
# The IDEA detector concept

Paolo Giacomelli
INFN Bologna

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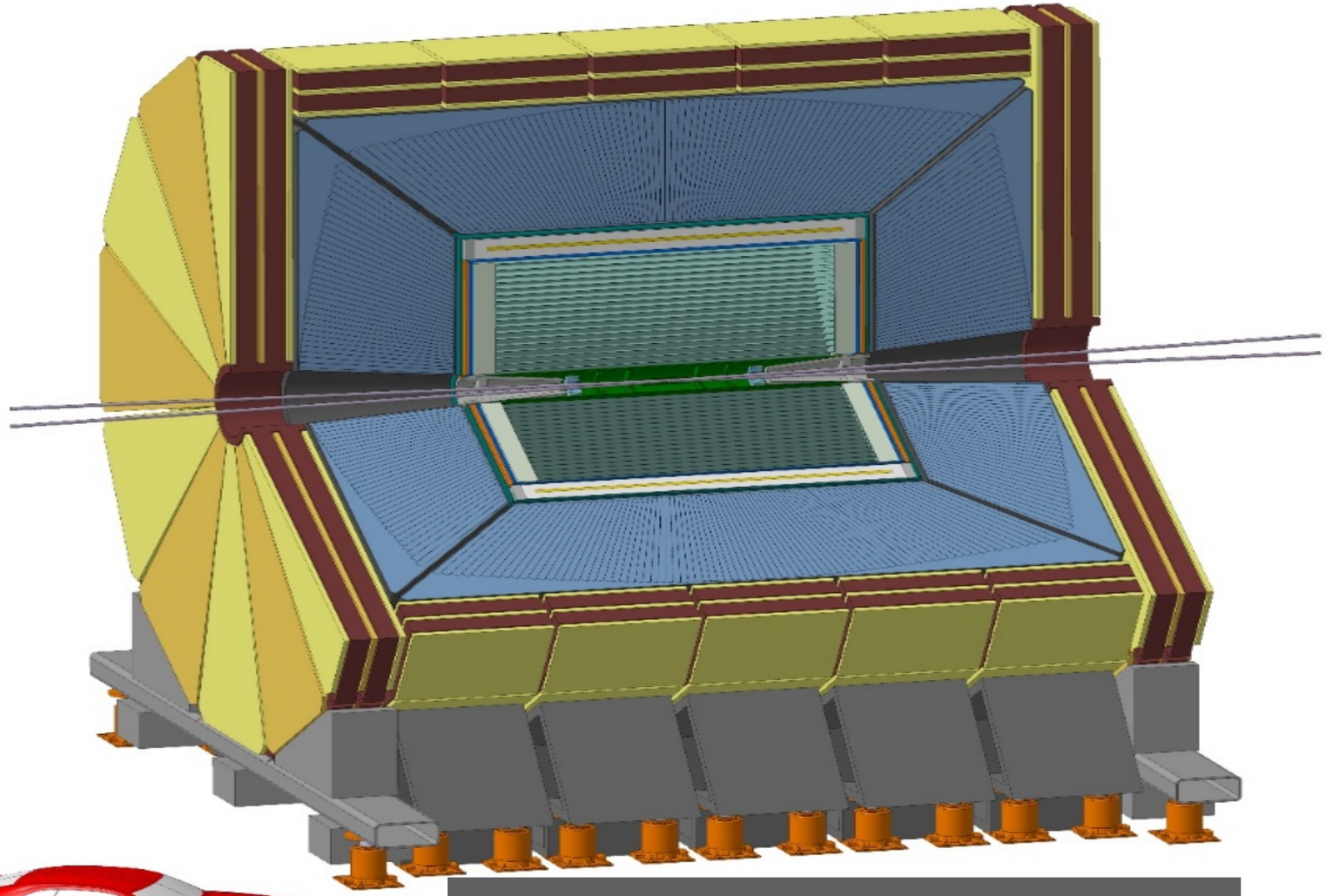

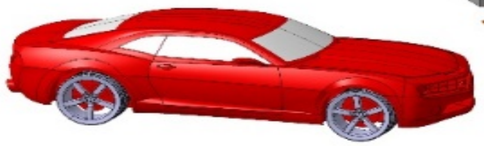

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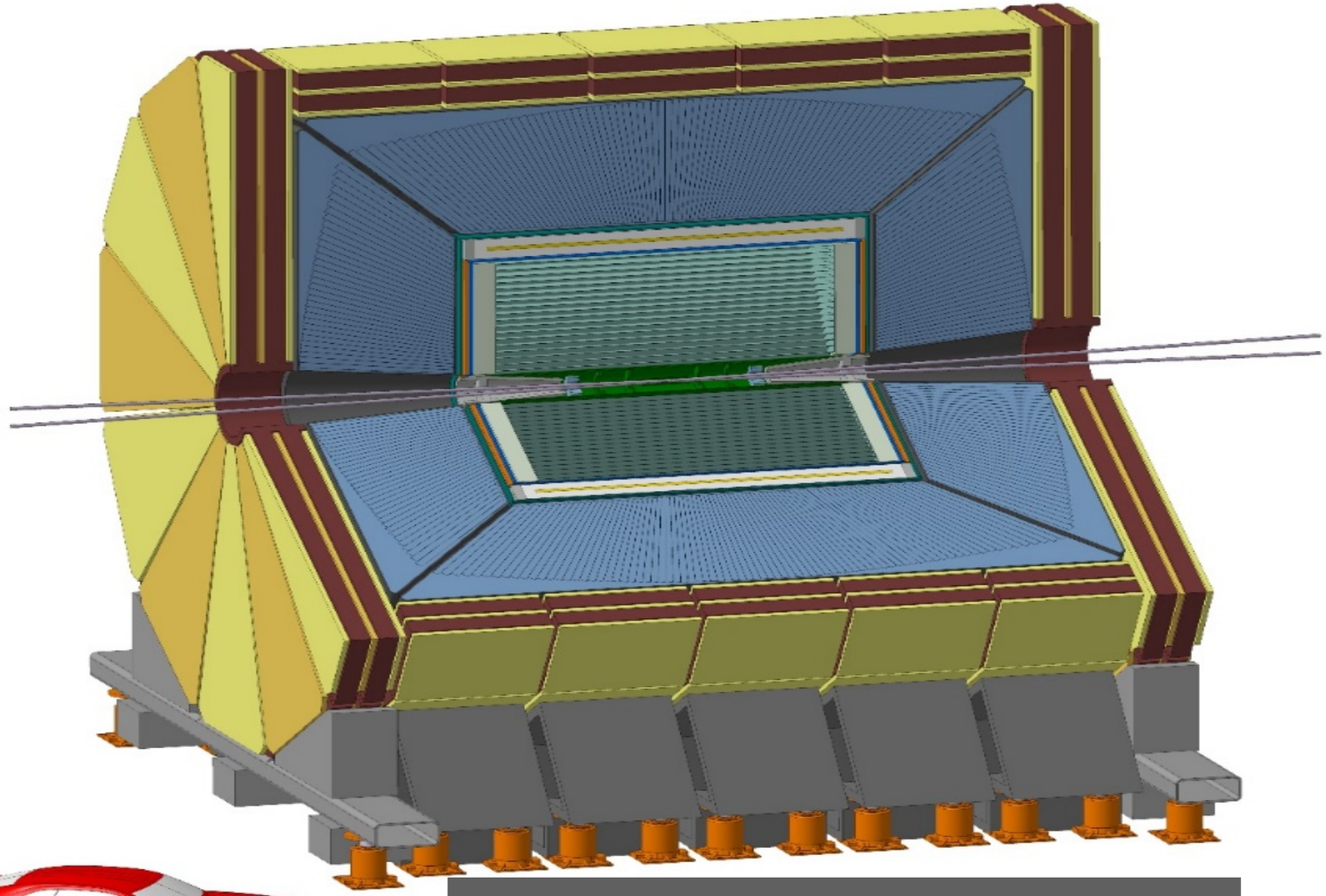

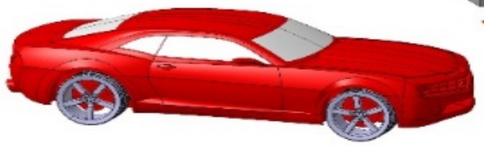

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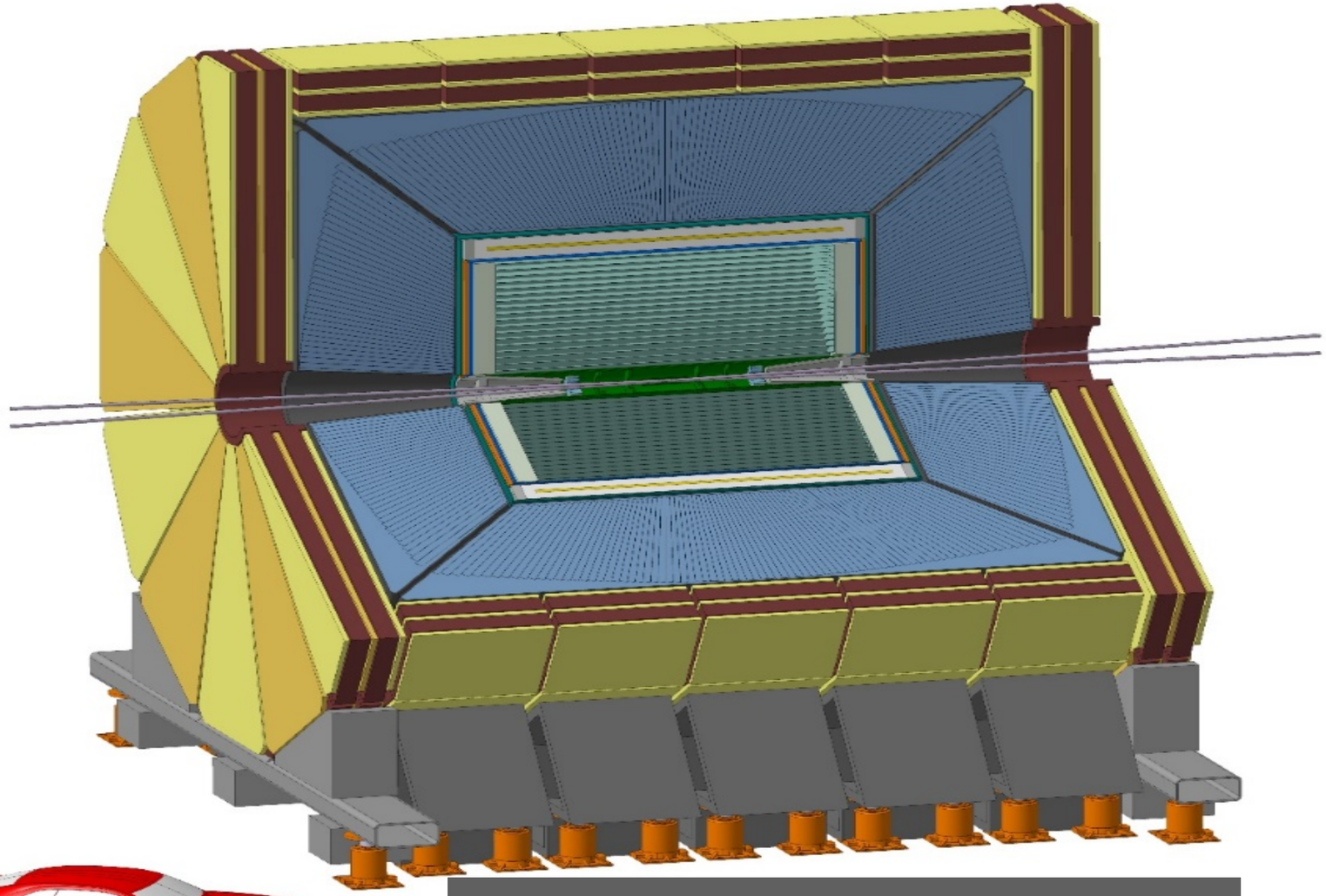

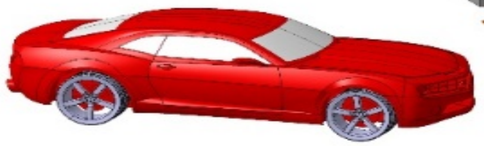

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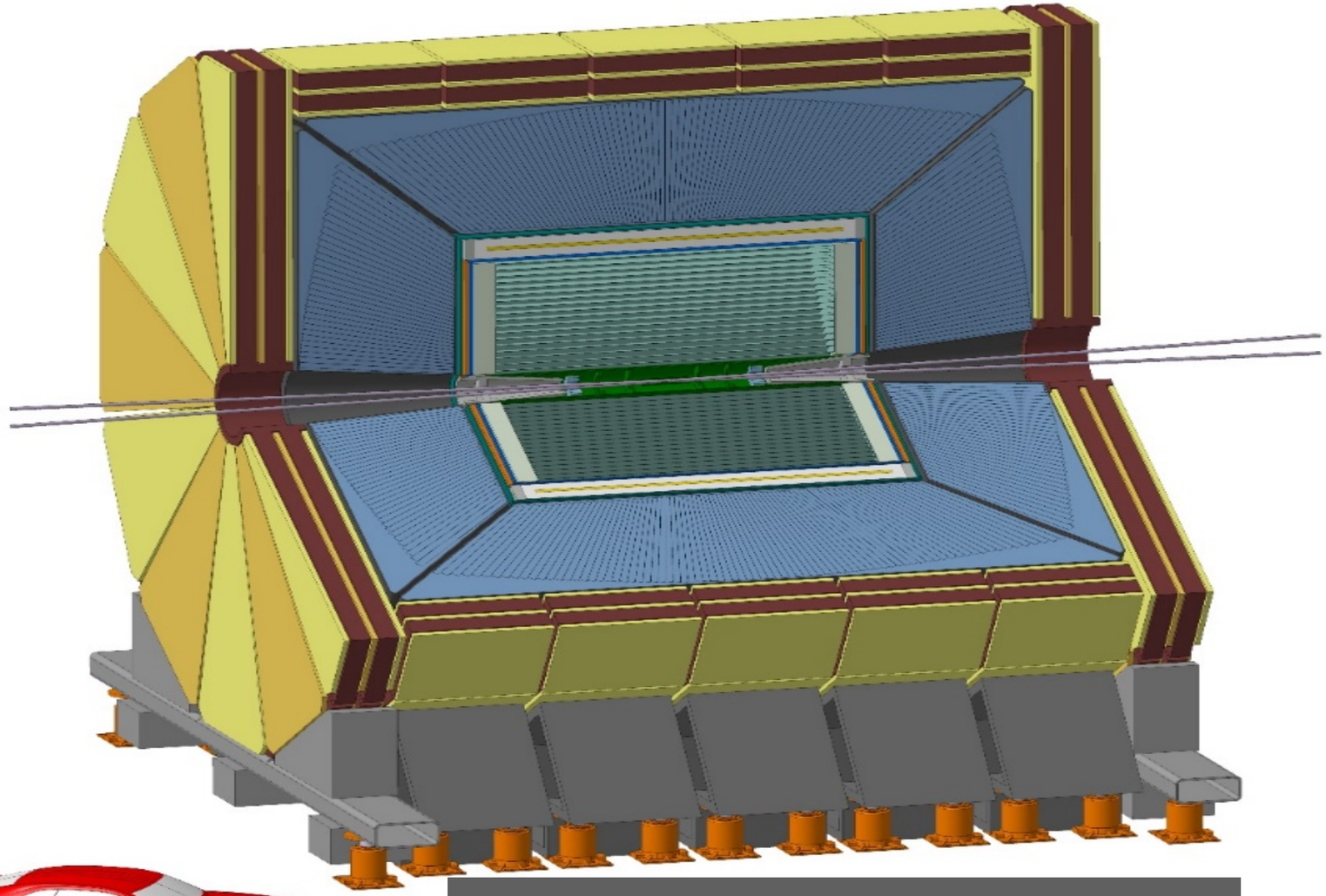

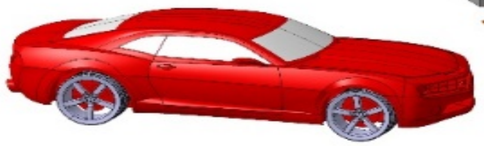

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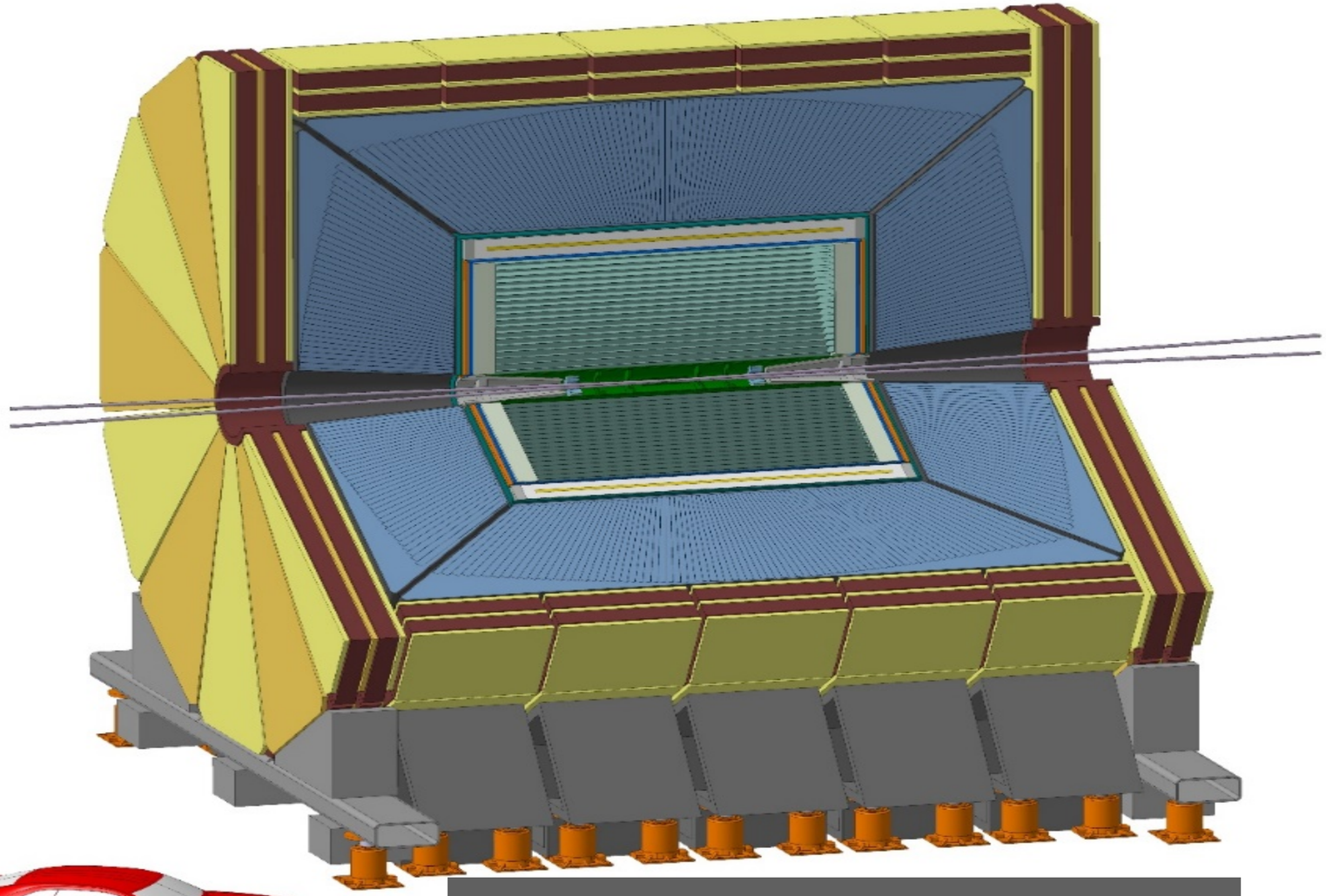

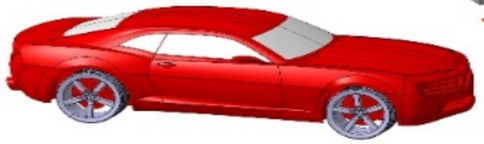

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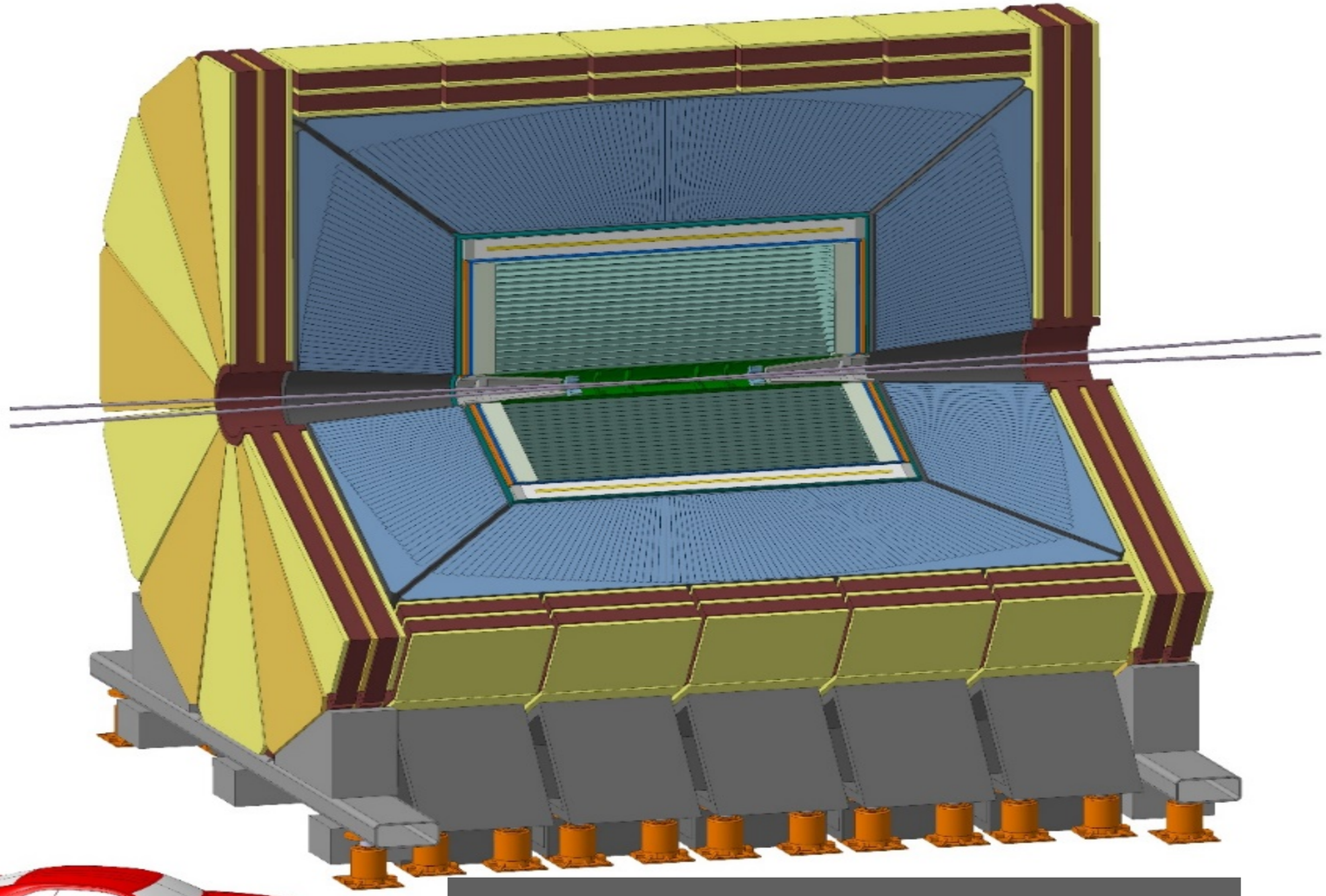

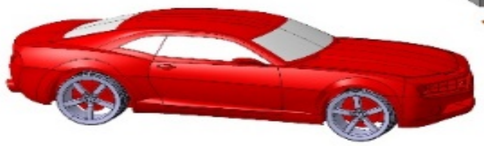

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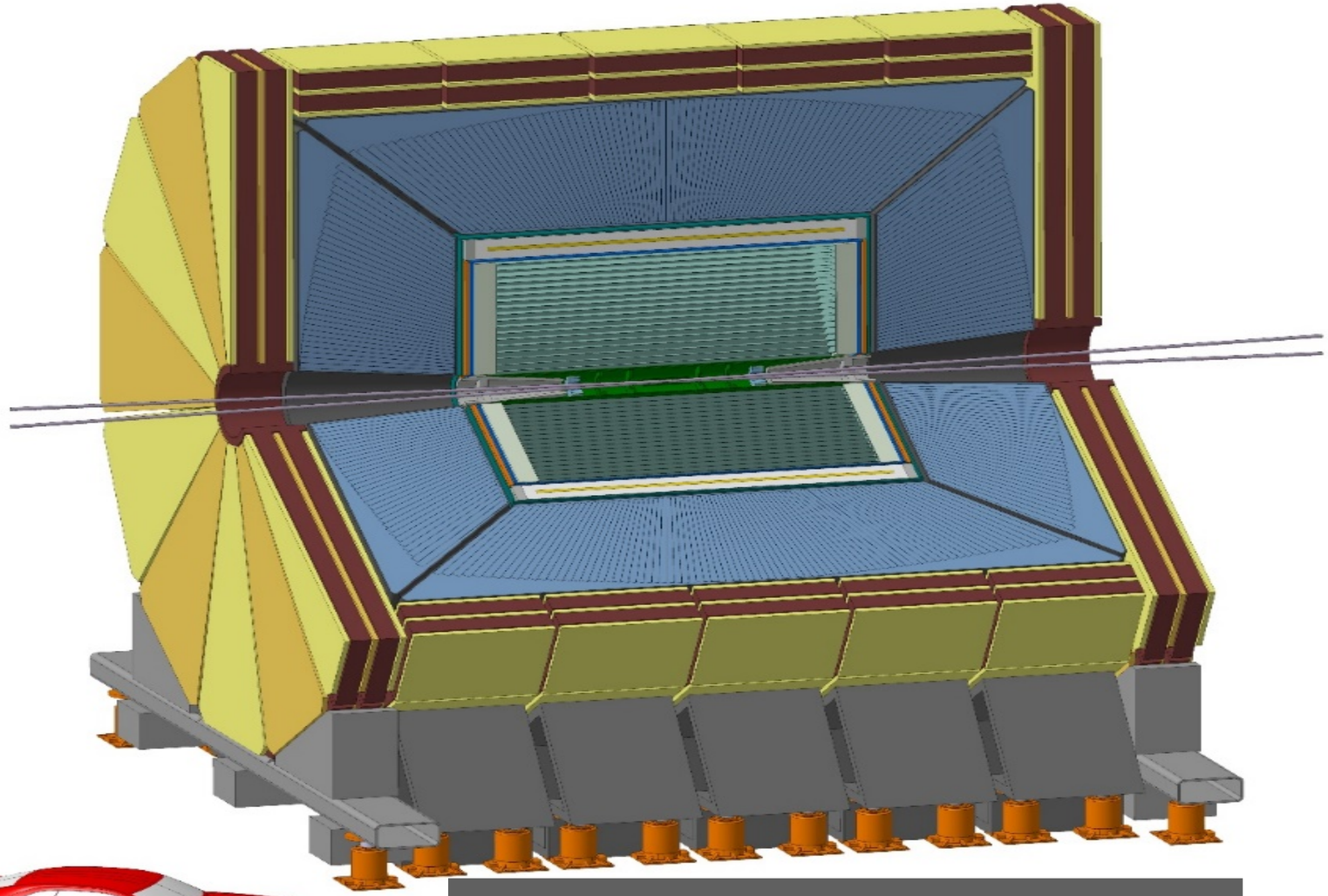

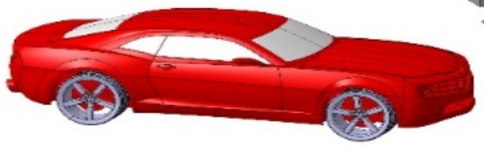

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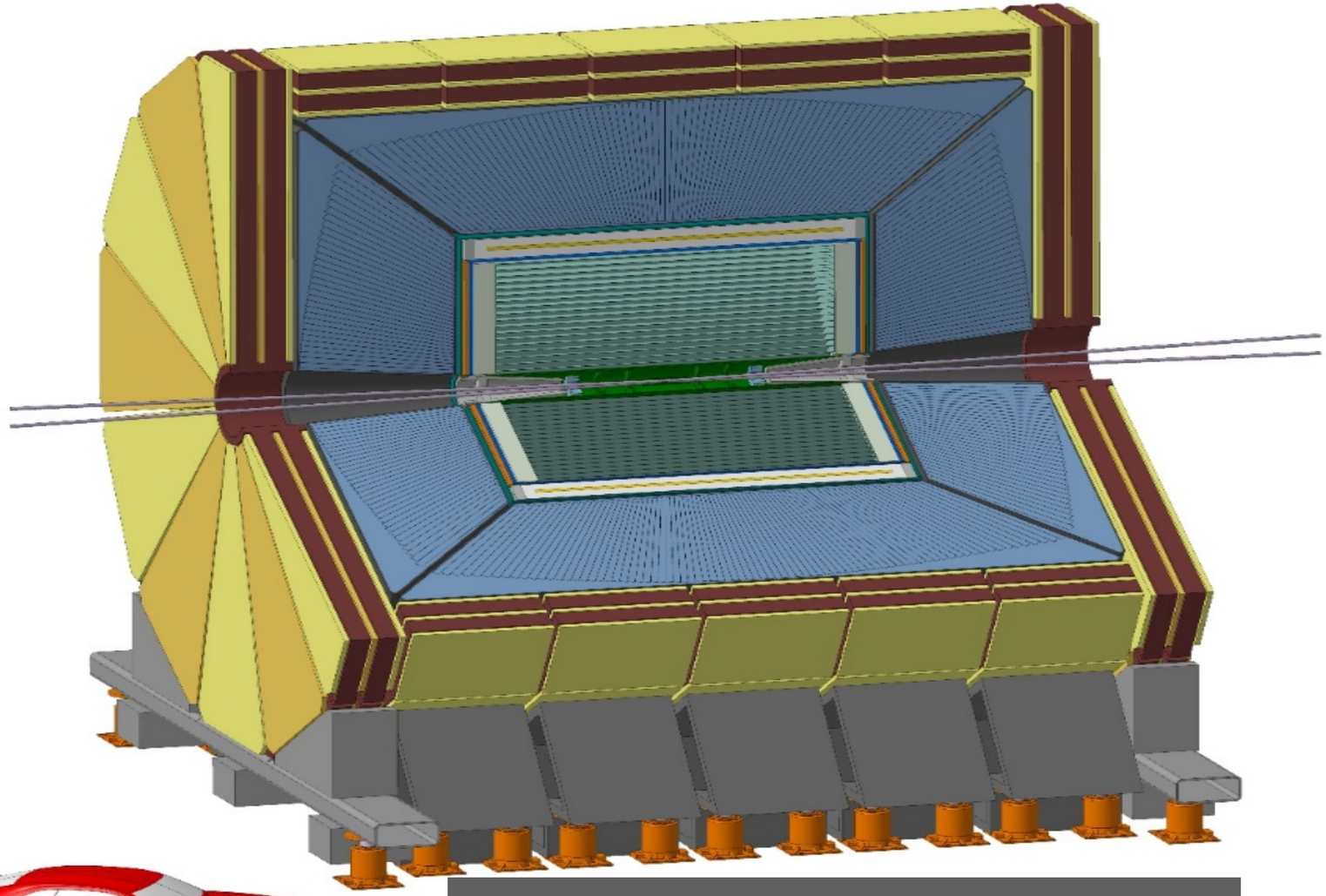

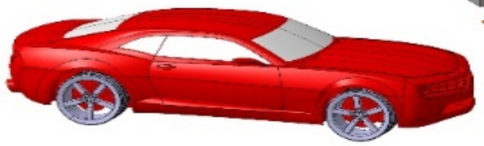

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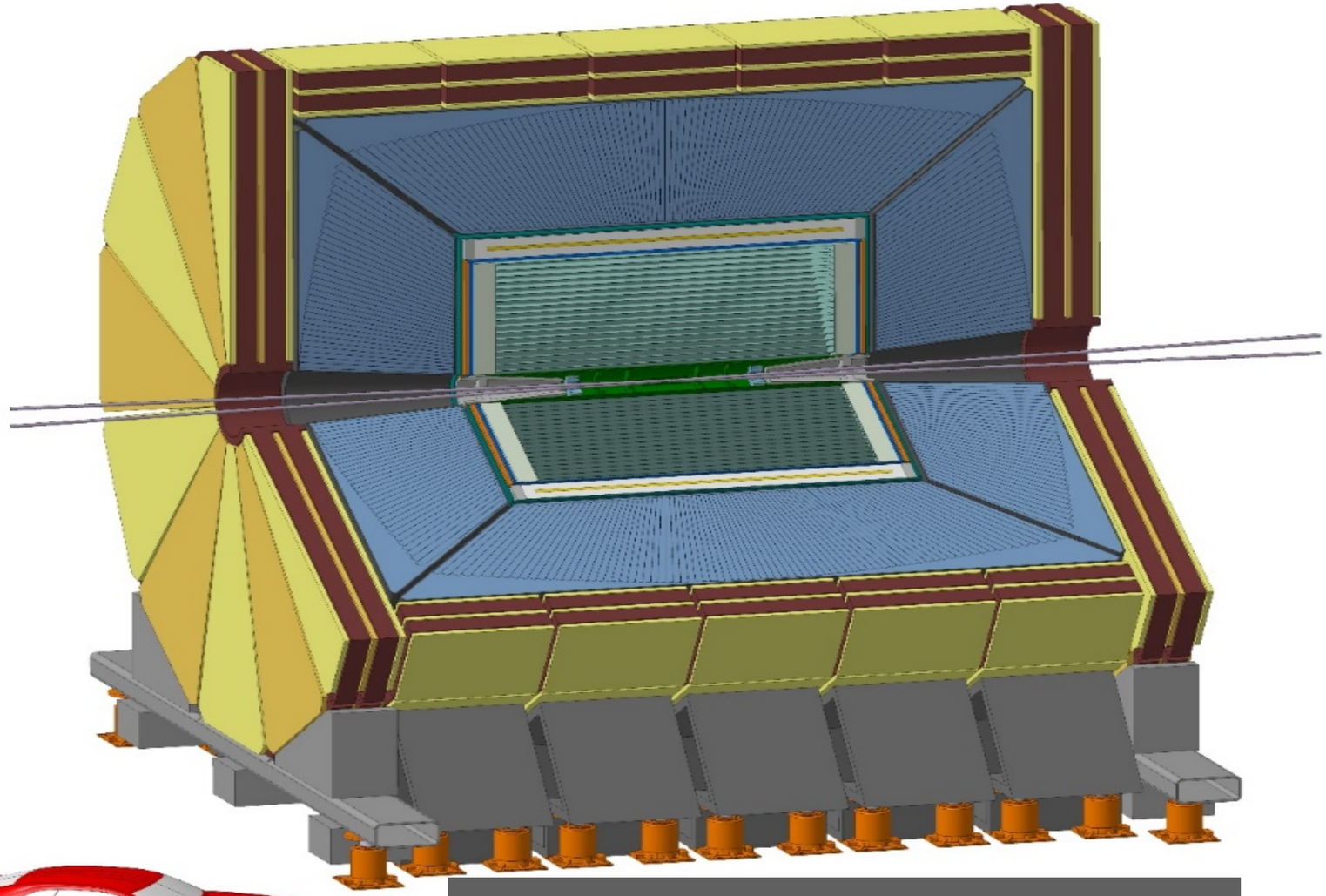

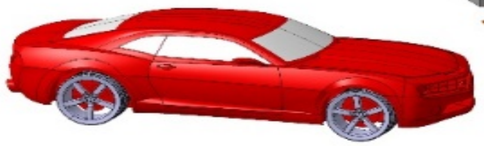

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https://pos.sissa.it/390/

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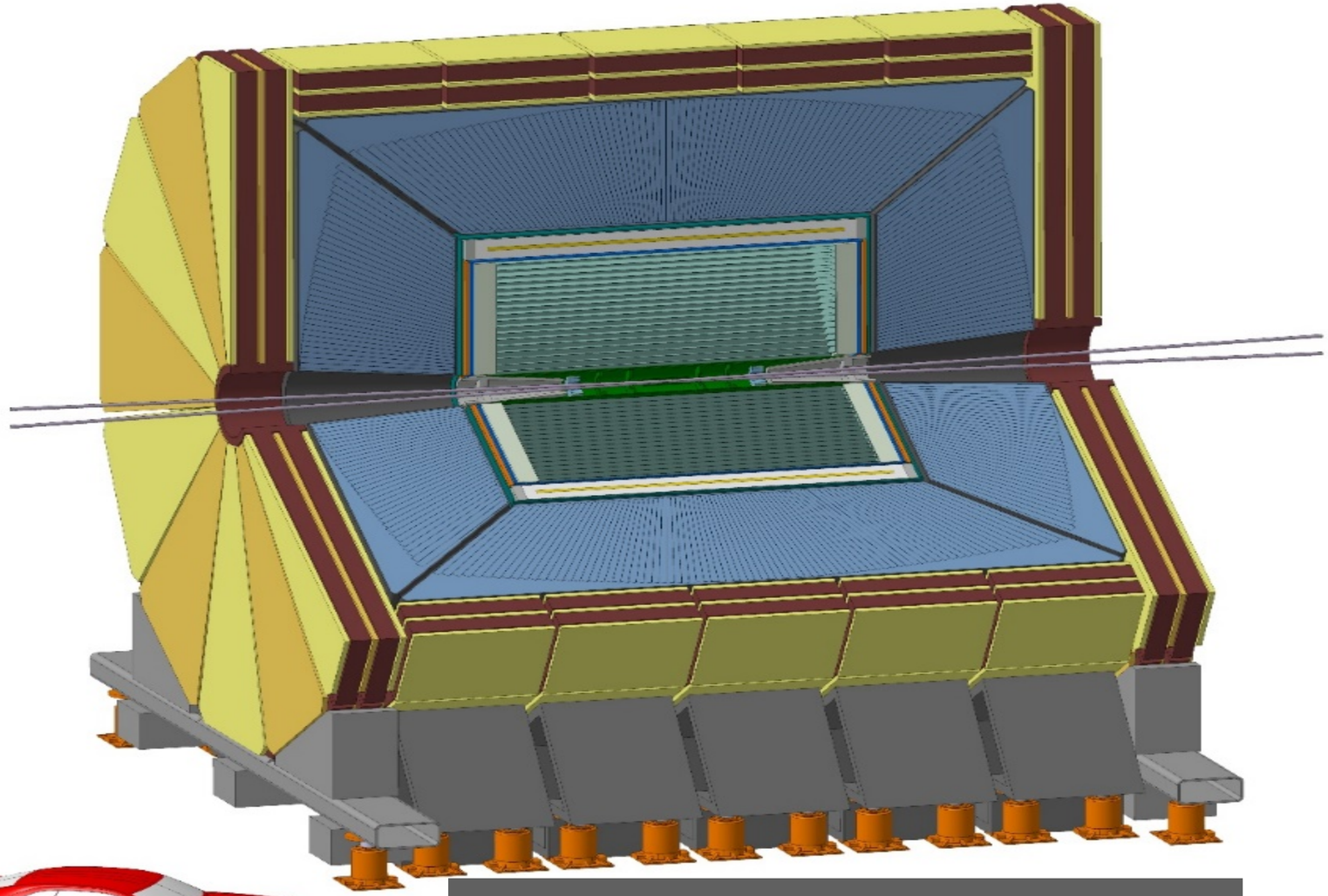

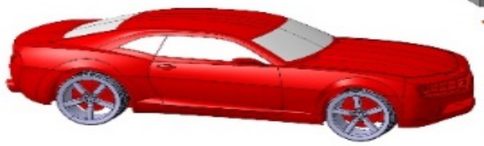

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**Acknowledgments**
I need to thank many colleagues, in particular:
F. Bedeschi

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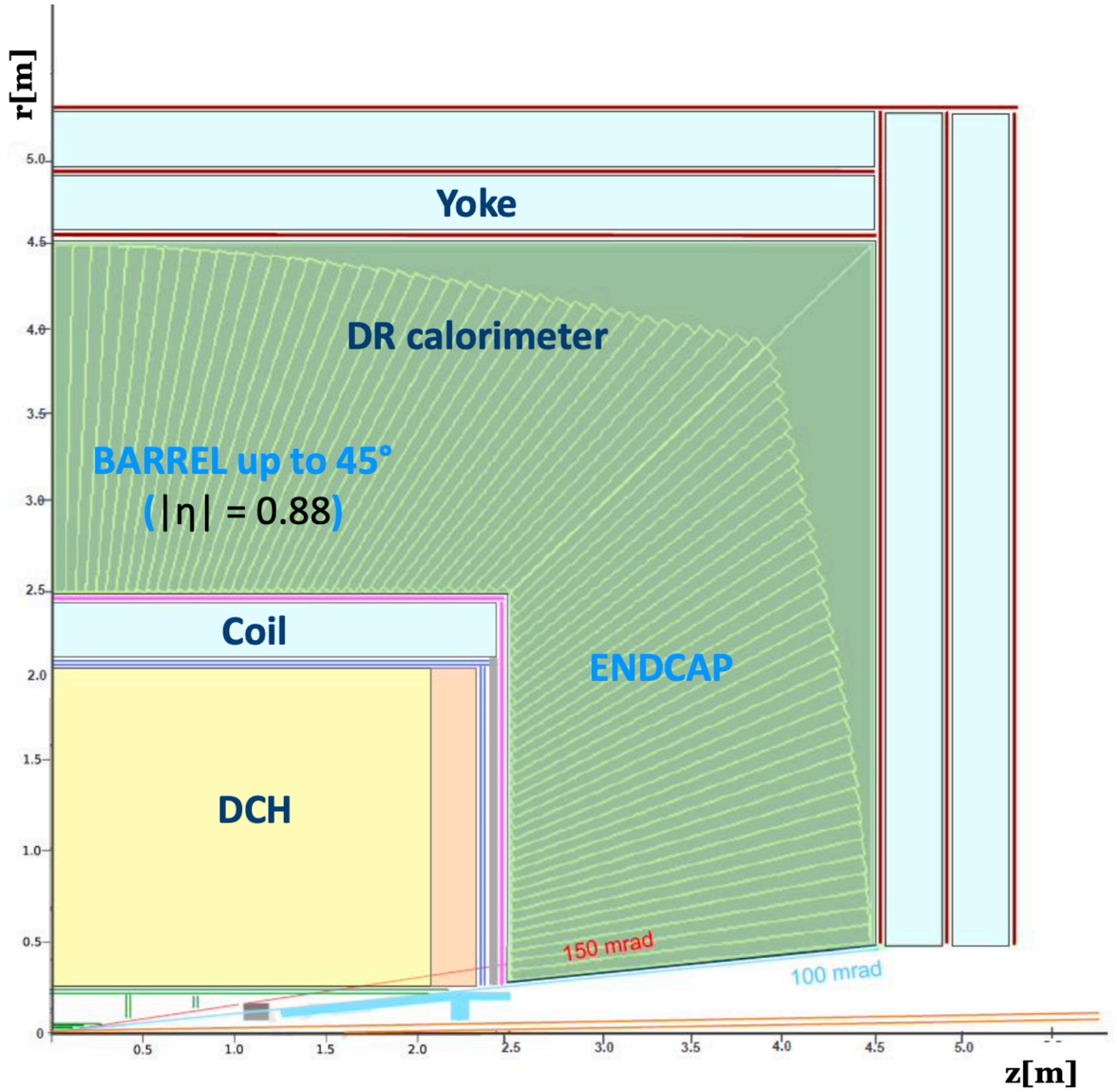

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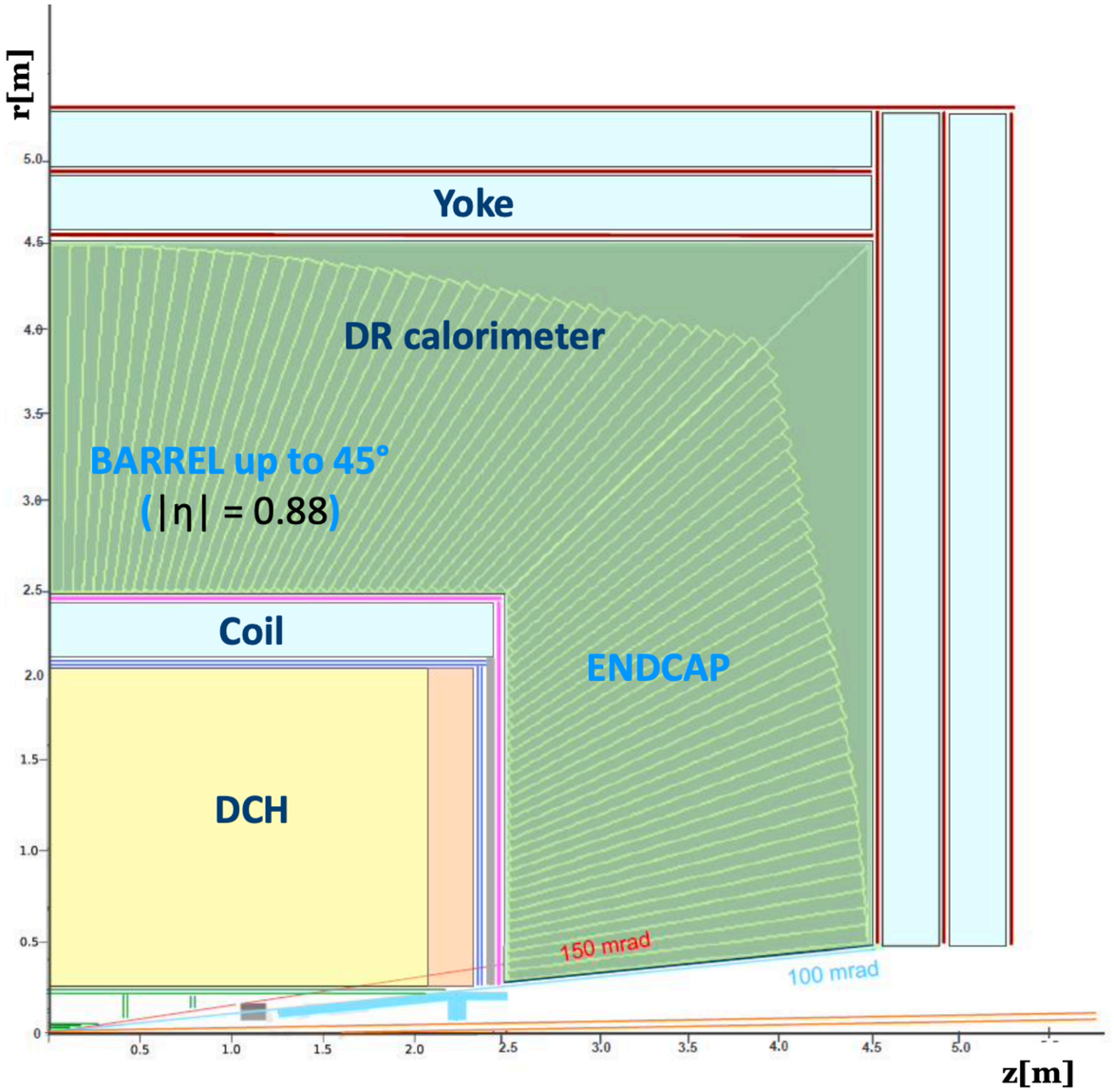
**Beam pipe**: R~1.0 cm



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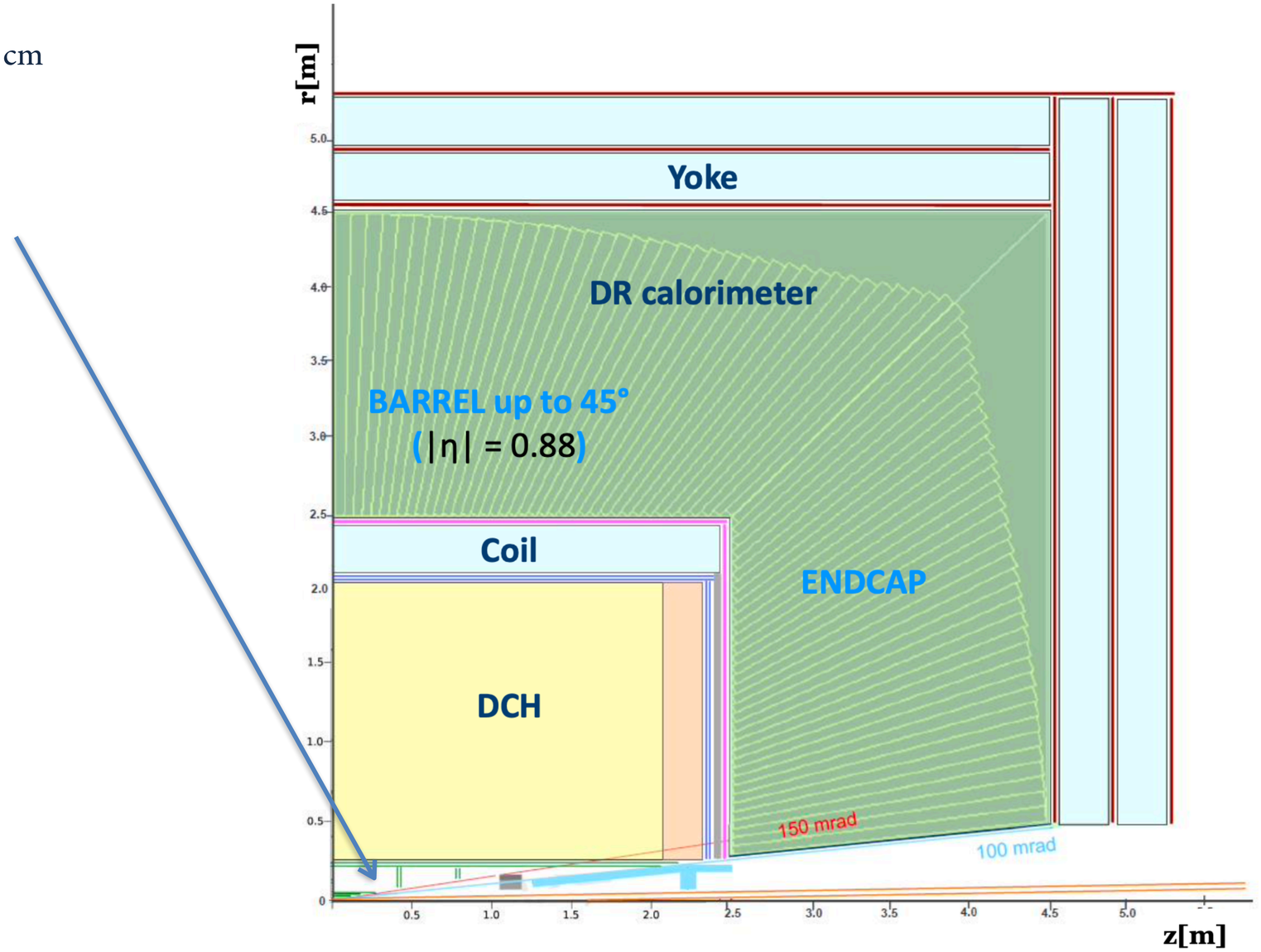
5 MAPS layers

R = 1.37-31.5 cm



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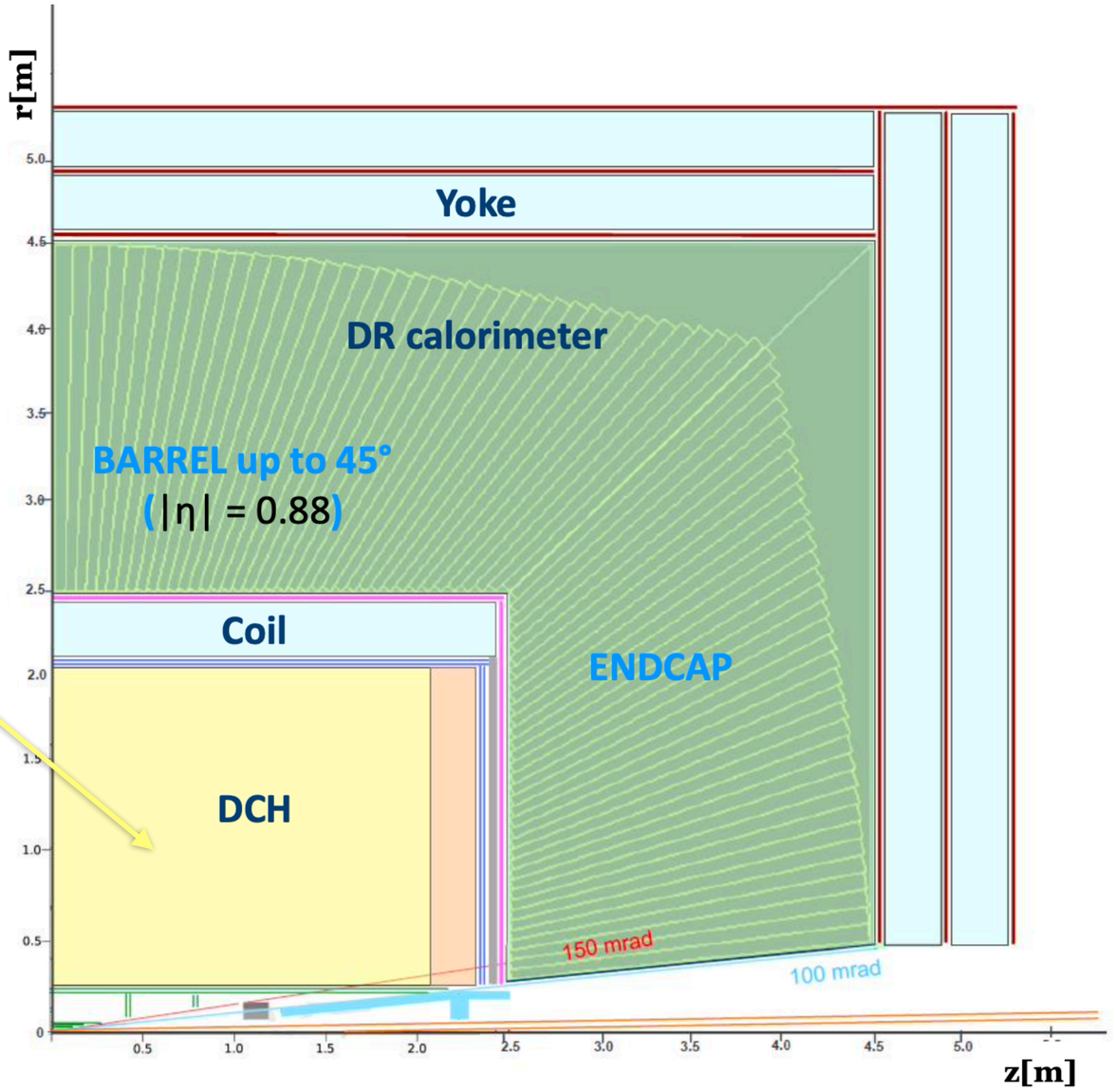
**Drift Chamber**: 112 layers

4 m long, R = 35-200 cm



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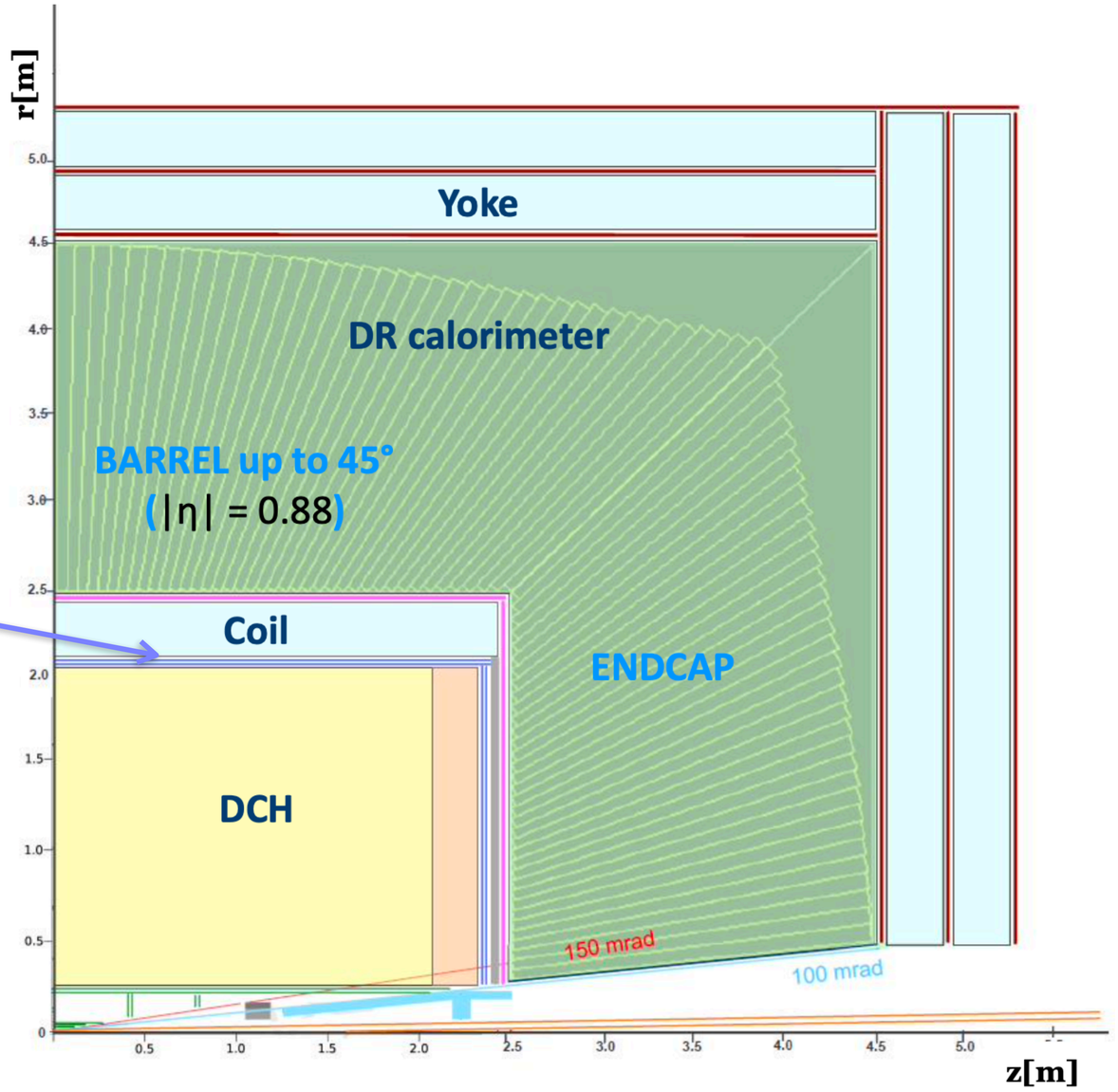

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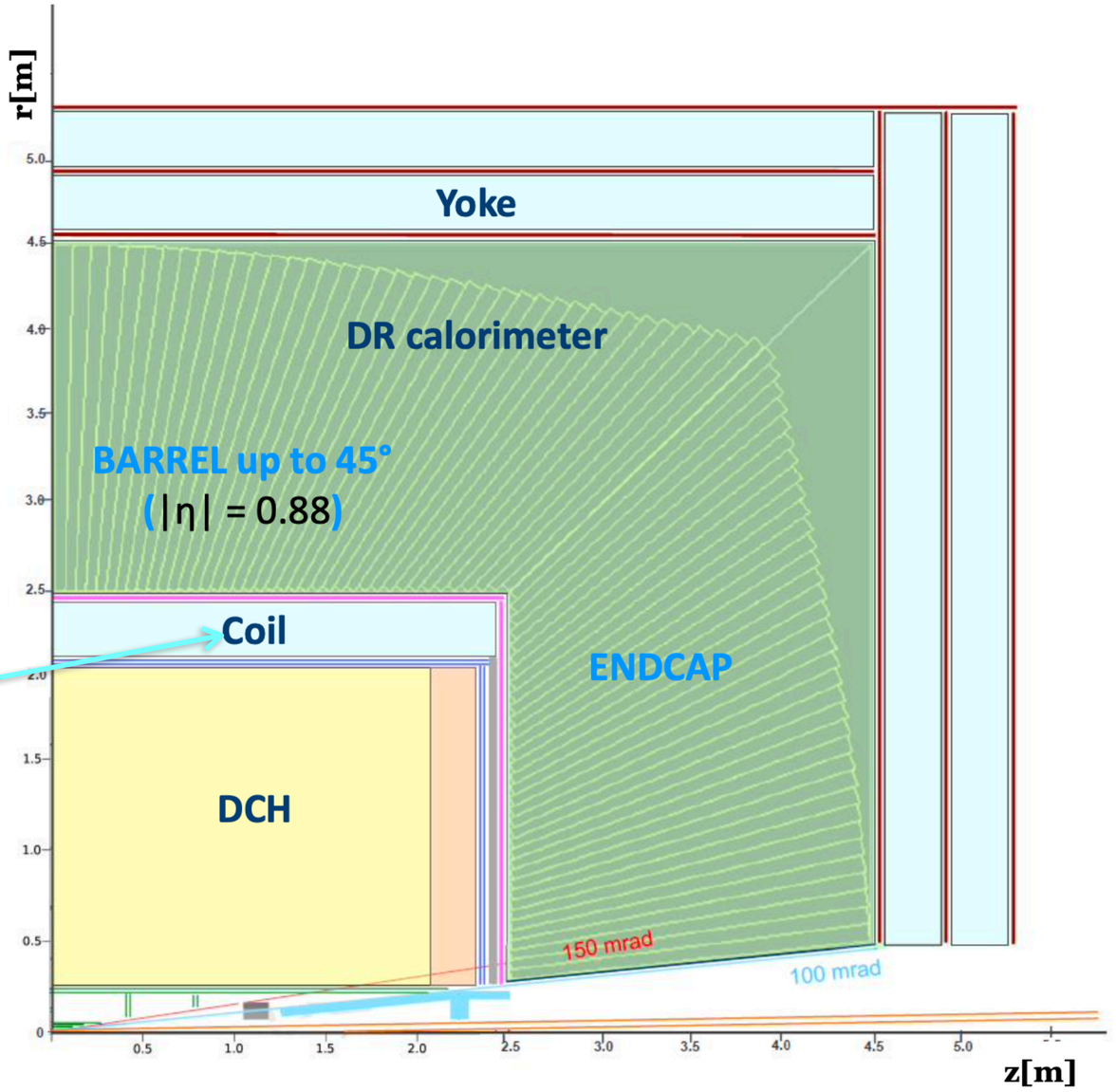
2 T, R ~ 2.1-2.4 m

0.74 $X_0$, 0.16 $\lambda$ @ 90°



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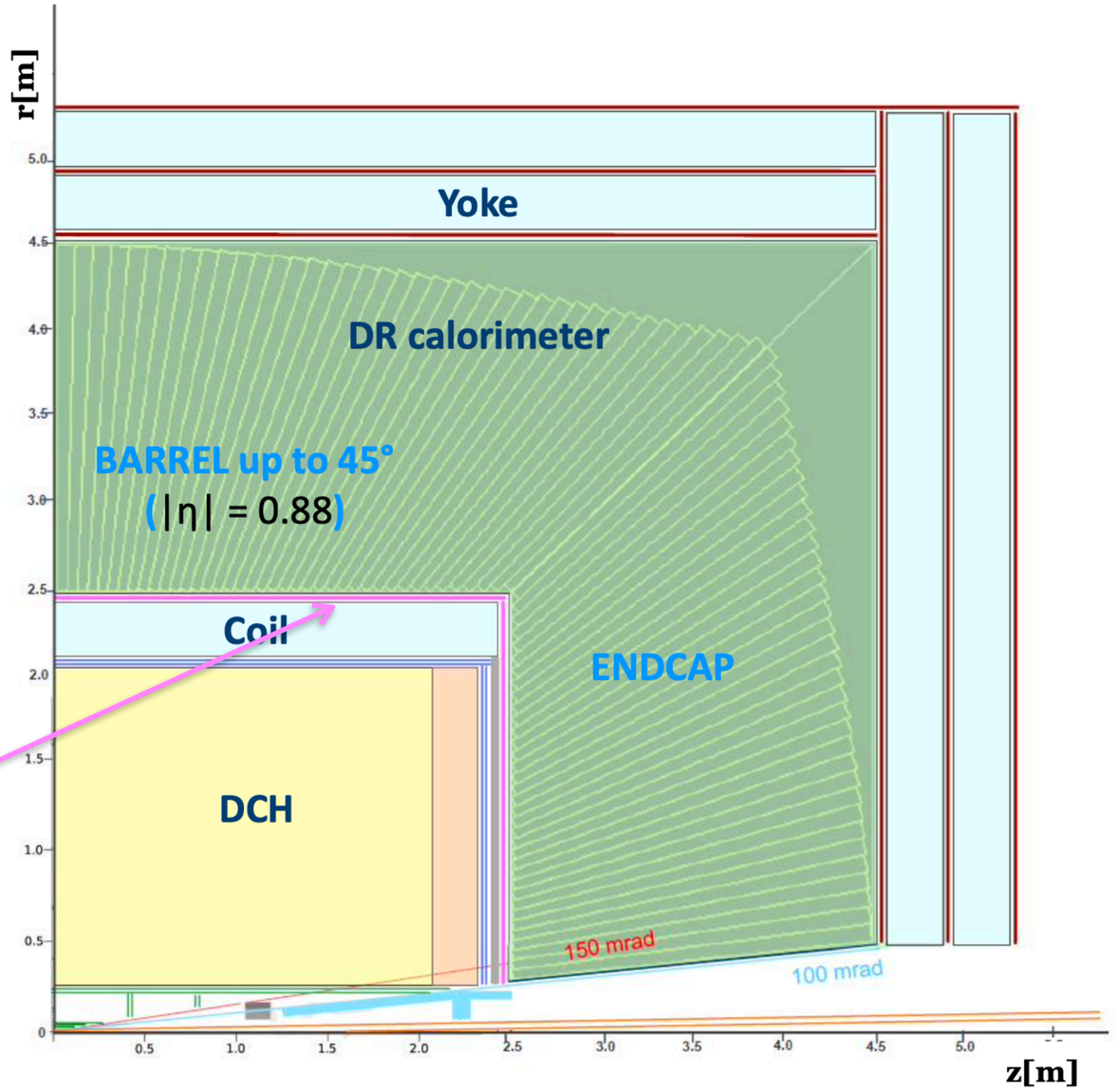

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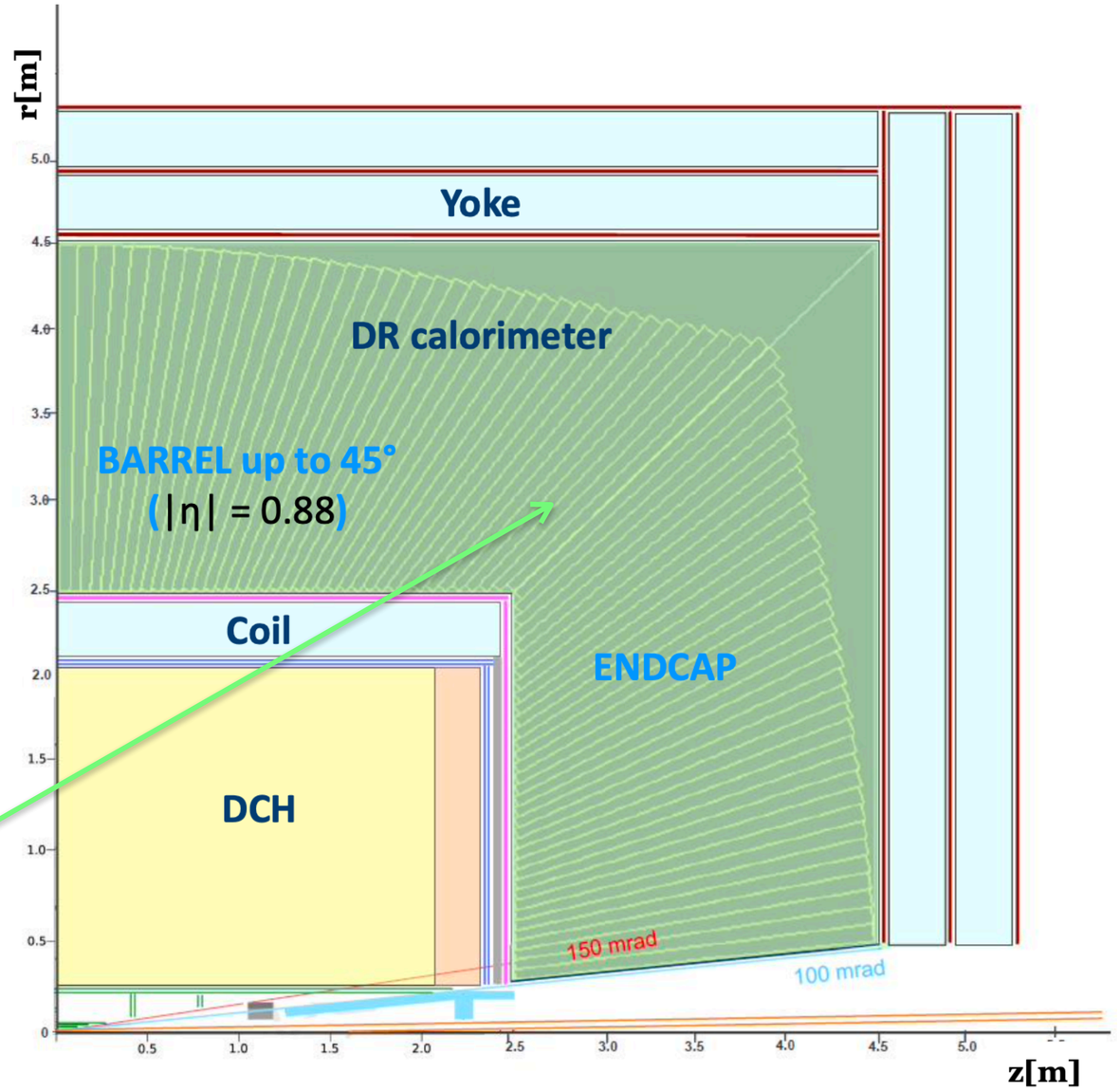

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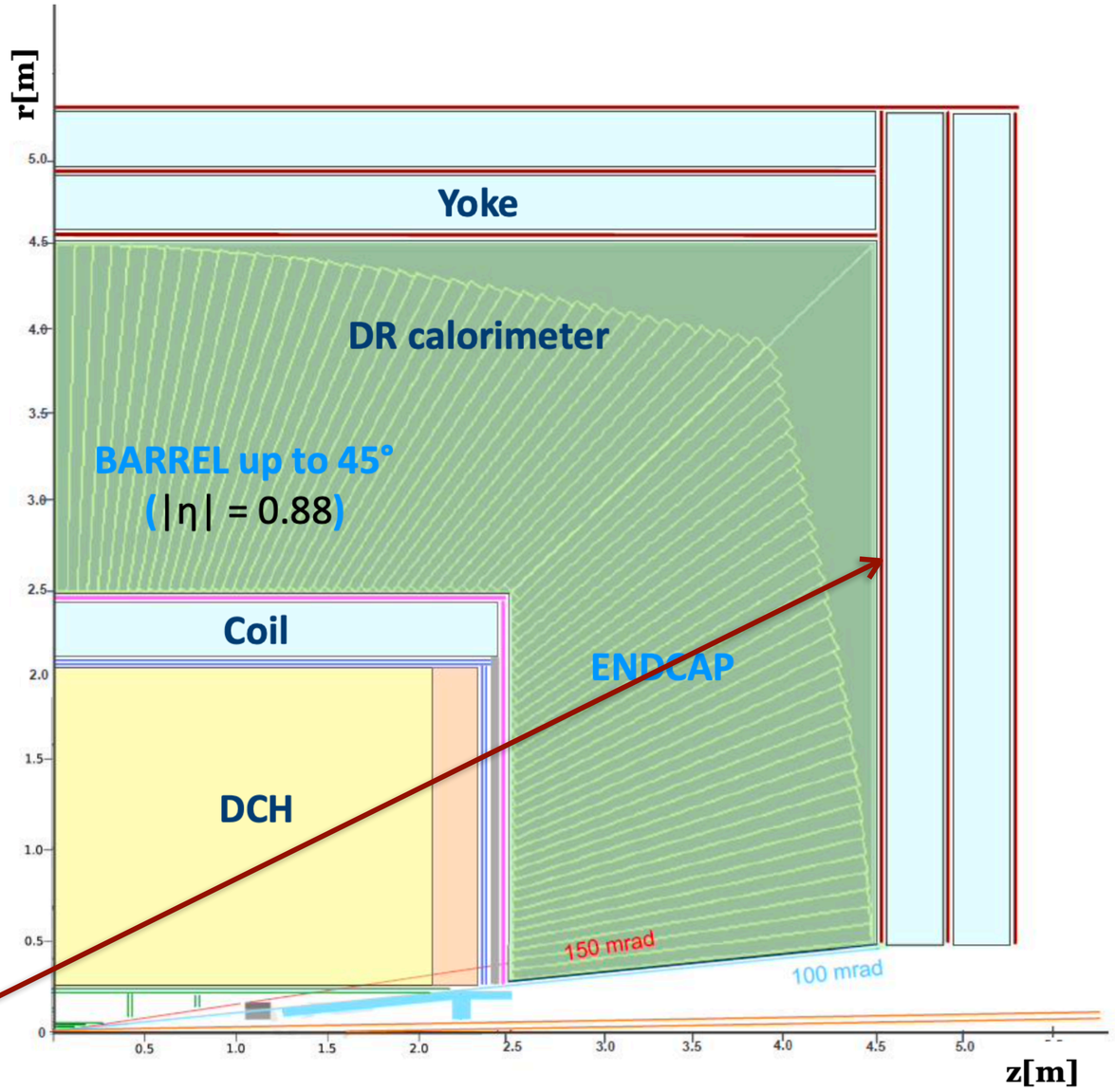
**Yoke + Muon chambers**



# Vertex detector: IDEA

## Mid-term review vertex detector overall layout

F. Palla

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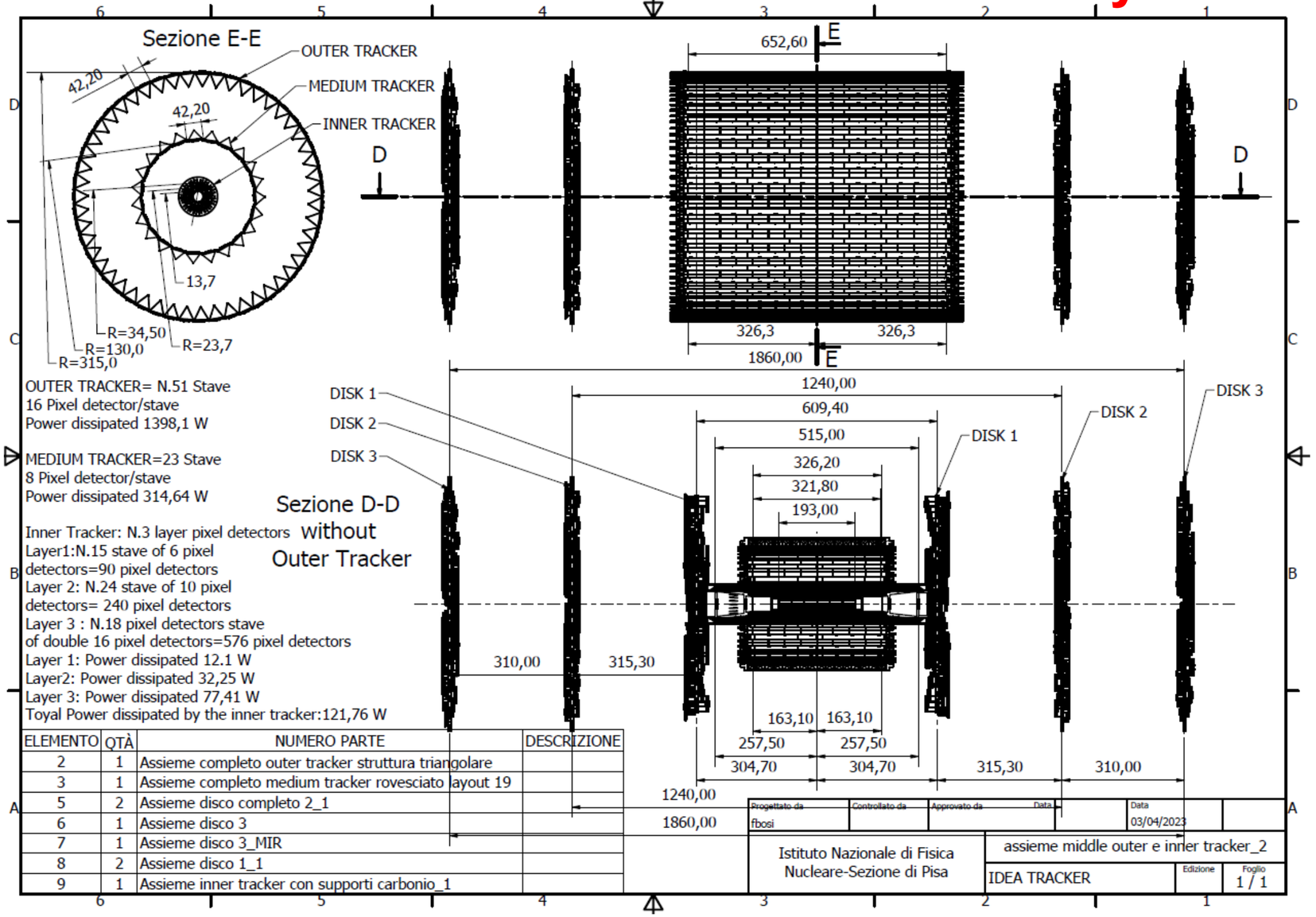


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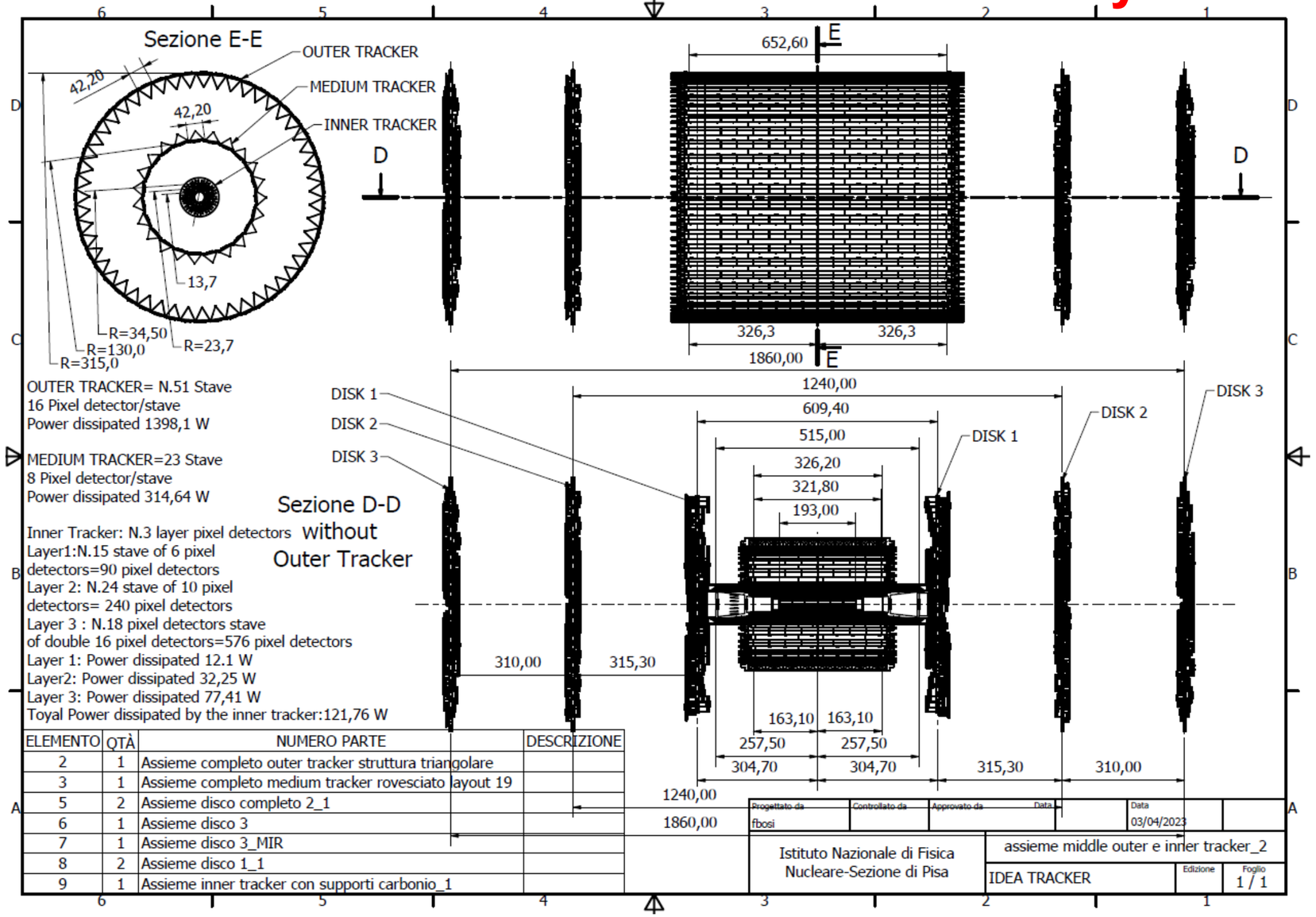


**Inner Vertex detector:**

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

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

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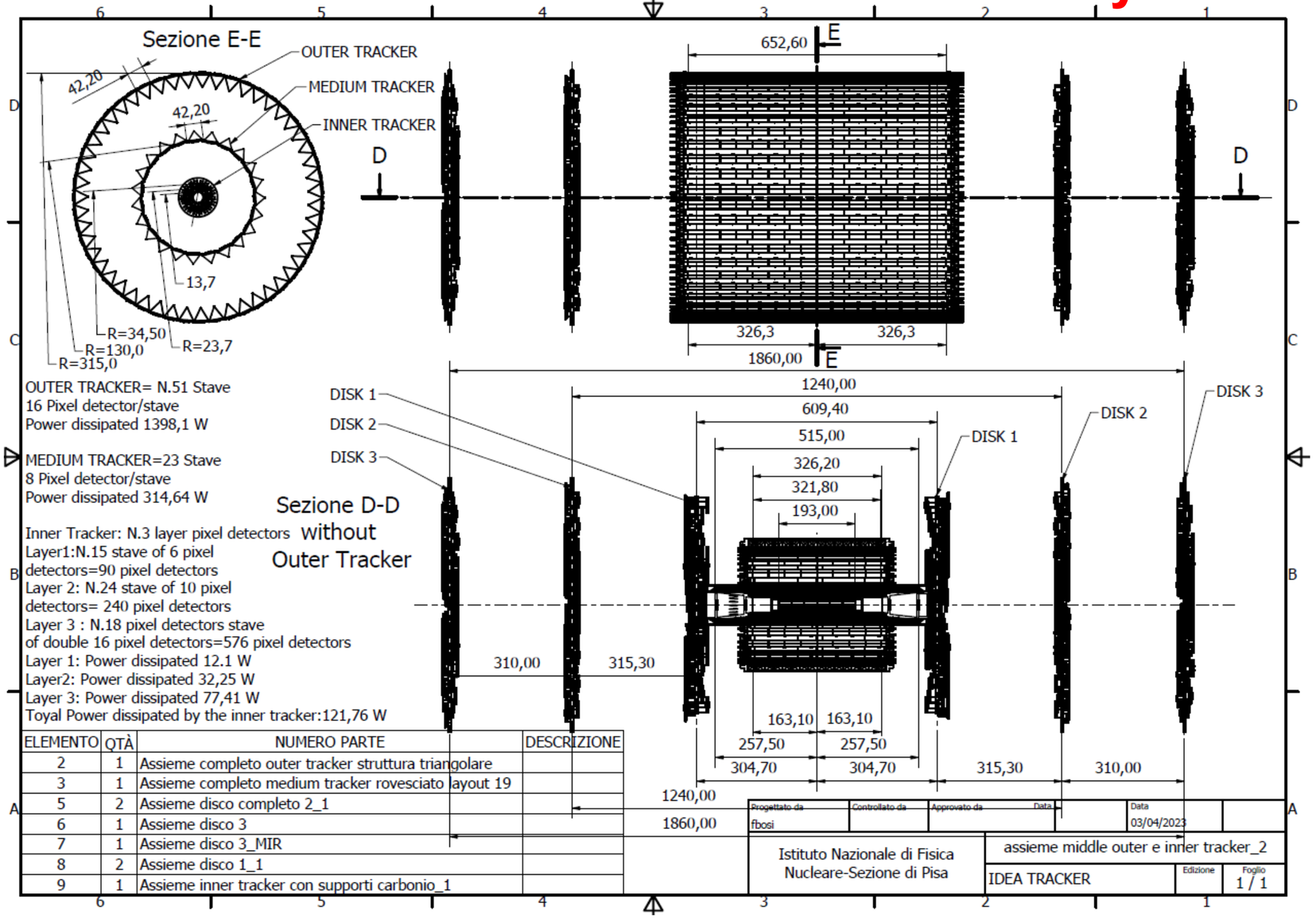


| ELEMENTO | QTÀ | NUMERO PARTE | DESCRIZIONE |
|---|---|---|---|
| 2 | 1 | Assieme completo outer tracker struttura triangolare | |
| 3 | 1 | Assieme completo medium tracker rovesciato layout 19 | |
| 5 | 2 | Assieme disco completo 2_1 | |
| 6 | 1 | Assieme disco 3 | |
| 7 | 1 | Assieme disco 3_MIR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

**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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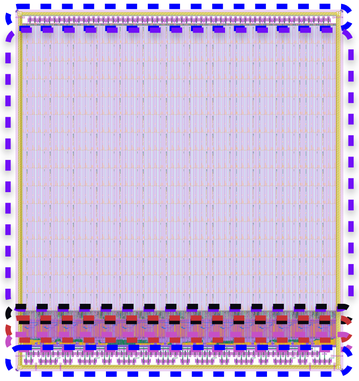
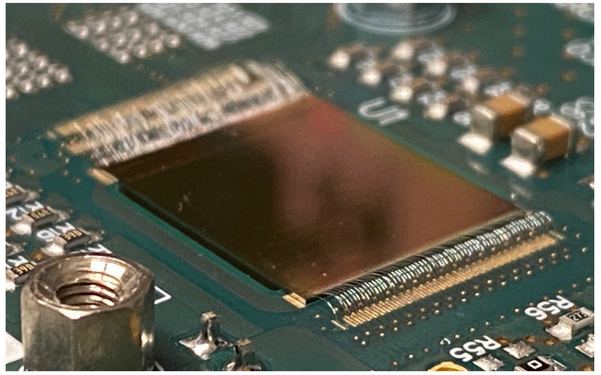
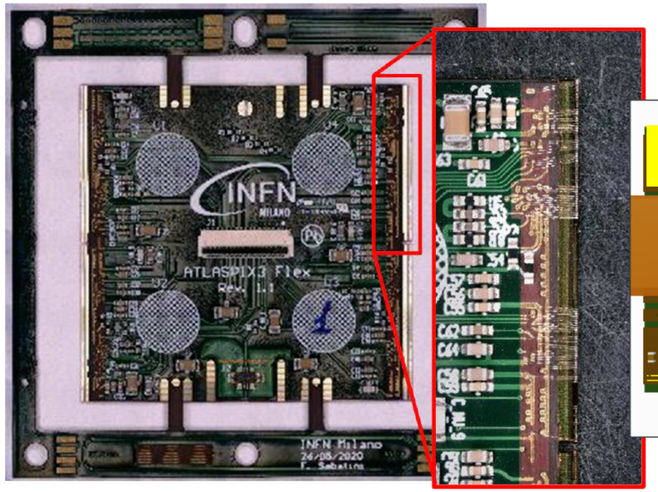
# Vertex detector: IDEA

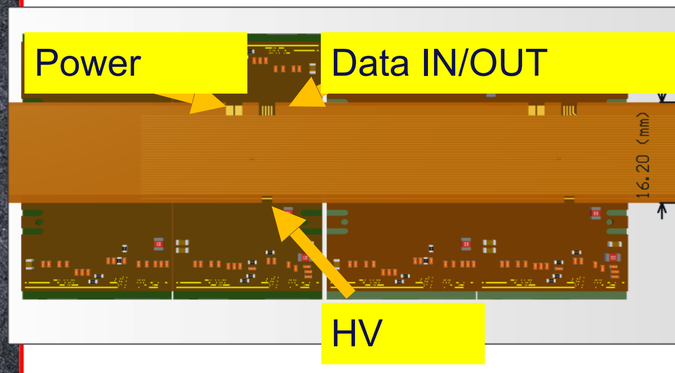
## Depleted Monolithic Active Pixel Detectors

- **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**







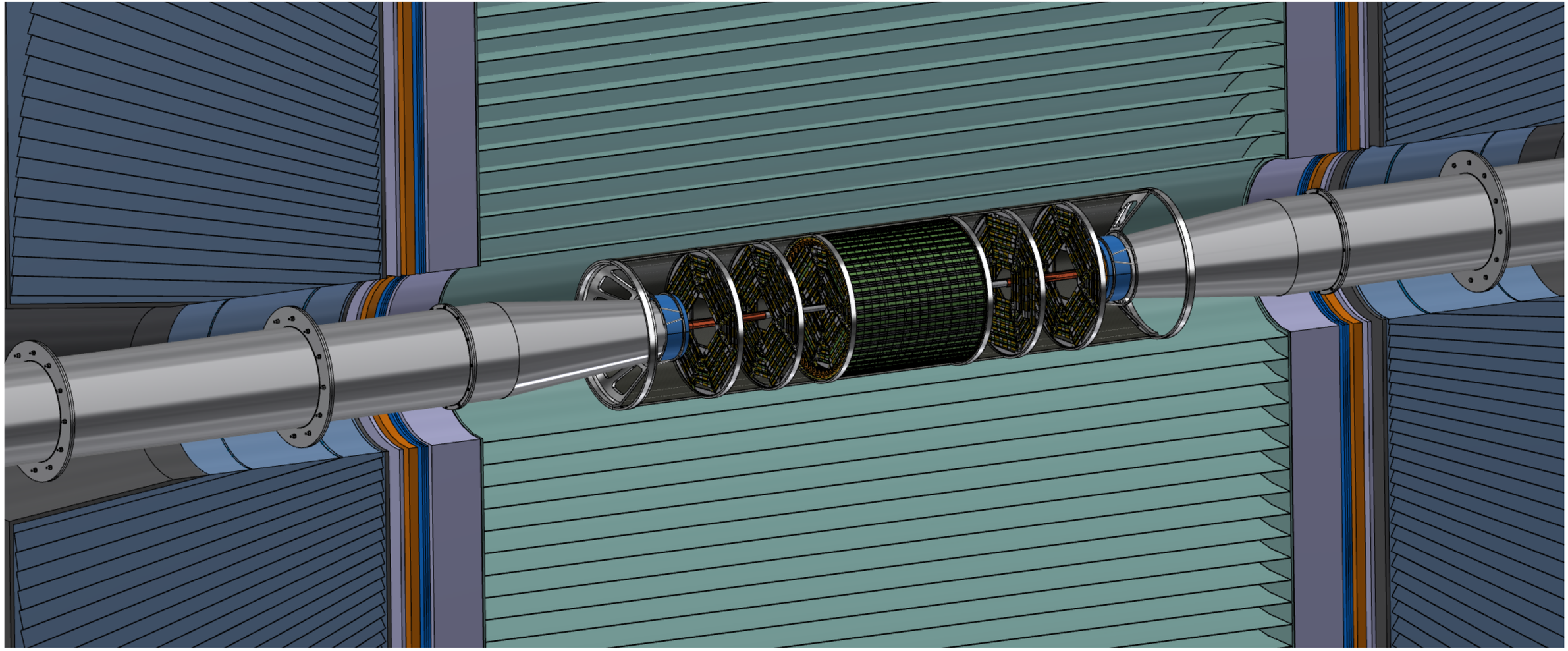

See talk by F. Palla for more details on the vertex tracker

F. Palla

# Vertex detector: IDEA



## General integration



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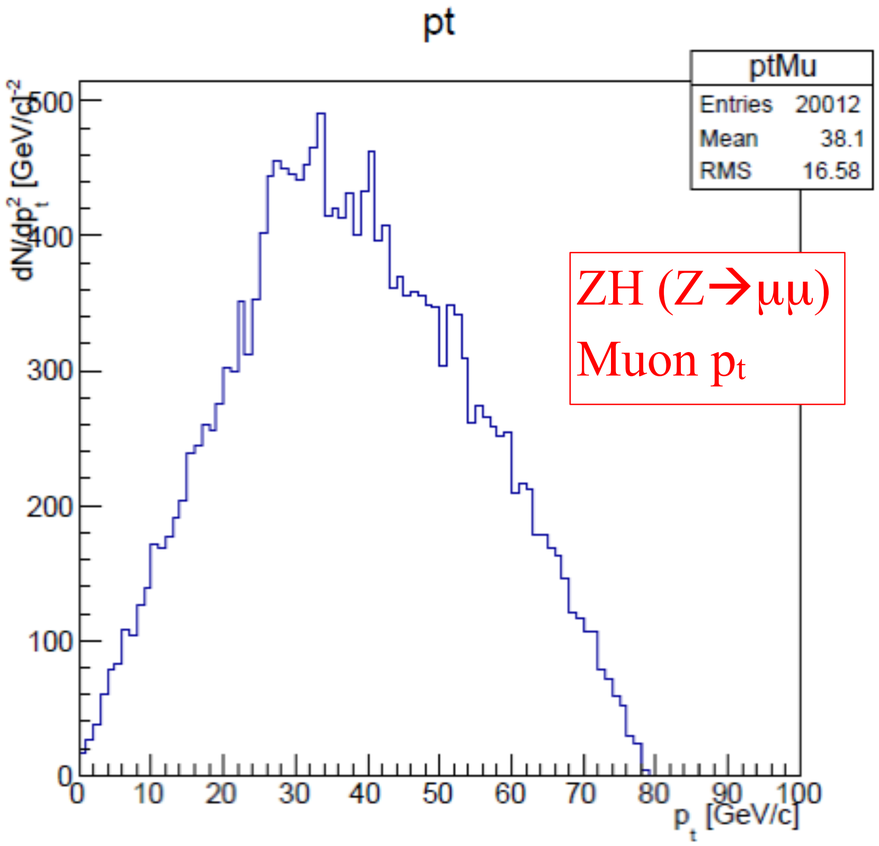
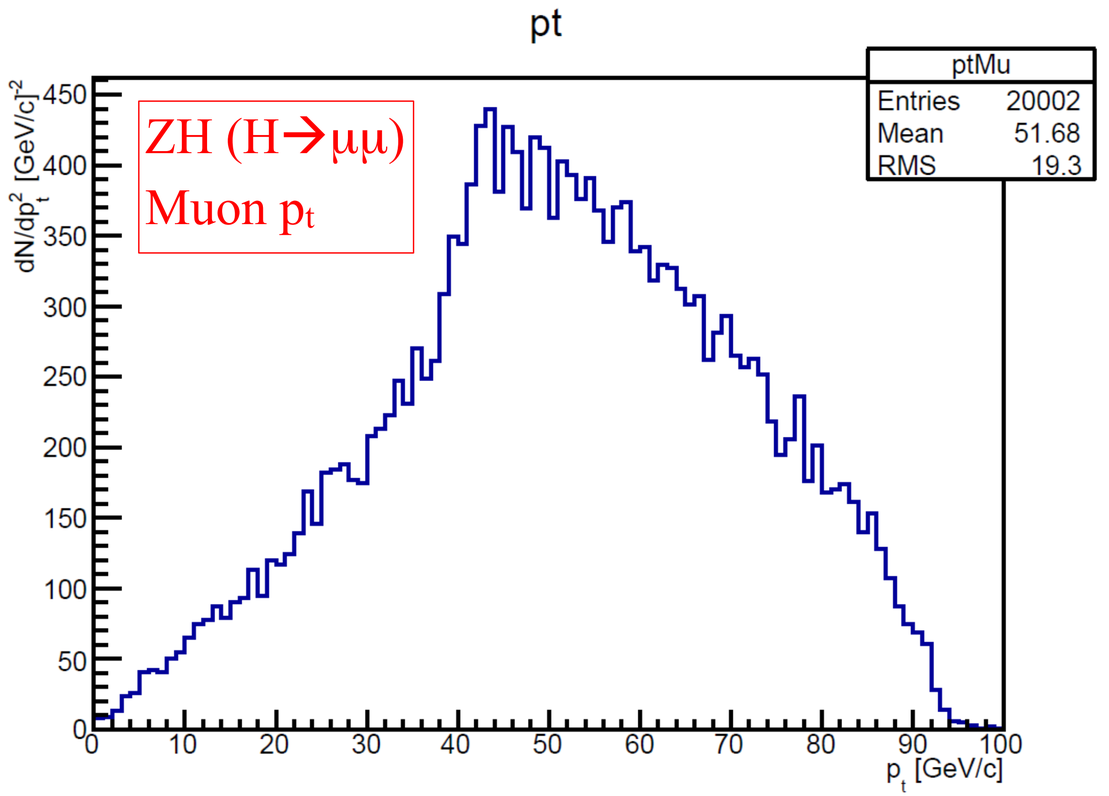
# Momentum measurement



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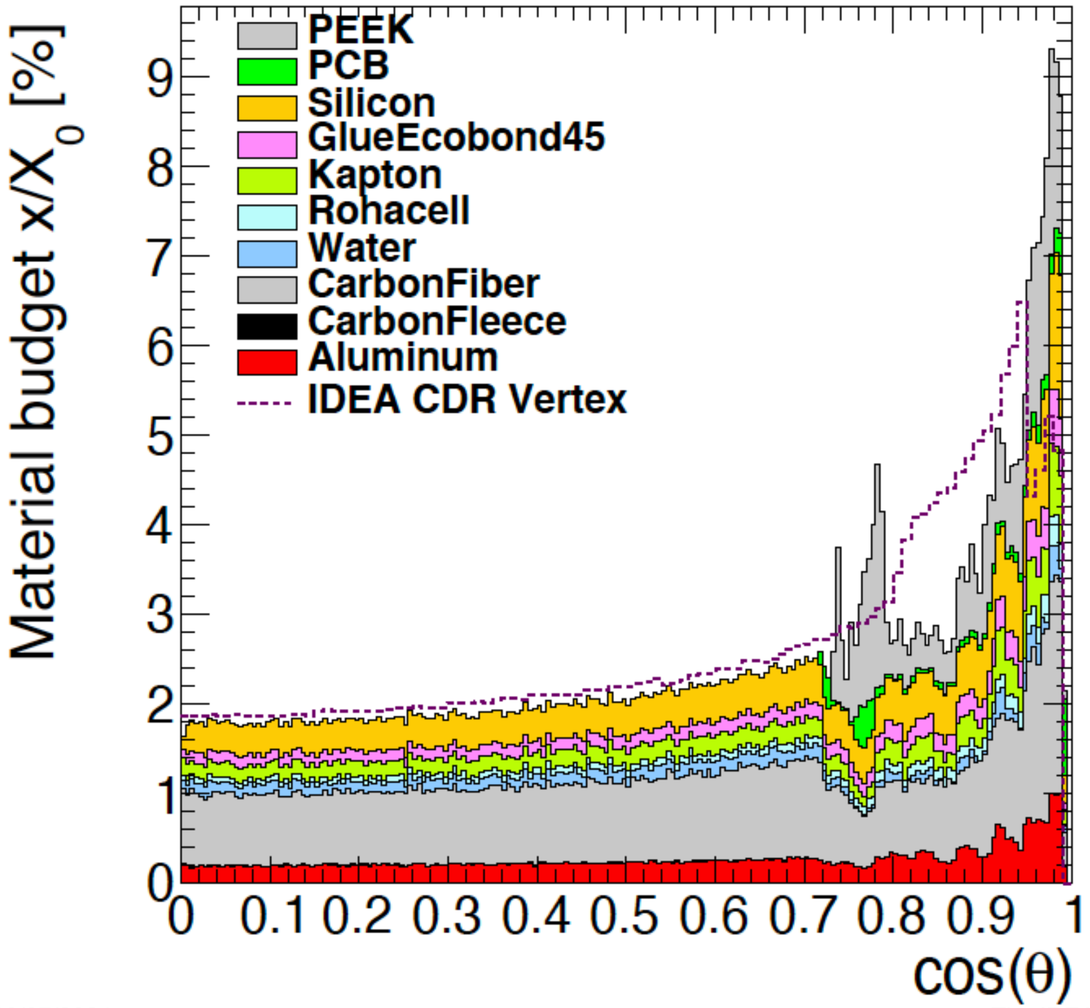
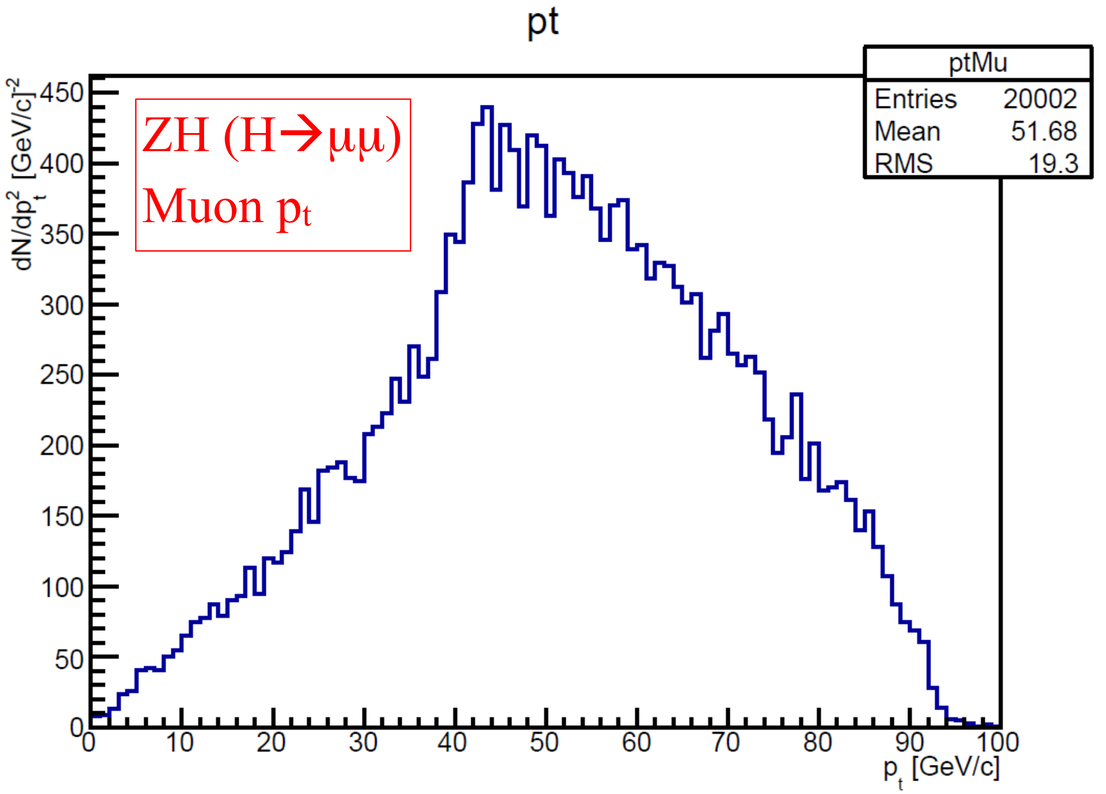
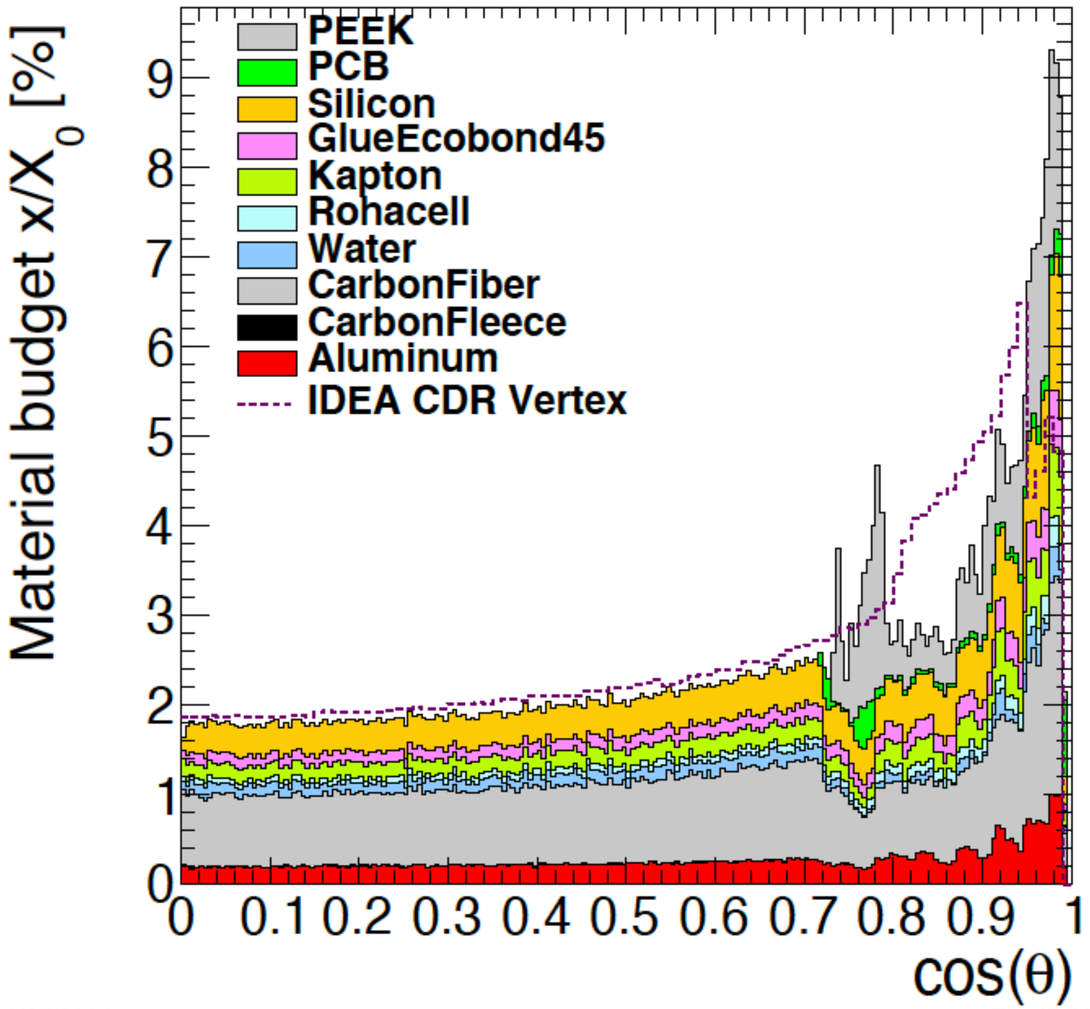
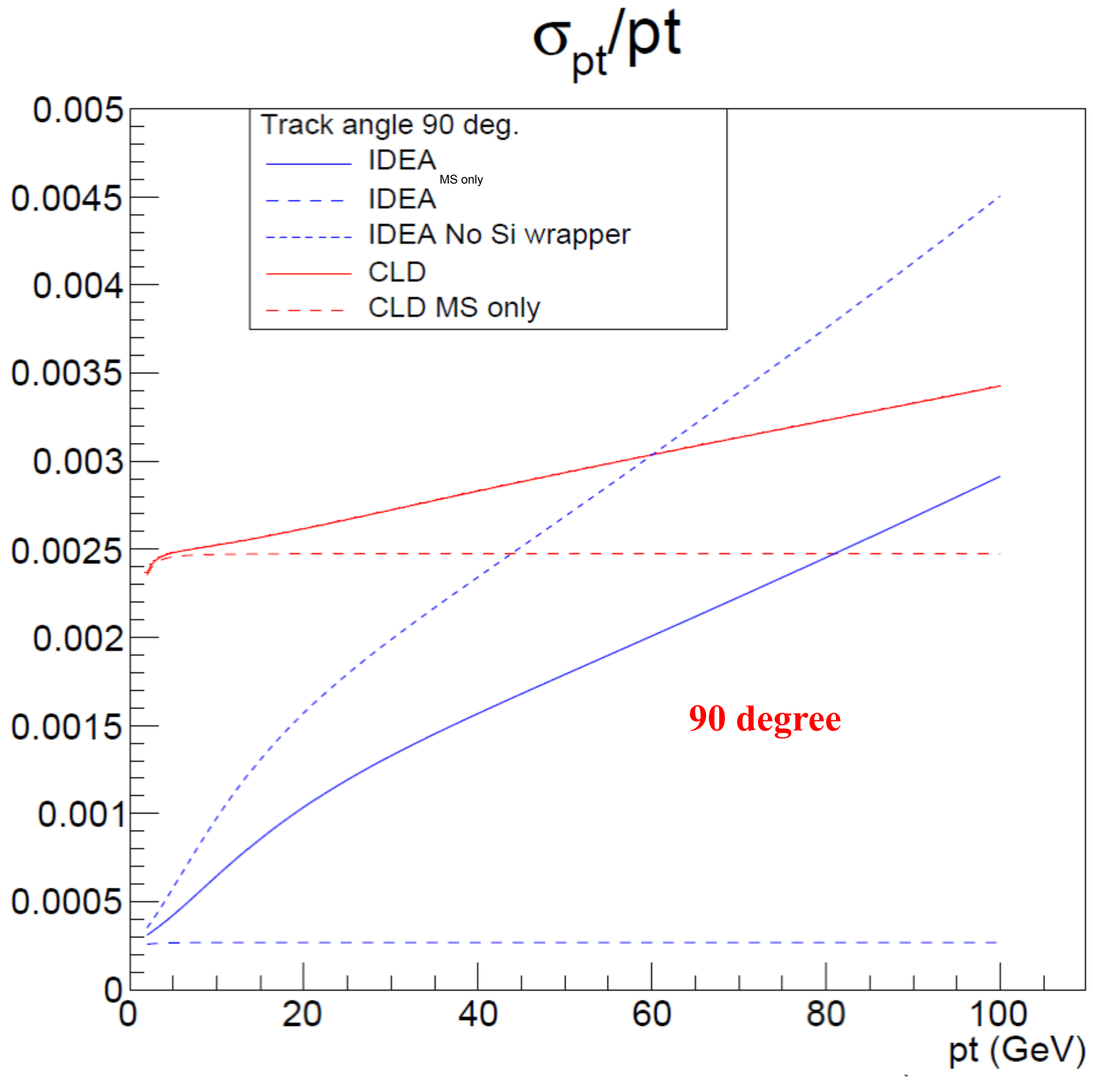


# Momentum measurement

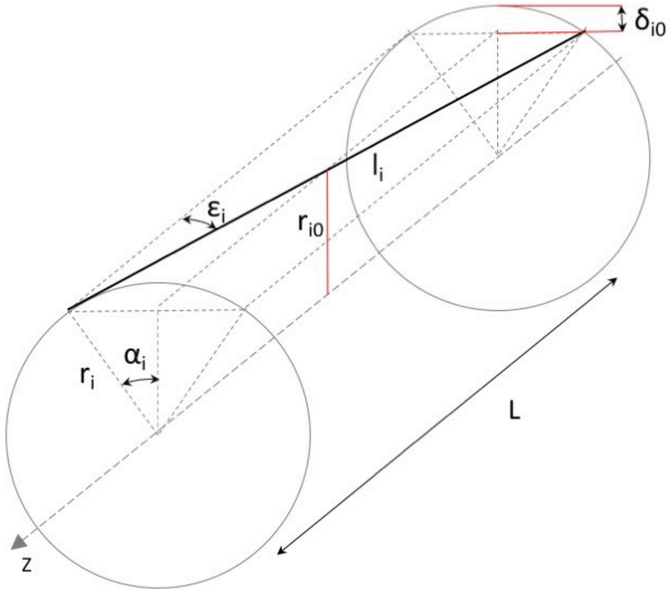
- Z or H decay muons in ZH events have rather low $p_t$
  - Transparency more important than asymptotic resolution



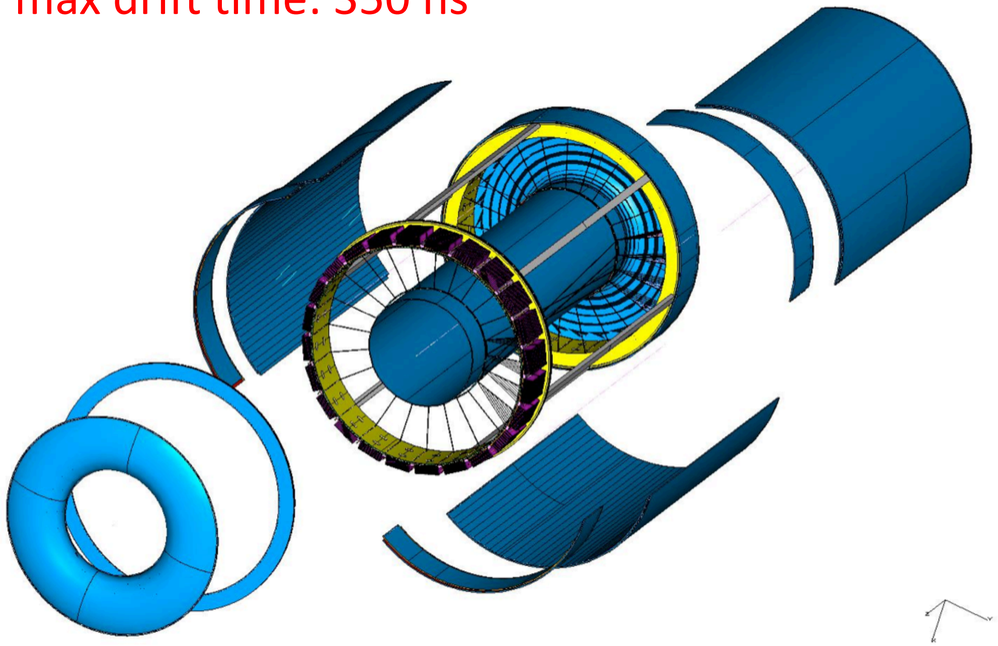



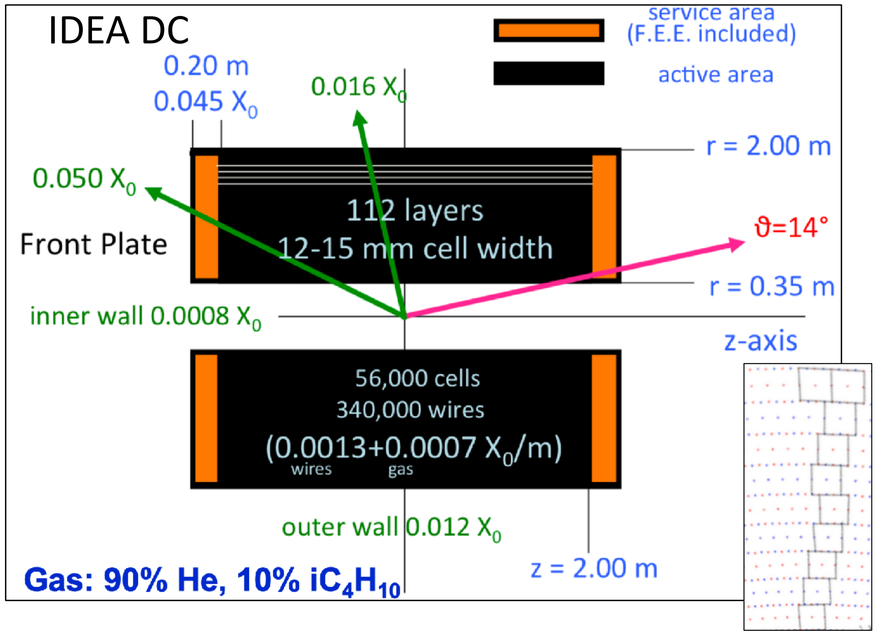
# Drift chamber

- 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



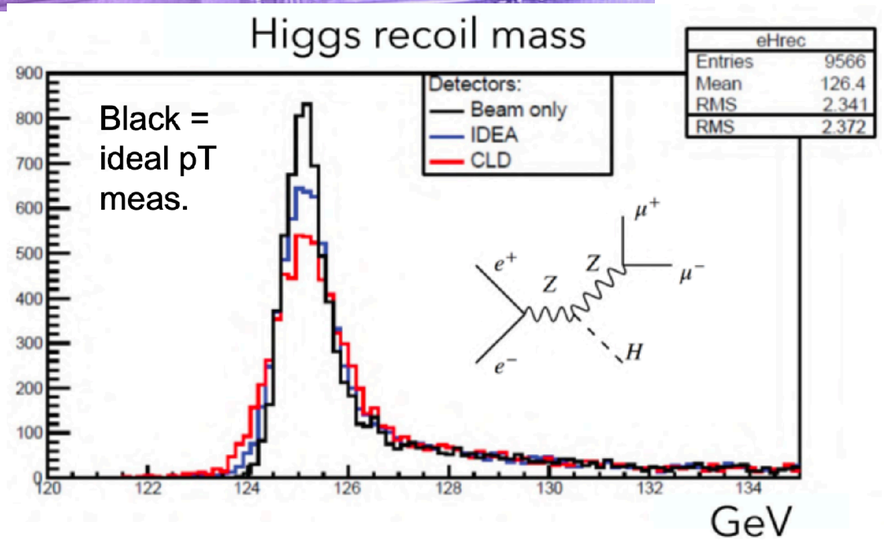

L = 4m

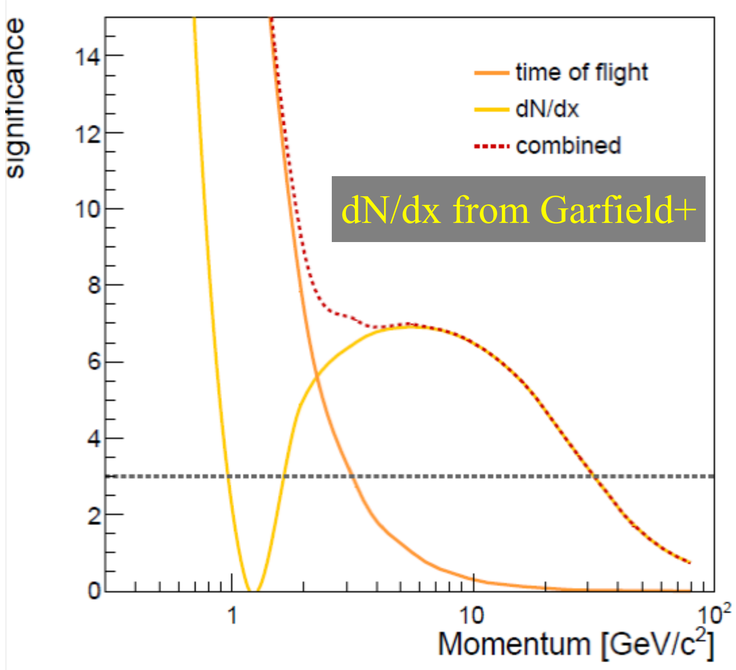


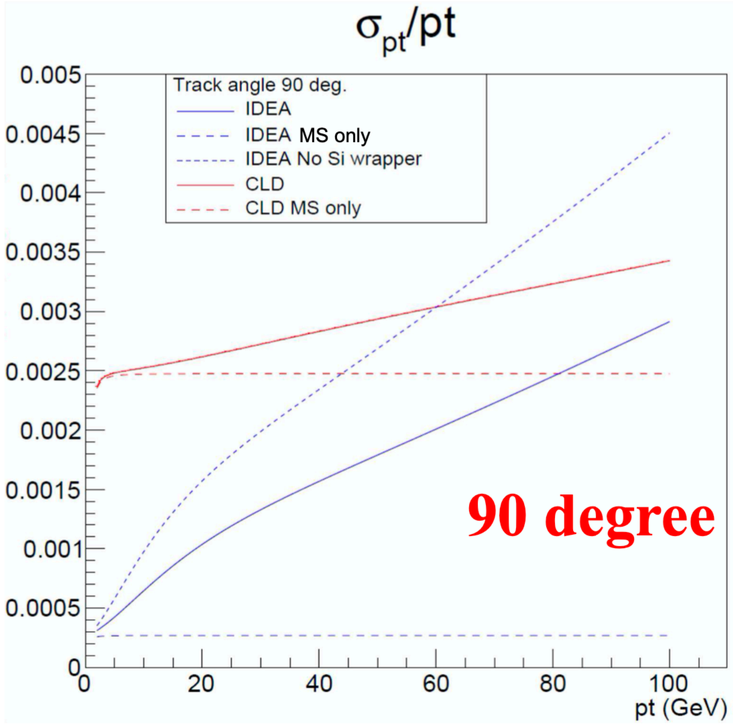


# Drift chamber

- 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 ($K^0_S$, $\Lambda$, BSM, LLPs)
  - Outstanding Particle separation via dE/dx or cluster counting (dN/dx)
    - >3$\sigma$ K/$\pi$ separation up to ~35 GeV

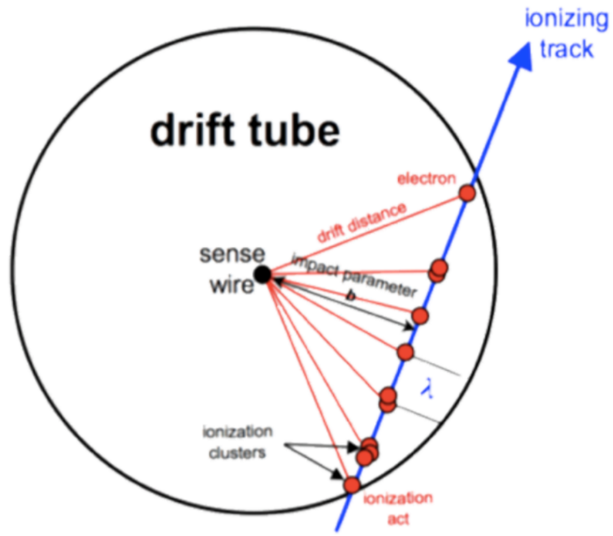


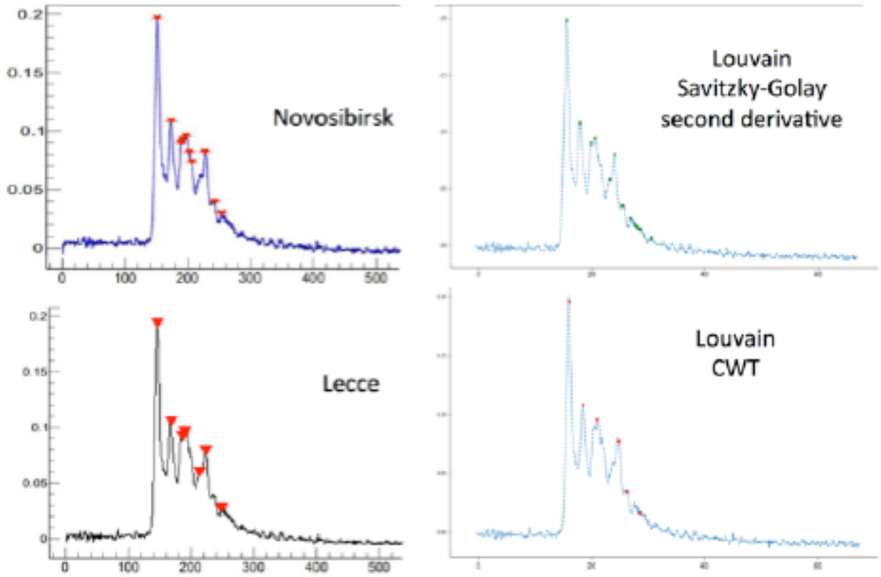



# Cluster counting

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

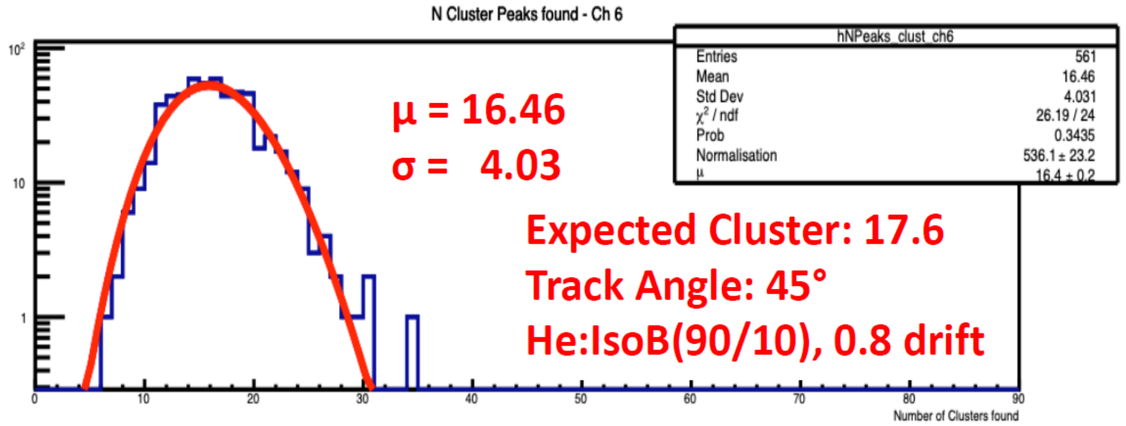



**counting peaks**




Test beam data 2022

**Number of Cluster Distribution**

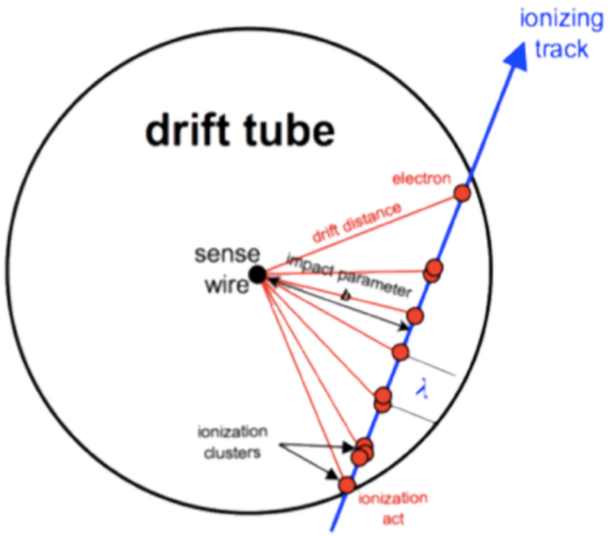



08/02/2022 FCC Physics Workshop - FG

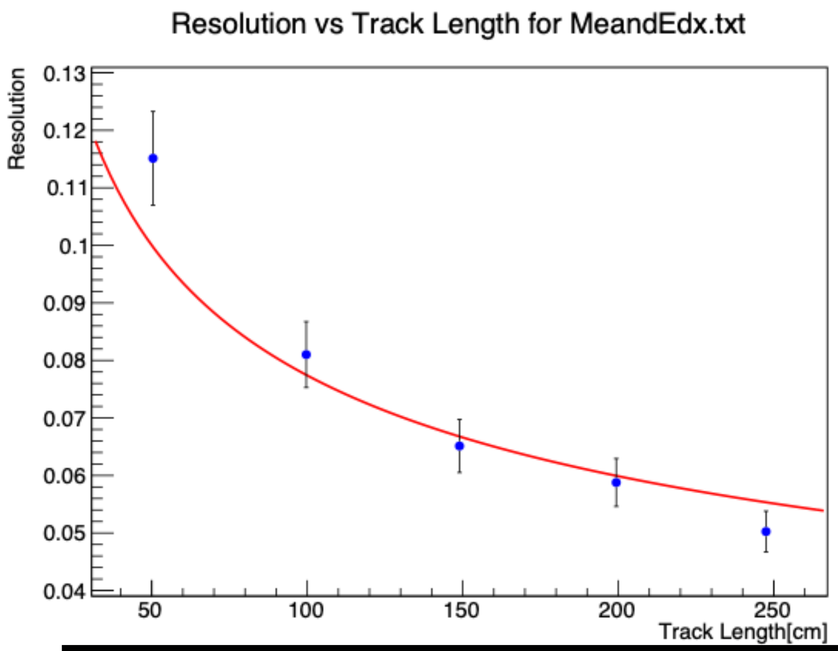
# Cluster counting

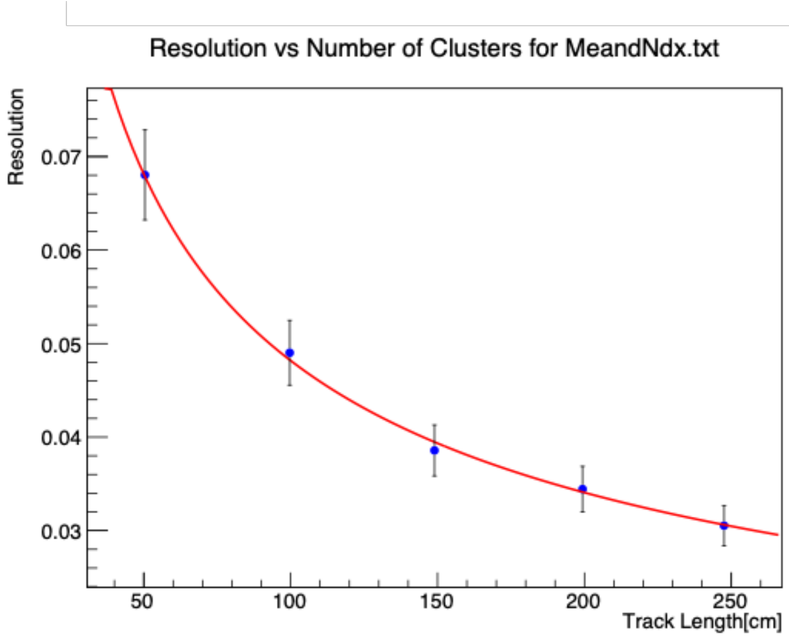
- Cluster counting 2x better than dE/dx
  - ➢ Poisson vs . Landau → no large tails
- Sample signal few GHz → on detector electronics R&D

Test beam 2024




**counting peaks**



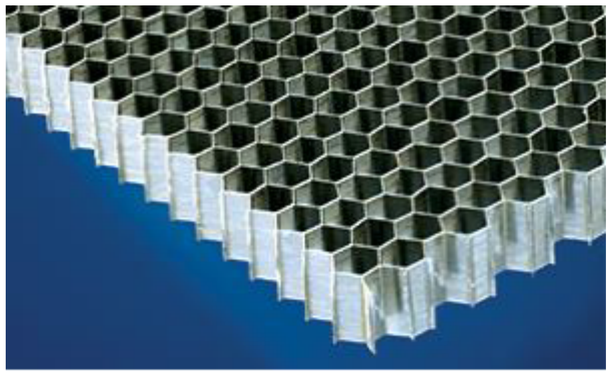




- For dN/dx method:
  - RTA algorithm has been used for peak finding.
  - dN/dx resolution dependence on the track length $L^{-0.5}$

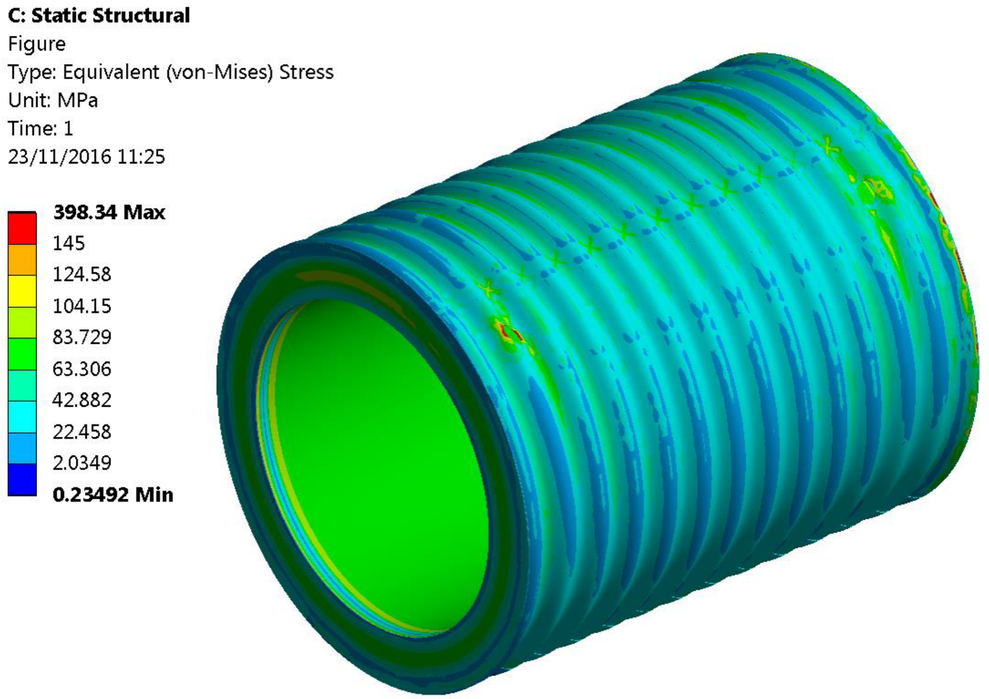
~ 2 times improvement in the resolution using dN/dx method as expected from the analytical calculation.

# 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: $X_0 = 0.04$

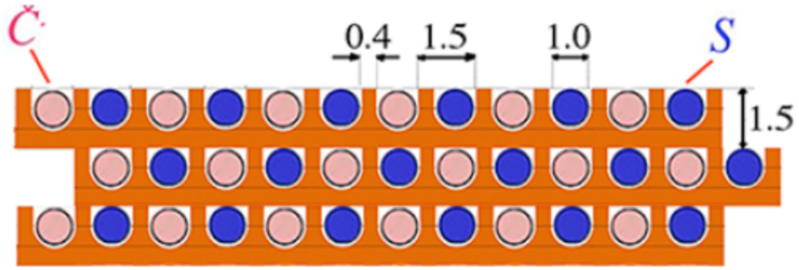


Courtesy of H. TenKate




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

# Dual Readout Calorimetry

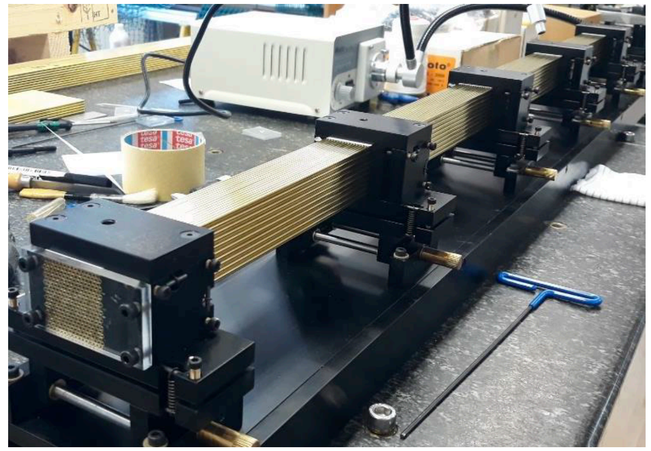



Alternate

Cherenkov fibers

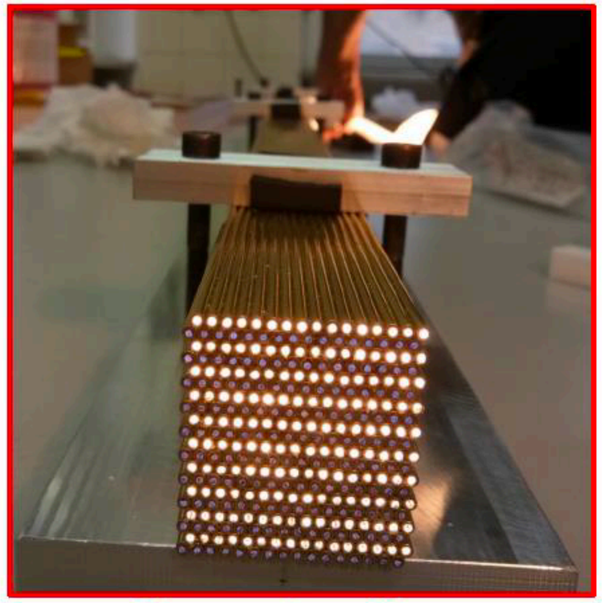
Scintillating fibers

~2m long capillaries



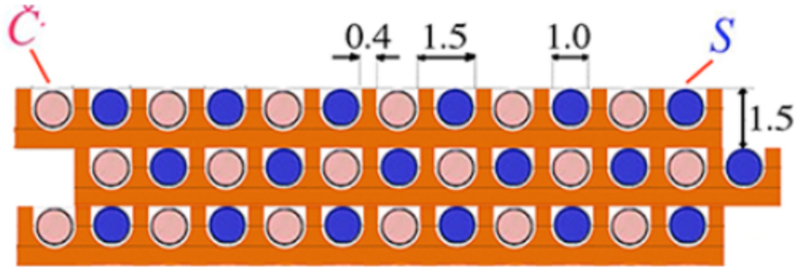
Newer DR calorimeter
( bucatini calorimeter)

Scintillation fibers



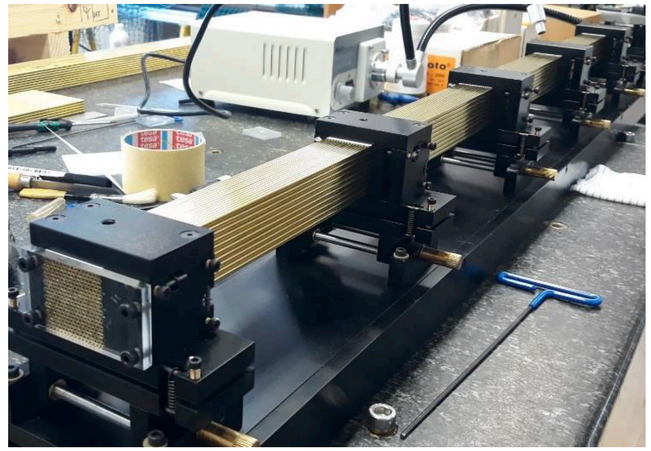
Cherenkov fibers

# Dual Readout Calorimetry




Alternate
Cherenkov fibers
Scintillating fibers

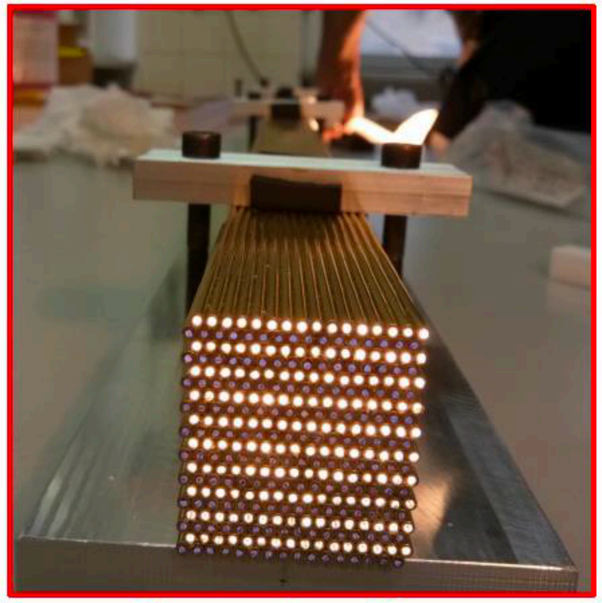
~2m long capillaries



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

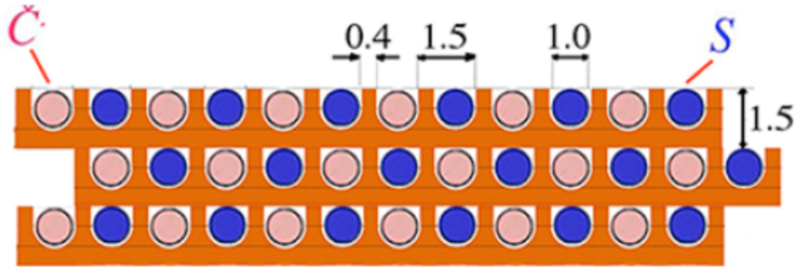
Newer DR calorimeter
( bucatini calorimeter)

Scintillation fibers



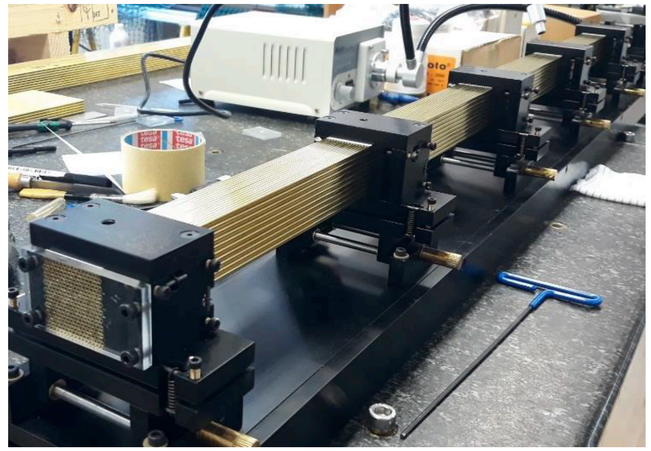
Cherenkov fibers

# Dual Readout Calorimetry




Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



- Measure simultaneously:
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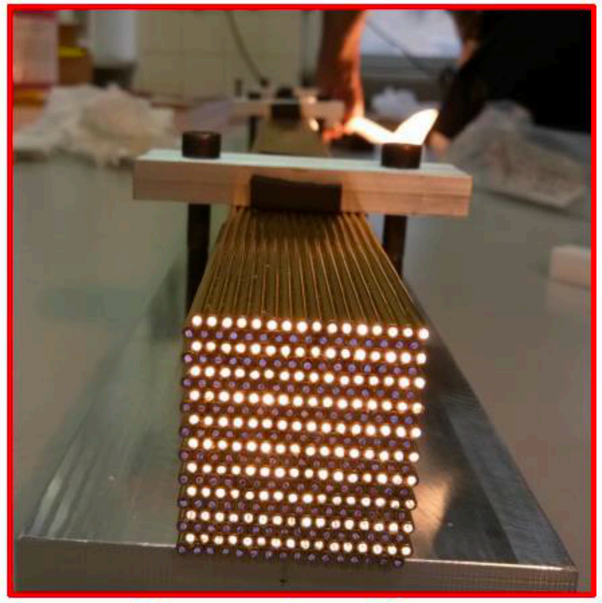
- Calibrate both signals with e-

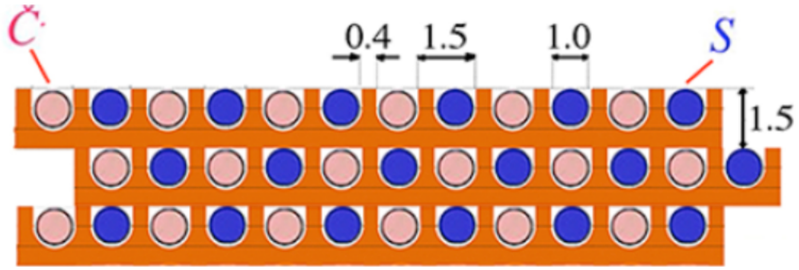
Newer DR calorimeter
( bucatini calorimeter)

Scintillation fibers



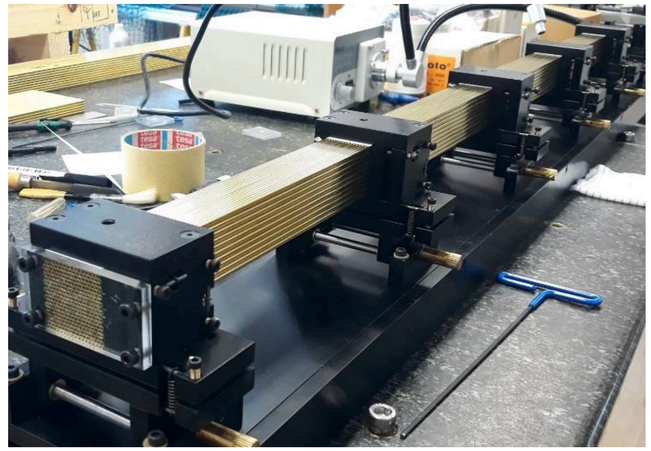
Cherenkov fibers

# Dual Readout Calorimetry




Alternate
Cherenkov fibers
Scintillating fibers

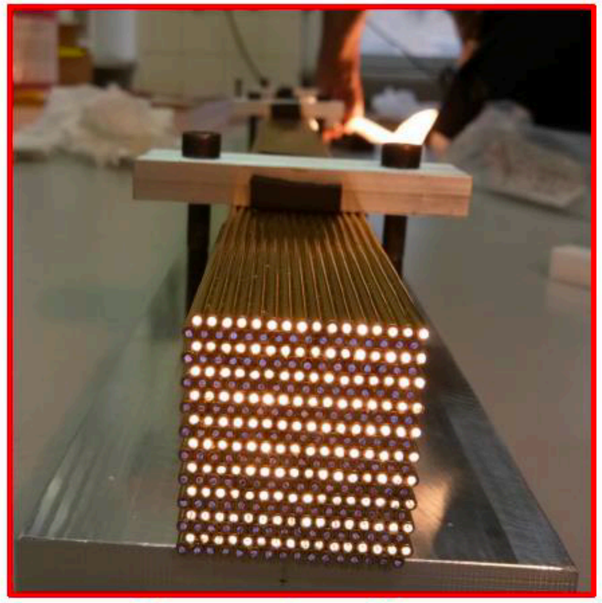
~2m long capillaries



- 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

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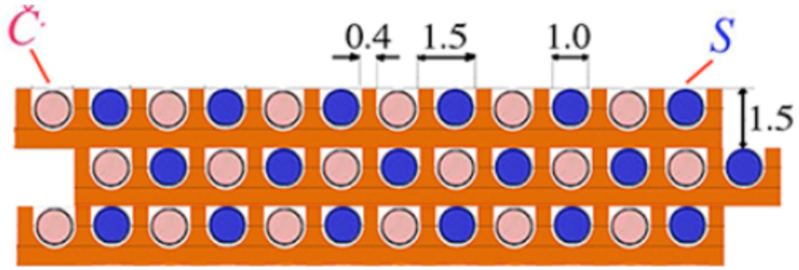
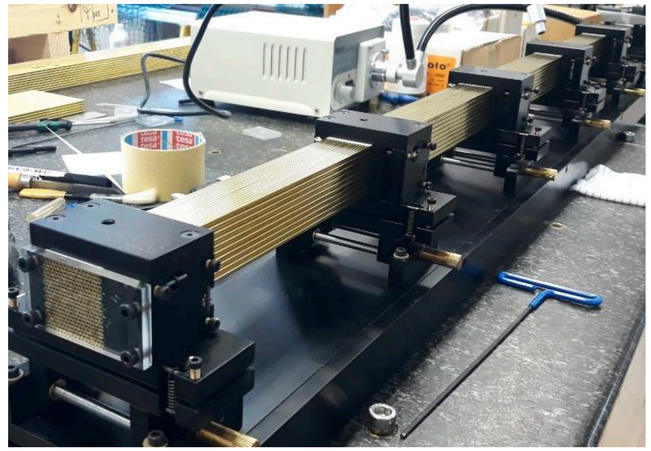



Alternate
Cherenkov fibers
Scintillating fibers

~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

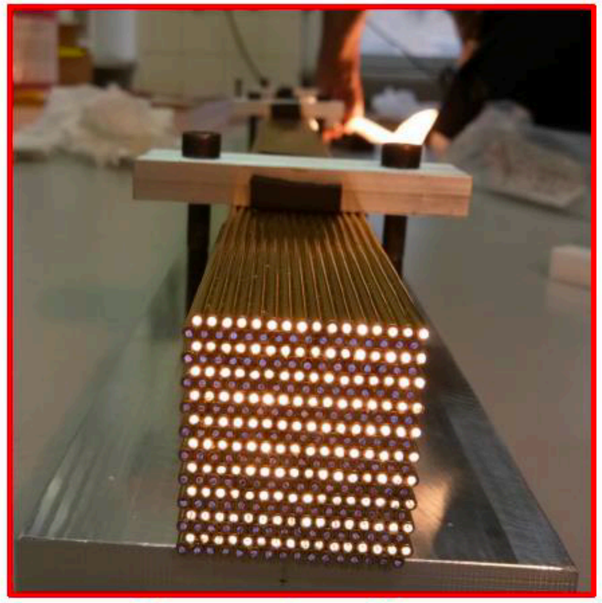
$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$

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

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

Newer DR calorimeter
( bucatini calorimeter)

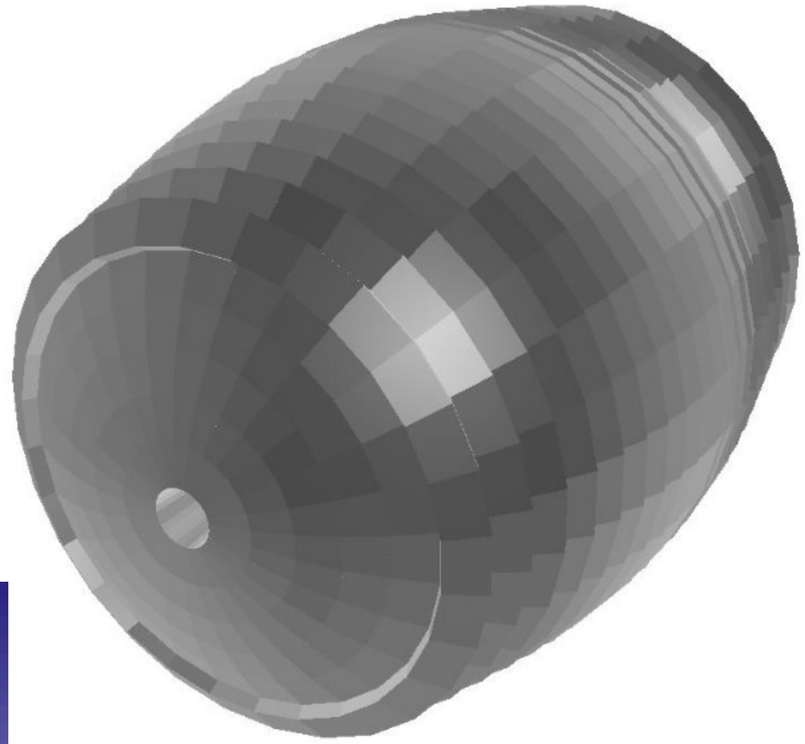
Scintillation fibers

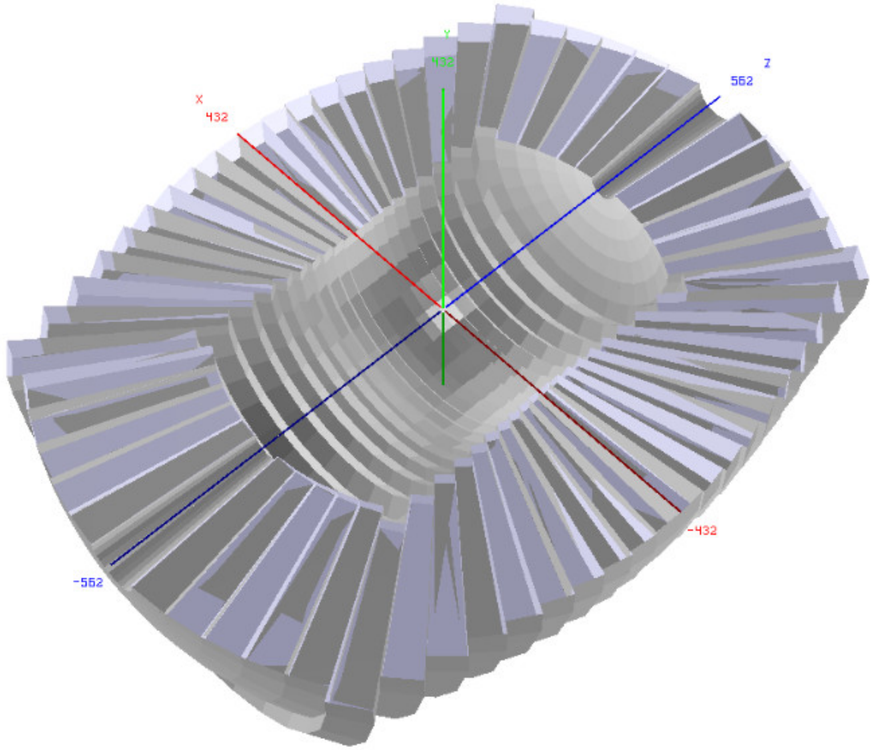


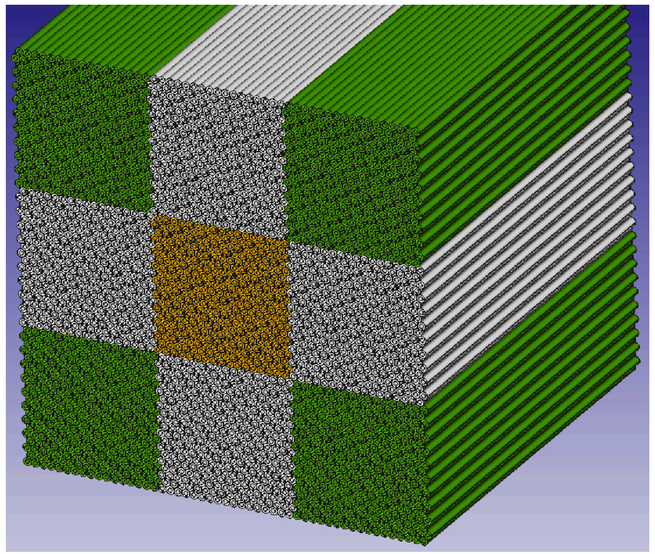
Cherenkov fibers

# Dual Readout Calorimeter

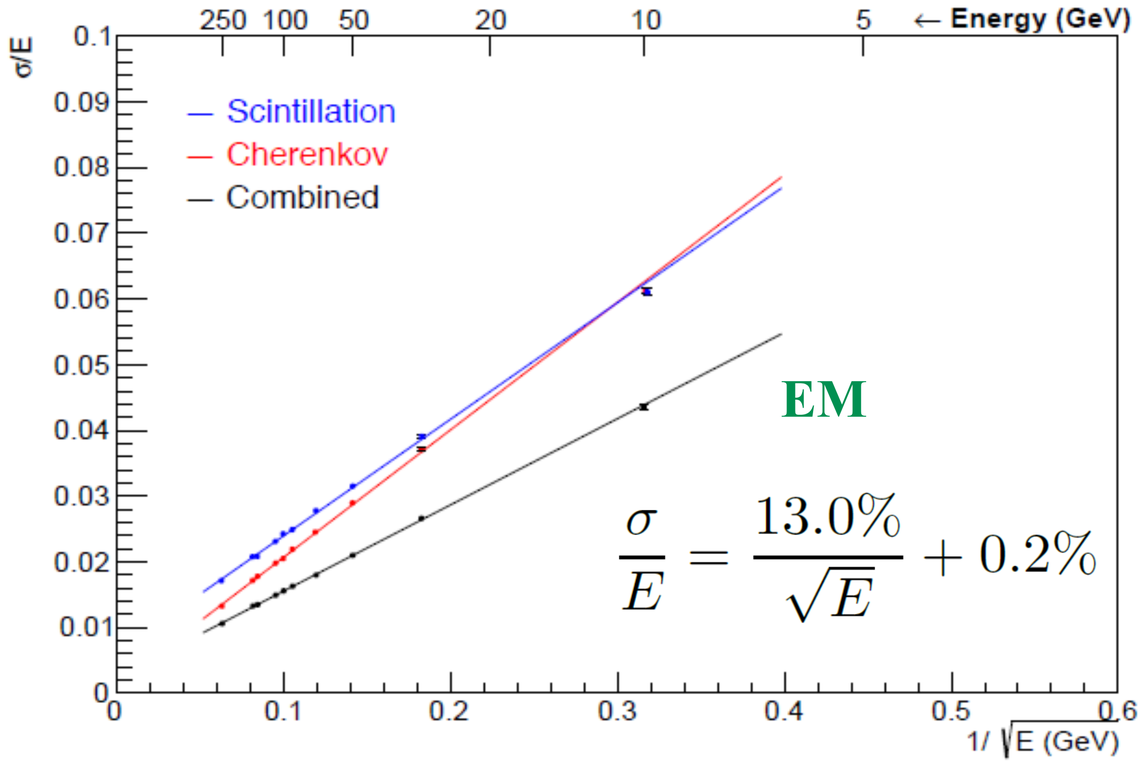
## Full GEANT4 implementation of the DR calorimeter

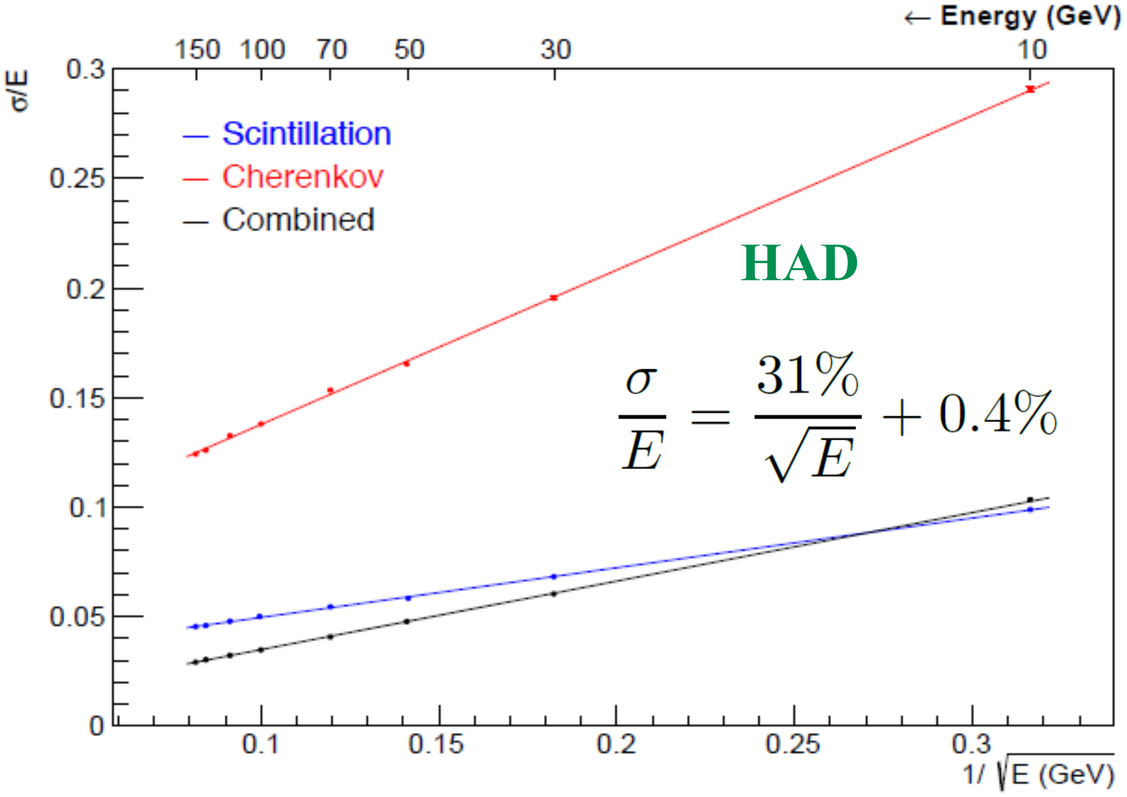




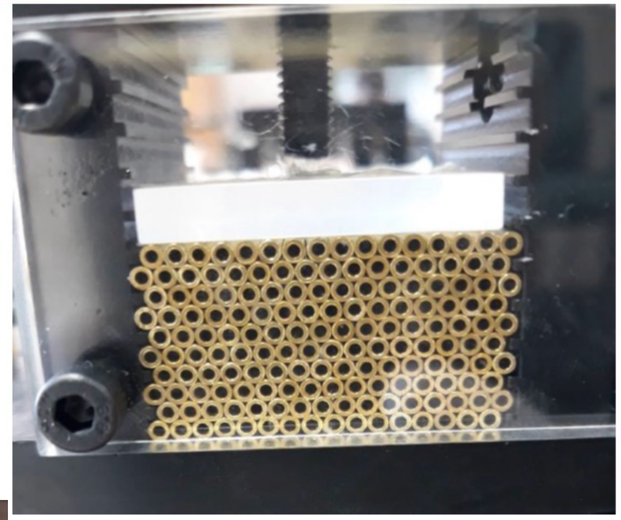
# Dual Readout Calorimeter

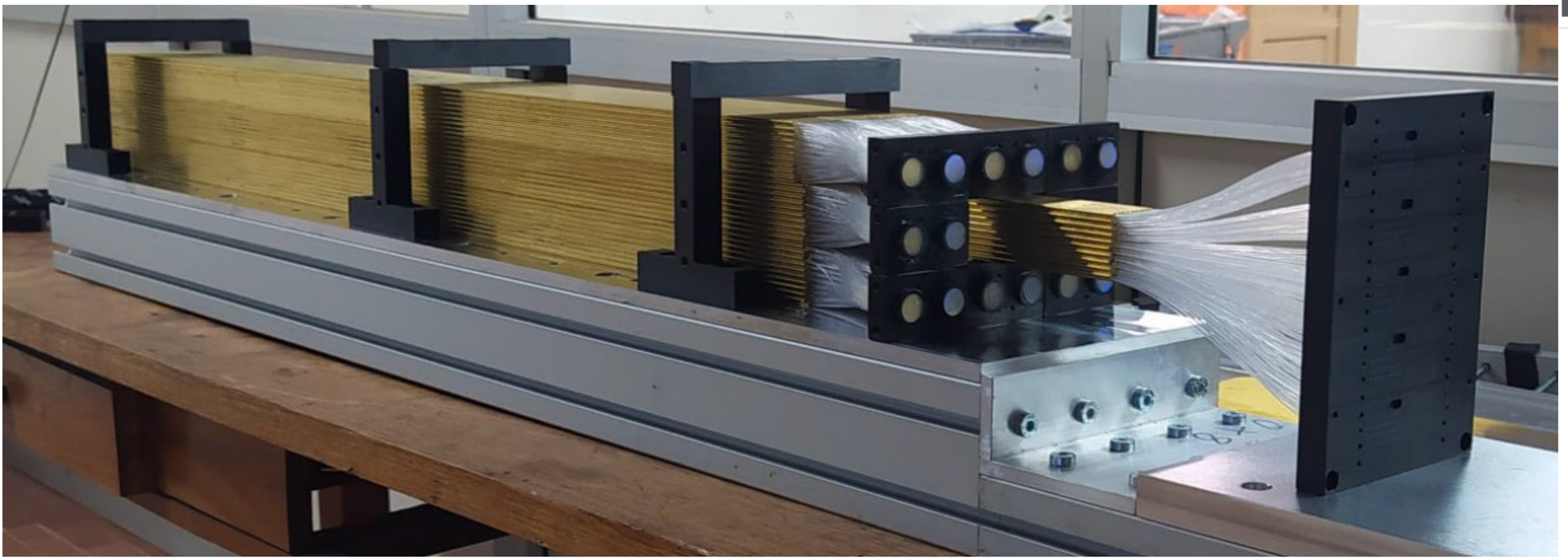


# DR calorimeter

- 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)





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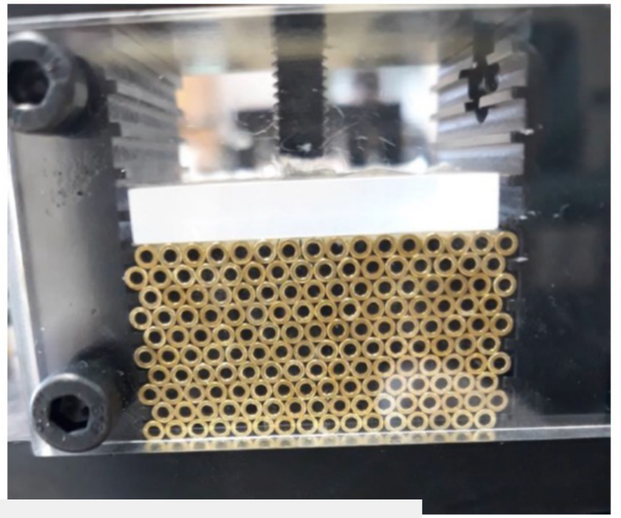
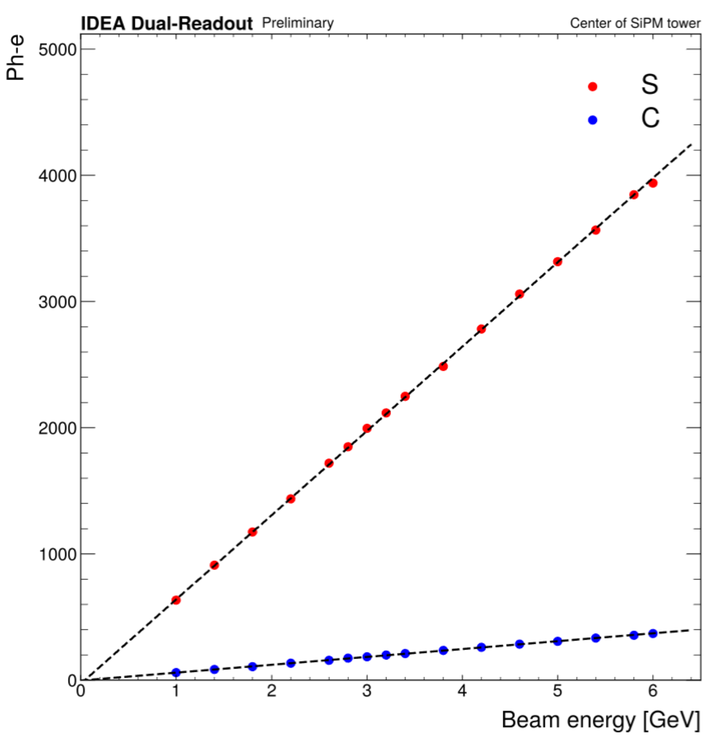
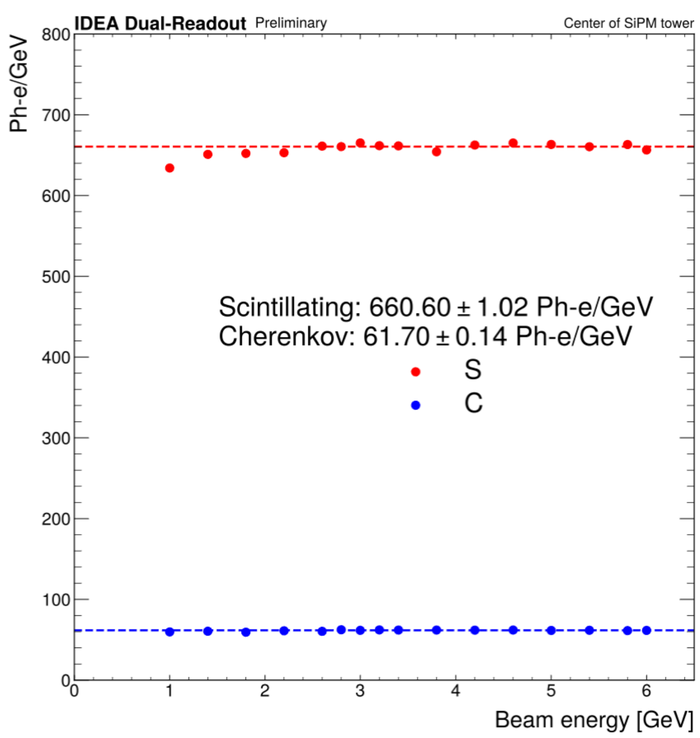
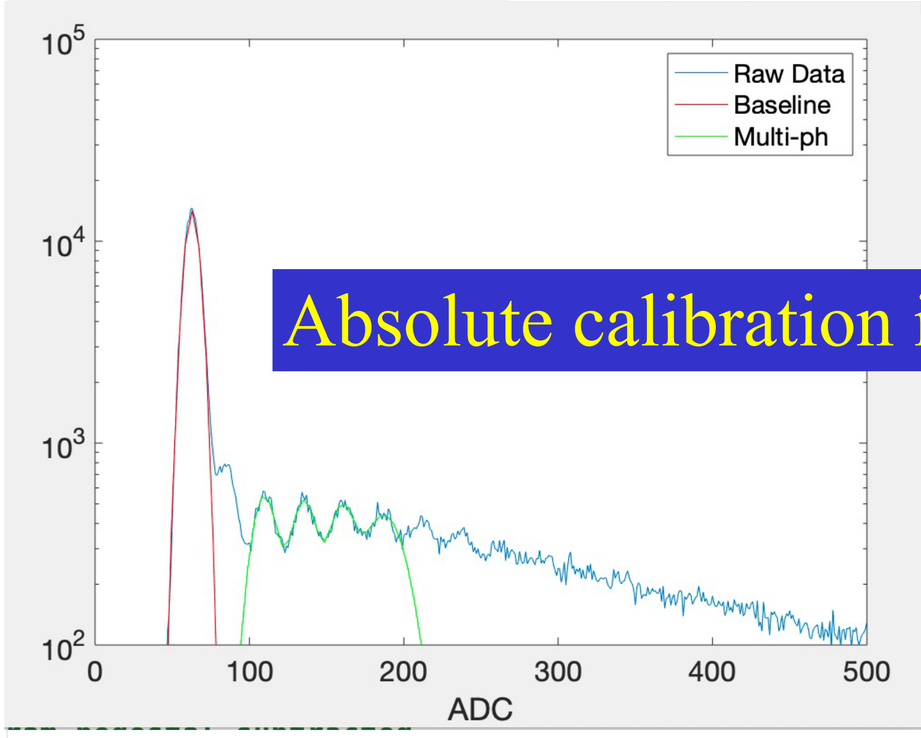


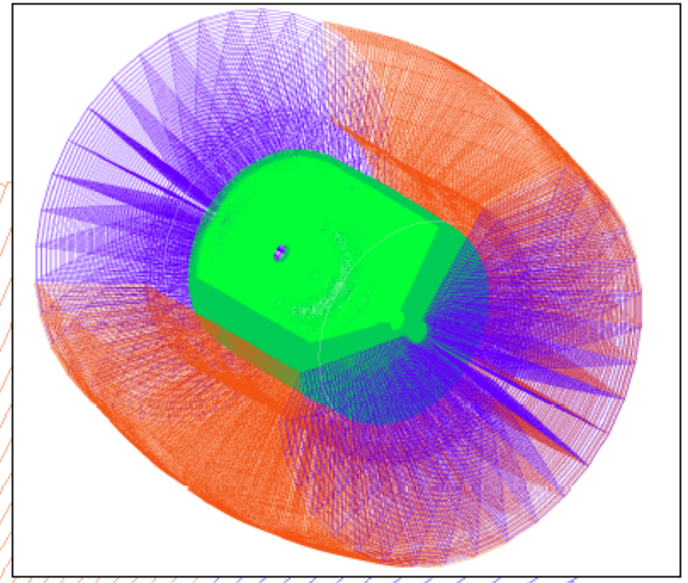


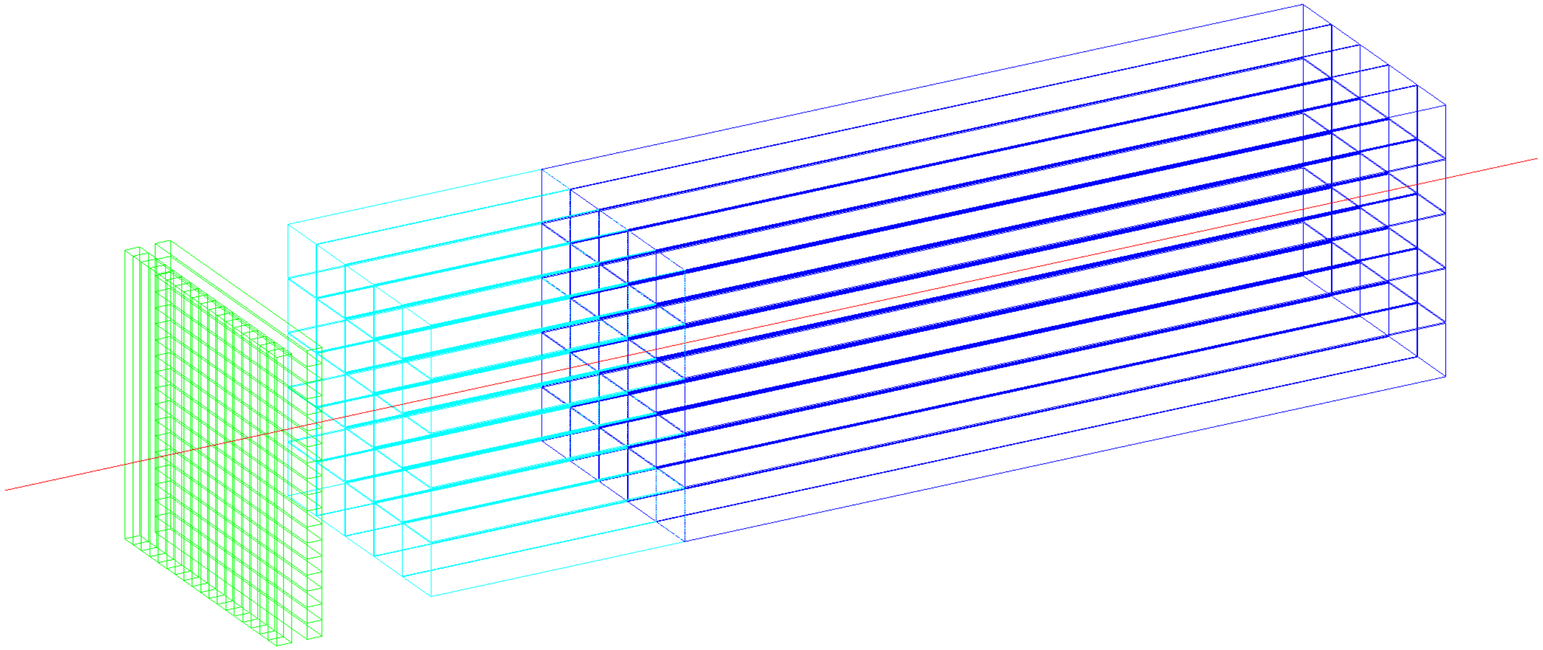




Absolute calibration in ph.e

# Crystal ECAL option



# Crystal ECAL option

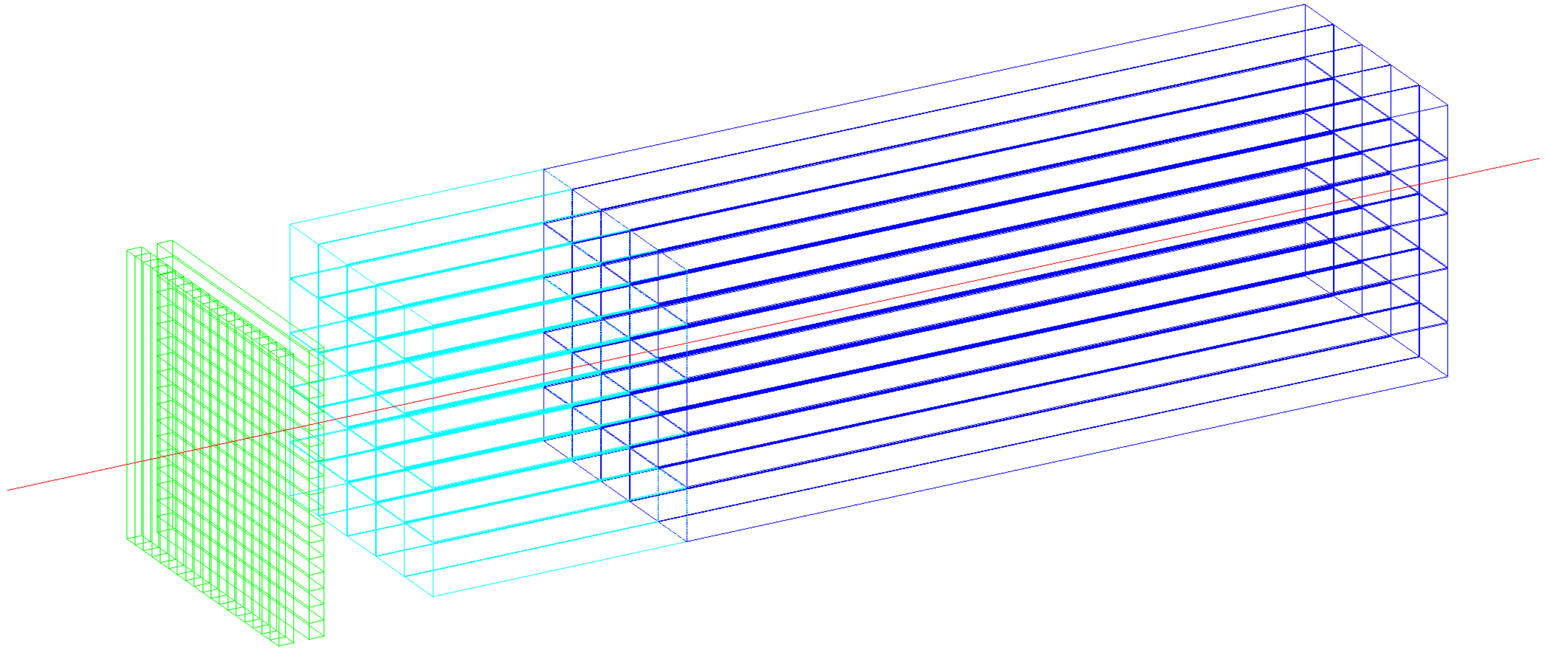


1x1x5 $cm^3$
PbWO

1x1x15 $cm^3$
PbWO

# Crystal ECAL option

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



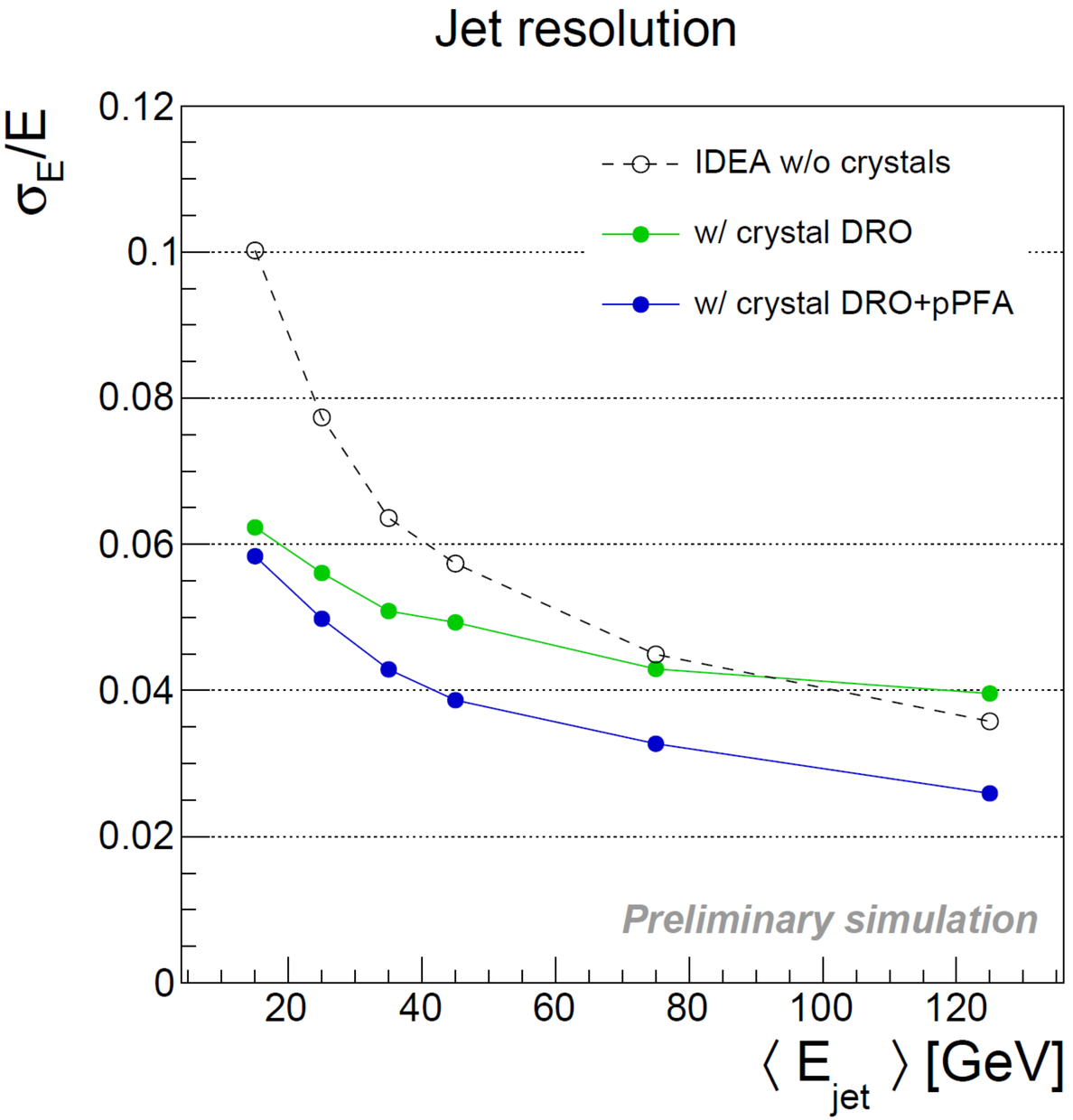
1x1x5 $cm^3$ PbWO

1x1x15 $cm^3$ PbWO

# Crystal ECAL 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)

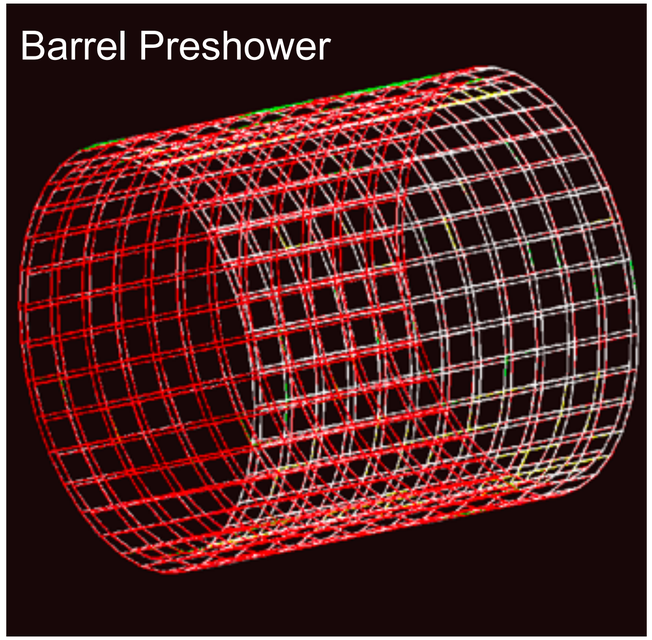


# Preshower and muon detector

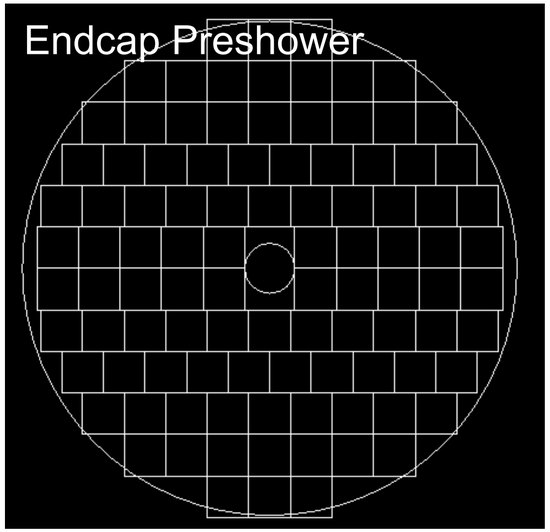
## Preshower Detector

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

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 1650 $m^2$

### Preshower

pitch = 0.4 mm
FEE capacitance = 70 pF
1.3 million channels

### Muon

pitch = 1.2 mm
FEE capacitance = 220 pF
5 million channels

# Some of the ongoing R&D

**Click here for more R&D information**

## More IDEA-related presentations at ICHEP2024

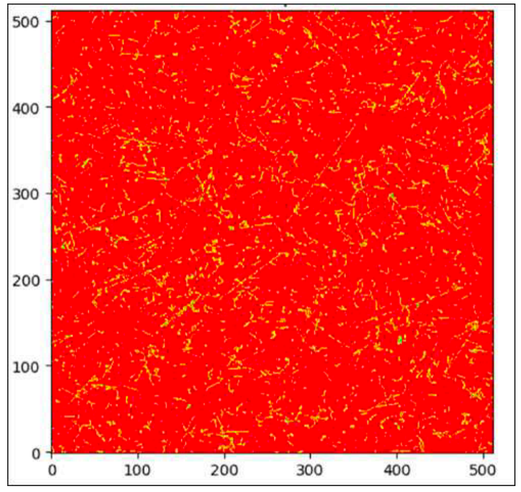
- F. Melendi, The μ-RWELL-based preshower and muon detectors of the IDEA detector concept
- W. Elmetenawee, Advancing Particle Identification in Helium-Based Drift Chambers: A Cluster Counting Technique Study through Beam Tests
- A. Ilg, Design, performance and future prospects of vertex detectors at the FCC-ee
- M. Abbrescia, Advancements in Tracking Techniques for Future Circular Collider Experiments
- A. Andreazza, The IDEA silicon tracker
- R. Zanzottera, The ATLASPIX3 CMOS pixel sensor performance
- R. Santoro, HiDRa - High-resolution Calorimeter for e+e-
- A. Loeschcke Centeno, Simulation and test beam results of a capillary tube, dual-readout calorimeter

# ARCADIA MD3 test

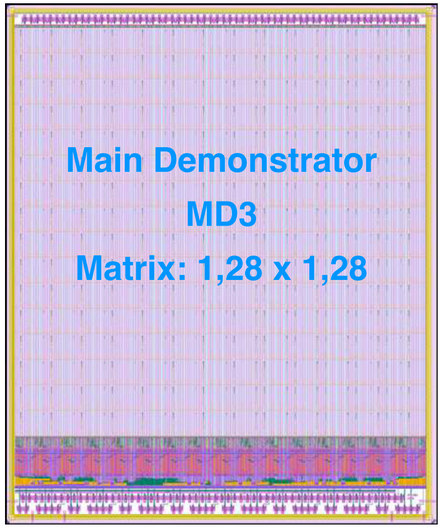
- 3 engineering runs with:
  - full-scale DMAPS
  - sensor R&D (monolithic FD-strips and readout, fast sensors with gain layer)
- High rate capability (100 MHz/cm$^2$) architecture on a scalable 512x512 pixel matrix (25 μm pitch) **MD3**

**Main Demonstrator chip:**

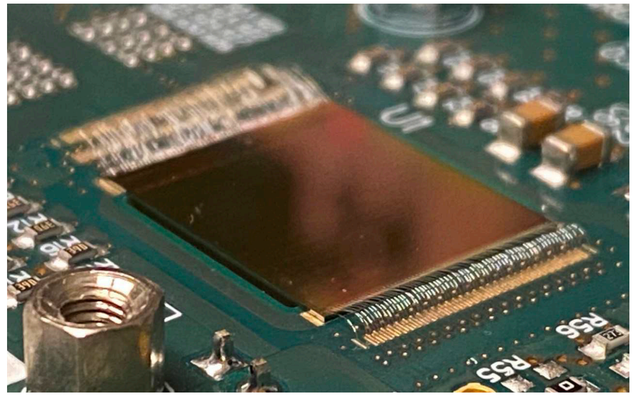
- measured 30 mW/cm$^2$ at full-speed (16 data Tx active) and 10 mW/cm$^2$ on low-rate mode (1 data Tx active)

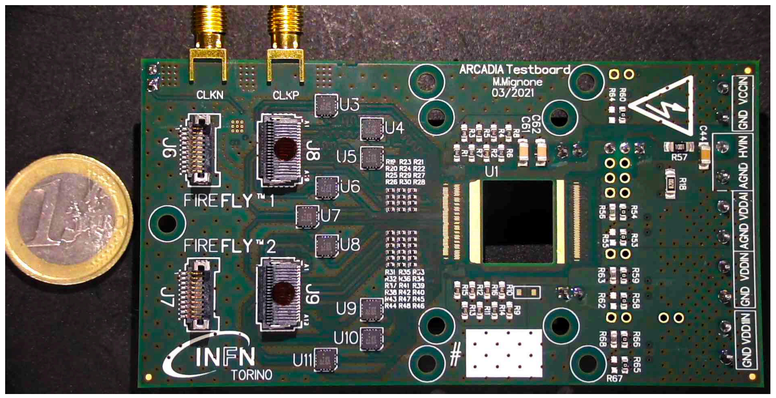



Cosmic ray data



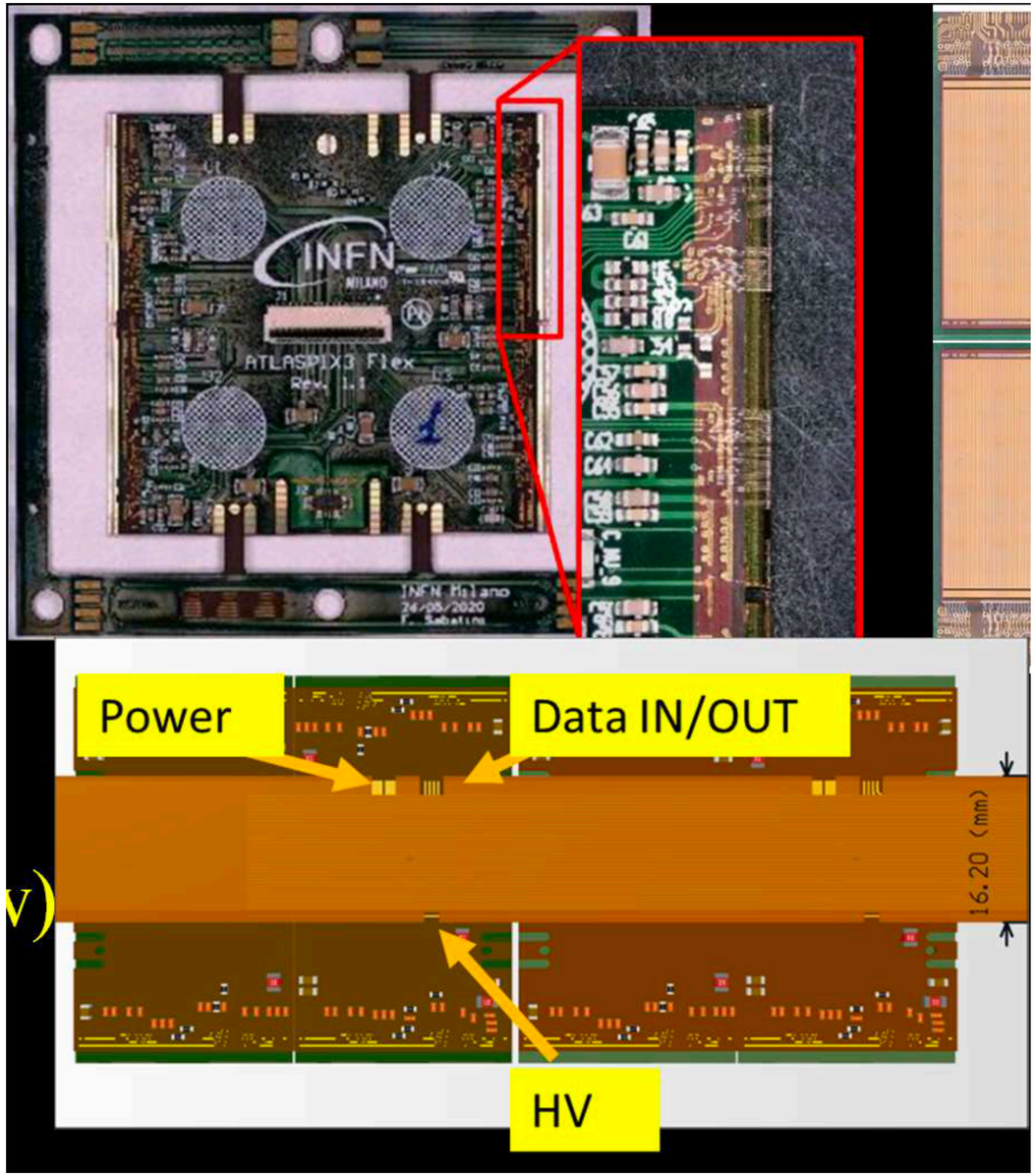

110 nm CMOS CIS technology, high-resistivity bulk, operated in full depletion mode





# 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)

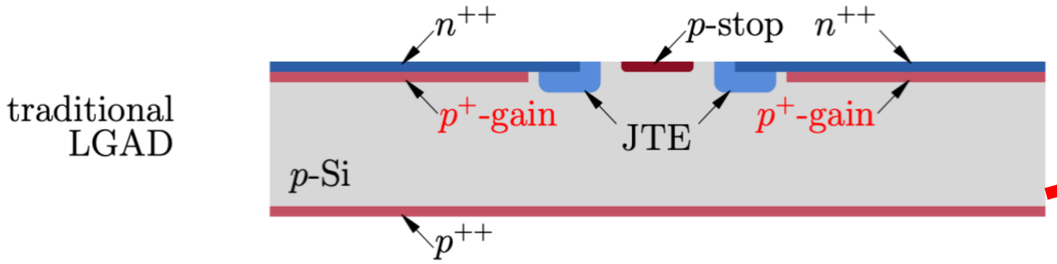


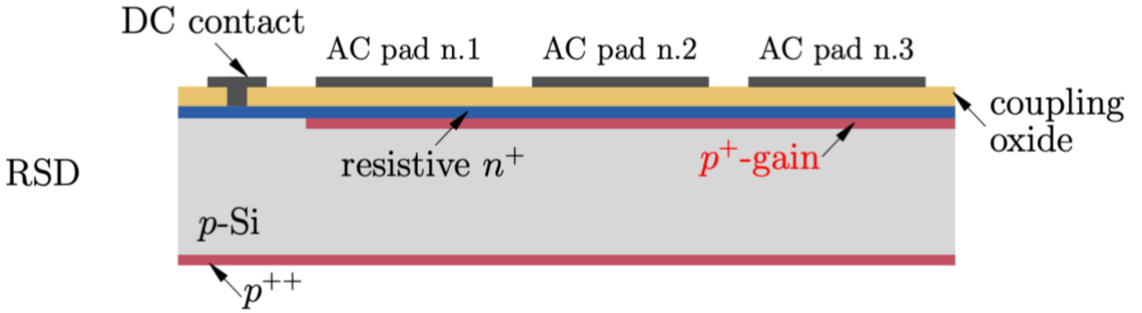
# Resistive LGAD

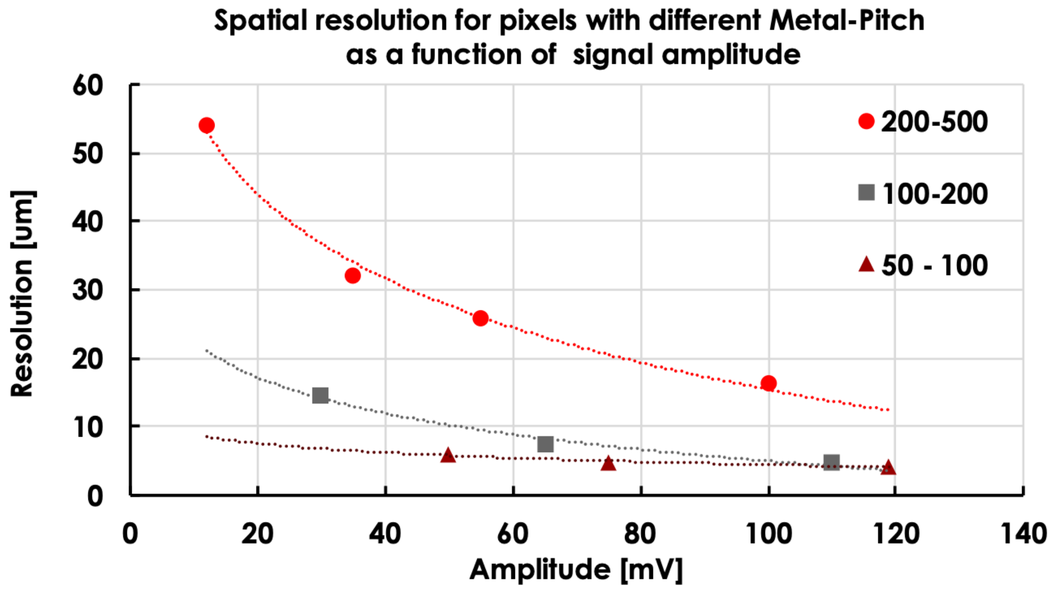


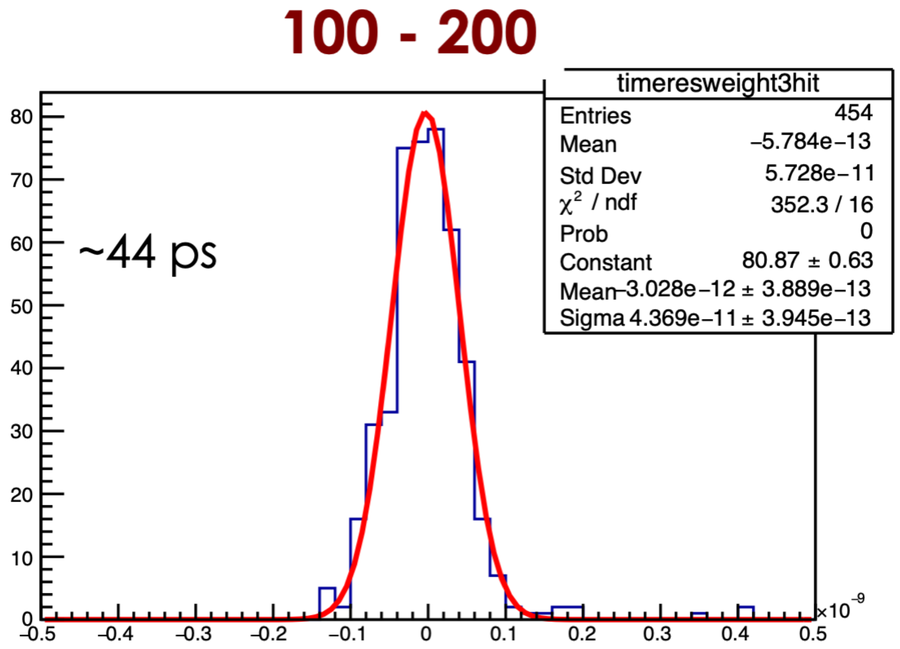
## ❖ Recent new activity with INFN-GE/(TO)

➢ Match time and position resolution



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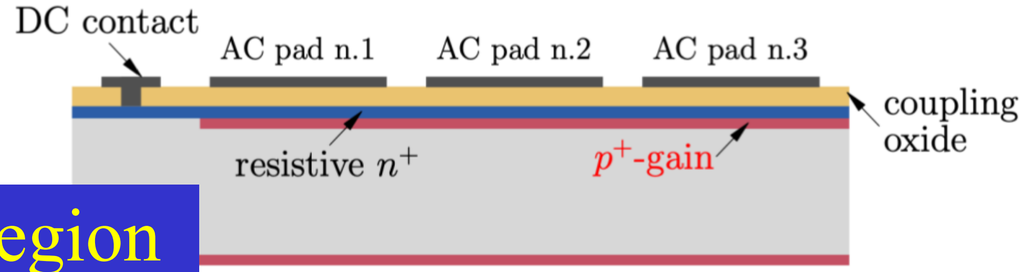
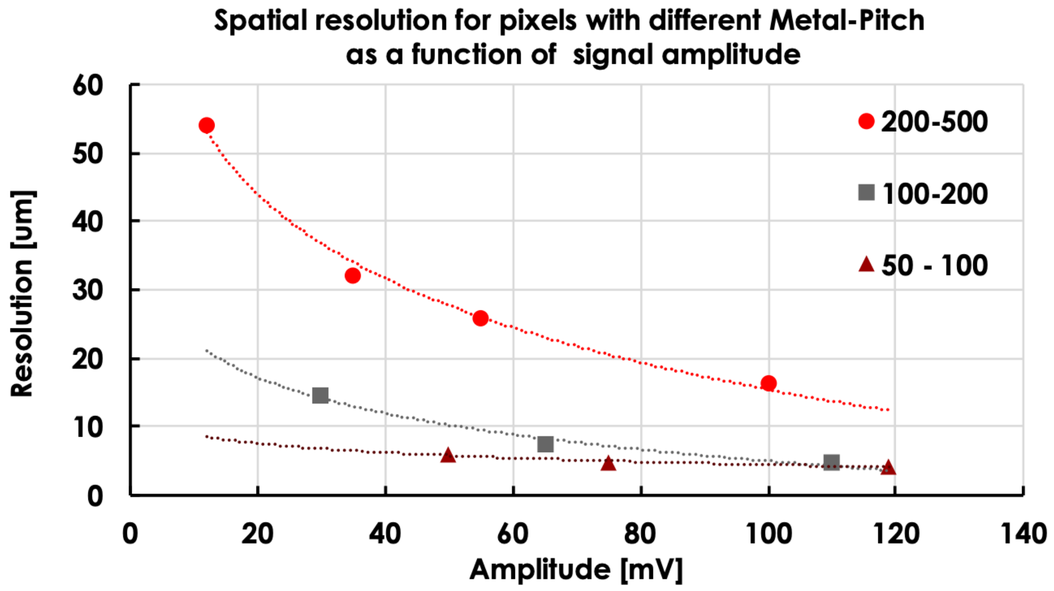
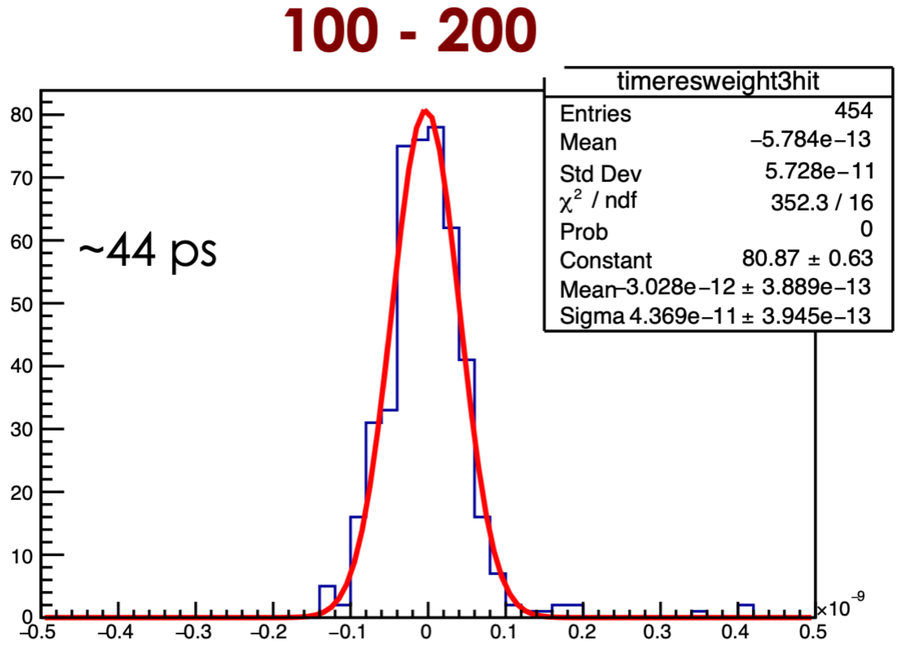



**Very attractive option for timing in Si wrapper region**

**Cost reduction is major area of R&D**

**Some "fast" devices also prototyped by Arcadia group**



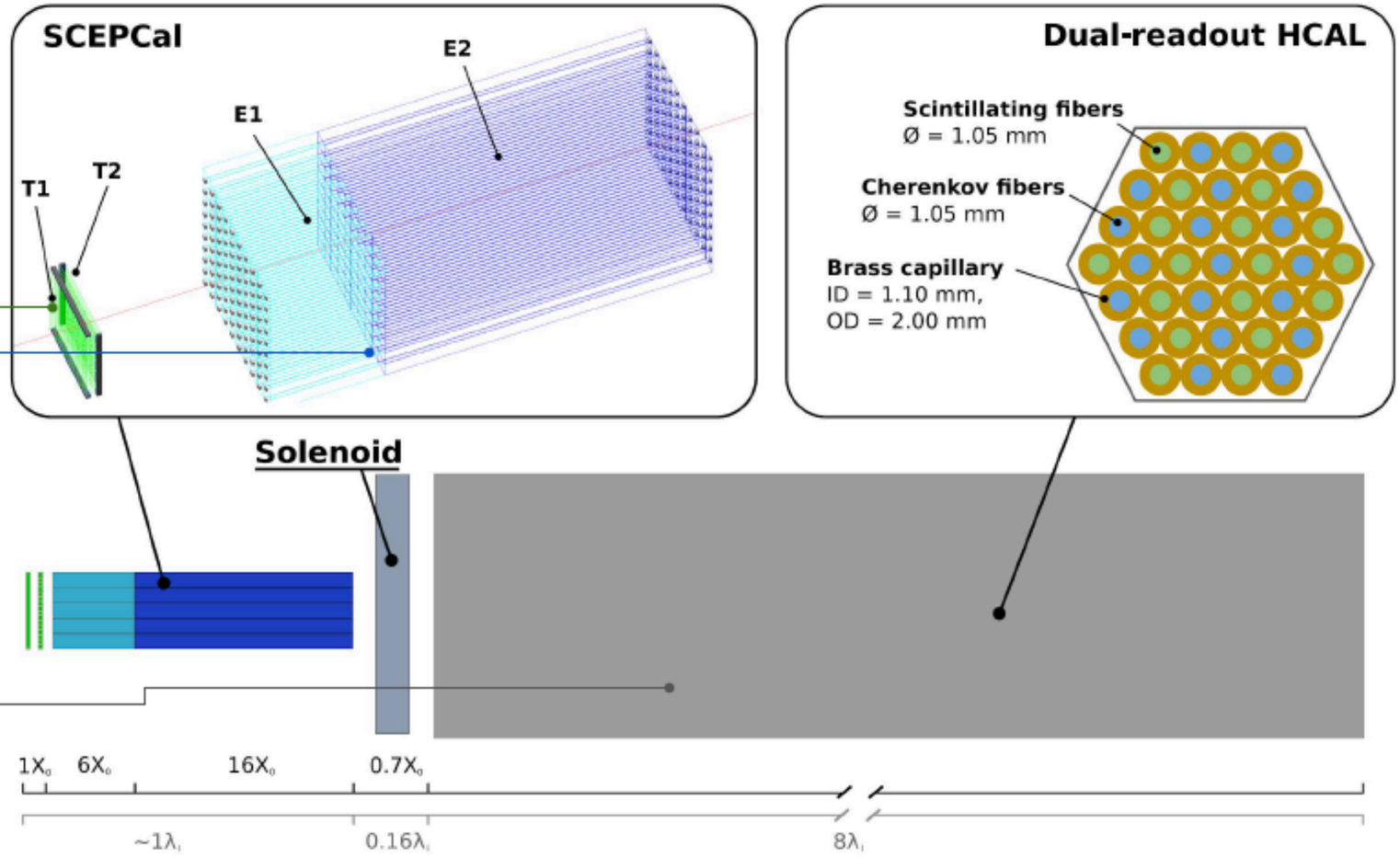



# Crystal ECAL with DR calorimeter

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



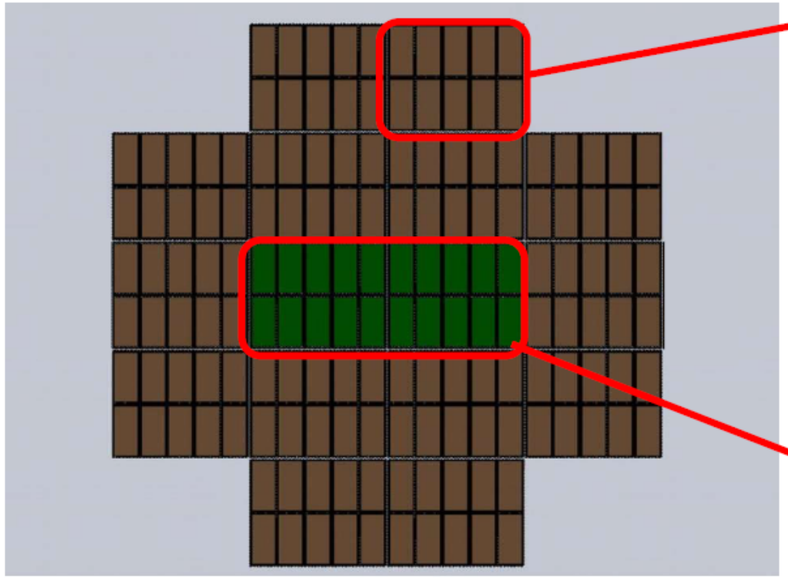

**M. Lucchini**

# DR calorimeter

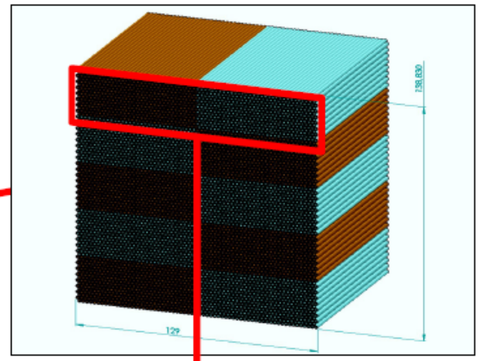
## ❖ Full containment hadronic prototype in progress

➢ Hidra2 call INFN CSN5

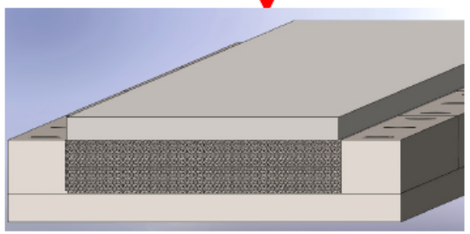
Hadronic-size prototype:
16 modules w/ highly granular core



~ 65 × 65 × 250 cm³



1 Module: 5 MMs
~ 13 × 13 cm²
5120 fibres

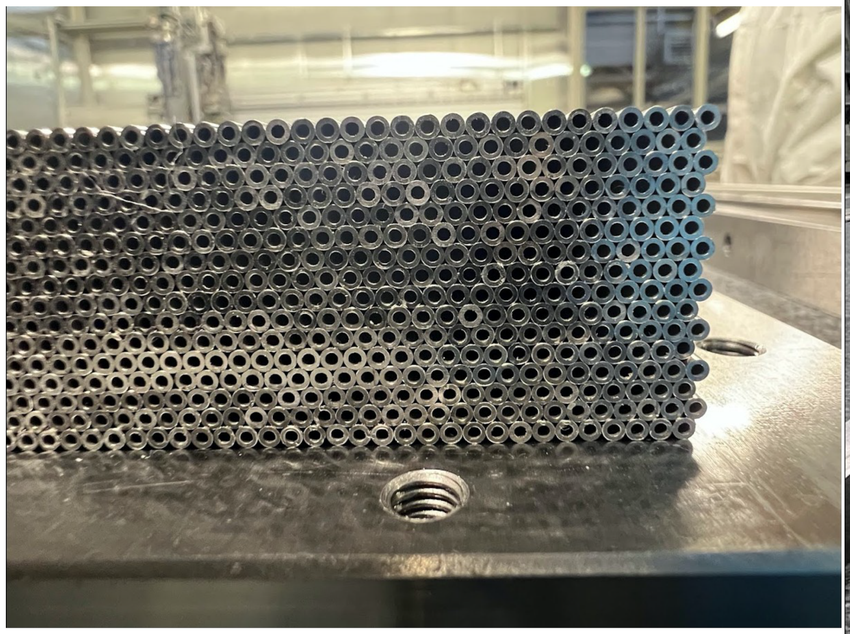


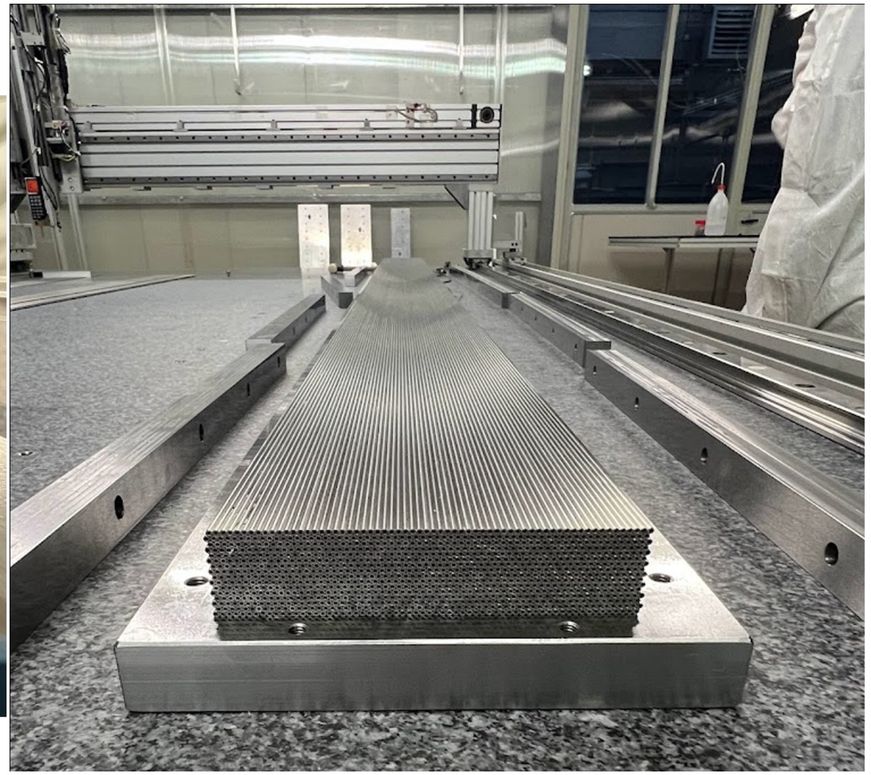
1 MiniModule:
64 × 16 = 1024 fibres in total
(512 S + 512 C)

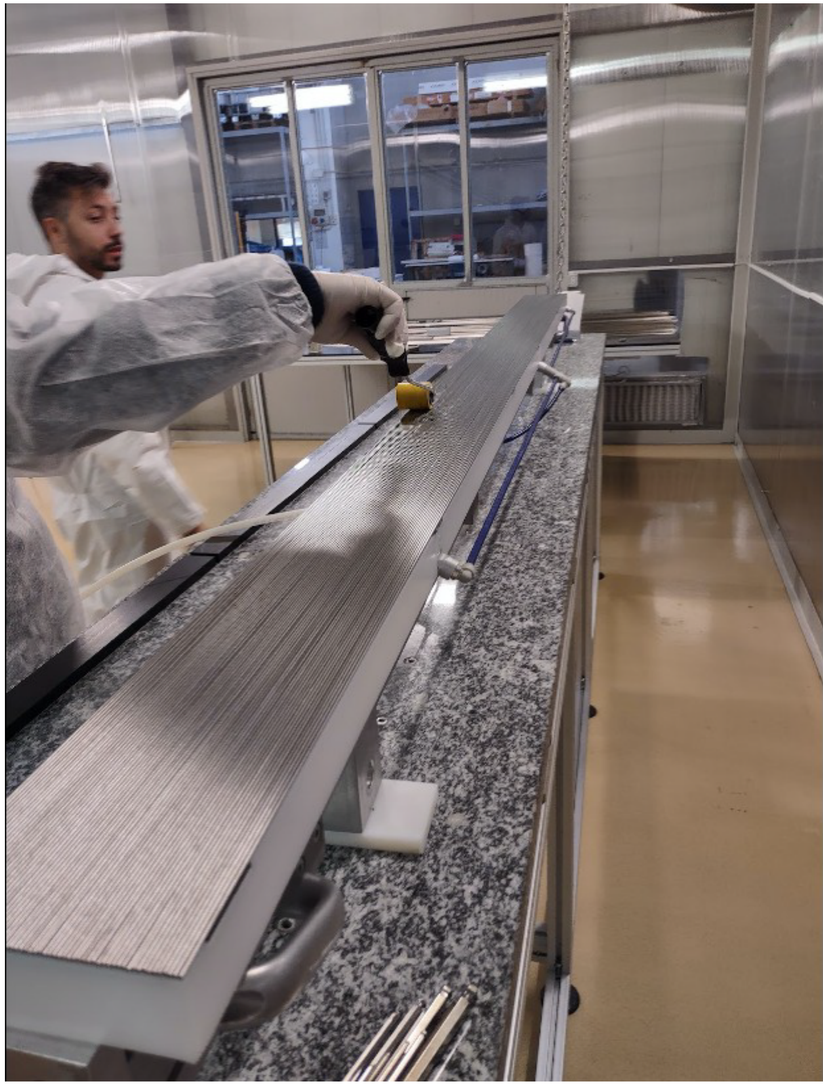
highly granular core:
10240 fibres to read out with SiPMs

# DR calorimeter

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







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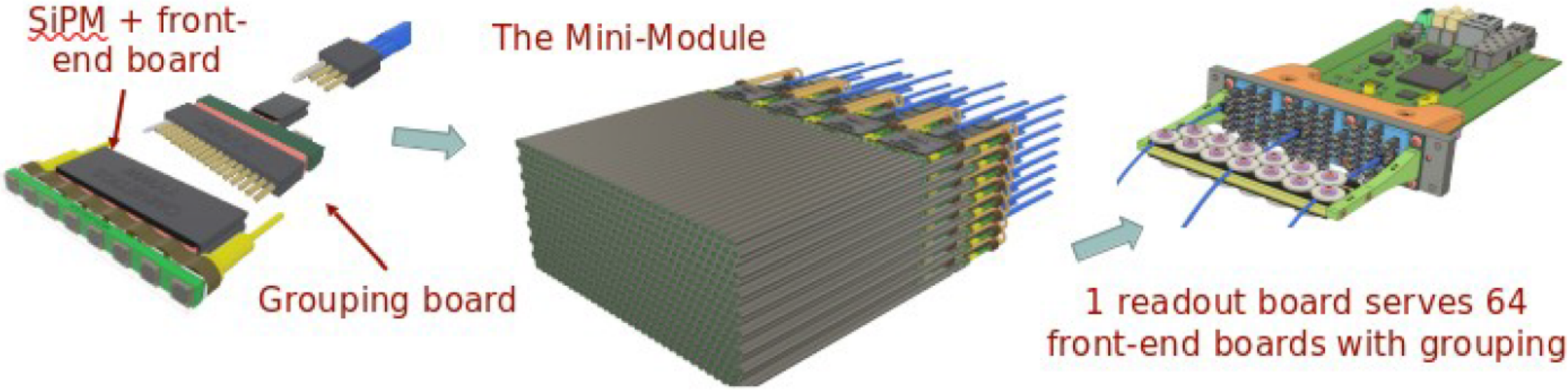
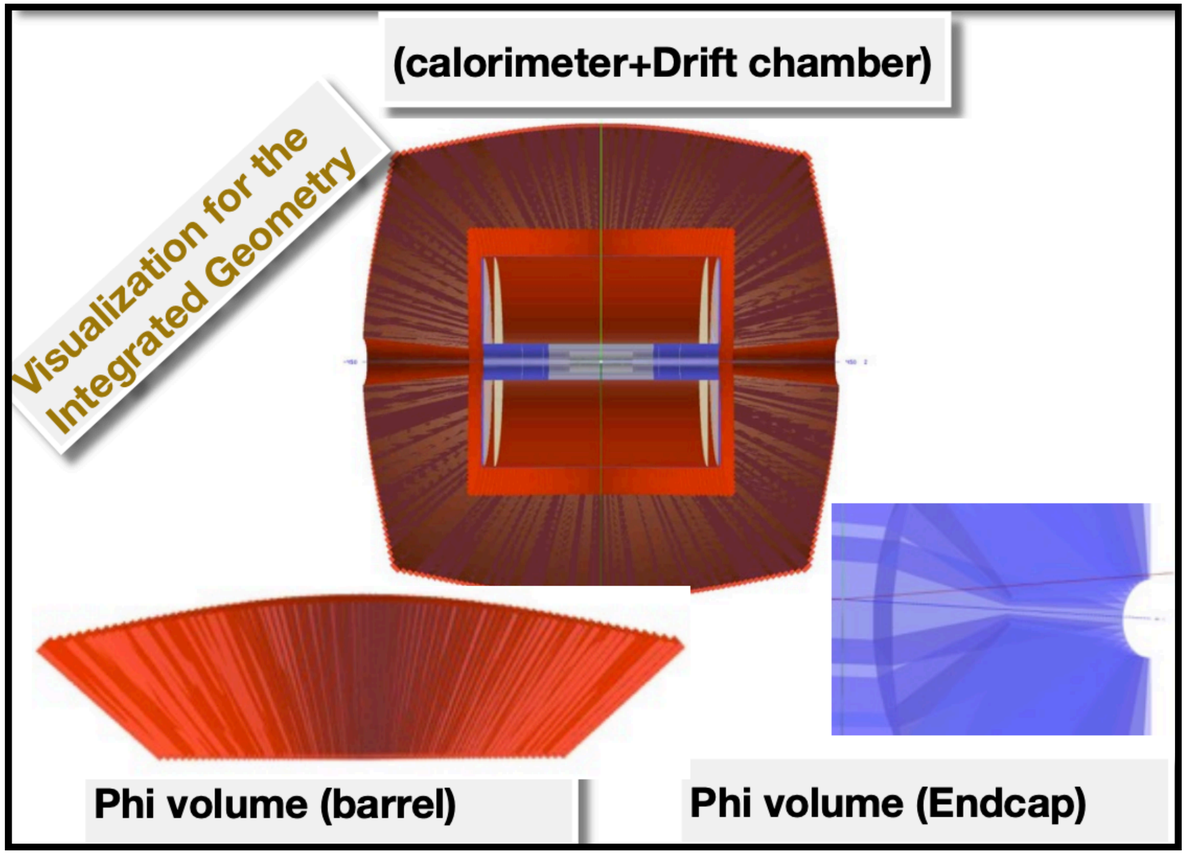


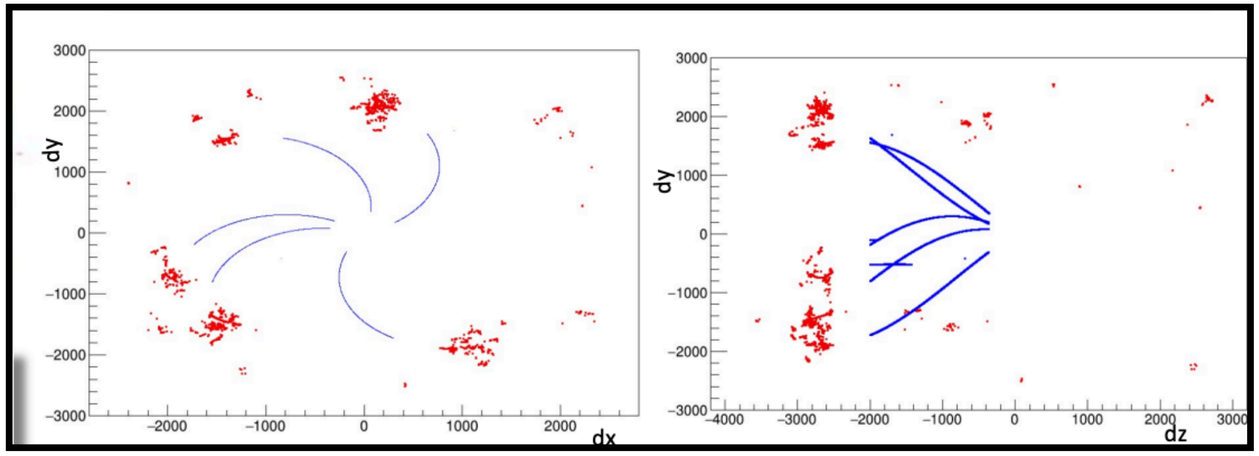
# Status of Simulation of IDEA concept




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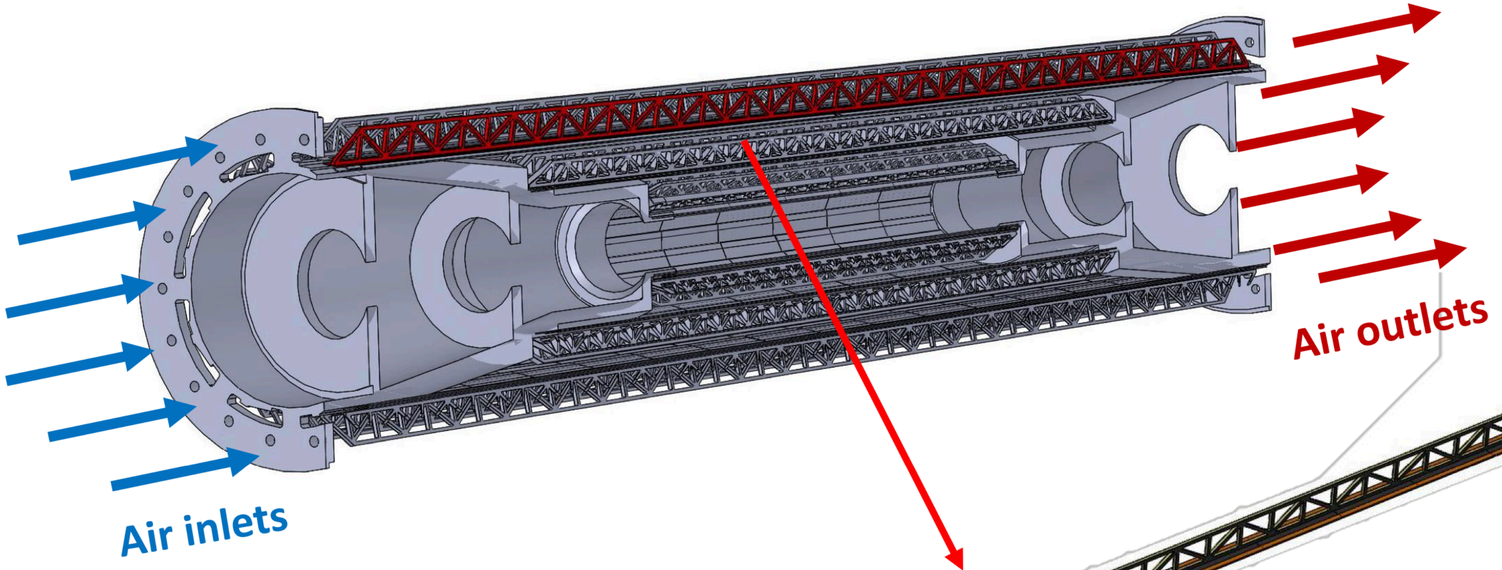
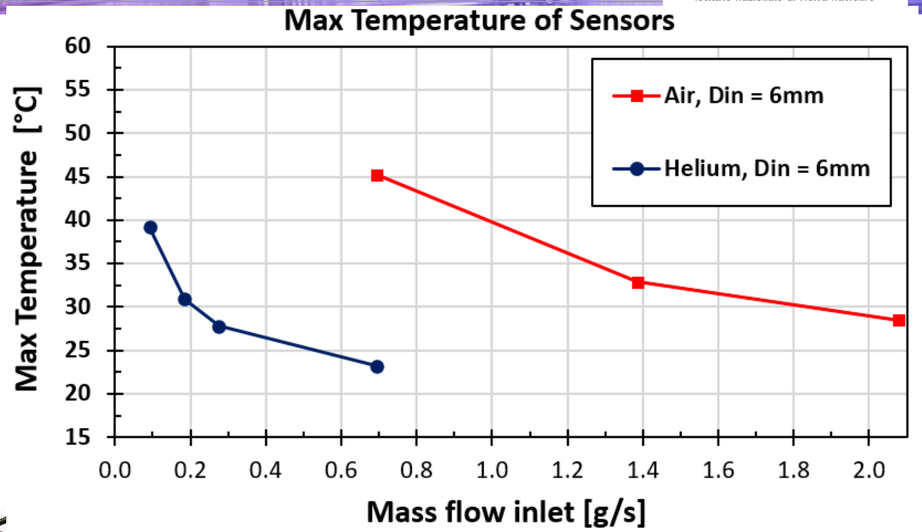
  - Now several international colleagues have joined these efforts
- Lots of possibilities for international colleagues to join IDEA and help on all these developments!!

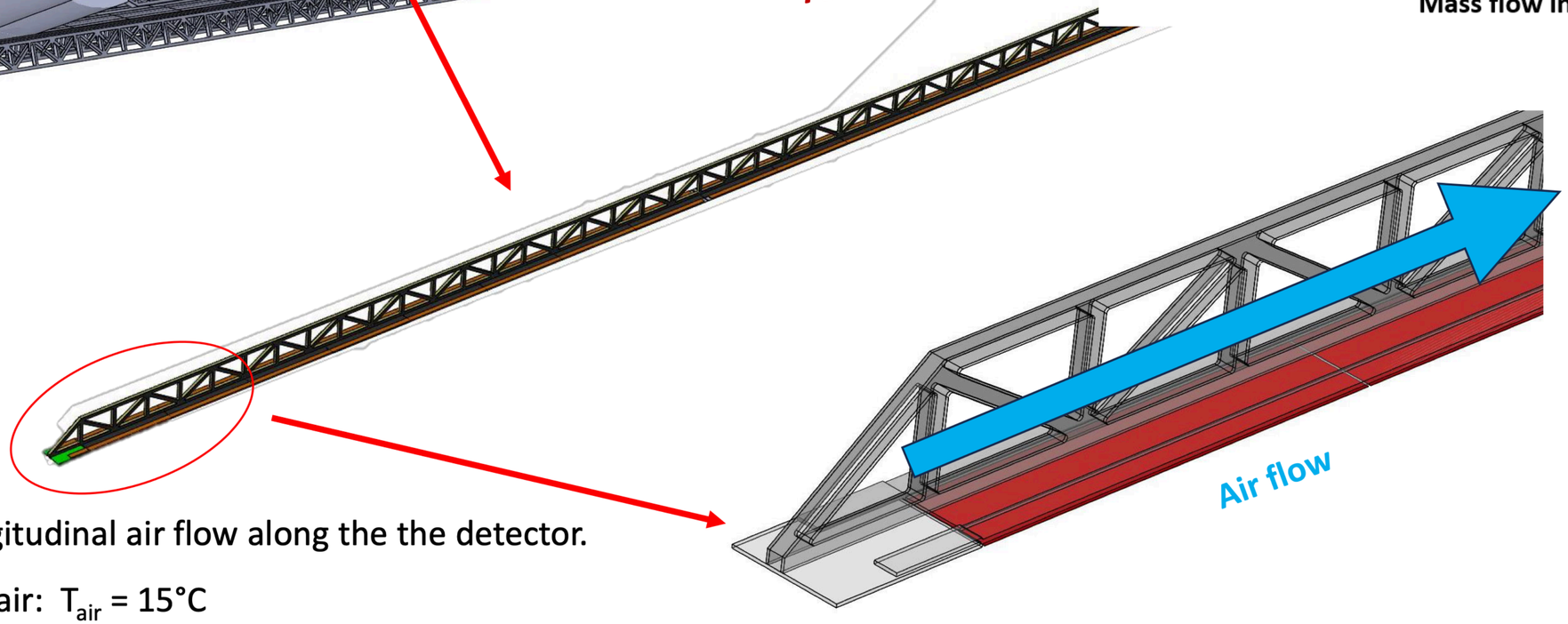
# Backup

# Vertex detector: IDEA

## AIR COOLING CONCEPT



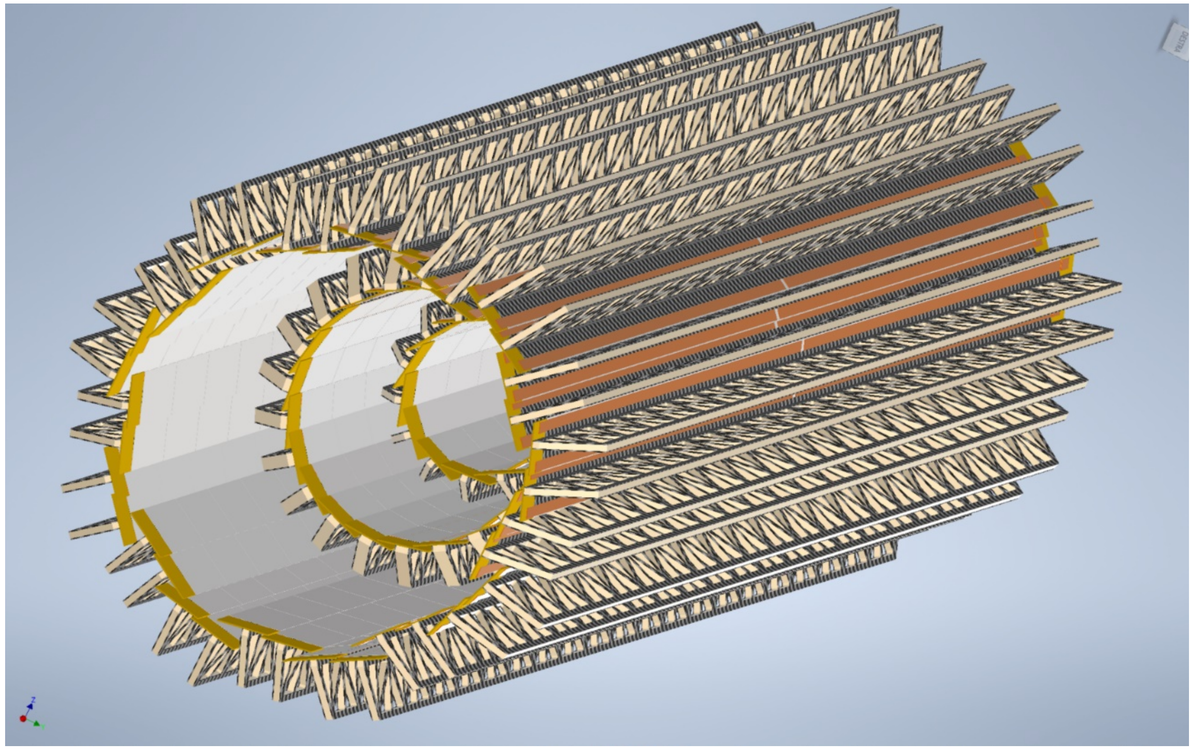



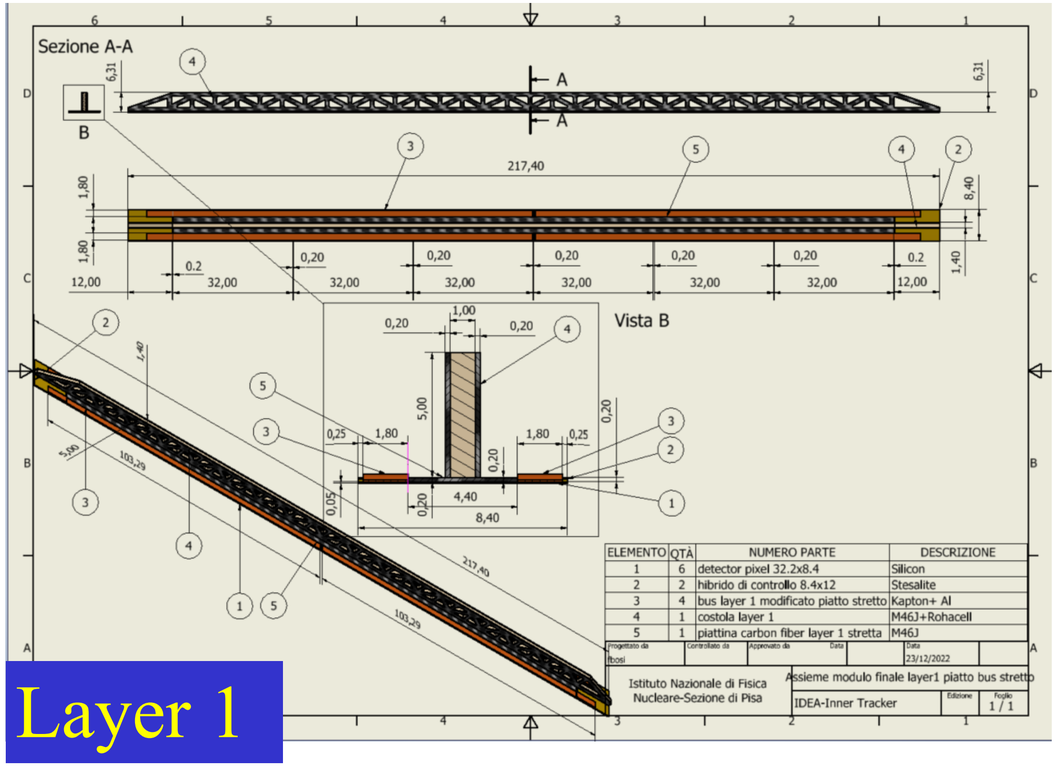

- Cooling method: longitudinal air flow along the the detector.
  - Temperature of air: $T_{air}$ = 15°C

C. Turrioni

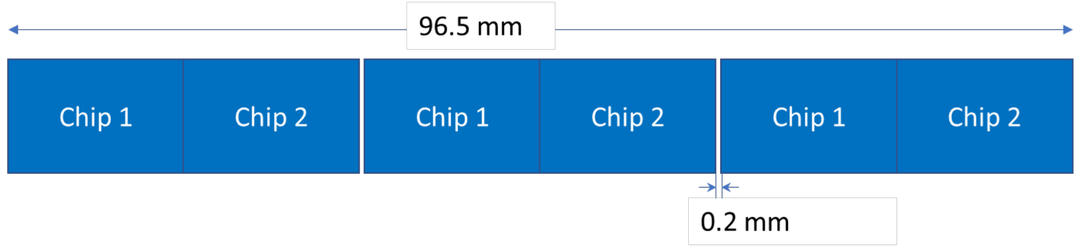
# Vertex detector mechanical integration

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






Layer 1



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- Vertex design based on:
  - ARCADIA inner 3 layers
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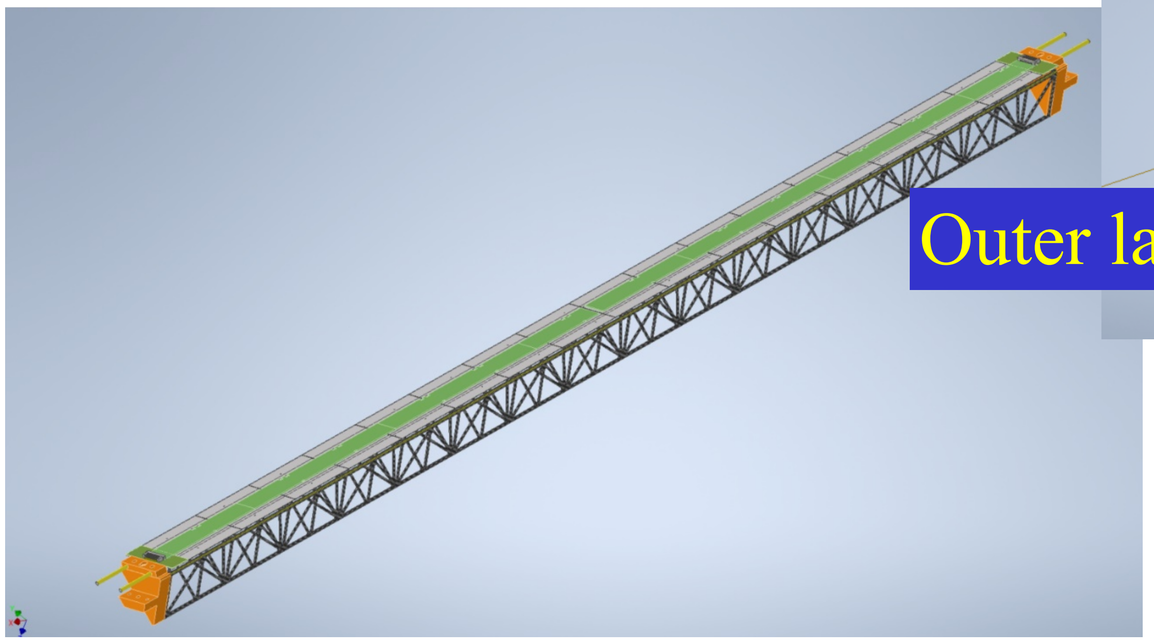
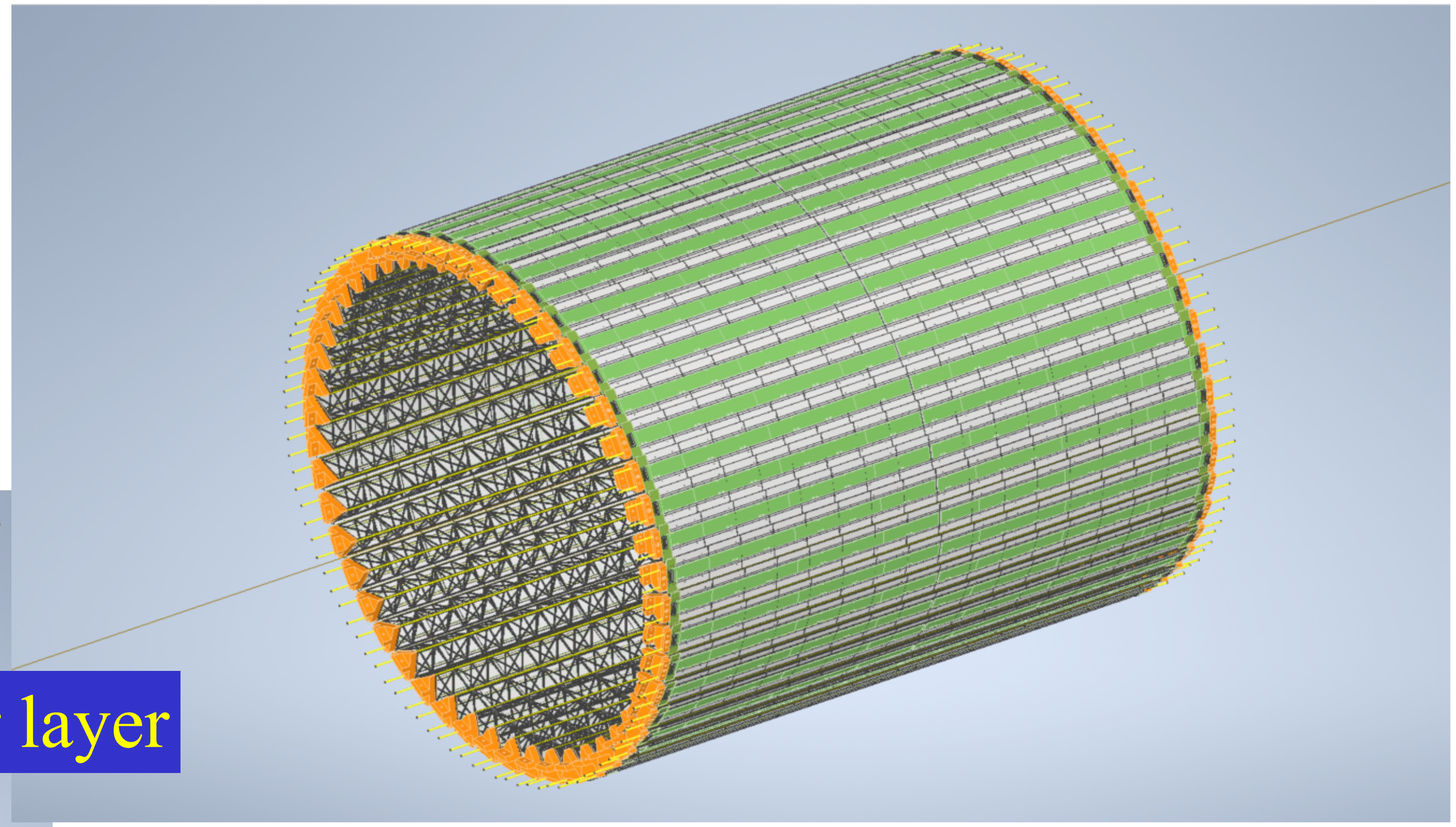
  - AtlasPix3 outer 2 layers/disks
    - Liquid cooled





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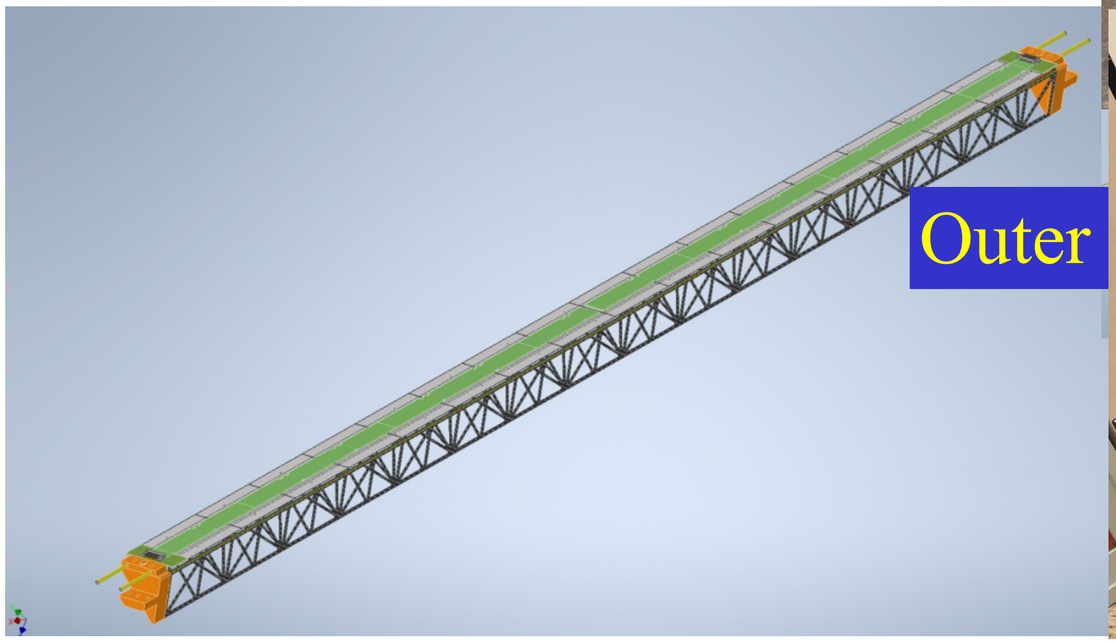
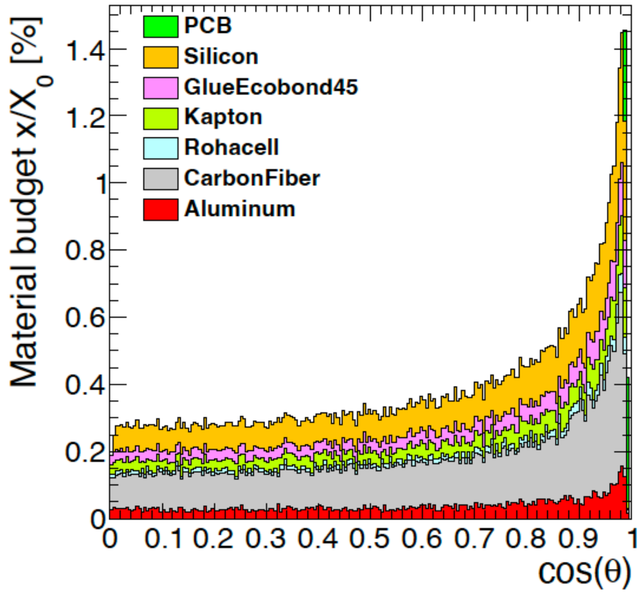
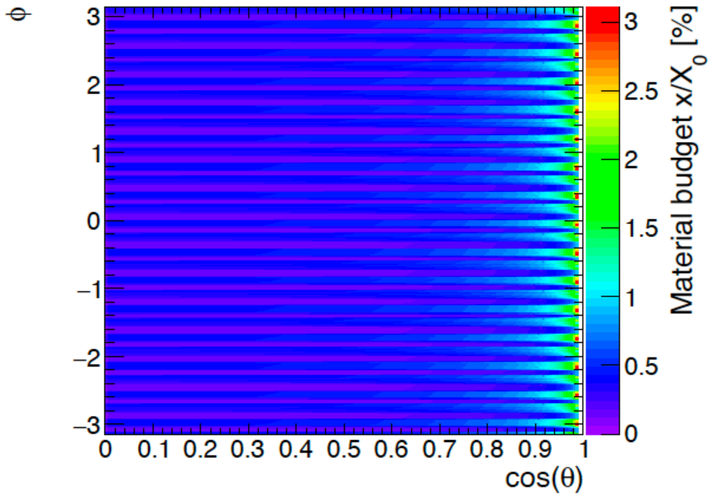


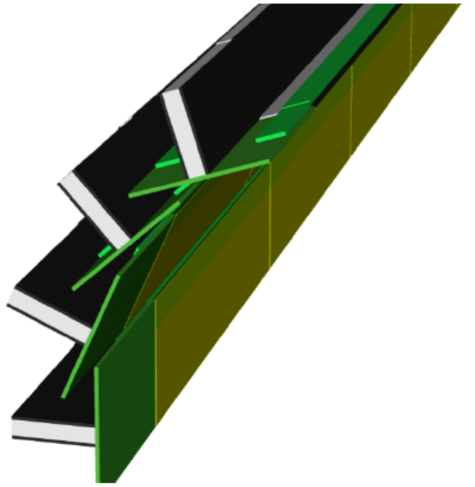

# Vertex inner barrel

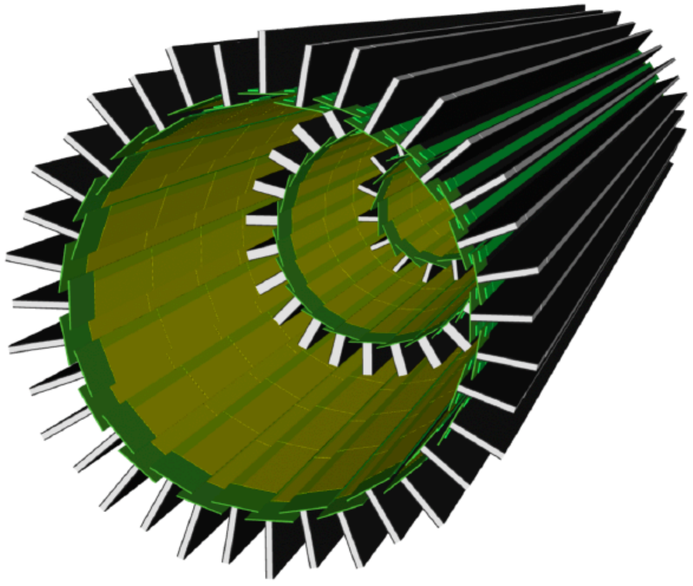
- Correct material stack, end-of-stave hybrid, insensitive sensor areas, ...
- Inner vertex support imported through DDCAD, but not included in material budget estimation
- Cooling cones not implemented yet, but outside of vertex acceptance
- Material budget in line with 0.3% per layer at $\cos(\theta)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




Layer 0, others in backup



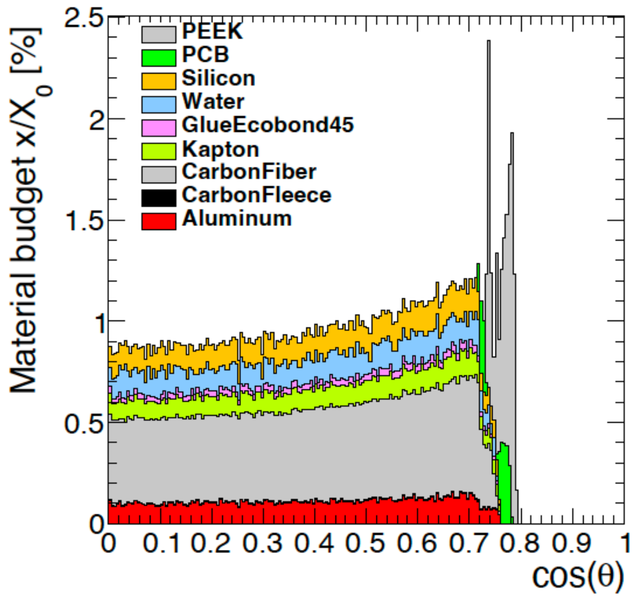


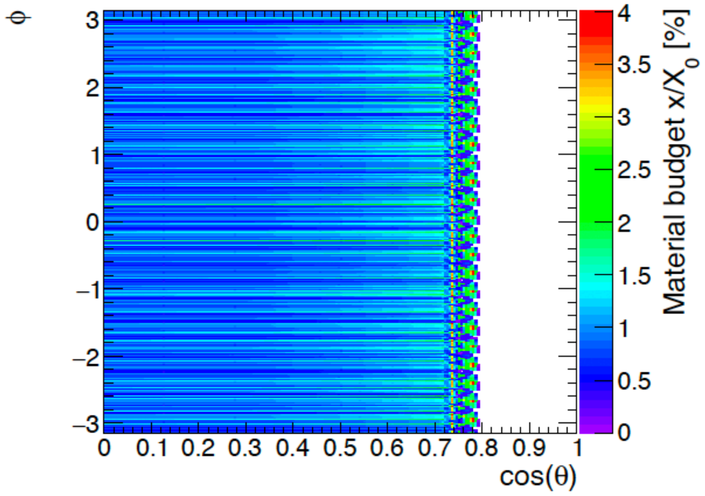
Vertex inner barrel, without support

A. Ilg

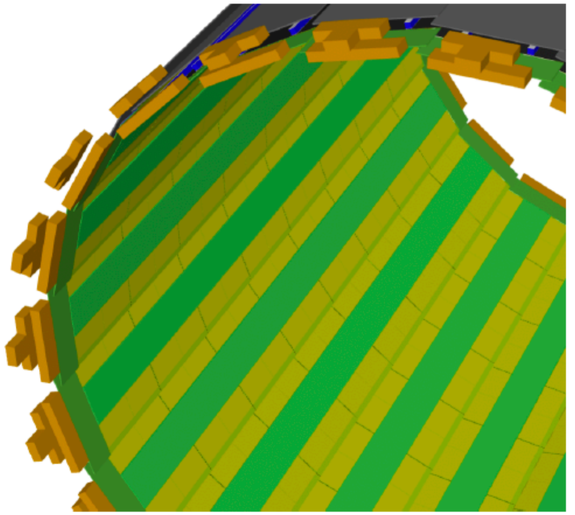
# Vertex outer barrel

- 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

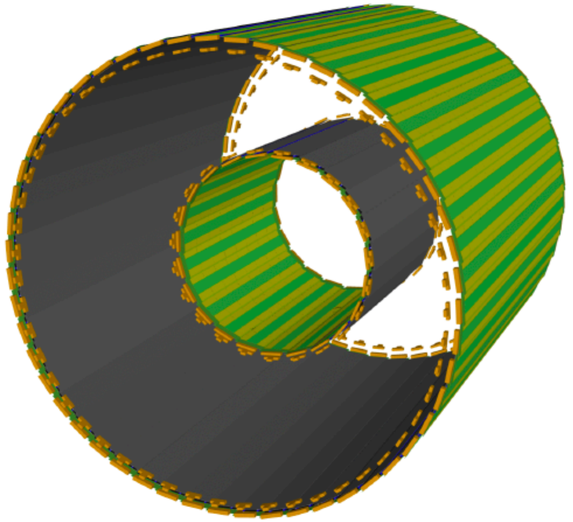



Complete outer barrel



Middle tracker

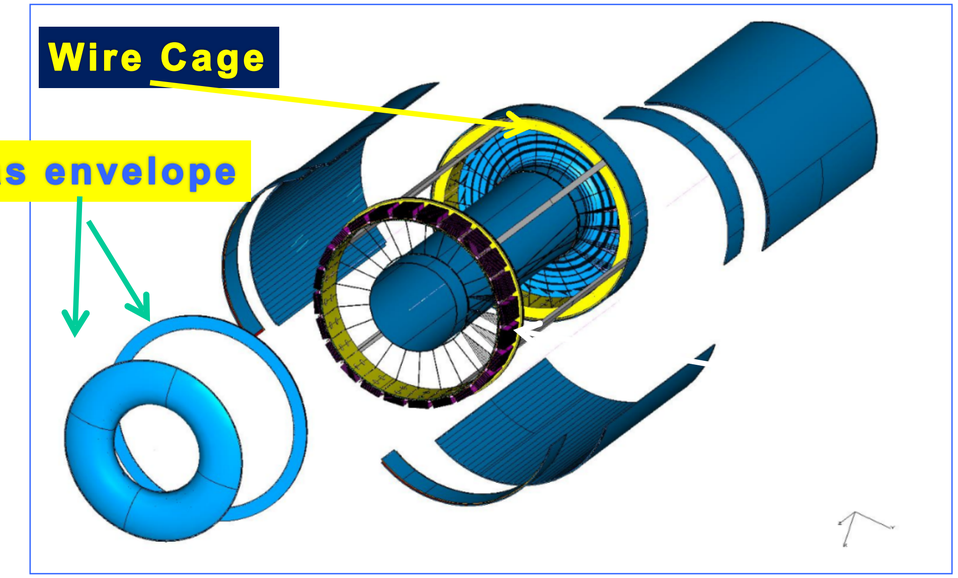


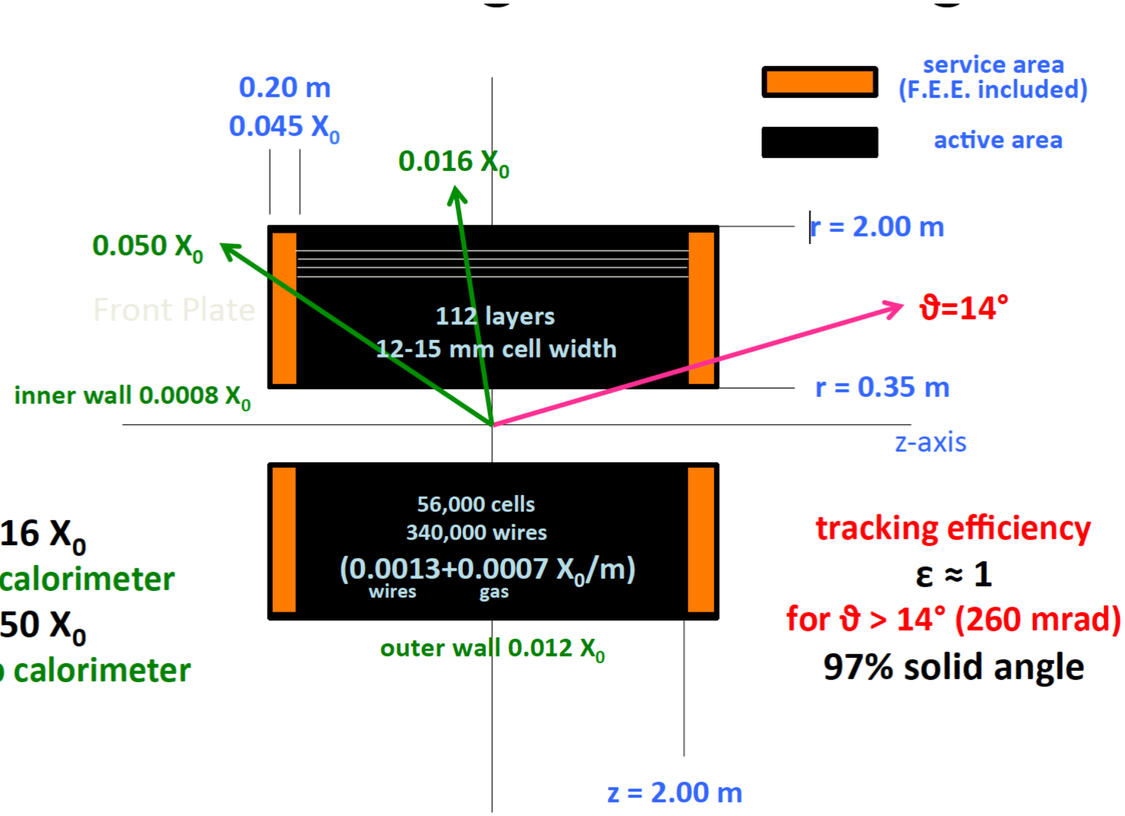
Complete vertex outer barrel system

A. Ilg

# Drift chamber

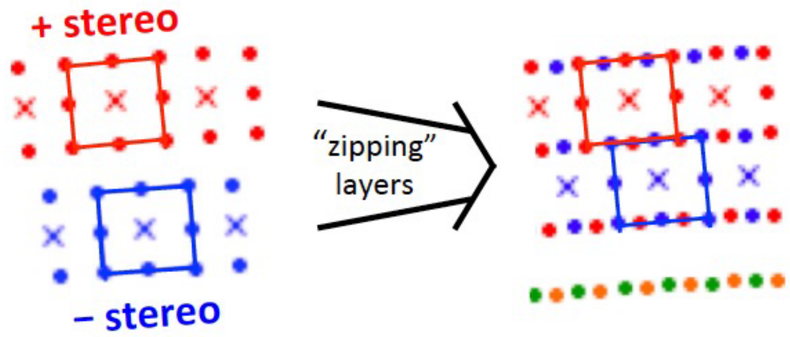
- 90% He - 10% $C_4H_{10}$ – All stereo – $\sigma \sim 100\ \mu m$
- Small cells, max drift time ~ 350 ns



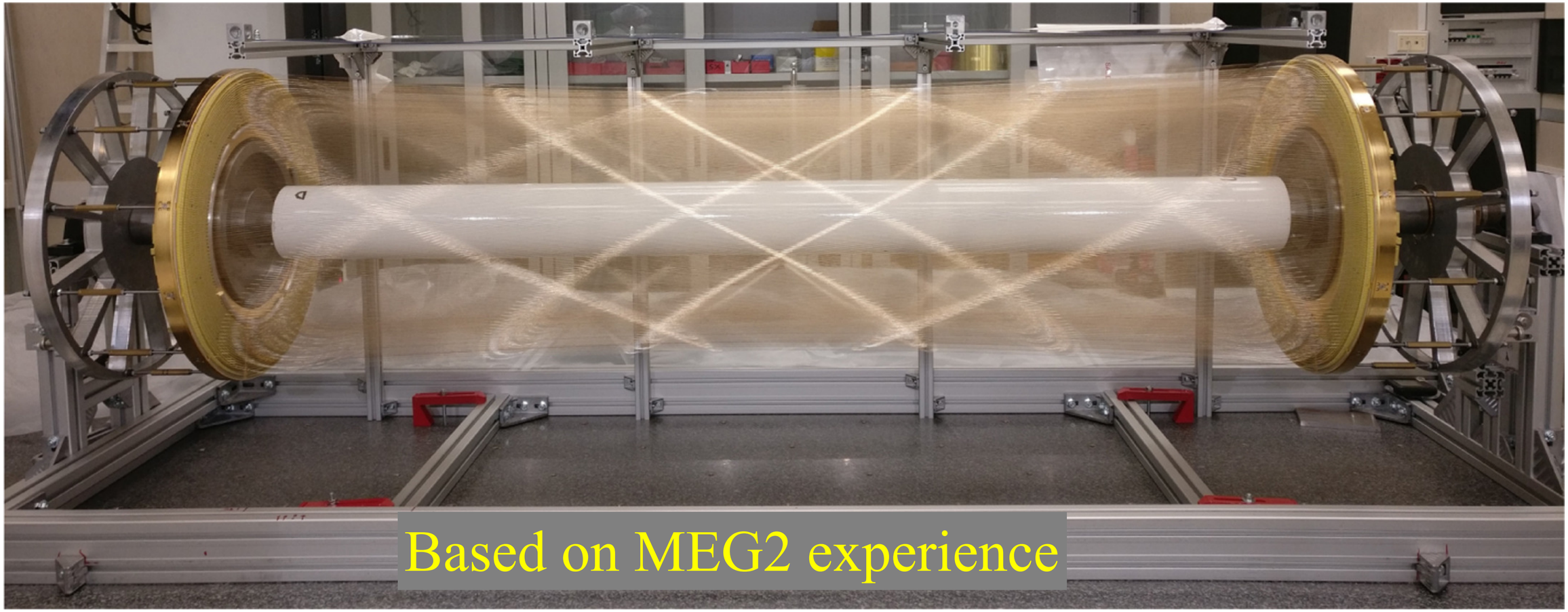

**0.016 $X_0$**
**to barrel calorimeter**
**0.050 $X_0$**
**to end-cap calorimeter**

**tracking efficiency**
**ε ≈ 1**
**for ϑ > 14° (260 mrad)**
**97% solid angle**

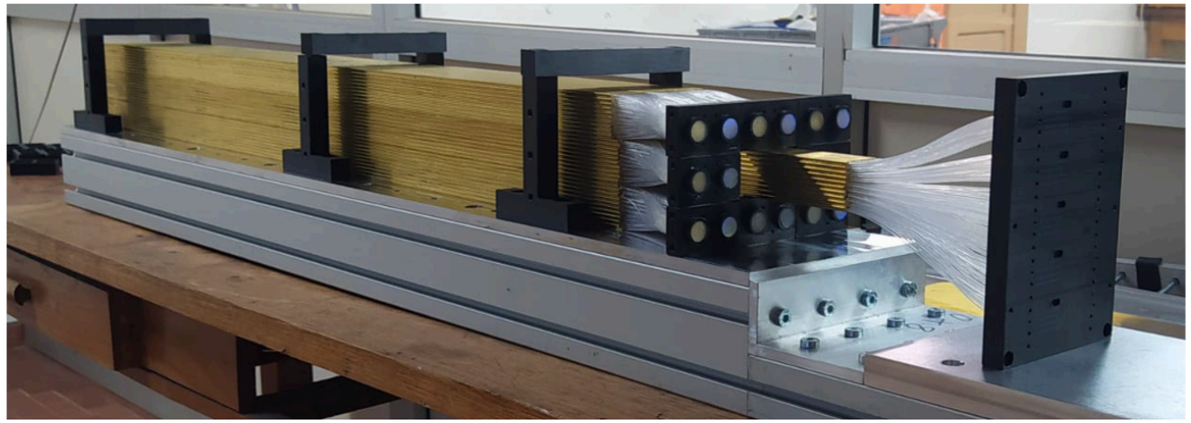


# Drift chamber

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



# 2020 Dual Readout prototype

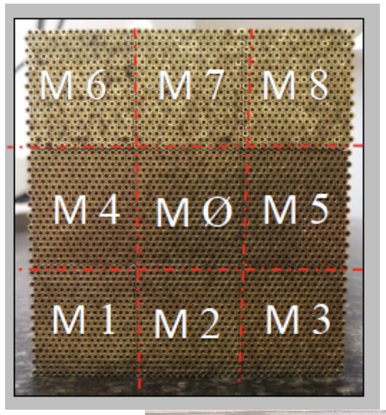


Electromagnetic dimensions of 10x10x100 $cm^3$

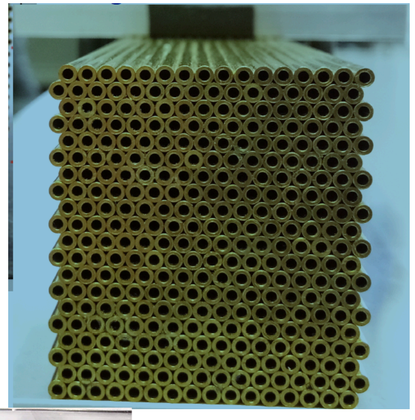
9 towers containing 16x20 capillaries (160 C and 160 S)

Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm
1-mm-thick fibers

**Full prototype - 9 towers**



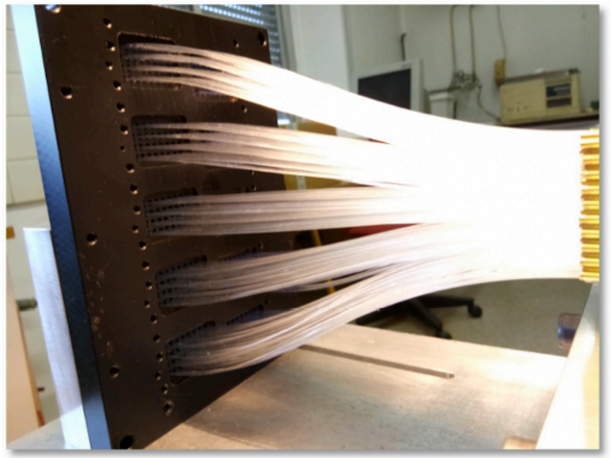

**Single tower**

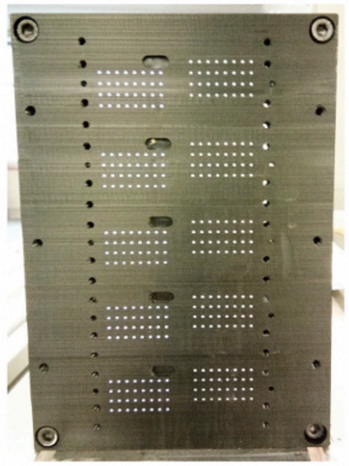


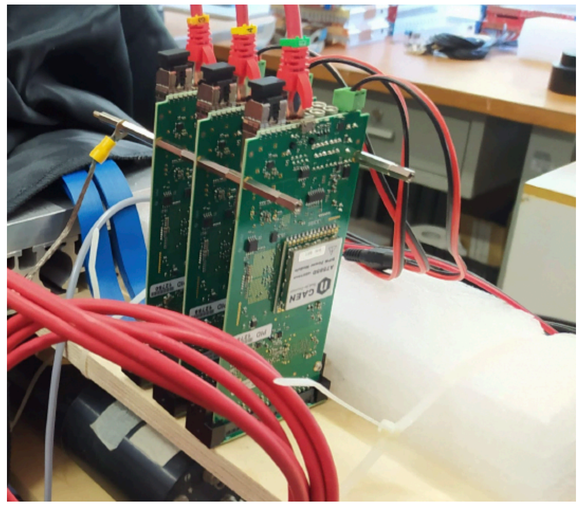

**"Bucatini calorimeter"**

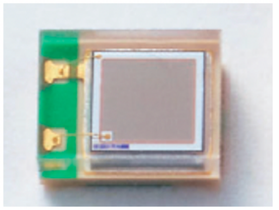
**Front end board housing 64 SiPM**

**Fiber guiding system**





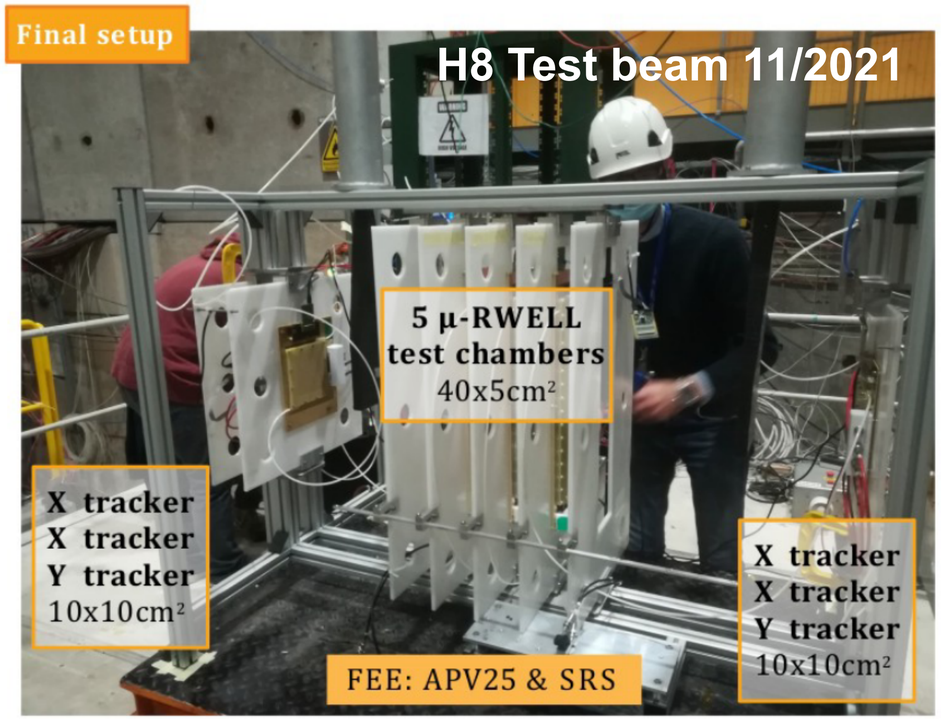




**Hamamatsu SiPM: S14160-1315**
**PS Cell size:** 15 $\mu m$

**Readout Boards CAEN A5202**

# μ-RWELL: Test beam 2021



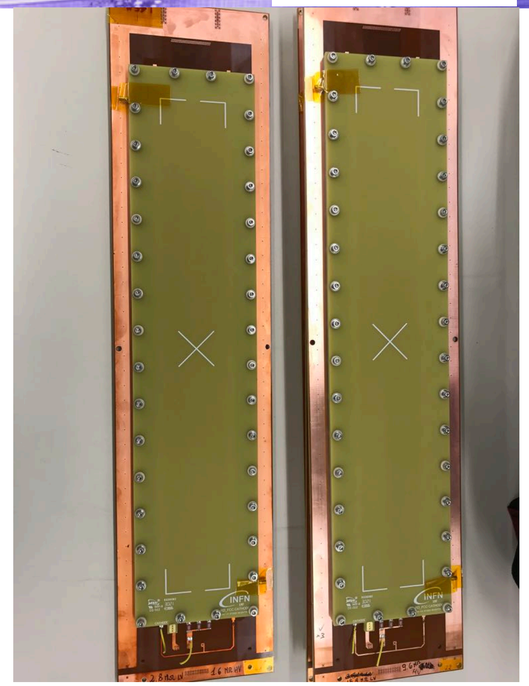

140-180 GeV/c muon and pion beam
Operated in Ar/$CO_2$/$CF_4$ (45/15/40)

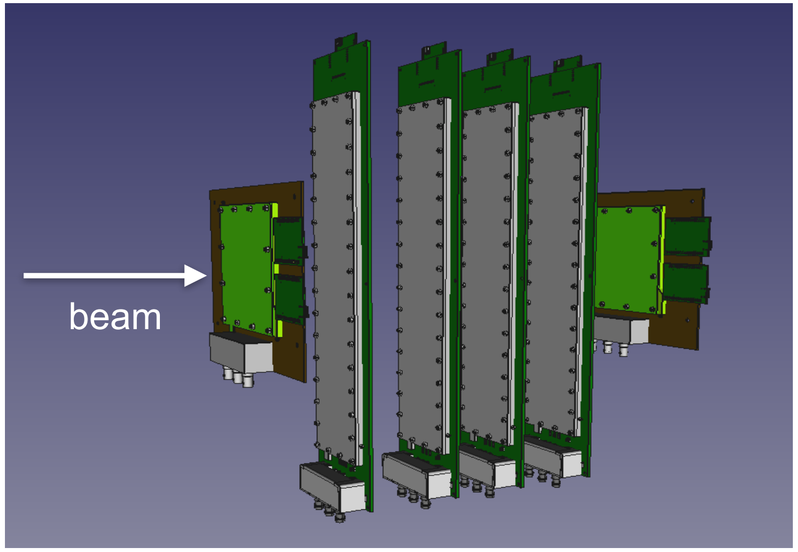
1- Signal shape
(cluster charge, cluster size)
2 - Detector performance
(efficiency, space resolution)

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

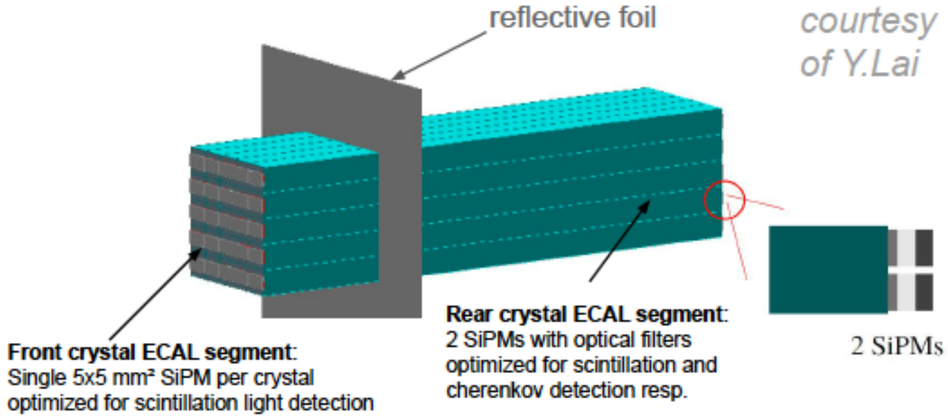
strips



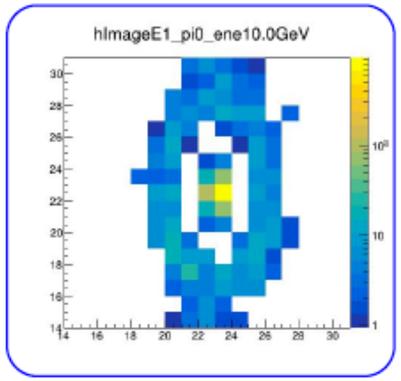



7 μ-RWELL prototypes with resistivity varying between 10 and 80 MOhm/□ will allow to define best resistivity for final 50x50 cm² detector

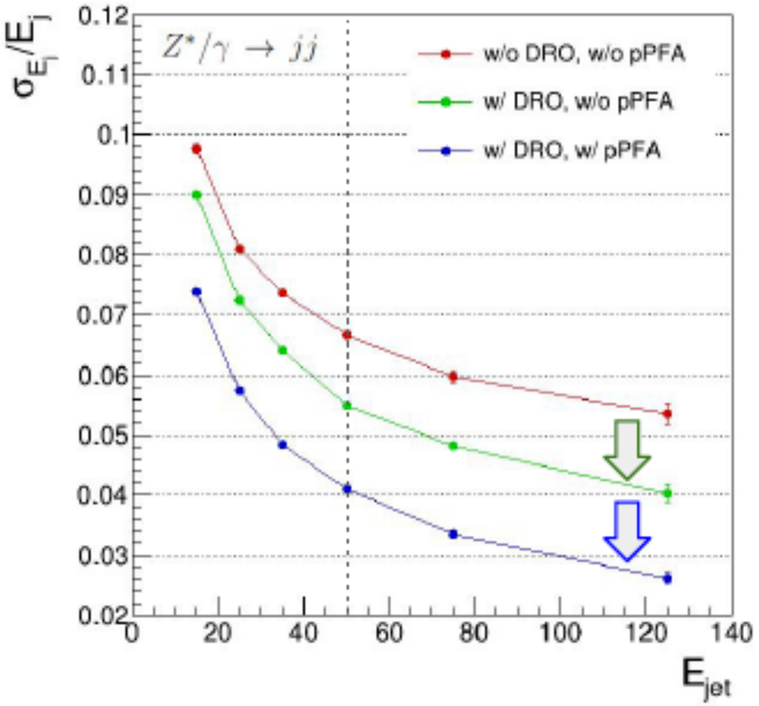
# Crystal ECAL with DR calorimeter




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




Jet resolution

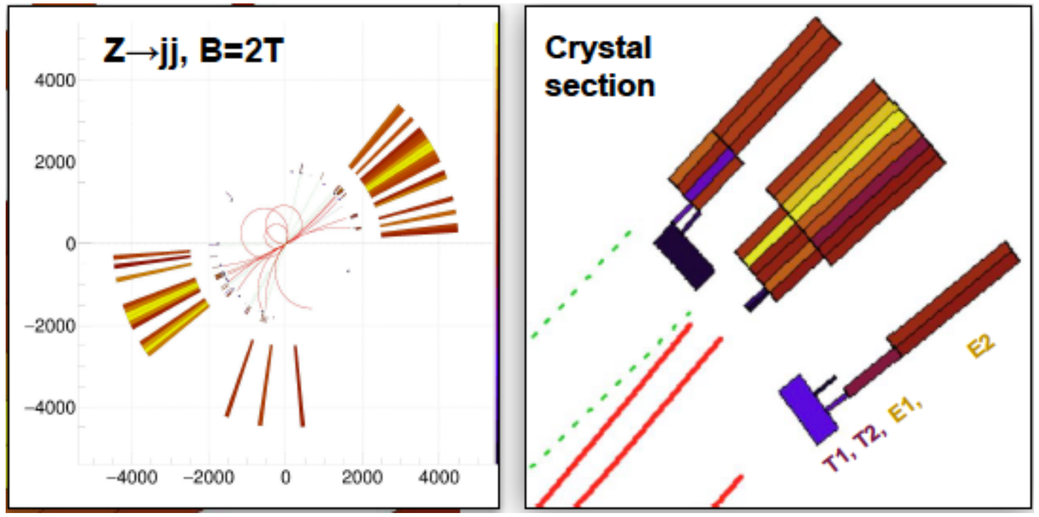



crystals + IDEA w/o DRO

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**

# 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

# 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 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

# 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

# μ-RWELL technology

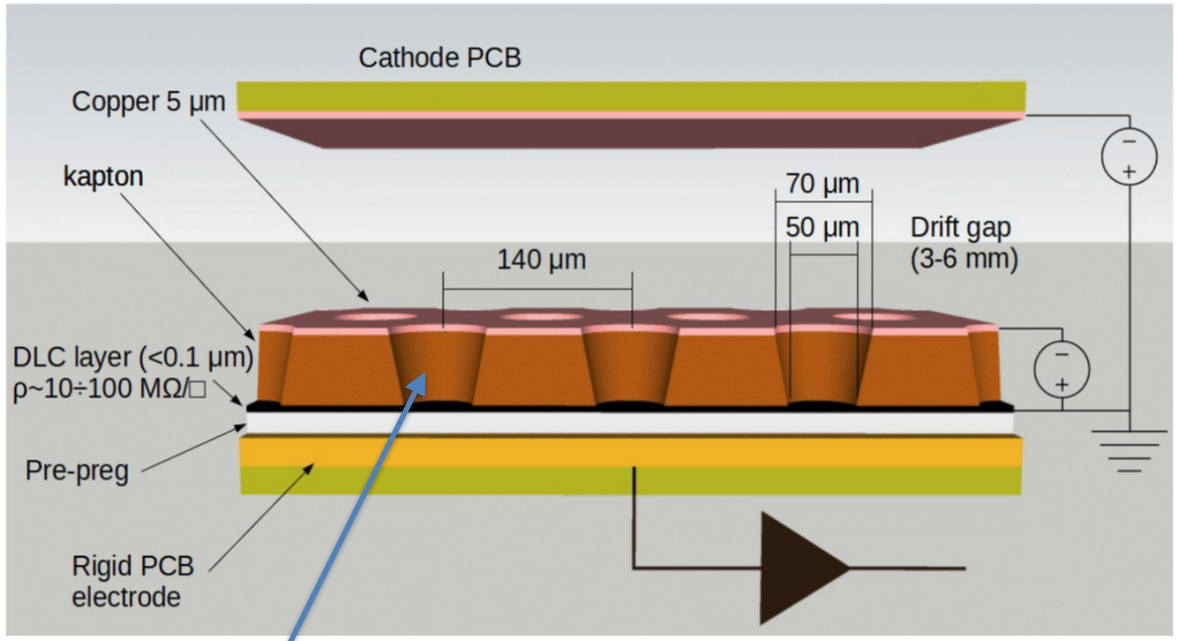
The μ-RWELL is composed of only two elements:

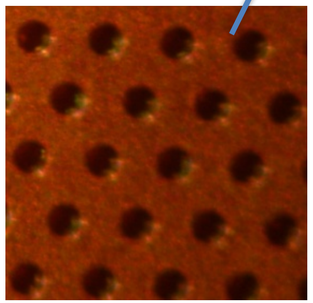
- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

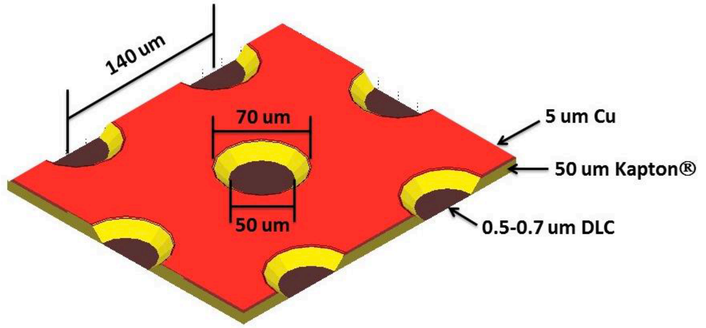
μ-RWELL_PCB = amplification-stage ⊕ resistive stage ⊕ readout PCB

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)