

# Analysis of ePIC Output With Afterburned Events

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# Introduction

- **What does the afterburner actually do?**
  - Most event generator writes events in head-on frame (no crossing angle or beam effects)
  - “Afterburner” introduces **beam crossing angle** and **beam effects (angular divergence & momentum spread)** to events and changes from head-on frame to Lab frame
    - Lab frame: Electron beam is along z axis (solenoid axis is aligned with electron beam) and Hadron beam takes full crossing angle
  - That results in all particles being **boosted** and **rotated** including addition of beam effects and those are saved into MCParticles in “Afterburned” HepMC file

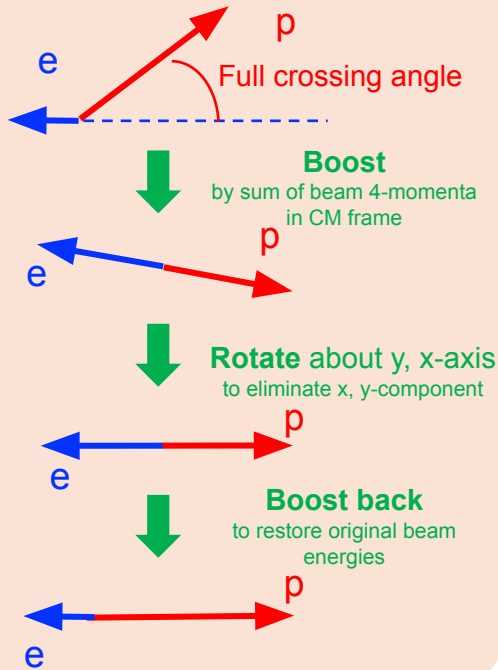
# Introduction

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  - That results in all particles being **boosted** and **rotated** including addition of beam effects and those are saved into MCParticles in “Afterburned” HepMC file
- **True MC** info from event generator is \*missing\* in “Afterburned” HepMC file
- However, we can retrieve True MC info!
- To extract True MC information from “Afterburned” file
  - Need to do reverse transformation from Lab frame to Head-on frame (“**post-burn**”)

# How to Get Back to True MC from Afterburned

\*Boost and rotation is determined by beam particles of event (event-by-event)\*

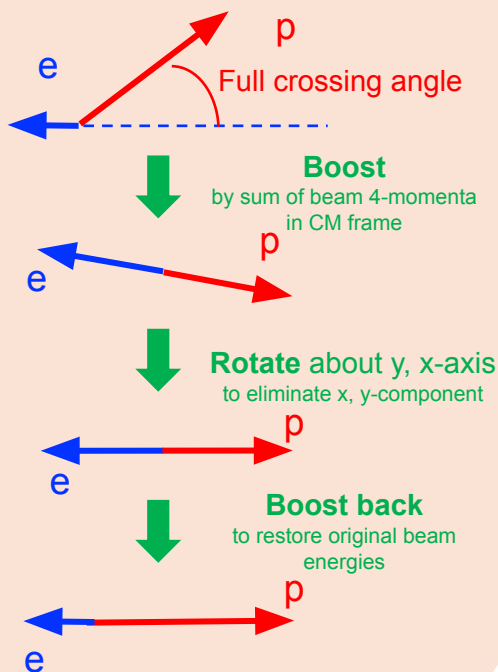
## Reverse Transformation Procedure



# How to Get Back to True MC from Afterburned

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## Reverse Transformation Procedure



## o Two approaches

- o **True MC events** for true MC to full-reco comparison
  - Remove ALL effects to get back generated MC information.
- o **Realistic events** remove only crossing angle, keep beam FX in events
  - This is an important distinction!! Crossing angle can be accounted-for in real events, but beam effects such as angular divergence are random and cannot be removed from a real event!

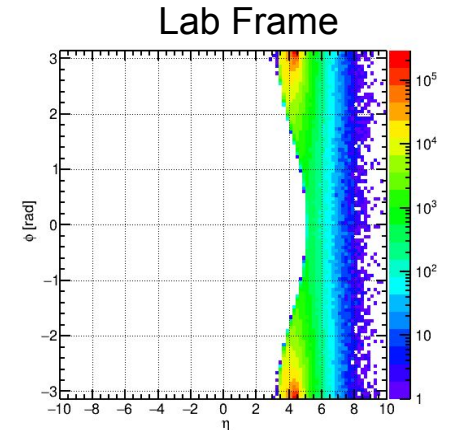
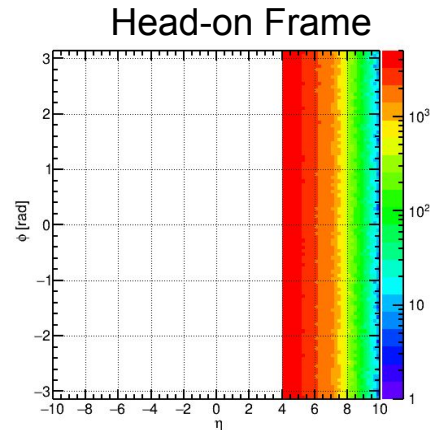
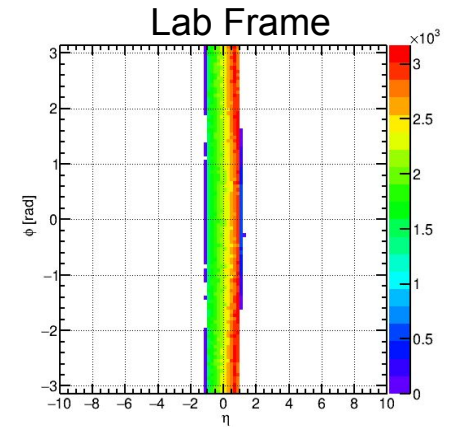
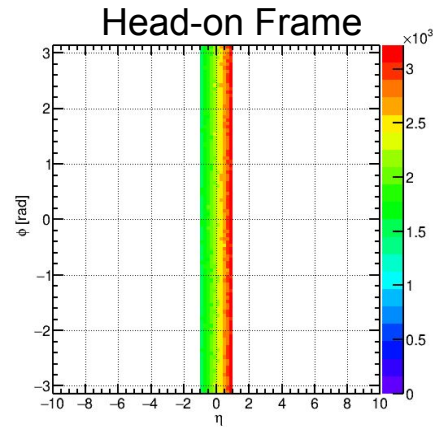
# PYTHIA ep $18 \times 275 \text{ GeV}^2$ Sample

Look into different pseudo-rapidity region

- **Top panel:** Mid-rapidity ( $|\eta| < 1$ )
- **Bottom panel:** Far-forward ( $\eta > 4$ )

Particles are selected by pseudo-rapidity cut in Head-on frame (Left column). And then those particles in Lab frame is drawn (Right column).

In Mid-rapidity region, boost-rotation doesn't affect much, but in far-forward region, it does, to make particles direct to hadron beam line.



# PYTHIA ep 18×275 GeV<sup>2</sup> Sample

Look into momentum components for different particles

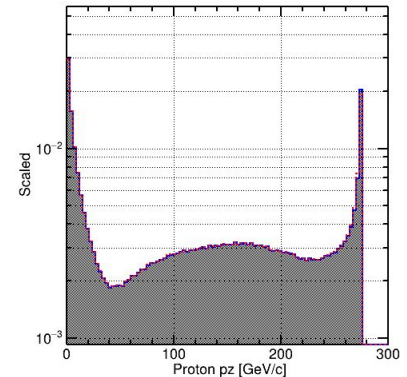
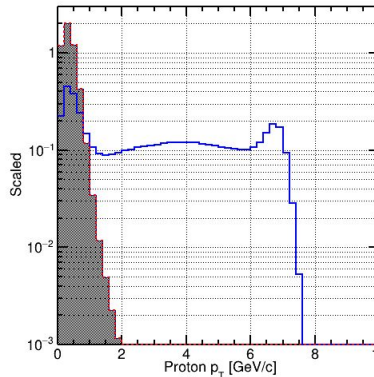
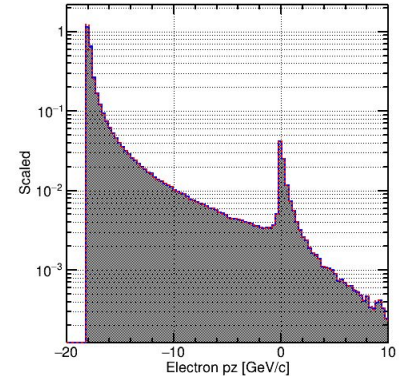
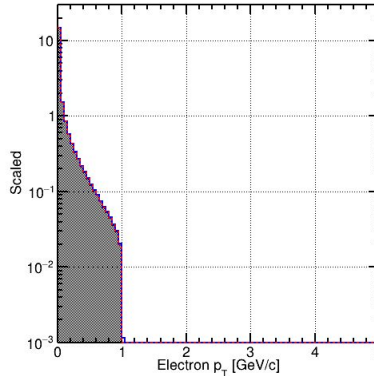
- Electron (top): mostly go to backward
- Proton (bottom): mostly go to forward

Here, all final-state electrons and all final-state protons are shown in  $p_T$  and  $p_z$  histograms.

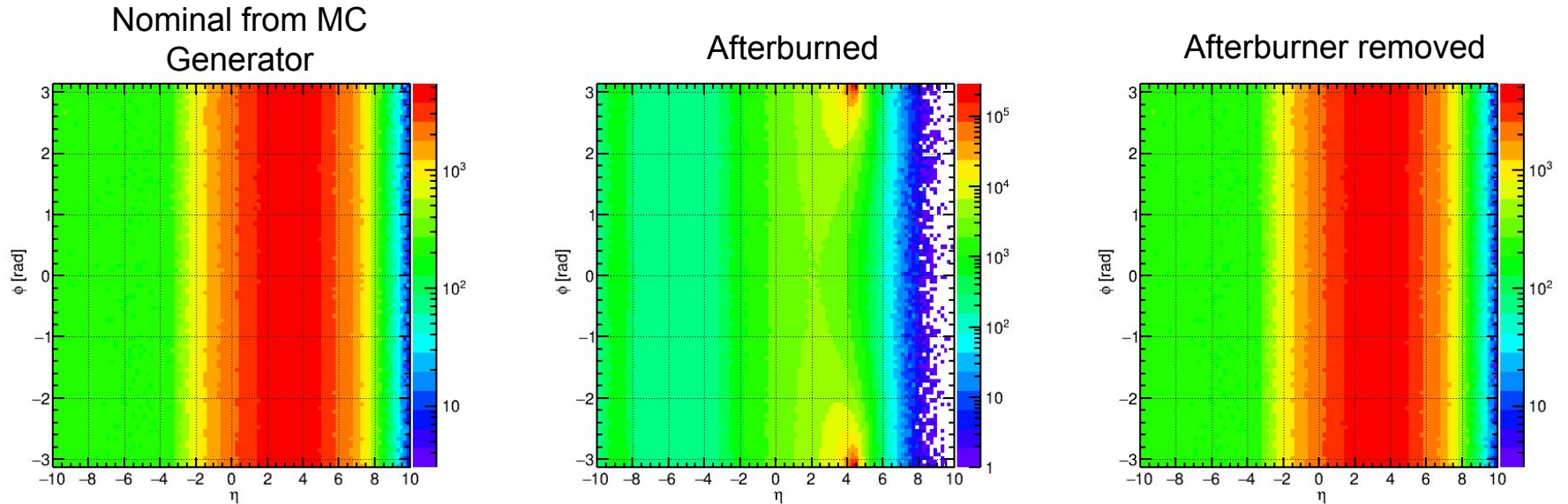
Color scheme: **Nominal**, **Afterburned**, and **Afterburner effects removed**

Impact of crossing angle ( $\theta_{CA}$ ) in  $p_T$

- 275 GeV proton expects  $\sim 6.8$  GeV ( $p_T = P_z * \sin(\theta_{CA})$ )



# PYTHIA ep $18 \times 275 \text{ GeV}^2$ Sample



All final-state particles are shown in eta-phi plane.

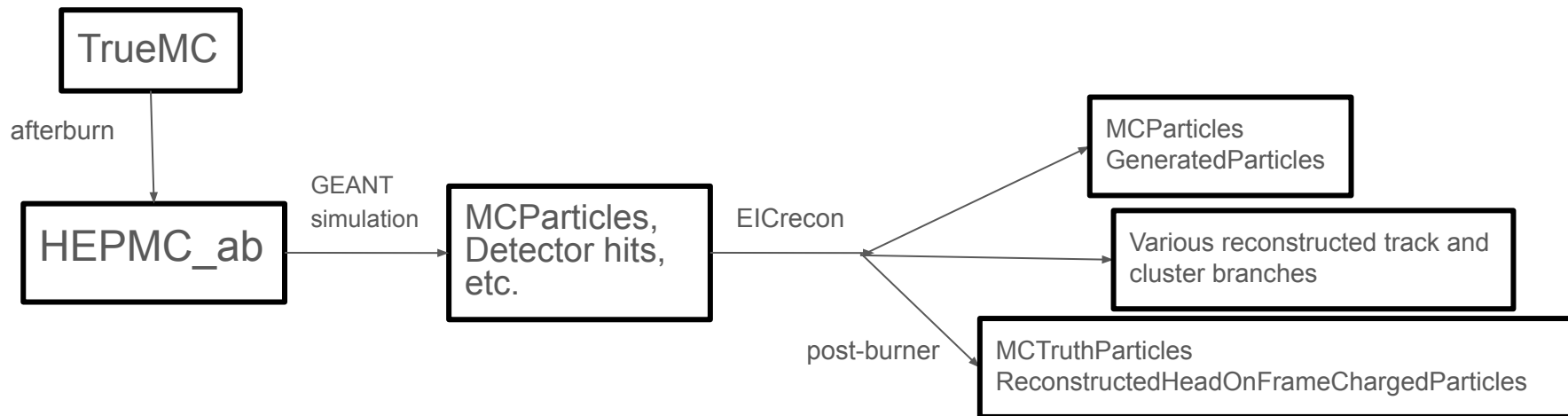
**Left figure:** Nominal distribution from MC event generator

**Middle figure:** Afterburned sample introduces a hot spot at  $\eta \sim 4.3$  (crossing angle = 25 mrad) where IP-6 hadron beam is aligned

**Right figure:** Take Afterburned sample (middle) and apply reverse transformation and resulting is in a good agreement with nominal



# How an analysis should work for a user



- Right now, EICrecon by default spits out “afterburned” MC information, which has all beam effects and the crossing angle, and spits out reconstructed particles in the crossing angle frame.
  - **The post-burner will remove the full set of “afterburned” modifications from MCParticles and store it in a new collection.**
  - **This gives you back the TrueMC information your generator produced.**
- It will also remove *only the crossing angle* from the ReconstructedChargedParticle (and others) branch(s) so the head-on frame is consistently used.

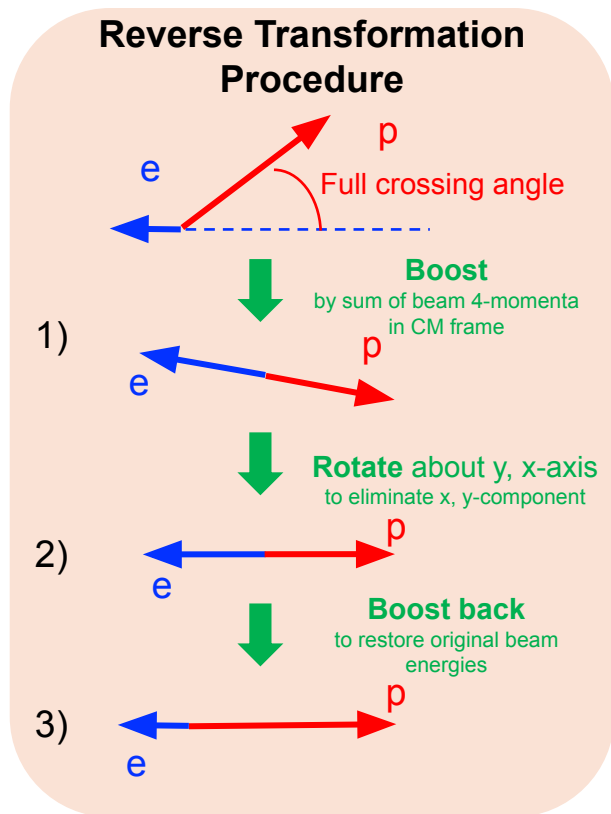
# Summary

- Final physics analyses will require proper handling of the crossing angle and beam effects.
  - Comparisons between output from npsim/EICrecon and MCTruth require these effects are properly removed from MCParticles and stored in a new branch to ensure resolutions for observables are accurate.
- A solution is already in place in EICrecon and we are testing it now.
  - We do not propose removing any information from EICrecon at this time - simply adding new output branches which contains the “post-burned” information.
- More discussion to come with software and physics working groups.
  - Especially on technical implementation, and user awareness (making sure users understand what the quantities mean, where to find detailed explanations, etc.).

Now for some additional comments and things to consider...

# How to Get Back to True MC from Afterburned

\*Boost and rotation is determined by beam particles of event (event-by-event)\*



```
// Defining beam particles
TLorentzVector e_beam(0.,0.,0.,0.);
TLorentzVector h_beam(0.,0.,0.,0.);
for(const auto& v : evt.vertices())
{
  for(const auto& p : v->particles_in())
  {
    TLorentzVector mc(p->momentum().px(), p->momentum().py(), p->momentum().pz(), p->momentum().e());
    if(p->pid() == 11 && p->status() == 4)
      e_beam.SetPxPyPzE(mc.Px(), mc.Py(), mc.Pz(), mc.E());
    if((p->pid() == 2112 || p->pid() == 2212) && p->status() == 4)
      h_beam.SetPxPyPzE(mc.Px(), mc.Py(), mc.Pz(), mc.E());
  }
}

// Defining boost, rotation, and boost-back
// Boost
TLorentzVector cmBoost = e_beam + h_beam;
TLorentzVector boost(-cmBoost[0], -cmBoost[1], -cmBoost[2], cmBoost[3]);
TVector3 b(0., 0., 0.);
b = boost.BoostVector();

e_beam.Boost(b);
h_beam.Boost(b);

// Rotate in Y and X
double rotAboutY = -1.0*TMath::ATan2(h_beam.Px(), h_beam.Pz());
double rotAboutX = 1.0*TMath::ATan2(h_beam.Py(), h_beam.Pz());

e_beam.RotateY(rotAboutY);
h_beam.RotateY(rotAboutY);
e_beam.RotateX(rotAboutX);
h_beam.RotateX(rotAboutX);

// Boost-back
TLorentzVector boostBack(0., 0., cmBoost[2], cmBoost[3]);
TVector3 bb(0., 0., 0.);
bb = boostBack.BoostVector();

e_beam.Boost(bb);
h_beam.Boost(bb);
```

# How to Get Back to True MC from Afterburned

```
// Accessing final-state particles
for(const auto& v : evt.vertices())
{
  for(const auto& p : v->particles_out())
  {
    TLorentzVector mc(p->momentum().px(), p->momentum().py(), p->momentum().pz(), p->momentum().e());
    mc.Boost(b);
    mc.RotateY(rotAboutY);
    mc.RotateX(rotAboutX);
    mc.Boost(bb);

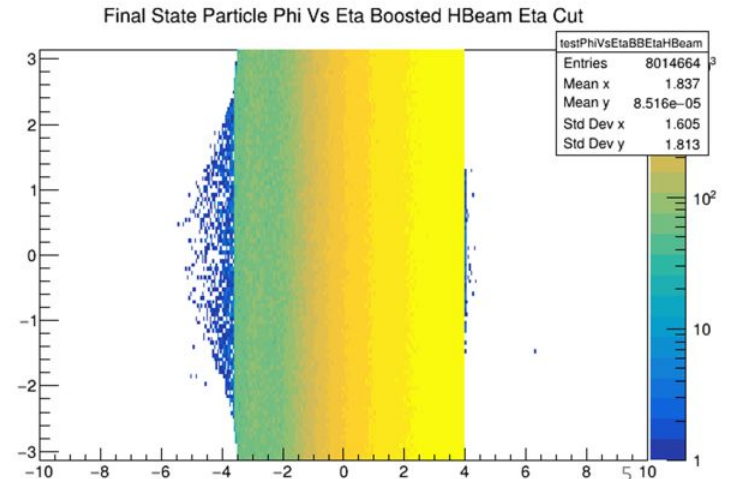
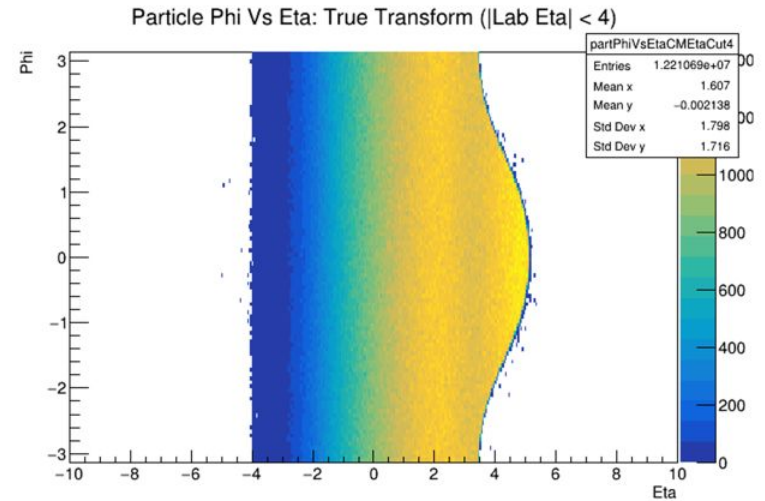
    // After this, all particles are back to true MC level
  }
}
```

## ○ Two approaches

- **True MC events** for true MC to full-reco comparison
  - Remove ALL effects to get back generated MC information.
- **Realistic events** remove only crossing angle, keep beam FX in events
  - This is an important distinction!! Crossing angle can be accounted-for in real events, but beam effects such as angular divergence are random and cannot be removed from a real event!

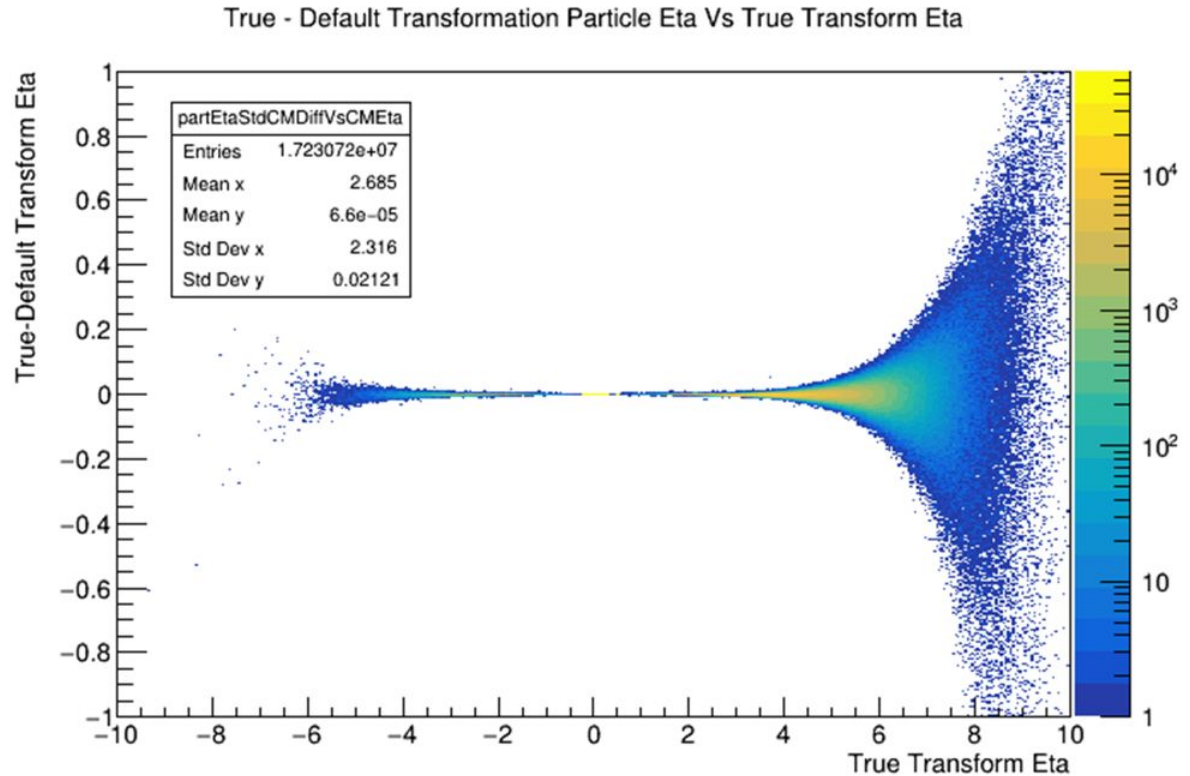
# How to Define Acceptance Cuts

- ❑ Because it has a single meaningful axis, the head-on frame is still likely the best frame for defining our physics quantities
- ❑ However, will our detector acceptance (the limit of HCal or tracking coverage) be symmetric around the electron beam or the hadron beam? If it is symmetric about the hadron beam, we should use eta as defined with respect to the hadron beam to place our cuts
- ❑ Both plots show the phi vs eta distribution where these quantities are defined in the head-on frame
  - Top plot applies a cut for  $|\eta| < 4$  where eta is defined relative to the electron beam
  - Bottom plot applies a cut for  $|\eta| < 4$  where eta is defined relative to the hadron beam
  - At negative eta, can define acceptance relative to the electron beam – this will eliminate distortions in electron going direction

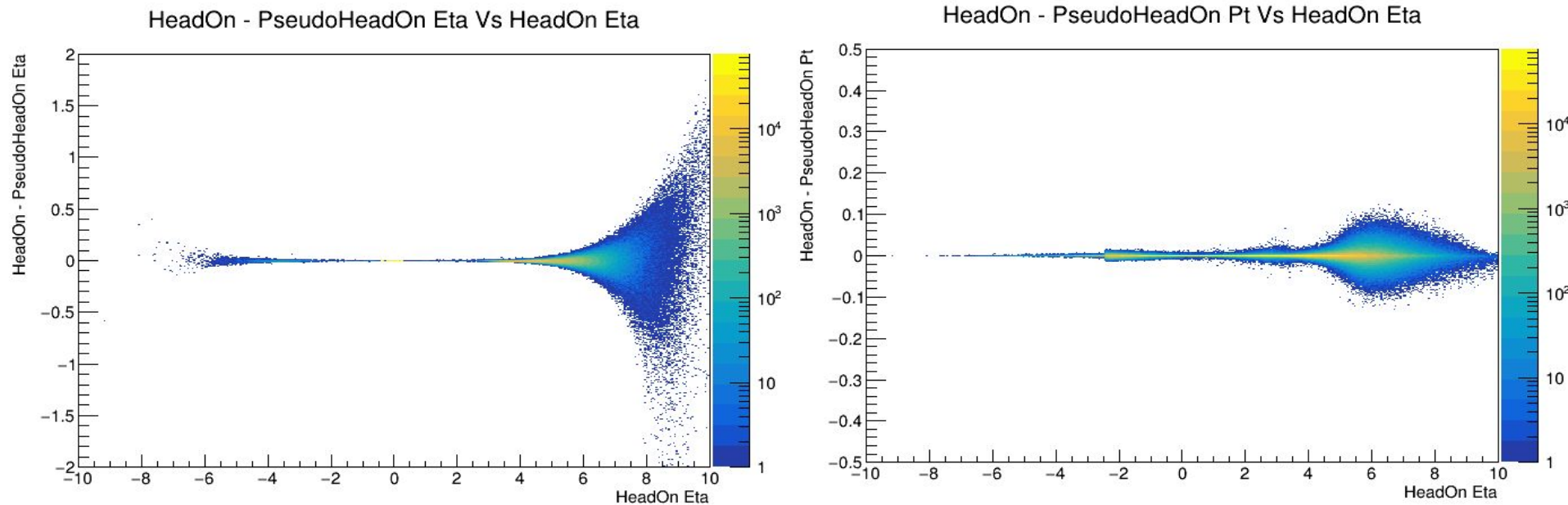


# Beam smearing effects in head-on frame

- All plots above used transformation constructed assuming perfect knowledge of incoming beams
- Divergence, beam energy spread, etc introduce momentum deviations which cannot be measured event by event
- Compare true transformation (assuming perfect knowledge) with default transformation (assume nominal beam energies and crossing angle)
- Deviations are small at mid-rapidity but grow sizable as you move forward



# Comparison of head-on and crossing angle frame (no beam FX)

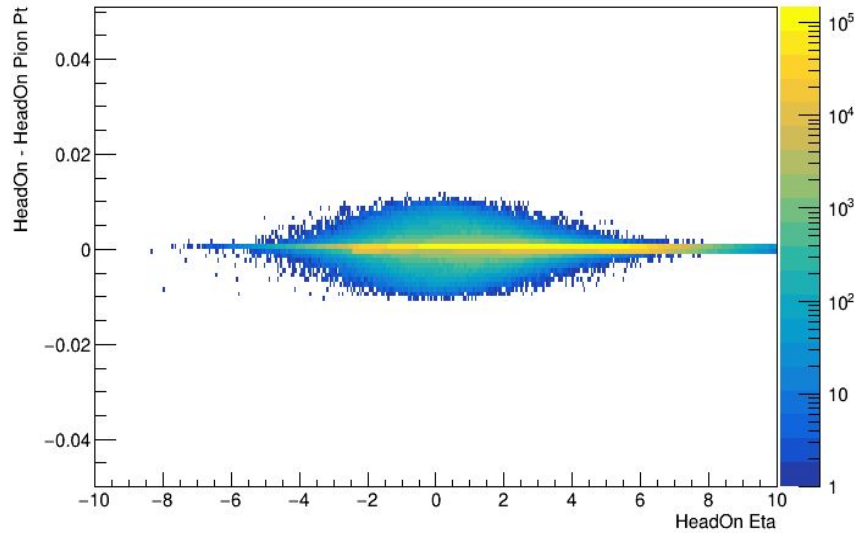


- Both plots show the difference between the head-on and pseudo head-on (crossing angle) frame for eta (left) and pT (right), both as a function of eta.
- The effect is largest in the forward direction.



# Head-On Frame: Pion Mass Assumption for boost

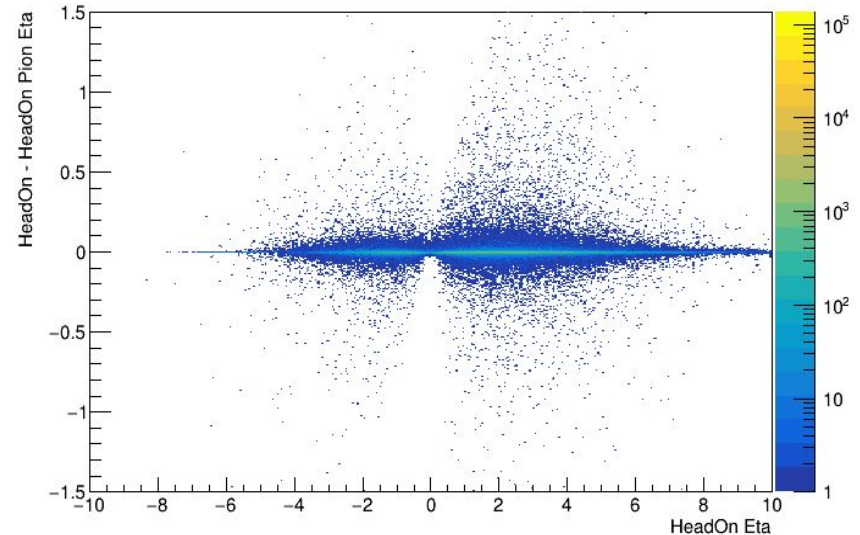
HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta



- Find 'maximal' deviation in boost to head-on frame from mis-PID
- Assume all tracks are pions and all neutrals are massless and calc difference between true boost and boost with these mass assumptions

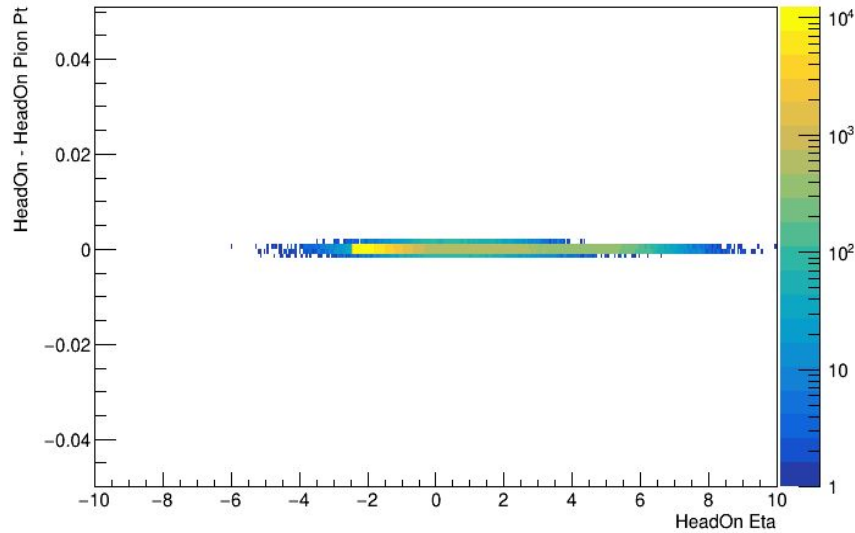
- The boost to the (pseudo)head-on frame operates on a 4-vector - particle energy (mass) needed
- What about tracks for which we don't have PID?

HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta



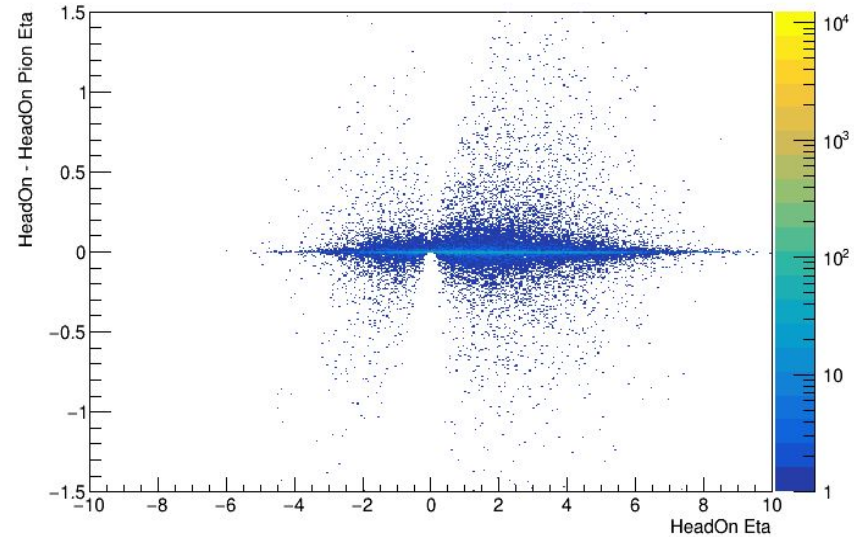
# Head-On Frame: Pion Mass Assumption (Electrons)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: Electrons



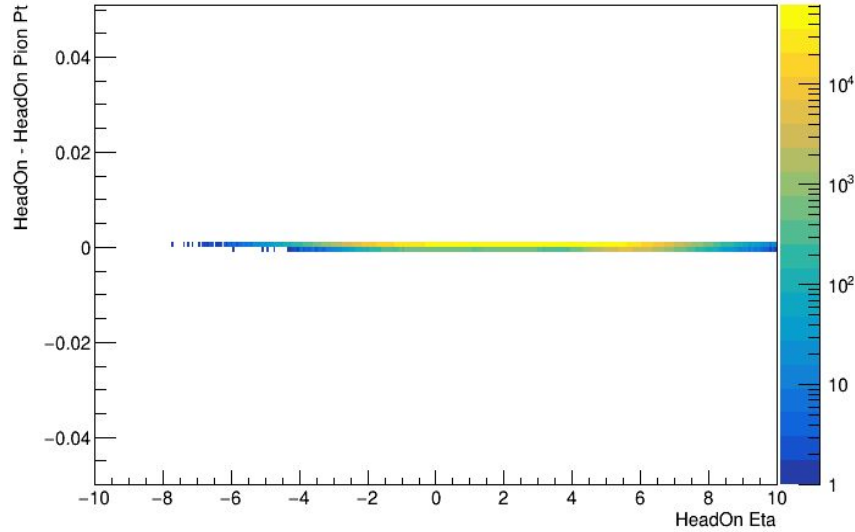
- Look at contributions from individual particles
- Electrons show largest deviation in eta if assumed to have pion mass

HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: Electrons



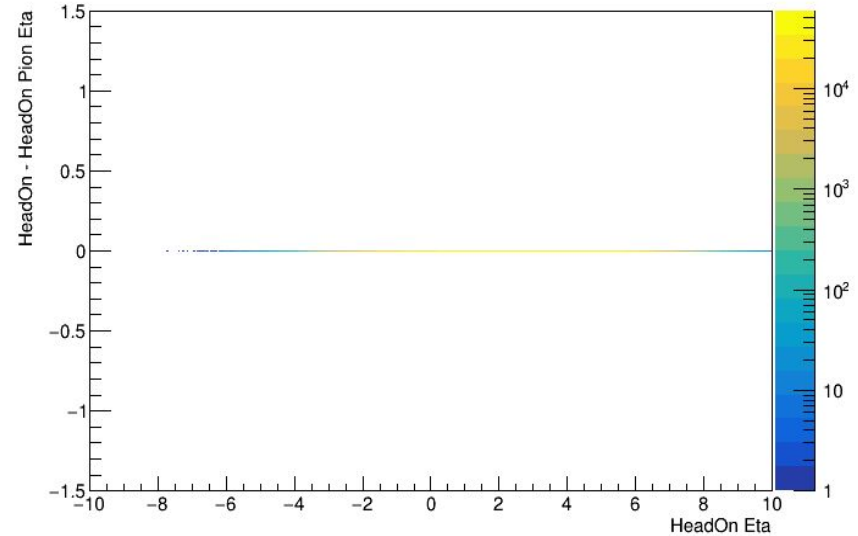
# Head-On Frame: Pion Mass Assumption (Pions)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: Pions



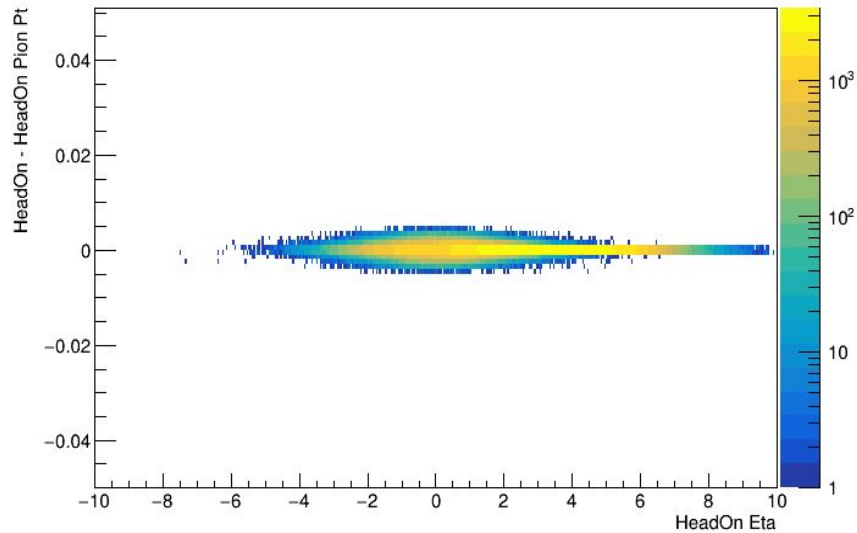
- Pions should exhibit no deviation as they are by definition using the correct mass

HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: Pions

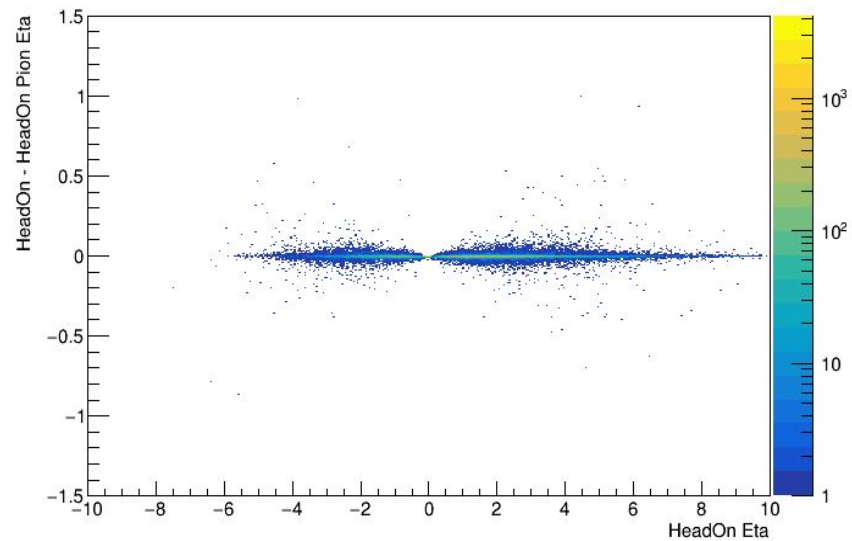


# Head-On Frame: Pion Mass Assumption (Kaons)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: Kaons

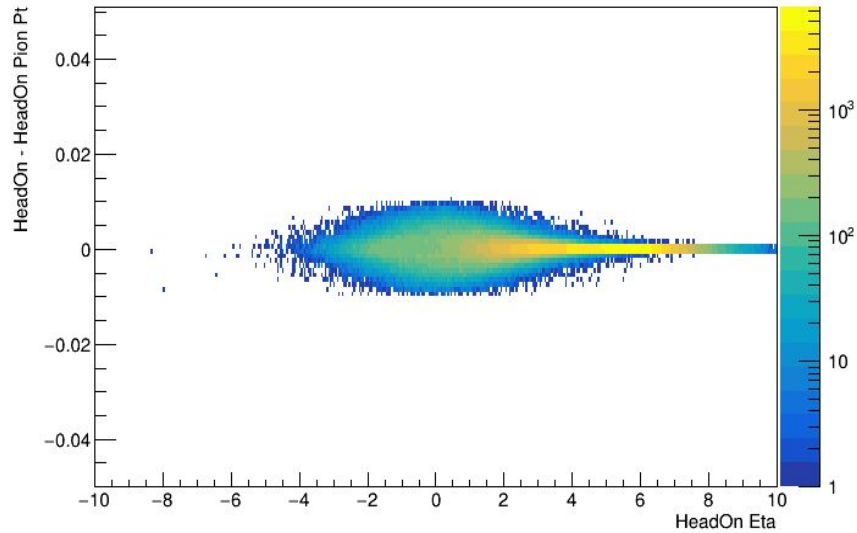


HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: Kaons



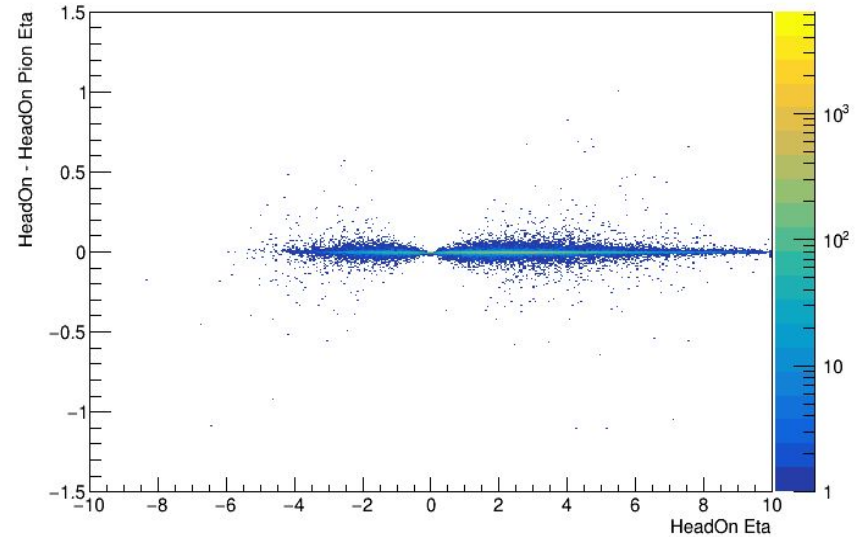
# Head-On Frame: Pion Mass Assumption (Protons)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: Proton



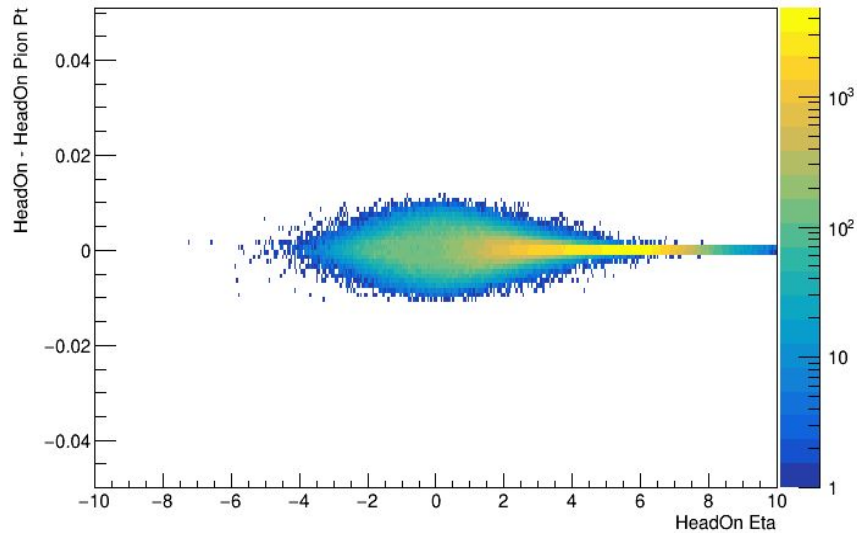
- Protons (and neutrons) show maximal deviation in transverse momentum between true head-on boost and head-on boost assuming pion mass

HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: Proton

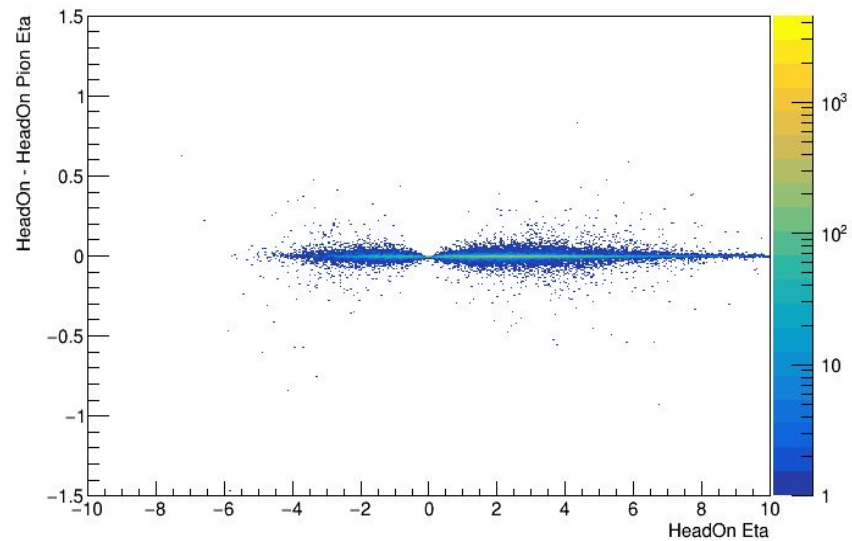


# Head-On Frame: Pion Mass Assumption (Neutrons)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: Neutron

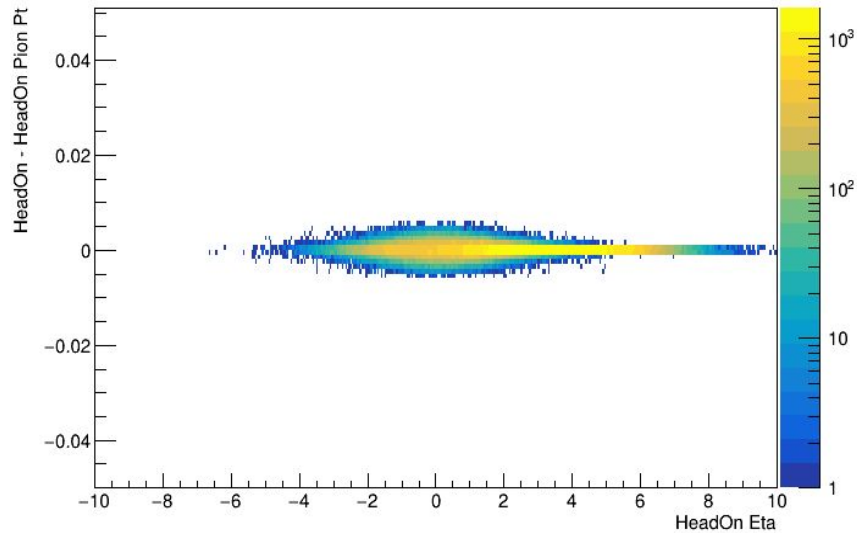


HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: Neutron



# Head-On Frame: Pion Mass Assumption (KLongs)

HeadOn - HeadOn Pion Mass Assumption Pt Vs HeadOn Eta: KLong



HeadOn - HeadOn Pion Mass Assumption Eta Vs HeadOn Eta: KLong

