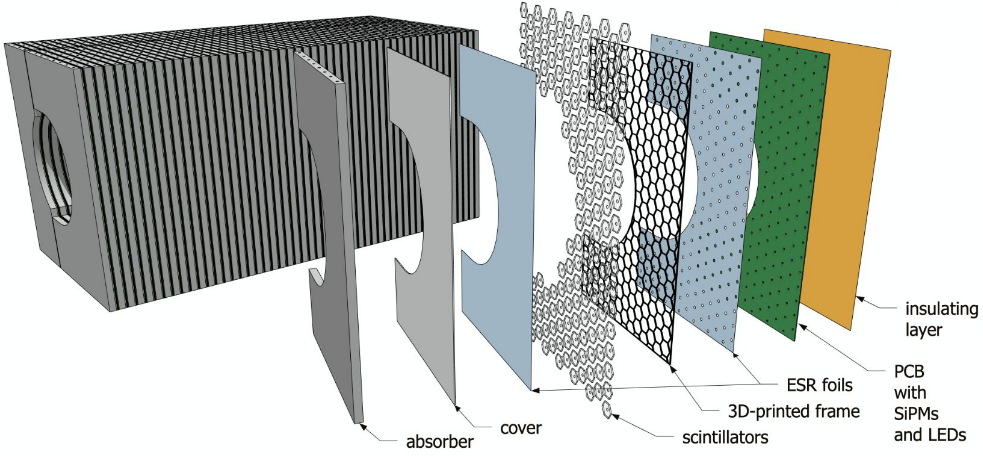
Jet studies with full calorimetry in forward direction

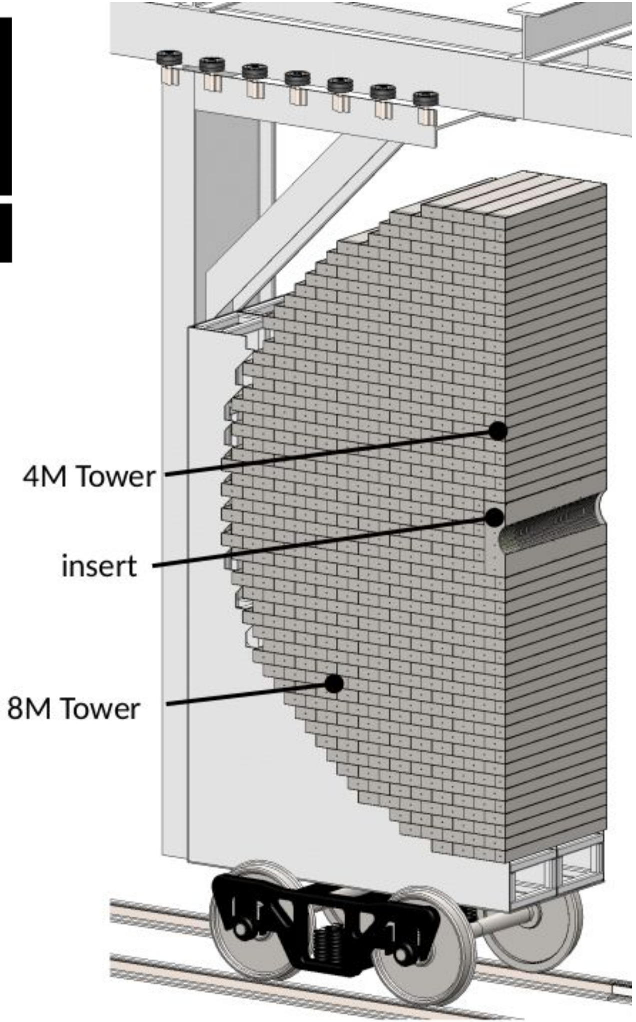
Miguel Arratia

UC RIVERSIDE

The high-granularity Insert

Covers 3.0<η<4.0 of forward HCAL

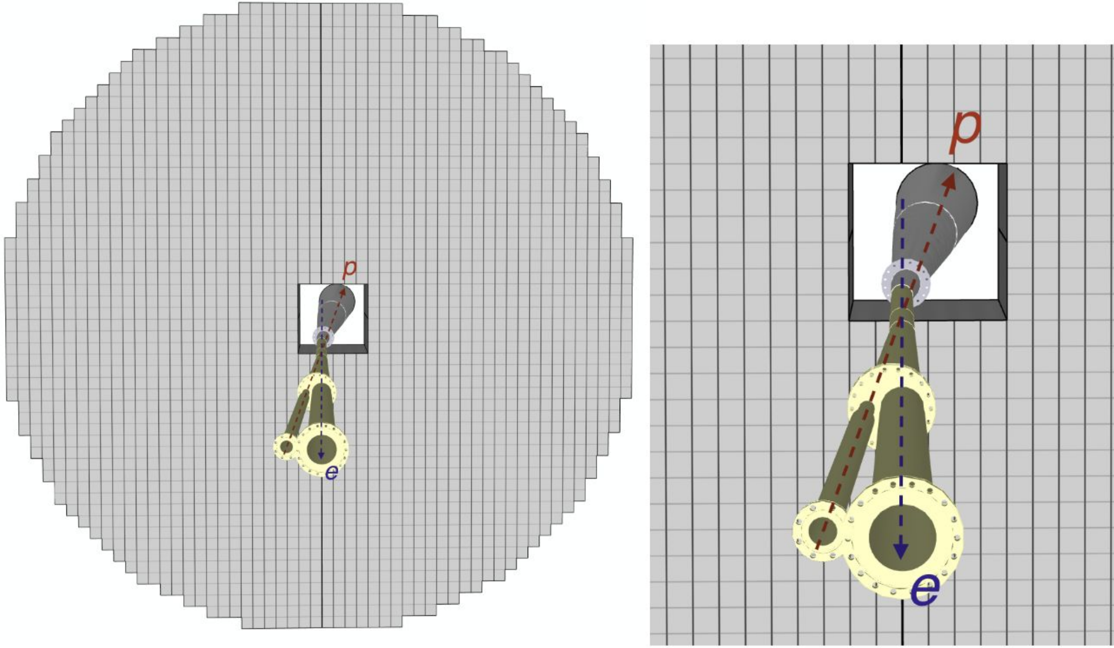




M. Arratia et al. NIMA 1047 (2023) 167866

Introduction

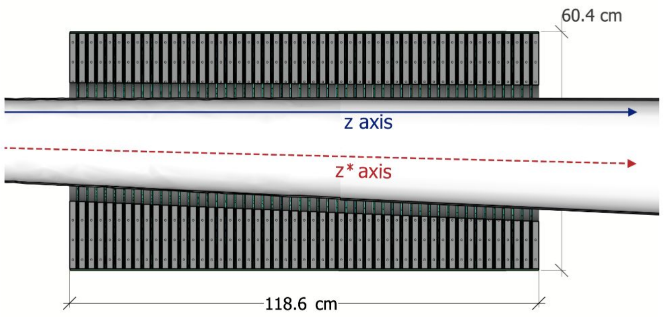
- A key goal of EIC: 2π azimuthal coverage in wide range in η with full calorimetry.
  - Nominally -4.0<η<4.0
  - At large |η|, detector designs are constrained by the shape of the beampipe.

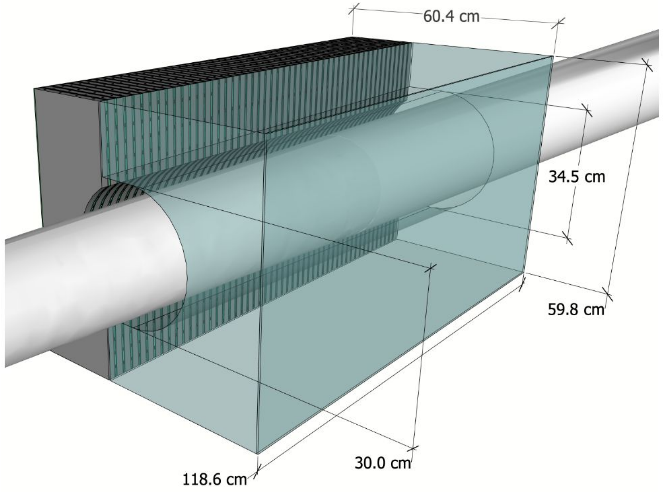


M. Arratia et al, Nucl. Instr. Meth. 1047, (2023), 167866

Design requirements

- High-granularity sampling hadronic calorimeter
- Surrounds the beampipe
    - Asymmetric geometry due to conical beampipe envelope with axis NOT || to lab-frame *z*.
    - Each layer has a different diameter and position of the hole
- Integrates with surrounding Endcap HCal.
    - Split in two parts with the surrounding endcap



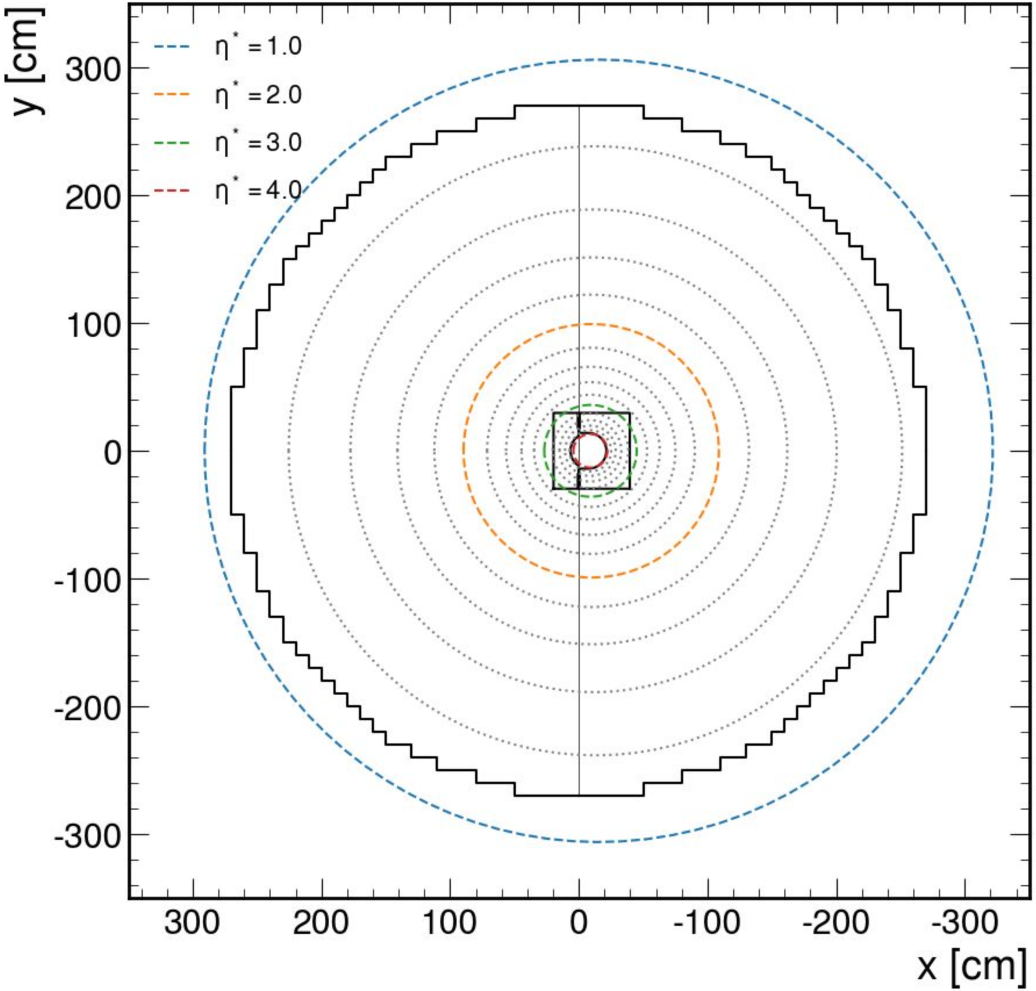


M. Arratia et al, Nucl. Instr. Meth. 1047, (2023), 167866

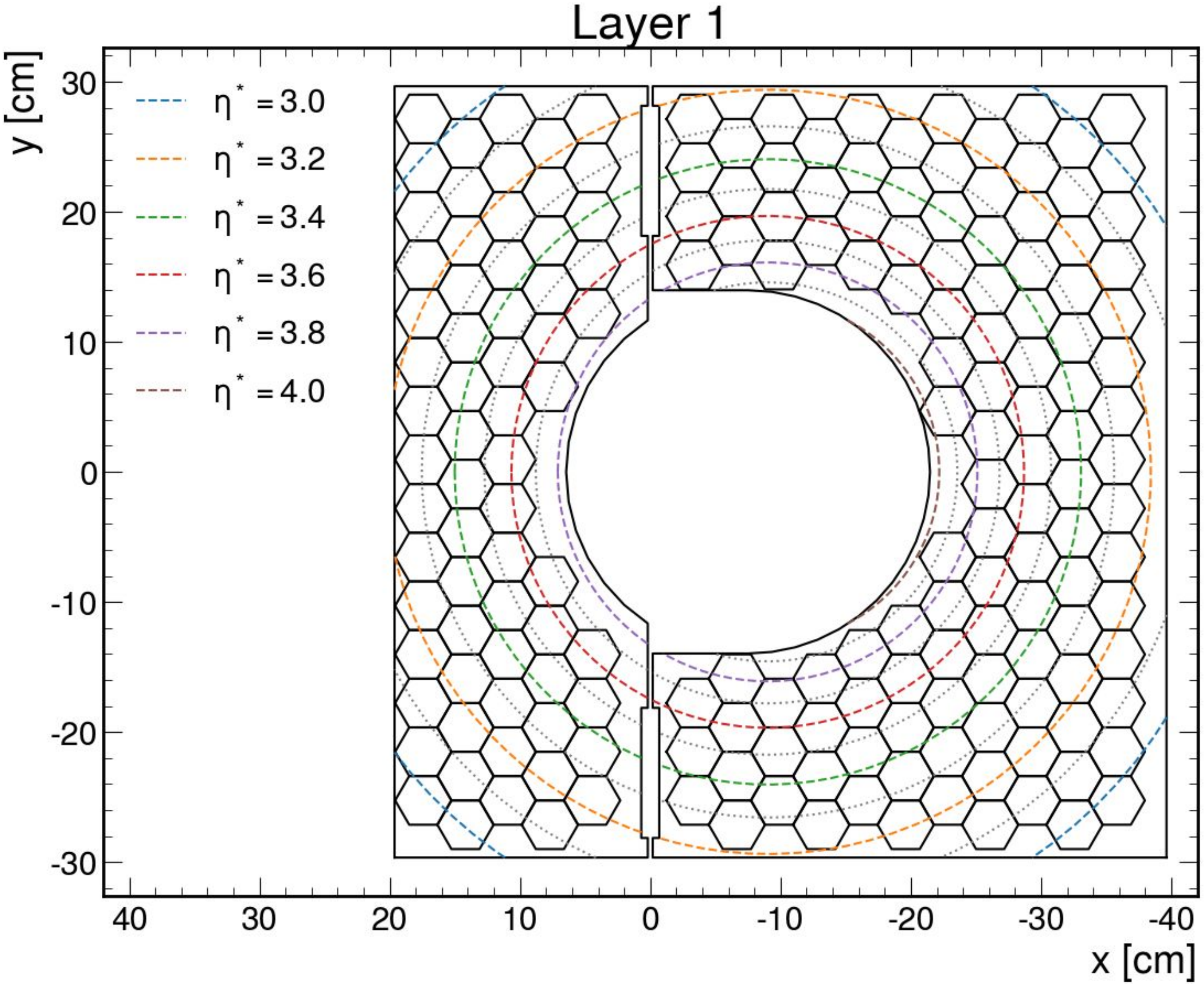
Coverage of the insert

Though much smaller than the endcap, it covers a very large range in pseudorapidity for its size:

- Endcap (without insert): roughly $1<\eta^*<3$
- Insert: roughly $3<\eta^*<4$,
  - about ⅓ of the total η^* coverage in ~1.5% of its total area
  - High density of incident particles

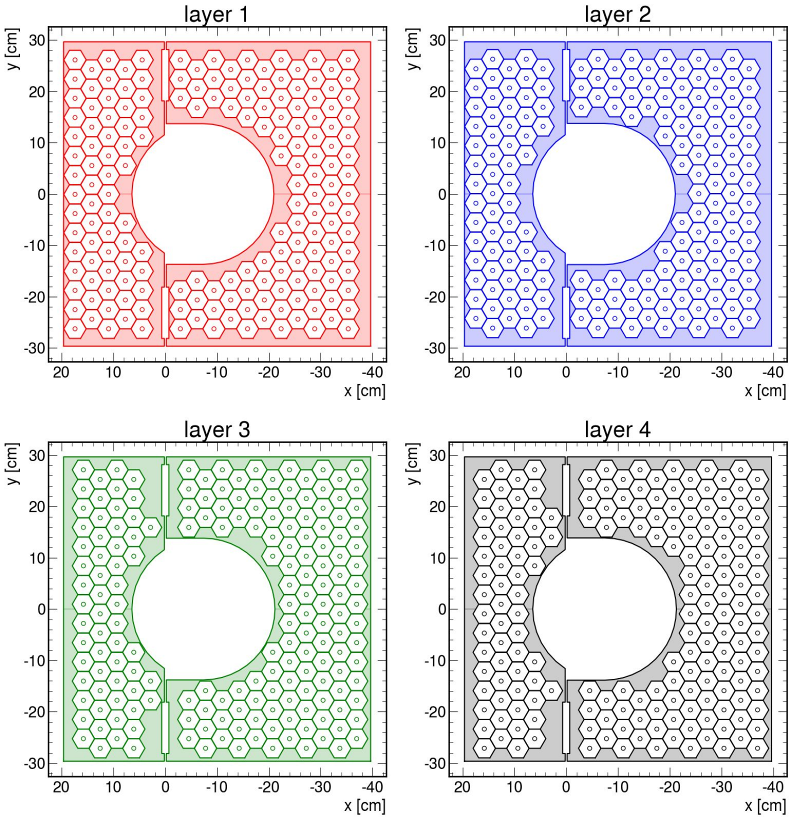


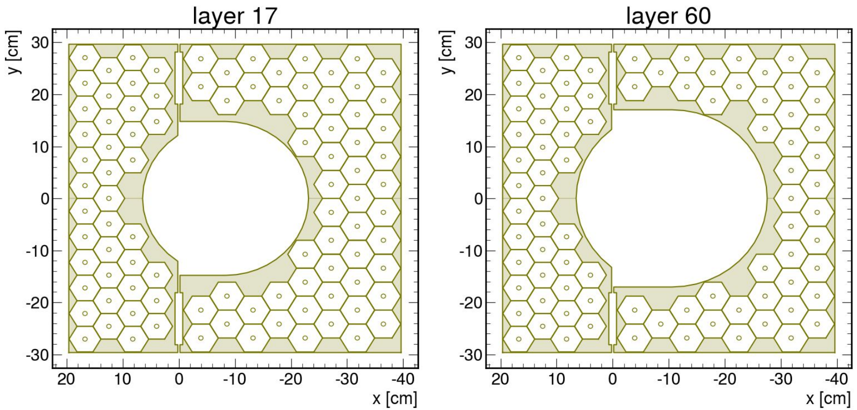
Rings of constant eta on the insert



Layer granularity

- 16 staggered, high-granularity layers
- 44 unstaggered, low-granularity layers
- Total channels: 6710





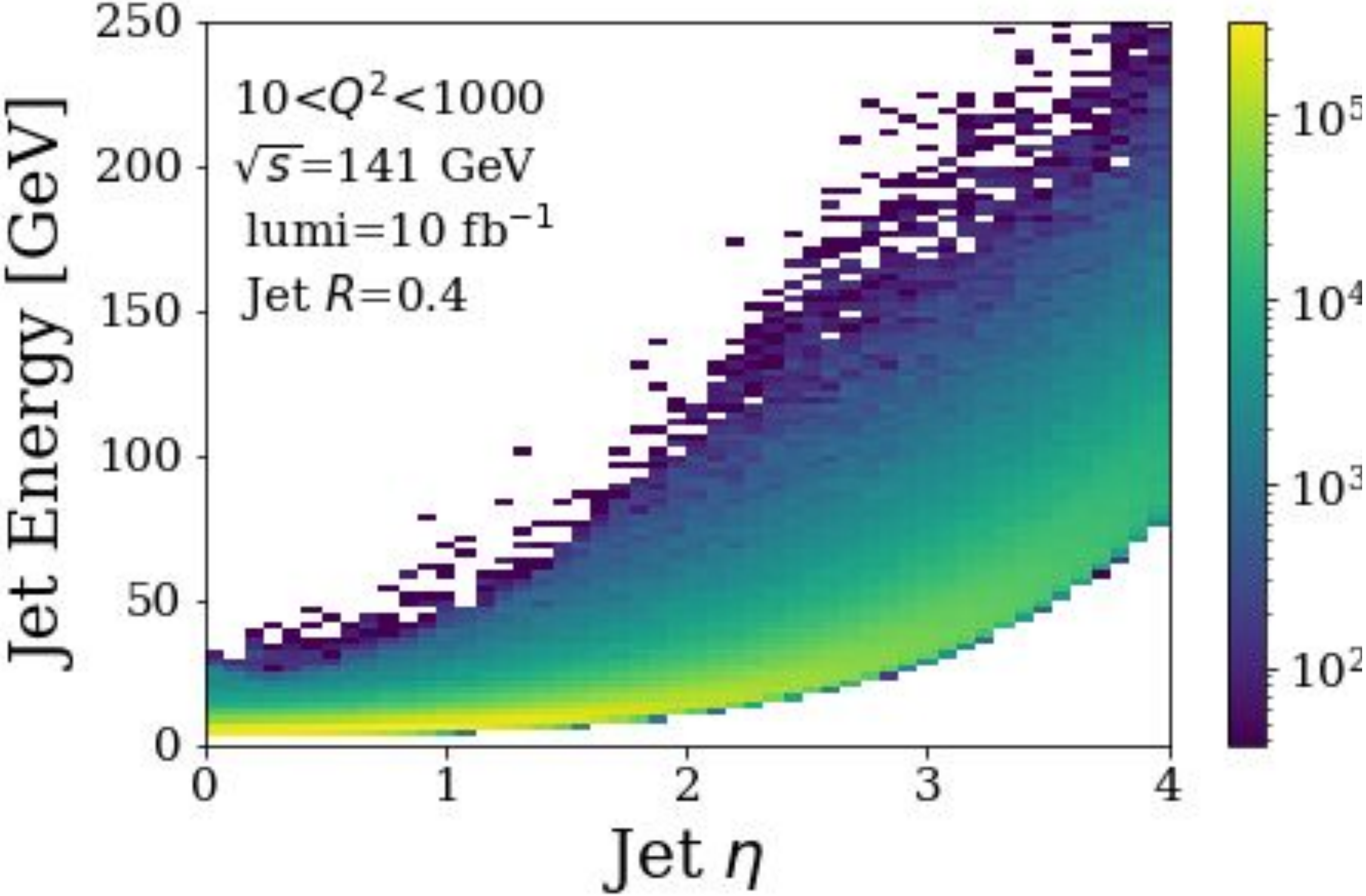
Insert Motivations

The calorimeter insert concept is the only way ever proposed to satisfy the first two detector requirements in forward HCAL. That is, it is the only way to cover up to eta=4.0

Detector Requirements Below we summarize the critical detector requirements that are imposed by the rich physics program of an EIC.

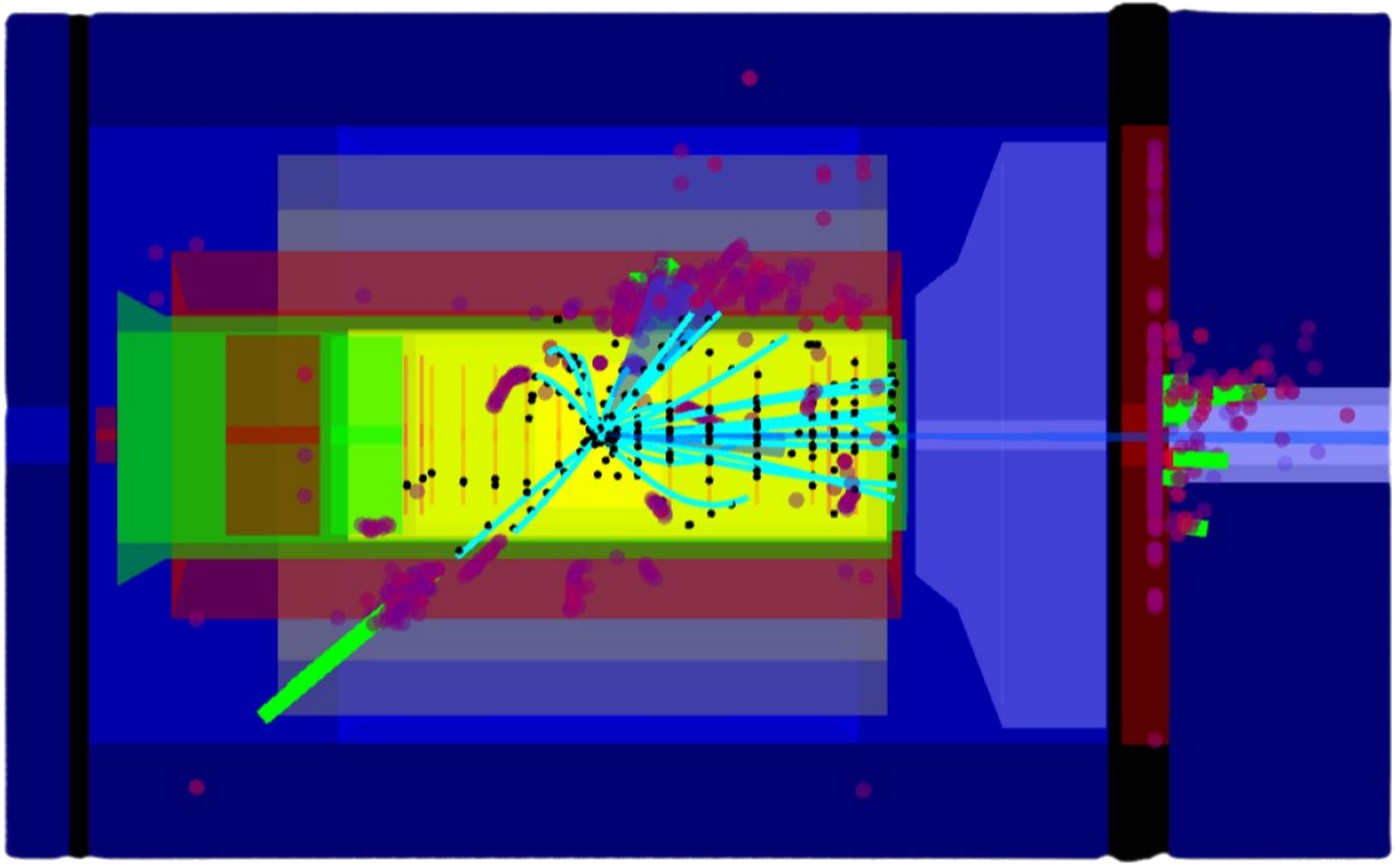
- The EIC requires a 4π hermetic detector with low mass inner tracking.
- The primary detector needs to cover the range of $-4 < \eta < 4$ for the measurement of electrons, photons, hadrons, and jets. It will need to be augmented by

Jet Spectra



$10<Q^2<1000$
$\sqrt{s}$=141 GeV
lumi=10 fb^{-1}
Jet R=0.4
Jet Energy [GeV]
Jet η
250
200
150
100
50
0
0
1
2
3
4
10^5
10^4
10^3
10^2

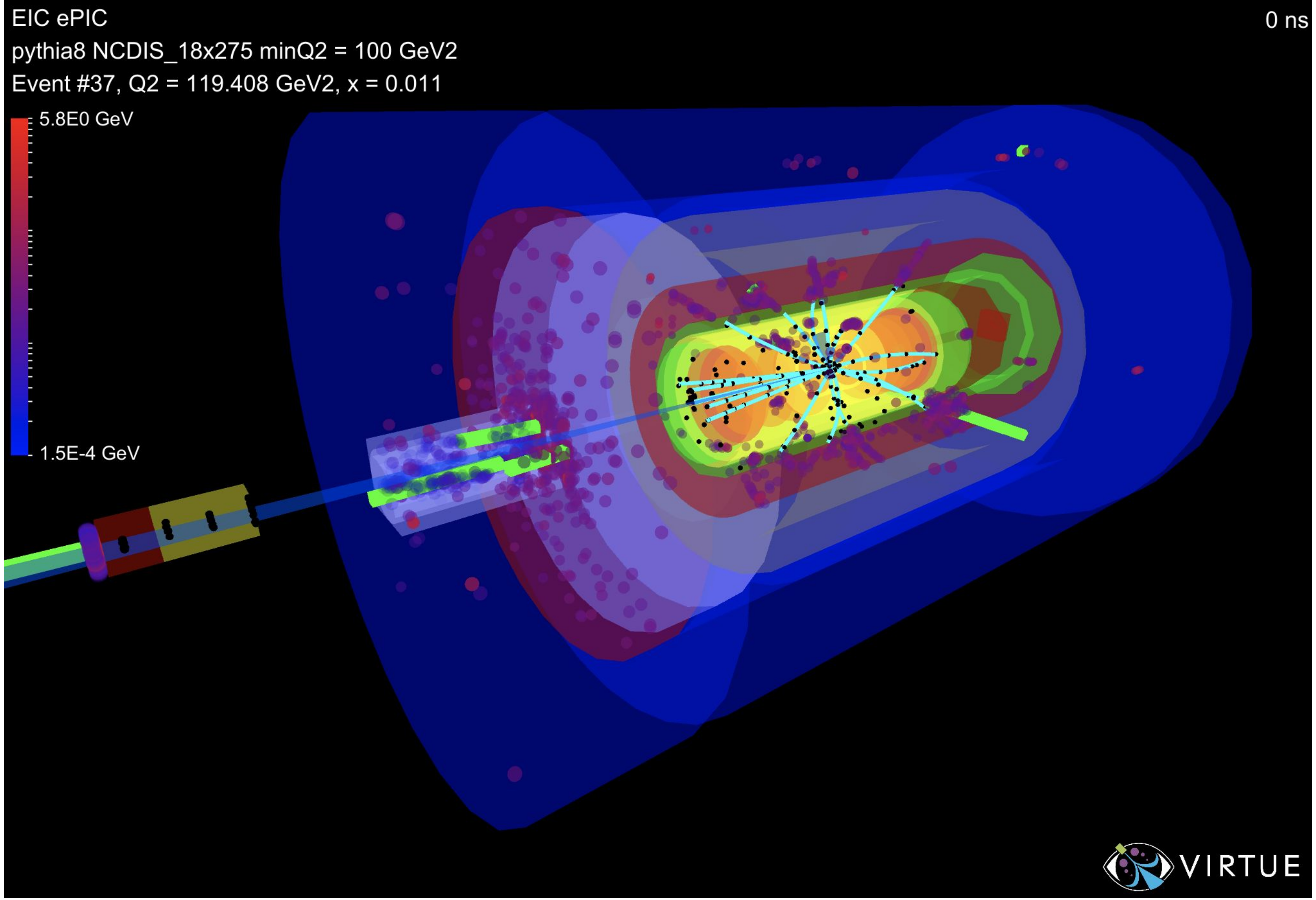
Insert is critical for hermeticity. This is needed for proper hadronic final state reconstruction, which is needed to limit QED corrections.



Forward jets

Insert covers the whole region of 3.0<η<4.0. We must have coverage in this region.

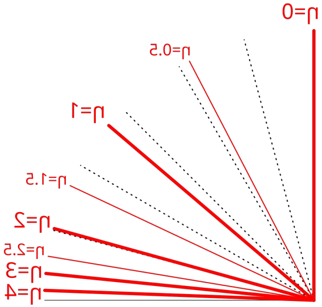
Note this is more than ⅓ of phasespace of HCAL in eta/phi space.

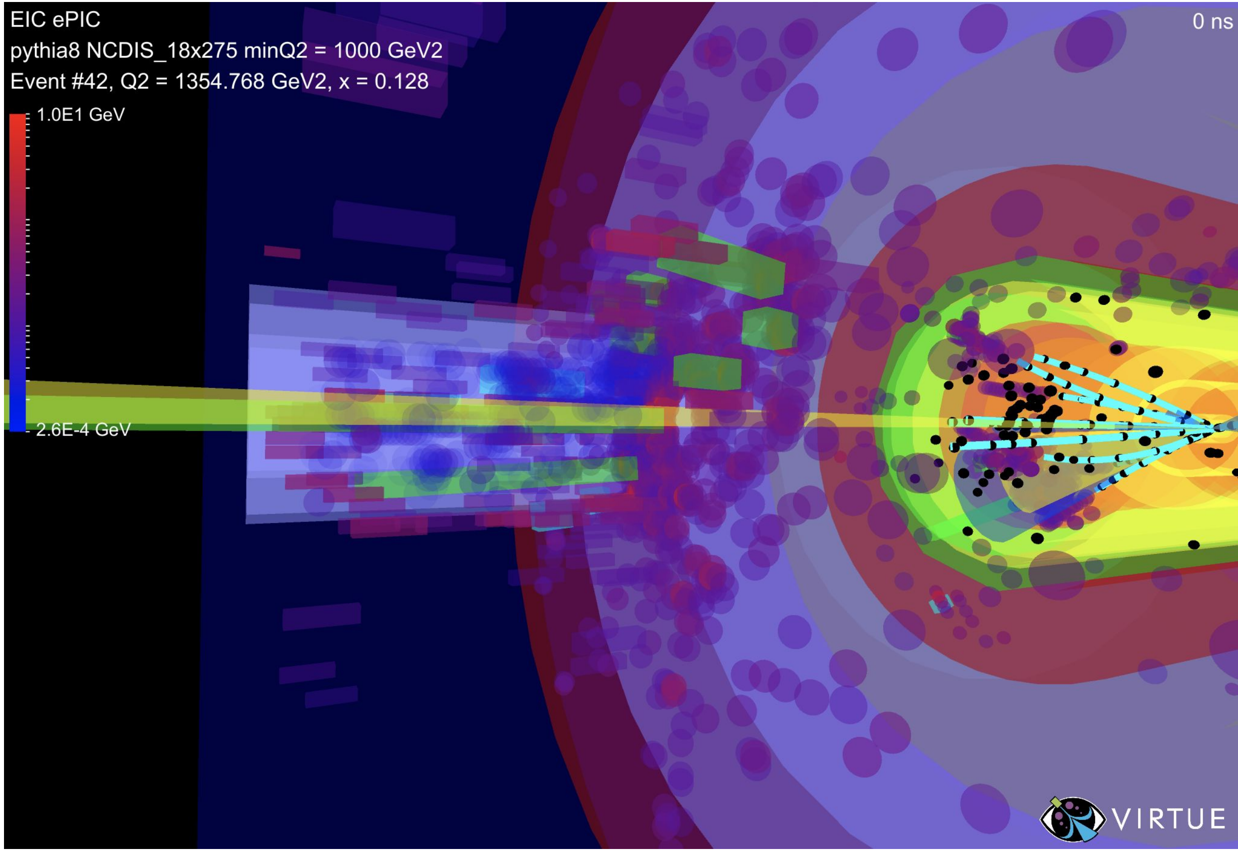


Forward jets

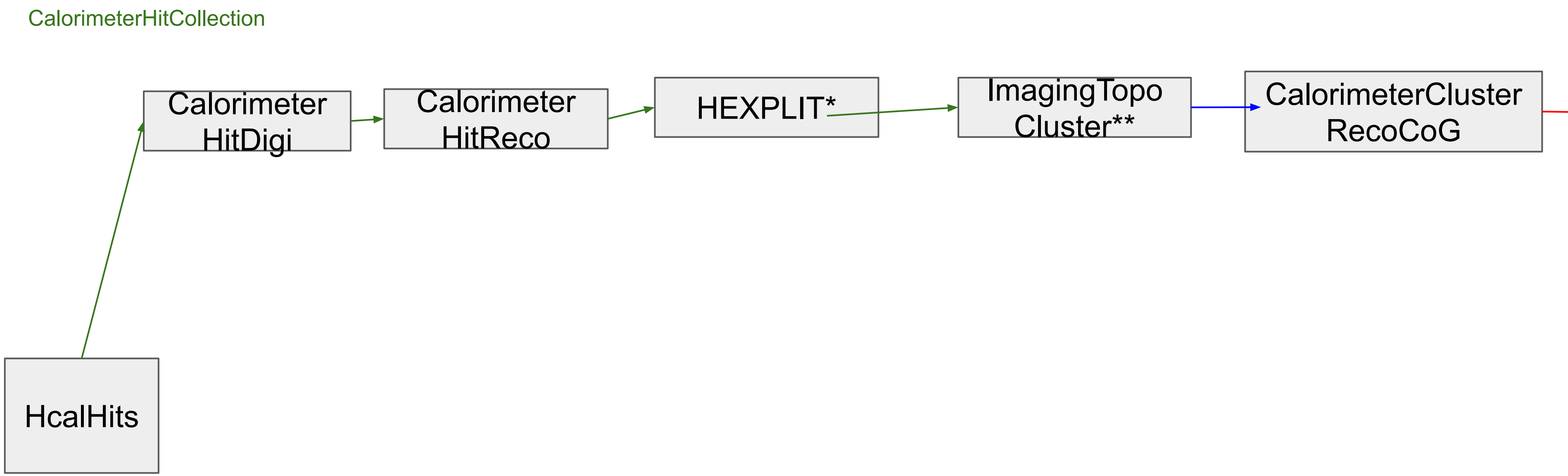
Higher granularity of insert is needed to account for increased particle density with eta

dE/dη constant, but eta diverges hyperbolically





The software reconstruction chain, clustering, for Insert is as advanced as anything else in ePIC



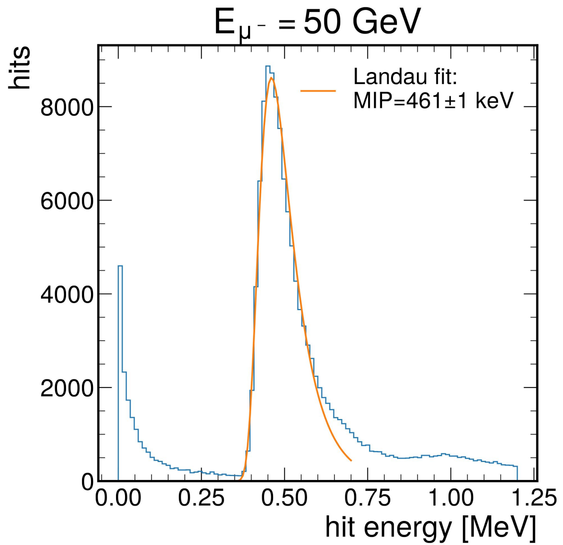
* https://doi.org/10.1016/j.nima.2023.169044

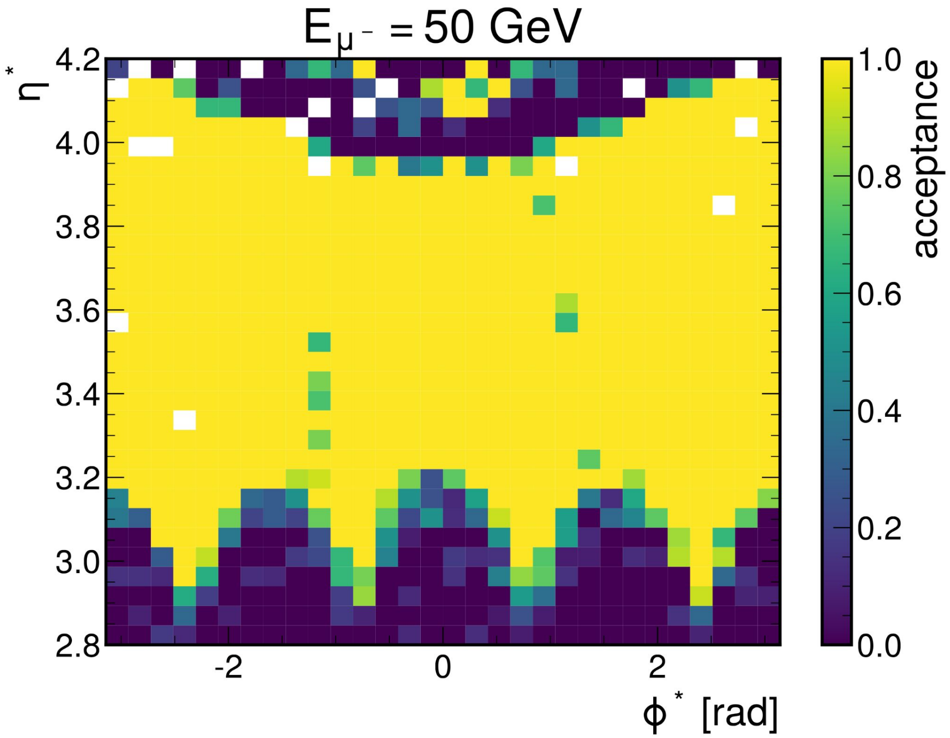
** https://doi.org/10.1140/epjc/s10052-017-5004-5

Muons

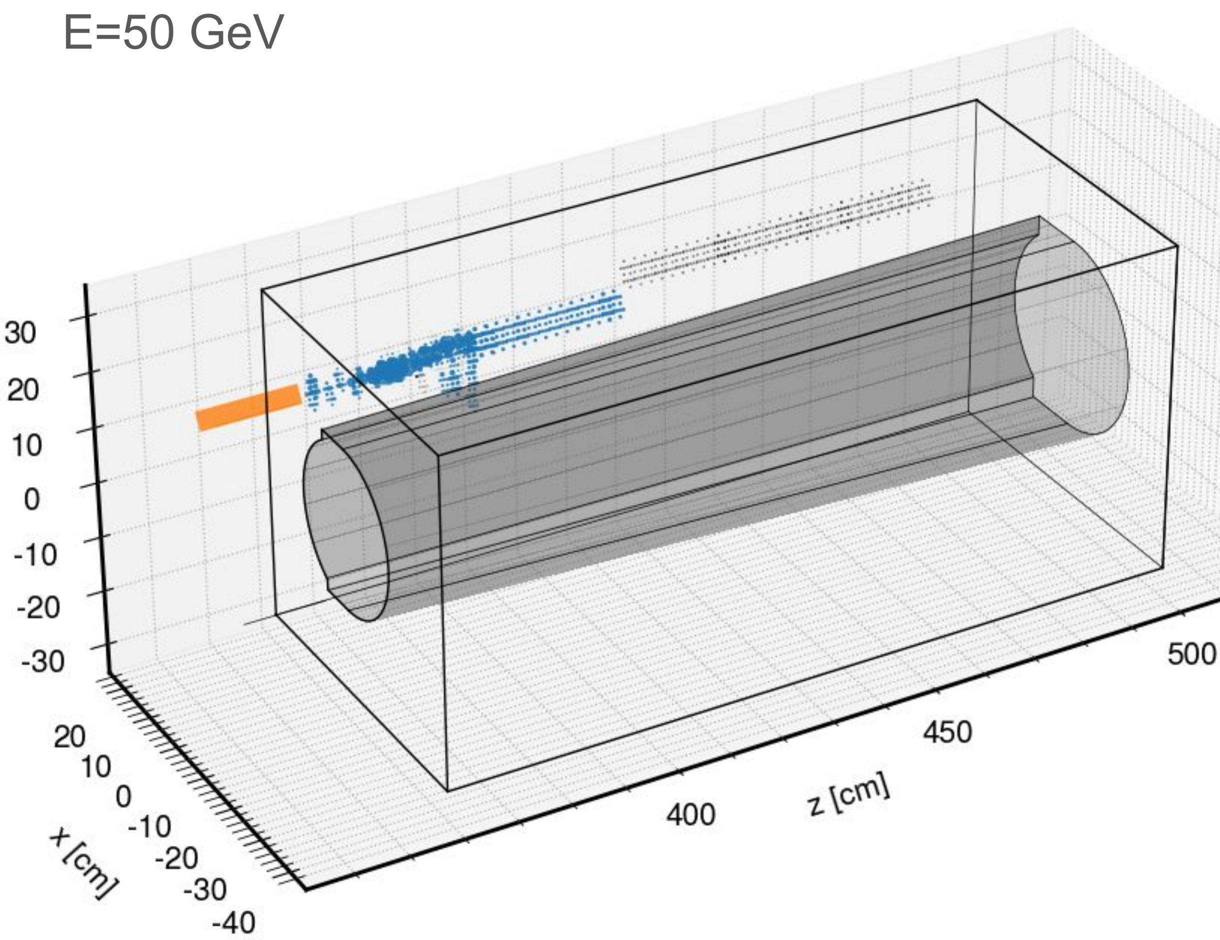
https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_muon

- Purpose:
  - Determine MIP value
  - Determine the acceptance (# of single μ- events with at least one hit>0.5 MIP)/(# total events)





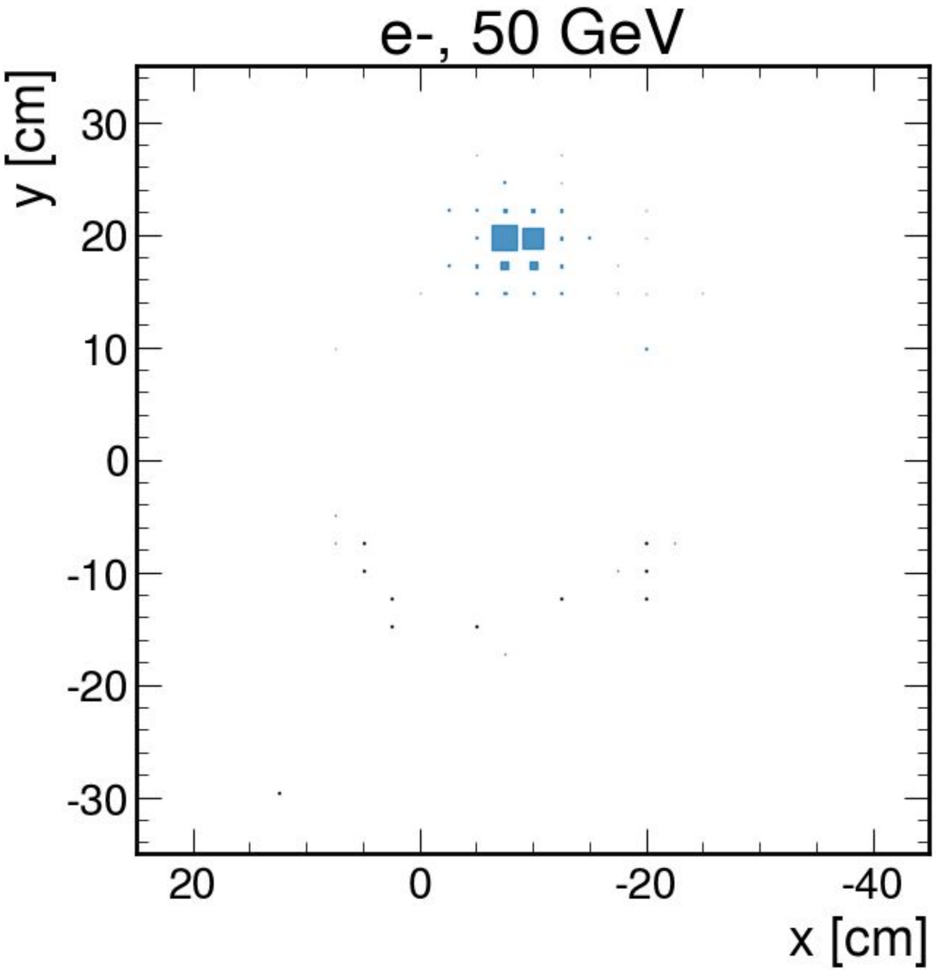
Muon
(event display)



Electron benchmark
(in progress)

Purpose:

- Determine energy scale of the forward Ecal endcap (FEMC)
- Checks that the clustering in the FEMC identifies one cluster per electron

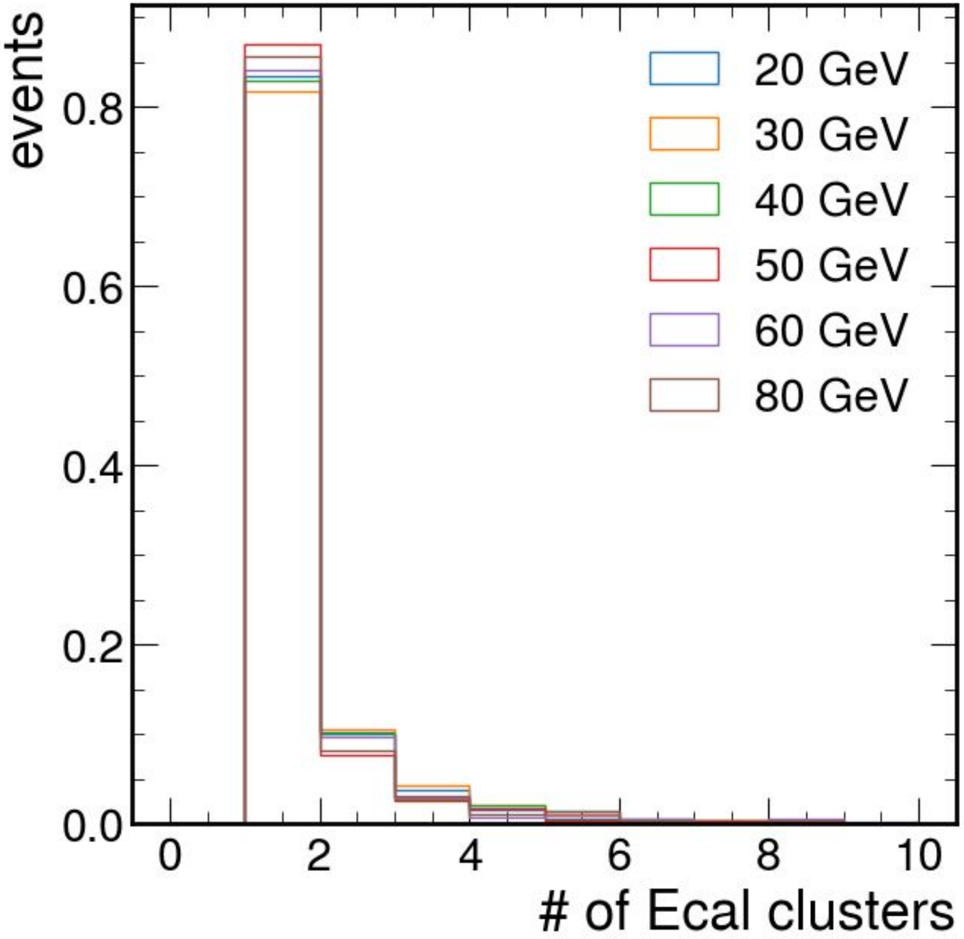


https://github.com/eic/detector_benchmarks/tree/femc_electron

Electron benchmark (in progress)

Purpose:

- Determine energy scale of the forward Ecal endcap (FEMC)
- Checks that the clustering in the FEMC identifies one cluster per electron

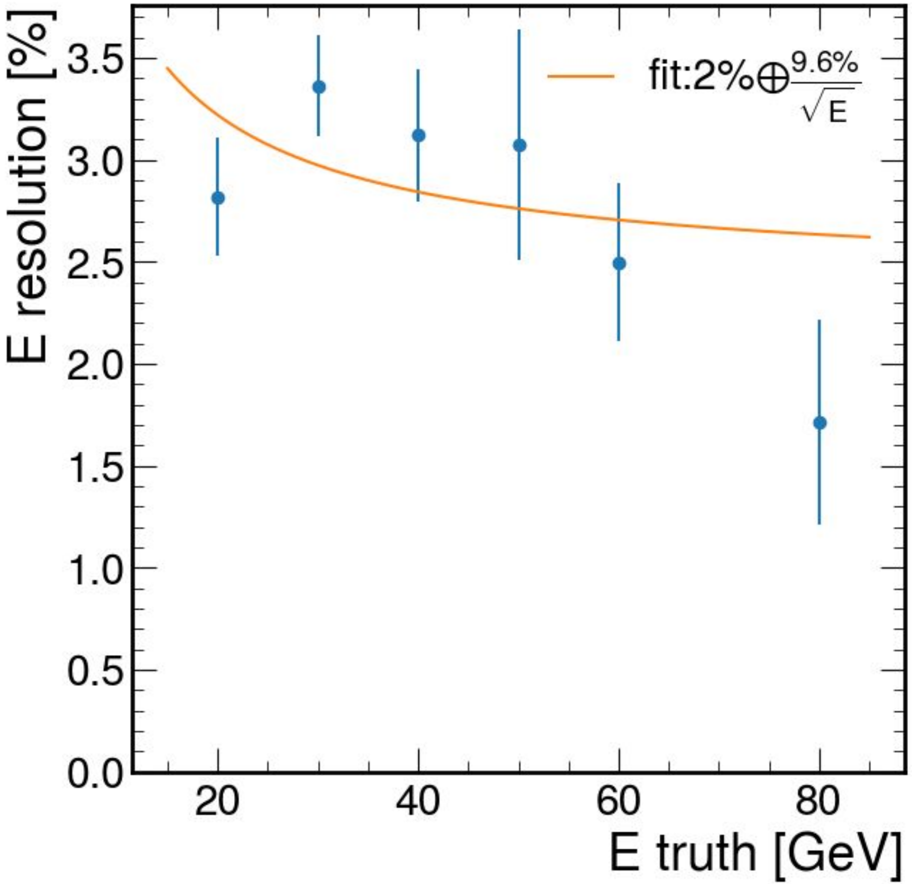


https://github.com/eic/detector_benchmarks/tree/femc_electron

Electron benchmark (in progress)

Purpose:

- Determine energy scale of the forward Ecal endcap (FEMC)
- Checks that the clustering in the FEMC identifies one cluster per electron

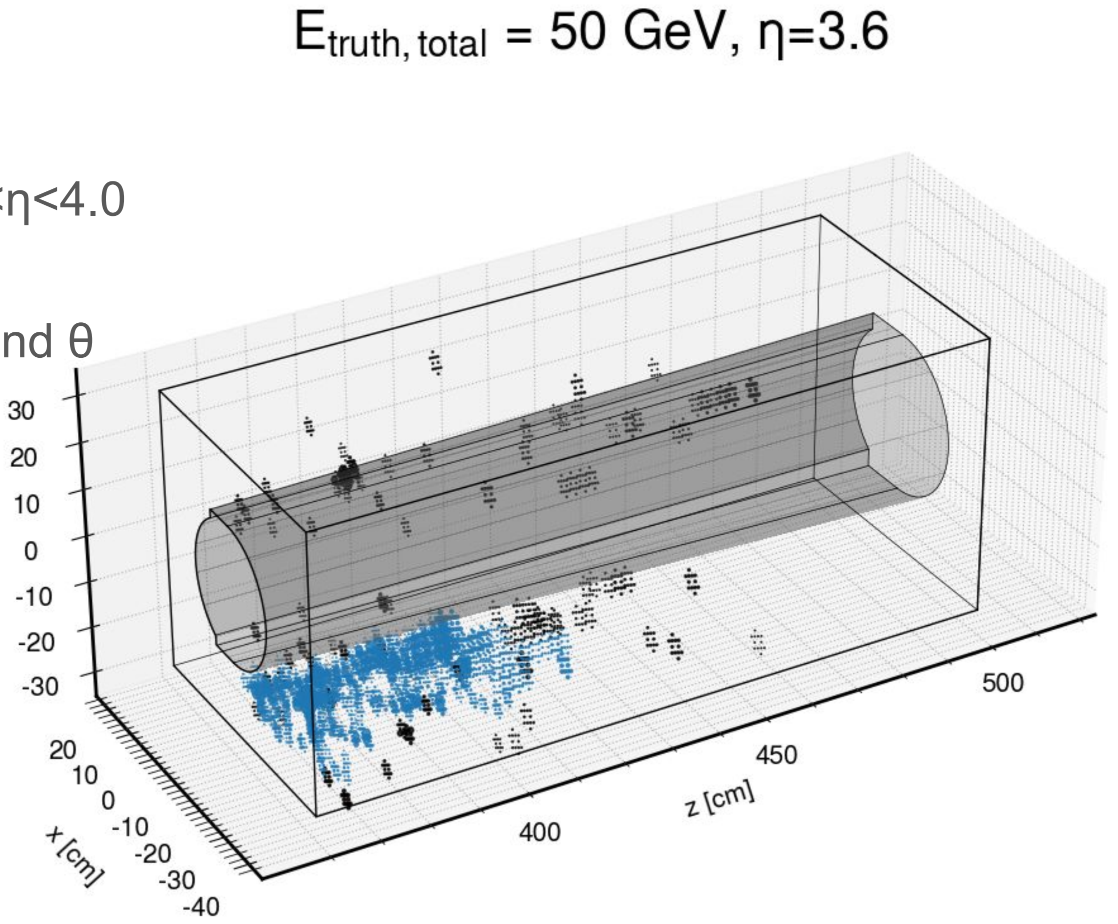


https://github.com/eic/detector_benchmarks/tree/femc_electron

Neutron benchmark

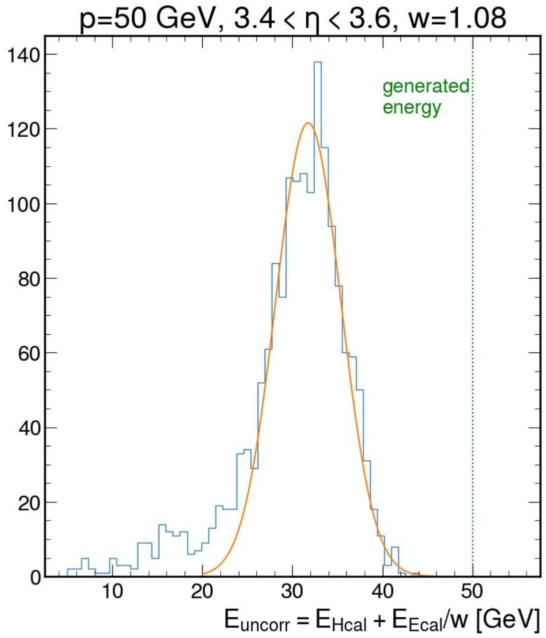
- Neutrons generated with $3.0<\eta<4.0$
- Determine energy and theta resolution as a function of p and θ

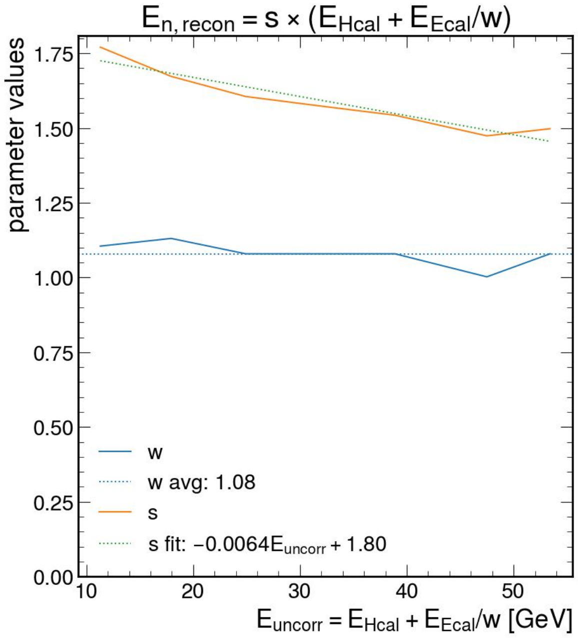
https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_neutron



Neutron energy reconstruction

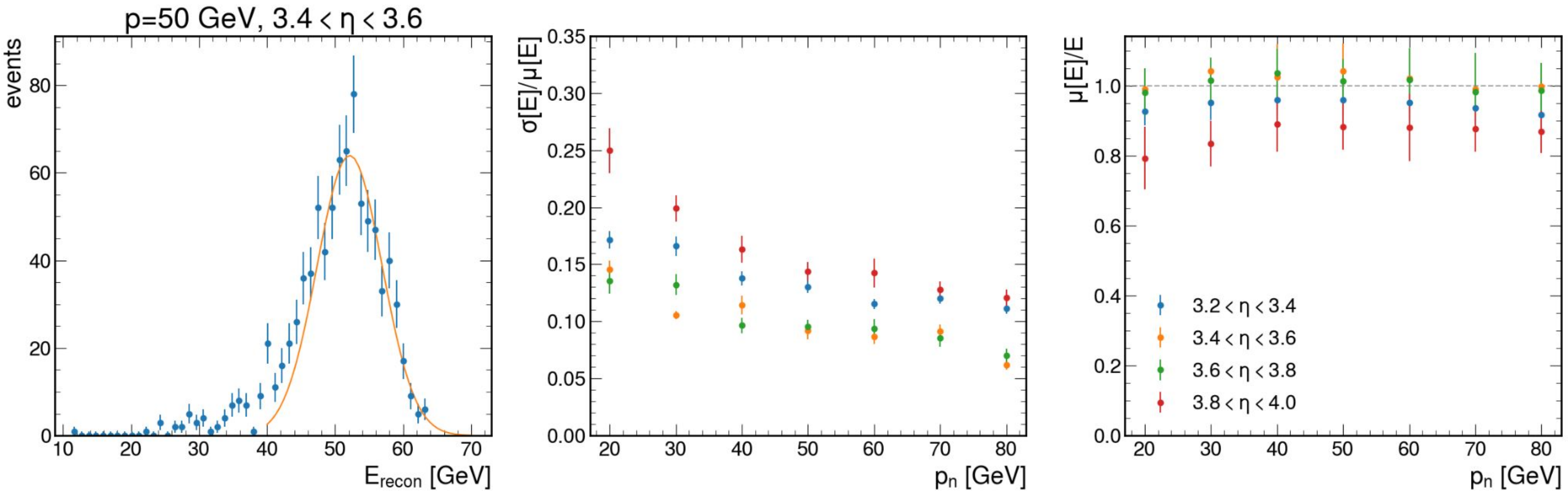
- Hcal sampling fraction determined at EM scale
- To correct for e/h effects:
  - w parameter: relative energy scale of Ecal vs. Hcal
    - Determined by minimizing σ/μ ratio for gaussian fits to $E_{uncorr}=E_{Hcal}+E_{Ecal}/w$ distribution
  - s parameter: Energy dependent overall scale of e/h. Determined as 1/μ of E_{uncorr}/E_{truth} distribution



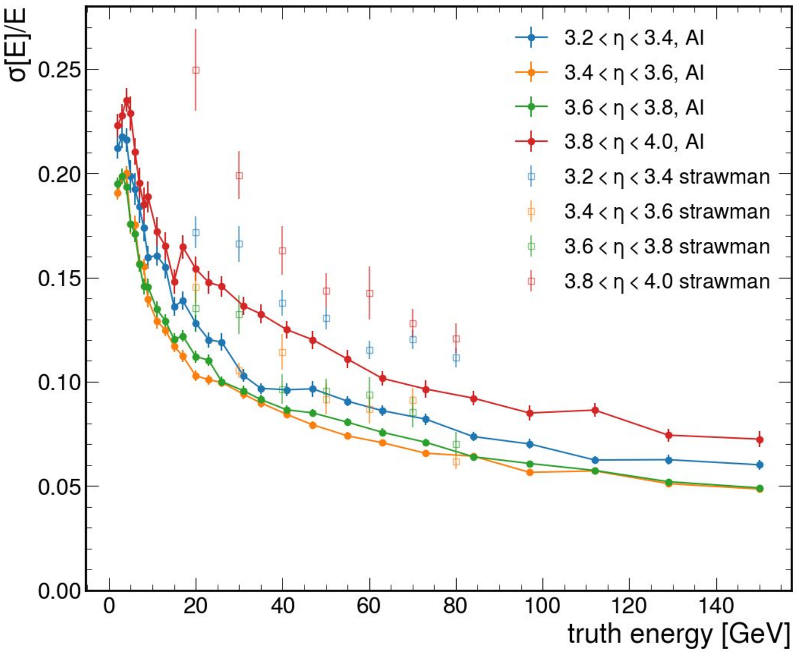


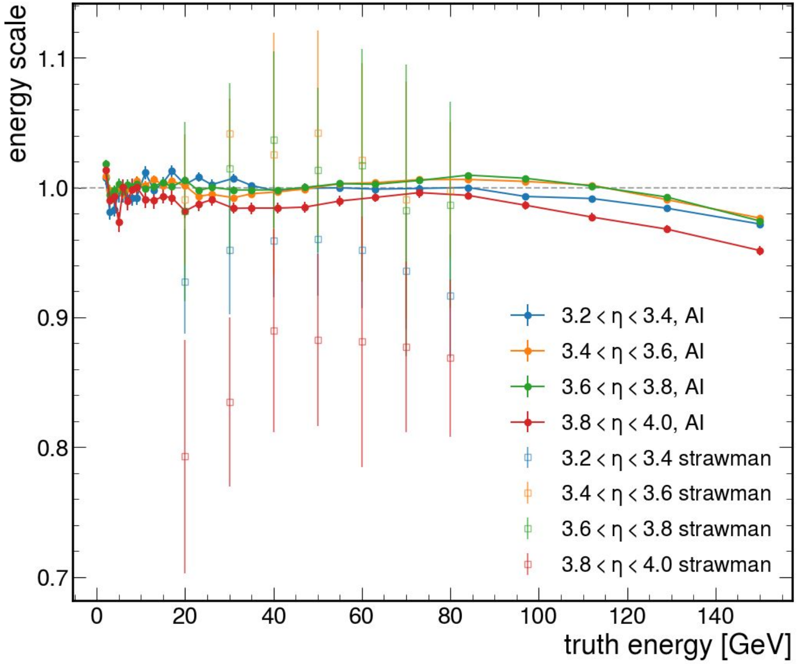
Neutron benchmark

https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_neutron



Reconstruction with Graph Neural Networks



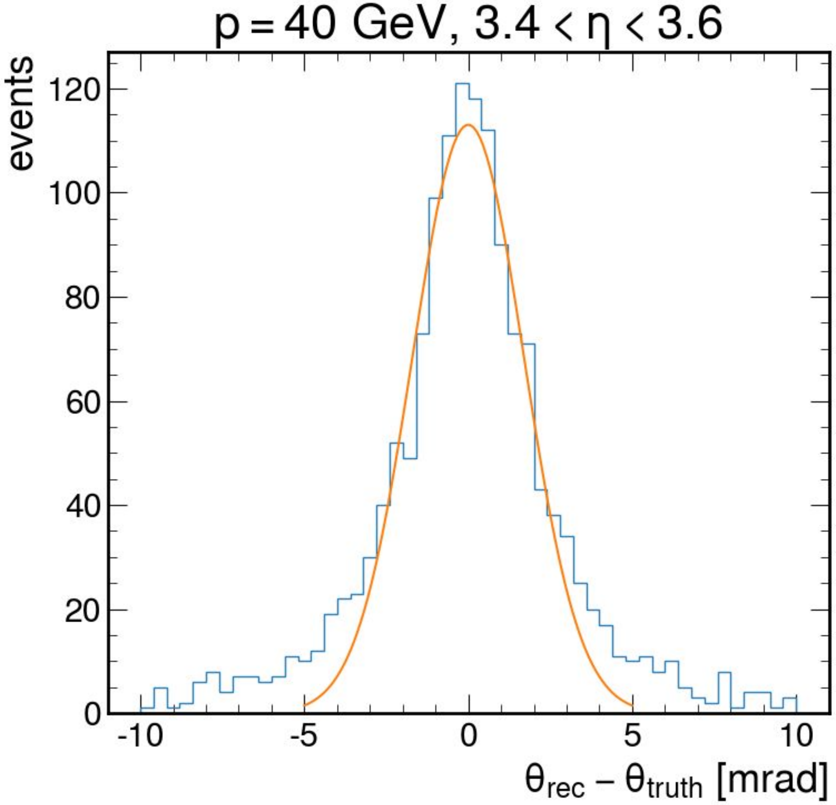


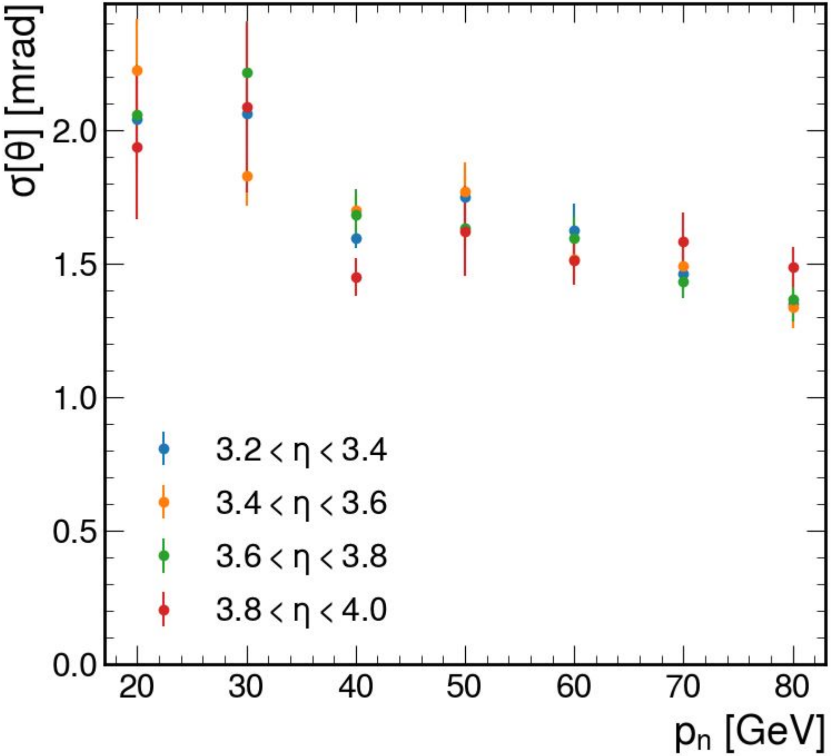
Methods in

F. Torales-Acosta et al. JINST 19 (2024) 06, P06002
F. Torales-Acosta et al. JINST 19 (2024) 05, P05003

Neutron benchmark (continued)

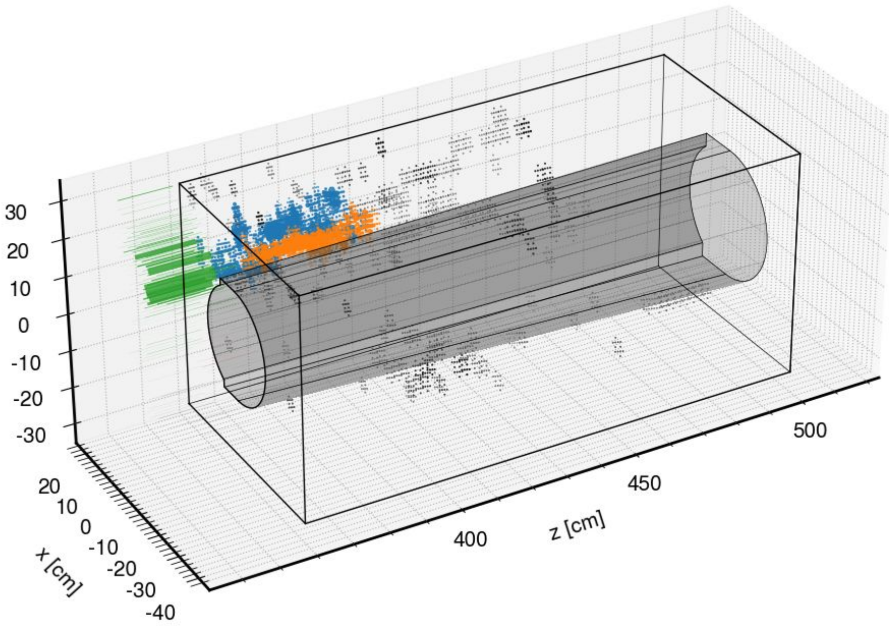
https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_neutron





In progress: τ benchmark as proxy for jets

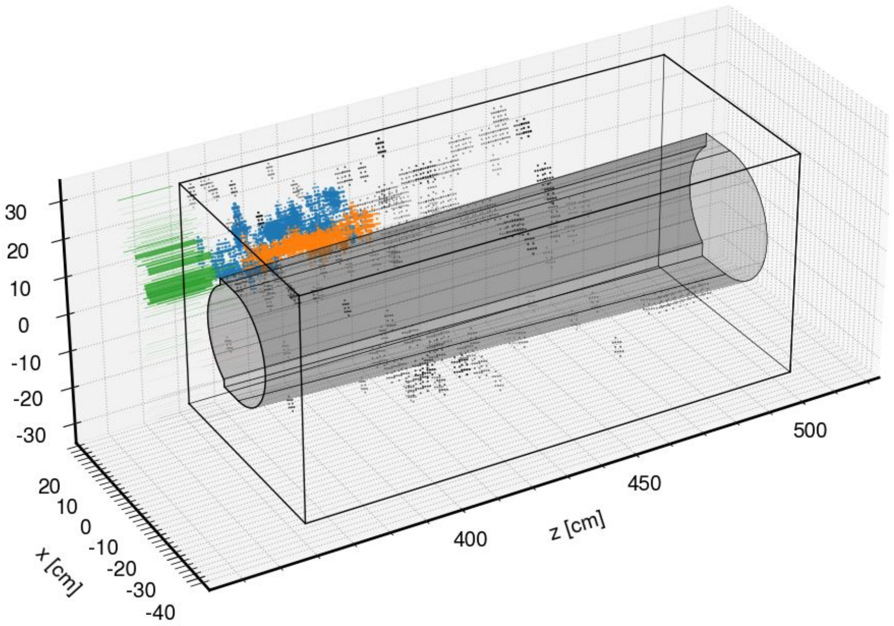
- Simulate τ with $3.0<\eta<4.0$
- Allow them to decay in dd4hep
  - ~65% of τ decays are hadronic
  - In analysis, only select events with no muons nor electrons
- Truth "hadronic final state" four momentum, $p_{hfs}=p_{\tau}-p_{\nu\tau}$
  - Further require $m_{hfs}>m_{\pi\pm}$ to ensure that there is more than one hadron in the jet



https://github.com/eic/detector_benchmarks/tree/insert_tau

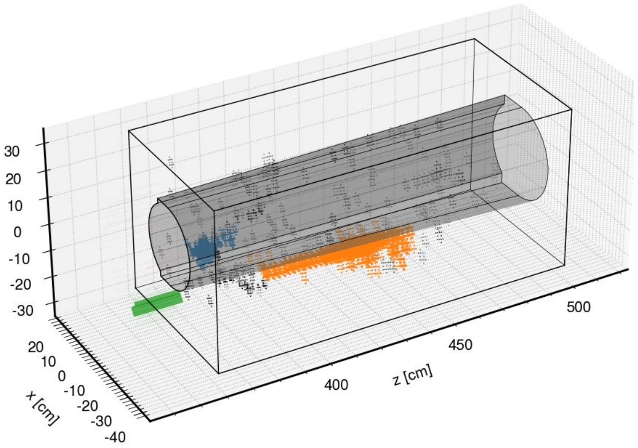
τ benchmark as proxy for jets

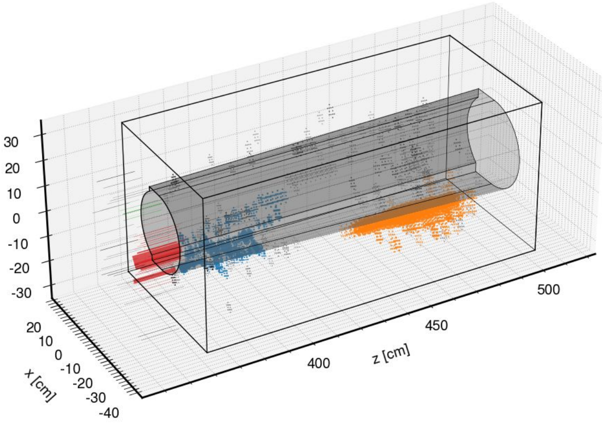
- Simulate τ with $3.0<\eta<4.0$
- Allow them to decay in dd4hep
  - ~65% of τ decays are hadronic
  - In analysis, only select events without an anti-ν_e nor an anti-ν_μ
- Truth "hadronic final state" four momentum, $p_{hfs}=p_\tau-p_{\nu\tau}$
  - Further require $m_{hfs}>m_{\pi\pm}$ to ensure that there is more than one hadron in the jet

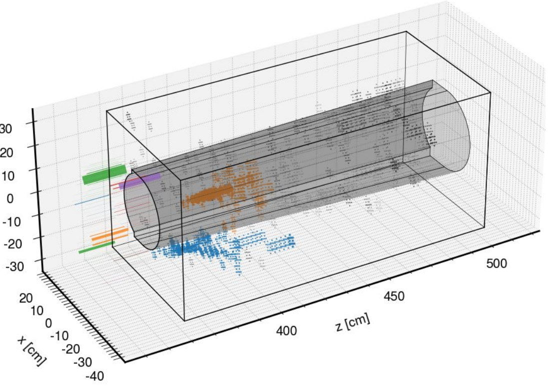


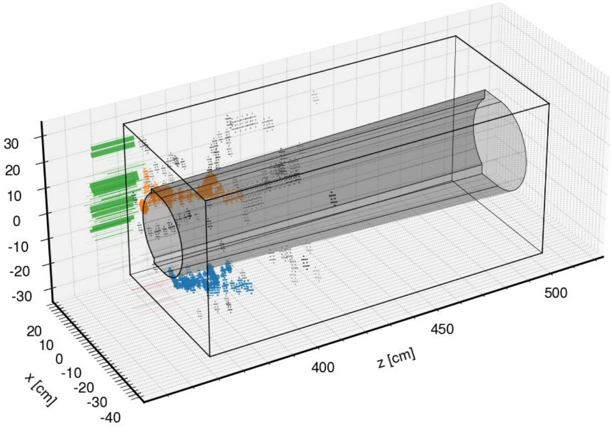
https://github.com/eic/detector_benchmarks/tree/insert_tau

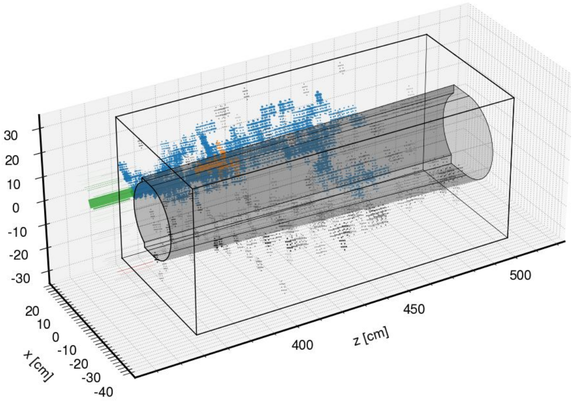
More events


30
20
10
0
-10
-20
-30
20
10
0
-10
-20
-30
-40
x [cm]
400
450
500
z [cm]


30
20
10
0
-10
-20
-30
20
10
0
-10
-20
-30
-40
x [cm]
400
450
500
z [cm]


30
20
10
0
-10
-20
-30
20
10
0
-10
-20
-30
-40
x [cm]
400
450
500
z [cm]


30
20
10
0
-10
-20
-30
20
10
0
-10
-20
-30
-40
x [cm]
400
450
500
z [cm]

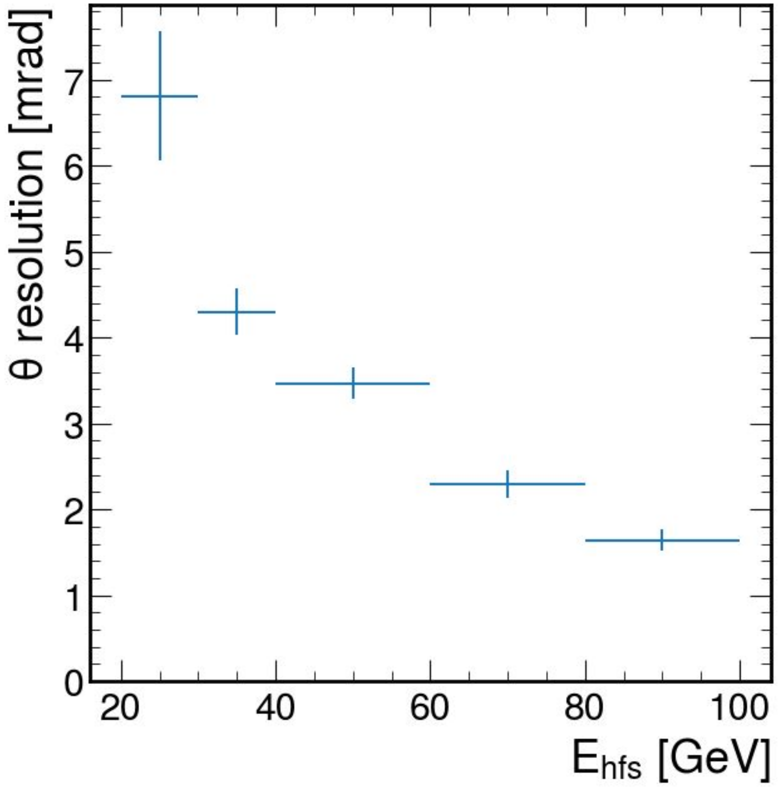

30
20
10
0
-10
-20
-30
20
10
0
-10
-20
-30
-40
x [cm]
400
450
500
z [cm]

Theta reconstruction

- Direction determined by sum of momenta, assuming all particles are massless

$$\vec{p}_{\text{tot}} = \sum_{i\in\text{clusters}} E_i \frac{\vec{x}_i}{|\vec{x}_i|}$$

- This should improve once energy corrections are included



Full calorimetry benchmarks

- Muons:
  - Acceptance
  - MIP energy scale
- Electrons (in progress)
  - Energy scale
  - Clustering in FEMC
- Neutrons:
  - Energy and angle resolution
- Tau (in progress)
  - Source for jets in insert through hadronic decay channel

Benchmarks done

- Insert (supplemented by FEMC)
  - Muon https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_muon
  - Neutron https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_neutron
  - Tau (hadronic decays) https://github.com/eic/detector_benchmarks/tree/master/benchmarks/insert_tau
    - TODO: update this to include EM/hadronic shower identification, and energy corrections
  - TODO charged pion, proton, di-hadron (for separation of showers).
- FEMC
  - Electron https://github.com/eic/detector_benchmarks/tree/master/benchmarks/femc_electron
  - Photon https://github.com/eic/detector_benchmarks/tree/master/benchmarks/femc_photon
  - π0 https://github.com/eic/detector_benchmarks/tree/master/benchmarks/femc_pi0
  - TODO muon, charged pion
- ZDC
  - Lambda https://github.com/eic/detector_benchmarks/tree/master/benchmarks/zdc_lambda
  - Sigma https://github.com/eic/detector_benchmarks/tree/master/benchmarks/zdc_sigma
  - Photon https://github.com/eic/detector_benchmarks/tree/master/benchmarks/zdc_photon
  - π0 https://github.com/eic/detector_benchmarks/tree/master/benchmarks/zdc_pi0
  - Neutron https://github.com/eic/detector_benchmarks/tree/zdc_neutron

Related work

M. Arratia et al. NIMA 1047 (2023) 167866
S. Paul & M. Arratia, NIMA .A 1060 (2024) 169044
M. Arratia et al. JINST 18 (2023) 05, P05045
M. Arratia et al. Instruments 7 (2023) 43
F. Torales-Acosta et al. JINST 19 (2024) 06, P06002
F. Torales-Acosta et al. JINST 19 (2024) 05, P05003
M. Arratia et al. arXiv:2501.08586
J Huang et al. et al. arXiv:2503.14622

Plans

Build upon strong foundation of various benchmarks, to extend to jets.

Identify key jet / HFS measurements to benchmark performance for physics studies.

Anyone interested in forward jets is welcome to contribute to effort.