ECCE Detector Concept and Software

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What is ECCE?

- An international consortium of people working to develop a detector capable of delivering the full EIC science mission as outlined in the EIC Yellow Report
- Looking to reduce risk by utilizing existing detectors and infrastructure
  - Reinvest savings into detectors and reduce schedule/technical risks
- Ready by start of EIC operations!

How Did ECCE Start?

- ECCE did not materialize out of the ether - largely guided by the community's desires for a detector based on the (community developed) EIC Yellow Report

- How can we achieve the design requirements?

<table>
<tr><th rowspan="2">η</th><th rowspan="2">Nomenclature</th><th colspan="6">Tracking</th><th colspan="3">Electrons and Photons</th><th colspan="2">$\pi/K/p$</th><th colspan="2">HCAL</th><th rowspan="2">Muons</th></tr>
<tr><th>Resolution</th><th>Relative Momentun</th><th>Allowed X/X_0</th><th>Minimum-p_T (MeV/c)</th><th>Transverse Pointing Res.</th><th>Longitudinal Pointing Res.</th><th>Resolution σ_E/E</th><th>PID</th><th>Min E Photon</th><th>p-Range</th><th>Separation</th><th>Resolution σ_E/E</th><th>Energy</th></tr>
<tr><td>< -4.6</td><td>Low-Q2 tagger</td><td colspan="14"></td></tr>
<tr><td>-4.6 to -4.0</td><td rowspan="2"></td><td colspan="14">Not Accessible</td></tr>
<tr><td>-4.0 to -3.5</td><td></td><td colspan="12">Reduced Performance</td><td rowspan="10">Muons useful for background suppression and improved resolution</td></tr>
<tr><td>-3.5 to -3.0</td><td rowspan="5">Backward Detector</td><td rowspan="2"></td><td rowspan="2">$\sigma_p/p \sim 0.1\%\times p\oplus 2\%$</td><td rowspan="14">~5% or less</td><td rowspan="5">150-300</td><td rowspan="3"></td><td></td><td rowspan="3">$1\%/E \oplus 2.5\%/\sqrt{E} \oplus 1\%$</td><td rowspan="3">$\pi$ suppression up to 1:10^{-4}</td><td rowspan="3">20 MeV</td><td rowspan="5">≤ 10 GeV/c</td><td rowspan="14">≥ 3σ</td><td rowspan="5">$50\%/\sqrt{E} \oplus 10\%$</td><td rowspan="14">~500MeV</td></tr>
<tr><td>-3.0 to -2.5</td><td></td></tr>
<tr><td>-2.5 to -2.0</td><td rowspan="3"></td><td rowspan="3">$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$</td><td></td></tr>
<tr><td>-2.0 to -1.5</td><td rowspan="2">dca(xy) ~ $40/p_T$ μm ⊕ 10 μm</td><td rowspan="2">dca(z) ~ $100/p_T$ μm ⊕ 20 μm</td><td rowspan="2">$2\%/E \oplus (4\text{-}8)\%/\sqrt{E} \oplus 2\%$</td><td rowspan="2">$\pi$ suppression up to 1:(10^{-3}-10^{-2})</td><td rowspan="2">50 MeV</td></tr>
<tr><td>-1.5 to -1.0</td></tr>
<tr><td>-1.0 to -0.5</td><td rowspan="4">Barrel</td><td rowspan="4"></td><td rowspan="4">$\sigma_p/p \sim 0.02\% \times p \oplus 5\%$</td><td rowspan="4">400</td><td rowspan="4">dca(xy) ~ $30/p_T$ μm ⊕ 5 μm</td><td rowspan="4">dca(z) ~ $30/p_T$ μm ⊕ 5 μm</td><td rowspan="4">$2\%/E \oplus (12\text{-}14)\%/\sqrt{E} \oplus (2\text{-}3)\%$</td><td rowspan="4">$\pi$ suppression up to 1:10^{-2}</td><td rowspan="4">100 MeV</td><td rowspan="4">≤ 6 GeV/c</td><td rowspan="4">$100\%/\sqrt{E} \oplus 10\%$</td></tr>
<tr><td>-0.5 to 0.0</td></tr>
<tr><td>0.0 to 0.5</td></tr>
<tr><td>0.5 to 1.0</td></tr>
<tr><td>1.0 to 1.5</td><td rowspan="5">Forward Detectors</td><td rowspan="3"></td><td rowspan="3">$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$</td><td rowspan="5">150-300</td><td rowspan="2">dca(xy) ~ $40/p_T$ μm ⊕ 10 μm</td><td rowspan="3">dca(z) ~ $100/p_T$ μm ⊕ 20 μm</td><td rowspan="5">$2\%/E \oplus (4^{*}\text{-}12)\%/\sqrt{E} \oplus 2\%$</td><td rowspan="5">3$\sigma$ e/π up to 15 GeV/c</td><td rowspan="5">50 MeV</td><td rowspan="5">≤ 50 GeV/c</td><td rowspan="5">$50\%/\sqrt{E} \oplus 10\%$</td><td></td></tr>
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<tr><td>3.0 to 3.5</td><td></td><td></td></tr>
<tr><td>3.5 to 4.0</td><td>Instrumentation to separate charged particles from photons</td><td></td><td colspan="12">Reduced Performance</td><td></td></tr>
<tr><td>4.0 to 4.5</td><td></td><td colspan="13">Not Accessible</td><td></td></tr>
<tr><td rowspan="2">> 4.6</td><td>Proton Spectrometer</td><td colspan="14" rowspan="2"></td></tr>
<tr><td>Zero Degree Neutral Detection</td></tr>
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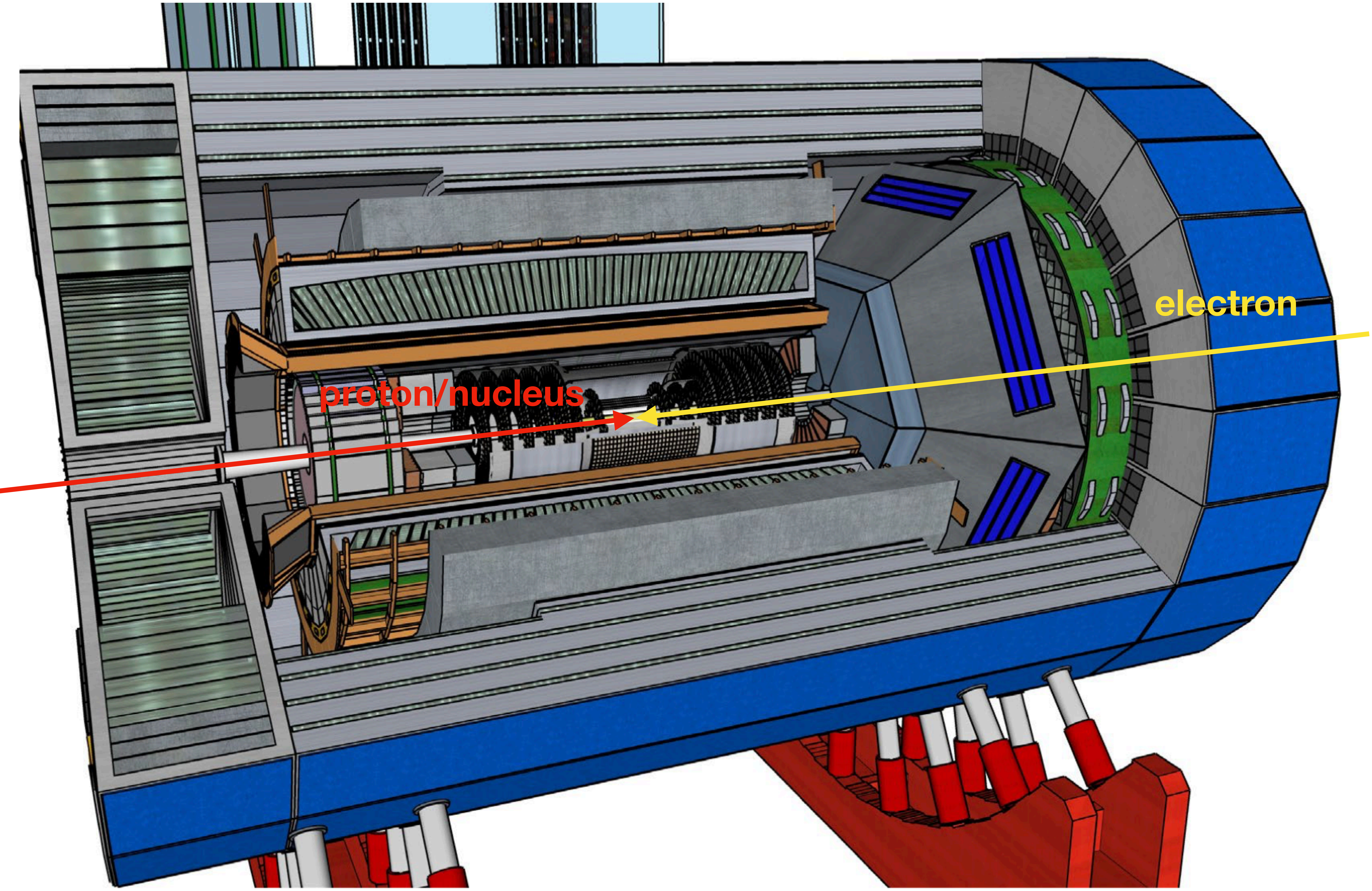
ECCE Geometry



ELECTRON ENDCAP

Tracking: Si discs + Large area μRWELL
Electron Detection:

- Inner: PbWO4 crystals (reuse some)
- Outer: SciGlass (backup PbGl)

h-PID: mRICH & AC-LGAD
HCAL: Fe/Sc (STAR re-use)

CENTRAL BARREL

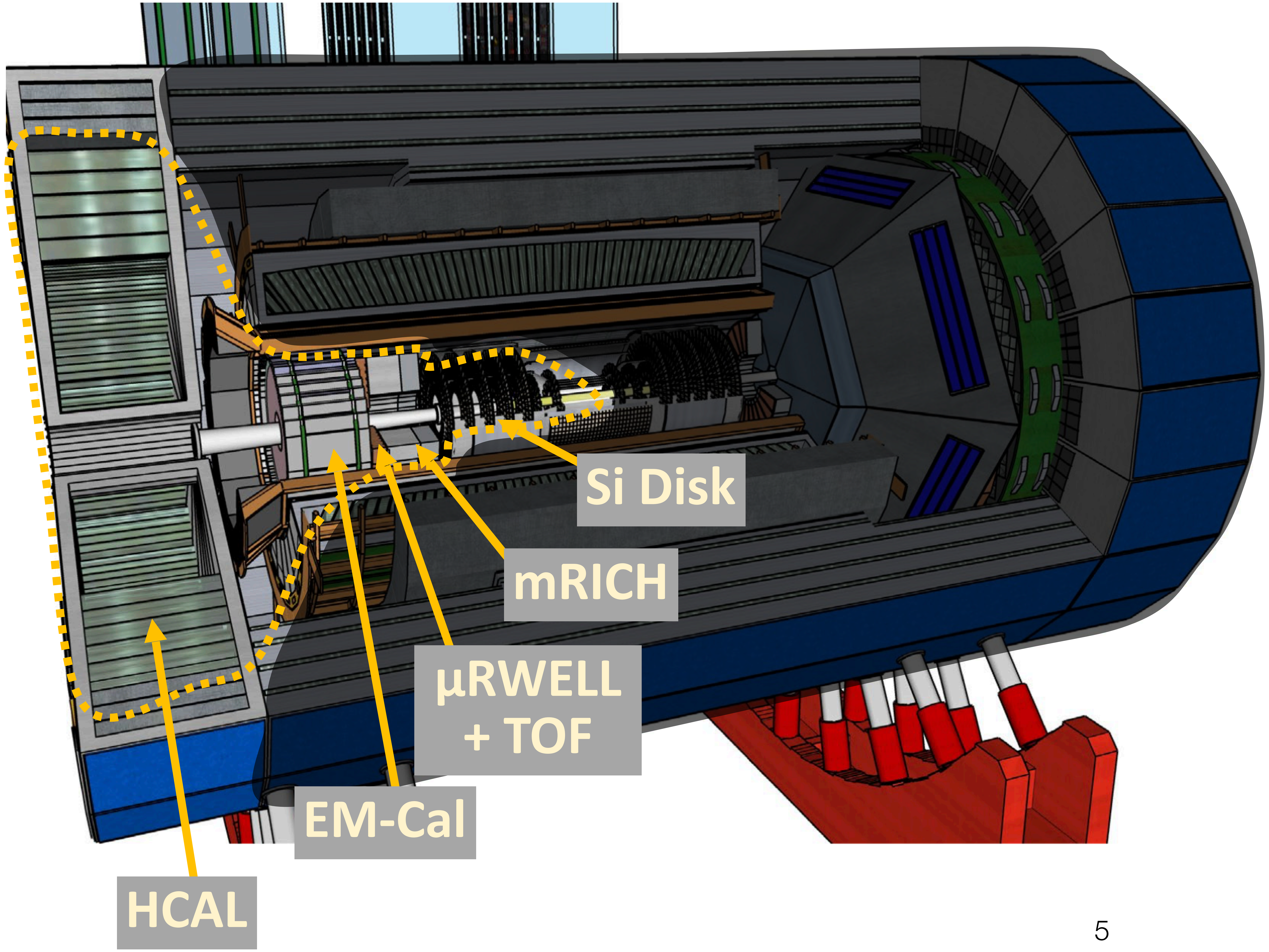
Tracking: MAPS Si + μRWELL
(design under optimization)
Electron PID: SciGlass (alt: PbGl or W(Pb)/Sc shashlik)
(plus instrumented frame)
h-PID: hpDIRC & AC-LGAD
HCAL: Fe/Sc (sPHENIX re-use)

HADRON ENDCAP

Tracking: Si discs + Large area μRWELL
PID: dual-RICH & AC-LGAD
Calorimetry:
Standard Pb/ScFi shashlik (PHENIX re-use)
Long. sep. HCAL
(other options under study)

4

ECCE Geometry



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5

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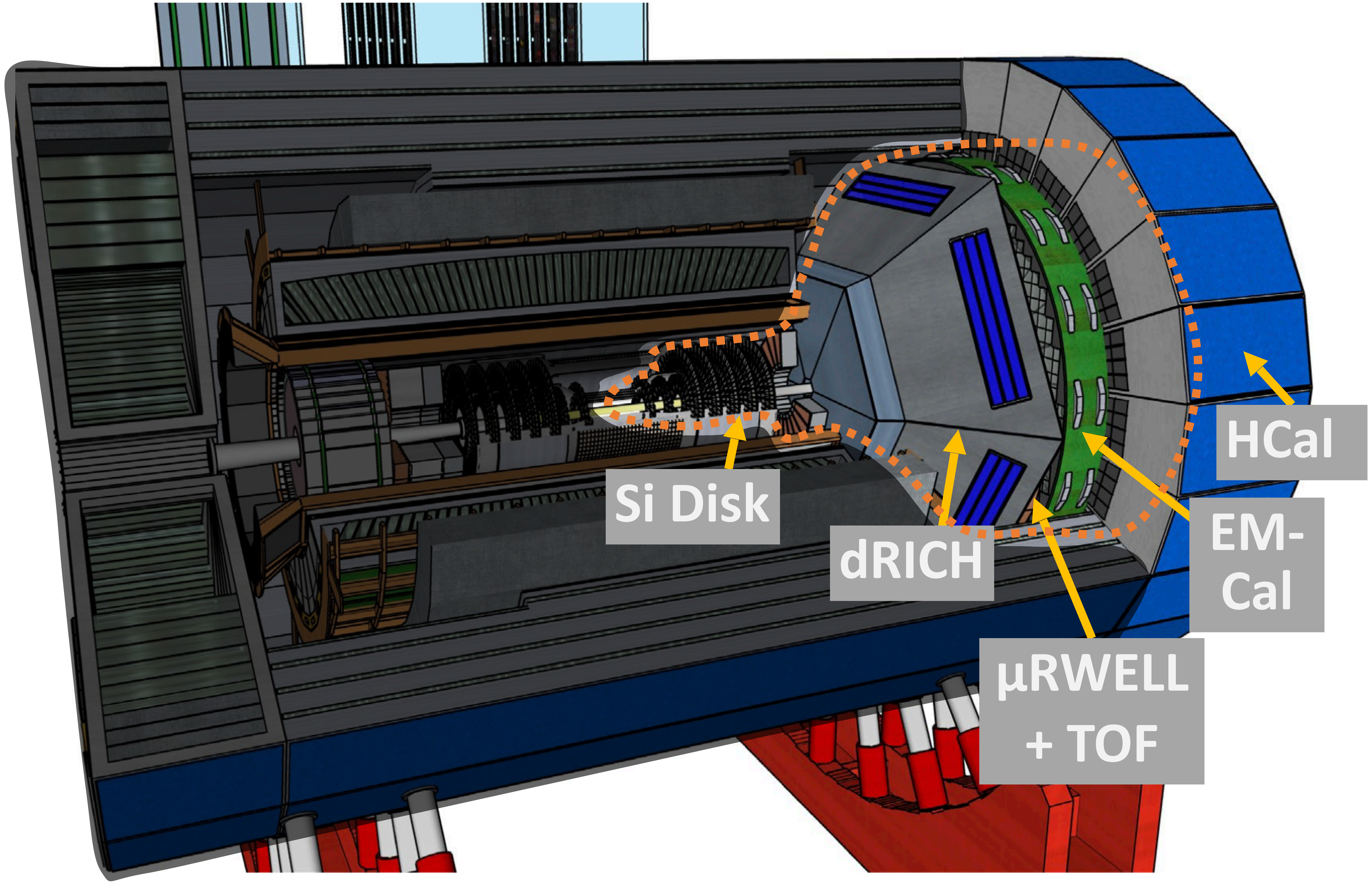

HADRON ENDCAP

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PID: dual-RICH & AC-LGAD
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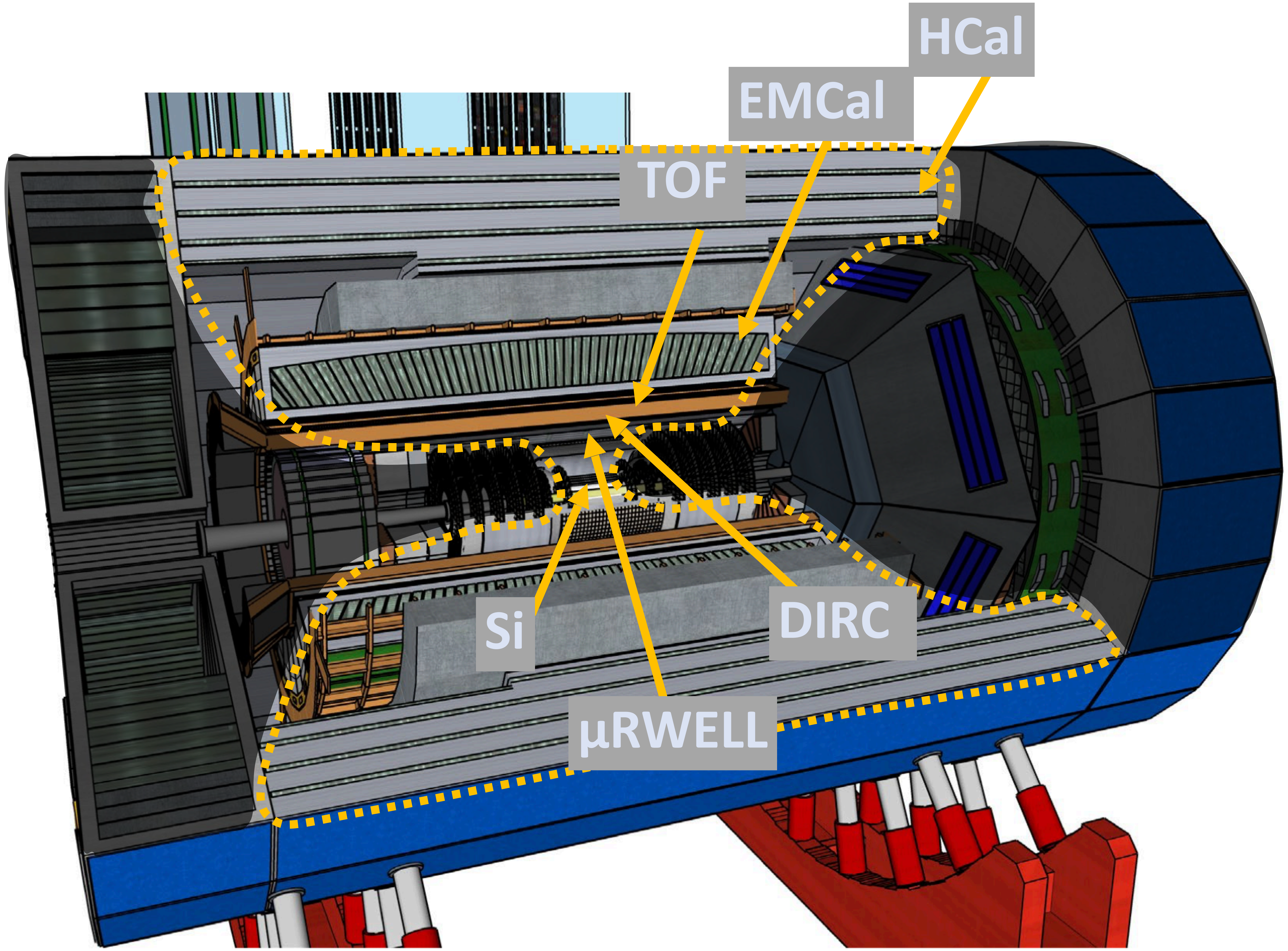
6

ECCE Geometry



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(plus instrumented frame)
h-PID: hpDIRC & AC-LGAD
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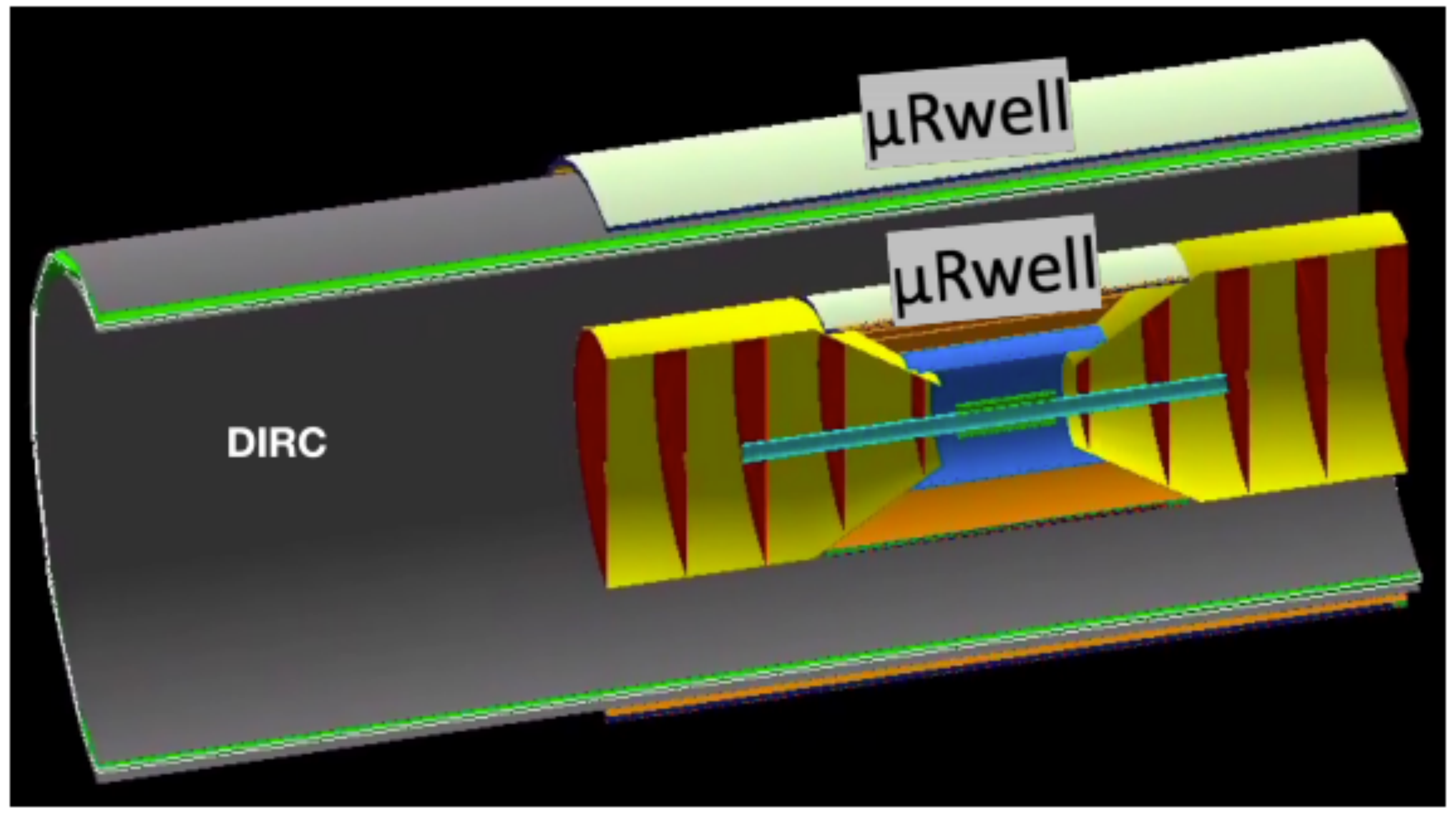
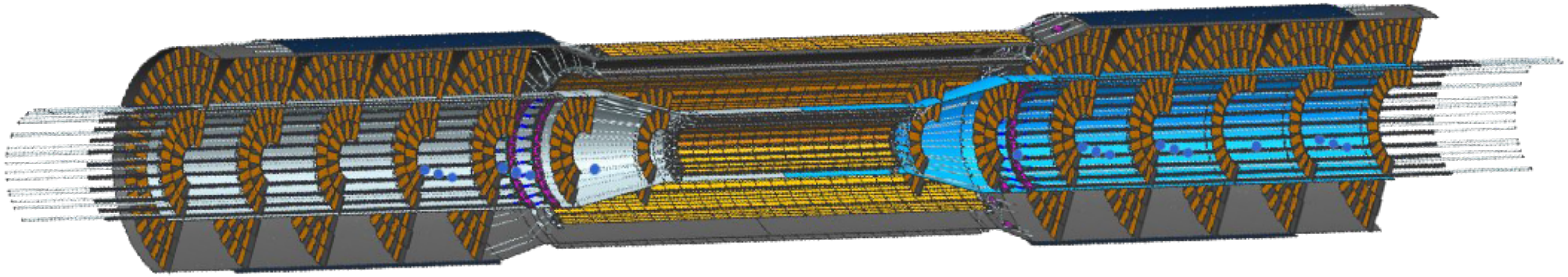
Tracking

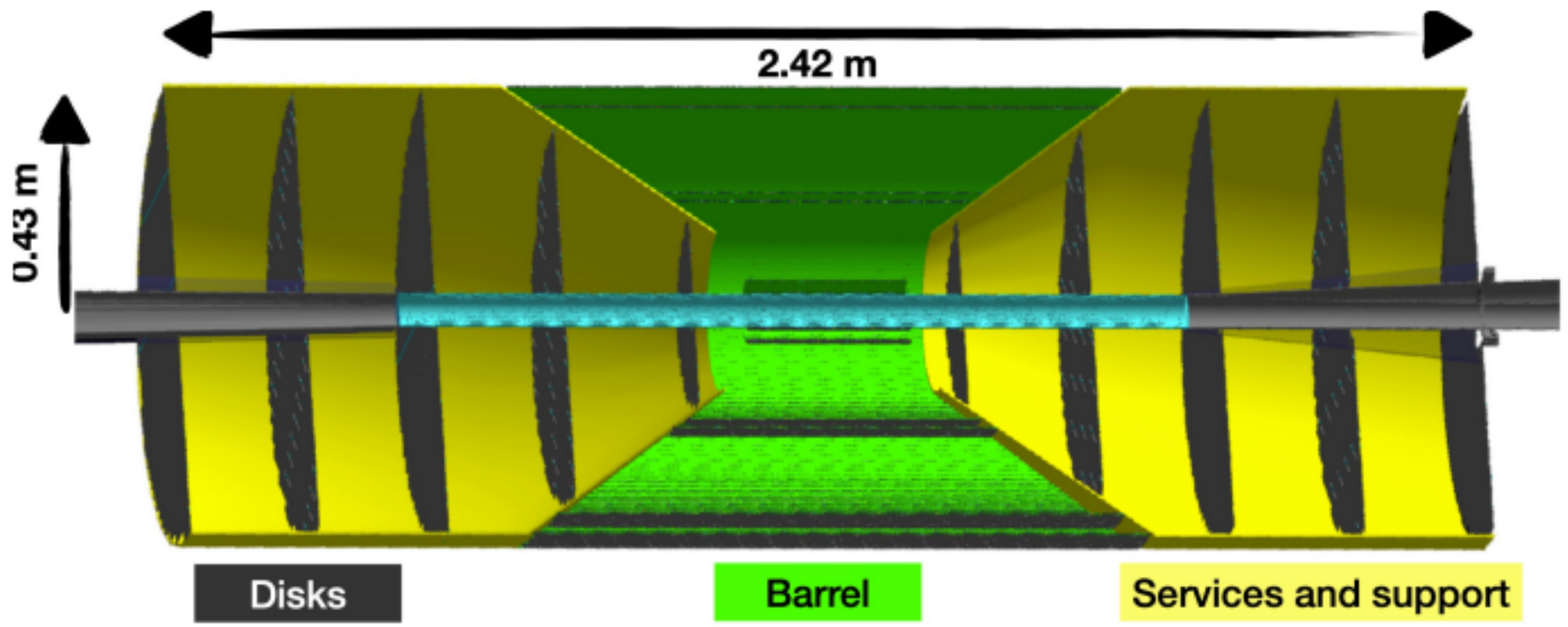
- Baseline layout:
  - Barrel: Silicon tracker (2 double layers) + AC-LGADS & µRwell around DIRC
  - Endcaps: Silicon disks + AC-LGADS & µRwell around calorimeters
- Design optimization and decisions ongoing!
  - AI/ML pipeline for optimizing detector design





Tracking

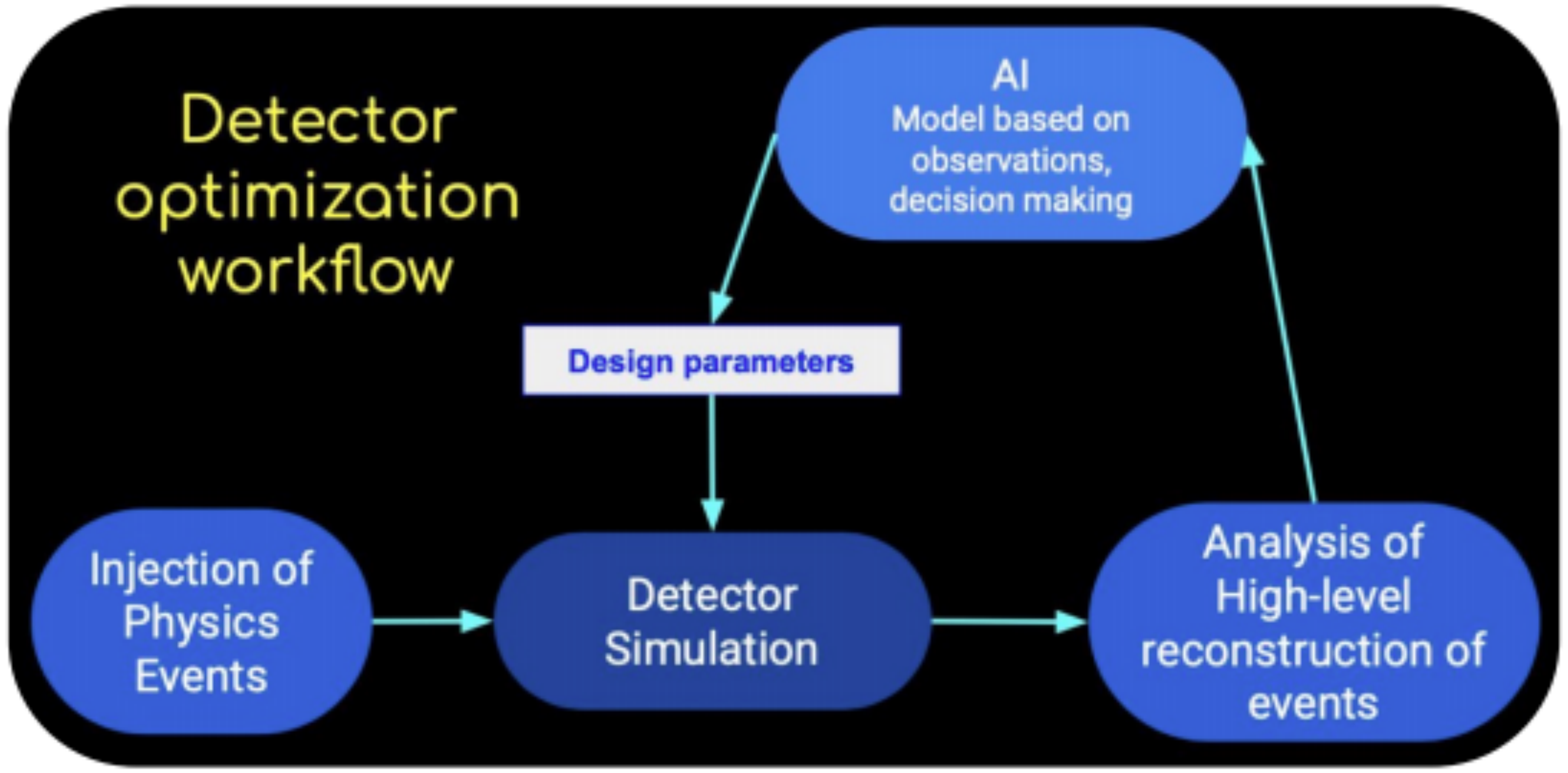
- Still exploring optimal design with various options
  - e.g. all silicon design, etc.
- Importance of modular software - can easily add/remove different designs to test functionality

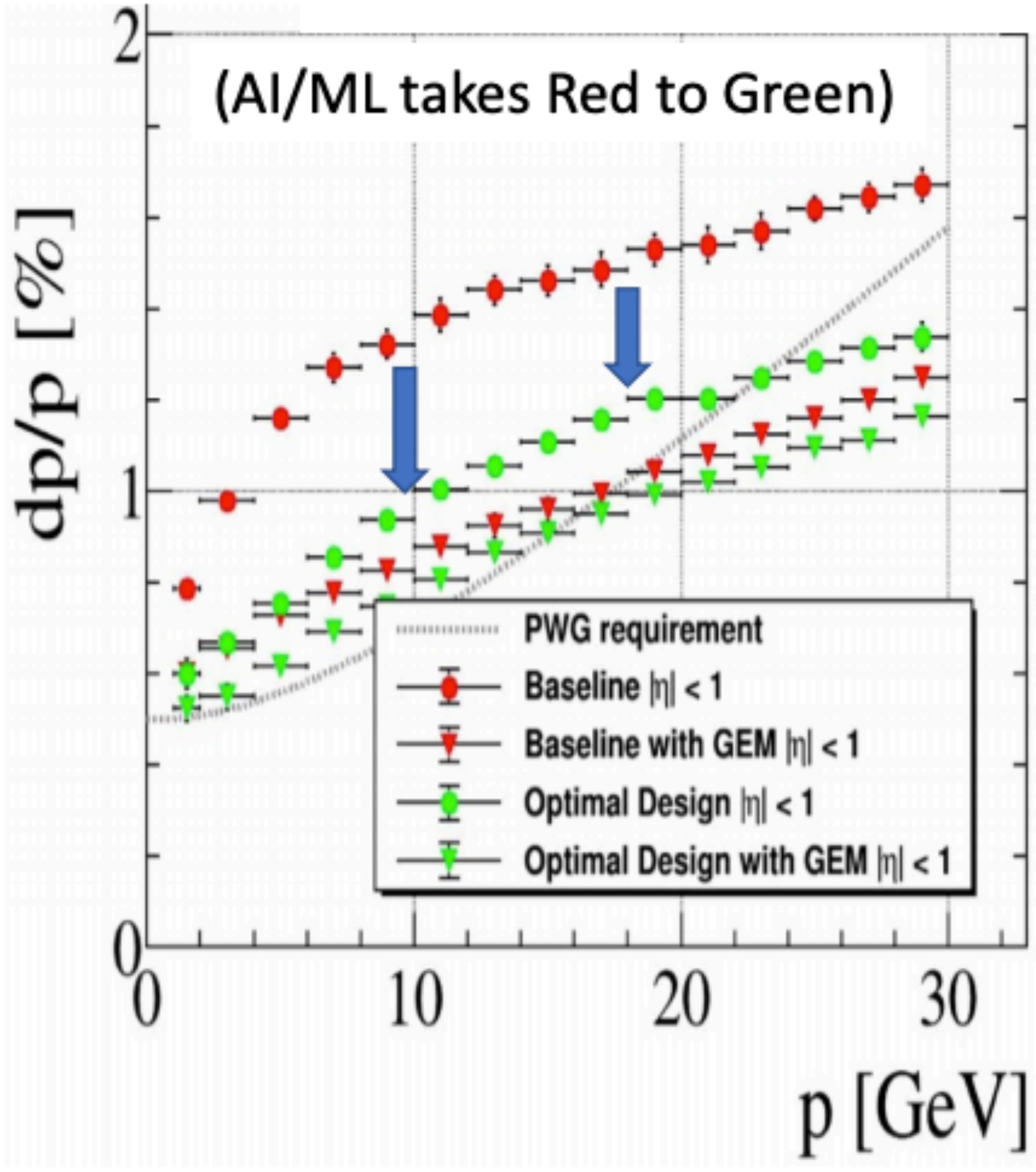


Detector Optimization with ML

- Utilize machine learning to optimize detector design

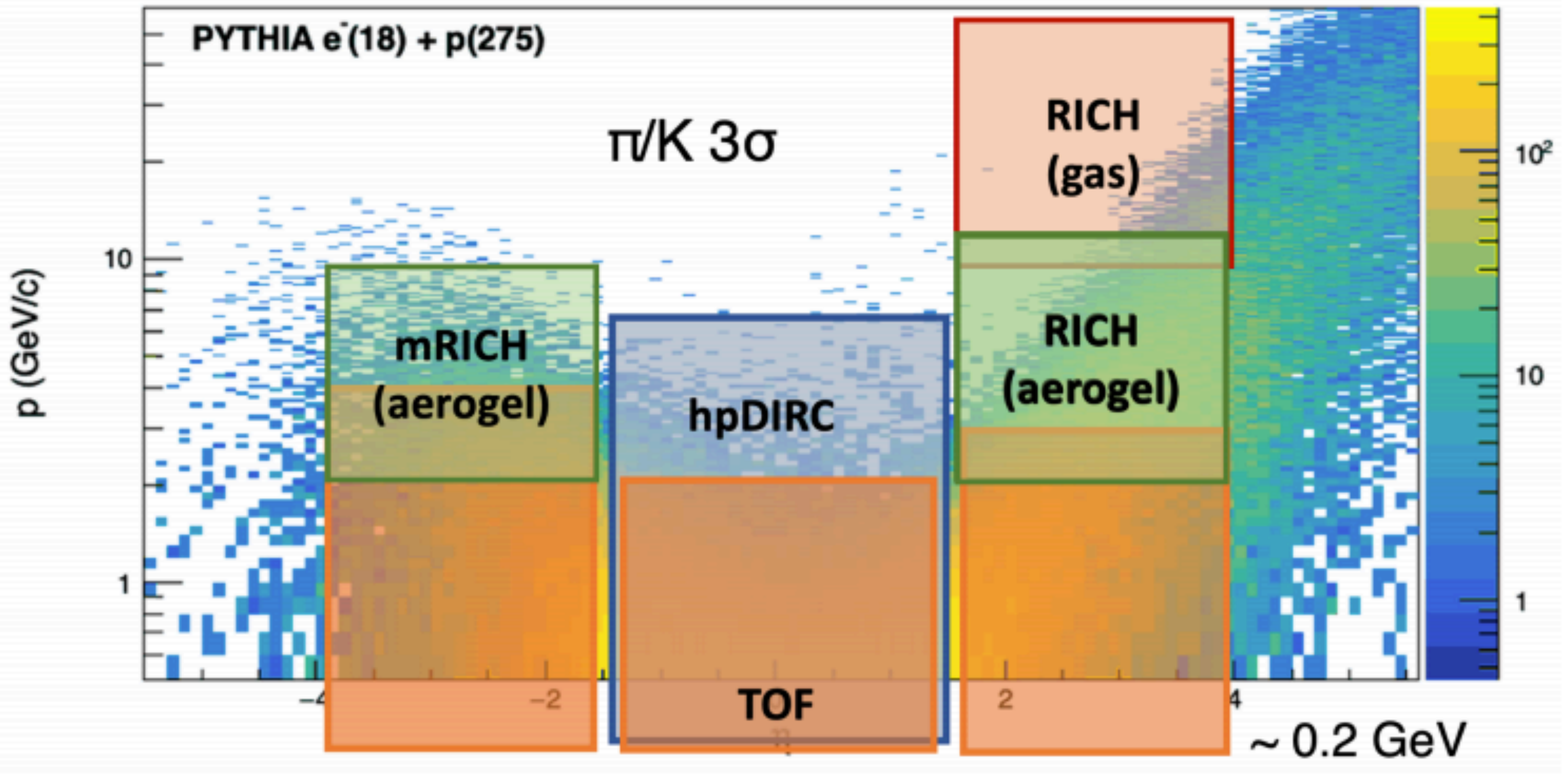
- Detector design parameters can be improved, leading to noticeable improvement in detector performance





Particle Identification

- EIC Yellow Report provides a comprehensive picture for PID detectors and physics requirements
- Combination of Cerenkov (RICH, DIRC) and time of flight (TOF)



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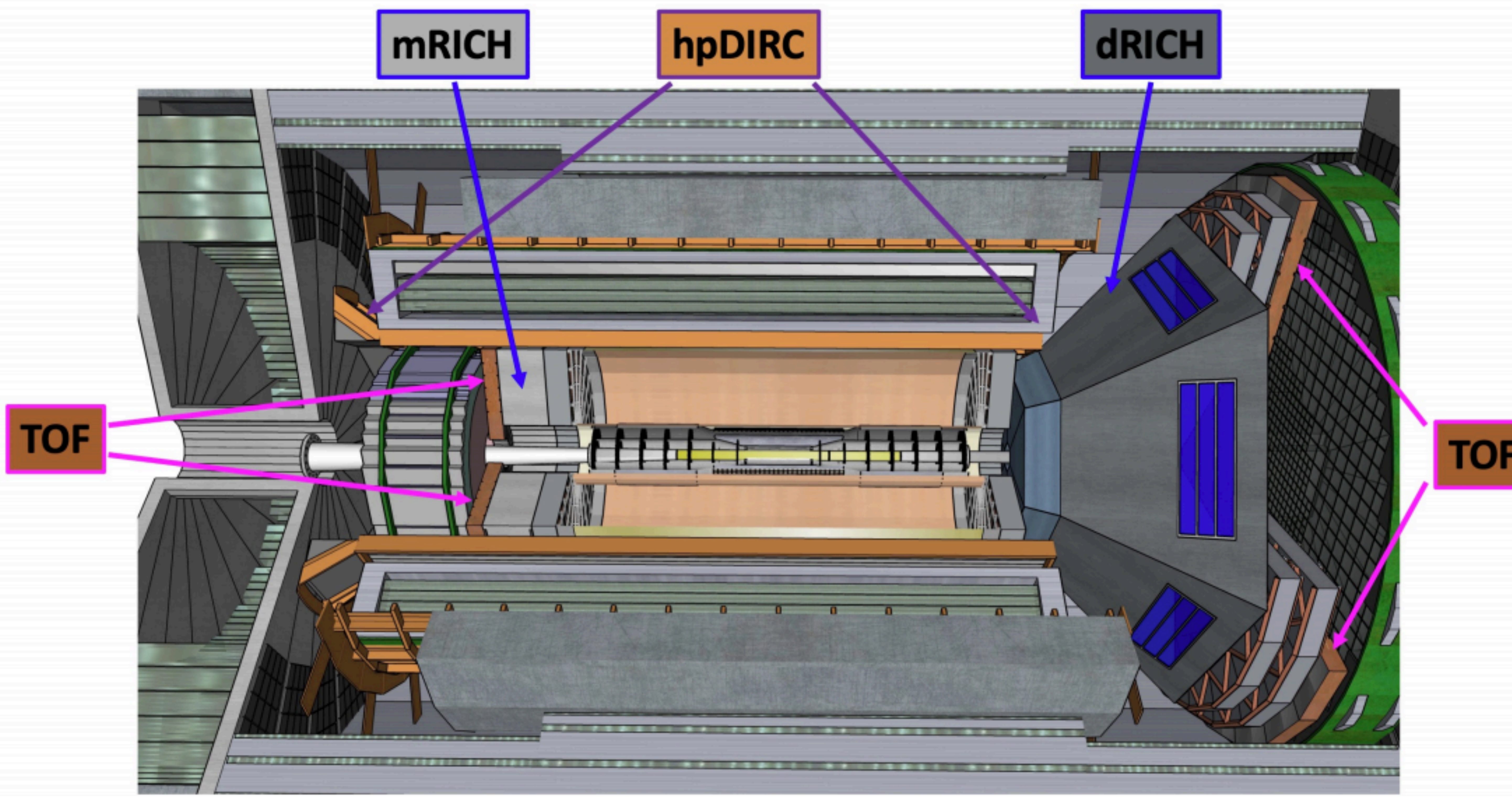
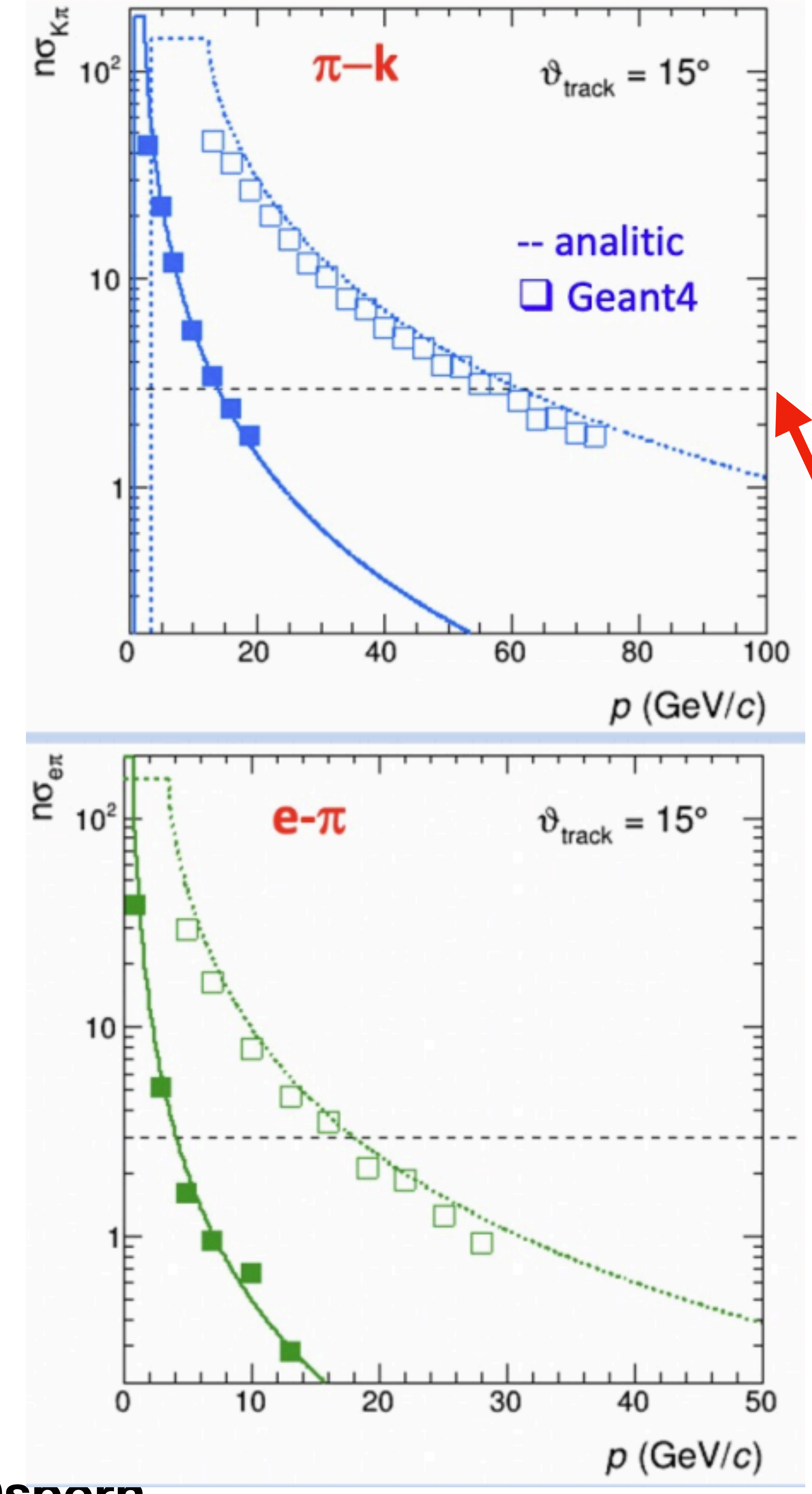
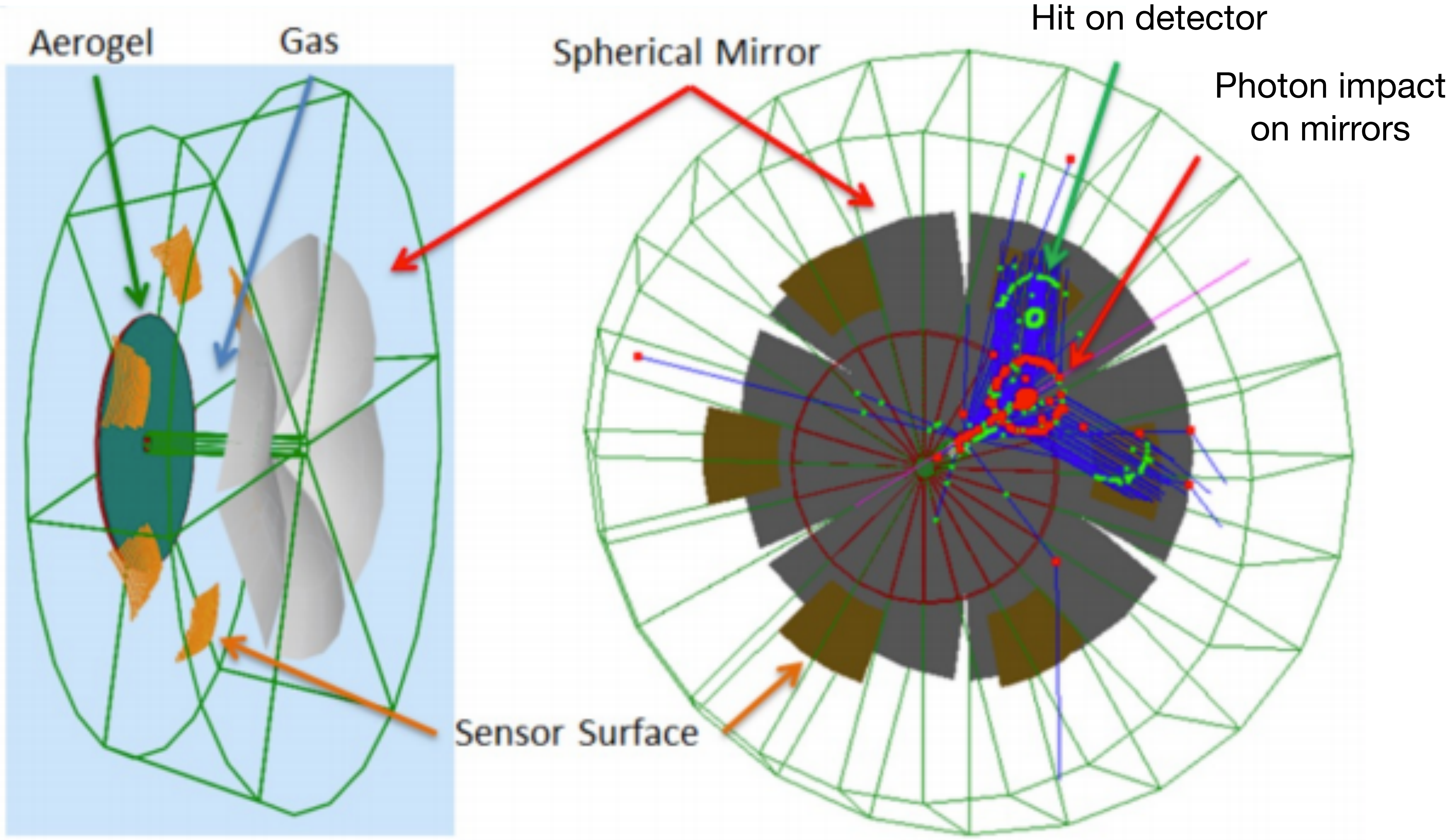


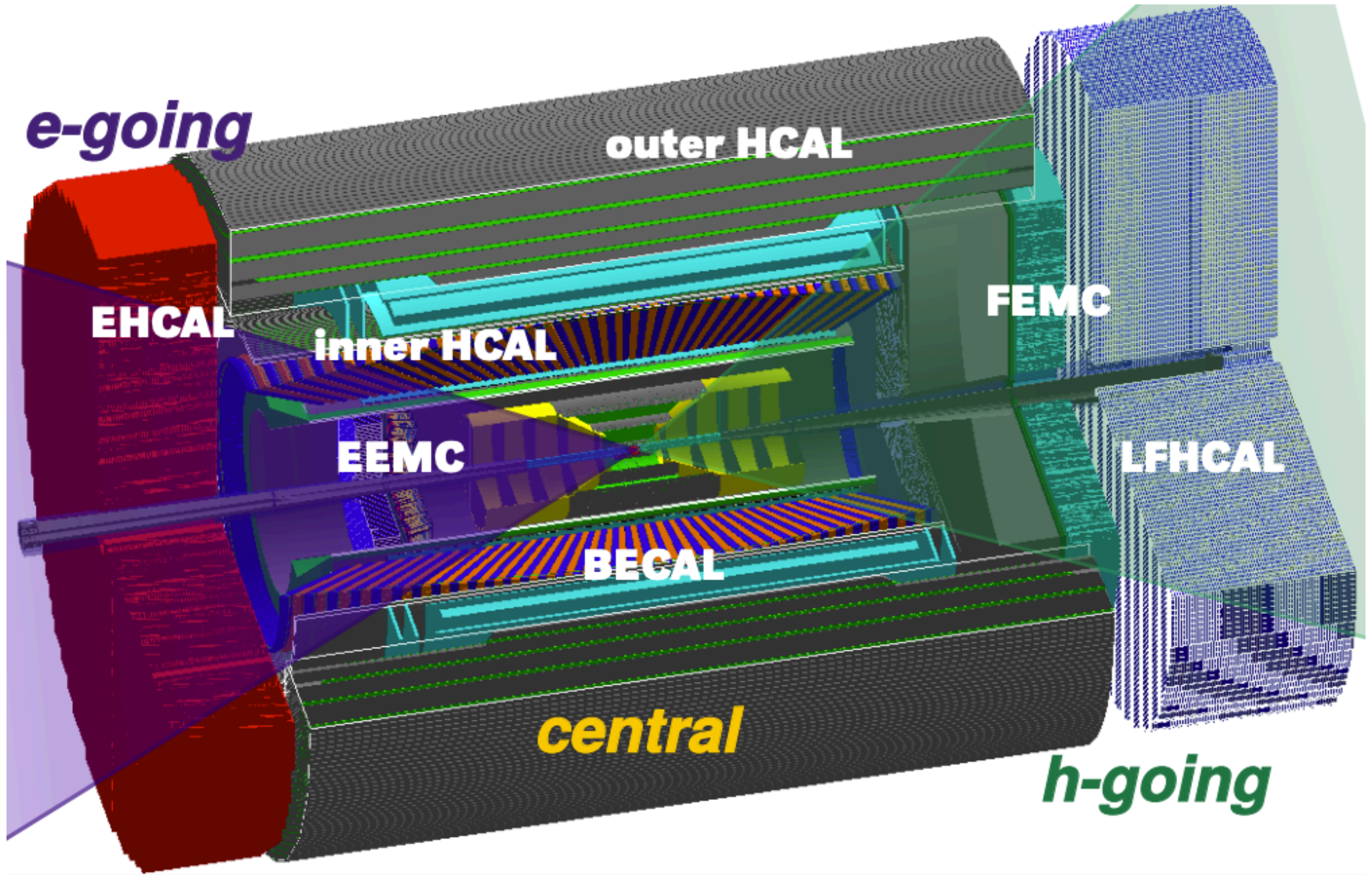
Particle Identification





- Geant4 descriptions of detectors have been implemented into ECCE simulations
- Testing and comparing particle separation power
    - Yellow Report specifications are 3σ ID

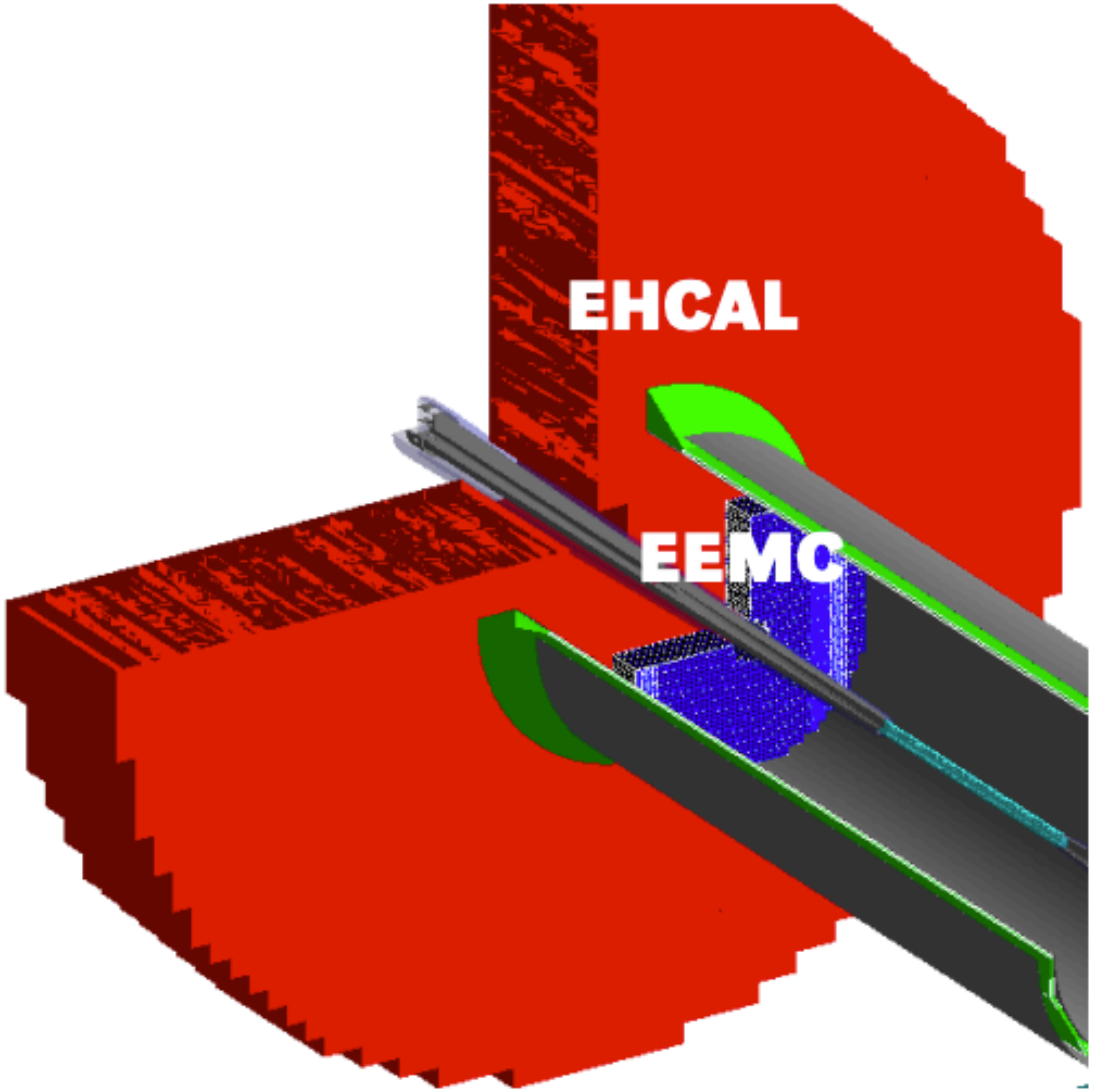
Calorimetry



- Reuse existing outer sPHENIX and STAR forward HCal
- Reuse existing PHENIX Shashlik EMCal
- Build new homogenous EMCals
- Build new inner HCal
- Build new forward HCal

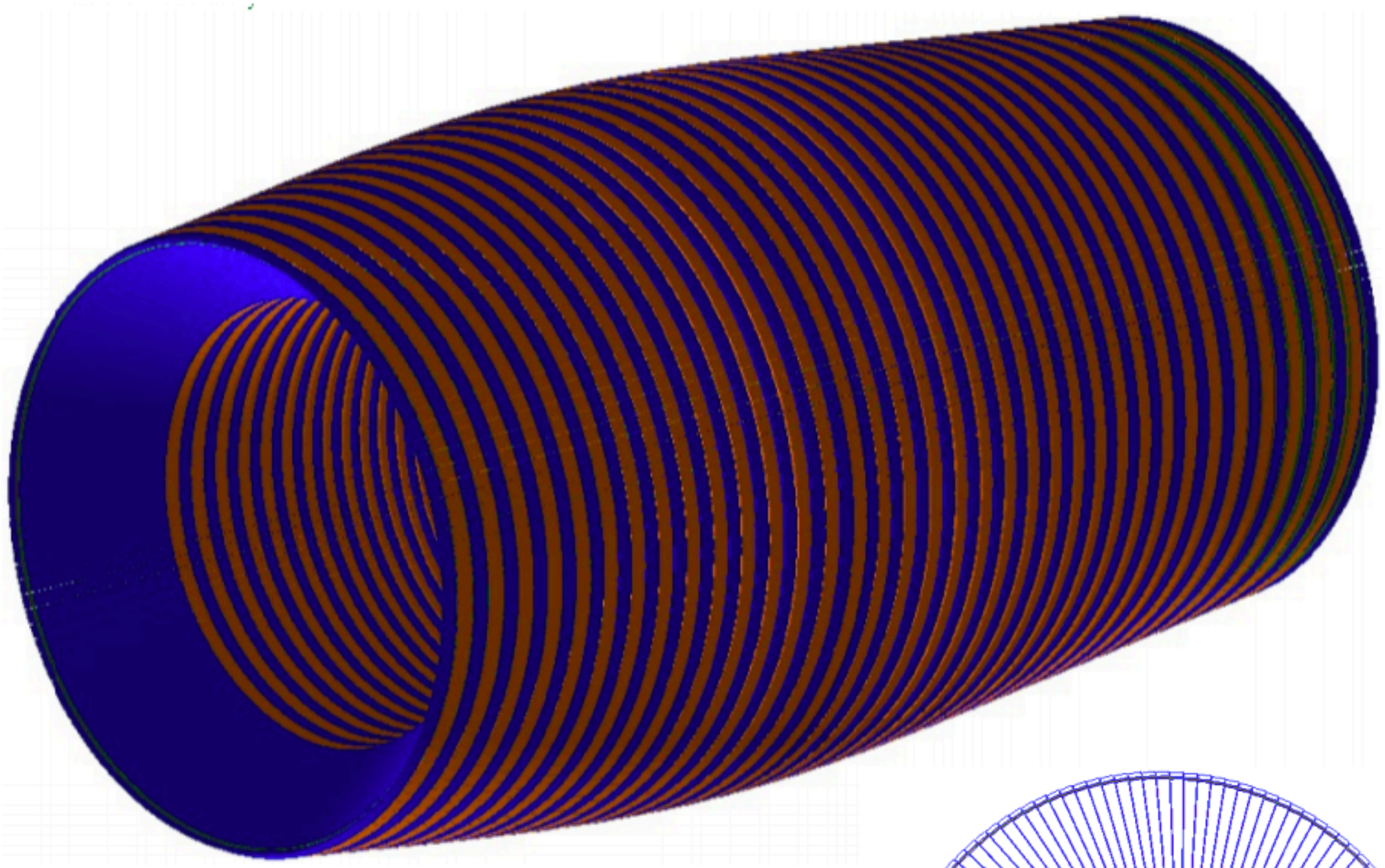
Electron Going Calorimetry

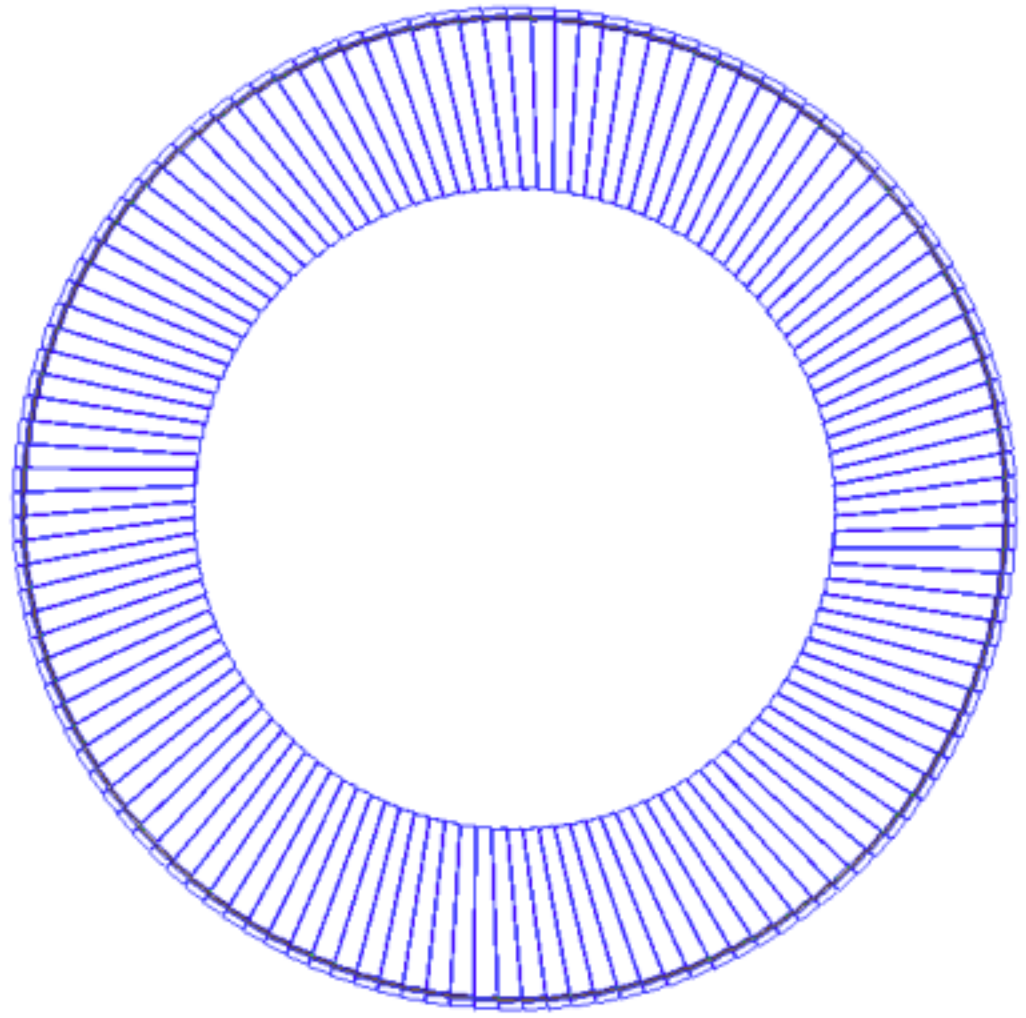
- Exploring several options for EMCal in electron going direction
  - e.g. $PbWO_4$ vs. scintillating-glass towers
- Reuse STAR forward HCal (with upgraded electronics) for cost/risk mitigation

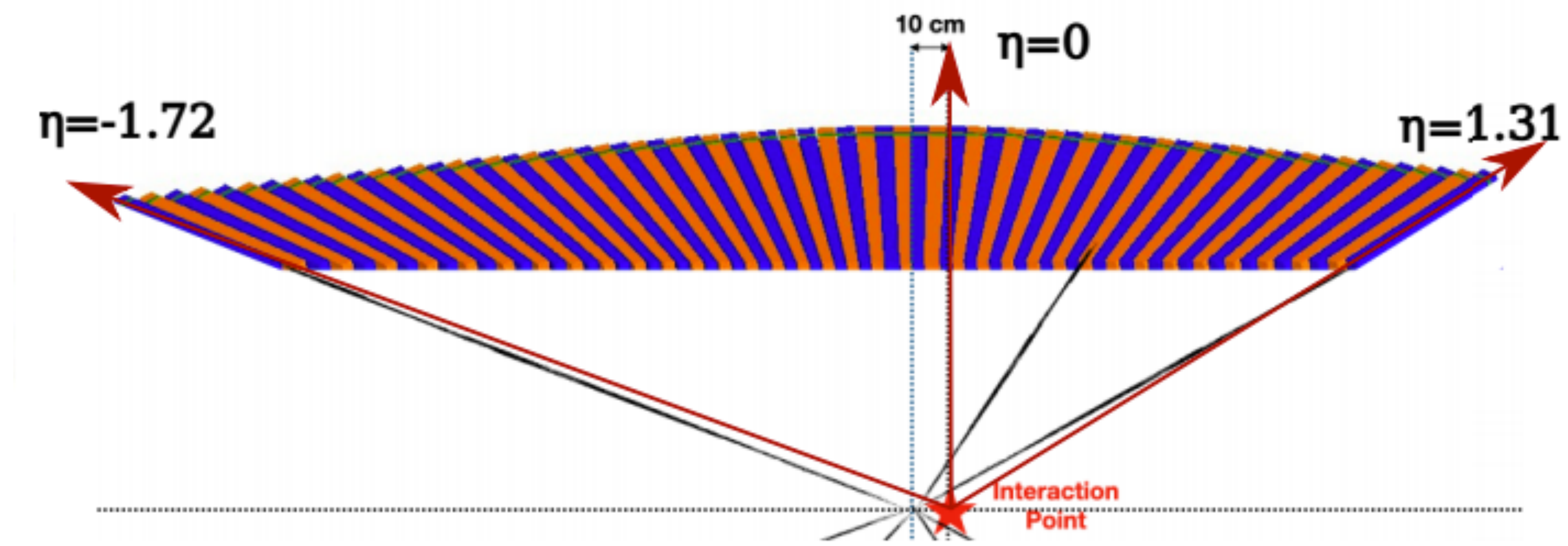


Central Calorimetry

- Central EMCal implemented as scintillating glass towers
- Projective in both η and ϕ to reduce channeling and improve resolution
    - Alternative - re-use sPHENIX 2D Spaghetti-calorimeter (SPACAL) with upgraded readout

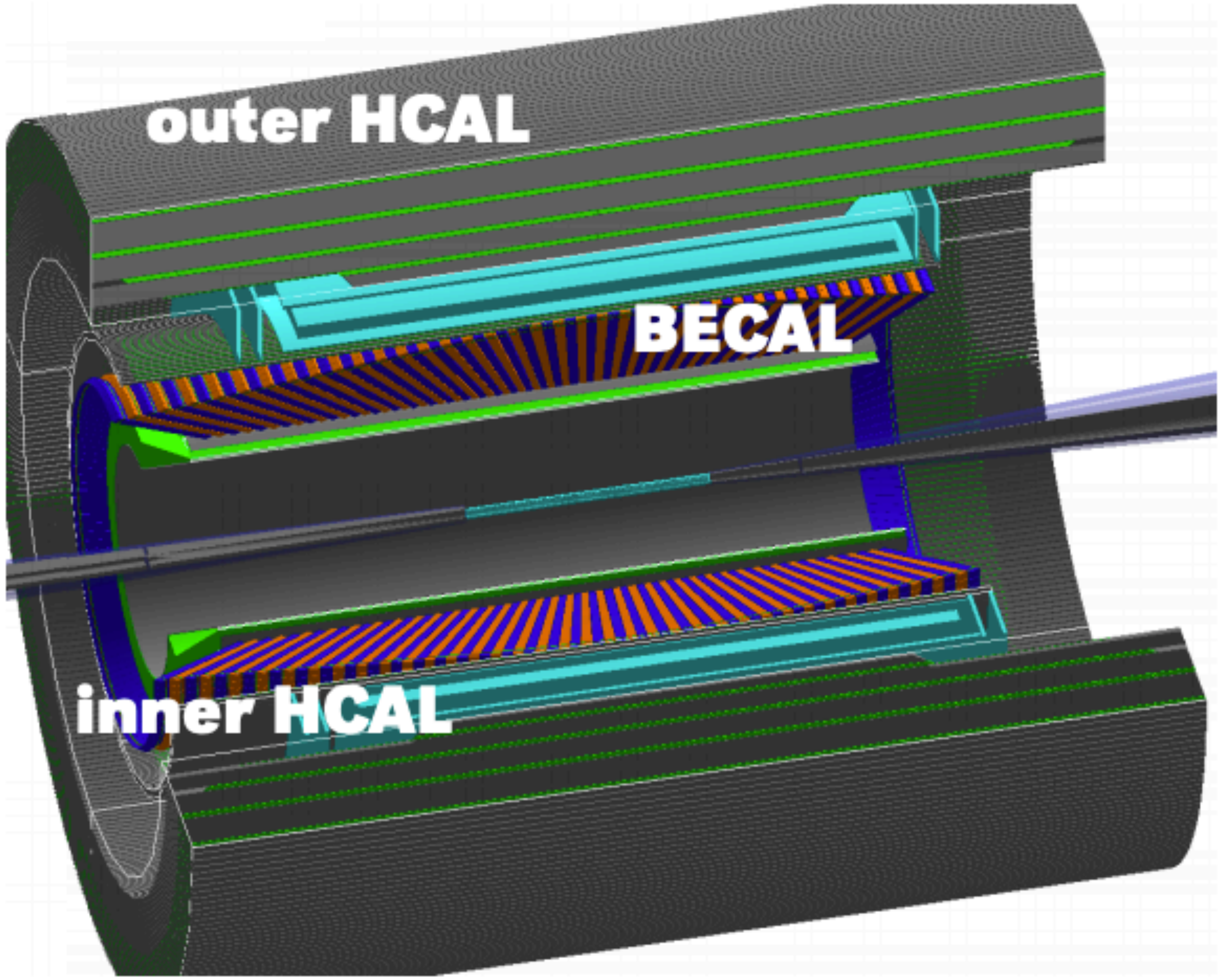






Central Calorimetry

- Re-use sPHENIX iron-scintillating tile calorimeter
  - Mitigate cost/risk and upgrade readout with new silicon photomultipliers (SiPMs)
- Inner HCal in steel support frame from BECAL

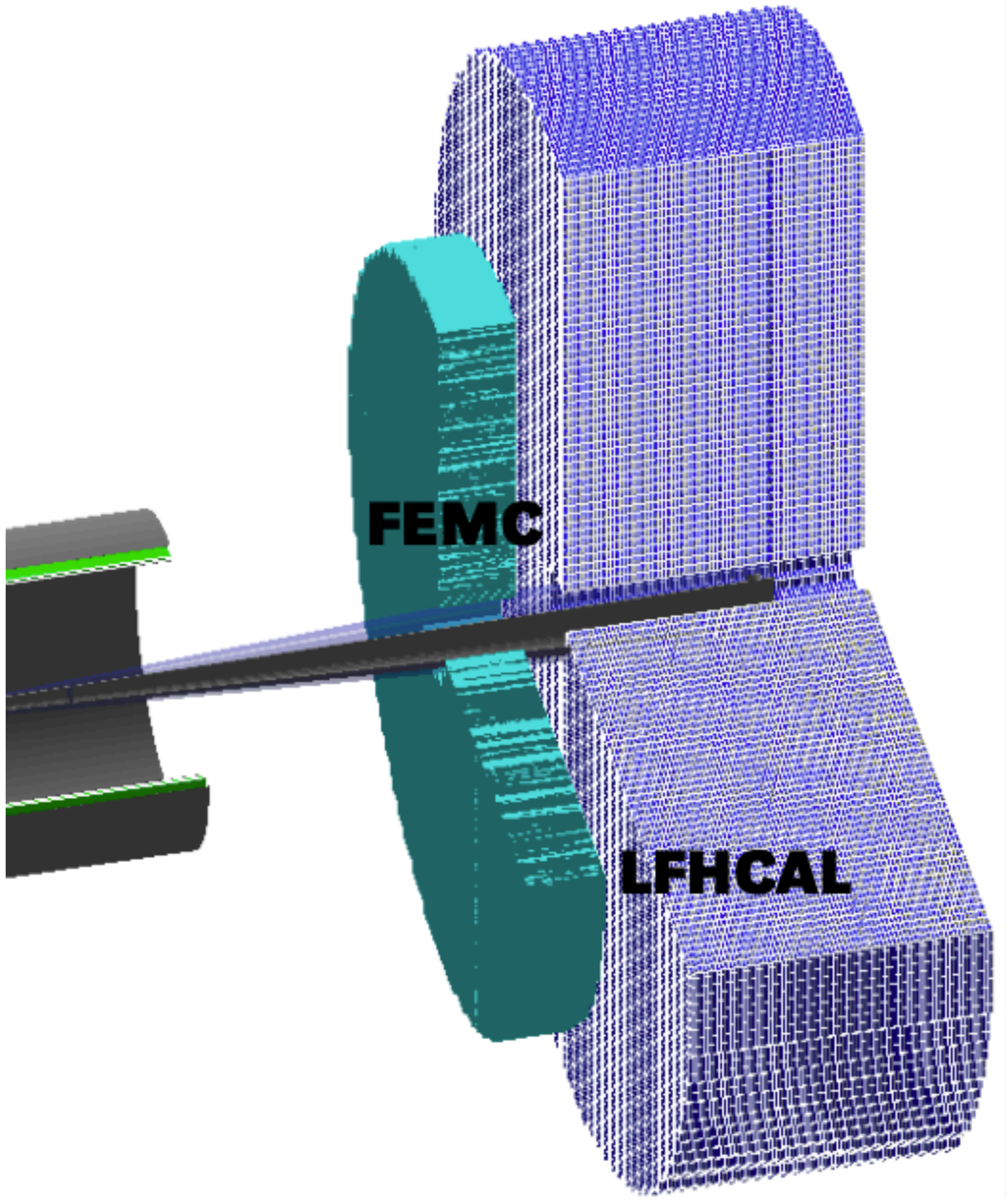


Hadron Going Calorimetry

- Good calorimetry in hadron going direction essential for (e.g.) SIDIS physics

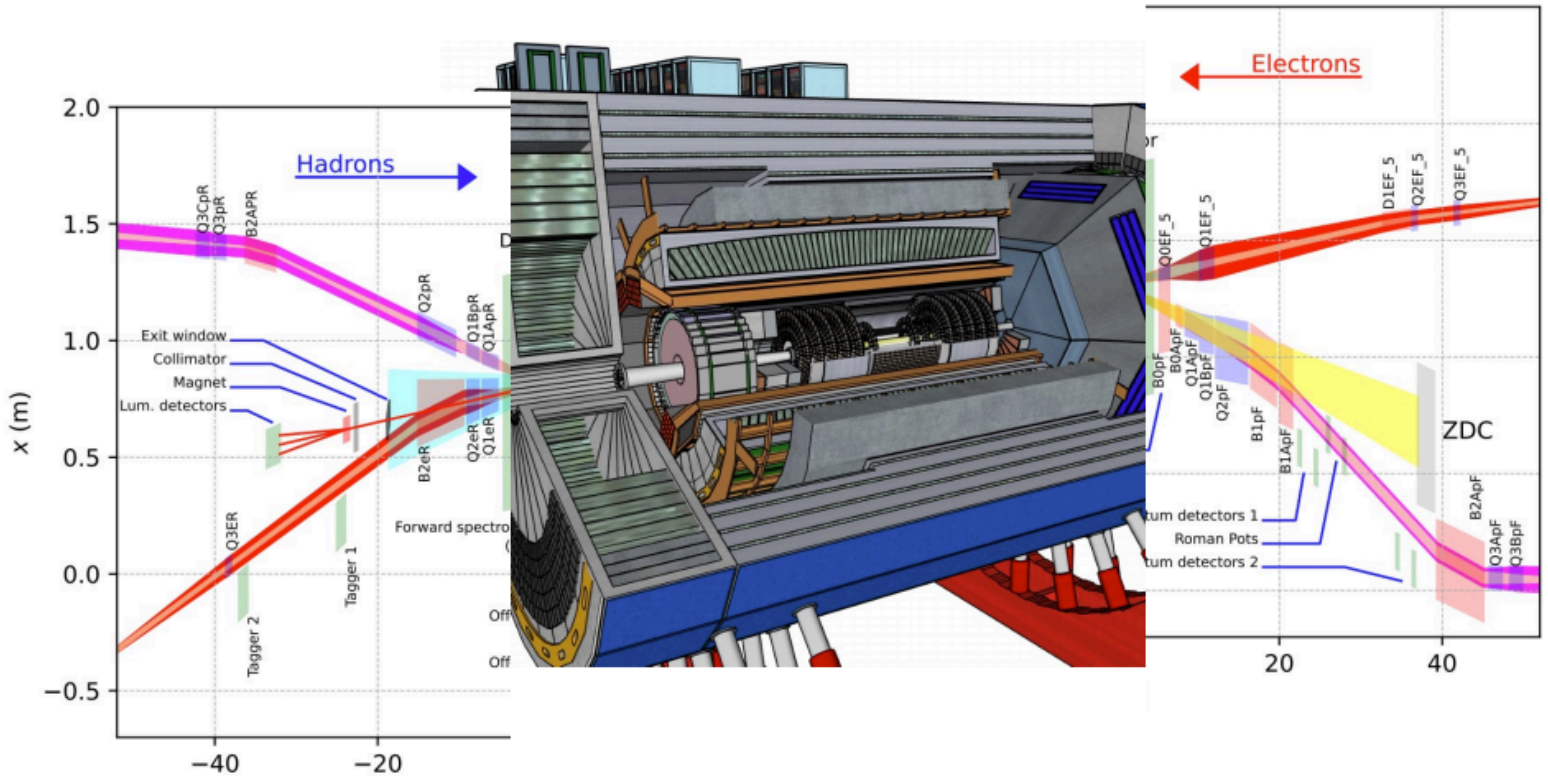
- FEMC - Pb scintillating Shashlik Calorimeter
  - Reuse PHENIX EMCal, upgraded SiPM readout

- LFHCal - Iron-scintillating tile calorimeter



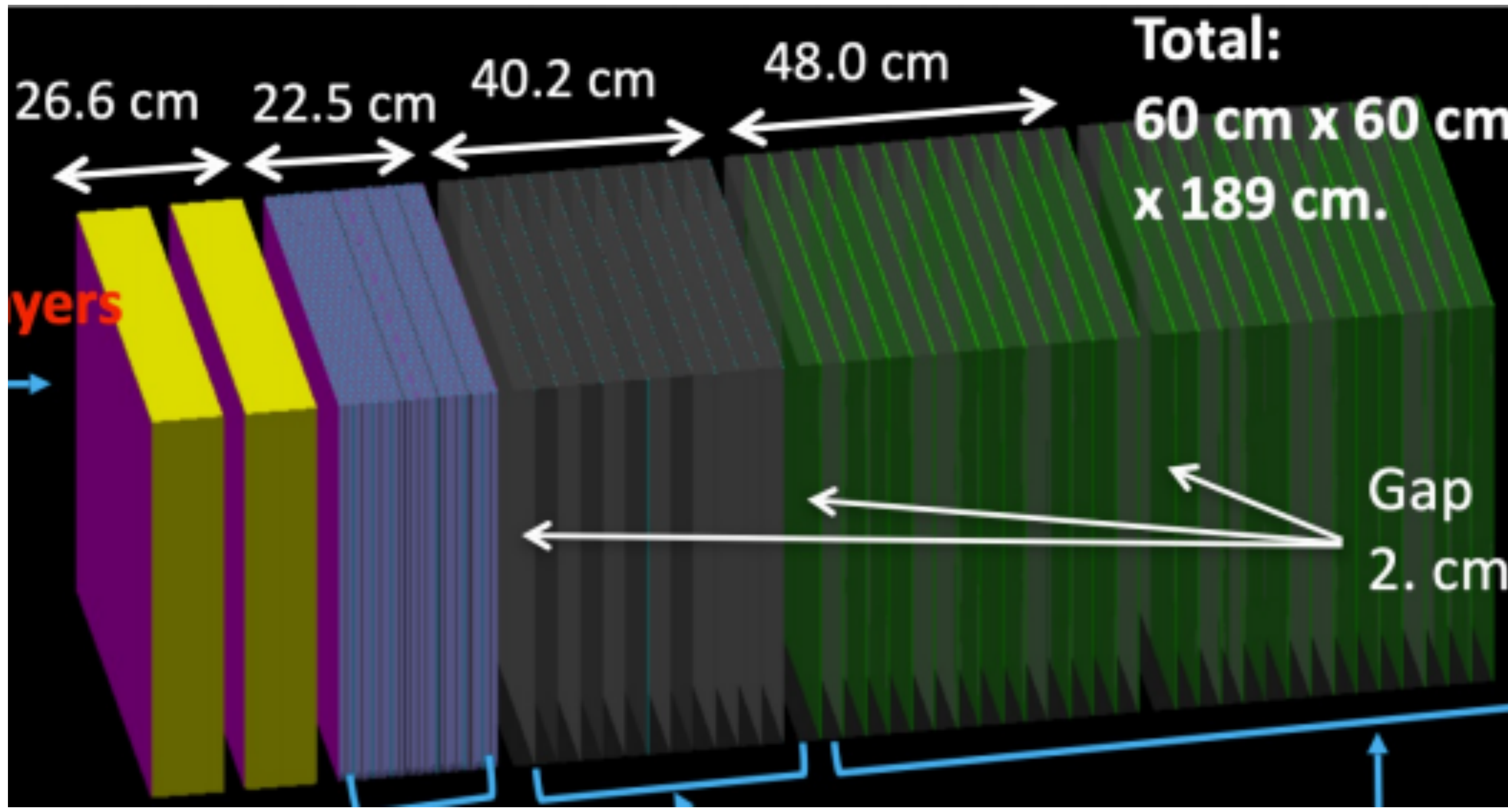
Forward and Backward Detectors

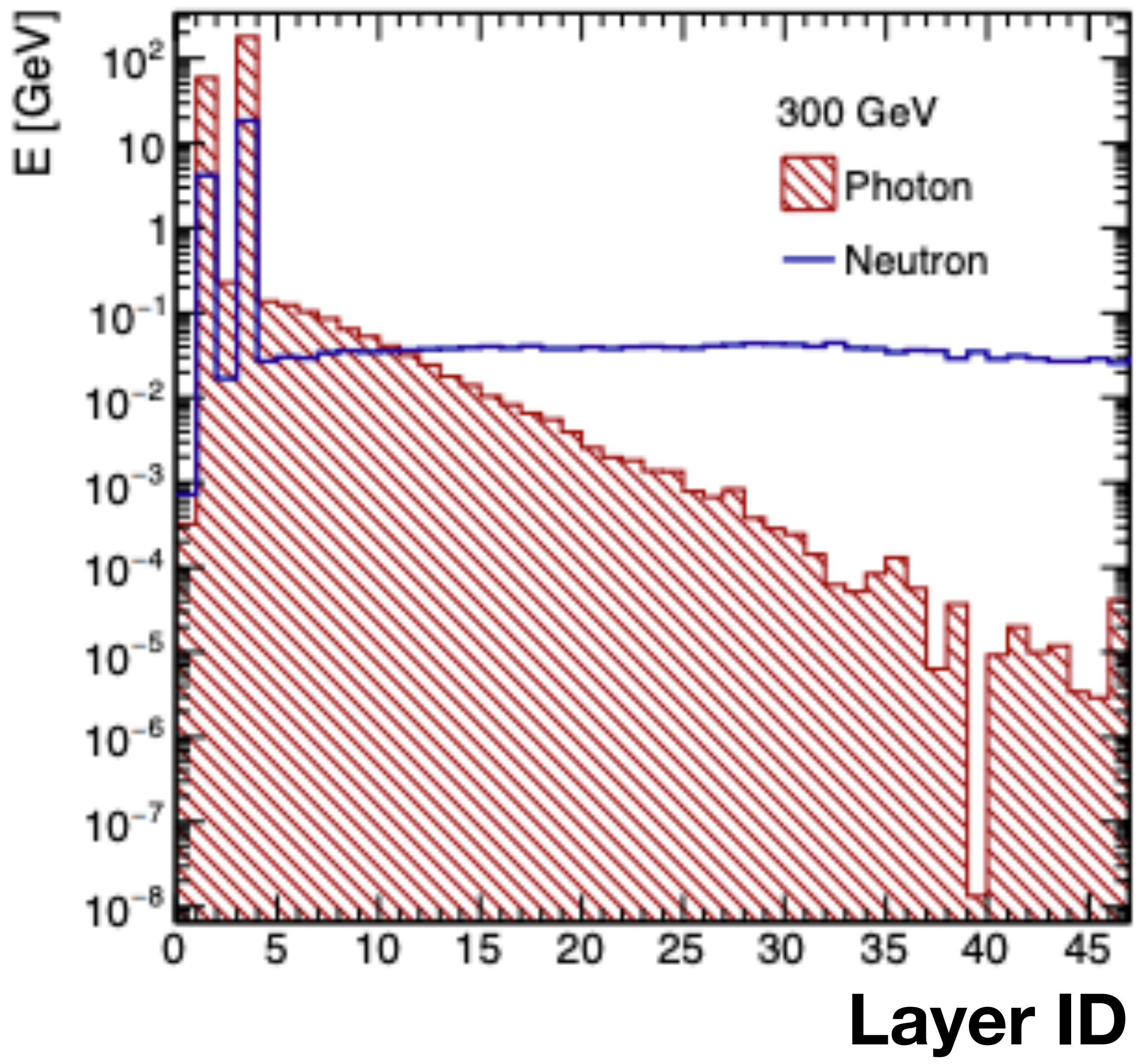
- Essential to EIC physics program
- Diffractive tagging and low Q^2 physics
- Development of a variety of far-forward and far-backward detectors ongoing



Example: ZDC

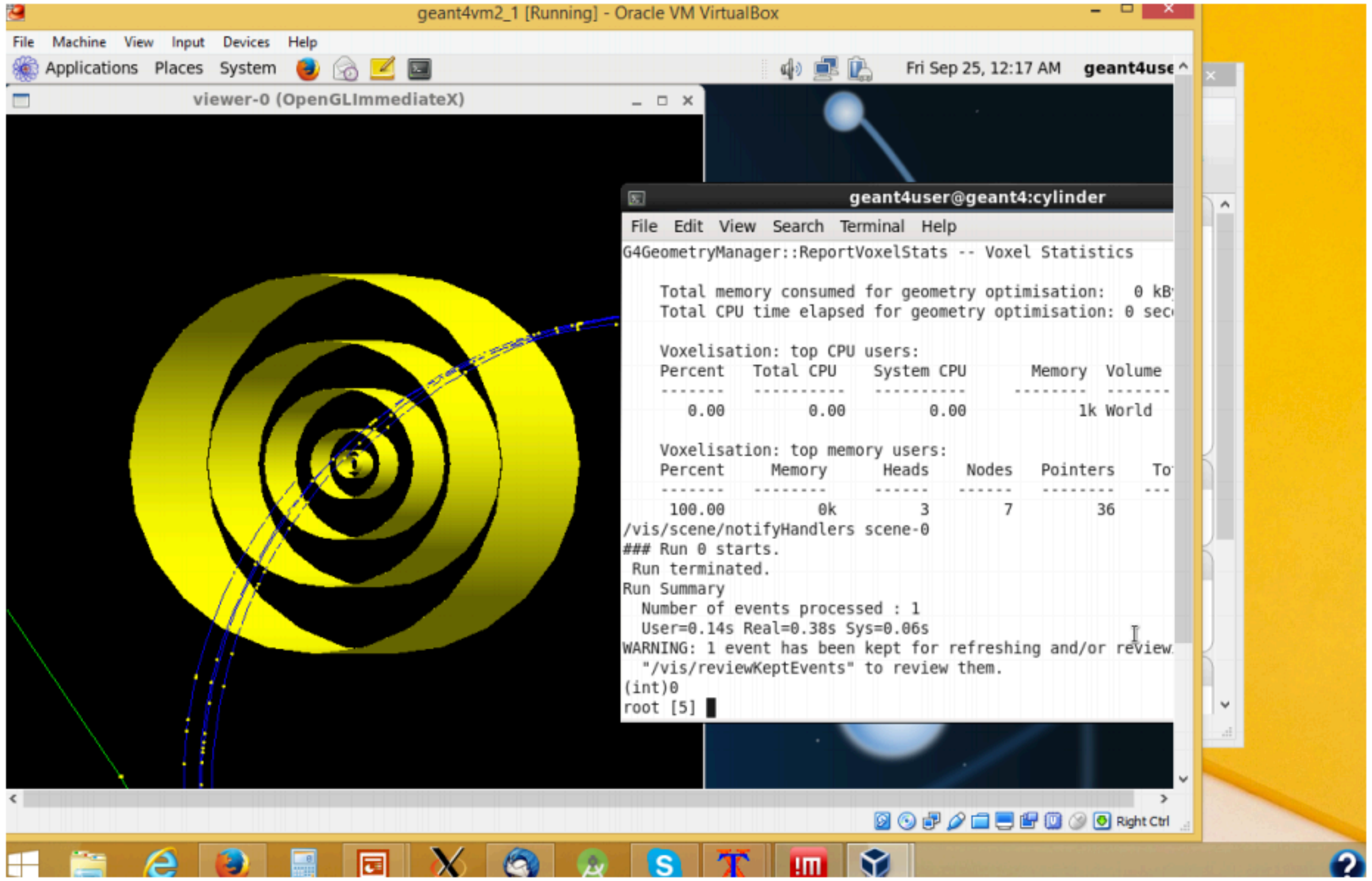
- Example of ongoing development - Zero Degree Calorimeter (ZDC)
  - Sandwiched layers of silicon + $PbWO_4$, tungsten+silicon, and lead-scintillator
- Used for tagging e.g. large η neutron production
- Additional ongoing studies with roman pots, low-Q^2 taggers, and more



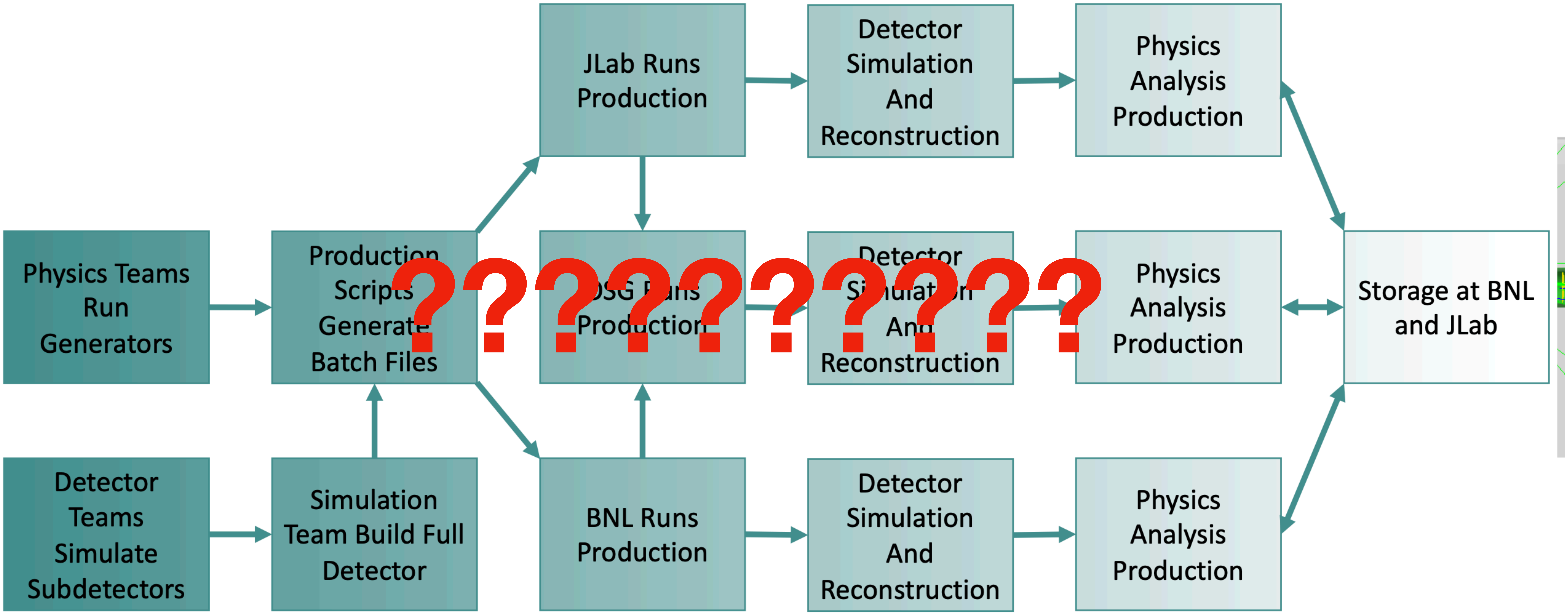


Software

- Distribute Singularity container nightly for software access anywhere, no account required
- Actively maintained open source repository
- Complete tutorial available: start from scratch to performing analysis in ~20 minutes



Full Simulation



Full Simulation

1. Physics groups generate physics Monte Carlo events

PYTHIA
DPMJet
PEPSI
gmc_trans
Djangoh
Milou
Rapgap
LEPTO

2. Detector groups optimize specific subdetectors in Geant4

3. Simulation groups assemble full detector in Geant4

4. Computing groups develop software for job processing and monitoring to produce data

    1. Data stored on disk at BNL and JLab

Full Simulation

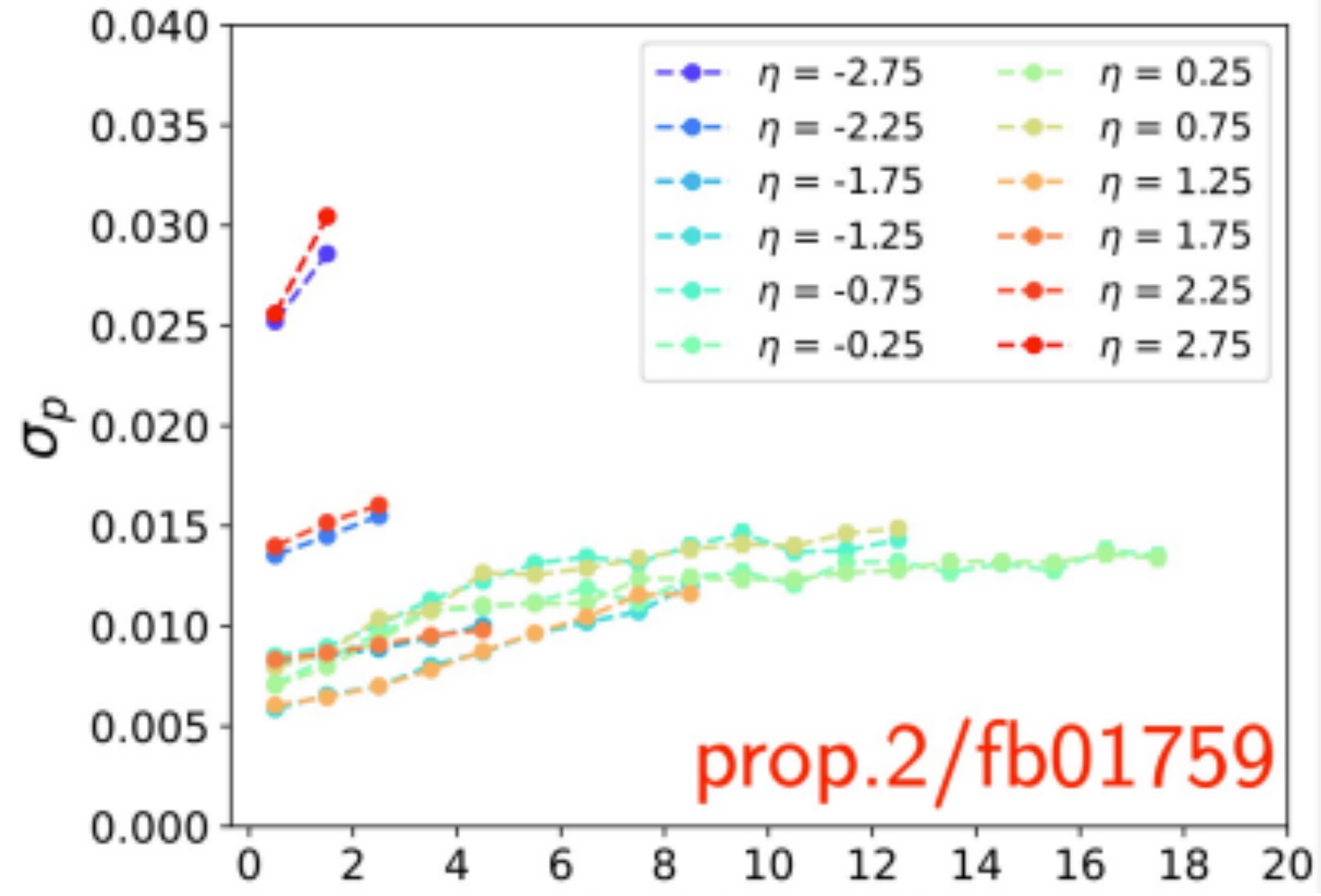
- Metadata is logged so that results are entirely reproducible

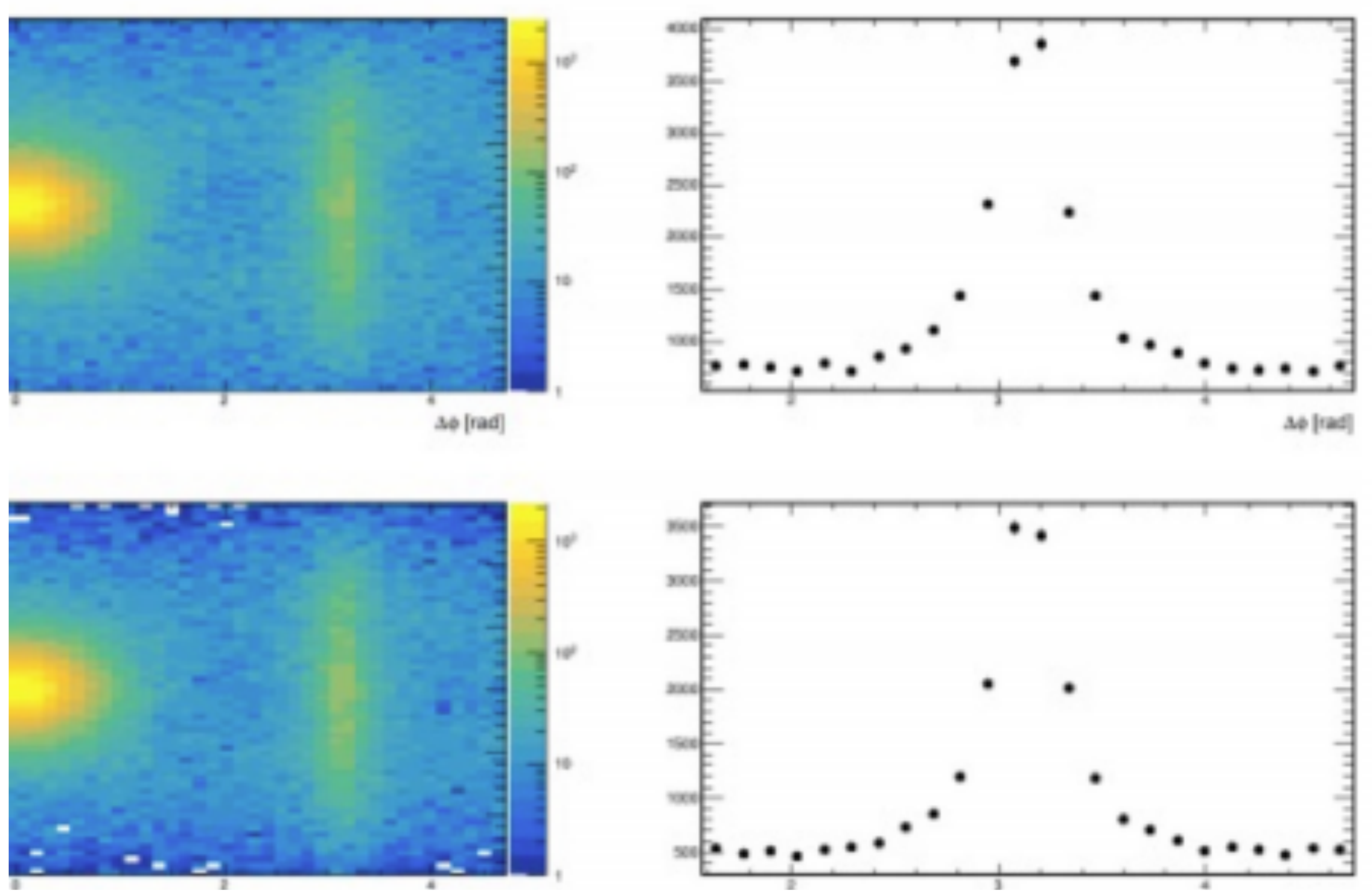
- All information used to produce the simulation data is stored in conjunction with the data itself

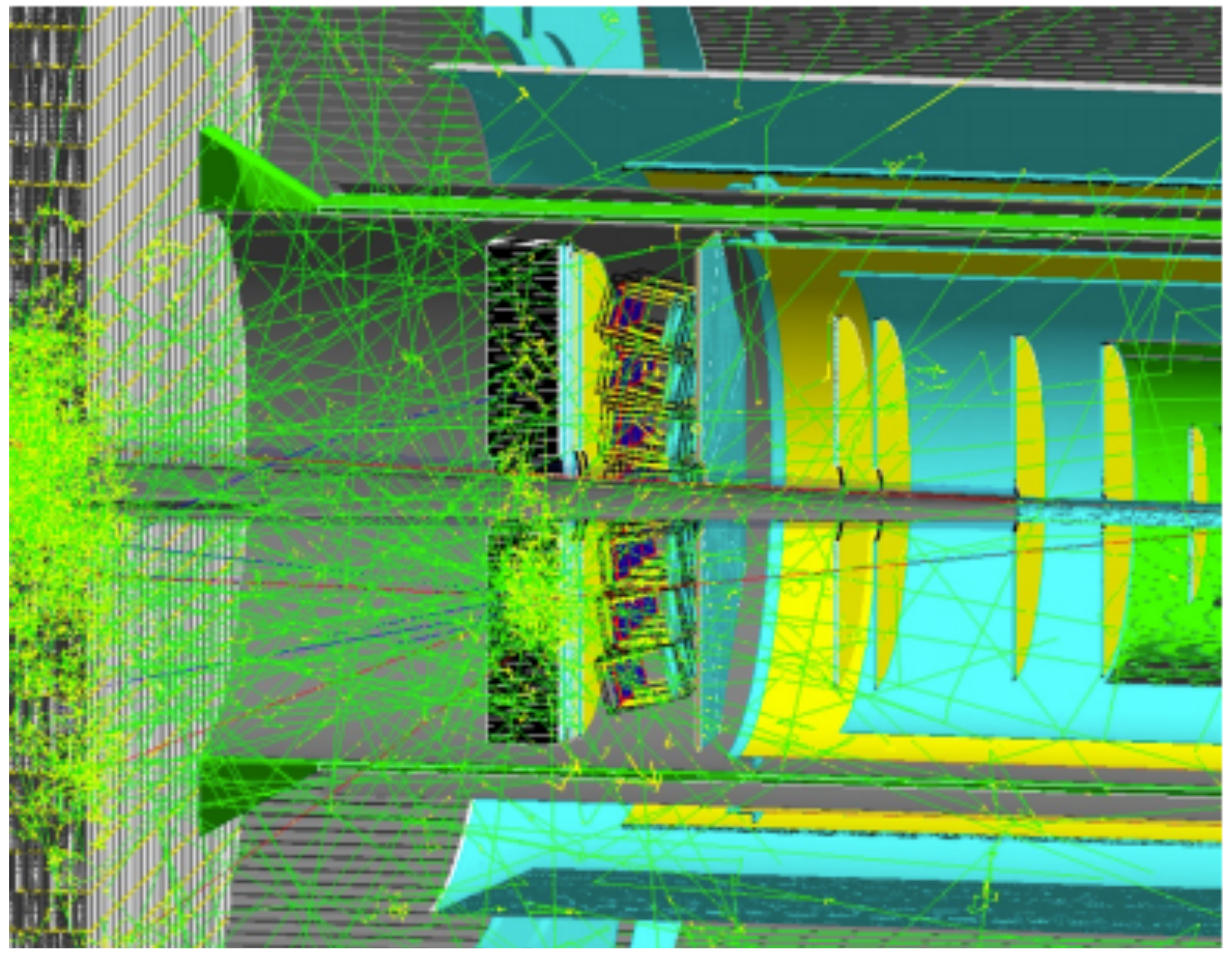
```
====== Your production details ======
Production started: 2021/07/25 17:10
Production site: BNL
Production Host: spool0680.sdcc.bnl.gov
ECCE build: prop.2
ECCE macros branch: production
ECCE macros hash: c131177
PWG: SIDIS
Generator: pythia6
Collision type: ep-10x100
Input file: /gpfs02/eic/DATA/YR_SIDIS/ep_10x100/ep_noradcor.10x100_run001.root
Output file: DST_SIDIS_pythia6_ep-10x100_000_0000000_05000.root
Output dir: /gpfs/mnt/gpfs02/eic/DATA/ECCE_Productions/MC/prop.2/c131177/SIDIS/pythia6/ep-10x100
Number of events: 5000
Skip: 0
=====================================
Seeds:
1322570549 (plus more)
md5sum:
01da8efd4555739dfa18fd96ee5b6a36
```

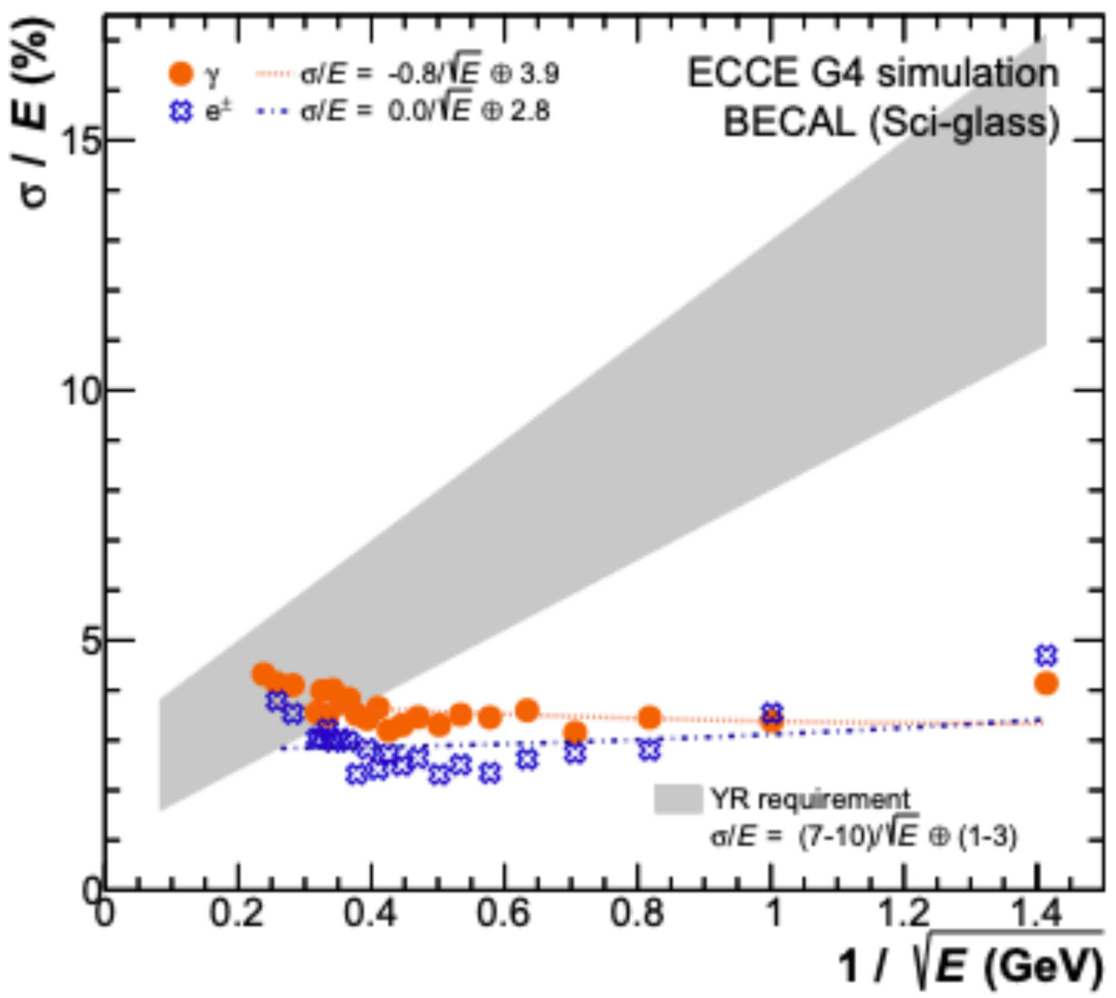
Fully and uniquely defines seed

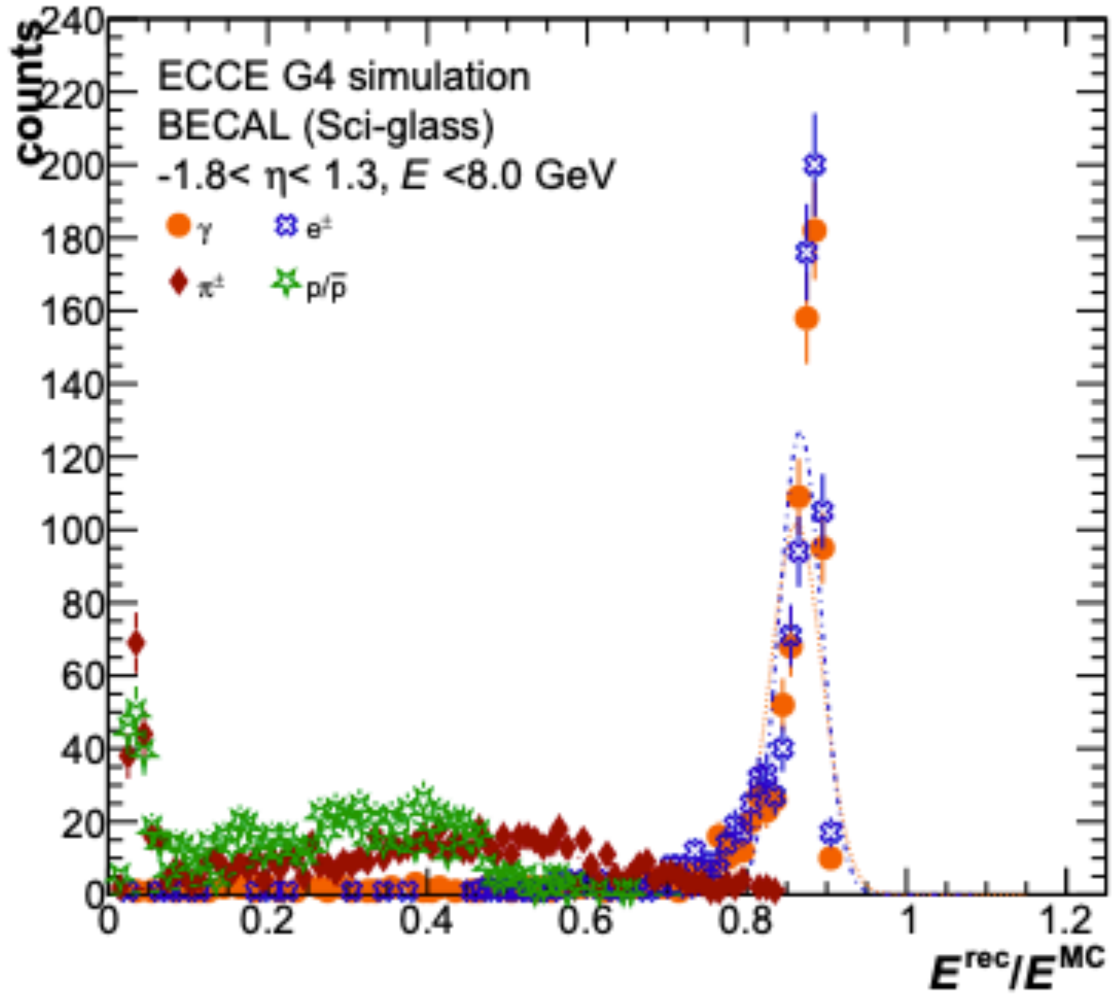
Full Simulation

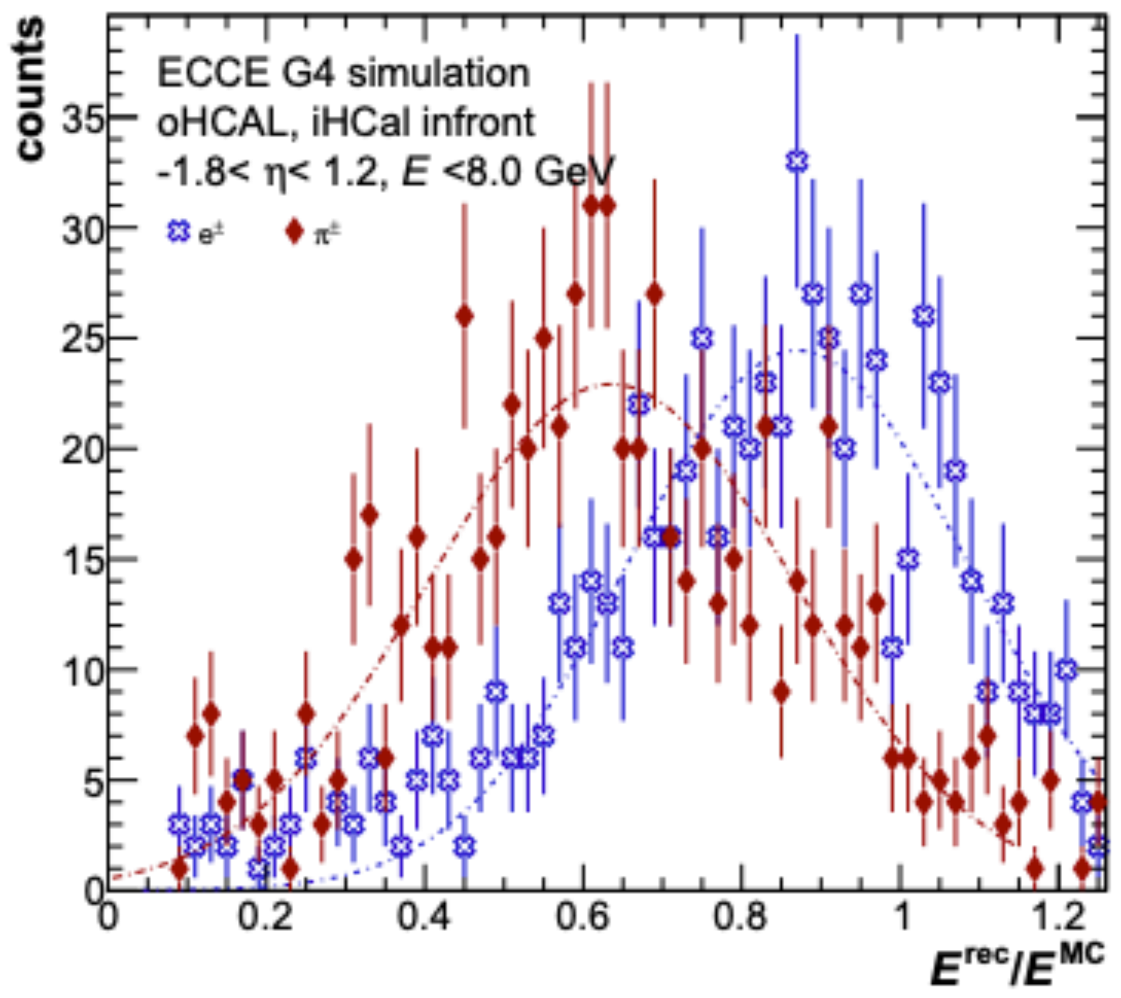


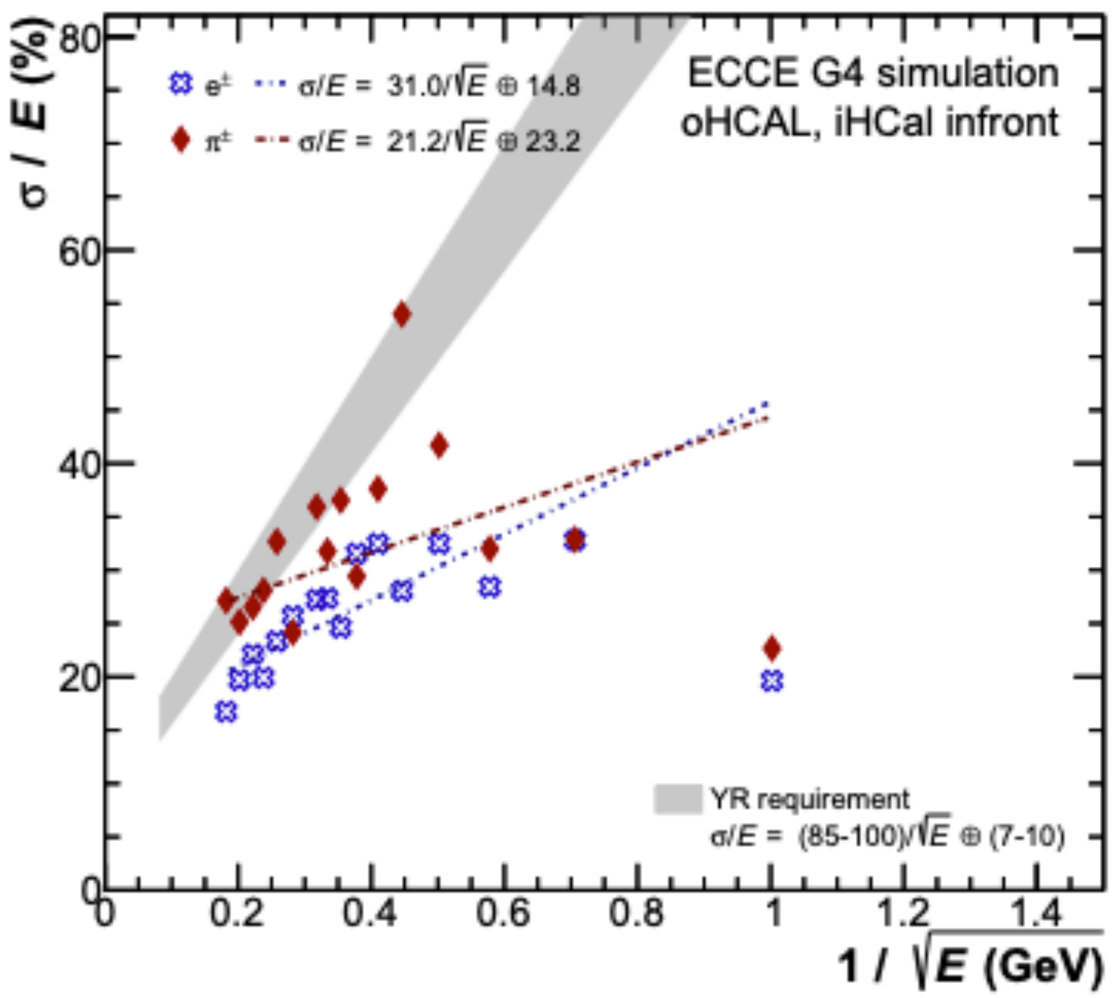












Conclusions

- ECCE software framework is well validated and has produced 150M *ep* collision simulation events for users to analyze
    - Simulation and software are used to optimize detector design
- Many different detector technologies implemented utilizing a variety of software packages
- Software is <u>ESSENTIAL</u> to the scientific process!
    - No detector simulations or data to analyze without software!
    - Necessary for any EIC experiment to guide and optimize detector designs