4th FCC / DRD France Workshop
Strasbourg, Nov. 222-24, 2023

The IDEA detector concept

Paolo Giacomelli
INFN Bologna

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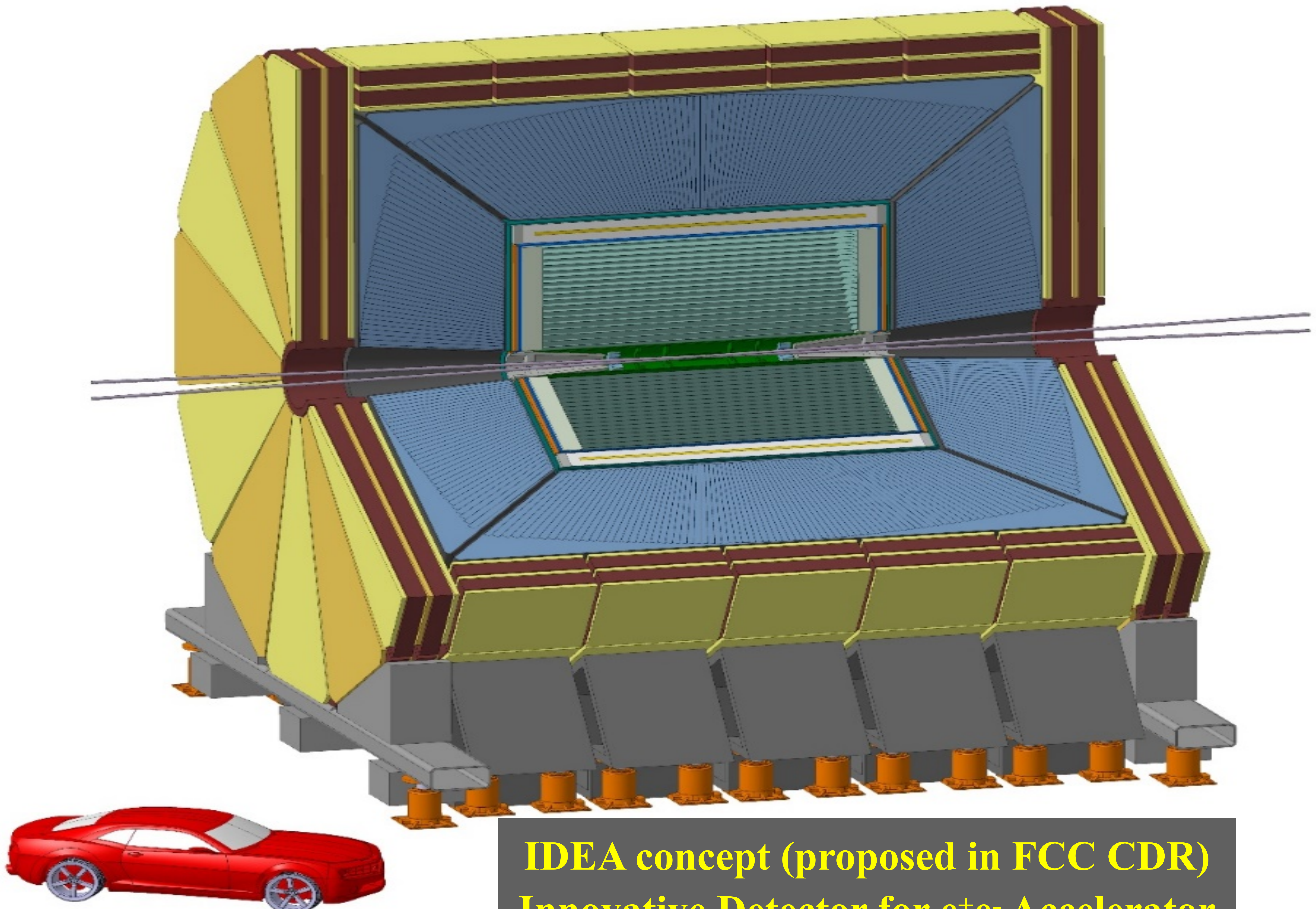
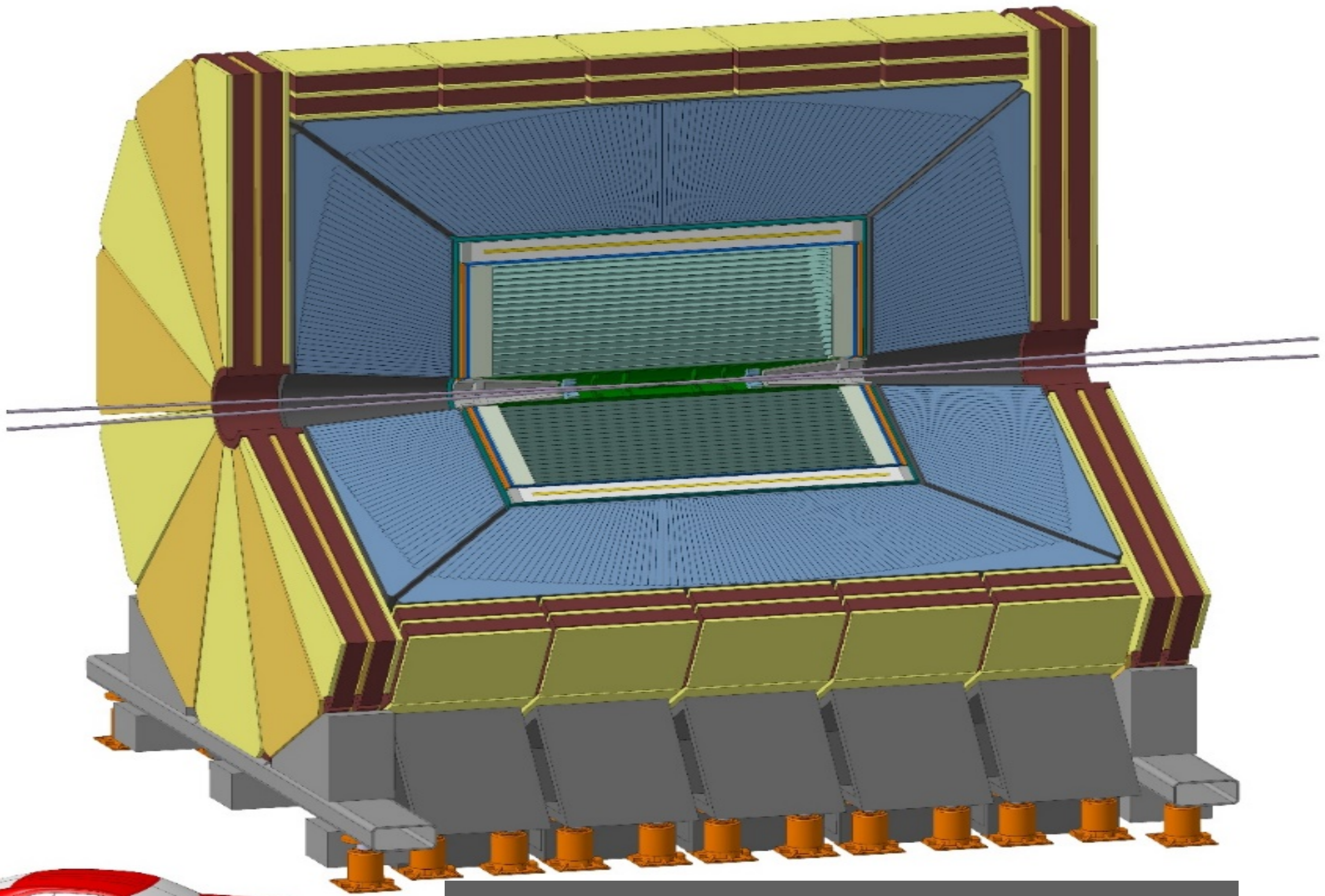


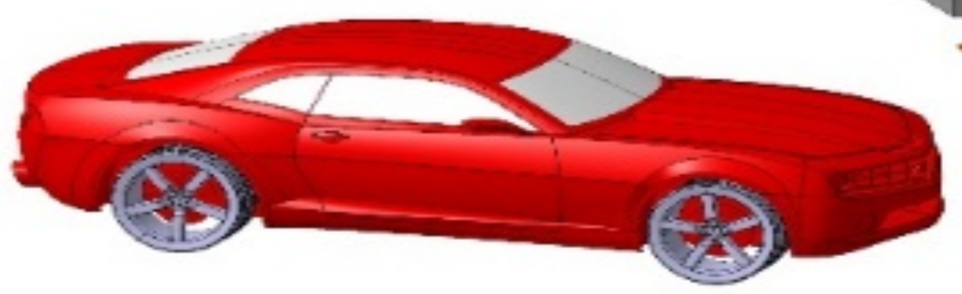
IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

- **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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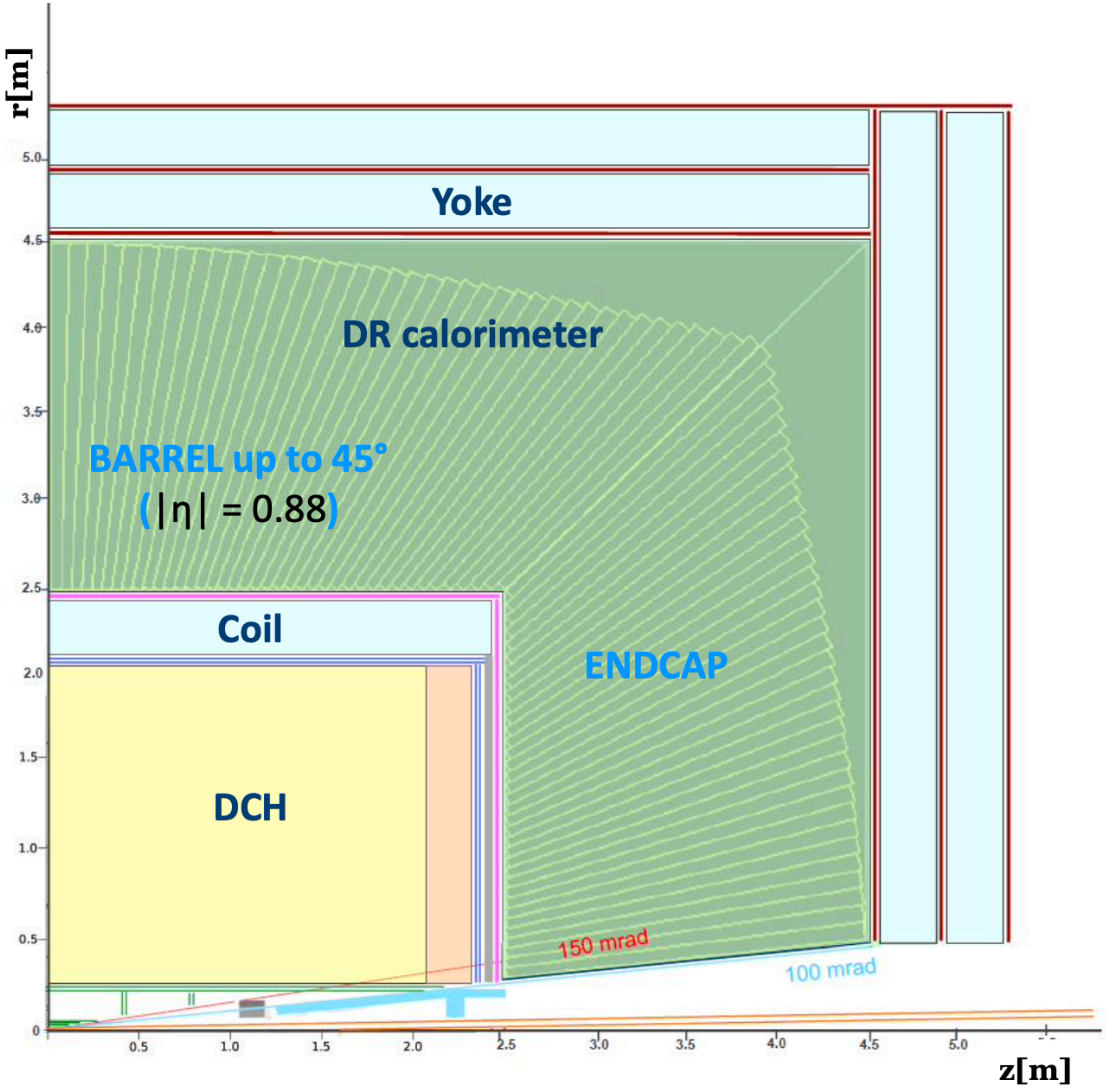
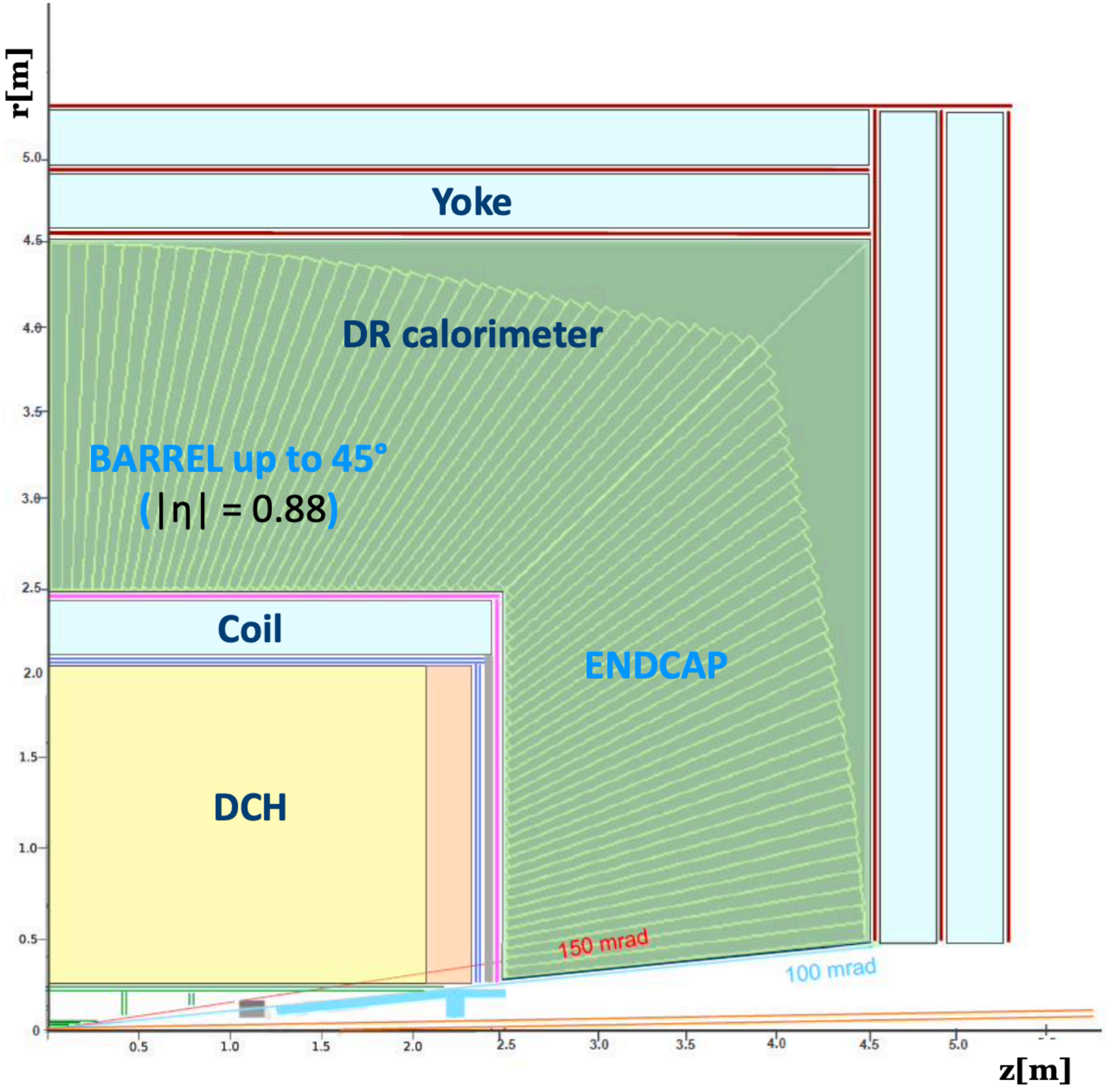
Acknowledgments
I need to thank many colleagues, in particular:
F. Bedeschi

IDEA detector layout



IDEA detector layout

Beam pipe: R~1.0 cm



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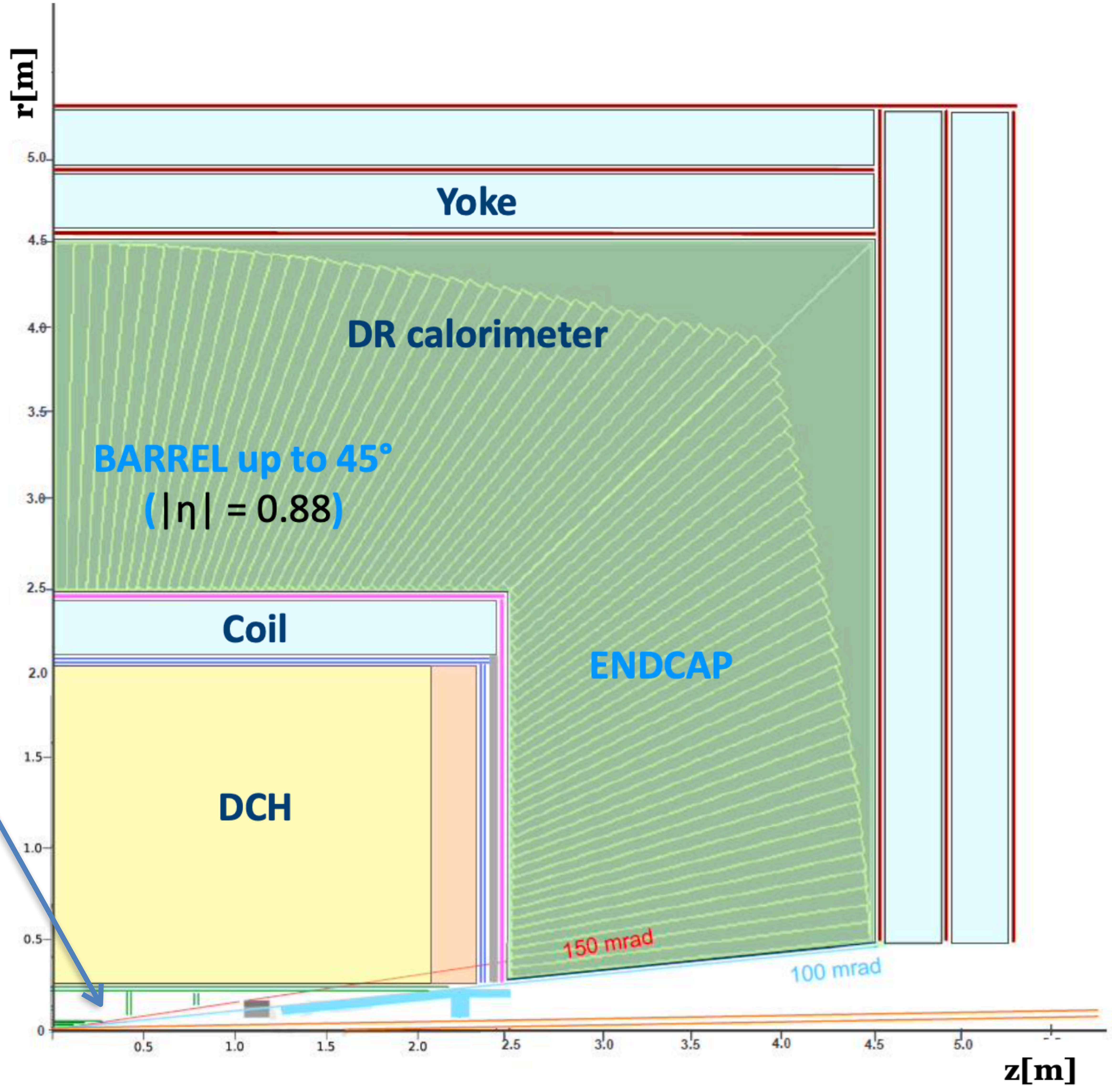
5 MAPS layers

R = 1.2-34 cm



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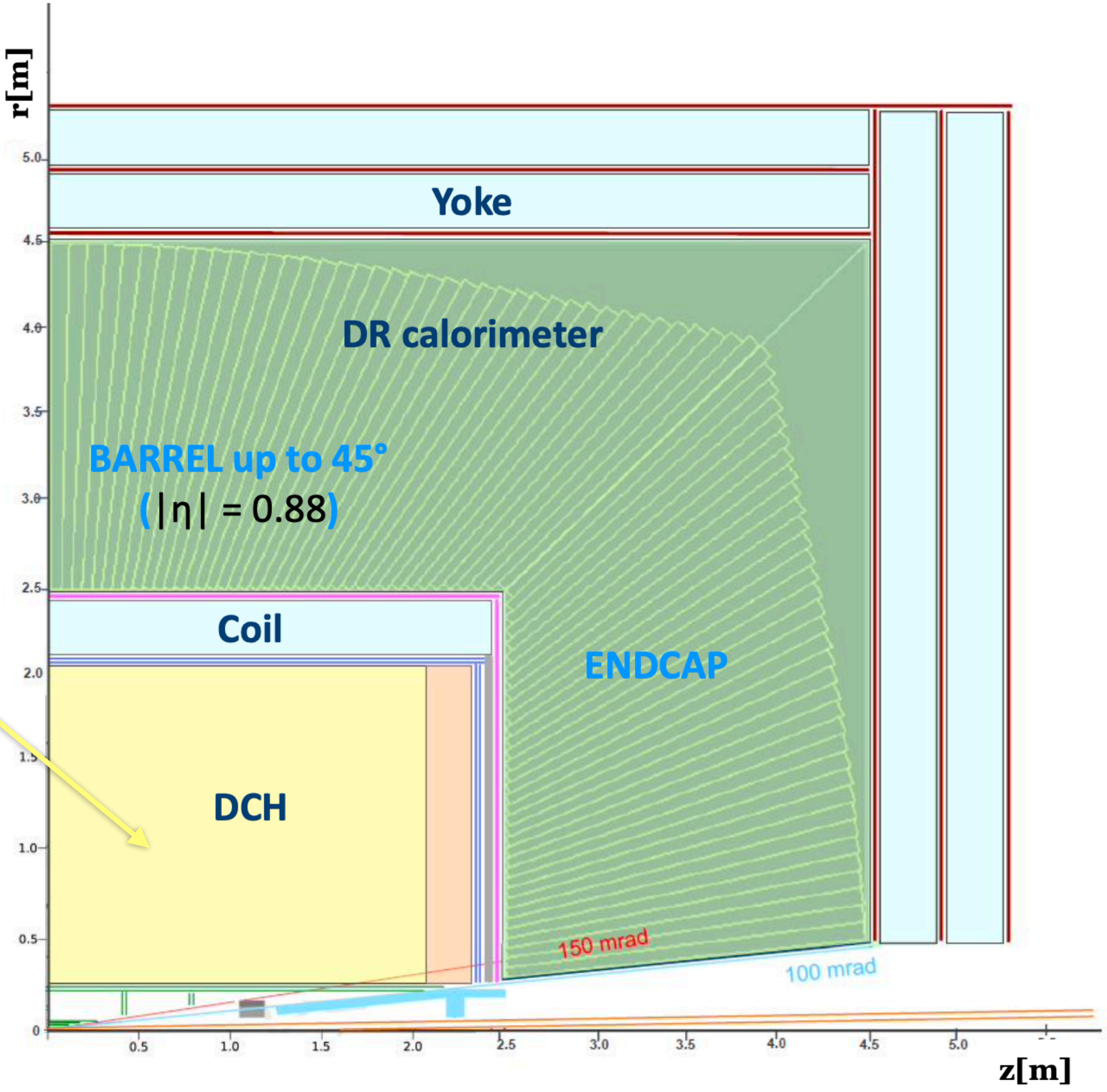
4 m long, R = 35-200 cm



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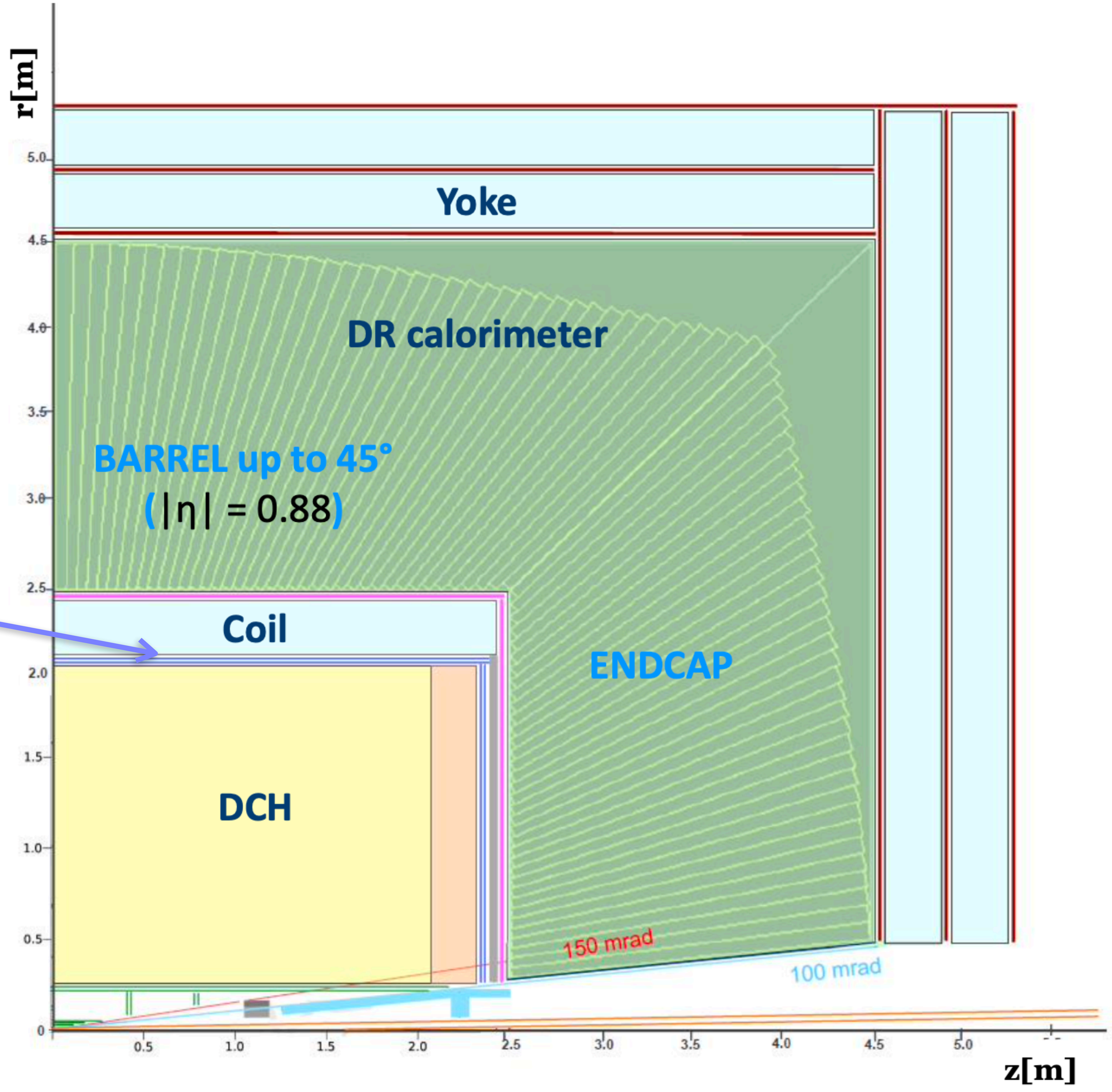
Si strips



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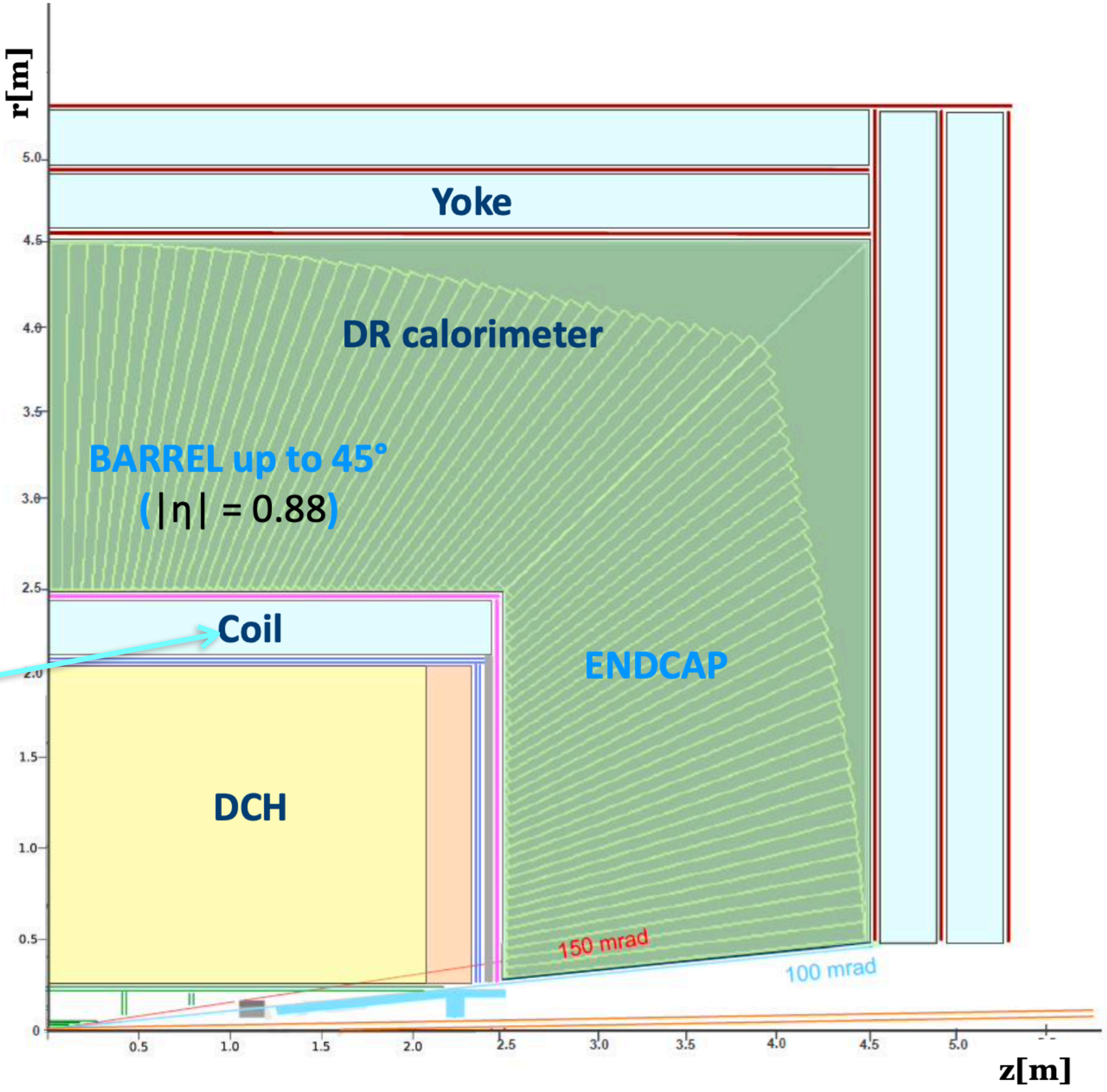
2 T, R ~ 2.1-2.4 m

0.74 X_0, 0.16 λ @ 90°



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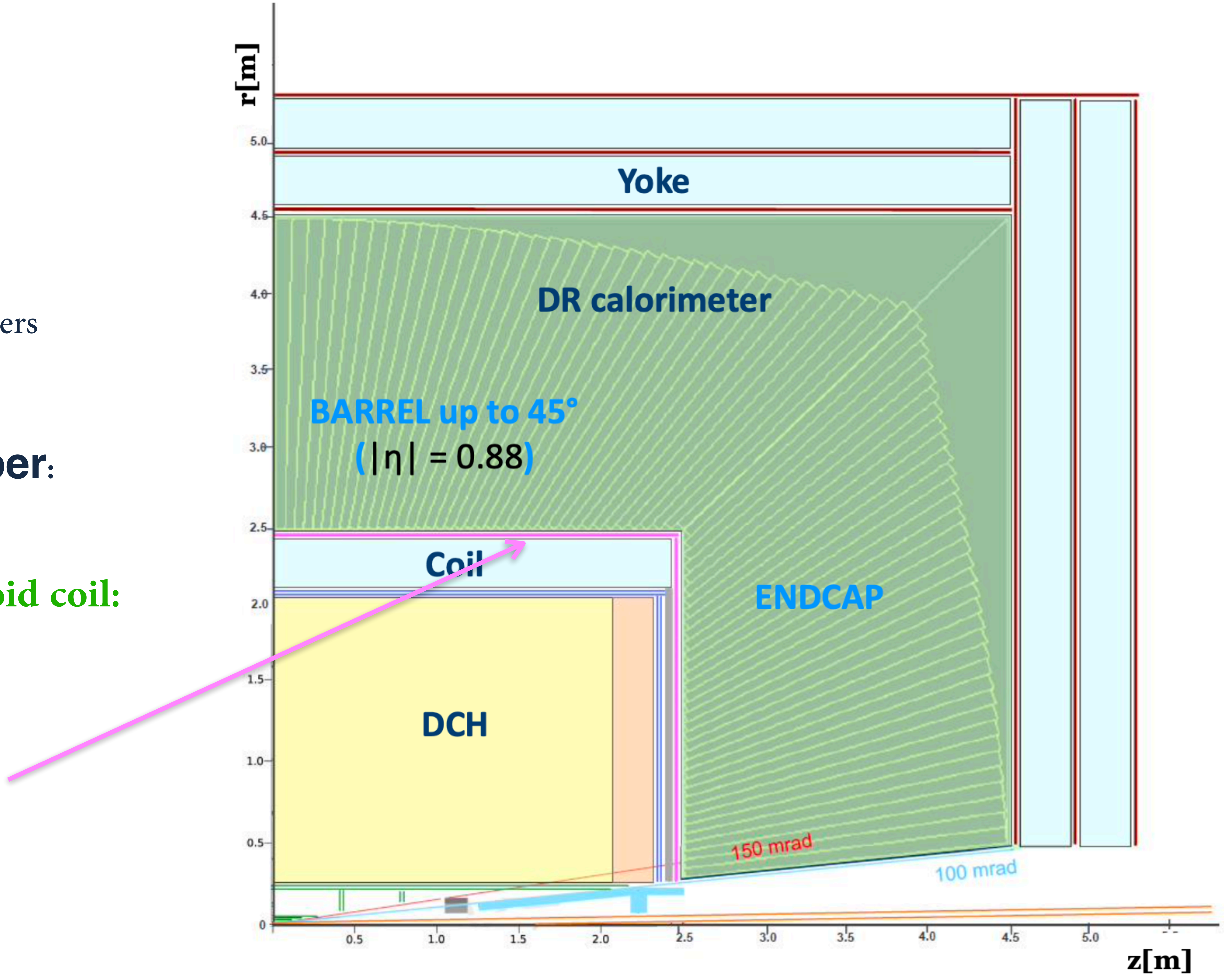

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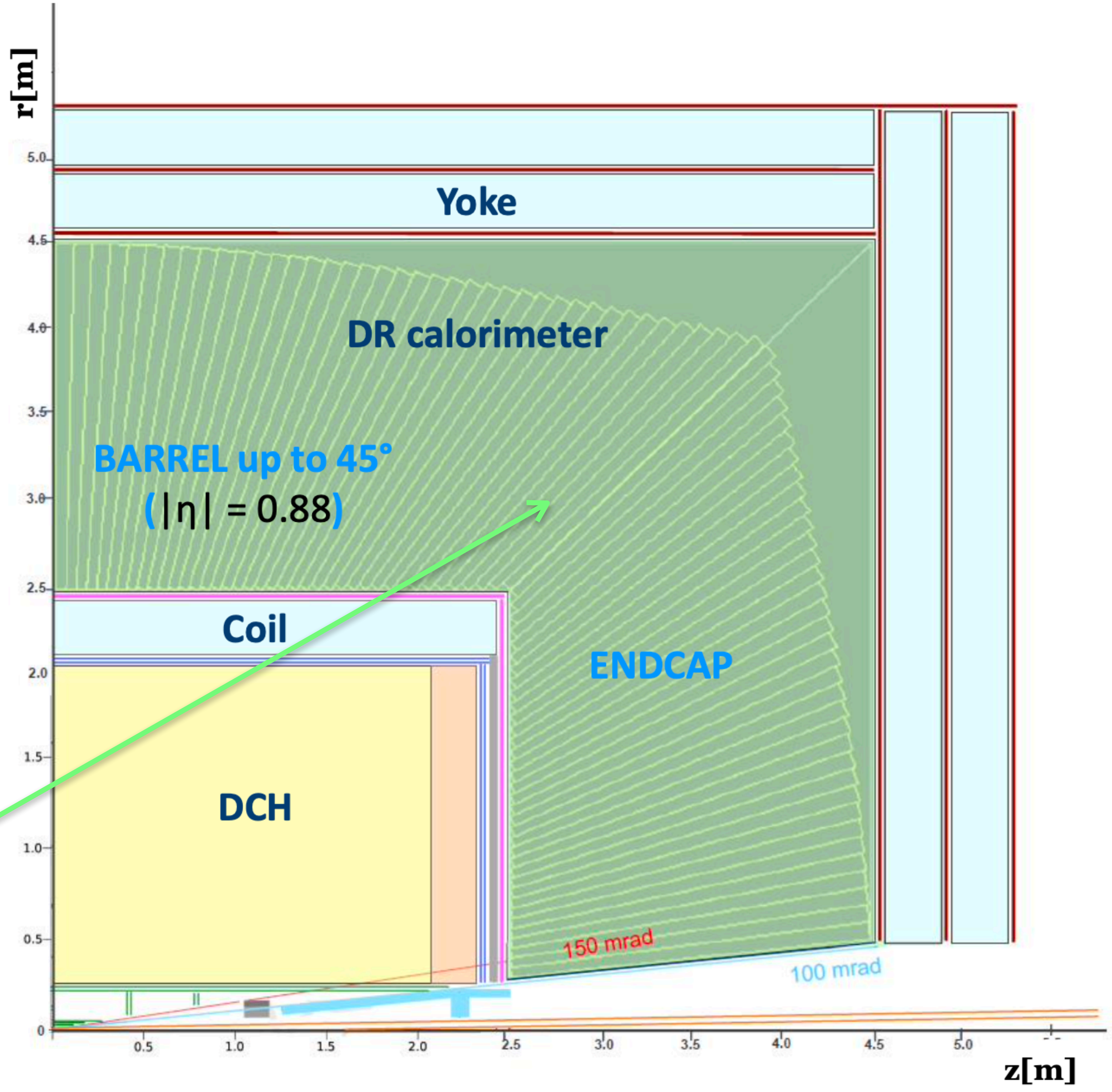
2m / 7 λ_{int}



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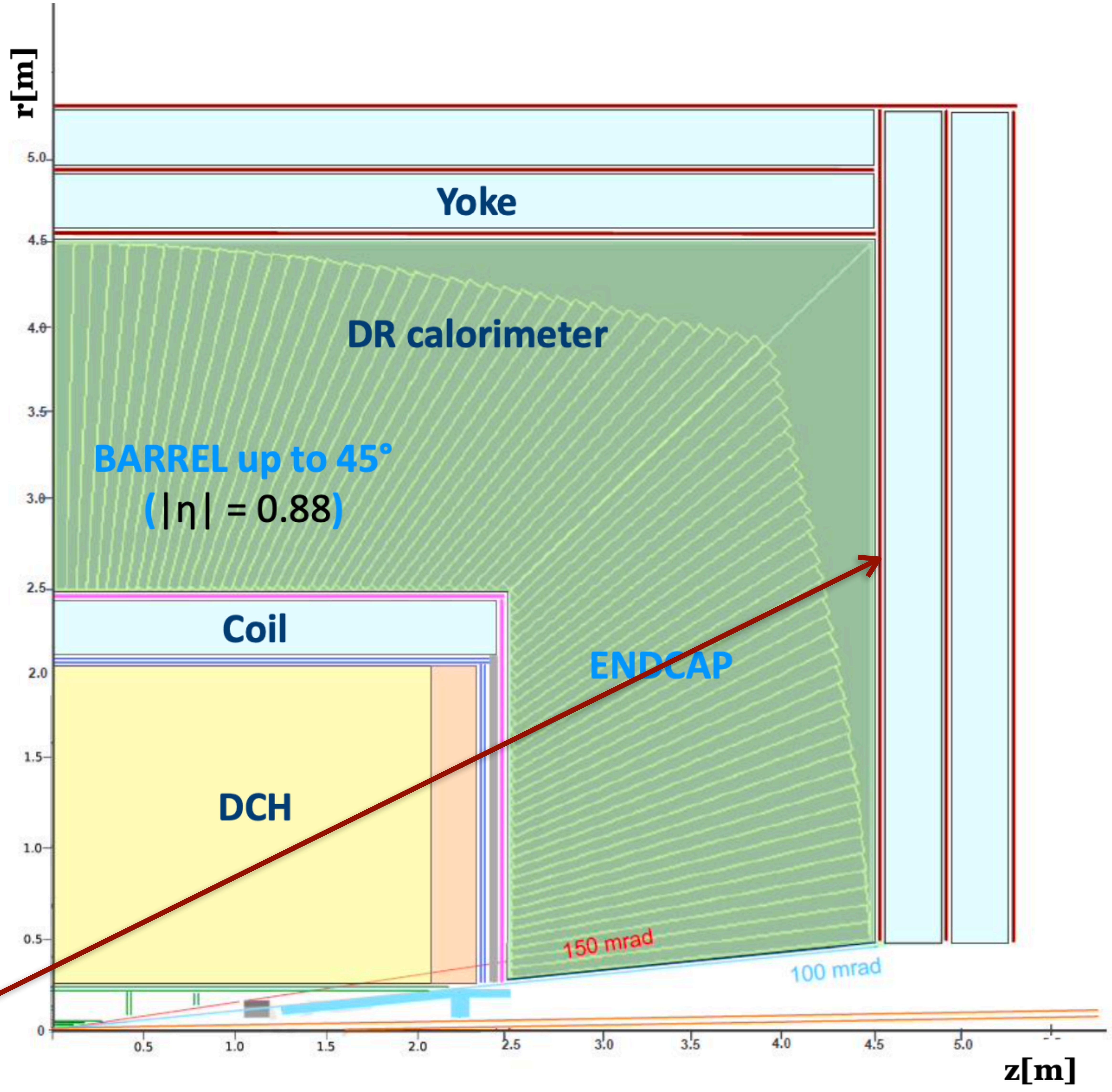
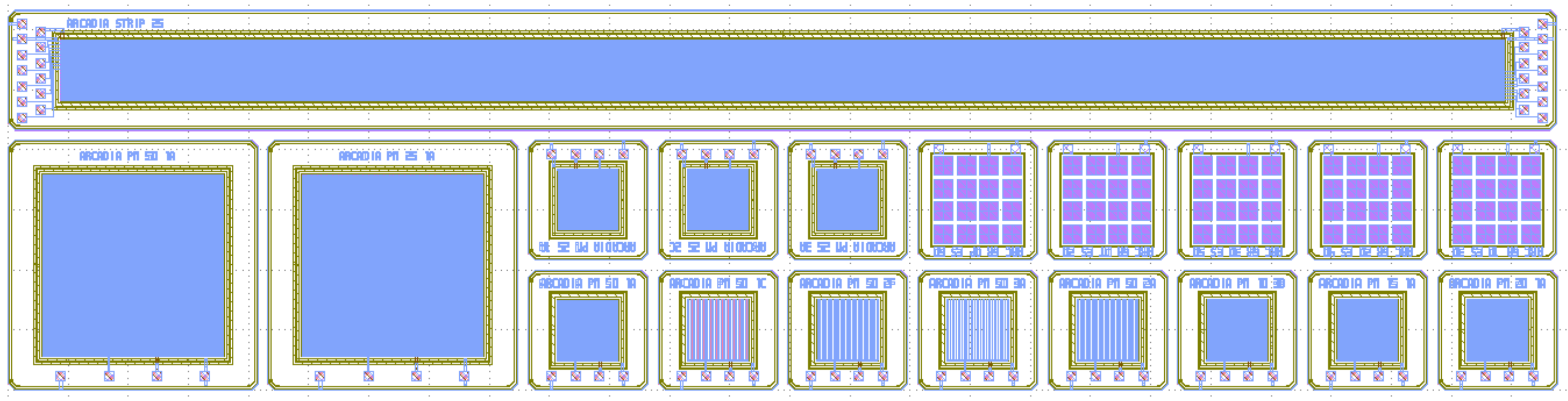
Yoke + Muon chambers

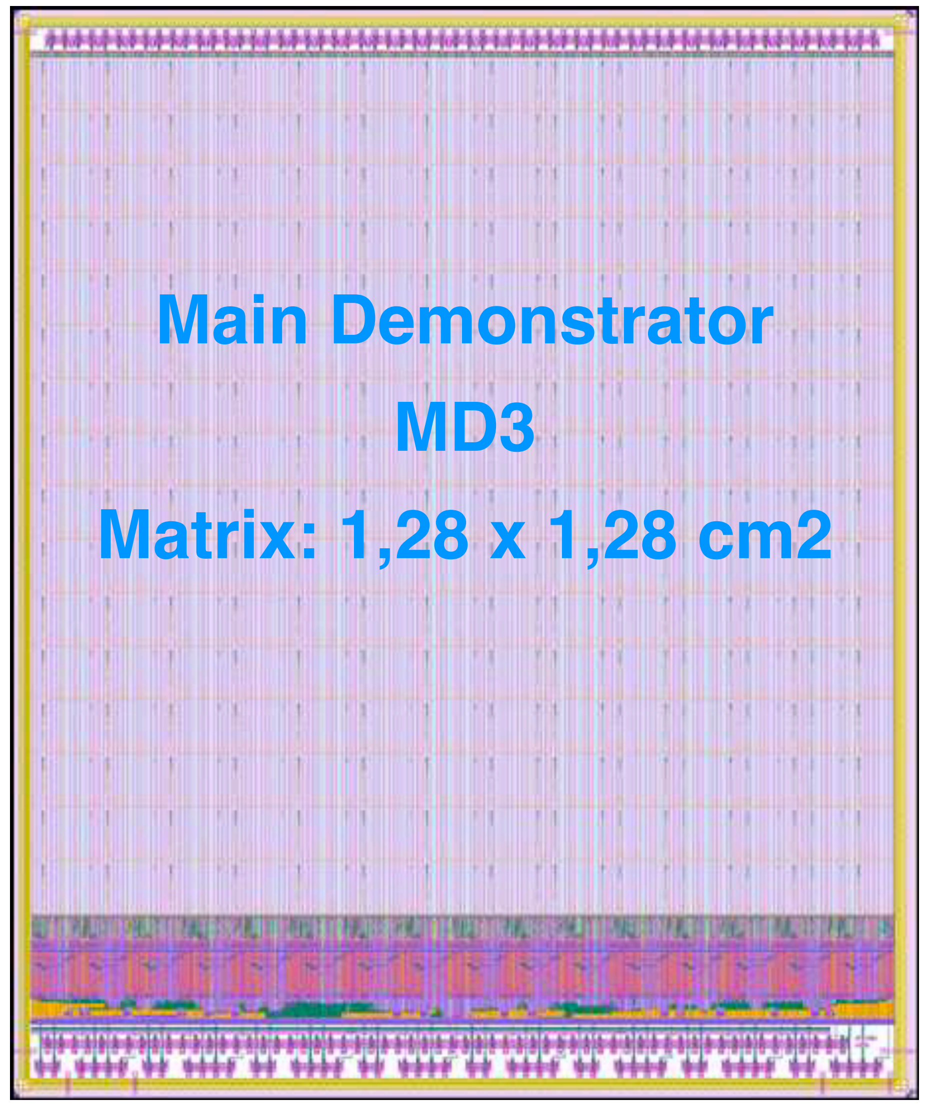


Vertex detector: IDEA

Inspired by ALICE ITS based on MAPS technology, using the ARCADIA R&D program and AtlasPix3

- Pixels 25 × 25 μm^2 (with developments to even smaller pixels)





- 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

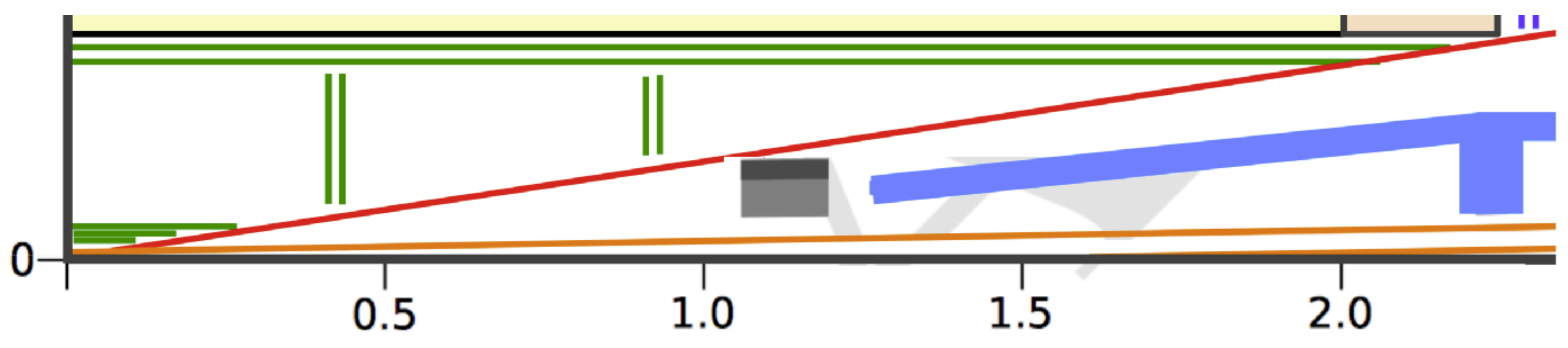
5 MAPS layers:

R = 1.2 - 2.3 - 3.1 cm

Pixel size: 20 x 20 μm^2

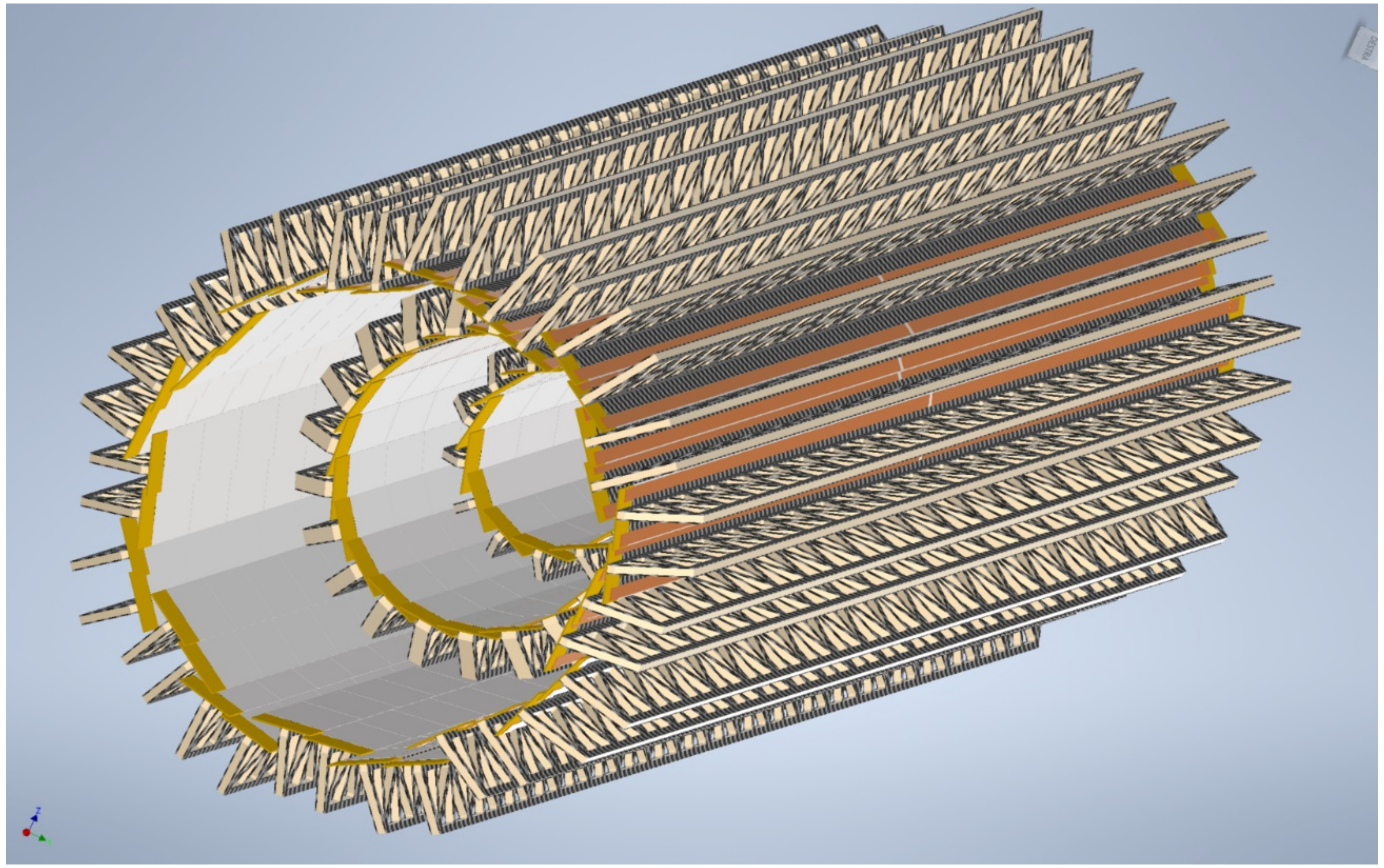
R = 32 - 34 cm

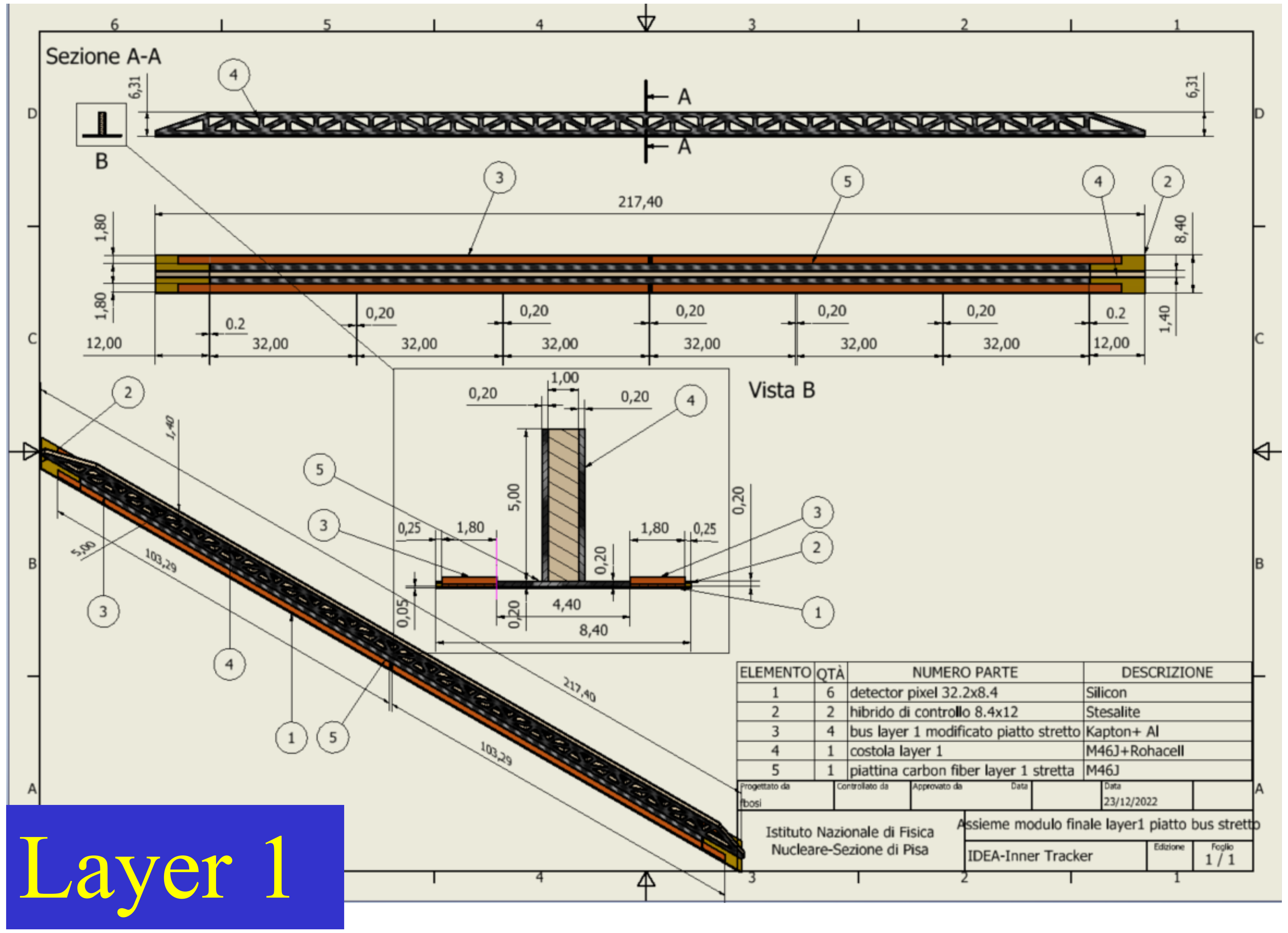
Pixel size: 50 x 100 μm^2

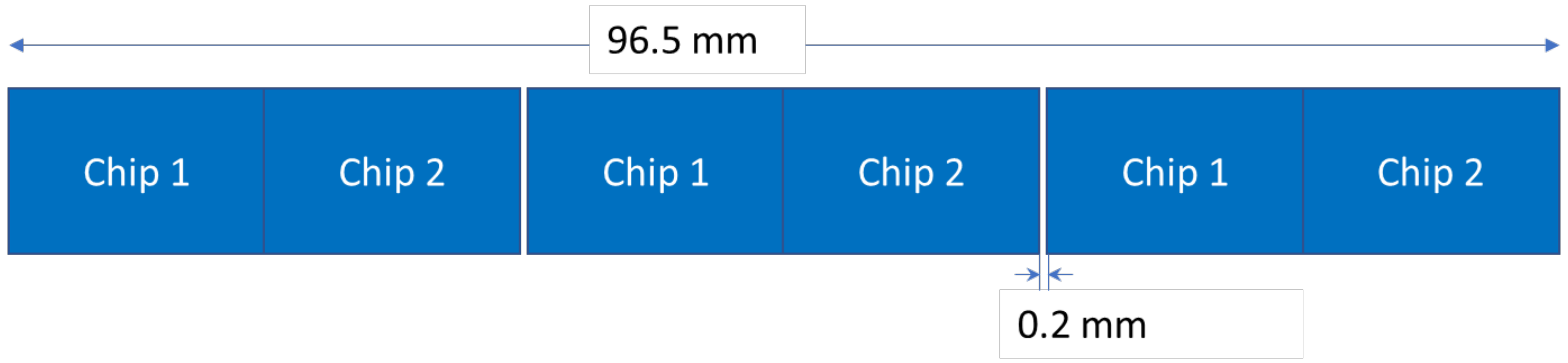


Mechanical integration

- Vertex design based on:
  - ARCADIA inner 3 layers
    - Air cooled







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  - AtlasPix3 outer 2 layers/disks
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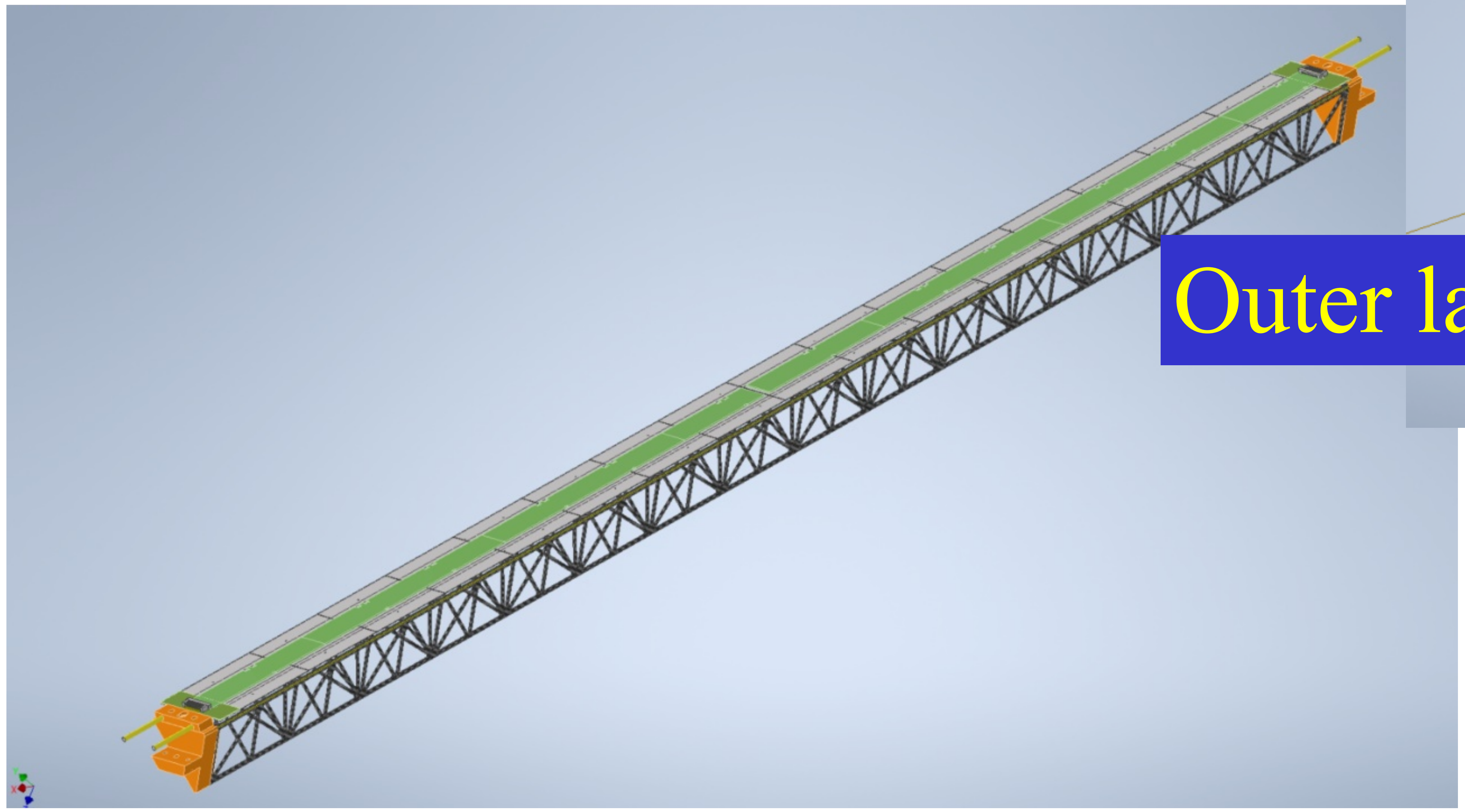

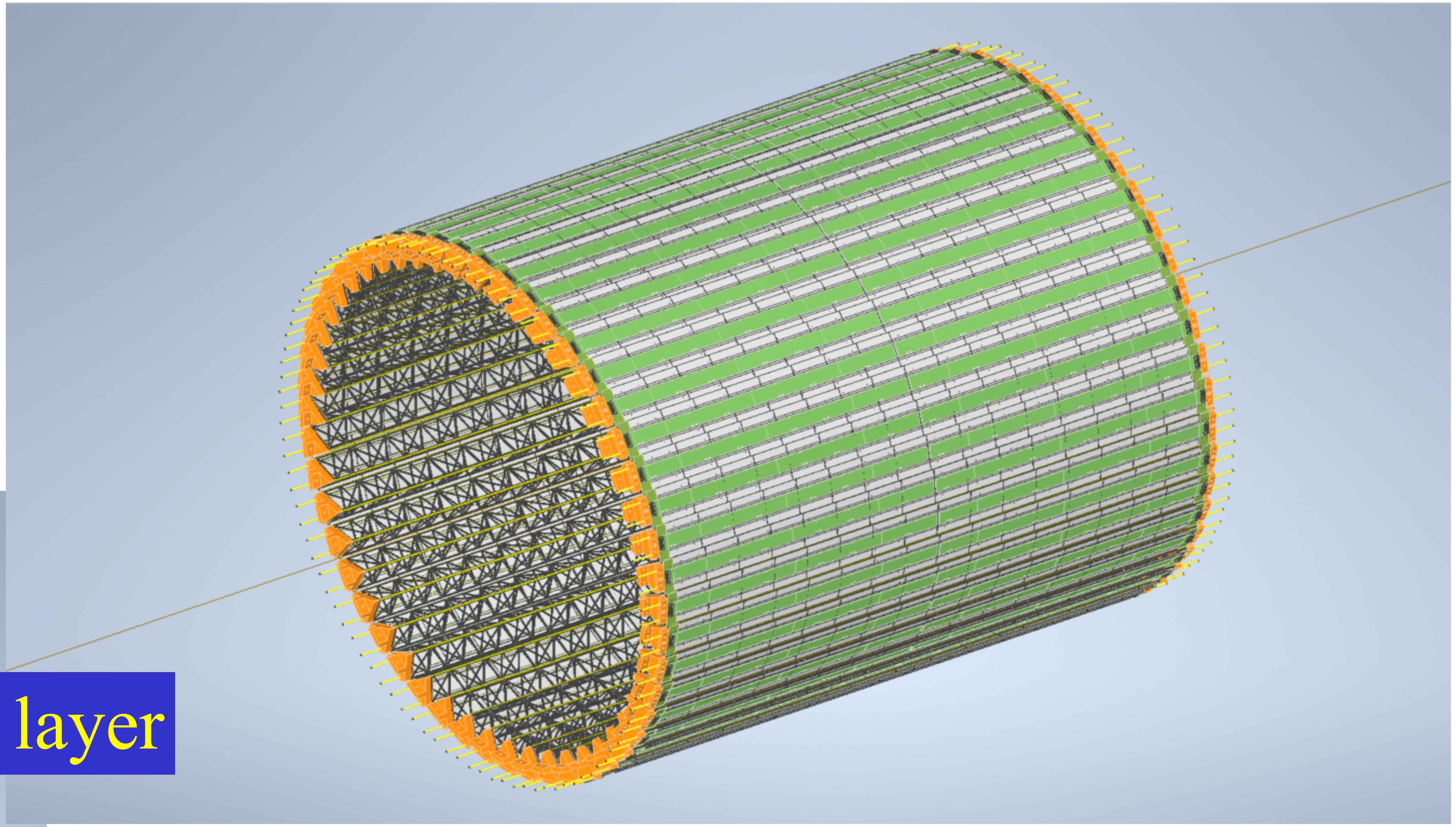

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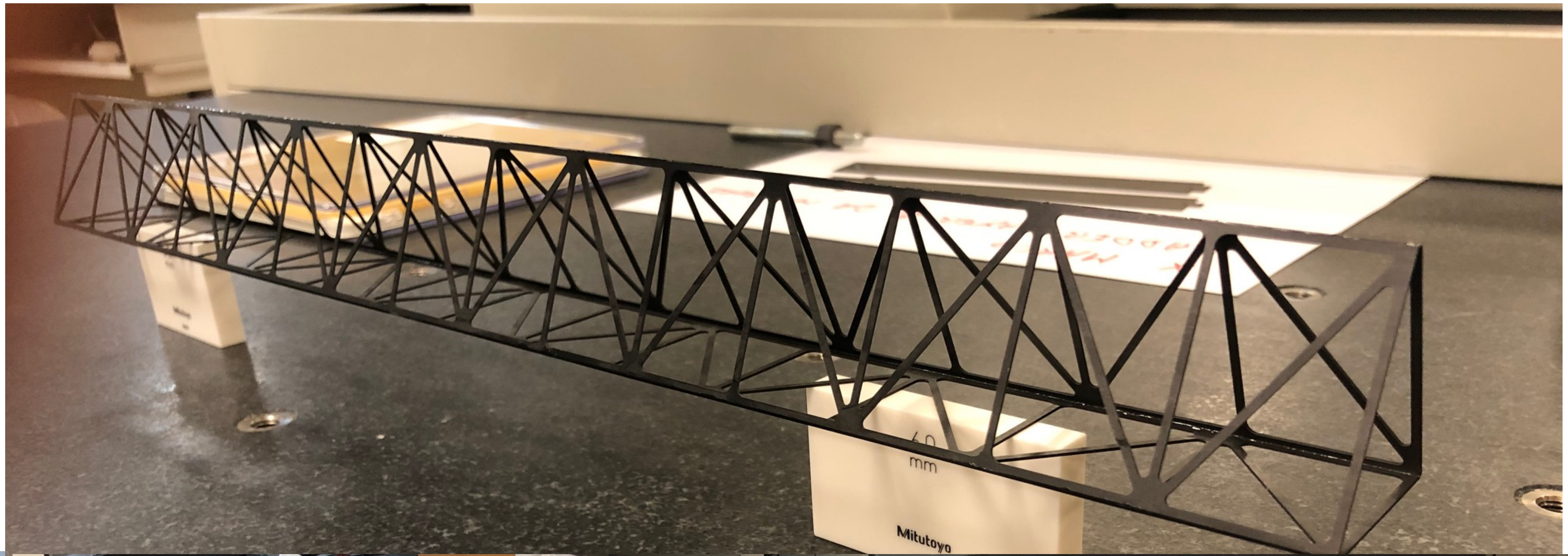
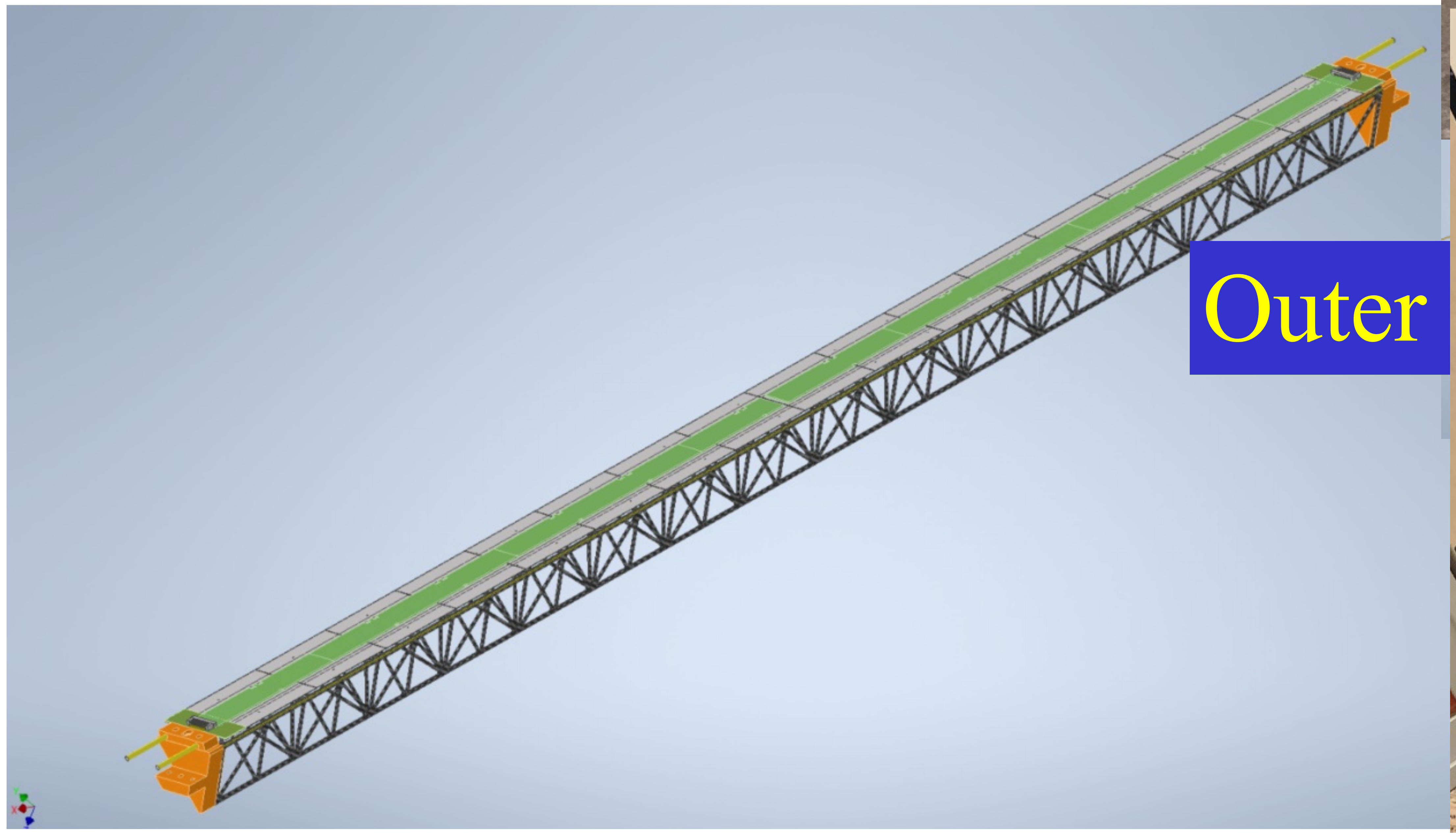
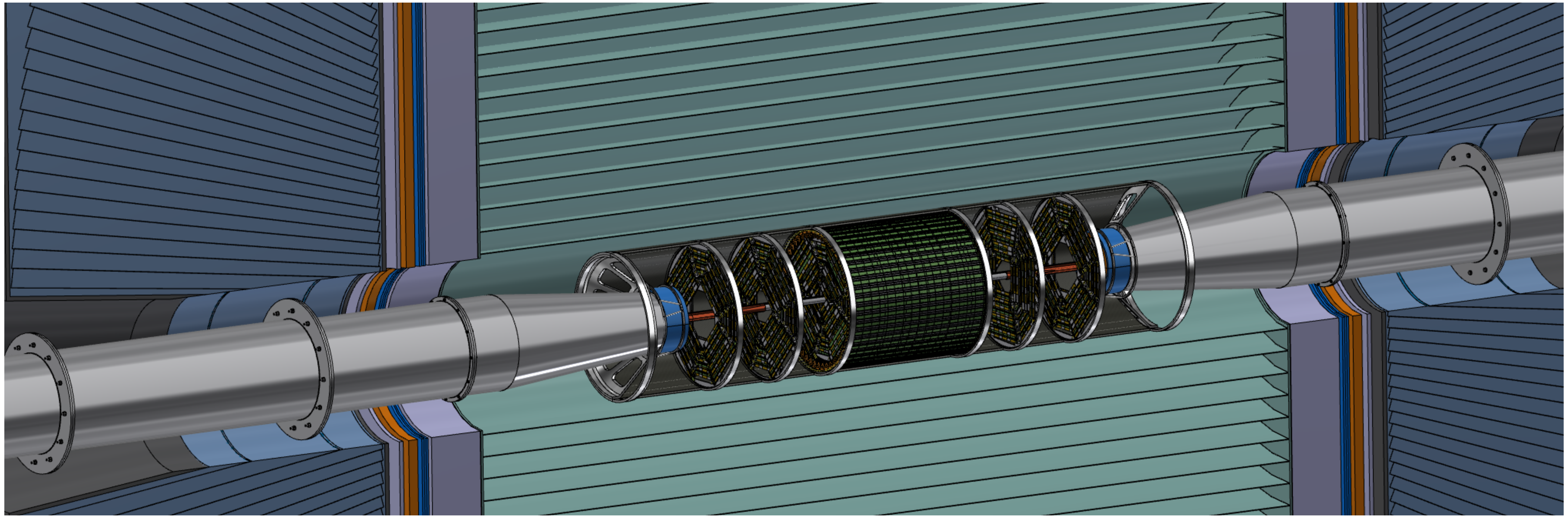




IDEA: integration of vertex detector

Inner and outer vertex trackers



See talk by F. Fransesini for the interaction region layout

Inside the same volume of the support tube that holds also the LumiCal

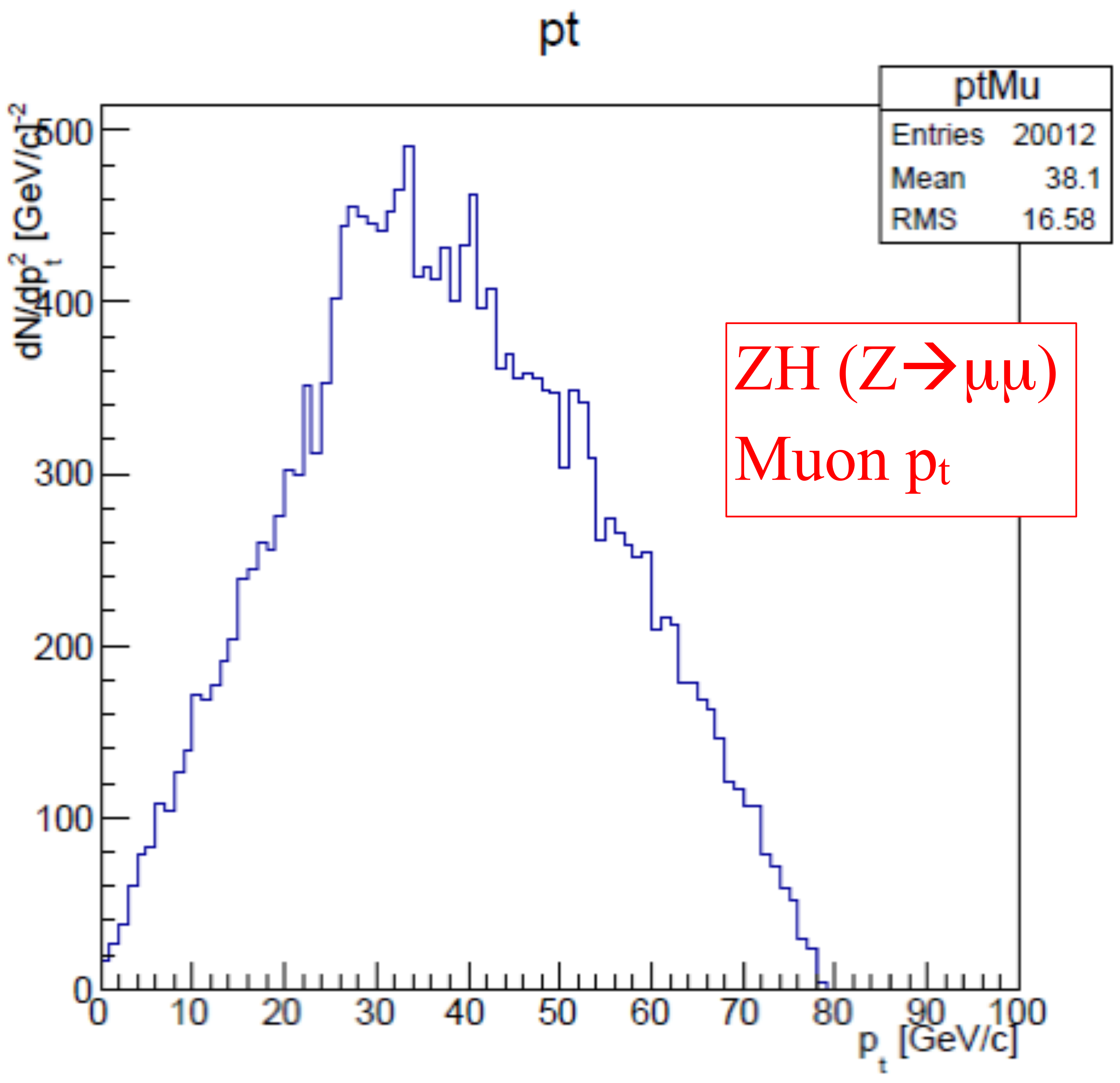
- Inner vertex detector supported by the beam pipe
- Outer vertex detector (2 barrel and 6 disks) fixed to the support tube

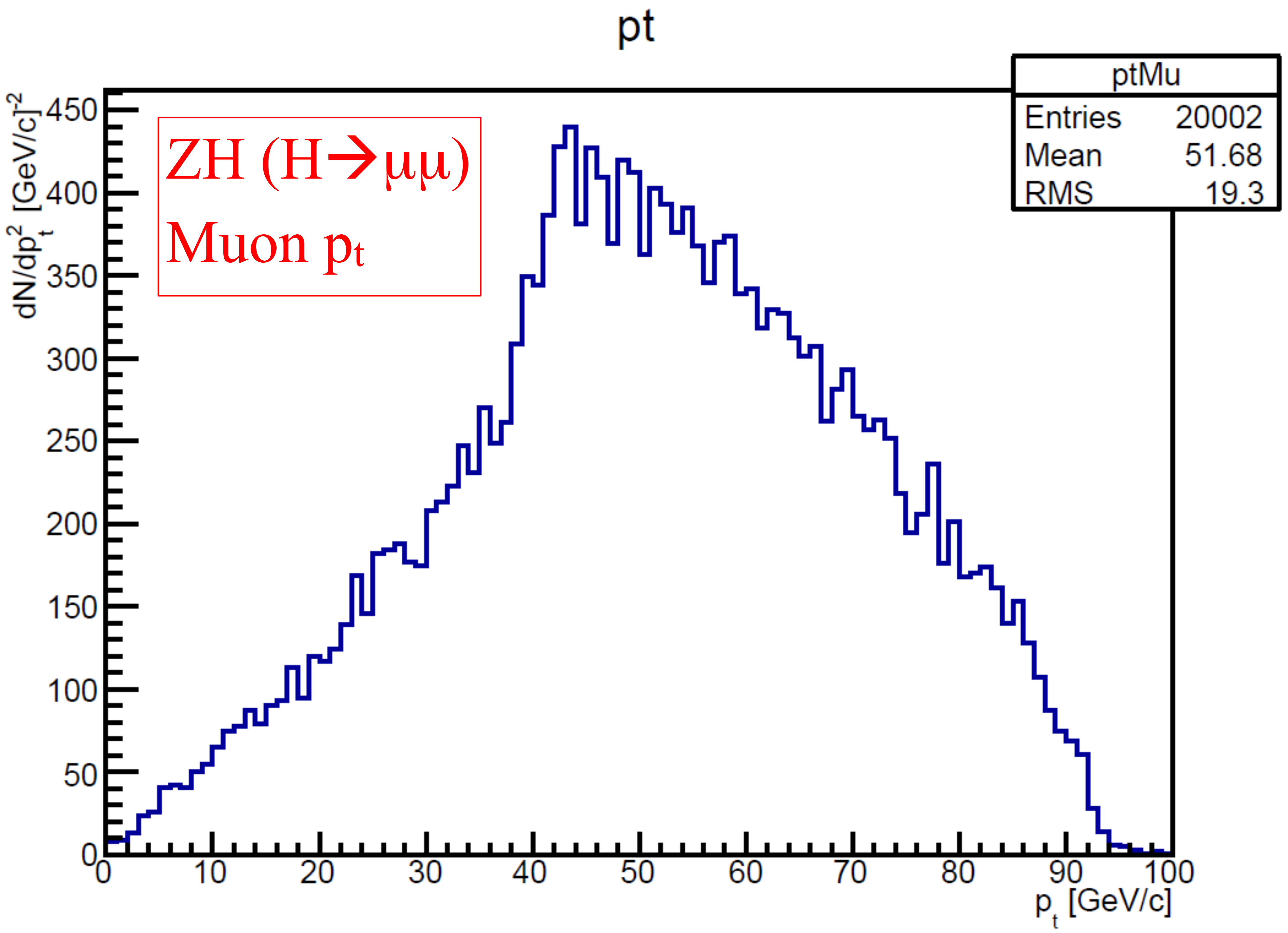
Minimal number of detector module variants

- One module type only for the Vertex
- One module type only for the Outer barrel and disks

F. Palla

Momentum measurement

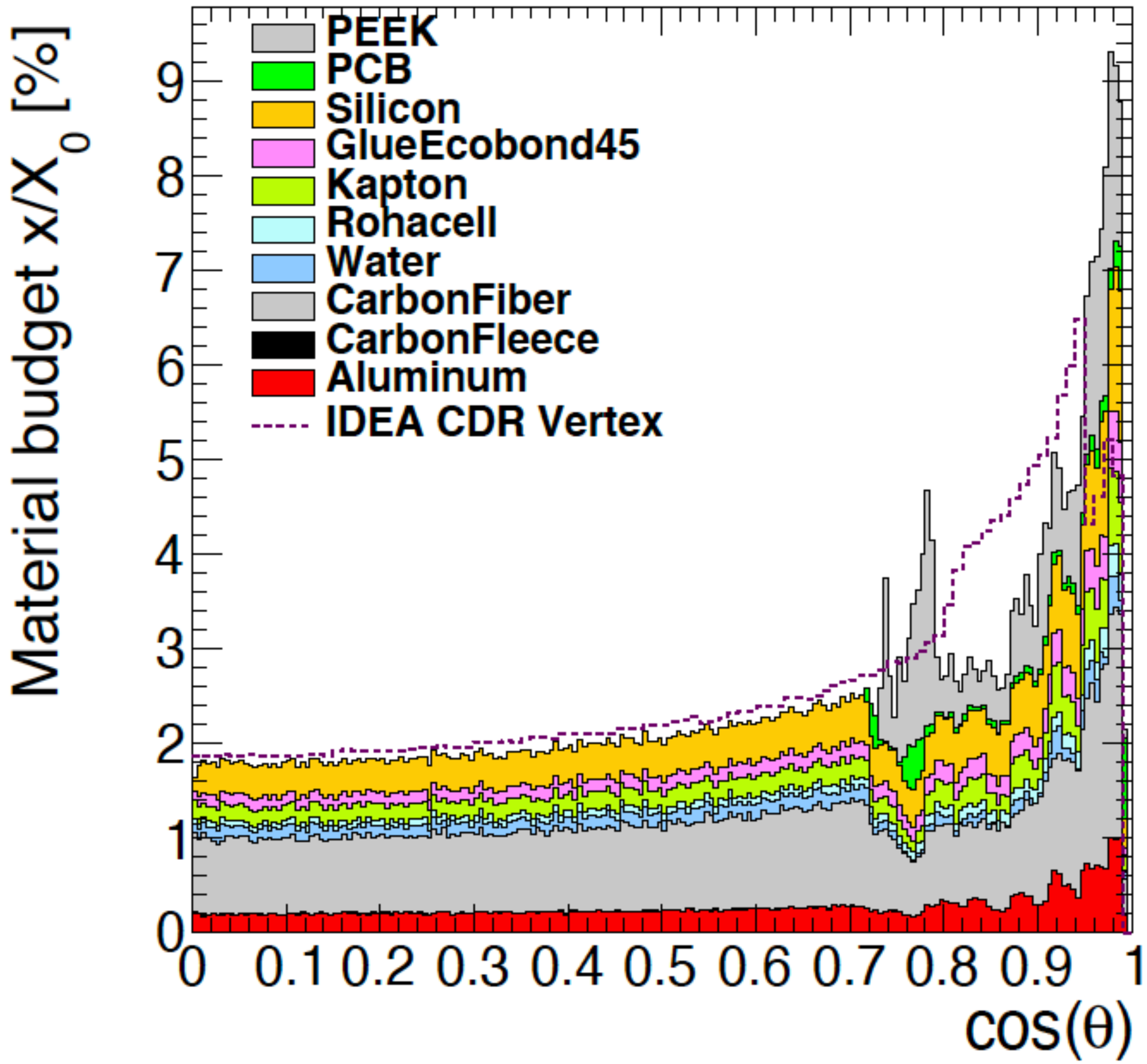


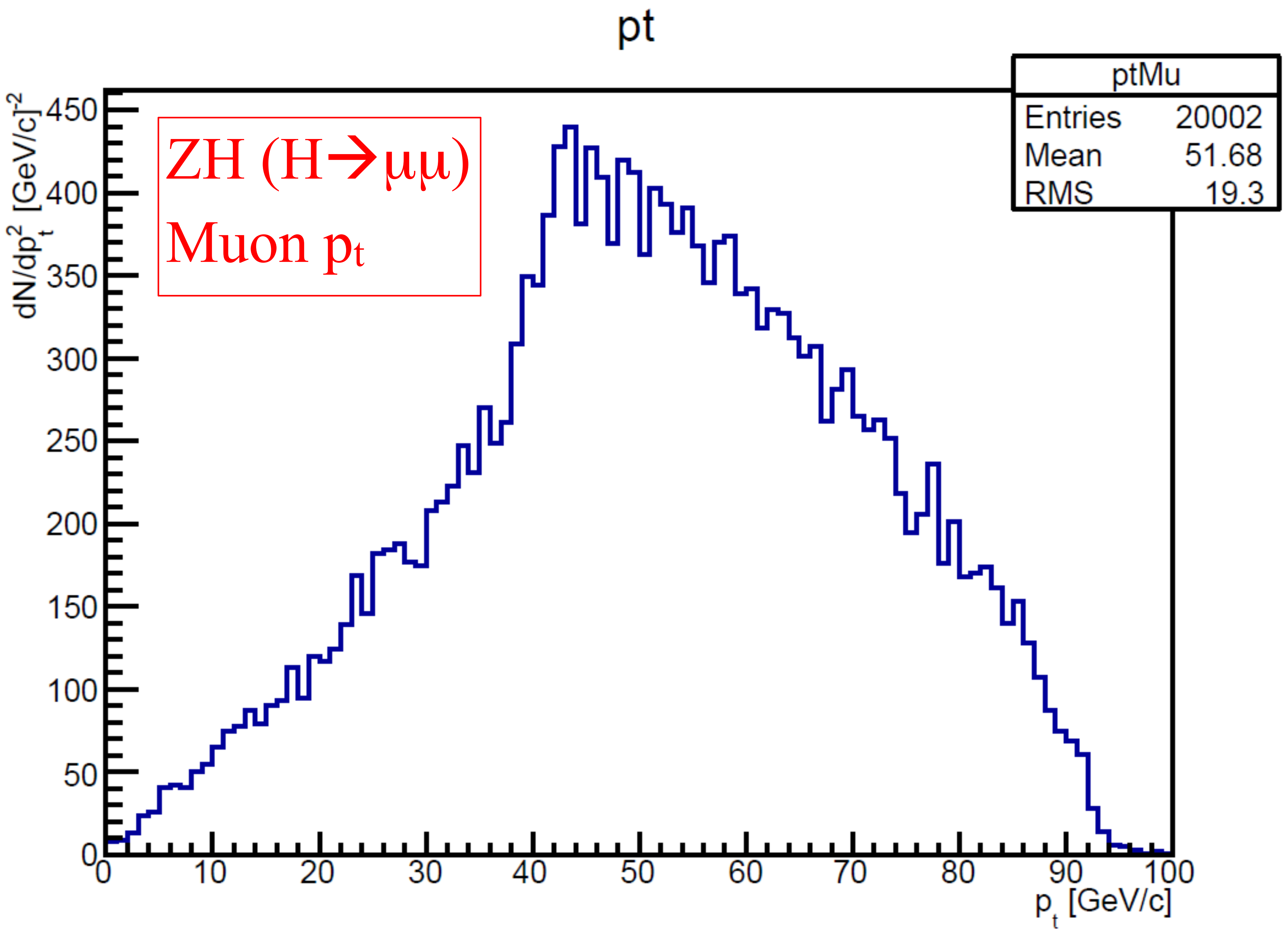


FUTURE CIRCULAR COLLIDER

Momentum measurement

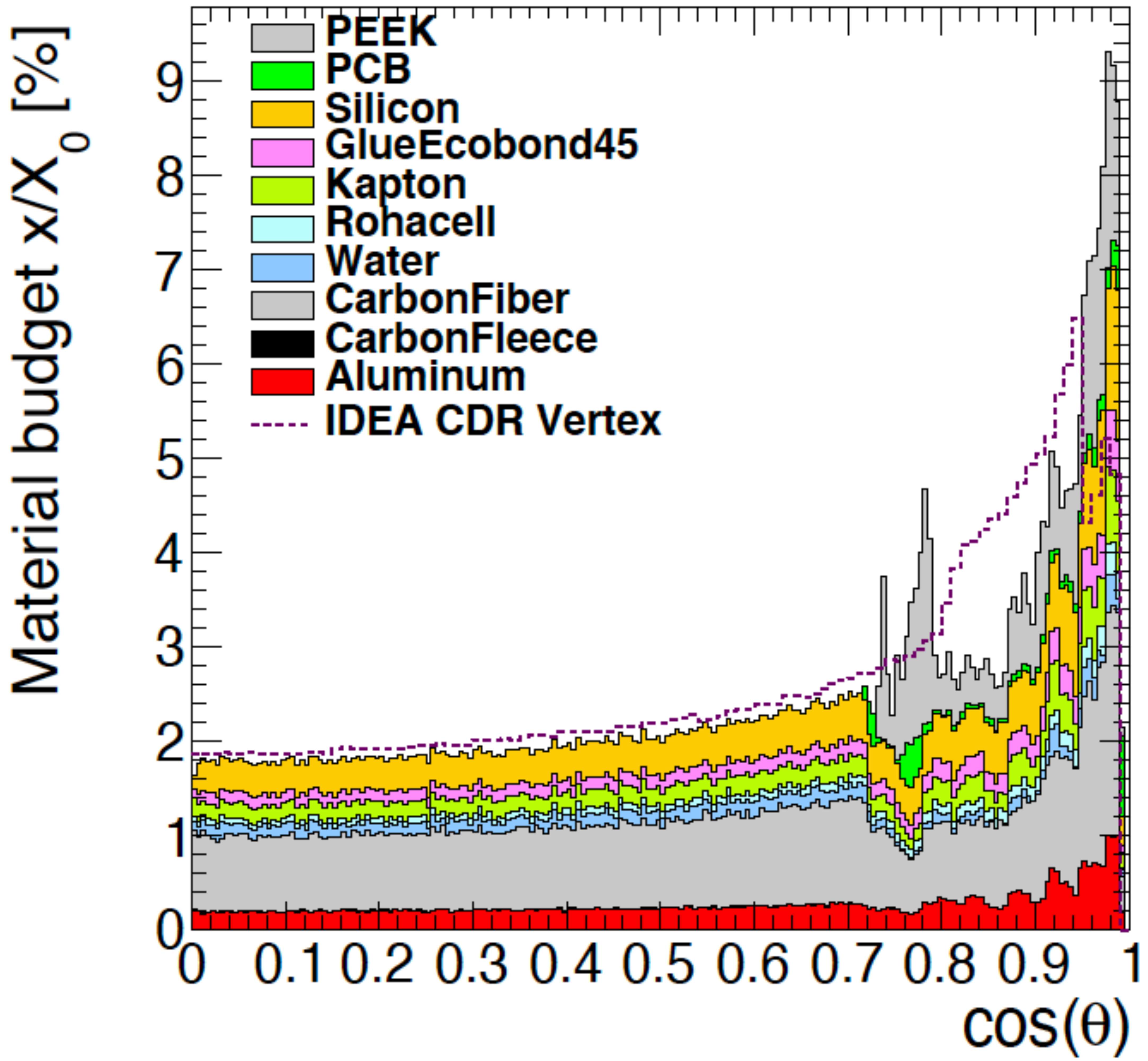
INFN Istituto Nazionale di Fisica Nucleare

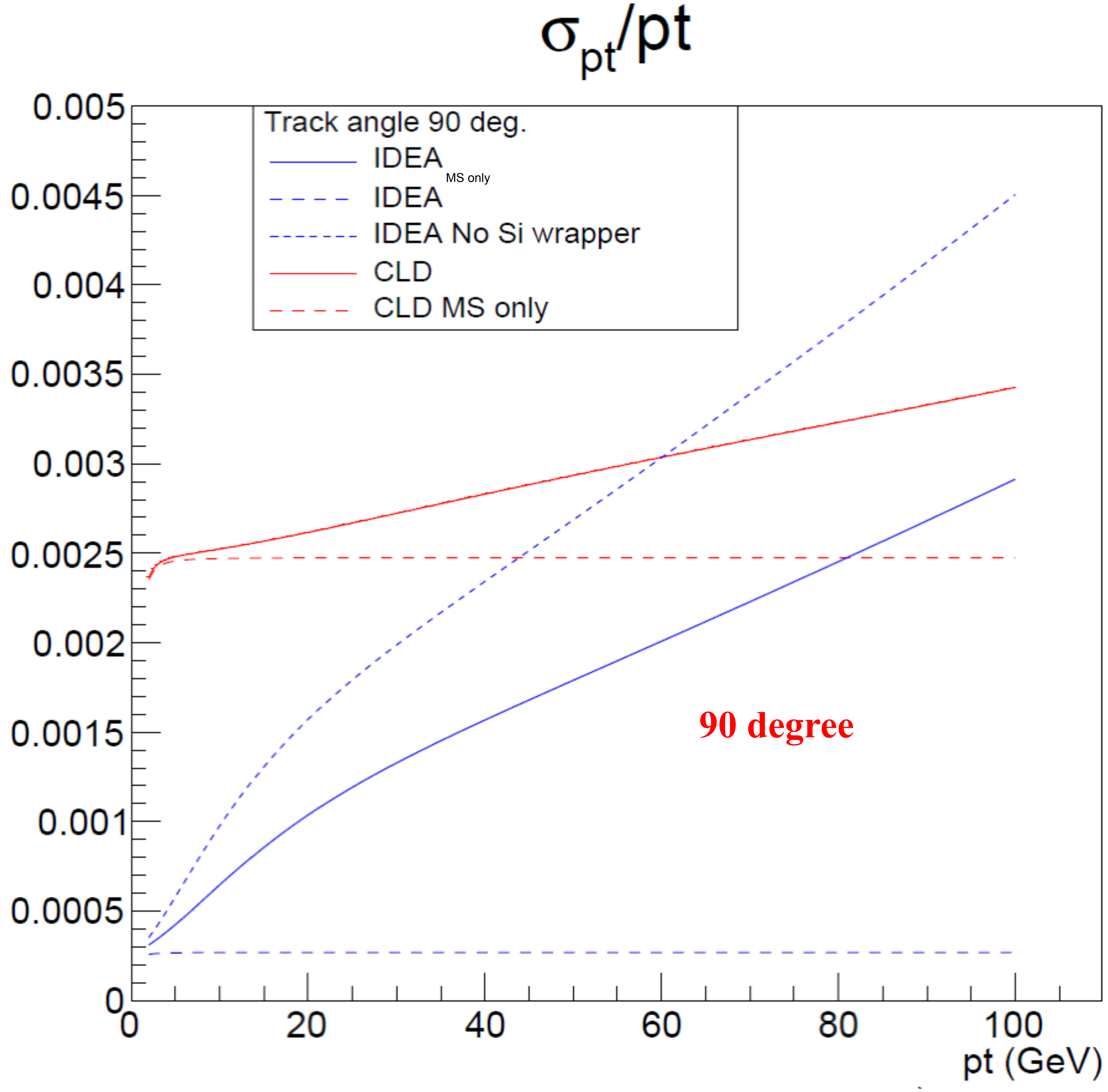




Momentum measurement

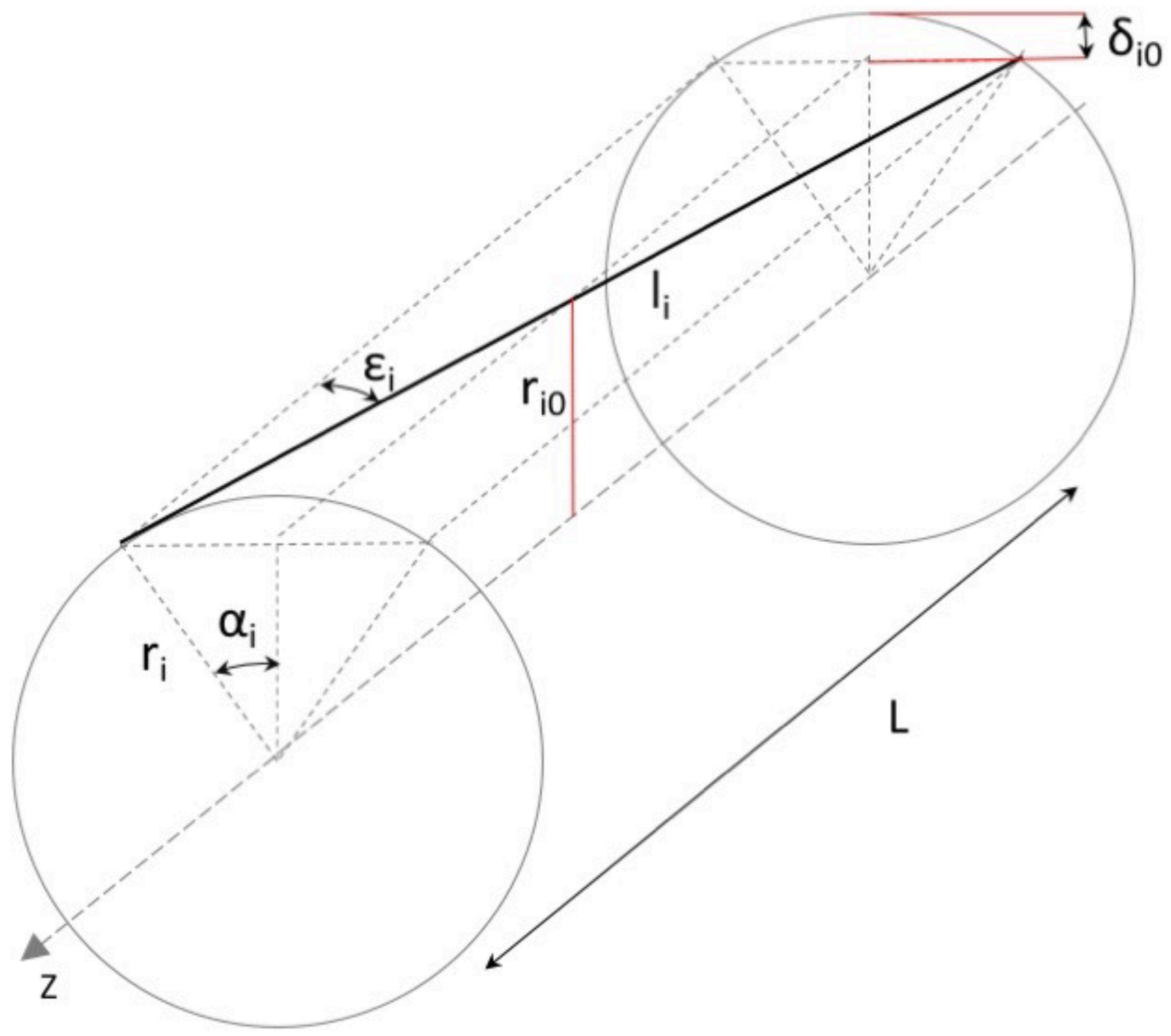
- ✦ Z or H decay muons in ZH events have rather low p_t
  - ❖ Transparency more important than asymptotic resolution

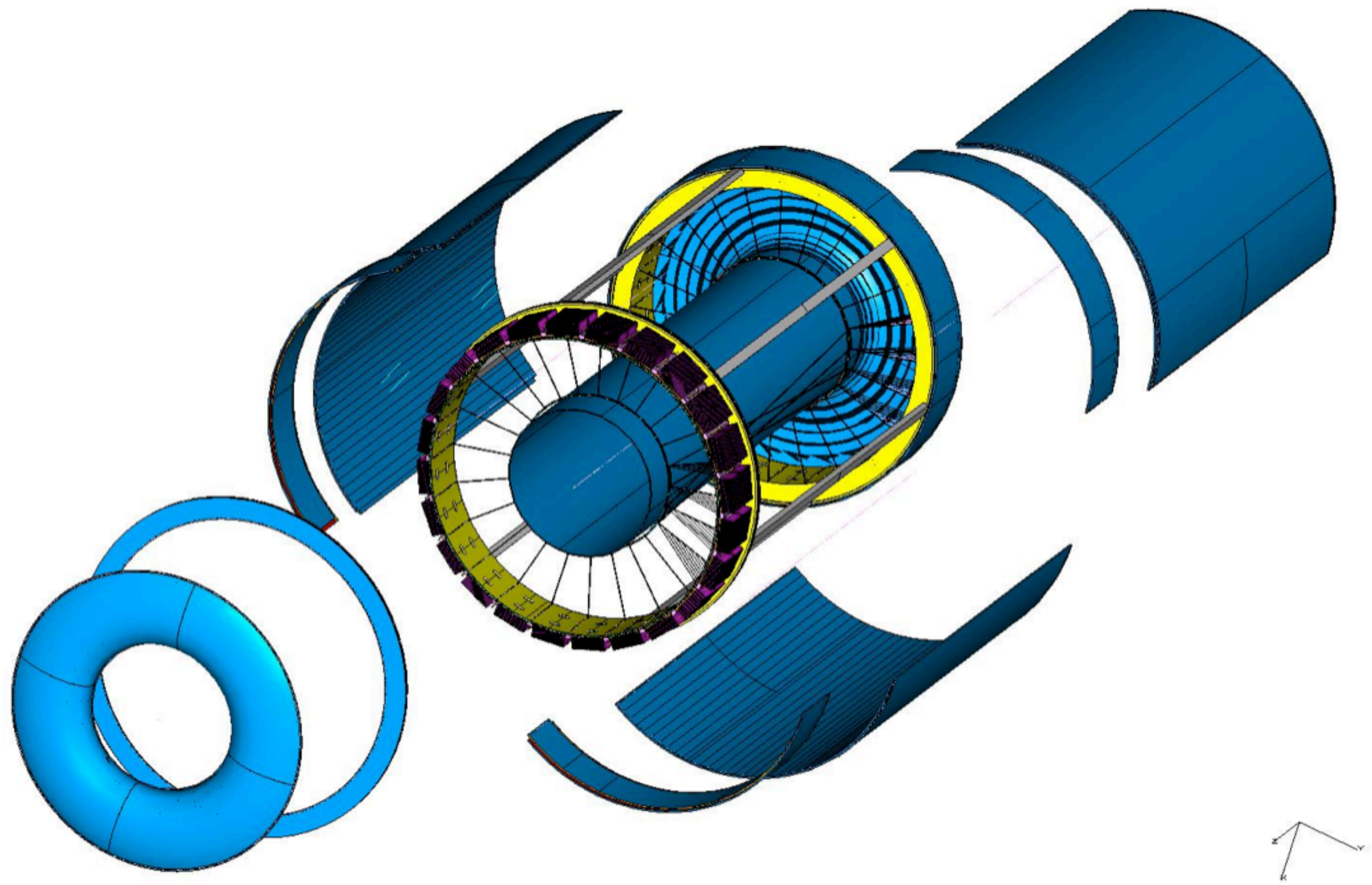


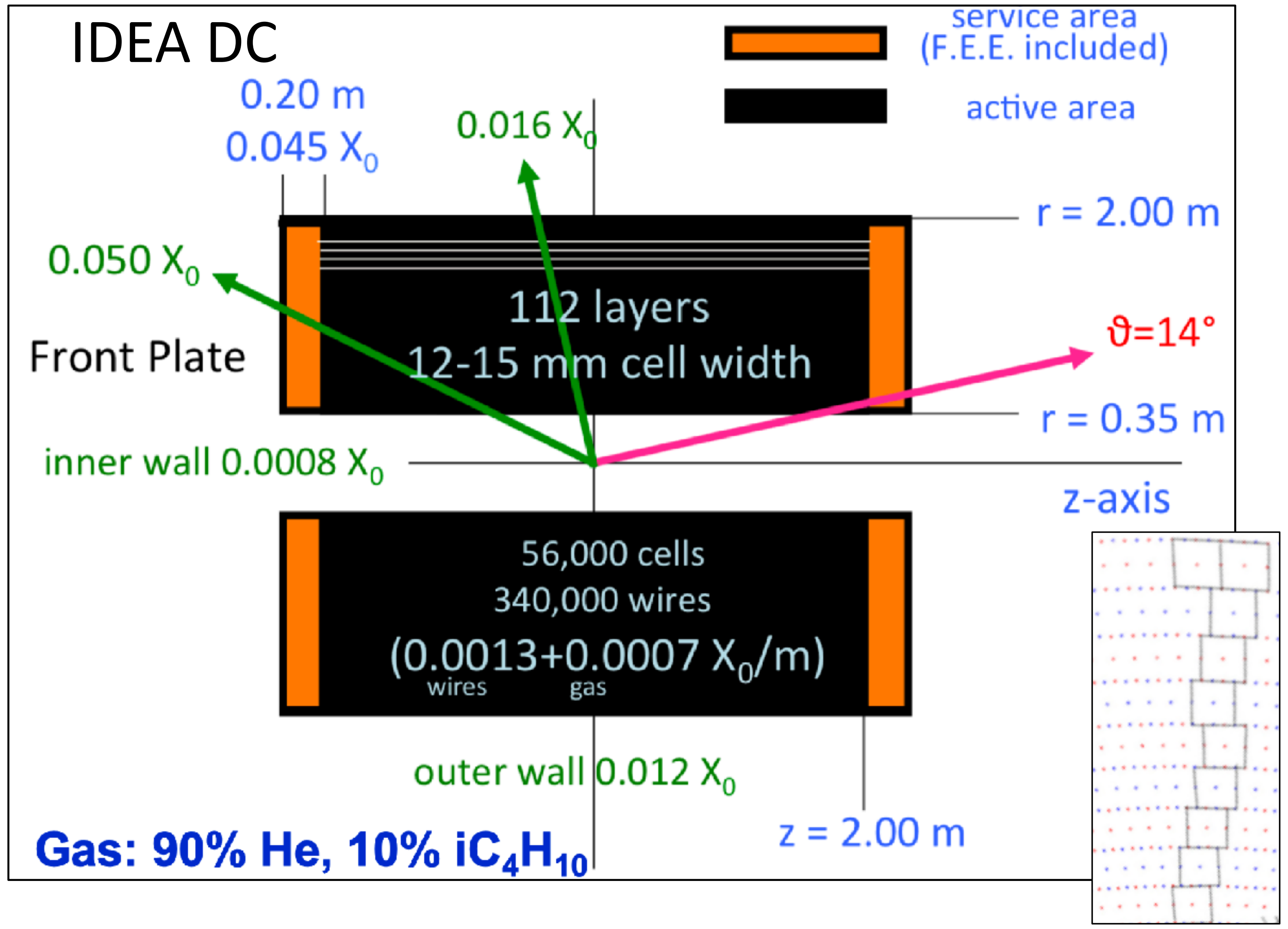


Drift chamber

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

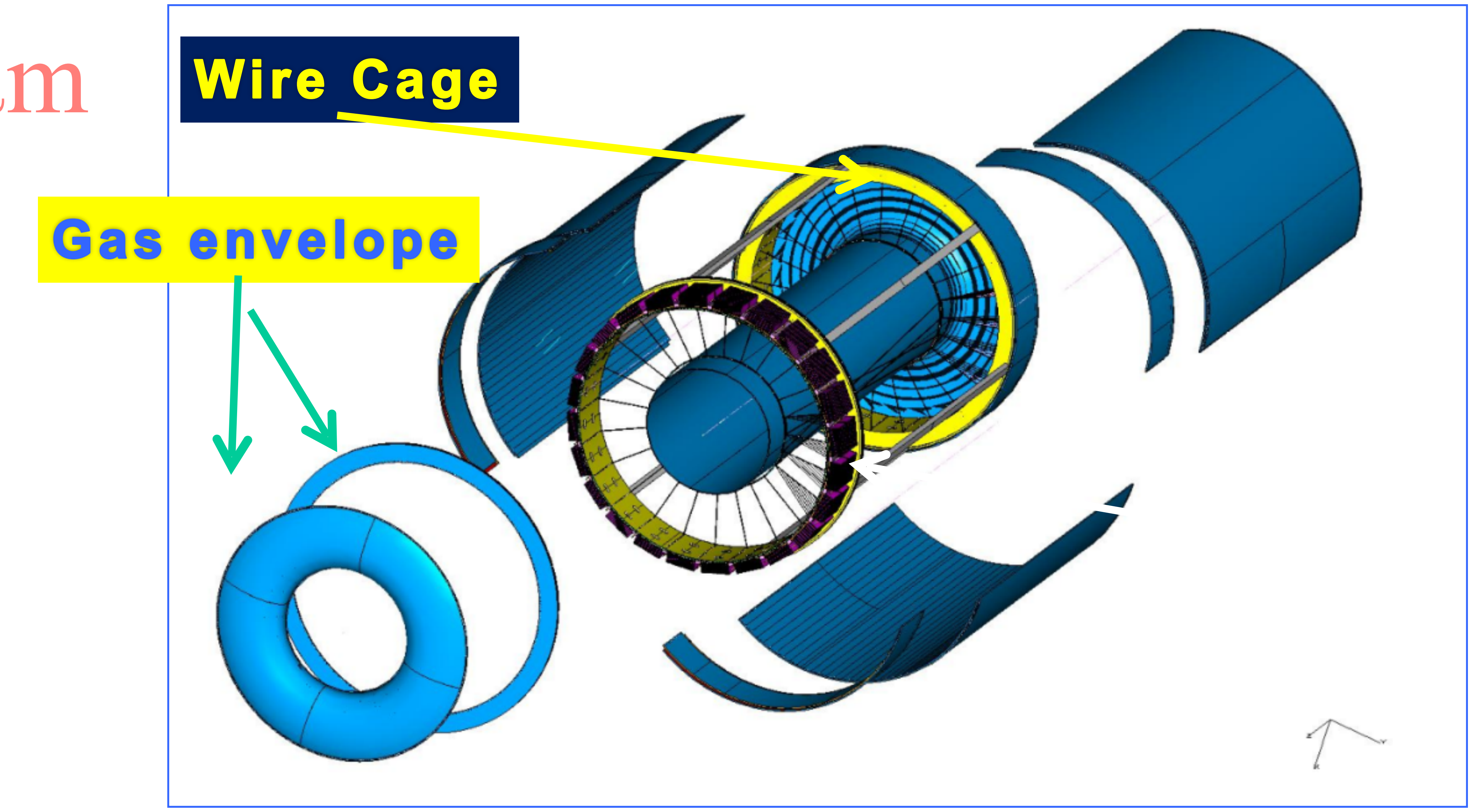


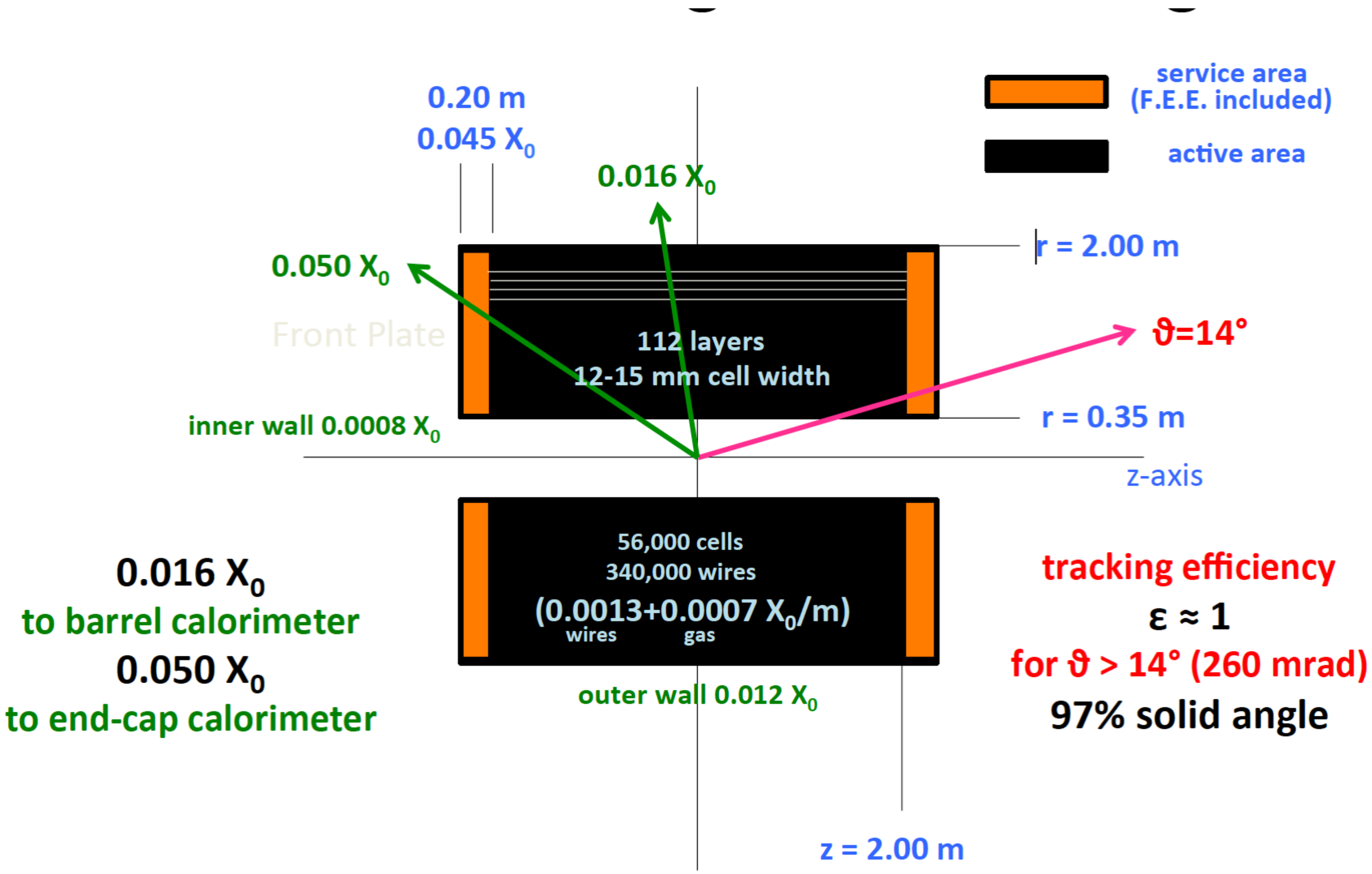


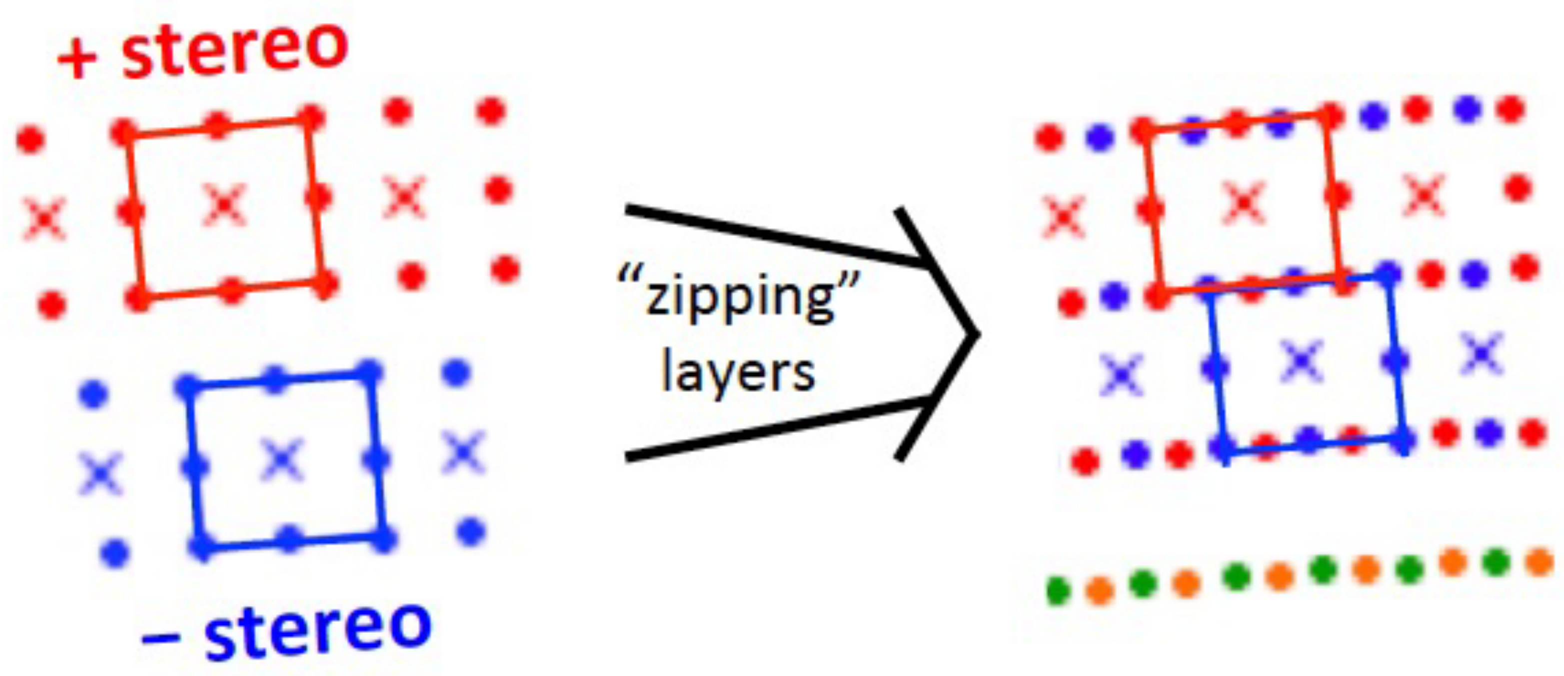


Drift chamber

- 90% He/ 10% C_4H_{10} – All stereo – $\sigma \sim 100\ \mu m$
- Small cells, max drift time ~ 400 ns







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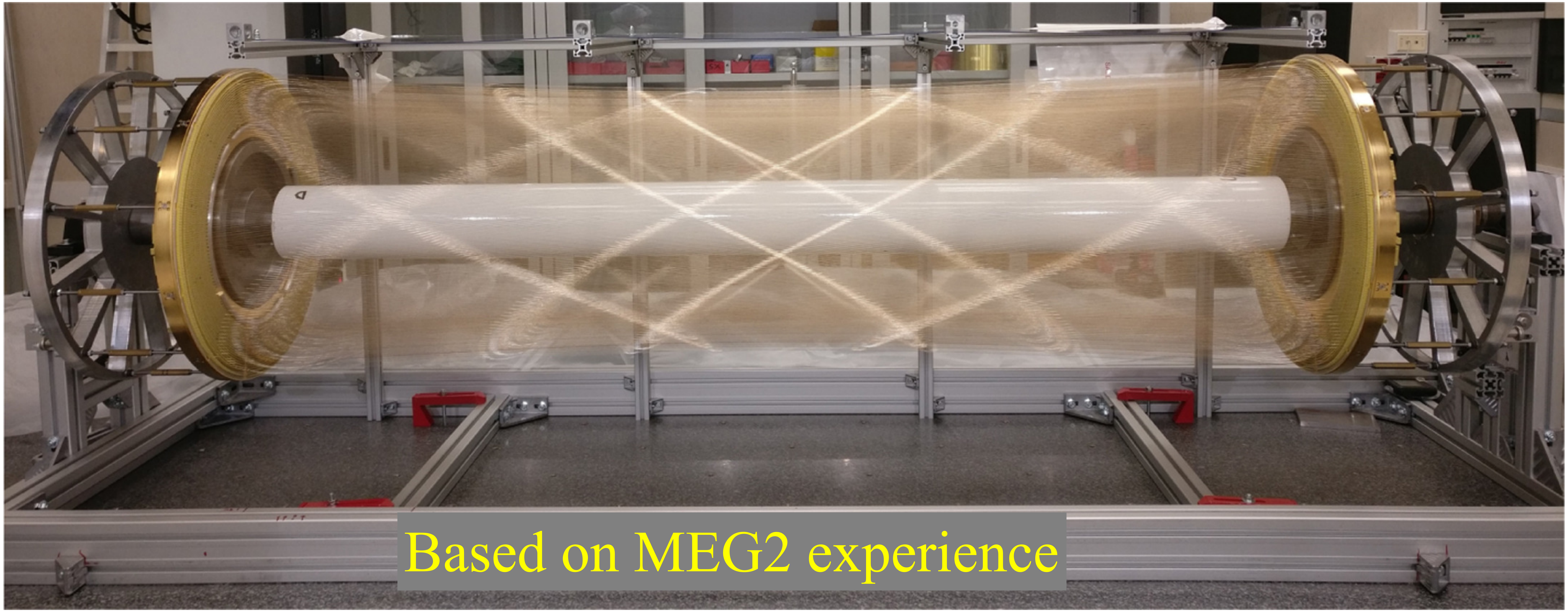
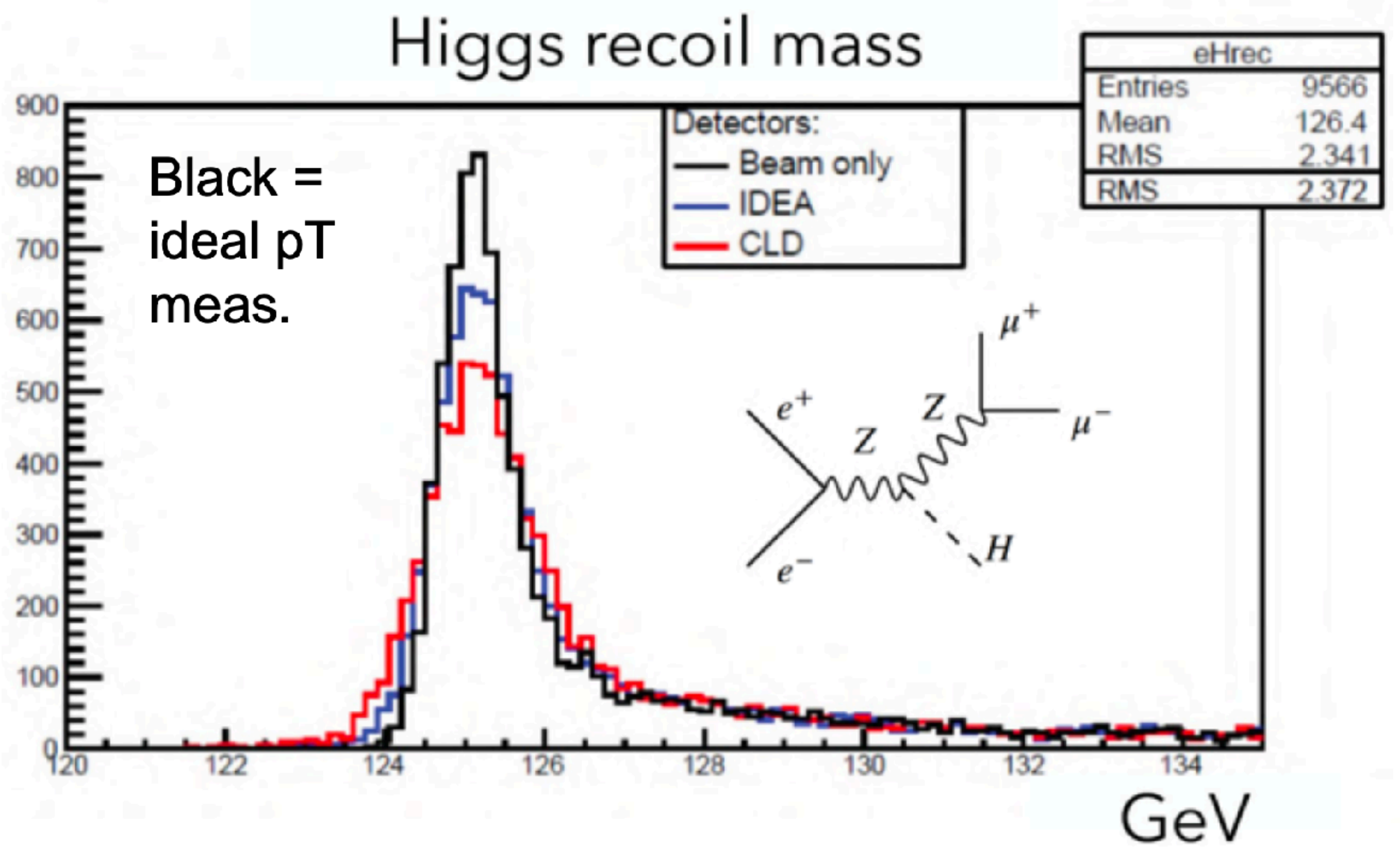
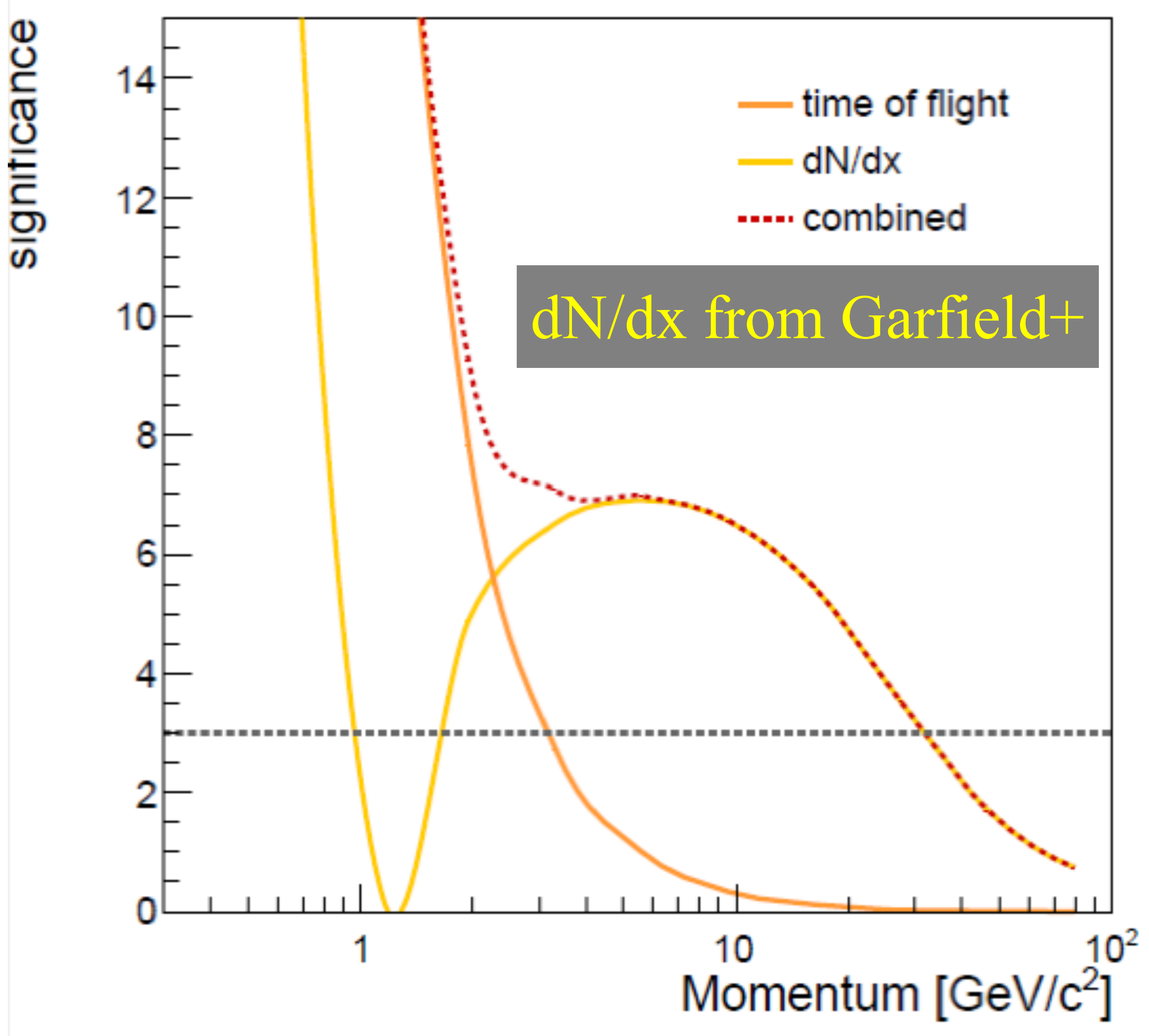
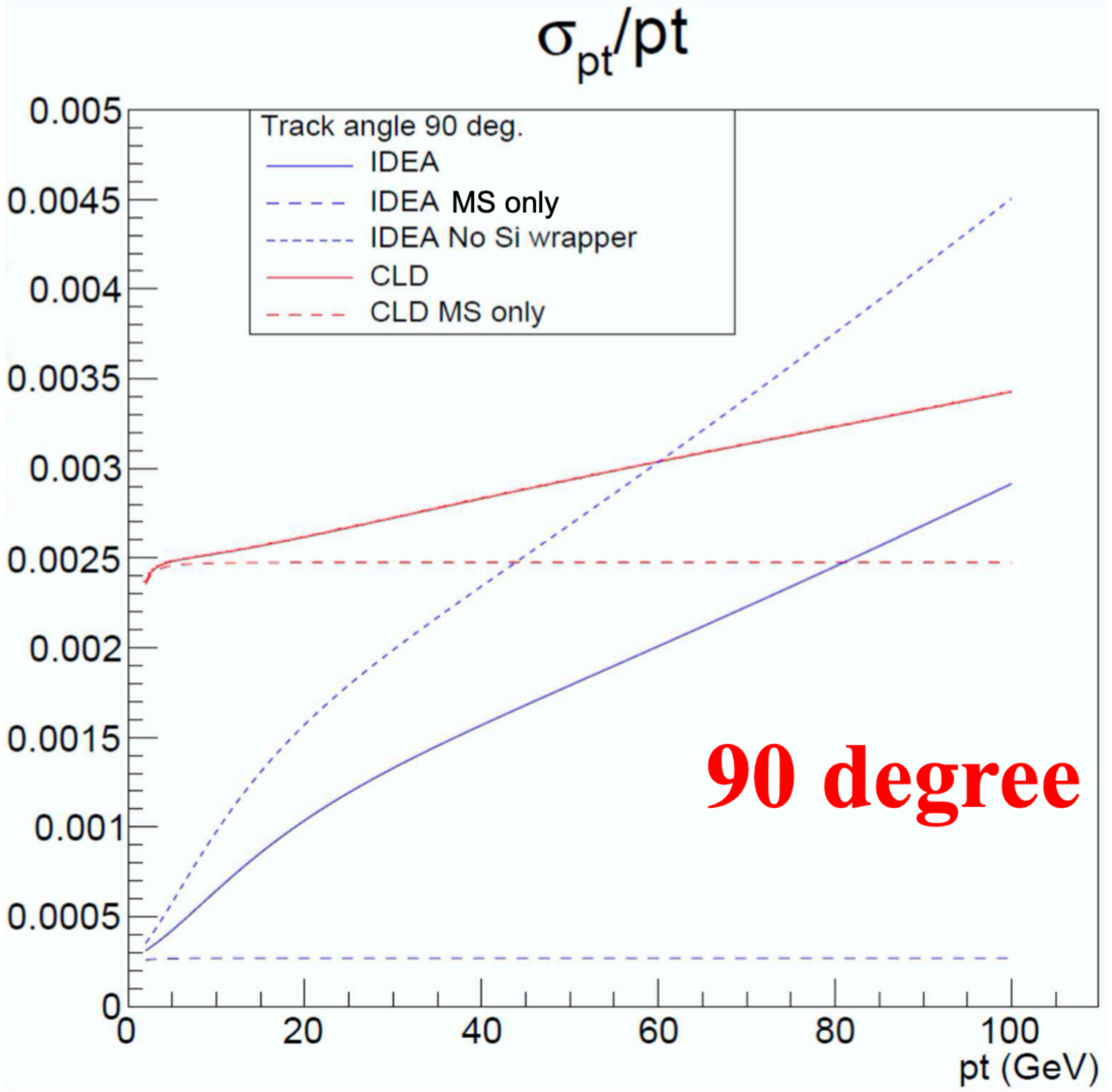


Drift chamber

- In general, tracks have rather low momenta ($p_T \lesssim 50$ GeV)
  - Transparency more relevant than asymptotic resolution
- Drift chamber (gaseous tracker) advantages
  - Extremely transparent: minimal multiple scattering and secondary interactions
  - Continuous tracking: reconstruction of far-detached vertices (K^0_S, Λ, BSM, LLPs)
  - Outstanding Particle separation via dE/dx or cluster counting (dN/dx)
    - >3σ K/π separation up to ~35 GeV

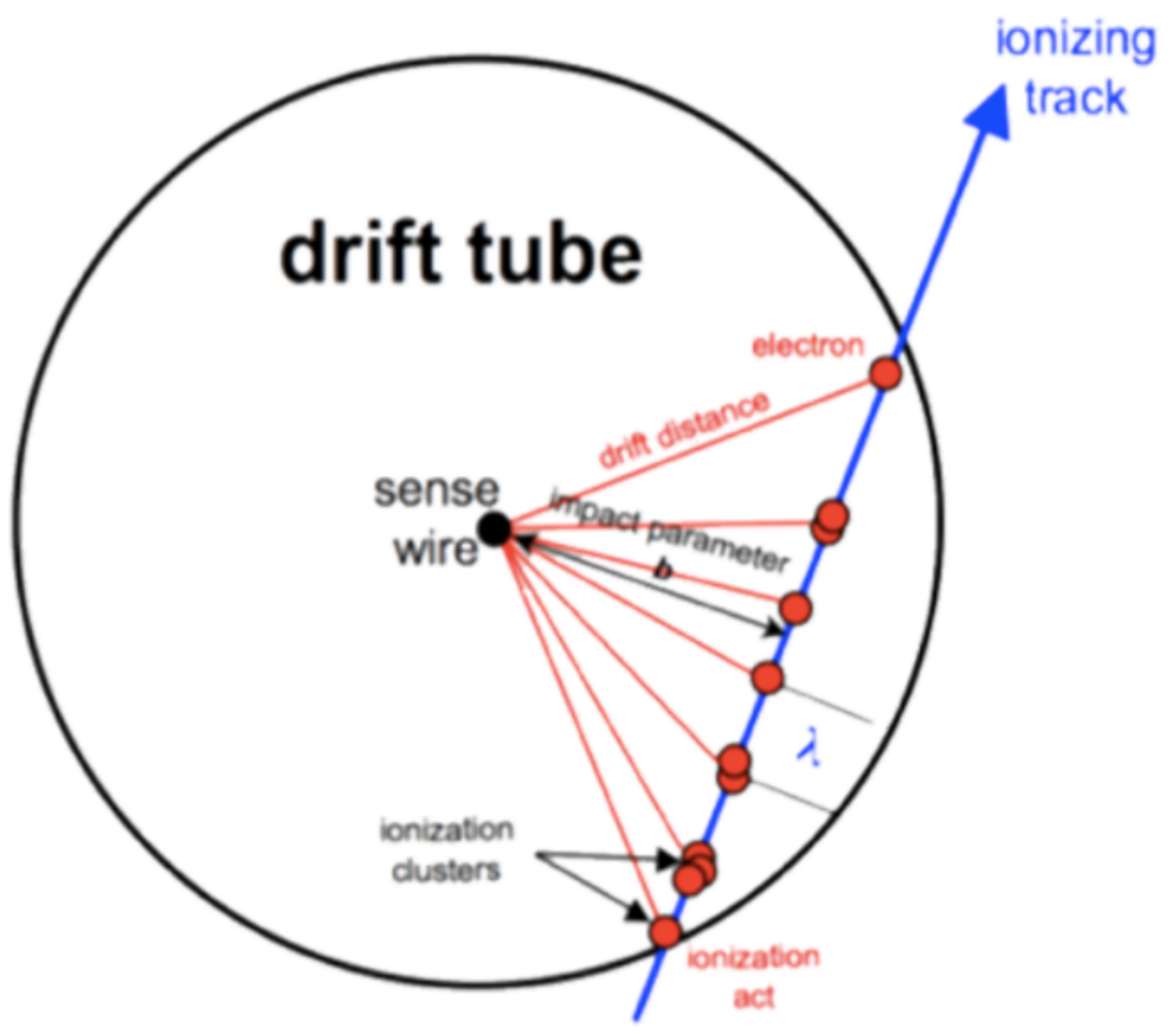


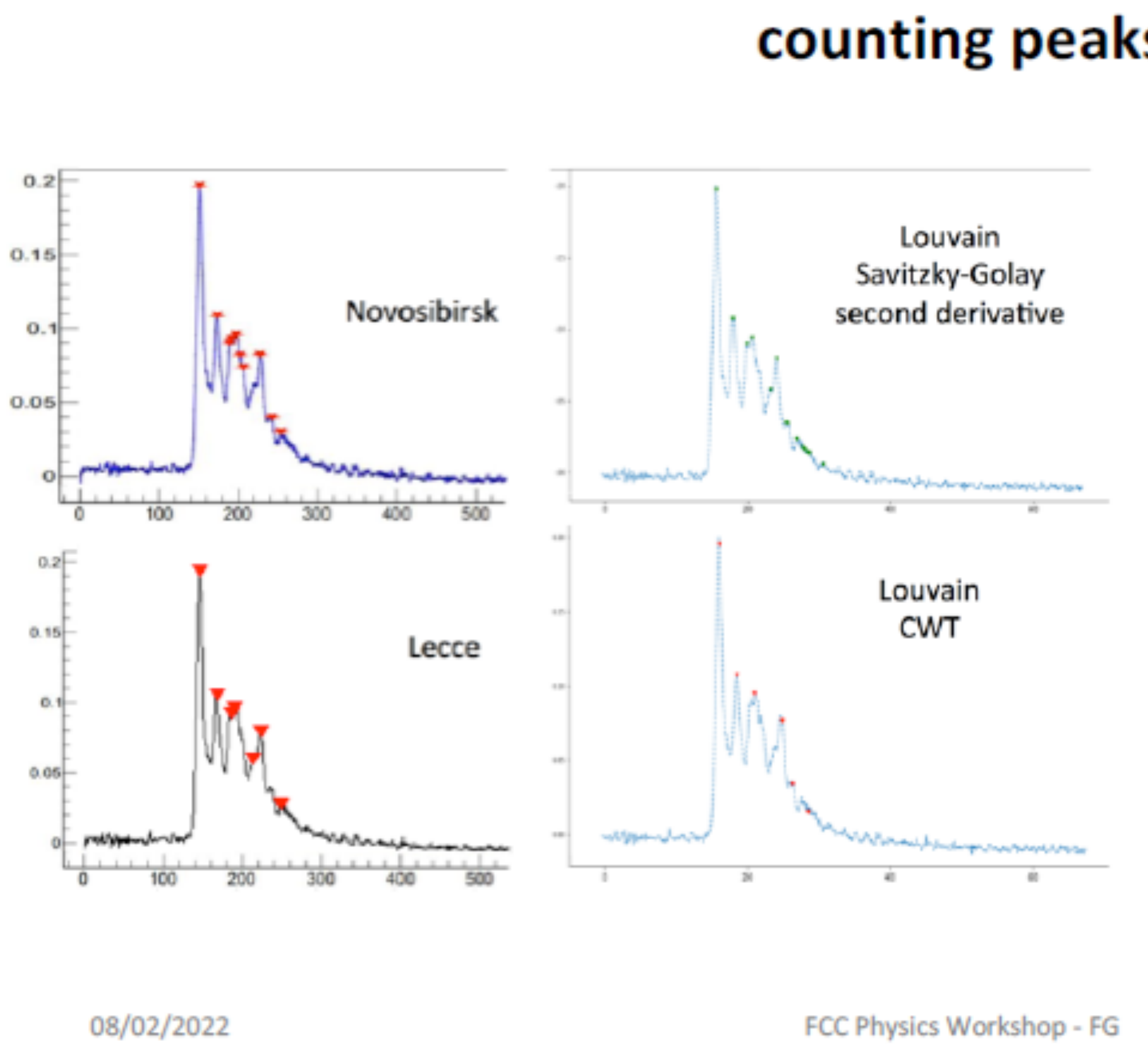




Cluster counting

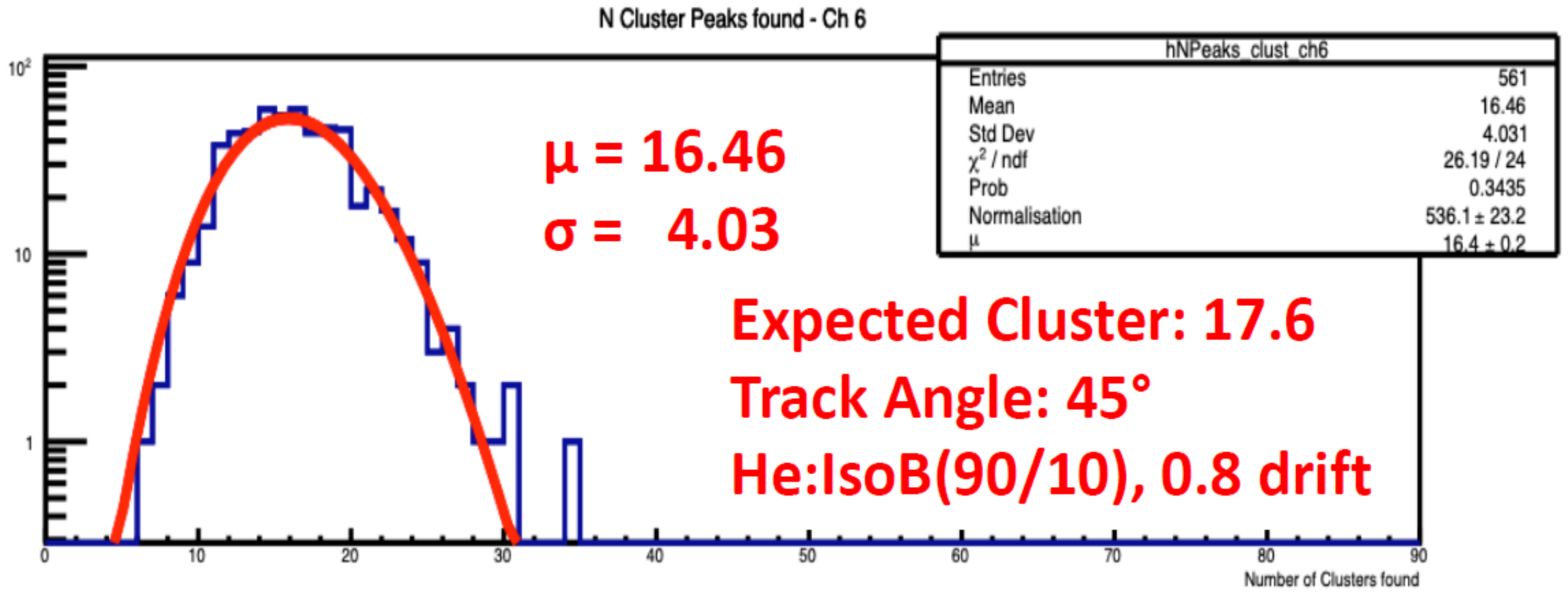
- Cluster counting x2 better than dE/dx
  - Poisson vs . Landau → no large tails
- Sample signal few GHz → on detector electronics R&D





Test beam data 2022

Number of Cluster Distribution



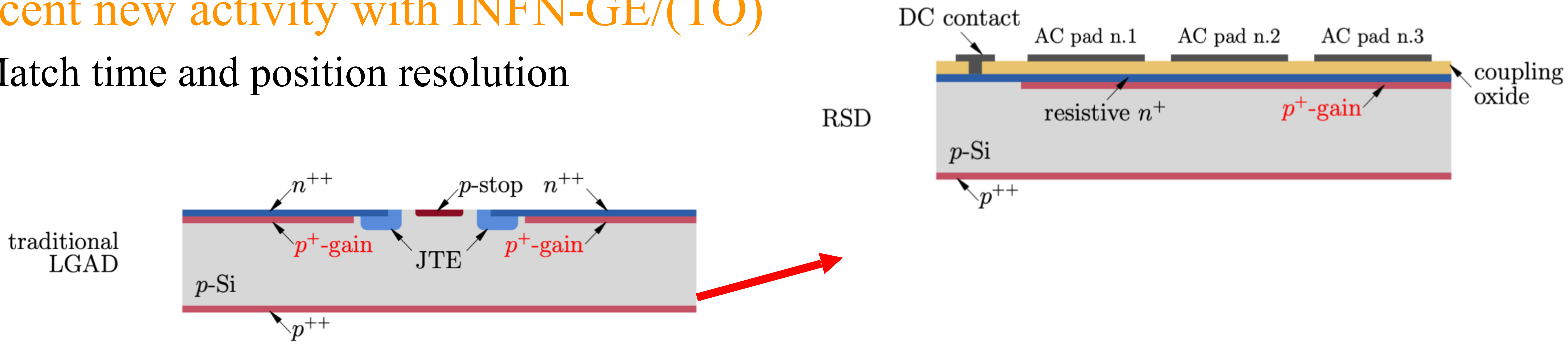
Drift chamber future plans

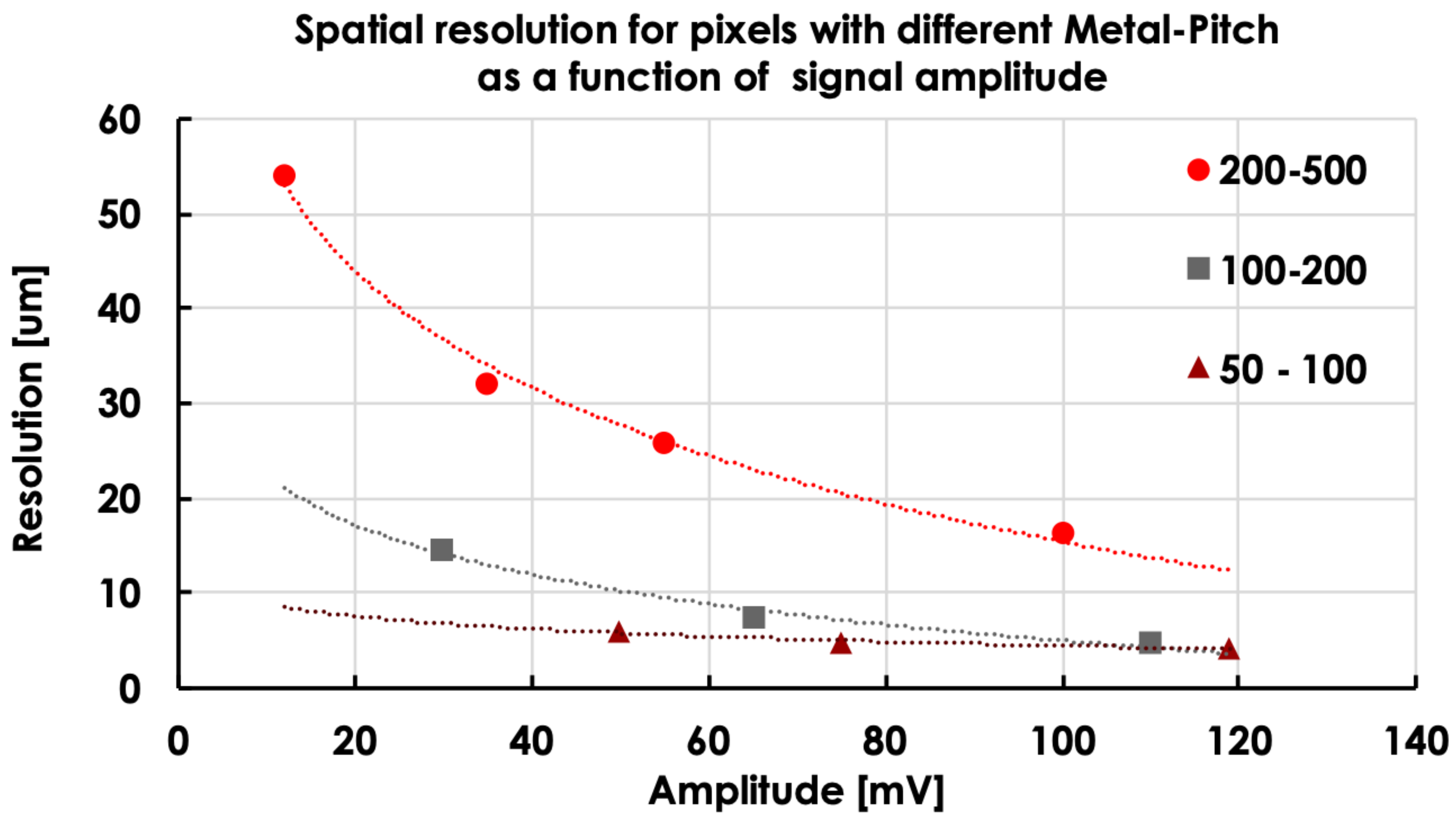
- Complete mapping of dN/dx data in all relevant βγ regions (few years)
  - Understand details of cluster counting performance
- Build large mechanical prototype (few years)
- Build full length functioning prototype with few cells (few years)
- Develop on-detector cluster counting electronics (few years)

- Towards a drift chamber TDR

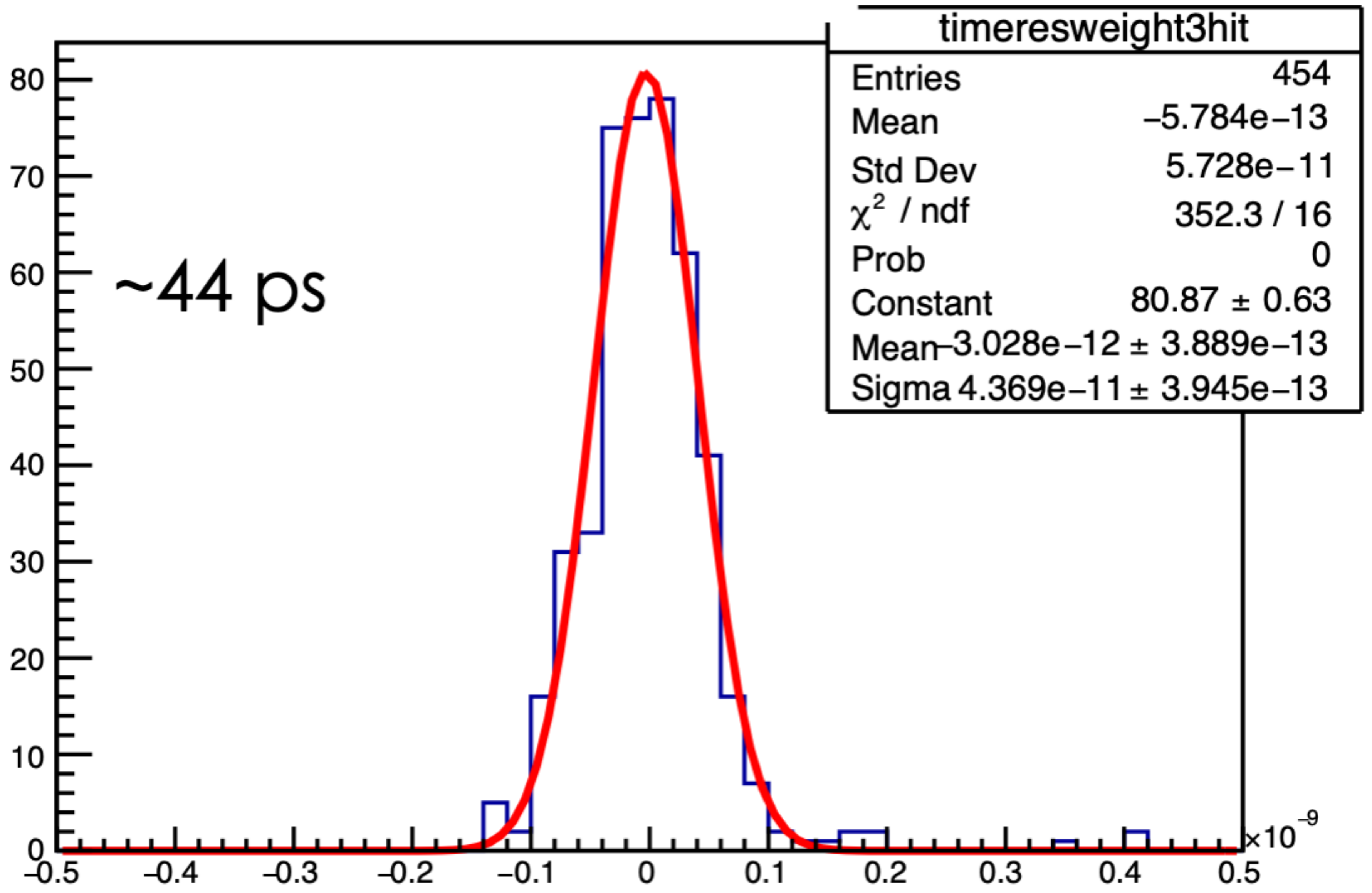
Resistive LGAD

- Recent new activity with INFN-GE/(TO)
  - Match time and position resolution





100 - 200



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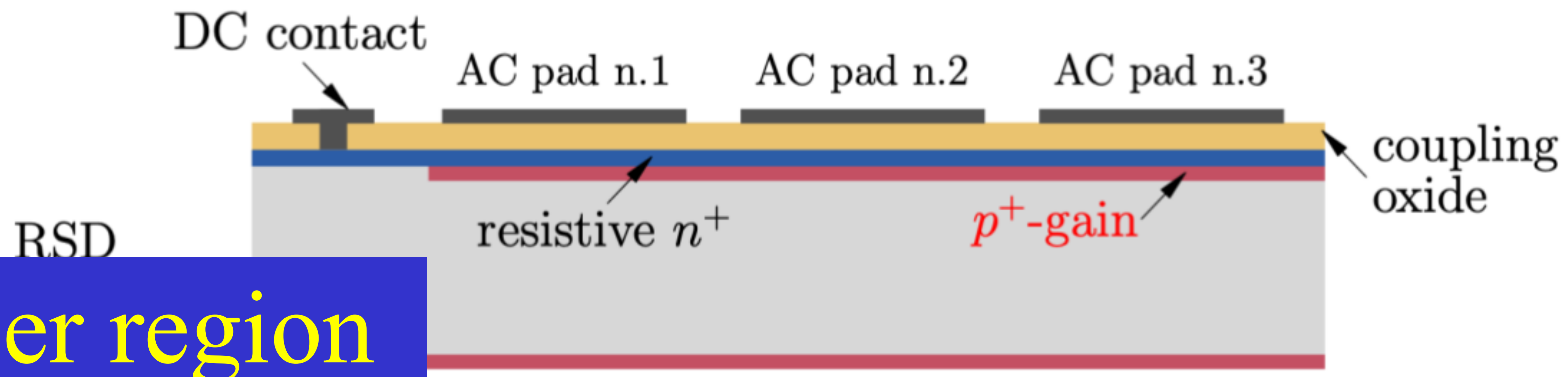
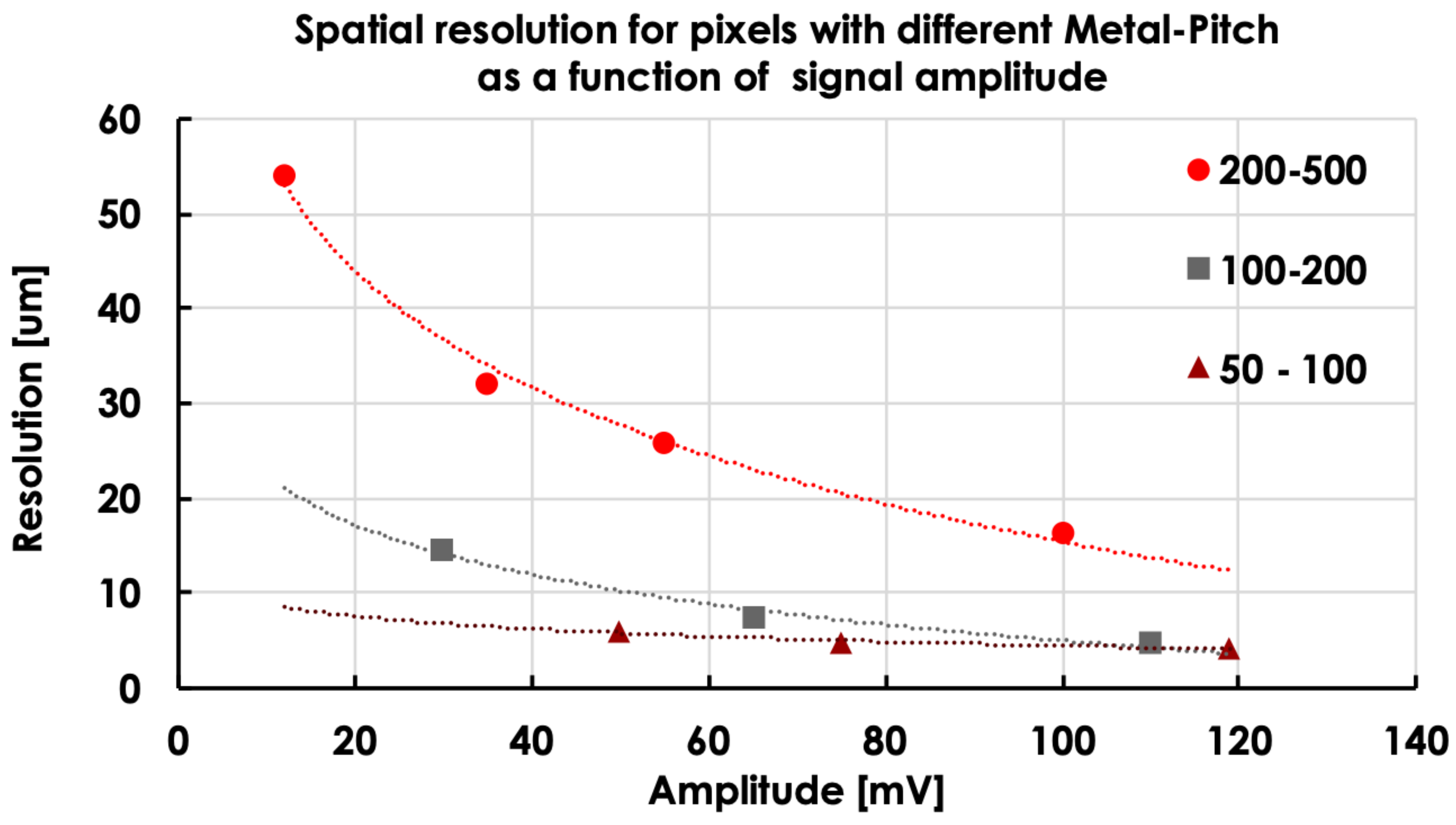


Very attractive option for timing in Si wrapper region
Cost reduction is major area of R&D
Some "fast" devices also prototyped by Arcadia group



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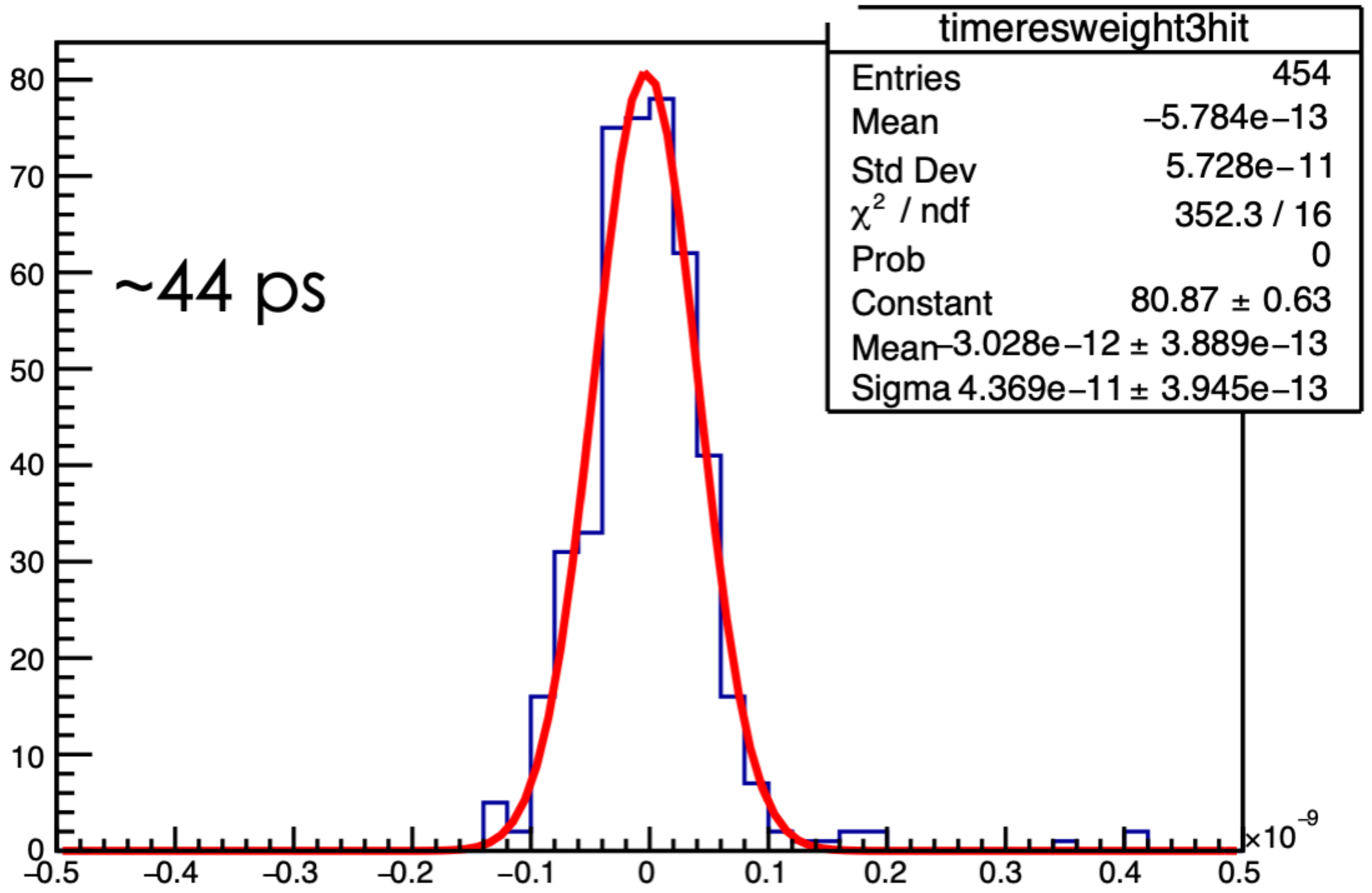
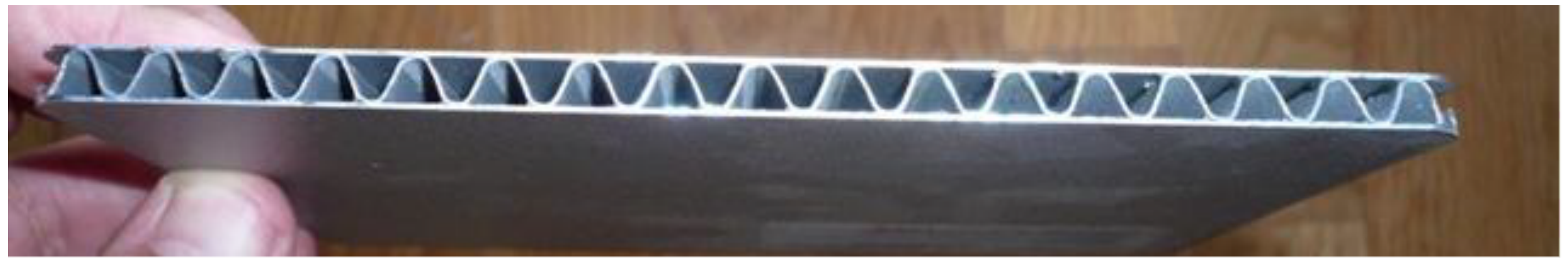
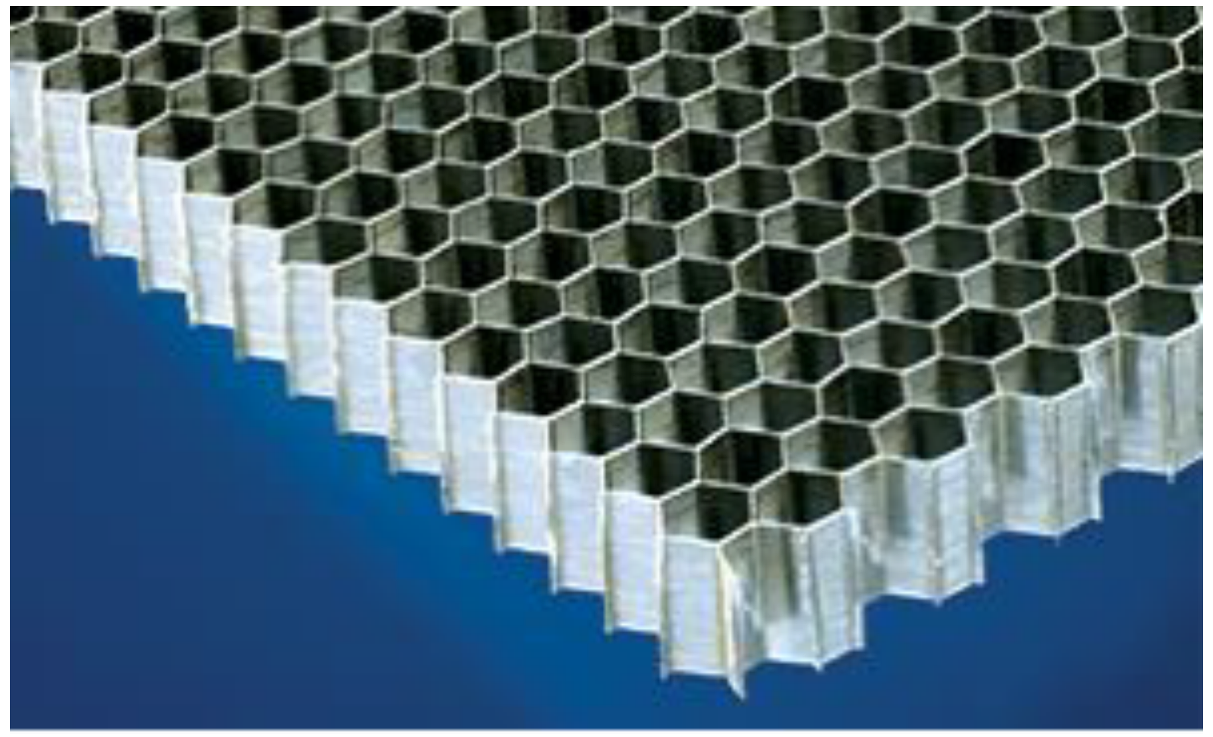


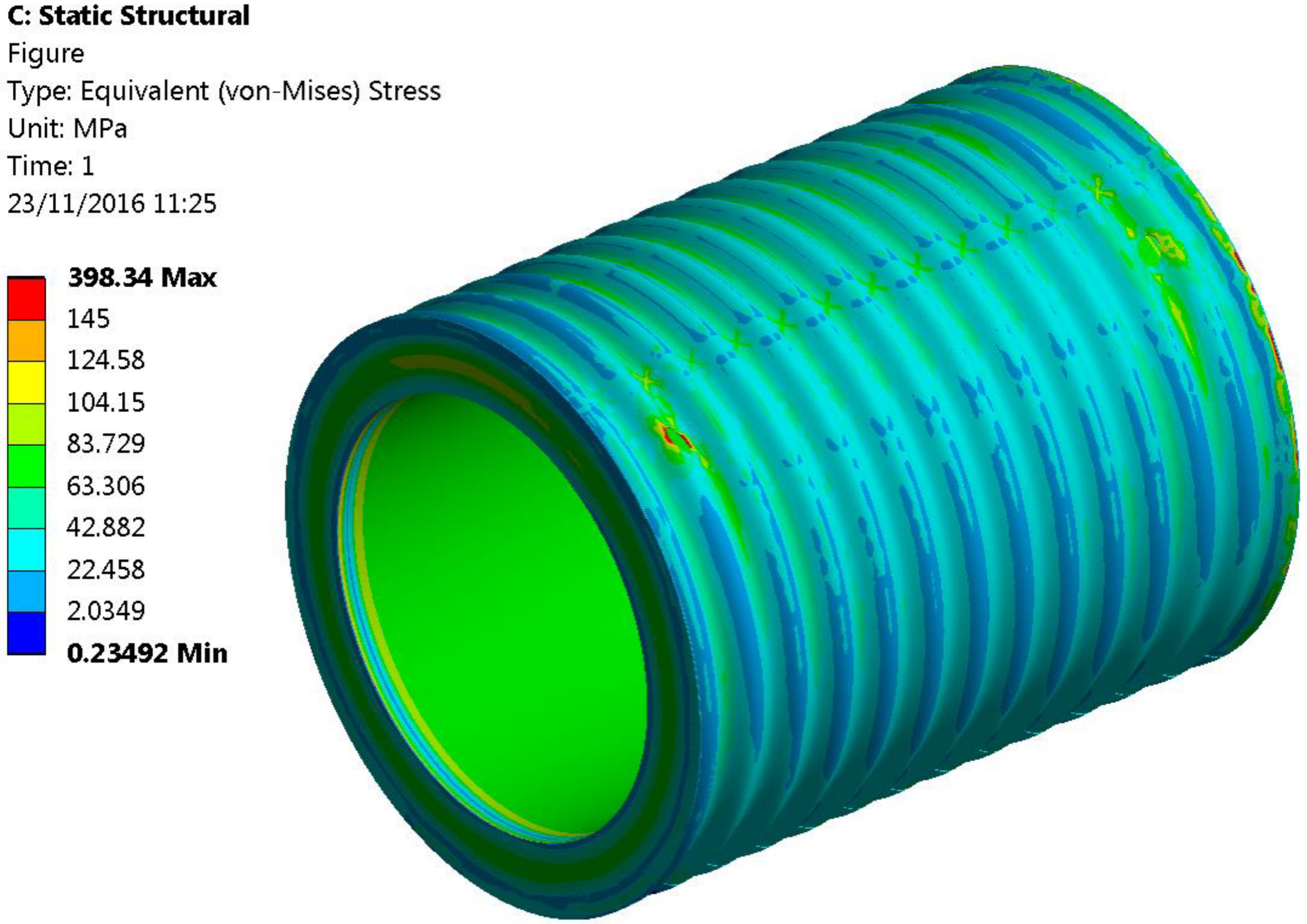
Superconducting solenoid

- 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: $X_0 = 0.04$

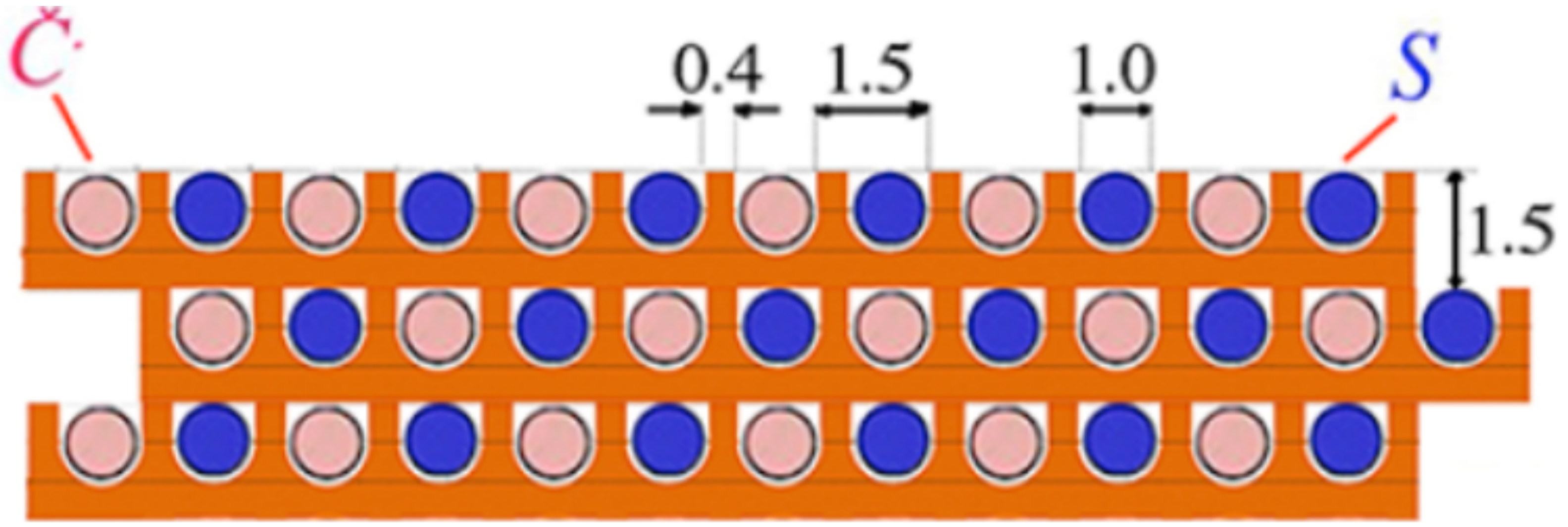




Courtesy of H. TenKate

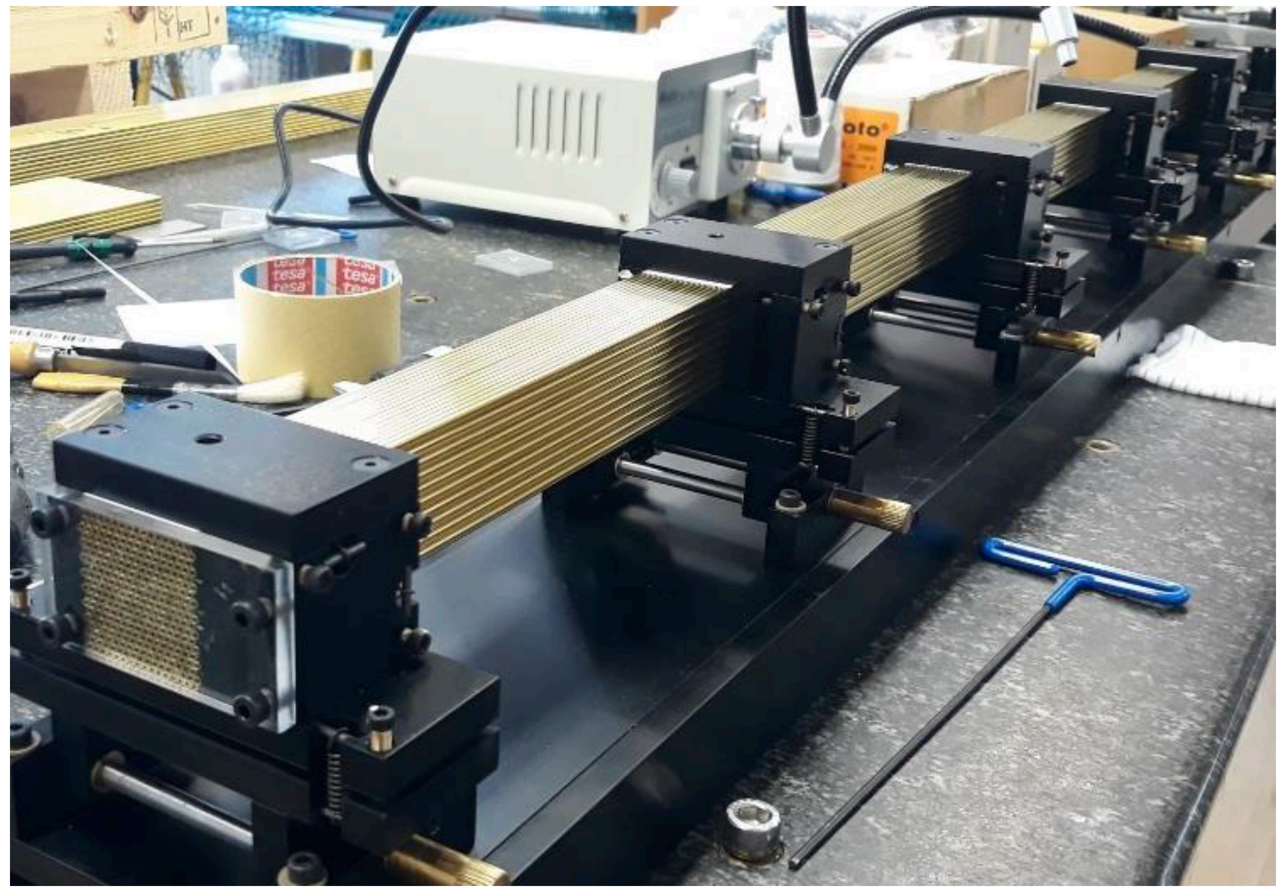


Dual Readout Calorimetry



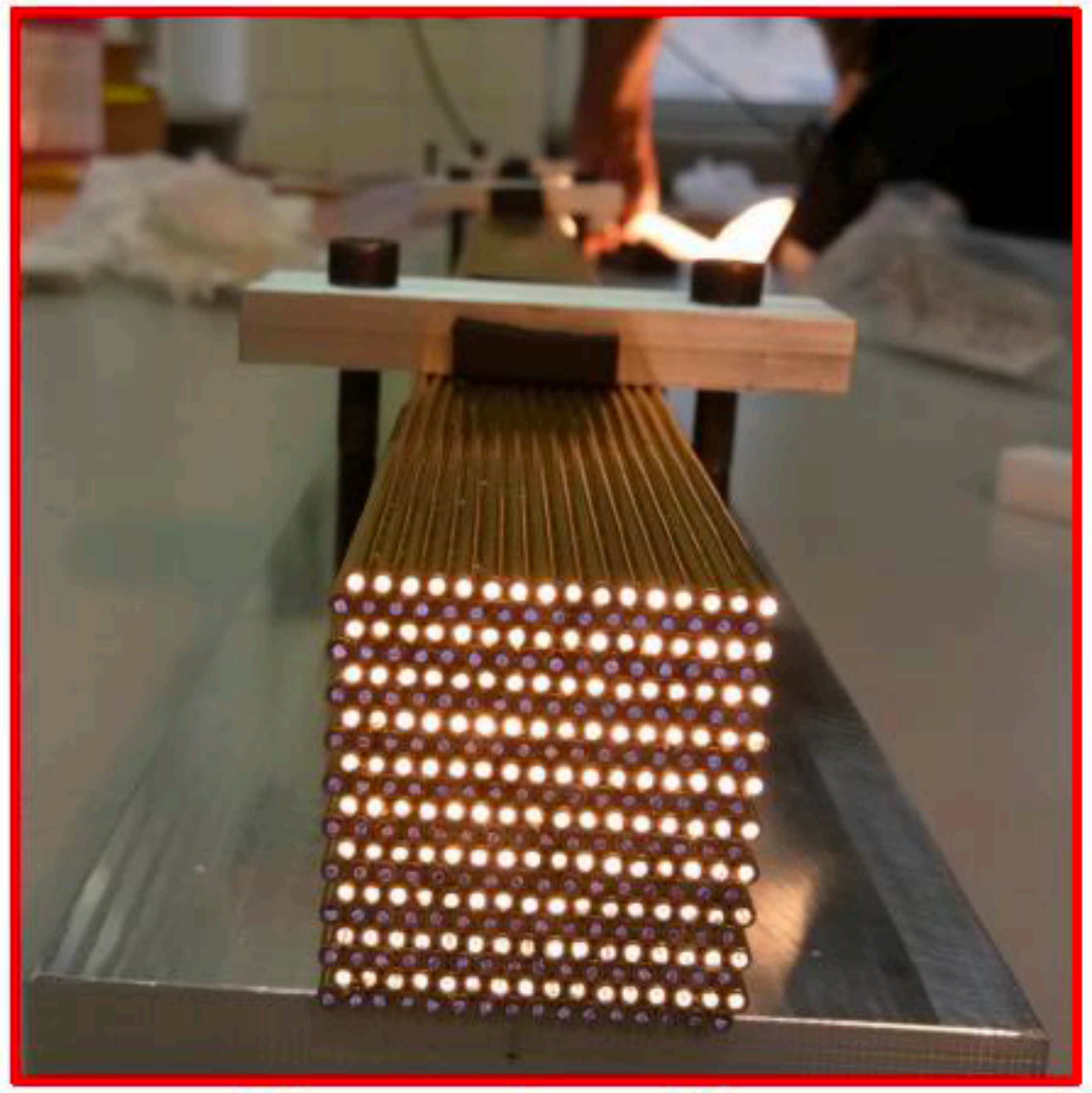
Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers



Cherenkov fibers

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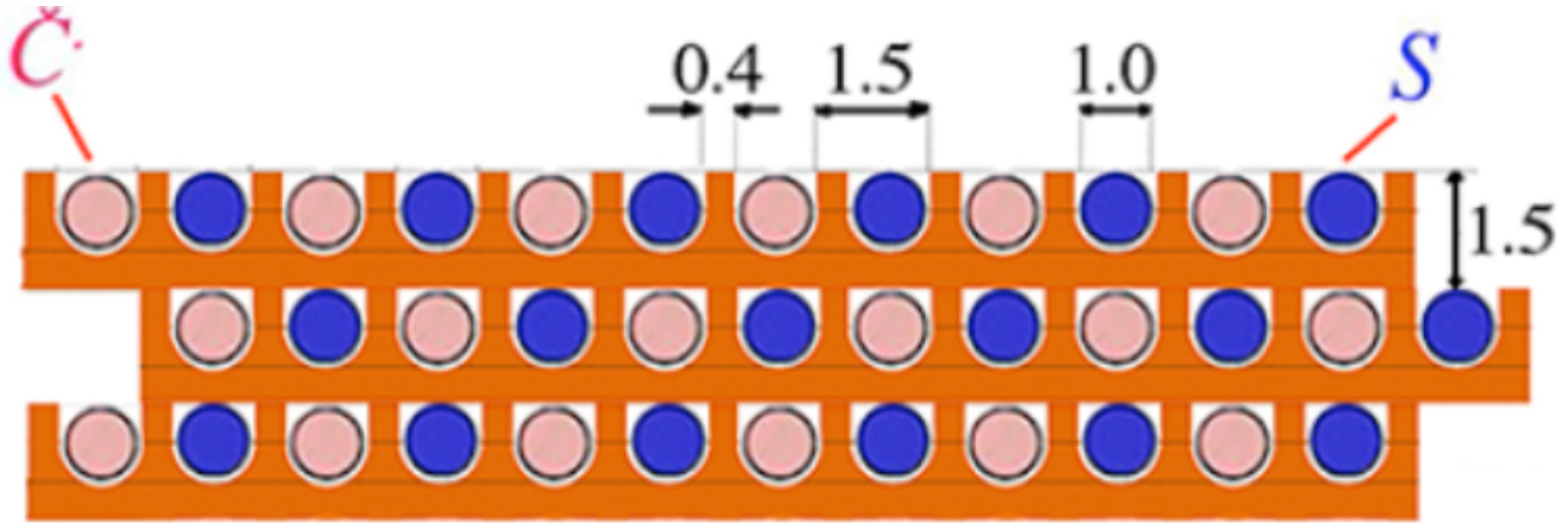

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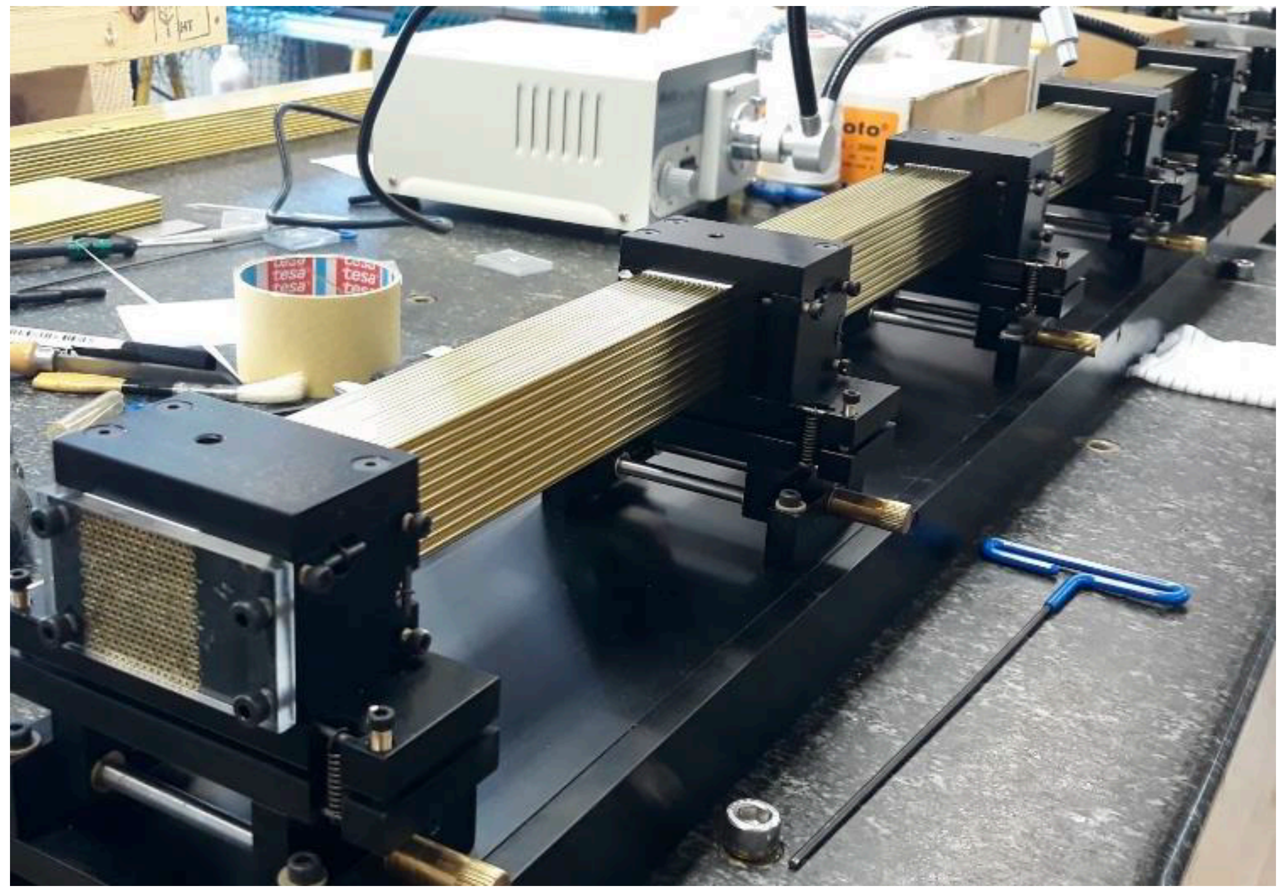
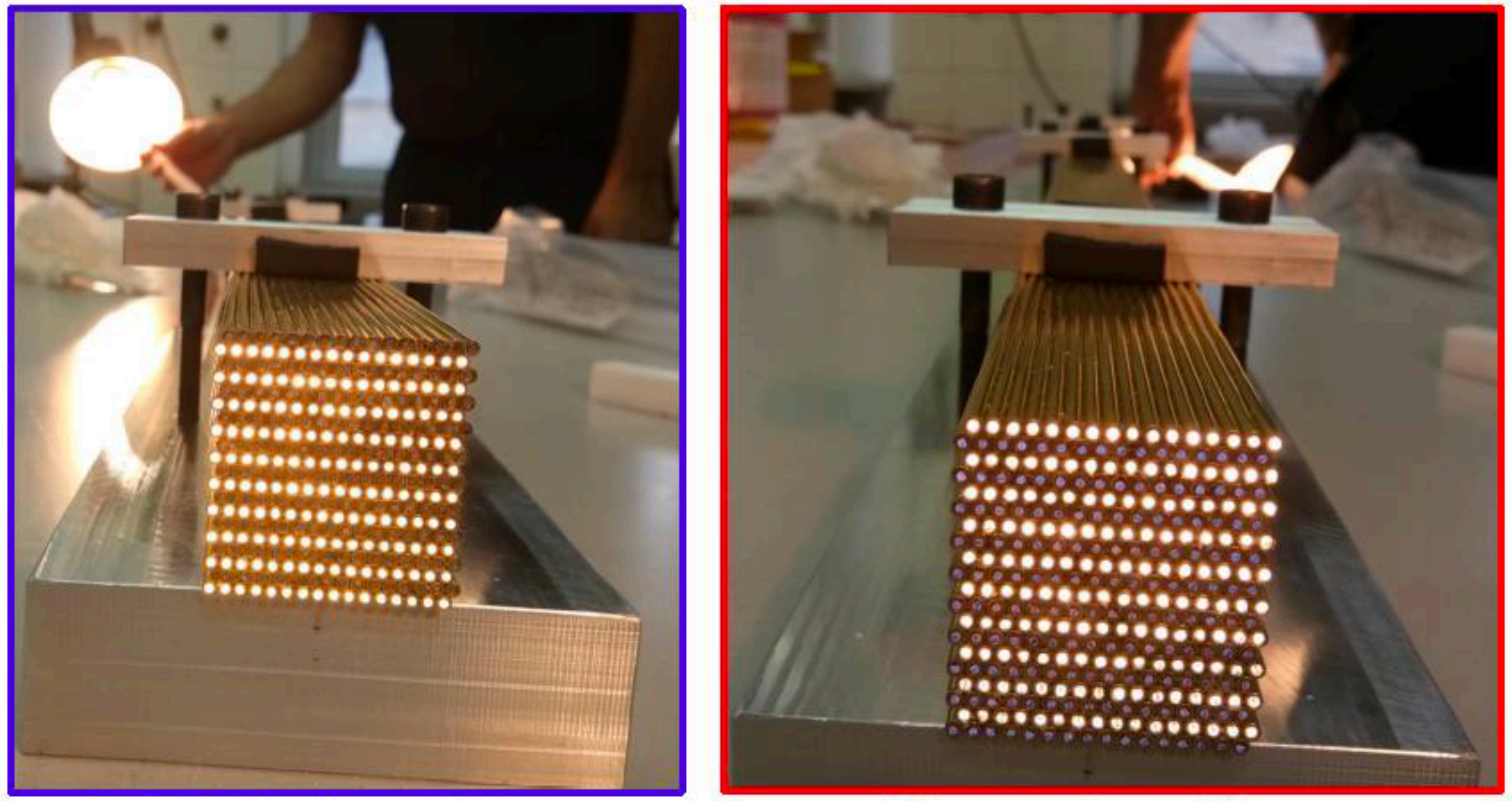
Scintillating fibers

~2m long capillaries



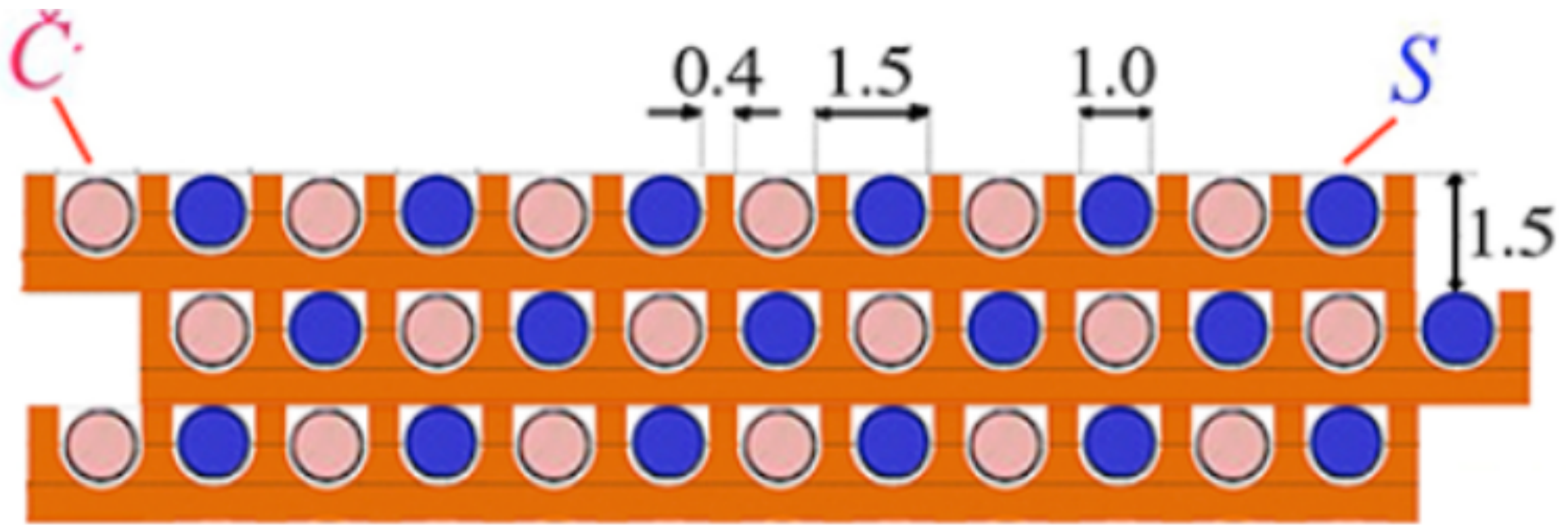
- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)

Newer DR calorimeter
(bucatini calorimeter)



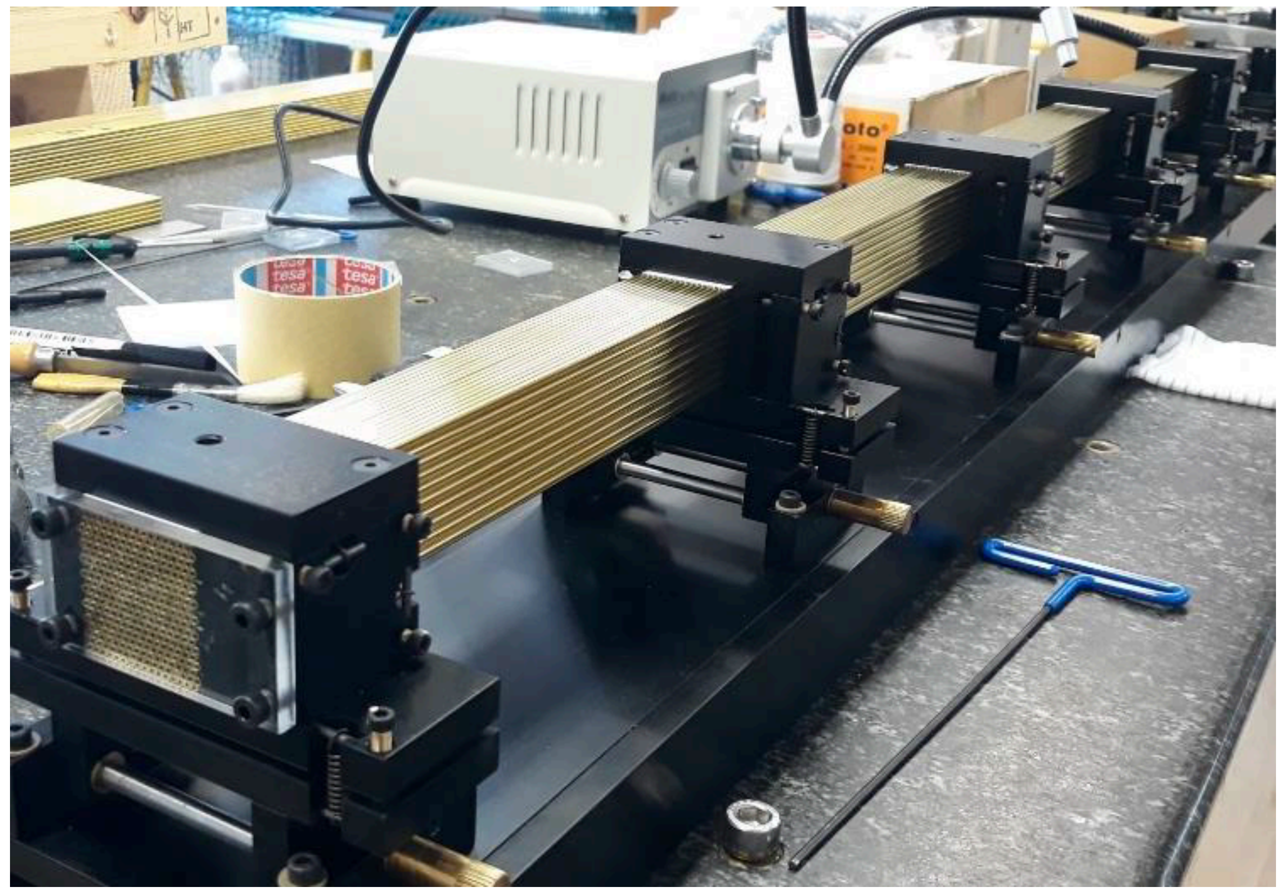
Scintillation fibers   Cherenkov fibers

Dual Readout Calorimetry



Alternate
Cherenkov fibers
Scintillating fibers

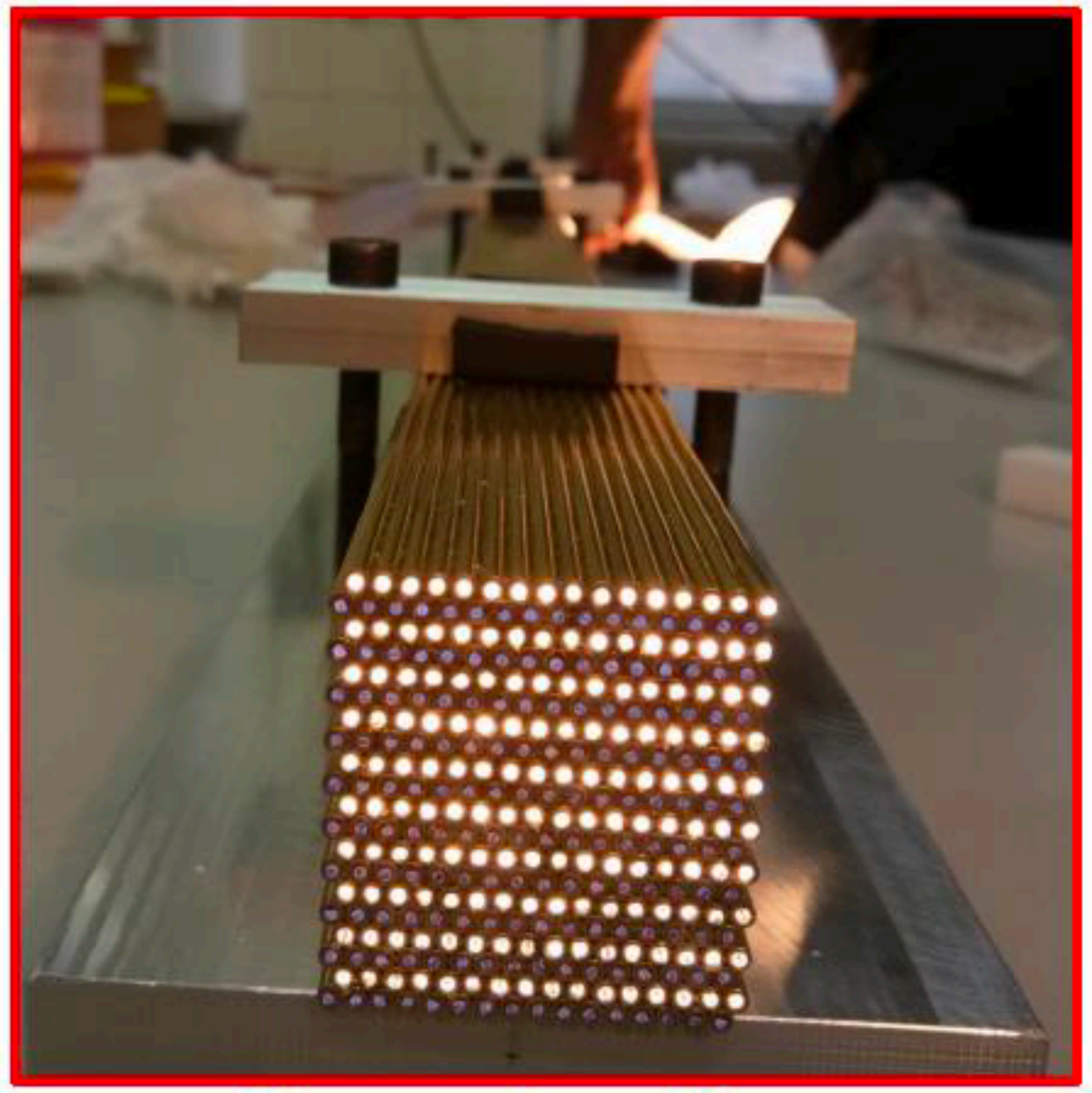
~2m long capillaries



- ❖ Measure simultaneously:
  - ➢ Scintillation signal (S)
  - ➢ Cherenkov signal (Q)
- ❖ Calibrate both signals with e-

Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers

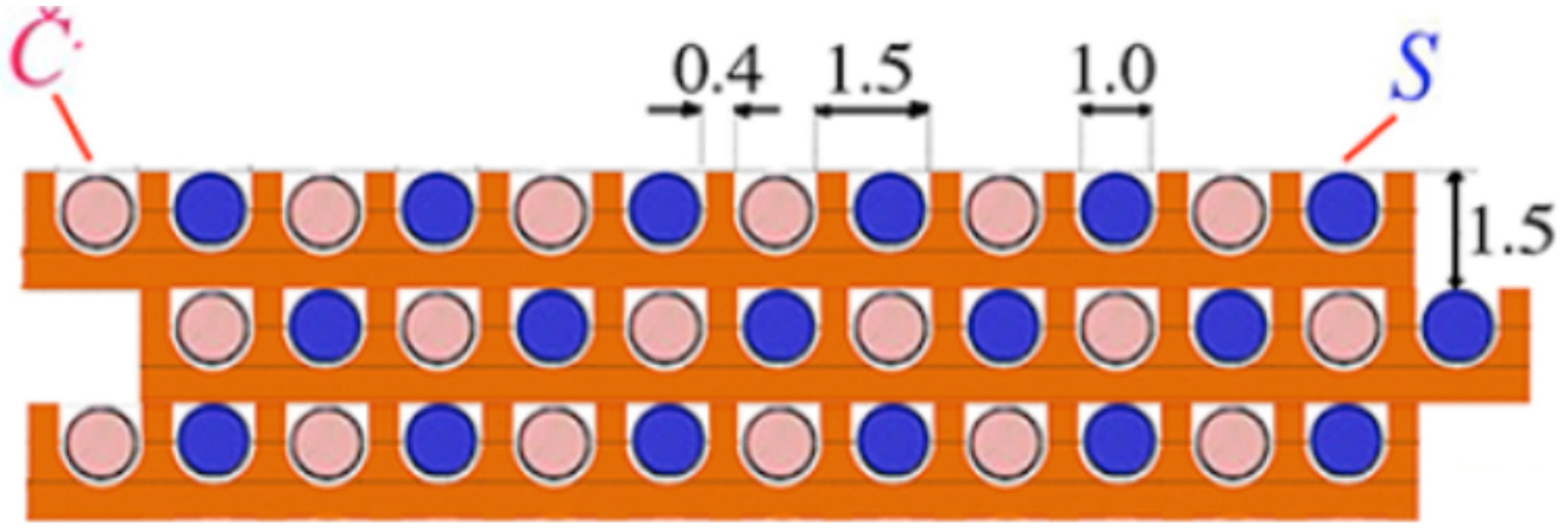


Cherenkov fibers

FUTURE CIRCULAR COLLIDER

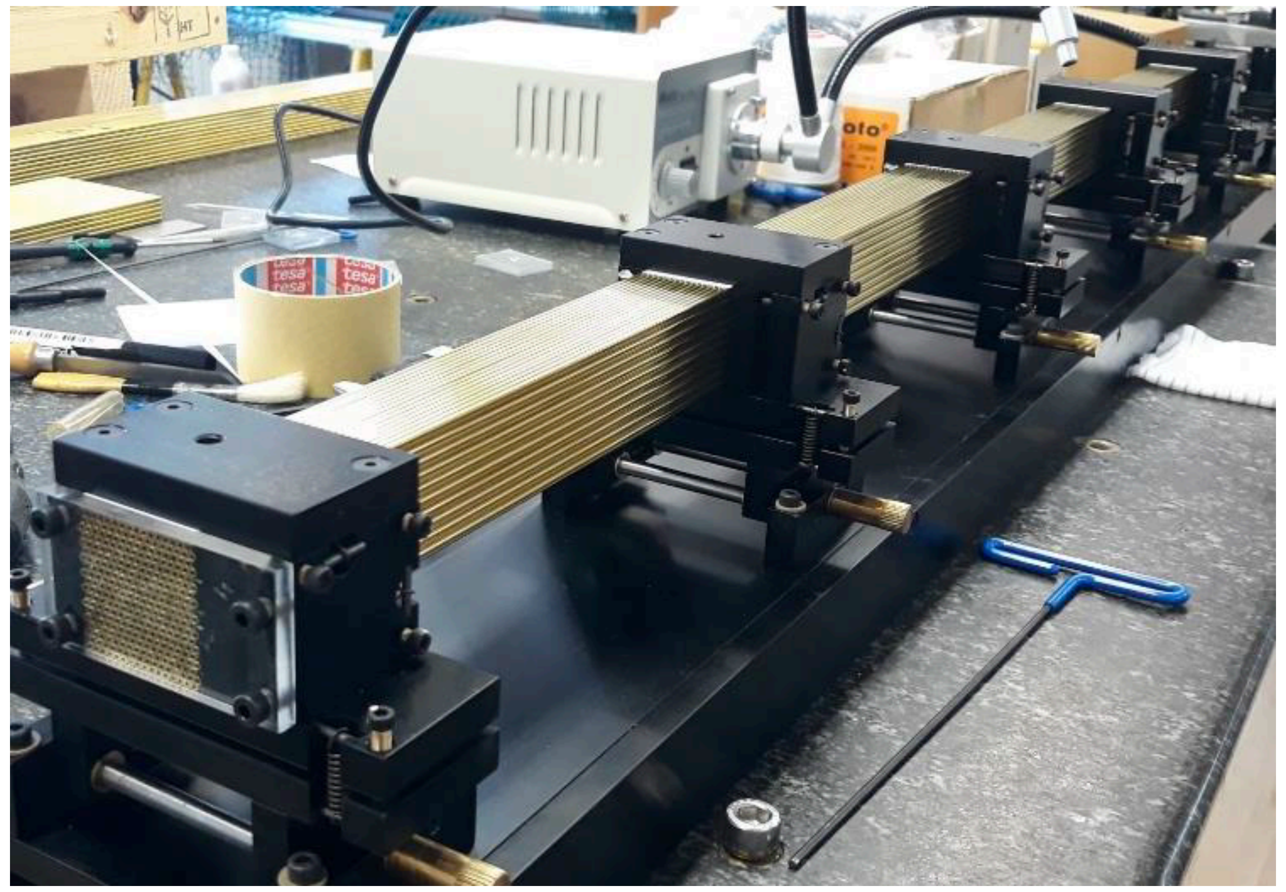
Dual Readout Calorimetry

INFN Istituto Nazionale di Fisica Nucleare



Alternate
Cherenkov fibers
Scintillating fibers

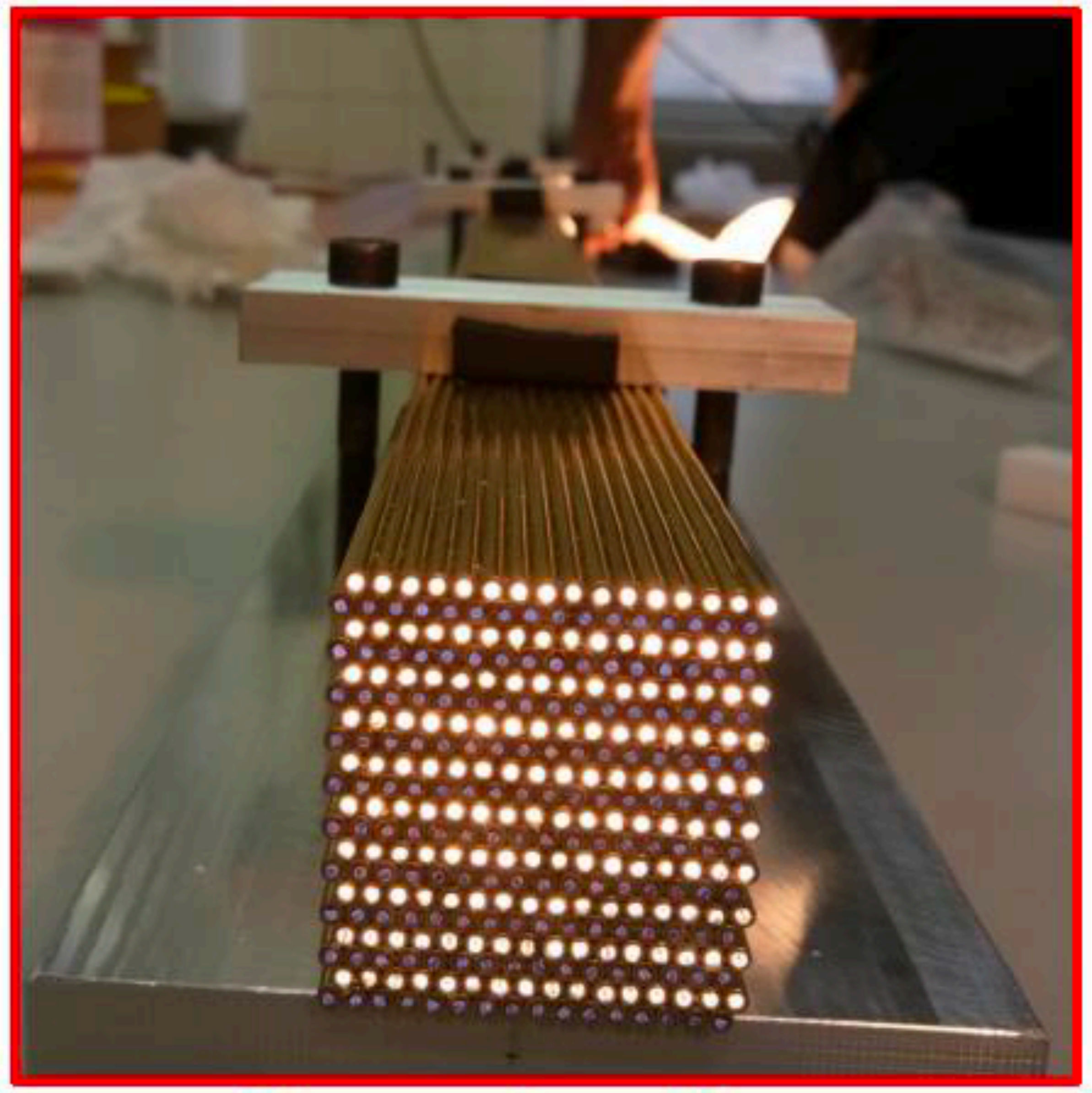
~2m long capillaries



- ❖ 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)

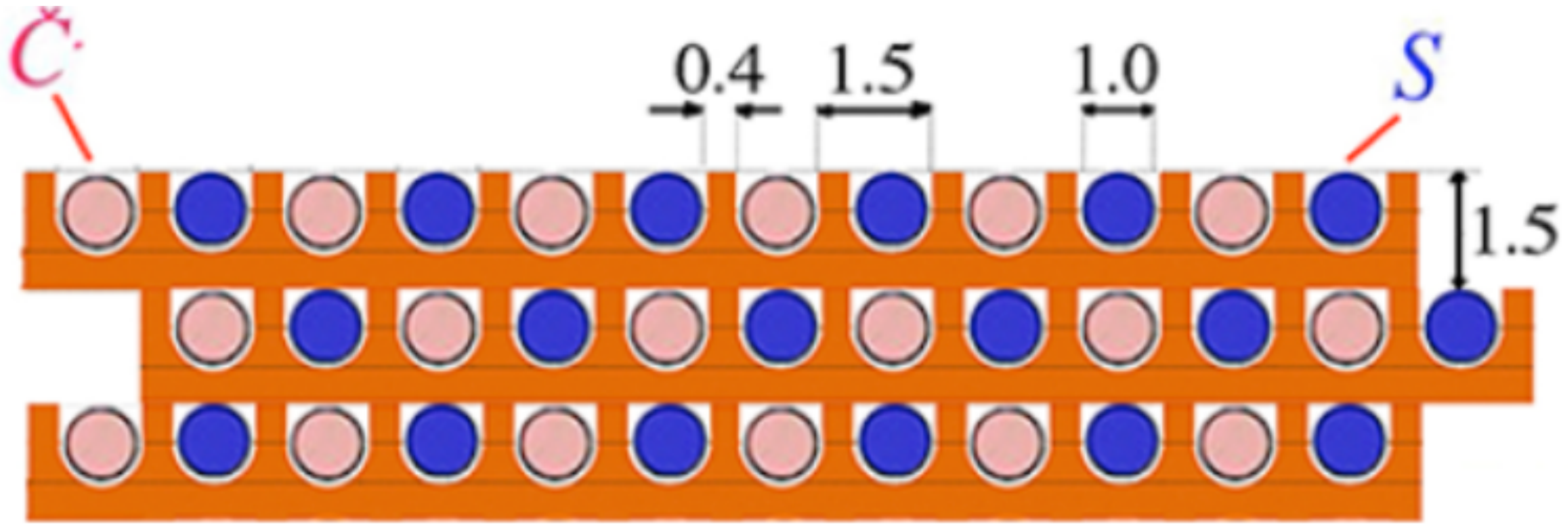
Scintillation fibers



Cherenkov fibers

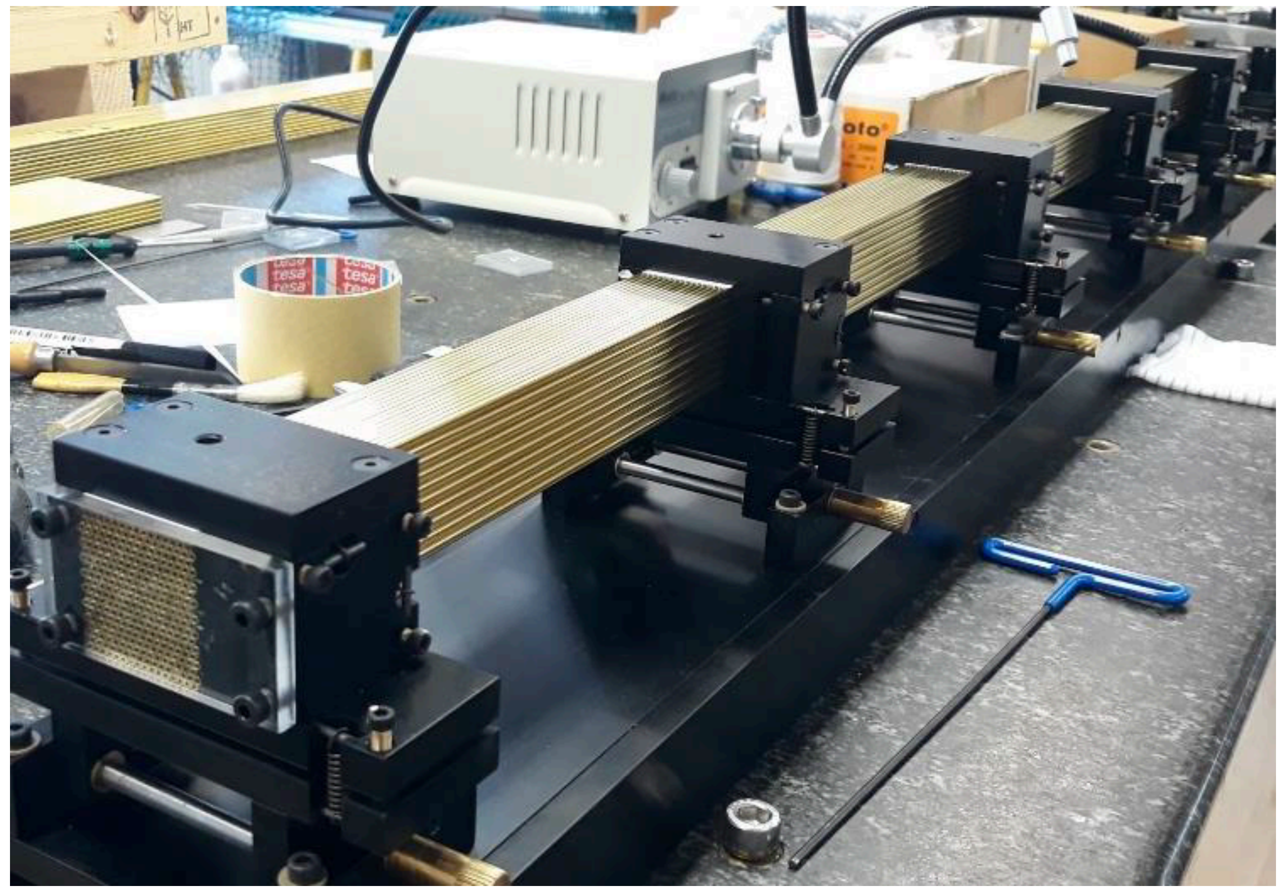
FUTURE CIRCULAR COLLIDER

Dual Readout Calorimetry



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

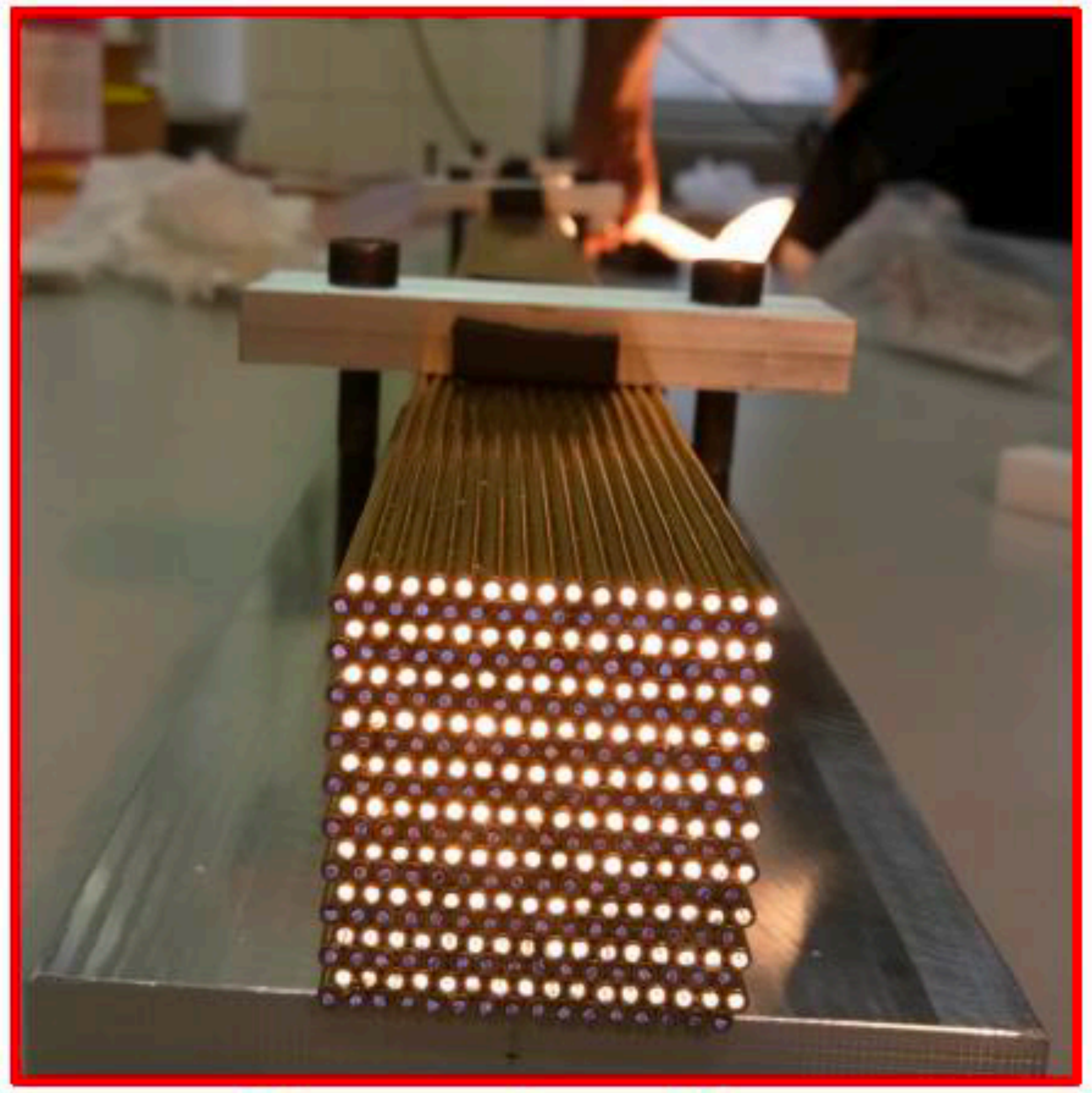
$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$

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

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

Newer DR calorimeter
(bucatini calorimeter)

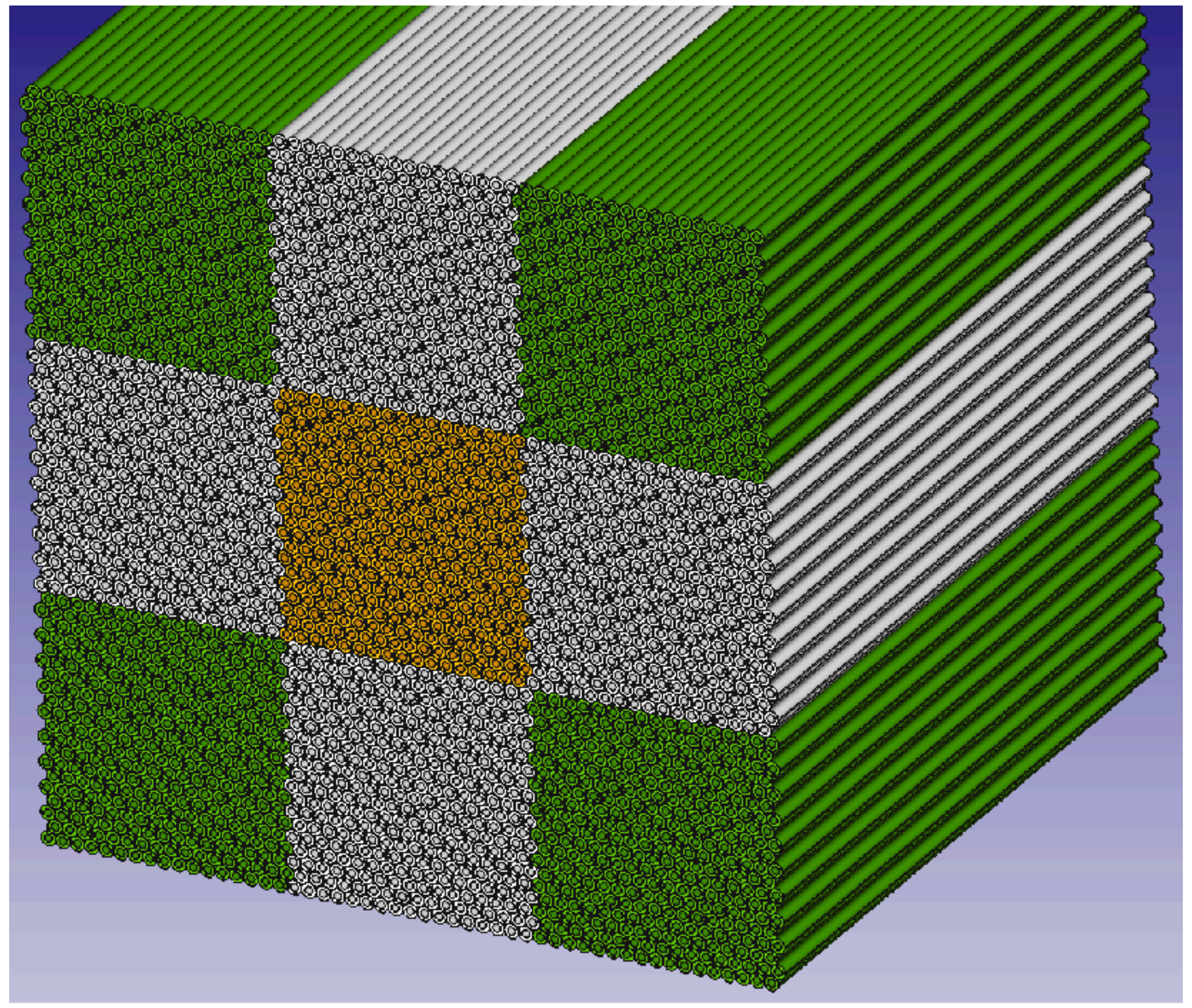
Scintillation fibers

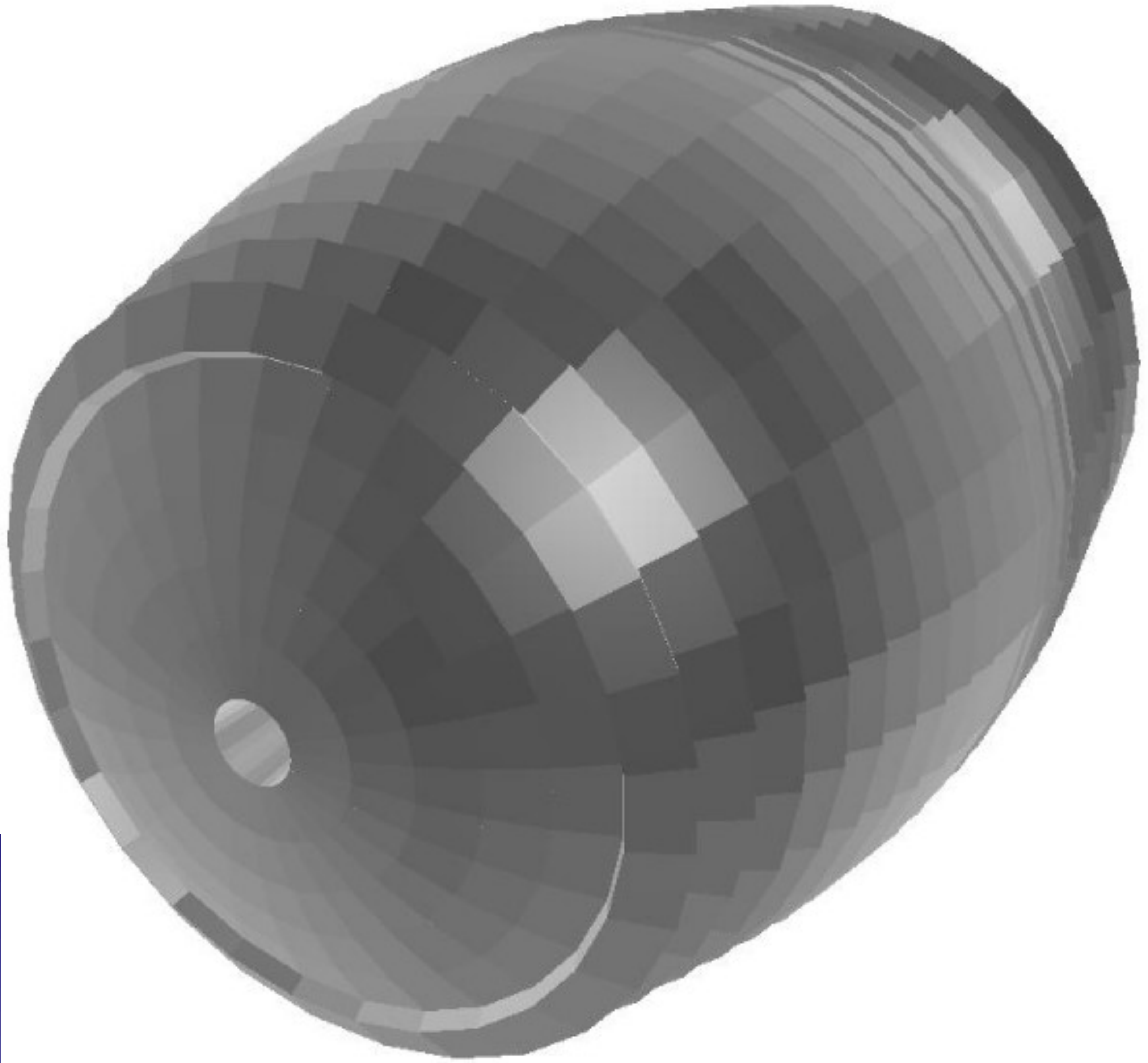


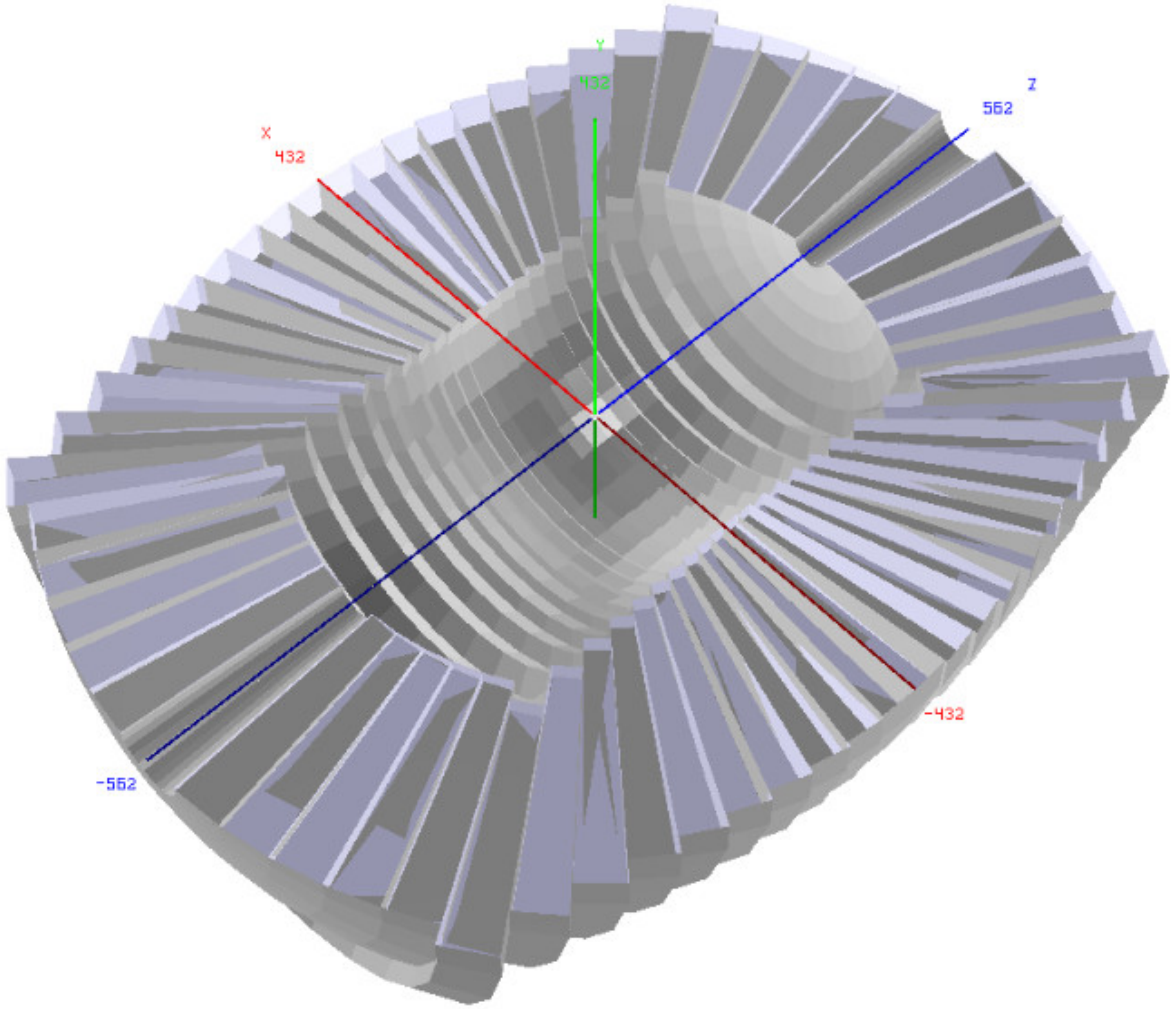
Cherenkov fibers

Dual Readout Calorimeter

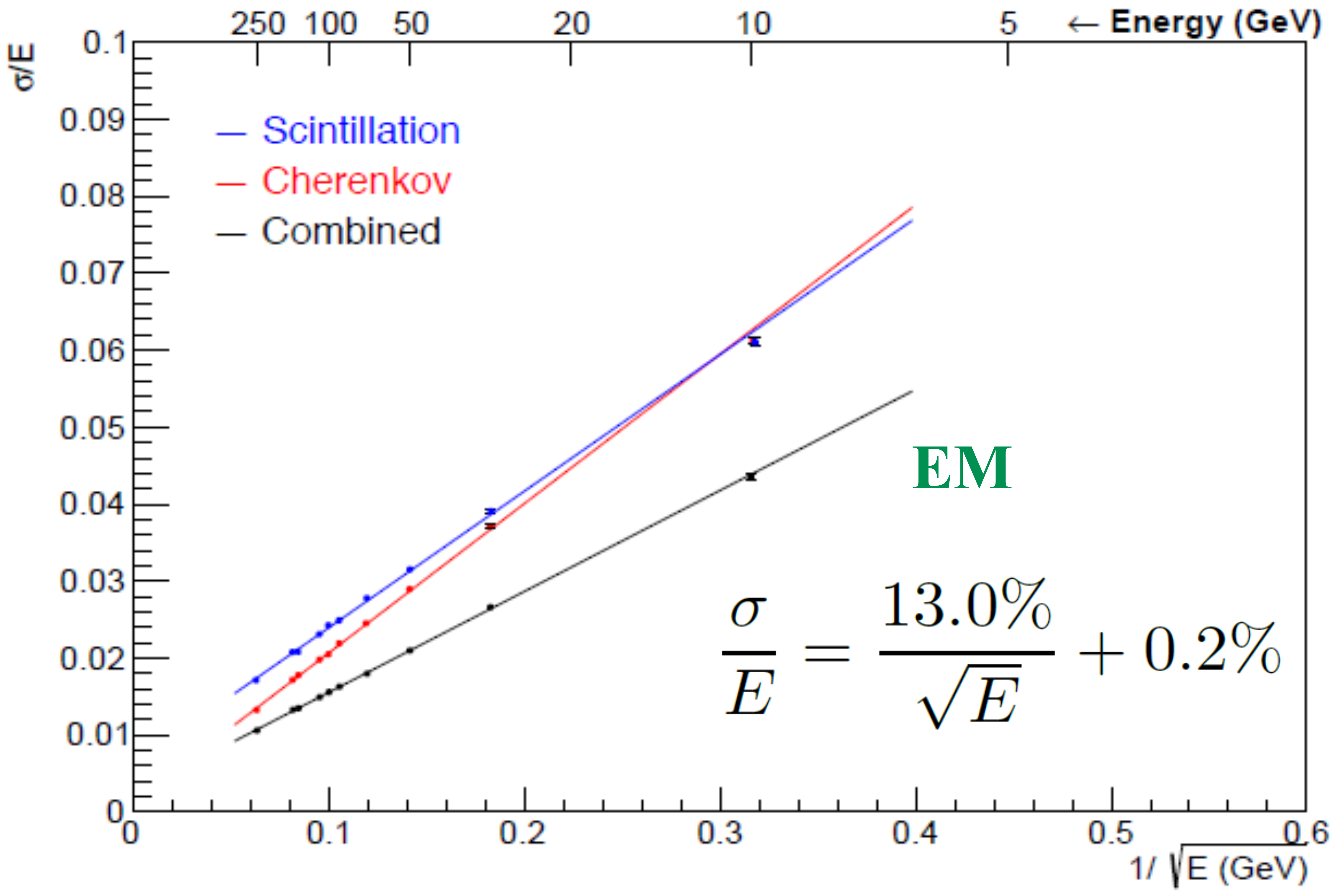
Full GEANT4 implementation of the DR calorimeter

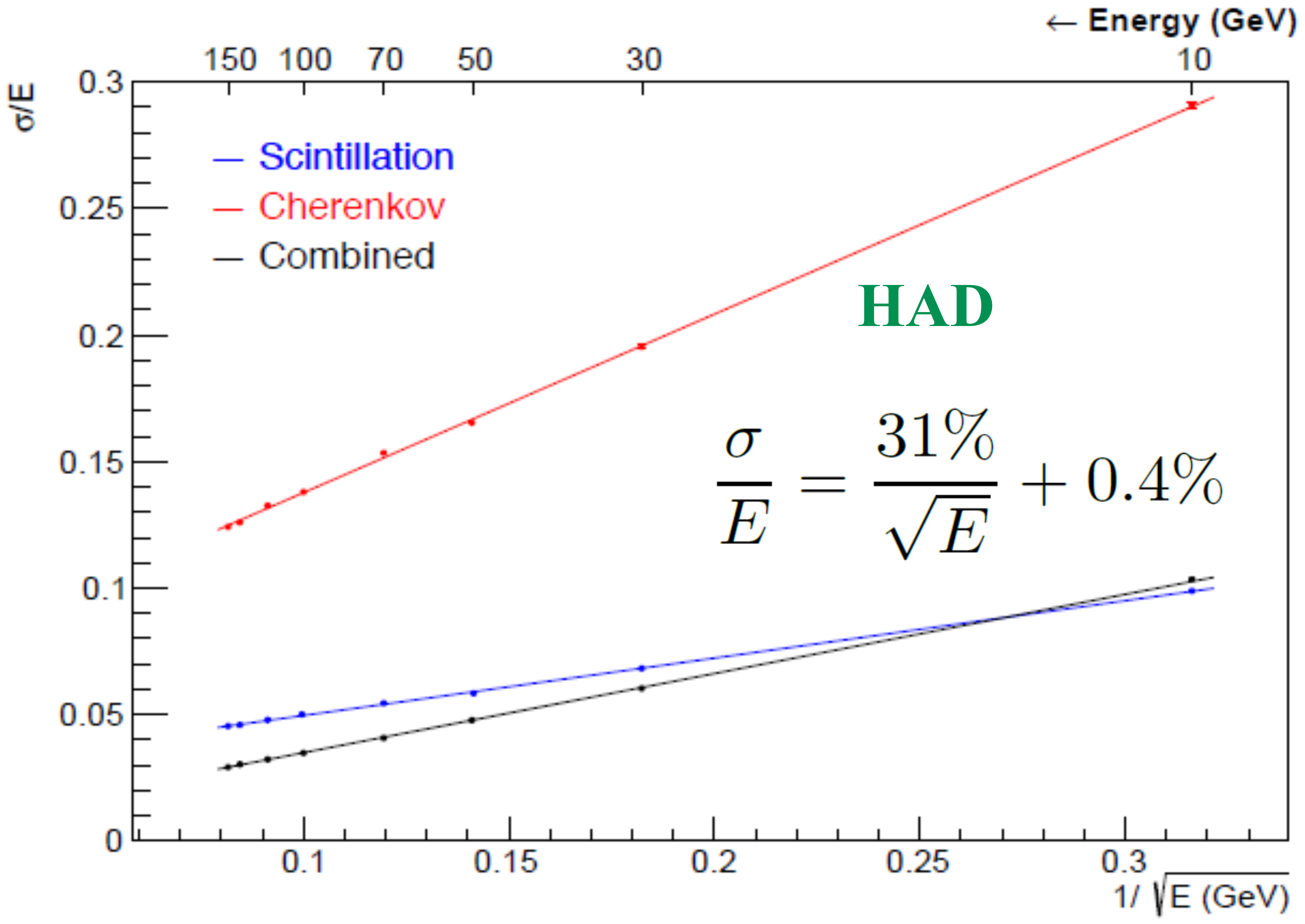




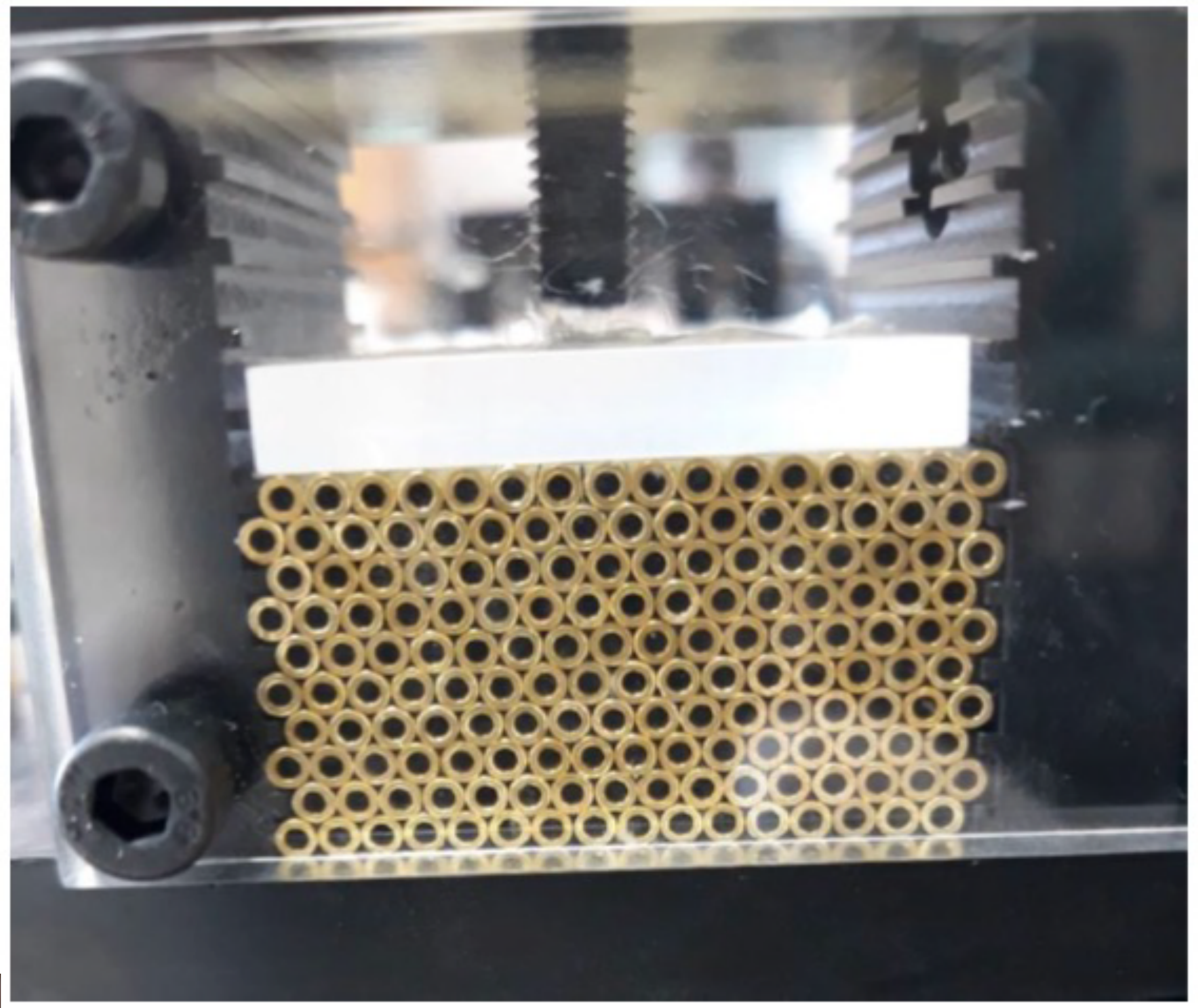


Dual Readout Calorimeter

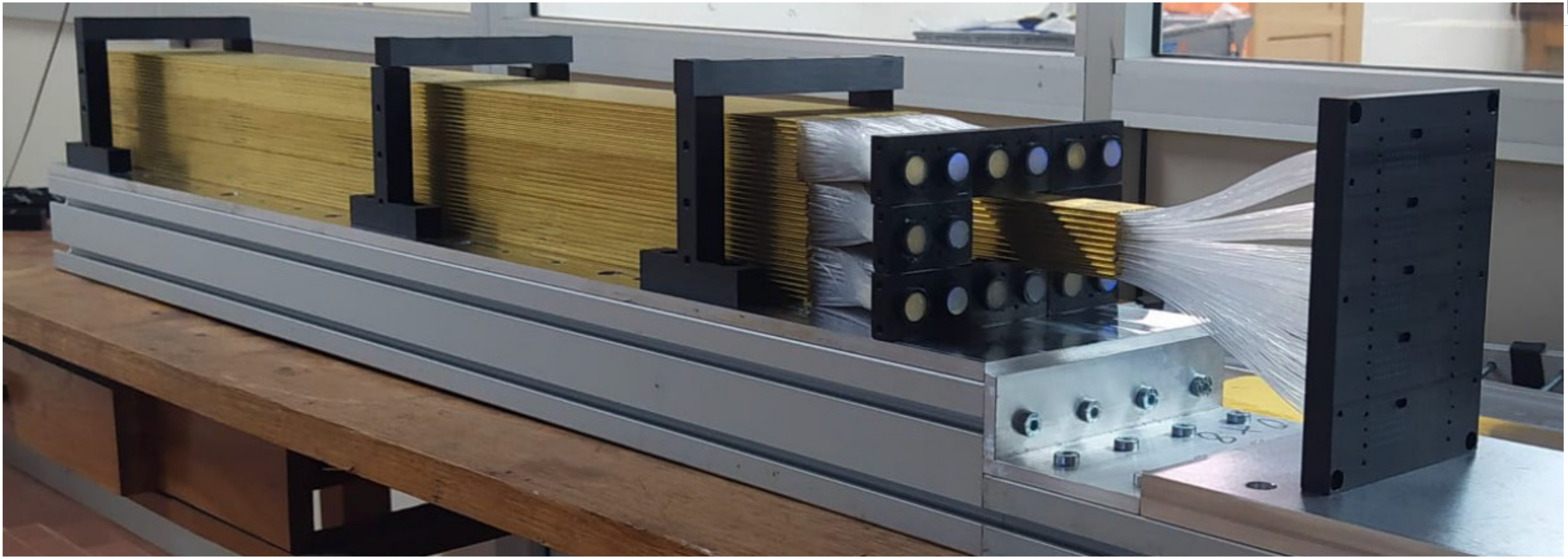




DR calorimeter



- International collaboration:
  - TTU (USA), Sussex (UK), several universities (Korea – 2 M$/5 yr), Chile
  - Princeton, Maryland (USA), CERN for crystal extension
- EM prototype built and tested on beams (DESY/CERN)



DR calorimeter

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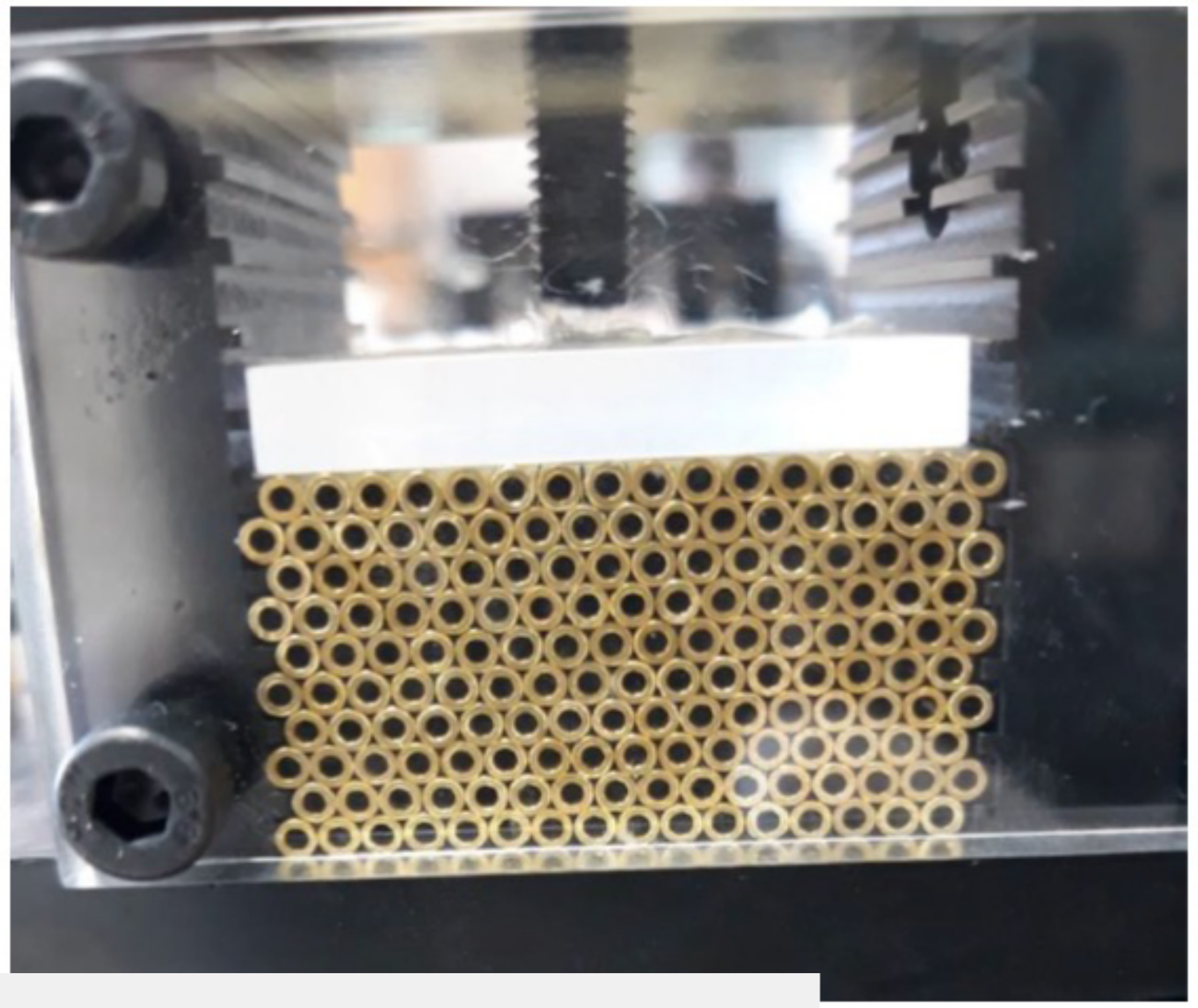
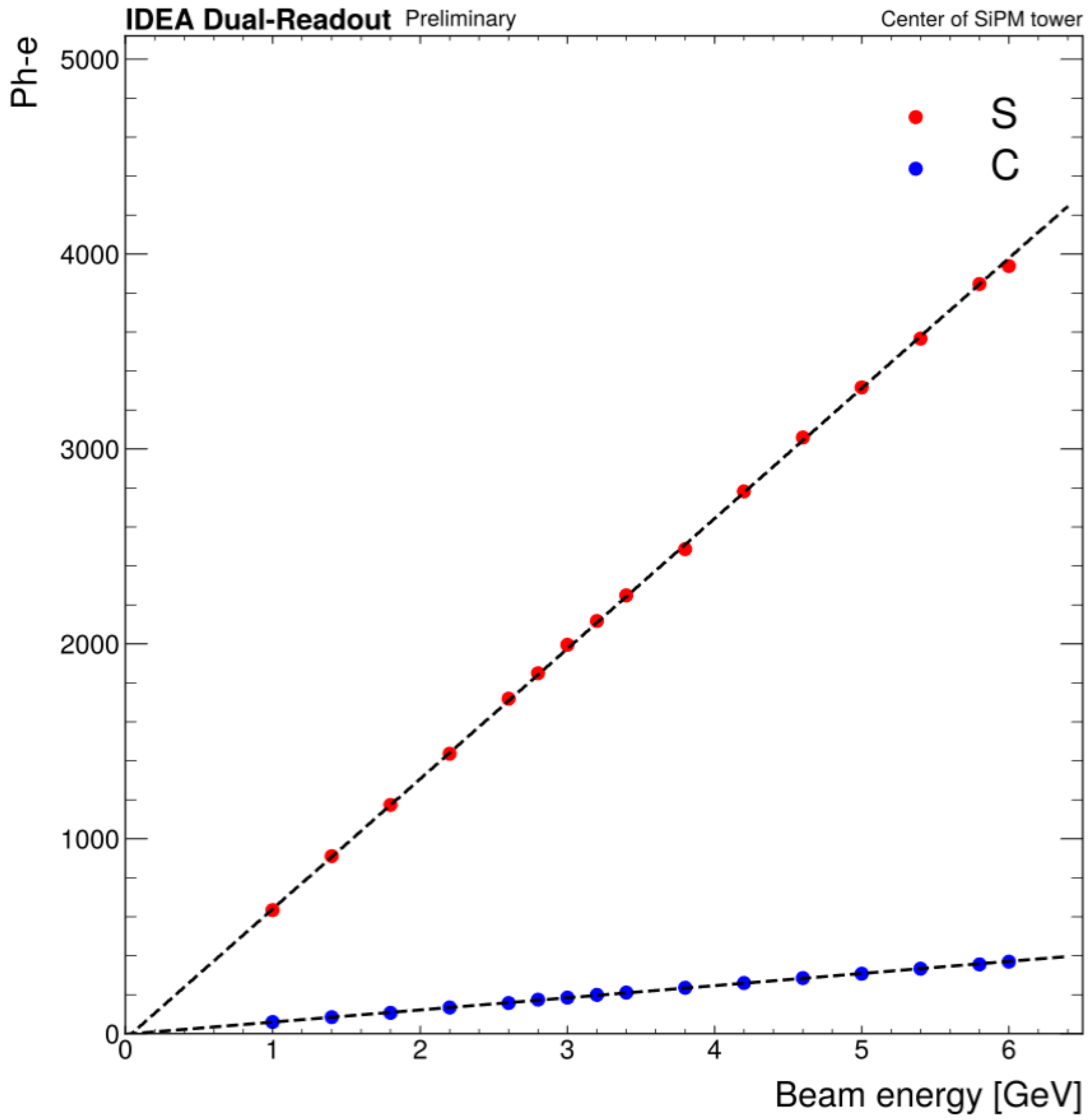
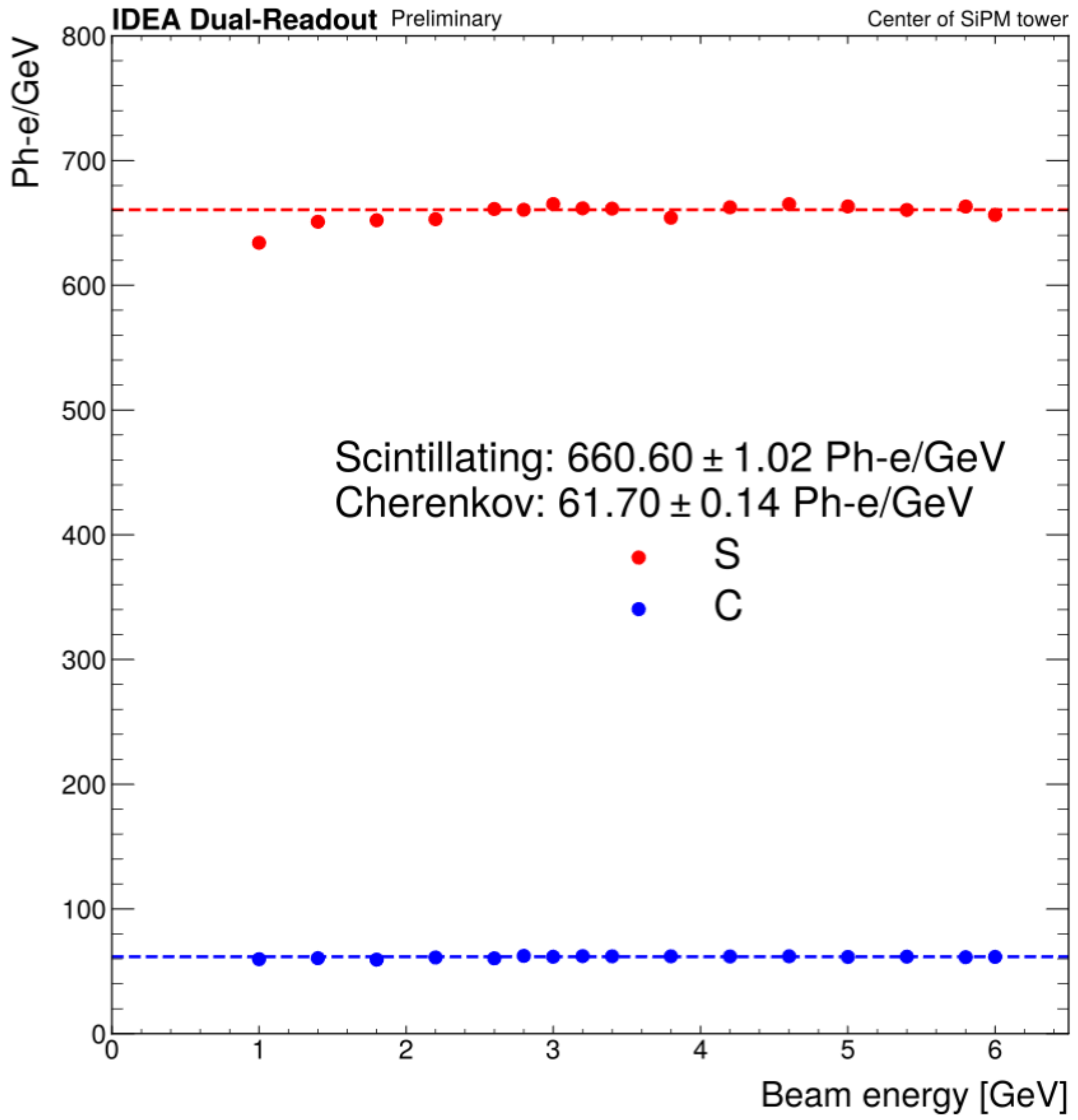
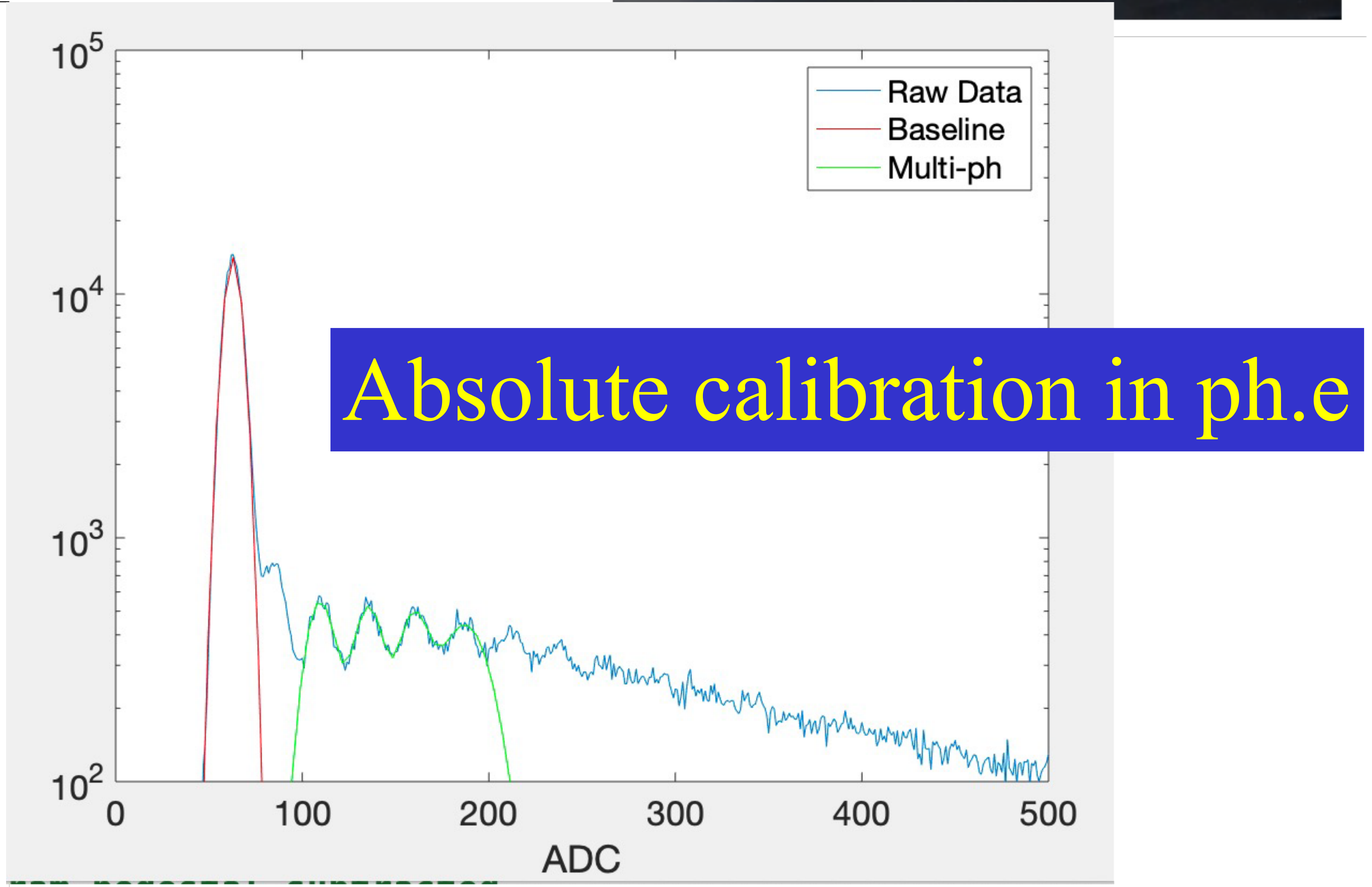




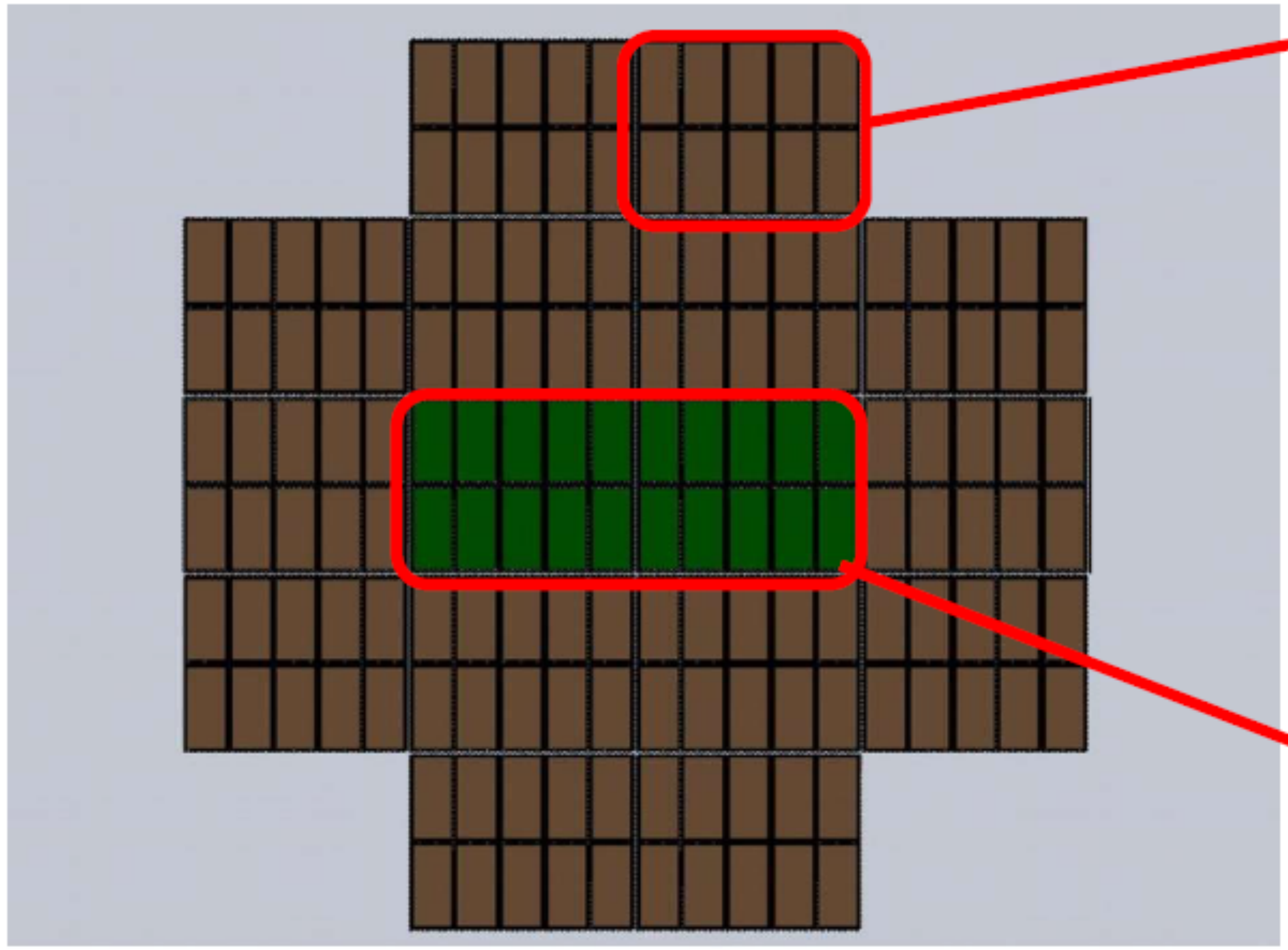




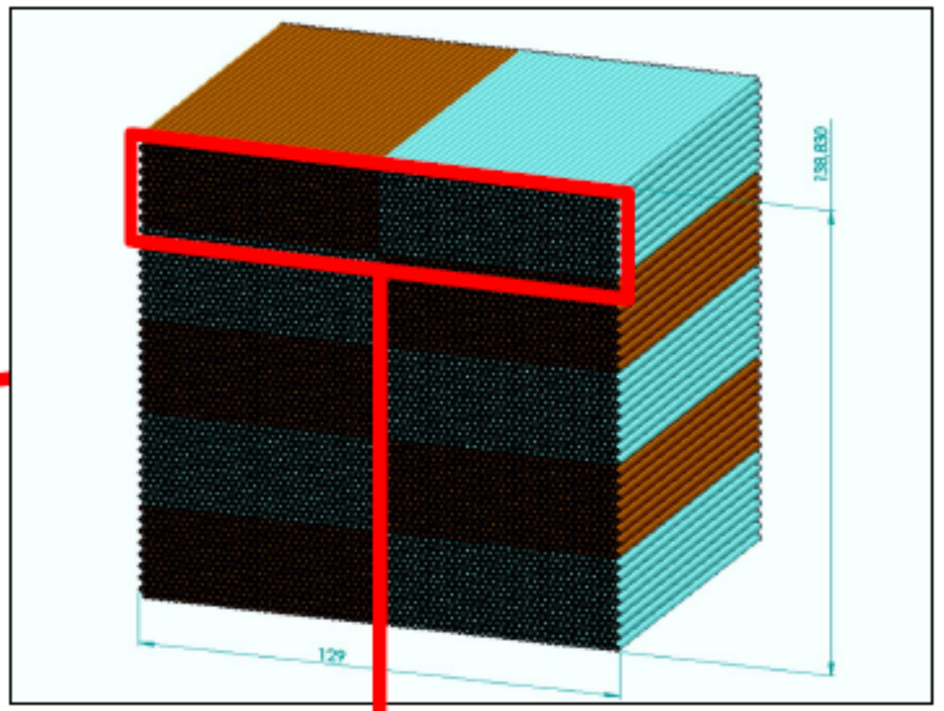
DR calorimeter

- Full containment hadronic prototype in progress
  - Hidra2 call CSN5

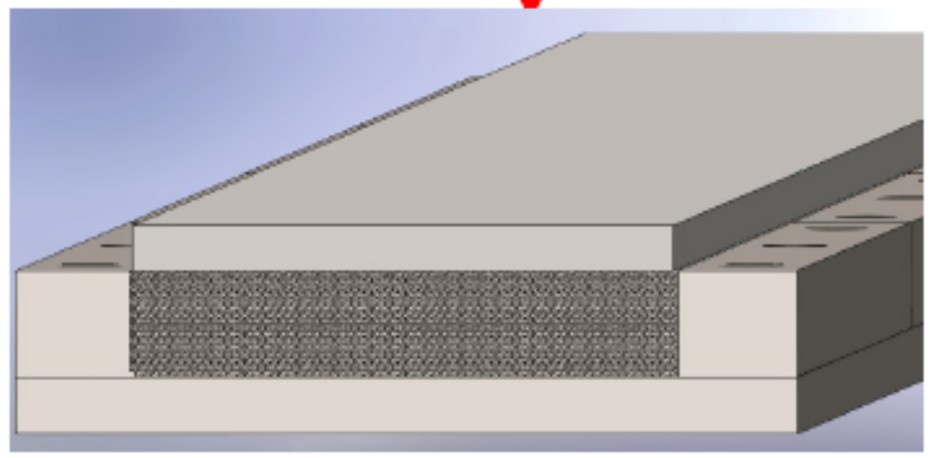
Hadronic-size prototype:
16 modules w/ highly granular core



~ 65 × 65 × 250 cm^3



1 Module: 5 MMs
~ 13 × 13 cm^2
5120 fibres

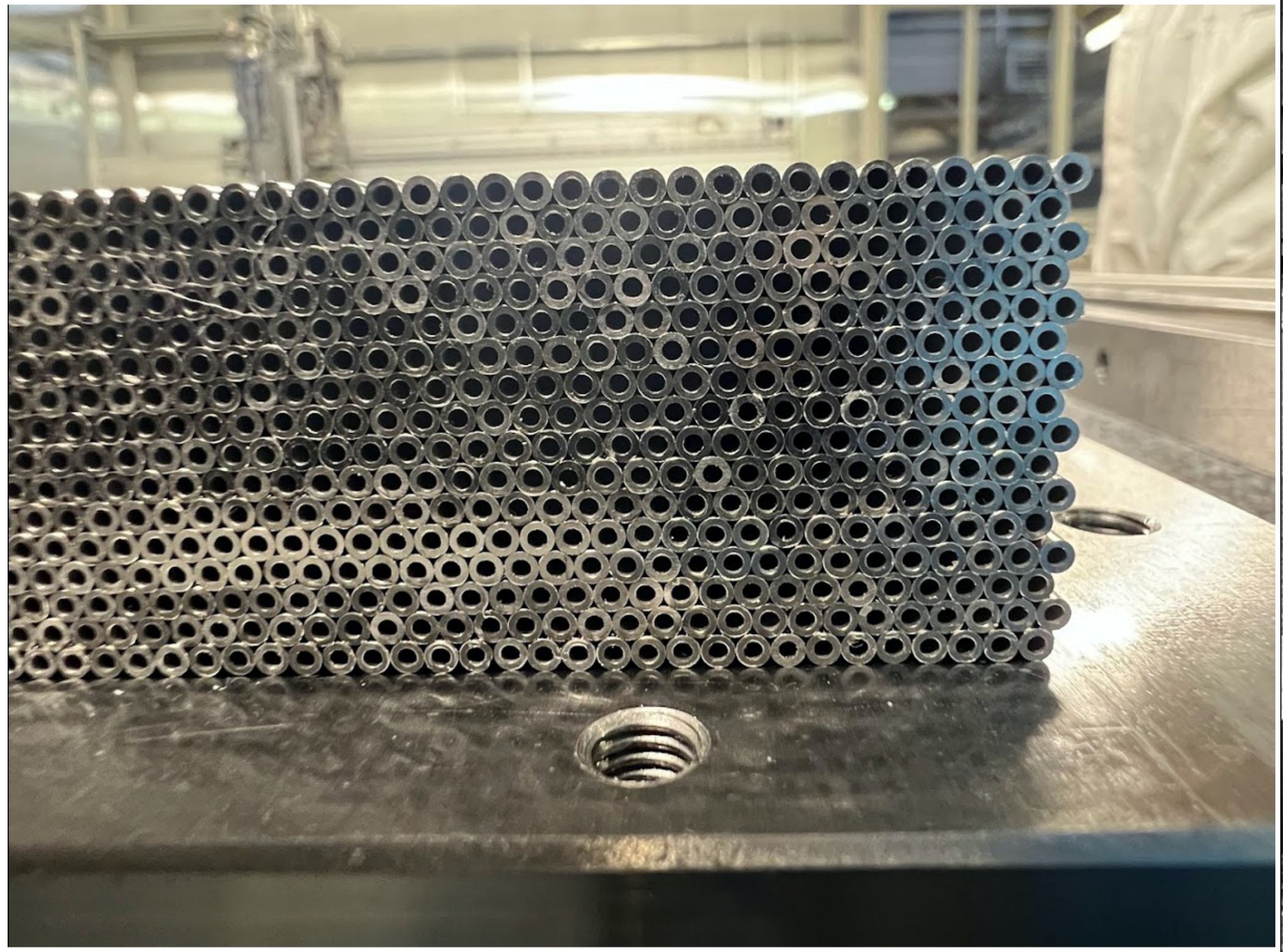


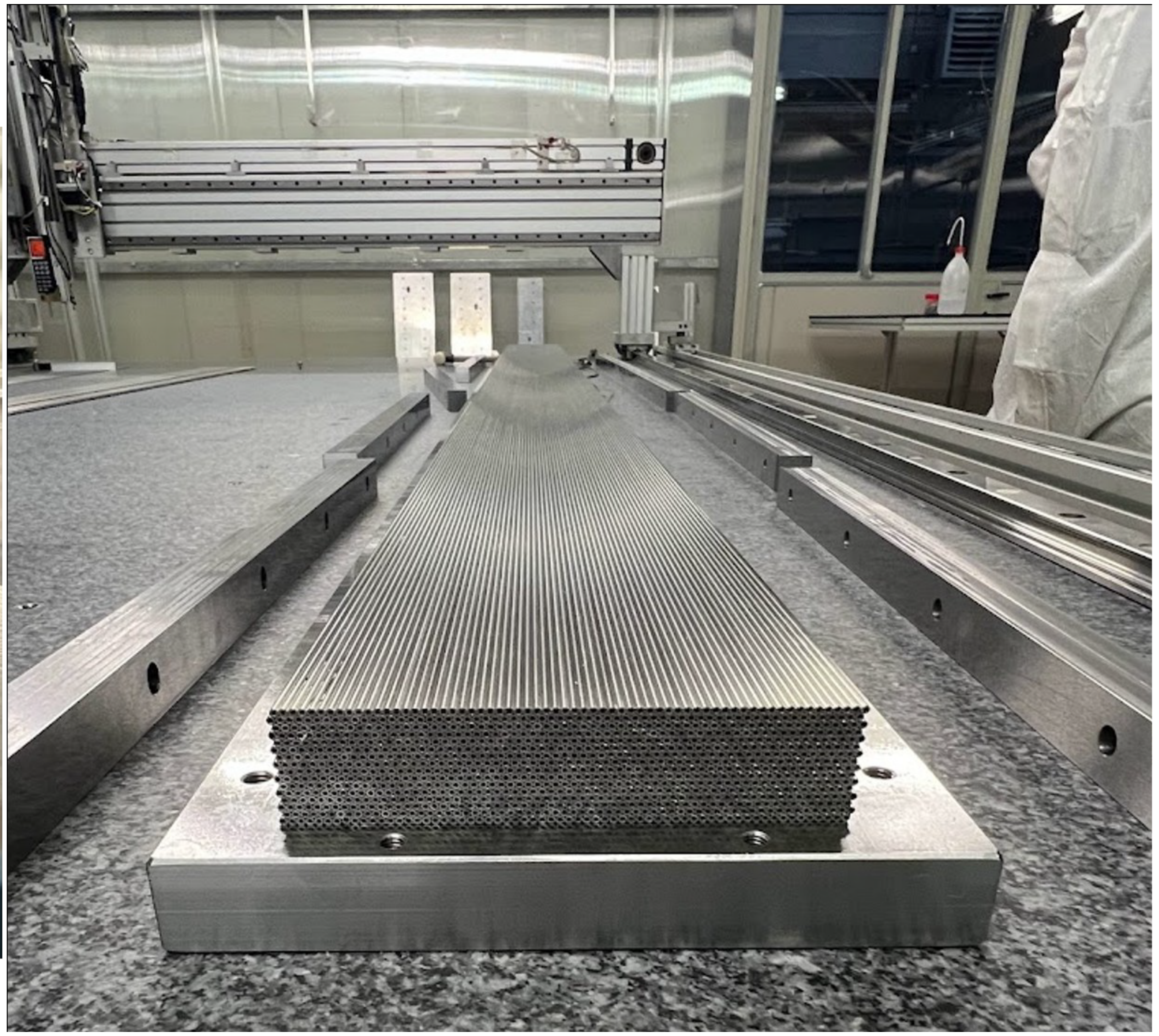
1 MiniModule:
64 × 16 = 1024 fibres in total
(512 S + 512 C)

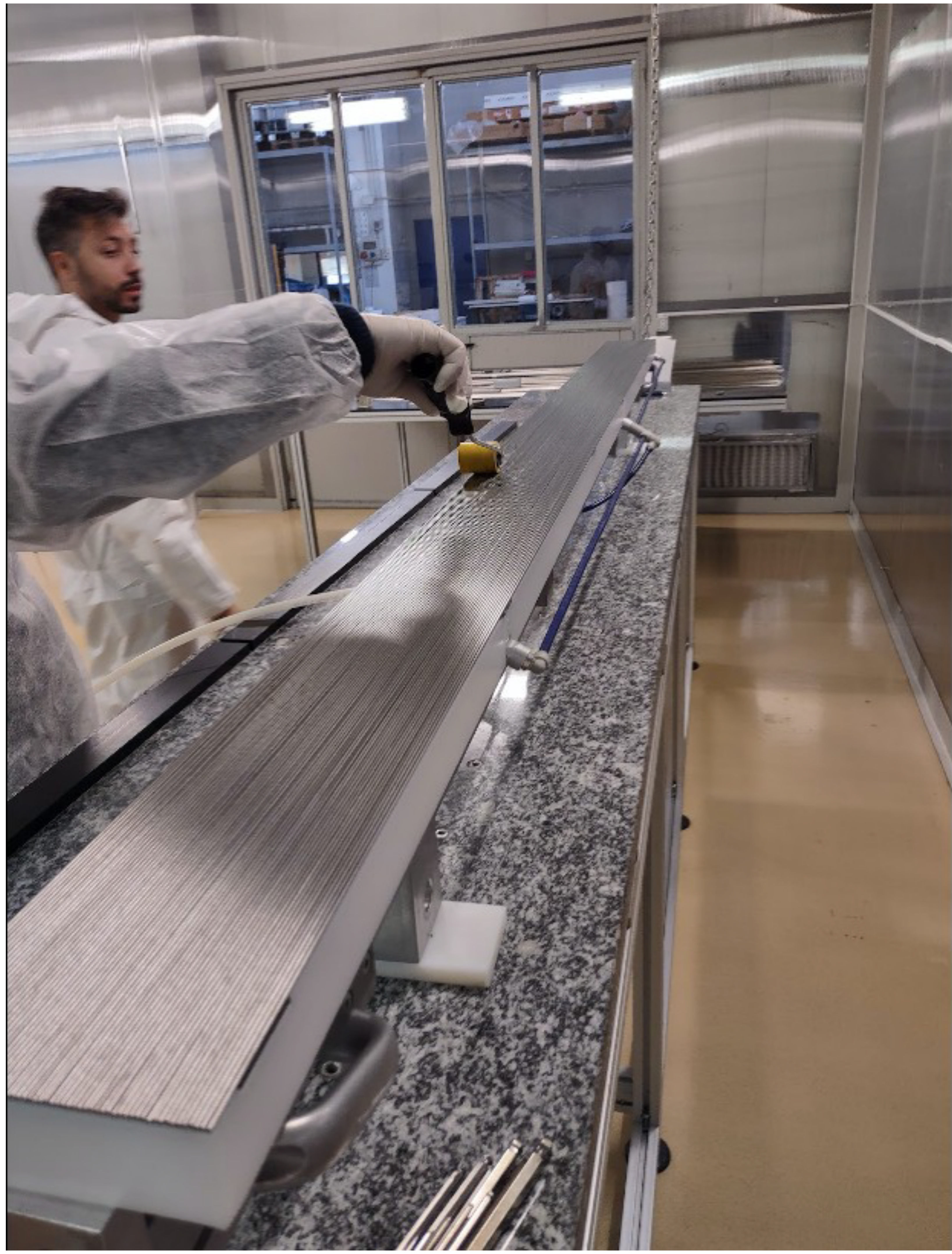
highly granular core:
10240 fibres to read out with SiPMs

DR calorimeter

- Full containment hadronic prototype in progress
  - Hidra2 call CSN5

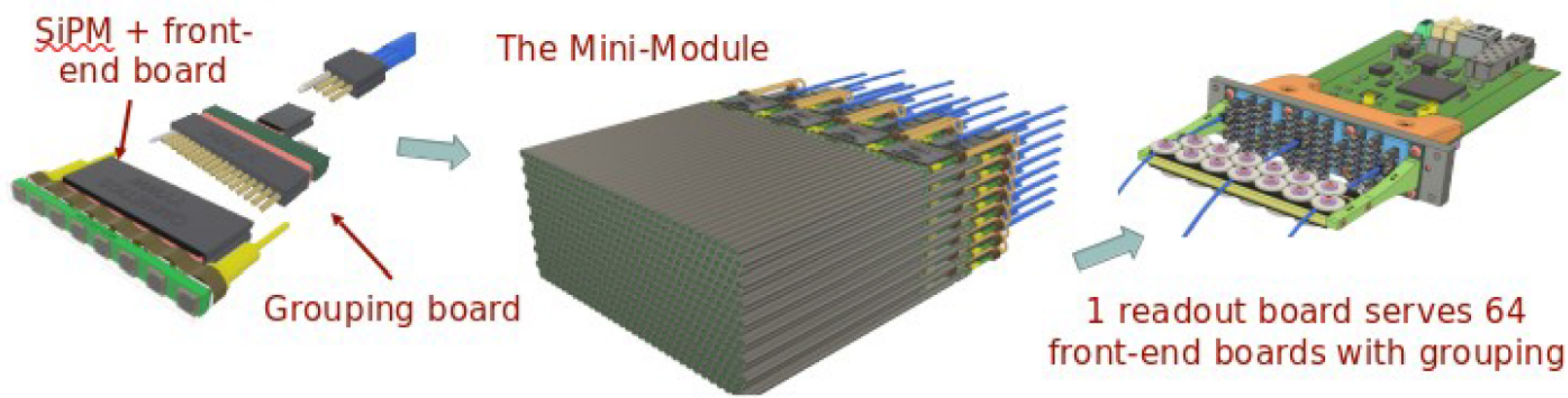






DR calorimeter

- ❖ Full containment hadronic prototype in progress
  - ➢ Hidra2 call CSN5

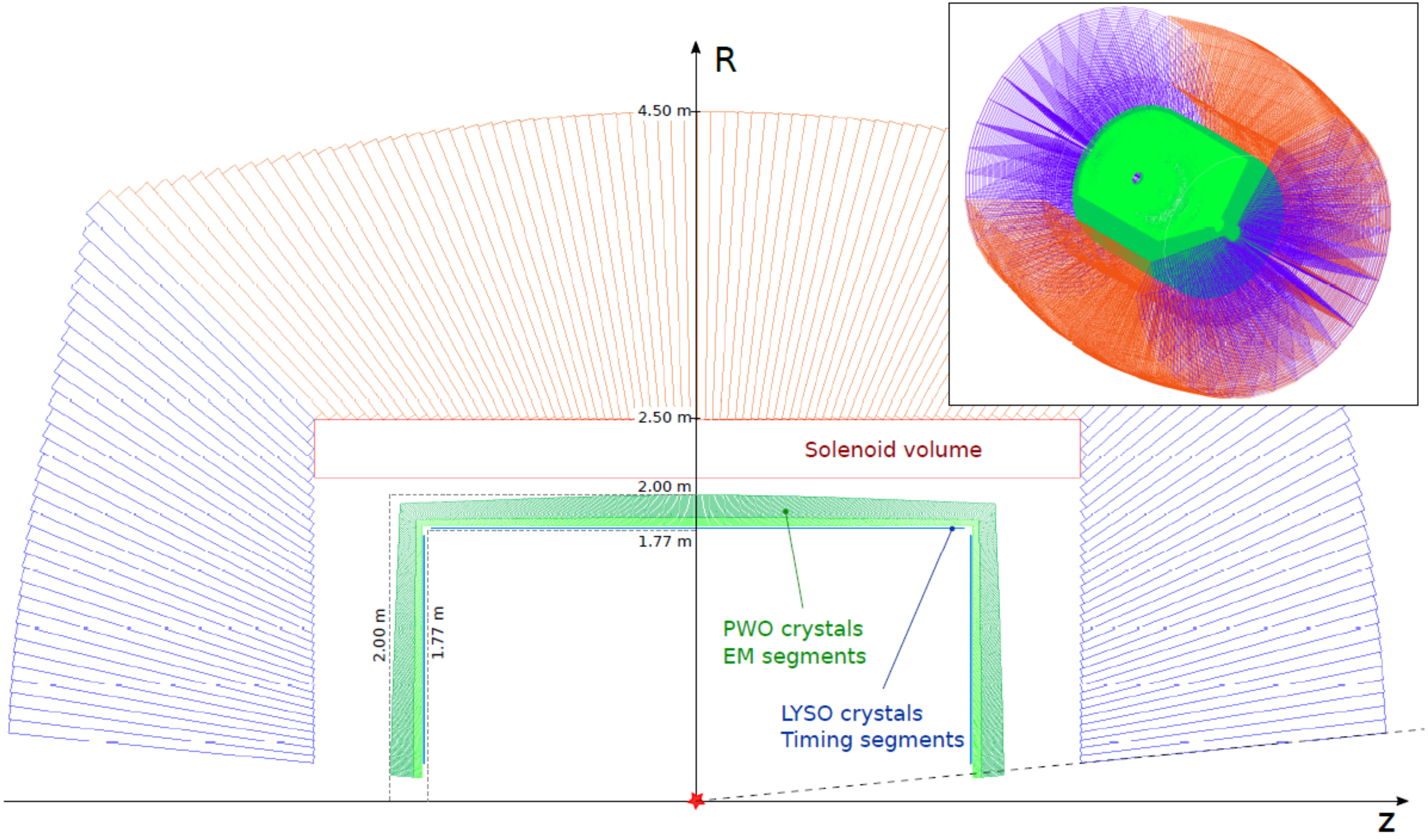


Dual readout future plans

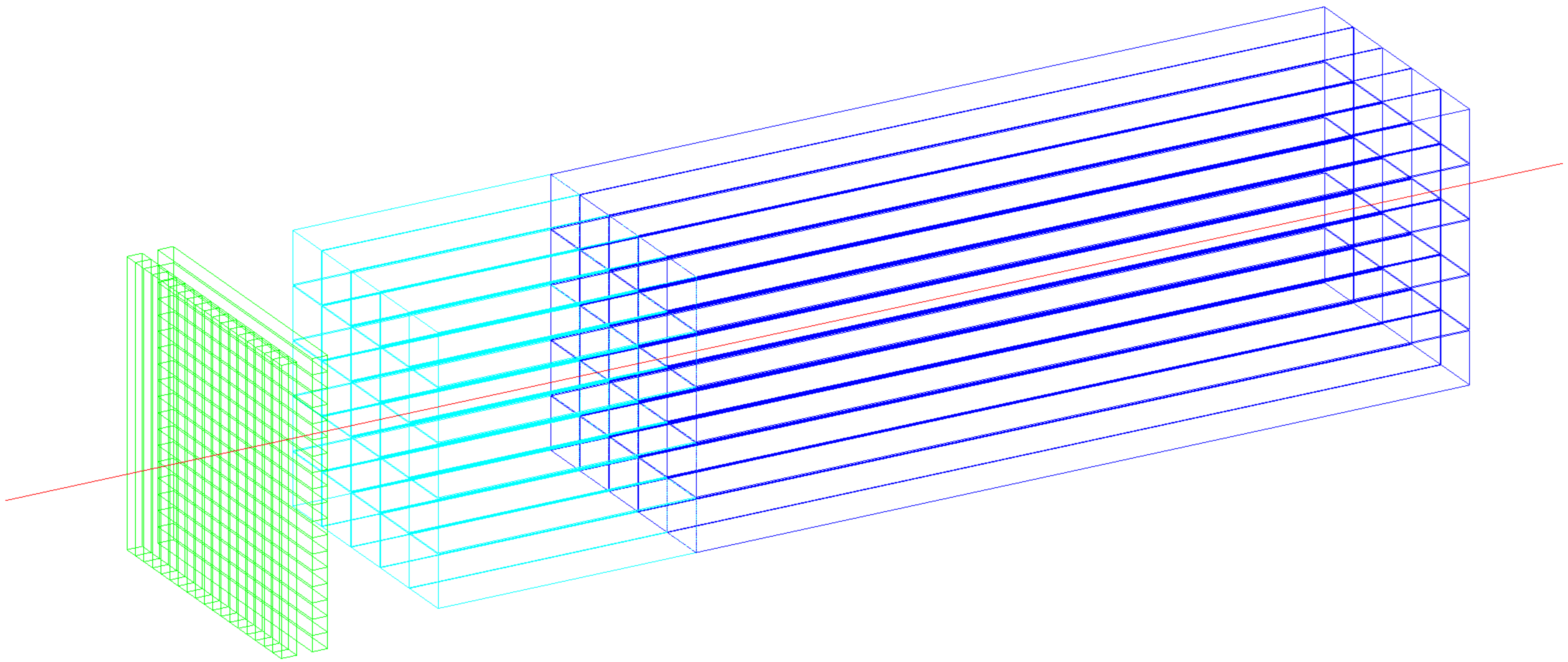
- Complete construction/test of Hidra2 prototype (two years)
  - Demonstrate resolution with full containment
- Develop scalable readout electronics (few years)
- Optimize metal matrix mechanics for large production (few years)
- Develop mechanical model of full system with services (few years)

- Towards a DR calorimeter TDR

Crystal option



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)

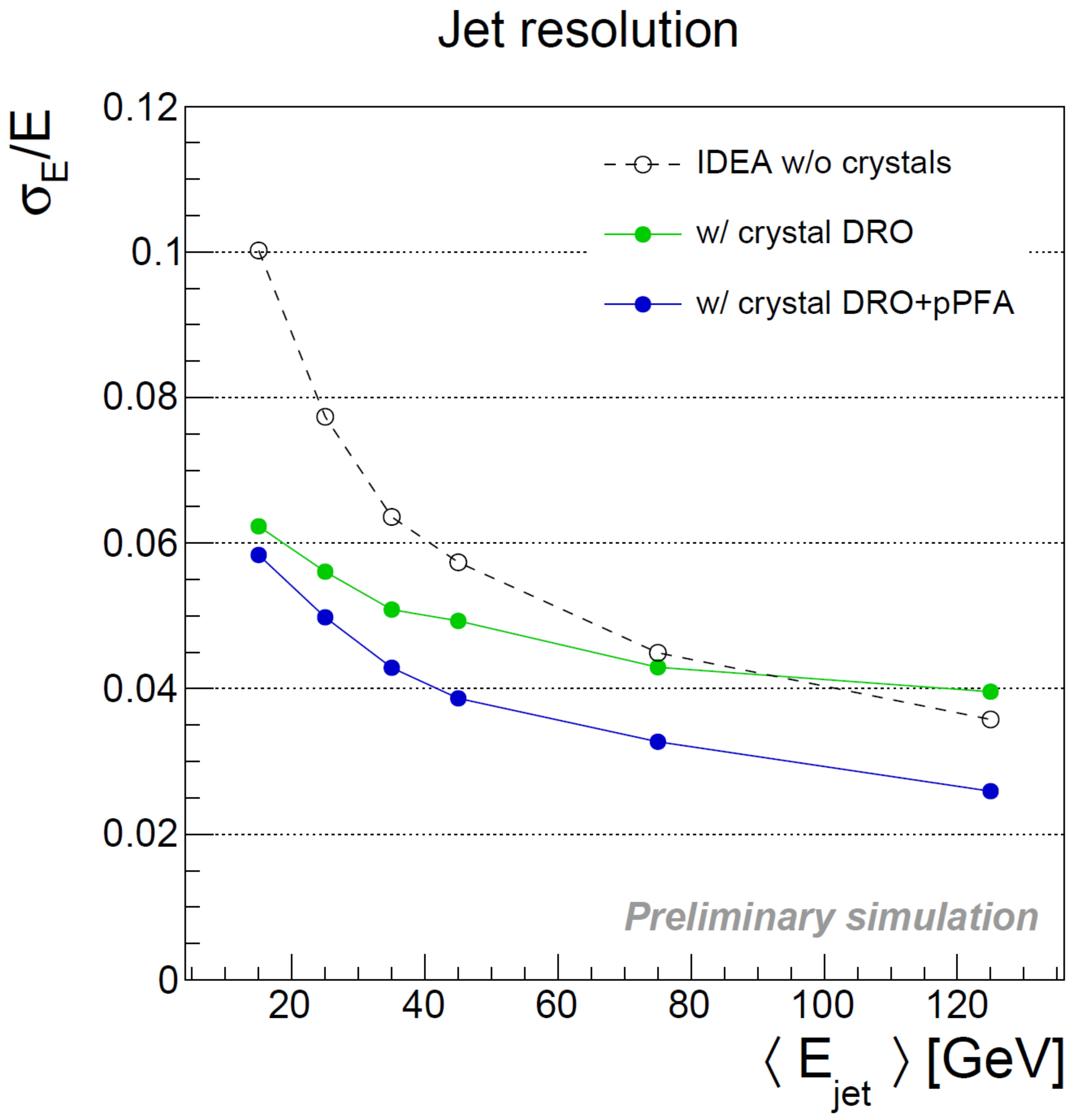
1x1x5 cm³
PbWO

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



Crystal option future plans

- Optimize crystal choice (few years)
- Develop scalable readout electronics (few years)
- Re-optimize fiber DR calorimeter (few years)
- Develop mechanical model of full system with services (few years)

- Towards an EM calorimeter TDR

μ-RWELL technology

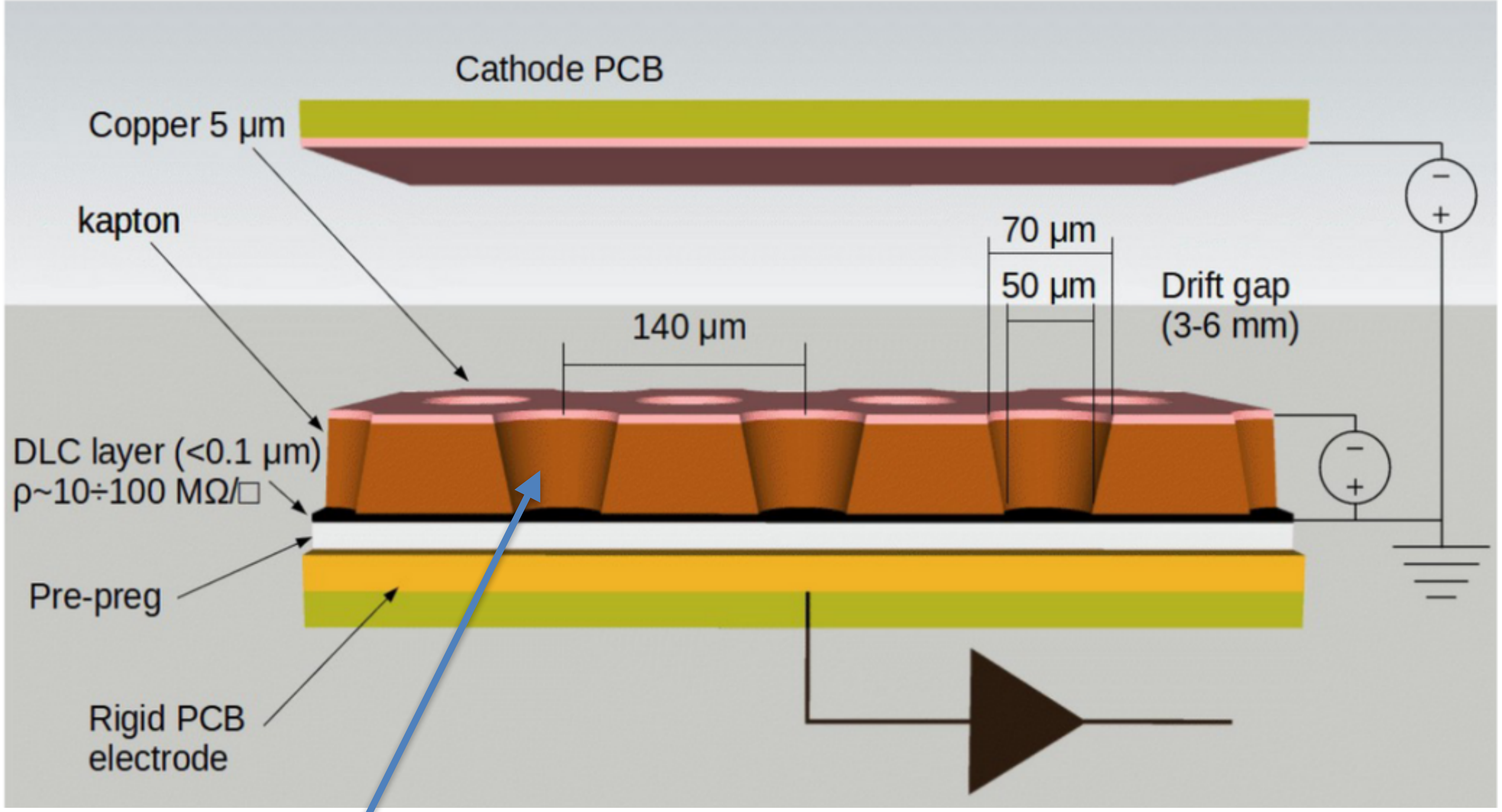
The μ-RWELL is composed of only two elements:

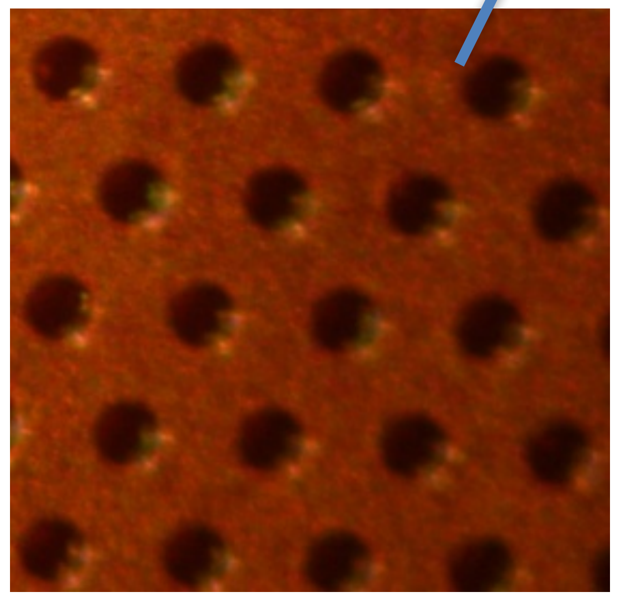
- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

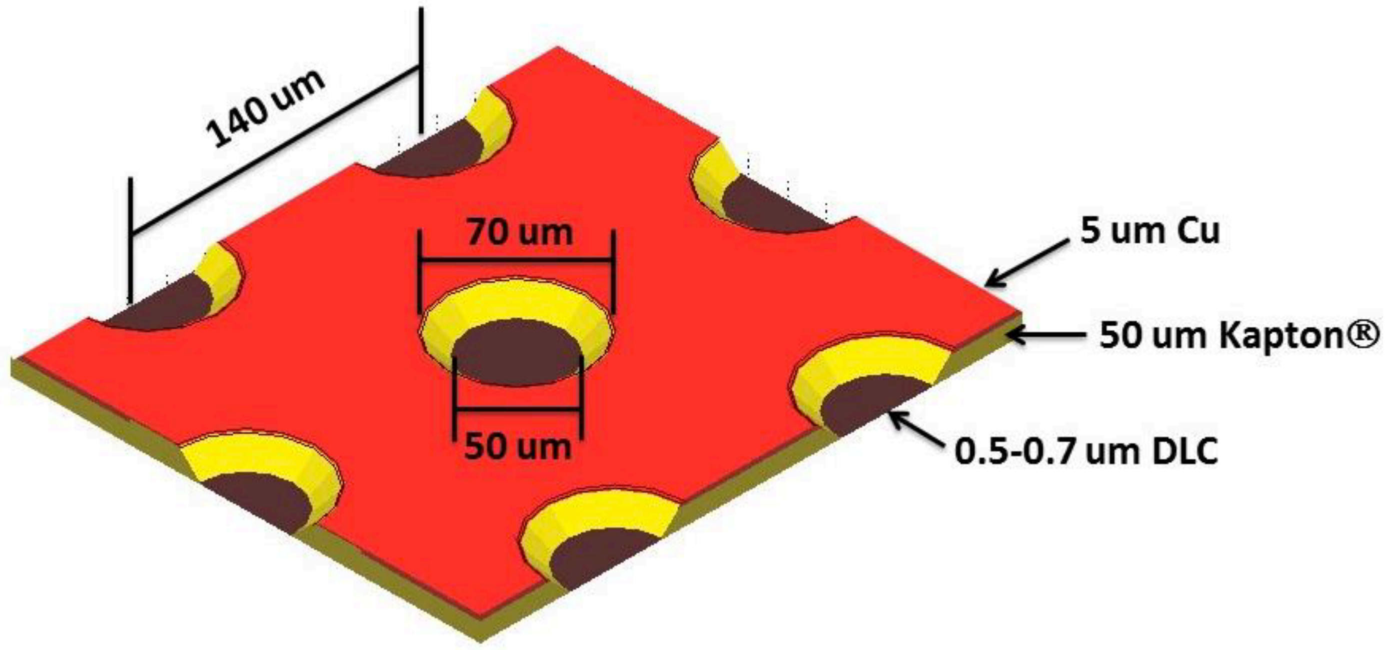
μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB

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







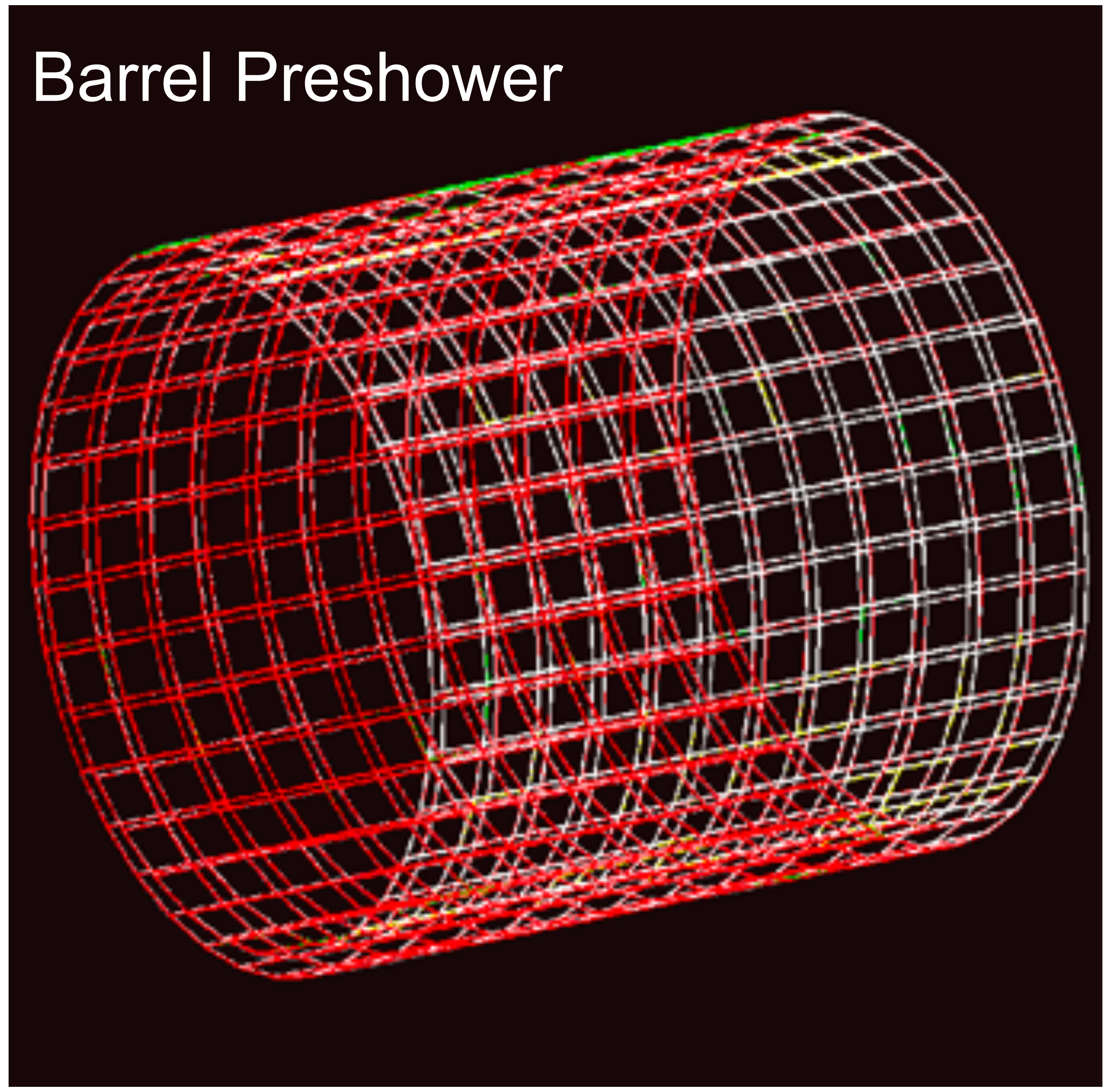
(*) G. Bencivenni et al., "The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD", 2015_JINST_10_P02008)

Preshower and muon detector

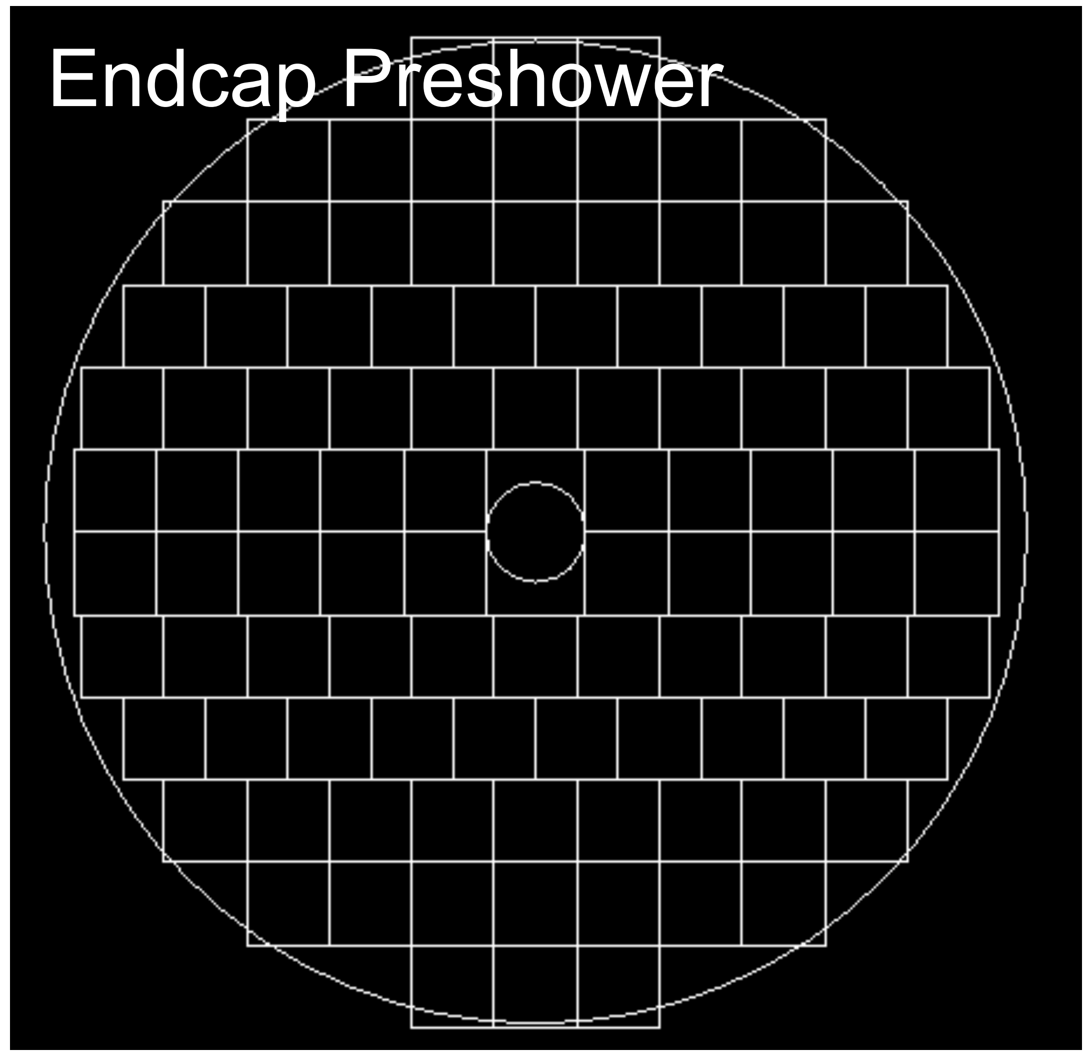
Preshower Detector

High resolution before the magnet
to improve cluster reconstruction

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



Similar design for
the Muon detector



Similar design for
the Muon detector

Muon Detector

Identify muons and search for LLPs

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

Detector technology: μ-RWELL

50x50 cm^2 2D tiles to
cover more than 4330 m^2

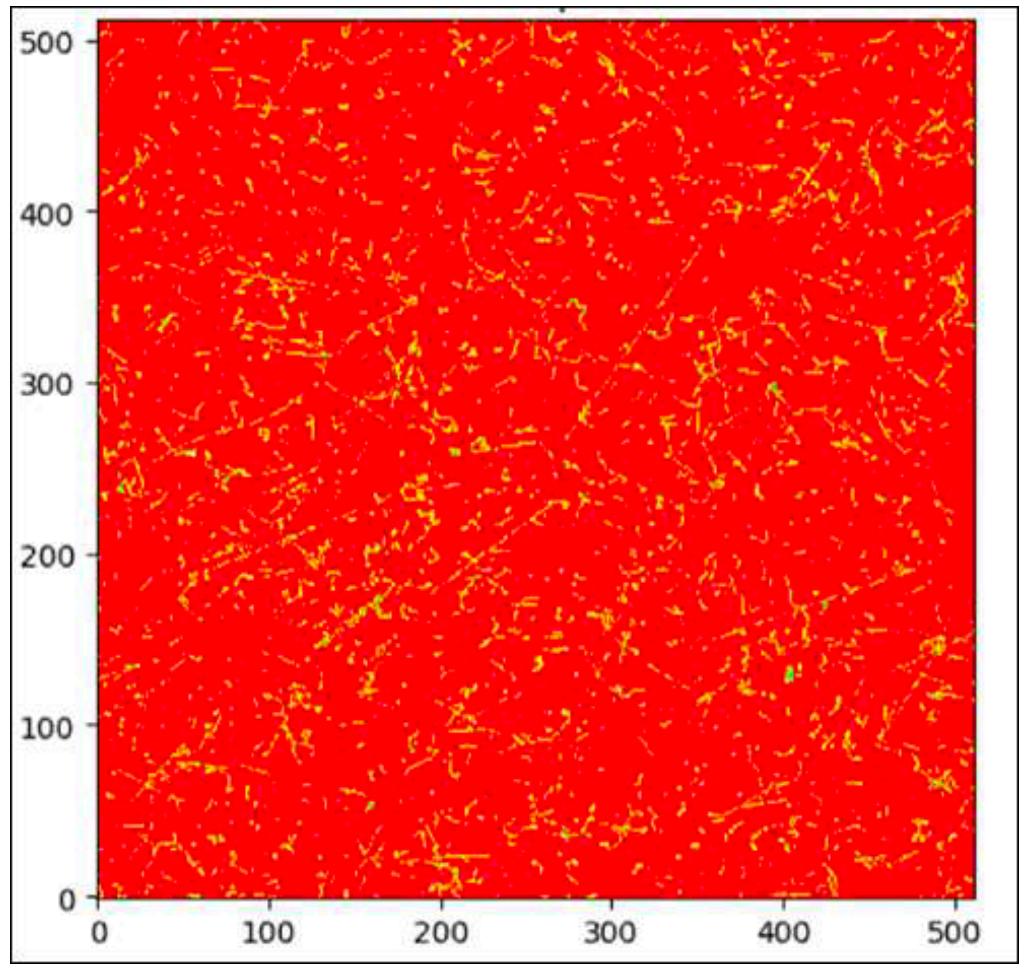
Preshower	Muon
pitch = 0.4 mm	pitch = 1.2 mm
FEE capacitance = 70 pF	FEE capacitance = 220 pF
1.3 million channels	5 million channels

Ongoing R&D

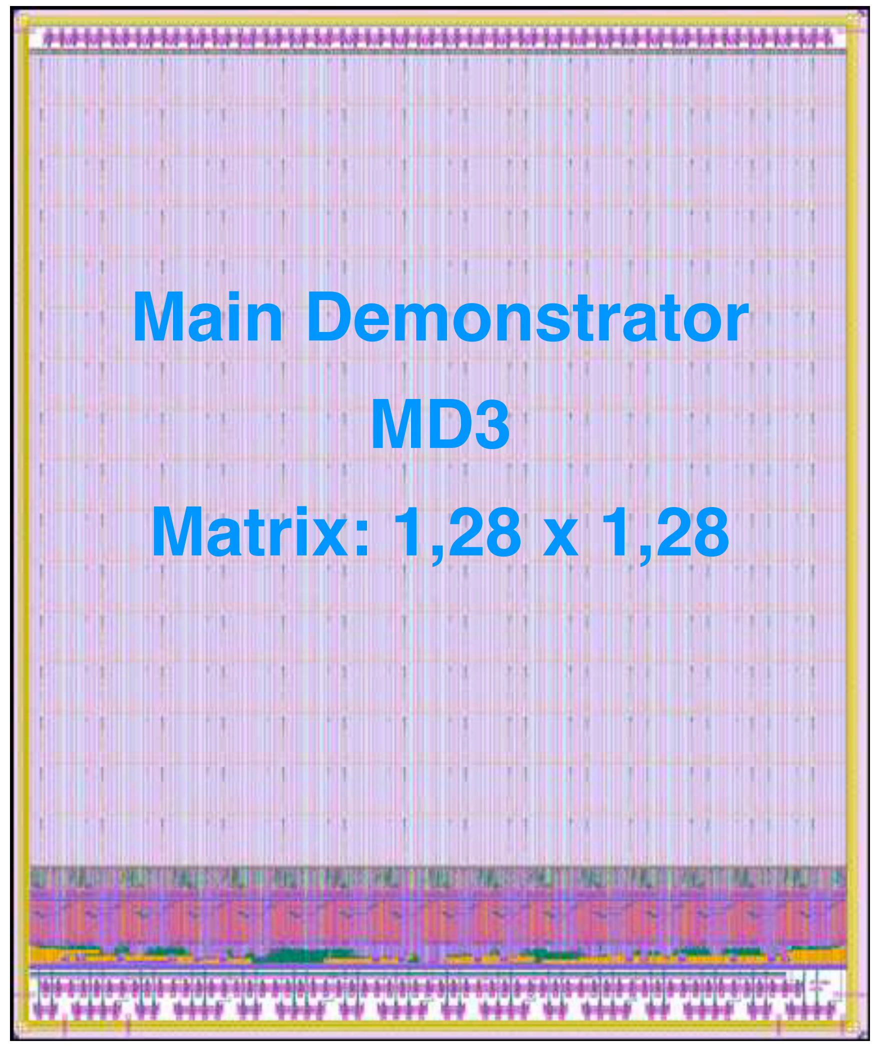
Click here for more R&D information

ARCADIA MD3 test

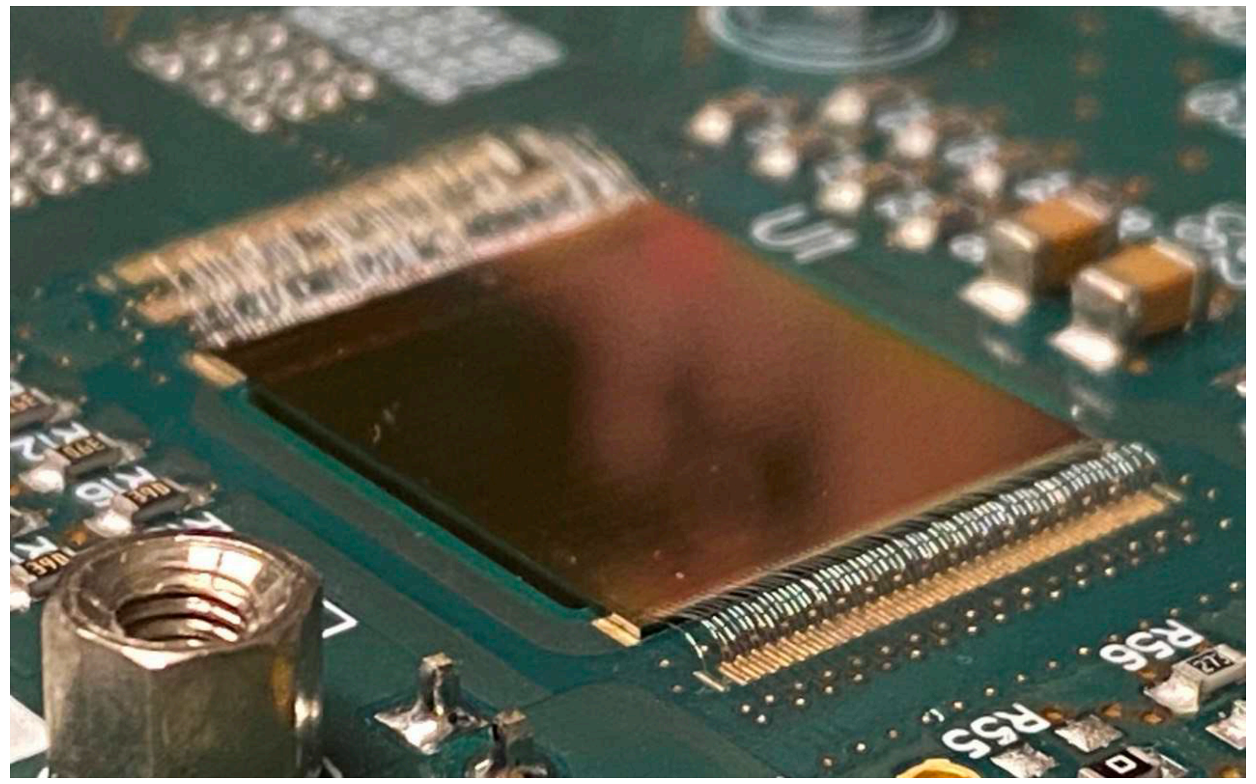
- 3 engineering runs with:
  - full-scale DMAPS
  - sensor R&D (monolithic FD-strips and readout, fast sensors with gain layer)
- High rate capability (100 MHz/cm^2) architecture on a scalable 512x512 pixel matrix (25 μm pitch) **MD3 Main Demonstrator chip:**
  - measured 30 mW/cm^2 at full-speed (16 data Tx active) and 10 mW/cm^2 on low-rate mode (1 data Tx active)

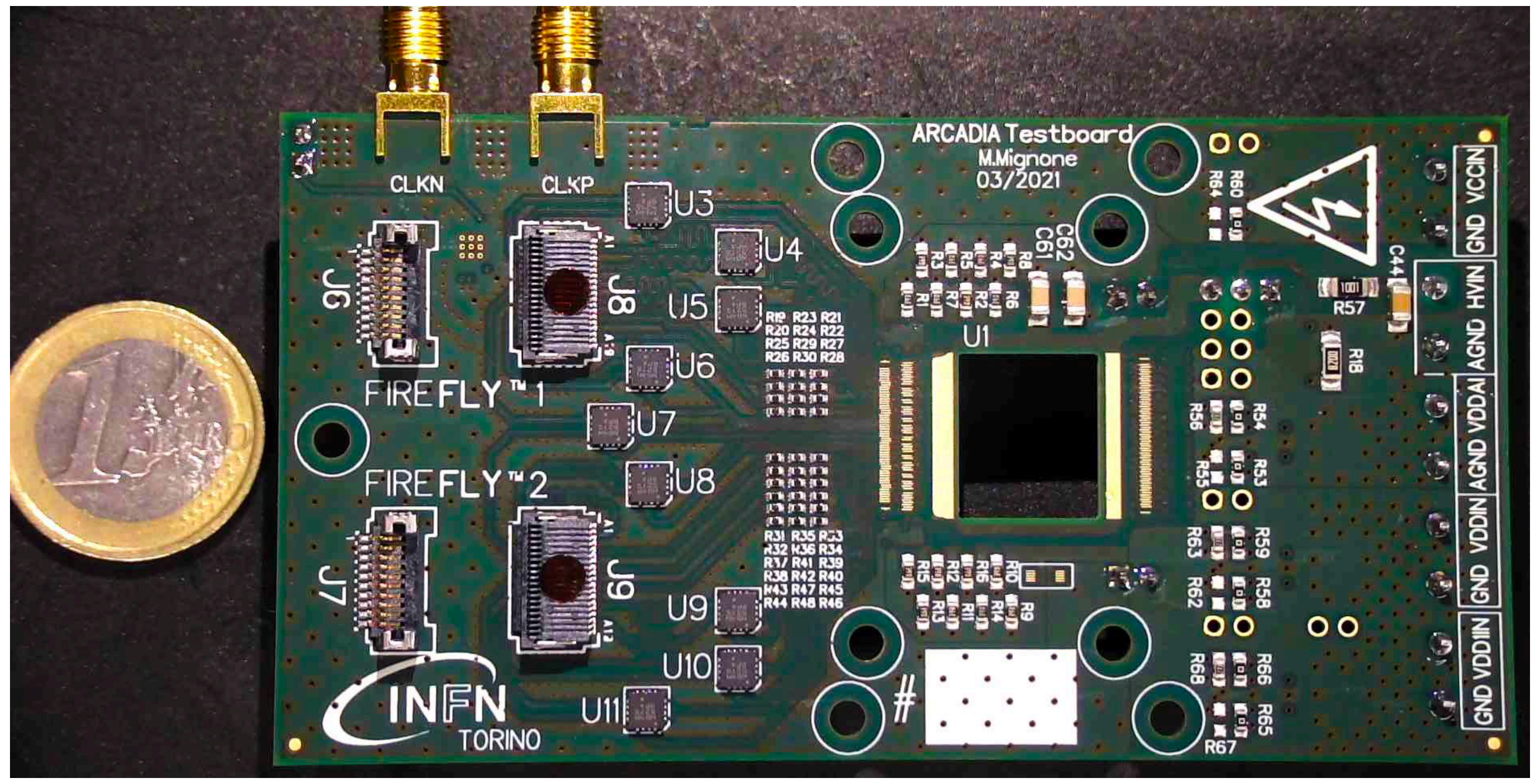


Cosmic ray data



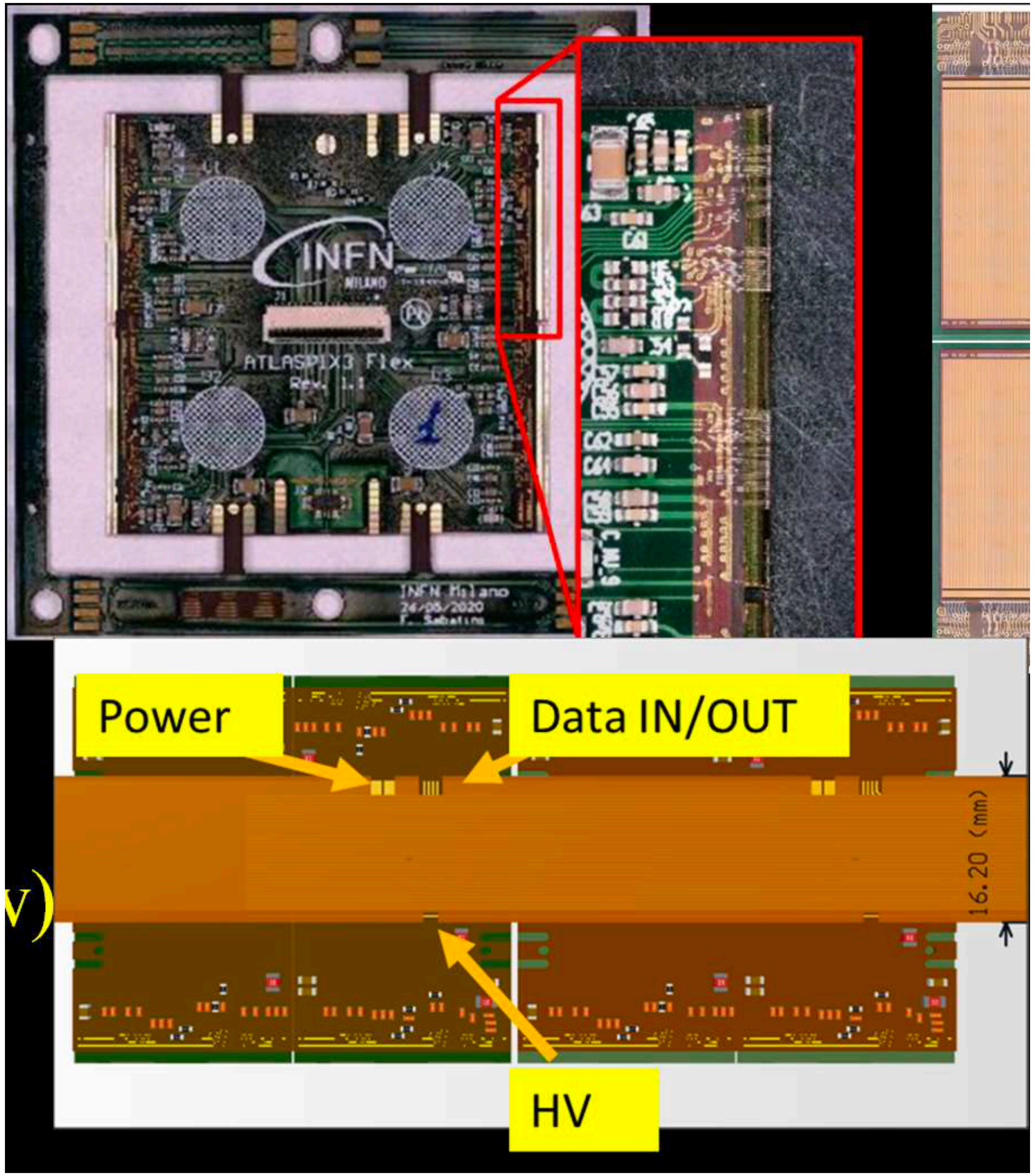
110 nm CMOS CIS technology, high-resistivity bulk, operated in full depletion mode





Silicon detectors: ATLASPix3

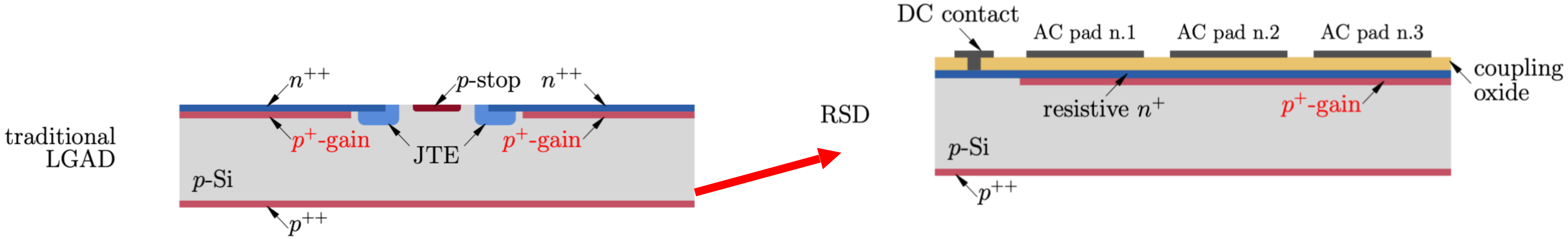
- Based on ATLASPIX3 R&D
  - 50x50 μm²
  - Up to 1.28 Gb/s downlink
  - TSI 180 nm process
  - 132 columns of 372 pixels
- Active length (r-phi x z)
  - 18.6 mm x 19.8 mm
- Module is made of 2x2 chips
- Power goal 100 mW/cm² (175 now)

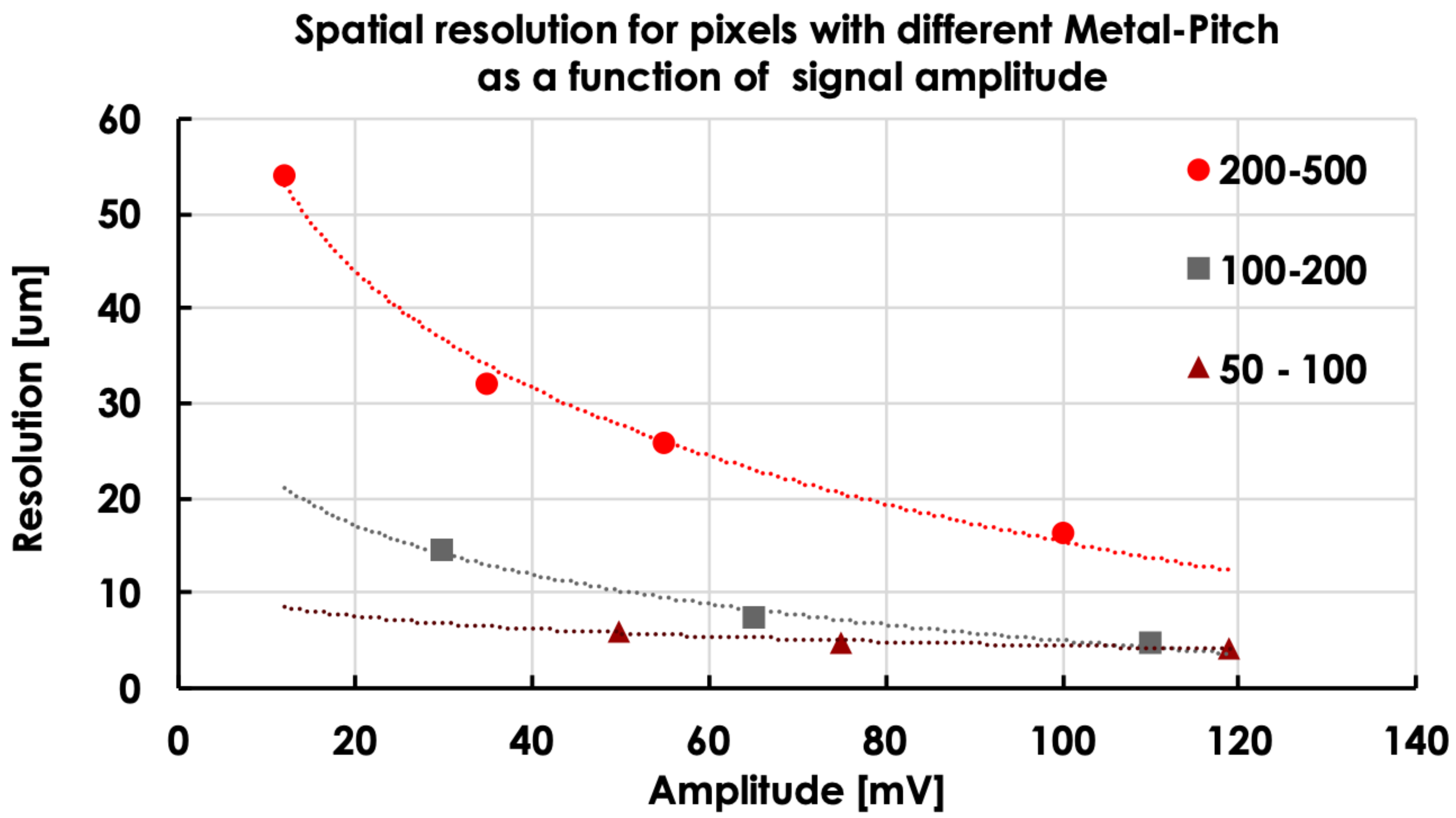


Resistive LGAD

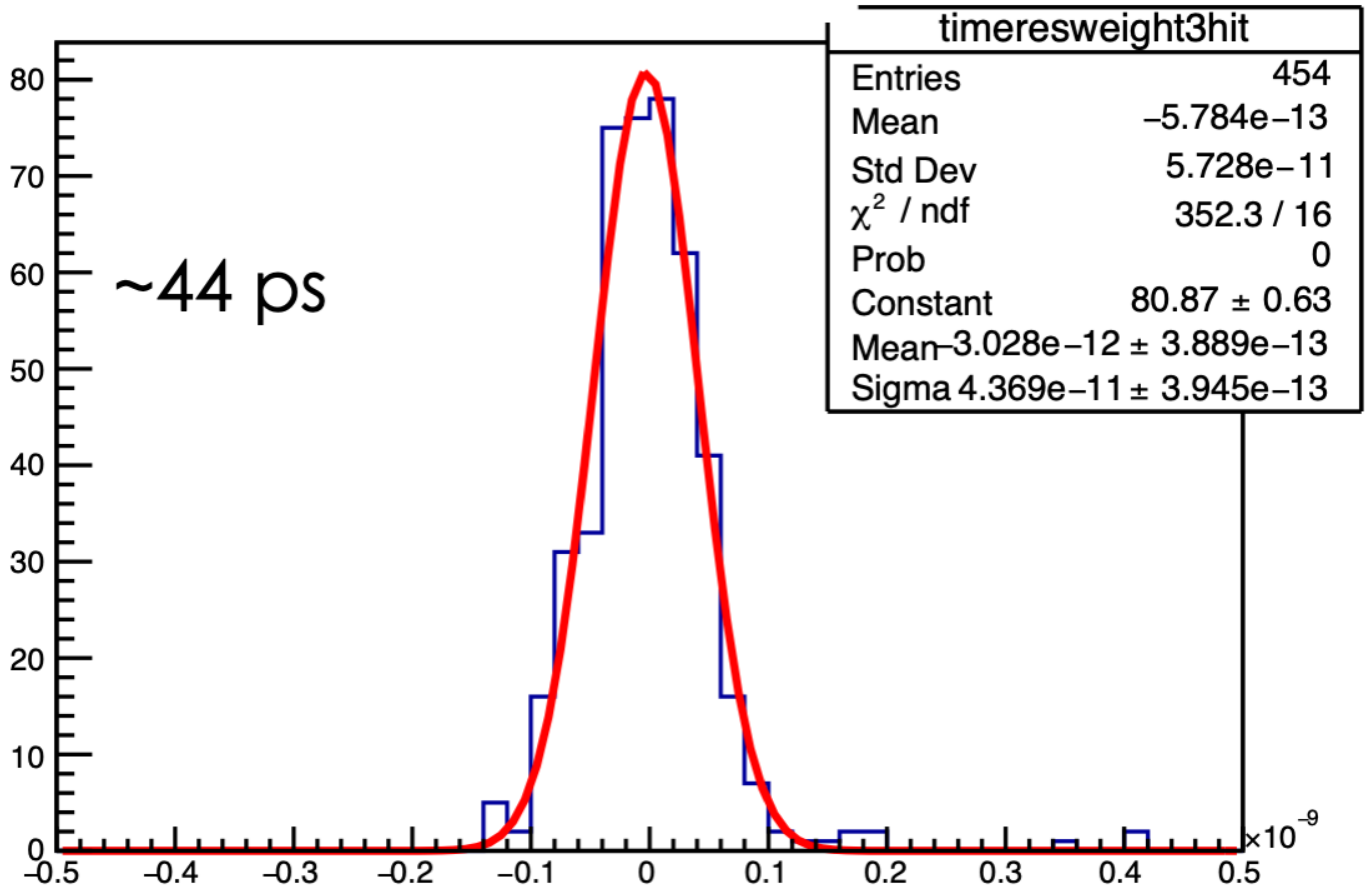
❖ Recent new activity with INFN-GE/(TO)

- Match time and position resolution





100 - 200



Resistive LGAD

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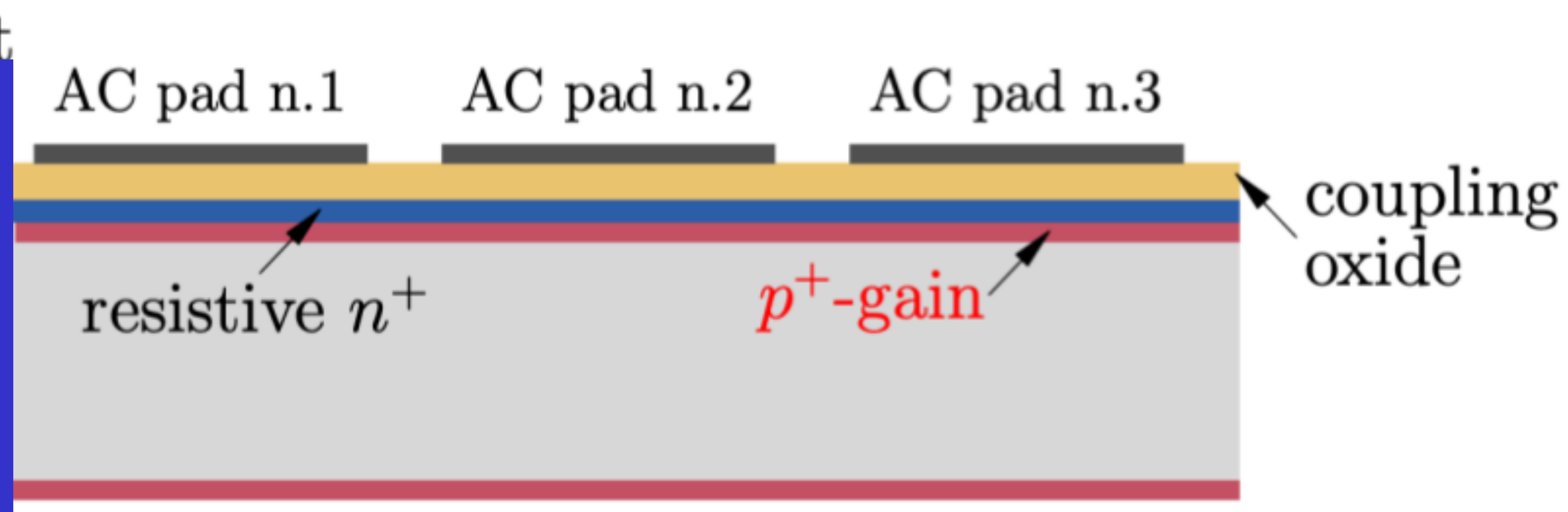


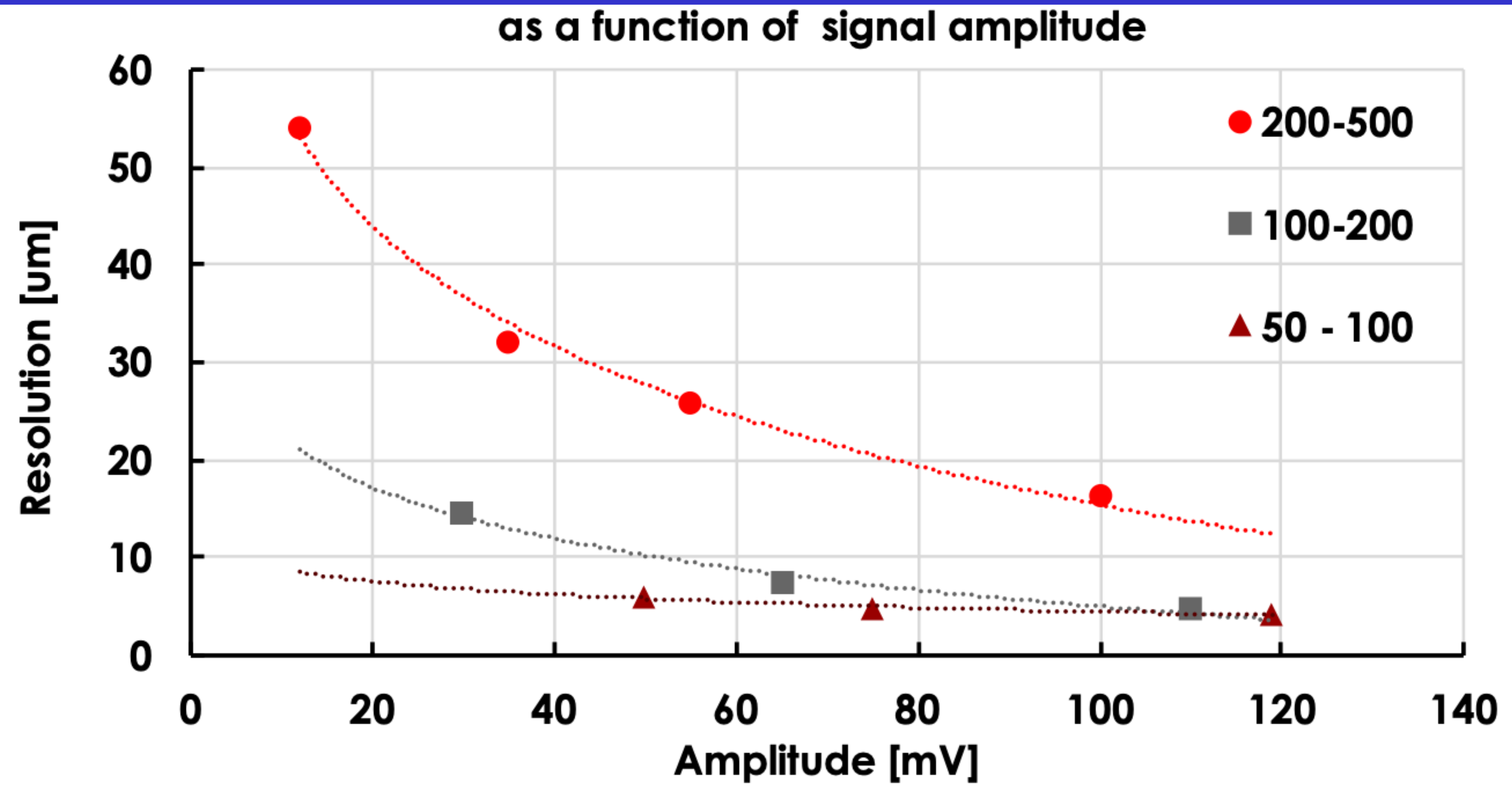
Very attractive option for timing in Si wrapper region

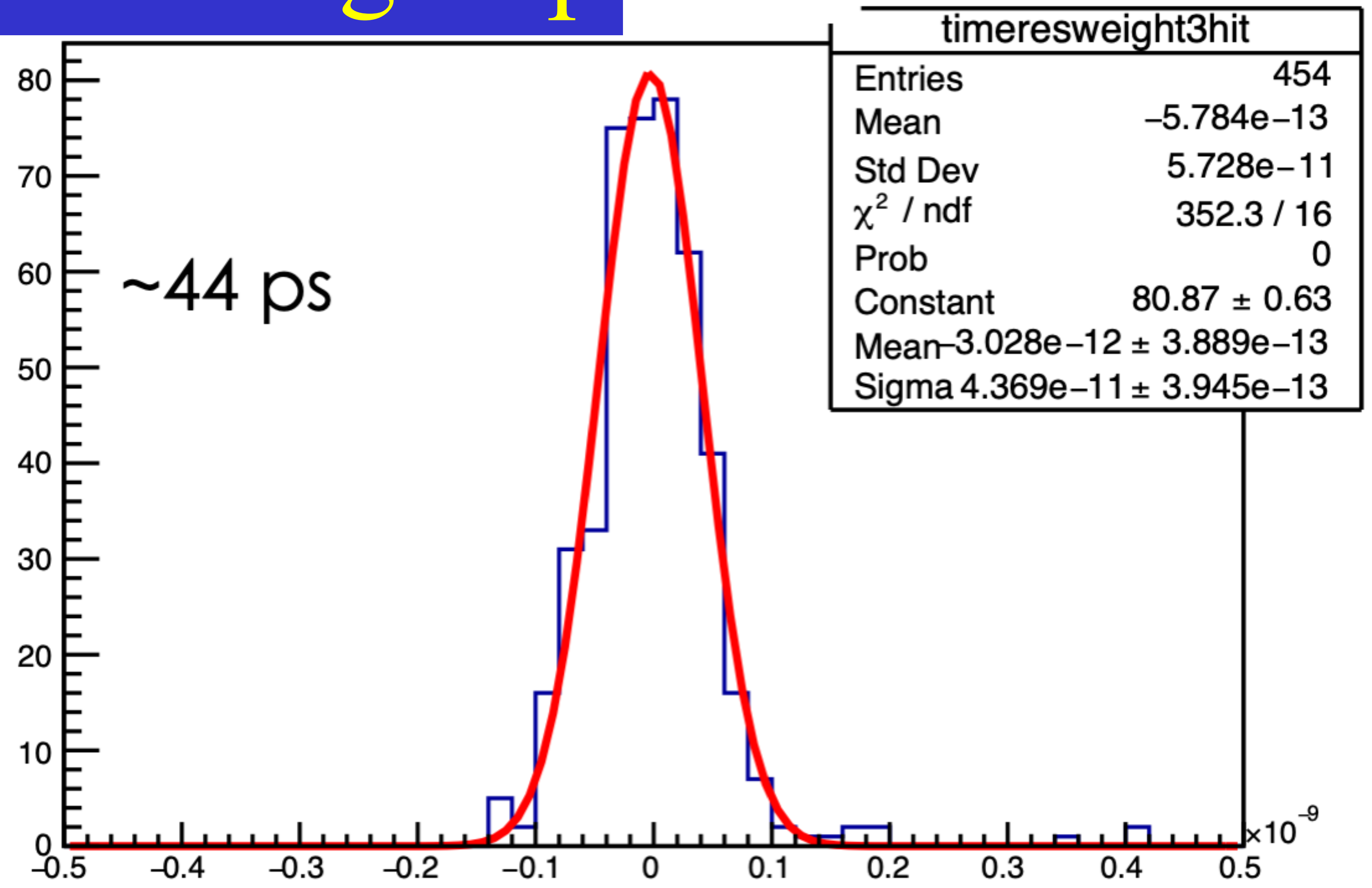
Cost reduction is major area of R&D

Interest from PG to contribute in this area

Some "fast" devices also prototyped by Arcadia group

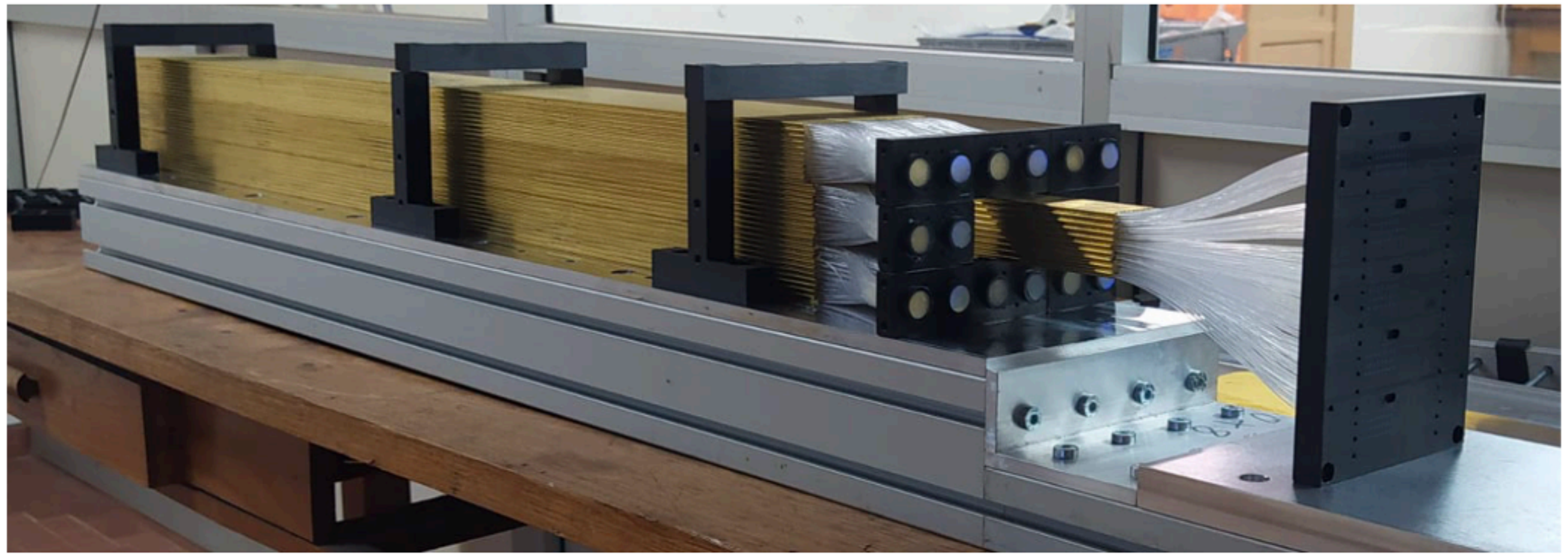
200



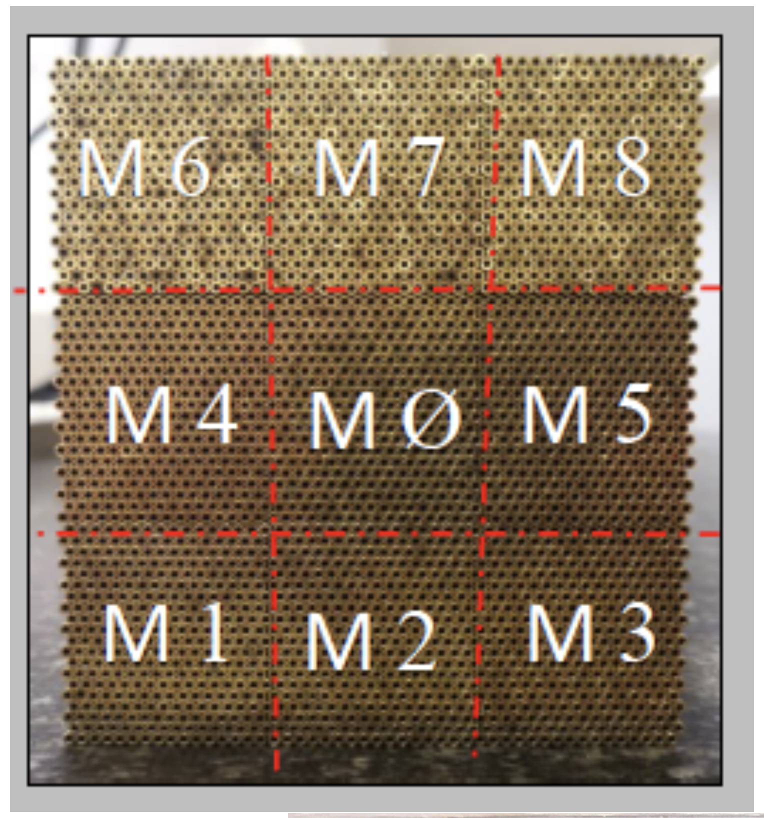


FUTURE CIRCULAR COLLIDER

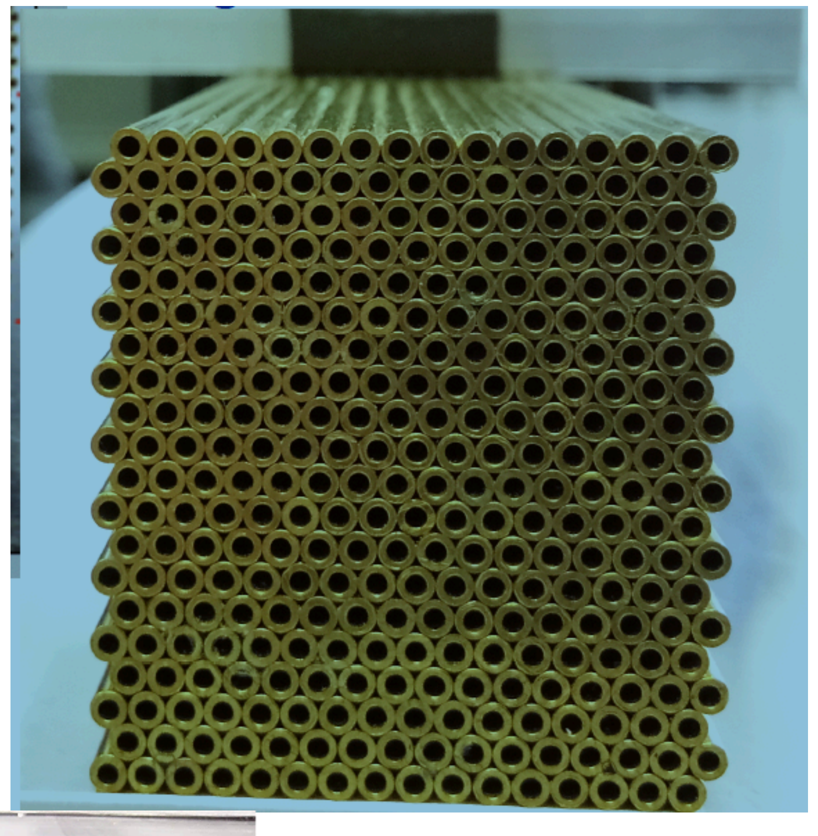
2020 Dual Readout prototype



Full prototype - 9 towers



Single tower



Electromagnetic dimensions of 10x10x100 cm^3

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

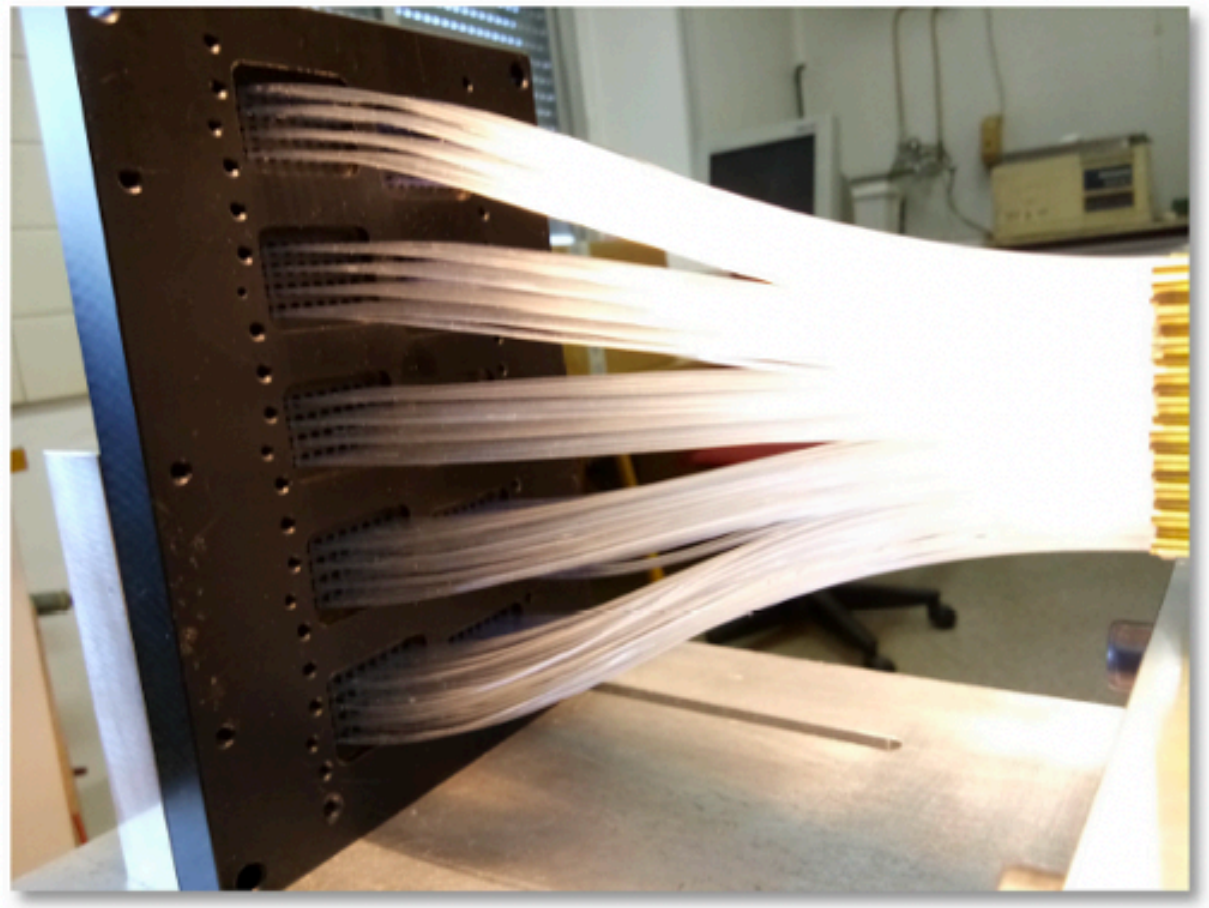
Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm

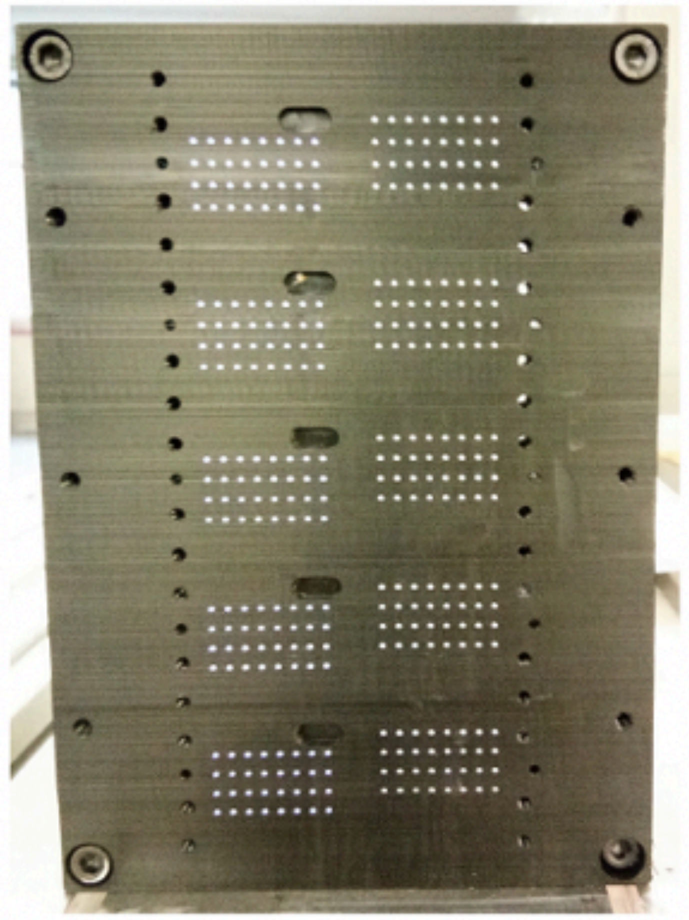
1-mm-thick fibers

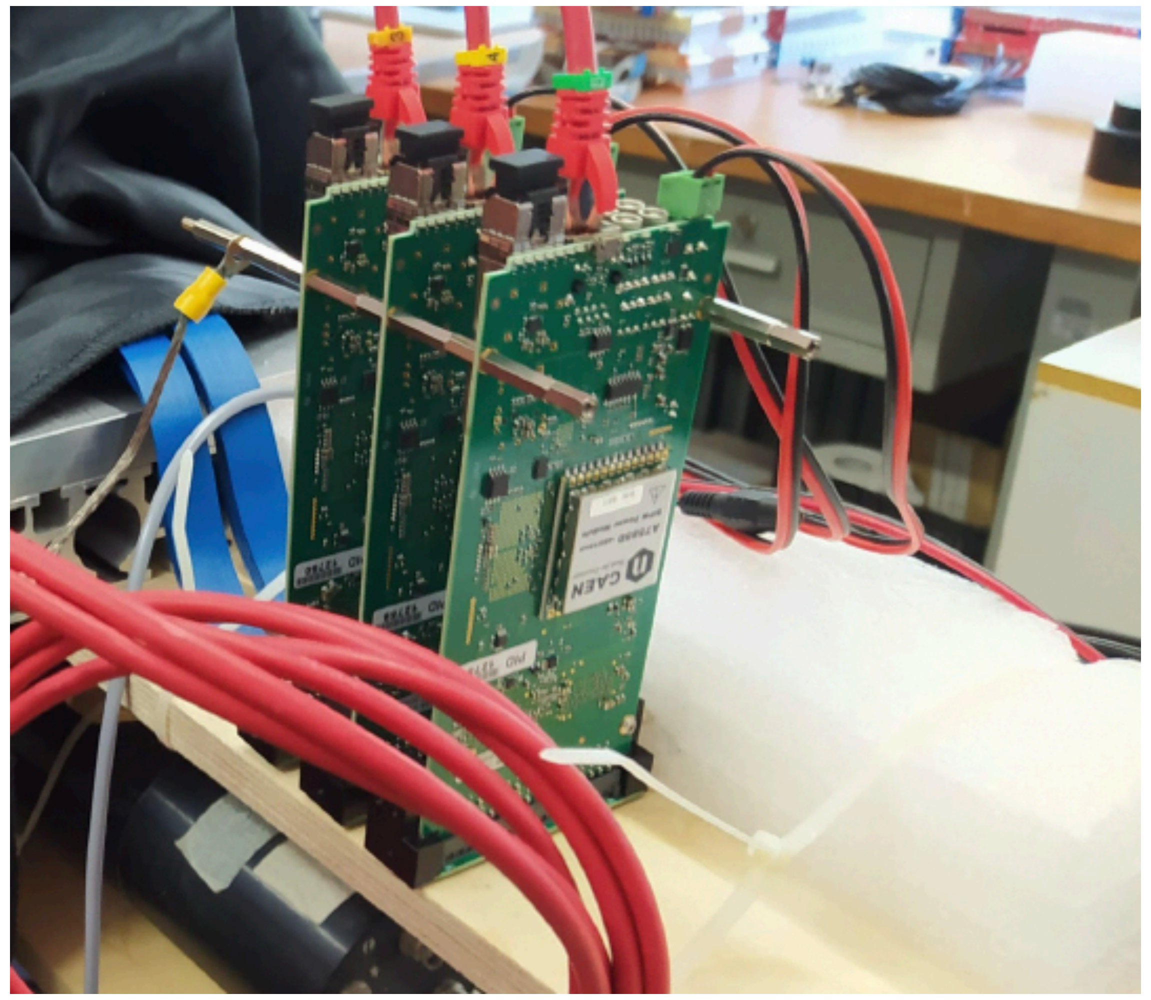
"Bucatini calorimeter"

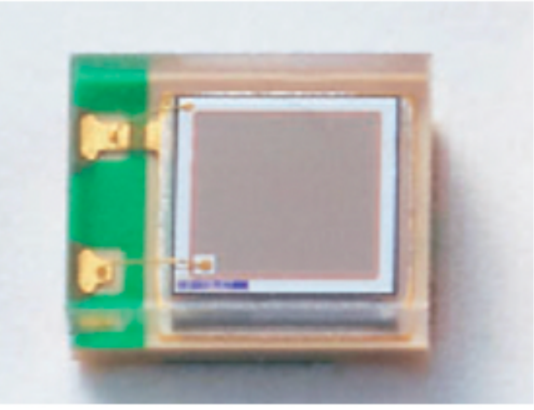
Front end board housing 64 SiPM

Fiber guiding system









Hamamatsu SiPM: S14160-1315 PS Cell size: 15 μm

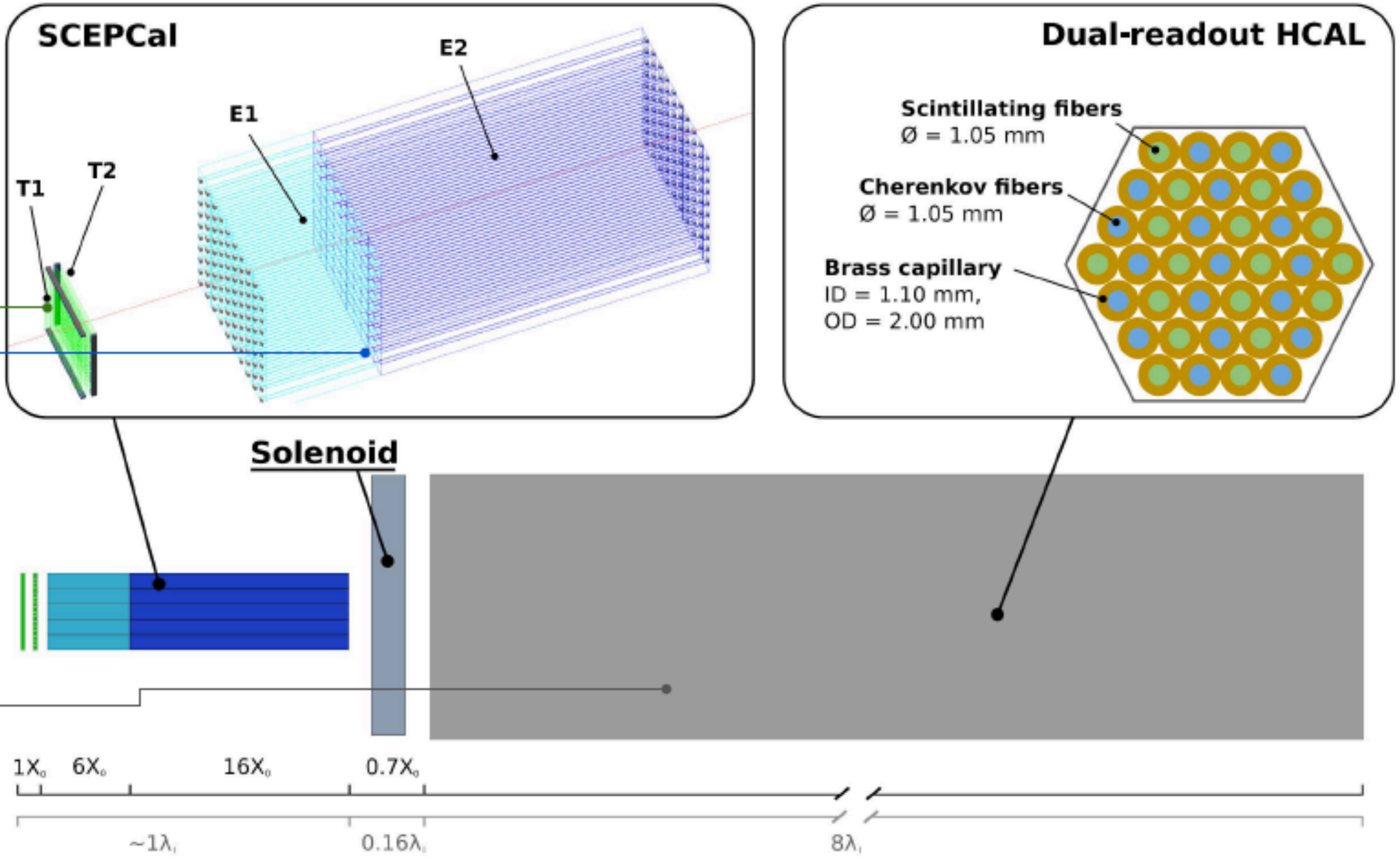
Readout Boards CAEN A5202

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



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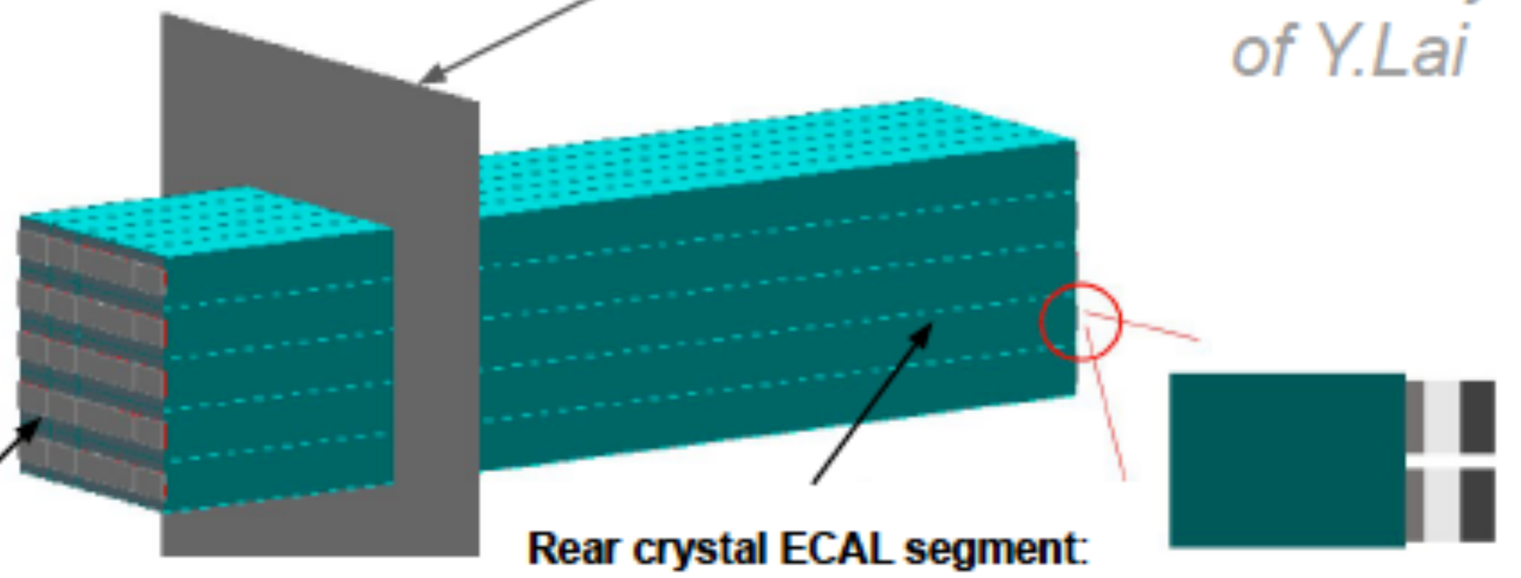
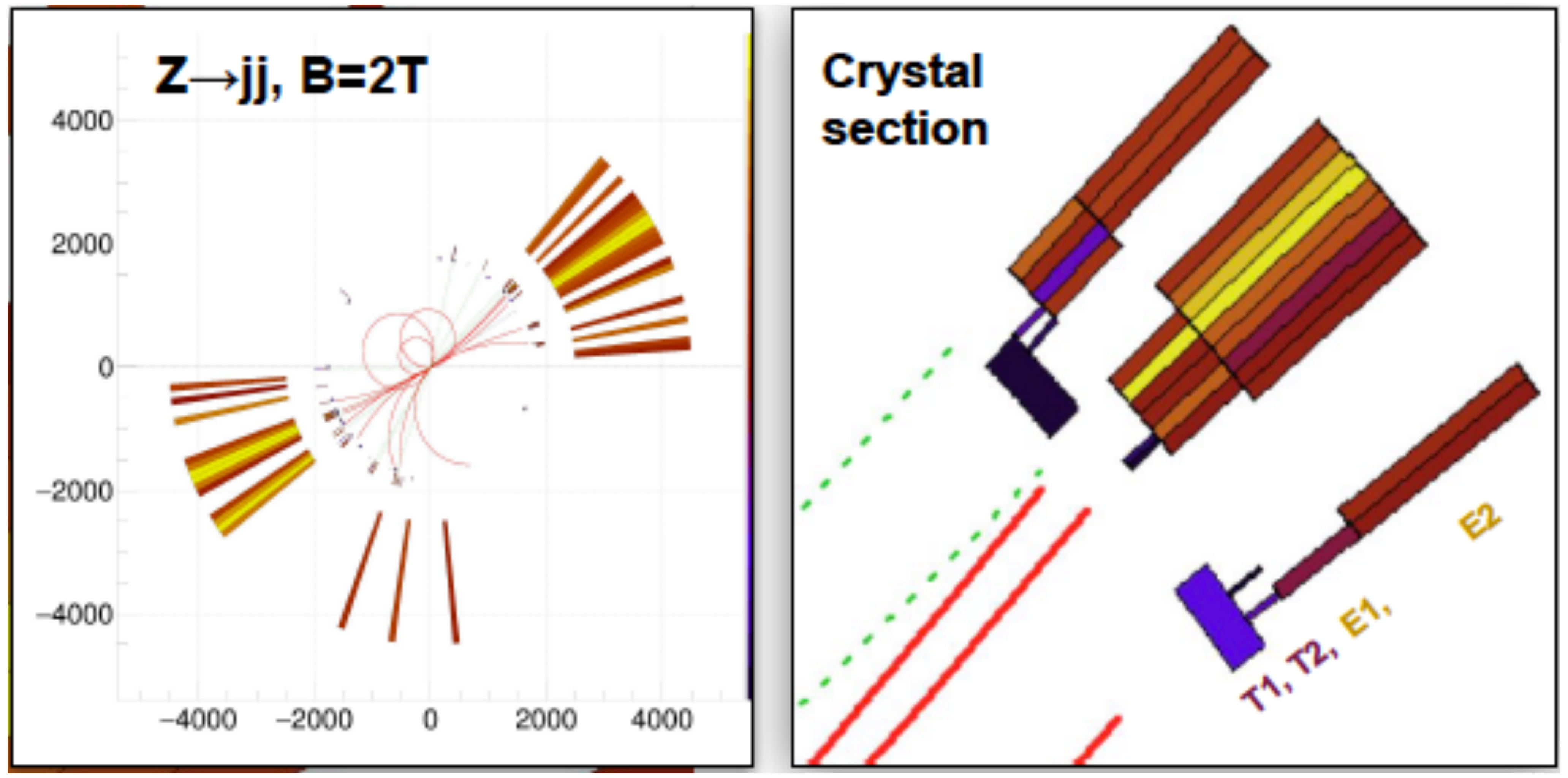
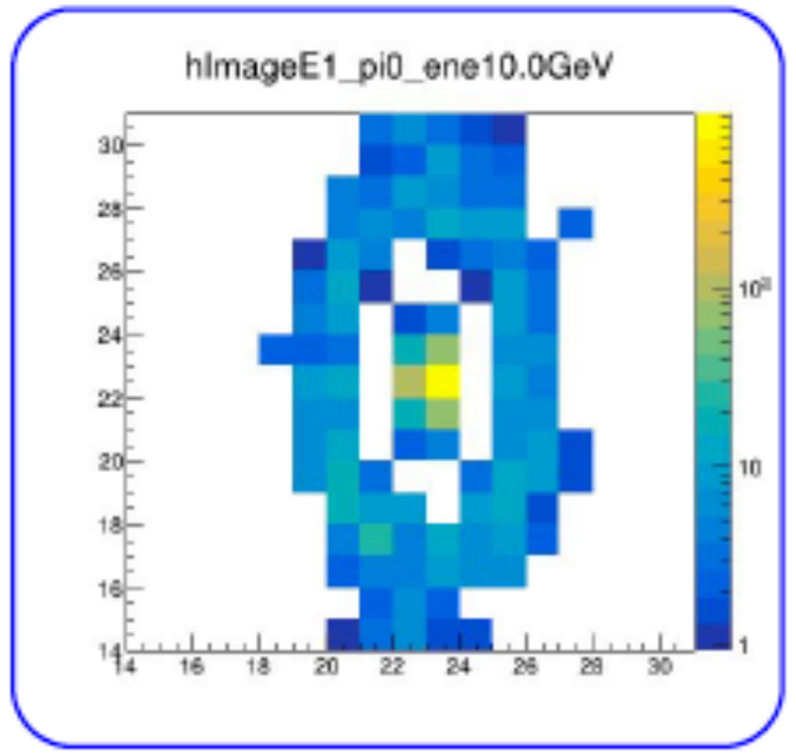
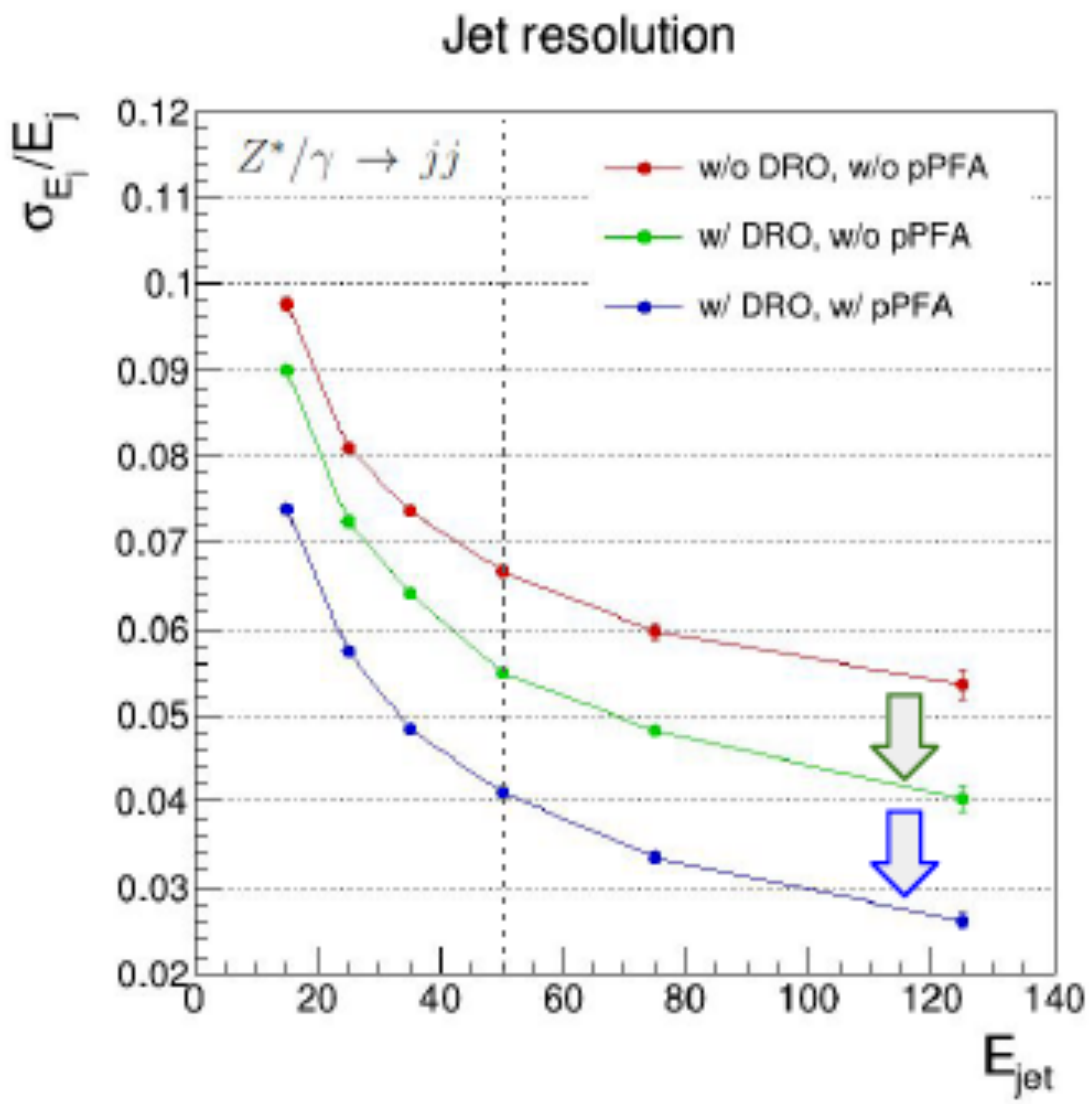
Crystal ECAL with DR calorimeter



Event display







crystals + IDEA w/o DRO

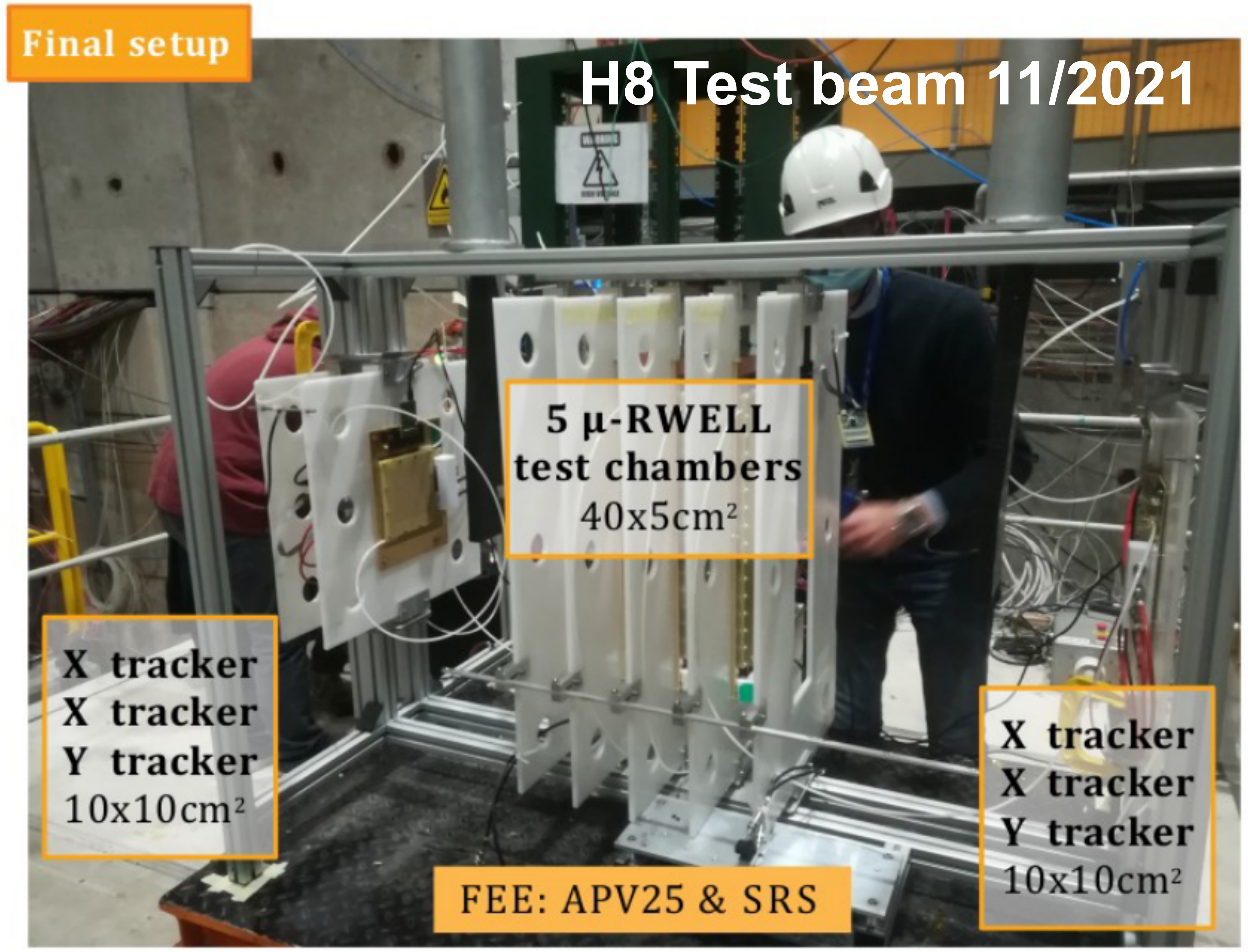
crystals + IDEA w/ DRO

crystals + IDEA w/ DRO + pPFA

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

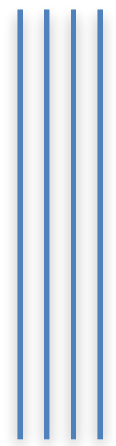


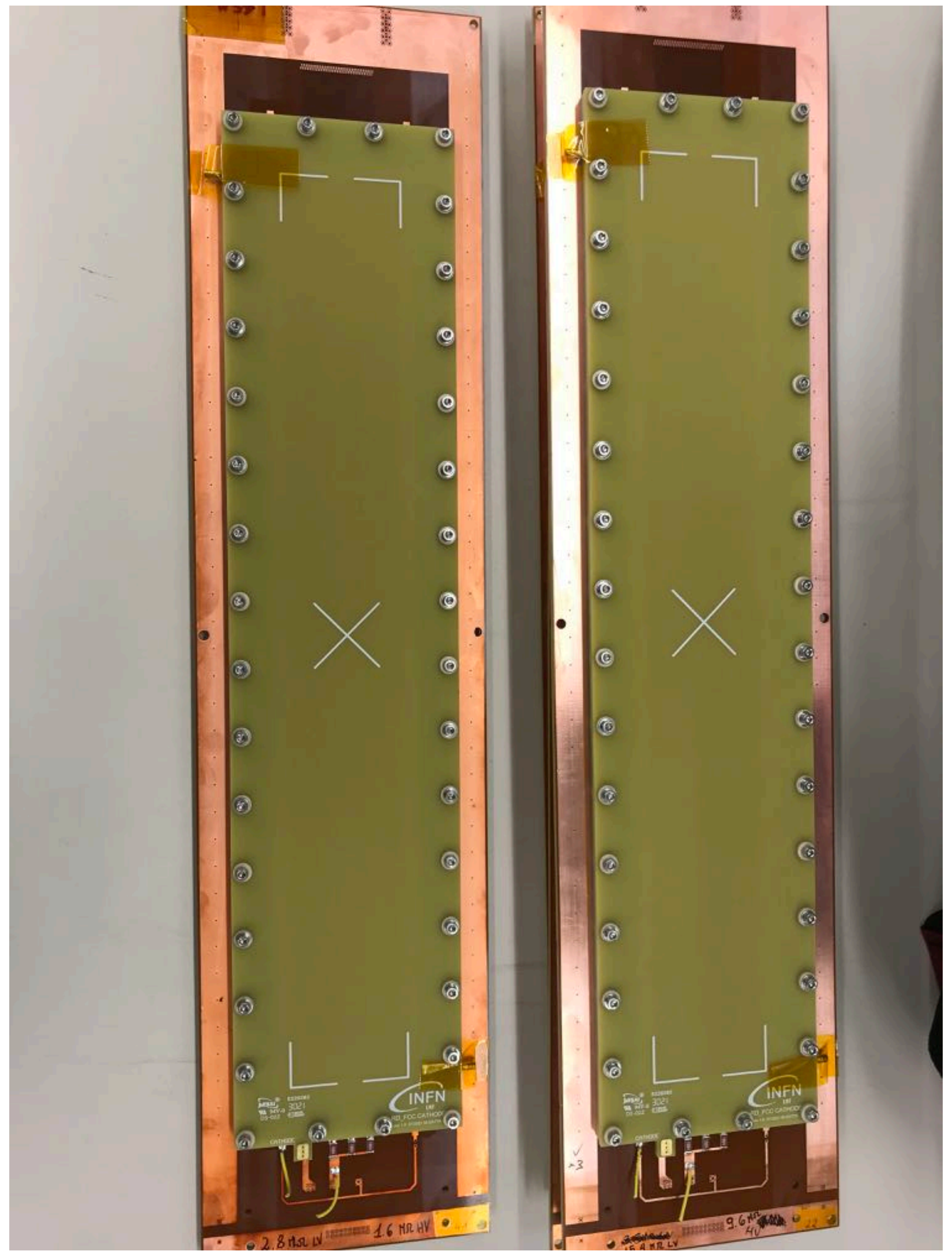
140-180 GeV/c muon and pion beam
Operated in $Ar/CO_2/CF_4$ (45/15/40)

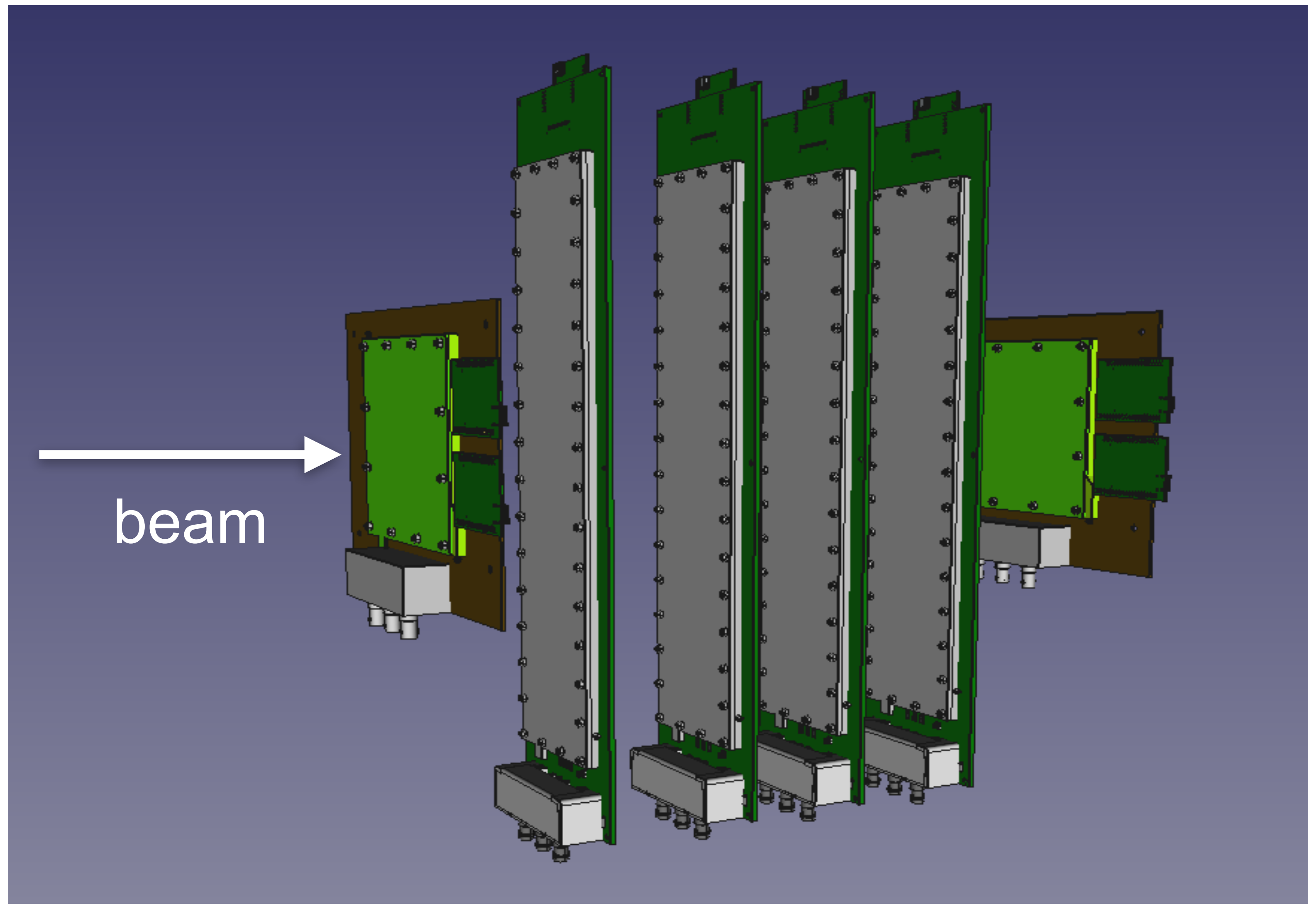
1- Signal shape
(cluster charge, cluster size)
2 - Detector performance
(efficiency, space resolution)

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







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

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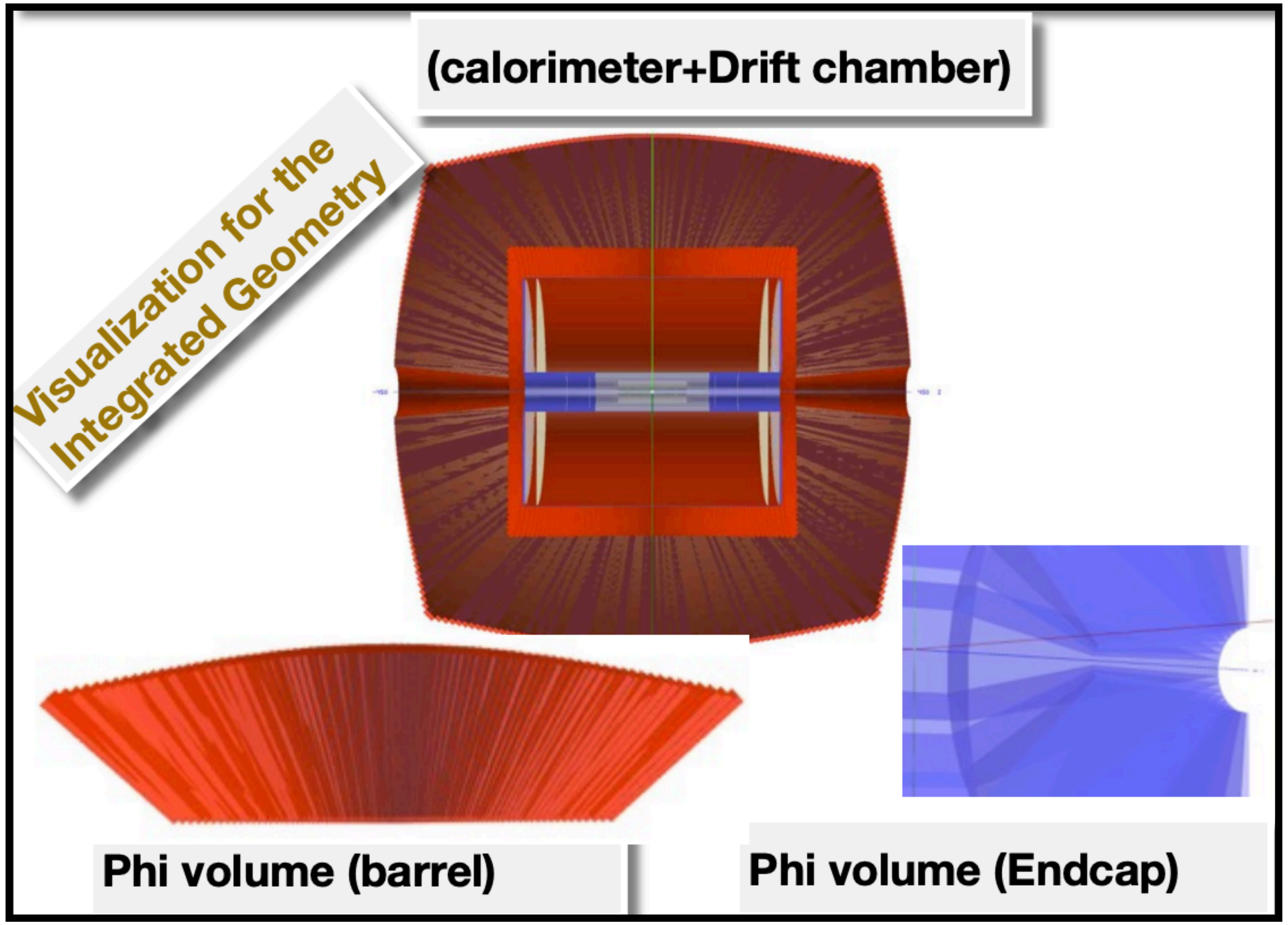
BOLOGNA
FERRARA
TORINO

Muon and pre-shower future plans

- Complete test of large 2D chamber design (50x50 cm^2) (next year)
- Complete readout electronics based on TIGER chip (next years)
- Develop chamber production plan with industry (few years)
- Develop plan for layout on detector with services (few years)

- Towards a Muon/pre-shower TDR

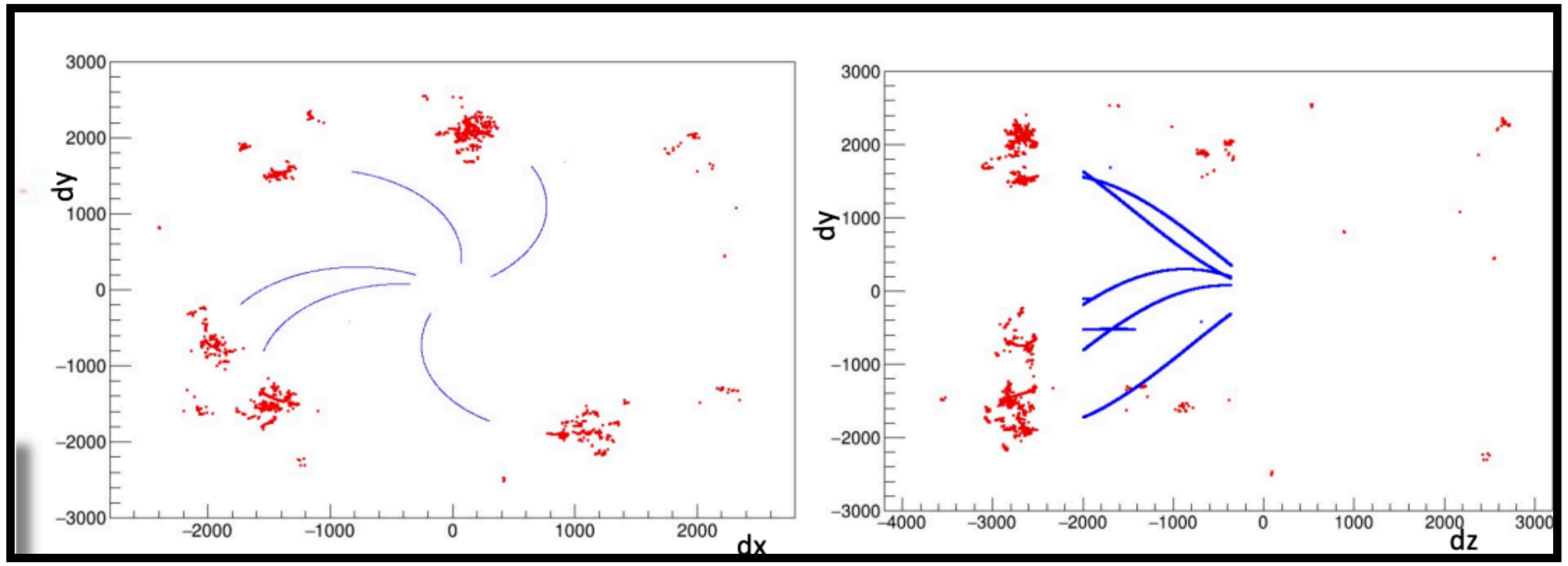
Status of Simulation of IDEA concept



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**

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      - Other areas (Simulation, DAQ&Trigger, software, etc.) ...

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FUTURE CIRCULAR COLLIDER

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- Lots of possibilities for French colleagues to join IDEA and help on all these developments!!

Backup