Charm Jet Tagging in ATHENA

A look at fast simulation in Delphes/delphes_EIC

Stephen Sekula (SMU)
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Basic Ideas

Charm quarks (e.g. produced from CC DIS s->c reactions) contain long-lived heavy charm hadrons that produce displaced substructures (vertices) within the jet.

For now, focus on simple approaches (**displaced track counting**). SMU summer research students looking now at kaon PID and electron PID approaches to enhance this method. Vertexing, etc. on the table as well -> approaches less clear there in Delphes (for now).

Former student Jared Burleson investigated jet substructure and tagging -> observed gains over just using displaced tracks -> aim for all inclusive machine learning approach -> assess robustness against detector design changes, etc.

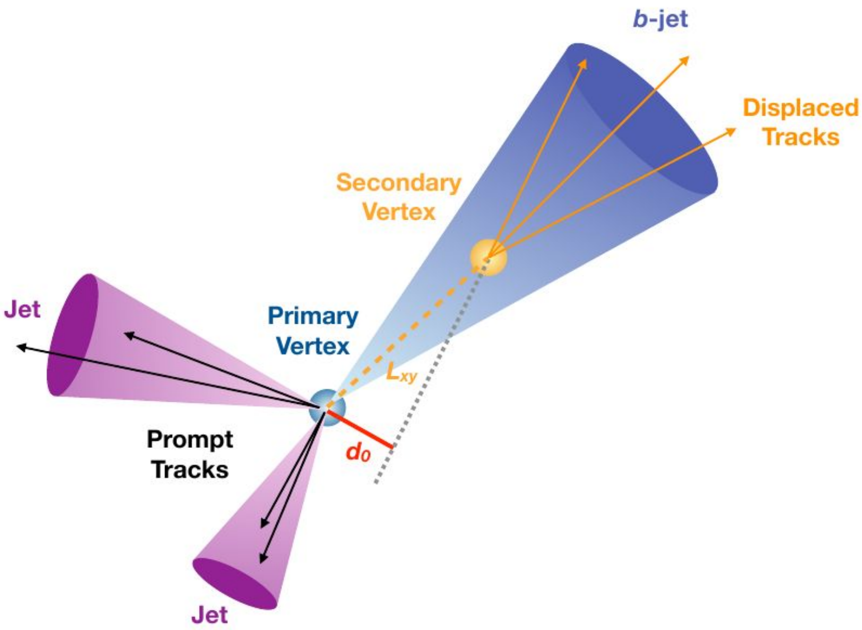


Image from ATLAS Experiment (arXiv:2106.03584). Depicted for pp collisions and b-jets, but applies equally well to charm jets at ep collider.

Signed 3-D Impact Parameter Significance

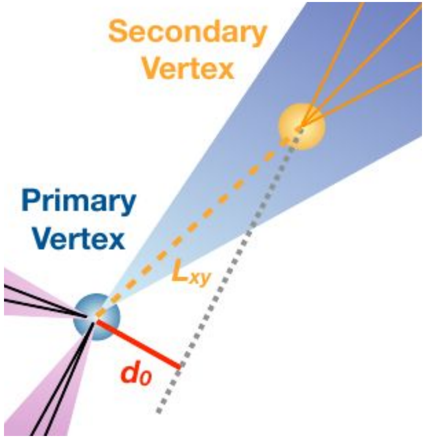
3-D impact parameter significance easily defined for track inside jet:

$$IP_{3D} = \sqrt{(d_0/\sigma_{d_0})^2 + (z_0/\sigma_{z_0})^2}$$

The sign of this quantity is determined from the sign of this dot-product:

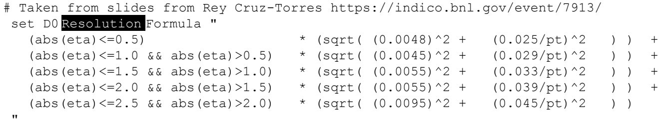
$$\vec{p}_j \cdot \vec{r}_0^{\,track}$$

For real displaced tracks from charm hadrons (cτ=100-300μm), this dot product will tend to be positive as the POCA on the track will point parallel to the jet momentum; for prompt decays from light jets, this product will be randomly positive or negative.



Delphes/EIC: track d0/z0 resolution coded up as follows: (defined to |η|=2.5) →

... but "tracking" goes all the way to |η|=4.0 in the rest of the Delphes card...



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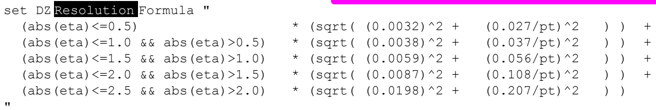
# Taken from slides from Rey Cruz-Torres https://indico.bnl.gov/event/7913/
 set D0ResolutionFormula "
   (abs(eta)<=0.5)                    * (sqrt( (0.0048)^2 +   (0.025/pt)^2   ) )  +
   (abs(eta)<=1.0 && abs(eta)>0.5)    * (sqrt( (0.0045)^2 +   (0.029/pt)^2   ) )  +
   (abs(eta)<=1.5 && abs(eta)>1.0)    * (sqrt( (0.0055)^2 +   (0.033/pt)^2   ) )  +
   (abs(eta)<=2.0 && abs(eta)>1.5)    * (sqrt( (0.0055)^2 +   (0.039/pt)^2   ) )  +
   (abs(eta)<=2.5 && abs(eta)>2.0)    * (sqrt( (0.0095)^2 +   (0.045/pt)^2   ) )
 "
```



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set DZResolutionFormula "
  (abs(eta)<=0.5)                     * (sqrt( (0.0032)^2 +   (0.027/pt)^2   ) )  +
  (abs(eta)<=1.0 && abs(eta)>0.5)     * (sqrt( (0.0038)^2 +   (0.037/pt)^2   ) )  +
  (abs(eta)<=1.5 && abs(eta)>1.0)     * (sqrt( (0.0059)^2 +   (0.056/pt)^2   ) )  +
  (abs(eta)<=2.0 && abs(eta)>1.5)     * (sqrt( (0.0087)^2 +   (0.108/pt)^2   ) )  +
  (abs(eta)<=2.5 && abs(eta)>2.0)     * (sqrt( (0.0198)^2 +   (0.207/pt)^2   ) )
"
```
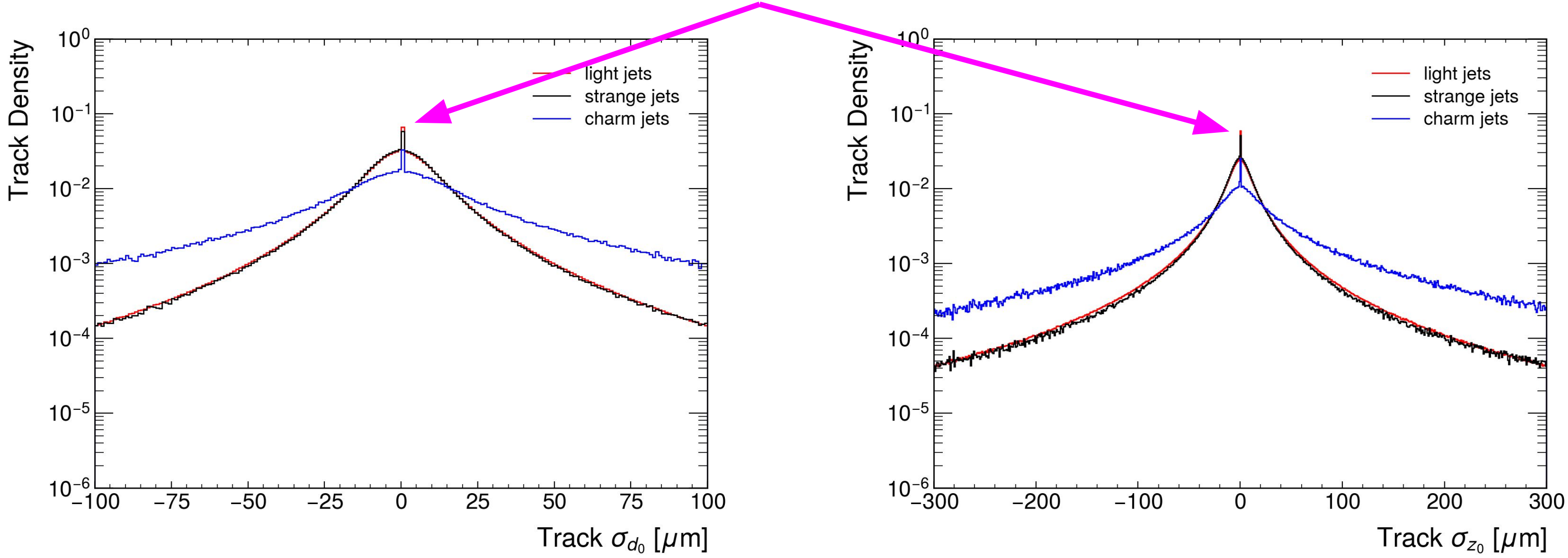

Software Framework

- PYTHIA8(.305) for CC DIS collisions (ep at 10 on 275 GeV) -> 20 million collisions
- DELPHES for fast simulation of final-state particles/smearing for detector effects
- 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 better version of a simple analysis framework I sketched up last year -> still very much a work-in-progress (OLeAA = Own Little e-A Analysis)
    - Analyze small output files in Jupyter/UPROOT

Basic Track Quantities: d0/z0 errors

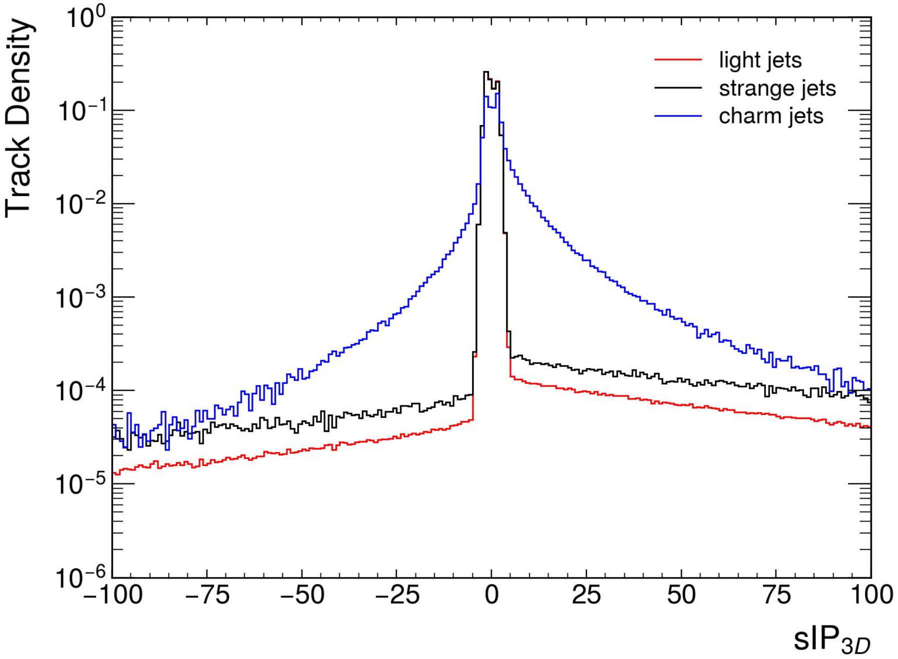
“Spike” at zero in both → tracks with $|\eta|>2.5$? → YES. Verified.



Charm Jet Tagging

Adopted without change the approach in Phys. Rev. D 103, 074023 (2021).

- ***"Tagged" if ≥2 tracks with: p_T > 0.5 GeV/c, sIP_{3D} > 3, and r_0 < 3mm.***
- In previous work (1.5T field, EIC YR baseline detector model), this yielded 20% (0.4%) charm (light+strange) jet efficiency.
- In current all-silicon + 3T model, same basic performance observed: 19.65% (0.44%) charm (light+strange) jet efficiency.
- *My concerns:*
  - *d0/z0 error spikes at zero → resolve!*
  - *"Funny" shapes of tails in sIP3D for light/strange jets → needs investigation*



Next Steps

- Understand/resolve d0/z0 error and sIP3D tails questions.
- We know from our previous work (assuming only a conservative across-the-board 3σ K/pi, etc. separation) that PID boosts jet tagging efficiency
    - **SMU Hamilton Research Scholar Stephanie Gilchrist** will revisit the impact of identified Kaons on jet tagging
    - **Highland Park High School summer intern Justine Choi** will revisit the impact of identified Electrons on jet tagging, with emphasis on calorimetry-based approaches to electron ID.
- I will 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.
    - 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)*