Jet substructure studies for the EIC

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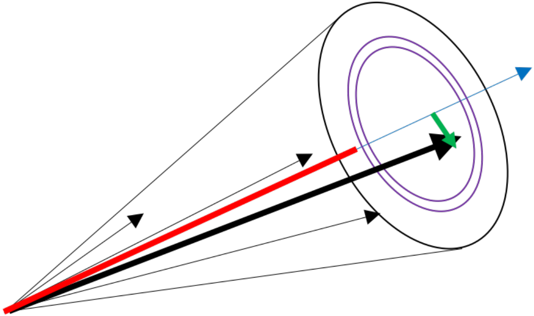
May 21, 2020

Reminder of Goals

- Short update in Jet/HF meeting on April 27
- Goals are to study basic jet substructure observables, as well as soft drop groomed jets, for inclusive jet production and inclusive HF jet production
- Working with EICSmear package to do fast simulation, so that a number of different detector geometries can be quickly implemented (should they need to be)
- Code is available on github

Reminder of Observables

- Typically, RHIC/LHC analyses use z, j_T, and r as shown here
- Have been used in:
  - Inclusive jet (ATLAS, ALICE, CMS, STAR)
  - Z^0-jet (LHCb)
  - γ-jet (ATLAS, CMS)



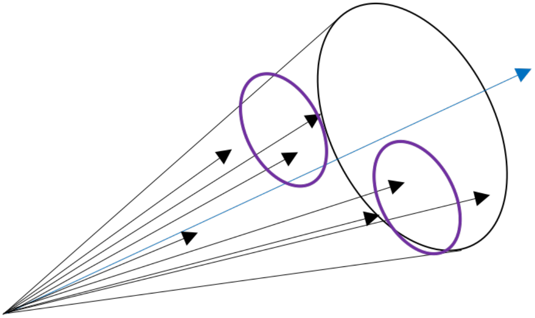
$$z = \frac{p_{jet} \cdot p_h}{|p_{jet}|^2}$$

$$j_T = \frac{|p_h \times p_{jet}|}{|p_{jet}|}$$

$$r = \sqrt{(\phi_h - \phi_{jet})^2 + (y_h - y_{jet})^2}$$

Reminder of Observables

- Can also look at jet substructure in soft drop groomed jets
- Typical soft drop observables are R_g and z_g
- Could look at others also, e.g. jet mass. Suggestions welcome



$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

$$R_g = \Delta R(p_{T,1}, p_{T,2})$$

Simulation Setup

- Using EICSmear to process events quickly and get ideas of resolution, etc.
- Run `PYTHIA` 6.4 as implemented in `PYTHIA eRHIC`, inclusive jet production
- Using steering file which has been tuned to HERA data, available in EICSmear
- At the moment run inclusive events, with $Q^2_{min} = 9$ GeV^2 to collect statistics of high p_T jets
  - Can relax this cut later
- Starting out with $\sqrt{s}$ of 18x275 and 10x100 since these are nominally the highest energies available for ep and eA scattering
- Working in the lab frame for now
  - Breit frame transformation in place, but we are still understanding/interpreting results...

Detector Resolution Specifications

- Use `DetectorHandbook` smearing file based on EIC Handbook from February
- Implemented into EICSmear by Kolja Kauder (thanks Kolja!)
- All resolution values shown here for reference

Detector	Eta coverage	Resolution
Tracking	$-3.5 < \eta < -2.5$	$\sigma(p)/p \sim 0.1p + 2.0\%$
Tracking	$-2.5 < \eta < -1$	$\sigma(p)/p \sim 0.05p + 1\%$
Tracking	$-1 < \eta < 1$	$\sigma(p)/p \sim 0.05p + 0.5\%$
Tracking	$1 < \eta < 2.5$	$\sigma(p)/p \sim 0.05p + 1\%$
Tracking	$2.5 < \eta < 3.5$	$\sigma(p)/p \sim 0.1p + 2\%$
EMCal	$-4.5 < \eta < -2$	$1/\sqrt{E} + 1\%$
EMCal	$-2 < \eta < -1$	$8/\sqrt{E} + 2\%$
EMCal	$-1 < \eta < 4.5$	$12/\sqrt{E} + 2\%$
HCal	$-3.5 < \eta < -1$	$45/\sqrt{E} + 6\%$
HCal	$-1 < \eta < 1$	$85/\sqrt{E} + 7\%$
HCal	$1 < \eta < 3.5$	$45/\sqrt{E} + 6\%$

Jet Clustering Criteria

Truth Criteria

- At truth event level, require:

$$Q^2_{min} > 16 \text{ GeV}^2$$

$$0.01 < y < 0.95$$

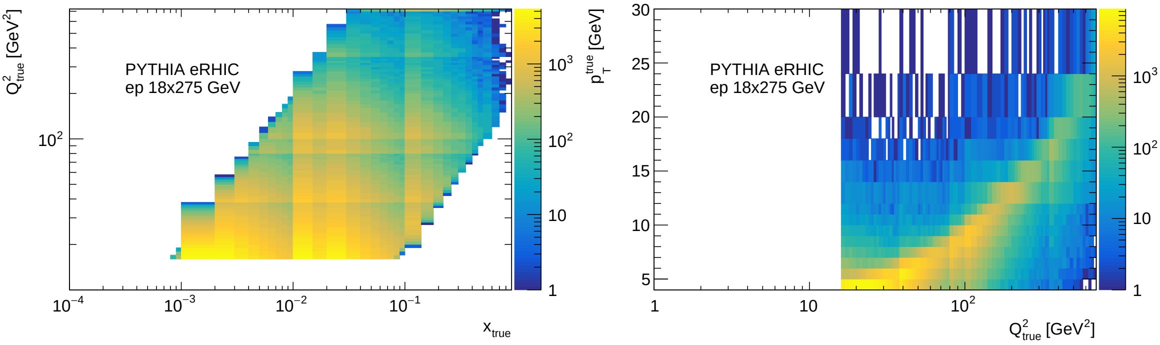
$$x_{min} > 10^{-5}$$

- Cluster final state particles, excluding scattered electron
- Require $|\eta^{part}| < 3.5$ and $p_T^{part} > 0.25$ GeV
- Use R=1 anti-k_T from `fastjet`

Smeared Criteria

- Impose same truth criteria (e.g. final state, η, p_T requirements)
- Then collect particles as follows:
  - Smeared particles with a nonzero 4-vector (p_x, p_y, p_z, E) are included as is
  - Smeared particles with $(p_x, p_y, p_z) = 0$ are (neutral) calorimeter clusters
    - Assign momentum based on truth PID
  - Smeared particles with $E = 0$ are tracks that did not have an associated calorimeter energy deposit
    - Assign energy based on truth PID

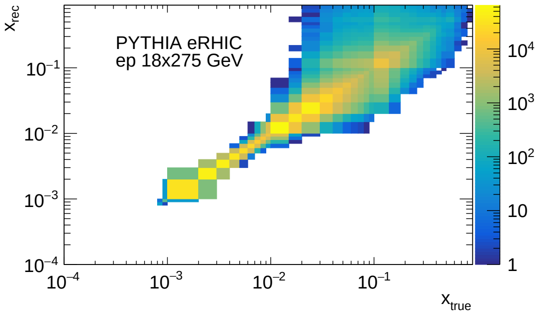
Event Level Kinematics

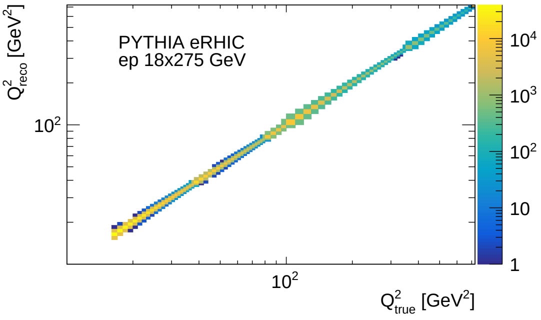


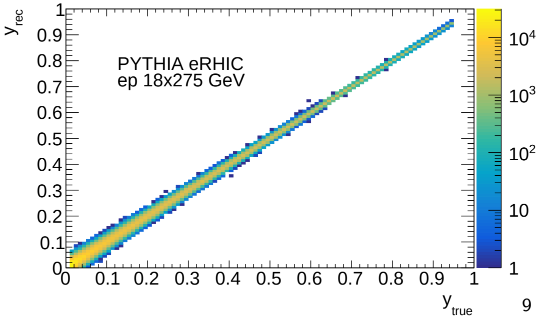
- Sanity checks - truth (x, Q^2) distributions look reasonable
- Clear correlation between truth jet p_T and Q^2

Event Kinematic Reconstruction

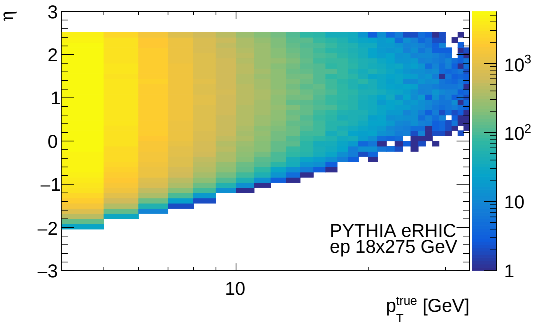
- Event kinematics reconstructed well
- Smearing more significant at higher x, smaller y

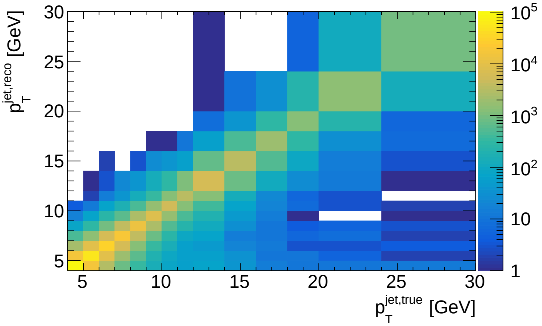






Jet Kinematics

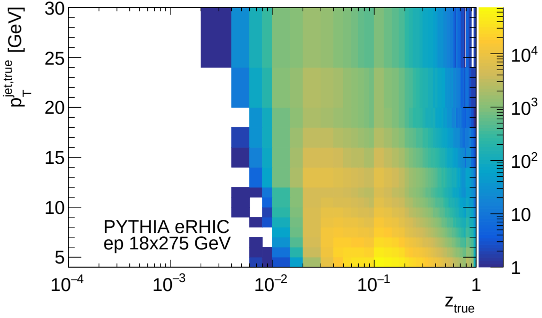


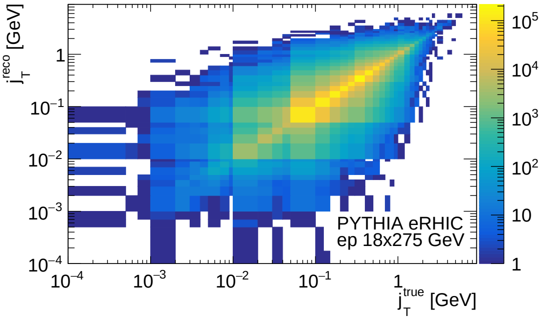


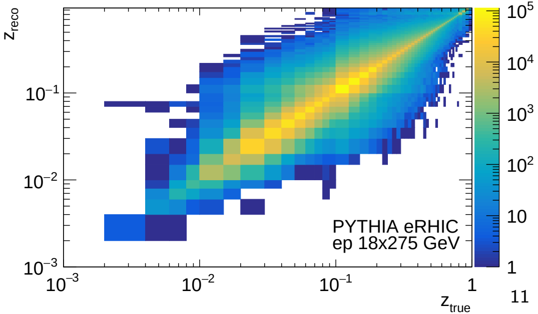
- Lab frame jets produced largely at central and forward rapidities
- Restrict jet to have $|\eta| < 2.5$ so that jet cone lies in full tracking acceptance
- Good jet p_T reconstruction

Hadronization Kinematics

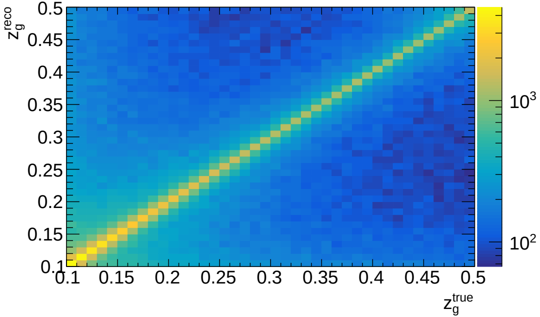
- Hadronization kinematic reach is mostly limited by lower p_T threshold of particles
- Hadronization observables limited by jet momentum resolution

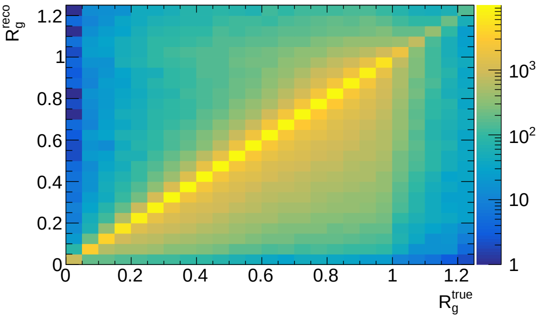






Jet Substructure Kinematics

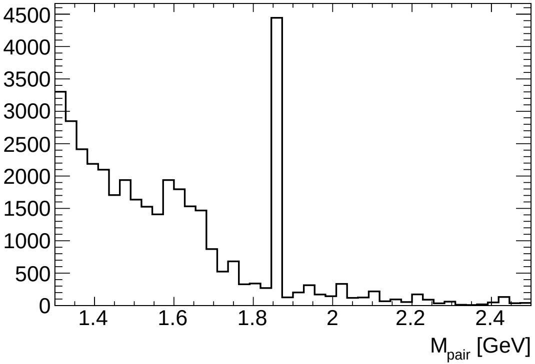




- Soft drop algorithm applied with $z_{cut} = 0.1$, $\beta = 0$
- Not sure why z_g show seemingly much worse correlation than other observables. Needs investigating
- R_g mostly well reconstructed
- Keep in mind this is integrated over $p_T > 4$ GeV, so low p_T jets dominate

Charm Jet Tagging

- Working on implementing charm jet tagging
- Can tag D^0 mesons within truth jet
  - Will look at capabilities for other D mesons also
- Understanding smeared distributions and D tagging-in-jet capabilities within EICSmear

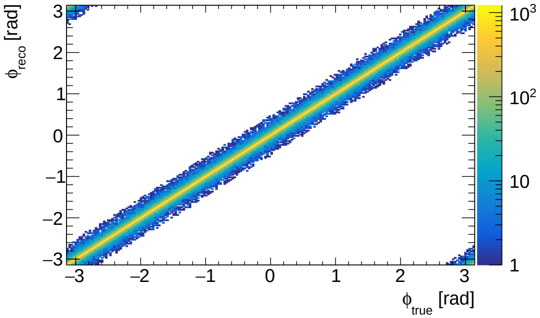


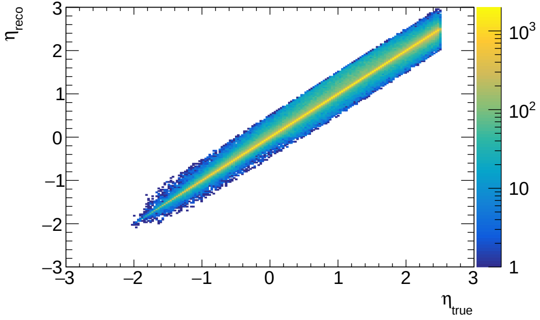
Conclusions

- Software framework for running PYTHIA eRHIC and EICSmear simulations in place
- Analyzing jet substructure and hadronization observables, reconstruction capabilities
- Preliminary looks at jet kinematics, reconstruction, and substructure capabilities today for a generic EIC detector
- To-Do
  - Working on charm jet tagging with a D meson to study D-jet correlations
  - Understand similar kinematic distributions as shown from today in Breit frame
  - Study different jet clustering cases, e.g. not 100% PID (track jets only?)
  - Would like to make some statistical projections for various beam energies
  - Framework in place to provide resolution estimates for jets, etc, to provide to DWGs and quickly implement their suggestions for detector resolutions

Back Up

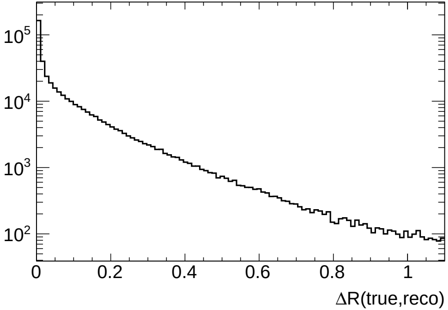
Jet Reconstruction ϕ and η Kinematics

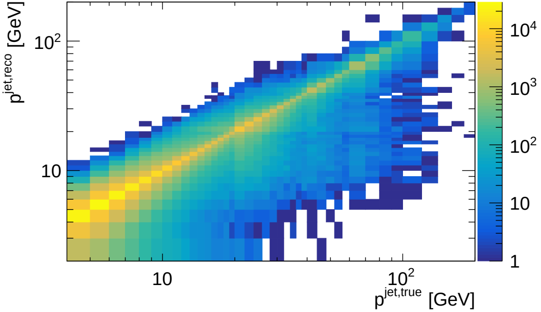




- Jet ϕ and η well reconstructed across default detector range

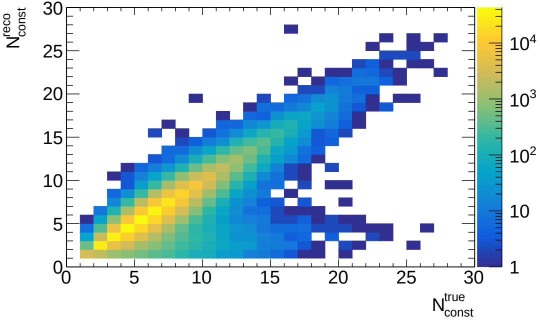
Jet Reconstruction Kinematics

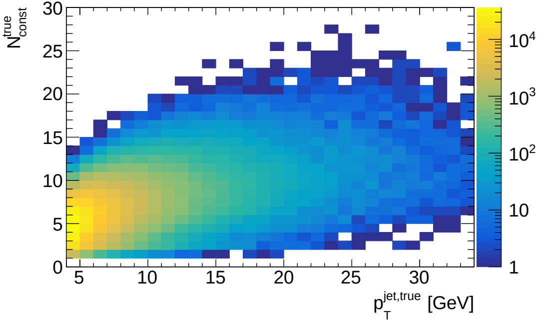




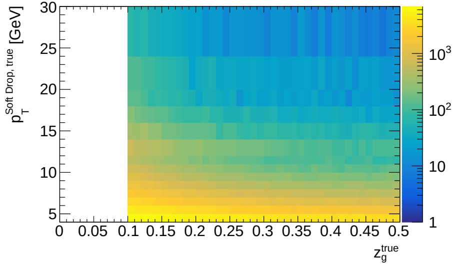
- Majority of truth jets have a reconstructed jet match within $\Delta R < 0.2$
- Jet momentum well reconstructed in general - perhaps also useful in conjunction with jet p_T for forward jets

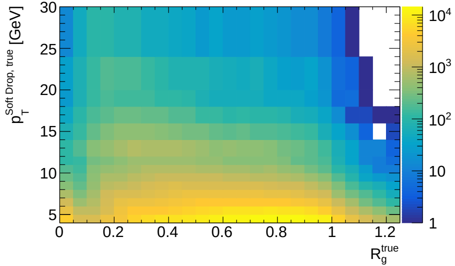
Jet Number of Constituents

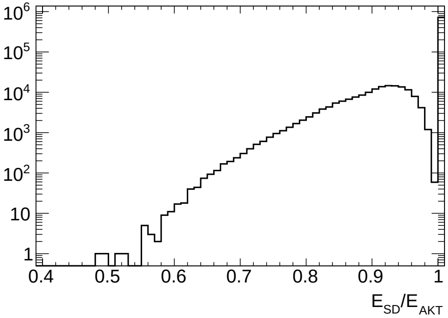




Soft Drop Kinematics

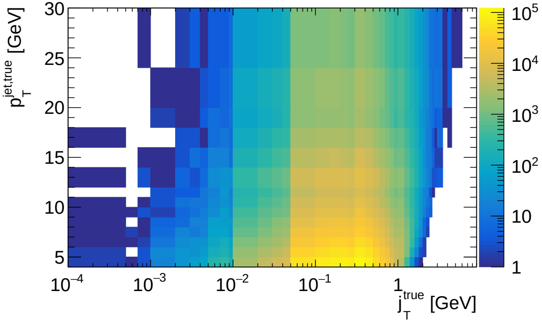


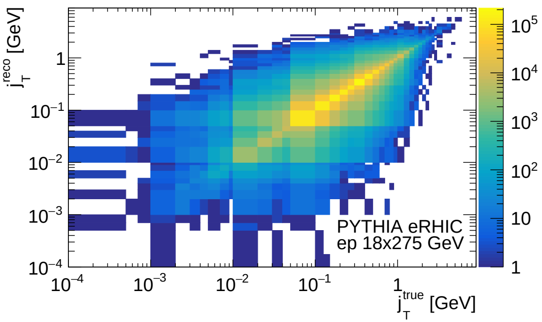




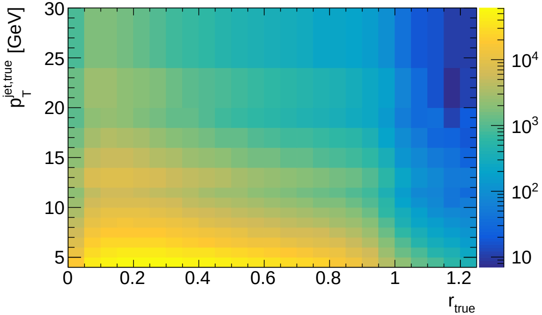
- Majority of jets already pass default grooming criteria of $z_{cut} = 0.1$ and $\beta = 0$

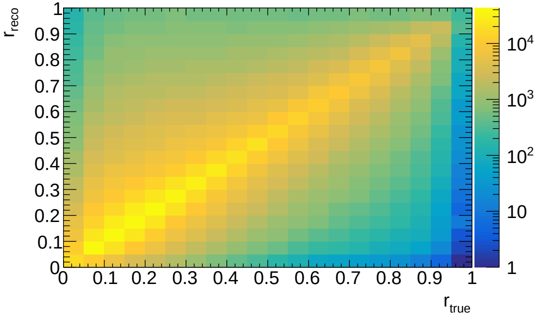
j_T Kinematics





r Kinematics





- r not reconstructed as well compared to other hadronization observables
- Expected to some degree, because it depends on y rather than η

z Kinematics