ALP@ePIC Update

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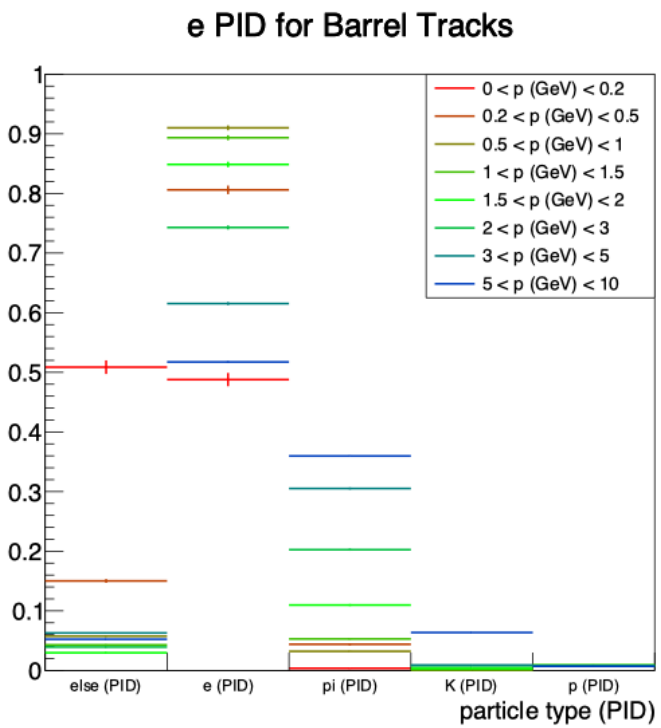
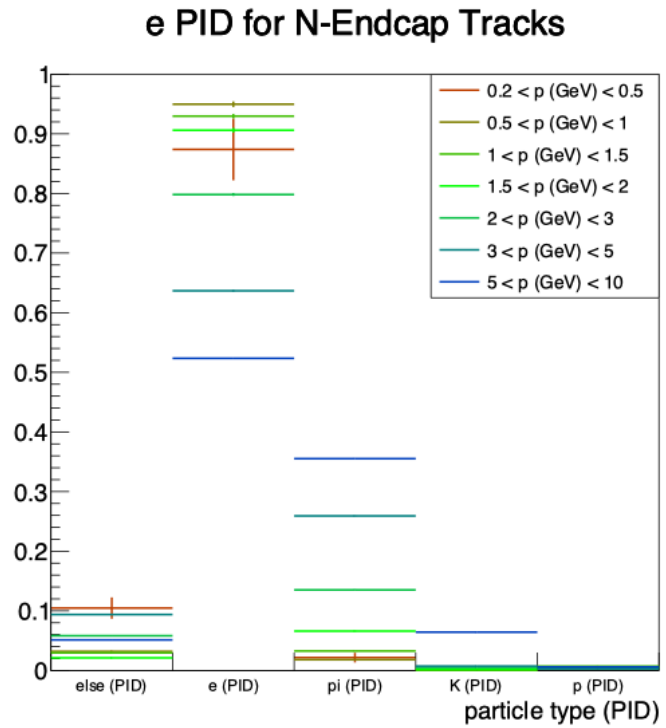
Aug 19, 2026

Selection cuts

Tracks	$p > 0.5\ GeV$ $\lvert\eta\rvert < 4$ $\lvert Z_{vtx}\rvert < 100\ mm$ $\lvert R_{XY,vtx}\rvert < 3\ mm$ $N_{hits} \geq 5$ **(Truth-)matched cluster** Reject Low-Q2 tagger
Electron	$0.8 < E_{cls}/p_{trk} < 1.4$ $E/E_{R<0.7} > 0.9$
Event	$N_{trk} = 1$ $E - P_Z < 10\ GeV$ $p_{T,miss}/E_T > 0.9$ Has ele candidate





- Left: Selection cuts from previous meeting
- Top-right: PID detector performance
- Today: Incorporate PID detectors for eID

Selection cuts

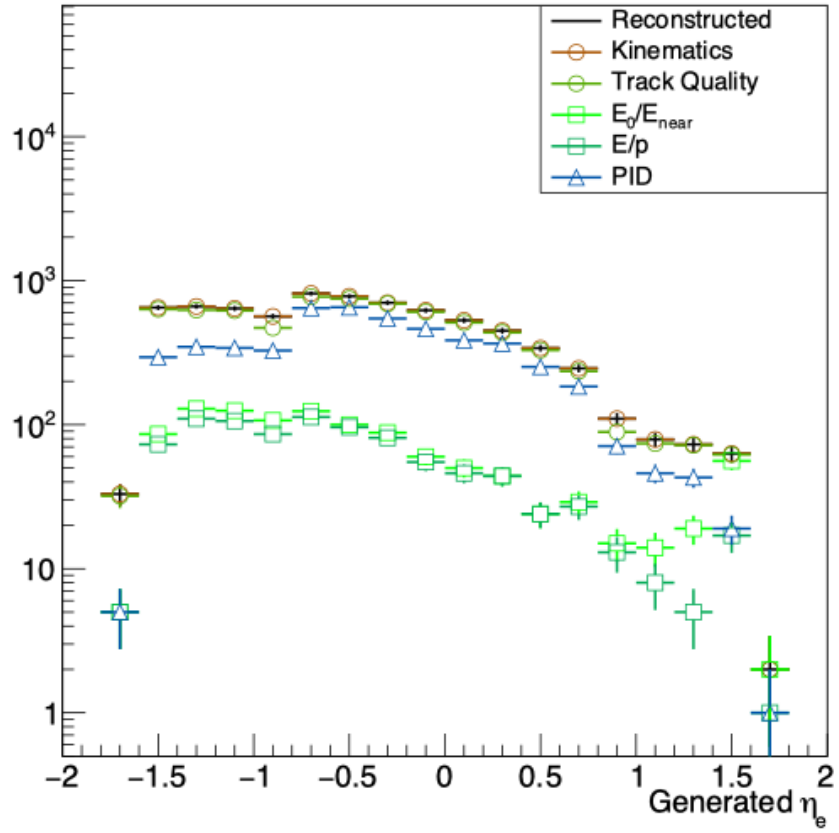
Tracks	$p > 0.5\ GeV$ $\lvert\eta\rvert < 4$ $\lvert Z_{vtx}\rvert < 100\ mm$ $\lvert R_{XY,vtx}\rvert < 3\ mm$ $N_{hits} \geq 5$ **(Truth-)matched cluster** Reject Low-Q2 tagger
Electron	$0.8 < E_{cls}/p_{trk} < 1.4$ $E/E_{R<0.7} > 0.9$
Event	$N_{trk} = 1$ $E - P_Z < 10\ GeV$ $p_{T,miss}/E_T > 0.9$ Has ele candidate

Tracks	$p > 0.2\ GeV$ $\lvert\eta\rvert < 4$ $\lvert Z_{vtx}\rvert < 100\ mm$ $\lvert R_{XY,vtx}\rvert < 3\ mm$ $N_{hits} \geq 5$ $N_{cls} > 0$ **OR PDG != 0** Reject Low-Q2 tagger	
Electron	$N_{cls} > 0$ $0.8 < E_{cls}/p_{trk} < 1.4$ $E/E_{R<0.7} > 0.9$	$N_{cls} = 0$ **AND** $p < 1\ GeV$ PDG (LUT) = 11
Event	$N_{trk} = 1$ $E - P_Z < 10\ GeV$ $p_{T,miss}/E_T > 0.9$	

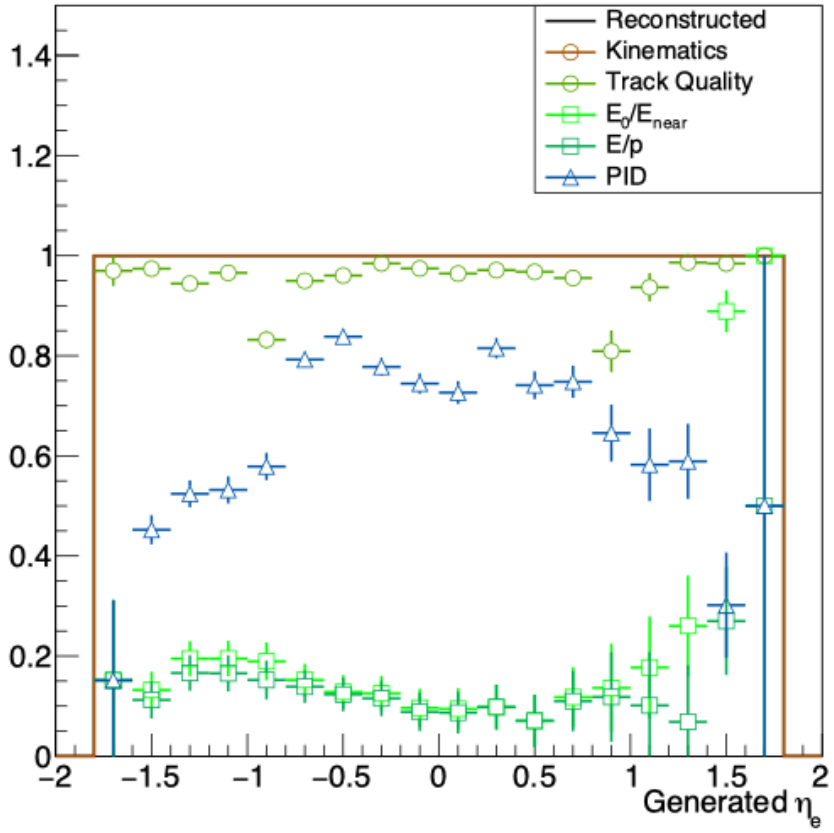
PID Performance (Barrel)

$* e + Pb \rightarrow e + Pb + a$, 10×110 GeV2, $m_a = 1$ GeV

Cut flow on Raw Yield



Efficiency ($N_i/N_{Recon.Char.Part.}$)

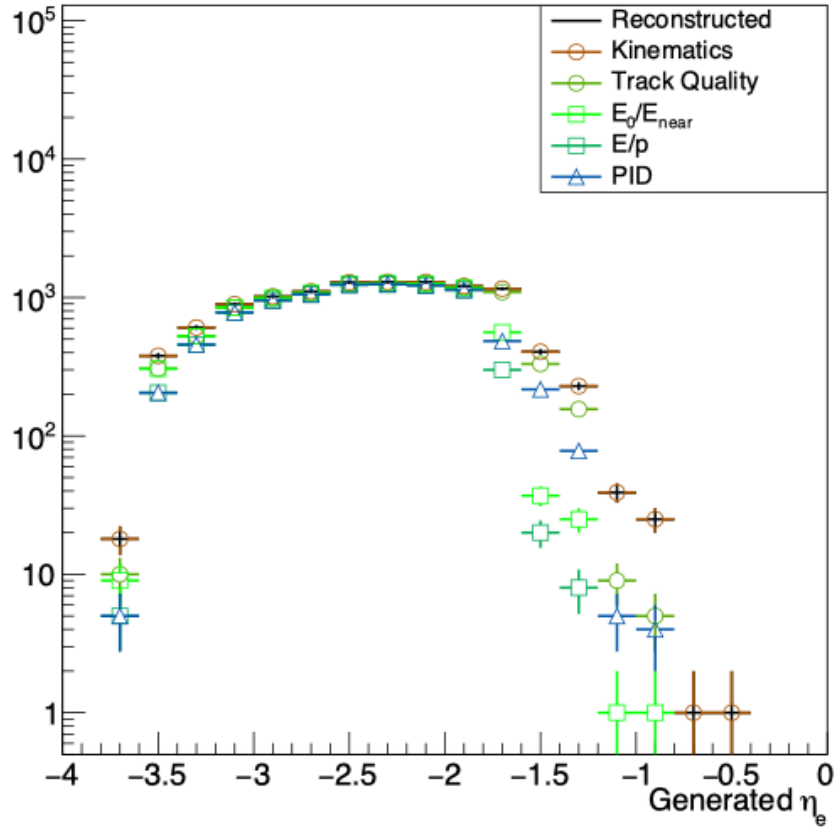


- Significant gain ($\sim 4\times$) in efficiency in the barrel region after removing the requirements on ECal match below p < 1 GeV

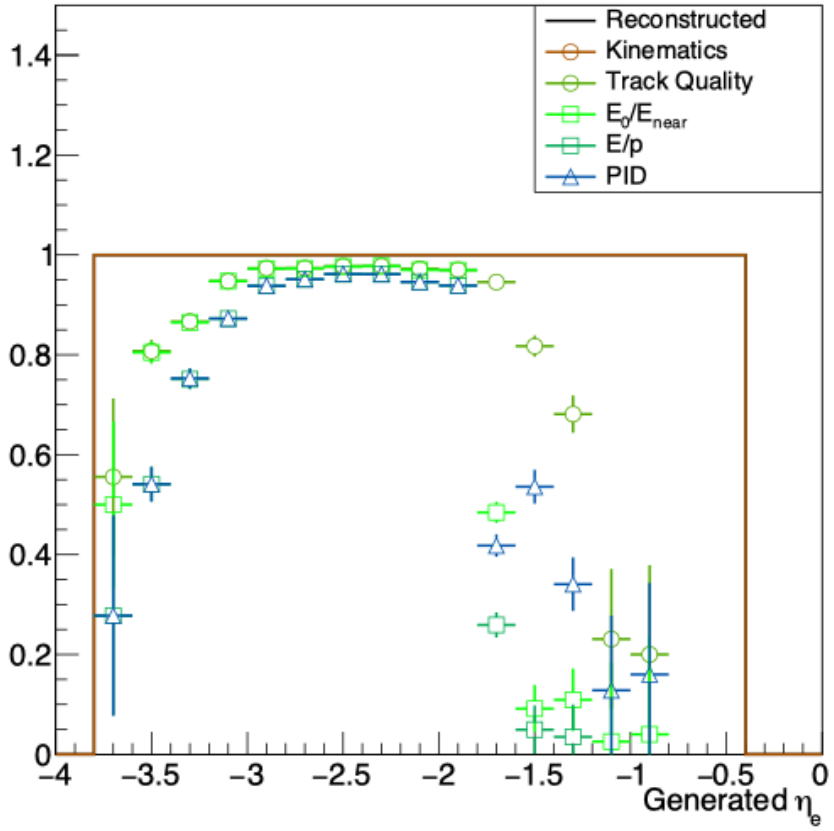
PID Performance (N-End)

$* e + Pb \rightarrow e + Pb + a$, 10×110 GeV2, $m_a = 1$ GeV

Cut flow on Raw Yield



Efficiency ($N_i / N_{Recon.Char.Part.}$)

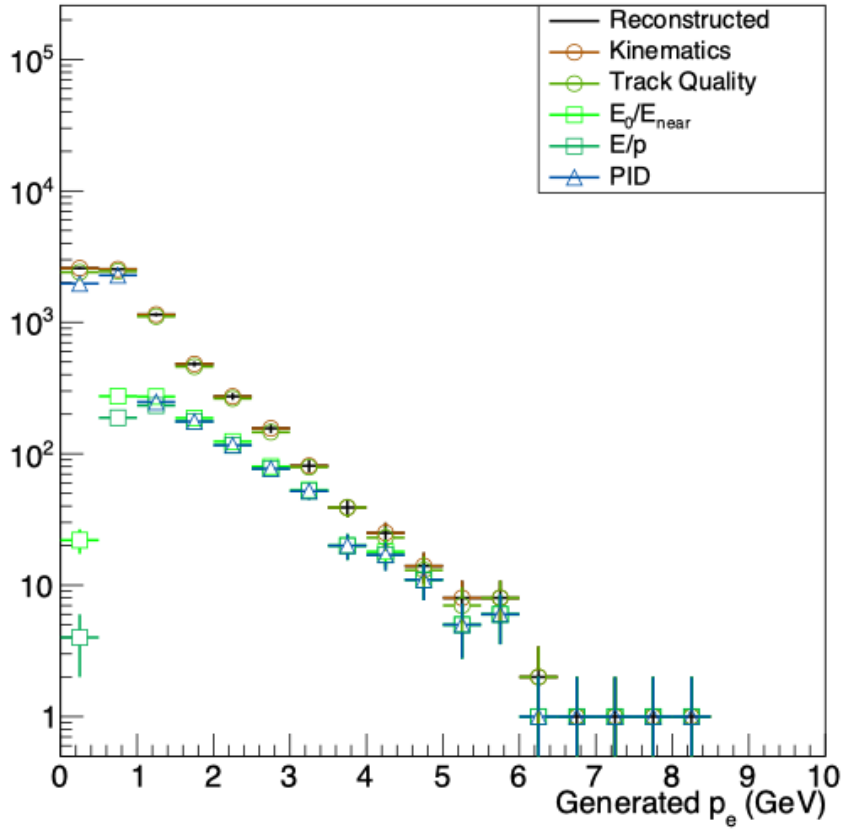


- No significant impact for N-Endcap (and P-Endcap) tracks

PID Performance (Barrel)

$* e + Pb \rightarrow e + Pb + a$, 10×110 GeV2, $m_a = 1$ GeV

Cut flow on Raw Yield



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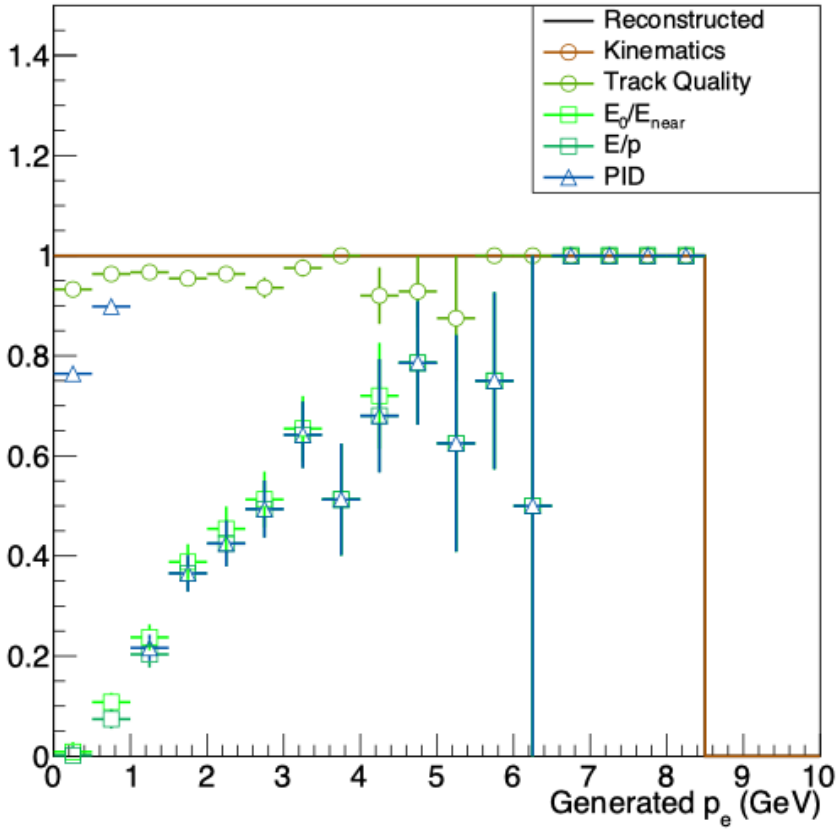
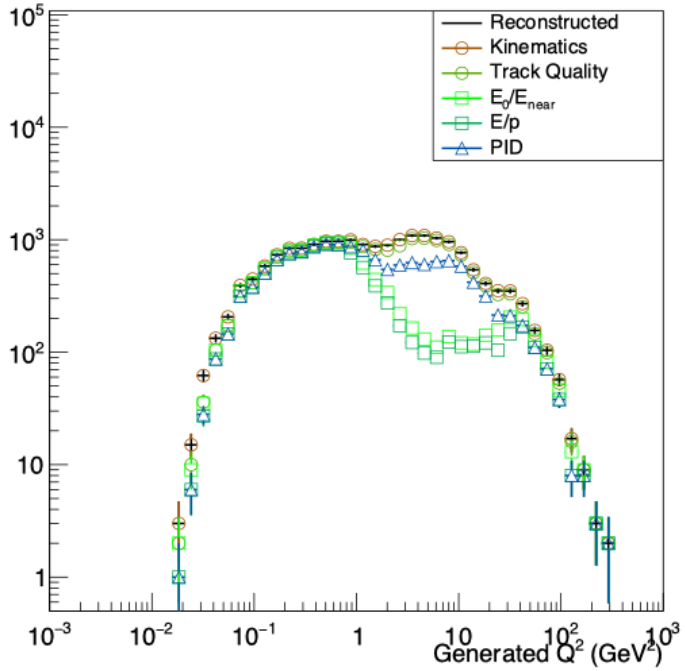
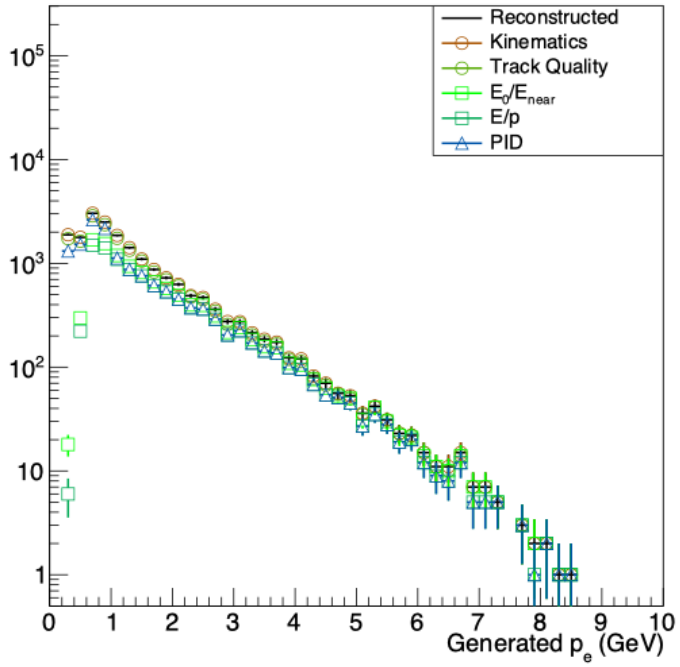
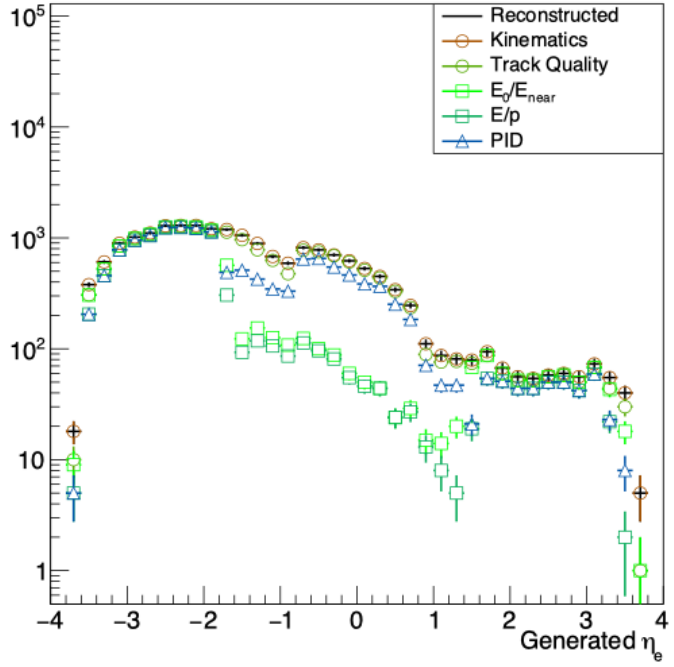


- Big jump in efficiency at the $p = 1$ GeV mark
- Large systematics expected from unfolding with real data
- Likelihood-based approach for eID in this regime (barrel, low-momentum)?

Summary



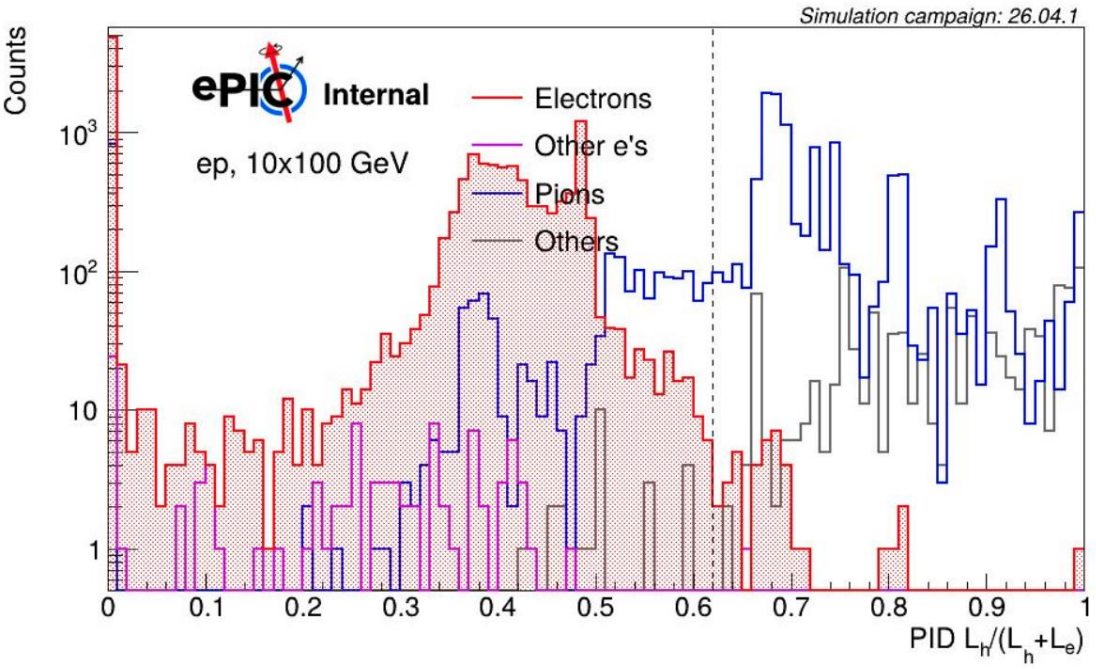




- By **relaxing** the **ECal matching** requirement, and relying on **PID detectors**, one should expect improvement in eID efficiency in the **low-momentum** ($\sim < 1\ GeV$, $y > 0.9$), **intermediate Q^2** ($\sim 10\ GeV^2$), and **barrel** region
- Likelihood-based approach might be worthwhile to address the “step function” behavior in electron momentum
- Pion contamination needs to be evaluated as well

Backup

eID via PID detectors

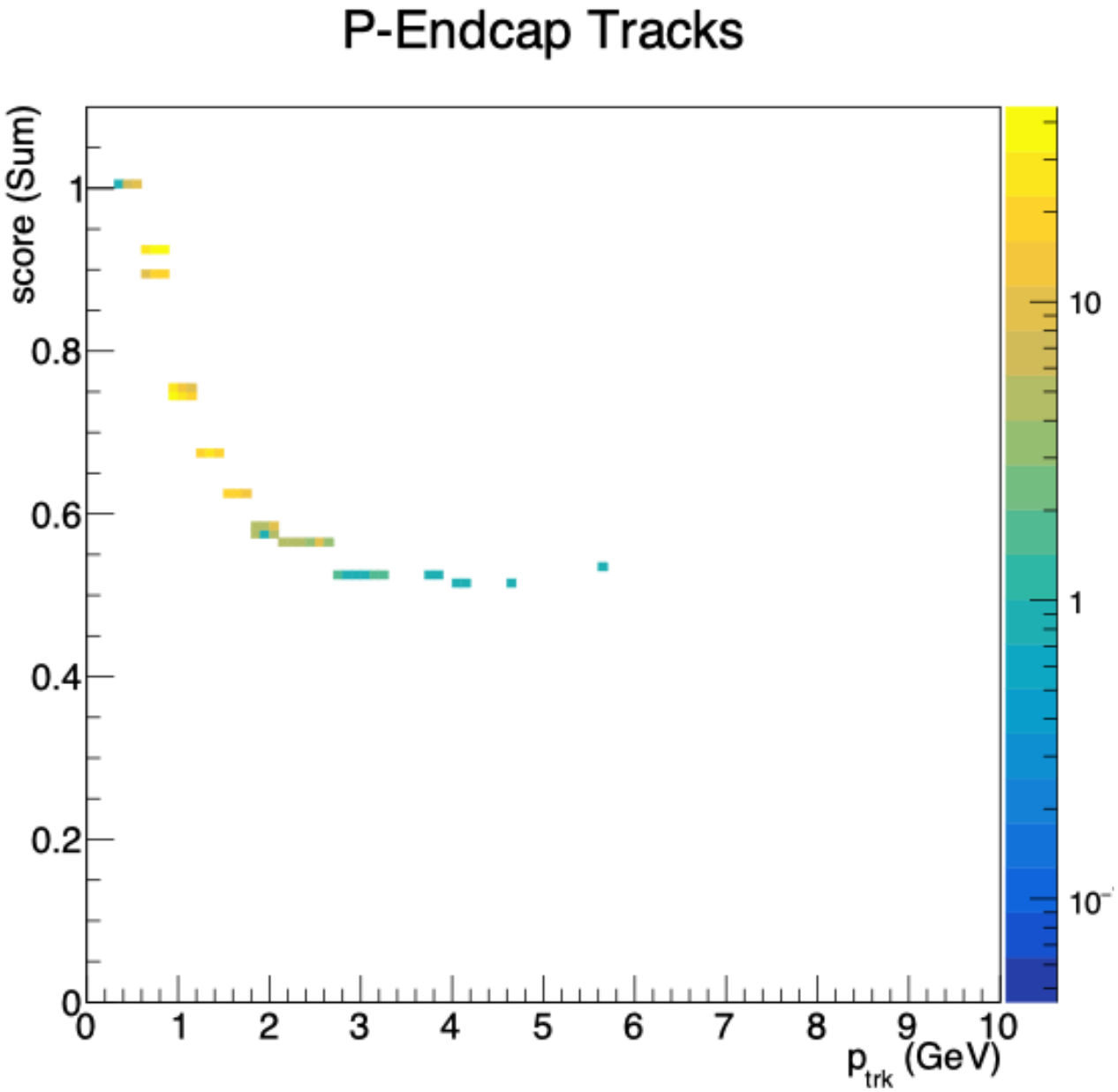


State of PID structures in our EDM

- Two implementations that rely on edm4hep::ParticleID:
  - [1] [2] **PID LUTs** for *pfRICH, DIRC, TOF, DRICH*: e±, π±, K±, p±
  - [3] **ML on clusters** for *EEEMCal*: e-, π-
  - EDM4hep insists on inverting the relation, i.e. ParticleID points to ReconstructedParticle [4] [5]
- The ML method currently "misuses" the **likelihood field and provide posterior P(hypot|meas)** instead of the **likelihood P(meas|hypot)**
- The LUTs also "misuse", providing **distribution of model outputs conditioned by true class P(prediction|hypot)**. Main charge for LUTs was to fill the PDG field, reproducing a realistic misclassification distribution.

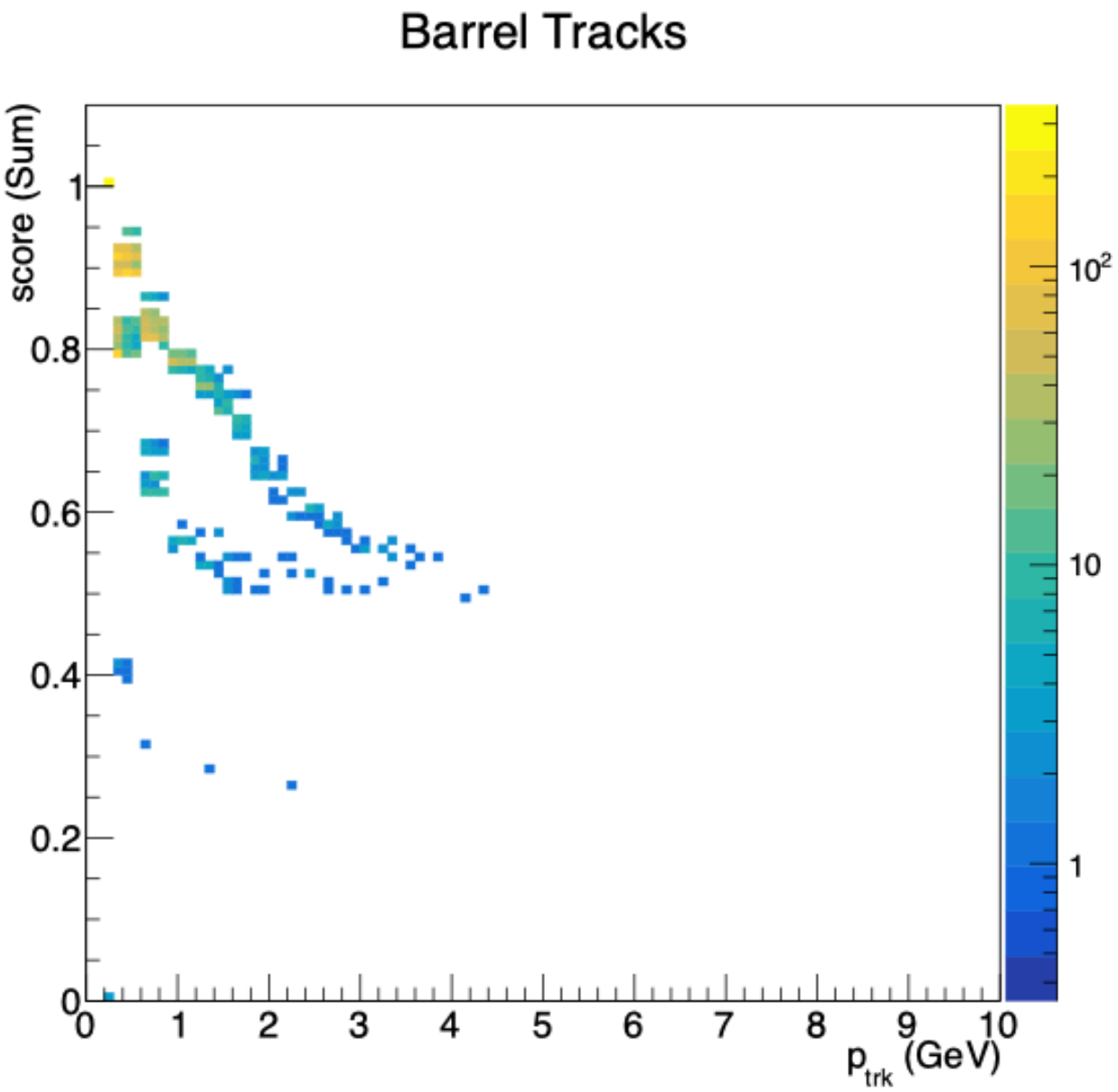
- eID based on the "likelihood" from PID detectors (LUT)
- Good e-h separation
- Score (nominal) $= \frac{\max(L_h|TOF,DIRC,\dots)}{\max(L_e)+\max(L_h)}$
- PID presentation from O. Hartbrich and D. Kalinkinin Joint SC-TC PID meeting (https://indico.bnl.gov/event/29822/contributions/113615/attachments/64927/111522/PID%20Data%20Model.pdf)
- Discusses the misuse of Likelihood field
  $L_{current}$ = <prediction | truth prior >
  = <prediction | detector > < detector | truth >
- Detector level info integrated out!
- Whereas (depending on exactly what we are trying to do), what we want is either <prediction | detector> or <detector | truth >

P-Endcap response



- Looking at electrons from $e + Pb \rightarrow e + a$
- eID score (sum) $= \frac{\sum_{TOF,dRICH} L_e}{\sum L_e + \sum L_h} = \left(\frac{L_e}{L_e + L_h}\right)_{dRICH}$
- Complete correlation between prior (momentum) and eID score (sum)

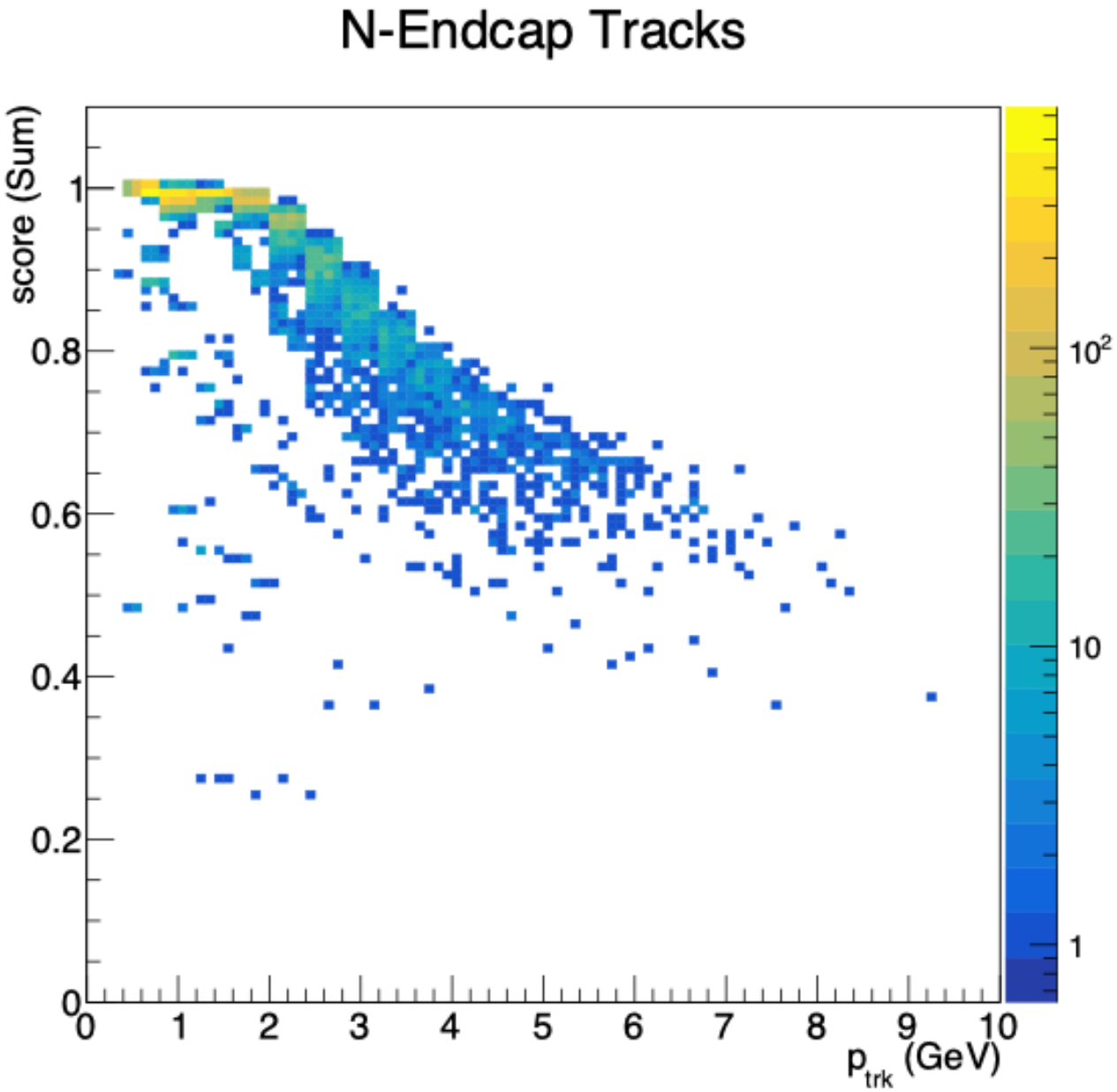
Barrel response



- Three “bands” coming from
  - DIRC only
  - TOF only
  - DIRC + TOF

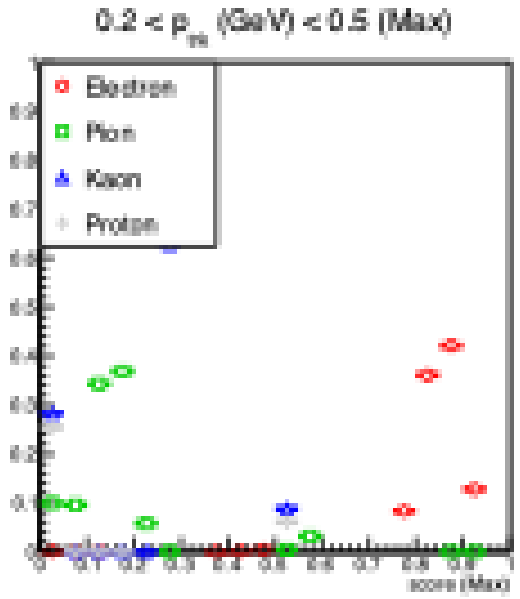
- Similar result as P-Endcap

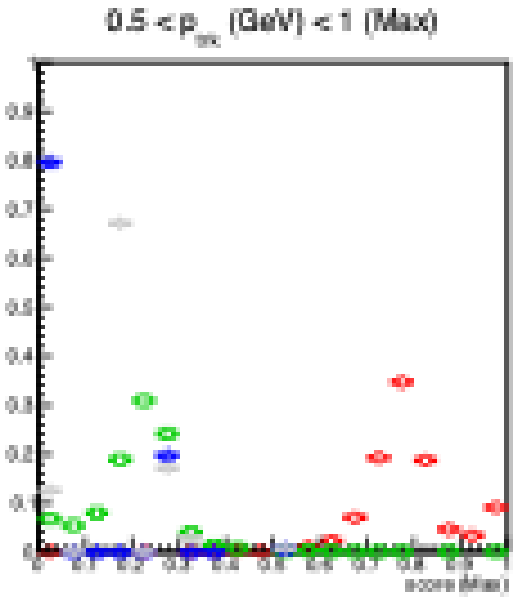
N-Endcap response

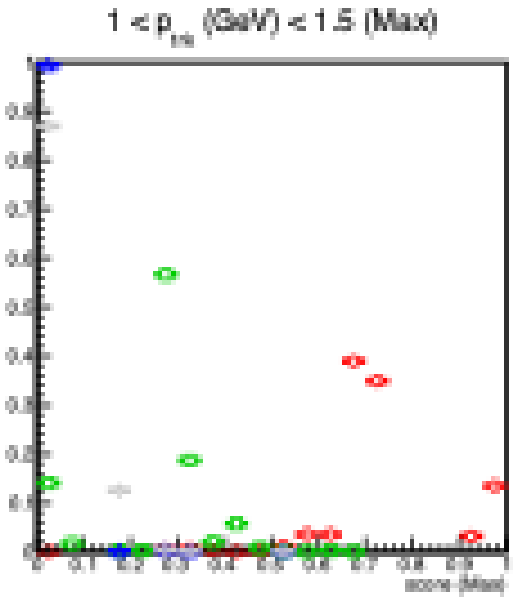


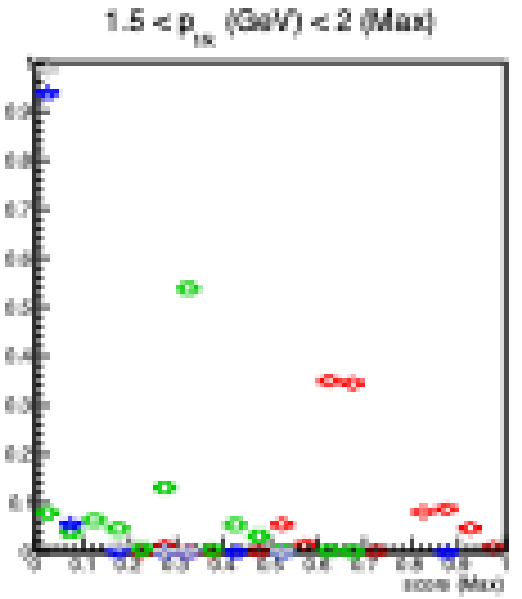
- Much more “smearing” then previous two
- Will investigate other significant priors (p, eta, phi, charge, truth PDG)

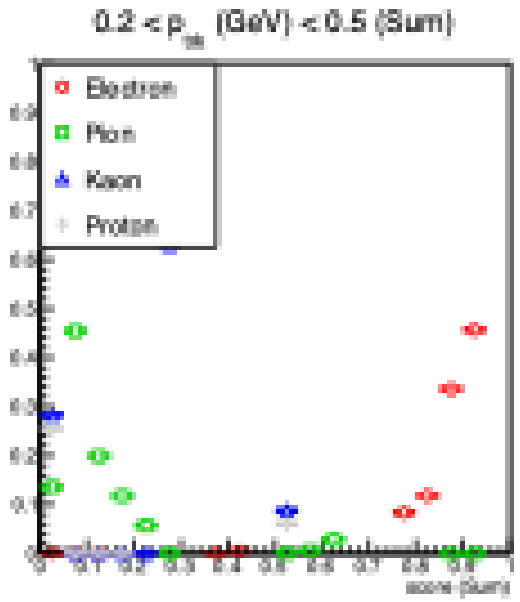
Barrel tracks

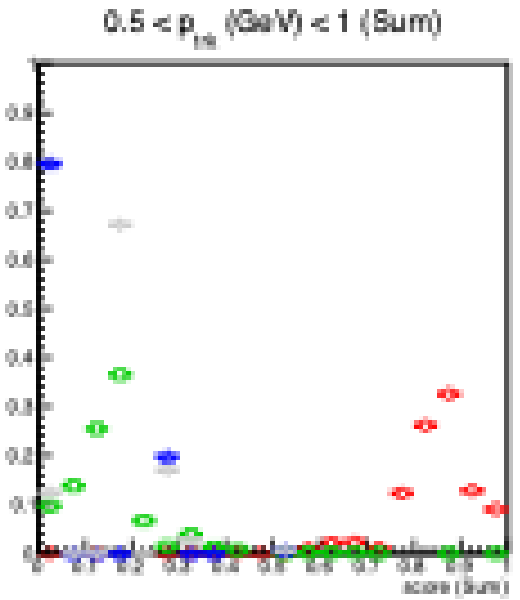


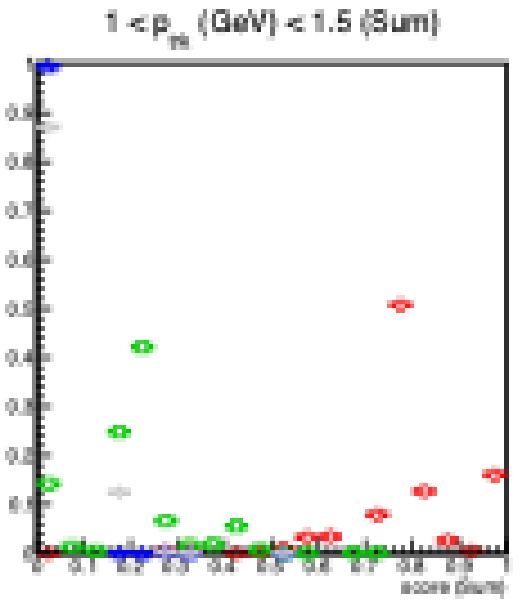


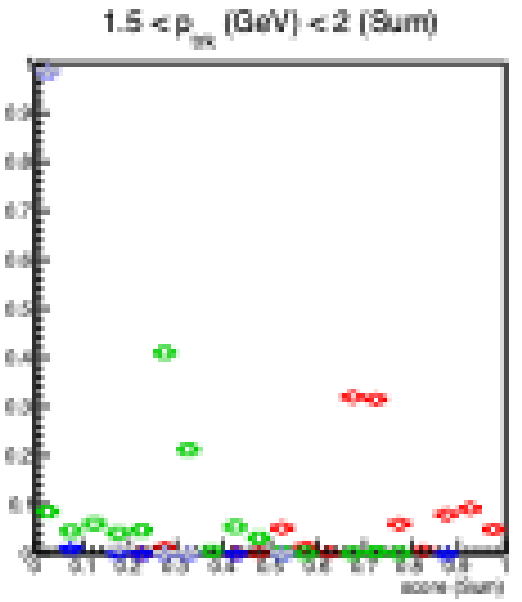




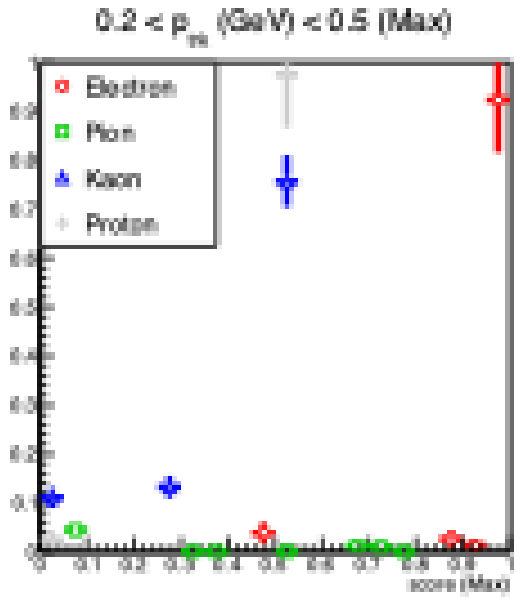


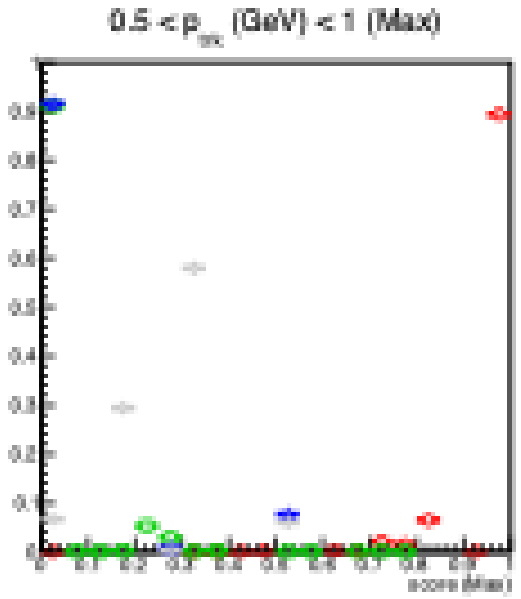


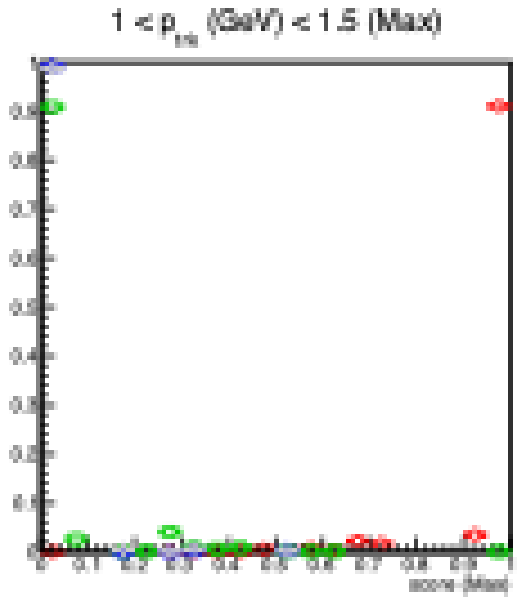


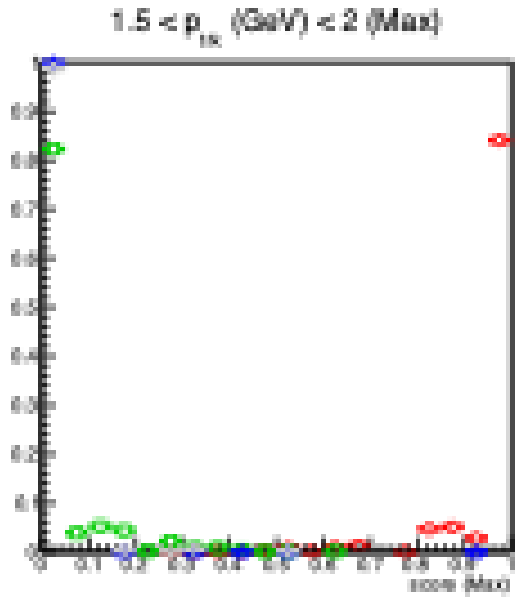


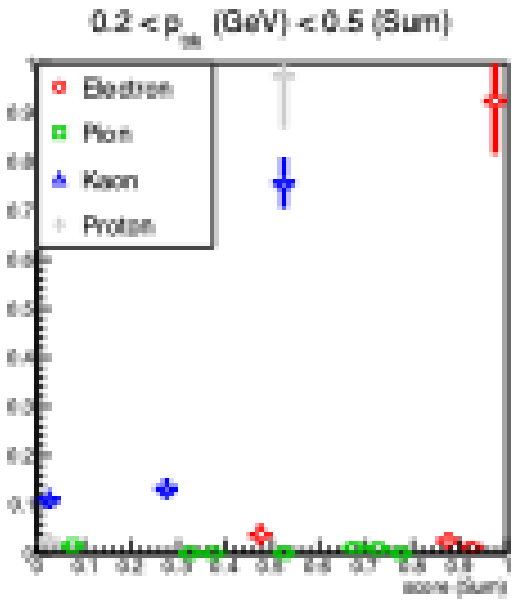
N-Endcap tracks

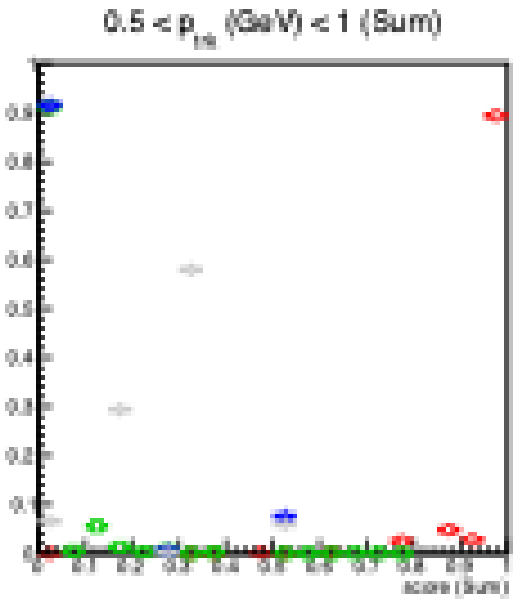


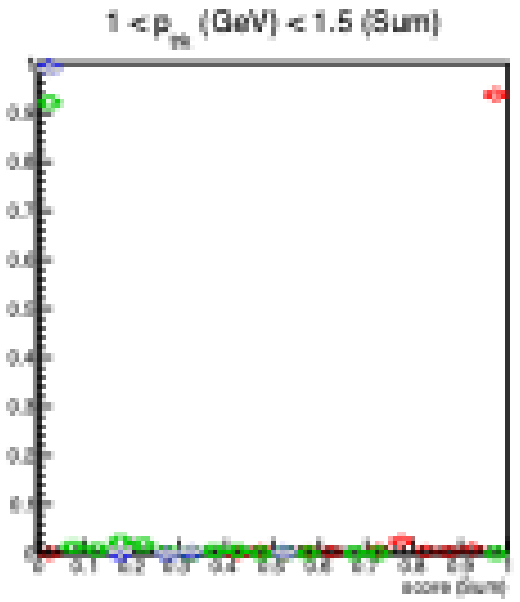


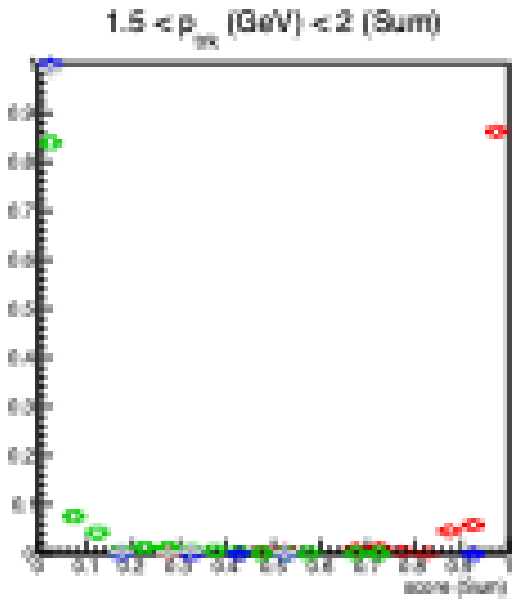




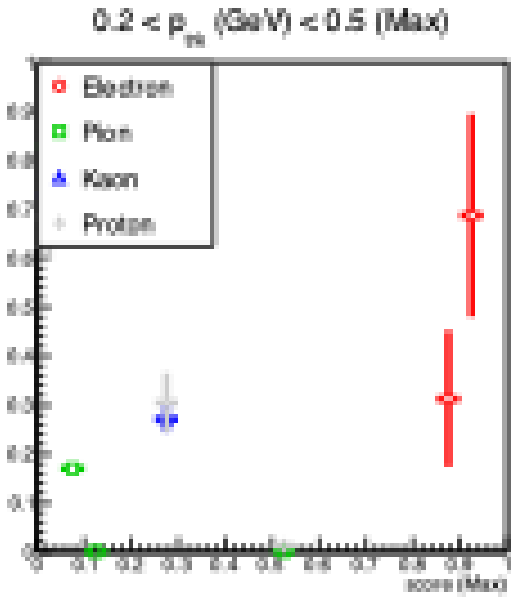


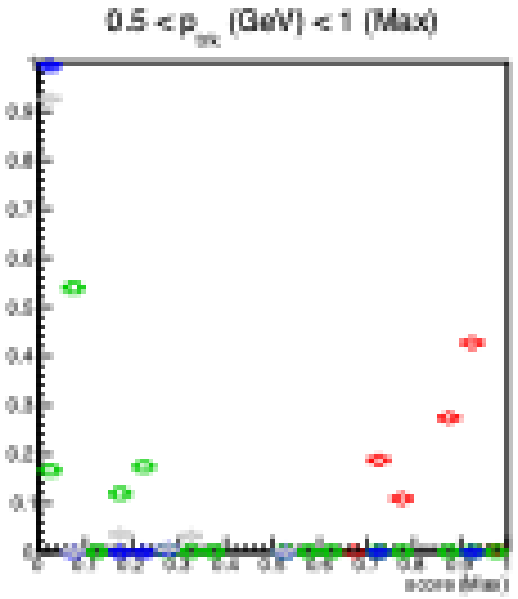


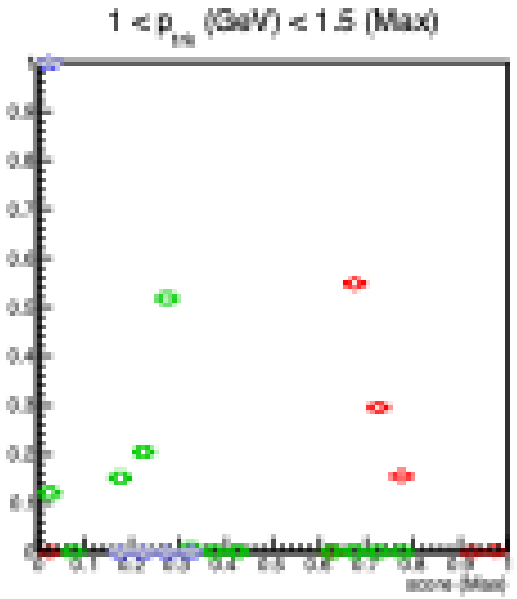


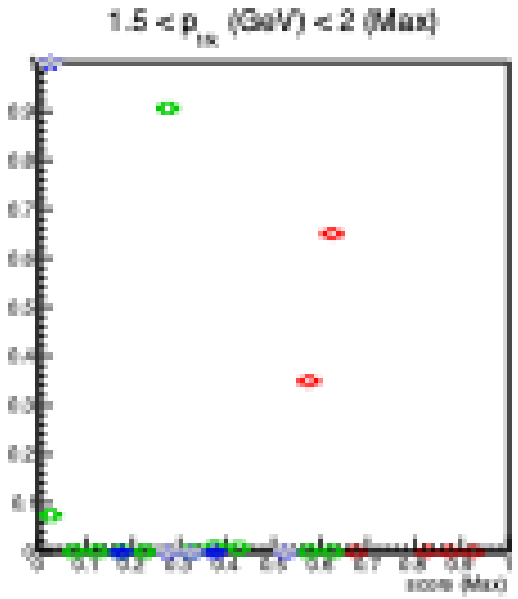


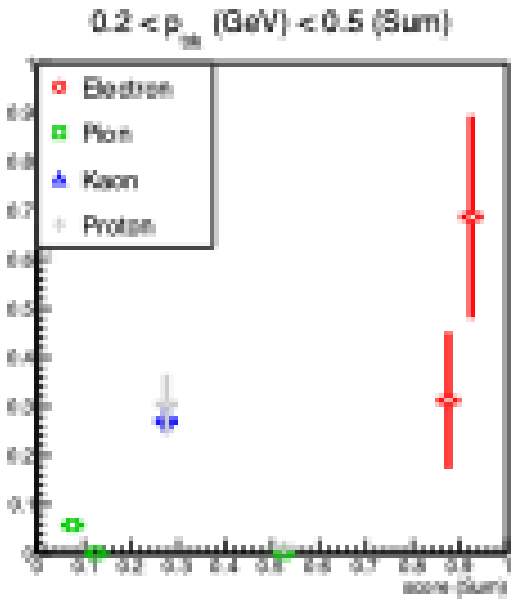
P-Endcap

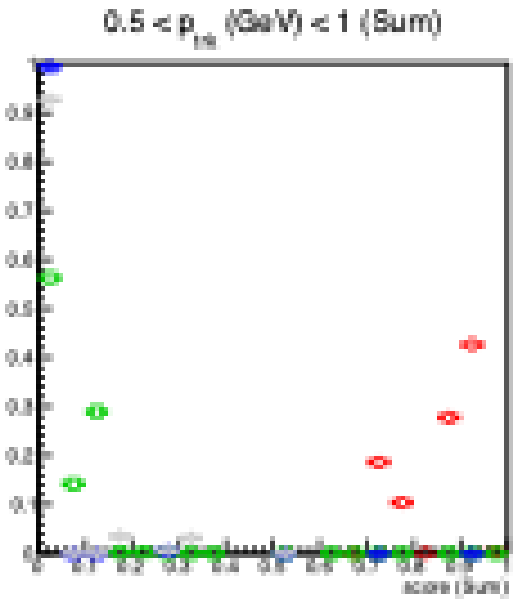

0.2 < p_TK (GeV) < 0.5 (Max)
Electron
Pion
Kaon
Proton
score (Max)

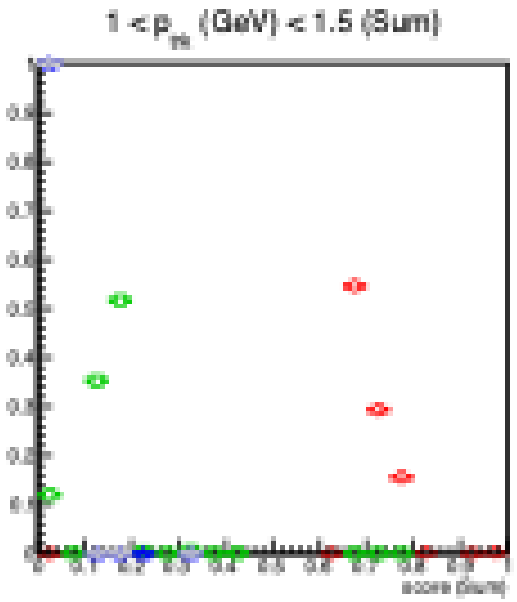

0.5 < p_TK (GeV) < 1 (Max)
score (Max)

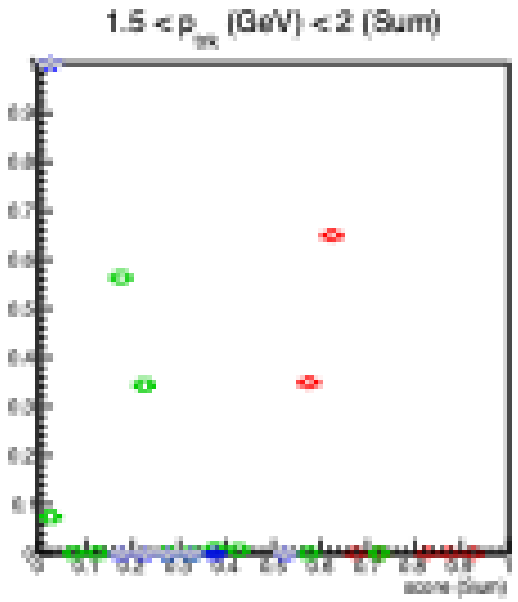

1 < p_TK (GeV) < 1.5 (Max)
score (Max)


1.5 < p_TK (GeV) < 2 (Max)
score (Max)

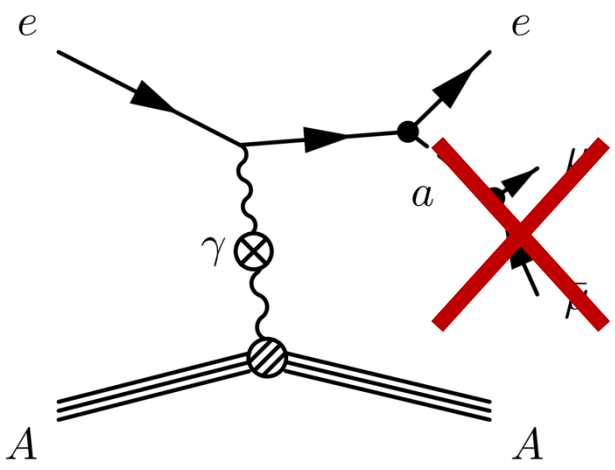

0.2 < p_TK (GeV) < 0.5 (Sum)
Electron
Pion
Kaon
Proton
score (Sum)

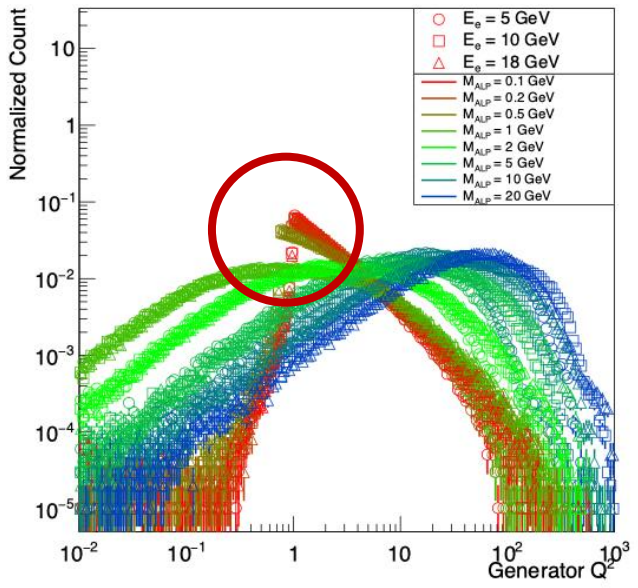

0.5 < p_TK (GeV) < 1 (Sum)
score (Sum)

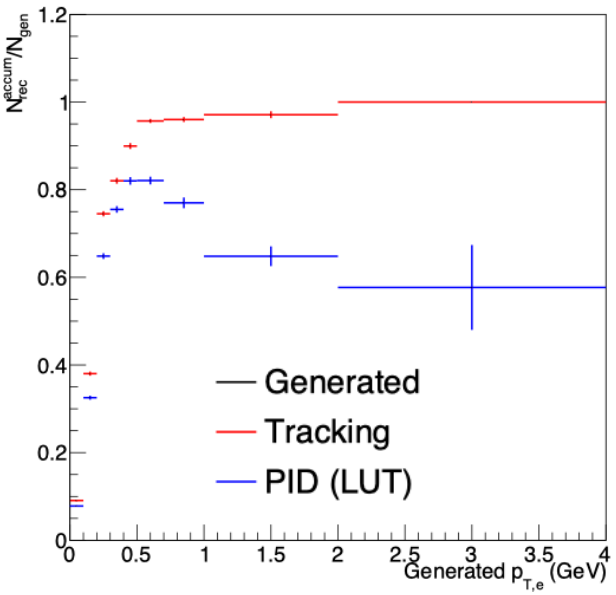

1 < p_TK (GeV) < 1.5 (Sum)
score (Sum)

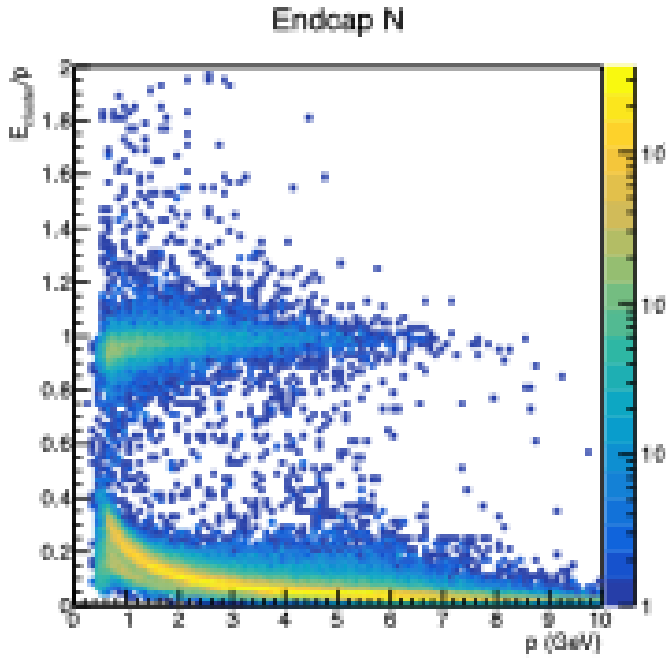

1.5 < p_TK (GeV) < 2 (Sum)
score (Sum)

Recap



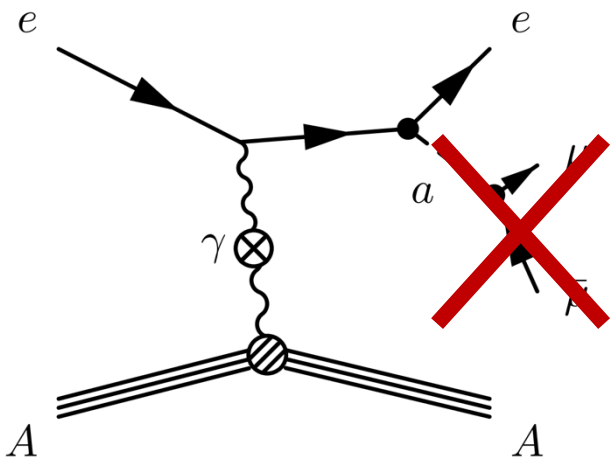


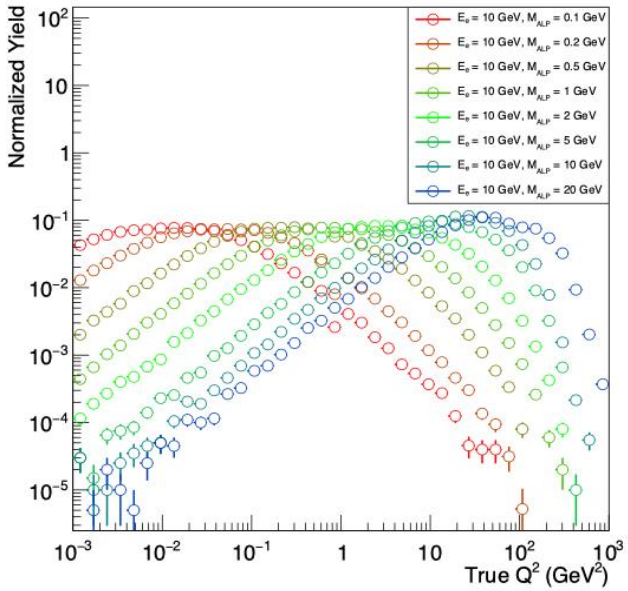


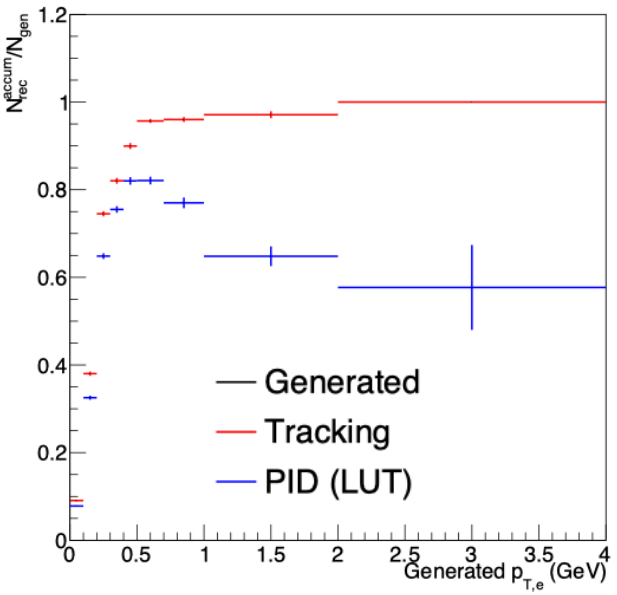


- Last update on Apr 21
- Focus: Non-decaying/ Invisibly-decaying ALP
- Event kinematics entirely defined by electron within central ePIC
- Bug with MadGraph5 event generation → has been addressed
- Strong ALP mass (m_a) dependence found in observed Q^2 (purely phenom. quantity)
- eID cannot entirely rely on PID systems?
- First look at ECal response

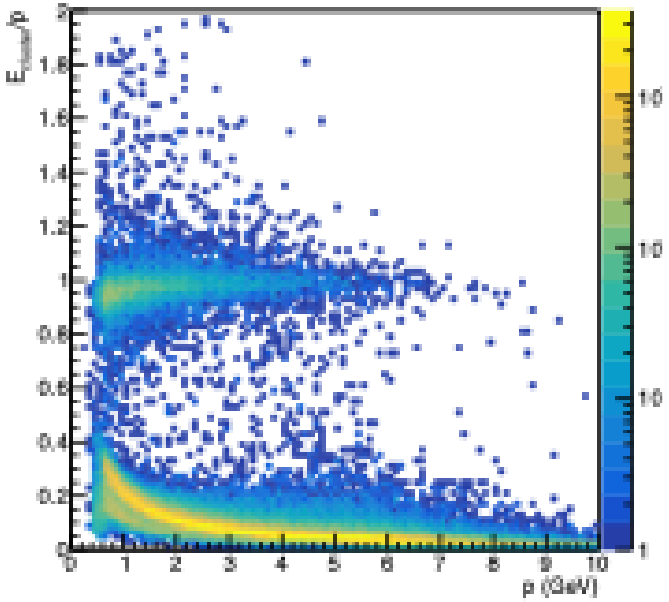
Recap







Endcap N



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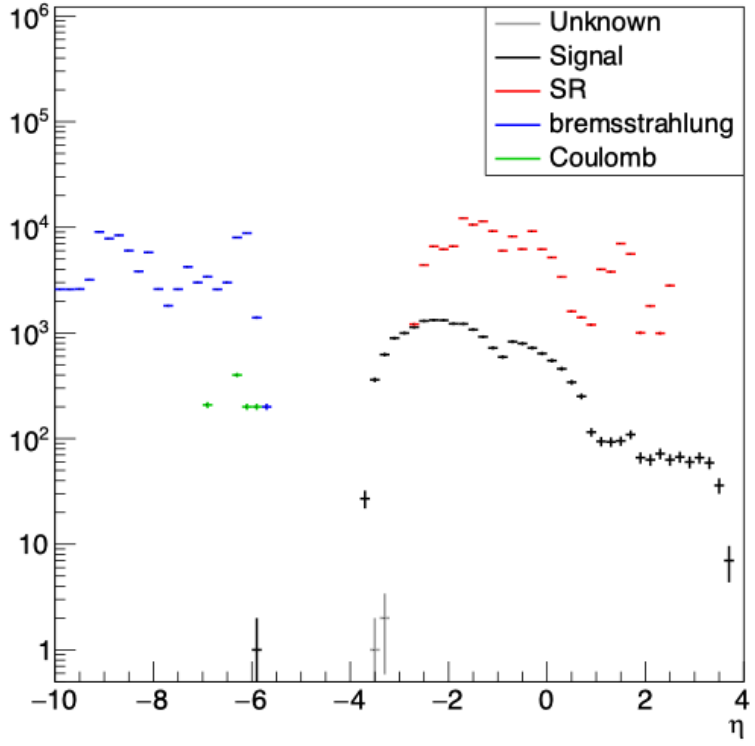
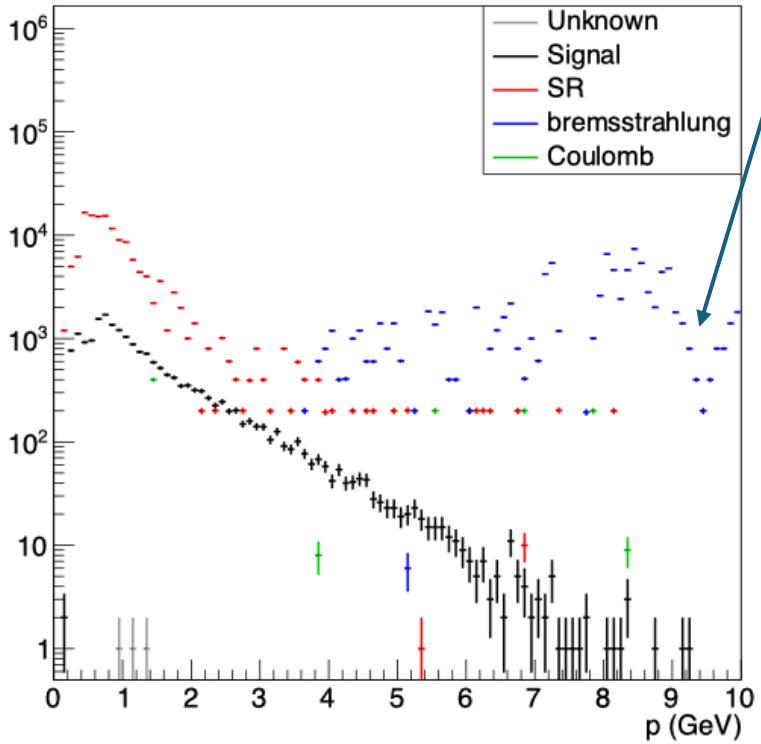
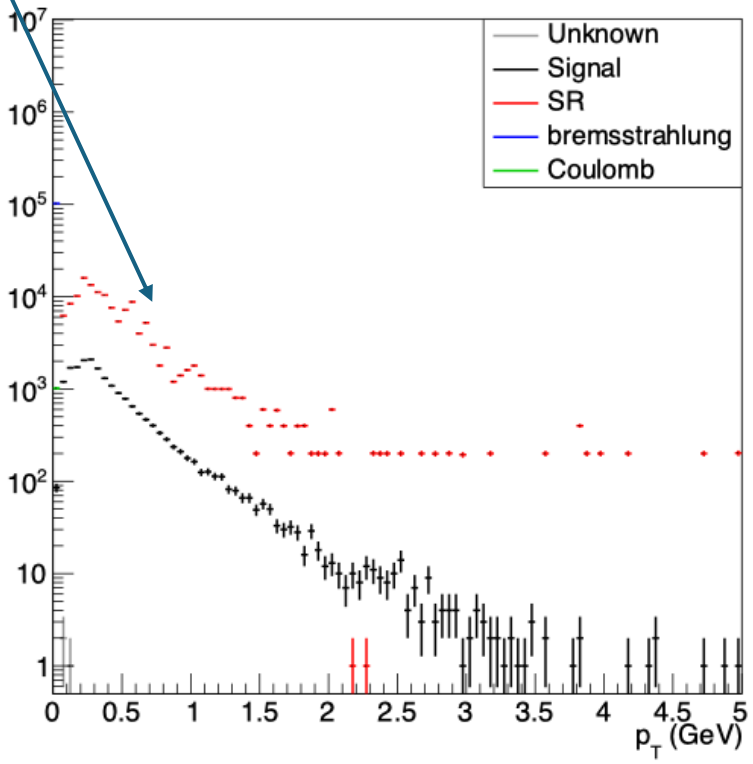
Rejecting machine backgrounds

Correlated BG, should be resolved in July campaign

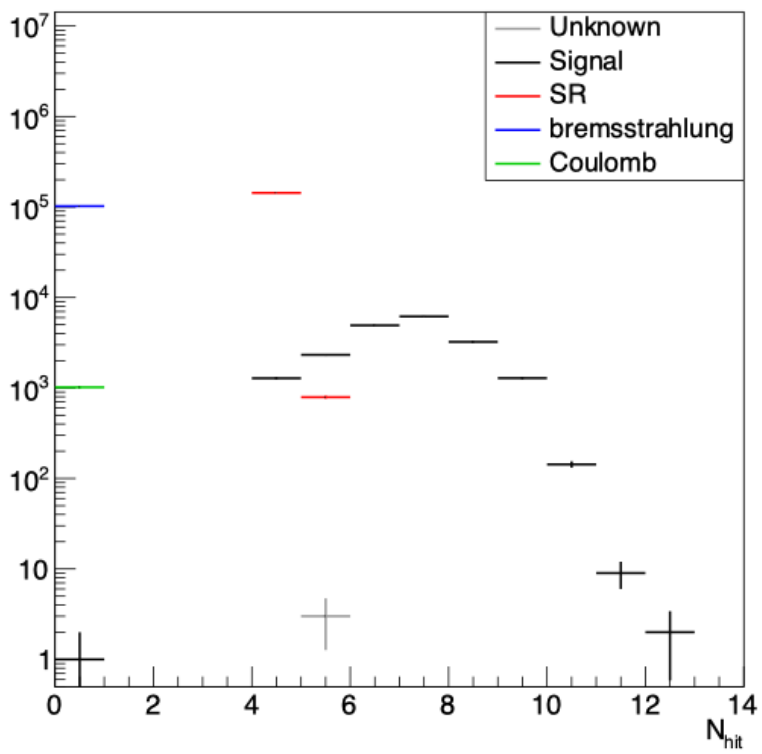


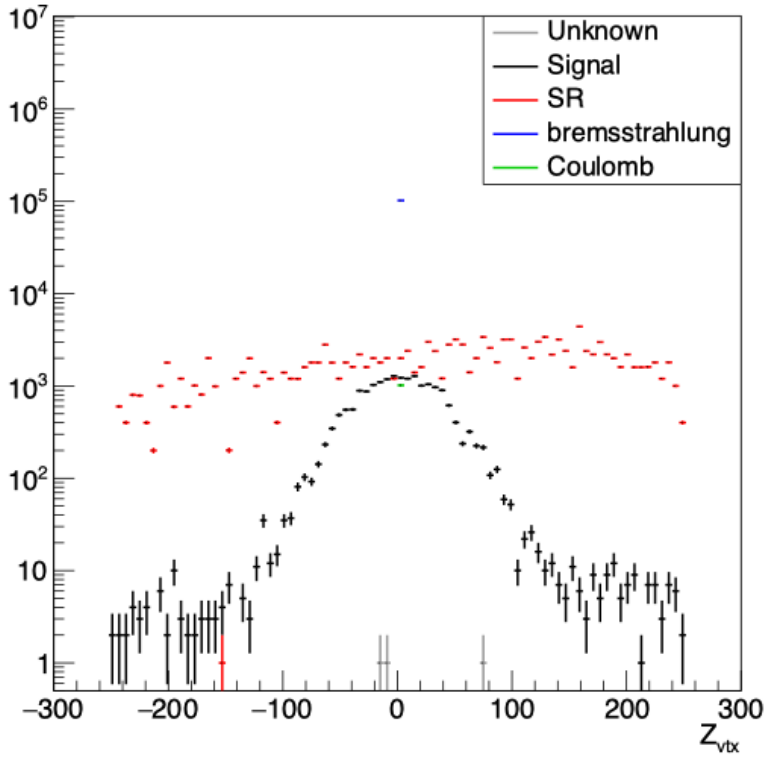


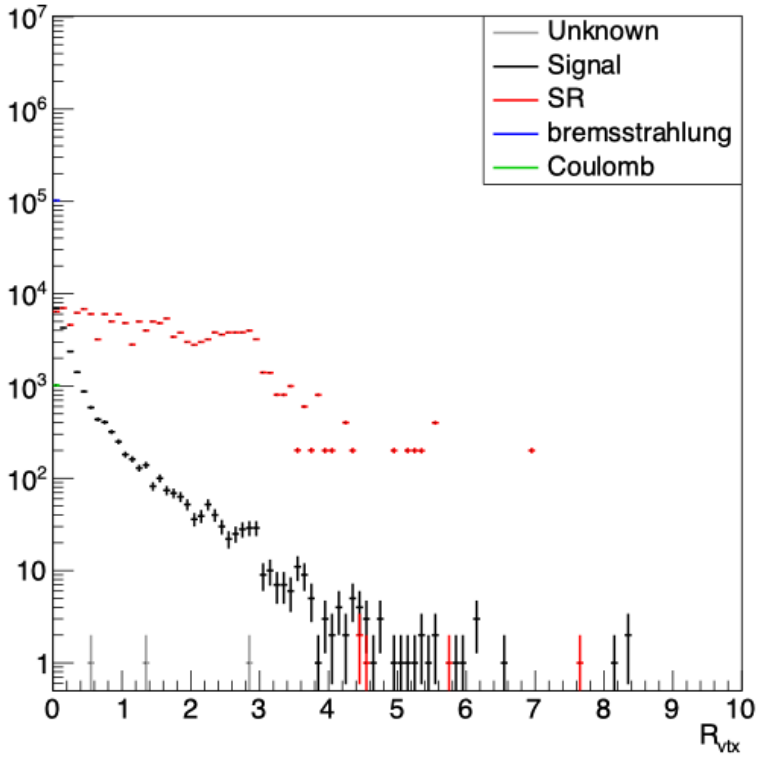


- Signal (ALP) tracks compared to machine backgrounds in June production
- brems and Coulomb tracks in low-Q^2 tagger
  → reject tracks in low-Q^2 tagger for now
- High-rate SR photons (~50k hits within 2μs window) → combinatoric fake tracks

Rejecting machine backgrounds

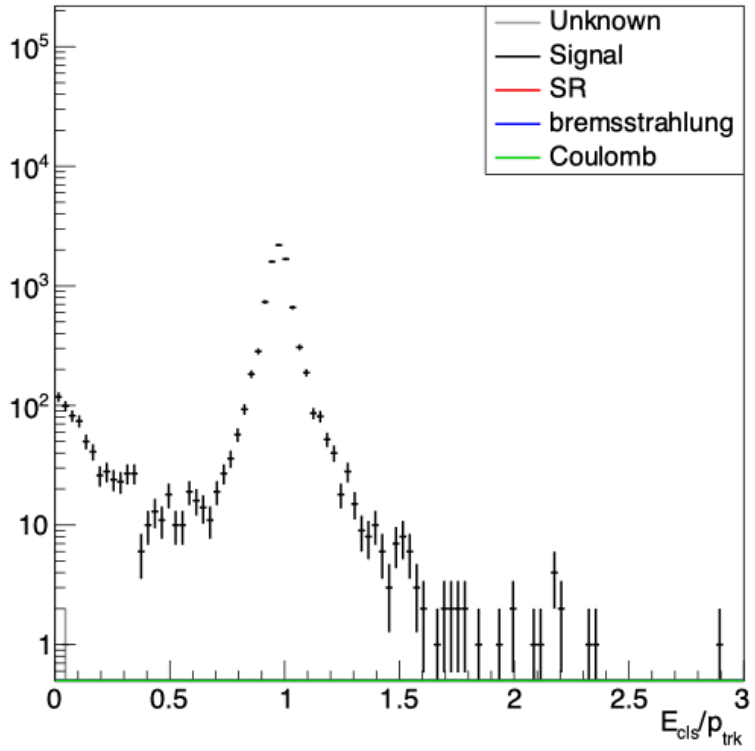


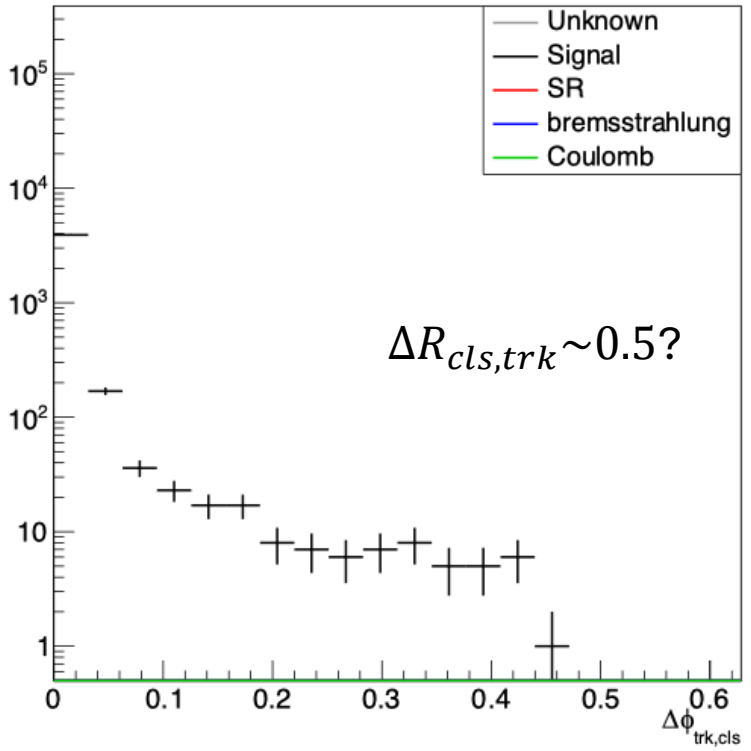


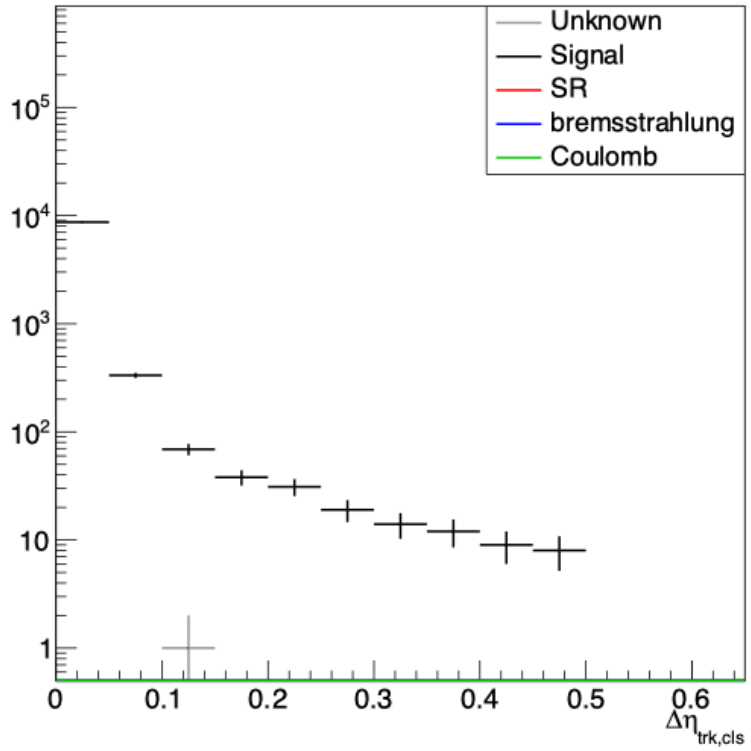


- N_{hits} cut at ≥ 5 (default) should reject most of the SR tracks
- Further beamline constraints should reject the remaining $\sim 50\%$

Rejecting machine backgrounds







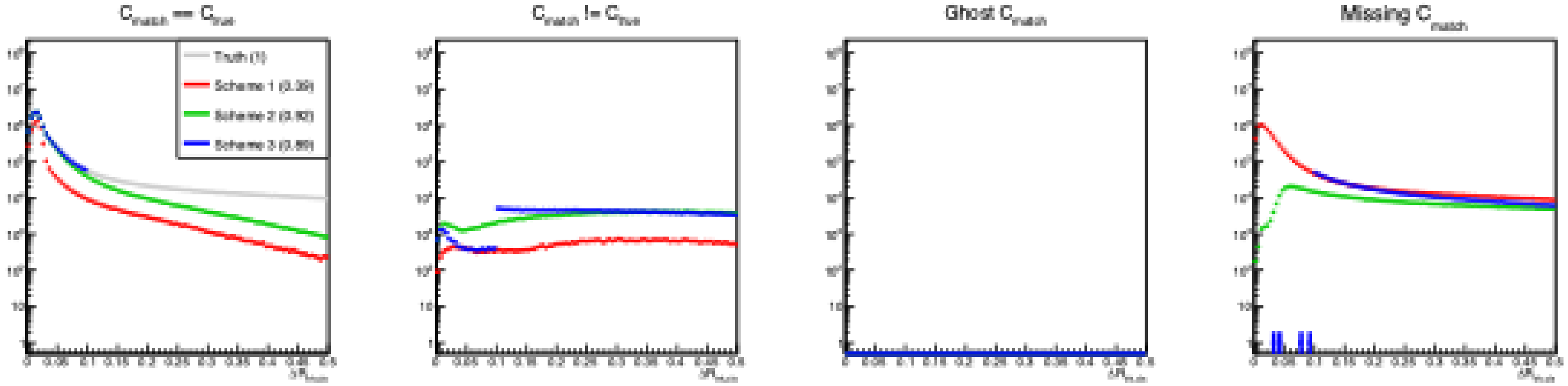
- Geometric matching ("TrackClusterMatch") to an ECal cluster, effectively requiring 6th hit, removes all of the SR fake tracks

➢This effectively imposes a lower limit on momentum (e.g., $p_T > 0.5\ GeV$ in barrel)

- Current simulation infrastructure is limited in statistics, this study needs to be revisited with either more SR simulation or real data

Cluster matching tests

* Based on DIS $1 < Q^2(GeV^2) < 10$ sample

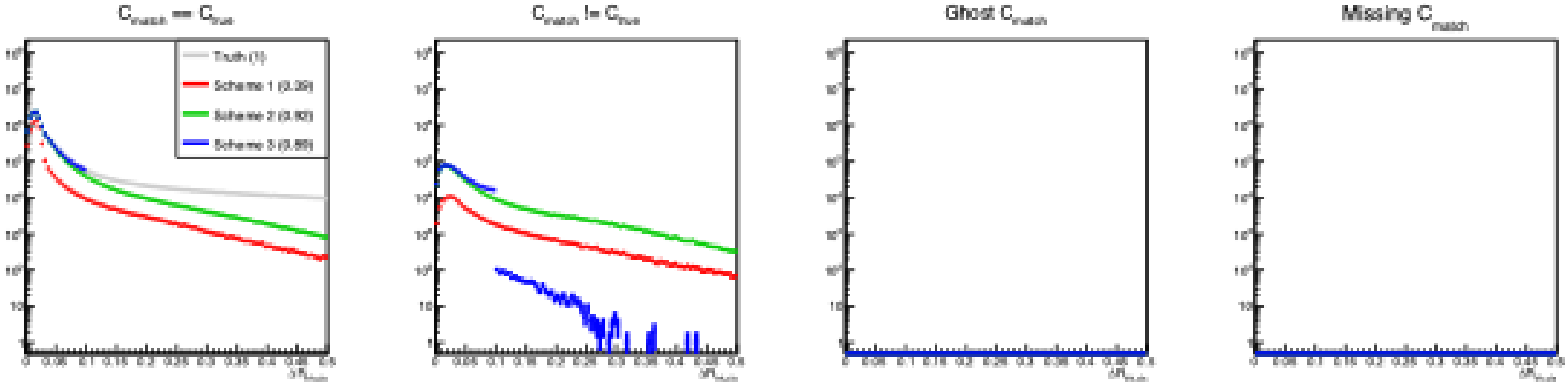


Truth-matched track-cluster

- Test of track-cluster matching algo
  - Scheme 1: “TrackClusterMatch” (nearest cluster within 0.5 in $\Delta\eta \times \Delta\phi$)
  - Scheme 2: Most energetic cluster within R = cluster radius + 1 cell size
  - Scheme 3: Most energetic cluster within R = 0.1 in $\Delta\eta \times \Delta\phi$ space
- No clear “winner”, will revisit this topic with cluster splitting
- Further studies (for now) using truth matches

Cluster matching tests

* Based on DIS $1 < Q^2(GeV^2) < 10$ sample

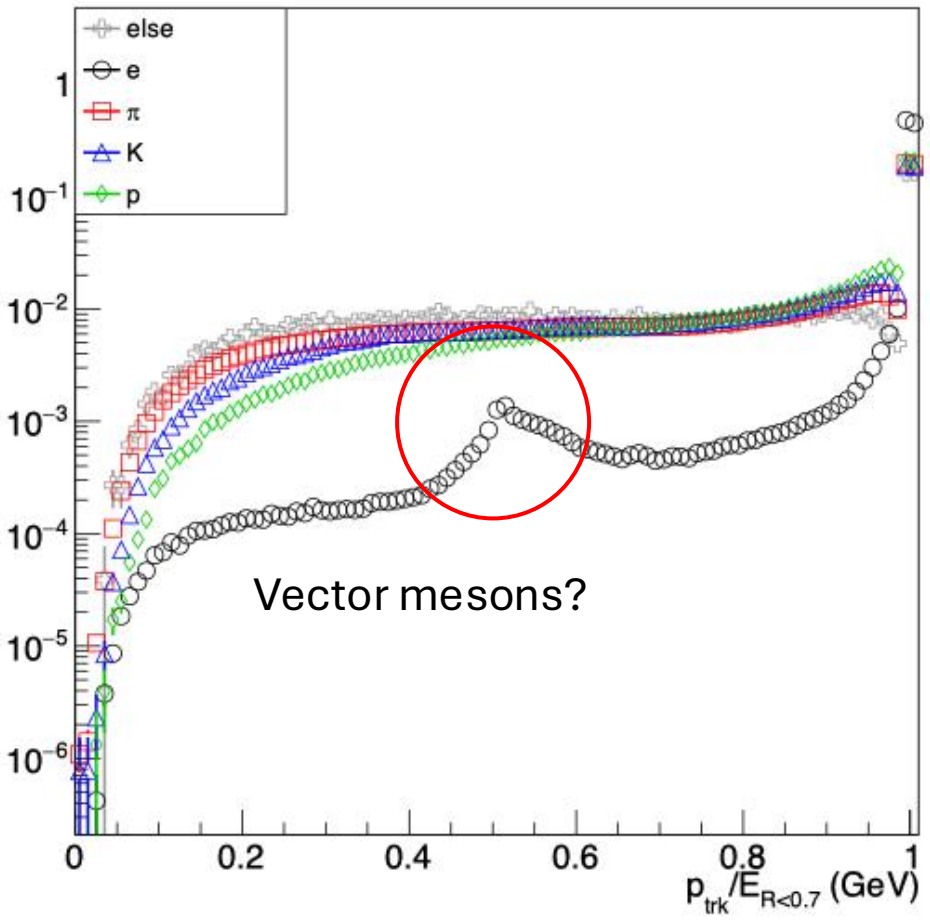


Algo-matched track-cluster

- Test of track-cluster matching algo
  - Scheme 1: “TrackClusterMatch” (nearest cluster within 0.5 in $\Delta\eta \times \Delta\phi$)
  - Scheme 2: Most energetic cluster within R = cluster radius + 1 cell size
  - Scheme 3: Most energetic cluster within R = 0.1 in $\Delta\eta \times \Delta\phi$ space
- No clear “winner”, will revisit this topic with cluster splitting
- Further studies (for now) using truth matches

Electron identification

* Based on DIS $1 < Q^2(GeV^2) < 10$ sample

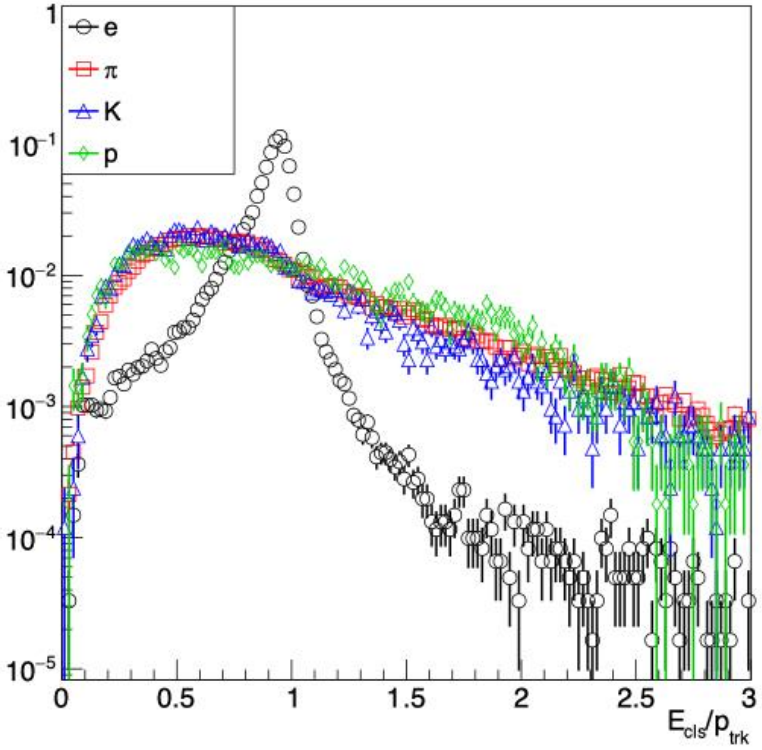


- Using inclusive DIS at $1 < Q^2(GeV^2) < 10$ sample for eID study
- The current strategy follows Inclusive PWG:
  - Track-cluster matching
  - Isolated cluster ($E/E_{\Delta R<0.7} > 0.9$)
  - $0.8 < E_{cls}/p_{trk} < 1.2$
  - Highest p_T track
- Isolation seems to work well for the most part, but perhaps some tuning required for non-primary electron ID.
- Also, requires cluster matching, which effectively imposes a lower momentum cut

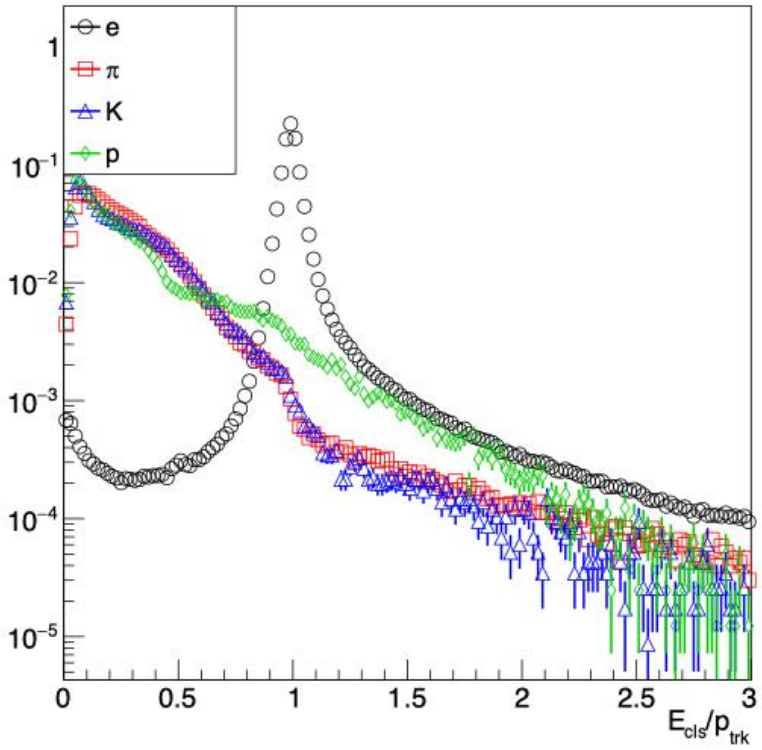
Electron identification

* Based on DIS $1 < Q^2(GeV^2) < 10$ sample

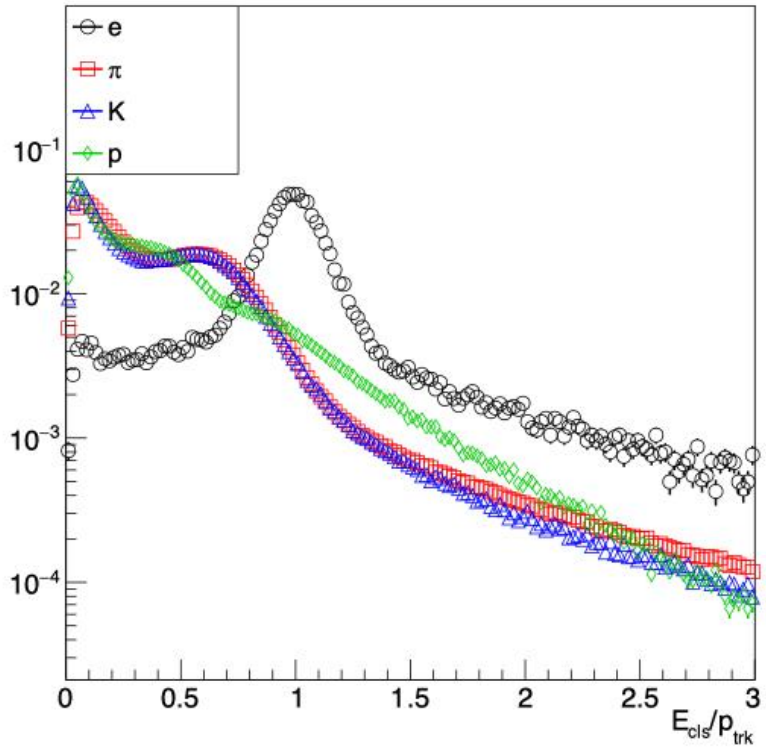
BEMC



N-Endcap EMC

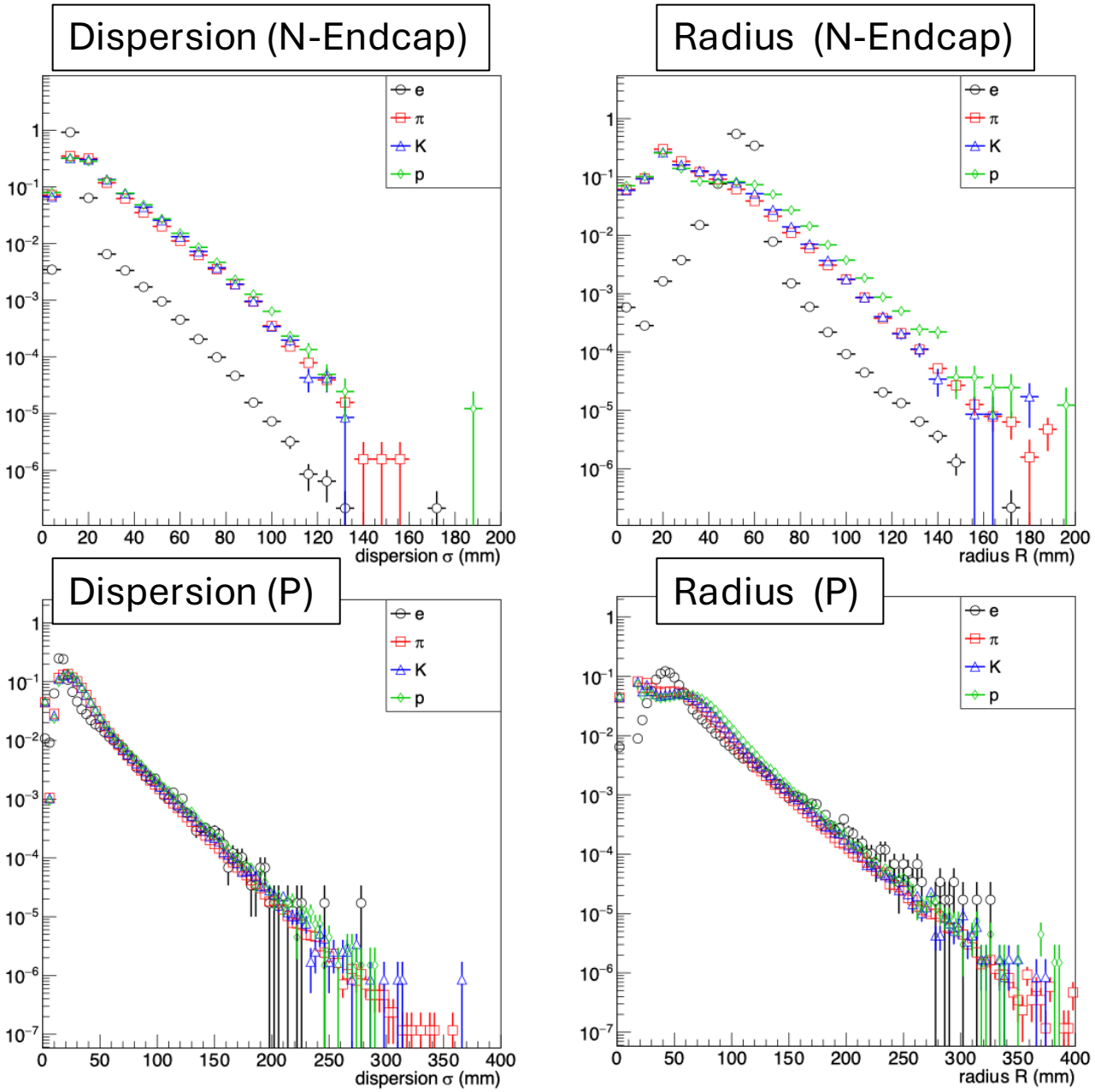


P-Endcap EMC



- E/p performs fairly well with varying degrees of success

Electron identification

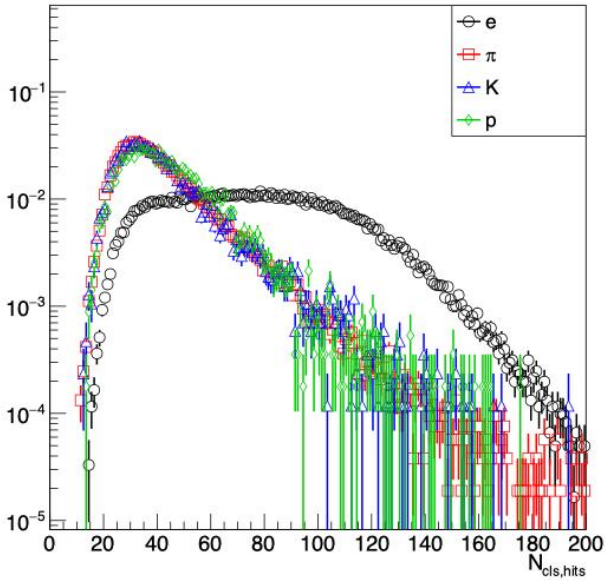


- Cluster energy deposit pattern explored for additional eID performance

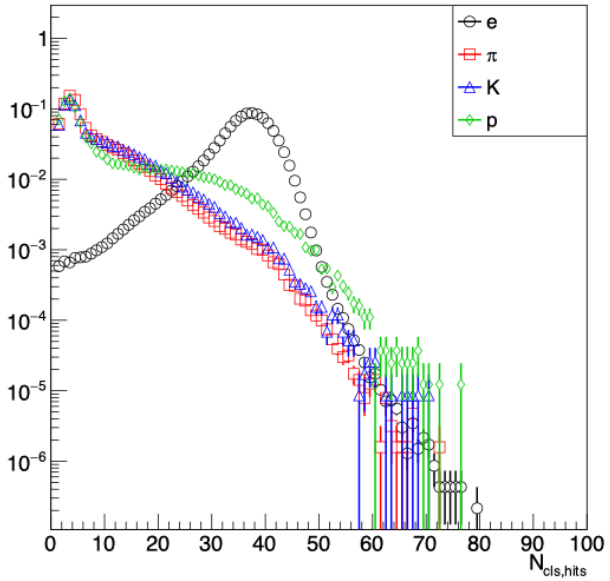
- Radius and dispersion have…
  - ➢ **Some biasing** in **N**-Endcap;
  - ➢ **No biasing** in **P**-Endcap;
  - ➢ **Empty** (at the moment) in **B**arrel

Electron identification

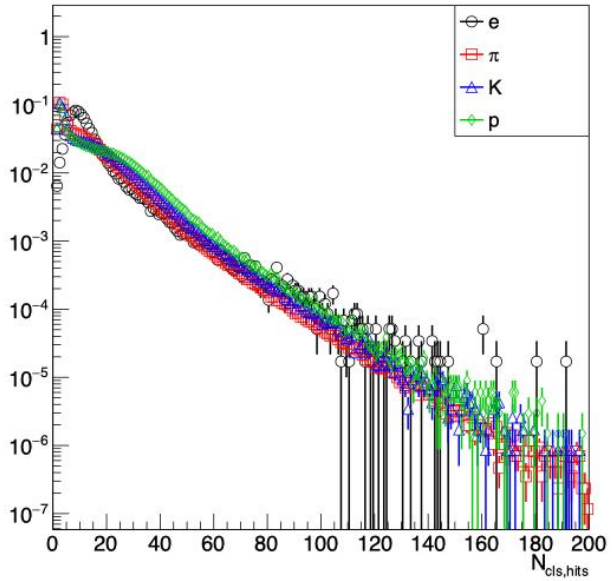
$N_{cls,hits}$ (Barrel)



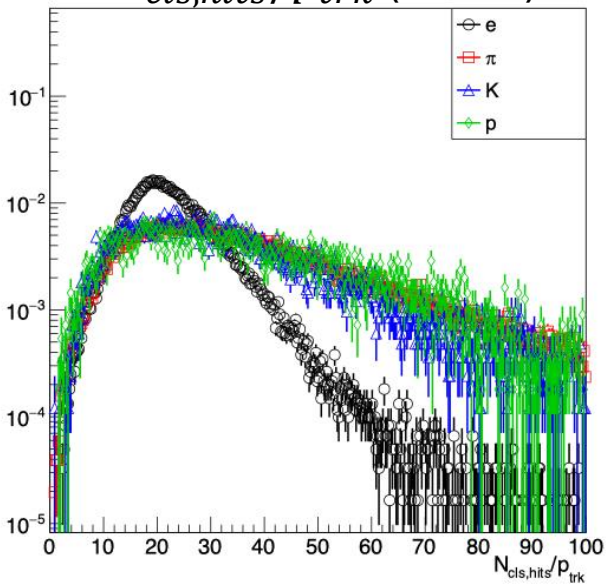
$N_{cls,hits}$ (N-Endcap)



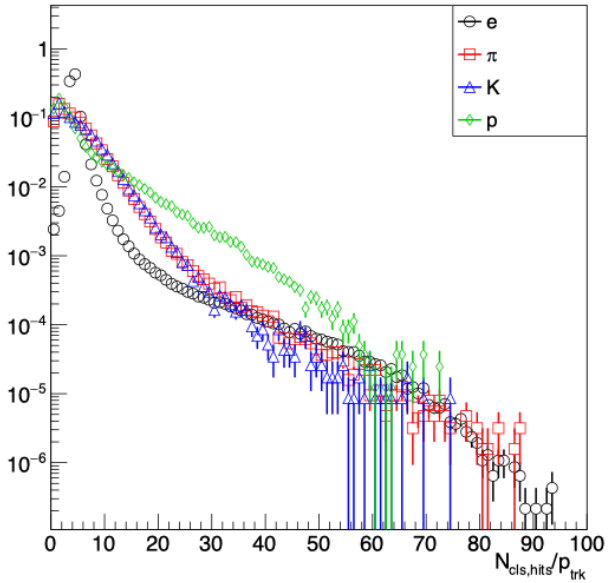
$N_{cls,hits}$ (P-Endcap)



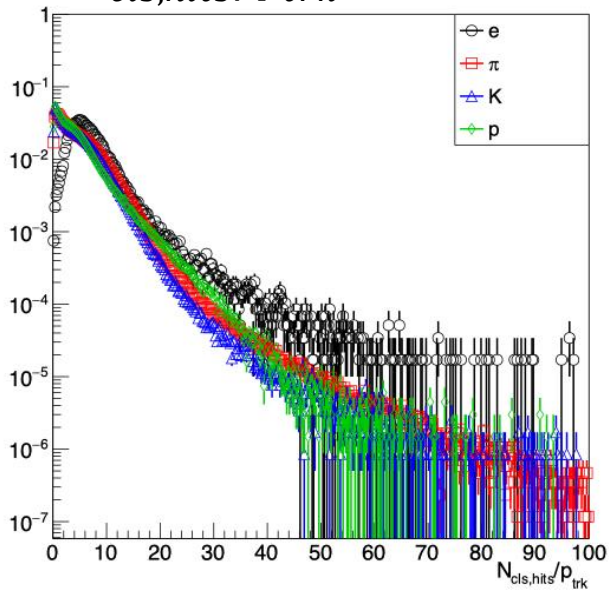
$N_{cls,hits}/p_{trk}$ (Barrel)



$N_{cls,hits}/p_{trk}$ (N-Endcap)

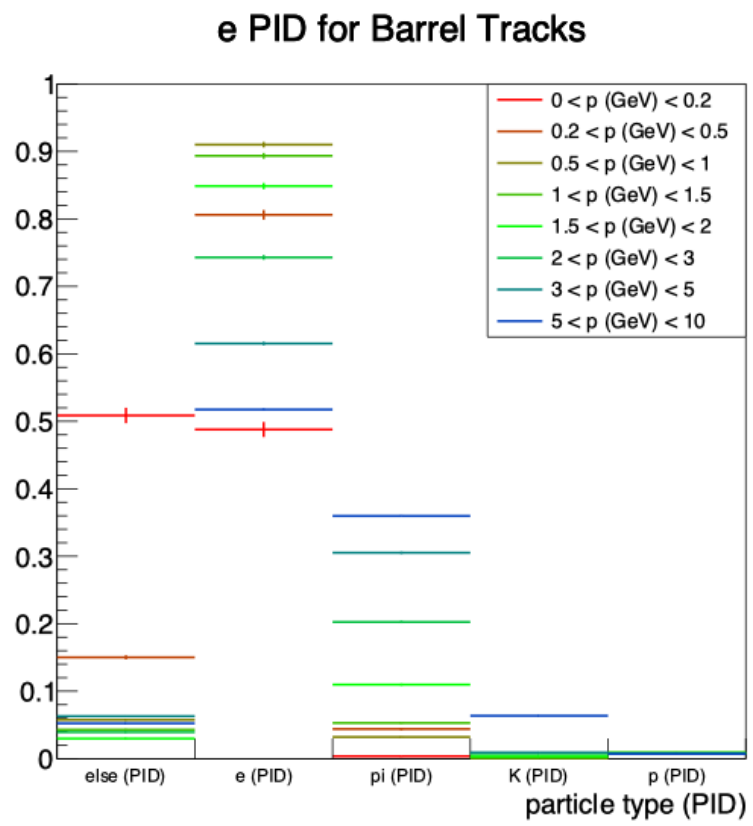


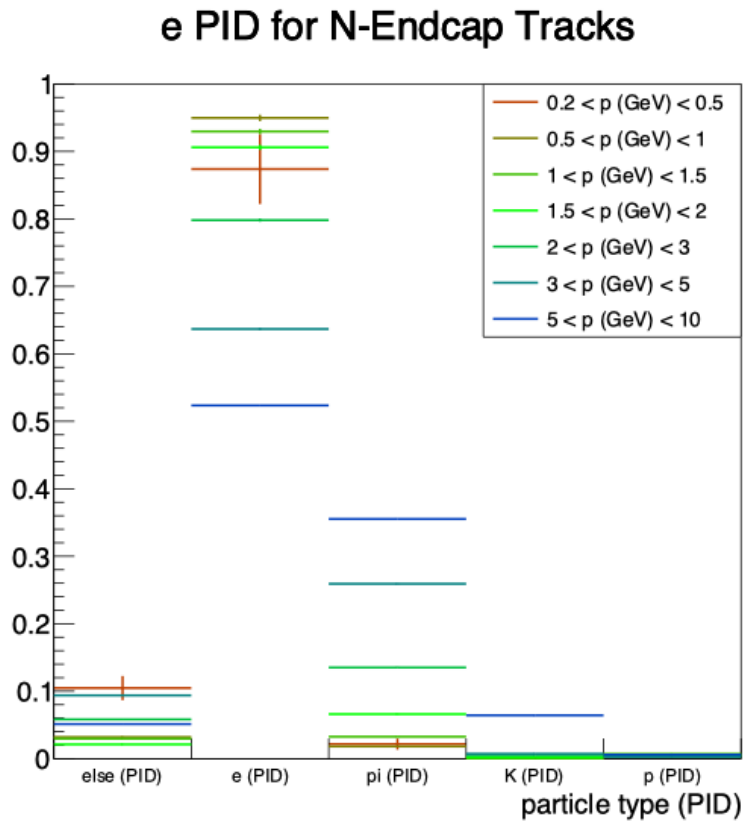
$N_{cls,hits}/p_{trk}$ (P-Endcap)

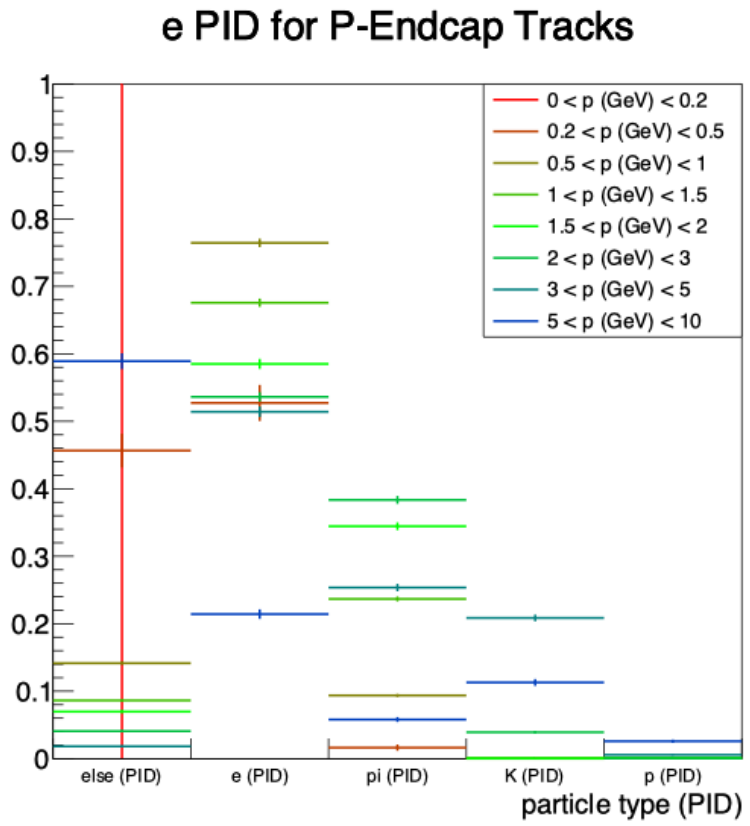


- N_{hits} naively looks usable;
- But more strongly correlated with momentum

Electron Identification

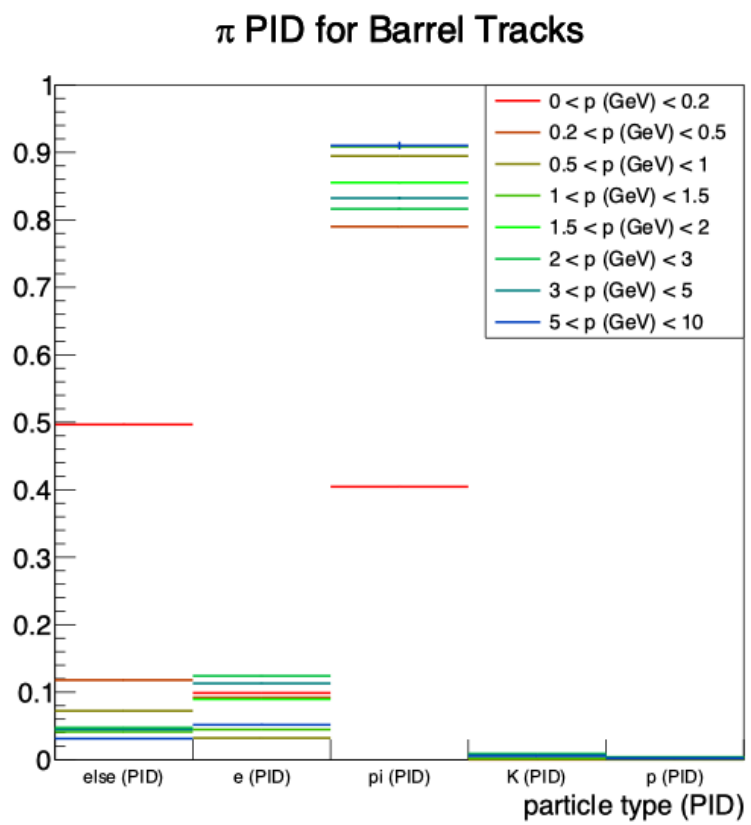


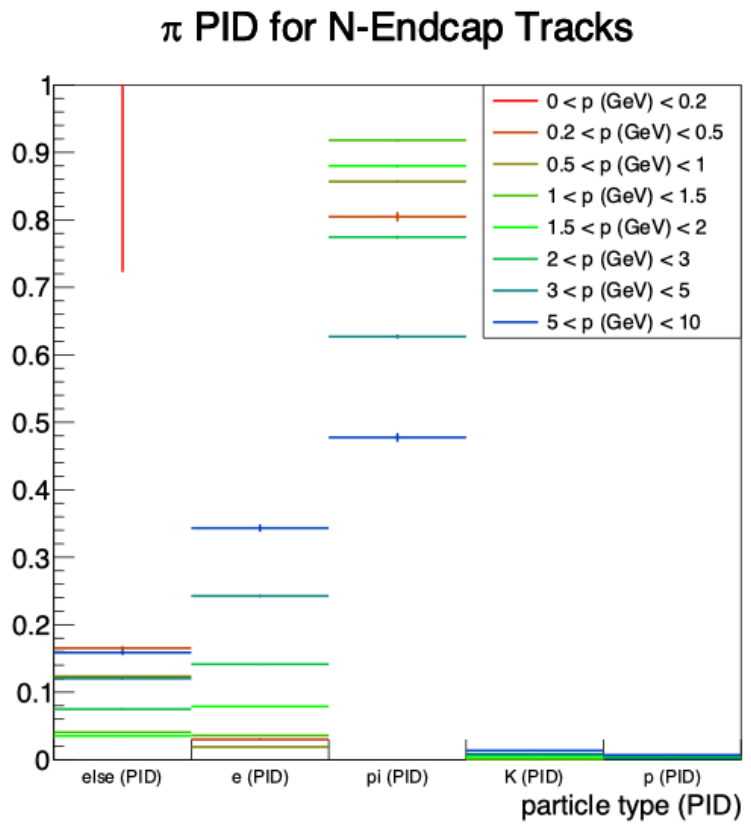


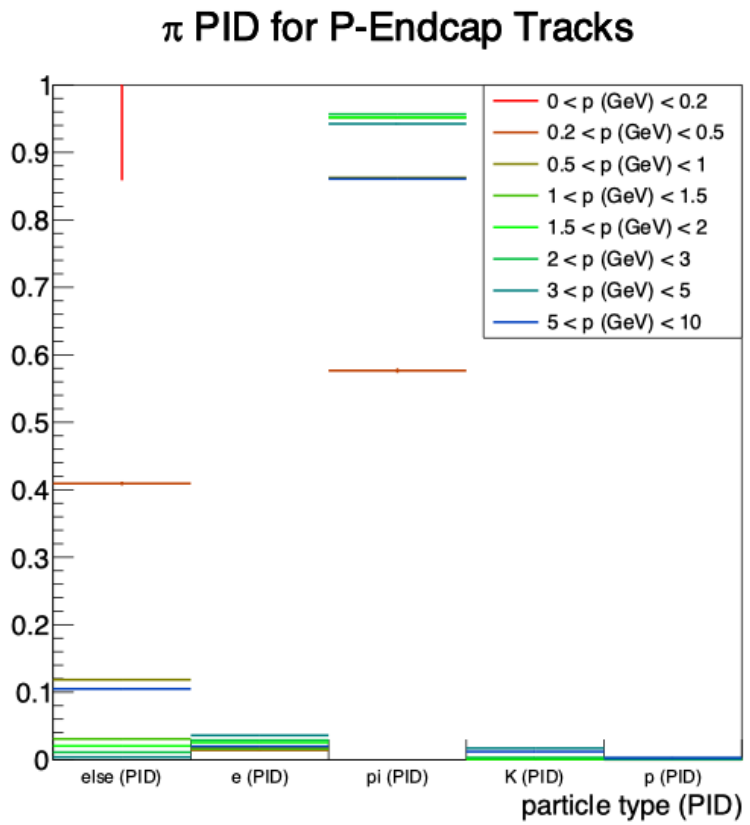


- PID detector perform well for low momentum electrons
  - $\sim 90\%$ up to $0.2 < p < 1.0$ GeV in Barrel, and $p < 2.0$ GeV in N-Endcap
- Will consider PID detectors for eID for tracks without a matched ECal cluster

Electron Identification







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  - $\sim 90\%$ up to $0.2 < p < 1.0$ GeV in Barrel, and $p < 2.0$ GeV in N-Endcap
- Will consider PID detectors for eID for tracks without a matched ECal cluster

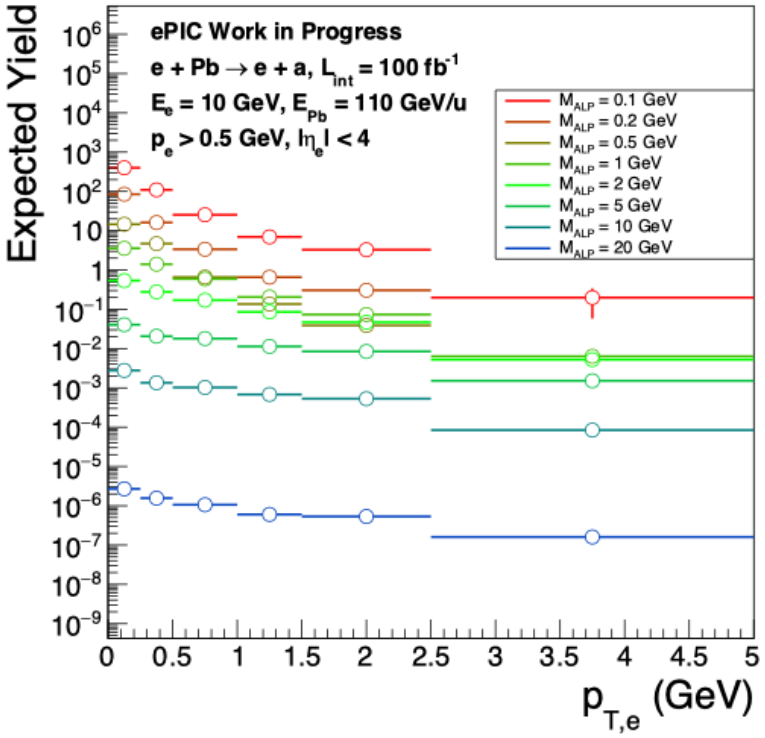
Selection cuts

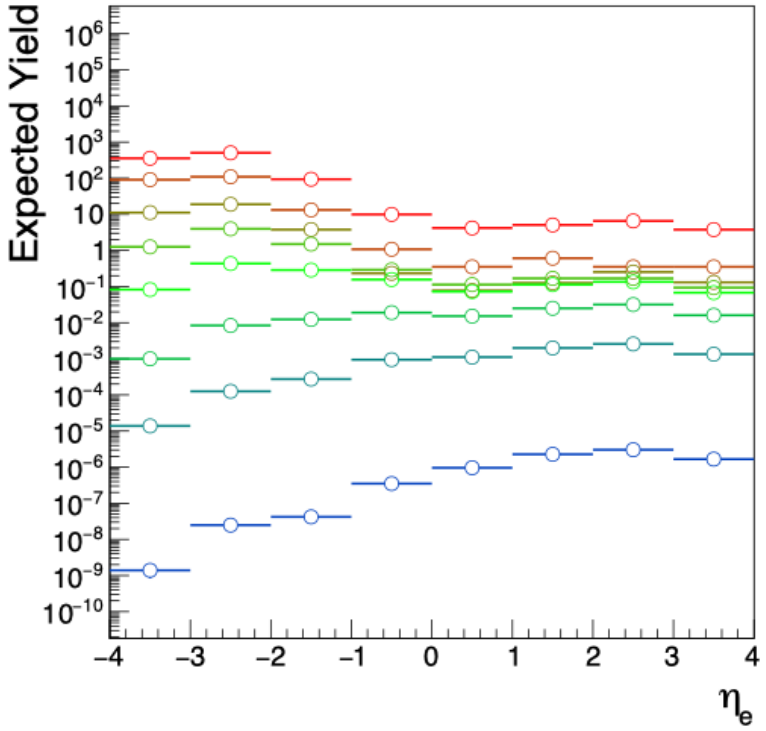
Tracks	$\boldsymbol{p > 0.5\ GeV}$ $\lvert\eta\rvert < 4$ $\lvert Z_{vtx}\rvert < 100\ mm$ $\lvert R_{XY,vtx}\rvert < 3\ mm$ $\boldsymbol{N_{hits} \geq 5}$ **(Truth-)matched cluster** Reject Low-Q2 tagger
Electron	$0.8 < E_{cls}/p_{trk} < 1.4$ $\boldsymbol{E/E_{R<0.7} > 0.9}$
Event	$N_{trk} = 1$ $E - P_Z < 10\ GeV$ $p_{T,miss}/E_T > 0.9$ Has ele candidate

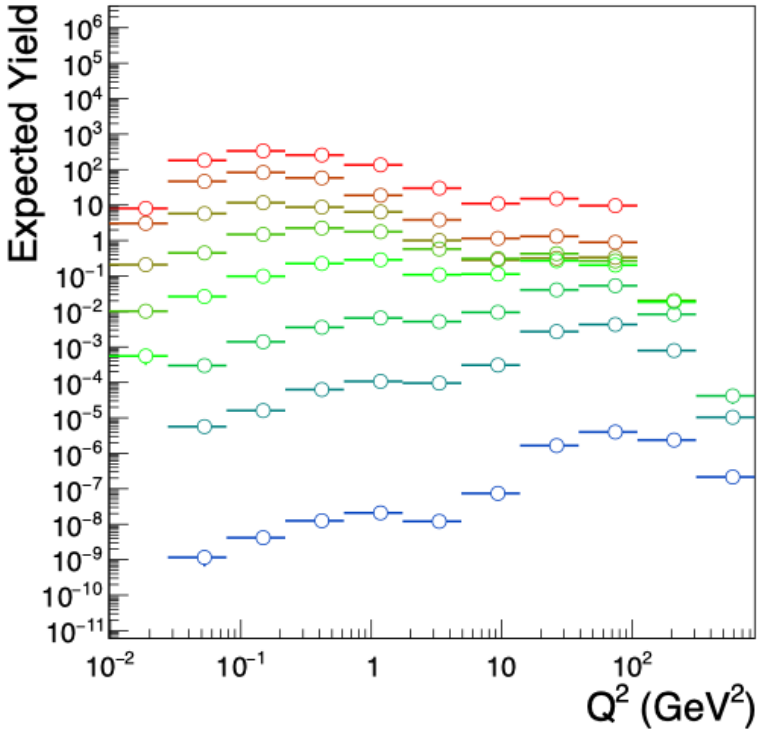
- These were the selection cuts considered for NIM-A
- Will consider relaxing **these** cuts related to eID, while including PID measurements
- Will consider tightening **these** cuts, to reject SR fake tracks without requiring ECal matching

Will be discussed by **Ganesh & Alyssa**

Expected signal





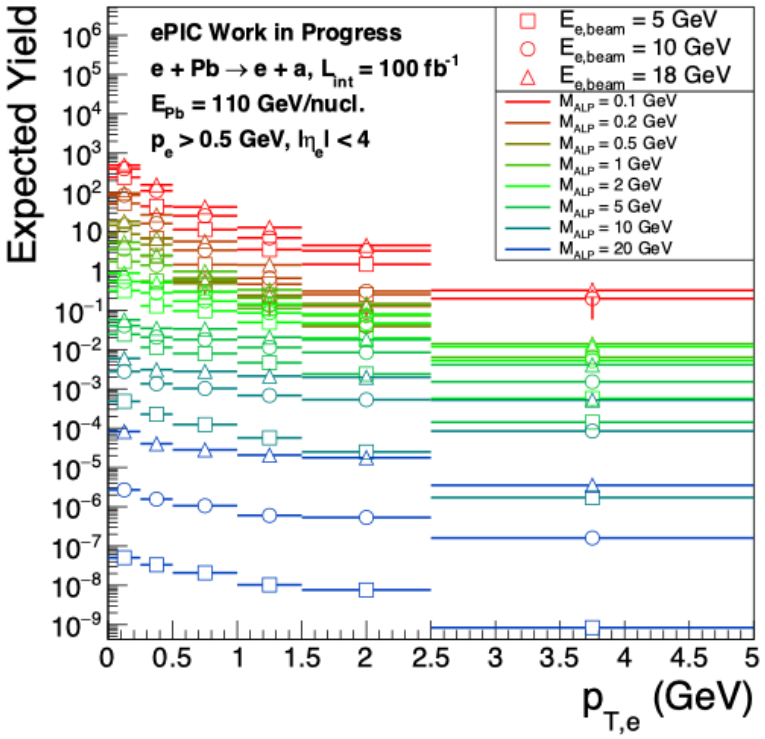


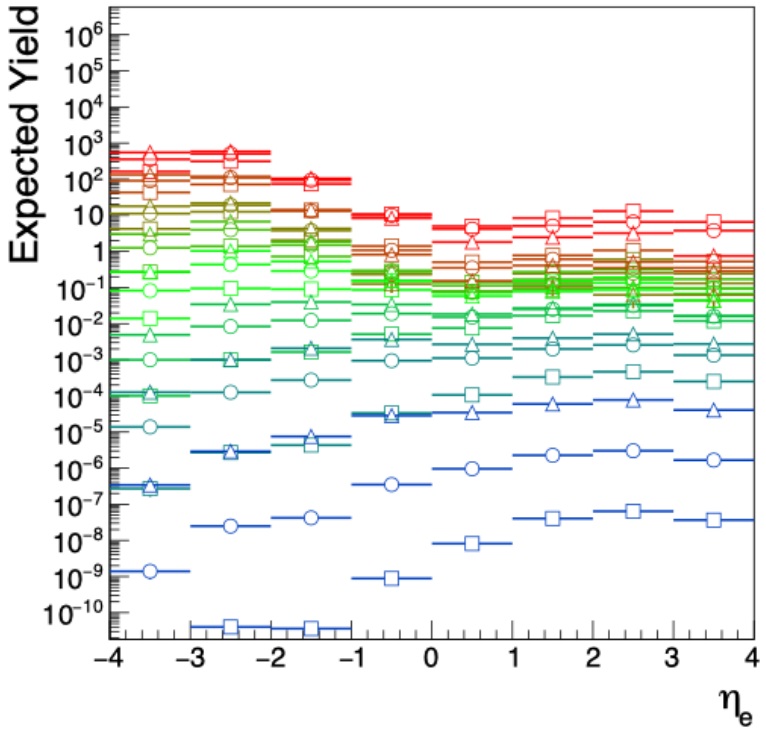
- Presented in EIC Asia Workshop
- Expected signal yield using “Tracking” cuts only

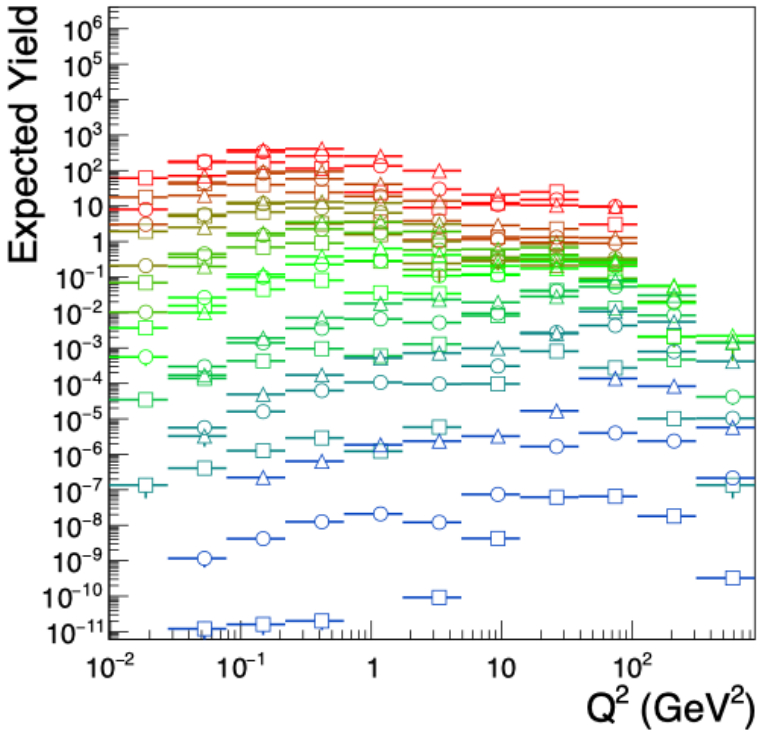
➢Searches possible for low-mass ($M_{ALP} < 1$ GeV) ALPs with $L_{int} = 100$ fb^{-1}

➢Limit-setting for high-mass ALPs

Expected signal







- Expected signal yield based on the tracking and clustering performance

➢Significant beam-energy dependence with high-mass ALP

➢Motivates $E_{e,beam} = 18$ GeV collisions

Conclusion

- Machine background rejection
  - Coulomb and bremsstralung most entirely fall in to low Q2 tagger
  - $N_{trk,hits} \geq 5$ rejects most of the SR
  - Requiring track-cluster matching rejects the rest
  - Some rejection provided by quality cuts
- Track-cluster matching
  - Several ideas have been tested
  - Without the presence of cluster splitting algo, the matching schemes tested here have their own limitations
  - Truth matching for now
- Electron Identification
  - The current scheme based on isolation and E/p performs well for cluster-matched tracks
  - Will investigate improvements from PID detectors for low momentum tracks