Jet Workshop Summary

Anthony Hodges

On Behalf of the Jet Workshop

RHIC/AGS Users' Meeting

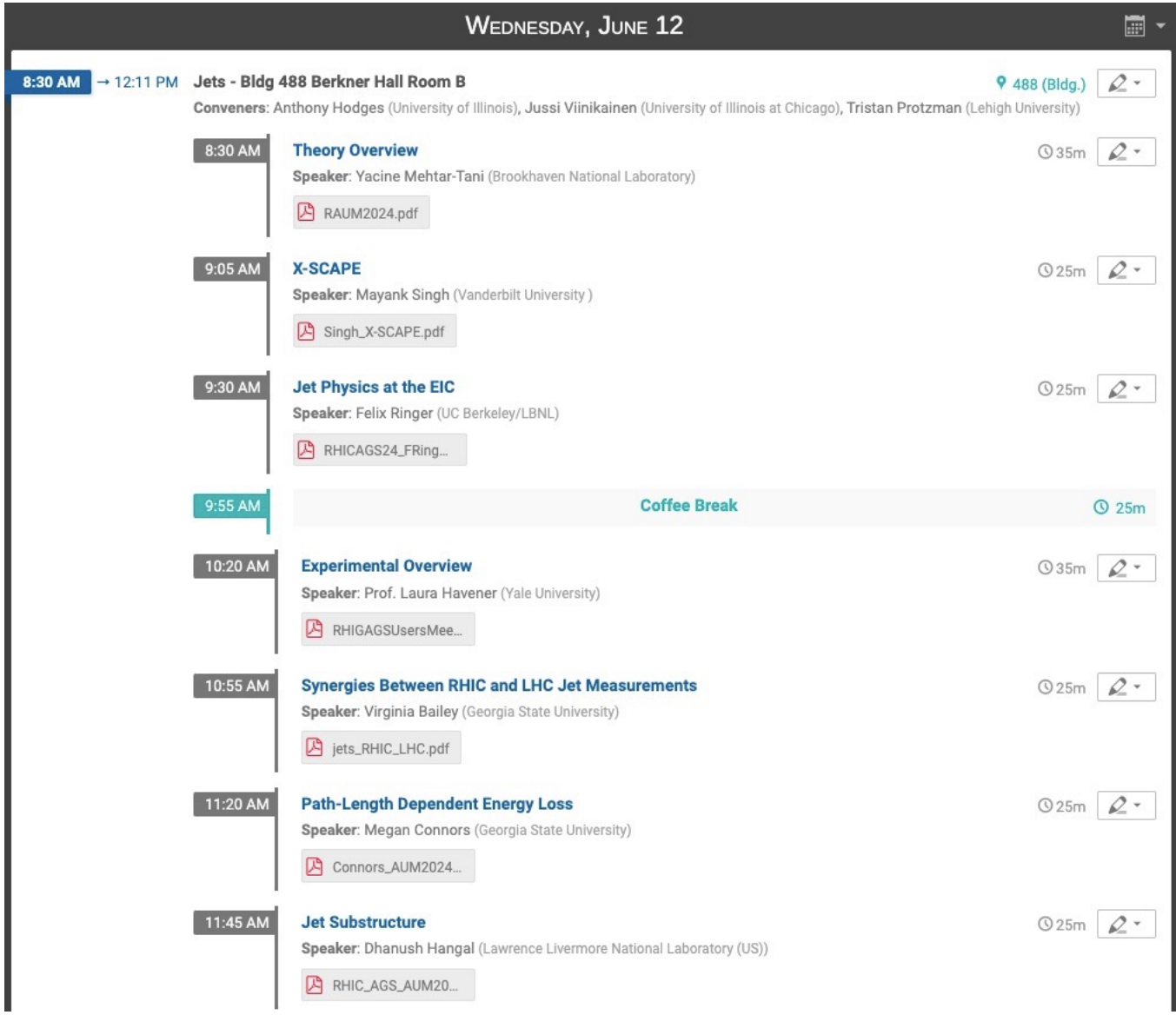
June 13th, 2024

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

NSF Ascend Fellow

The Workshop at a Glance

- Two overview talks from theory and experimental perspective
- Talks focused on variety of physics topics
- All centered, of course, on jets!



WEDNESDAY, JUNE 12

8:30 AM → 12:11 PM **Jets - Bldg 488 Berkner Hall Room B** 488 (Bldg.)

Conveners: Anthony Hodges (University of Illinois), **Jussi Viinikainen** (University of Illinois at Chicago), **Tristan Protzman** (Lehigh University)

8:30 AM **Theory Overview** 35m
Speaker: Yacine Mehtar-Tani (Brookhaven National Laboratory)
RAUM2024.pdf

9:05 AM **X-SCAPE** 25m
Speaker: Mayank Singh (Vanderbilt University)
Singh_X-SCAPE.pdf

9:30 AM **Jet Physics at the EIC** 25m
Speaker: Felix Ringer (UC Berkeley/LBNL)
RHICAGS24_FRing...

9:55 AM **Coffee Break** 25m

10:20 AM **Experimental Overview** 35m
Speaker: Prof. Laura Havener (Yale University)
RHIGAGSUsersMee...

10:55 AM **Synergies Between RHIC and LHC Jet Measurements** 25m
Speaker: Virginia Bailey (Georgia State University)
jets_RHIC_LHC.pdf

11:20 AM **Path-Length Dependent Energy Loss** 25m
Speaker: Megan Connors (Georgia State University)
Connors_AUM2024...

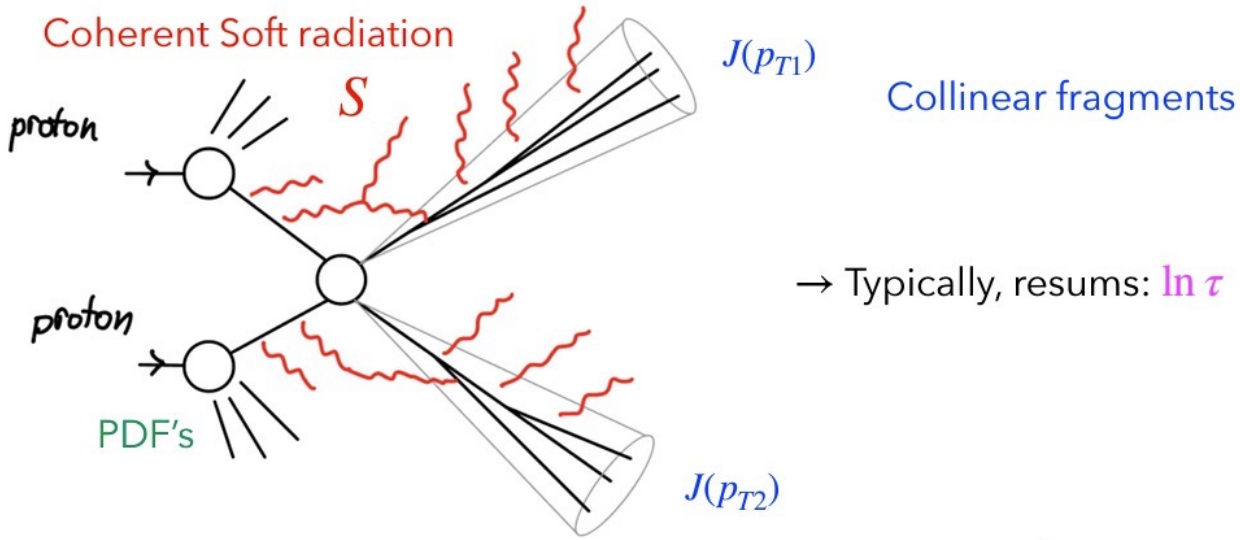
11:45 AM **Jet Substructure** 25m
Speaker: Dhanush Hangal (Lawrence Livermore National Laboratory (US))
RHIC_AGS_AUM20...

Setting the Stage, What Are Jets?

- Textbook definition: “jets are collimated, high-energy spray of hadrons resultant from the fragmentation of a hard-scattered parton”

Setting the Stage, What Are Jets?

- Textbook definition: “jets are collimated, high-energy spray of hadrons resultant from the fragmentation of a hard-scattered parton”
- In theory:



$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_{T1}\mathrm{d}p_{T2}\,\mathrm{d}\tau} \equiv xf(x_1)\,xf(x_2) \otimes H(\mu^2) \otimes S \otimes J(p_1)\,J(p_2)\;\delta\left(\tau - \sum_{i\in\Omega} p_i\right)$$

Theory Overview: Yacine Mehtar-Tani

Setting the Stage, What Are Jets?

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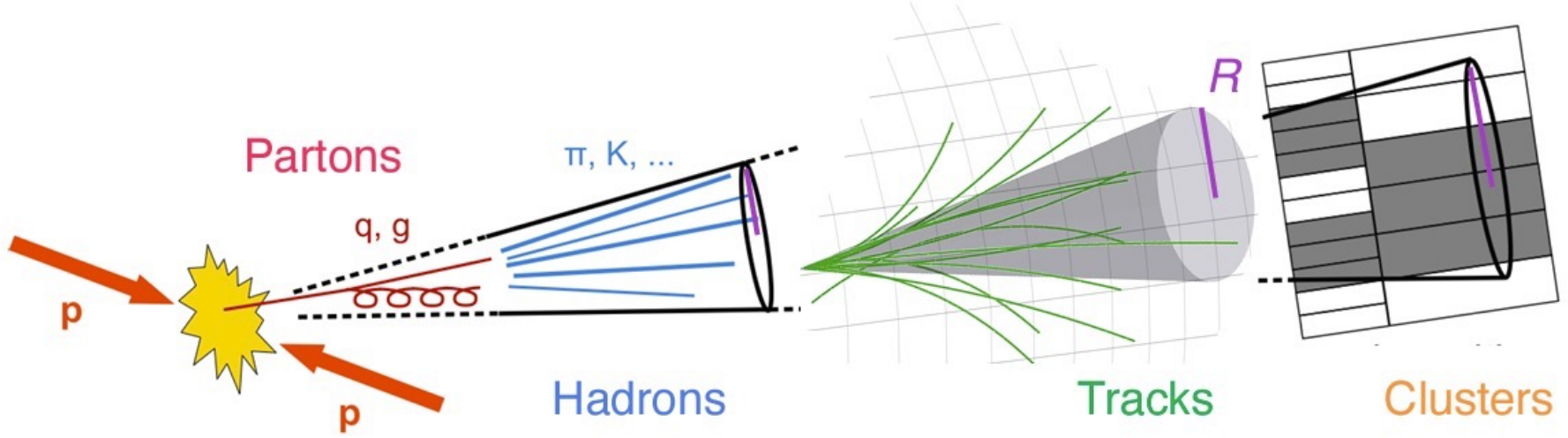
- In experiment:

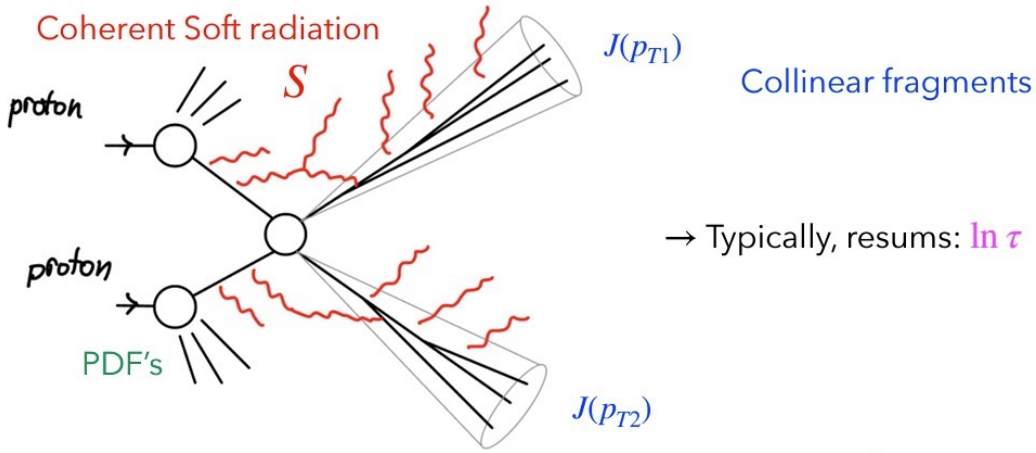


Grouped together using *jet clustering algorithms* to form **experimental jets** with a p_T and resolution parameter R

Experimental Overview: Laura Havener

Why Do We Study Jets?

- Jets serve as proxies for the partons that created them, which we are interested in studying
- For theorists: Jets are perturbatively calculable objects
- For experimentalists: jets use high-resolution detector response regimes



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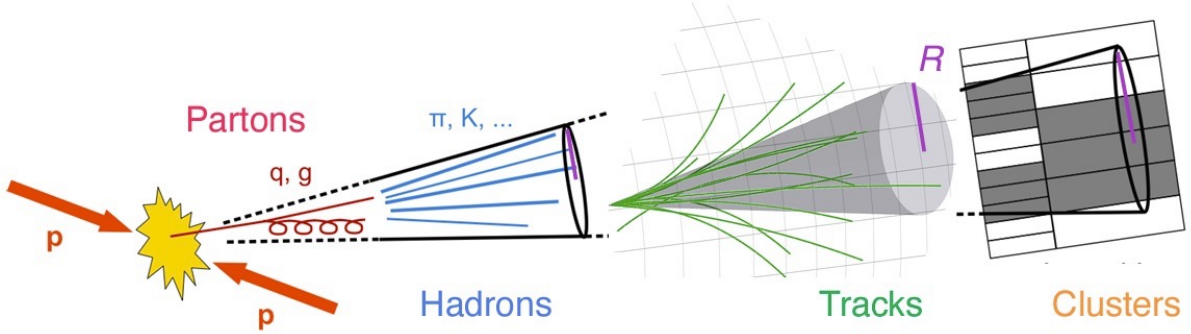
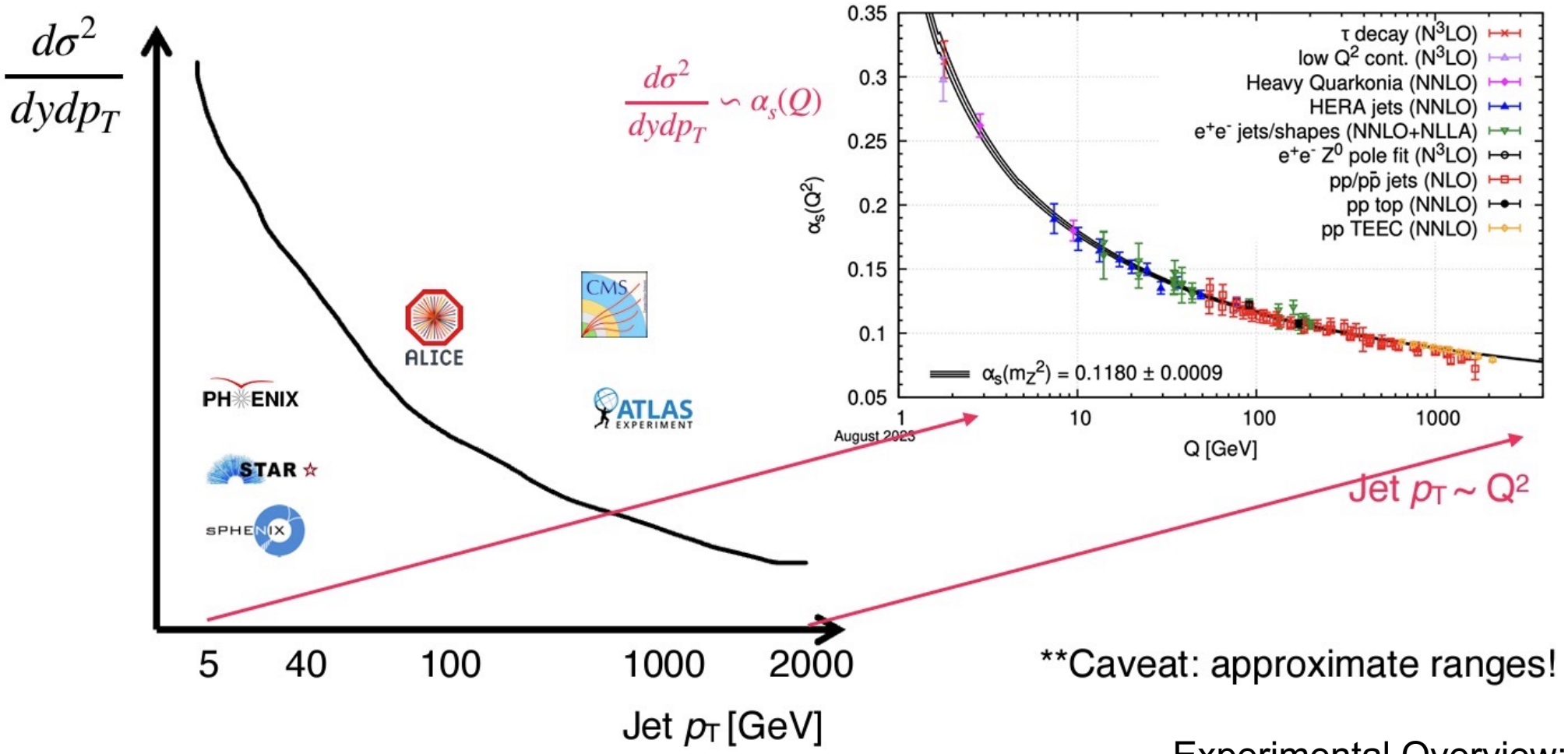


Grouped together using *jet clustering algorithms* to form **experimental jets** with a p_T and resolution parameter R

Why Do We Study Jets?

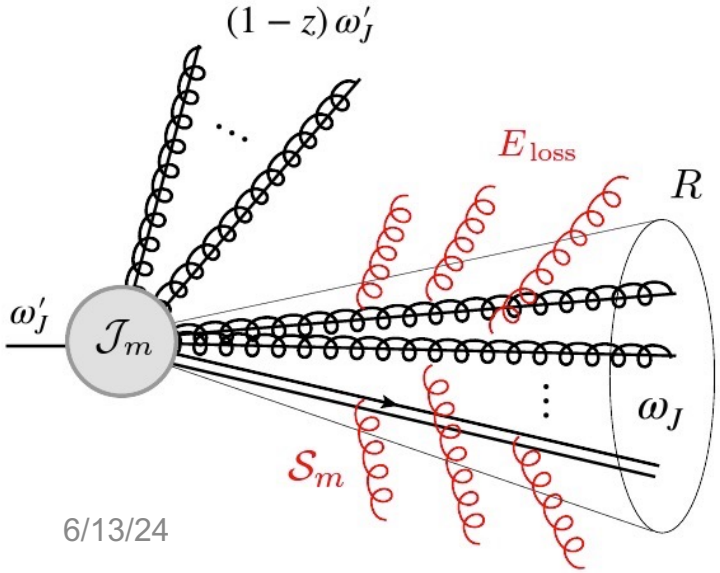
- Jets are a critical probe of the QCD phase space!

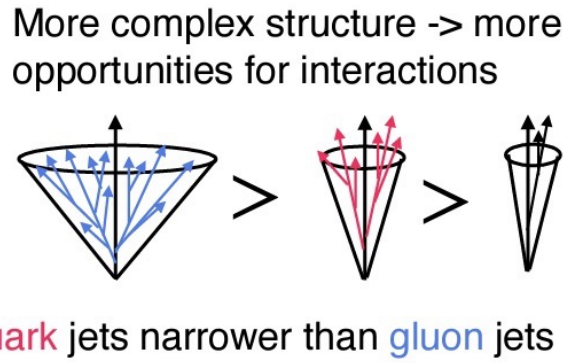


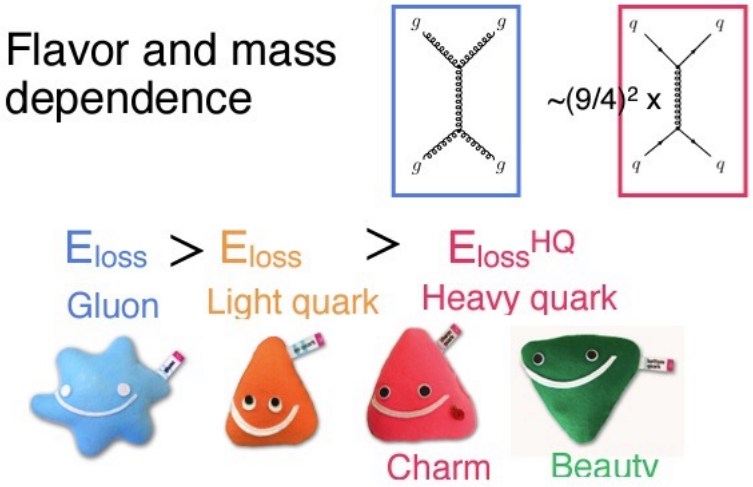
Experimental Overview: Laura Havener

Why Do We Study Jets... In Heavy-Ion Collisions?

- Jet-Medium interactions important probe of Quark-Gluon Plasma formed in heavy-ion collisions
- Large underlying event offers challenges our understanding of particle correlations (positive spin!)
- Elucidate important QCD question, e.g. quark vs. gluon QCD interactions, mass dependence…





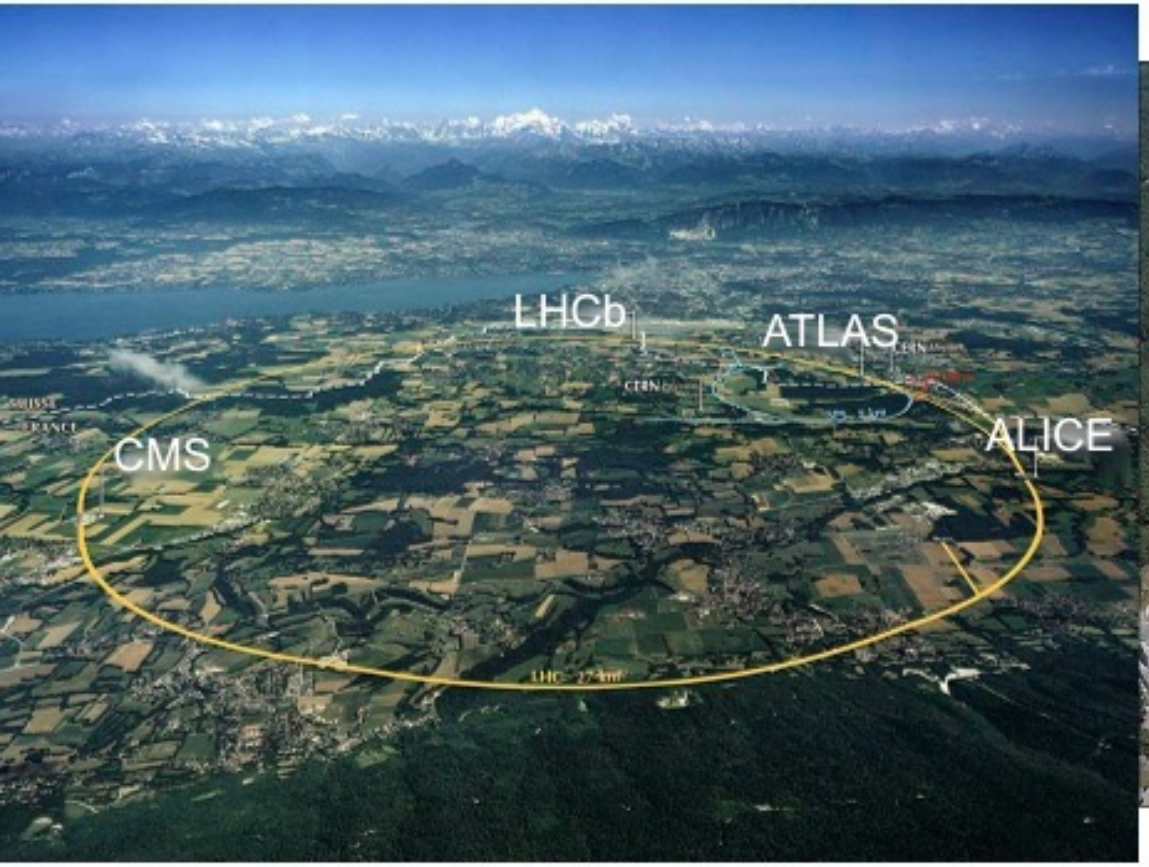


Experimental Overview: Laura Havener

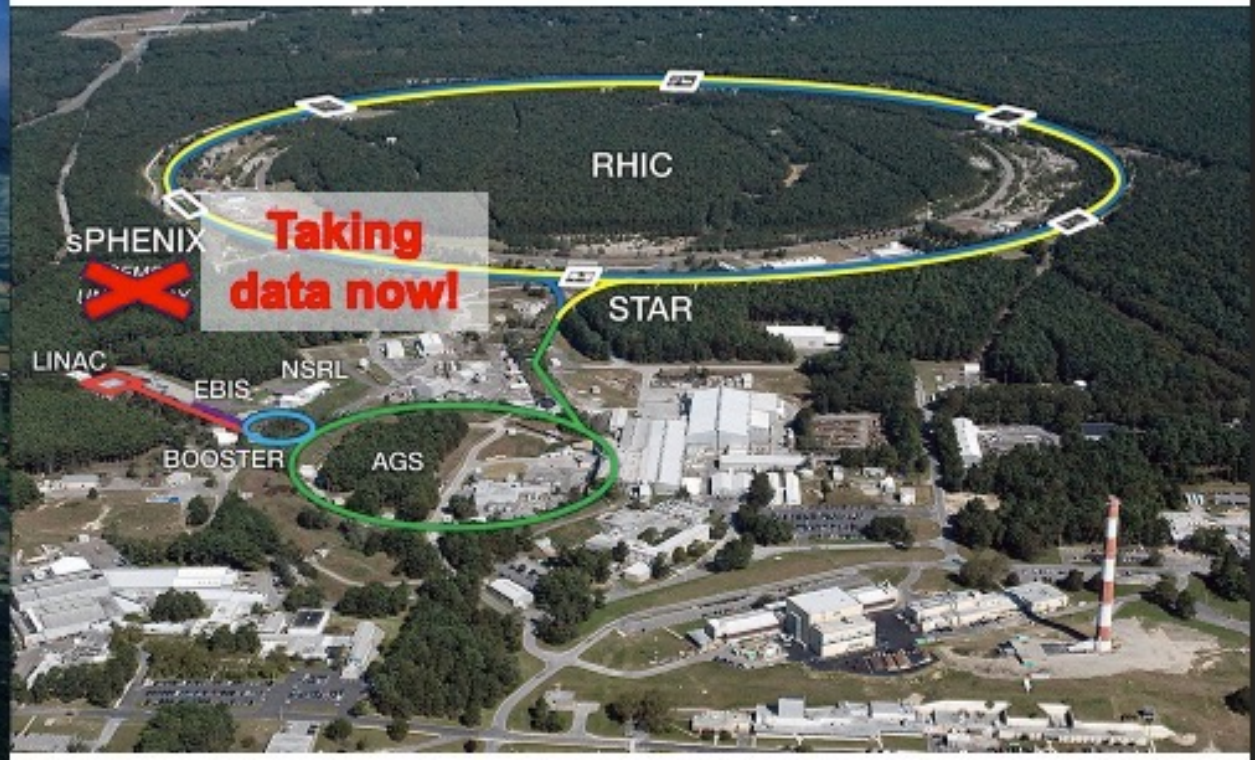
Why Do We Study Jets…

At the LHC vs. At RHIC?

Large Hadron Collider (LHC) at CERN



Relativistic Heavy Ion Collider (RHIC) at BNL

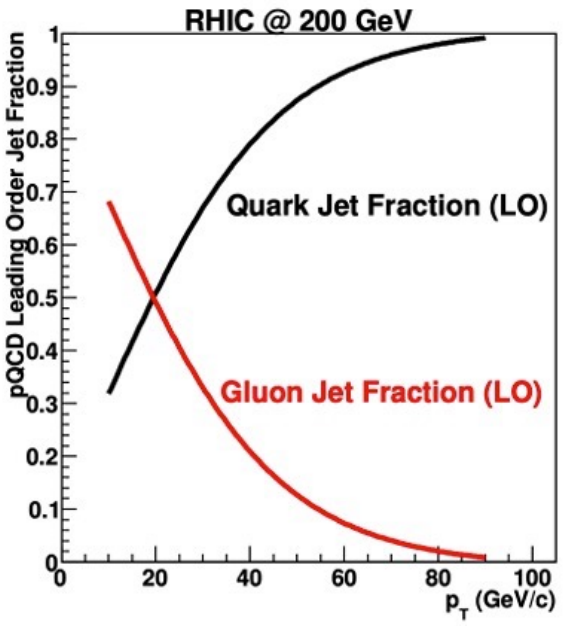


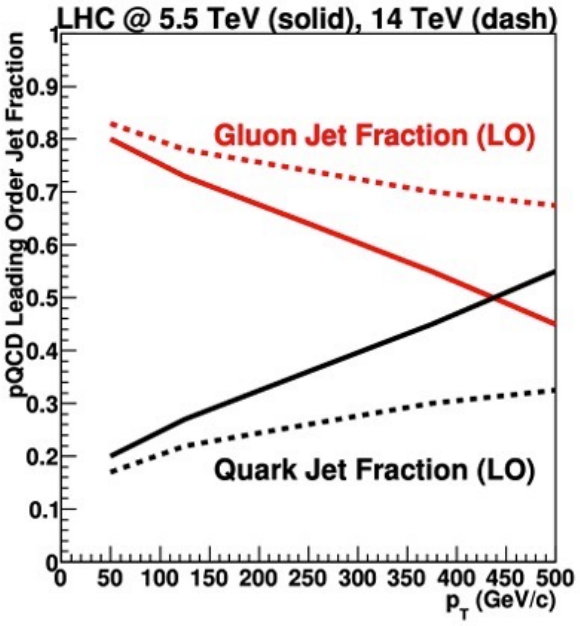
RHIC and LHC Synergies: Virginia Bailey

Different Jet Populations

- Jets at RHIC offer a more quark-rich sample
- Jets at LHC offer interesting physics opportunities to study inclusive *vs.* quark-rich samples
- Additionally, jets at RHIC exist closer to the medium scale

arXiv:1501.06197





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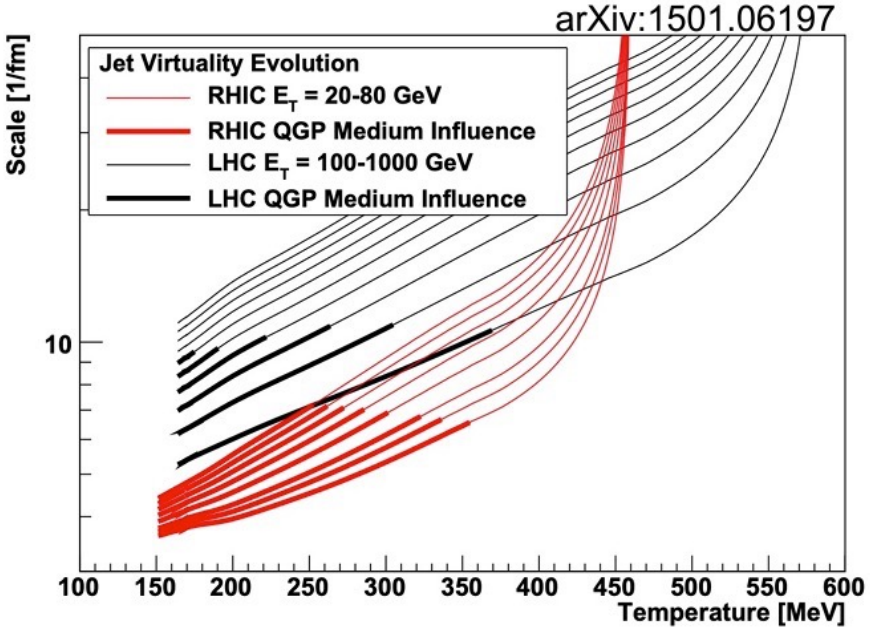
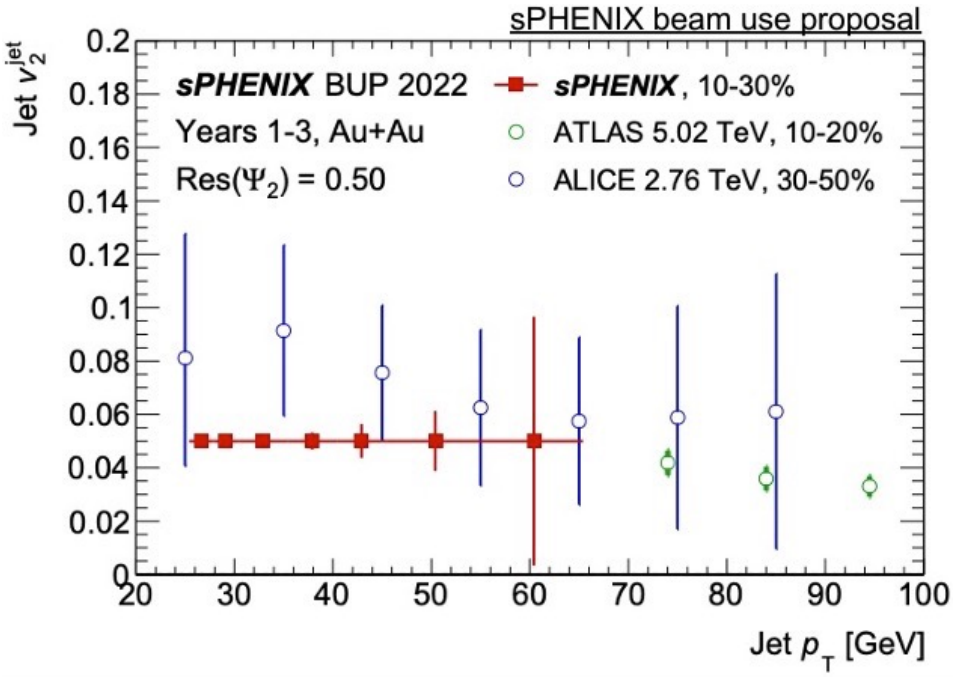
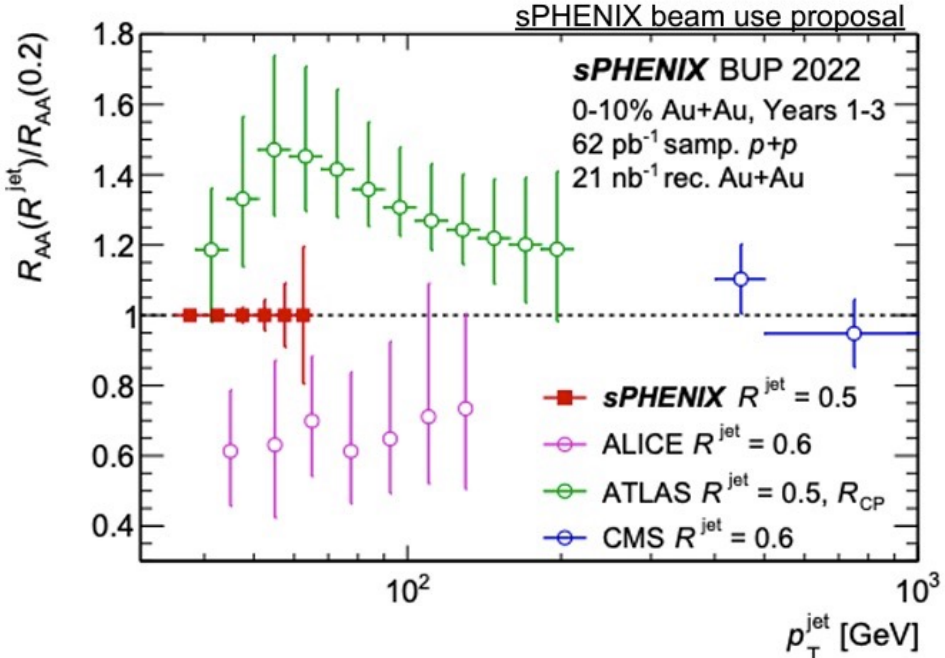


RHIC and LHC Synergies: Virginia Bailey

The Power Of Multiple Machines…

- Generally one wants multiple experiments (2-3)
  - To serve as cross-checks on collider results
  - Also to complement varying strengths
- Cross-checks across *colliders* now possible as well, thanks to LHC-detector sPHENIX's development at RHIC

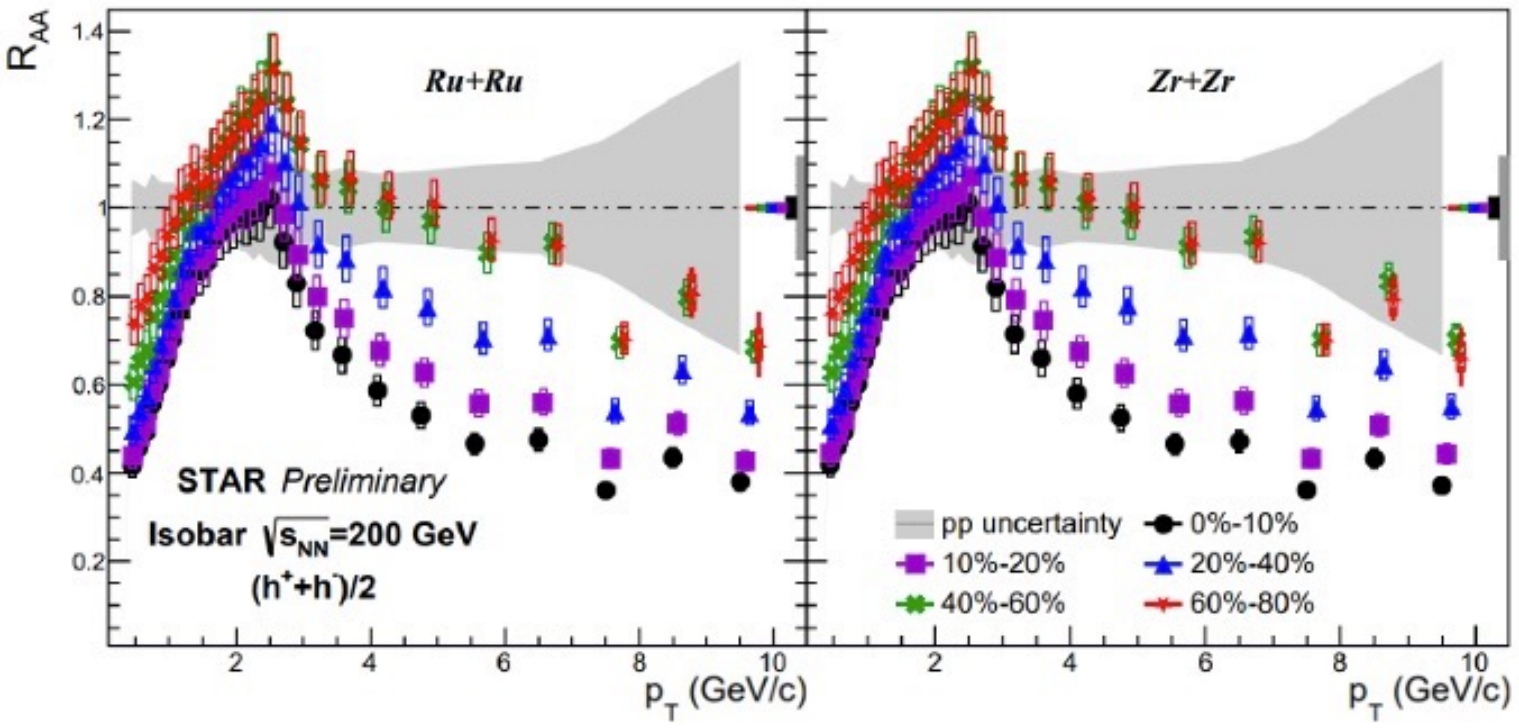




RHIC and LHC Synergies: Virginia Bailey

What Do Jets See in Heavy-Ion Collisions?

- How finely can jets resolve the medium?
- Strong, system-independent, centrality *dependent* R_{AA} hints that jets can resolve differential path-lengths



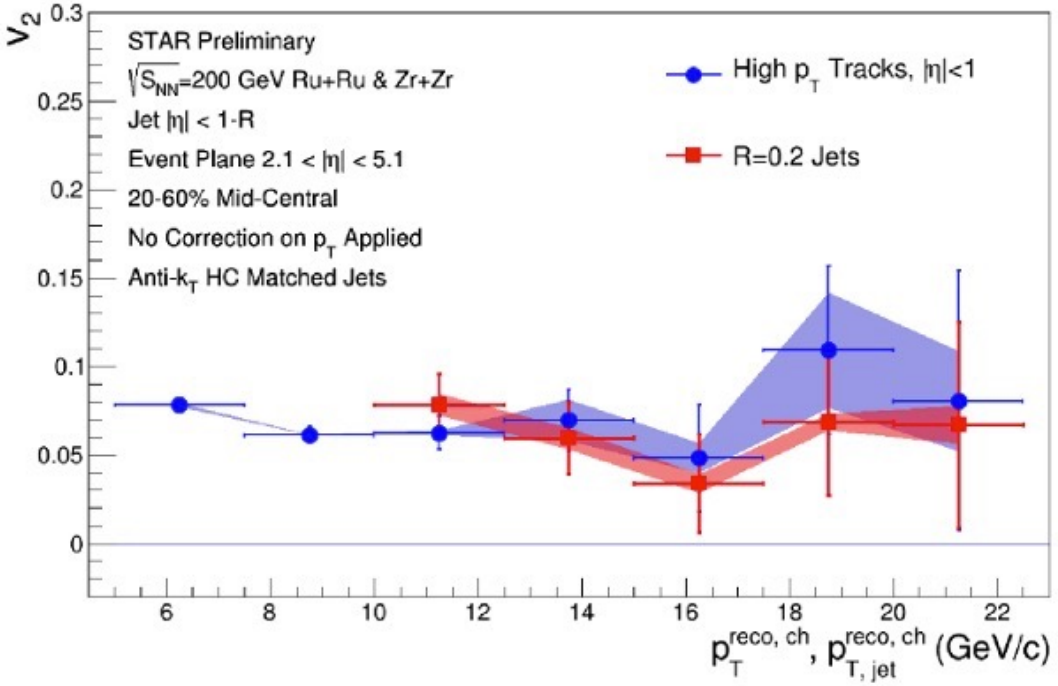
$$R_{AA} = \frac{1}{N^{AA}} \frac{d^2N^{AA}/d\eta dp_T}{T_{AA} d^2\sigma^{NN}/d\eta dp_T}$$

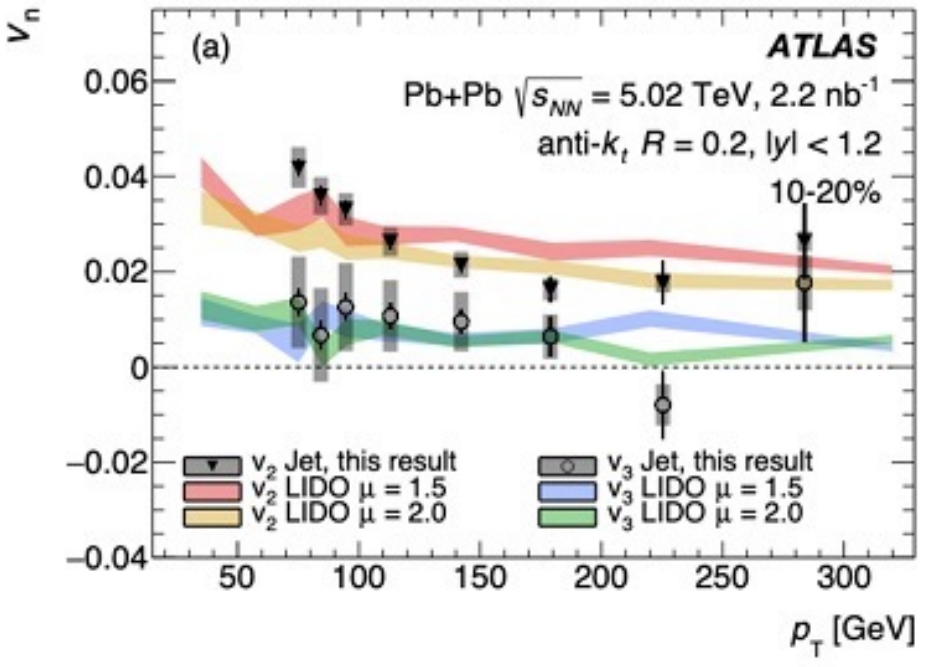
$$T_{AA} = \langle N_{coll} \rangle / \sigma_{inel}^{NN}$$

Path-length-dependent Energy Loss: Megan Connors

Clear Path-Length Dependence

- Not only non-zero v_2 for high p_T jets, but non-zero v_3 measured at LHC!
- Jets are sensitive not only to differences in pathlength, but *fluctuations* of the pathlength as well

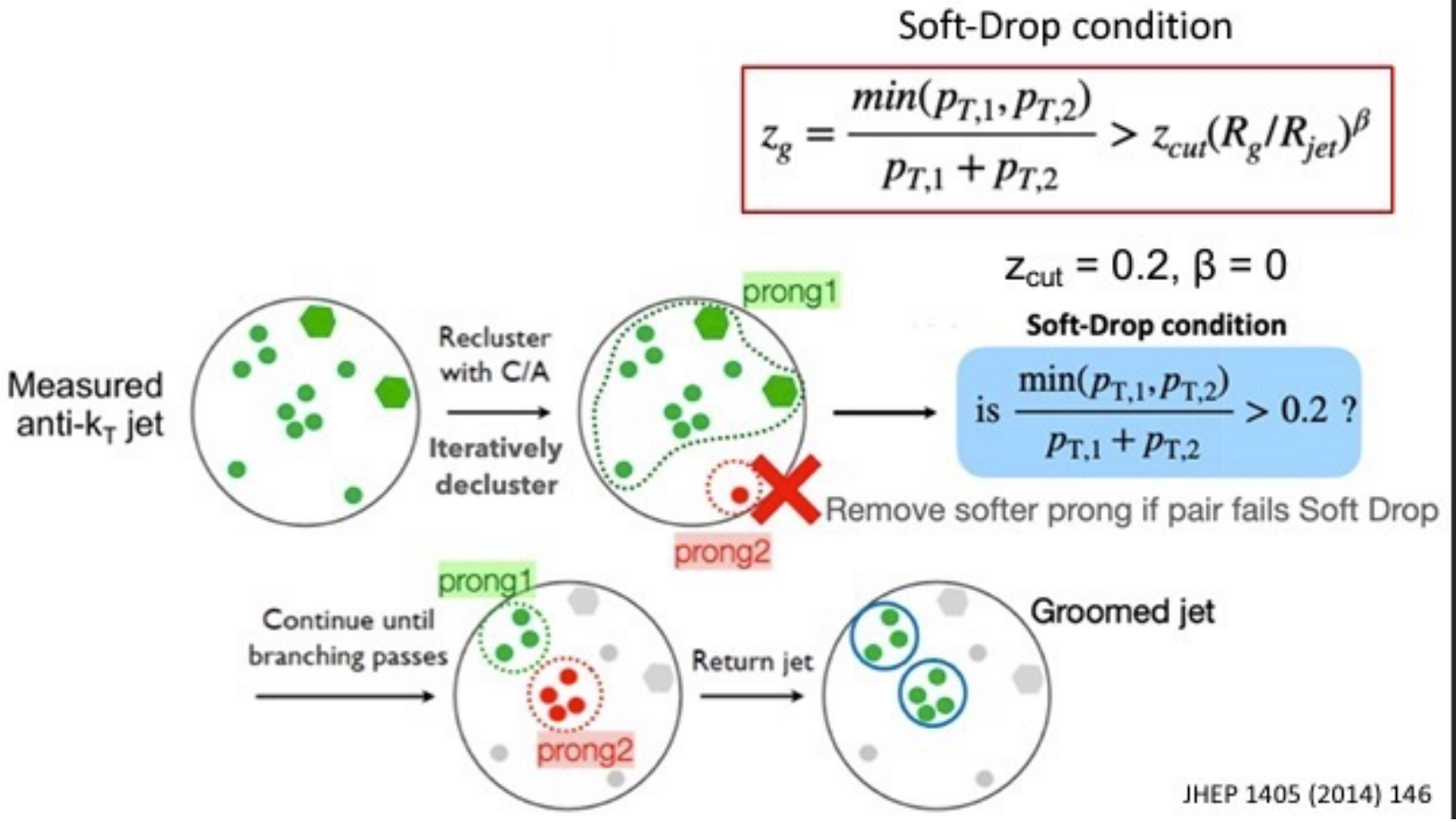




Path-length-dependent Energy Loss: Megan Connors

How Finely Can We Resolve Jets?

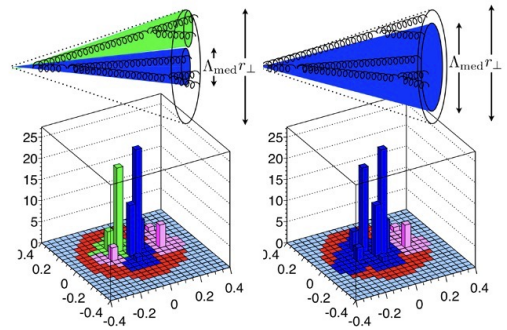
- Jet grooming can be used to study the hard splittings within jets
- Gives experimental access to the hadronization/fragmentation process



Jet Substructure: Dhanush Hangal

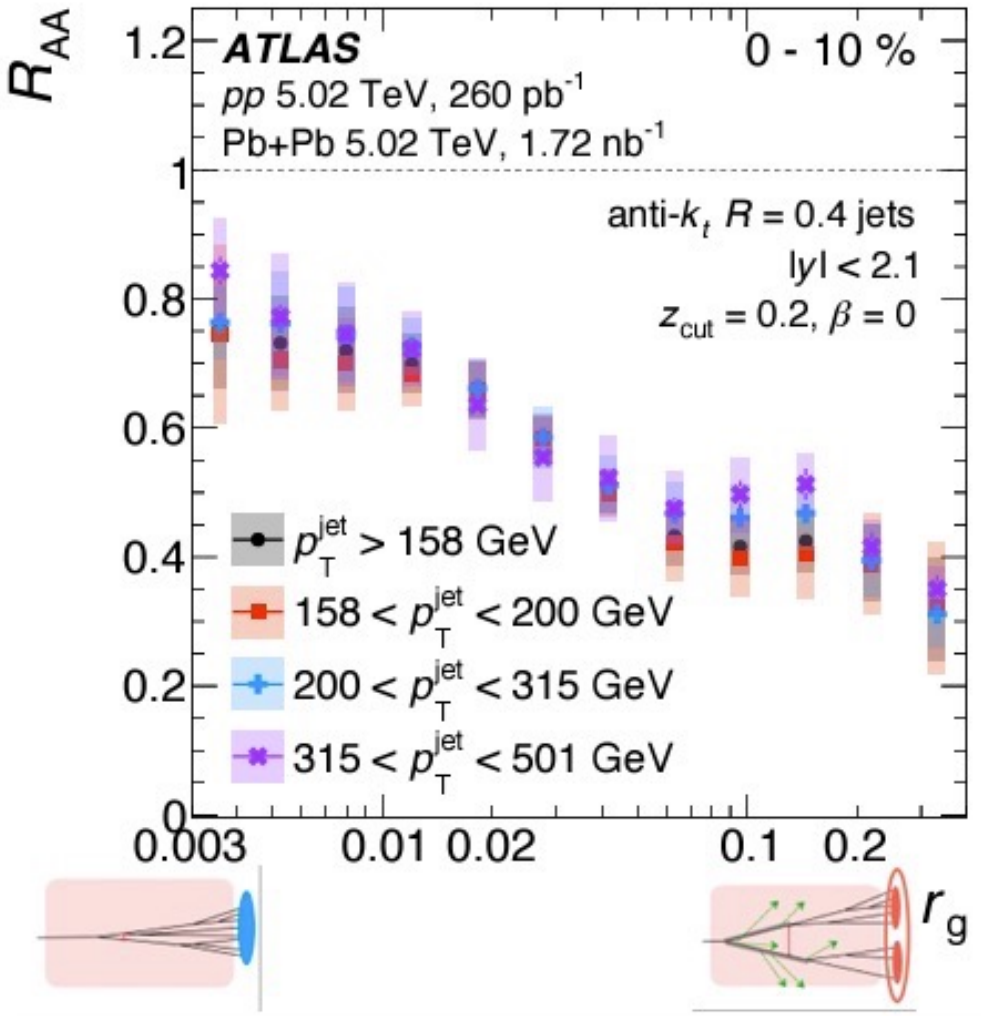
How Finely Can the *Medium* Resolve Jets?

- ATLAS result hints that at high p_T, medium modification is more sensitive to coherence effects
- Large r_g → medium sees two colored objects → more energy loss
- Small r_g → medium sees *one* colored object → less energy loss



Two effective color charges

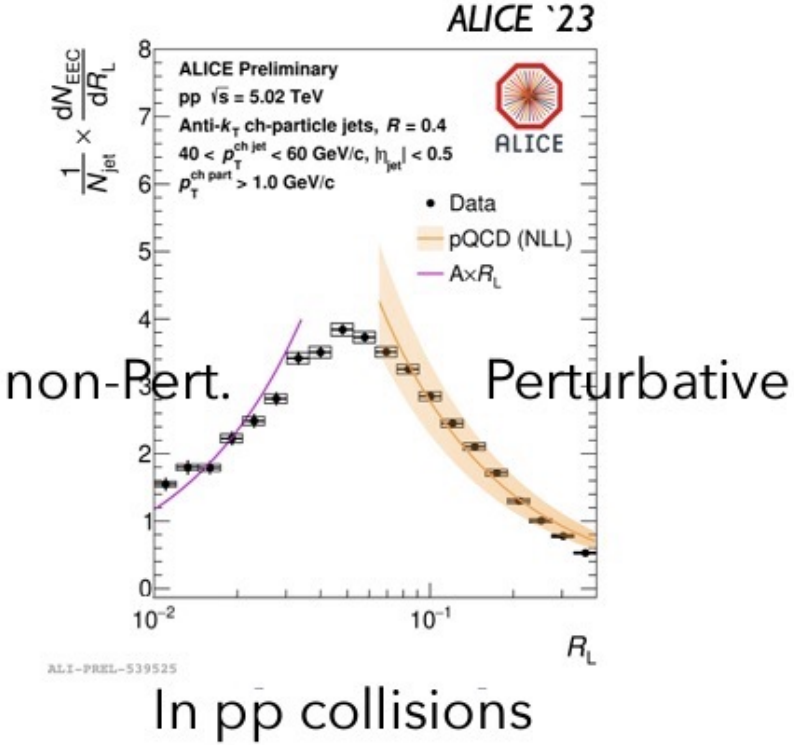
One effective color charge



Jet Substructure: Dhanush Hangal

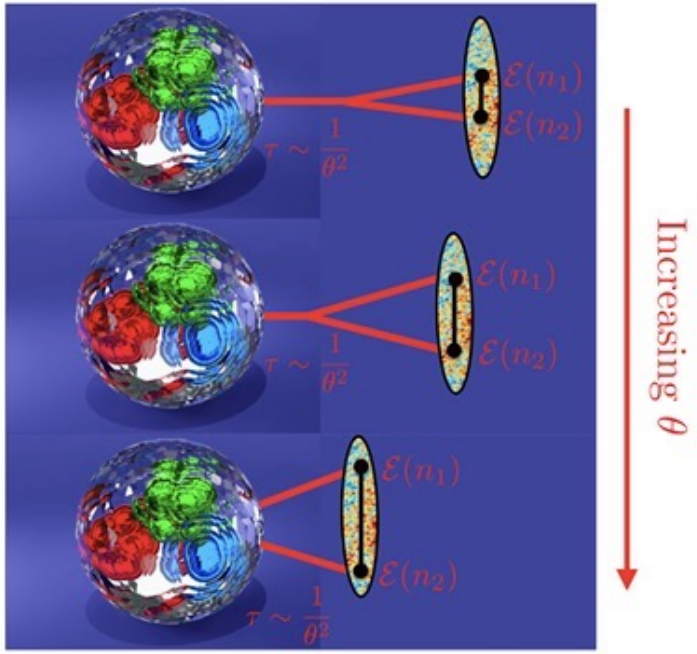
Energy-Energy Correlators!

- Energy N-point Correlators becoming increasingly popular
- Possible to delineate regions of perturbative and non-perturbative physics related to free-hadrons and partons, respecitvely



non-Pert. Perturbative

In pp collisions



(a)

Basham et al (1978)… Dixon,Moult ,Zhu 2019

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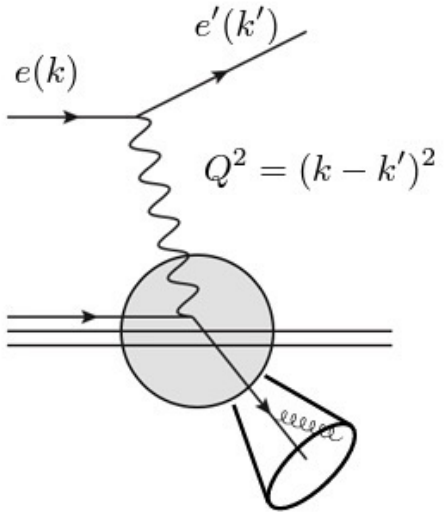
The Field

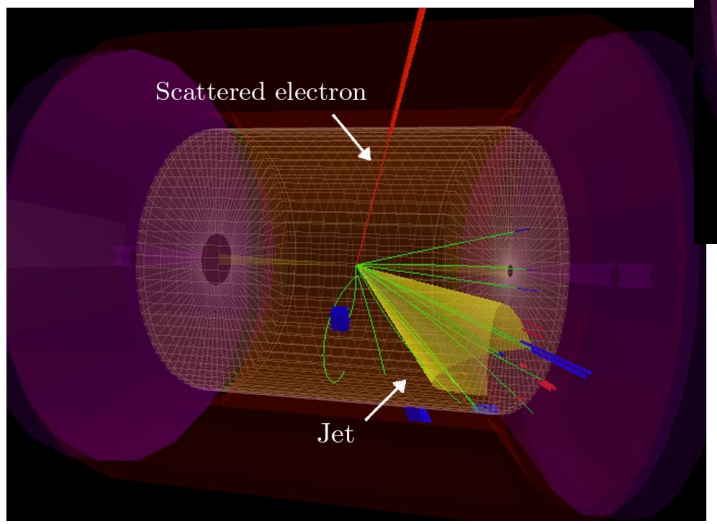
Looking Towards the Future: Jets at the EIC

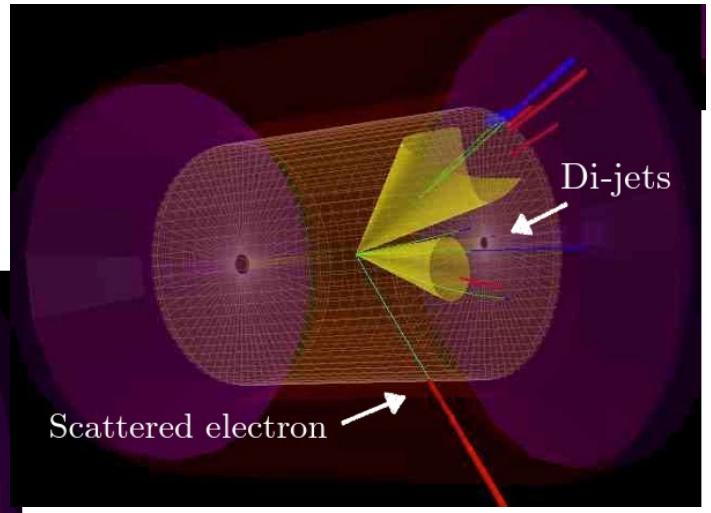
- Aim of Electron-Ion collider is to probe the spin structure of nuclear matter with unprecedented precision
- Jets still an important part of the EIC physics mission!



Arratia, Jacak, FR, Song `19
see also Aschenauer et al.

Jets At the EIC: Felix Ringer





Looking Towards the Future: Jets at the EIC

- Aim of Electron-Ion collider is to probe the spin structure of nuclear matter with unprecedented precision

  - Electron-jet imbalance at the EIC

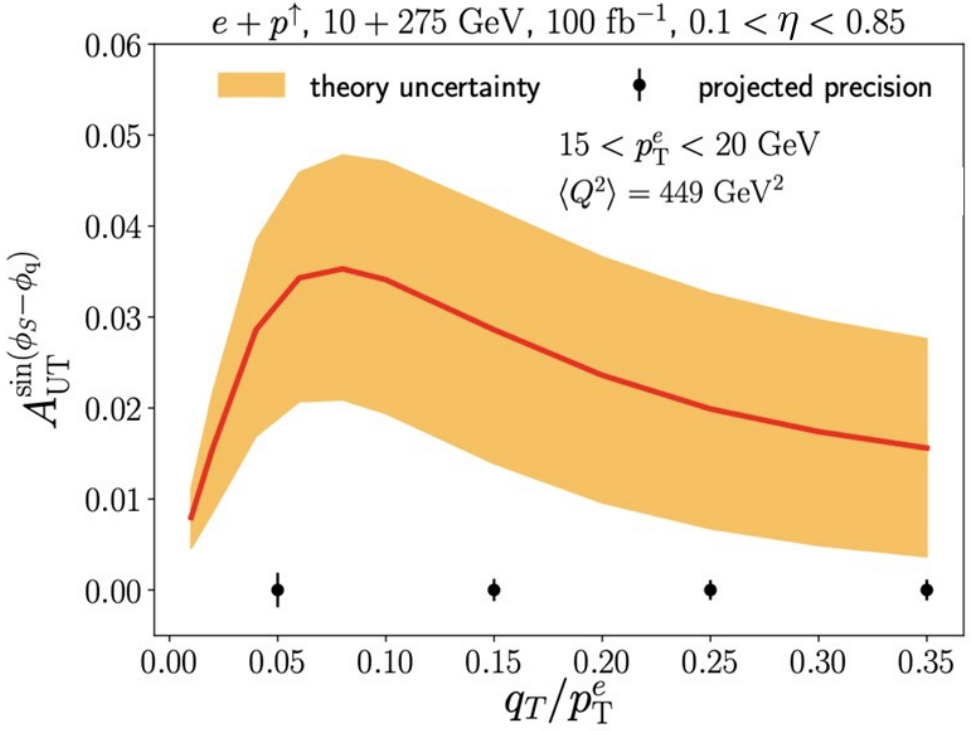
$$\vec{q}_T = \vec{p}_T^{\,e} + \vec{p}_T^{\,\mathrm{jet}}$$

  - Sensitivity to TMD PDFs but no TMD FF
  - TMD factorization

$$F_{UU} = \sigma_0 \, H_q(Q,\mu) \sum_q e_q^2 \, J_q(p_T^{\mathrm{jet}} R, \mu)$$

$$\times \int \frac{\mathrm{d}^2 \vec{b}_T}{(2\pi)^2} \, e^{i \vec{q}_T \cdot \vec{b}_T} \, f_q^{\mathrm{TMD}}(x, \vec{b}_T, \mu) \, S_q(\vec{b}_T, y_{\mathrm{jet}}, R, \mu)$$

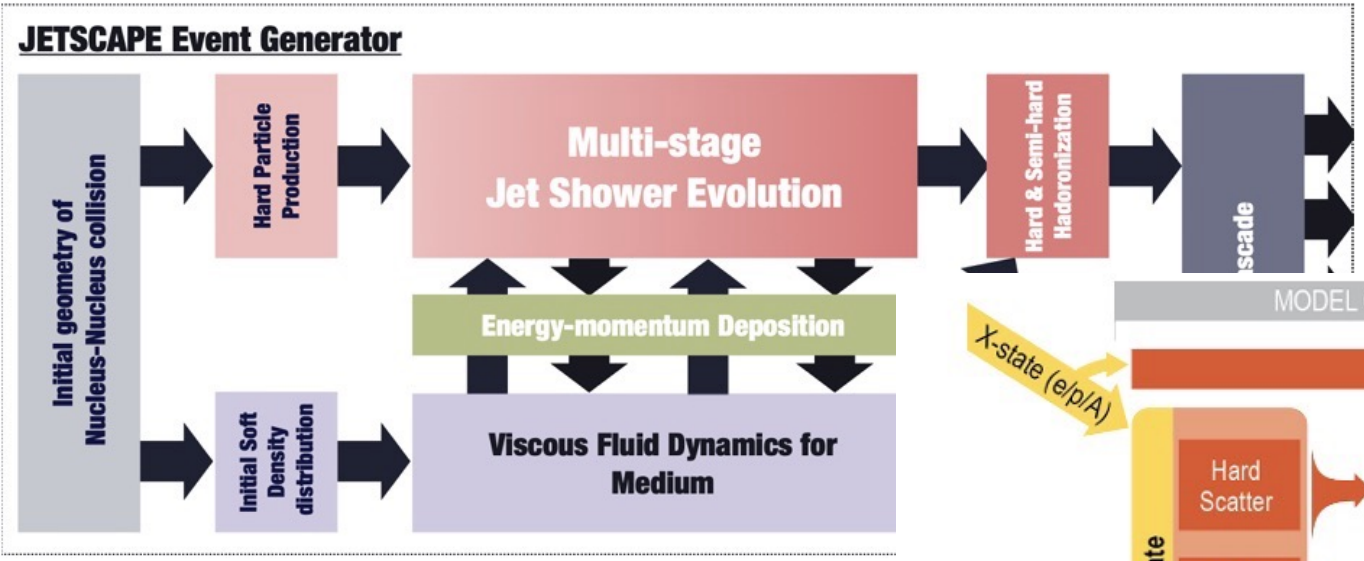
  - Sensitivity to the Sivers function



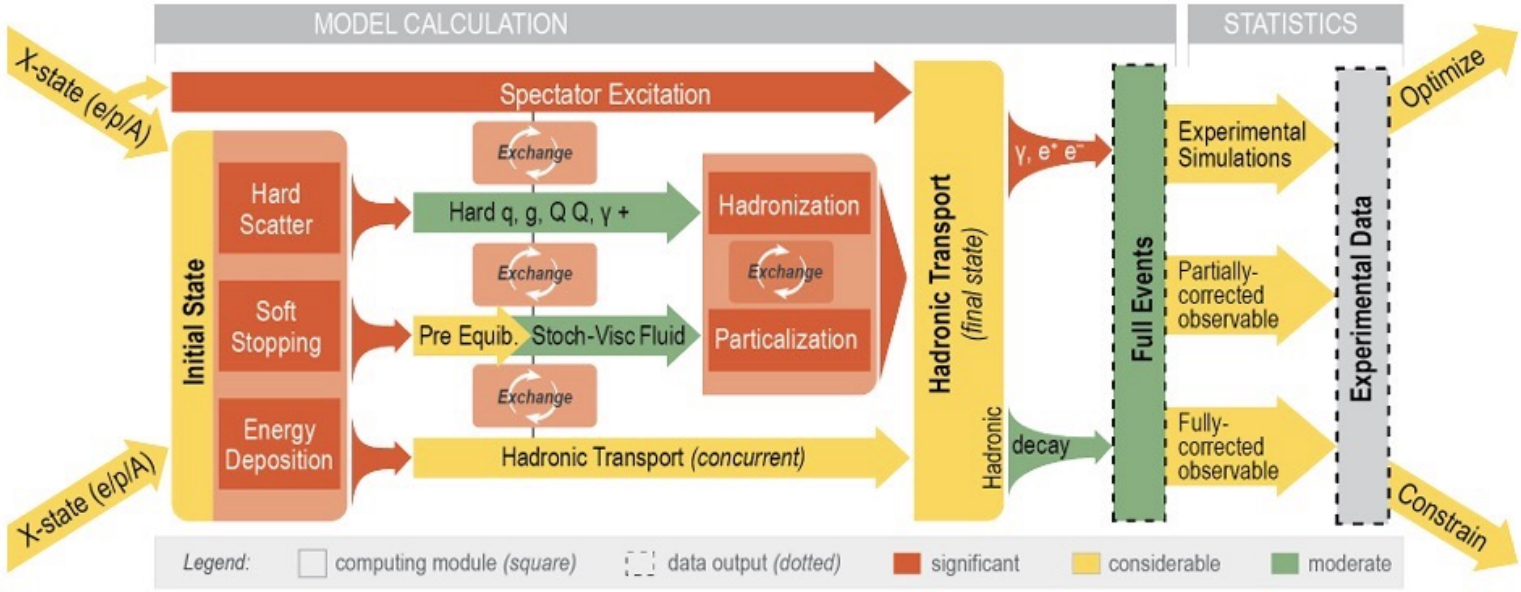
Jets At the EIC: Felix Ringer

A Framework For Theory and Experiment

- JET/XSCAPE modular framework allows for the simultaneous usage of many theory models and event generators



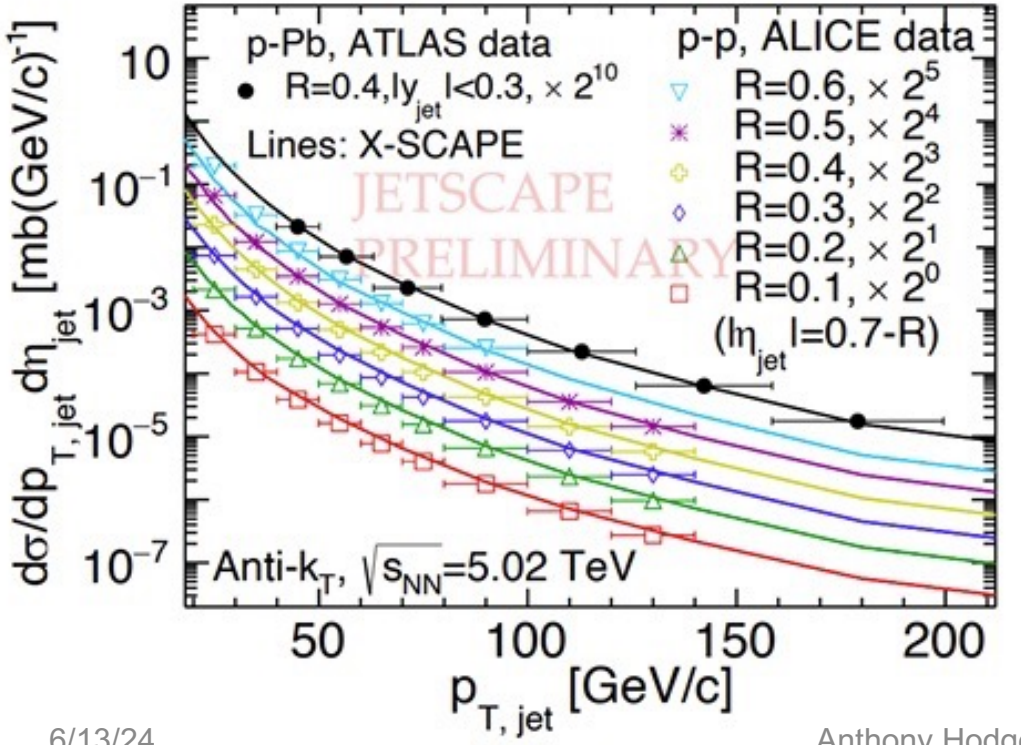
X-Scape: Mayank Singh

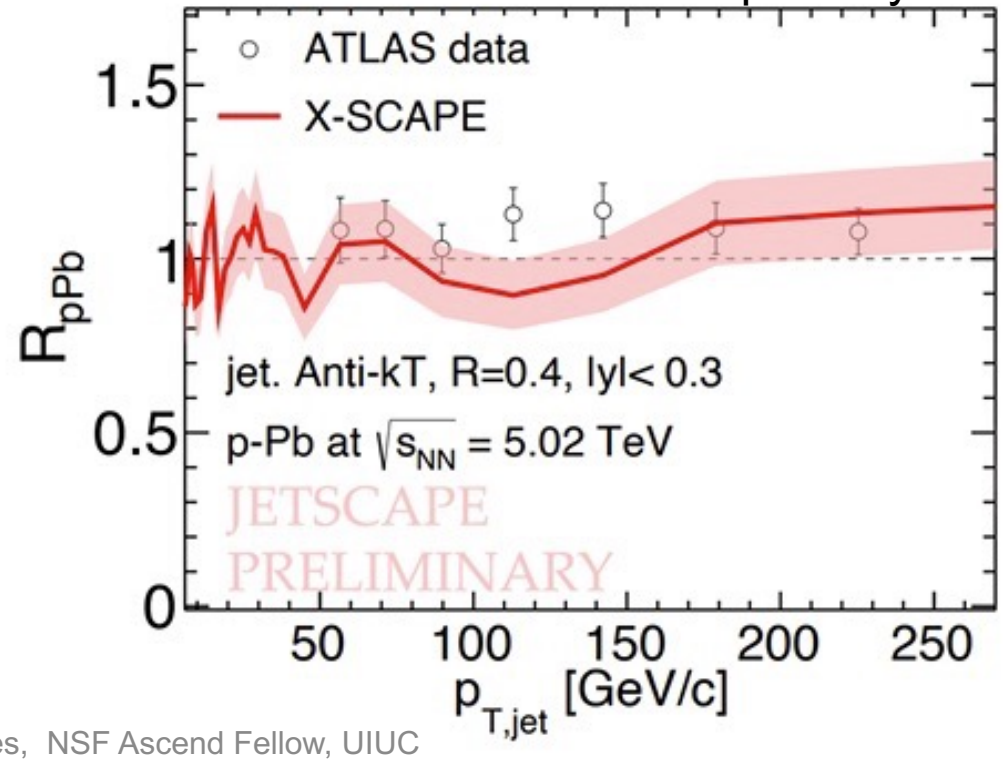


XSCAPE in Asymmetric Systems

- A theory/experiment framework for xA systems
- Shows good agreement with LHC data already
- Improves ease of model discrimination with unified framework

X-Scape: Mayank Singh





Some Concluding Remarks

- Jets a multifaceted way to make precision measurements of QCD phenomenon
- The field is rapidly approaching a transition from the familiar “Golden Age” of Heavy-Ion physics to the new frontier of EIC physics
- Proper accounting of what we’ve learned in the past 20 years of RHIC and LHC jet physics is a *necessity*
- The successful conclusion of the sPHENIX, STAR, and RHIC science missions are a *necessity*
- The development of models that can simultaneously describe multiple aspects of jet physics are necessary more than ever to begin approaching a more unified understanding of hot and cold QCD physics

This talk