Virtual Reality visuals by Sean Preins

Charm Jet Tagging in ATHENA

Kaons, Electrons, and Displaced Tracks in Jets - Full and Fast Simulation

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Basic Ideas

Charm quark jets (e.g. produced from CC DIS s→c reactions) contain long-lived heavy charm hadrons that produce displaced substructures (vertices) within the jet. This can “tag” the jet as heavy flavor.

Current efforts focused on:

- *Displaced track counting*
- *Particle ID of Kaons (fast simulation) and Electrons (Full-Simulation Calorimeter-based approaches)*
    - *c→e + X ≅ 13% (inclusive)*
    - *c→K(OS*) + X ≅ 35% (inclusive)*
    - *c→K(SS*) + X ≅ 5% (inclusive)*

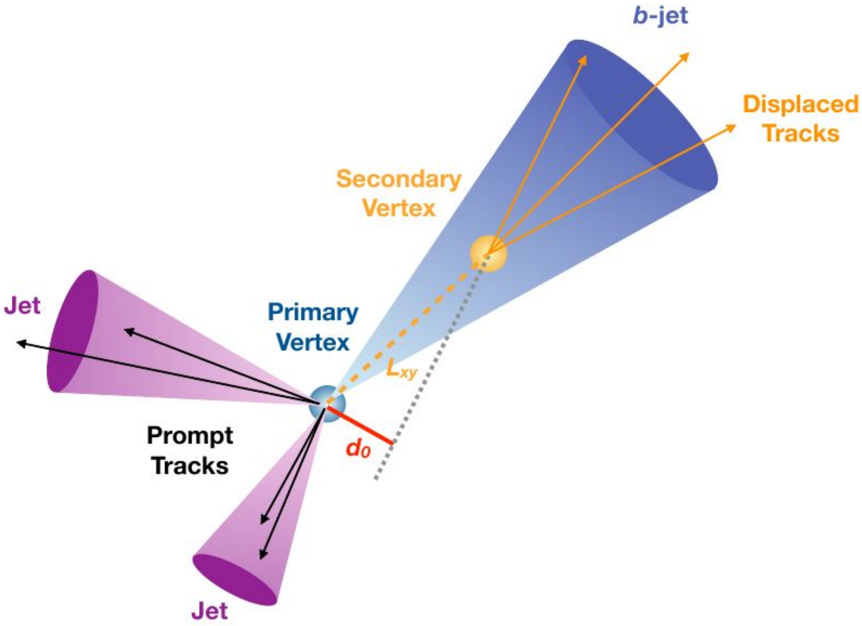


Image from ATLAS Experiment (arXiv:2106.03584). Depicted for pp collisions and b-jets, but applies equally well to charm jets at ep collider.

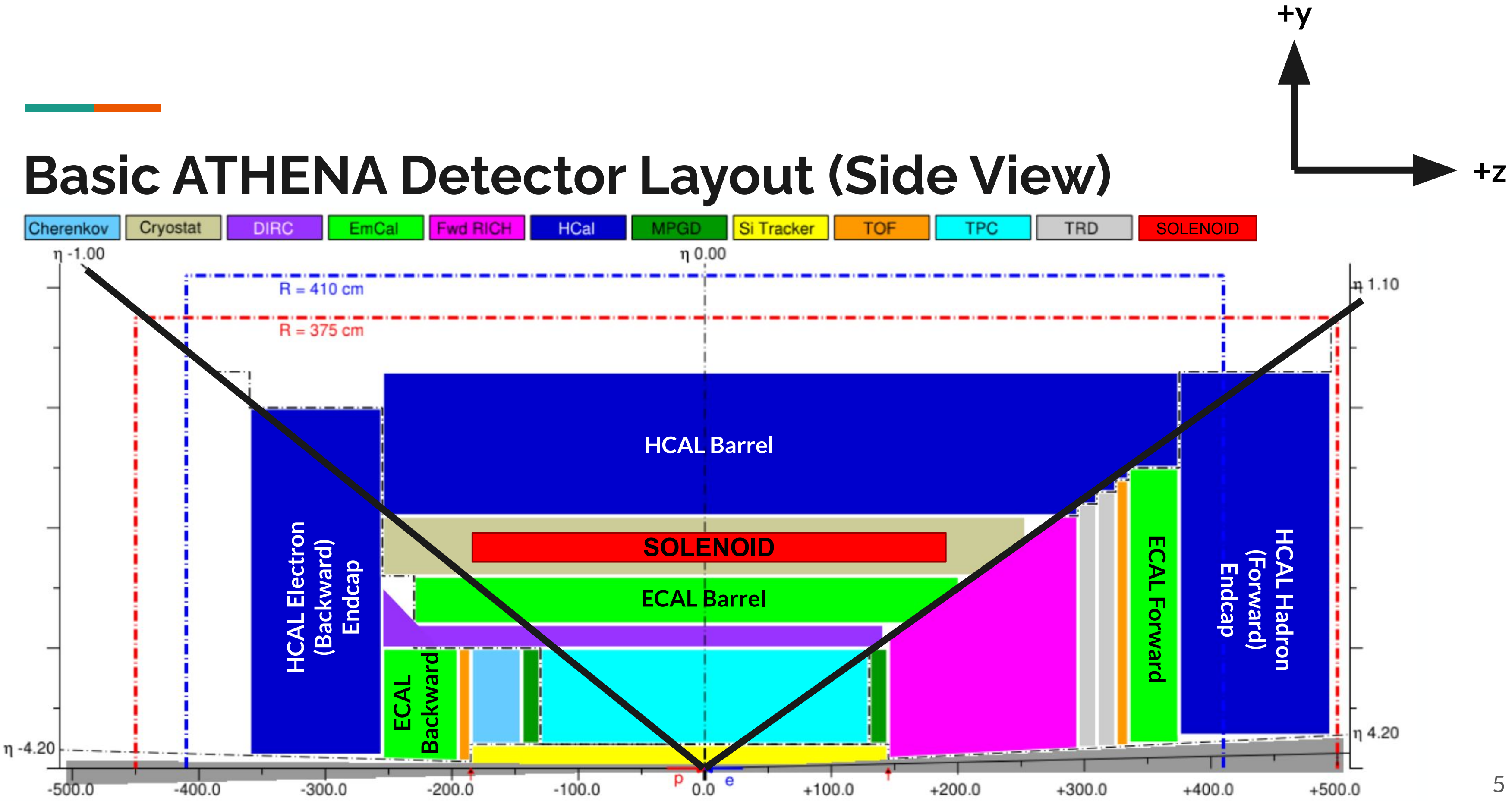
[*] OS = Opposite-Sign, SS = Same-Sign. Here, “sign” refers to the sign of the (anti-)charm quark charge.

Software Framework

- PYTHIA8(.305) for CC DIS collisions (ep at 10 on 275 GeV) -> 20 million collisions
- DD4hep (athena, ip6, etc.) for full simulation; single-particle events for now, only calorimetry.
- DELPHES for fast simulation of final-state particles/smearing for detector effects (tracks, neutrals, jets, particle flow)
- delphes_EIC for ATHENA-like detector configuration, including tracking, PID, ECAL, and HCAL.
    - All-silicon tracker model (momentum smearing and resolution), 3T magnetic field.
- OLeAA for analysis of DELPHES files
    - A simple analysis framework I sketched up last year (OLeAA = Own Little e-A Analysis)
    - Analyze small output files in Jupyter/UPROOT

Calorimeter-based Electron ID in Full and Fast Simulation

Basic ATHENA Detector Layout (Side View)



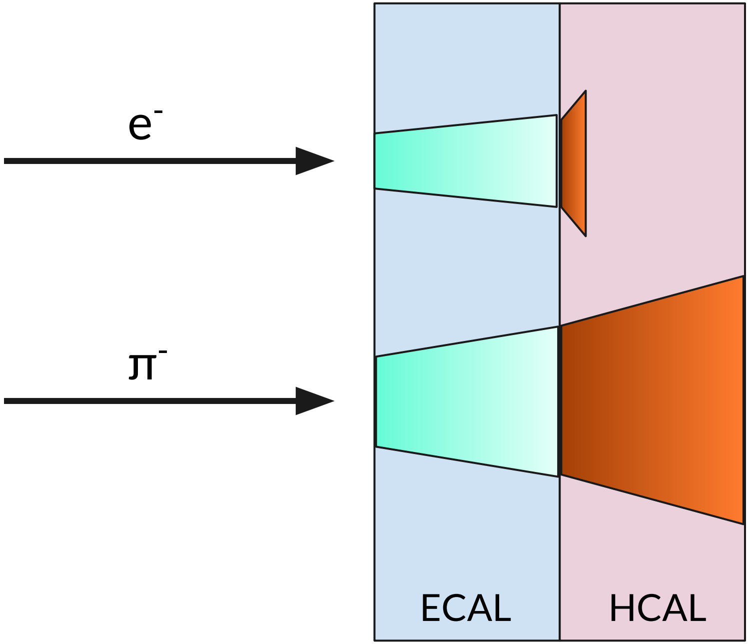
Full Simulation of Electron/Pion-Calorimeter Interactions

Using **DD4HEP (Pythia8 + GEANT4)** model of ATHENA with ECAL and HCAL in backward (electron), central (barrel), and forward (hadron) directions.

- Single-beam (electron or pion) simulation with p = 1 GeV/c and θ=[5,175]°
- 1 million events in each run (electrons/pions in backward or central+forward directions)
- Anticipated pattern of interactions shown right.

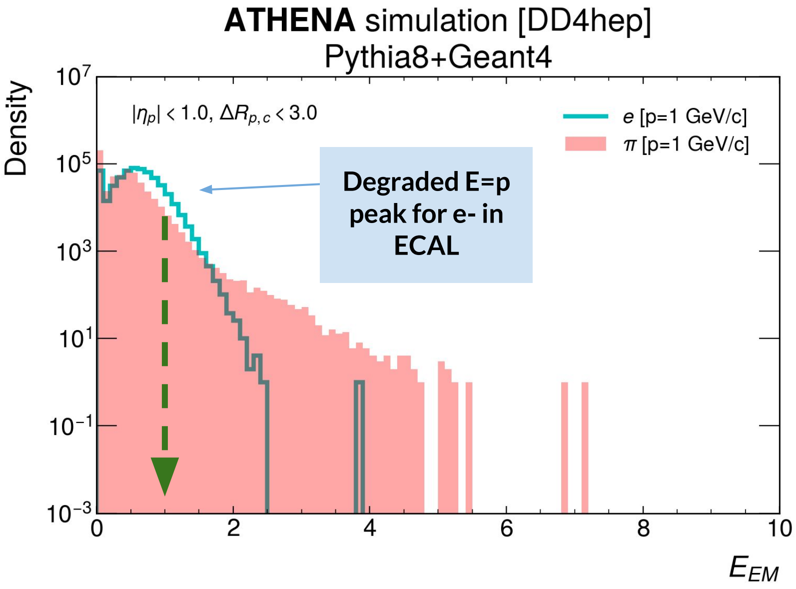
In Delphes, you can only distribute energy according to a fixed fraction with no variation (e.g. no probabilistic distribution functions allowed) → ***improve with information from full simulation! (*)***

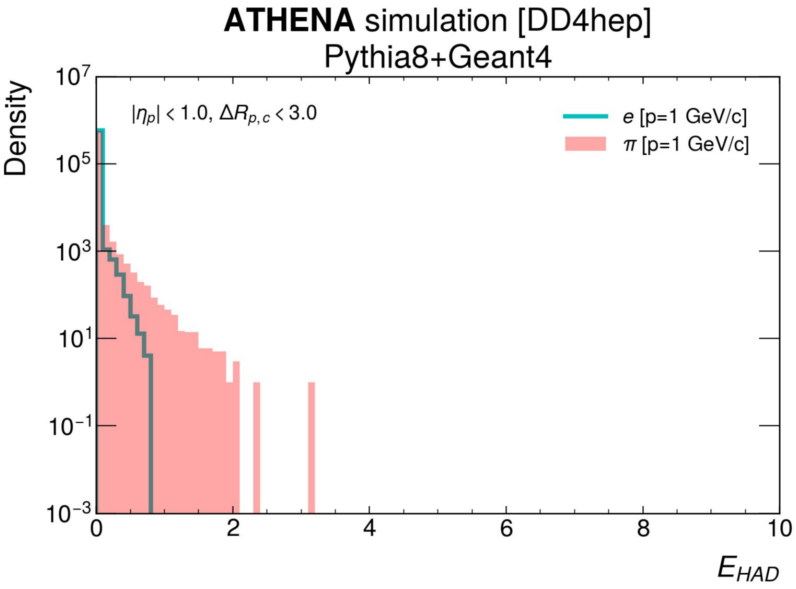
(*) also improve with feature request to Delphes?



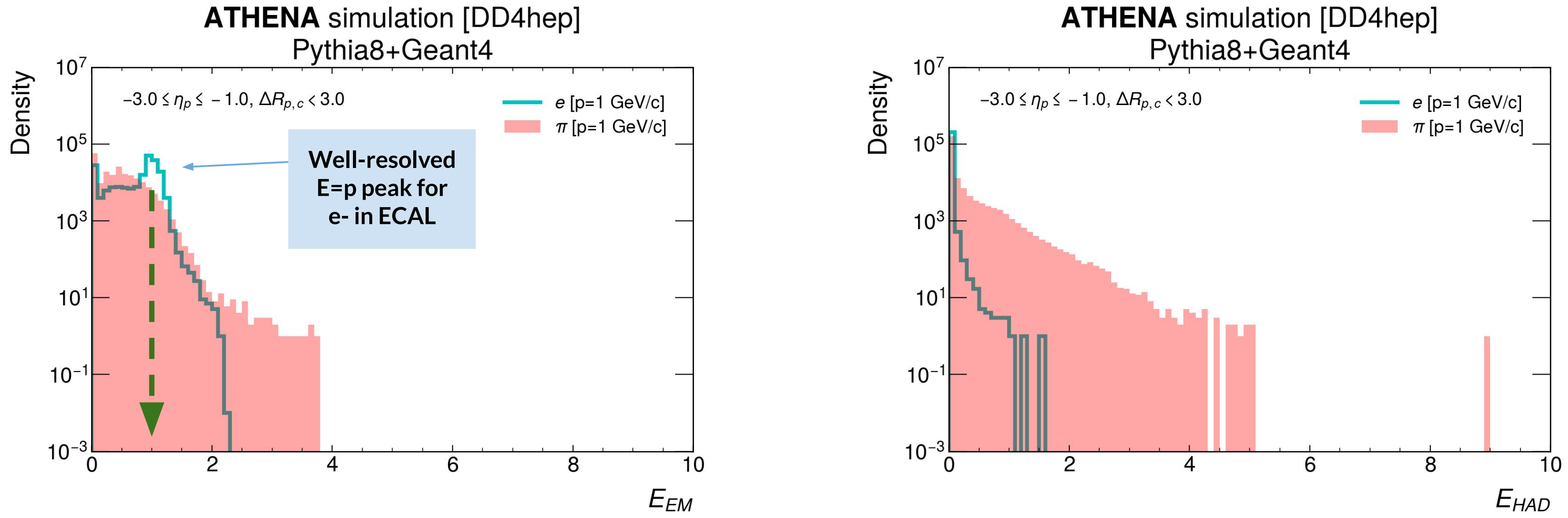
DD4HEP - Barrel Region ECAL and HCAL

The barrel energy “peak” at E=p for electrons is degraded (compare to fwd/bwd plots)

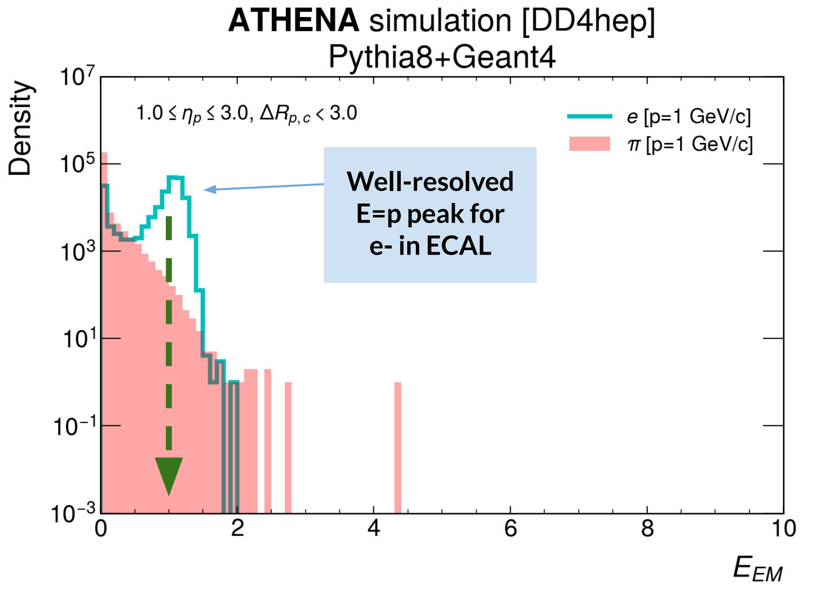


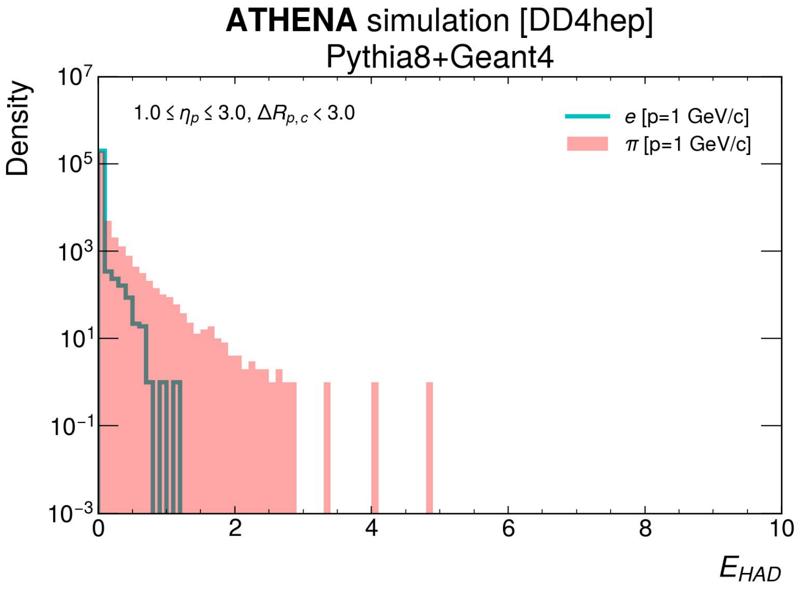


DD4HEP - Backward (Electron) Region ECAL and HCAL

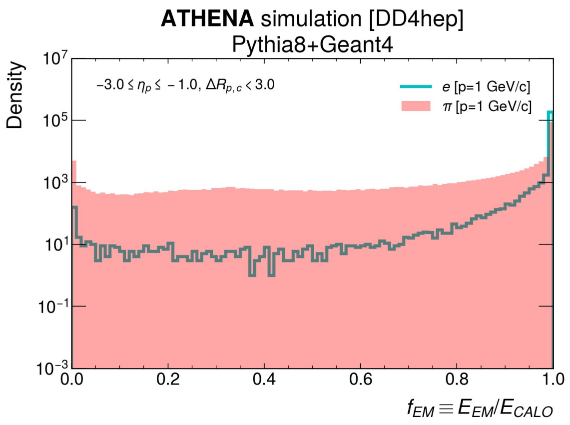


DD4HEP - Forward (Hadron) Region ECAL and HCAL

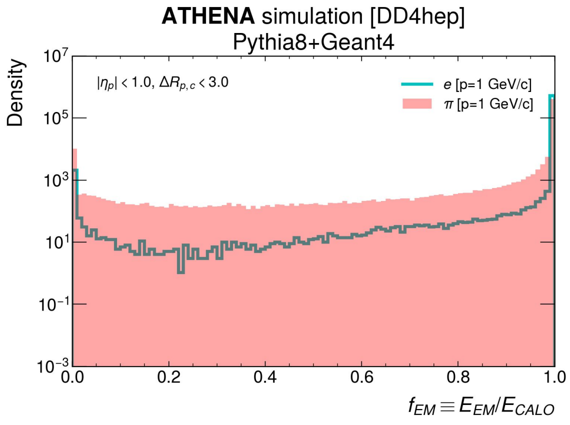




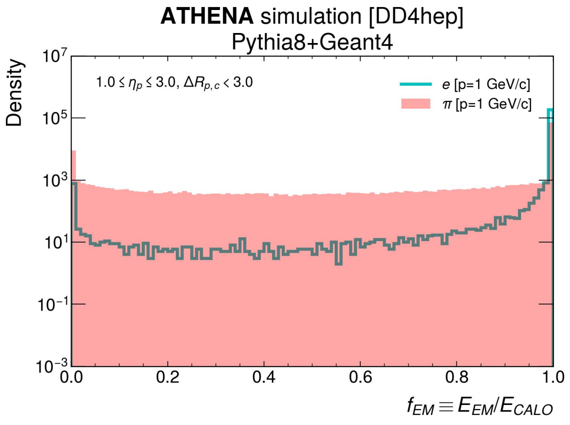
ECAL Energy Fractions



Backward



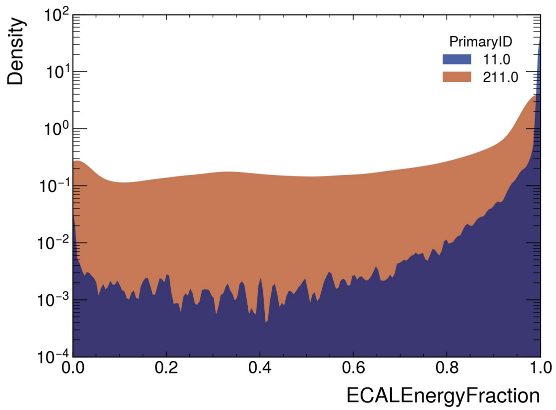
Barrel



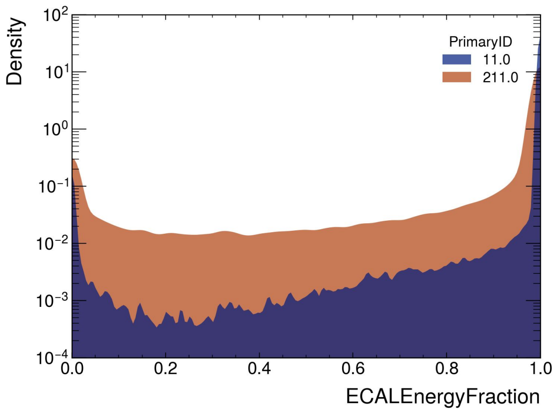
Forward

These are still early days, but the basic physics is right - *electrons tend to have EM energy fractions VERY close to 1.0, while pions are more spread out.*

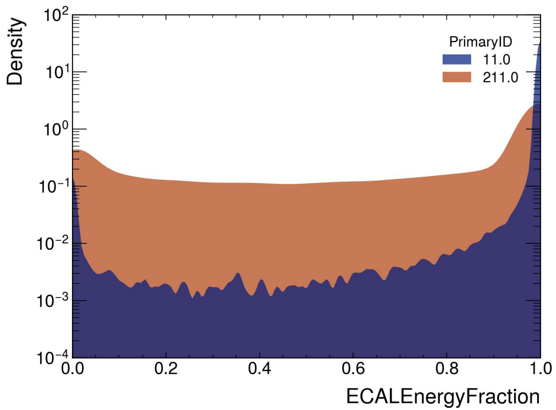
ECAL Energy Fractions - KDE Smoothed



Backward



Barrel



Forward

From this, fine-binned probability density functions (PDFs) for backward/barrel/forward e/π can be generated, loaded into OLeAA, and used to redistribute (probabilistically) energy for these particles.

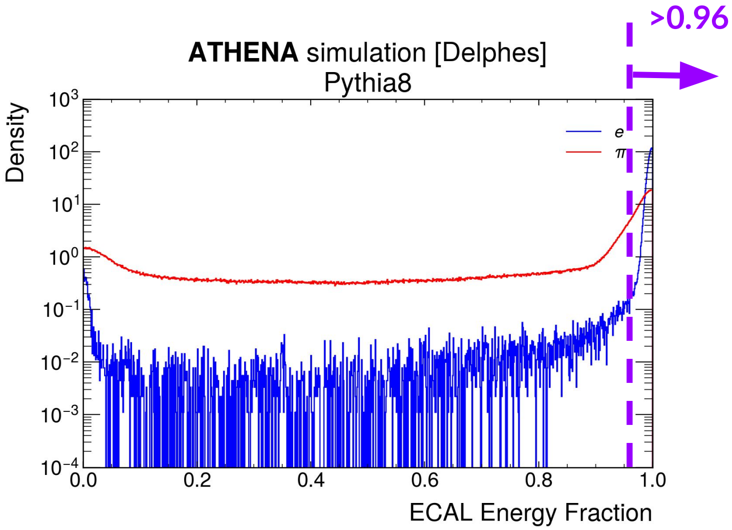
J. Choi

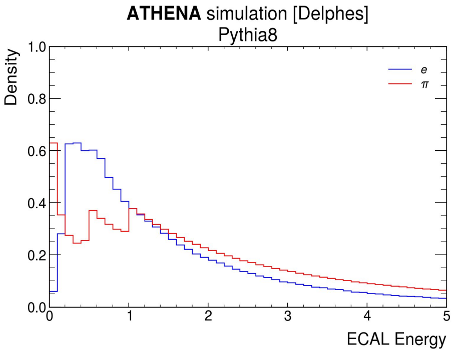
Electron ID using EM Energy Fraction

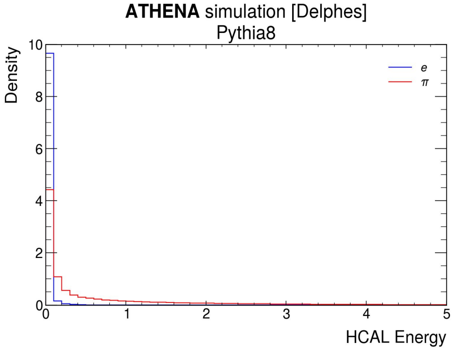
Find an “optimal” cut on f_{EM} that separates electrons from pions, then use this to define a list of electron candidates and define an “e-Tagged” jet selection.

$$\frac{\varepsilon_s}{\frac{n_\sigma}{2} + \sqrt{B}}$$

Use Punzi figure of merit (arXiv:physics/0308063) replacing $\sqrt{B}$ with ε_B. Set n_σ=3.







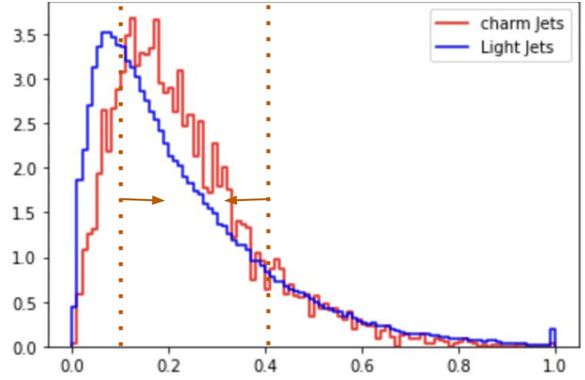
Approach is 96% (27%) efficient on true e (π).

Kaons in Jets in Delphes

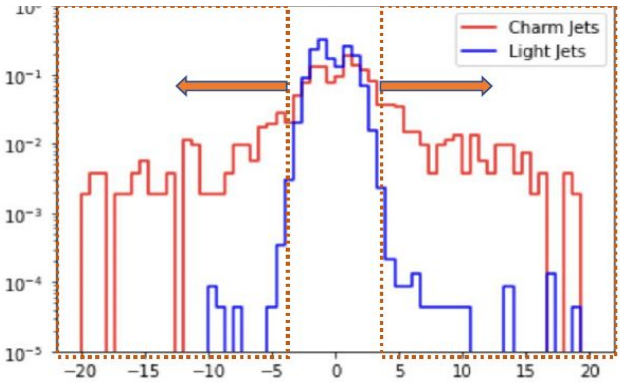
S. Gilchrist

Kaons in Charm and Light Jets: Properties

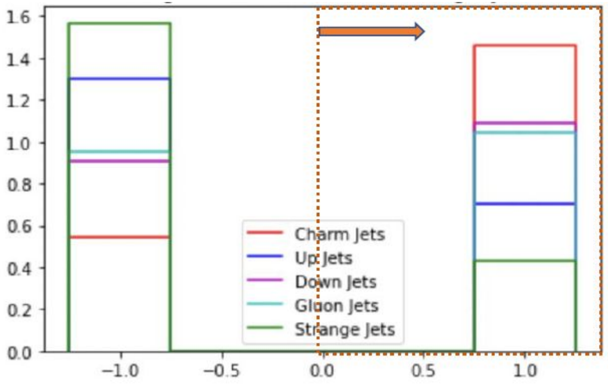
Kaons selected by looking inside jets and matching Energy Flow Tracks to tracks in the PID identification lists associated with the mRICH, barrel DIRC, and dual RICH performance maps. These are reconstructed, not truth, kaons (some contamination from pions and protons)



Kaon-to-Jet p_T Ratio



Kaon sIP_{3D}



Kaon Charge

K-Tagger: First Steps

"By eye" tuning of cuts: soft kaons (p_T = [0.0, 3.5] GeV), high flight significance in 3-D ($|sIP_{3D}|>4$), and positively charged (opposite-signed to the charm quark)

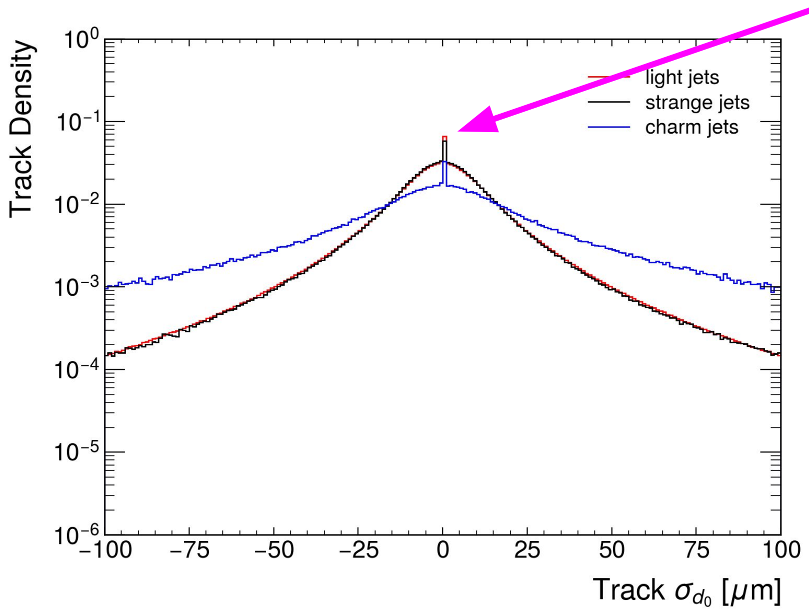
Jets	NOT sIP3DTagged	(NOT sIP3DTagged) AND K-Tagged	sIP3DTagged OR K-Tagged
Charm	80%	6.1%	26%
Light	99.5%	0.04%	0.5%

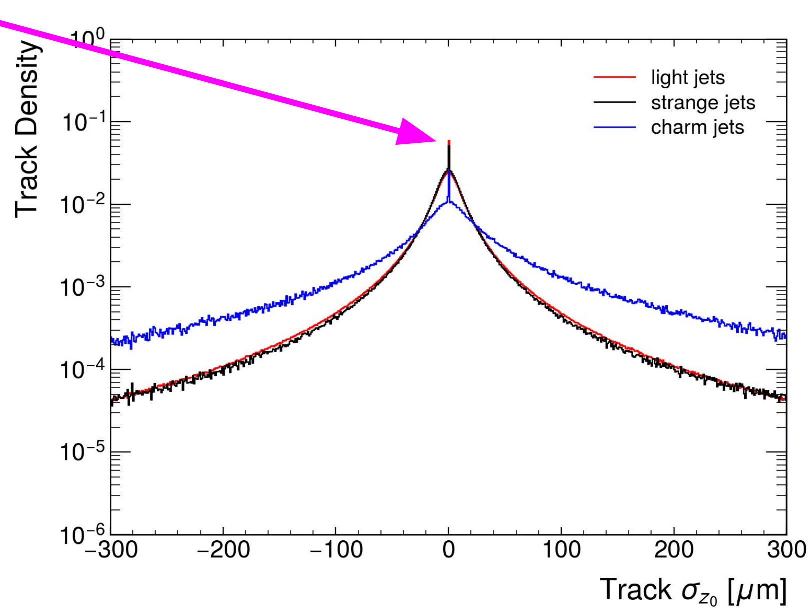
Adds a new sample of Charm Jets not previously tagged using only displaced-track tagging. Small increase in Light-Jet contamination but can be mitigated with optimization of approach.

Displaced Tracks in Delphes

Last time: d0/z0 errors in Fast Sim/Delphes

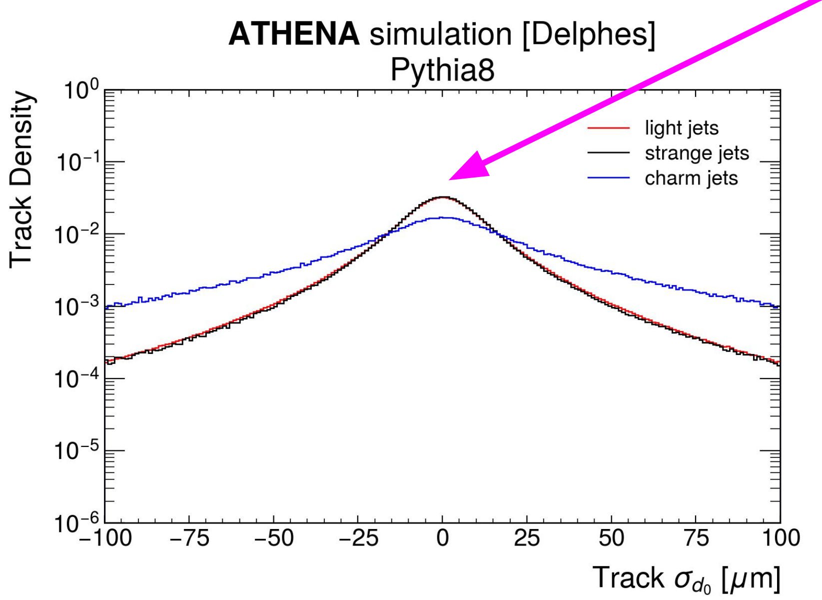
Tracks with |η|>2.5 not included in d0/z0 error model from all-silicon detector -> tracks with zero error resulted.

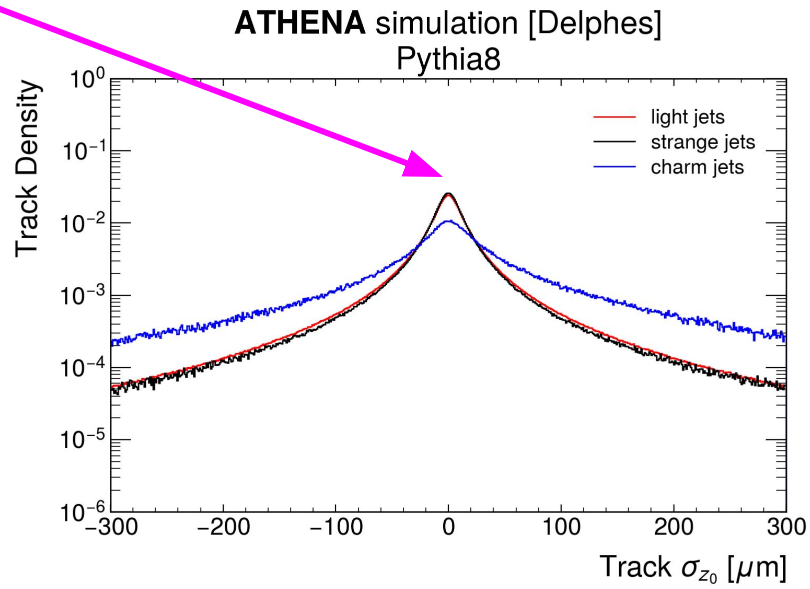




Reached out to Rey Cruz Torres → will extend model

Until then: simply artificially extend |η| bin maximum edge from 2.5 → 4.0



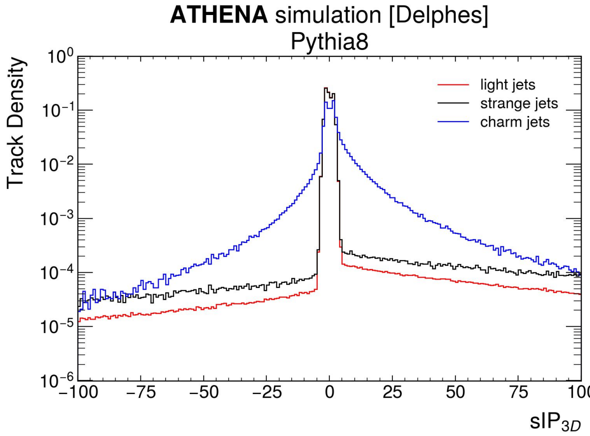


Tagger Synthesis

Charm Jet Tagging (updated)

All methods are rectangular cuts-based.

- *"sIP3D-Tagged"*
  - *≥2 tracks with: p_T > 0.5 GeV/c, sIP_{3D} > 3, and r_0 < 3mm. (Phys. Rev. D 103, 074023 (2021) - no reoptimization since YR)*
  - *"Funny" shapes of tails in sIP3D for light/strange jets → needs investigation*
- *"k-Tagged"*
  - *Jet contains at least one identified kaon with low pT, high flight significance, and positive charge.*
- *"e-Tagged"*
  - *IN PROGRESS*

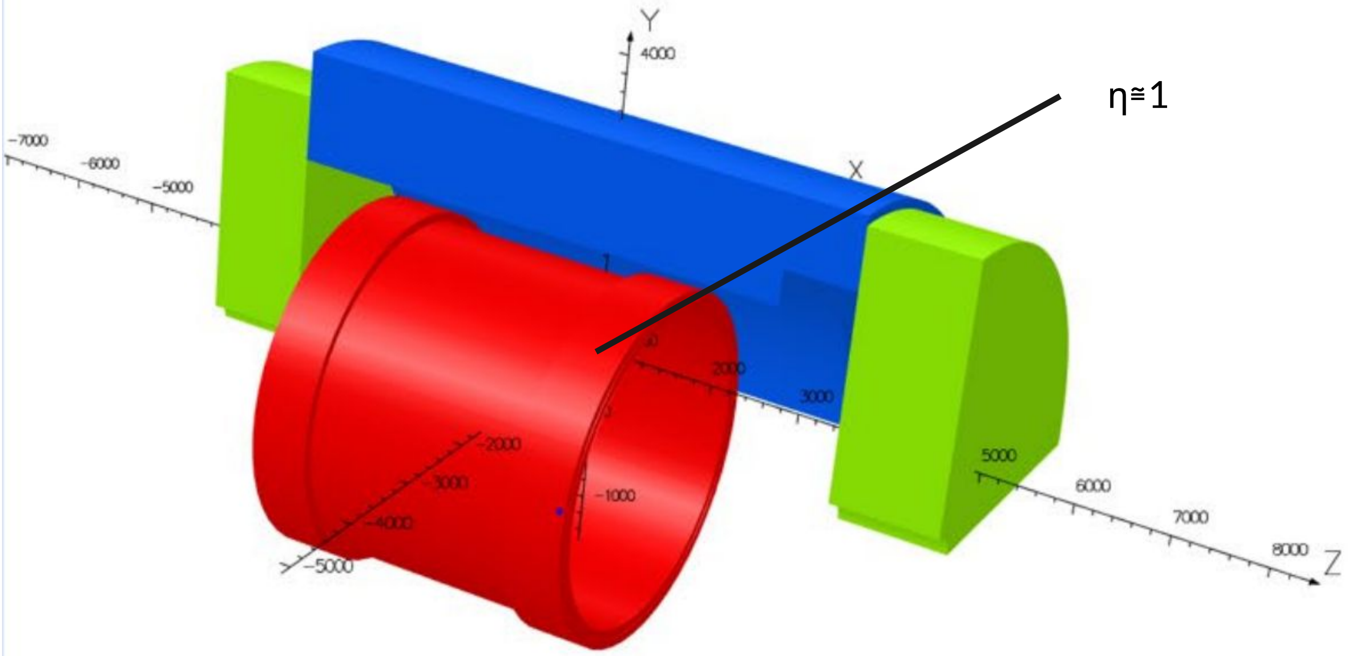


Method	Charm Eff. (%)	Light Eff. (%)
1: sIP3DTagged	20.1	0.45
2: k-Tagged	13.5	0.05
3: e-Tagged	IN PROGRESS	IN PROGRESS
Tagged by 1 or 2	26.4	0.50

Next Steps

- We are approaching a baseline framework for evaluation detector/accelerator consequences:
  - Electron ID/tagging sensitive to Calorimeter modeling/choices/effects/energy loss in materials
  - Kaon ID sensitive to PID system models
  - Displaced tracks sensitive to tracking models
- Investigate beam crossing, etc. effects (which will affect all downstream work, of course), as well as vertex reconstruction and jet substructure approaches.
  - Combine this in a simple neural network (already in place) to see how different components contribute and to assess robustness of arbitrary multivariate approaches.
  - Continue to iterate as simulations changes/improves and as full simulation is available.
- ***Translate tagging yield into impact on charm jet population from 1 year of EIC collisions -> impact on intrinsic strangeness assessment.*** *(work in collaboration with Fred Olness at SMU)*

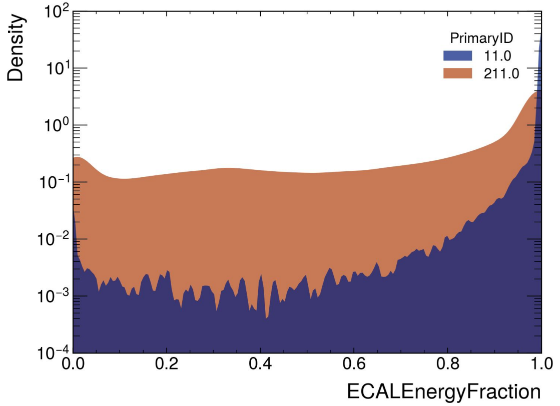
APPENDIX



Magnet yoke provides extra interaction lengths in the barrel segment of the ATHENA detector (between ECAL and HCAL in present model), degrading energy reconstruction in the calorimeters - needs to be accounted, models, corrected/compensated.

Helmholtz coil alternative can be studied in context of charm jet work if it is available in DD4hep/ATHENA model.

Correcting Delphes Energy Fractions in OLeAA



Backward

Example: true pions or electrons in backward direction using accept/reject Monte Carlo method:

- Store the KDE-smoothed shapes at 1000-bin histograms, one each for true electrons and true pions. Normalize shape to unit area (convert to PDF from density plot). Load into OLeAA as TH1D objects in the TreeWriterModule.

- If |PdgID| == 11 (electron), load the true electron PDF; if |PdgID| == 211 (pion), load the true pion PDF. Otherwise, retain the Delphes energy fraction default.

- For a track, throw two uniform random numbers, x (in the range [0,1]) and y (in the range [0, max(PDF)]). Compare PDF(x) to y. If y < PDF(x), set f_{EM} for track as x; otherwise, throw random numbers x,y until y < PDF(x).