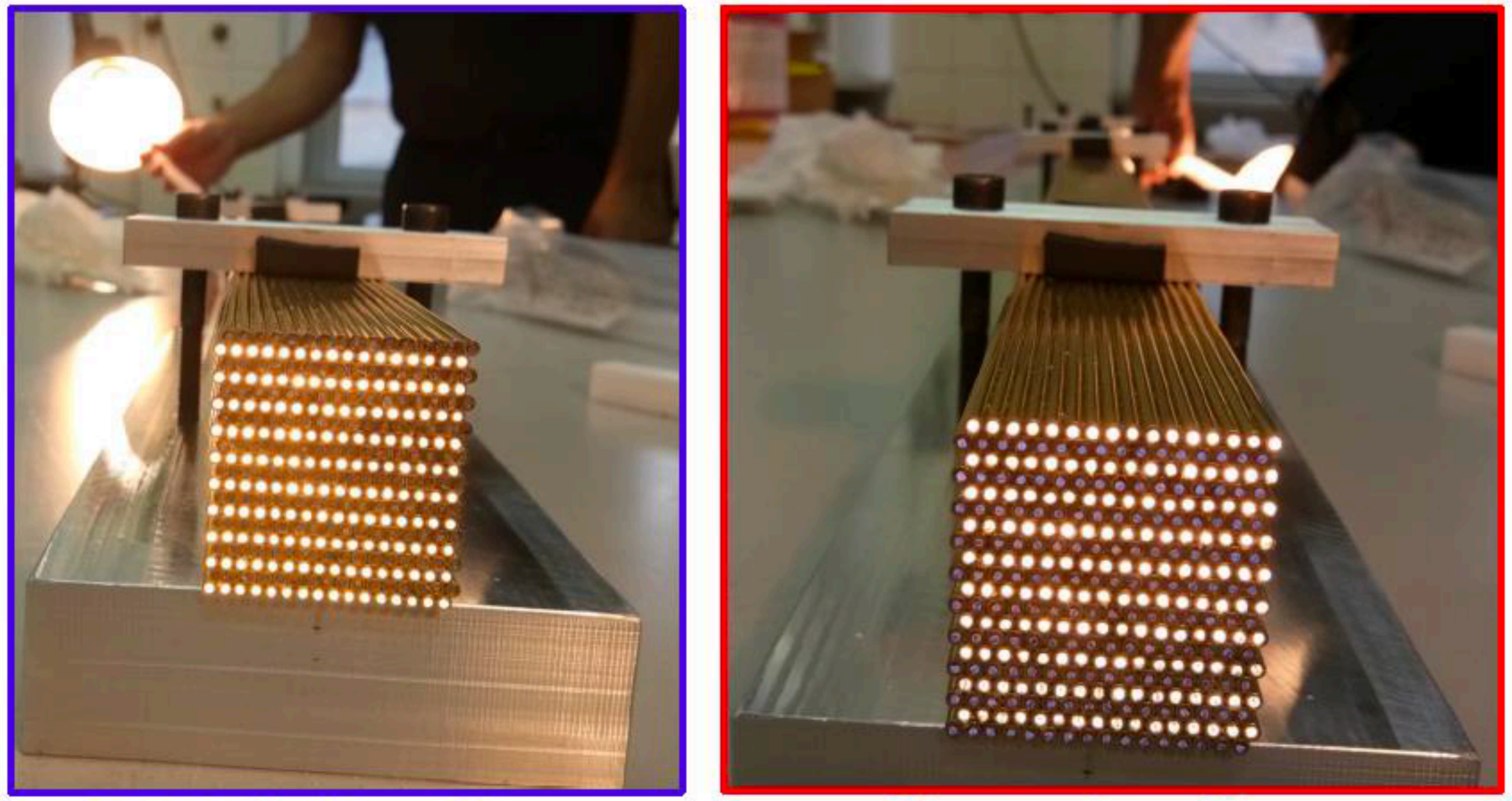
- Unfold event by event f_{em} to obtain corrected energy

Newer DR calorimeter
(bucatini calorimeter)



Scintillation fibers

Cherenkov fibers

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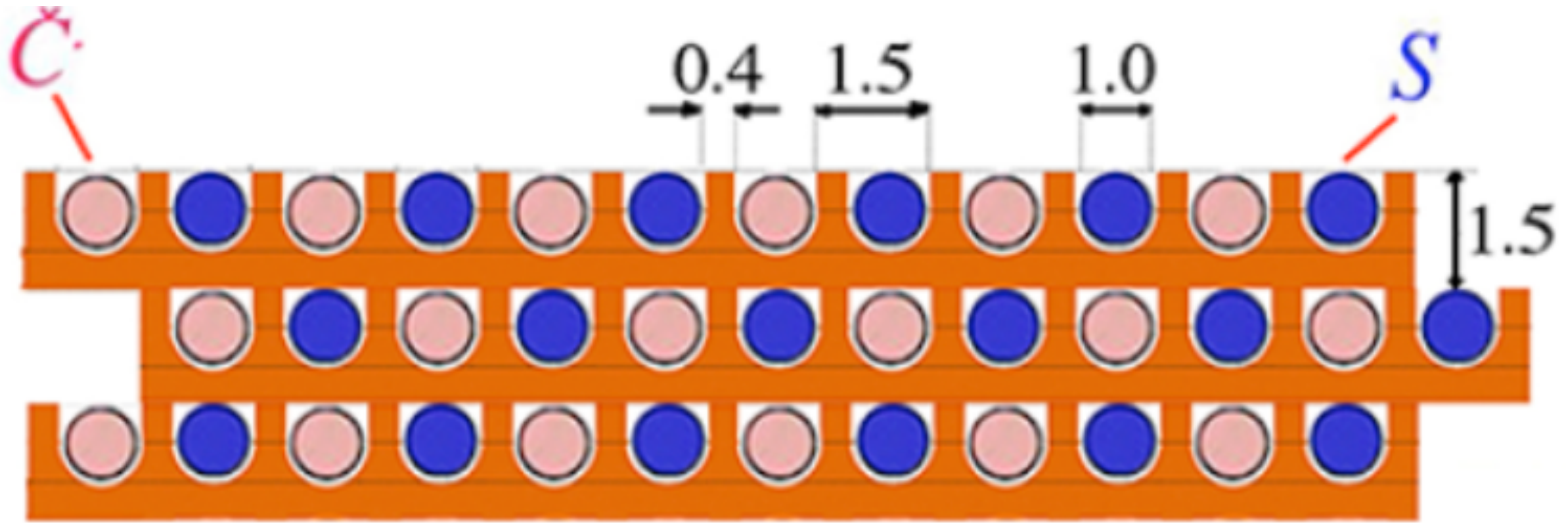

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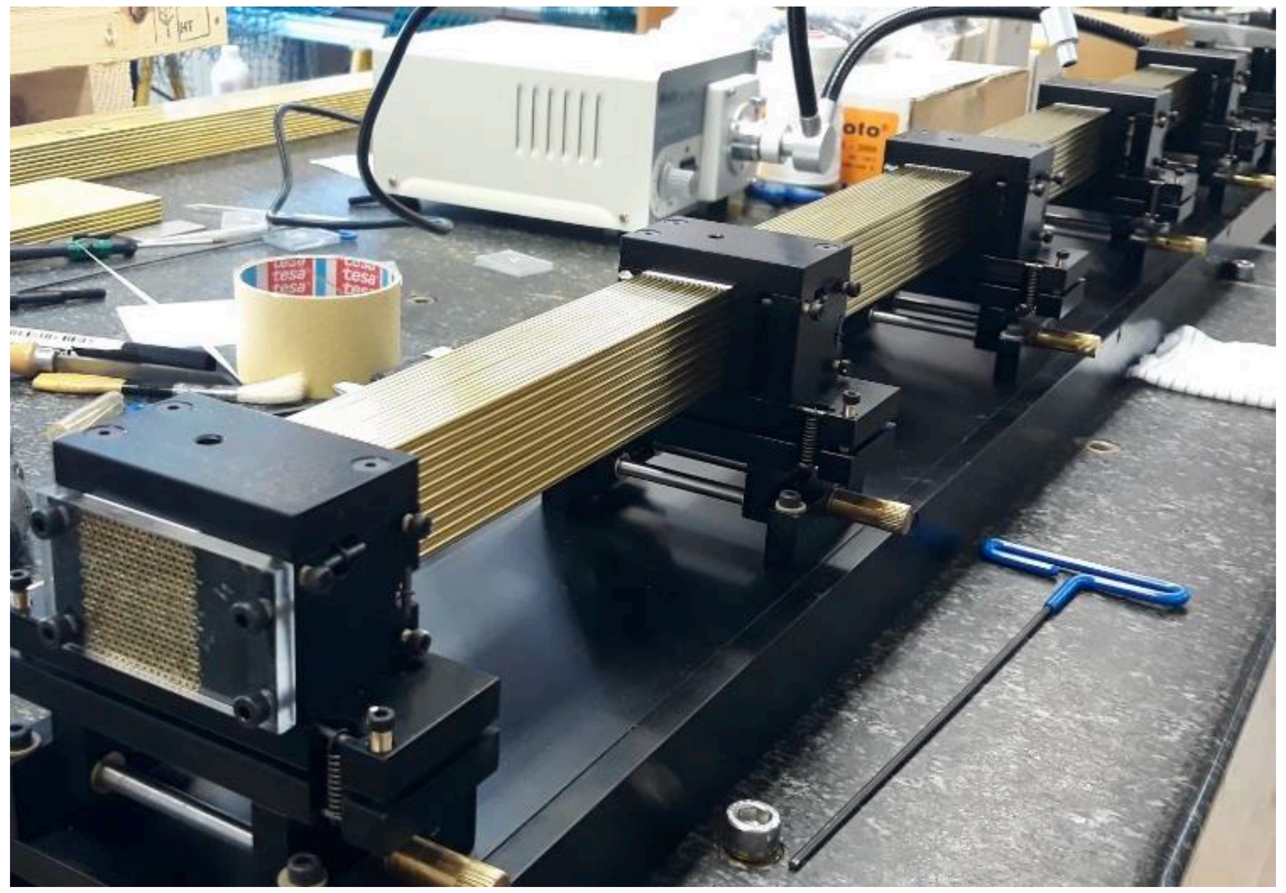

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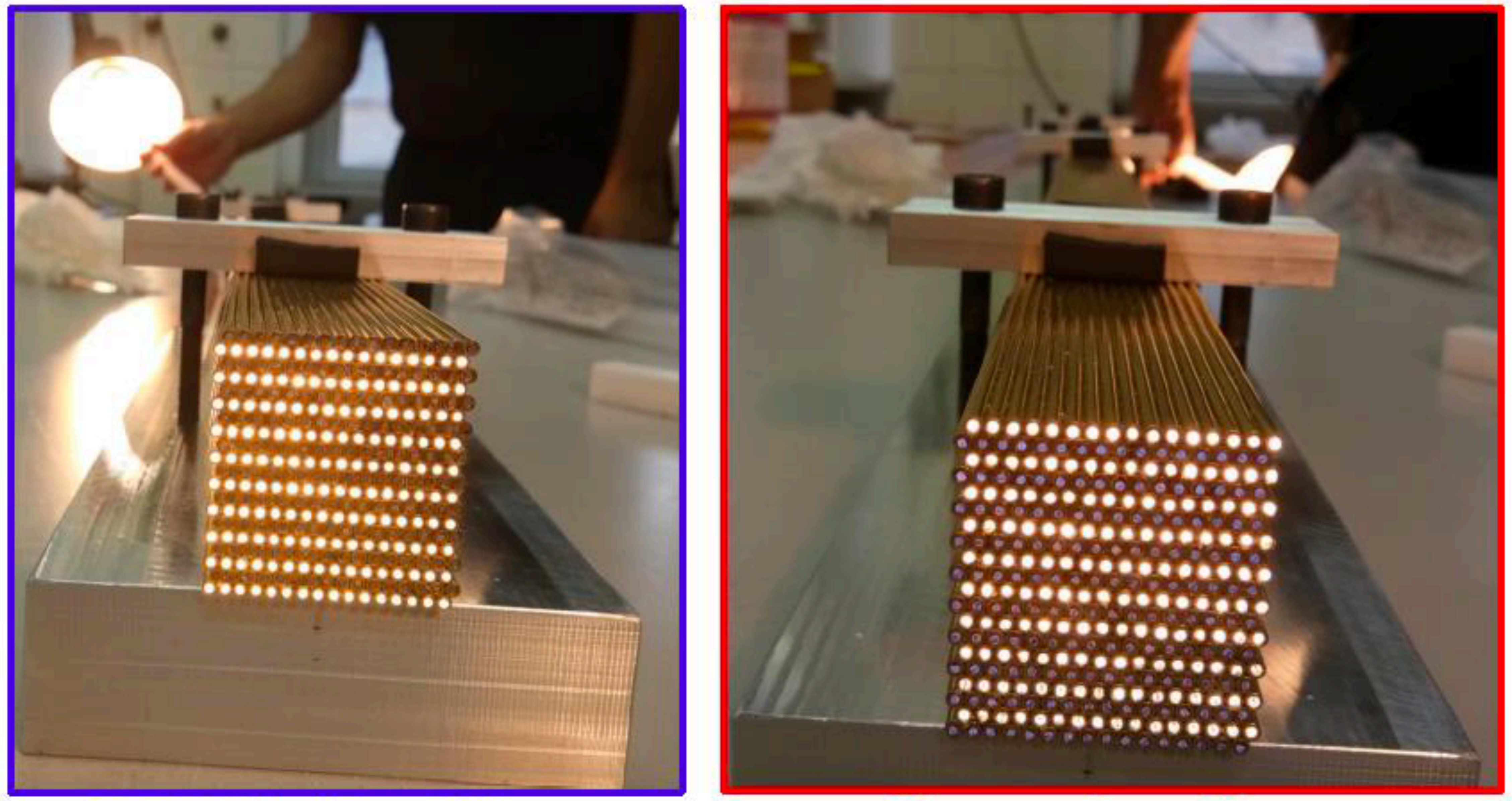
$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$

$$C = E\left[f_{em} + (h/e)_C(1 - f_{em})\right]$$

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

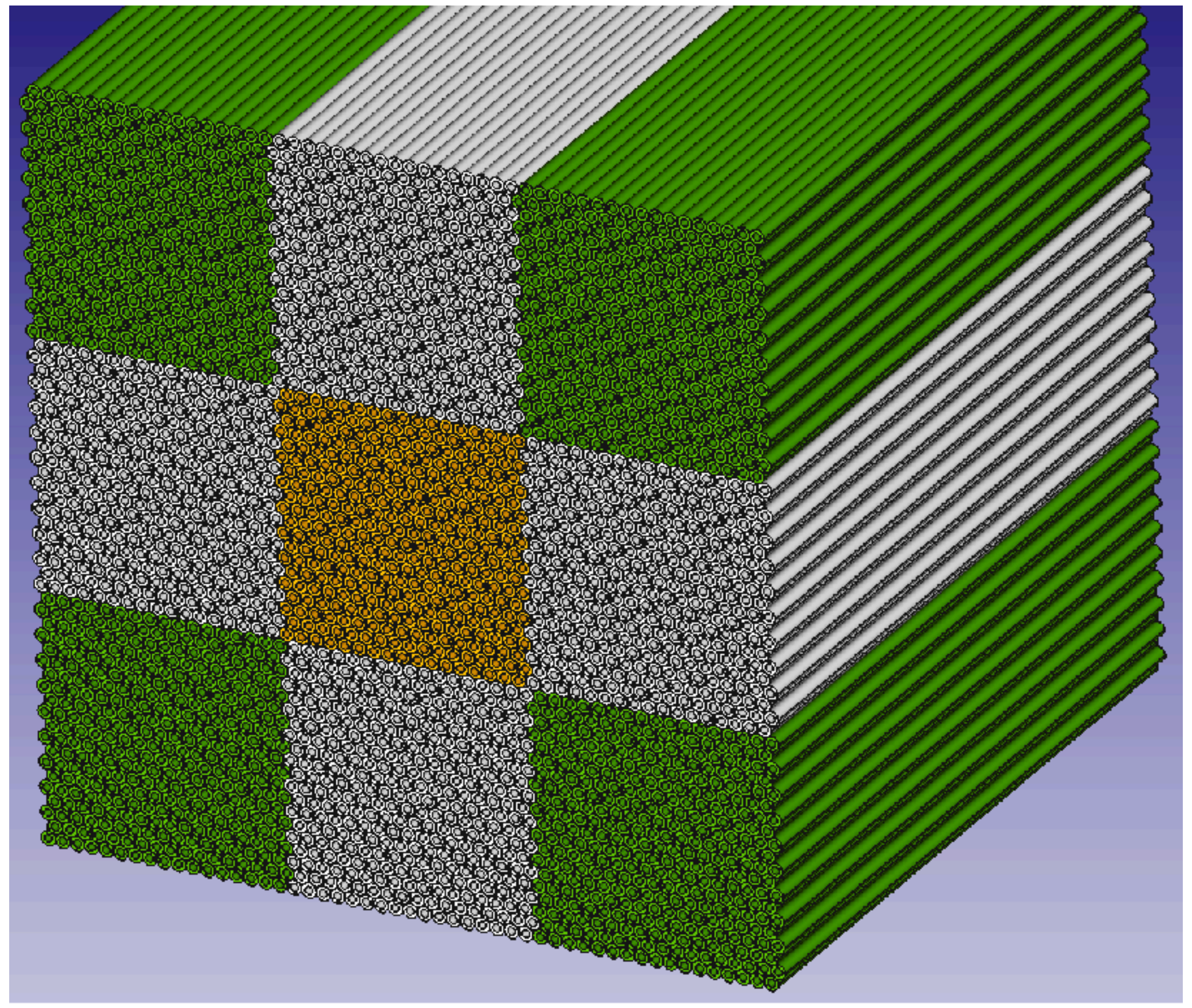
Newer DR calorimeter
(bucatini calorimeter)

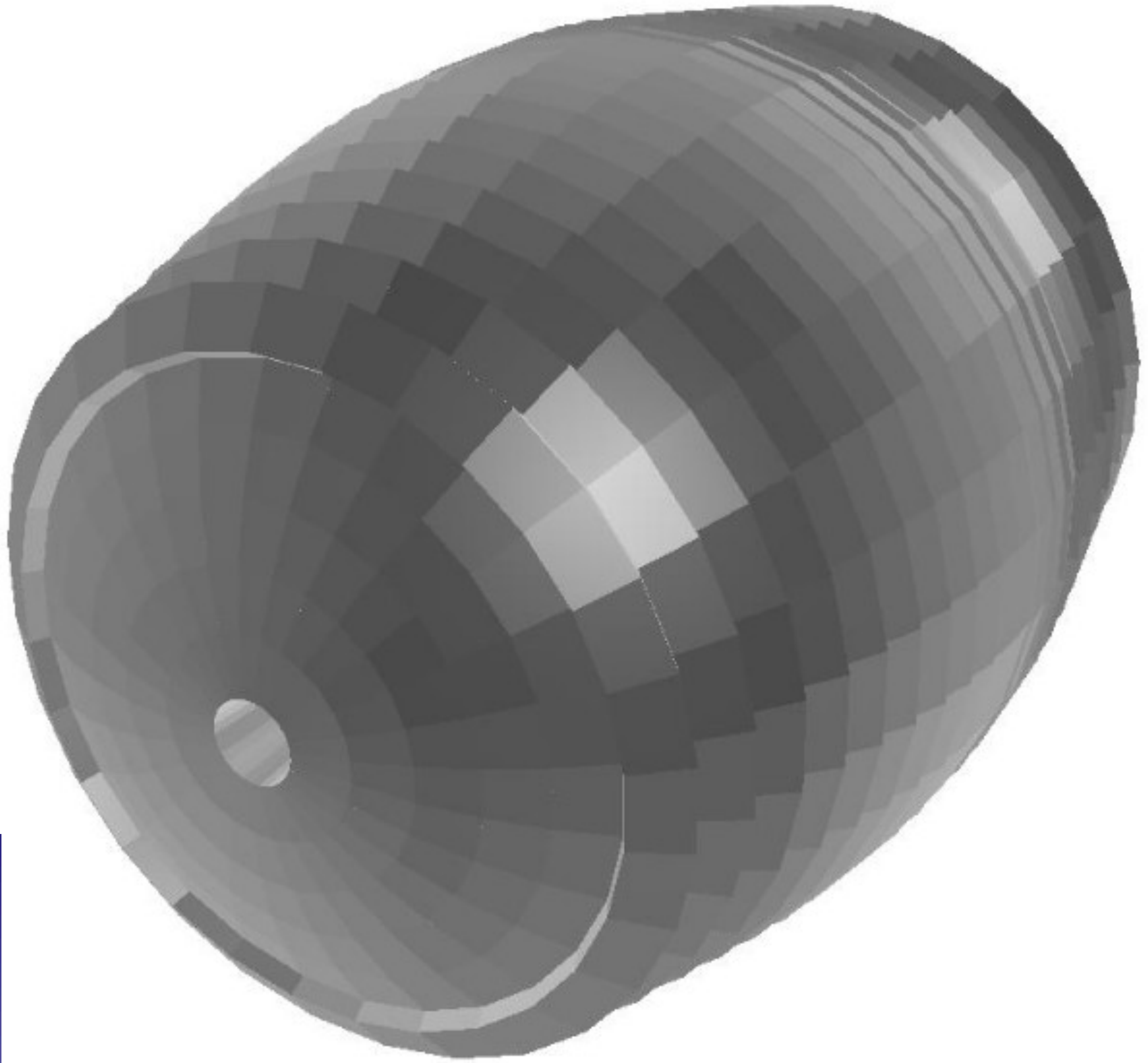


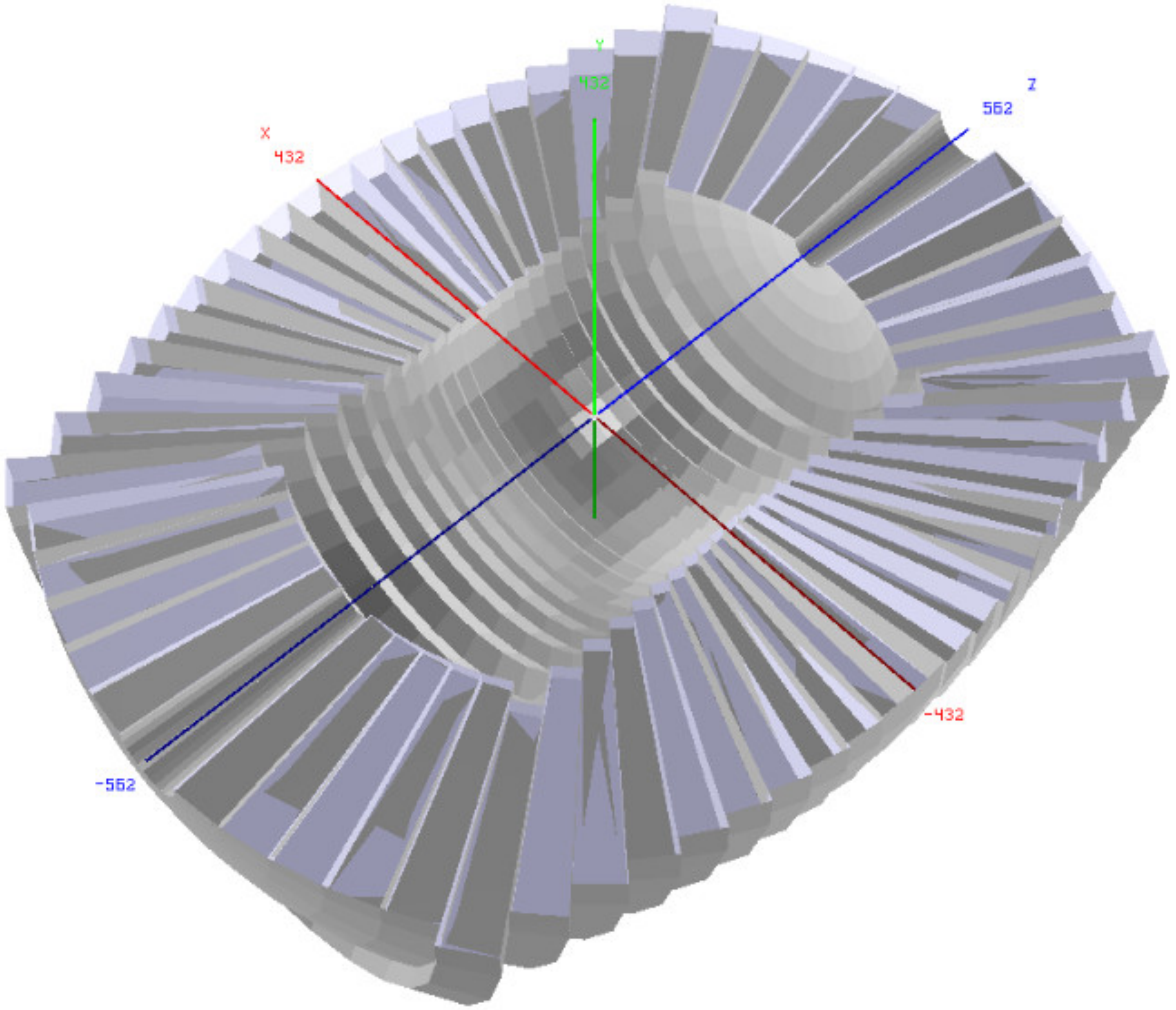
Scintillation fibers   Cherenkov fibers

Dual Readout Calorimeter

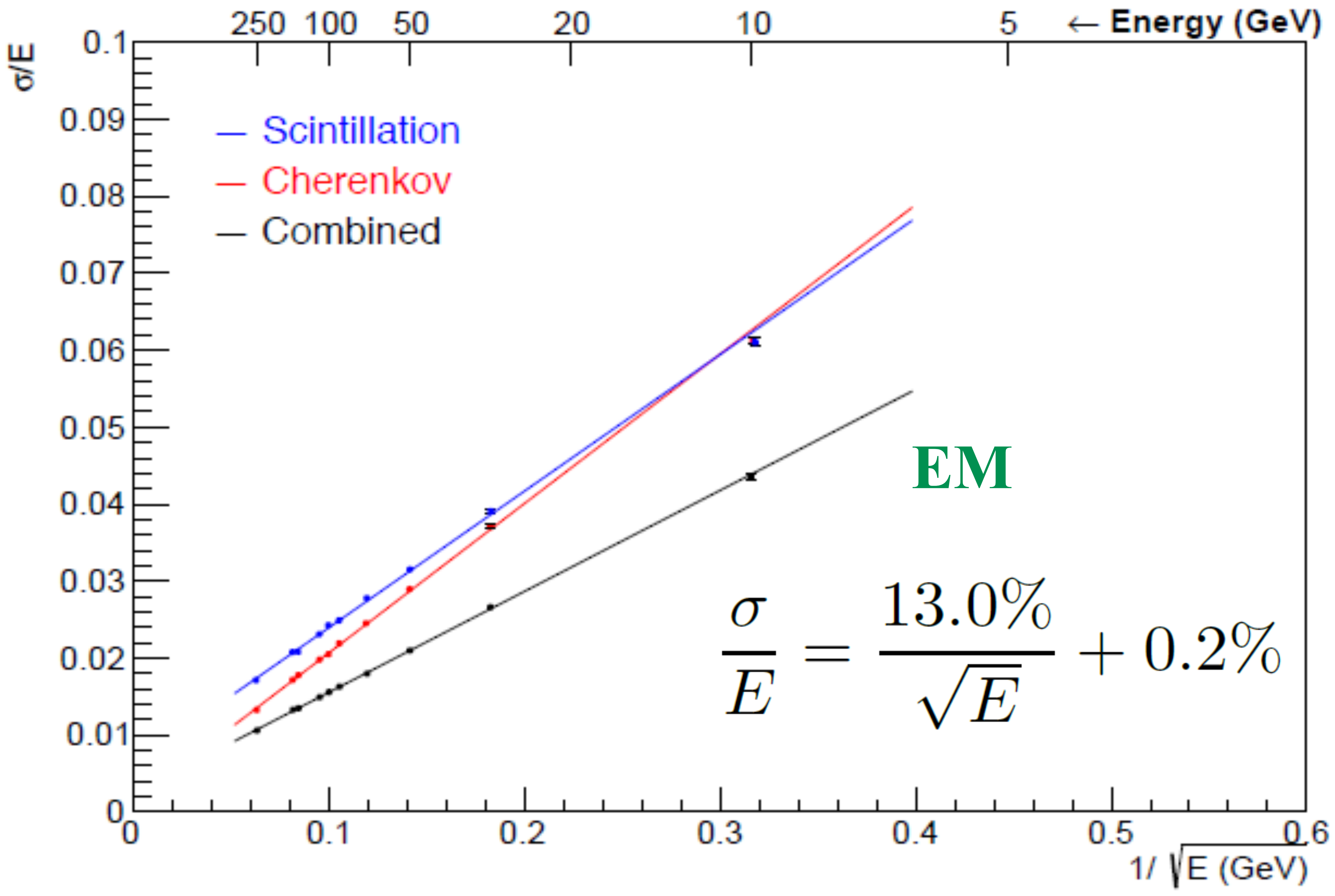
Full GEANT4 implementation of the DR calorimeter

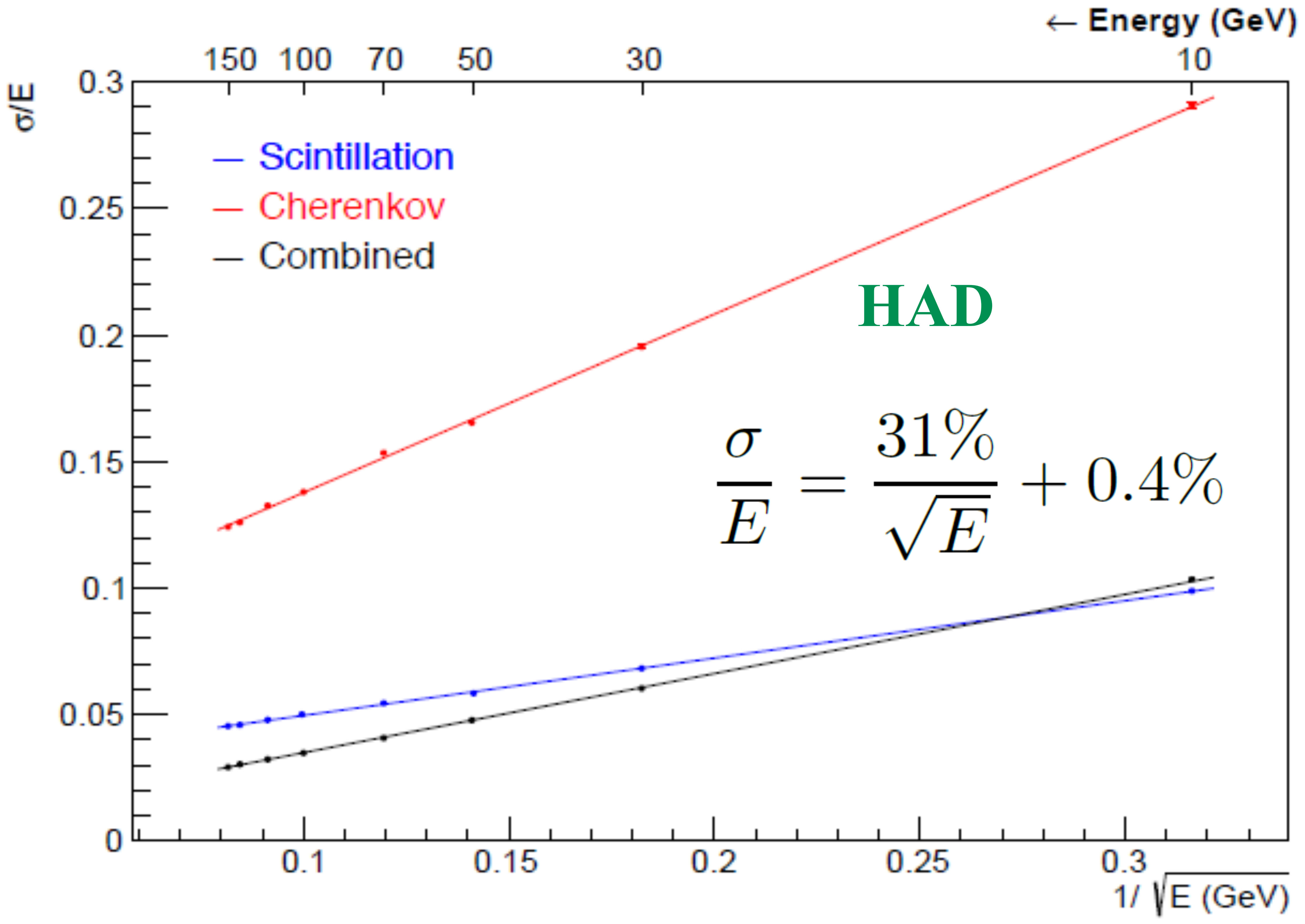




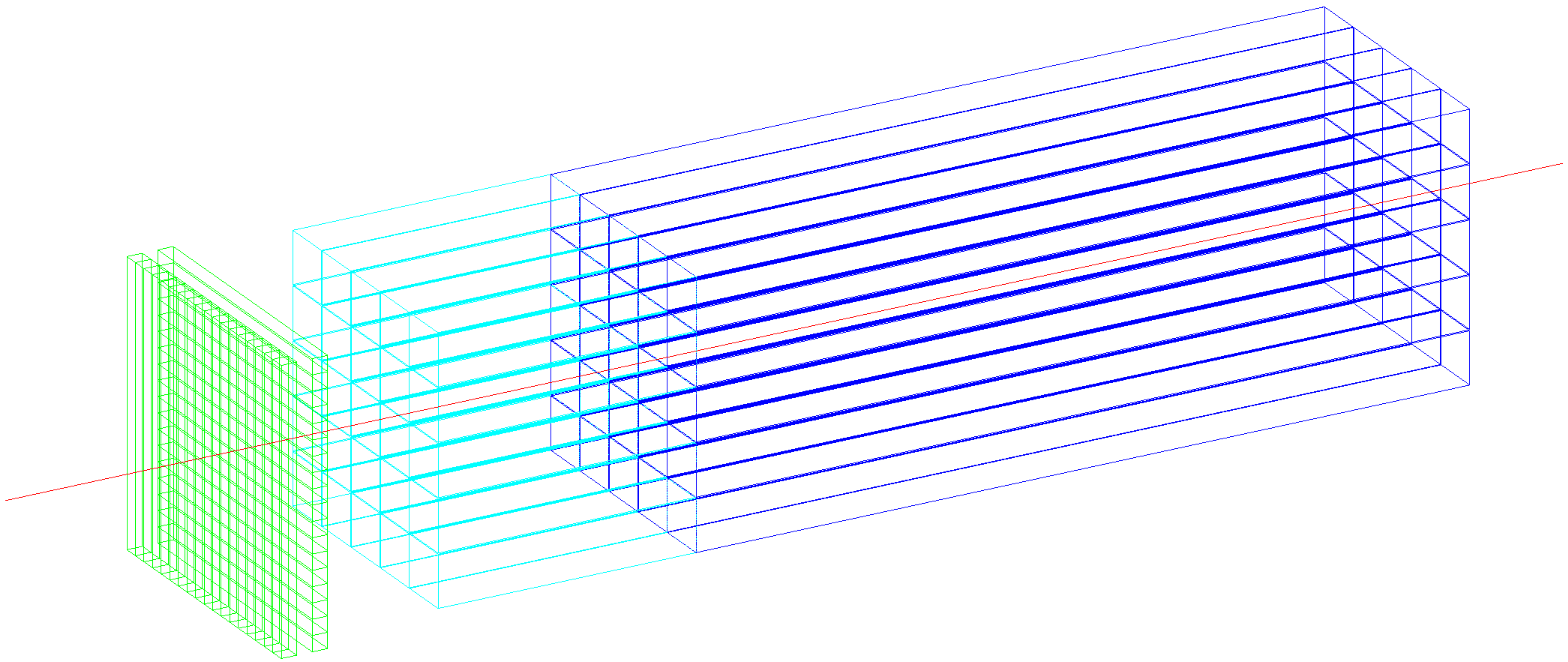


Dual Readout Calorimeter





Crystal option



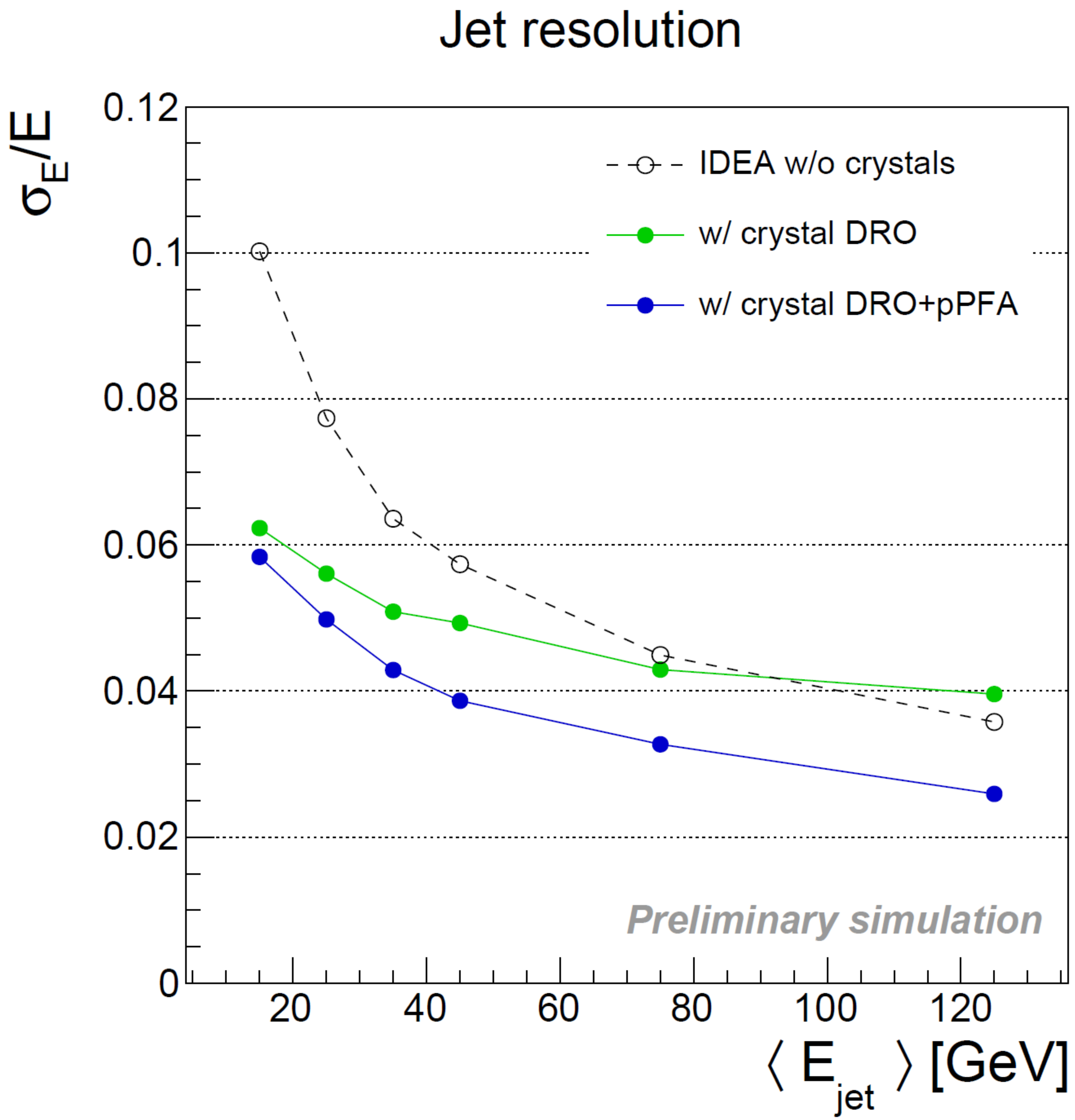
- **ECAL layer:**
  - PbWO crystals
  - front segment 5 cm (~5.4 X_0)
  - rear segment for core shower
  - (15 cm ~16.3 X_0)
  - 10x10x200 mm³ of crystal
  - 5x5 mm² SiPMs (10-15 um)

1x1x5 cm³ PbWO

1x1x15 cm³ PbWO

Crystal option

- ~20 cm $PbWO_4$
- $\sigma_{EM} \approx 3\%/\sqrt{E}$
- DR w. filters
- Timing layer
  - LYSO 20-30 ps
- PF for jets



μ-RWELL technology

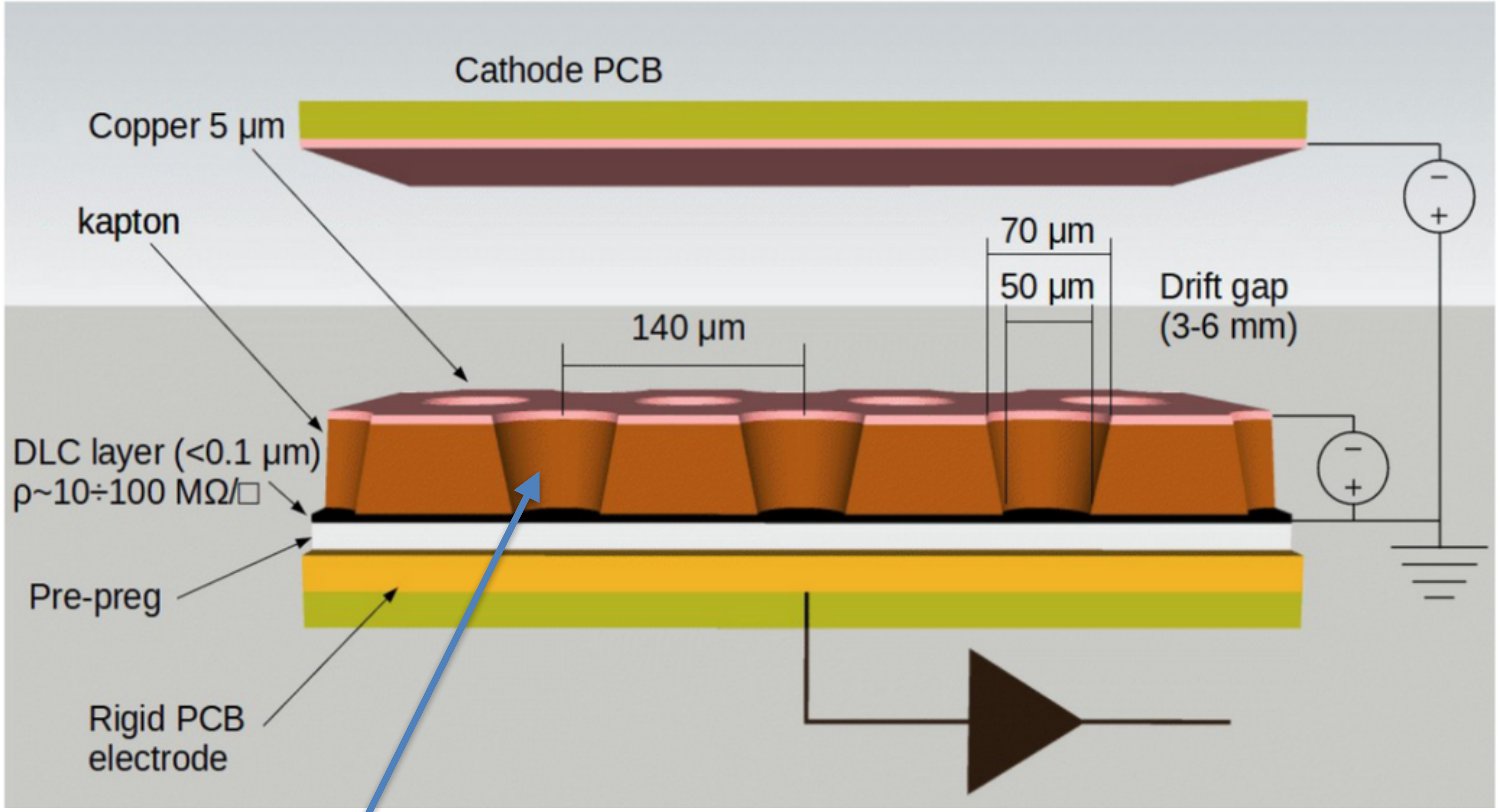
The μ-RWELL is composed of only two elements:

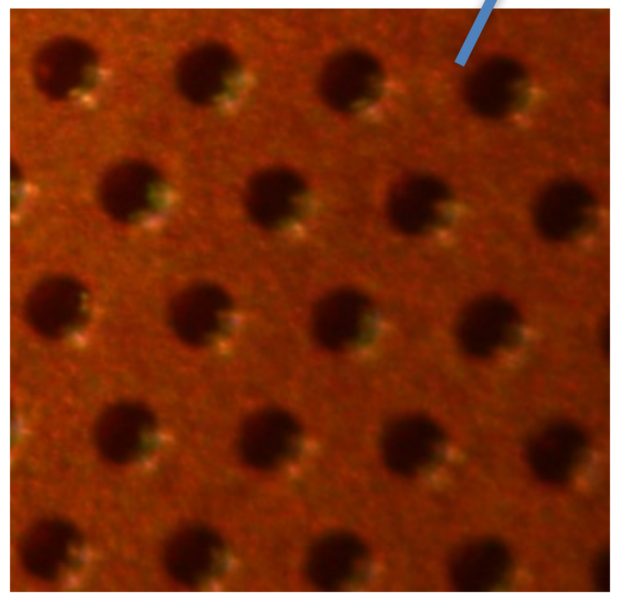
- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

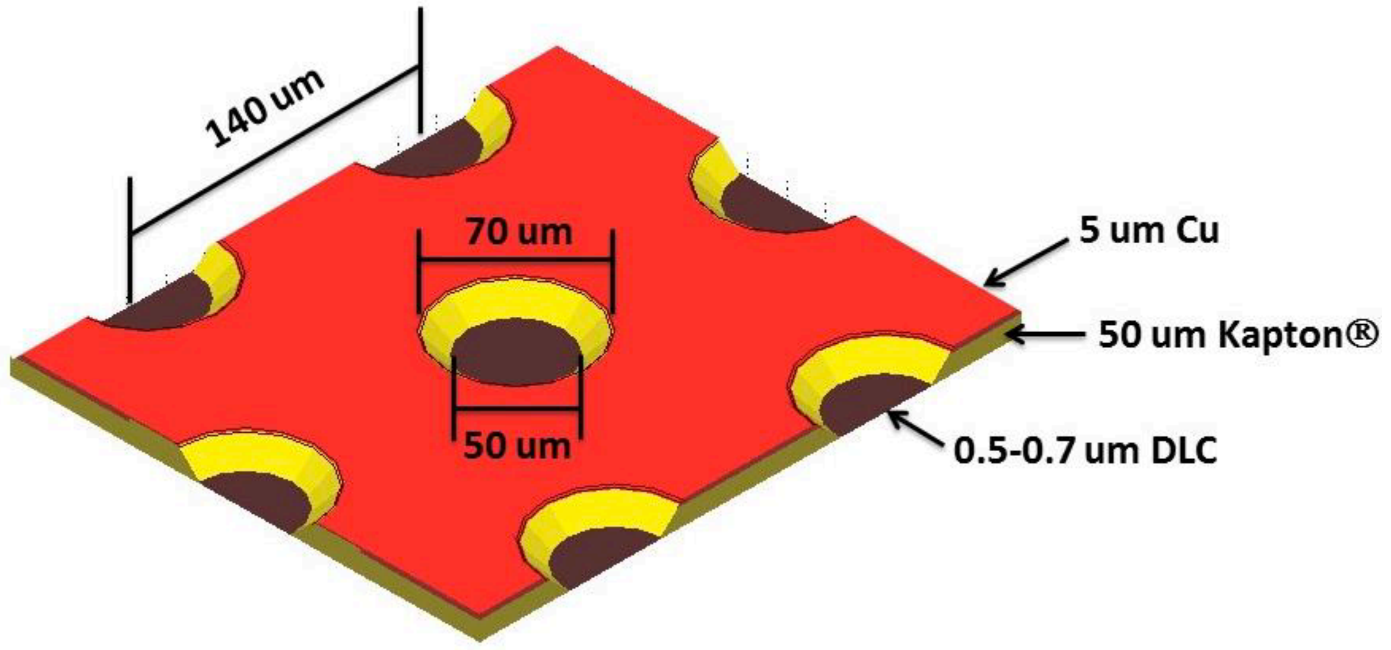
μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB

μ-RWELL operation:

- A charged particle ionises the gas between the two detector elements
- Primary electrons drift towards the μ-RWELL_PCB (anode) where they are multiplied, while ions drift to the cathode
- The signal is induced capacitively, through the DLC layer, to the readout PCB
- HV is applied between the Anode and Cathode PCB electrodes
- HV is also applied to the copper layer on the top of the kapton foil, providing the amplification field







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

Preshower and muon detector

Preshower Detector

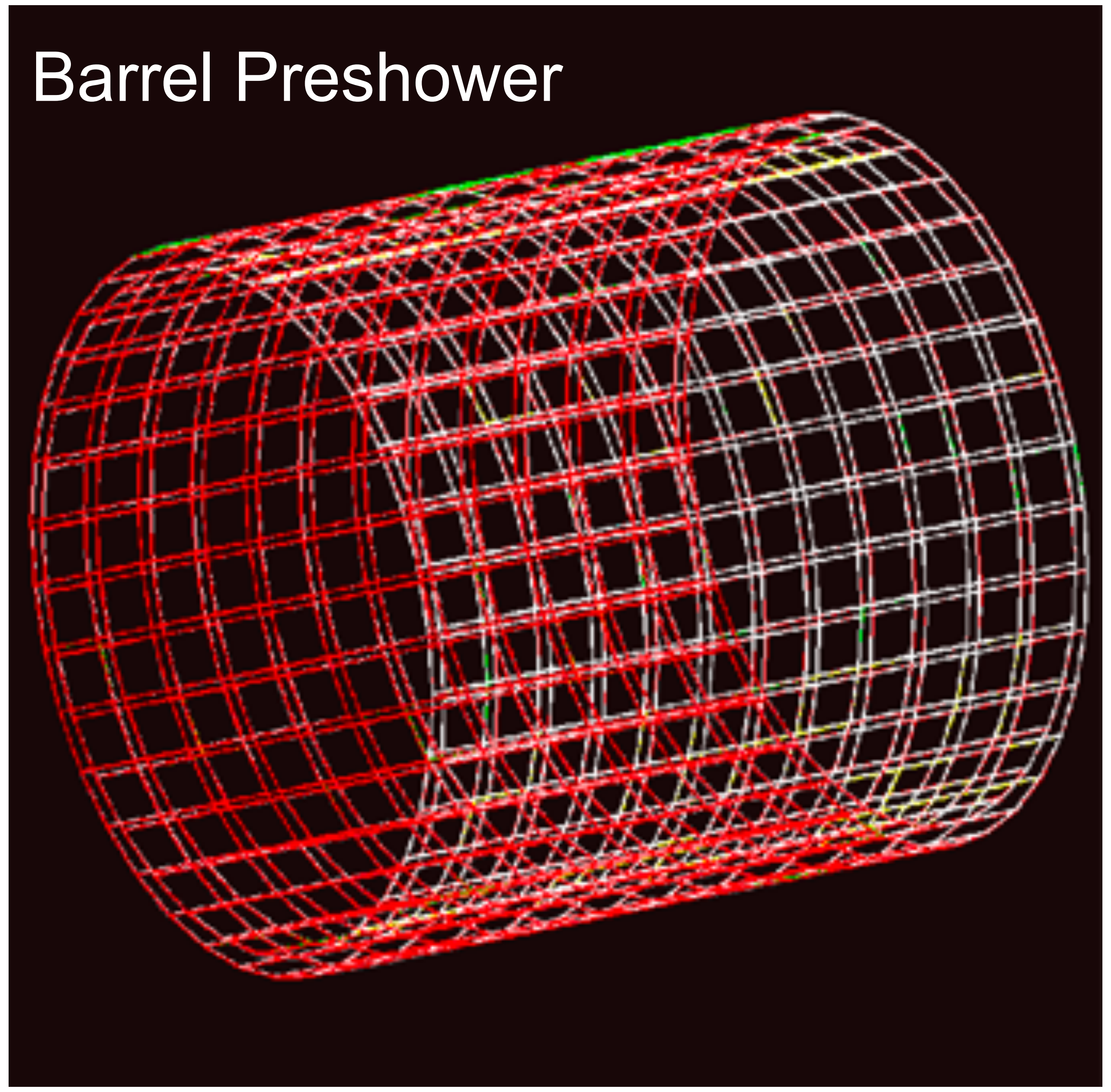
High resolution before the magnet
to improve cluster reconstruction

Efficiency > 98%
Space Resolution < 100 μm
Mass production
Optimization of FEE channels/cost

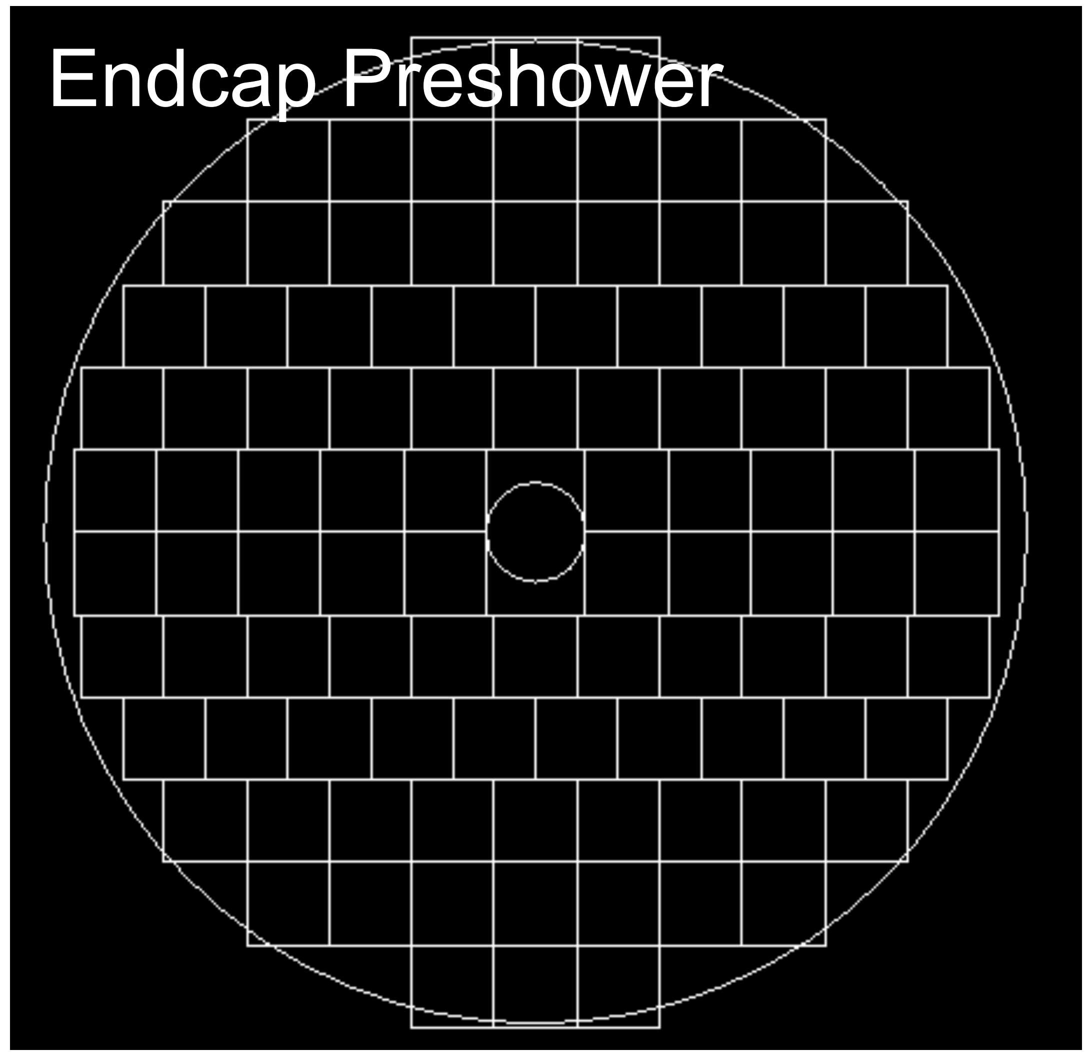
Muon Detector

Identify muons and search for LLPs

Efficiency > 98%
Space Resolution < 400 μm
Mass production
Optimization of FEE channels/cost



Similar design for
the Muon detector



Similar design for
the Muon detector

Detector technology: μ-RWELL

$50 \times 50\ cm^2$ 2D tiles to
cover more than $4330\ m^2$

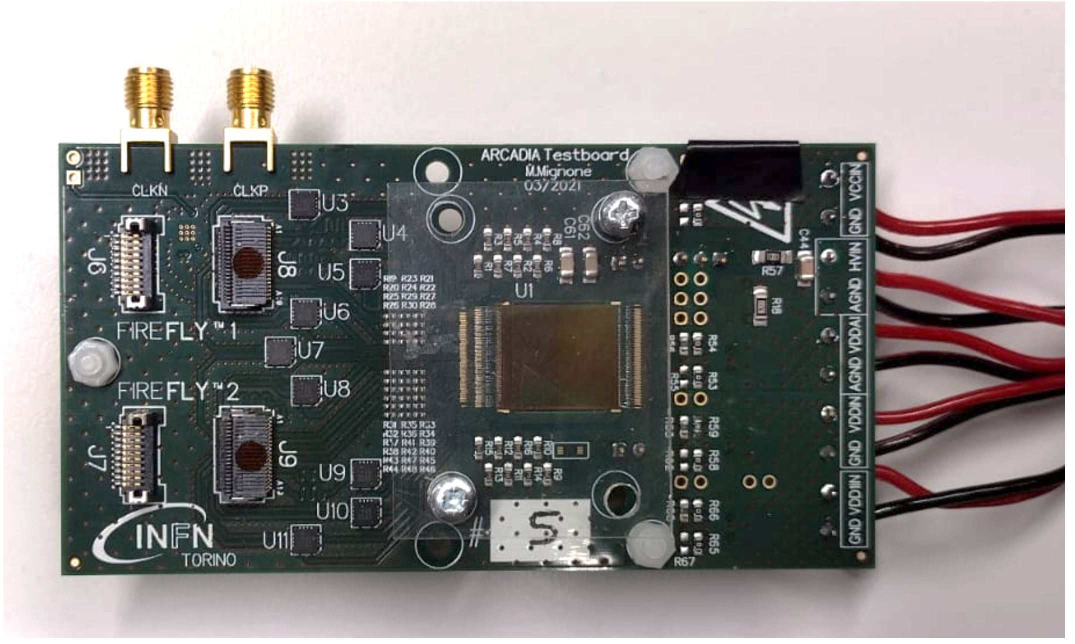
Preshower	Muon
pitch = 0.4 mm	pitch = 1.5 mm
FEE capacitance = 70 pF	FEE capacitance = 270 pF
1.5 million channels	5 million channels

Ongoing R&D

Click here for more R&D information

ARCADIA MD1 test

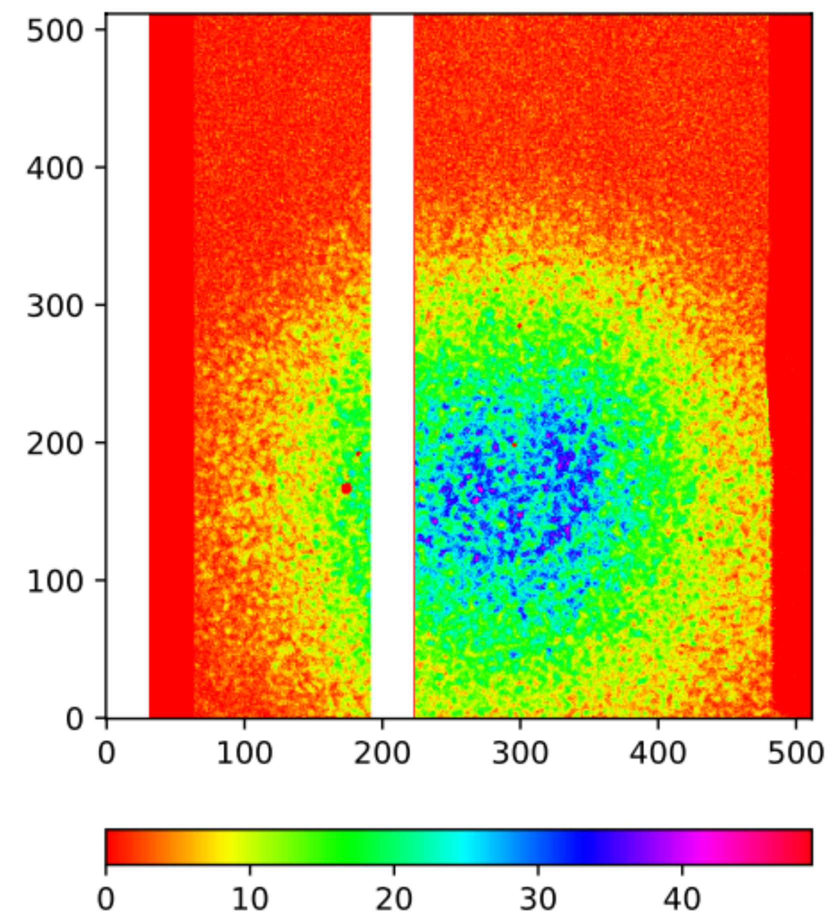
Preliminary results: on-line QA-plots



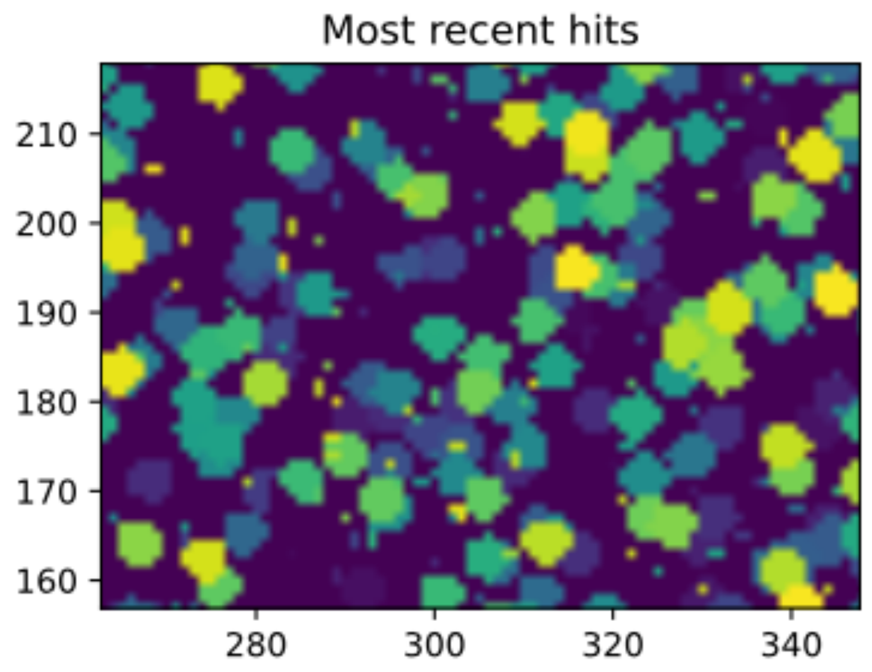
110 nm CMOS CIS technology, high-resistivity bulk, operated in full depletion mode

Pixel size = 25x25 μm^2
Matrix = 512 x 512
Thickness = 200 μm

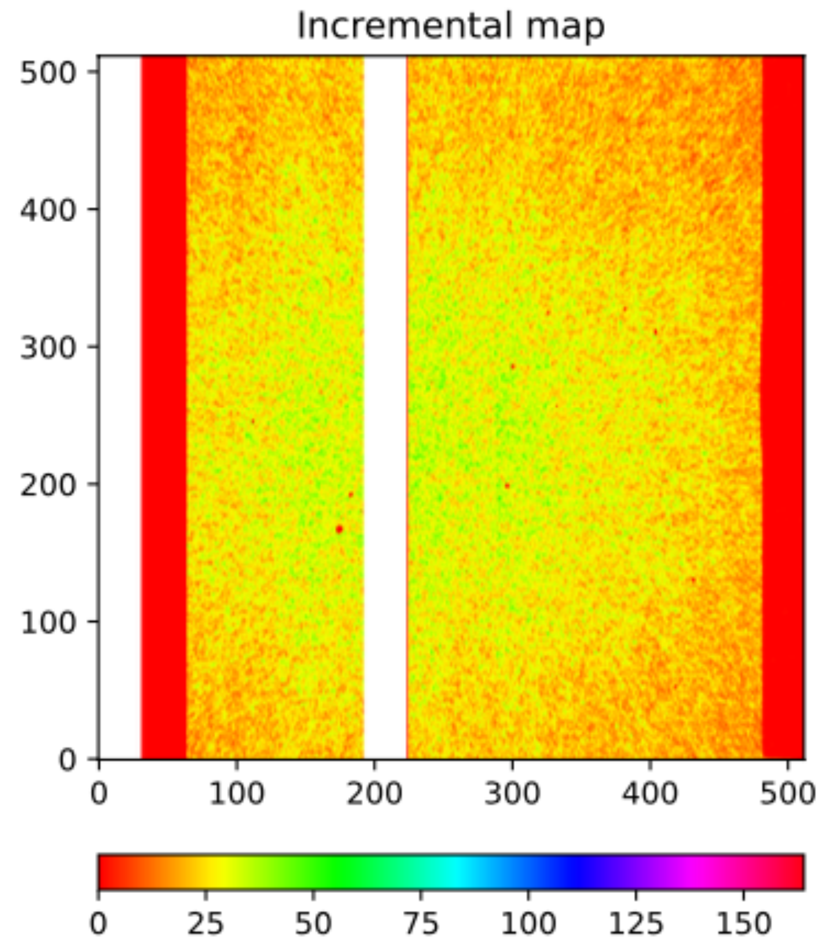
s



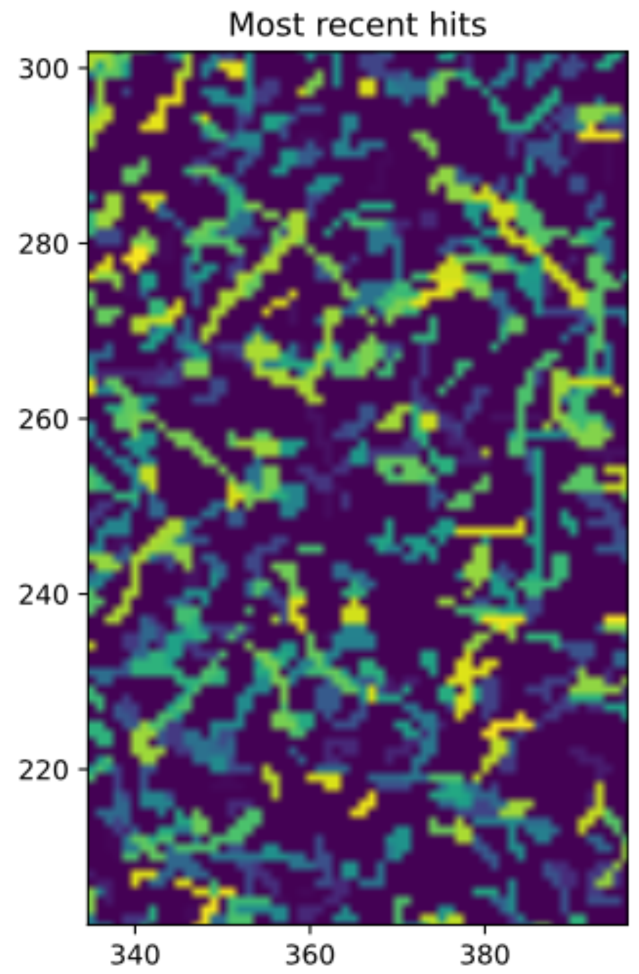
Few events (zoom)



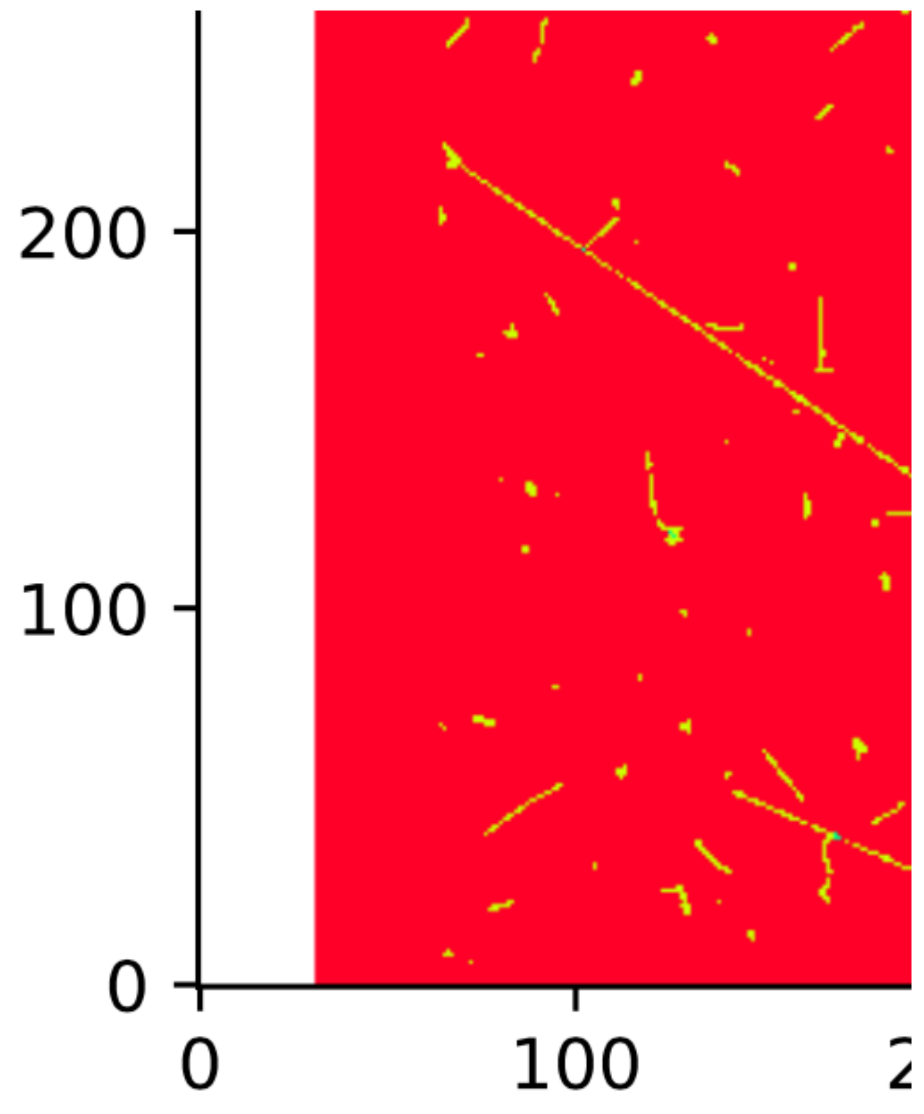
^{90}Sr

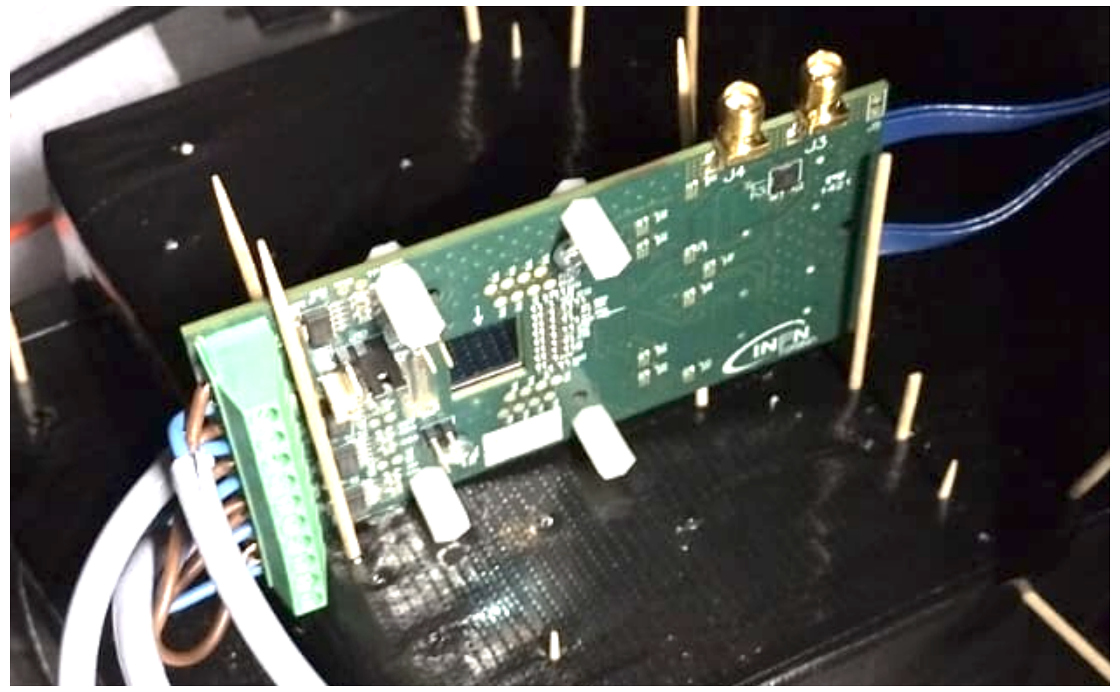


Few events (zoom)

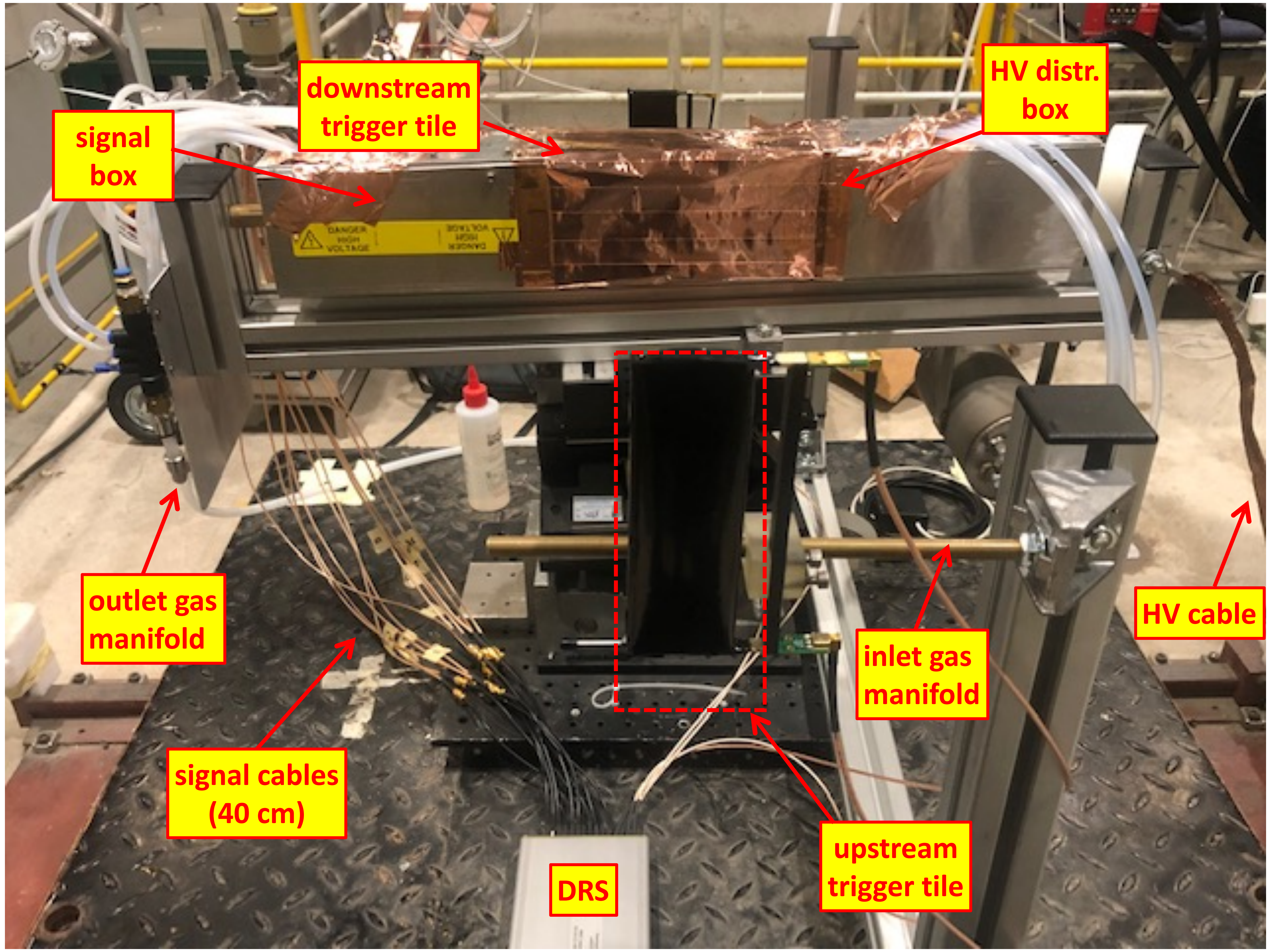


Few cosmic tracks
(Tilted sensor)



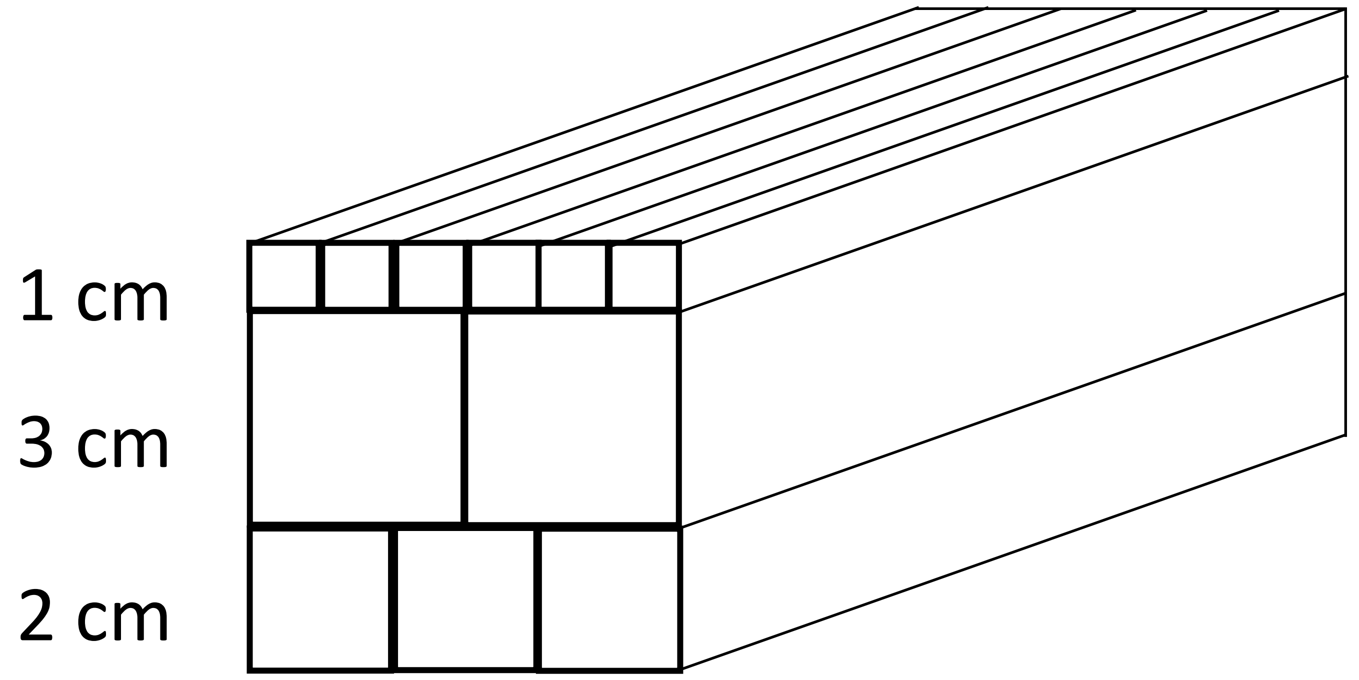


Wire chamber: Cern test beam 11-2021

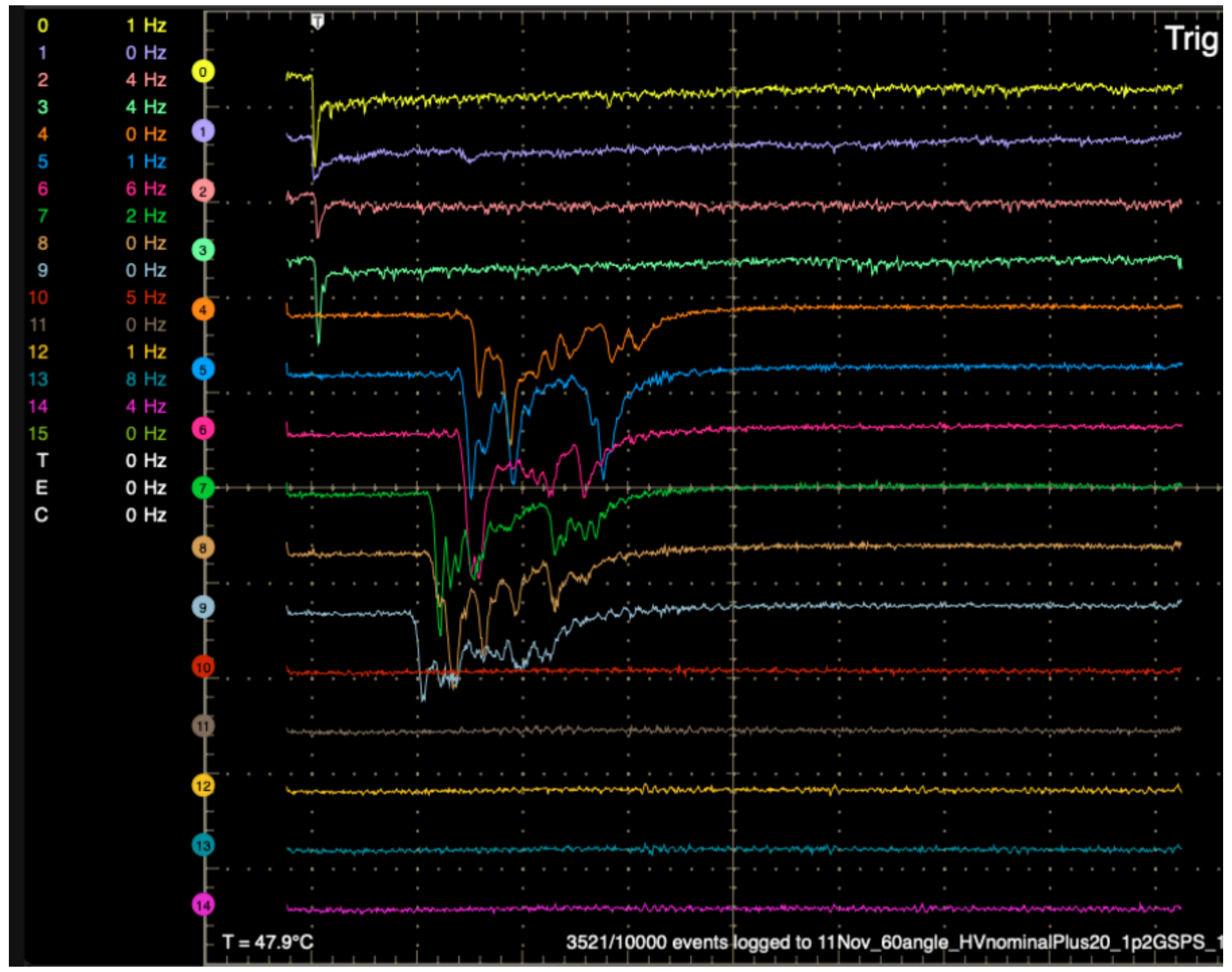


The experimental setup
at CERN H8 beam
November 2021

Drift tubes pack

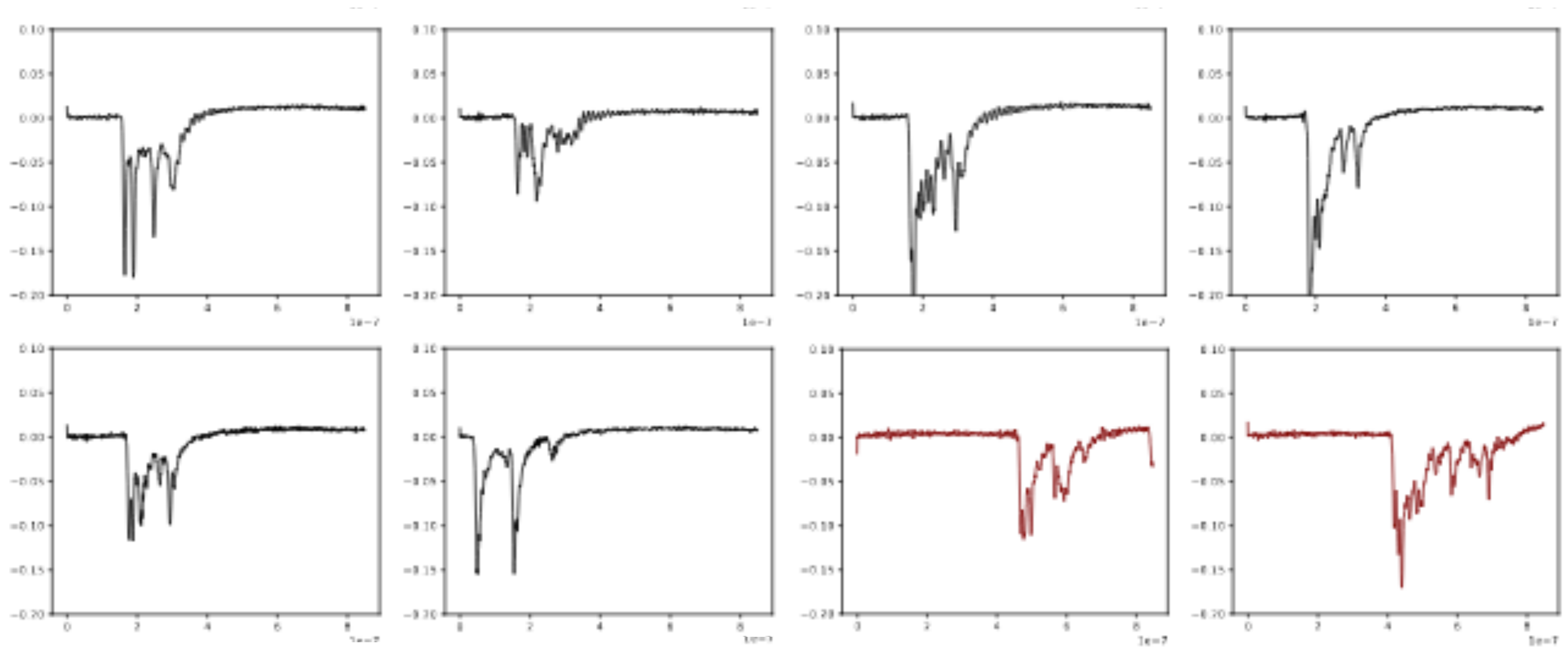


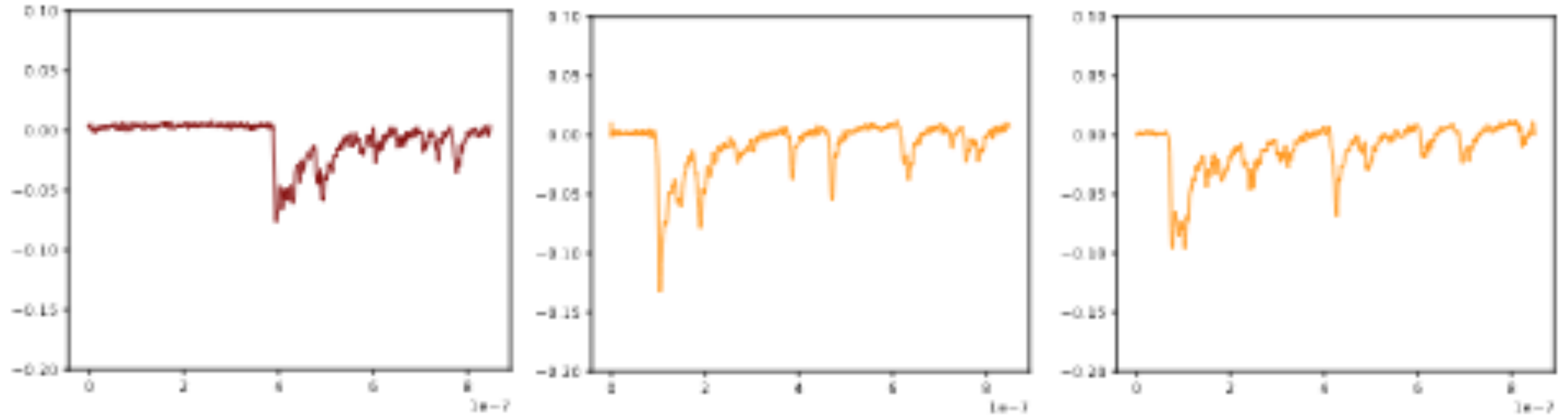
Event display



Wire chamber

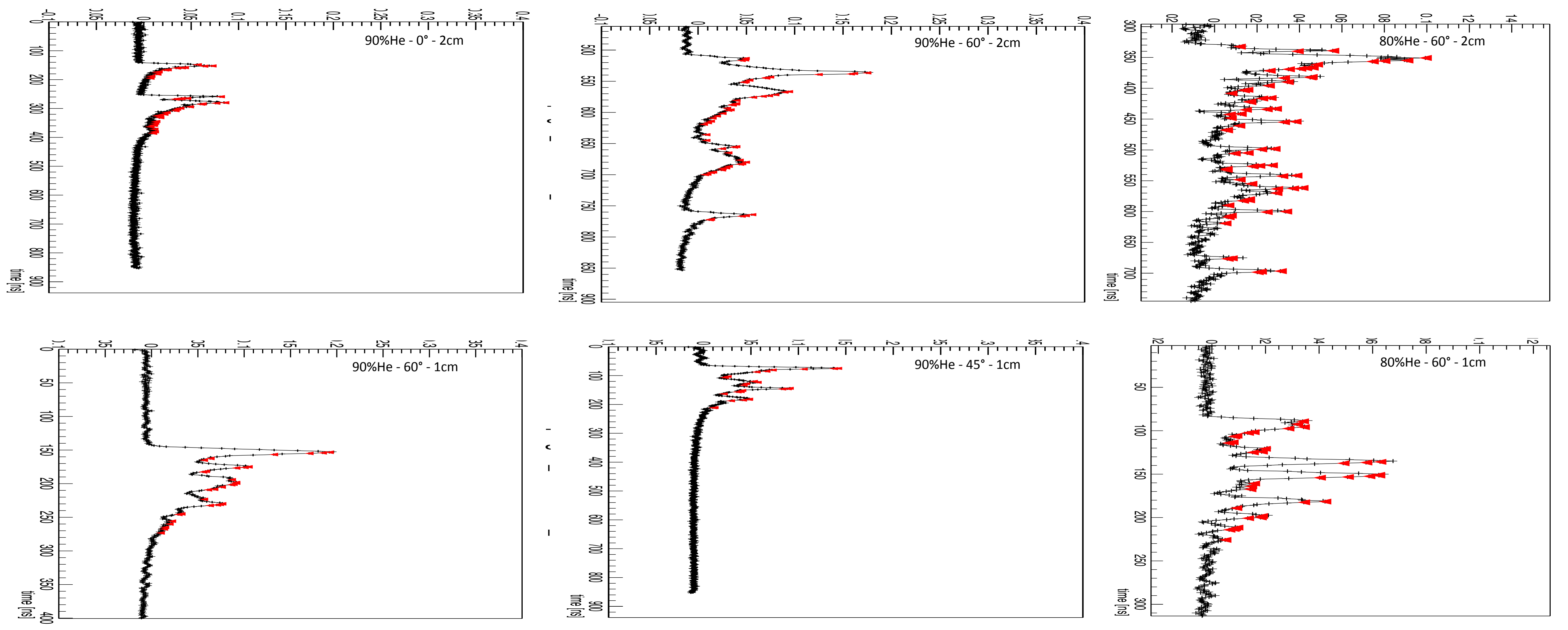
Typical pulse spectra



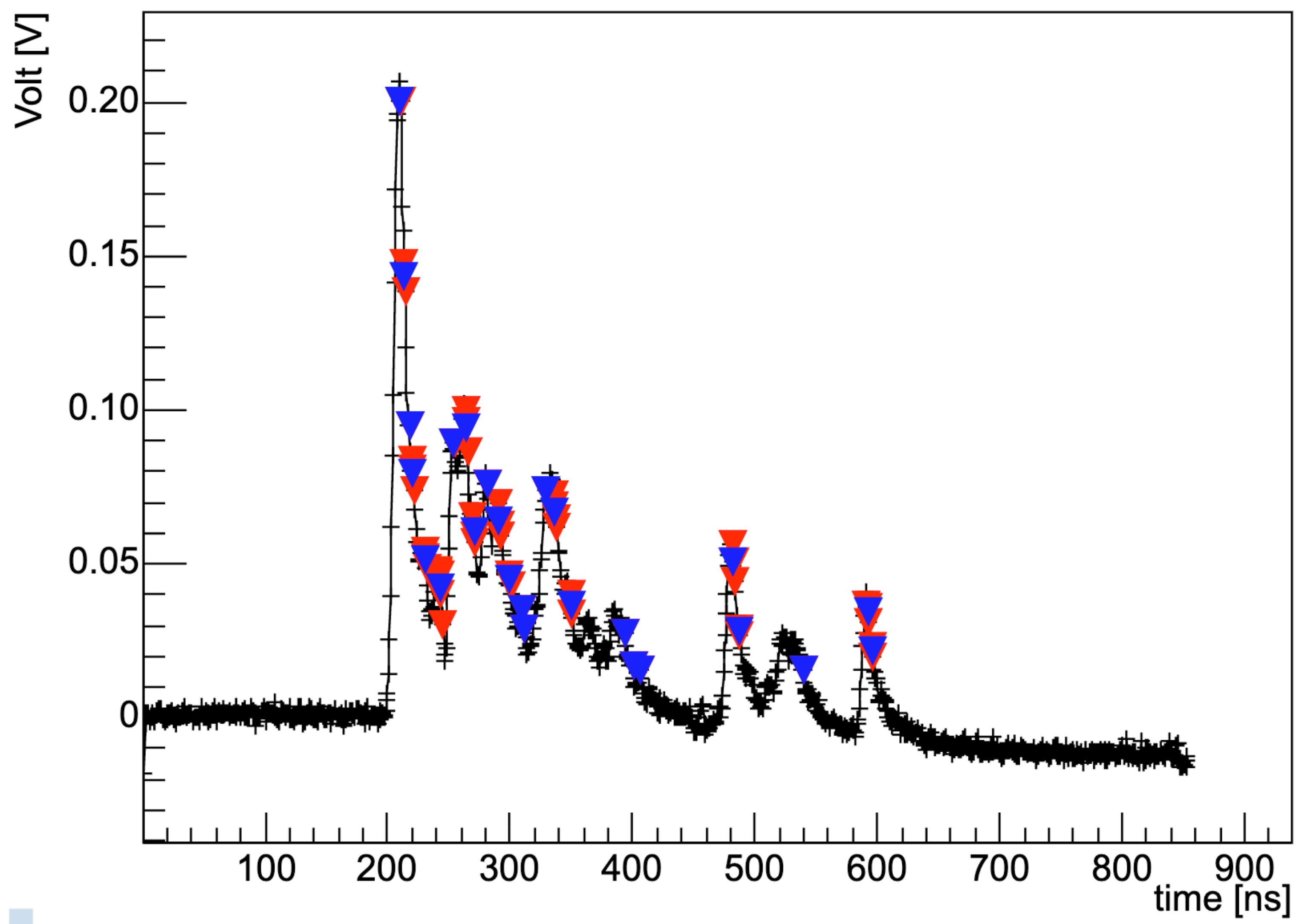


1 cm tube
2 cm tube
3 cm tube

Electron peak finding



Ionization clusters (▼) and single electron pulses (▼)



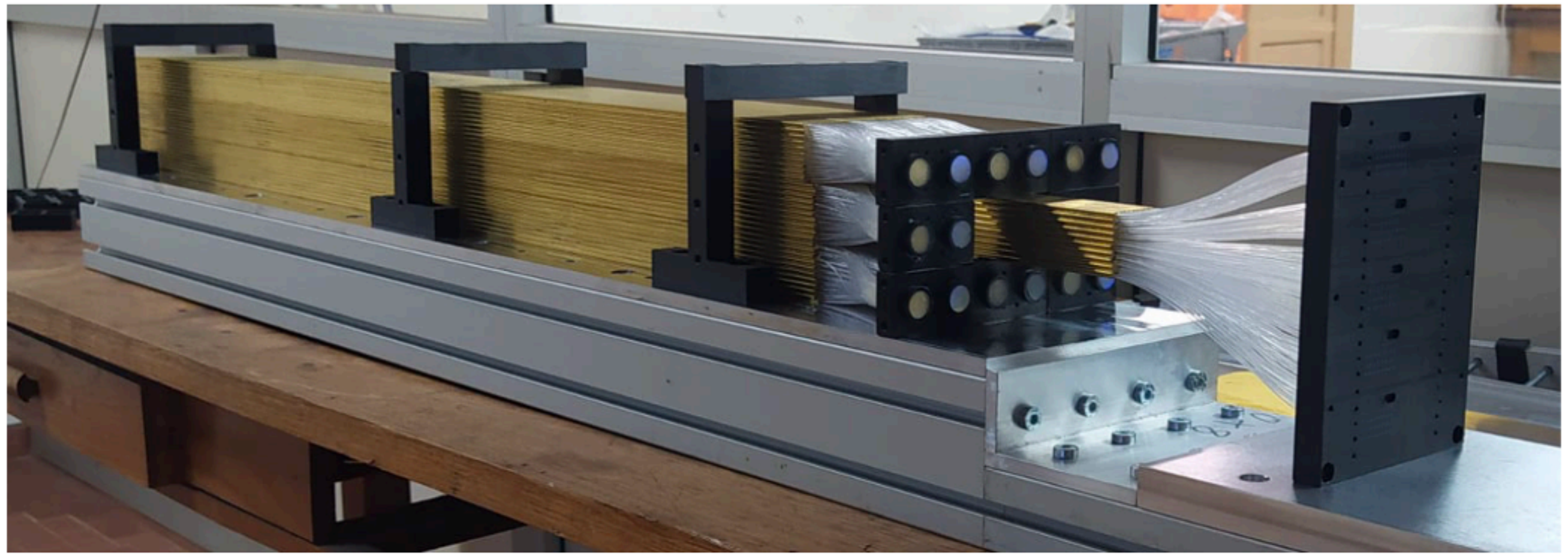
Future activities

- Beam test scheduled for next June at CERN H8 aimed at:
  - measuring the cluster density as a function of $\beta\gamma$ at different muon beam momenta
  - defining the relativistic rise and the Fermi plateau of dE/dx and dN/dx in He based gas mixtures (lack of experimental data and discrepancies among different simulation models)
- Checking the particle identification performance with cluster counting and with dE/dx using as a benchmark the CP violating process:

$$B_s \rightarrow D_s K$$

Plenty of scope for new collaborators!

2020 Dual Readout prototype



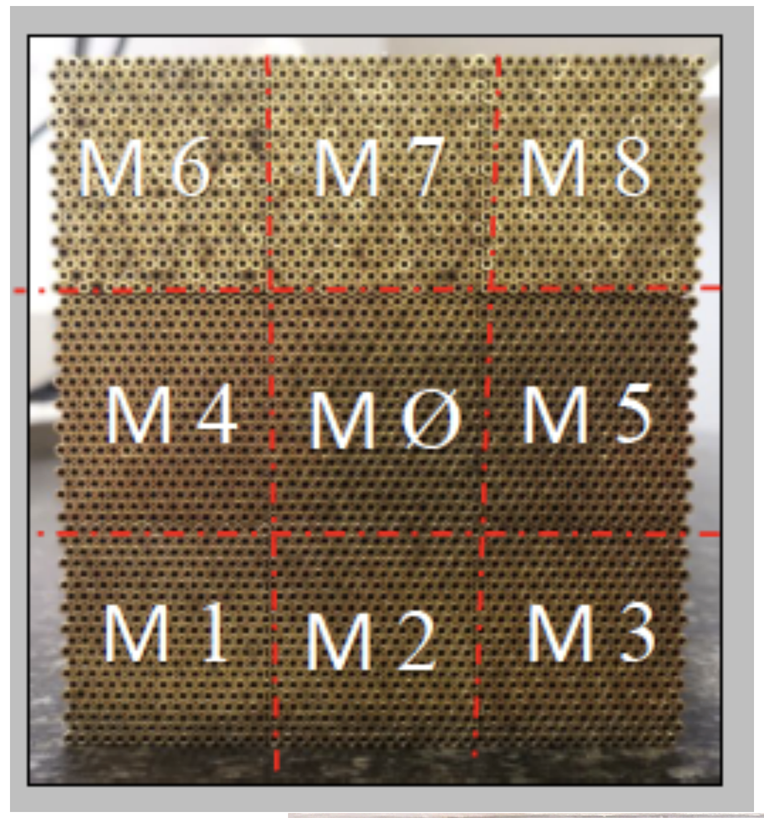
Electromagnetic dimensions of 10x10x100 cm^3

9 towers containing 16x20 capillaries (160 C and 160 S)

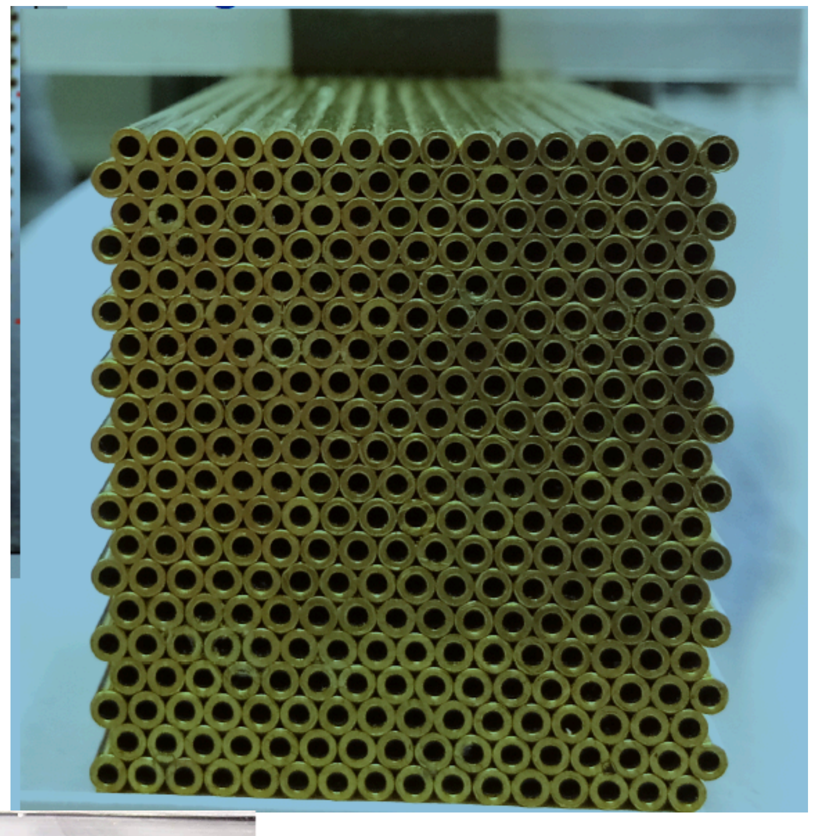
Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm

1-mm-thick fibers

Full prototype - 9 towers



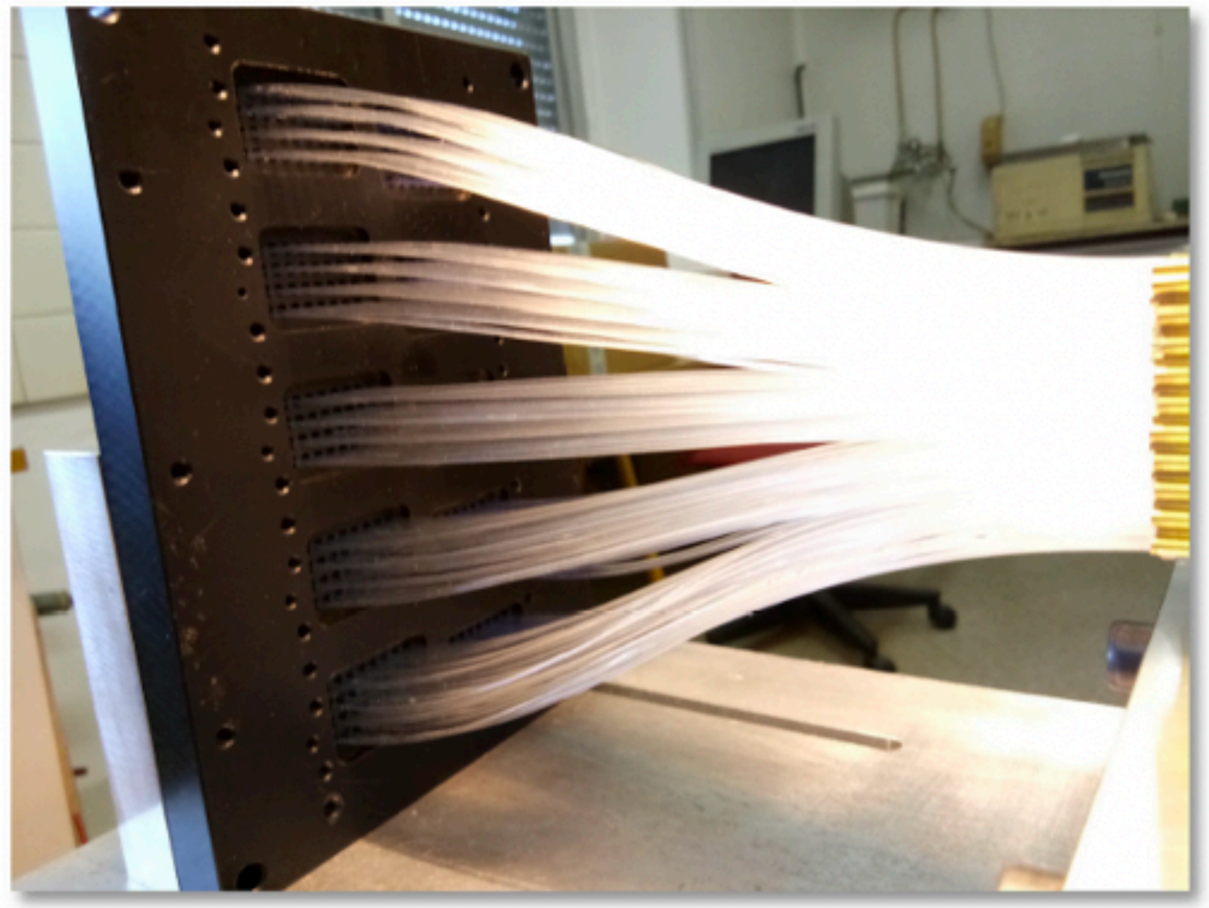
Single tower

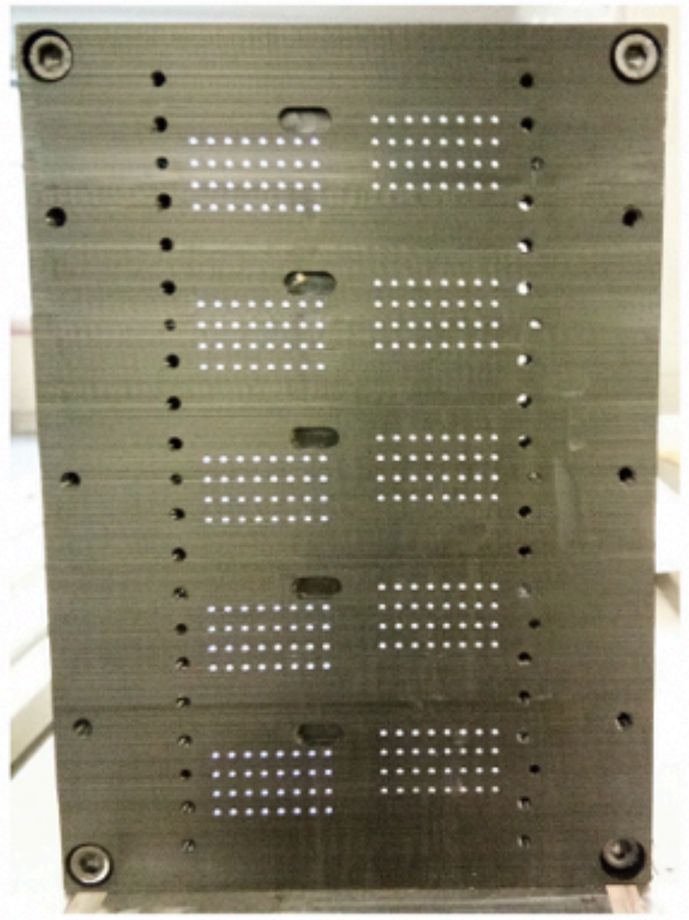


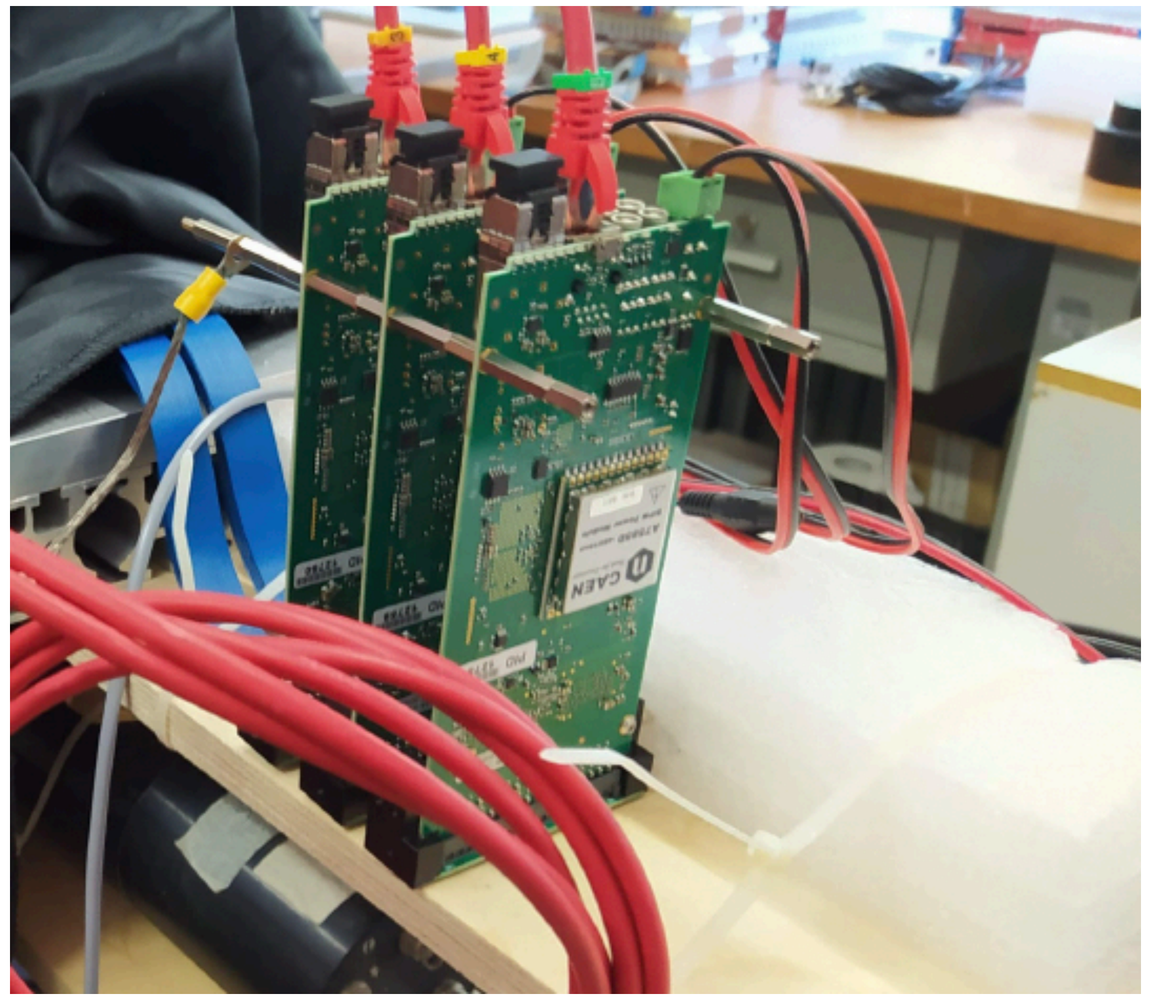
"Bucatini calorimeter"

Front end board housing 64 SiPM

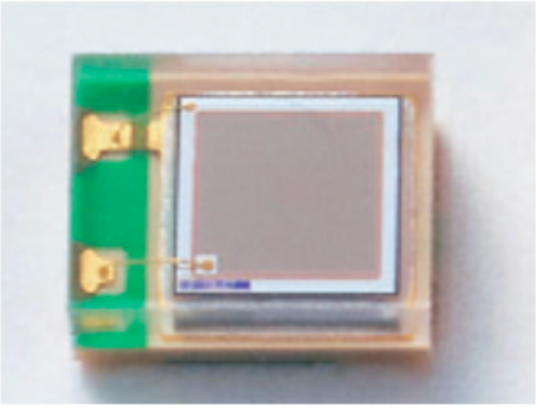
Fiber guiding system







Readout Boards CAEN A5202



Hamamatsu SiPM: S14160-1315

PS Cell size: 15 μm

2020 Dual Readout prototype

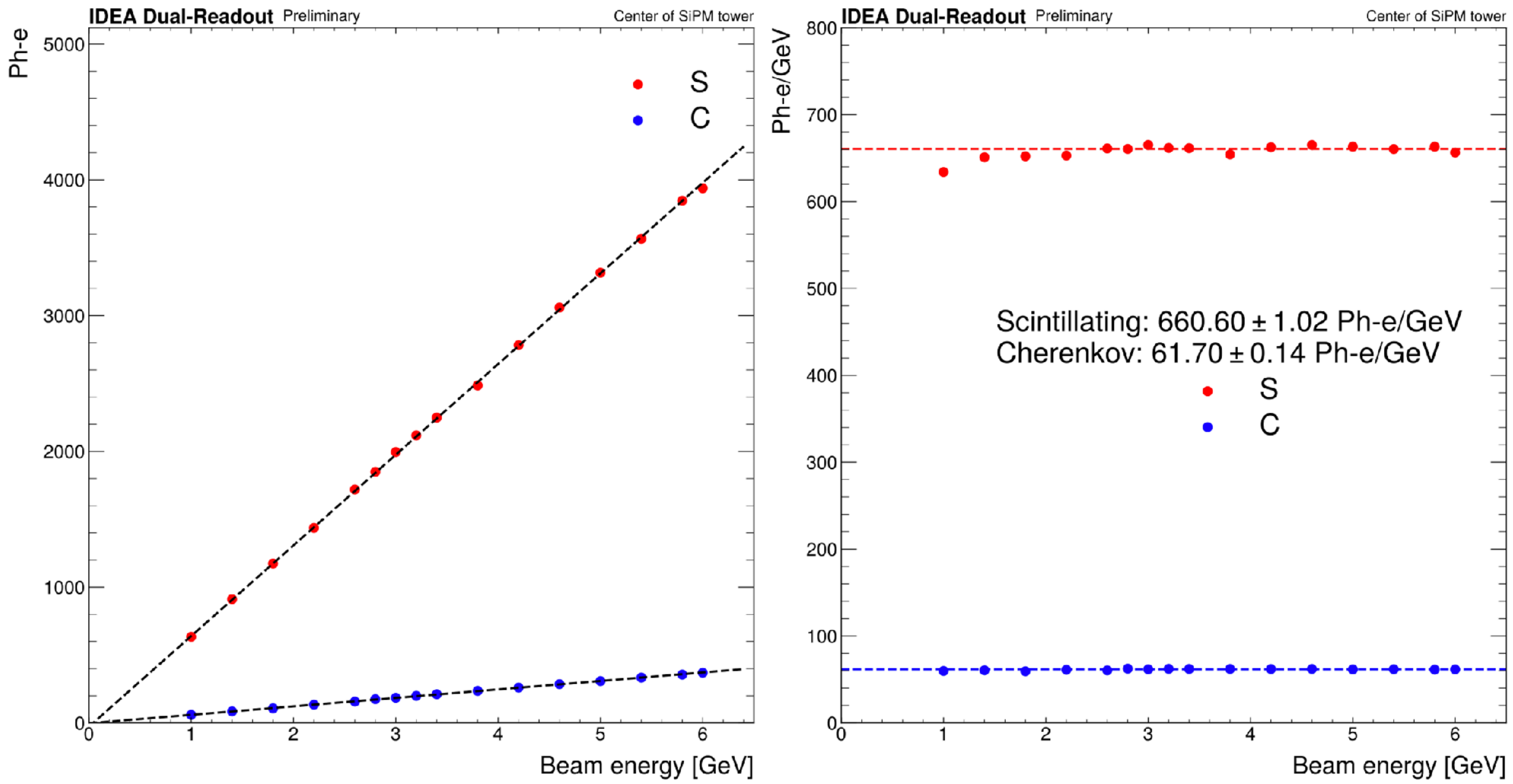
Two test beams in 2021: DESY and CERN

Front end board
housing 64 SiPM

2020 Dual Readout prototype

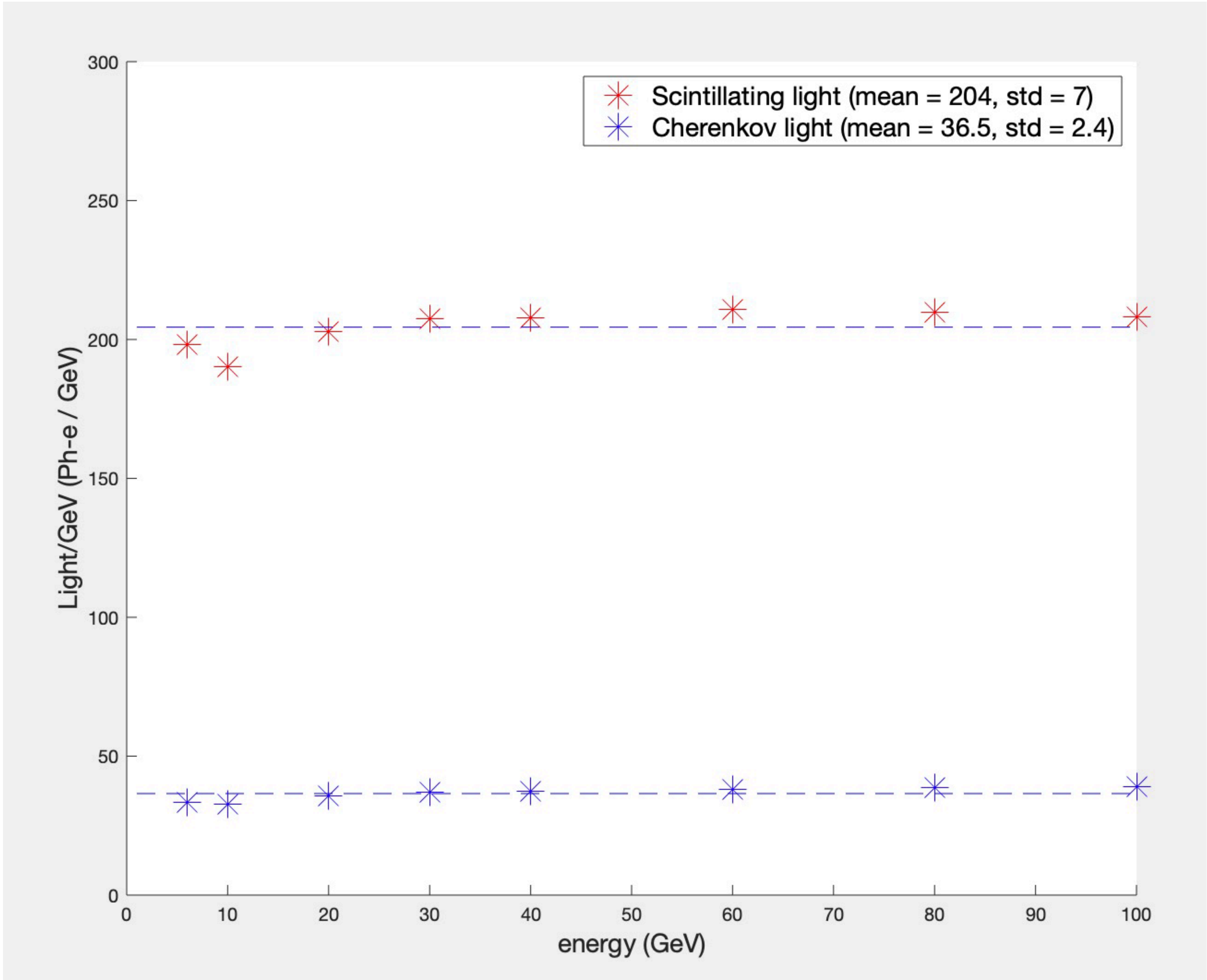
Two test beams in 2021: DESY and CERN

DESY with e⁻ 1-6 GeV



Preliminary - no filters used

SPS with e^+ 10-125 GeV

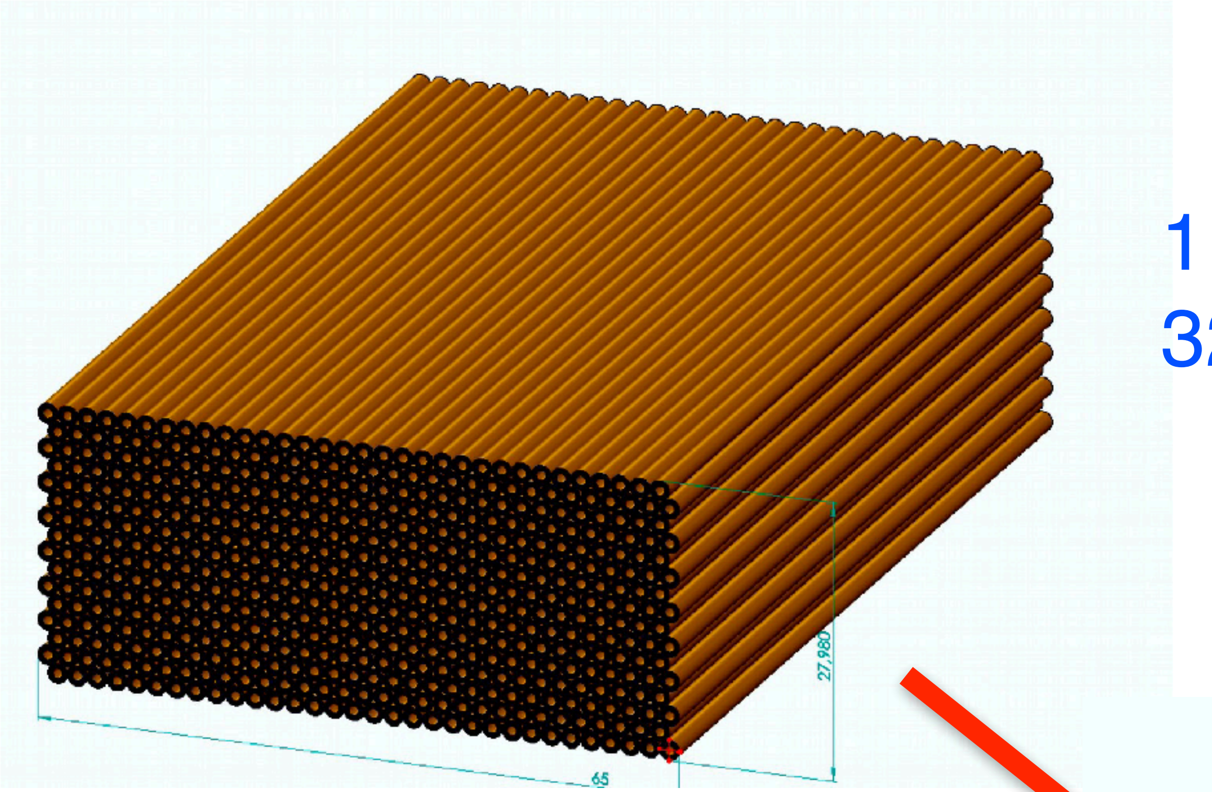


Preliminary

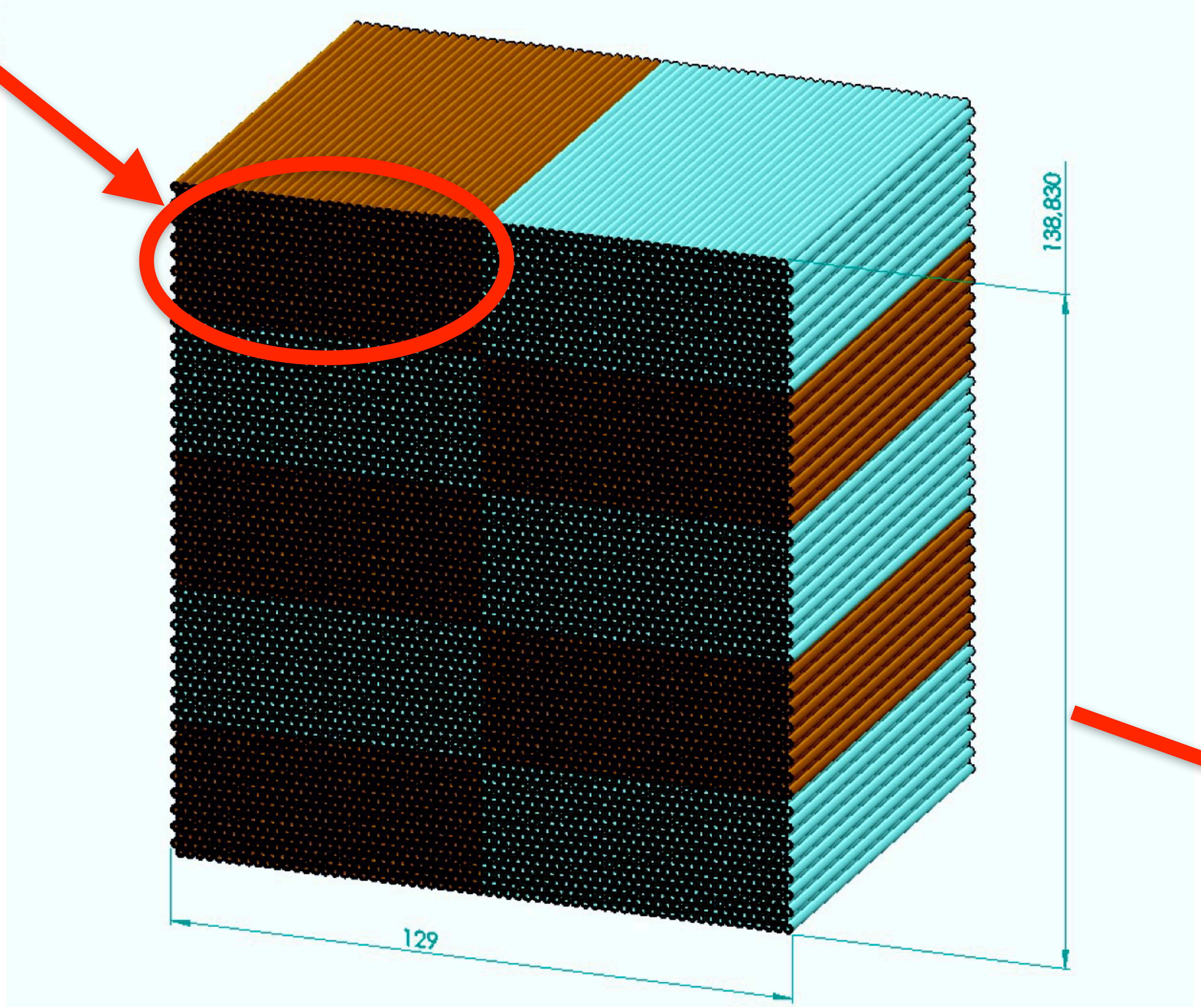
yellow filters used over scintillating fibers, neutral filters used over clear fibers

DR future prototypes

HiDRa2



1 Mini-Module (MM):
32 x 16 channel (512 ch)



1 Module:

2 x 5 MMs
→ 10 FEE boards
(8-channel grouping)
~ 13 x13 x 200 cm^3

Full hadronic shower containment calorimeter

17 modules, ~ 65 x 65 x 200 cm^3

- 2 central modules with SiPMs
→ ~ 10 k SiPMs, ~ 20 FEE boards
- all others with PMTs
→ ~ 150 PMTs

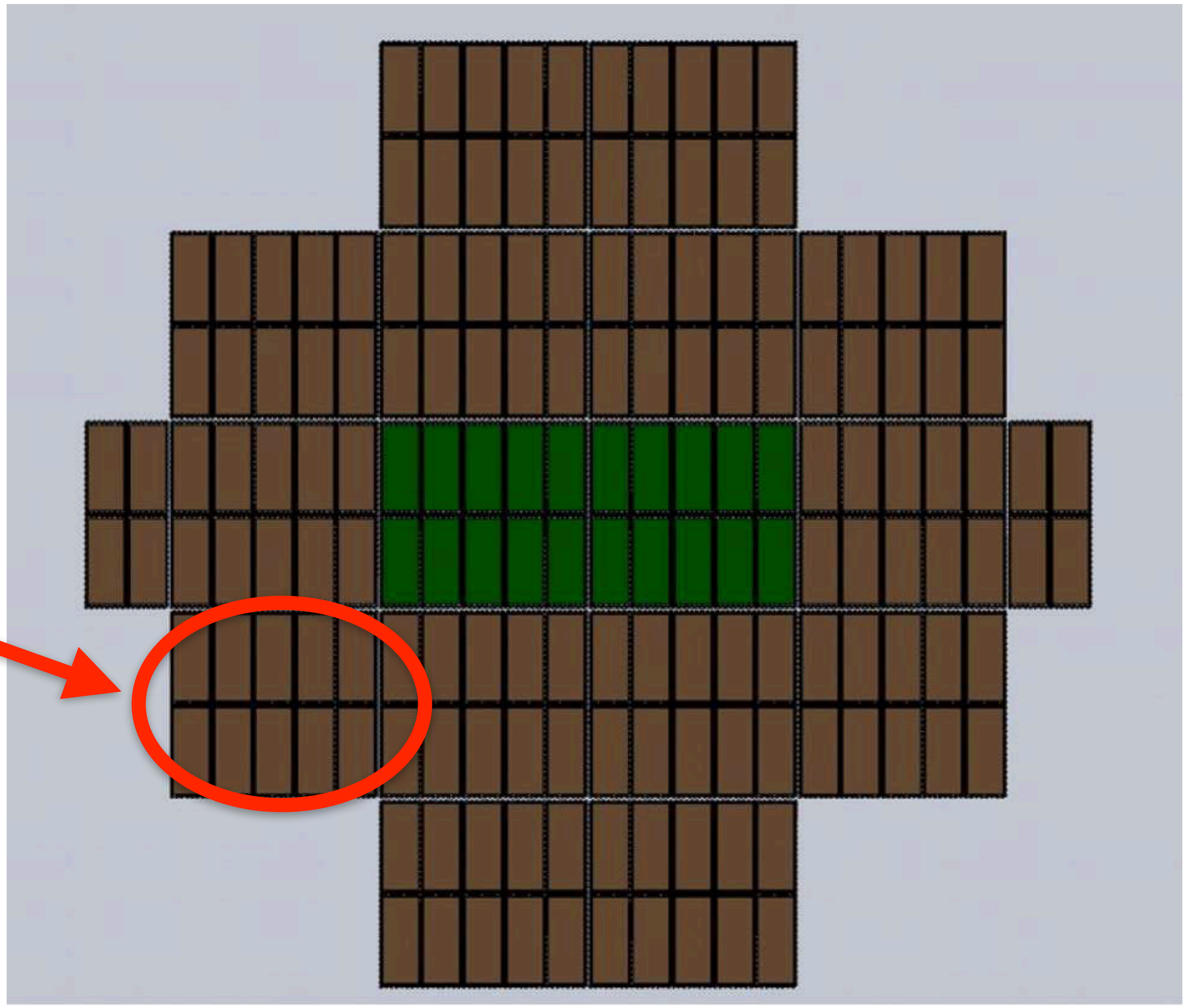
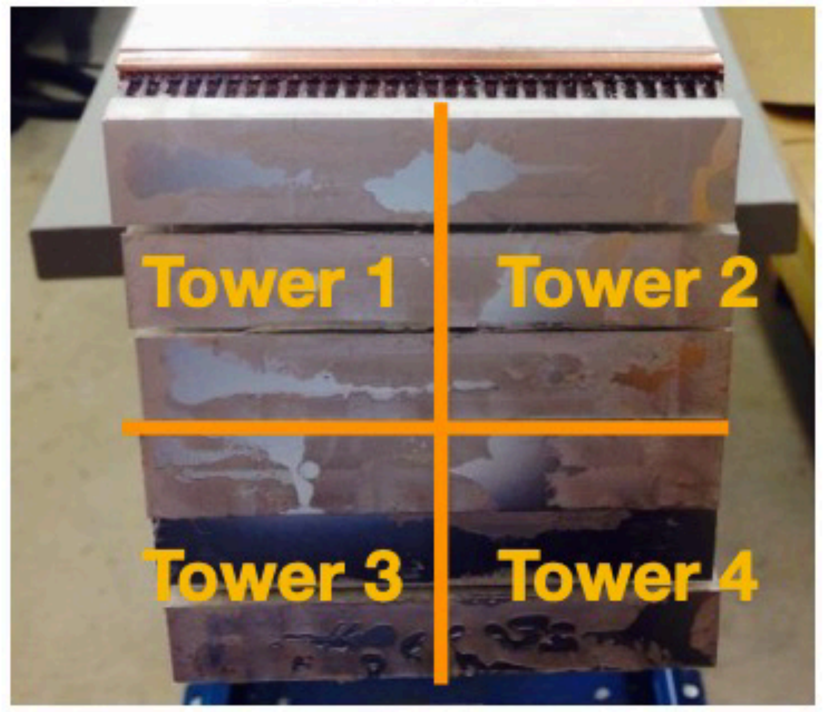


Plate based + 3D printing calo (Korea)

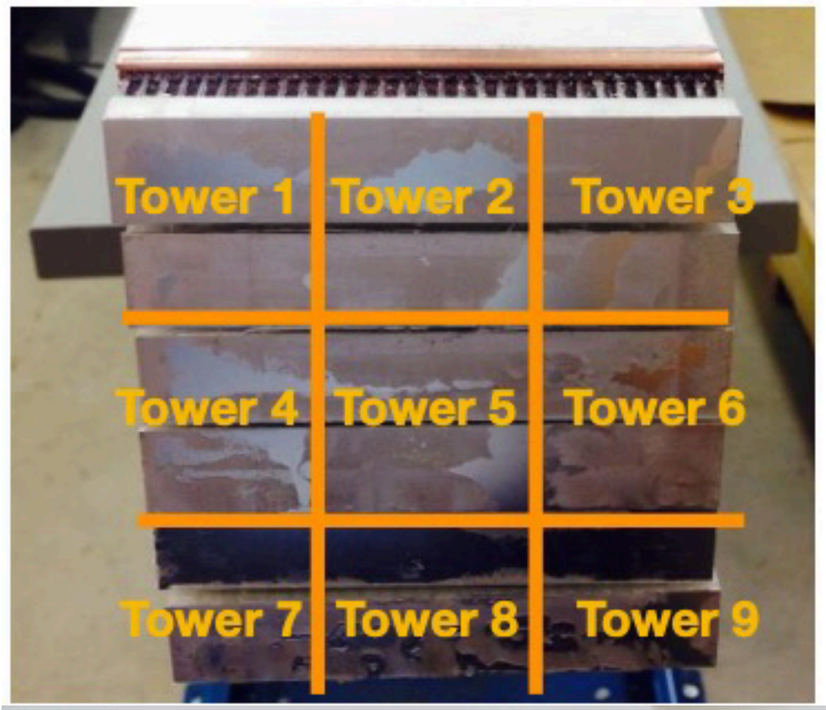
"Short-term plan"

Module #1 (2x2)

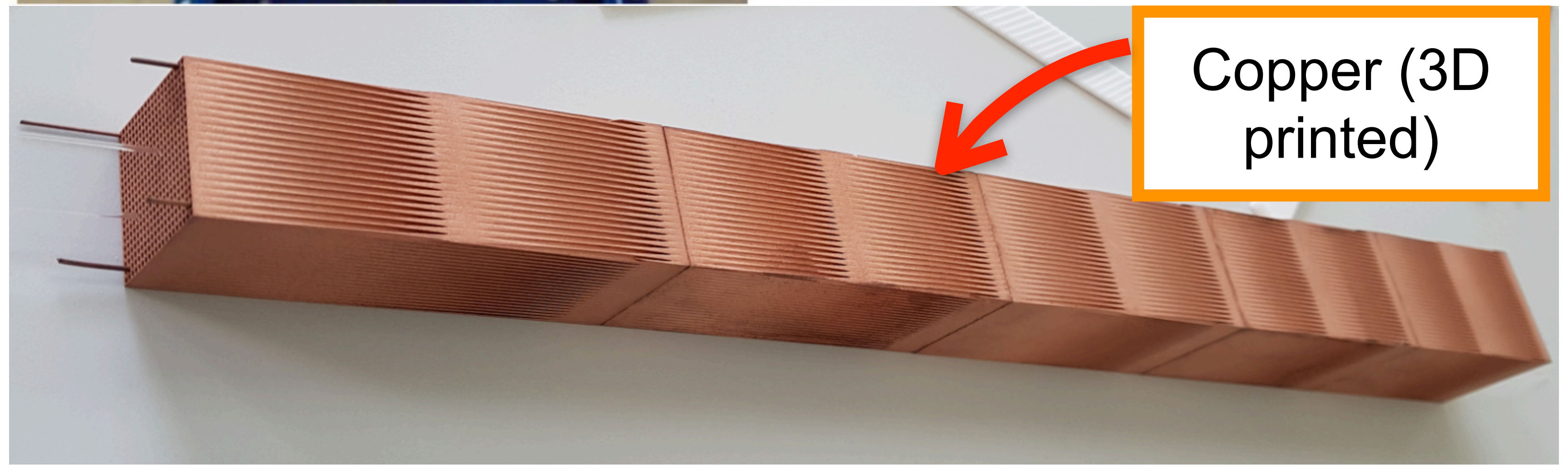


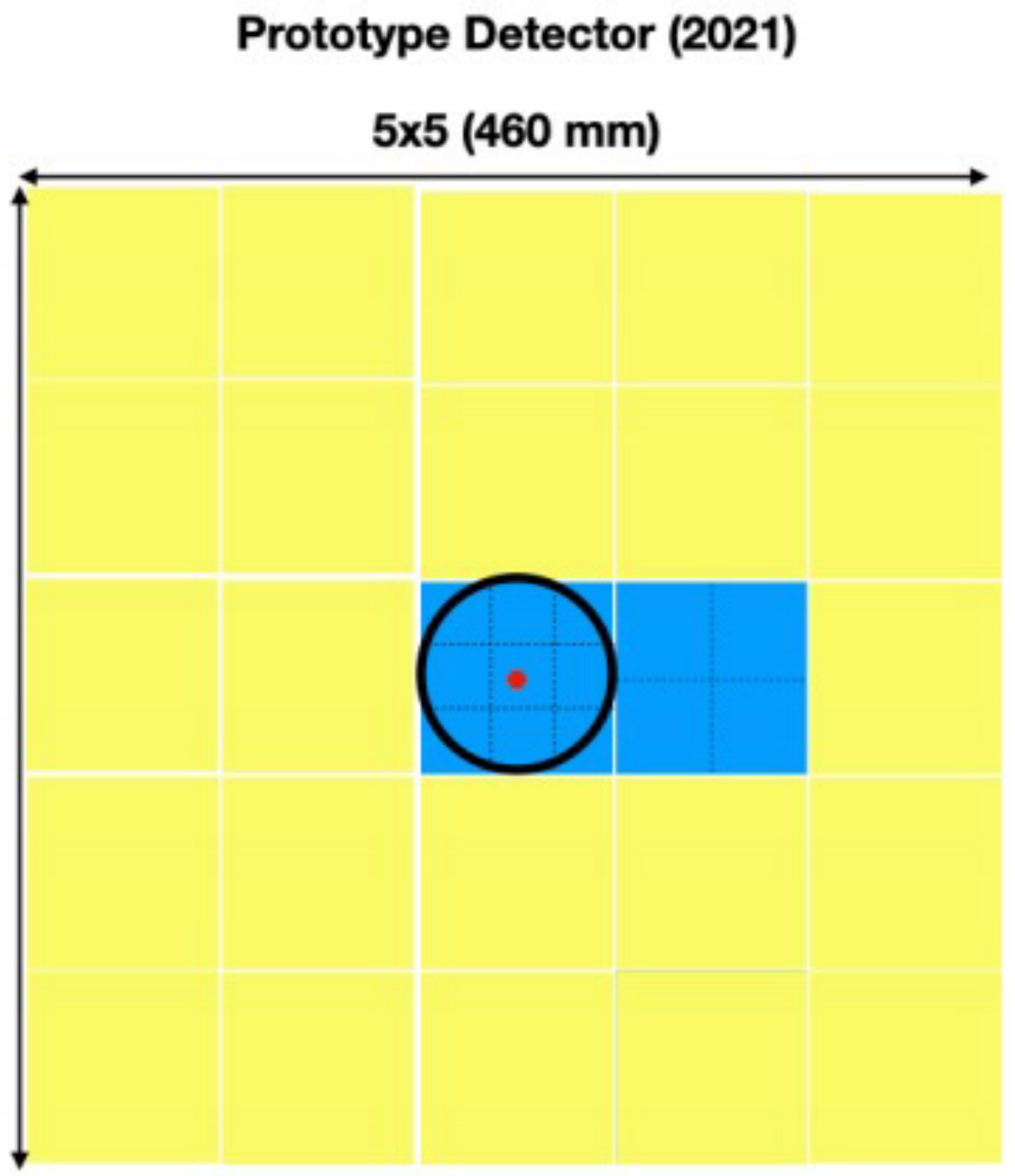
Tower#1	Tower#2
Tower#3	Tower#4

Module #2 (3x3)

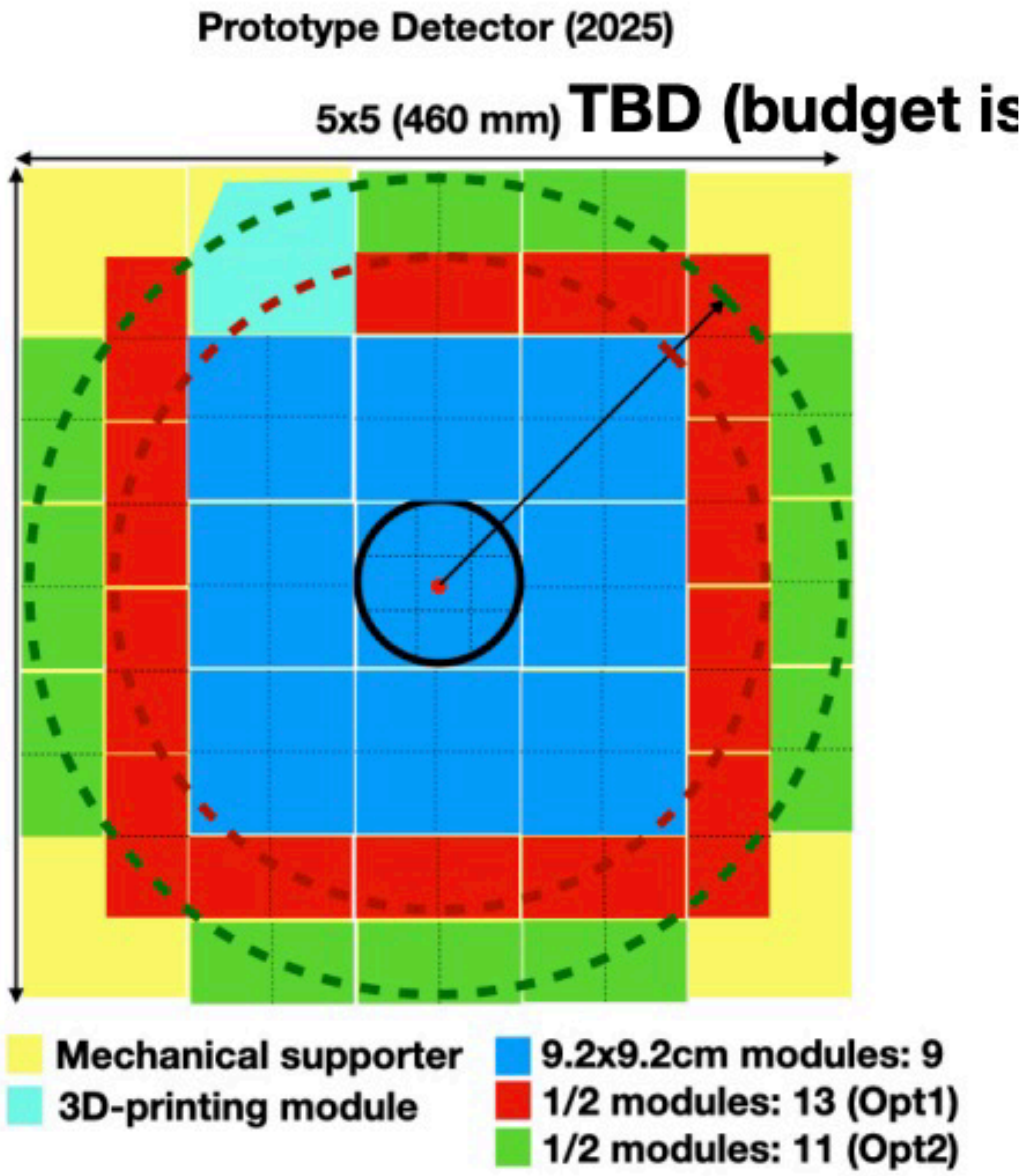


Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9





"Mid-term plan"



Building more and more modules 2022-2025

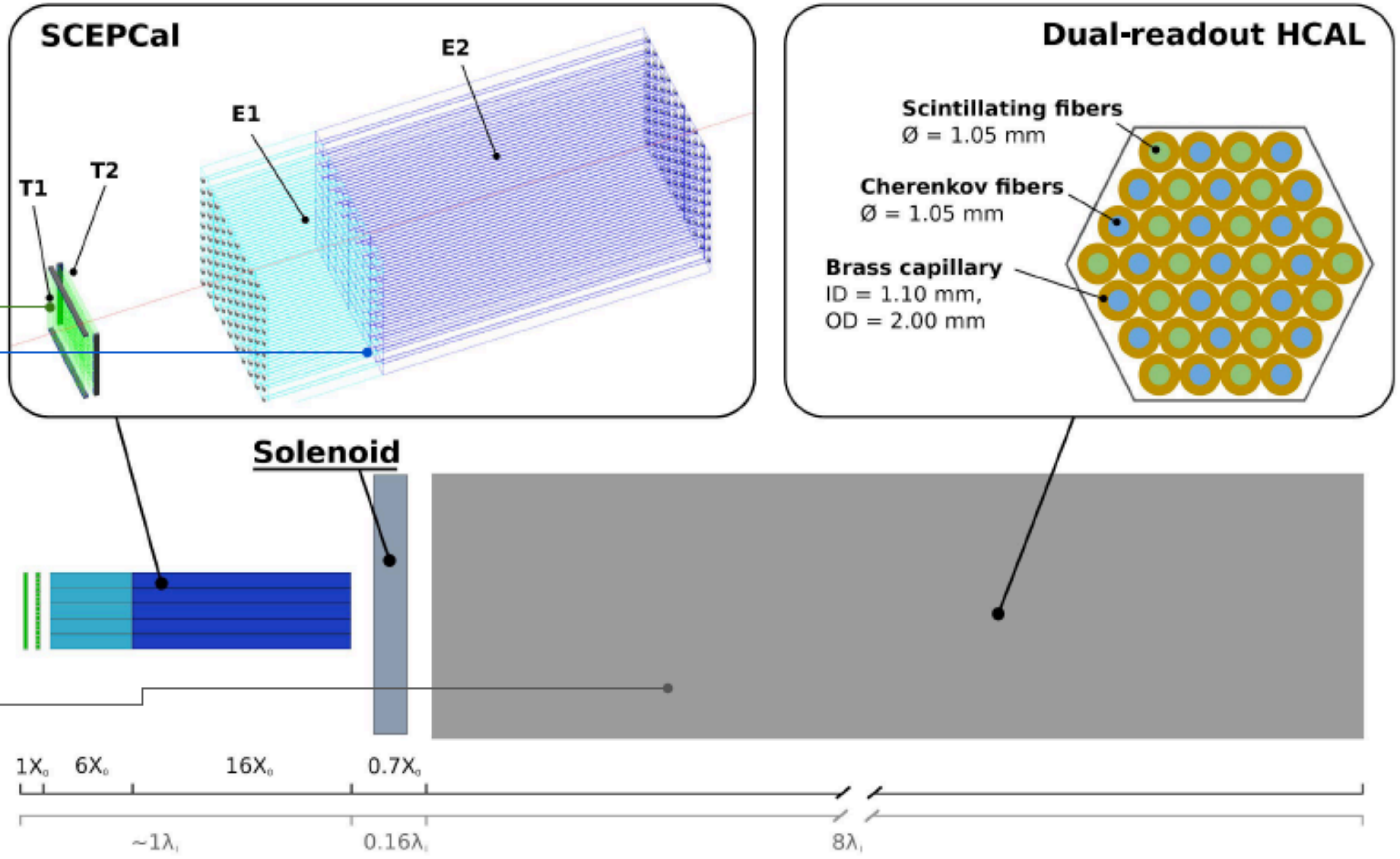
Strong collaboration on DR calorimetry between INFN, Korea and USA

Crystal ECAL with DR calorimeter

Layout overview

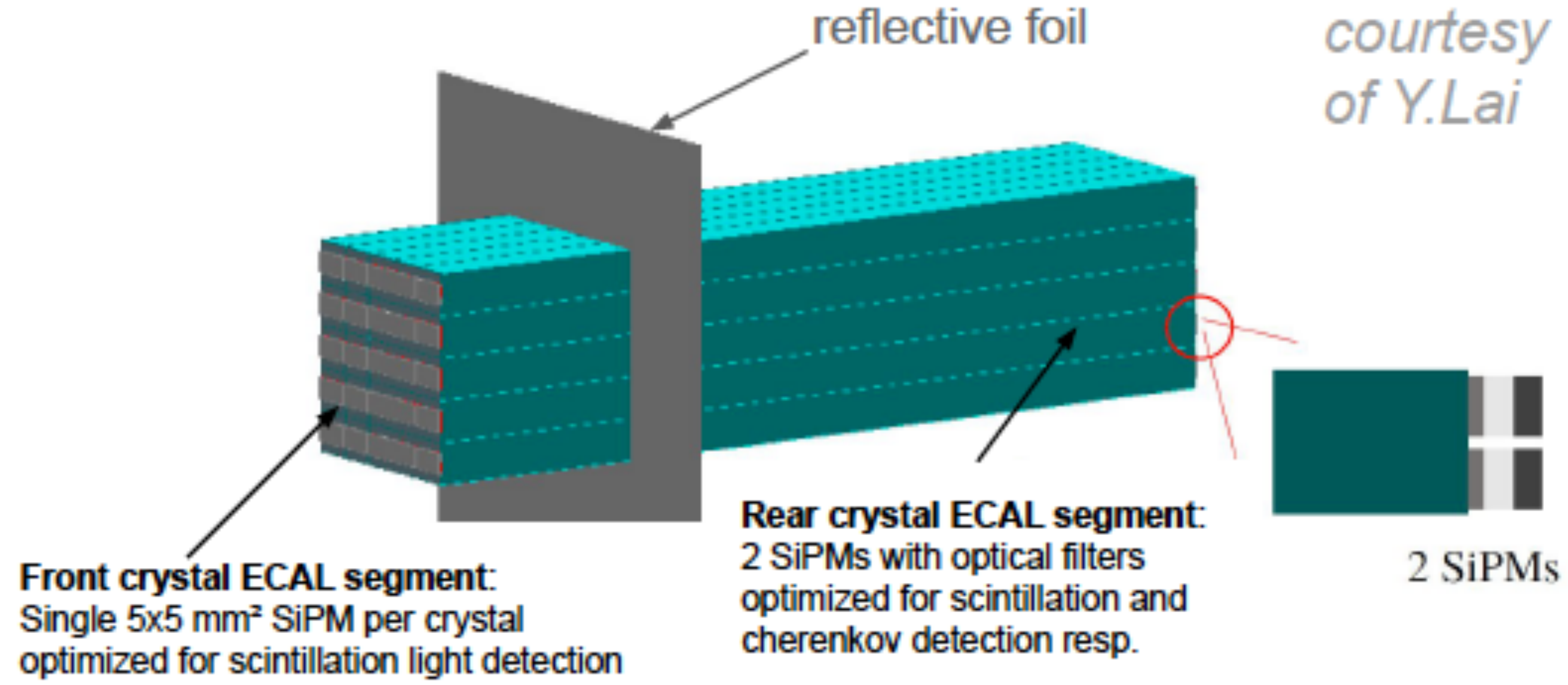
- **Transverse and longitudinal segmentations** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

- **Timing layers** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x60 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layers** — $\sigma^{EM}_E/E \sim 3\%/\sqrt{E}$
  - PWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)
- **Ultra-thin IDEA solenoid**
  - $\sim 0.7X_0$
- **HCAL layer** — $\sigma^{HAD}_E/E \sim 26\%/\sqrt{E}$
  - Scintillating and “clear” PMMA fibers (for Cherenkov signal) inserted inside brass capillaries

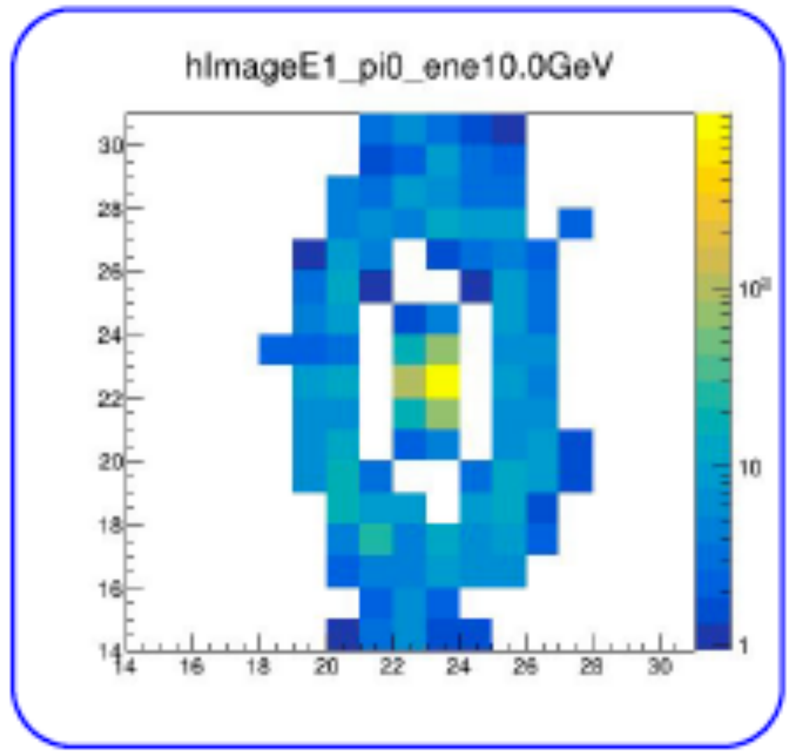


M. Lucchini

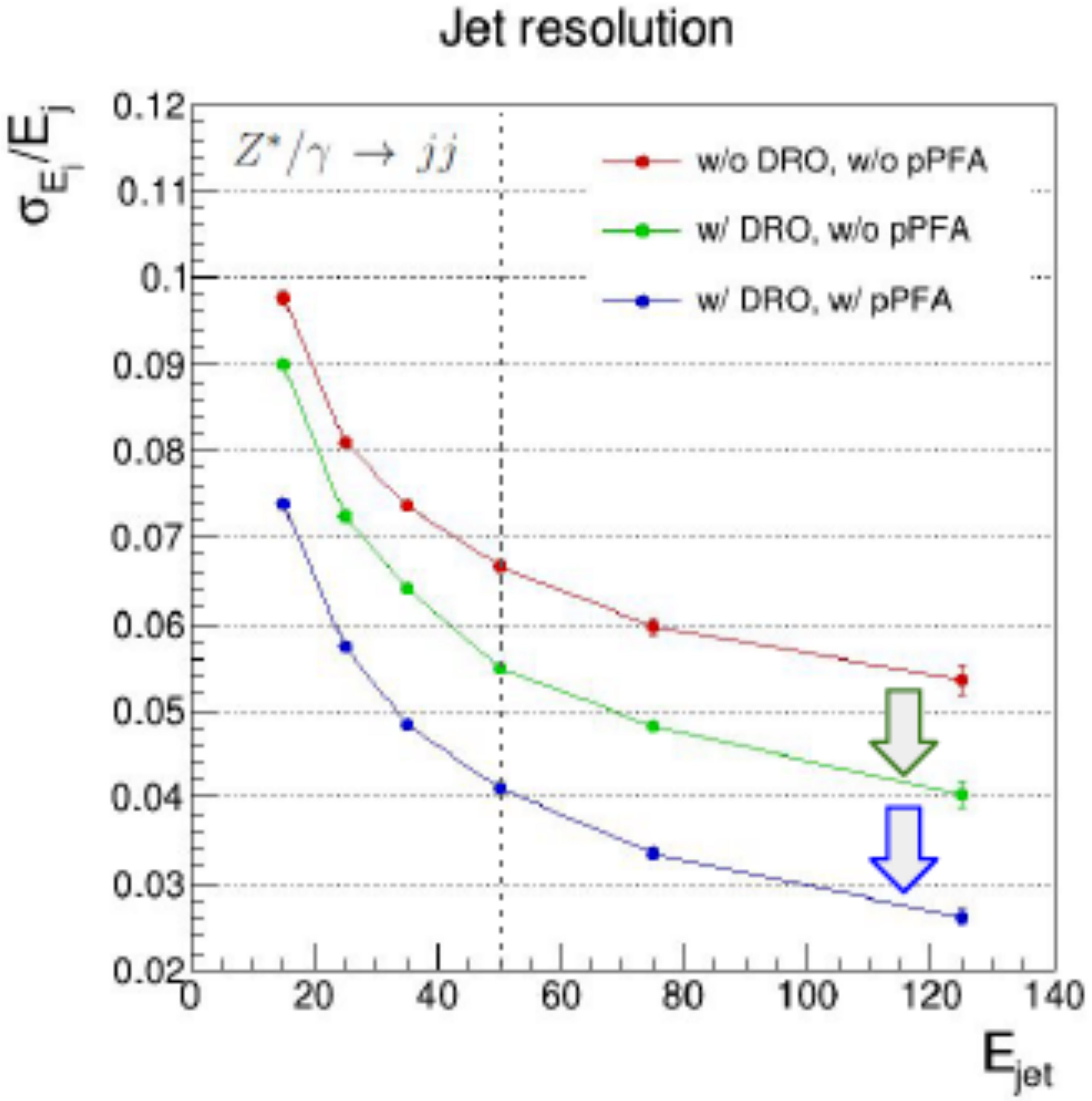
Crystal ECAL with DR calorimeter



$\pi^0 \to \gamma\gamma$ events



Jet resolution

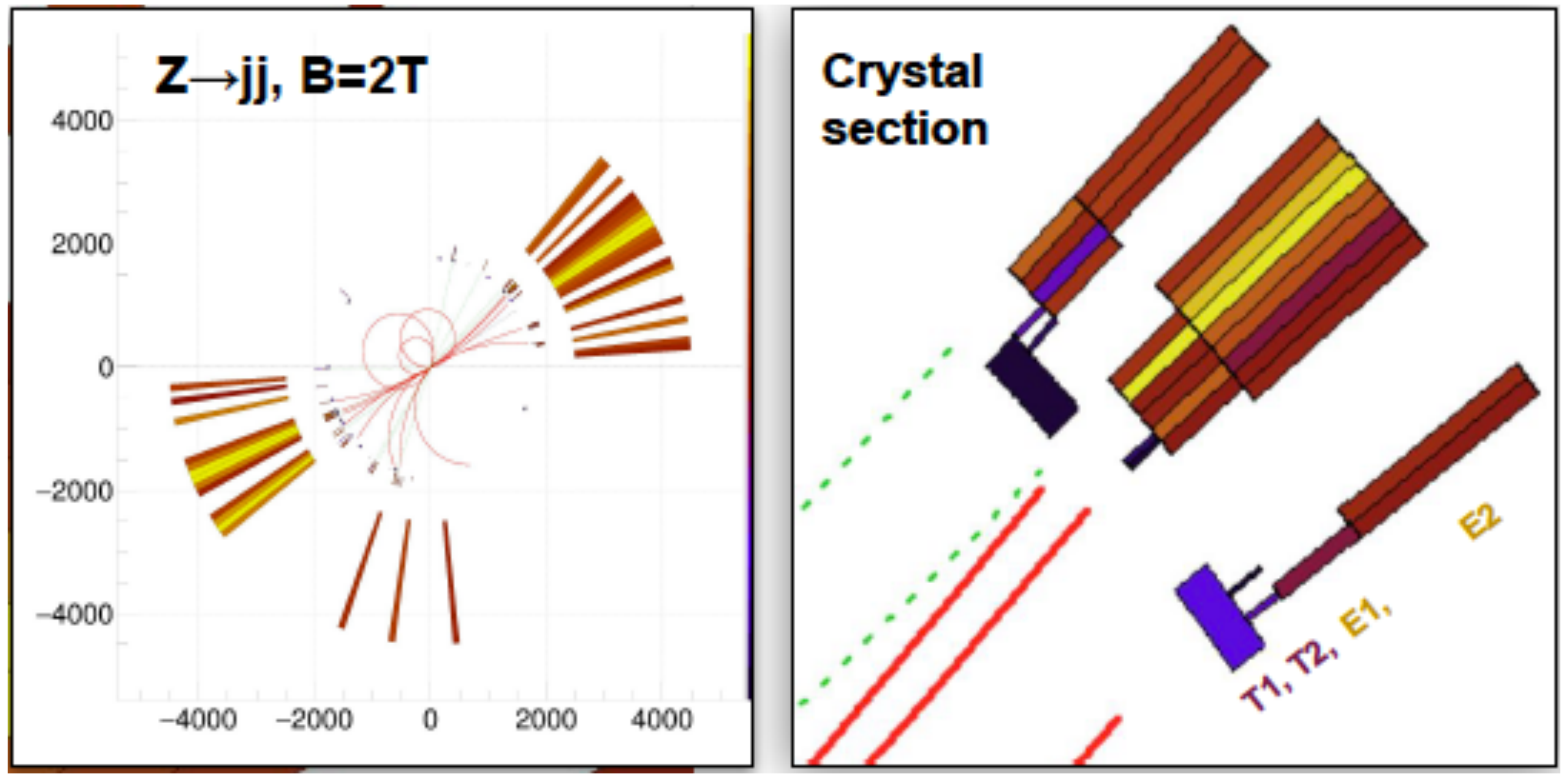


crystals + IDEA w/o DRO

crystals + IDEA w/ DRO

crystals + IDEA w/ DRO + pPFA

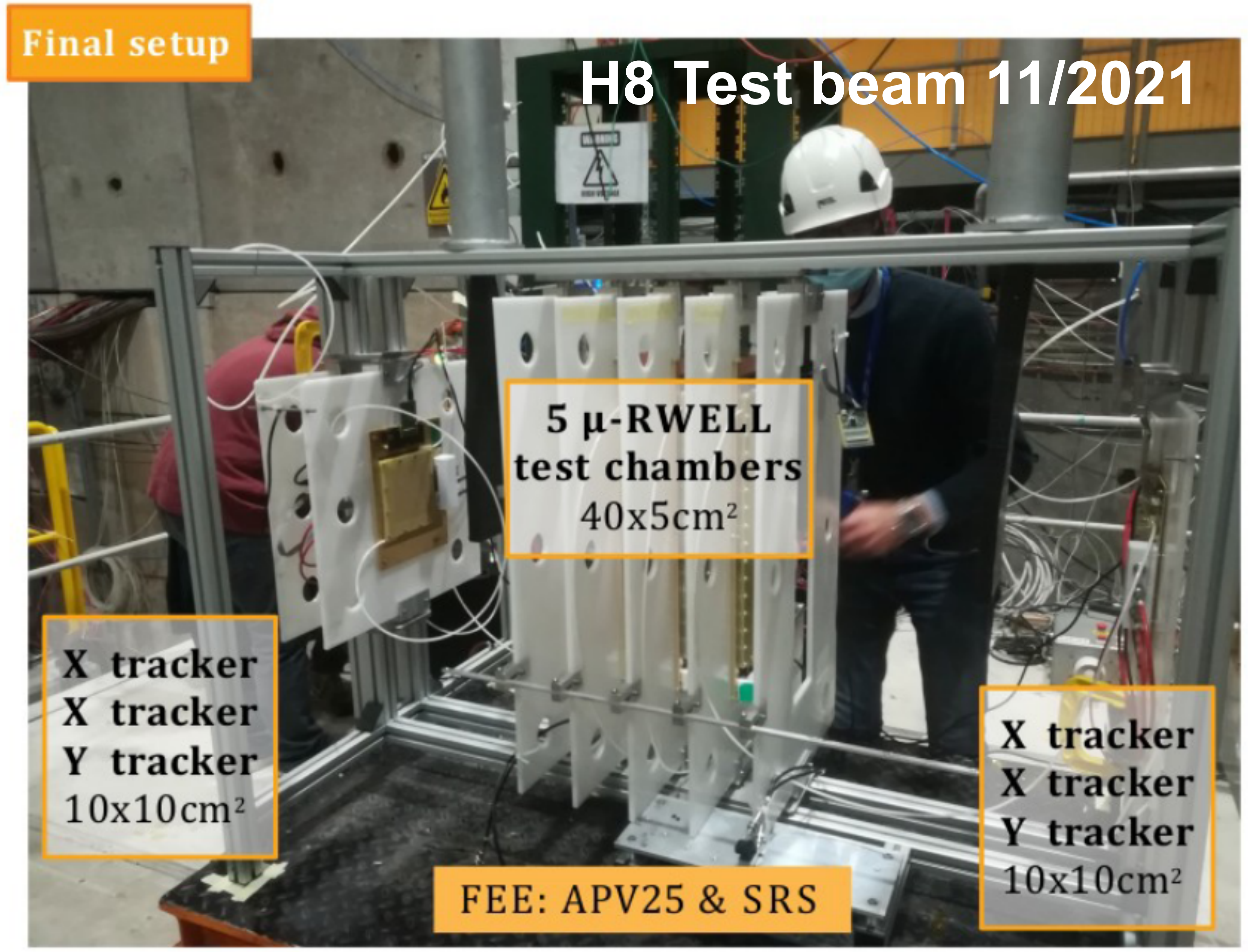
Event display



Sensible improvement in jet resolution using dual-readout information combined with a particle flow approach → 3-4% for jet energies above 50 GeV

M. Lucchini

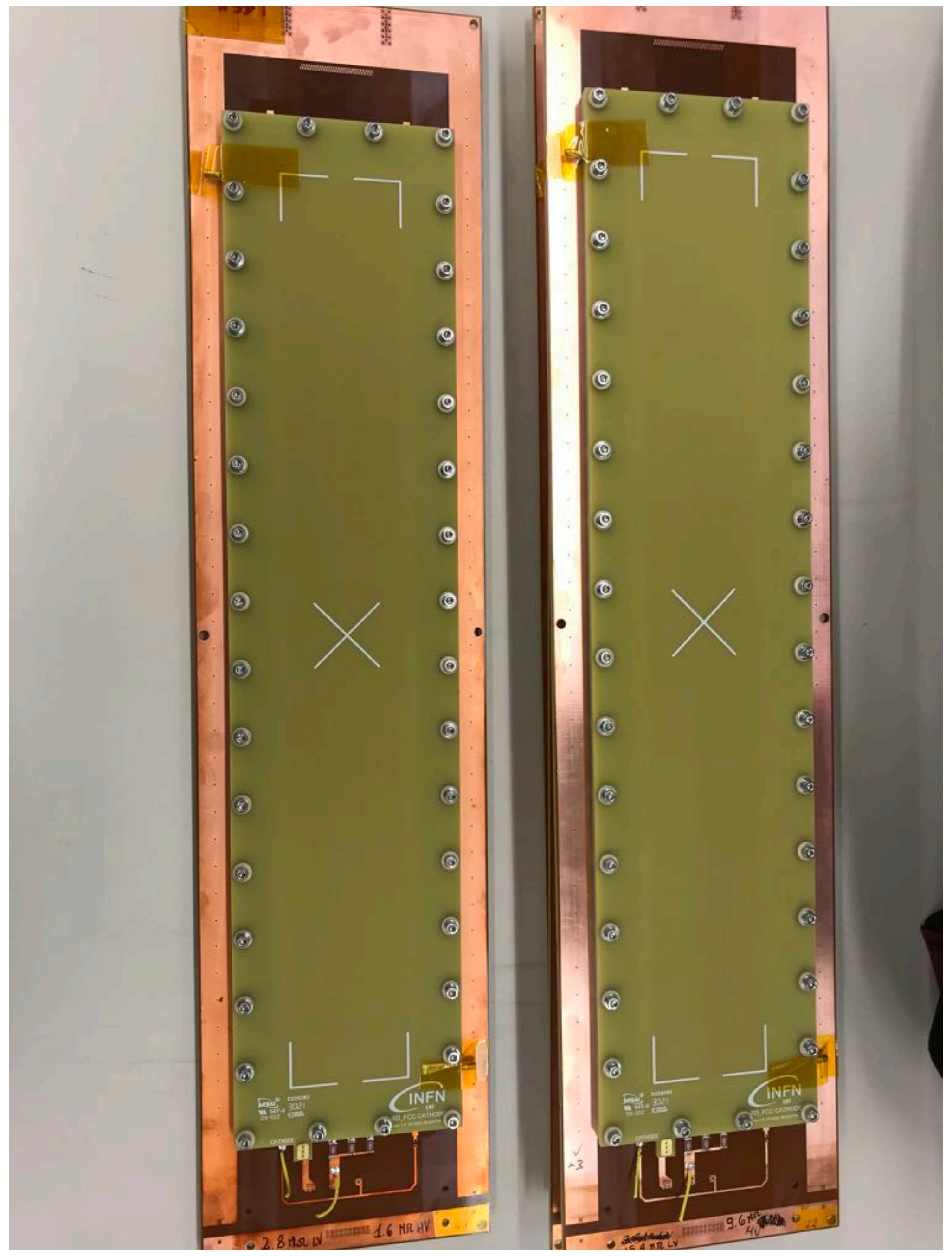
μ-RWELL: Test beam 2021



140-180 GeV/c muon and pion beam
Operated in $Ar/CO_2/CF_4$ (45/15/40)

1- Signal shape
(cluster charge, cluster size)
2 - Detector performance
(efficiency, space resolution)

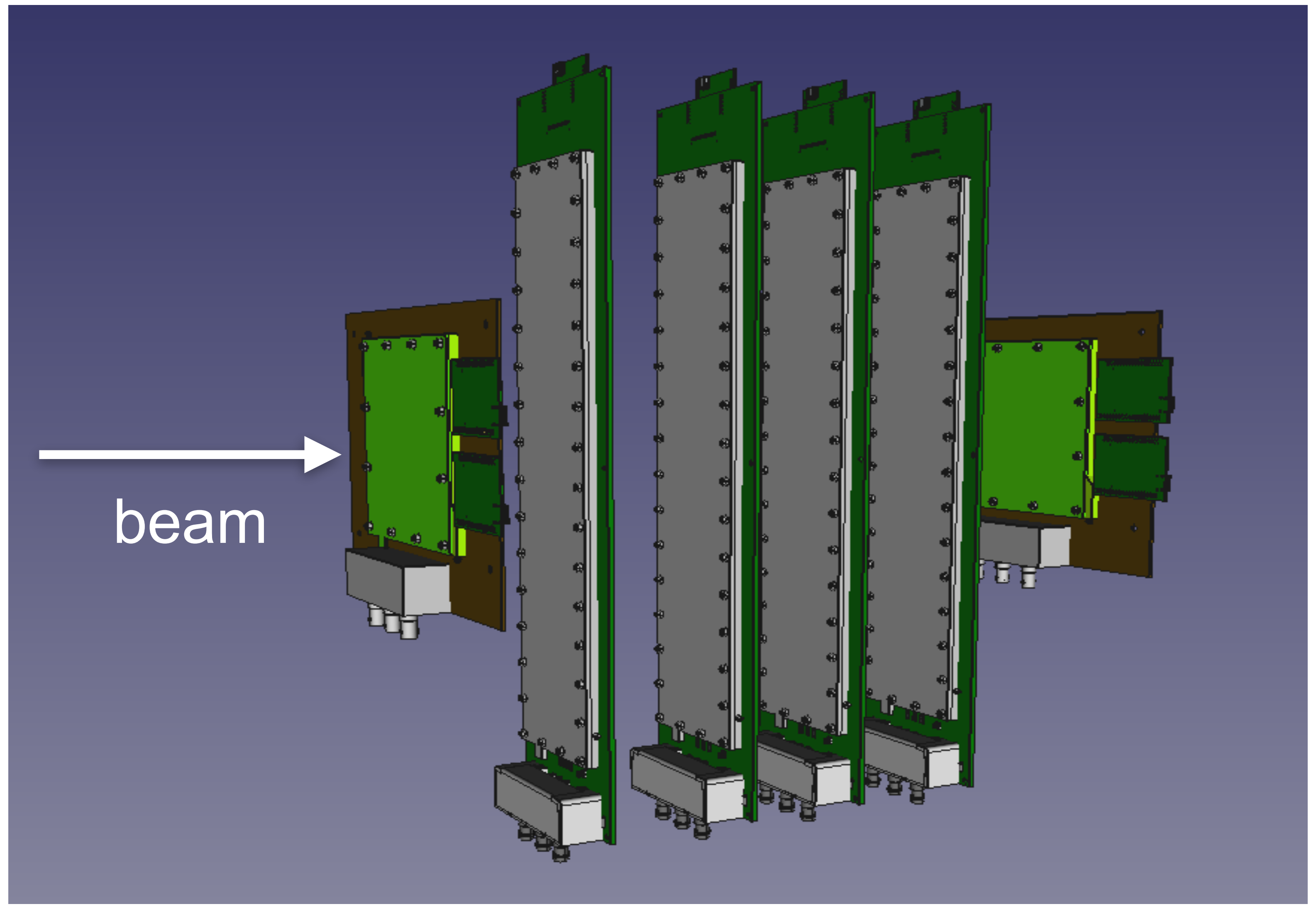
New μ-RWELL prototypes
with 40 cm long strips



a) Design optimization:
- different HV filter applied

b) Detector characterization
- HV scan at 0°
- HV scan at different angles and drift field

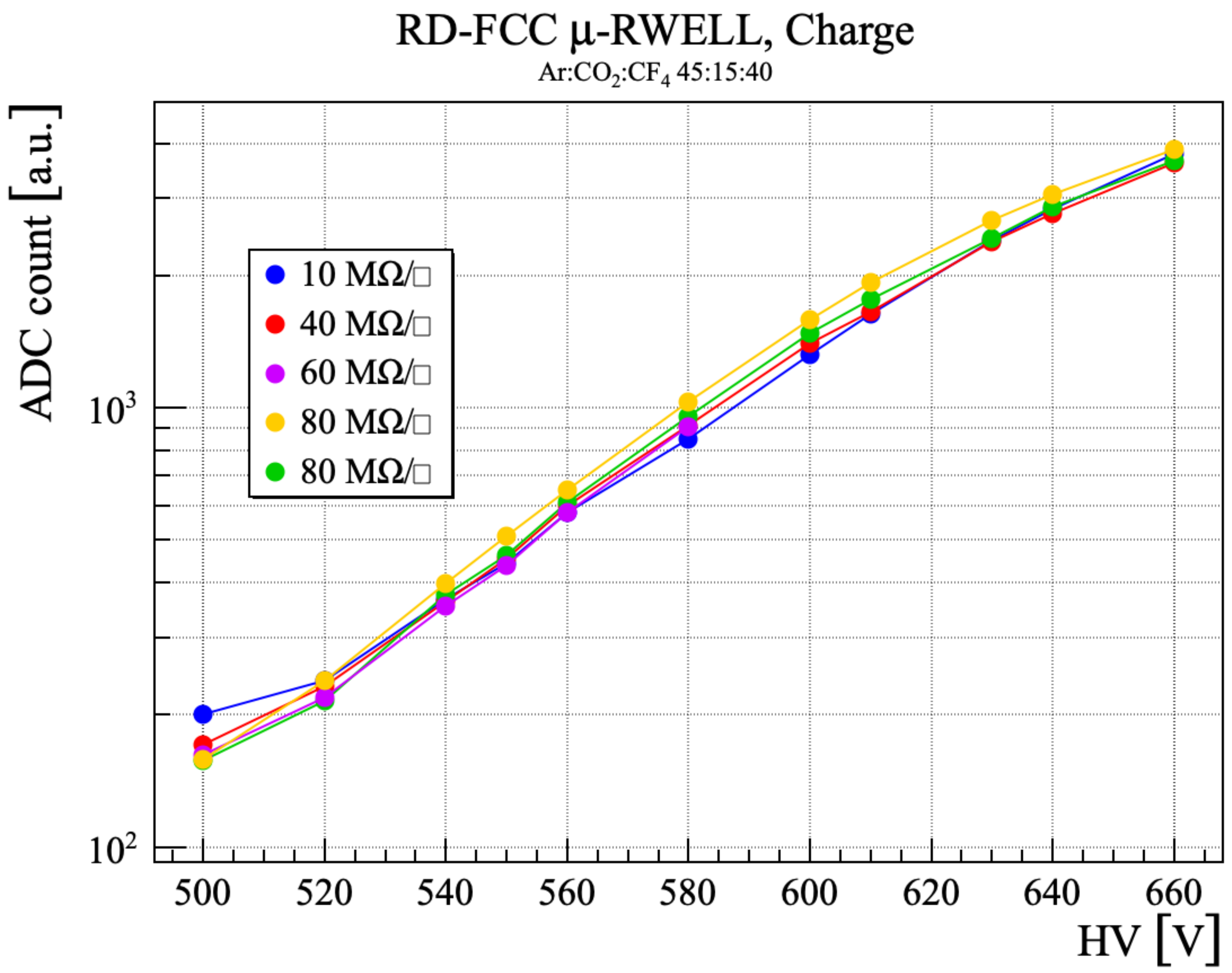
strips

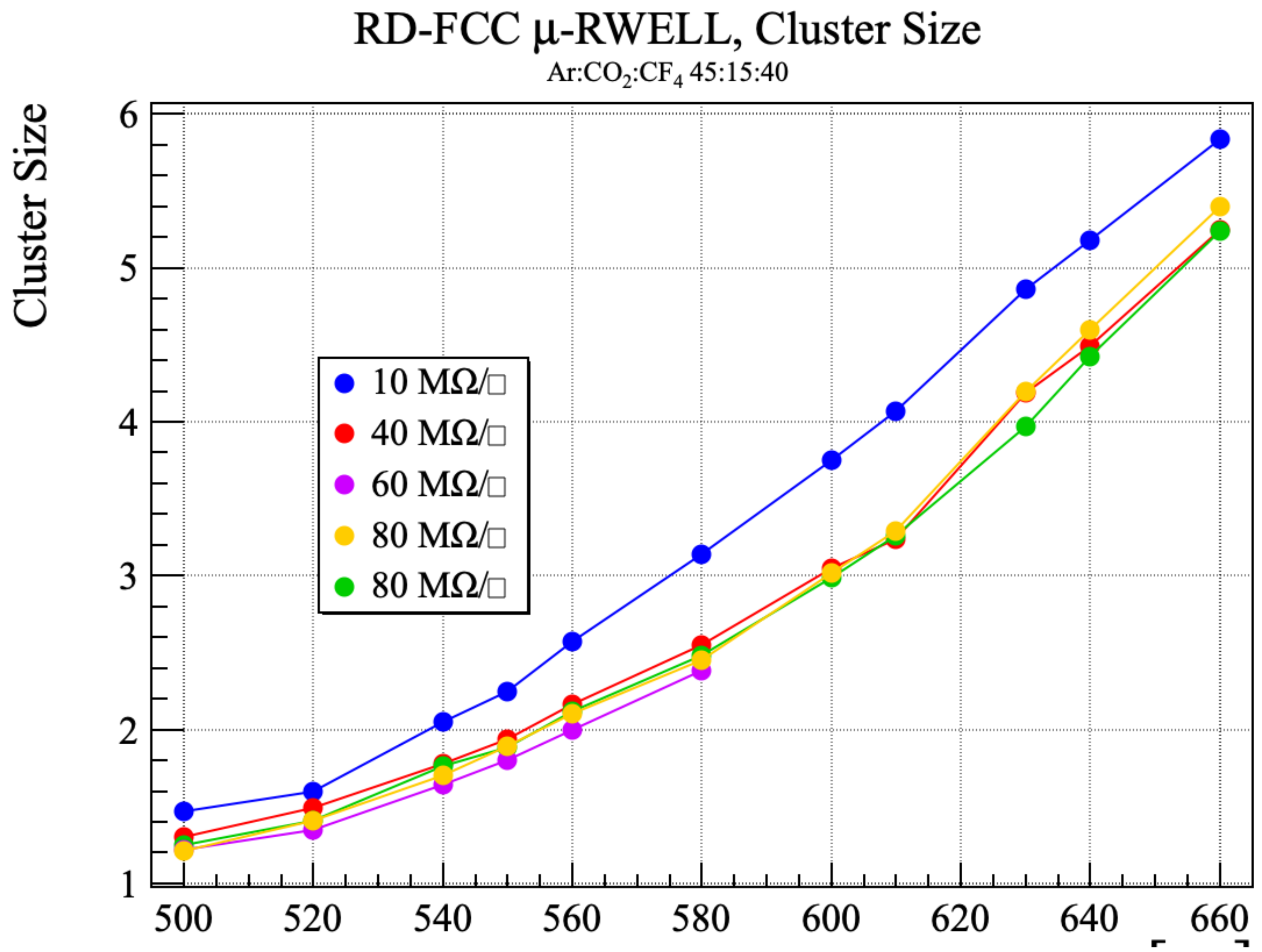


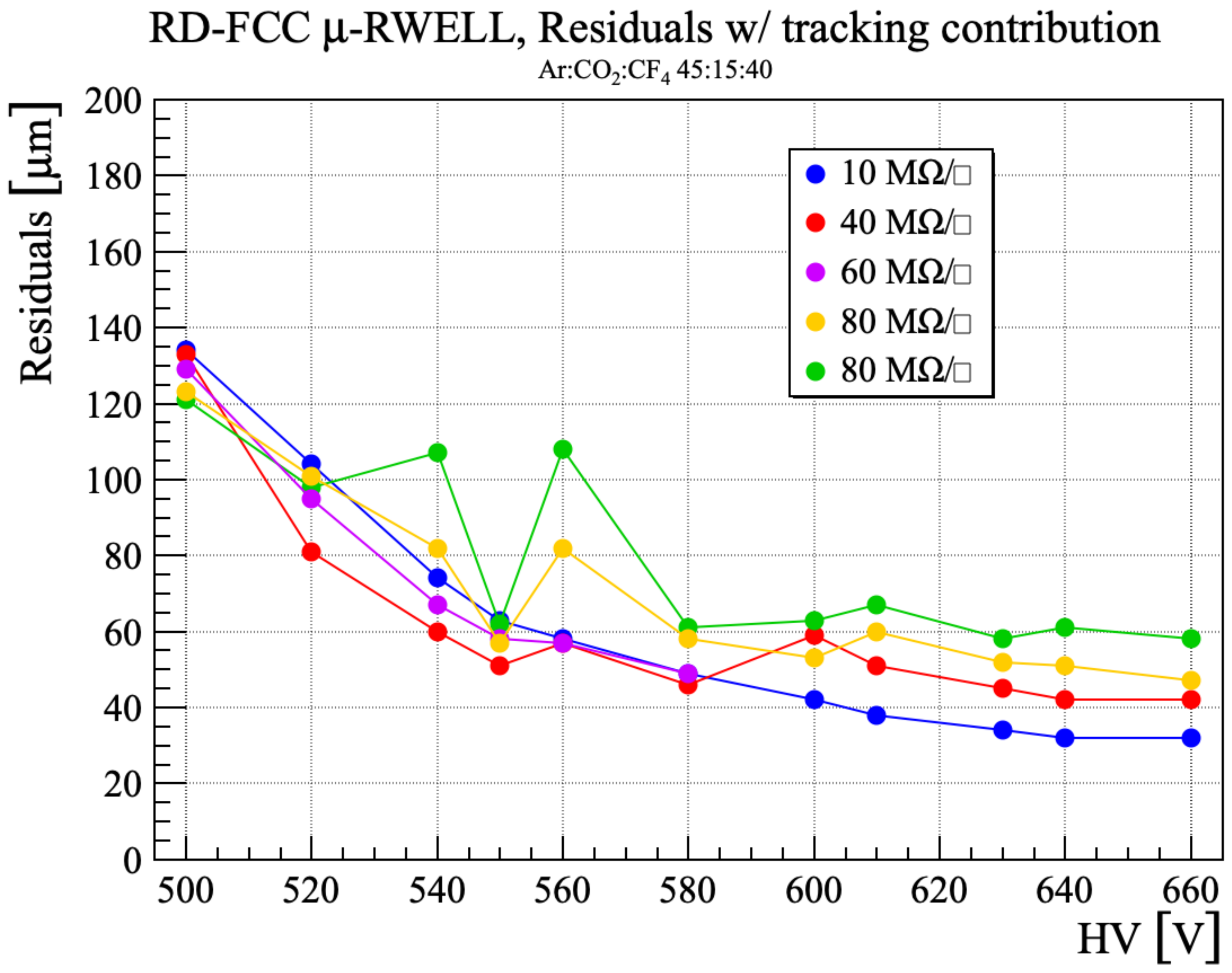
7 μ-RWELL prototypes with resistivity varying between 10 and 80 MOhm/☐ will allow to define best resistivity for final 50x50 cm^2 detector

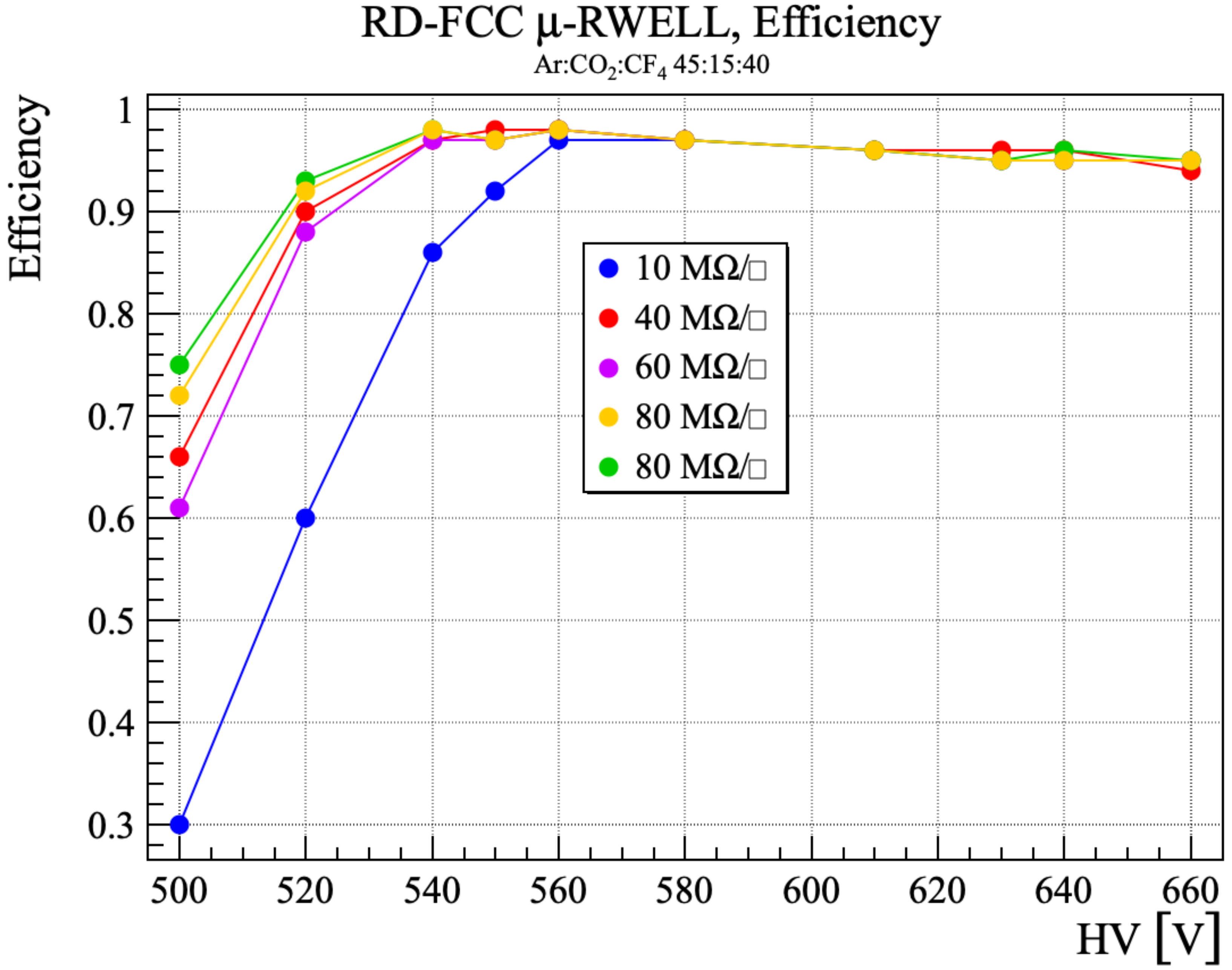
LNF
BOLOGNA
FERRARA
TORINO

Results from test beam data

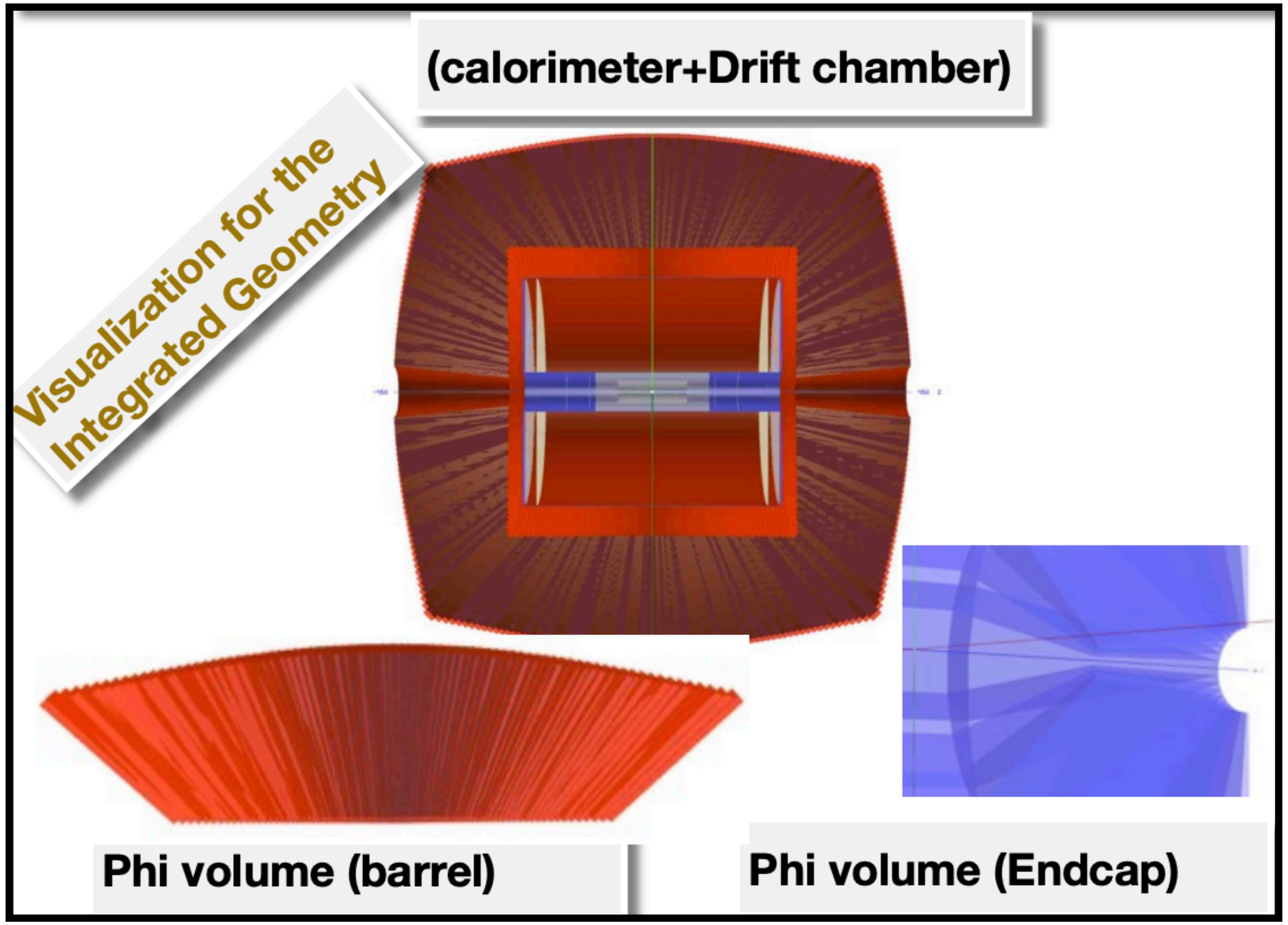








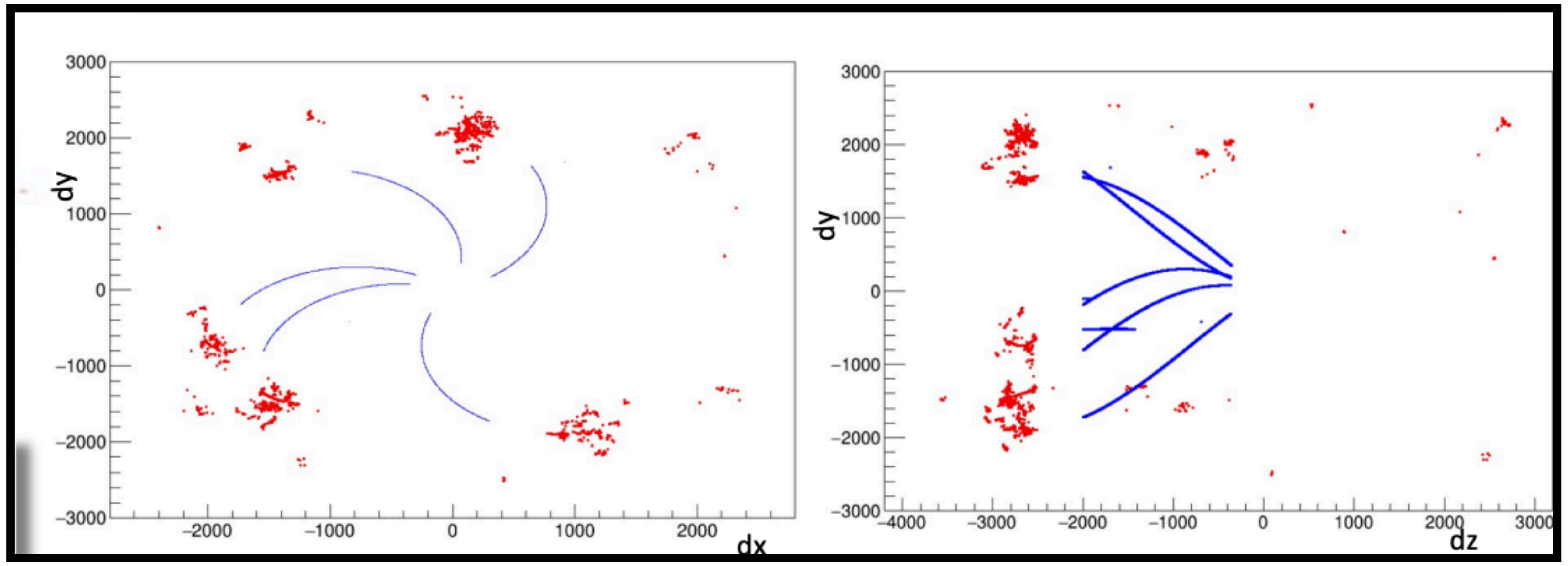
Status of Simulation of IDEA concept



FASTSIM Delphes IDEA card used for performance studies FCCSW

Very sophisticated compared to default.

Latest additions: Vertexing, LLP, PID, dN/dx, dE/dx



FULLSIM: standalone GEANT4 description

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

Conclusions

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FUTURE CIRCULAR COLLIDER

Conclusions

INFN Istituto Nazionale di Fisica Nucleare

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  - INFN was central in all these R&D activities and started many of them
  - Now several international colleagues have joined these efforts
- Lots of possibilities for International colleagues to join IDEA and help on all these developments!!

Backup

DR calorimeter

Dual-readout fiber-sampling calorimeter

- Longitudinally unsegmented fiber-sampling calorimeter
  → measure both EM & hadronic components simultaneously
  → fine unit structure with a high granularity
- Projective geometry with a uniform sampling fraction
  → more fibers in the rear than the front

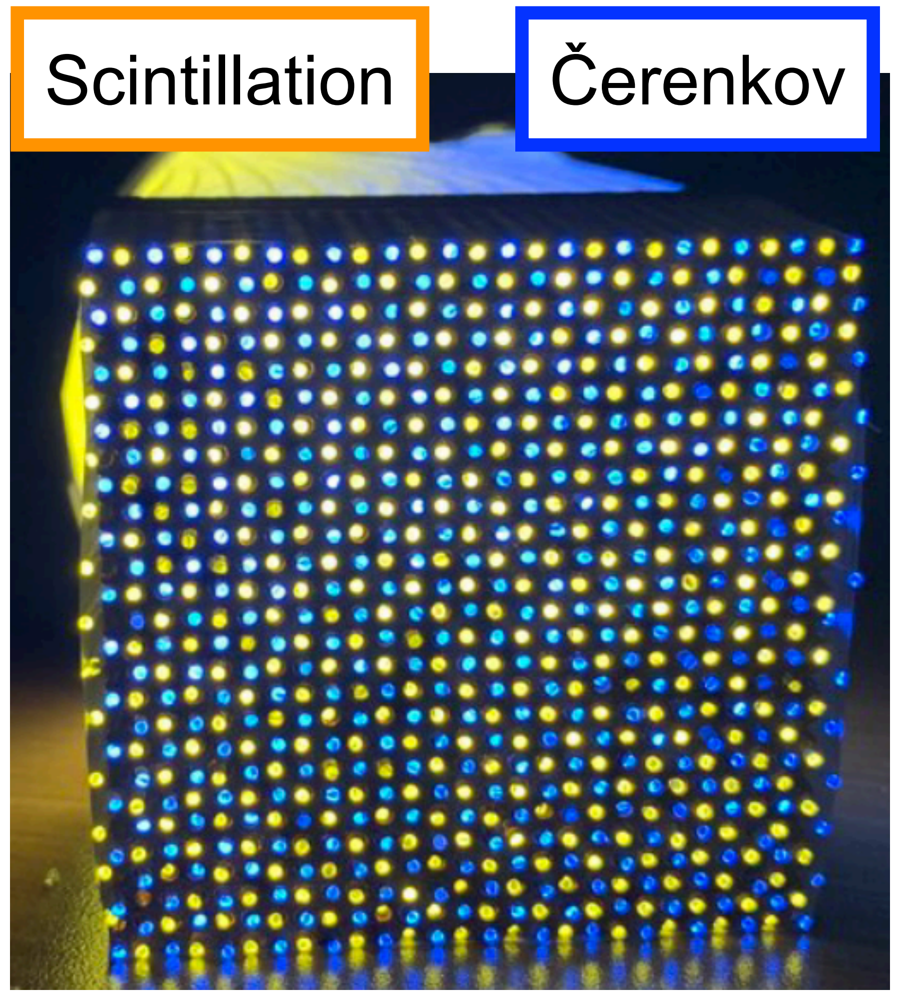
$$S = E[f_{em} + \left(\frac{h}{e}\right)_s (1 - f_{em})],$$

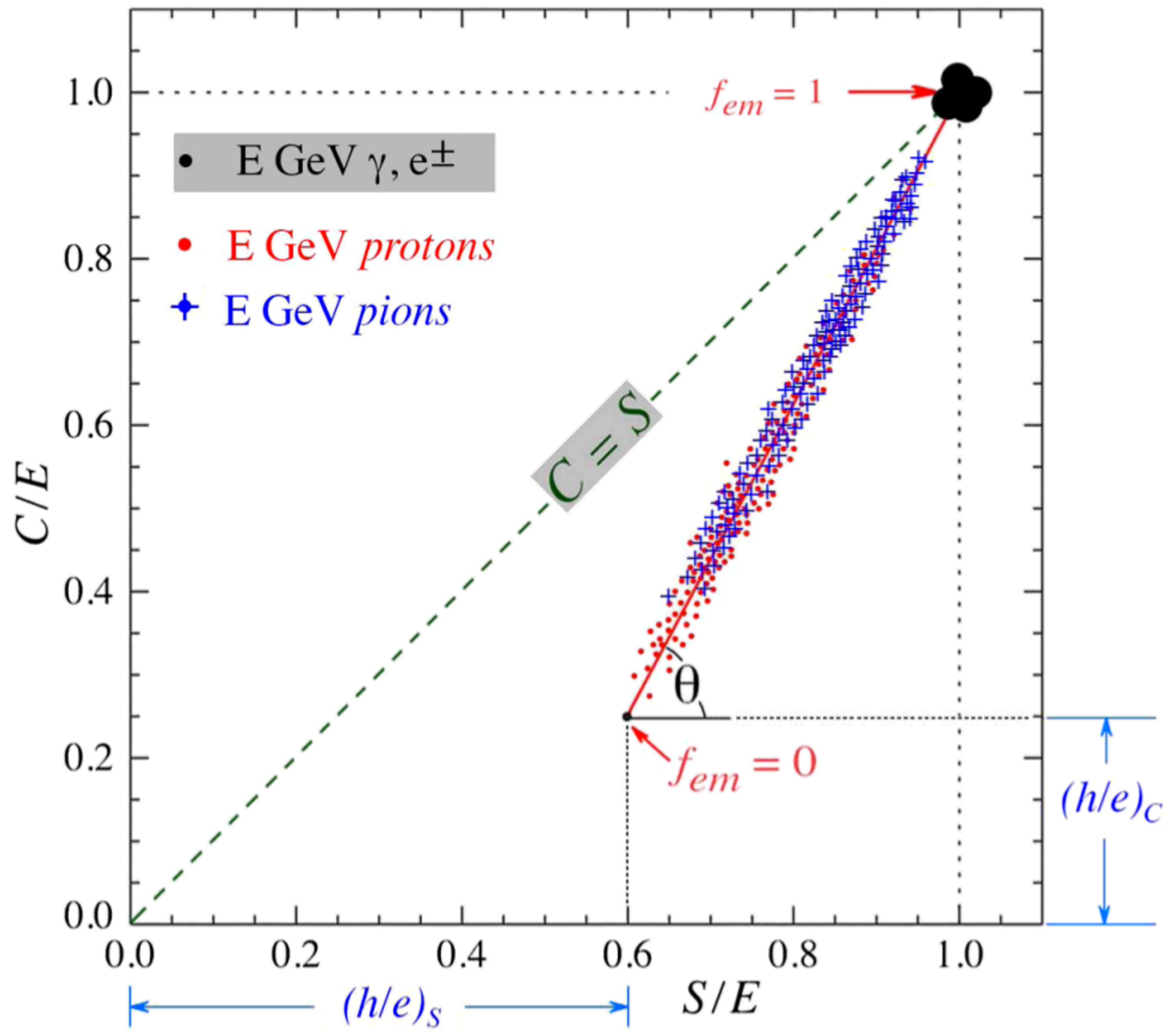
$$C = E[f_{em} + \left(\frac{h}{e}\right)_c (1 - f_{em})]$$

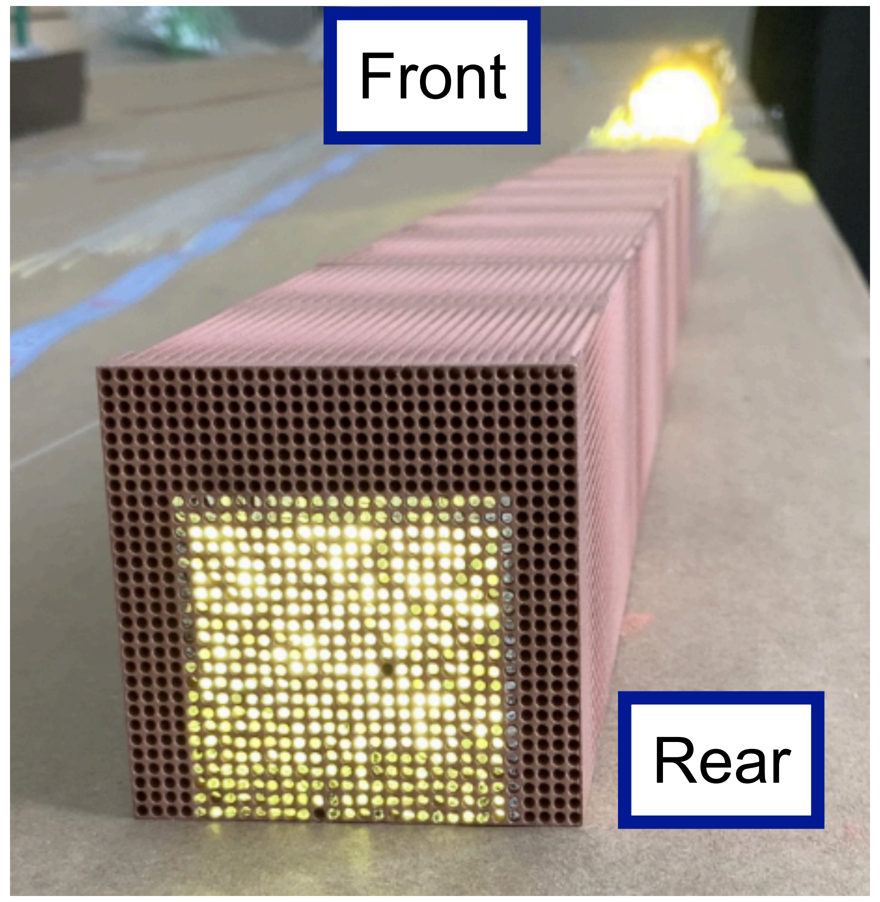
$$f_{em} = \frac{(h/e)_c - (C/S)(h/e)_s}{(C/S)[1-(h/e)_s] - [1-(h/e)_c]}$$

$$\cot\theta = \frac{1-(h/e)_s}{1-(h/e)_c} \equiv \chi,$$

$$E = \frac{S - \chi C}{1 - \chi}$$







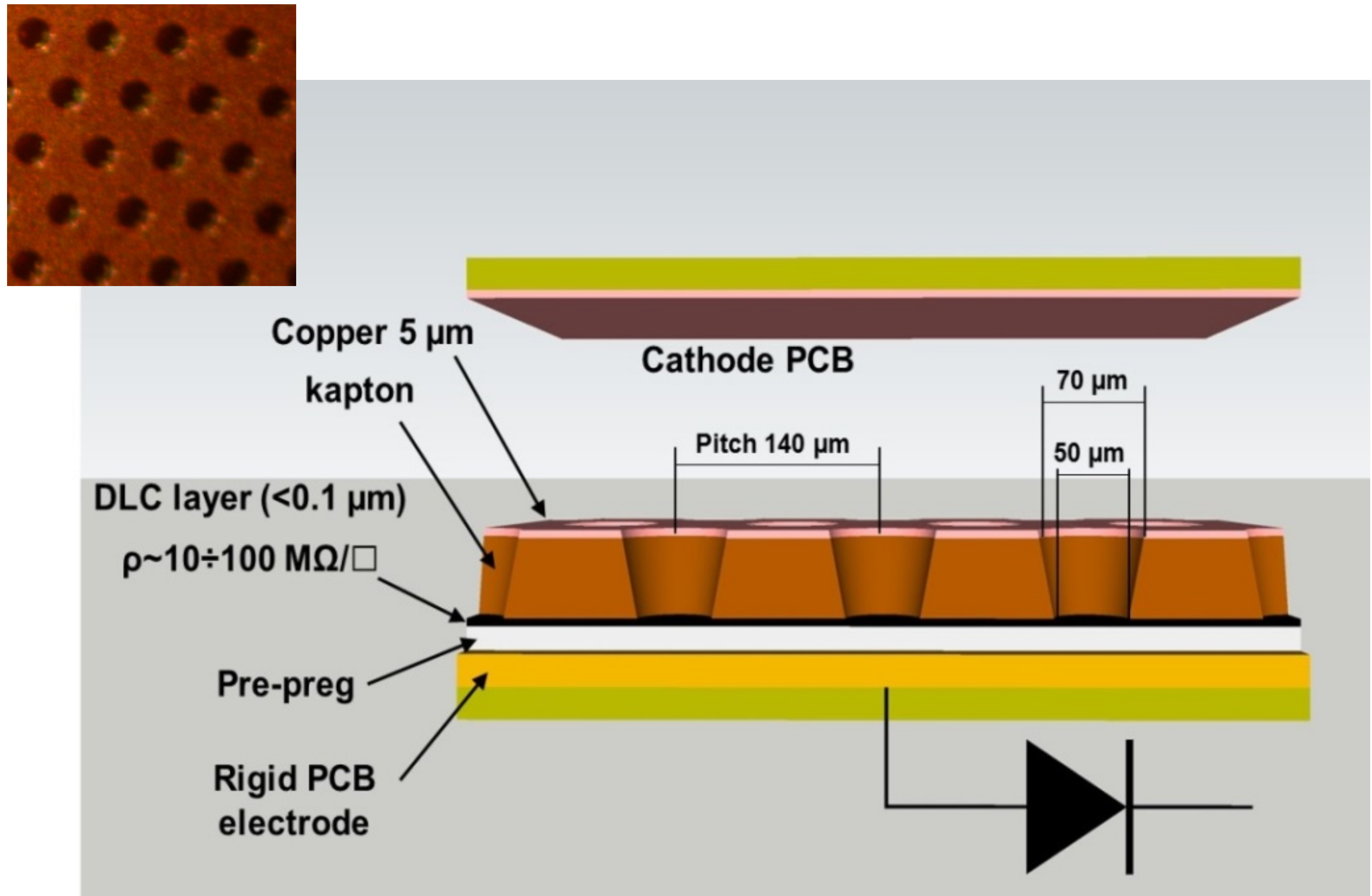
Preshower and Muon detector

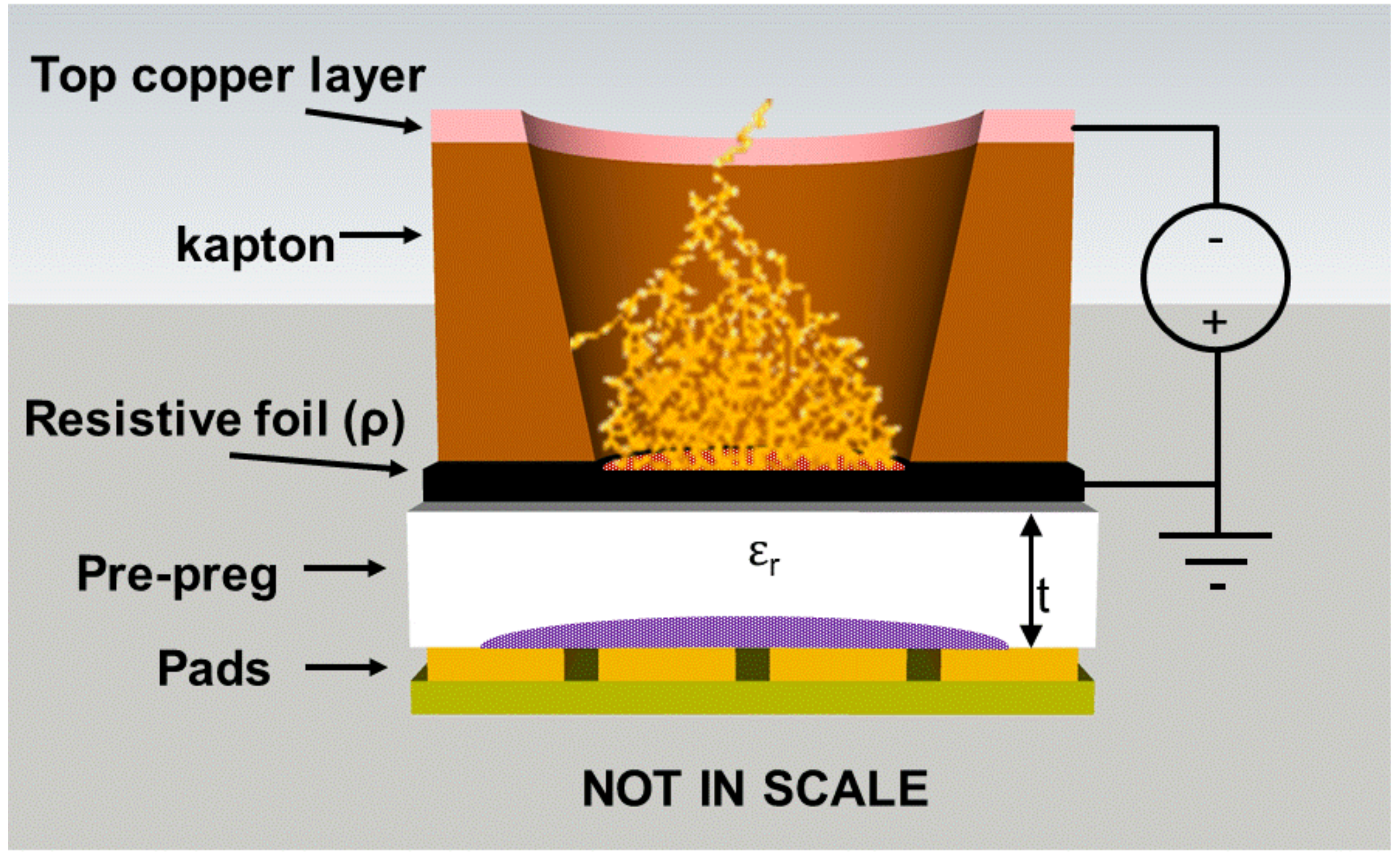
Detector technology: μ-RWELL

The μ-RWELL is composed of only two elements:

- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB





- The "WELL" acts as a multiplication channel for the ionization produced in the gas of the drift gap
- The charge induced on the resistive layer is spread with a time constant, τ ~ ρ×C

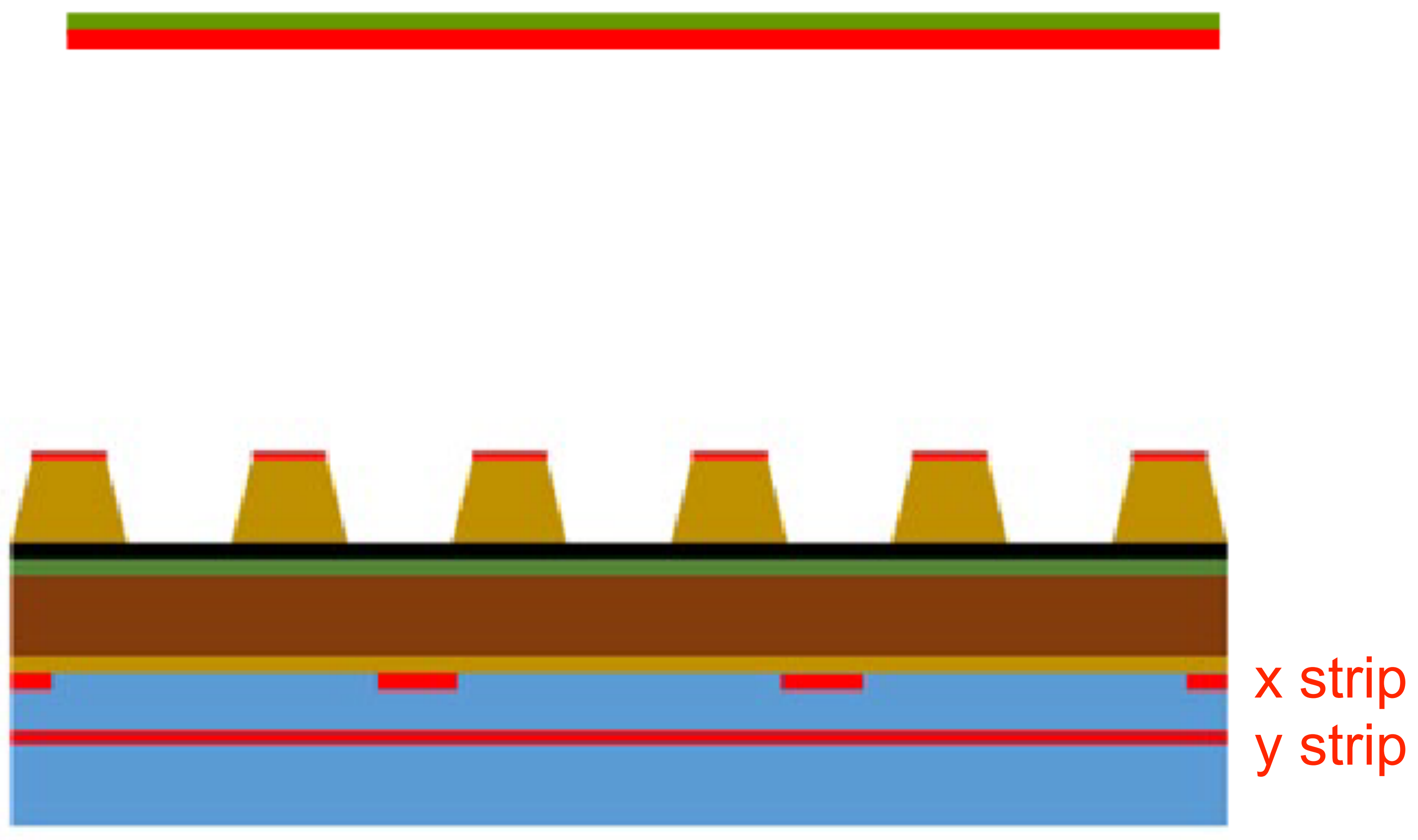
$$C = \varepsilon_0 \times \varepsilon_r \times \frac{S}{t} \cong 50\ pF/m \text{ (pitch-width 0,4 mm)}$$

2D μ-RWELL ideas

μ-RWELL with 2D anode readout

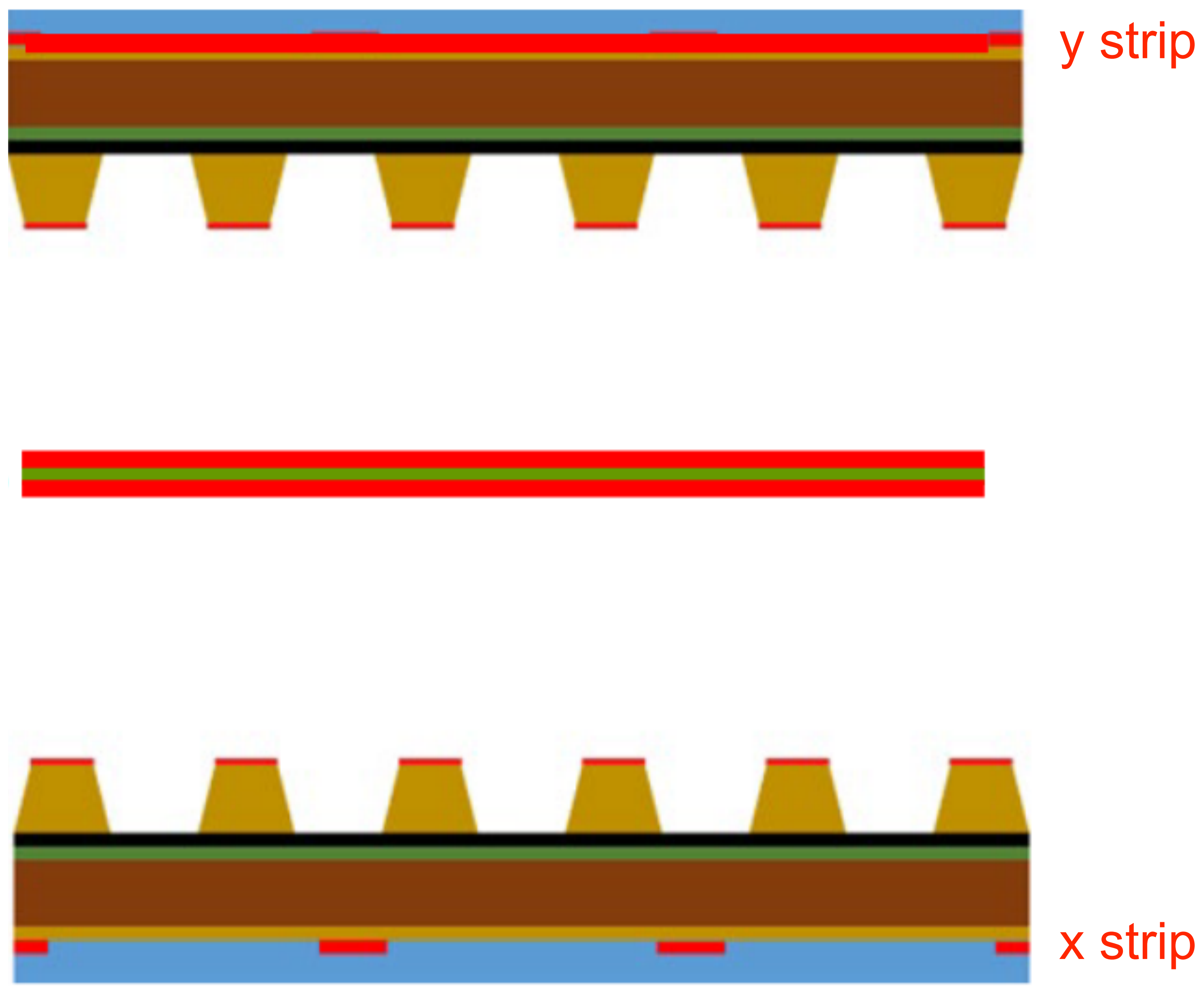
Good performance
but need higher gain wrt. to 1D
μ-RWELL

More complex PCB construction



2 stacked 1D μ-RWELL

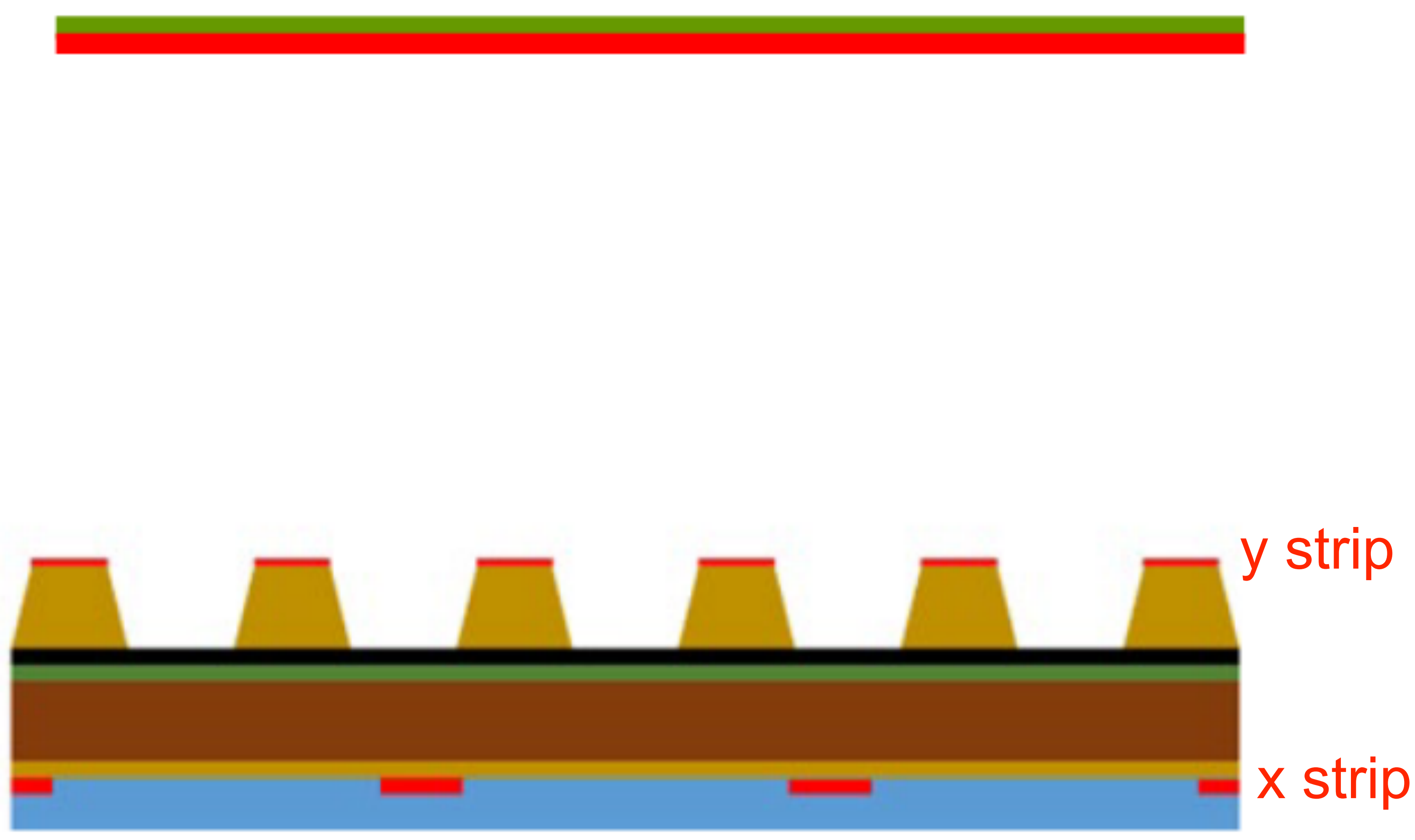
1 view per μ-RWELL
easy PCB construction
2D performance to be
measured



μ-RWELL with strips on top and anode

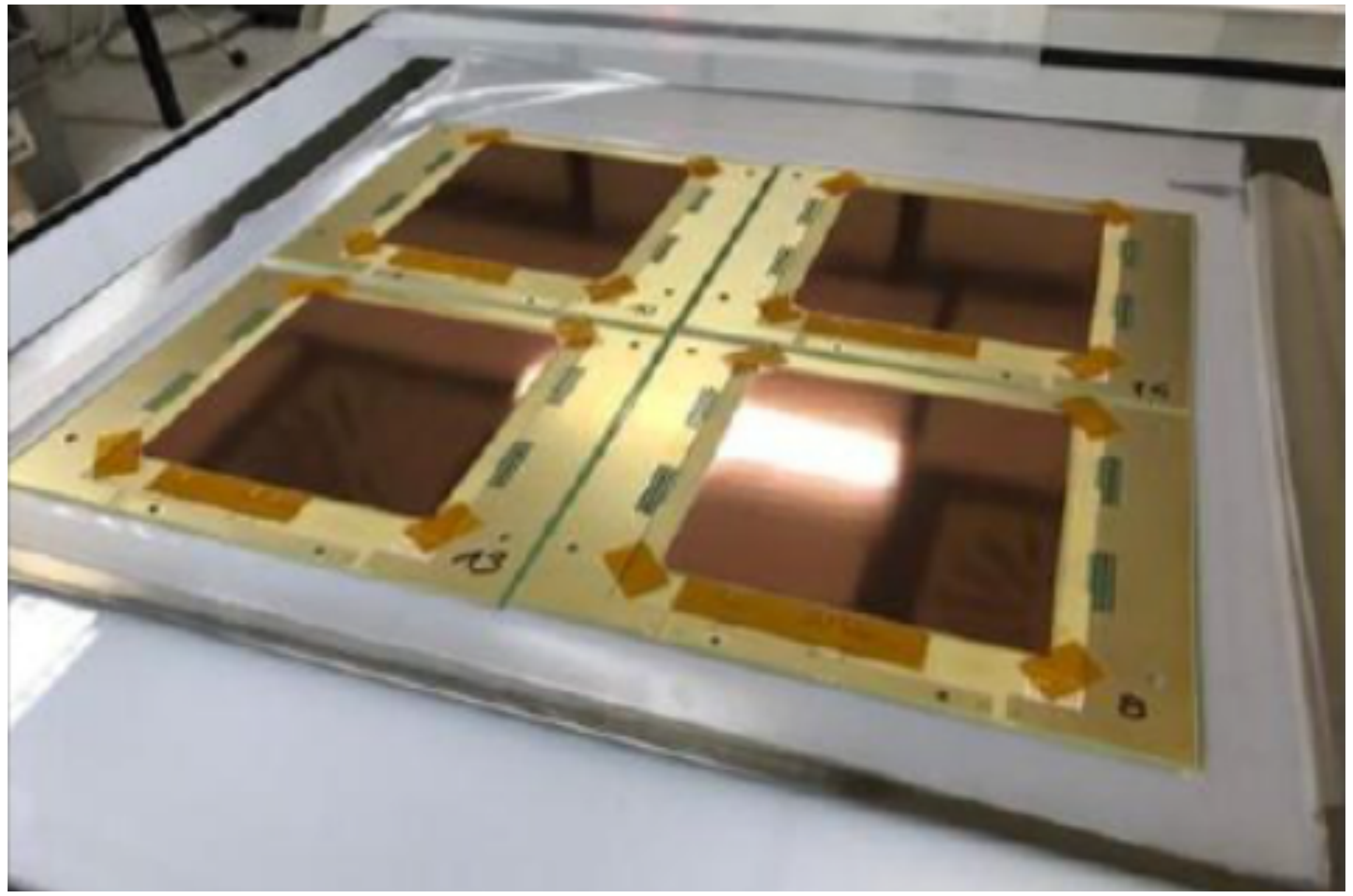
HV on DLC,
TOP to ground

2D performance to be
measured



Technology transfer with ELTOS

DLC sputtering with new INFN-CERN machine @ CERN



Step 1: producing μ-RWELL_PCB

- with top patterned (pad/strip)
- without bottom patterned

Step 2: DLC patterning

- in ELTOS with BRUSHING-machine

Step 3: DLC foil gluing on PCB

- double 106-prepreg (~2x50 μm thick) (already used in ELTOS)
- pre-smoothing + 106-prepreg (~50 μm thick)
- single 1080-prepreg (~75 μm thick)

Step 4: top copper patterning

Step 5: Kapton etching on small PCB

Finalization

Detector @ CERN for final preparation

Test with TIGER electronics

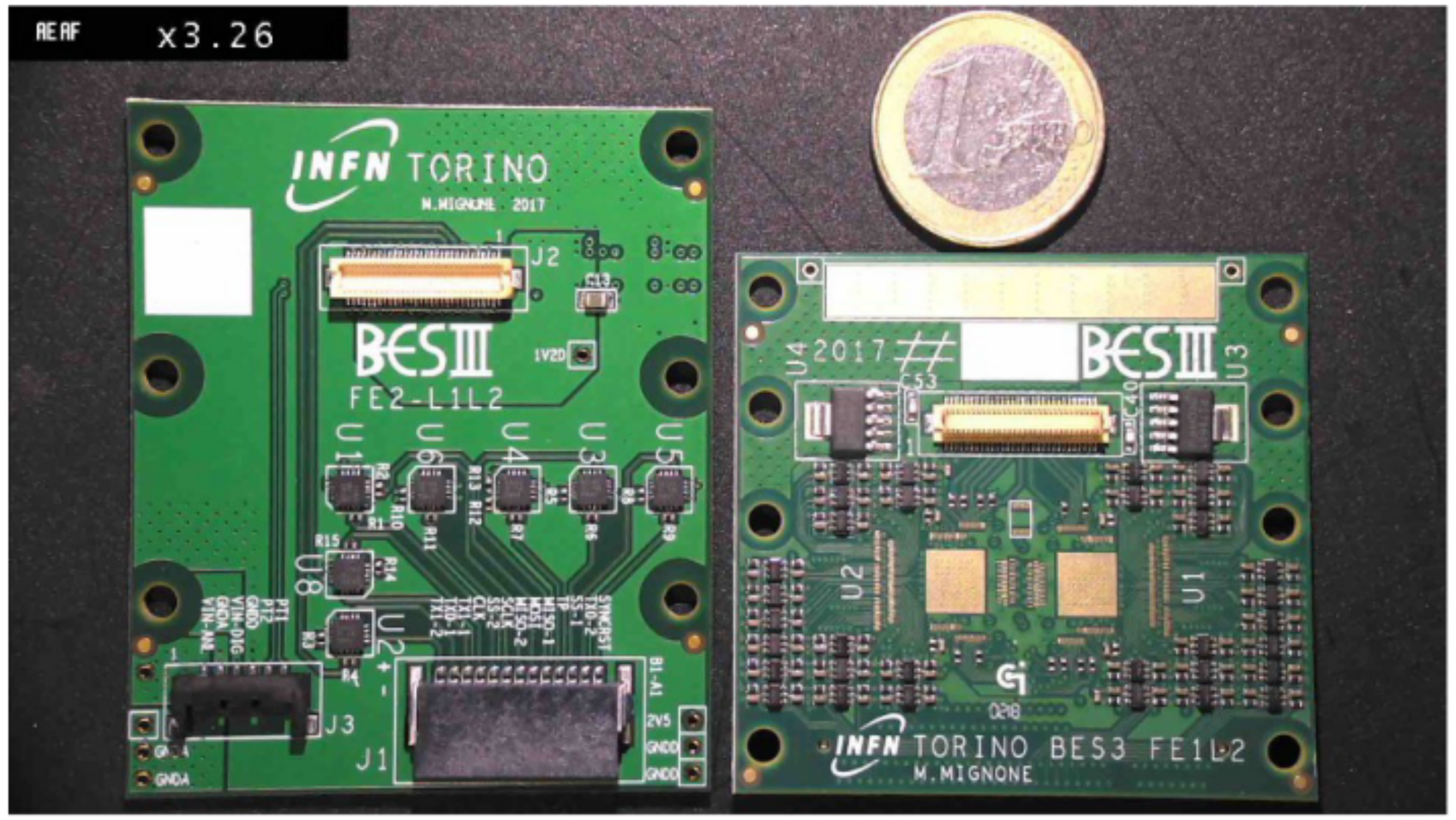


Table 2
Measured performance of the TIGER ASIC.

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

Test with TIGER ASIC

Developed for BESIII CGEM-IT

Prepare new readout card based on System On Modules (SOM)

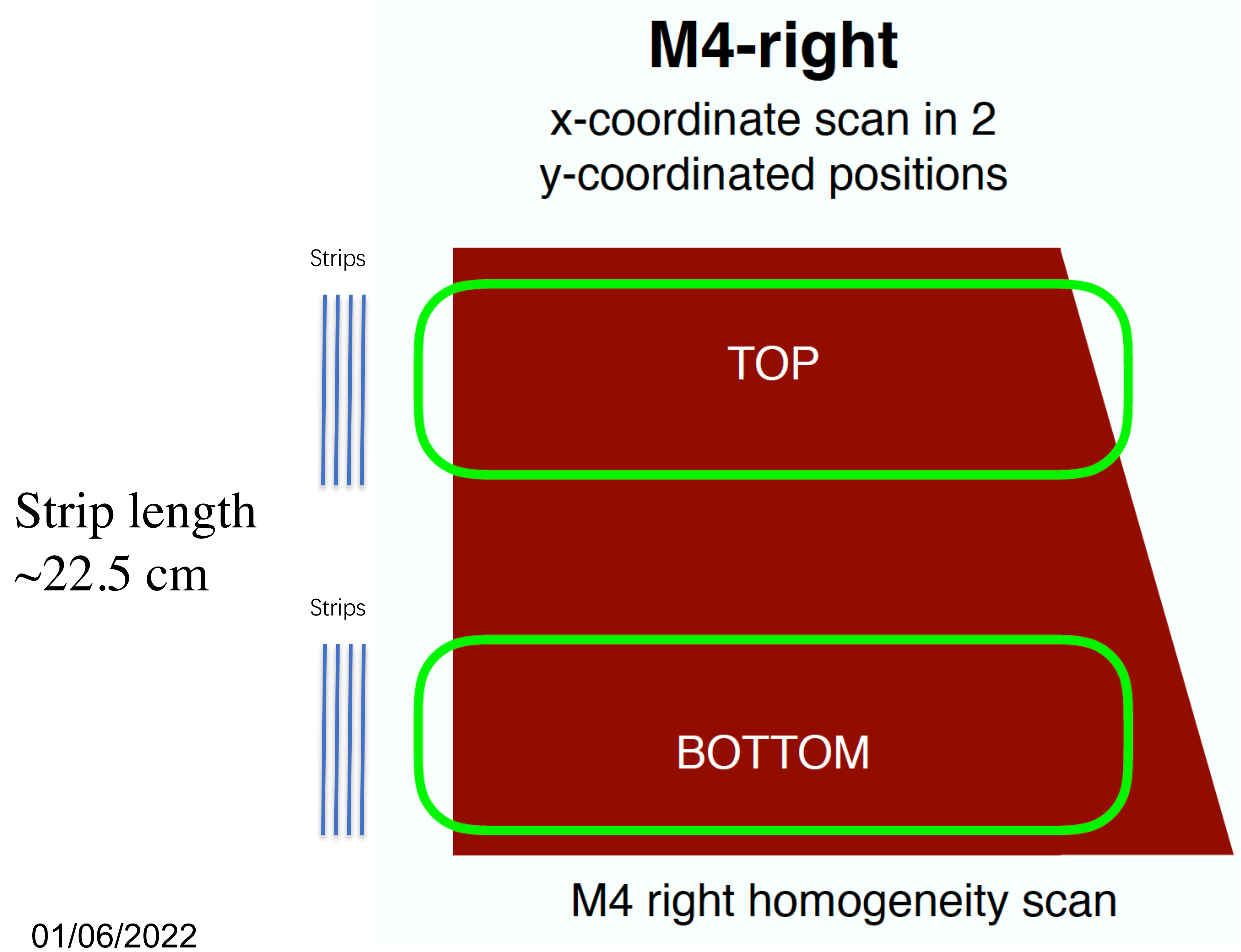
<u>Aim</u>

Develop dedicated ASIC for μ-RWELL

μ-RWELL-based detectors

2022-2024 R&D program

- Define the best resistivity of the DLC for both μRWELL fundamental tiles and build the 50×50 cm^2 prototypes for the pre-shower and muon systems.
- Optimize the engineering mass construction process together with the ELTOS industry.
- Develop a custom-made ASIC for the μRWELL with the experience obtained from the TIGER chip and to test the μRWELL prototypes.
- Develop a new reconstruction algorithm, ML-based, to improve the resolution of μRWELL.
- Simulation of the CEPC decay channels of interest to optimize the detector design with special emphasis on Long Lived Particles to show the impact of a performing tracked in the muon system instead of a tagger.



Development of a new ASIC

- Two large microRWell chambers M4 in Bologna;
- Ferrara has procured the Tiger electronics;
- Plan to start equipping the M4s with the TIGER next spring;
- Use a cosmic telescope to characterize the detector and the electronics and later to expose the chamber with the TIGER electronics to a test beam;
- Funding received to develop a new ASIC starting from the experience of the TIGER.