FUTURE CIRCULAR COLLIDER

second annual
US WORKSHOP

MARCH 25-27
hosted by MIT

2024

The IDEA detector concept

Paolo Giacomelli
INFN Bologna

These projects have received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreements No. 101004761 (AIDAinnova), 101057511 (EURO-LABS).

The IDEA detector concept

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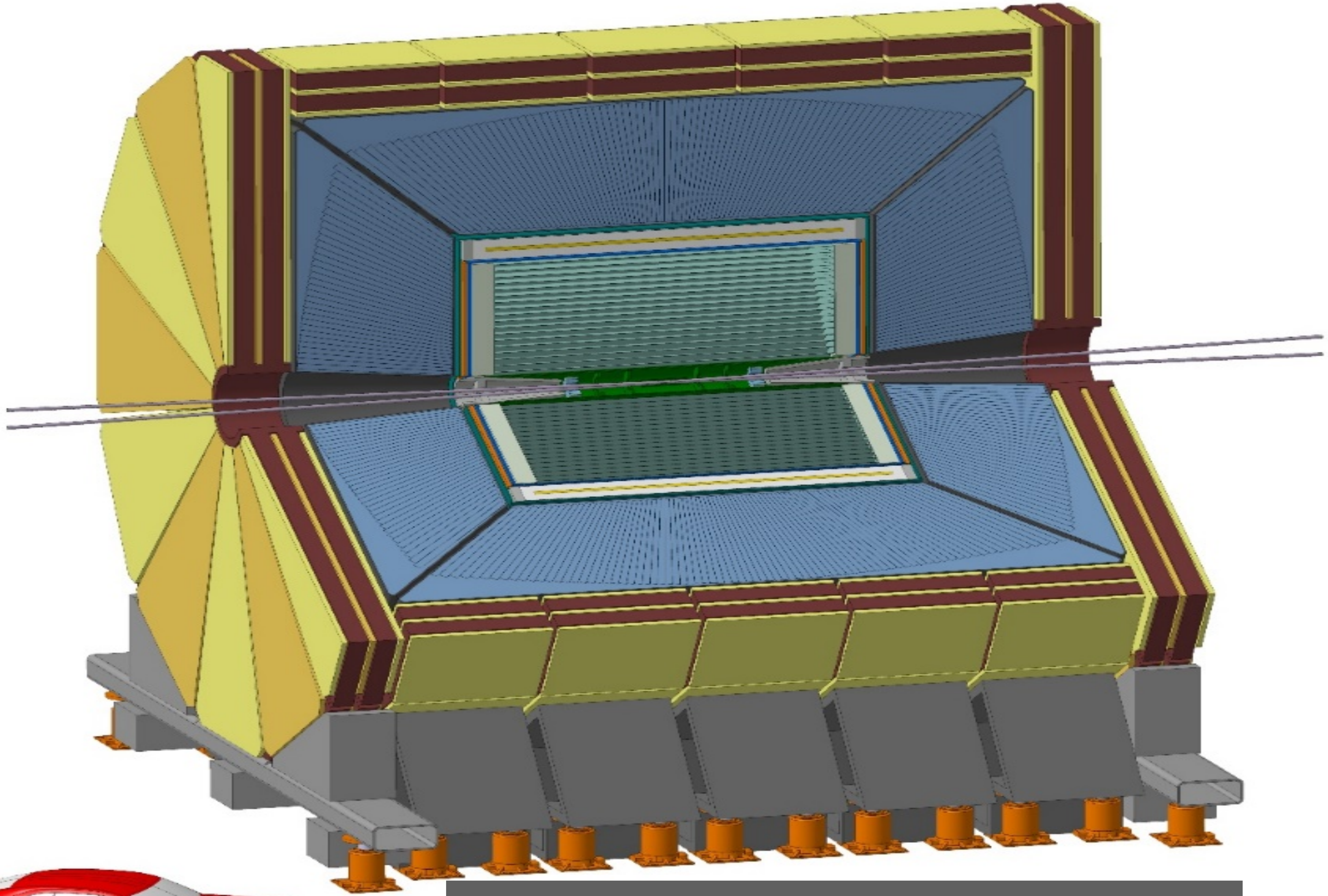
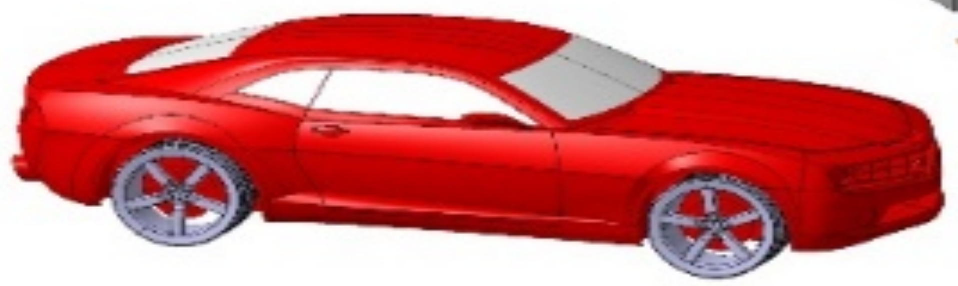
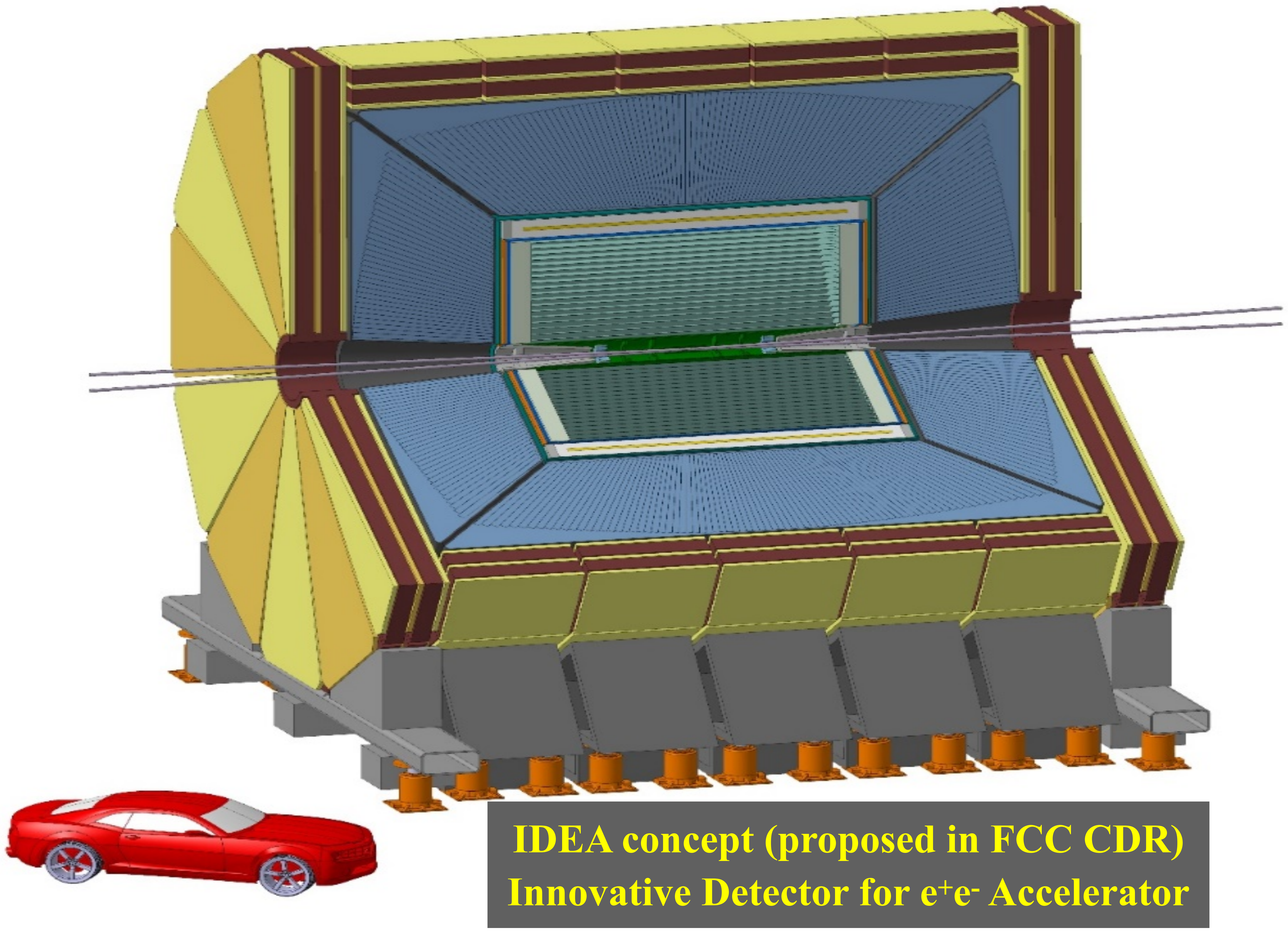




IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

The IDEA detector concept



- New, innovative, possibly more cost-effective concept

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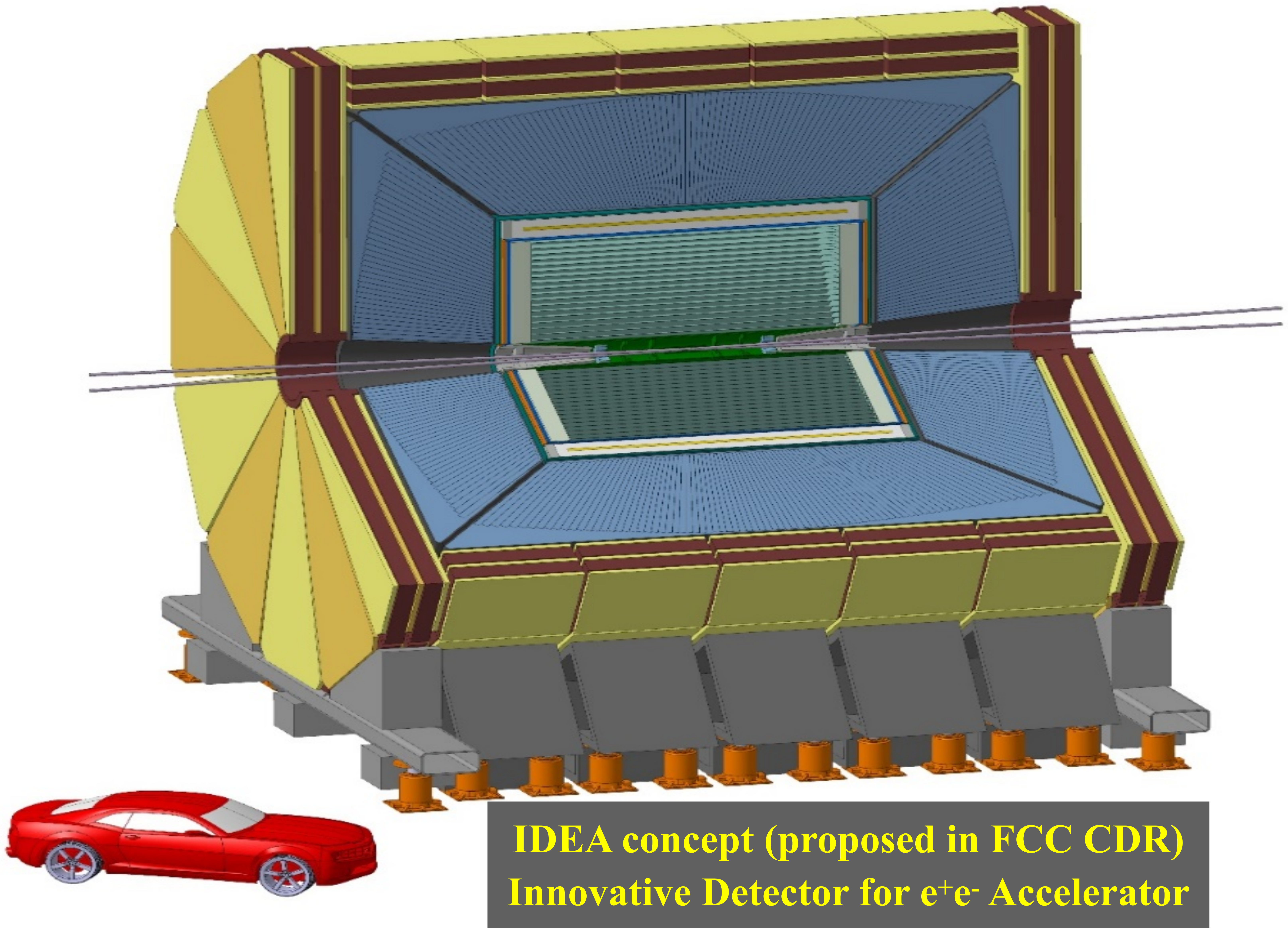

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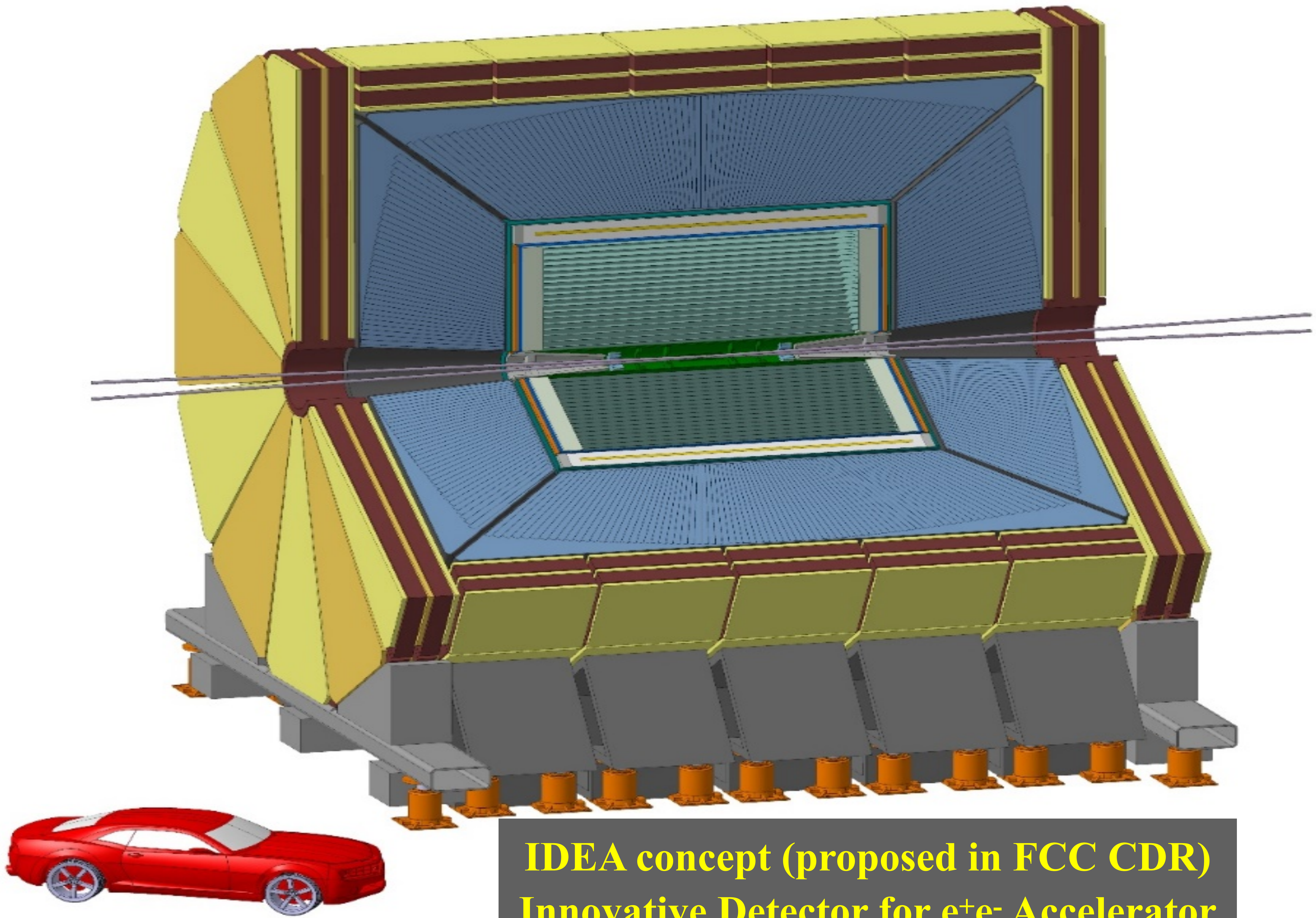

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  - Silicon vertex detector
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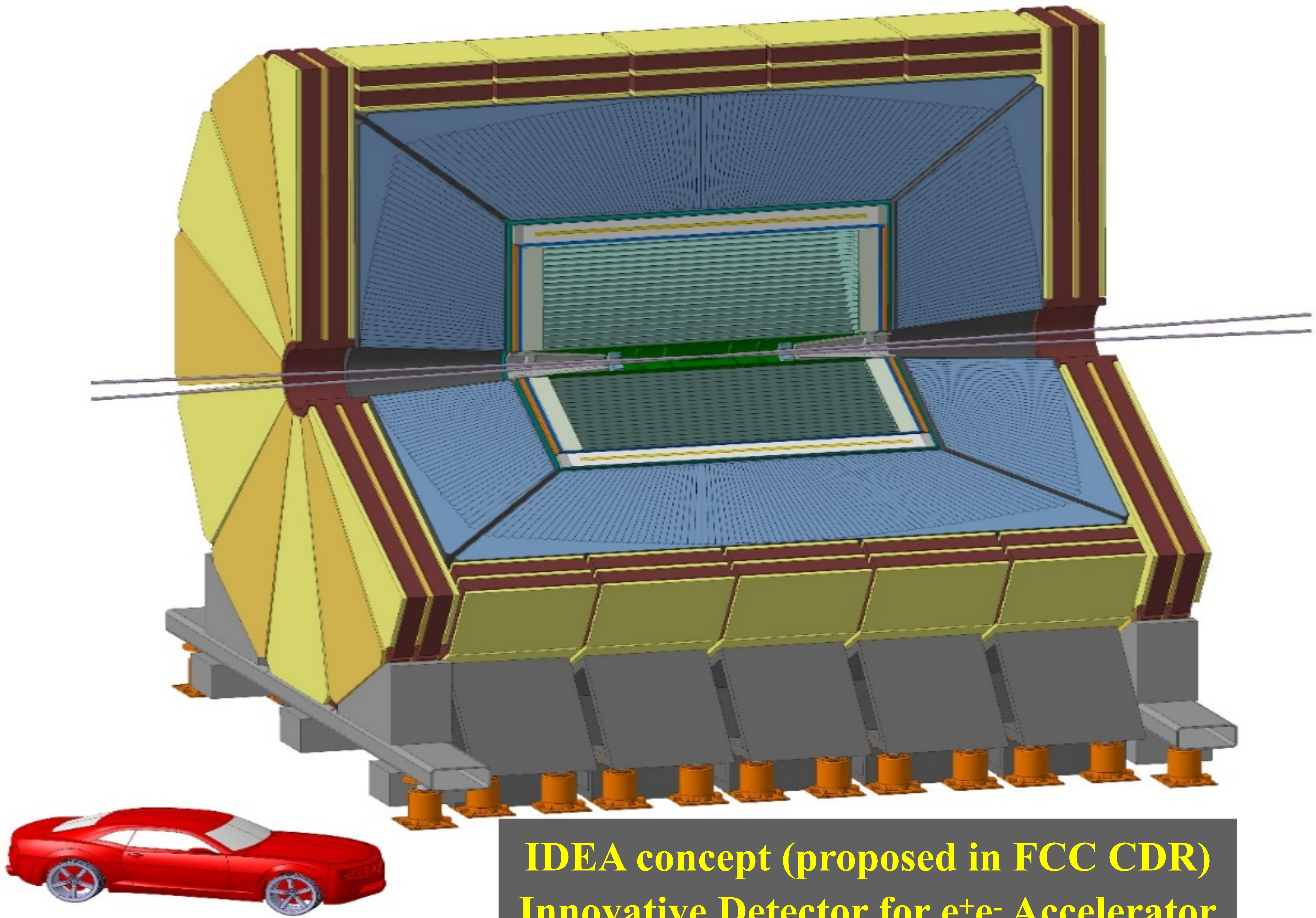

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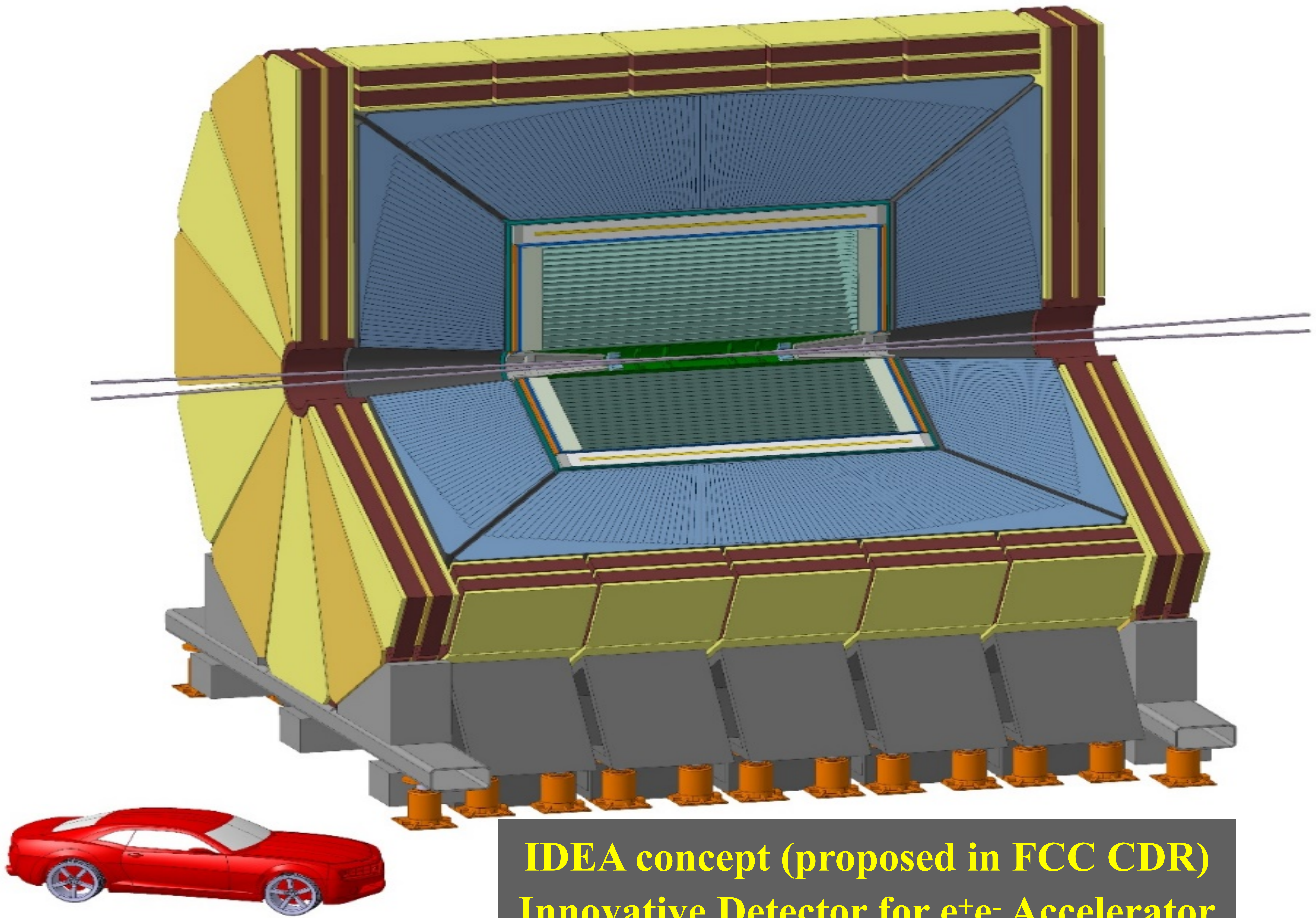

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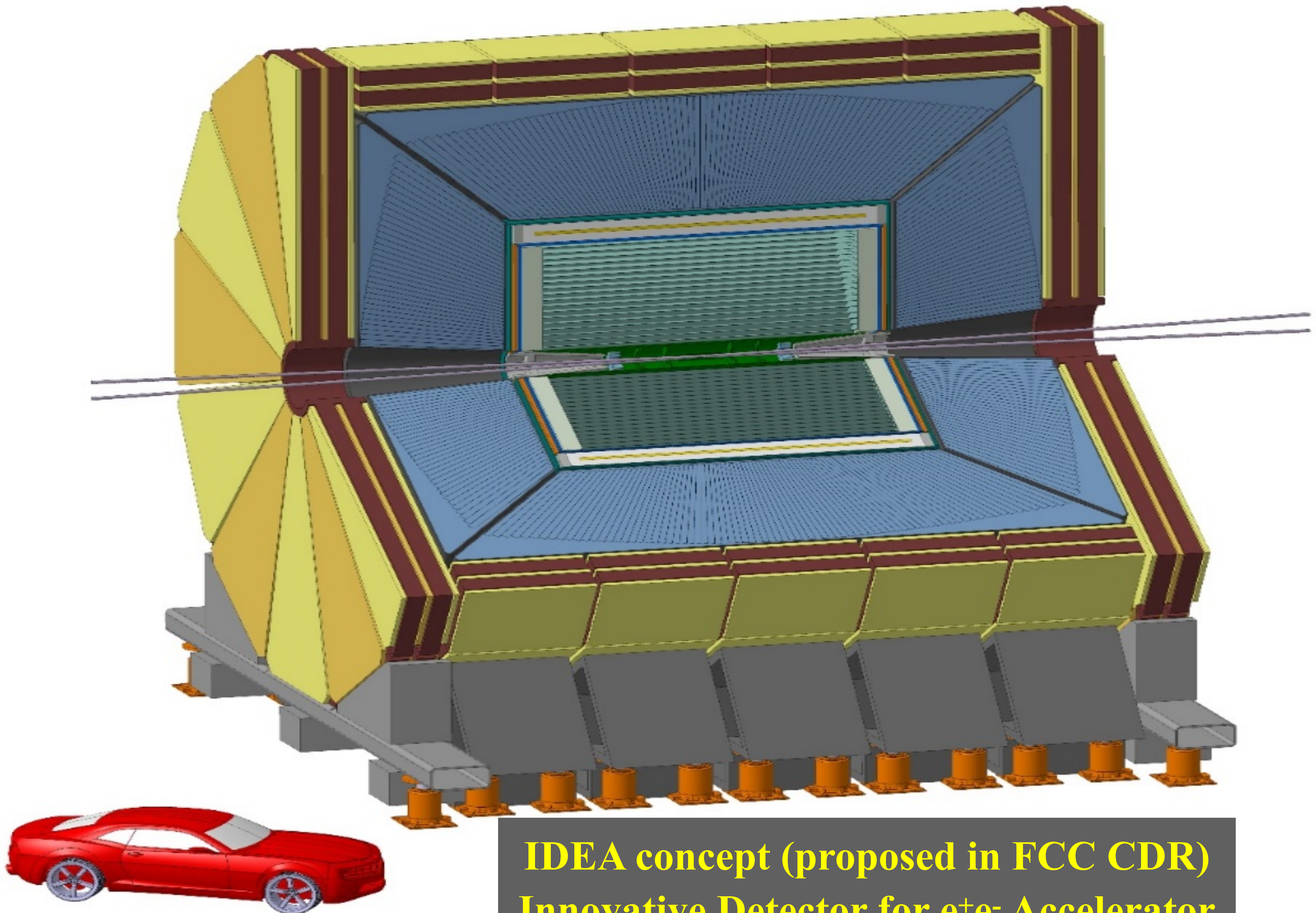

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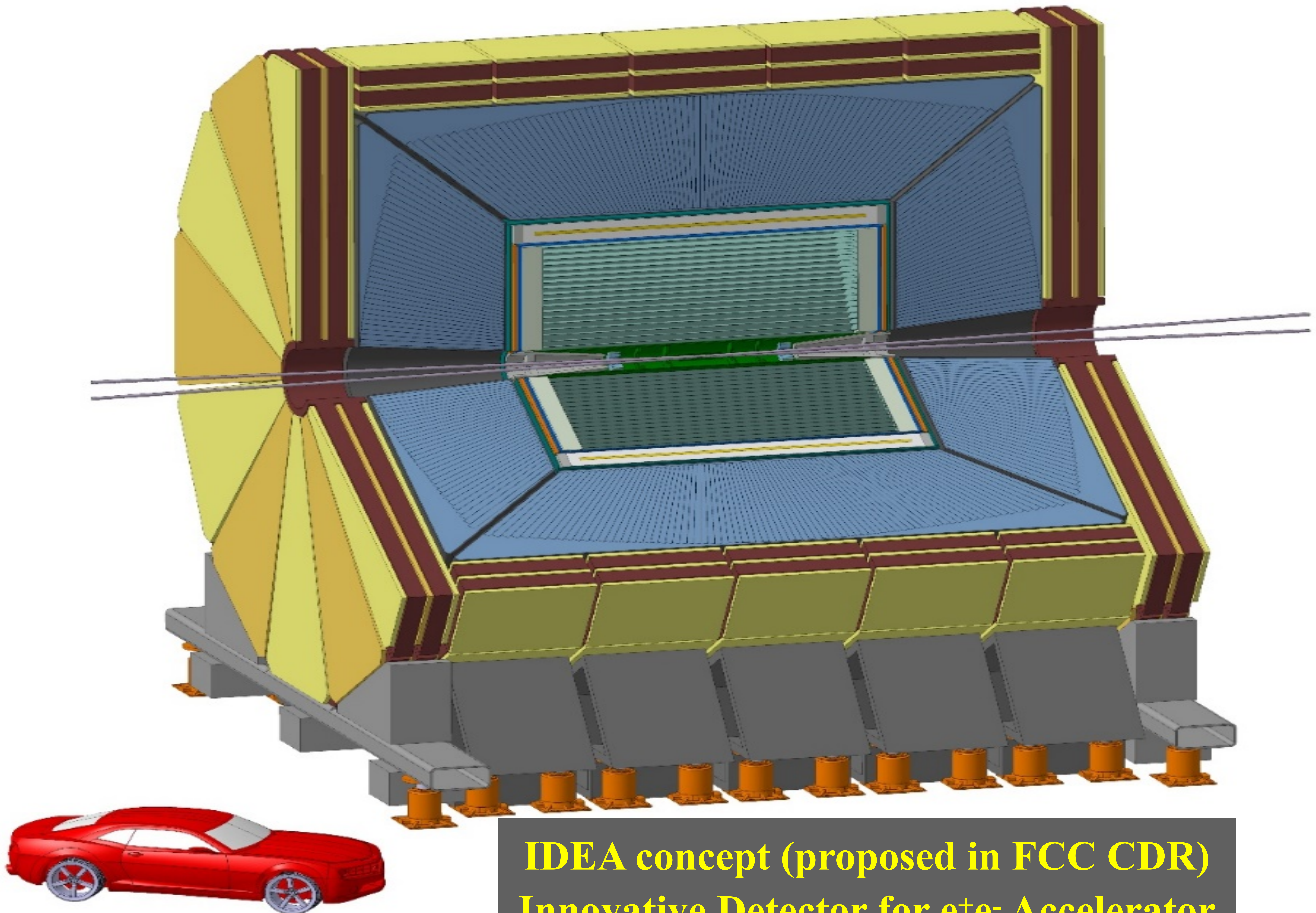

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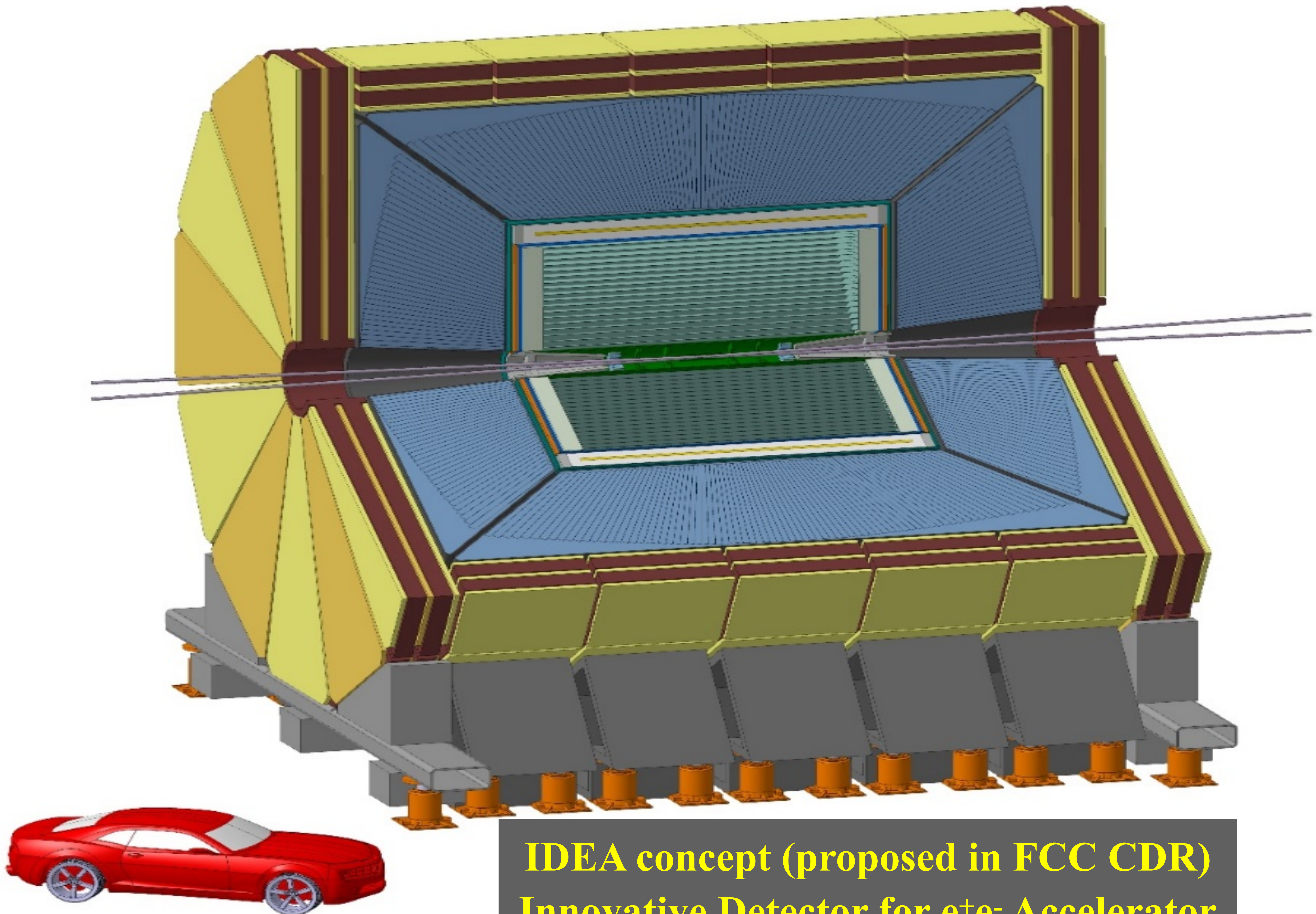

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https://pos.sissa.it/390/

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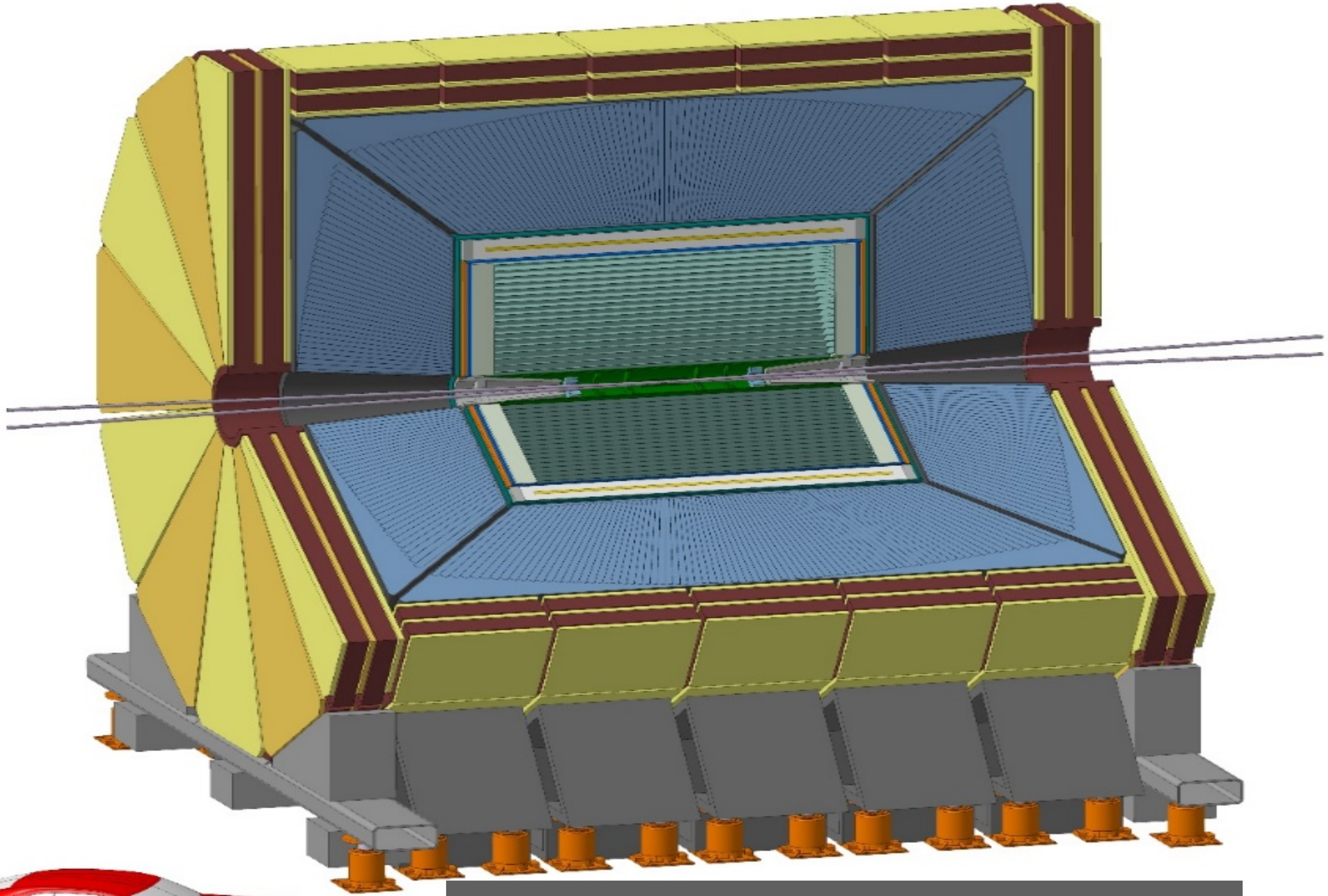

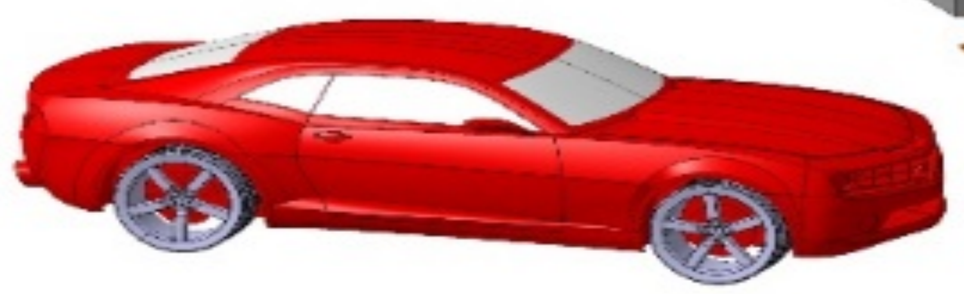

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Acknowledgments
I need to thank many colleagues, in particular:
F. Bedeschi

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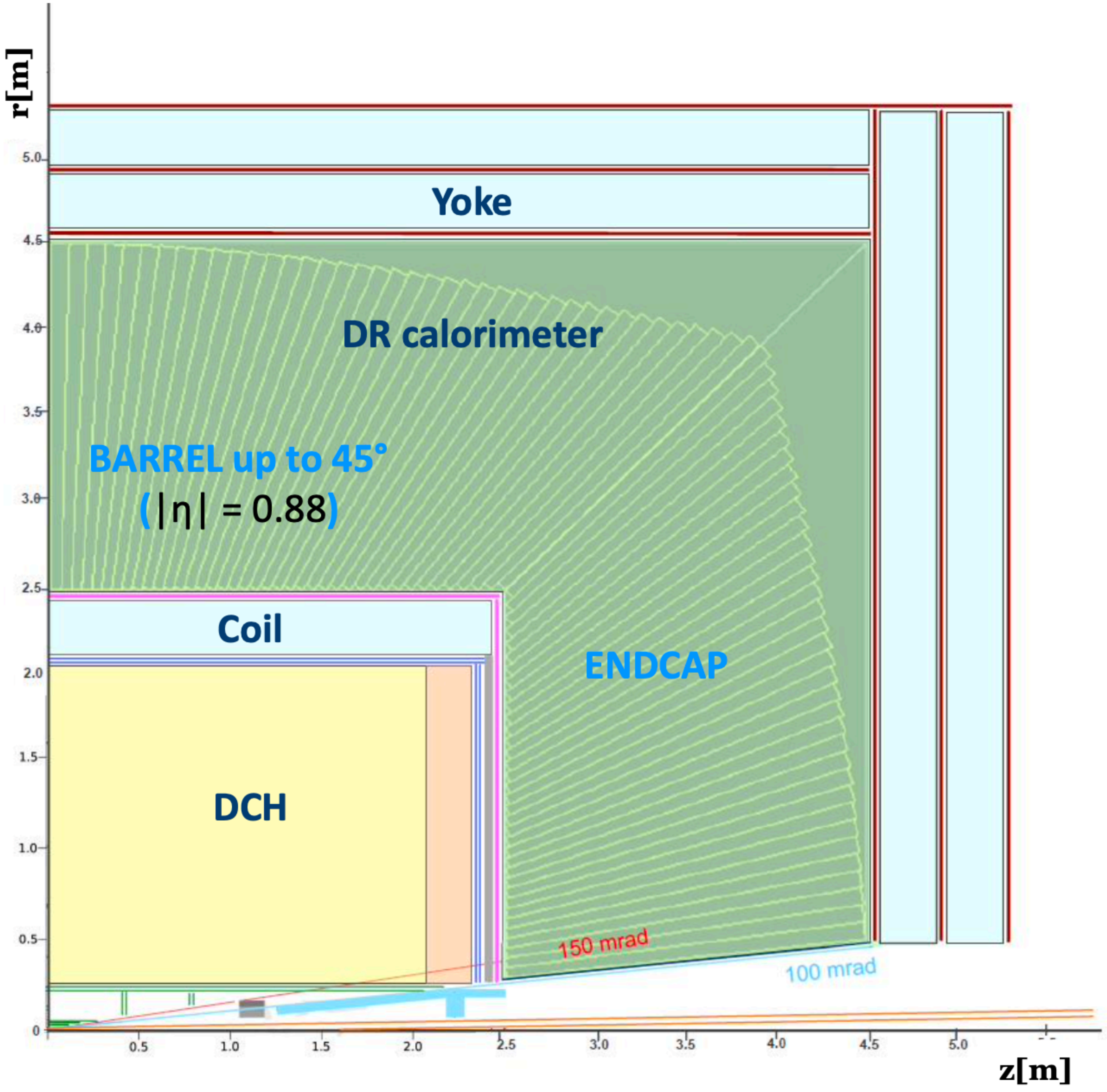
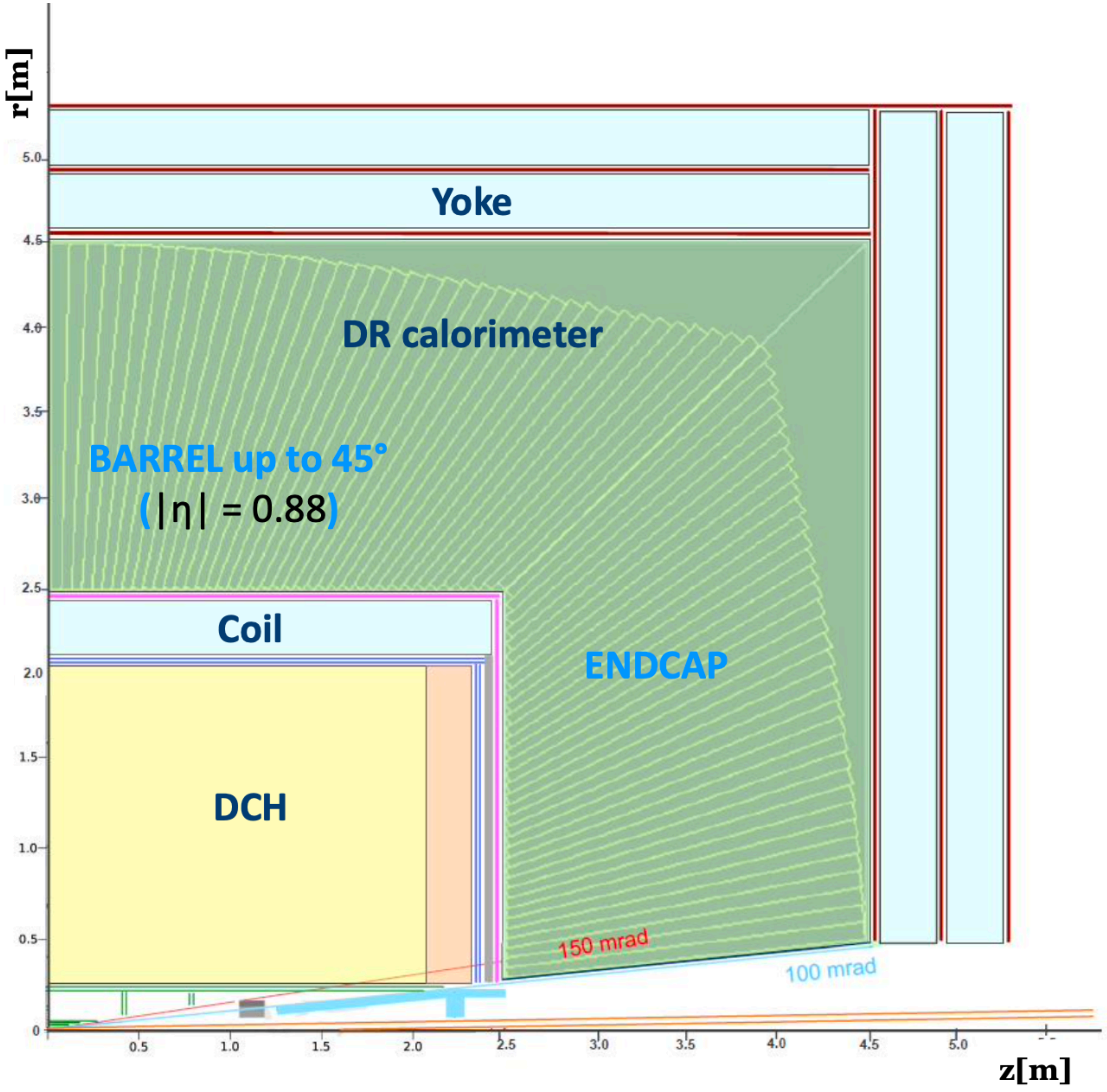


IDEA detector layout

Beam pipe: R~1.0 cm



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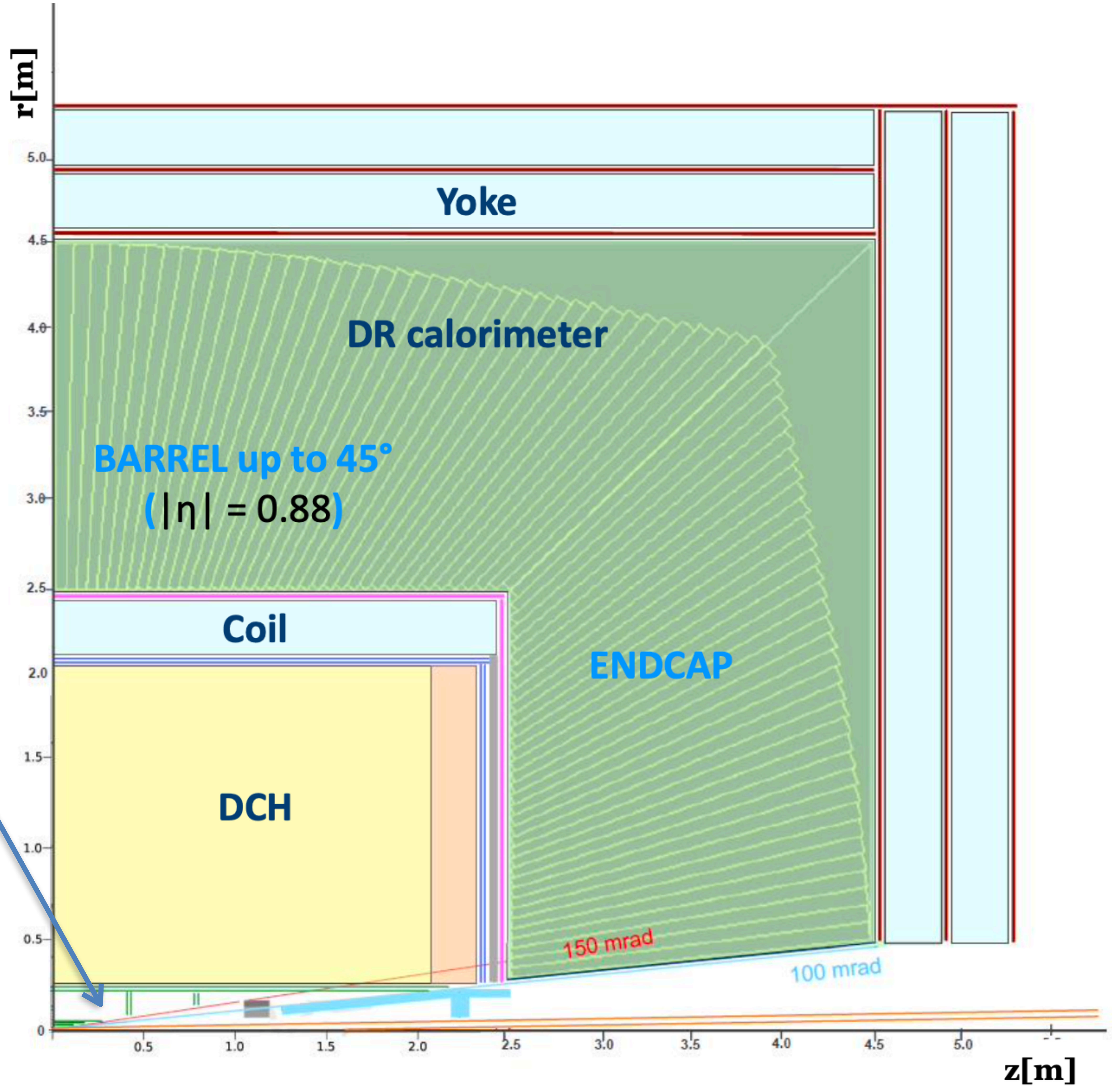
5 MAPS layers

R = 1.37-31.5 cm



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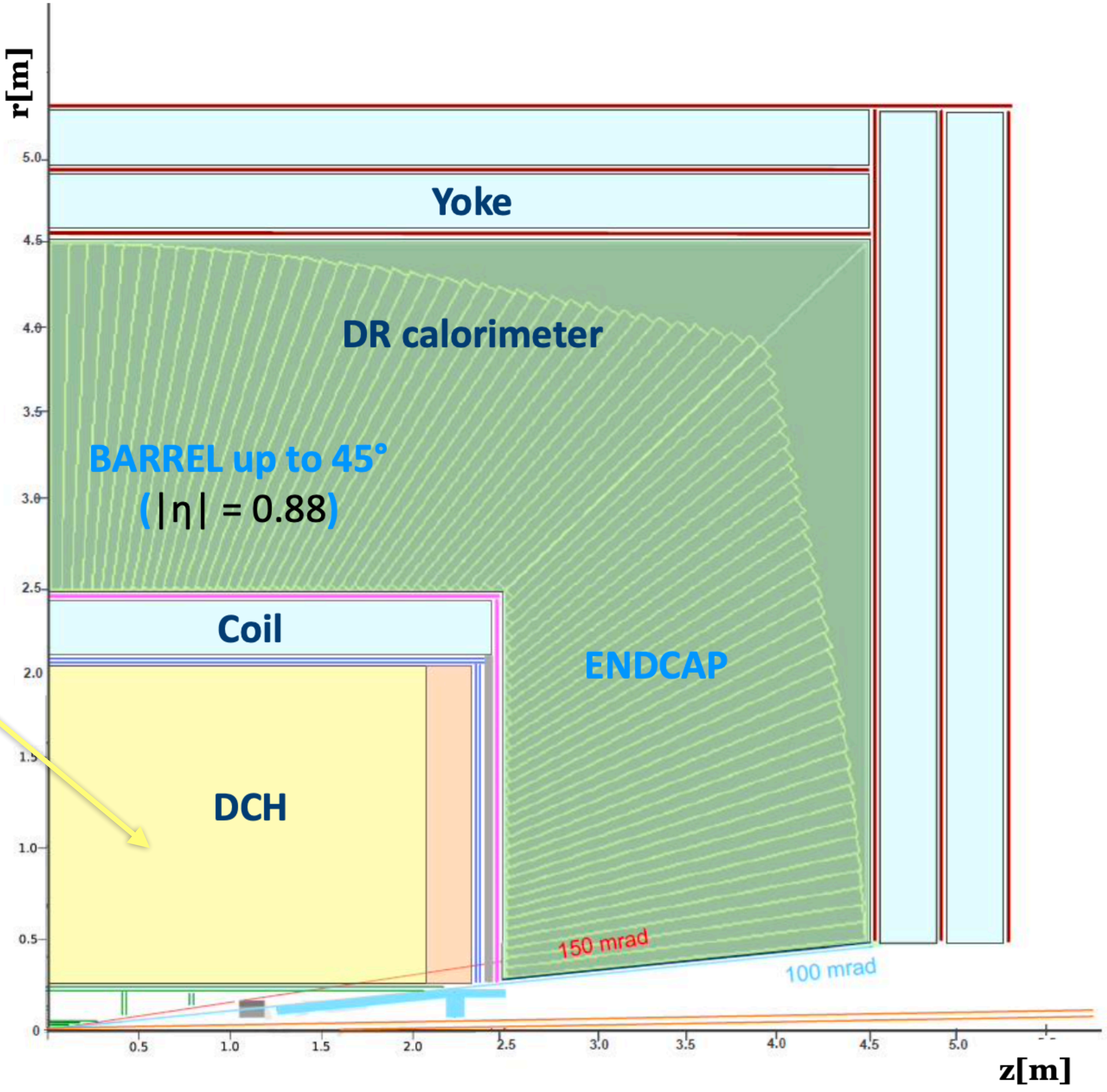

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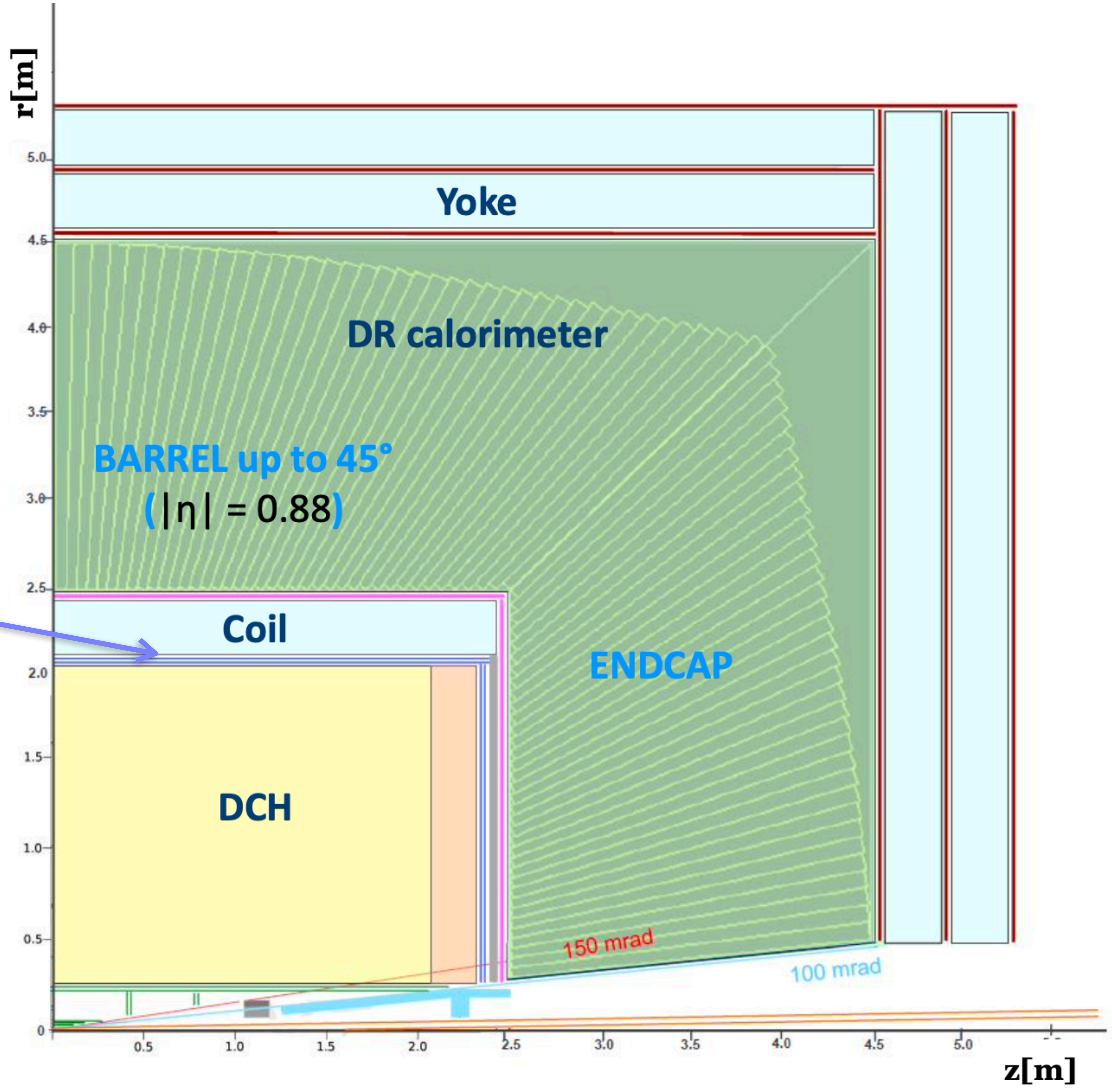
Si strips



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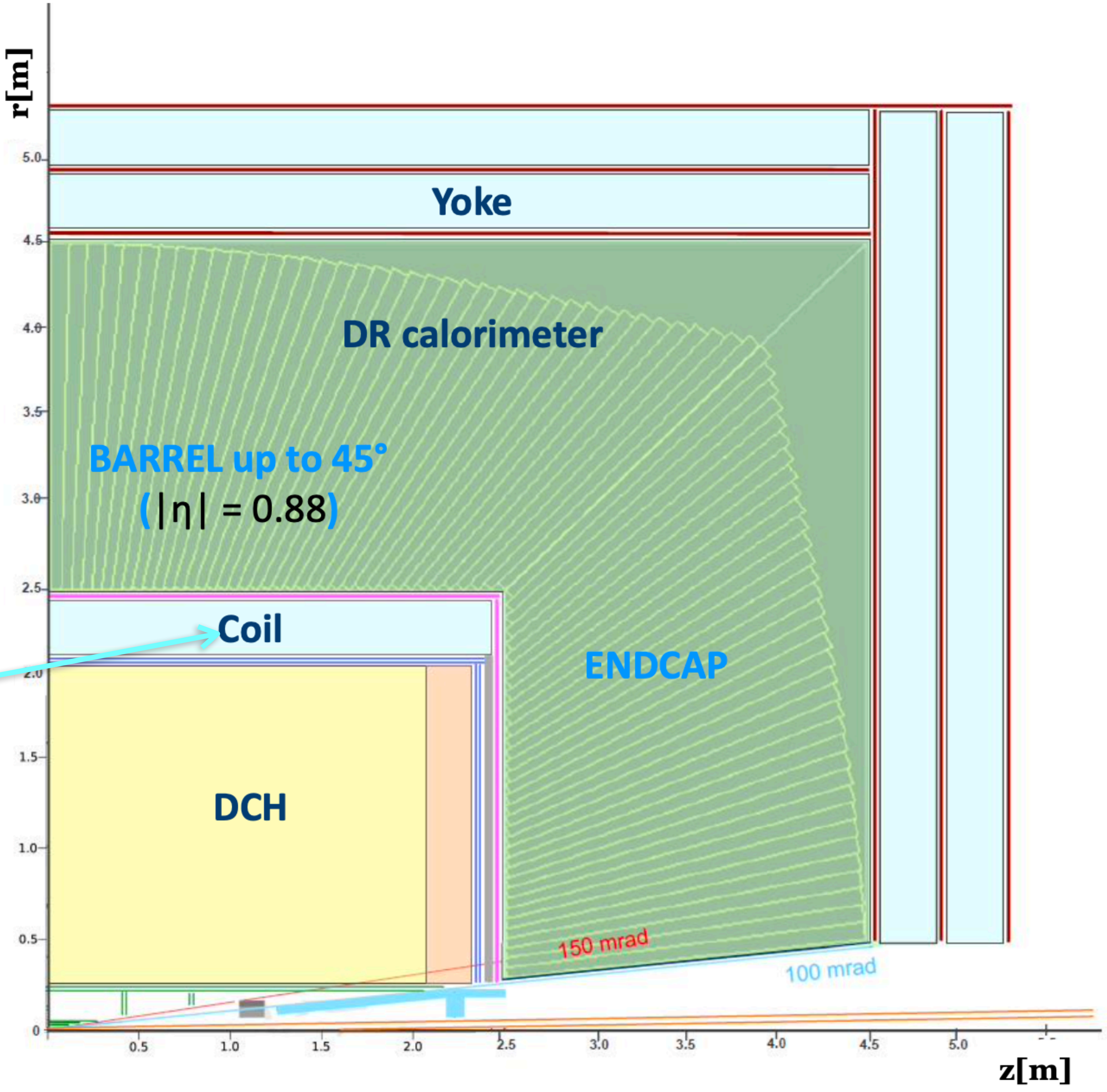
2 T, R ~ 2.1-2.4 m

0.74 X_0, 0.16 λ @ 90°



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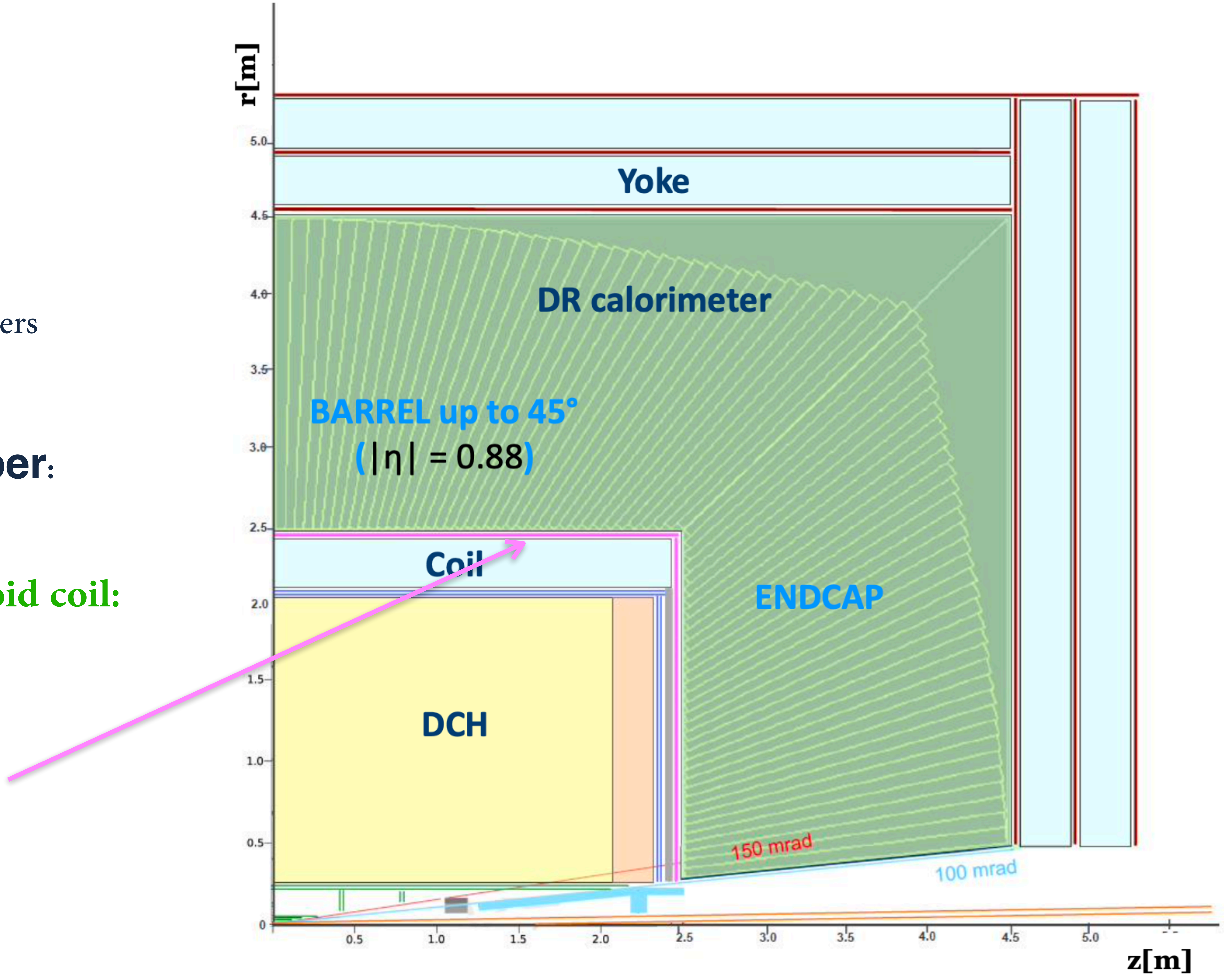

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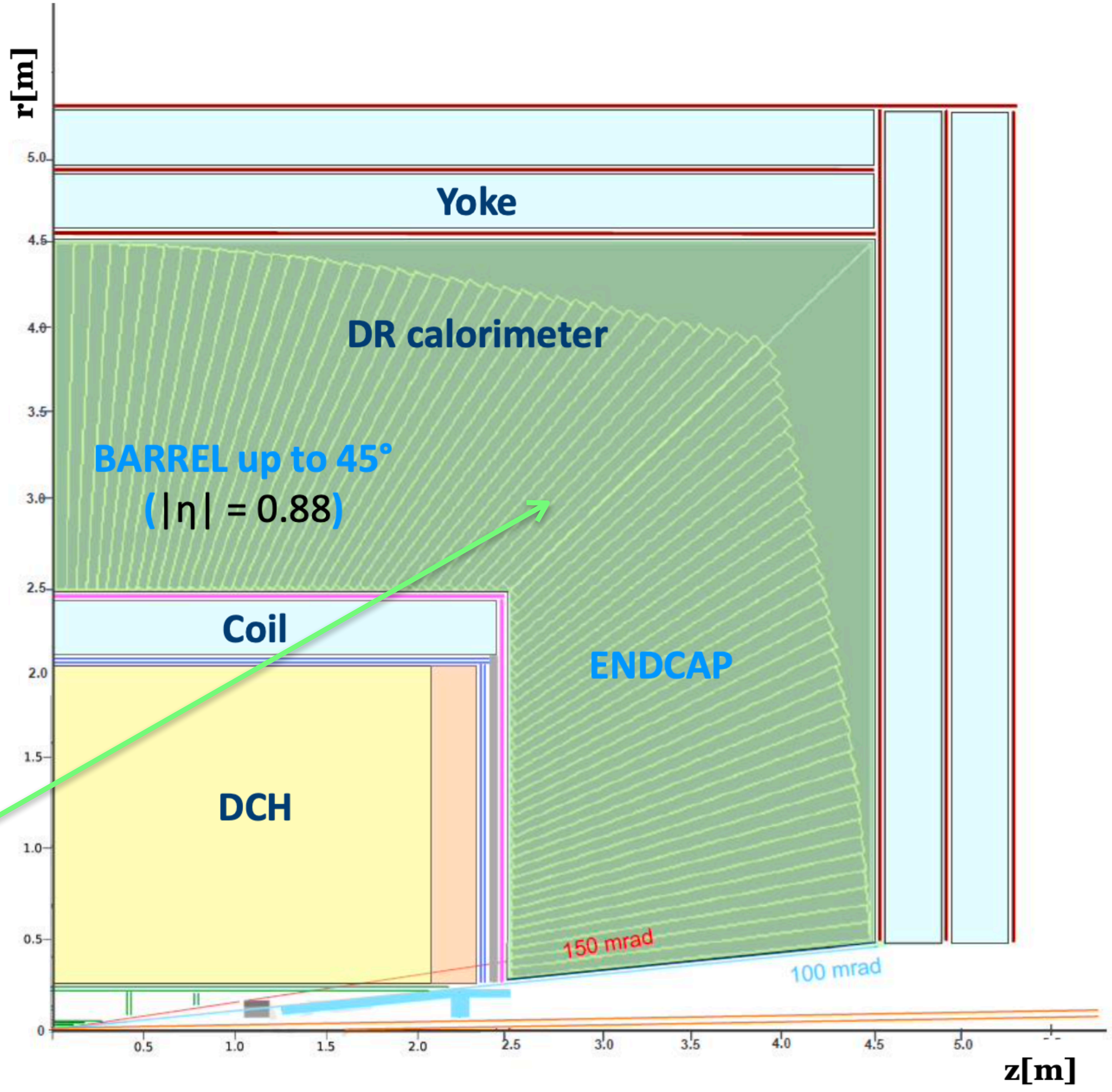
2m / 7 λ_{int}



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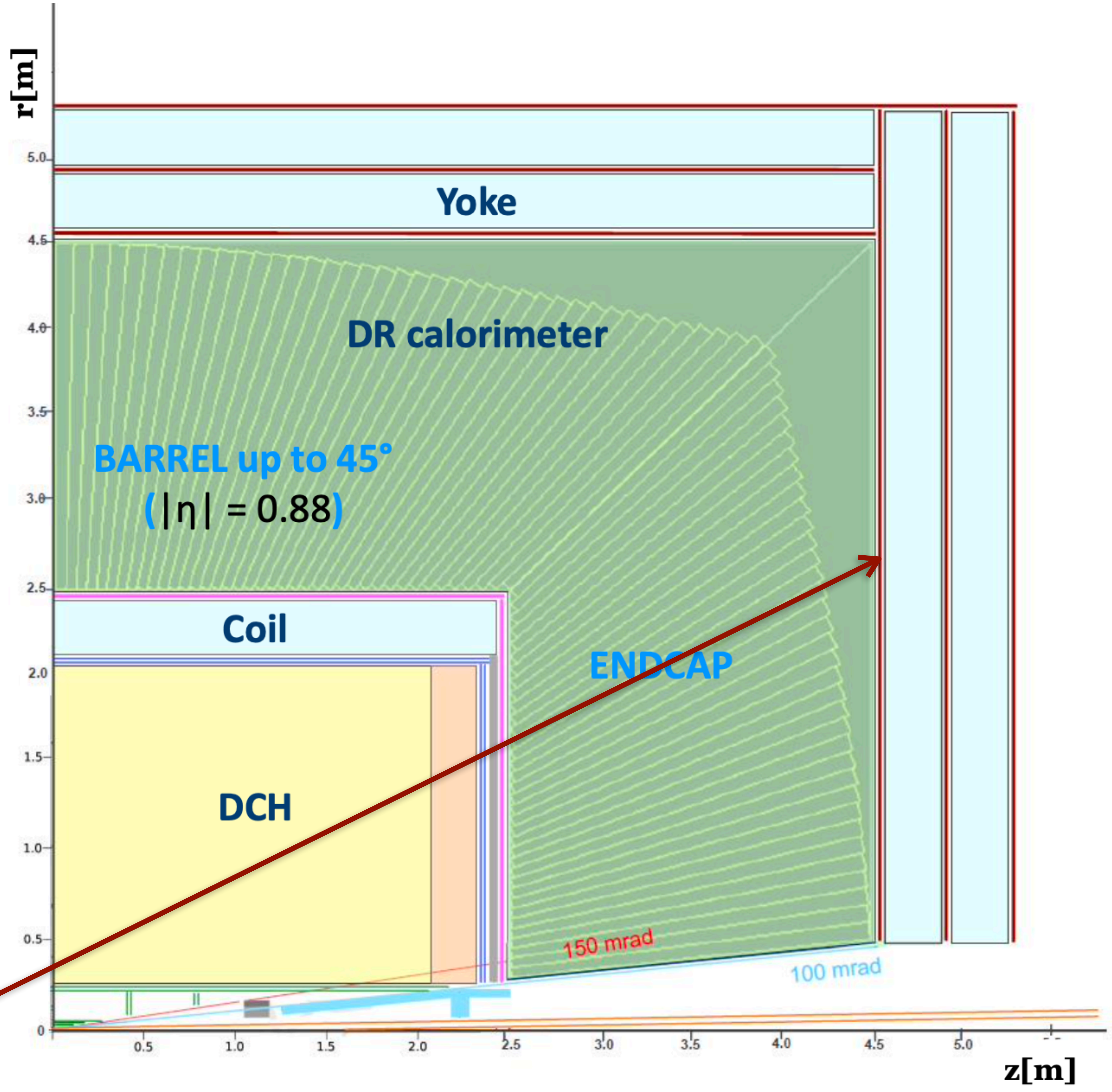
Yoke + Muon chambers



Vertex detector: IDEA

Mid-term review vertex detector overall layout

F. Palla

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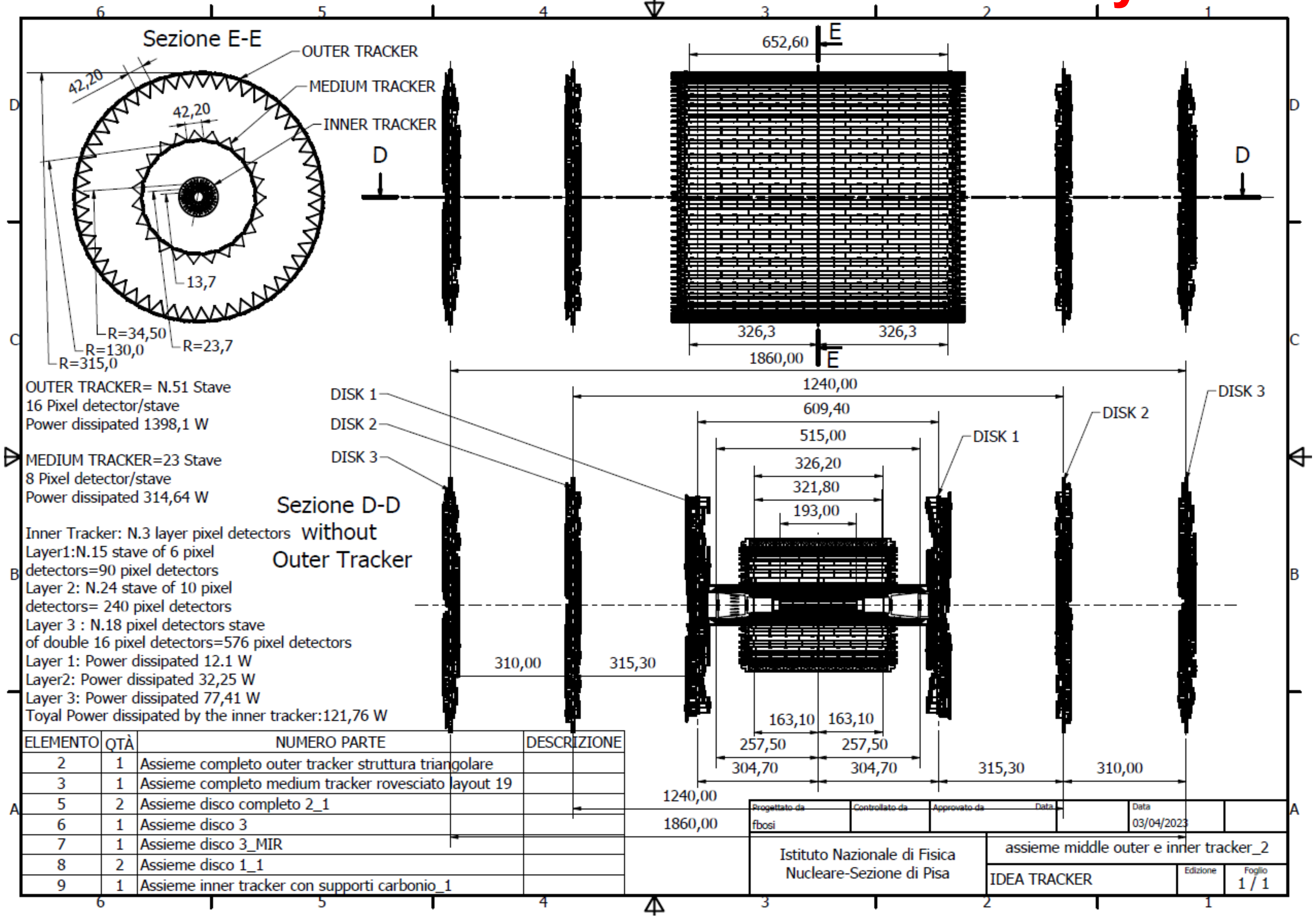
Mid-term review vertex detector overall layout

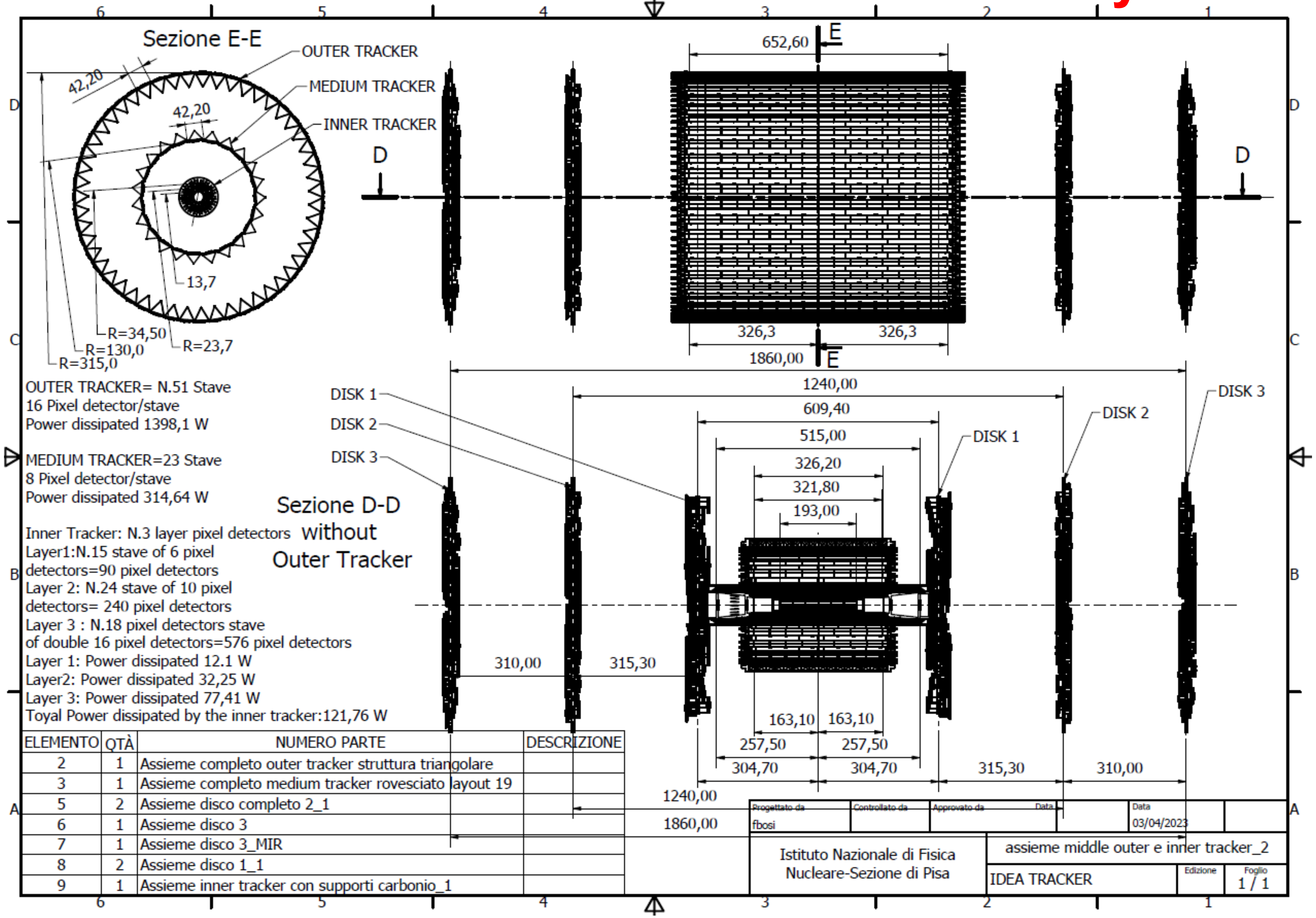


ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
2	1	Assieme completo outer tracker struttura triangolare	
3	1	Assieme completo medium tracker rovesciato layout 19	
5	2	Assieme disco completo 2_1	
6	1	Assieme disco 3	
7	1	Assieme disco 3_MIR	
8	2	Assieme disco 1_1	
9	1	Assieme inner tracker con supporti carbonio_1	

F. Palla

Vertex detector: IDEA

Mid-term review vertex detector overall layout



Inner Vertex detector:

Modules of $25 \times 25\ \mu m^2$ pixel size

3 barrel layers at
- 13.7, 22.7 and 34.8 mm radius

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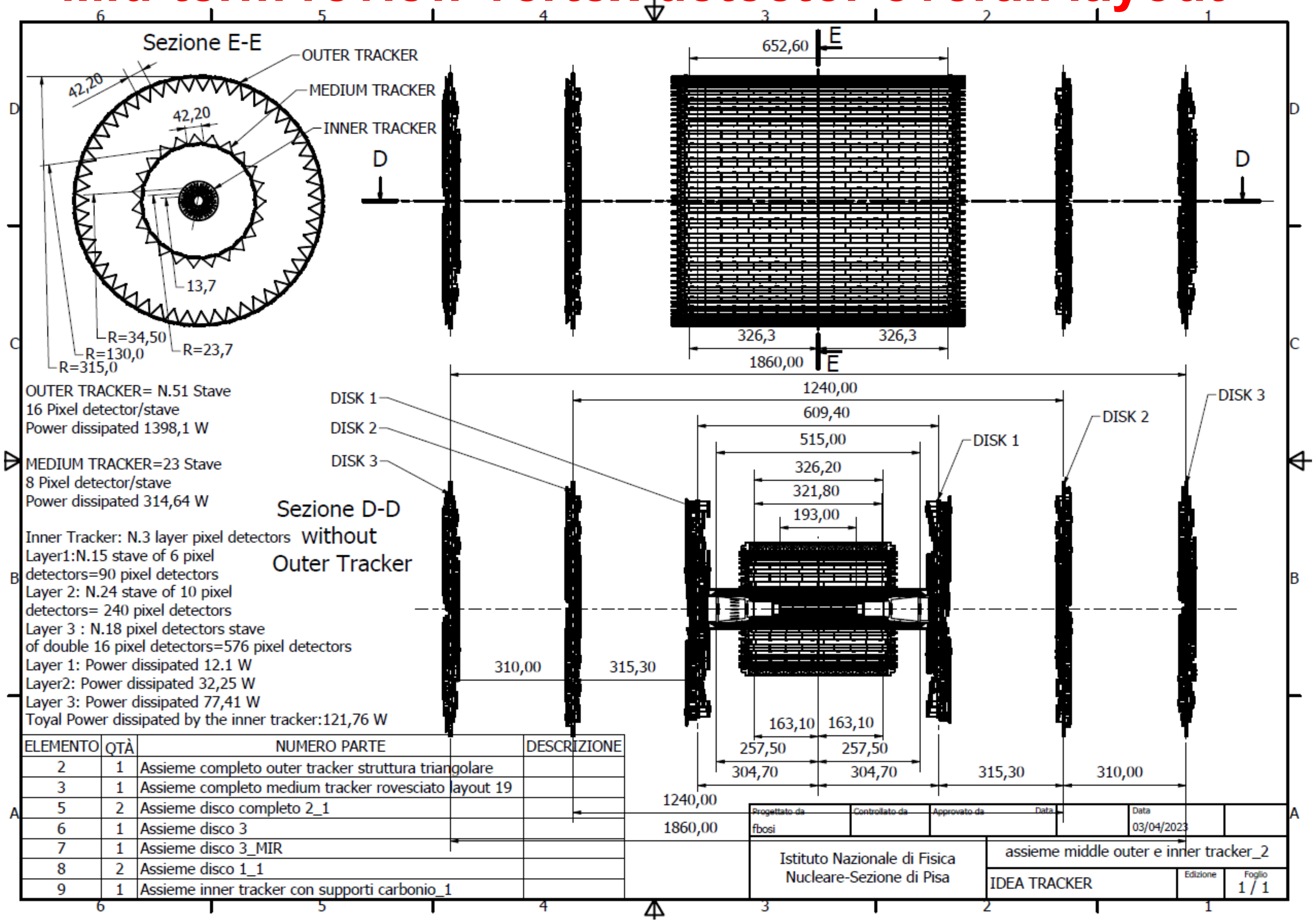

Outer vertex tracker:

Modules of $50 \times 150\ \mu m^2$ pixel size

- Intermediate barrel at 13 cm radius (improved reconstruction for $p_T > 40$ MeV tracks)
- Outer barrel at 31.5 cm radius
- 3 disks per side

Inner Vertex detector:

Modules of $25 \times 25\ \mu m^2$ pixel size

3 barrel layers at
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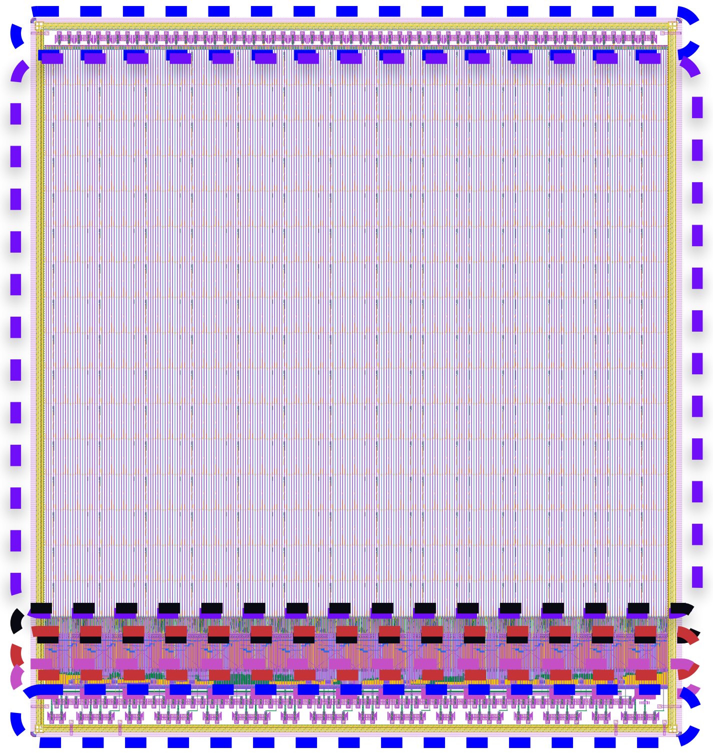
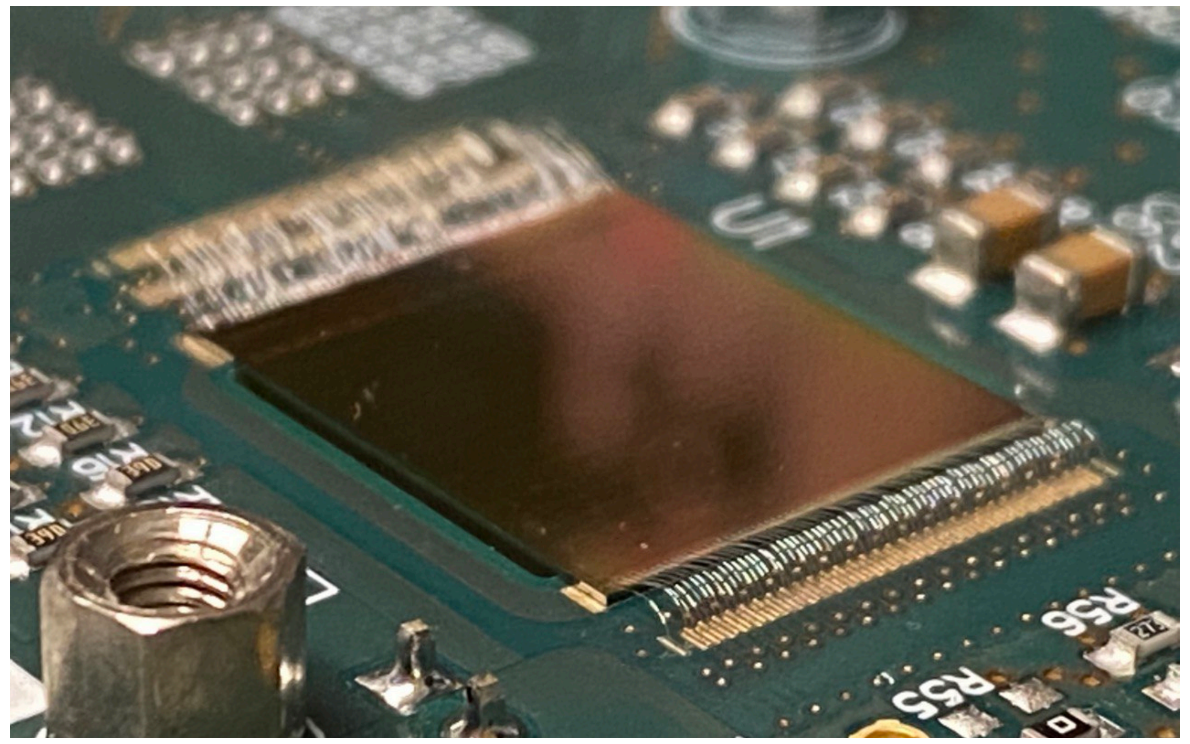
F. Palla

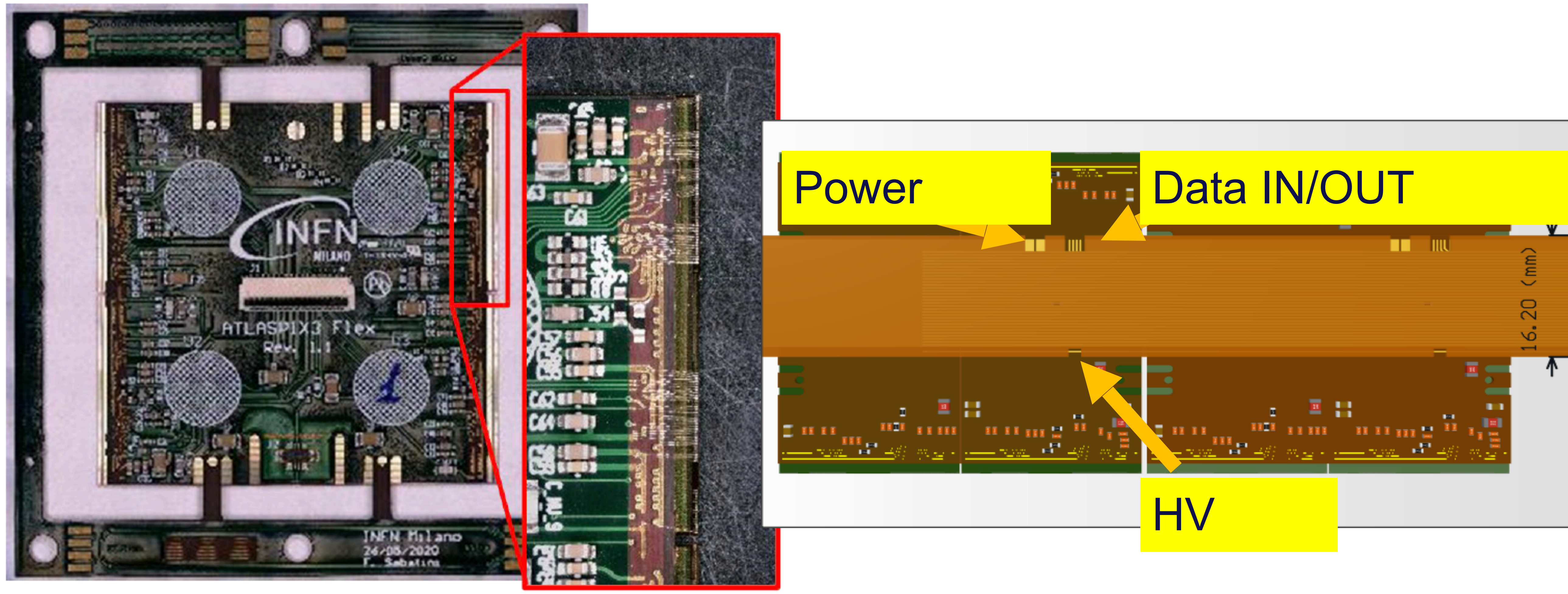
Vertex detector: IDEA

Depleted Monolithic Active Pixel Detectors

- **Inner Vertex (ARCADIA based):**
  - Lfoundry 110 nm process
  - *50 μm thick*
  - Dimensions: $8.4 \times 32\ mm^2$
  - Power density 30 mW/cm²
  - **100 MHz/cm²**
- **Outer Vertex and disks (ATLASPIX3 based)**
  - TSI 180 nm process
  - *50 μm thick*
  - Module dimensions: $42.2 \times 40.6\ mm^2$
  - Power density 170 mW/cm²
  - **Up to 1.28 Gb/s downlink**





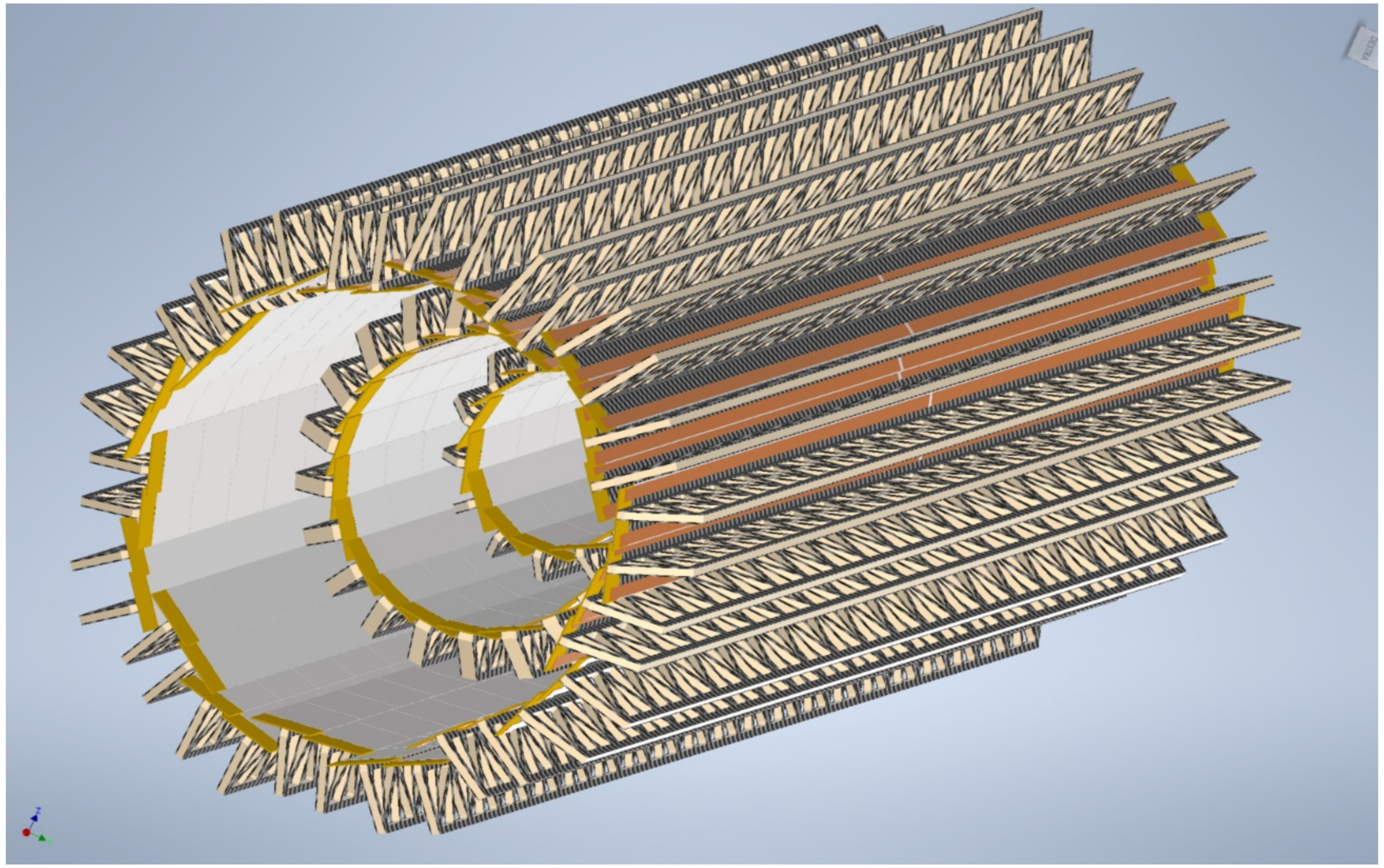


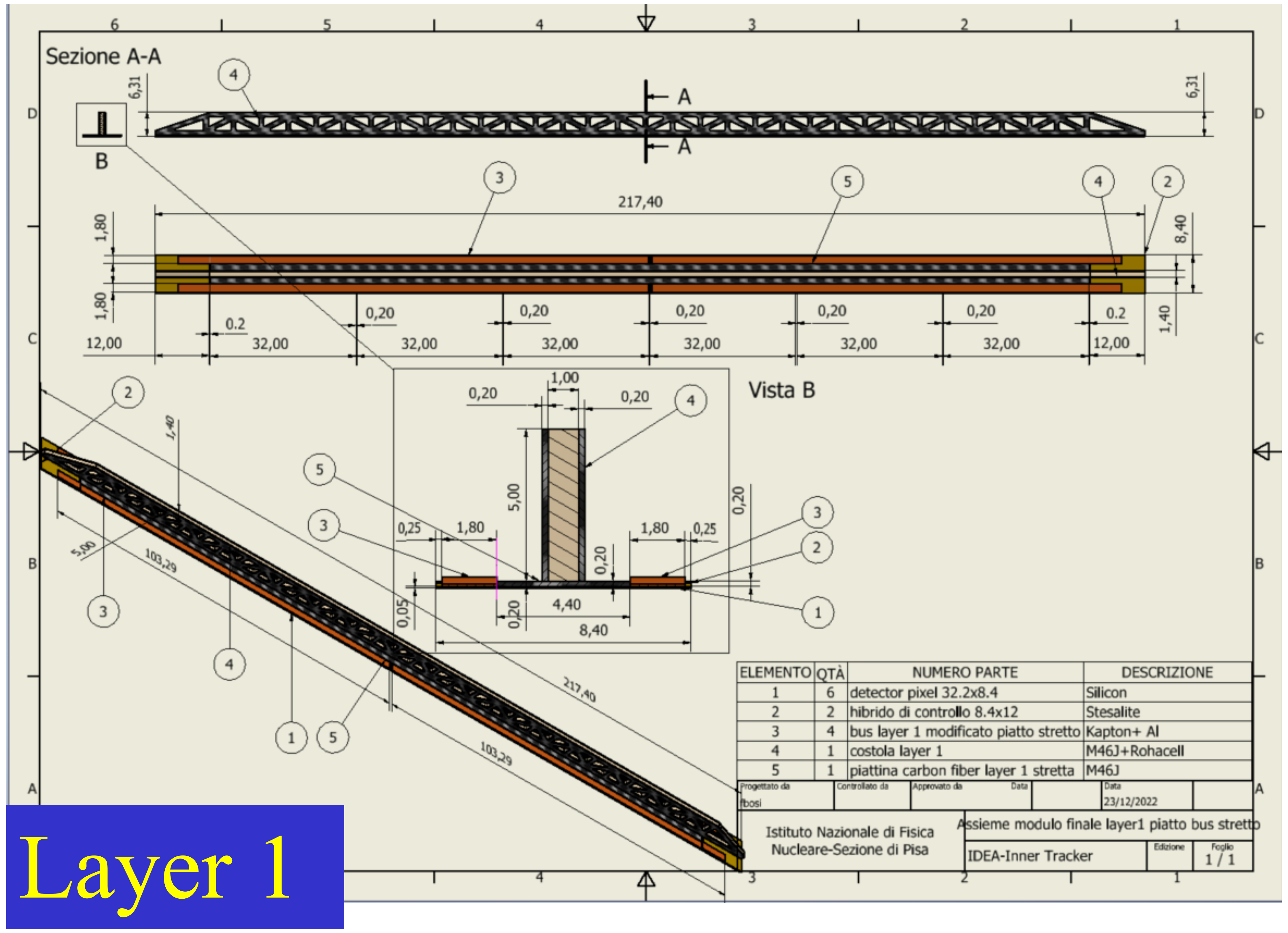
See talk by F. Palla for more details on the vertex tracker

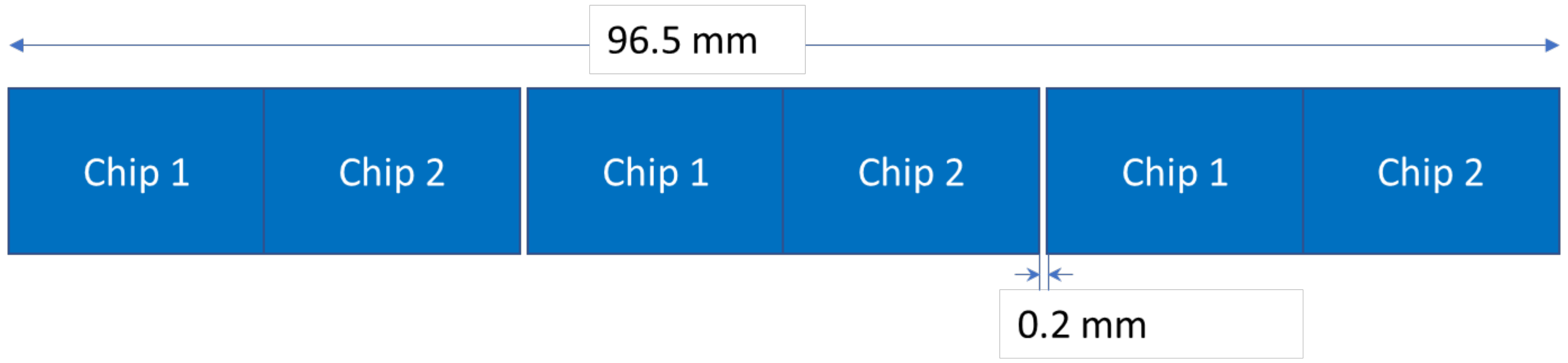
F. Palla

Vertex detector mechanical integration

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







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- Vertex design based on:
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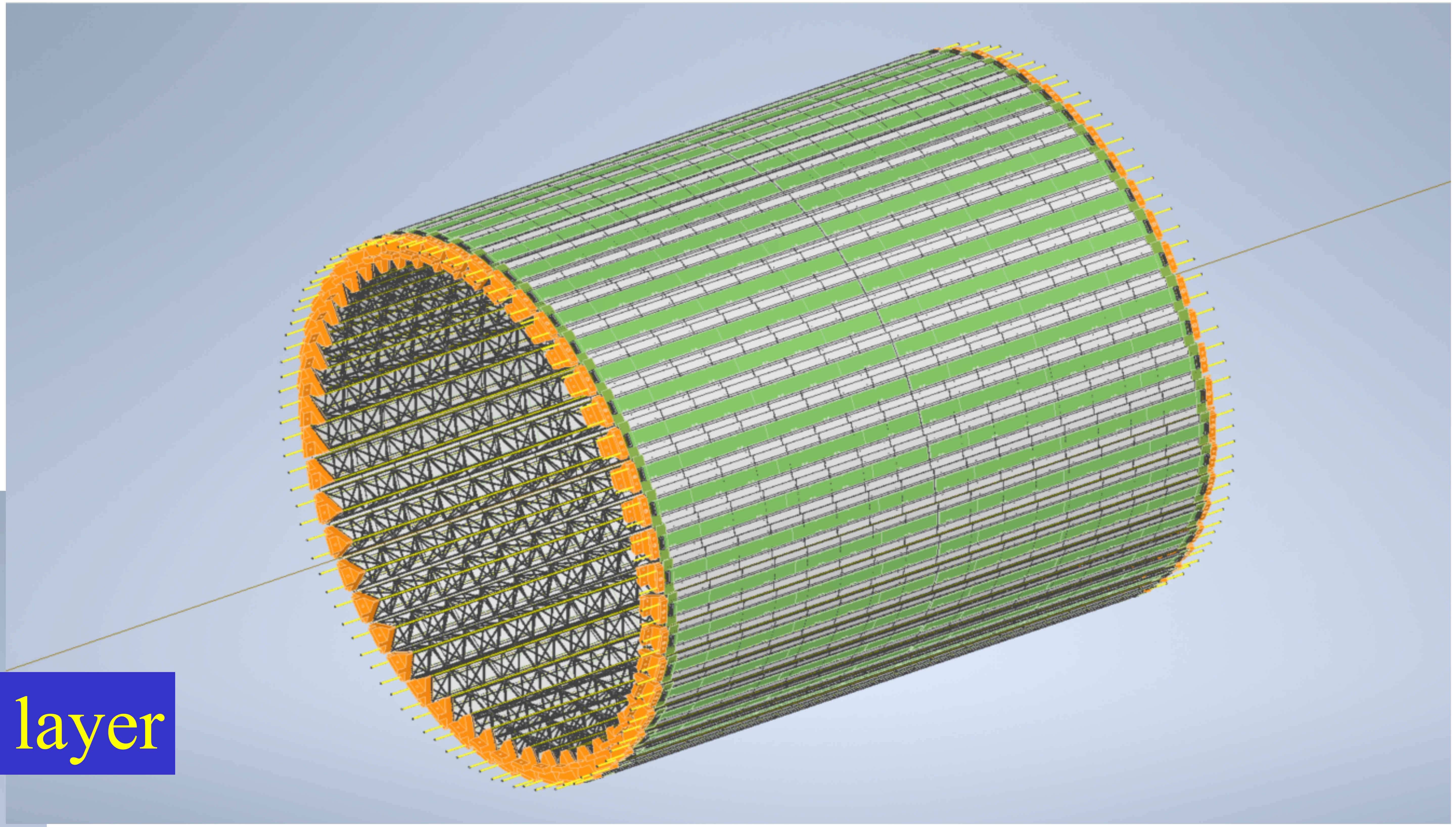
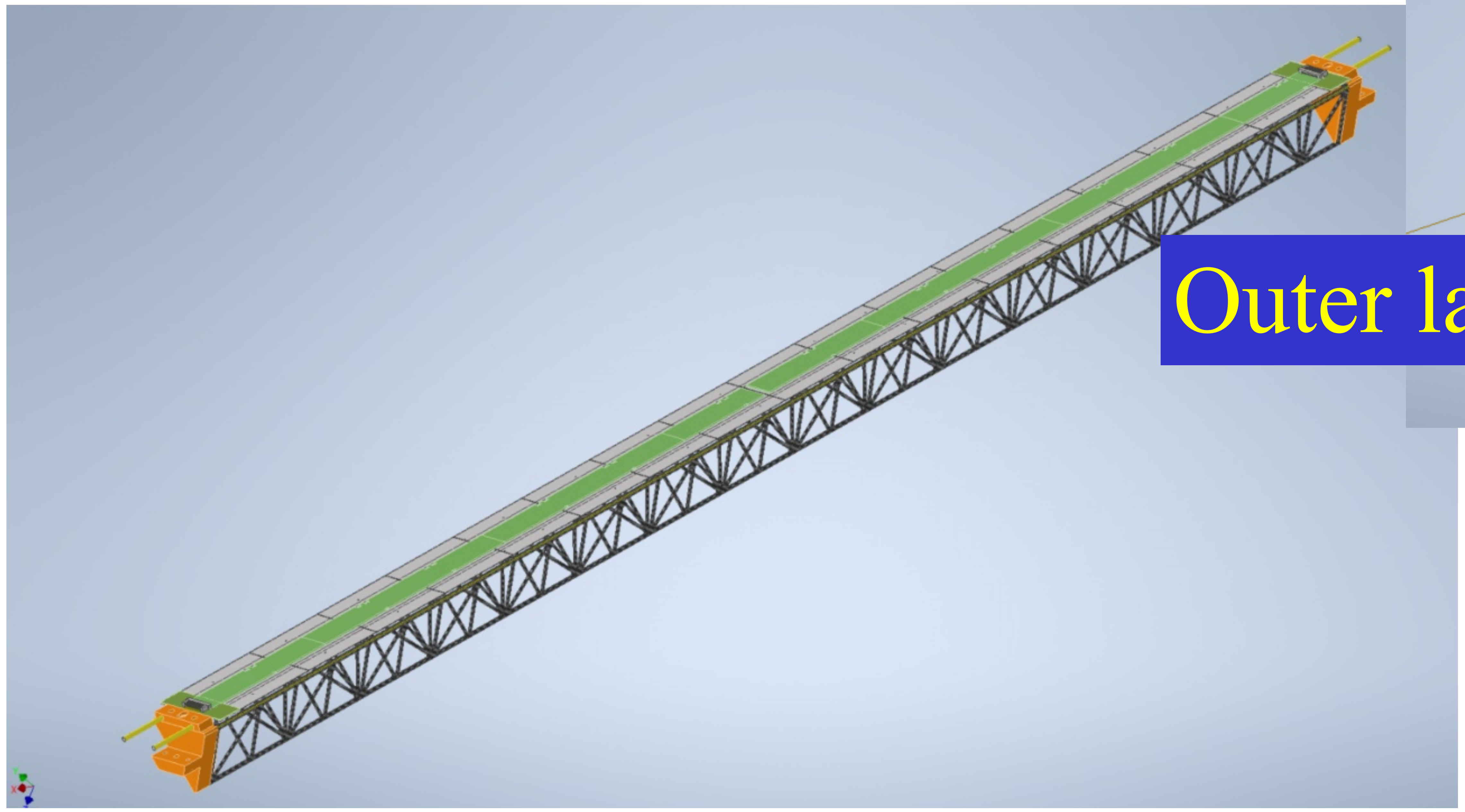
  - AtlasPix3 outer 2 layers/disks
    - Liquid cooled



Outer layer



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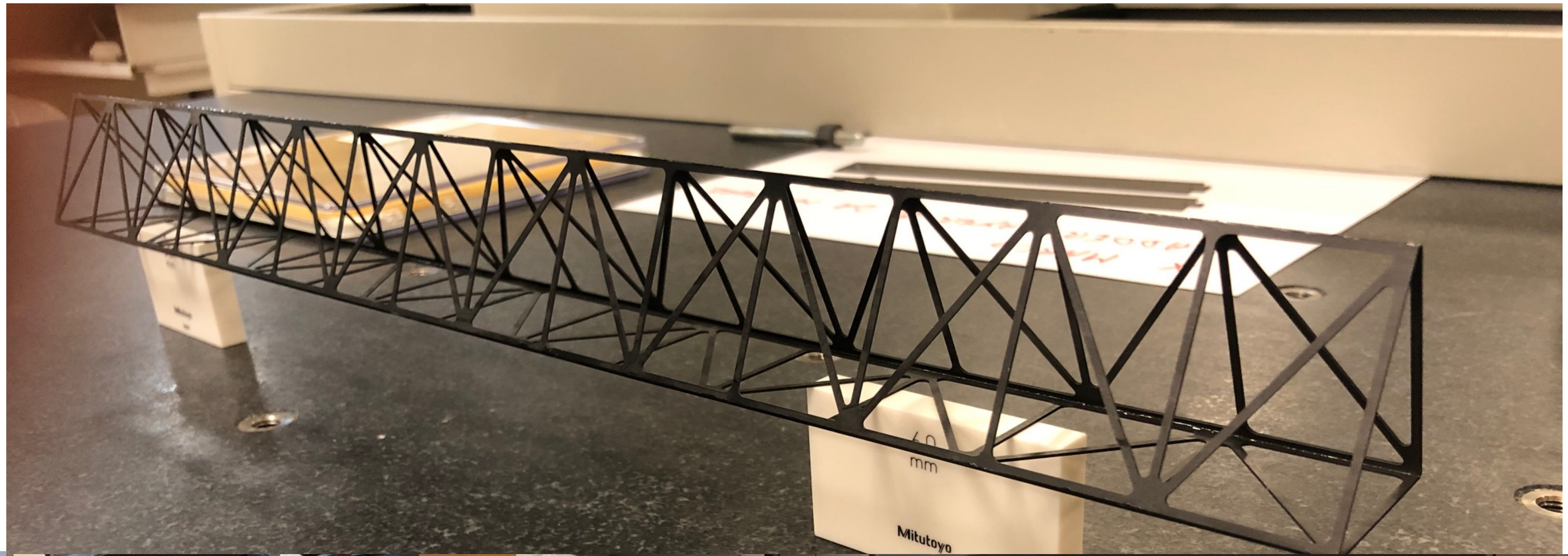
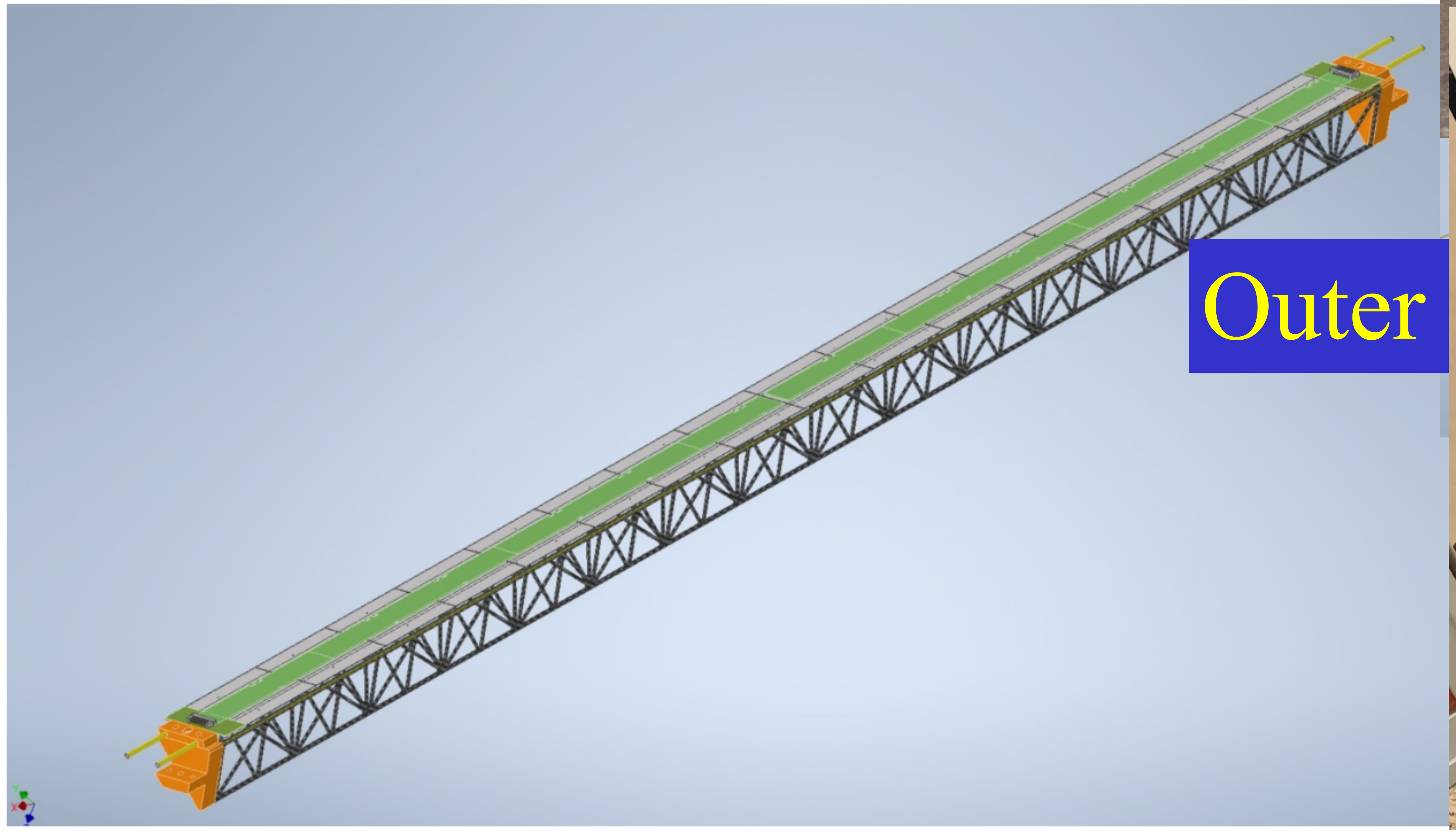
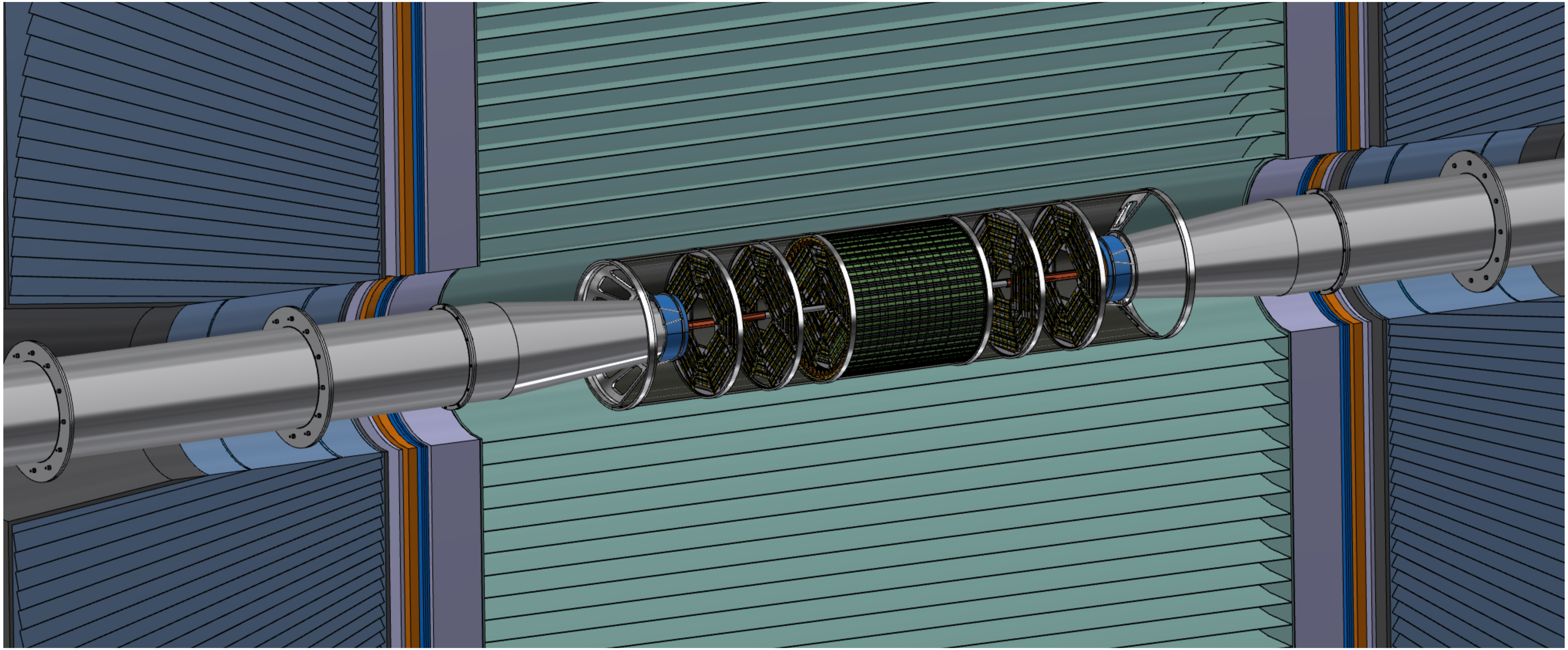




Outer

Vertex detector: IDEA

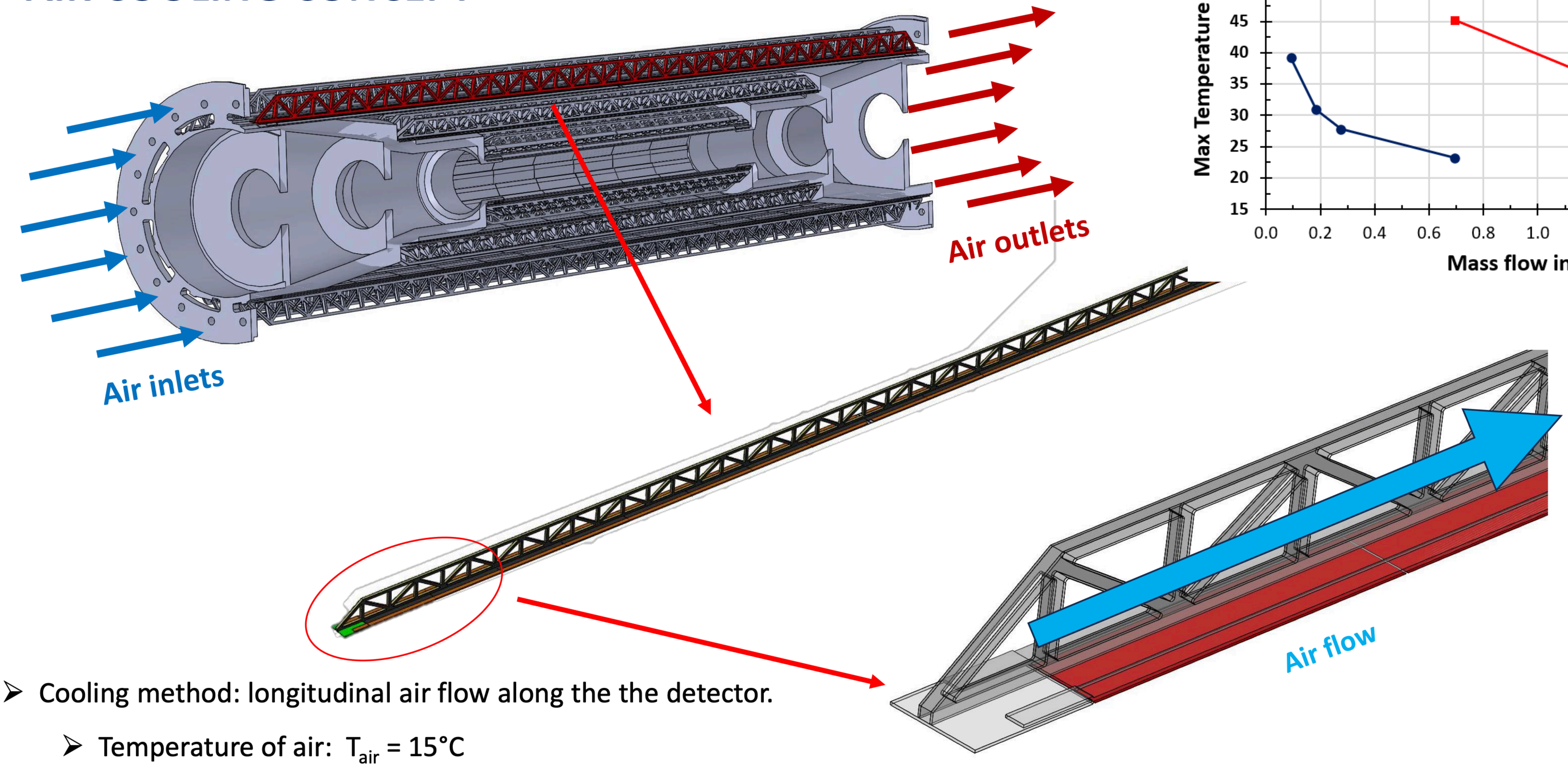
General integration

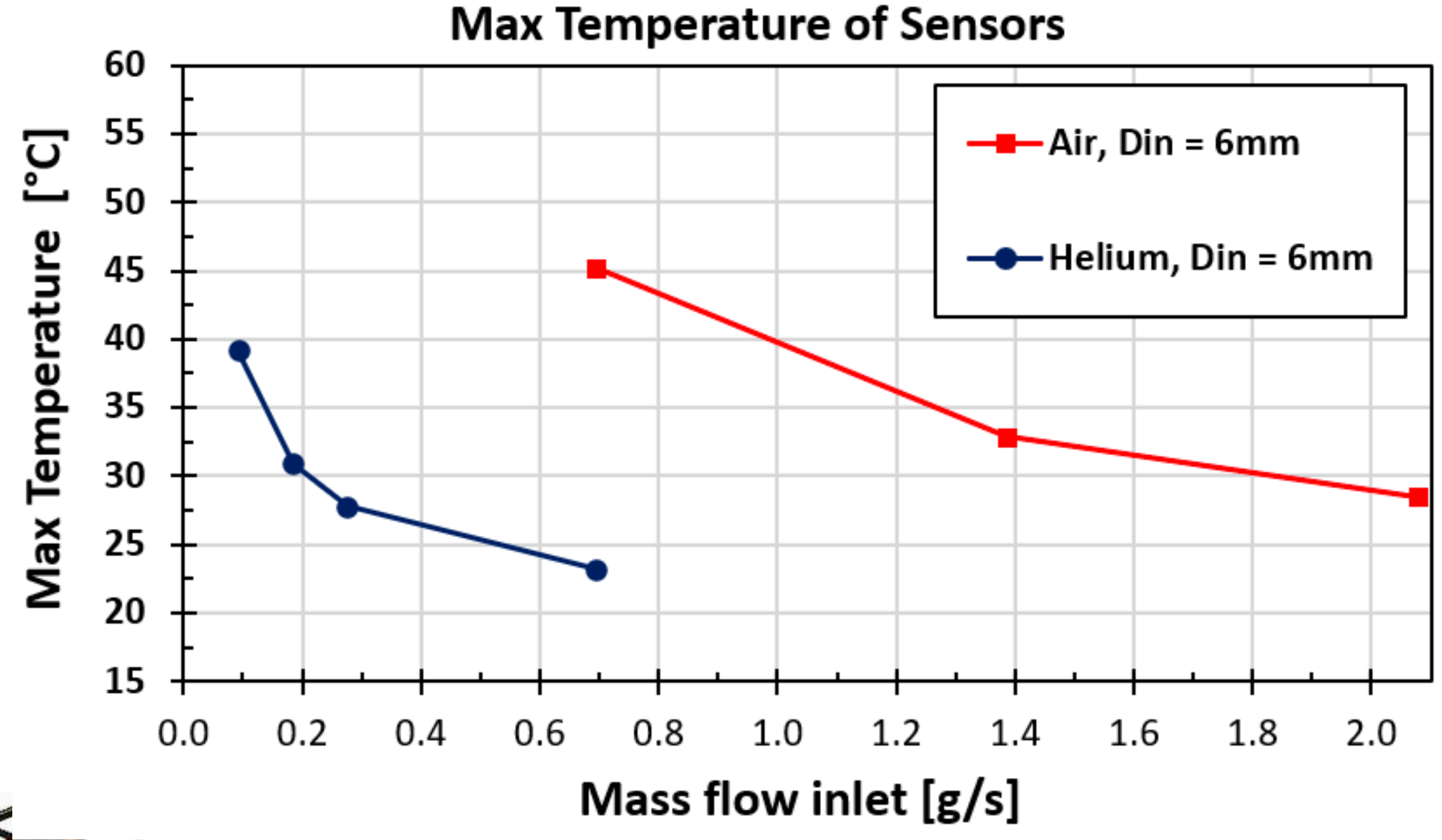


F. Palla

Vertex detector: IDEA

AIR COOLING CONCEPT

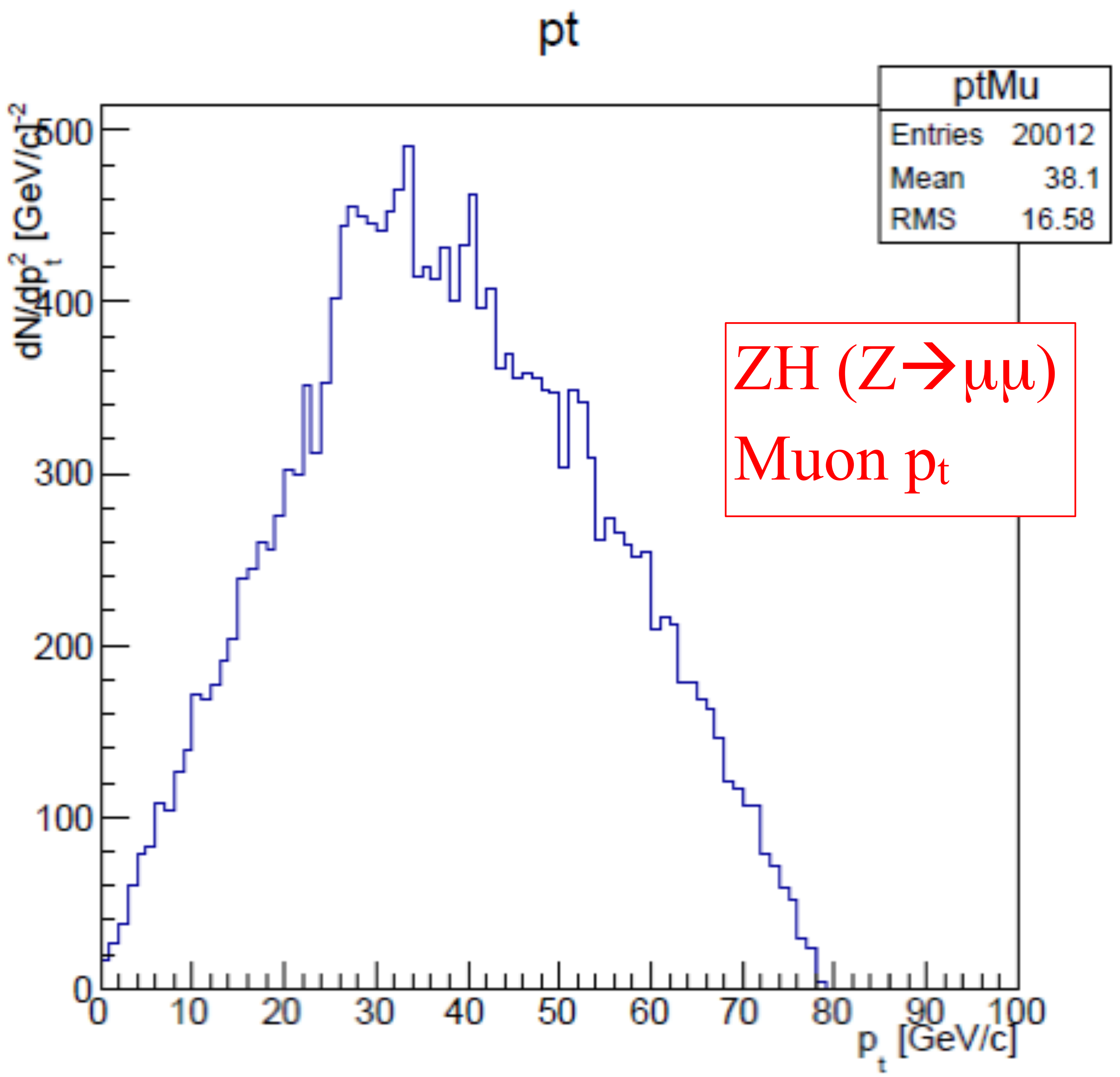


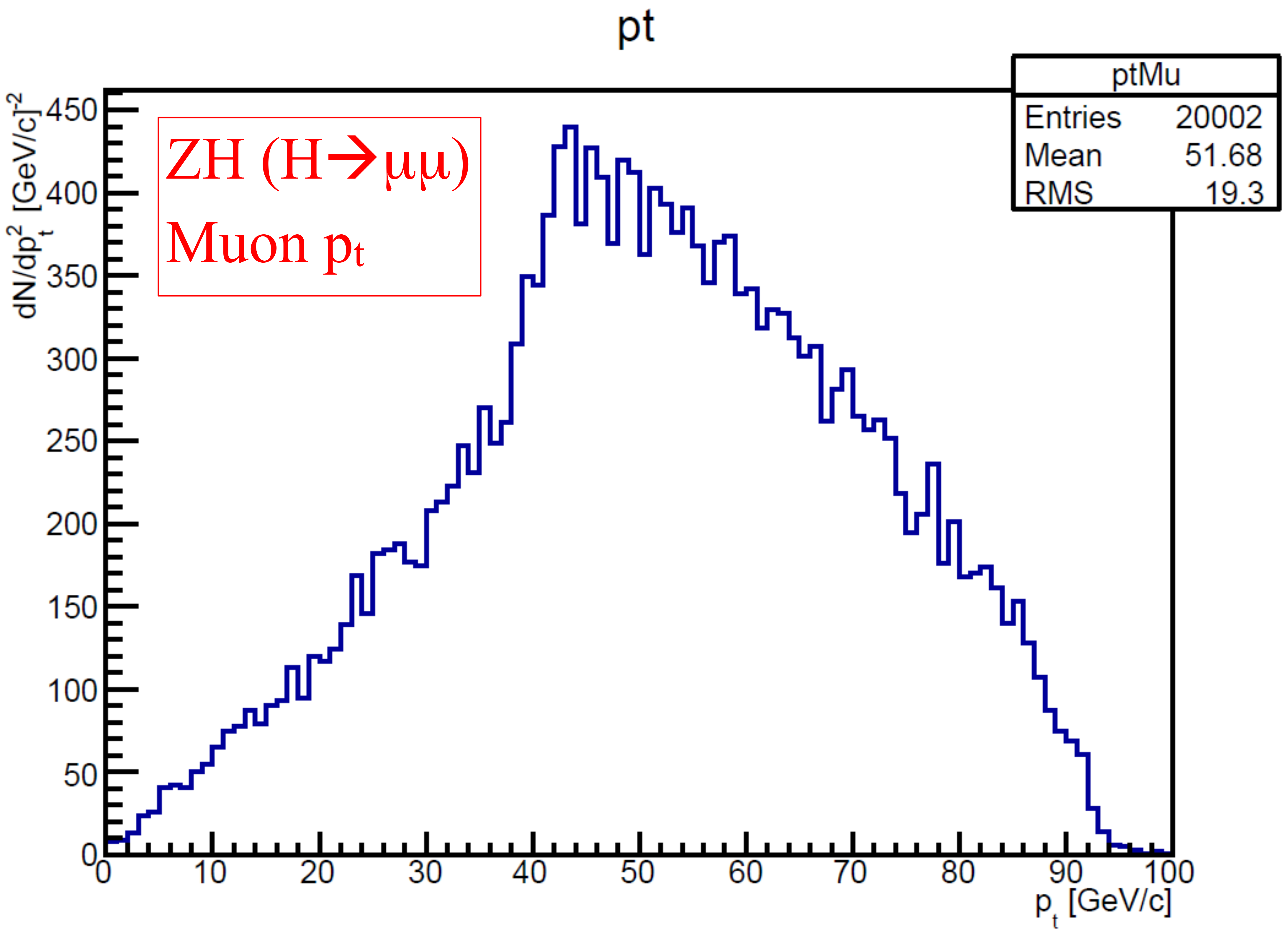


- Cooling method: longitudinal air flow along the the detector.
  - Temperature of air: T_{air} = 15°C

C. Turrioni

Momentum measurement





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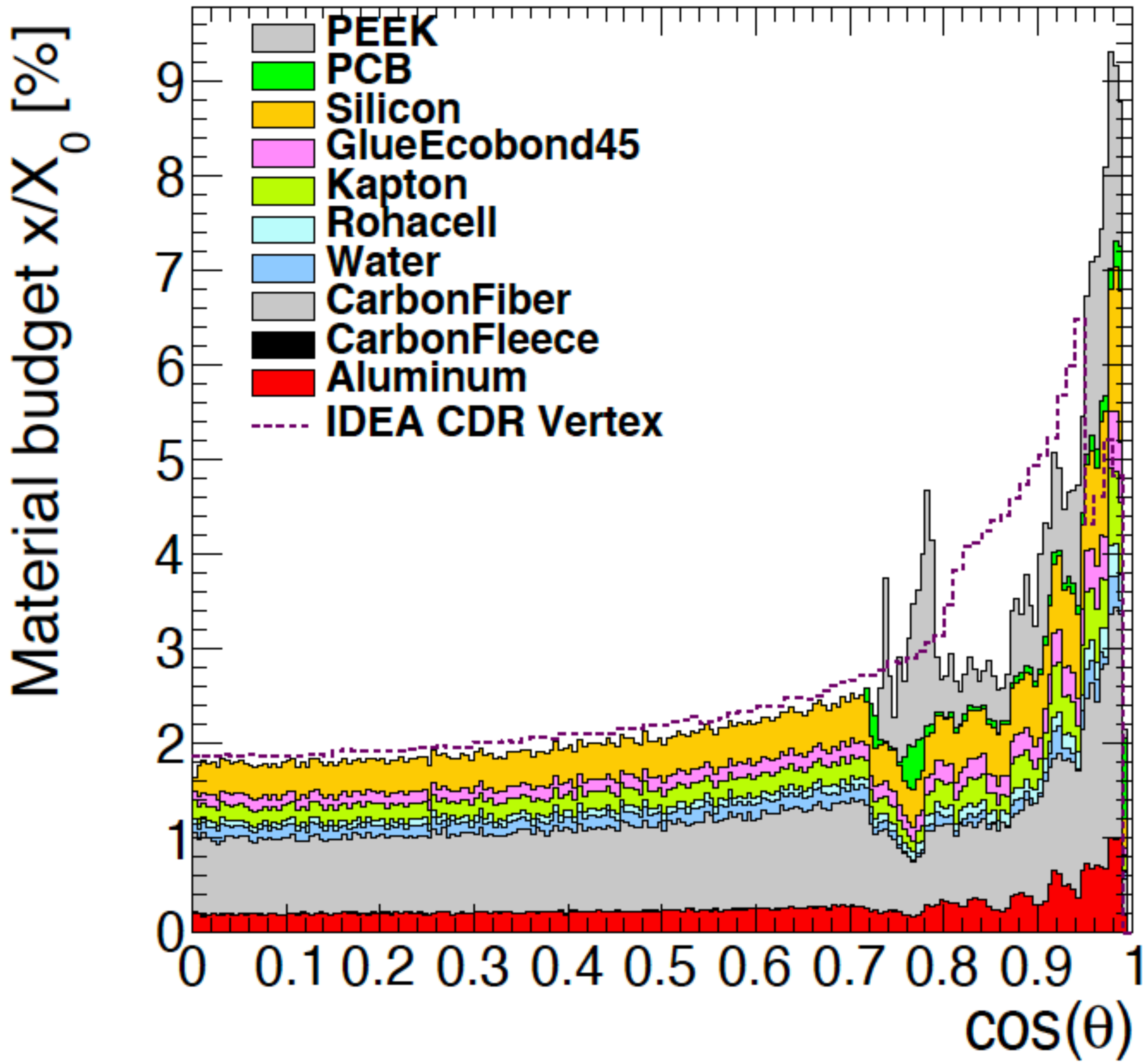
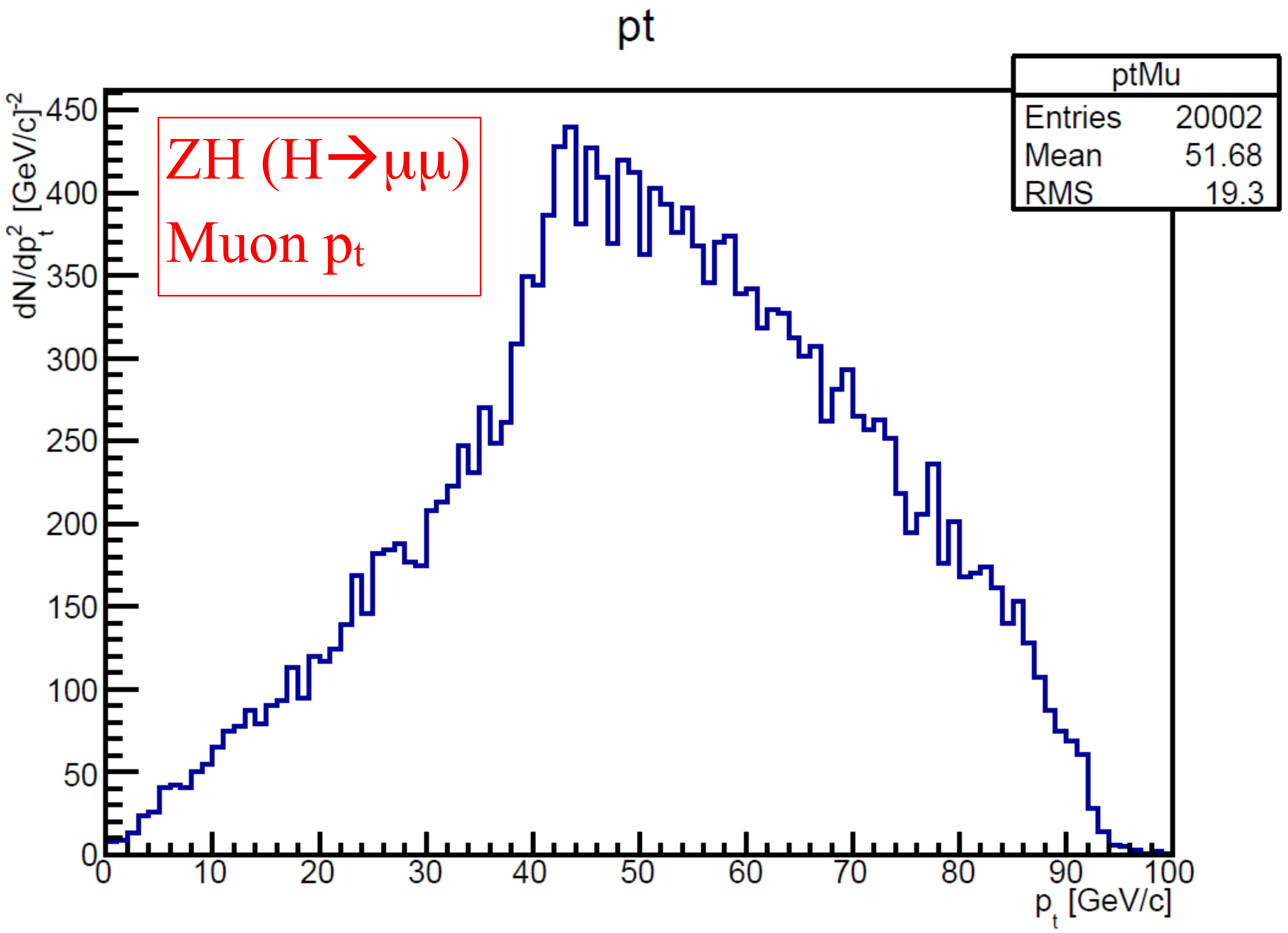
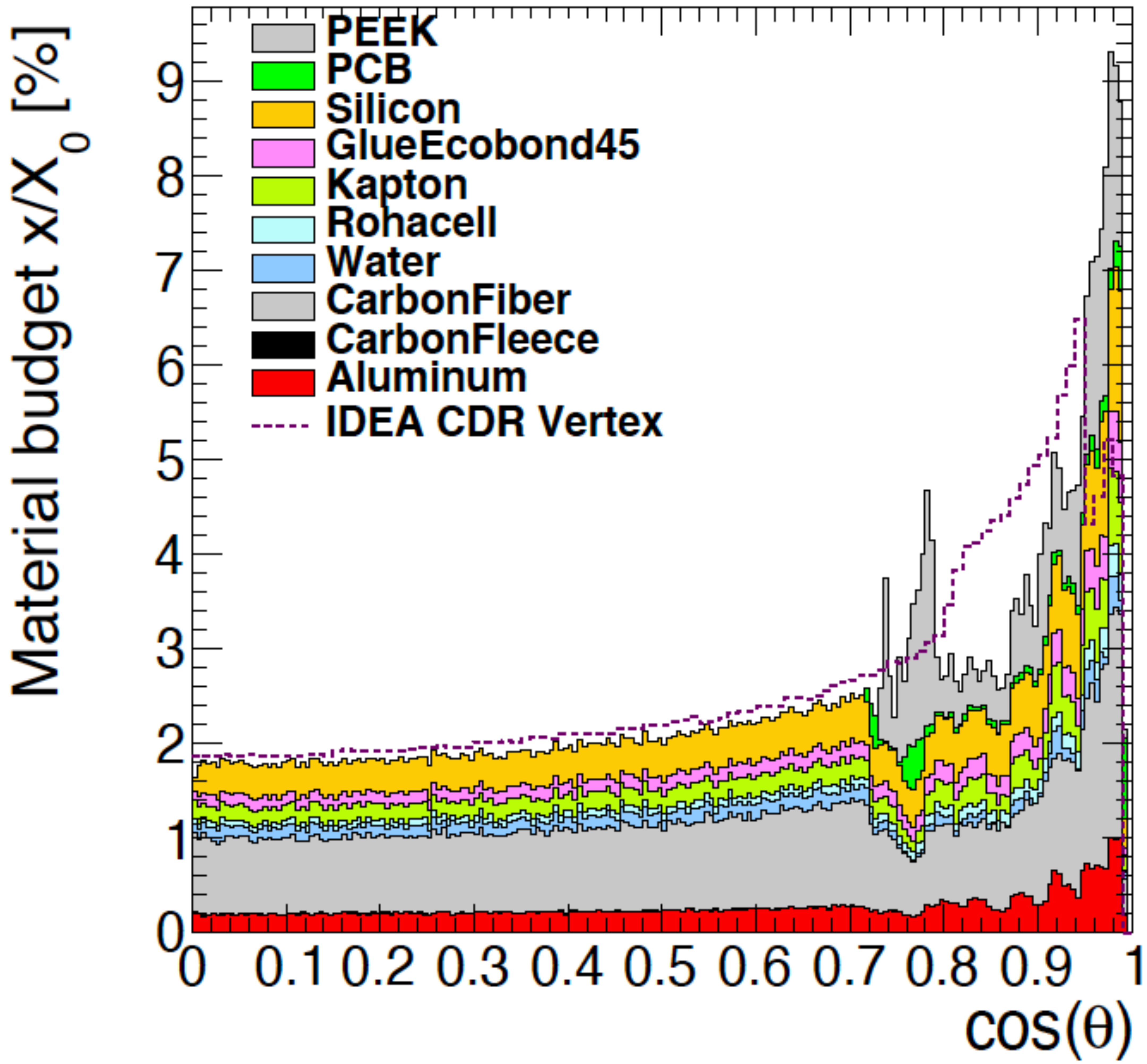


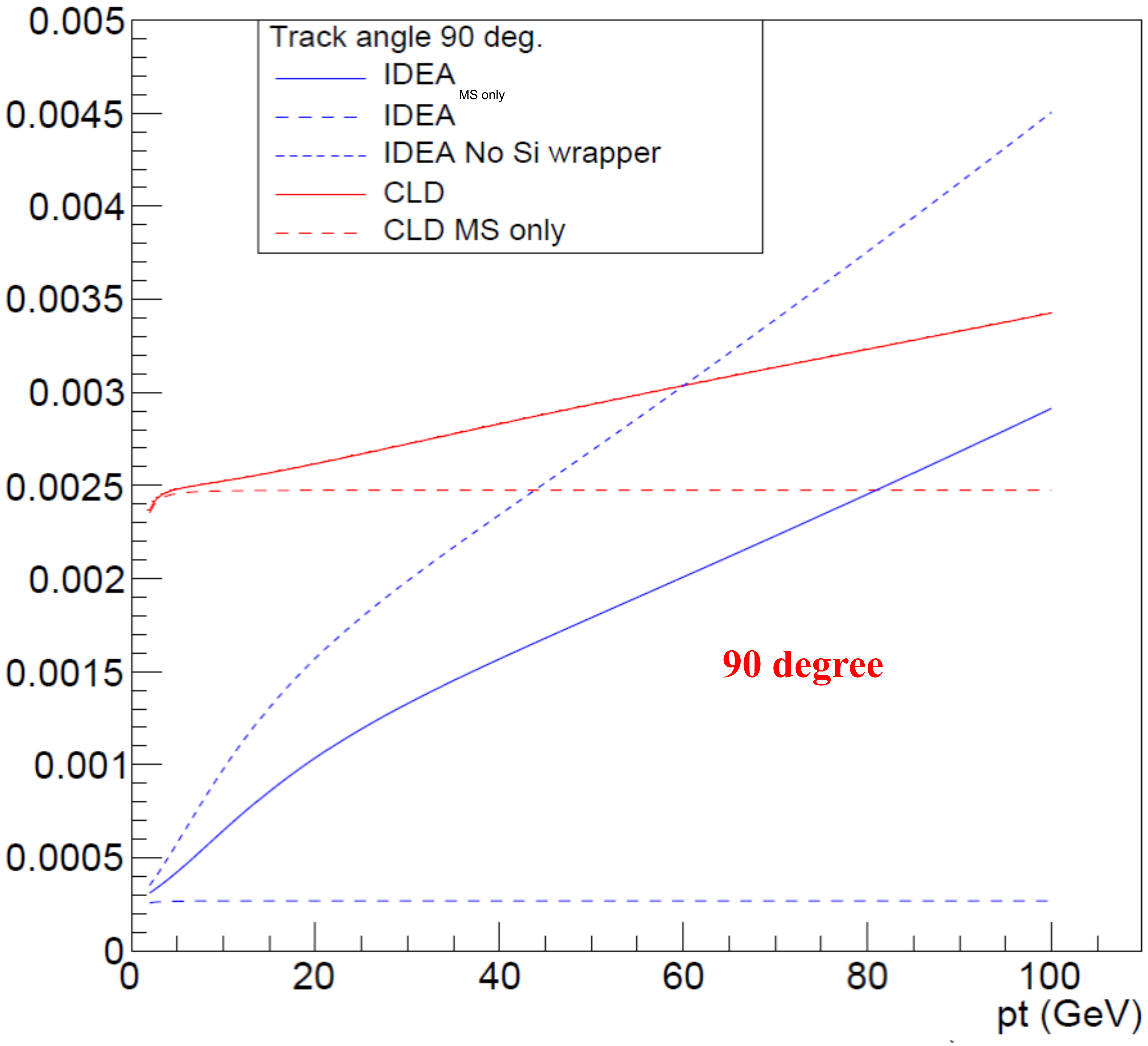


Momentum measurement

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

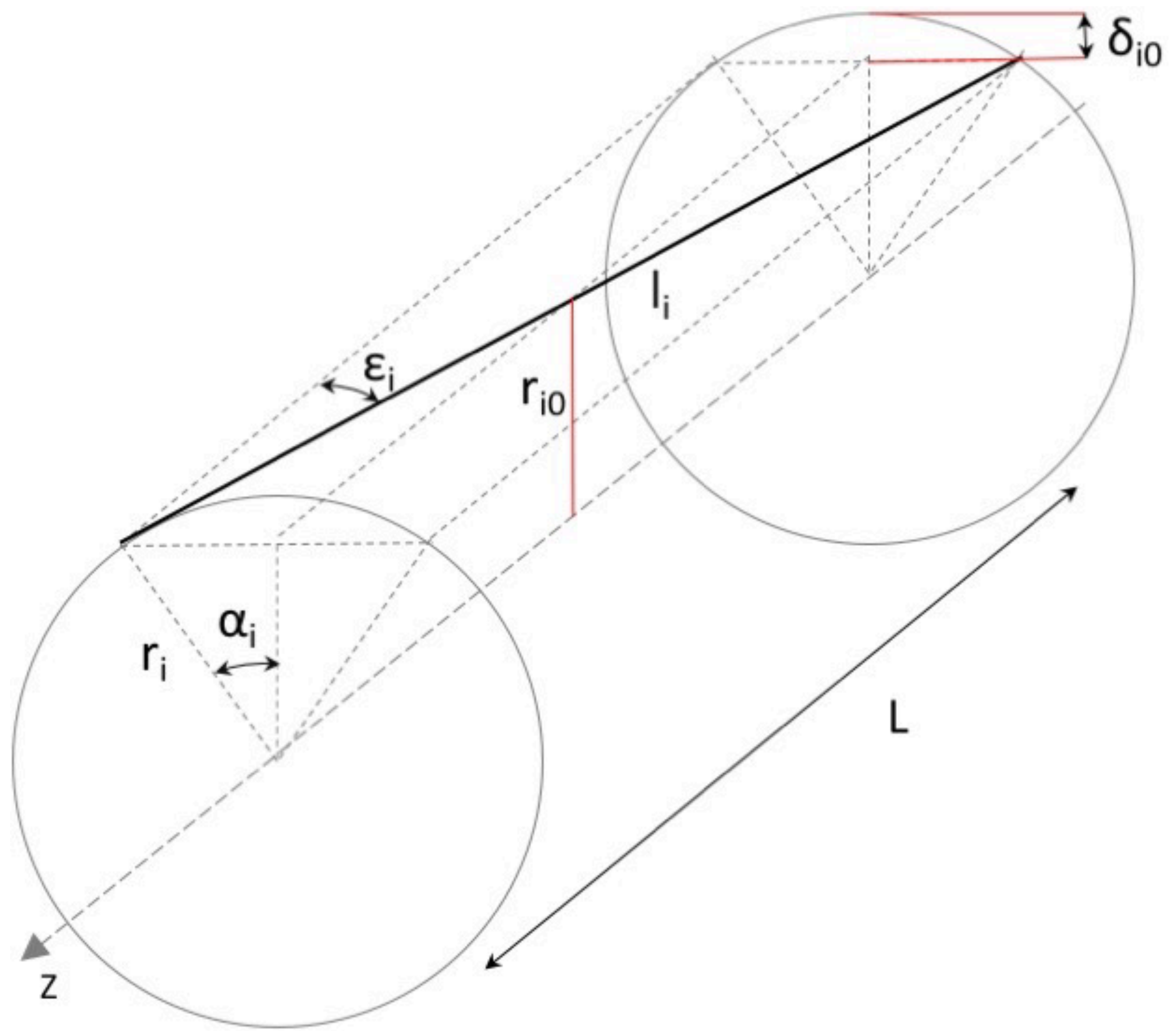


σ_{pt}/pt

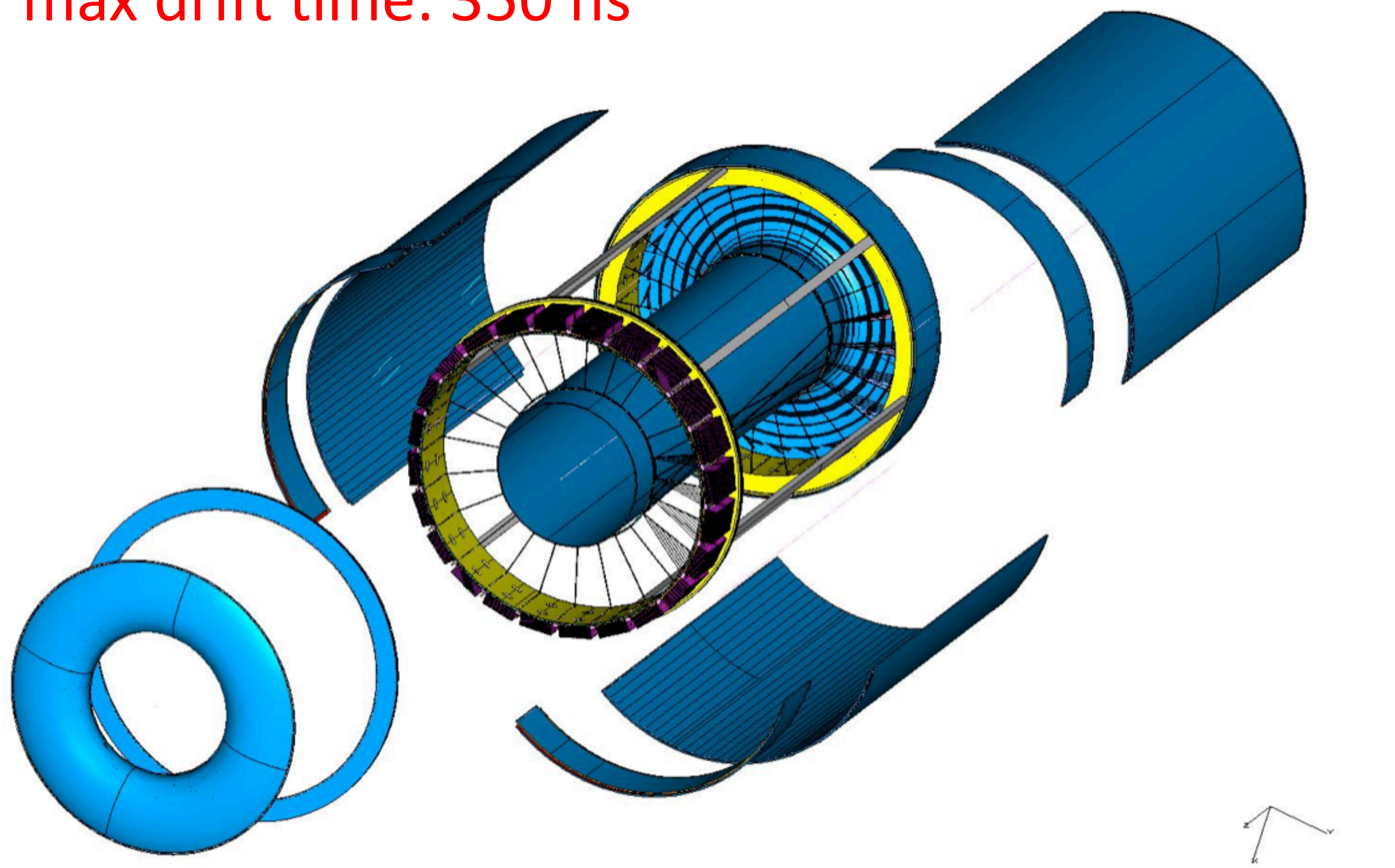


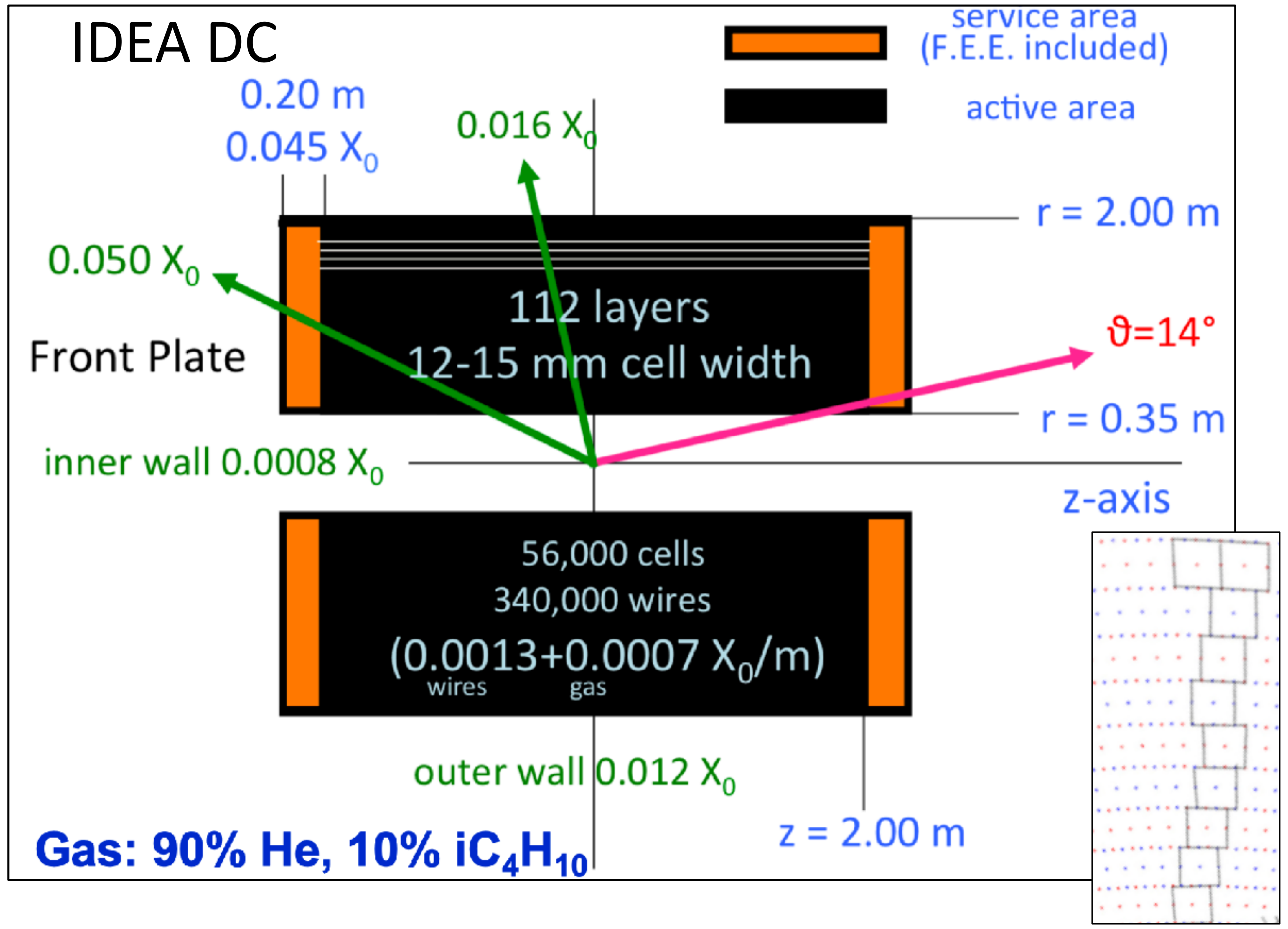
Drift chamber

- 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 90°
  - All stereo wires (56448 cells, 343968 wires)
    - Tungsten wires dominant contribution
  - 112 layers for each 15° azimuthal sector
  - max drift time: 350 ns



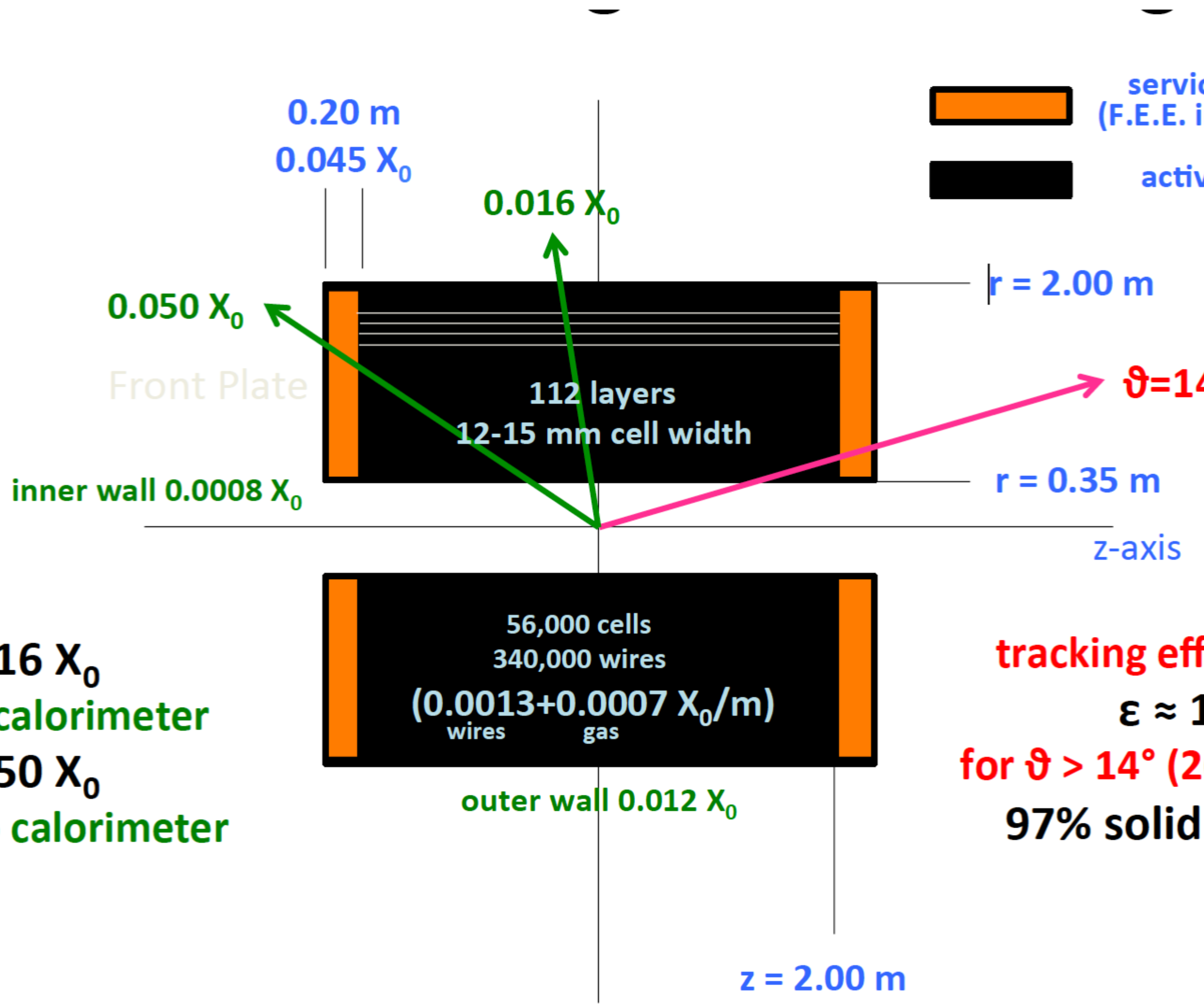
L = 4m





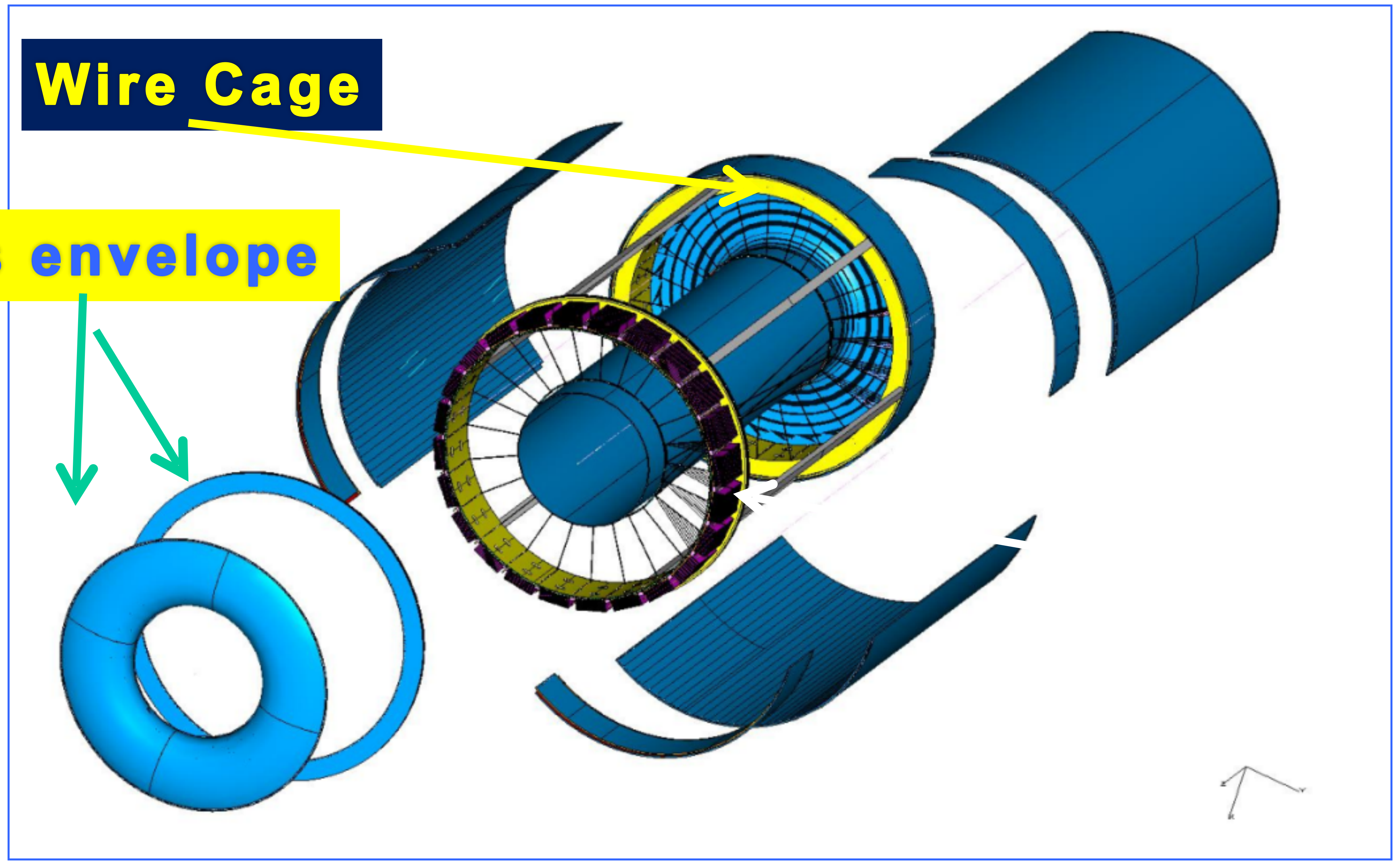
Drift chamber

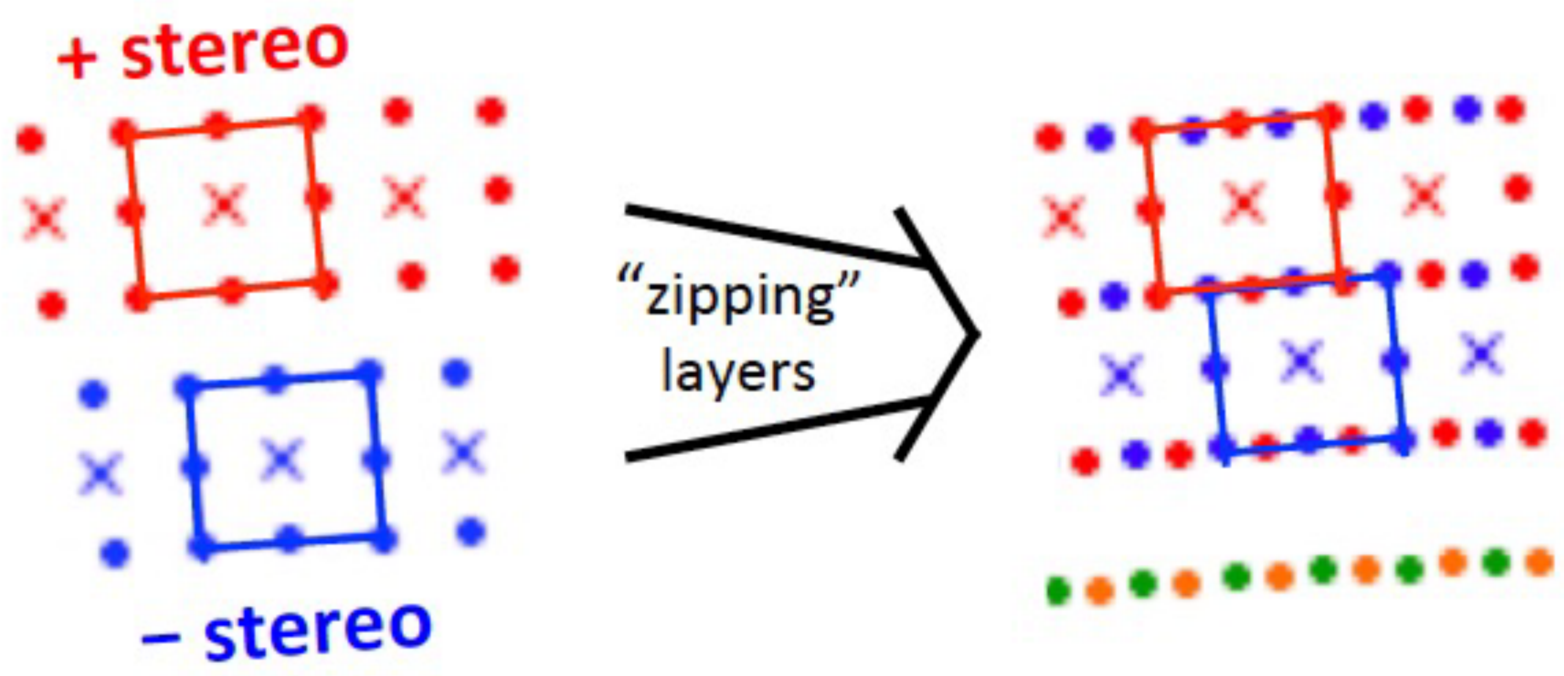
- ❖ 90% He - 10% C_4H_{10} – All stereo – $\sigma \sim 100\ \mu m$
- ❖ Small cells, max drift time ~ 350 ns



0.016 X_0
to barrel calorimeter
0.050 X_0
to end-cap calorimeter

tracking efficiency
$\varepsilon \approx 1$
for ϑ > 14° (260 mrad)
97% solid angle





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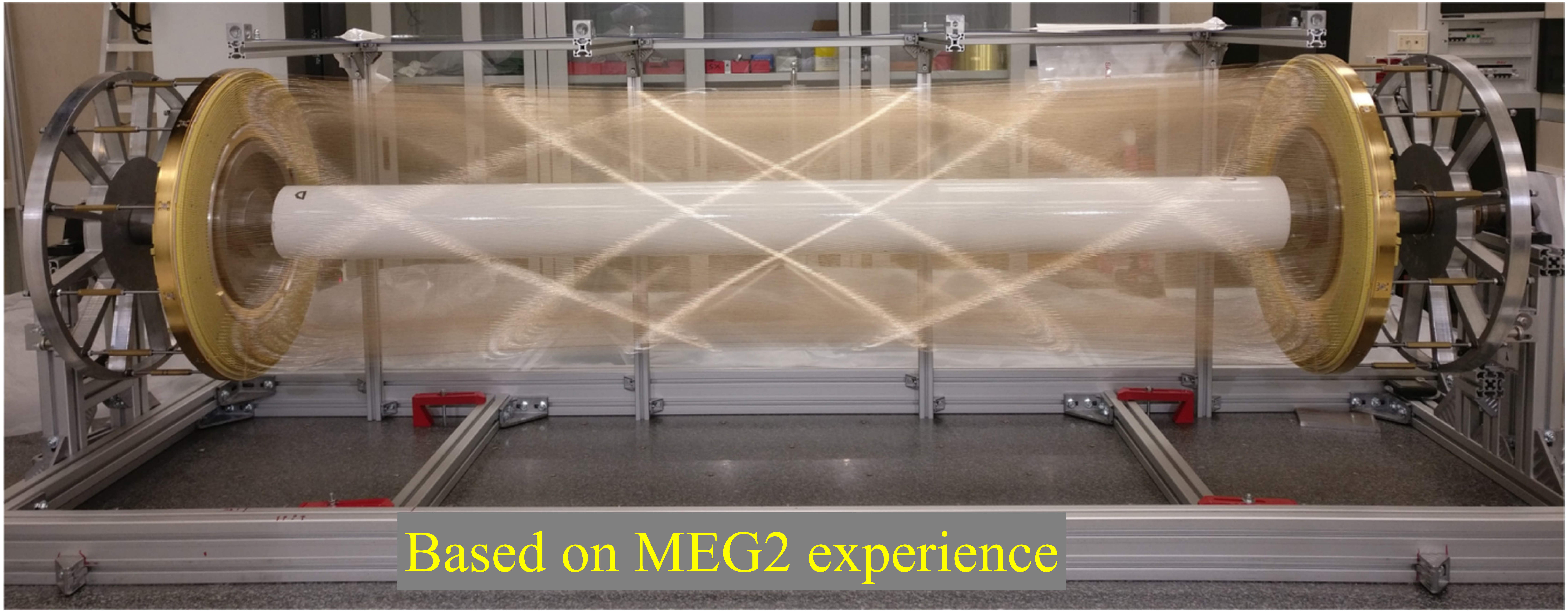
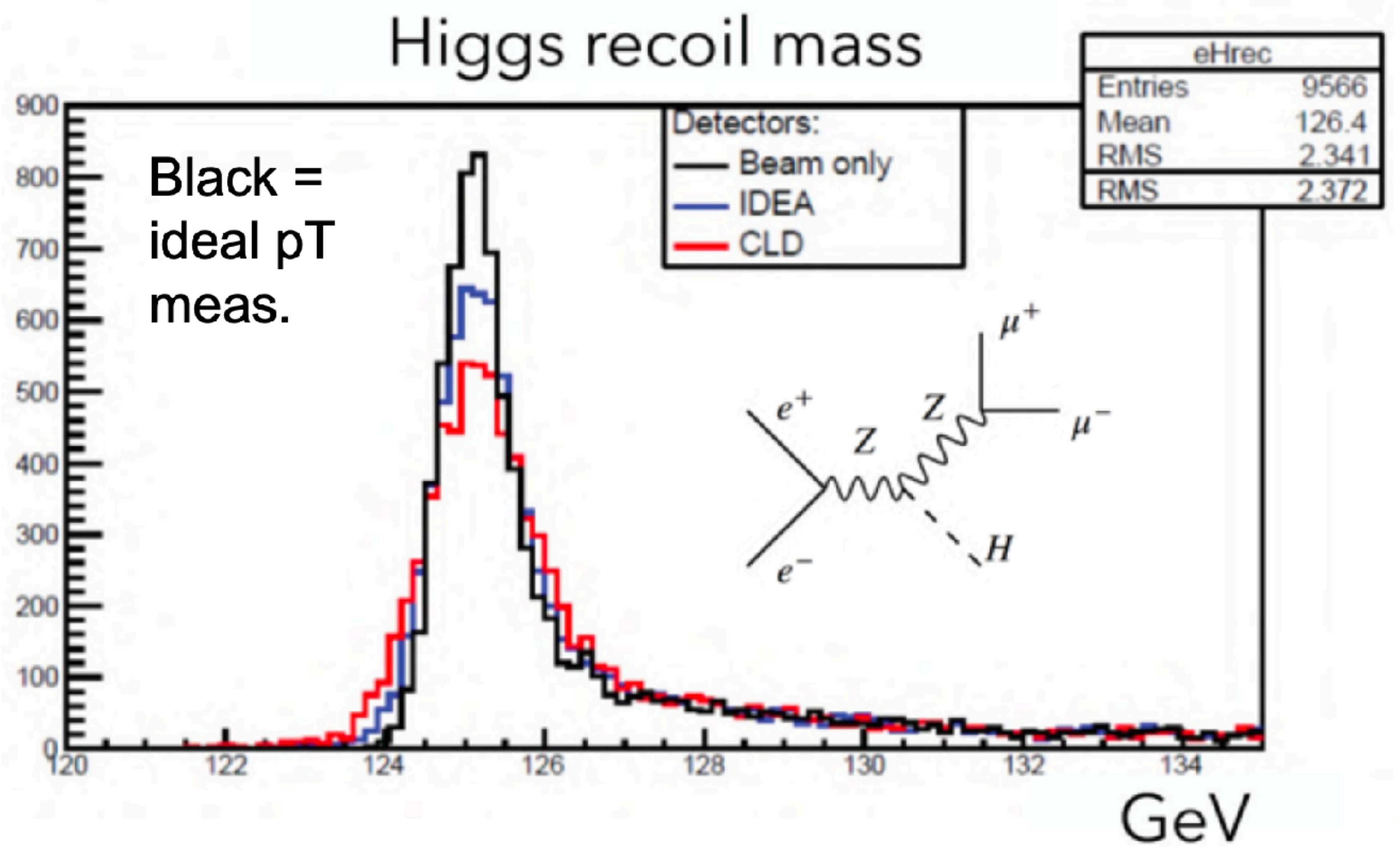
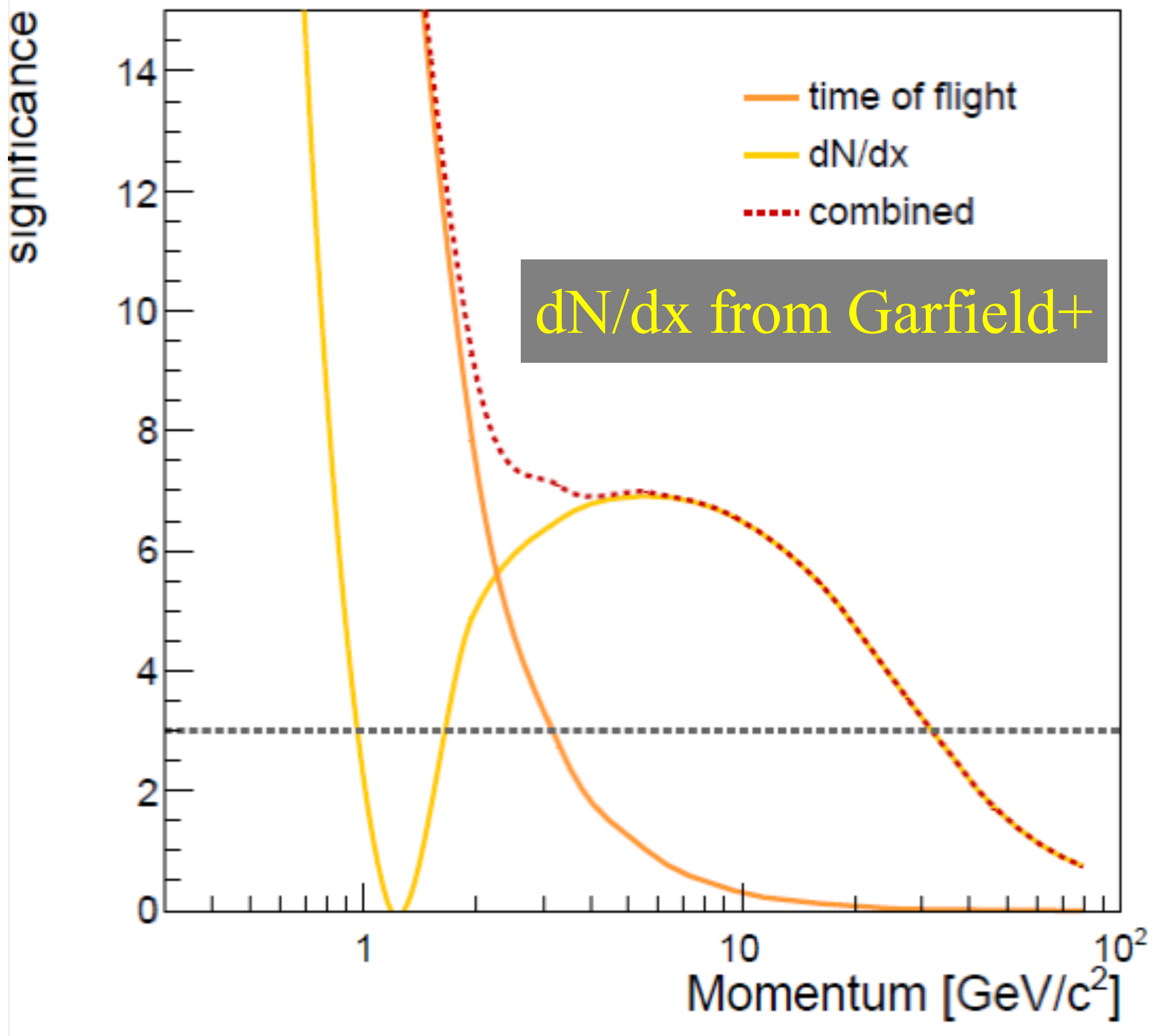


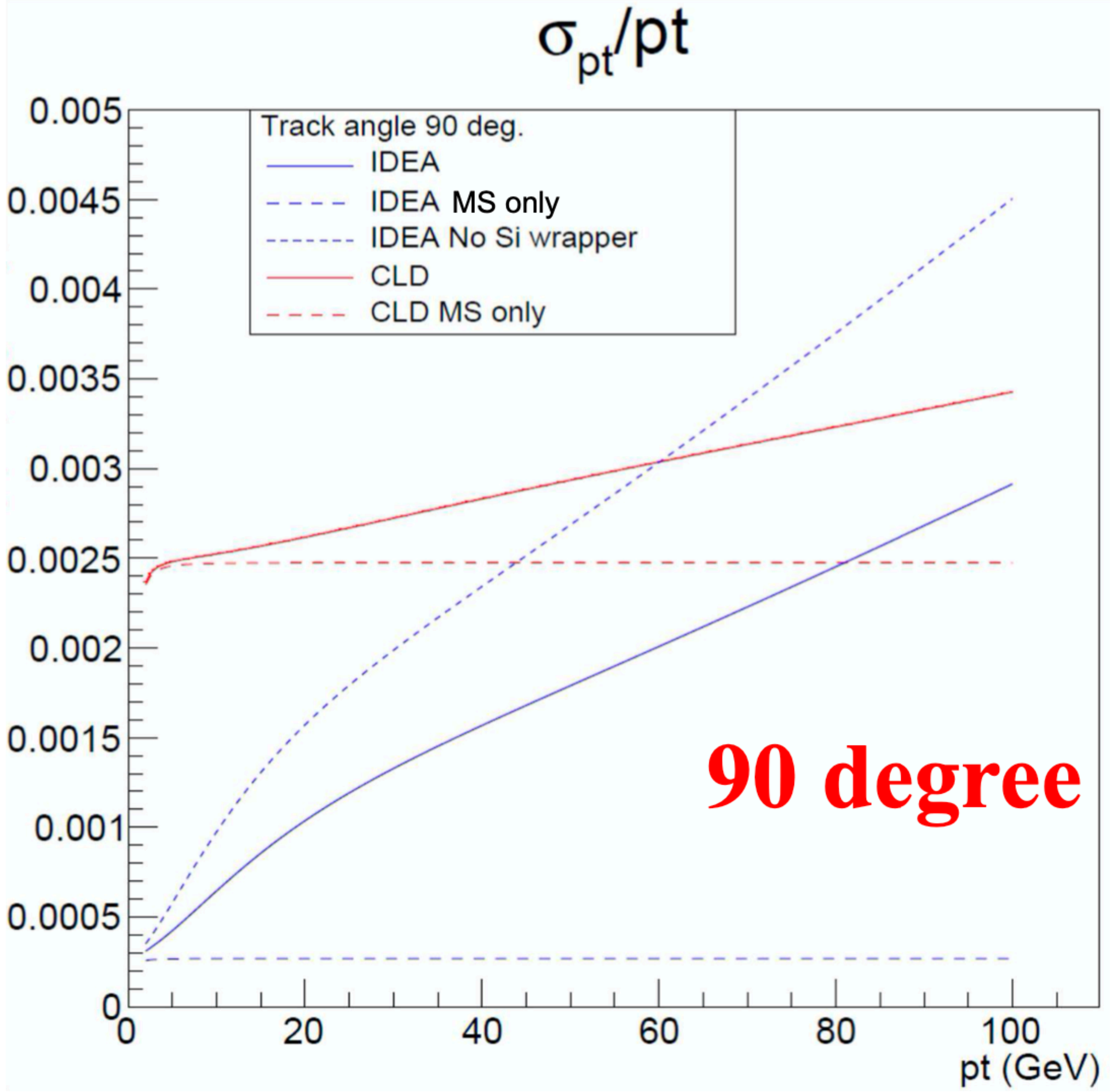
Based on MEG2 experience

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)
    - $>3\sigma$ K/π separation up to ~35 GeV

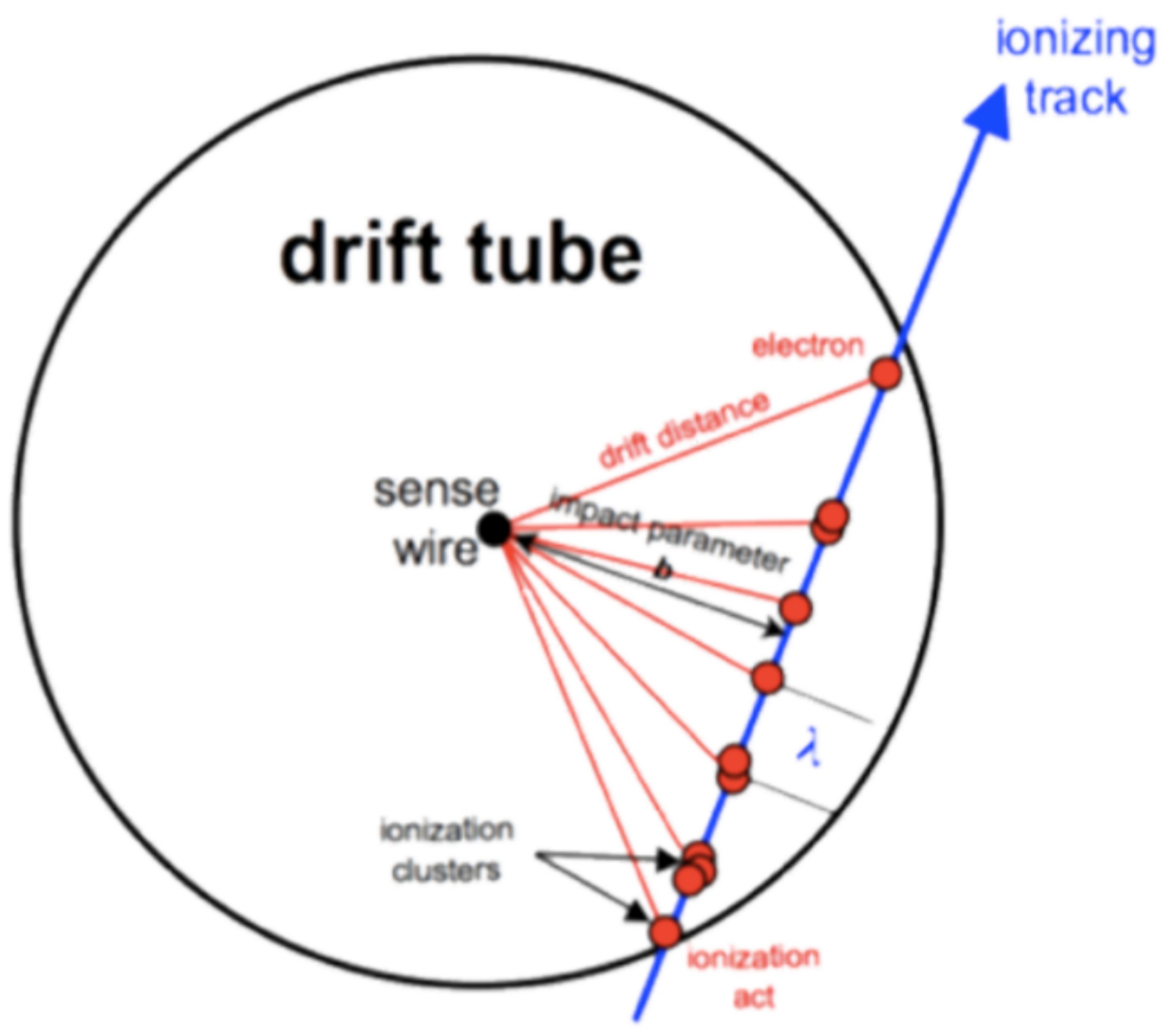




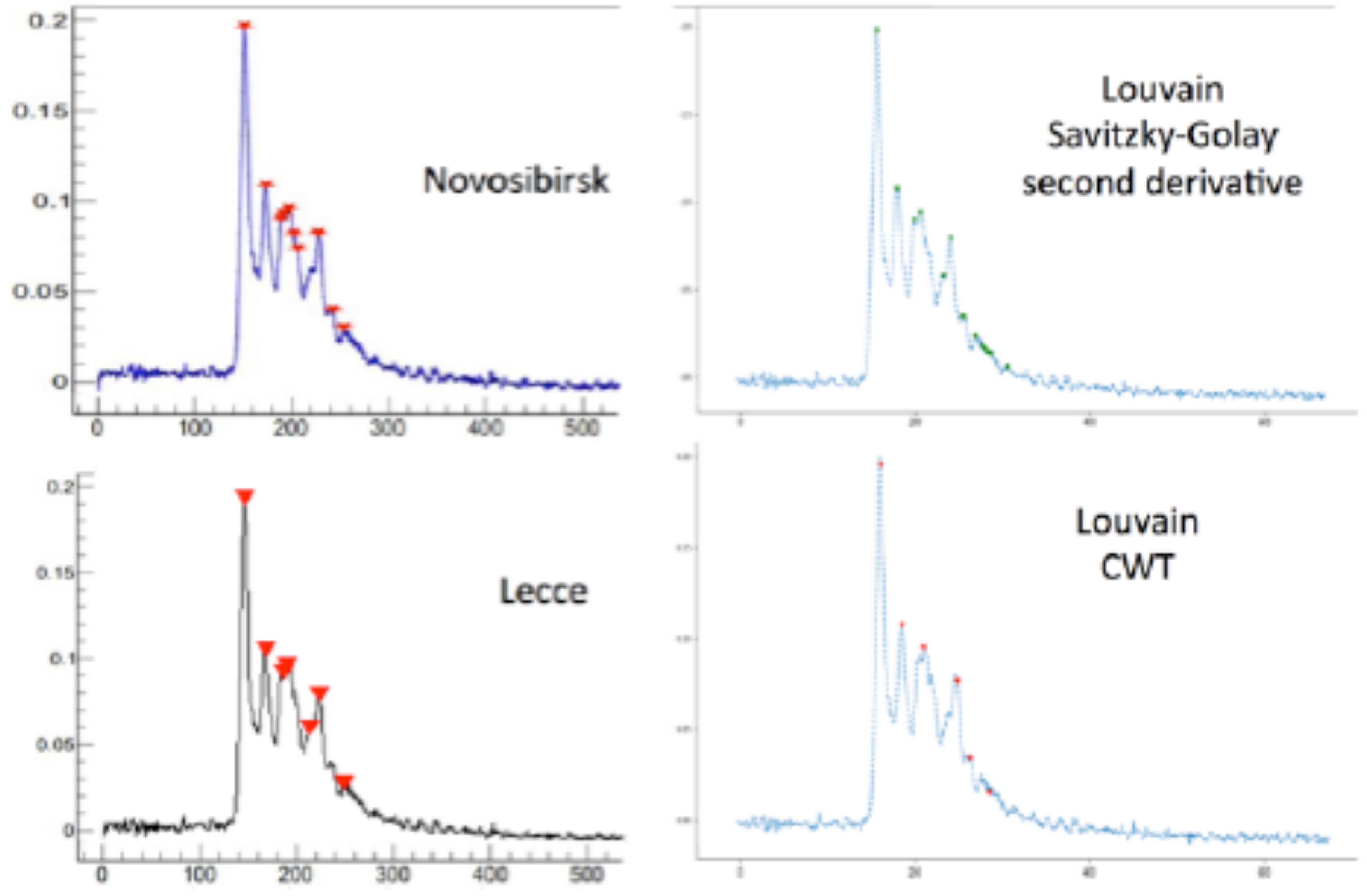


Cluster counting

- ❖ Cluster counting 2x better than dE/dx
  - ➢ Poisson vs . Landau → no large tails
- ❖ Sample signal few GHz → on detector electronics R&D

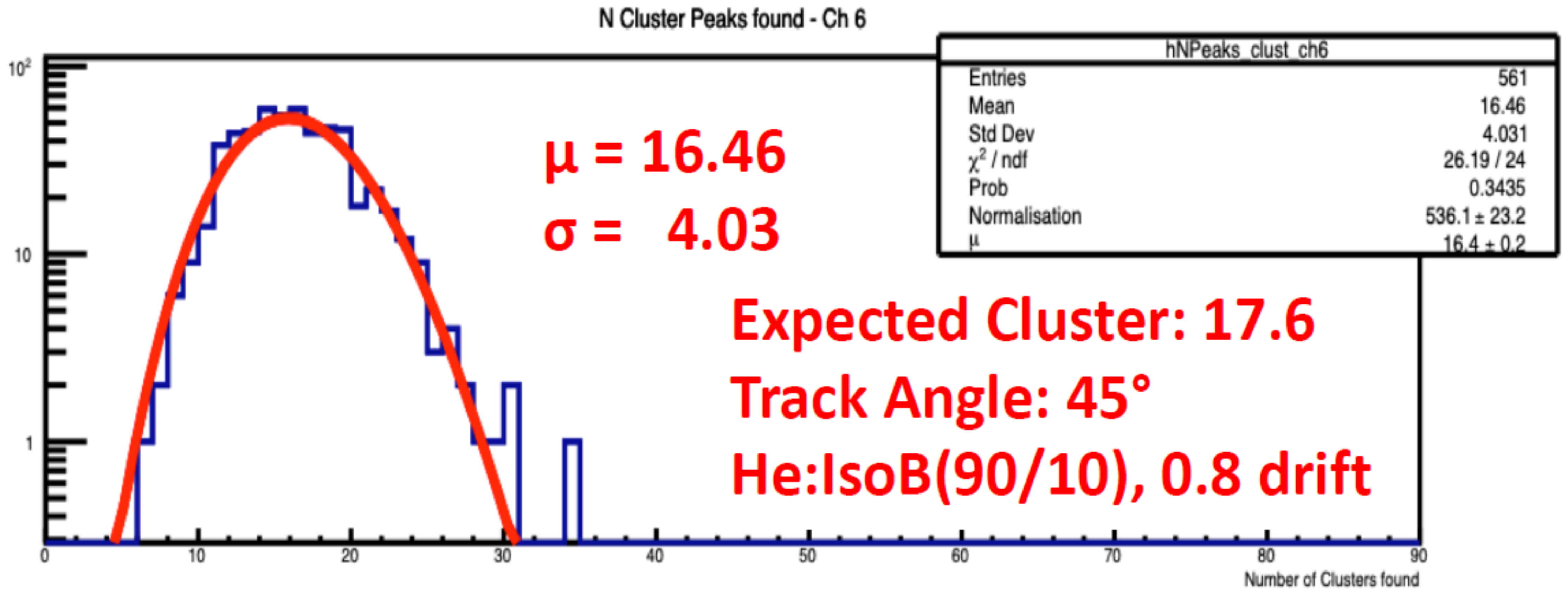


counting peaks



Test beam data 2022

Number of Cluster Distribution



08/02/2022 FCC Physics Workshop - FG

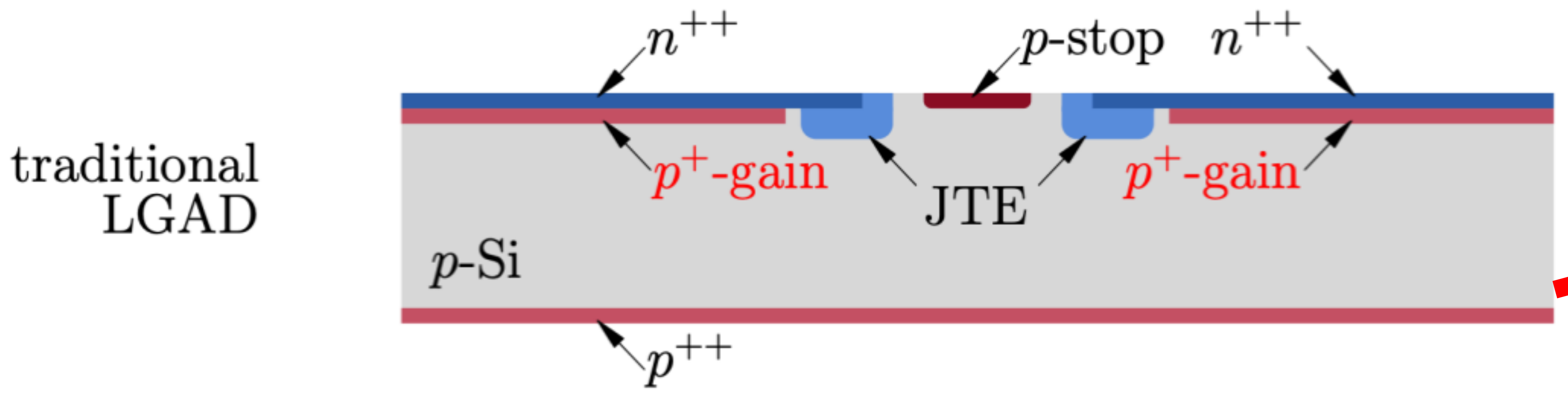
Drift chamber future plans

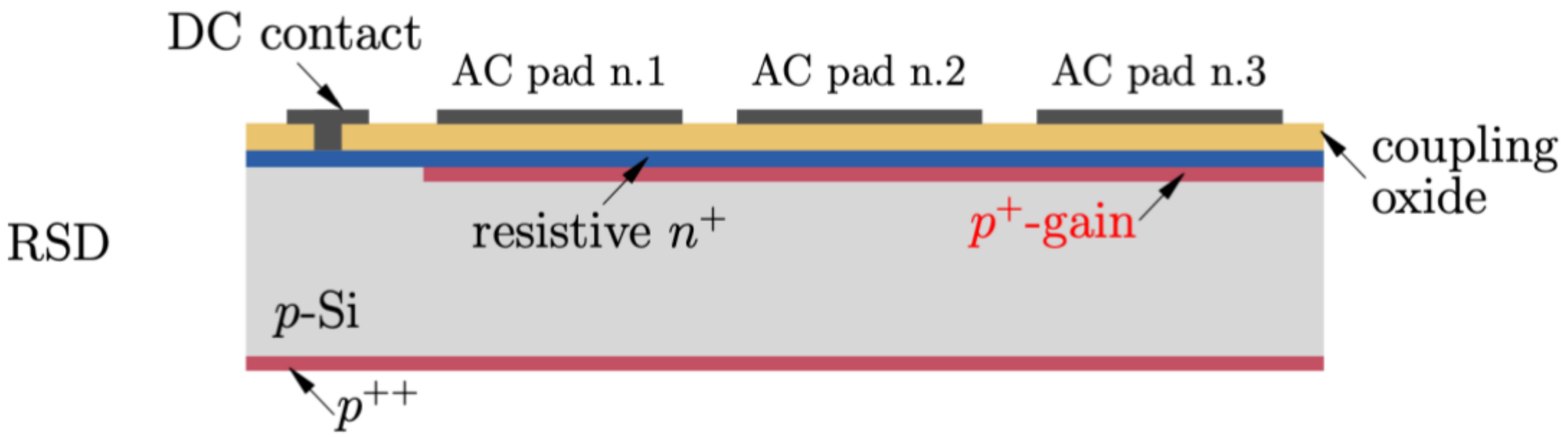
- Complete mapping of dN/dx data in all relevant βγ regions (few years)
  - Understand details of cluster counting performance
- Build large mechanical prototype (few years)
- Build full length functioning prototype with few cells (few years)
- Develop on-detector cluster counting electronics (few years)

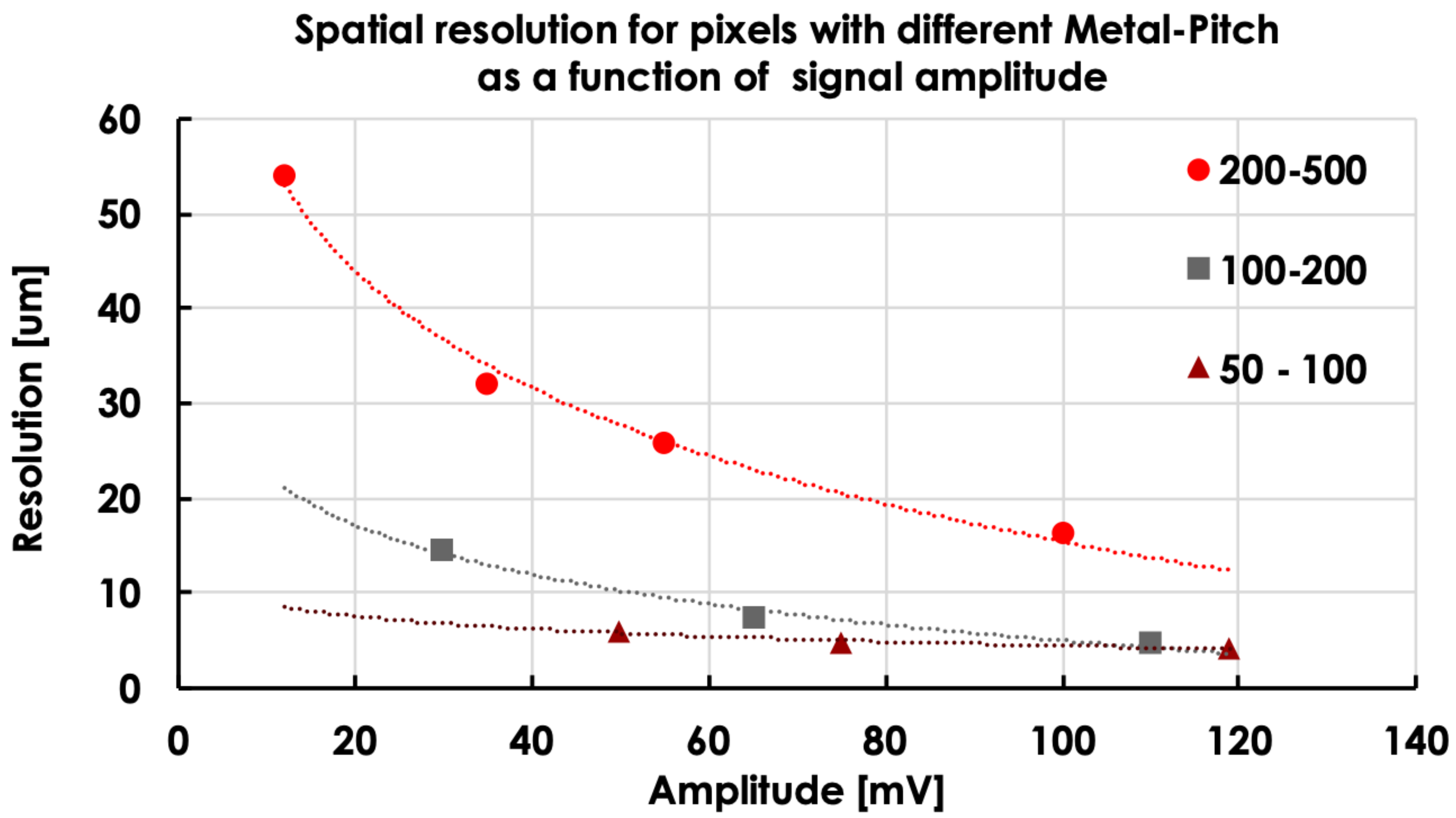
- Towards a drift chamber TDR

Resistive LGAD

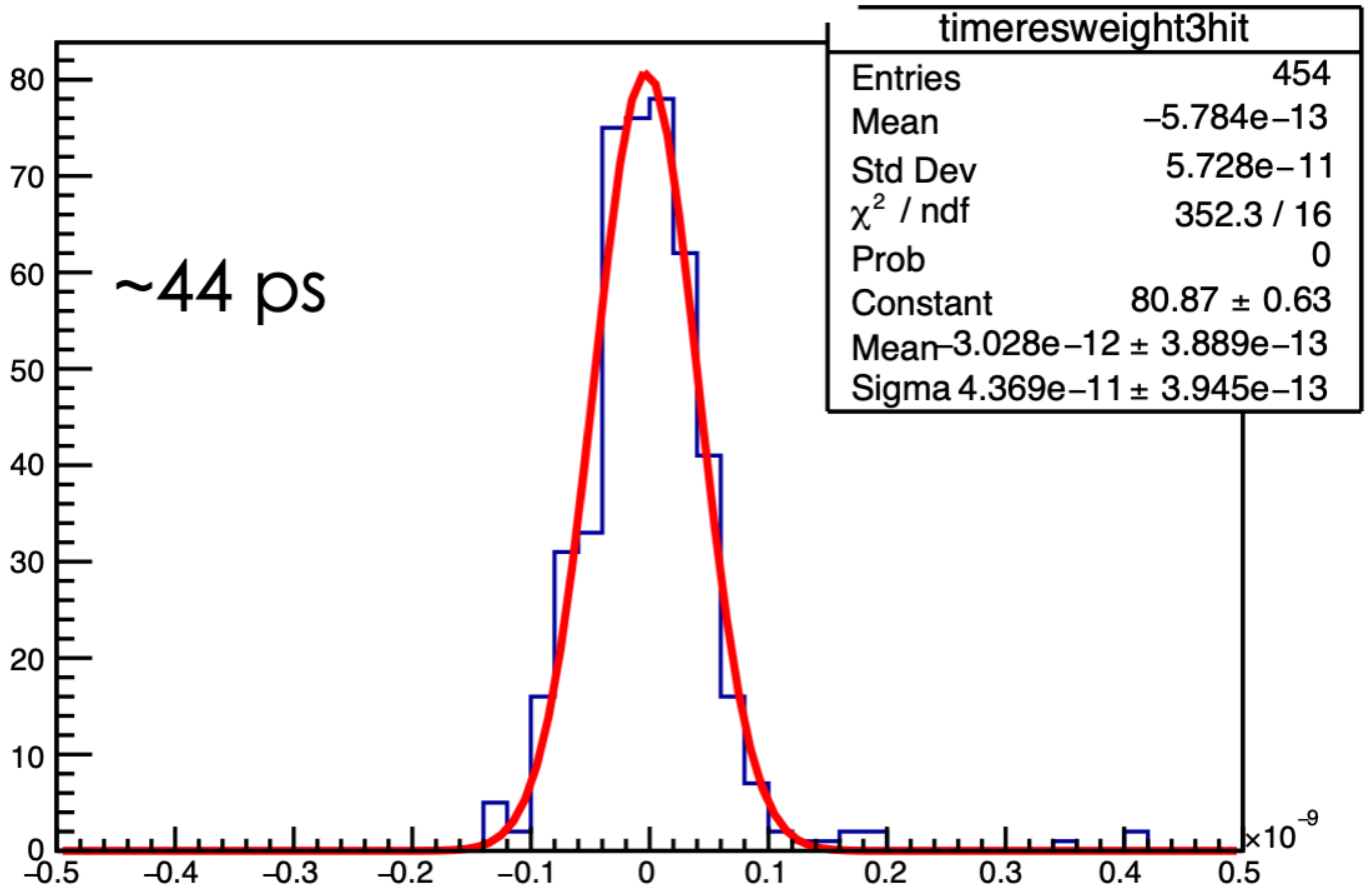
- Recent new activity with INFN-GE/(TO)
  - Match time and position resolution







100 - 200



Resistive LGAD

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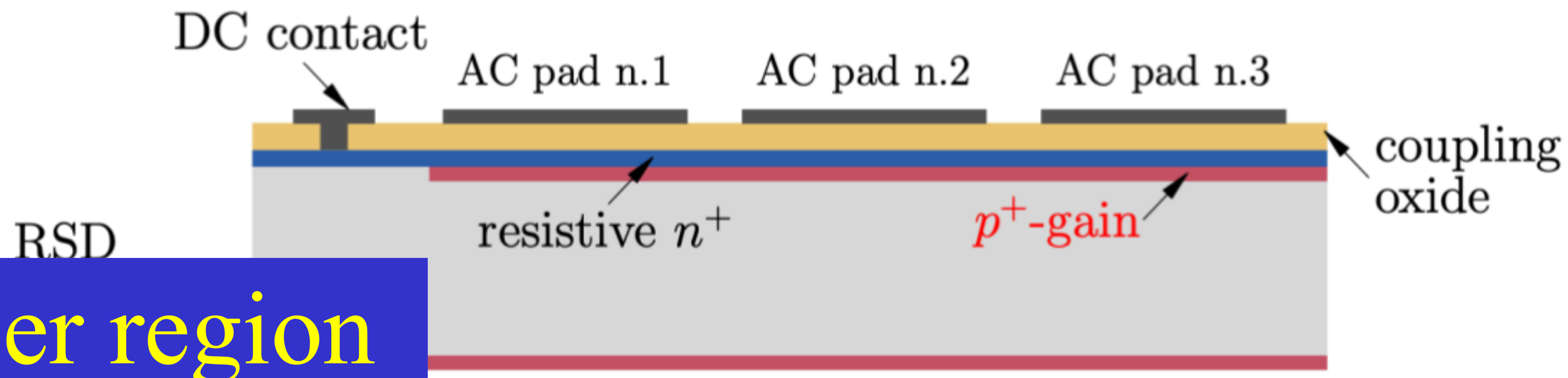
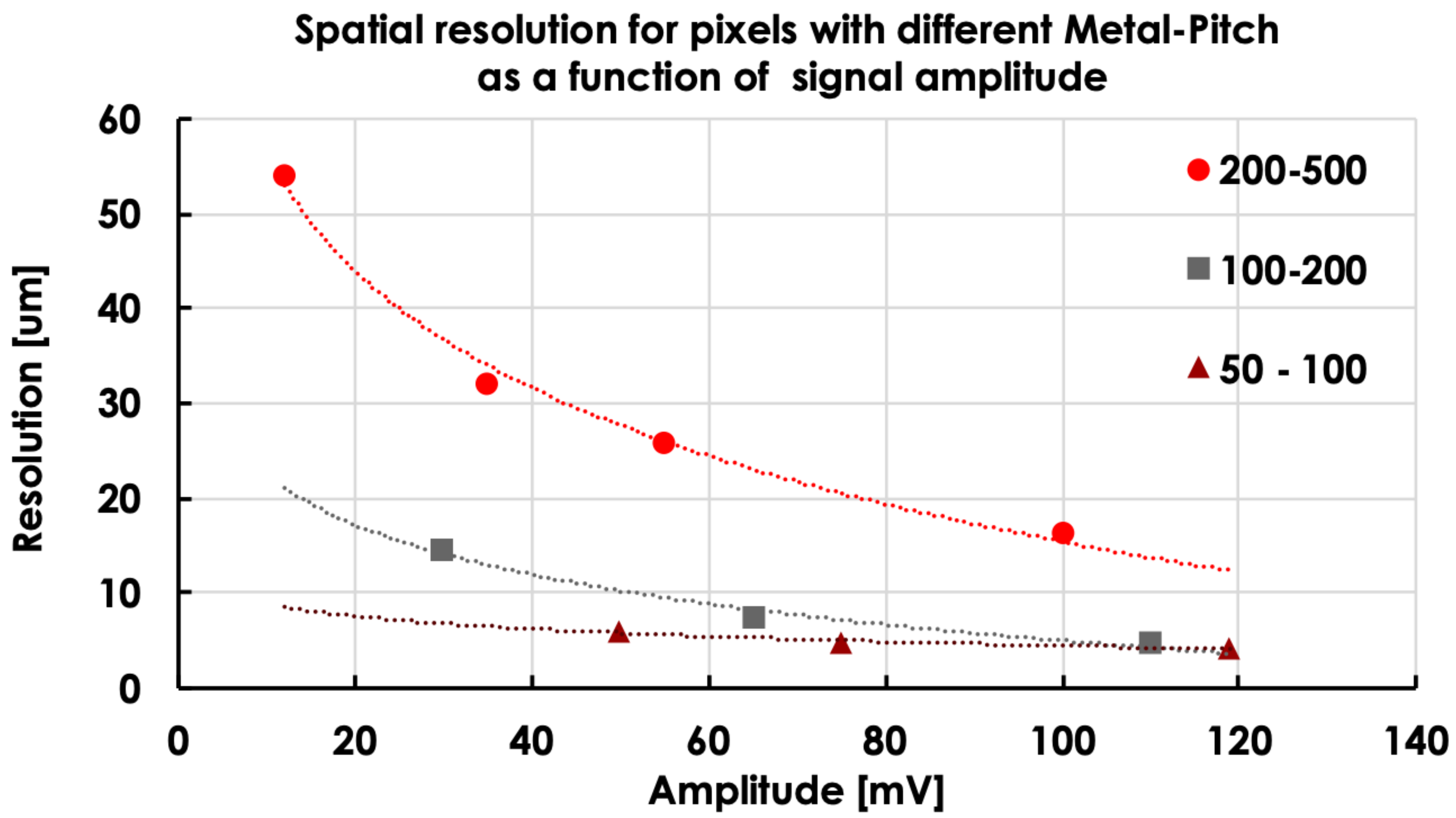
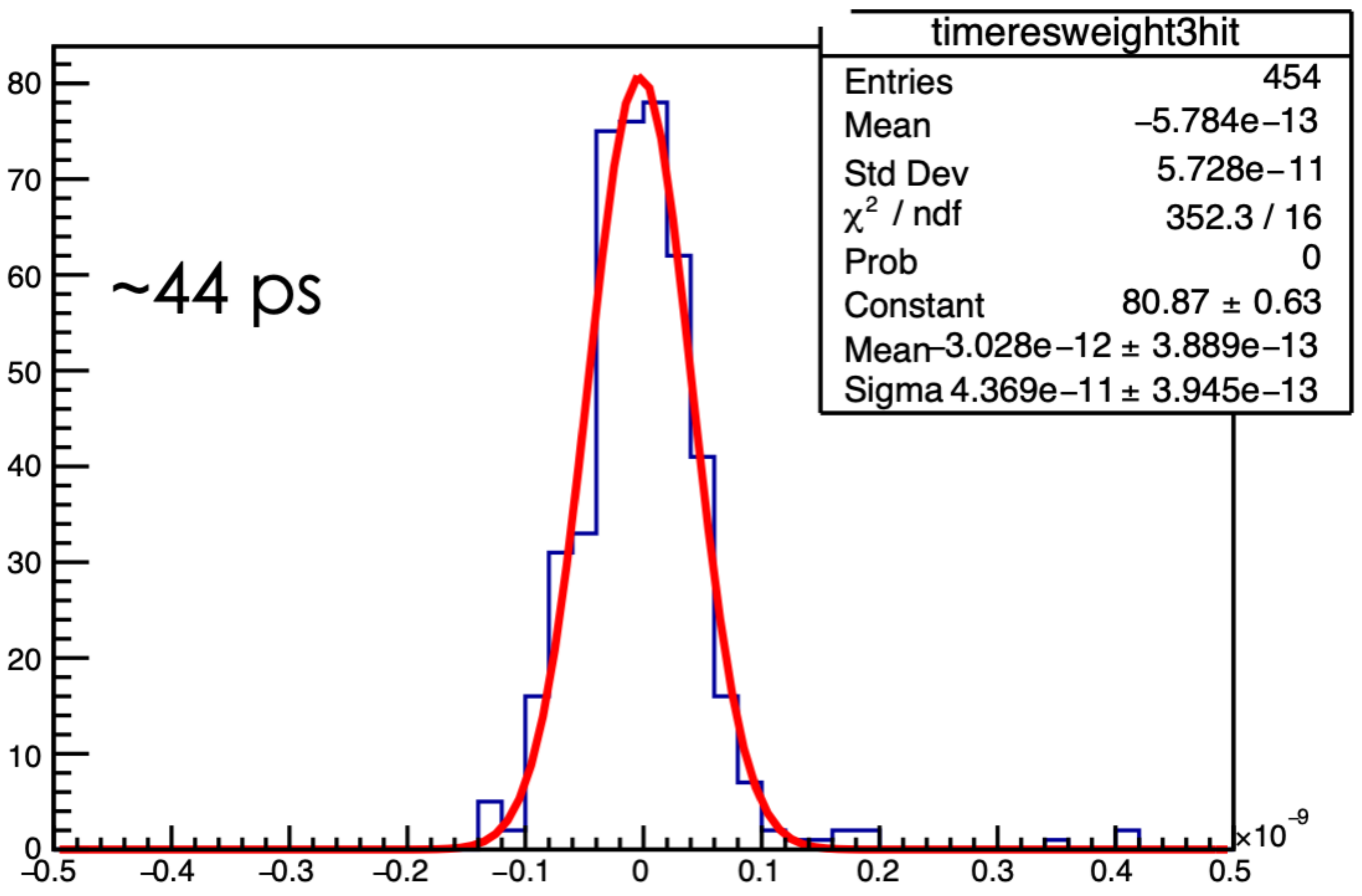


Very attractive option for timing in Si wrapper region
Cost reduction is major area of R&D
Some “fast” devices also prototyped by Arcadia group

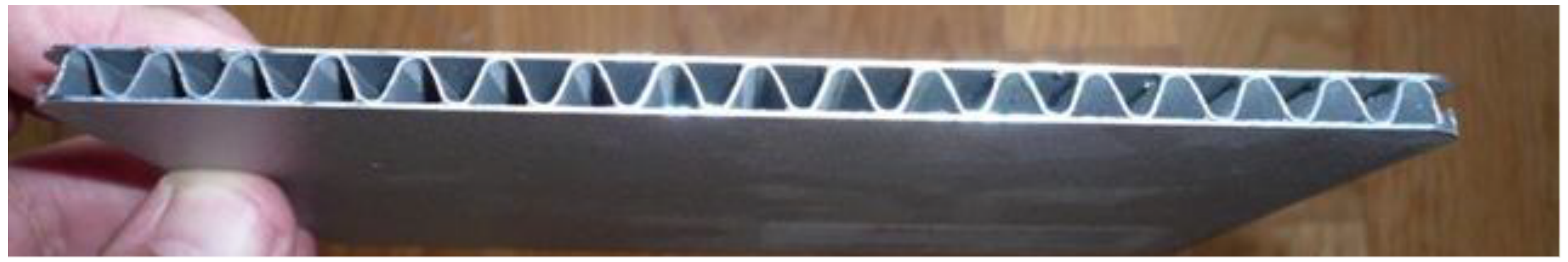


100 - 200

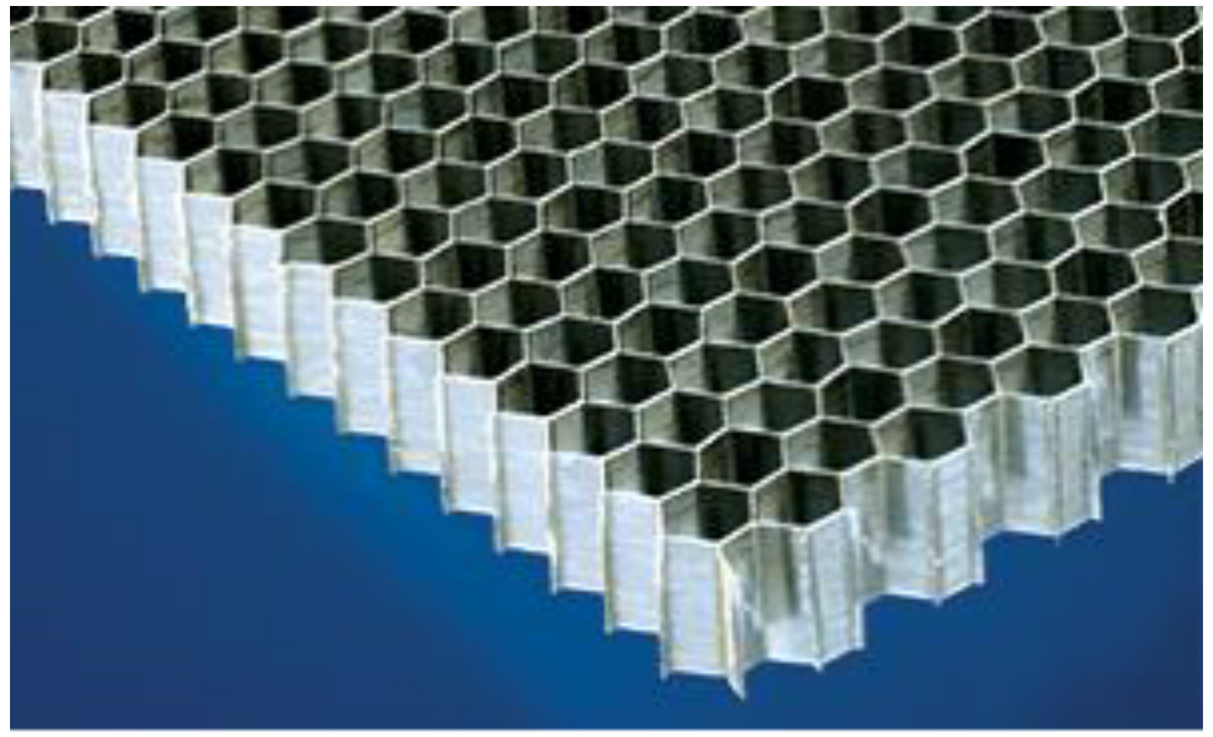


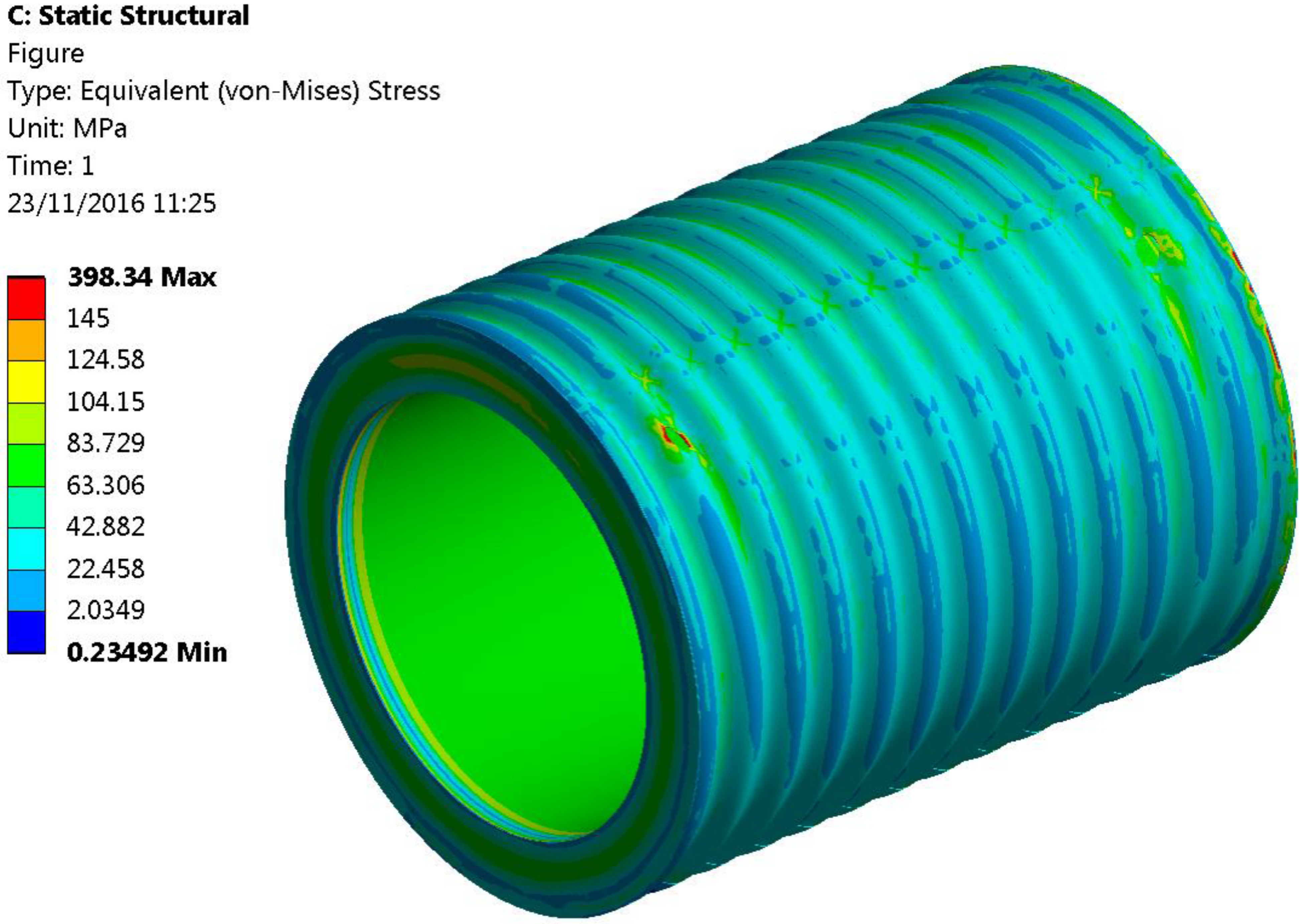
Superconducting solenoid

- ❖ 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: $X_0 = 0.04$



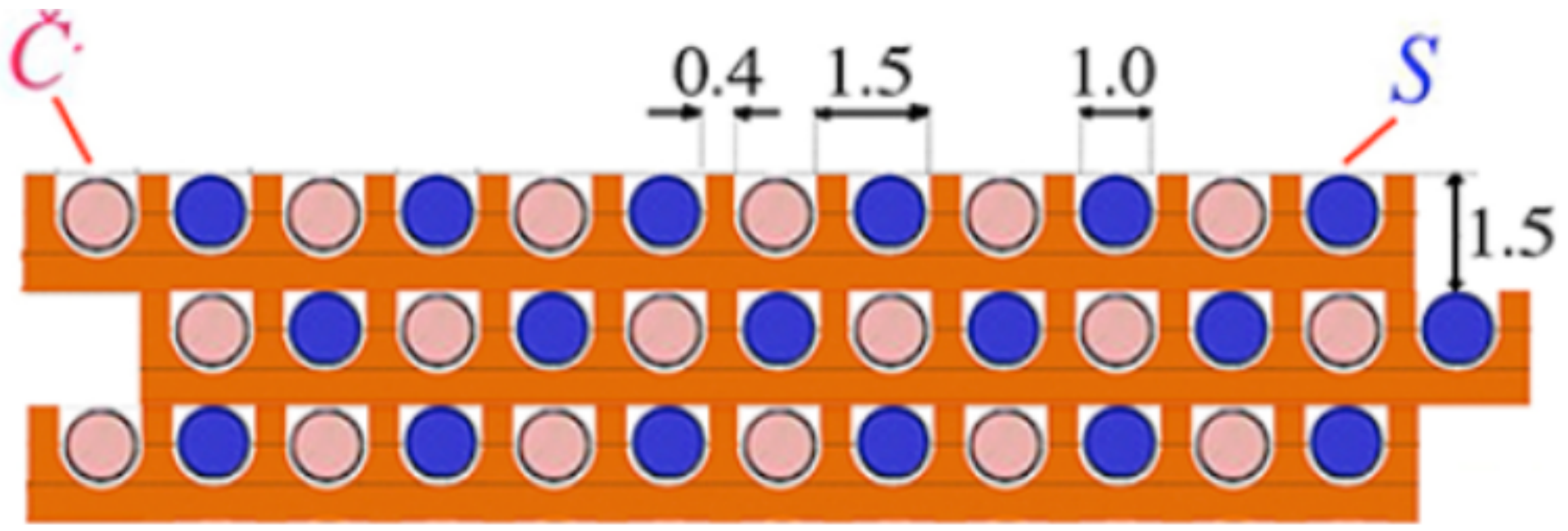
Courtesy of H. TenKate





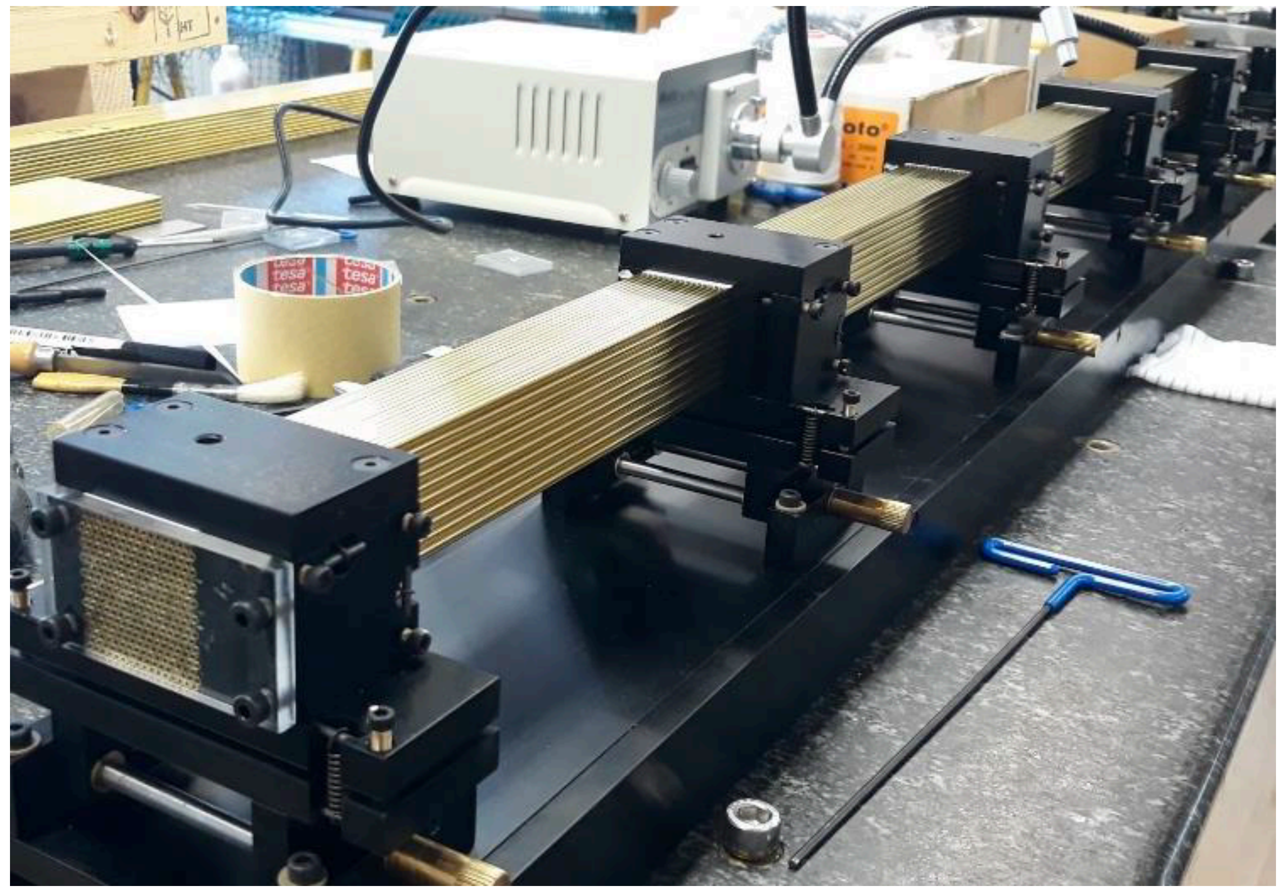
Interest from Genova (in synergy with DUNE) on alternative superconducting magnets like MgB_2

Dual Readout Calorimetry



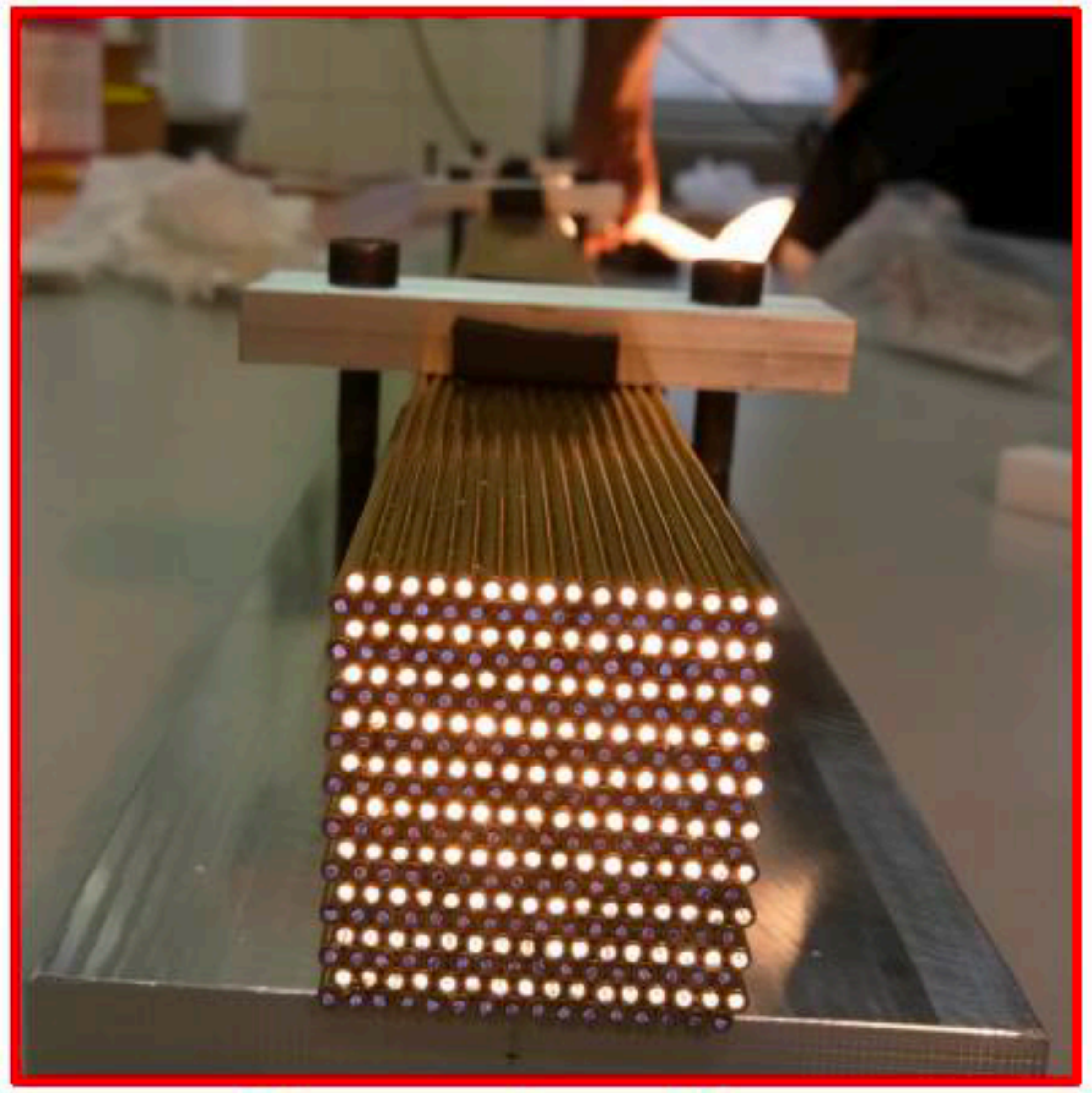
Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



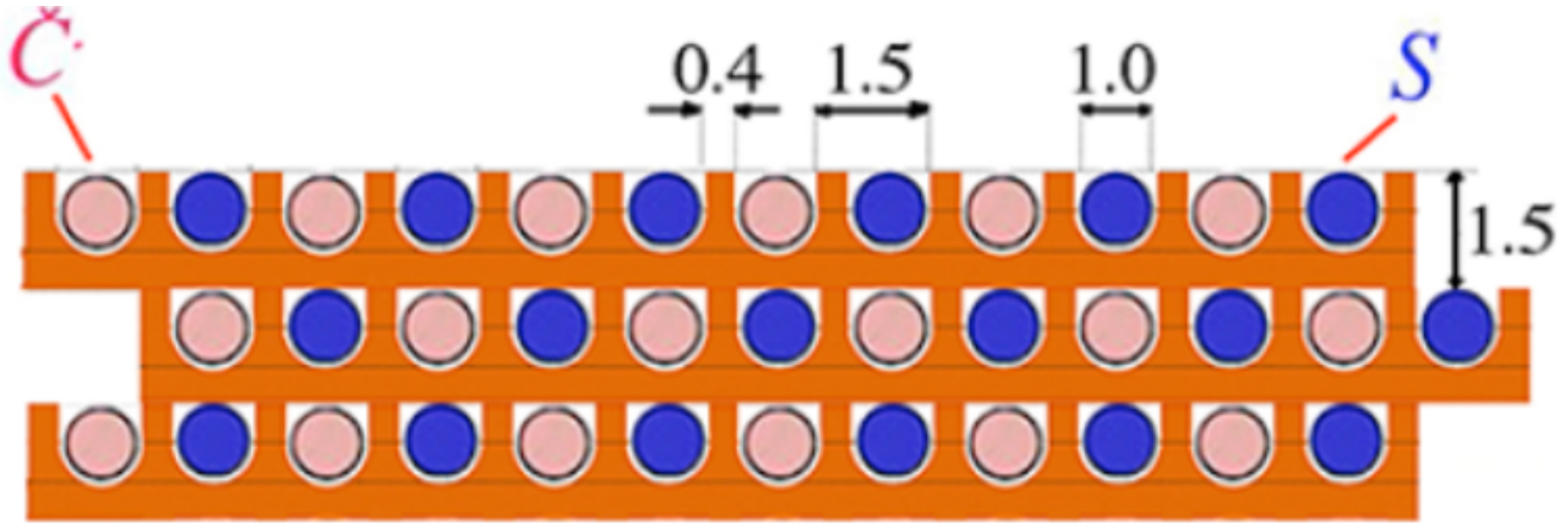
Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers



Cherenkov fibers

Dual Readout Calorimetry



Alternate
Cherenkov fibers
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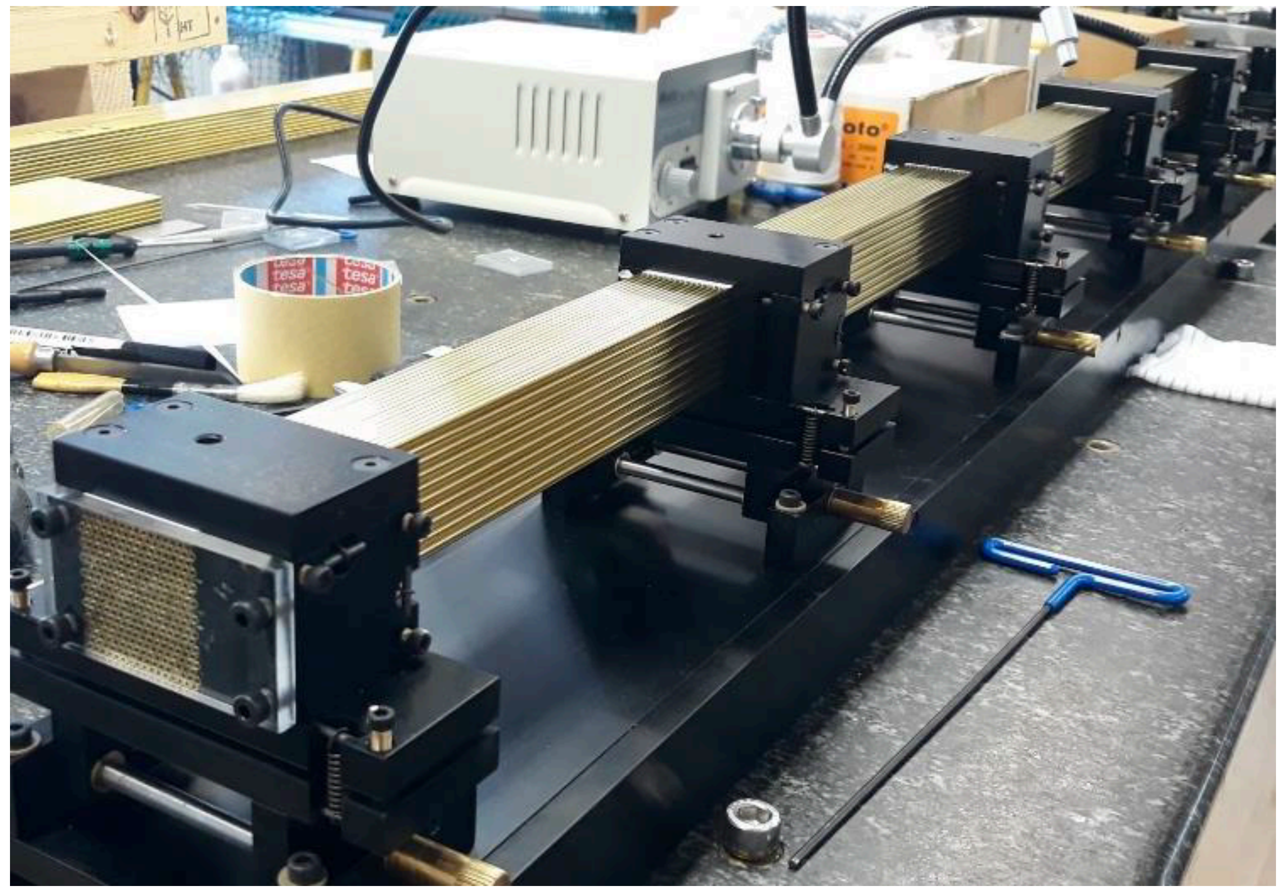
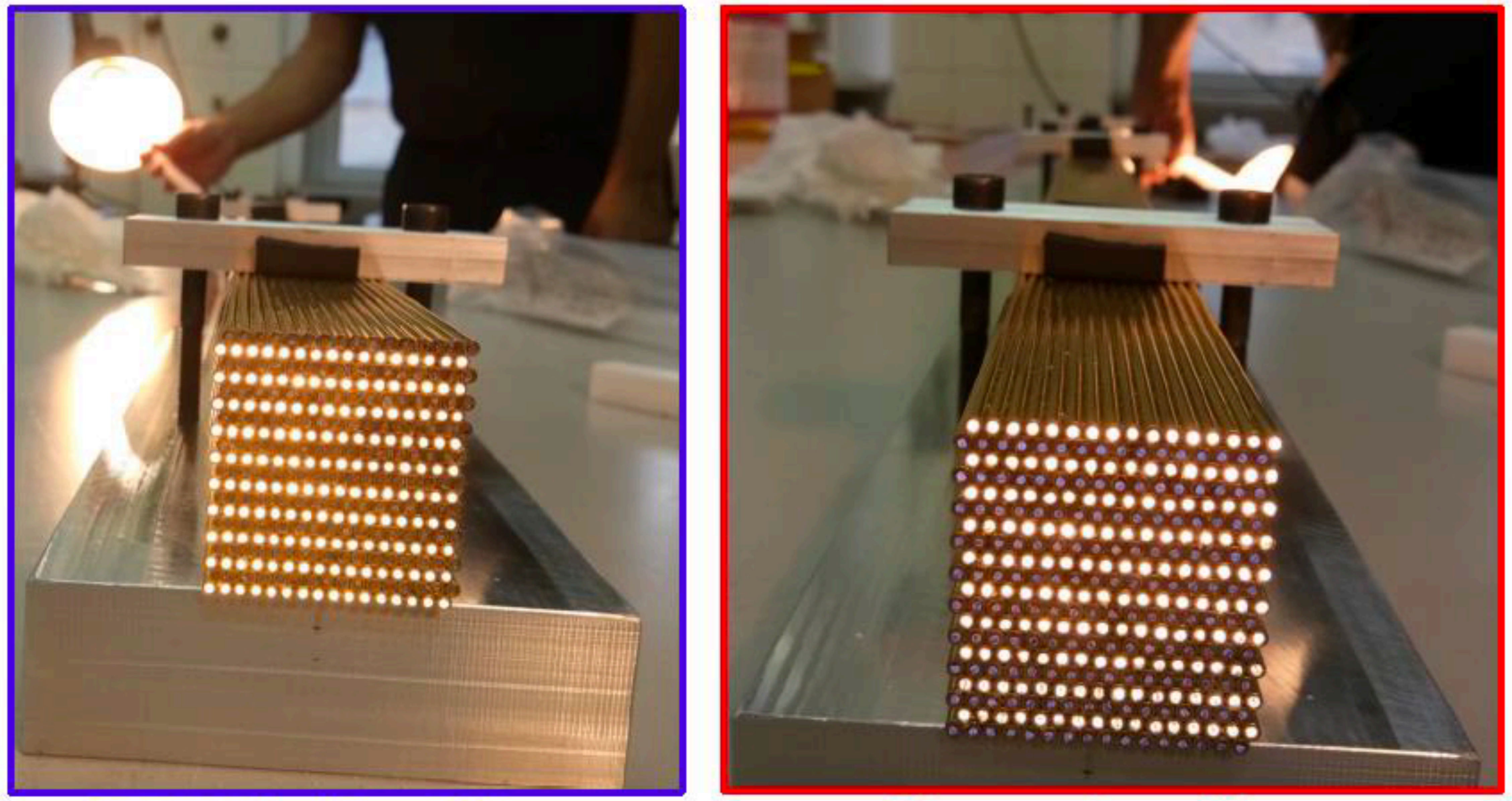
~2m long capillaries



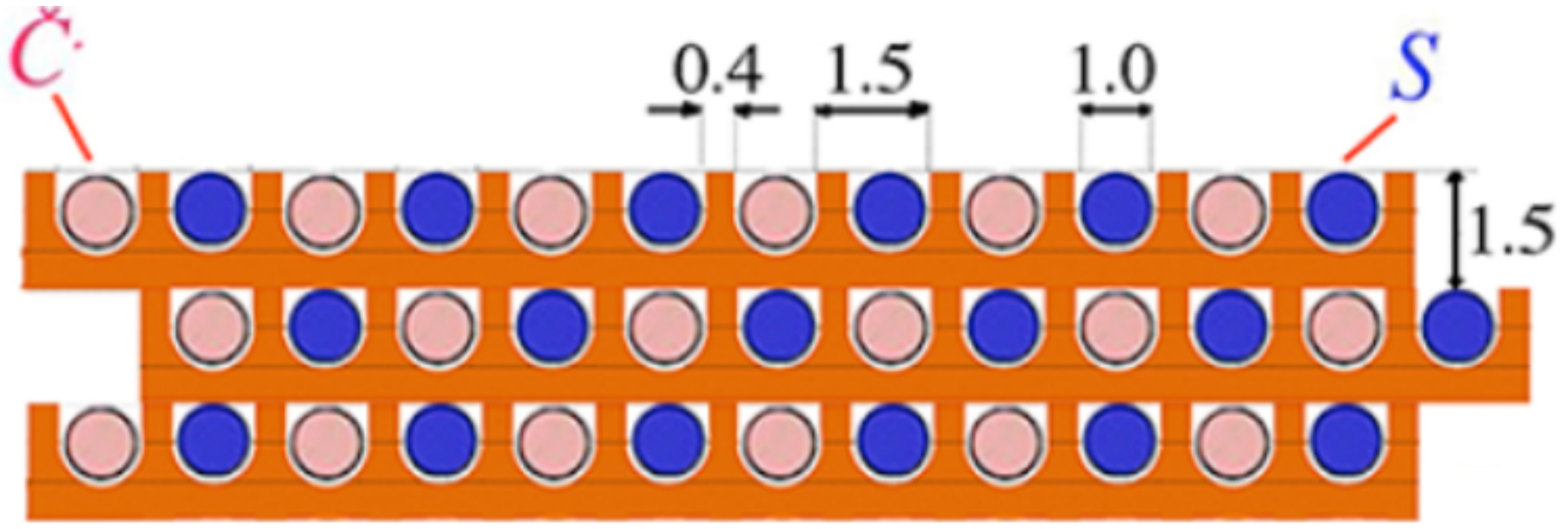
- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)

Newer DR calorimeter
(bucatini calorimeter)



Scintillation fibers   Cherenkov fibers

Dual Readout Calorimetry



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Cherenkov fibers
Scintillating fibers

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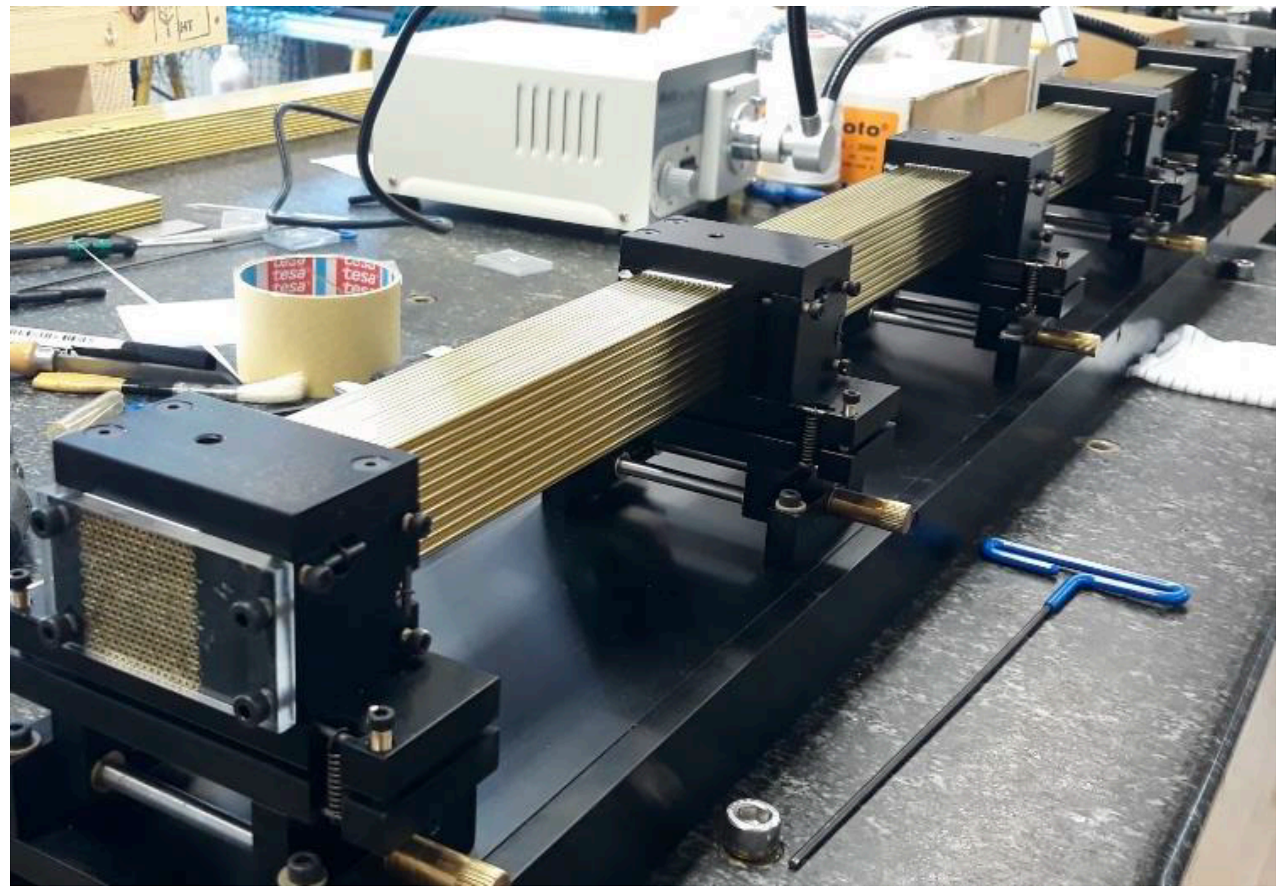
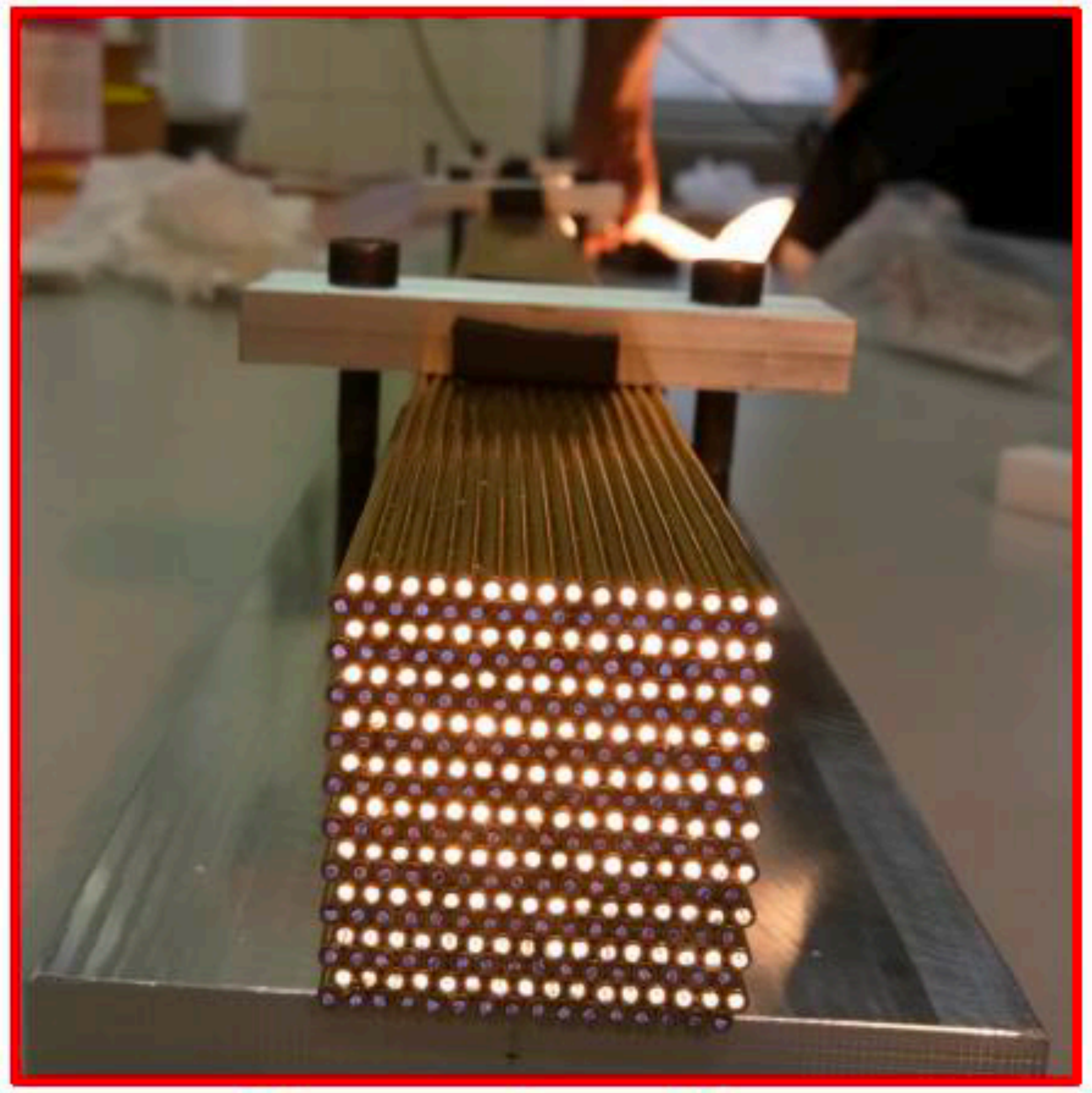


- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)
- Calibrate both signals with e-

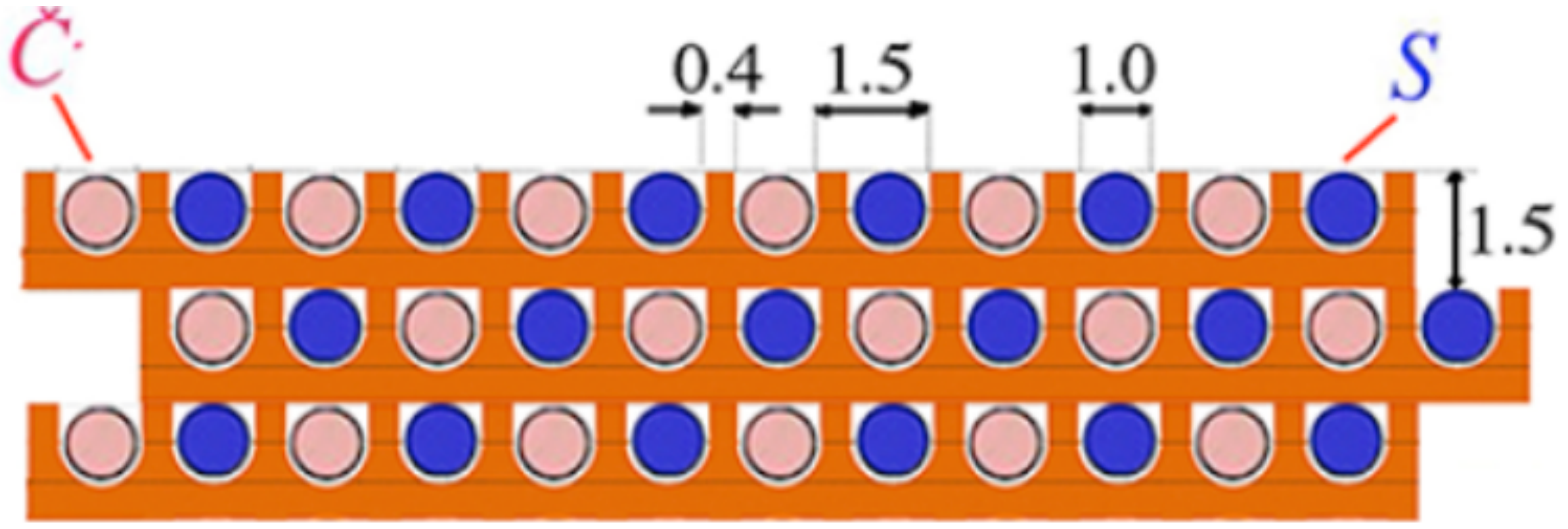
Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers



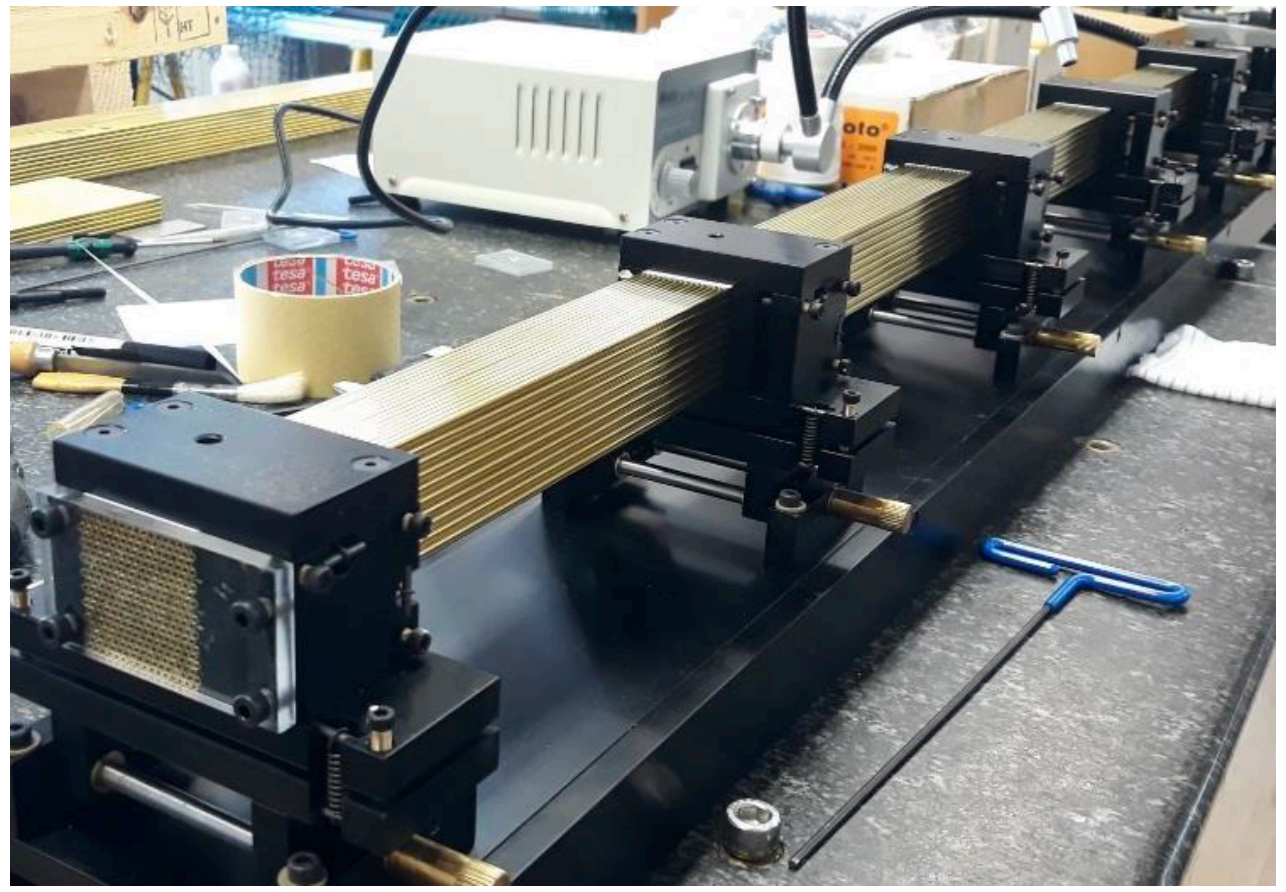
Cherenkov fibers

Dual Readout Calorimetry



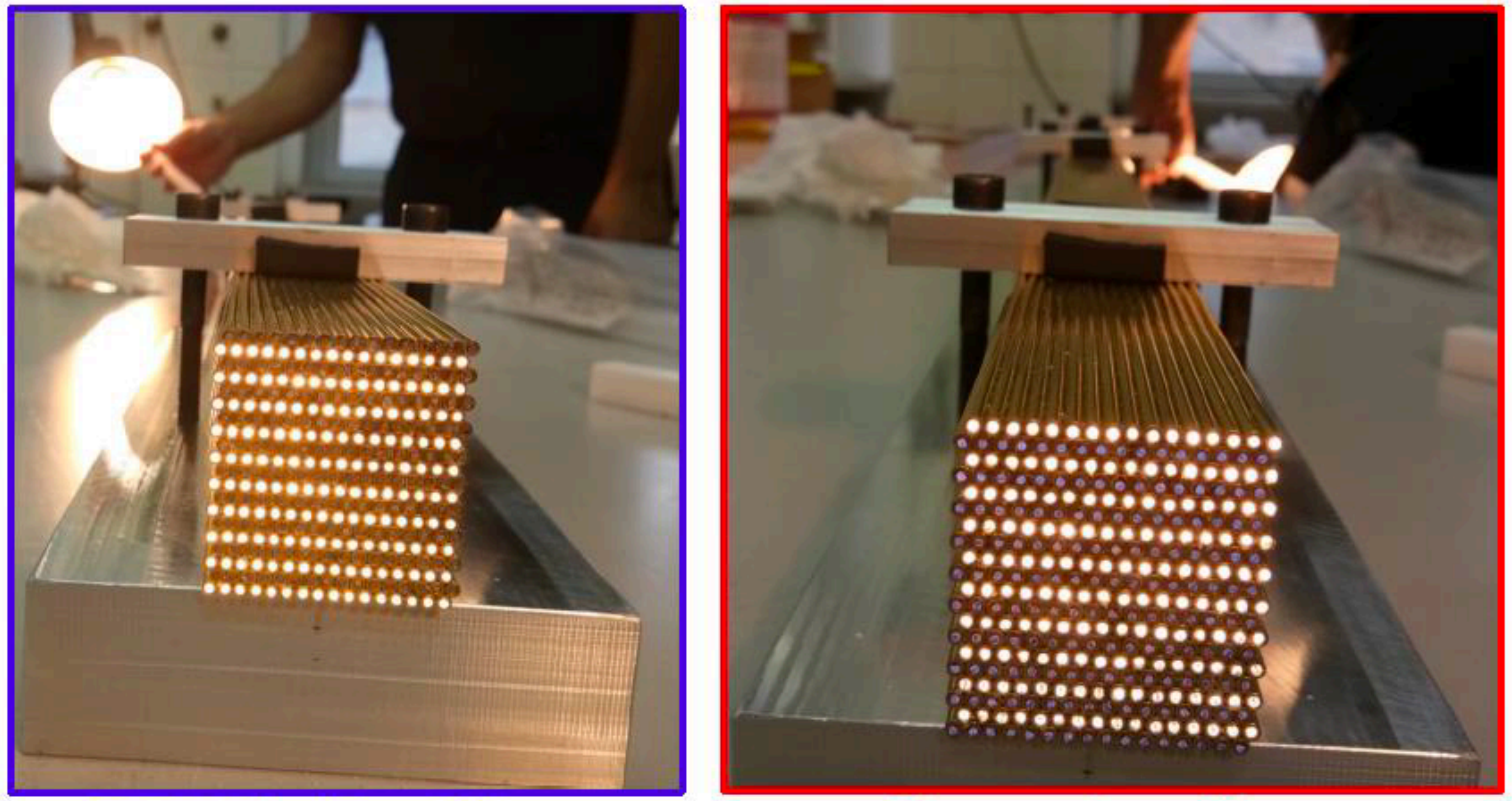
Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



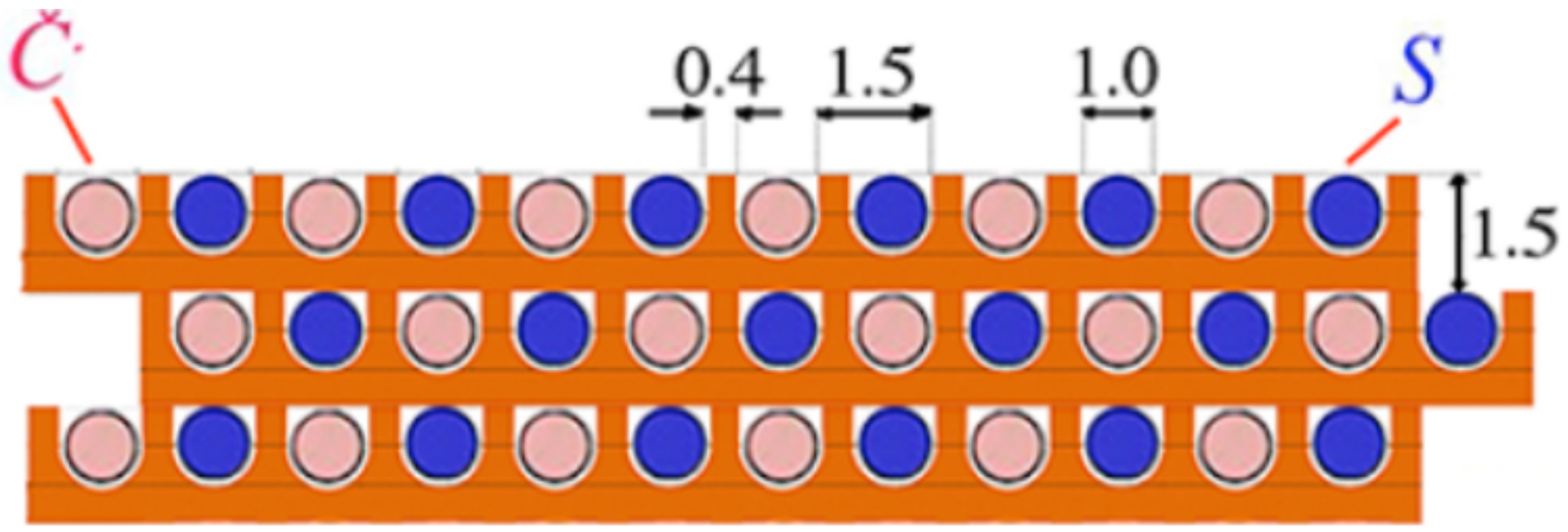
- Measure simultaneously:
  - Scintillation signal (S)
  - Cherenkov signal (Q)
- Calibrate both signals with e-
- Unfold event by event f_{em} to obtain corrected energy

Newer DR calorimeter
(bucatini calorimeter)



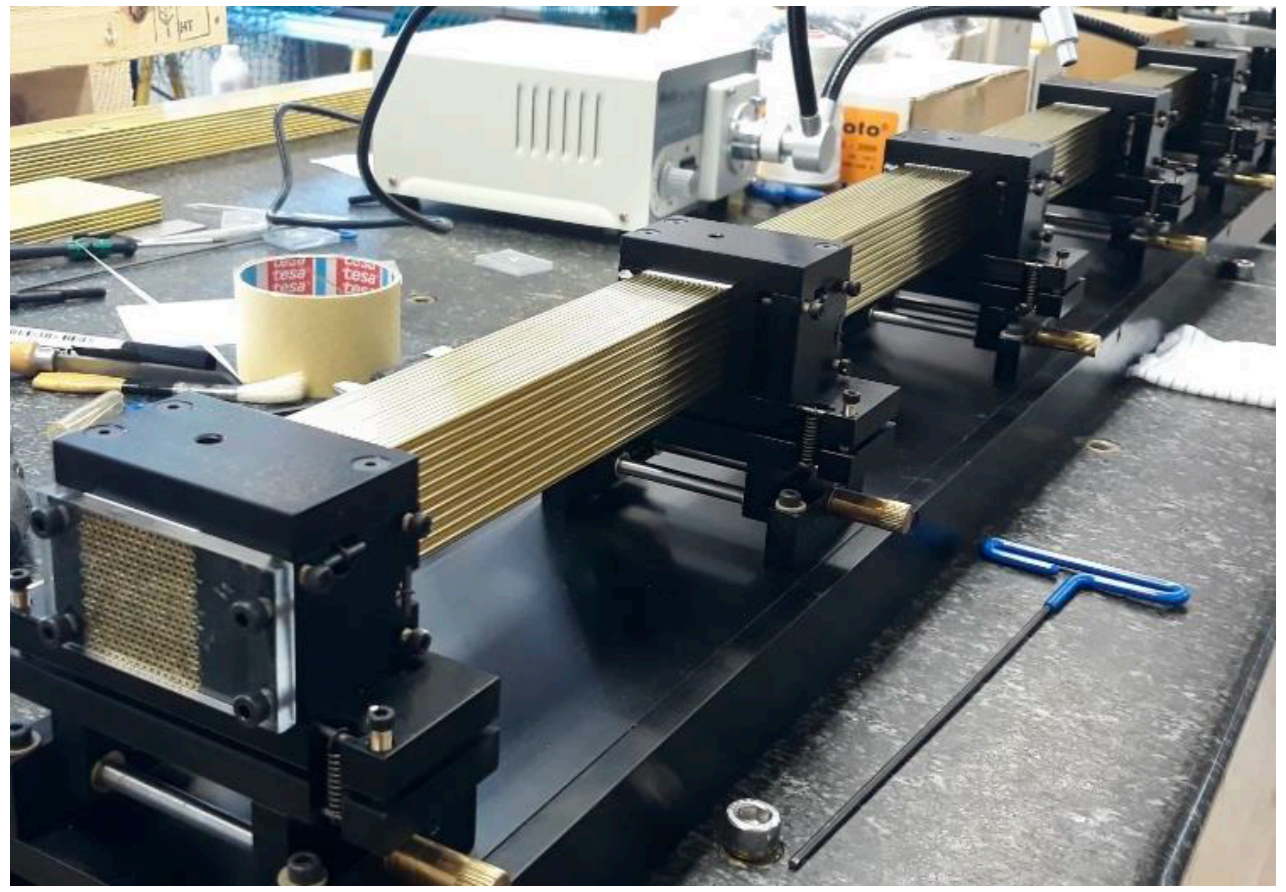
Scintillation fibers Cherenkov fibers

Dual Readout Calorimetry



Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



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

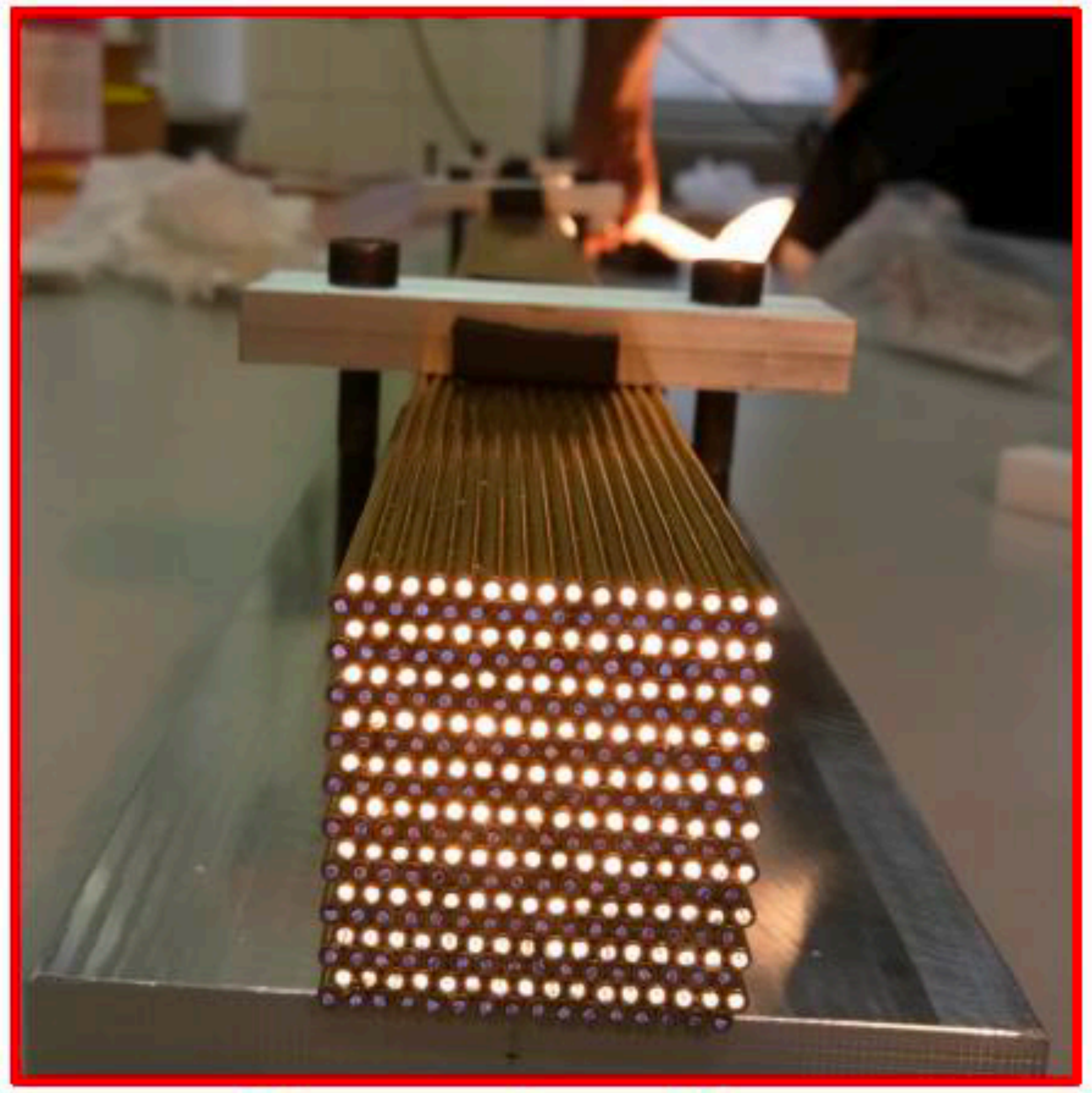
$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$

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

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

Newer DR calorimeter
(bucatini calorimeter)

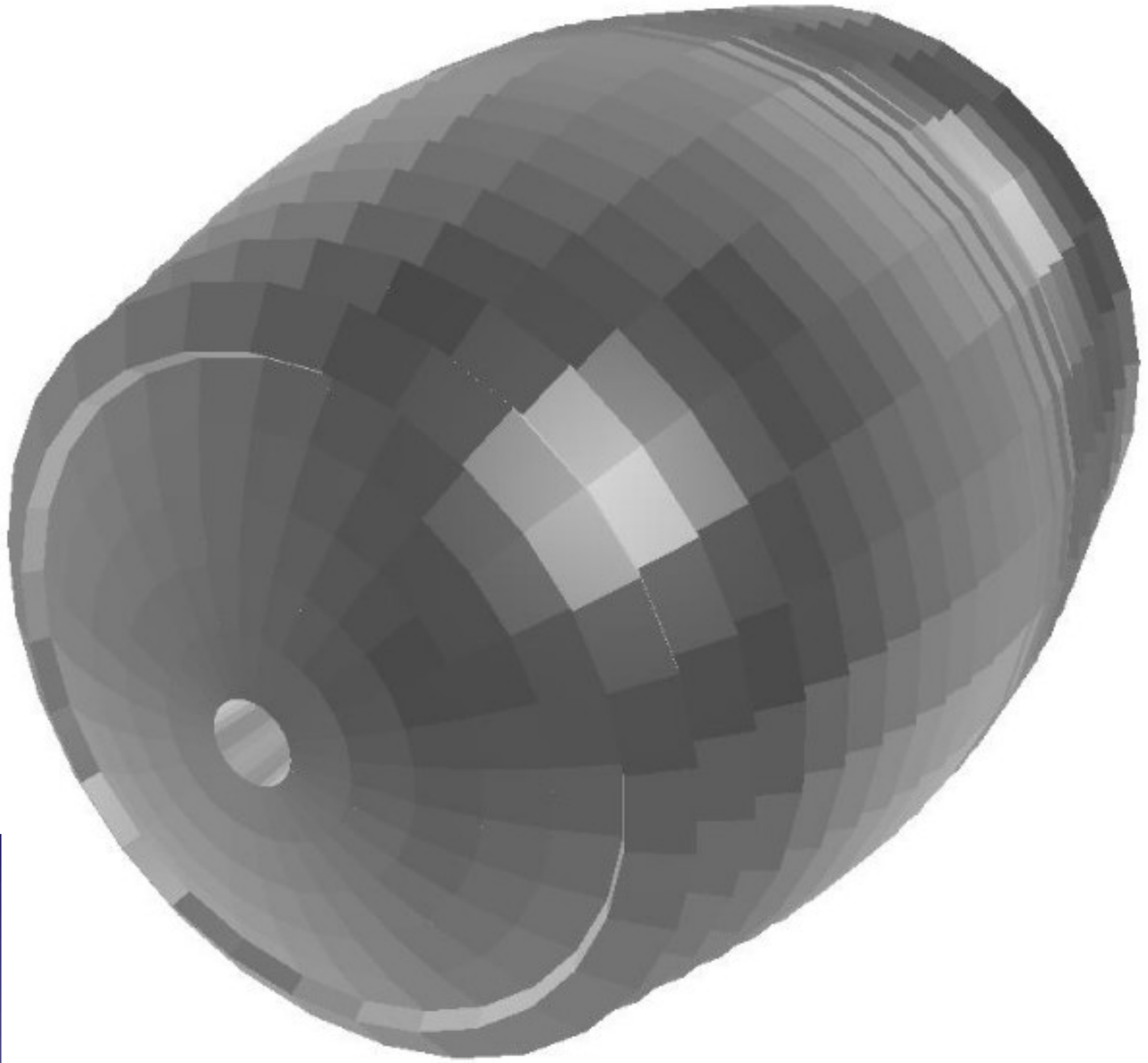
Scintillation fibers

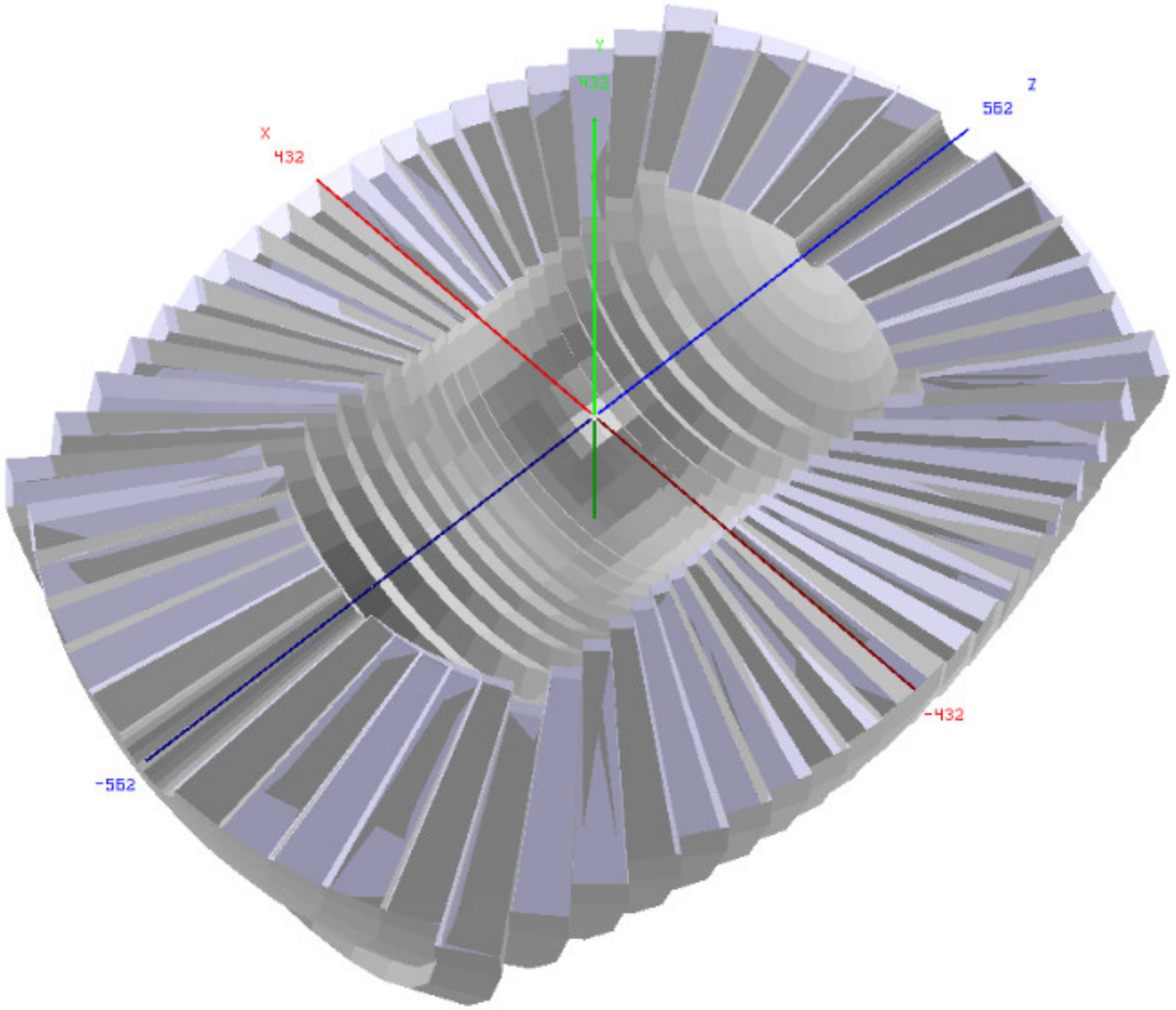


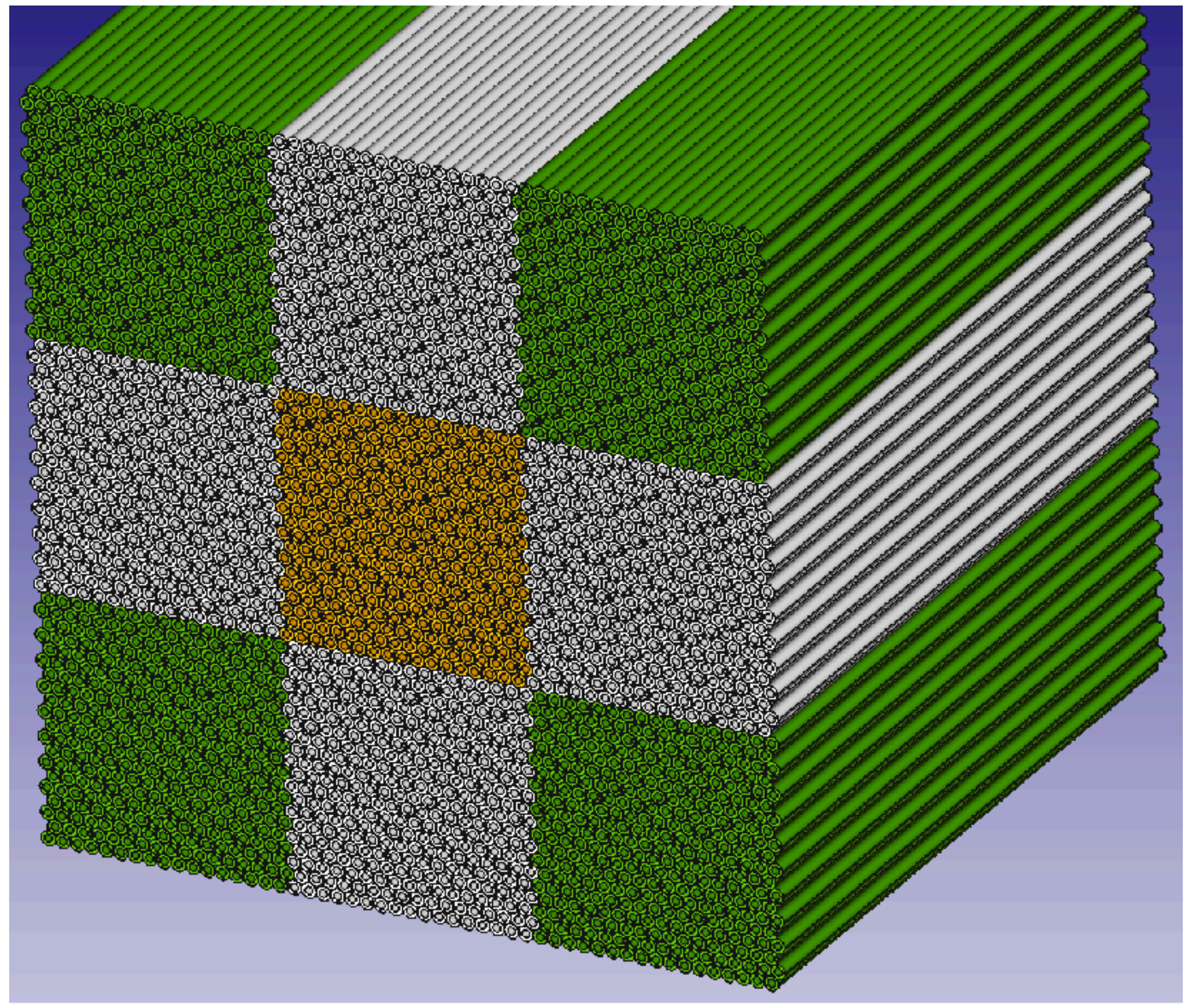
Cherenkov fibers

Dual Readout Calorimeter

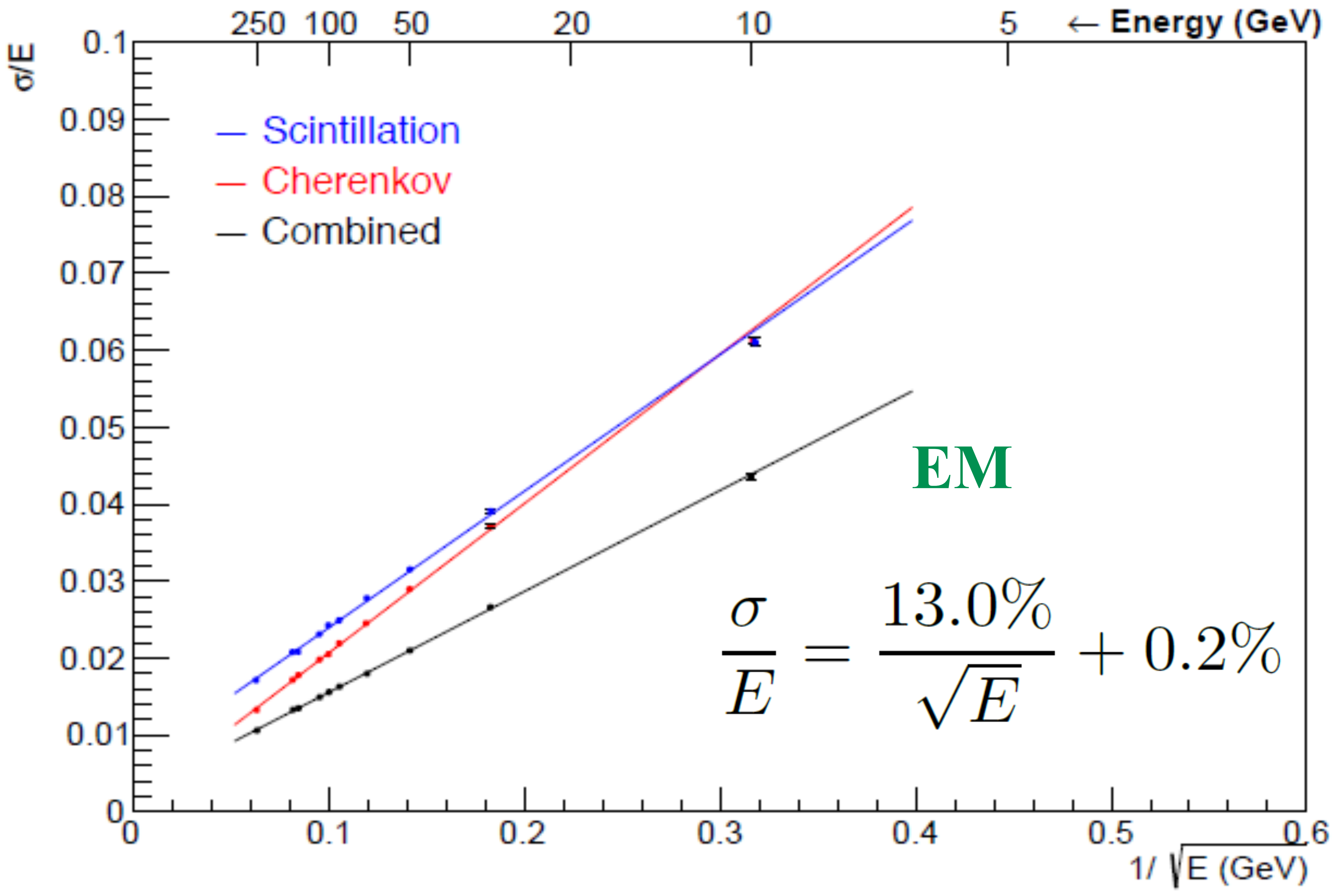
Full GEANT4 implementation of the DR calorimeter

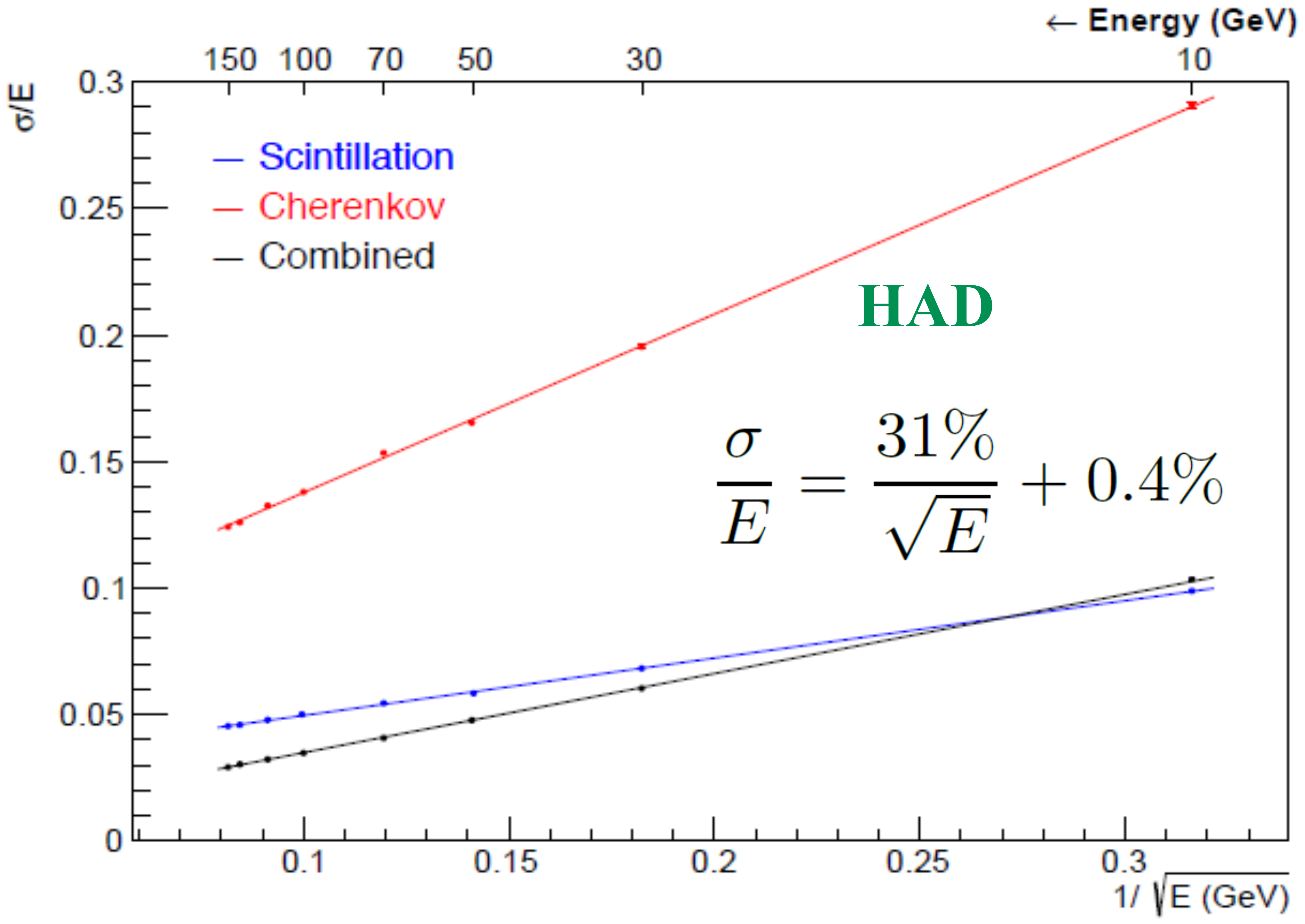




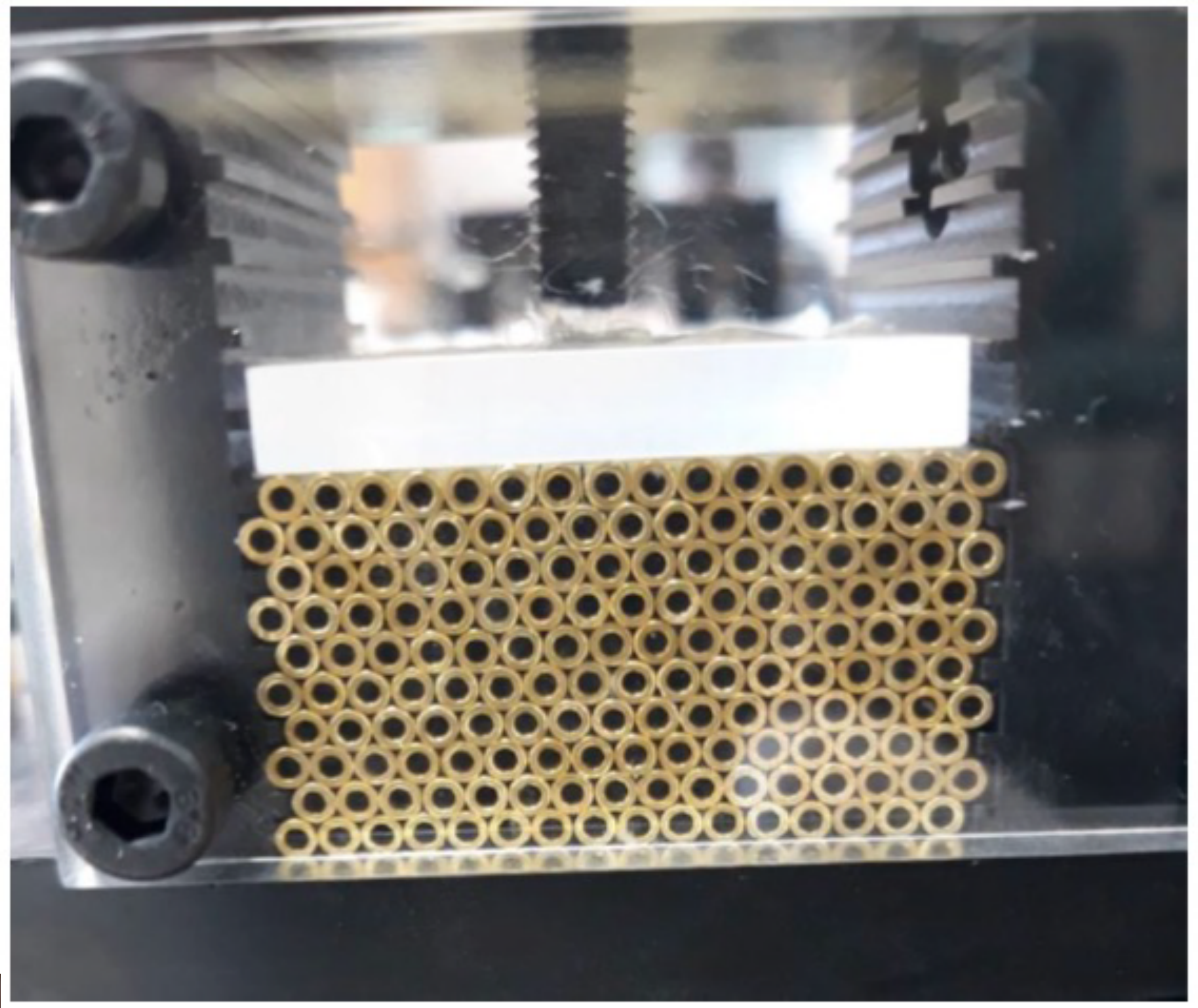


Dual Readout Calorimeter

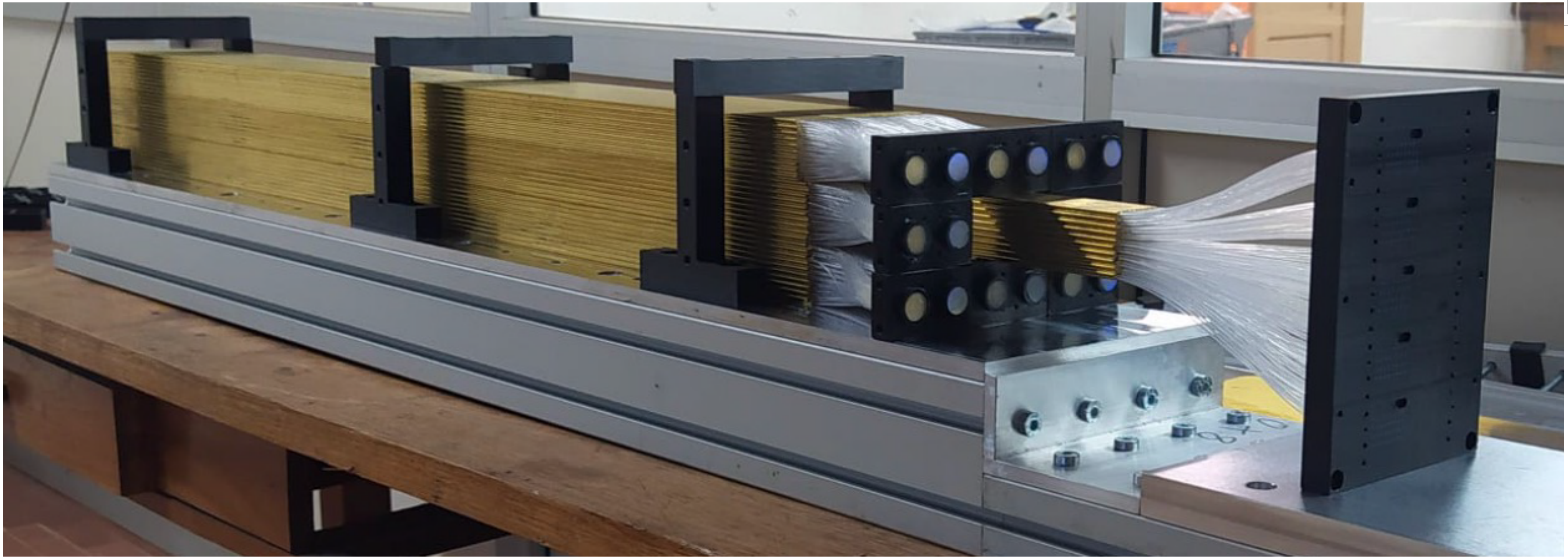




DR calorimeter



- 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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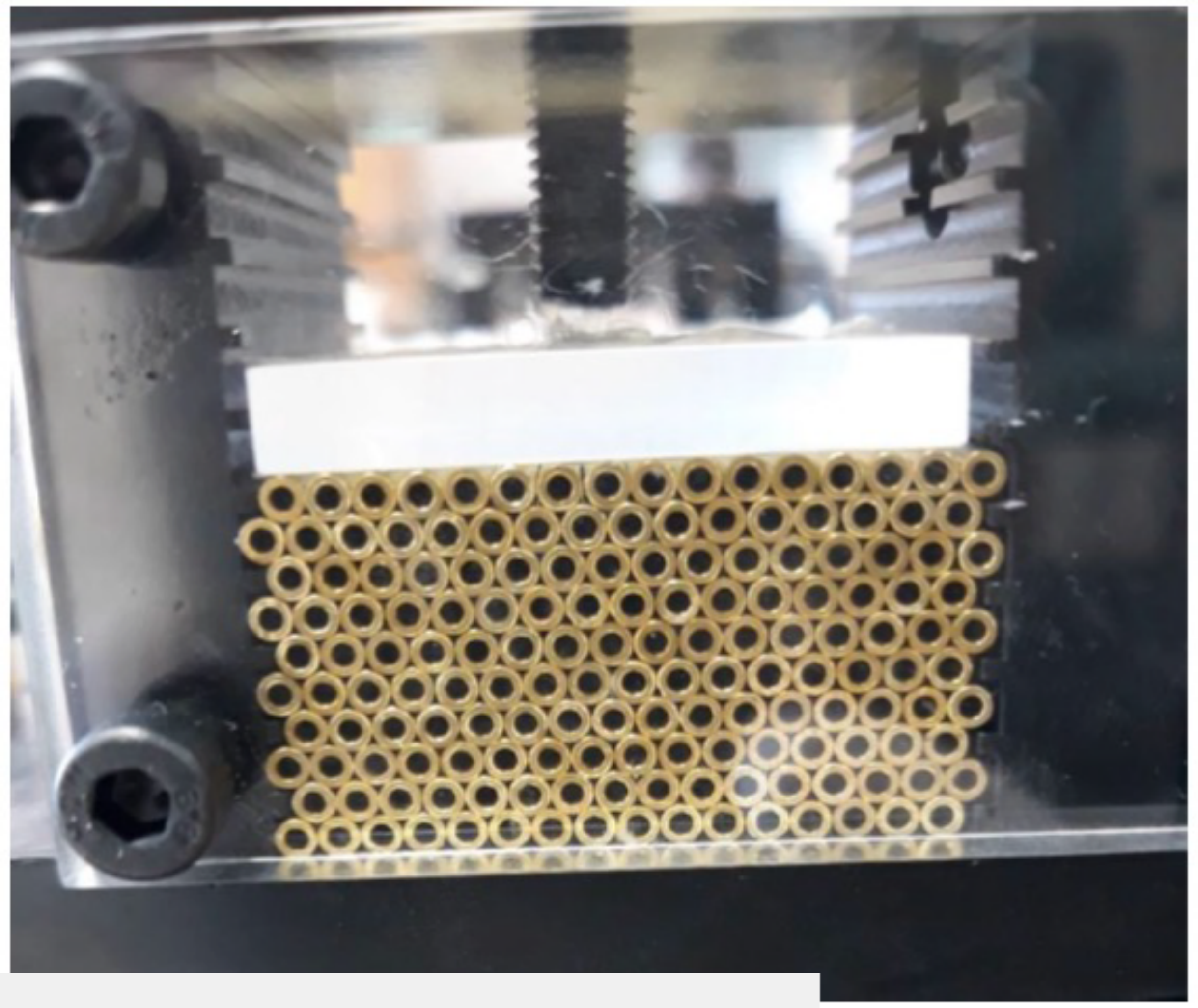
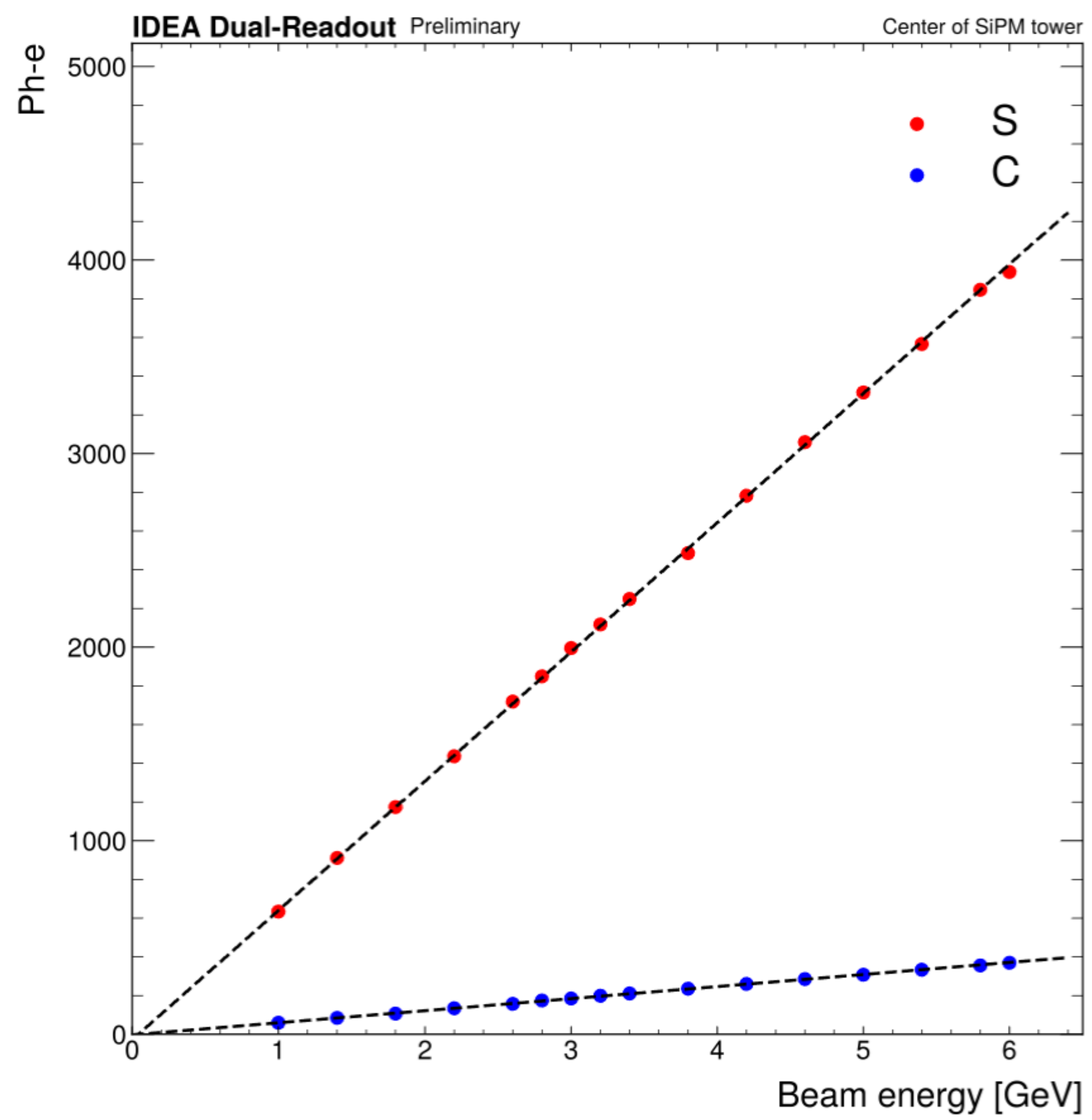
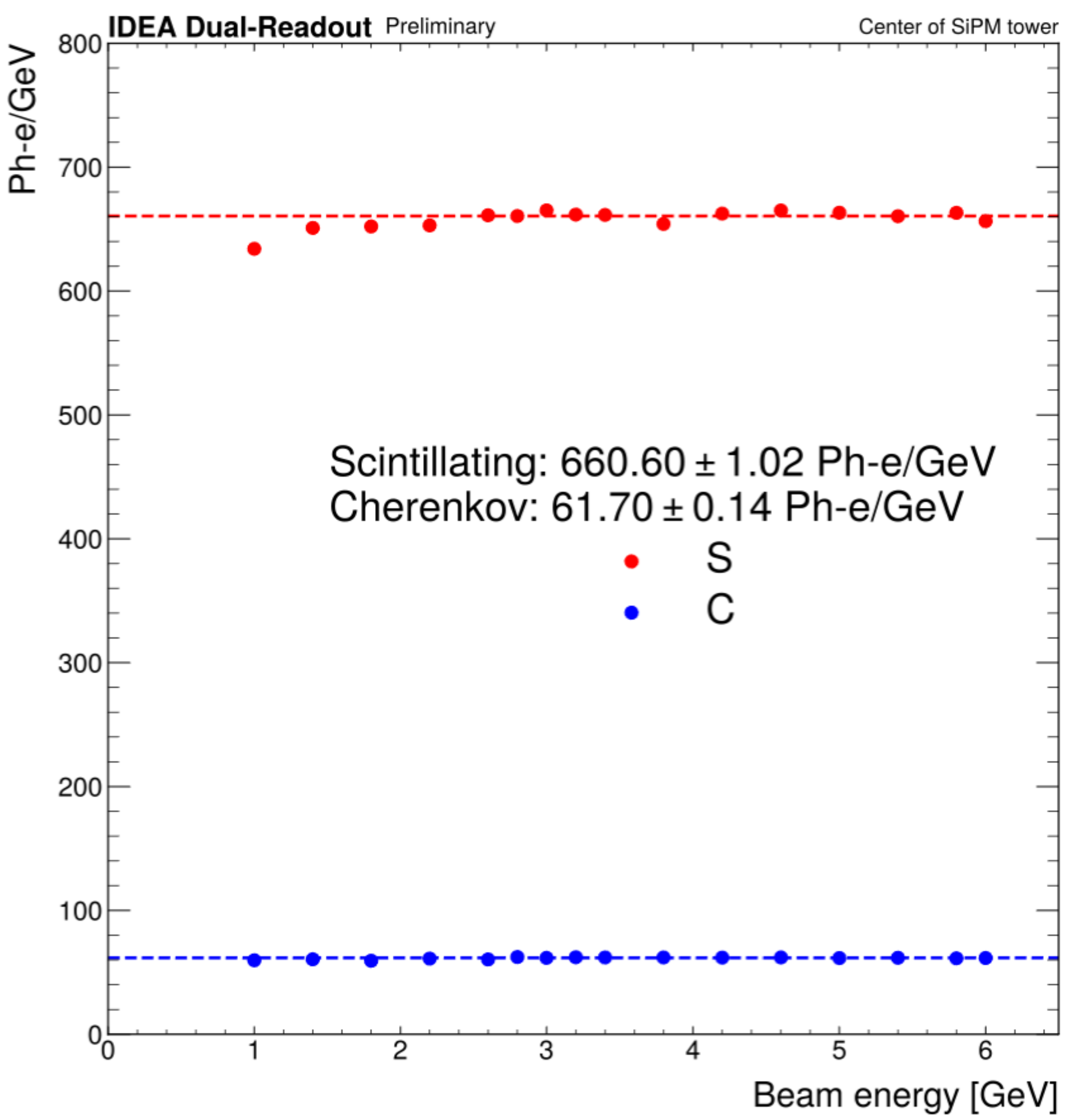
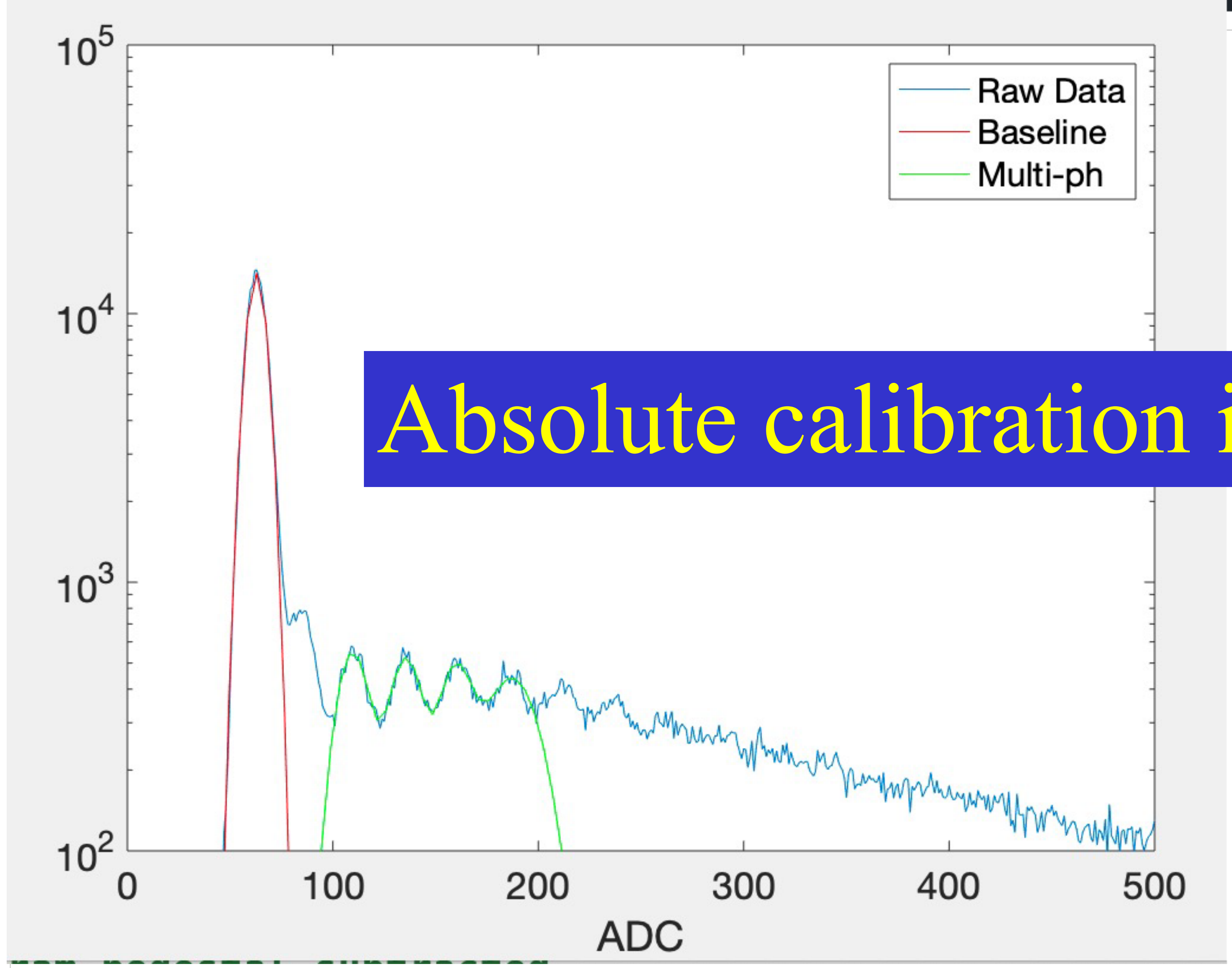






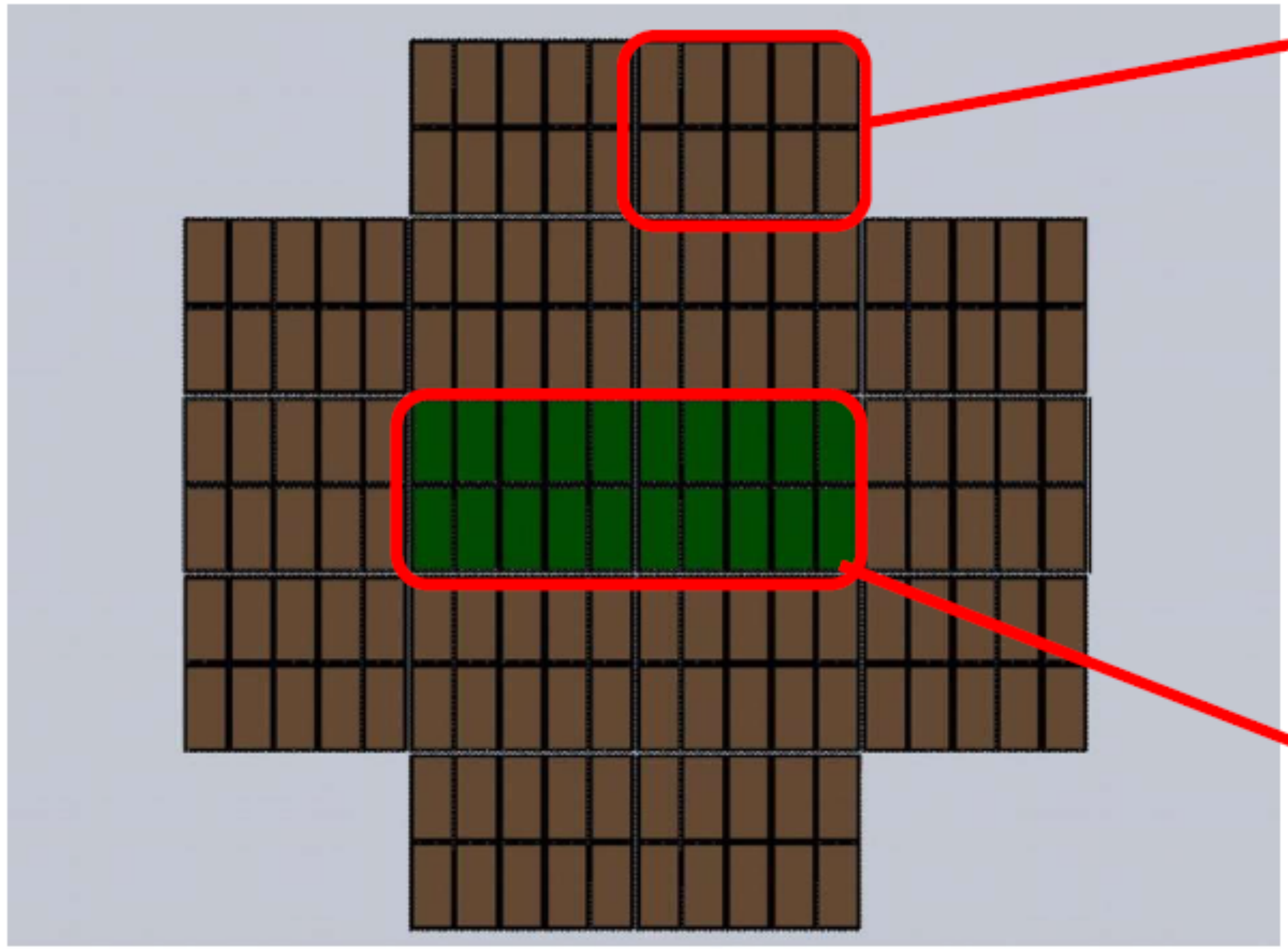


Absolute calibration in ph.e

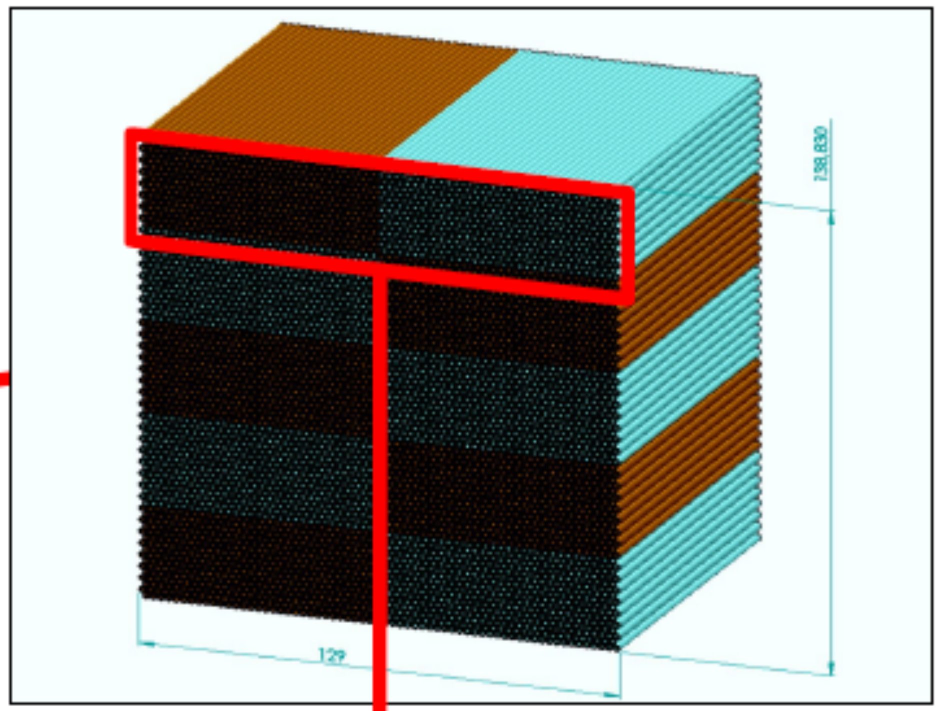
DR calorimeter

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

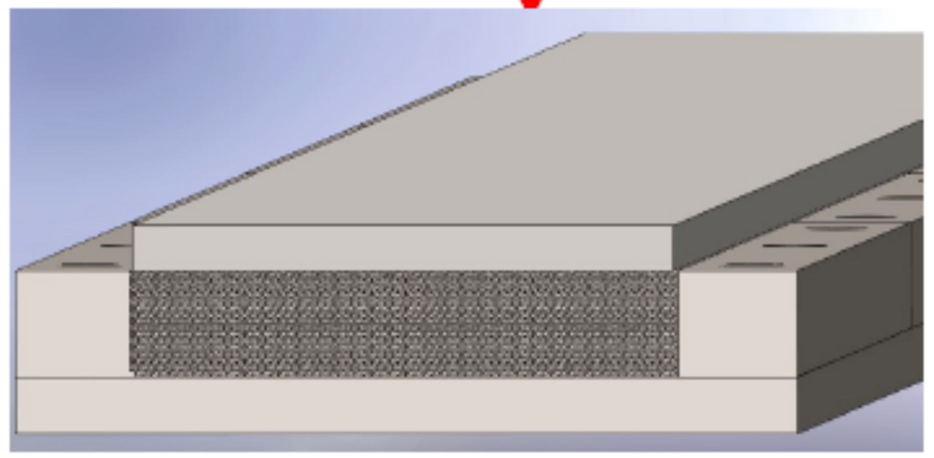
Hadronic-size prototype:
16 modules w/ highly granular core



~ 65 × 65 × 250 cm^3



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

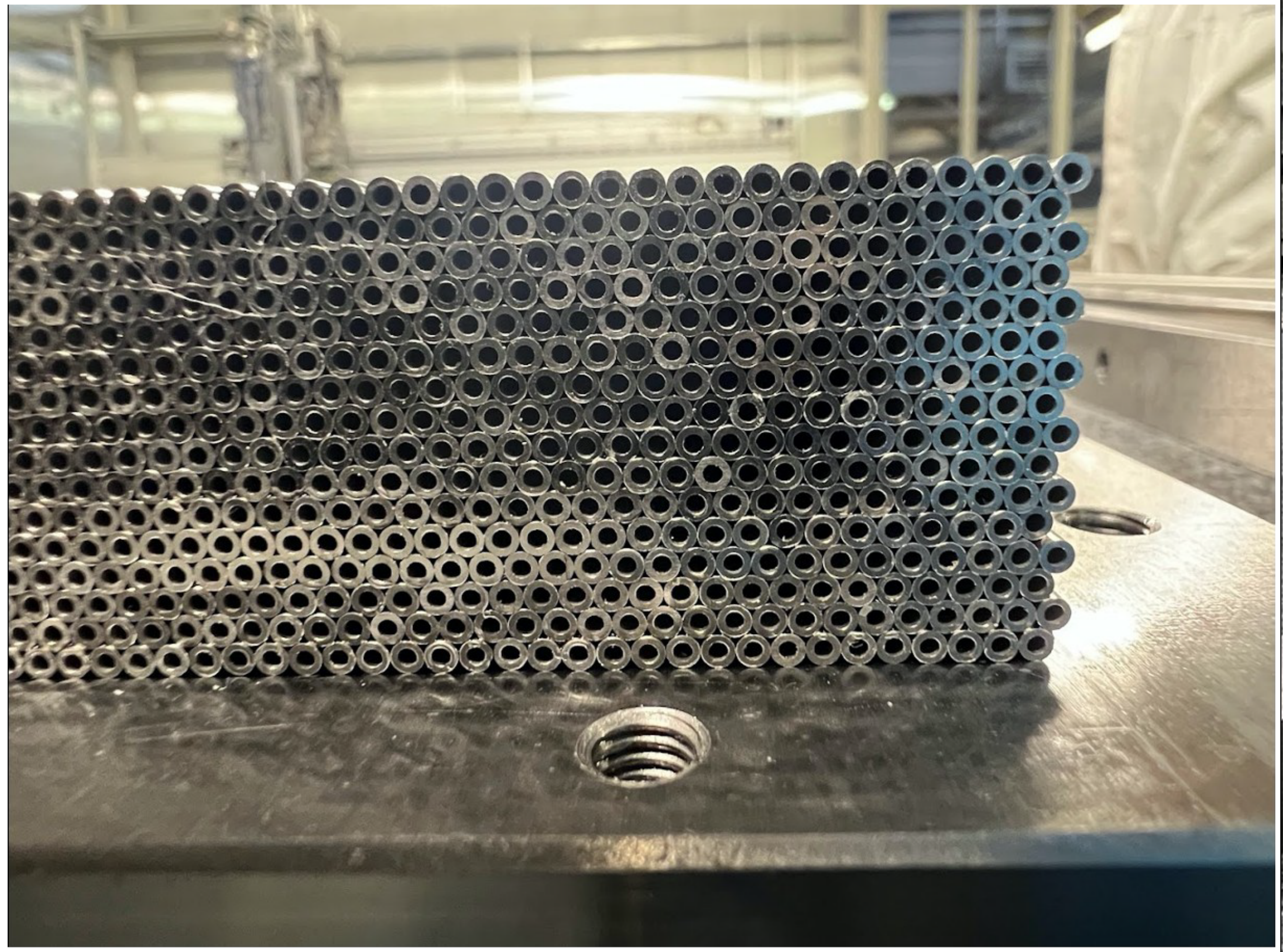


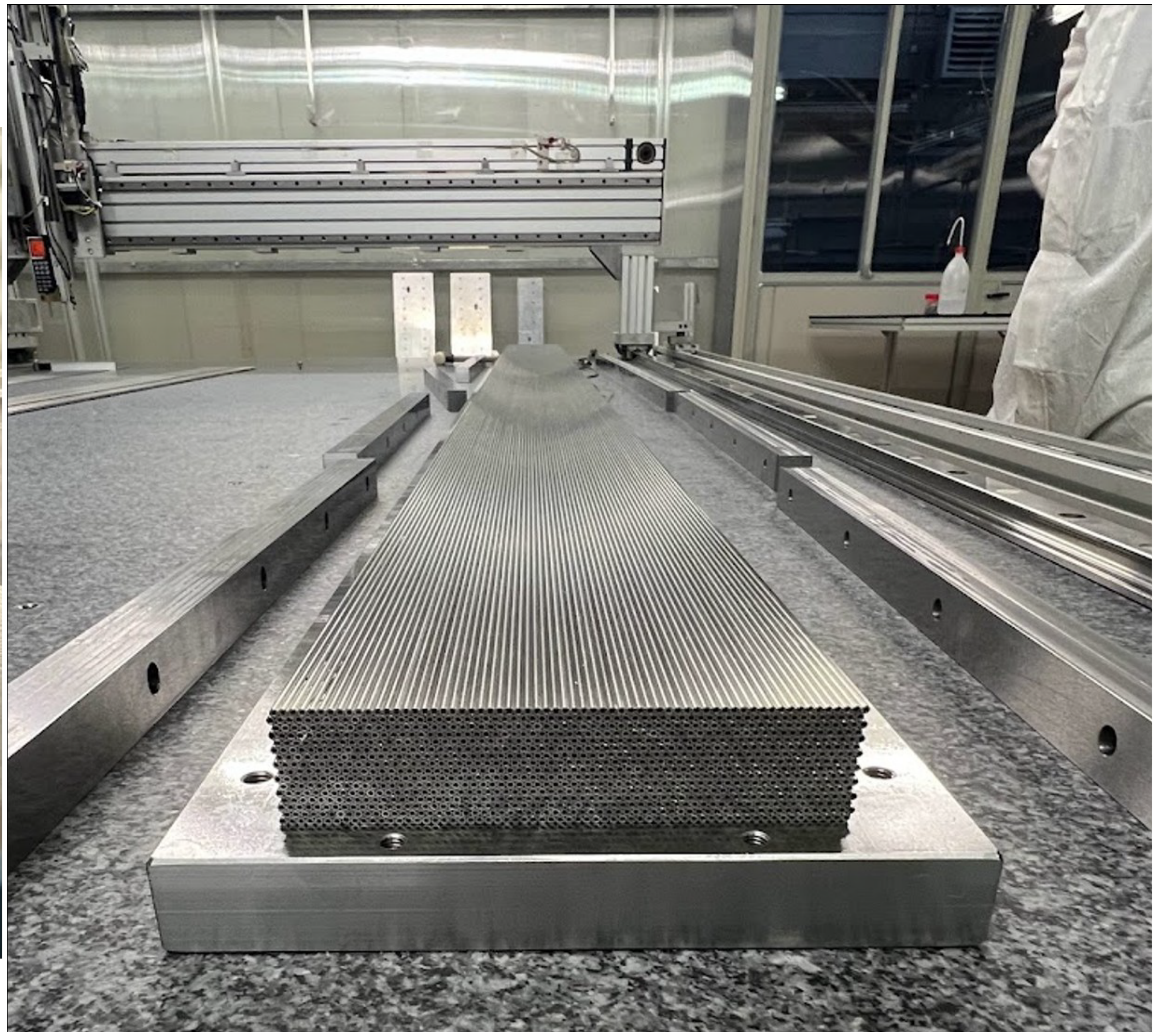
1 MiniModule:
64 × 16 = 1024 fibres in total
(512 S + 512 C)

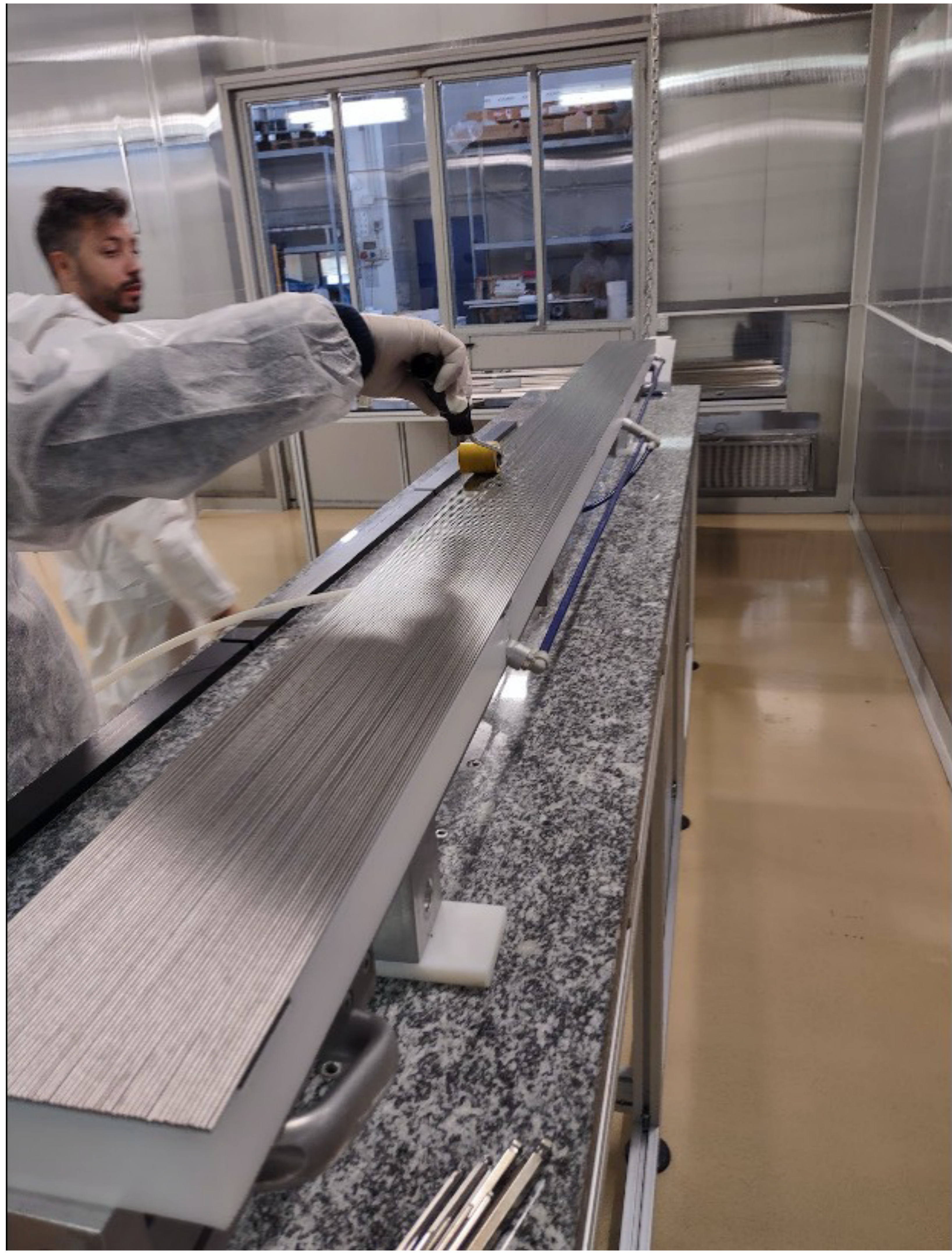
highly granular core:
10240 fibres to read out with SiPMs

DR calorimeter

- Full containment hadronic prototype in progress
  - Hidra2 call INFN CSN5

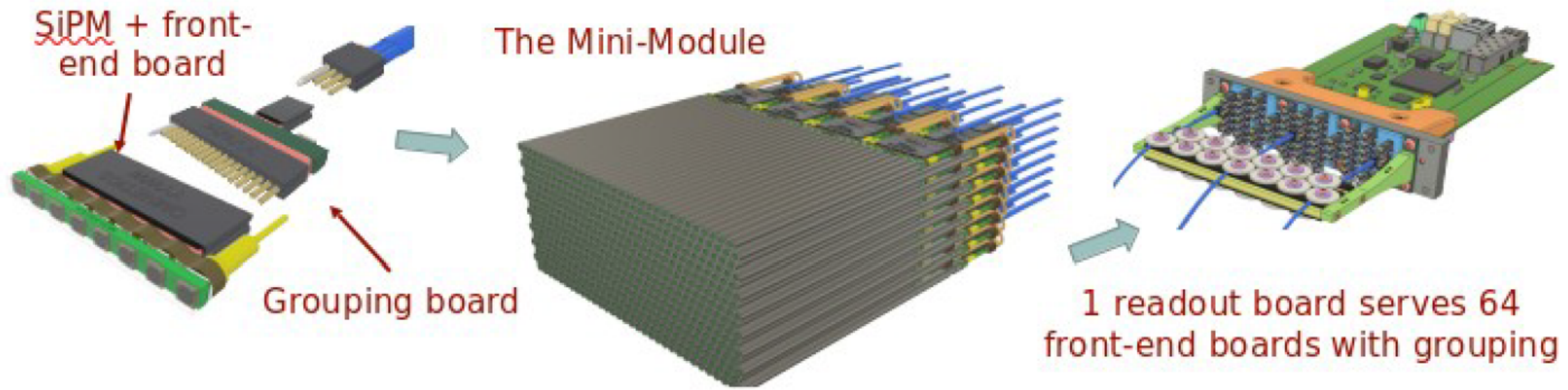






DR calorimeter

- Full containment hadronic prototype in progress
  - Hidra2 call INFN CSN5

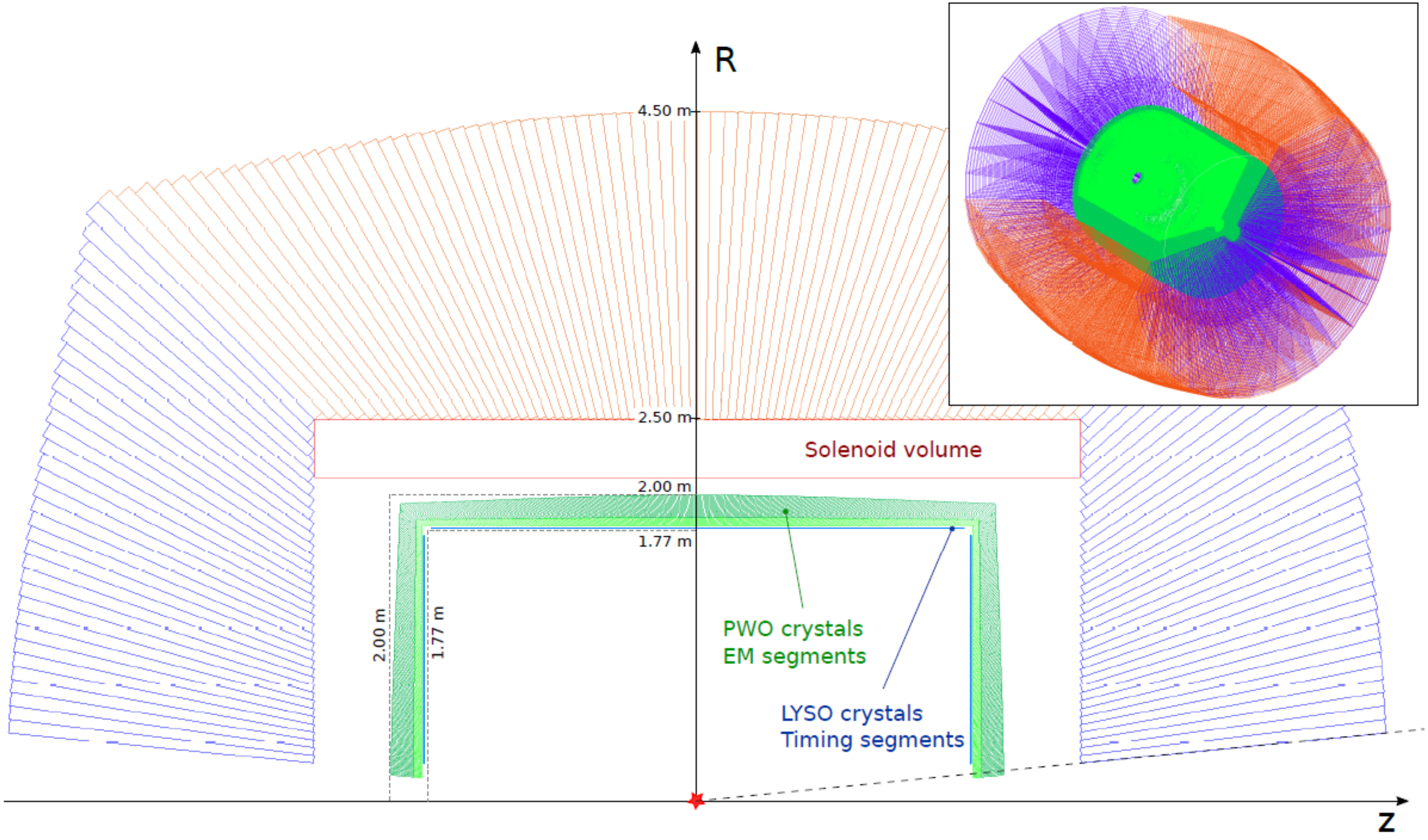


Dual readout future plans

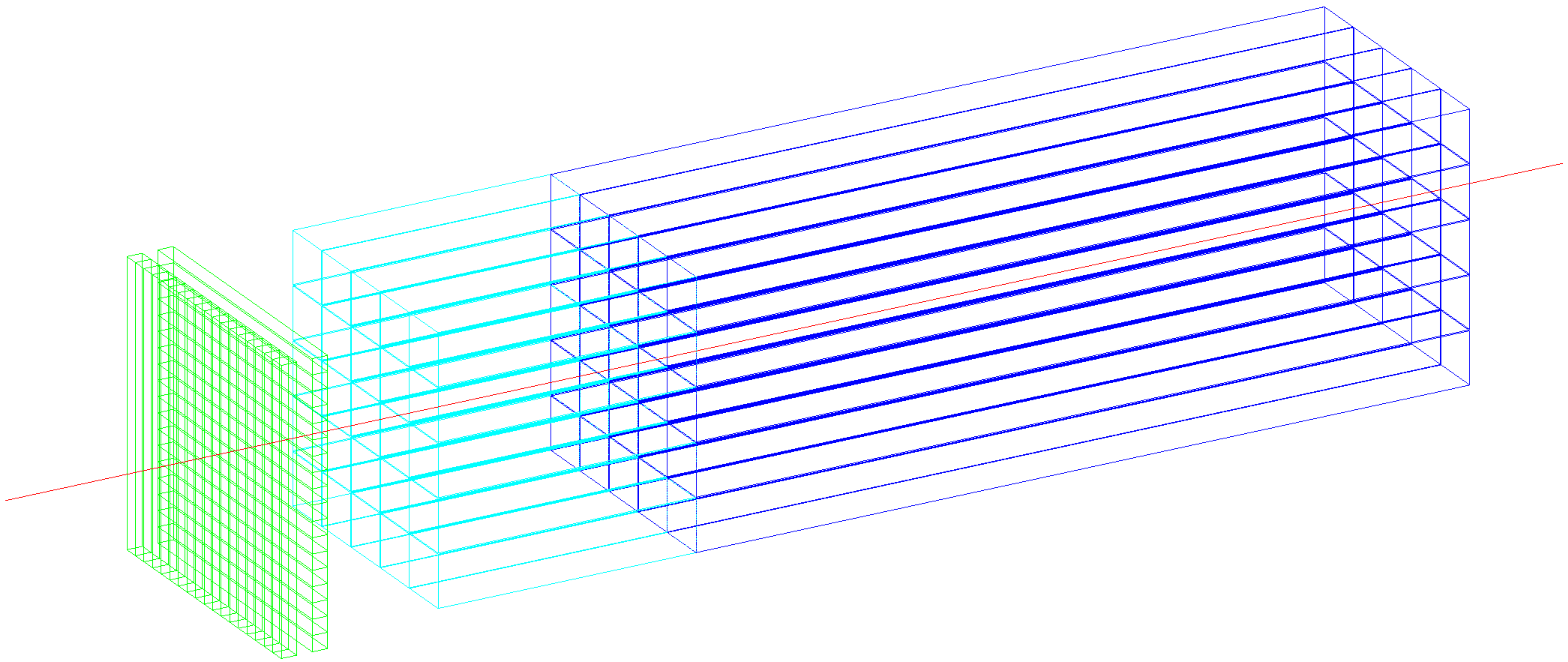
- Complete construction/test of Hidra2 prototype (one year)
  - Demonstrate resolution with full containment
- Develop scalable readout electronics (few years)
- Optimize metal matrix mechanics for large production (few years)
- Develop mechanical model of full system with services (few years)

- Towards a DR calorimeter TDR

Crystal option



Crystal option



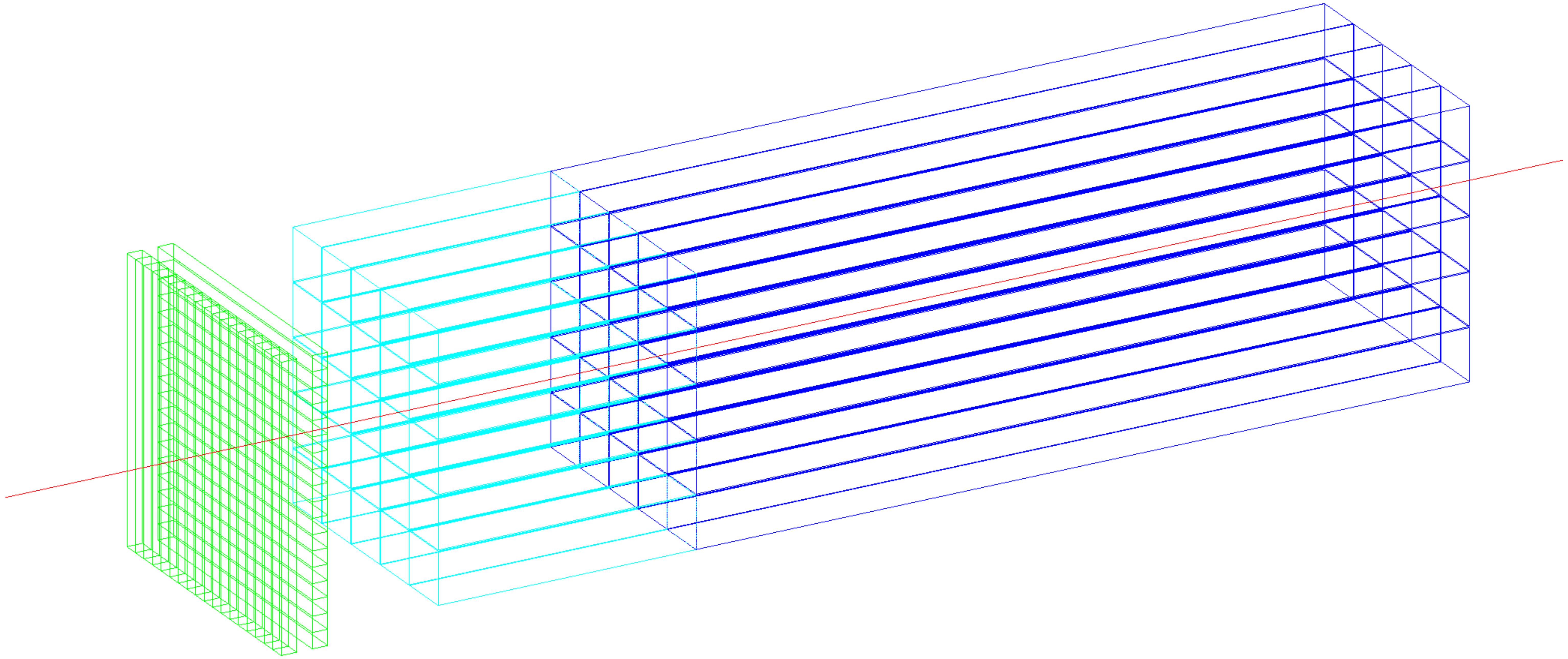
1x1x5 cm^3
PbWO

1x1x15 cm^3
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

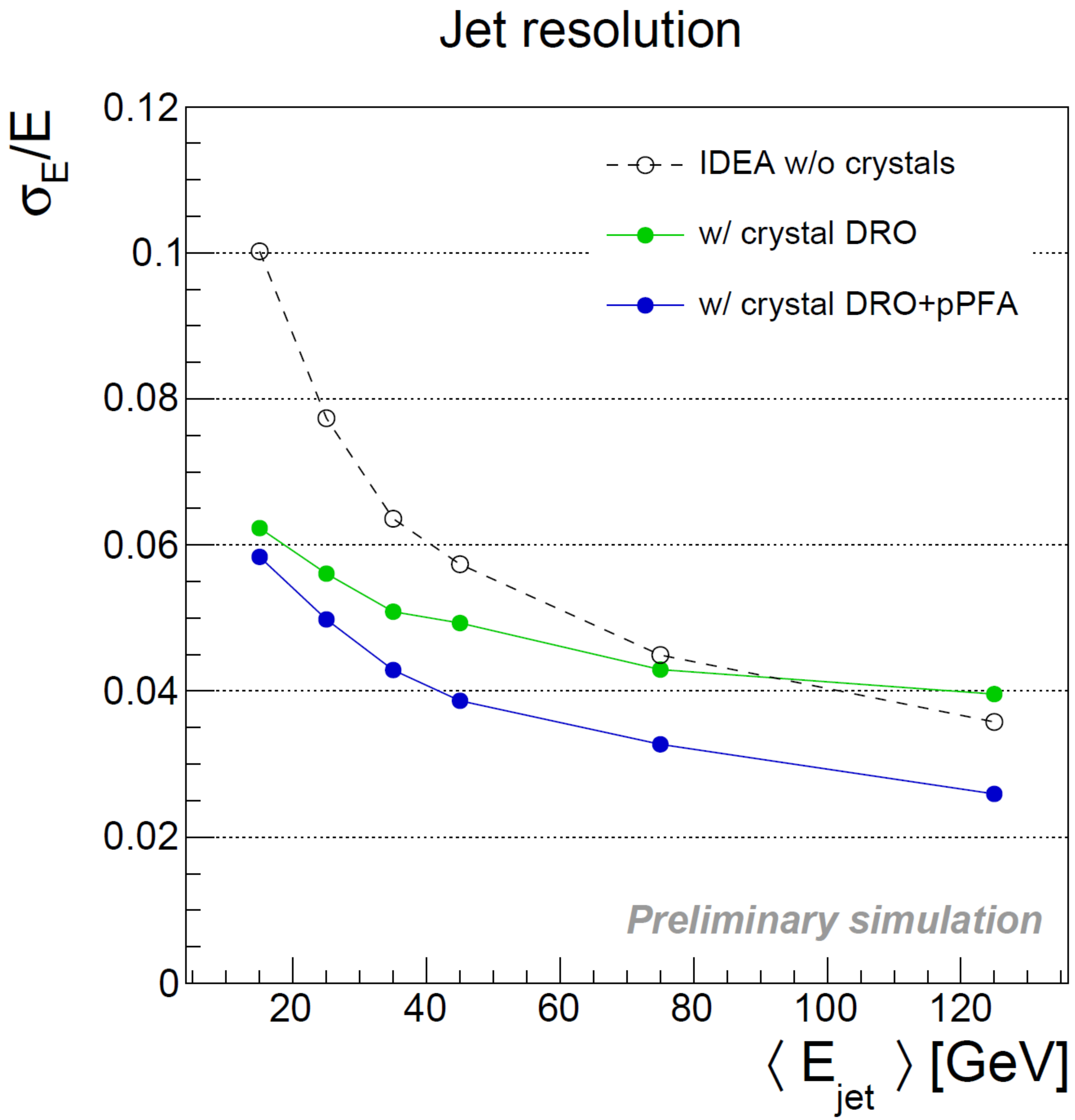


1x1x5 cm^3 PbWO

1x1x15 cm^3 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
  - **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)



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

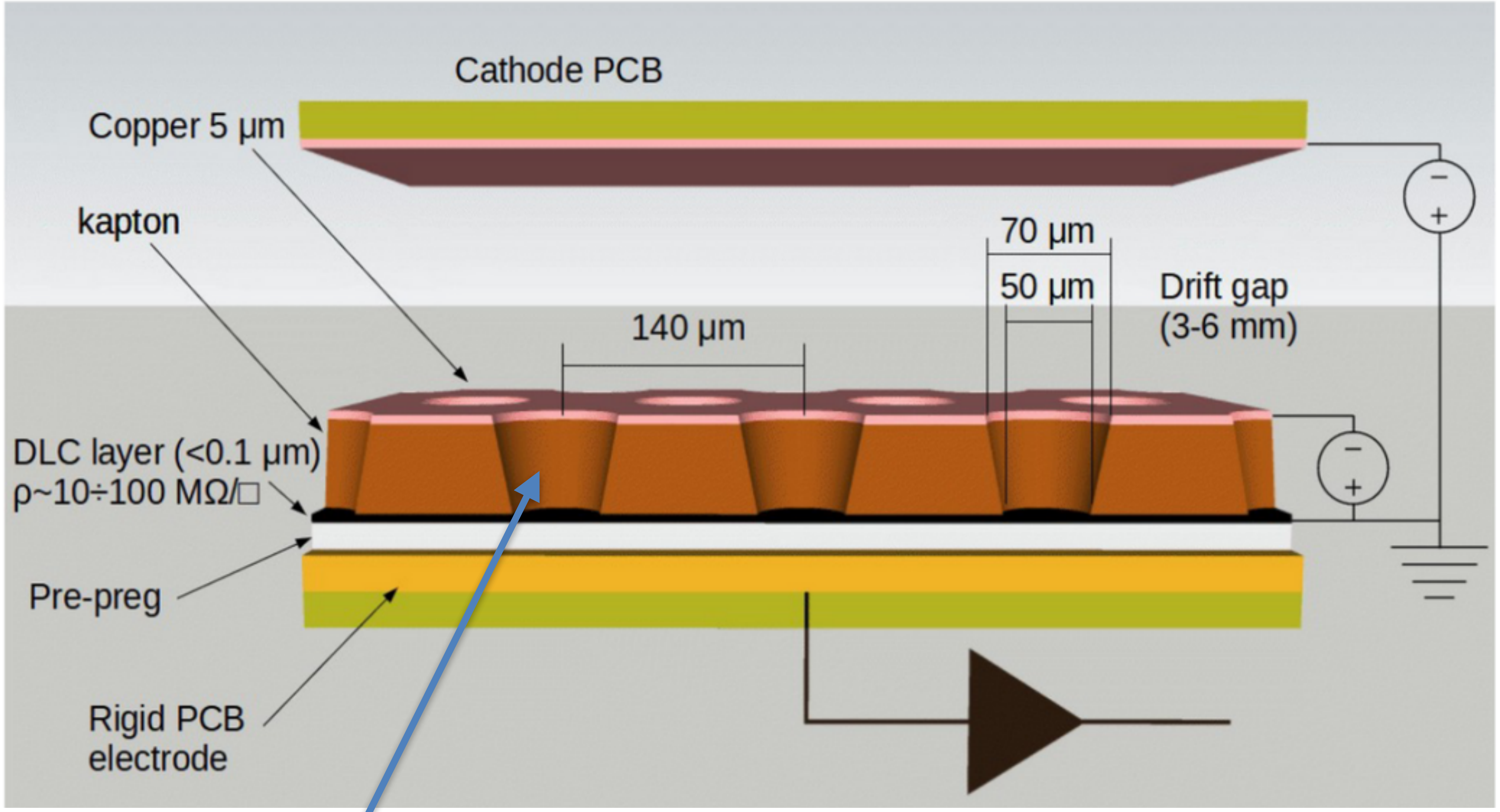
The μ-RWELL is composed of only two elements:

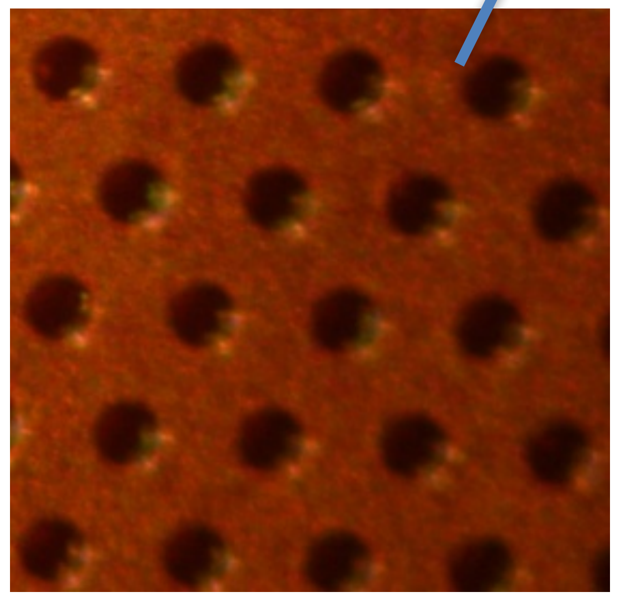
- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

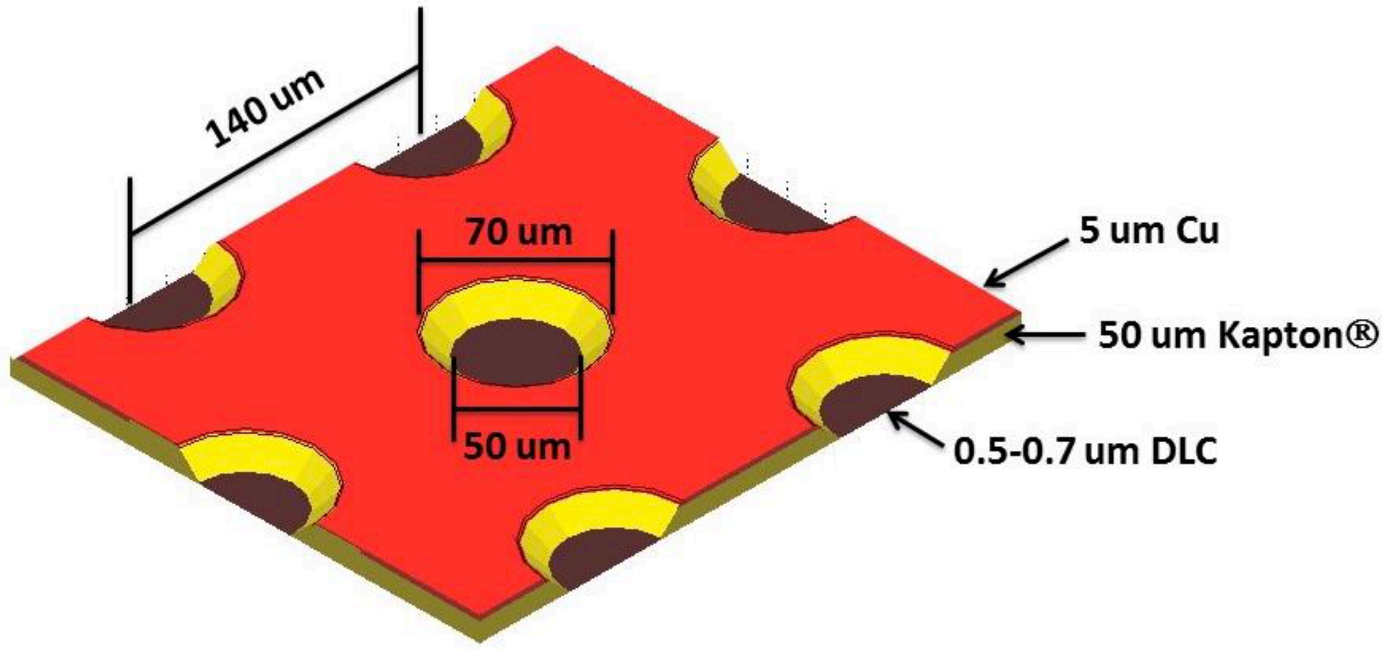
μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB

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

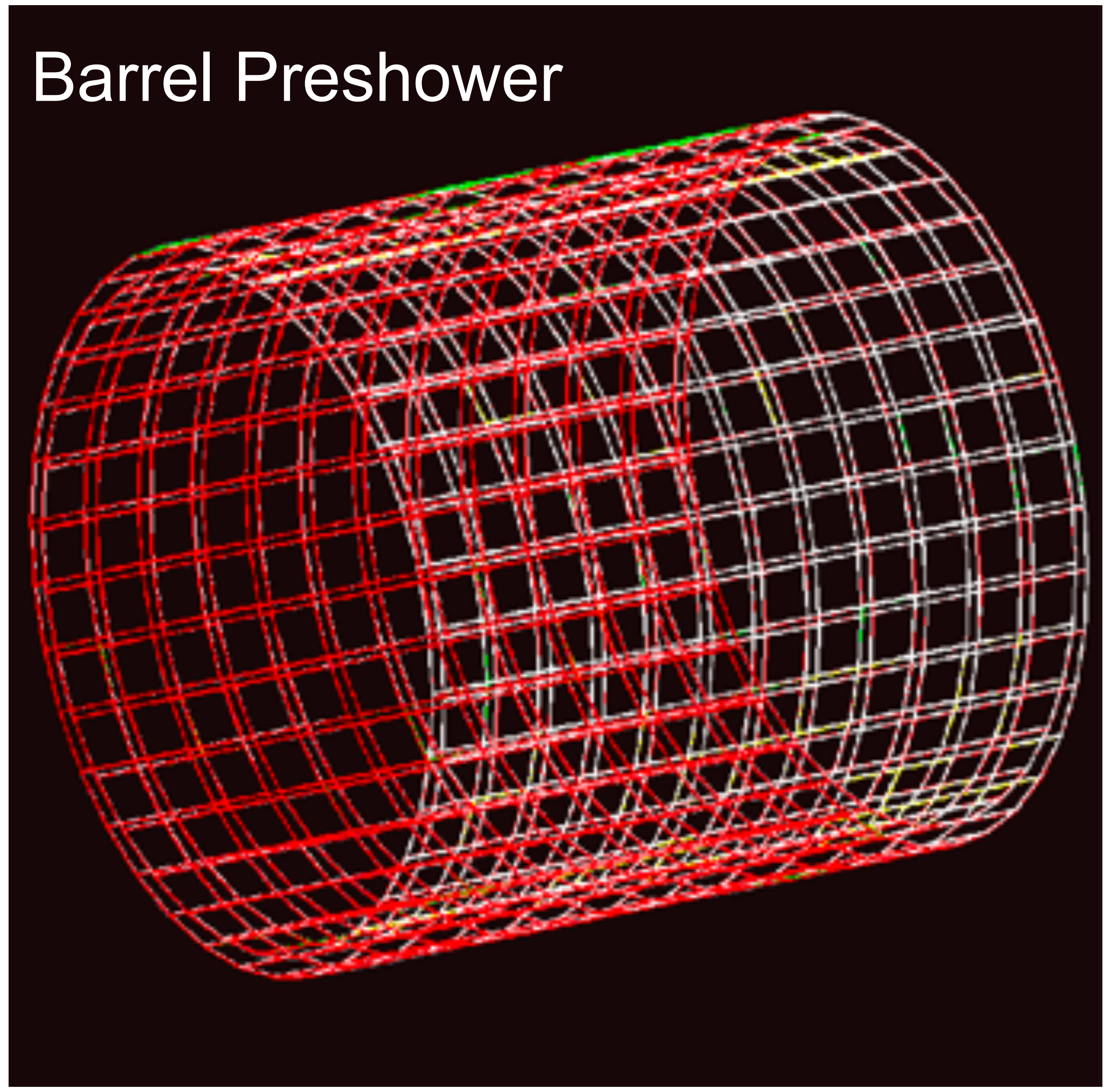
High resolution after the magnet
to improve $\pi^{\pm}/e^{\pm}$ and 2γ separation

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

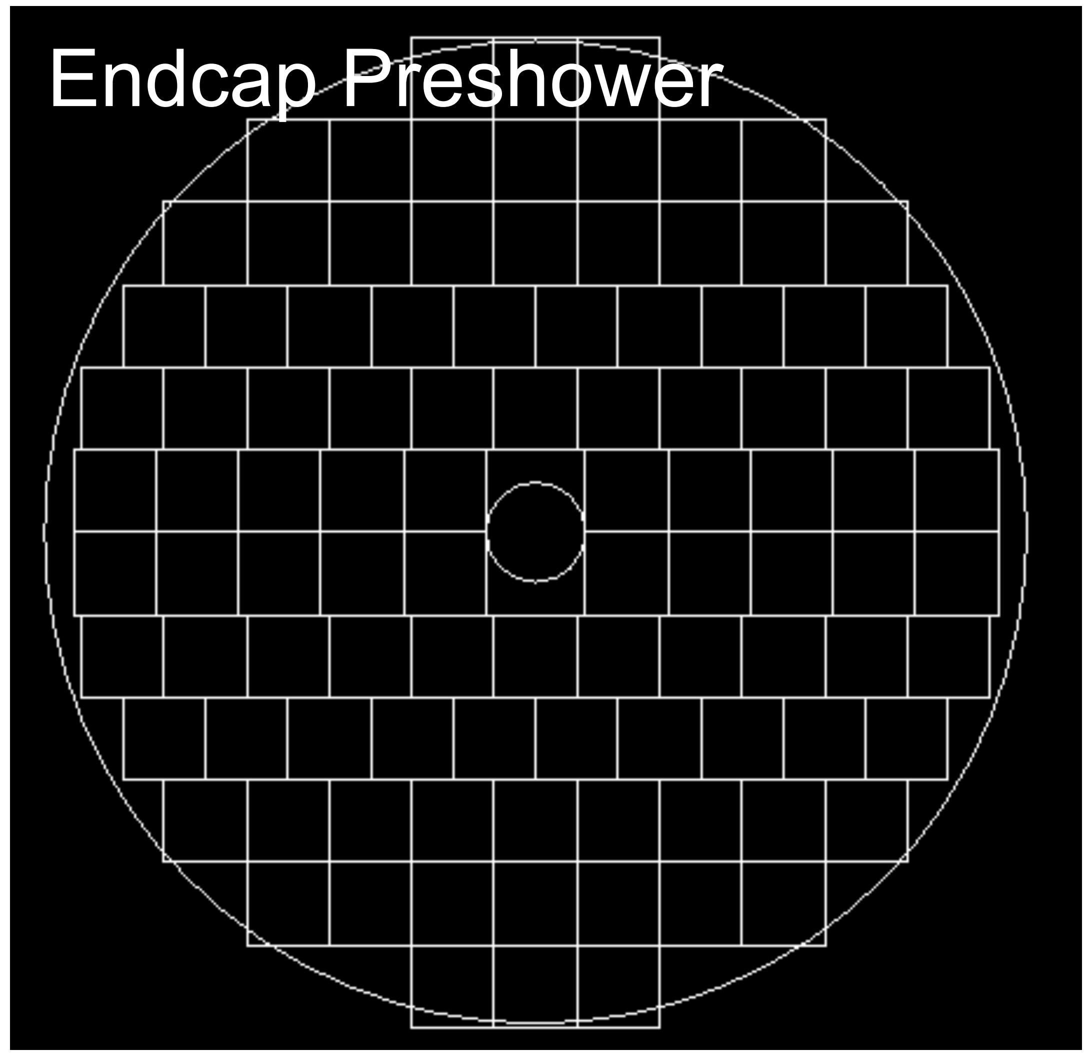
Muon Detector

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

50x50 cm^2 2D tiles to cover more than 1650 m^2

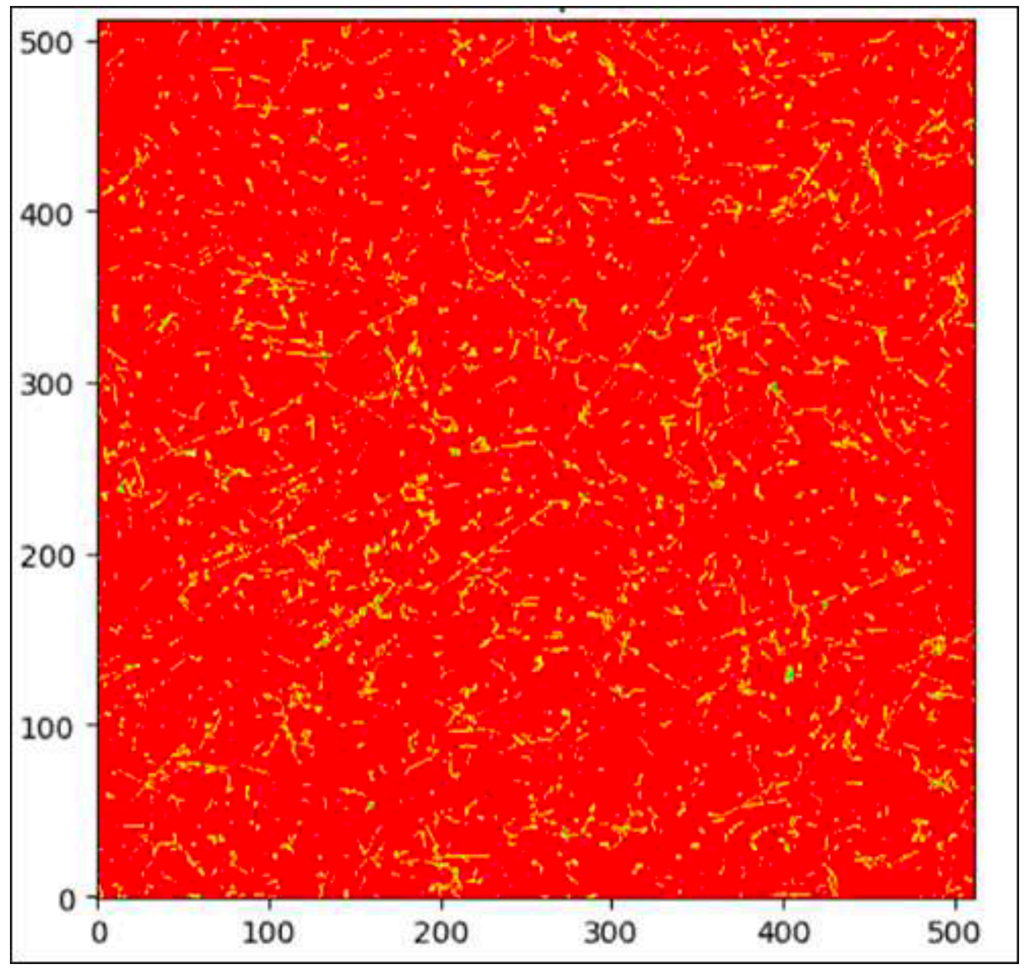
Preshower	Muon
pitch = 0.4 mm	pitch = 1.2 mm
FEE capacitance = 70 pF	FEE capacitance = 220 pF
1.3 million channels	5 million channels

Ongoing R&D

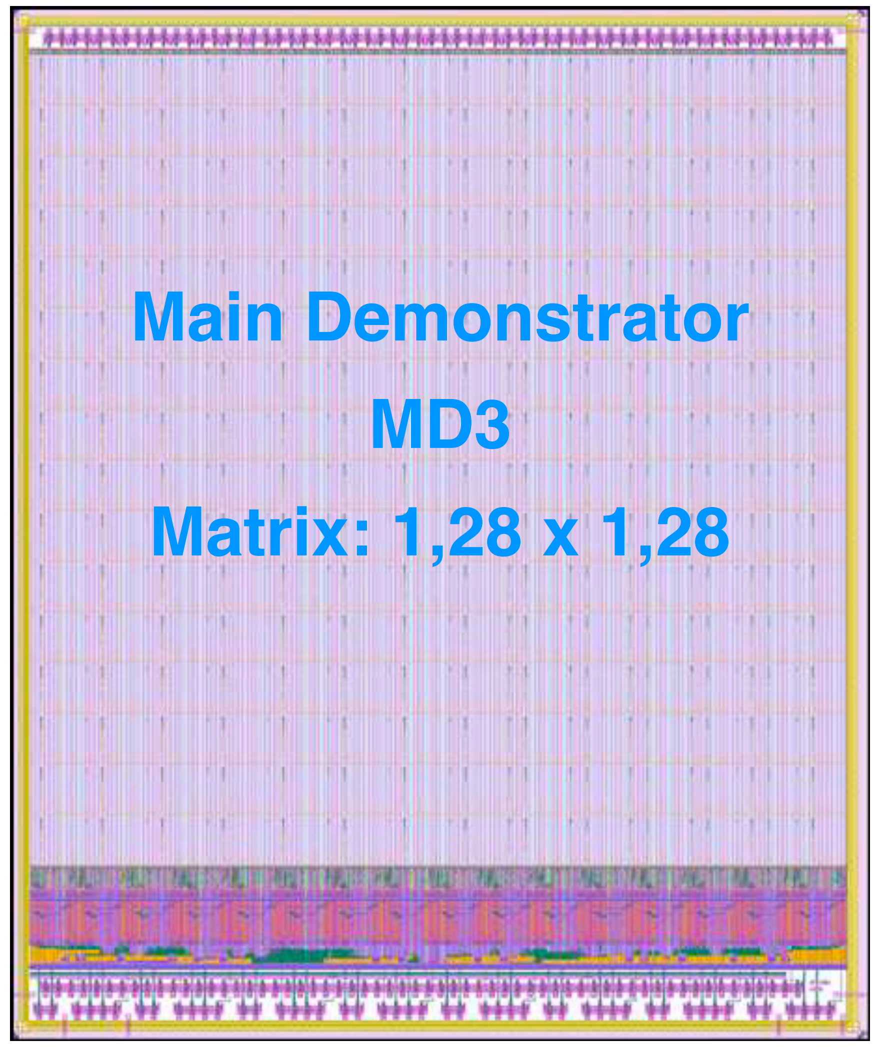
Click here for more R&D information

ARCADIA MD3 test

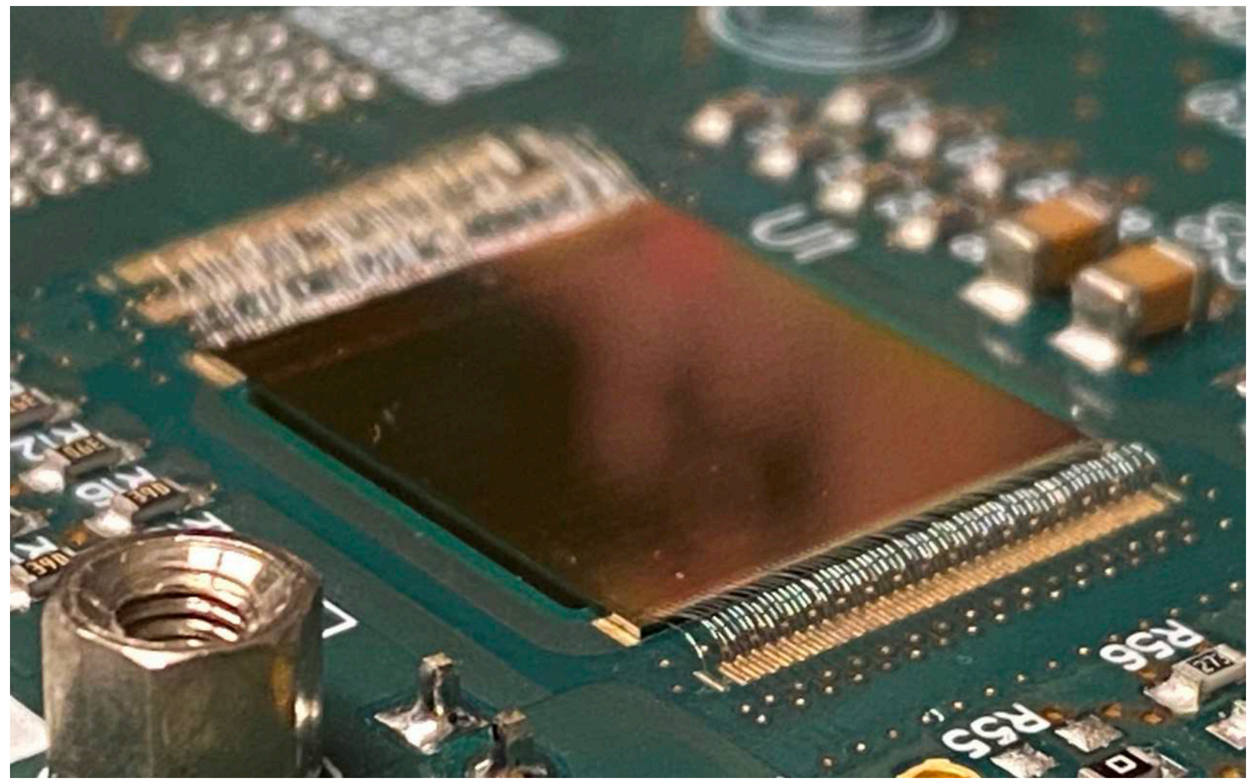
- 3 engineering runs with:
  - full-scale DMAPS
  - sensor R&D (monolithic FD-strips and readout, fast sensors with gain layer)
- High rate capability (100 MHz/cm^2) architecture on a scalable 512x512 pixel matrix (25 µm pitch) **MD3 Main Demonstrator chip:**
  - measured 30 mW/cm^2 at full-speed (16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

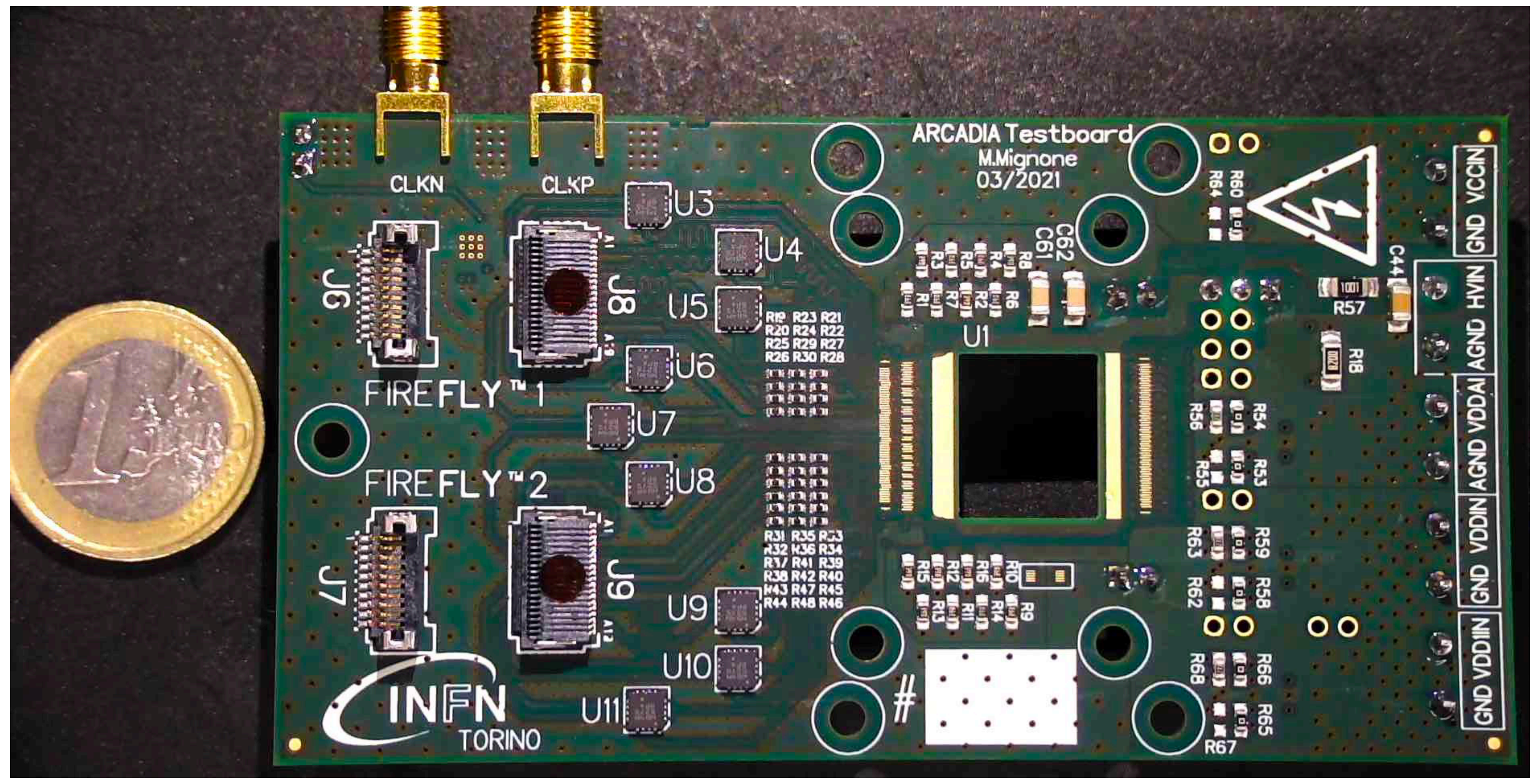


Cosmic ray data



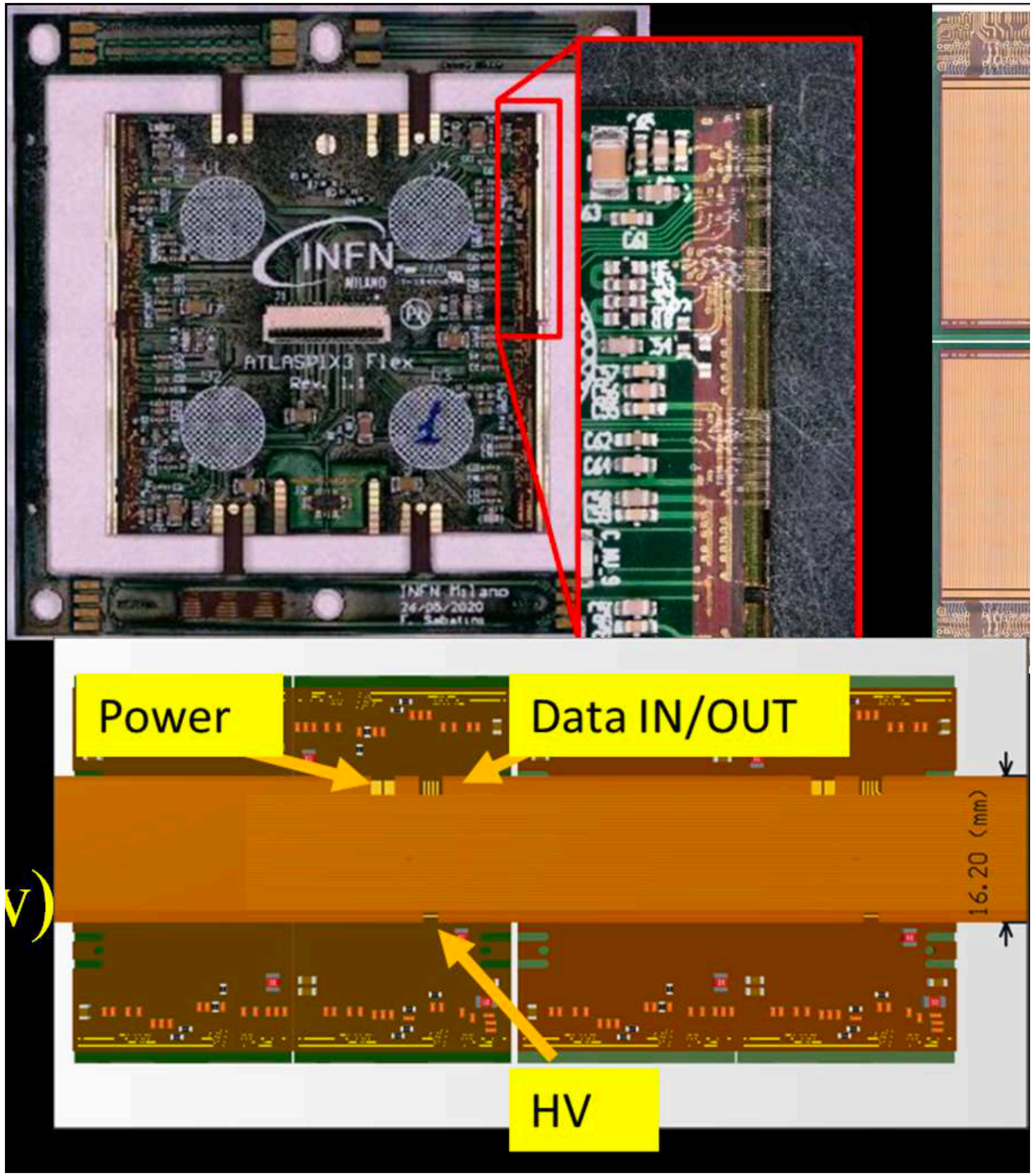
110 nm CMOS CIS technology, high-resistivity bulk, operated in full depletion mode



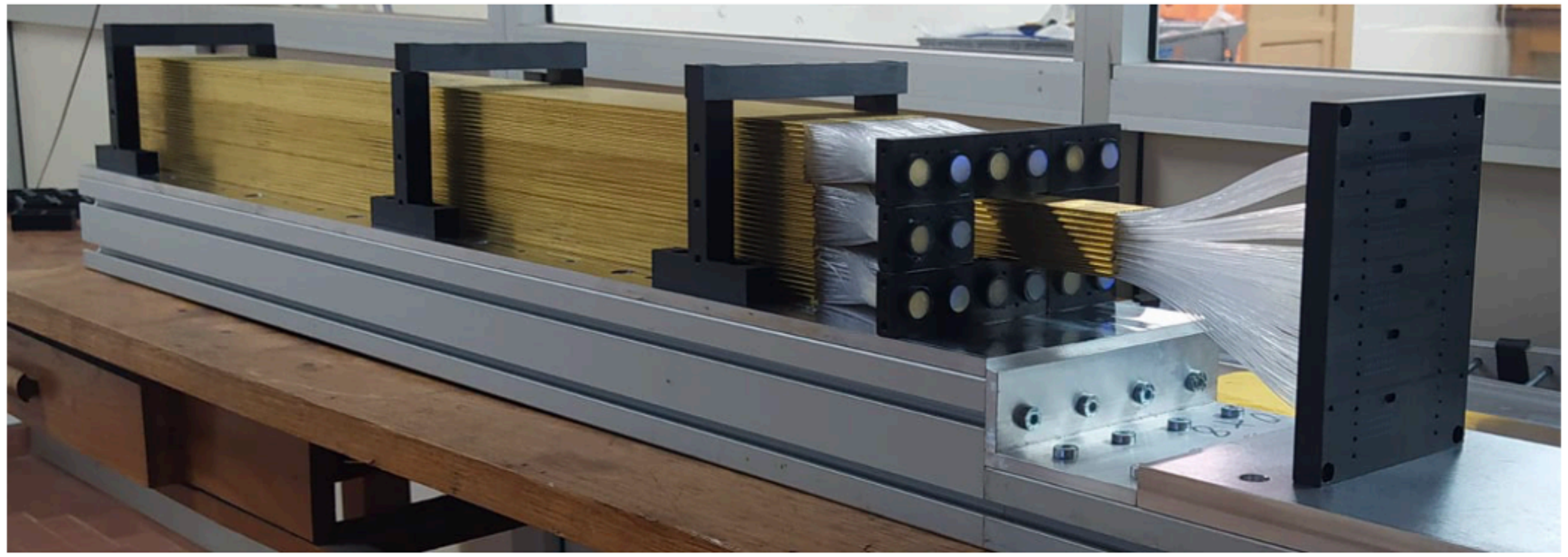


Silicon detectors: ATLASPix3

- ❖ Based on ATLASPIX3 R&D
  - 50x50 μm^2
  - 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)



2020 Dual Readout prototype



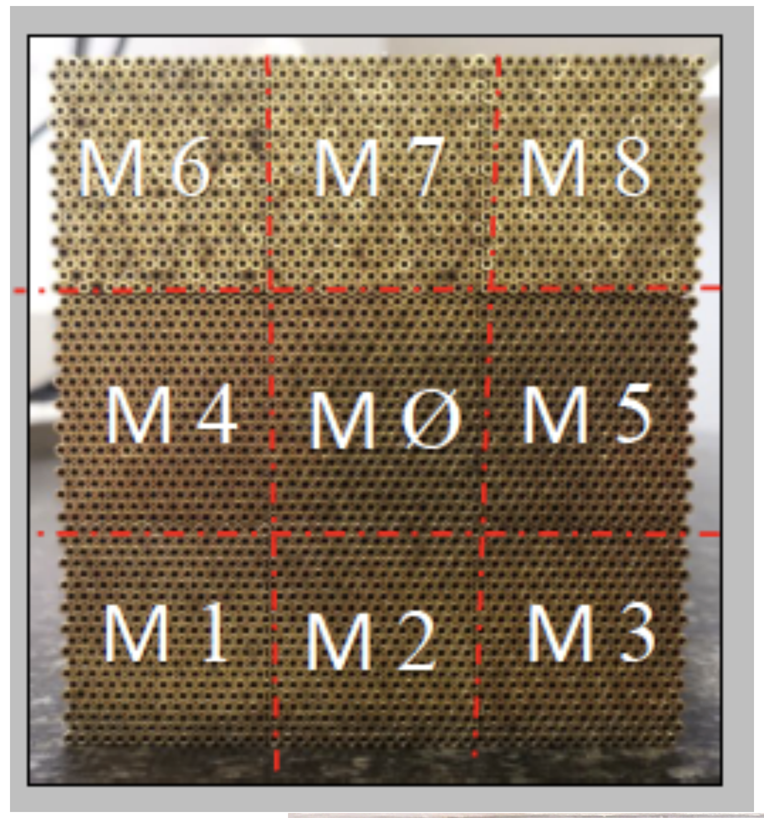
Electromagnetic dimensions of 10x10x100 cm^3

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

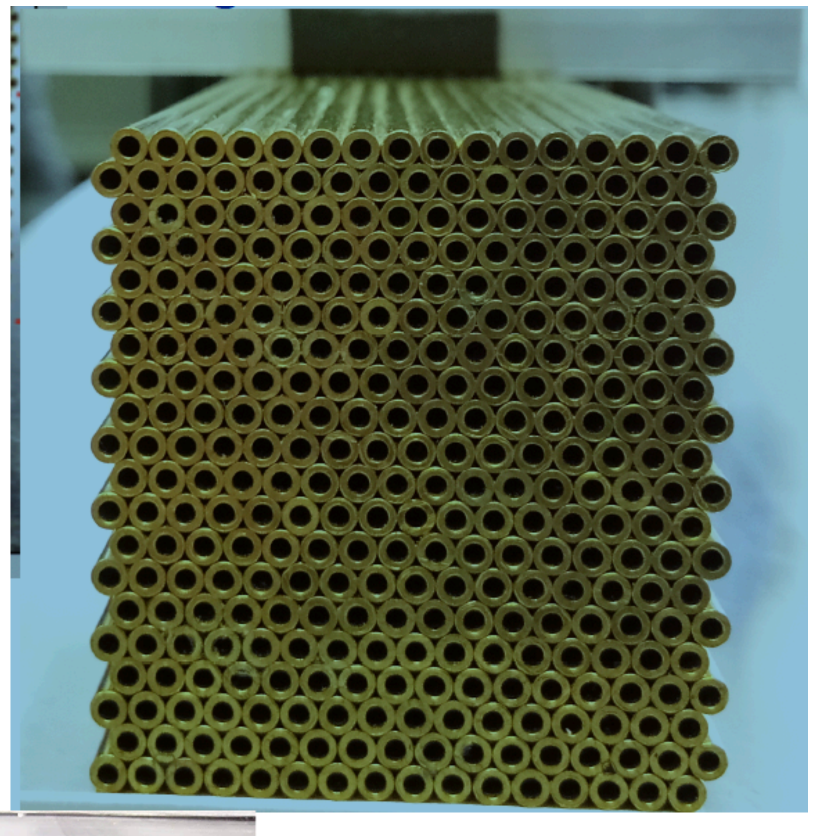
Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm

1-mm-thick fibers

Full prototype - 9 towers



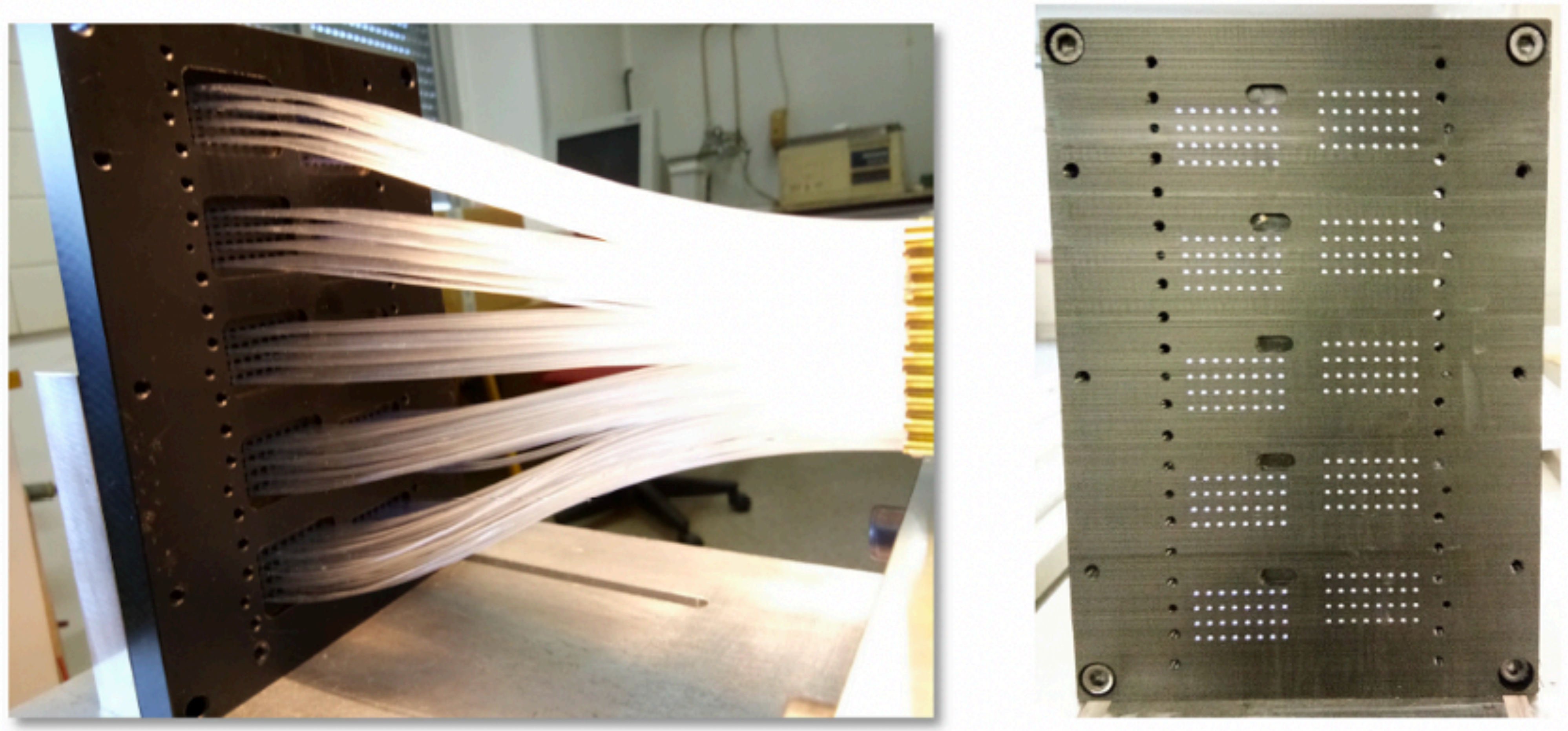
Single tower

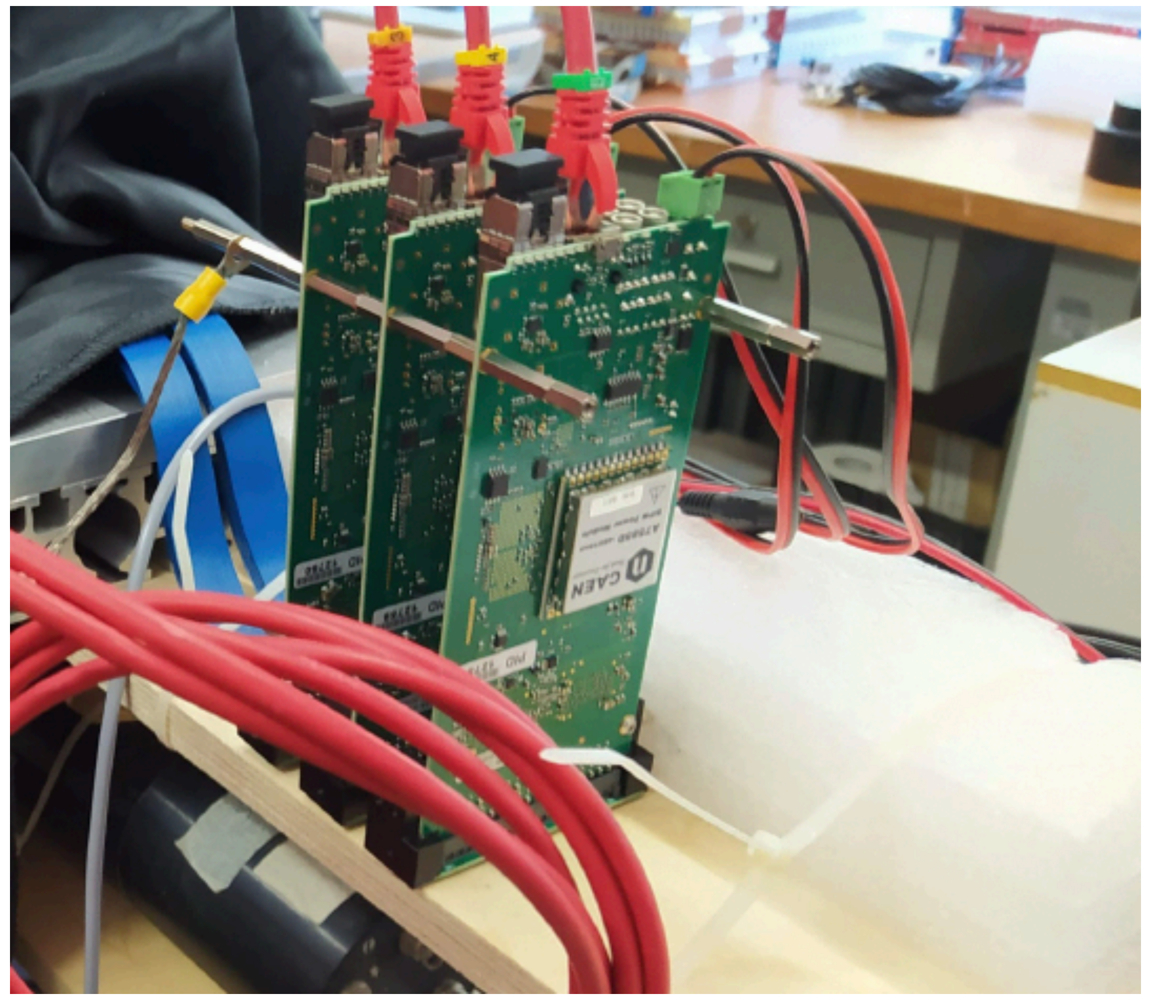


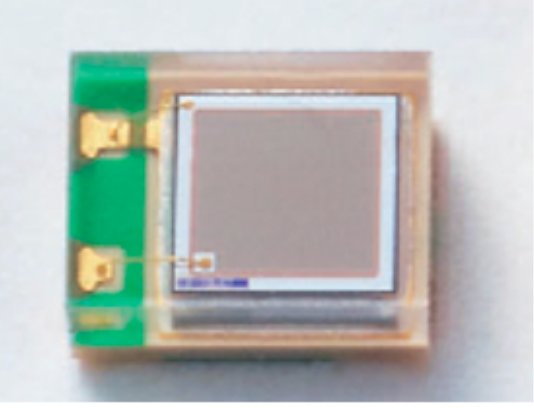
"Bucatini calorimeter"

Front end board housing 64 SiPM

Fiber guiding system







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

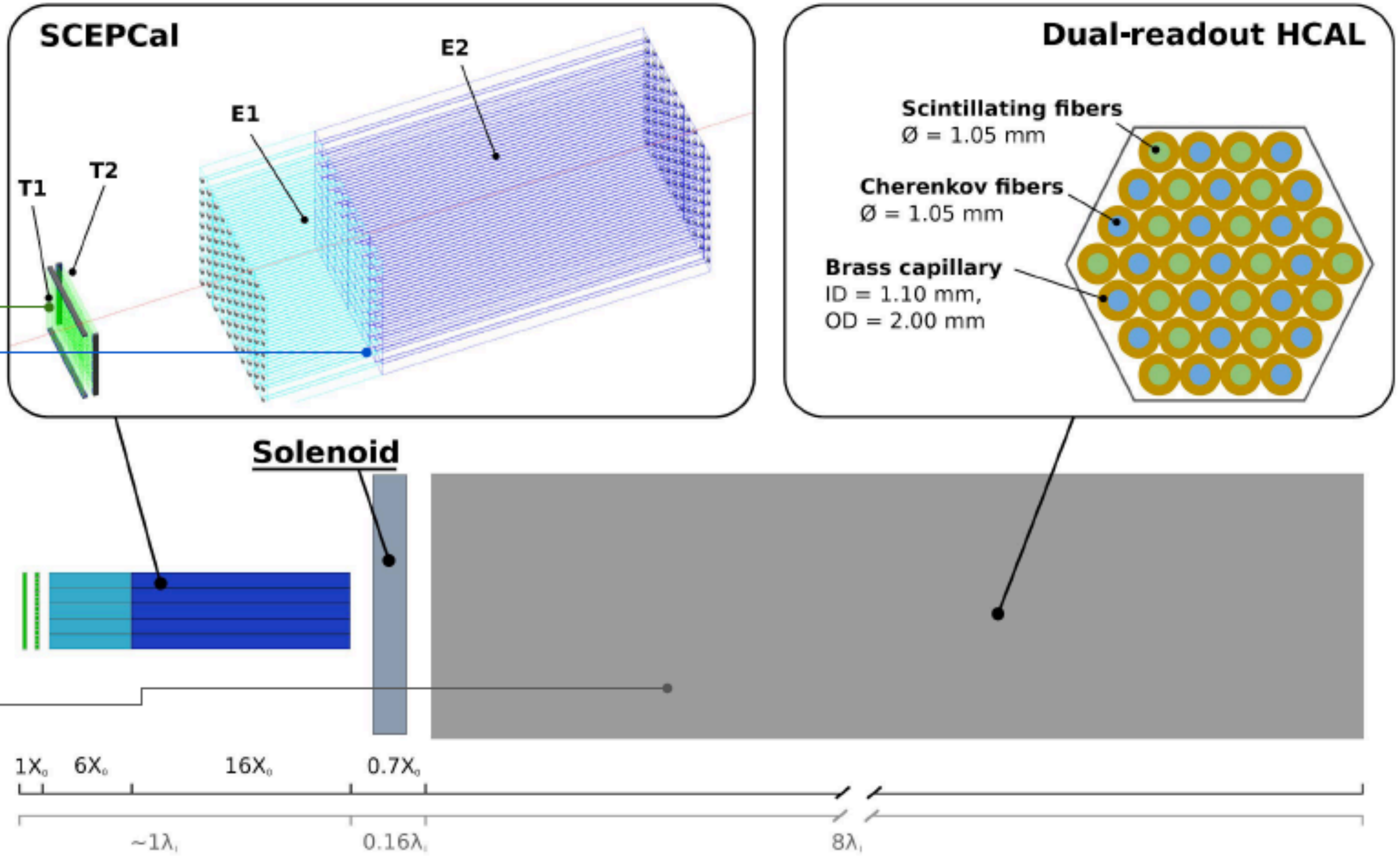
Readout Boards CAEN A5202

Crystal ECAL with DR calorimeter

Layout overview

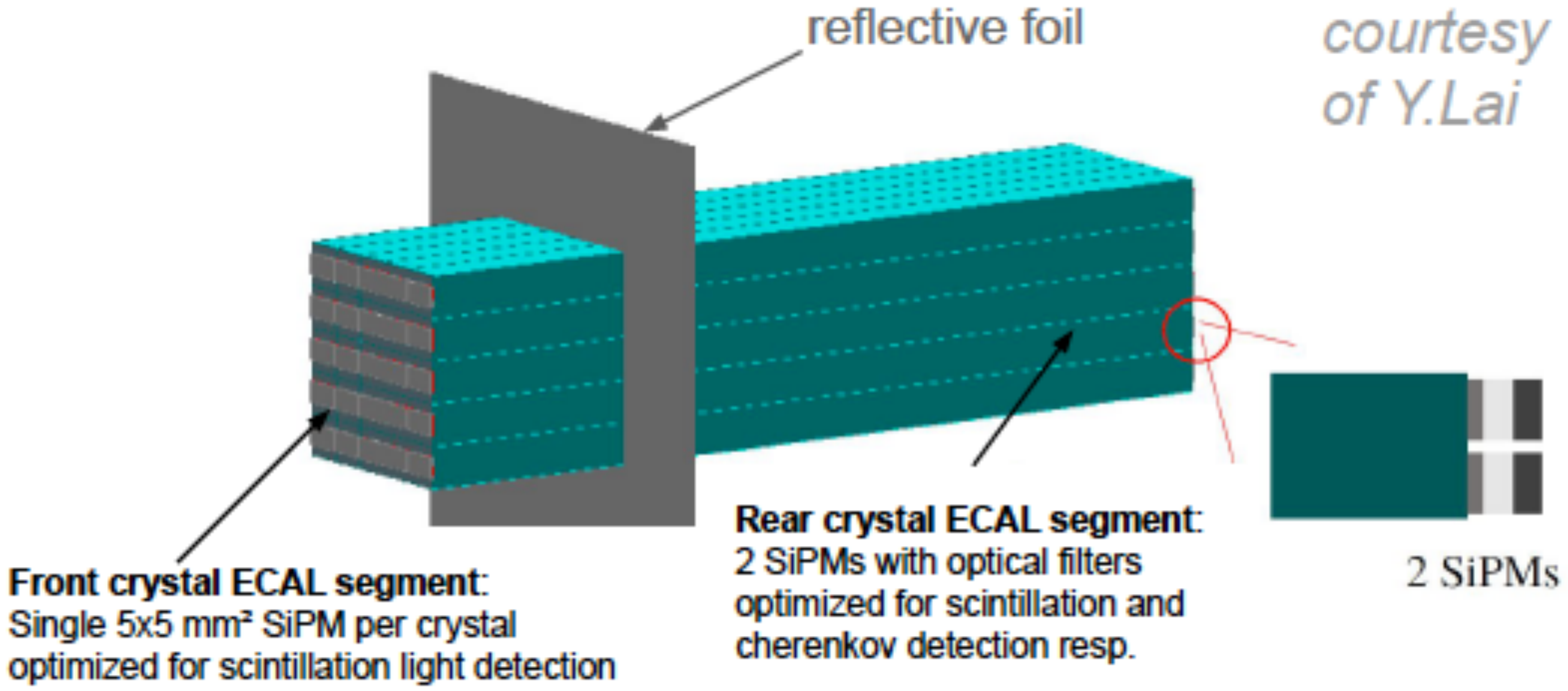
- **Transverse and longitudinal segmentations** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

- **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

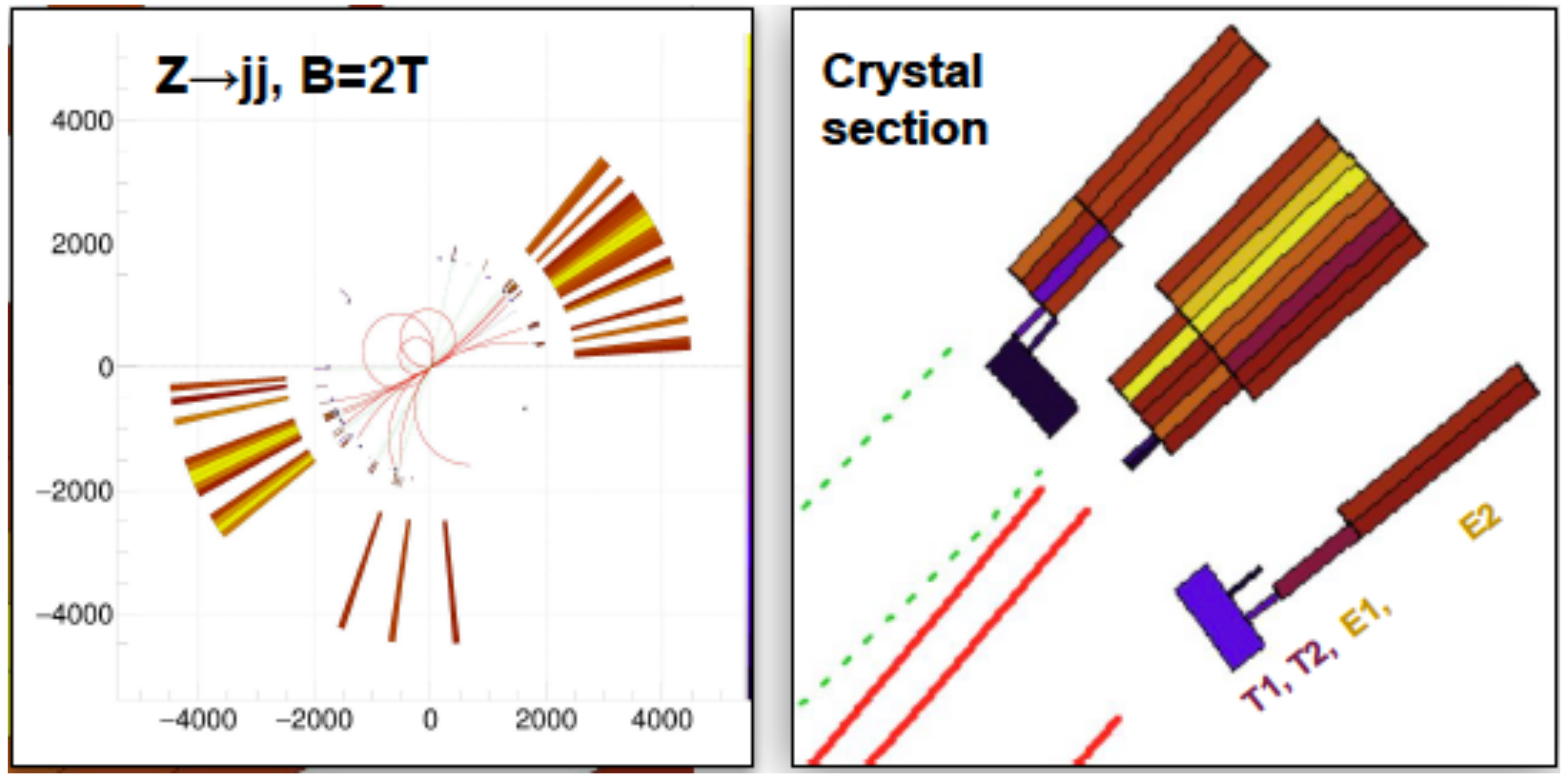


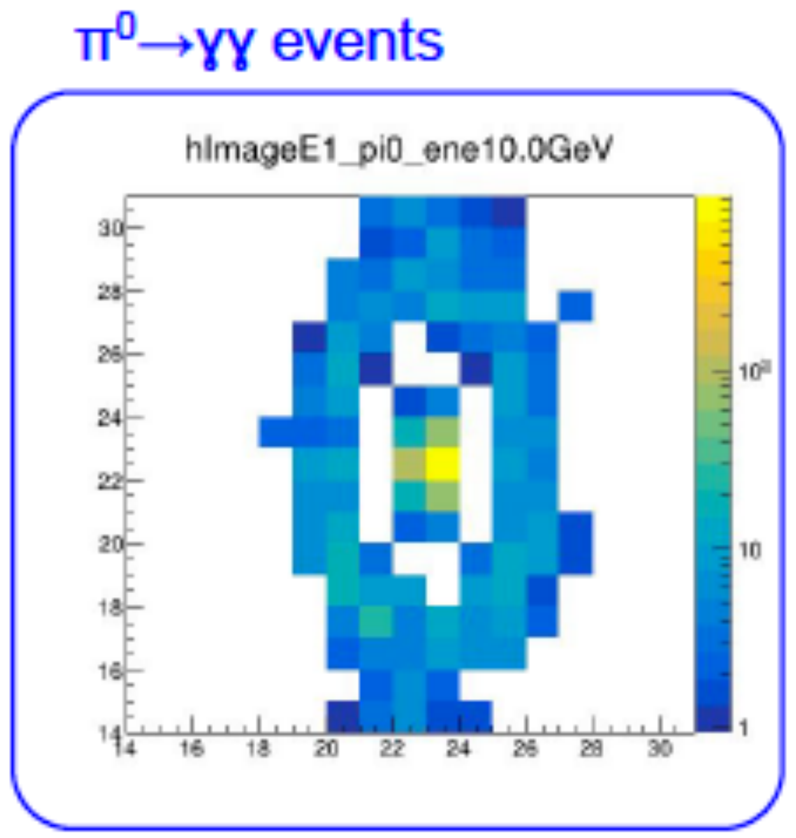
M. Lucchini

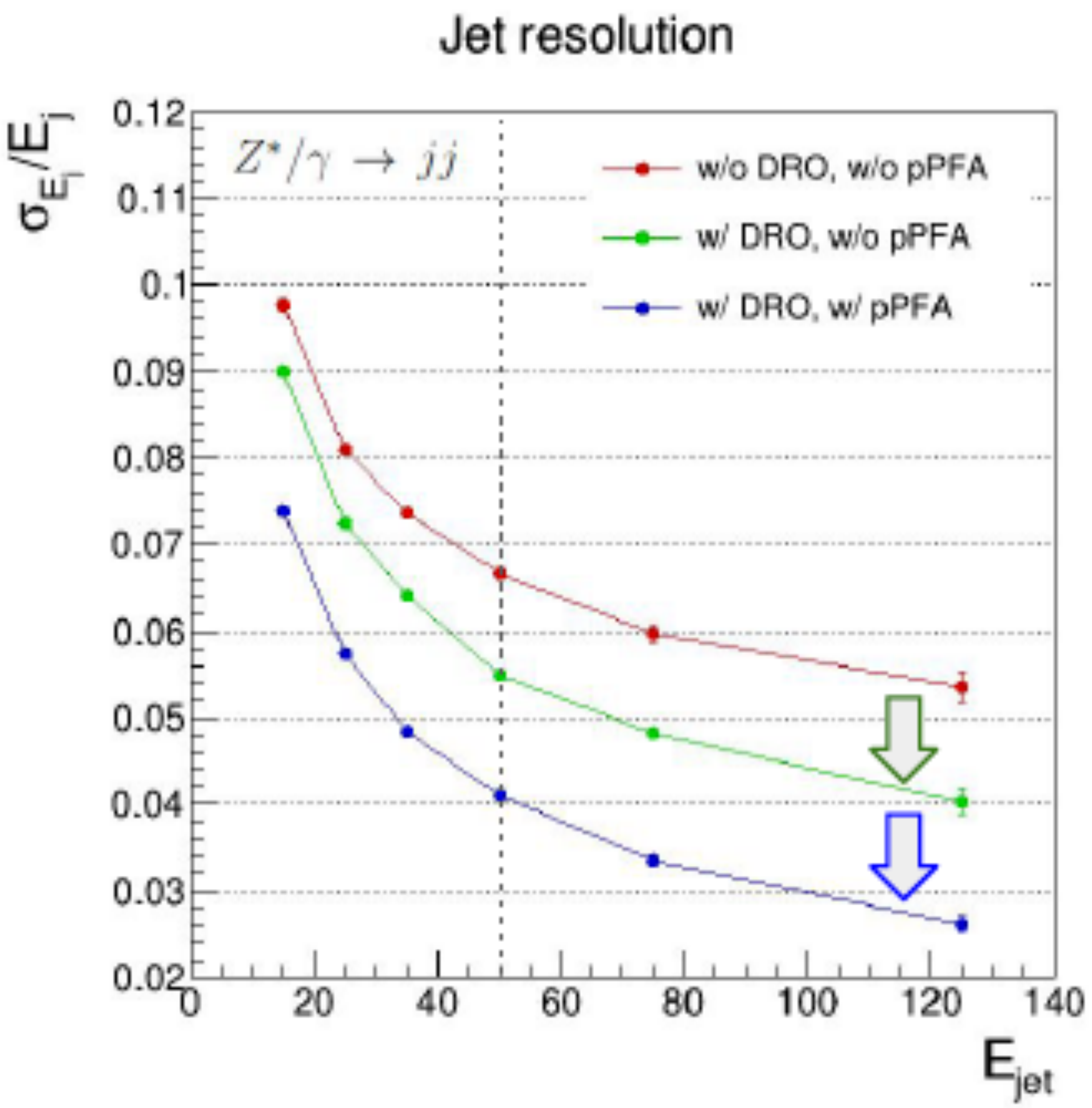
Crystal ECAL with DR calorimeter



Event display







crystals + IDEA w/o DRO

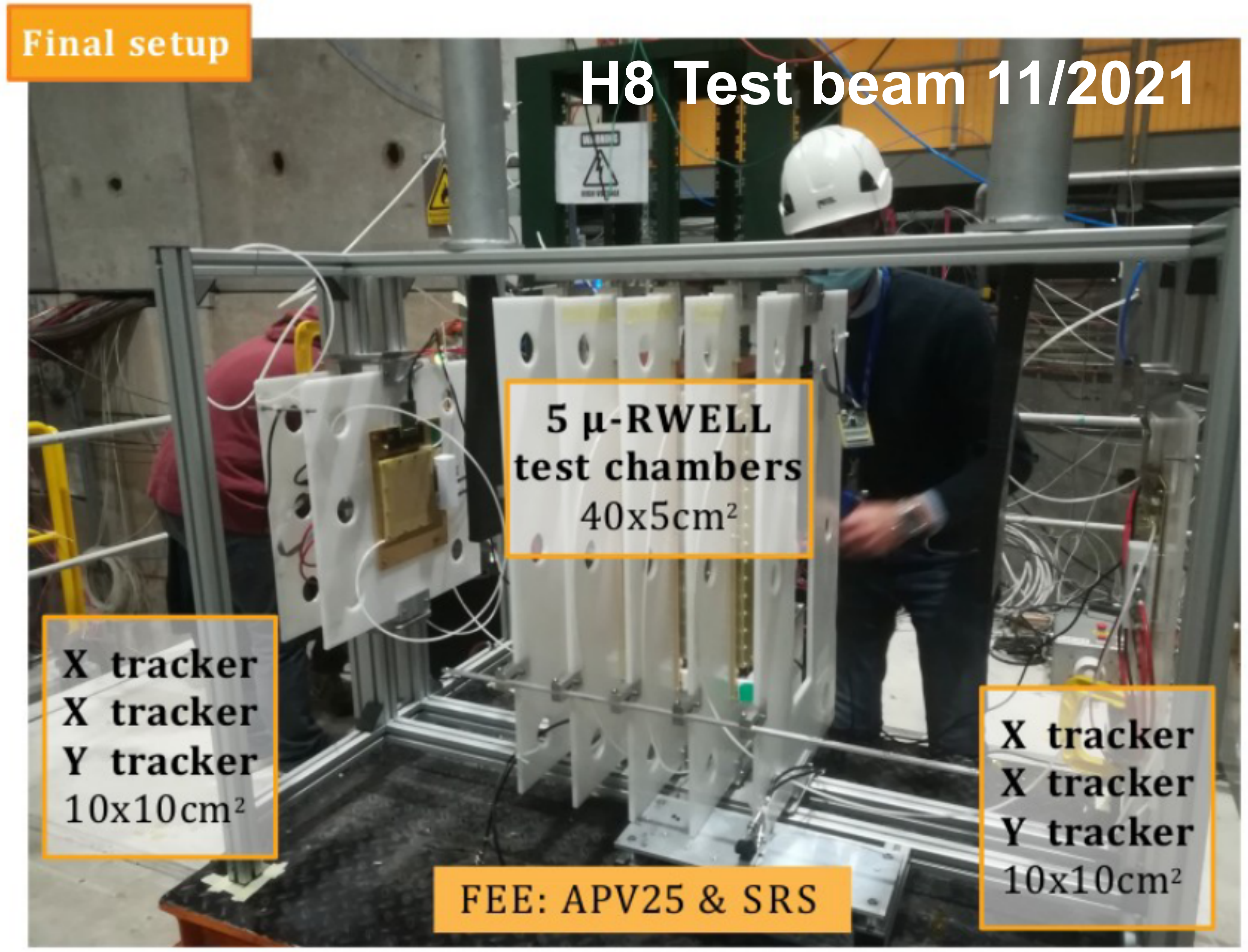
crystals + IDEA w/ DRO

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)

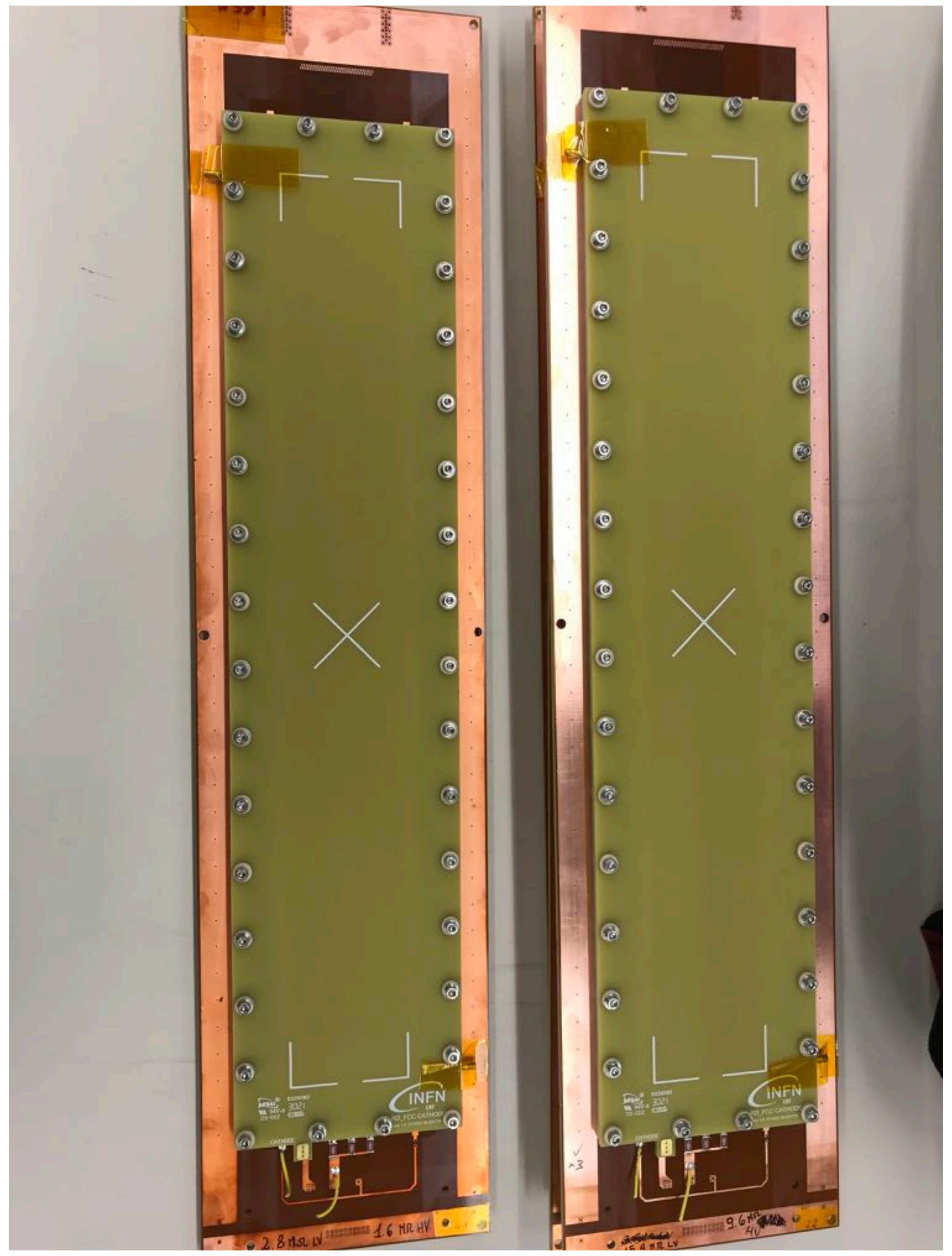
1- Signal shape
(cluster charge, cluster size)
2 - Detector performance
(efficiency, space resolution)

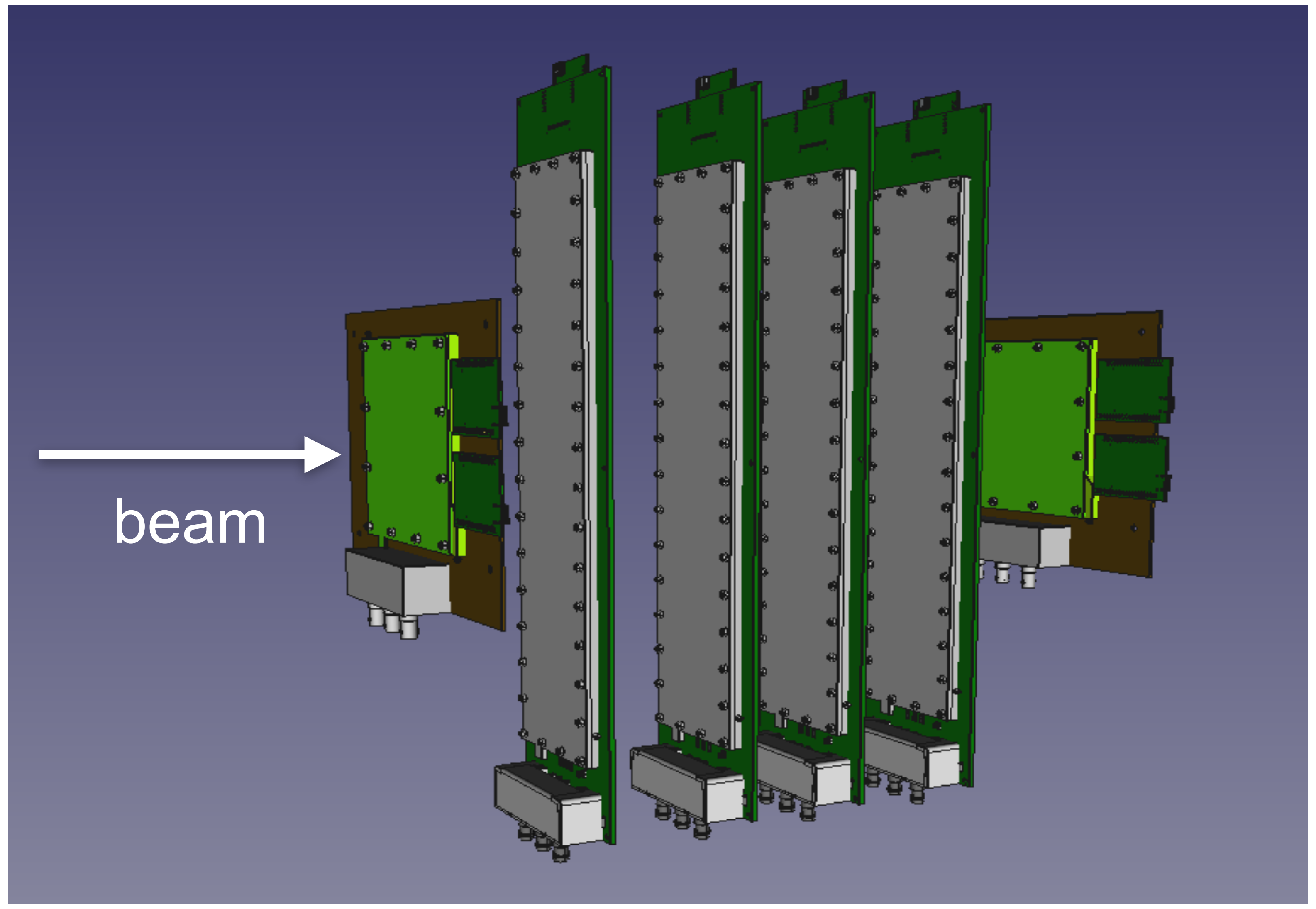
New μ-RWELL prototypes
with 40 cm long strips

a) Design optimization:
- different HV filter applied

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

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

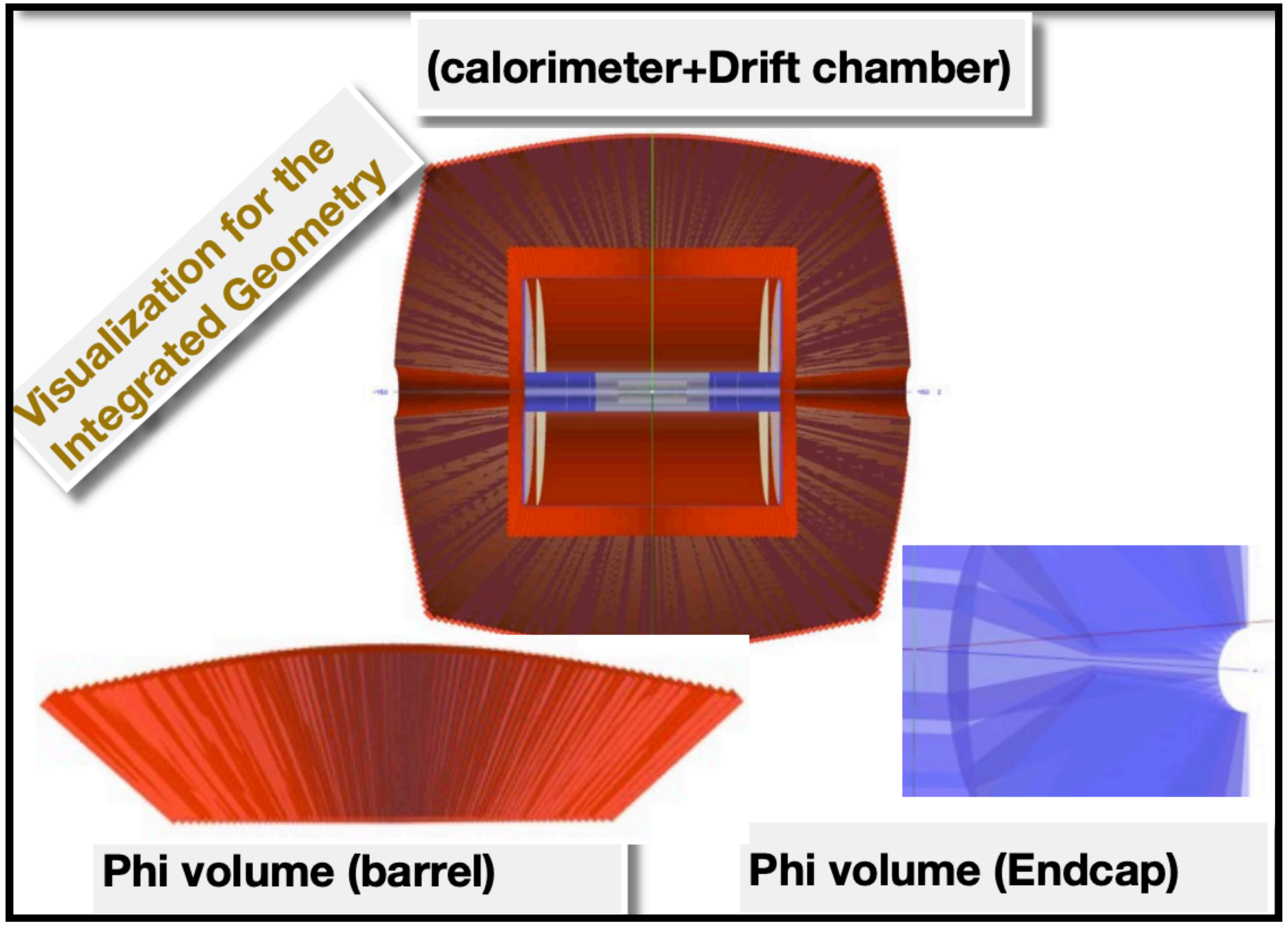
LNF
BOLOGNA
FERRARA
TORINO

Muon and pre-shower future plans

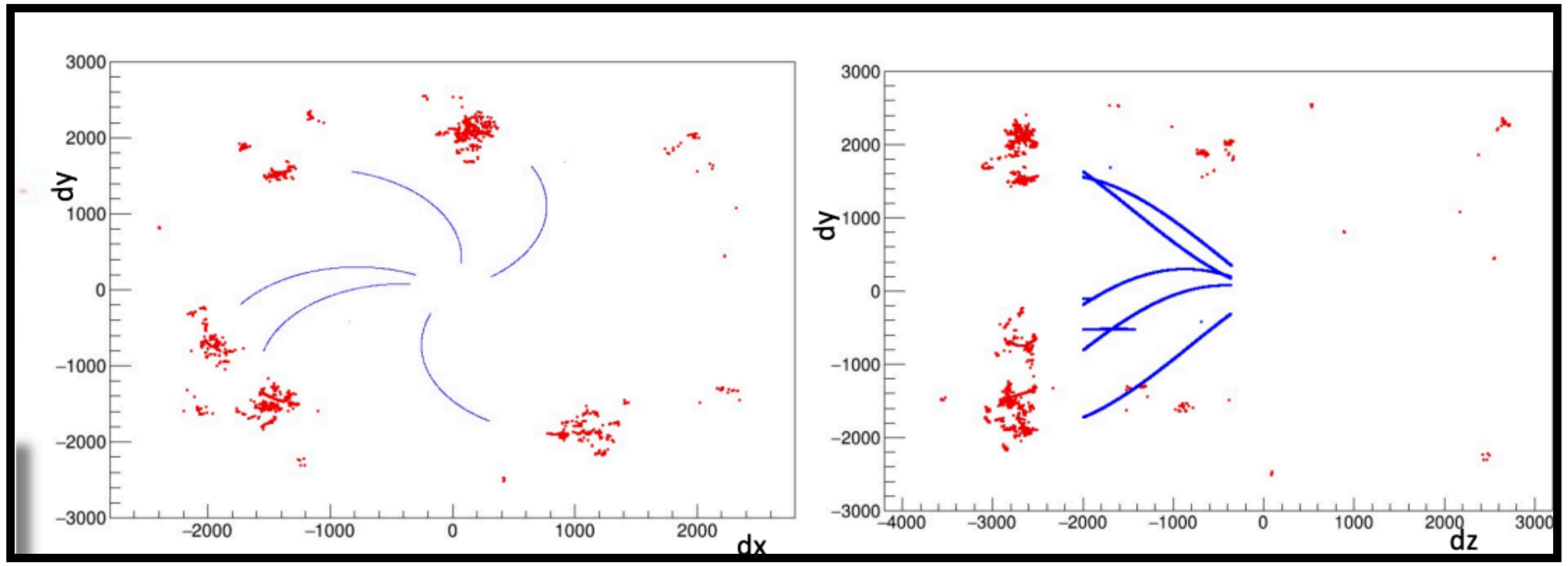
- Complete test of large 2D chamber design (50x50 cm^2) (this year)
- Complete readout electronics based on TIGER chip (next years)
- Develop chamber production plan with industry (few years)
- Develop plan for layout on detector with services (few years)

- 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.) ...
      - There are already collaborations FNAL/Padova on ARCADia and CalVision on DR calorimetry

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      - EURO-LABS allows up to 20% of its funding to go to non-EU research groups
    - We have excellent connections with AIDAinnova and EURO-LABS (P.G. is the PI of both projects...)

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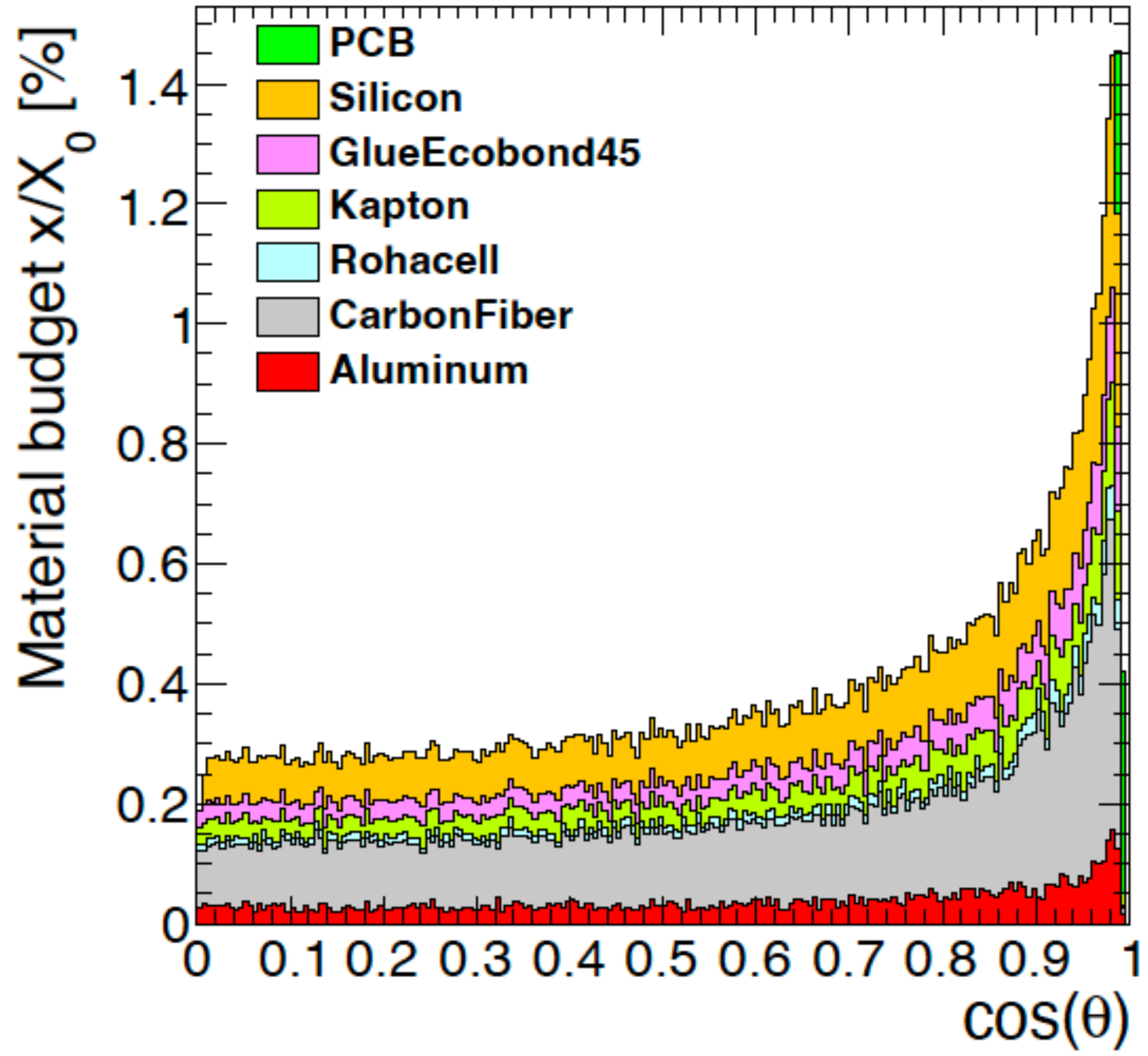
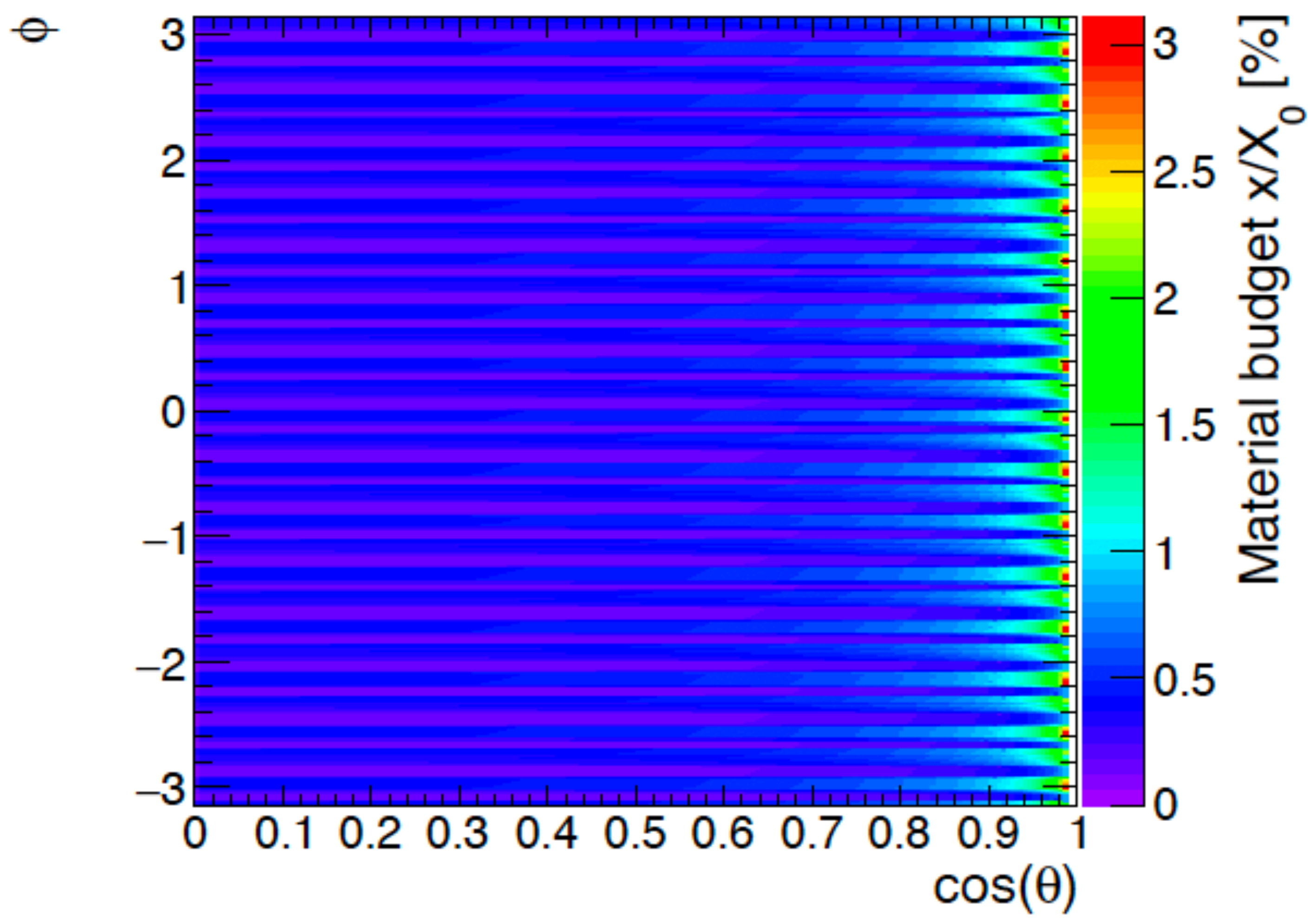
  - Now several international colleagues have joined these efforts
- Lots of possibilities for US colleagues to join IDEA and help on all these developments!!

Backup

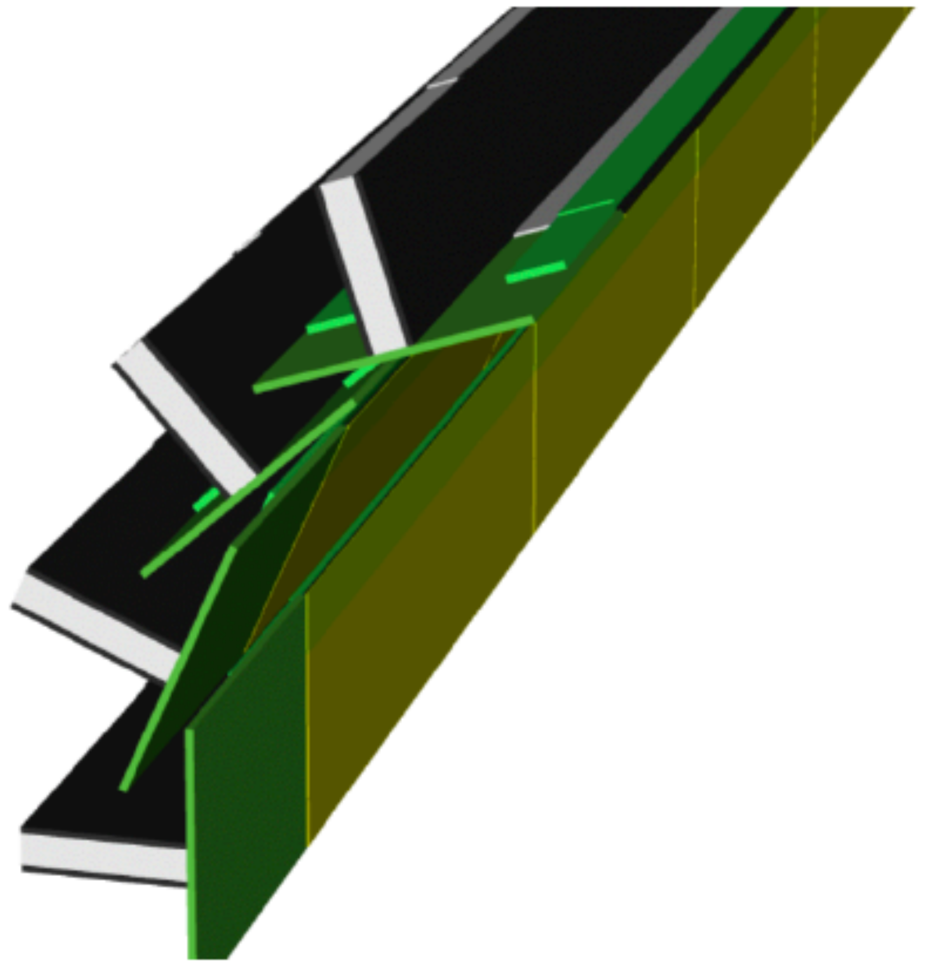
Vertex inner barrel

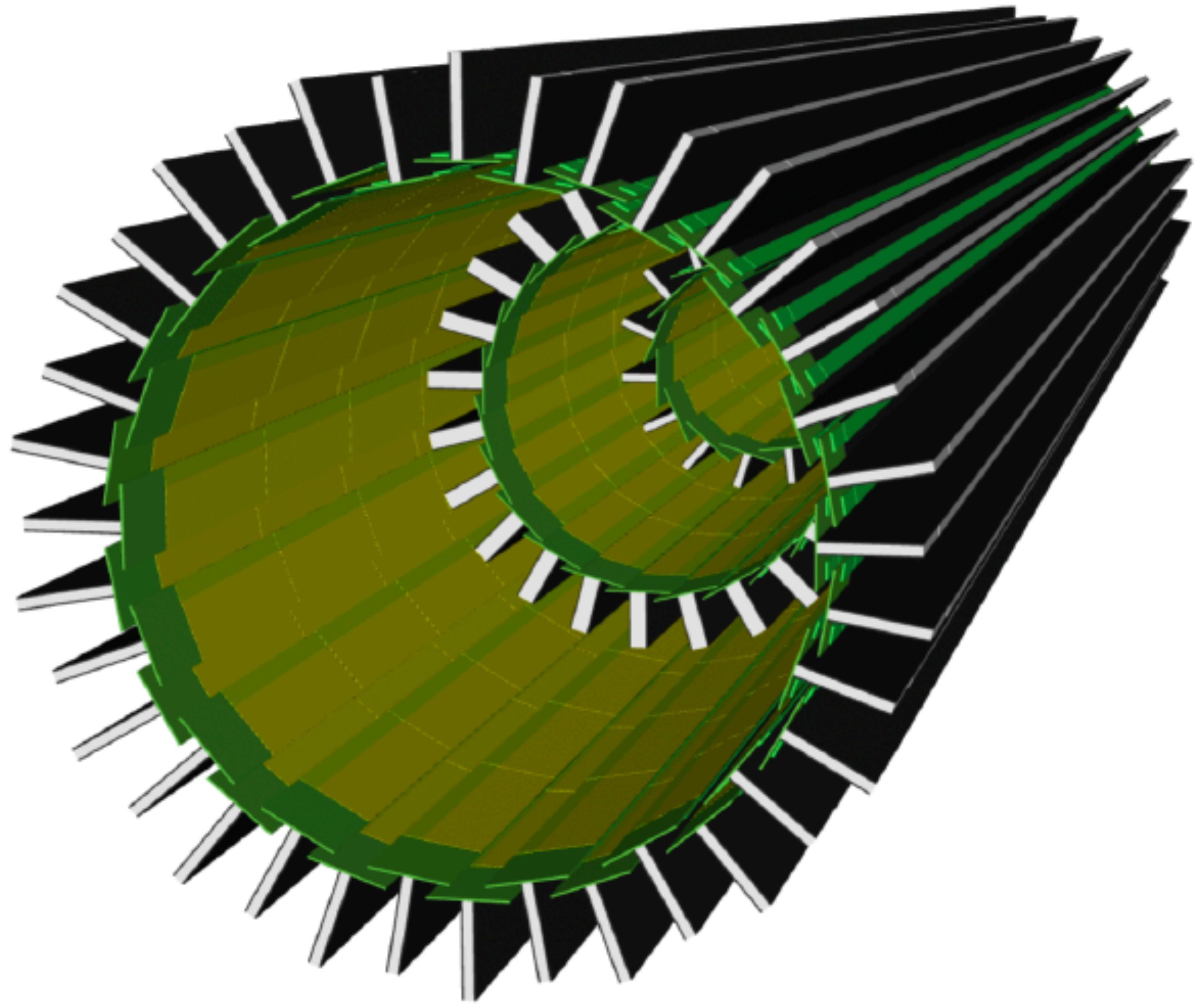
- Correct material stack, end-of-stave hybrid, insensitive sensor areas, ...
- Inner vertex support imported through DDCAD, but not included in material budget estimation
- Cooling cones not implemented yet, but outside of vertex acceptance
- Material budget in line with 0.3% per layer at $\cos(\theta) = 0$ (CDR assumption)





Layer 0, others in backup



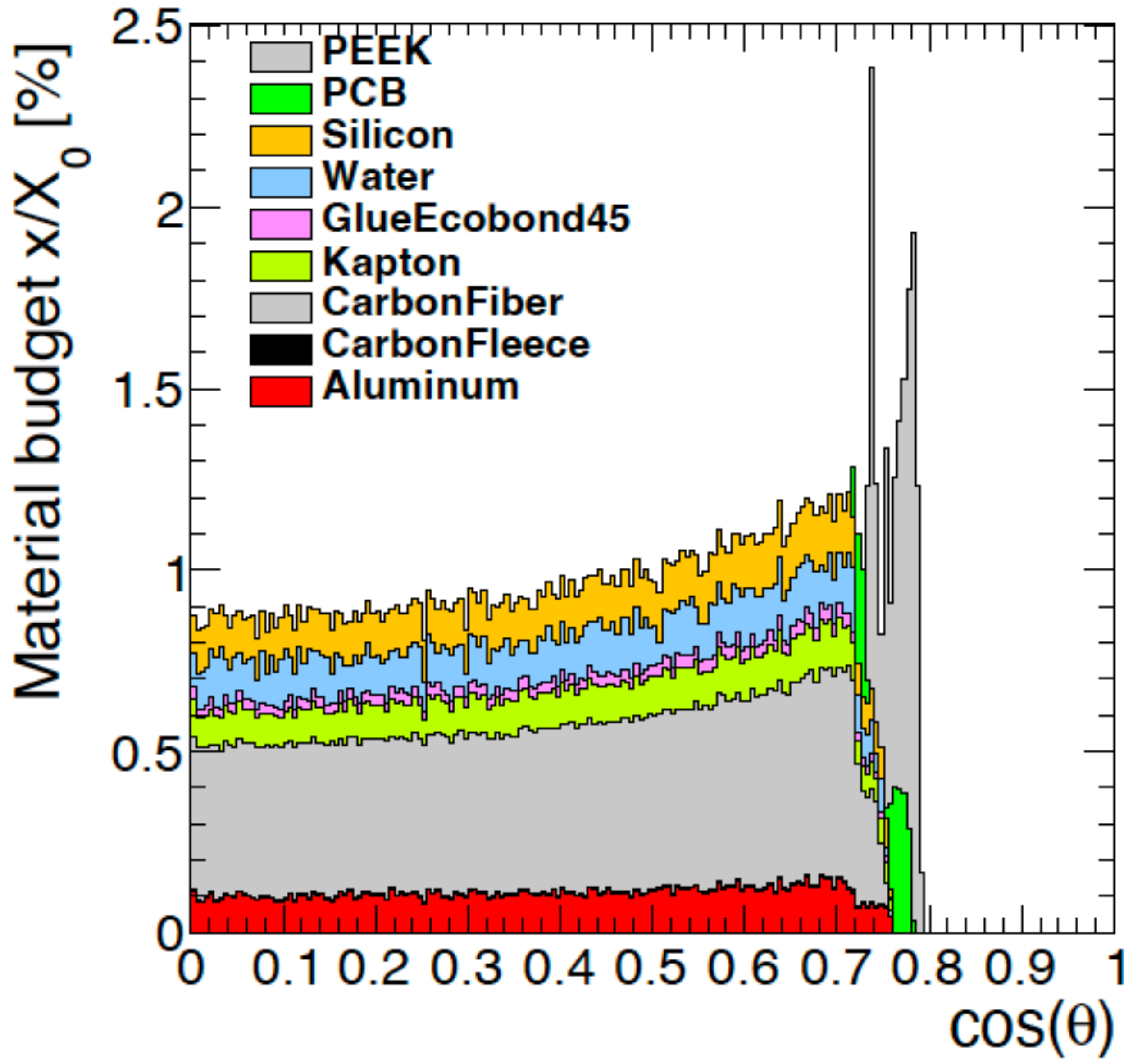


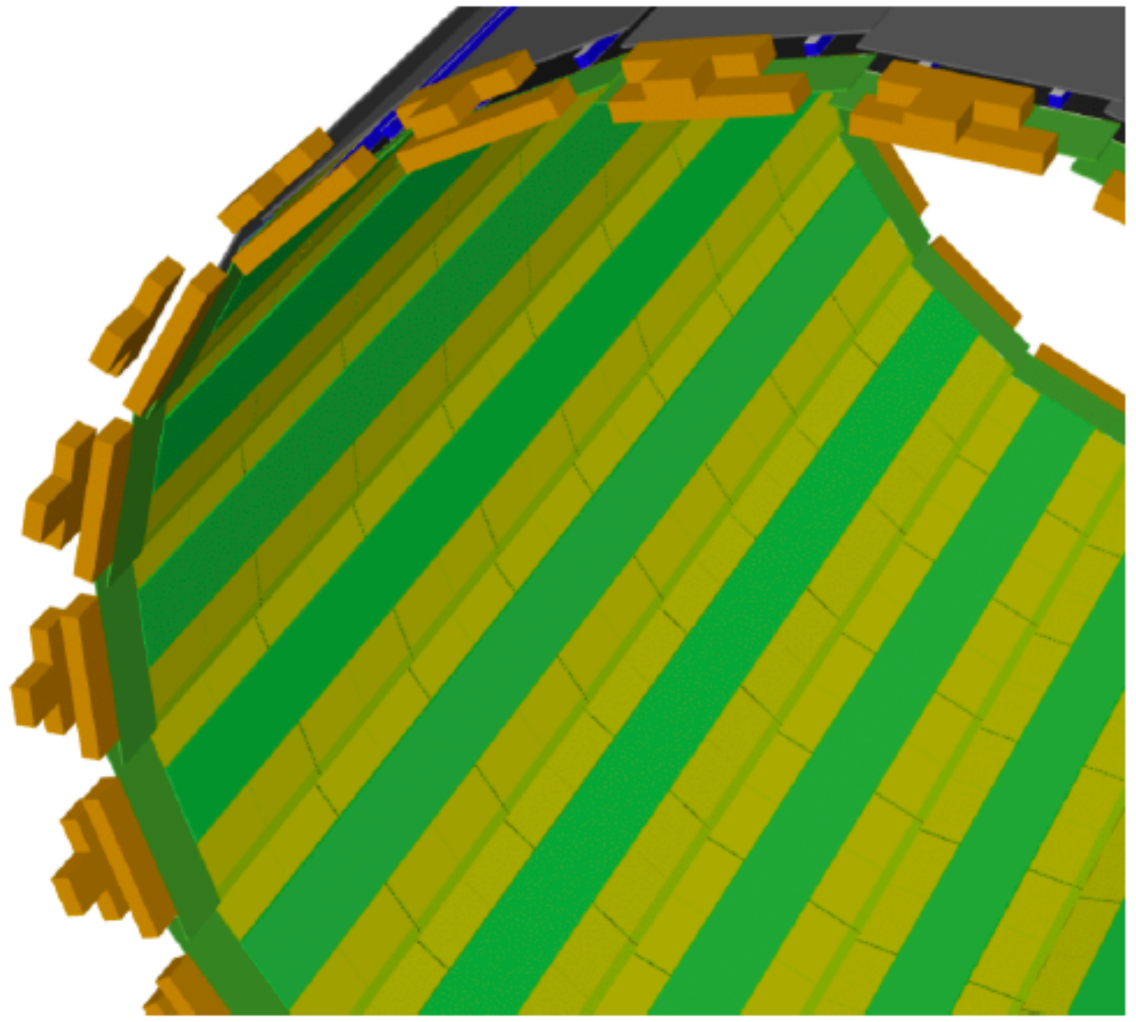
Vertex inner barrel, without support

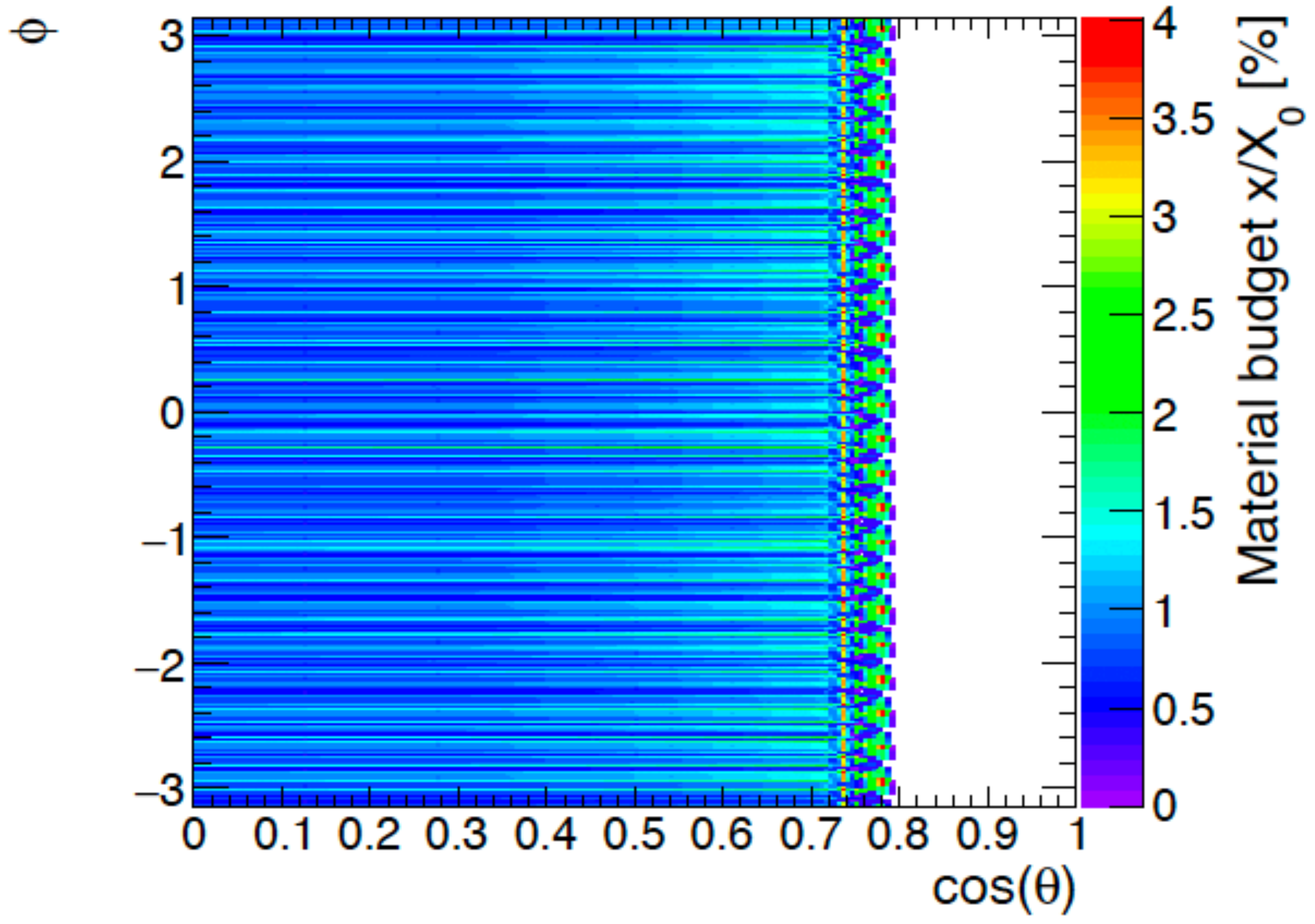
A. Ilg

Vertex outer barrel

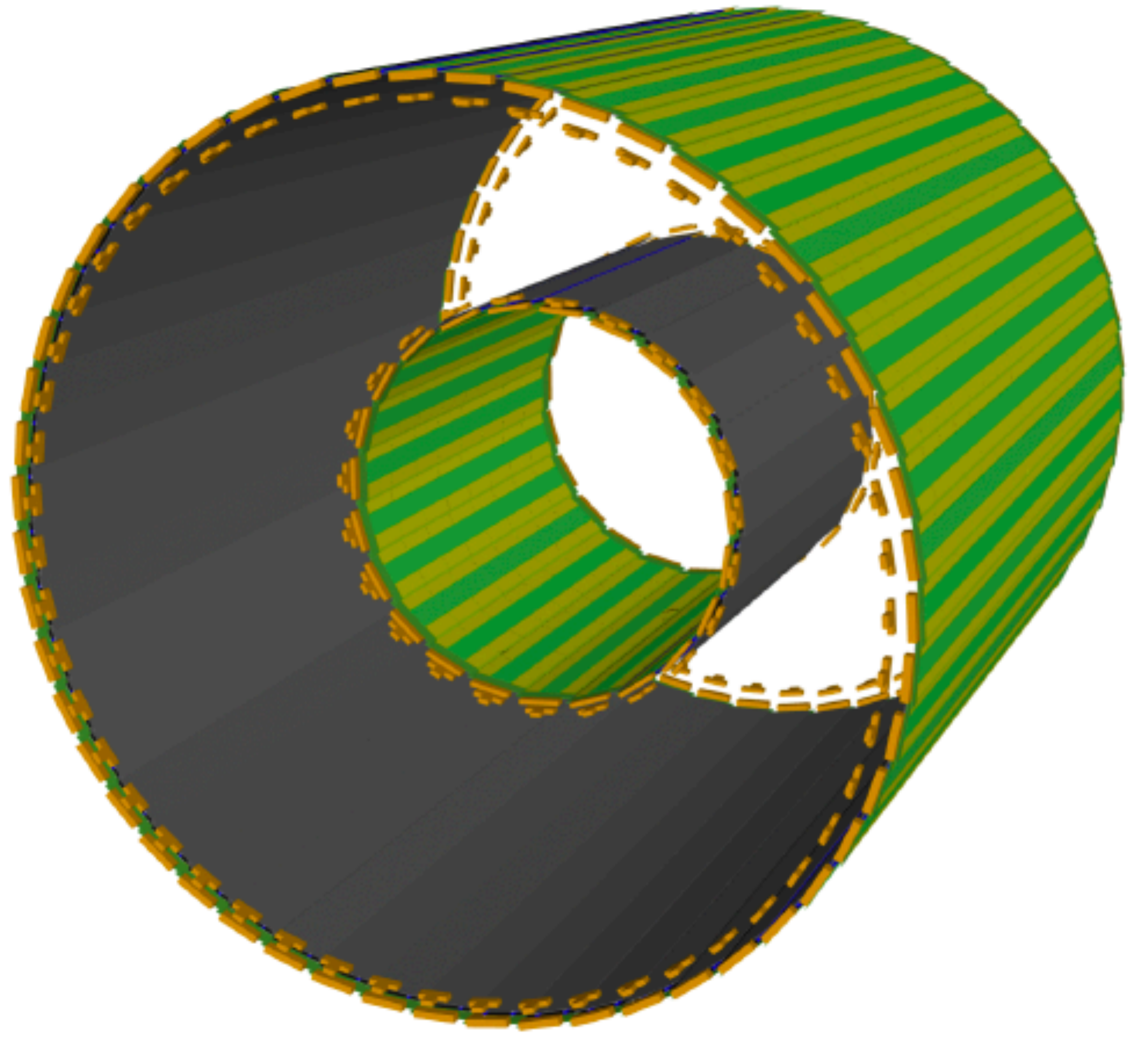
- Proxy volumes for truss structure and cooling pipes
- Proxy volume for end-of-stave holder (material budget contribution optimised with F. Palla)
- Still significant contribution from PEEK stave holder




Middle tracker



Complete outer barrel


Complete vertex outer barrel system

A. Ilg