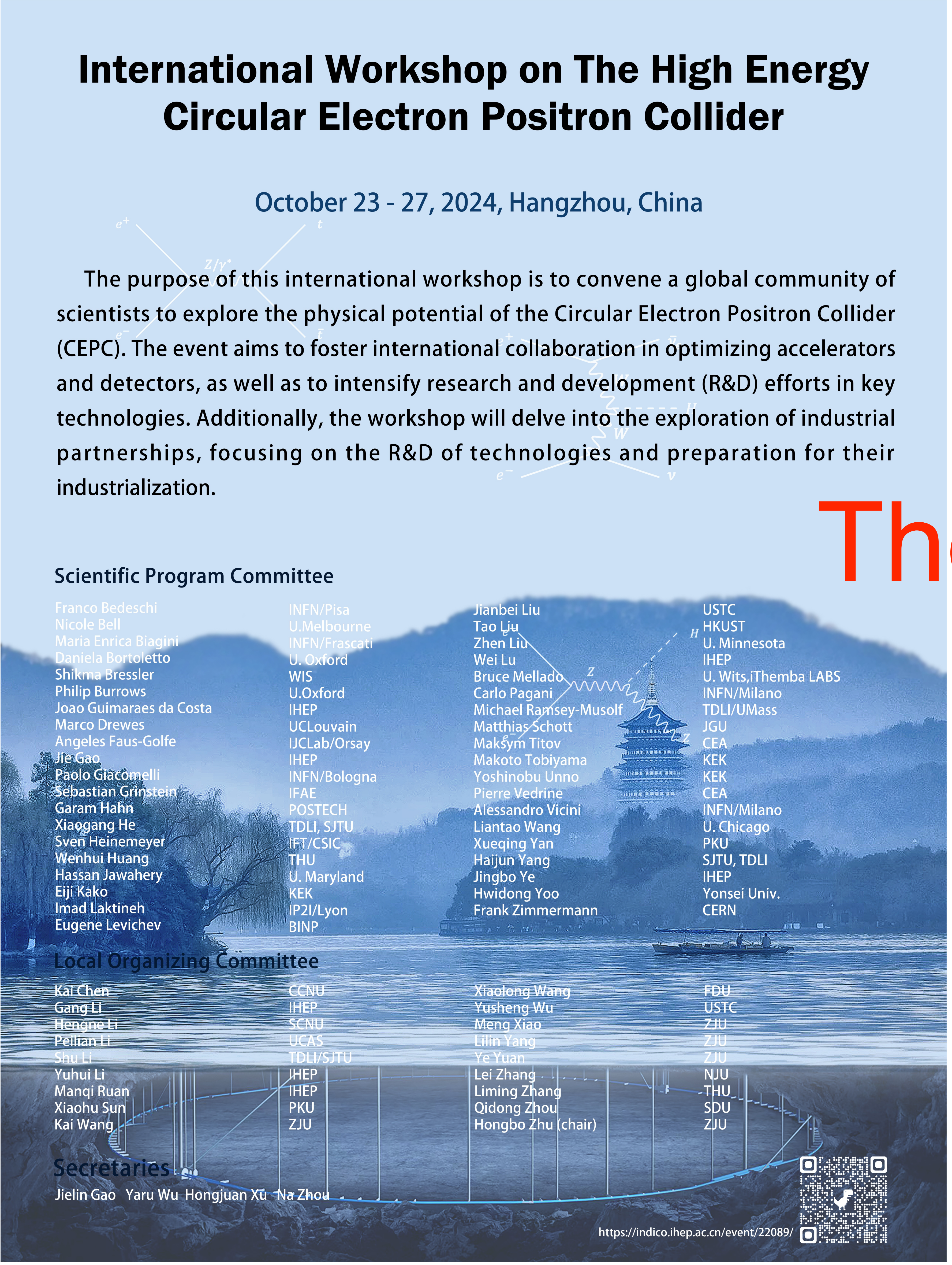

CEPC workshop
Hangzhou, 25/10/2024

The IDEA drift chamber

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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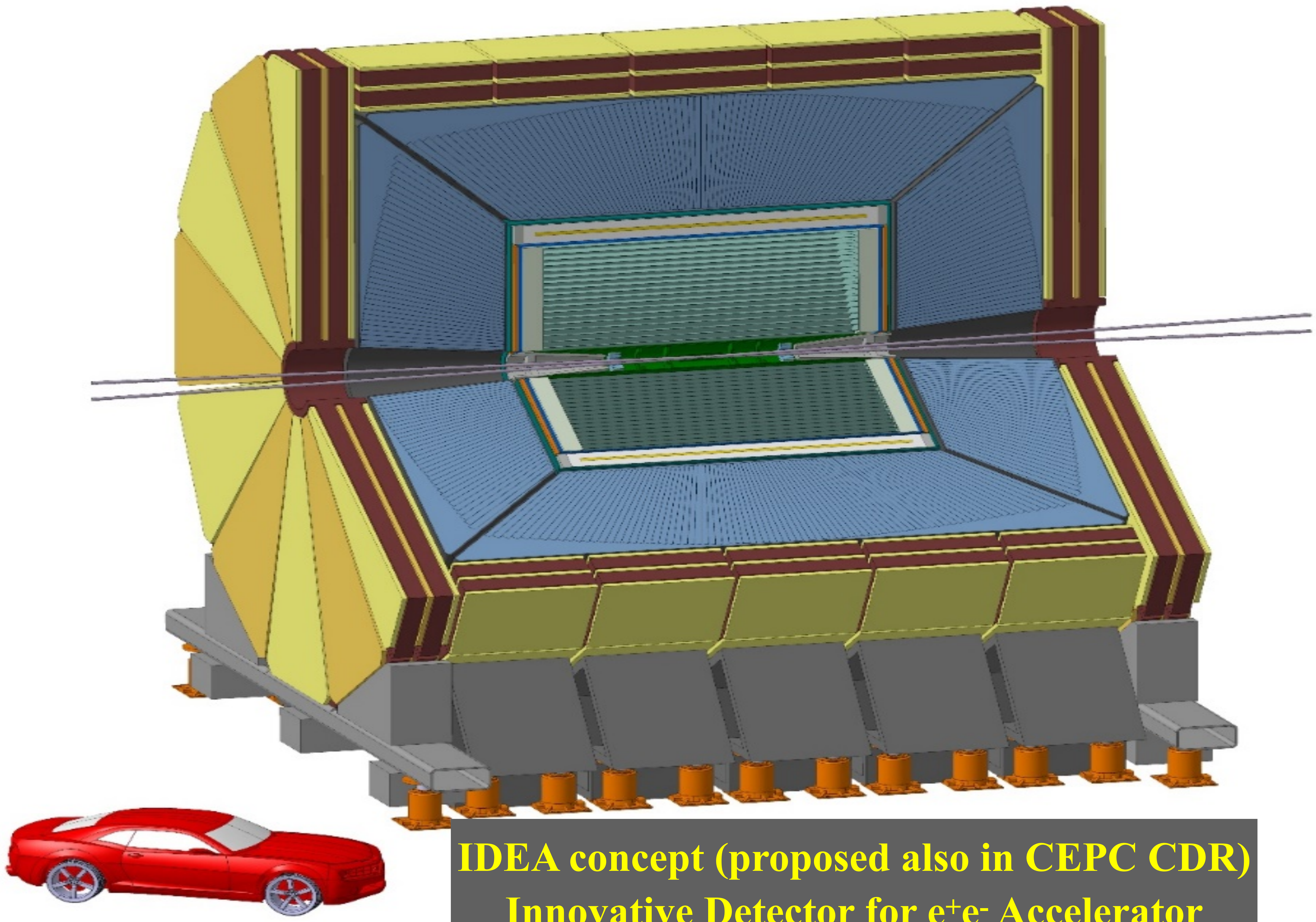
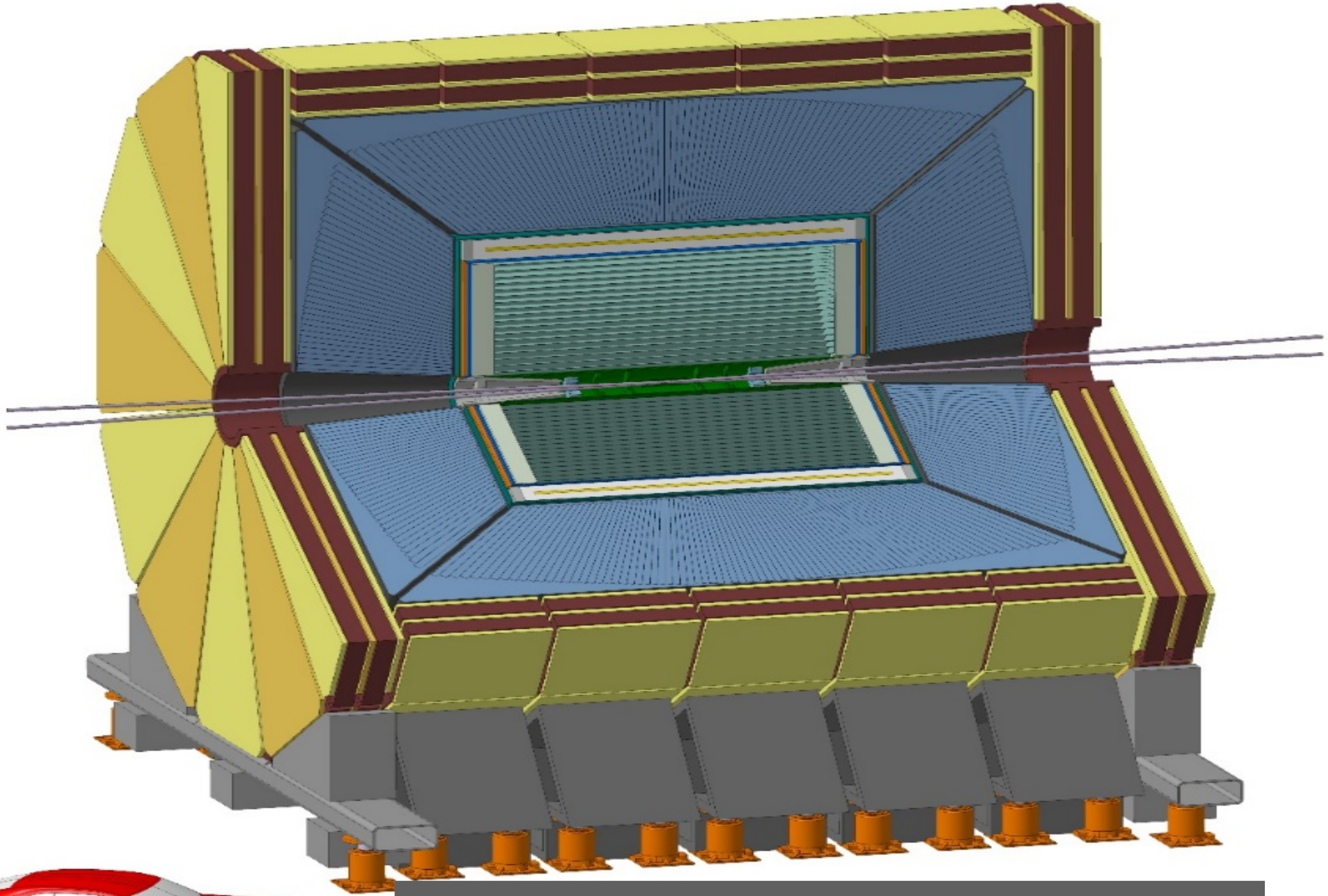
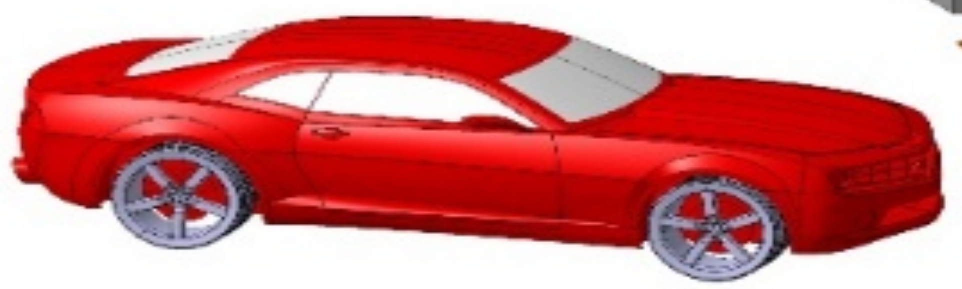


IDEA concept (proposed also in CEPC CDR)
Innovative Detector for e^+e^- Accelerator

The IDEA detector concept





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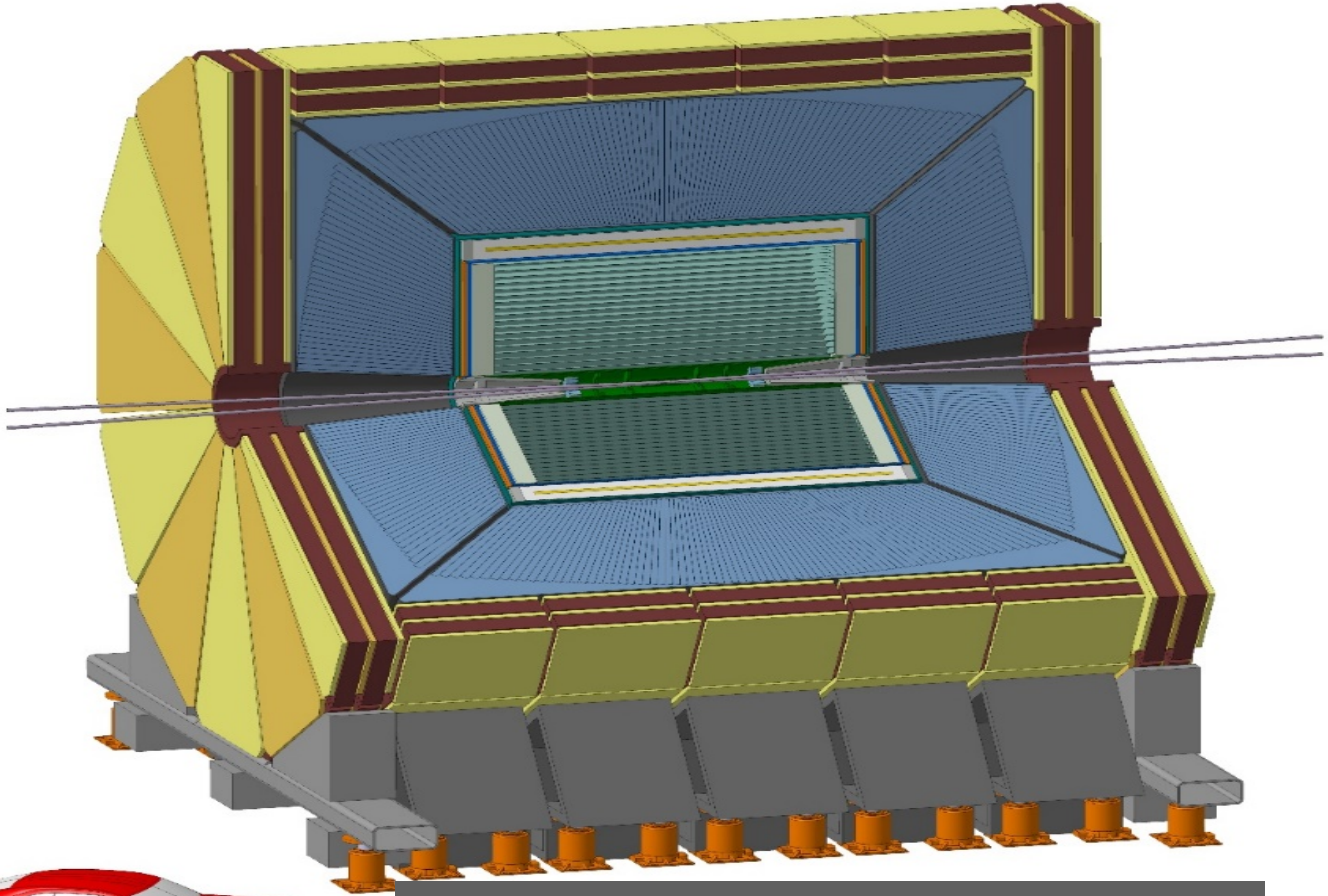

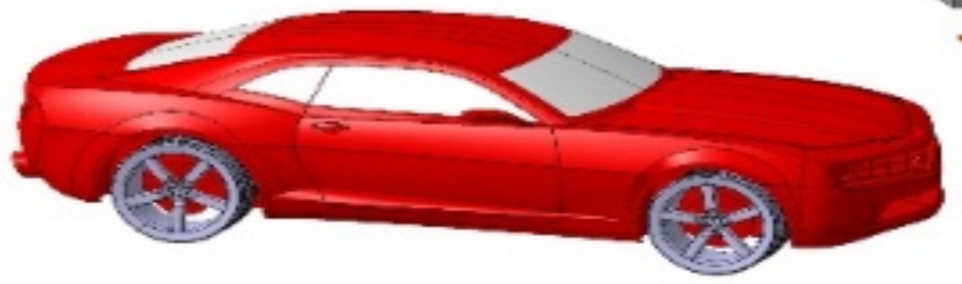

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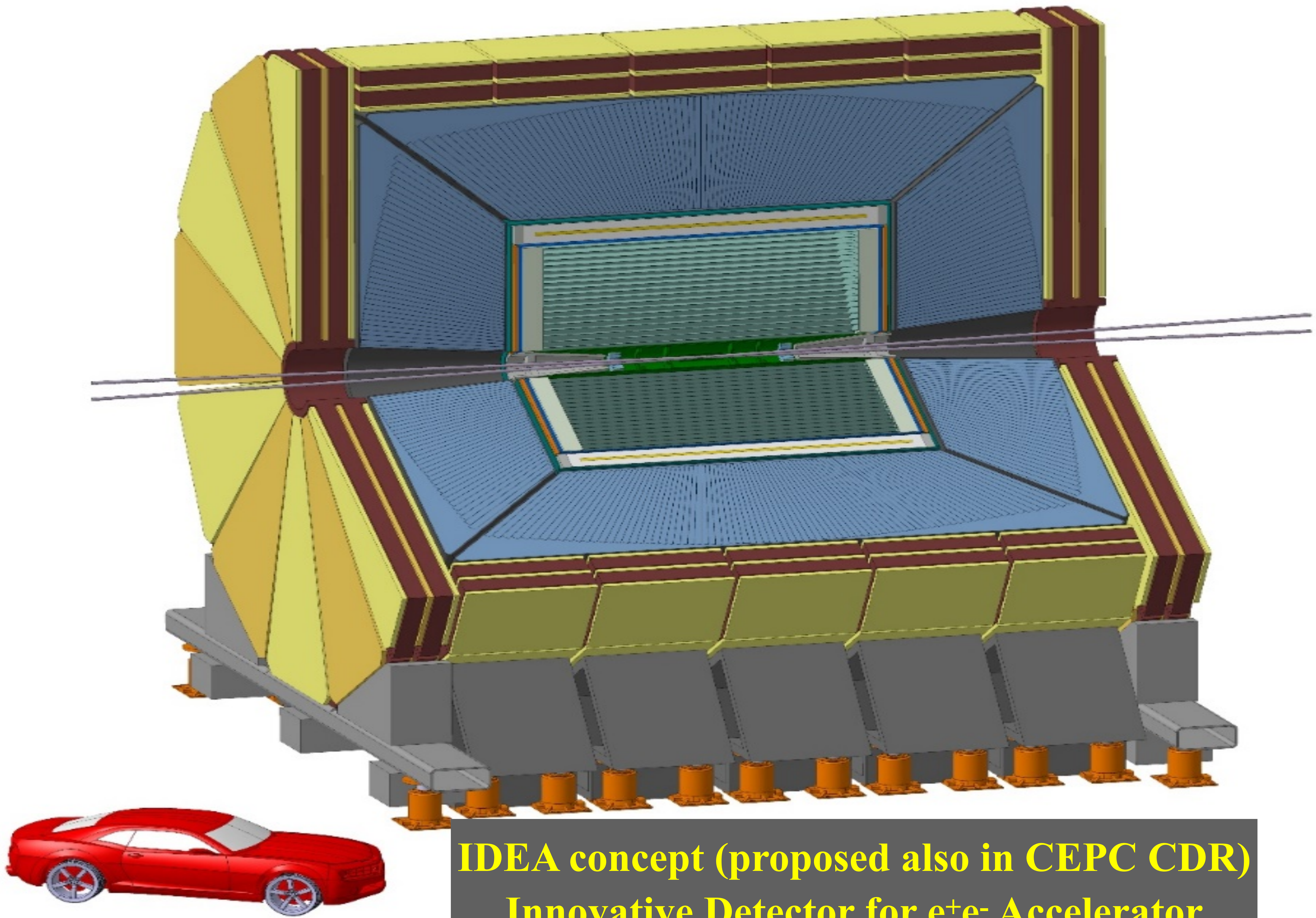

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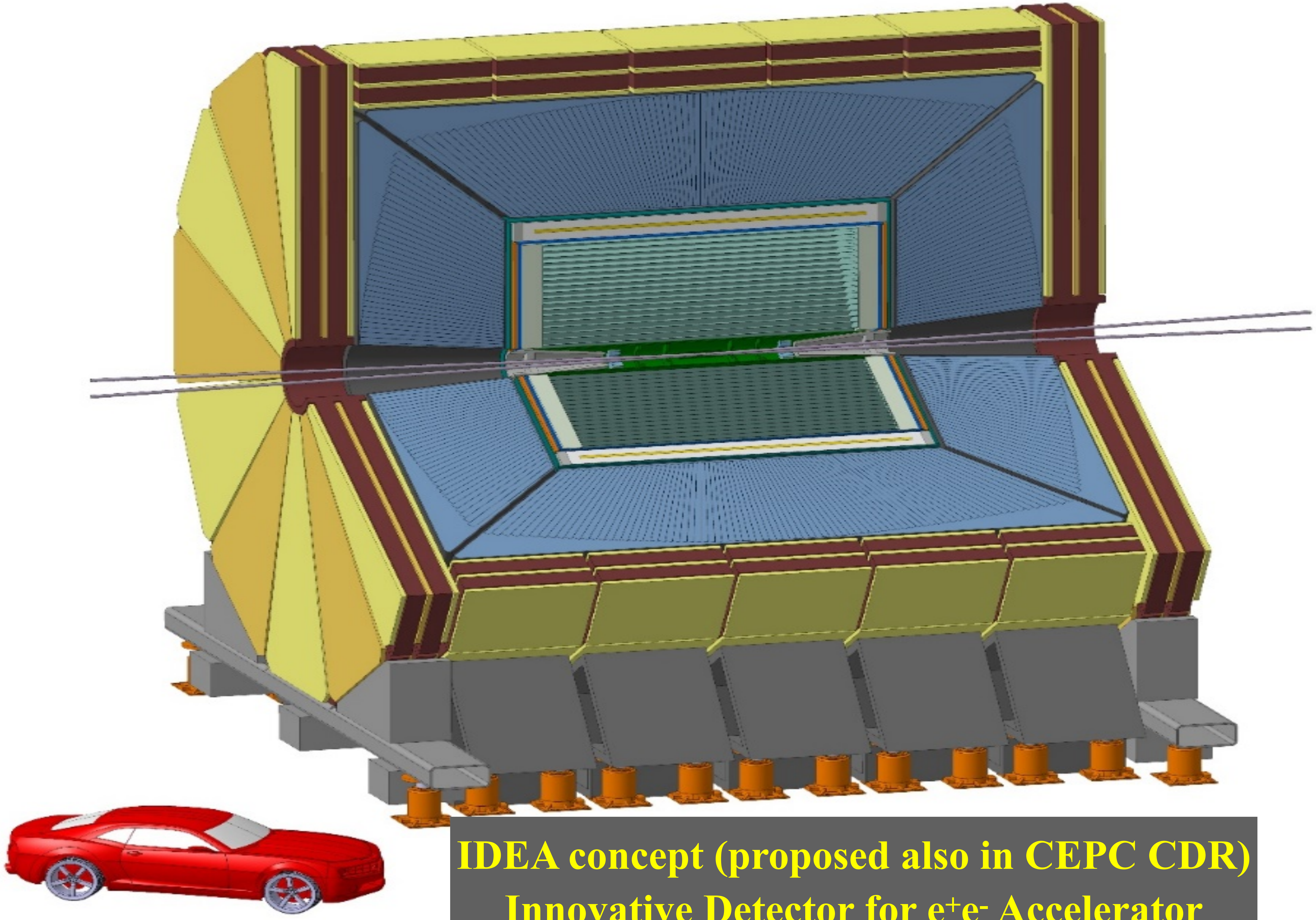

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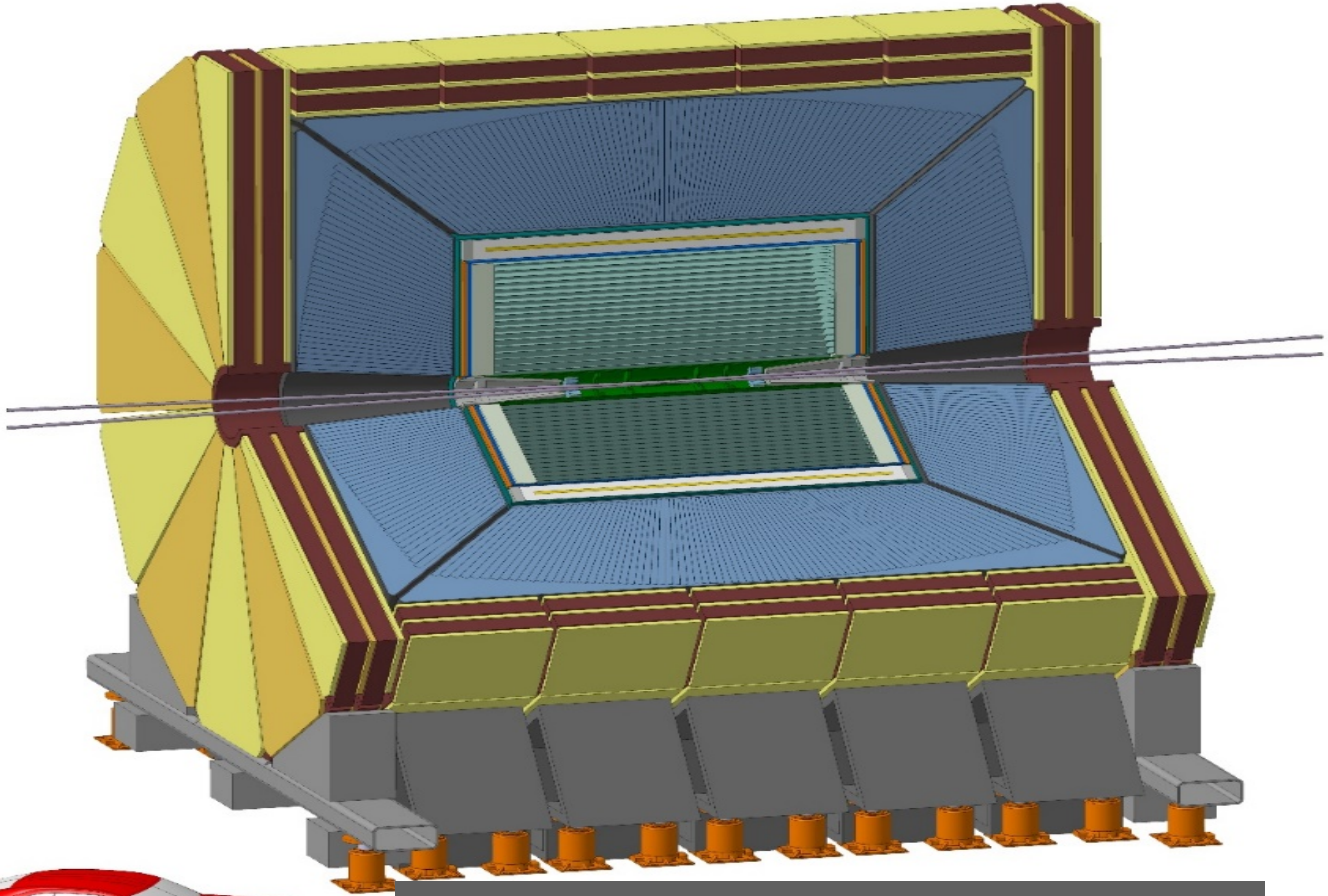

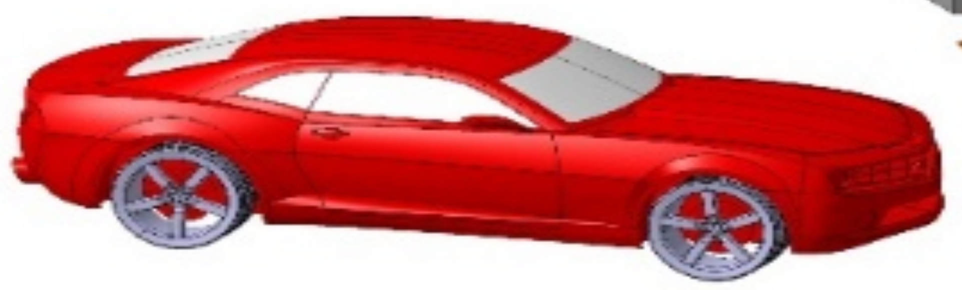

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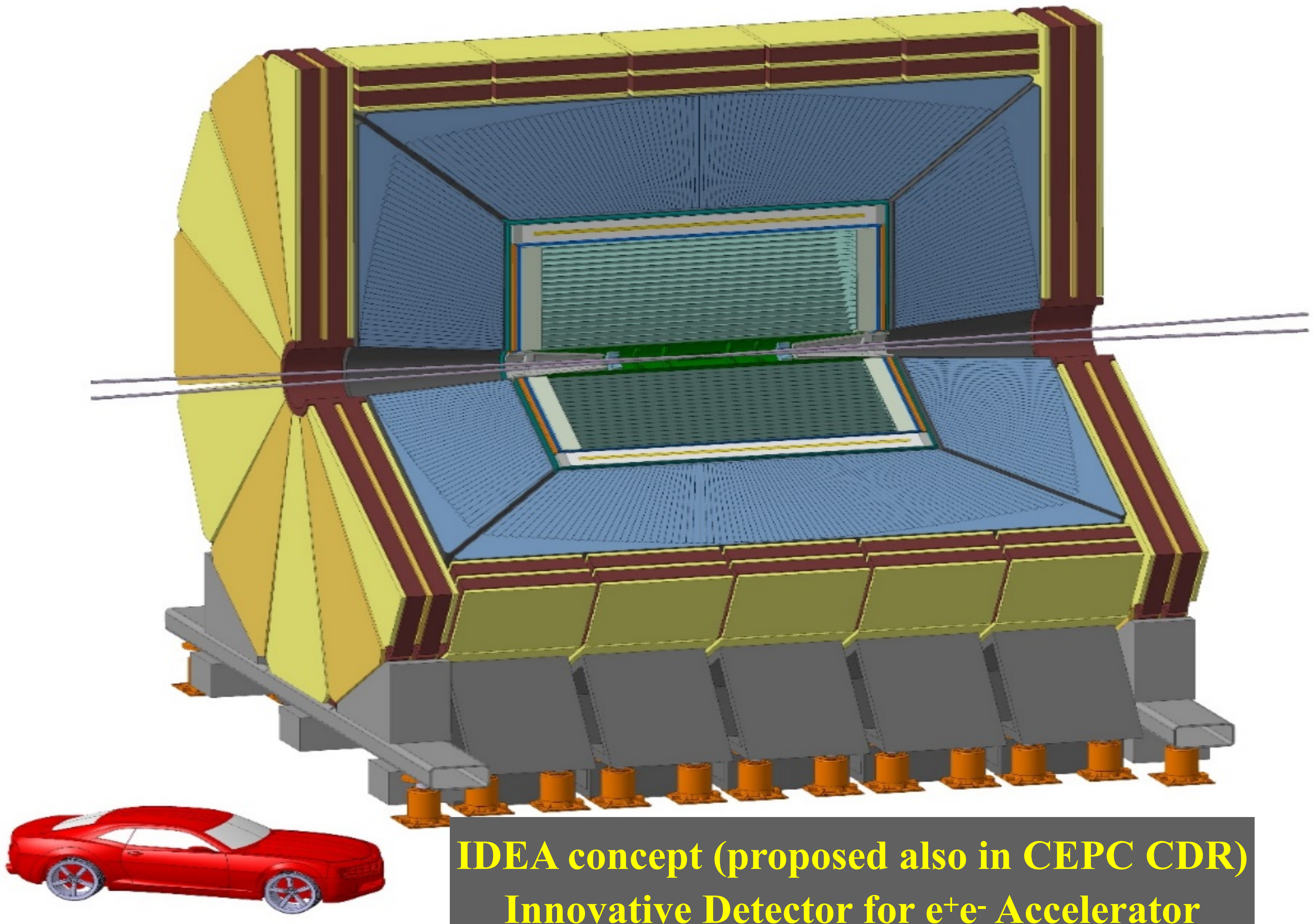

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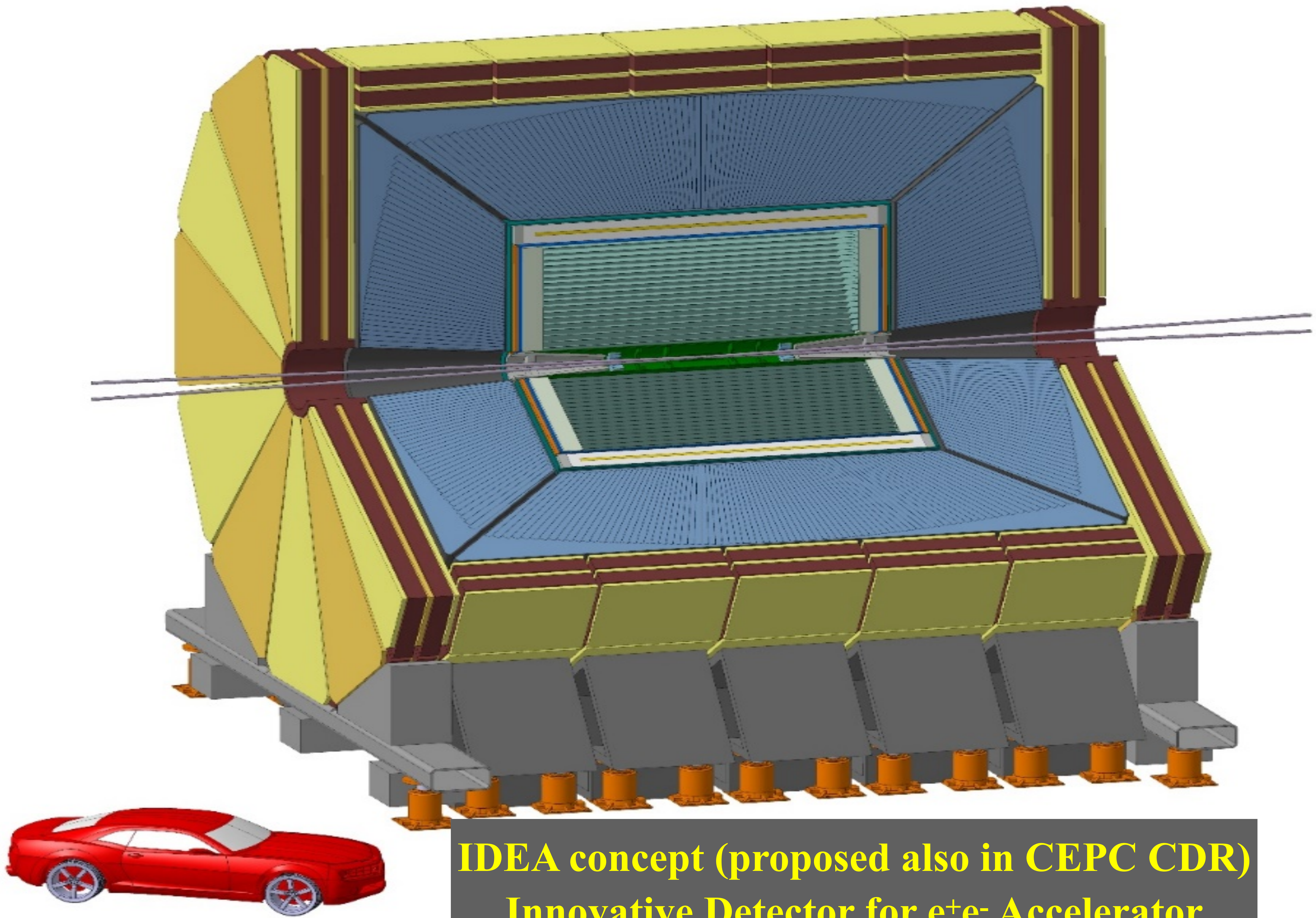

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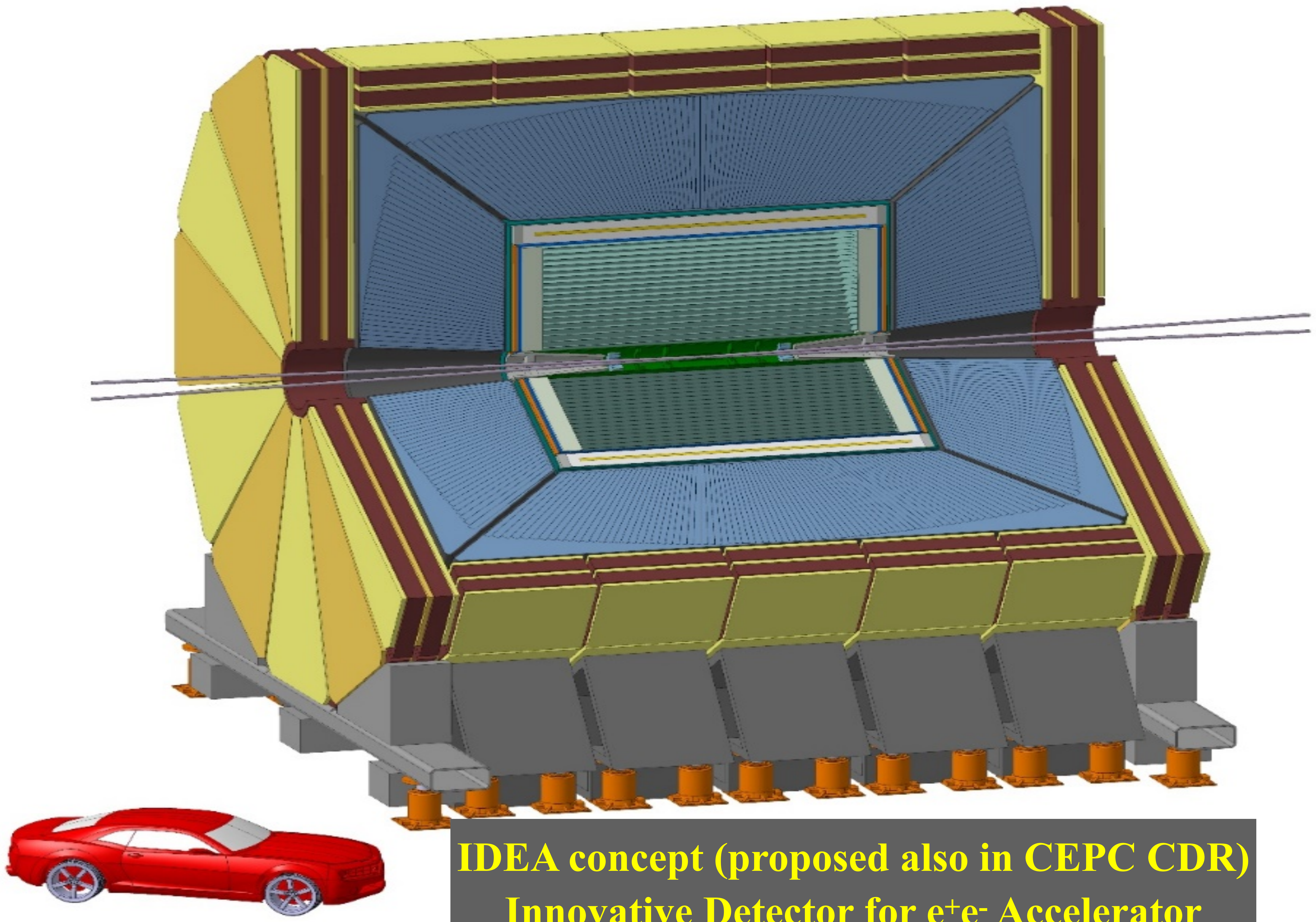
https://pos.sissa.it/390/



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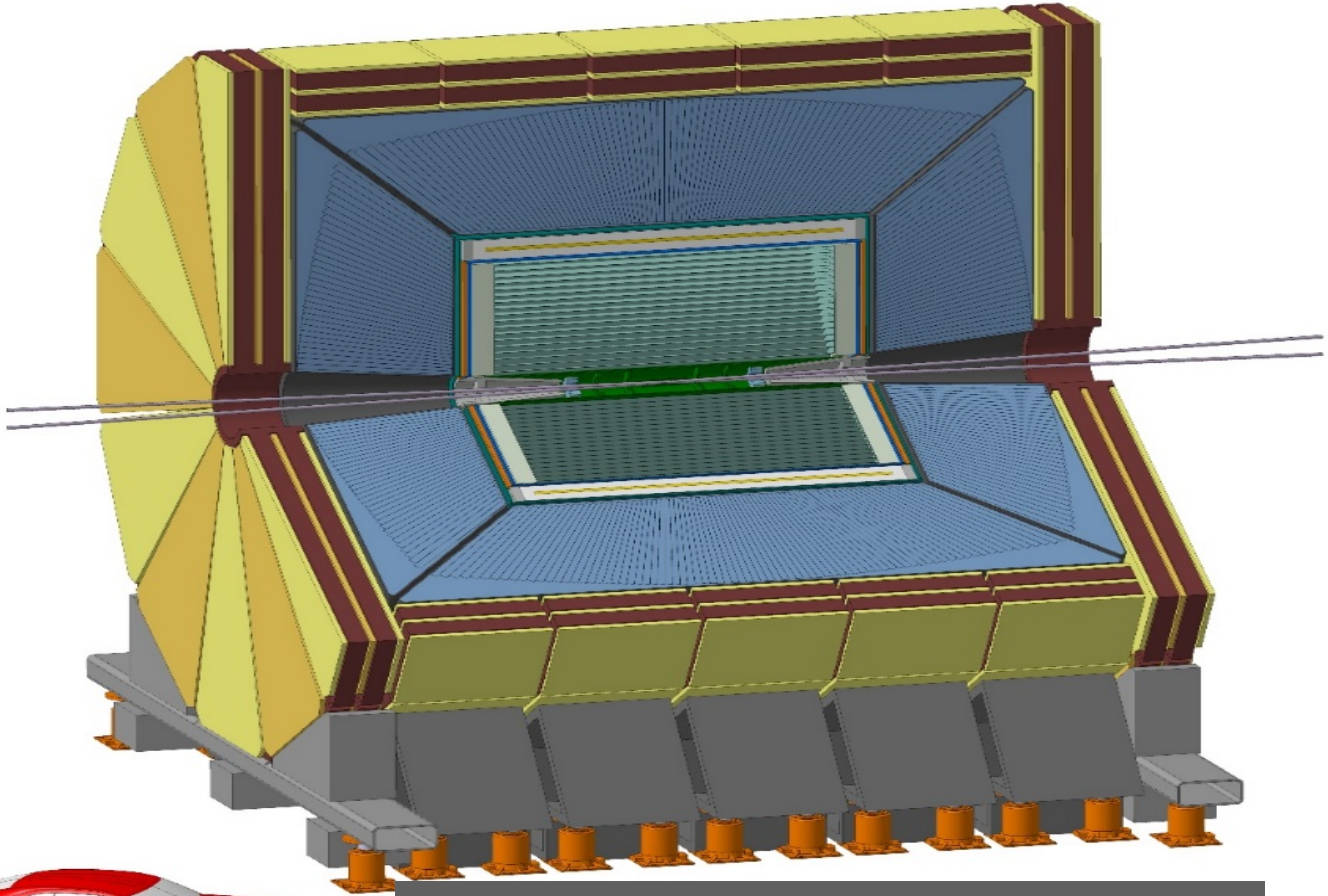

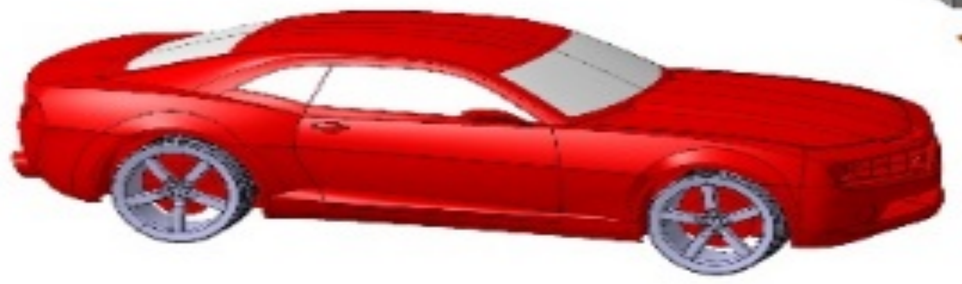

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Acknowledgments
I need to thank many colleagues, in particular:
N. de Filippis

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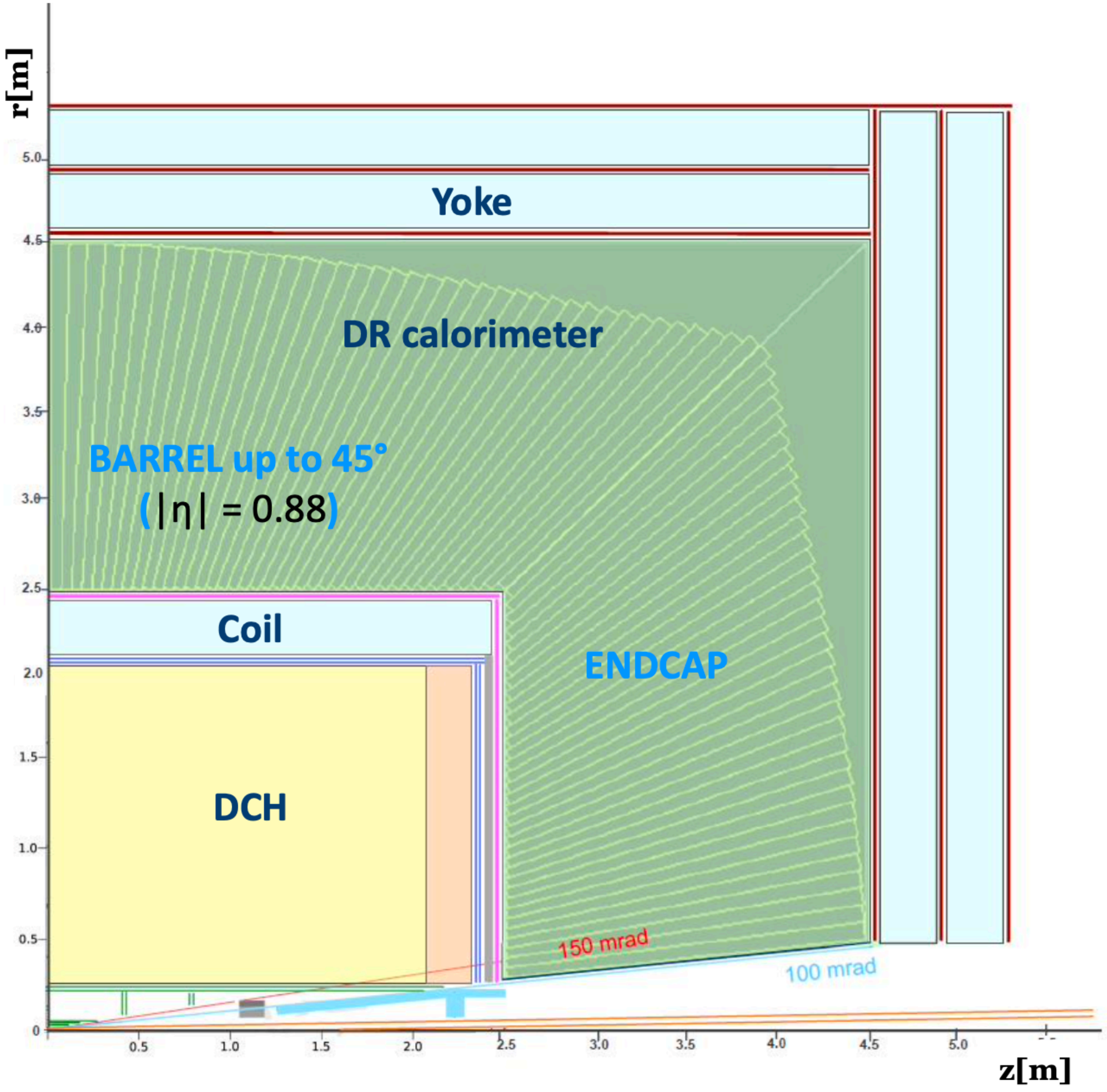
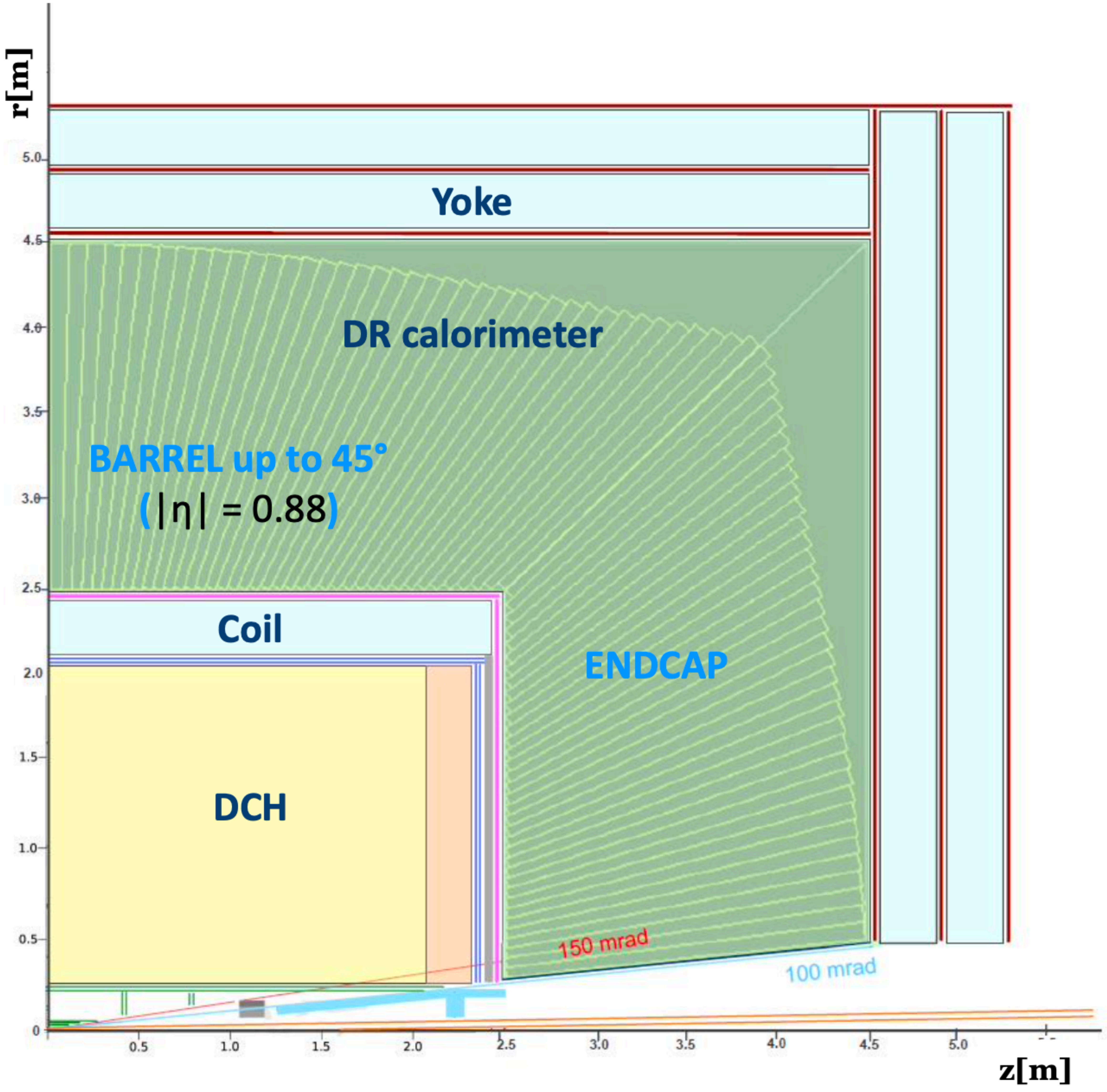


IDEA detector layout

Beam pipe: R~1.0 cm



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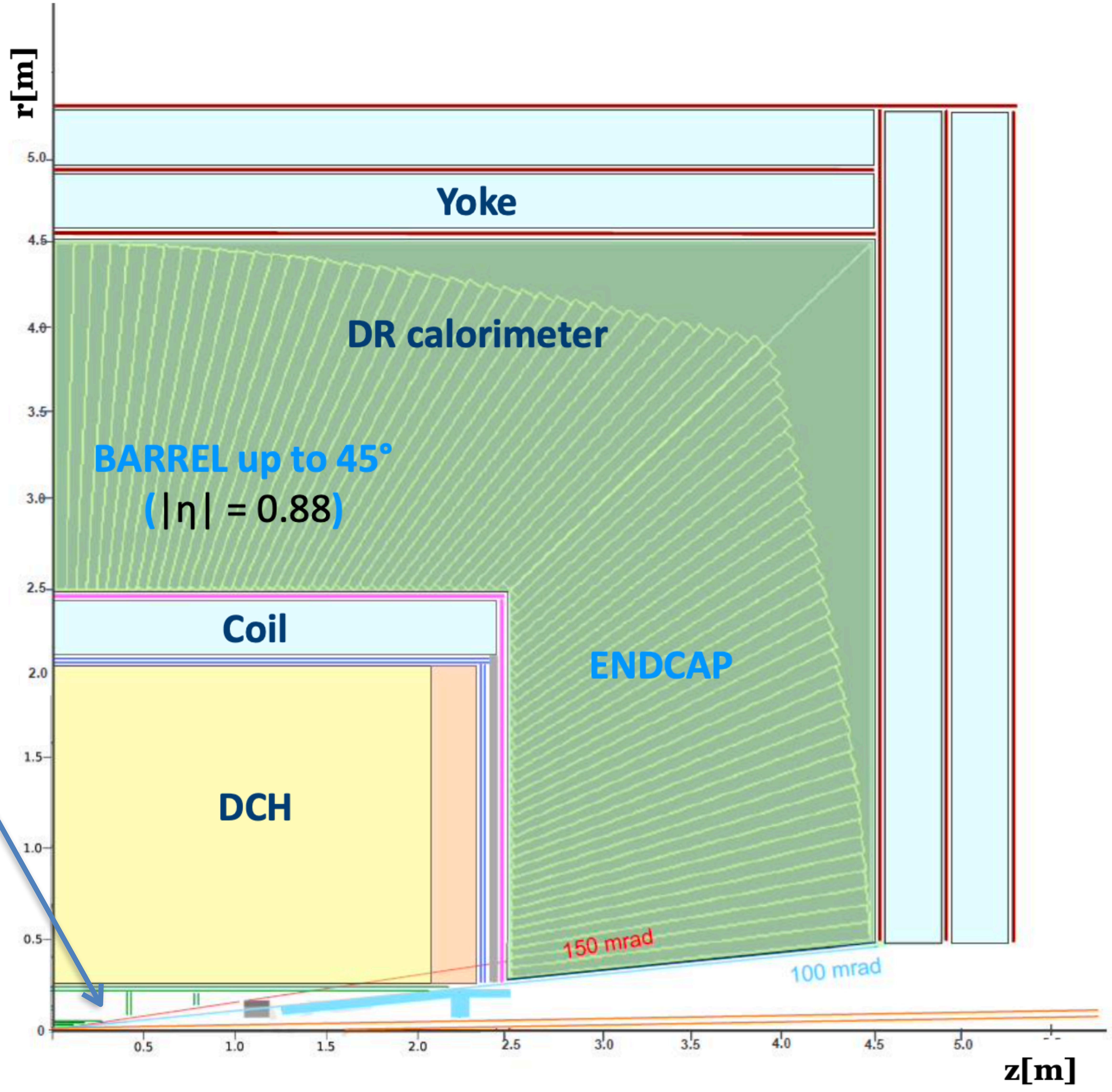
R = 1.37-31.5 cm



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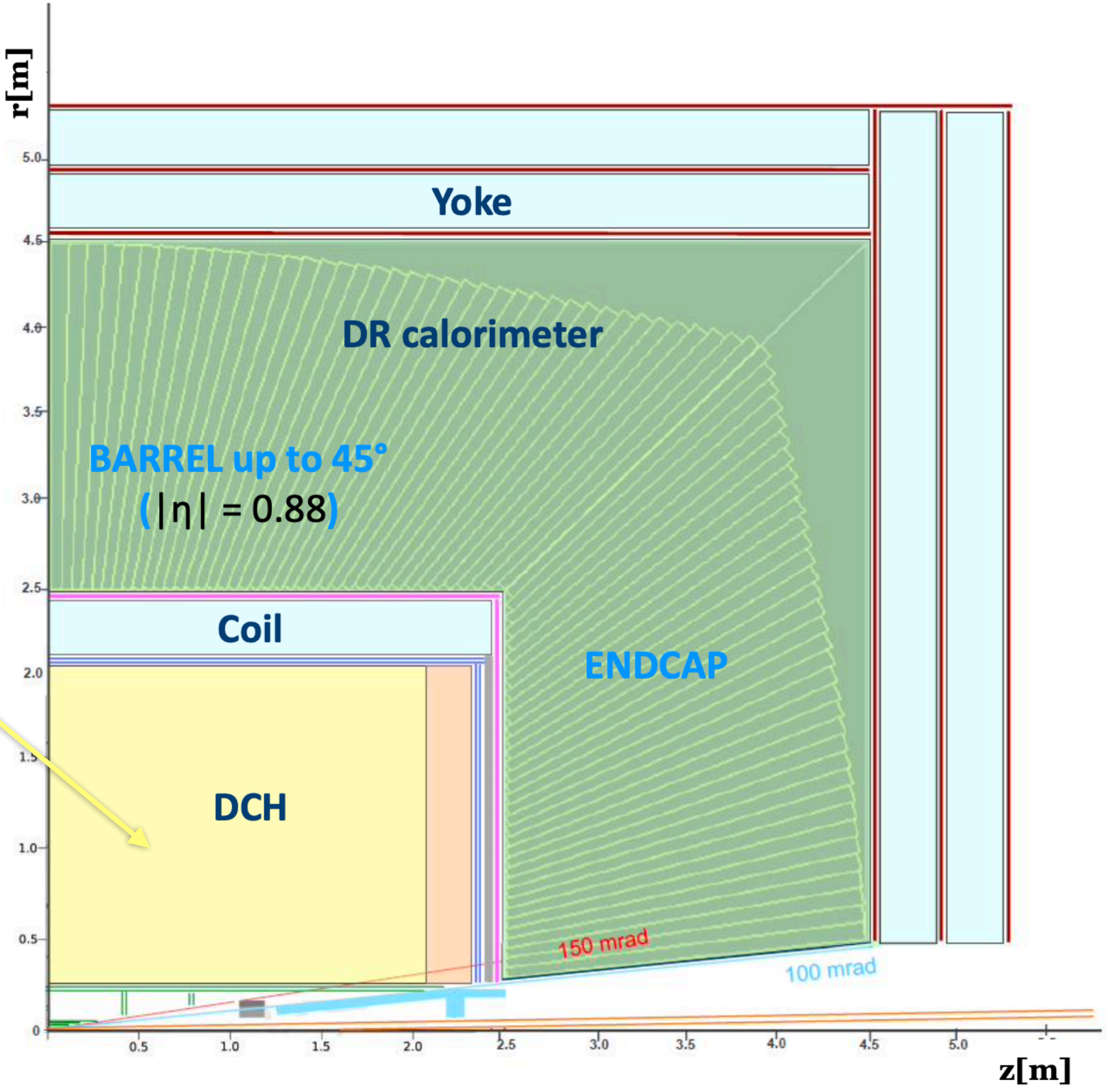
Drift Chamber: 112 layers

4 m long, R = 35-200 cm



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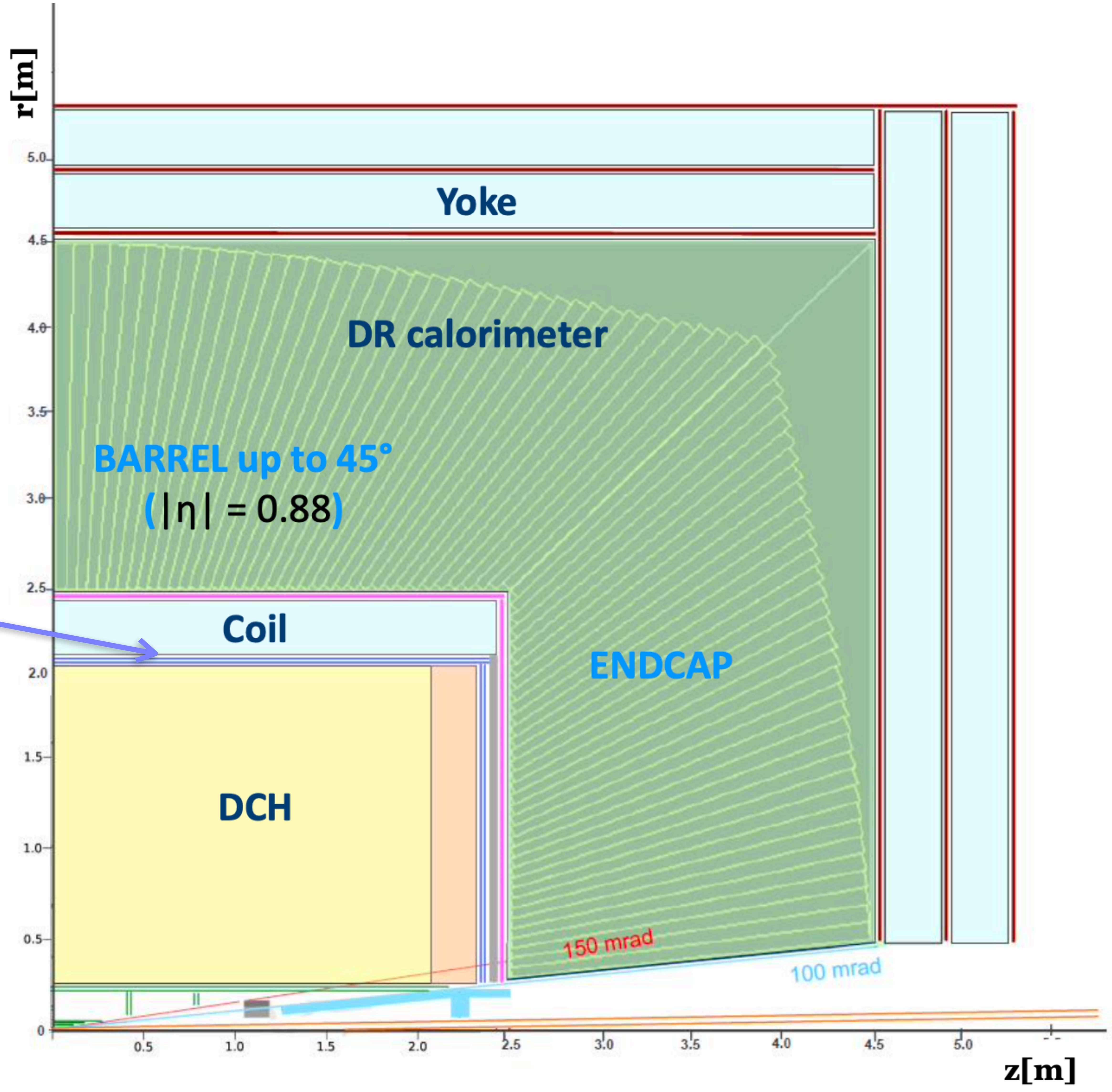
Si strips



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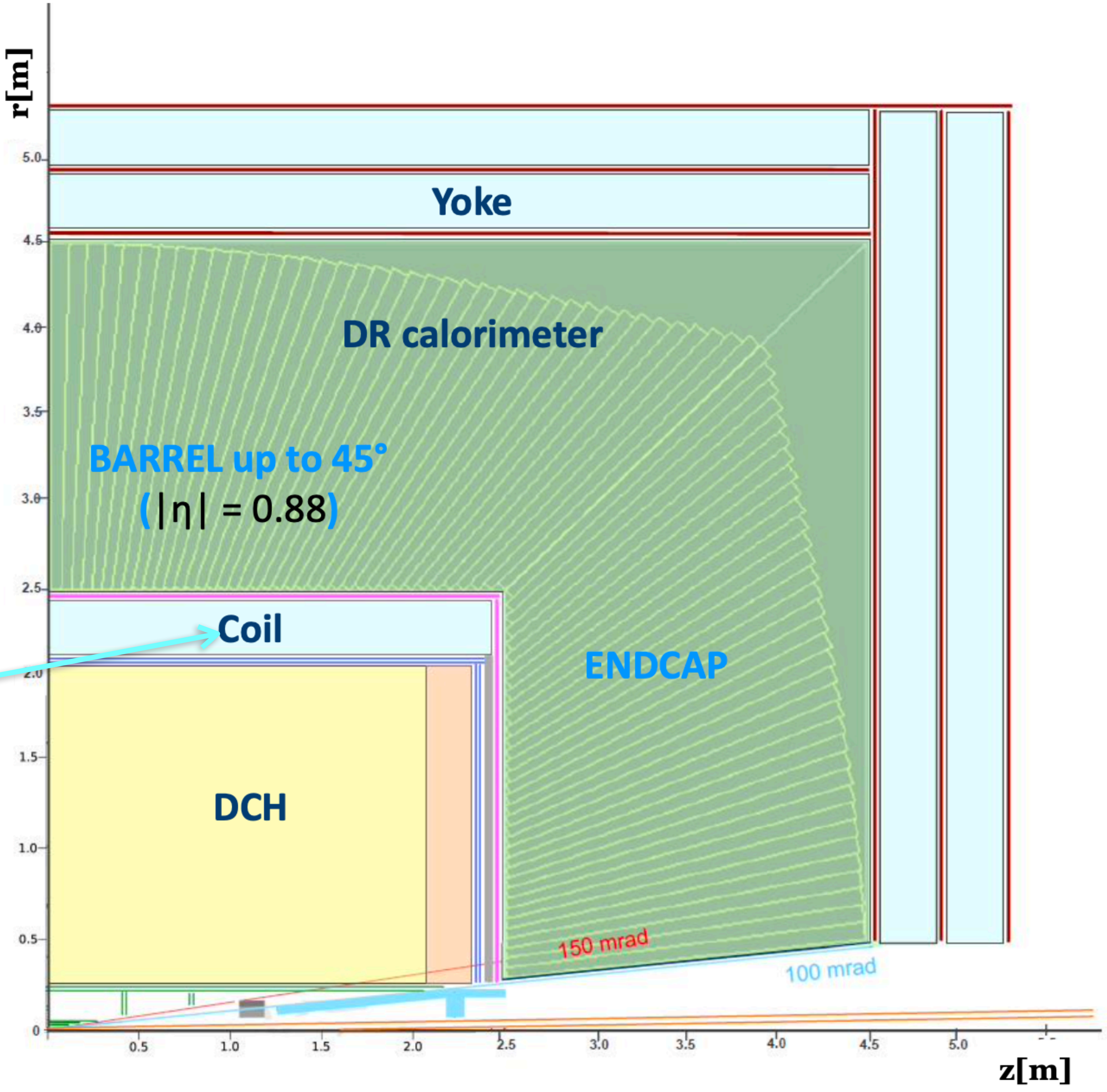
2 T, R ~ 2.1-2.4 m

0.74 X_0, 0.16 λ @ 90°



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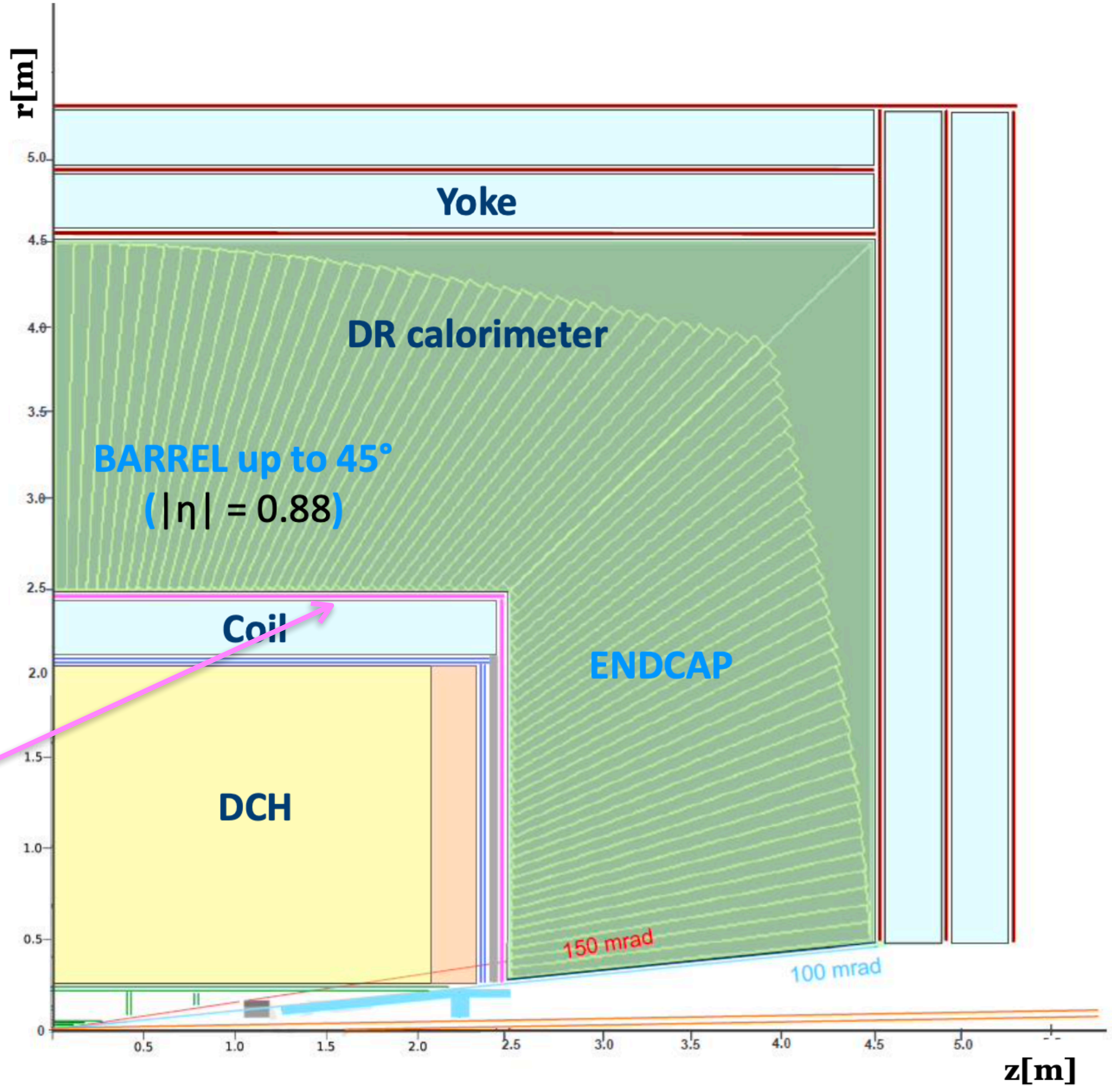

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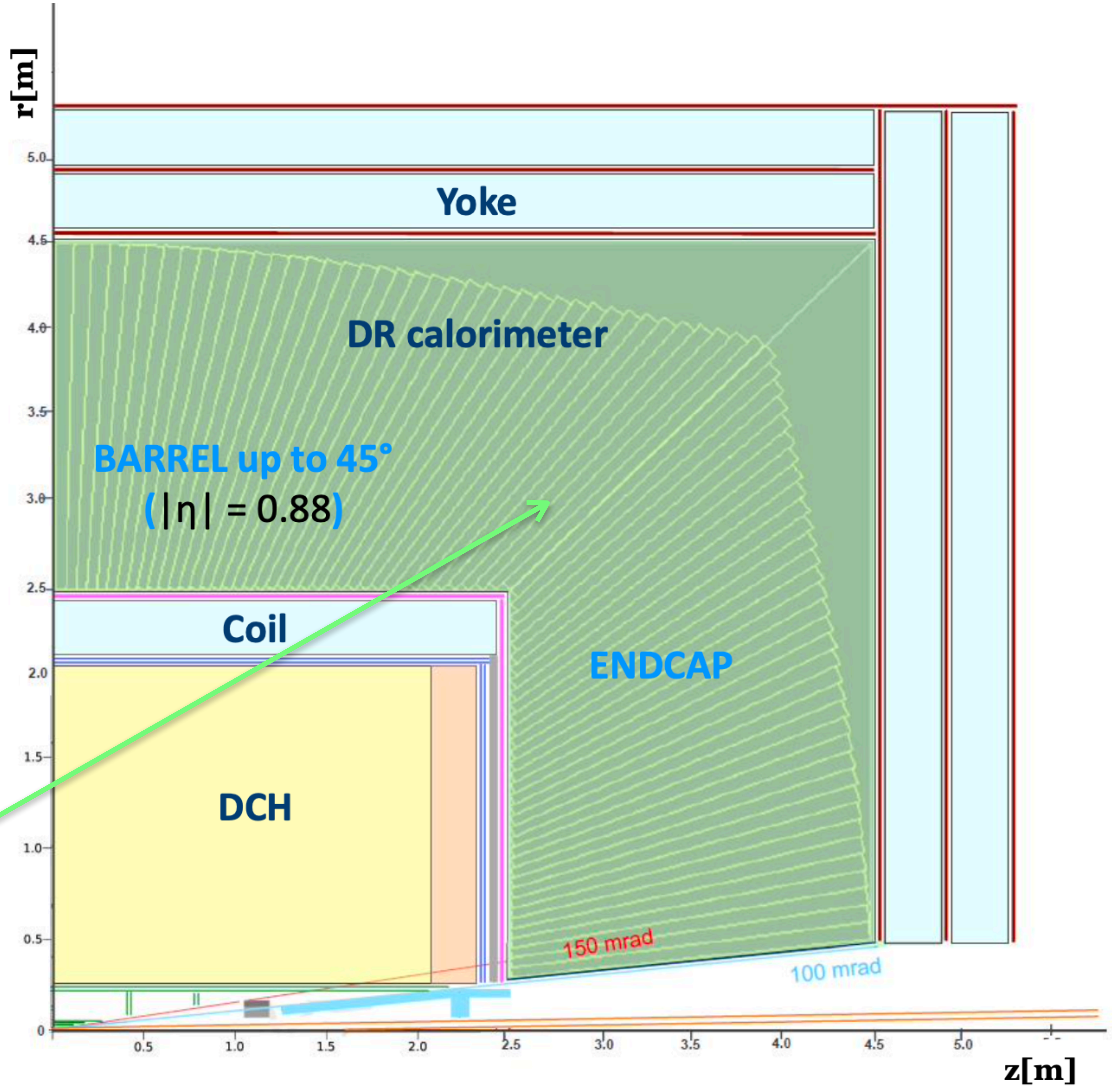

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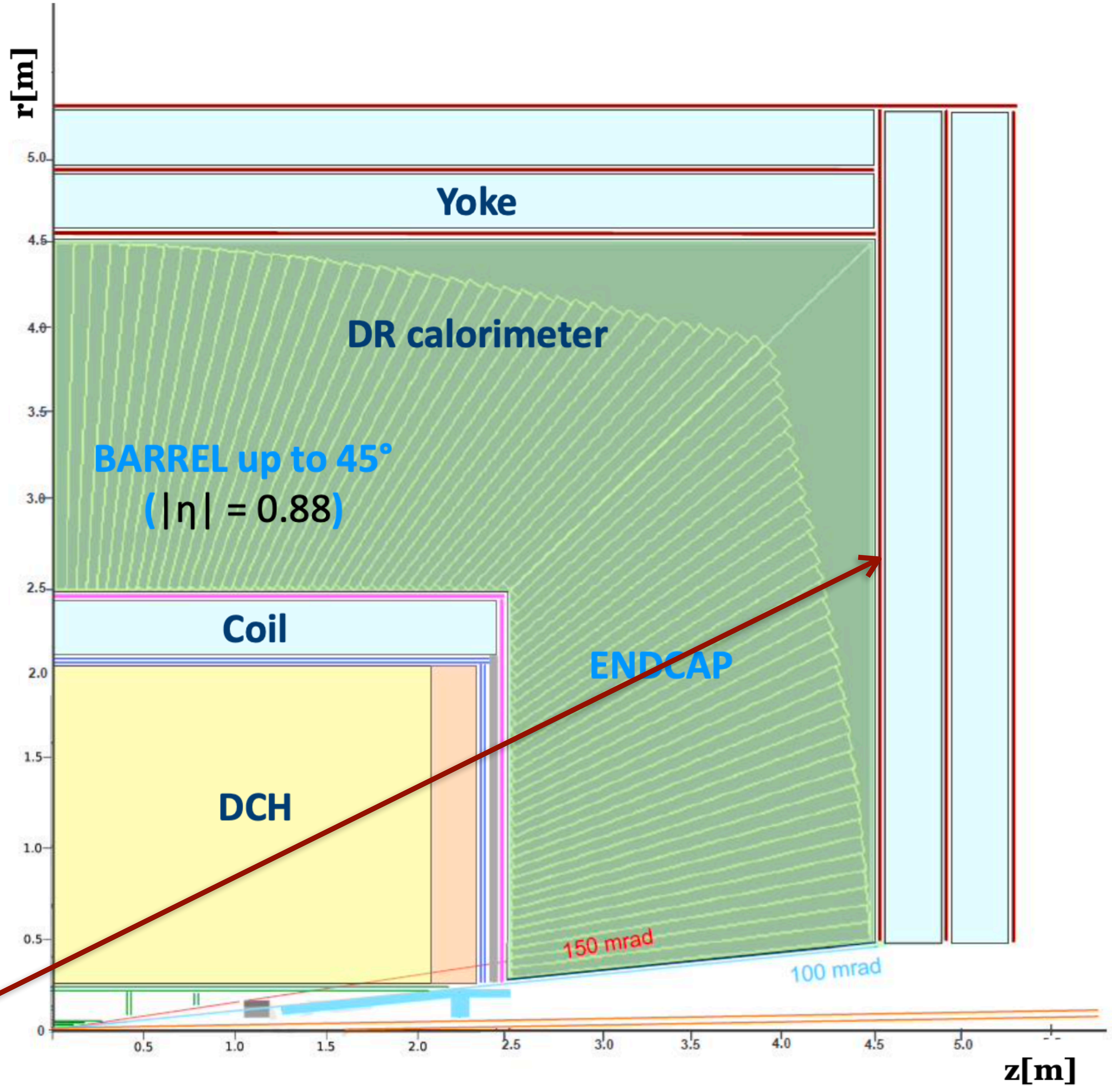
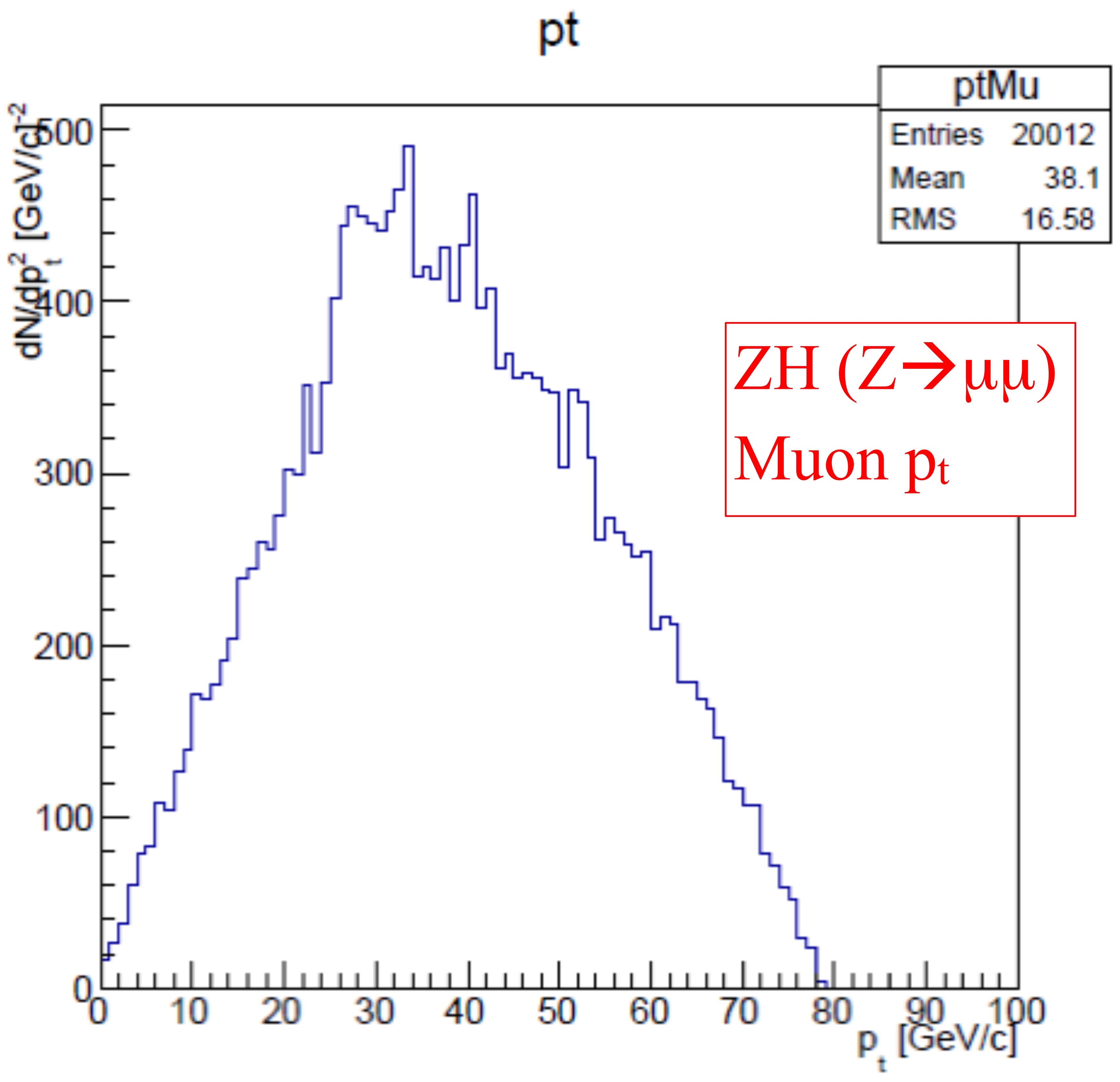
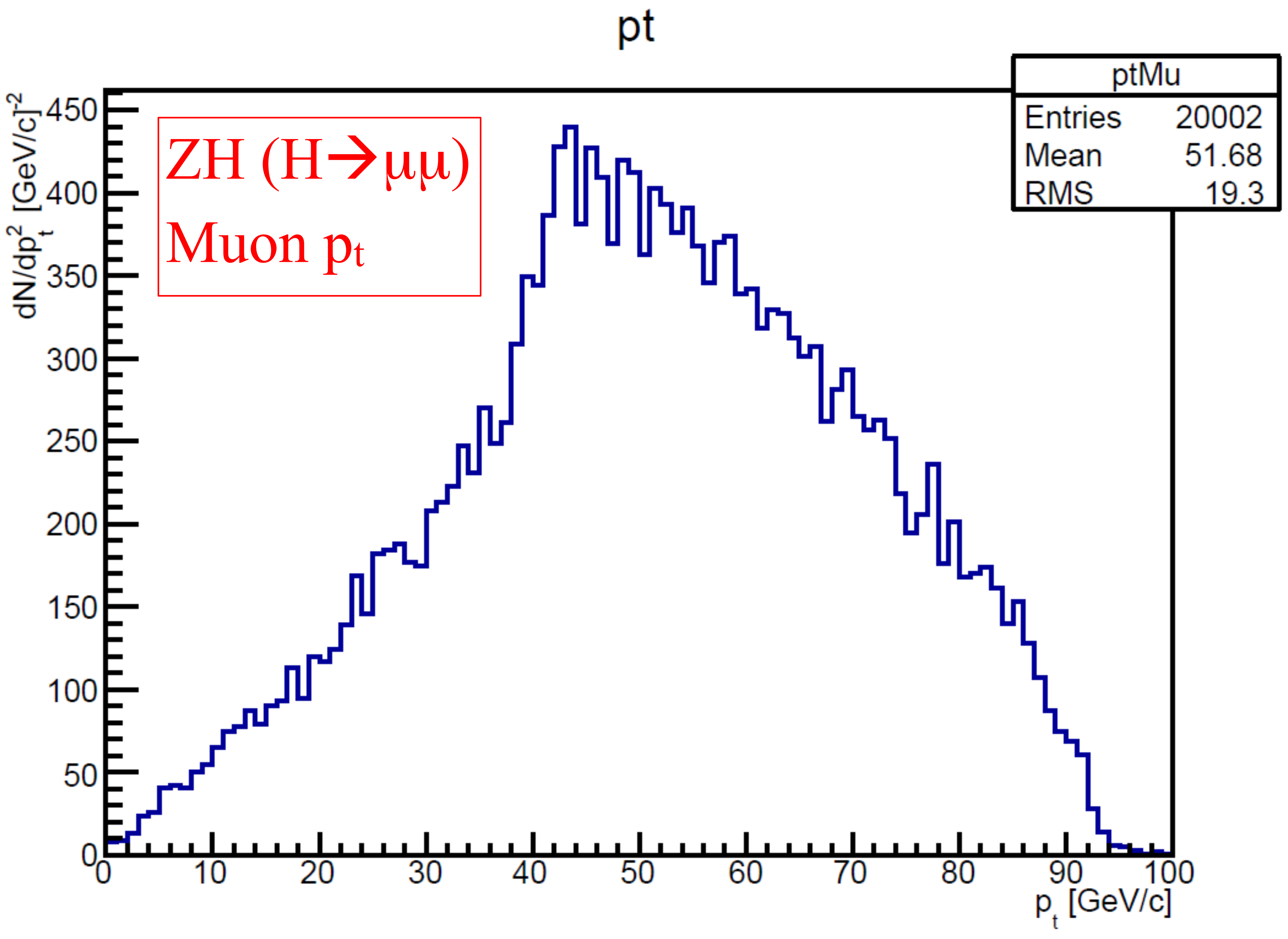
Yoke + Muon chambers



Momentum measurement





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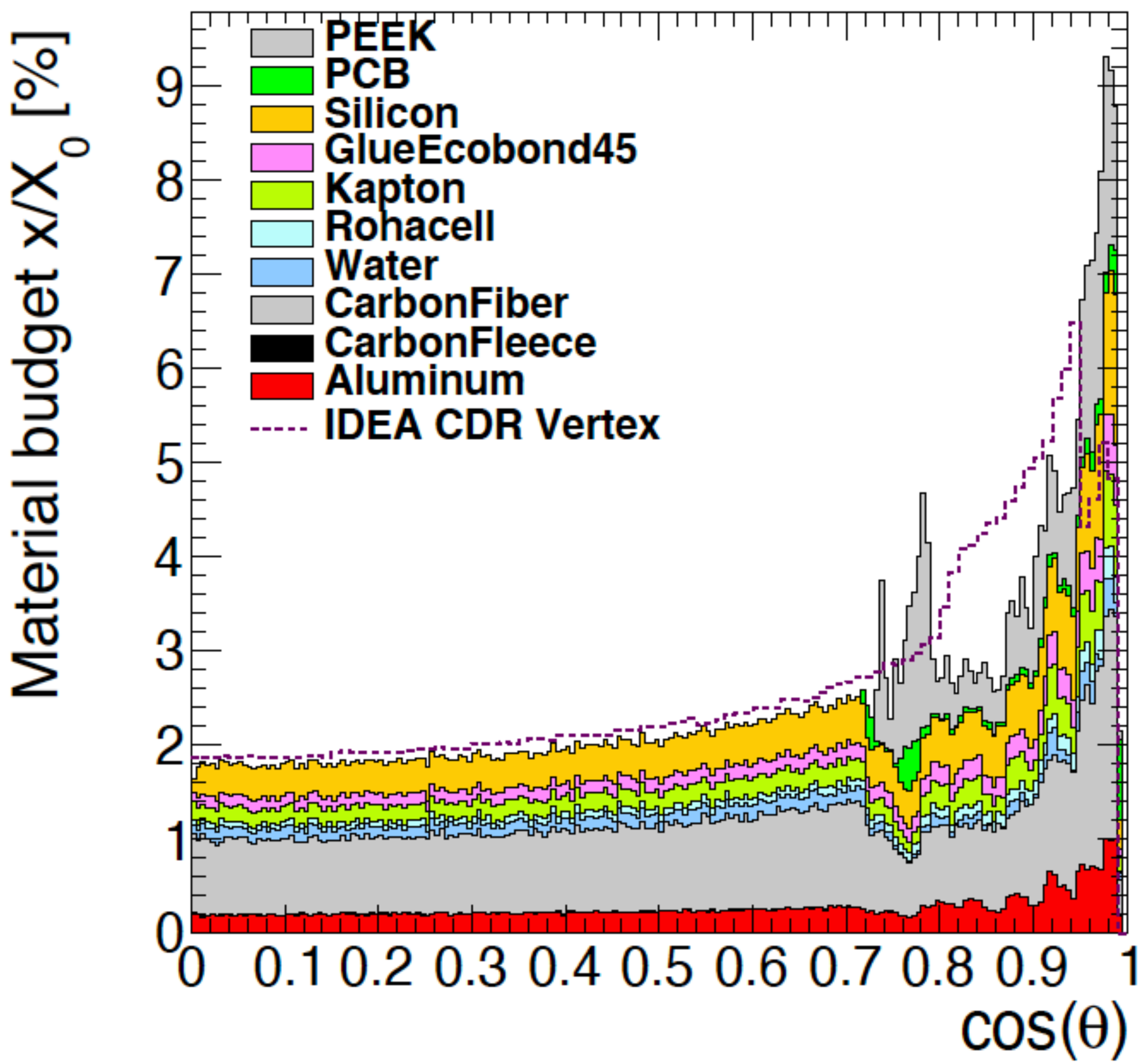
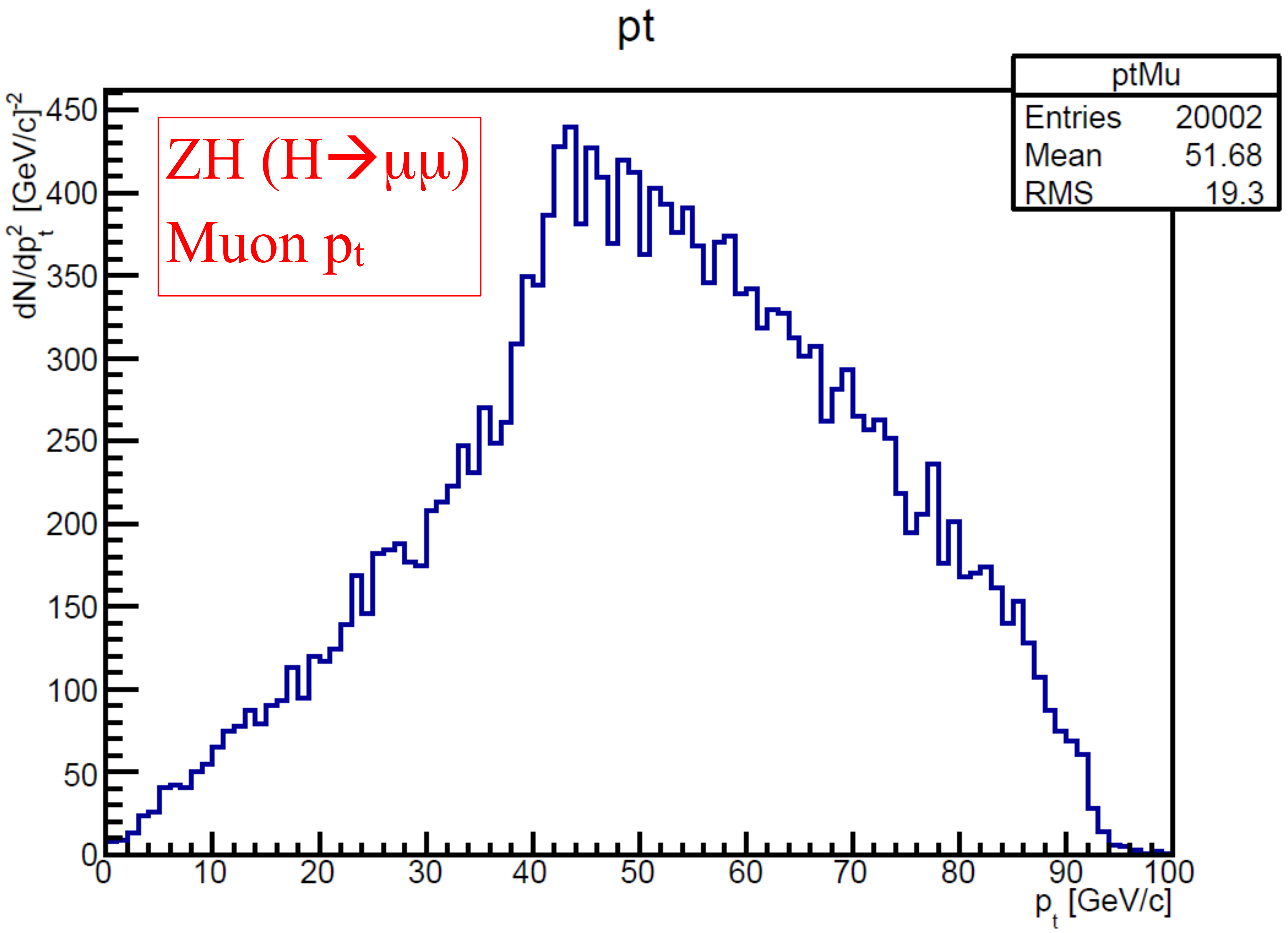
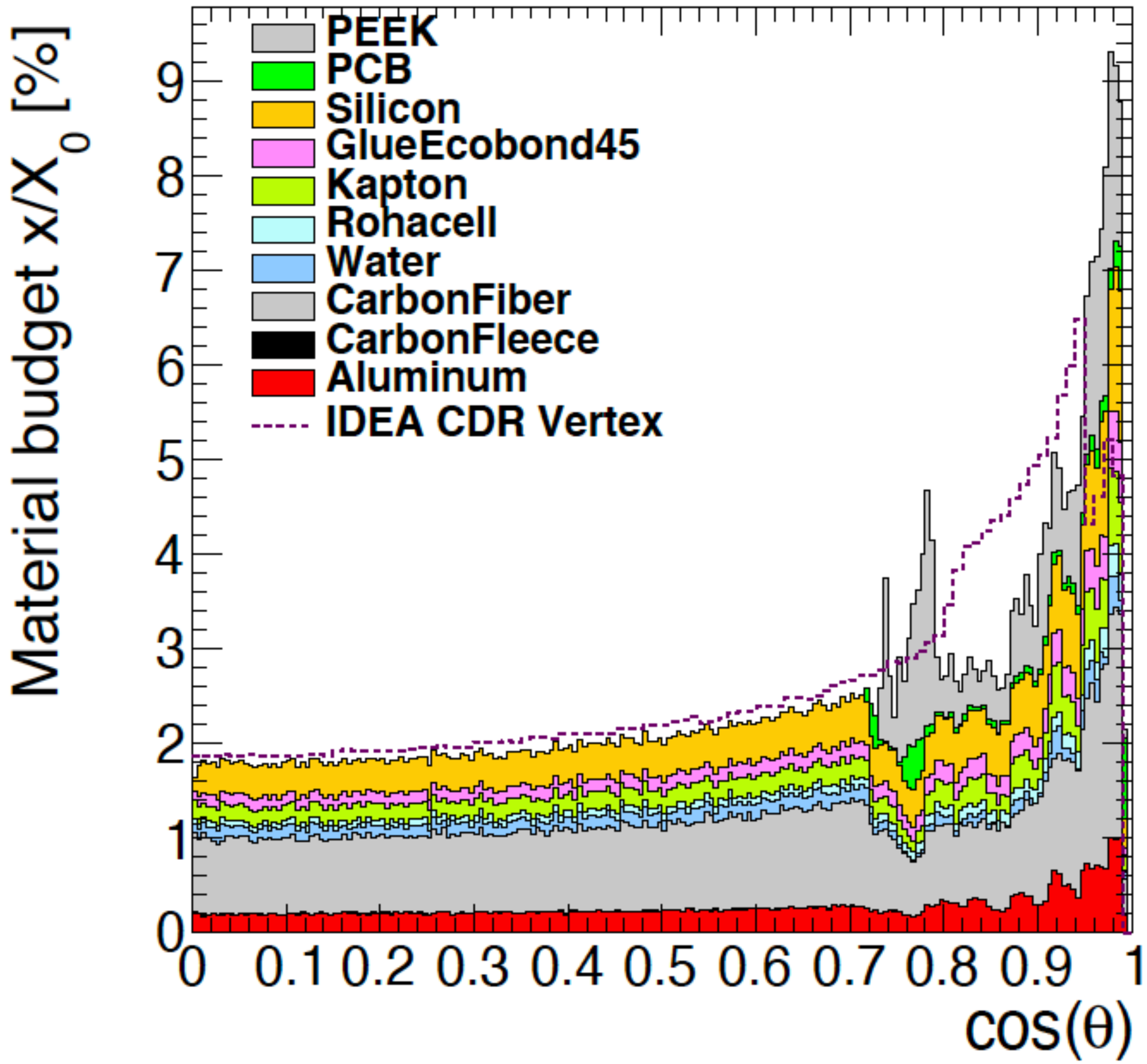
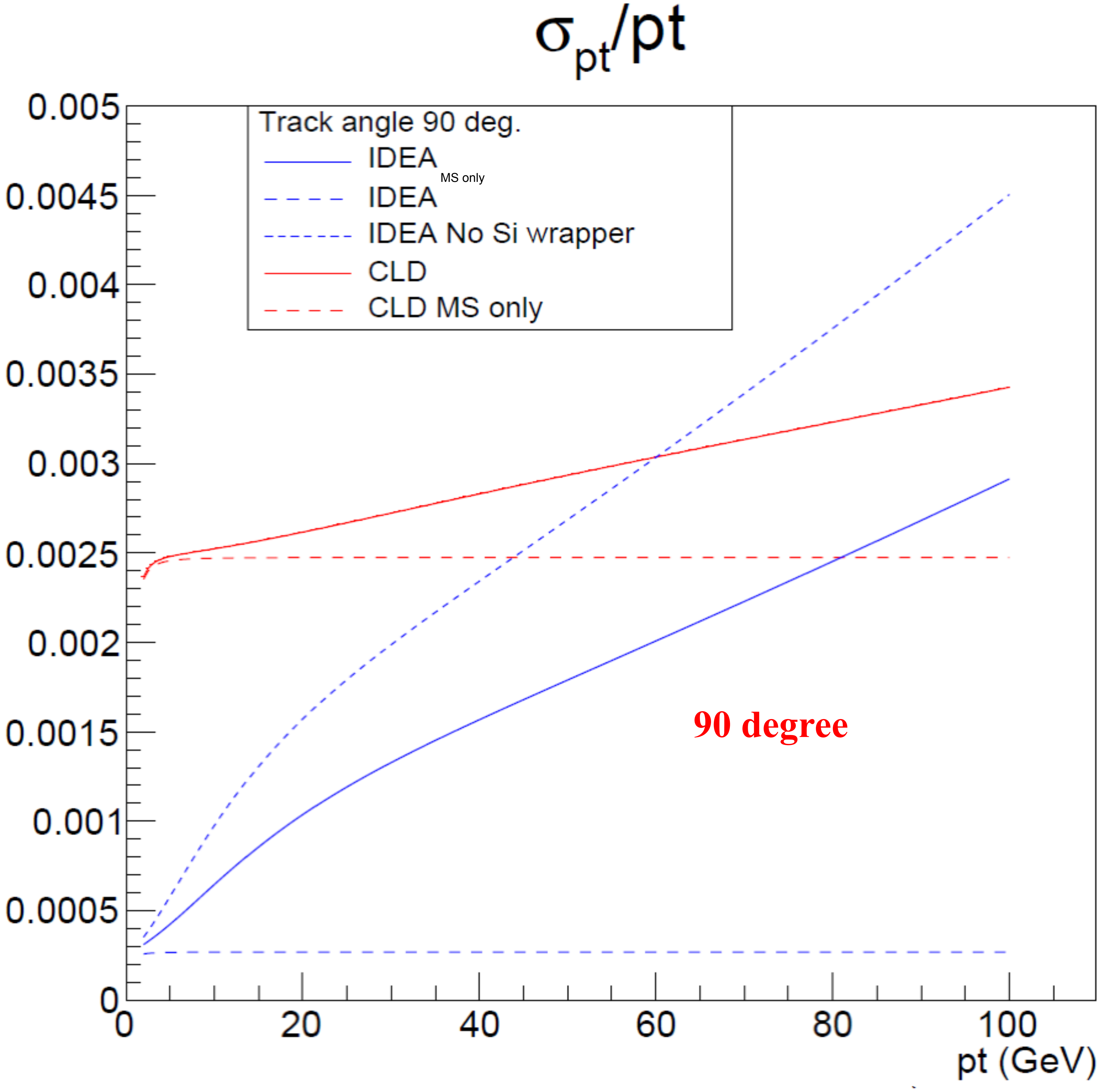




Momentum measurement

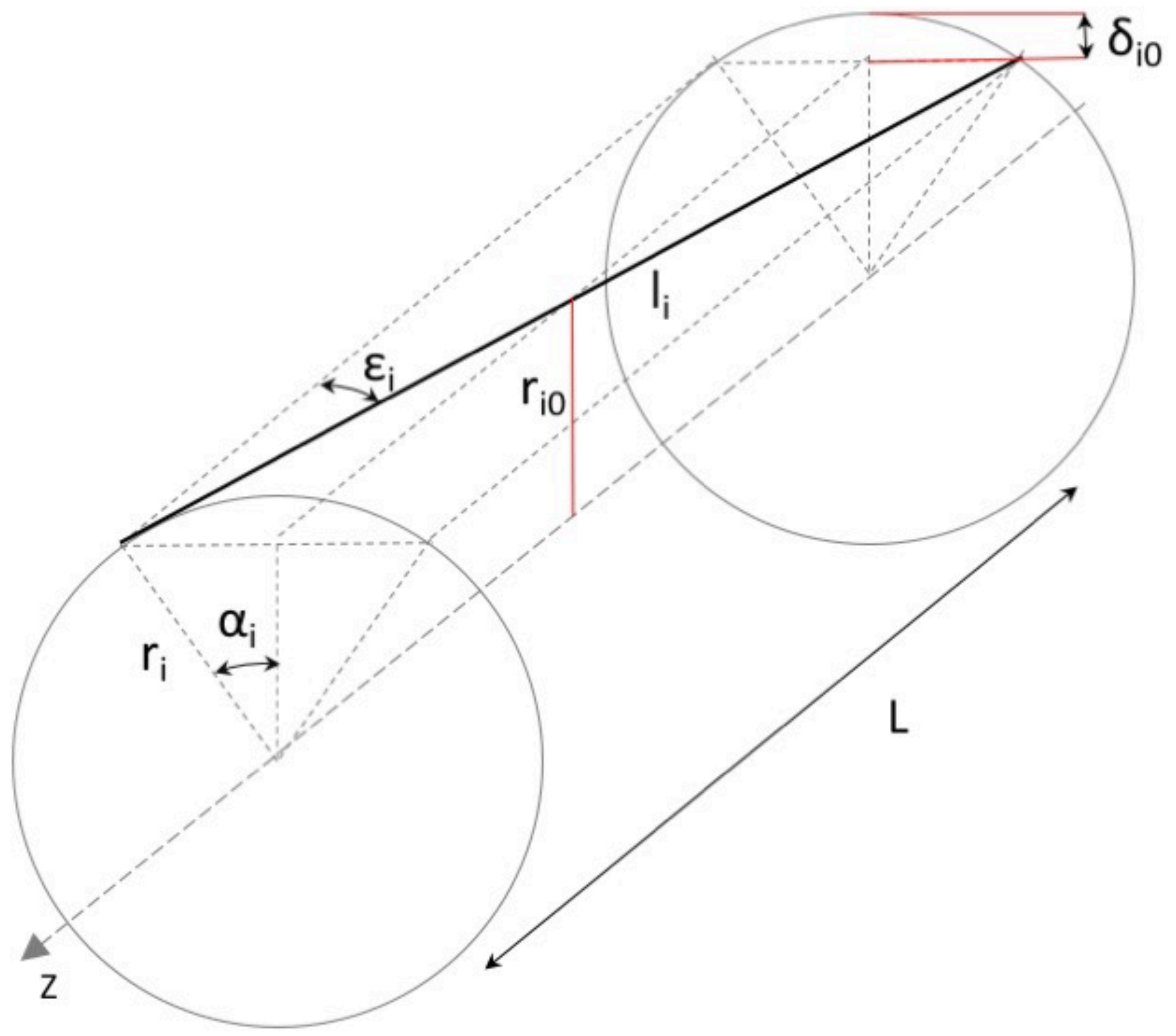
- Z or H decay muons in ZH events have rather low p_t
  - Transparency more important than asymptotic resolution



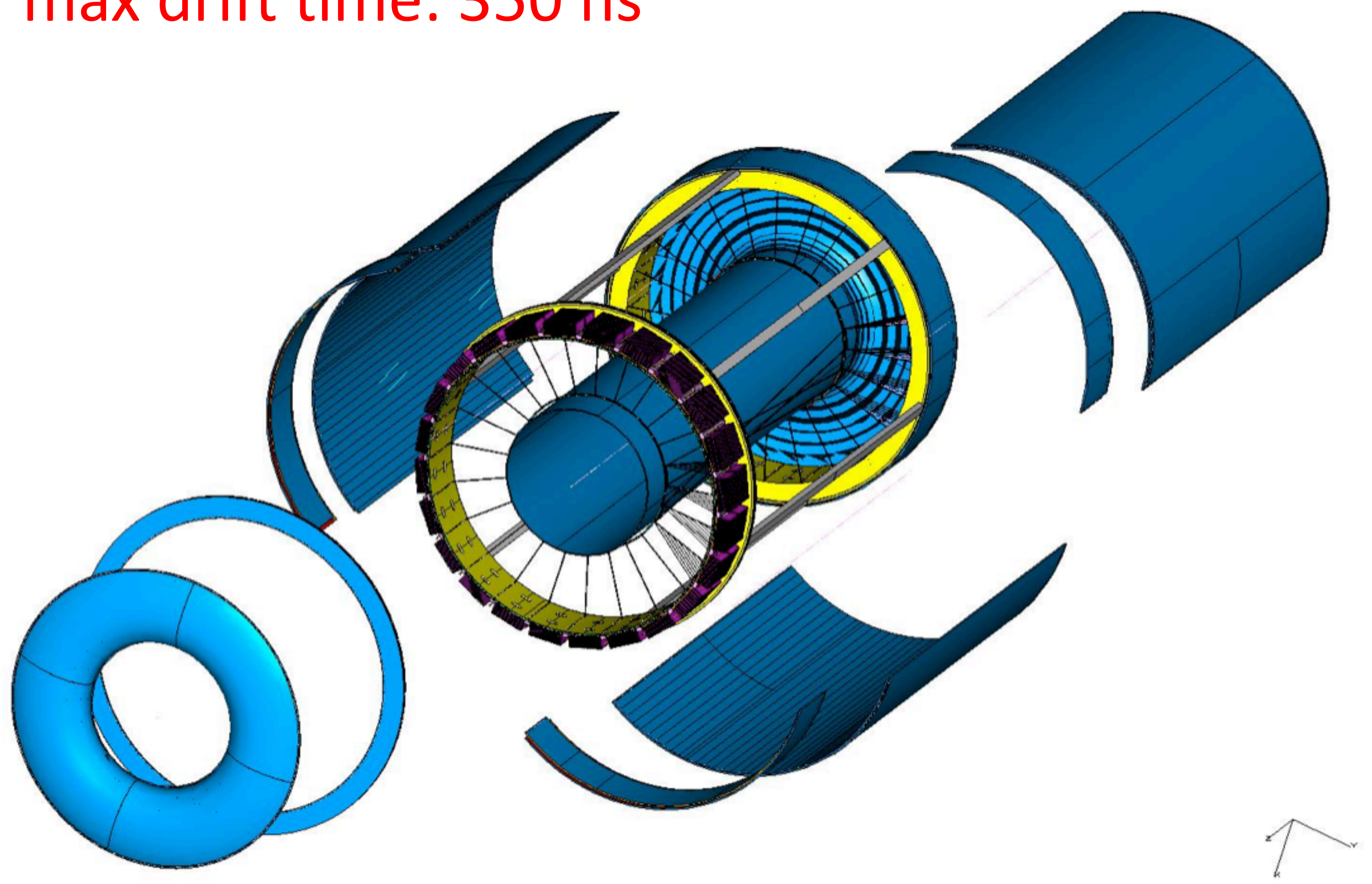


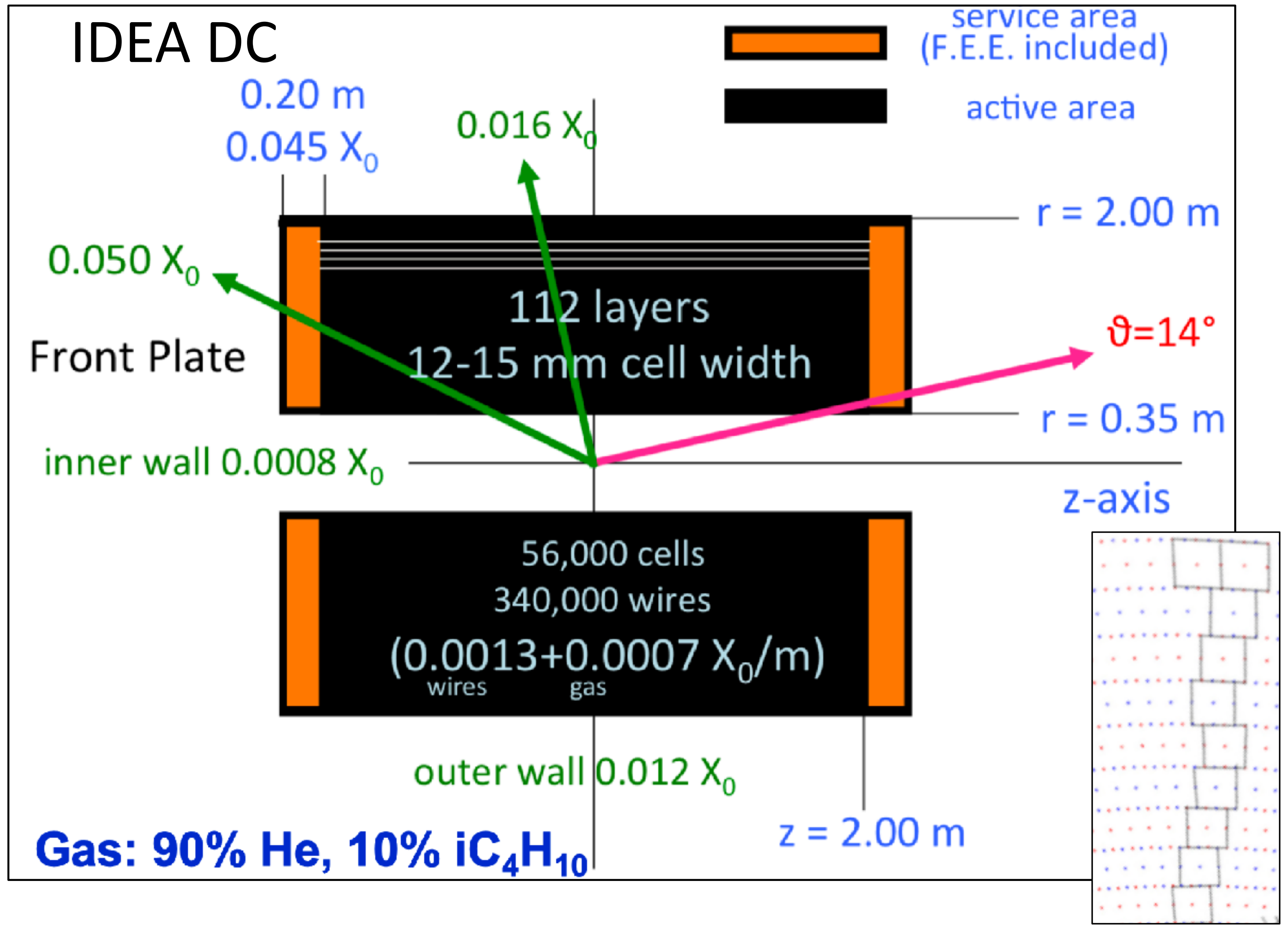
Drift chamber

- 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



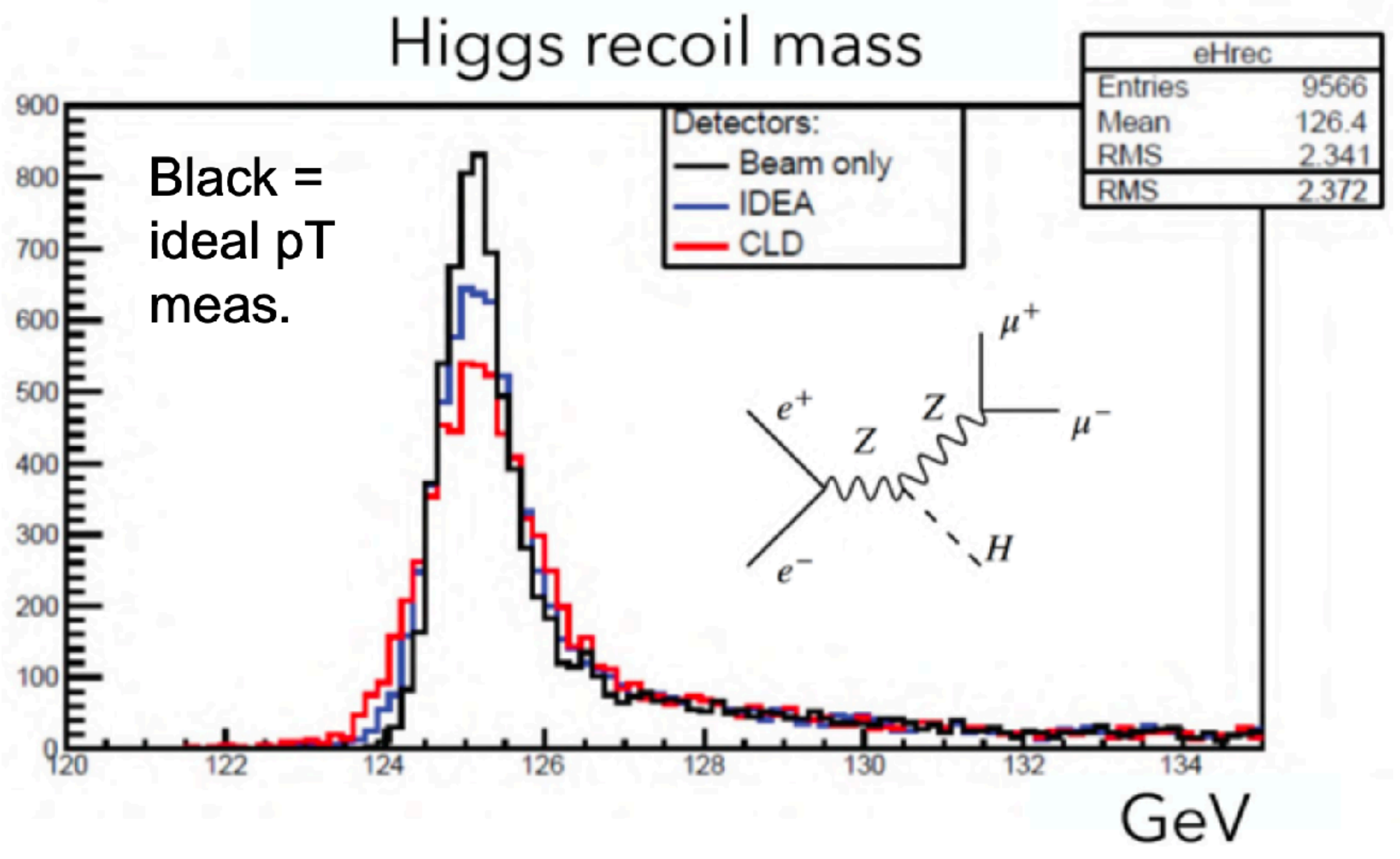
L = 4m

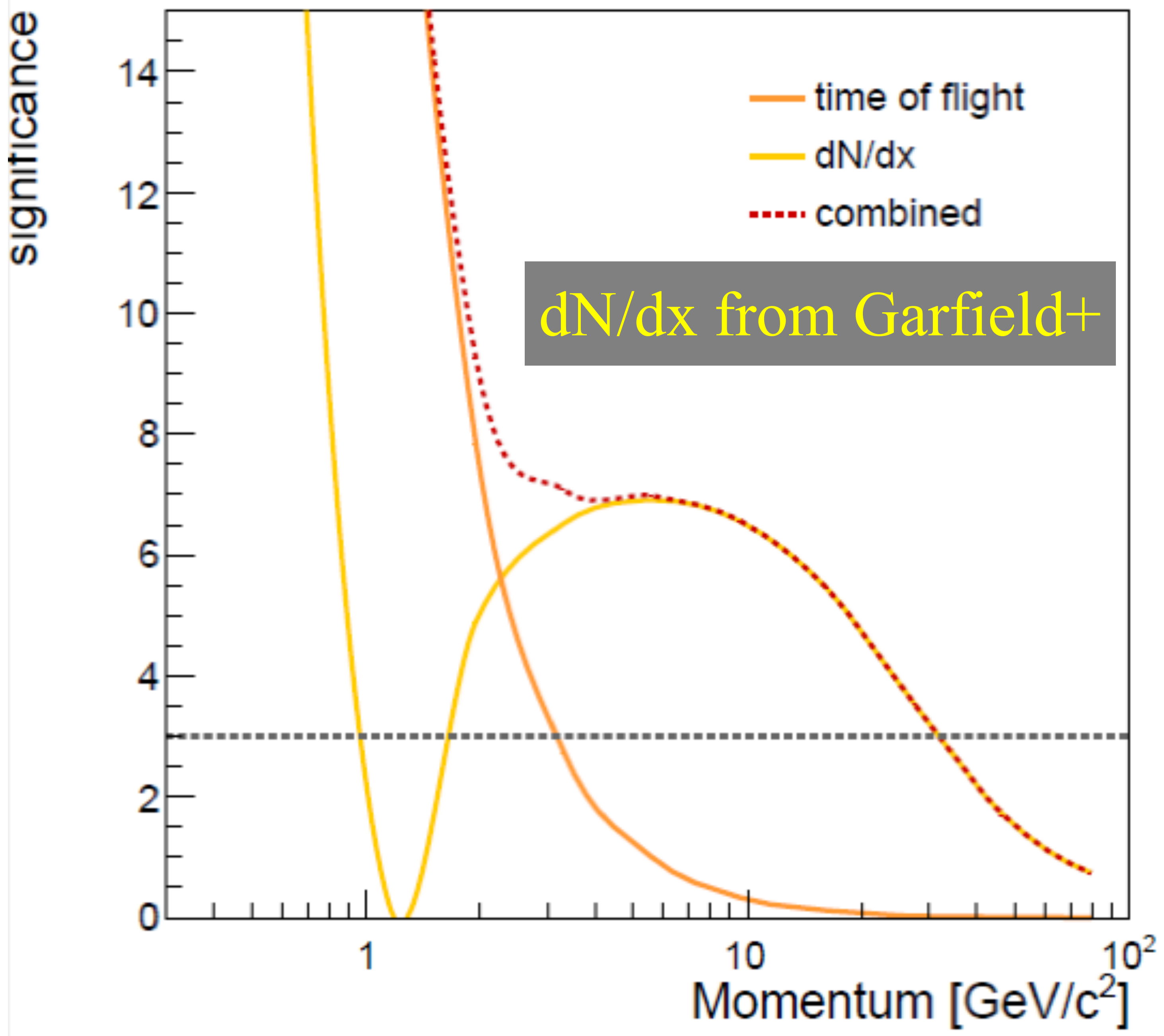


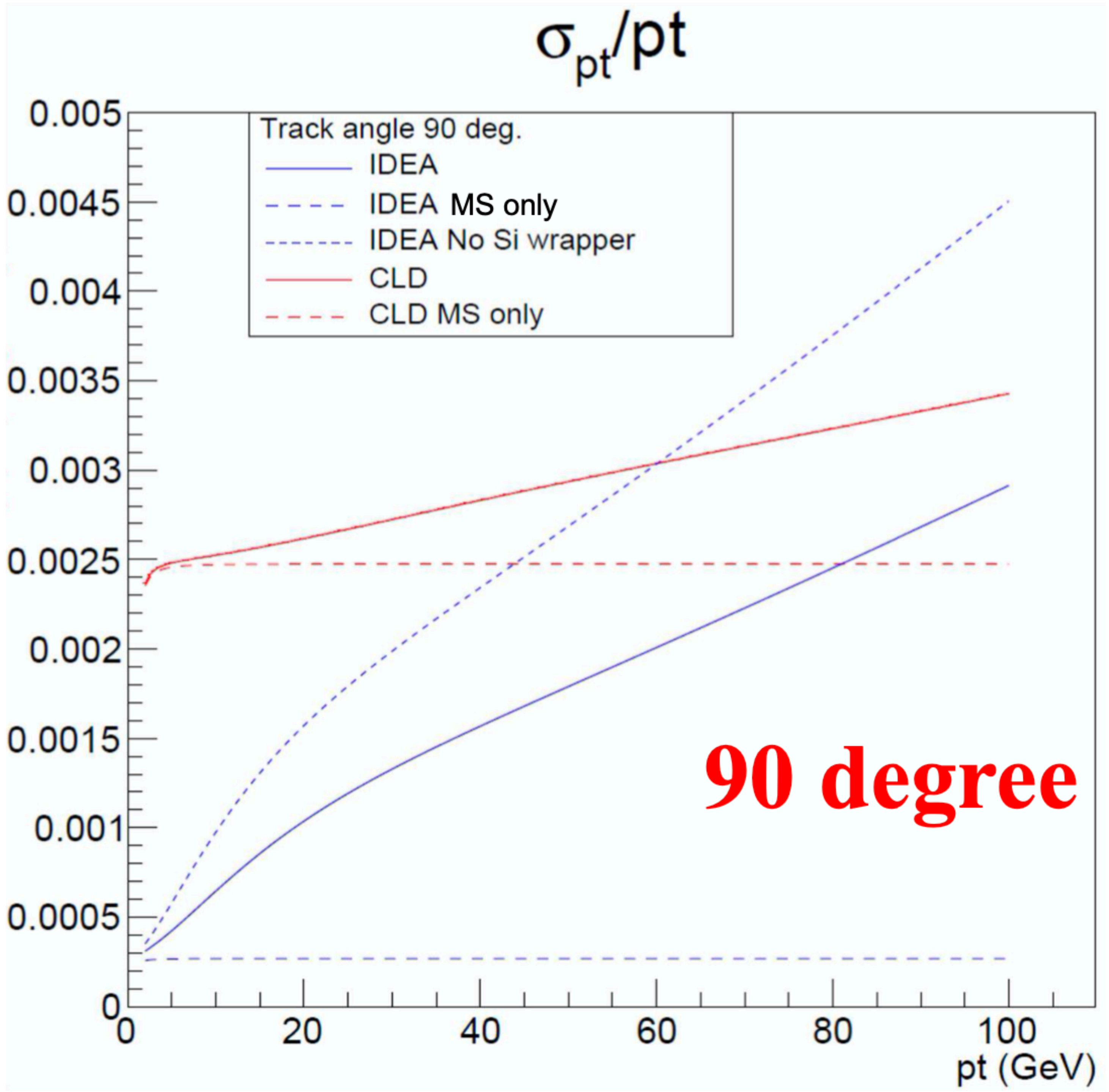


Drift chamber

- 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, Λ, BSM, LLPs)
  - Outstanding Particle separation via dE/dx or cluster counting (dN/dx)
    - >3σ K/π separation up to ~35 GeV







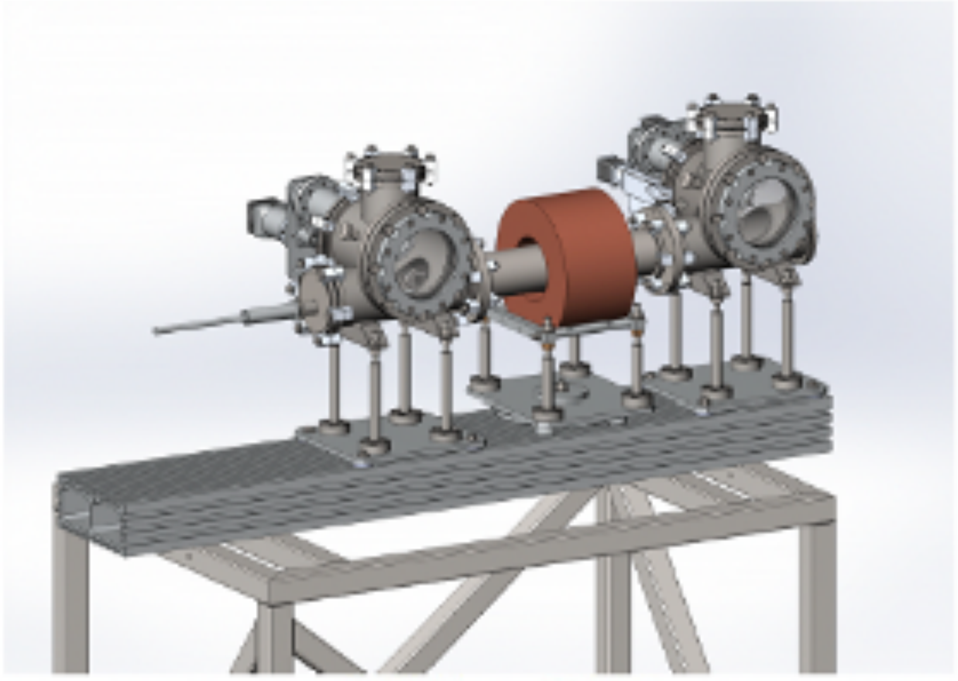
Challenges for large-volume chambers

- **Electrostatic stability** condition: $\frac{\lambda^2}{4\pi\varepsilon}\frac{L^2}{w^2} < wire\ tension < YTS \cdot \pi r_w^2$

λ = linear charge density (gas gain)
L = wire length, r_w wire radius, w = drift cell width
YTS = wire material yield strength

The proposed drift chambers for FCC-ee and CEPC have lengths **L = 4 m** and plan to exploit the cluster counting technique, which requires gas gains **~5×10⁵**.
This poses serious constraints on the drift cell width (**w**) and on the wire material (**YTS**).

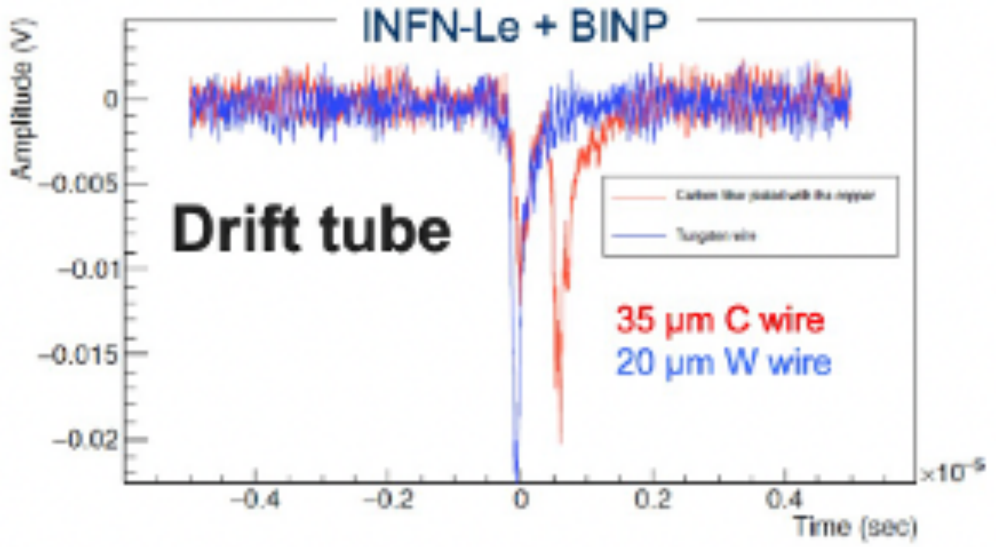
⇒ new wire material studies



- **Non-flammable gas / recirculating gas systems**

Safety requirements (**ATEX**) demands stringent limitations on flammable gases;
Continuous increase of **noble gases cost**

⇒ gas studies

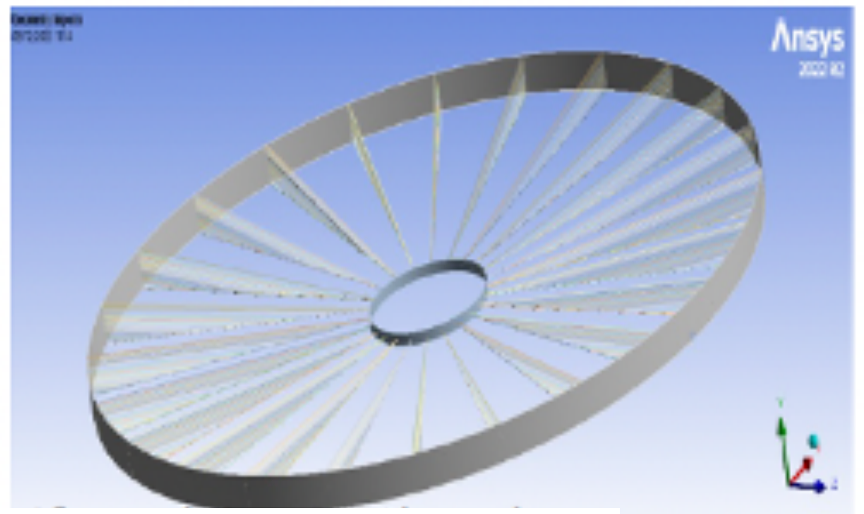


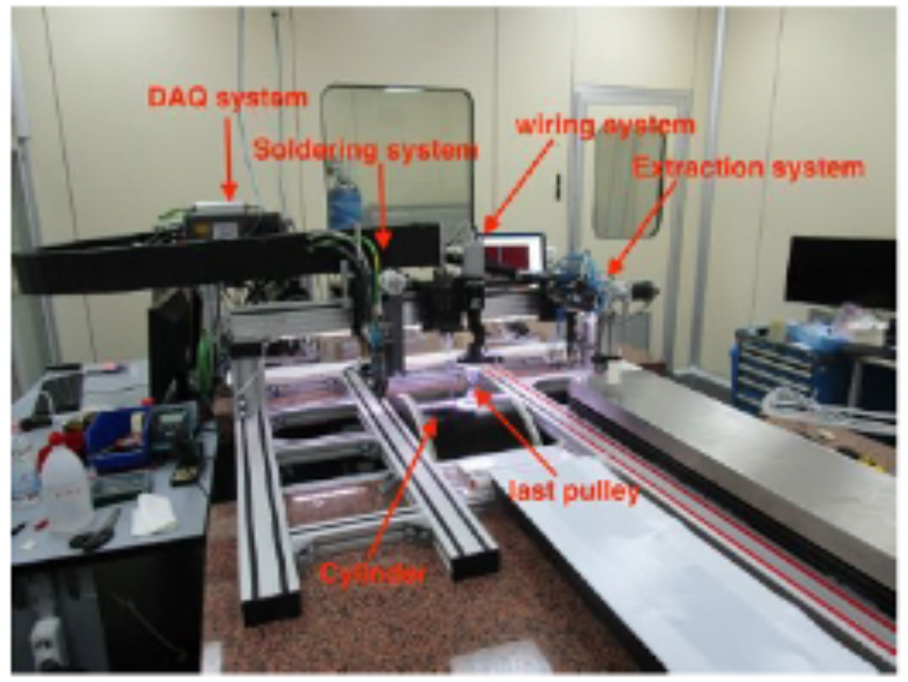
- **Data throughput**

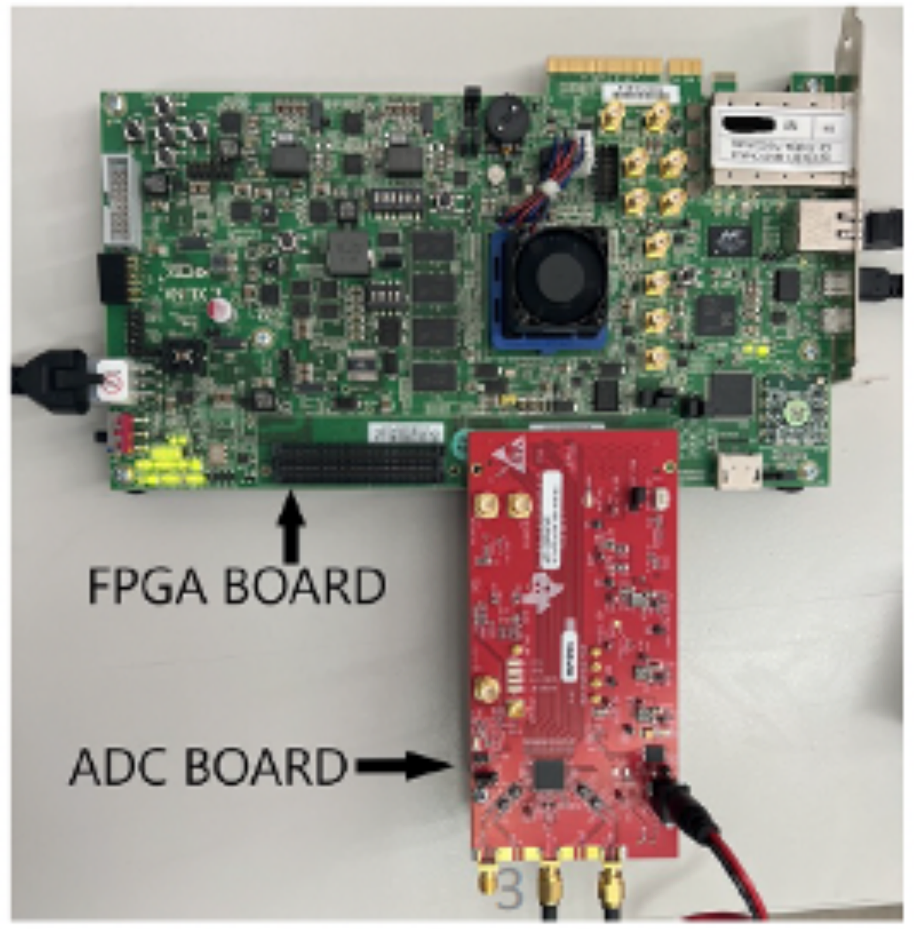
Large number of channels, high signal sampling rate, long drift times (slow drift velocity), required for cluster counting, and high physics trigger rate (Z_0-pole at FCC-ee) imply data transfer rates in excess of **~1 TB/s**

⇒ on-line real time data reduction algorithms

- **New wiring systems for high granularities / / new end-plates / new materials**







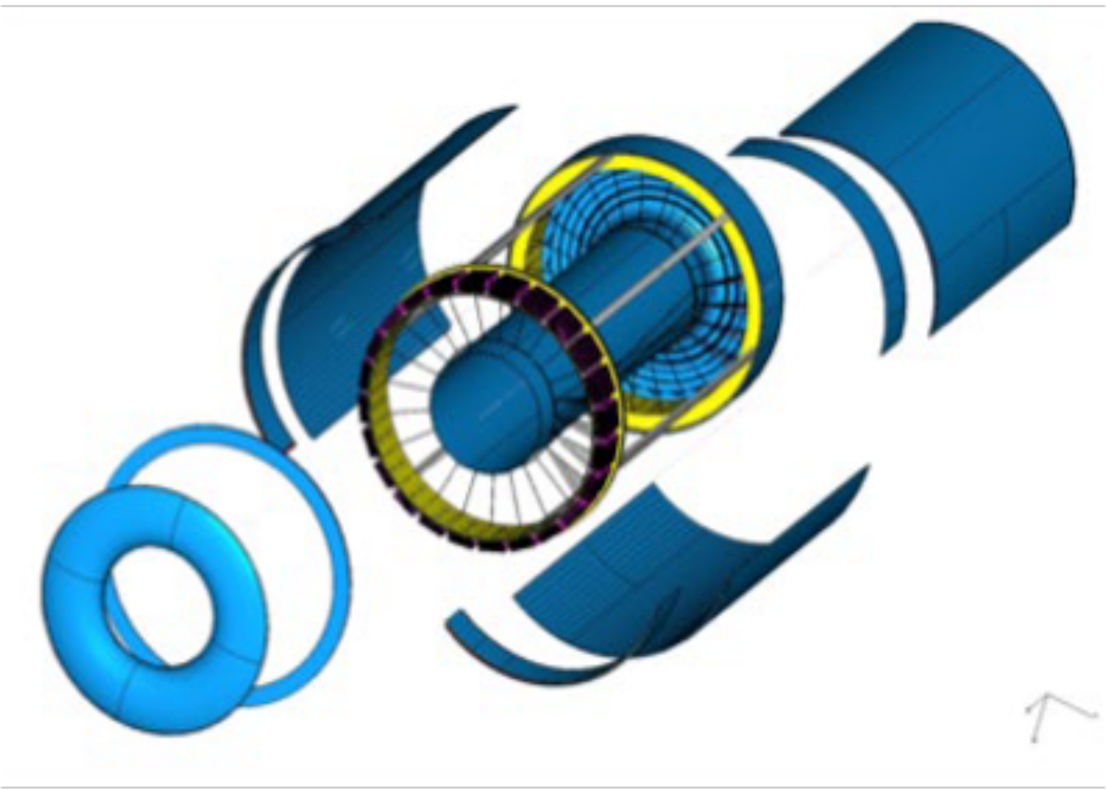
01/03/2023

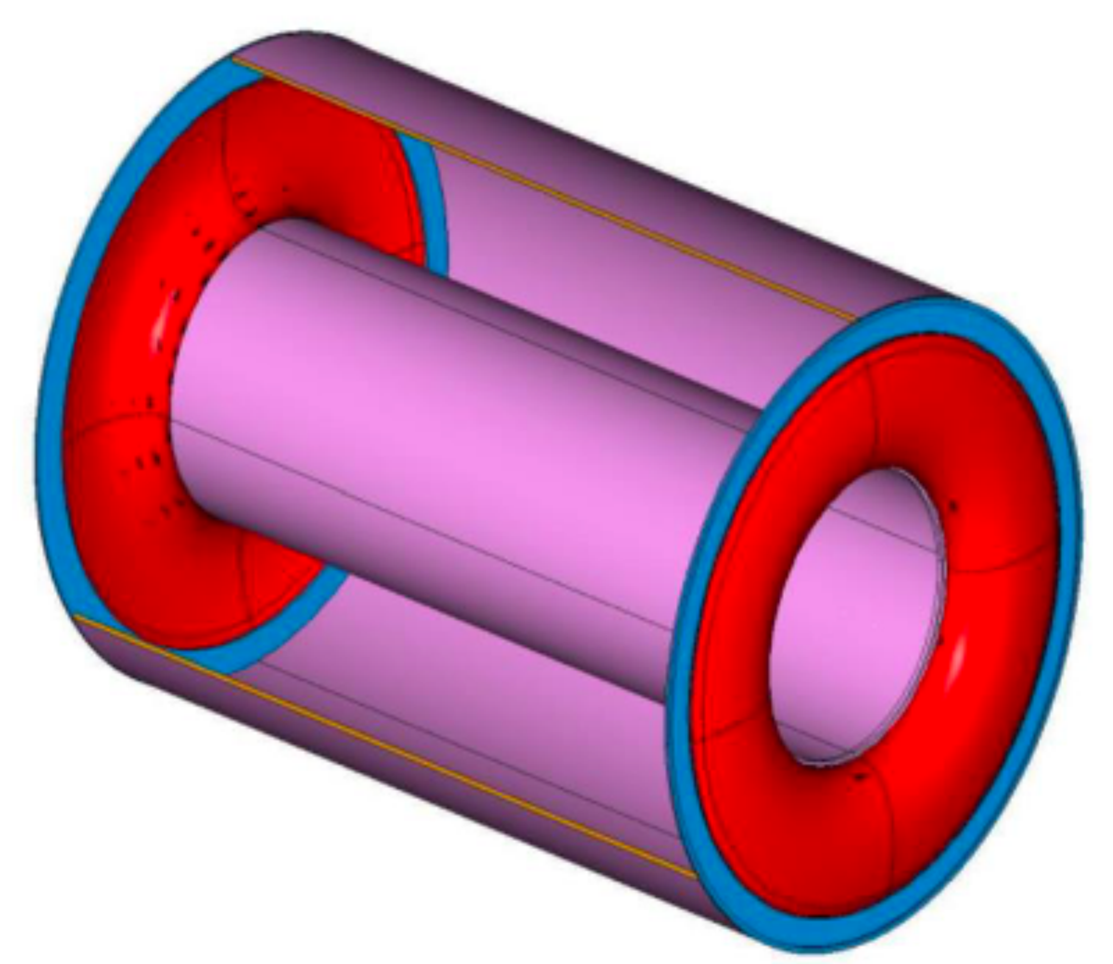
Drift chamber - mechanical structure

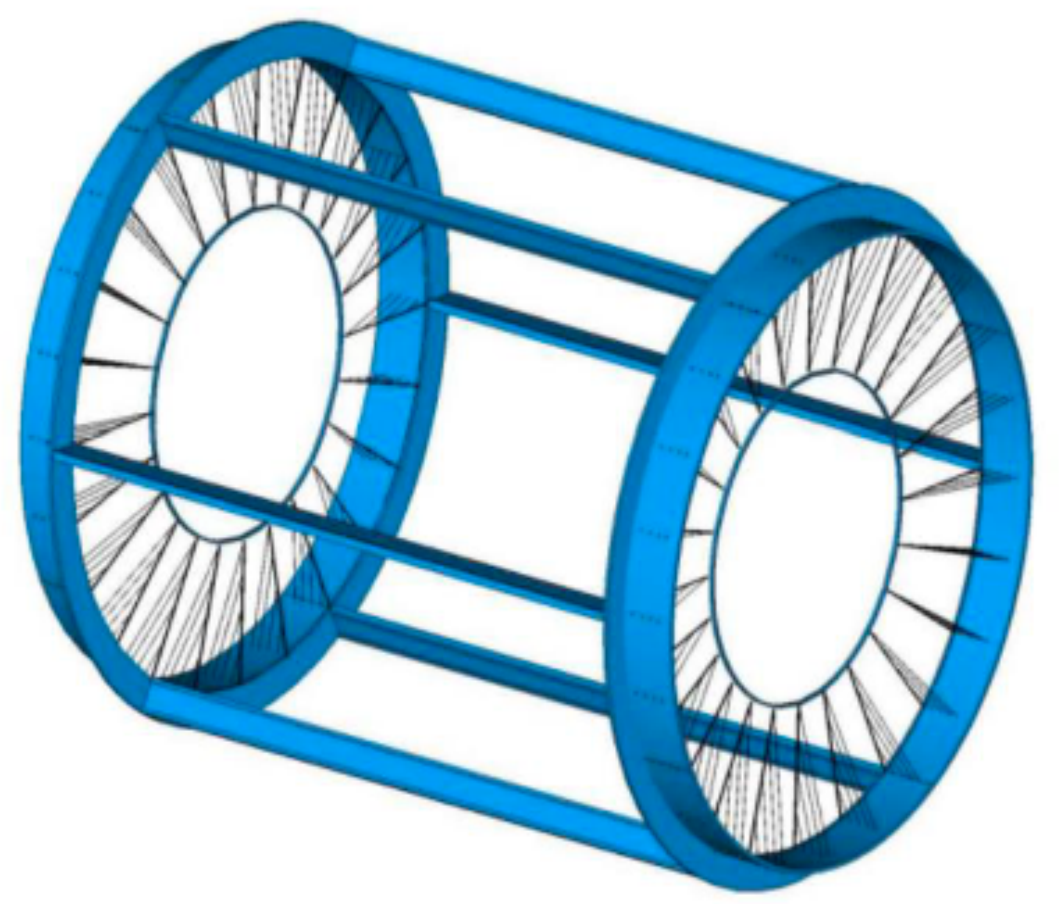
New concept of construction allows to reduce material to $\approx 10^{-3} X_0$ for the barrel and to a few $x\ 10^{-2} X_0$ for the end-plates.

Gas containment
Gas vessel can freely deform without affecting the internal wire position and mechanical tension.

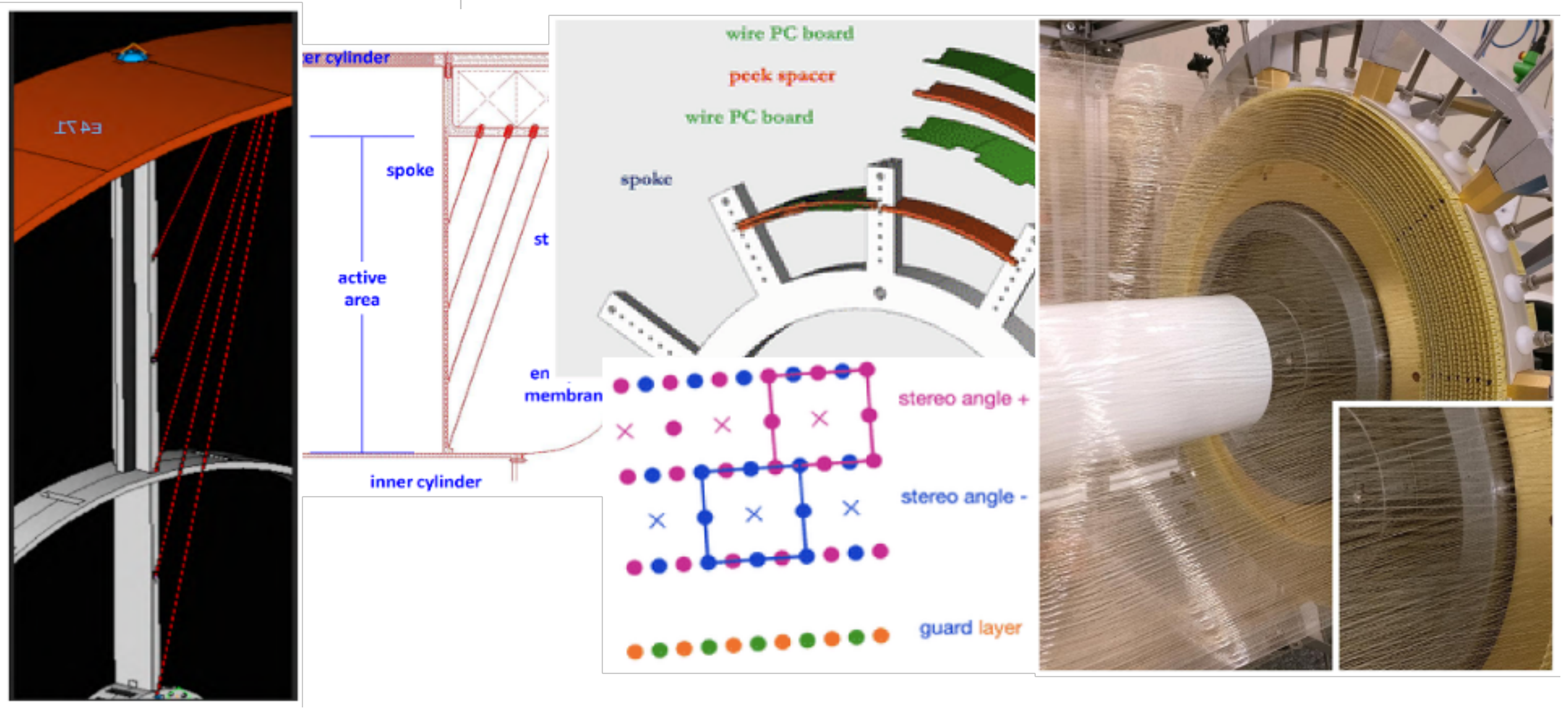
Wire cage
Wire support structure not subject to differential pressure can be light and feed-through-less



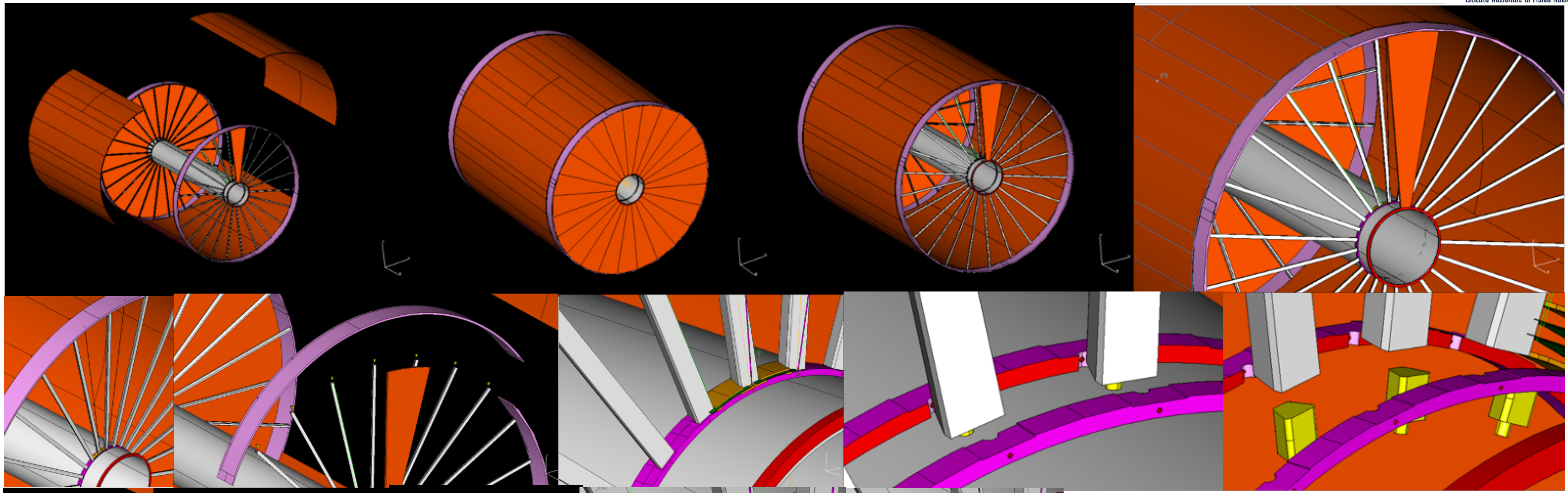


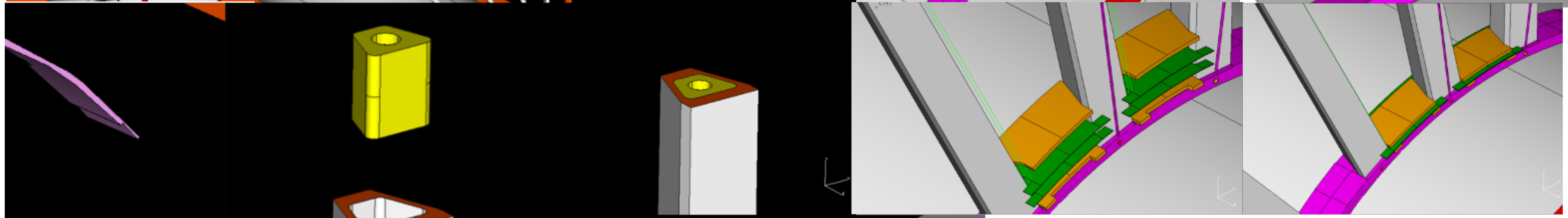


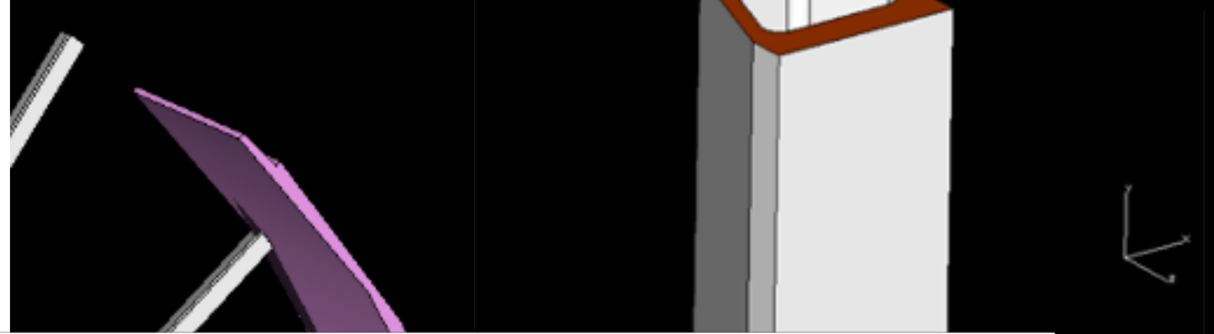
- New tension recovery schema
- Experience inherited from the MEG2 DCH

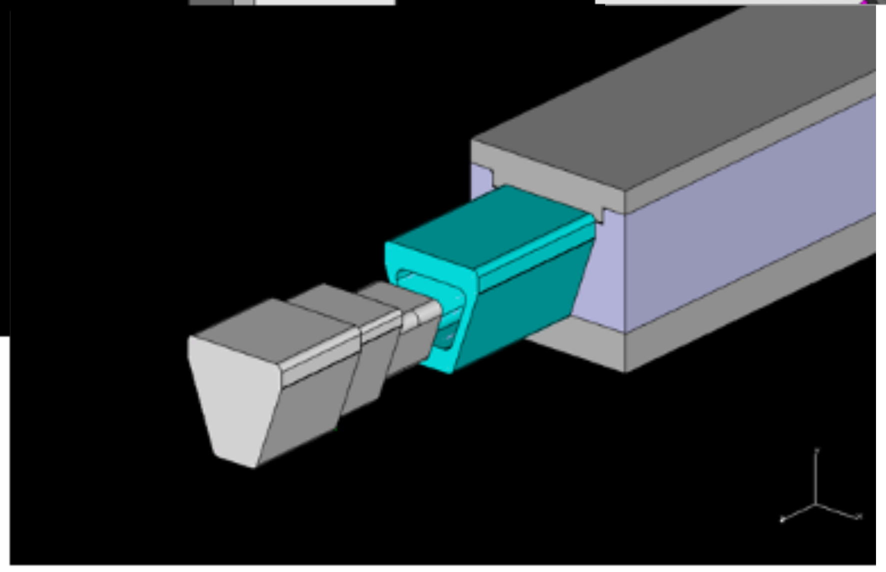


Mechanical structure: a complete model









Plan to start the construction of a DCH prototype full lenght, three sectors

A realistic complete model ready:

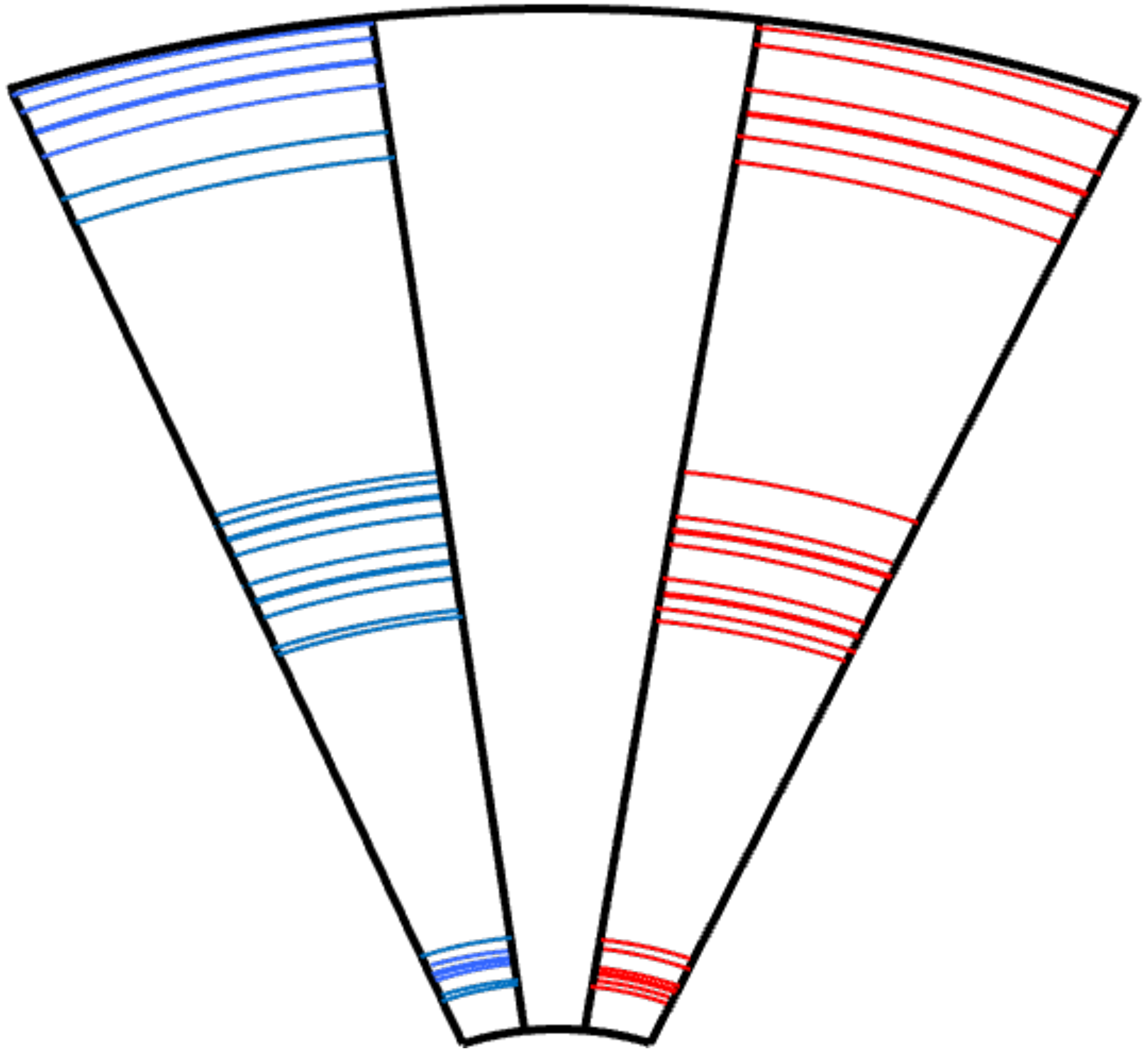
- mechanically accurate
- precise definition of the connections of the cables on the structure
- connections of the wires on the PCB
- location of the necessary spacers
- connection between wire cage and gas containment structure

Full length prototype - goals

- **Check the limits of the wires' electrostatic stability at full length and at nominal stereo angles**
- **Test different wires**: uncoated Al, C monofilaments, Mo sense wires, …, of different diameters
  - Test different wire anchoring procedures (soldering, welding, gluing, crimping, …) to the wire PCBs
  - Test different materials and production procedures for spokes, stays, support structures and spacers
  - Test compatibility of proposed materials with drift chamber operation (outgassing, aging, creeping, …)
- Validate the **concept of the wire tension recovery scheme** with respect to the tolerances on the wire positions
  - Optimize the layout of the wires' PCBs (sense, field and guard), according to the wire anchoring procedures, with aim at minimizing the end-plate total material budget
- Starting from the new concepts implemented in the MEG2 DCH robot, **optimize the wiring strategy**, by taking into account the 4m long wires arranged in multi-wire layers
- Define and validate **the assembly scheme** (with respect to mechanical tolerances) of the multi-wire layers on the end plates
  - Define the front-end cards channel multiplicity and their location (cooling system necessary?)
- **Optimize the High Voltage and signal distribution** (cables and connectors)
- Test performance of **different versions of front-end, digitization and acquisition chain**

Full length prototype - wiring

Target: a full length DCH prototype with 3 sectors per endcap



- 8 spokes (4 per endcap)
- Internal ring
- part of the outer ring
- part of the cylindrical panel

First two layers of superlayer #1

V and U guard layers (2 x 9 guard wires)
V and U field layers (2 x 18 field wires)
U layer (8 sense + 9 guard)
U and V field layers (2 x 18 field wires)
V layer (8 sense + 9 guard)
V and U field layers (2 x 18 field wires)
V and U guard layer (2 x 9 guard wires)

Last two layers of superlayer #7

V and U guard layers (2 x 21 guard wires)
V and U field layers (2 x 42 field wires)
U layer (20 sense + 21 guard)
U and V field layers (2 x 42 field wires)
V layer (20 sense + 21 guard)
V field layer (42 field wires)

First two layers of superlayer #8

U field layer (46 field wires)
U layer (22 sense + 23 guard)
U and V field layers (2 x 46 field wires)
V layer (22 sense + 23 guard)
V and U field layers (2 x 46 field wires)
V and U guard layer (2 x 23 guard wires)

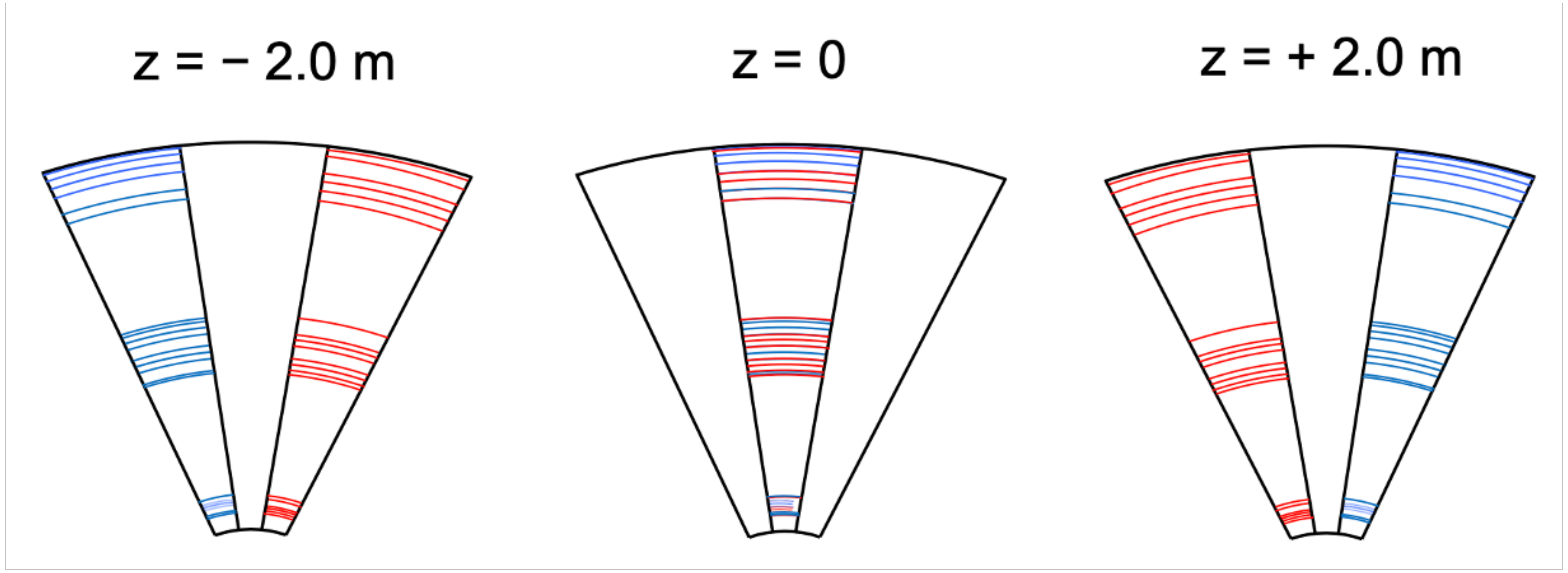
Last two layers of superlayer #14

V and U guard layers (2 x 35 guard wires)
V and U field layers (2 x 70 field wires)
U layer (34 sense + 35 guard)
U and V field layers (2 x 70 field wires)
V layer (34 sense + 35 guard)
V and U field layers (2 x 70 field wires)
V and U guard layer (2 x 35 guard wires)

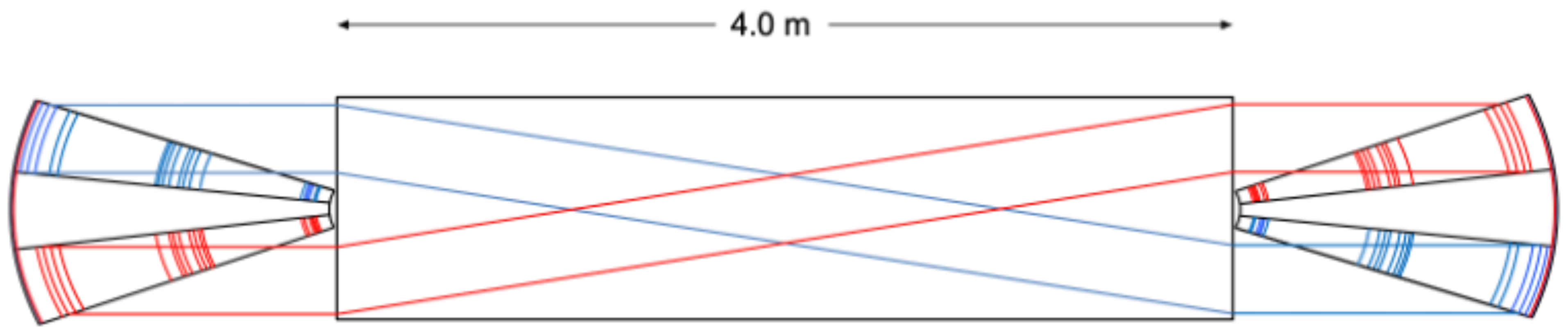
TOTAL LAYERS: 8
Sense wires: 168
Field wires: 965
Guard wires: 264

PCBoards wire layers: 42
Sense wire boards: 8
Field wire boards: 22
Guard wire boards: 12
HV values: 14

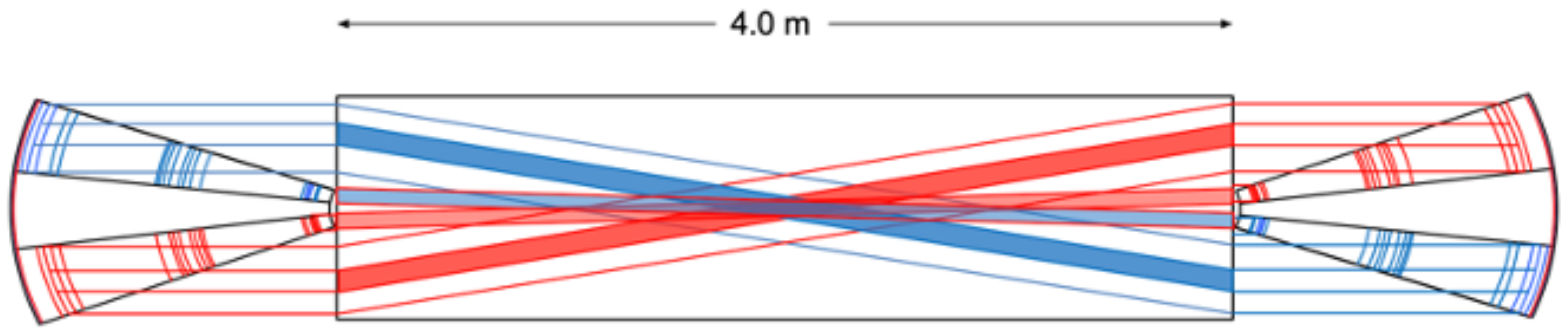
Full length prototype - coverage



MAX COVERAGE



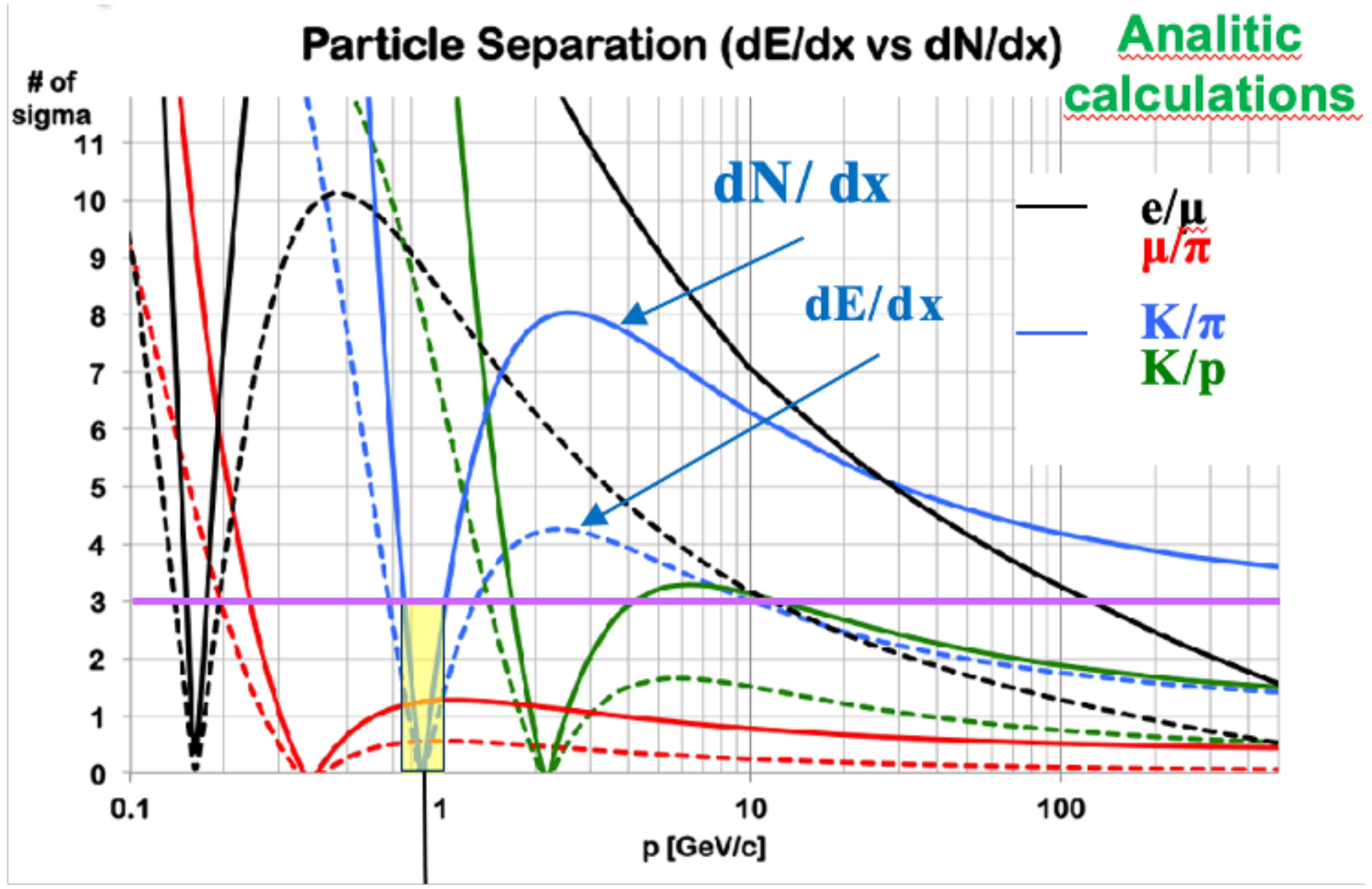
ELECTRONICS COVERAGE

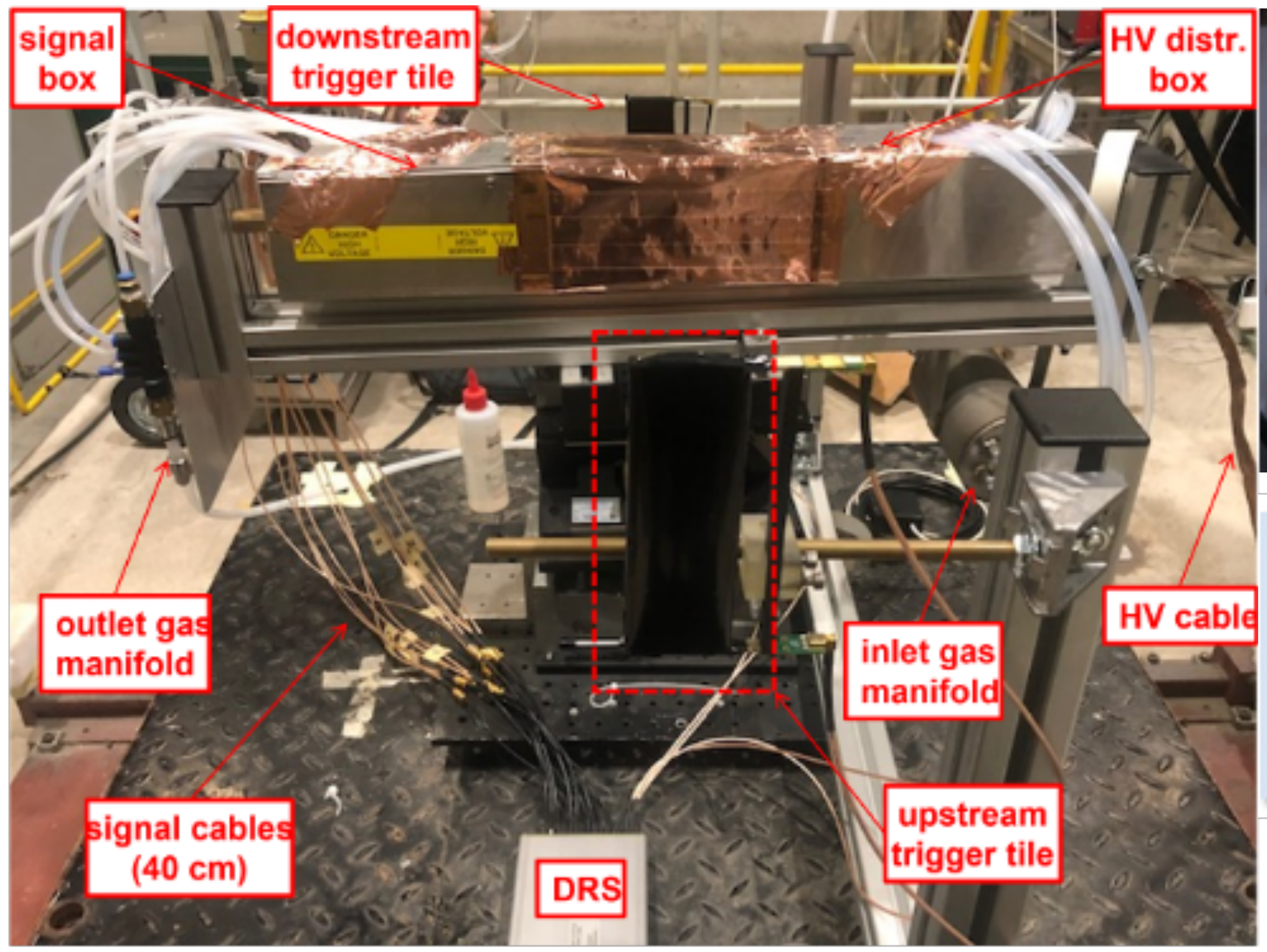


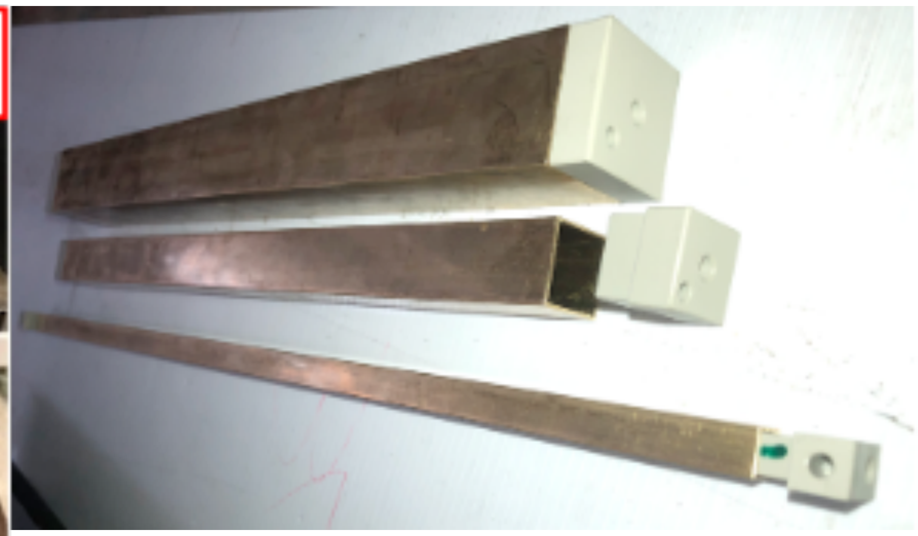
Minimum stereo angle 50 mrad
Maximum stereo angle: 250 mrad

Cluster counting

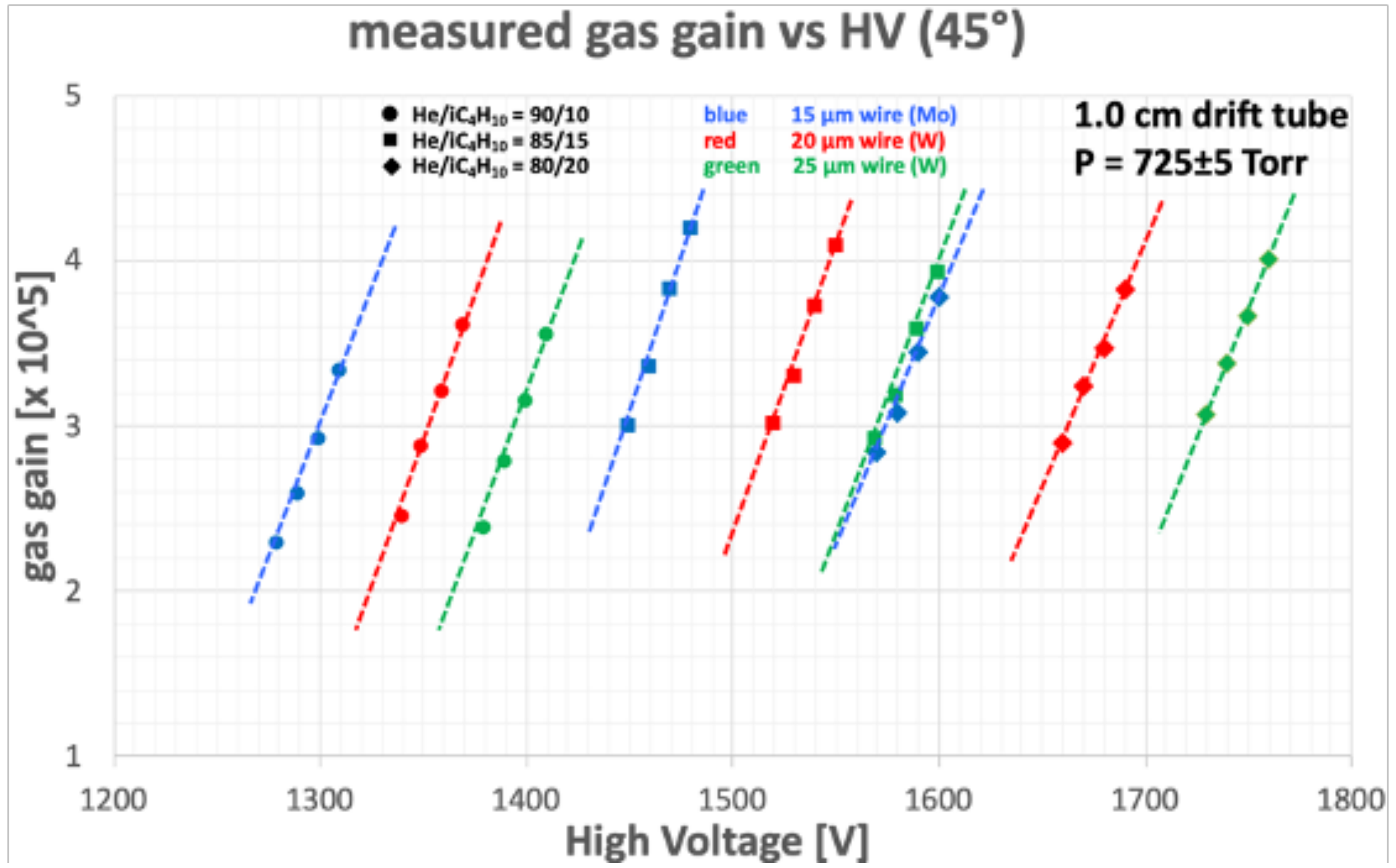
- Analitic calculations: Expected excellent K/π separation over the entire range except $0.85<p<1.05$ GeV (blue lines)
- Simulation with Garfield++ and with the Garfield model ported in GEANT4:
  - the particle separation, both with dE/dx and with dN_{cl}/dx, in GEANT4 found considerably worse than in Garfield
  - the dN_{cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of $\beta\gamma$ with a steeper slope
  - finding answers by using real data from beam tests







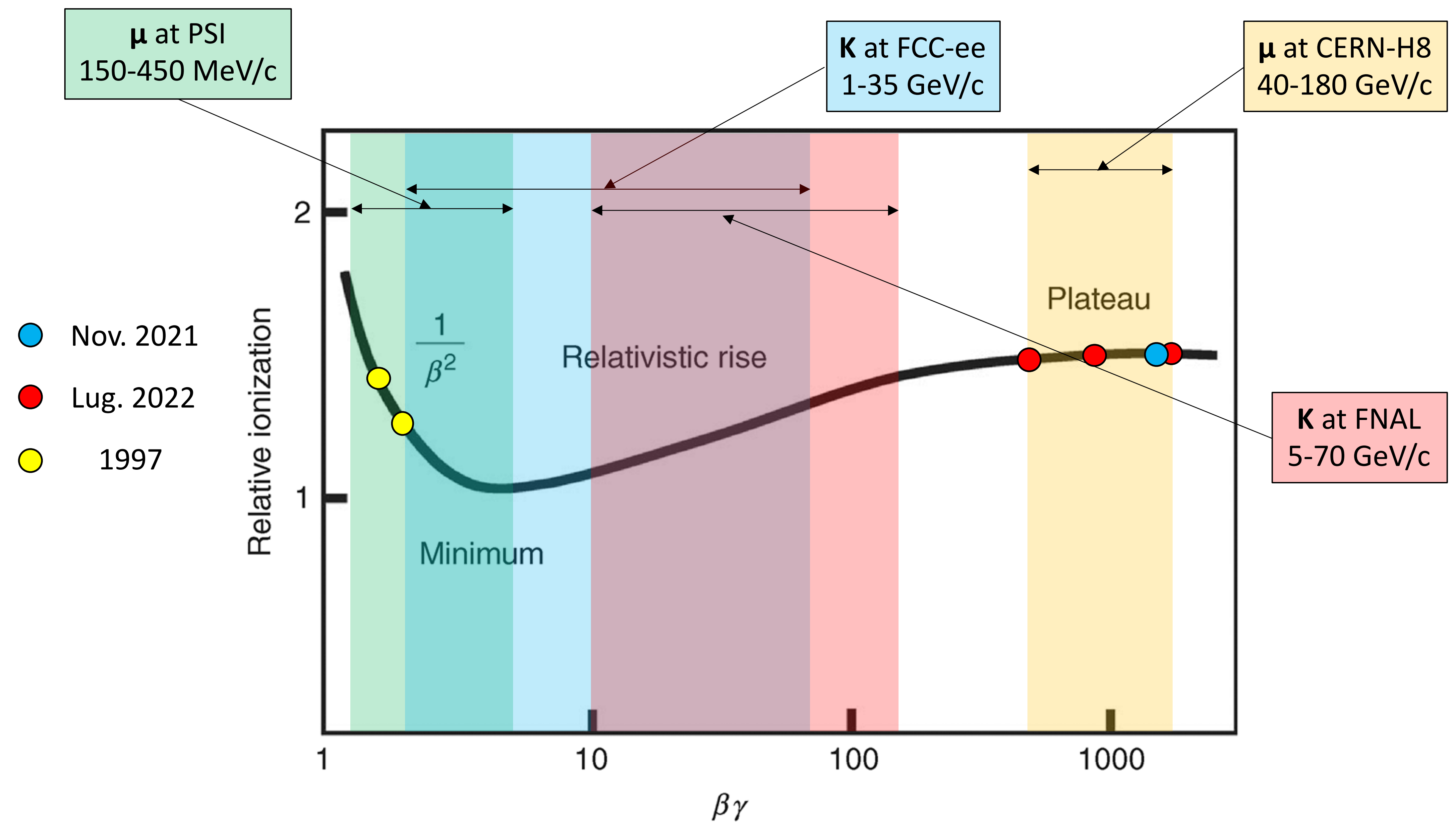
90%He-10%iC_4H_{10}
nominal HV+20, 45°,
Gas gain ~ $2 \cdot 10^5$,
165 GeV/c

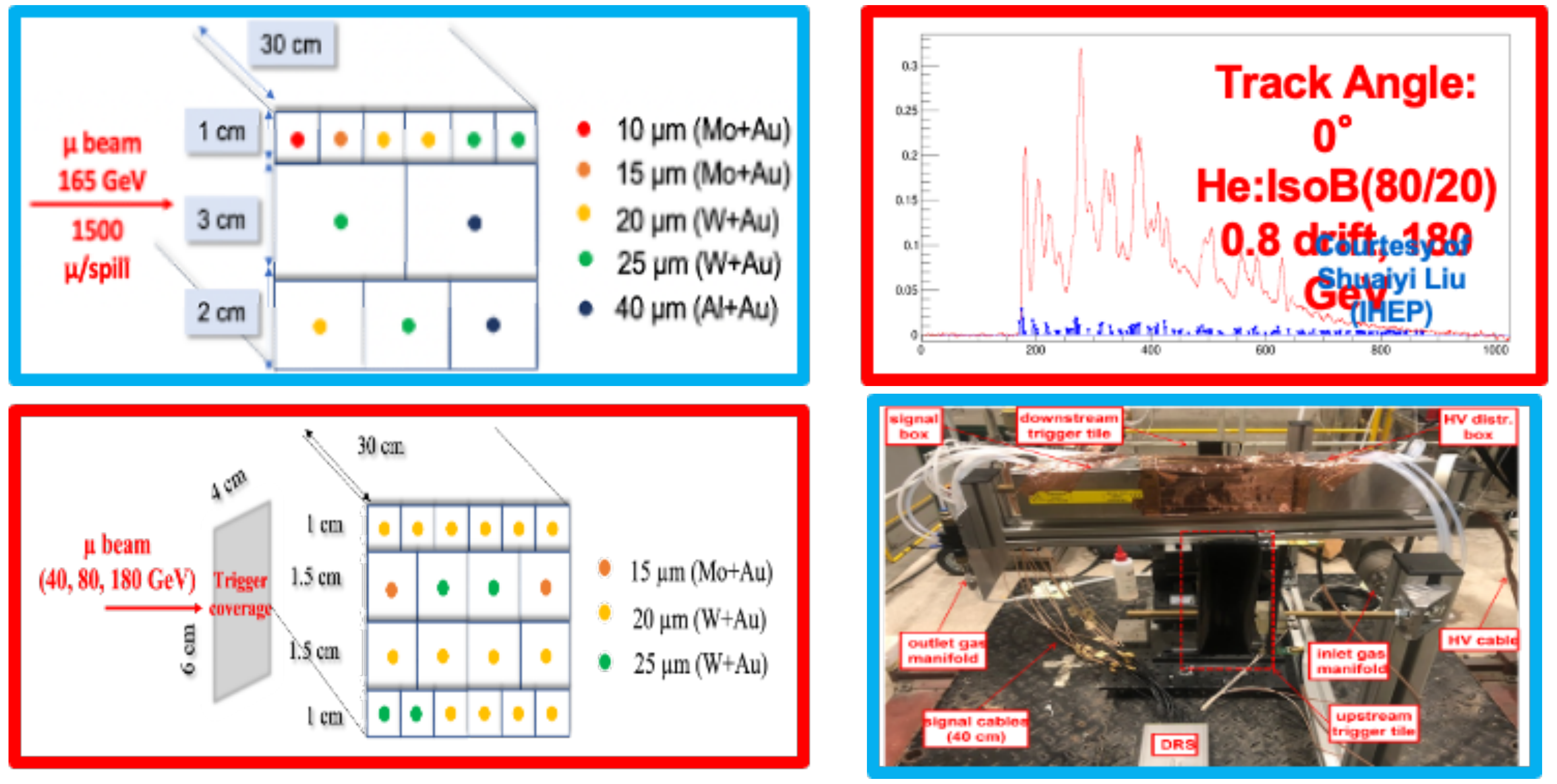


Beam tests in 2021, 2022 and 2023

Beam tests to experimentally asses and optimize the **performance of the cluster counting/timing** techniques:

- Two **muon beam tests** performed at **CERN-H8** **($\beta\gamma$ > 400)** in Nov. 2021 and July 2022 (p_T = 165/180 GeV).
- A **muon beam test** (from 4 to 12 GeV momentum) in 2023 performed at **CERN**. A new testbeam with the same configuration starting on July 10, 2024
- Ultimate test at **FNAL-MT6** in 2025 with π and **K** **($\beta\gamma$ = 10−140)** to fully exploit the relativitic rise.





Beam tests in 2021, 2022 and 2023

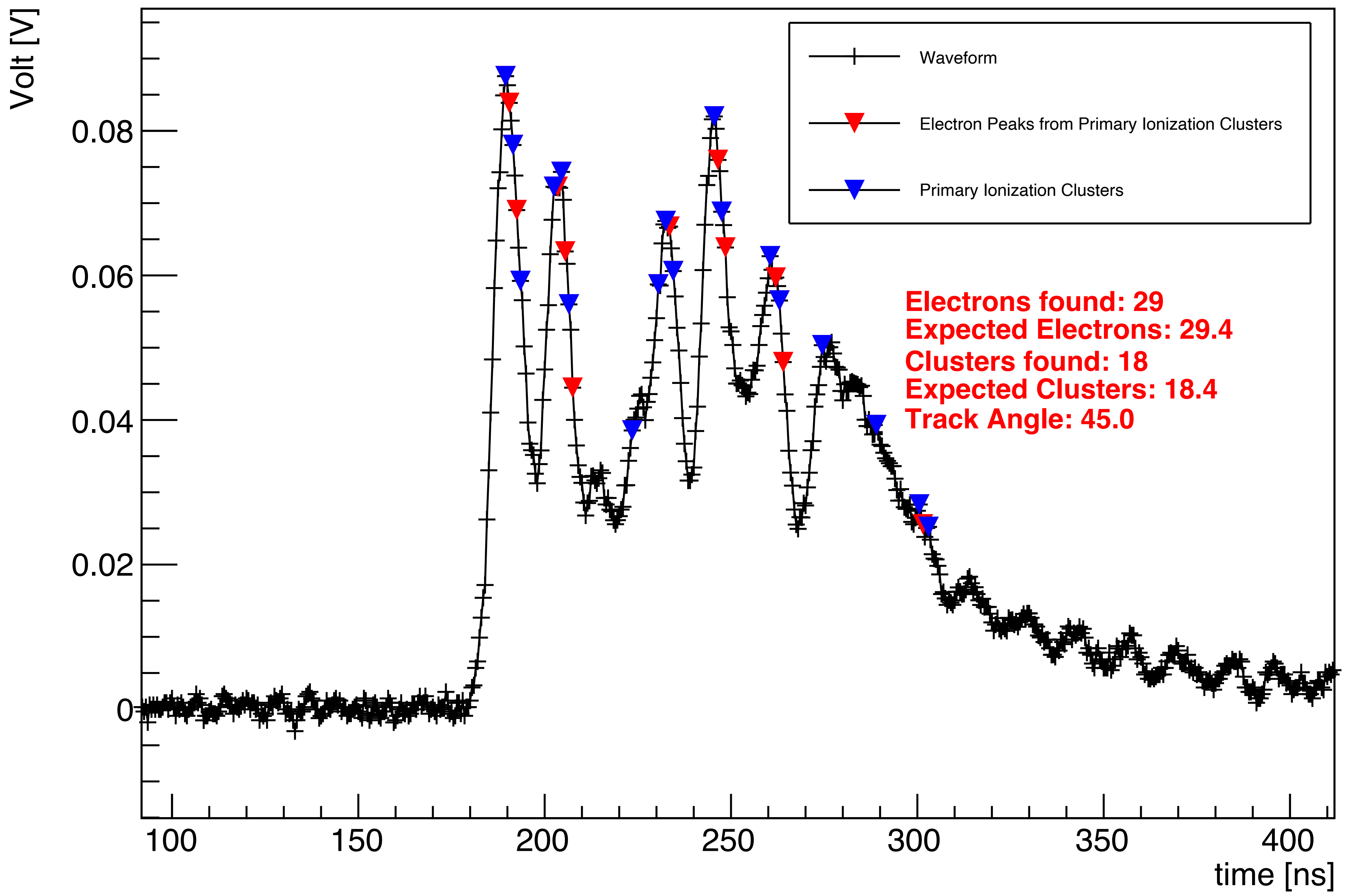
- Several algorithms developed for electron peak finding:
  - ✓ Derivative Algorithm (DERIV)
  - ✓ and Running Template Algorithm (RTA)
  - ✓ NN-based approach (developed by IHEP)
- Clusterization algorithm to merge electron peaks in consecutive bins
- Poissonian distribution for the number of clusters as expected
- Different scans have been done to check the performance: (HV, Angle, gas gain, template scan)

Expected number of electrons =
δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise)* 1.6 electrons/cluster * 1/cos(α)

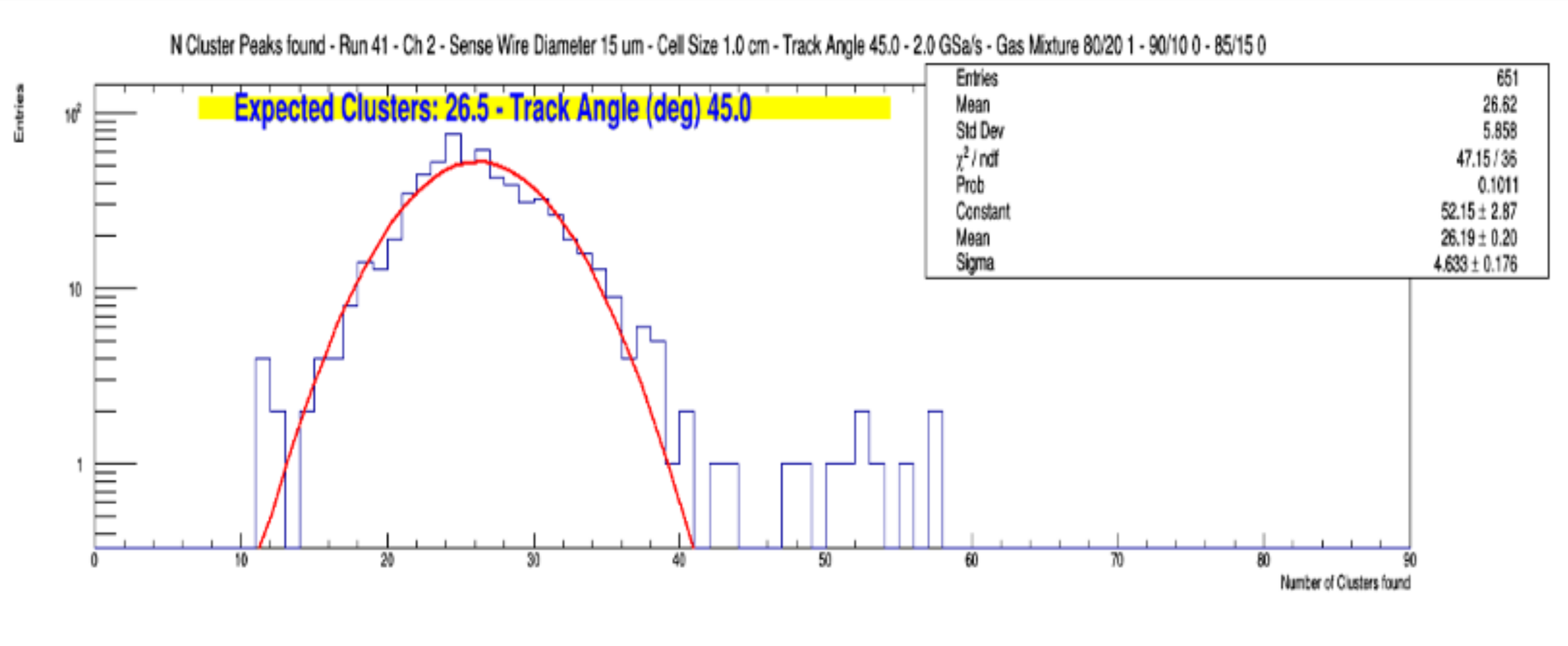
- α = angle of the muon track w.r.t. normal direction to the sense wire
- δ cluster/cm (M.I.P) changes from 12, 15, 18 respectively for He:IsoB 90/10, 85/15 and 80/20 gas mixtures.
- drift tube size are 0.8, 1.2, and 1.8 respectively for 1 cm, 1.5 cm, and 2 cm cell size tubes.

[1] H. Fischle, J. Heintze and B. Schmidt, Experimental determination of ionization cluster size distributions in counting gases, NIMA 301 (1991)

Sense Wire Diameter 15 μm; Cell Size 1.0 cm
Track Angle 45; Sampling rate 2 GSa/s
Gas Mixture He:IsoB 80/20



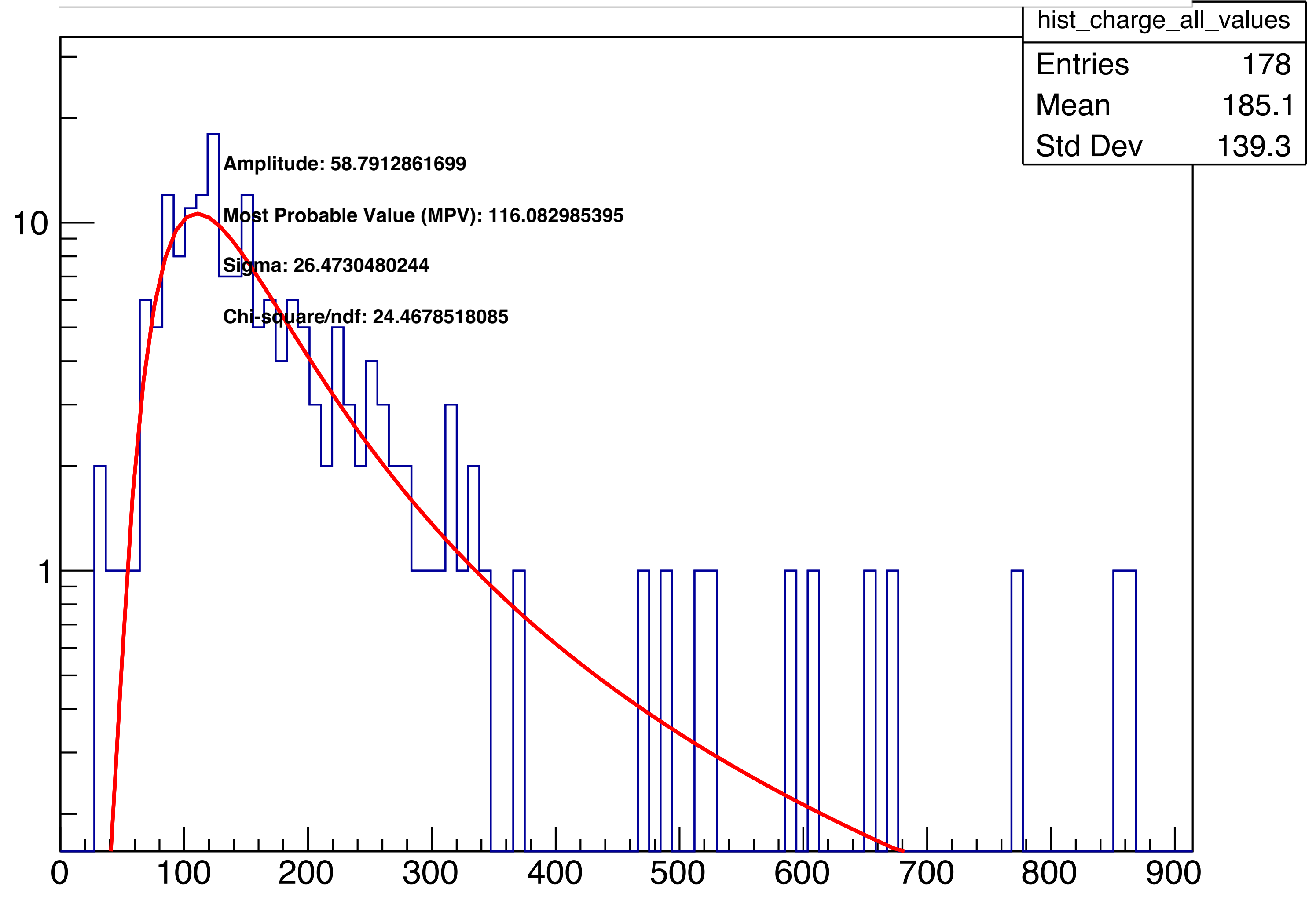
Poissonian distribution for the number of clusters



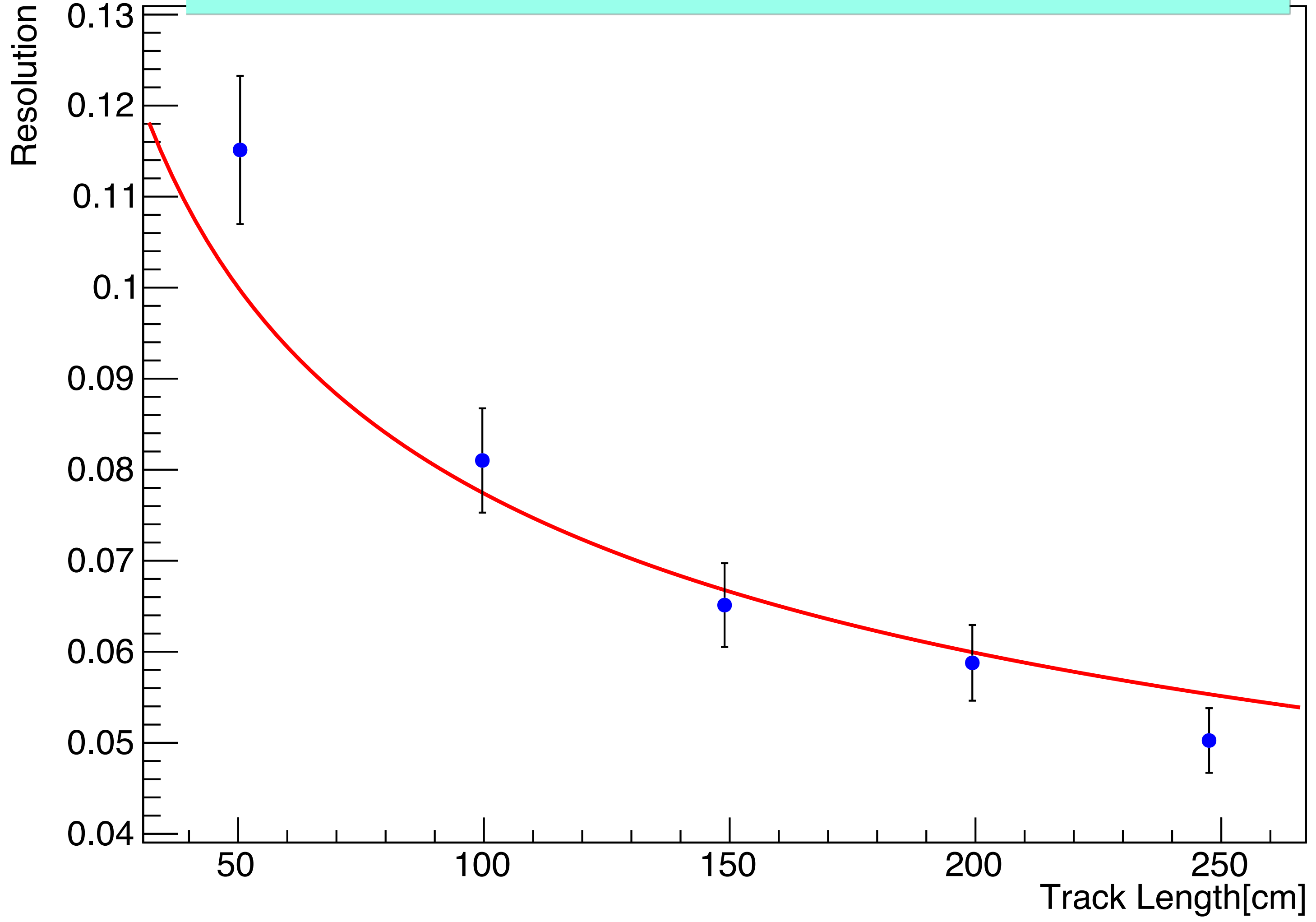
Beam tests: resolutions

- **Landau distribution** for the charge along a track
- Selected the distribution with 80% of the charges for the dE/dx truncation, to be compared with dN/dx
- **NEW results**

Integral charges along a 2 m track length

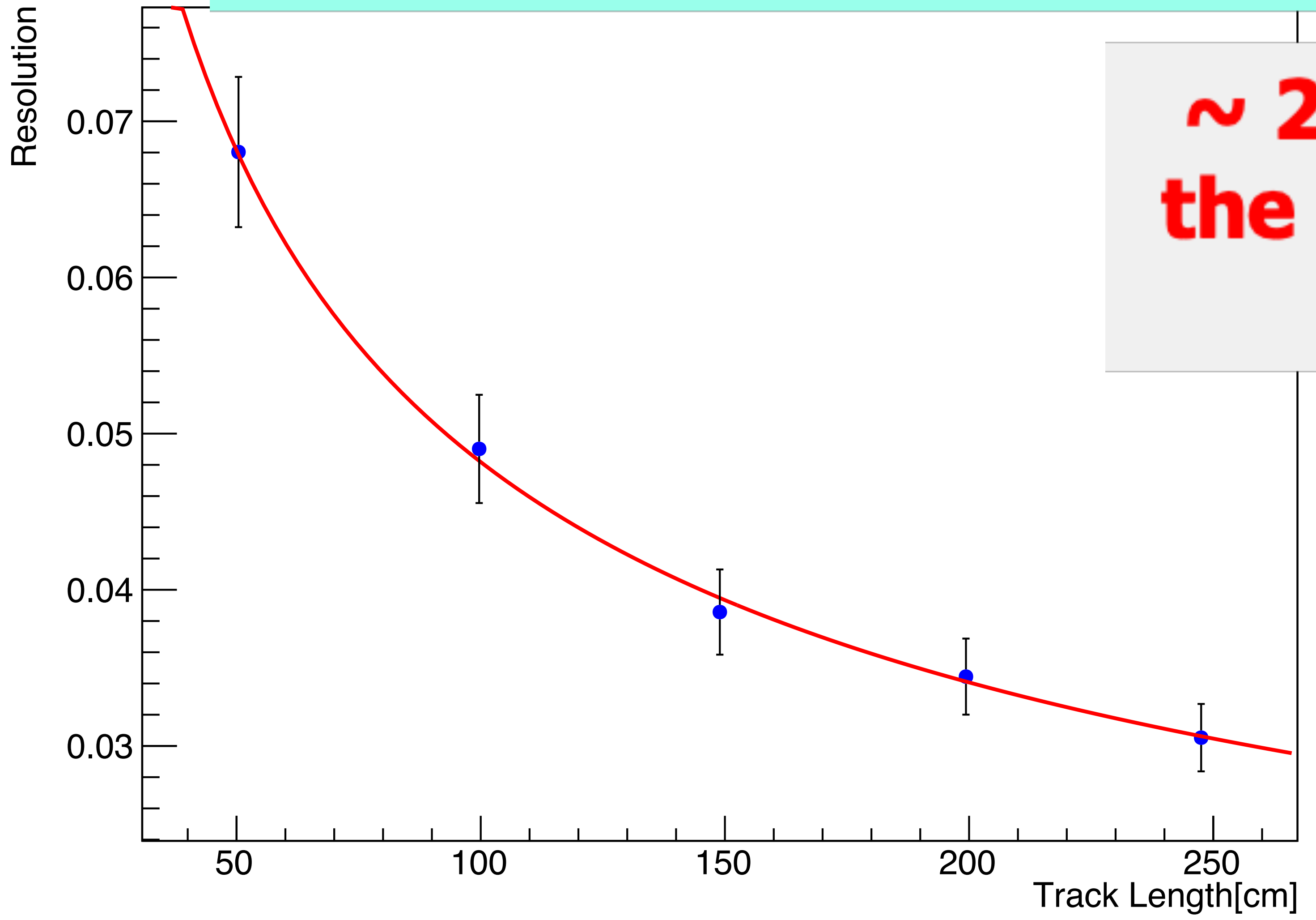


dE/dx Resolution scan vs track length resolution



dE/dx resolution dependence on the track length $L^{-0.37}$

dN/dx scan vs track length Resolution



dN/dx resolution dependence on the track length $L^{-0.5}$

~ 2 times improvement in the resolution using dN/dx method

A complete report given at ICHEP

Conclusions

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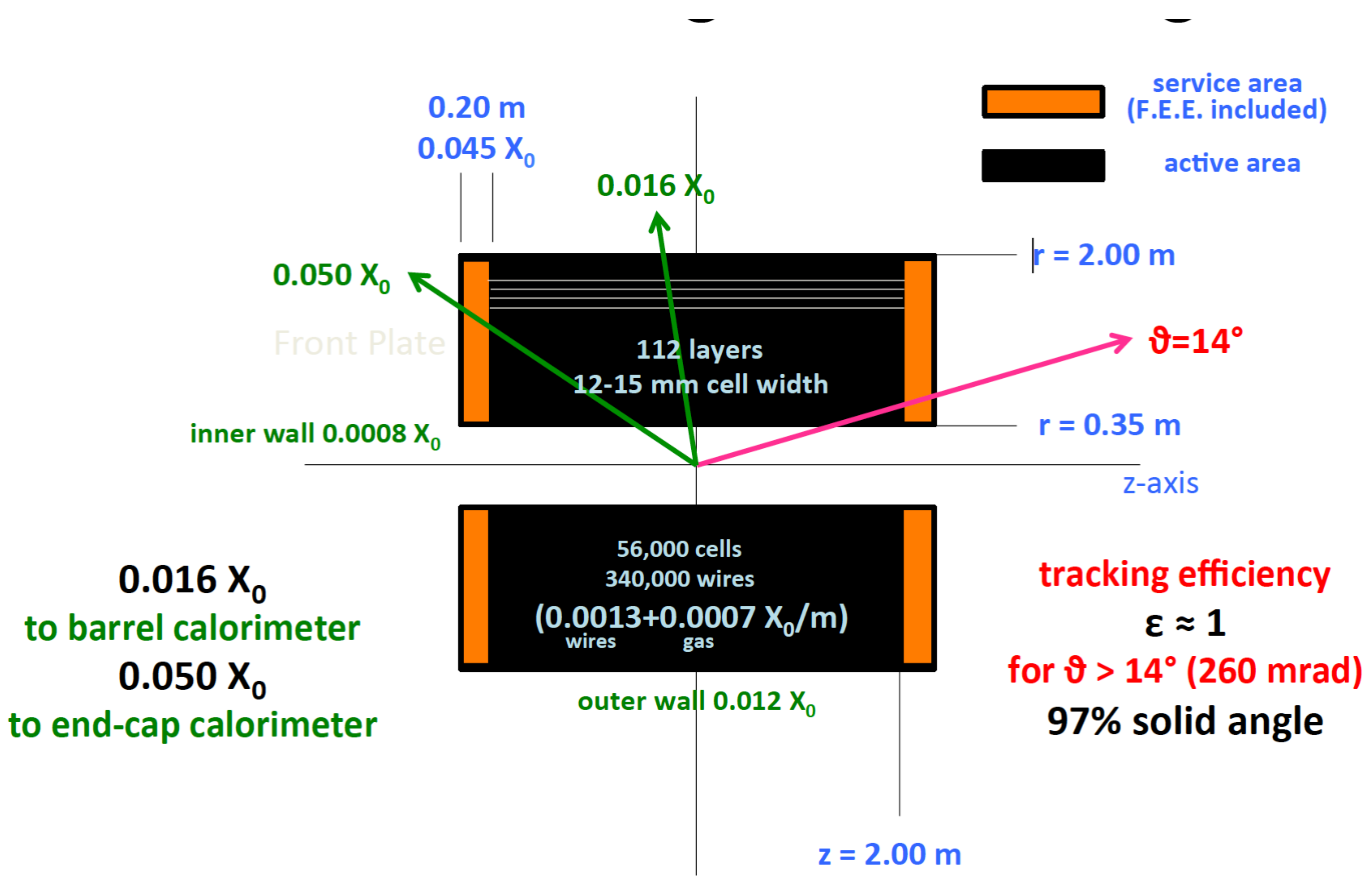
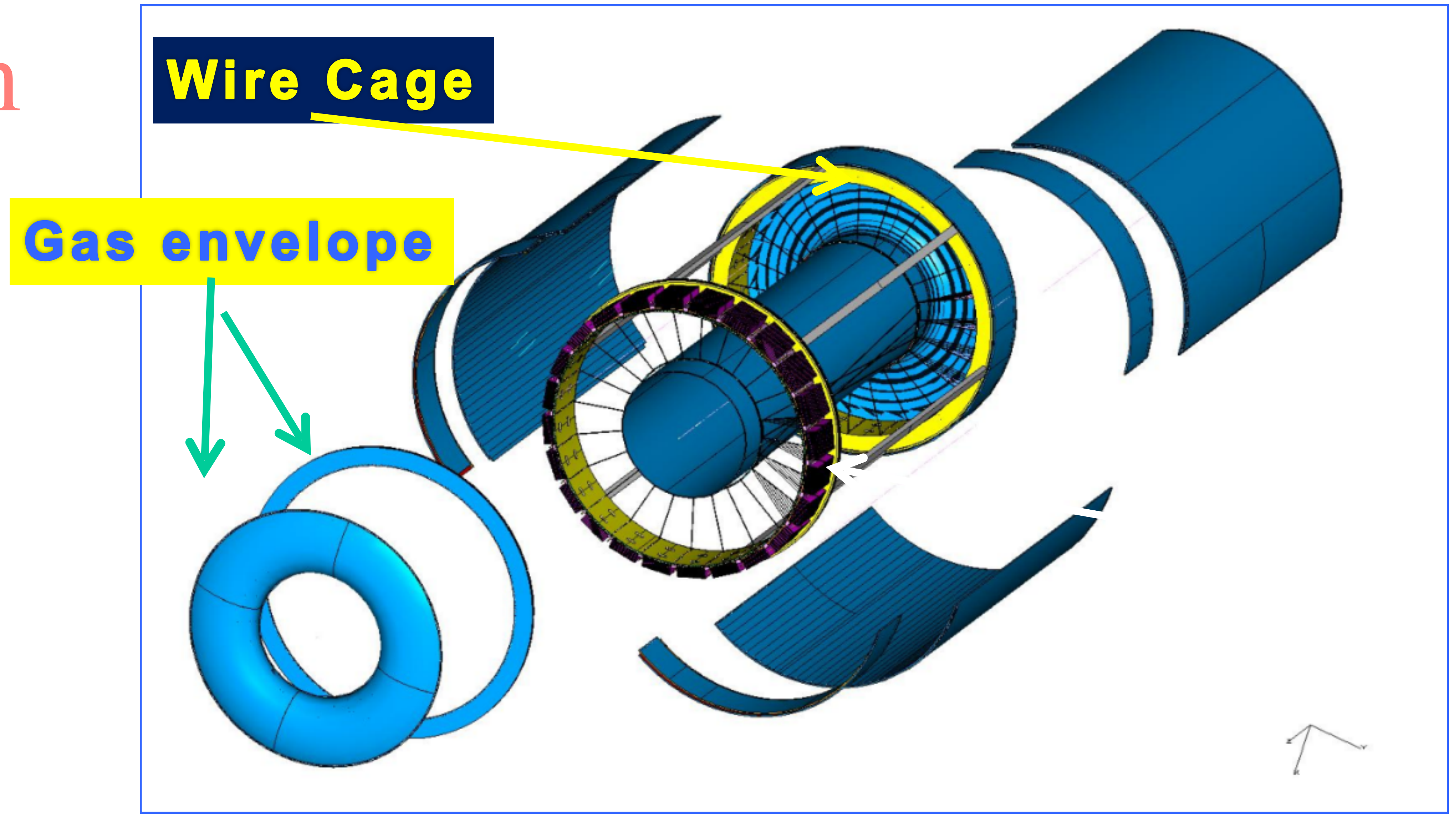
- Efforts to build an international collaboration enforced
  - Well established with IHEP for NN-based cluster counting algorithms

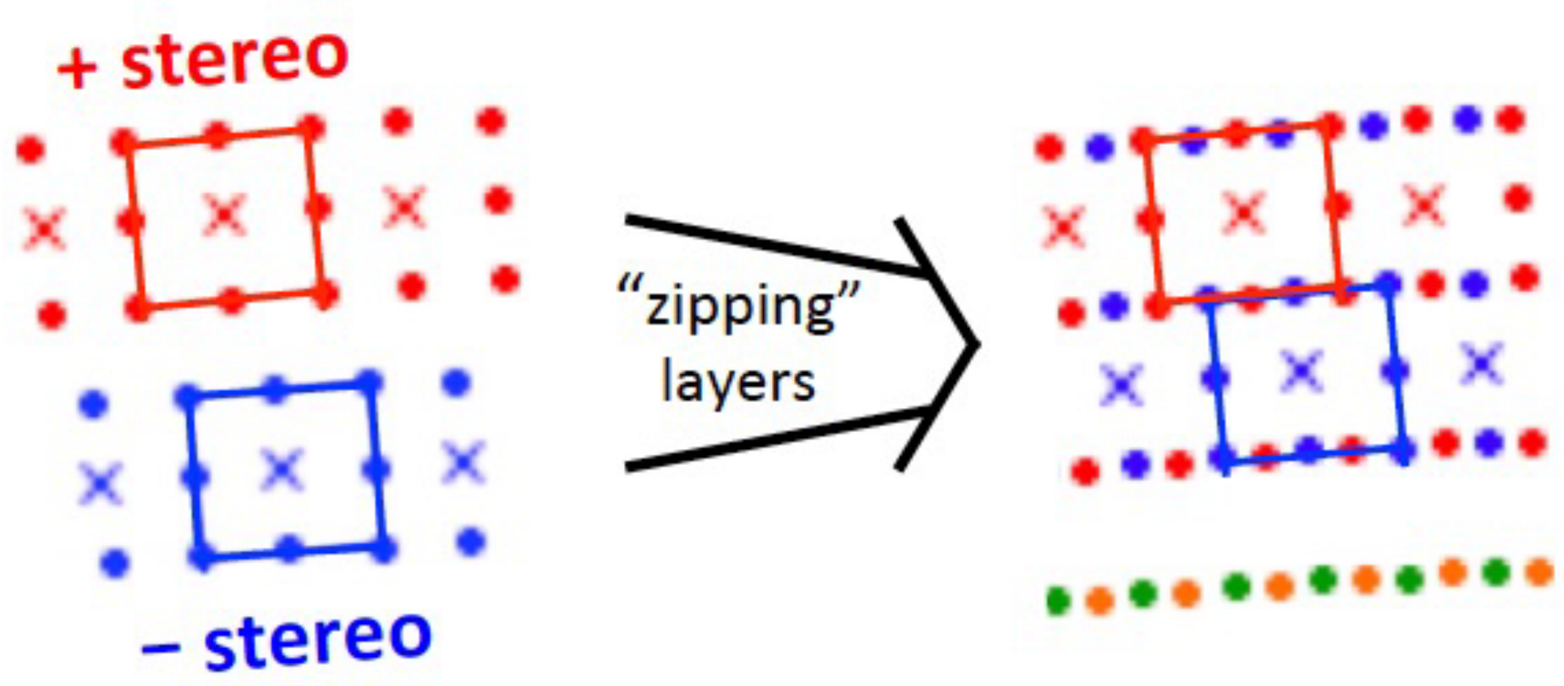
Backup

Drift chamber

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







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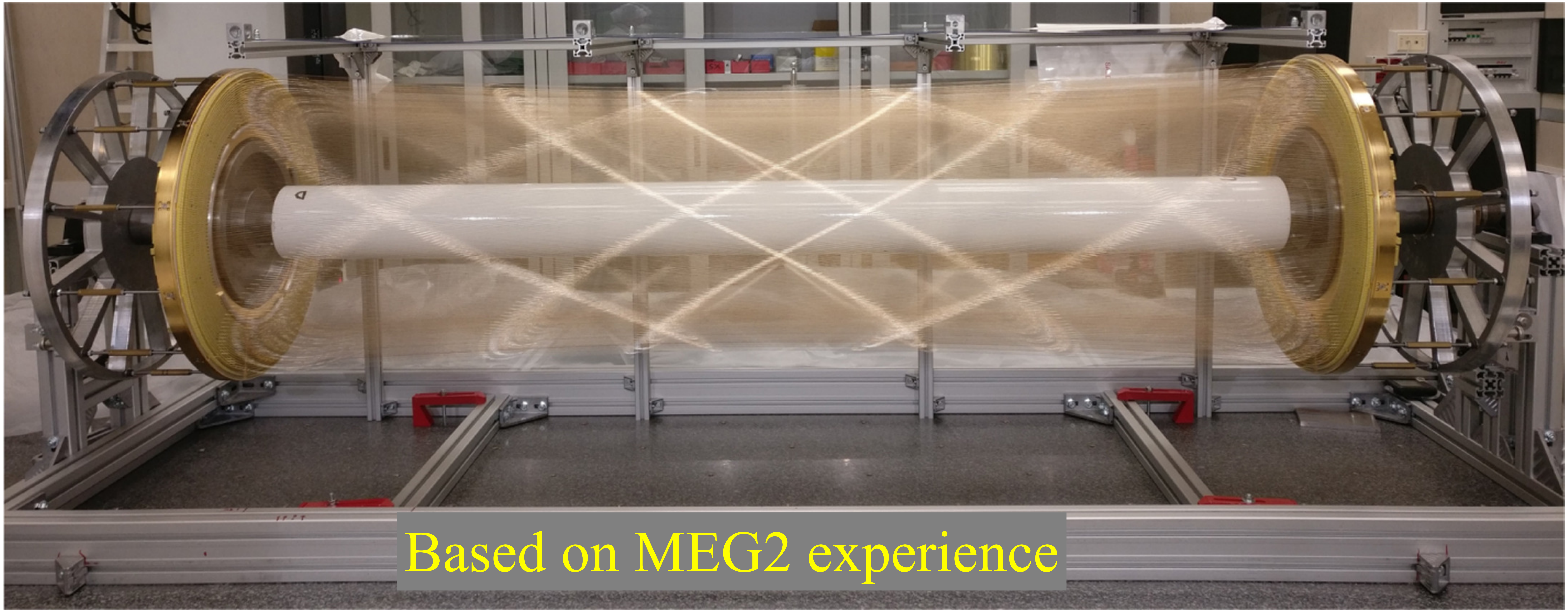


Based on MEG2 experience

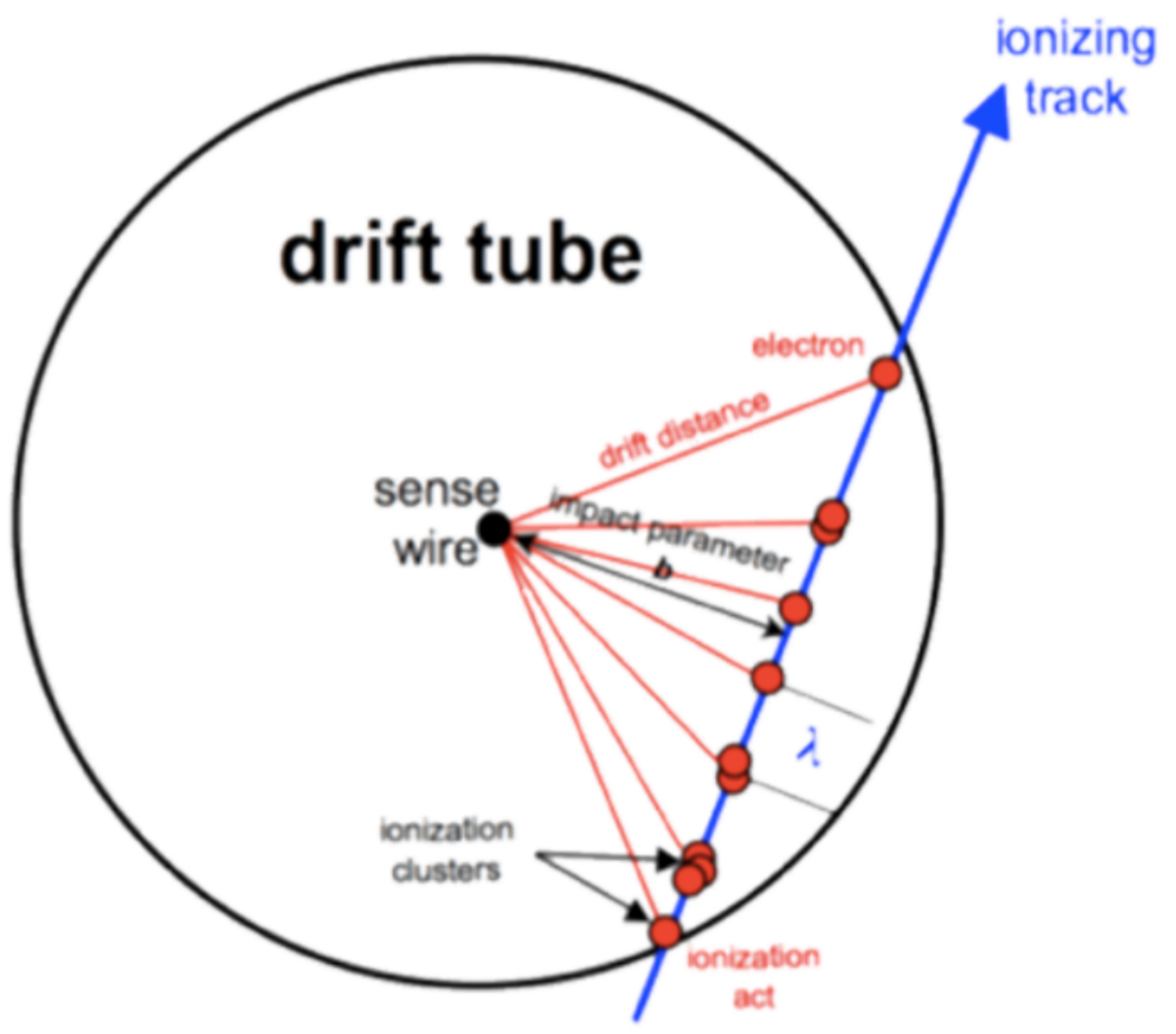
Drift chamber future plans

- 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)

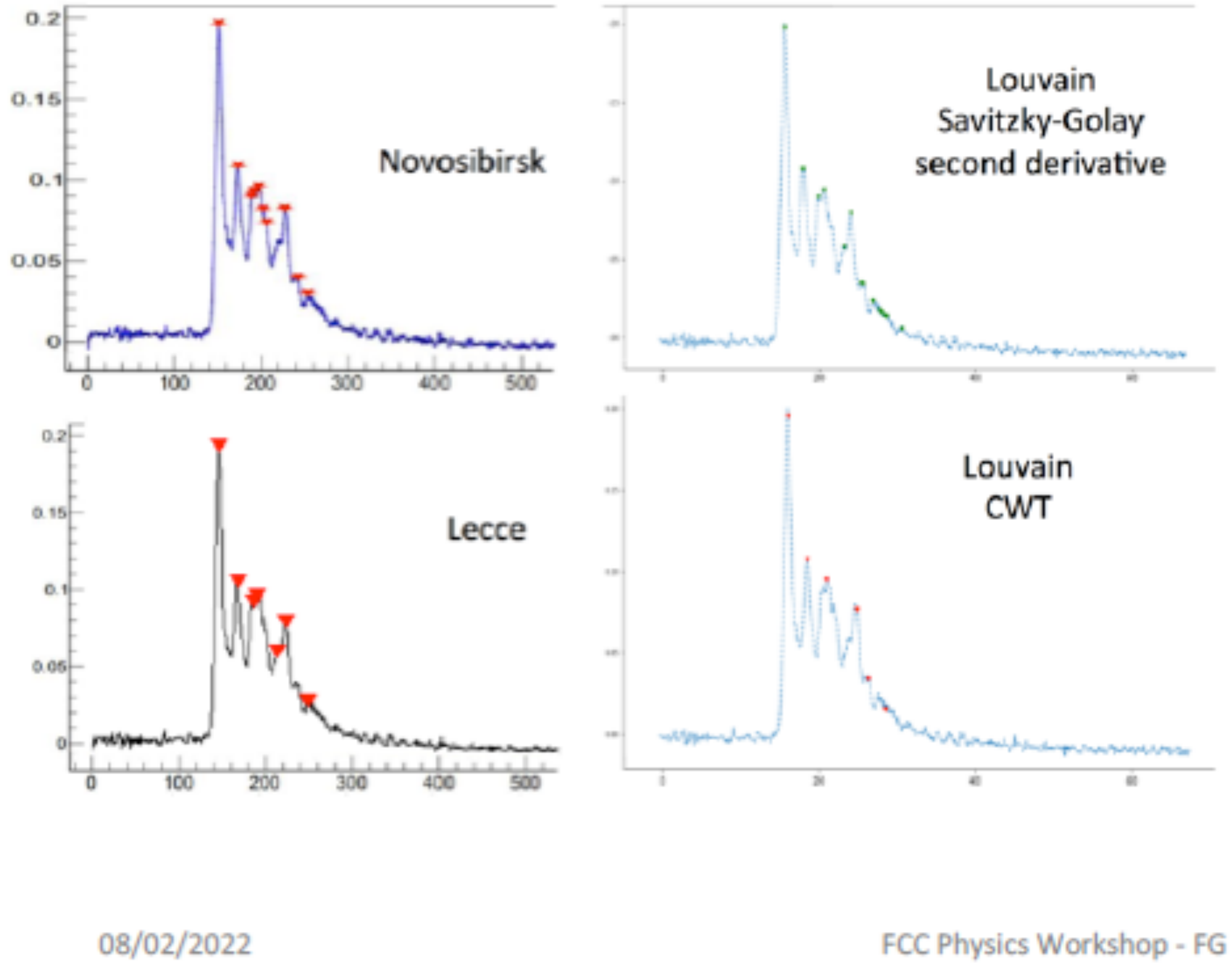
- Towards a drift chamber TDR

Cluster counting

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

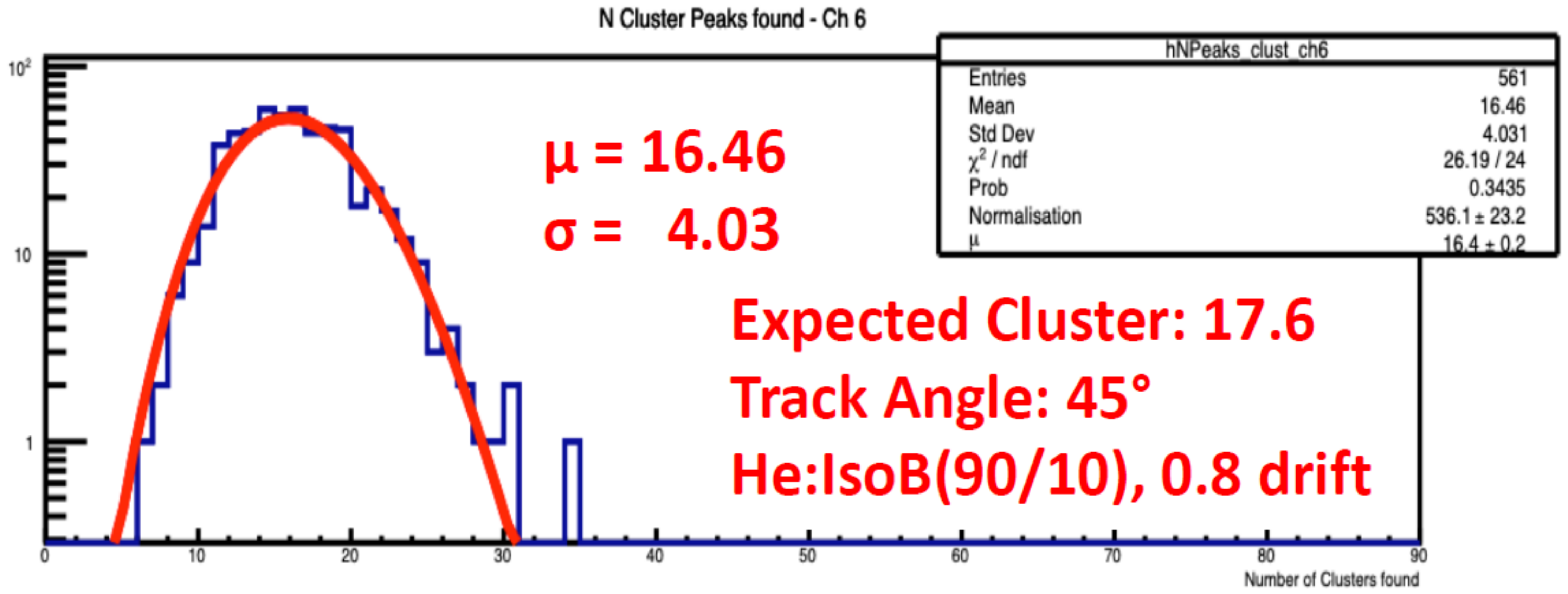


counting peaks



Test beam data 2022

Number of Cluster Distribution



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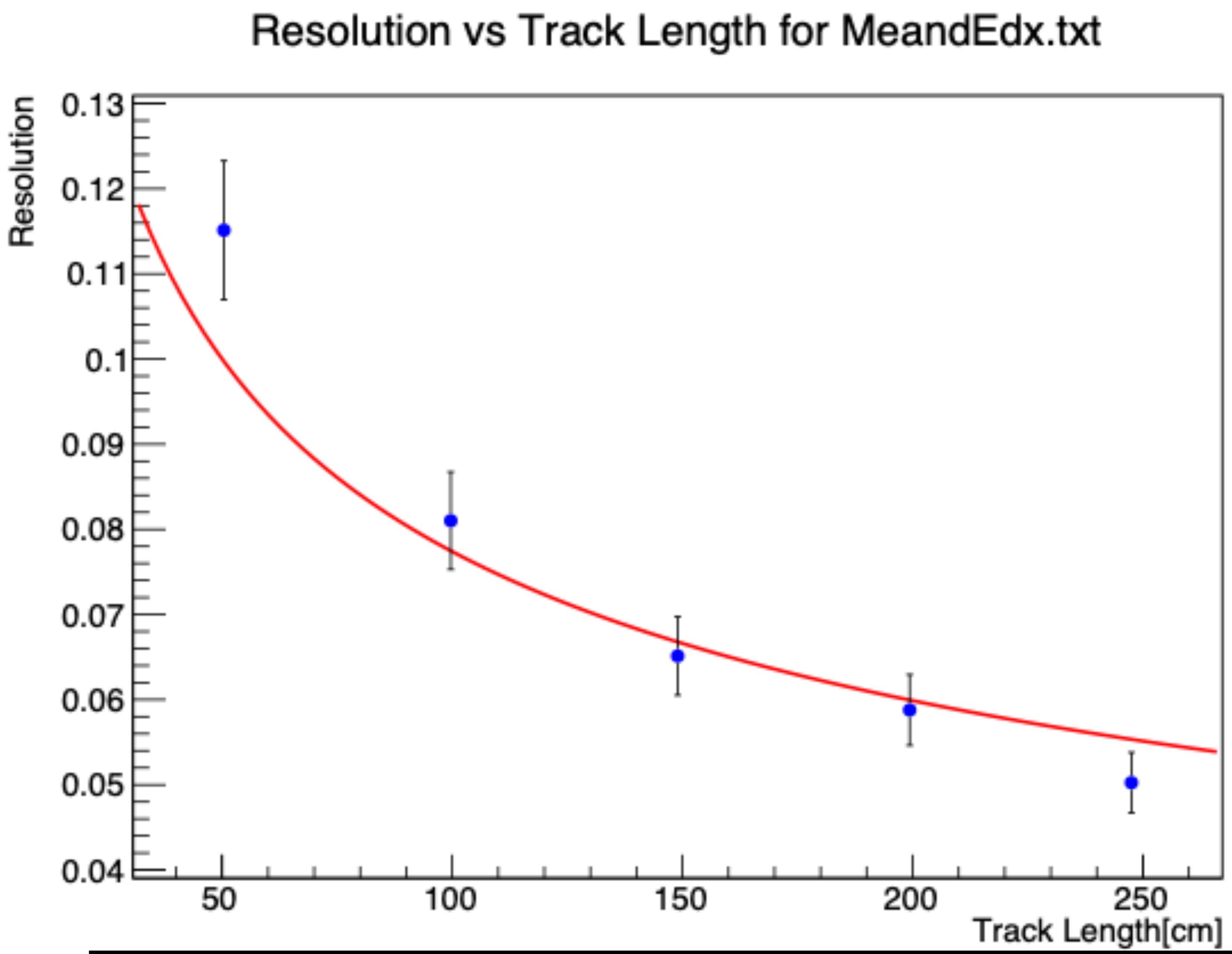
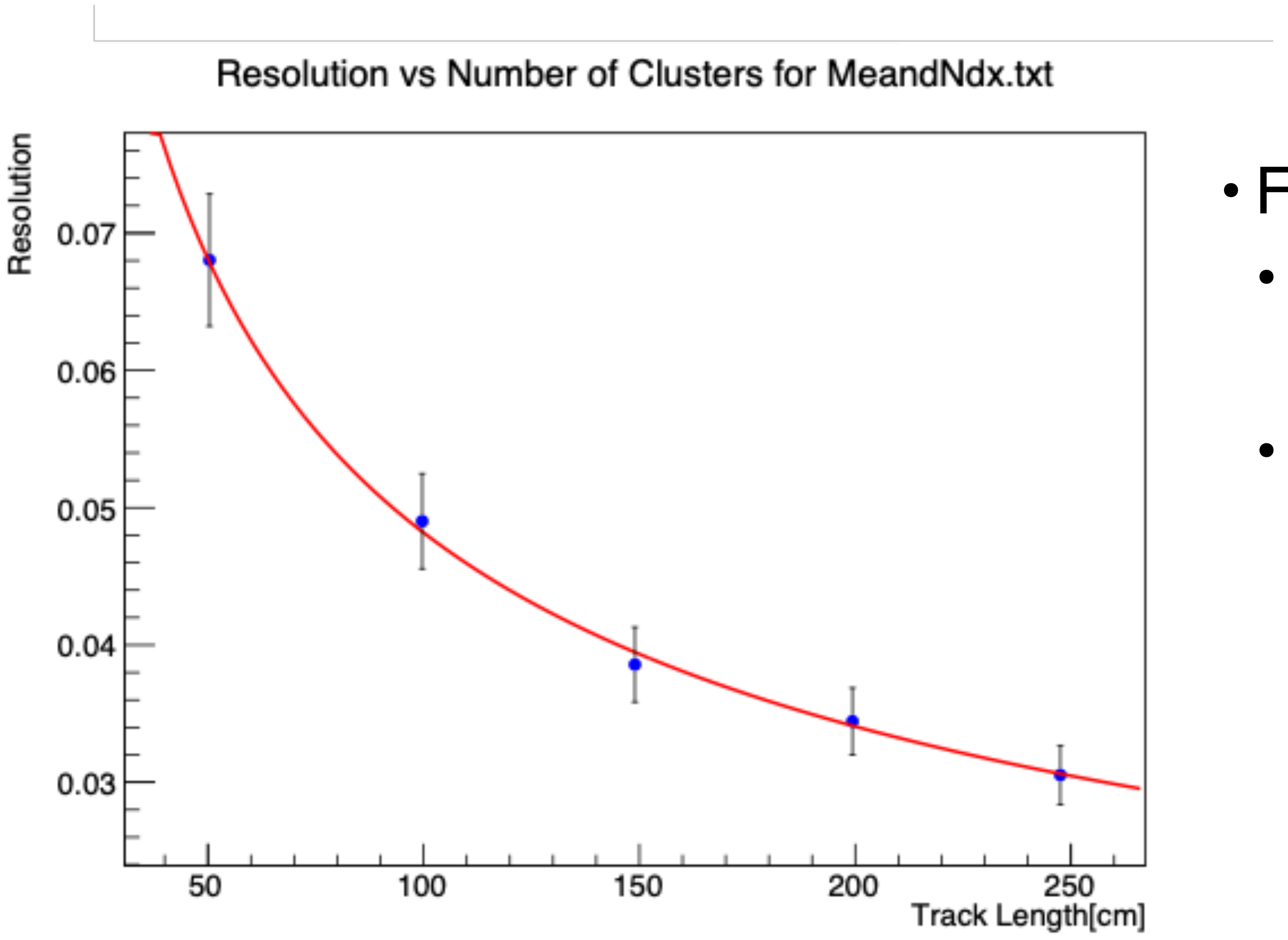
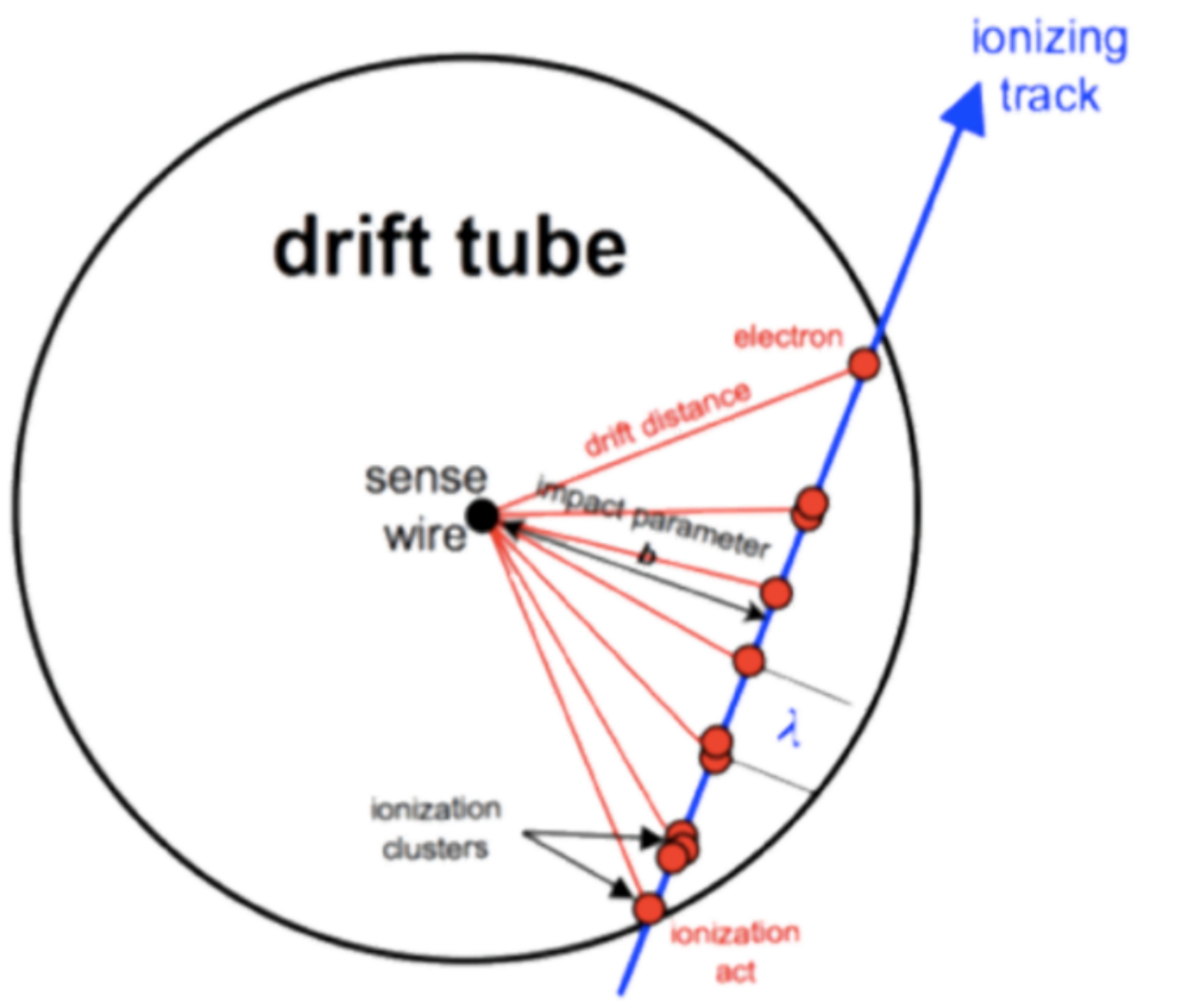
Test beam 2024

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.