

# RHIC 25:

## A quarter century of discovery

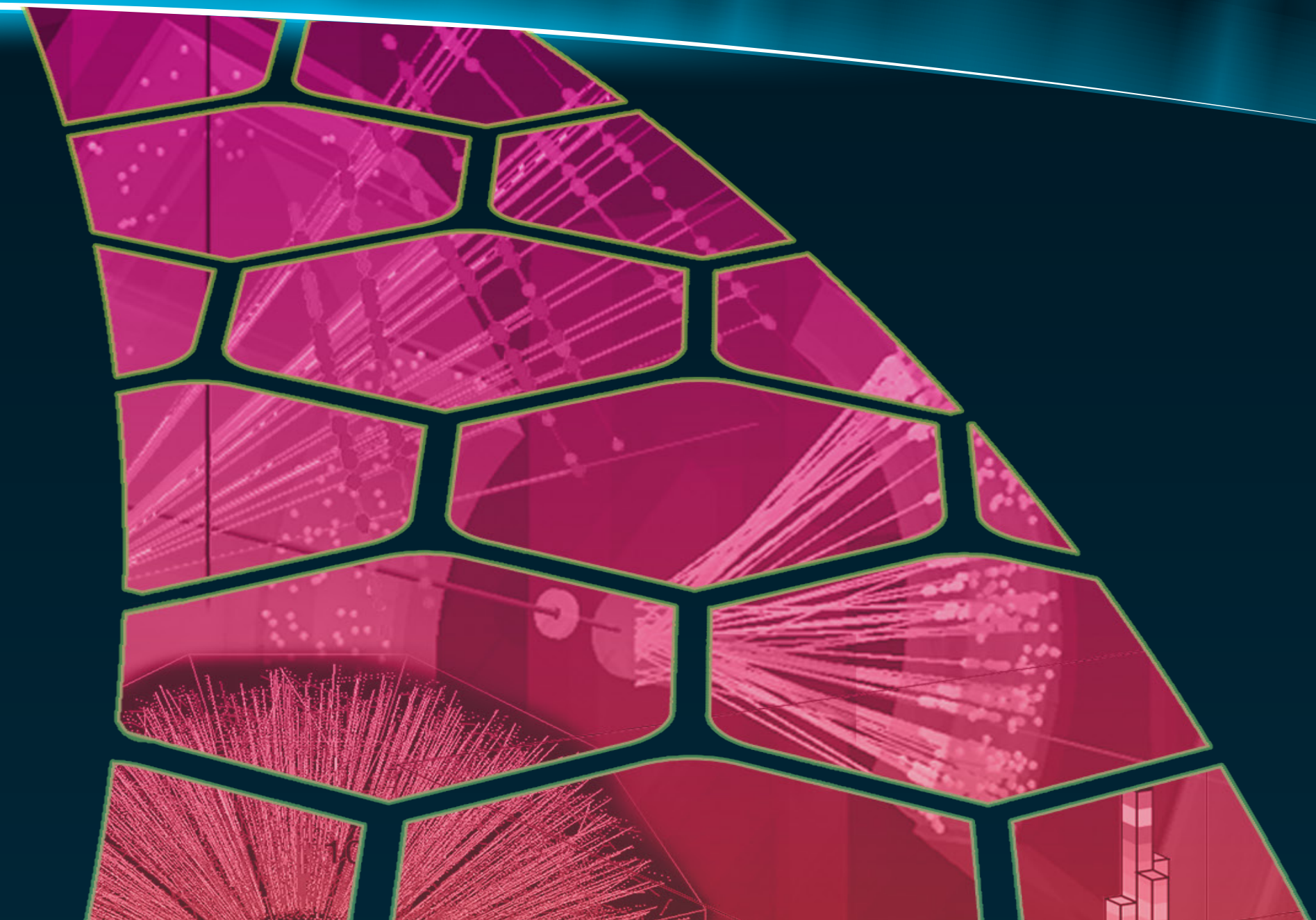
May 20-23, 2025

### Workshop Report: Jets

Dennis V. Perepelitsa, Sevil Salur



University of Colorado **Boulder**





09:00	<b>High-pT physics in sPHENIX</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Daniel Lis</i> 09:00 - 09:25	
	<b>Jet theory highlights</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Dr Carlota Andres</i> 09:25 - 09:50	
10:00	<b>Jets in STAR</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Andrew Tamis</i> 09:50 - 10:15	

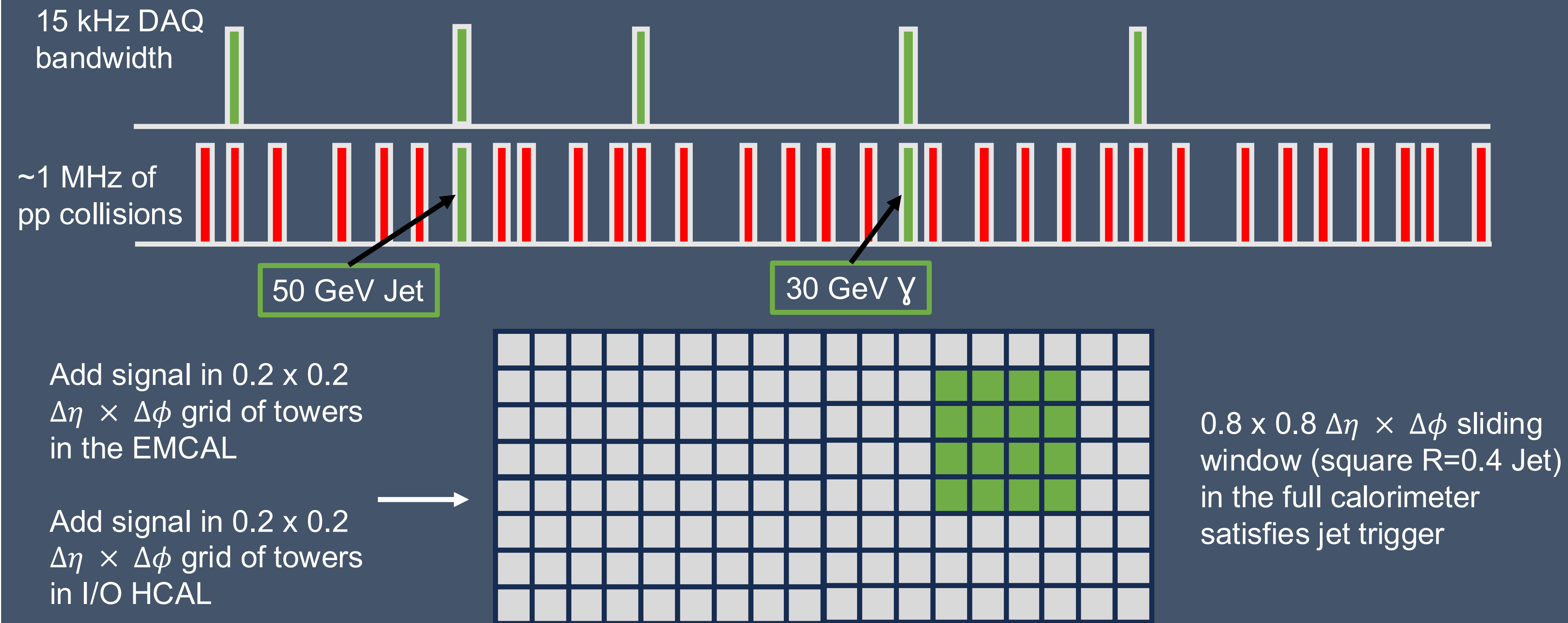
11:00	<b>Jets at the LHC</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Riccardo Longo et al.</i> 10:45 - 11:15	
	<b>EECs in Jets</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Beatrice Liang-Gilman</i> 11:15 - 11:40	
	<b>Data and Analysis Preservation at RHIC</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Eric LANCON</i> 11:40 - 12:00	
12:00	<b>Jets in ePIC</b> <i>Medical Large Conference Room, Bldg 490</i>	<i>Derek Anderson</i> 12:00 - 12:25	

Seven speakers from RHIC/  
LHC/EIC experiments,  
theory, data preservation

$\approx$  40 participants  
(2/3rds in person)

Some (highly  
selective) highlights  
follow...

# sPHENIX Rare-probes Trigger System



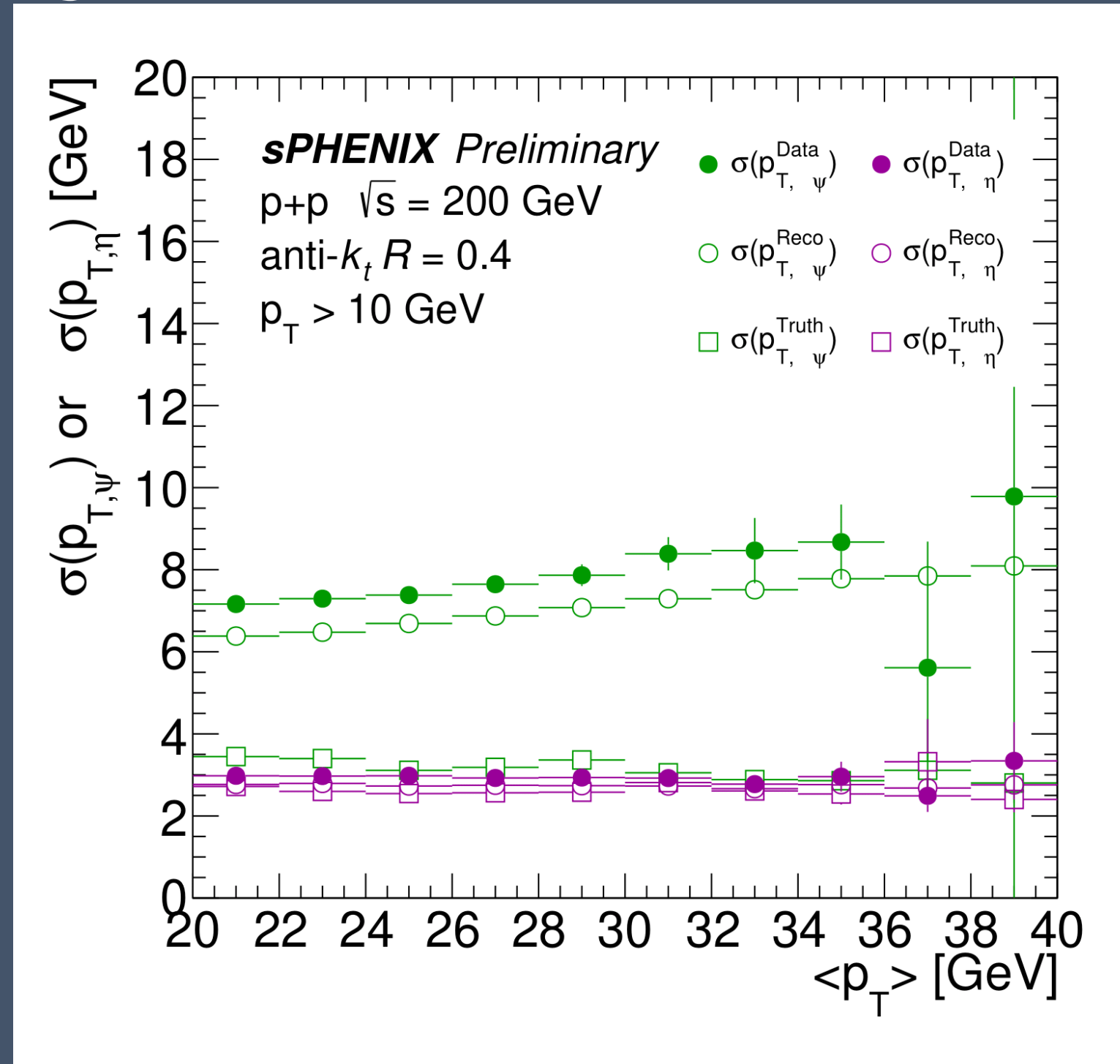
May 21, 2025

RHIC/AGS Users Meeting

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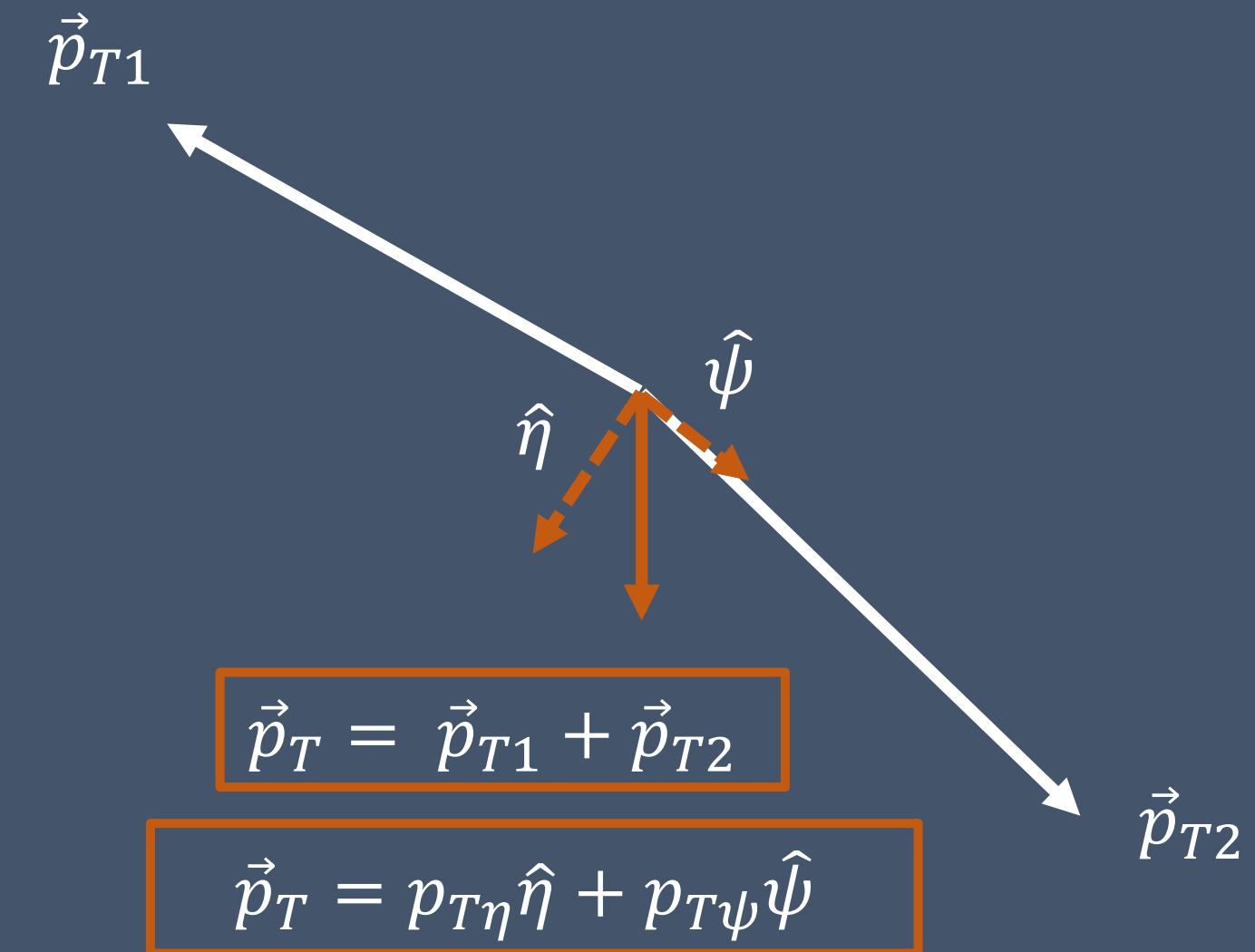
Experimental details from sPHENIX - fast rare probes trigger

# Dijet Bisector Method



$\hat{\eta}$  - direction of  $\frac{\Delta\phi}{2}$   
 $\hat{\psi}$  - direction perpendicular to  $\hat{\eta}$

**The idea:** the width of  $p_{T\eta}$  is less sensitive to detector resolution affects than  $p_{T\psi}$ , but  $p_{T\eta}$  and  $p_{T\psi}$  are equally sensitive to isotropic initial state radiation





# Summary

sPHENIX has analyzed the run-24 pp data-set and has produced many preliminary physics results with high- $p_T$  probes with fast turn-around!

Upcoming run-25 Au+Au running will provide a large data-set for QGP physics

Thank you!

sPHENIX Talks:

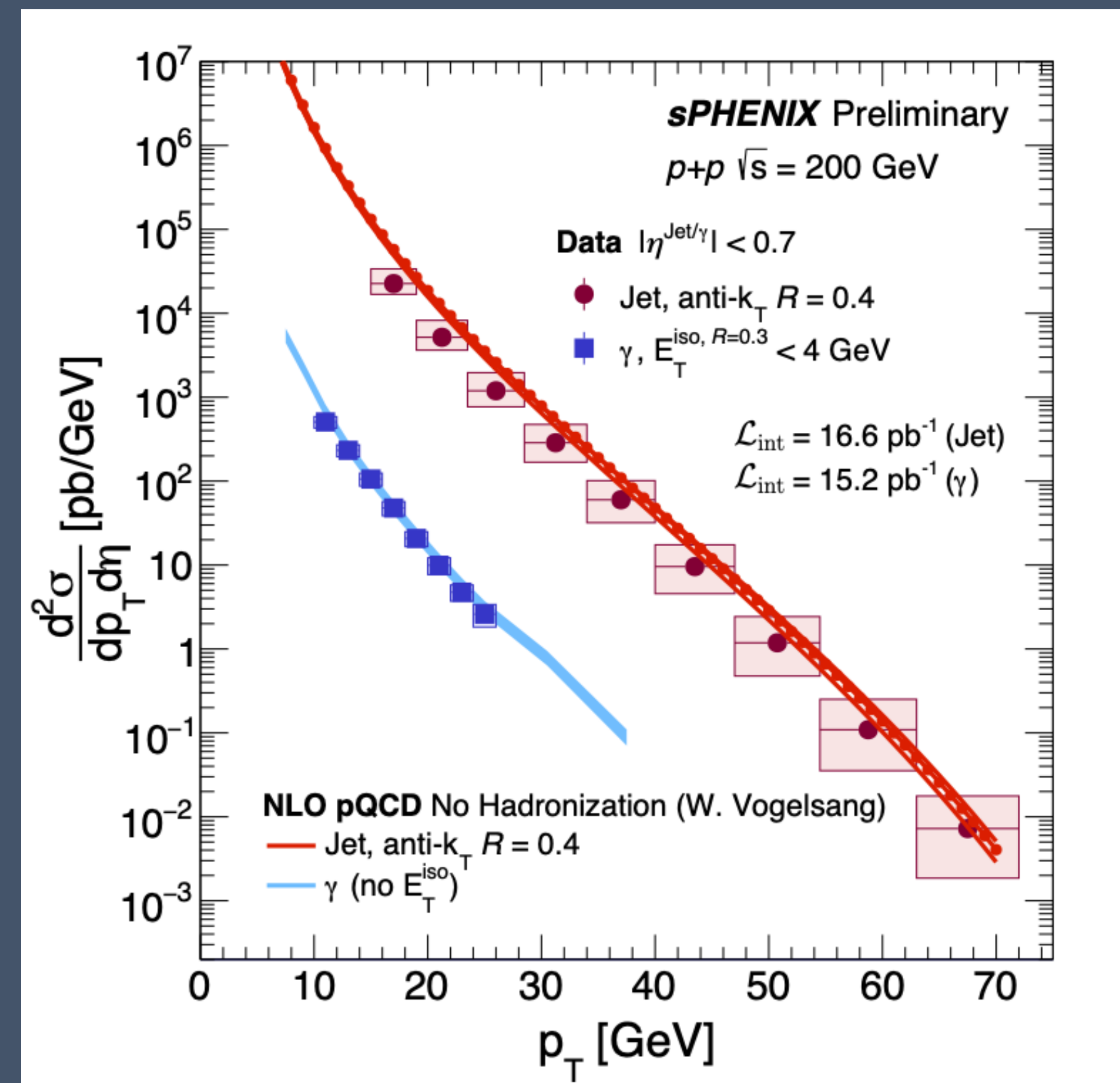
sPHENIX Heavy Flavor Overview – Alexander P. Tue. 9:30 am  
The Cold QCD Program at sPHENIX – Virgile M. Tue. 1:55 pm  
sPHENIX Run 25 Report – Rosi R. Thur. 11:20 am  
sPHENIX Highlights – Jaebeom P. Thur. 1:30 pm

And many posters!

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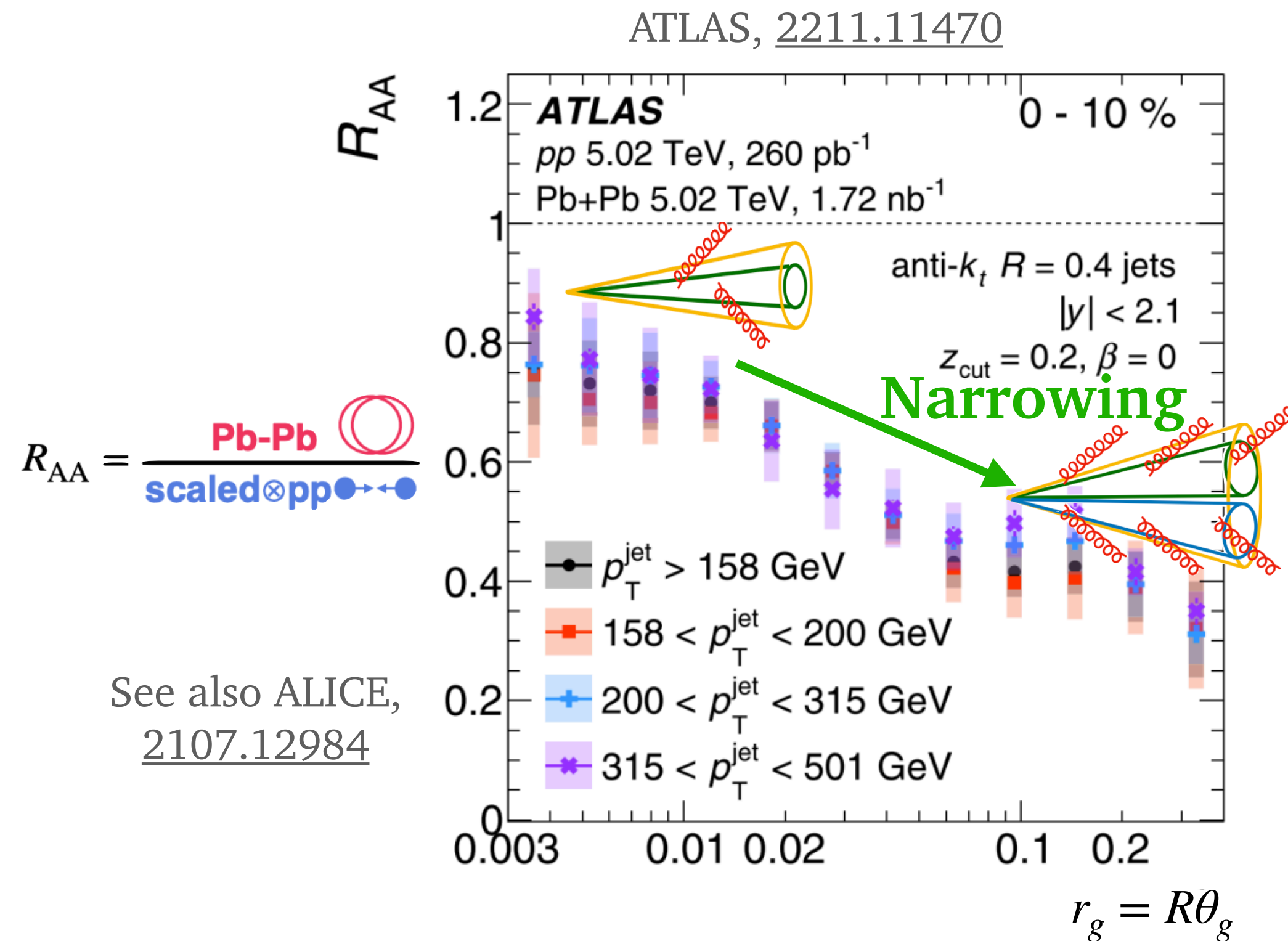
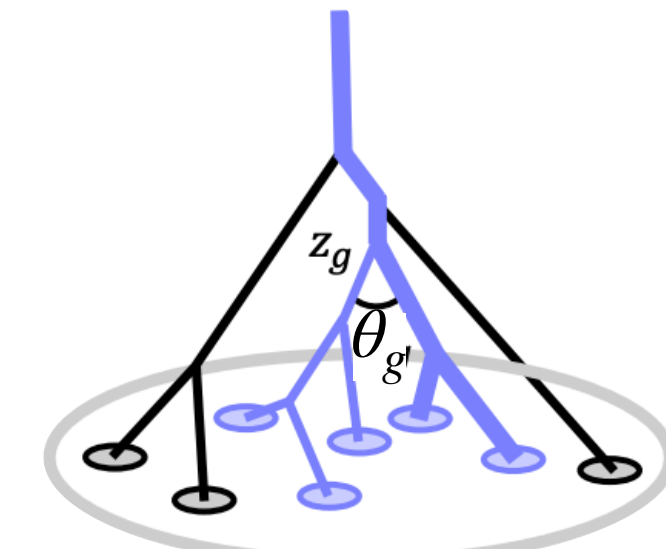
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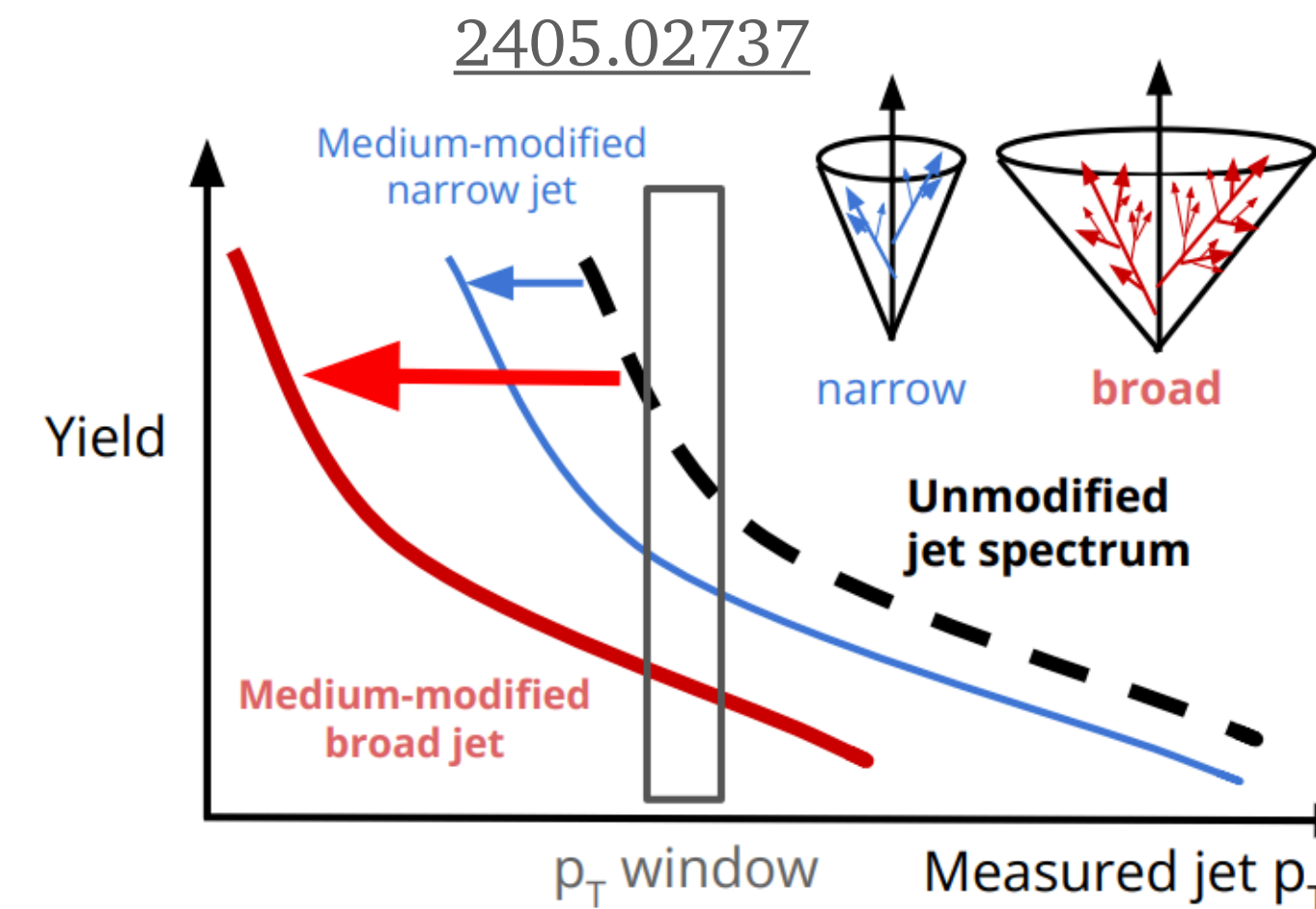
First jet & isolated photon physics results from sPHENIX!

# Groomed jet radius

[Soft Drop grooming]



## Selection bias



See also CMS,  $\theta_g$  in  $\gamma$ -tagged jets [2405.02737](#)

ALICE,  $\theta_g$  balanced vs. unbalanced in [HP2024](#)

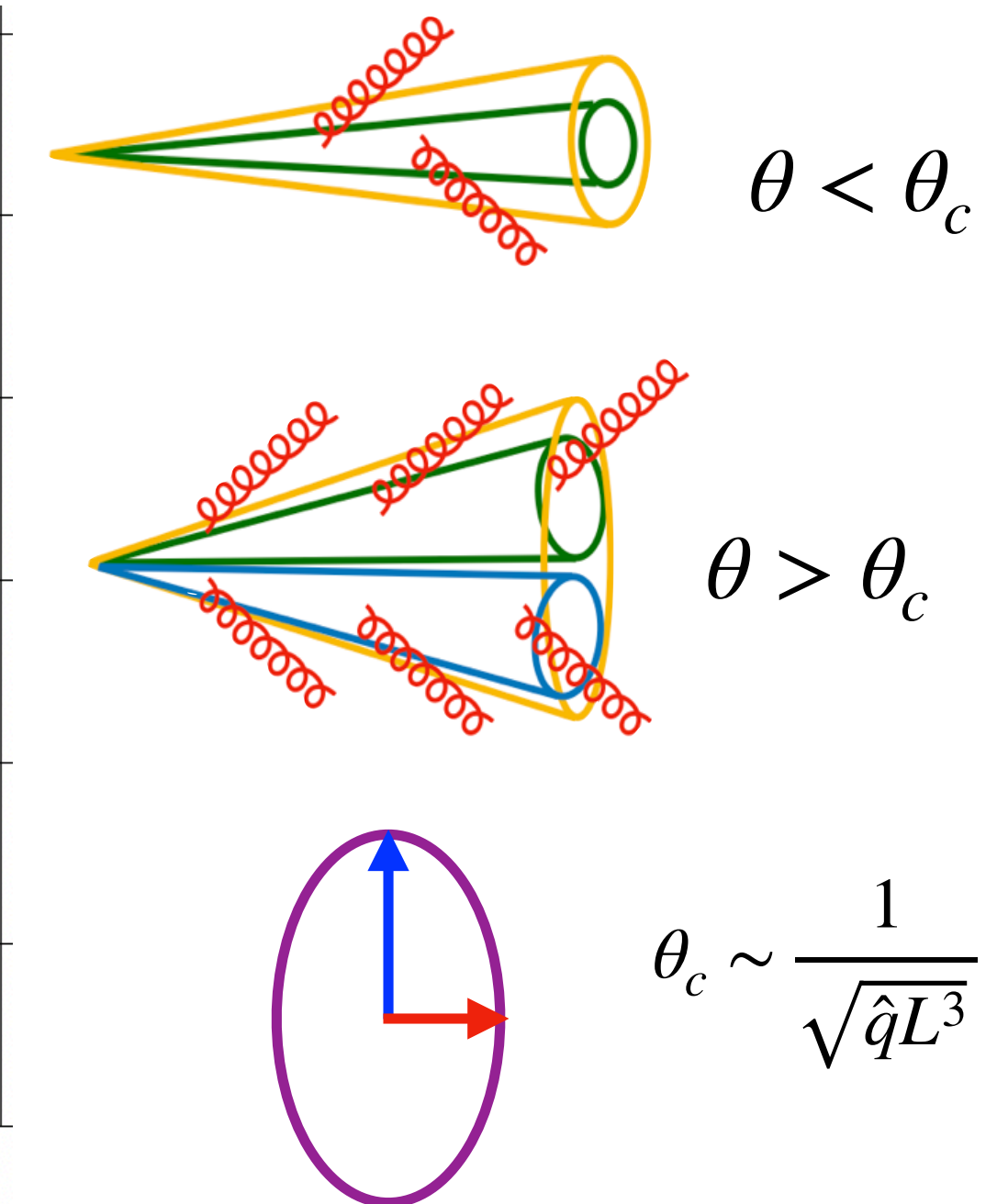
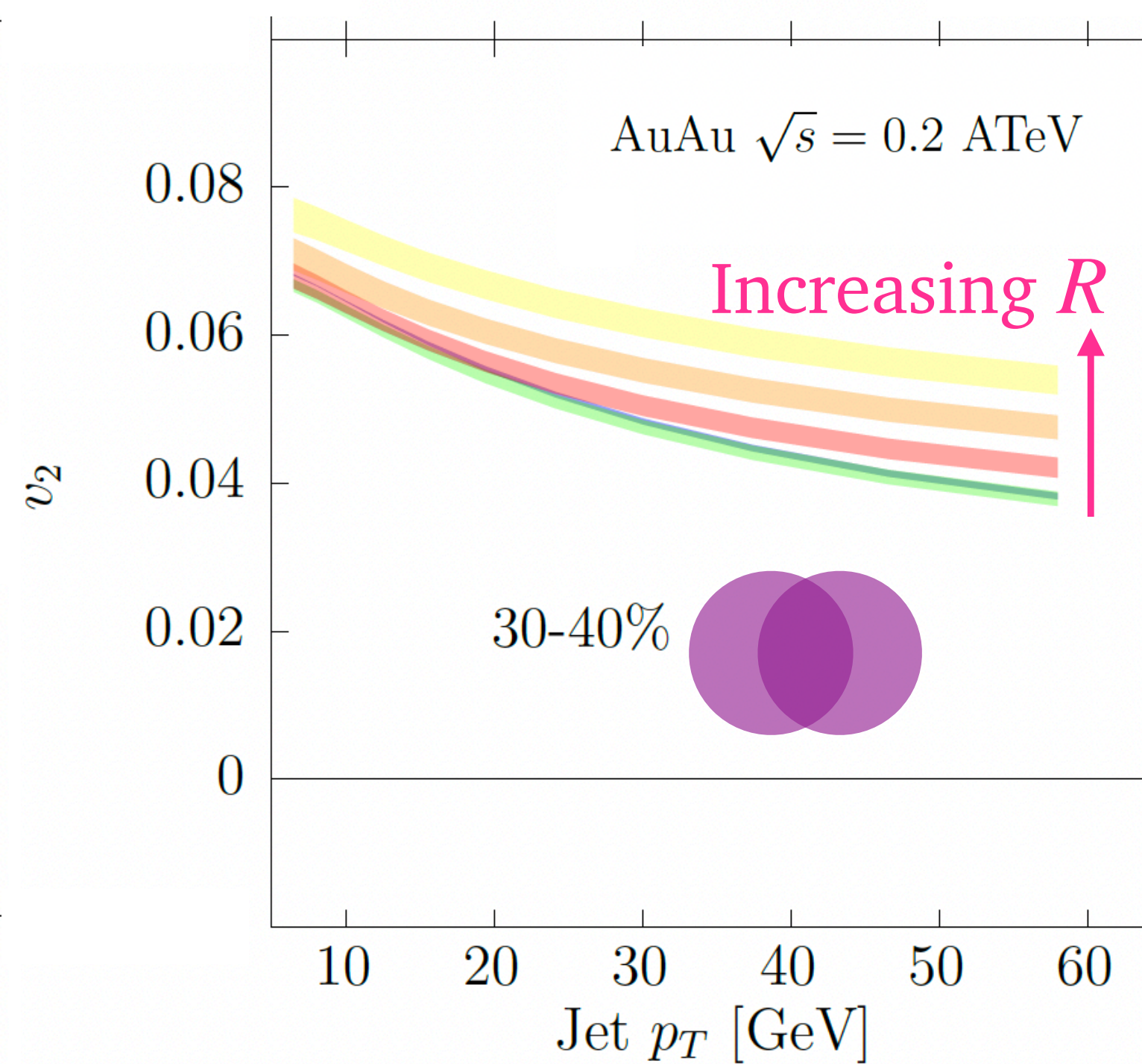
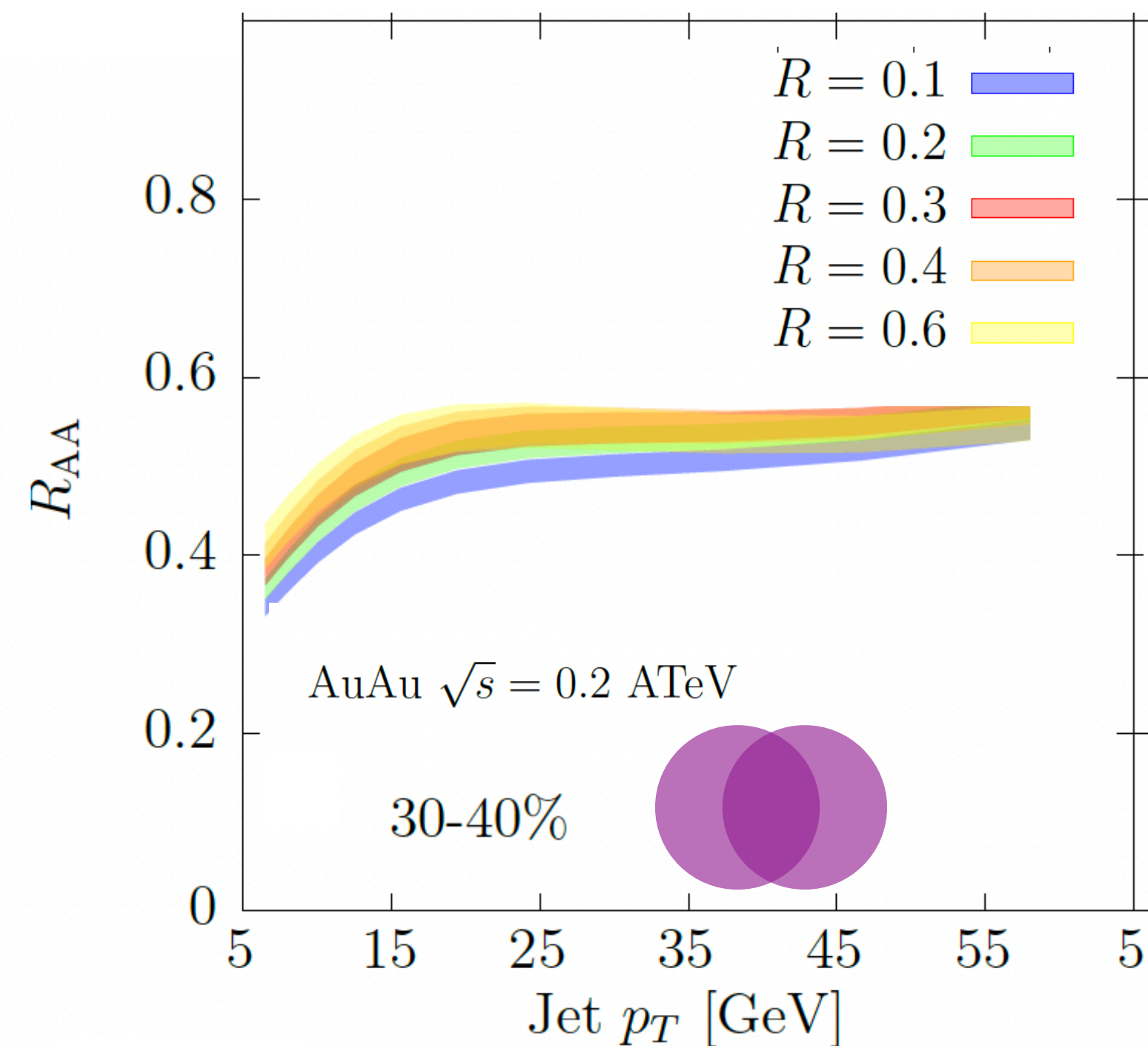
Jets narrowed by the QGP or wider jets less likely to survive?



# Inclusive jets and $v_2$

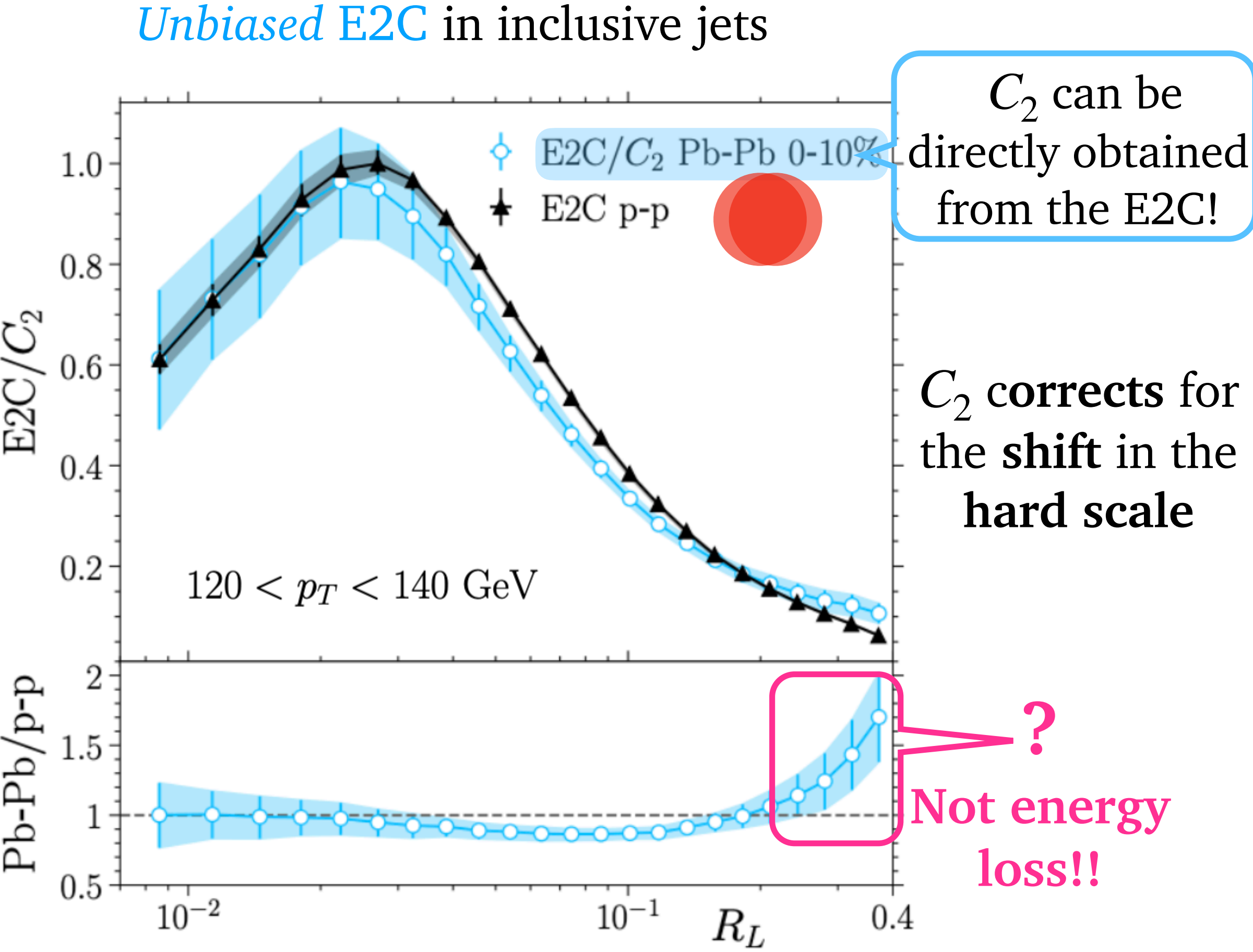
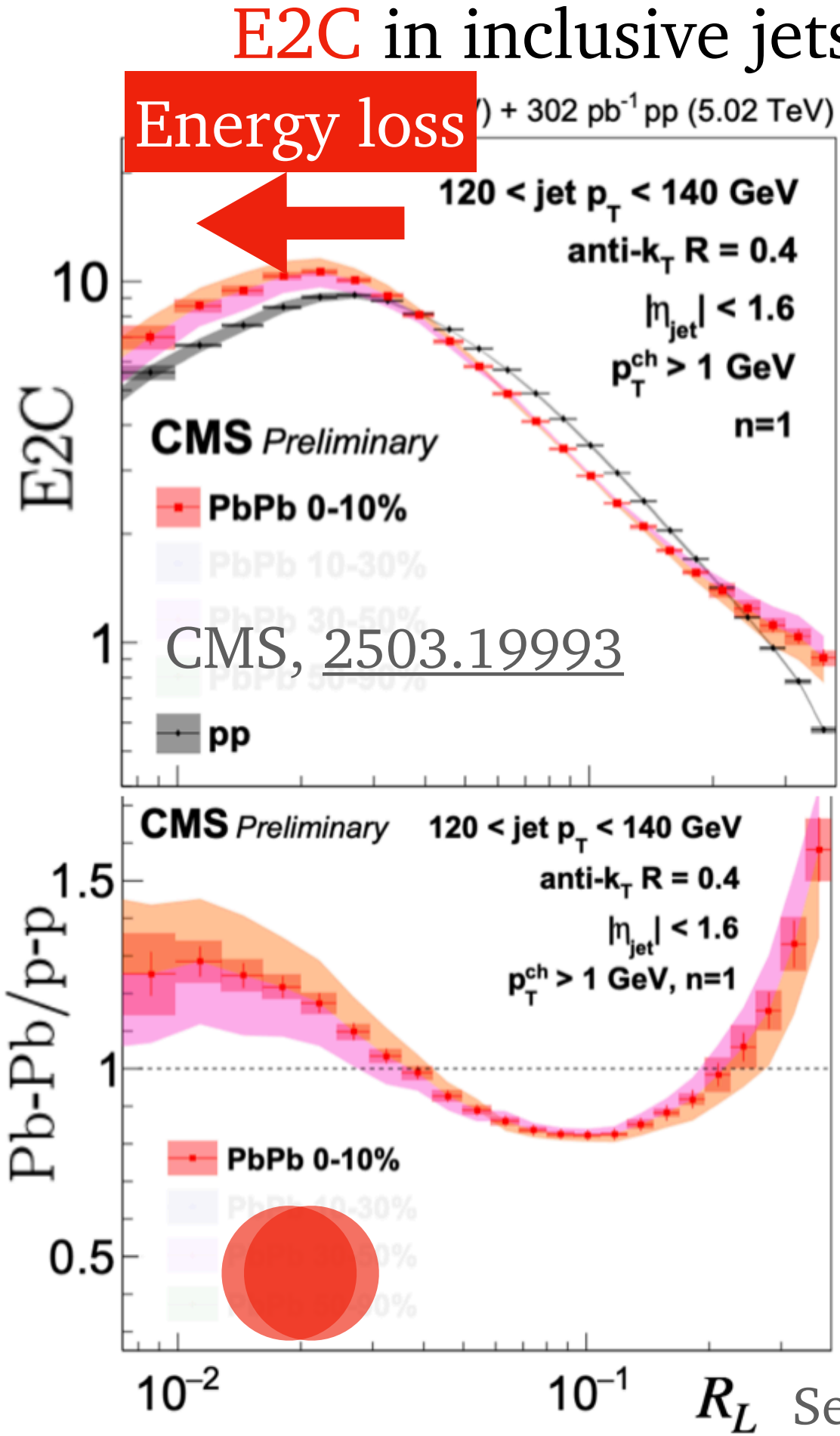
Mehtar-Tani, Pablos, Tywoniuk, [2402.07869](#)  
[2101.01742](#)

Jet  $v_2$ : stronger dependence on the dynamics of color coherence



# E2C in PbPb

CA, Holguin, Kunnawalkam Elayavalli,  
Viinikainen, [2409.07514](#), [2409.07526](#)



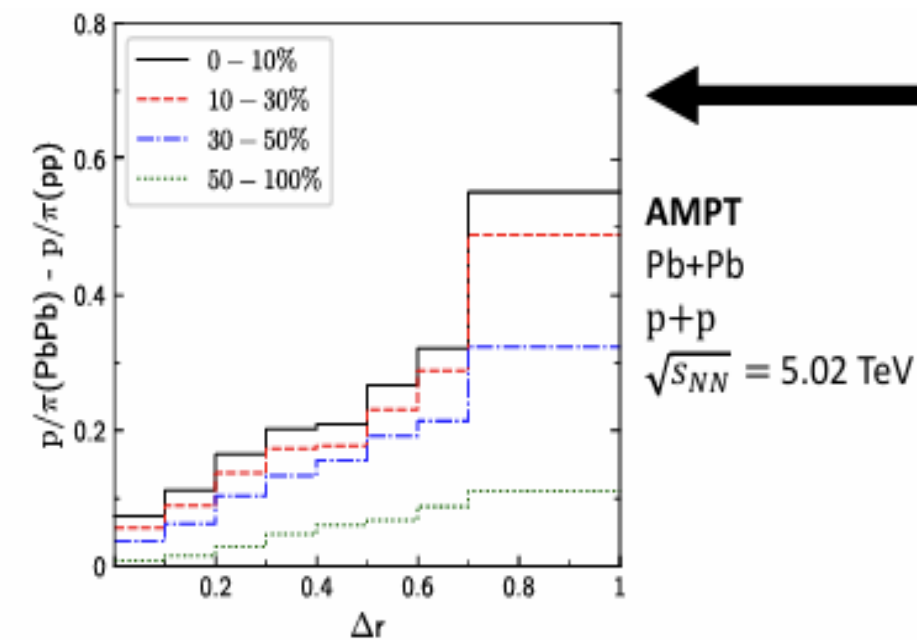


Au

# Baryon/Meson Ratio

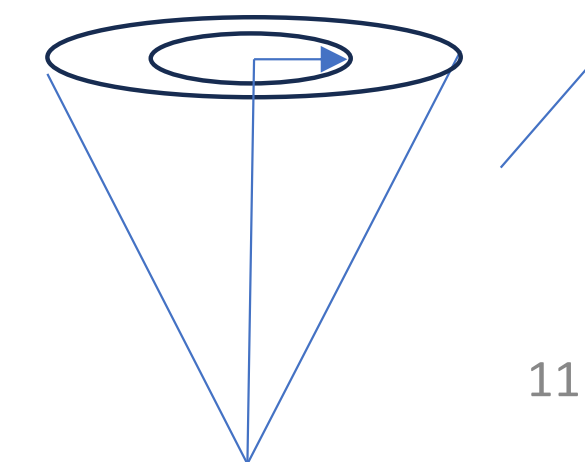
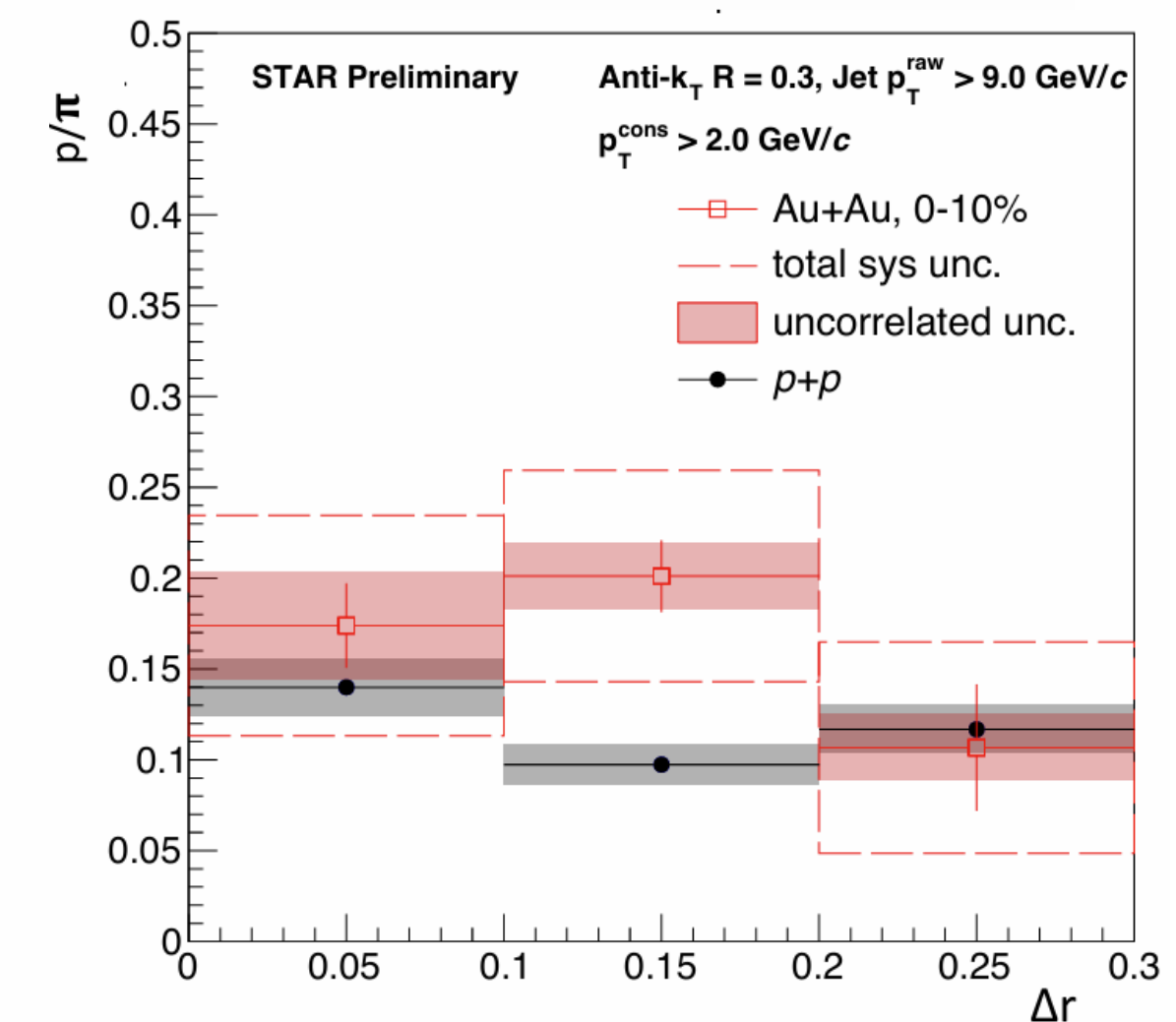
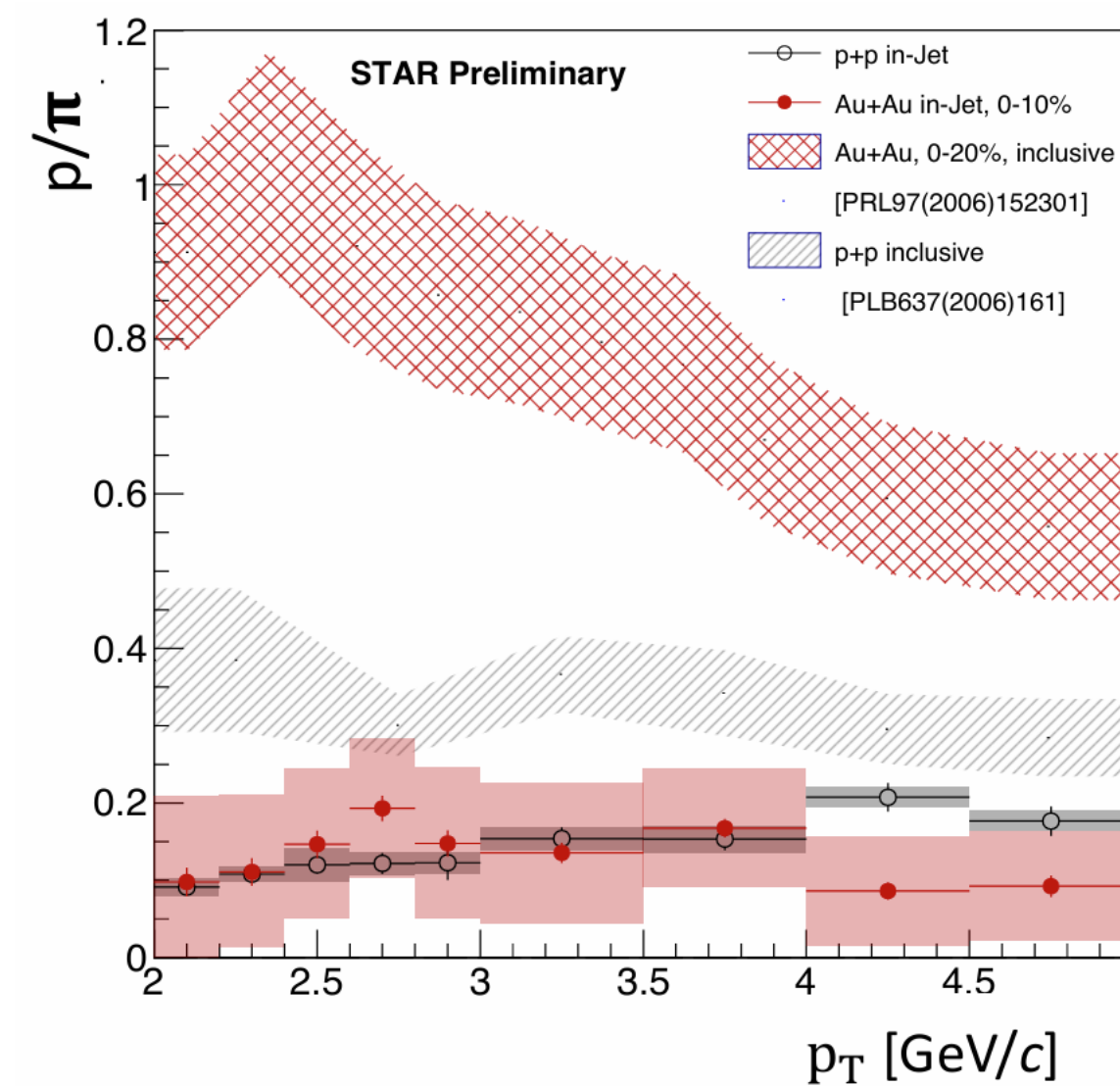
- Is jet hadrochemistry modified by QGP?
  - Coalescence hadronization
  - Jet wake
- **No baryon enhancement observed over momentum range scanned, except hint at  $\Delta R = 0.15$**

Gabe Dale-Gau: QM2025



AMPT simulations:  $p/\pi$  is modified for jets in QGP

A. Luo et al. [PLB(2022)137638]



5/21/2025

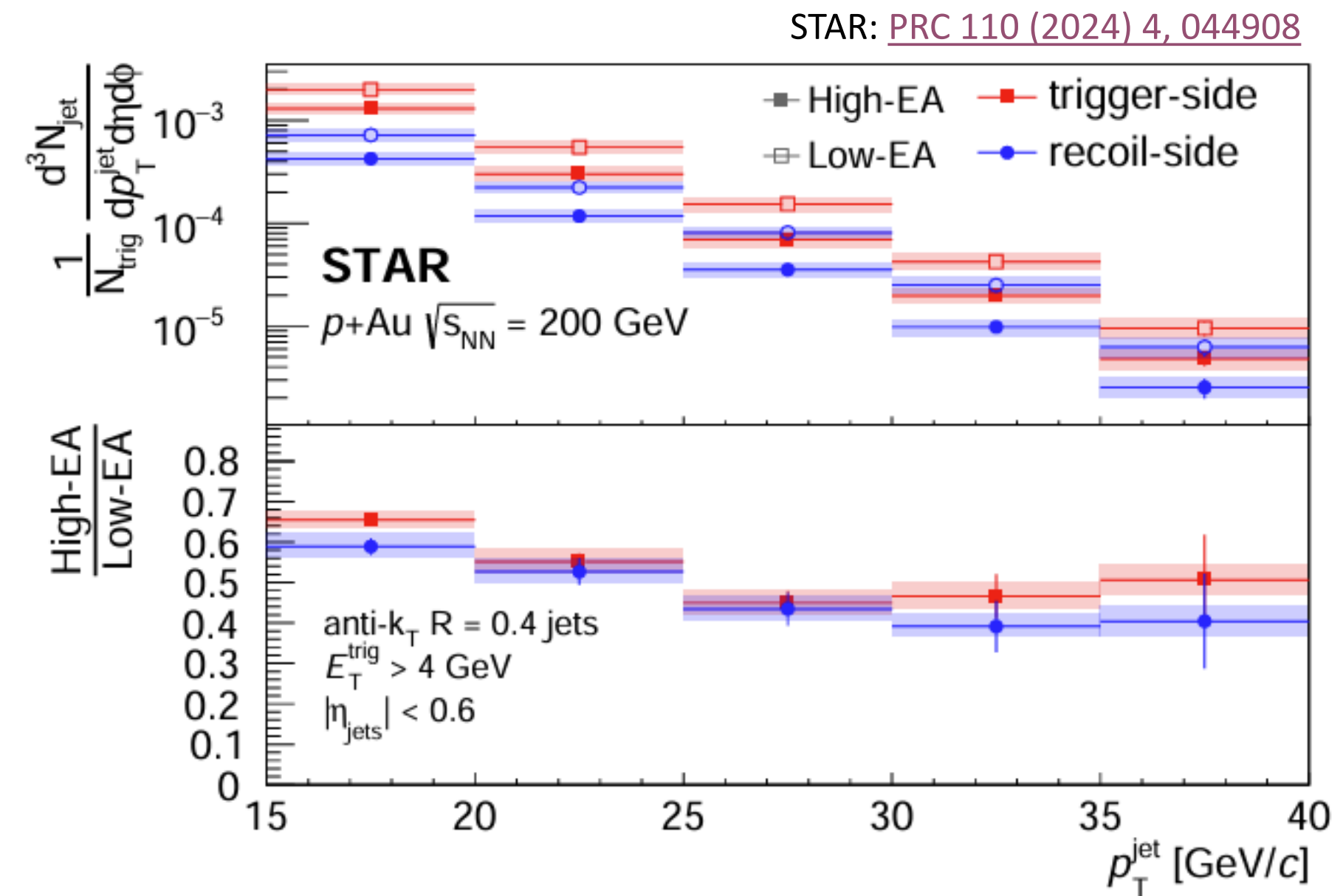
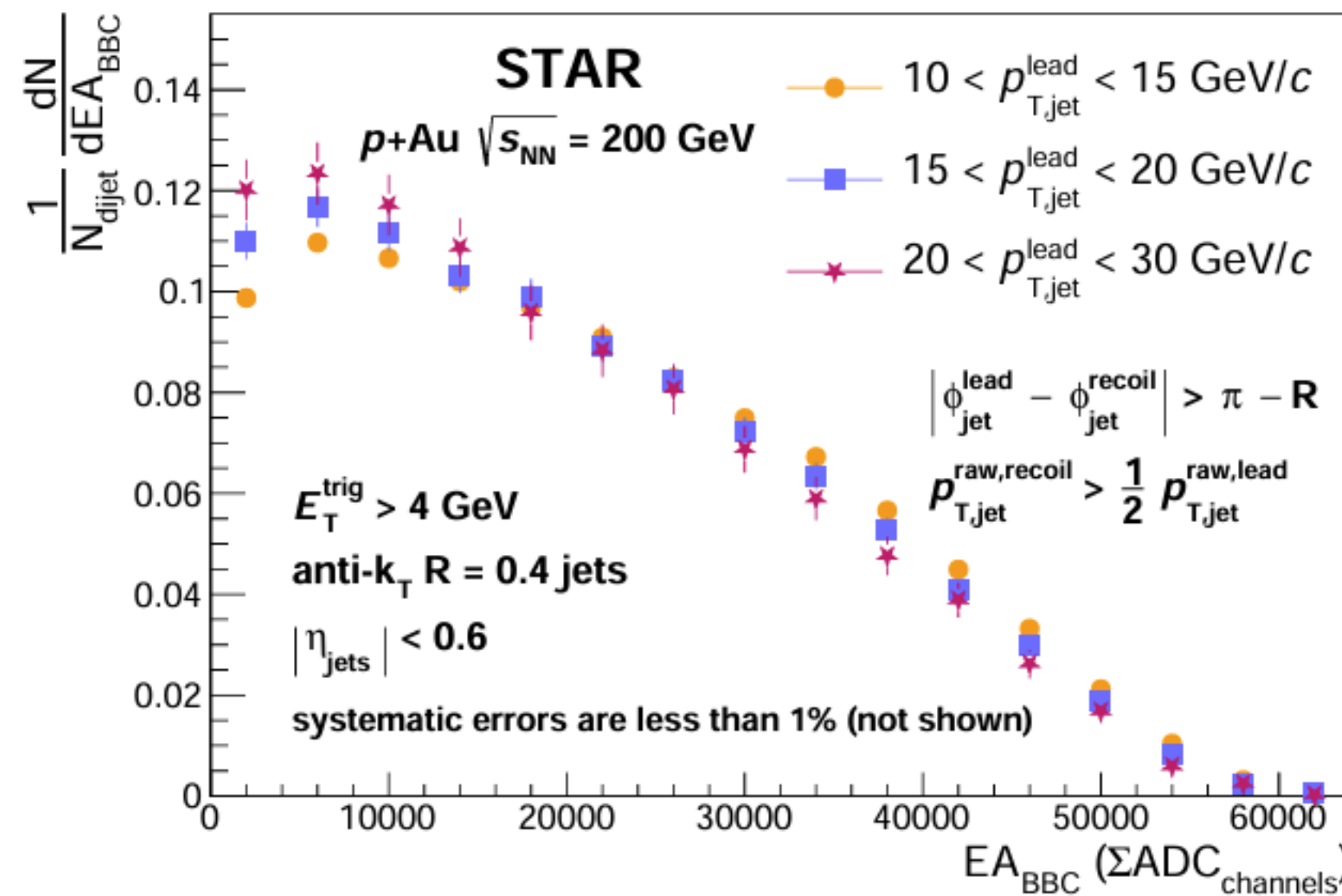
RHIC/AGS Users' Meeting - Tamis

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Measuring hadrochemical equilibration (or not) of jets in A+A

# Quenching Disfavored in p+Au

- Suppression seen in high event activity p+Au events, but quenching disfavored as explanation
- Potentially due to EA- $Q^2$  anti-correlation



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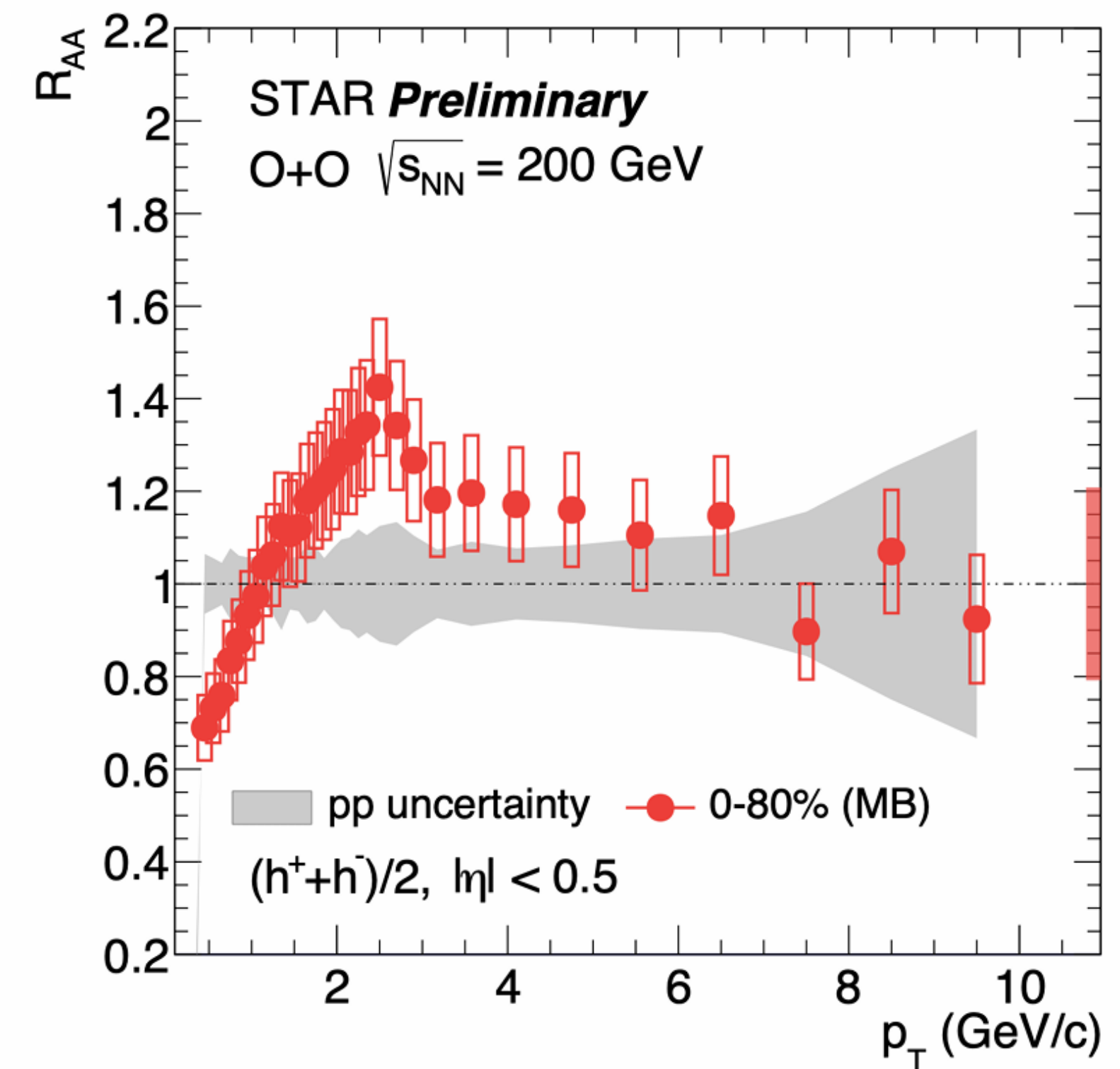
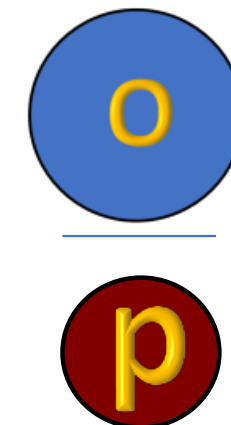
Modified jet production in central p+Au but from selection/bias effects





## O+O Hadron $R_{AA}$

- Charged hadron  $R_{AA}$  consistent with unity at large momentum
- Work is being done on p+p baseline for jet  $R_{AA}$  comparison

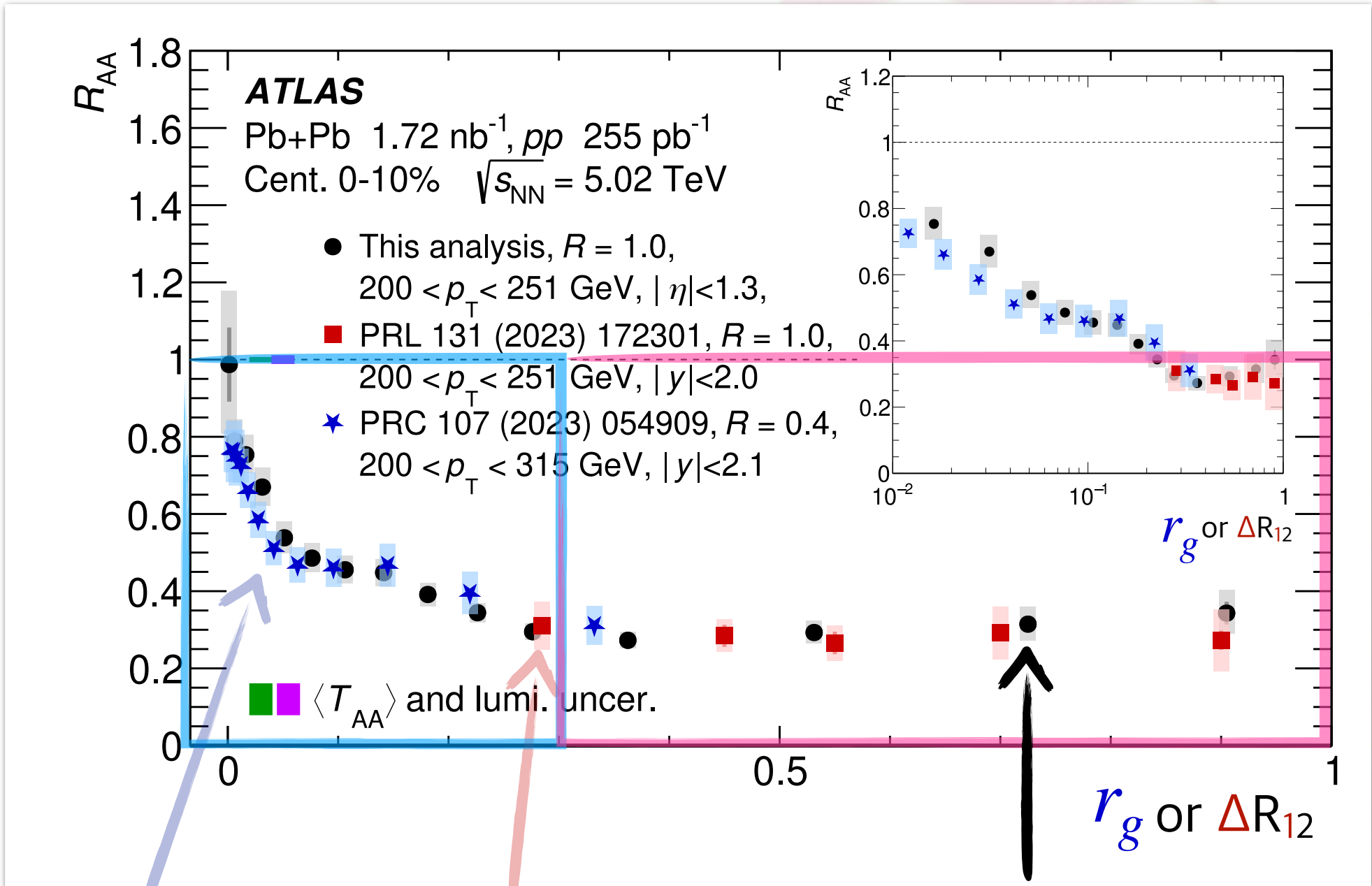
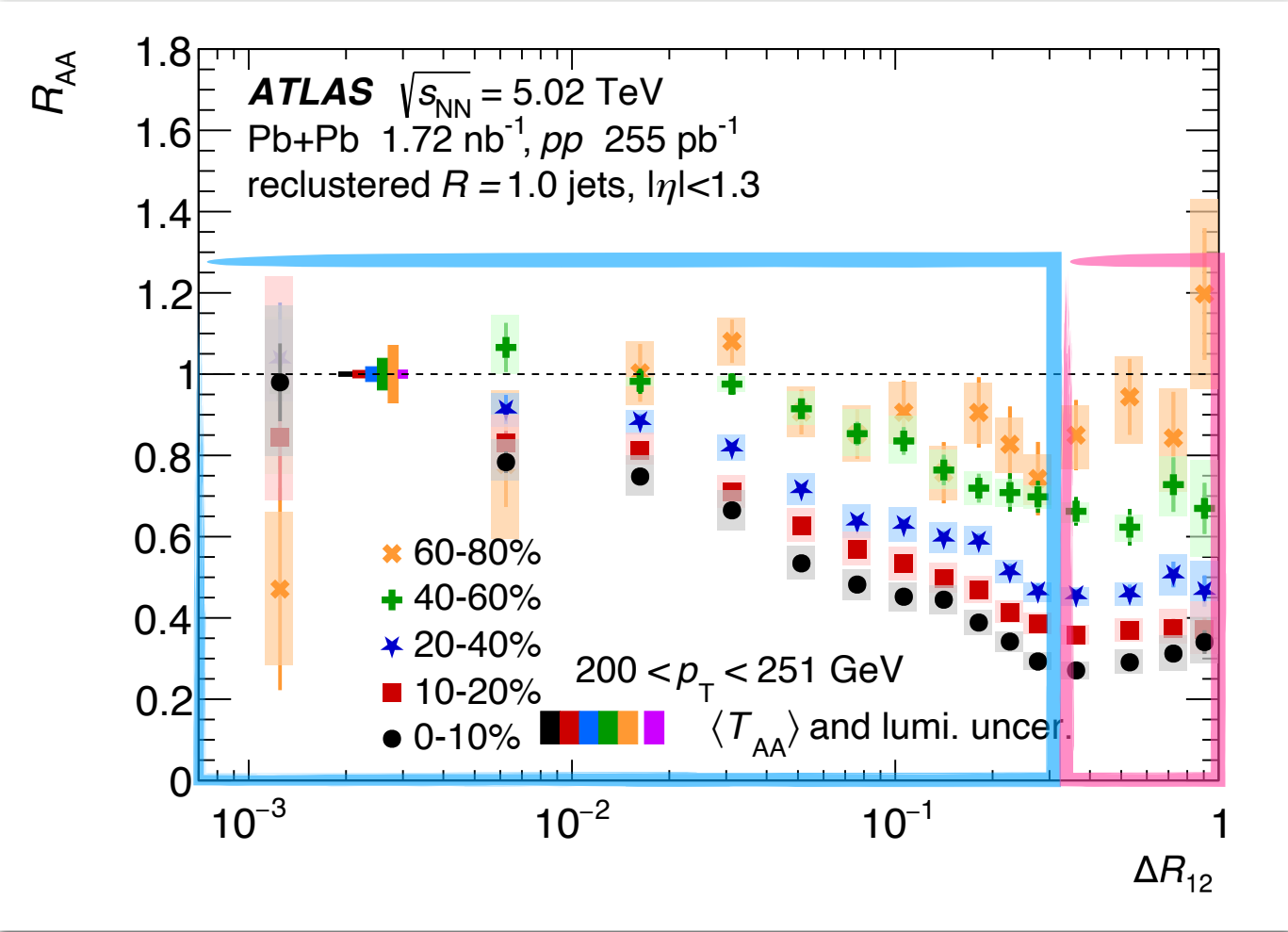


Search for energy loss in O+O — here the minimum bias charged hadron  $R_{AA}$

# ATLAS jet substructure: Episode 3

arXiv:2504.04805

Angular separation  $\Delta R_{12} = \sqrt{\Delta y_{12}^2 + \Delta \phi_{12}^2}$



- Same  $R = 1.0$  jets as **PRL 131 (2023) 172301**, with substructure evaluated using tracks with  $p_T > 4$  GeV and SoftDrop ( $z_{\text{cut}} = 0.15, \beta = 0$ )

- Sharp  $R_{AA}$  decrease with  $\Delta R_{12}$ , followed by flattening behavior
- New analysis provides a **bridge** between the previous two measurements

Standard size ( $R=0.4$ ) de-clustered & groomed jets; Substructure with tracks (●) & calo-clusters (□)

Large  $R$  jets ( $R=1.0$ ) re-clustered; Substructure with  $R=0.2$  jets

Large  $R$  jets ( $R=1.0$ ) re-clustered; Substructure with tracks

Riccardo Longo

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21st May 2025

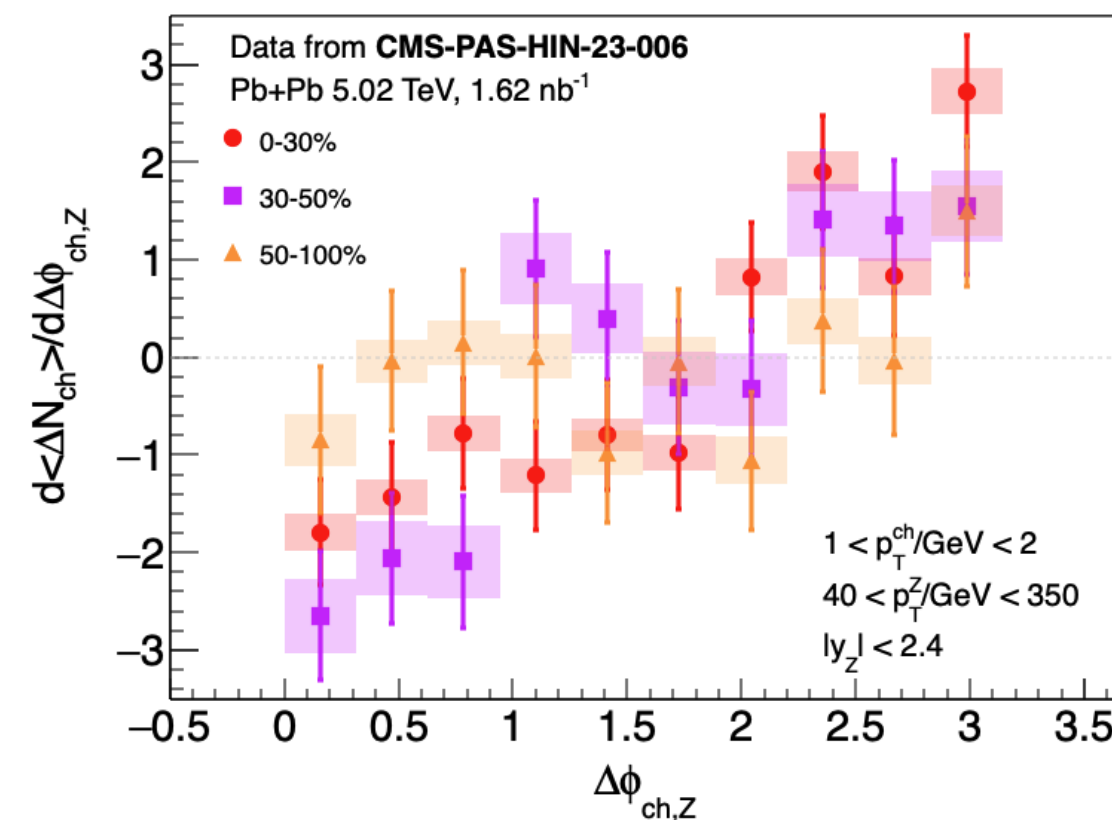
Multiple techniques to measure jet sub-structure (tracks, sub-jets, PFlow)



# Diffusion wake: CMS Z+h results

CMS-PAS-HIN-23-006

But other interesting features still to be understood...



...e.g. centrality ordering

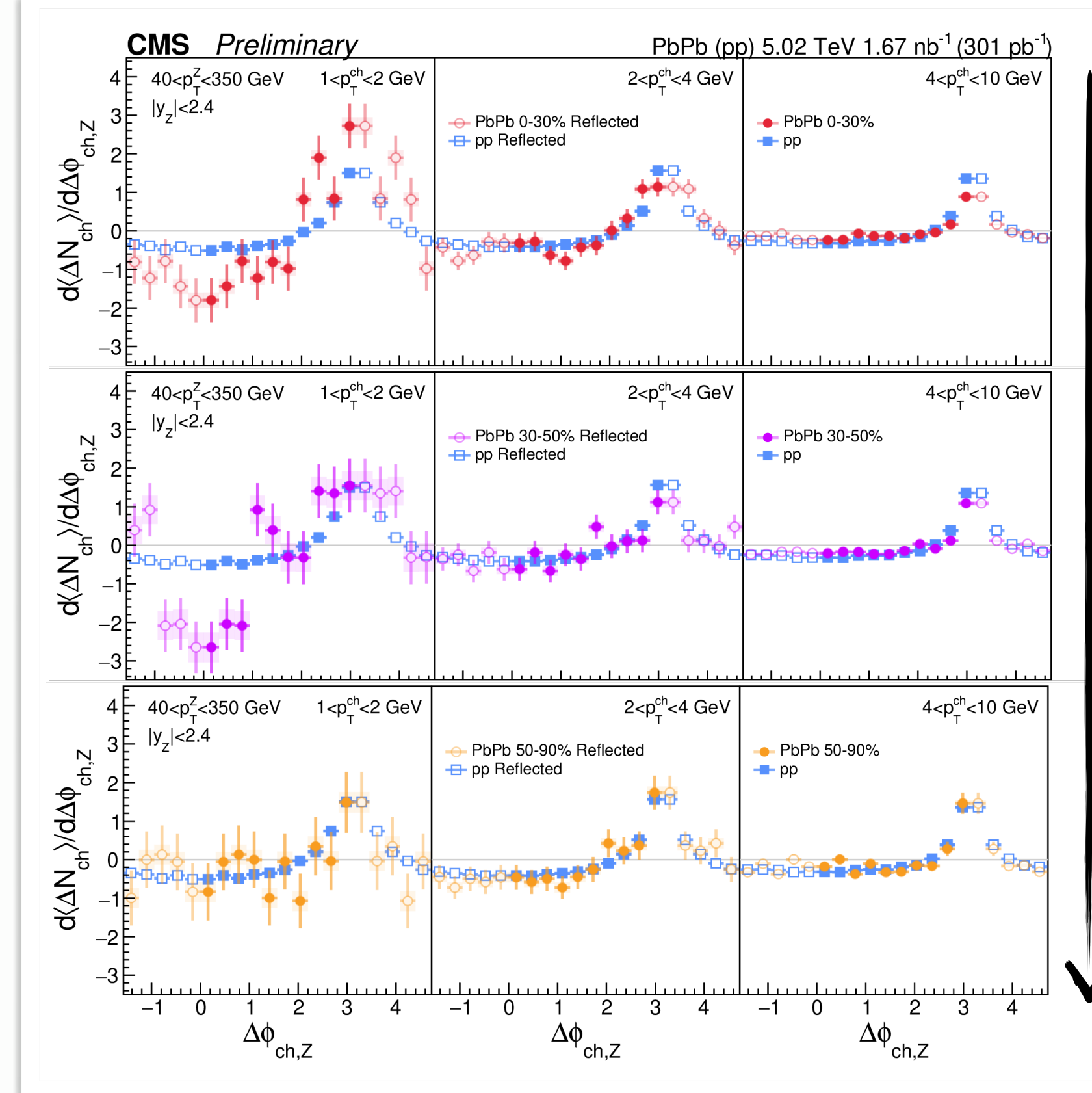
No data from ATLAS at different centralities for comparison

Can models capture also this behavior?

Do model describe other standard candles?

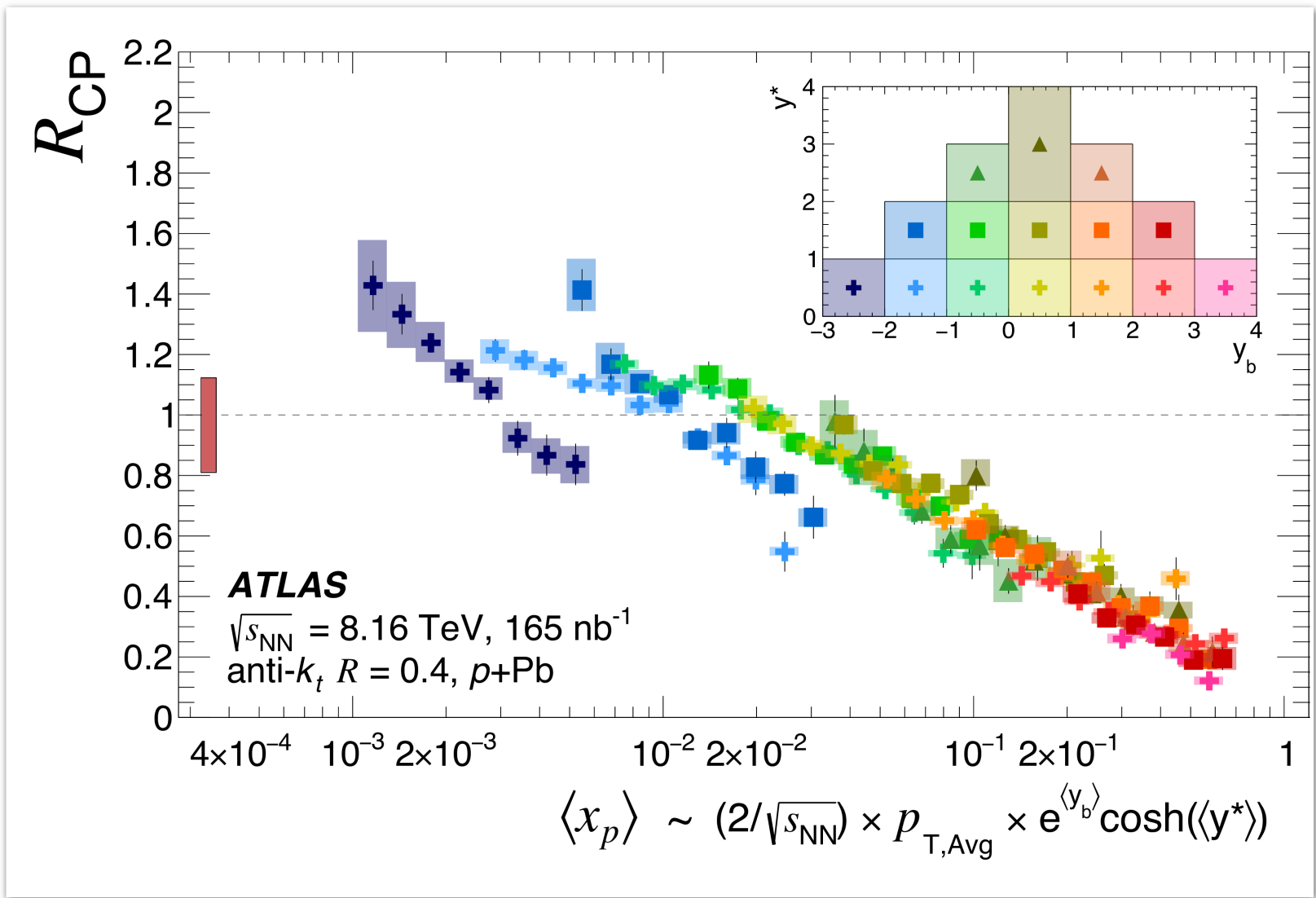
=> Plenty of questions to answer with Run 3 high statistics samples!

Hadron  $p_T$  selection

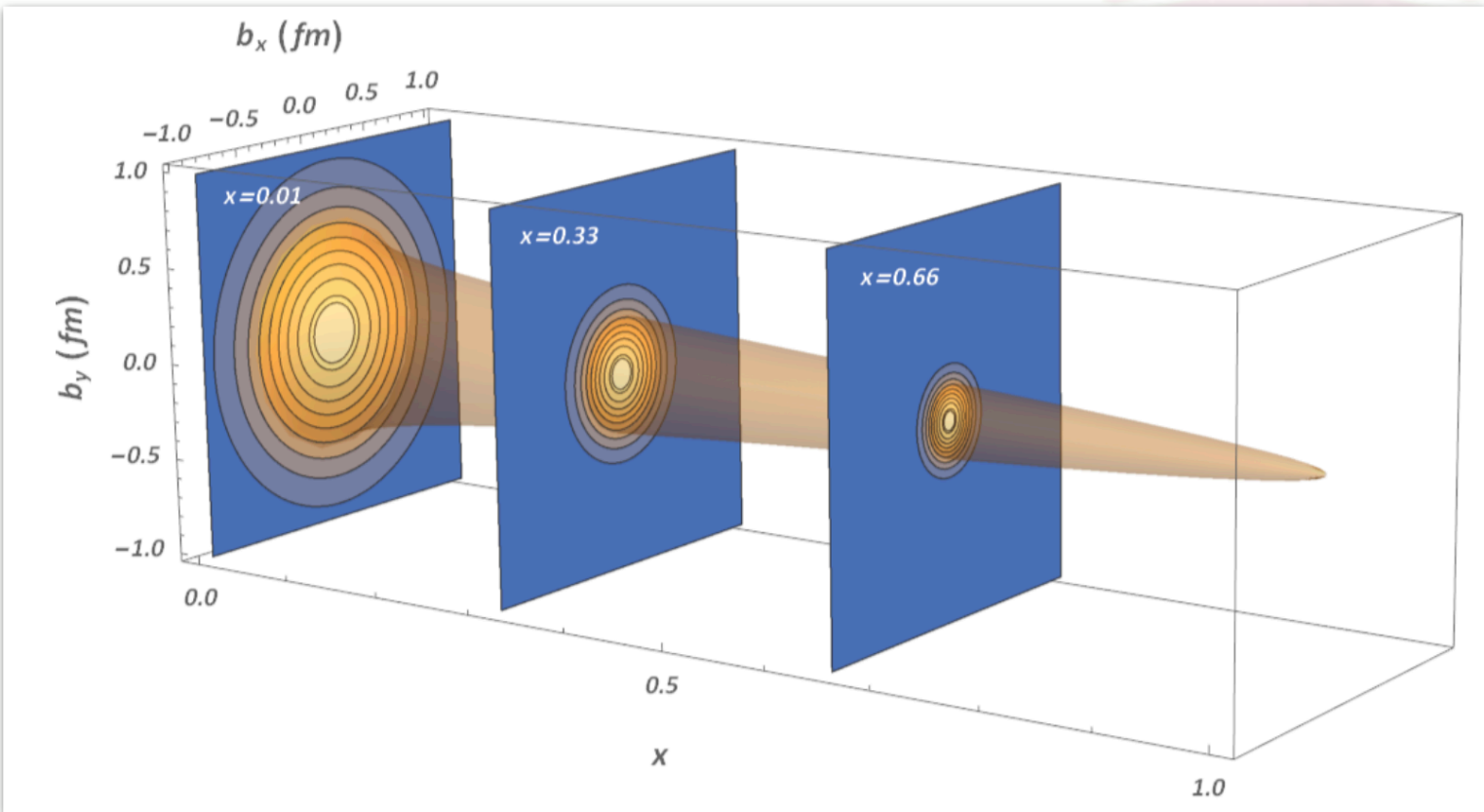


# Effect of proton configuration in p+A

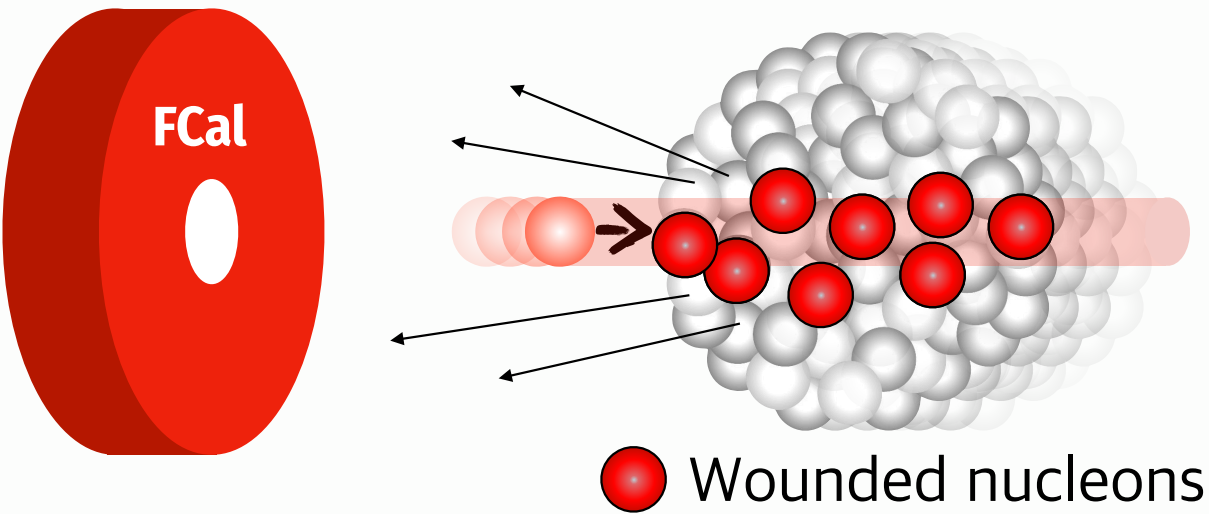
Are we looking at GPDs from another corner?



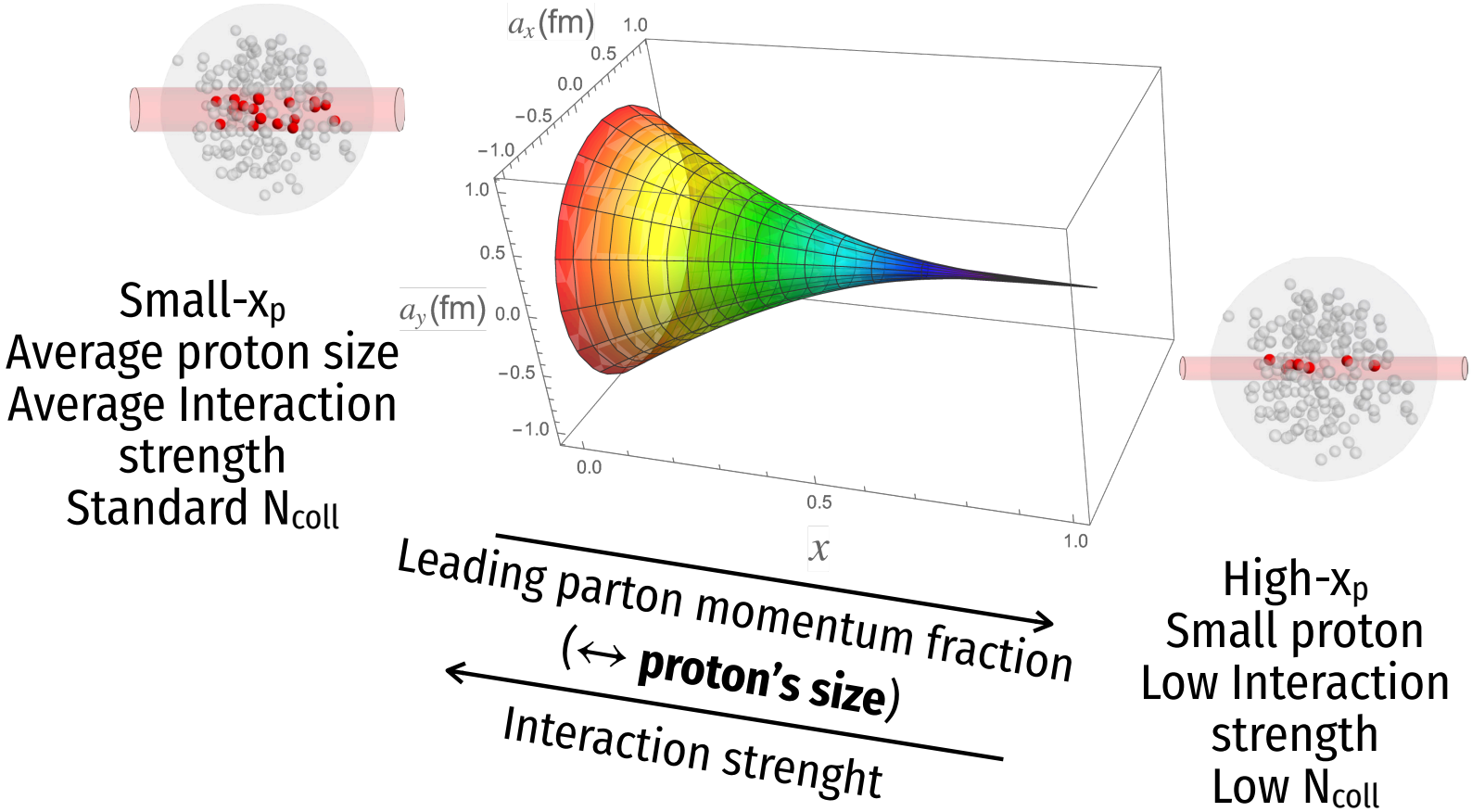
Potential point of contact with the EIC!



Dupré et al.,  
PRD 95 (2017)  
011501



● Wounded nucleons

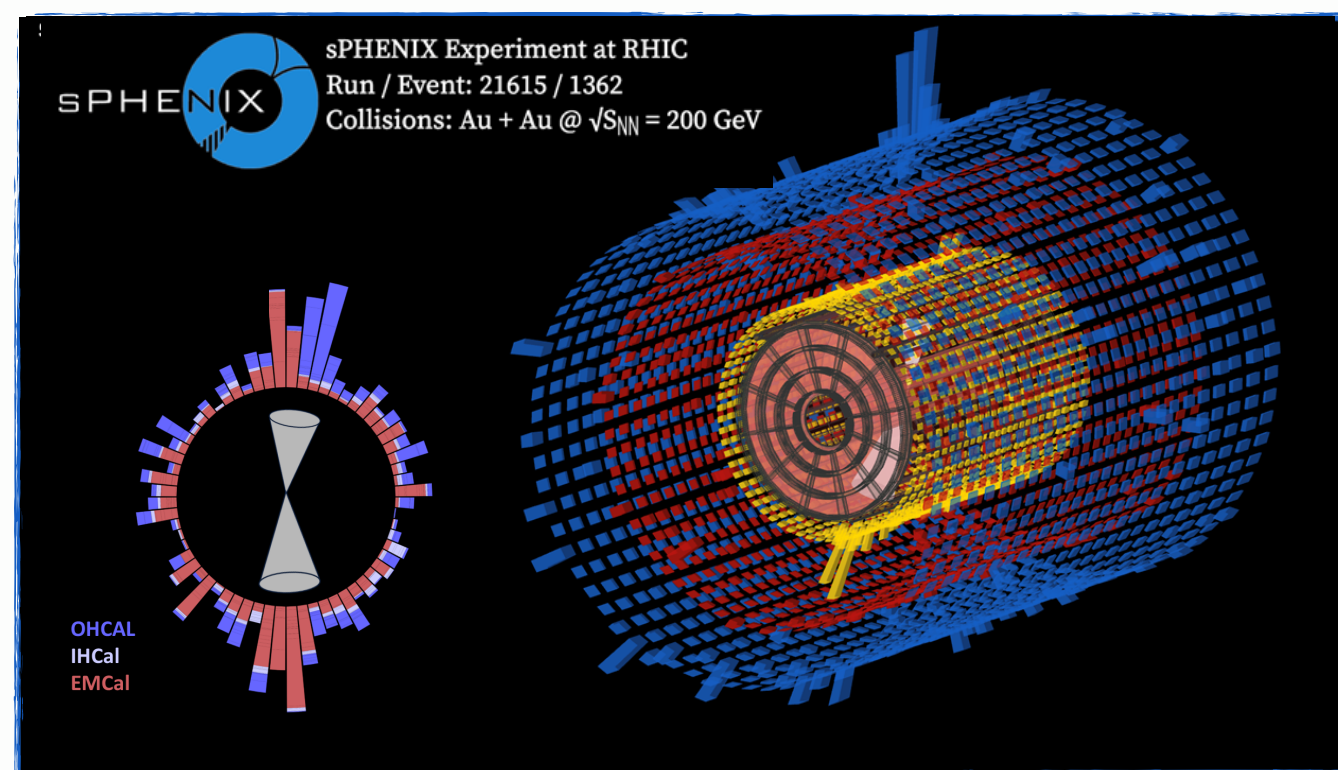


Alvioli et al., PRD 98 (2018) 071502  
Brodsky et al., MDPI Physics 4 (2022) 2, 633-646

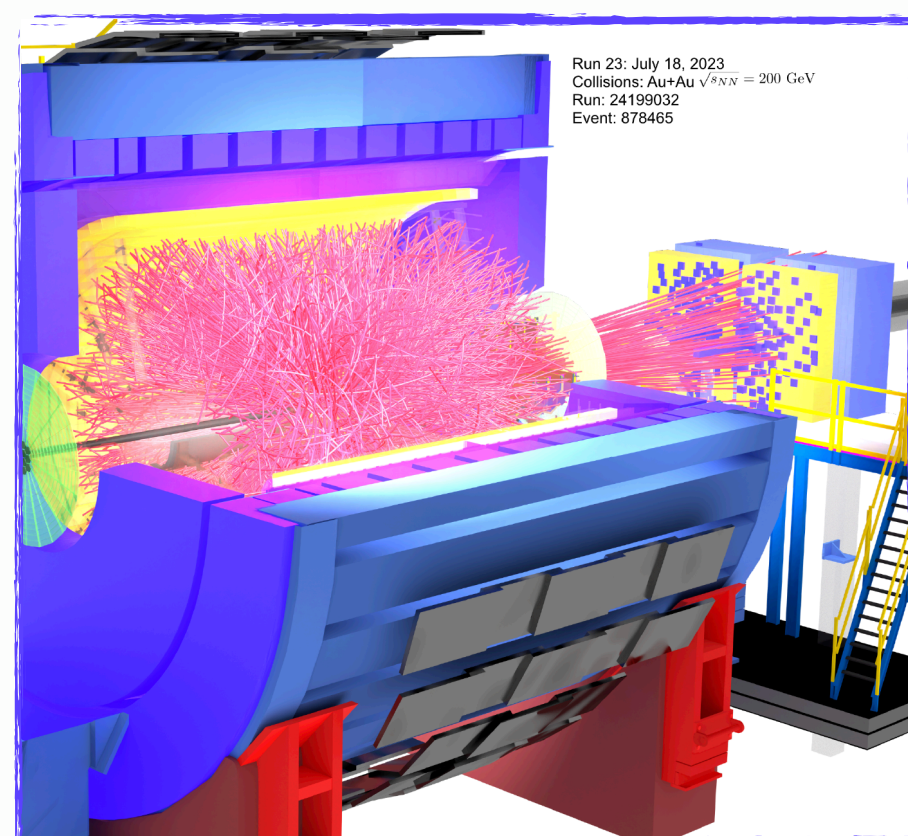
21st May 2025



# A last, and personal, opinion ....

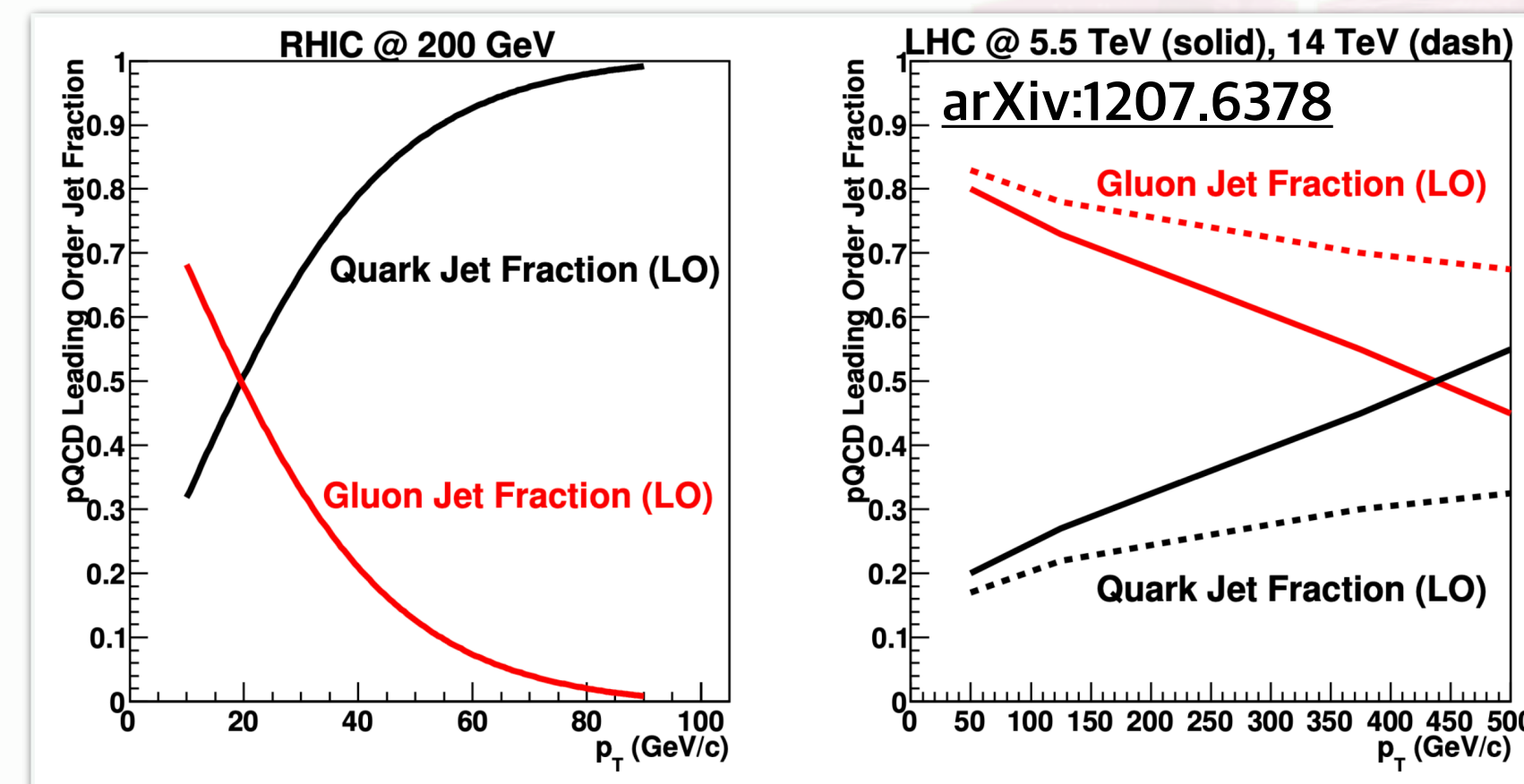


After outstanding efforts, sPHENIX is now shining!



STAR Forward Upgrade is a major leap in the experiment capabilities for p+A

- Jets @ RHIC have very different q/g mixing compared to LHC  
→ Ideal to study parton energy loss in a complementary regime
- Great opportunities are available for cold nuclear matter studies, color-fluctuations measurements, low-x investigations in p+Au... it would be invaluable to have a p+Au run before RHIC shutdown!
- I am firmly convinced we would regret not taking this opportunity



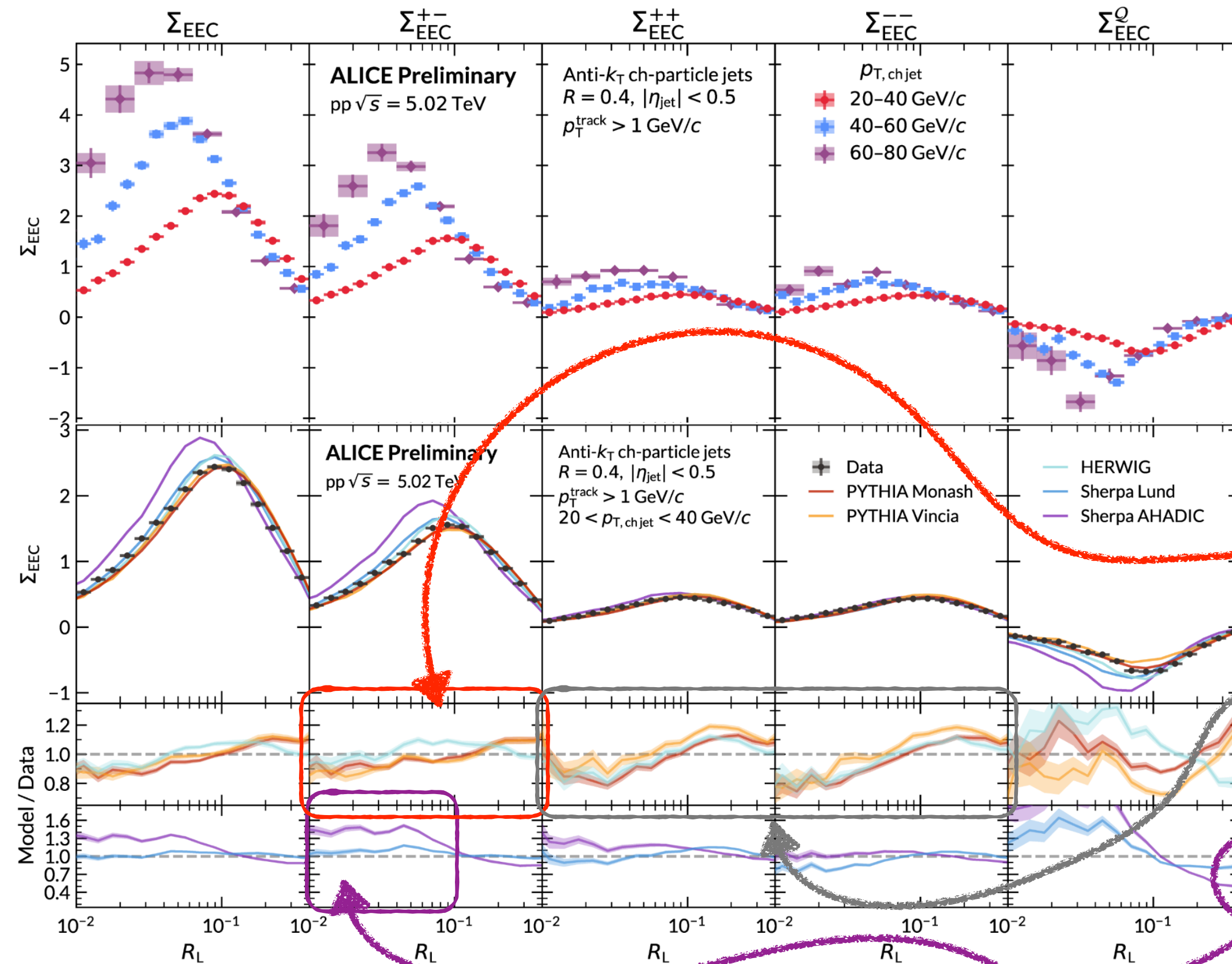


# Charged EEC

ALICE

T. Hwang QM 2025

$$\Sigma_{\text{EEC}}^{\text{Q}}(R_{\text{L}}) = \frac{1}{N_{\text{jet}}} \int dR \sum_{i,j \in \text{jet}} q_i q_j \frac{p_{\text{T},i}}{p_{\text{T}}^{\text{jet}}} \frac{p_{\text{T},j}}{p_{\text{T}}^{\text{jet}}} \delta(R - R_{\text{L}})$$



- Correlations of unlike-and like-sign pairs show familiar features.
- Charge-weighted EEC is overall negative: more unlike-sign pairs.
- **Data favor string-breaking models?**
- Model differences tell us:
  - **PYTHIA** and **HERWIG** differ most in unlike-sign EEC
  - Parton shower: **Monash** and **Vincia** differ most in like-sign EEC
  - Hadronization: **Lund** and **AHADIC** differ most in low- $R_L$  unlike-sign

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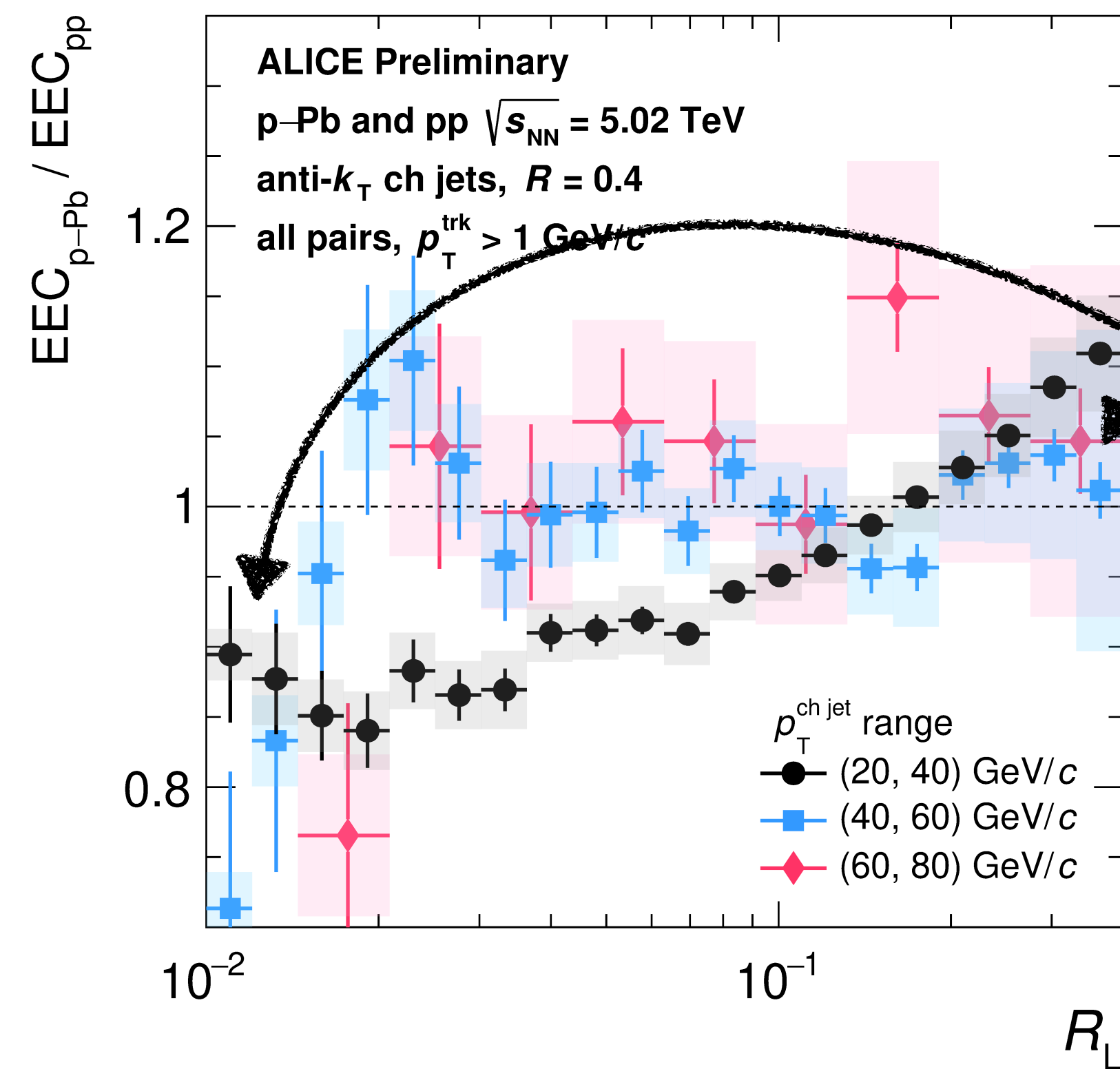
# Jets in $p+p$ as probes of parton shower & hadronization models



## pPb / pp ratio

ALICE

A. Nambrath QM 2025



- pp baseline also background subtracted
- Higher jet  $p_T$  does not show modification
- $20 < p_{T,jet} < 40$  GeV/c ratio shows:
  - Small-angle region: ~10% suppression
  - Large-angle region: ~10% enhancement

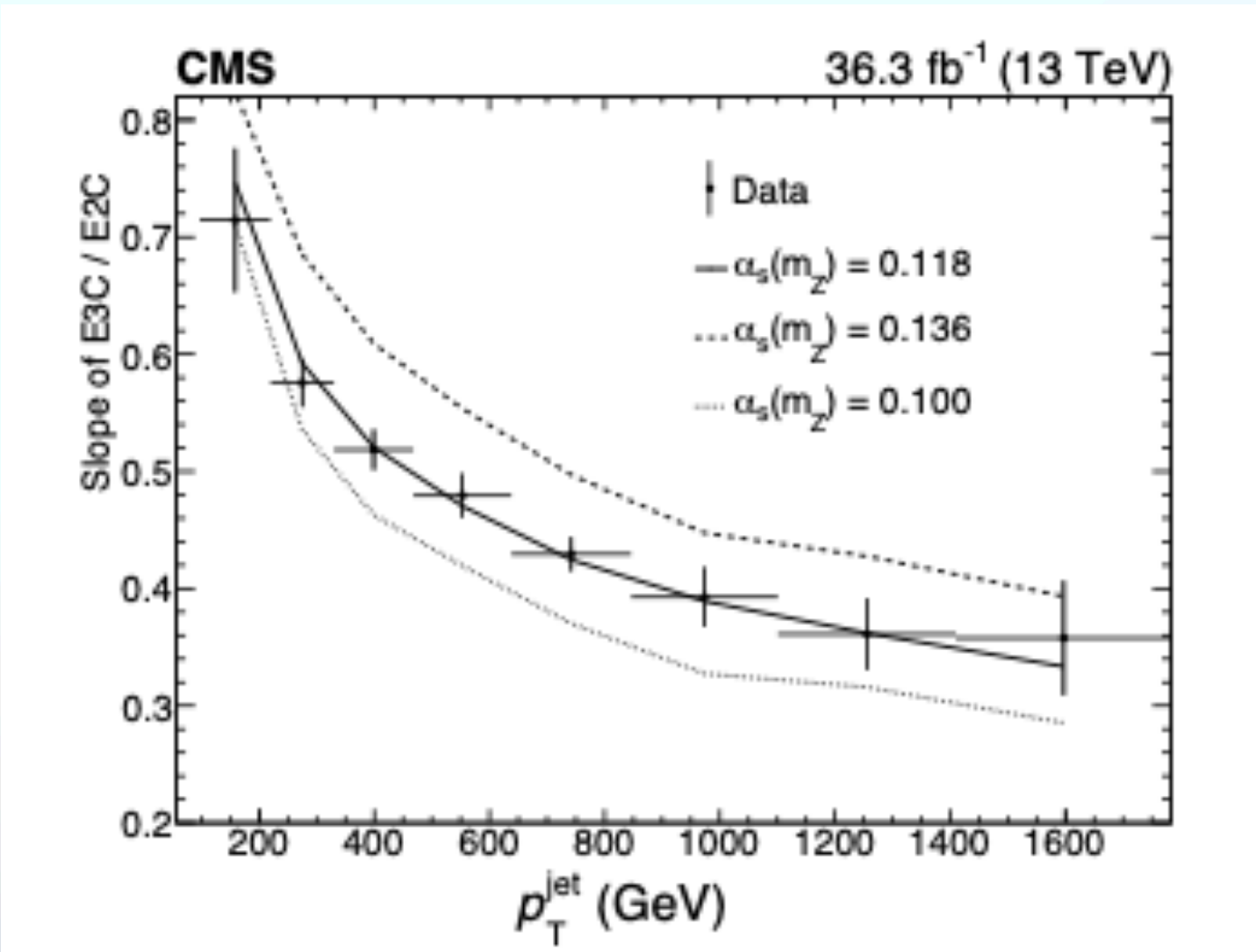
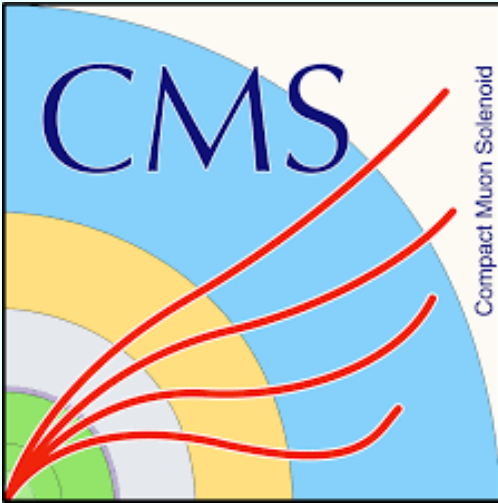
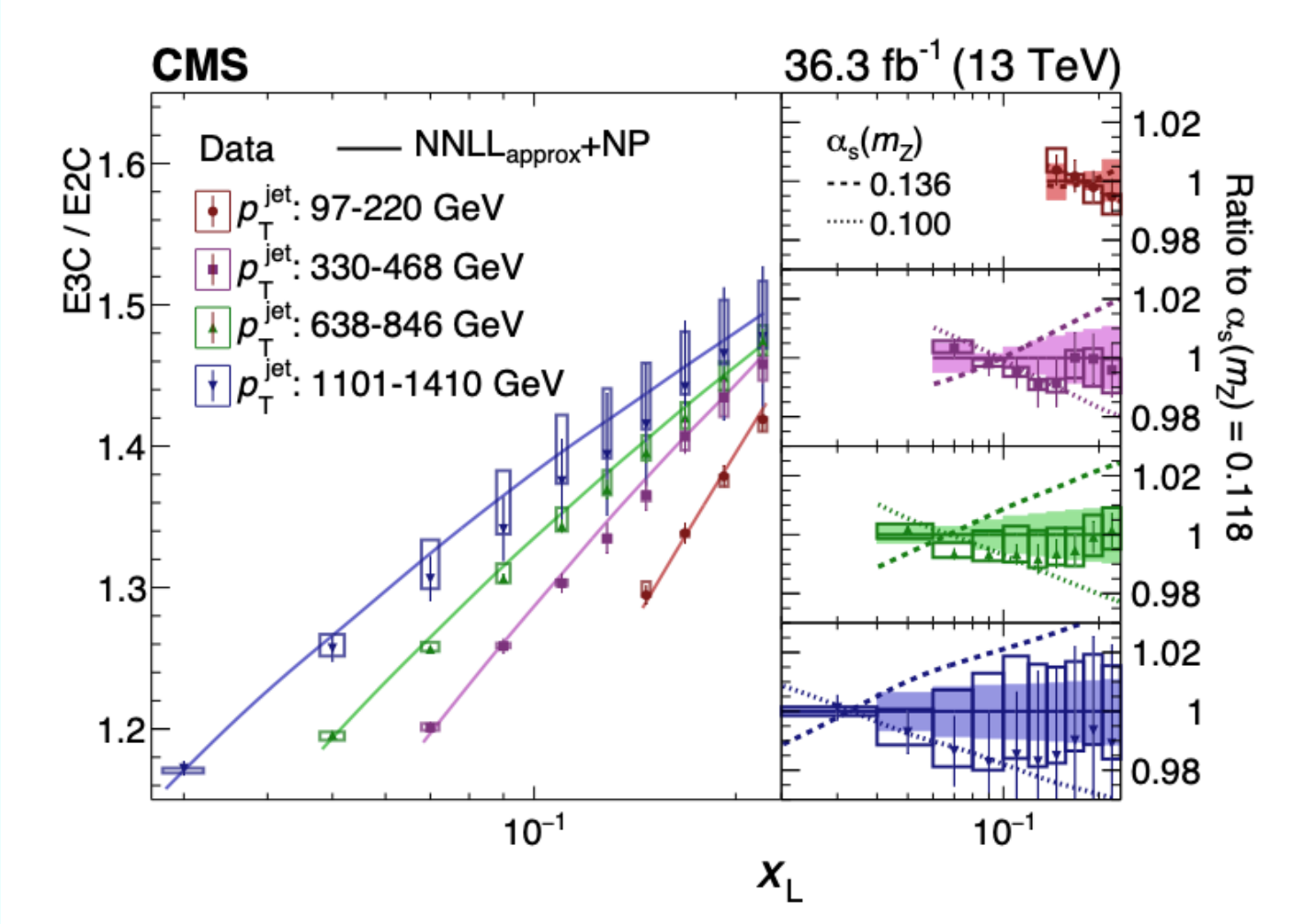
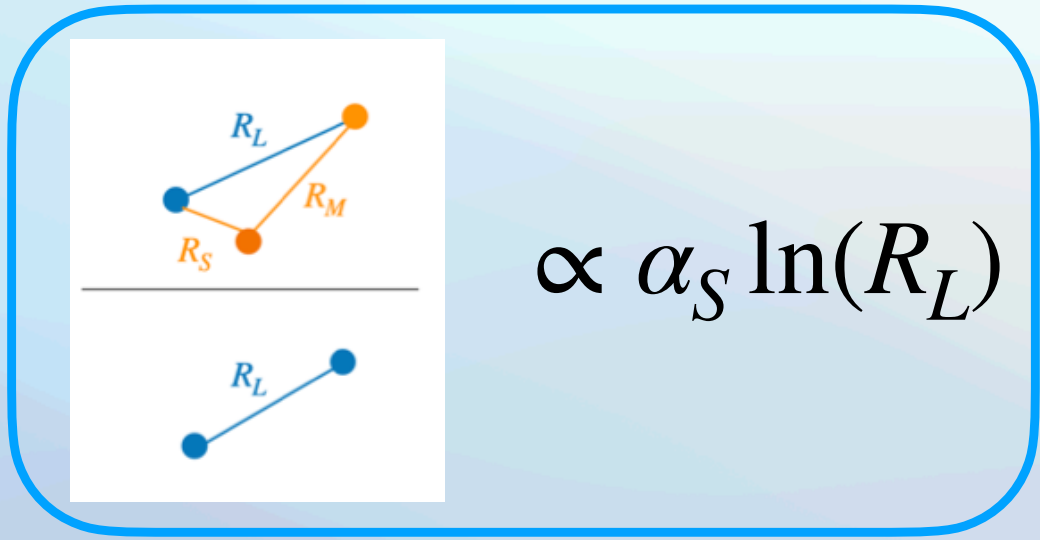
What is responsible for this modification??

Surprising modification of EECs in p+Pb, still working to understand

## E3C / EEC ratio

CMS

- Perturbative regime:
- Change in slope of E3C / EEC with jet  $p_T$  is sensitive to the running of the strong coupling constant!
- Slope  $\sim R_L^{\gamma_3-\gamma_2} \propto \alpha_s \ln(R_L)$



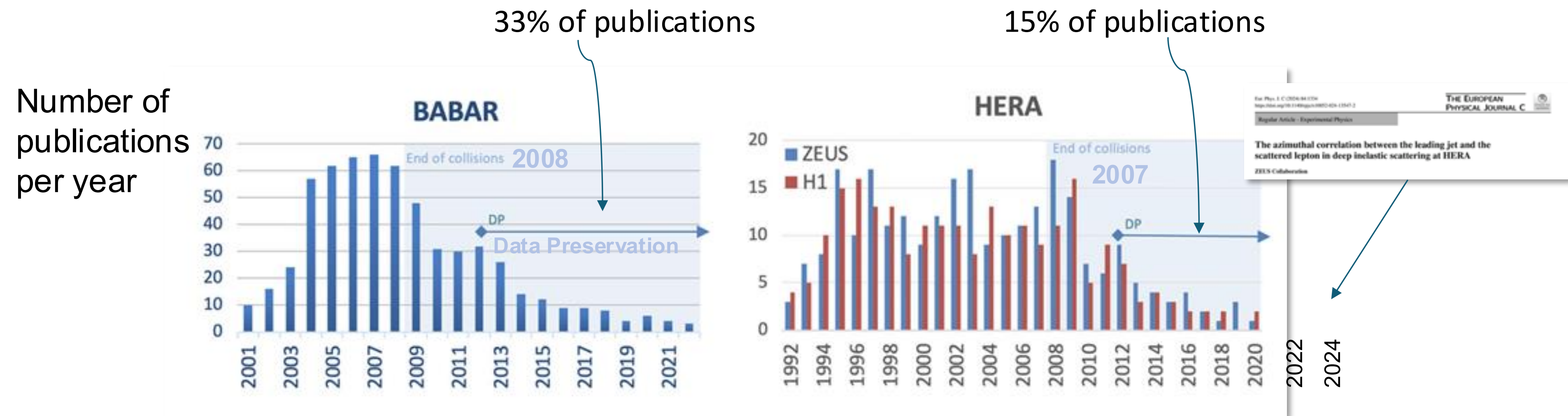
arXiv:2402.13864

$$\alpha_s(m_Z) = 0.1229^{+0.0014}_{-0.0012}(\text{stat})^{+0.0030}_{-0.0033}(\text{theo})^{+0.0023}_{-0.0036}(\text{exp})$$

Using 3-point EECs to measure the strong coupling constant



# Data Lives Long: Evidence from Other Facilities



*Significant fraction of publications in Data Preservation mode*

BaBar: More than 1/3 of total publications

HERA experiments: 17% more publications

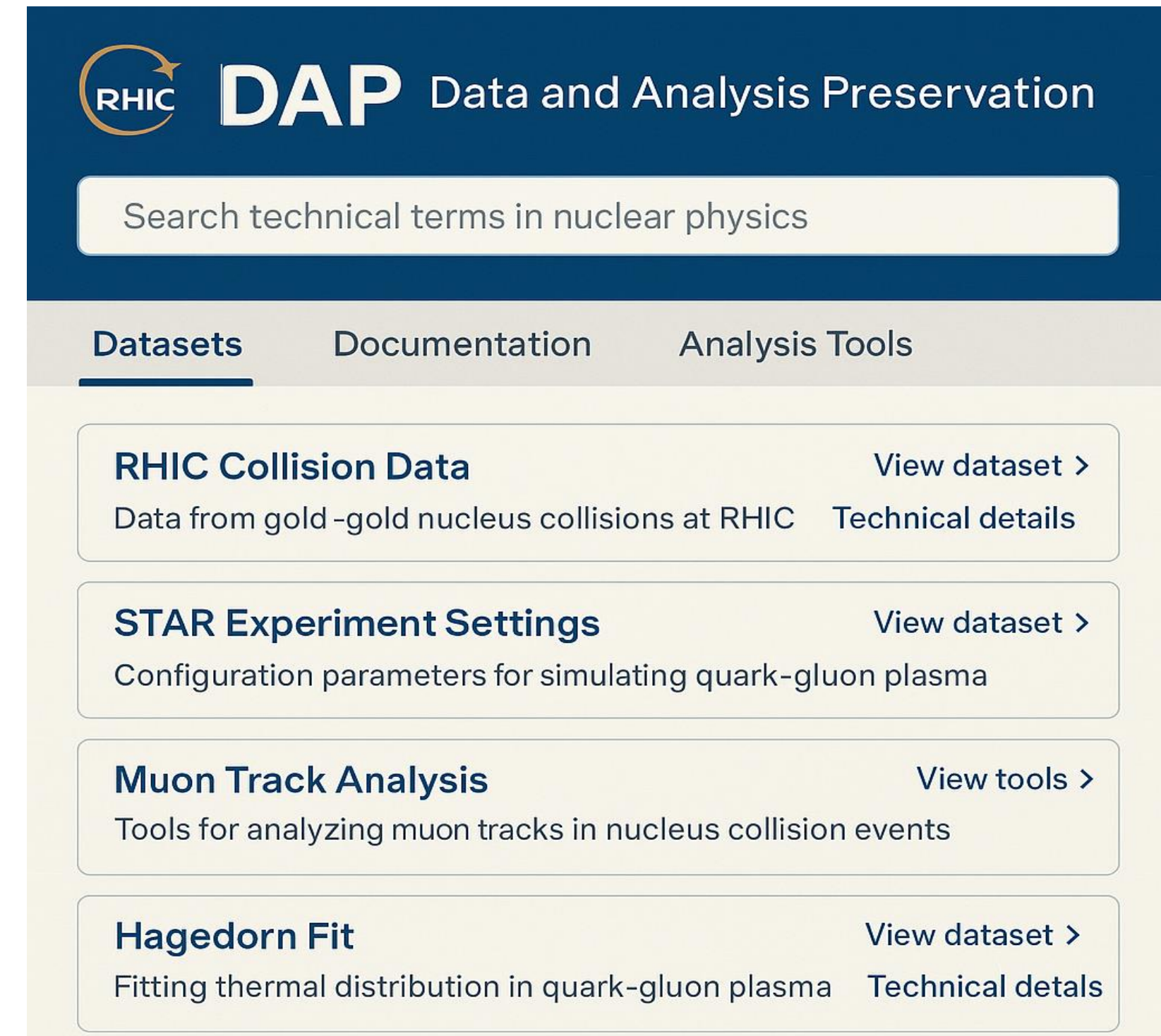
*Scientific output often continues for decades*

Data has a long lifetime after the end of experimental operations

# RHIC Data Preservation Portal

*Single unified access point:*

- Intuitive search interface
- Documentation browser
- Analysis workspace
- Progressive disclosure for users of all expertise levels





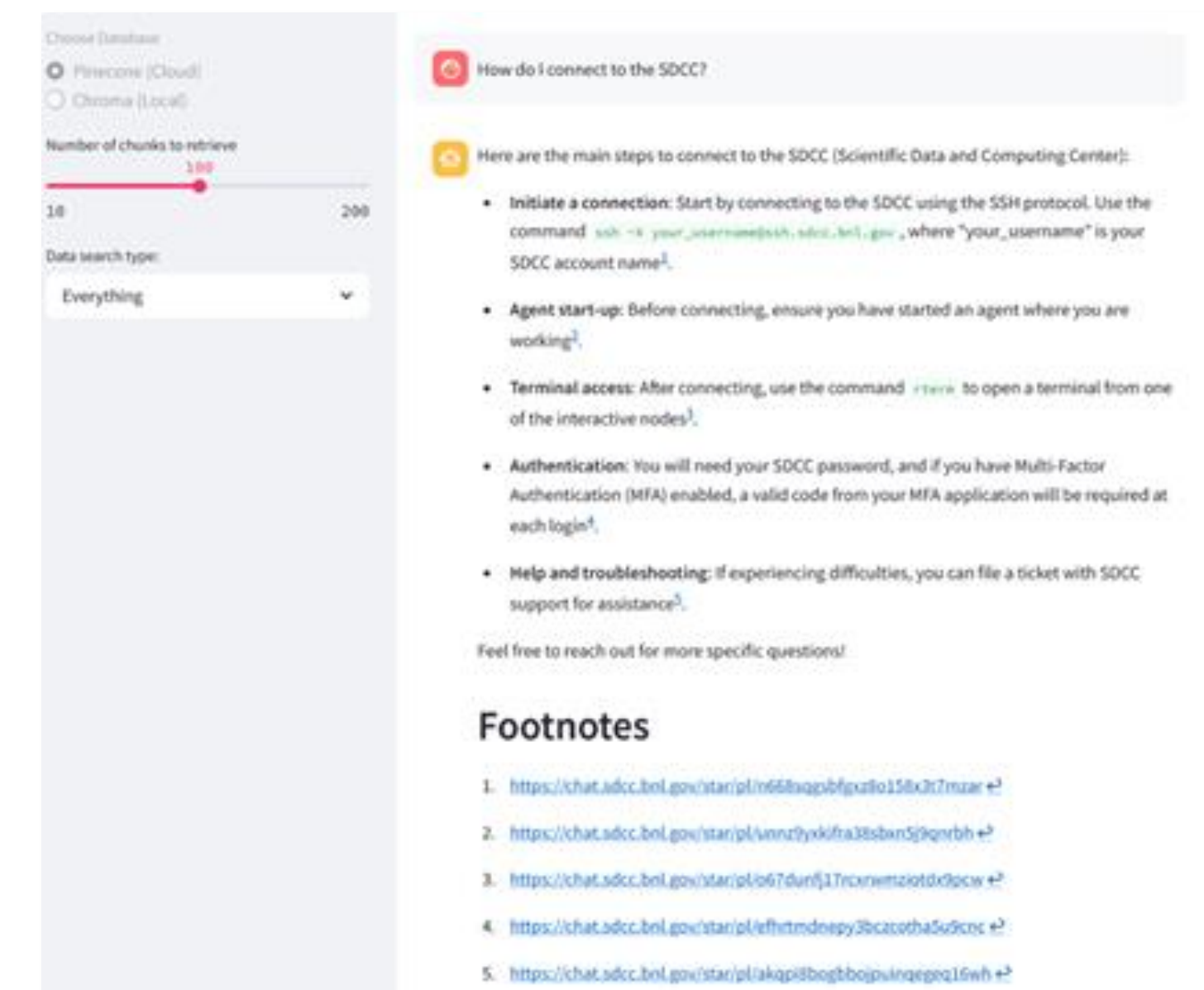
# AI-Assisted Example

## *Developments based on ChatSTAR*

- Natural language interface to RHIC documentation
- Context-aware responses grounded in experiment data
- Provides code snippets and technical guidance



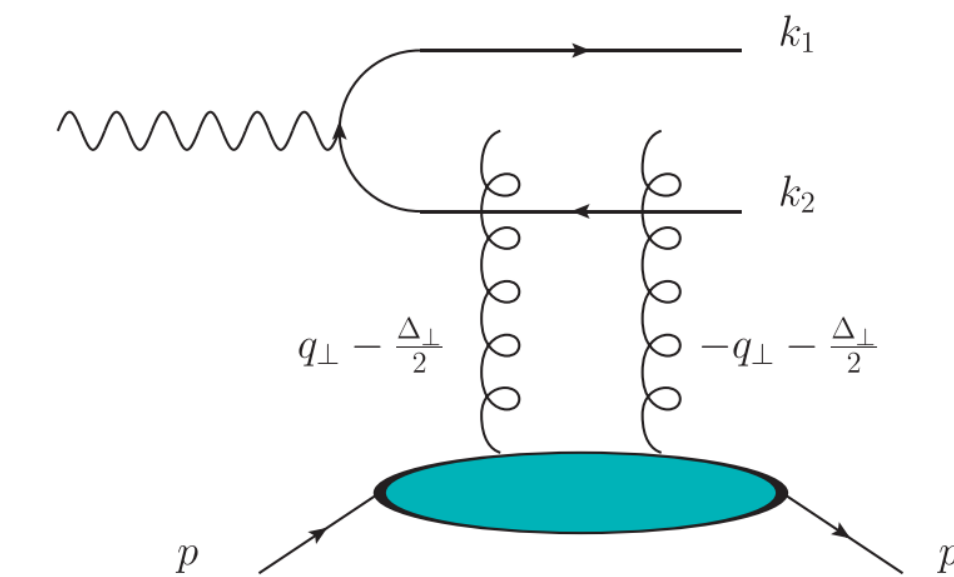
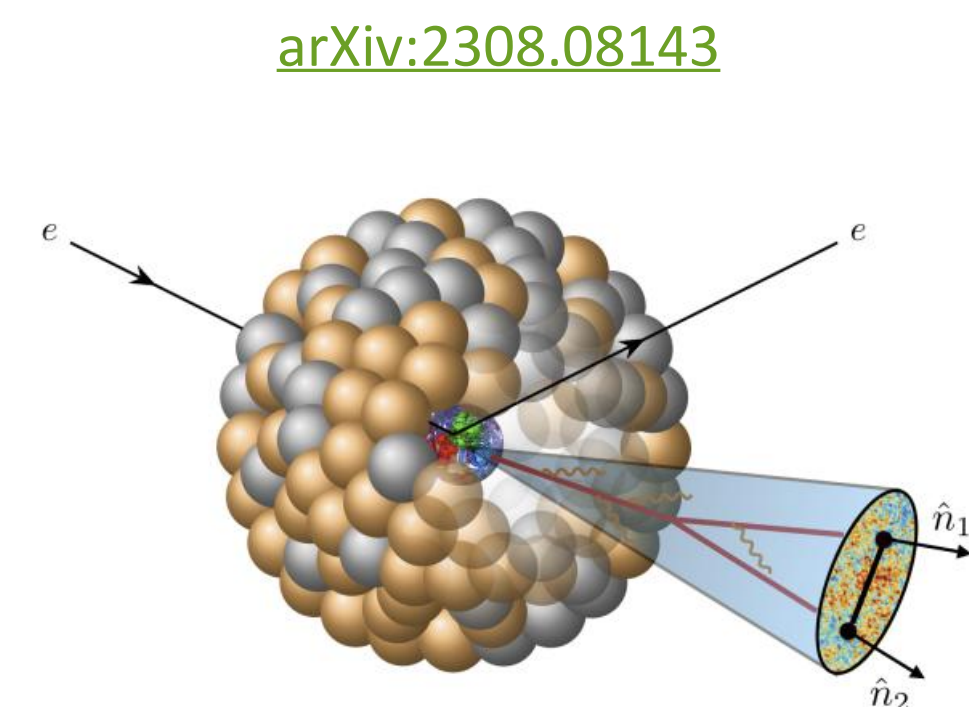
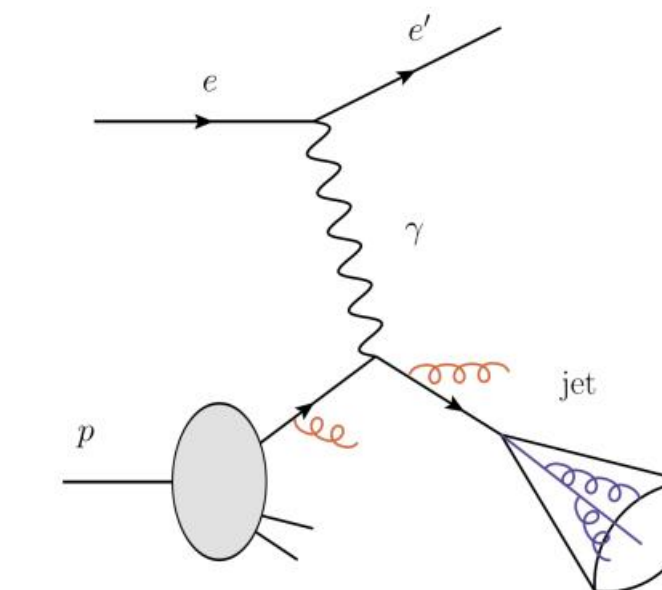
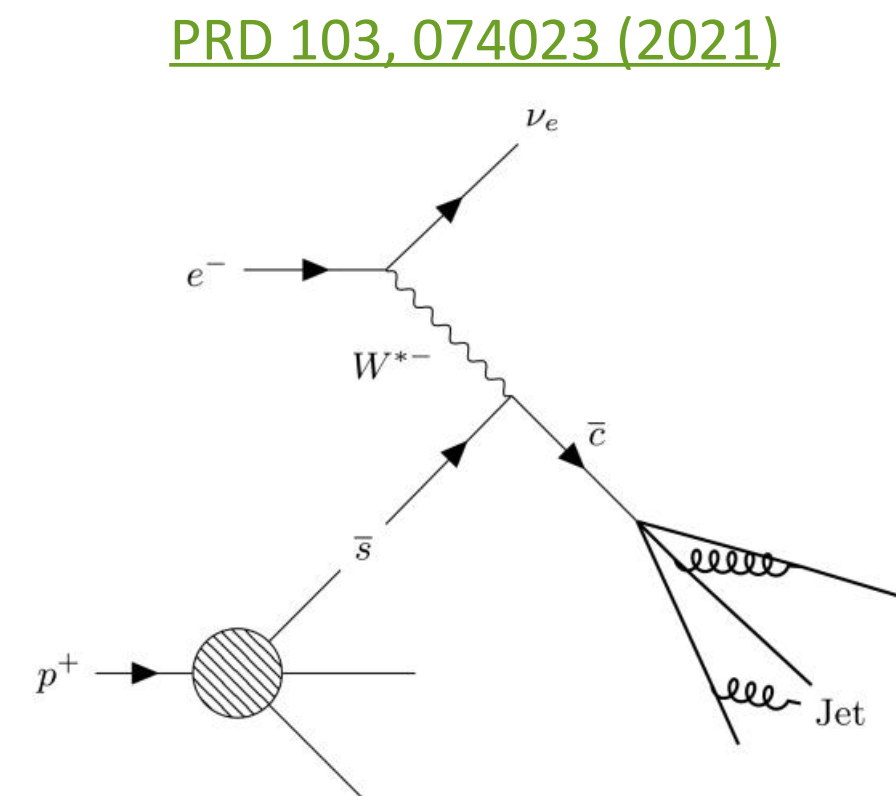
STAR chat



## Introduction | Jets vs. EIC Physics Goals



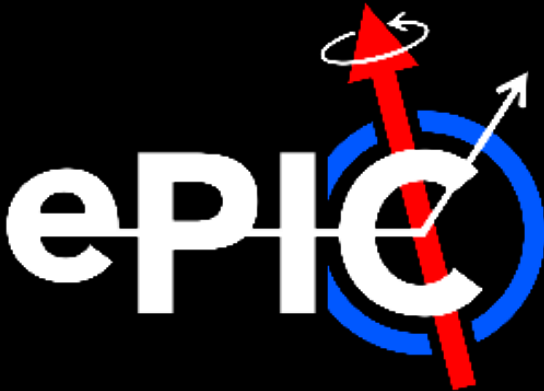
- **Jets are extremely powerful probes!**
  - Dynamically generated, sensitive to **many** scales
  - Good proxy for parton kinematics
  - Like SIDIS (multiple particles in FS), but also encode correlations b/n particles
    - ☞ **Via both jet clustering & substructure**
- Can provide input on all areas of EIC physics program
  - **(n)PDFs,**
    - › e.g. [PRD 102, 074015 \(2020\)](#)
  - **Spin/flavor structure of nuclei,**
    - › e.g. [PRD 103, 074023 \(2021\)](#)
  - **Saturation/extreme parton density,**
    - › e.g. [PRL 116, 202301 \(2016\)](#)
  - **TMDs/GPDs,**
    - › e.g. [PRL 116, 202301 \(2016\)](#)
  - **Cold nuclear matter effects,**
    - › e.g. [arXiv:2308.08143](#)



Jets expected to play a key role in many aspects of EIC science



Jets in DIS | Clustering Algorithms (3/3)

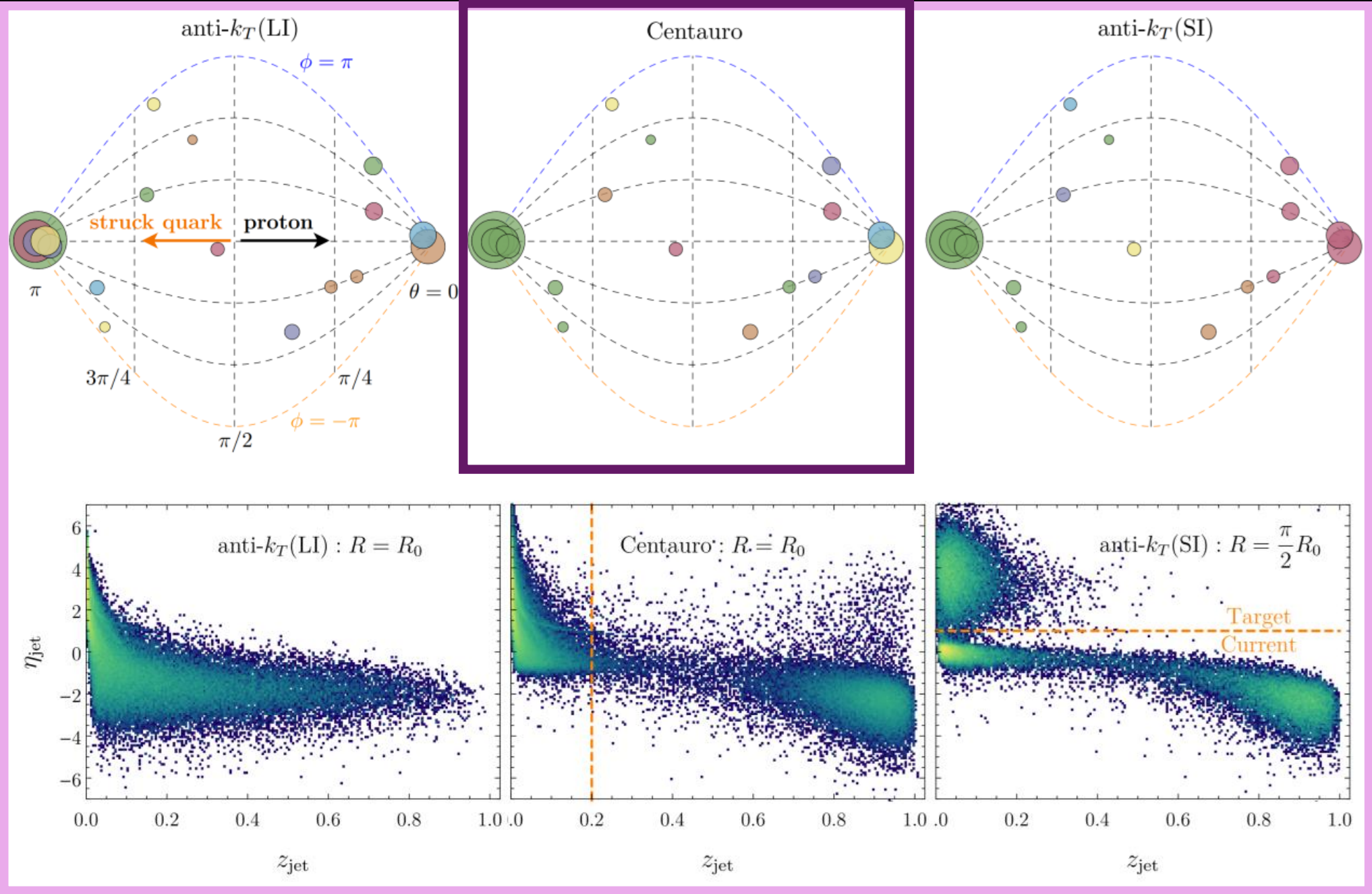


- **Another option:** asymmetric algorithms, e.g. Centauro

$$d_{ij} = \left[ (\Delta f_{ij})^2 + 2f_i f_j (1 - \cos \Delta \phi_{ij}) \right] / R^2,$$
$$d_{iB} = 1,$$
$$f_i = f(\bar{n}_i) = \bar{n}_i + \sigma(\bar{n}_i),$$
$$\bar{n}_i = 2p_i^\perp / (E_i - p_{z,i})$$

- ☞ Behaves like a  $k_T$  algorithm in forward region, like a spherically-symmetric algorithm in backward
  - ›  $f_i$  can be tuned to match other algorithms in other regions

- **Right:** illustration of clustering in DIS for different algorithms



PRD 104, 034005 (2021)

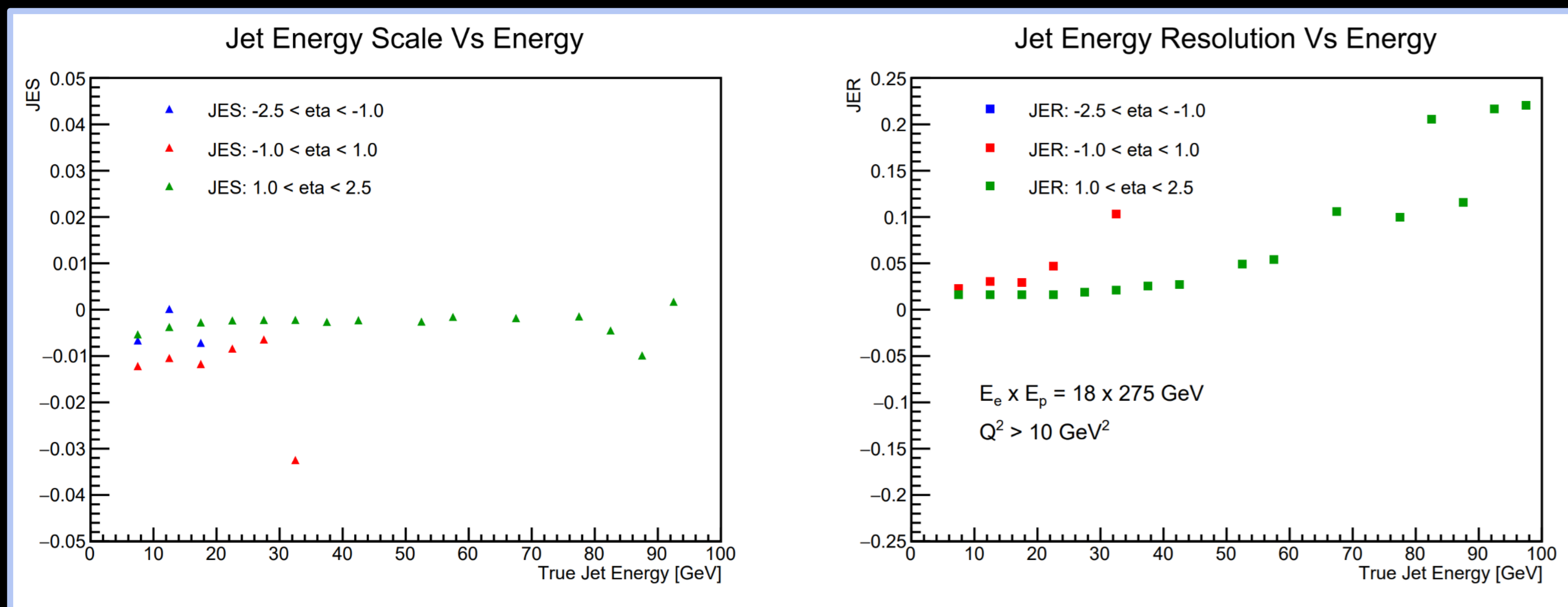
$$z_{jet} = P \cdot p_{jet} / P \cdot q$$

Important conceptual developments on jet clustering

# Ongoing Efforts | Jet Energy Scale/Resolution



Work by Brian Page



- **Above:** JES (left) & JER (right) for **charged jets**
  - Reco jets from tracks, truth jets from stable final particles
  - Jets matched via  $\Delta r = \Delta\varphi \oplus \Delta\eta < 0.1$
- Only charged particles used due to lack of adequate PF algorithm , and **to assess tracking performance**
  - ☞ **Note:** baseline particle flow algorithm a development priority for 2025

May 21st, 2025

Derek Anderson (ISU), RHIC/AGS AUM 2025

14/20

Benchmarking jet performance & further developing measurement methods



09:00	<b>High-pT physics in sPHENIX</b>	<i>Daniel Lis</i>	
	<i>Medical Large Conference Room, Bldg 490</i>	09:00 - 09:25	
	<b>Jet theory highlights</b>	<i>Dr Carlota Andres</i>	
	<i>Medical Large Conference Room, Bldg 490</i>	09:25 - 09:50	
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	<i>Medical Large Conference Room, Bldg 490</i>	09:50 - 10:15	

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	<i>Medical Large Conference Room, Bldg 490</i>	11:15 - 11:40	
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	<i>Medical Large Conference Room, Bldg 490</i>	11:40 - 12:00	
12:00	<b>Jets in ePIC</b>	<i>Derek Anderson</i>	
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# Thank you!