The ePIC detector

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HSF-India/ePIC Workshop
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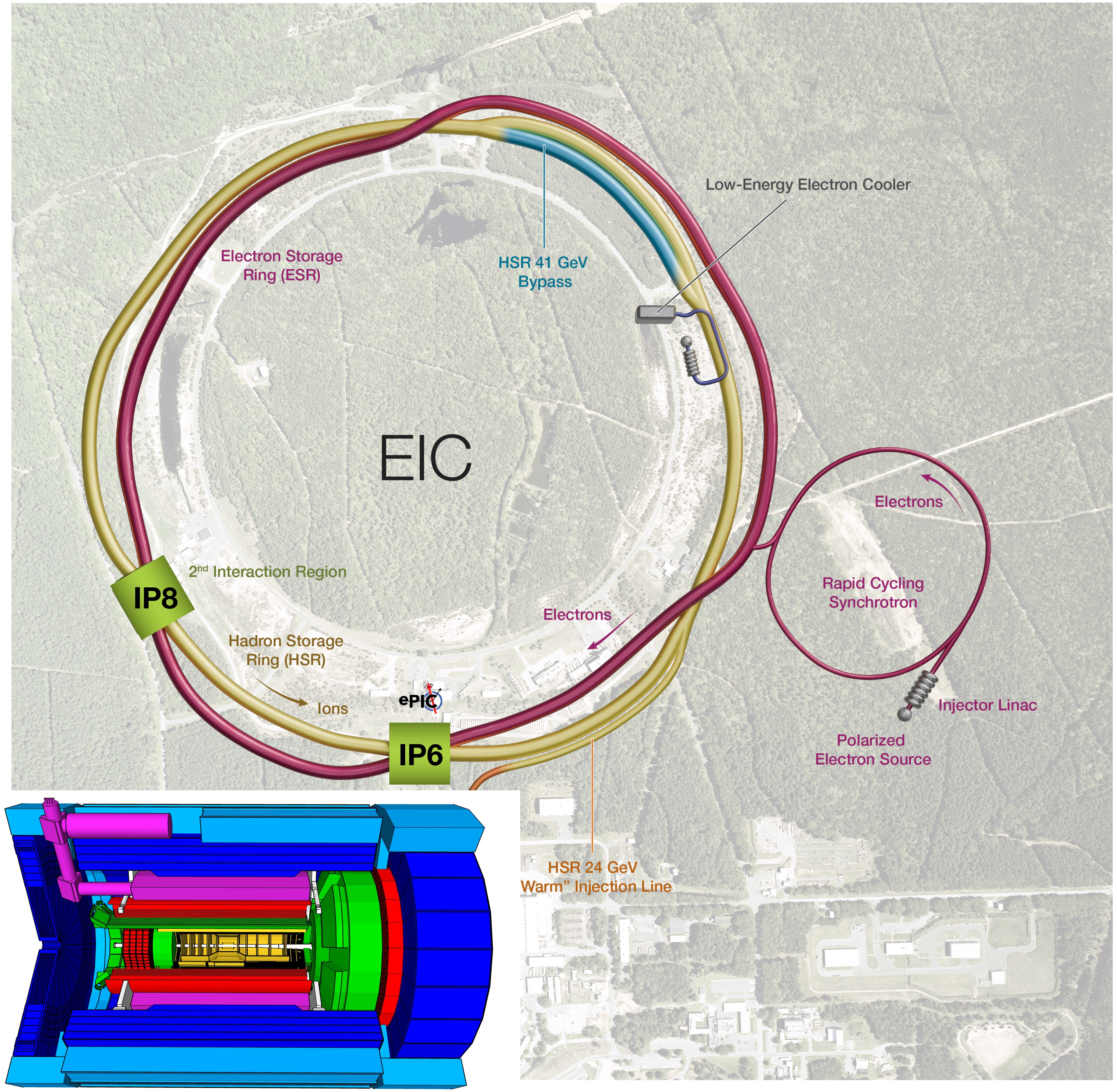
The electron-ion collider (EIC)



- Based on RHIC:
  - use exiting hadron storage ring energy: 41–275 GeV
  - add electron storage ring in RHIC tunnel energy: 5–18 GeV

  $\rightarrow \sqrt{s} = 29 - 141$ GeV (per nucleon)

- $\vec{e} + \vec{p}^{\uparrow}, \overrightarrow{He}^{\uparrow}$

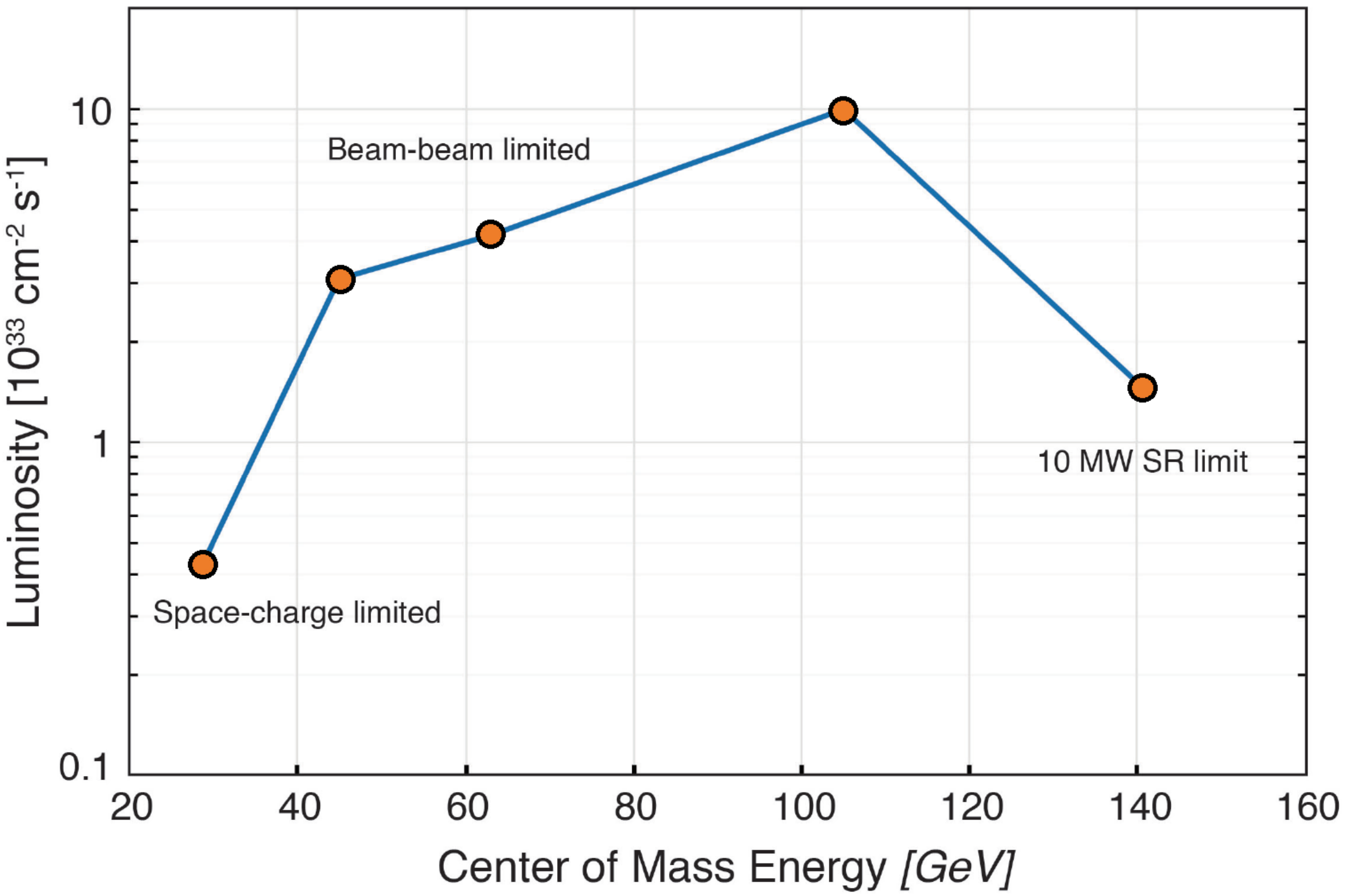
  ~ 70% polarisation

  + heavier, unpolarised hadrons, up to Uranium

- $\mathscr{L} = 10^{33-34}$ cm^{-2} s^{-1}

  $\leftrightarrow \mathscr{L}_{\text{int}} = 10 - 100$ fb^{-1}/year

Luminosity and centre-of-mass energy: ep collisions



Luminosity for eA similar within factor 2–3

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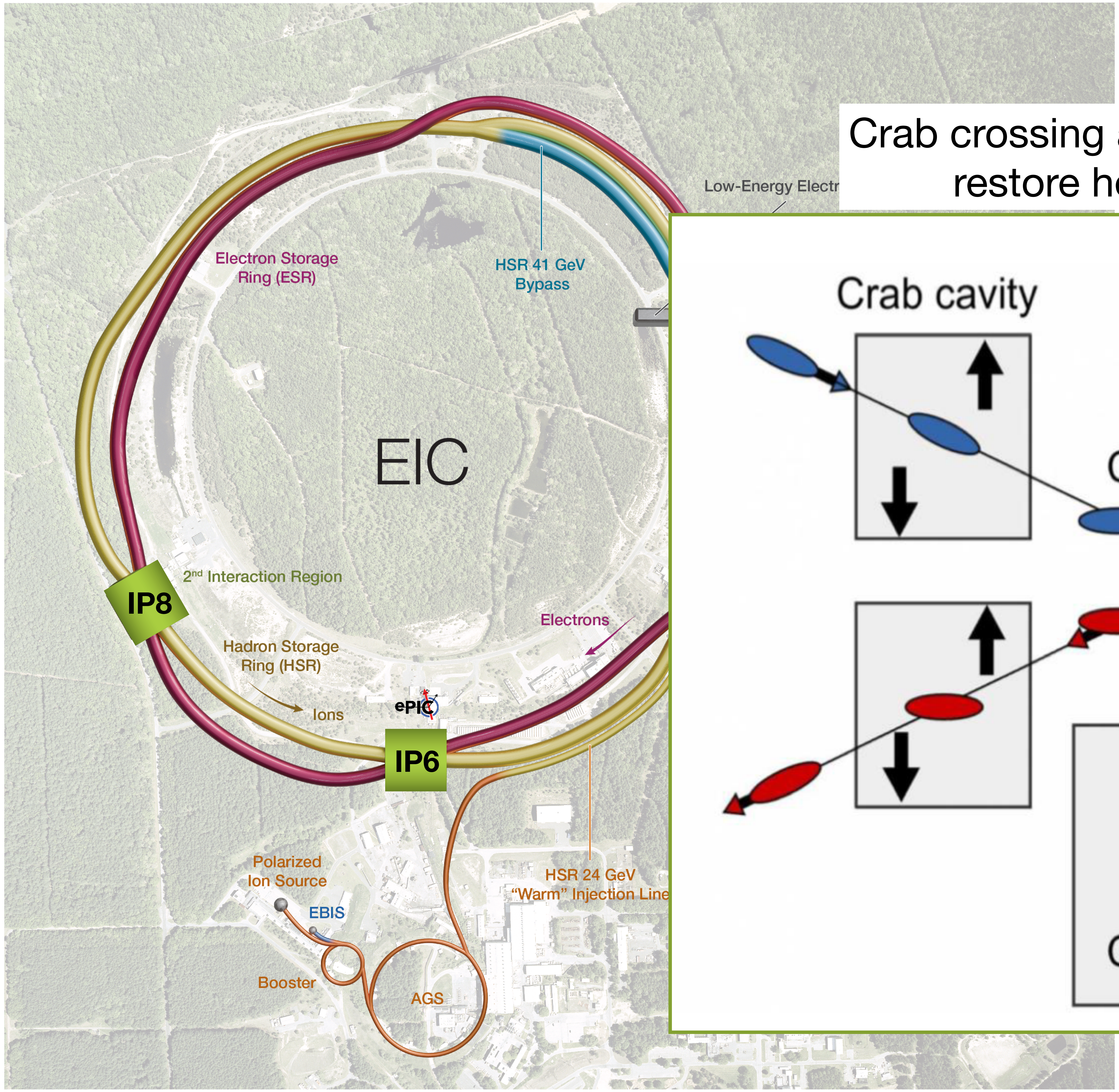
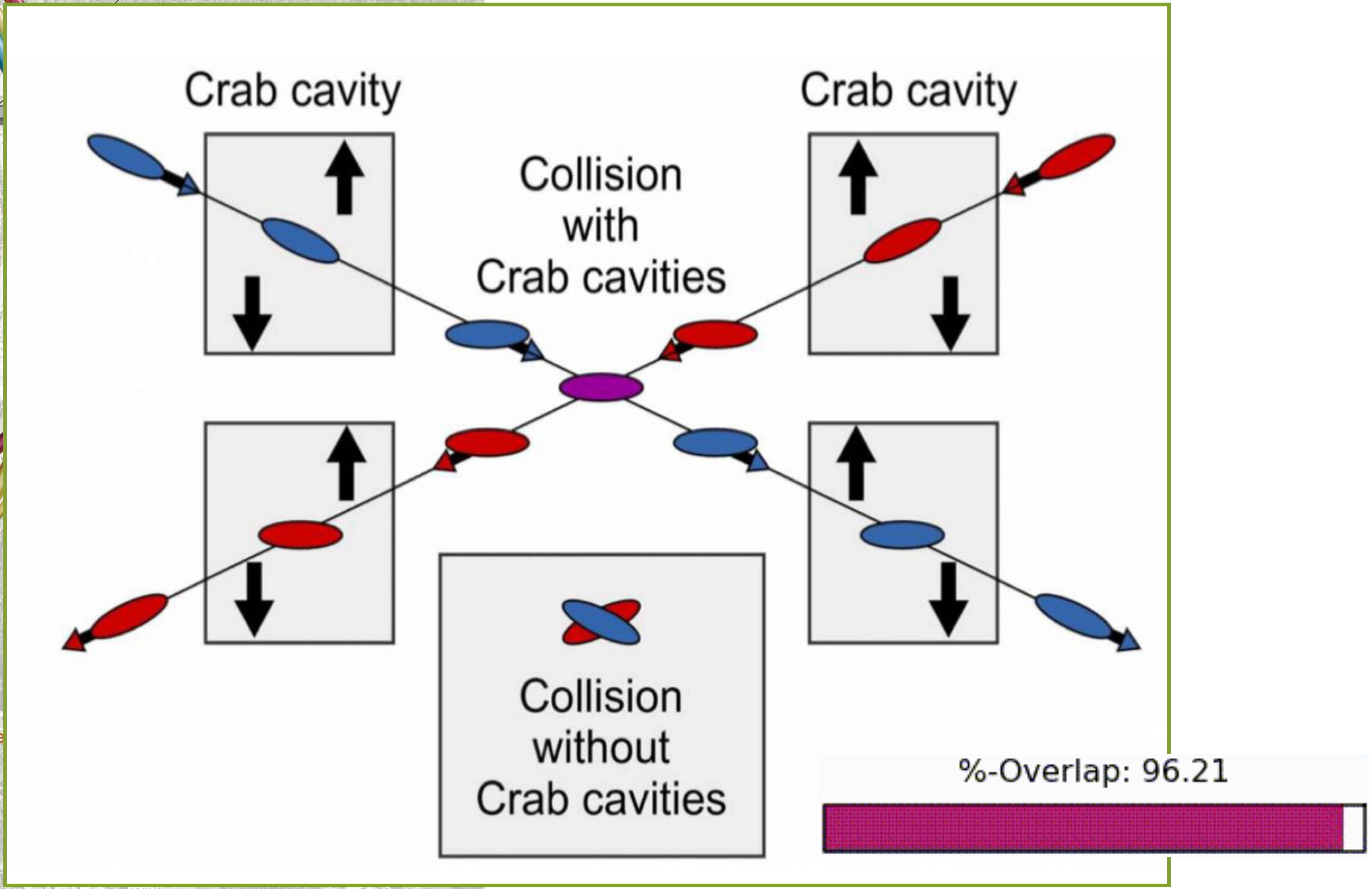
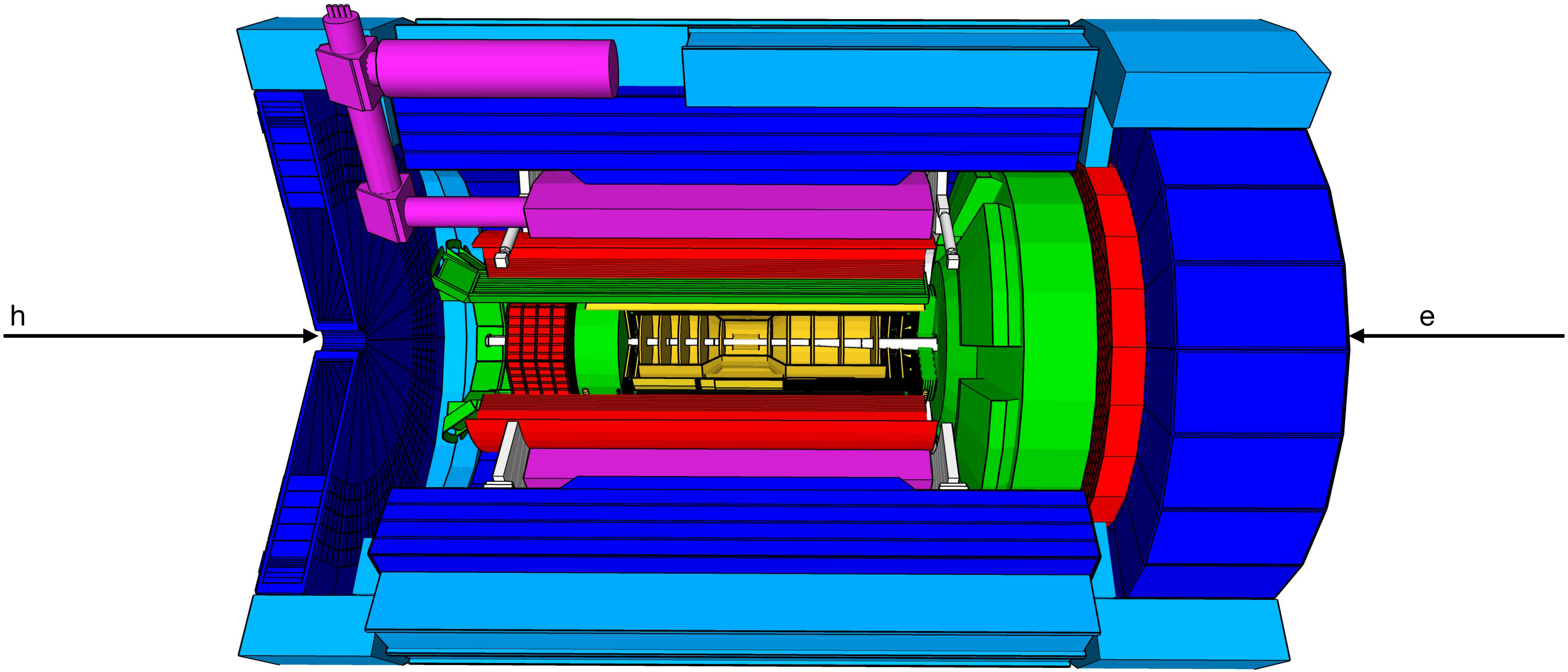


Crab crossing angle (25 mrad) at IP6:
restore head-on collisions

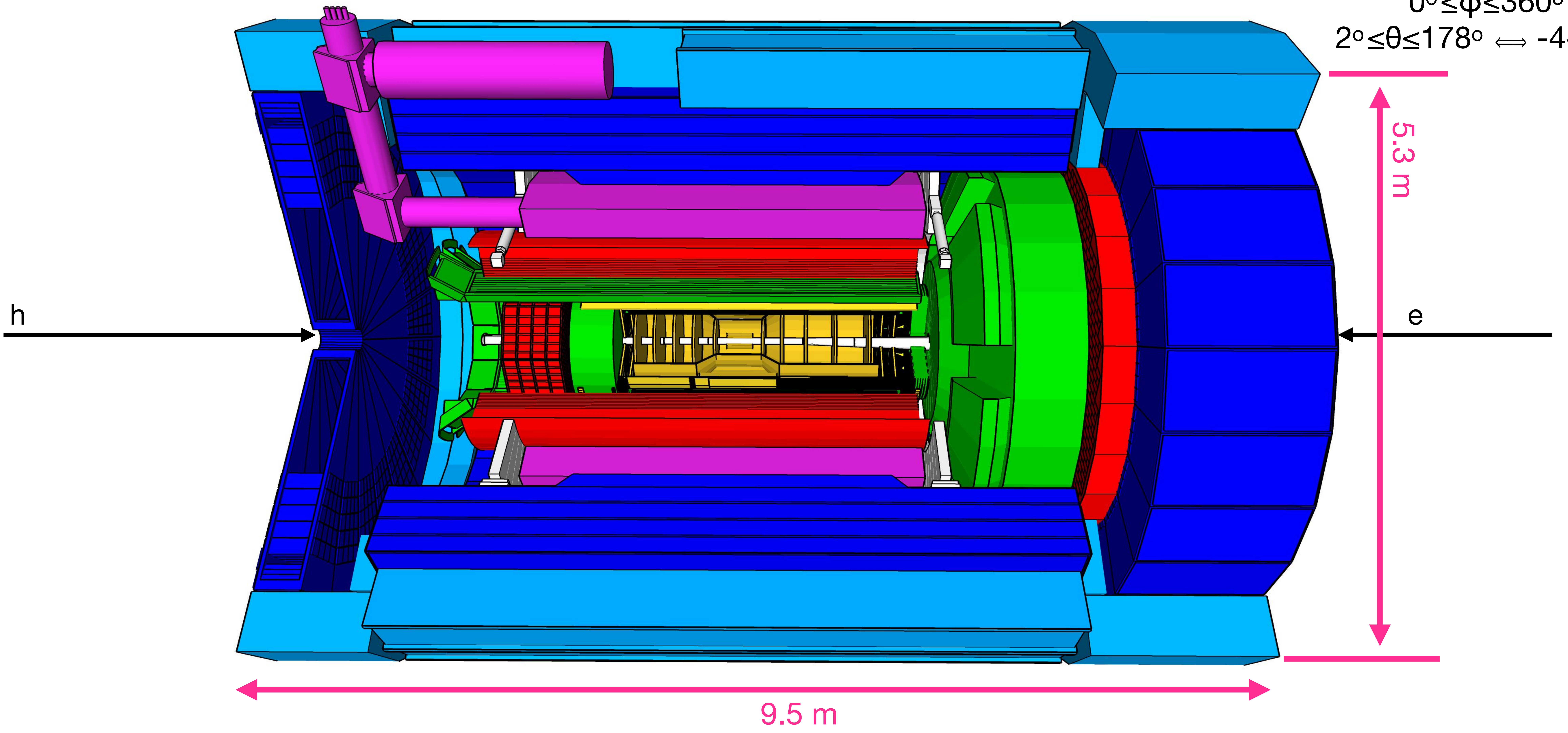


The electron-proton/ion collider (ePIC) detector



The electron-proton/ion collider (ePIC) detector

hermetic coverage:
$0^o \leq \phi \leq 360^o$
$2^o \leq \theta \leq 178^o \iff -4 < \eta < 4$



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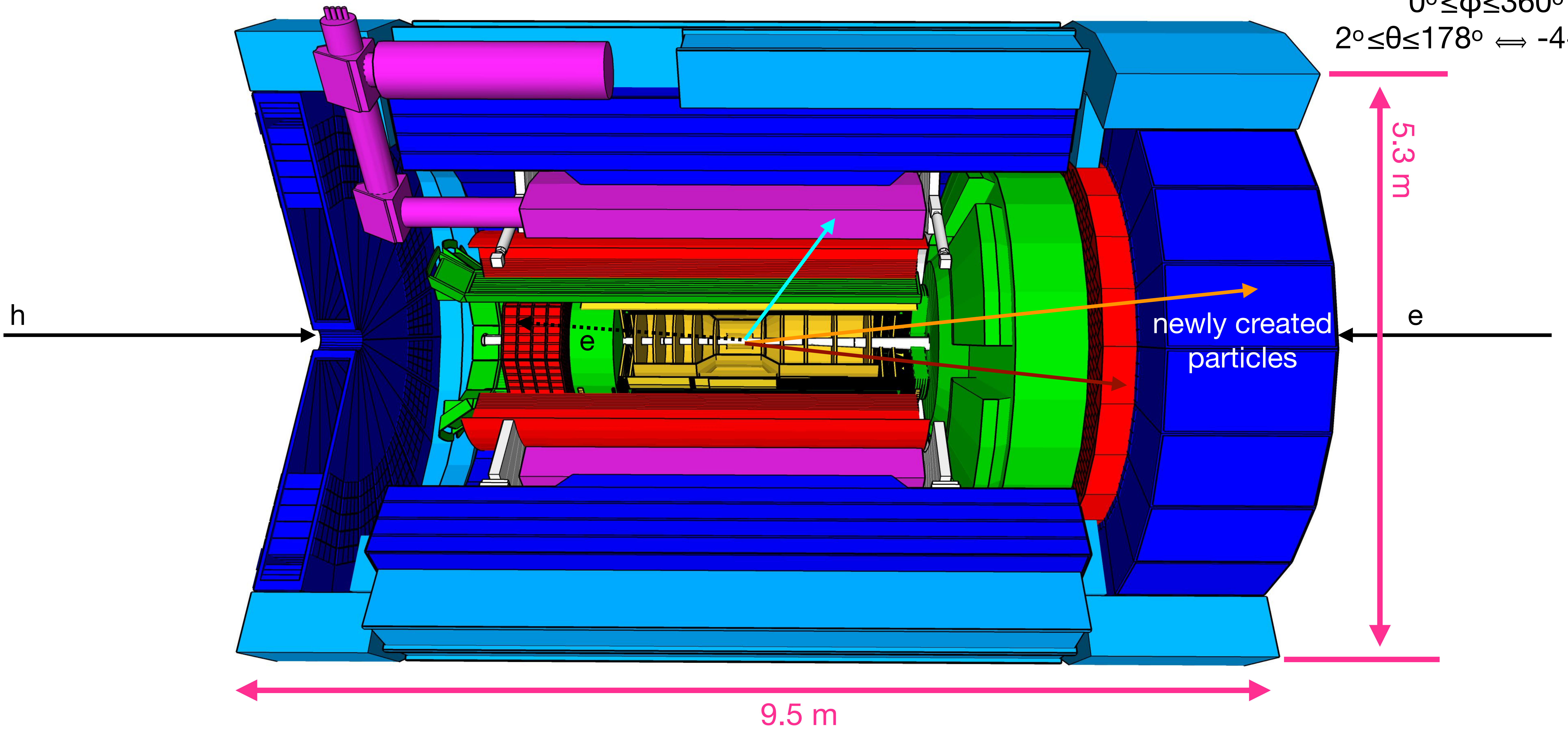

The electron-proton/ion collider (ePIC) detector

- Tracking
- PID
- Electromagnetic calorimeter
- Hadronic calorimeter

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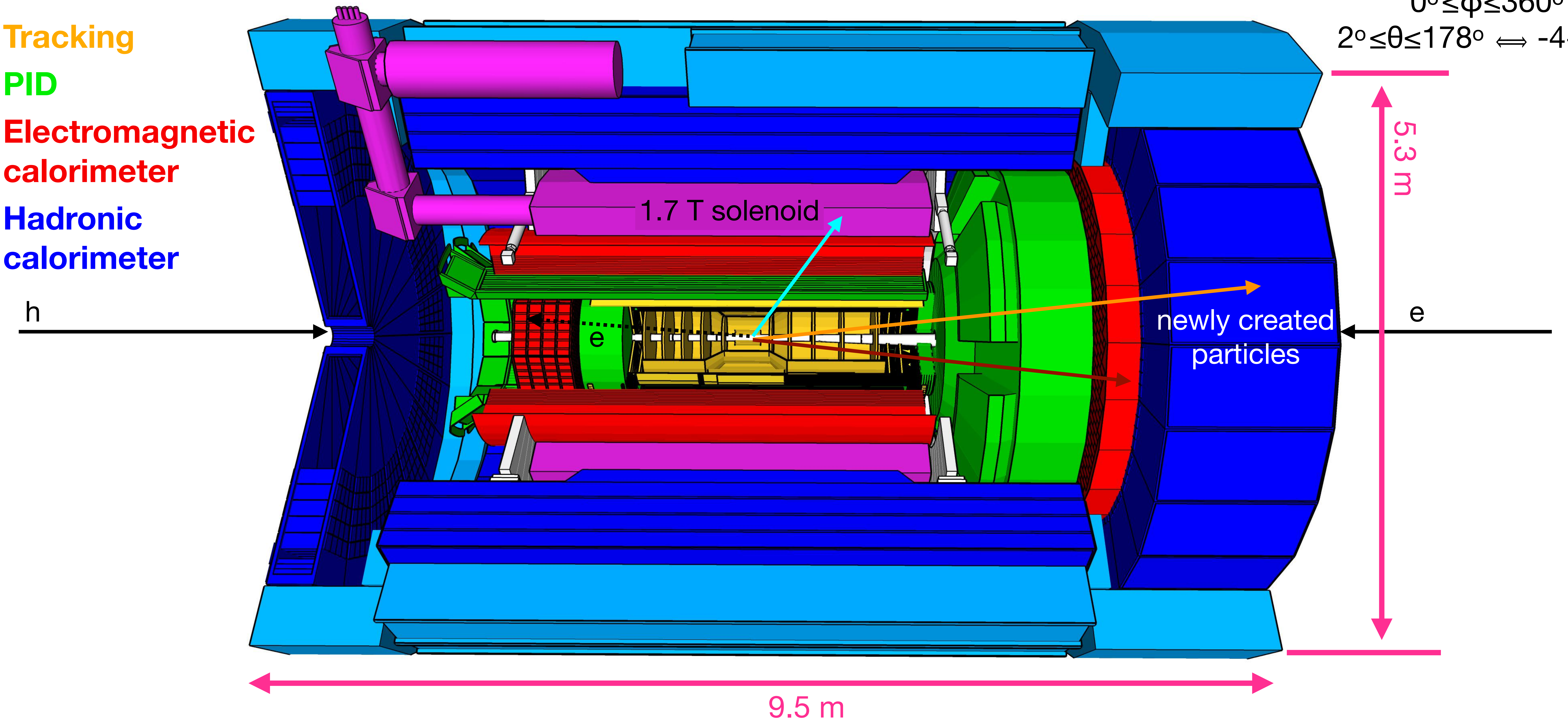

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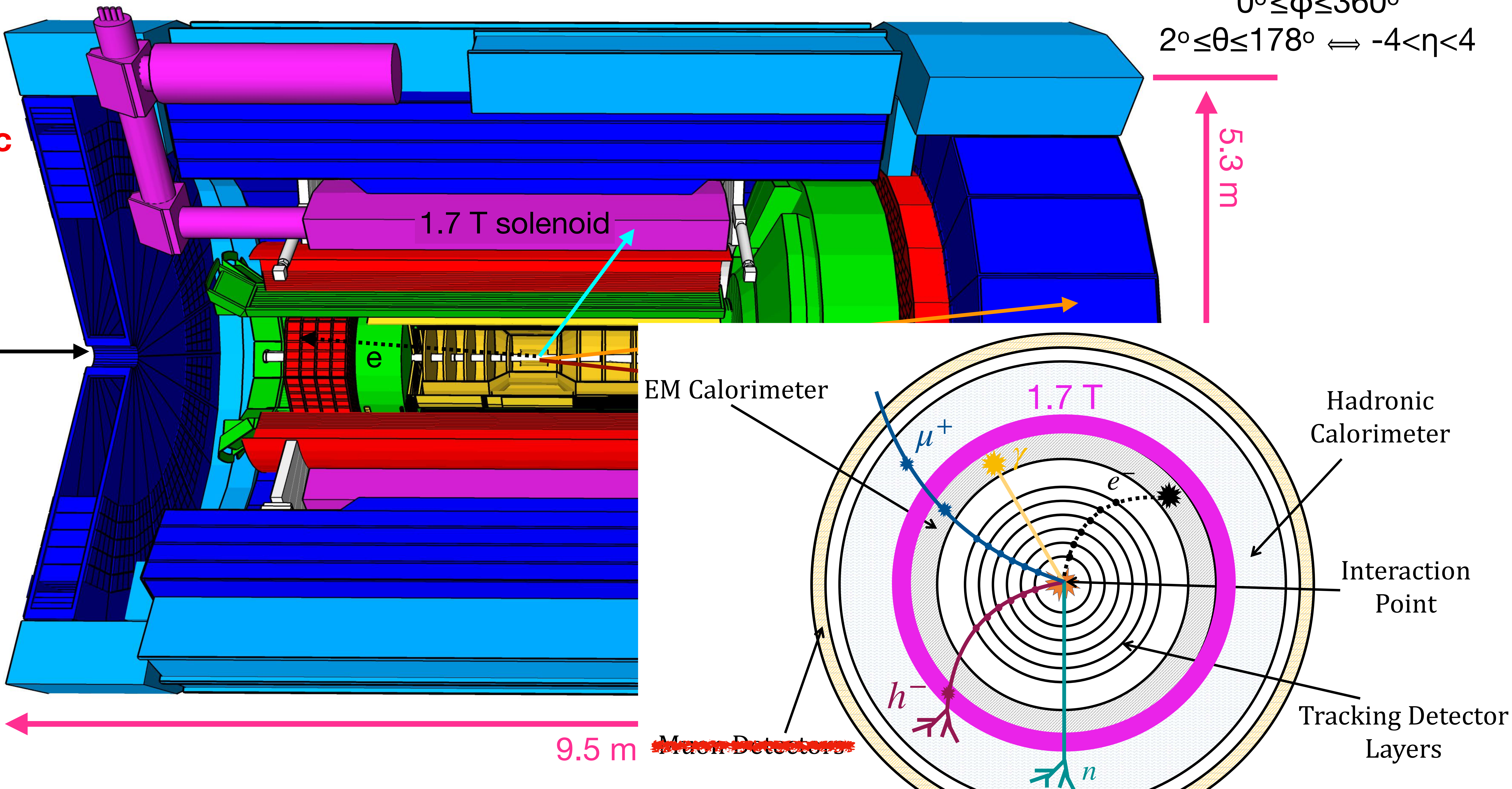

Cf. talk Stephen JD Kay 13/05/2025

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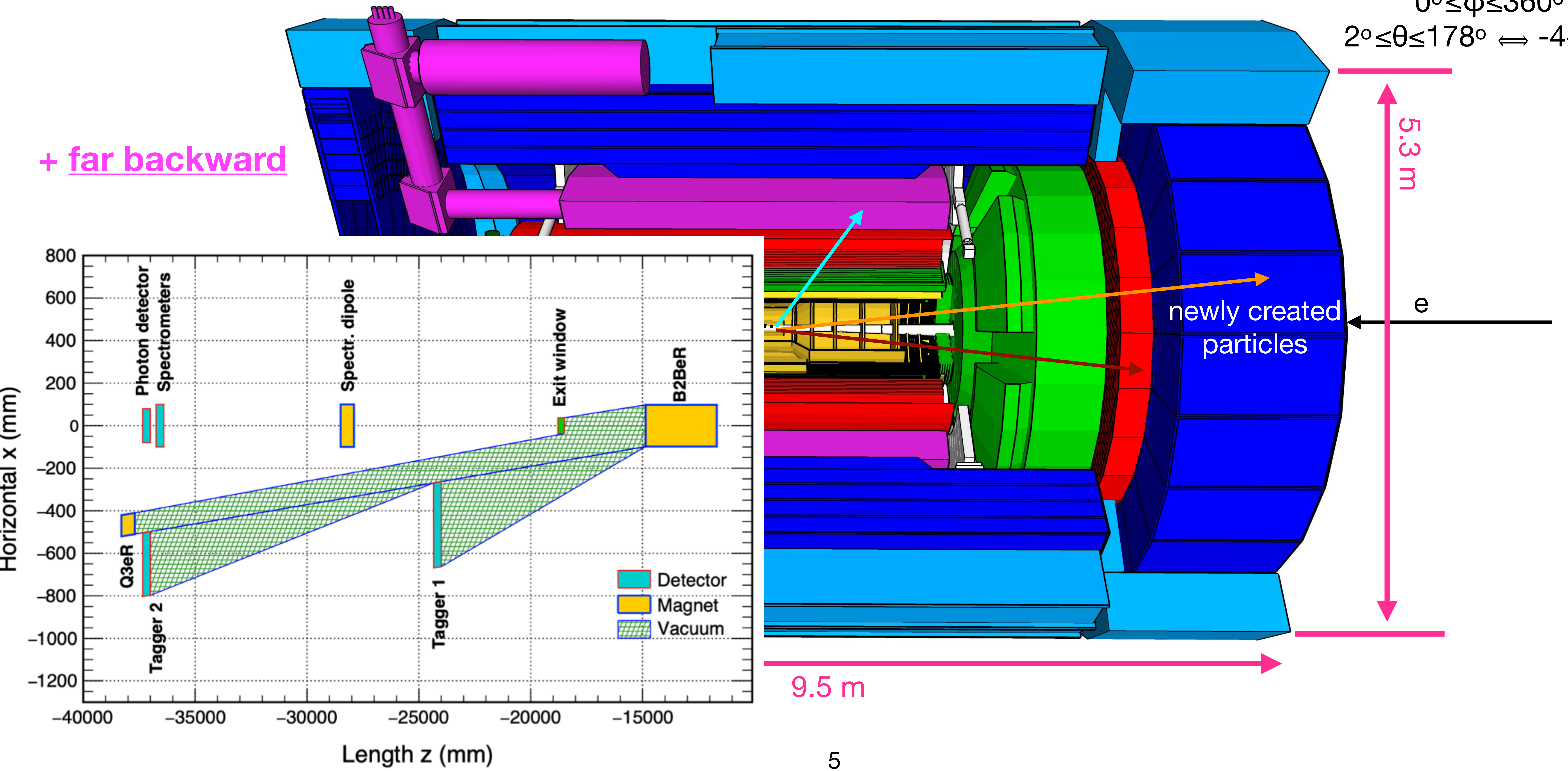
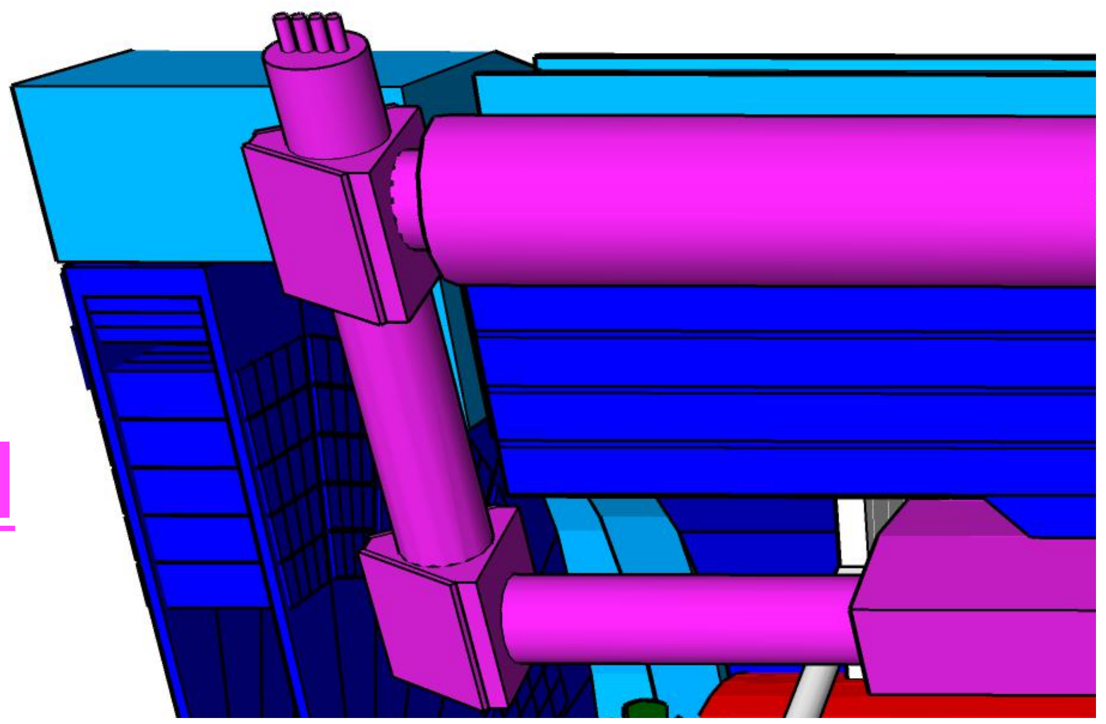
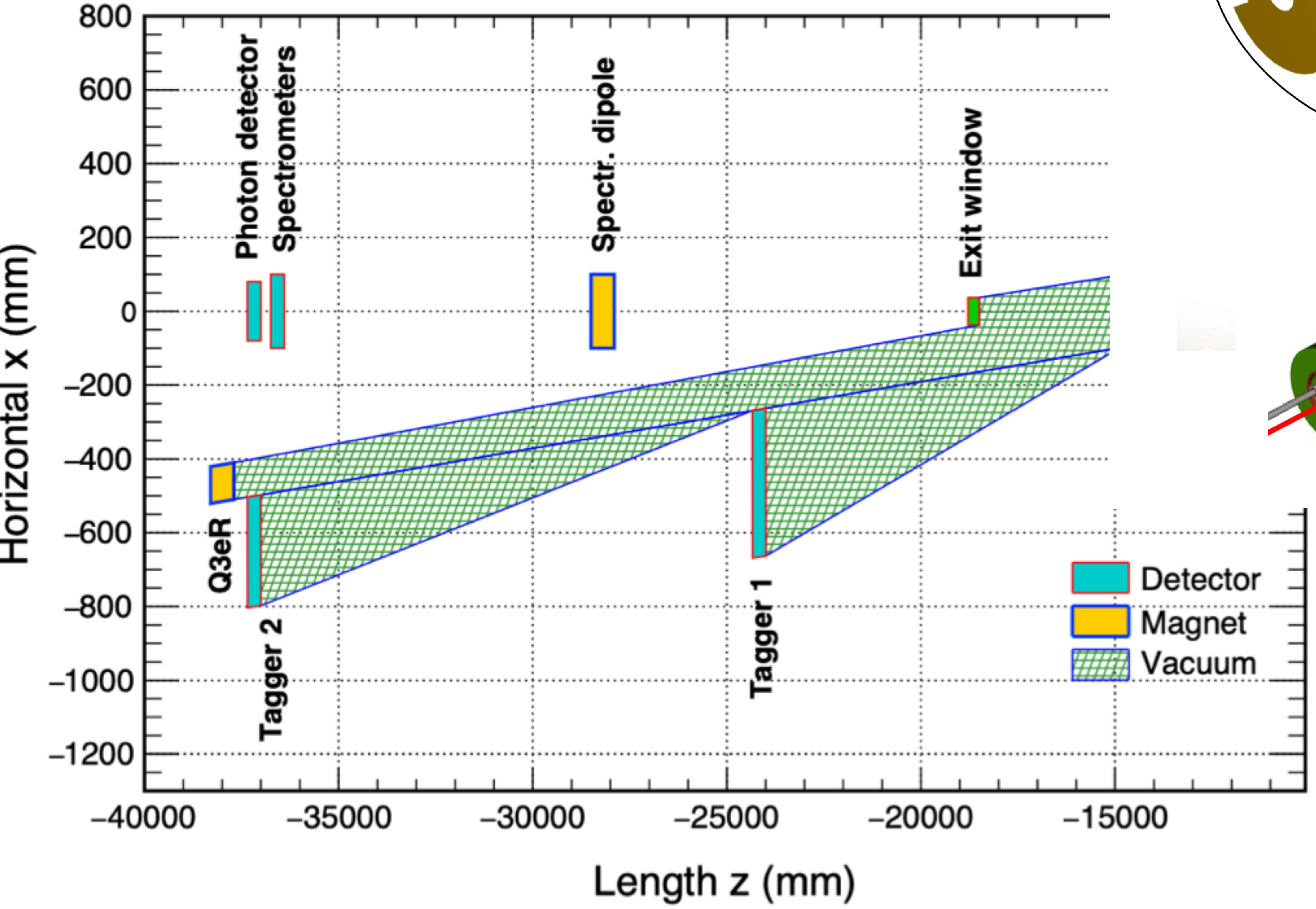


The electron-proton/ion collider (ePIC) detector

+ far backward





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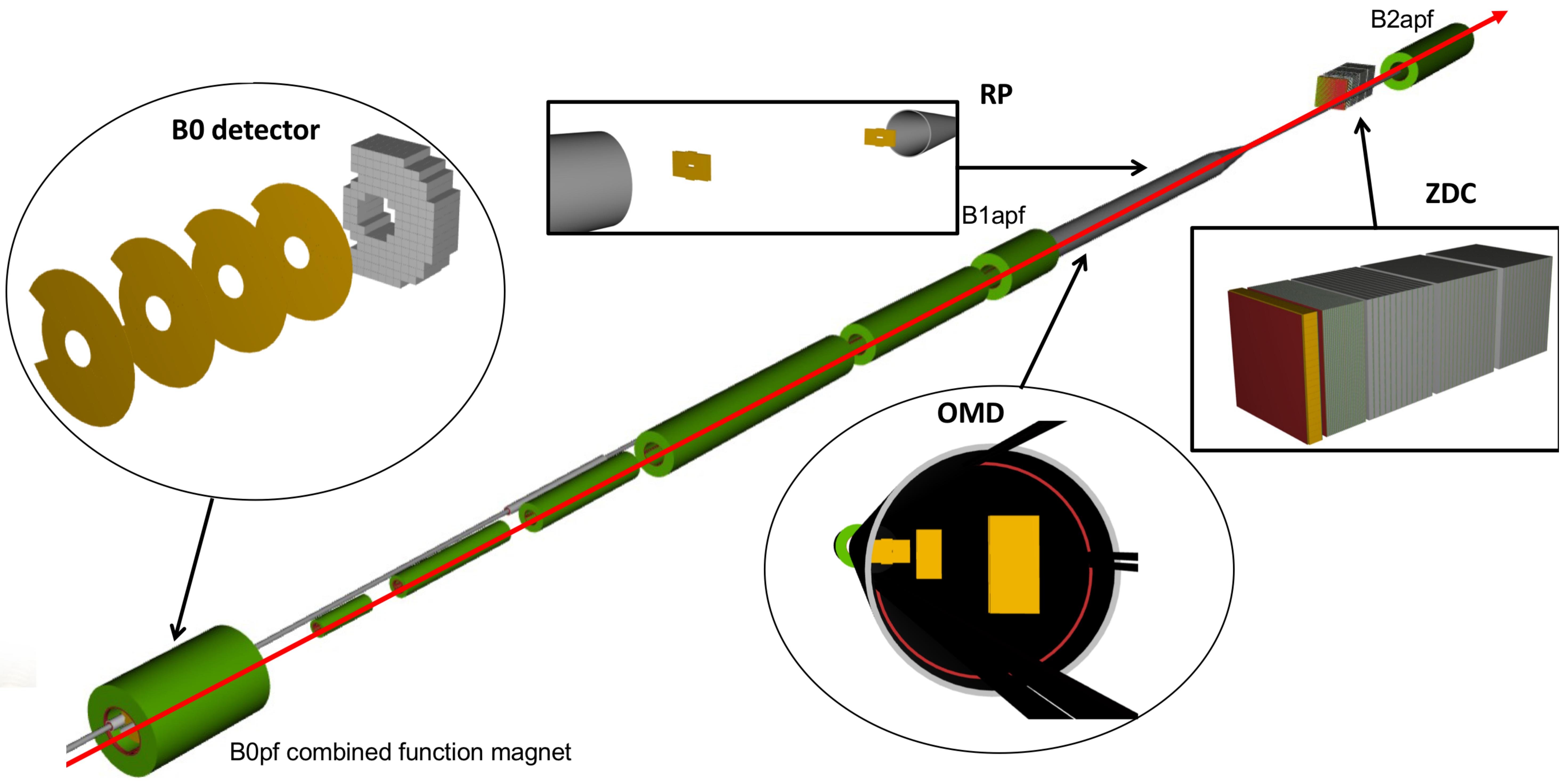

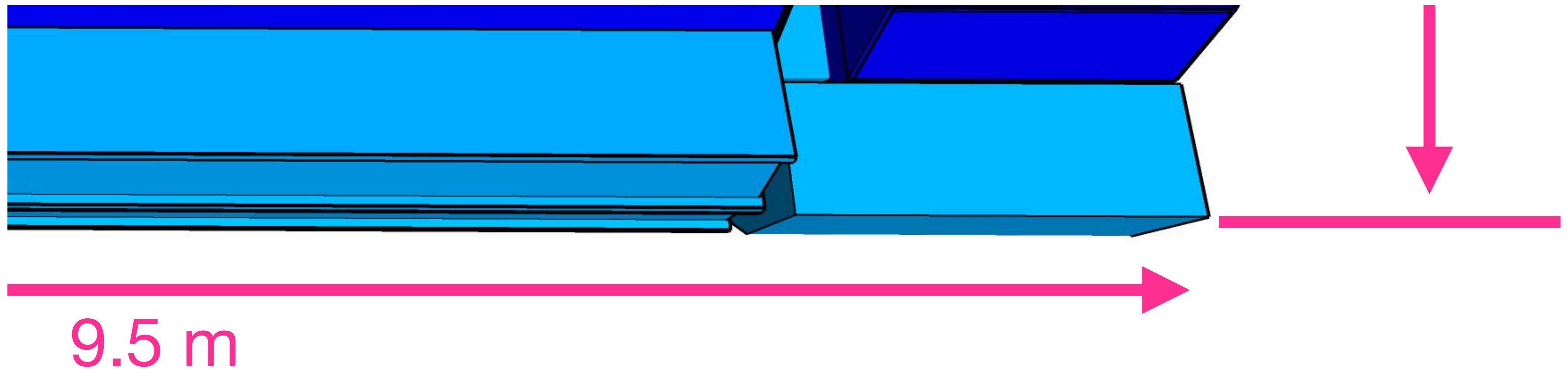

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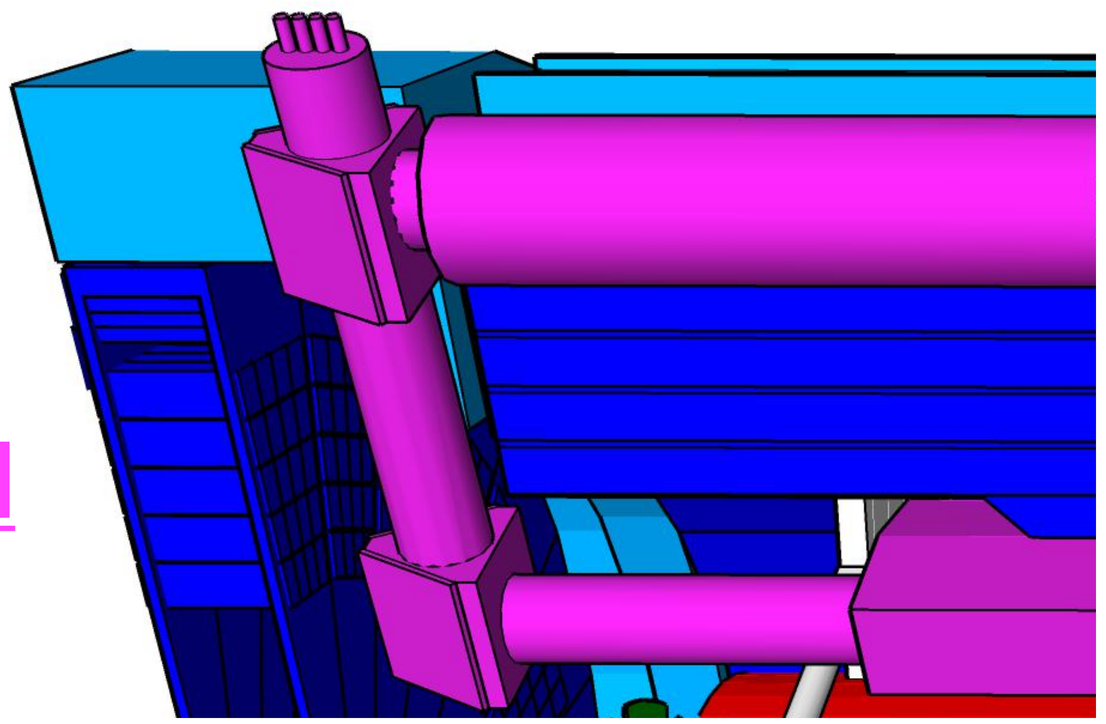

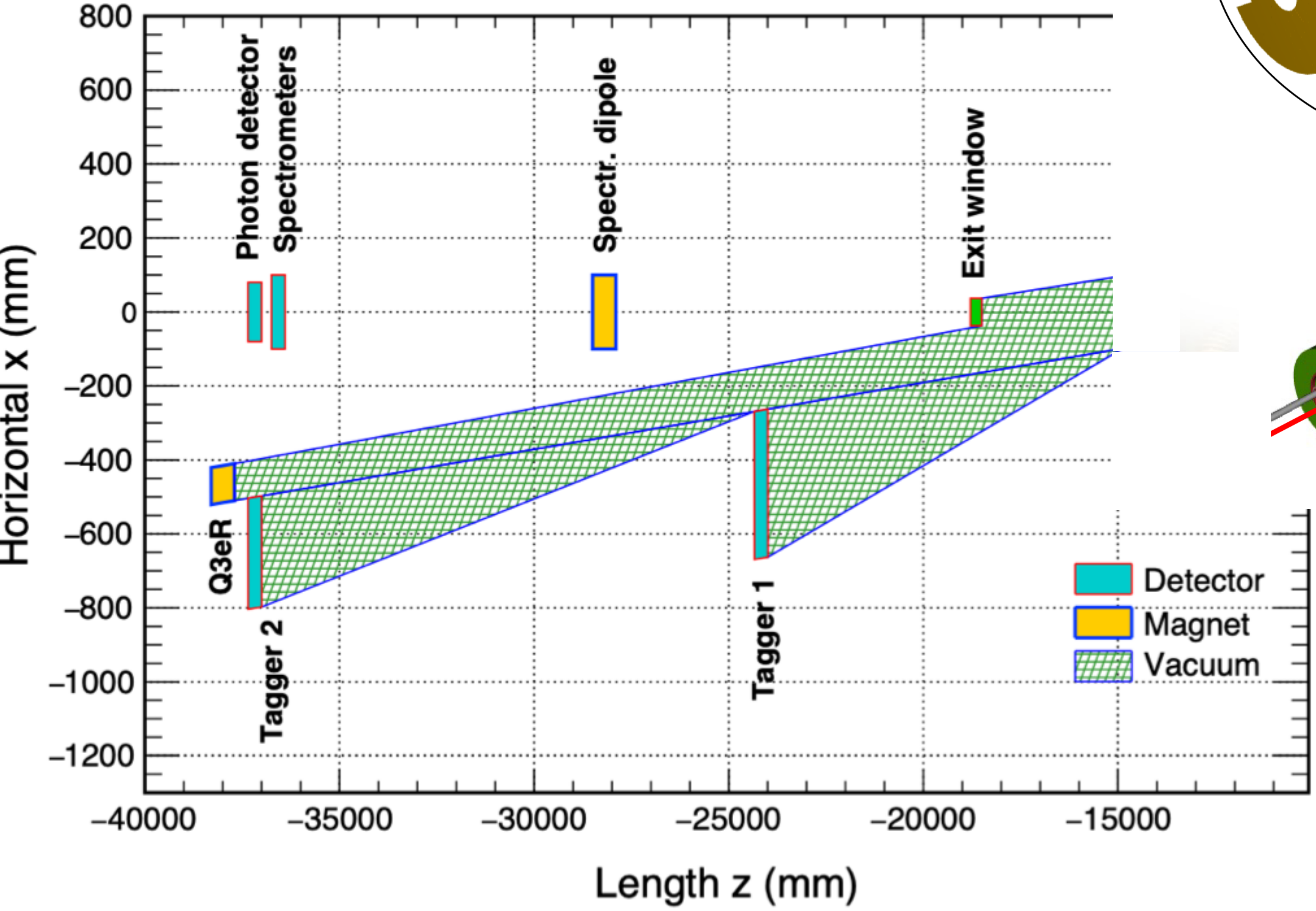

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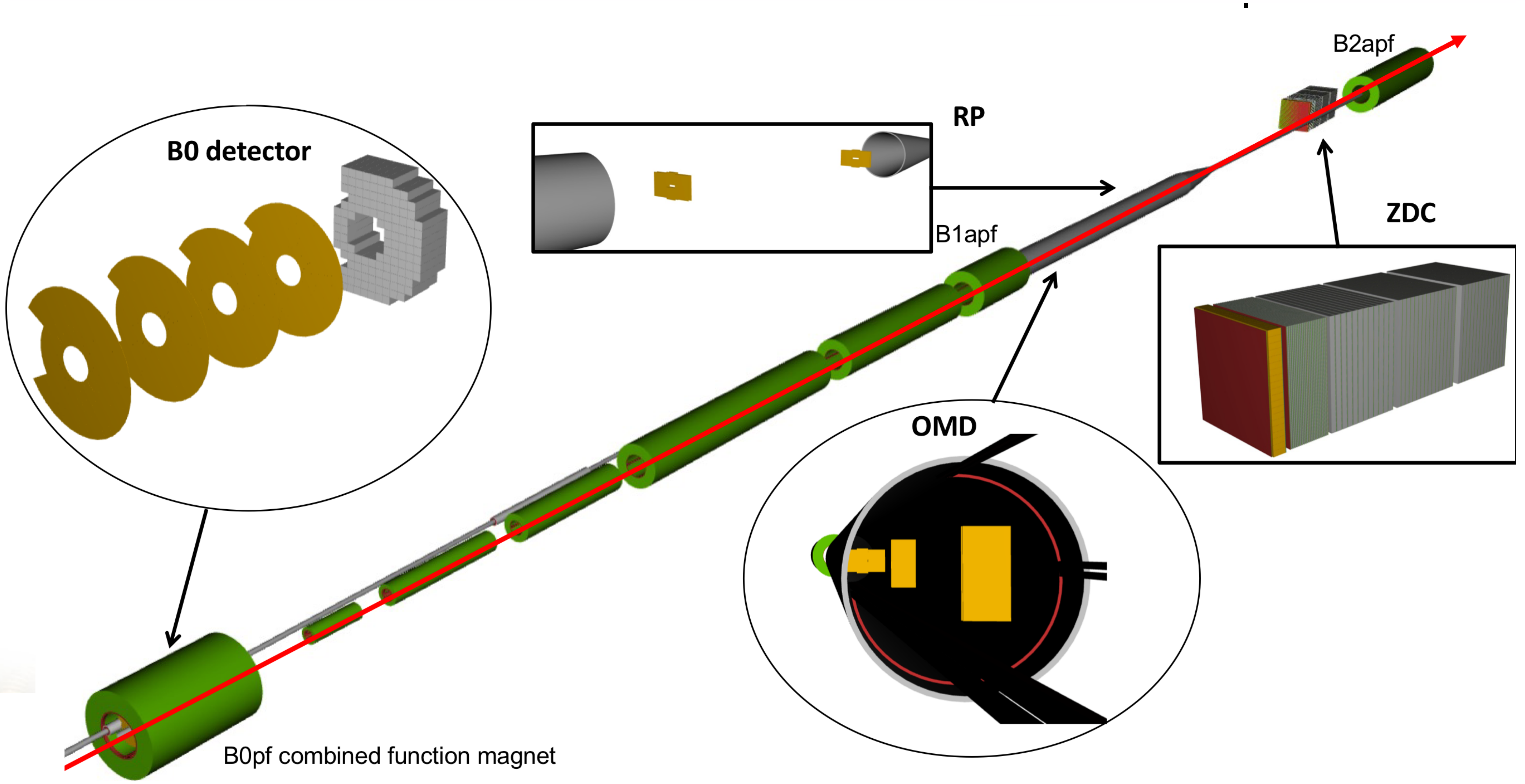
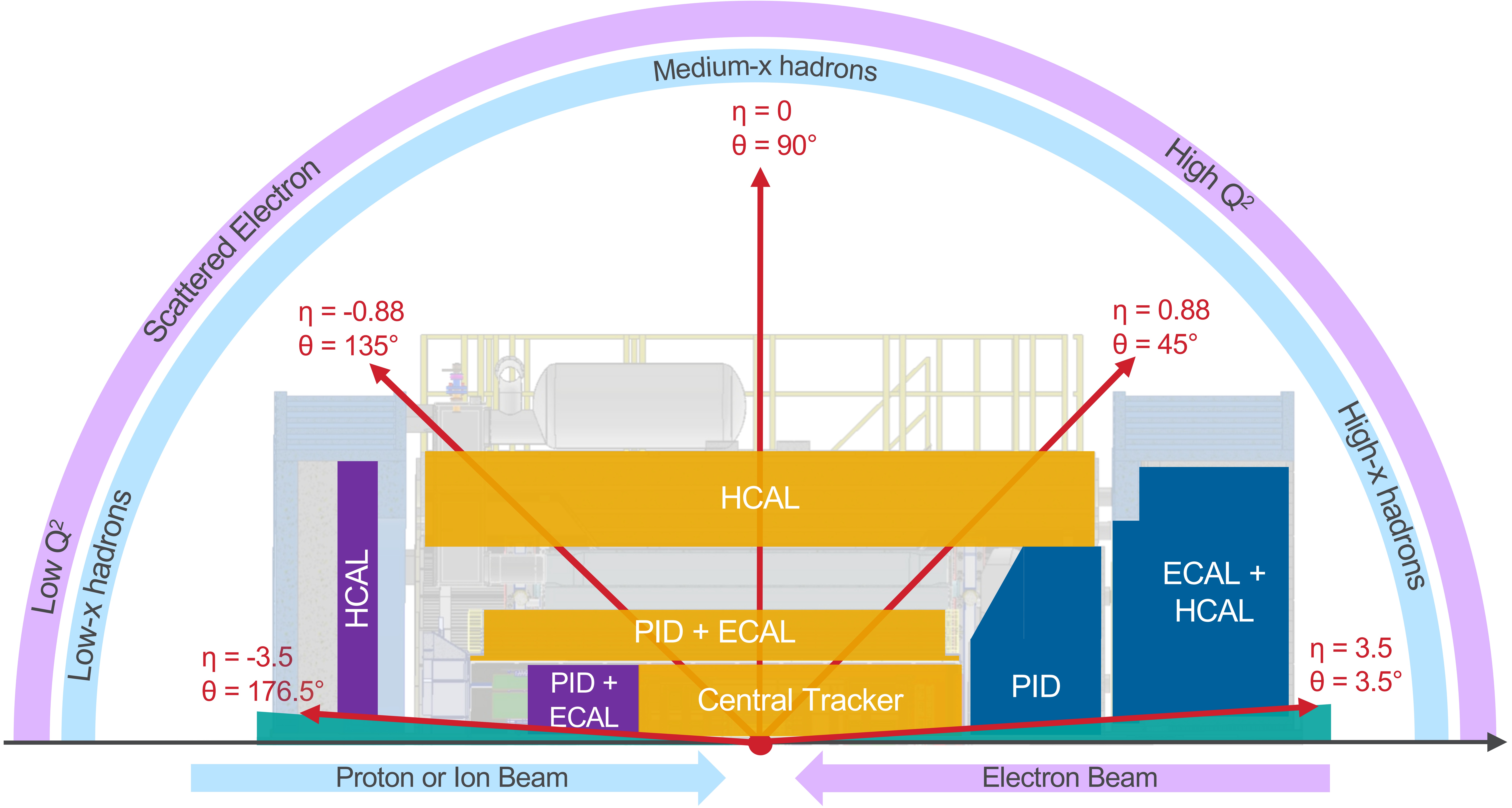


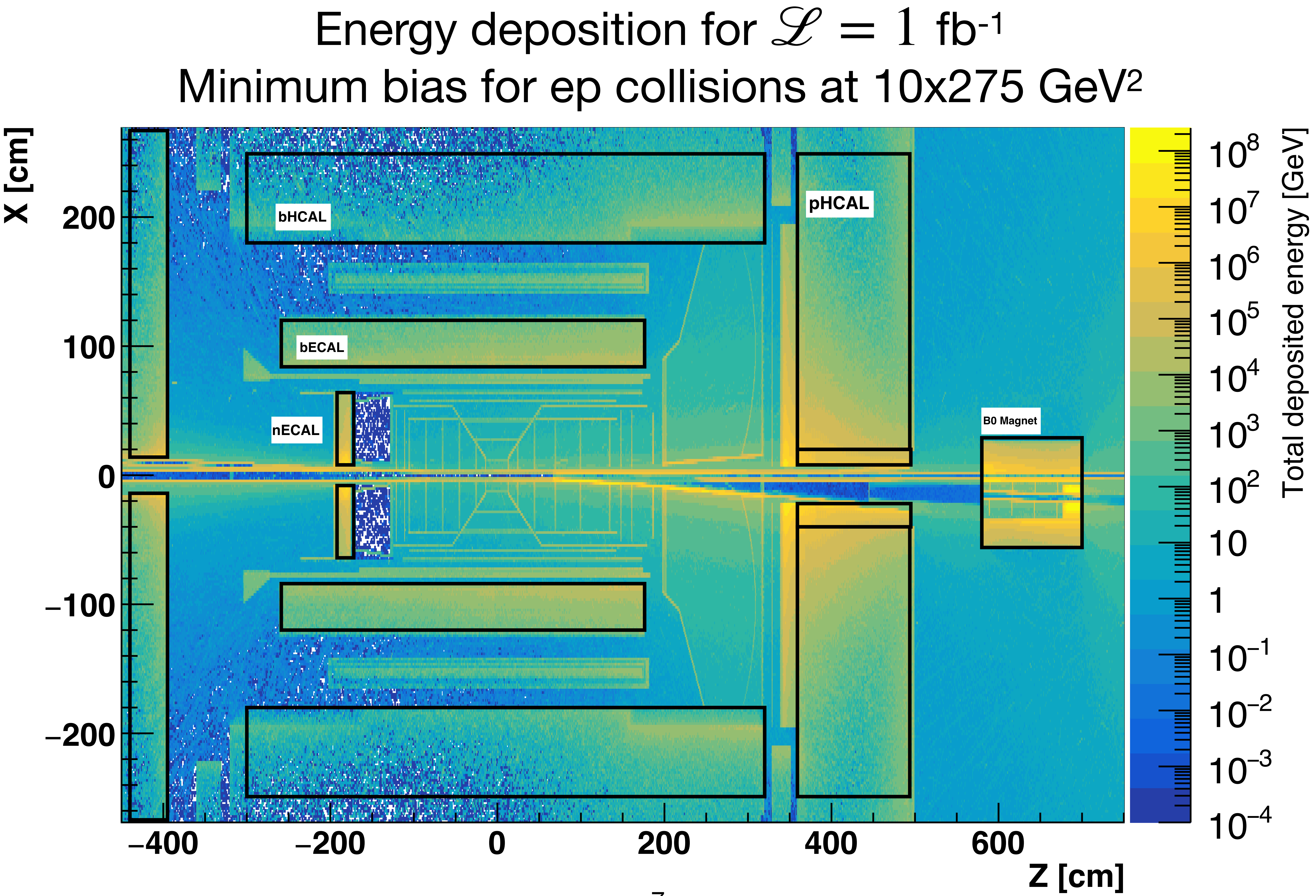
9.5 m

Data acquisition:
- no trigger
- all collision data is digitised
- with strong zero-suppression at front-end electronics

Kinematic coverage of central detector

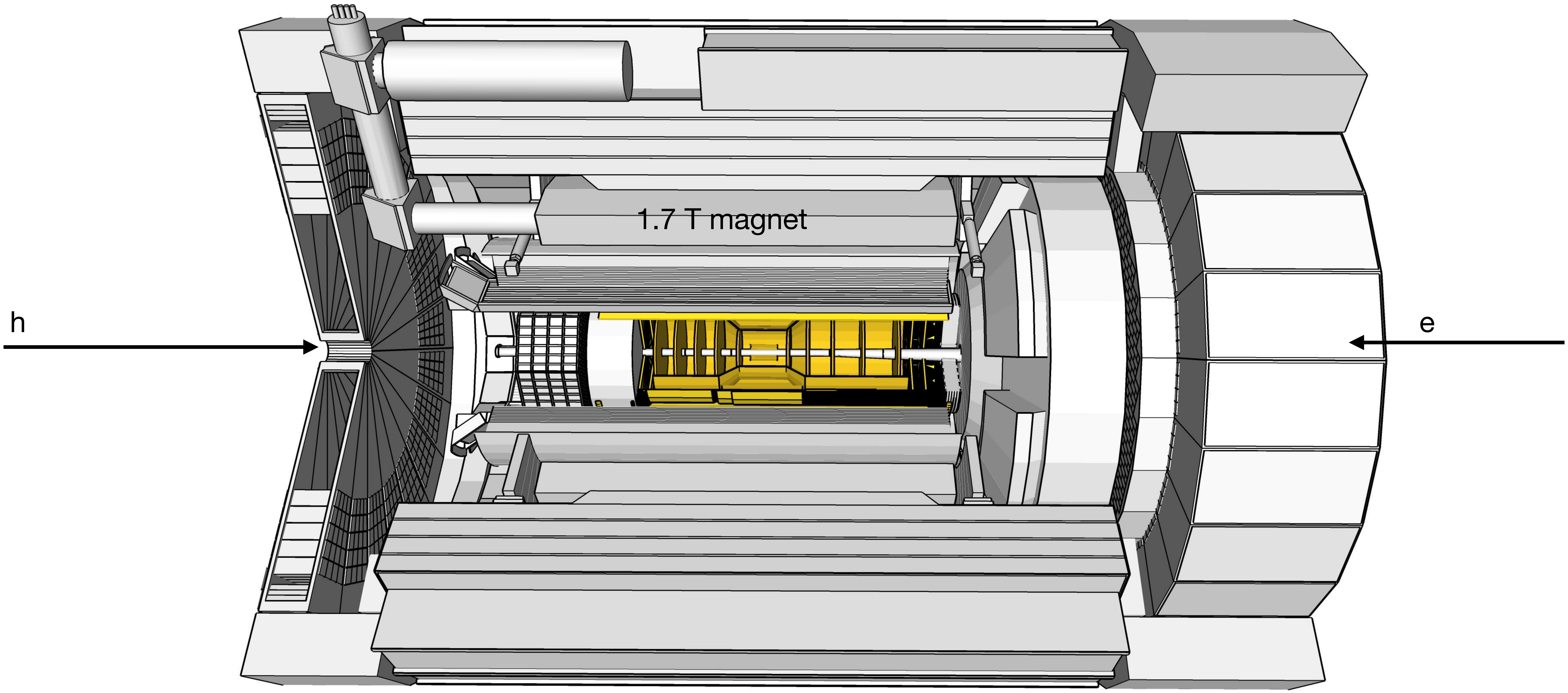


Radiation



Energy deposition for $\mathscr{L} = 1$ fb^{-1}
Minimum bias for ep collisions at 10x275 GeV^2
bHCAL
bECAL
nECAL
pHCAL
B0 Magnet
X [cm]
Z [cm]
Total deposited energy [GeV]
200
100
0
−100
−200
−400
−200
0
200
400
600
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}

The tracking system



The tracking system

1.7 T solenoid

- Monolithic Active Pixel Sensor (MAPS)

  Silicon vertexing/inner tracker: high spatial and moment

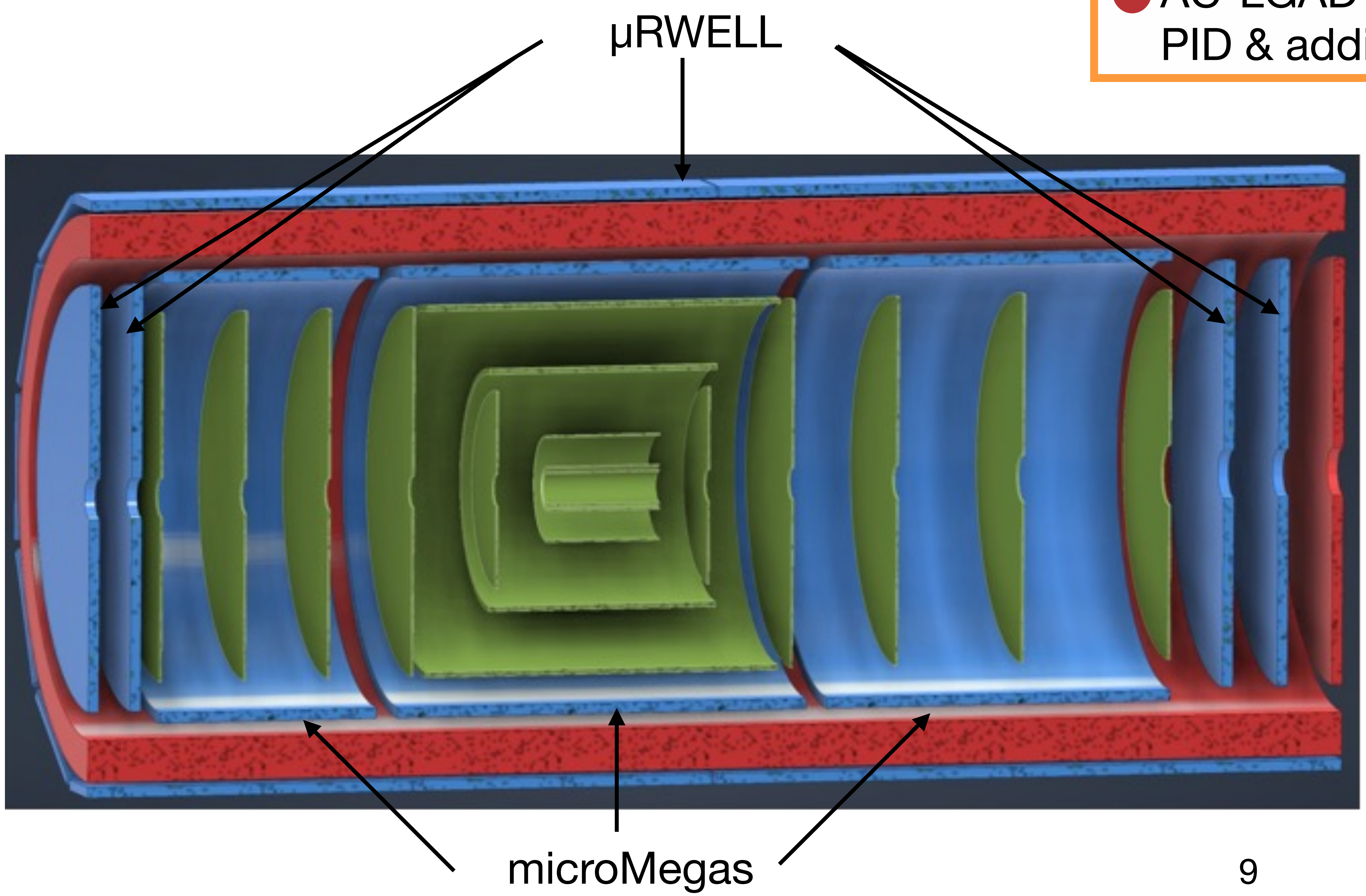
- Micro-pattern gaseous detectors

  μRWELL/microMegas:

  timing (resolution: 10–20 ns) & pattern recognition

- AC-LGAD based TOF:

  PID & additional tracking point



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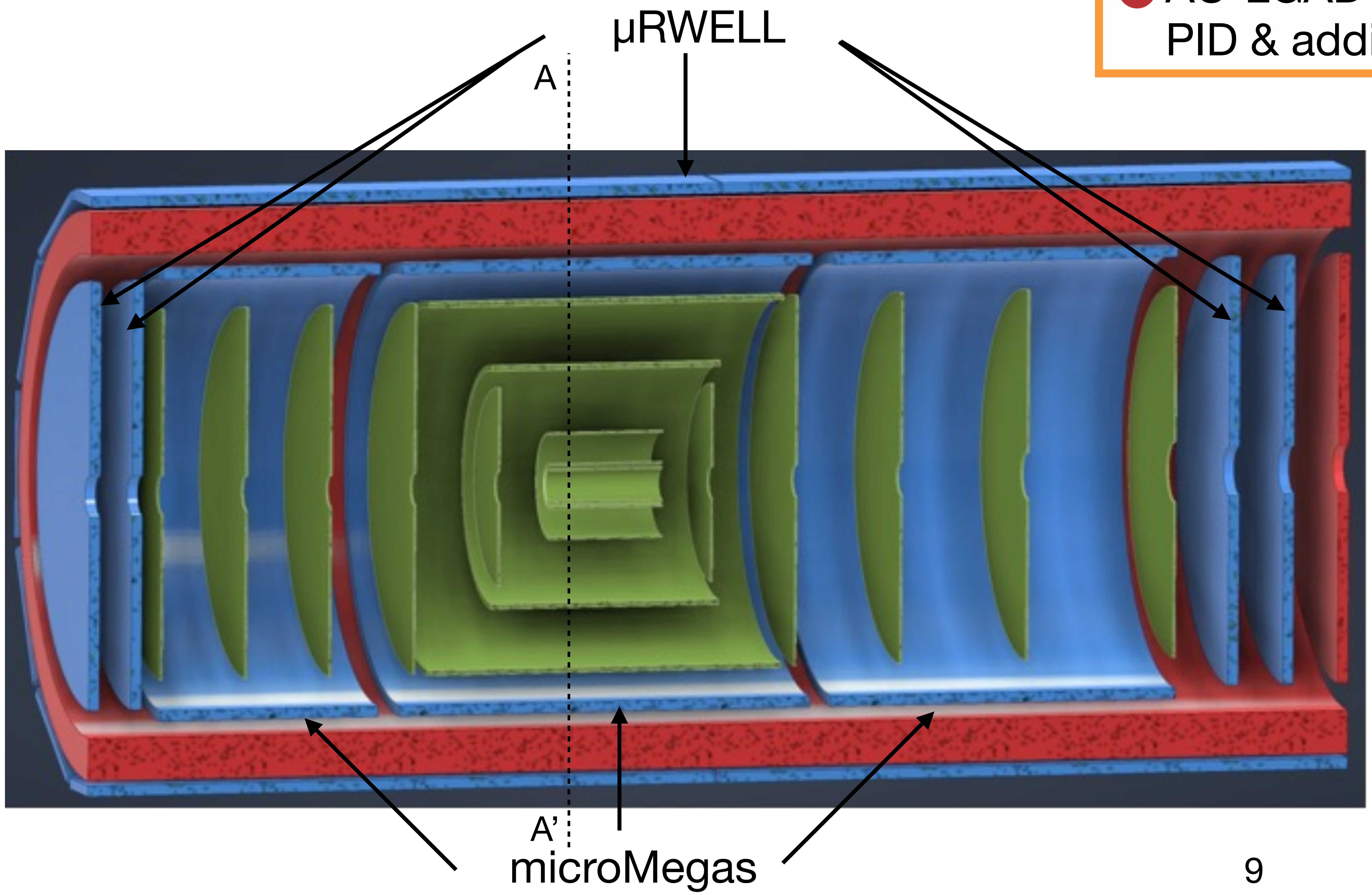

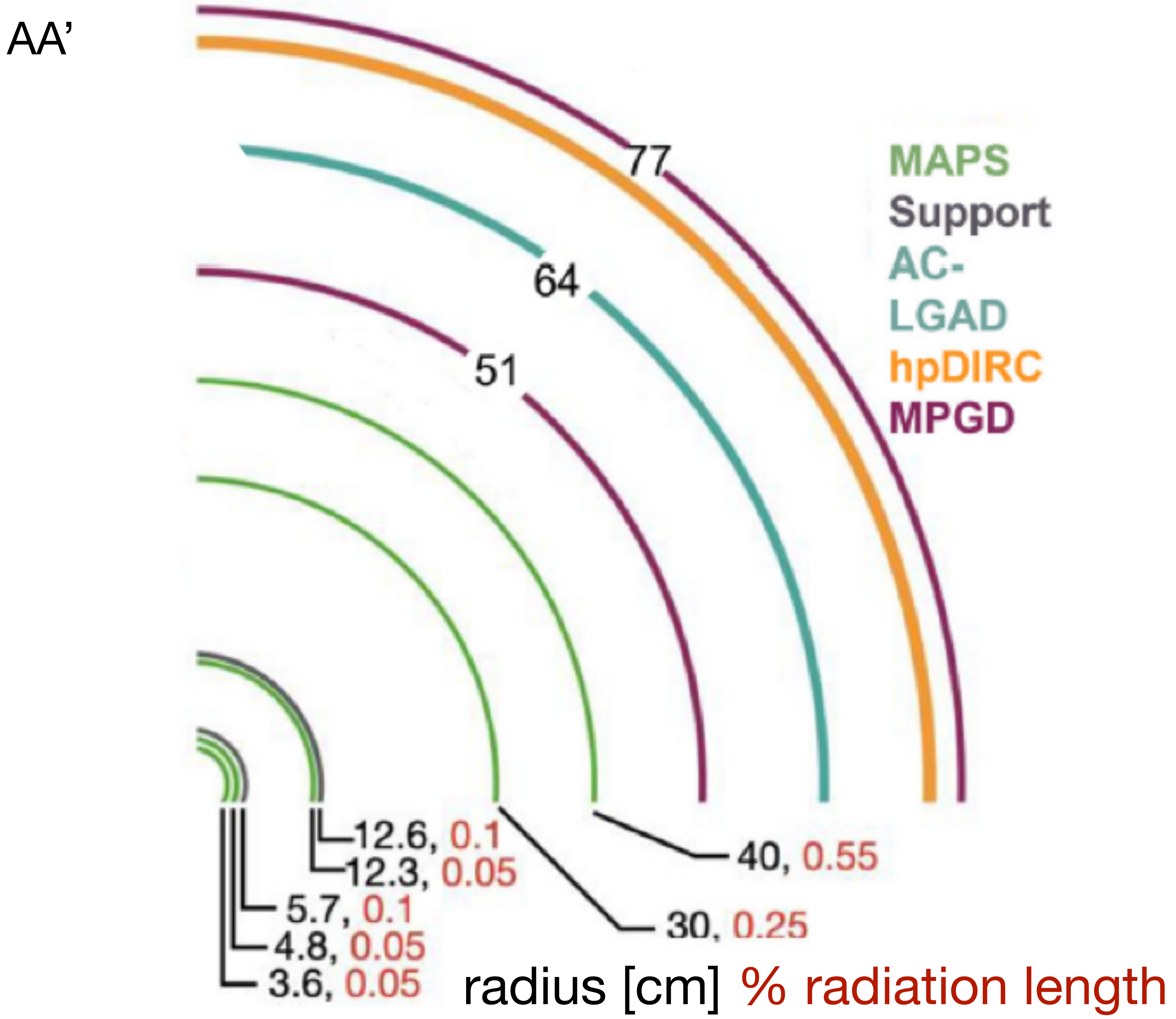

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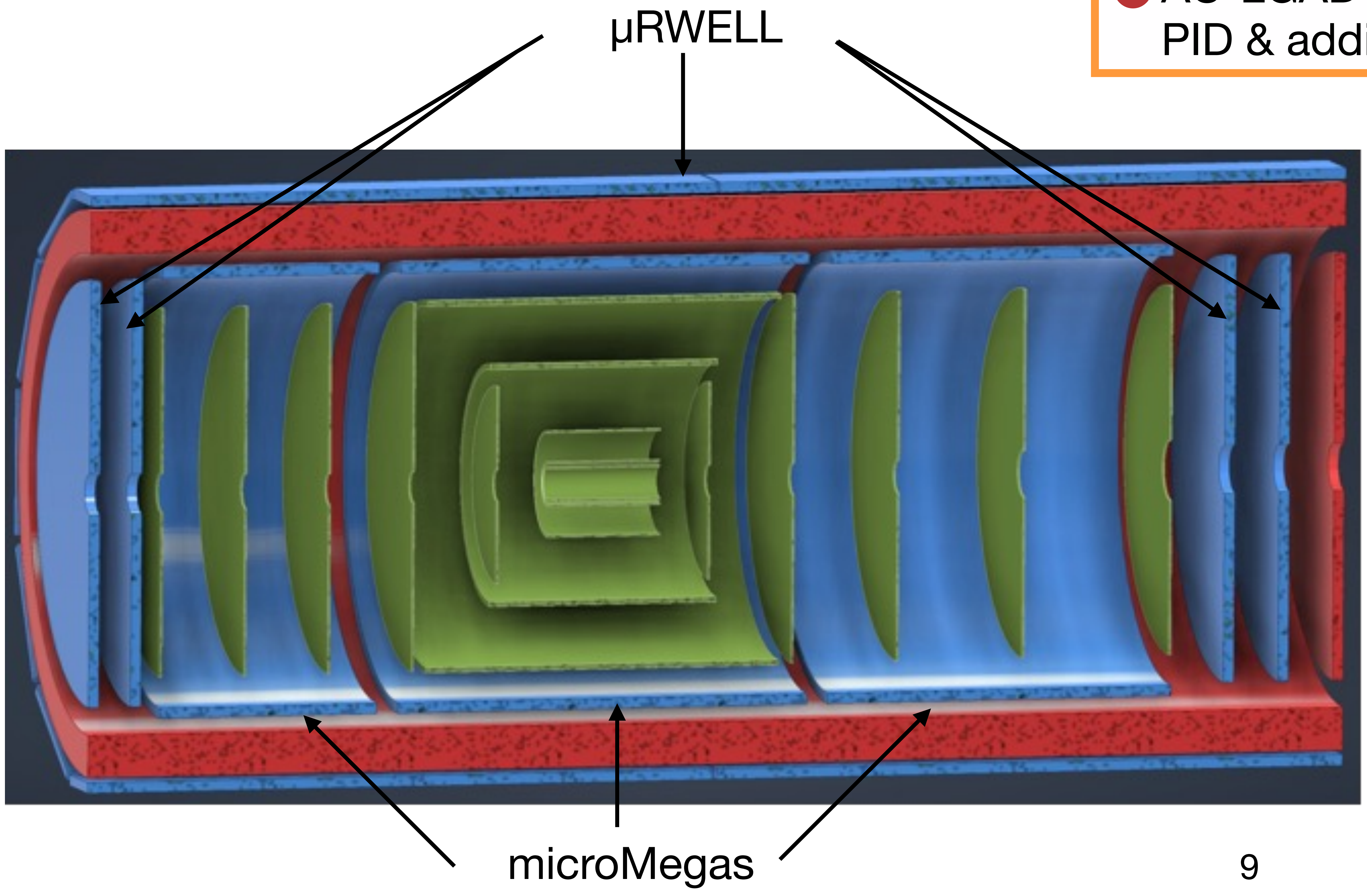
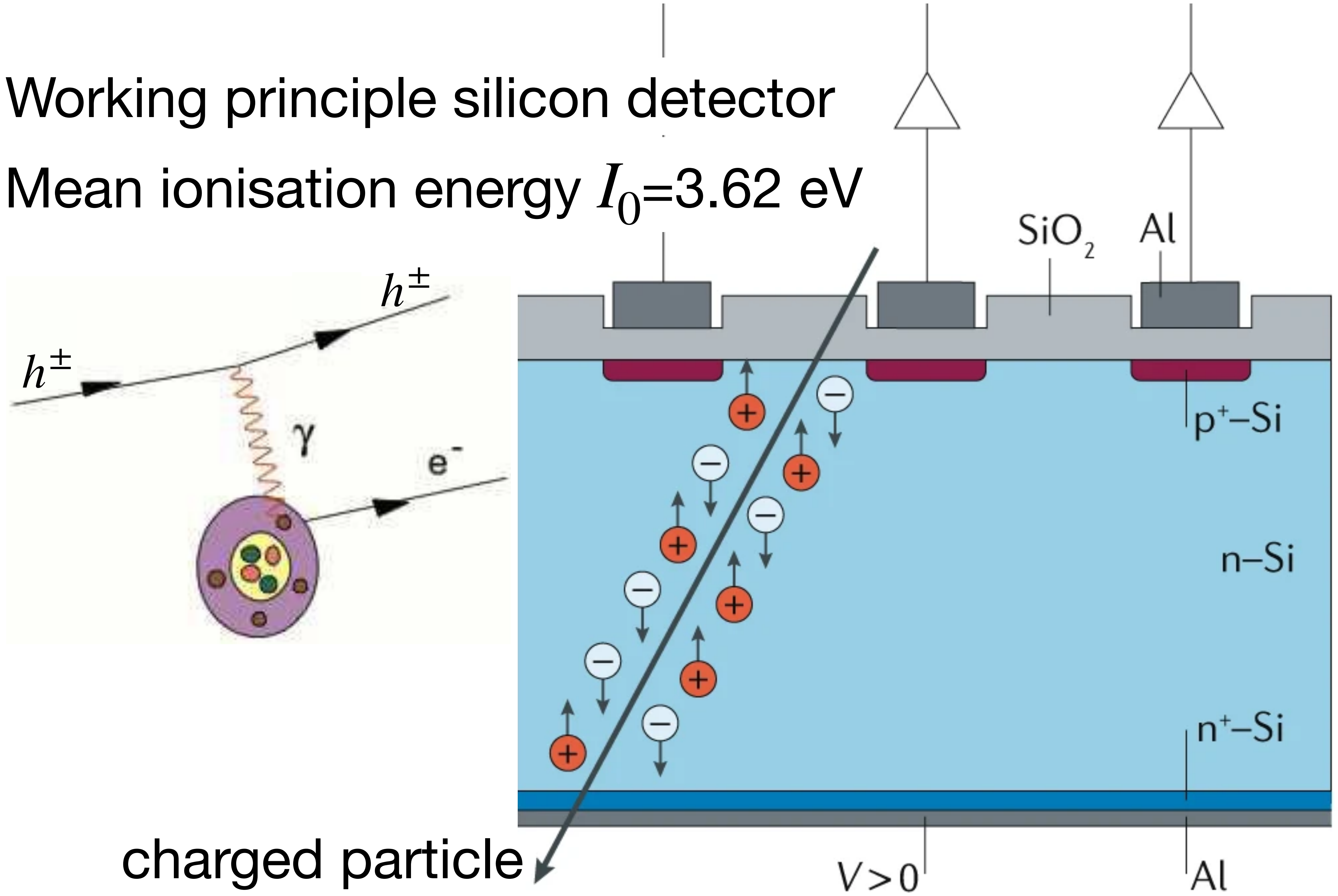


Working principle silicon detector

Mean ionisation energy I_0=3.62 eV



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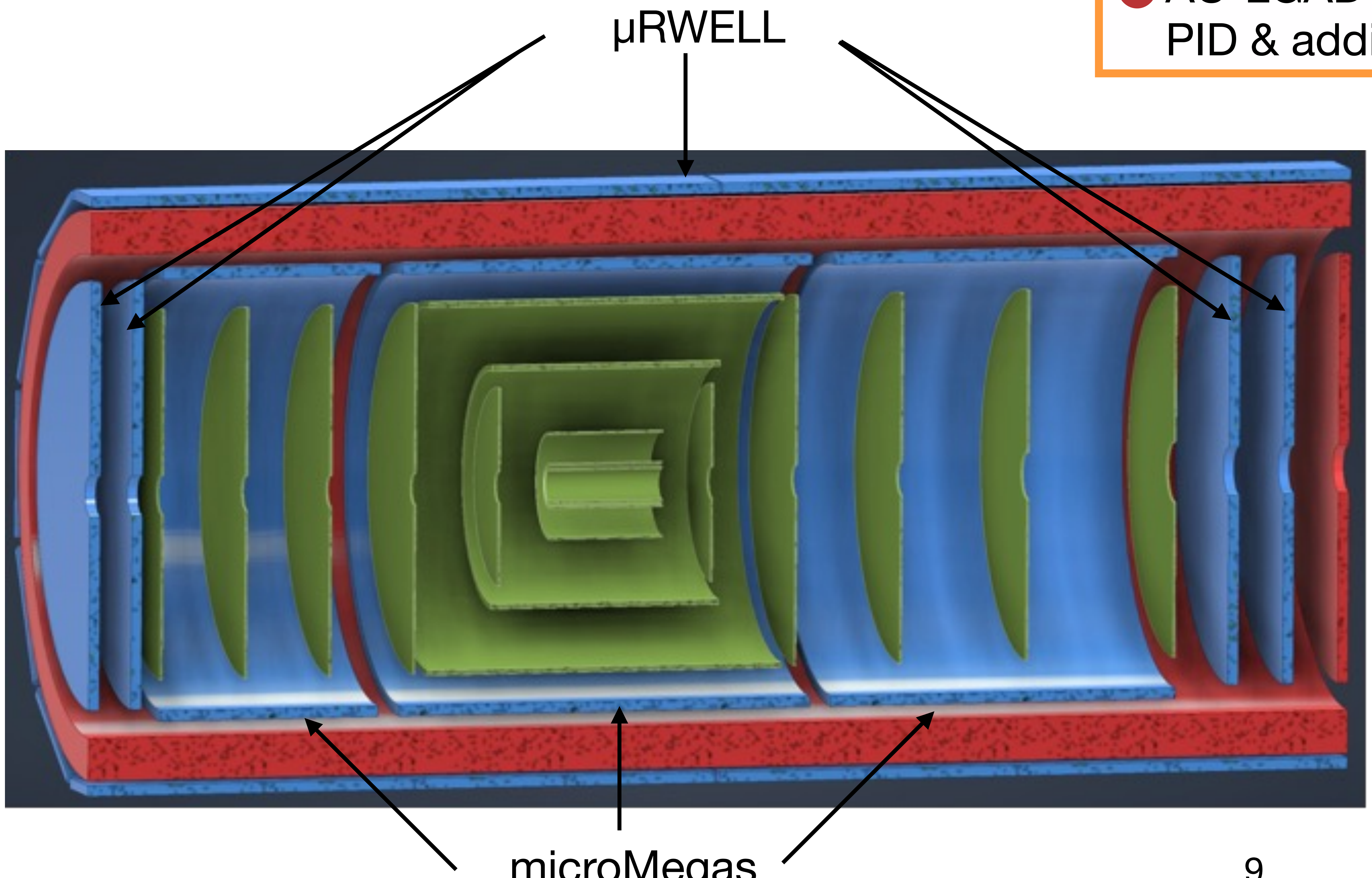
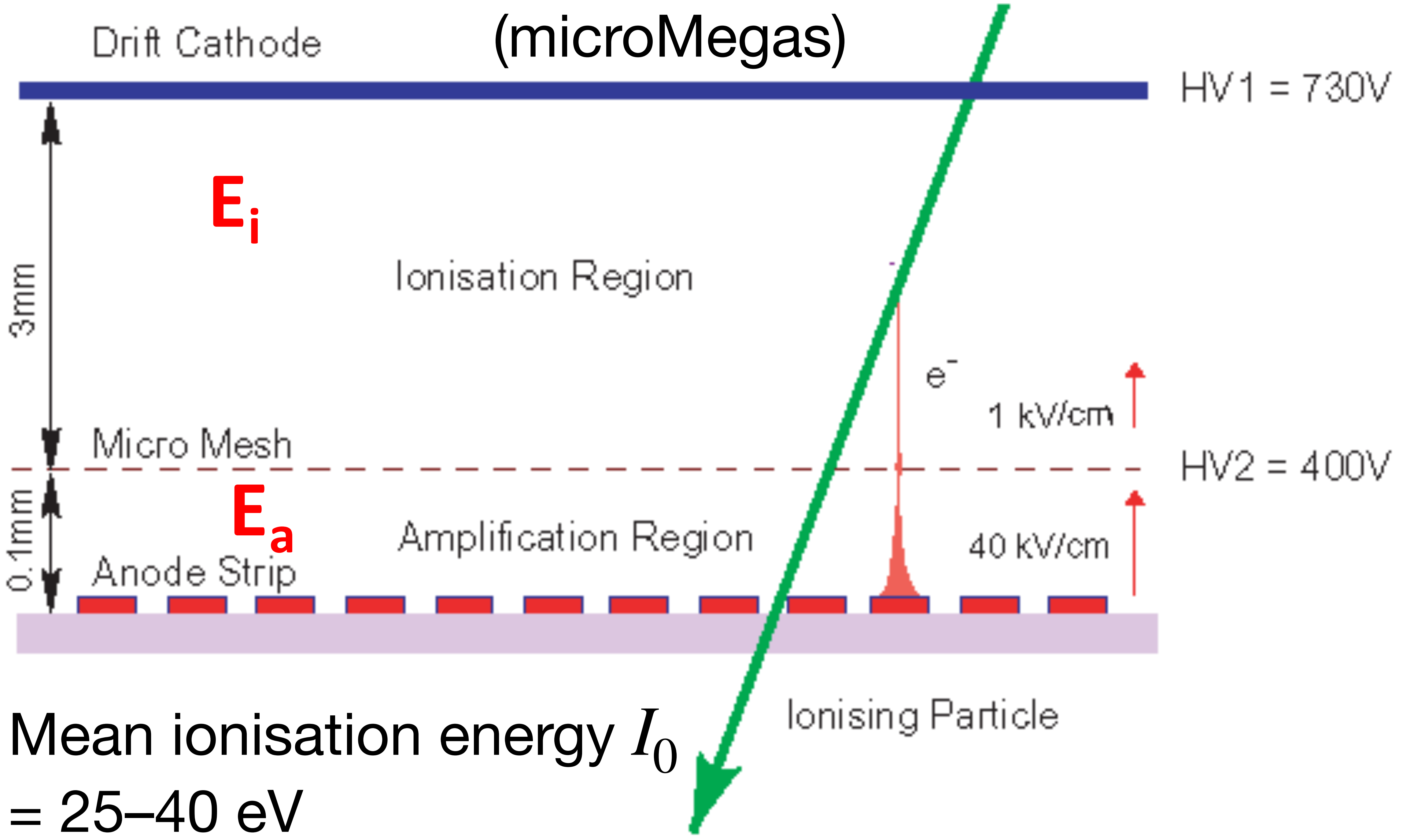


Working principle micro-pattern gaseous detectors (microMegas)



Mean ionisation energy I_0 = 25–40 eV

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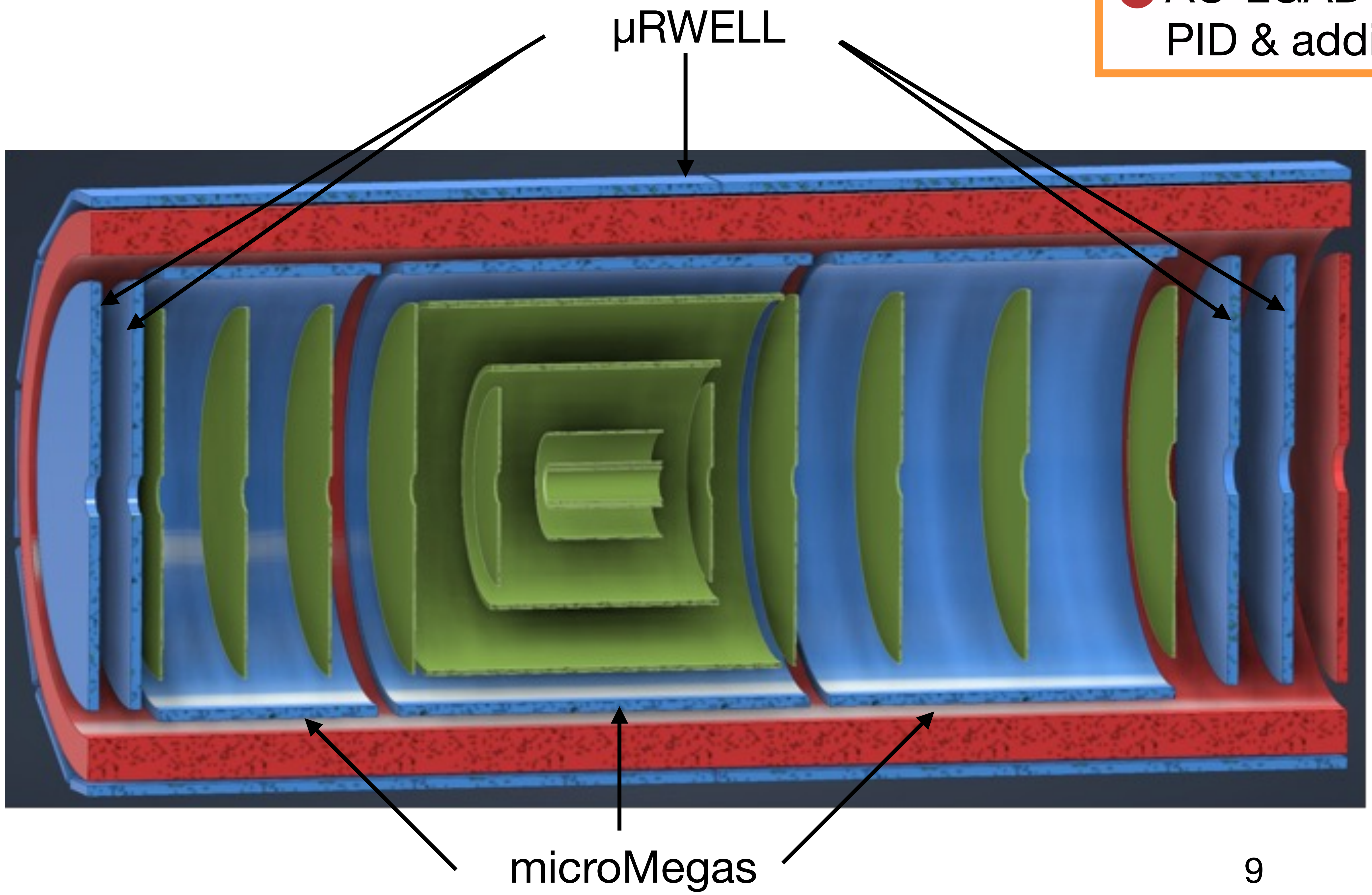

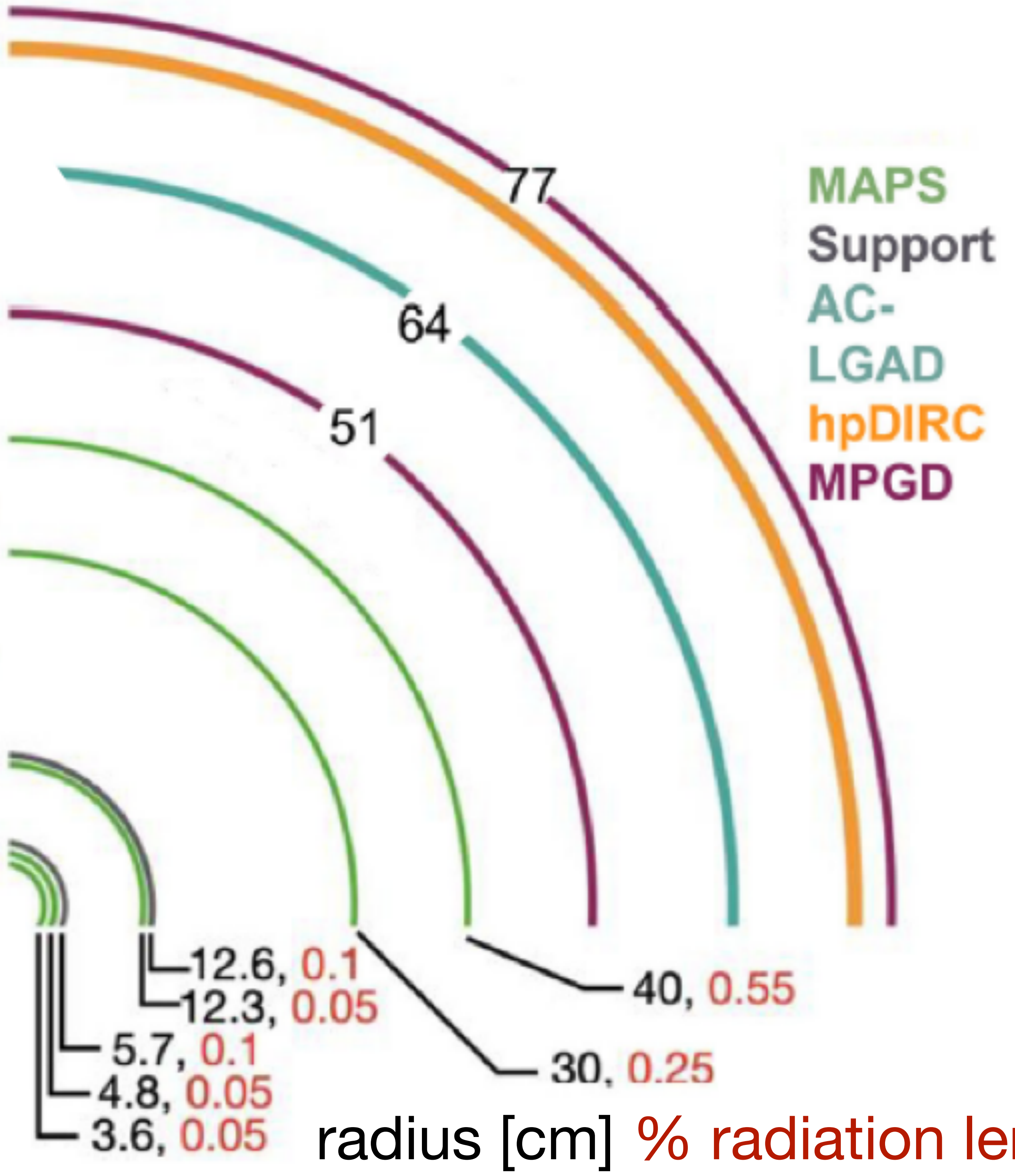

radius [cm] % radiation length
(radiation length=$\langle L \rangle$ at which e^- E reduced by 1/e)

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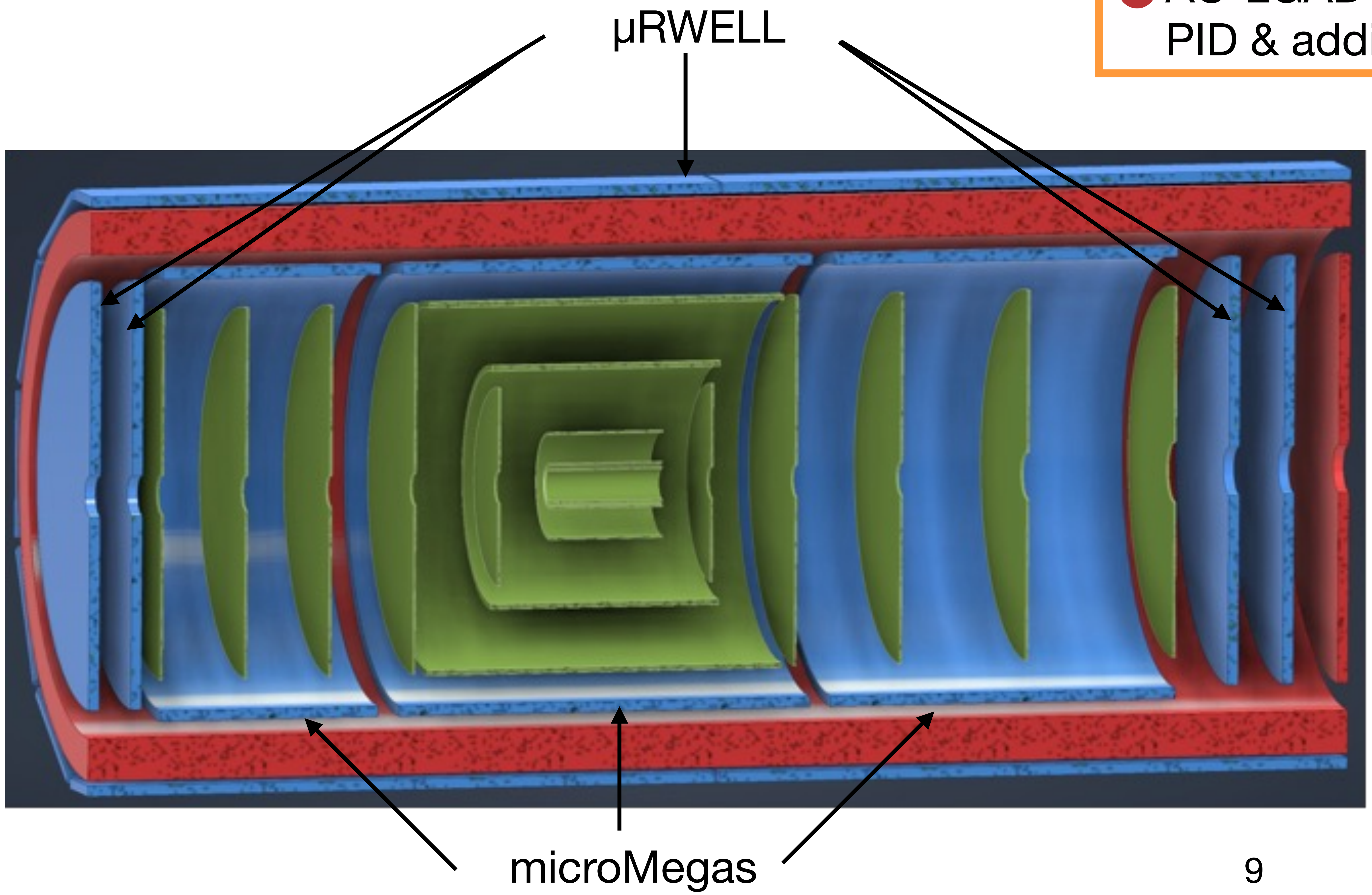

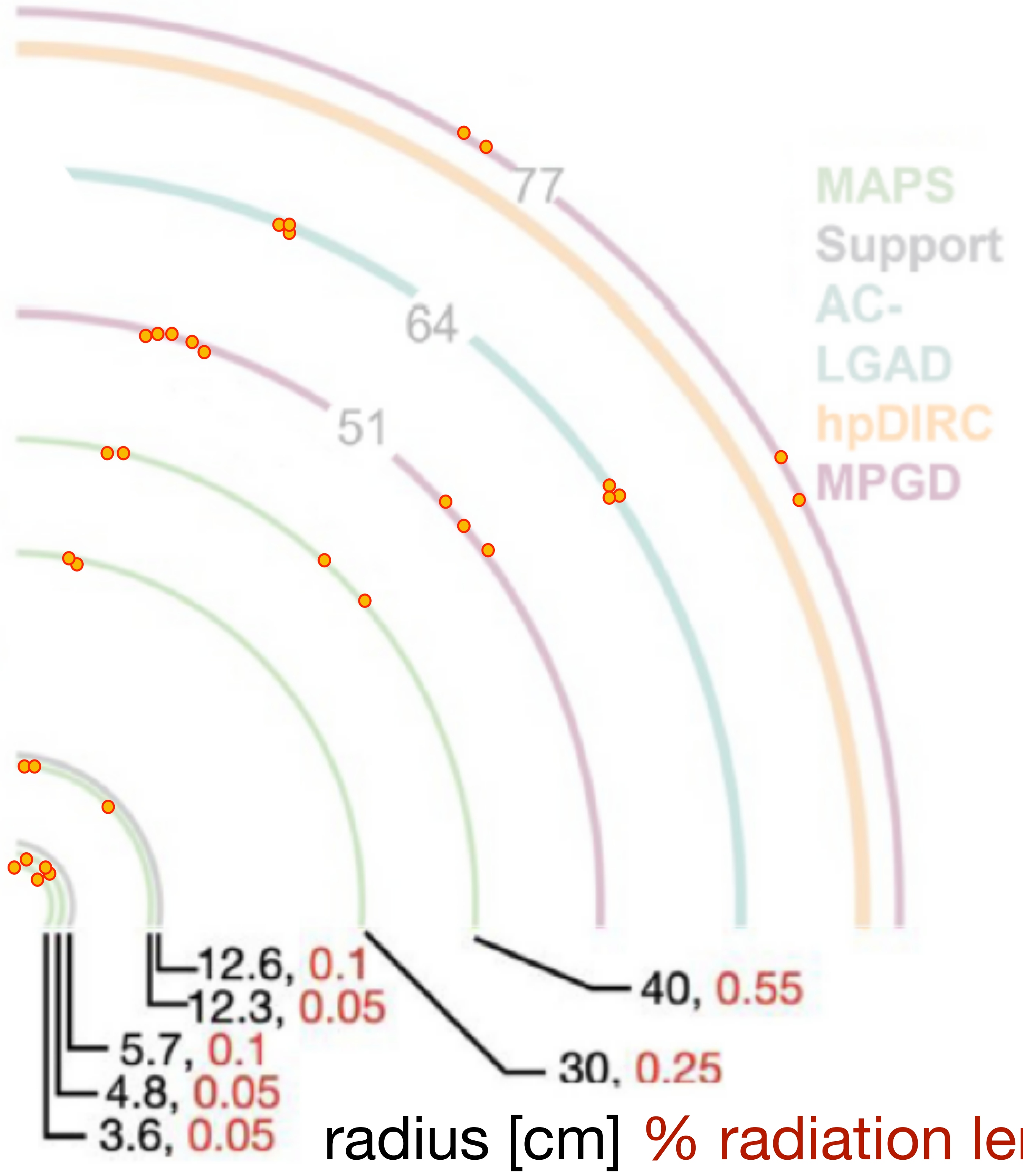

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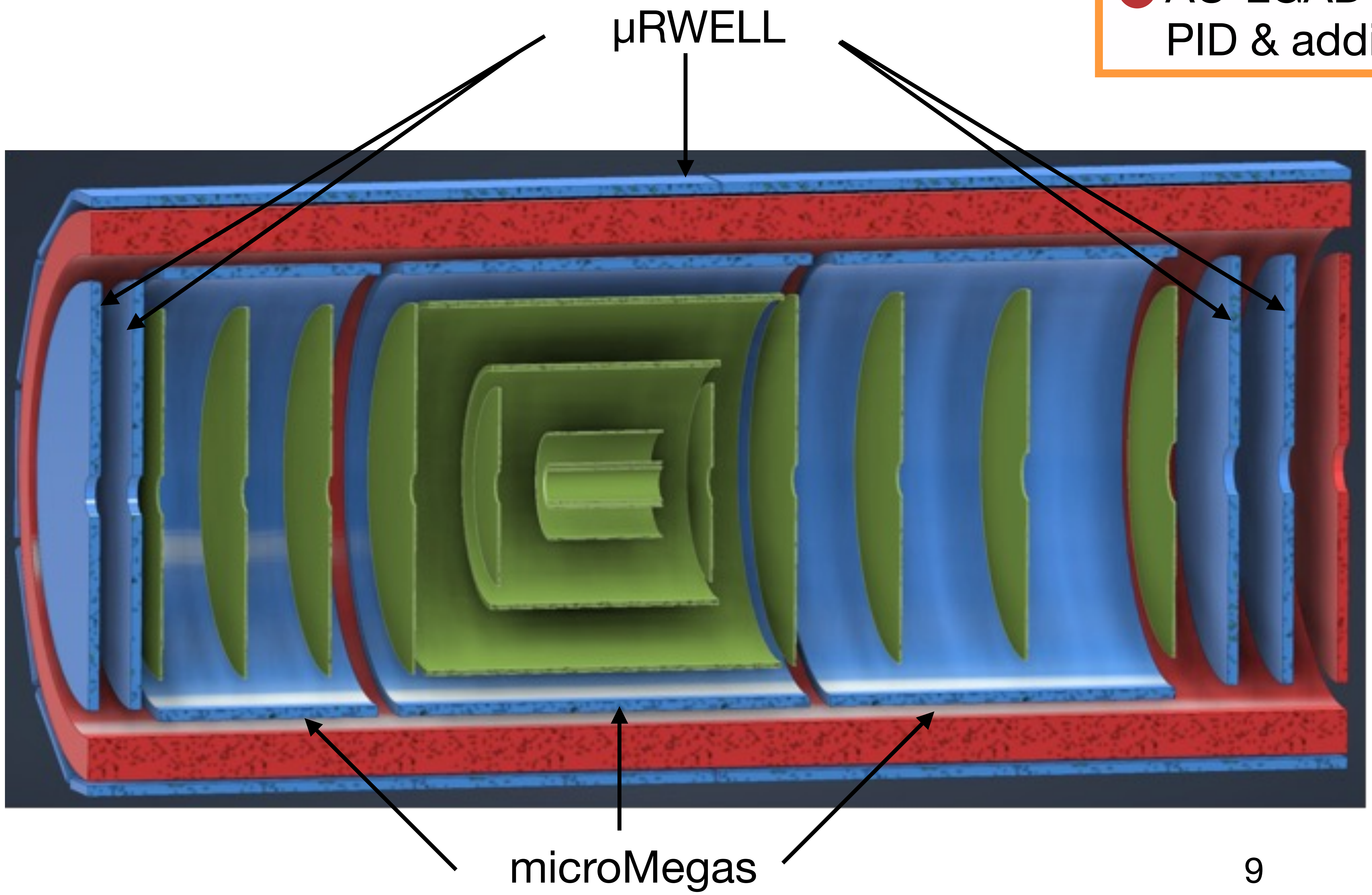

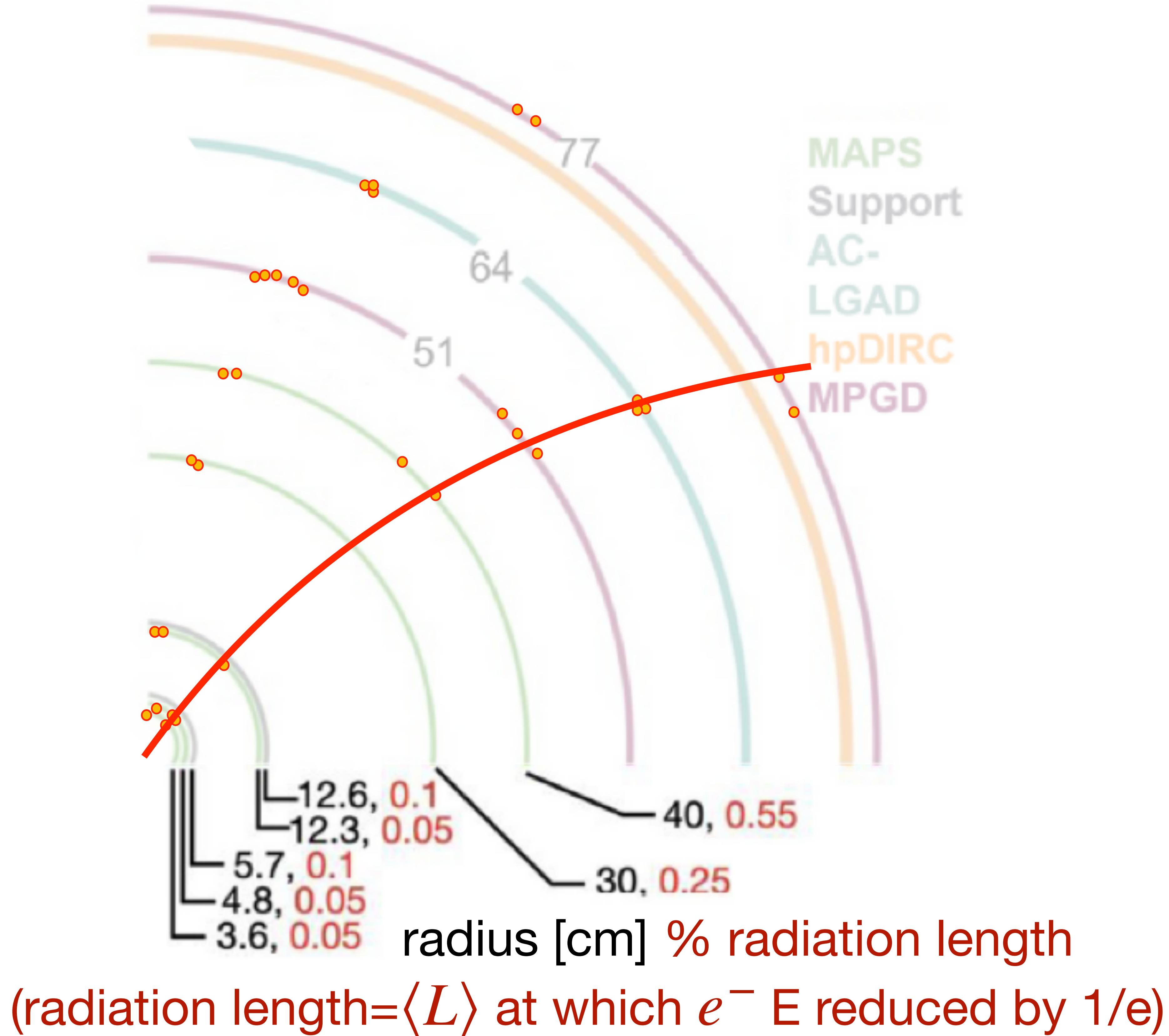

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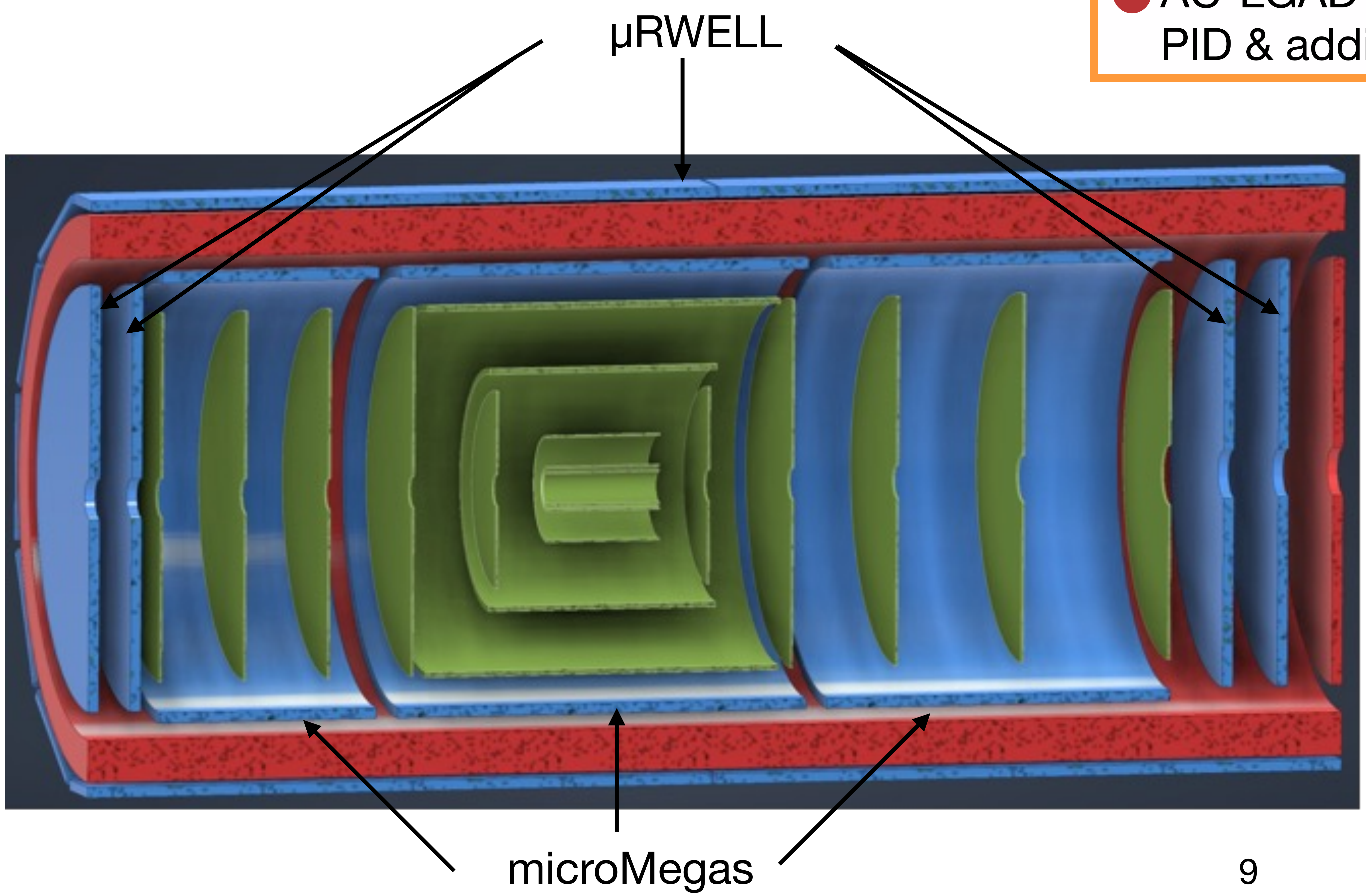

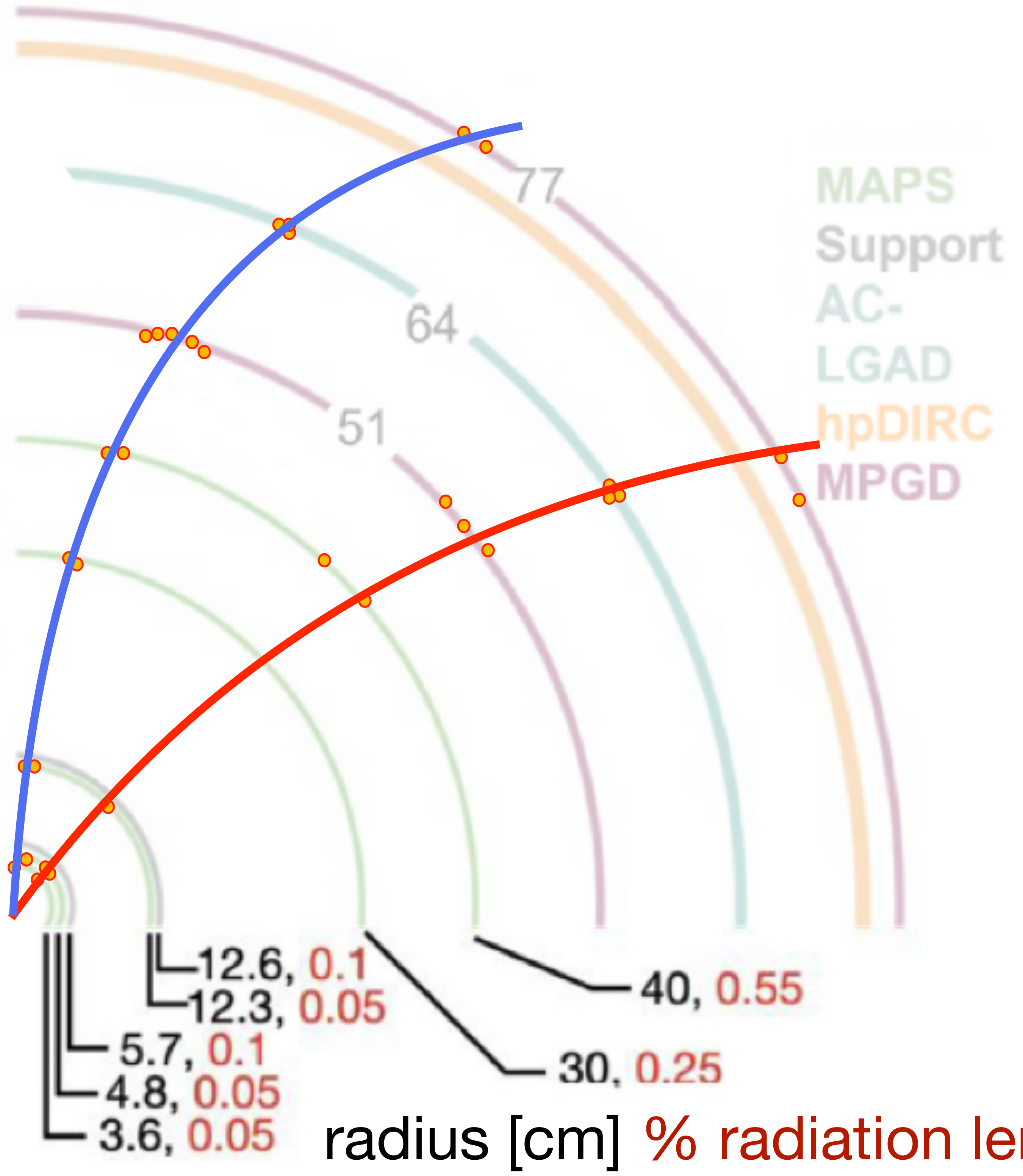

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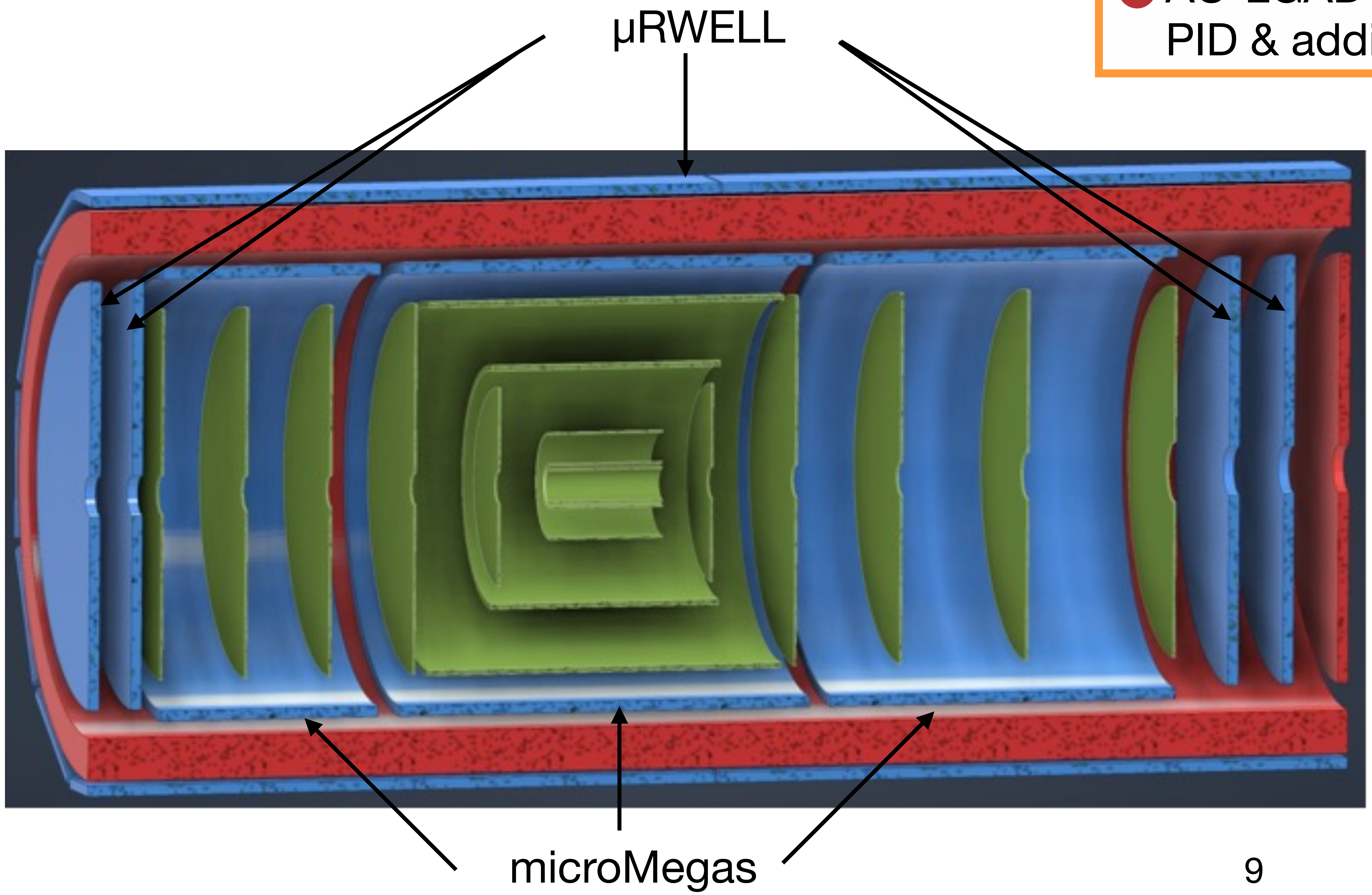

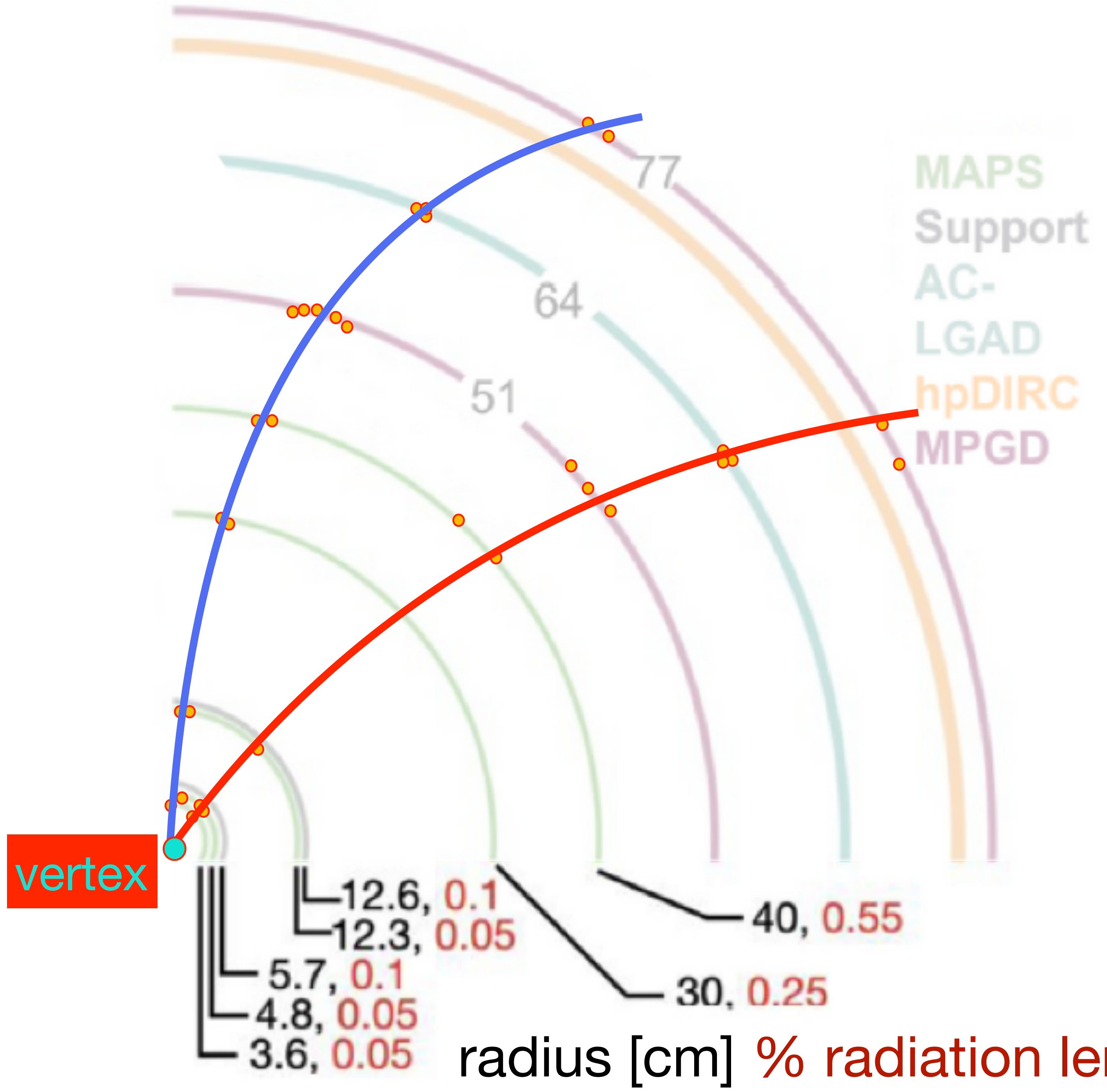

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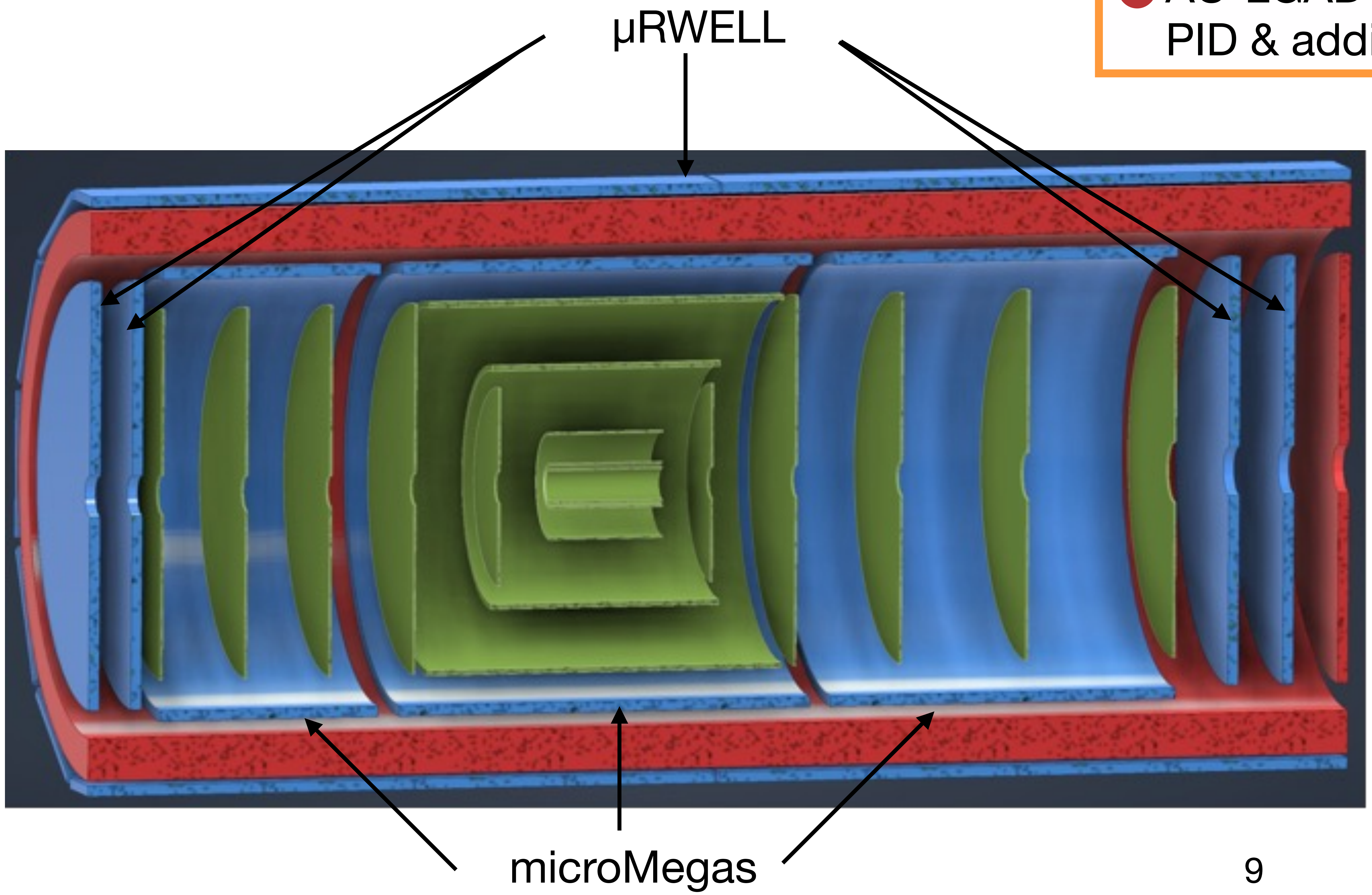

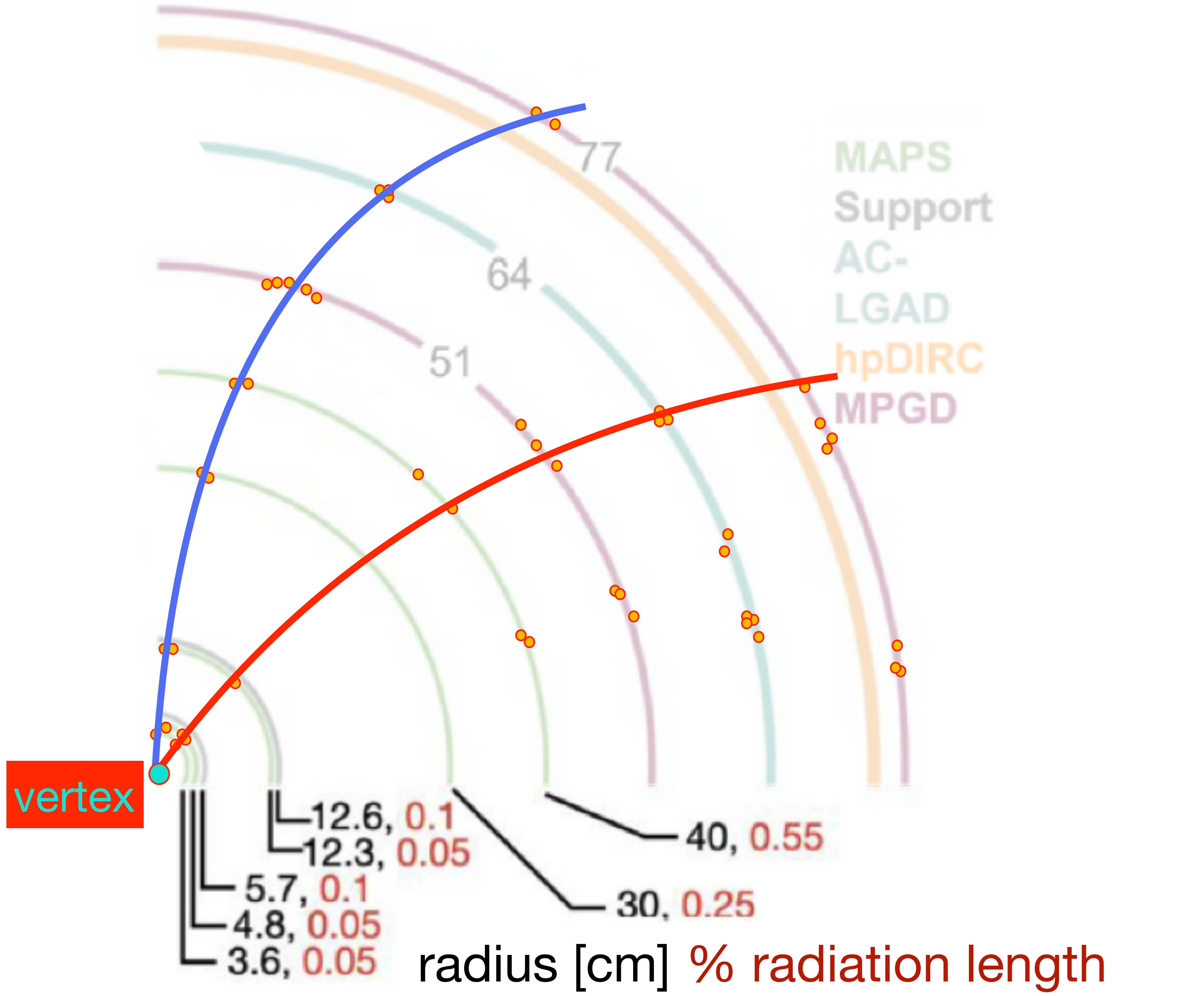

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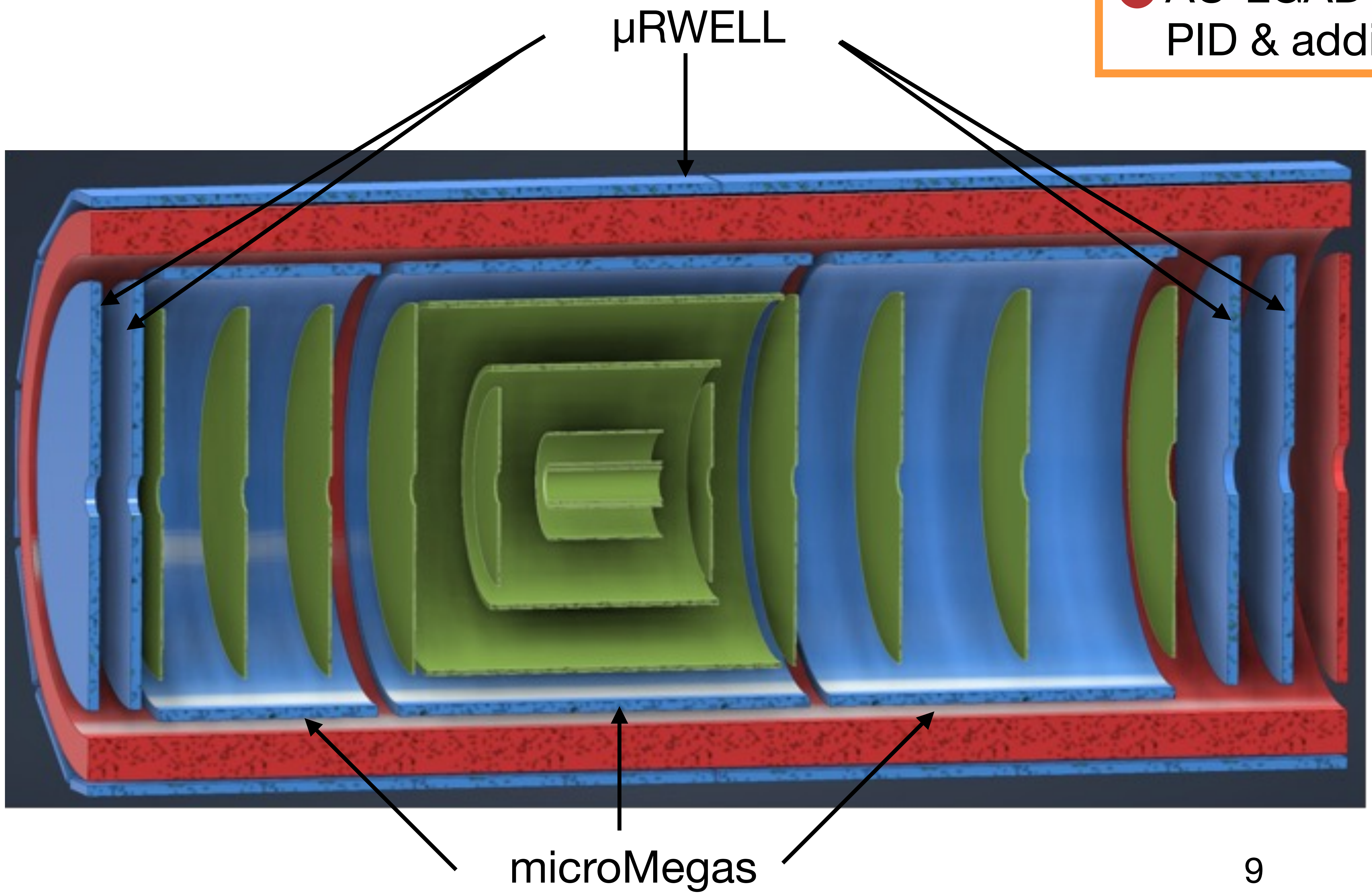

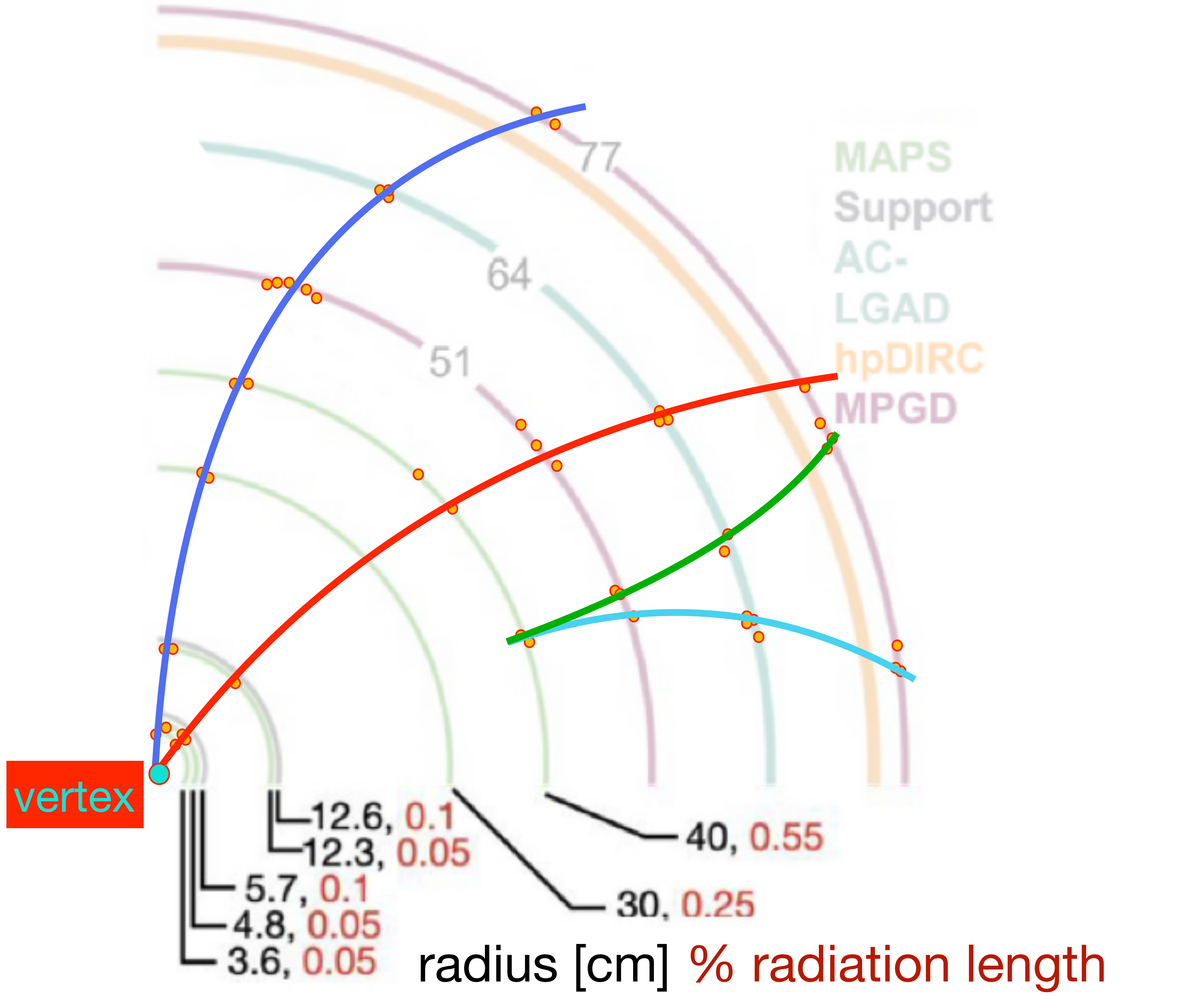

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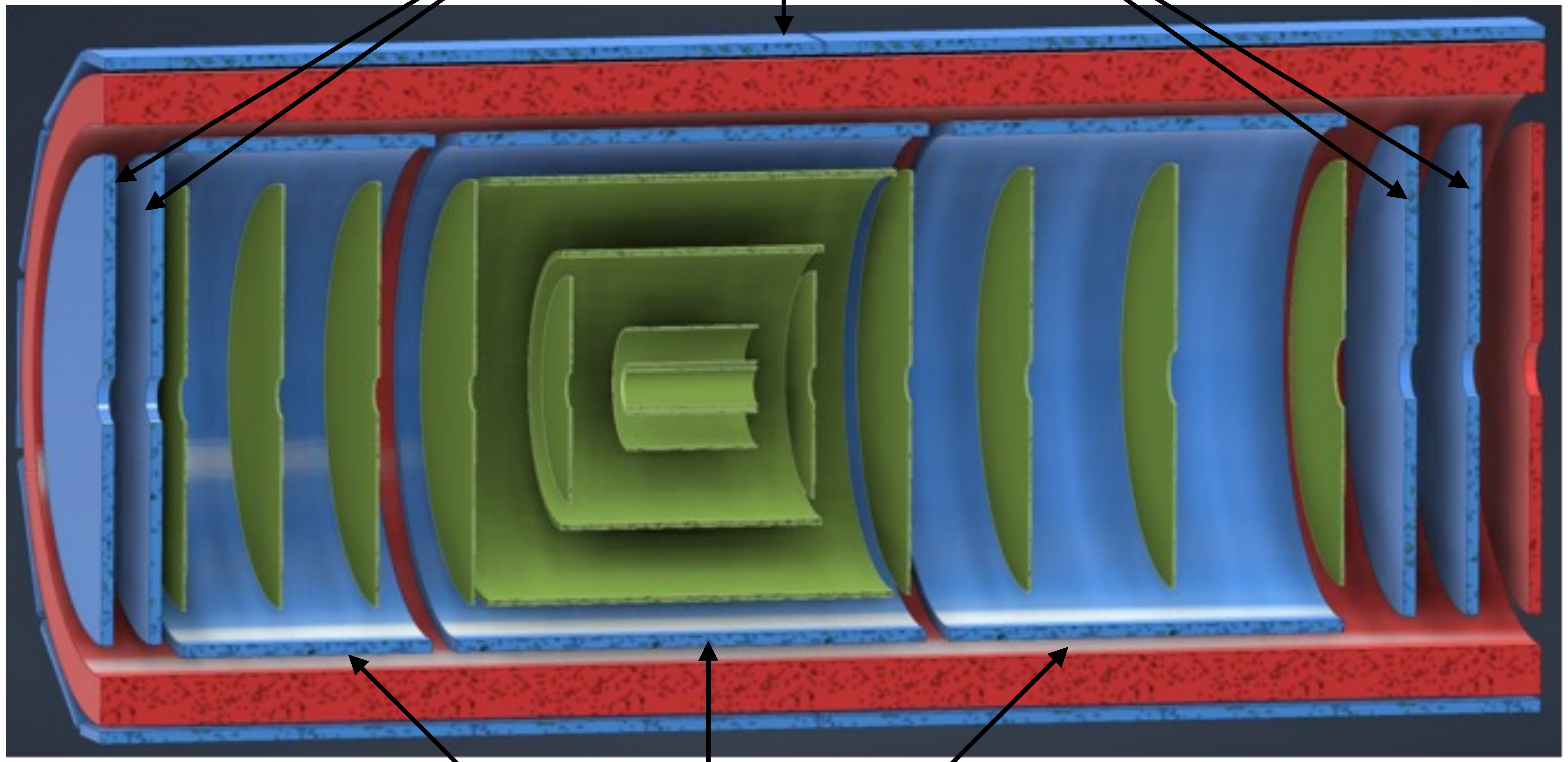
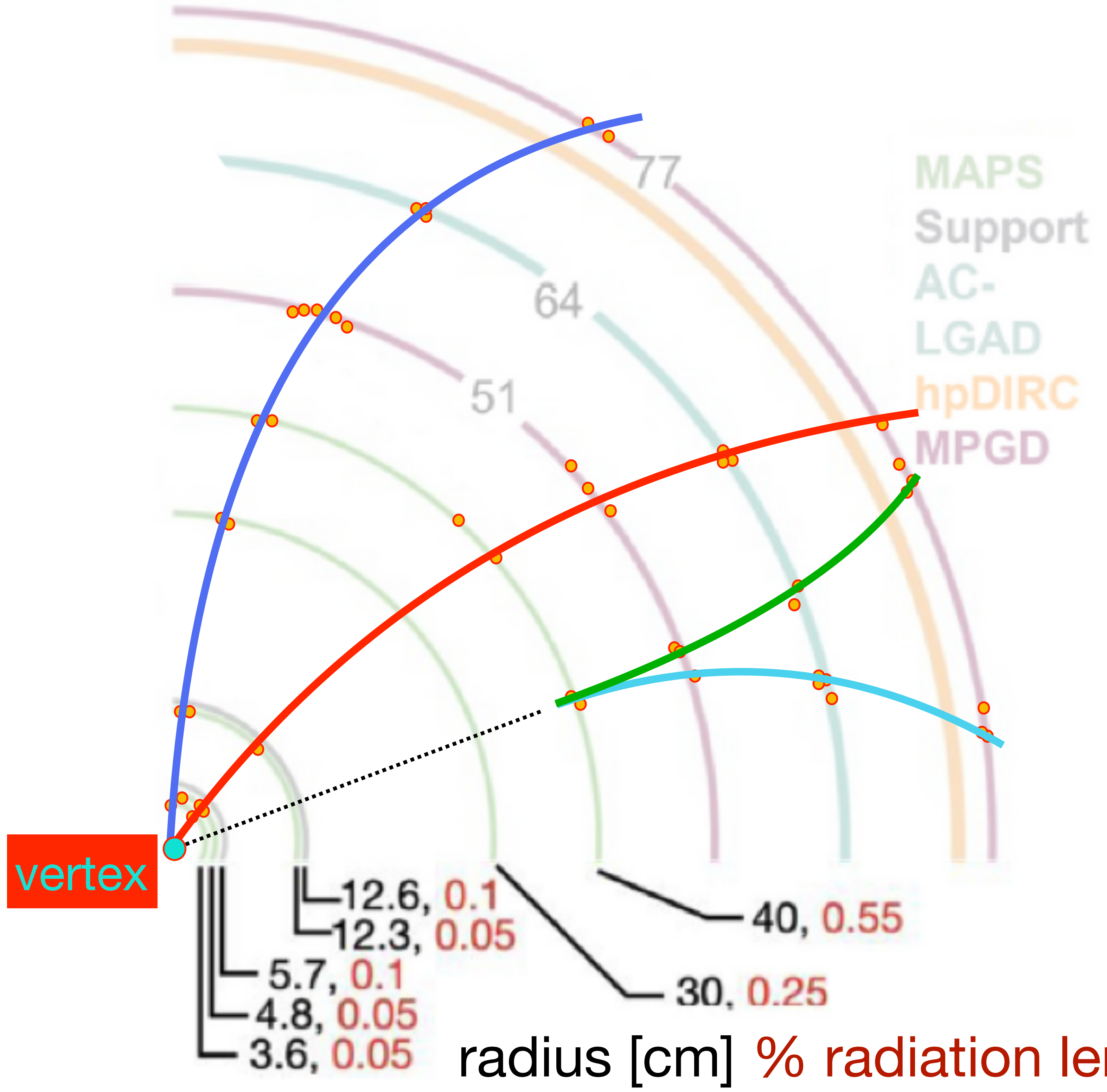
µRWELL



microMegas



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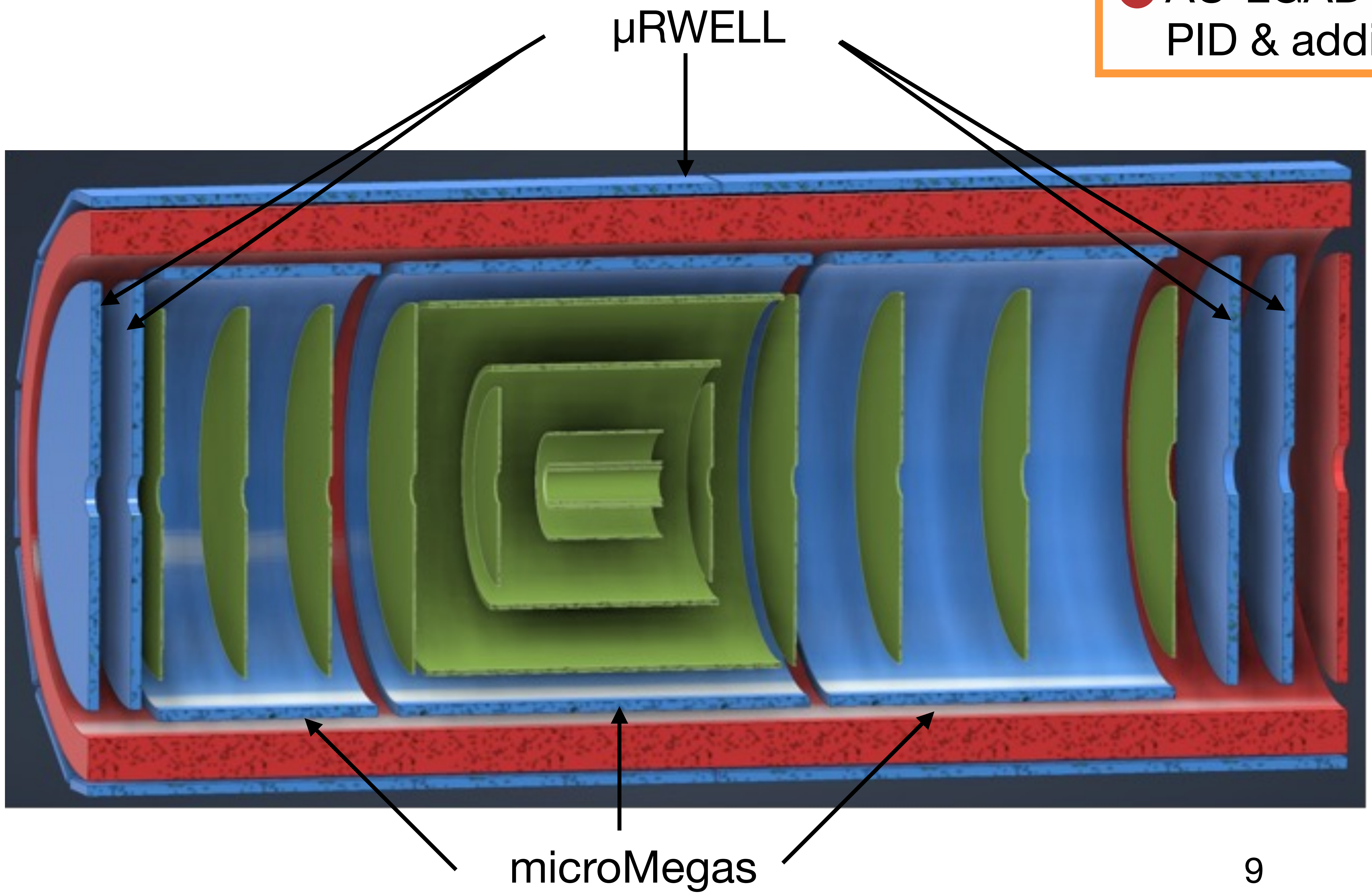

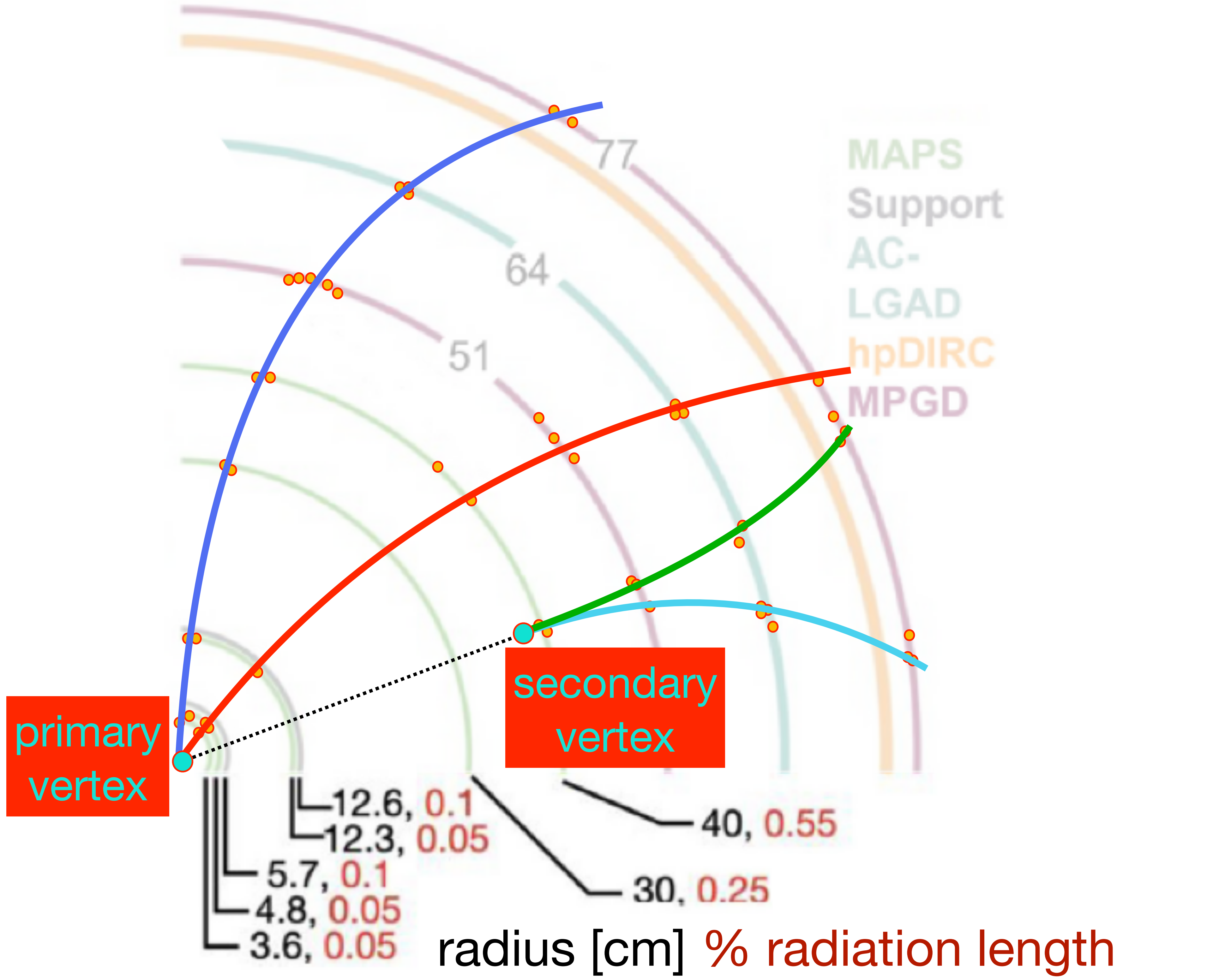

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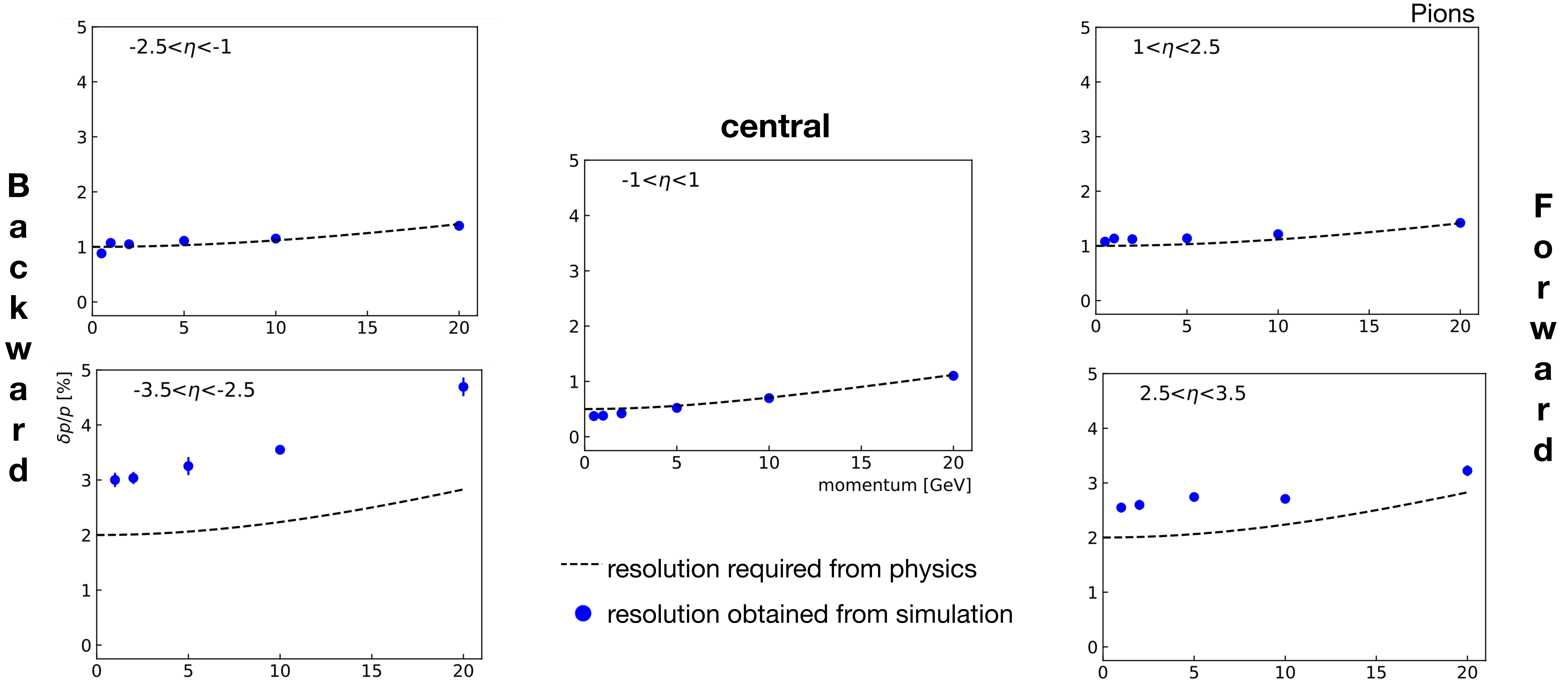
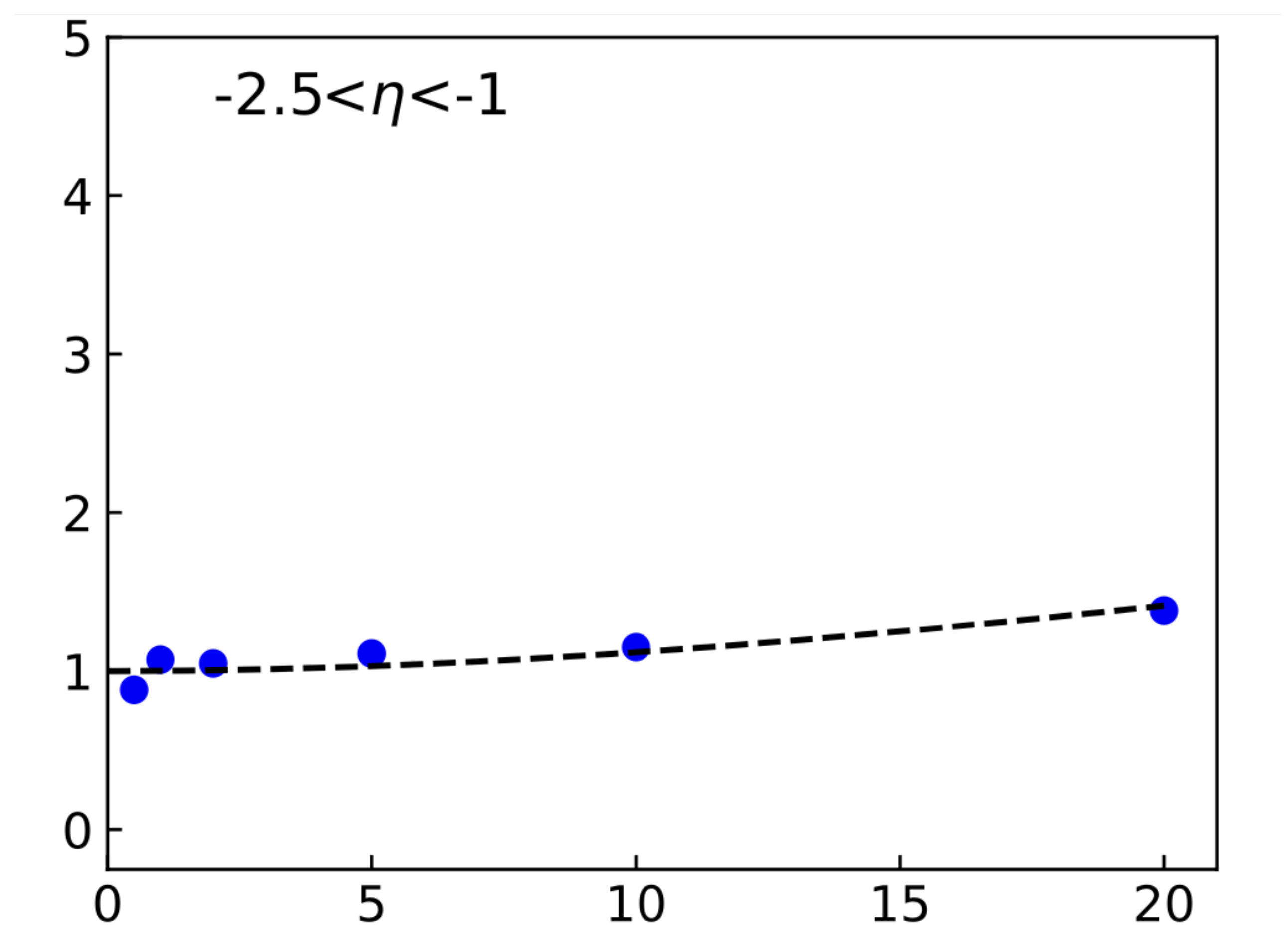
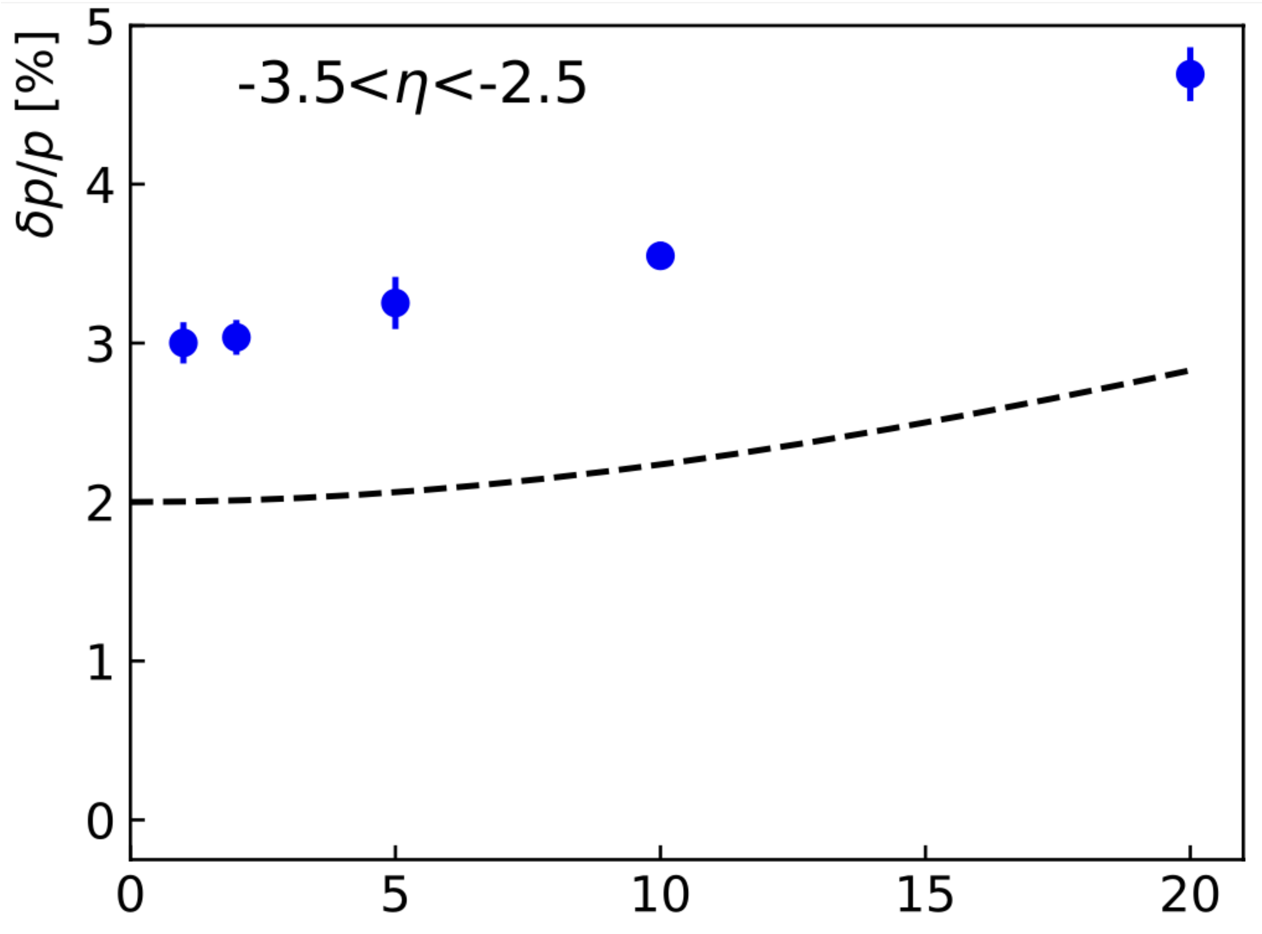
Momentum resolution



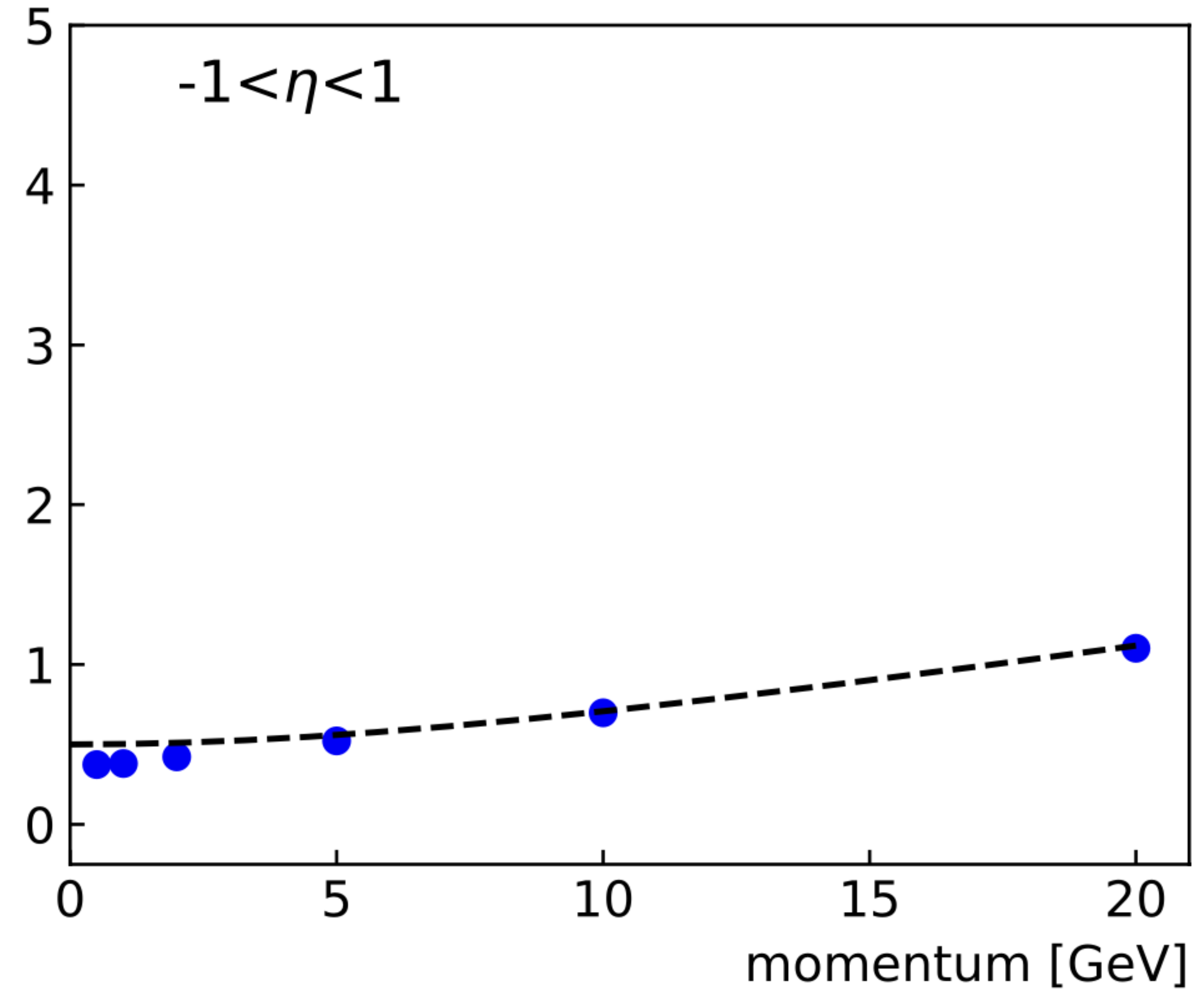
Momentum resolution

Backward



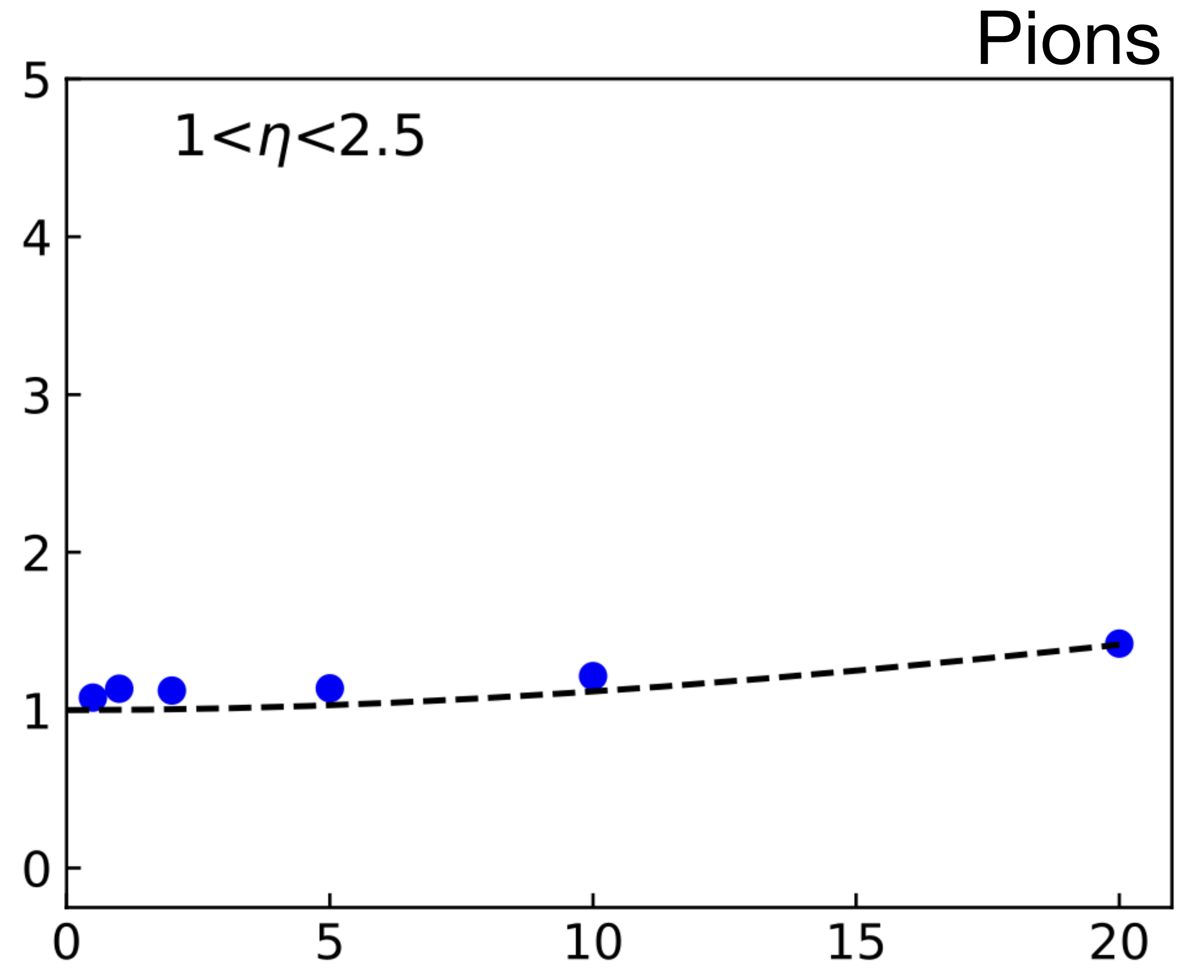


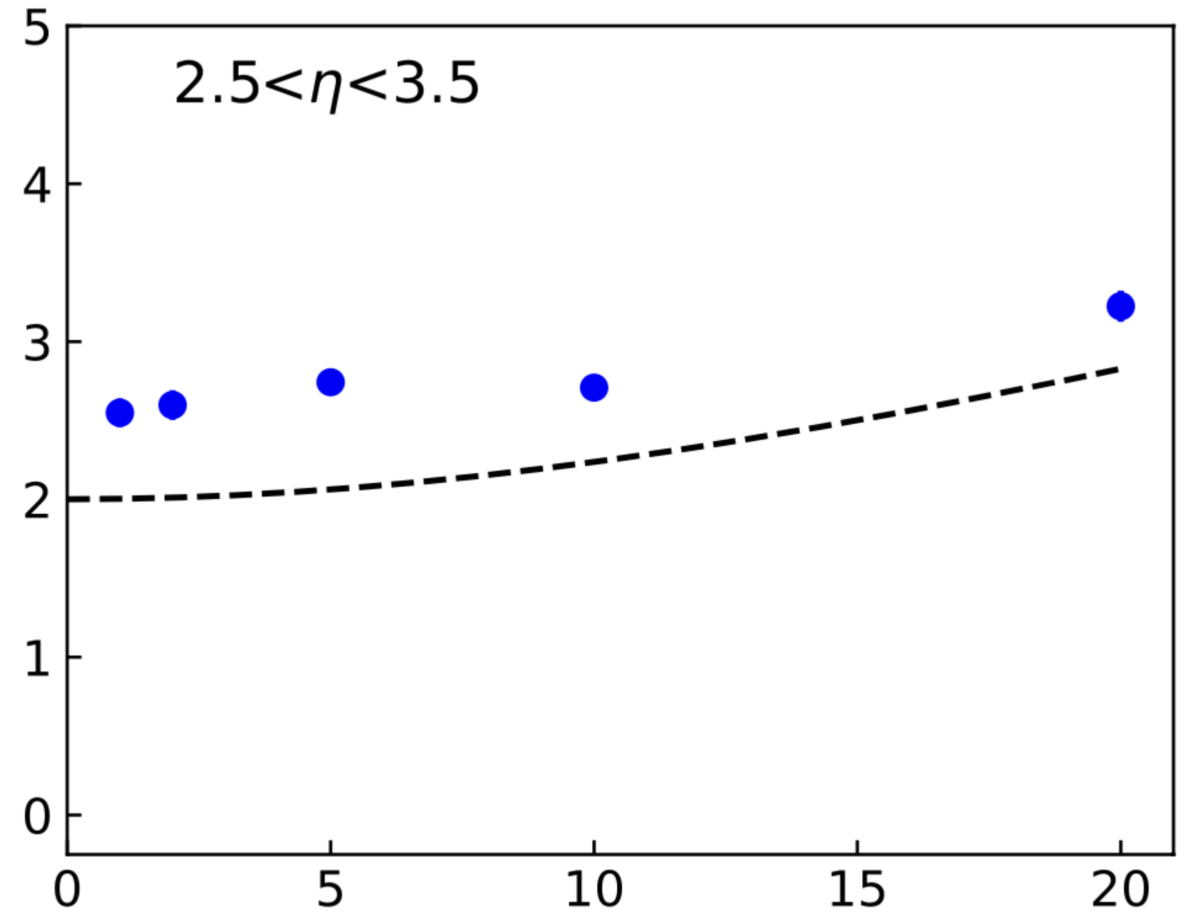
central



- - - resolution required from physics

● resolution obtained from simulation



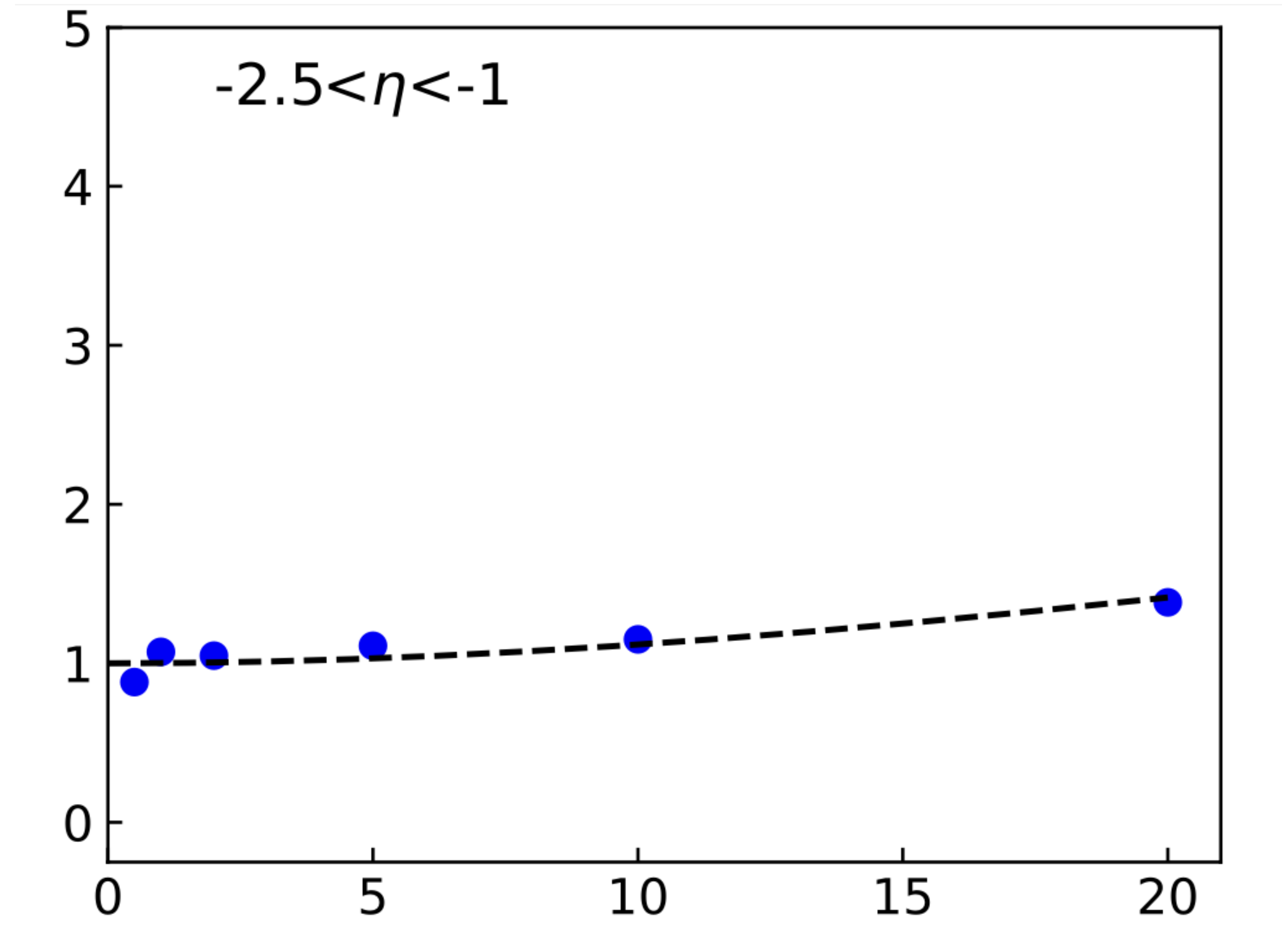


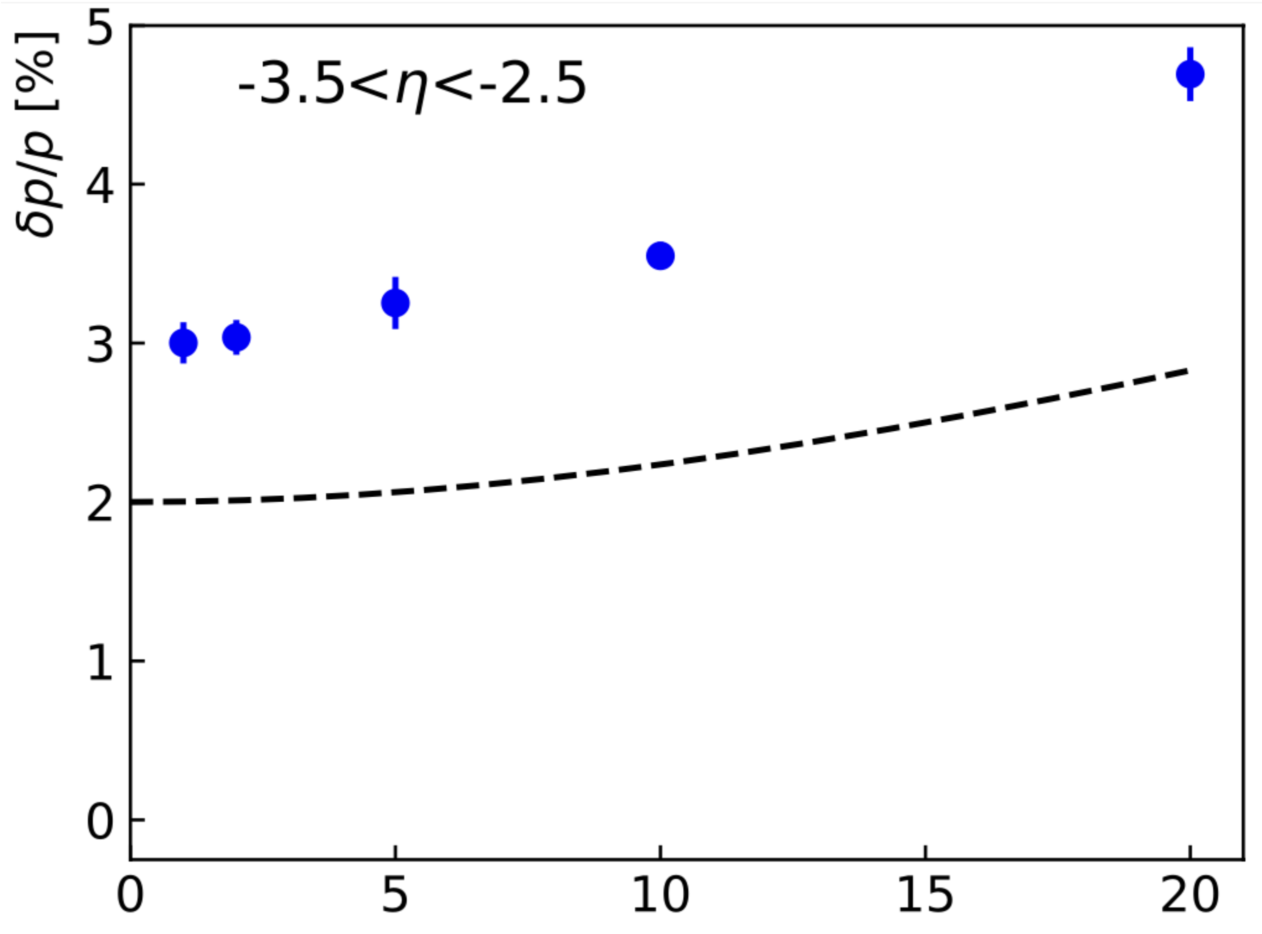
Forward

requirements met with 2 T field strength

Momentum resolution

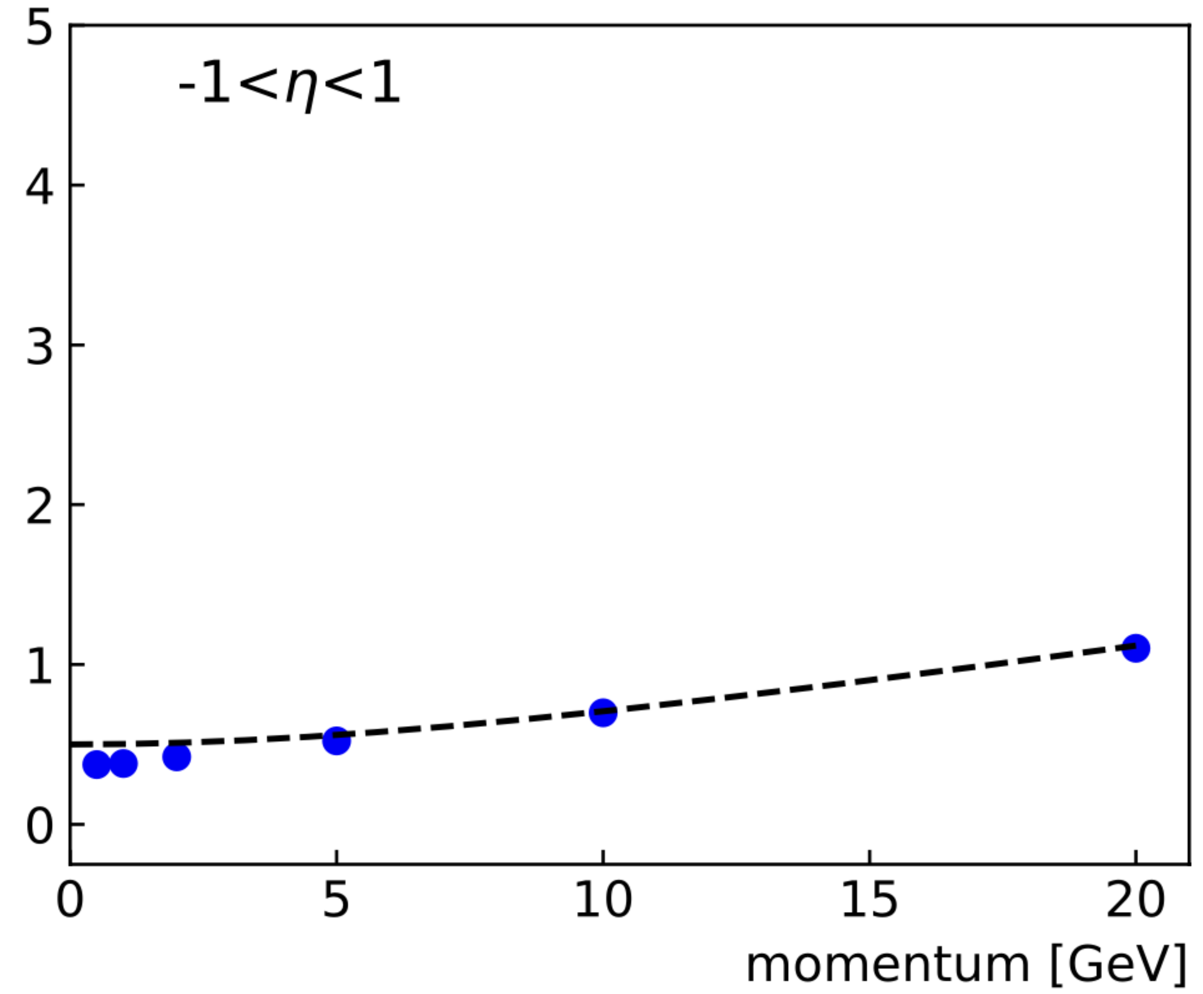
Backward





complemented with
electromagnetic calorimeter

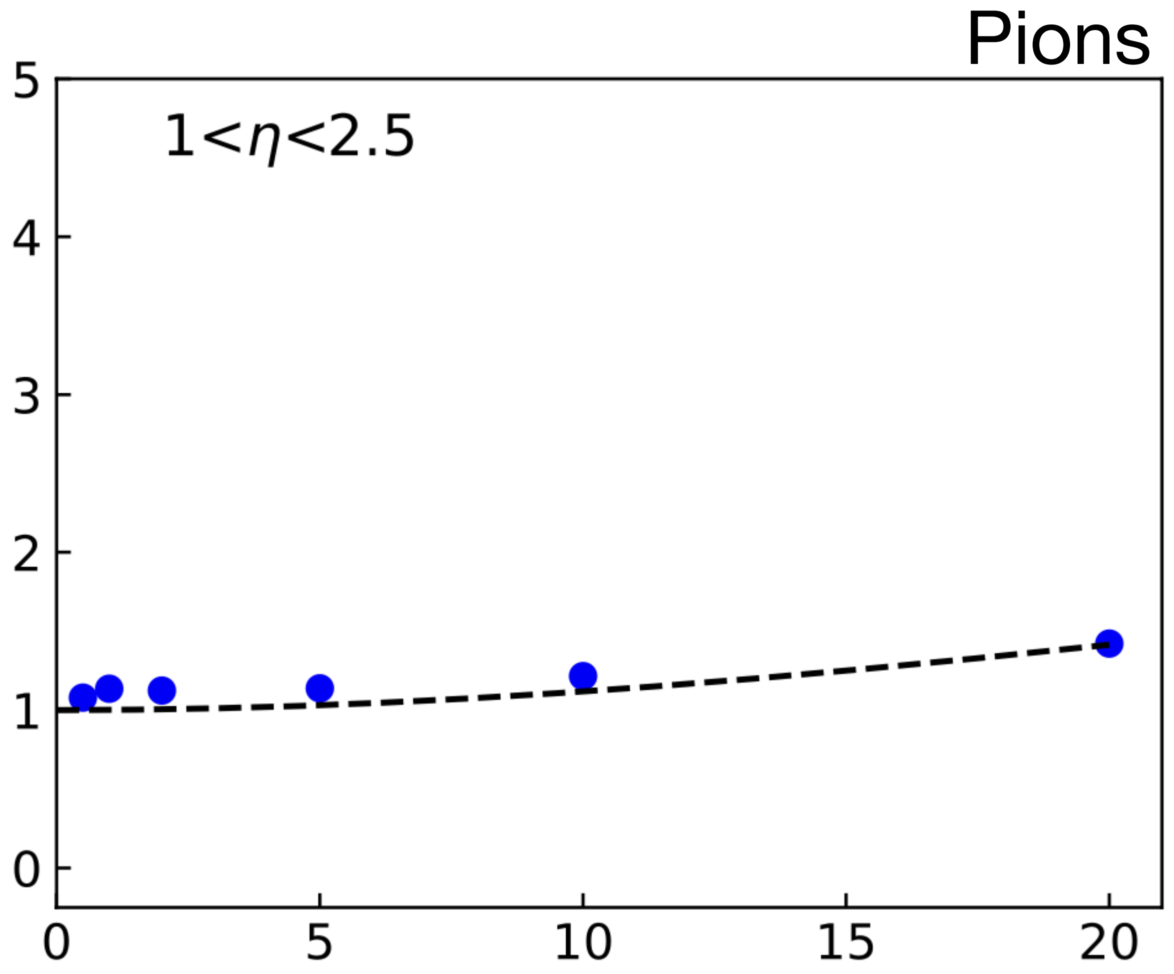
central

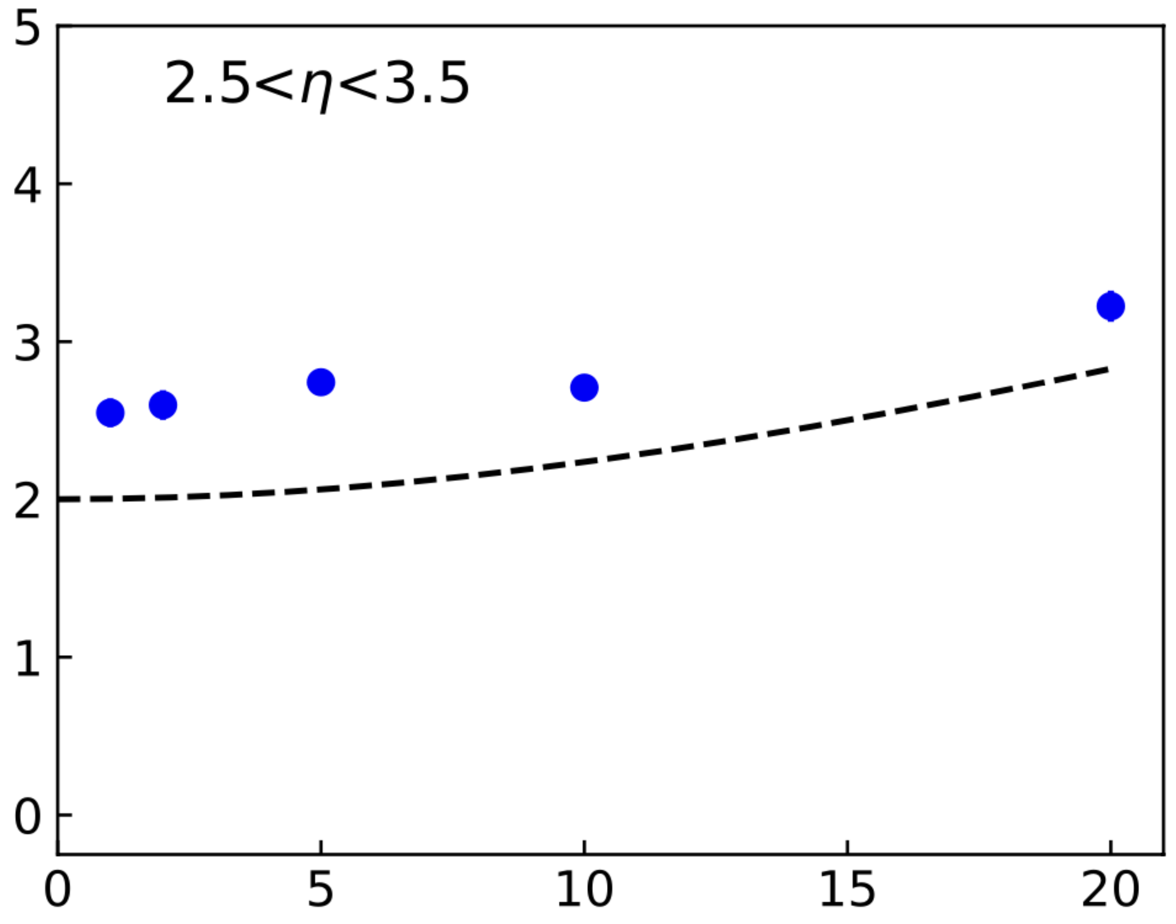


resolution required from physics

resolution obtained from simulation

Forward

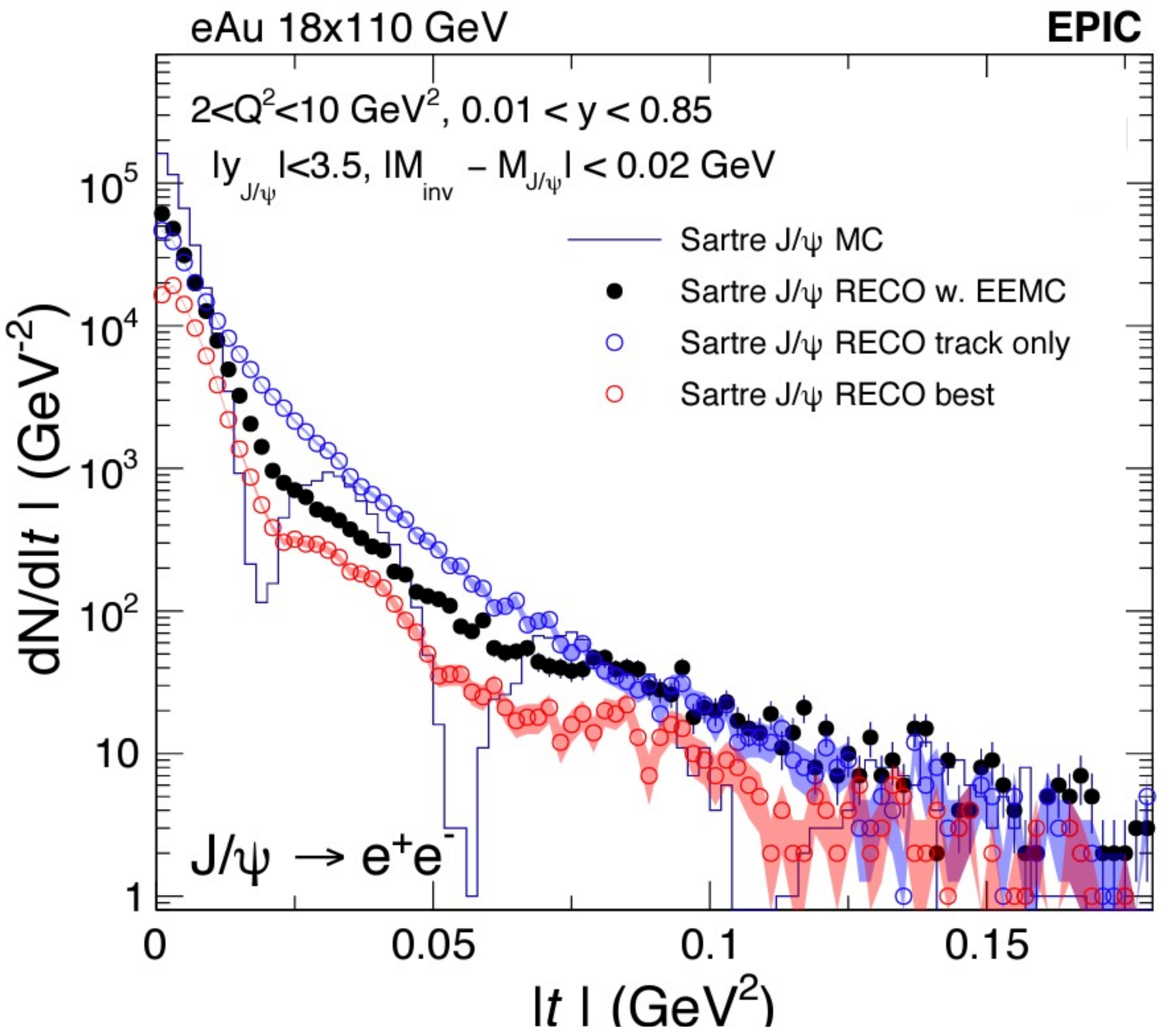




requirements met with
2 T field strength

Track reconstruction in the backward region: illustration

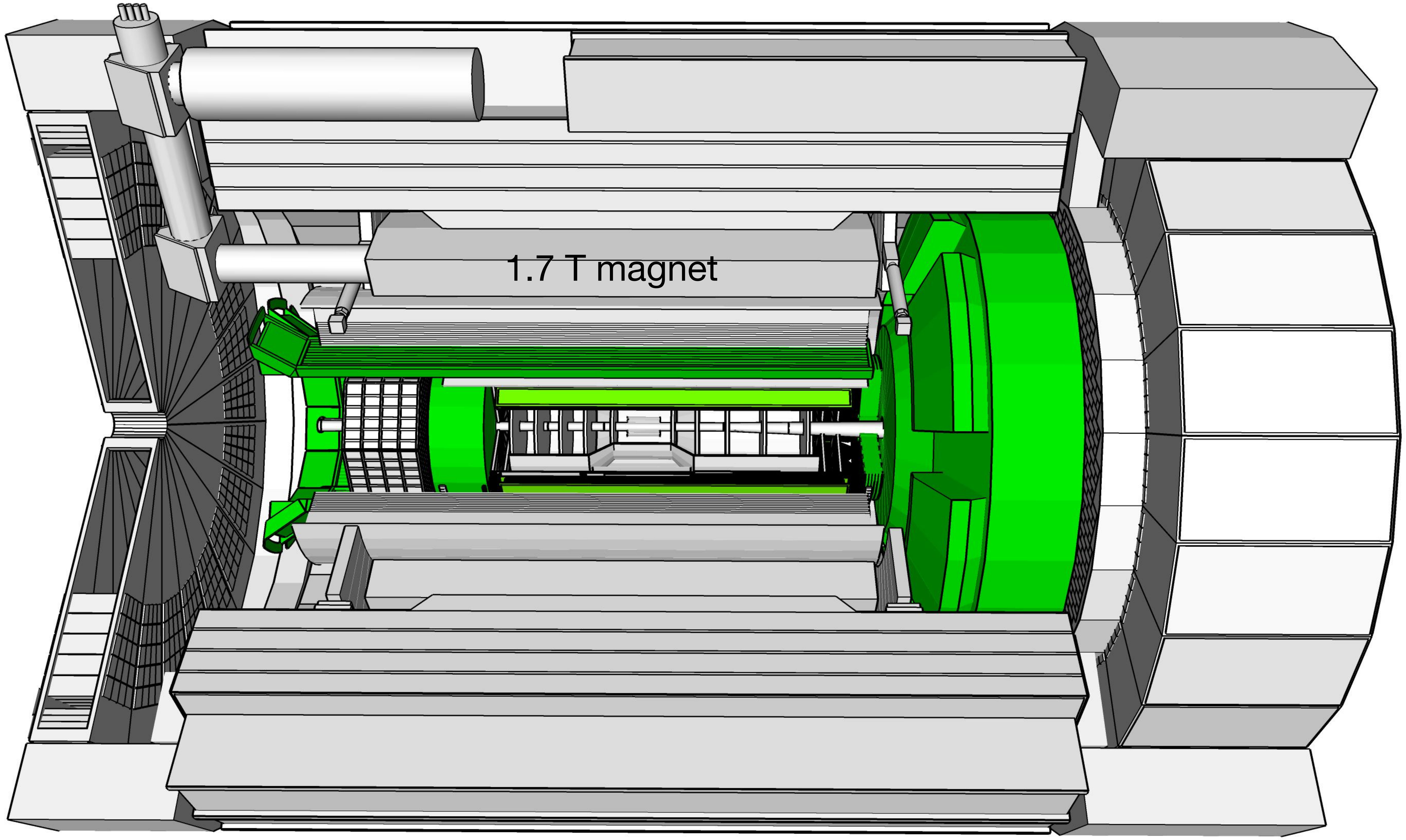
$$e + \text{Au} \rightarrow e + \text{Au} + J/\psi$$



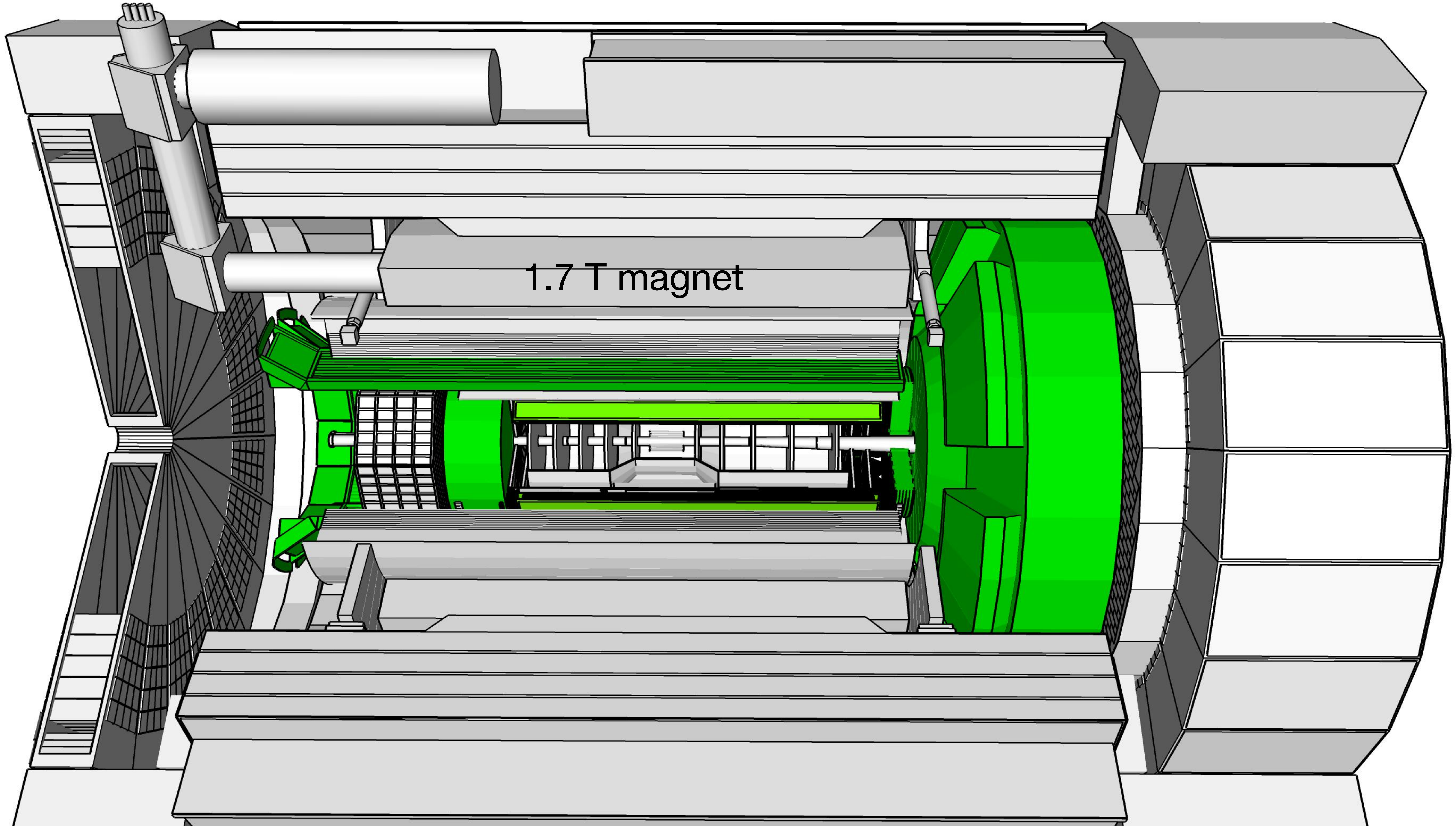
Reconstruction of scattered e^- in the backward region by the tracking system and the EM calorimeter

K. Tu, DIS 2023

Particle identification

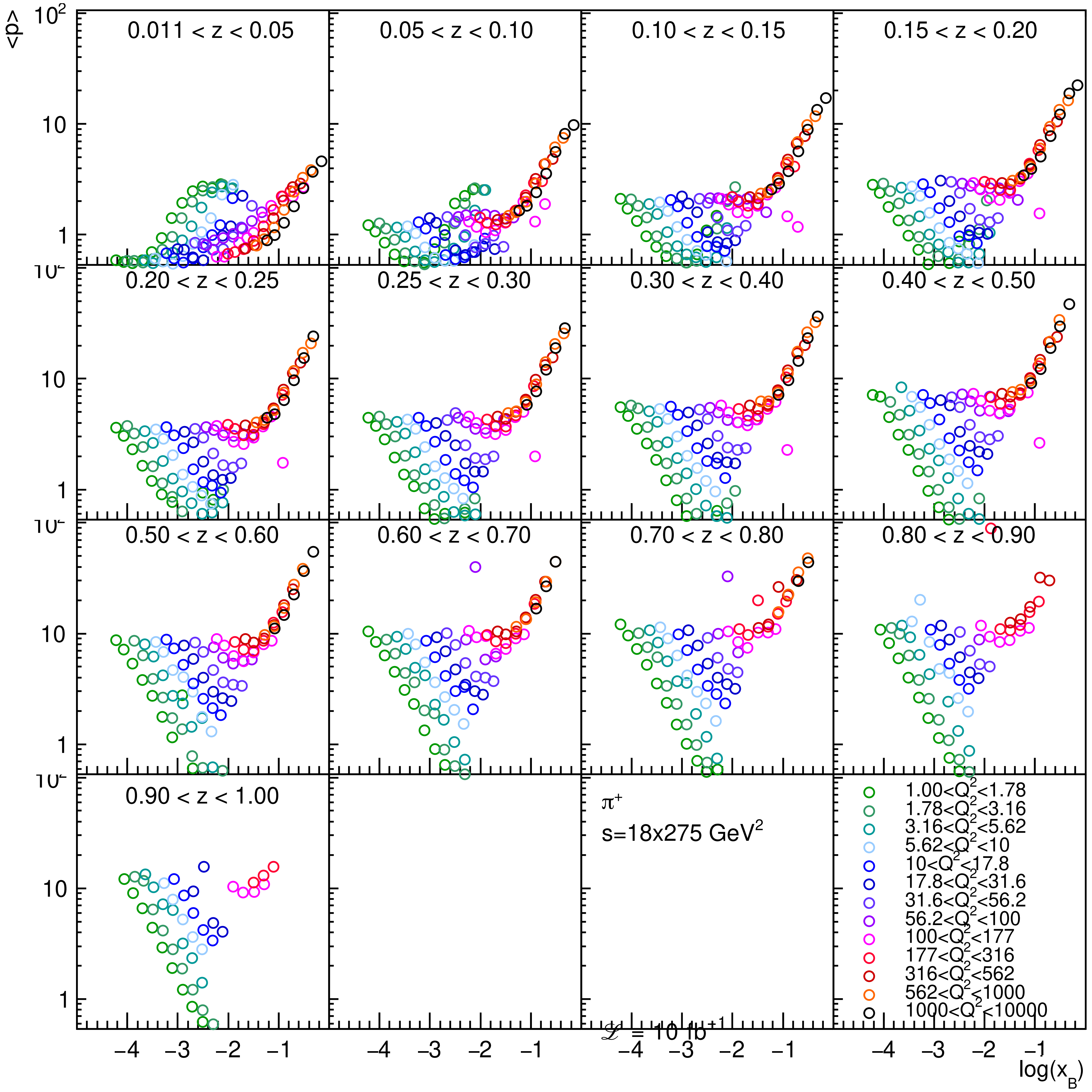


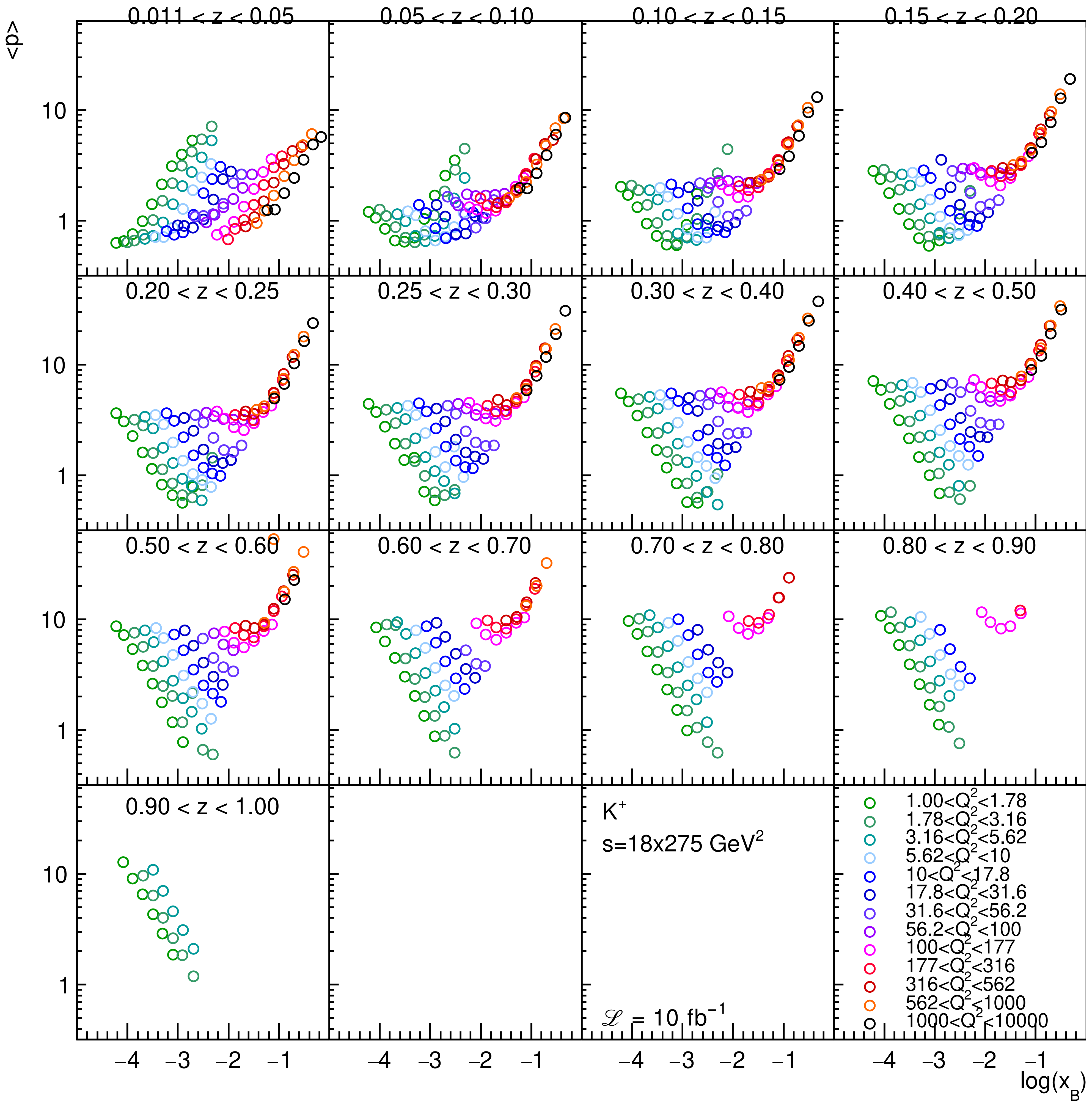
Particle identification



1. Support electromagnetic calorimeters in providing $e^{\pm}/\pi^{\pm}$ separation: suppress $\pi^{\pm}$ contamination down to 10^{-4}
2. Provide hadron identification (π, K, p) over a wide rapidity and momentum range

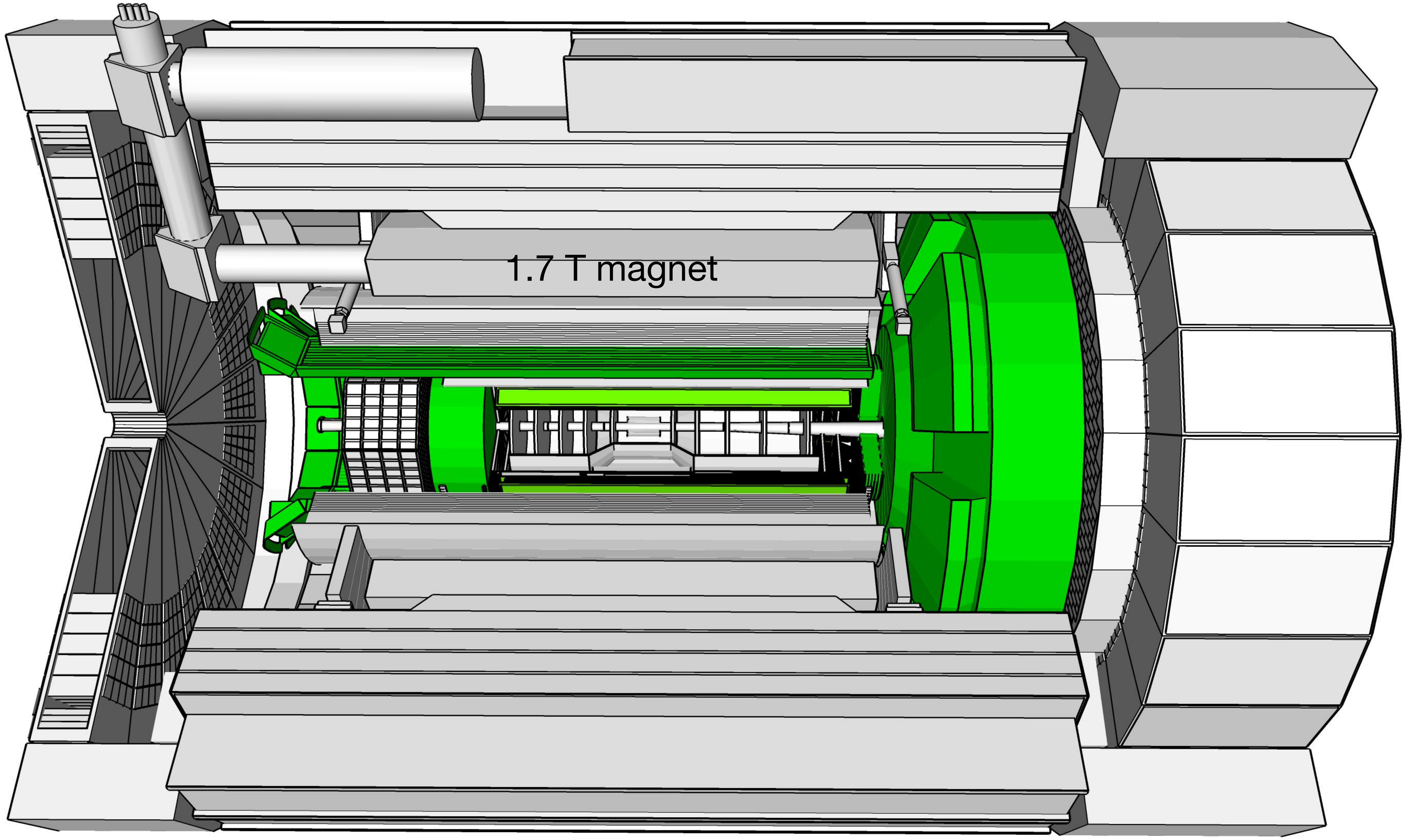
Kinematic coverage and hadron momentum reach



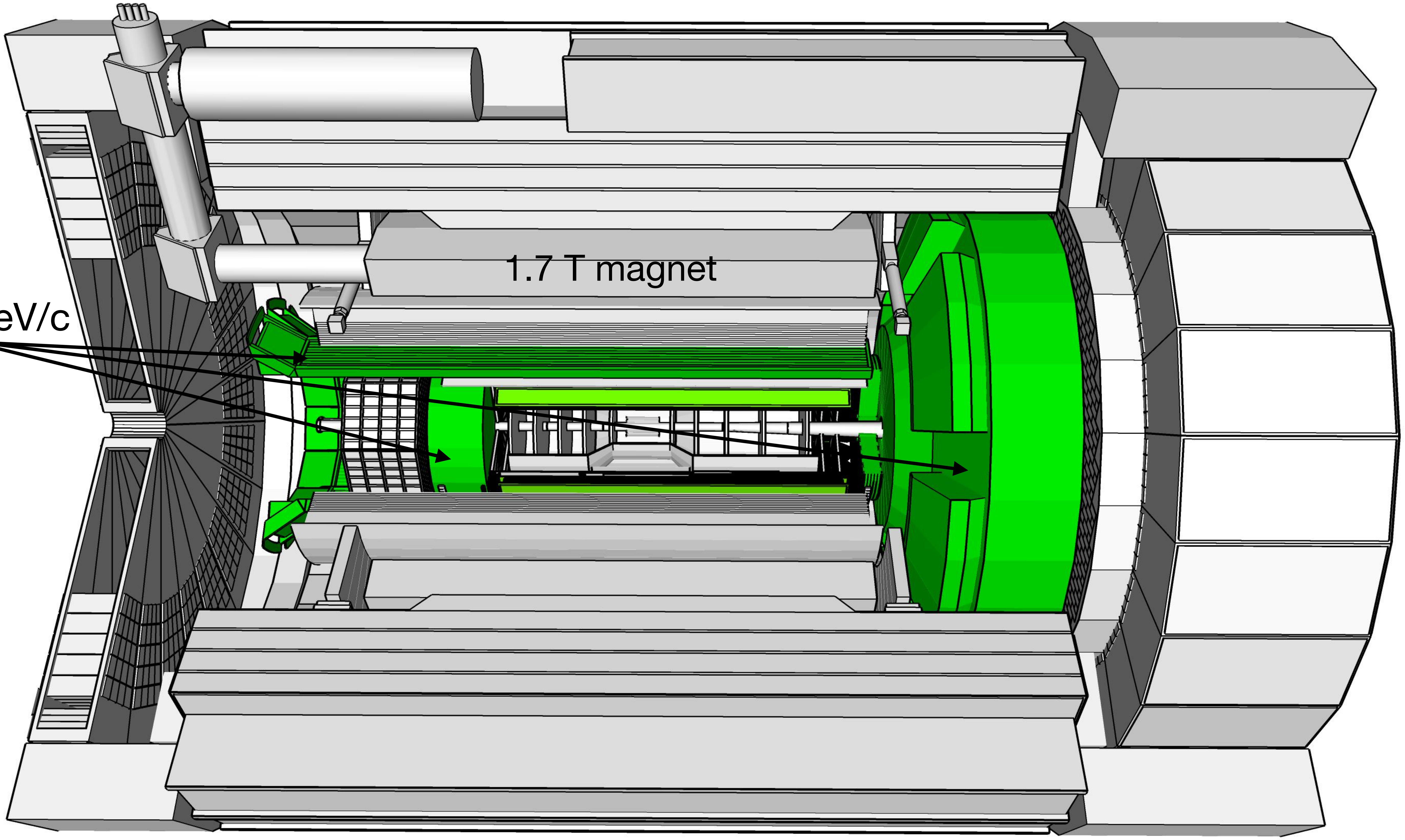


studies for semi-inclusive DIS

Particle identification

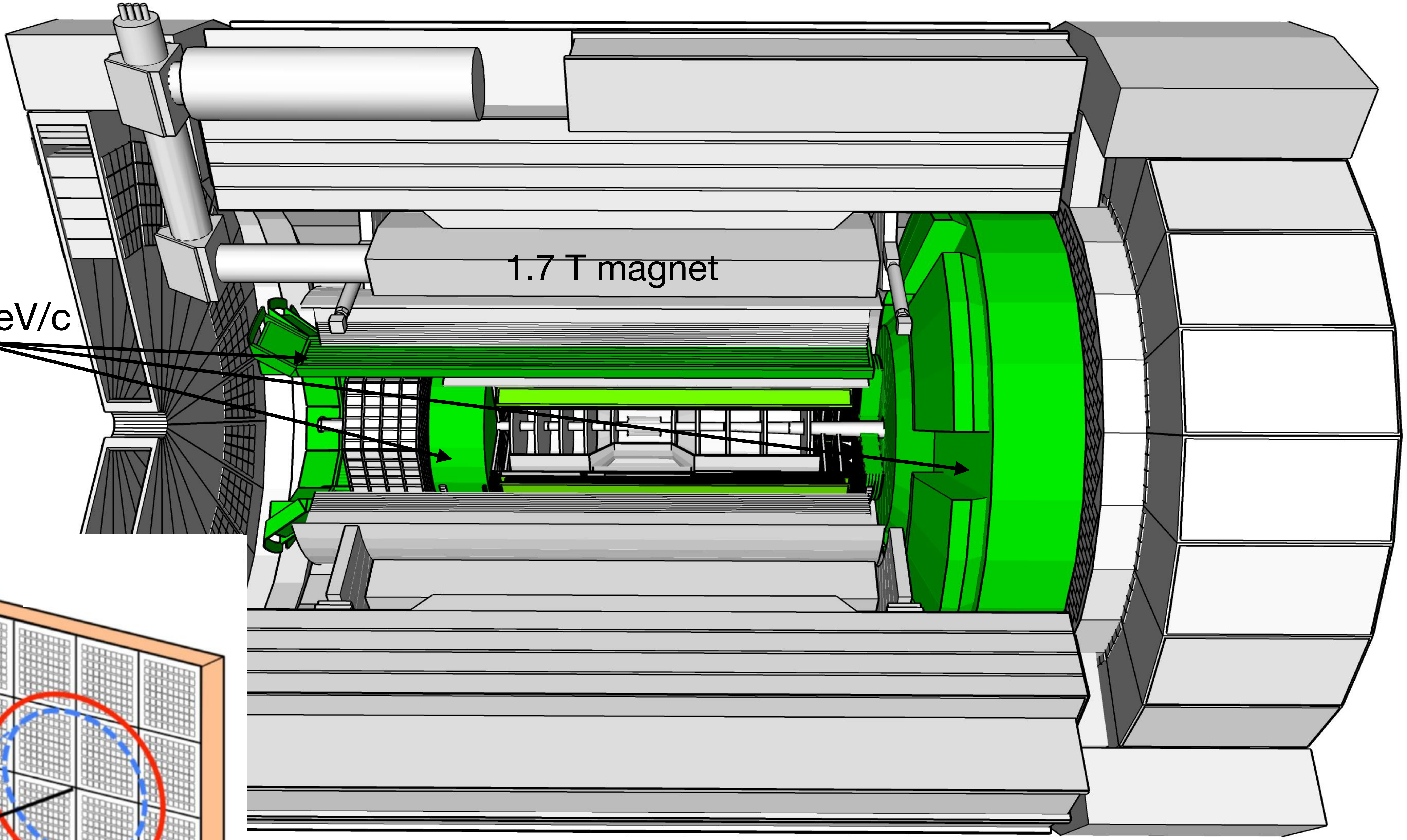


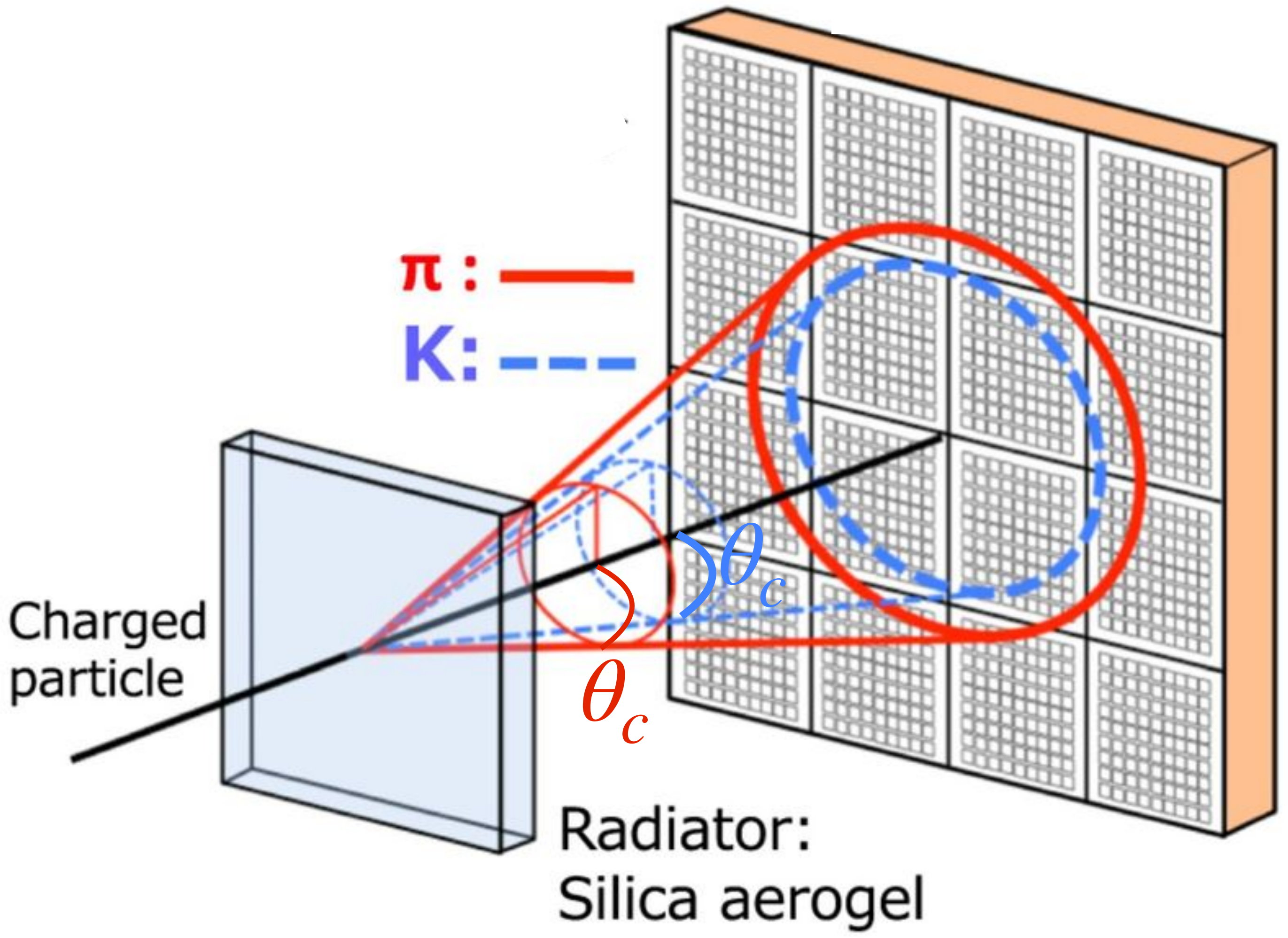
Particle identification



Particle identification

detectors based on Cherenkov radiation for 1 GeV/c<p<50 GeV/c

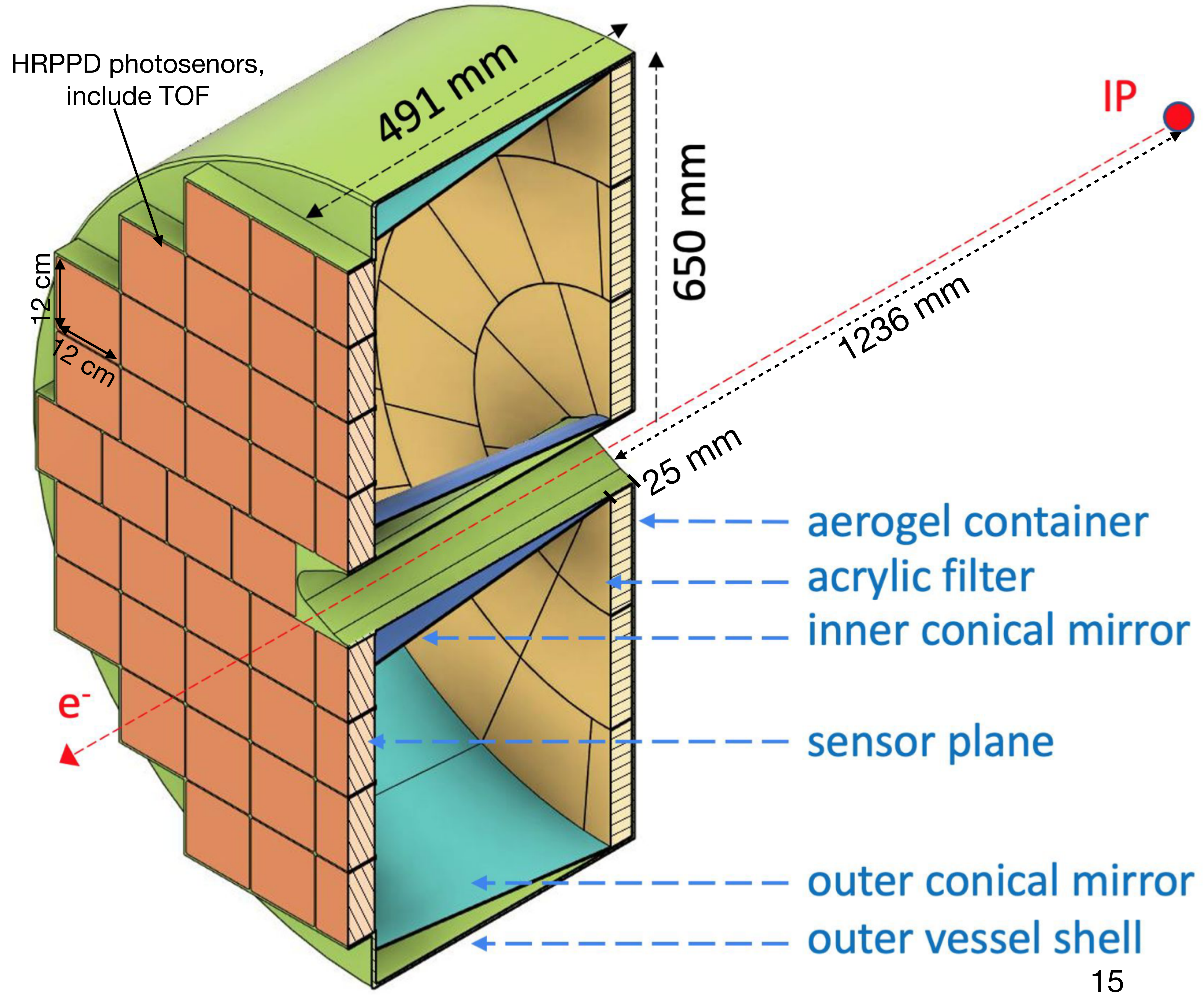


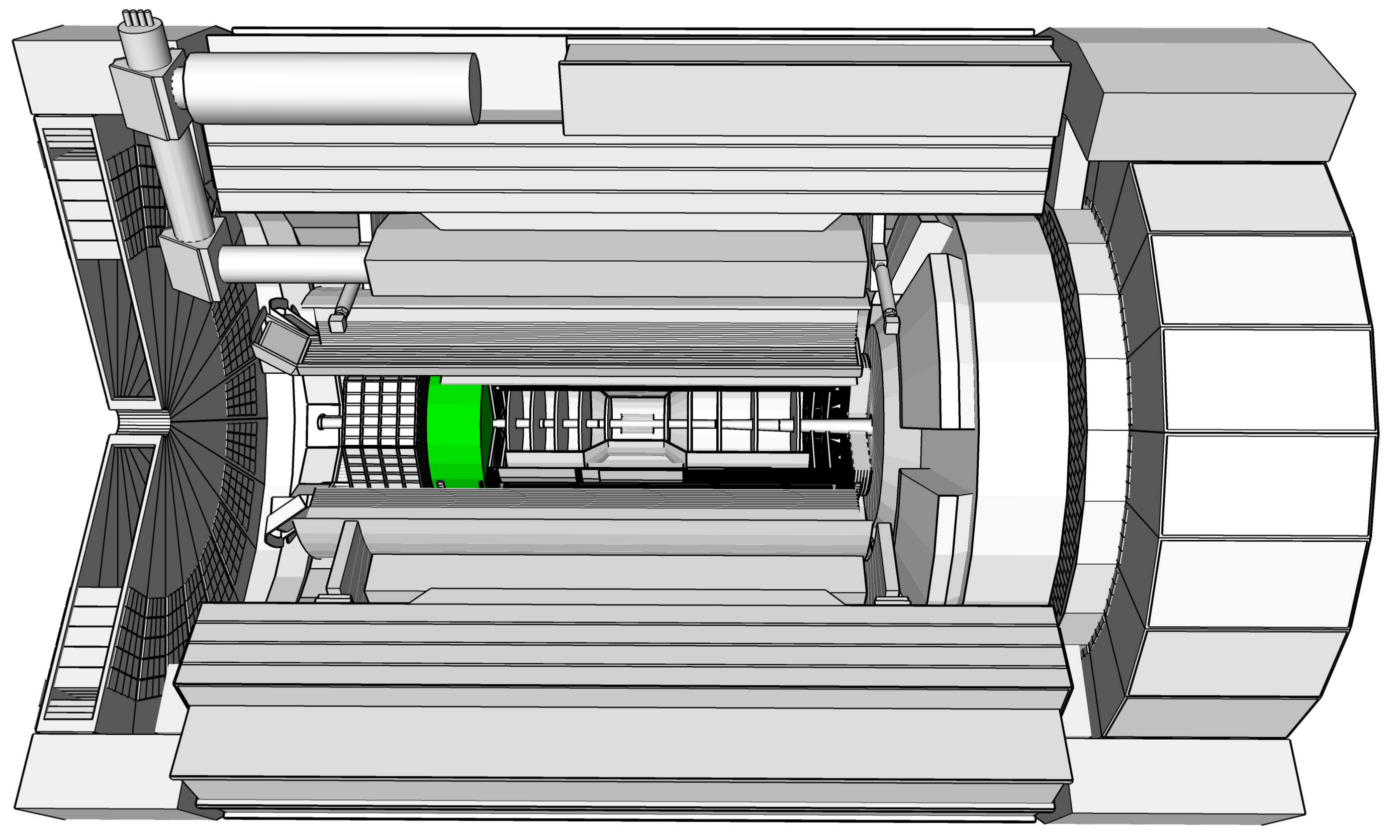


$$\cos\theta_c \propto \frac{1}{v}$$

Particle identification – Cherenkov: backward

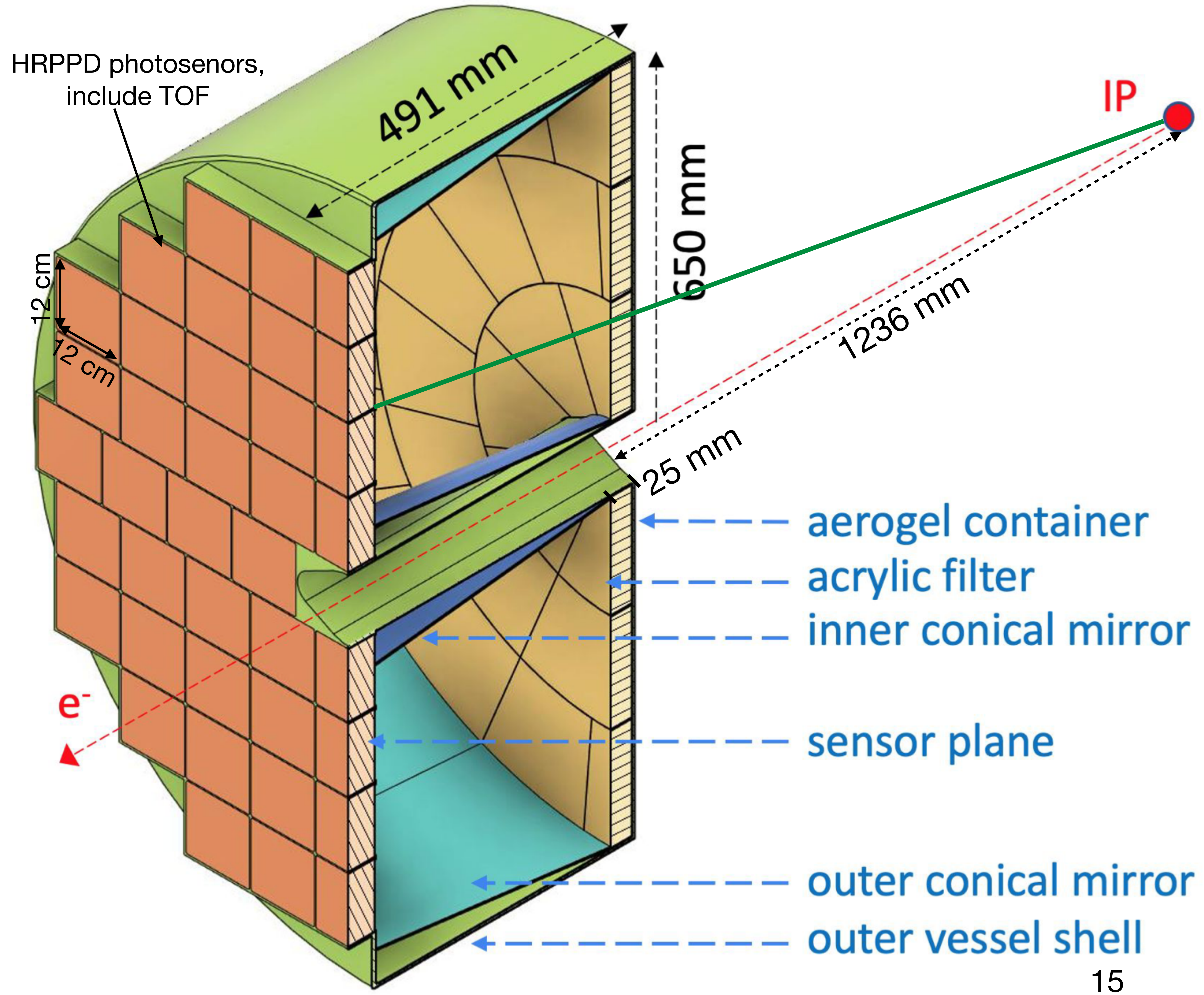
Proximity focussing ring-imaging Cherenkov detector (RICH)

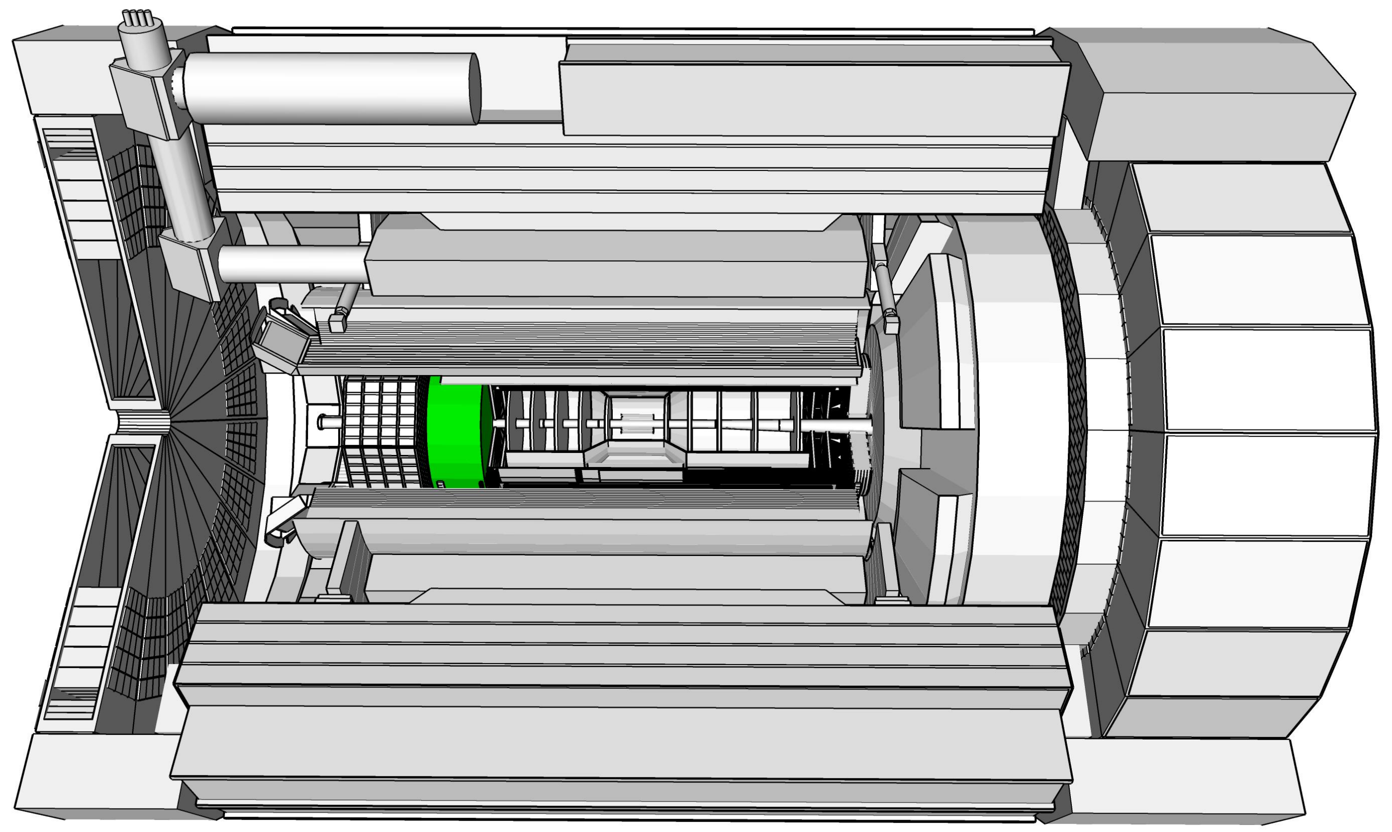




Particle identification – Cherenkov: backward

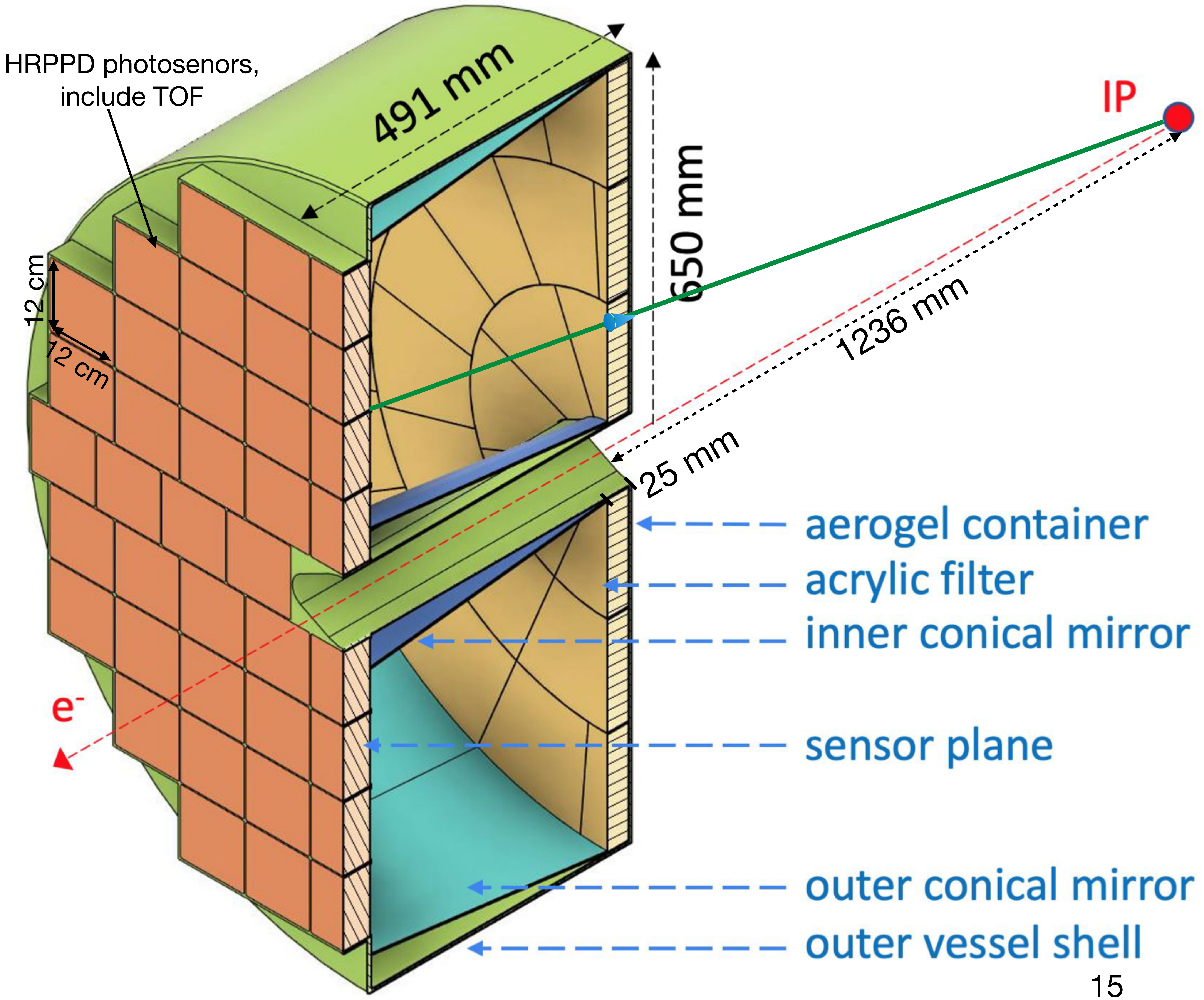
Proximity focussing ring-imaging Cherenkov detector (RICH)

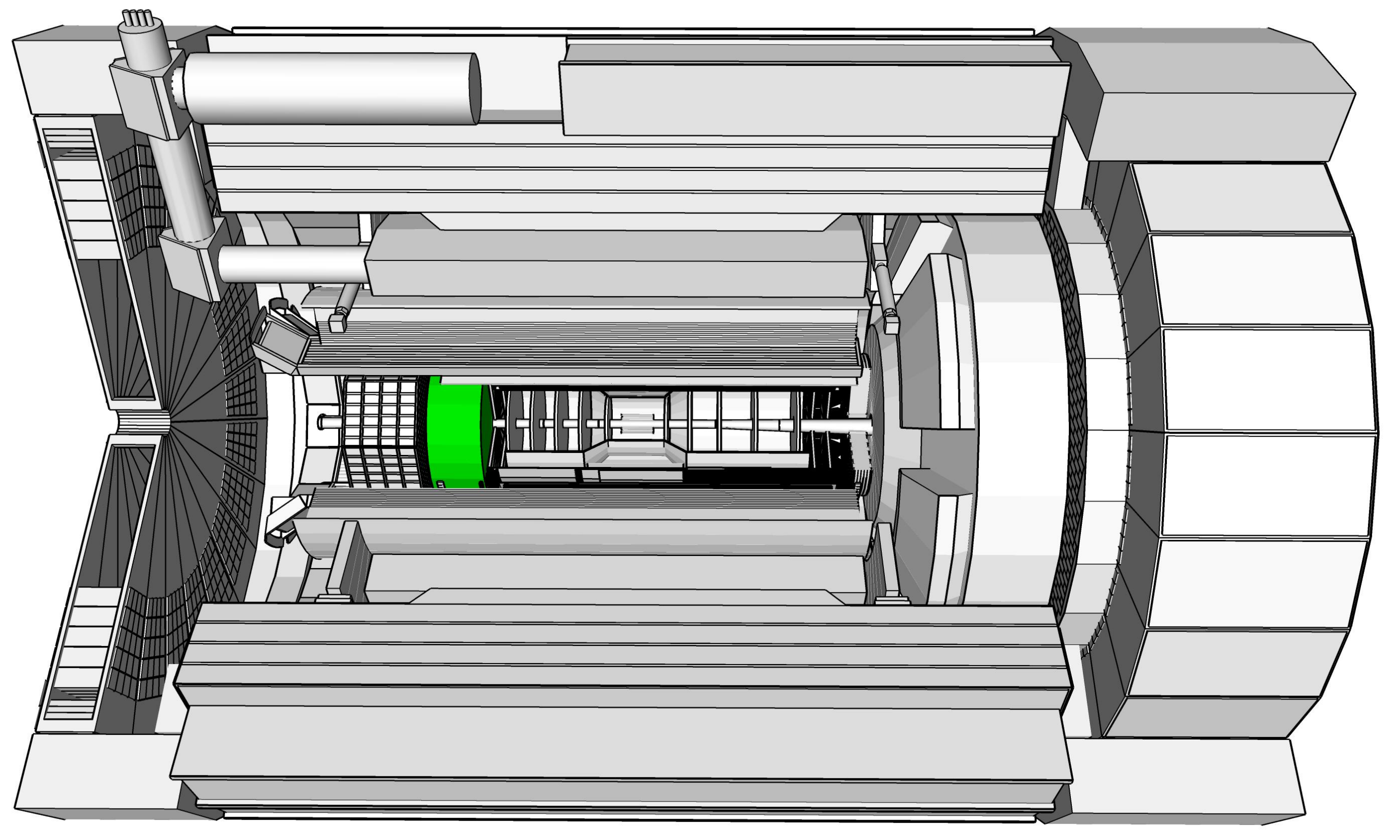




Particle identification – Cherenkov: backward

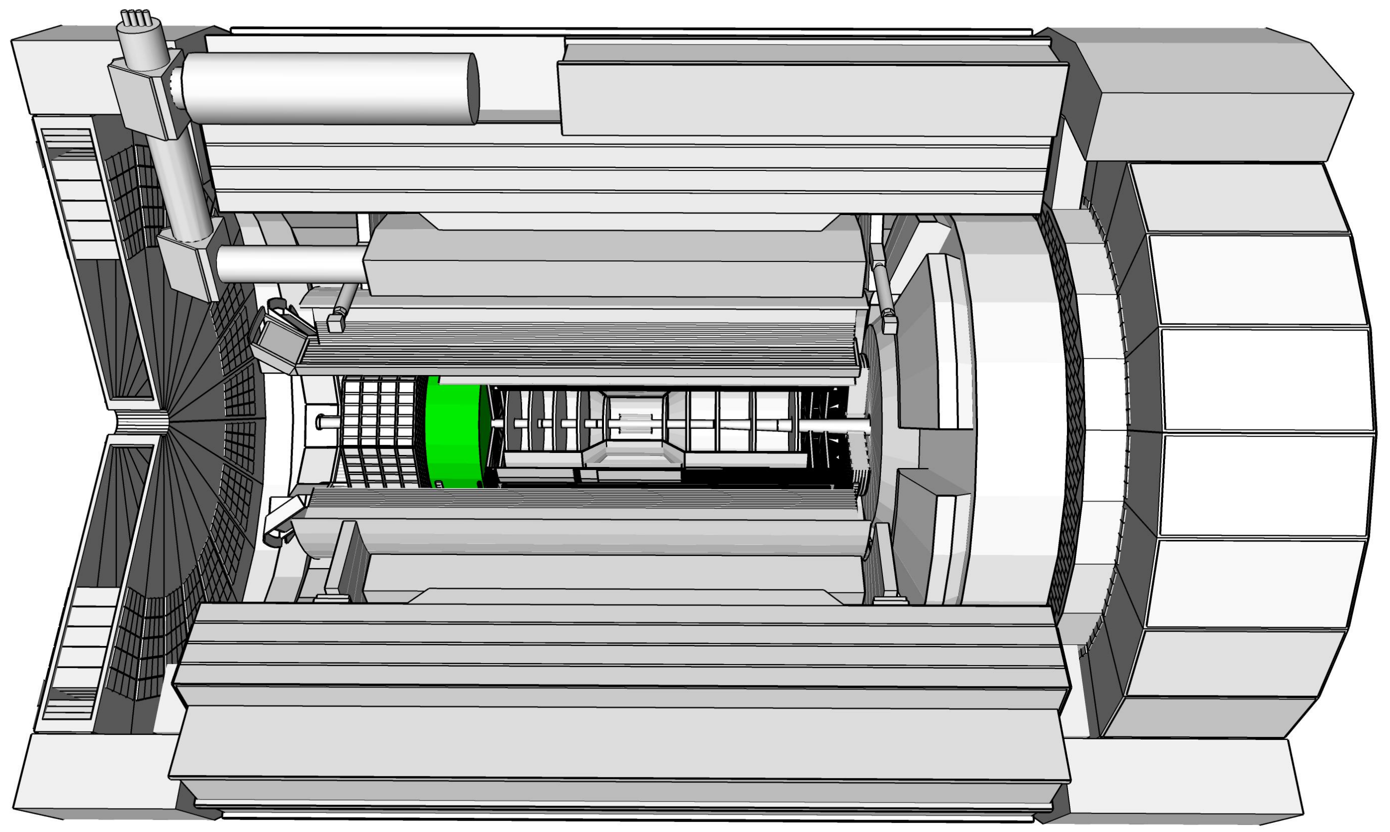
Proximity focussing ring-imaging Cherenkov detector (RICH)

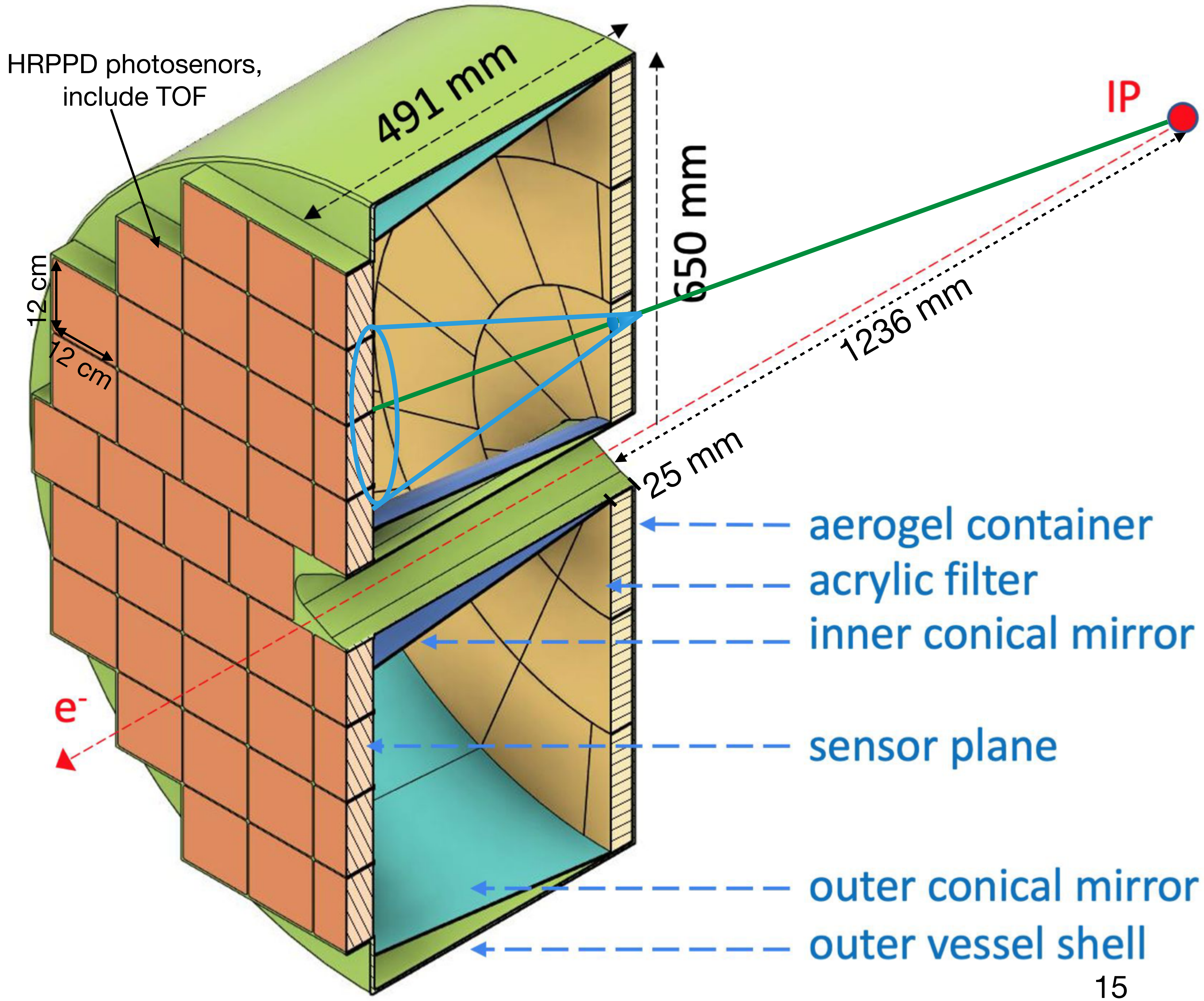




Particle identification – Cherenkov: backward

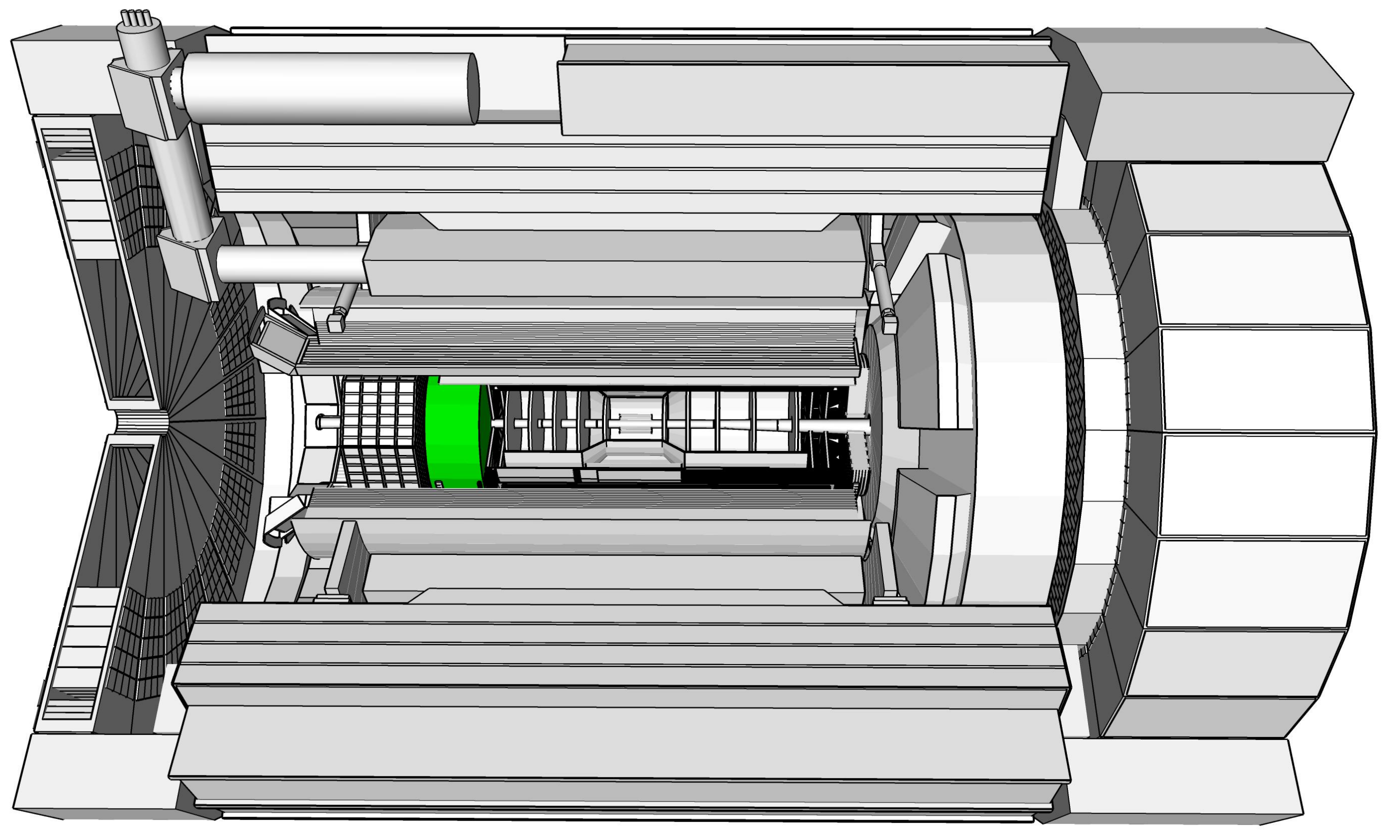
Proximity focussing ring-imaging Cherenkov detector (RICH)

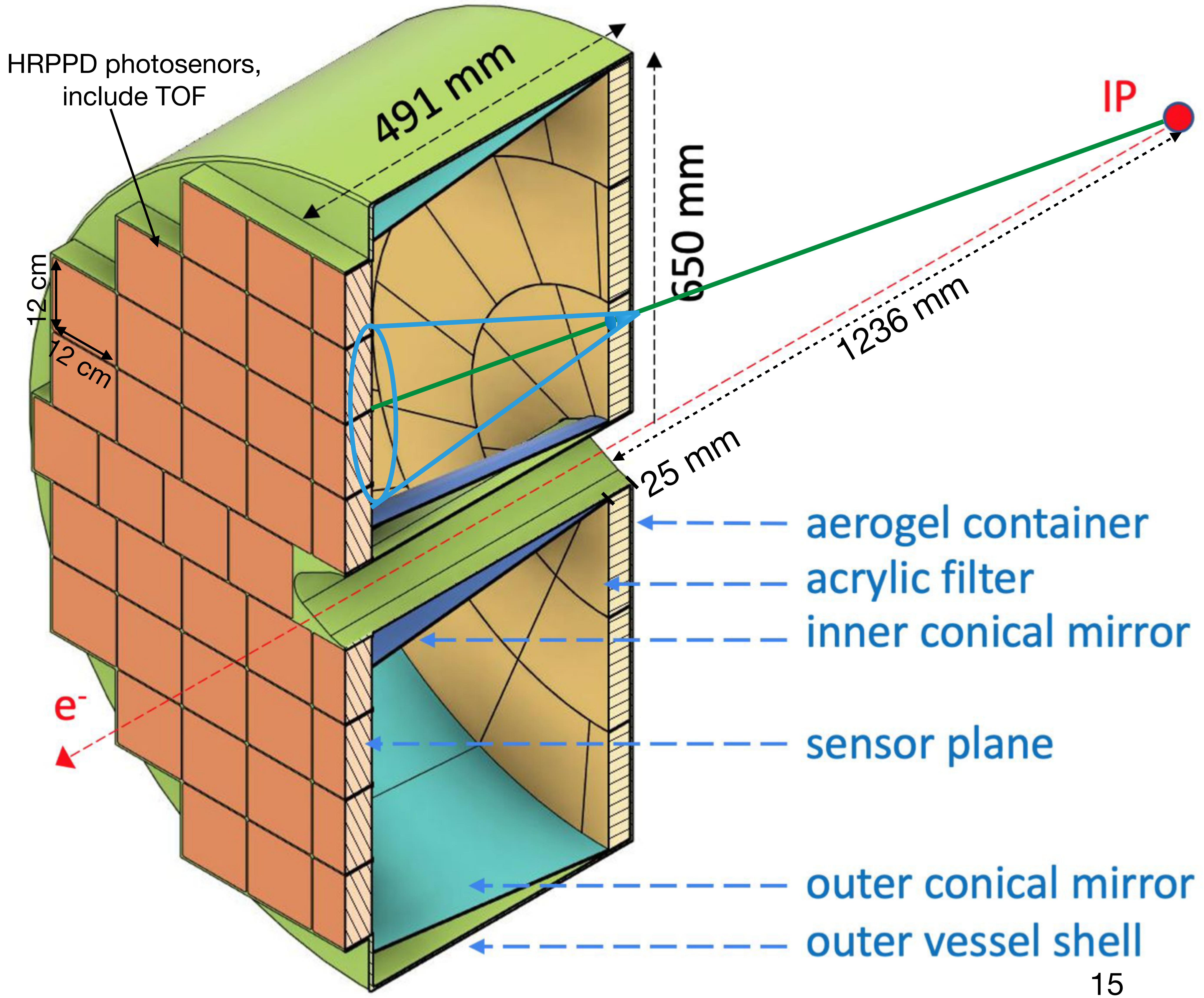


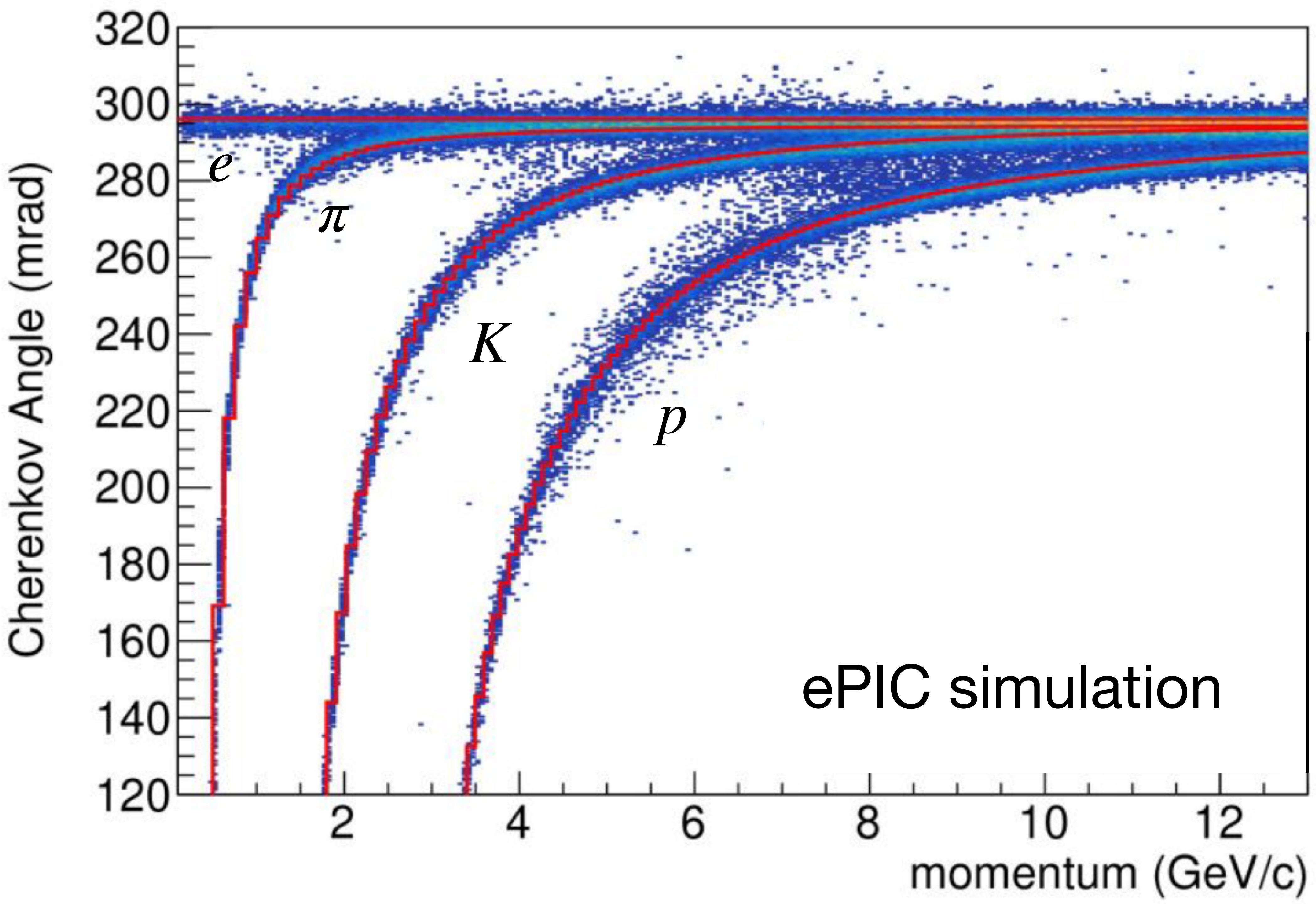


Particle identification – Cherenkov: backward

Proximity focussing ring-imaging Cherenkov detector (RICH)

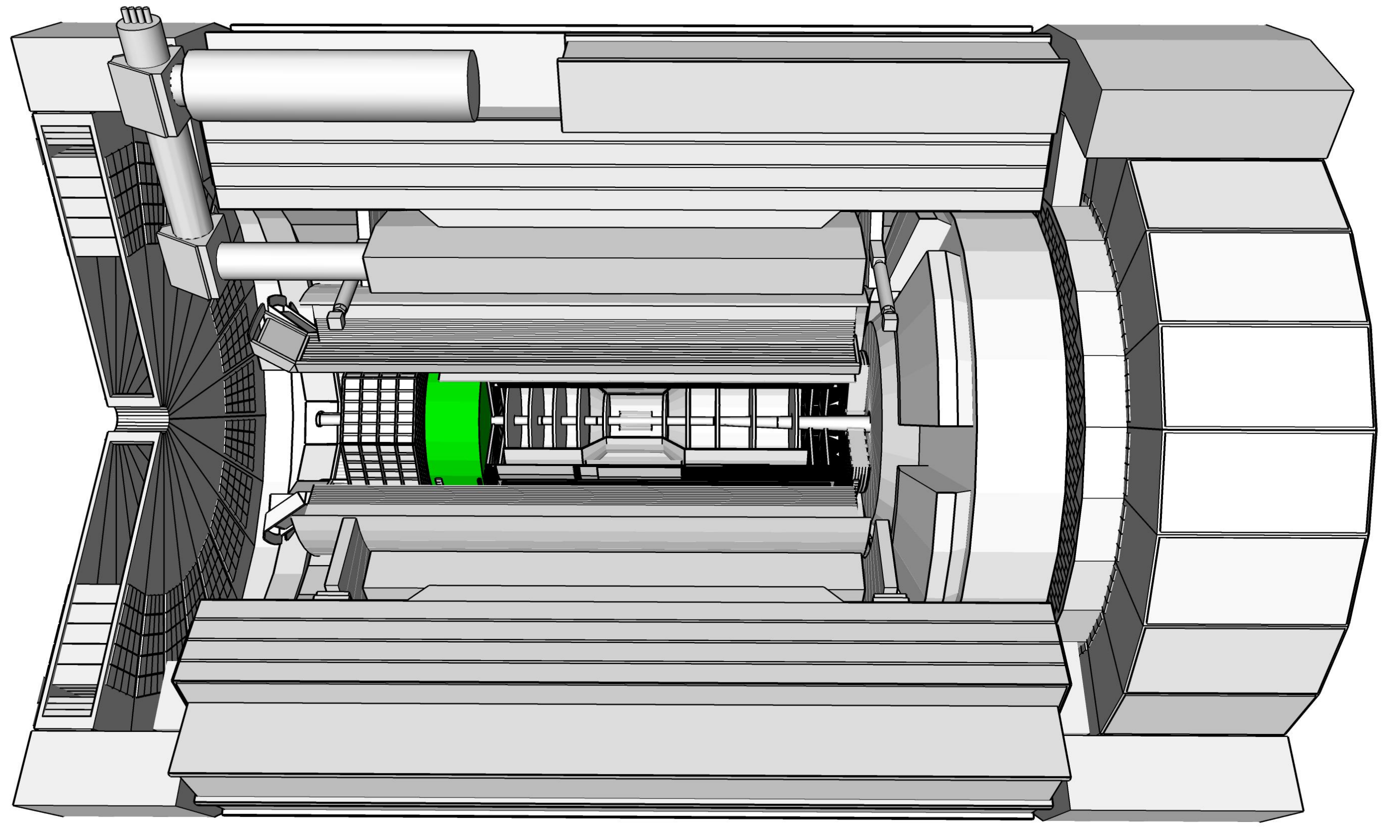


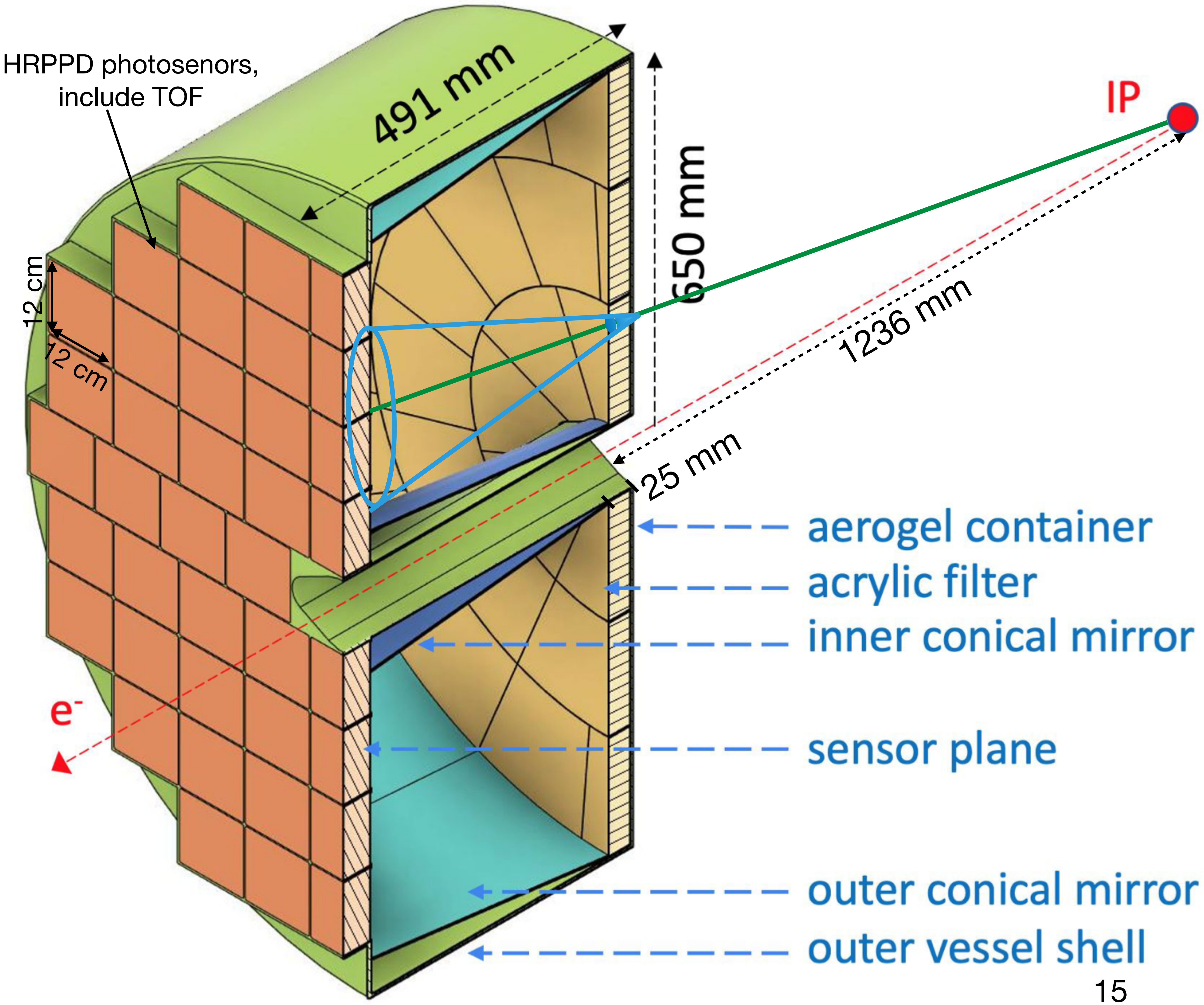


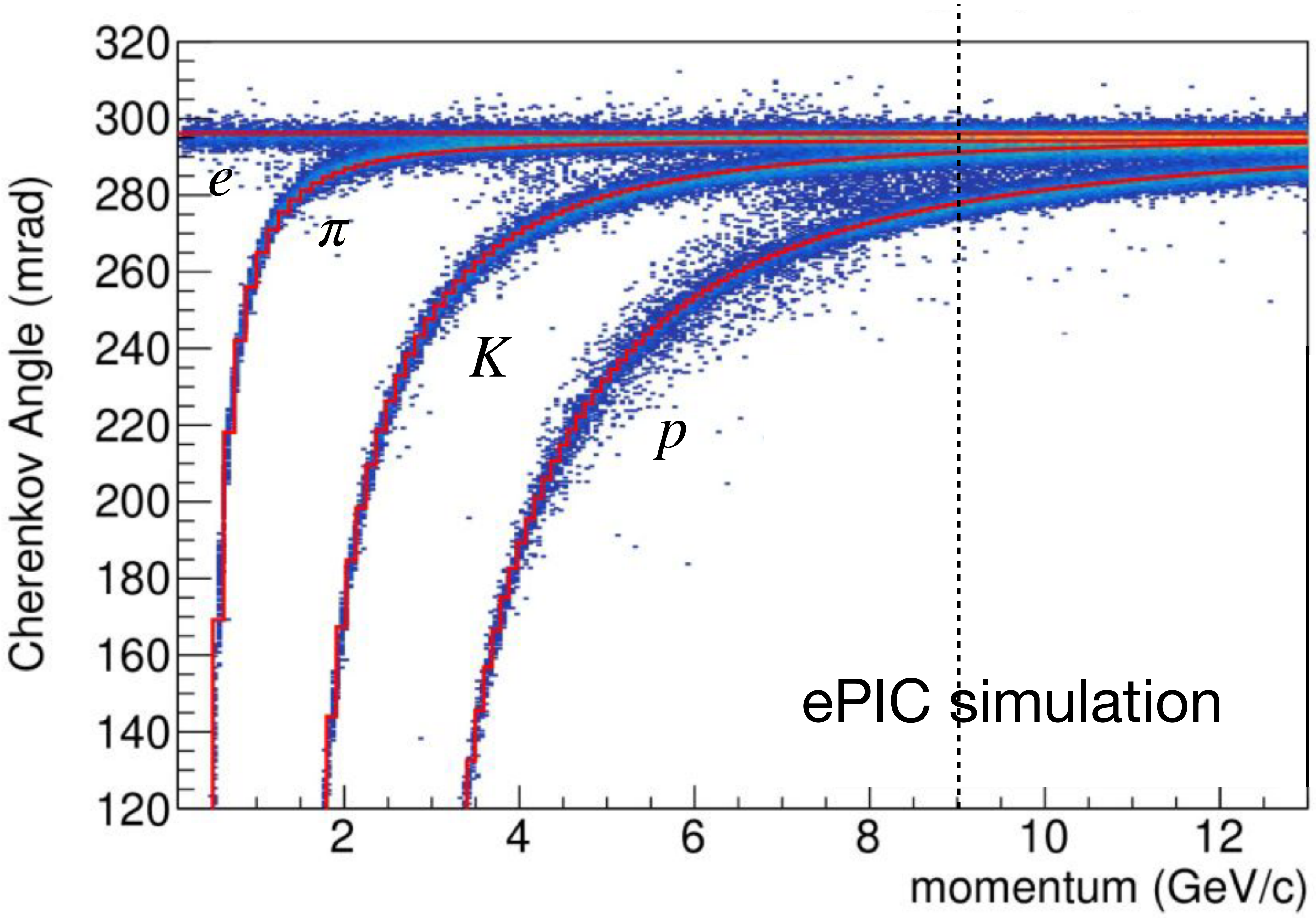


Particle identification – Cherenkov: backward

Proximity focussing ring-imaging Cherenkov detector (RICH)

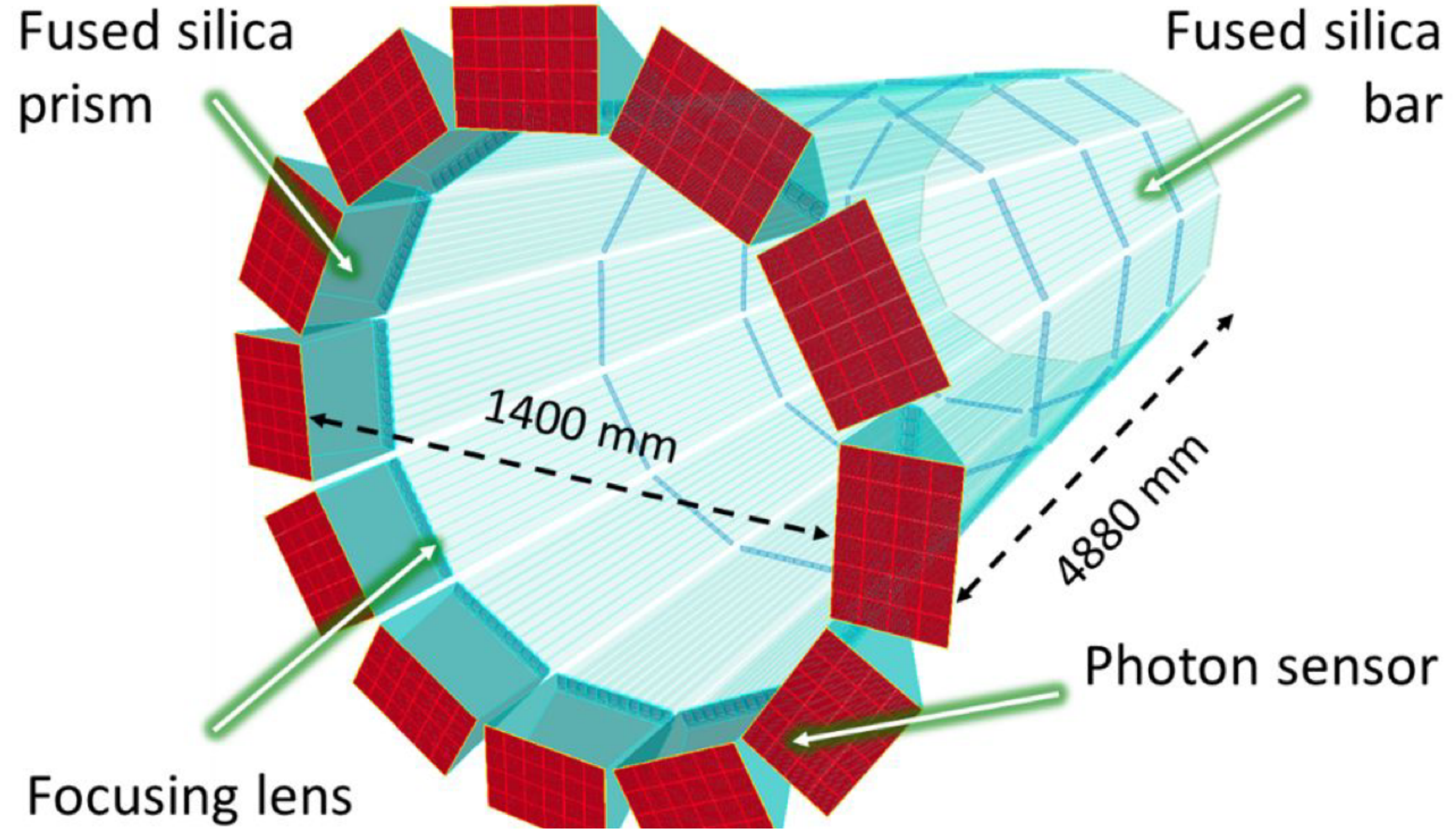


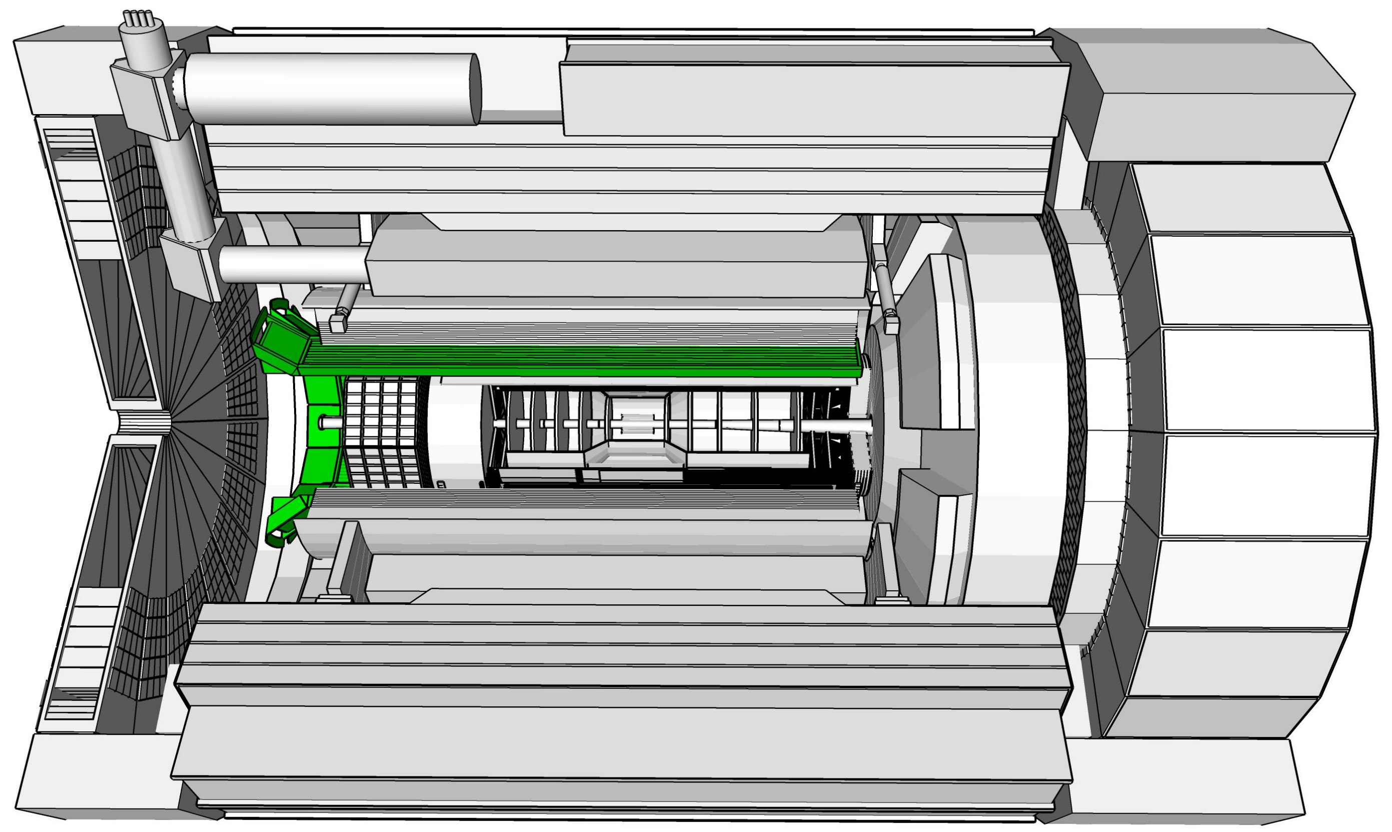




Particle identification – Cherenkov: central

High-performance DIRC (detection of internally reflected Cherenkov light)

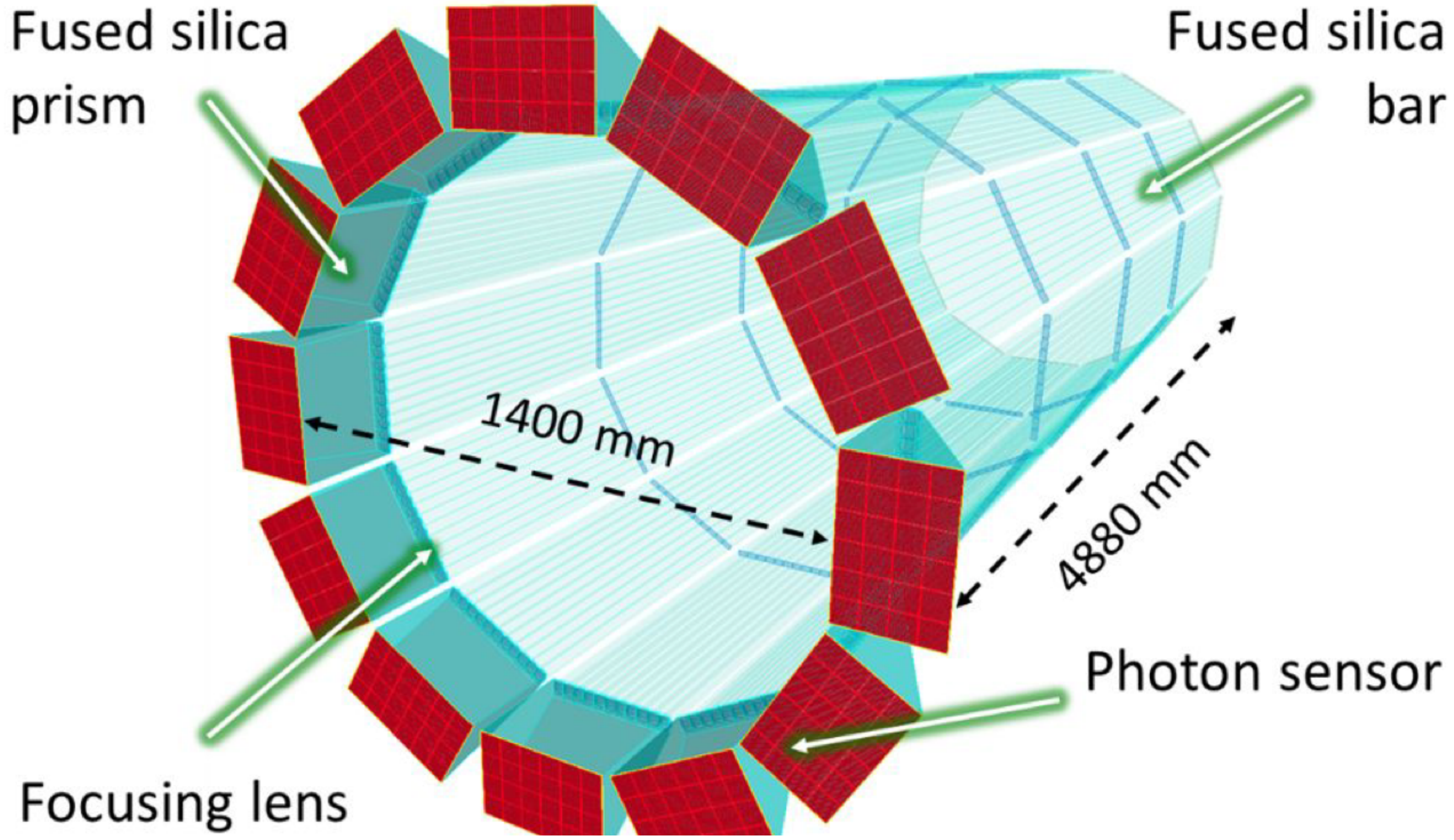


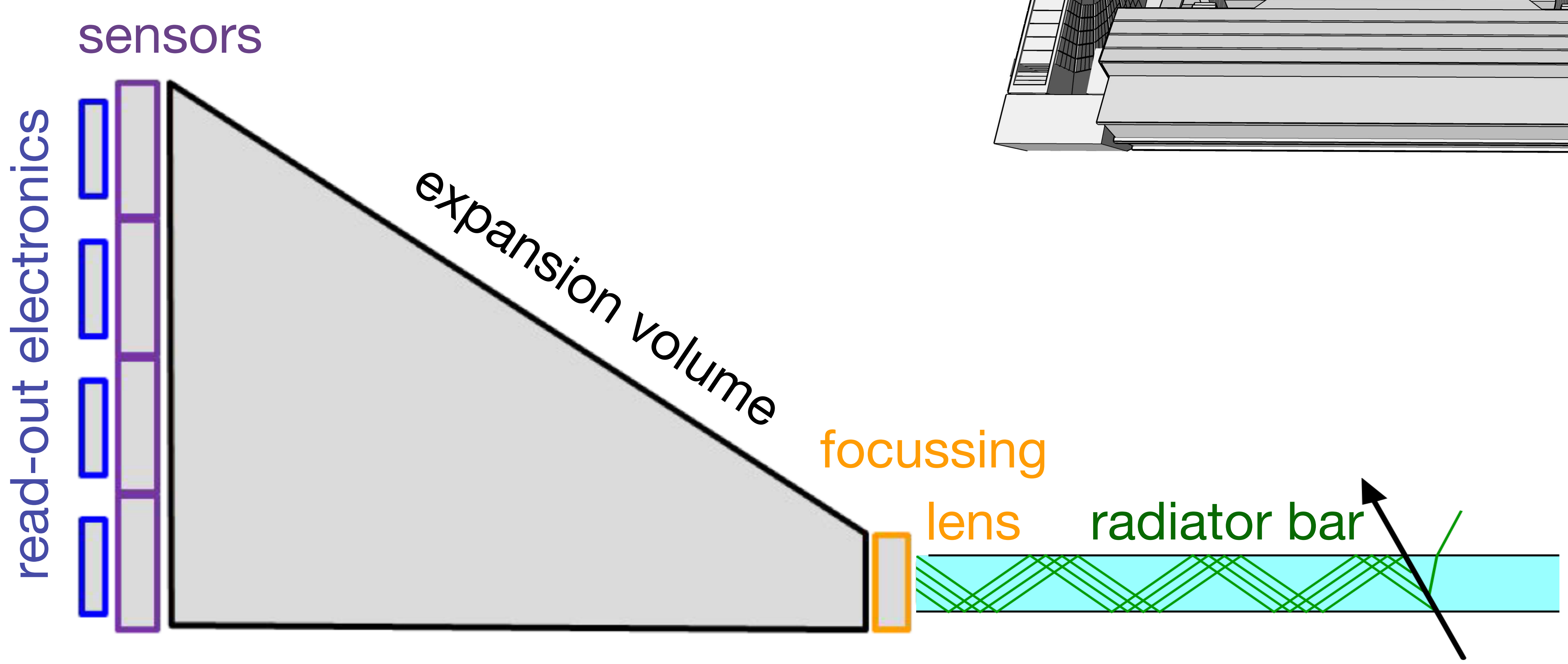


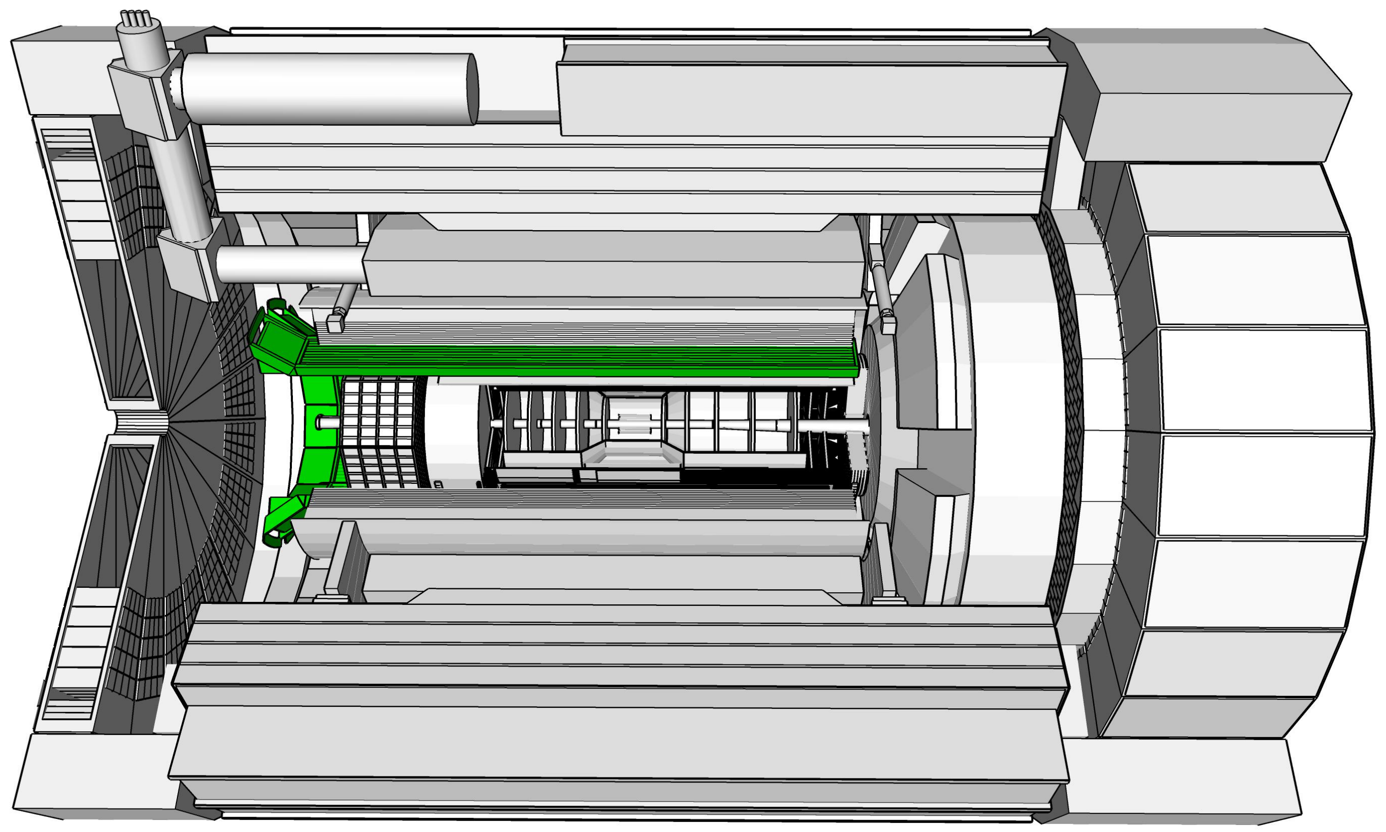
PID for $p \leq 6$ GeV

Particle identification – Cherenkov: central

High-performance DIRC (detection of internally reflected Cherenkov light)



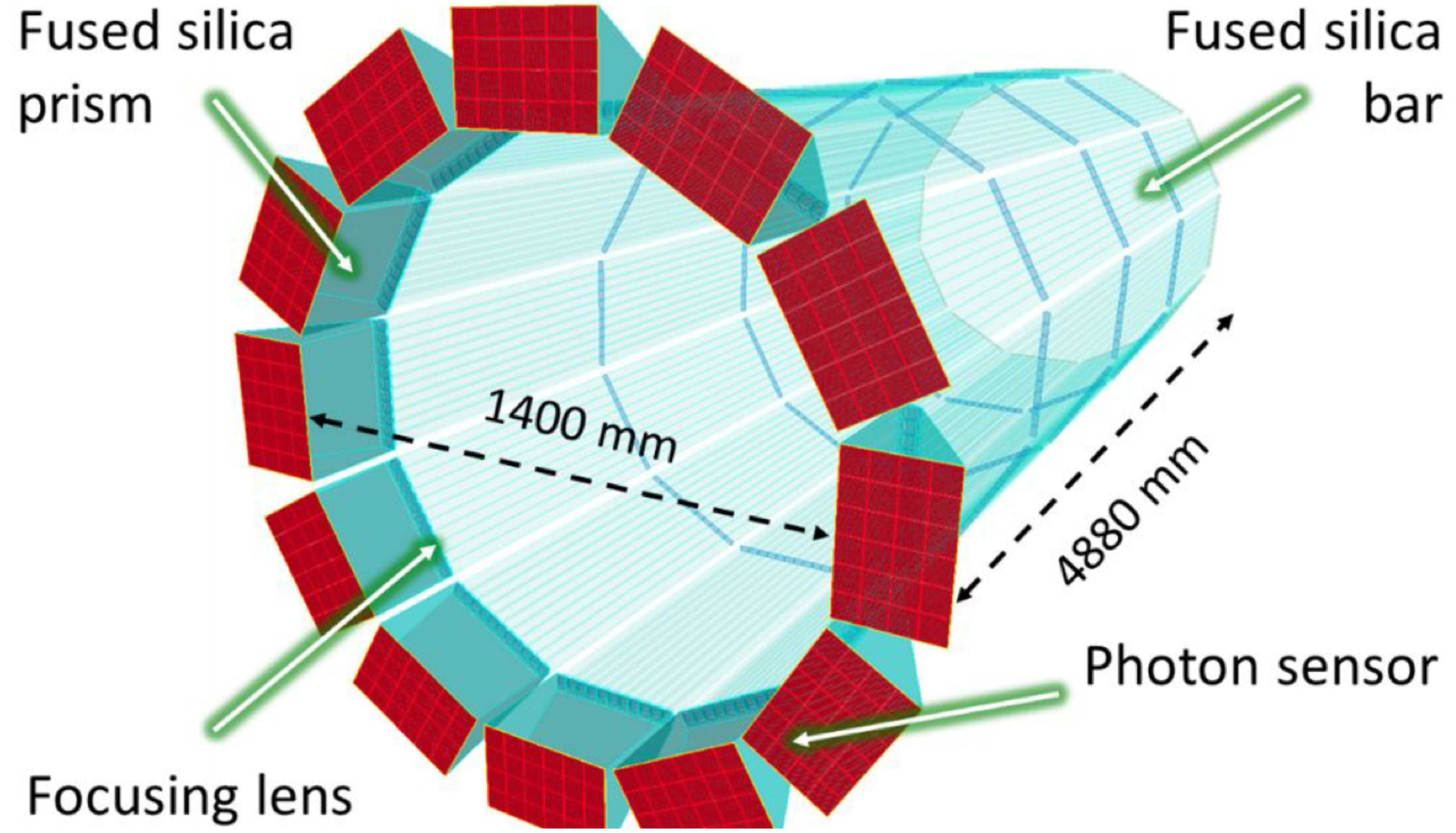


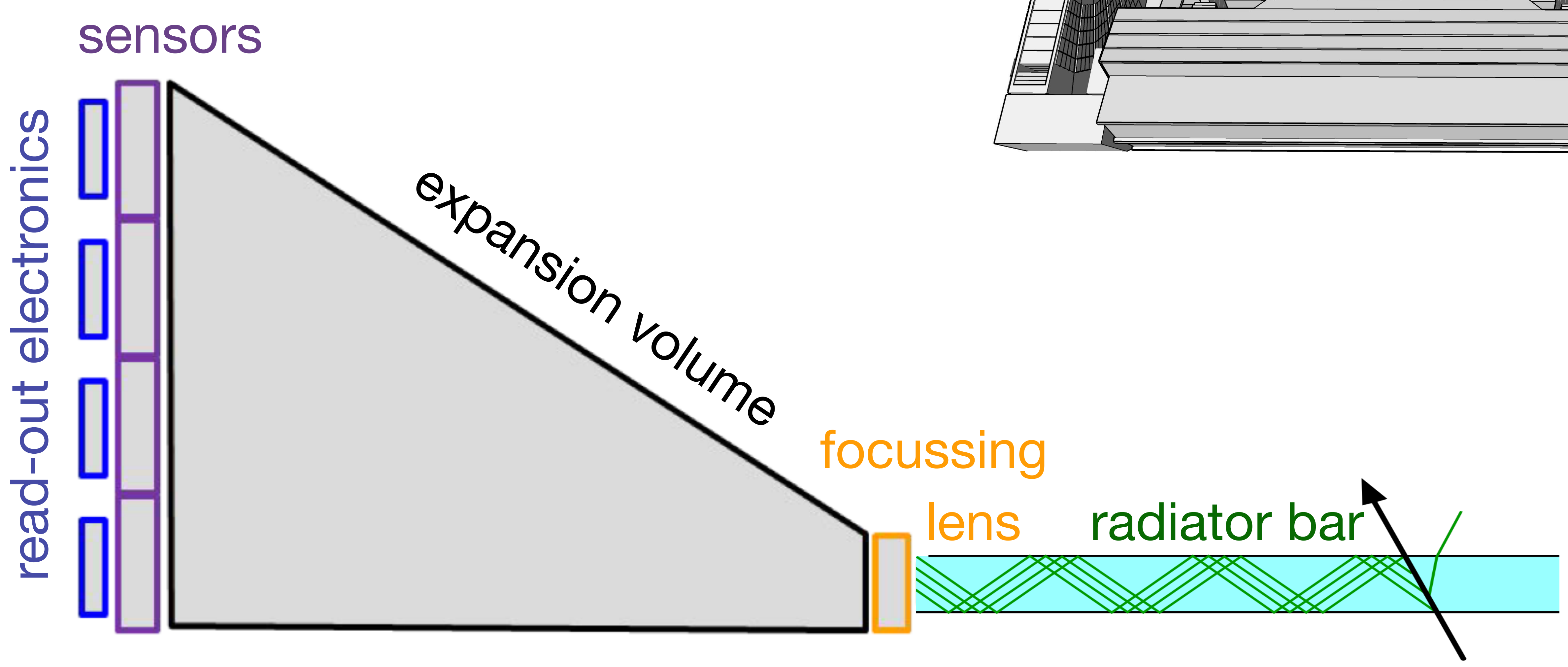


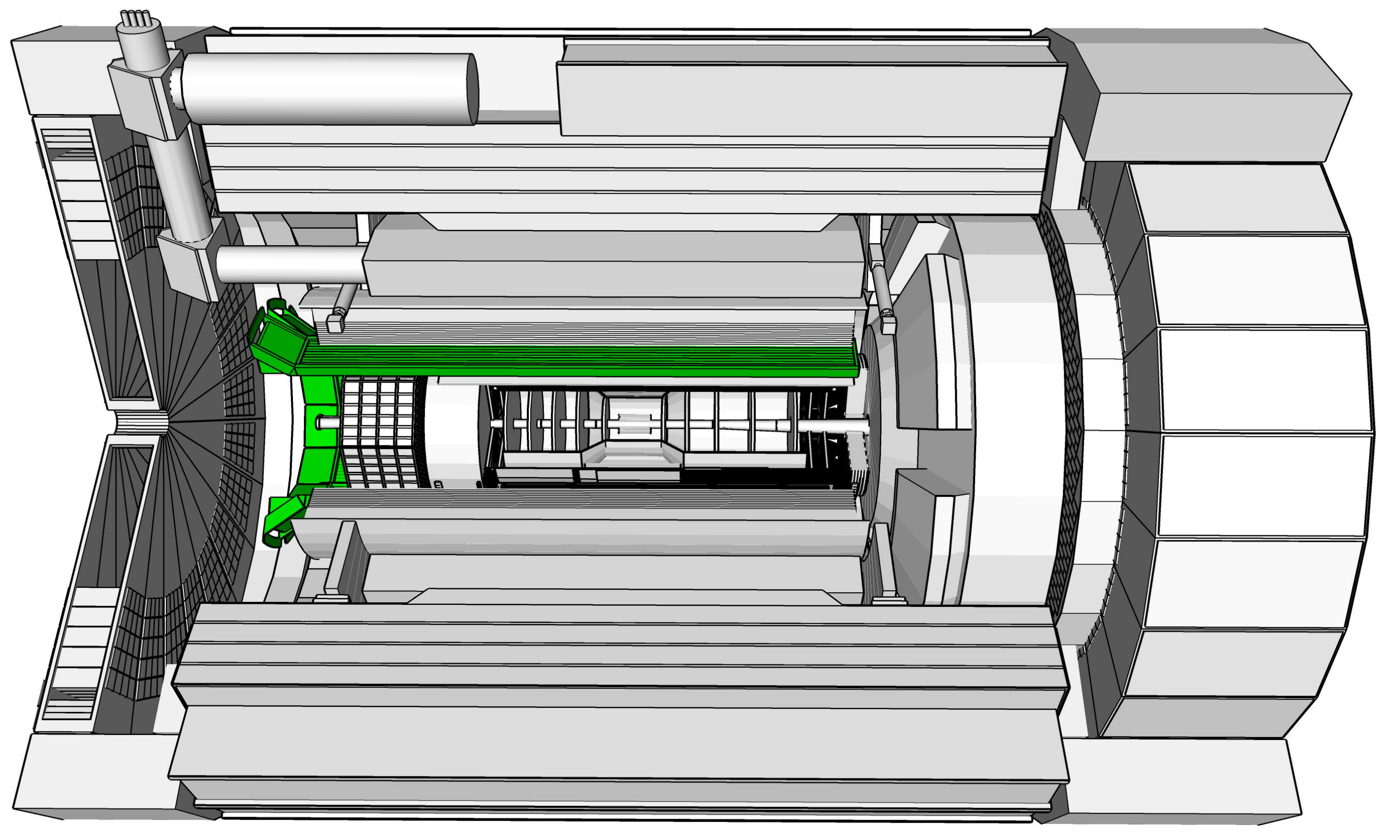
PID for $p \leq 6$ GeV

Particle identification – Cherenkov: central

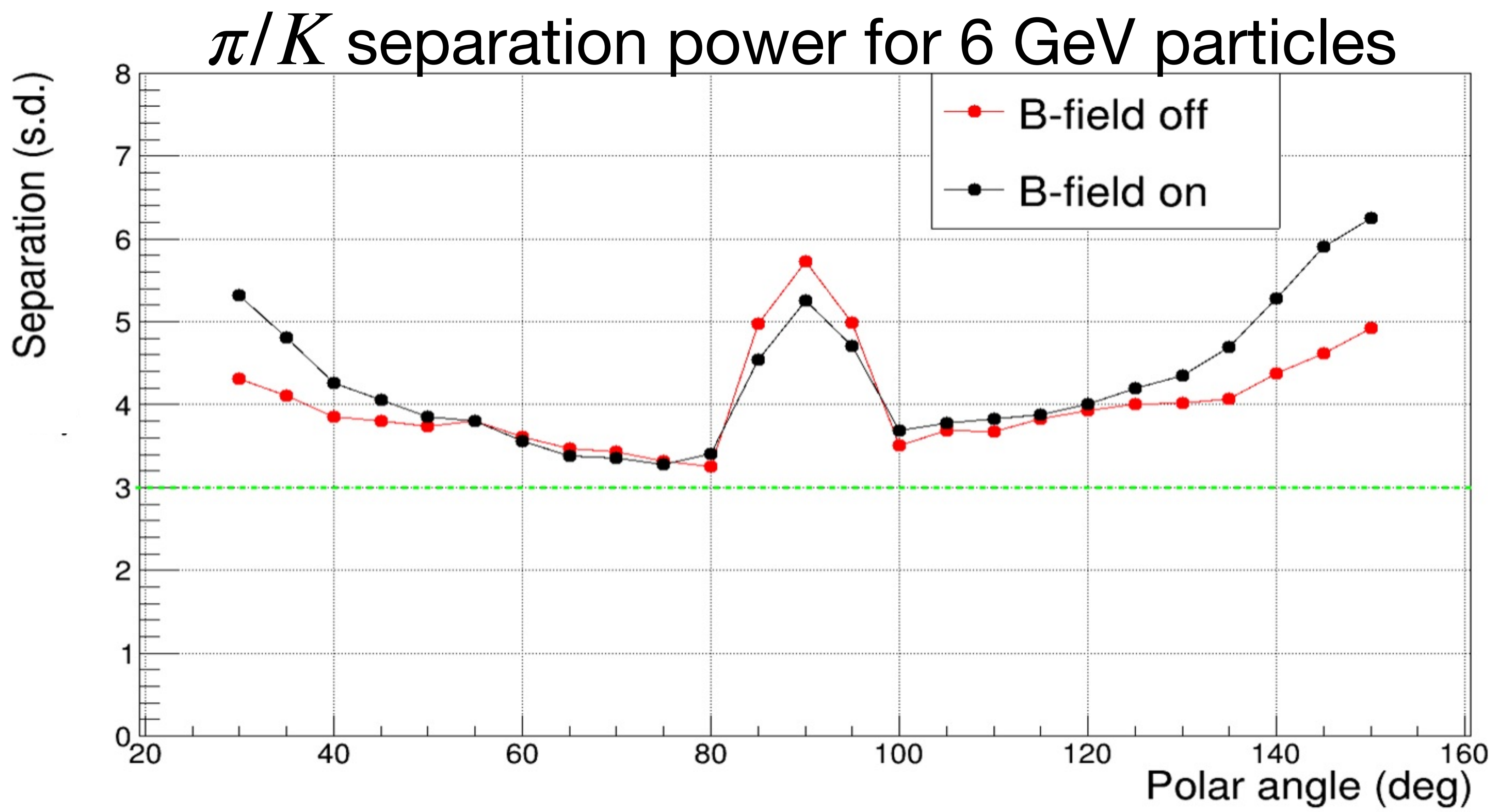
High-performance DIRC (detection of internally reflected Cherenkov light)





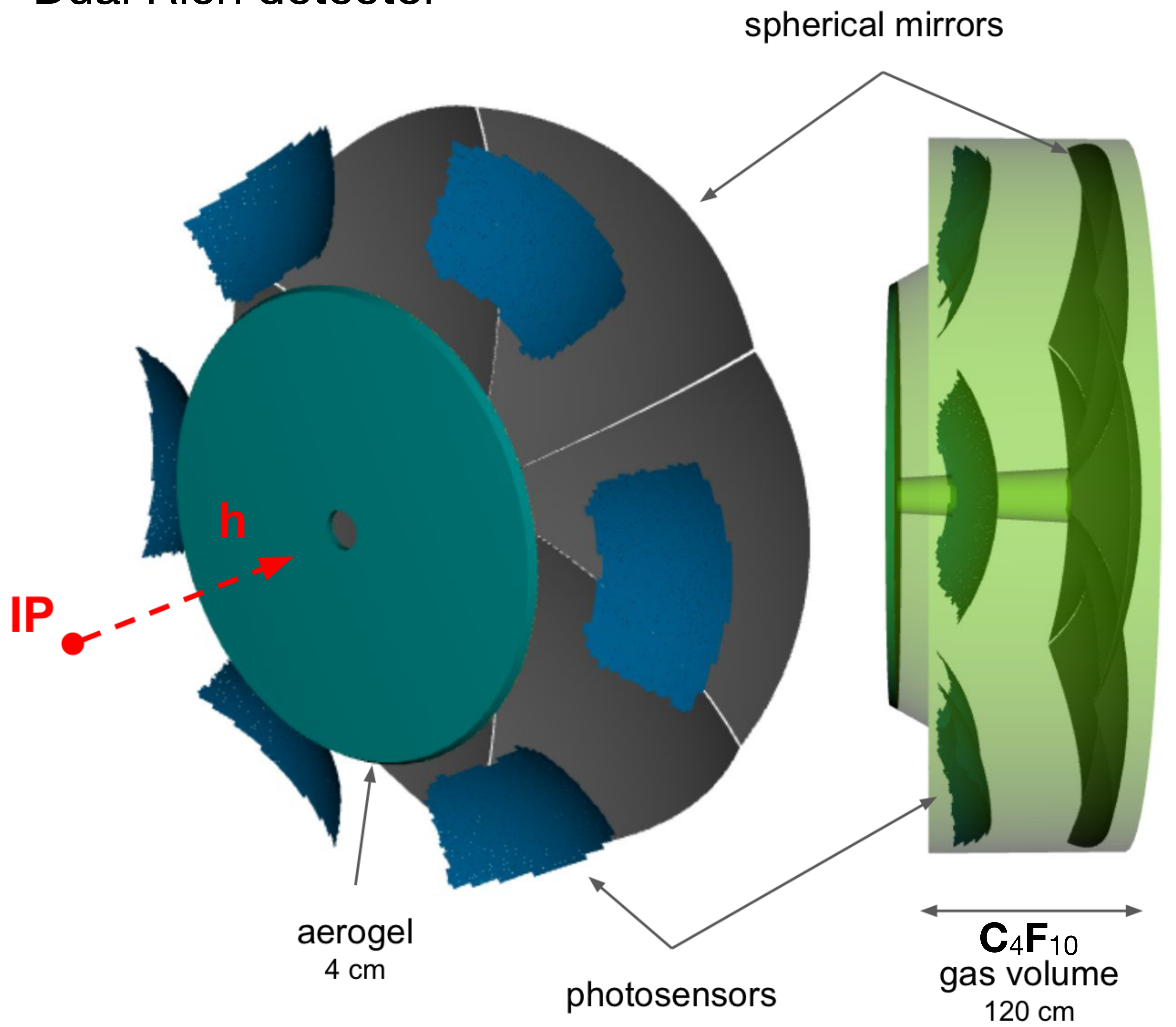


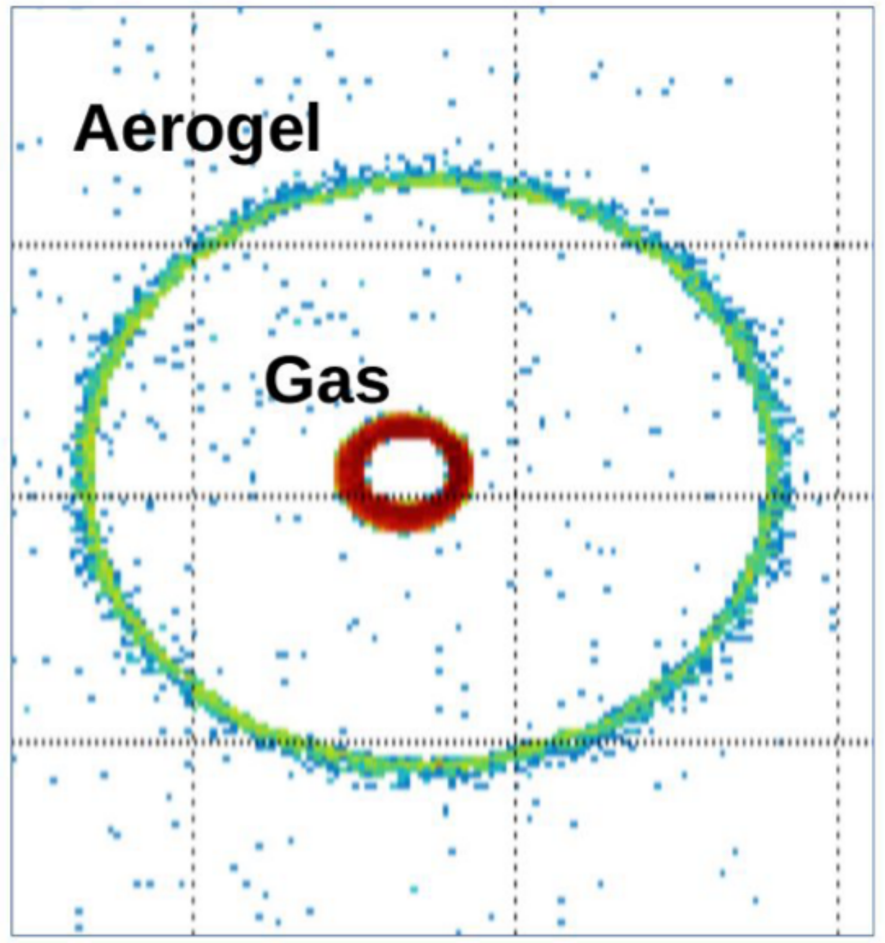
PID for $p \leq 6$ GeV



Particle identification – Cherenkov: forward

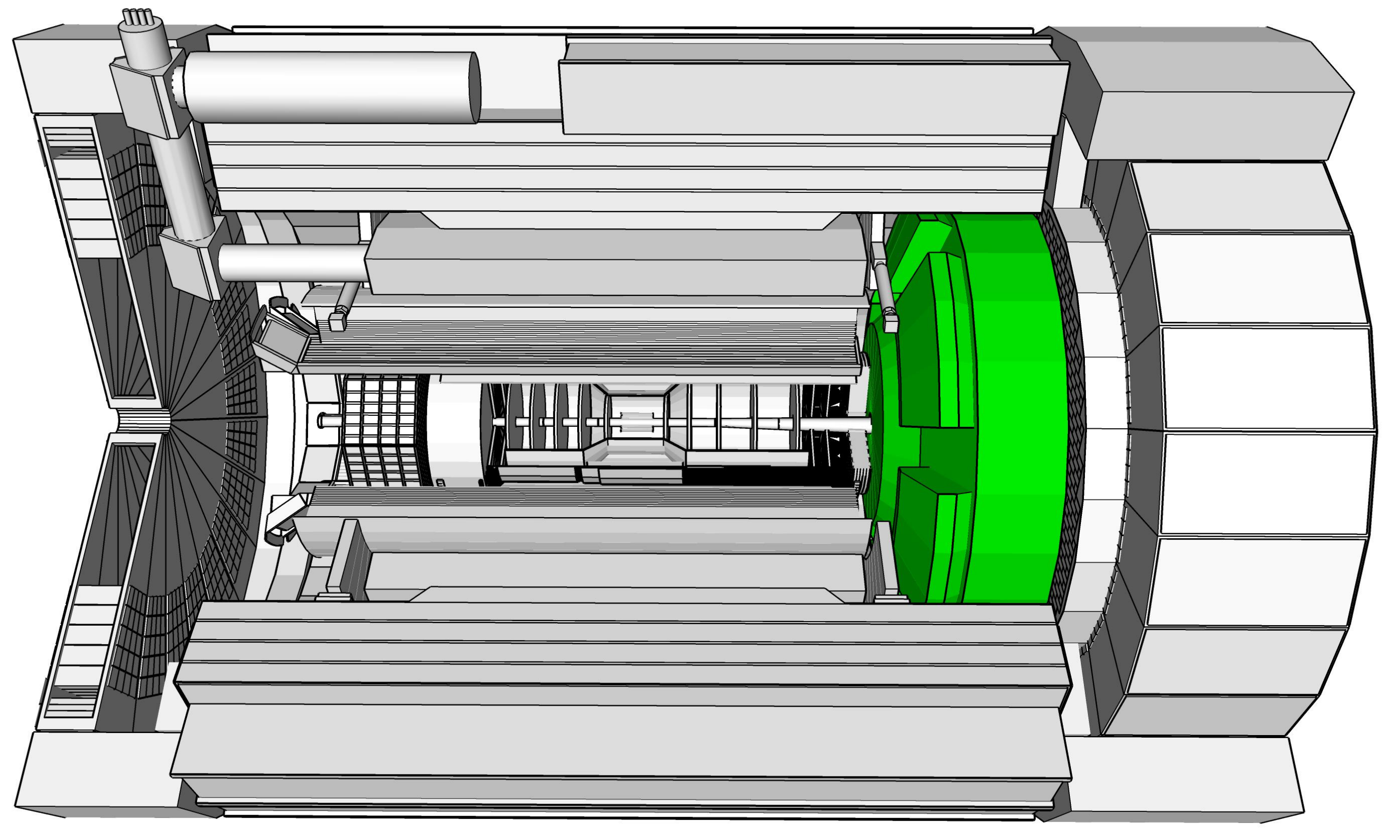
Dual Rich detector





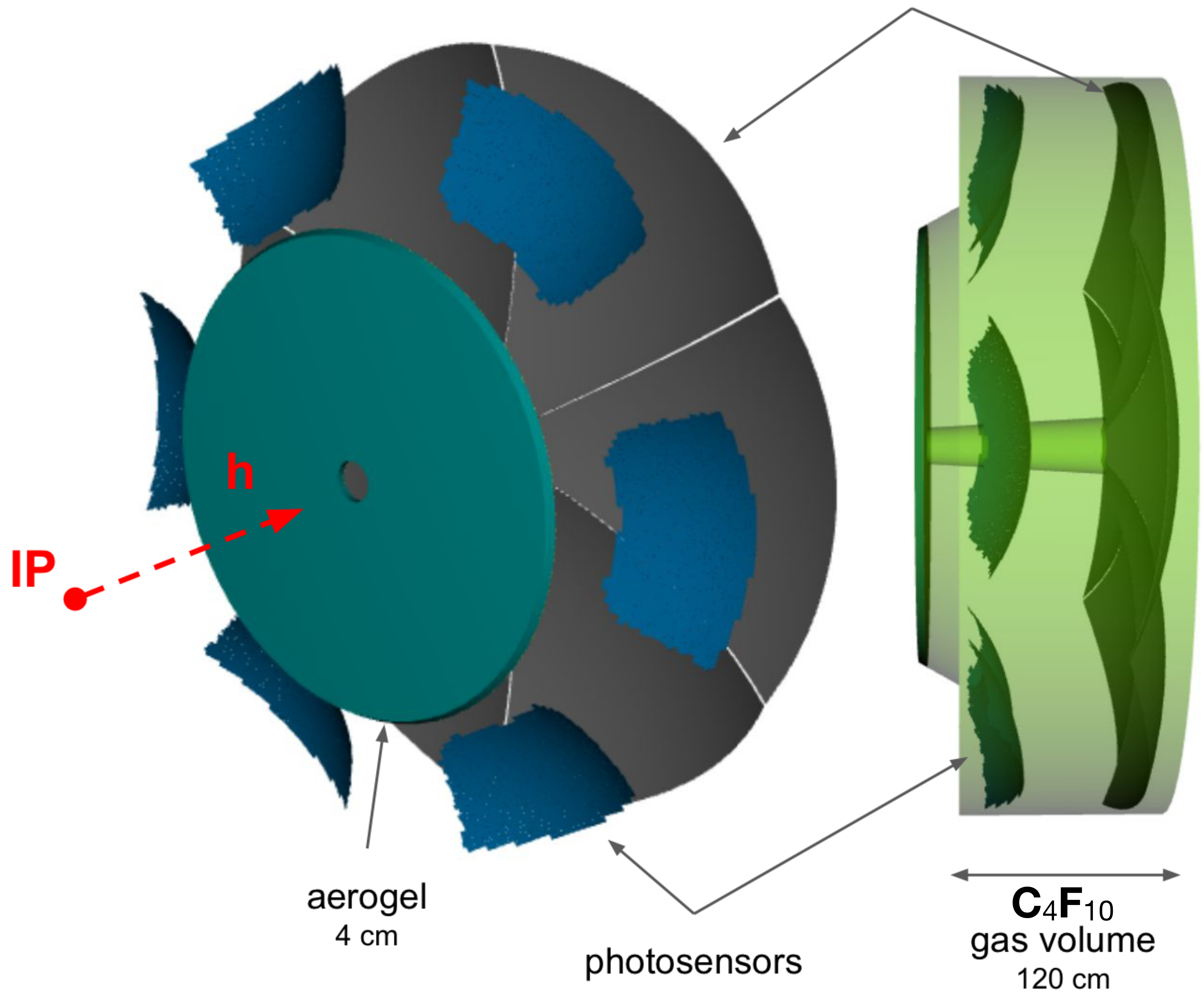
n=1.02
lower momentum

n=1.0008
high momentum



Particle identification – Cherenkov: forward

Dual Rich detector



n=1.02
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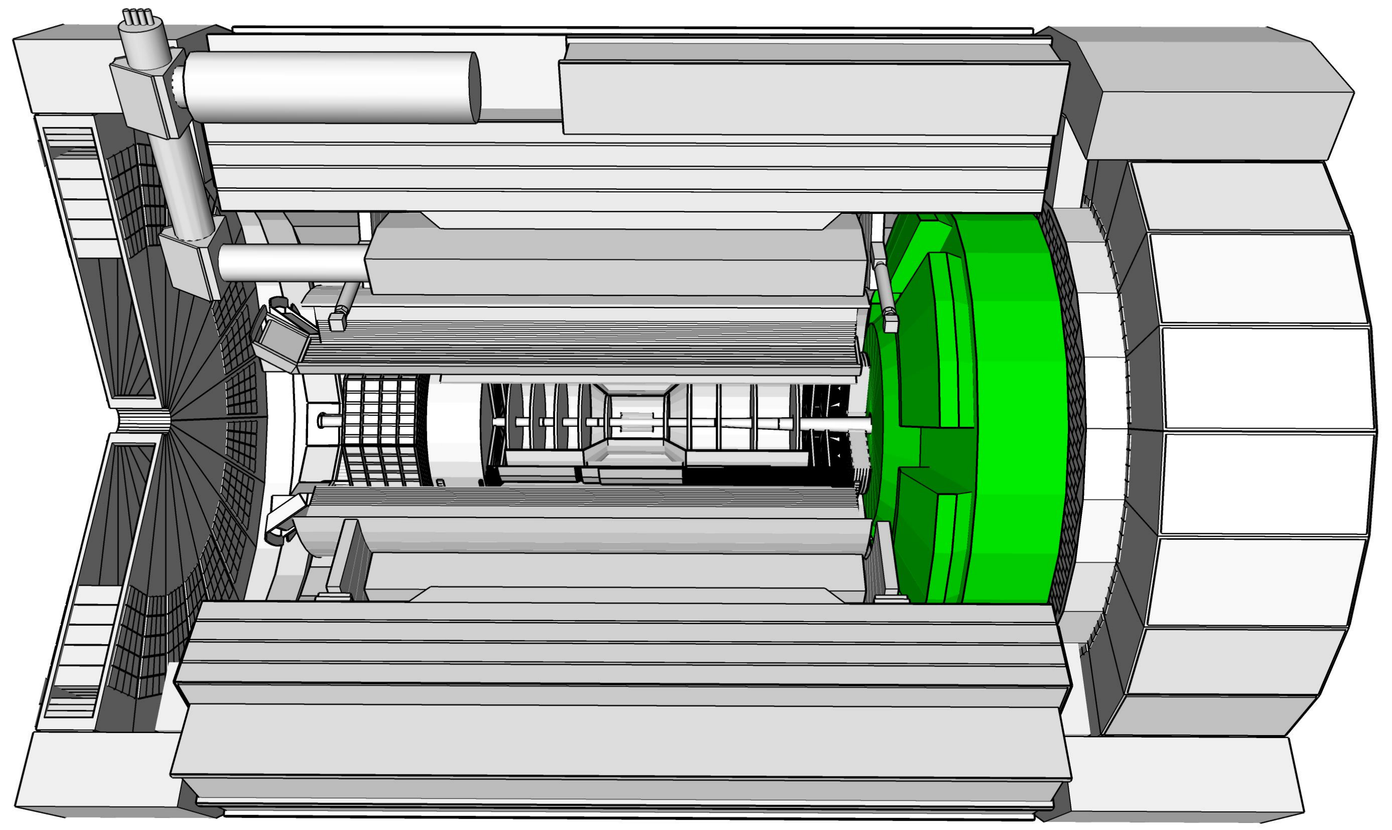
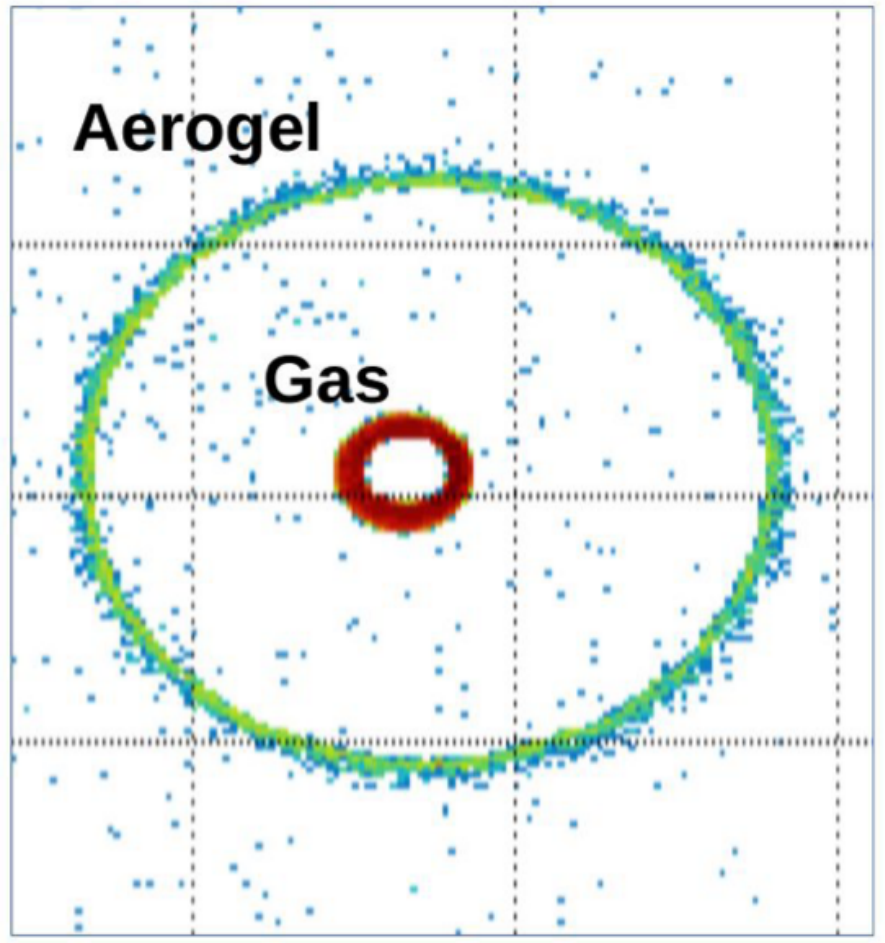
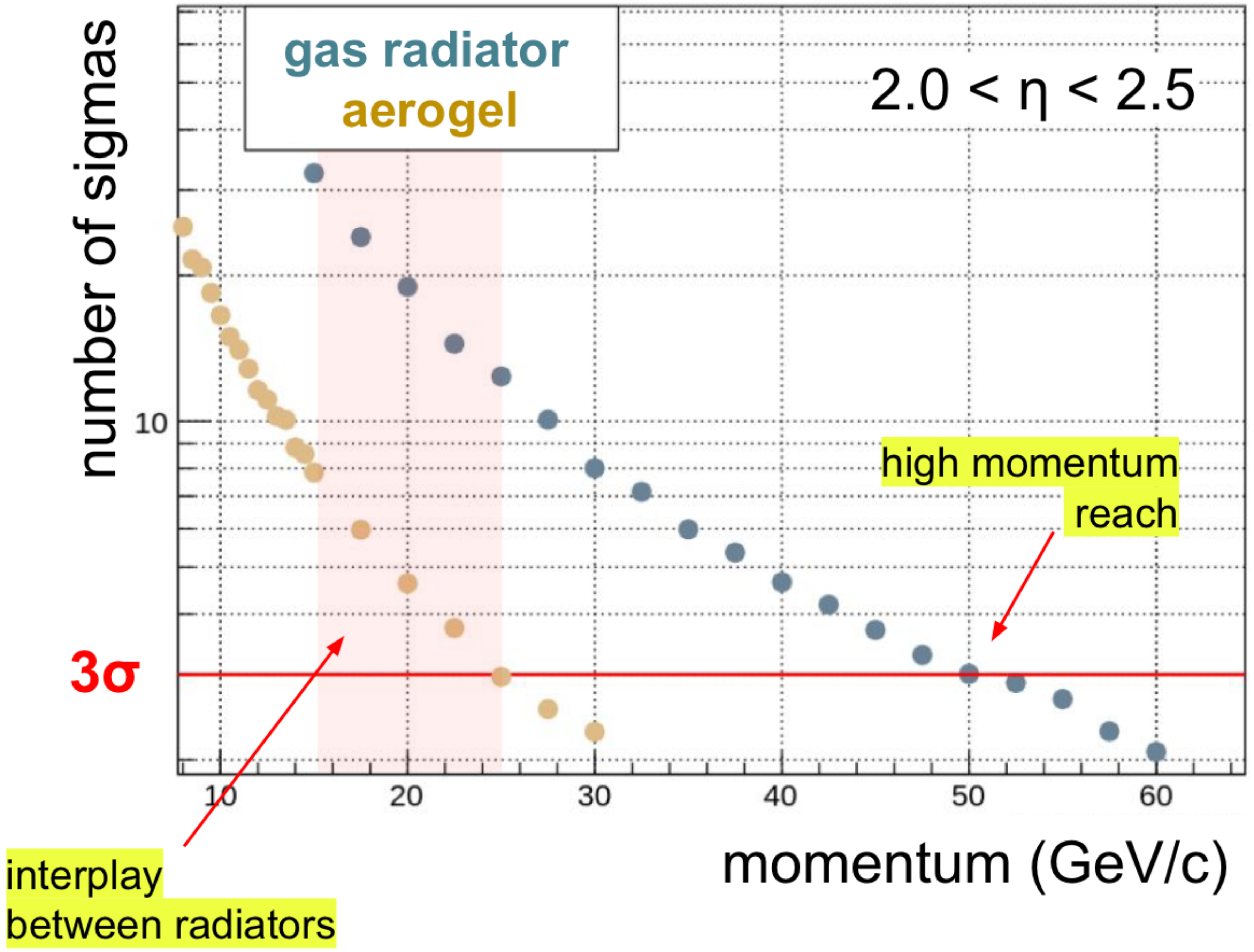




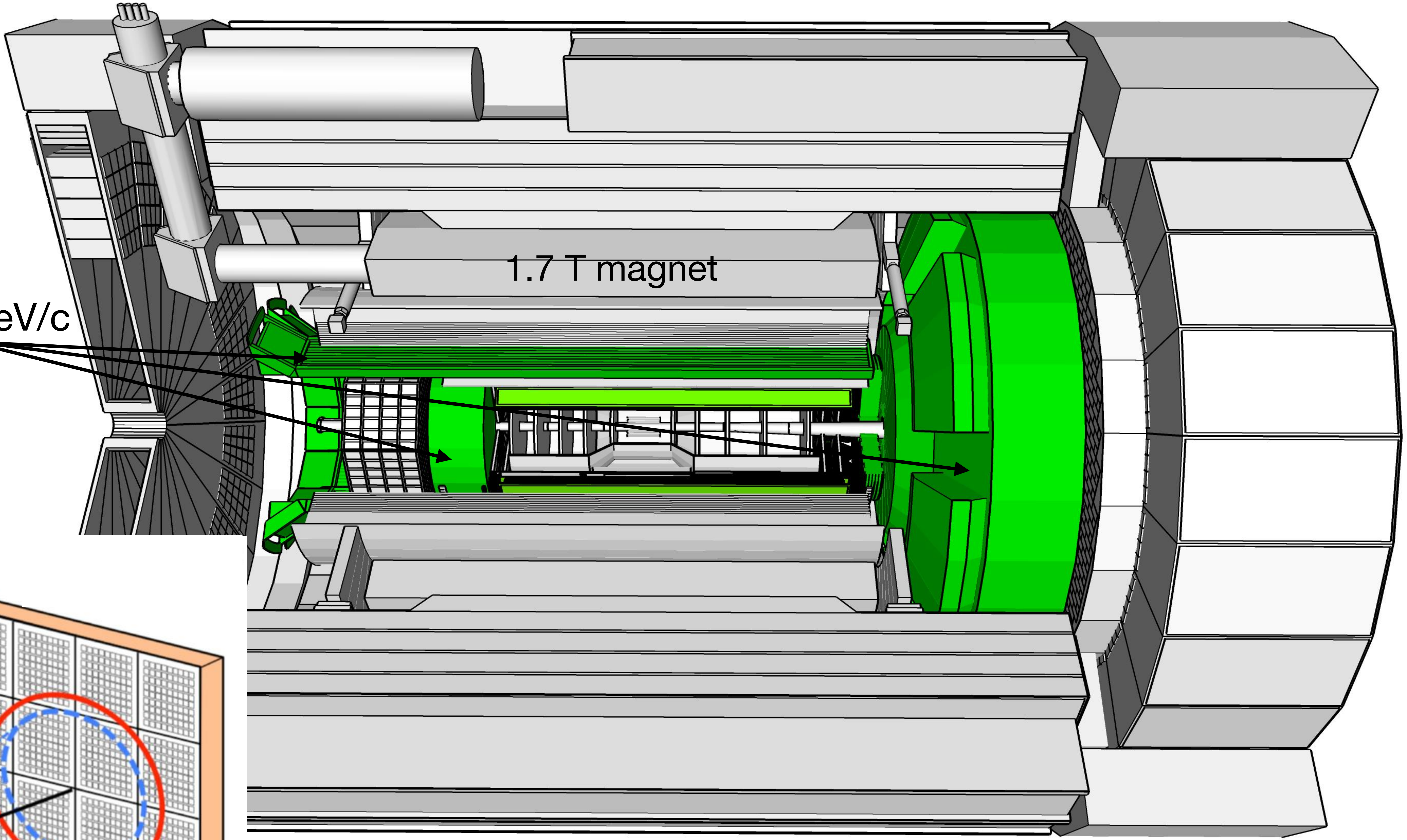
π/K separation power

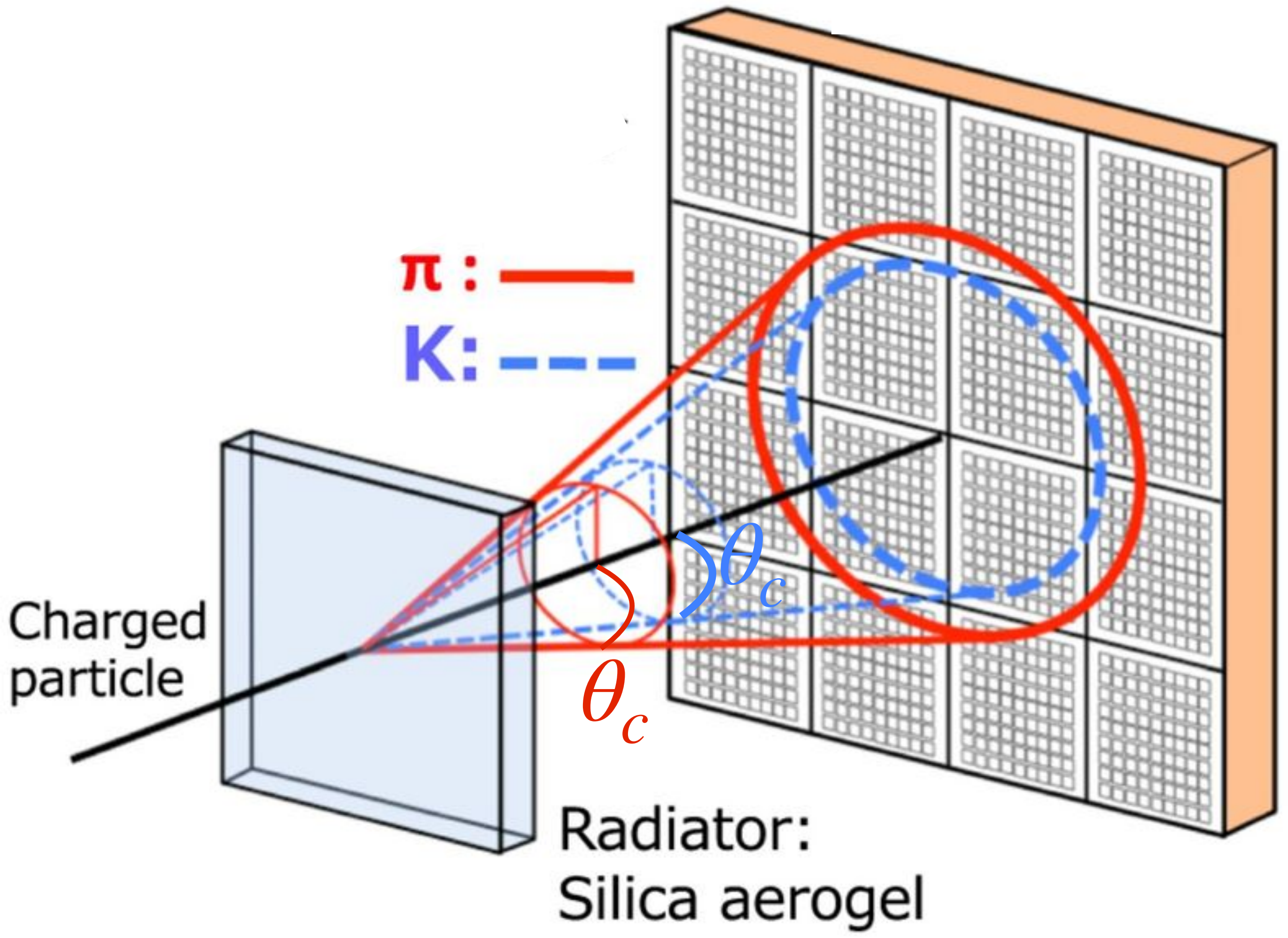


within ePIC
simulation framework

Particle identification

detectors based on
Cherenkov radiation
for 1 GeV/c<p<50 GeV/c





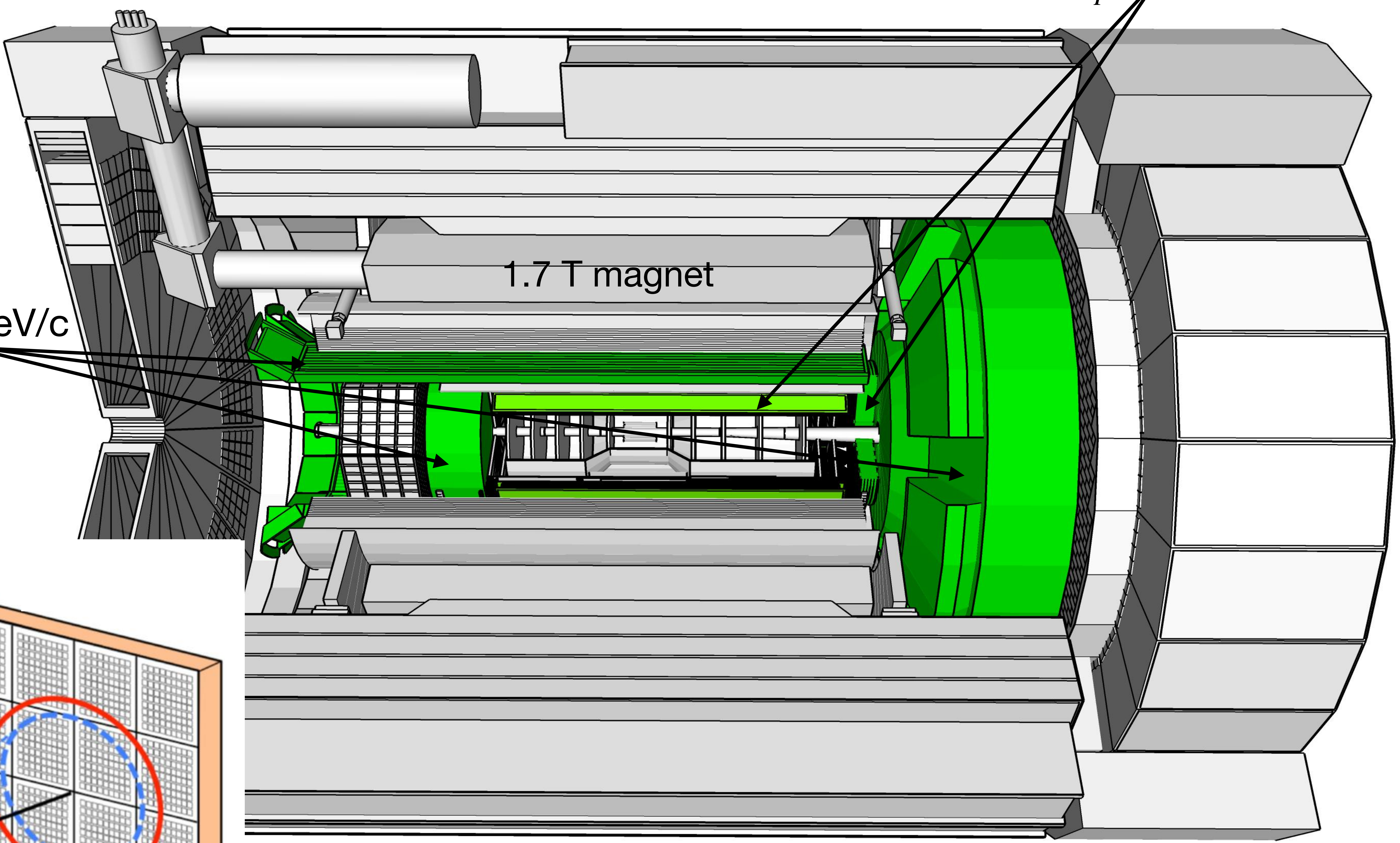
$$\cos\theta_c \propto \frac{1}{v}$$

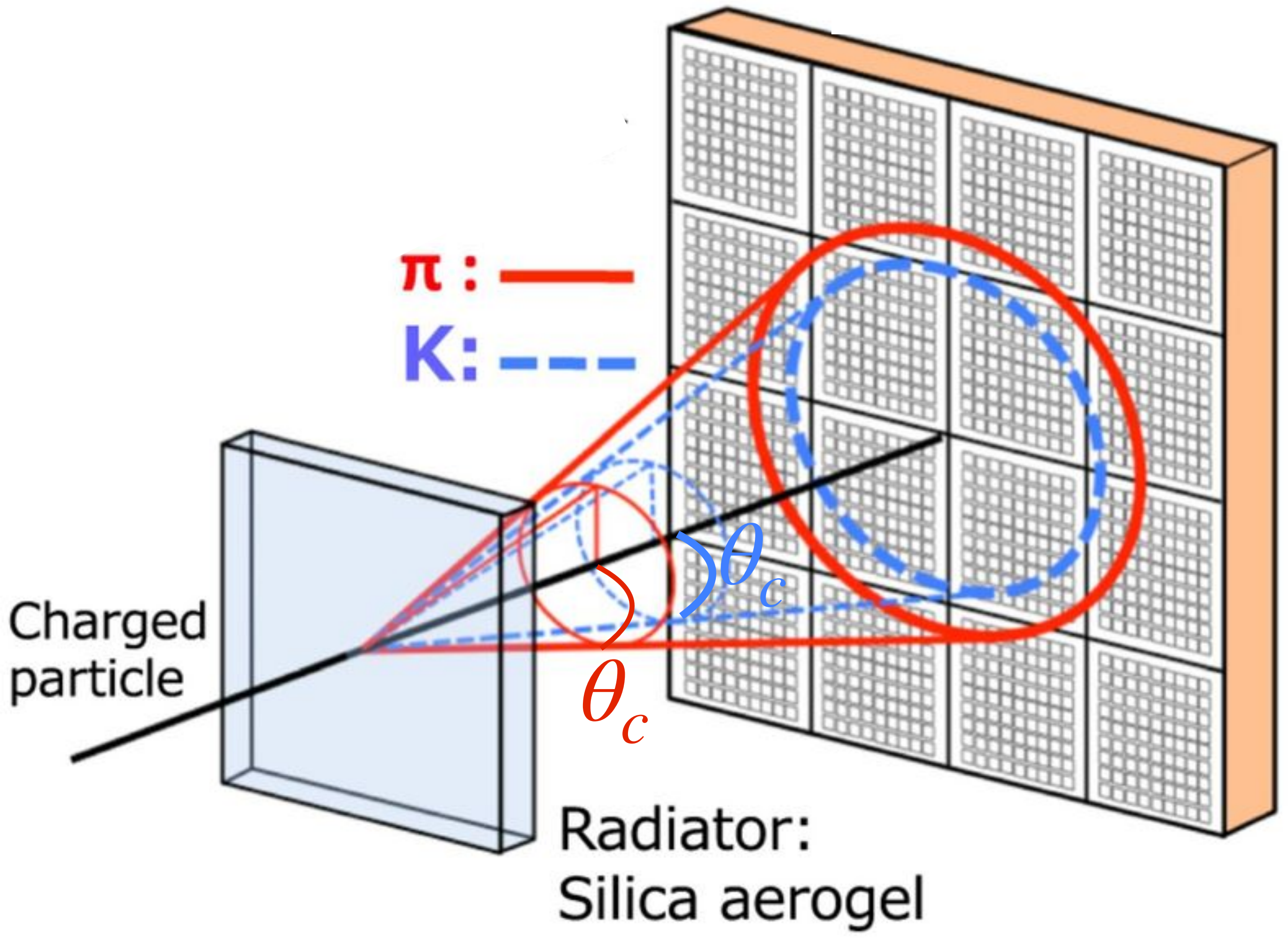
Particle identification

AC-LGAD based TOF, for p < 0.5 – 3 GeV/c

$$v = \frac{L}{t_{stop} - t_{start}}$$

detectors based on Cherenkov radiation for 1 GeV/c<p<50 GeV/c



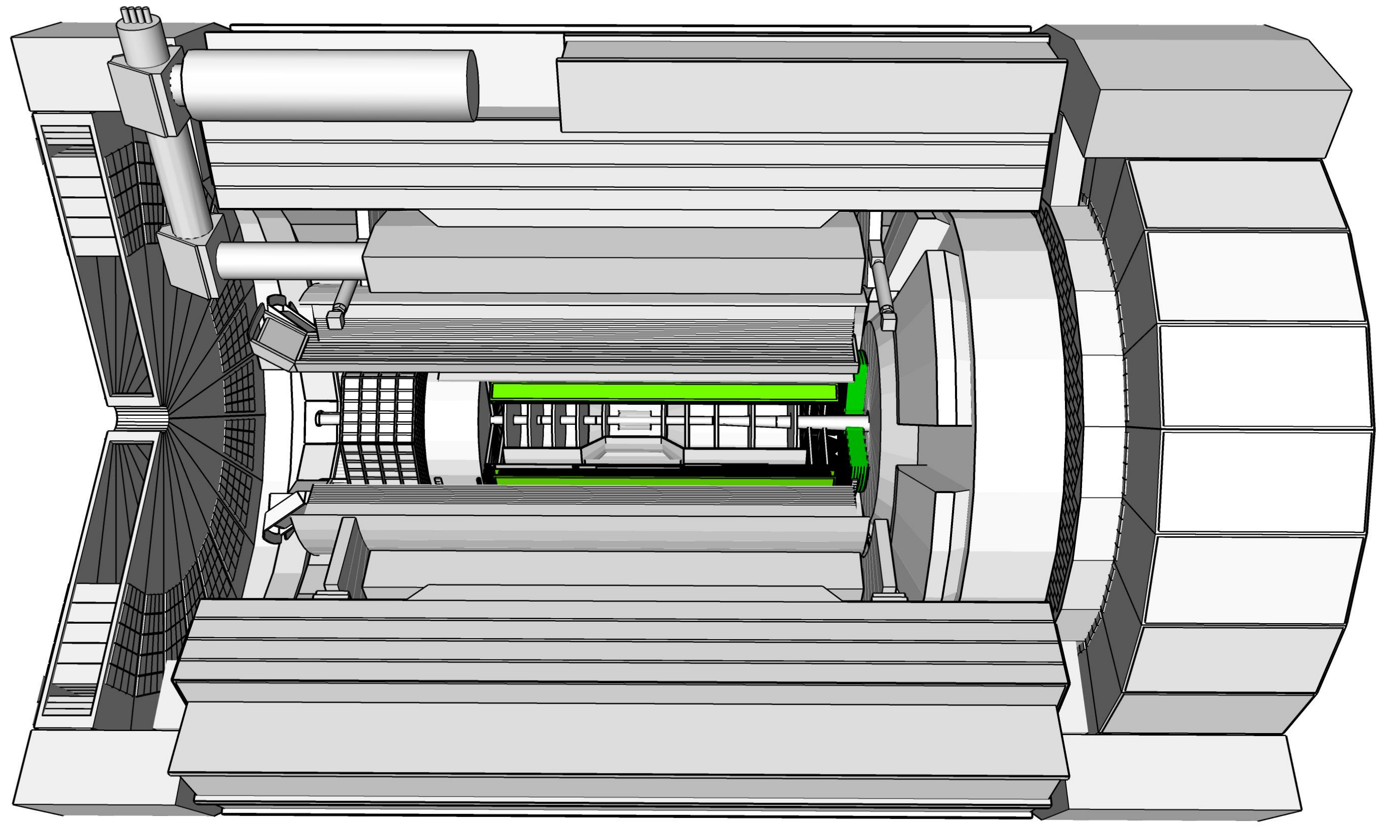


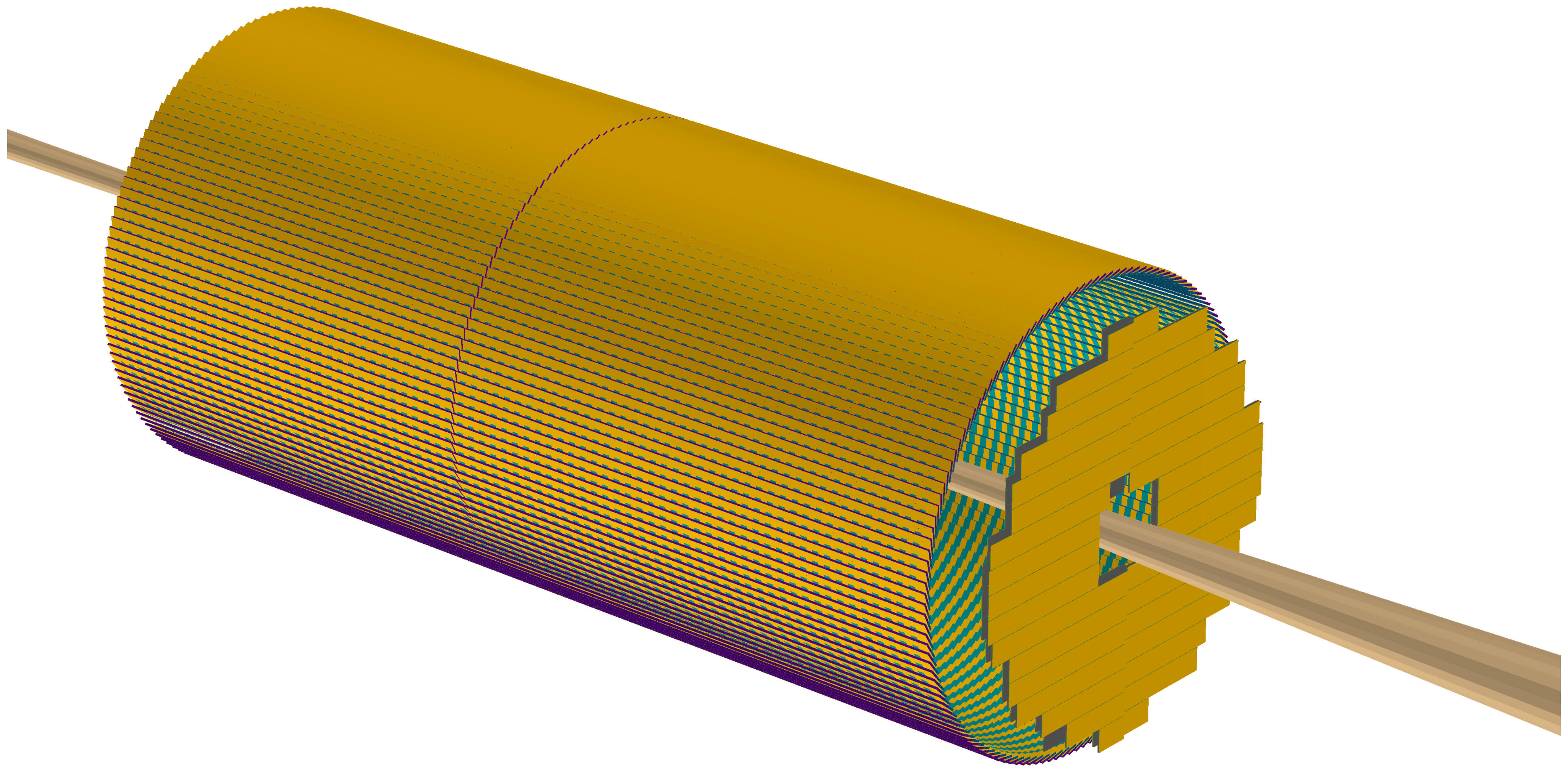
$$\cos\theta_c \propto \frac{1}{v}$$

Particle identification: time of flight (TOF)

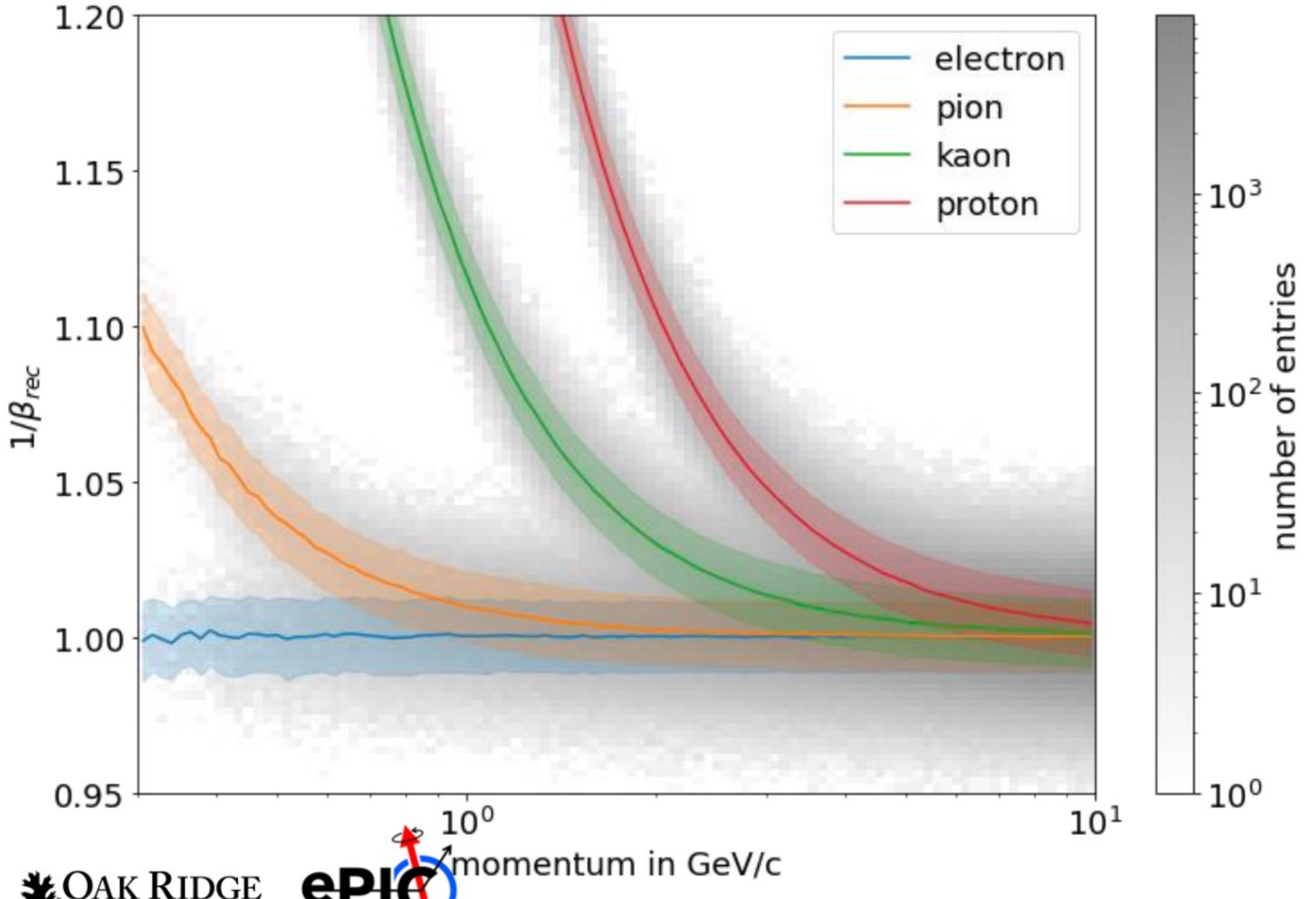
AC-LGAD based TOF

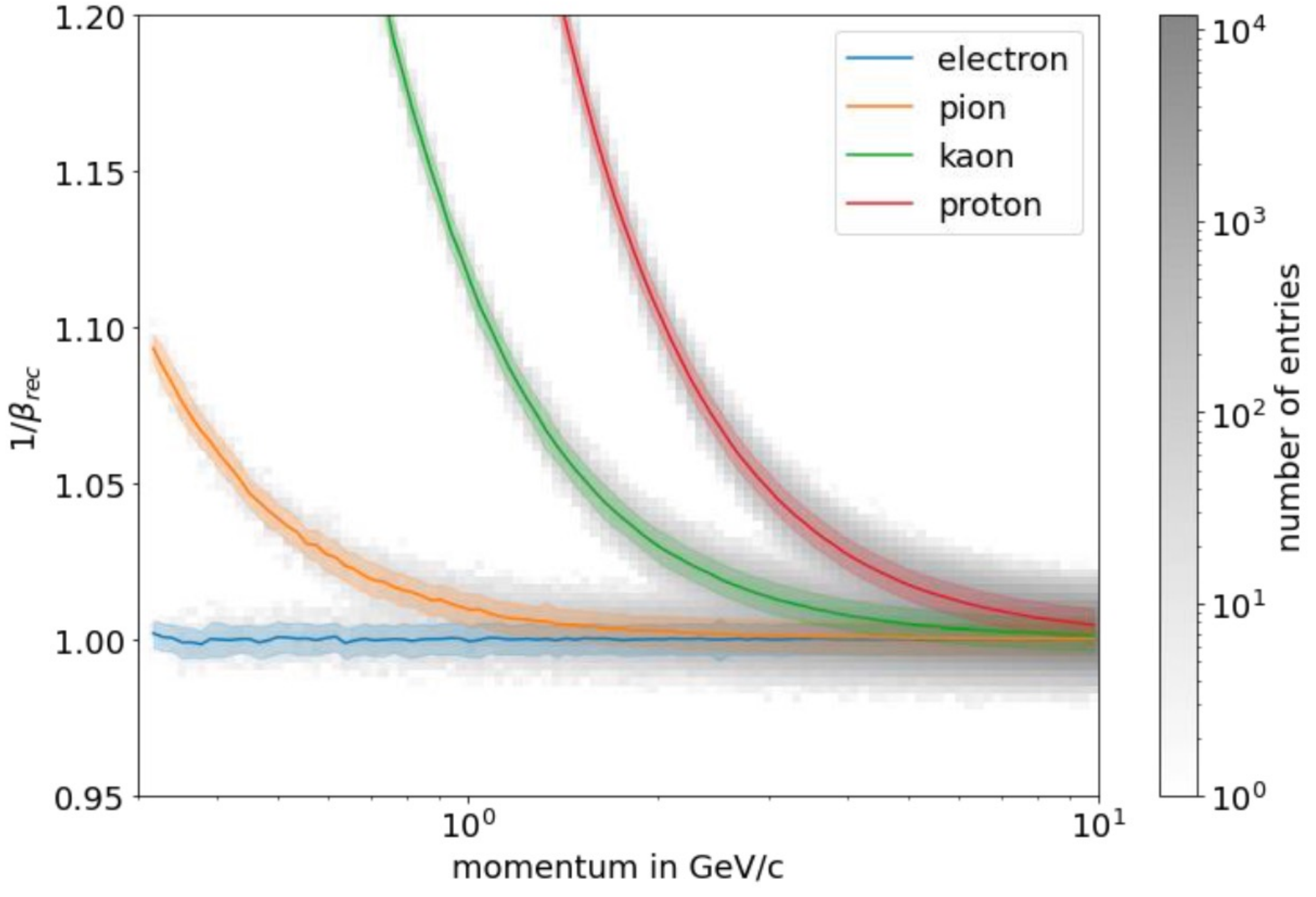
30 µm space resolution
25-35 ps time resolution





Barrel Region
- e/pi up to 0.5 GeV/c
- pi/K up to 1.9 GeV/c
- K/p up to 3.1 GeV/c



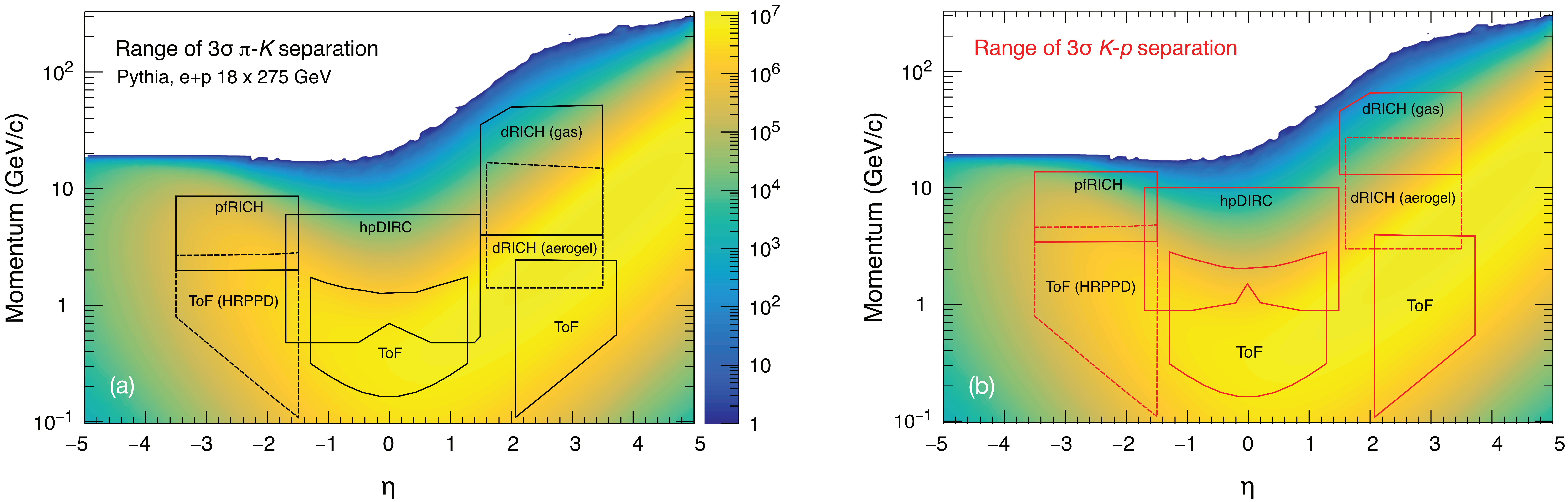


Endcap Region
- e/pi up to 0.8 GeV/c
- pi/K up to 2.7 GeV/c
- K/p up to 4.6 GeV/c

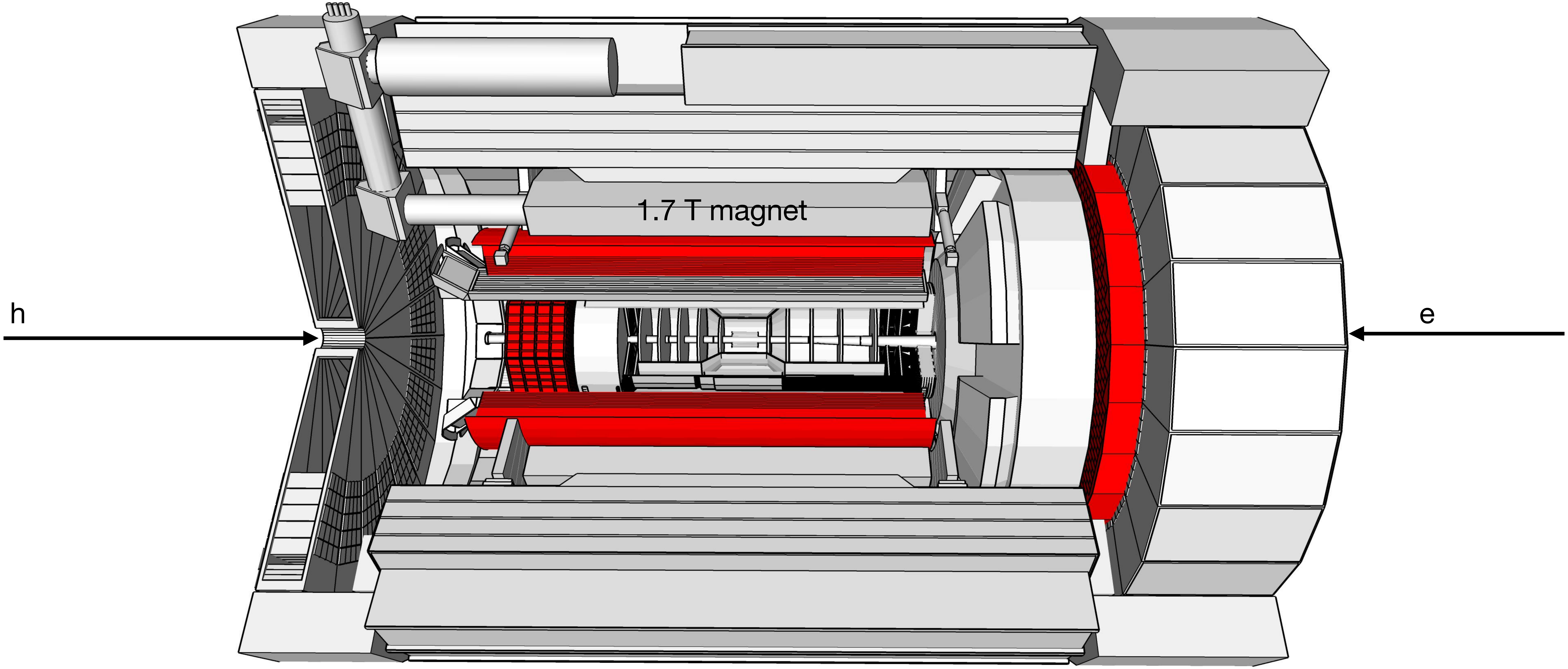
OAK RIDGE National Laboratory ePIC

TOF Simulations in ePIC

Particle identification: coverage

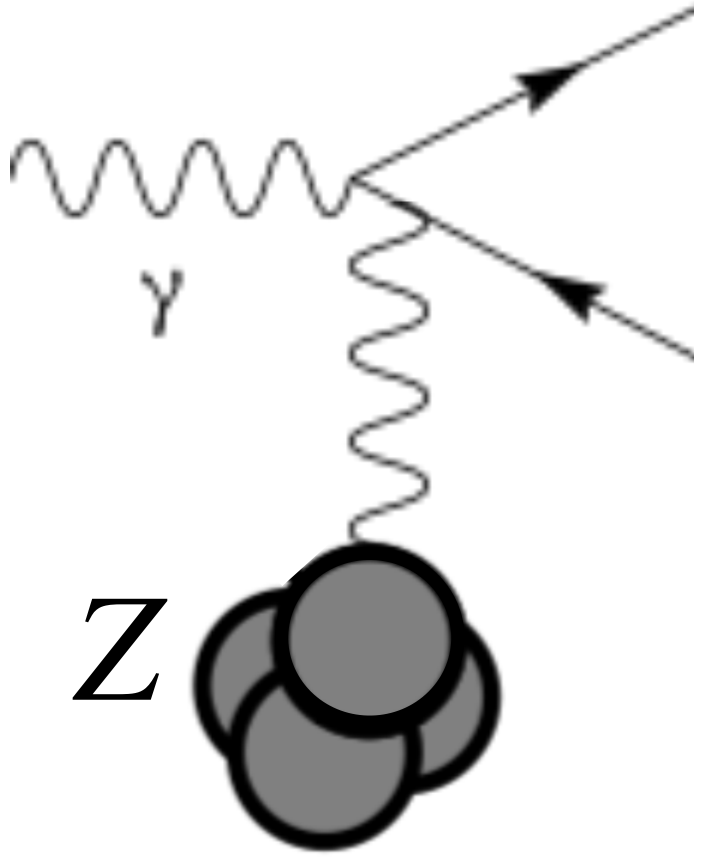


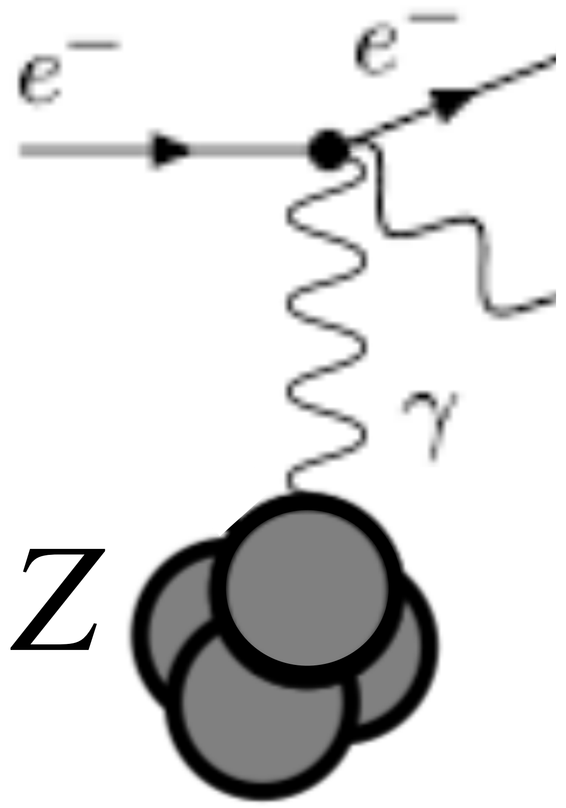
Electromagnetic calorimeter



Electromagnetic calorimeter

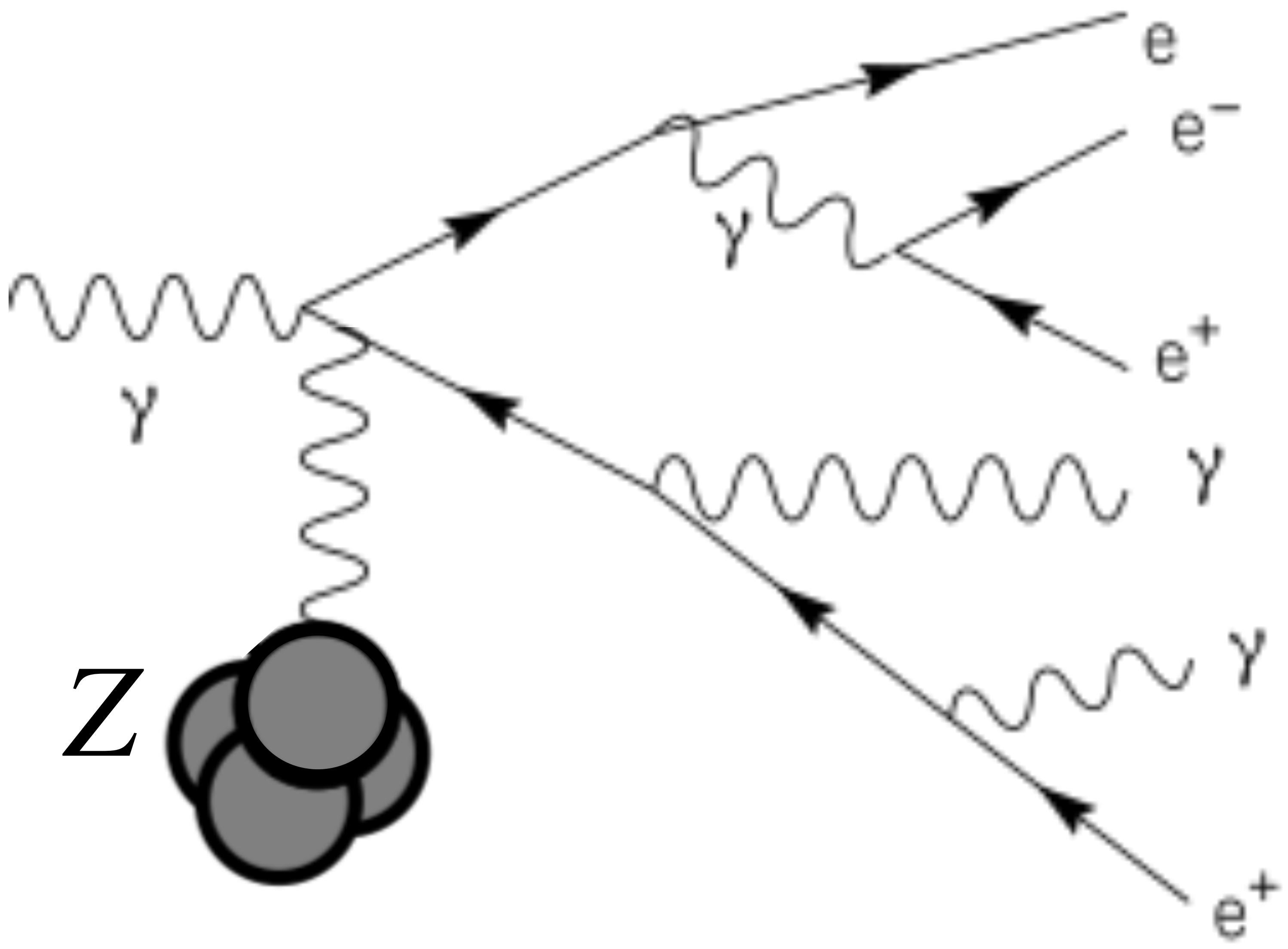
Electromagnetic showers

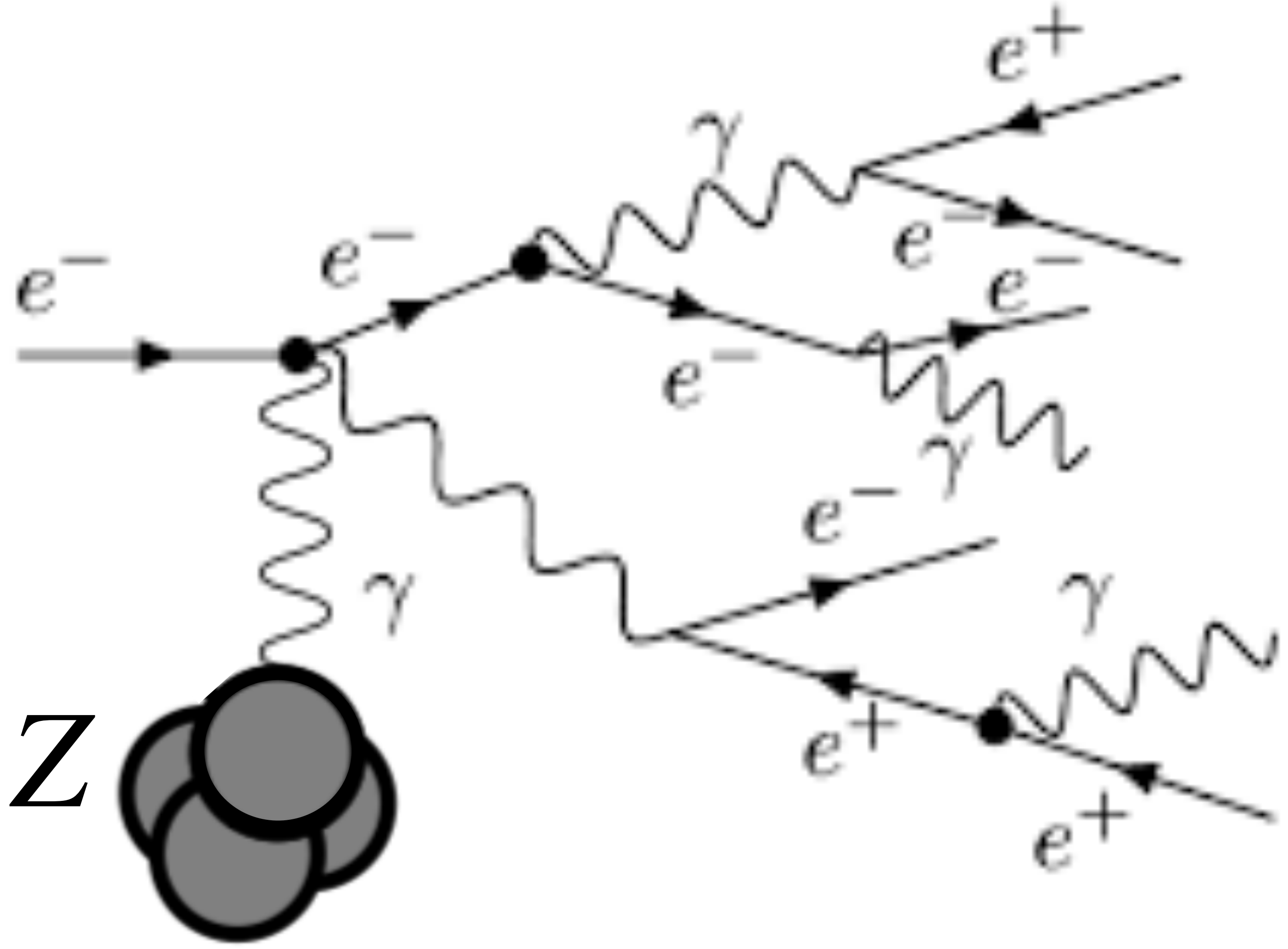




Electromagnetic calorimeter

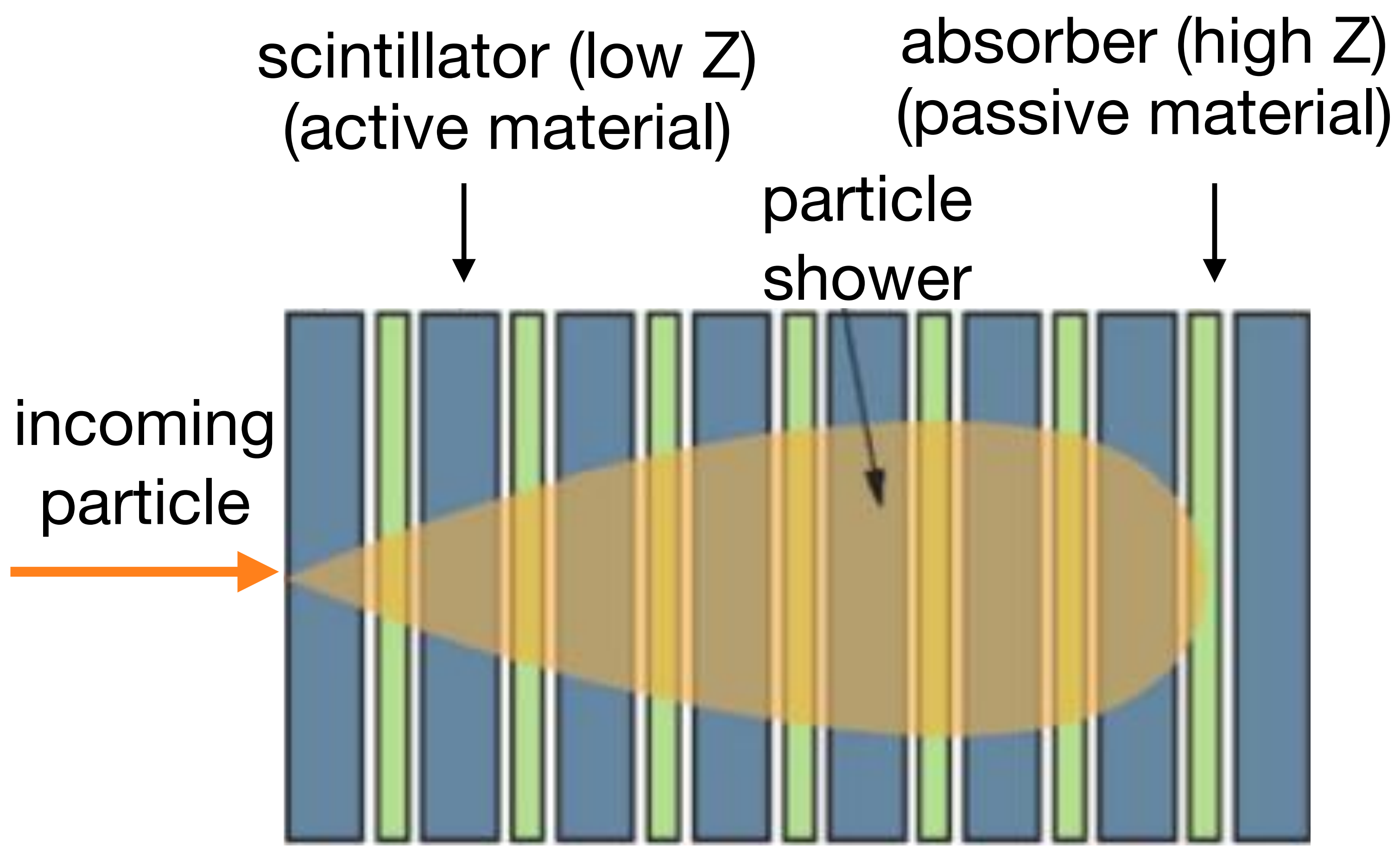
Electromagnetic showers

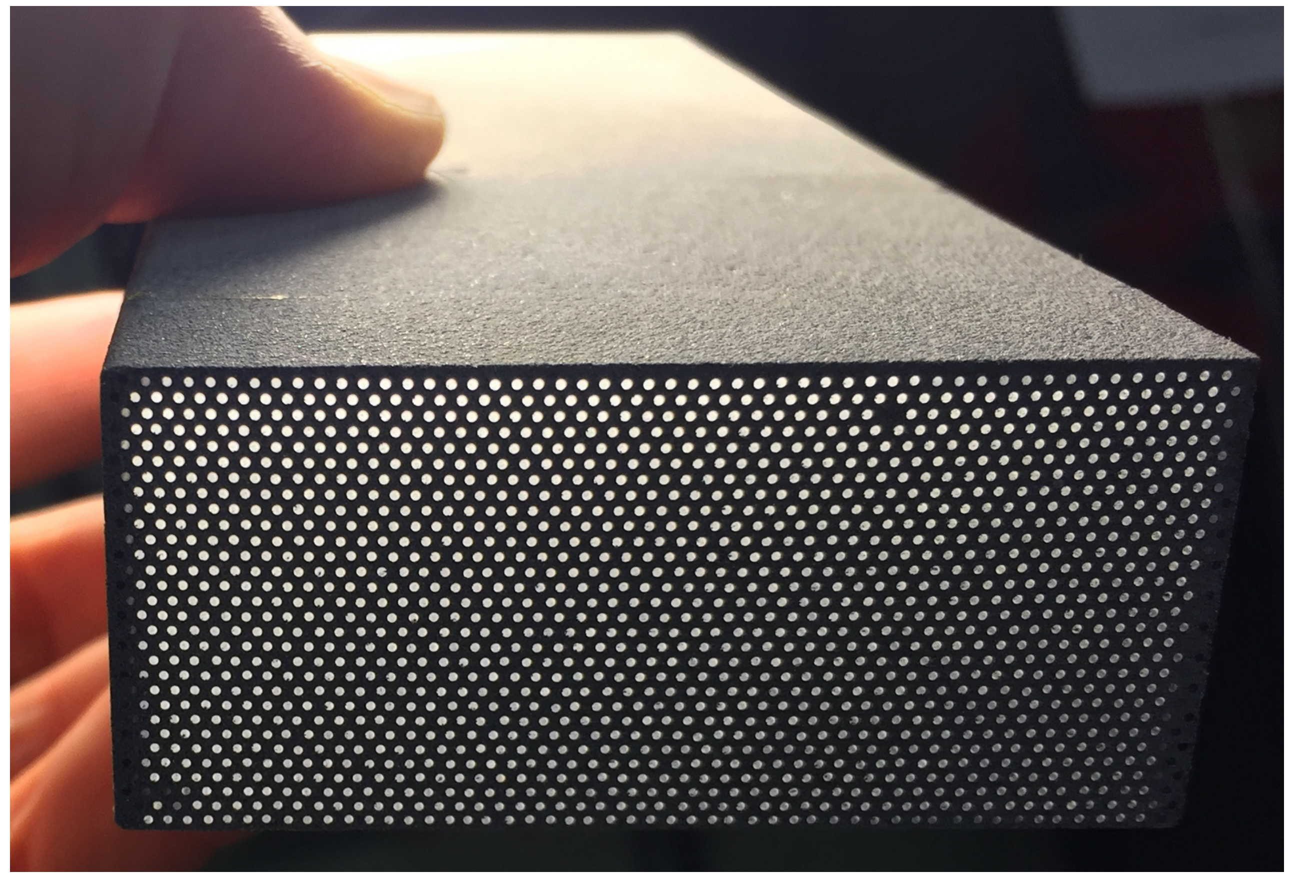


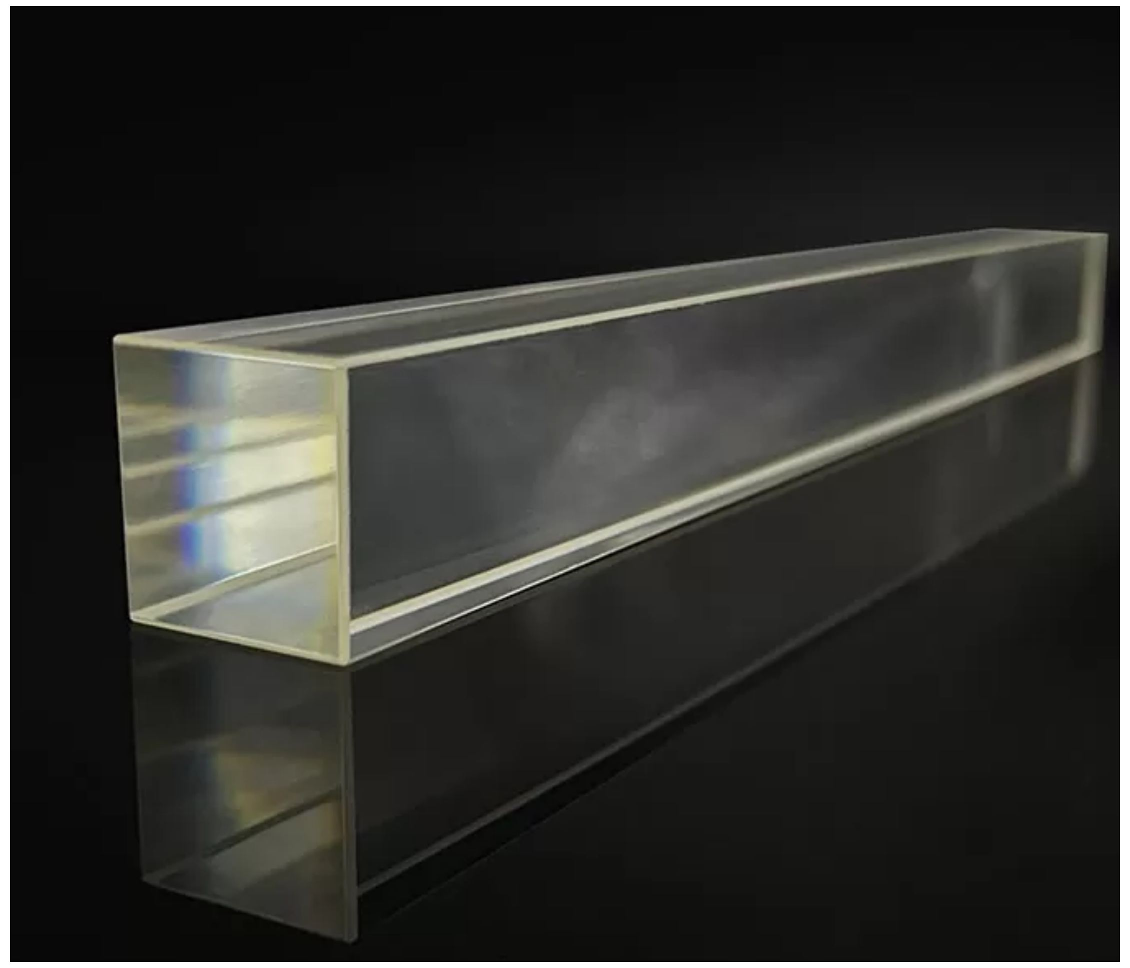


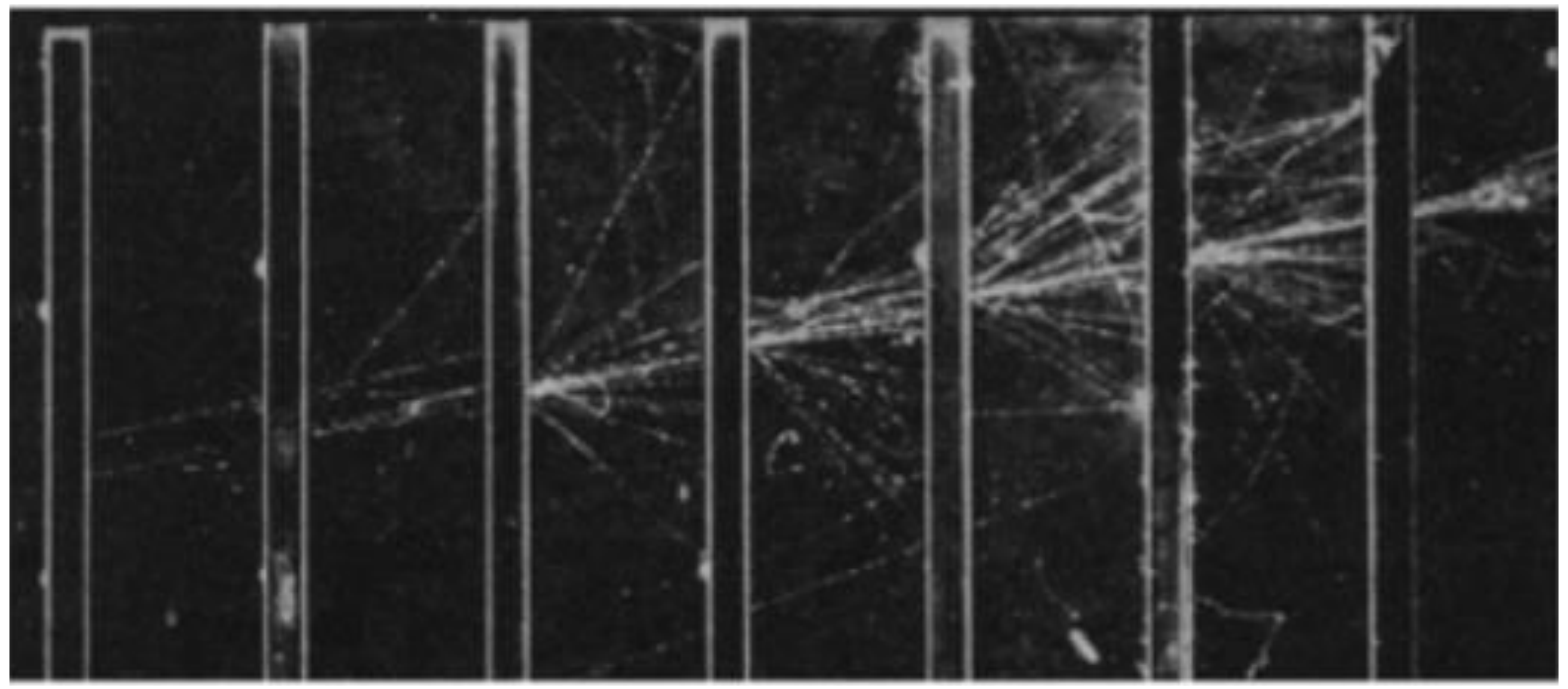
Electromagnetic calorimeter

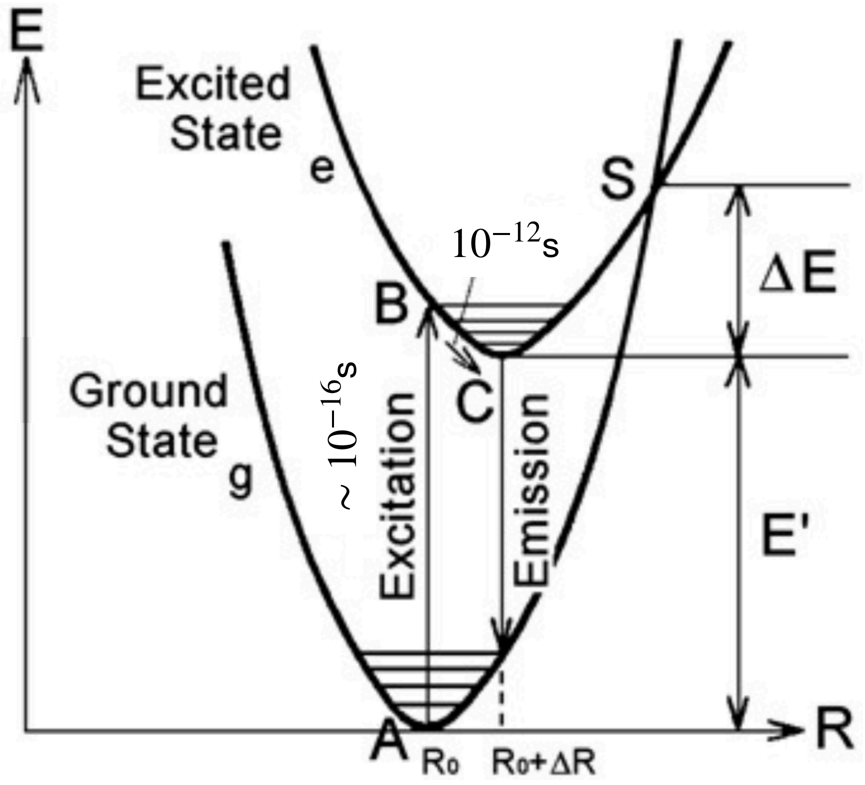
Reconstruction of electromagnetic showers

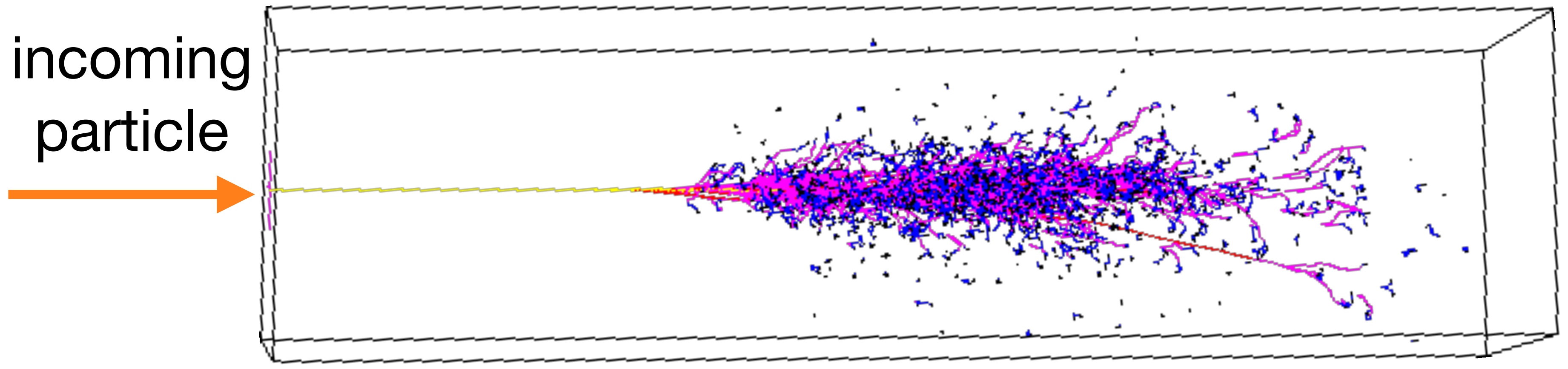




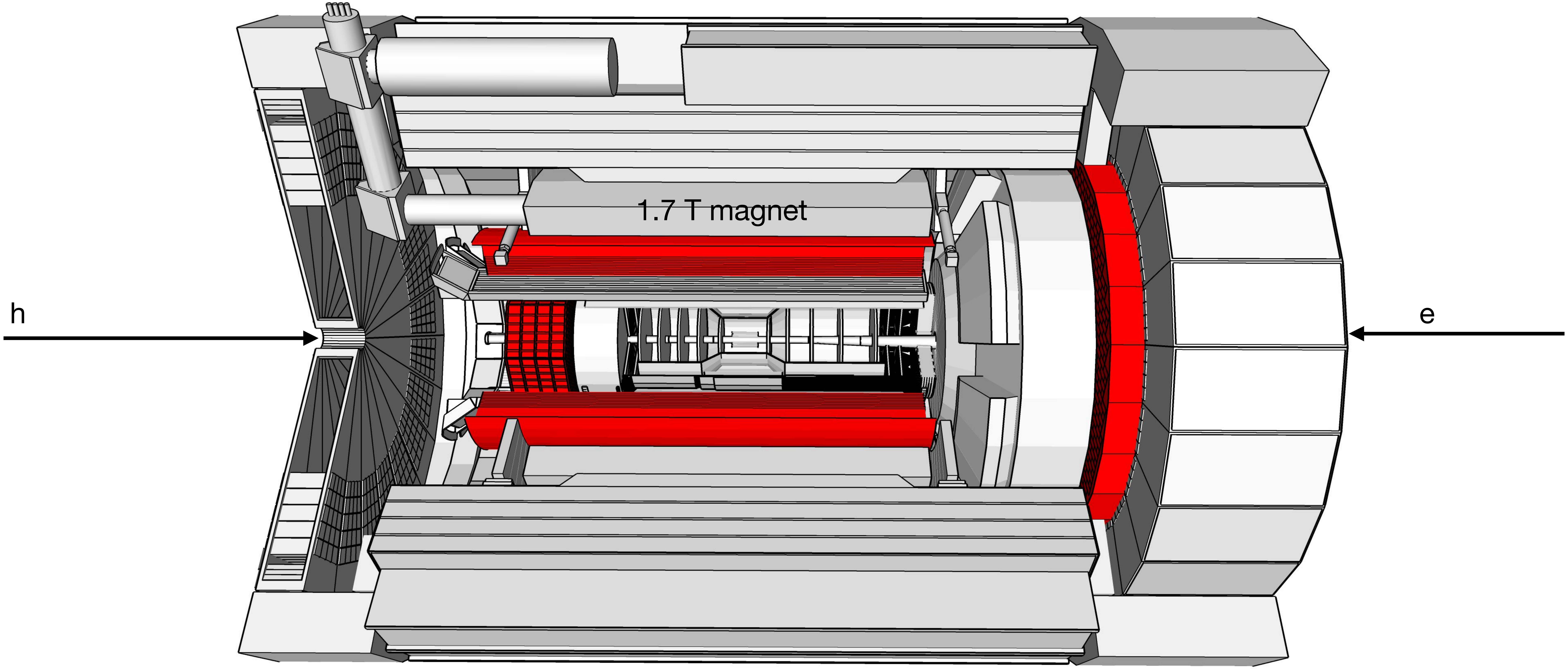




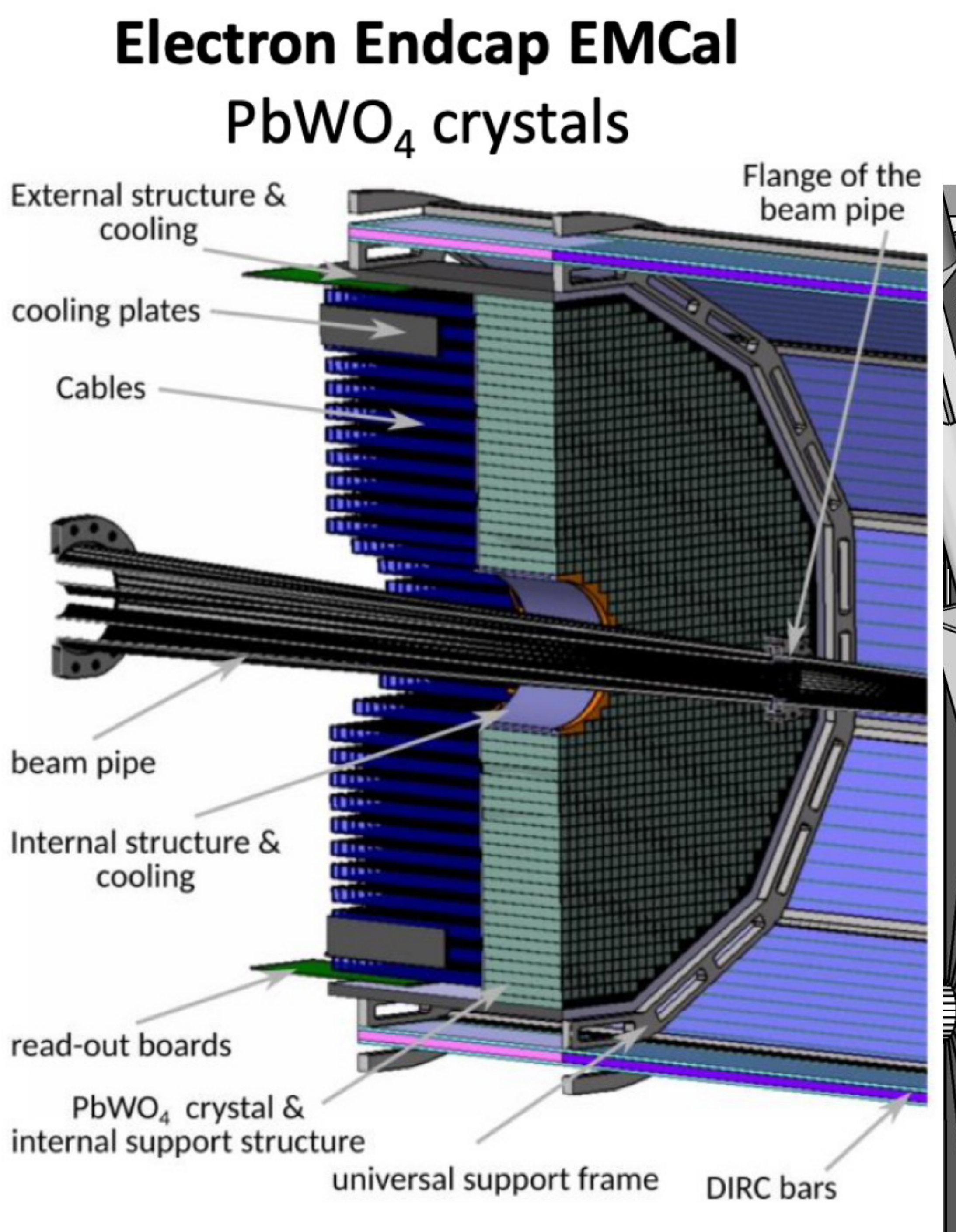


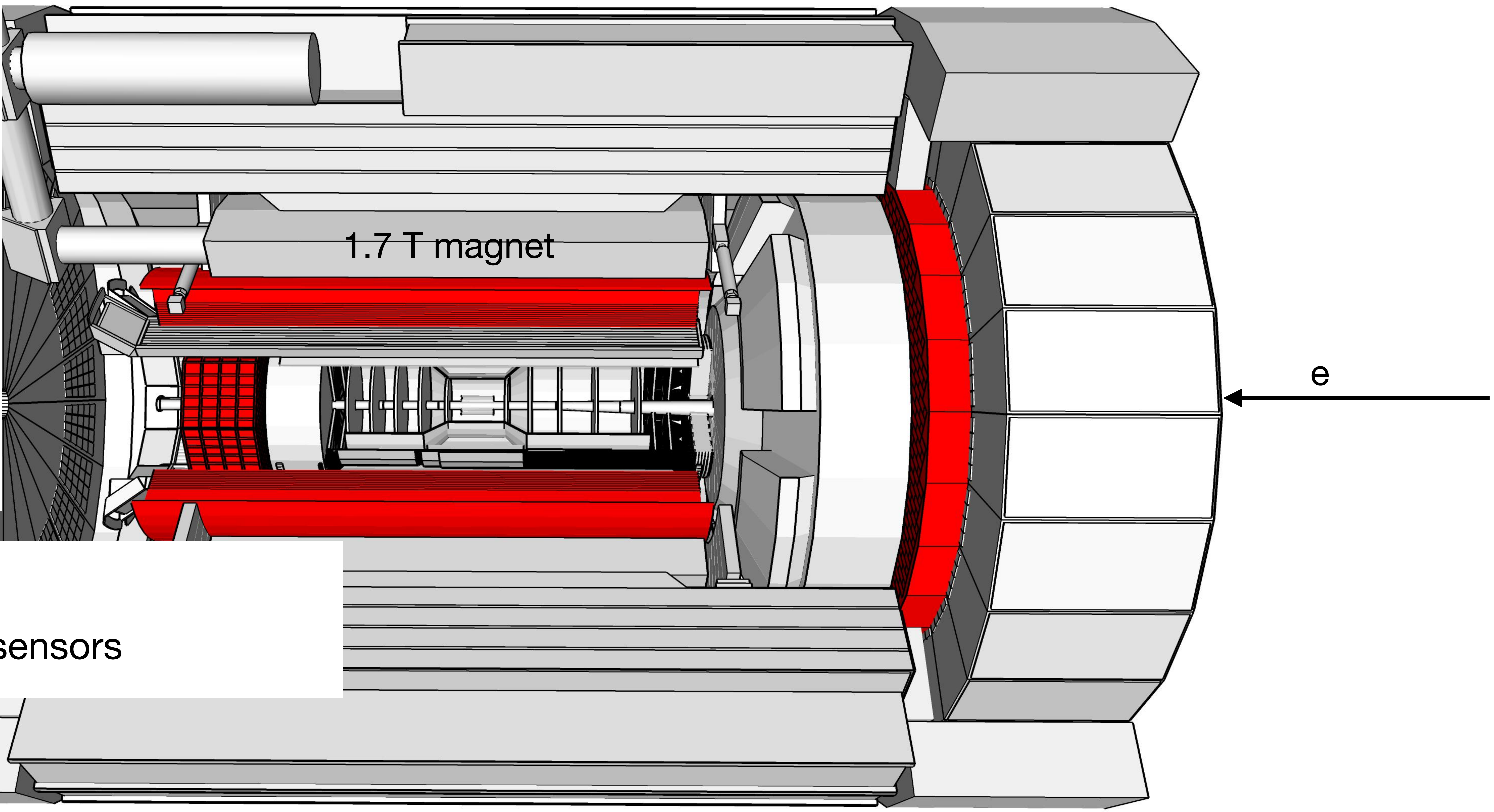


Electromagnetic calorimeter



Electromagnetic calorimeter



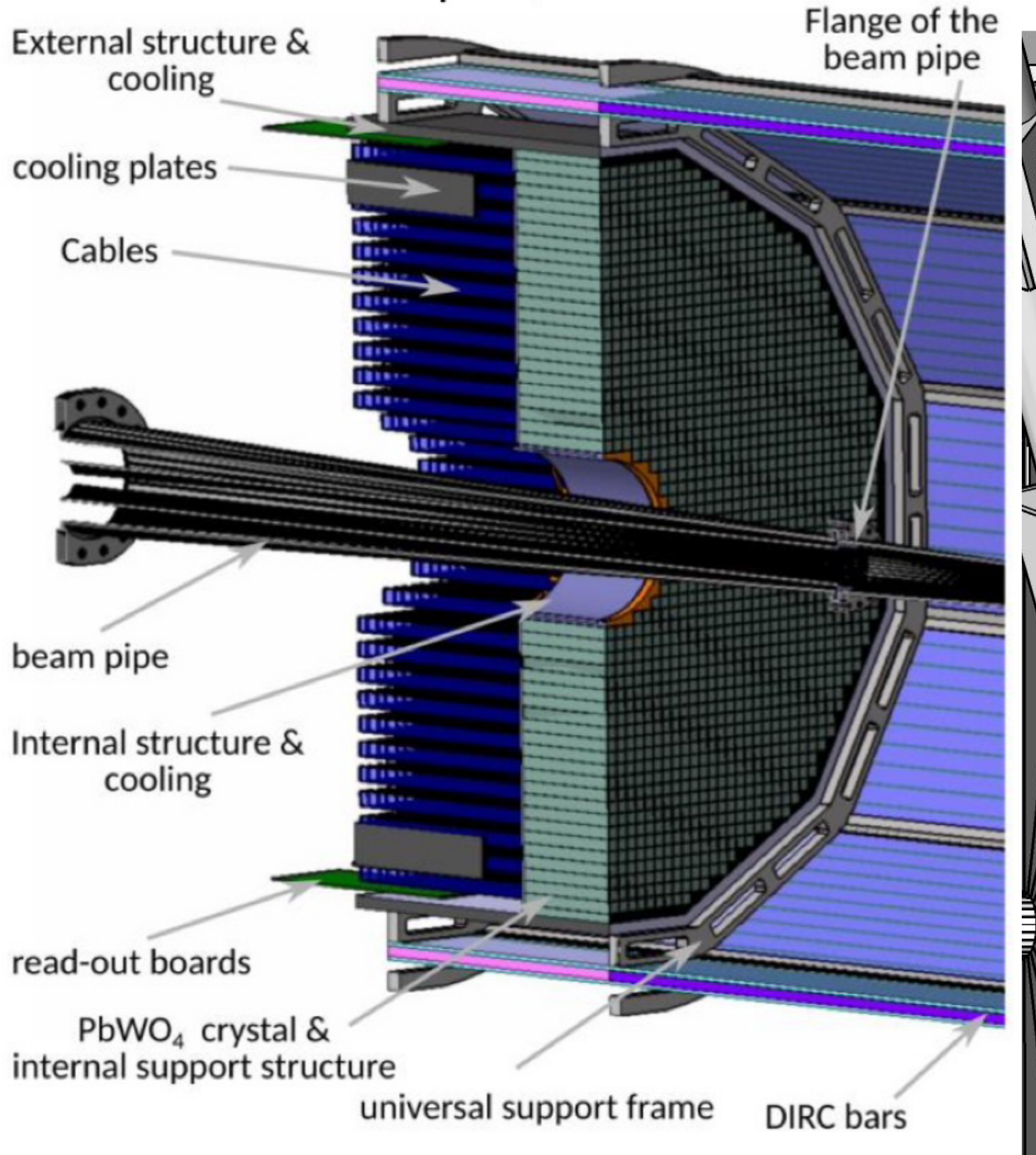


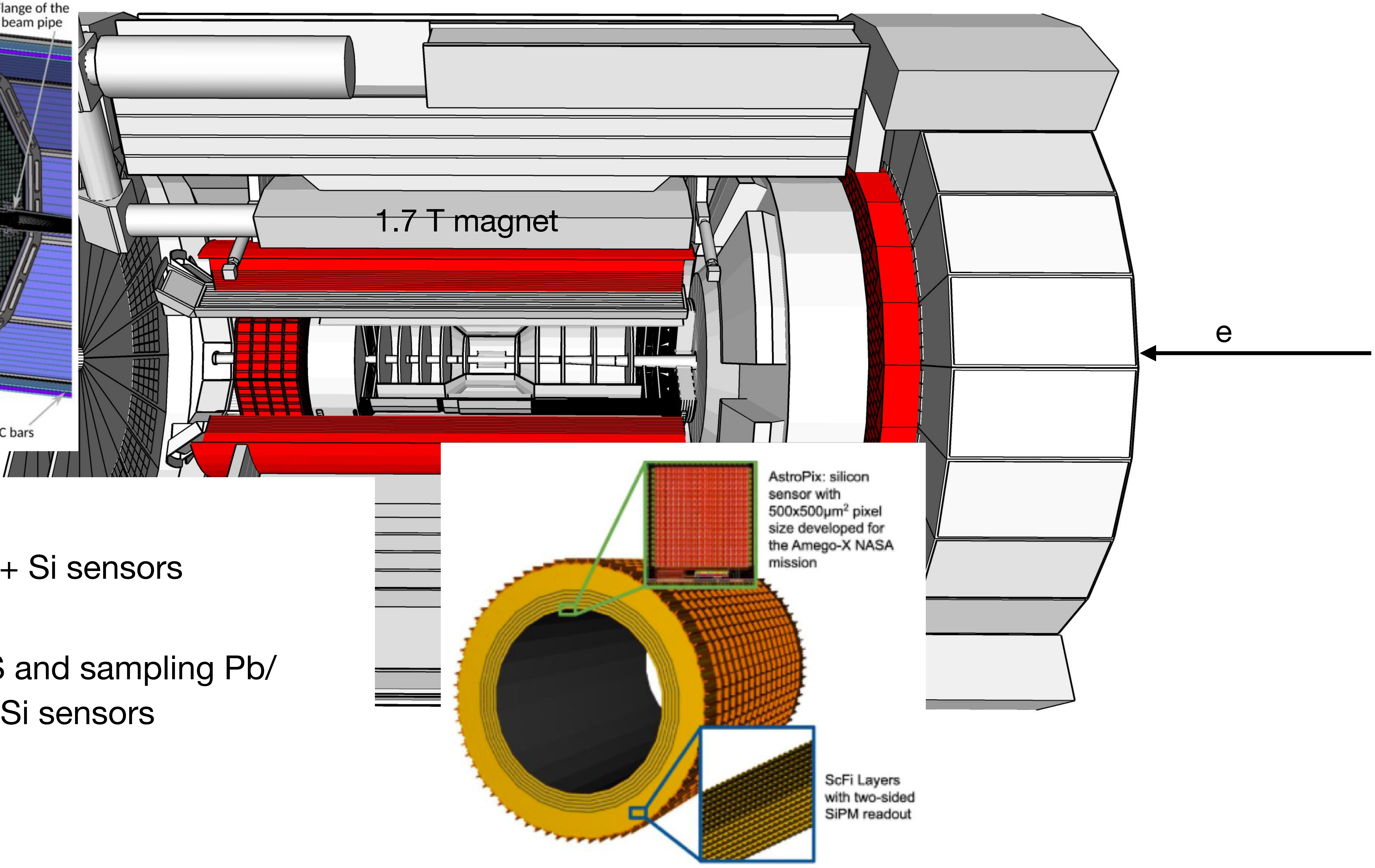
- Backward EMCAL:
  high-precision $PbWO_4$ + Si sensors

Electromagnetic calorimeter

Electron Endcap EMCal

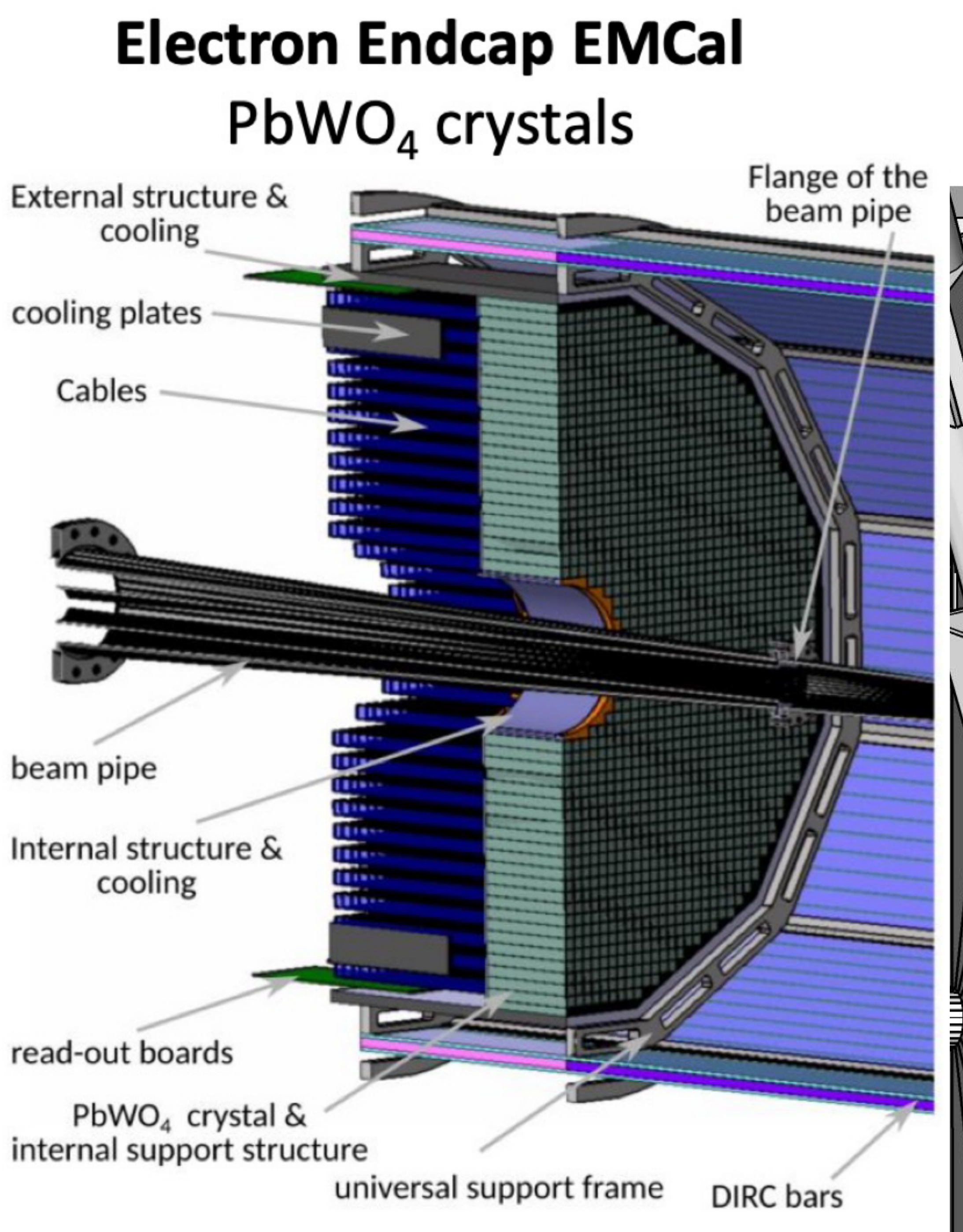
$PbWO_4$ crystals

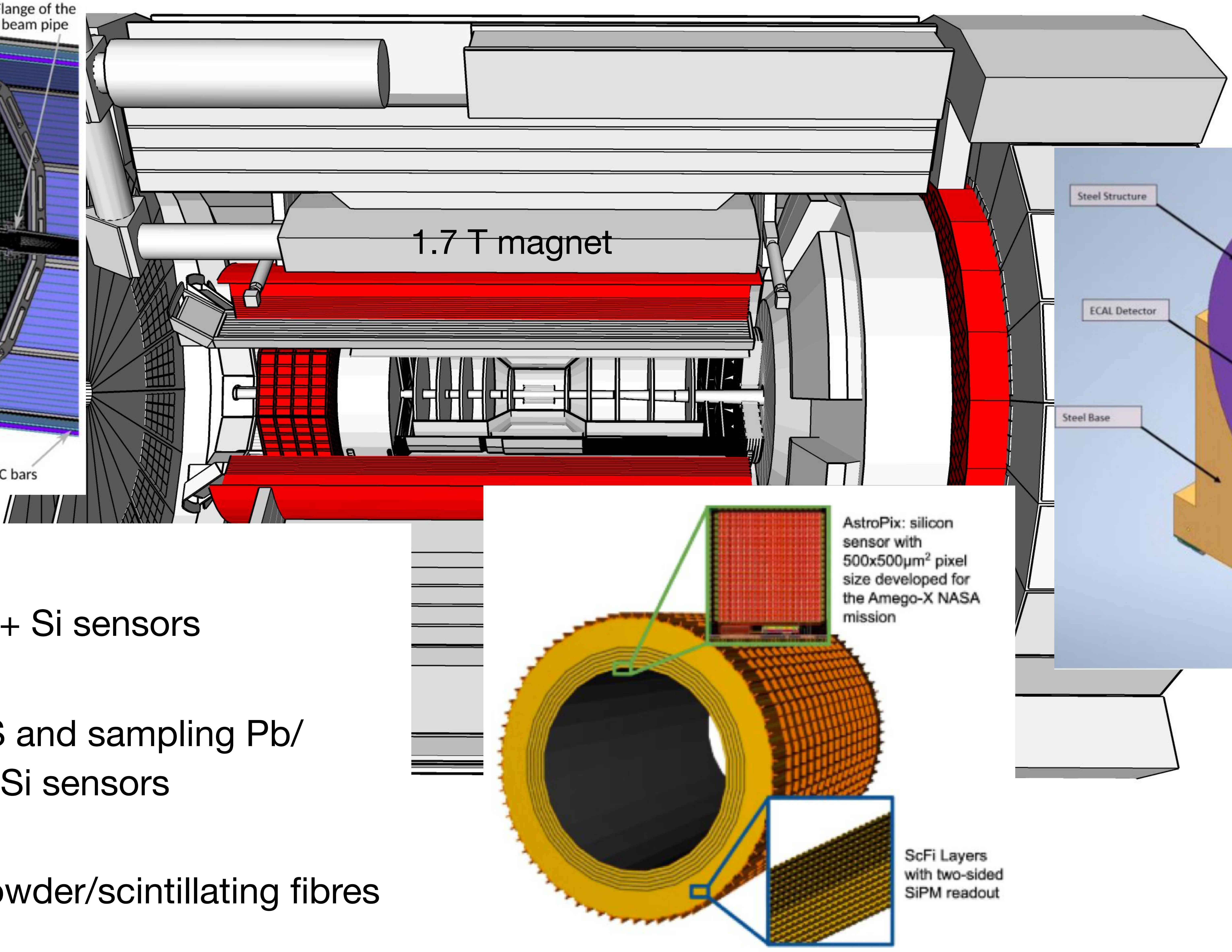


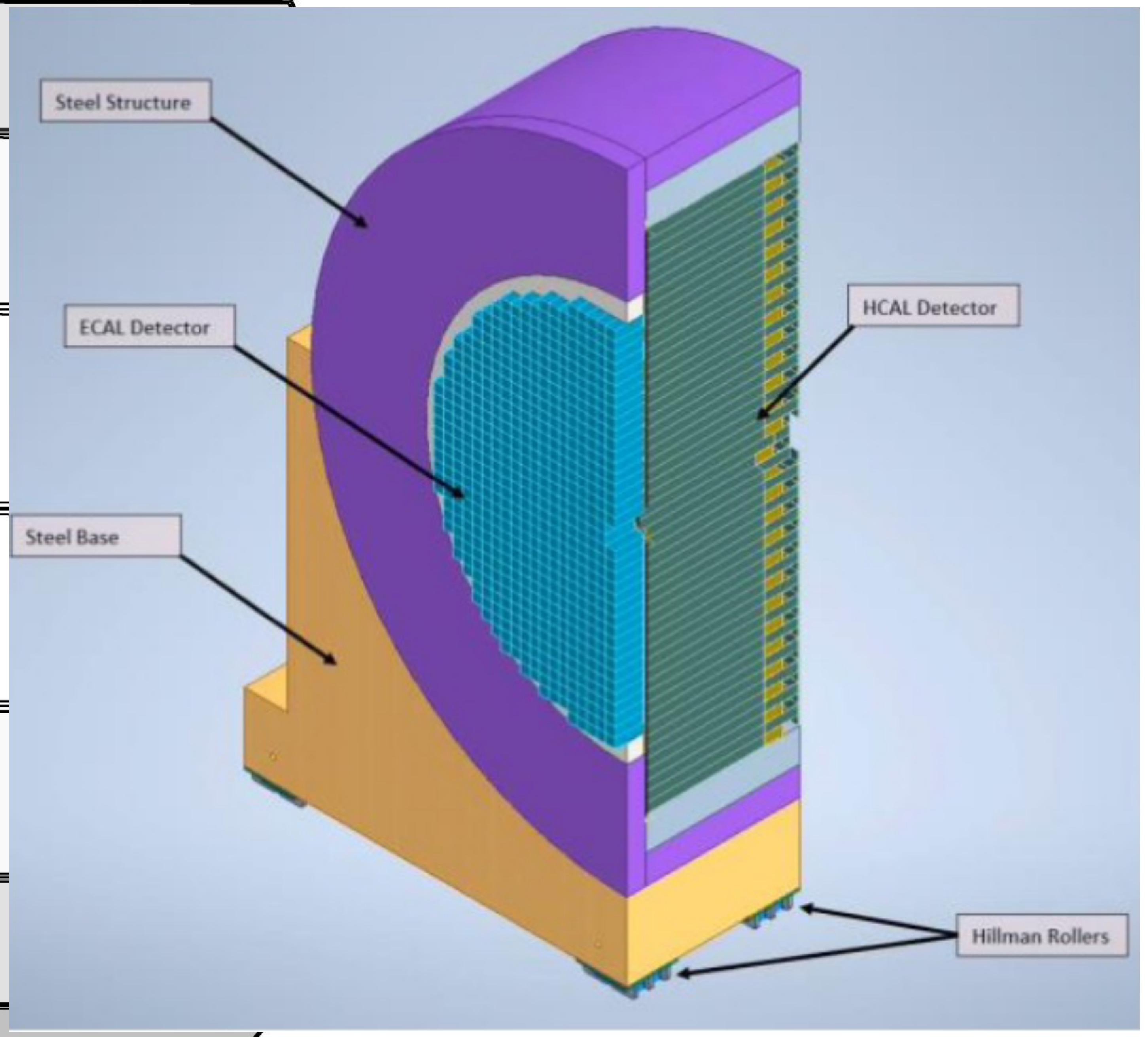


- Backward EMCAL:
  high-precision $PbWO_4$ + Si sensors
- Barrel EMCAL:
  3D imaging with MAPS and sampling Pb/scintillating fibres with Si sensors

Electromagnetic calorimeter

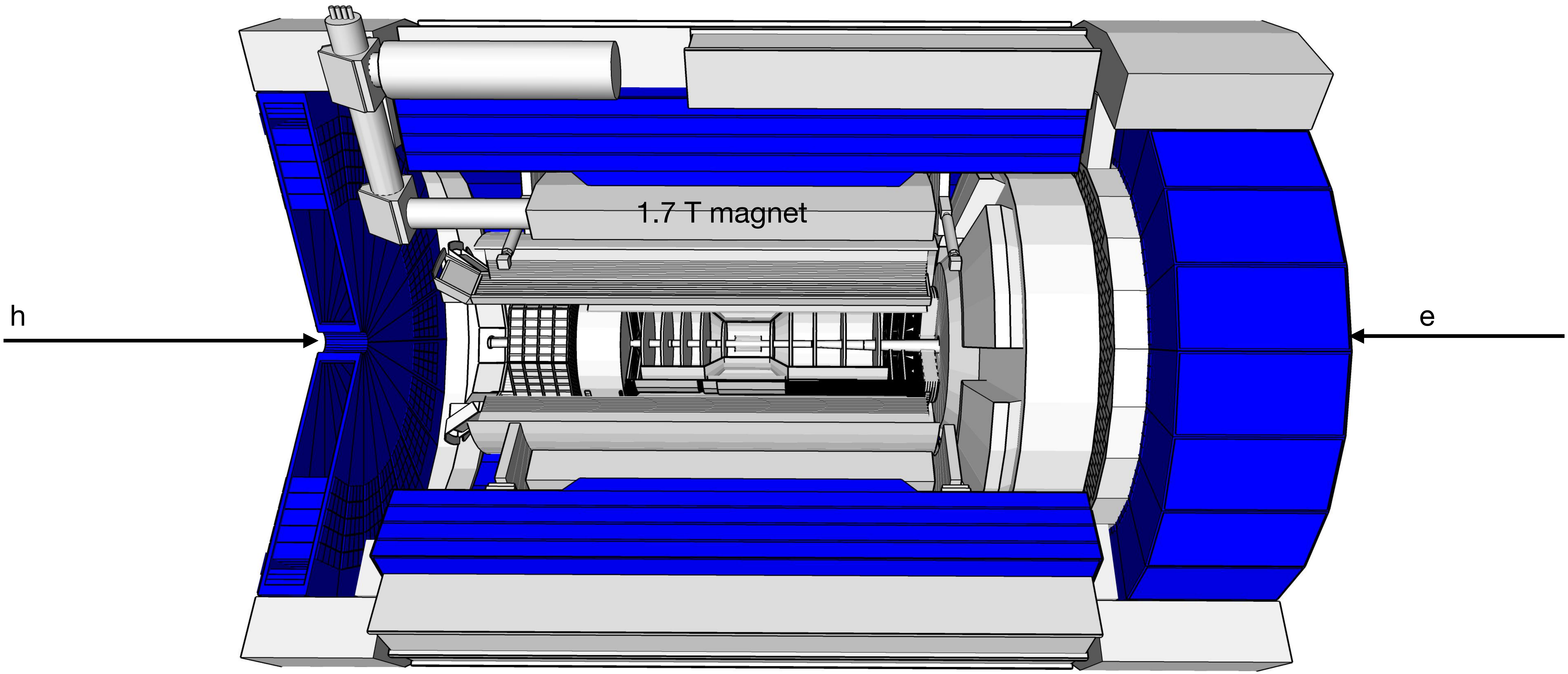






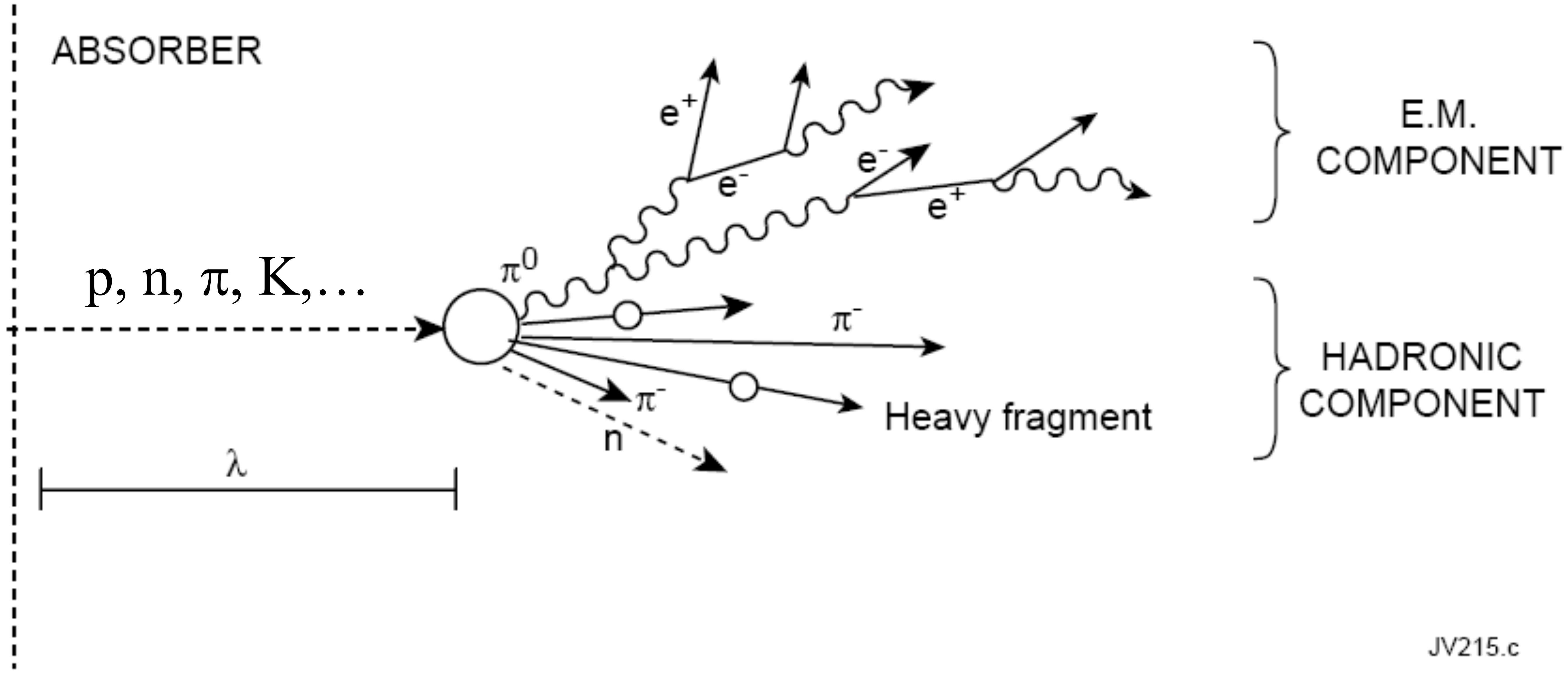
- Backward EMCAL:
  high-precision $PbWO_4$ + Si sensors
- Barrel EMCAL:
  3D imaging with MAPS and sampling Pb/scintillating fibres with Si sensors
- Forward EMCAL:
  finely segmented W powder/scintillating fibres

Hadronic calorimeter



Hadronic calorimeter

Hadronic showers



Hadronic calorimeter

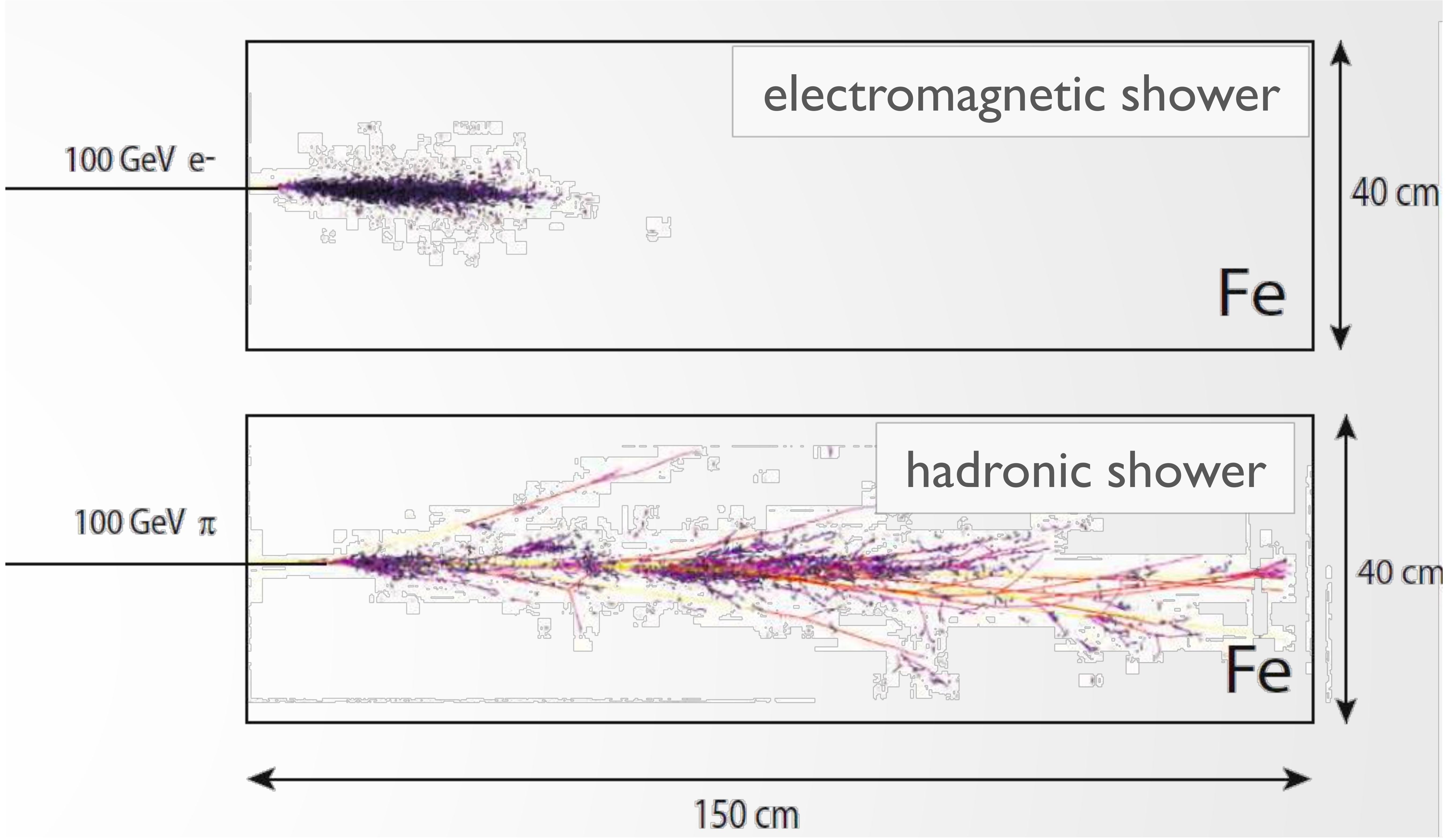
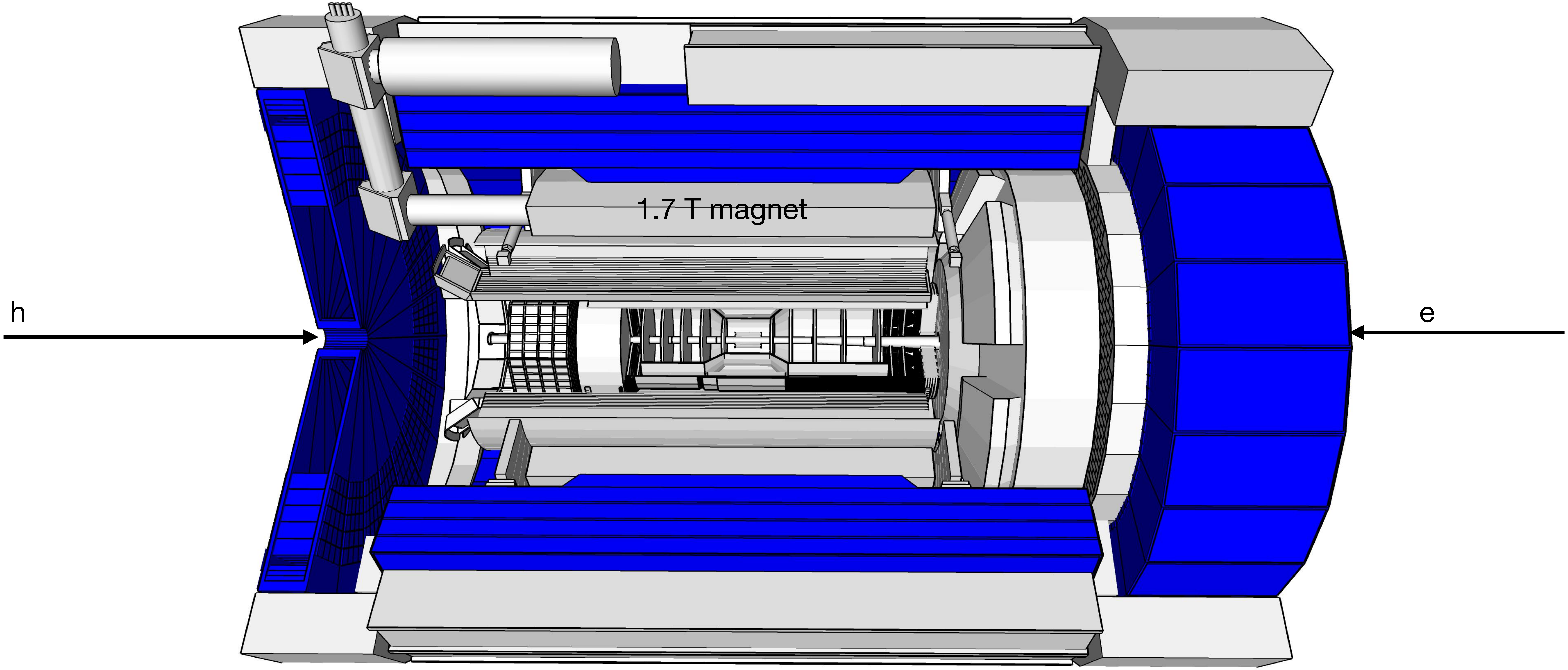
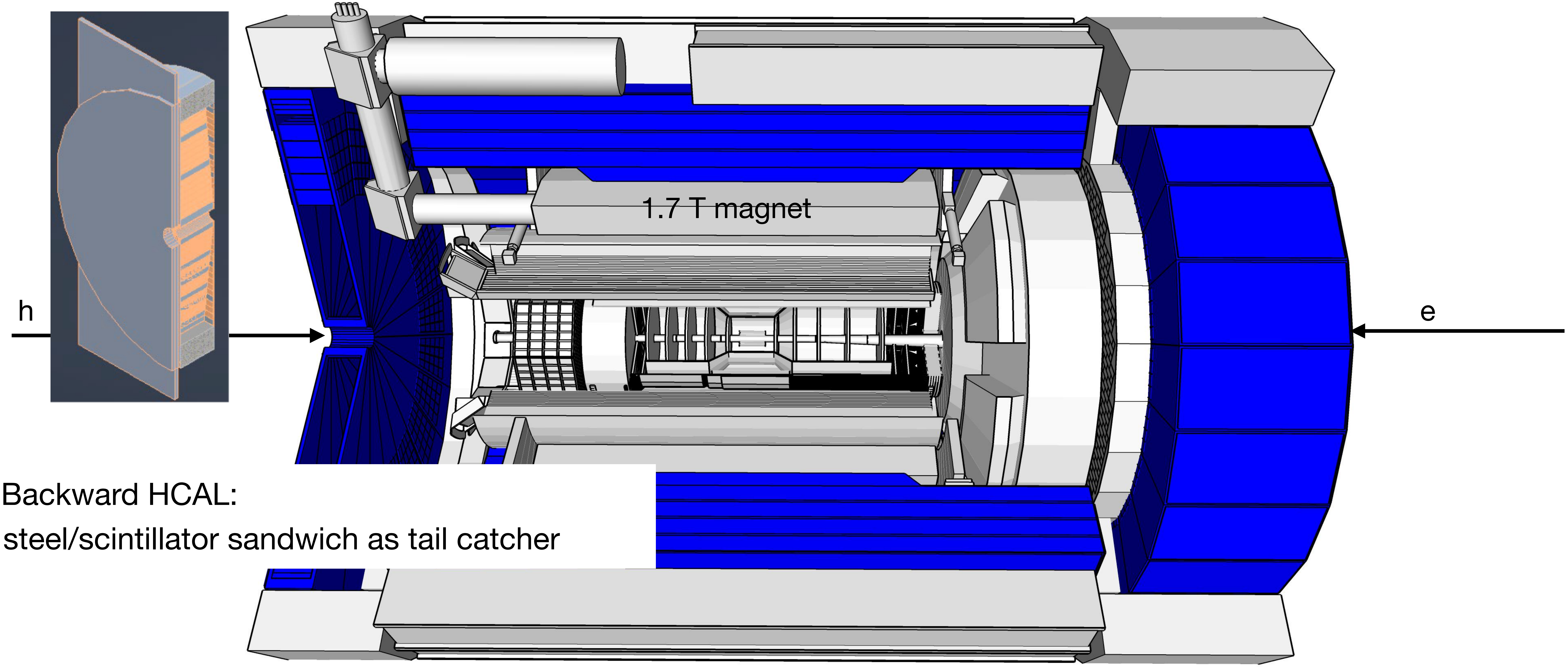


Fig. from R. Schoefbeck
Experimental Particle Physics Lecture
20 Novembre 2020

Hadronic calorimeter

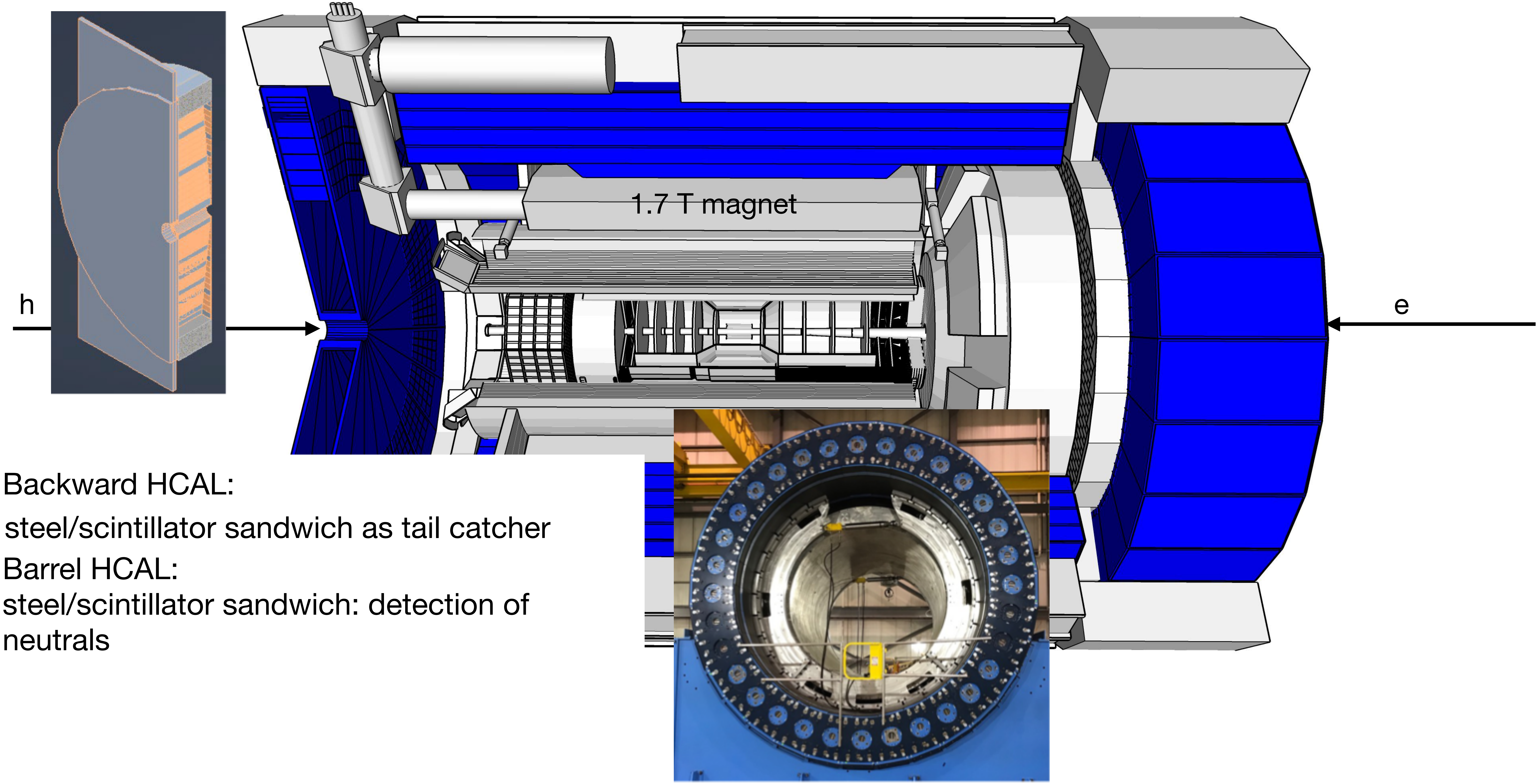


Hadronic calorimeter



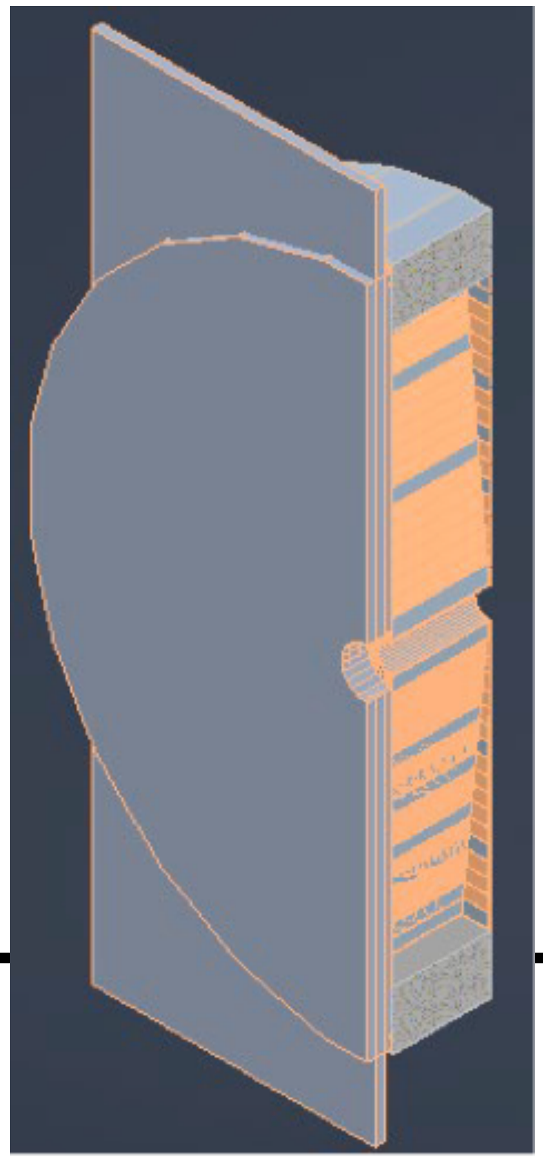
- Backward HCAL:
  steel/scintillator sandwich as tail catcher

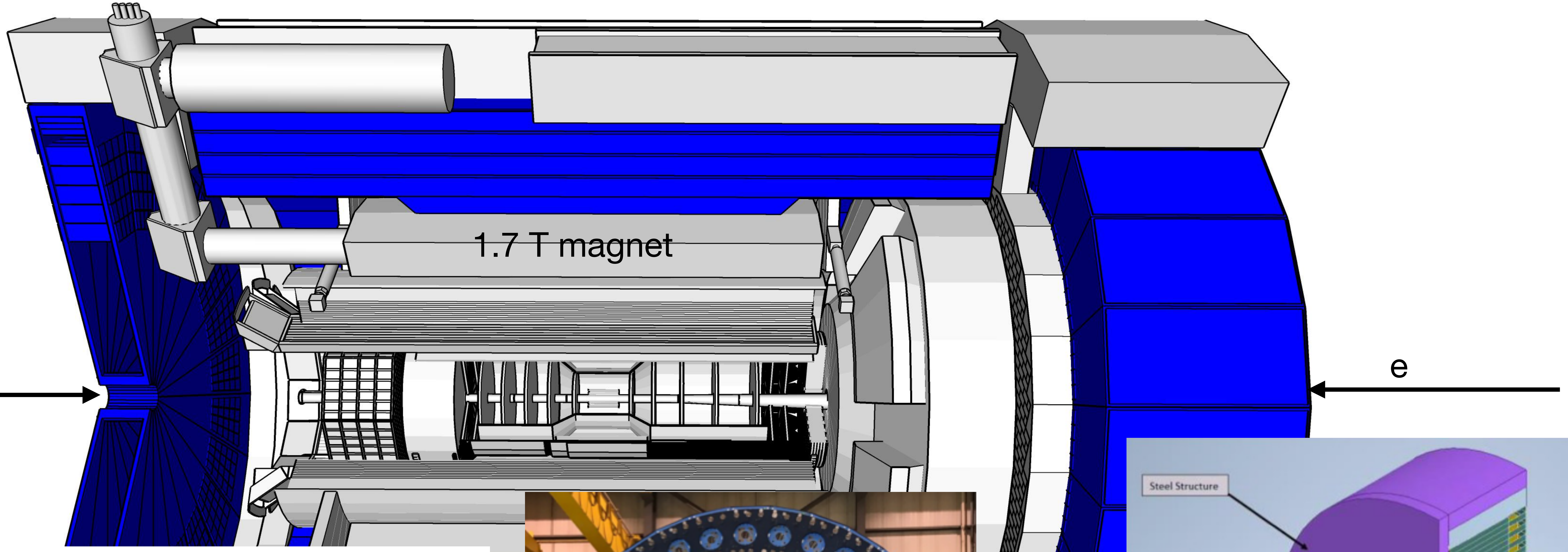
Hadronic calorimeter



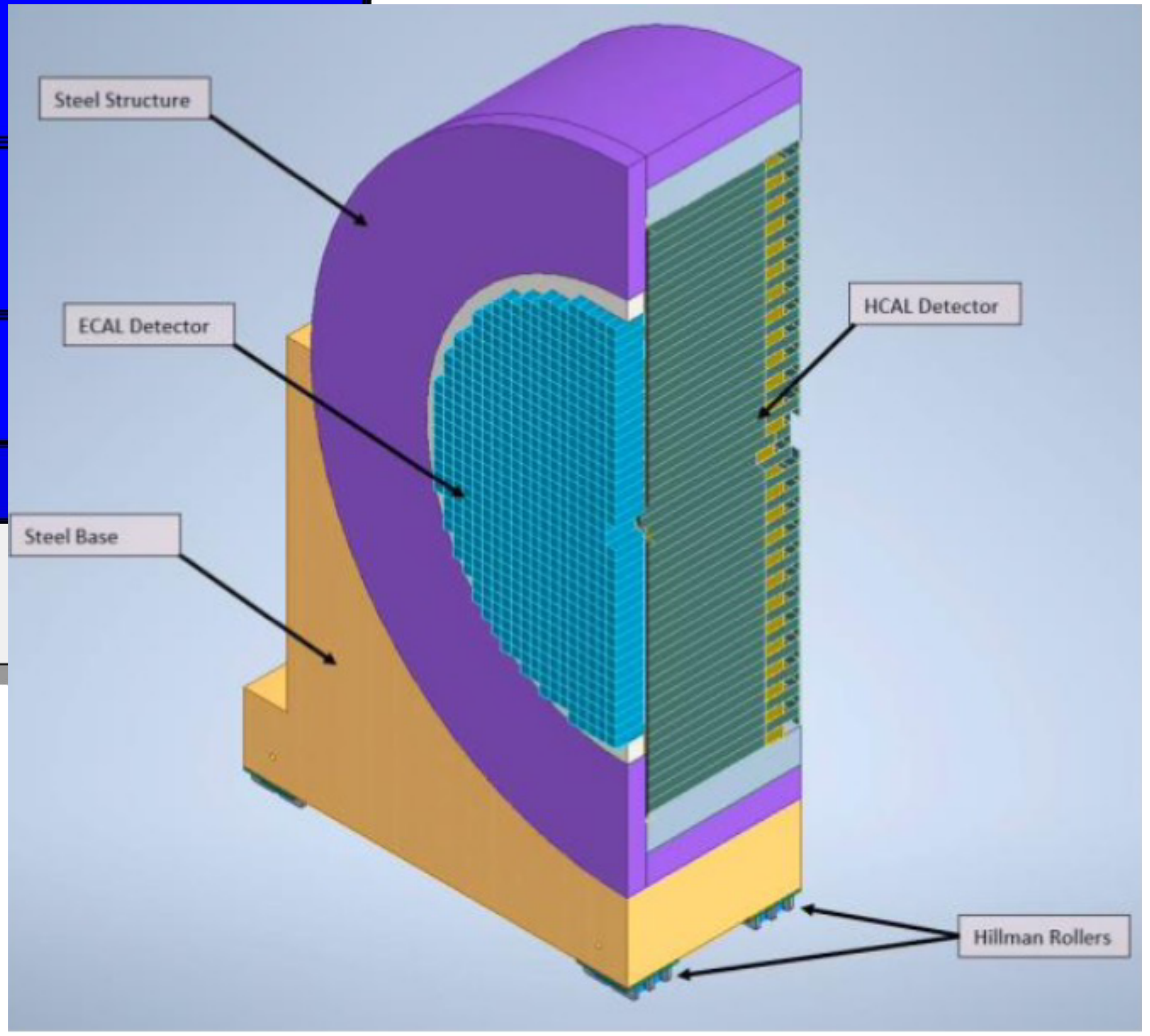
- Backward HCAL:
  steel/scintillator sandwich as tail catcher
- Barrel HCAL:
  steel/scintillator sandwich: detection of neutrals

Hadronic calorimeter

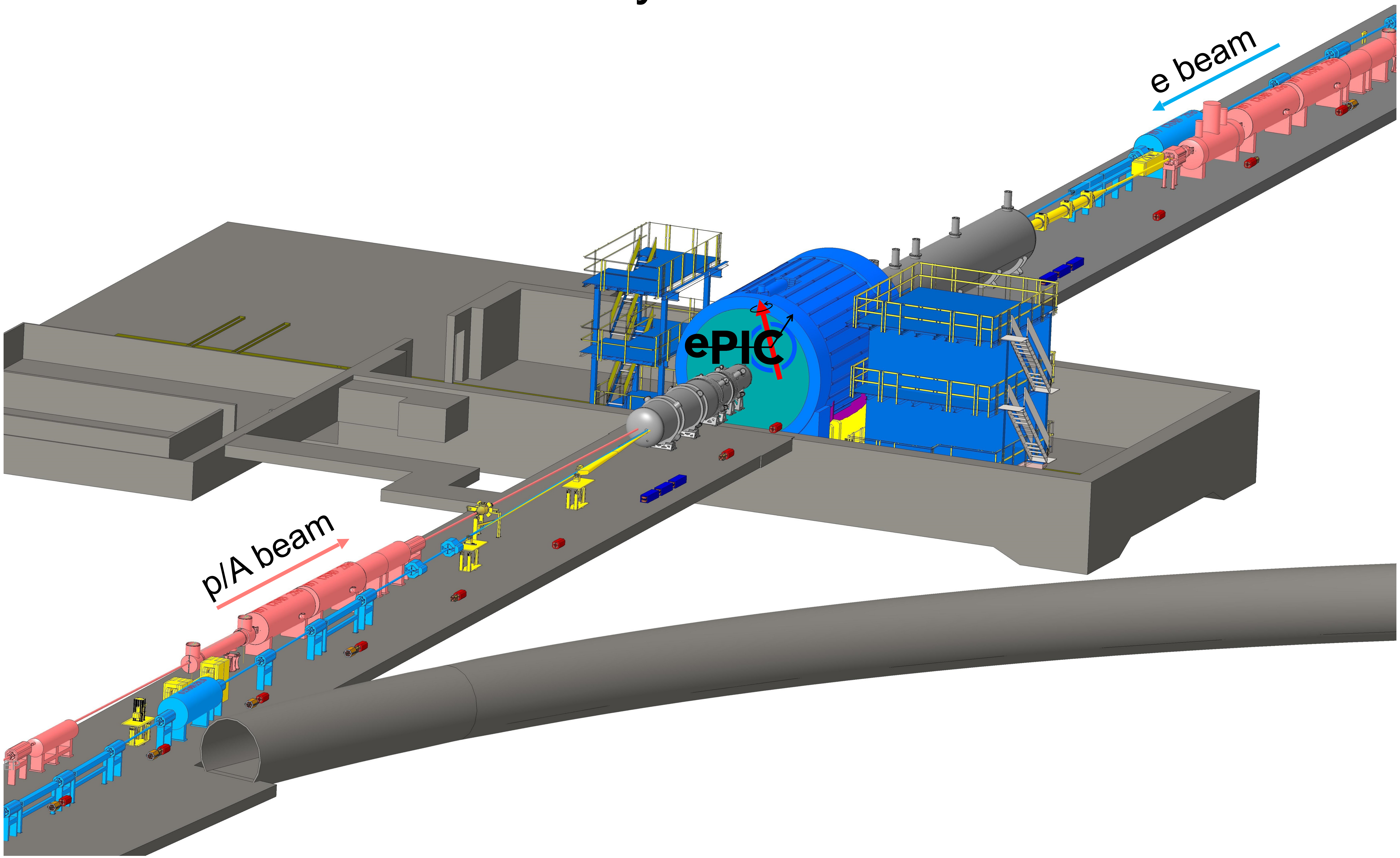




- Backward HCAL:
  steel/scintillator sandwich as tail catcher
- Barrel HCAL:
  steel/scintillator sandwich: detection of neutrals
- Forward HCAL:
  steel/scintillator sandwich longitudinally segmented, high granularity: good E resolution



Far-backward and far-forward systems



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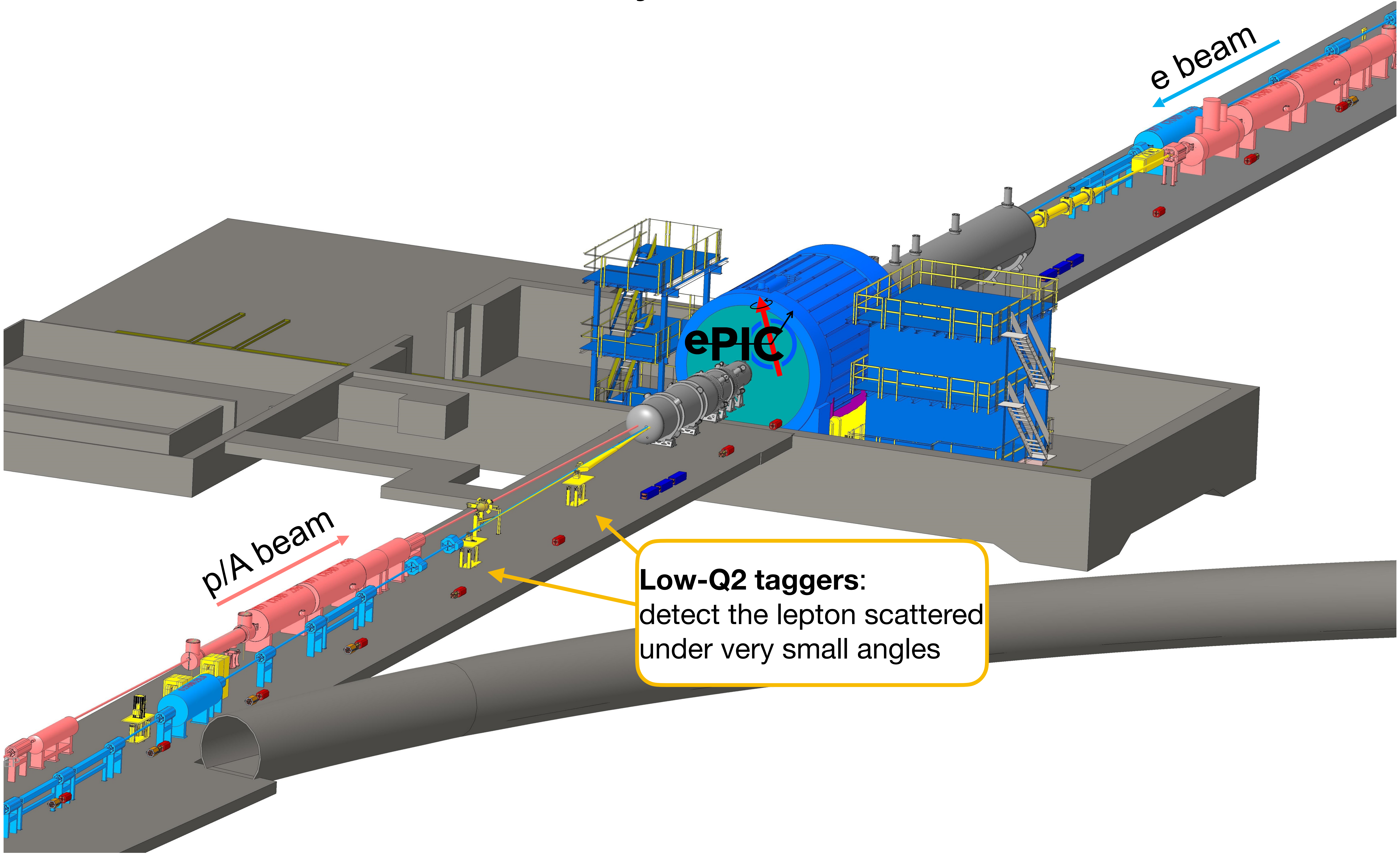
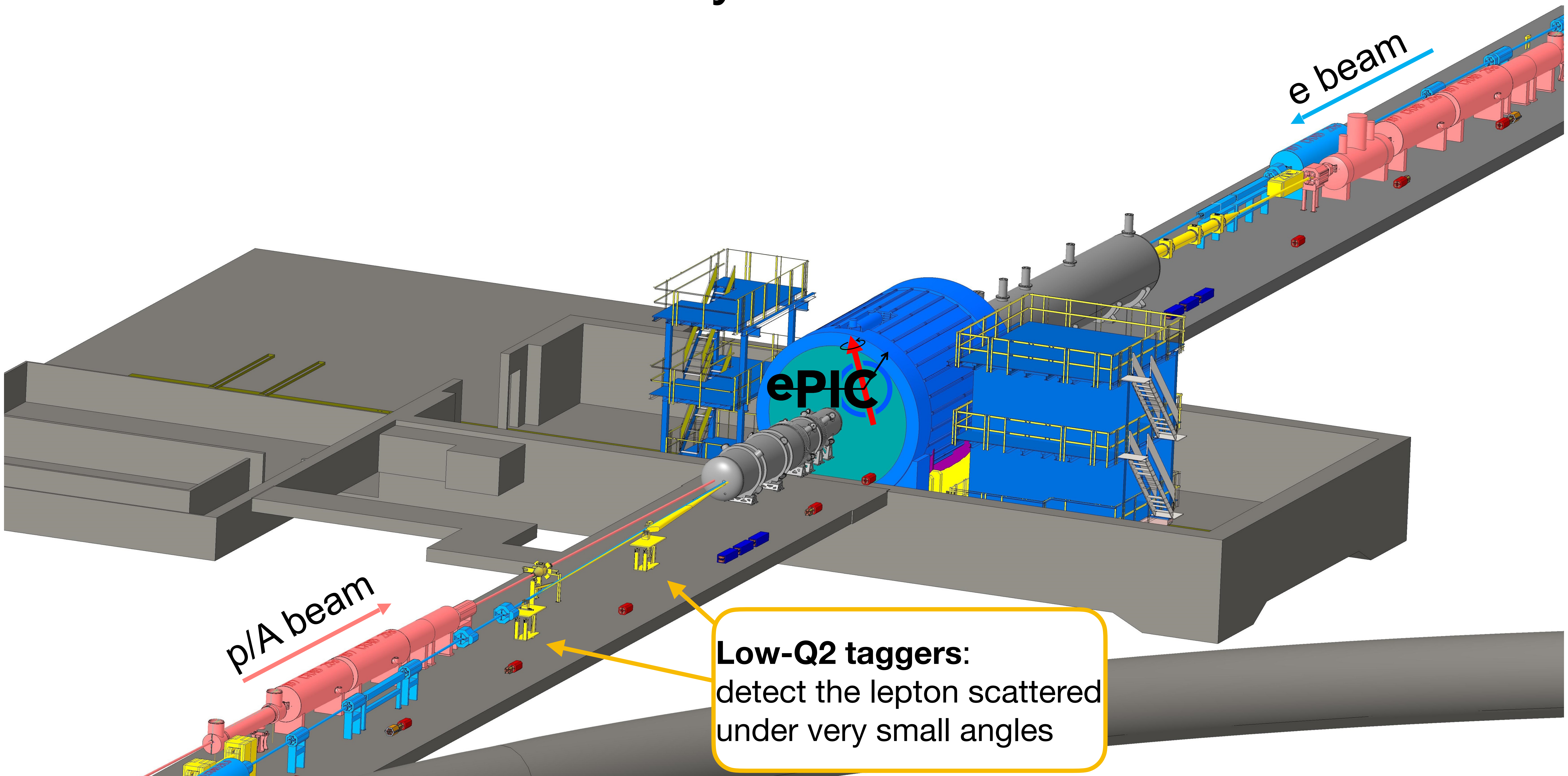
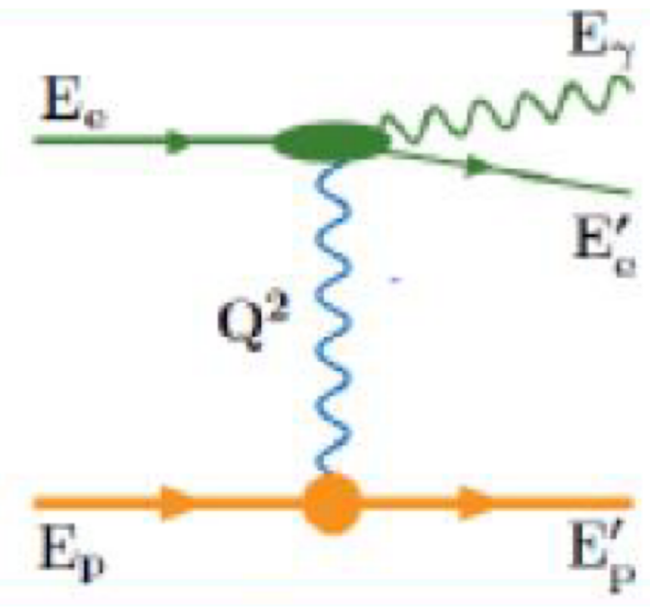


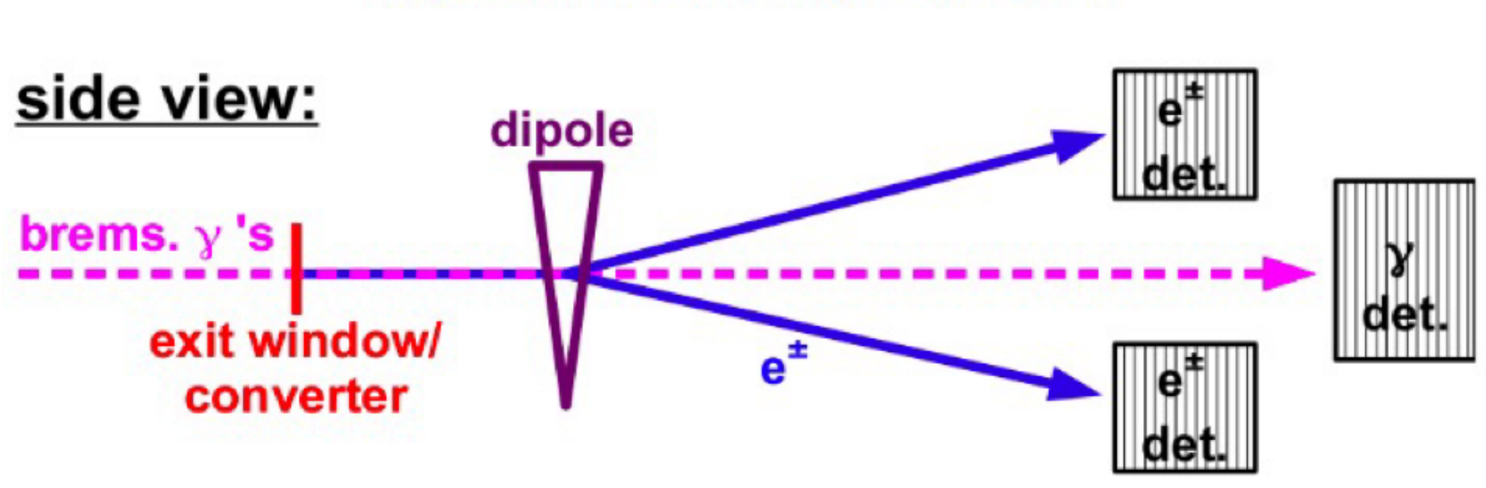
Far-backward and far-forward systems



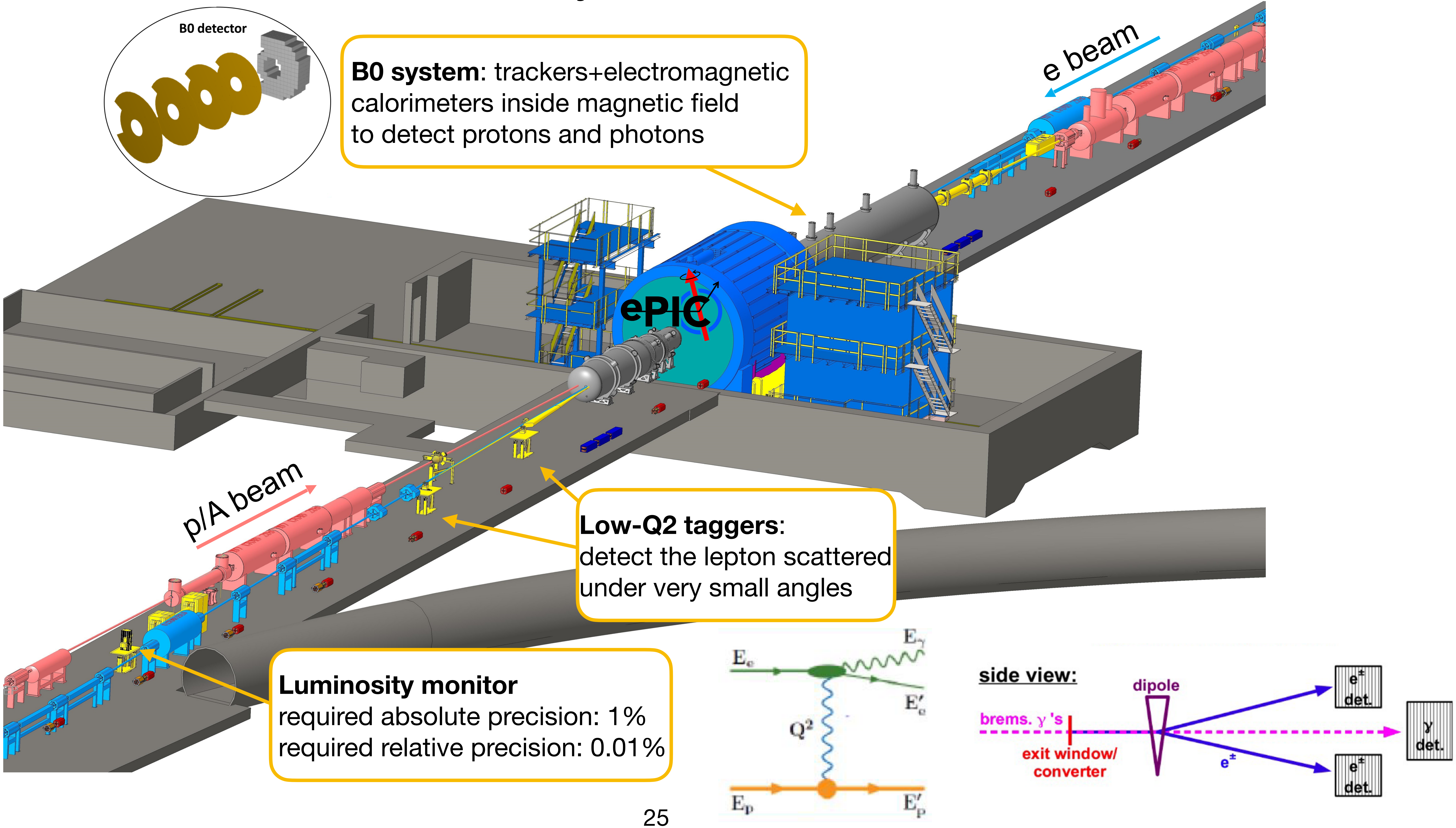
Low-Q2 taggers:
detect the lepton scattered
under very small angles

Luminosity monitor
required absolute precision: 1%
required relative precision: 0.01%





Far-backward and far-forward systems

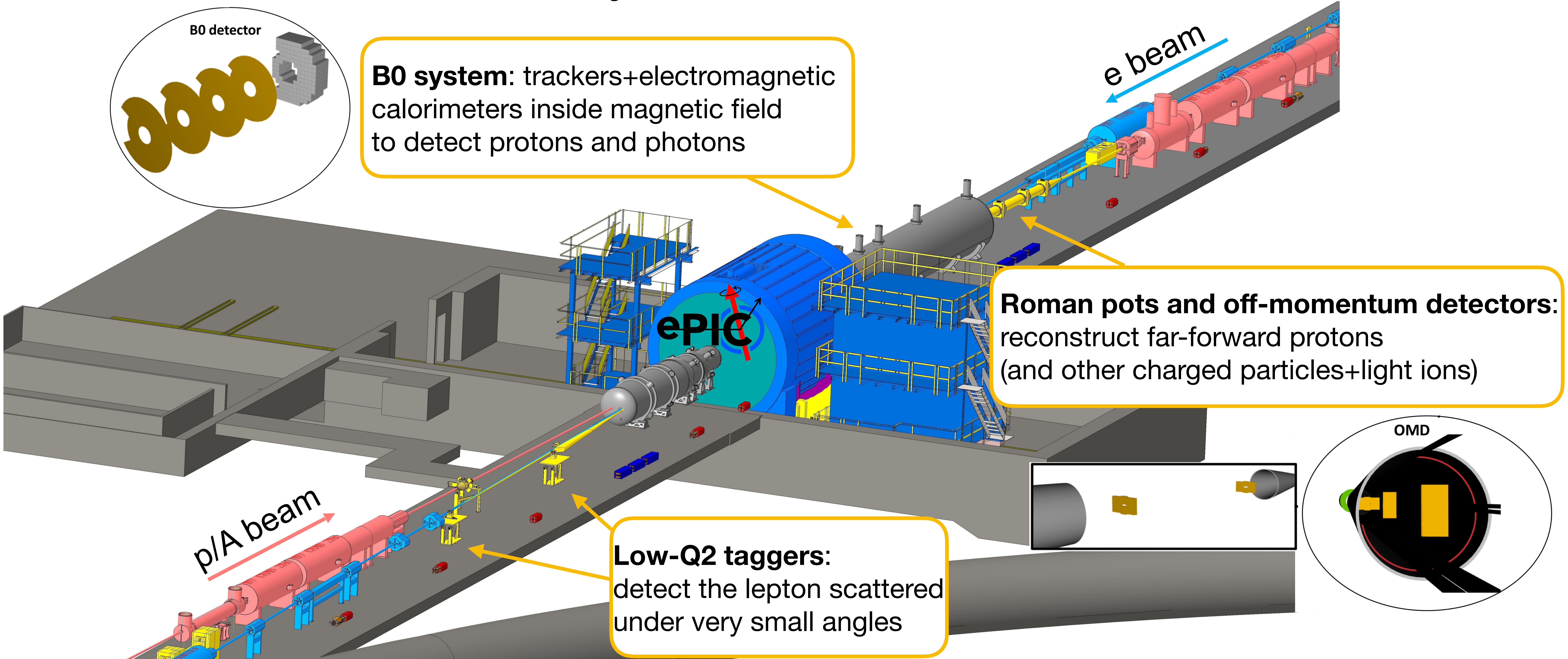


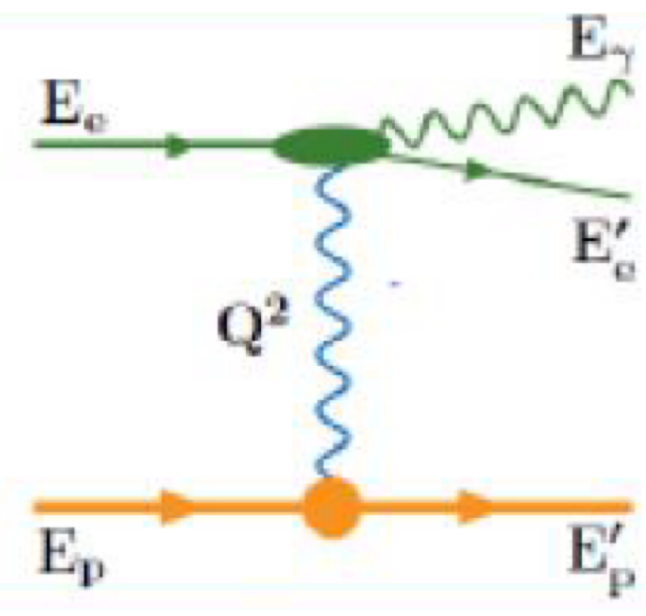
B0 system: trackers+electromagnetic calorimeters inside magnetic field to detect protons and photons

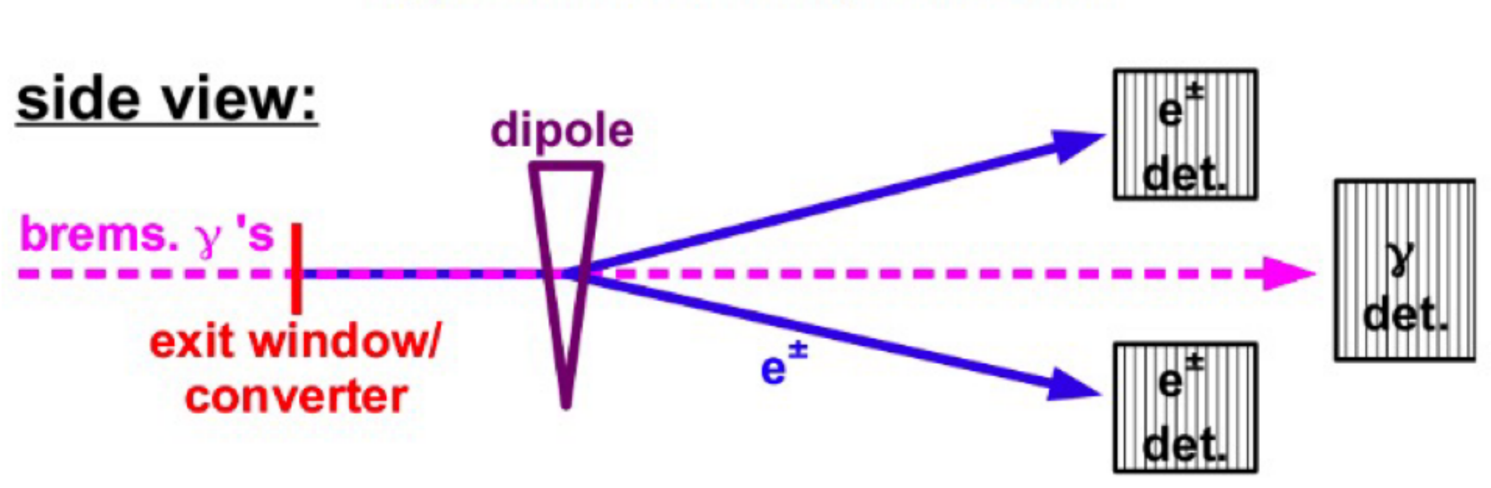
Low-Q2 taggers: detect the lepton scattered under very small angles

Luminosity monitor
required absolute precision: 1%
required relative precision: 0.01%

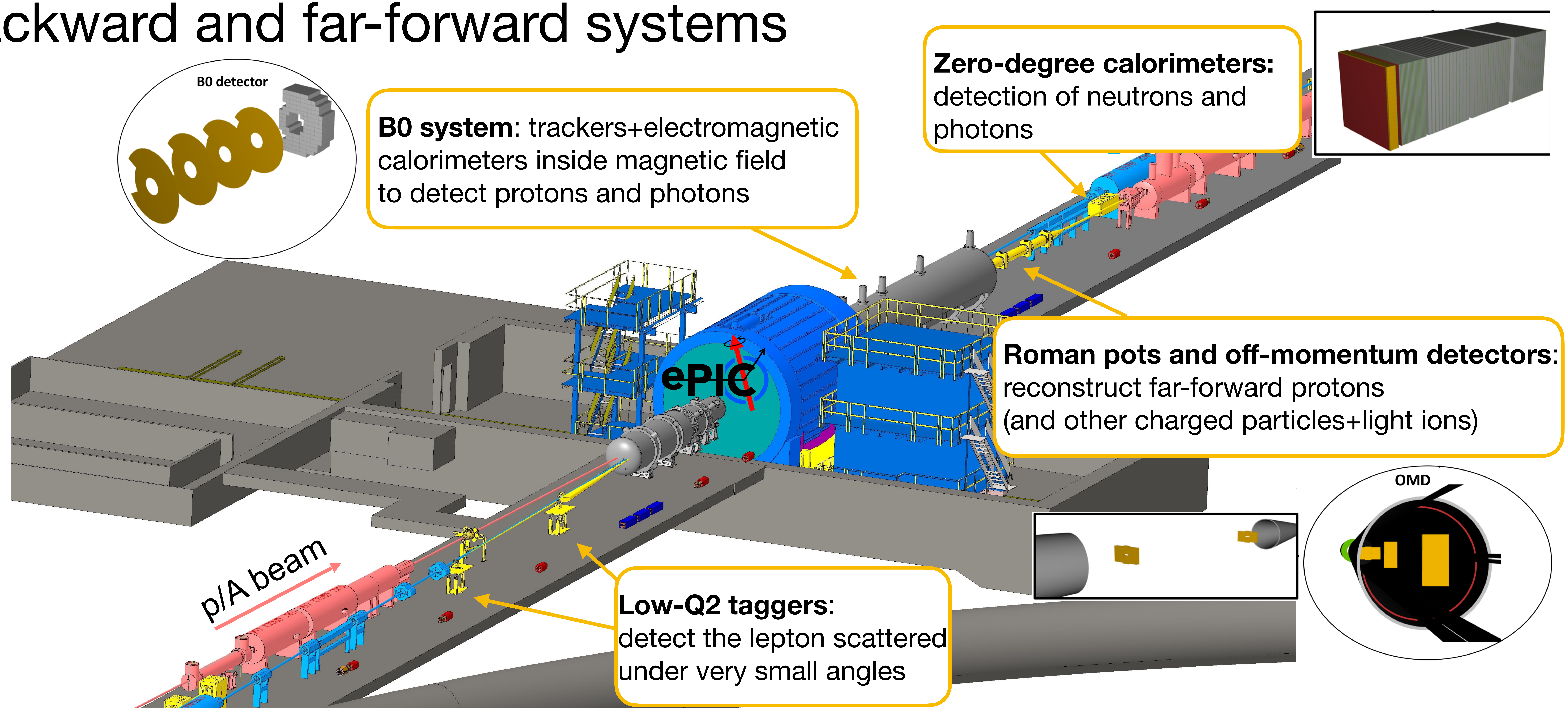
Far-backward and far-forward systems







Far-backward and far-forward systems



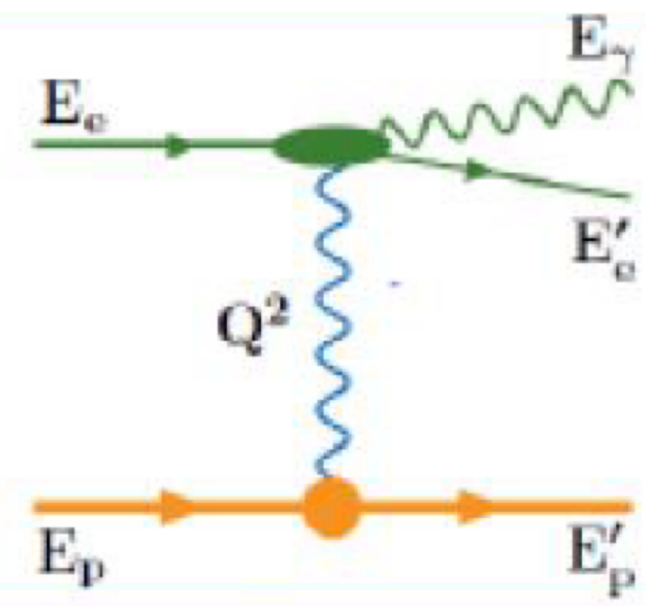
B0 system: trackers+electromagnetic calorimeters inside magnetic field to detect protons and photons

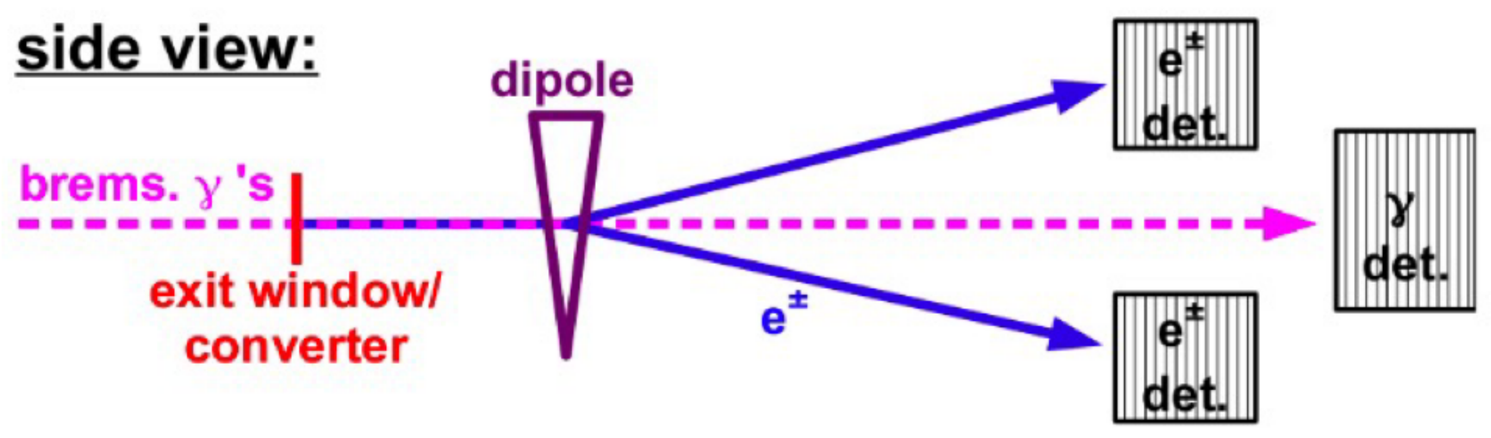
Zero-degree calorimeters: detection of neutrons and photons

Roman pots and off-momentum detectors: reconstruct far-forward protons (and other charged particles+light ions)

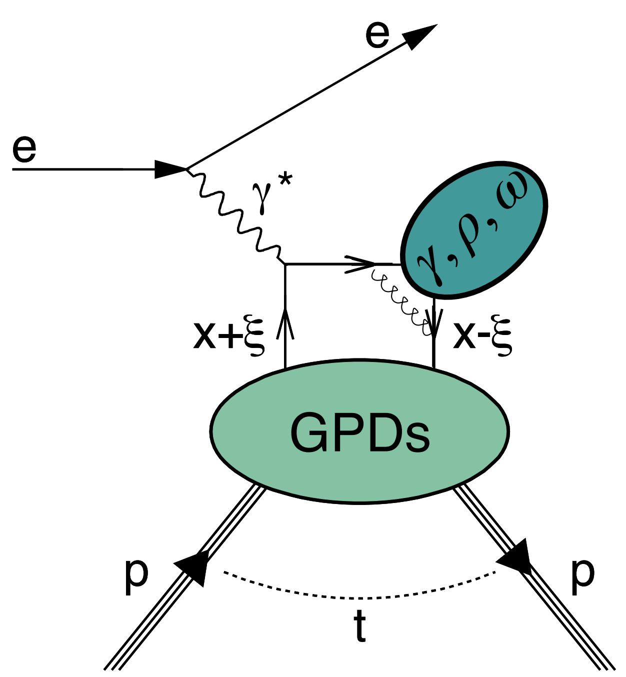
Low-Q2 taggers: detect the lepton scattered under very small angles

Luminosity monitor
required absolute precision: 1%
required relative precision: 0.01%



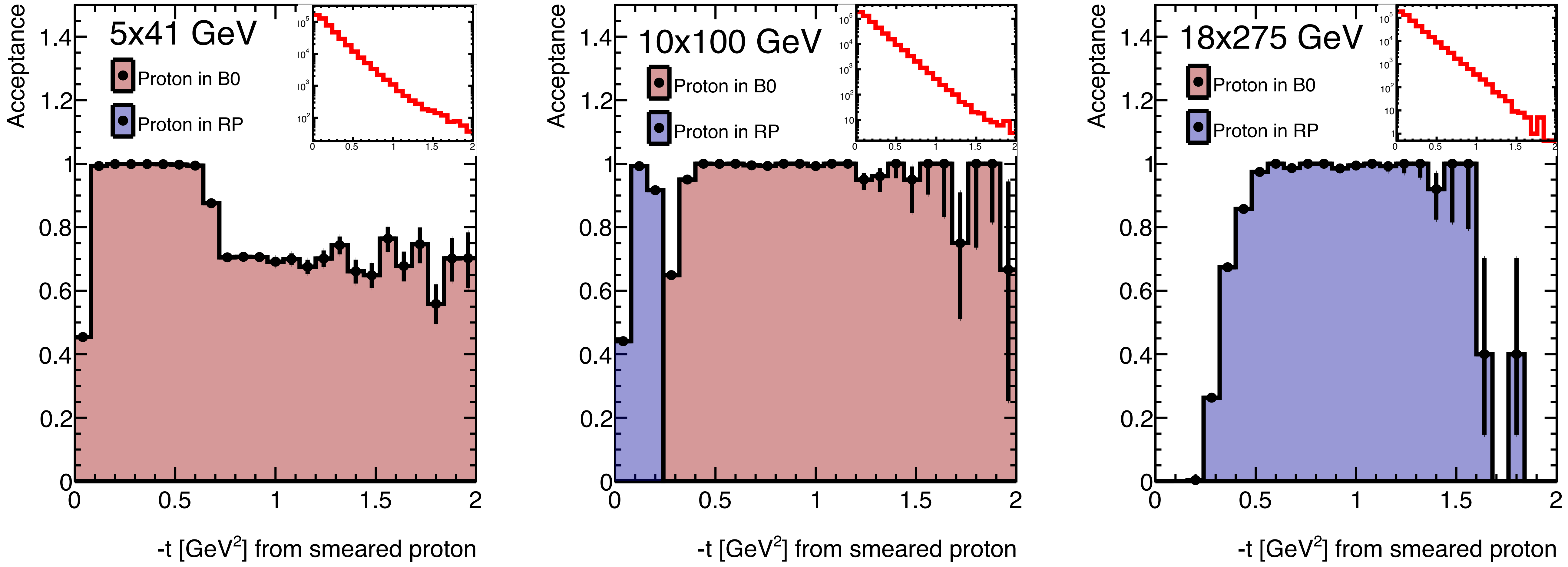


The far-forward system and proton detection for exclusive processes



Exclusive production on proton

ECCE



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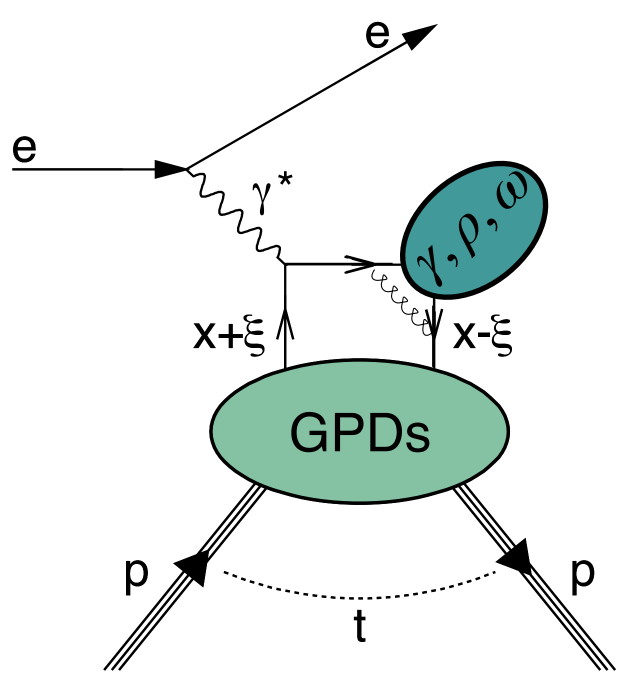
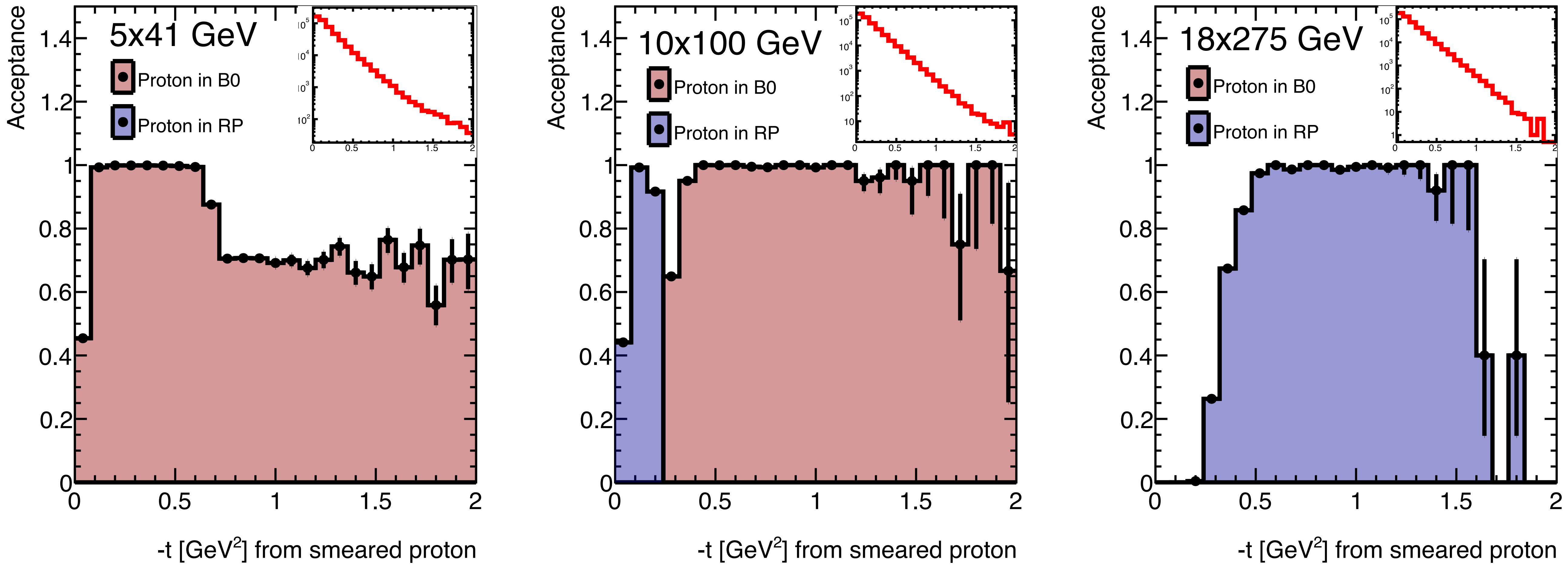
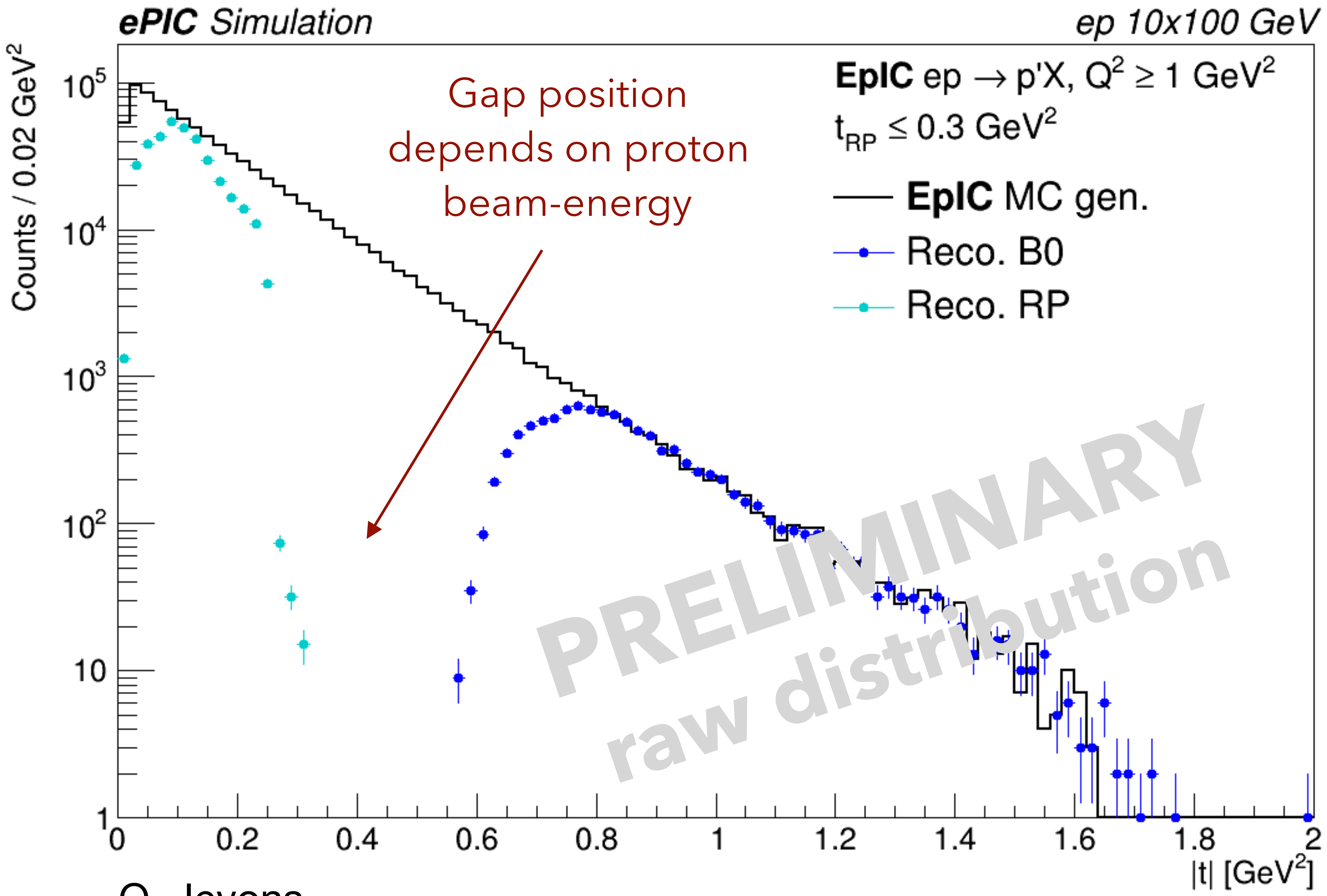


ECCE

Exclusive production on proton





O. Jevons

Summary

- EIC accelerator and ePIC optimised in order to address the key deliverables of the EIC, using polarised beams.
- Fully instrumented central detector:
  - tracking detectors: vertex and momentum reconstruct
  - electromagnetic calorimeters: reconstruction of electrons and photons, suppression of (pion) background
  - hadronic calorimeters: detection of neutral hadrons, improved reconstruction of hadrons in jets
  - Cherenkov-based and TOF-based PID detectors: electron/pion separation and pion, kaon, proton PID
- Far-backward system:
  - luminosity monitor
  - low-Q2 taggers
- Far-forward system:
  - reconstruction of scattered beam protons and of charged particles produced close to the beam line
  - reconstruction of light ions
  - detection of photons and neutrons (emitted by the beam ions in the interaction)