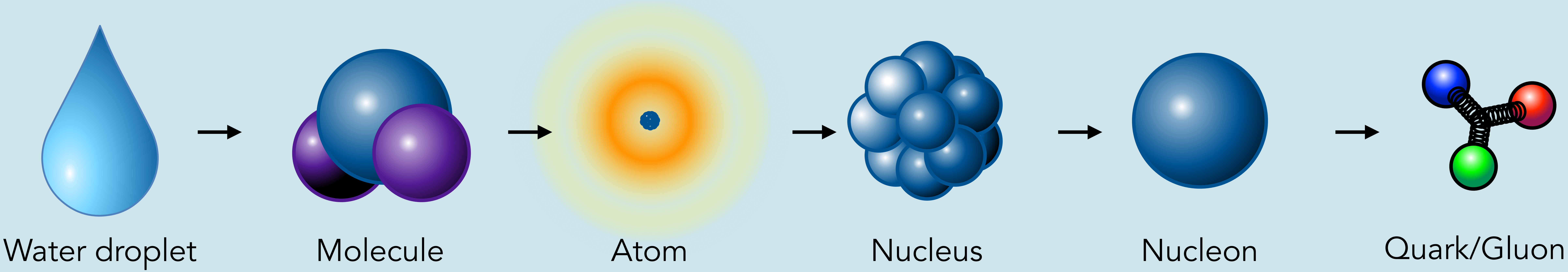
ePIC Experiment Overview

Satoshi Yano

Hiroshima University

EICで展開する新たな素粒子・原子核物理

The rise of "Femtotechnology"



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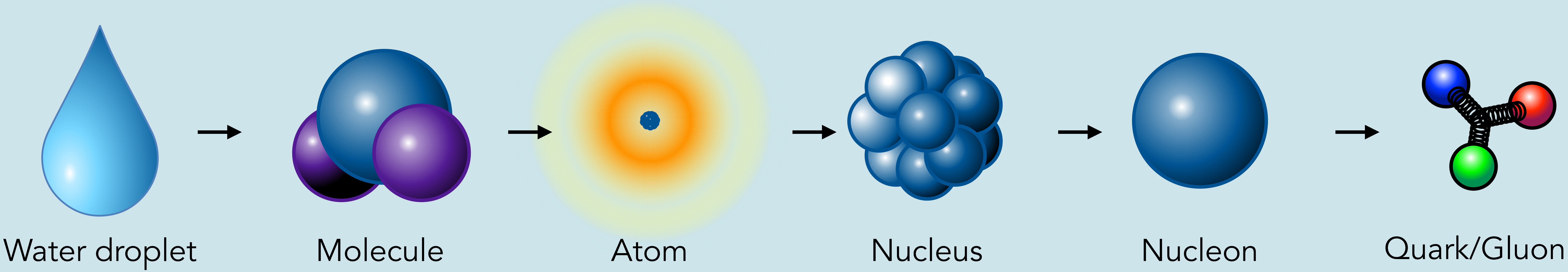

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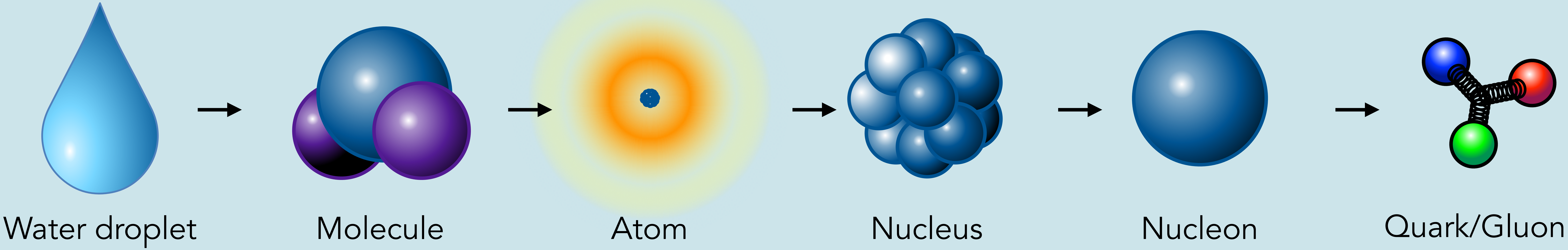

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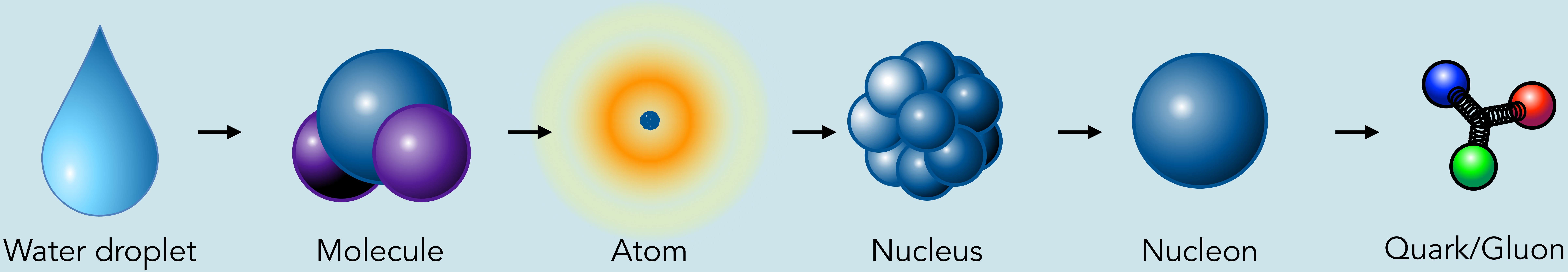

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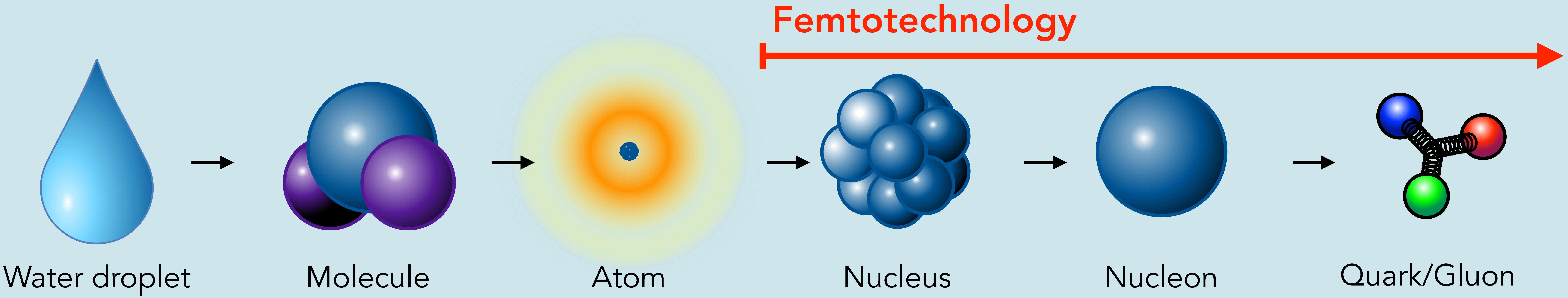

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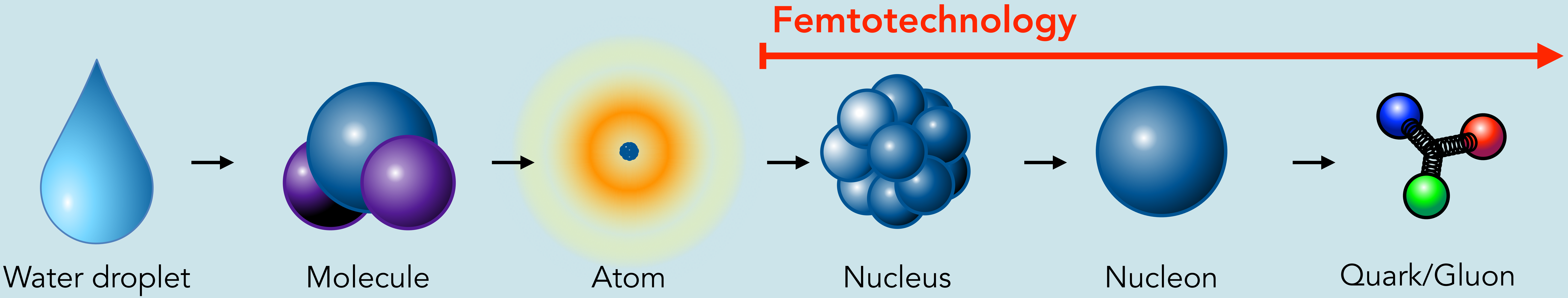

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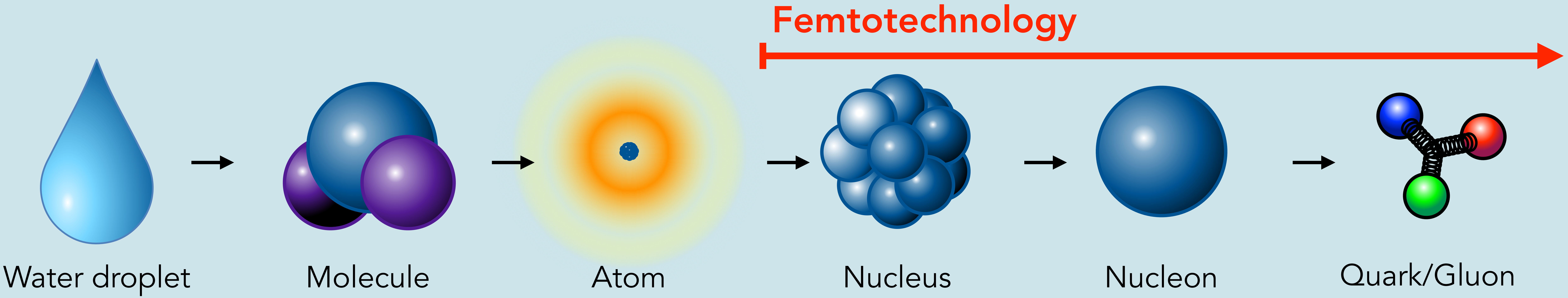

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A complete understanding of how quarks and gluons form nuclei is essential to the realization of

"Fermtotechnology"

How to “see” inner structure of nucleus/nucleon

- DIS (Deep Inelastic Scattering) is a clean method to “see” the inner structure of nucleus and nucleon

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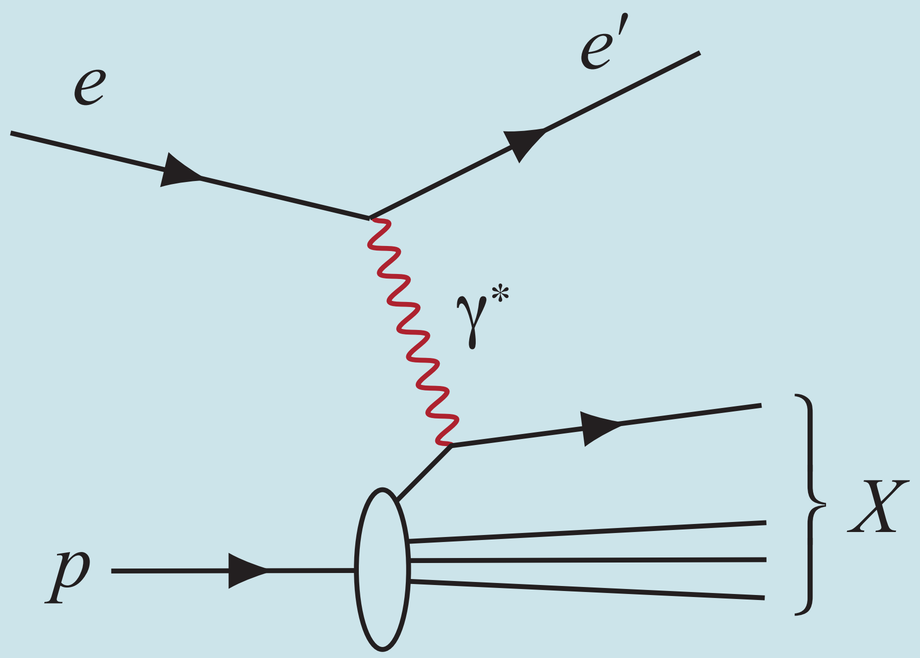

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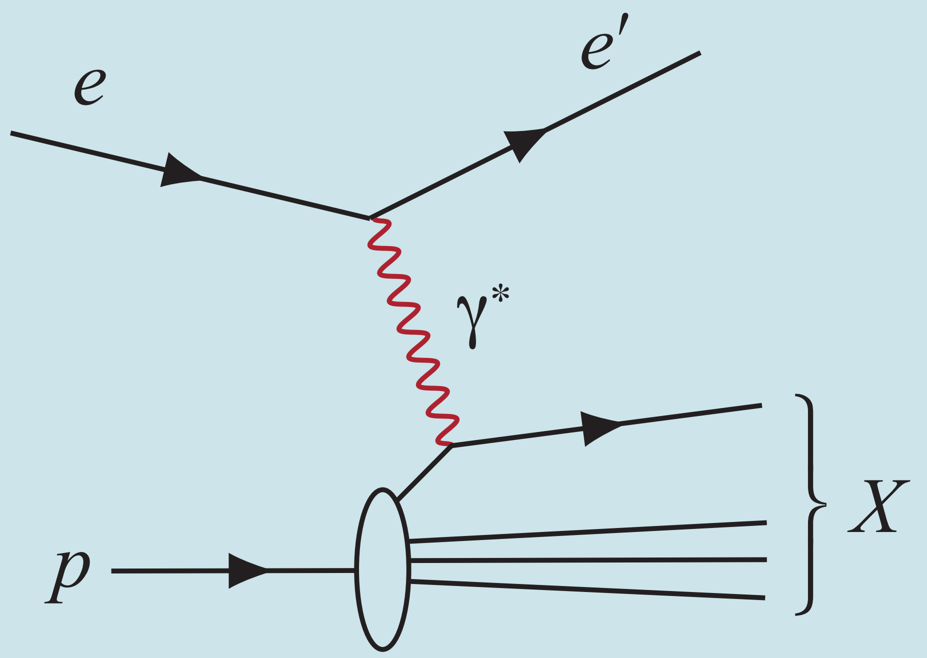
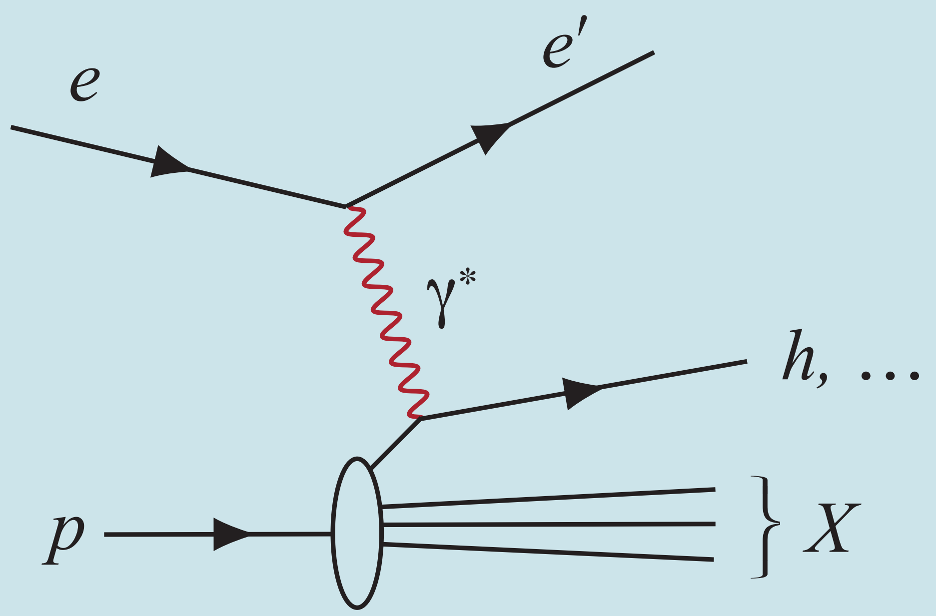


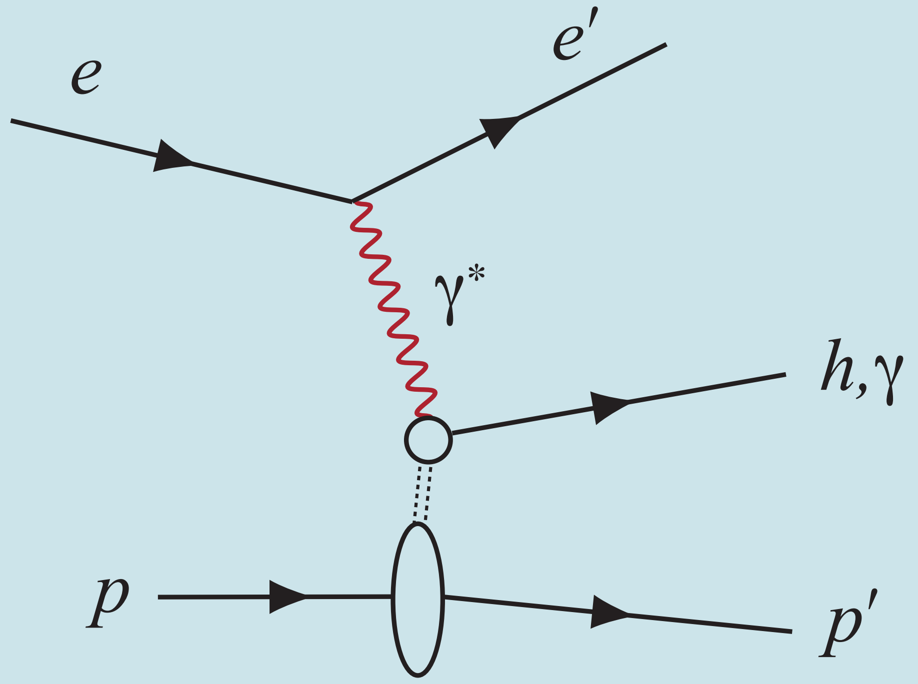
Neutral Current DIS

Detection of scattered electron with high-precision event kinematics



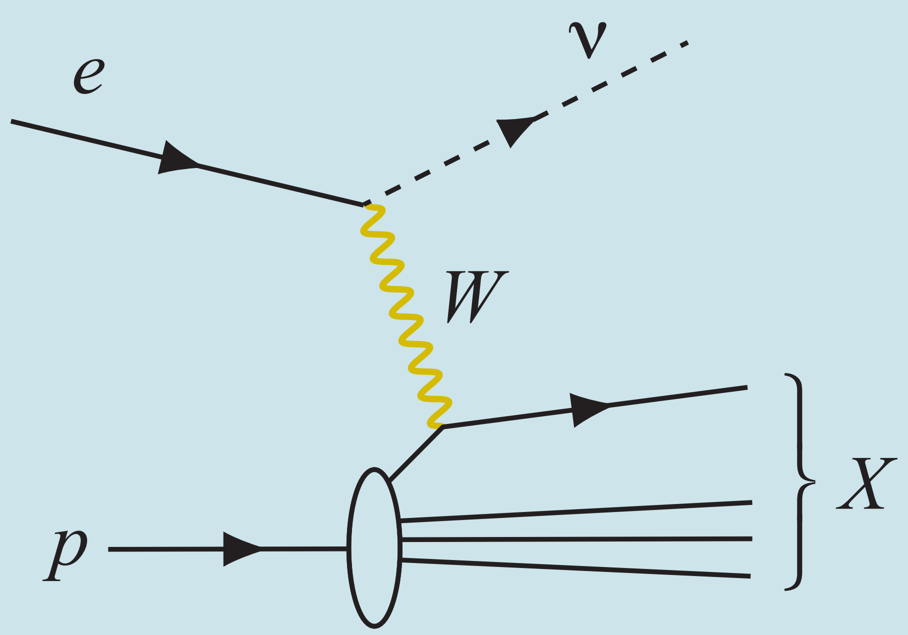
Semi-Inclusive DIS

Precise detection of scattered electron in coincidence with at the least 1 hadron



Deep Exclusive DIS

Detect all particles in event



Charged Current DIS

Event kinematic from final state particles (Jacquet-Blondel method)

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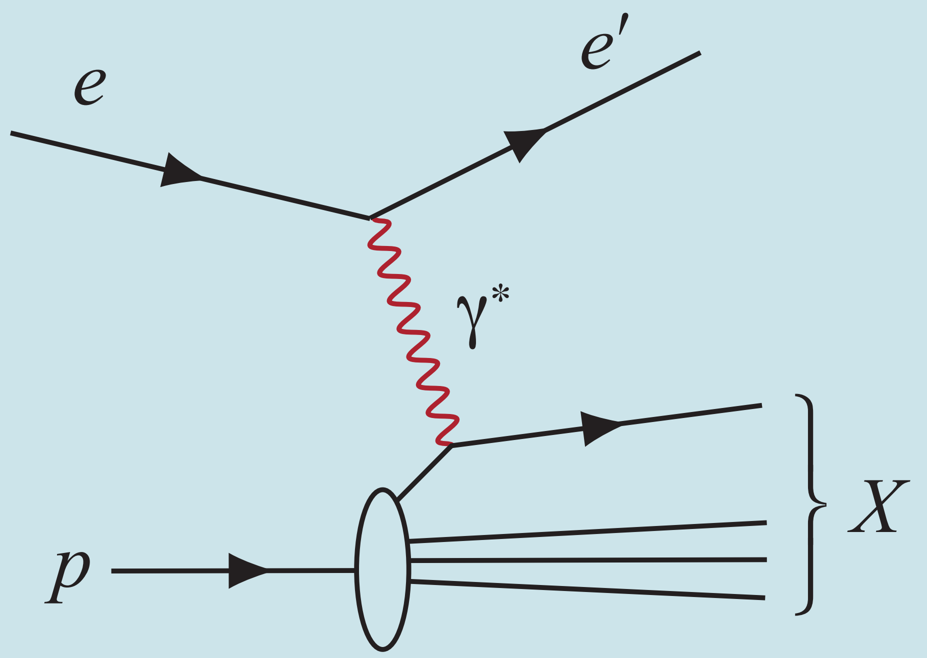

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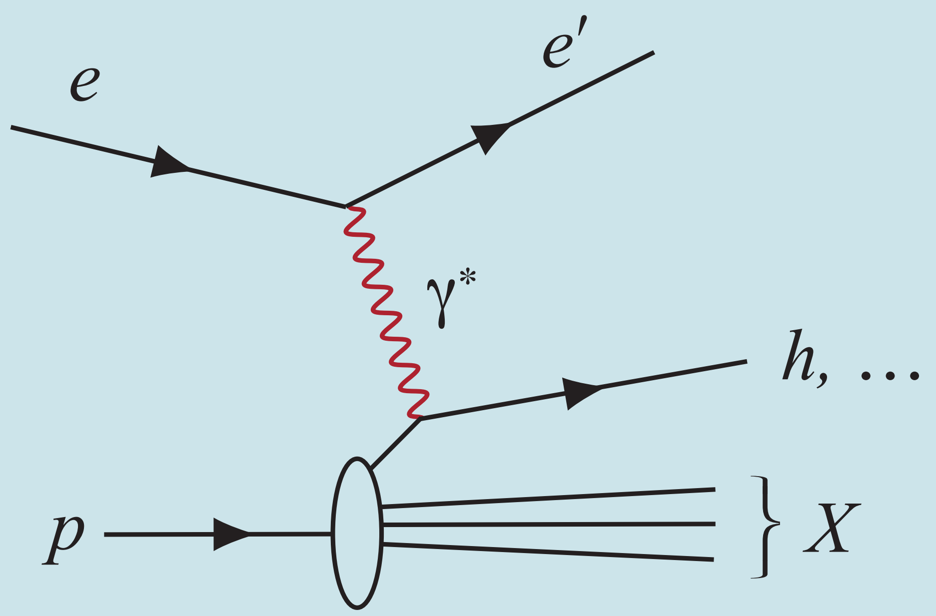

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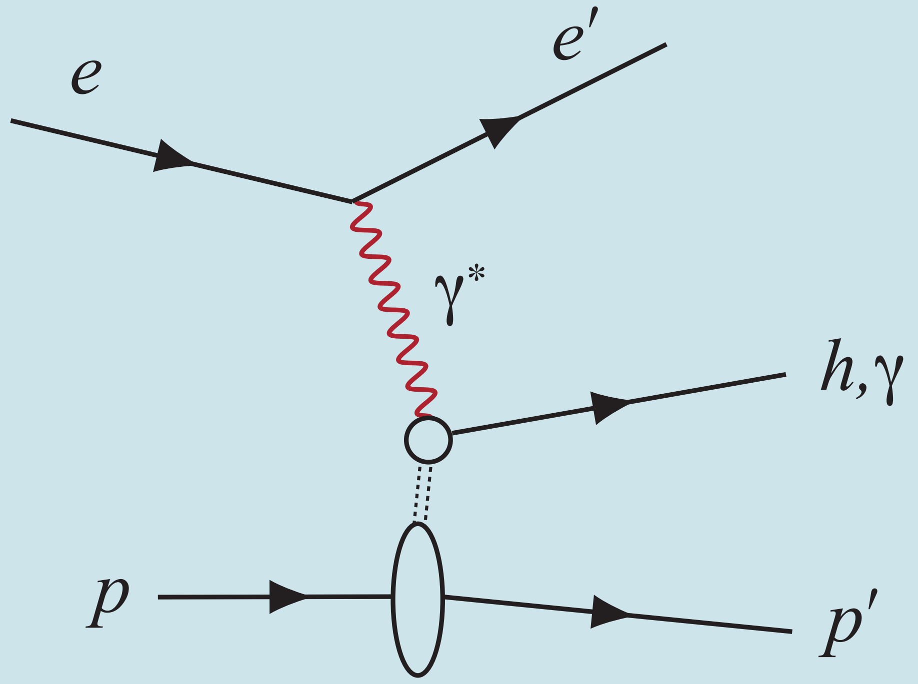

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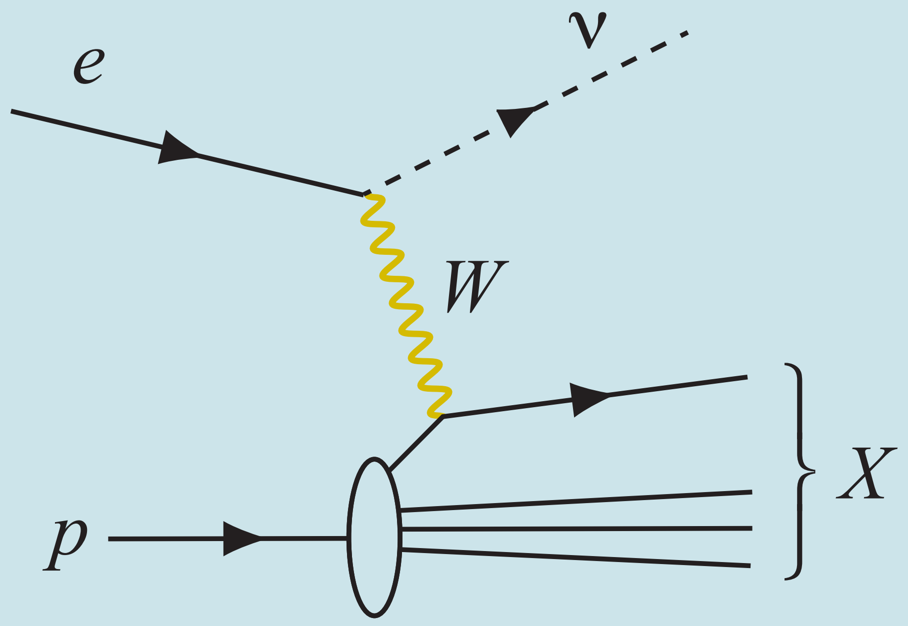

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The physics accessible in each process is different
Exhaustive measurements can reveal how nuclei and nucleons are composed of partons

Electron-Ion Collider

- World's first polarized electron-proton and electron-nucleus collider
  - For e-p/A collisions at the EIC
    - Polarized beams: e, p/d/^{3}He…Cu/Au/U (Wide range of nuclei)
    - Luminosity ~ 10^{33} - 10^{34} $cm^{-2}s^{-1}$ = 10 - 100 fb^{-1}/year
    - 29 - 140 GeV (Variable $\sqrt{s}$)

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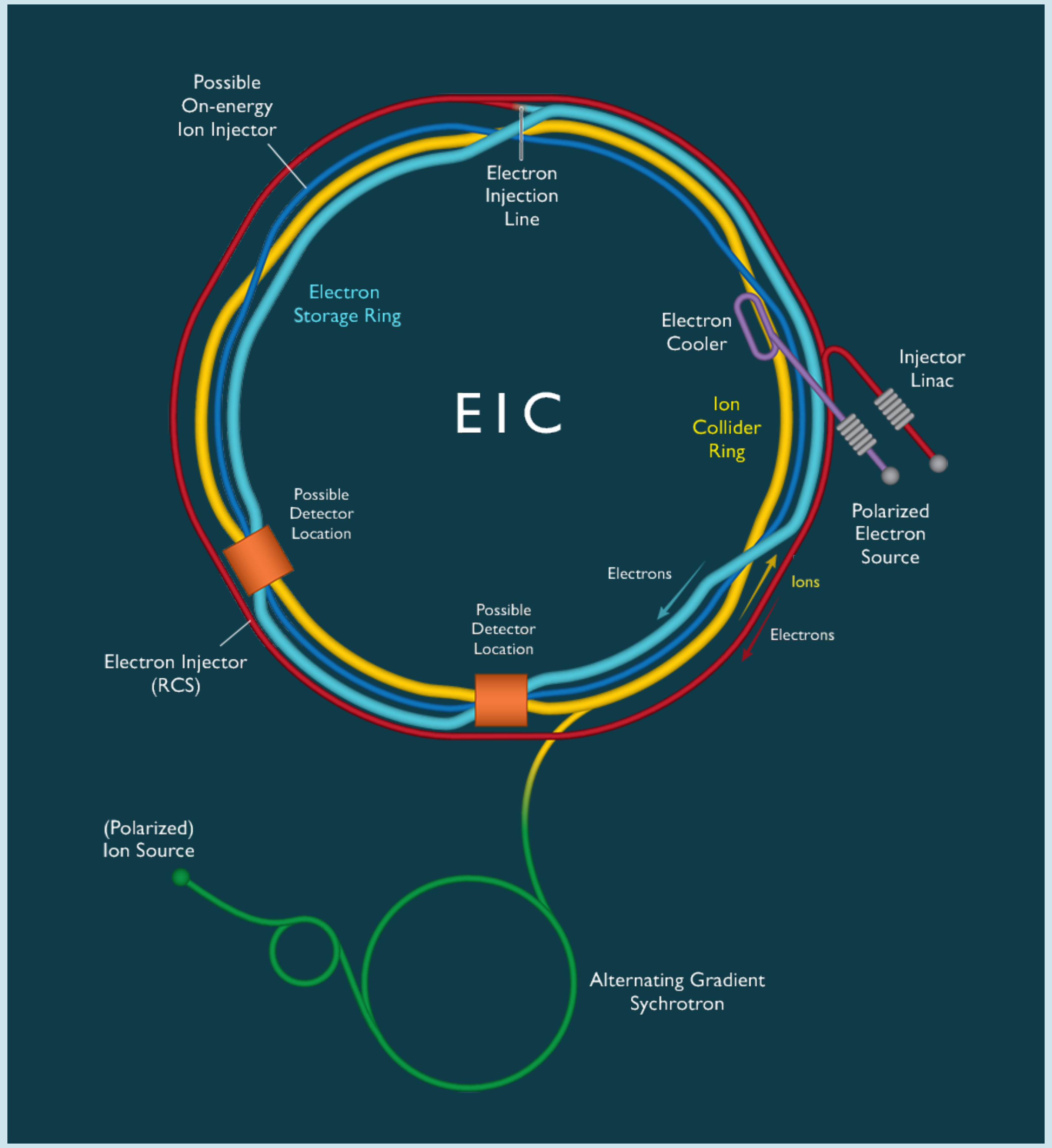

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  - **2020: Approve Mission Need (CD-0)**
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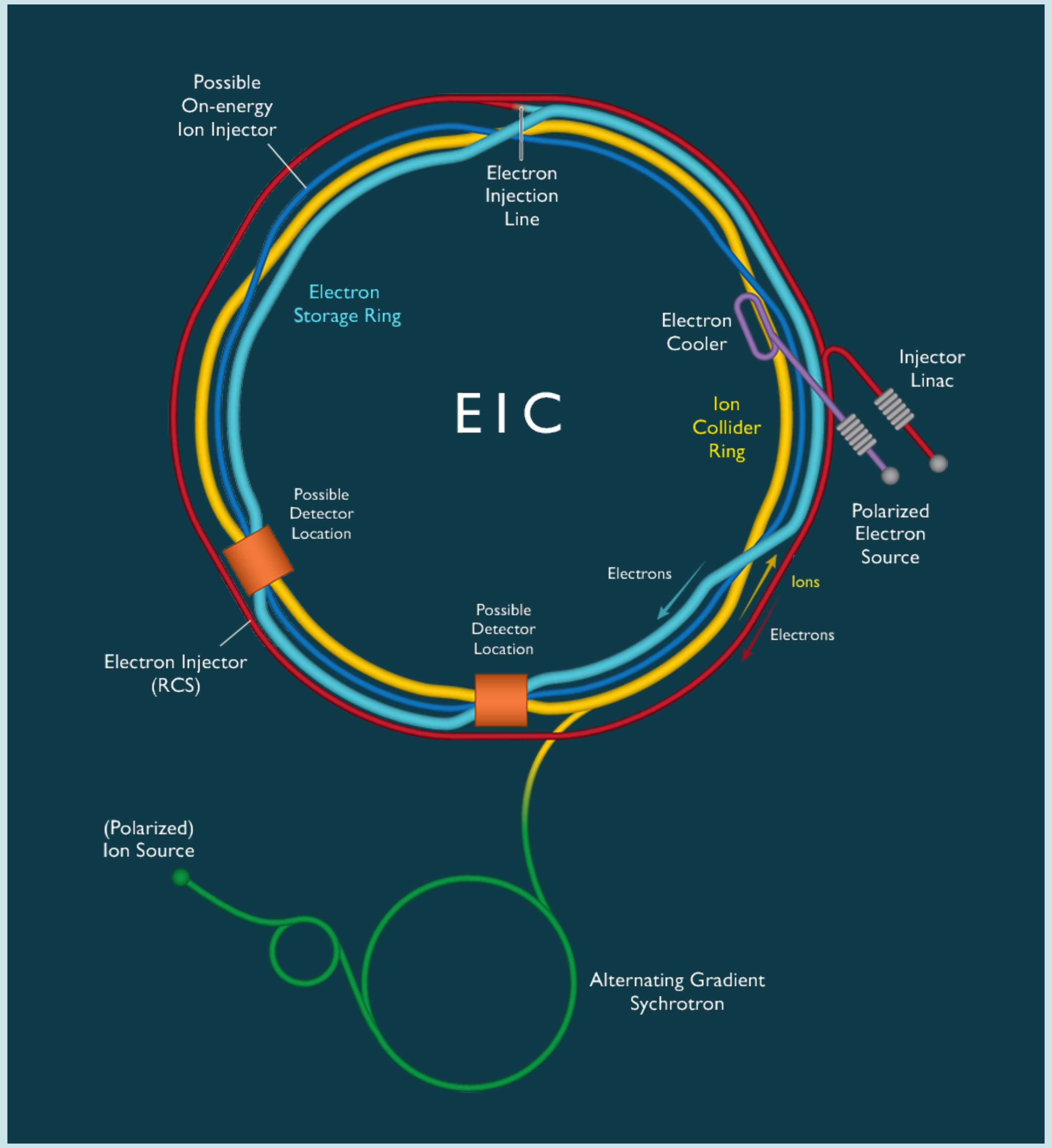

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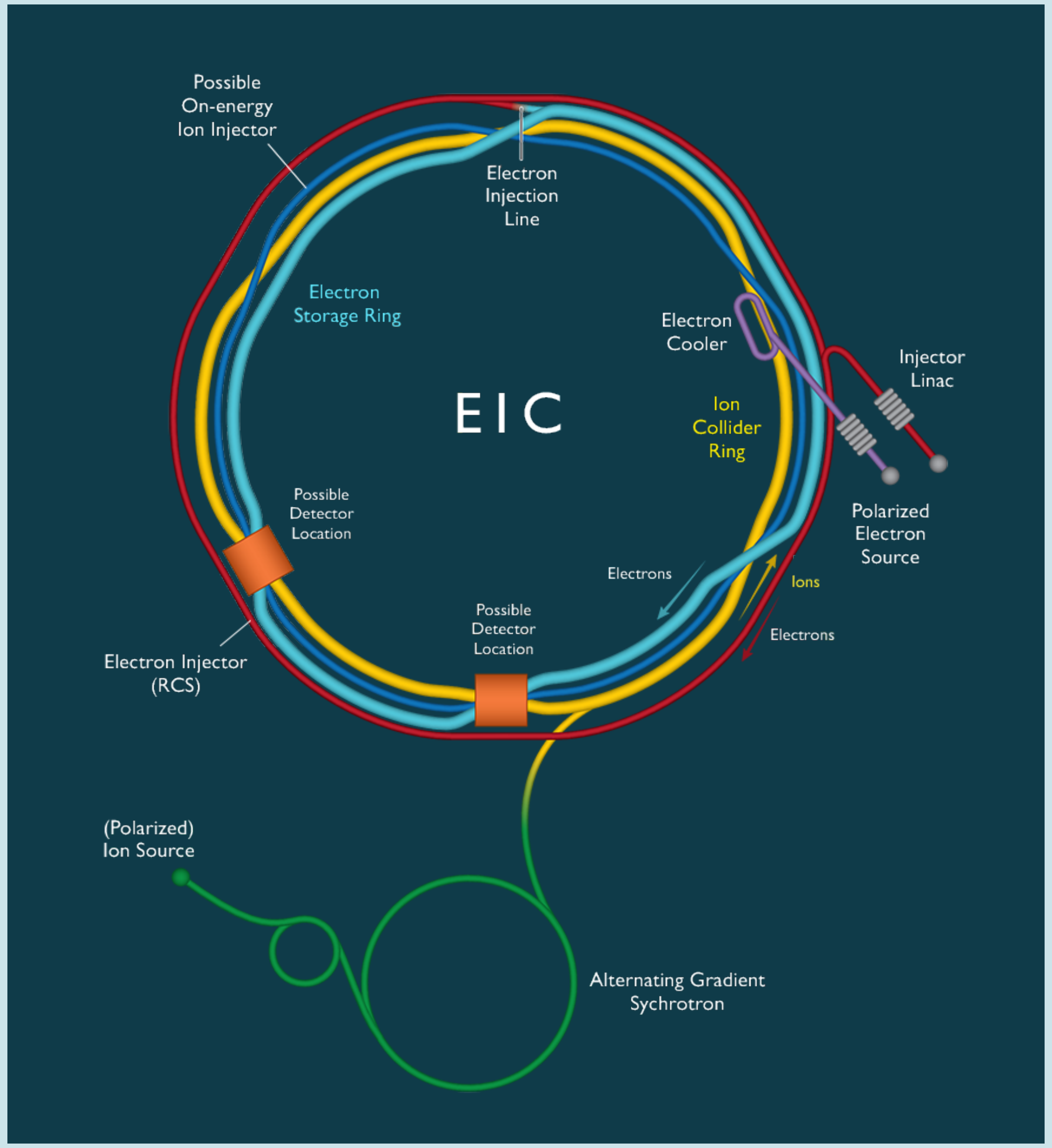


The EIC is a unique project, the world's only one approved for the ultimate understanding of QCD
Most likely, the only novel high-energy collider in the next 15-20 years

Major Nuclear Physics Facilities for the Next Decade

Report of the NSAC Facilities Subcommittee accepted on April 26, 2024, by NSAC

"The EIC will be a new world-leading DOE facility at the forefront of scientific discovery. The Subcommittee ranks the EIC as **(a) absolutely central** in its potential to contribute to world-leading science in the next decade."

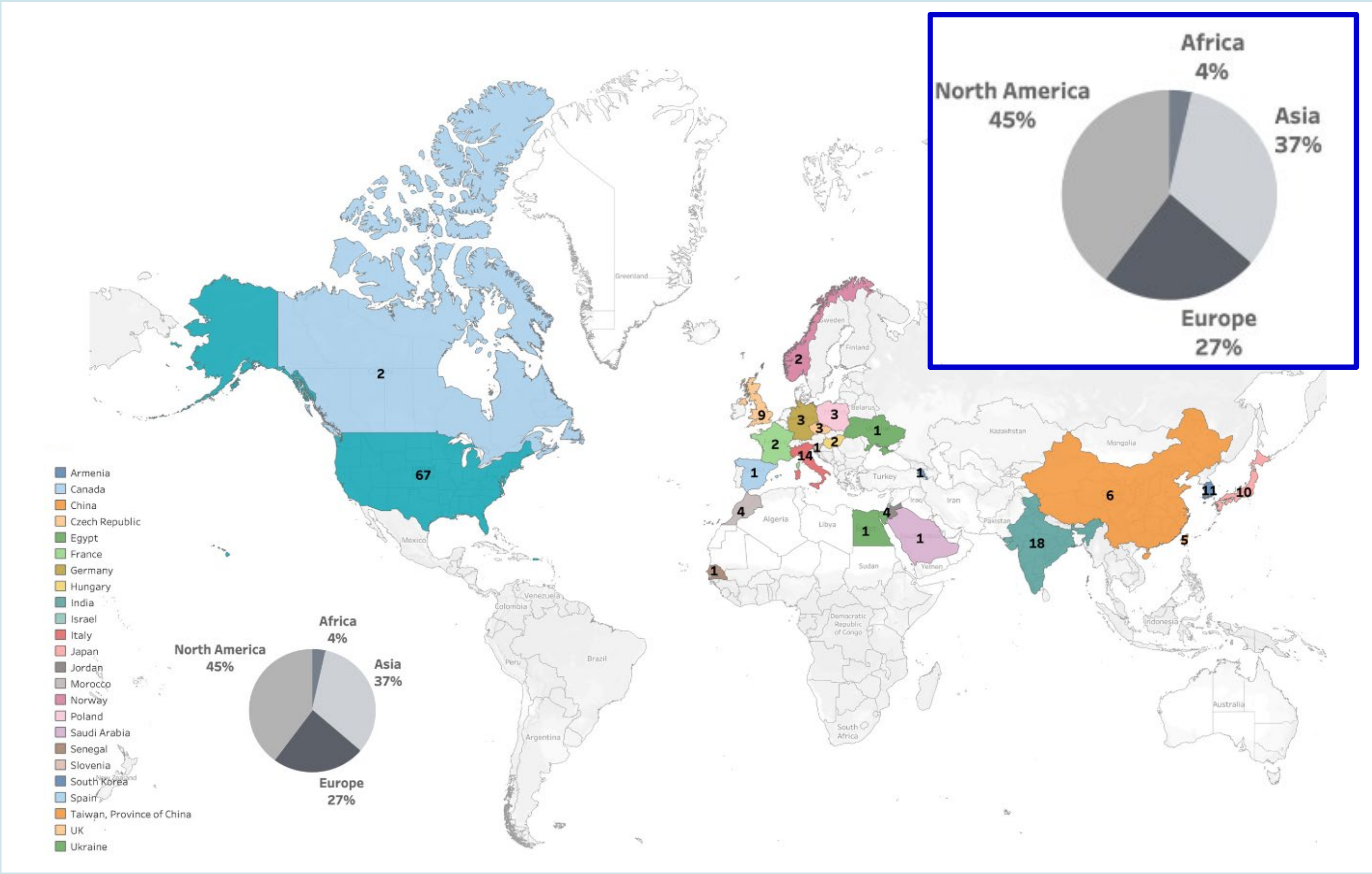
"Concerning readiness of the facility for construction, we rank the EIC in category **(a) ready to initiate construction**."

DOE/NSF Nuclear Science Advisory Committee

Slide from Silvia's talk at CERN last week

ePIC Collaboration

- ePIC is the only experiment approved for construction at EIC
  - electron-Proton/Ion Collider = ePIC
  - >650 members, 177 institutes, 26 countries
  - 45% North America, 37% Asia, 27% Europe, 4% Africa



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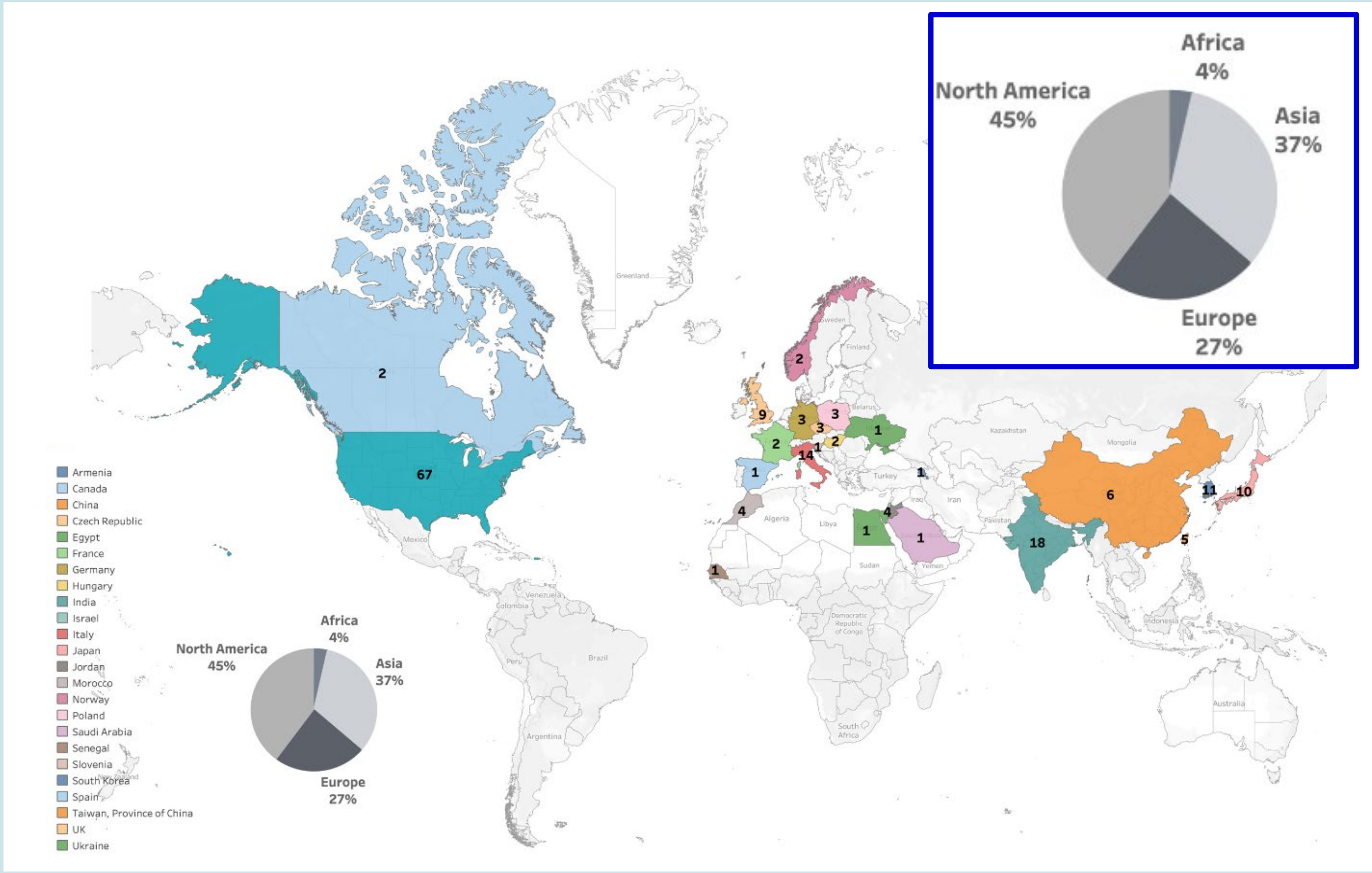

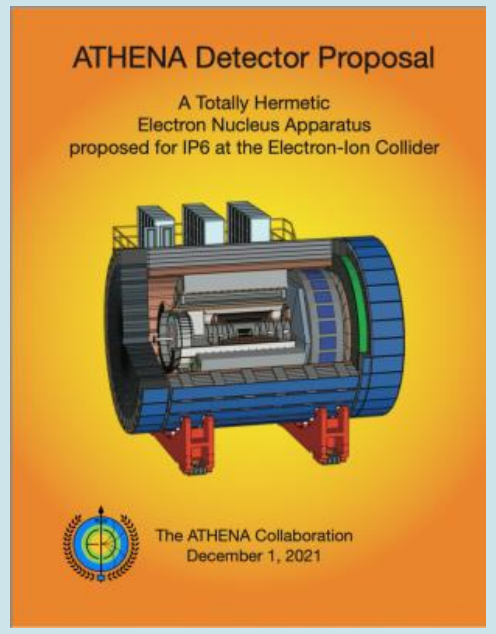

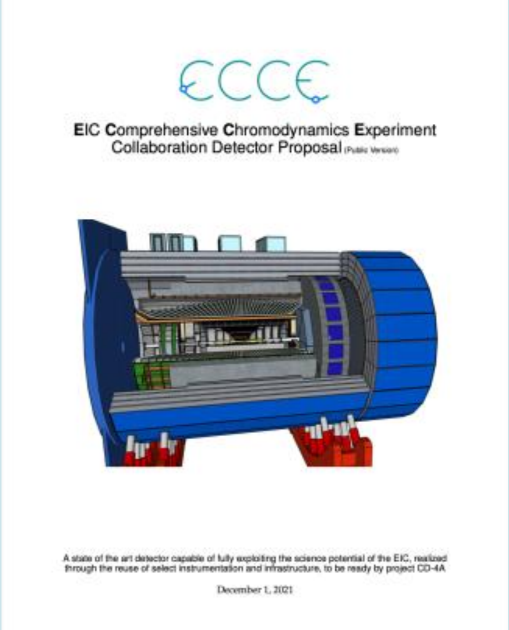

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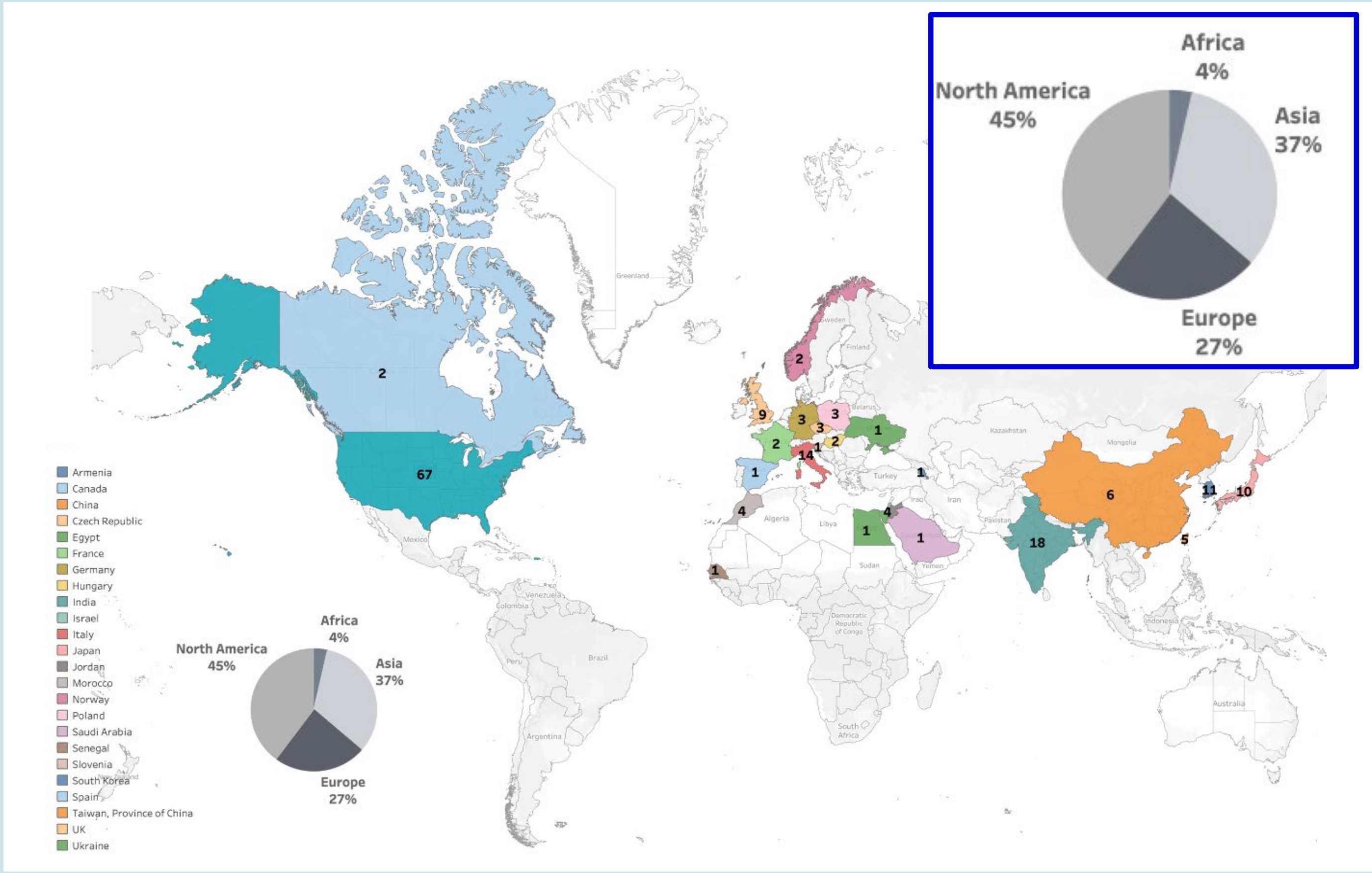

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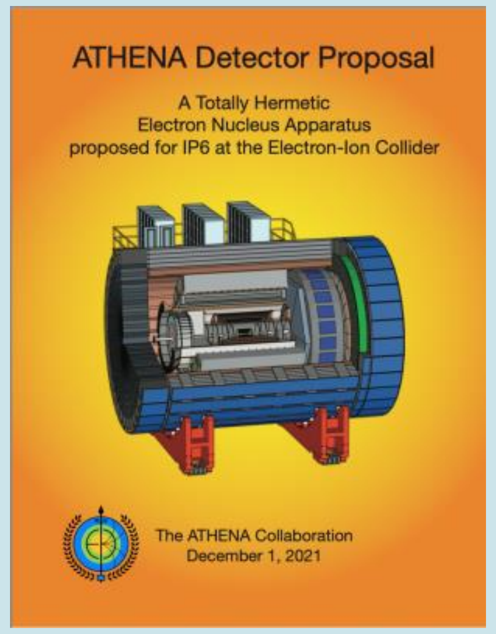

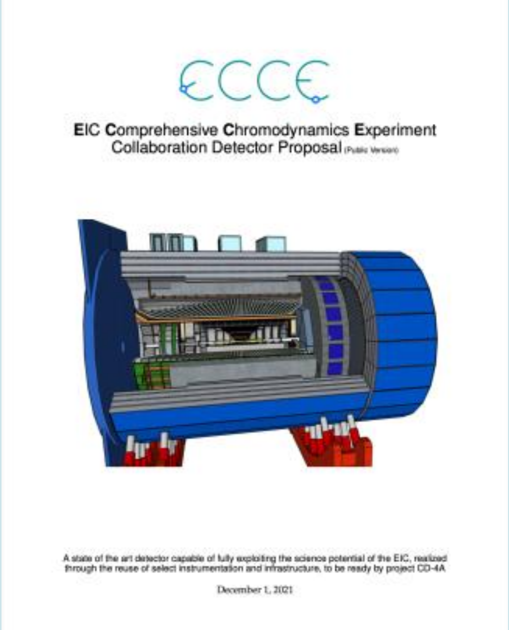

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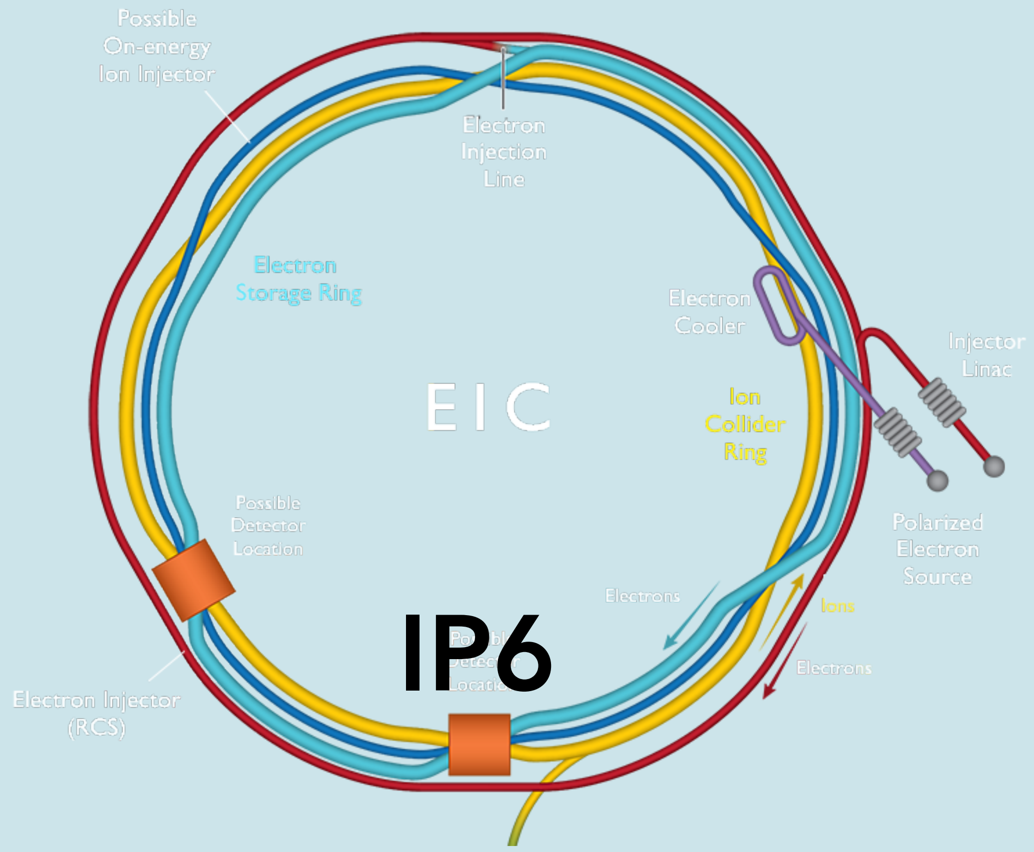

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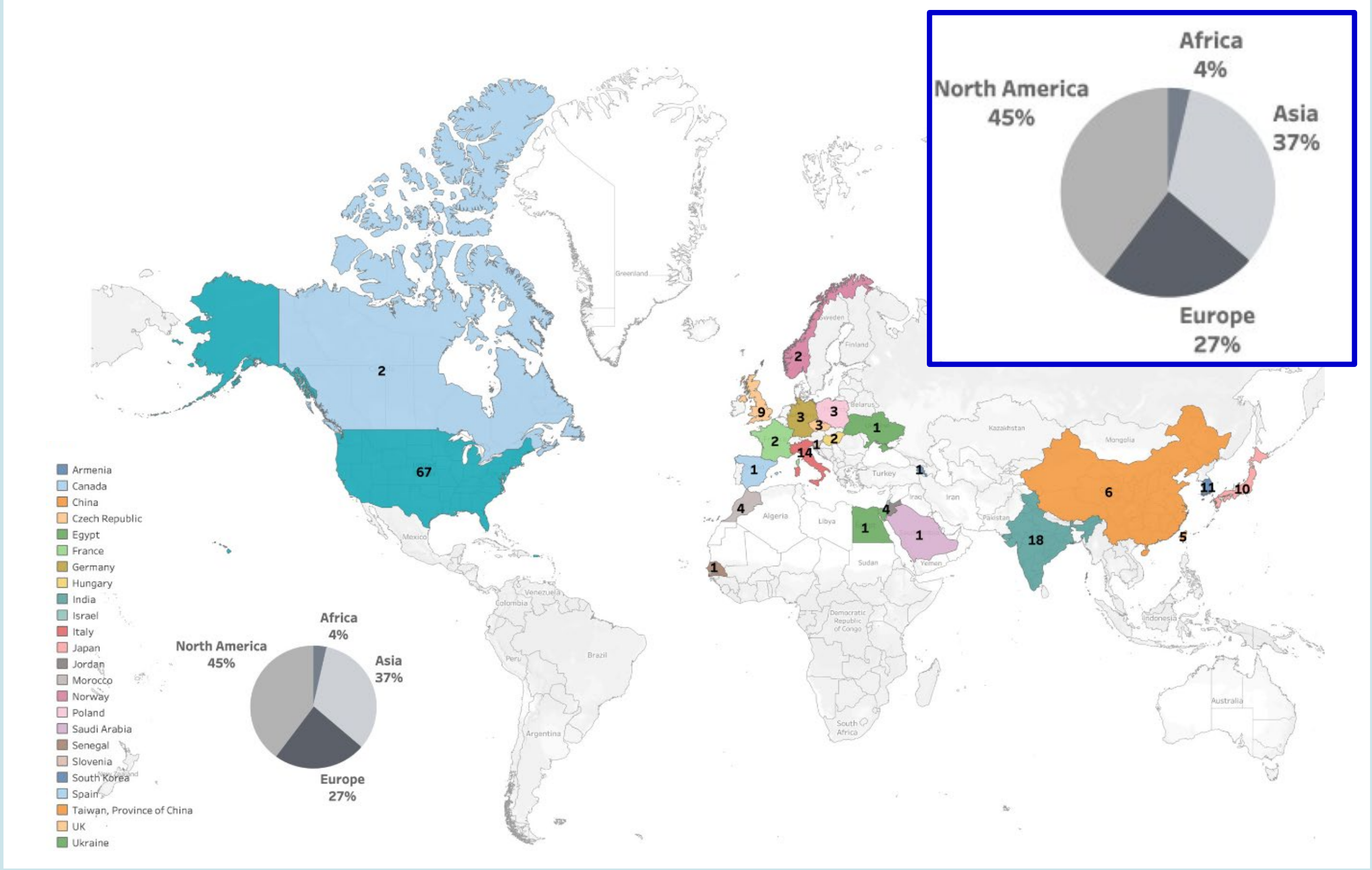

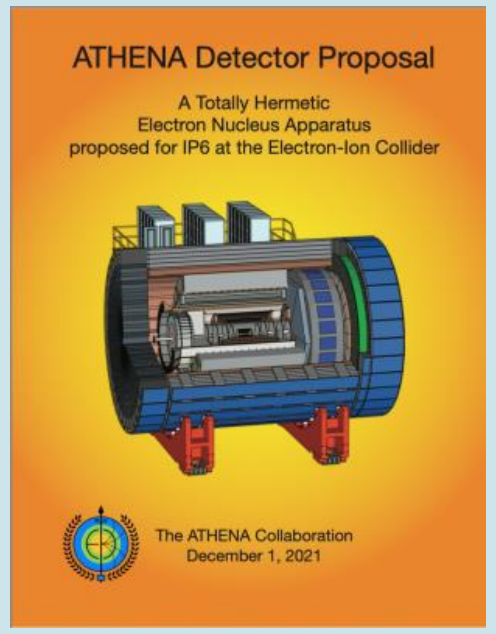

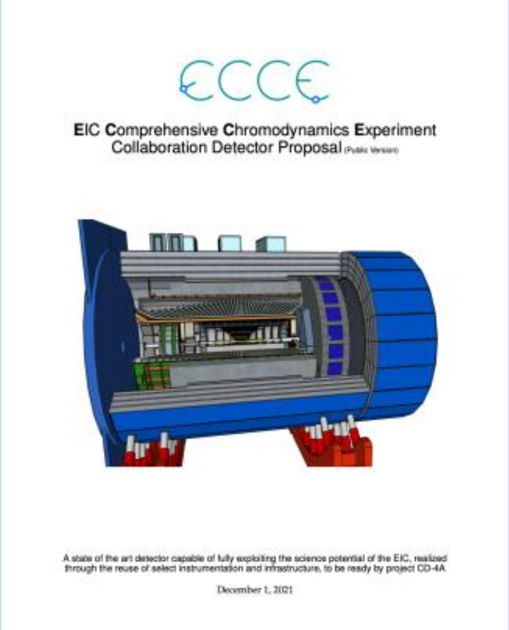

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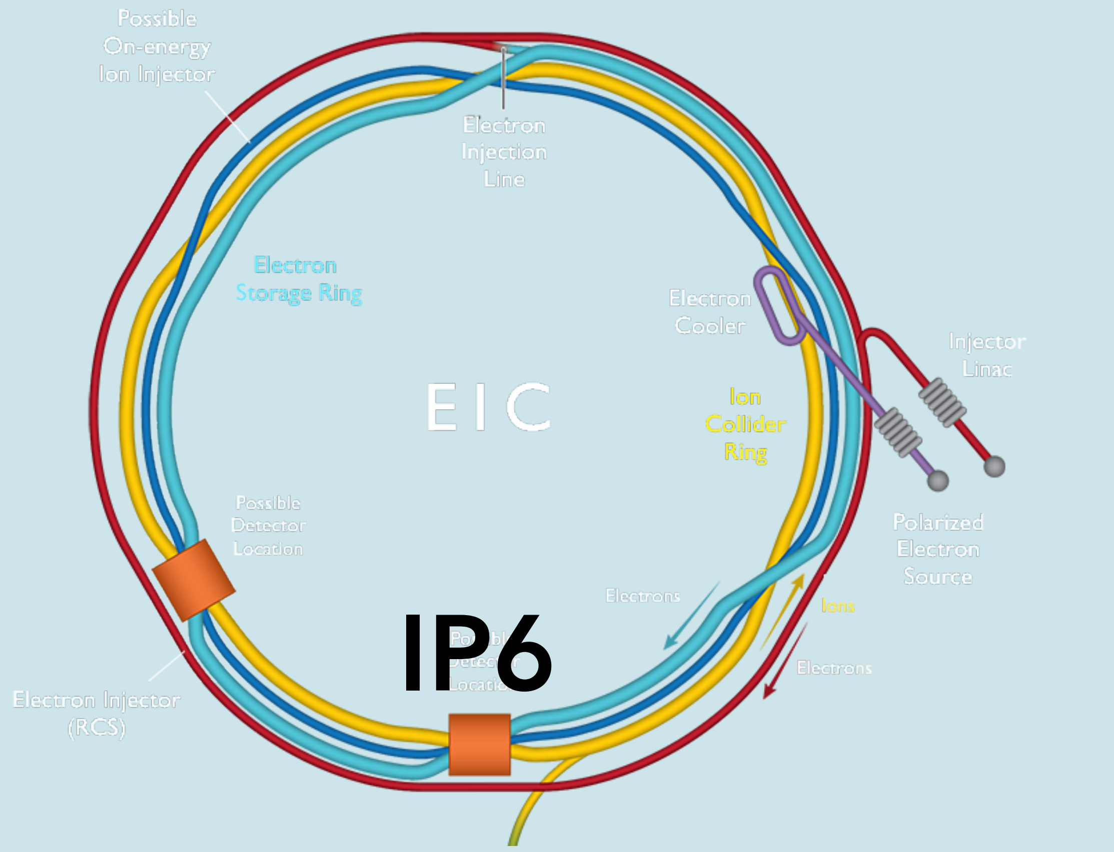
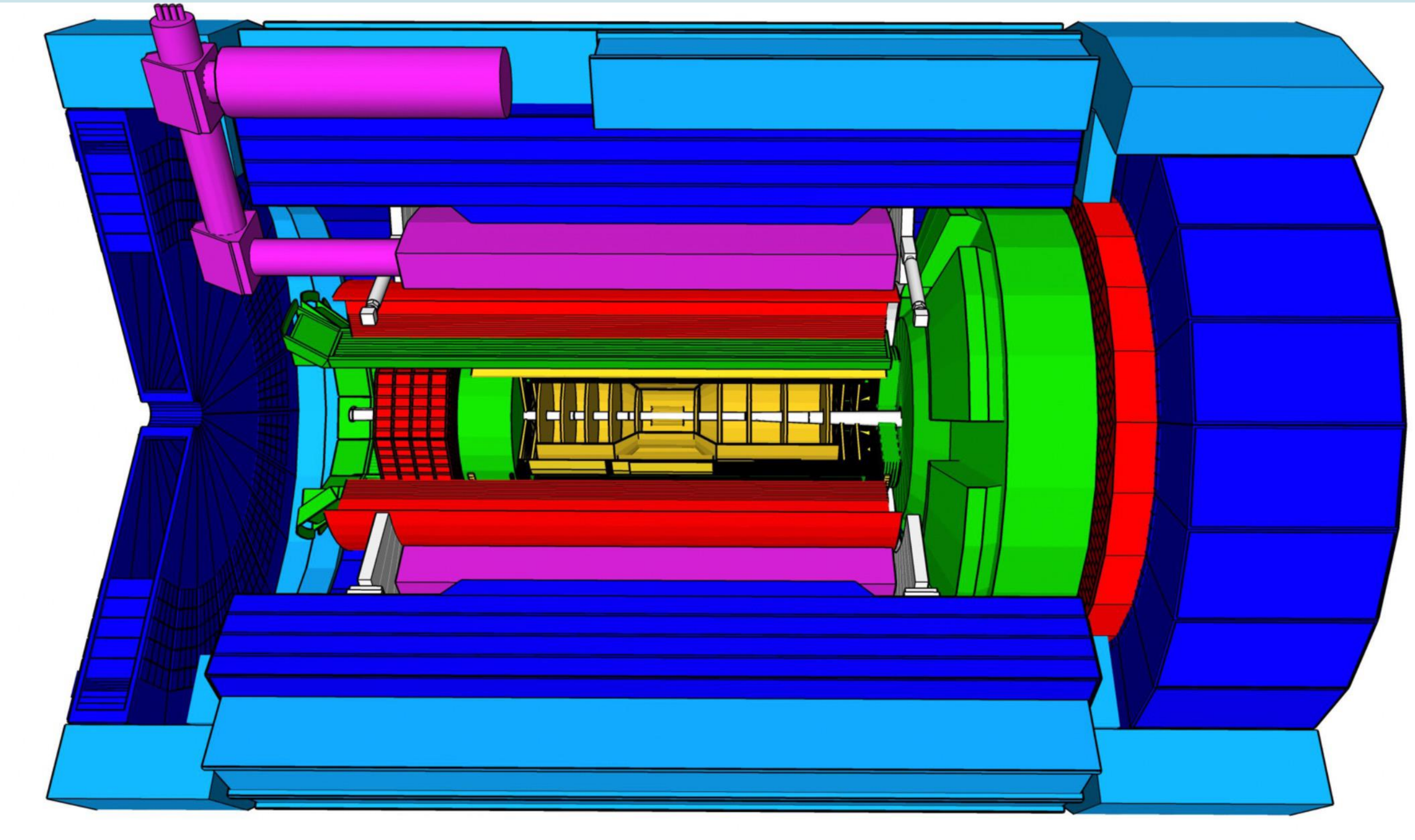


The ePIC collaboration is the strongest team from all over the world to achieve all possible physical targets at EIC

ePIC Detector Concept



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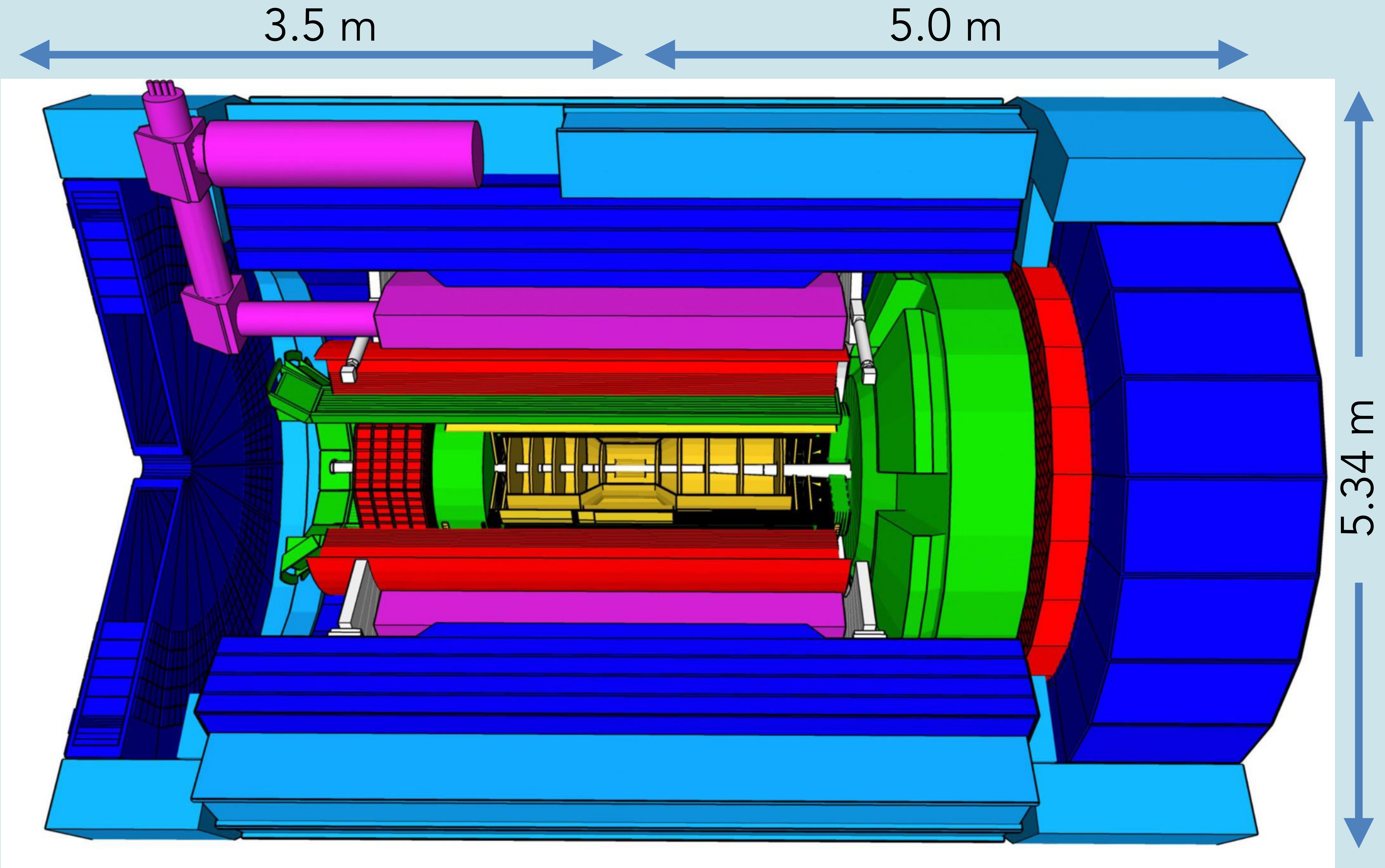
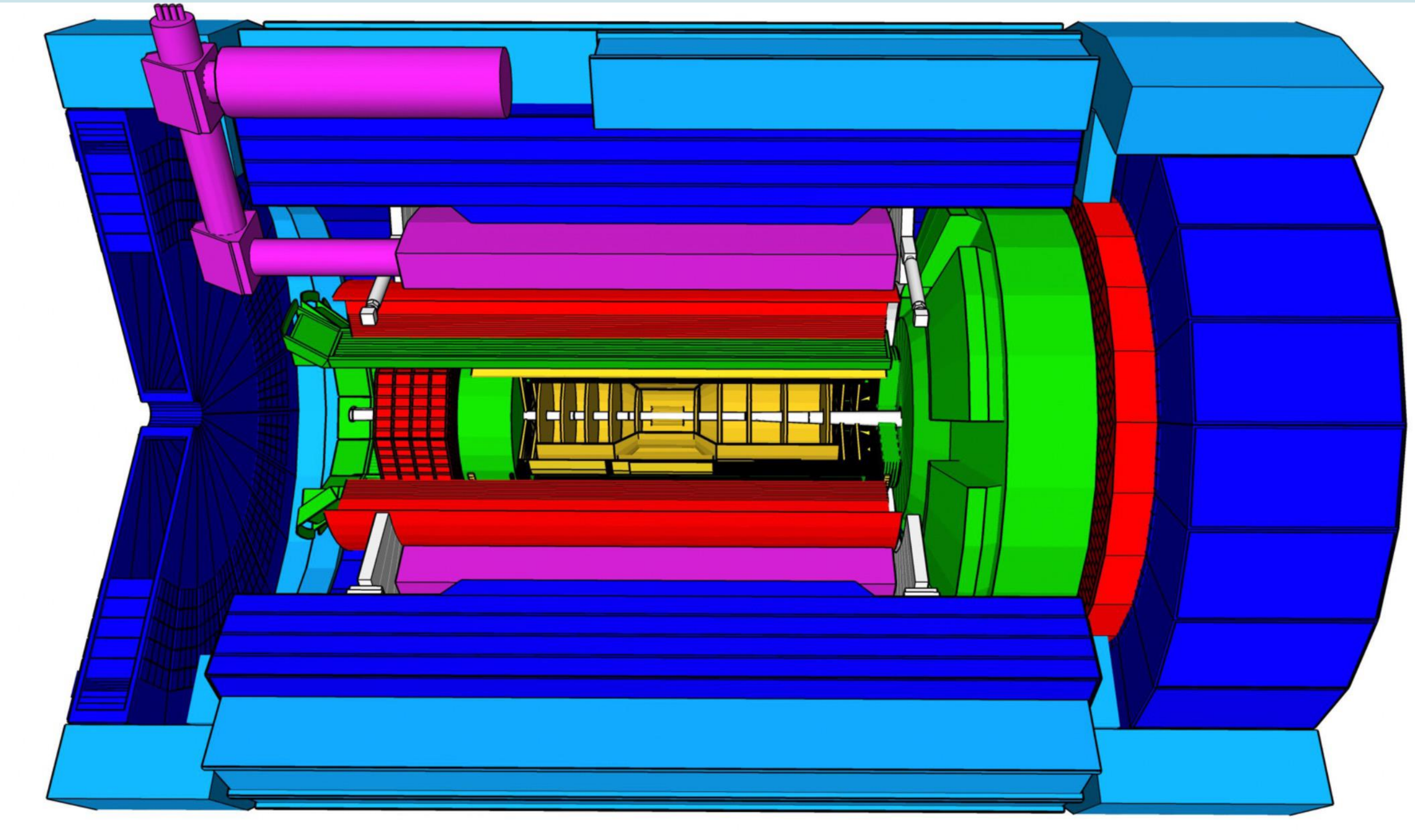


ePIC Detector Concept

Proton/Ion beam

40 - 275 GeV



Electron beam

2.5 - 18 GeV

ePIC Detector Concept

Backward

Forward

Proton/Ion beam

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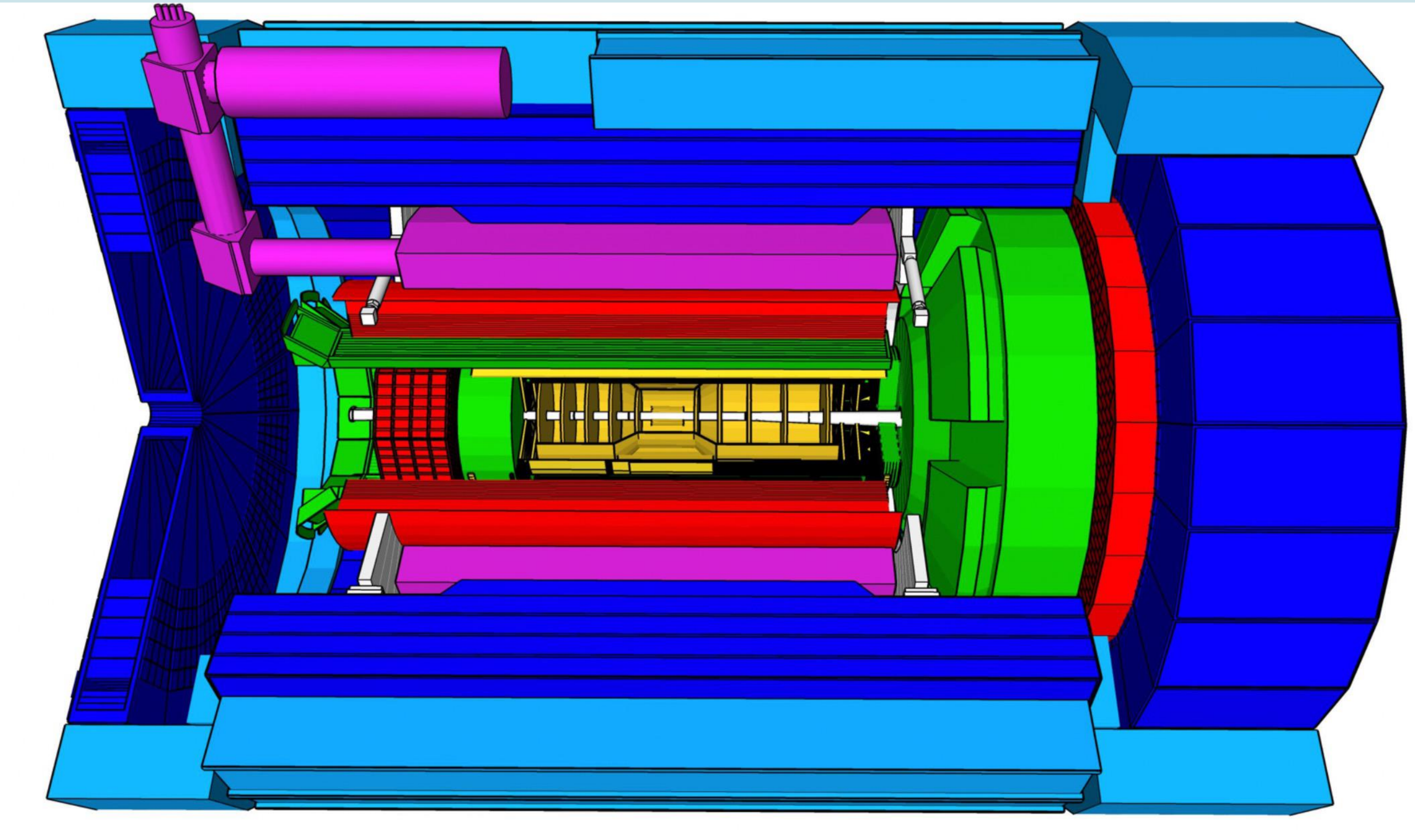


Electron beam

2.5 - 18 GeV

ePIC Detector Concept

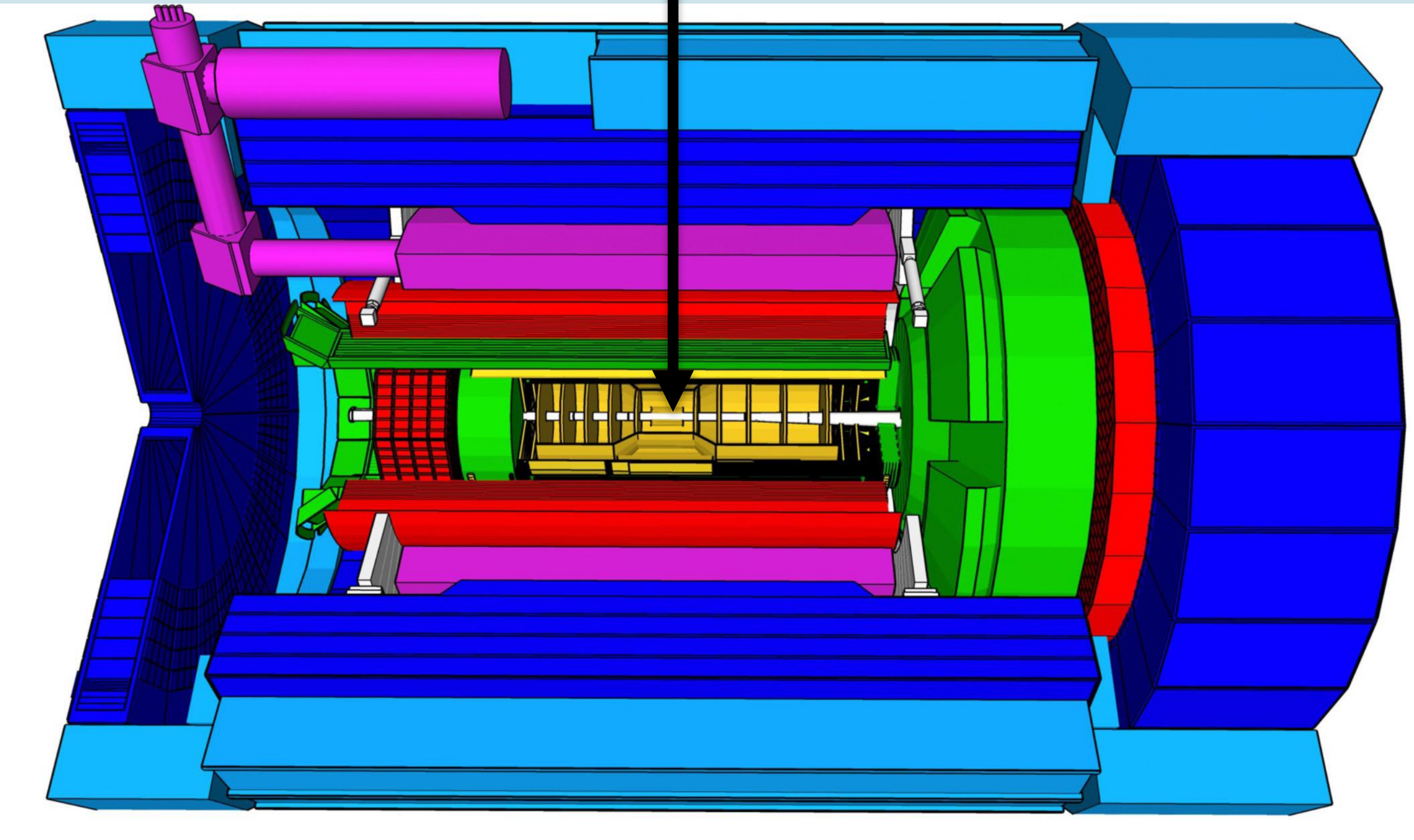
Collision Point

Backward

Forward

Proton/Ion beam

Electron beam



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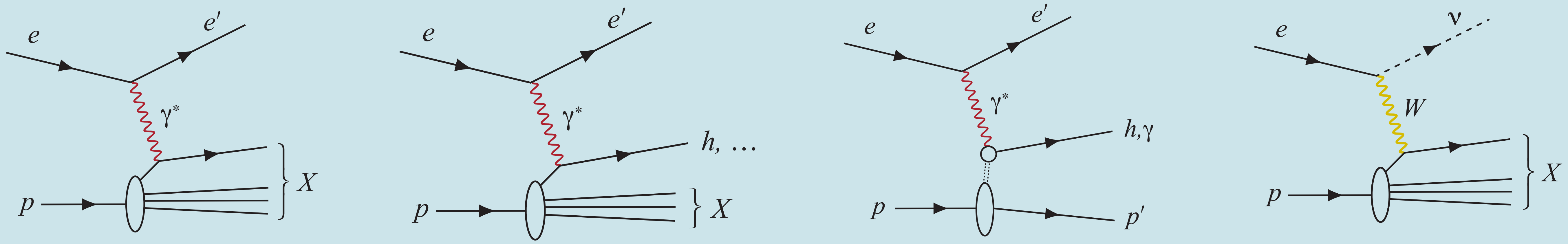

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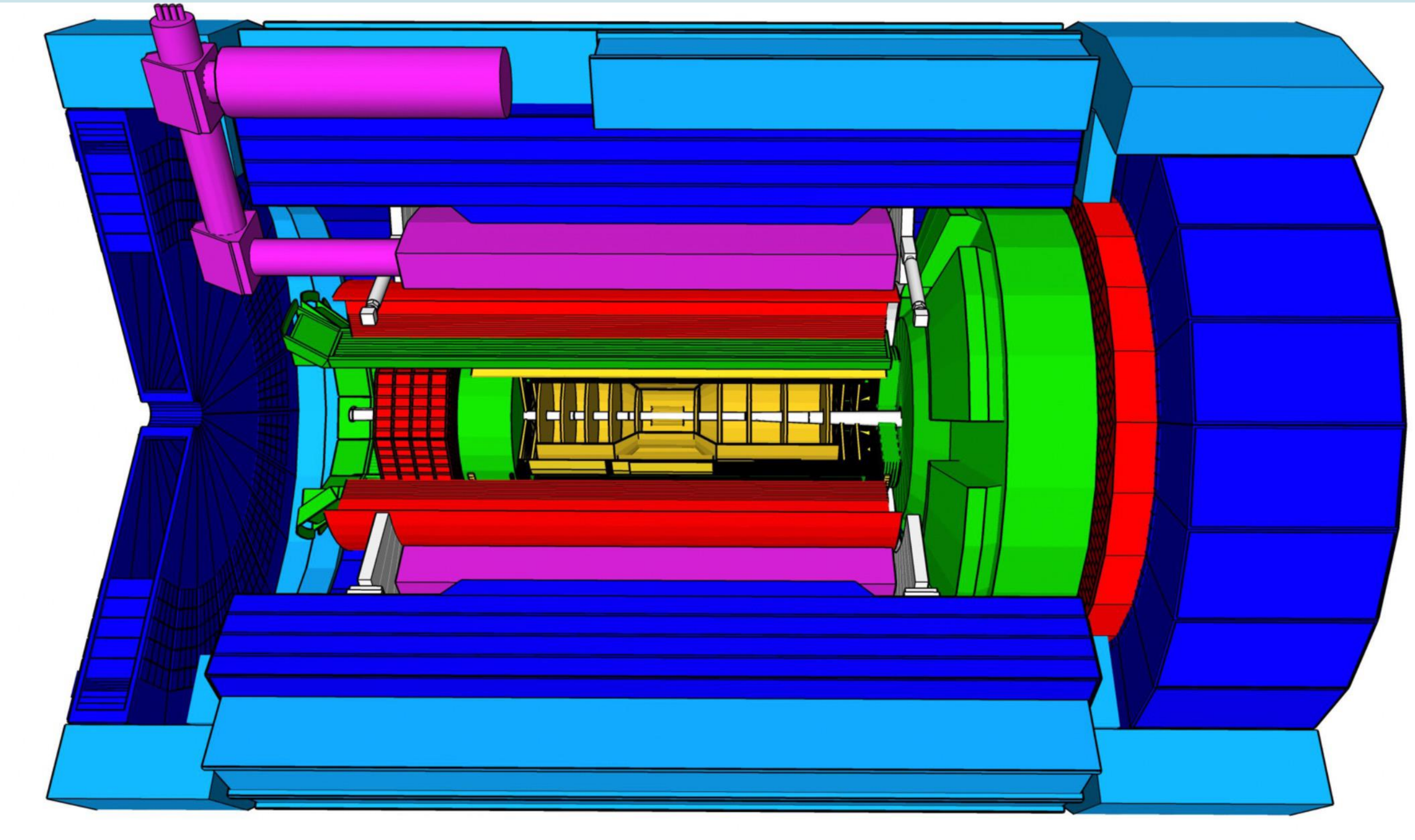
Proton/Ion beam



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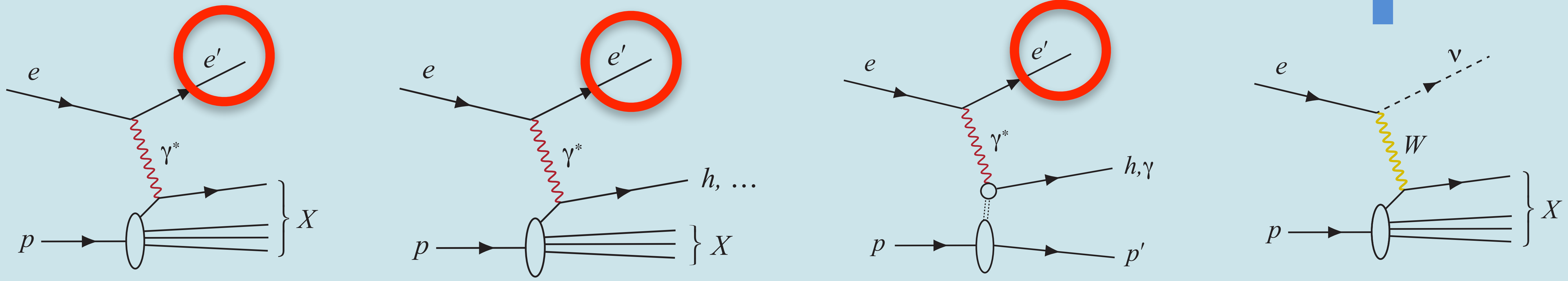
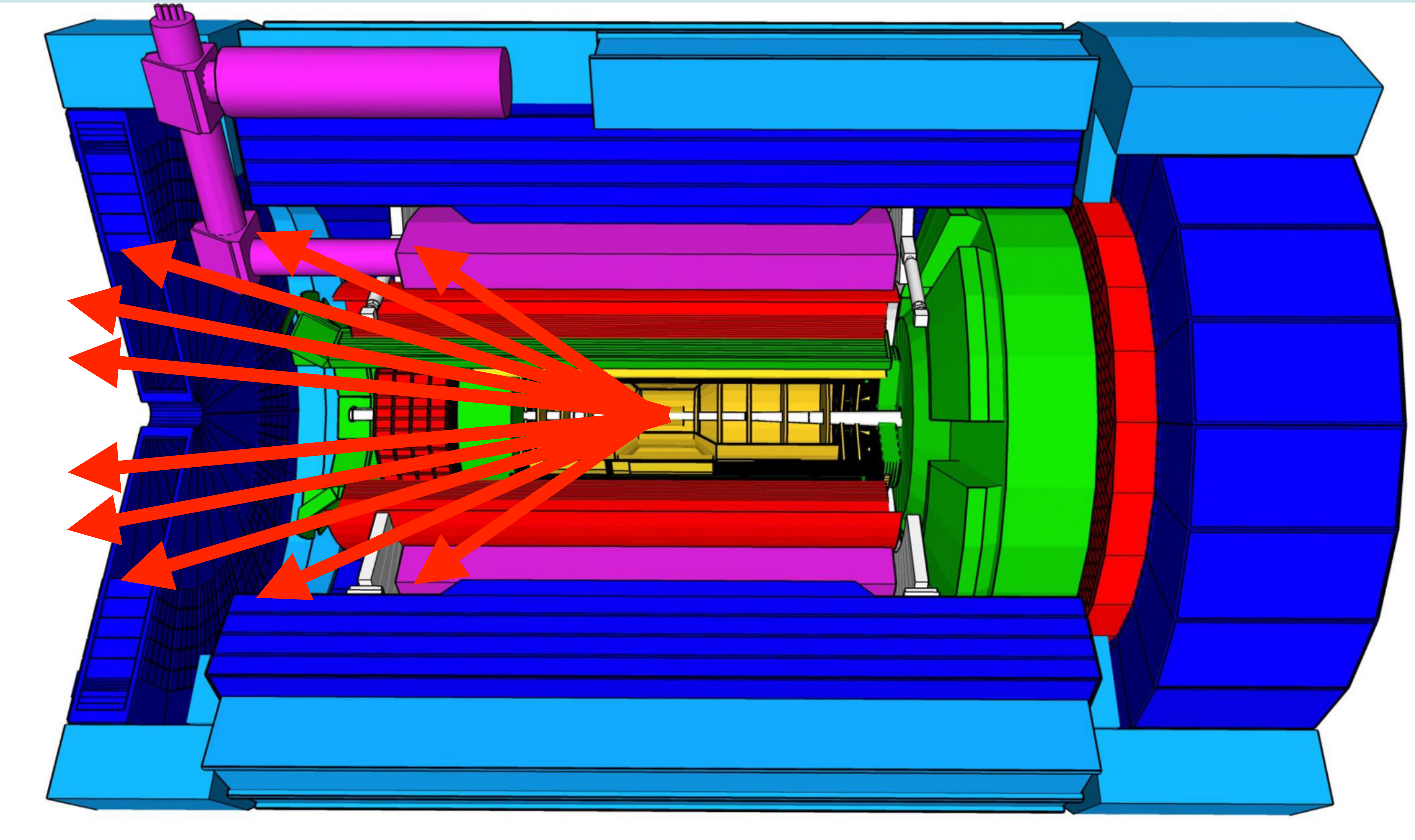


Forward

Scattered electron
η < -2.5 (mostly)

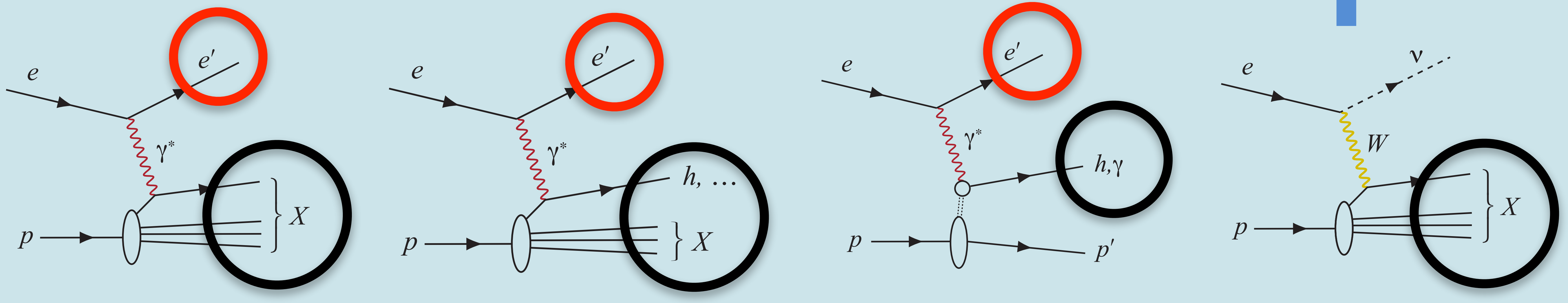
Proton/Ion beam



Electron beam

e-going endcap
Focus on electron measurement

ePIC Detector Concept



Backward

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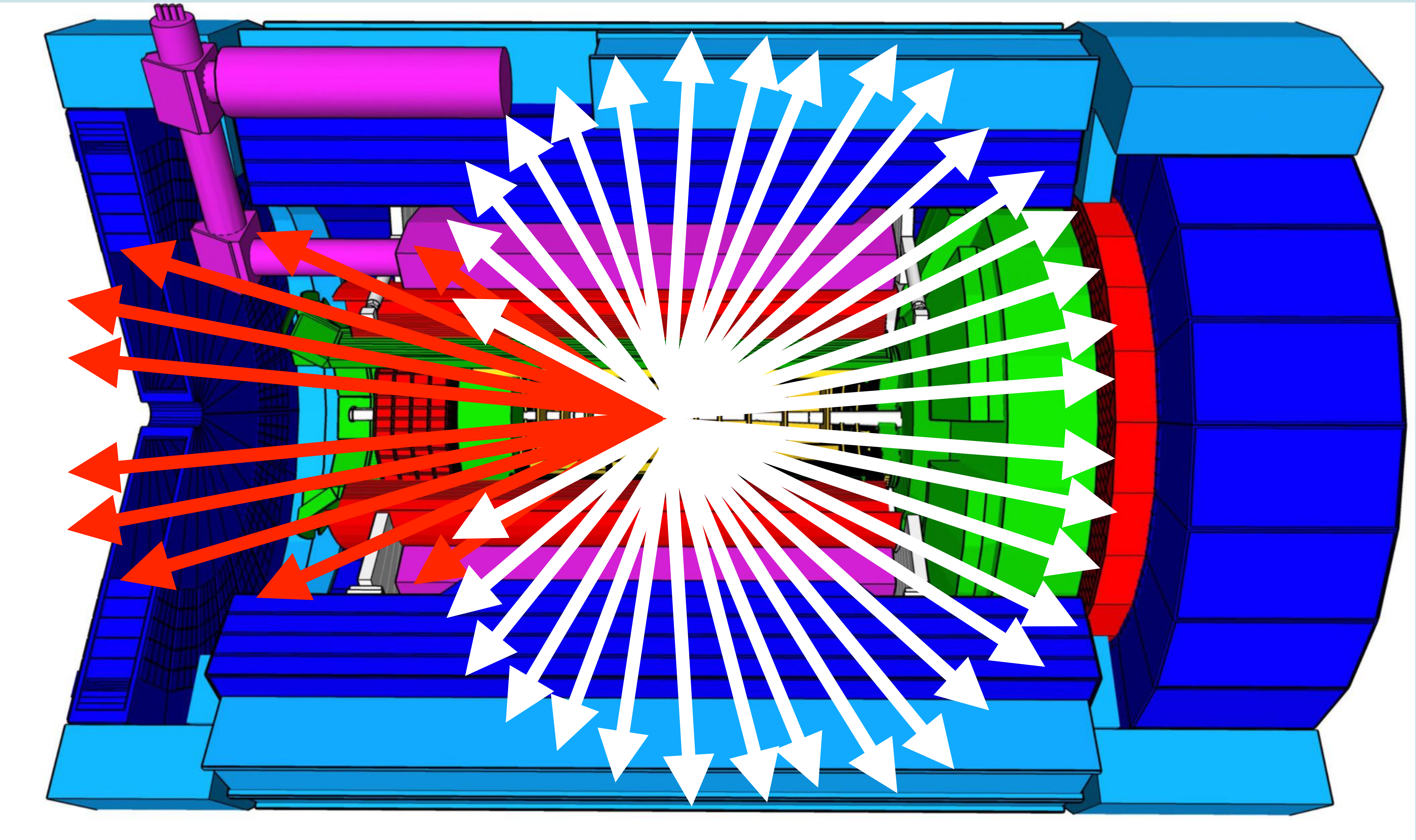
Proton/Ion beam

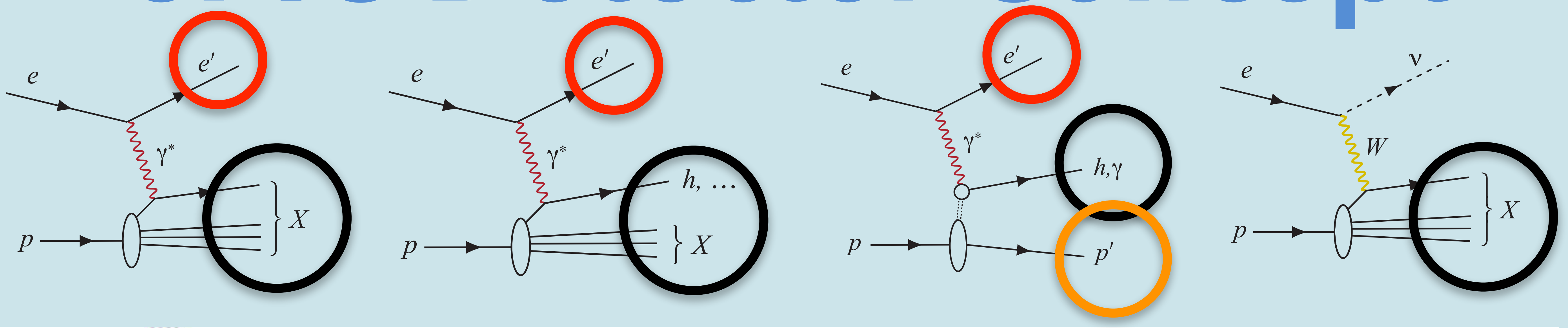
e-going endcap
Focus on electron
measurement



Produced particles
(incl. jets)
mid ~ forward η

Electron beam

ePIC Detector Concept



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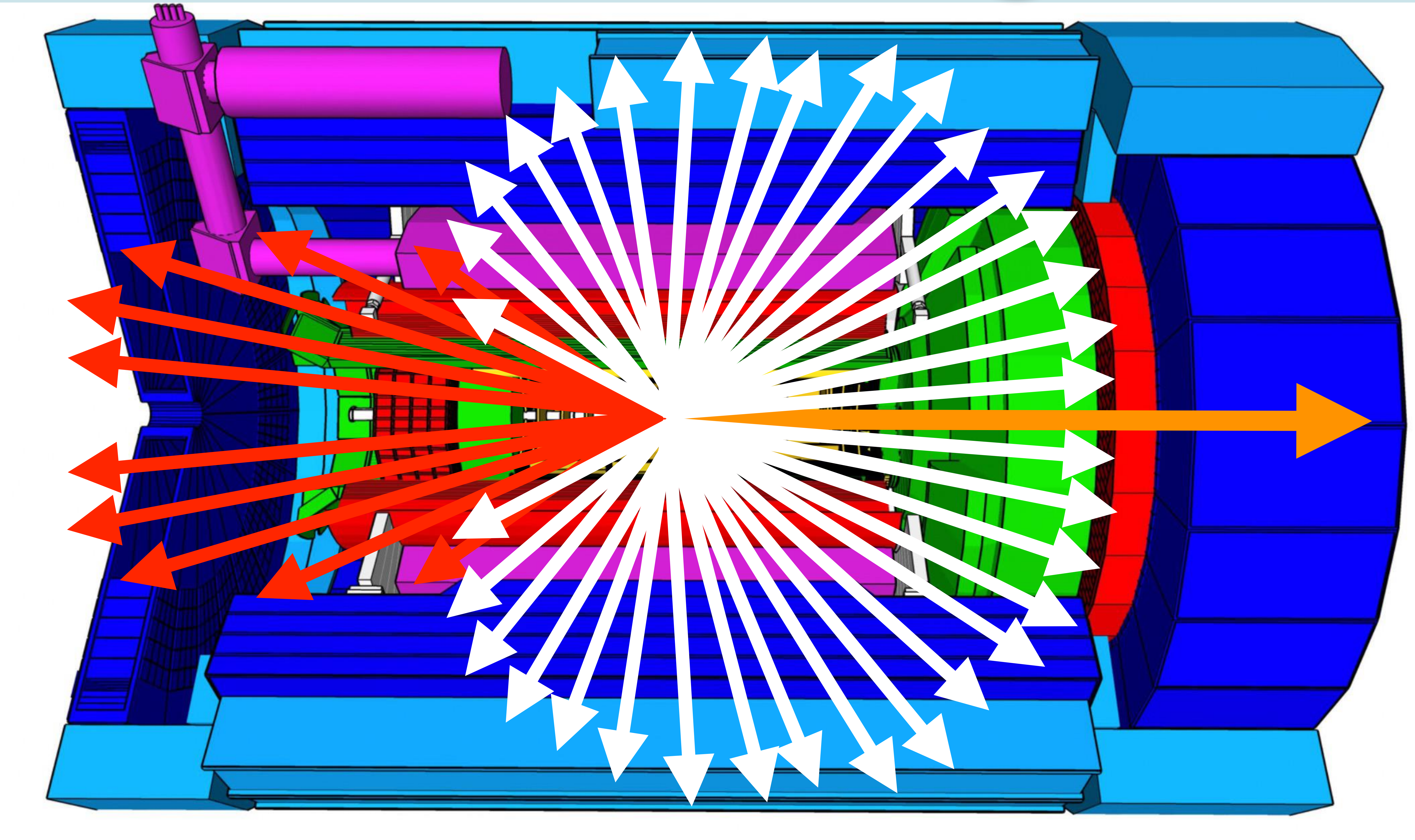


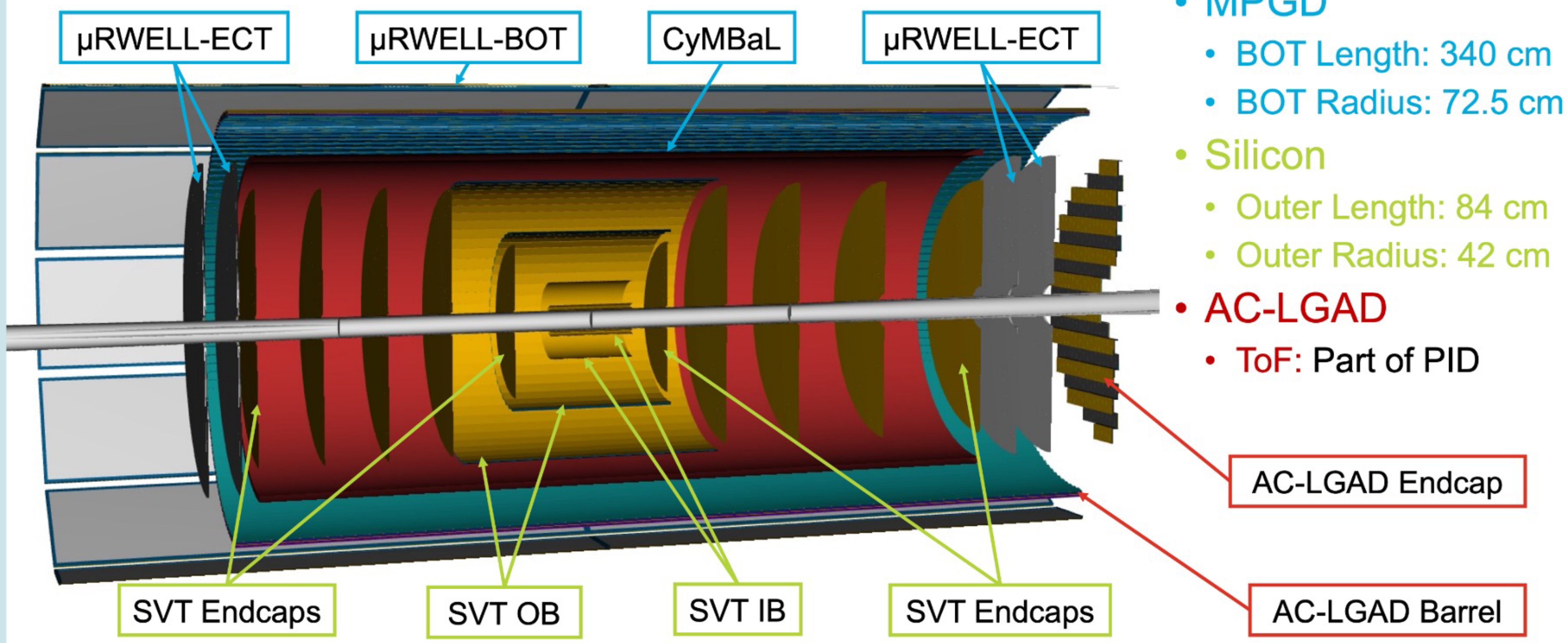
Proton/Ion beam

Electron beam

e-going endcap
Focus on electron
measurement

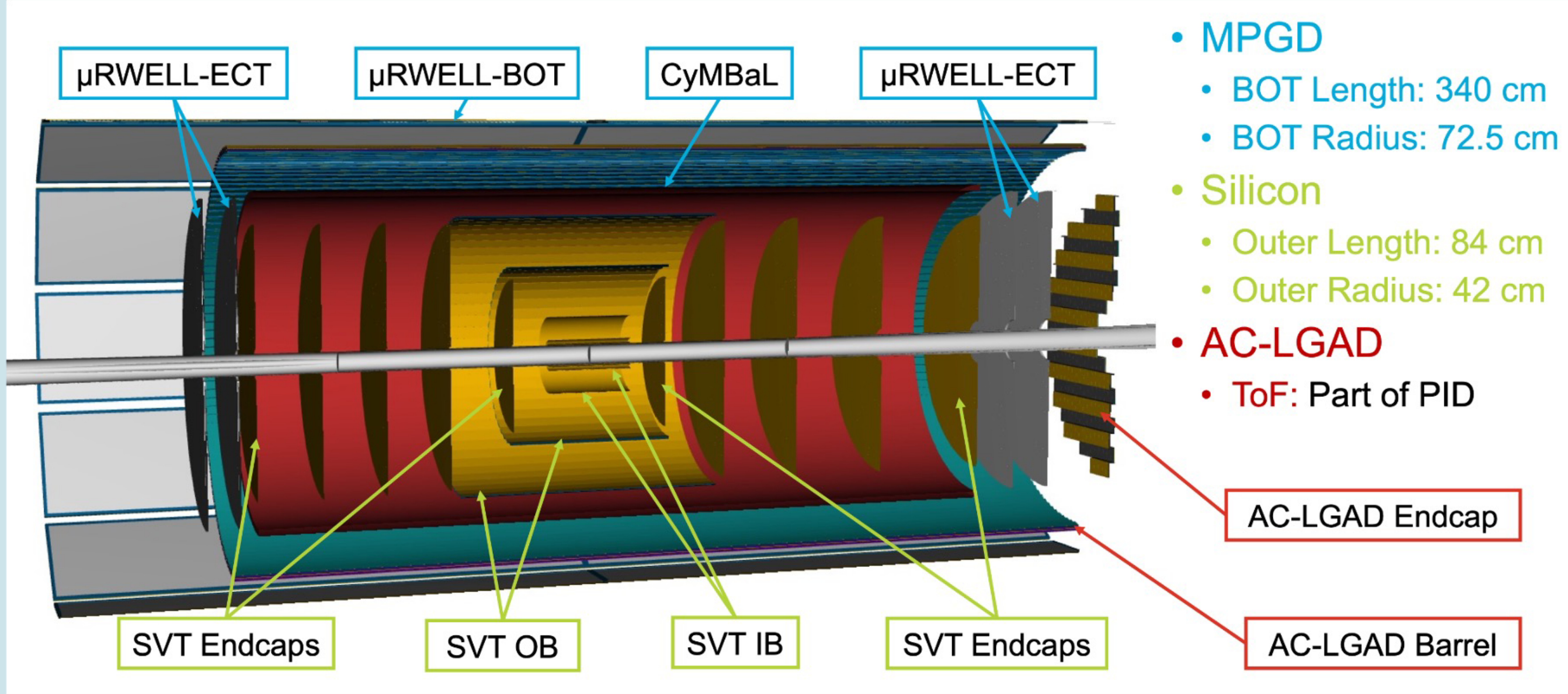
EP hadron beam
Far-forward
<2.1° (~37 mrad)

Tracking System



- MPGD
  - BOT Length: 340 cm
  - BOT Radius: 72.5 cm
- Silicon
  - Outer Length: 84 cm
  - Outer Radius: 42 cm
- AC-LGAD
  - ToF: Part of PID

Tracking System



Silicon Vertex Tracker (SVT):

- Small pixels (20 µm) 65nm MAPS tech.
- Low material budget (0.05% X/X_0) per layer
- Based on ALICE ITS3
- Disks forward and backward

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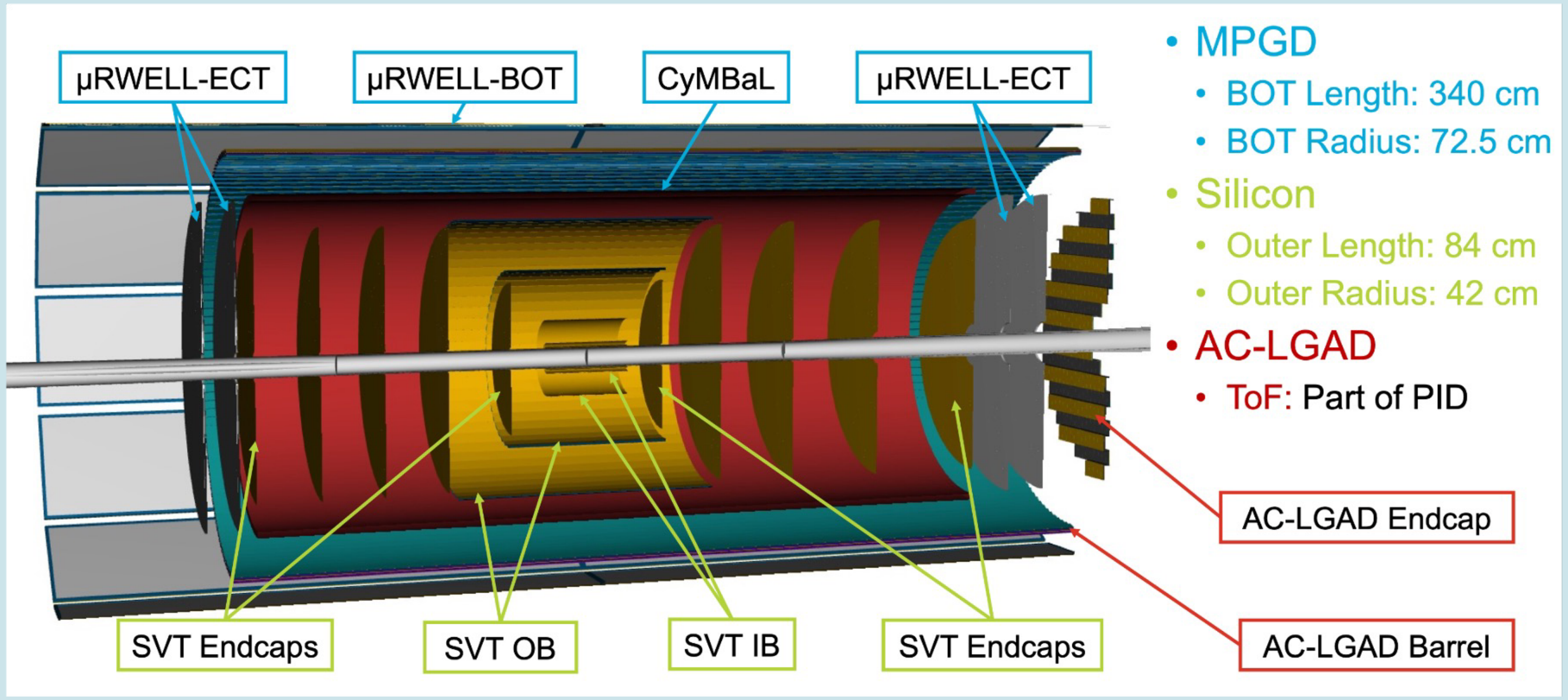

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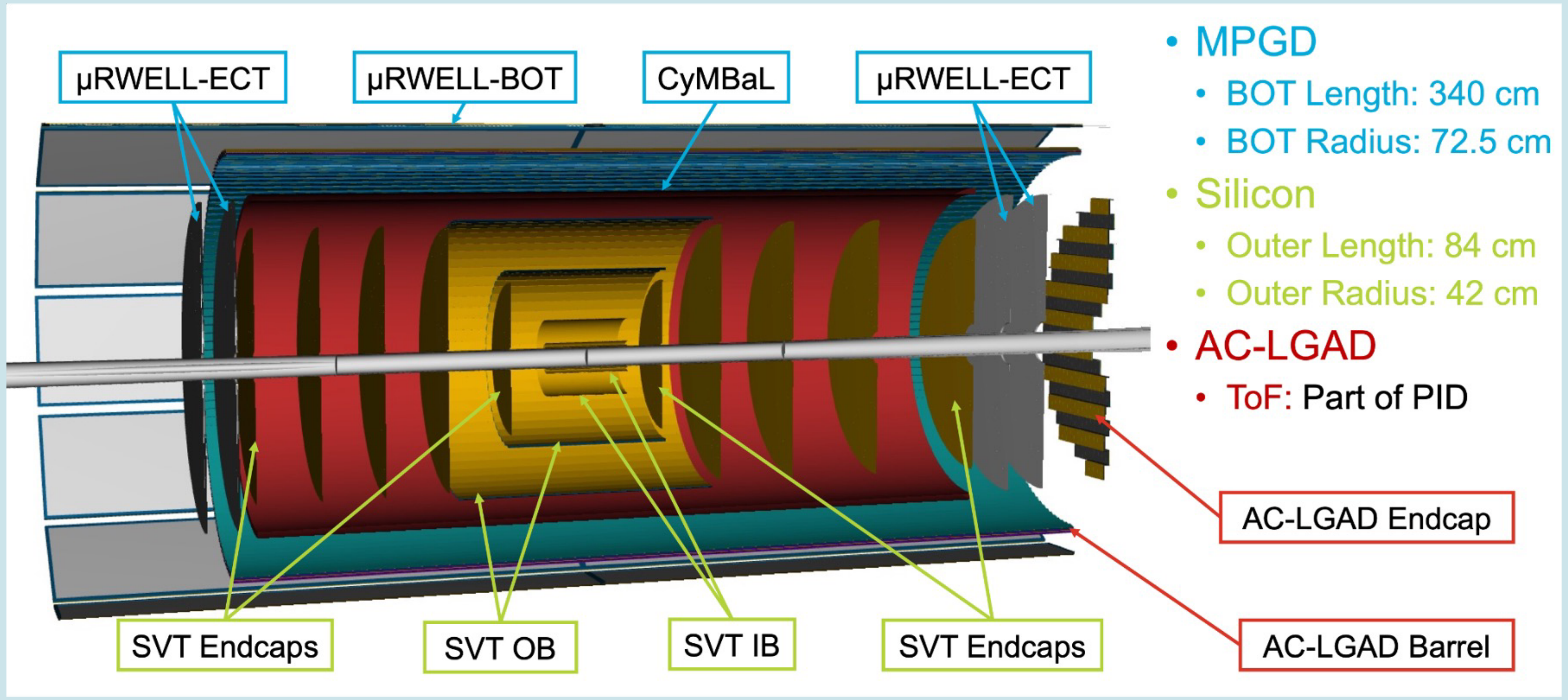
Micro Pattern Gas Detector (MPGD):

- μMEGAS and μRwell provide additional hits for pattern recognition
- 10 ns time resolution

Tracking System



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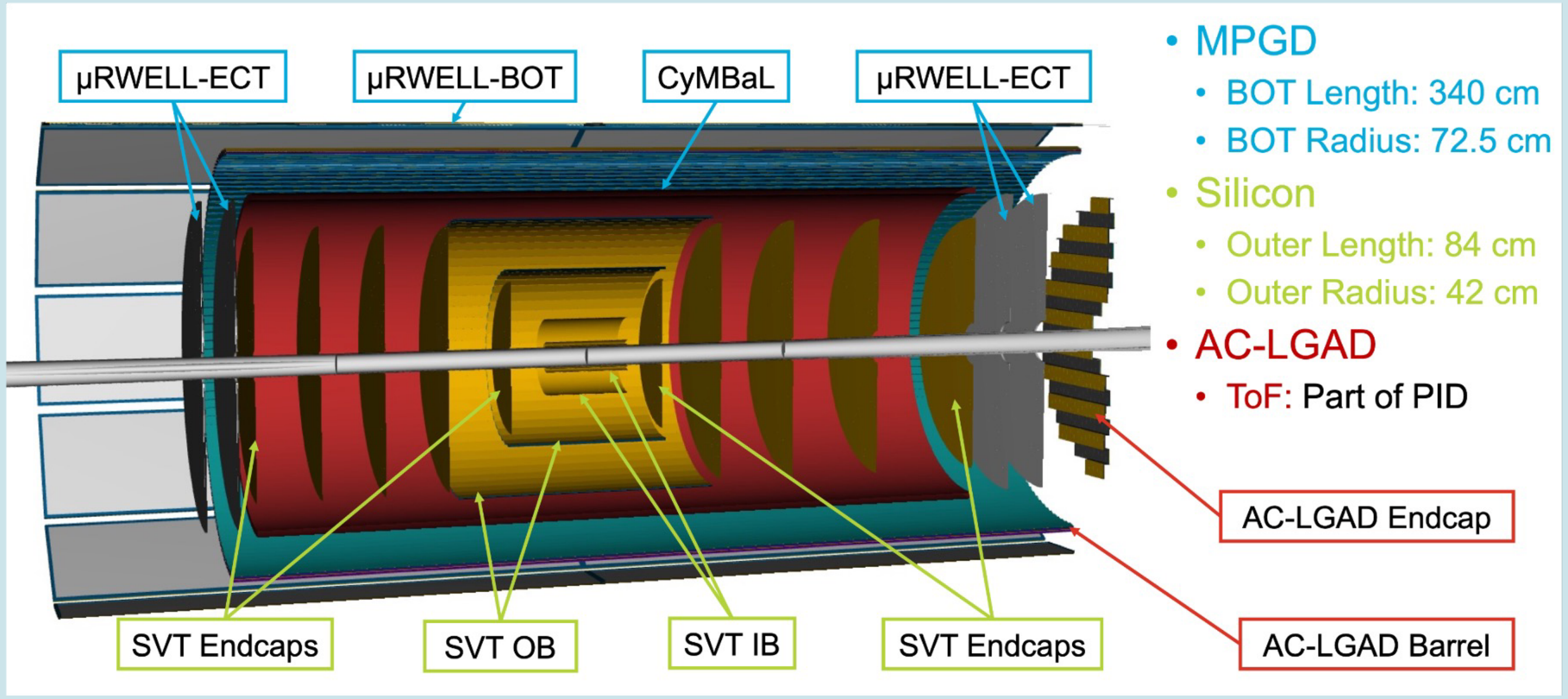
Micro Pattern Gas Detector (MPGD):

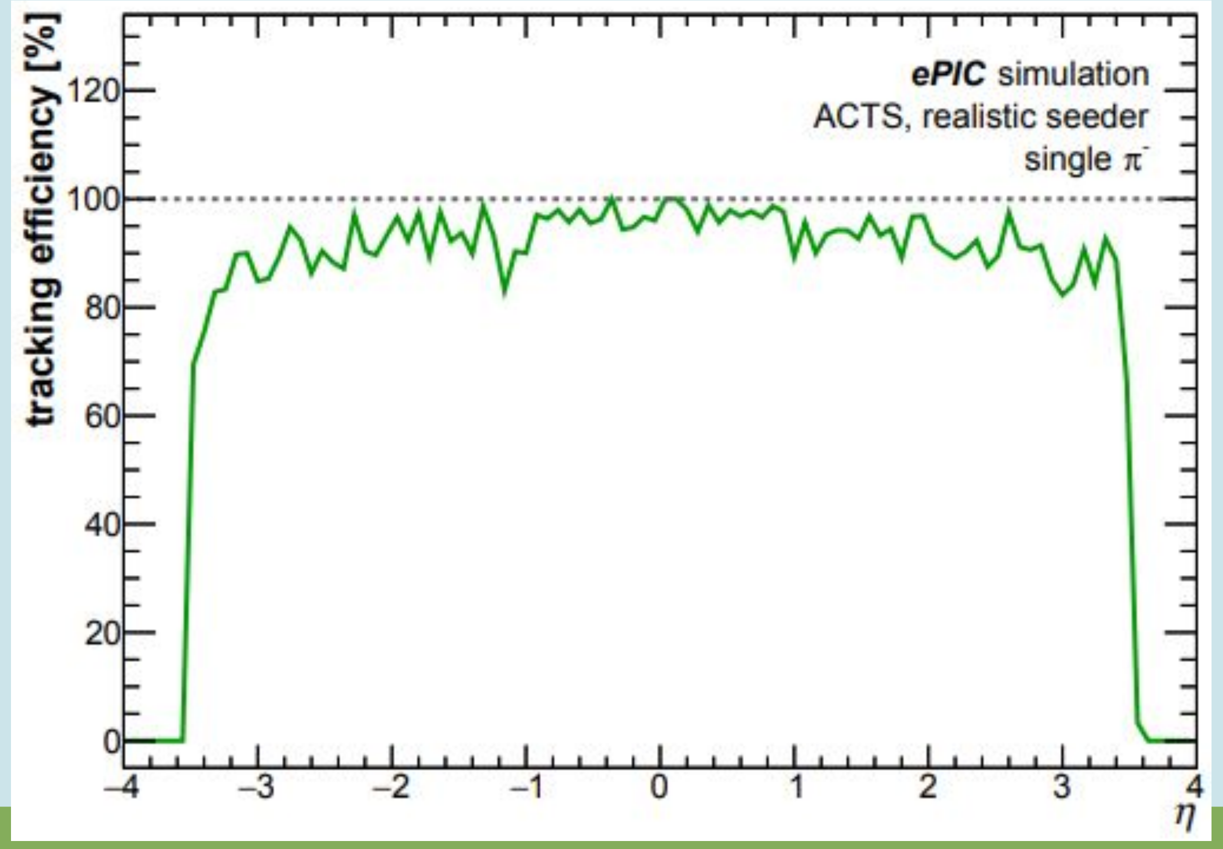
- μMEGAS and μRwell provide additional hits for pattern recognition
- 10 ns time resolution

AC-LGAD

- 30 ps and 30 μm timing and spatial resolution
- Background rejection

Tracking System





Silicon Vertex Tracker (SVT):

- Small pixels (20 μm) 65nm MAPS tech.
- Low material budget (0.05% X/X_0) per layer
- Based on ALICE ITS3
- Disks forward and backward

Micro Pattern Gas Detector (MPGD):

- μMEGAS and μRwell provide additional hits for pattern recognition
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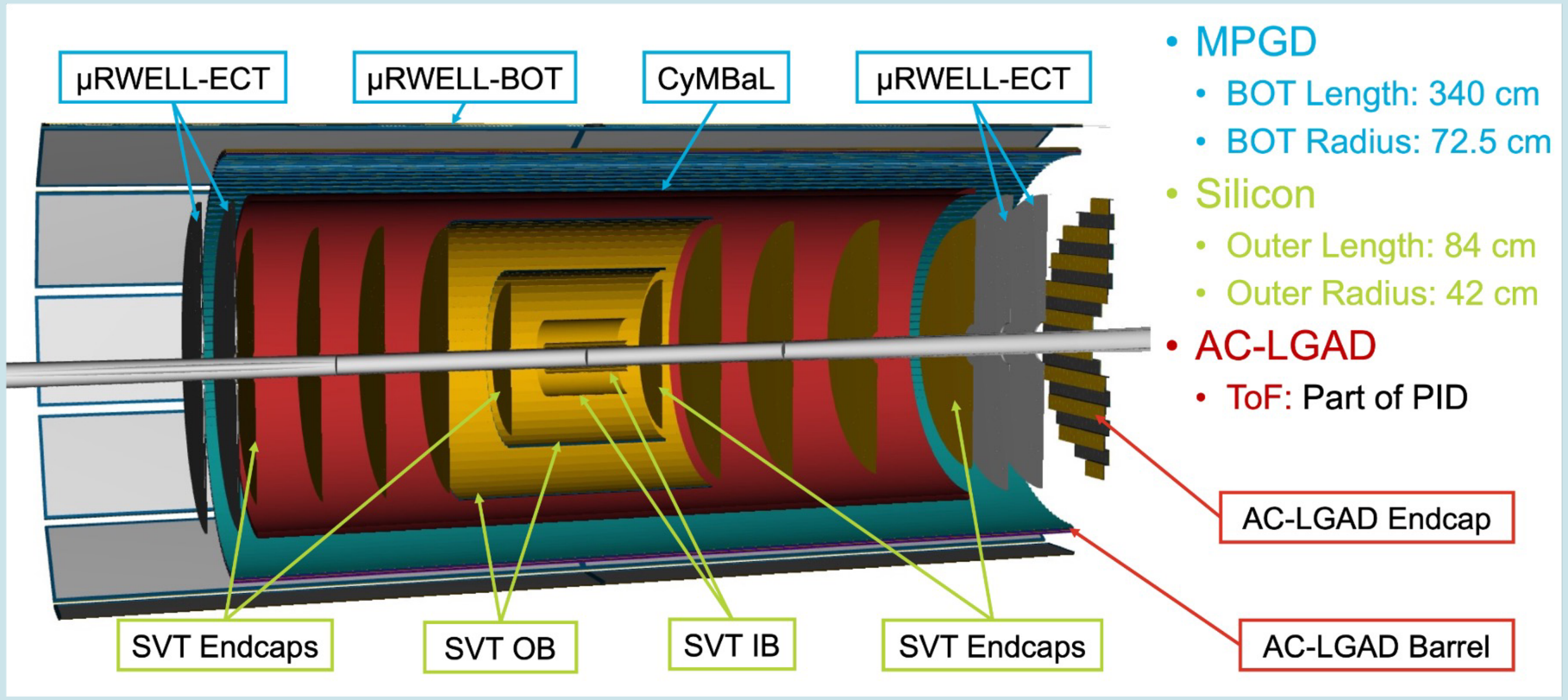
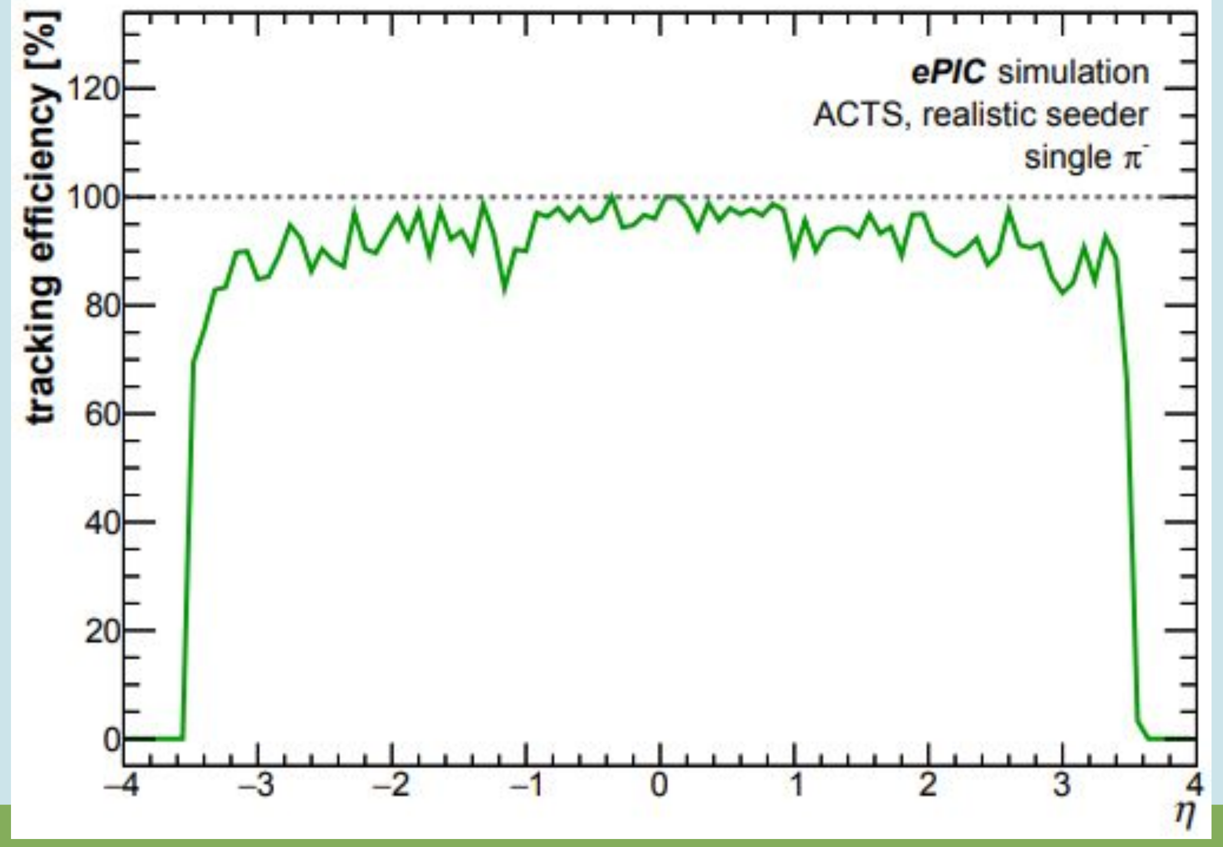
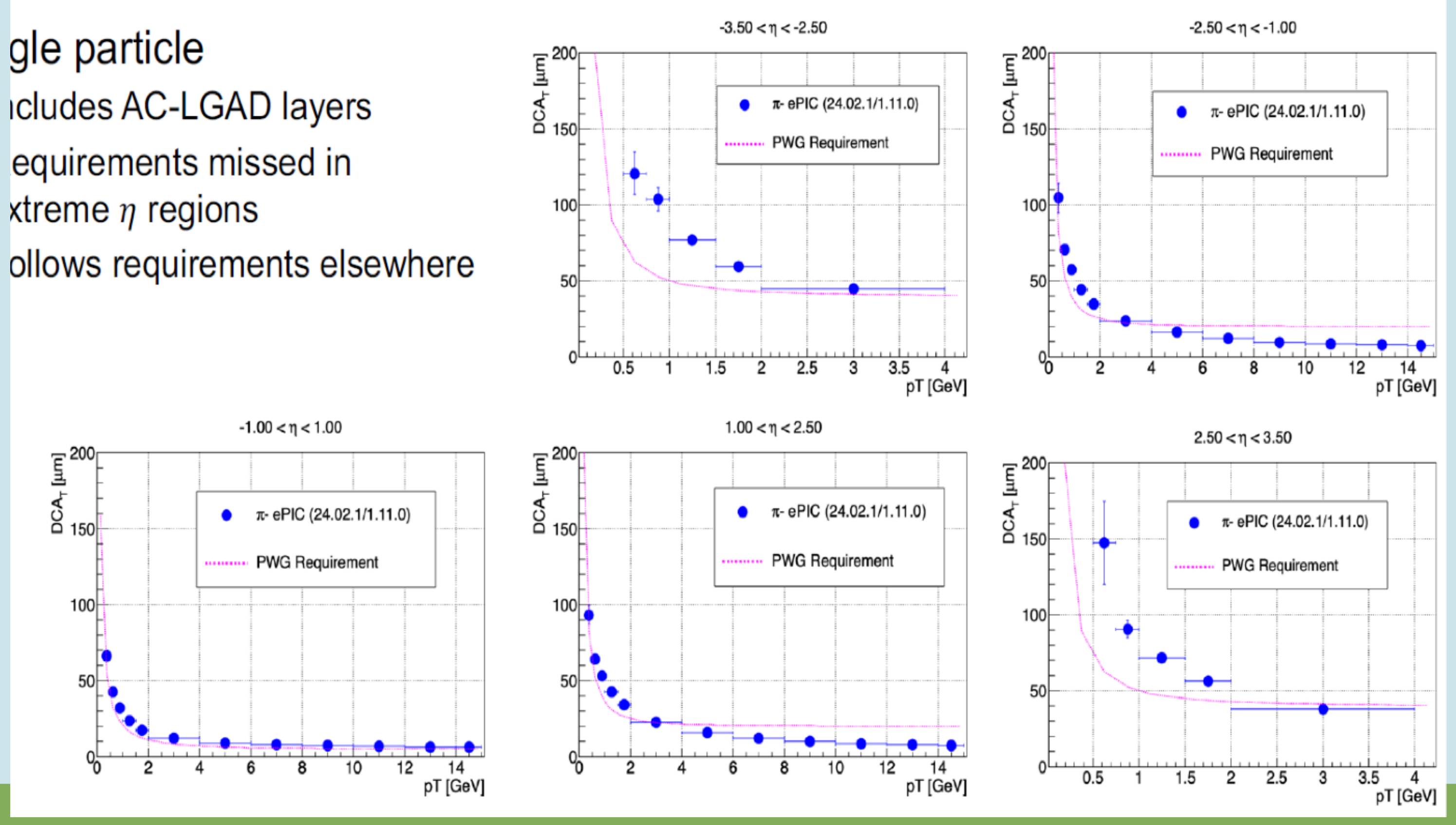
Tracking System







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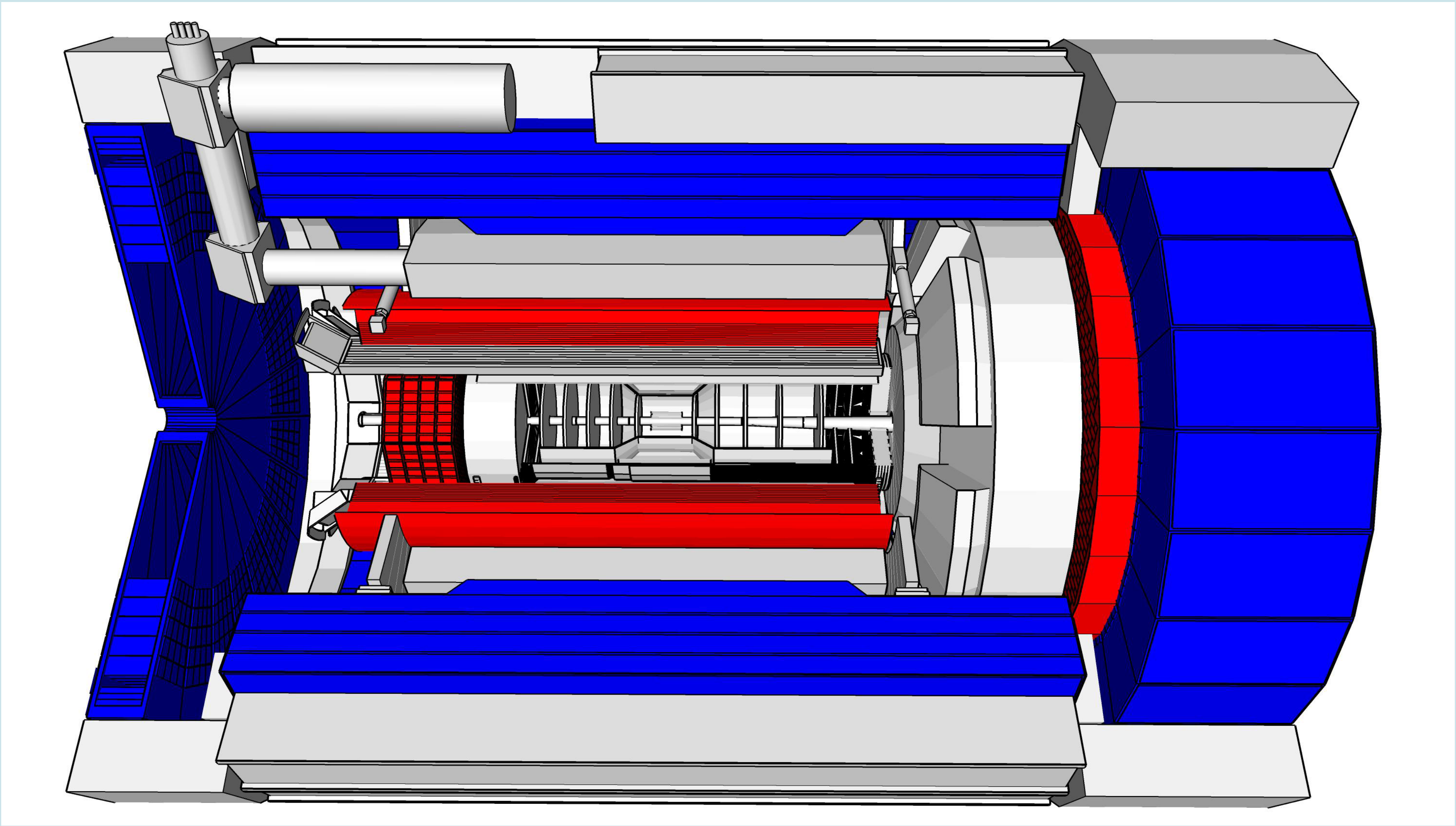
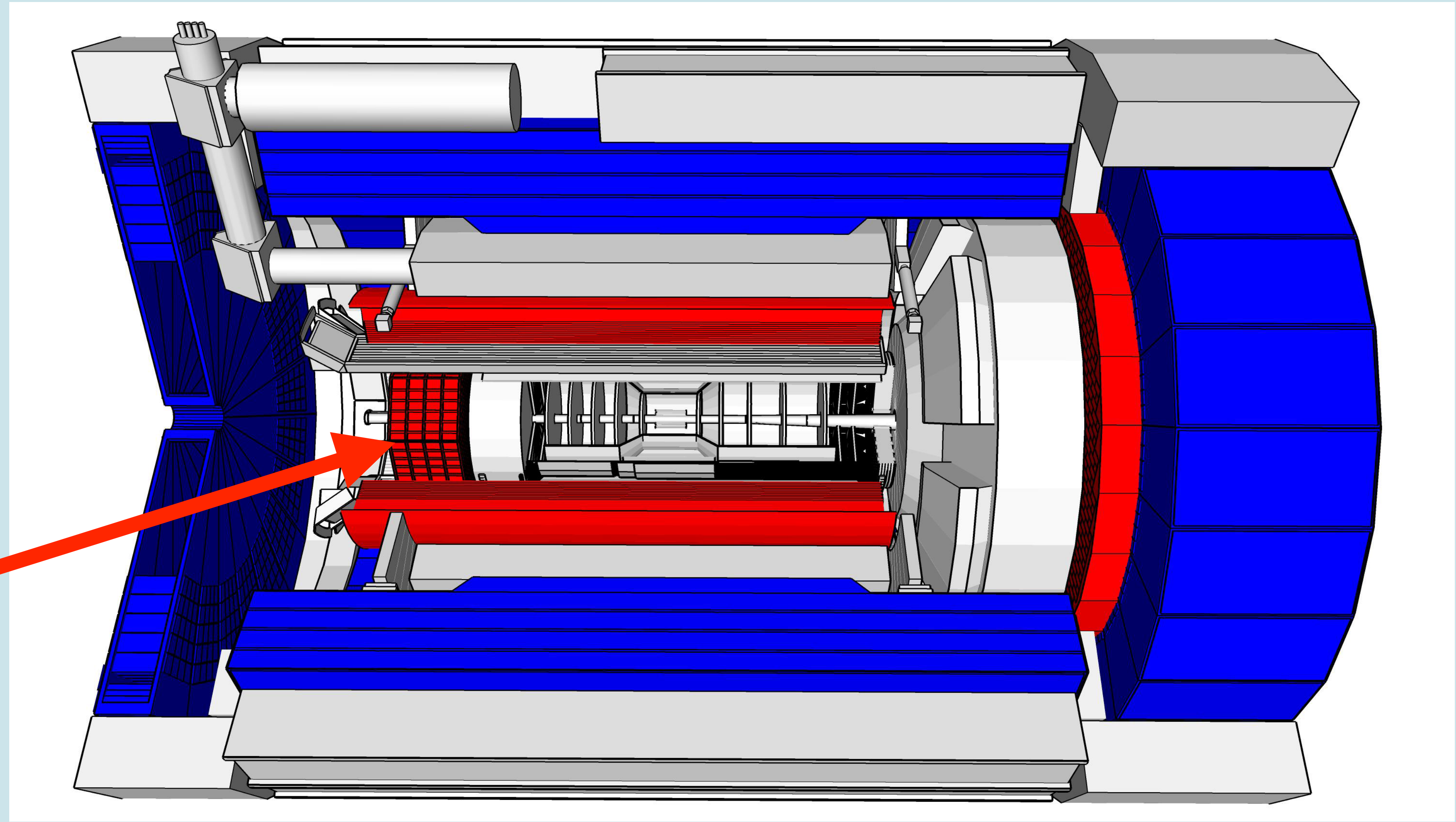
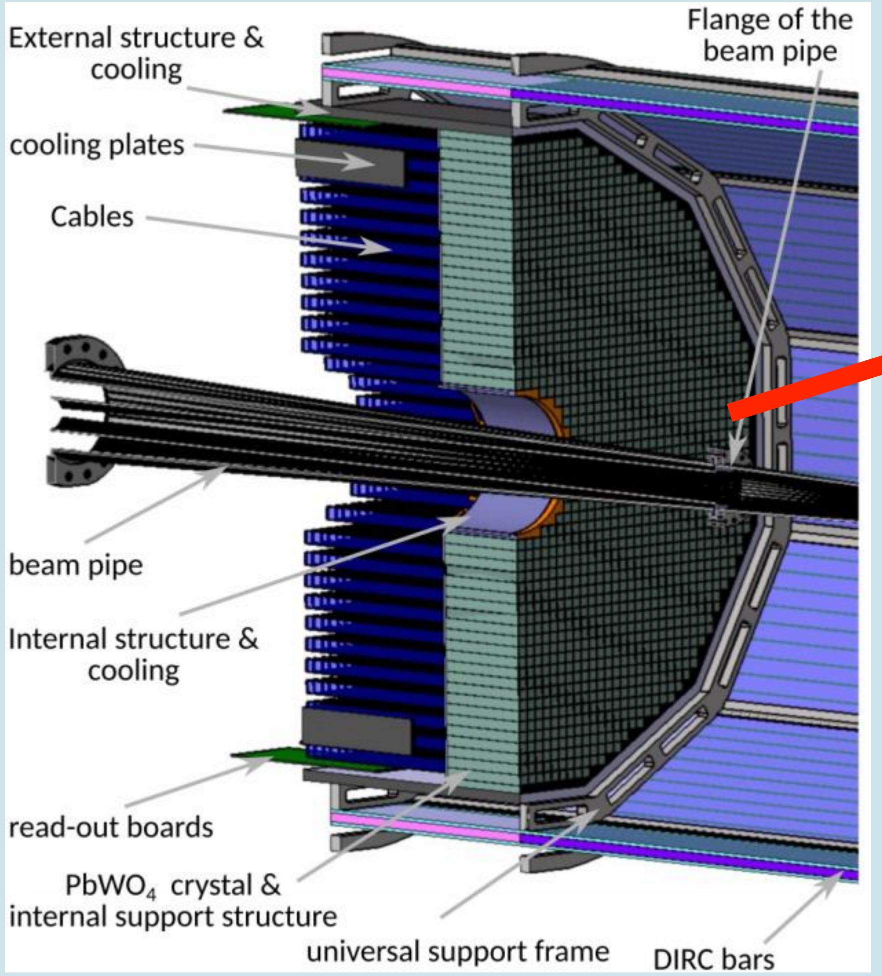
Calorimeter Design



Calorimeter Design



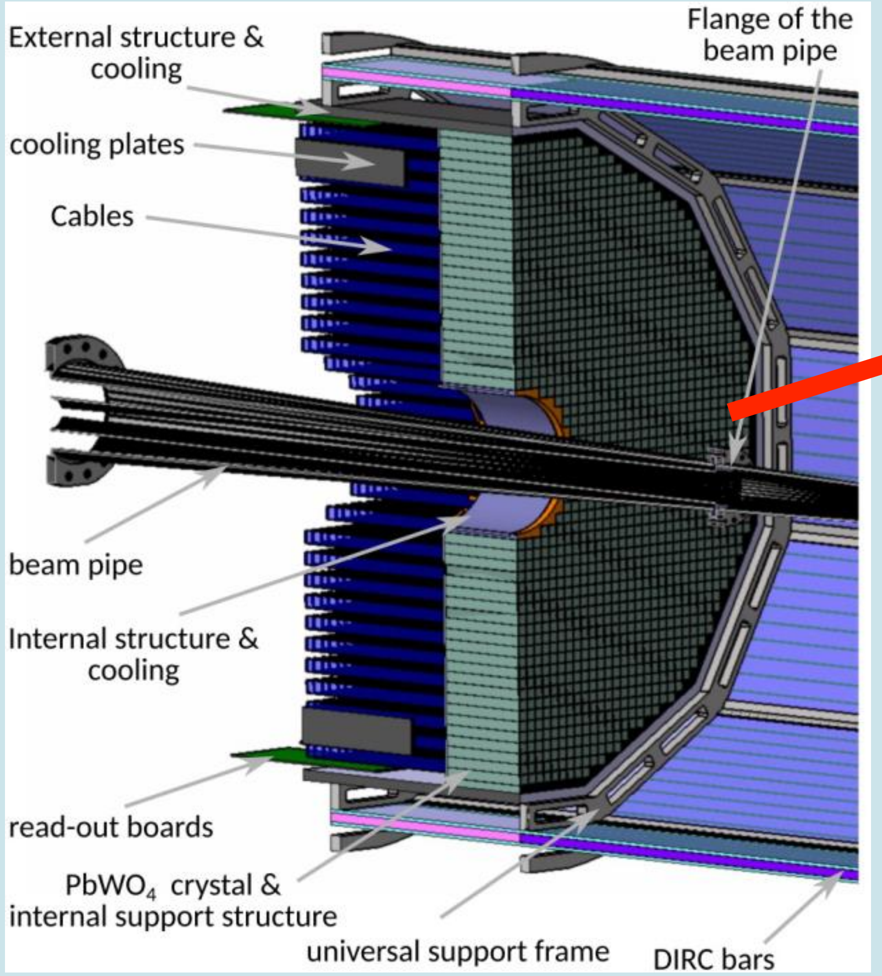


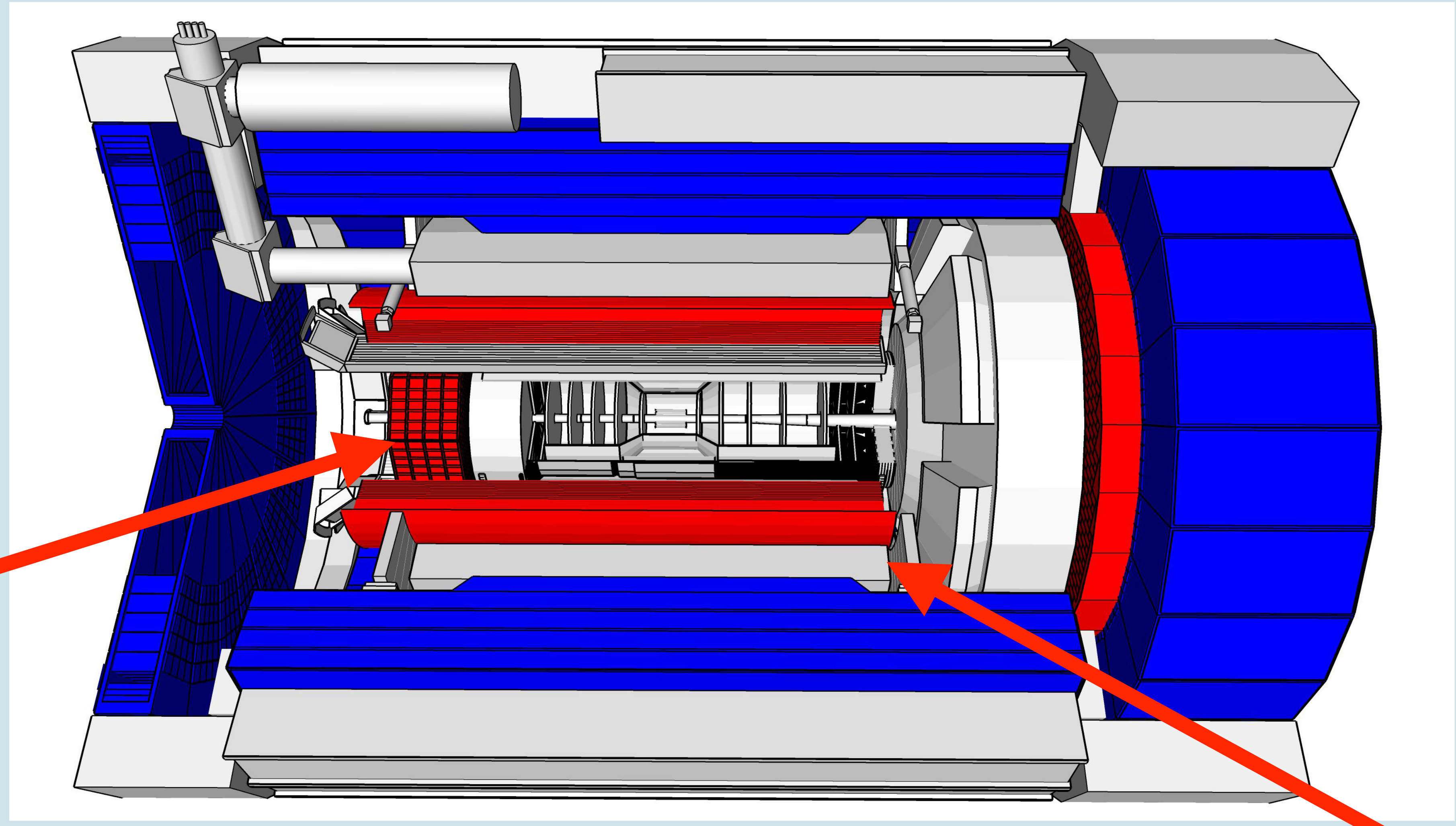
Backward EMCal (-3.5<η<-1.7)

$PbWO_4$ crystal

Scattered electron reconstruction

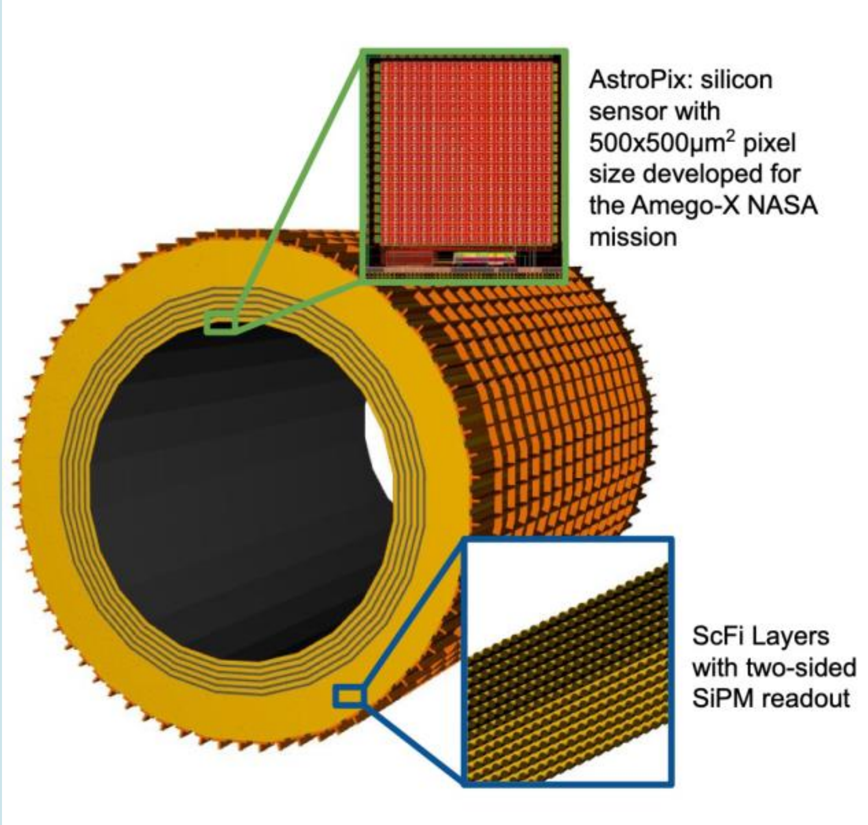
Calorimeter Design





Imaging Barel EMCal (-1.7<η<1.4)

6 layers of Si sensors with SciFi/Pb layers

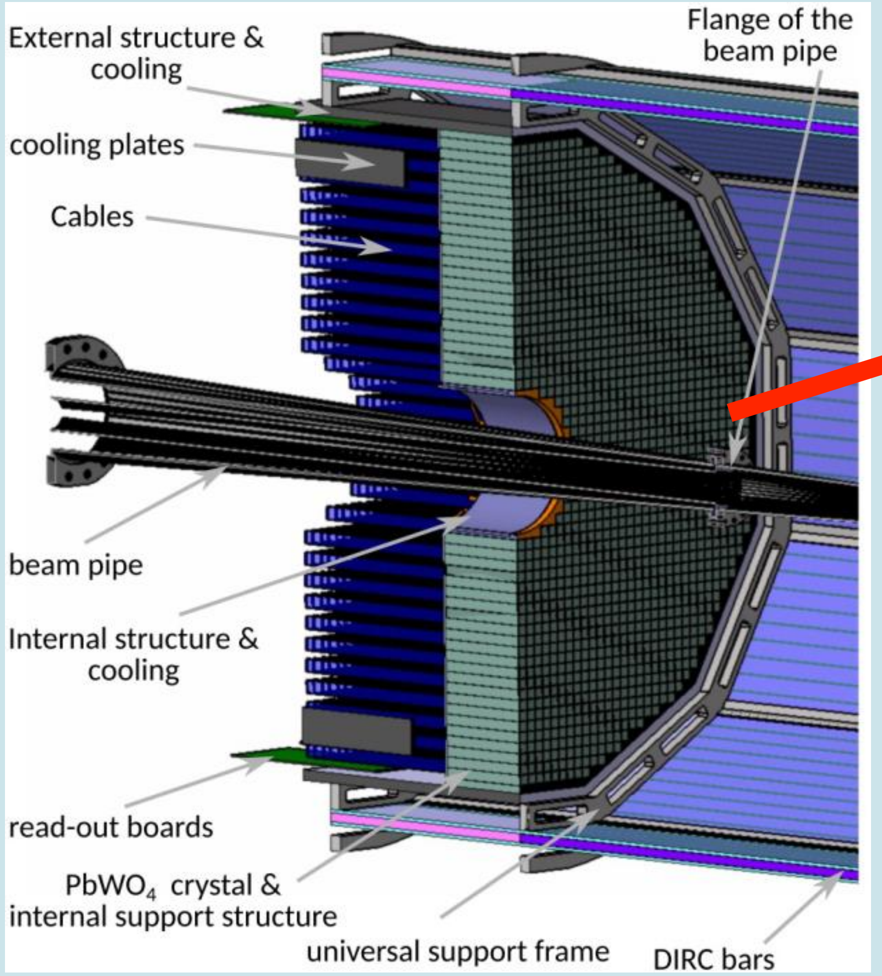


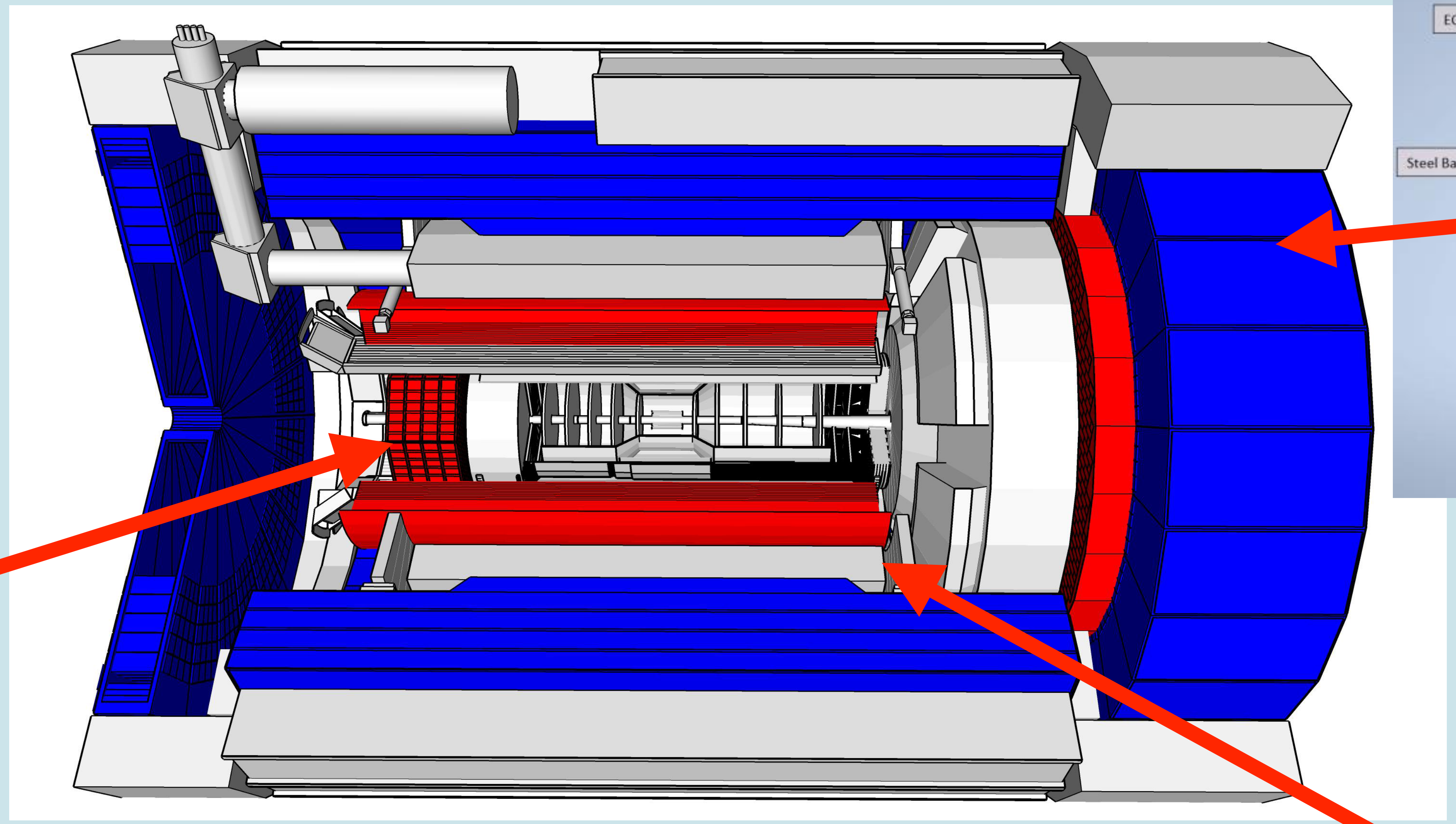
Backward EMCal (-3.5<η<-1.7)

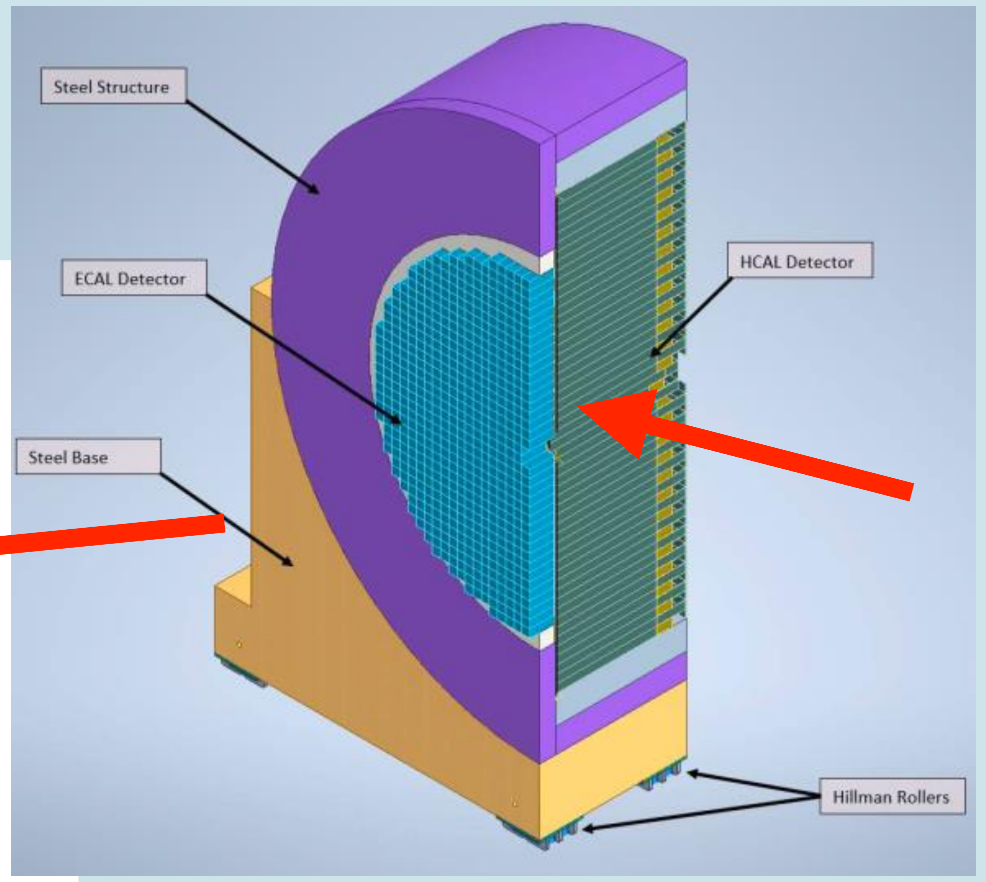
$PbWO_4$ crystal

Scattered electron reconstruction

Calorimeter Design

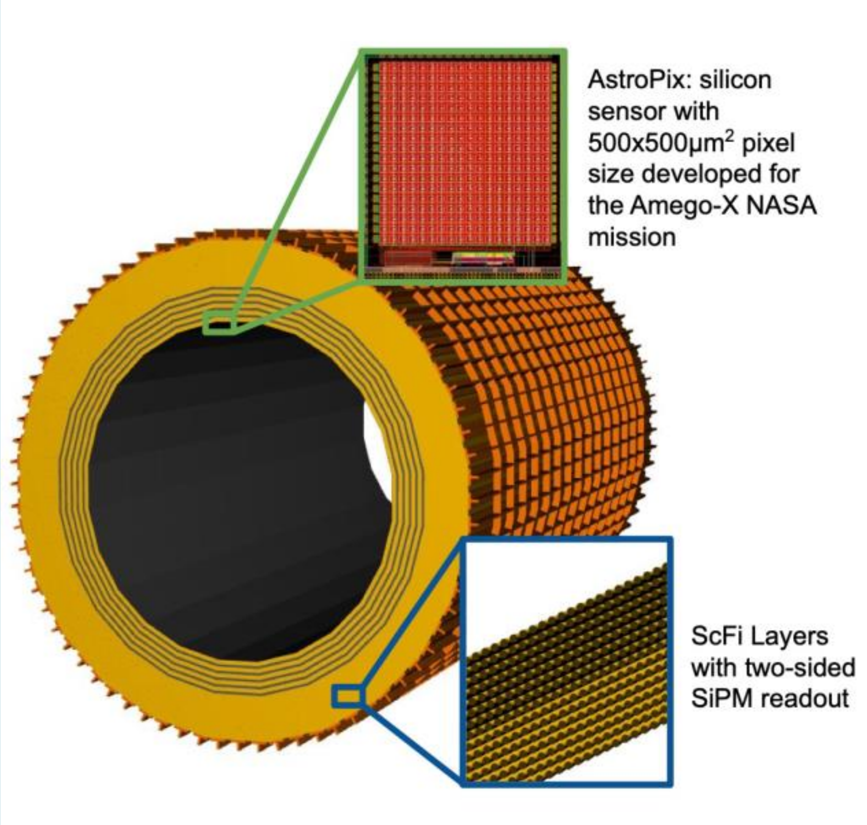






EMCal
(1.4<η<3.7)
W/ScFi blocks
π/γ separation

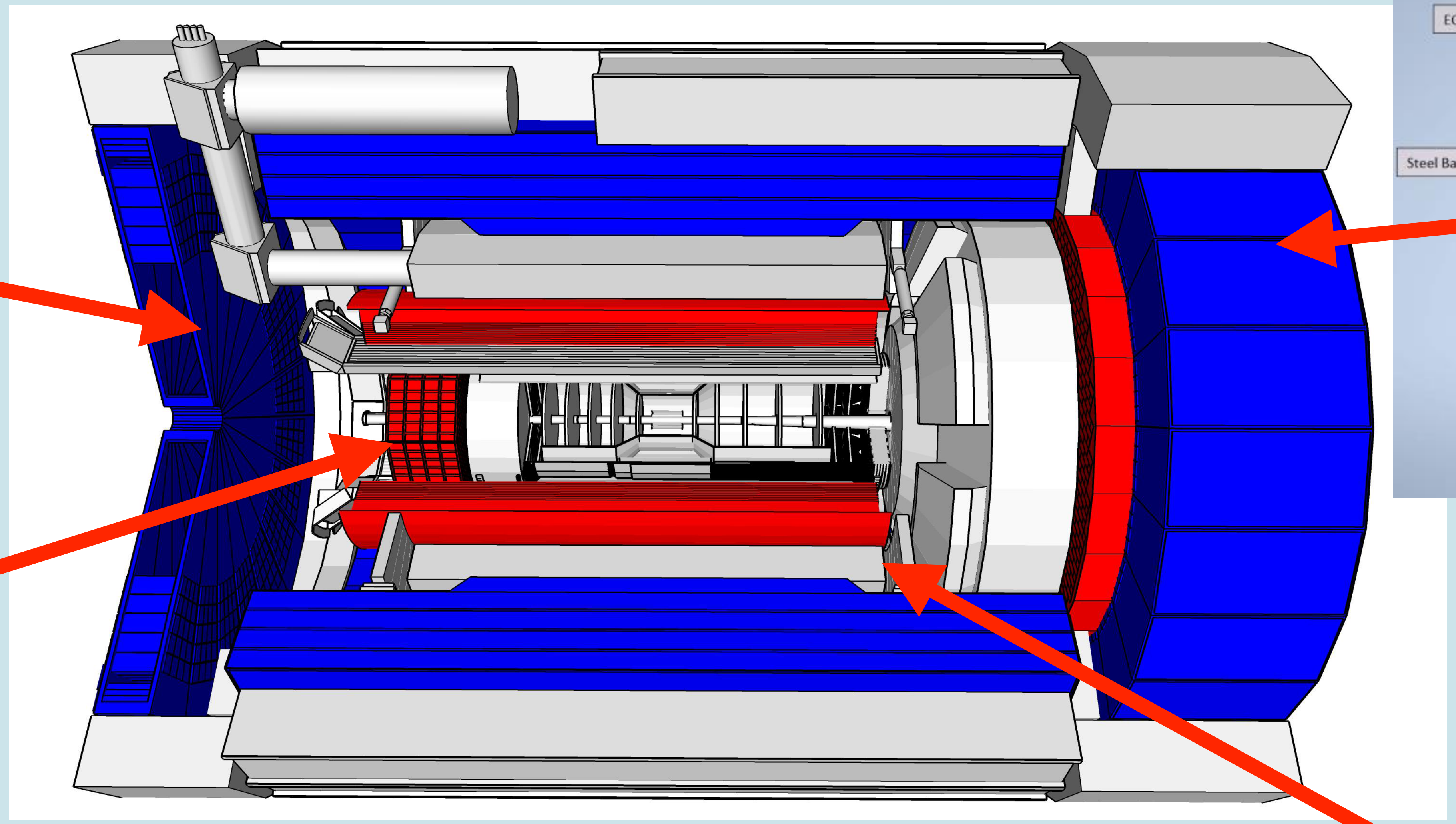
Imaging Barel EMCal (-1.7<η<1.4)
6 layers of Si sensors with SciFi/Pb layers

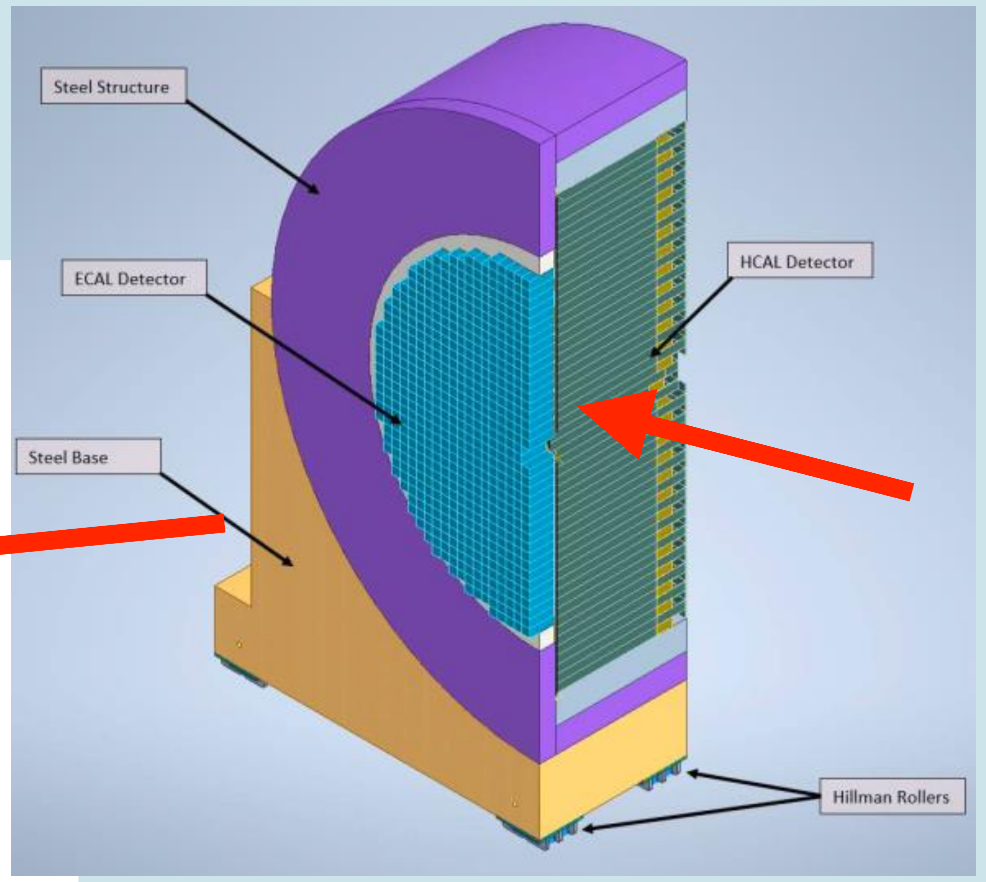


Backward EMCal (-3.5<η<-1.7)
$PbWO_4$ crystal
Scattered electron reconstruction

Calorimeter Design

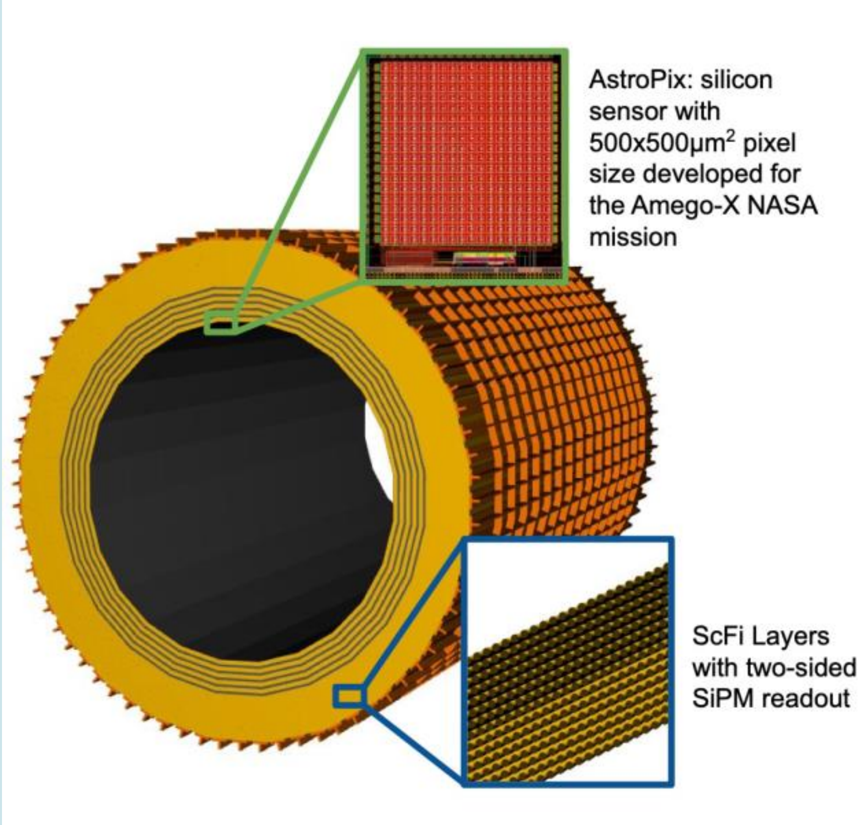
Backward HCal (-3.5<η<-1.7)
Steel/Sci sampling
<20 GeV neutron

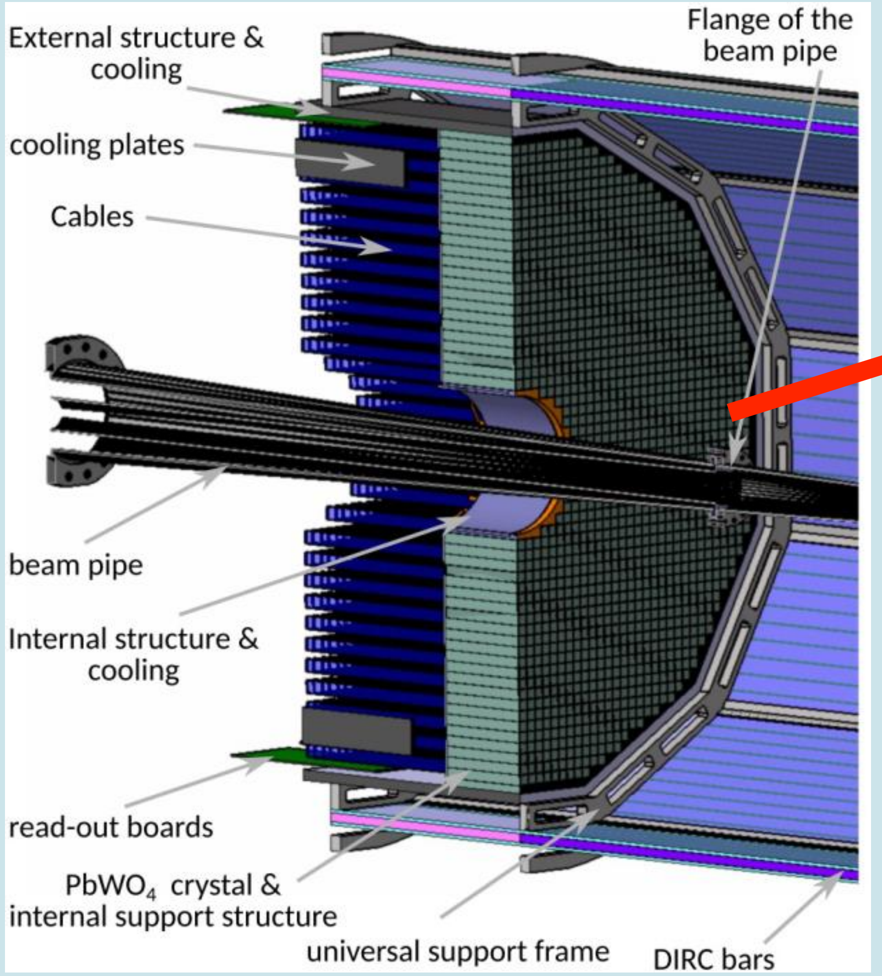




EMCal
(1.4<η<3.7)
W/ScFi blocks
π/γ separation

Imaging Barel EMCal (-1.7<η<1.4)
6 layers of Si sensors with SciFi/Pb layers





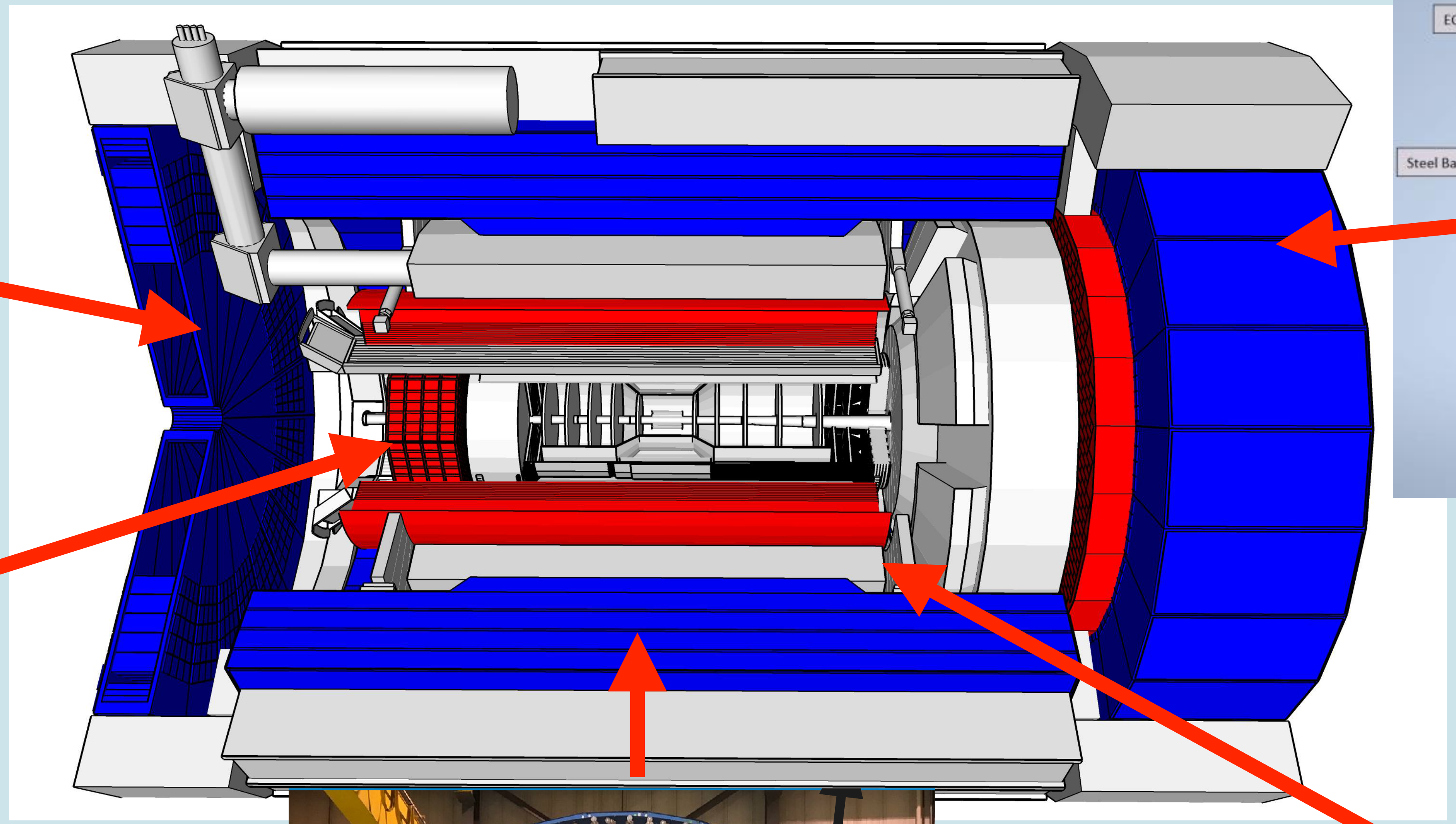
Backward EMCal (-3.5<η<-1.7)
$PbWO_4$ crystal
Scattered electron reconstruction

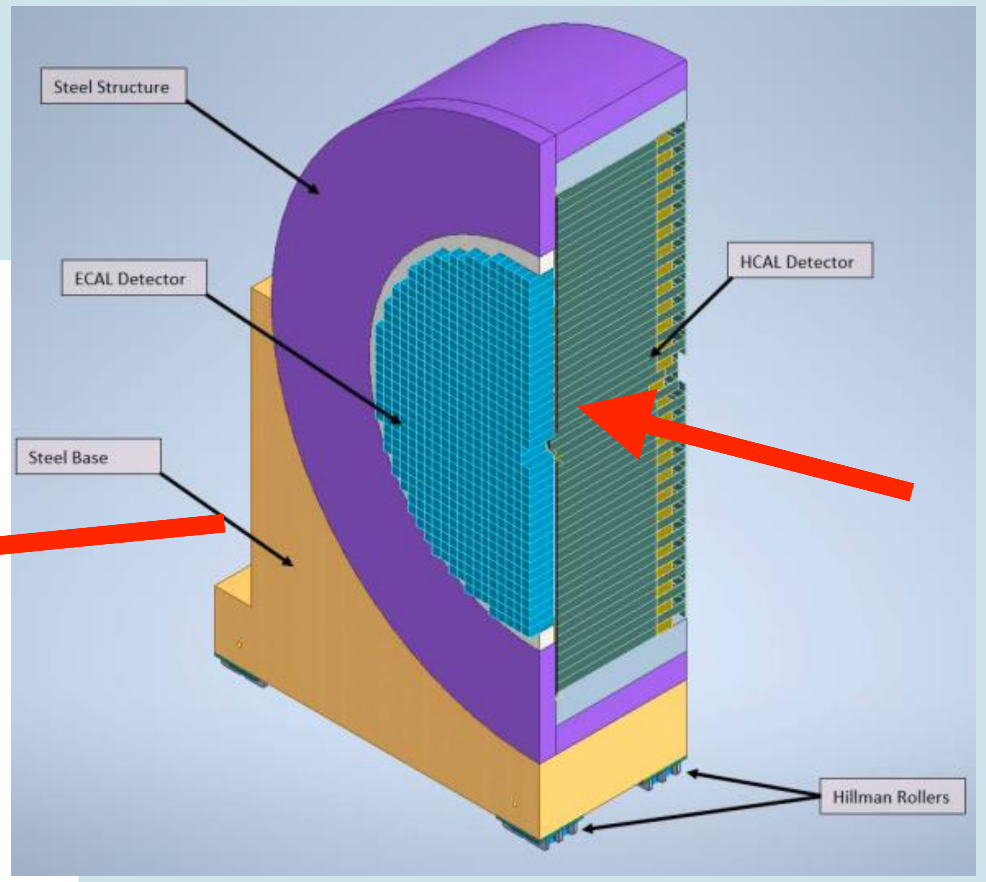
Calorimeter Design

Backward HCal (-3.5<η<-1.7)

Steel/Sci sampling

<20 GeV neutron





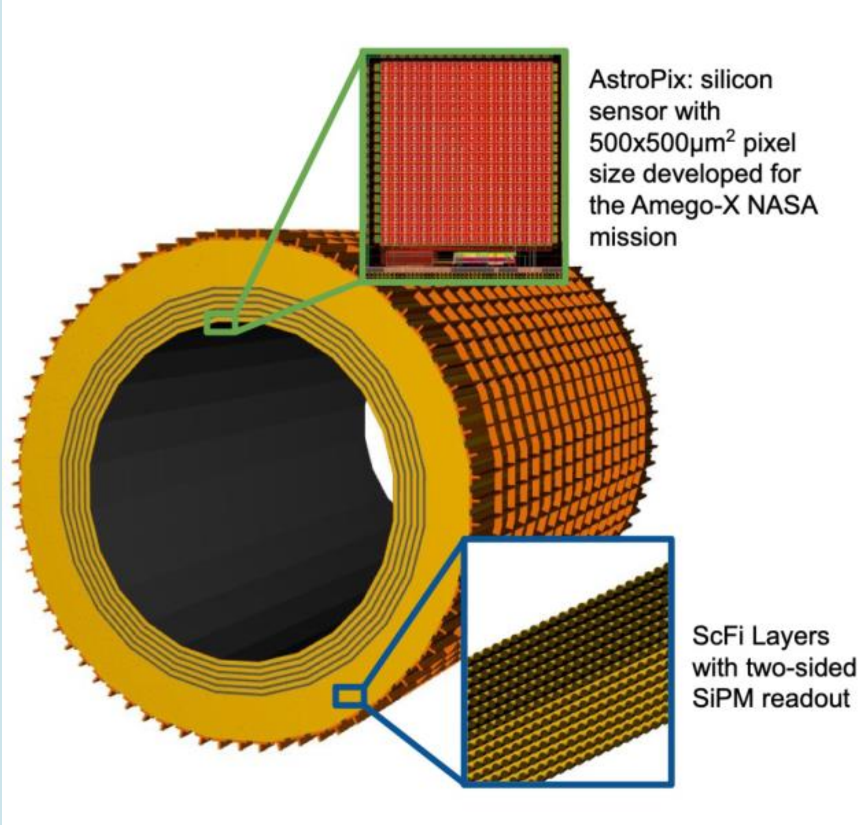
EMCal (1.4<η<3.7)

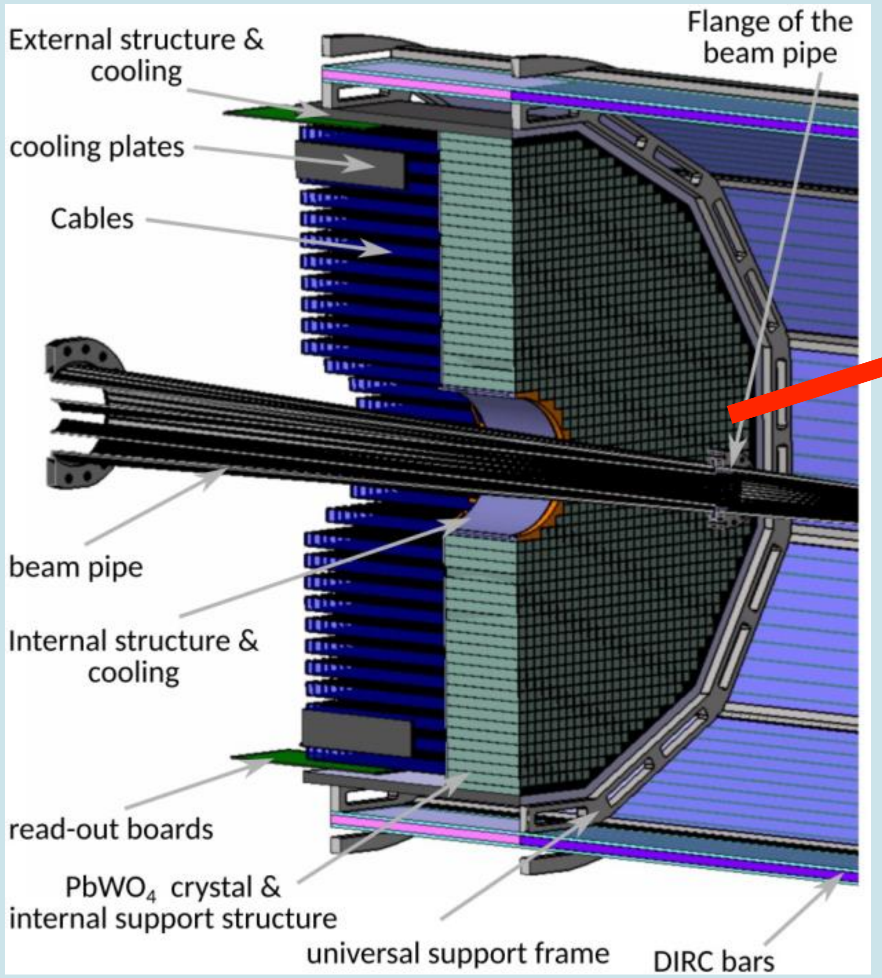
W/ScFi blocks

π/γ separation

Imaging Barel EMCal (-1.7<η<1.4)

6 layers of Si sensors with SciFi/Pb layers





Backward EMCal (-3.5<η<-1.7)

$PbWO_4$ crystal

Scattered electron reconstruction

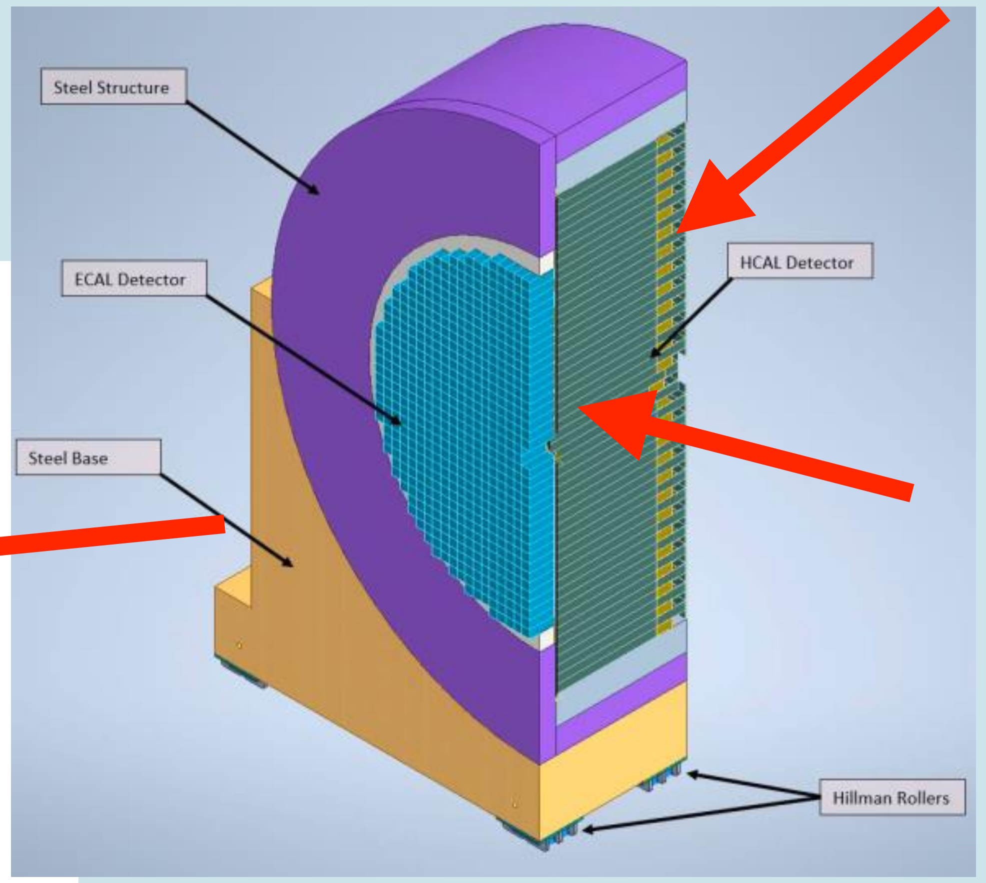
Barrel HCal

sPHENIX re-use

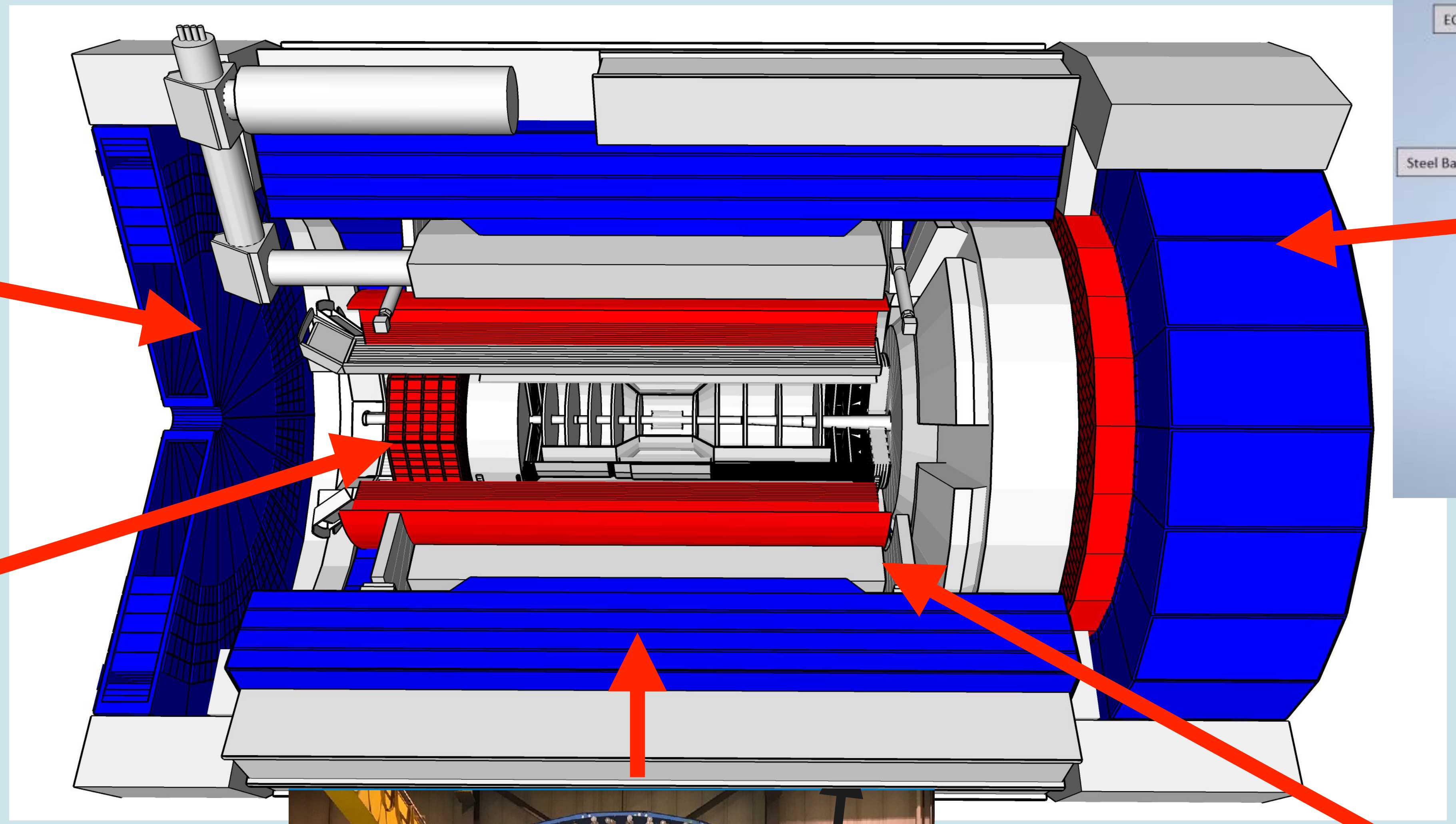
Calorimeter Design

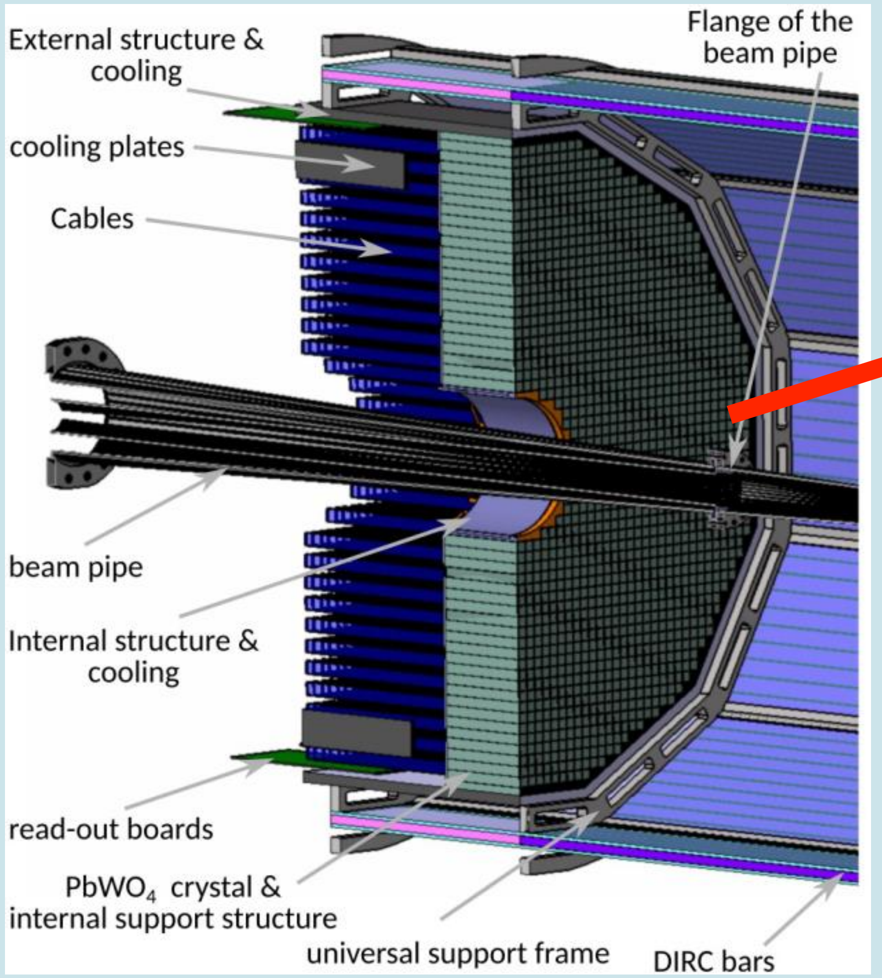
Backward HCal (-3.5<η<-1.7)
Steel/Sci sampling
<20 GeV neutron

LFHCal (1.4<η<3.7)
Steel/Sci sampling
<20 GeV neutron



EMCal (1.4<η<3.7)
W/ScFi blocks
π/γ separation

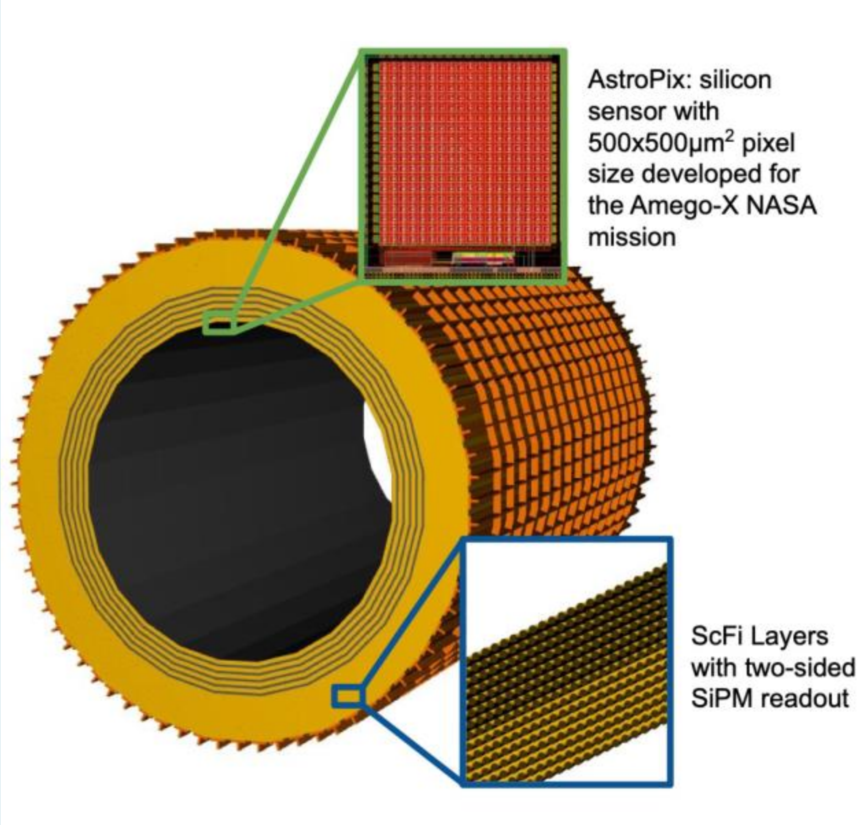




Backward EMCal (-3.5<η<-1.7)
$PbWO_4$ crystal
Scattered electron reconstruction

Barrel HCal
sPHENIX re-use

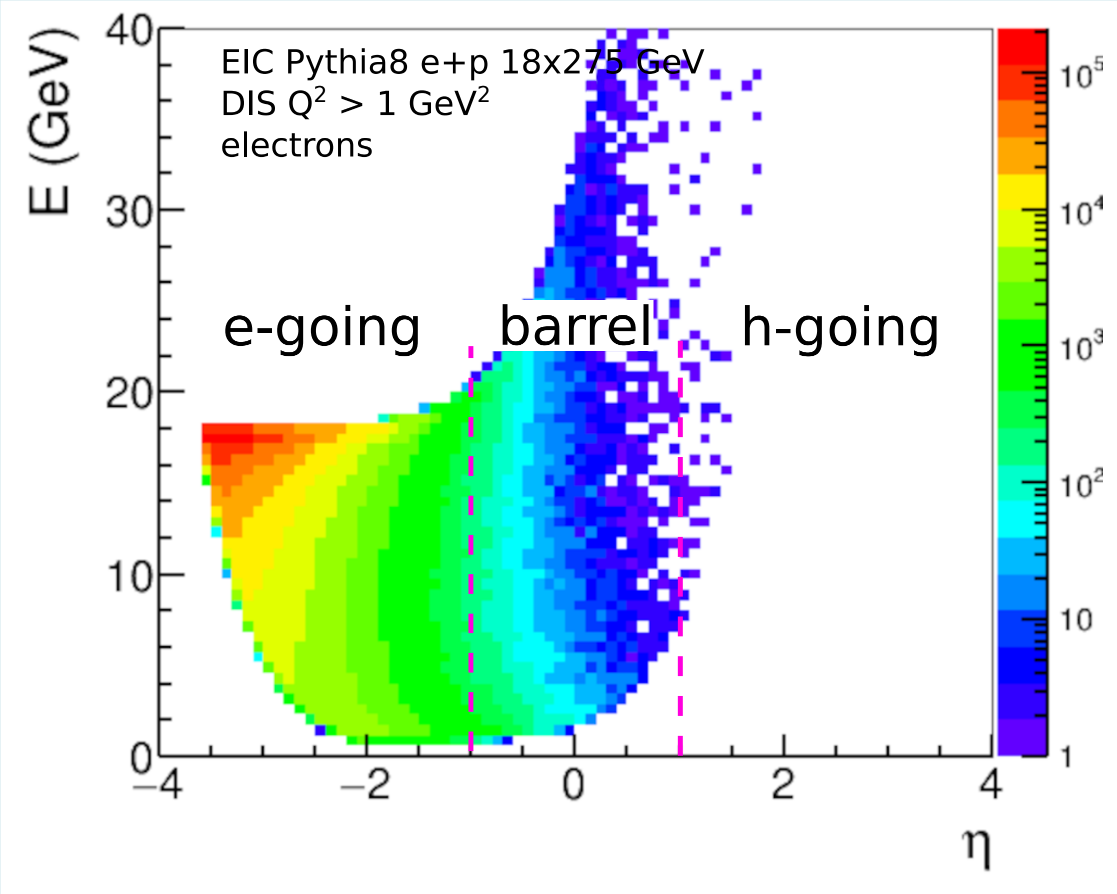
Imaging Barel EMCal (-1.7<η<1.4)
6 layers of Si sensors with SciFi/Pb layers



Calorimeter Performance

- EMCal plays a very important role in scatted electron measurement
  - e′ distributes η<-2 region with E>10 GeV

Scattered electron



Calorimeter Performance

- EMCal plays a very important role in scatted electron measurement
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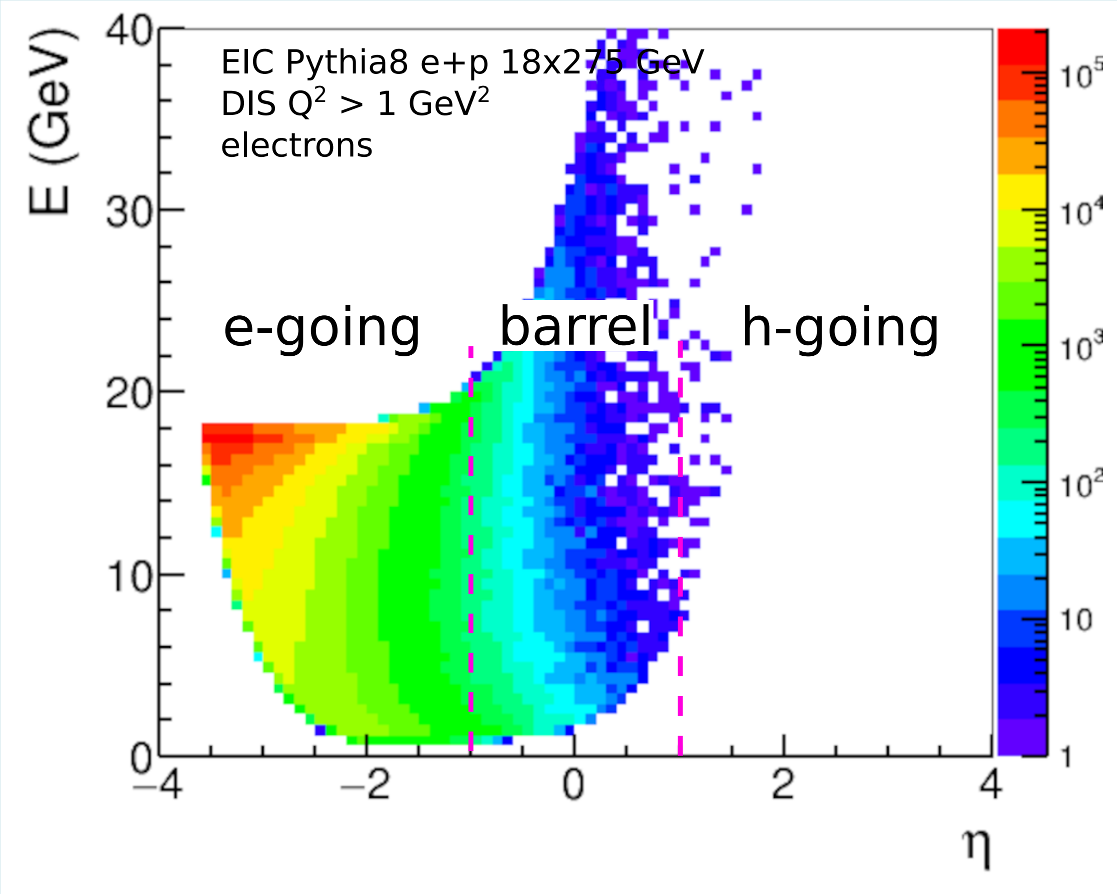
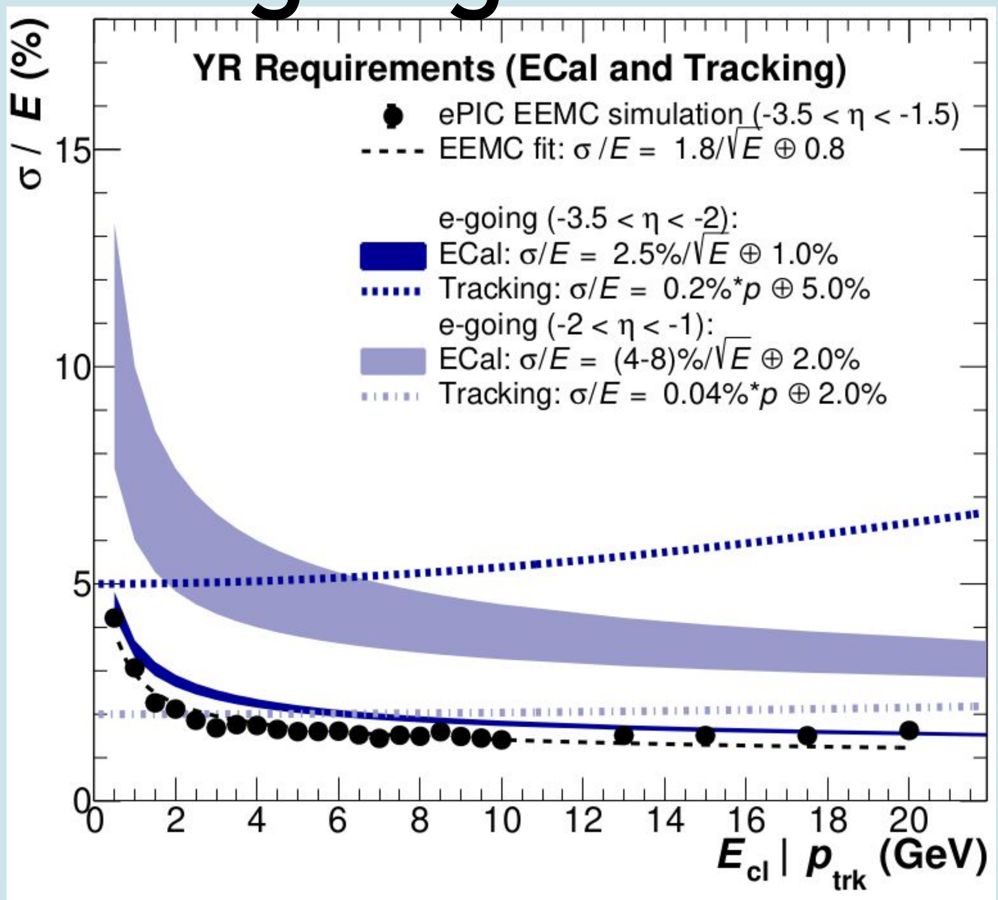
Scattered electron



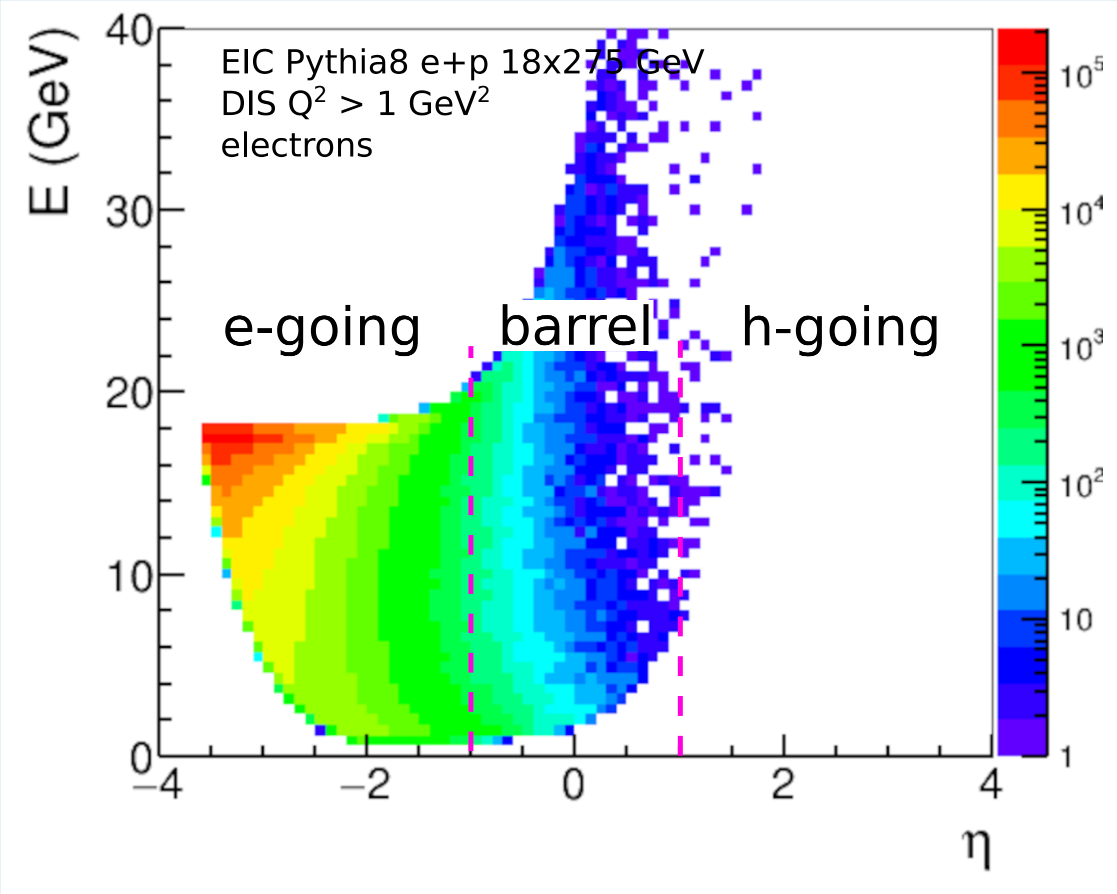
e-going E reso.



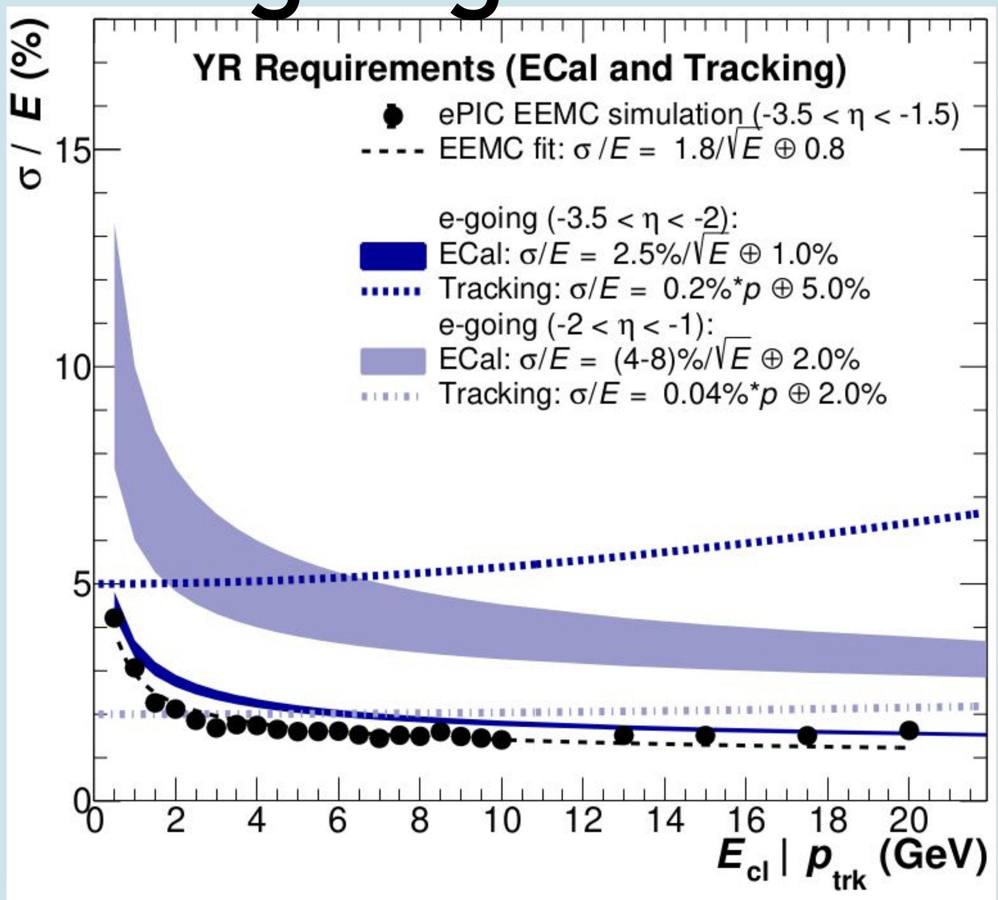
Calorimeter Performance

- EMCal plays a very important role in scatted electron measurement
  - e′ distributes η<-2 region with E>10 GeV
- γ merging from π^0 starts p~35 GeV/c with the imaging EMCal

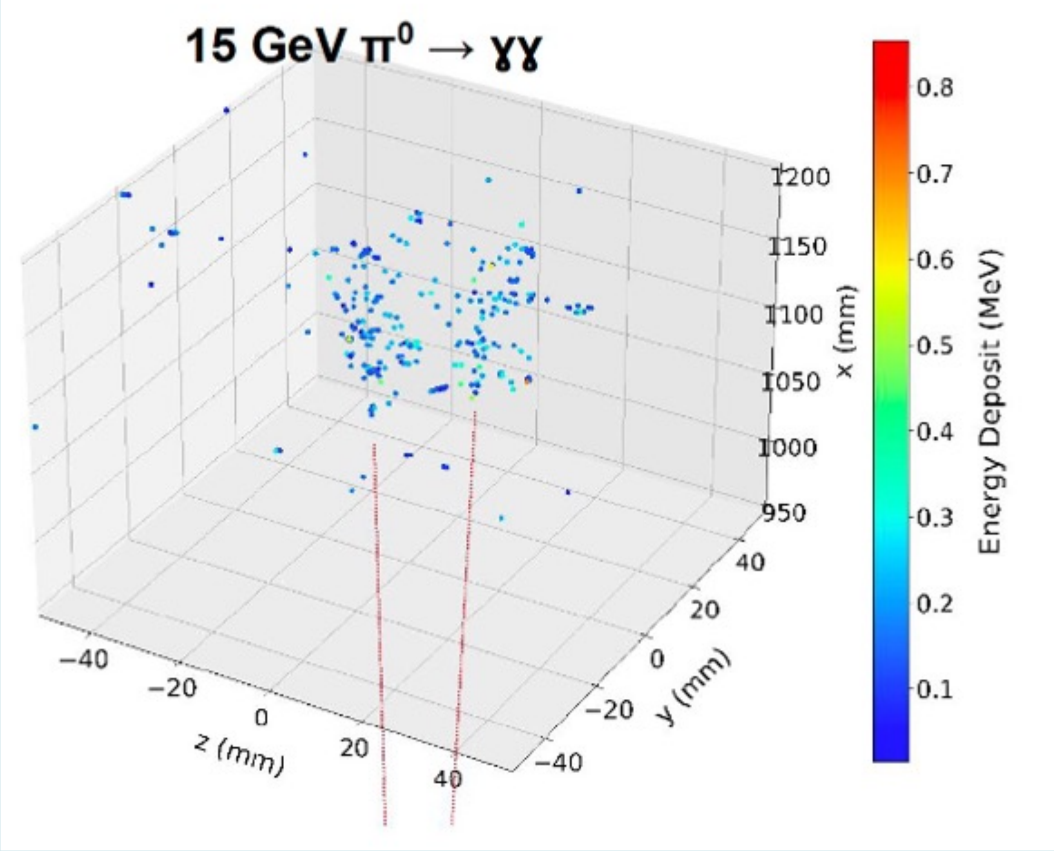
Scattered electron



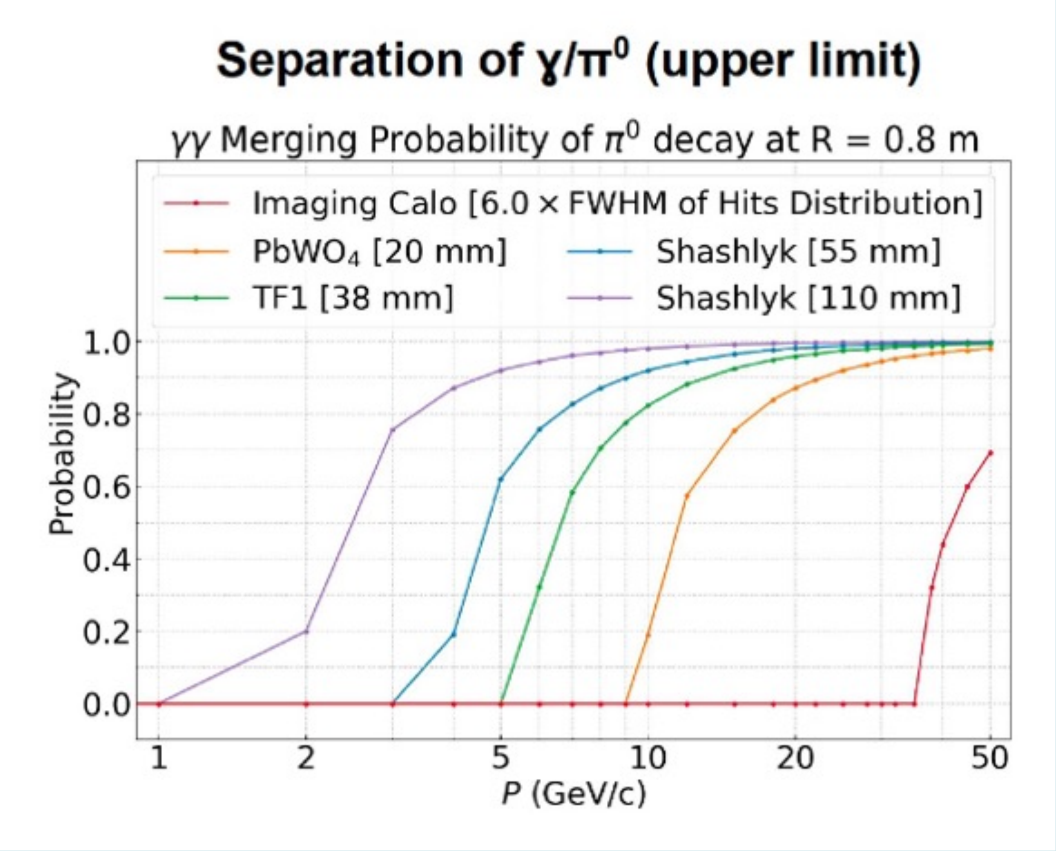
e-going E reso.



Shower imaging



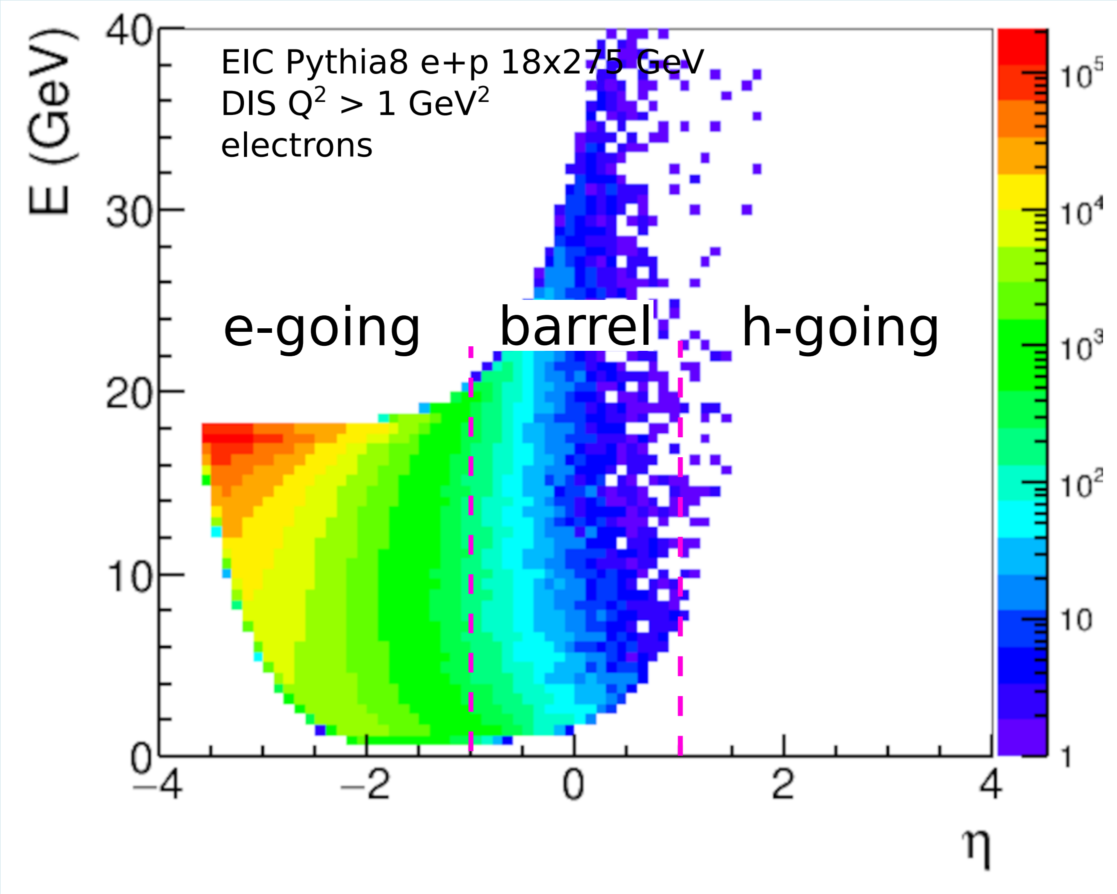
Cluster merging prob.



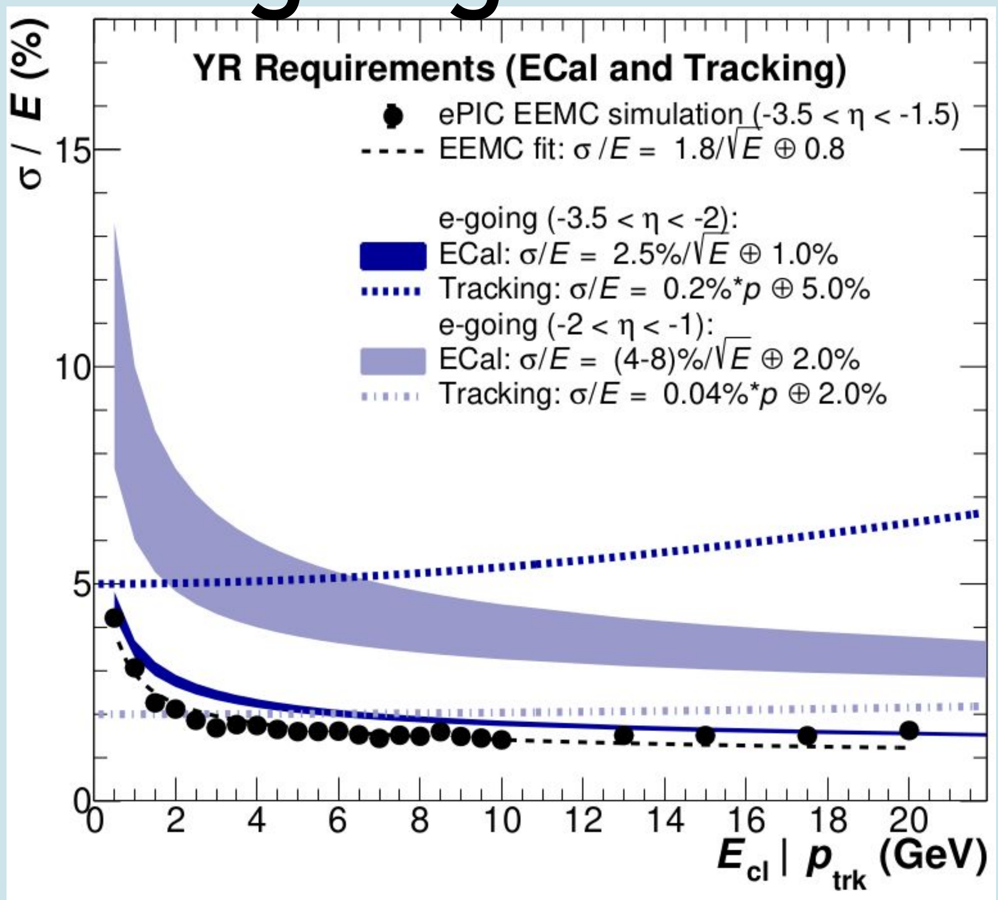
Calorimeter Performance

- EMCal plays a very important role in scatted electron measurement
  - e′ distributes η<-2 region with E>10 GeV
- γ merging from π^0 starts p~35 GeV/c with the imaging EMCal
- High-p_T jet is generated at the forward region

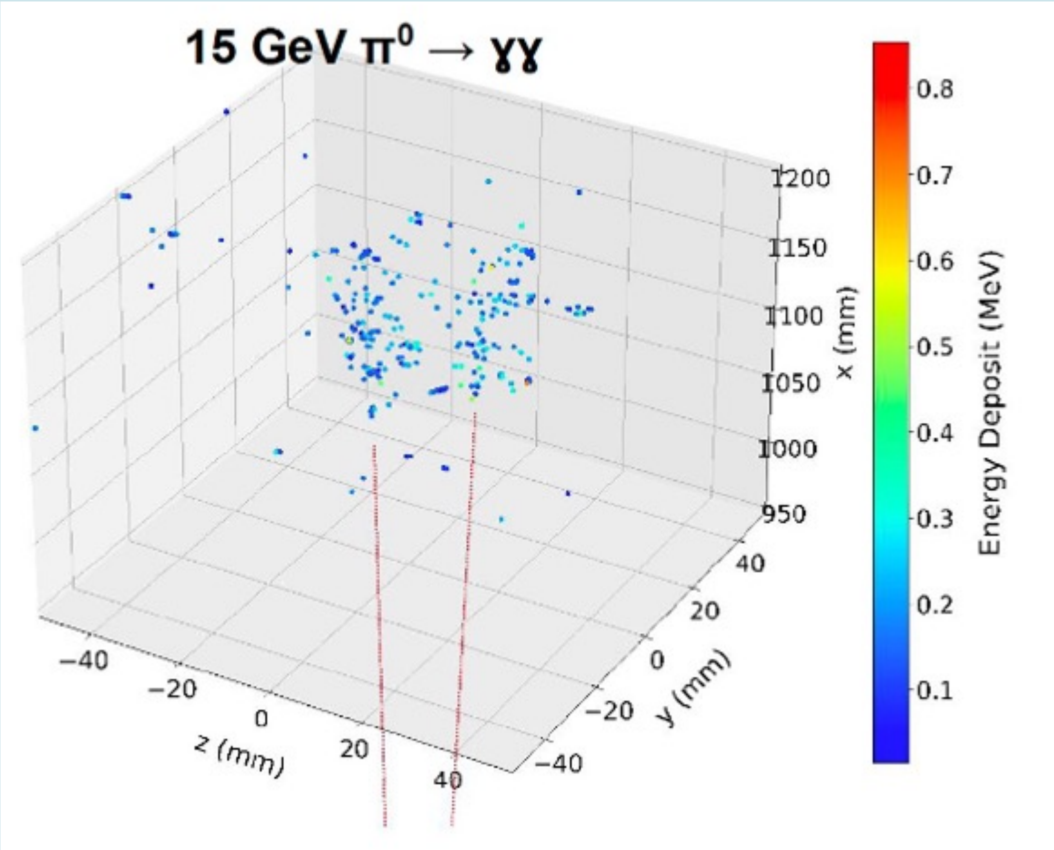
Scattered electron



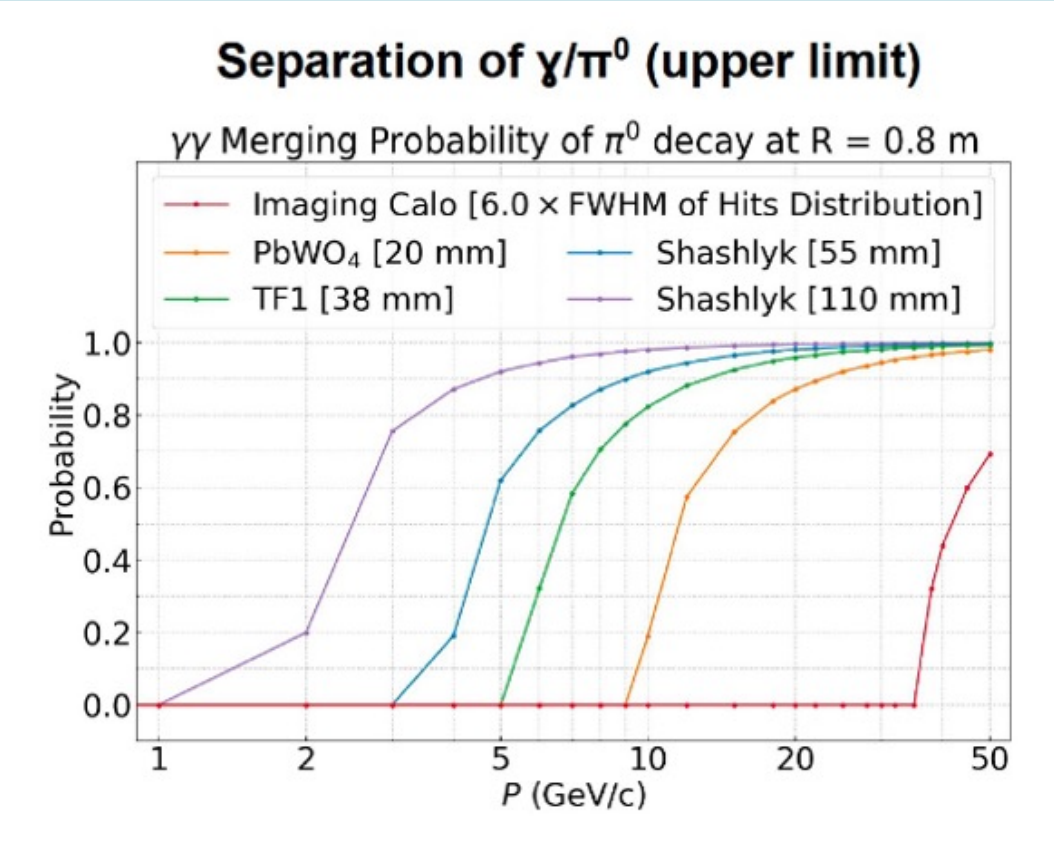
e-going E reso.



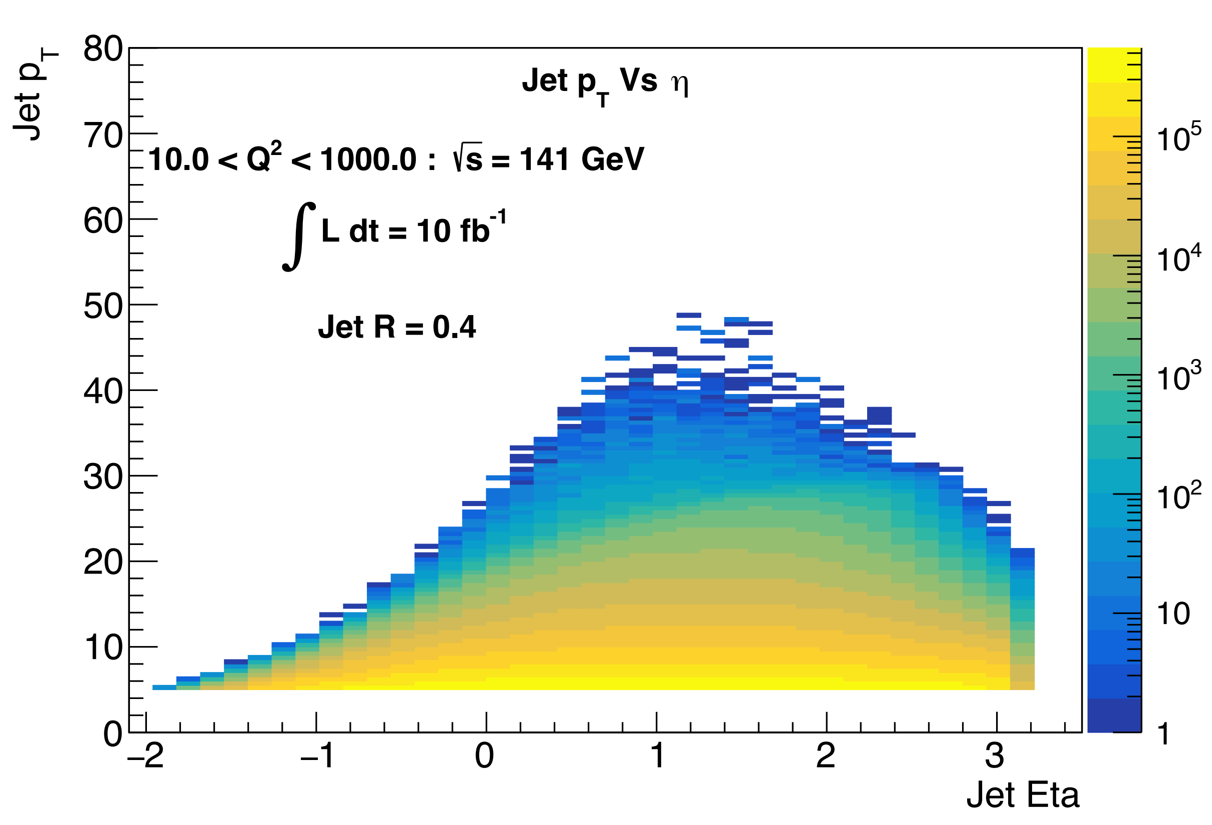
Shower imaging



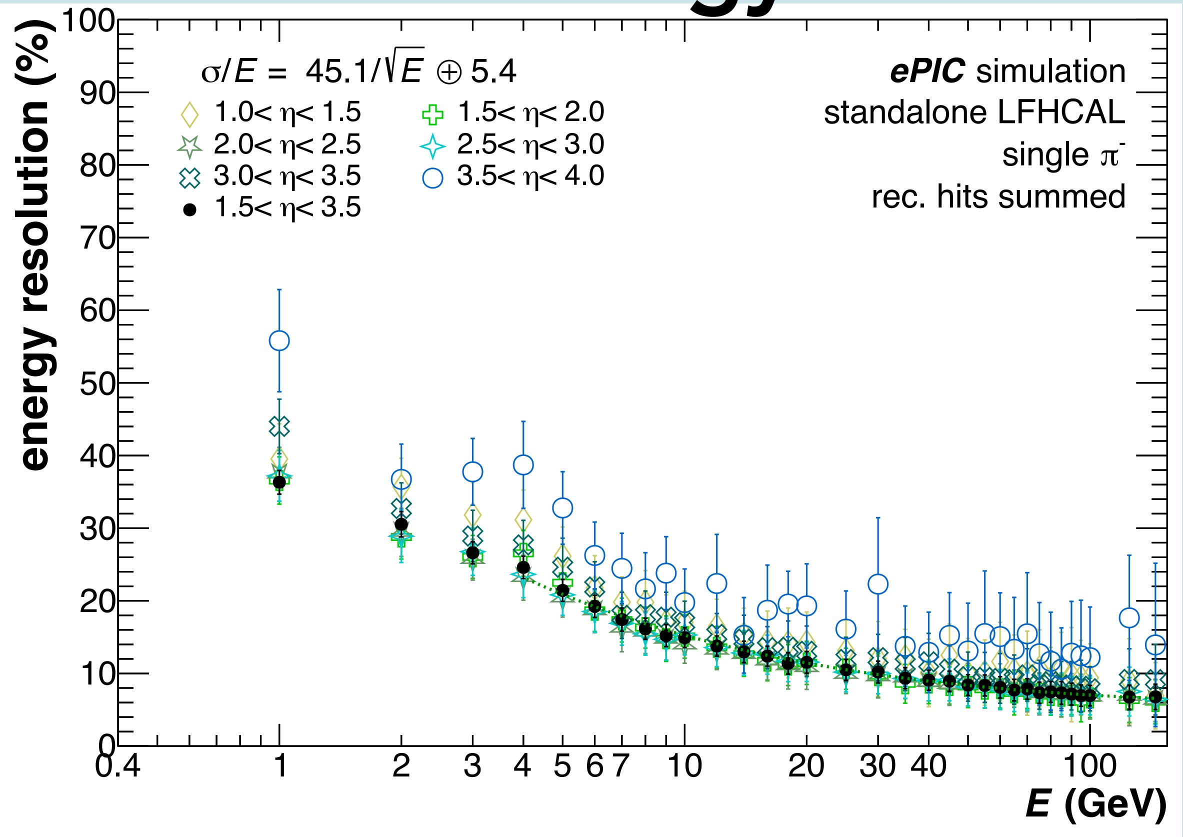
Cluster merging prob.



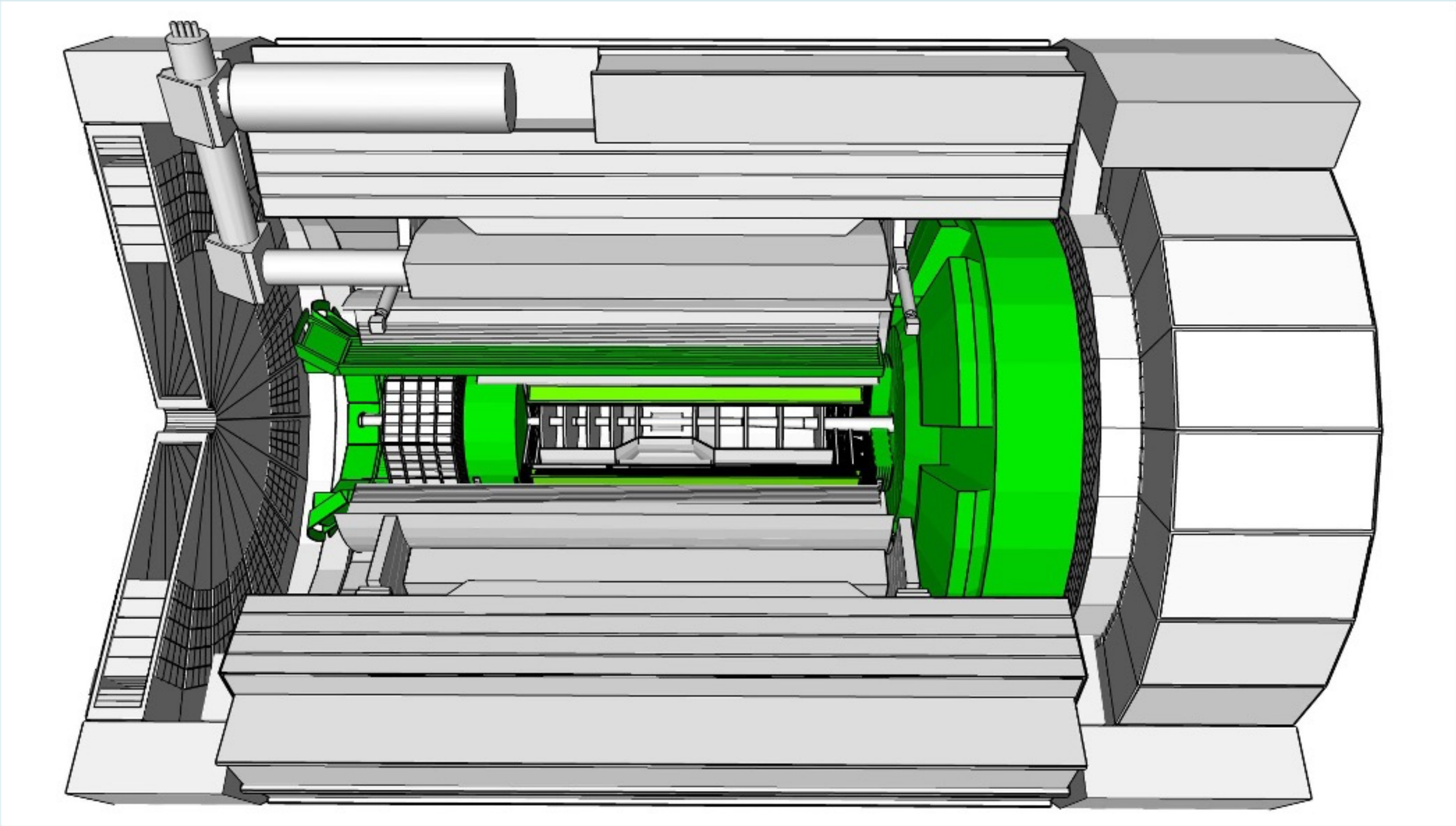
Jet kinematics



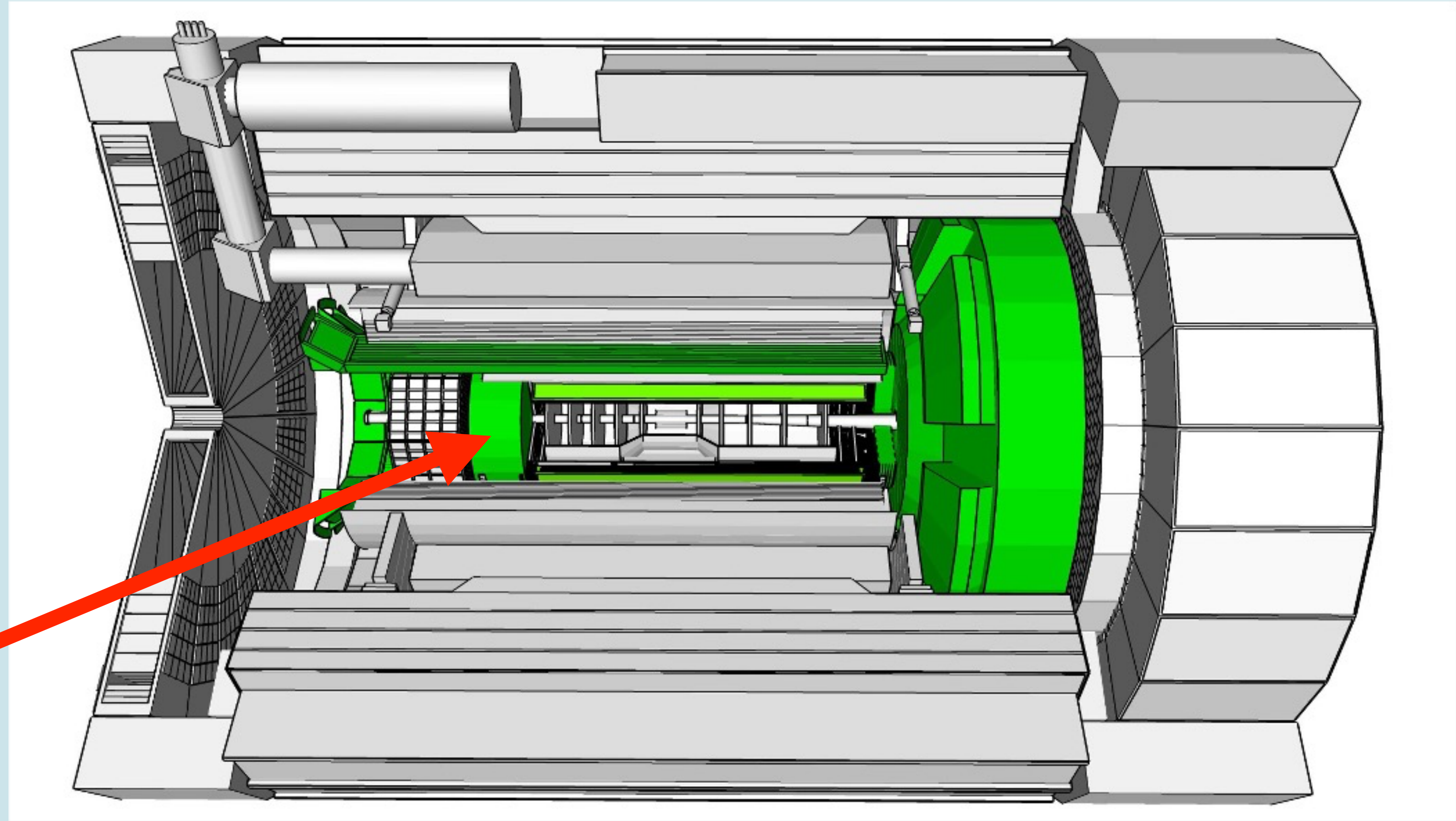
LFHCal energy reso.

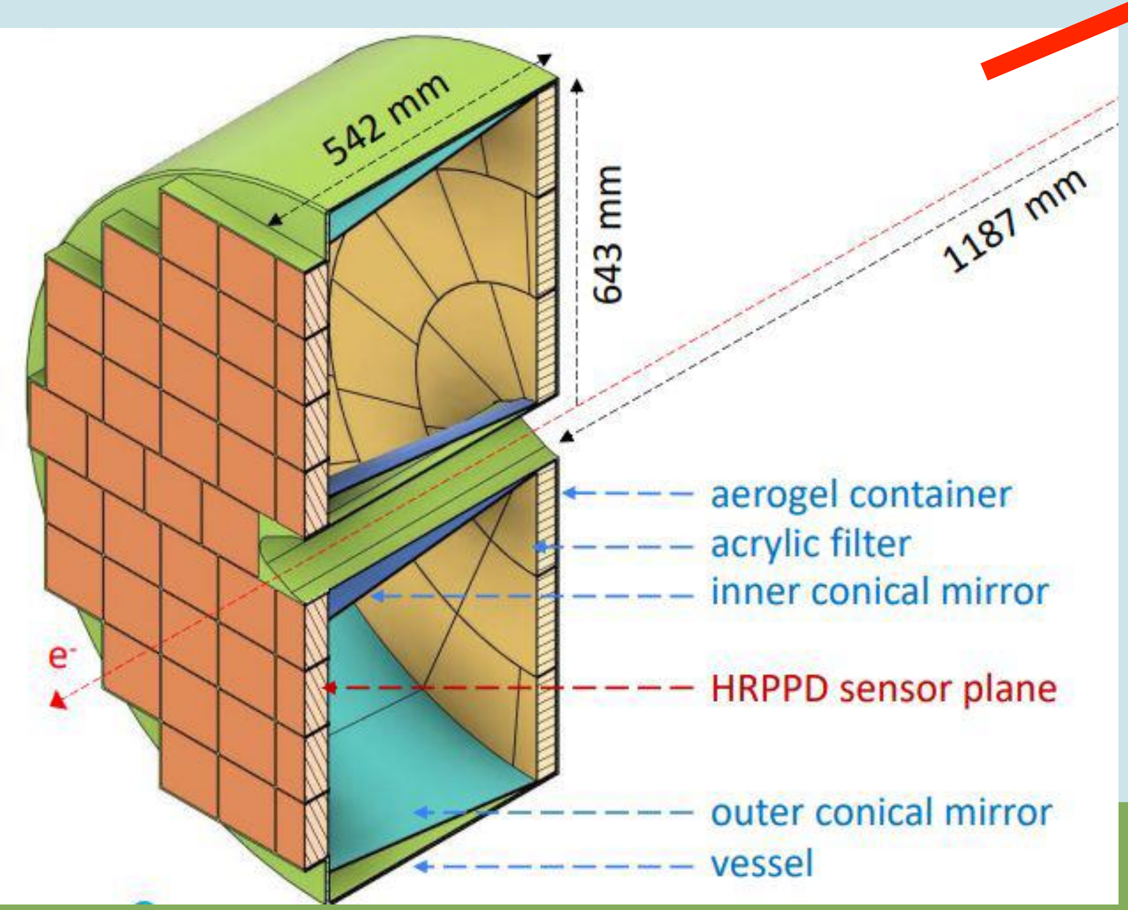


PID Detector Design



PID Detector Design





Proximity Focused RICH (pfRICH)

~40 cm proximity gap

Aerogel + HRPPD sensor (t0)

PID by timing information

π/K separation up to 10 GeV/c

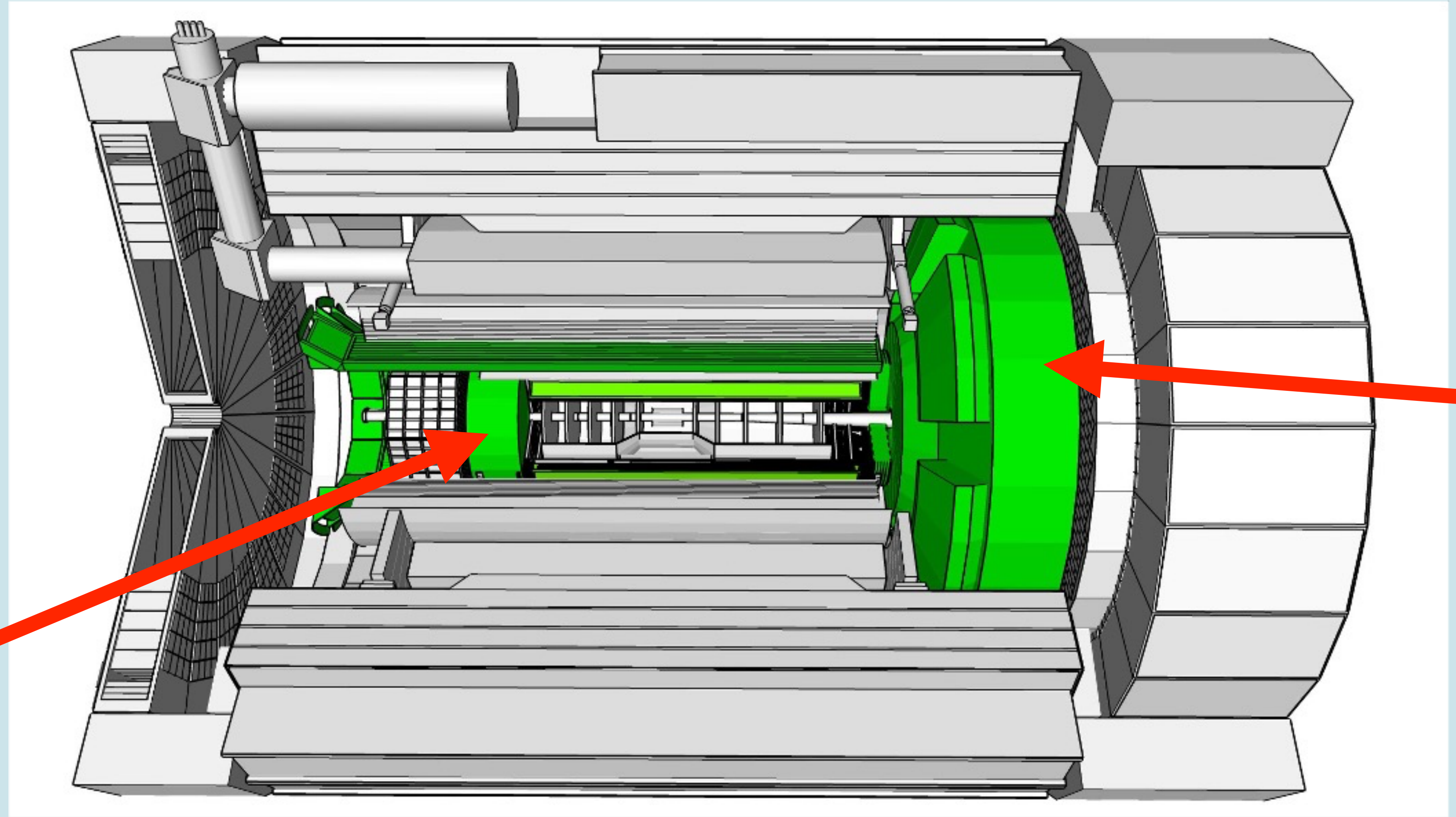
e/π separation up to 2.5 GeV/c

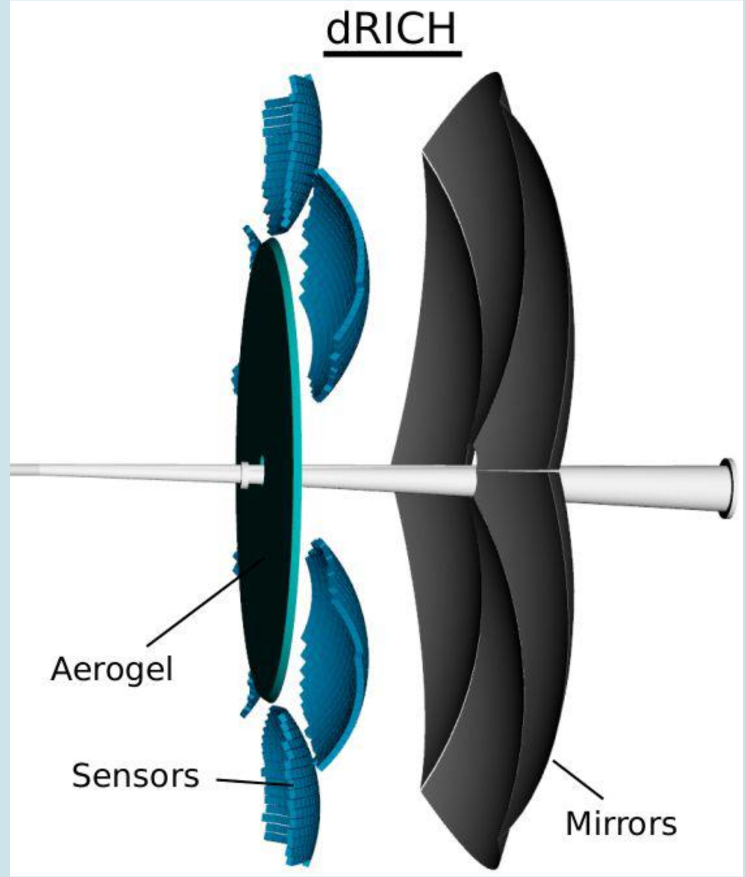
PID Detector Design

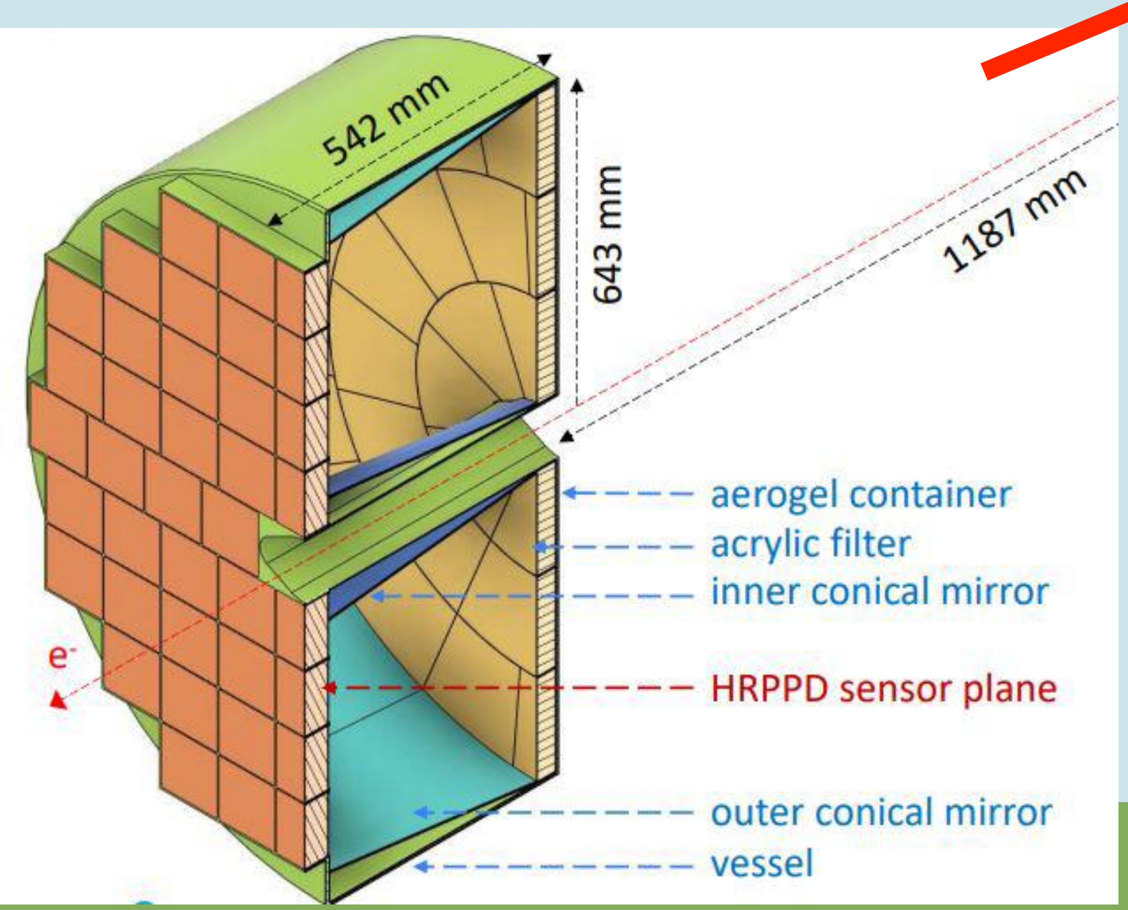
Dual-Radiator RICH (dRICH)

C2F6 Gas / Aerogel + SiPMs

π/K separation up to 50 GeV/c







Proximity Focused RICH (pfRICH)

~40 cm proximity gap

Aerogel + HRPPD sensor (t0)

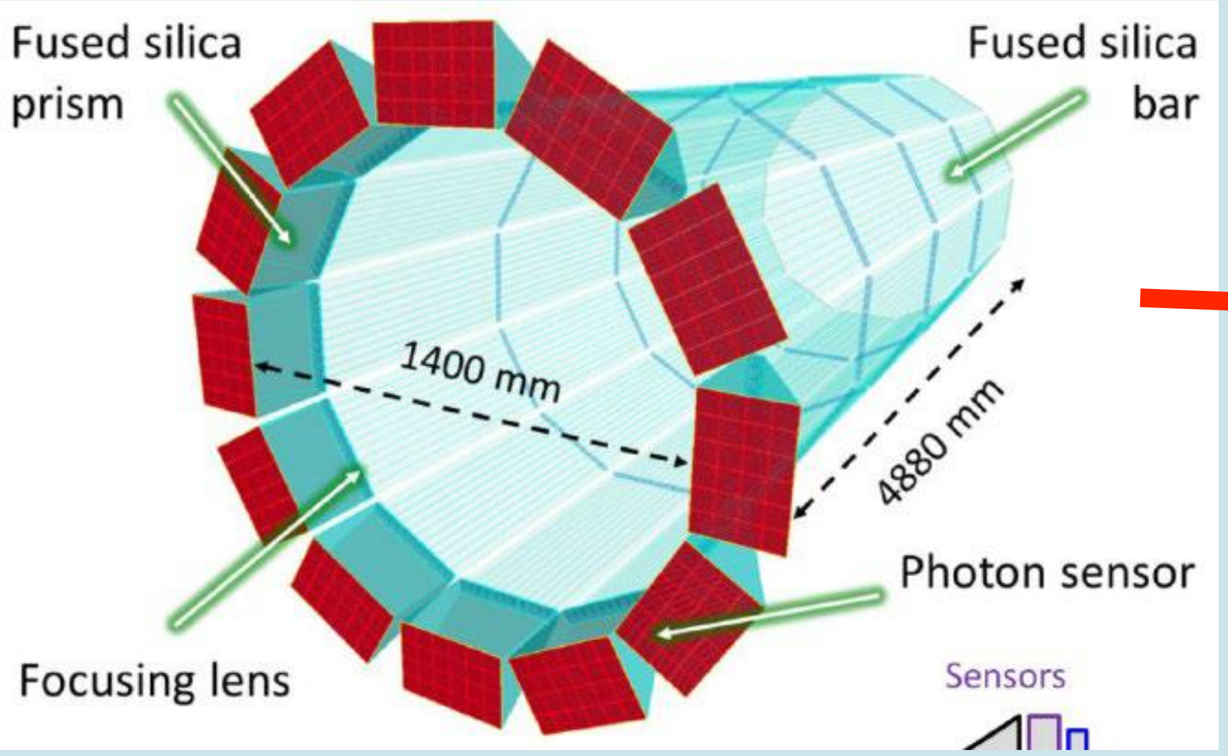
PID by timing information

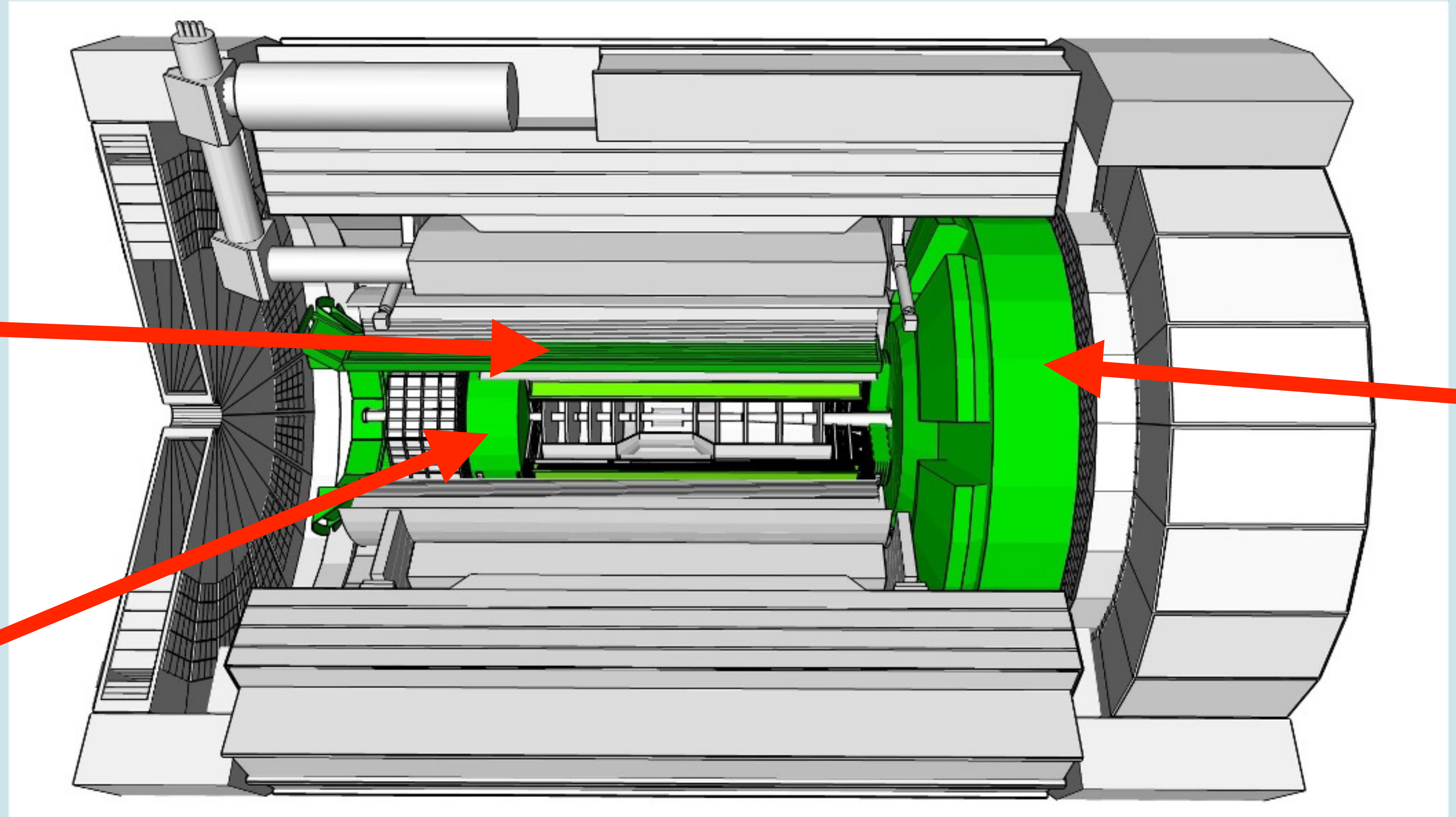
π/K separation up to 10 GeV/c

e/π separation up to 2.5 GeV/c

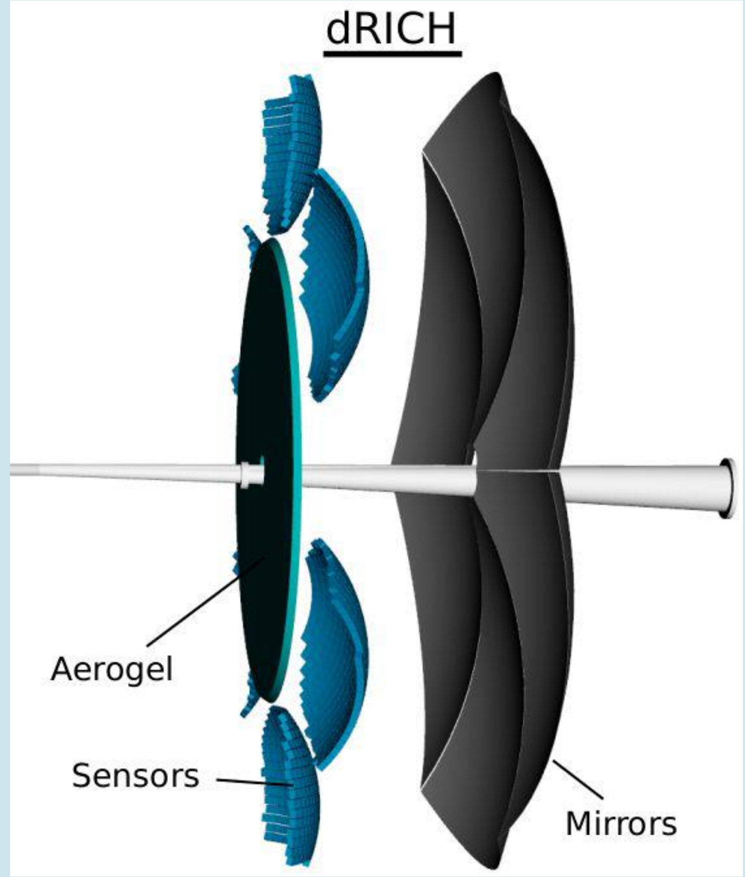
PID Detector Design

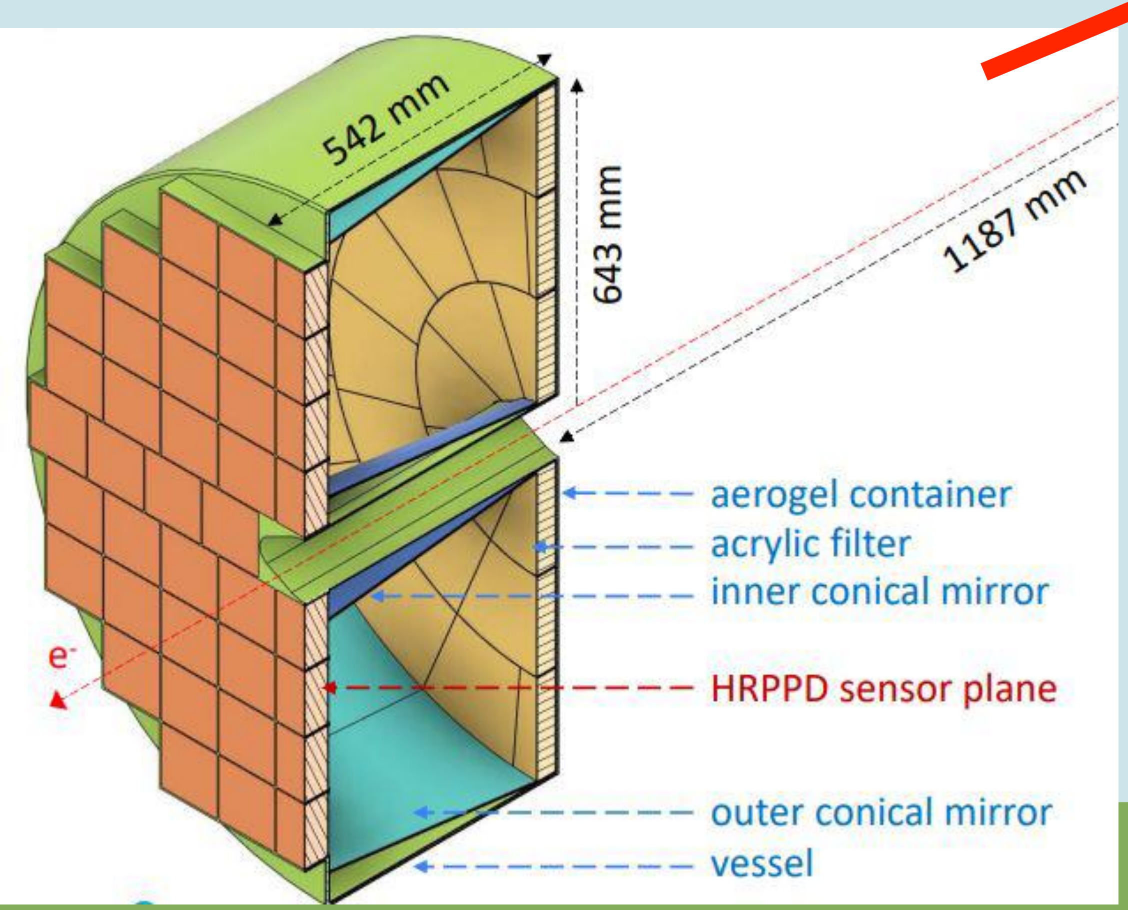
High-Performance DIRC (hpDIRC)
Quartz bar radiator (reuse BaBar) + MCP-PMTs
π/K separation up to 6 GeV/c





Dual-Radiator RICH (dRICH)
C2F6 Gas / Aerogel + SiPMs
π/K separation up to 50 GeV/c

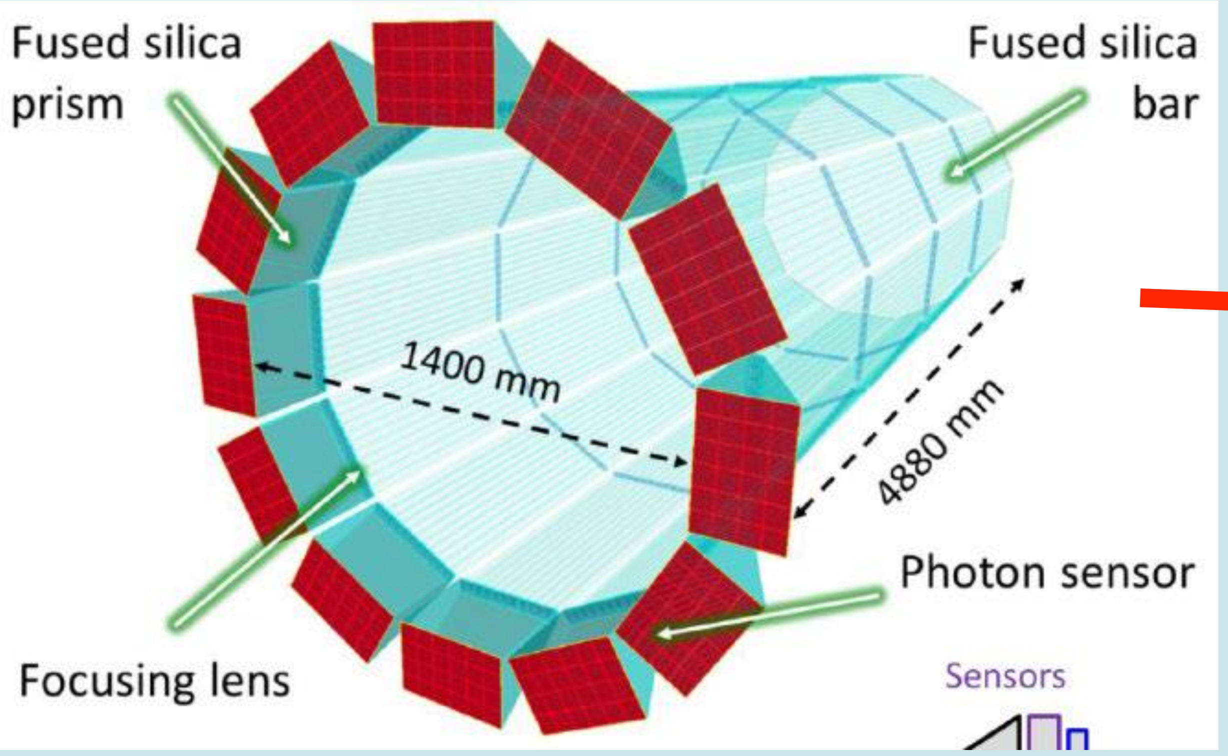


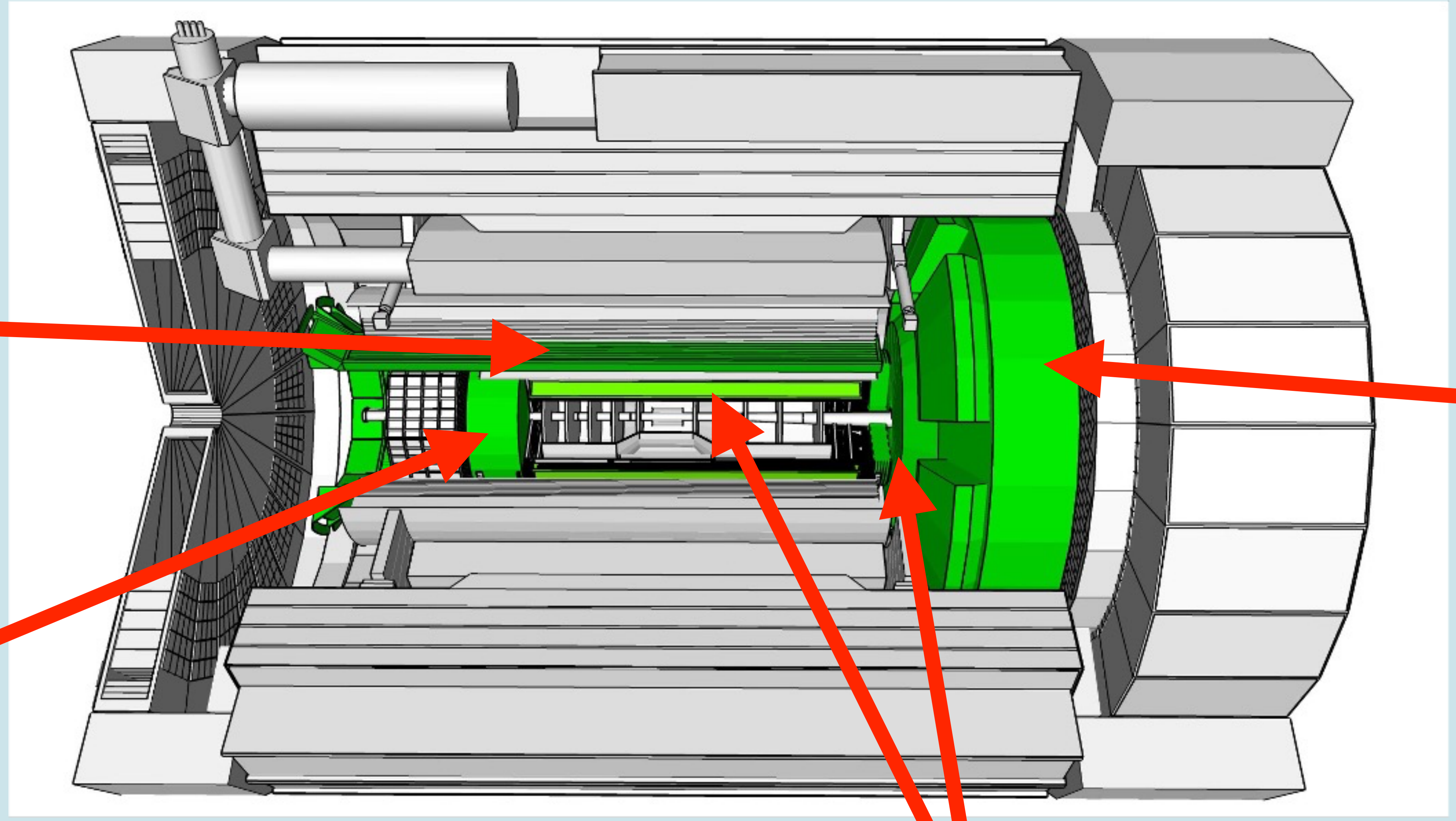


Proximity Focused RICH (pfRICH)
~40 cm proximity gap
Aerogel + HRPPD sensor (t0)
PID by timing information
π/K separation up to 10 GeV/c
e/π separation up to 2.5 GeV/c

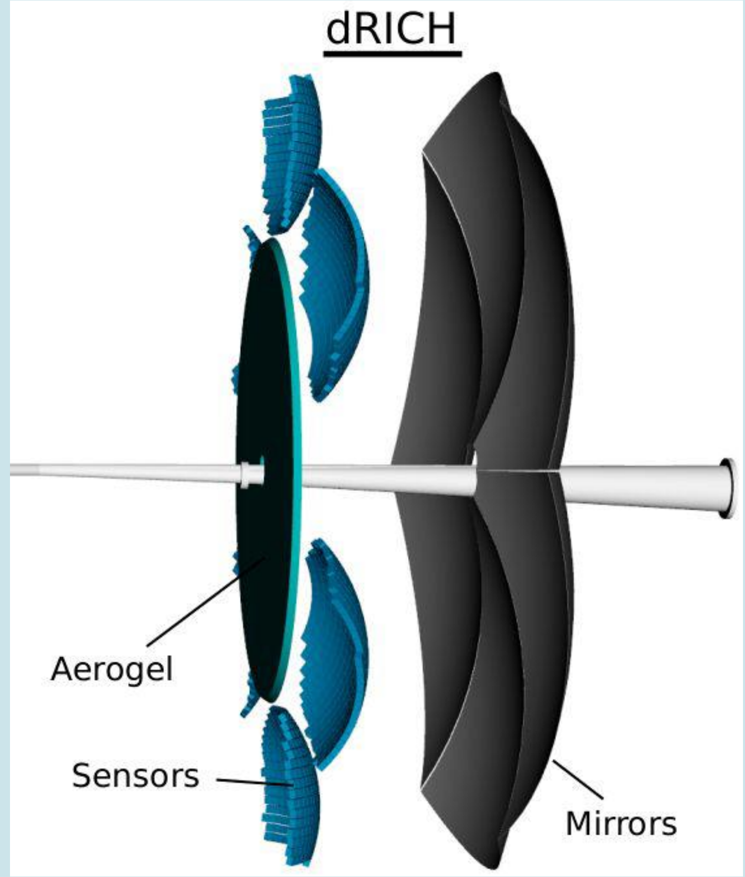
PID Detector Design

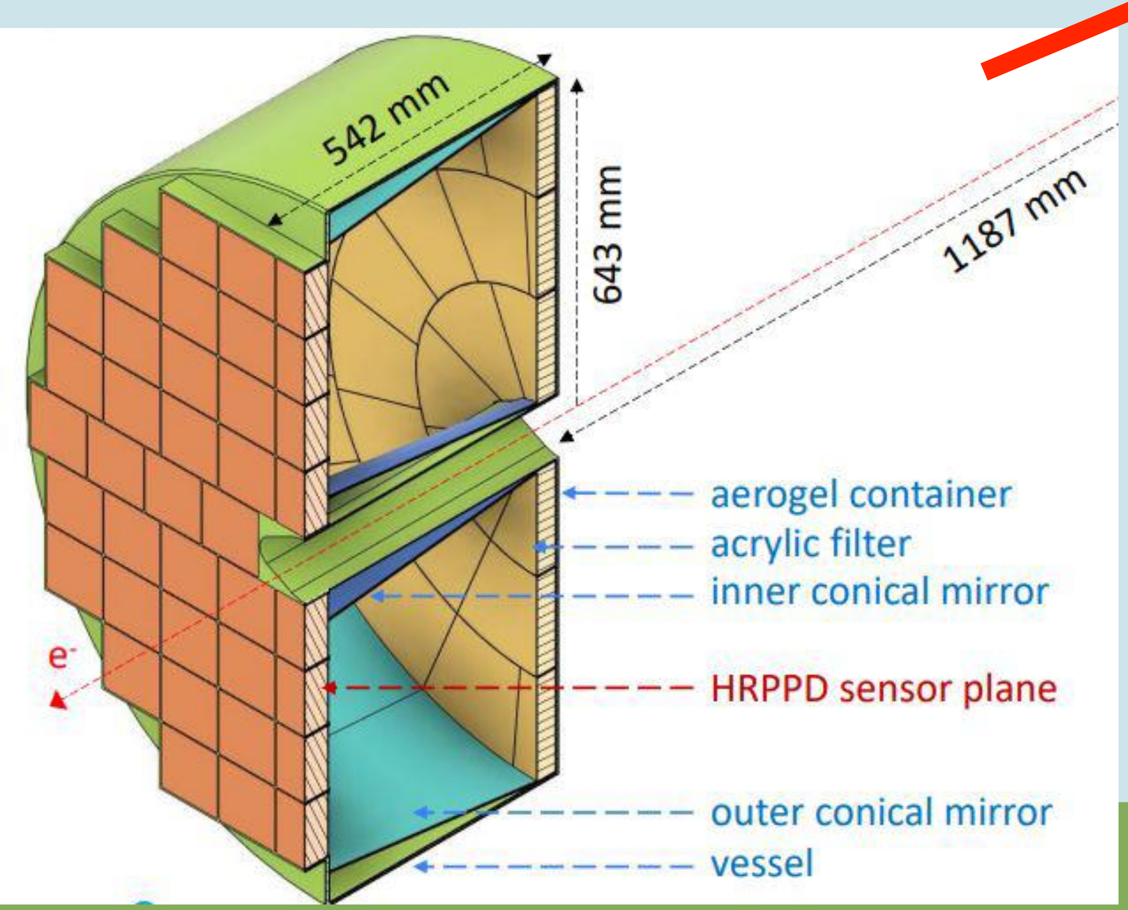
High-Performance DIRC (hpDIRC)
Quartz bar radiator (reuse BaBar) + MCP-PMTs
π/K separation up to 6 GeV/c



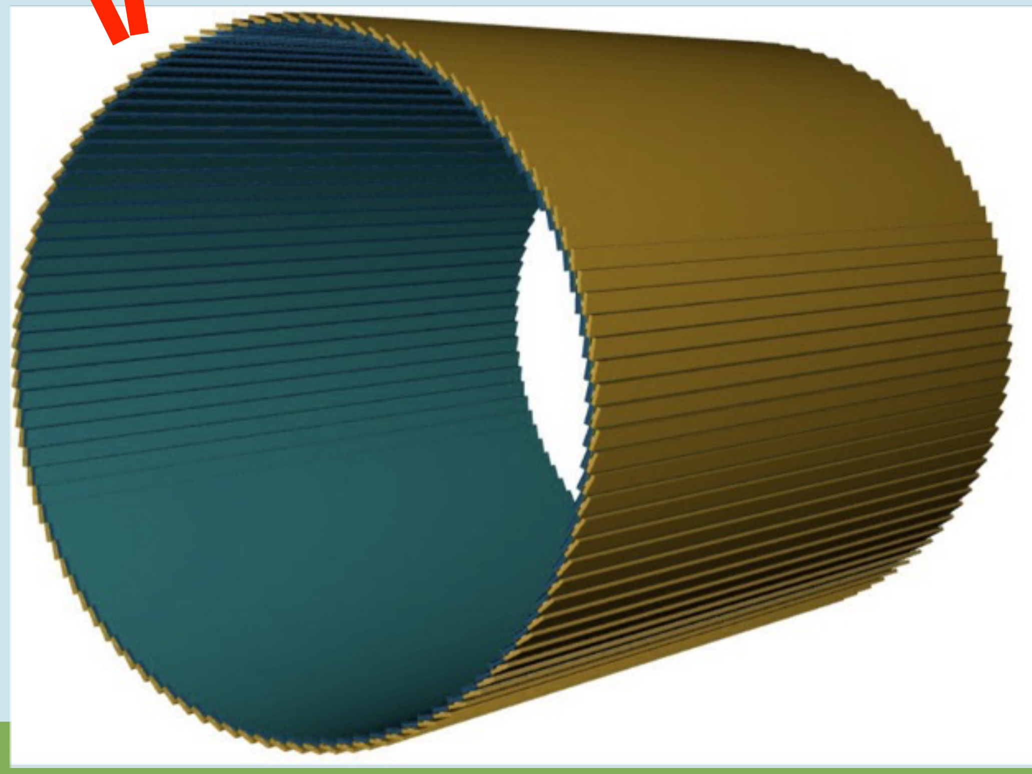


Dual-Radiator RICH (dRICH)
C2F6 Gas / Aerogel + SiPMs
π/K separation up to 50 GeV/c





Proximity Focused RICH (pfRICH)
~40 cm proximity gap
Aerogel + HRPPD sensor (t0)
PID by timing information
π/K separation up to 10 GeV/c
e/π separation up to 2.5 GeV/c

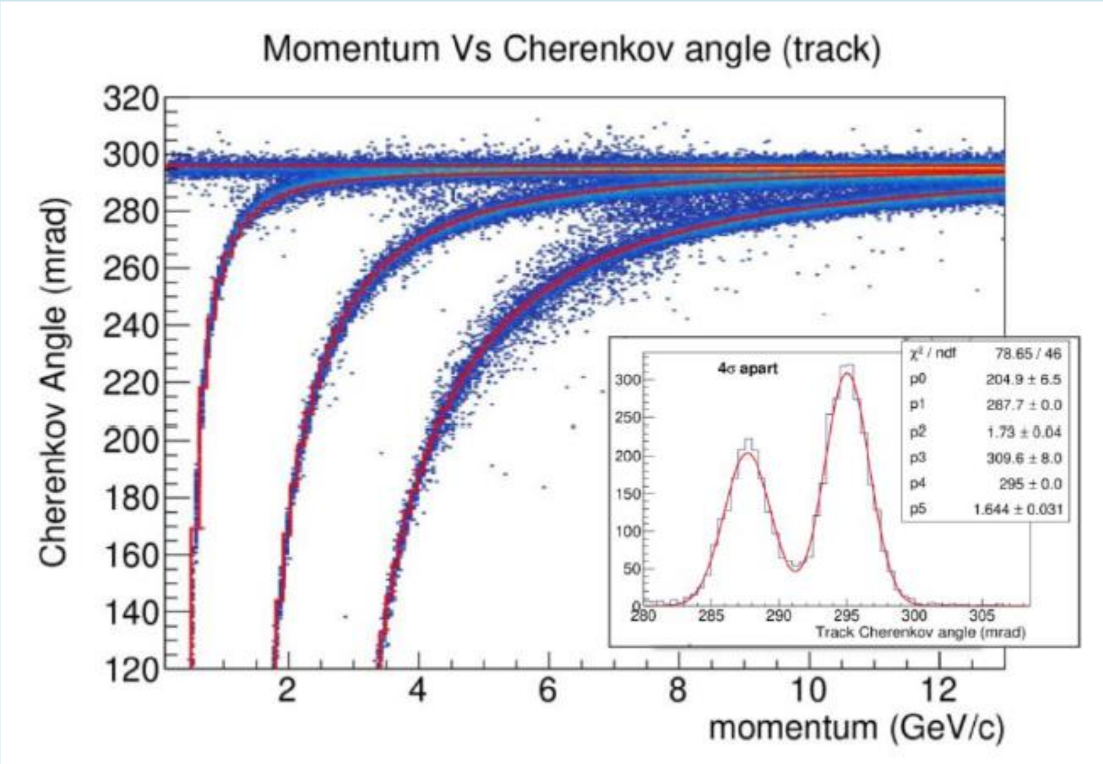


Time-of-Flight (TOF)
AC-LGAD
~30 ps time resolution
~30 μm spatial resolution
π/K separation up to 1.5 (2.5) GeV/c for barrel (forward)

PID Detector Performance

- Electron identification, electron-pion separation at low momentum (high-y) complementary to the electromagnetic calorimeter

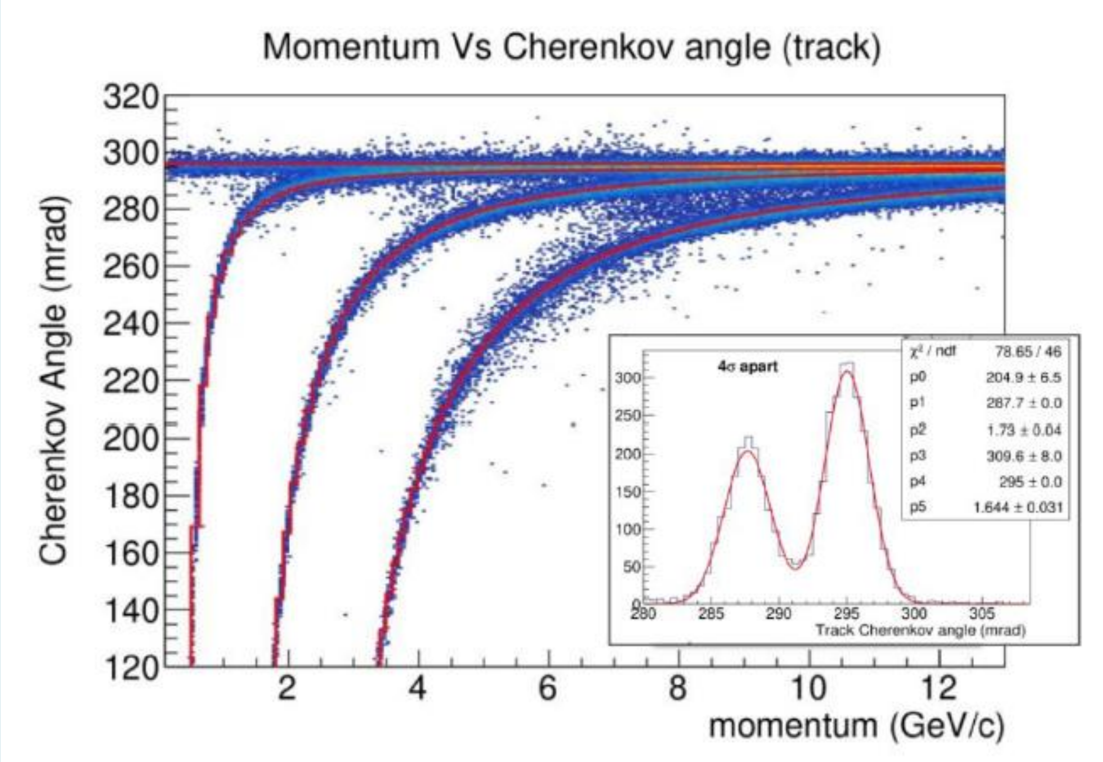
pfRICH performance



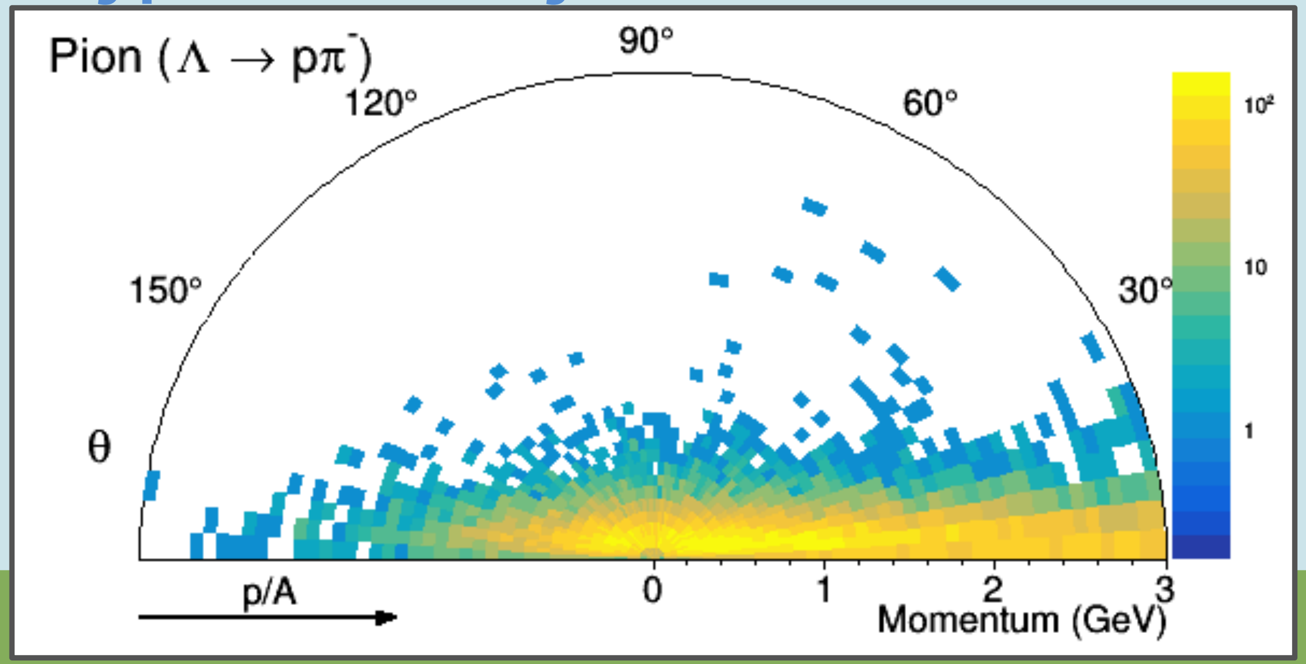
PID Detector Performance

- Electron identification, electron-pion separation at low momentum (high-y) complementary to the electromagnetic calorimeter
- Hadron identification, pion-kaon-proton separation for SIDIS

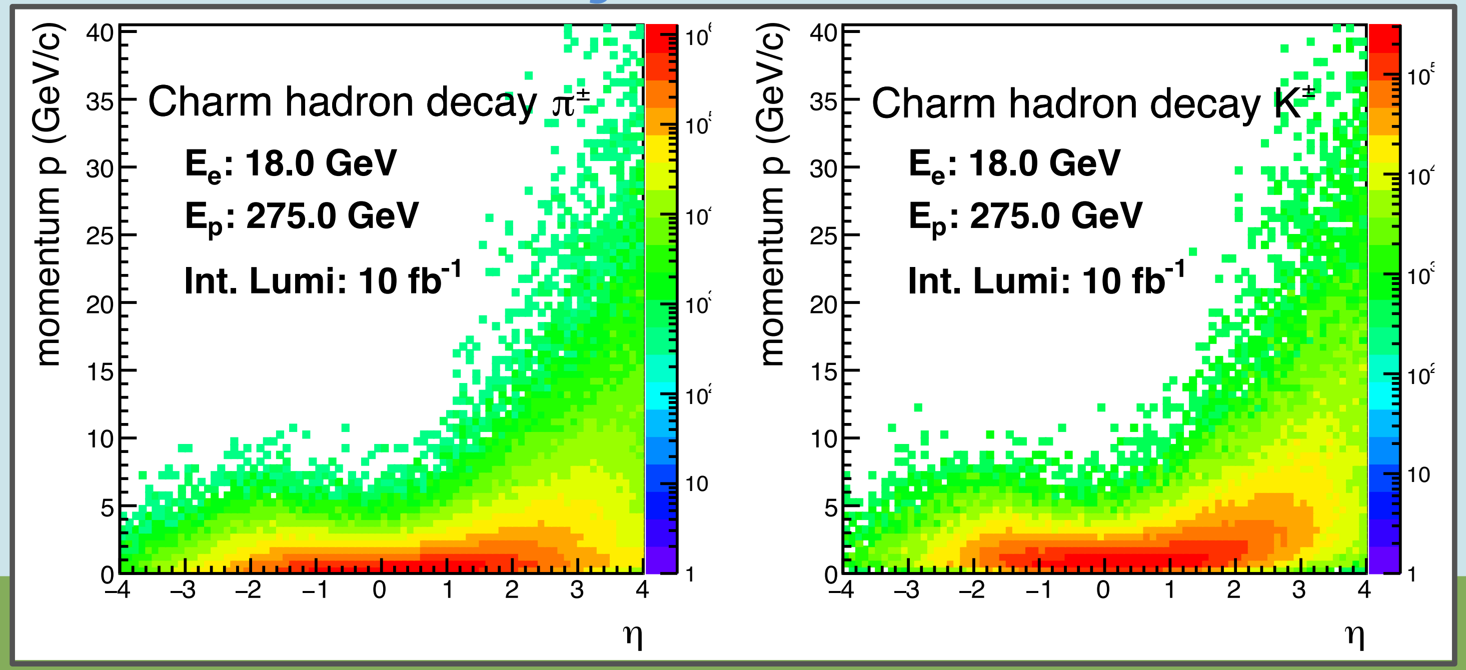
pfRICH performance



Hyperon decay hadron kinematics



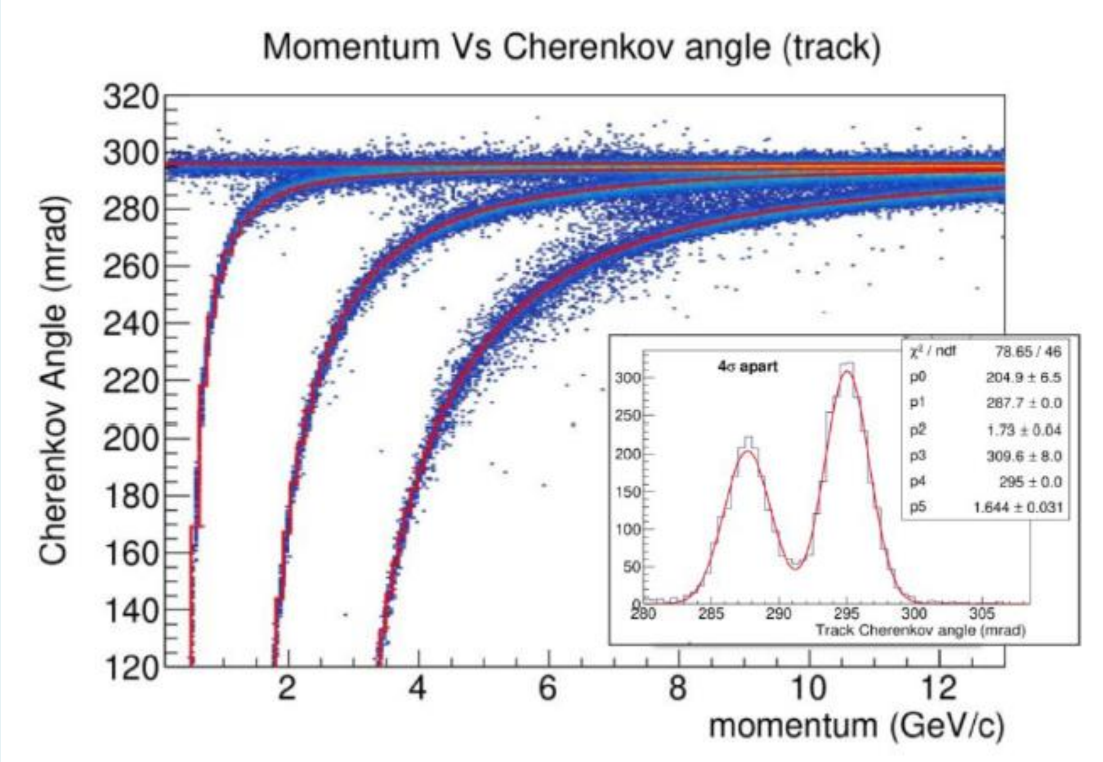
Charm decay hadron kinematics



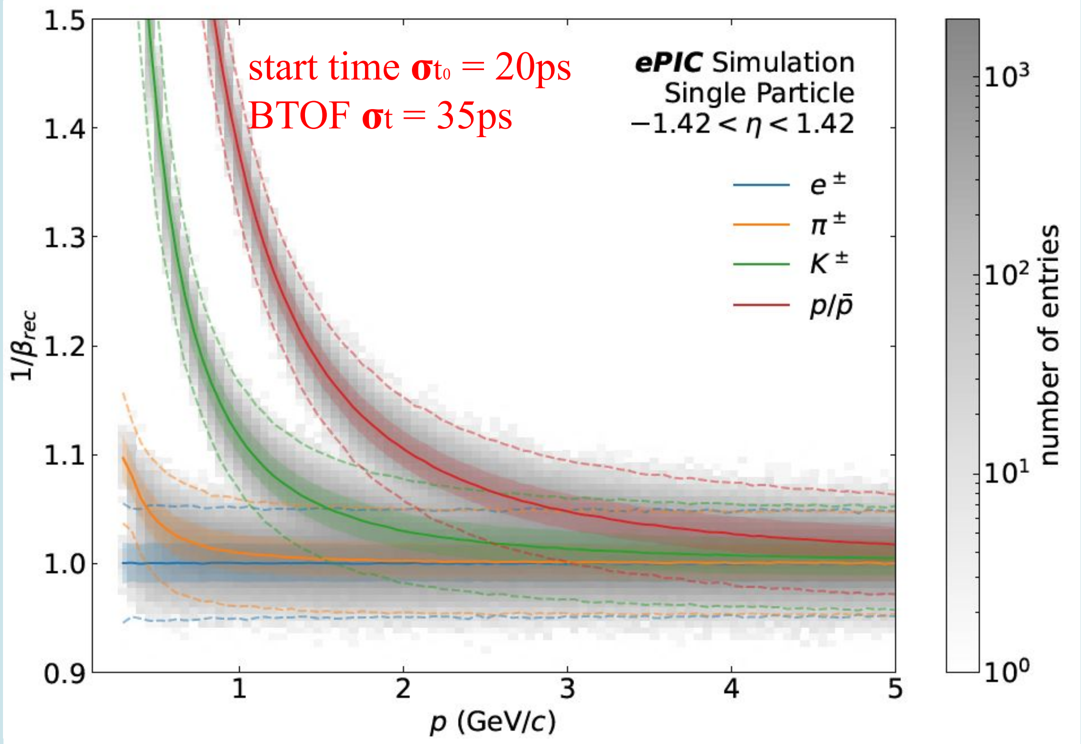
PID Detector Performance

- Electron identification, electron-pion separation at low momentum (high-y) complementary to the electromagnetic calorimeter
- Hadron identification, pion-kaon-proton separation for SIDIS

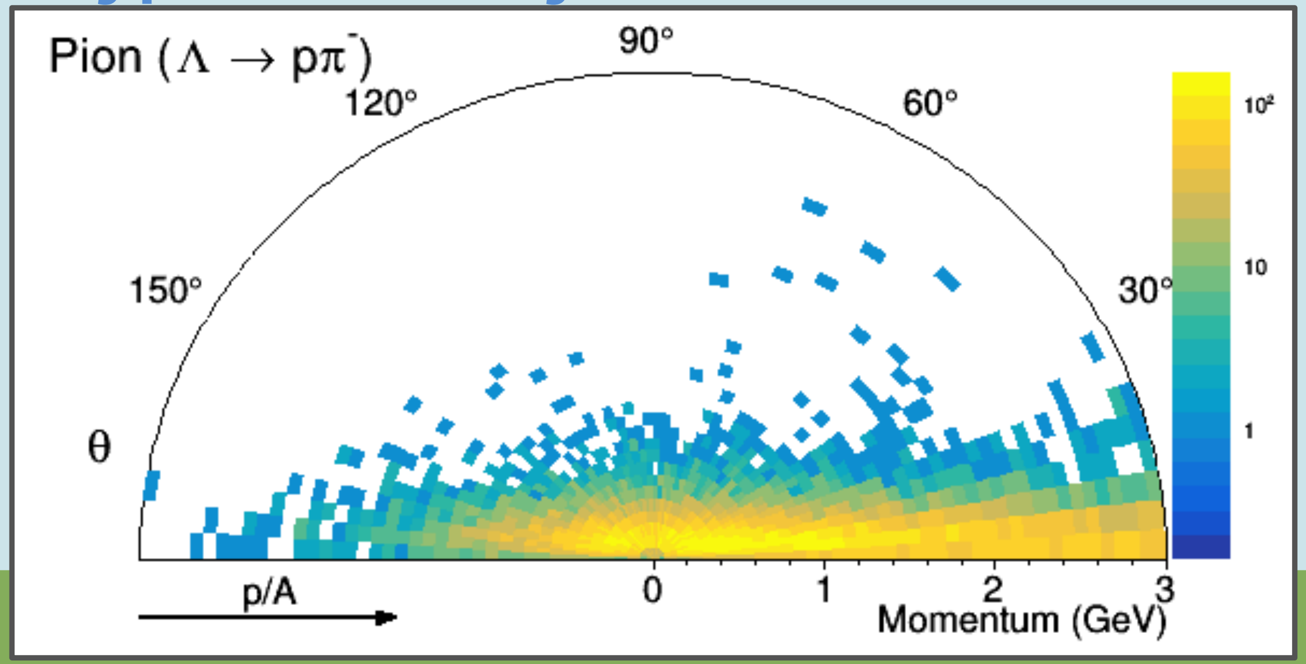
pfRICH performance



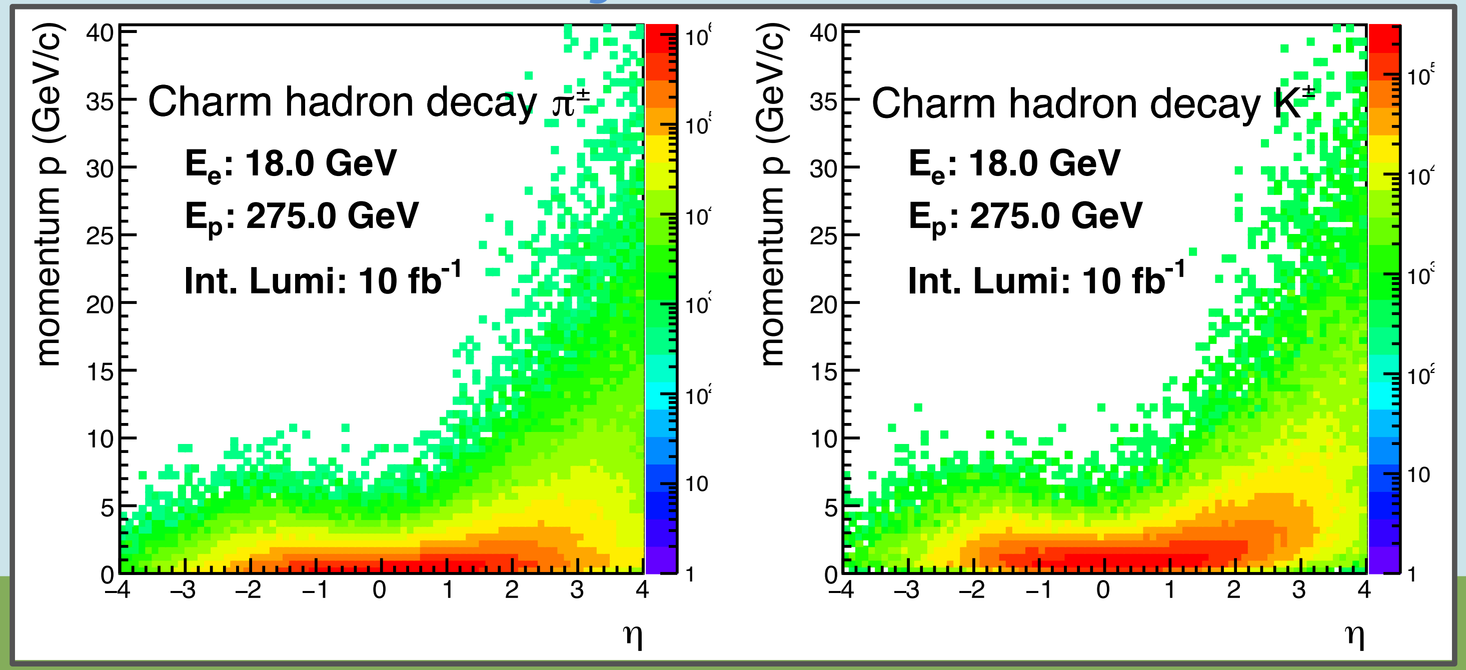
Barrel TOF performance



Hyperon decay hadron kinematics



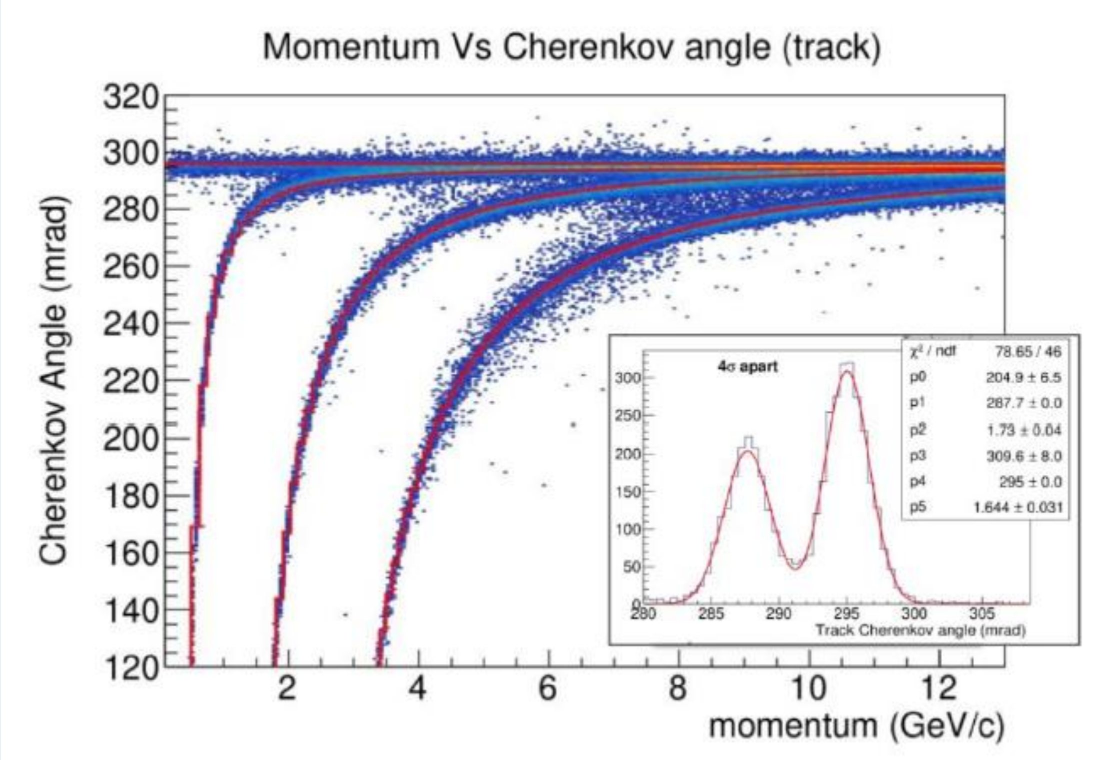
Charm decay hadron kinematics



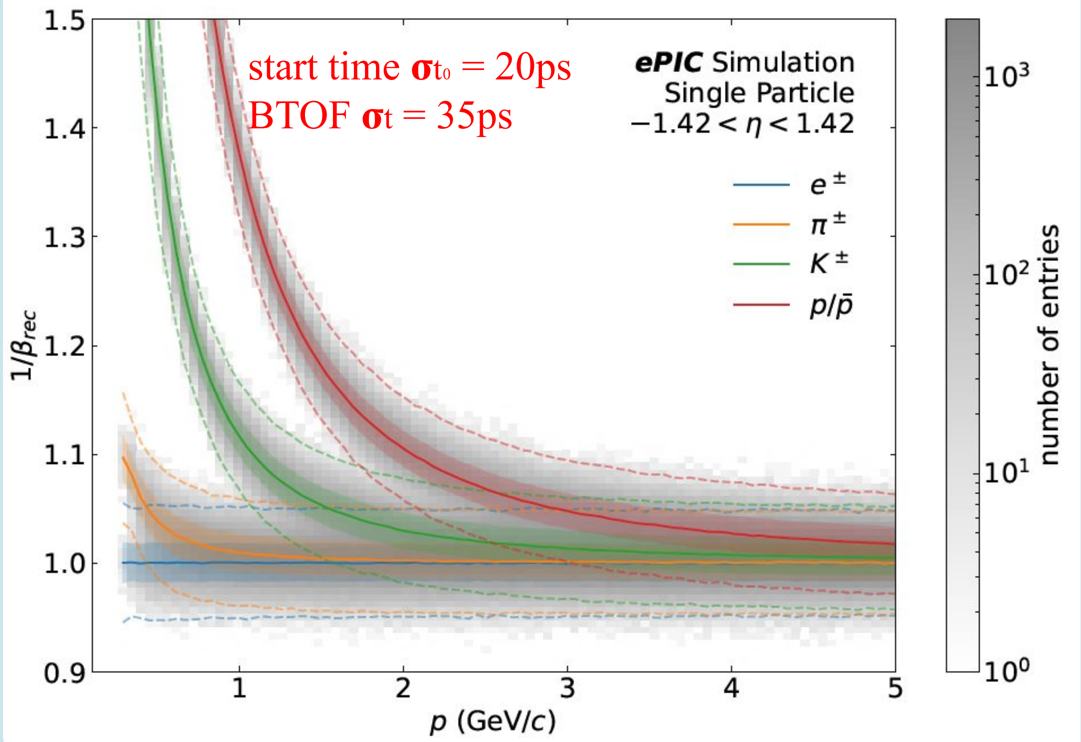
PID Detector Performance

- Electron identification, electron-pion separation at low momentum (high-y) complementary to the electromagnetic calorimeter
- Hadron identification, pion-kaon-proton separation for SIDIS

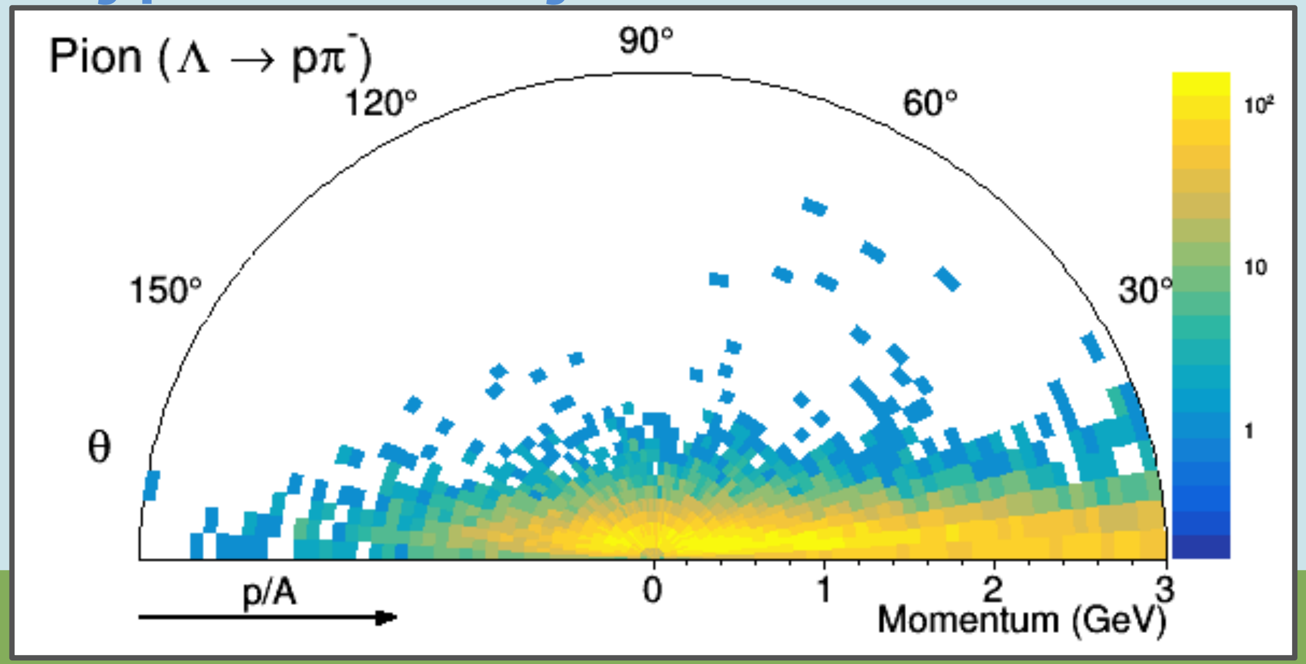
pfRICH performance



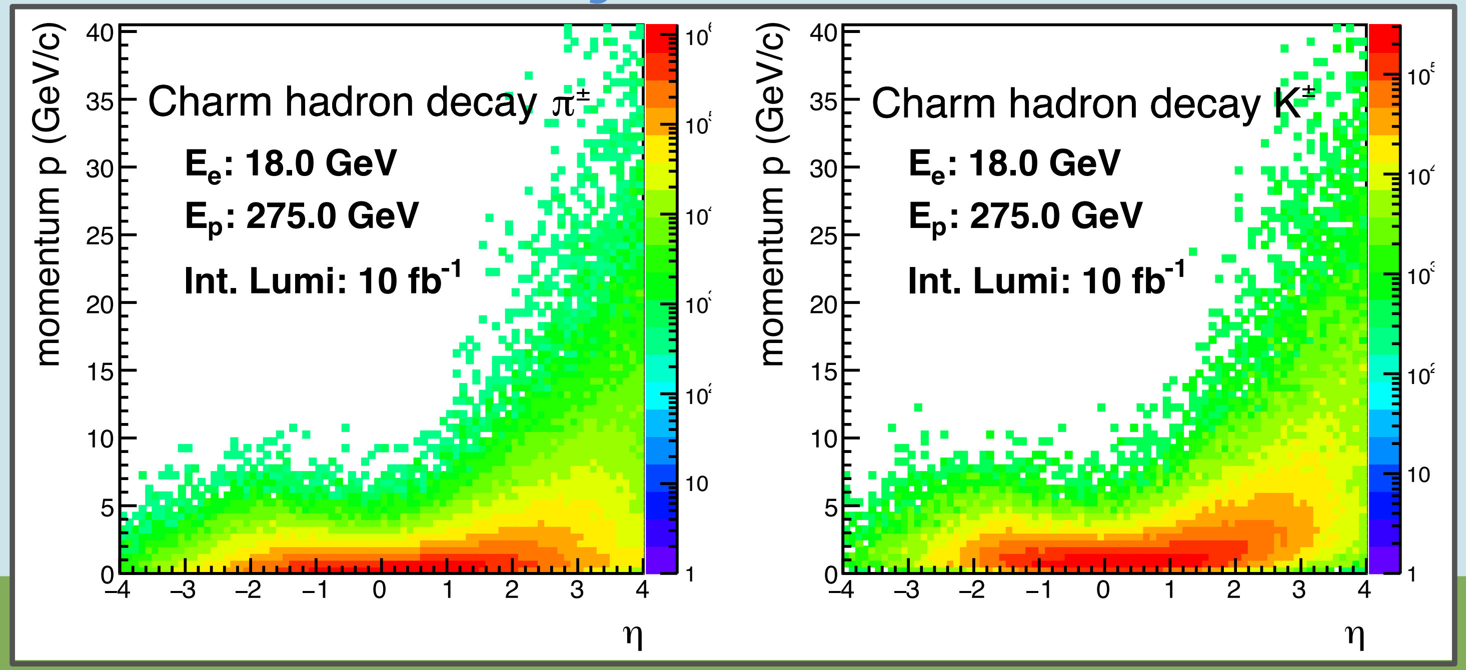
Barrel TOF performance

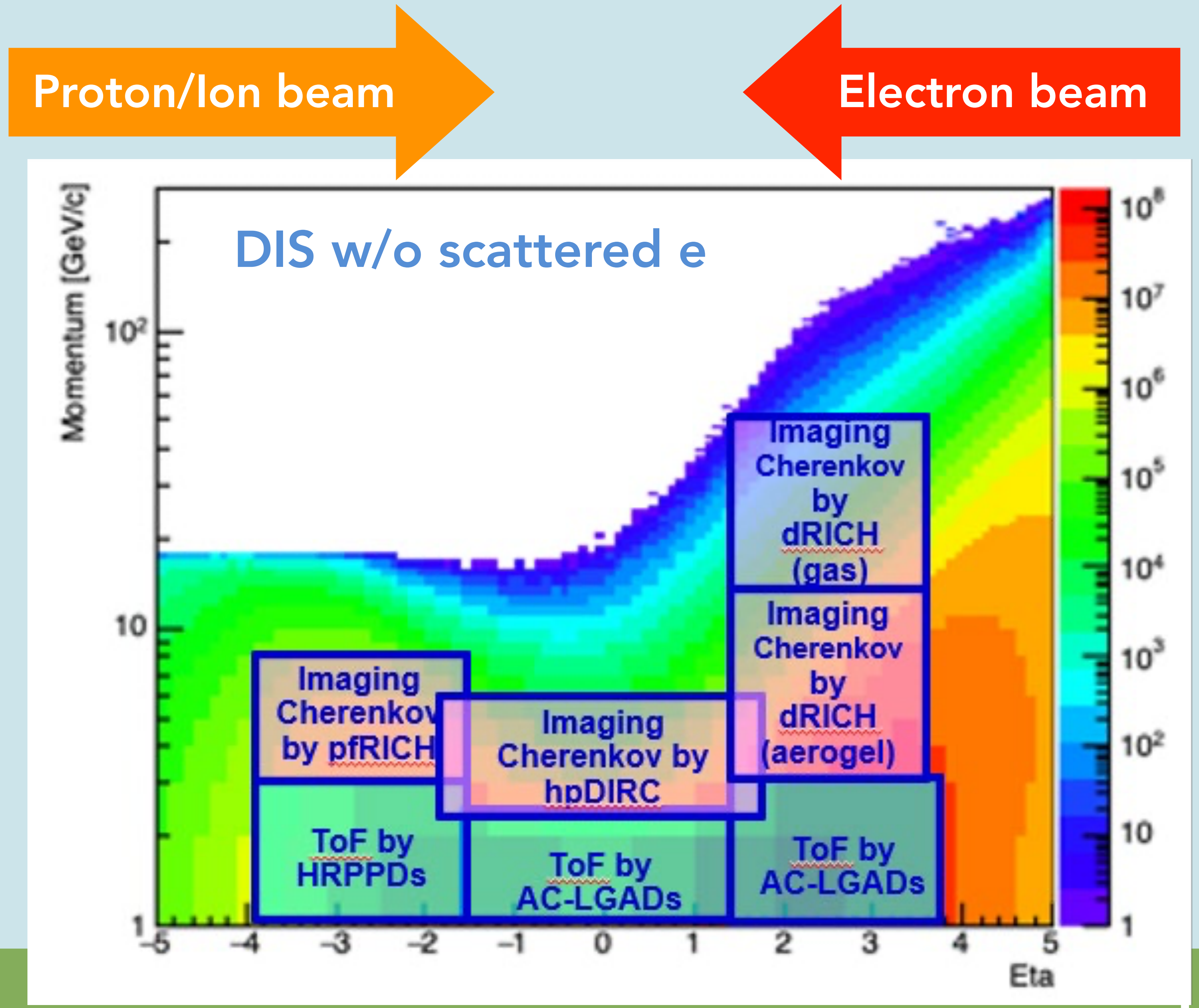


Hyperon decay hadron kinematics

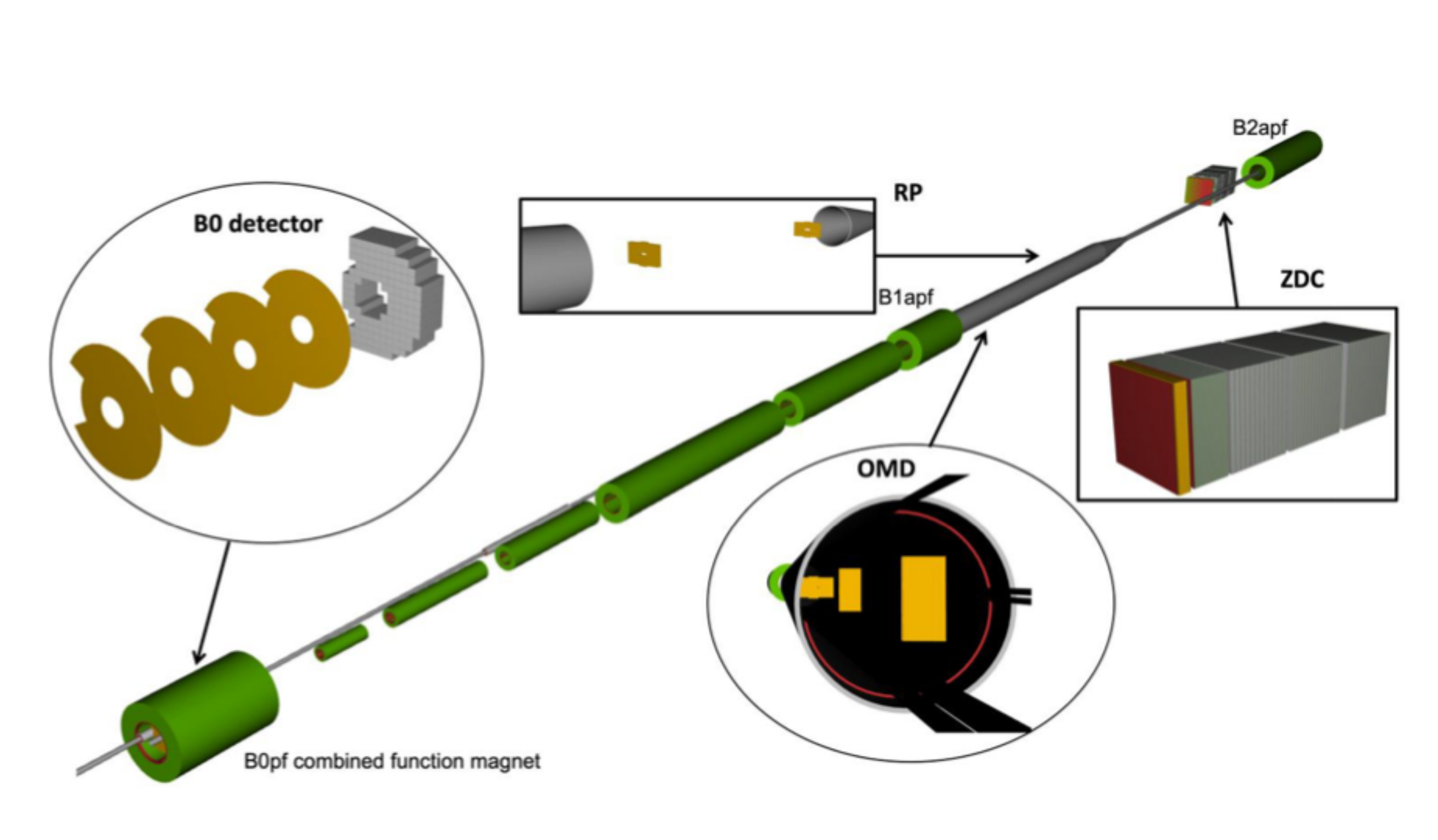


Charm decay hadron kinematics



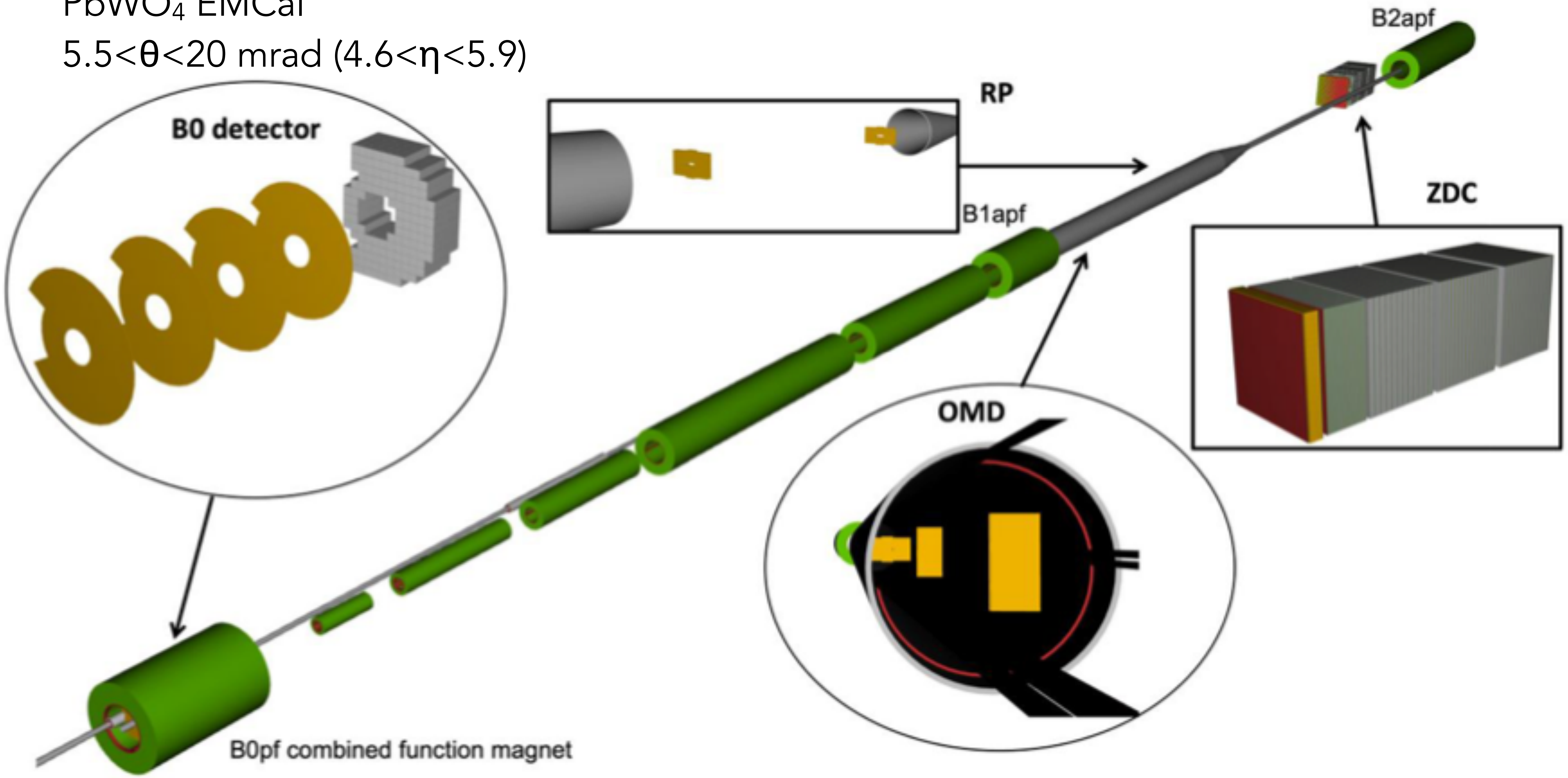


Far-Forward Detector Design



Far-Forward Detector Design

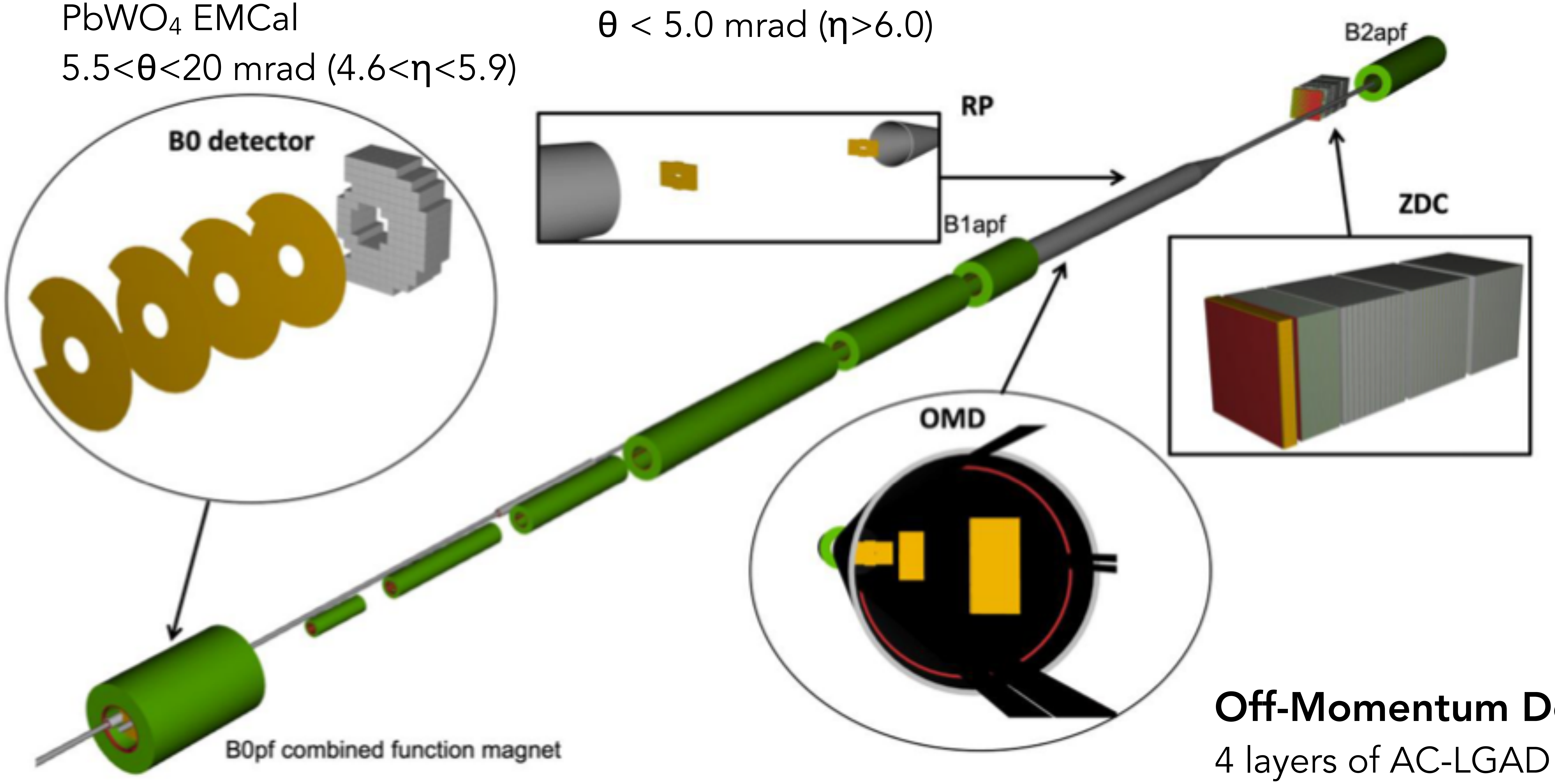
B0 detector
4 AC-LGAD layers
$PbWO_4$ EMCal
$5.5<\theta<20$ mrad ($4.6<\eta<5.9$)

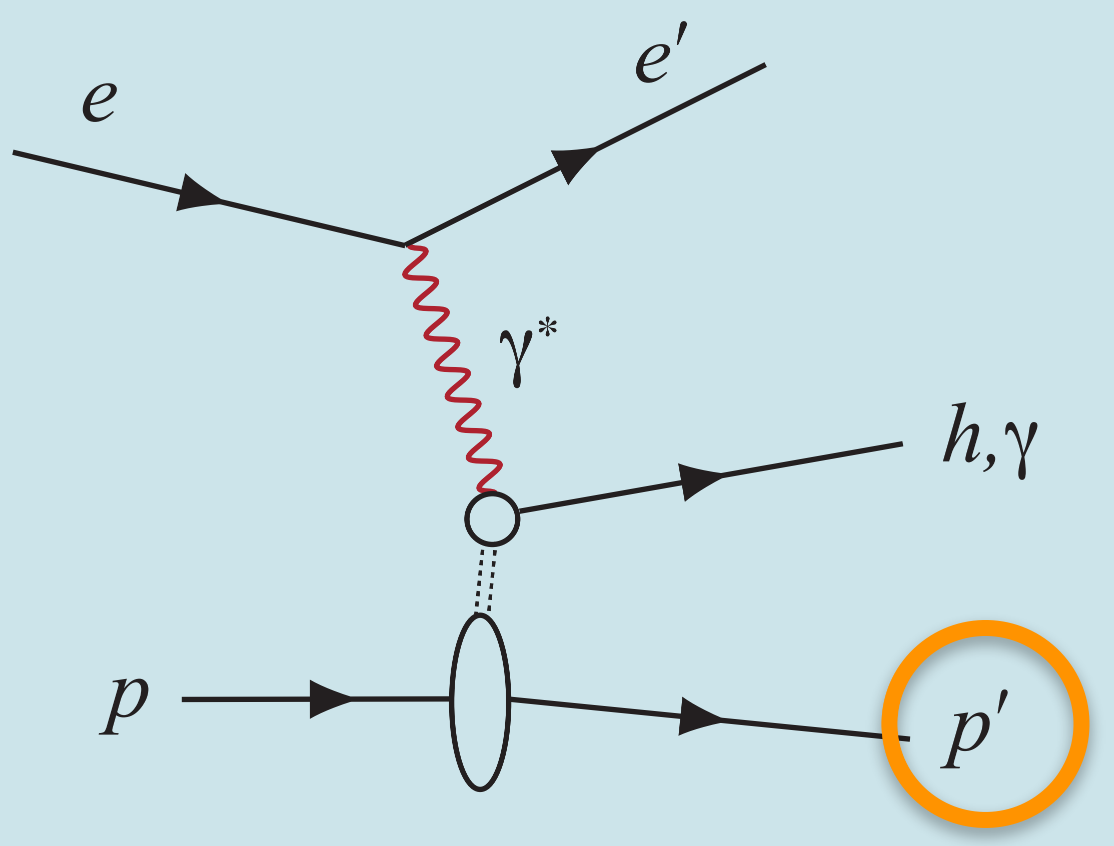


Far-Forward Detector Design

B0 detector
4 AC-LGAD layers
$PbWO_4$ EMCal
$5.5<\theta<20$ mrad ($4.6<\eta<5.9$)

Roman Pods
2 stations with 2 AC-LGAD layers each
θ < 5.0 mrad (η>6.0)





Off-Momentum Detector
4 layers of AC-LGAD layer
θ < 5.0 mrad (η>6.0)

Far-Forward Detector Design

B0 detector
4 AC-LGAD layers
$PbWO_4$ EMCal
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Roman Pods
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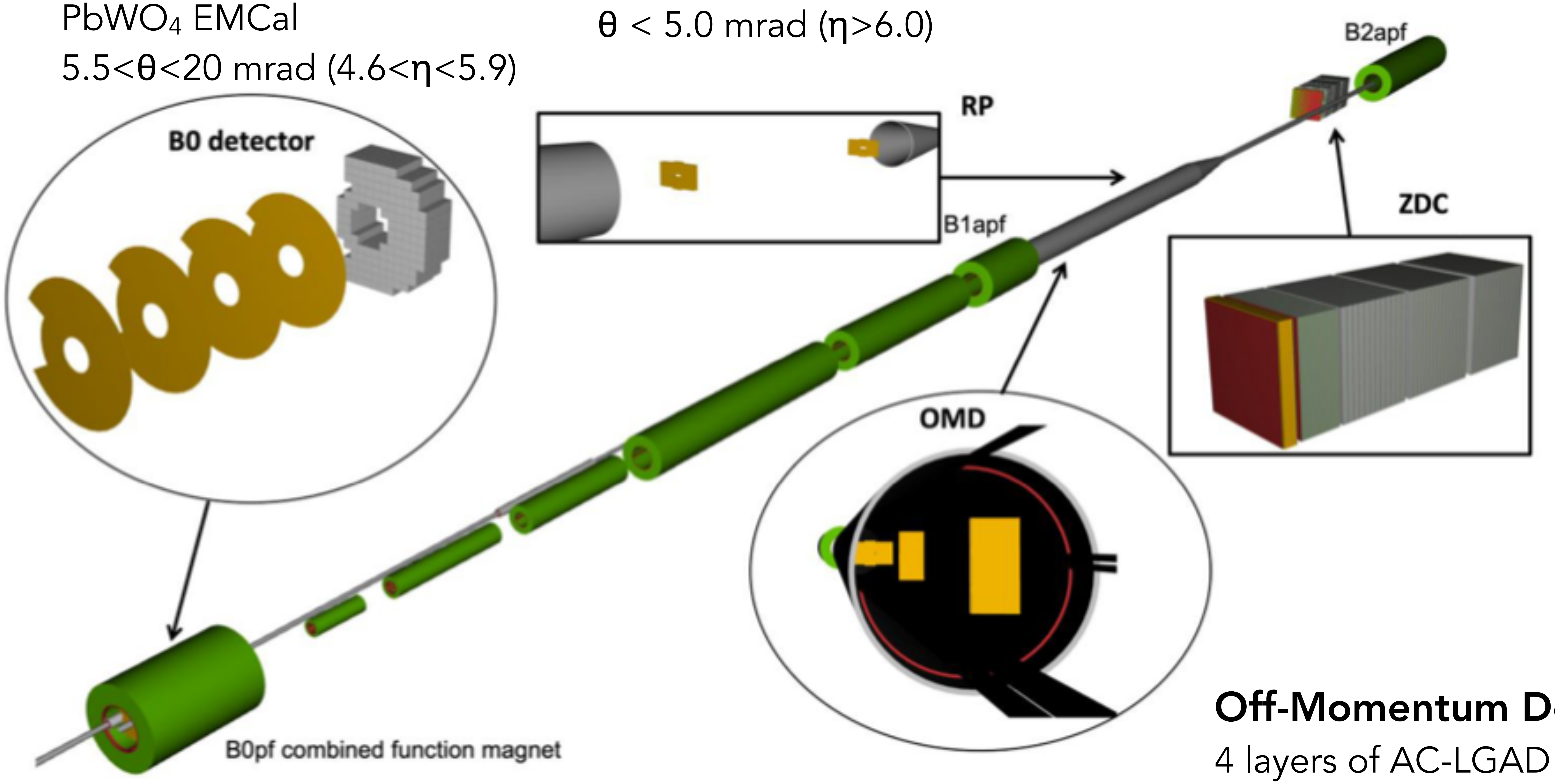
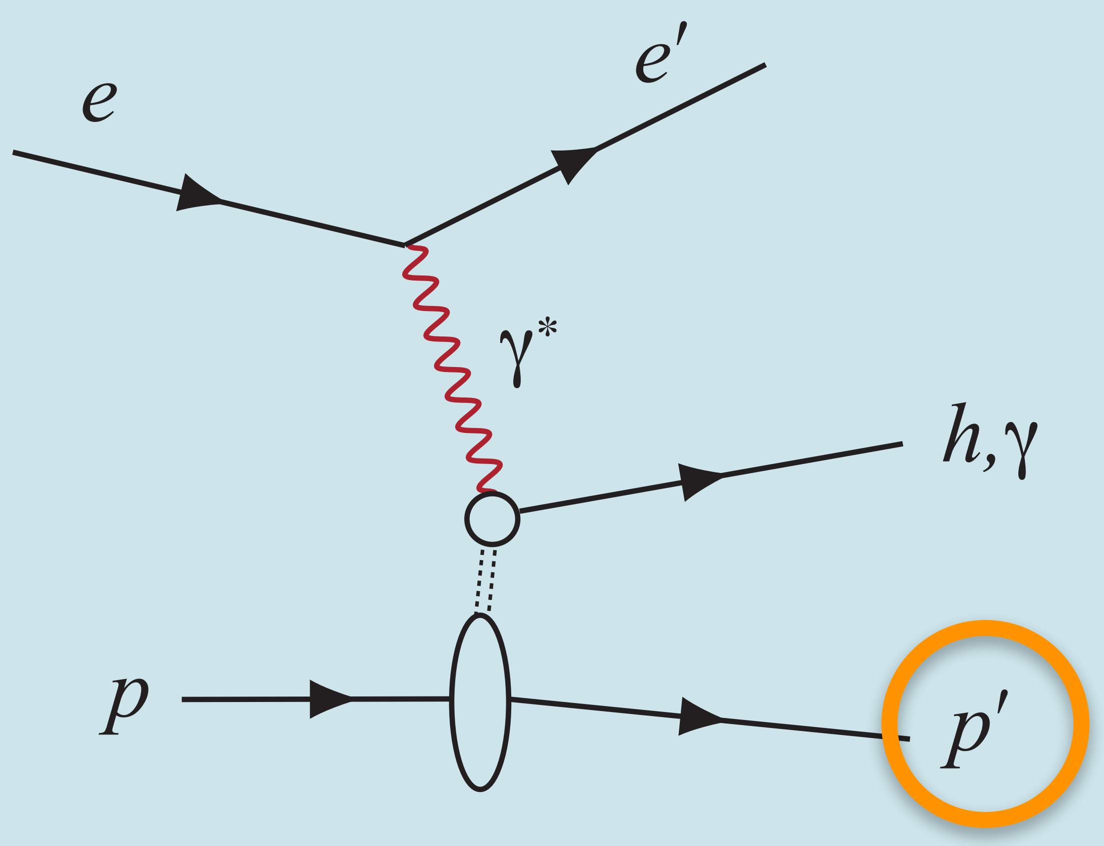


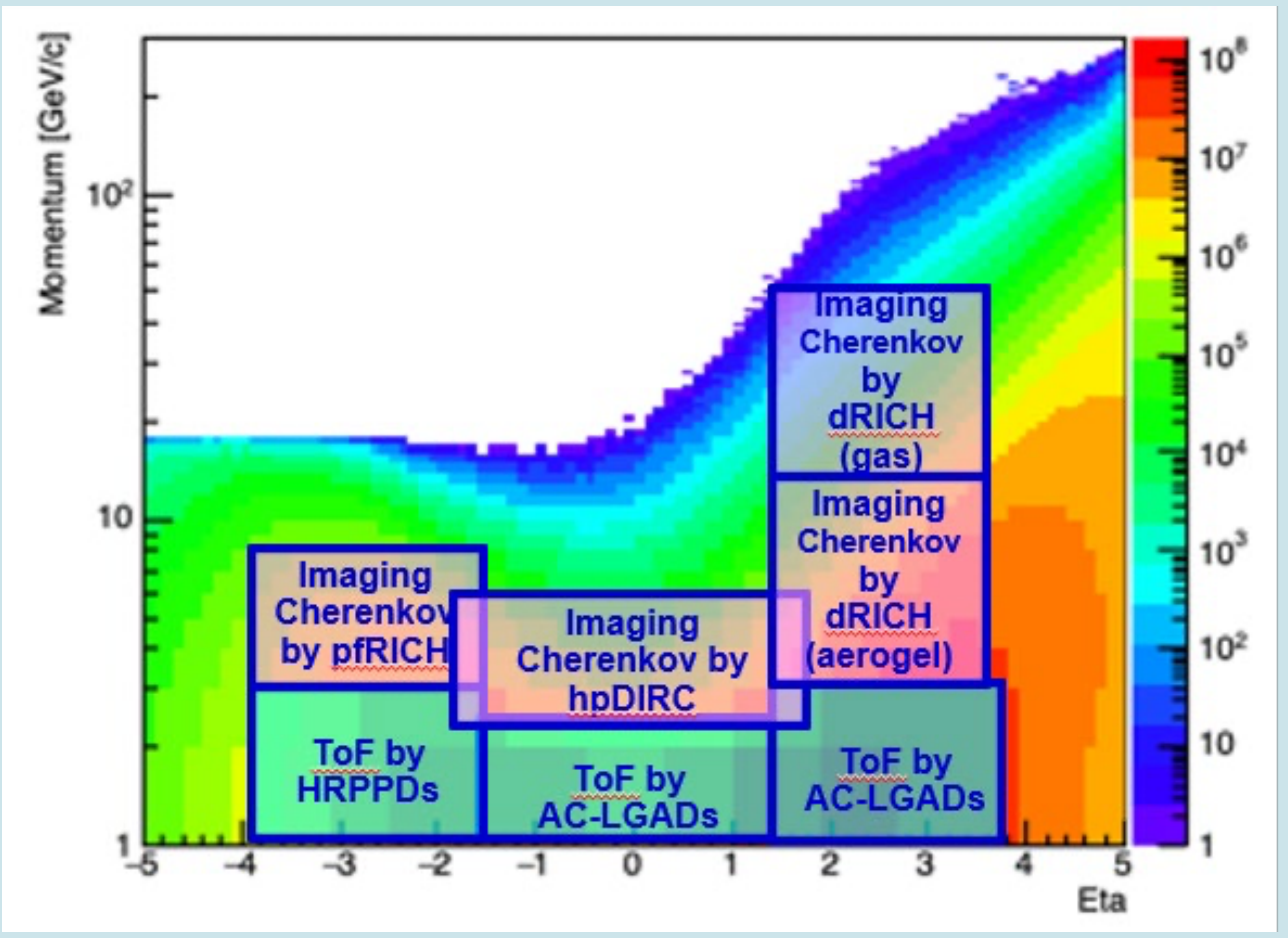


Zero Degree Calorimeter
1st: Si layers + PbWO4/LYSO
2nd: W/Si Imaging EMCal
3rd: Pb/Sci HCal
$\theta < 5.0$ mrad ($\eta>6.0$)

Off-Momentum Detector
4 layers of AC-LGAD layer
$\theta < 5.0$ mrad ($\eta>6.0$)

Far-Forward/Backward Detector Performance

- B0 detector can reconstruct charged particles and photons at 4.6<η<5.9 region by using a bending magnet
  - Parent particles can be reconstructed



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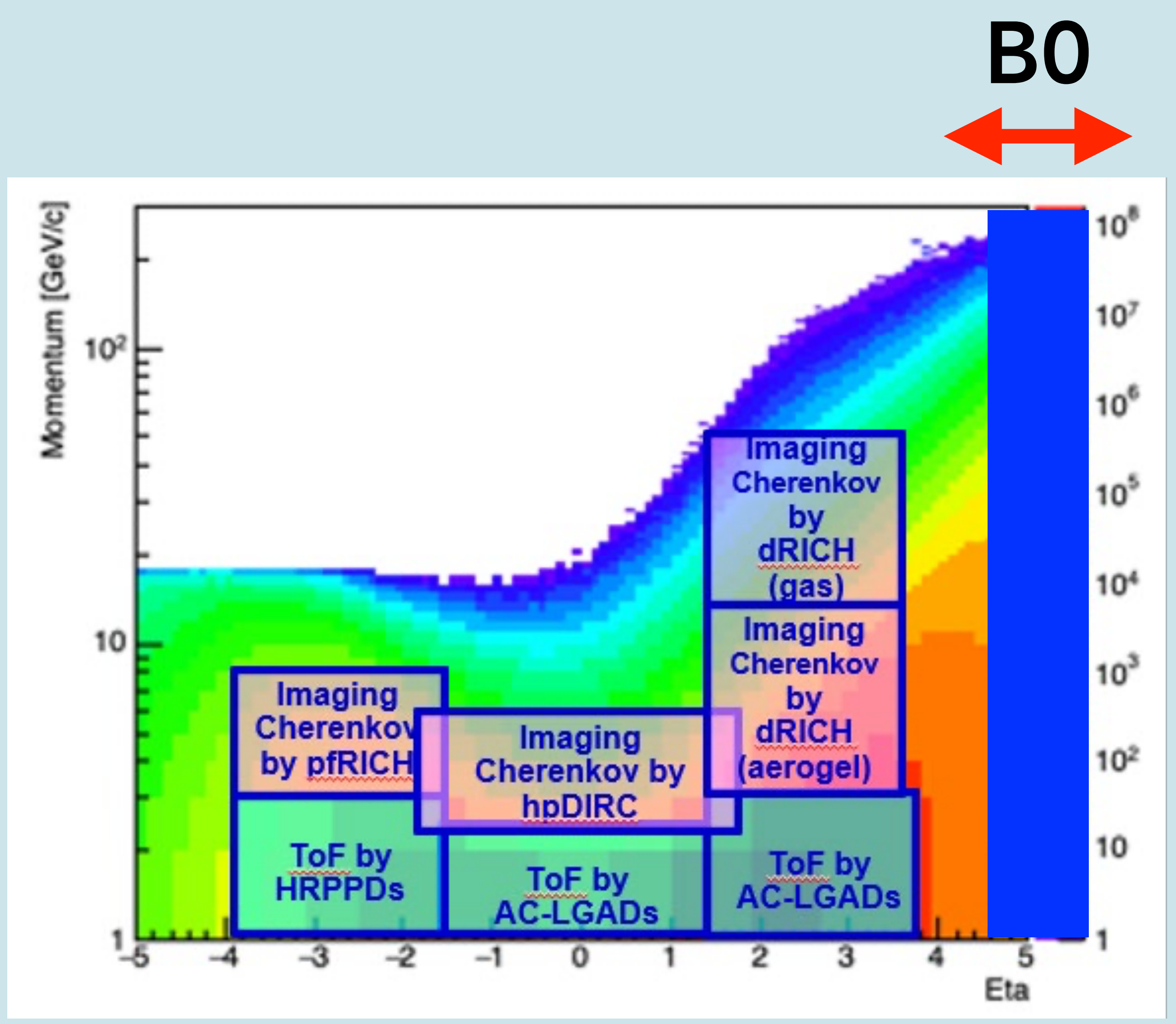

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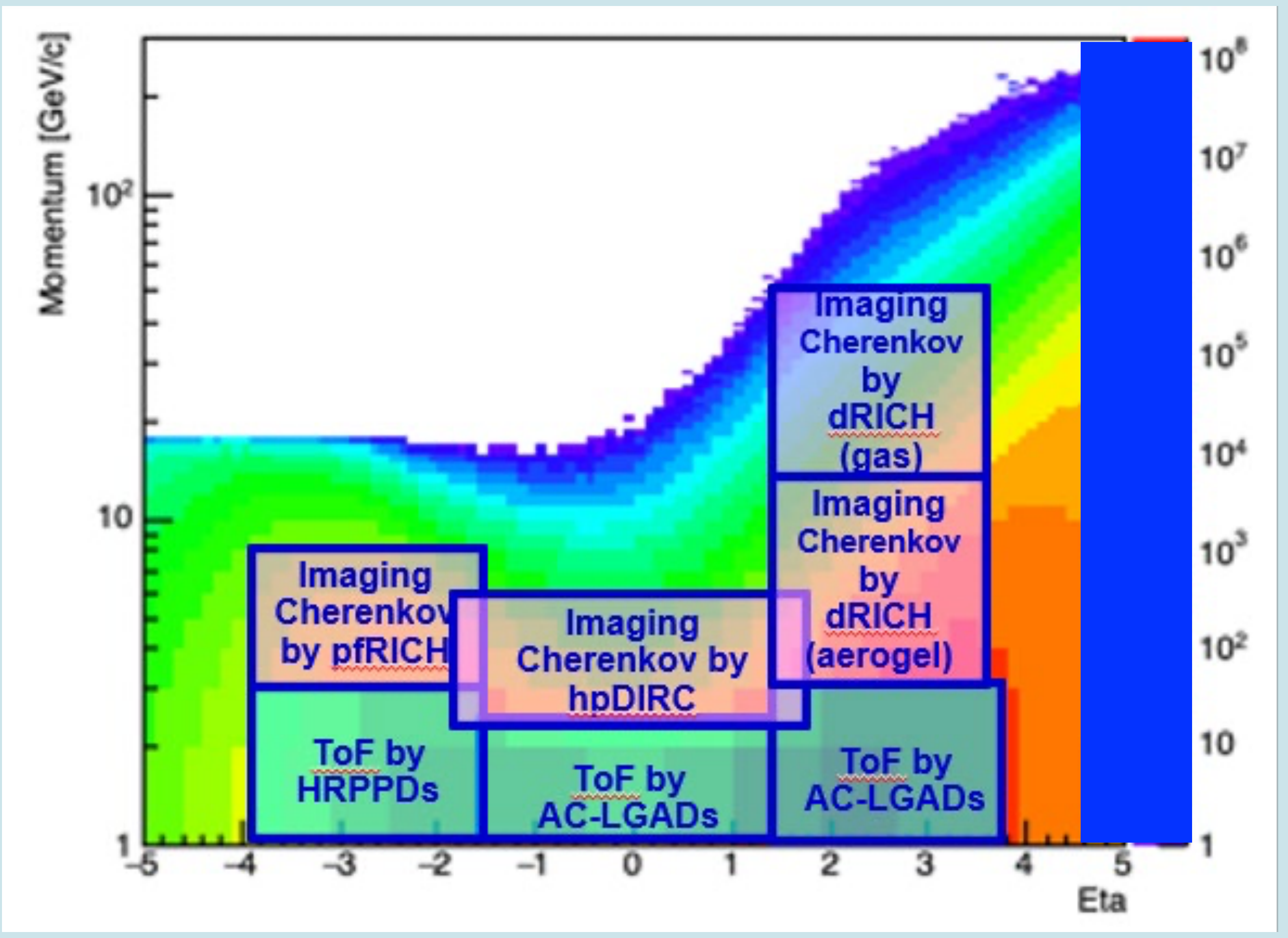
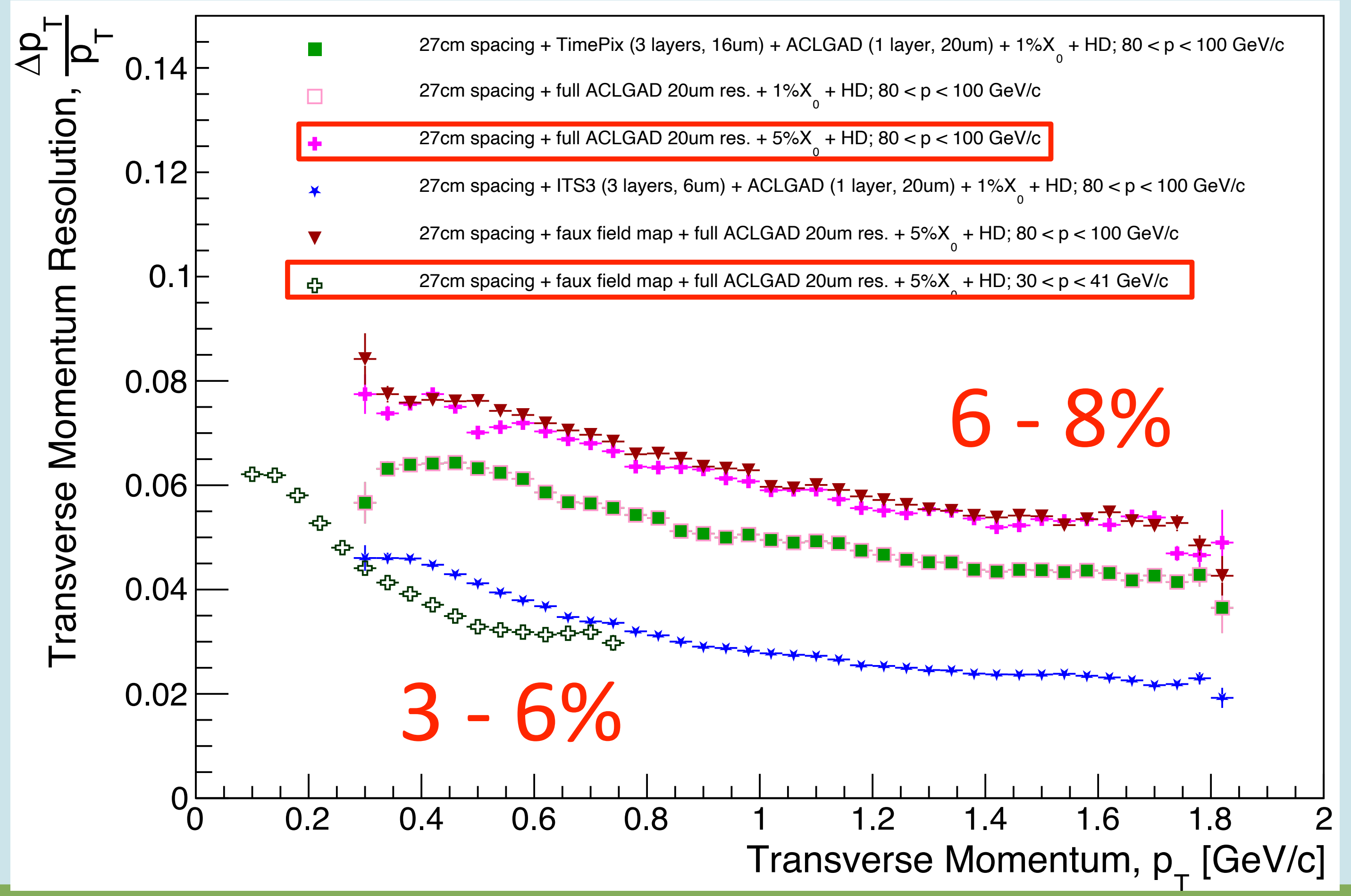
B0



B0 tracking reso.



Far-Forward/Backward Detector Performance

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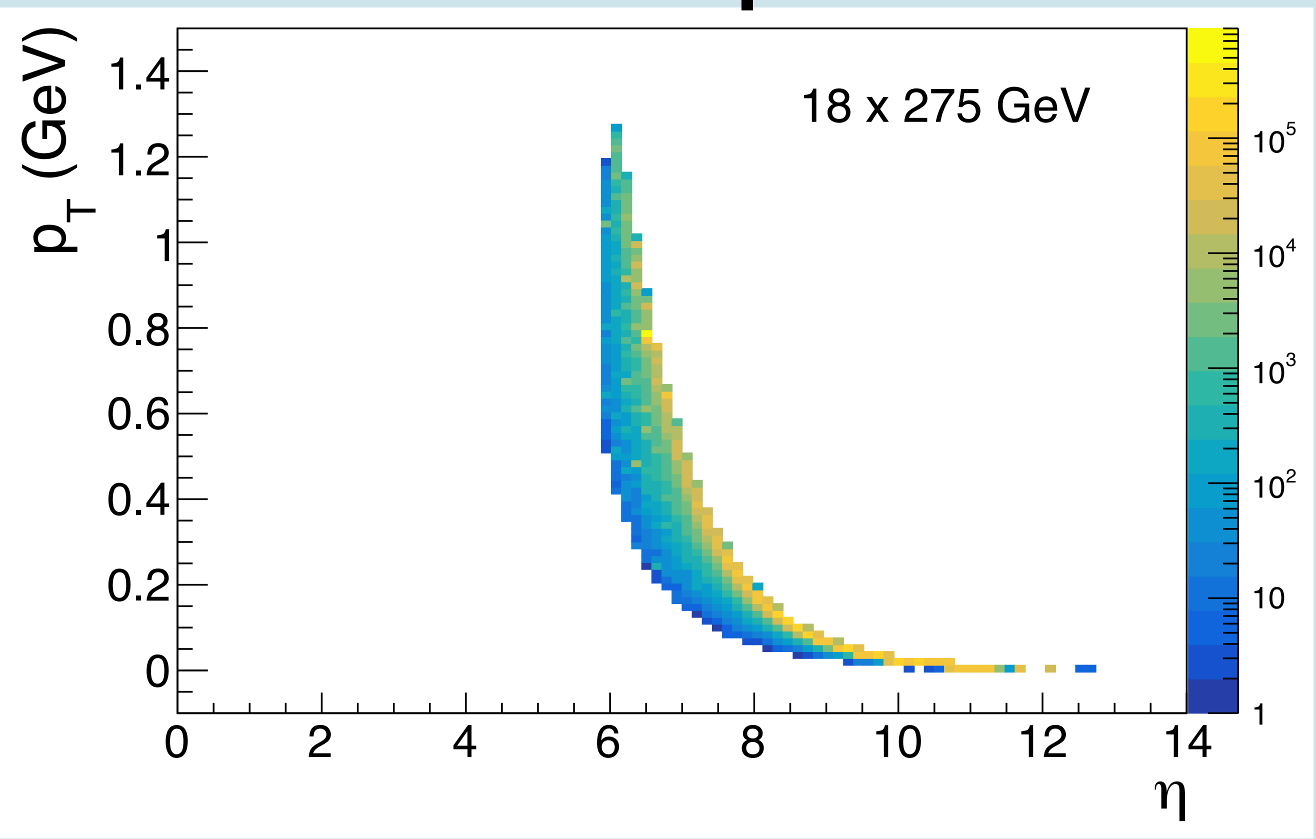
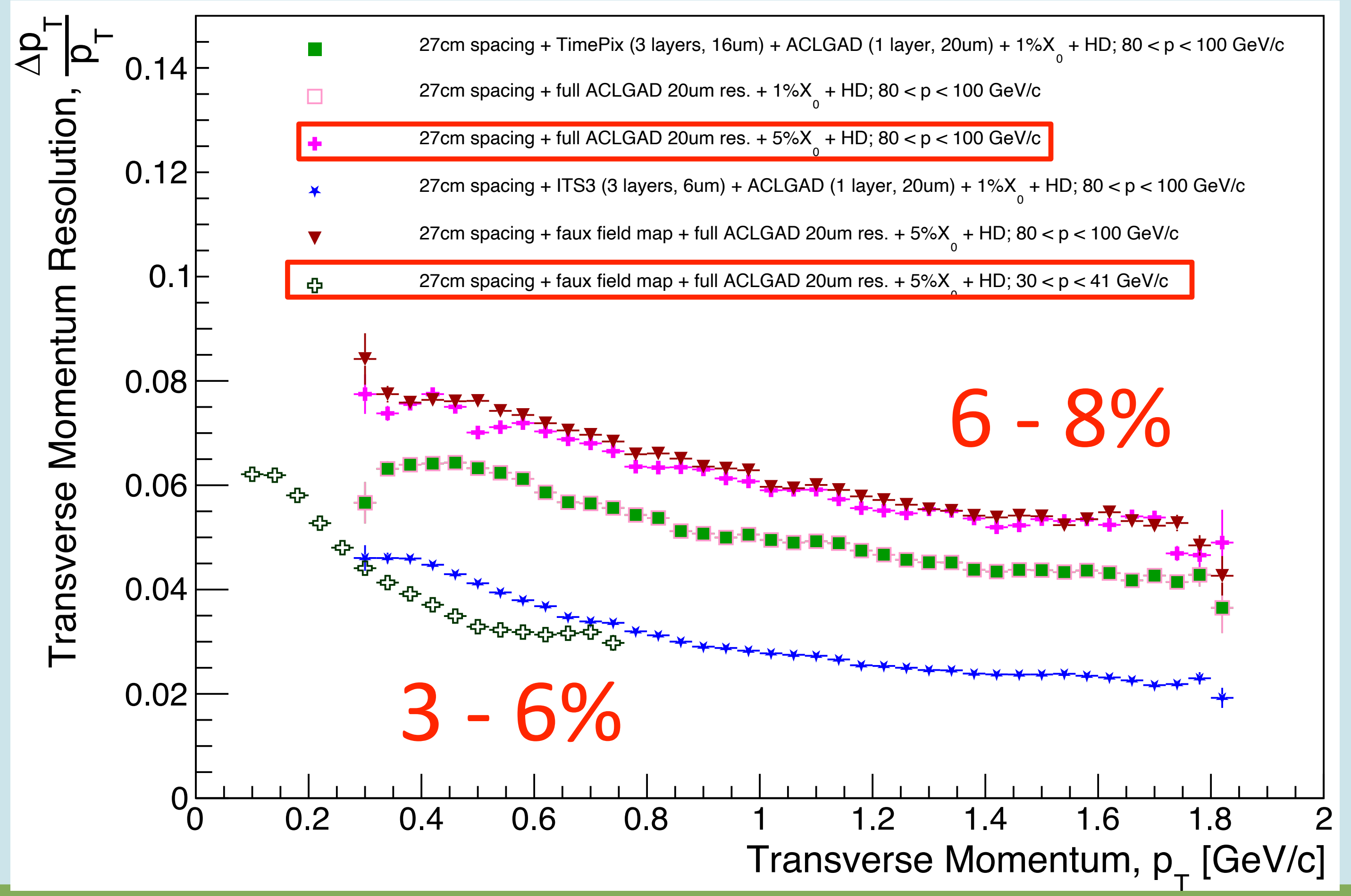
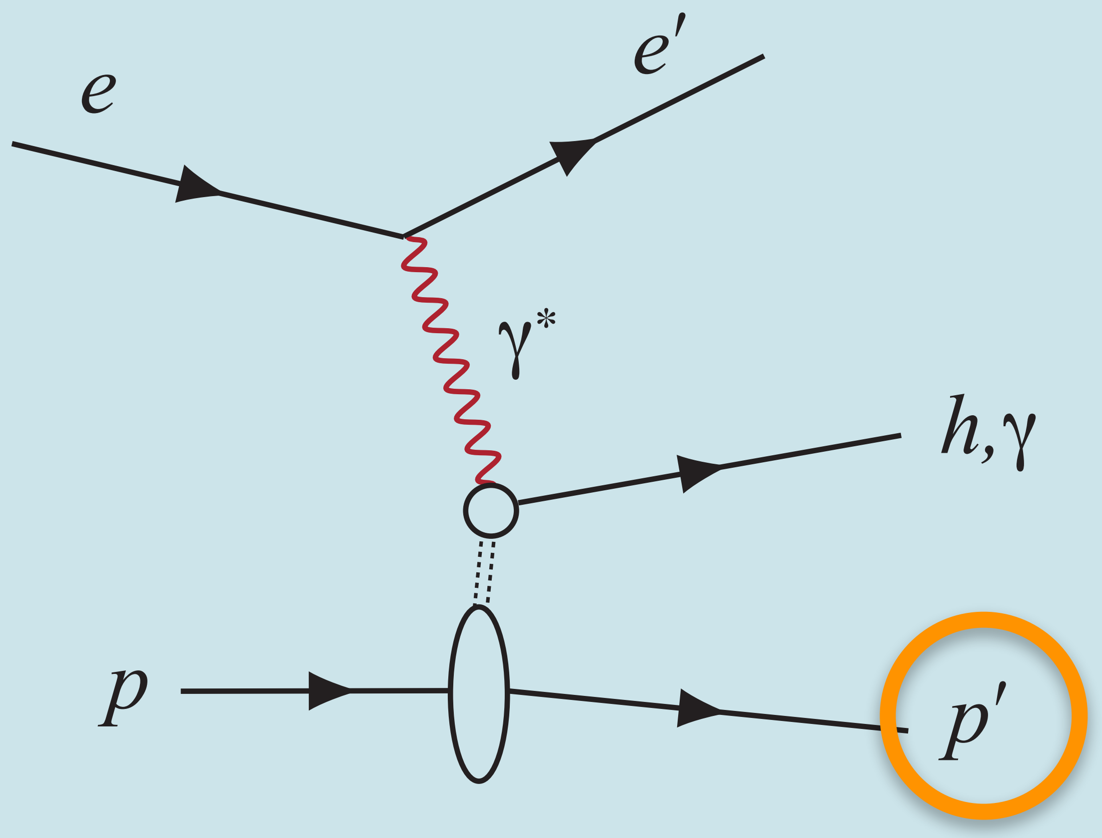
Scattered proton



B0 tracking reso.





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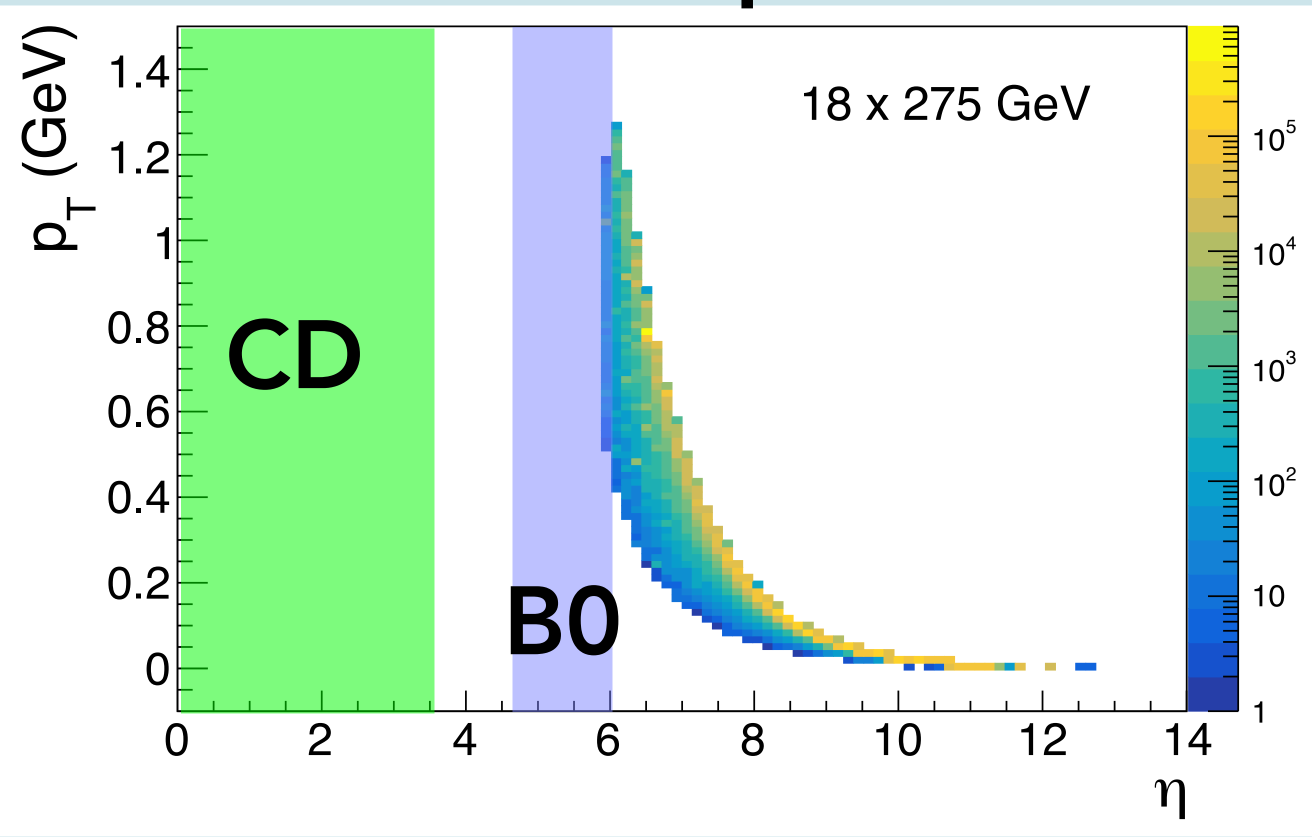
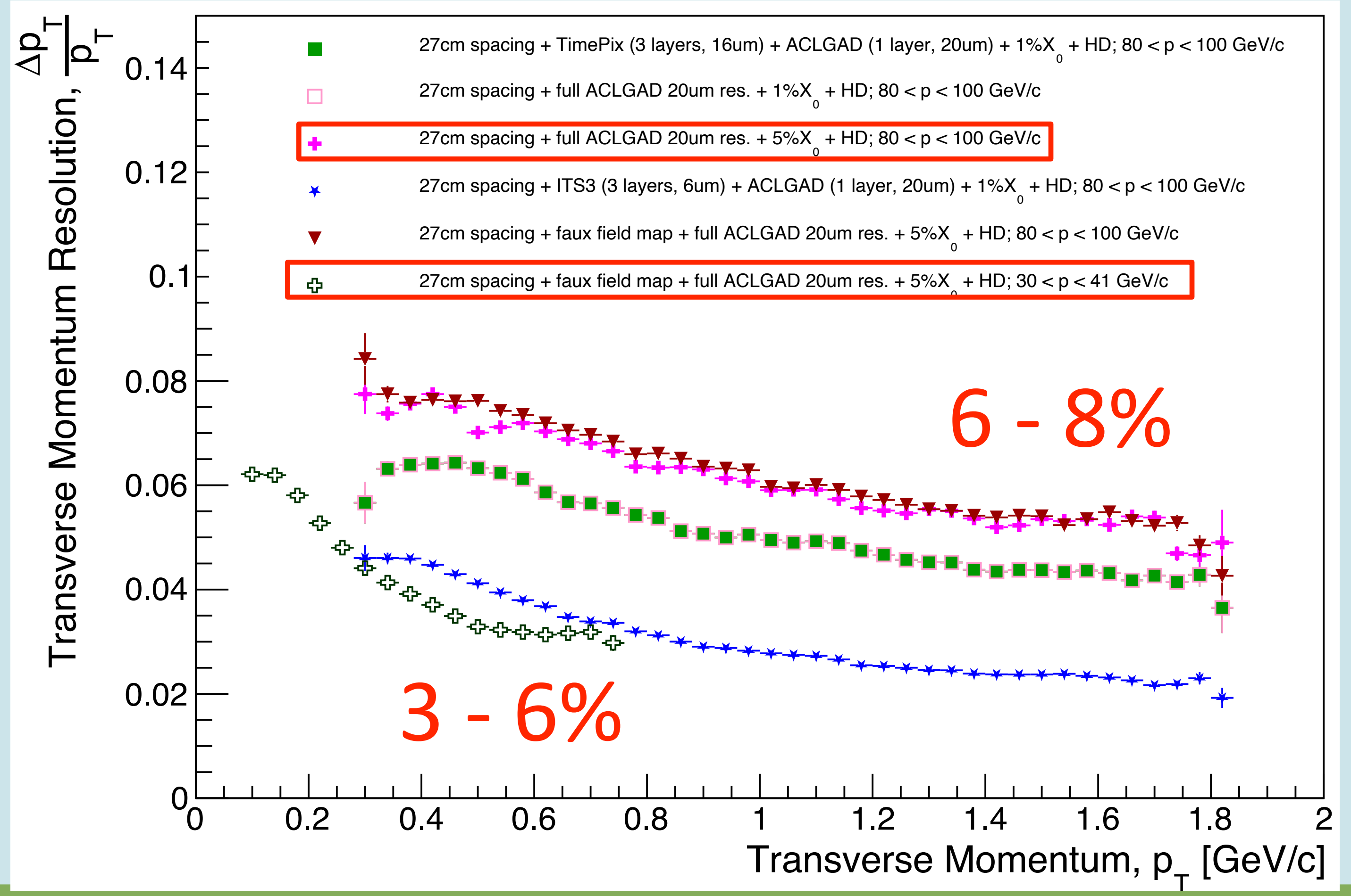
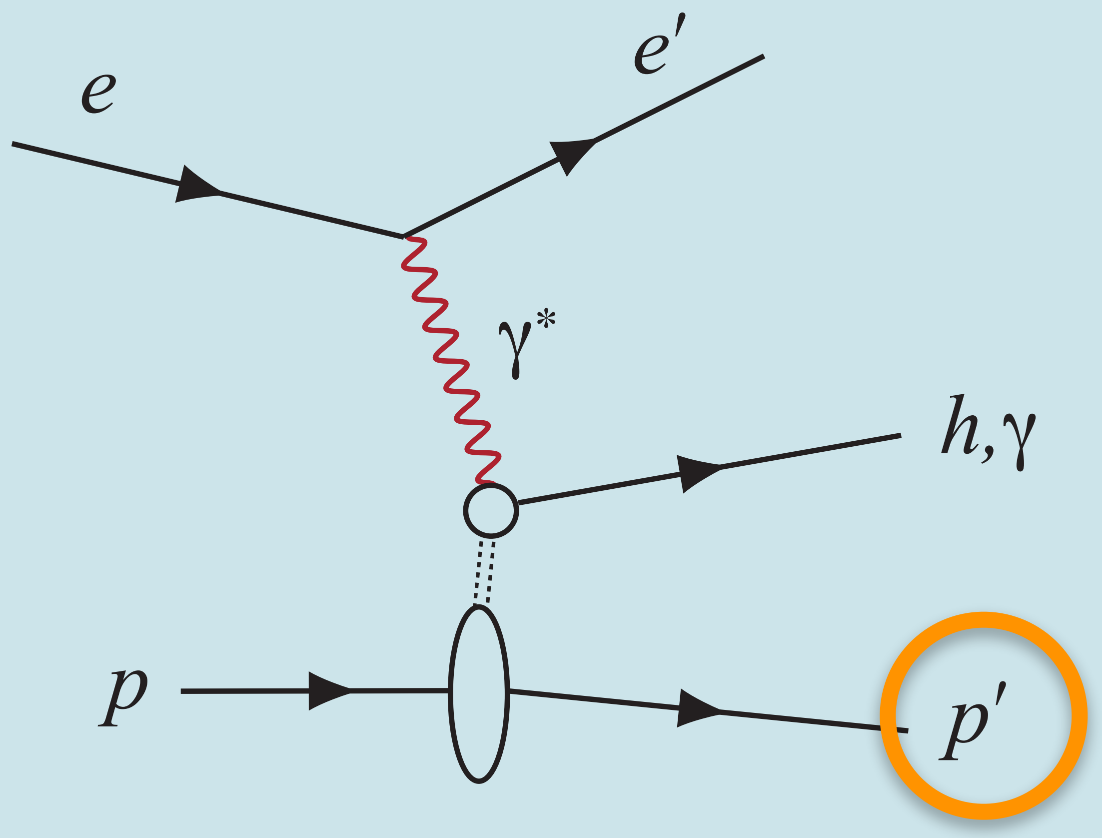


B0 tracking reso.

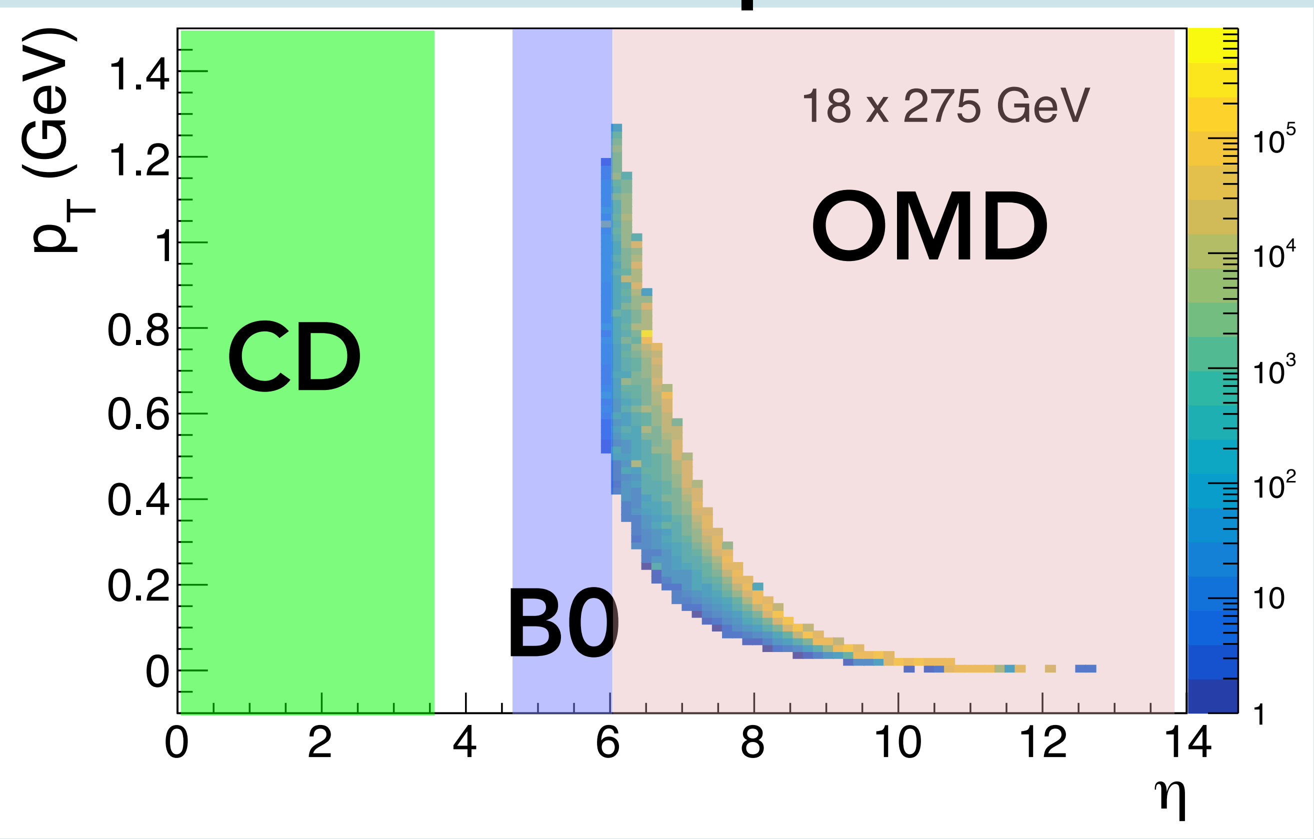




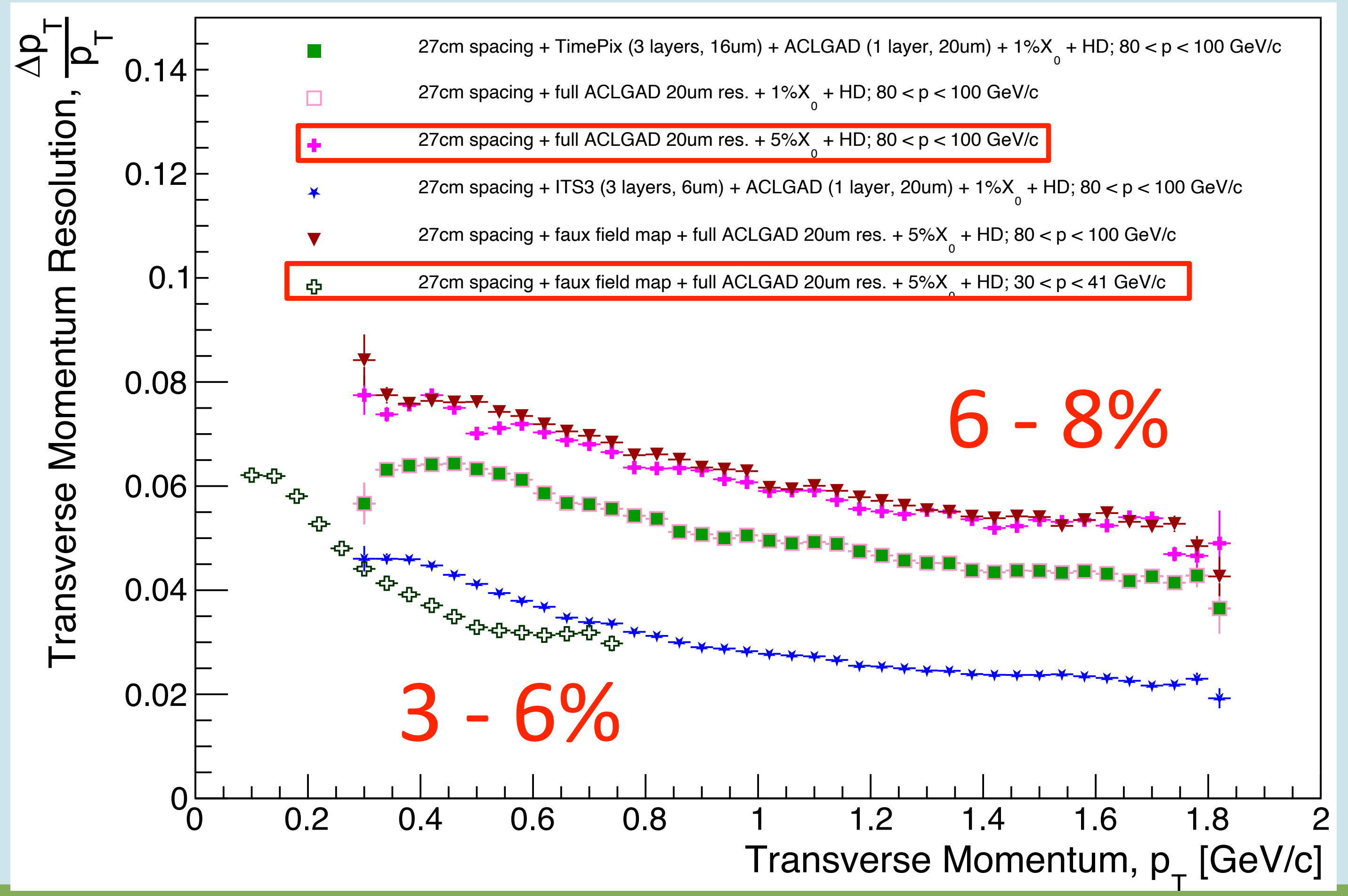
Far-Forward/Backward Detector Performance

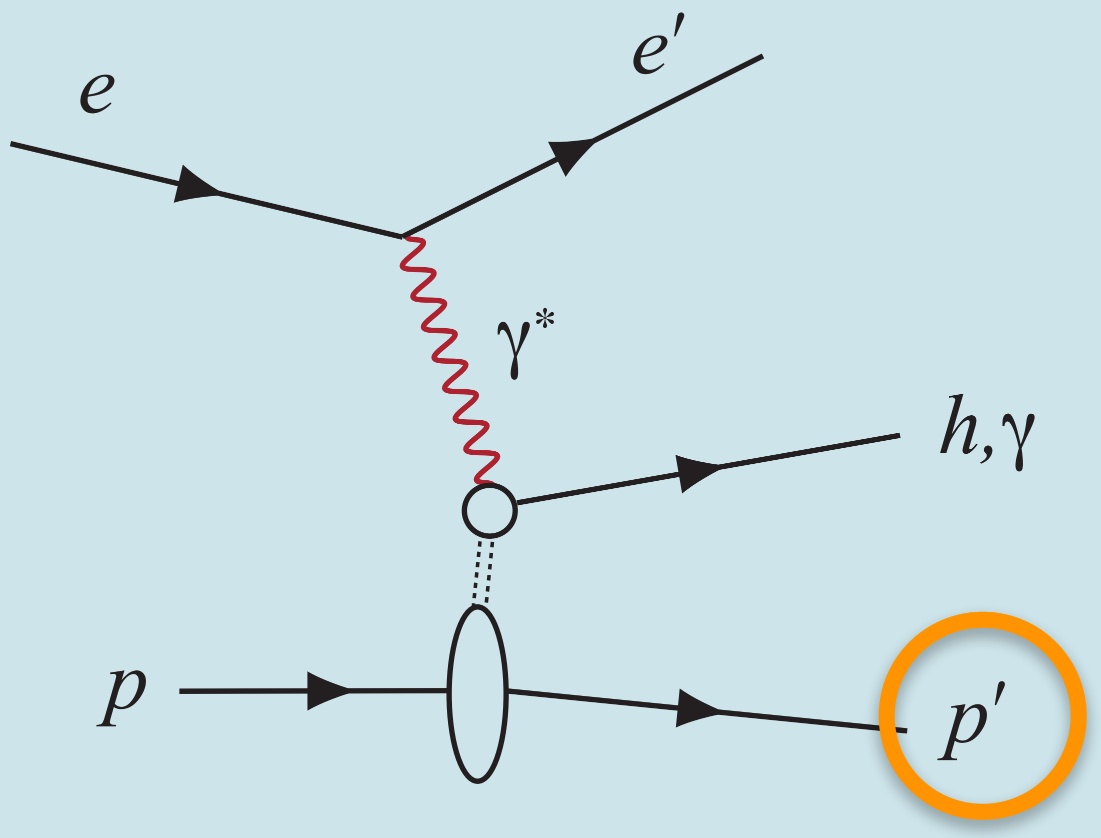
- B0 detector can reconstruct charged particles and photons at 4.6<η<5.9 region by using a bending magnet
  - Parent particles can be reconstructed
- OMD can detect 40%~65% momentum proton w.r.t steering magnet

Scattered proton



B0 tracking reso.

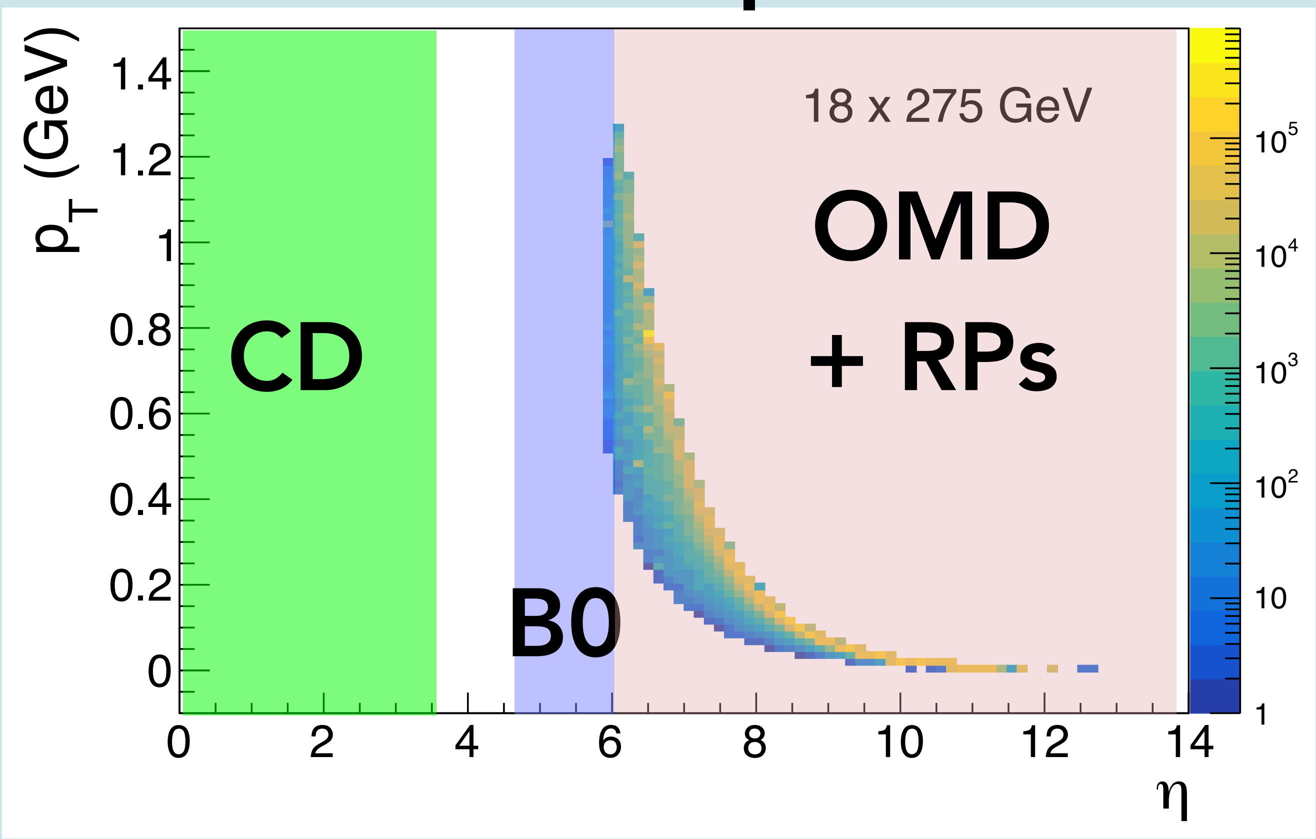




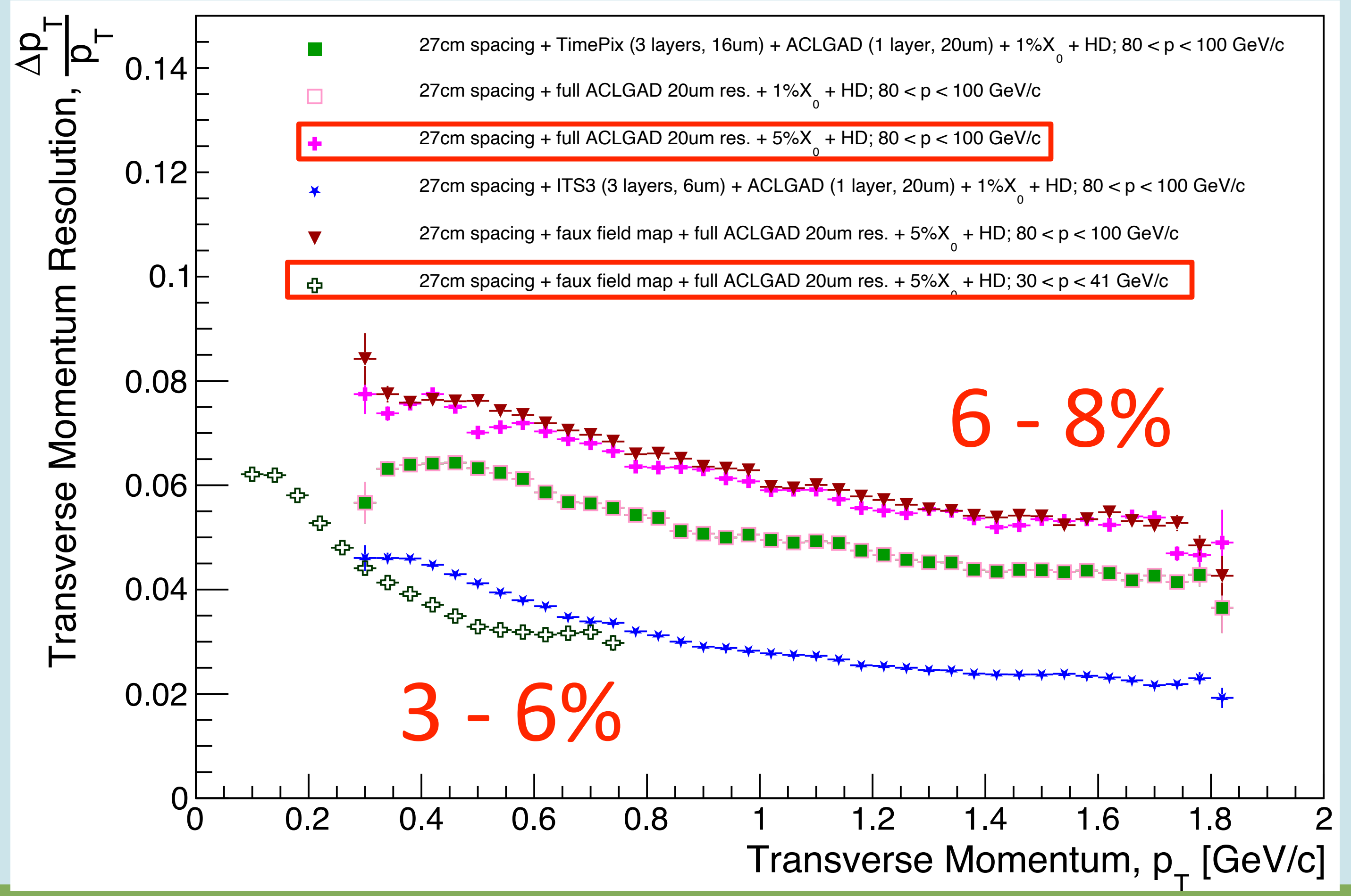
Far-Forward/Backward Detector Performance

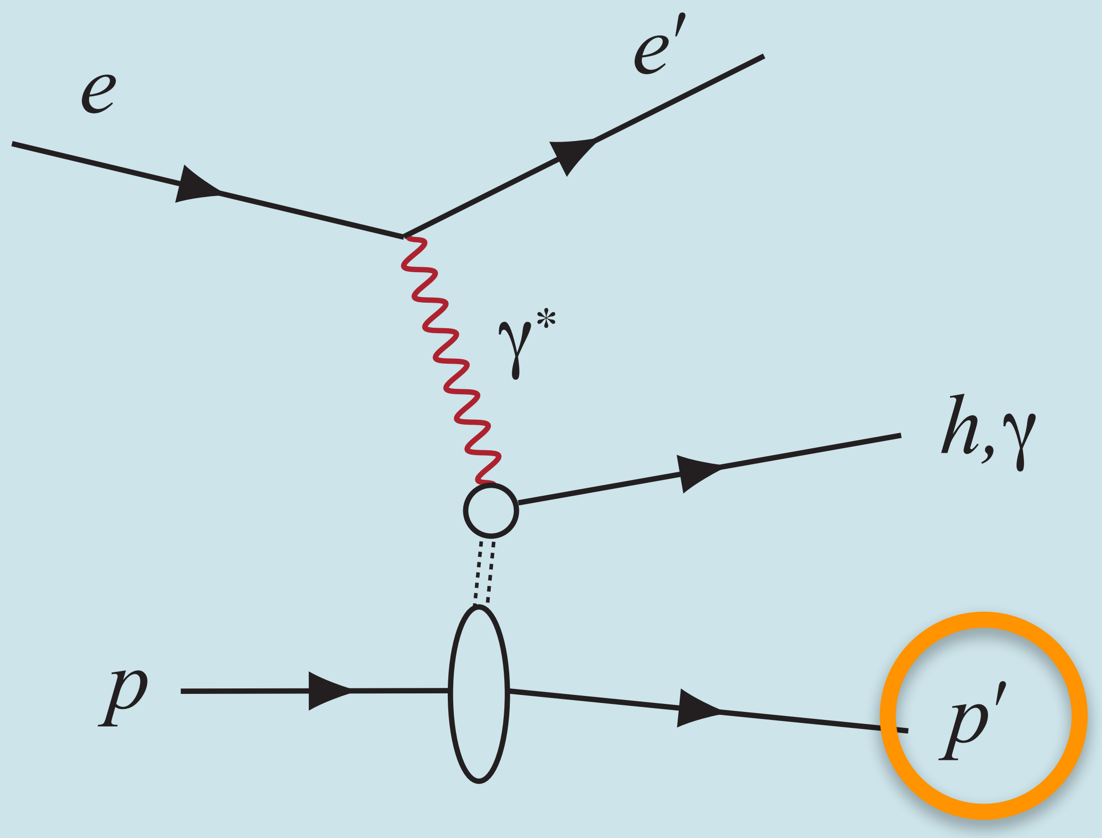
- B0 detector can reconstruct charged particles and photons at 4.6<η<5.9 region by using a bending magnet
  - Parent particles can be reconstructed
- OMD can detect 40%~65% momentum proton w.r.t steering magnet
- RPs can detect 60 - 95% momentum, proton

Scattered proton



B0 tracking reso.





Far-Forward/Backward Detector Performance

- B0 detector can reconstruct charged particles and photons at $4.6<\eta<5.9$ region by using a bending magnet
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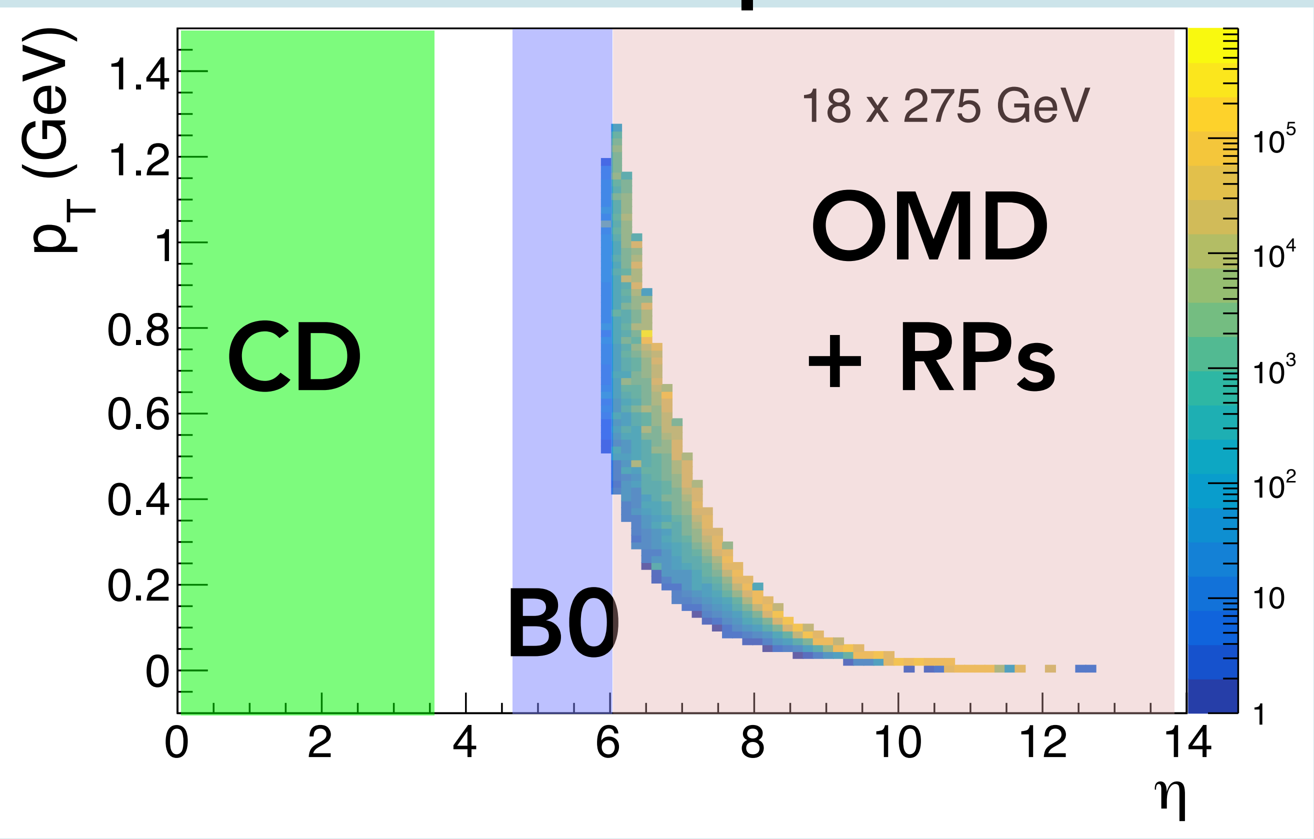
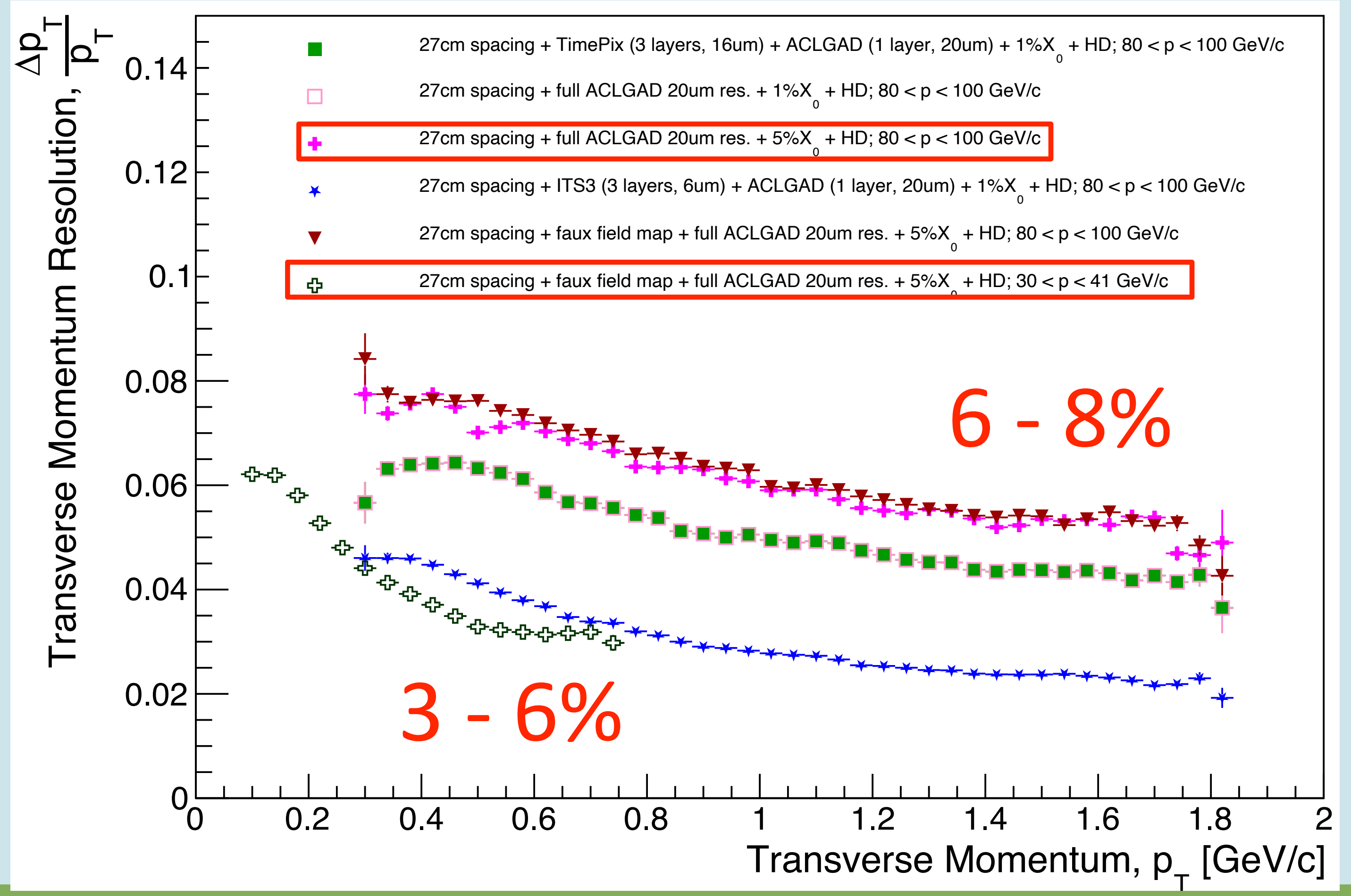
- RPs can detect 60 - 95% momentum, proton

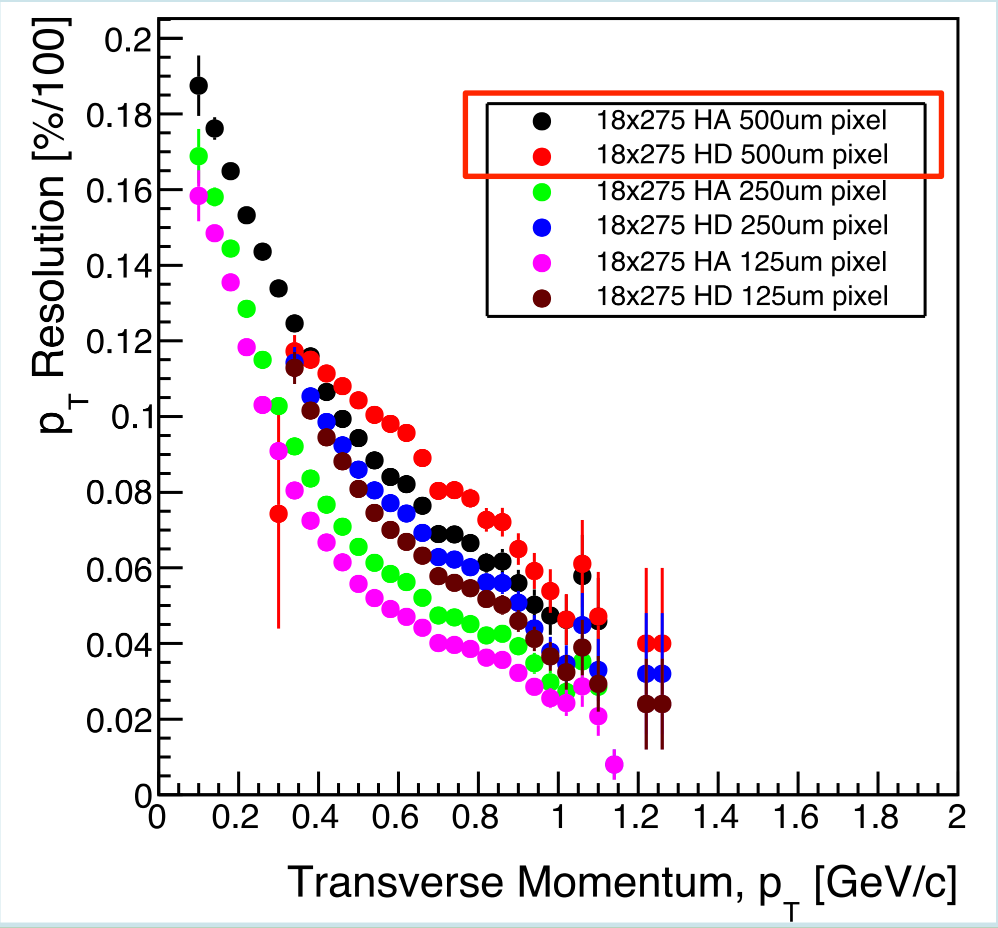
Scattered proton

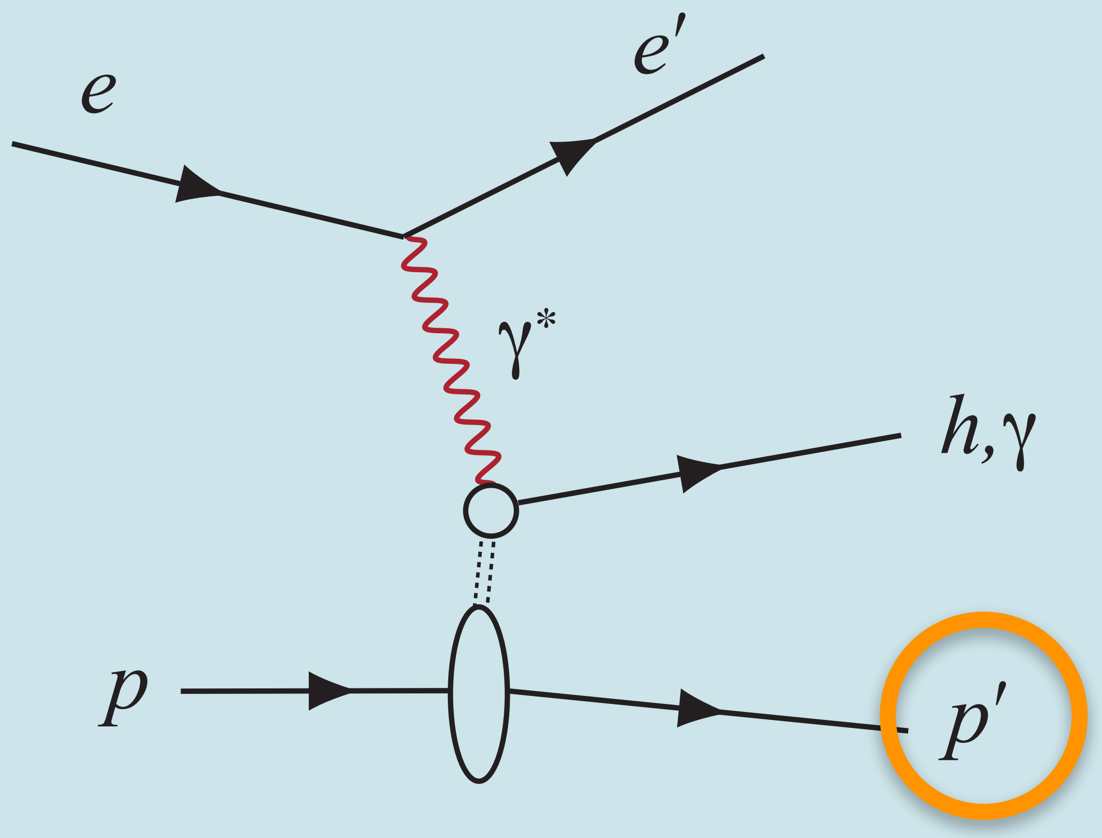


B0 tracking reso.



RPs/OMD trackingreso.

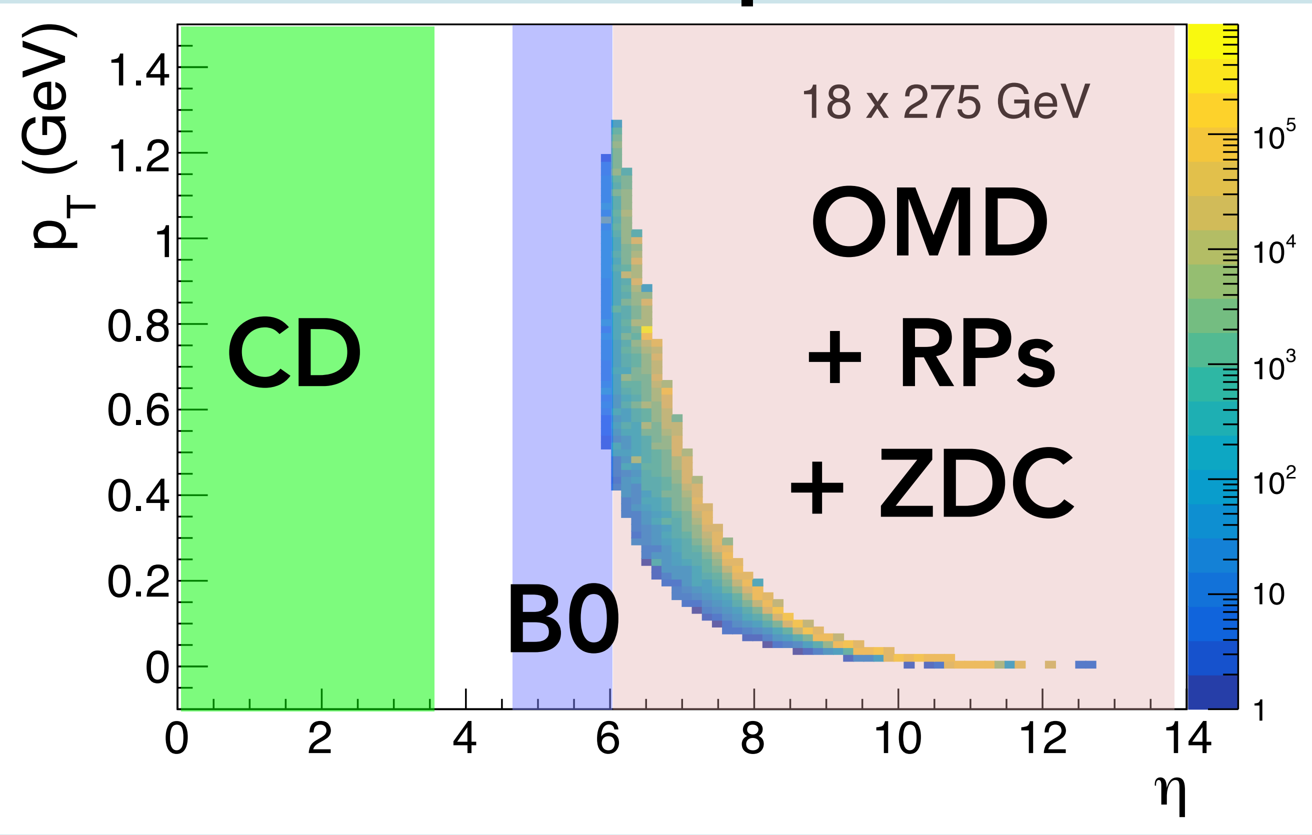




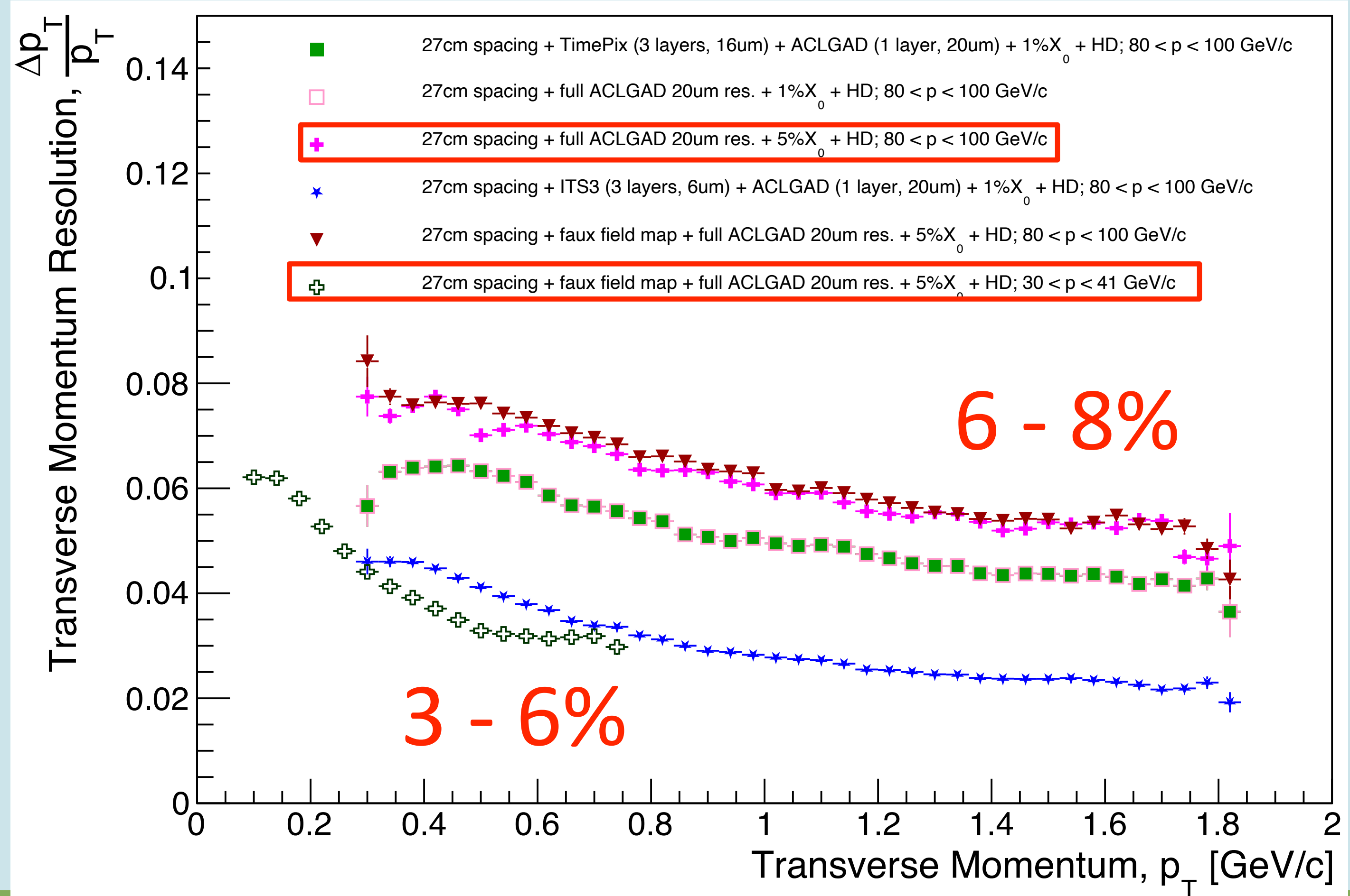
Far-Forward/Backward Detector Performance

- B0 detector can reconstruct charged particles and photons at 4.6<η<5.9 region by using a bending magnet
  - Parent particles can be reconstructed
- OMD can detect 40%~65% momentum proton w.r.t steering magnet
- RPs can detect 60 - 95% momentum, proton
- ZDC can detect neutron/photon

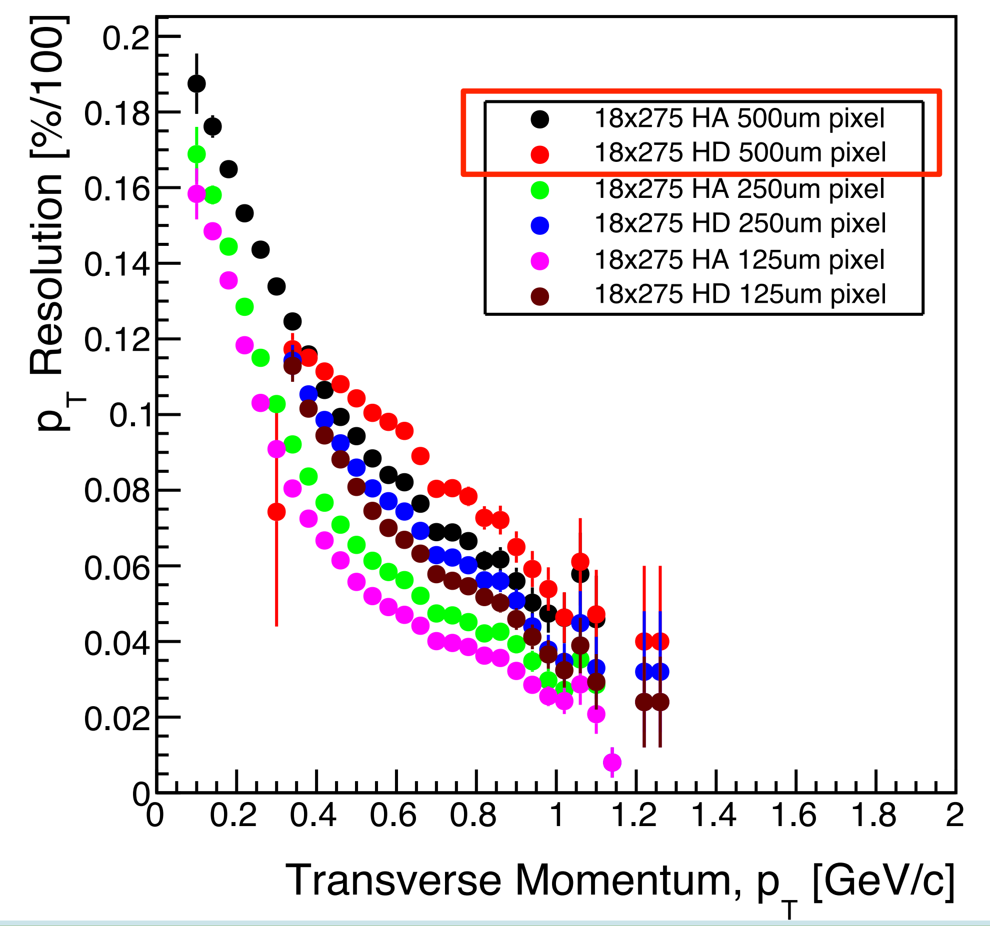
Scattered proton



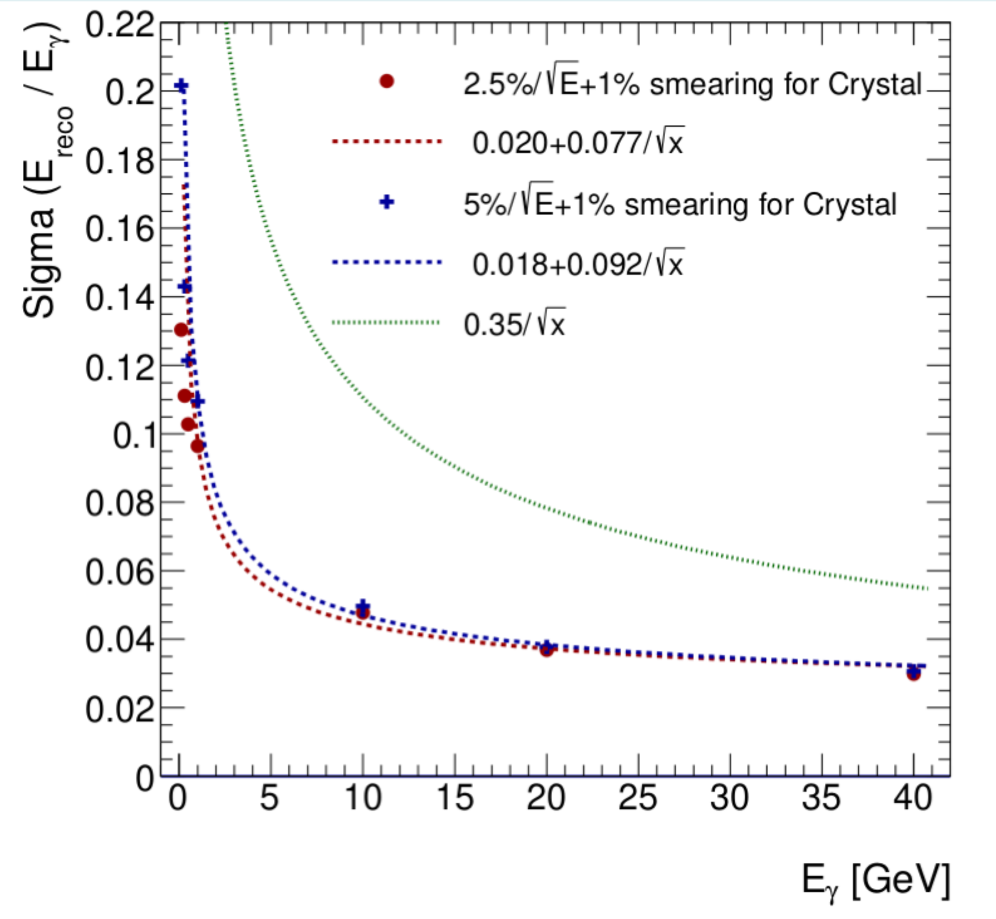
B0 tracking reso.



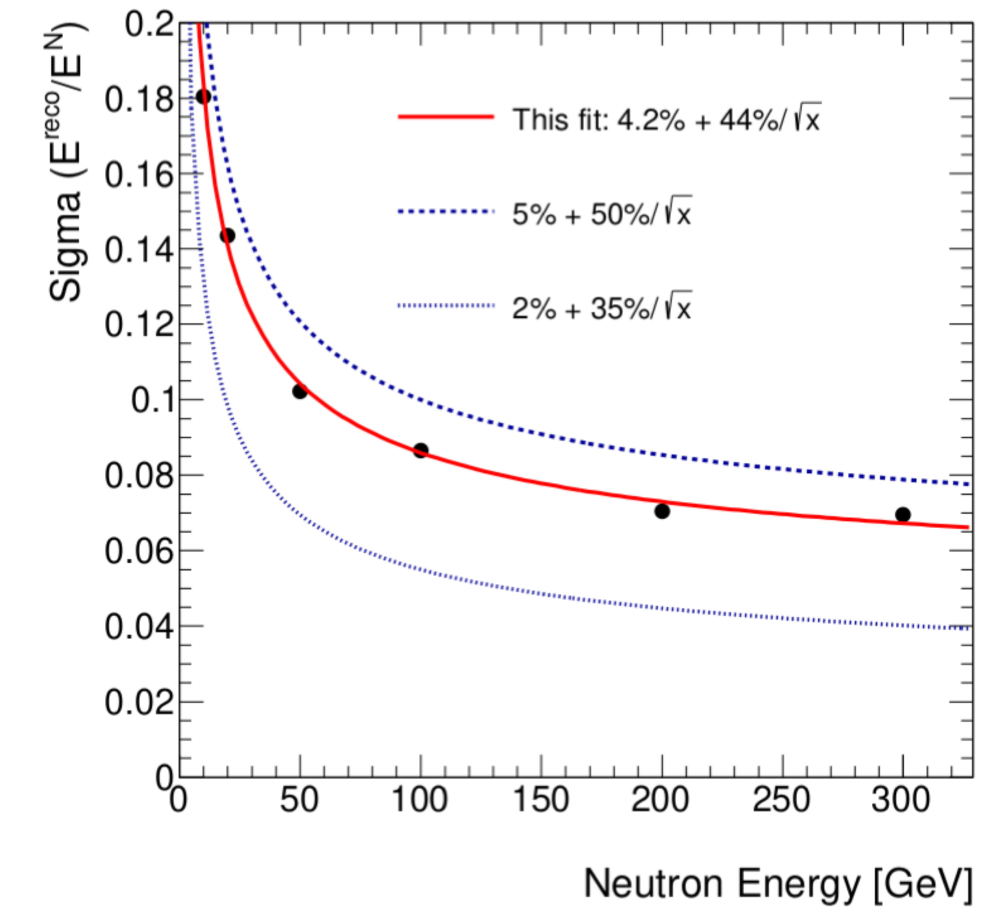
RPs/OMD trackingreso.

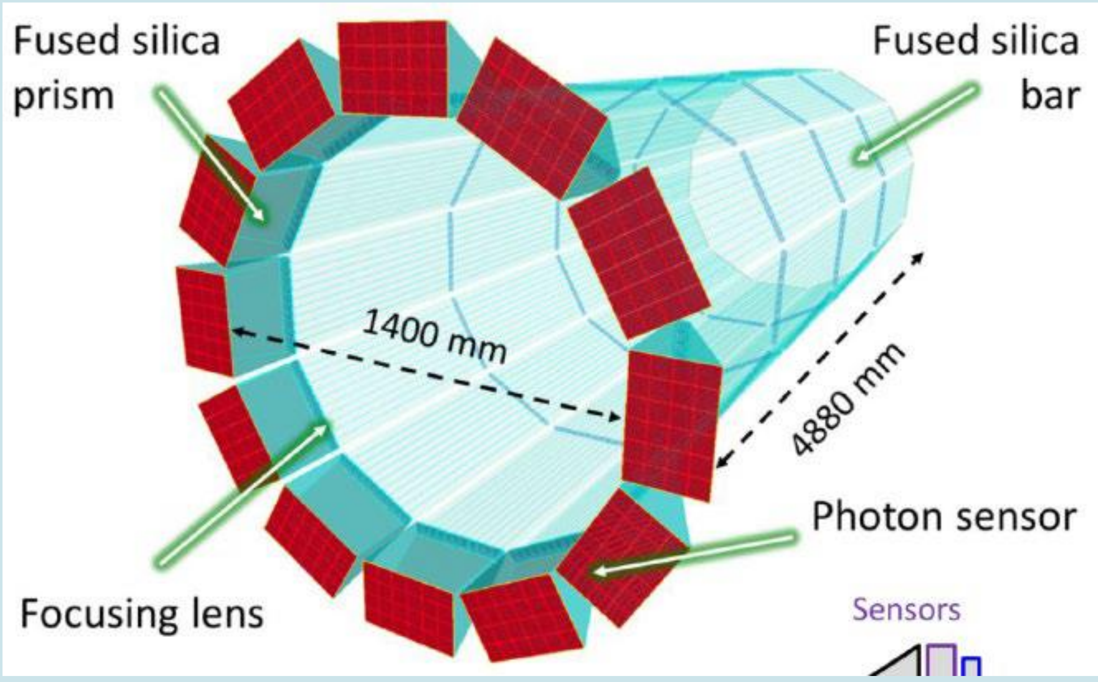


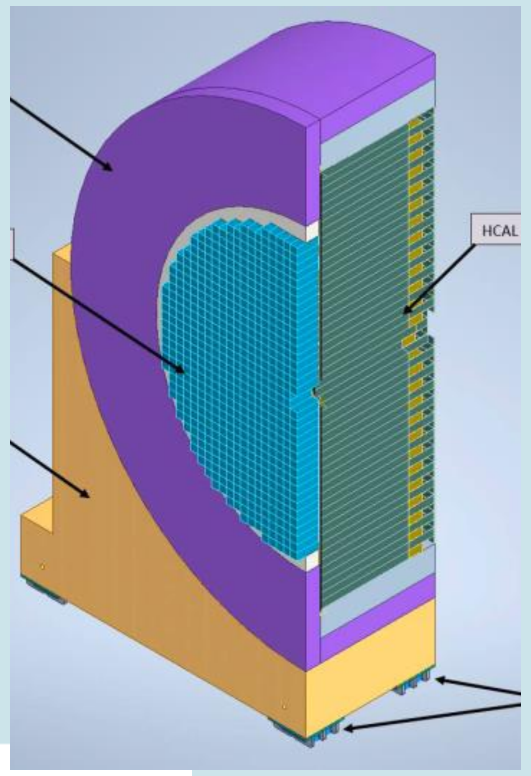
ZDC EMCal reso.

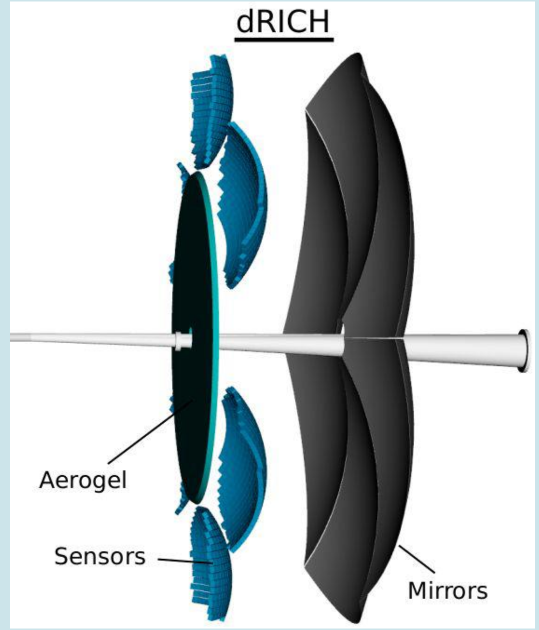


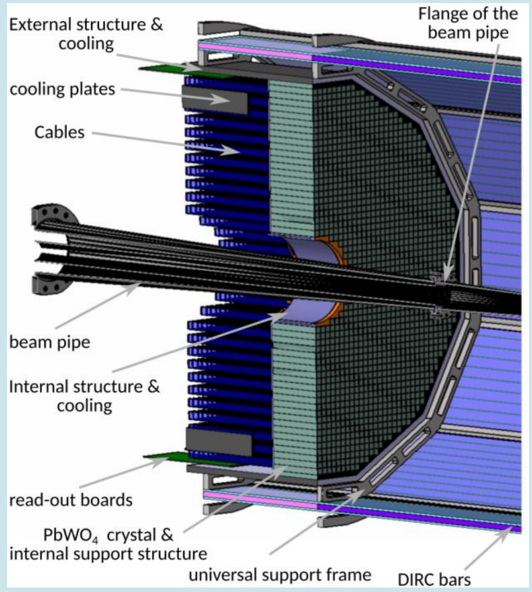
ZDC HCal reso.

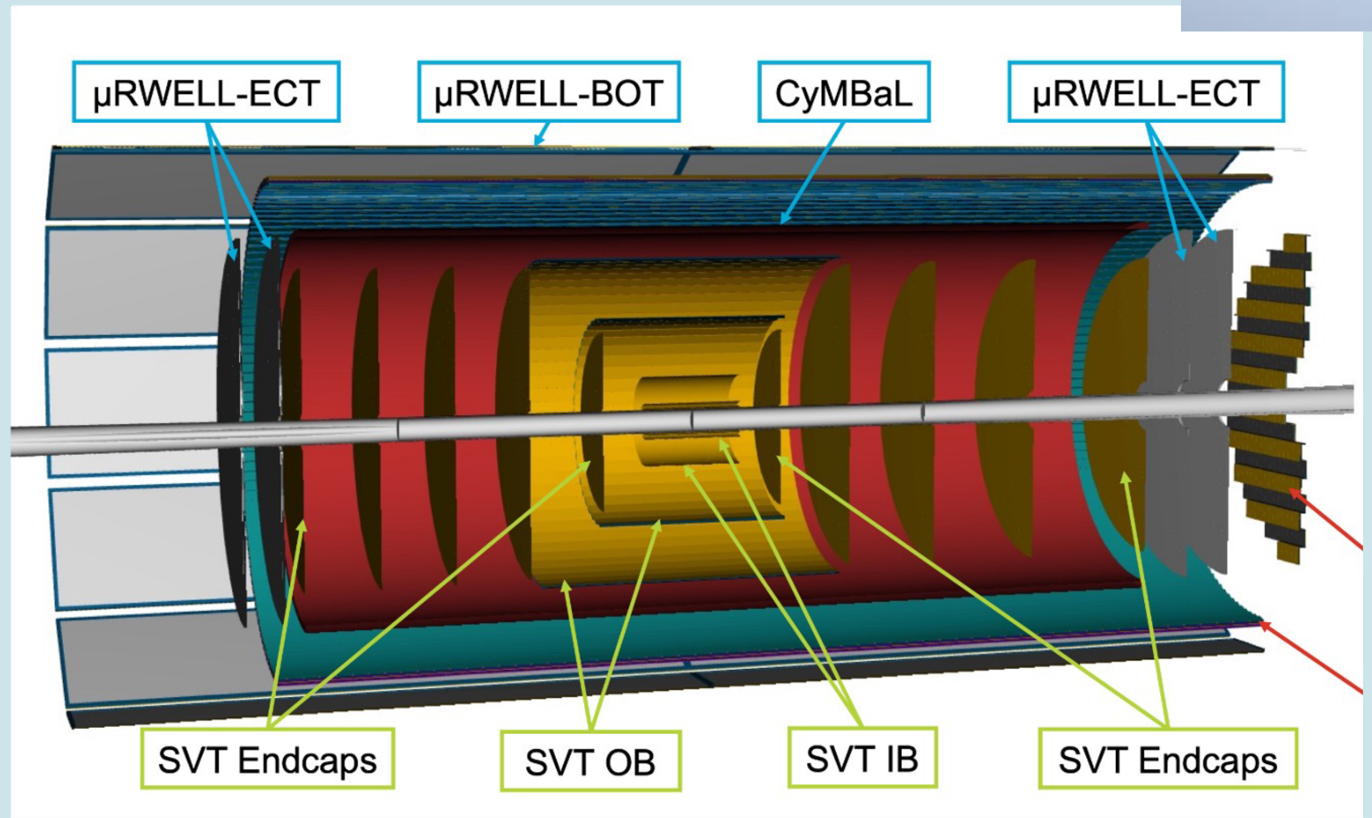


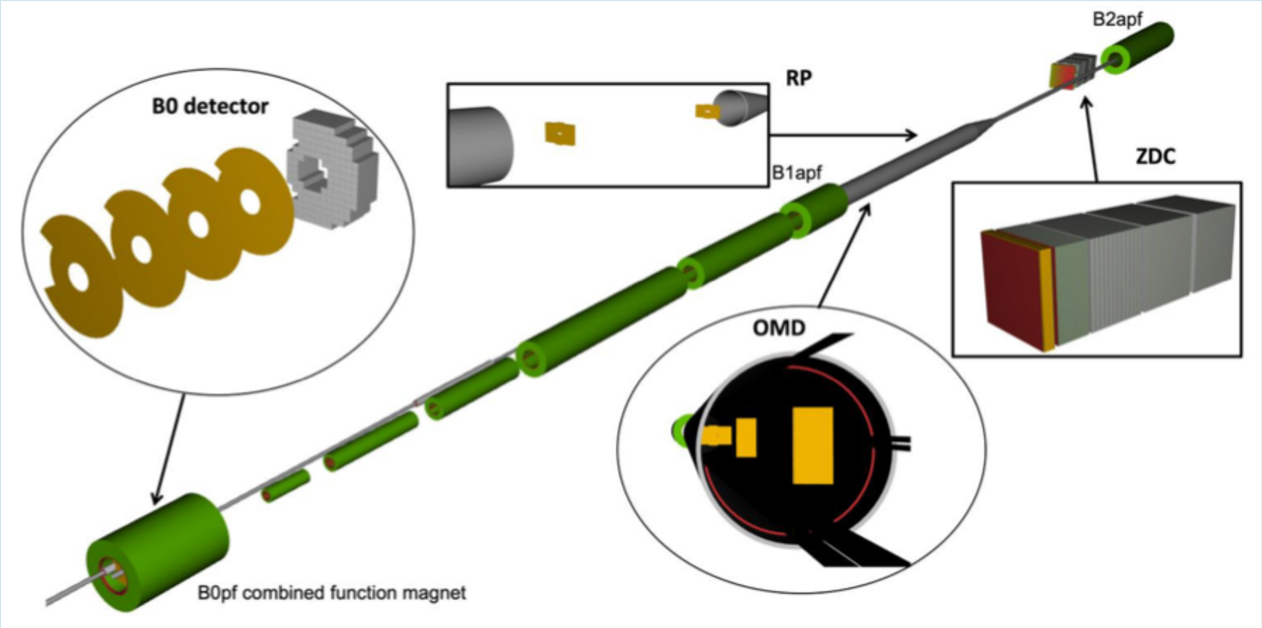

Fused silica prism
Fused silica bar
1400 mm
4880 mm
Photon sensor
Focusing lens
Sensors

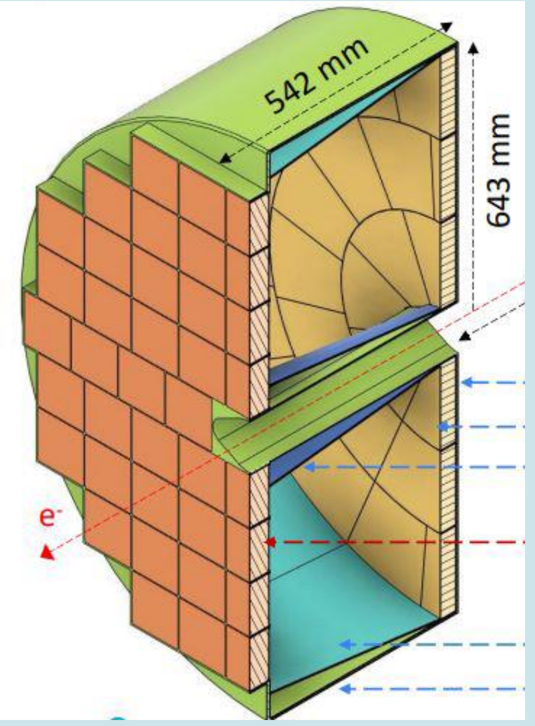

HCAL

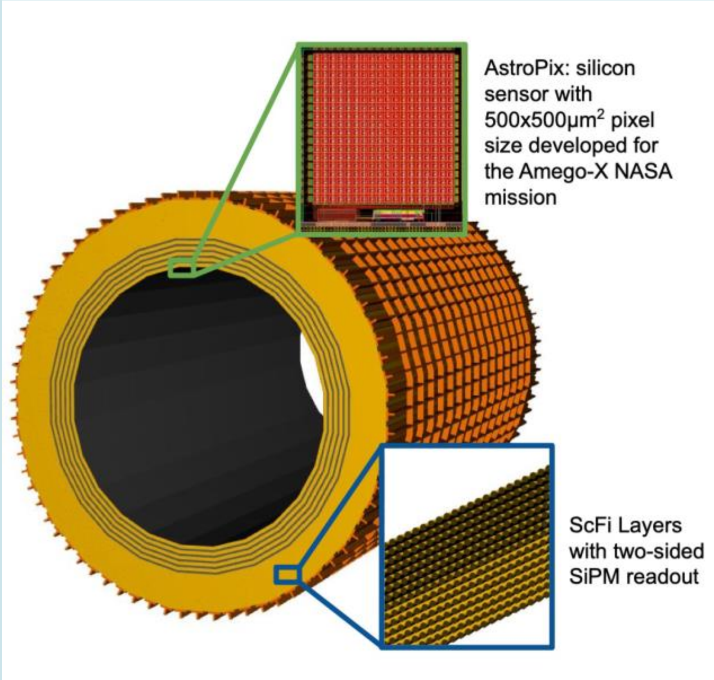

dRICH
Aerogel
Sensors
Mirrors

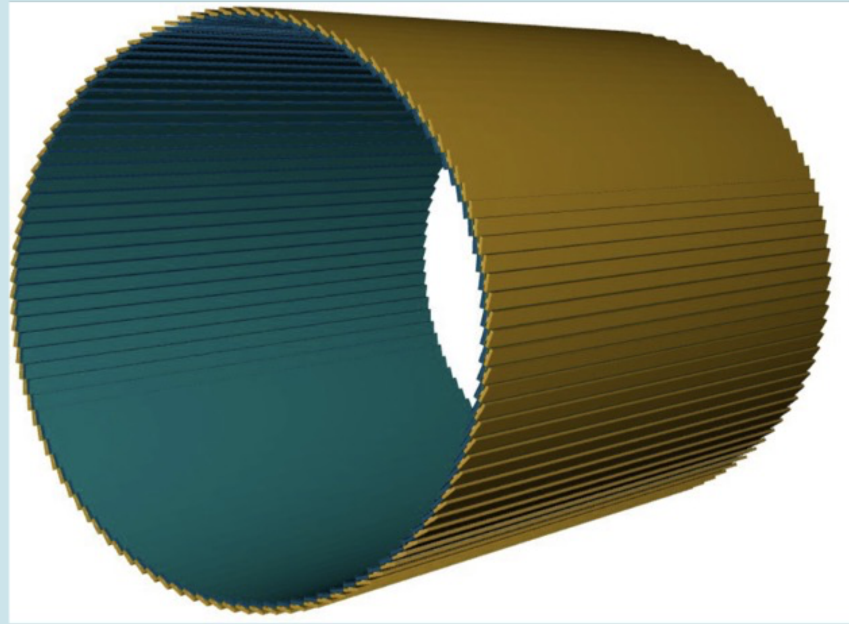

External structure & cooling
Flange of the beam pipe
cooling plates
Cables
beam pipe
Internal structure & cooling
read-out boards
$PbWO_4$ crystal & internal support structure
universal support frame
DIRC bars

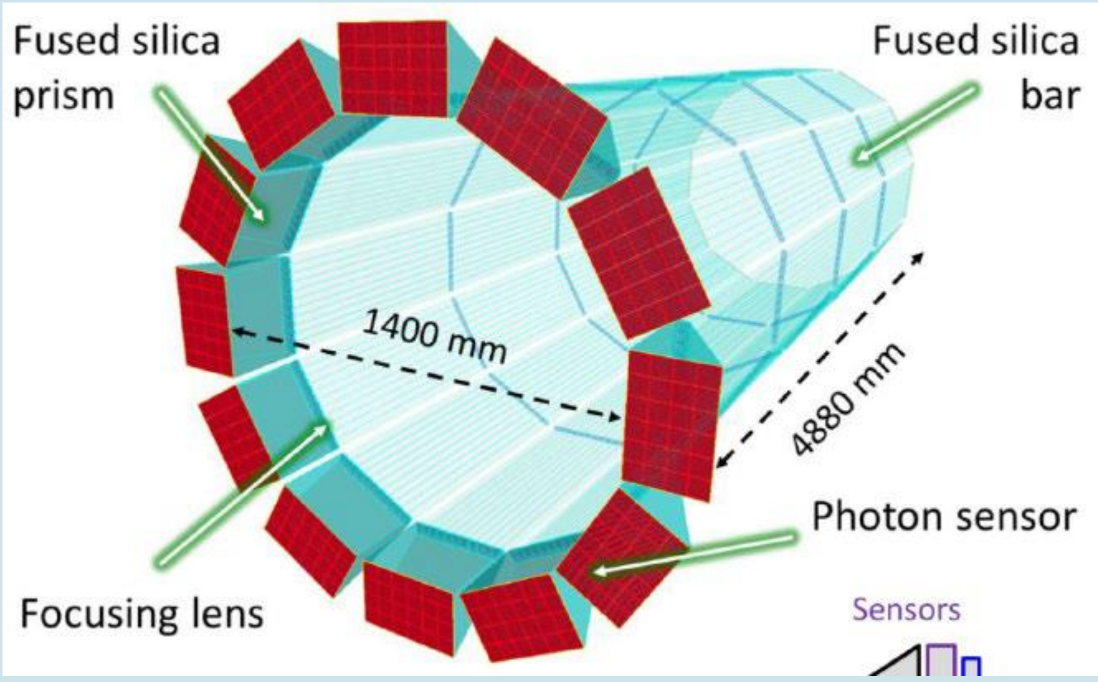

μRWELL-ECT
μRWELL-BOT
CyMBaL
μRWELL-ECT
SVT Endcaps
SVT OB
SVT IB
SVT Endcaps

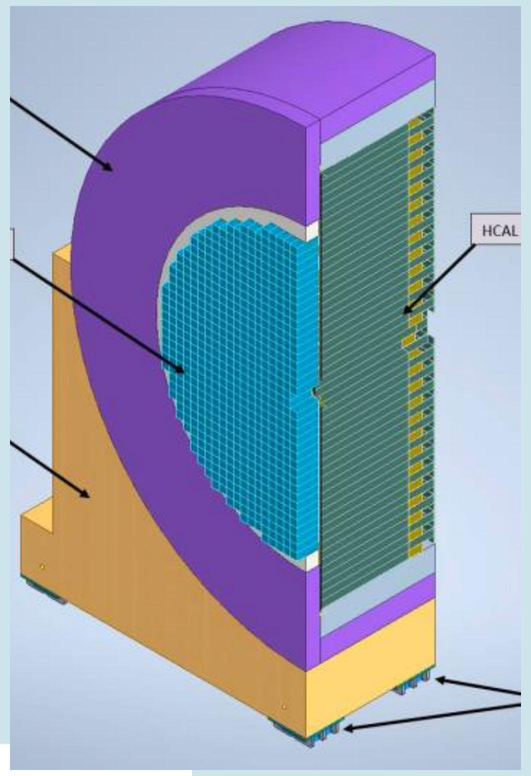

B0 detector
RP
B1apf
B2apf
ZDC
OMD
B0pf combined function magnet

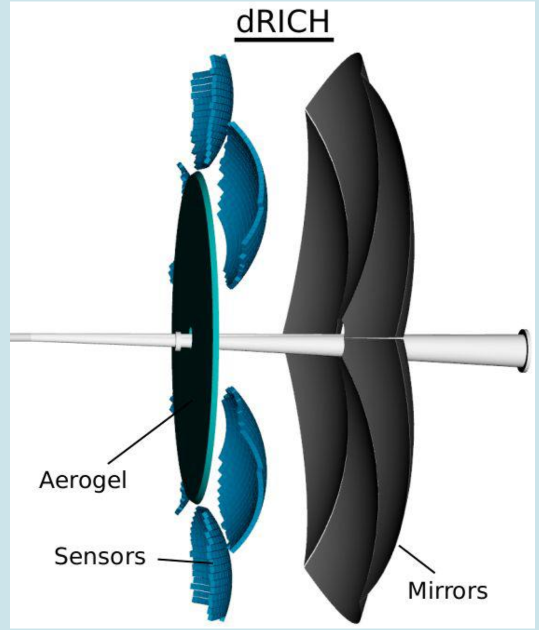

542 mm
643 mm
e⁻

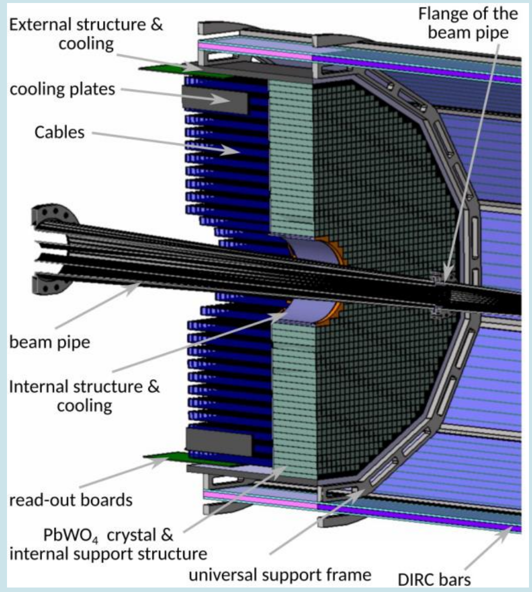

AstroPix: silicon sensor with 500x500μm² pixel size developed for the Amego-X NASA mission
ScFi Layers with two-sided SiPM readout

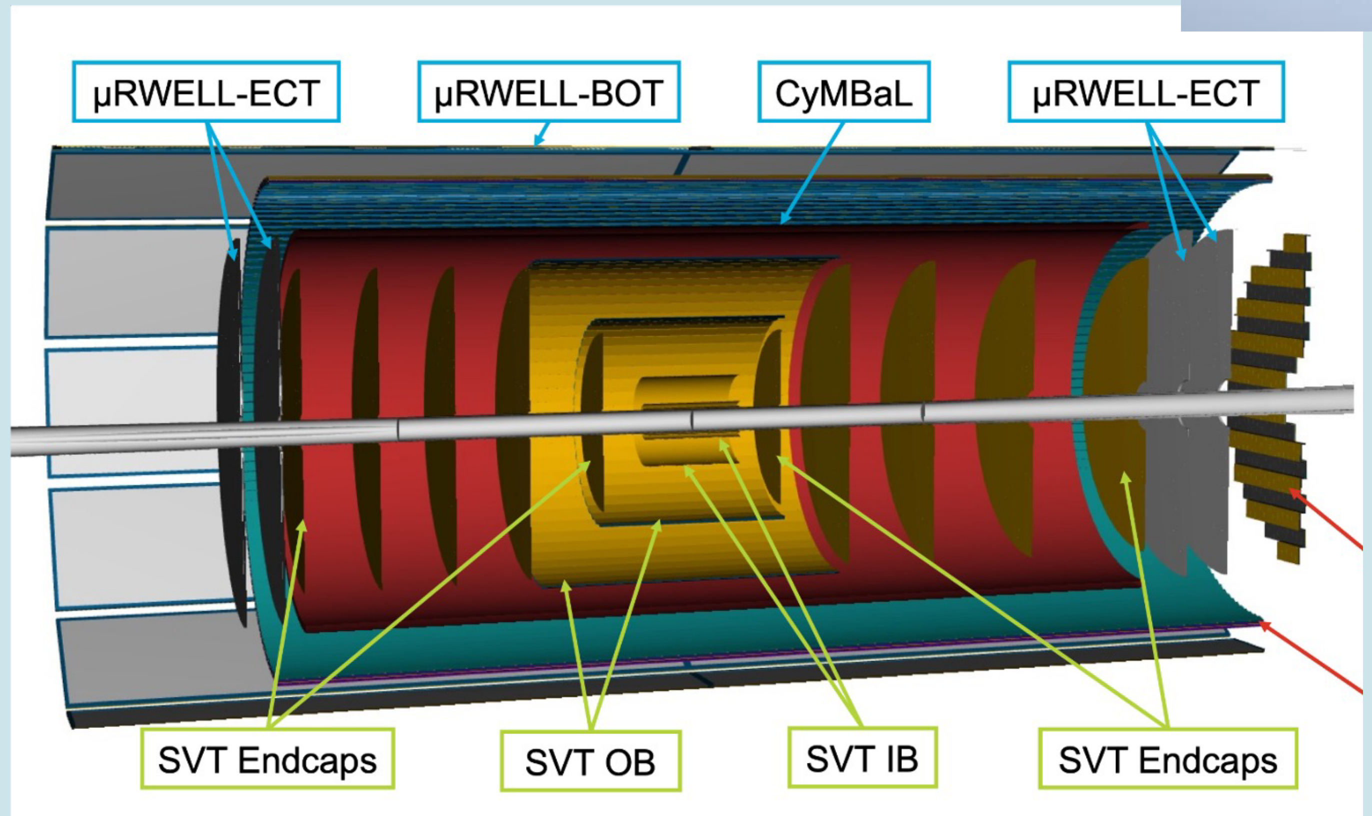


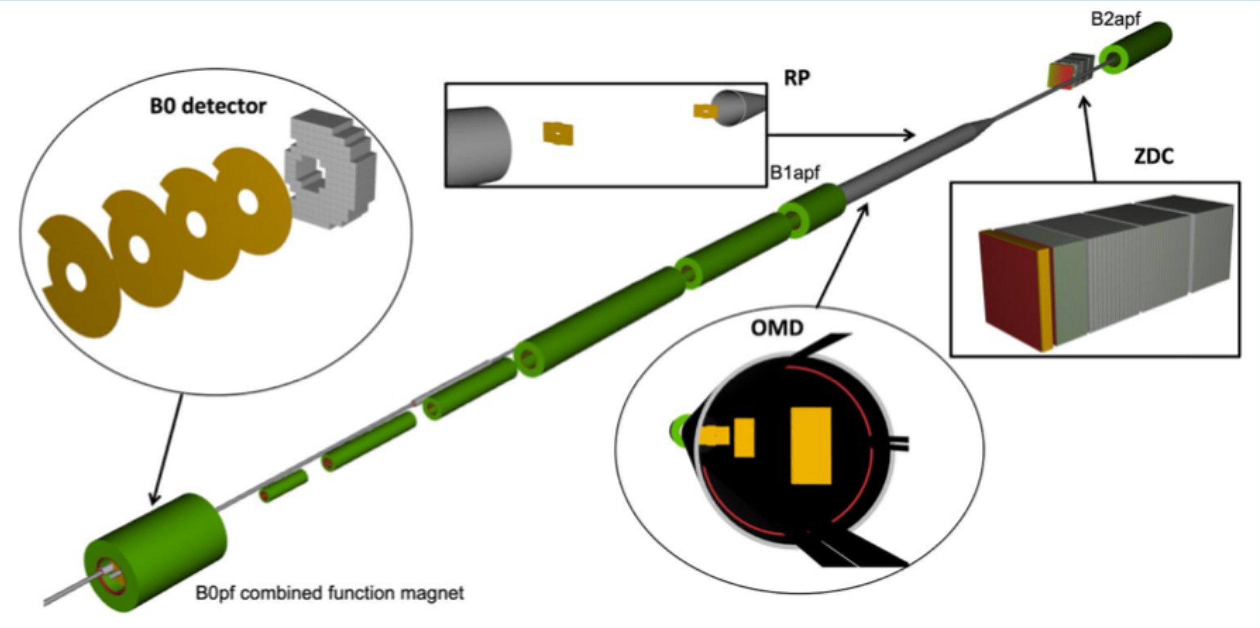


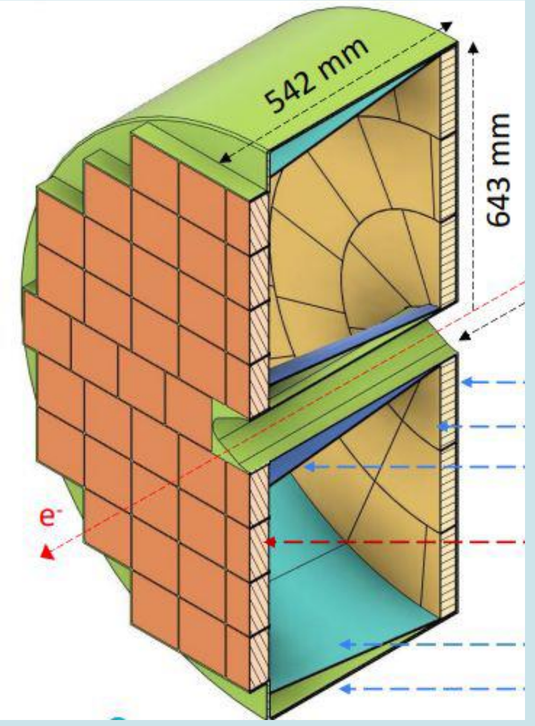


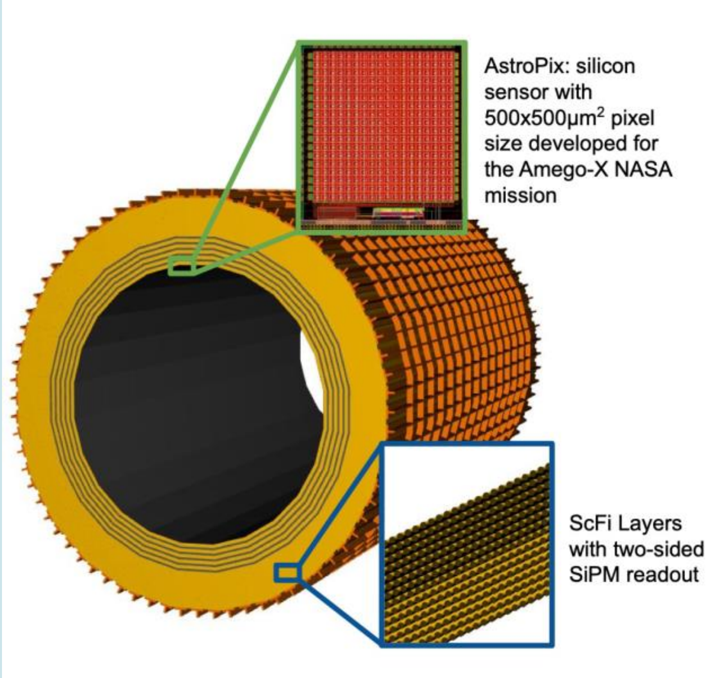


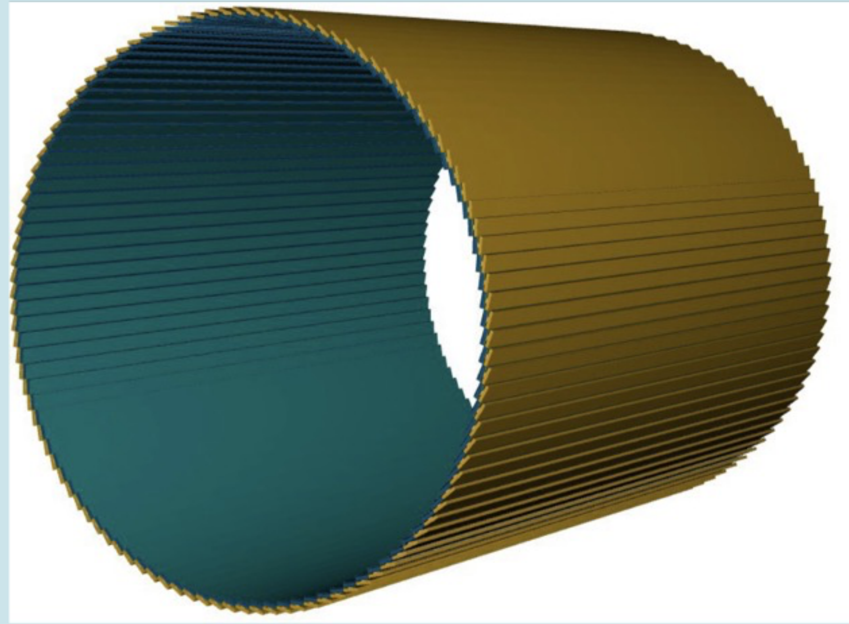








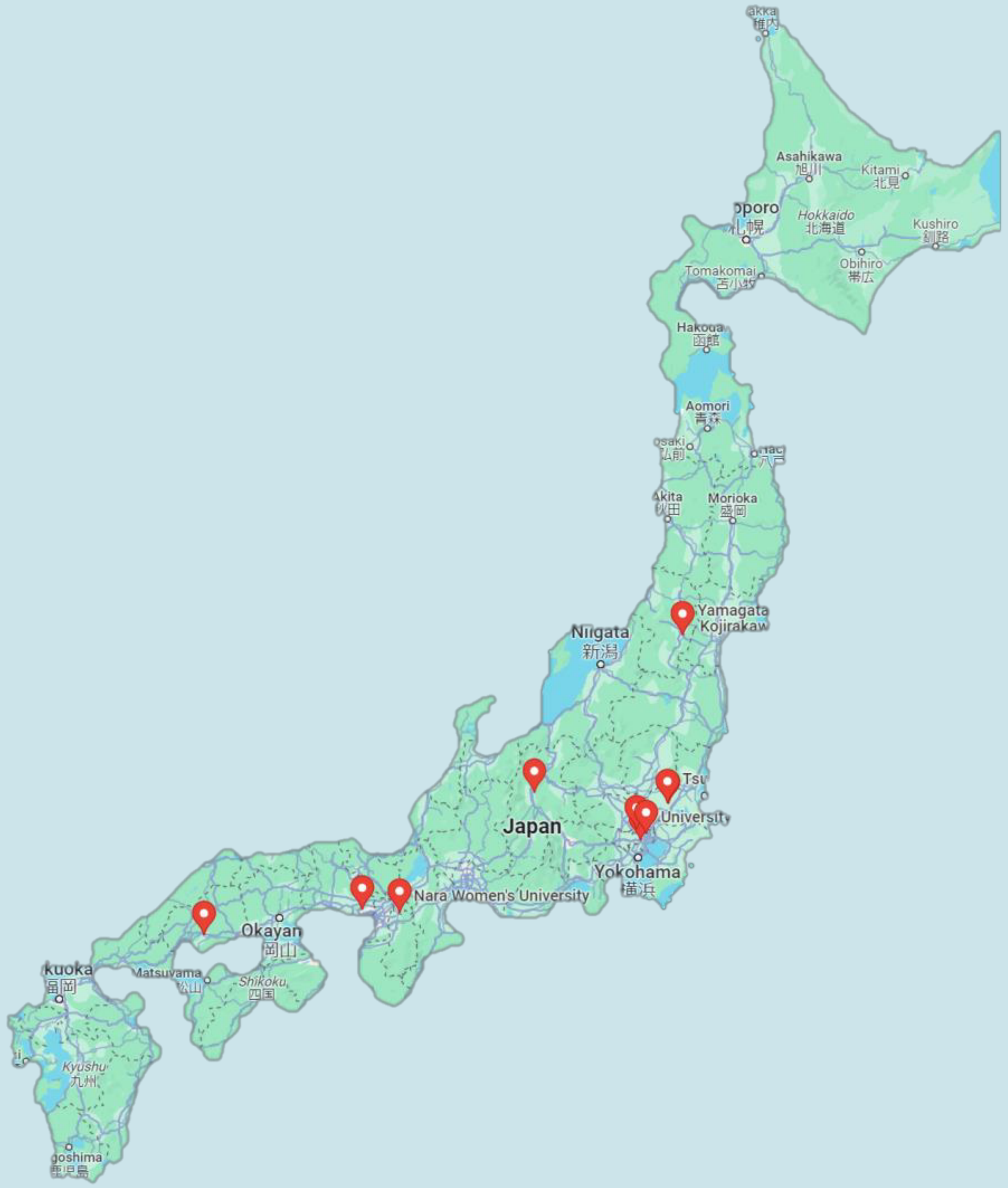




The ePIC detector is a masterpiece of semi-conductor technology = “nanotechnology”

ePIC-Japan team

- **Member institutes in Japan**
  - Nucleon structure
    - Yamagata University
    - RIKEN
    - Nihon University
  - High-energy nuclear physics
    - University of Tsukuba
    - University of Tokyo
    - Nara Woman's University
    - Hiroshima University
  - High-energy particle physics
    - Shinshu University
    - Kobe University
  - Data acquisition
    - SPADI-Alliance



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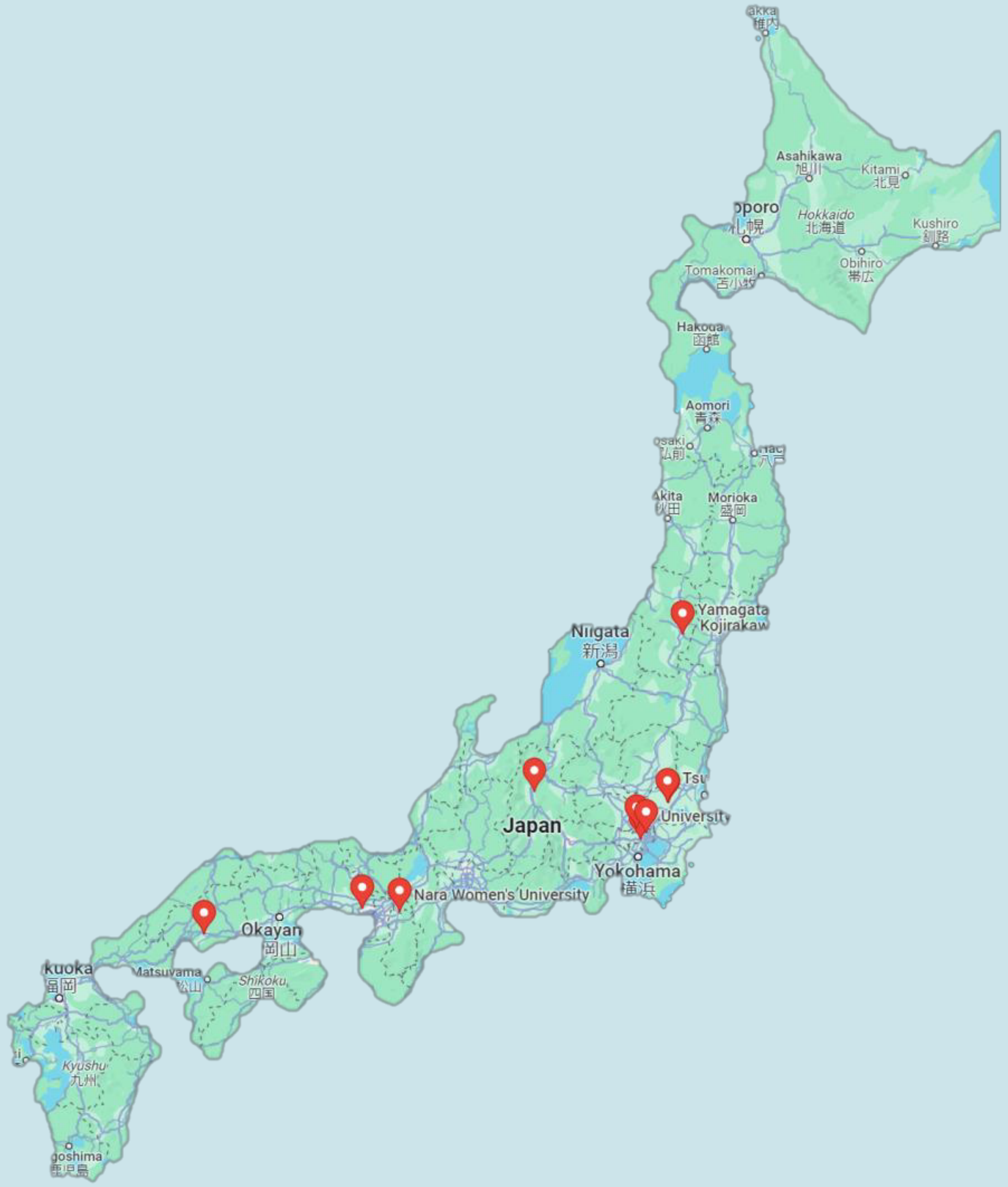
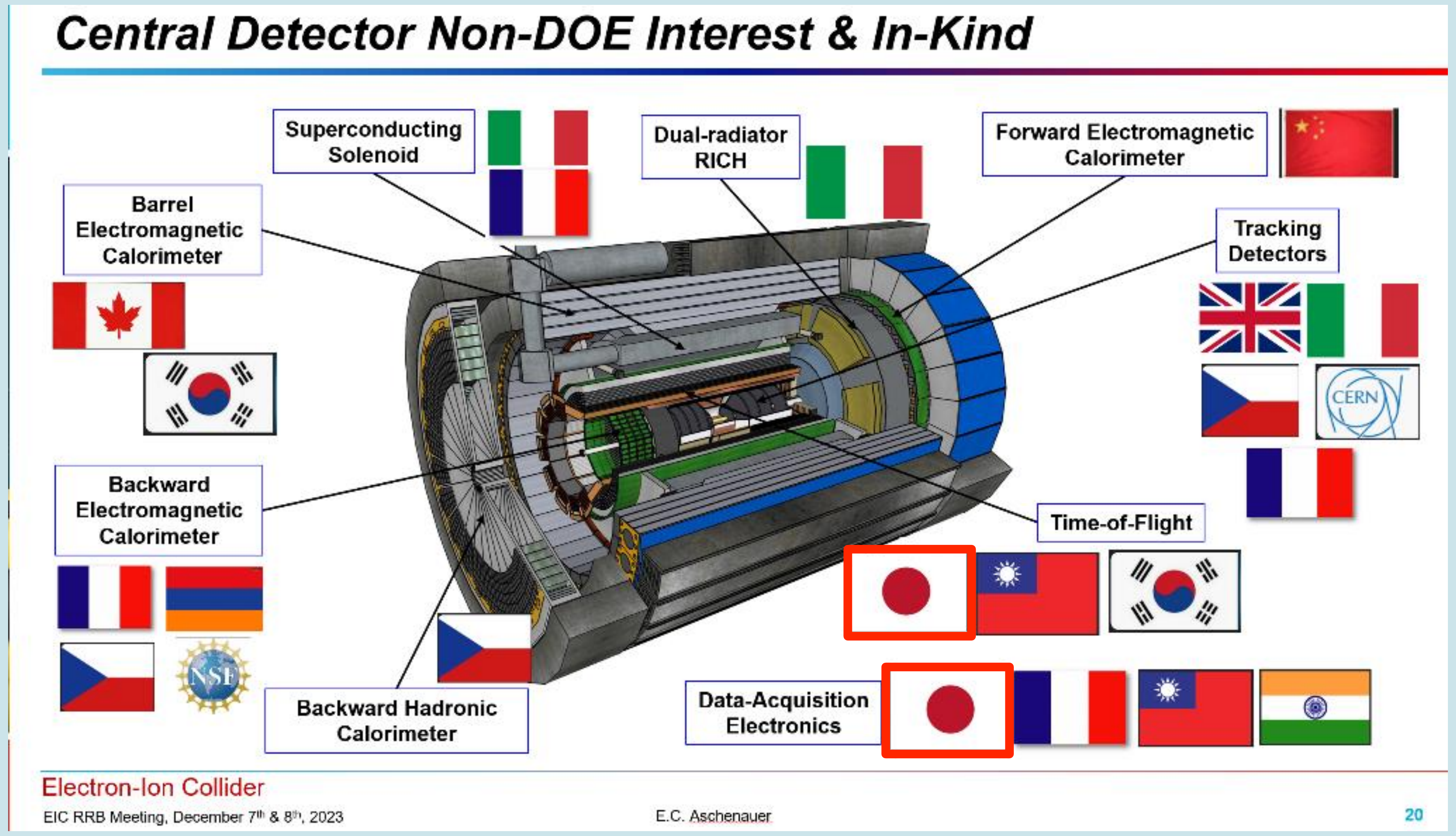
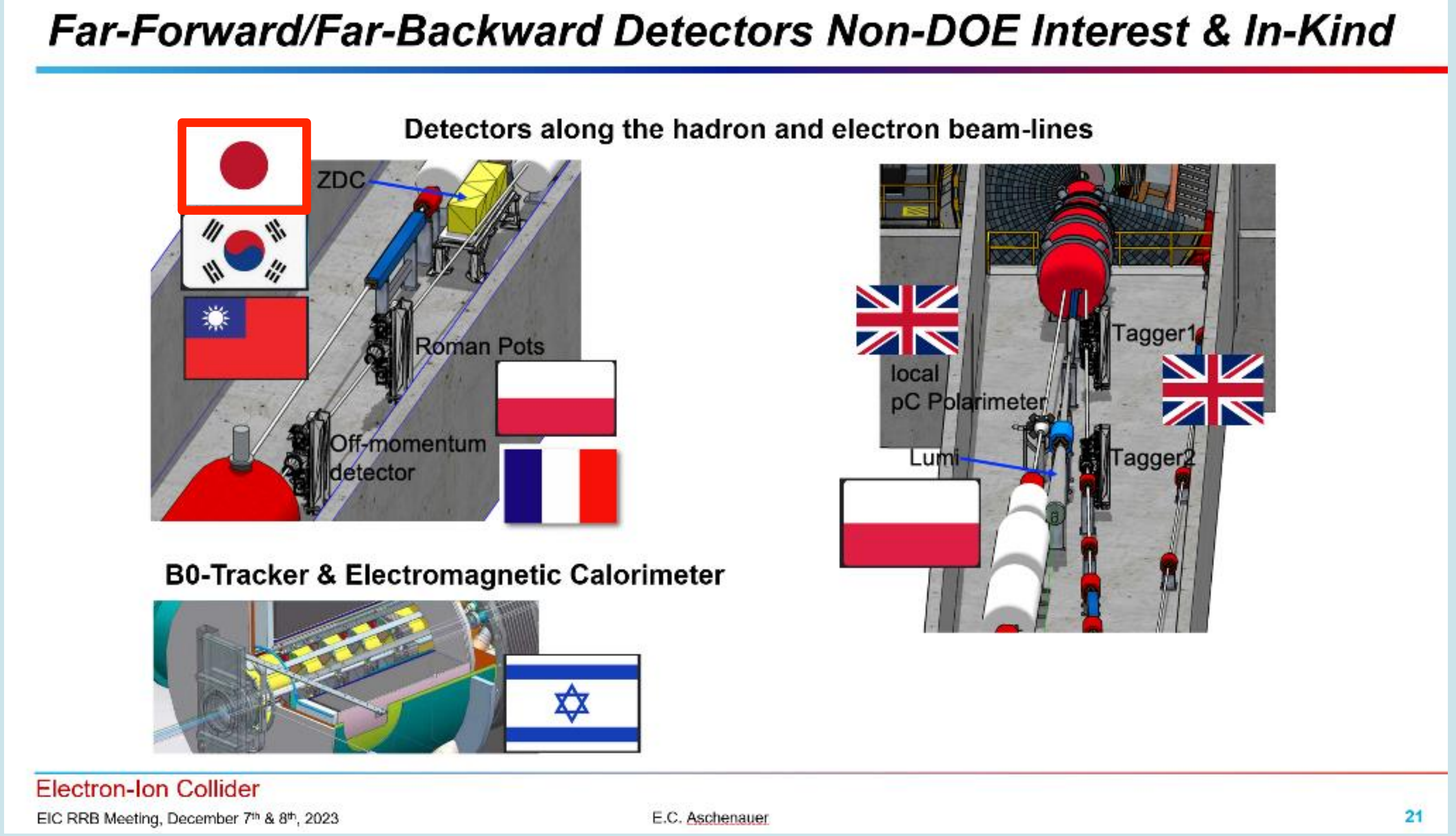


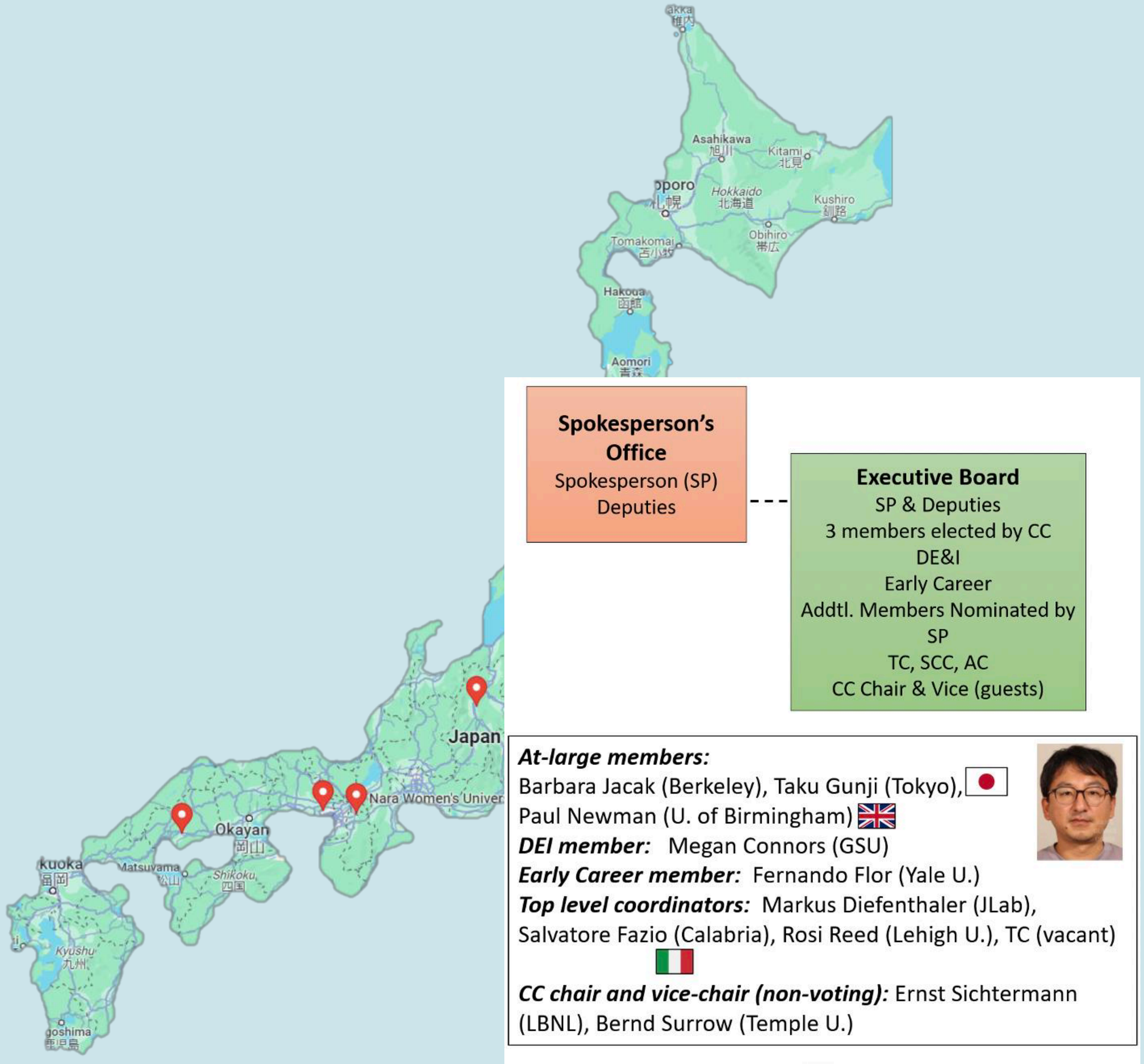


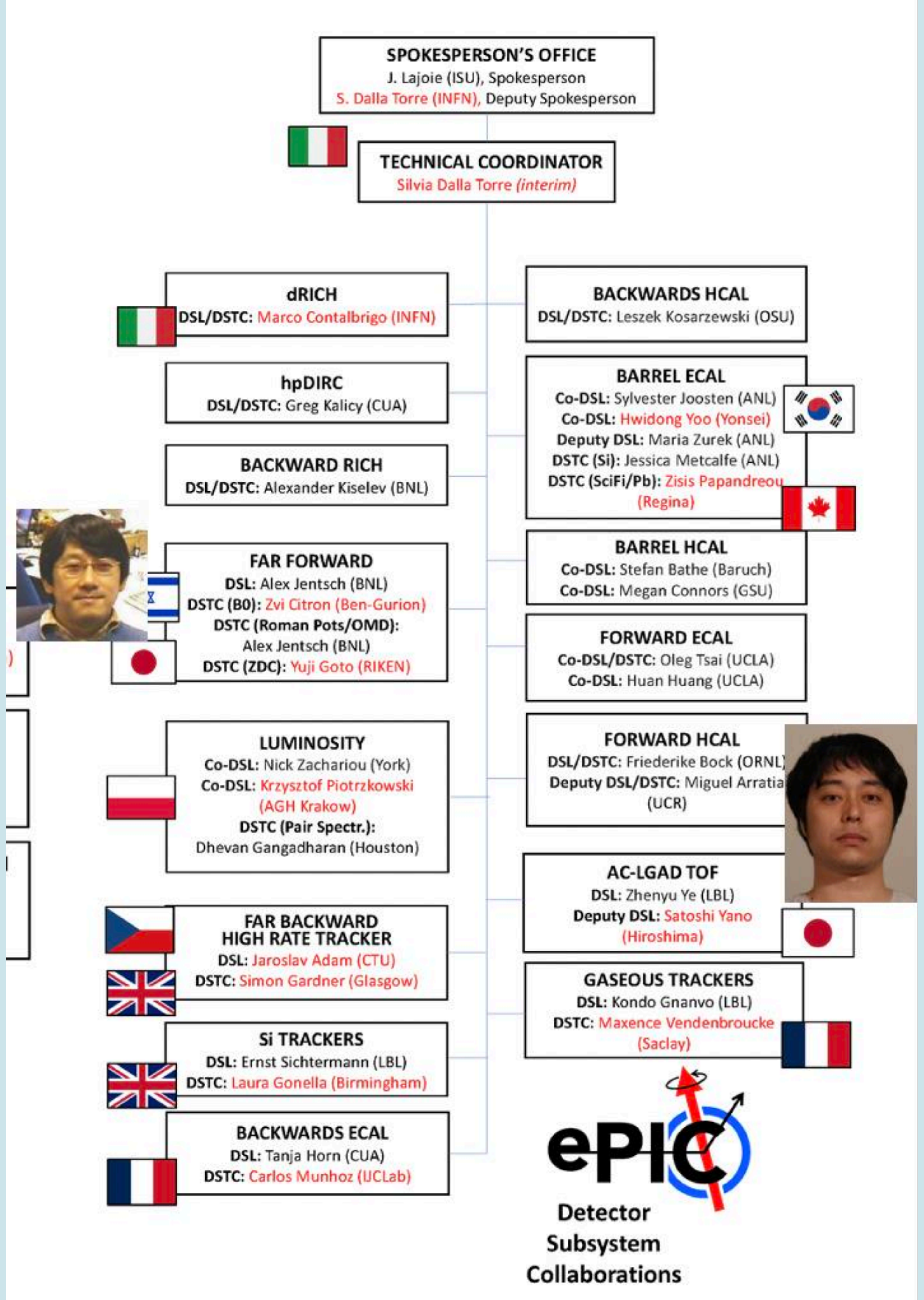


Japanese team is involved in AC-LGAD TOF, ZDC, and Data Acquisition

ePIC-Japan team

- **Member institutes in Japan**
  - Nucleon structure
    - Yamagata University
    - RIKEN
    - Nihon University
  - High-energy nuclear physics
    - University of Tsukuba
    - University of Tokyo
    - Nara Woman's University
    - Hiroshima University
  - High-energy particle physics
    - Shinshu University
    - Kobe University
  - Data acquisition
    - SPADI-Alliance





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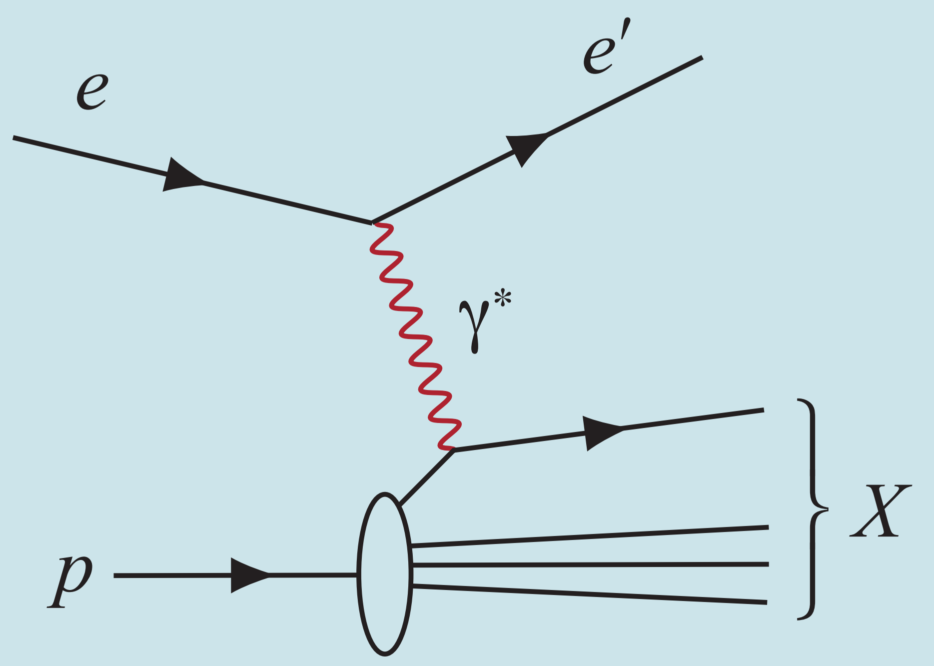
The EIC is a significant experiment that will satisfy our intellectual curiosity and create a new era for mankind!

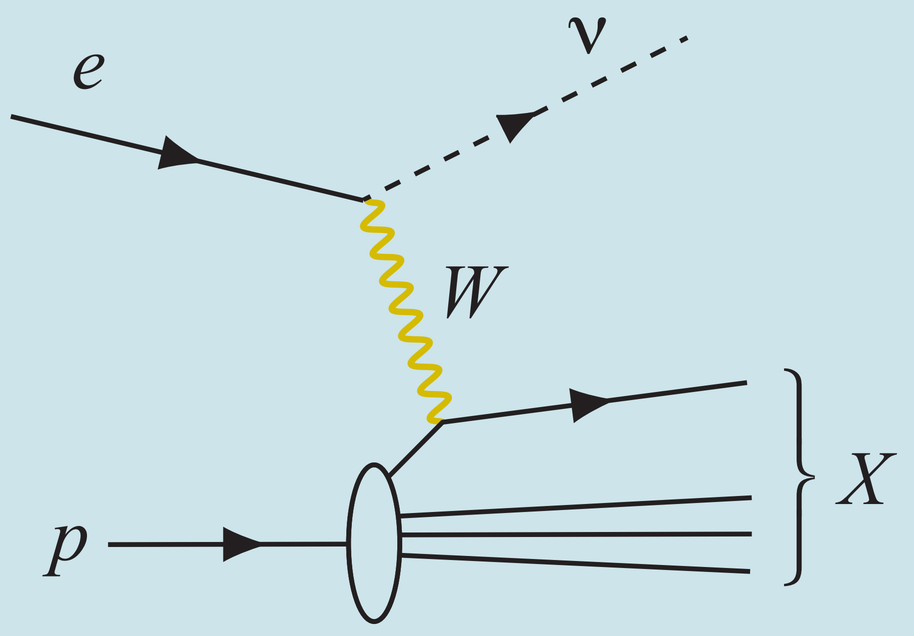
Thank you!

Experimental Process to Access EIC Physics



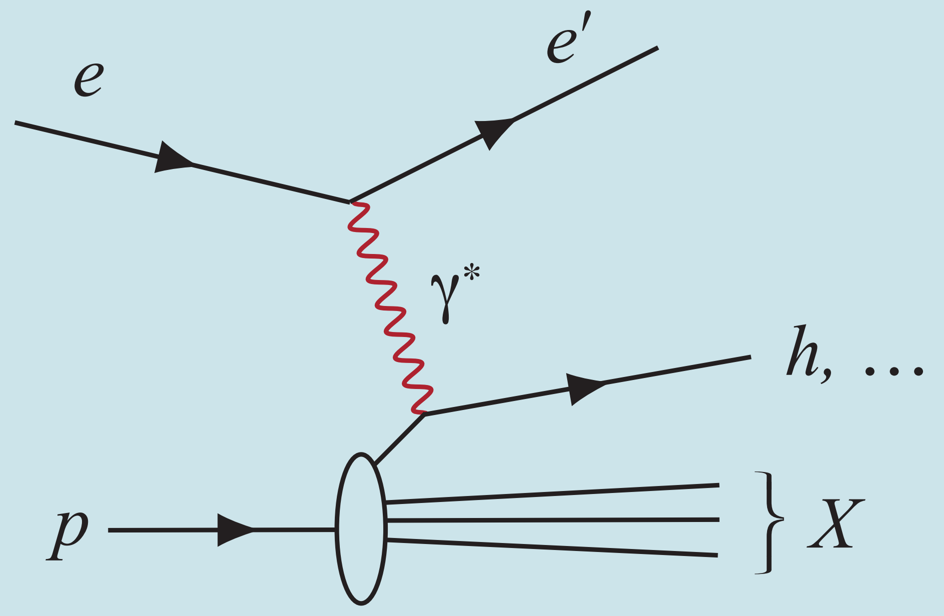
Neutral Current DIS

Detection of scattered electron with high-precision event kinematics



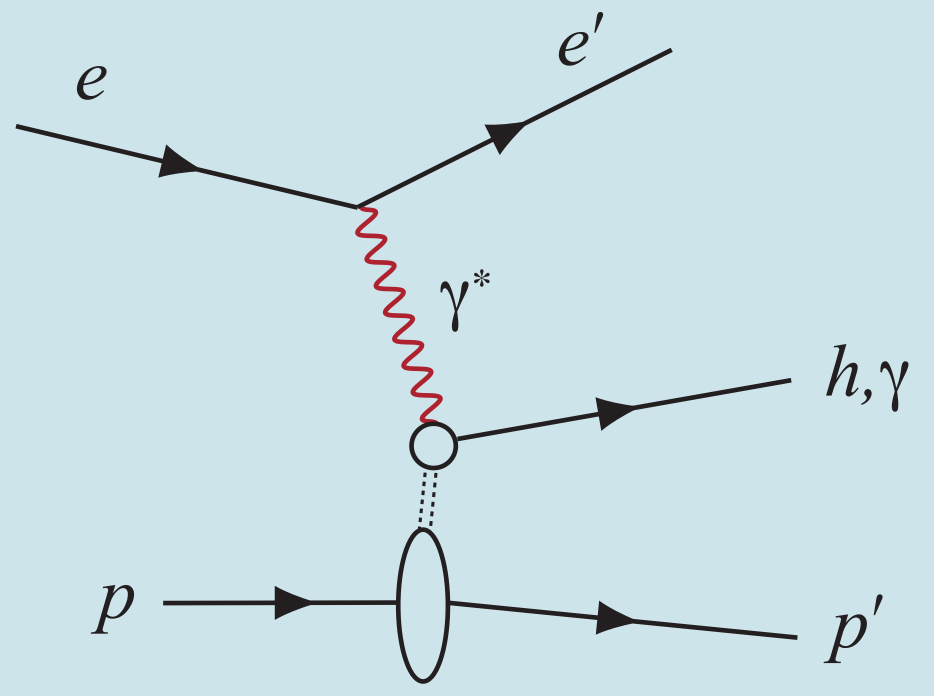
Charged Current DIS

Event kinematic from final state particles (Jacquet-Blondel method)



Semi-Inclusive DIS

Precise detection of scattered electron in coincidence with at the least 1 hadron



Deep Exclusive DIS

Detect all particles in event

Parton Distributions in nucleons and nuclei

QCD at Extreme Parton Densities - Saturation

Spin and Flavor Structure of nucleons and nuclei

Tomography Transverse Momentum Dist.

QCD at Extreme Parton Densities - Saturation

Tomography Spatial Imaging

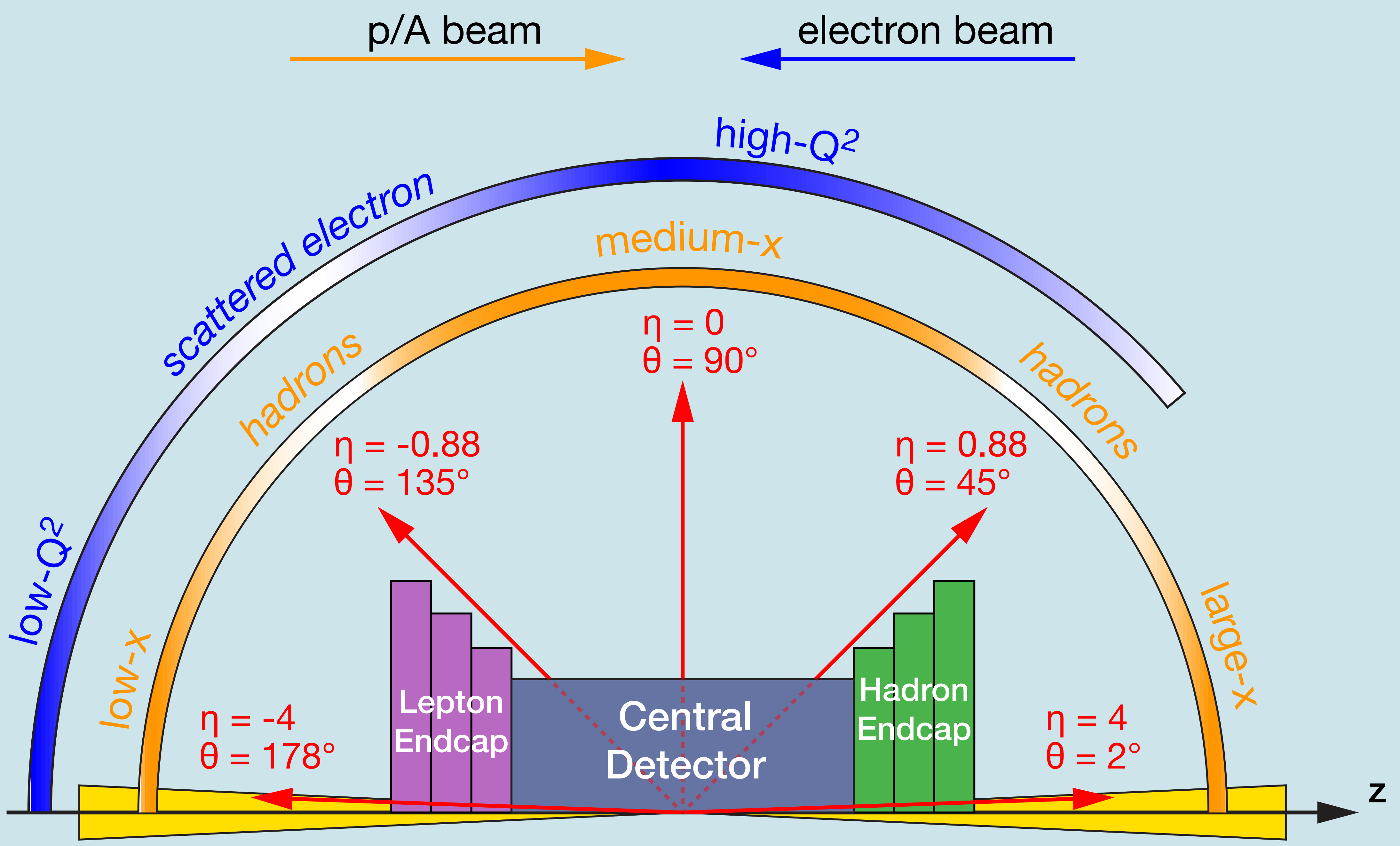
$\sim 1 \text{ fb}^{-1}$

$\sim 10 \text{ fb}^{-1}$

$\sim 100 \text{ fb}^{-1}$

Requirements for an EIC detector

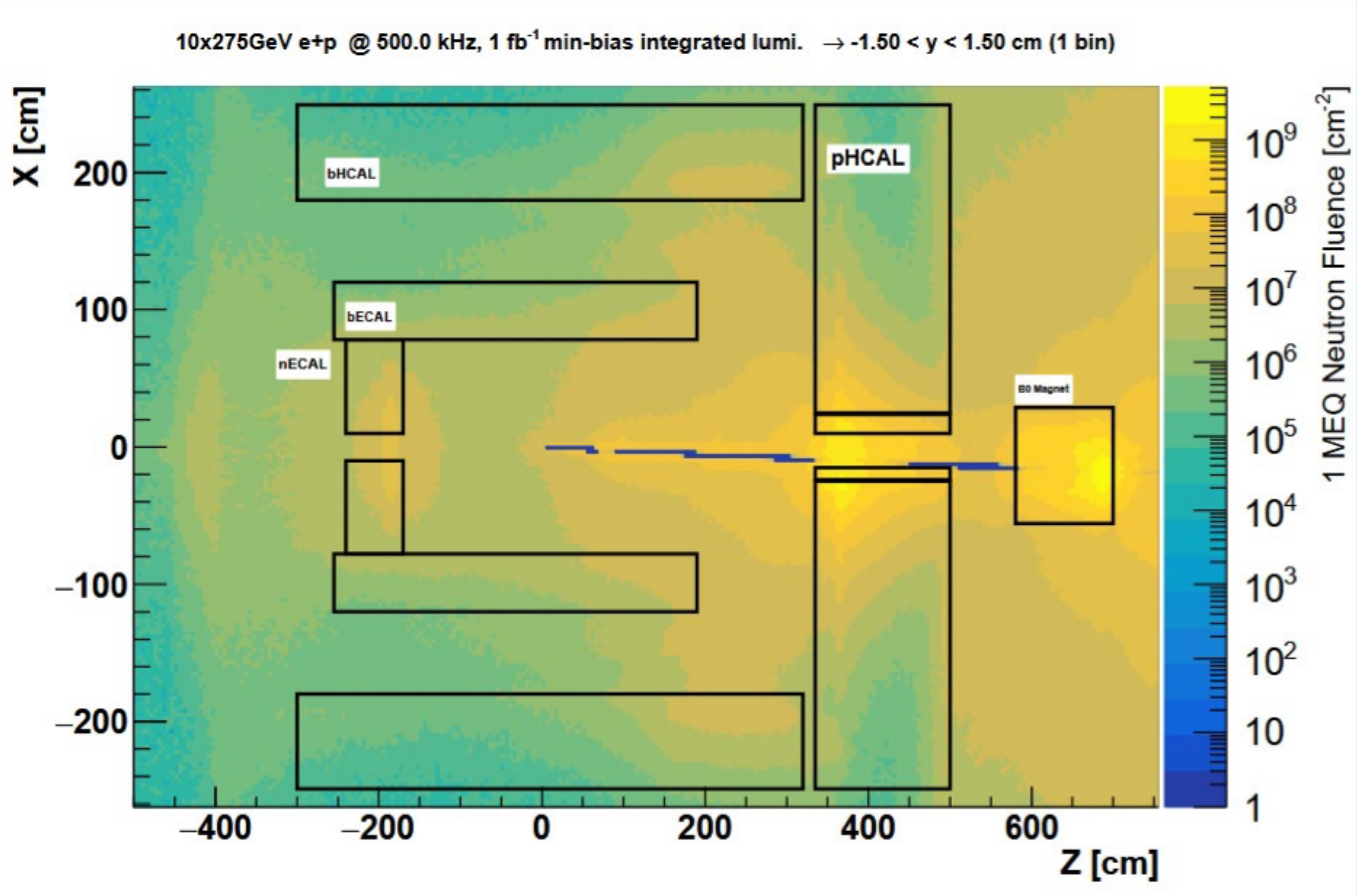
- Precise primary and secondary vertex determination
  - Heavy flavor hadron and hyperon reconstruction
- Precise low-mass tracking at an extensive range
  - Good low momentum resolution
- Particle identification at an extensive range
  - π / K / p separation
- High-resolution EMCal covering a very wide rapidity region
  - Scattered electron identification and kinematic determination
- Reasonable resolution HCal covering a very wide rapidity region
  - Neutral hadron, n / K^0_L identification for PFA (full jet reco.)
- Far-Forward and Far-Backward detectors
  - Large acceptance for diffraction, tagging neutrons from nuclear breakup

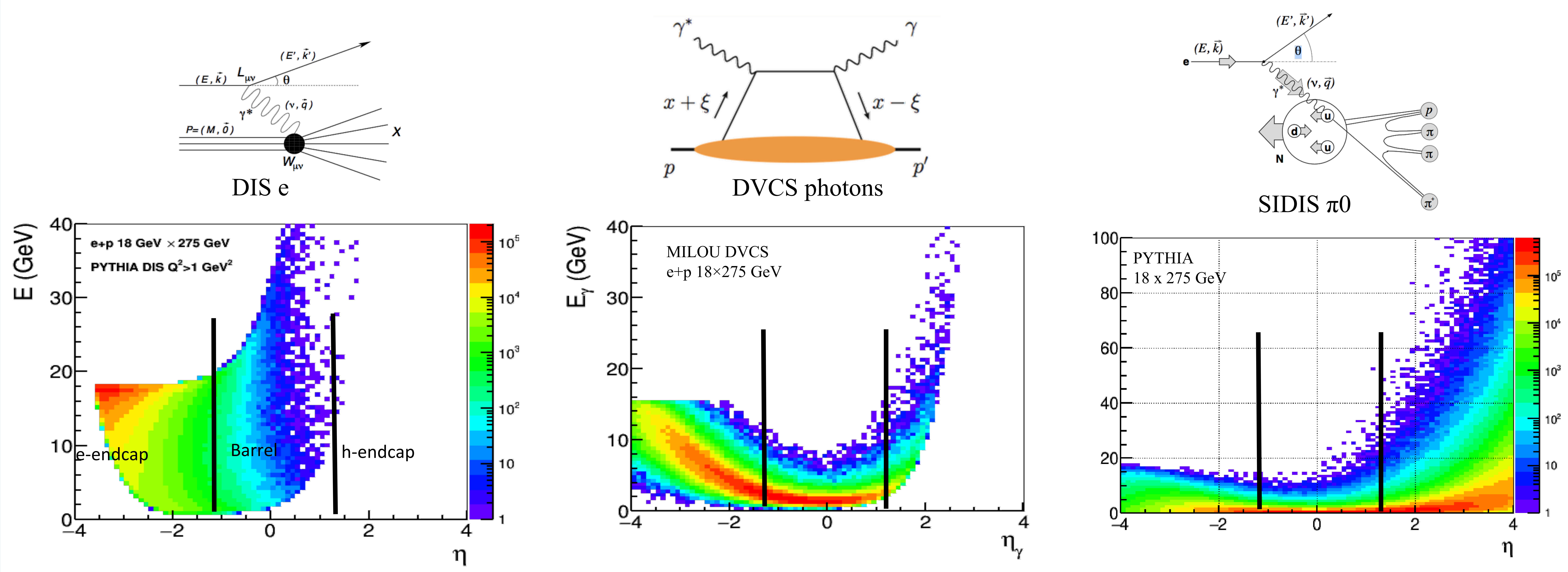


Expected radiation 10^{10} n_{eq}/cm^2 at EIC ($10^{15\text{-}16}$ n_{eq}/cm^2 at HL-LHC)

Precise vertex, tracking, PID, and calorimetry, **hermetic** detector system ($|\eta|>0$, $|\phi|<\pi$)

Requirements for an EIC detector




DIS e
DVCS photons
SIDIS π0
e+p 18 GeV × 275 GeV
PYTHIA DIS Q²>1 GeV²
E (GeV)
η
e-endcap
Barrel
h-endcap
MILOU DVCS
e+p 18×275 GeV
E_γ (GeV)
η_γ
PYTHIA
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η