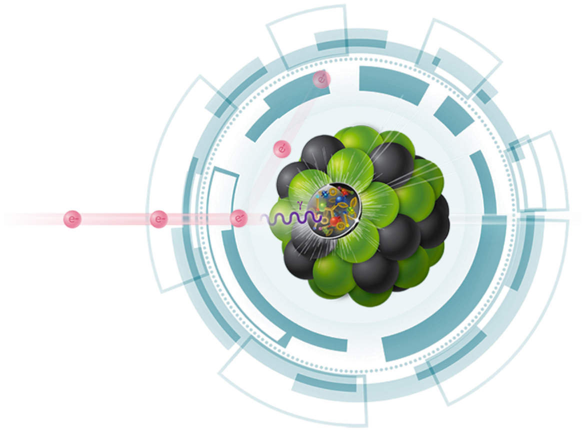


Jets and JETSCAPE for an EIC

Kolja Kauder

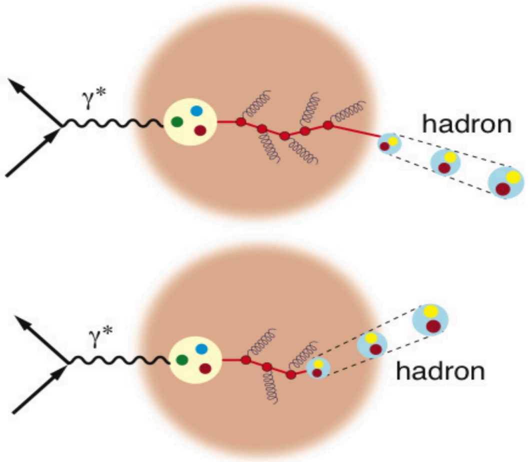
Joined June 2018

Supervisor: Thomas Ullrich

LDRD Goals

- Identify novel jet studies particularly suited to eP, eA
- Theoretically robust observables
- Feasibility studies for EIC measurements

- Develop a state-of-the-art Monte-Carlo (MC) Event Generator for in-medium jet fragmentation



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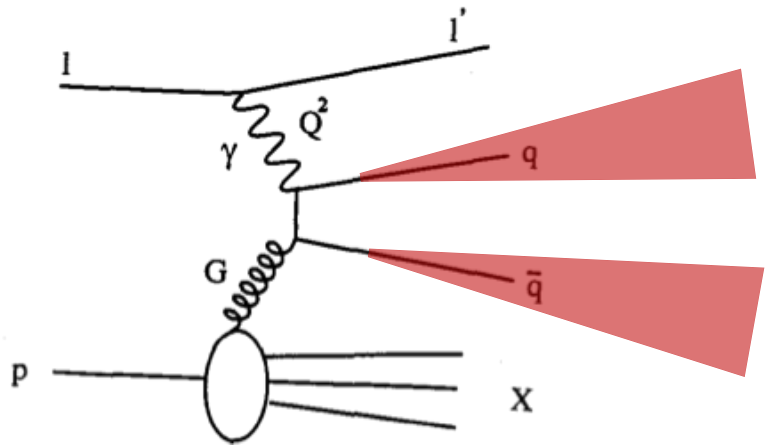
Jets as Parton Proxy

- E.g., cross sections, dijet invariant mass, asymmetries

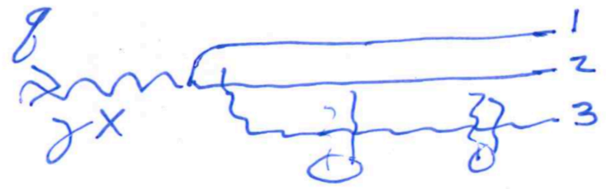


- Focus is on jet ~ parton
- What belongs to the jet?
- How many jets are in the event?

Novel: **Winner-Take-All** and/or **Groomed** axes: Potential for probing soft wide-angle radiation and for substantial background reduction in existing measurements

Started work with B. Page, F. Ringer
see arXiv 1911.06840
see recent talks from Ignazio Scimemi

Novel: Dipole size from 3-jet events. Use **N-Jettiness** to disentangle soft, broad, overlapping jets?



Started work with B. Page, T. Ullrich
see talk by Al Mueller at EICUG Meeting 2019

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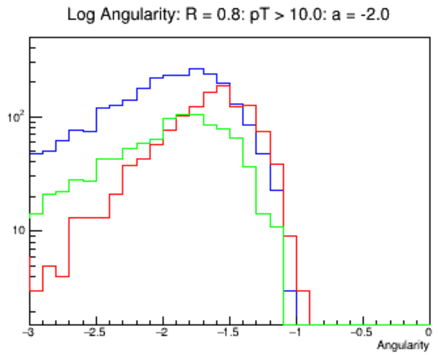
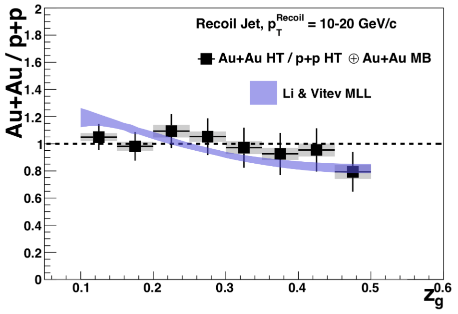
Jets beyond σ

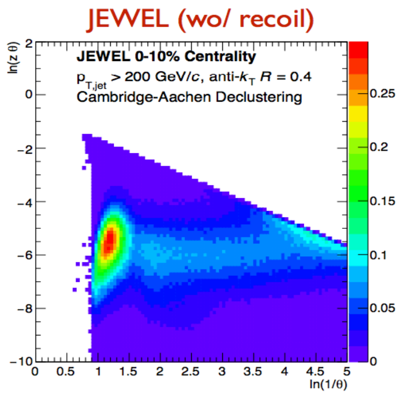


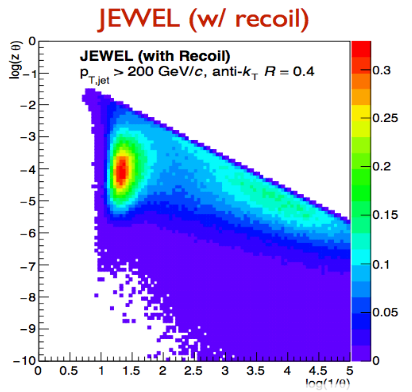
Angularity family

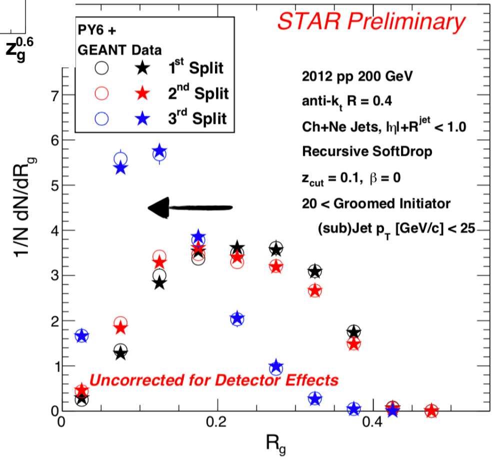
$$\tau_a \equiv \frac{1}{p_T} \sum_{i \in J} p_T^i \left(\Delta \mathcal{R}_{iJ}\right)^{2-a}$$

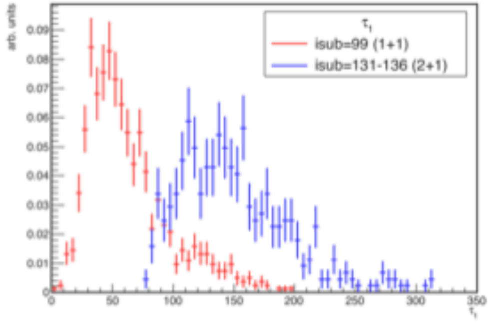
De-clustered (groomed) observables











N-(Sub)jettiness

- Fundamental QCD
- flavor separation
- Explore signatures of jet sub-structure modification in eA

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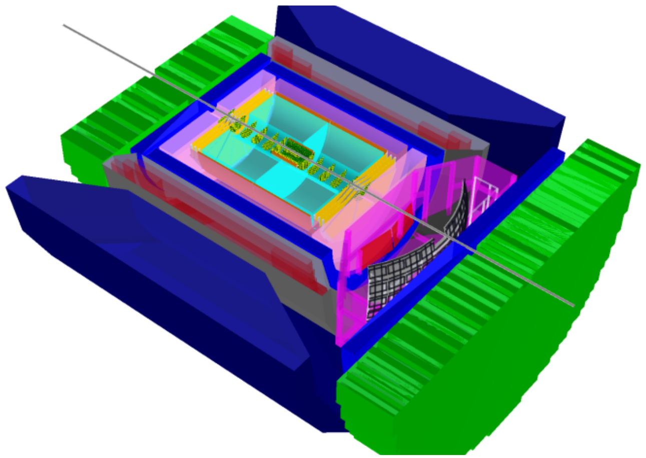
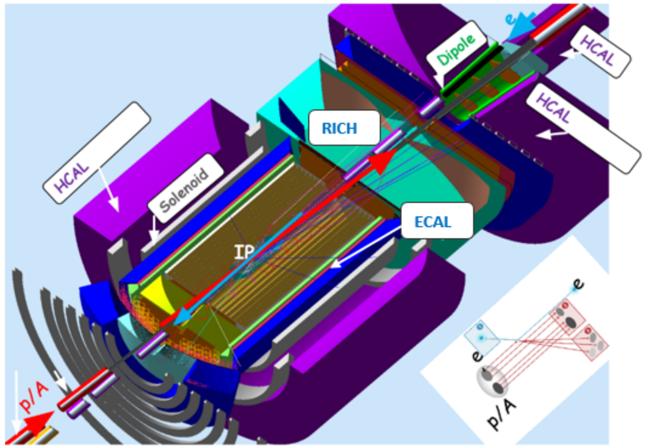
Expanding the Toolbox

Feasibility studies rely **crucially** on

- MC Generators, especially for e+A
- Detector simulations, fast and slow





General Purpose EIC MC's

Electron-Proton:

Herwig
Traditional focus on showers, Qtilde and Dipoles shower, cluster hadronization model, NLO matching and merging.

Pythia
Sophisticated soft physics, pt-ordered, DIRE and Vincia shower, string hadronization, NLO merging using event files.

Sherpa
Focus on perturbative improvements, CS and DIRE shower, cluster or string hadronization, NLO matching and merging.

- Tremendous development in recent years
- Thriving community beyond the Big Three

Slide from Simon Plätzer

Electron-Ion:

- BeAGLE.
- (Pythia+Angantyr?)

JETSCAPE is an ideal, orthogonal, candidate to double this number … especially toward modularity and jet physics

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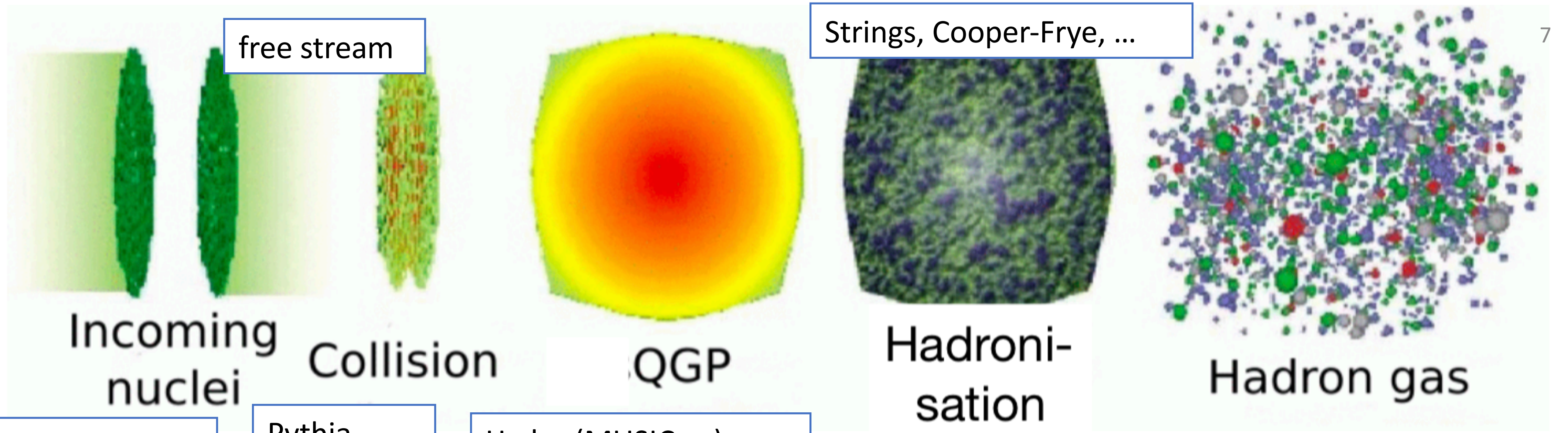


free stream

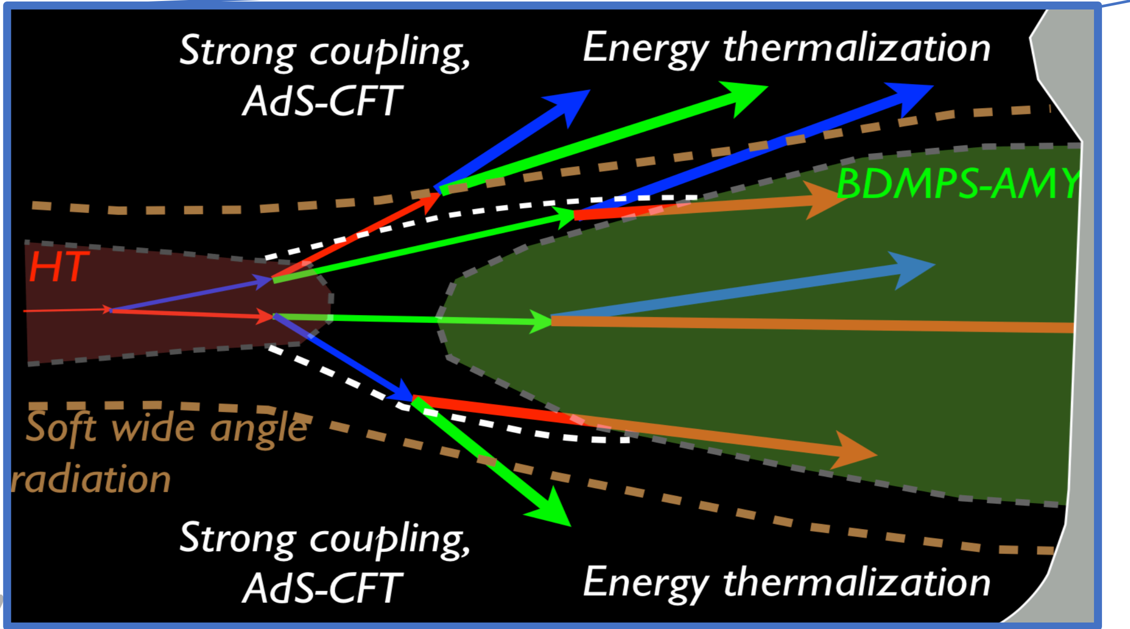
Strings, Cooper-Frye, …

Glauber, IPGlasma, …

Pythia, …

Hydro (MUSIC, …)
Energy loss, …

Rescattering, SMASH, …

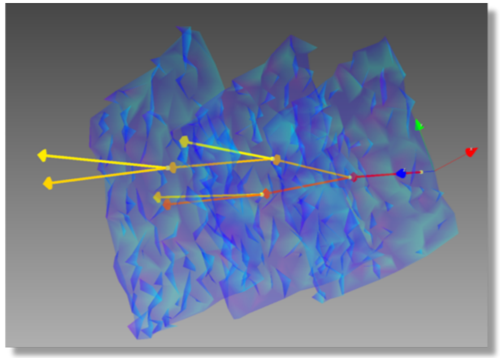


- Experts at every stage
- Multi-Stage Energy Loss
- … no one group can do it all

→ Unify in JETSCAPE

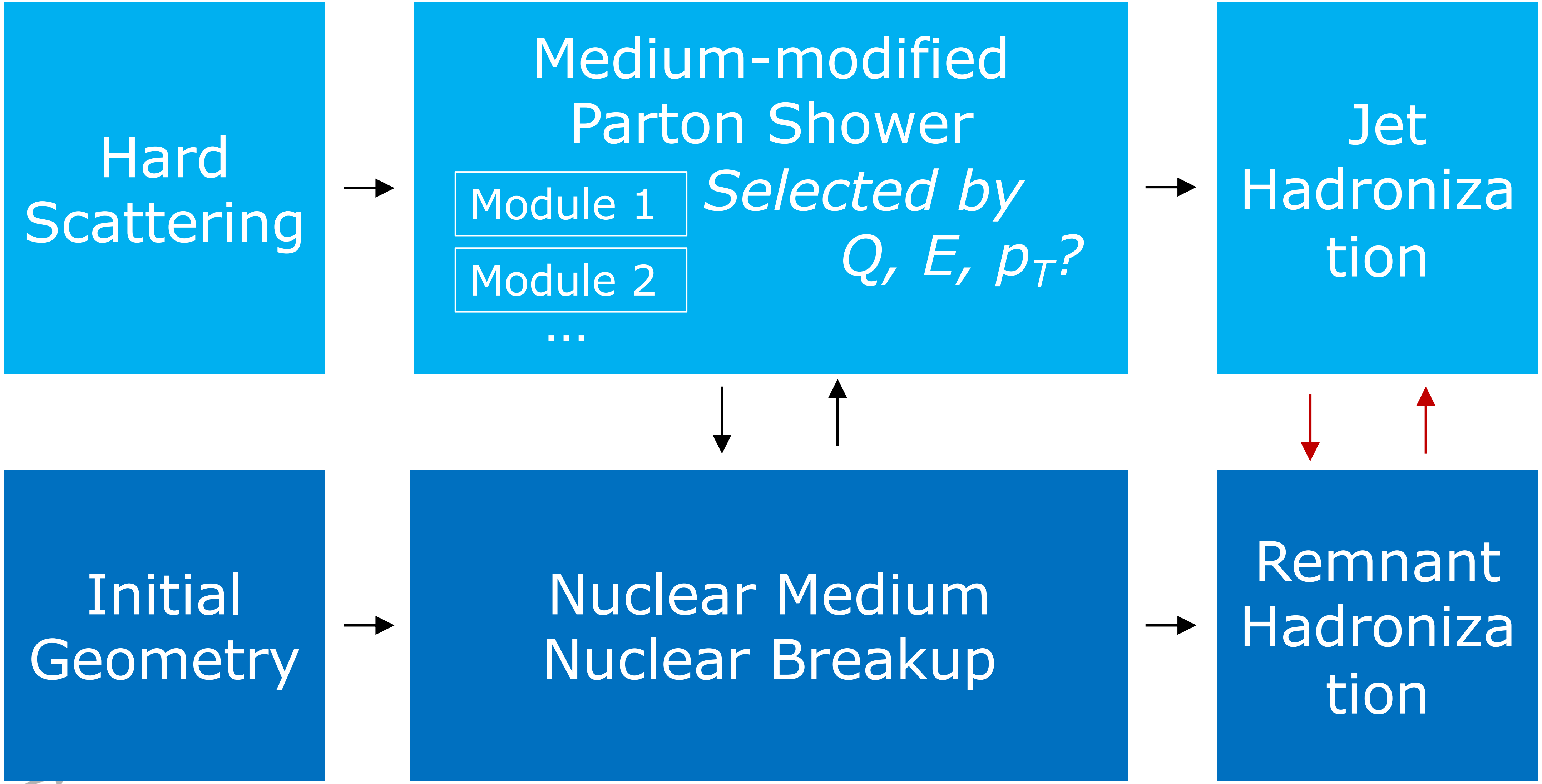
A. Majumder, Hard Probes '15

JETSCAPE Strengths



- Modular **Framework**
  - Focus on a single aspect
    – framework provides the rest
  - Easily extensible – testing a new model may require a single class and few lines of code
  - Modern technology: Tasks, Signals/Slots, C++11, Graphs…
- Large, versatile collaboration
  - Expertise in exp. and th. physics, computer science, statistical science, …
  - Substantial manpower and resources

JETSCAPE for EIC



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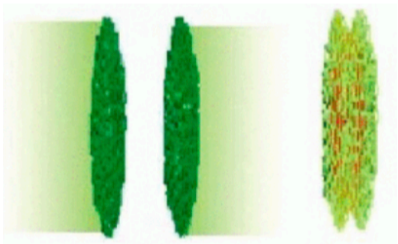
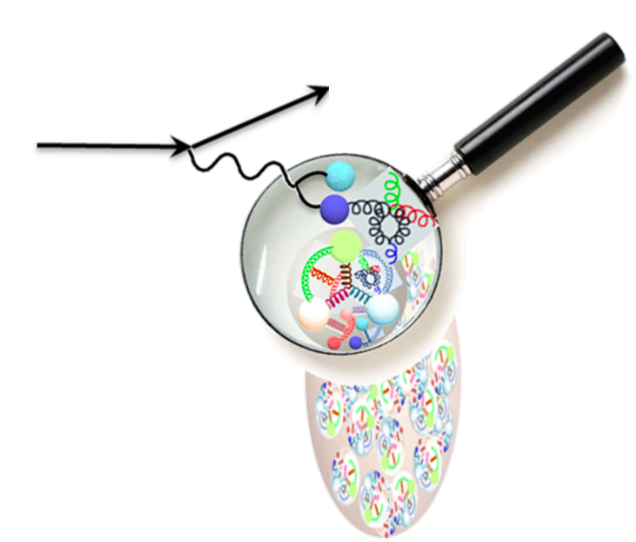


Hard Process

- Currently: hard scattering from tuned Pythia6
  - Can select PDF in generator
  - Full MB mix accepted
  - Radiative correction available
    (but currently cannot be parsed)



Future:

- Herwig, Sherpa, …
- Separate radiative correction module?

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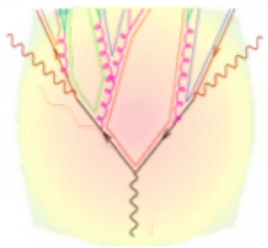
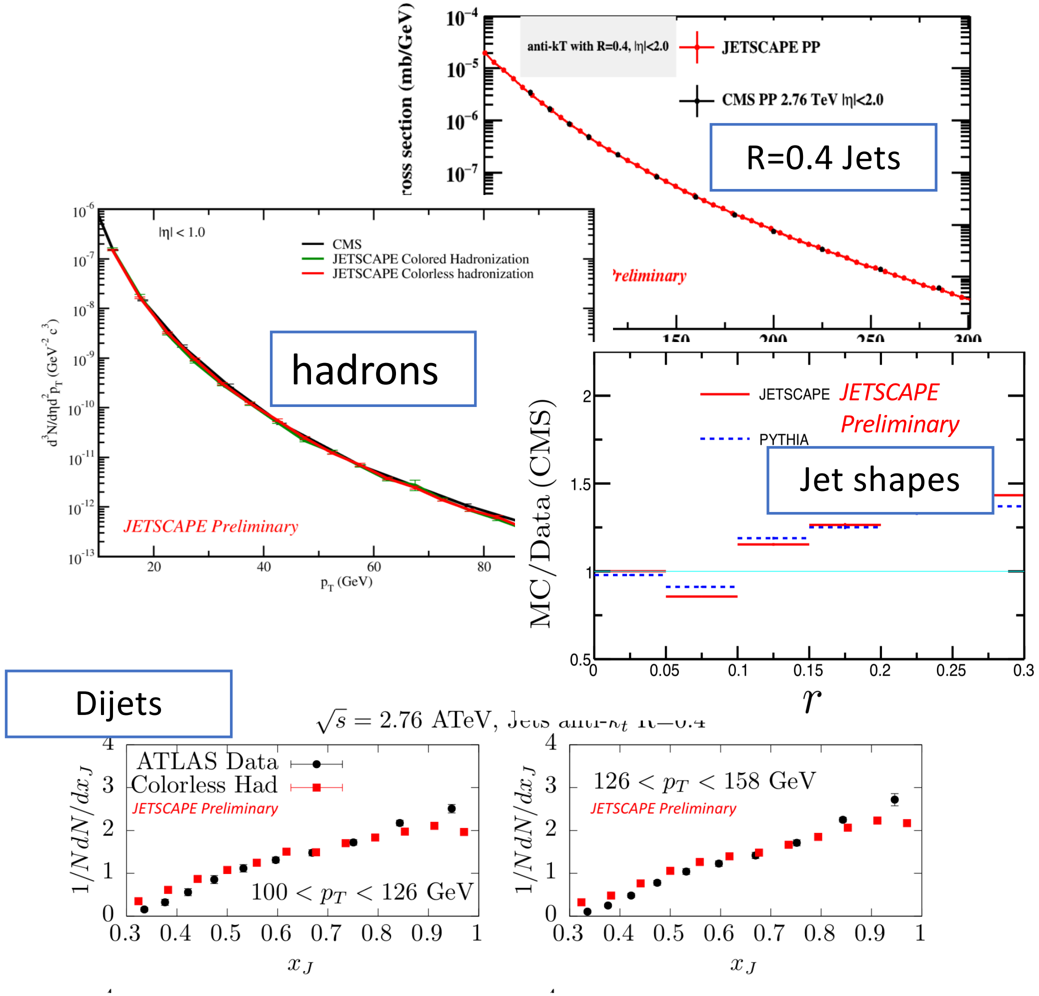
Vacuum Shower



- Vacuum fragmentation with MATTER and qhat = 0
  - Virtuality ordered
  - Individual showers are generated for all "hard" partons and underlying event hadrons
  - Virtuality regenerated before shower
- Tuned to mid-η at LHC energies, demonstrated excellent agreement



BROOKHAVEN NATIONAL LABORATORY

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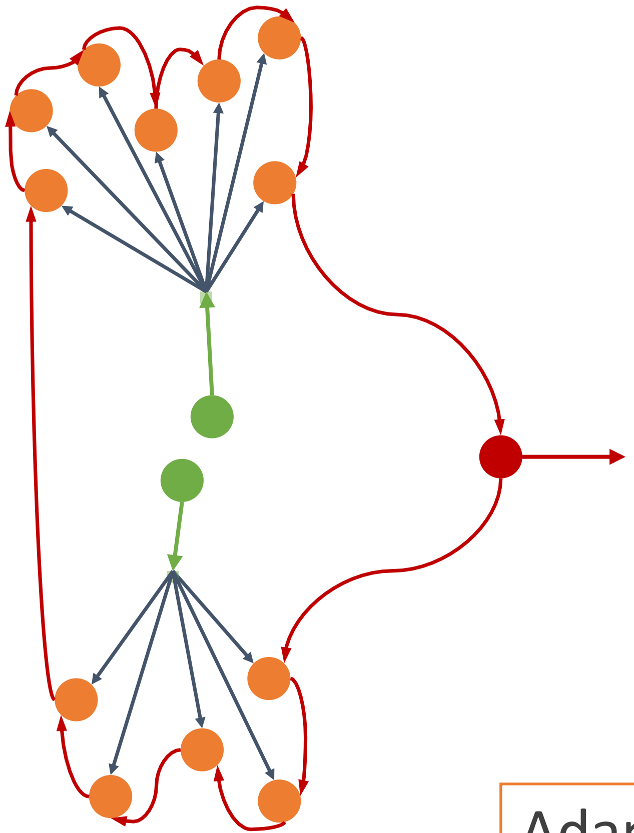
Hadronization Options



“Colorless”:

- ❖ All showers hadronize together
- ❖ Intended for situations where color information is not maintained in E-loss module
- ❖ One parton down the beam pipe closes the loop
- ❖ Then hand off to Pythia8

Adaptions:

- Use true remnant kinematics

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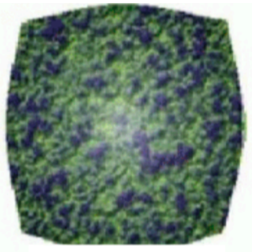
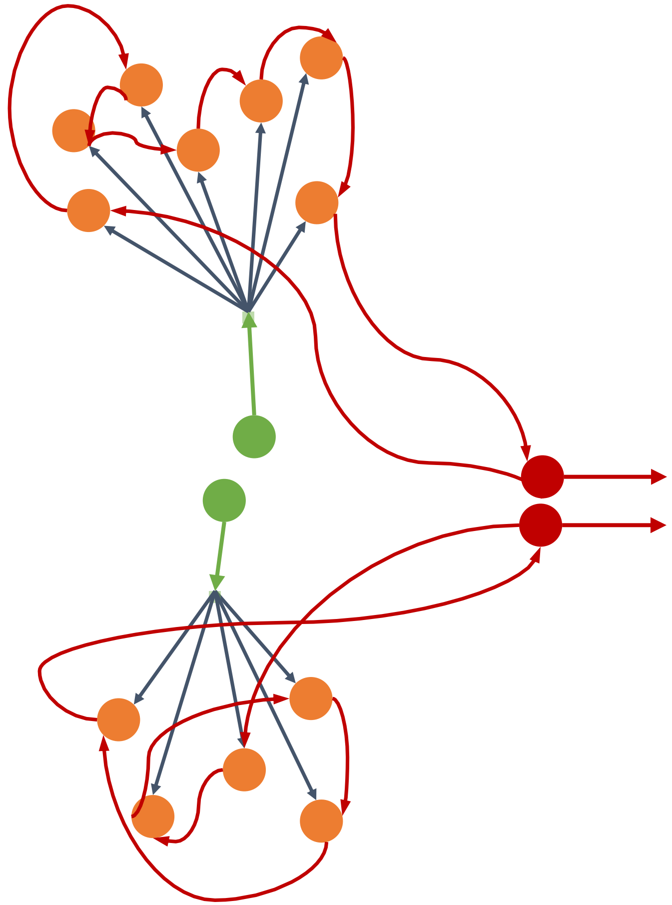
Hadronization Options





"Colored":

- ❖ Showers hadronize individually
- ❖ One beam parton closes each loop
- ❖ +/- η assigned interchangeably
- ❖ Then hand off to Pythia8

Adaptions:

- Use true remnant kinematics
- Re-distribute remnant momentum among showers

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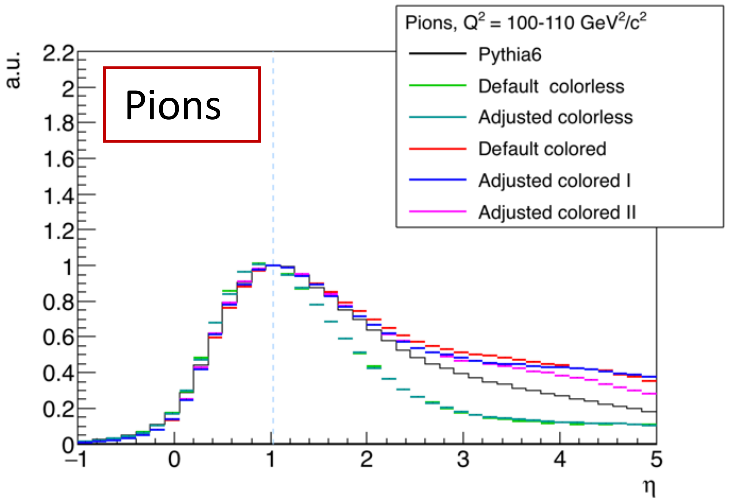
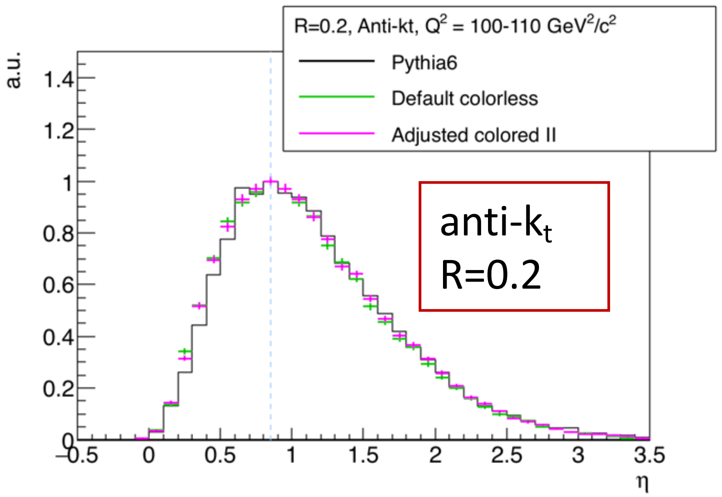
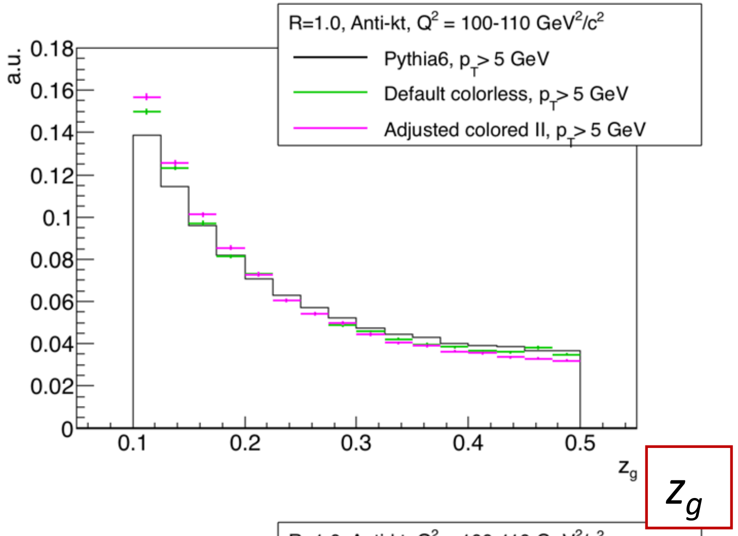
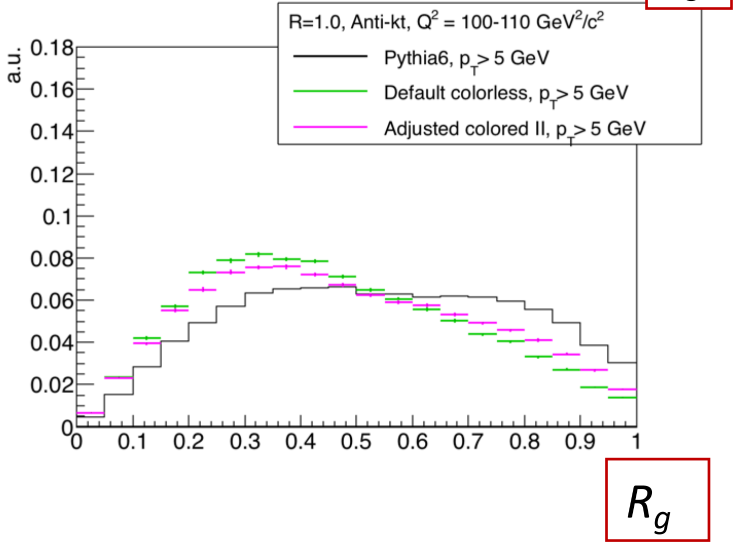
e+P Status









- Good performance for hadrons, jets, sub-structure
- Further improvements (beyond fine-tuning): Maintain color structure throughout event → out of my scope

PGF, Q^2 = 100–110 GeV^2
20 on 250 GeV e+P
Breit Frame

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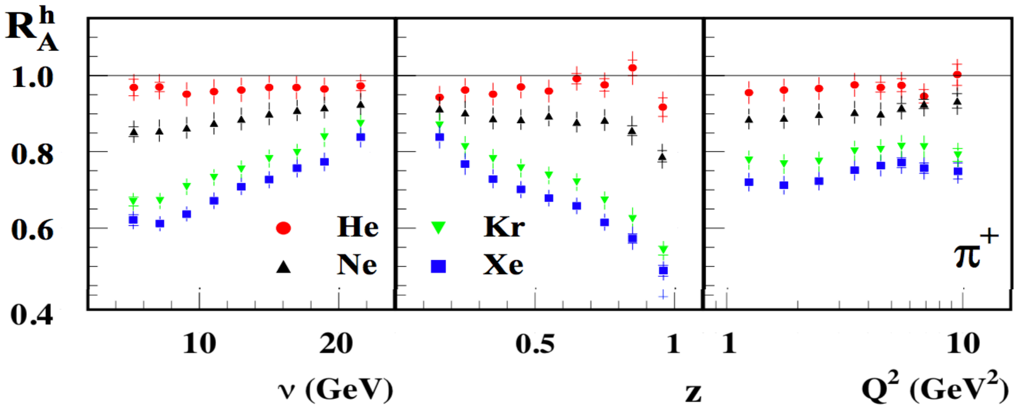
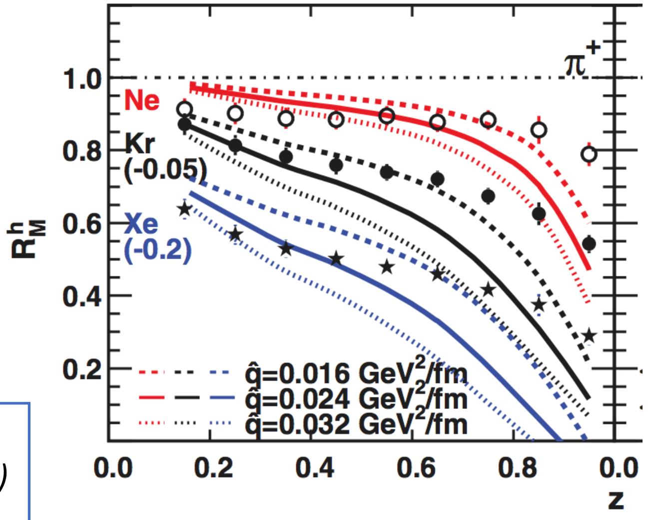
In a Medium



FXT, 27.6 GeV
e on X



HERMES, Nucl. Phys. B780: (2007)
Deng, Wang - PRC 81, 024902 (2010)
Majumder, Wang - arXiv:0806.2653

No e+A jet data exists – use FXT hadron suppression as proxy

HERMES data has been reasonably described using:

- DGLAP eqns effectively modified by multiple scattering (Higher Twist)
- Jet transport parameter **qhat ~0.024 GeV²/fm**
- Medium length from Woods-Saxon

Same physics as MATTER in a variable Brick - repeat!

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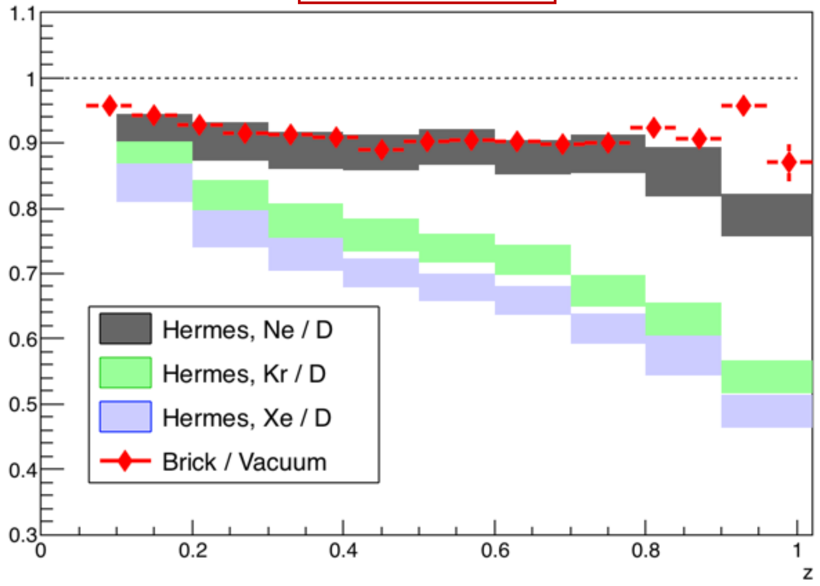
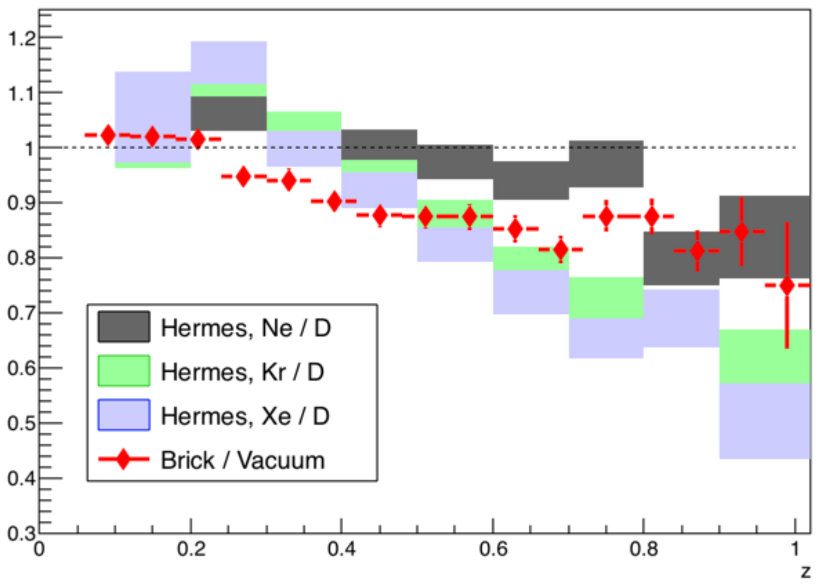
First Look

Pions (π^+)



Protons



- Brick / Vacuum, not Deuterium
- Pion suppression too small, protons promising
- Proof of concept! NOT even preliminary

qhat = 0.02 GeV^2 / fm
L = 5 fm
FXT, 27.6 GeV *e* on X

HERMES, Nucl. Phys. B780: (2007)

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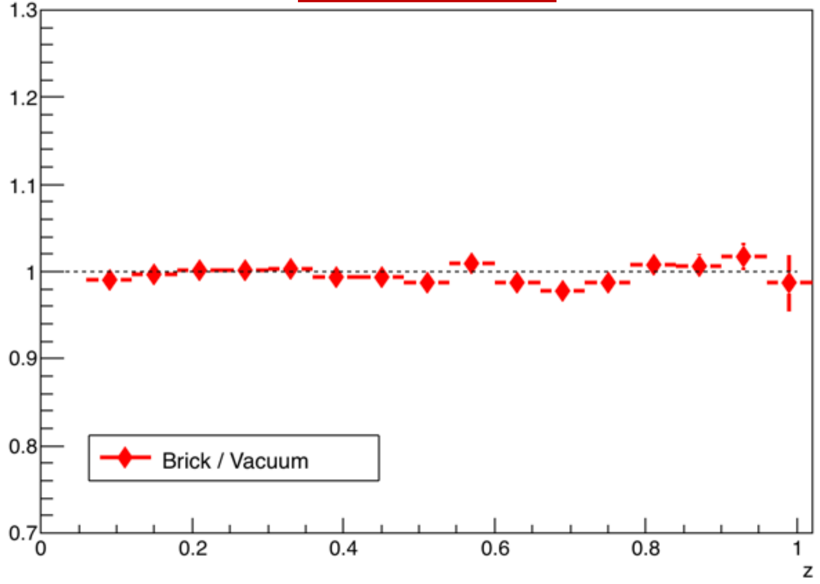
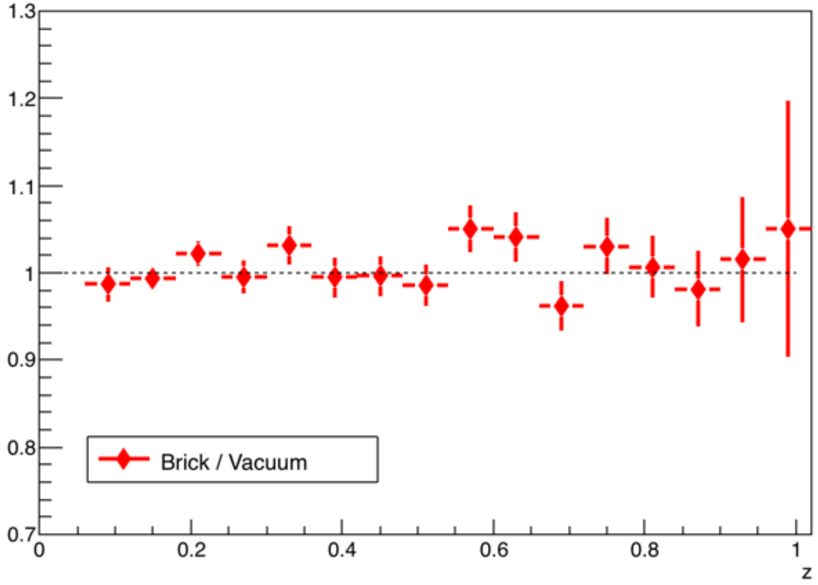
Sanity Check

Pions (π^+)



Protons



- Not shown: qhat, L dependence is too weak, double-check that
  Brick → Vacuum as qhat → 0

qhat = 2E-5 GeV² / fm
L = 5 fm
FXT, 27.6 GeV *e* on X

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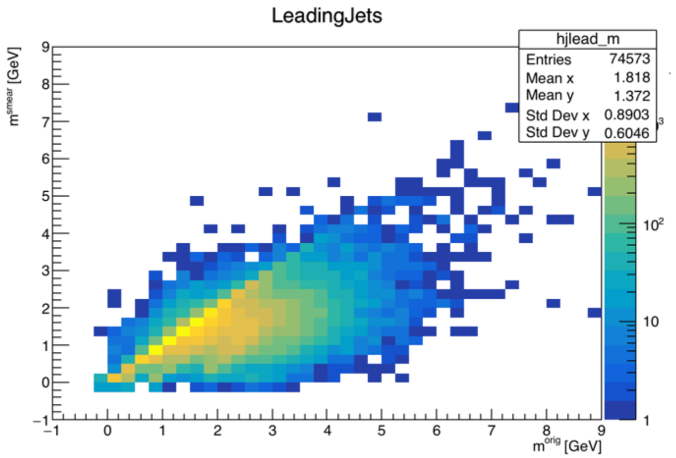
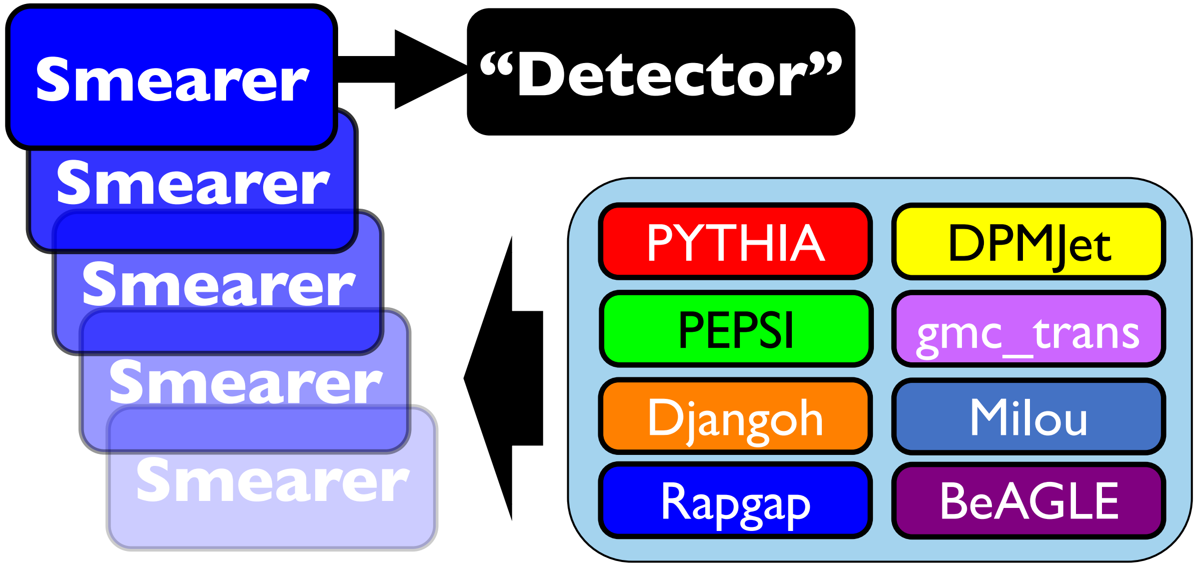
Detector Simulations



Assumed coordinator responsibilities for the BNL/EIC software stack

- Maintain fast simulation `EicSmear`
- Maintain MC Generators
- Contribute to Eic Software Community



Status and Outlook

- **Develop JETSCAPE as an ideal, complementary, candidate to double the current number of e+A GPMCs**
  - **e+P** (essentially) done
  - **e+A:** Reference quenching tuned to HERMES is **nearing completion**
  - Now include into official distribution, leverage collaboration, **use to explore quenching @ EIC!**
- Use new tools such as WTA, grooming to both improve existing measurements and gain new, sensitive observables

Activity 2019

Papers

- The JETSCAPE framework
  J. Putschke, KK, JETSCAPE Collaboration
  submitted to Comp. Phys. Comm., arXiv:1903.07706
- First fully unfolded measurements of jet splitting in p+p $\sqrt{s}$=200 GeV at STAR
  STAR Collaboration (co-PA)
  to be submitted to PLB
- Observation of charmed baryon-to-meson ratio enhancement at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
  STAR Collaboration (GPC)
  submitted to PRL (arXiv:1910.14628)
- Underlying Event Measurements in p+p Collisions at $\sqrt{s}$=200 GeV
  STAR Collaboration (GPC)
  to be submitted to PLB

Talks

- JETSCAPE for EIC
  MCEGs for future ep and eA facilities, Vienna, Austria
- Using JETSCAPE to Simulate Jets at an EIC
  POETIC, LBNL
- Using JETSCAPE to Simulate Jets at an EIC,
  DNP, Crystal City, VA
- Exploring Jet Observables at an EIC with the JETSCAPE framework
  EICUG Users' Meeting, Paris, France
- Eic-Smear and its parameterizations
  EICUG Users' Meeting, Paris, France
- Eic-Smear and its parameterizations
  EIC Software Meeting on Detector and Physics Simulations, BNL
- Eic-Smear and its parameterizations
  EIC Software Meeting, Trieste, Italy
- Using JETSCAPE to Simulate Jets at an EIC
  DIS, Turin, Italy
- Jets in eA Collisions
  MCEGs for future ep and eA facilities, Hamburg, Germany

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Backup

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NB: Jet Reconstruction

Sequential Clustering:

1. Calculate a **distance d_{ij}** between two particles and a **beam distance d_{iB}** for all particles.
2. Find **smallest** of all d_{ij}, d_{iB}
3. If it's a d_{ij}, **recombine** particles i and j. If it's a d_{iB}, call particle i a ***jet***
4. Repeat from step 2 until no particles are left

↑

De-facto standard. For substructure: also provides **cluster history**

Resulting clusters are **jets**.

- **Operational** definition. No unambiguous jet definition exists!

Advantages:

- Minimize sensitivity to hadronization: **IR-safe and collinear-safe** algorithm and instrumentation
- Measure energy flow: connect to dynamics of **partons**
- Comparison to **QCD** calculations beyond event generators