OAK RIDGE National Laboratory

Jet substructure at the EIC

Jets for 3D Imaging at the EIC Workshop

Joe Osborn, ORNL

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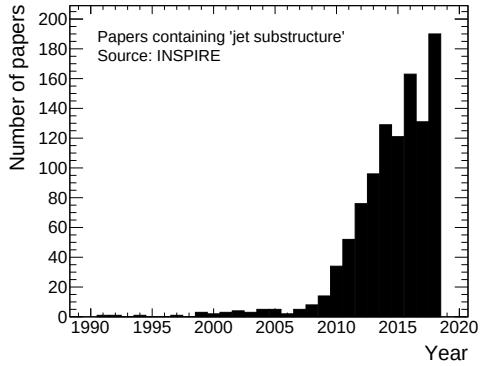
Jet Substructure

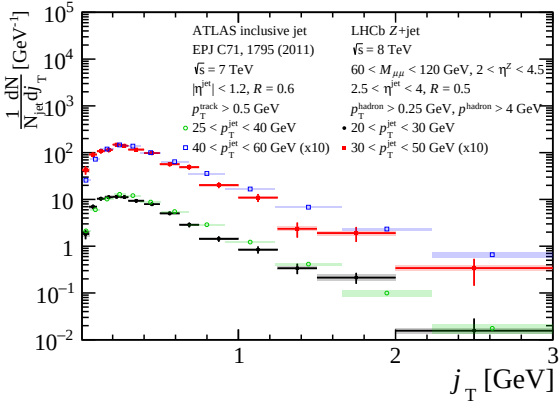
- Searching "find fulltext 'jet substructure' and tc p" on INSPIRE yields number of published papers
- Number of papers per year has exploded in last decade
- Papers discuss wide range of physics interests
  - Searches for new particles
  - Heavy flavor jet tagging
  - BSM searches (e.g. dark matter)
  - Heavy ion collisions
  - Machine learning
  - QCD color connections
  - ...



Jet Substructure in QCD

- Within the QCD community, jet substructure has been used to explore

Jet Substructure in QCD



Phys. Rev. Lett. 123, 232001 (2019)

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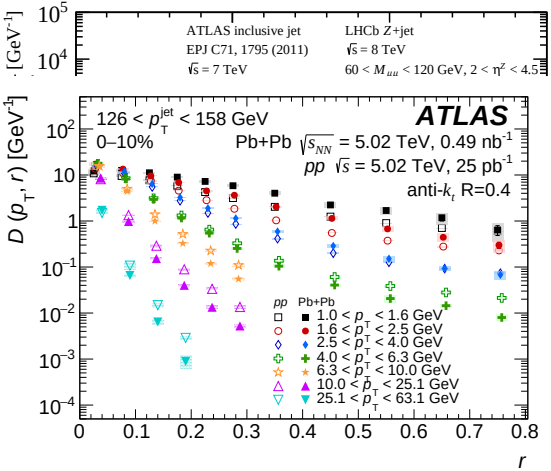
  - Hadronization

Jet Substructure in QCD



Phys. Rev. C 100, 064901 (2019)

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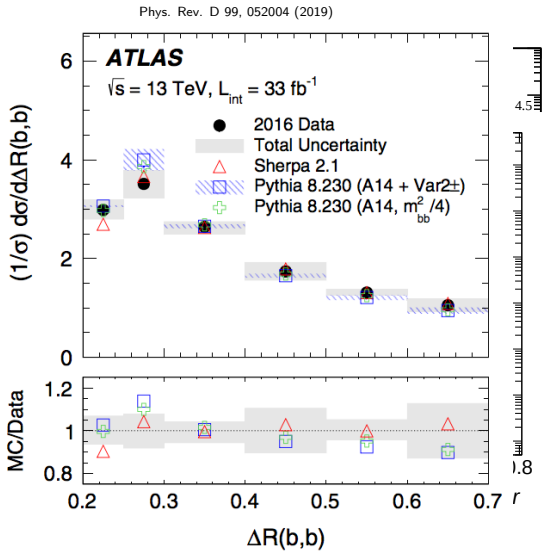

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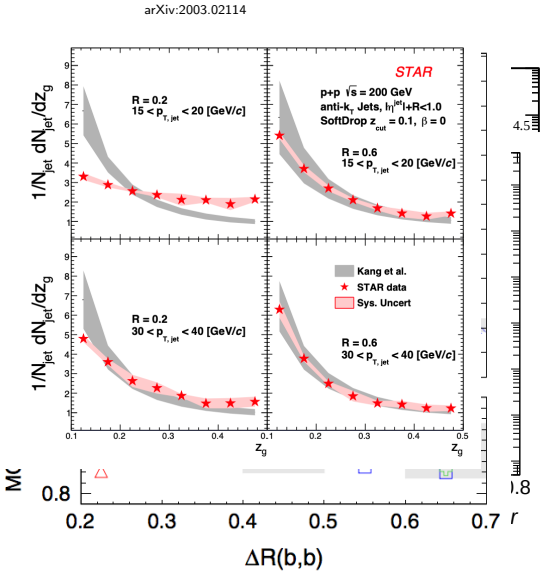

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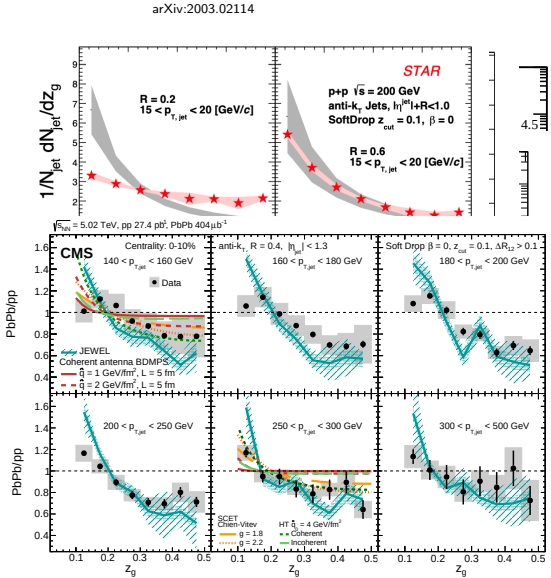
Jet Substructure in QCD

arXiv:2003.02114



Phys. Rev. Lett. 120, 142302 (2018)

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  - Energy loss in medium

Jet Substructure in QCD

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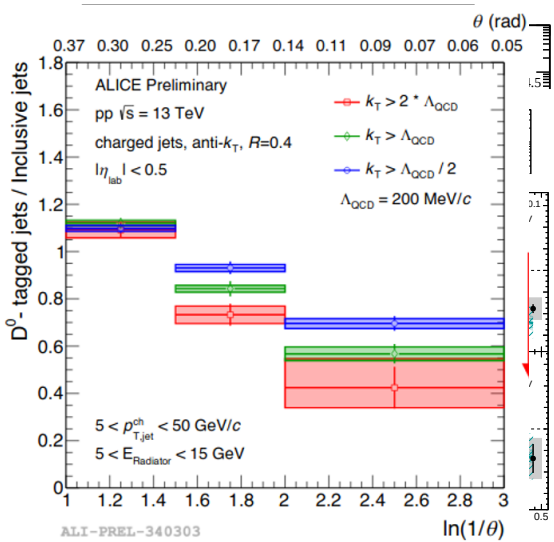
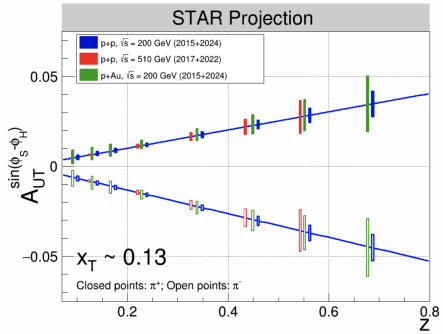


Phys. Rev. Lett. 120, 142302 (2018)

- Within the QCD community, jet substructure has been used to explore
  - Hadronization
  - Fragmentation
  - Energy loss in medium
  - Fundamental predictions of QCD as a gauge theory
  - . . .

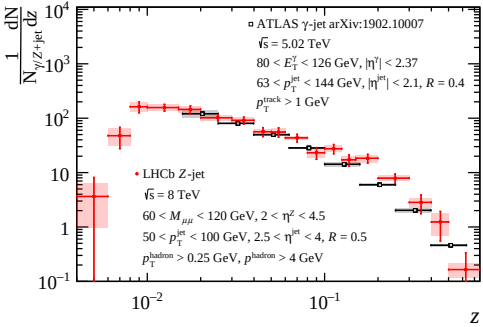
Jet Substructure in the 2020's

RHIC



See M. Zurek talk

LHC



See C. Aidala talk

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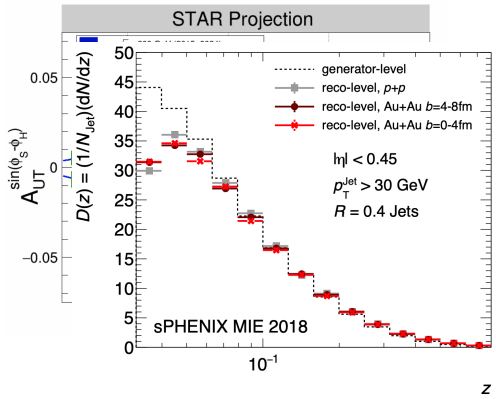

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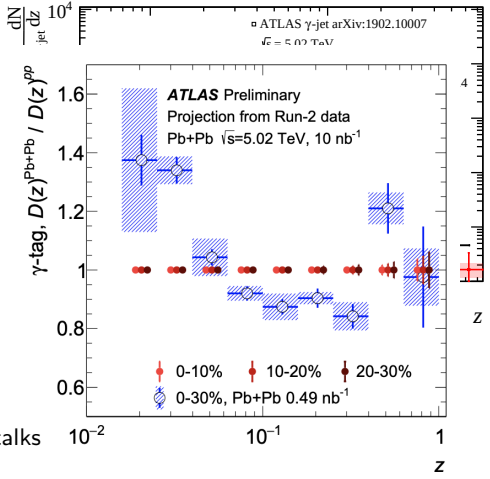
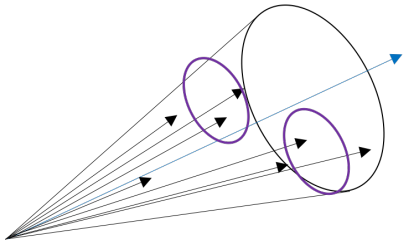


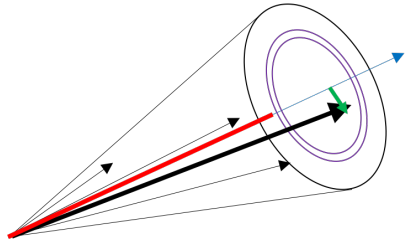
See D. Perepelitsa, A Shabetai talks

Jet Substructure Physics at EIC

Fragmentation



Hadronization



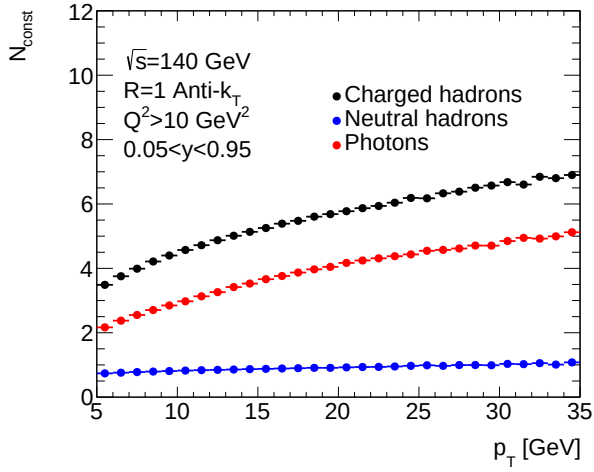
- Jet substructure will be able to access a wide variety of physics at the EIC, notably
  - Fragmentation
  - Hadronization
  - Interplay between the two, inherently a dynamic process (!)
- Fundamental aspects of QCD!
  - How are hadrons formed from their constituents?

Jets at the EIC

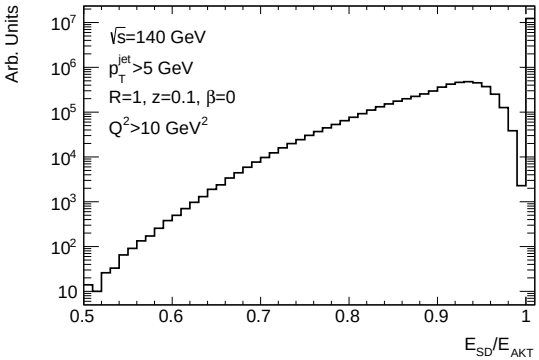
- Jets at the EIC will look very different than at current hadron colliders
- Not only are the interactions/multiplicities etc. different, but the detectors will look very different!
  - Full EM+H calorimetry
  - PID (!)
  - Large areas of pseudorapidity covered - "4π" detector
- How do these considerations affect jet substructure studies?

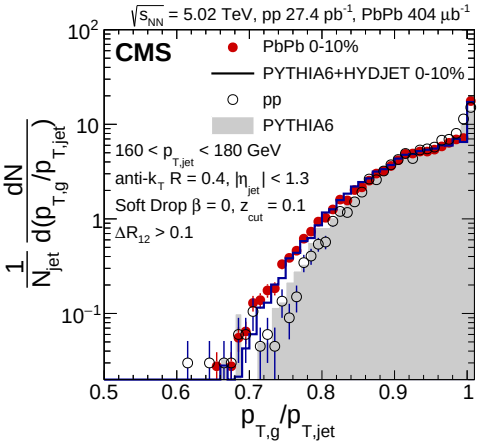
Jet Multiplicities

- Jets will inherently have lower multiplicities
  - Lower $\sqrt{s}$, electron beam, ...
- Places importance on high reconstruction efficiency
- Plot shows for R=1 anti-k_T jets (!)



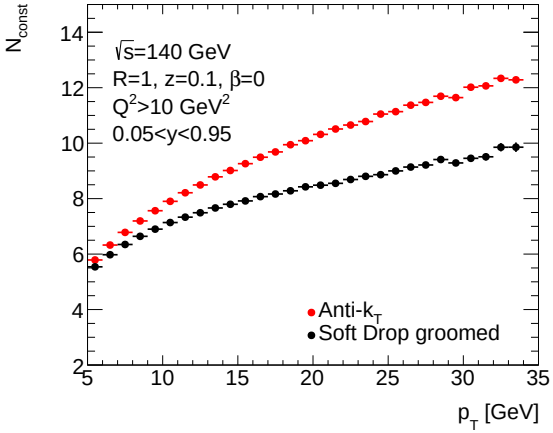
Jet Grooming Comparison





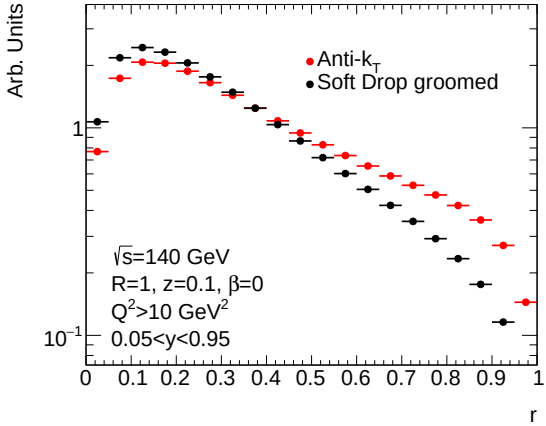
- Groomed jets at the EIC are much rarer than corresponding jets at (e.g.) the LHC
- Jets are frequently groomed at LHC, while jets at EIC are more likely to already satisfy grooming criteria

Groomed Multiplicities



- Groomed jets average 0-2 constituents removed

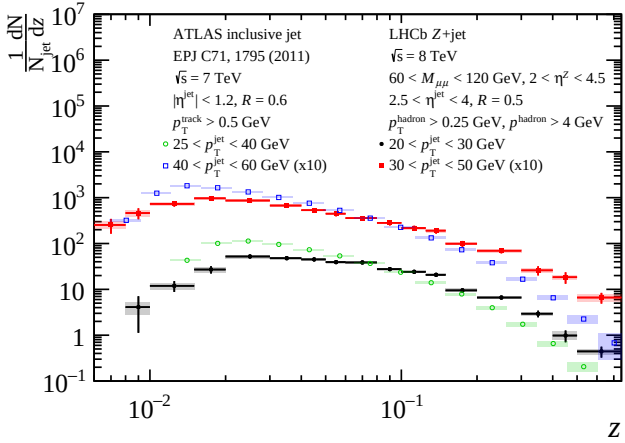
Groomed Multiplicities



- Groomed jets average 0-2 constituents removed
- What can we learn from constituents that are groomed away?
  - Target+current interactions?
  - Soft contributions to jets/FFs?

Breit Frame For Studying Hadronization

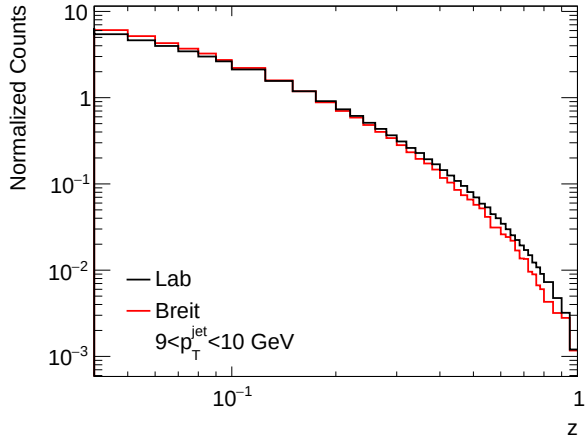
- LHCb and ATLAS see that quark jets are (on average) more collimated than gluon jets



Phys. Rev. Lett. 123. 232001 (2019)

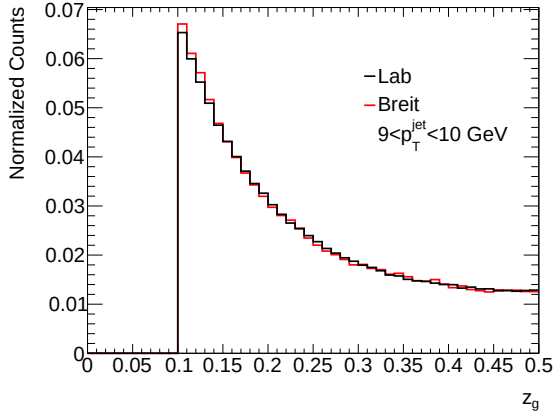
Breit Frame For Studying Hadronization

- LHCb and ATLAS see that quark jets are (on average) more collimated than gluon jets
- Can use Breit and lab frames to switch quark/gluon fractions



Subjet Differences

- Can perform similar exercise for soft drop observables
- z_g only shows (small) differences at small z_g



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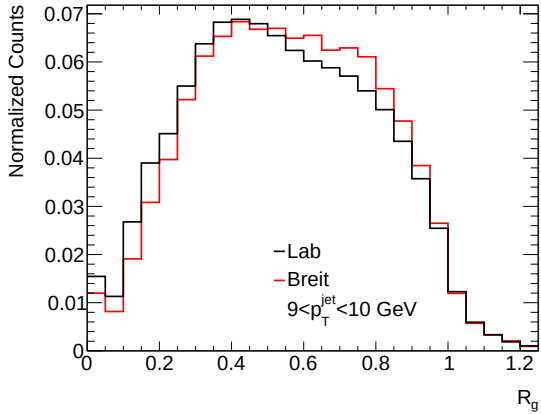
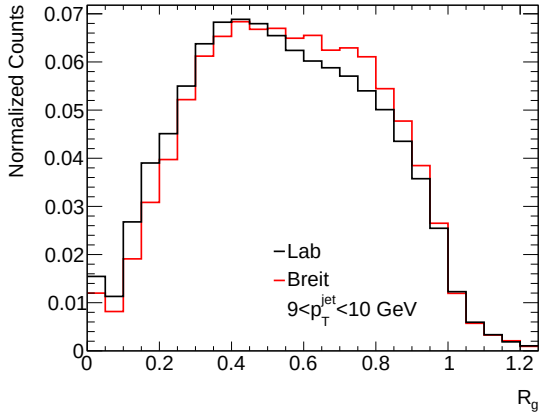
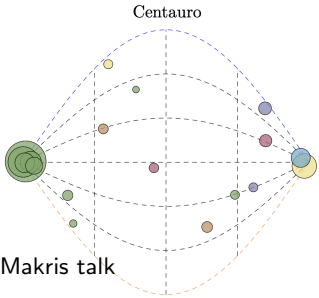


Subjet Differences

- Can perform similar exercise for soft drop observables
- z_g only shows (small) differences at small z_g
- R_g seems to show more significant differences between the two frames
- Can we infer or better understand (average) properties of fragmentation? e.g. p_T splittings of quarks and gluons vs. geometric distance

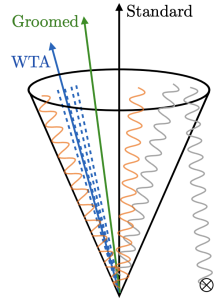


Jet Definitions at EIC?



See Y. Makris talk

2006.10751



See L. Zheng, W. Waalewijn talks

JHEP 04 (2020) 211

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- Should the same be true for EIC? What about jet axis?

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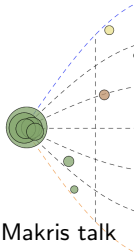

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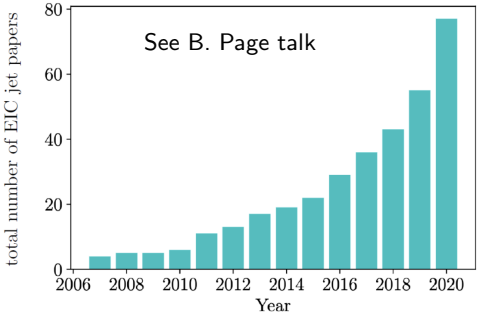

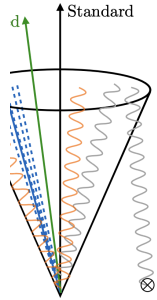

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JHEP 04 (2020) 211

- At hadron colliders, anti-k$_T$ algorithm is the standard for a variety of reasons
- Should the same be true for EIC? What about jet axis?
- A lot of recent theory work starting to address these questions - experimentally we should start thinking about this
  - e.g. Centauro algorithm, other spherically invariant algorithms, etc.
  - e.g. standard jet axis, Winner-take-all axis, etc.

PID at EIC

- Throughout the Yellow Report process, there has been significant back and forth between PWG and DWG on requirements for an EIC detector
- To do the jet substructure physics we want to do, what matters and/or is lacking?

PID at EIC

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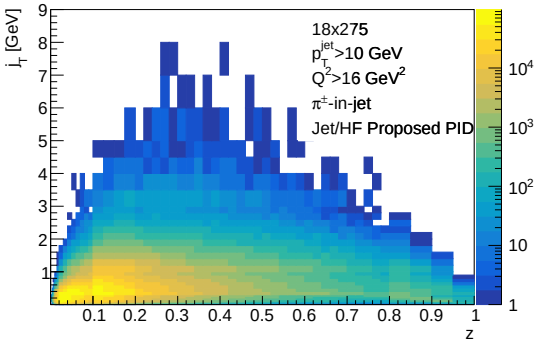
- To do the jet substructure physics we want to do, what matters and/or is lacking?
- PID currently has the strongest requirements
- What PID requirements are needed?

PID Detector Requirements



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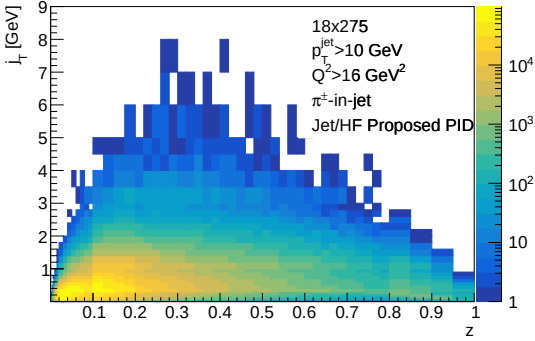
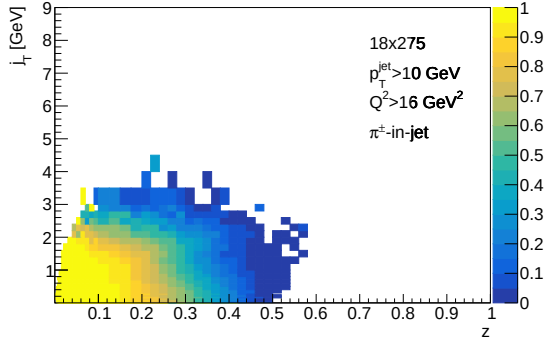
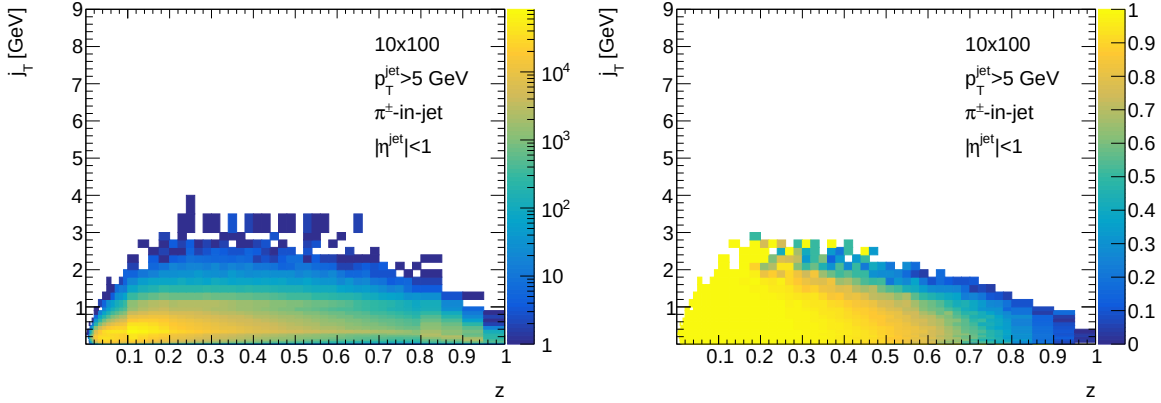




- The available PIDed (z, j_T) phase space that could be probed with Jet/HF PWG PID requirements
- The ratio of the PID detector matrix requirements to Jet/HF PWG PID requirements

PID Detector Requirements



- Lowering the p_T^{jet} requirement to 5 GeV trivially allows some phase space back in
- However, this recovery is limited to $Q^2 < 100$ GeV^2, as one might expect (see backup)
- For jet substructure at large p_T^{jet}, PID capabilities need to reach to higher p

Conclusions

- Jet substructure is a rapidly growing field in QCD research
- Jets will look very different at the EIC than at hadron colliders
  - Use as an opportunity for comparing and contrasting different "strengths" of $e + p$ vs. $p + p$

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- Jets will look very different at the EIC than at hadron colliders
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- Jet substructure will allow for robust studies of hadronization and fragmentation
  - Can we use jet substructure to learn about both the fragmenting parton as well as the soft interactions that occur in the hadronization process?

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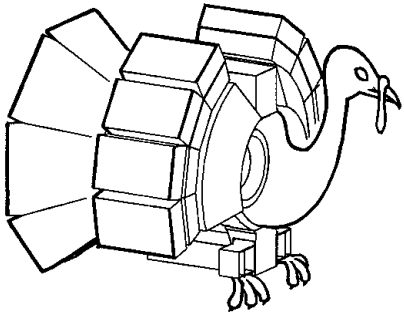
  - Use as an opportunity for comparing and contrasting different "strengths" of $e + p$ vs. $p + p$
- Jet substructure will allow for robust studies of hadronization and fragmentation
  - Can we use jet substructure to learn about both the fragmenting parton as well as the soft interactions that occur in the hadronization process?
- PID will be crucial! To study how hadrons are formed, we should know what hadron we are studying!
  - We need to do our best to determine what detector technologies are possible so that we know what we will (or won't) lose in terms of physics reach

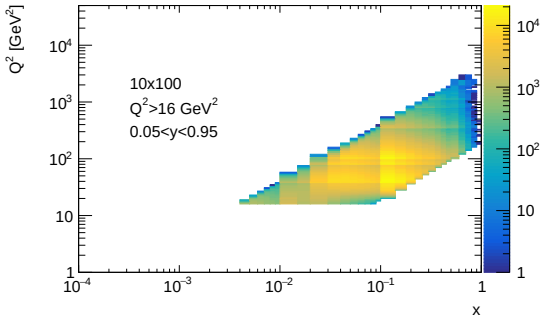
Have a safe and fun Thanksgiving (if you celebrate it)!

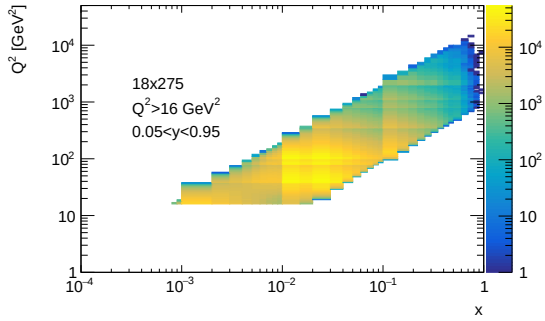


Early CAD drawings of the PHENIX experiment at RHIC!

Back Up

Event Kinematics

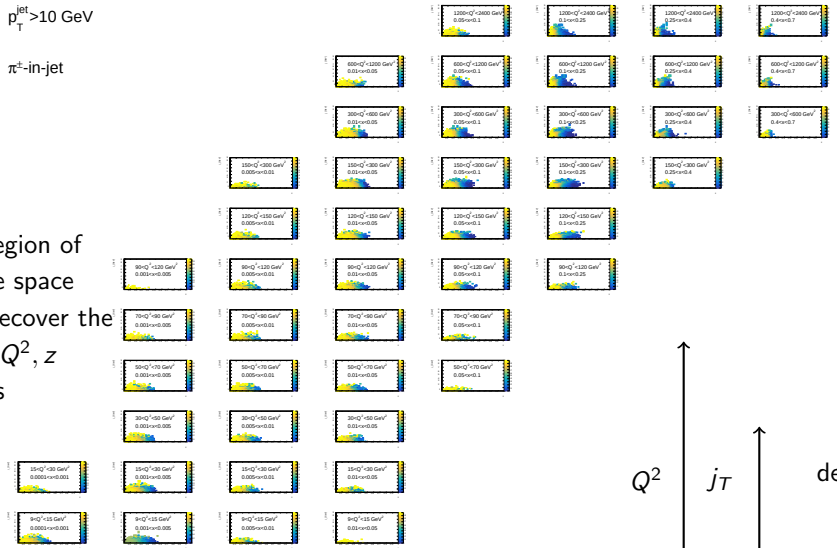




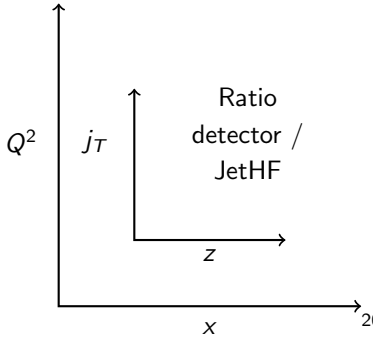
- Jets will access a large area of (x, Q^2) space at both highest energies

p_T^{jet}>10 GeV

$\pi^{\pm}$-in-jet



- No region of phase space can recover the high Q^2, z losses

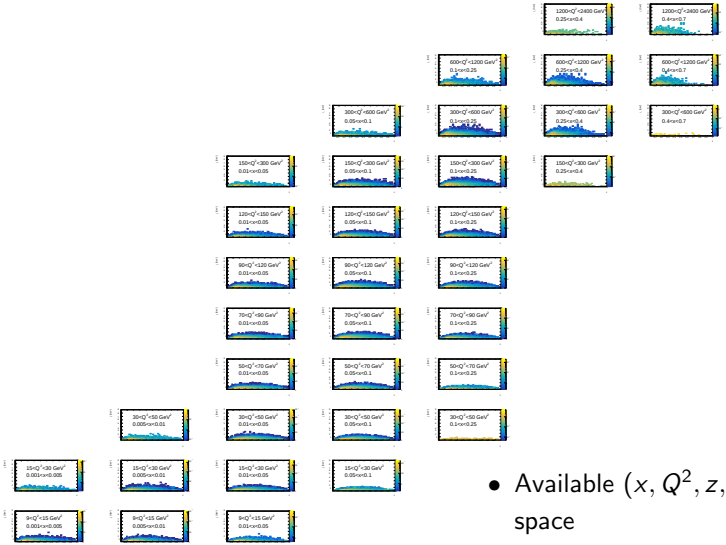


10x100

p_T^{jet}>5 GeV

π^+-in-jet

$|\eta^{jet}|$<1



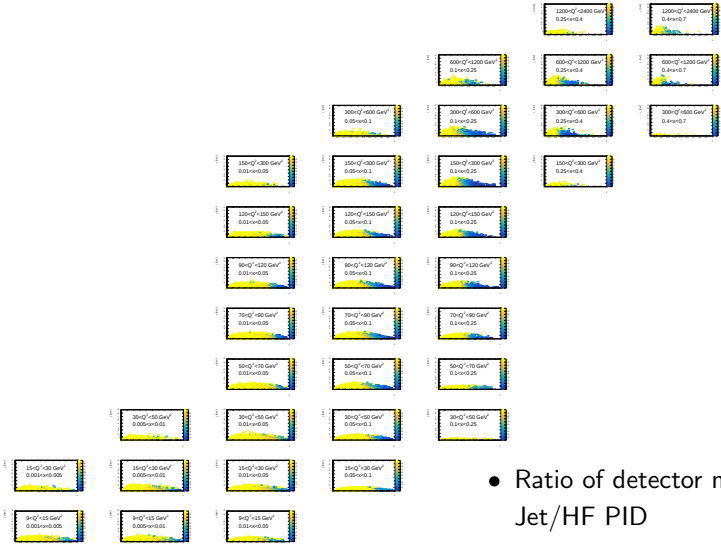
- Available (x, Q^2, z, j_T) phase space

10x100

p_T^{jet}>5 GeV

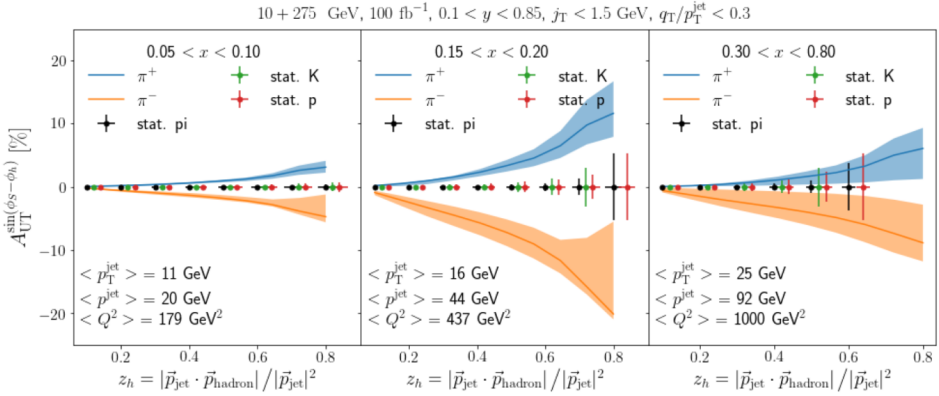
π^+-in-jet

$|\eta^{jet}|$<1



- Ratio of detector matrix to Jet/HF PID

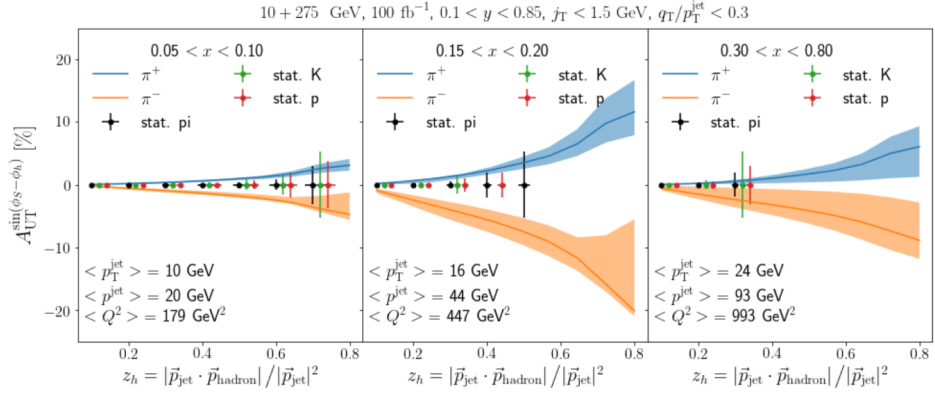
PID Detector Requirements



- Jet/HF proposed detector PID requirements

M. Arratia, '20 YR

PID Detector Requirements



- Current default detector PID requirements
- Substantial loss of PIDed statistics at high z and Q^2

M. Arratia, '20 YR