Physics studies with the SiPM-on-tile ZDC

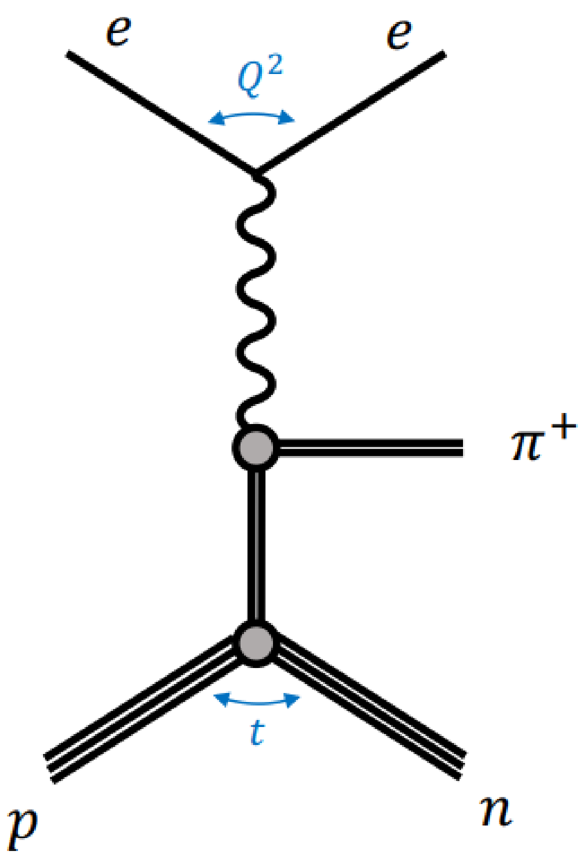
Barak Schmookler

Motivation

- We want to identify some (exclusive) physics processes which we can use to study the performance of the SiPM-on-tile ZDC.
- We then would like to put the performance studies into the official ePIC physics benchmarks repository: https://github.com/eic/physics_benchmarks. This will allow the results to be easily reproducible, as well as allow them to be run as part of the monthly simulation campaign.

Deep Exclusive Meson Production (DEMP)

$e^- + p^+ \rightarrow e^- + pi^+ + n$



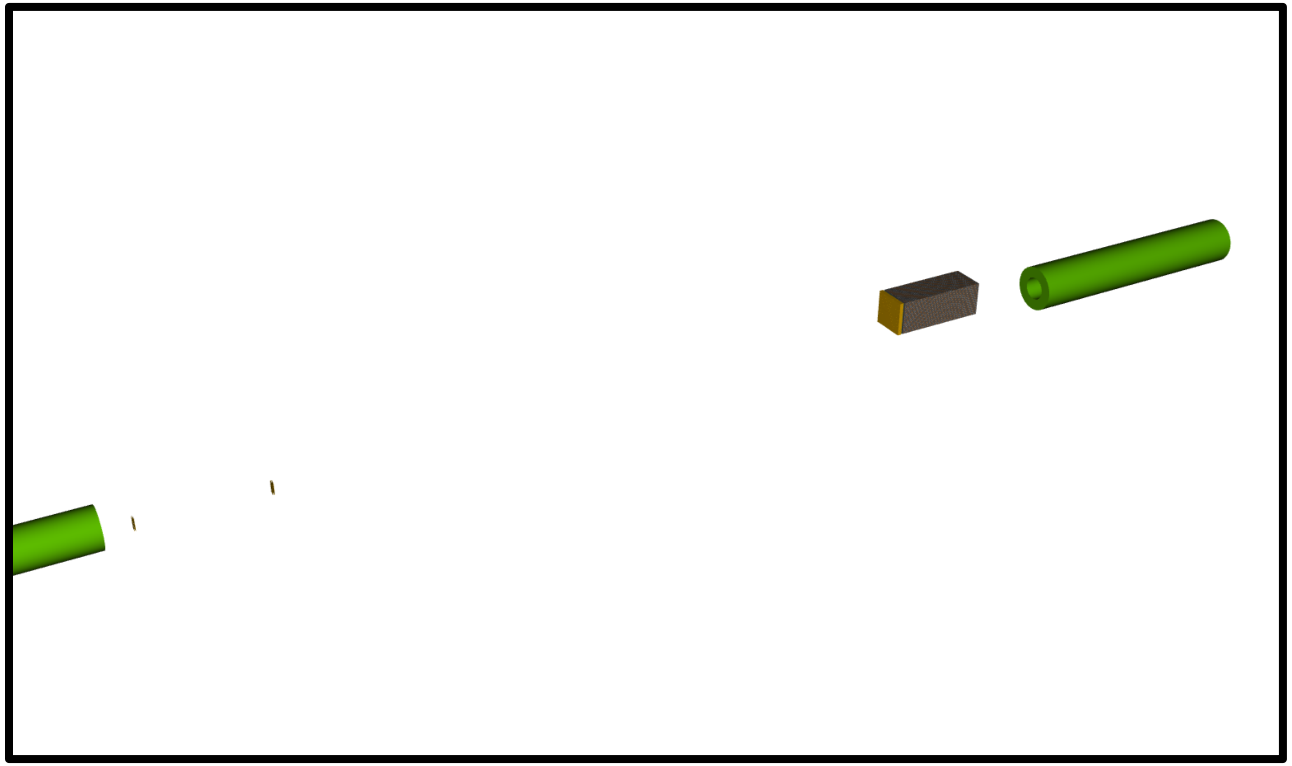
There are some good reasons to use this process for the first set of physics studies:

1. Simple 3-particle final state. Electron and positive pion go into the main detector. The neutron goes into the ZDC.
2. Good reconstruction of the neutron angle is needed for accurate **t** reconstruction. See ECCE's paper for details.
3. Generated events from the *DEMPgen* event generator exist on S3 in HepMC3 format. These events have the IP6 crossing angle and beam smearing effects already applied

SiPM-on-tile ZDC in the ePIC geometry

- The SiPM-on-tile ZDC detector geometry exists in the ePIC repository, but it is not used in either default configuration (Craterlake or BryceCanyon).
- We created a new branch in the ePIC repository, where we use the SiPM-on-Tile ZDC with the LYSO crystal calorimeter in front. In this branch, we also remove the beampipe near the ZDC region.

https://github.com/eic/epic/tree/ZDC_LYSO



SiPM-on-tile ZDC in the EICRecon

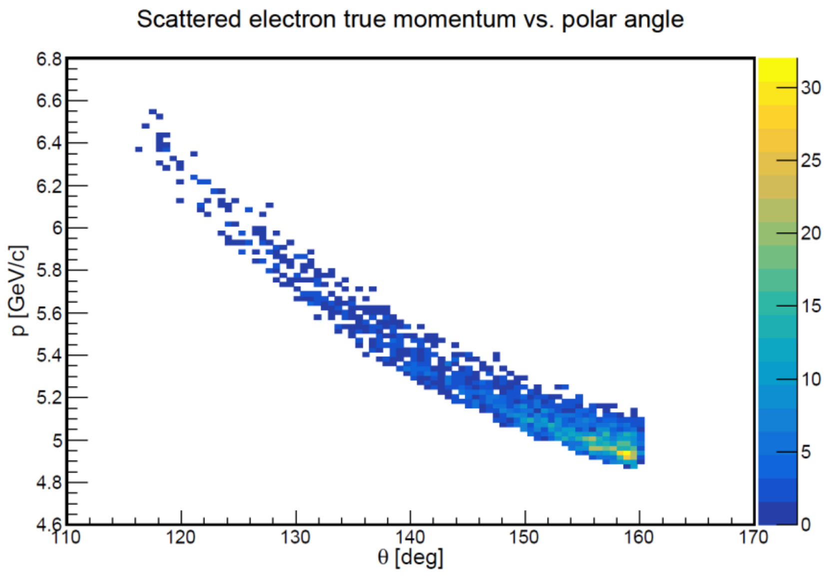
https://github.com/eic/EICrecon/blob/sipmzdc/src/detectors/ZDC/ZDC.cc

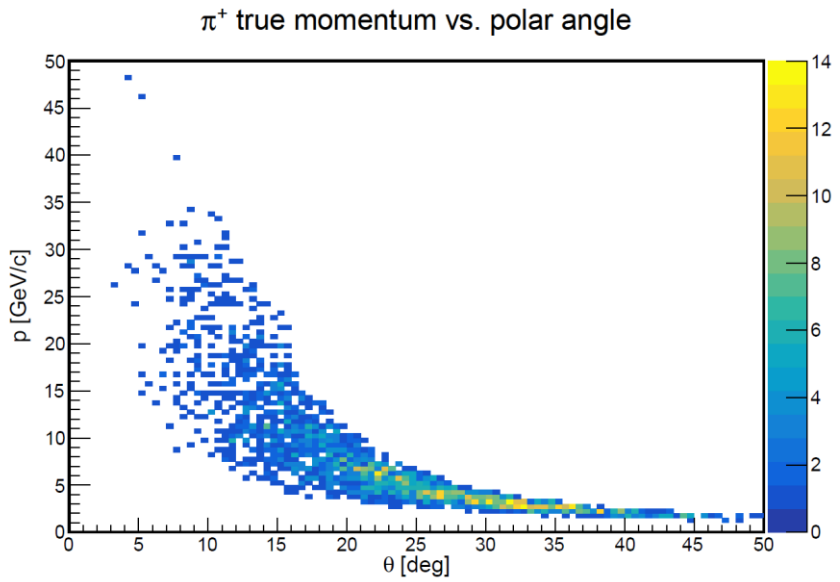
```
app->Add(new JChainMultifactoryGeneratorT<CalorimeterHitDigi_factoryT>(
 "ZDCRawHits", {"HcalFarForwardZDCHits"}, {"ZDCRawHits"},
  {
    .tRes = 0.0 * dd4hep::ns,
    .capADC = 32768,
    .dyRangeADC = 200 * dd4hep::MeV,
    .pedMeanADC = 400,
    .pedSigmaADC = 10,
    .resolutionTDC = 10 * dd4hep::picosecond,
    .corrMeanScale = 1.0,
  },
  app   // TODO: Remove me once fixed
));
app->Add(new JChainMultifactoryGeneratorT<CalorimeterHitReco_factoryT>(
  "ZDCRecHits", {"ZDCRawHits"}, {"ZDCRecHits"},
  {
    .capADC = 32678,
    .dyRangeADC = 200. * dd4hep::MeV,
    .pedMeanADC = 400,
    .pedSigmaADC = 10,
    .resolutionTDC = 10 * dd4hep::picosecond,
    .thresholdFactor = 0.0,
    .thresholdValue = -100.0,
    .sampFrac = 1.0,
```

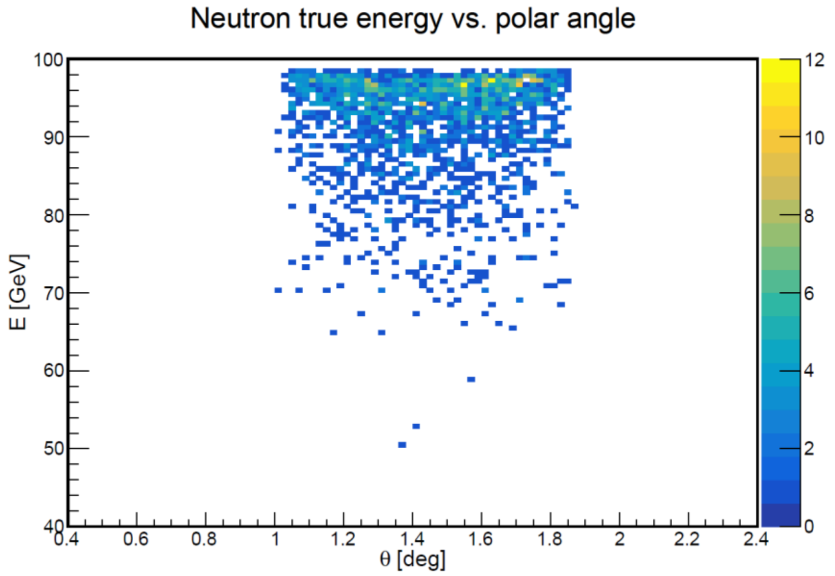
- We also implemented basic digitization for this ZDC in EICRecon.
- We implemented the digitization in this branch: https://github.com/eic/EICrecon/tree/sipmzdc

Some results with DEMP simulation – truth level

5x100 GeV



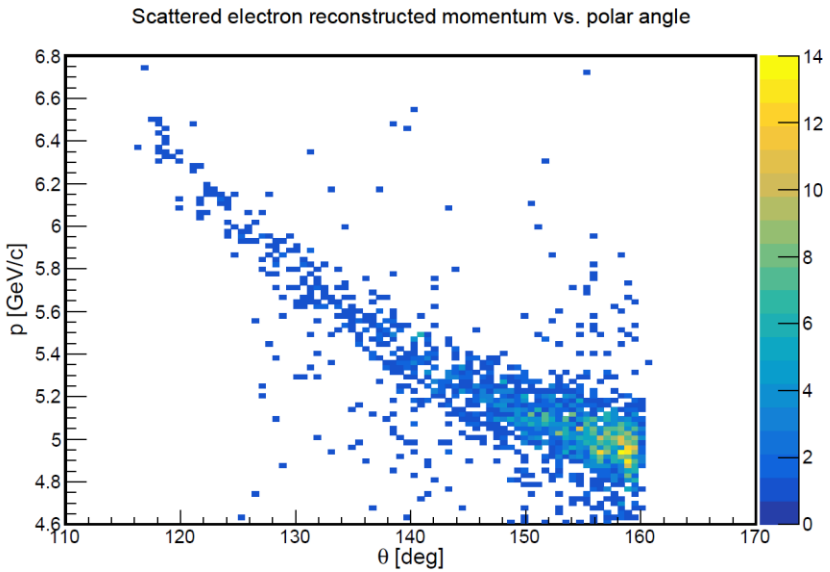


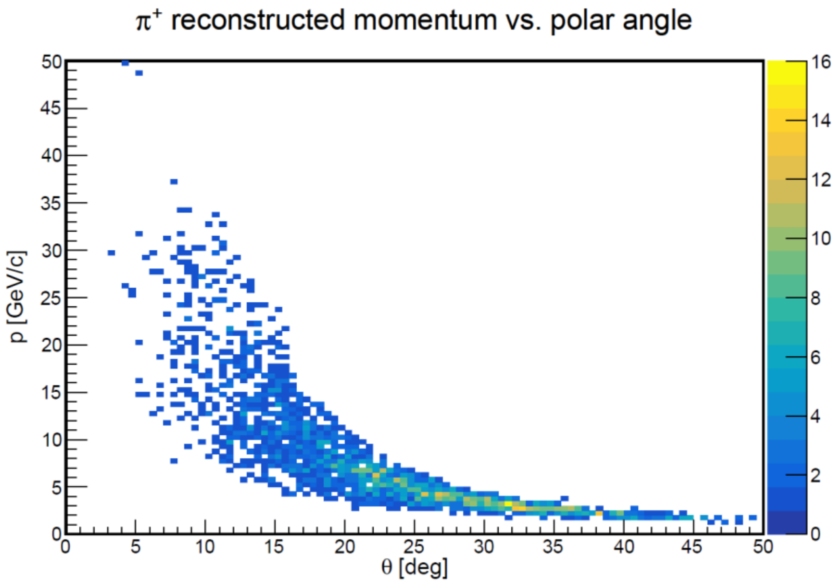


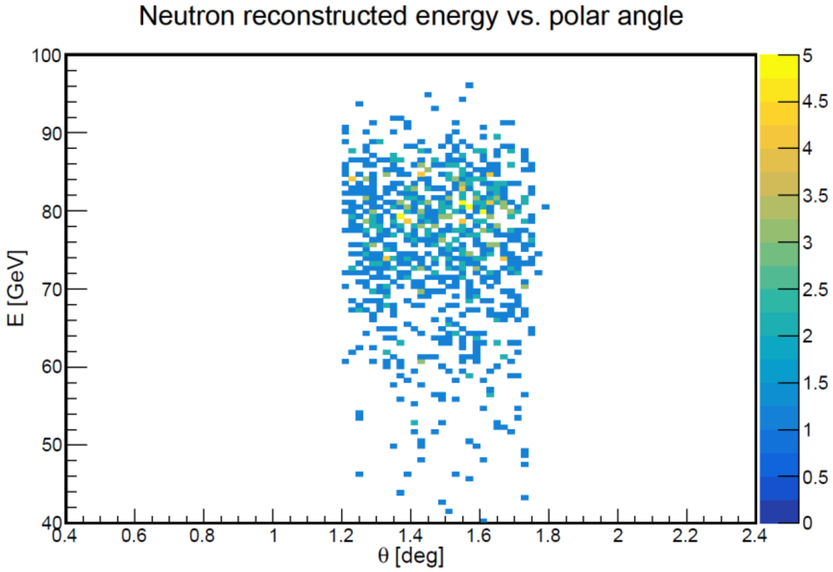
Neutron centered around 25 mRad (1.4 degrees), which is the proton beam direction

Some results with DEMP simulation – reconstructed level

5x100 GeV





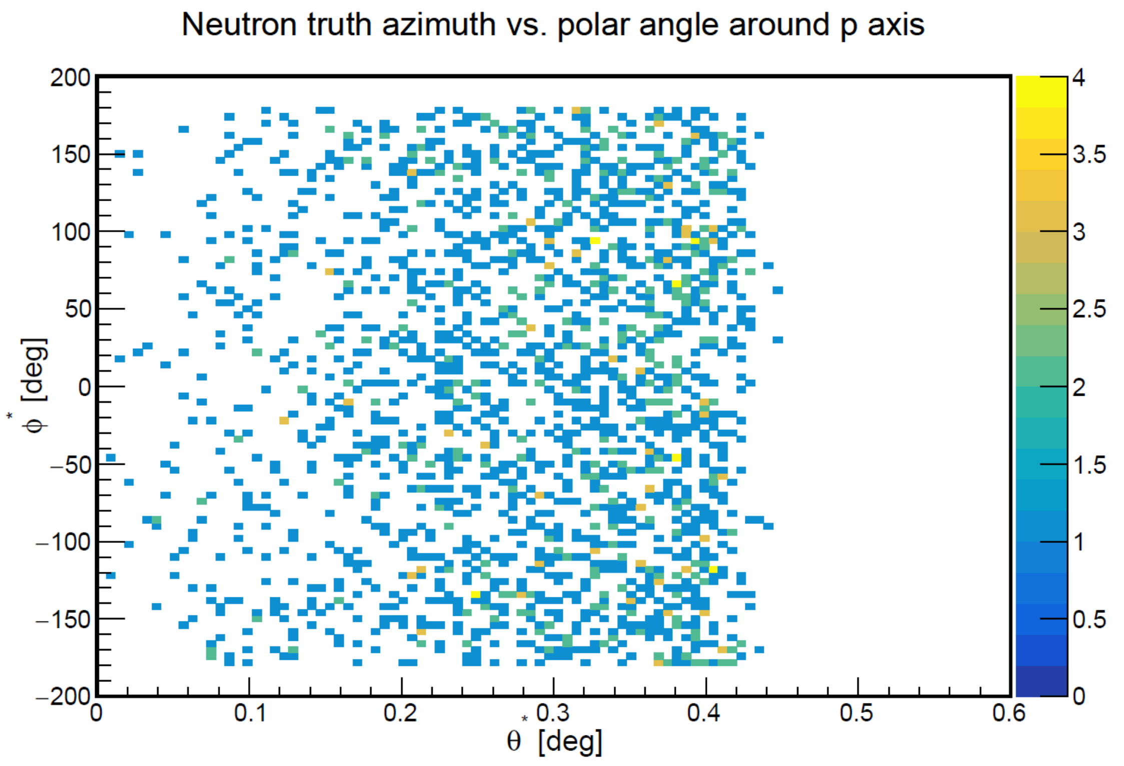


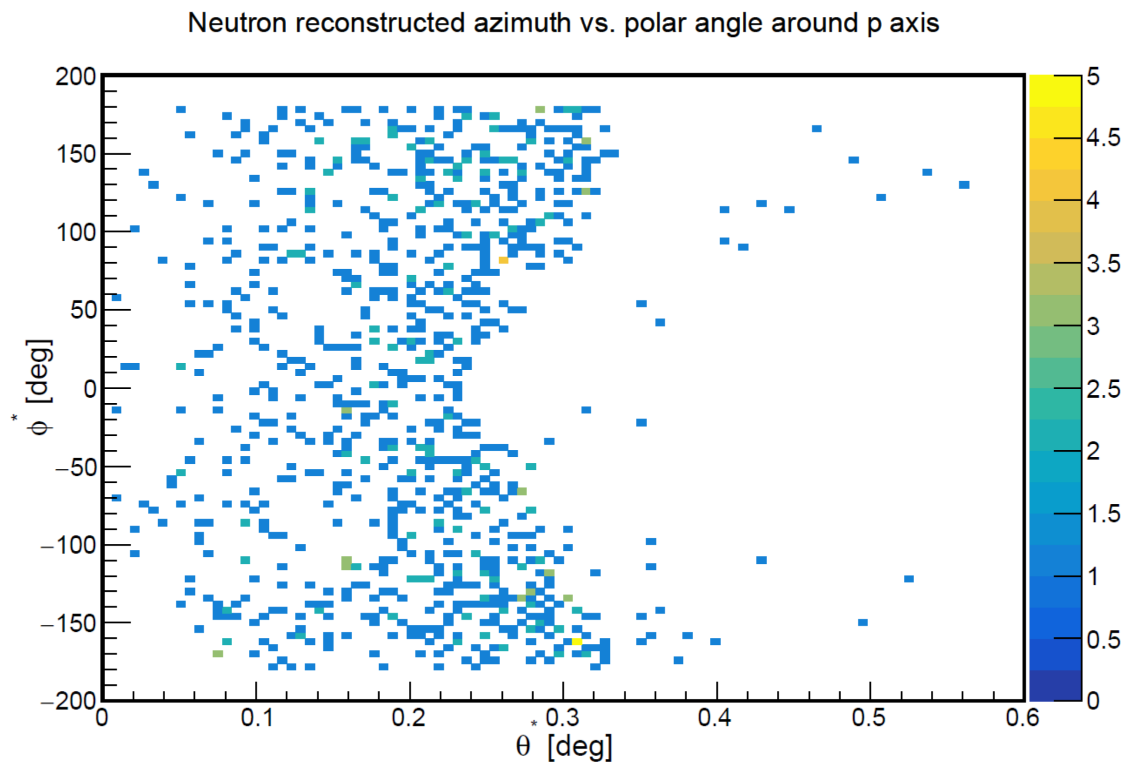
Electron and pion are reconstructed using the central detector tracker (i.e. ReconstructedChargedParticles)

The neutron is reconstructed in the ZDC using the HEXSPLIT algorithm: https://arxiv.org/pdf/2308.06939.pdf

Reconstruction of both neutron angles (relative to proton beam direction)

5x100 GeV



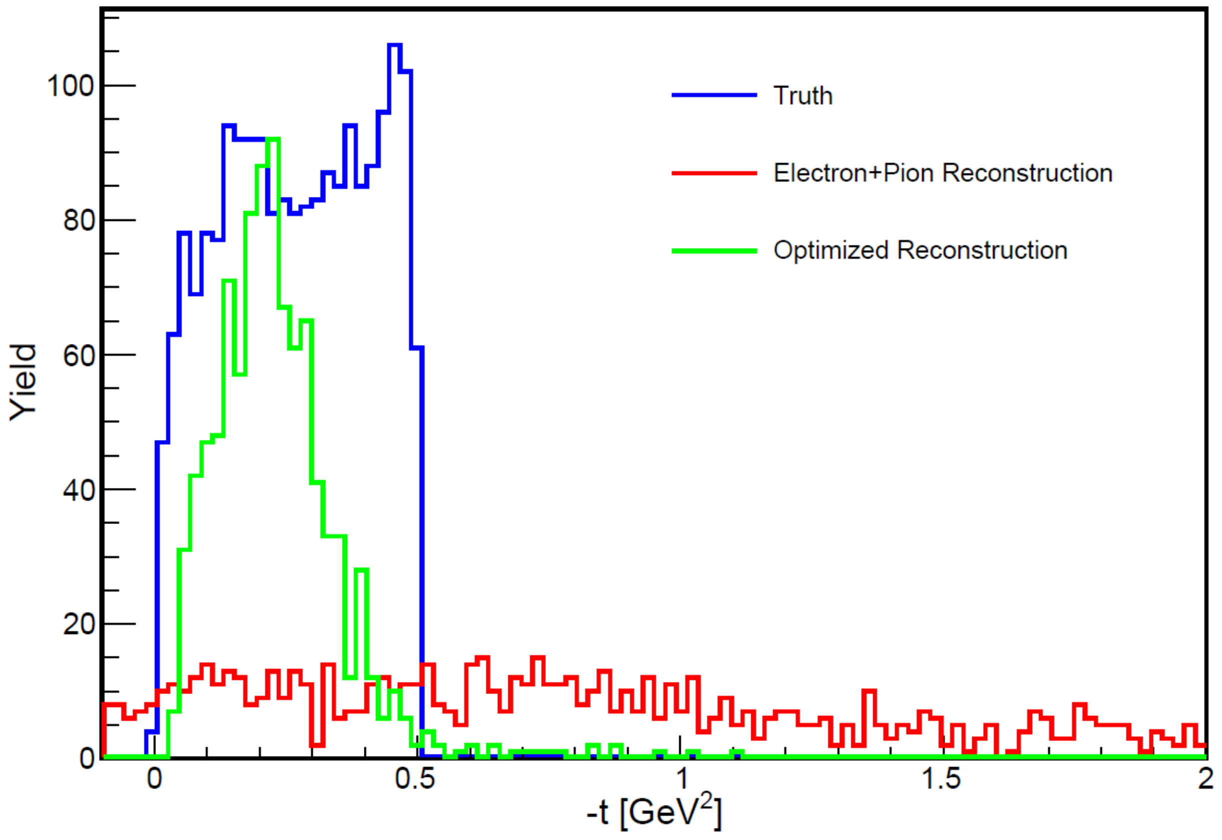


Reconstruction of t

- Tried two methods to reconstruct the t momentum transfer variable:
  1. Using the scattered electron, the positive pion, and the electron beam only: $t = \ (p_e - p_{e\prime} - p_\pi\ )^2$
  2. Determining the missing momentum (three vector) as $p_{miss} = p_e + p_p - p_{e\prime} - p_\pi$. Then, replacing the angles in that missing momentum vector by the reconstructed neutron angles and forcing the mass of the 4-momentum to the neutron mass, we get the optimized neutron reconstruction. The t variable is then calculated as $t = (\ p_p - p_n\ )^2$.
- In all these reconstruction equations, the electron beam and proton beam are set to constants (i.e. we don't know the event-by-event fluctuations), with the proton beam having a 25 mRad angle in the x-z plane.

Reconstruction of t

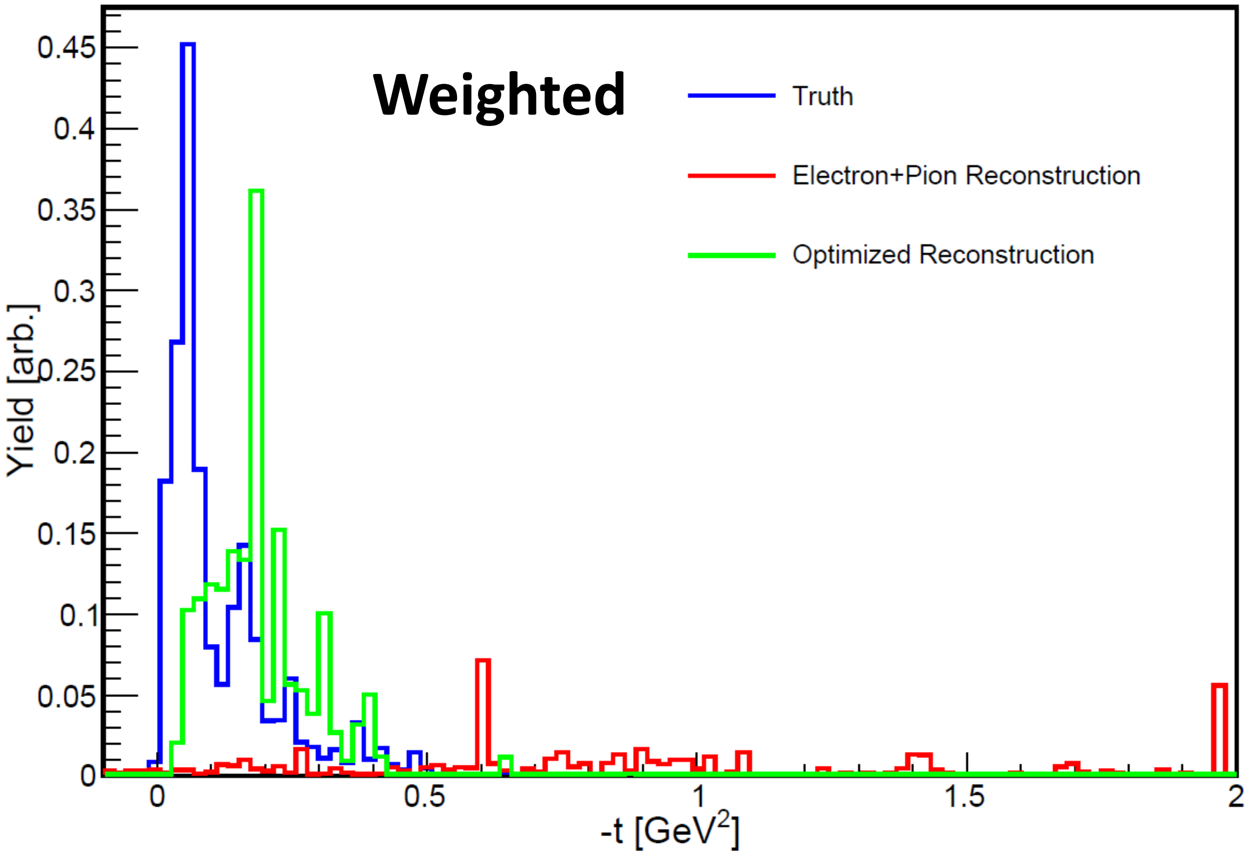
5x100 GeV



- The reconstructed distributions come from the calculation shown on the previous slide. The truth distribution comes from using the true proton beam 4-vector (including event-by-event fluctuations) and the true neutron 4-vector.
- The shape of the truth distribution looks a bit strange. This is because the DEMP events have an event weight, which was not included in this plots. This weight is saved to the HepMC file (and the EICRecon ROOT file) for each event and can be applied as a weight.

Reconstruction of **t**

5x100 GeV



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Summary

- We have identified a good first physics process to benchmark the SiPM-on-tile ZDC.
- We've created branches that implement this ZDC into the ePIC framework and EICRecon.
- We have done some analysis with DEMP events and stored the analysis code in the physics benchmarks repository: https://github.com/eic/physics_benchmarks/tree/demp_zdc.