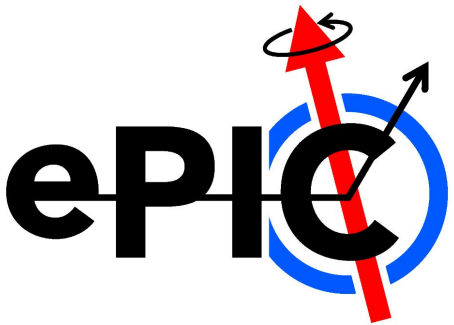
Jet and HF Status and Overview

Cheuk-Ping Wong, Wenqing Fan, & Brian Page
for the Jets and HF WG



Introduction

- Conveners:
  - Brian Page - bpage@bnl.gov
  - Miguel Arratia - miguela@ucr.edu
  - Wengmei Zha - first@ustc.edu.cn
  - Cheuk-Ping Wong - cpwong@lanl.gov
- Meeting information
  - Indico - https://indico.bnl.gov/category/420/
  - Zoom - https://bnl.zoomgov.com/j/1603663395?pwd=RHpSY2RXSGNXL2J3V2VXZ2Q1ZmNXUT09
  - Meeting time - Wednesday EST 10 pm / Thursday EST 1 pm
- Wiki: https://wiki.bnl.gov/EPIC/index.php?title=JetsHF
- Mattermost: https://eic.cloud.mattermost.com/main/channels/jets-hf-conveners

  Haven't join ePIC Mattermost yet?

  Contact your conveners to get an invitation link.

Simulation Benchmarks

	Analysis	Analyzer(s)	Subsystem(s)
Jet	Jet energy scale and resolutions	Brian Page	Tracking and calorimetry (hermicity)
	Forward jets	Miguel	Forward calorimeter acceptance
	Jet substructures (e.g. angularity)	Brian Page	Tracking and calorimetry (calorimetry granularity)
	TMD via Centauro jets	John Lajoie	Tracking and calorimetry
Heavy flavor	Open HF R_{eA}: D & B mesons, λ_c	Xuan Li Wenqing Fan	Tracking & vertexing, PID
	Open HF-tagged jets R_{eA}	Xuan Li	Tracking & vertexing, PID, calorimetry
	Trace anomaly via charmonium	Xinbai Li	Ecal, PID

Simulation Needs

	Analysis	Analyzer(s)	Analysis Needs
Jet	Jet energy scale and resolutions	Brian Page	Calorimeter clustering Track projection
	Forward jets	Miguel	
	Jet substructures (e.g. angularity)	Brian Page	
	TMD via Centauro jets	John Lajoie	
Heavy flavor	Open HF R_{eA}: D & B mesons, λ_c	Xuan Li Wenqing Fan	Vertexing PID
	Open HF-tagged jets R_{eA}	Xuan Li	
	Trace anomaly via charmonium	Xinbai Li	

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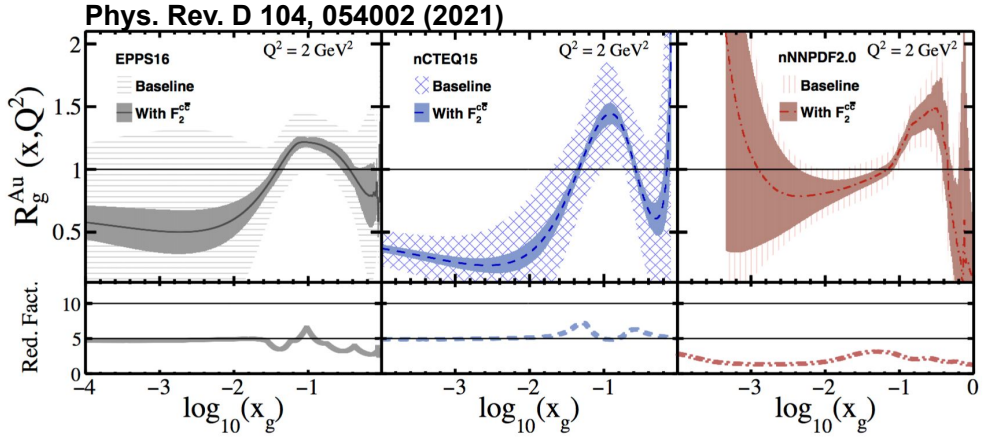
Heavy flavor measurements @ePIC

Wenqing Fan

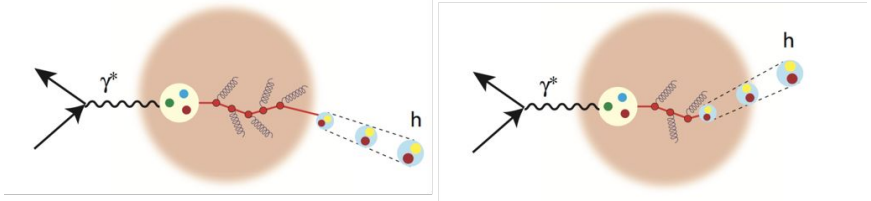
ePIC collaboration meeting, 01/11/2023

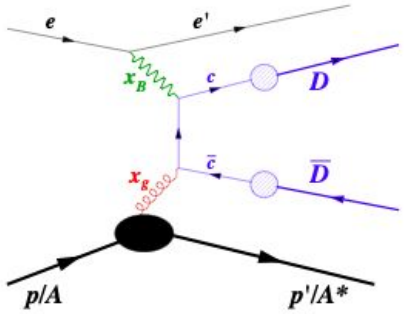
Physics motivation and key measurements

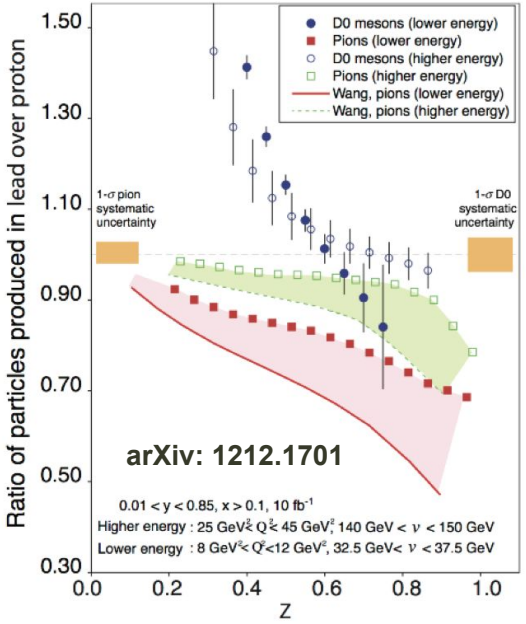
- Study gluon dynamics inside nucleon/nucleus
  - Gluon nPDF, gluon helicity, gluon TMD etc
    (by measuring open charm hadron / tagged charm jets)



- Study hadronization scale and color transport inside the nuclear medium
  - R_{eA}: open charm hadron (D mesons, Λ_c etc)



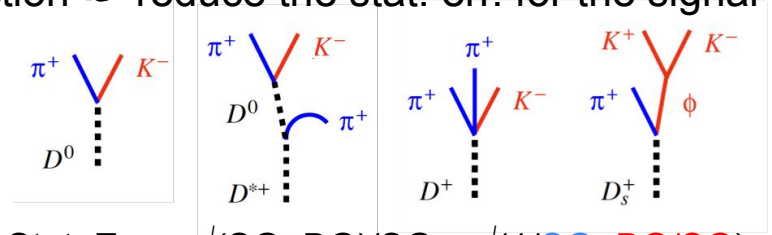




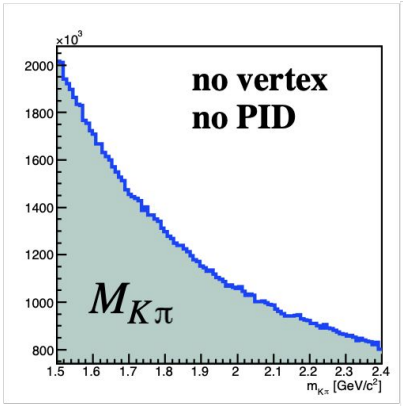
More details of ongoing analysis:
https://wiki.bnl.gov/EPIC/index.php?title=JetsHF

Open charm hadron measurements via hadronic decays

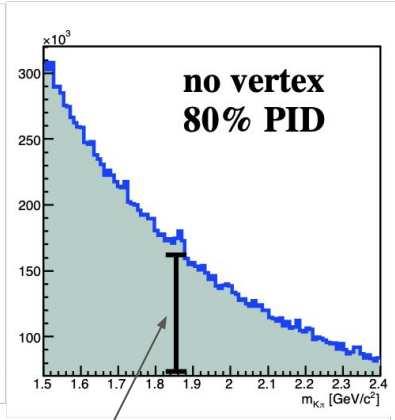
- Key of precision heavy flavor hadron reconstruction ☛ reduce the stat. err. for the signal extraction
  - High statistics (increase SG)
    - ➢ High luminosity + good detector acceptance
  - High purity (decrease BG/SG)



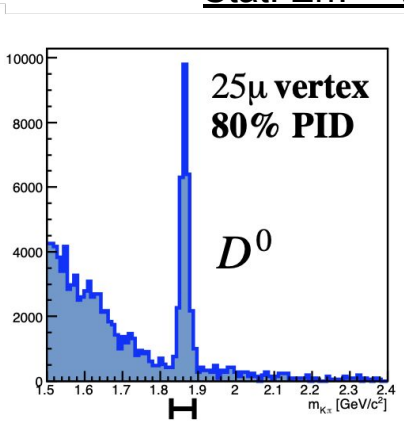
Stat. Err. = $\sqrt{(SG+BG)}/SG = \sqrt{(1/SG+BG/SG)}$



arXiv: 1610.08536



Reduce the comb. bkg. level



Reduce the integration window

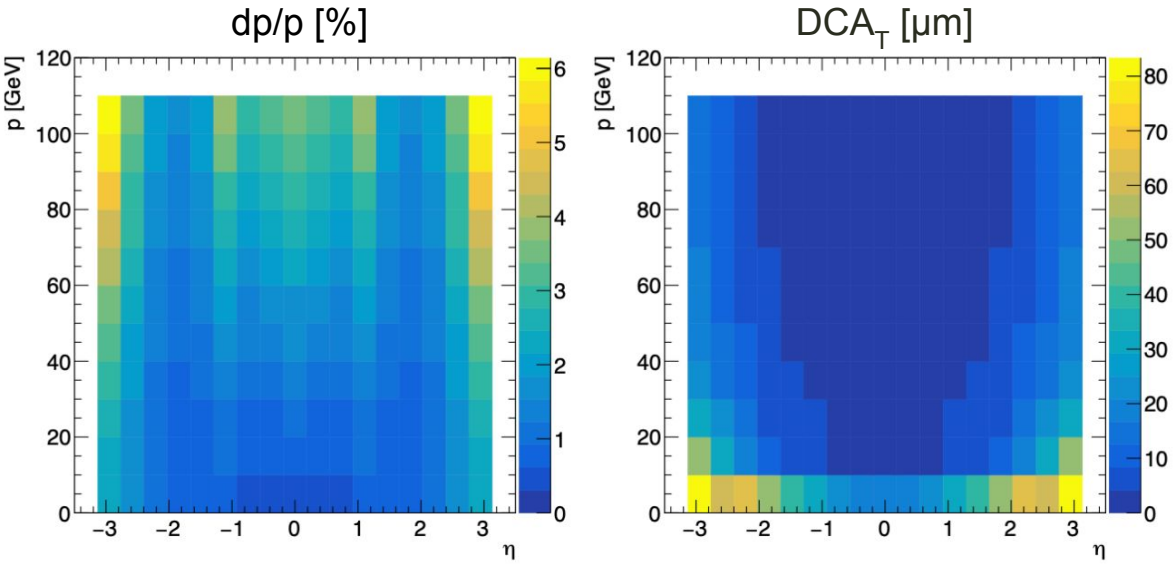
Particle	cτ
D^0	123 μm
$D^\pm$	312 μm
B^0	456 μm
$B^\pm$	491 μm
Λ_c	60 μm

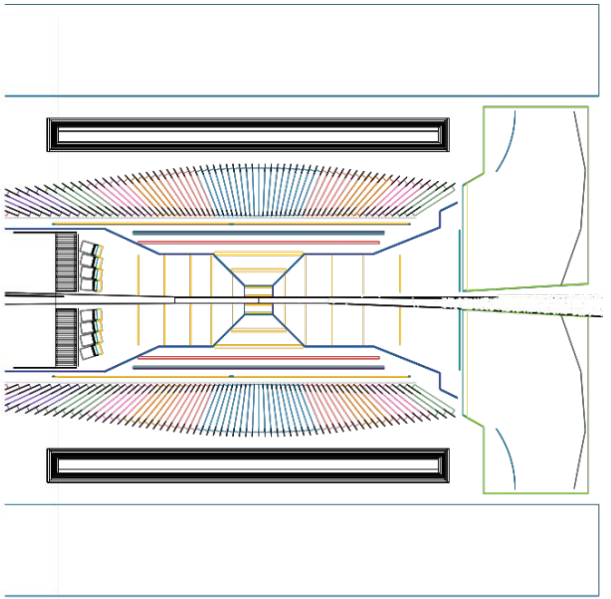
Reduce BG/SG

- Good π/K/p separation power
- Good pointing resolution
- Good momentum resolution

Detector performance

- Tracking and vertexing





- PID with Cherenkov detectors and LGAD TOF: π/K/p separation
  - Forward: dRICH + LGAD TOF
  - Barrel: DIRC + LGAD TOF
  - Backward: mRICH/pfRICH

Fast simulation setup

- Single track smearing using parameters from fast simulation with ePIC baseline tracking (assuming single pion resolution for all charged particles)
  - p (magnitude) smeared by p resolution along the true p direction
  - Vertex position smeared by $DCA_{r\phi}$ and DCA_z
- No primary vertex smearing
- PID: π/K/p separation in certain momentum range
  - In the barrel region: no PID if particles can not reach DIRC @76cm: using 2r = ρ = p/(0.3B)
    ☛ p_T > 0.19GeV for 1.7T
  - Without TOF: no π/K/p separation below the firing and detectable threshold for π, no K/p separation below the firing and detectable threshold for K
  - With TOF: detector matrix parameters (low p range identification covered by TOF)

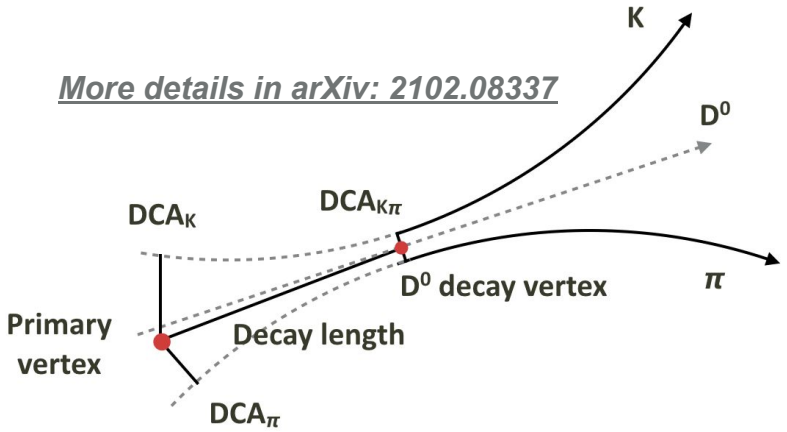
Table from the Yellow Report (YR)

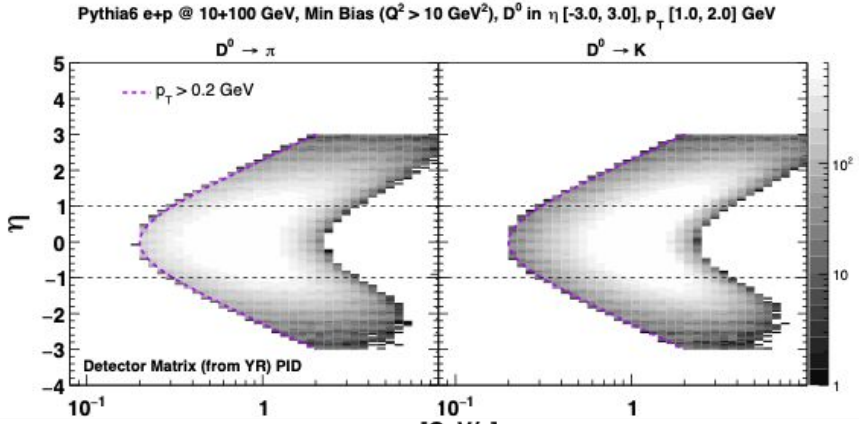
Detector Matrix	
Barrel	< 6 GeV
Forward	< 10 GeV
Backward	< 50 GeV

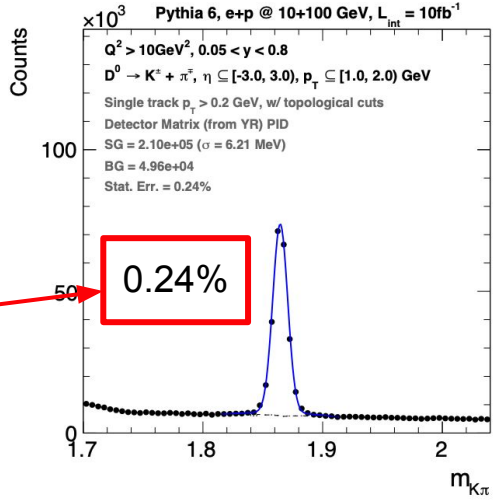
Fast simulation: example of D^0 measurement

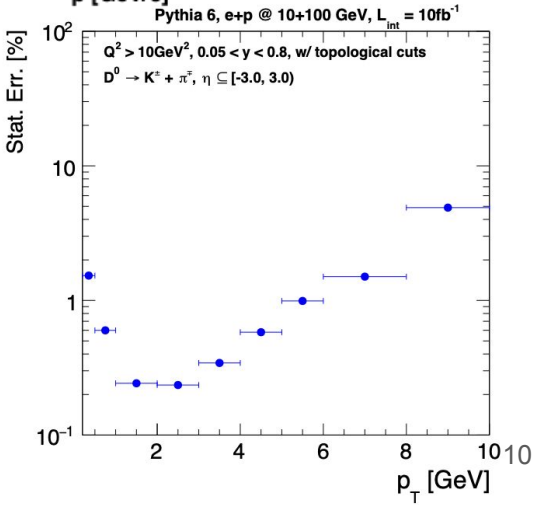
- D^0 selection
  - p_T > 0.2GeV
  - Identified π/K (with TOF)
  - Decay topology cuts

More details in arXiv: 2102.08337







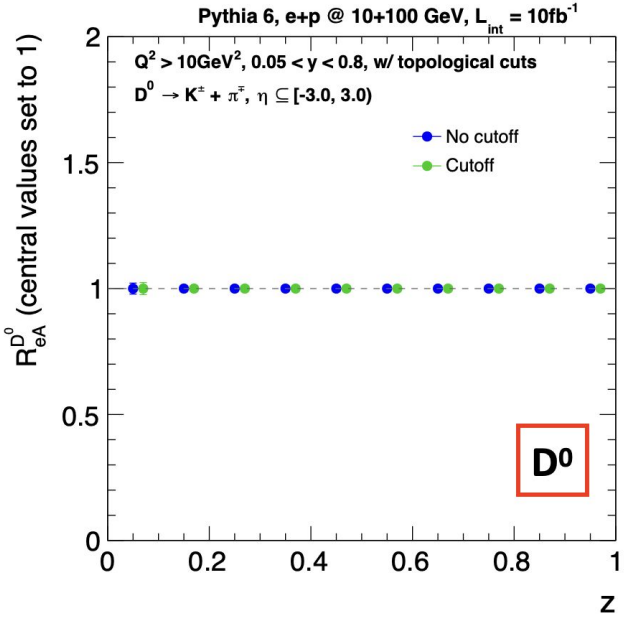


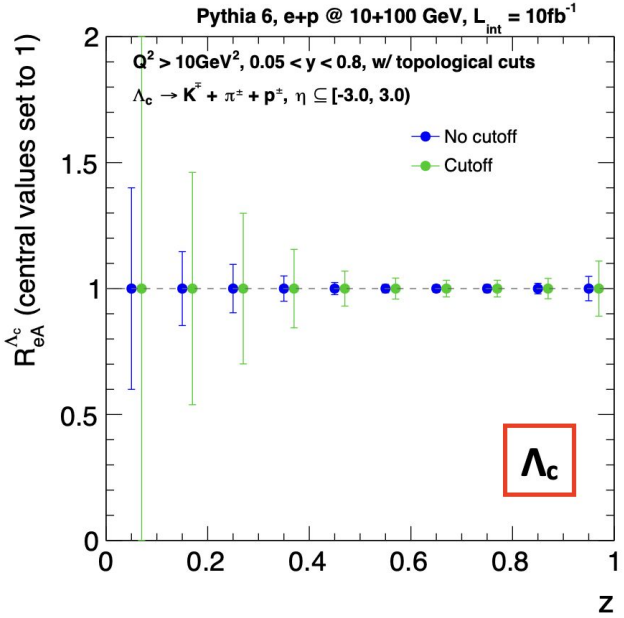
Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

- ☛ decrease with increasing SG
- ☛ decrease with decreasing BG

Precision of R_{eA} mesurement

- Projected stat. uncertainty on R_{eA}
  - With or without TOF: negligible impact on D^0 measurement but larger impact on Λ_c measurement
  - Moderate accuracy for Λ_c: 1-10%
- With or without TOF: negligible impact on D^0 measurement but larger impact on Λ_c measurement





Future plan: towards full simulation analysis

- Perform HF analysis in full simulation
  - Pythia DIS events on S3 storage (DD4HEP + juggler/eicrecon)
  - w/ beam crossing, event vertex distribution: σ_x = 0.13mm, σ_y = 0.008mm, σ_z = 35.6mm
- Available info
  - Reconstructed particle momentum and matched MC true particles
- Missing info
  - No clear ancestry information for MC true particles (cannot tag the decay ancestry)
  - Reconstructed PID (currently using truth)
  - No reconstructed primary vertex, no reconstructed secondary vertex
  - DCA values not available (currently the tracking algorithm calculate them w.r.t (0,0,0) rather than the true event vertex)
- **More information needed for HF studies in full simulation**

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Parent and daughter index look wrong: only 27 MC particles saved in this event

Summary and future plan

- Rich physics from heavy flavor measurements
- Good tracking/vertexing and PID performance with the ePIC detector for precision heavy flavor measurements
- Some fast simulation studies have been done: high precision measurement for D^0 and Λ_c
- Next step: test in full simulation the key observables
  - More information needed in the reconstructed output files

Jets in Full Simulation - A First Look

Brian Page
ePIC Collaboration Meeting: January 11, 2023

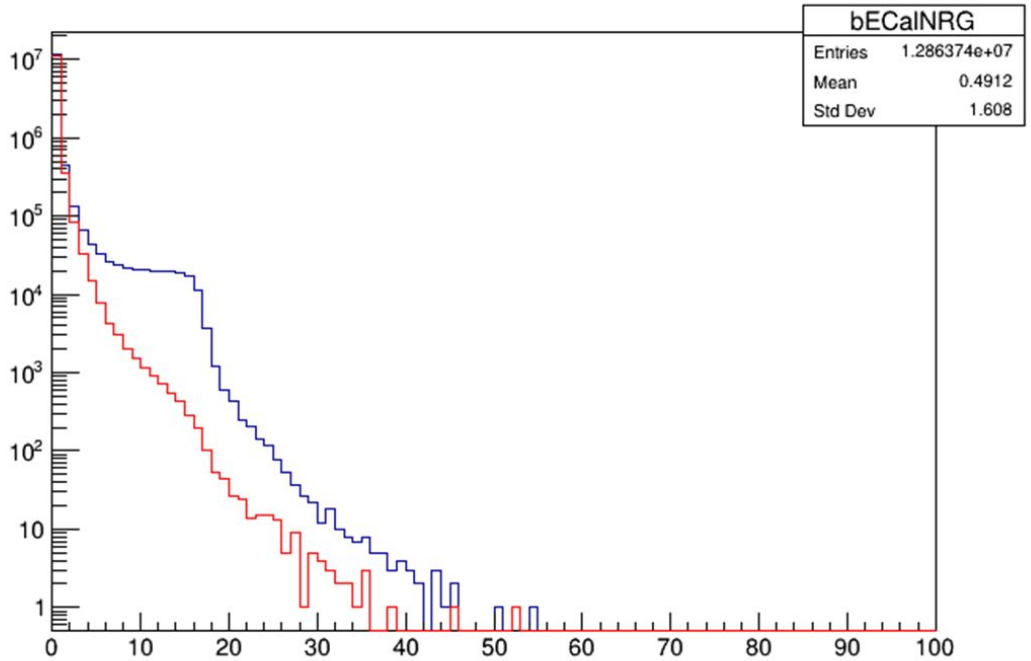
Outline

- ❏ Simulation and Jet Configuration
- ❏ Considerations and Found Issues
- ❏ Jet Kinematics
- ❏ Jet Energy Resolutions

Simulation Sample and Jet Definitions

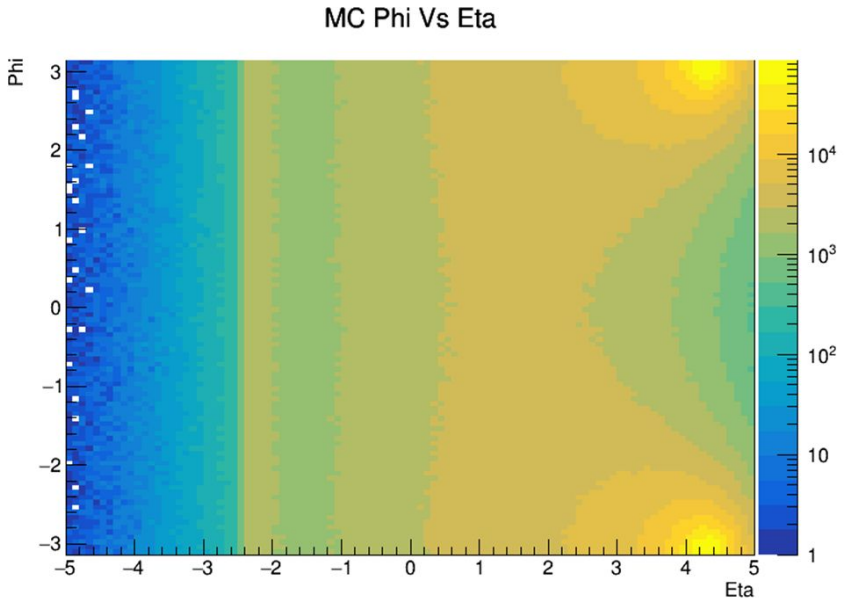
- Simulation Sample
  - PYTHIA-8, 18x275, Q2 > 10 GeV2
  - 22.11.2 Arches
- Jet Definitions
  - Anti-kT, R=1.0, min-pT = 1.0 GeV
  - MC Jets (All Particles)
  - MC Jets (Only Charged Particles)
  - Reco Track Only Jets
  - Reco Track + EMCal Jets

Analysis Needs: Electron Rejection

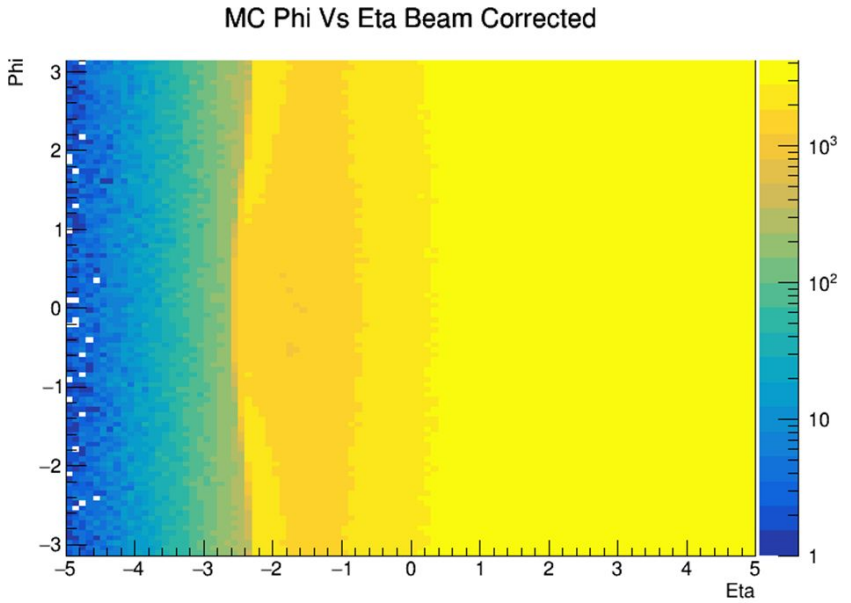


- Remove electrons from jet clustering to avoid scattered beam particle
- In nECal, pECal, and reco charged particles - do this with association branch
- This branch seems to be missing for the barrel SciGlass calo
- Identify position of electron from MC record and remove clusters within 0.1 in eta-phi

Analysis Needs: Crossing Angle Correction



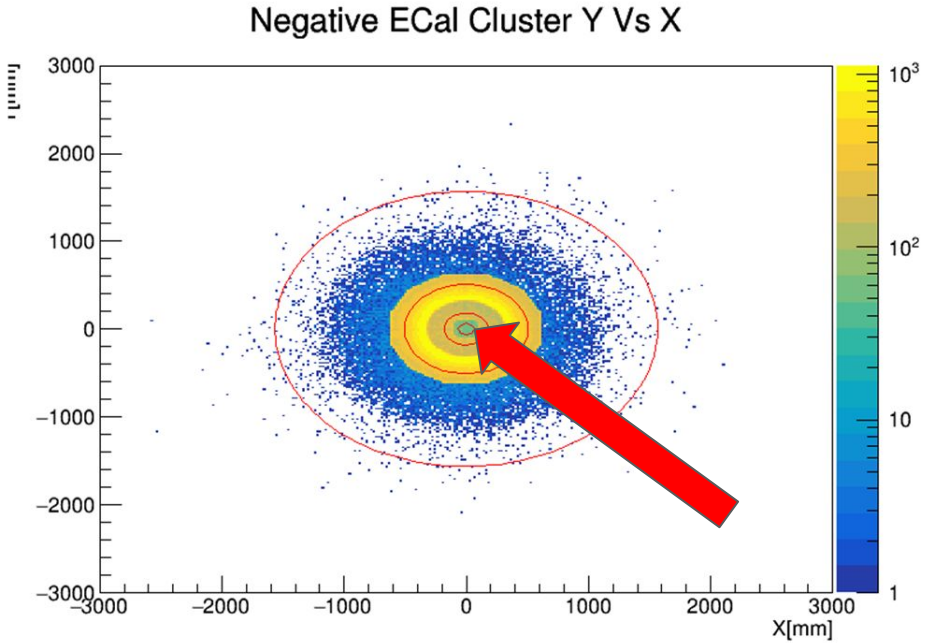
- Simulation generated with a crossing angle that causes distortions in eta-phi
- For this study, correct by simply calculating particle/track/cluster positions w.r.t. the outgoing hadron beam

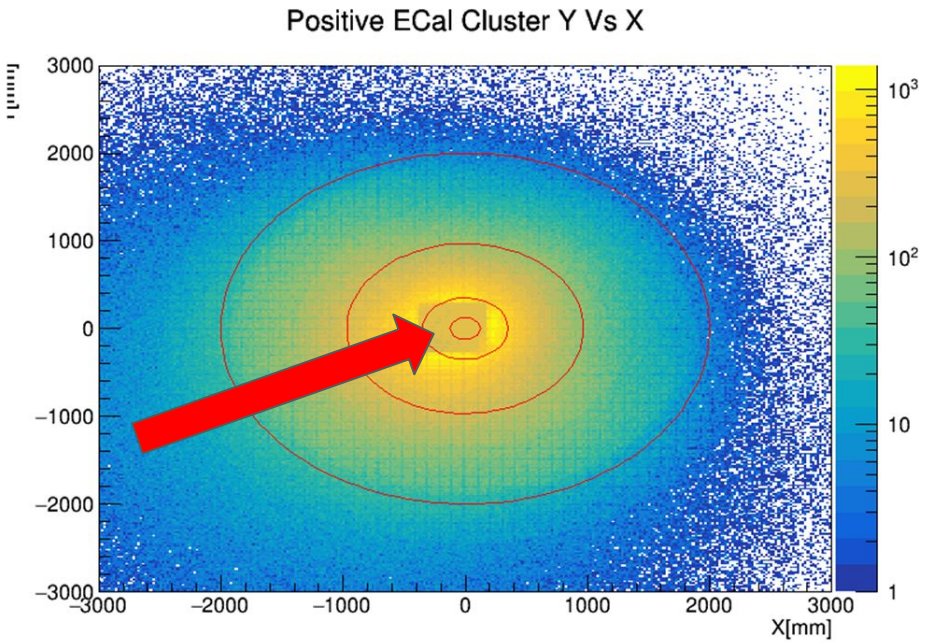


- This correction will cause distortions in the backward region (no universal axis)
- Don’t apply correction for eta < 1.4

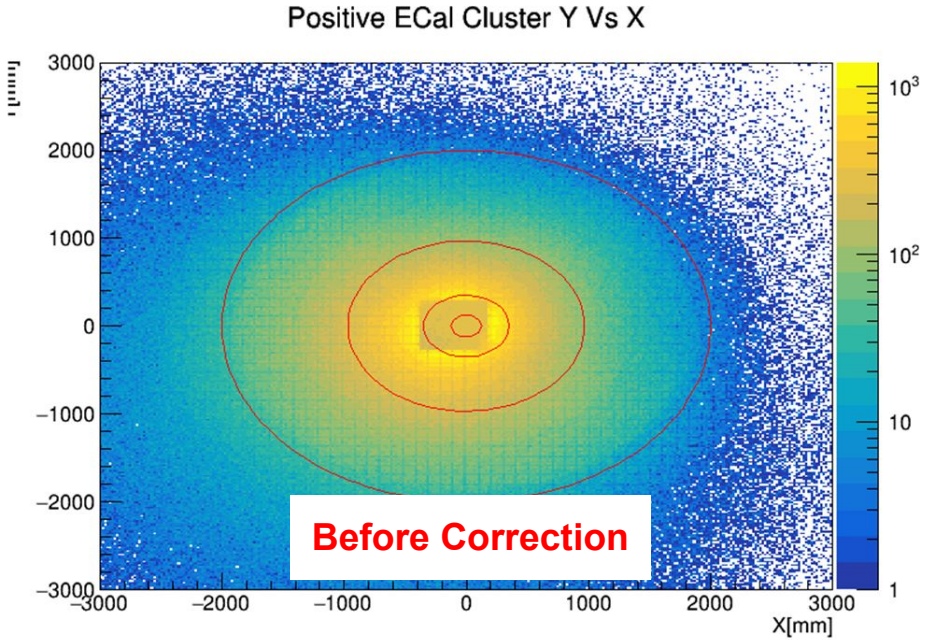
Issue: Clusters in Gaps

- See that cluster positions intrude into the gap area around the beam pipes
- Individual hits do not show this problem
- Manually cut out clusters in this region for jet analysis



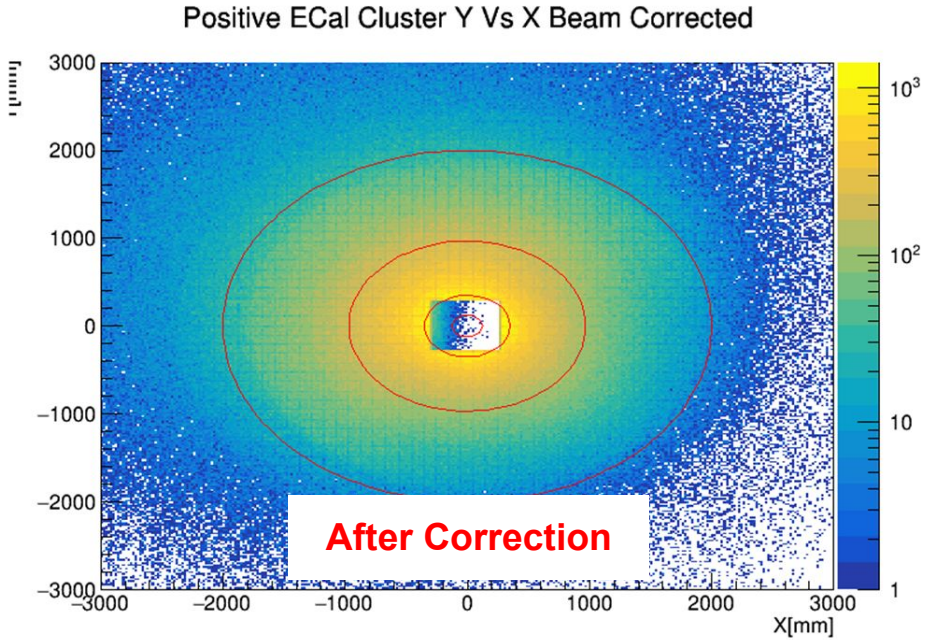


Issue: pECal Cluster Azimuthal Anisotropy

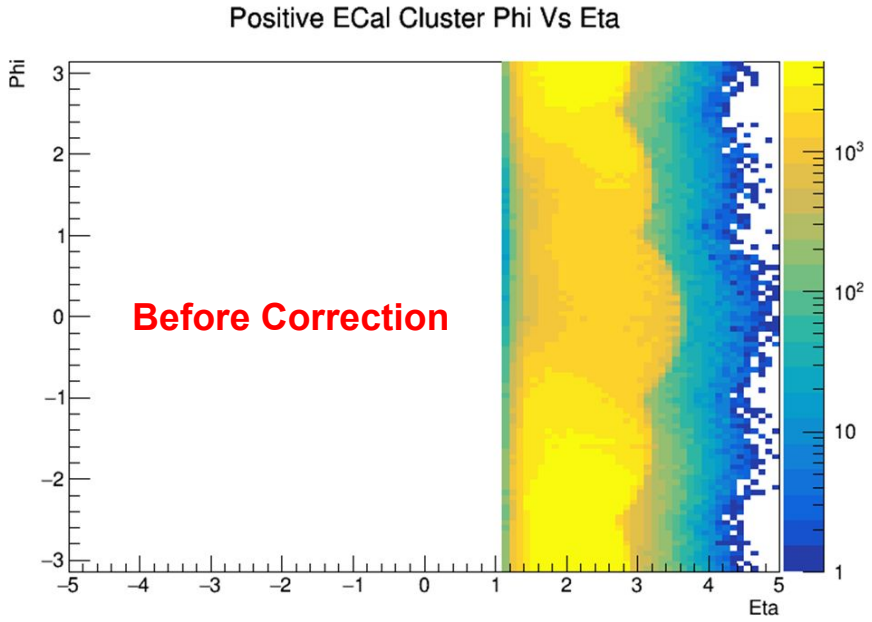


- Even after the correction, there still seems to be an azimuthal anisotropy in the distribution of clusters

- See that the crossing angle correction ‘centers’ the gap for positive endcap clusters as expected

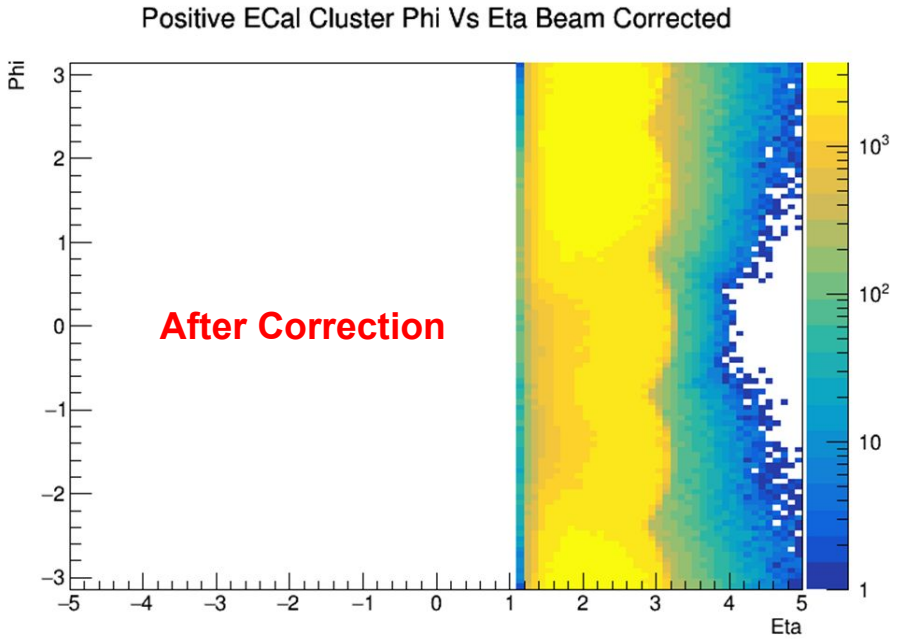


Issue: pECal Cluster Azimuthal Anisotropy

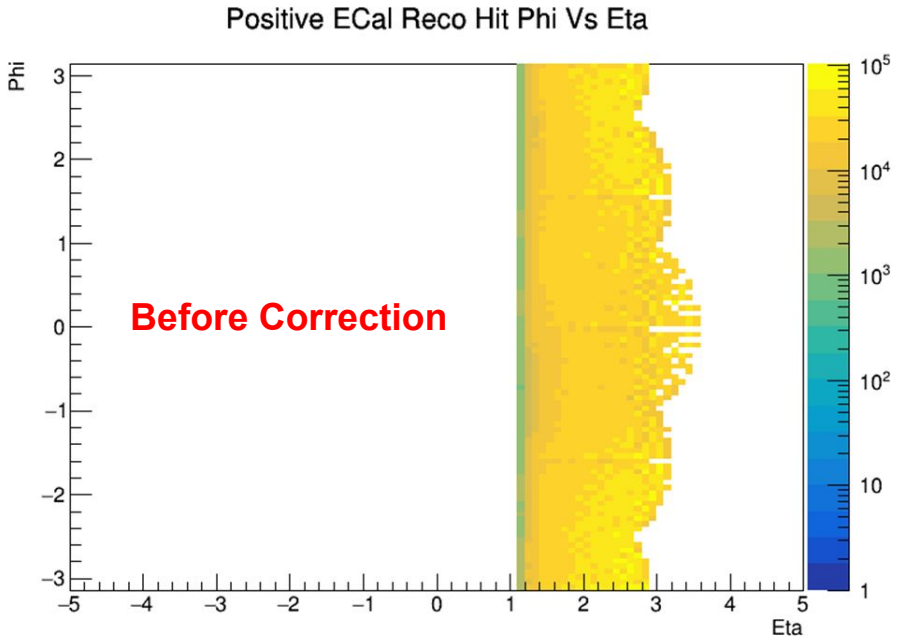


- Correction smooths out ‘bulges’ (scalloping from square hole exists)
- However, we still see hotspots in phi

- Look at previous cluster distribution in eta-phi space

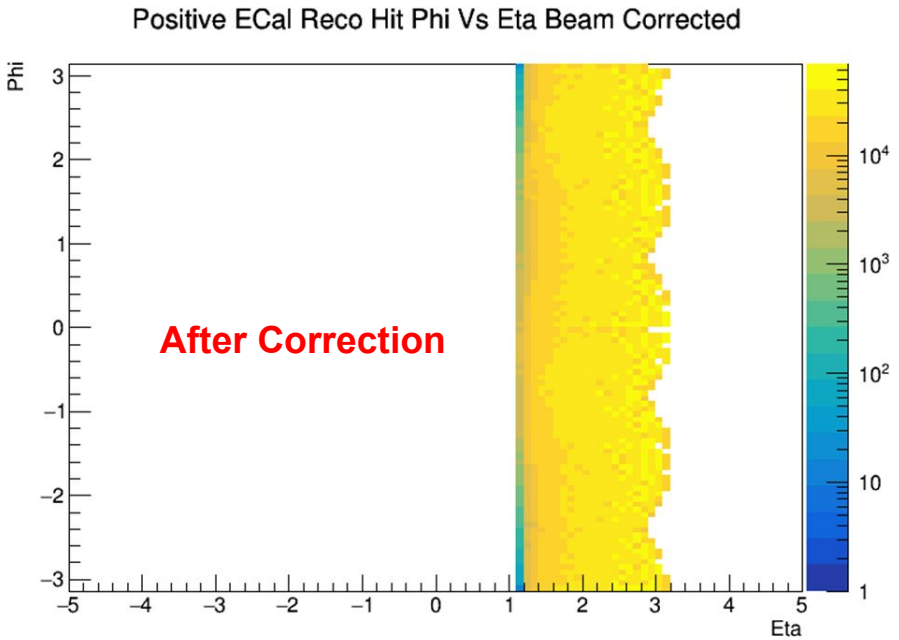


Issue: pECal Cluster Azimuthal Anisotropy

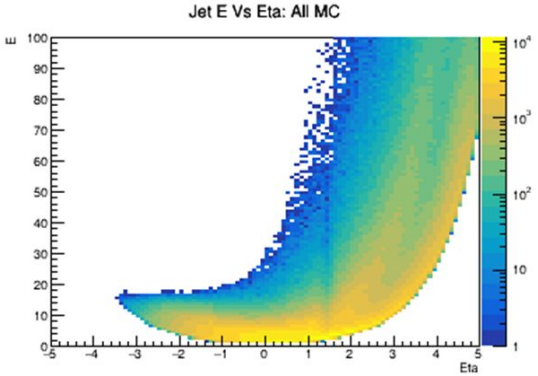


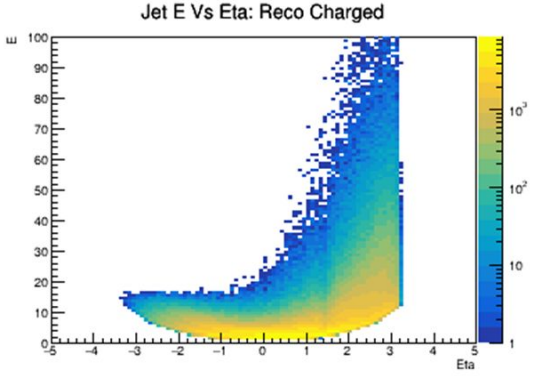
- The corrected hit distribution is much smoother than the clusters built from them
- Some bias in clustering procedure?

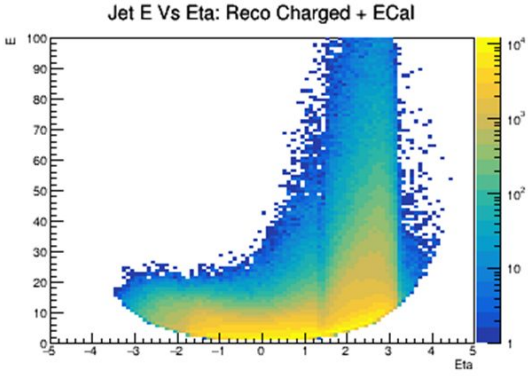
- Look at Reconstructed Hits instead of clusters



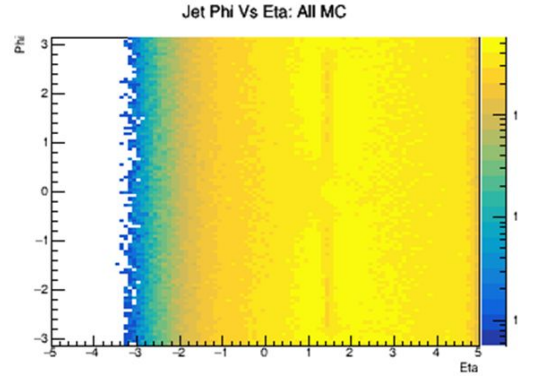
Jet Kinematics



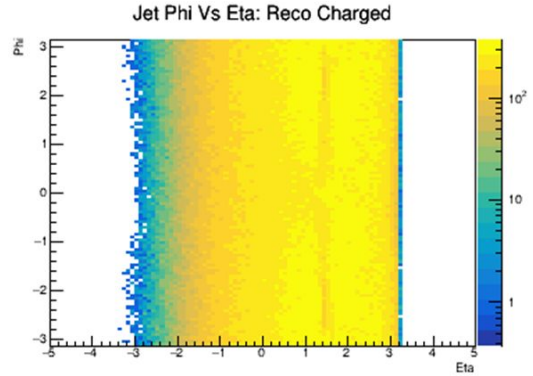




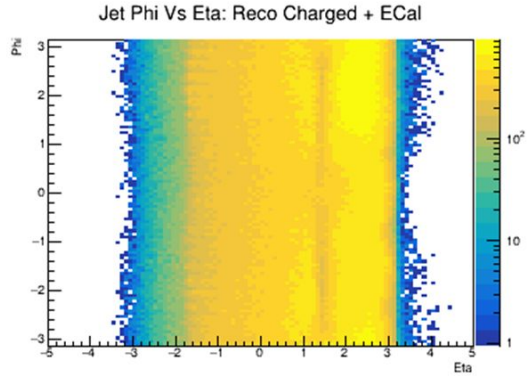
Full Monte Carlo



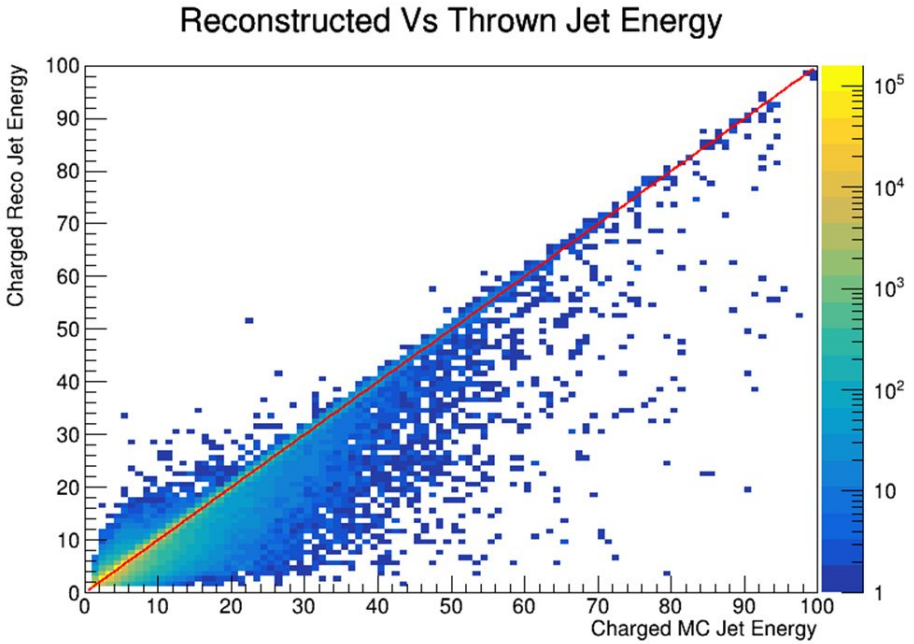
Reco Tracks



Reco Tracks + ECal

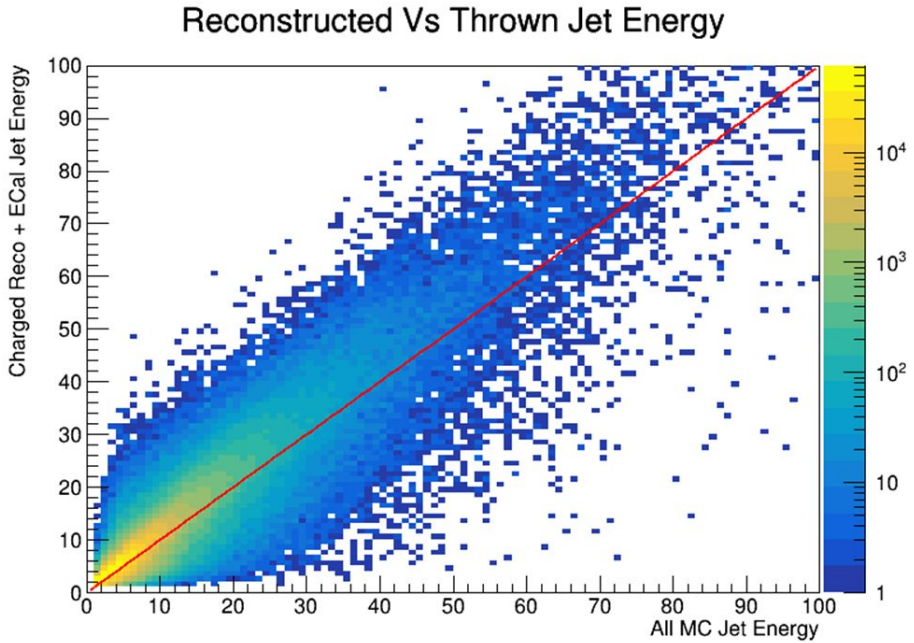


Jet Reco Vs Truth Correlations

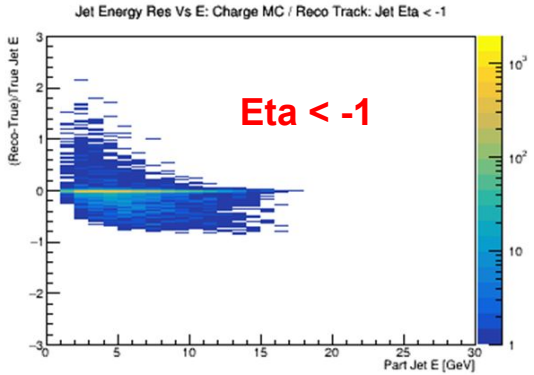


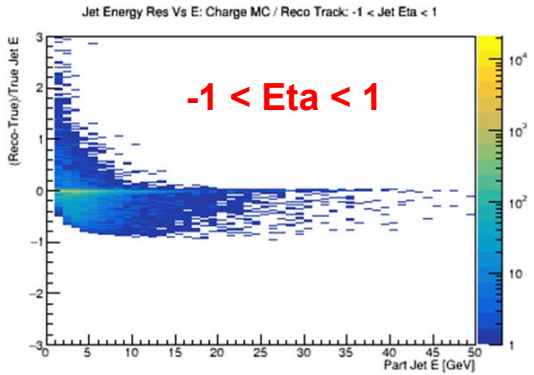
- Track only vs charged MC jets basically gives performance of tracker (its quite good)
- Track + ECal comparison shows double counting energy is a dominant feature in this method

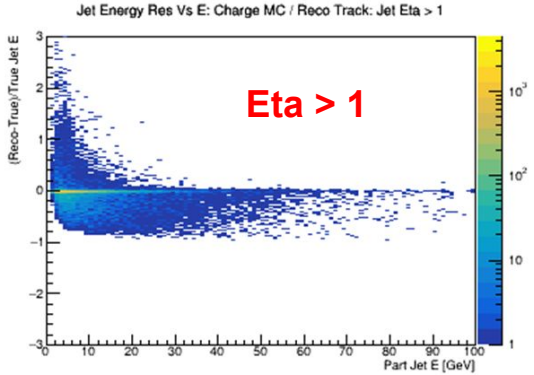
- Compare track only reco jets to charged particle MC jets
- Compare track + ECal reco jets to full MC jets



Jet Energy Resolutions in Eta Bins: Track Only Jets

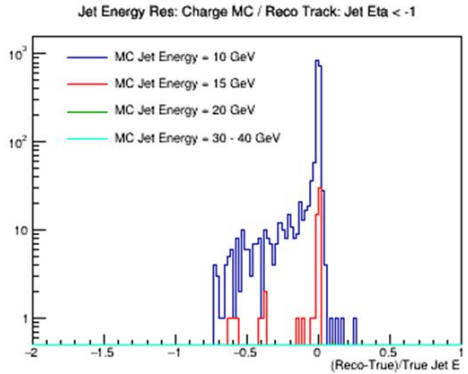


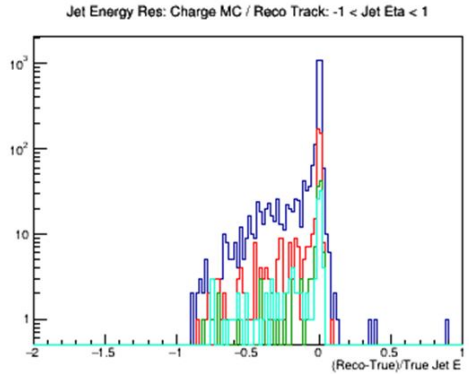


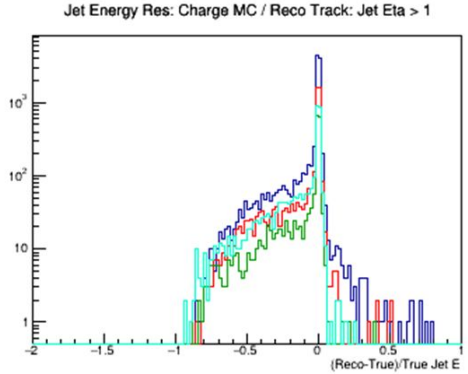


- ‘Resolution’ plots for track only jets compared to charged particle MC
- (Reco - Truth)/Truth Vs Truth Energy for three eta bins
- These should not be taken as final resolutions - simply a demonstration of where we are

Jet Energy Resolutions in Eta Bins: Track Only Jets

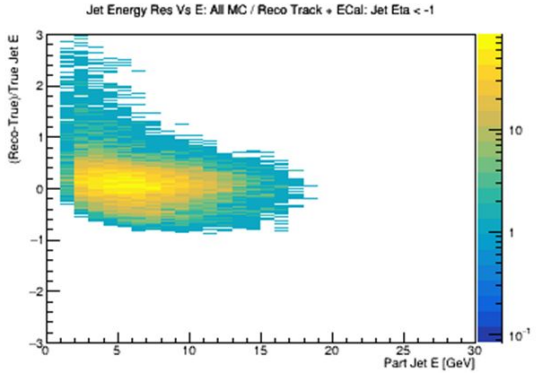


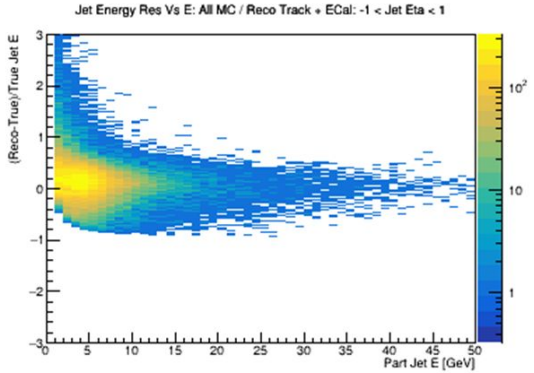


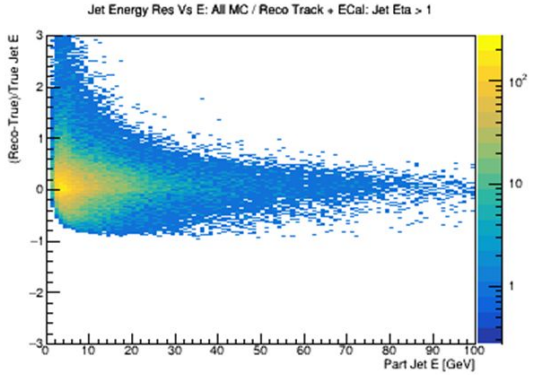


- ‘Resolution’ plots for track only jets compared to charged particle MC
- (Reco - Truth)/Truth Vs Truth Energy for three eta bins
- These should not be taken as final resolutions - simply a demonstration of where we are

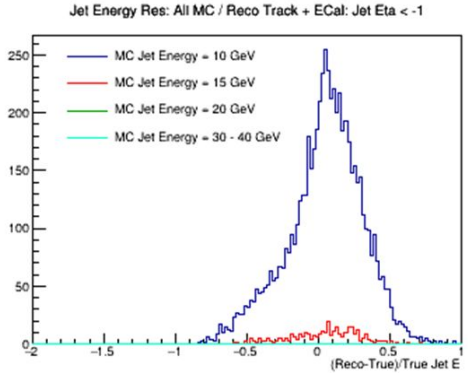
Jet Energy Resolutions in Eta Bins: Track + ECal Jets

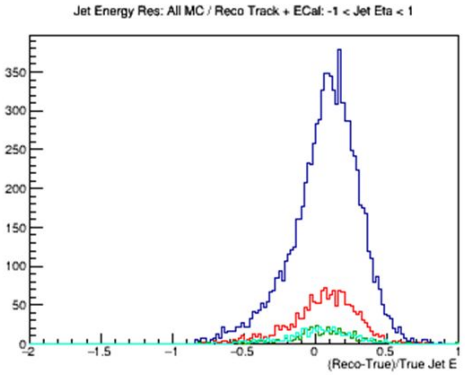


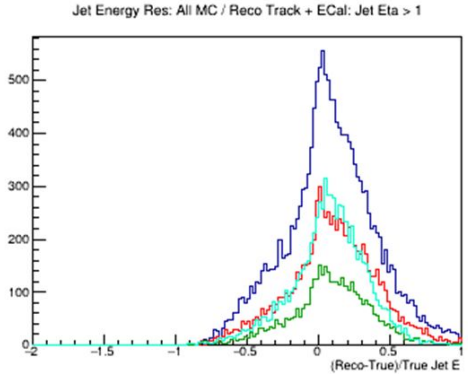




Jet Energy Resolutions in Eta Bins: Track + ECal Jets







Conclusions

- Have taken a first stab at running a jet analysis on the output of the full simulation campaign
- Many caveats and issues found - but beginning to see some useable output
- Track only jets give indication of tracker performance - looks good so far
- Future work:
  - Look at calorimeter (ECal + HCal) only jets
  - Analyze BryceCanyon geometry (contingent on imaging cluster issue)
  - Begin to look at more complex jet observables / analyses

Future Plans

Looking Ahead - Needs

- Truly impressive how far the software framework has come since this summer, however, several capabilities still needed to evaluate jet and HF observables
- Need consistent and holistic treatment of the hadronic final state
  - Integrated track-cluster projection/matching
  - Calorimeter cross calibration and weighting
  - Some form of Energy Flow algorithm
- Need realistic vertex (primary and secondary) reconstruction as well as PID
- In parallel, need to continue finding and addressing bugs and unexpected features in existing (and future) simulations

Looking Ahead - New Personpower, New Projects

- Within the last month, we have had several individuals / groups approach us with offers to work on specific topics or provide general help
  - Kevin Adkins (Morehead State)
  - Zuhal Demiroglu (Stony Brook)
  - Derek Anderson (Iowa State)
- Assistance with expanding jet functionality within the epic-analysis framework
- Development of a ‘jet factory’ within EICrecon to provide some standard jet output in reco files. Also, likely useful for future benchmark implementation
  - Possible candidate for one of the newly envisioned SWG subgroups

Looking Ahead - Horizontal Integration

- I will never pass up an chance to encourage better communication between WGs :-)
- Many opportunities for cross WG collaboration (electron finder, track-cluster matching, epic-analysis framework, energy flow, vertexing, etc)
- Possibly utilize planned SWG subgroup structure (Physics Algorithms) to help coordinate and organize these efforts