Supported in part by U.S. DEPARTMENT OF ENERGY | Office of Science

Jets at STAR

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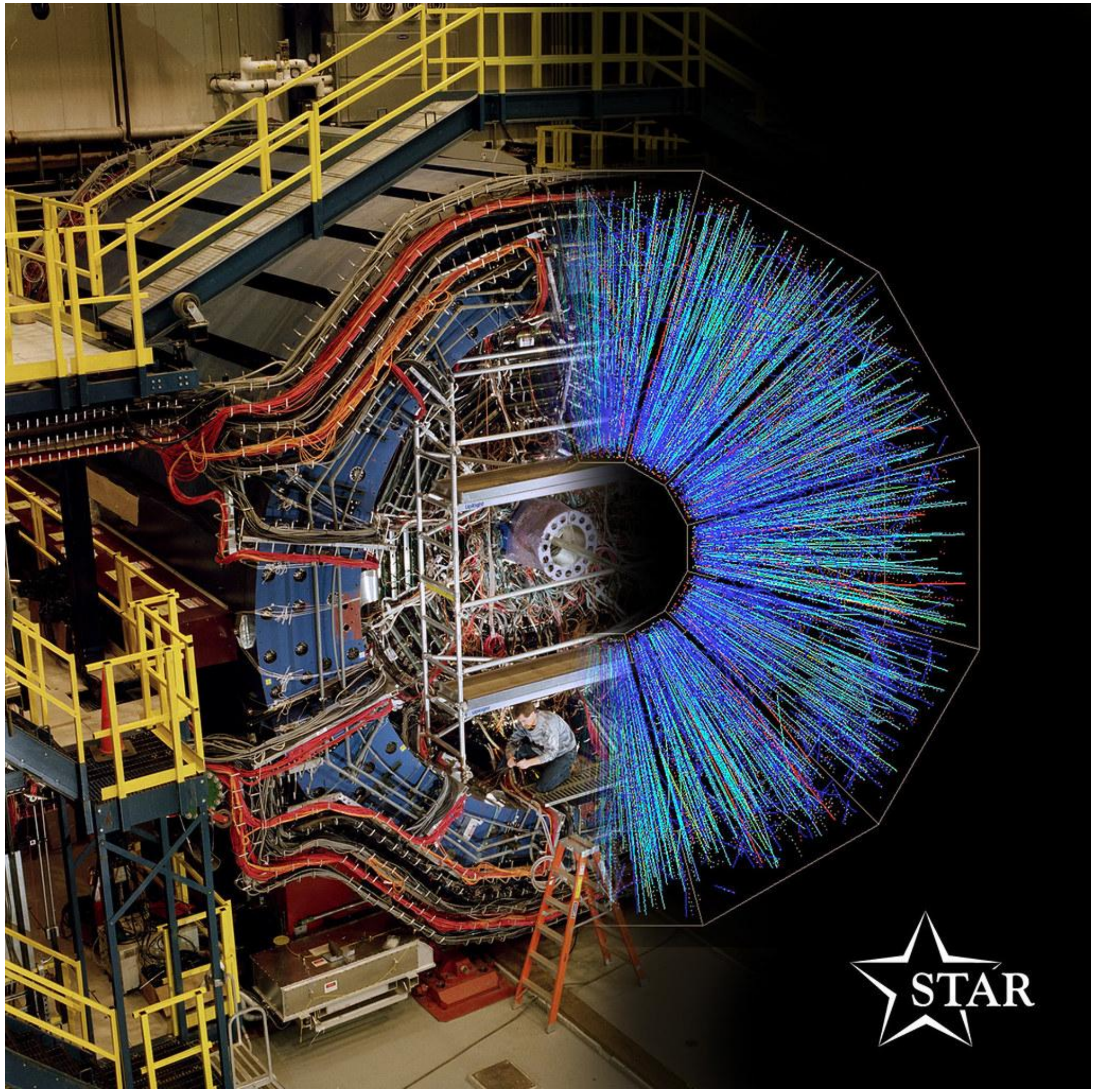
For the STAR Collaboration

5/21/25

RHIC 25:
A quarter century of discovery
May 20-23, 2025

Jet Measurement at STAR

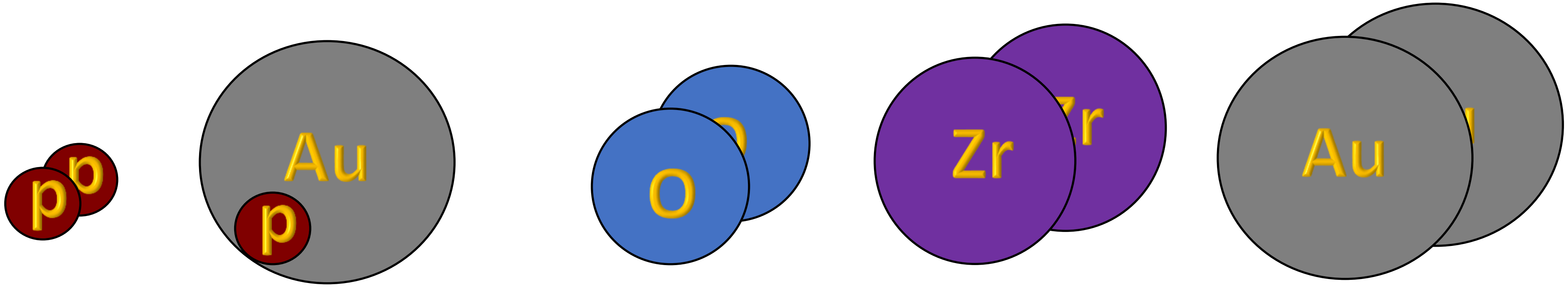


- Time Projection Chamber (TPC)
  - Charged track angular information and momentum -> PID
- Barrel Electromagnetic Calorimeter (BEMC)
  - Neutral energy deposits
- Heavy Flavor Tracker (HFT)
  - Displaced decay vertices
- Time of Flight (TOF)
  - PID

- Allows for measurement of full jet momentum and charged substructure

Collision Systems

- STAR has collected data from a wide variety of collision systems
- Studying jets across all them provides vital information about behavior in and outside of the QGP, **as well as of its onset**



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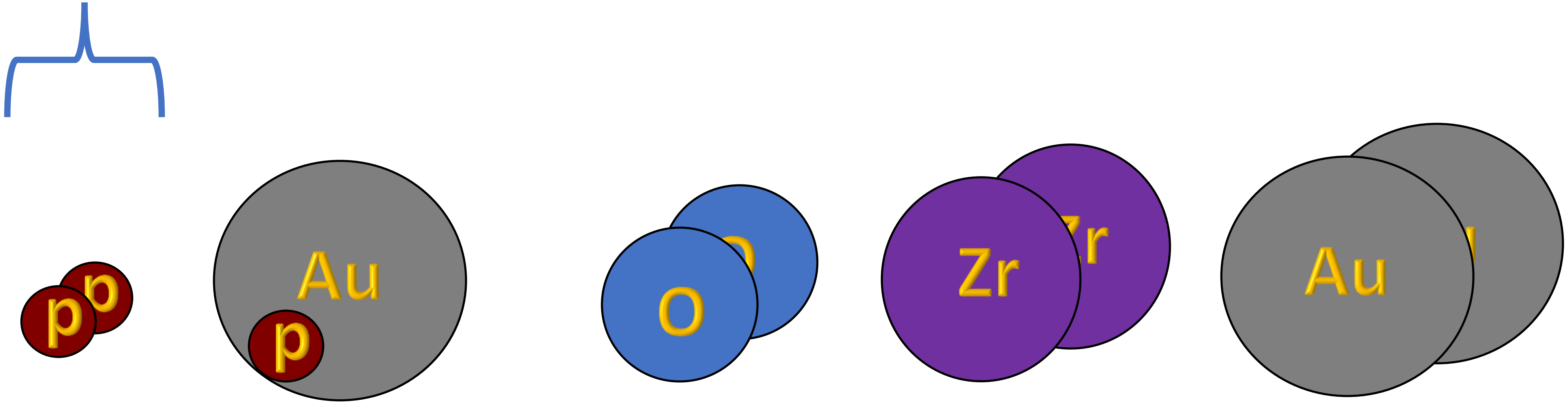
Vacuum



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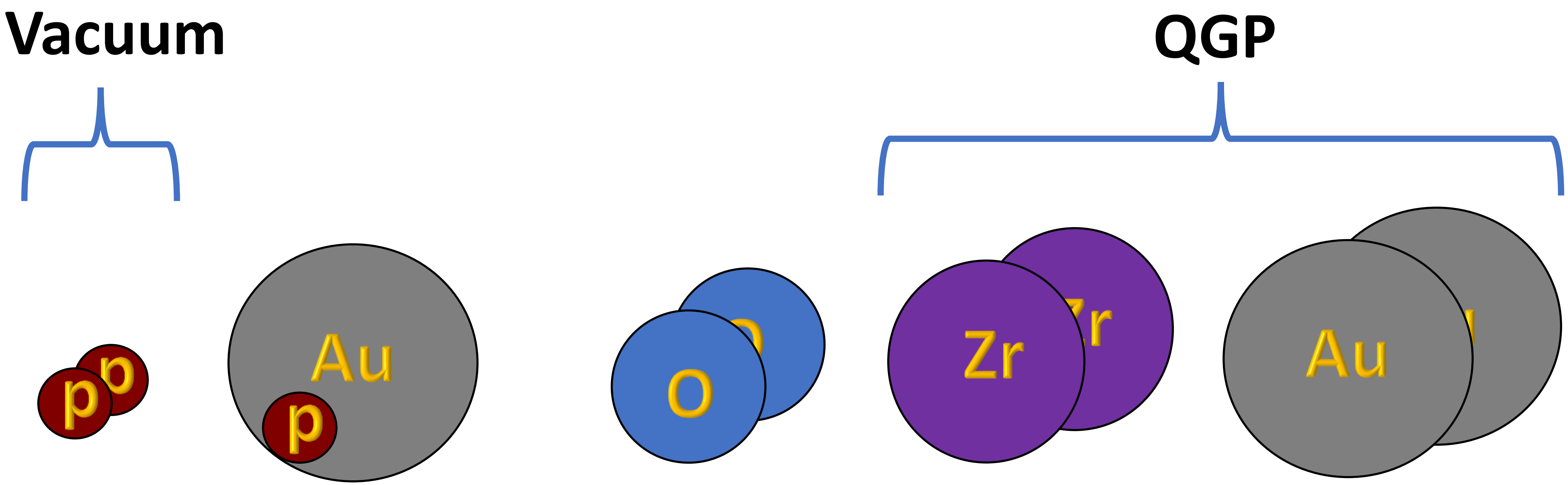

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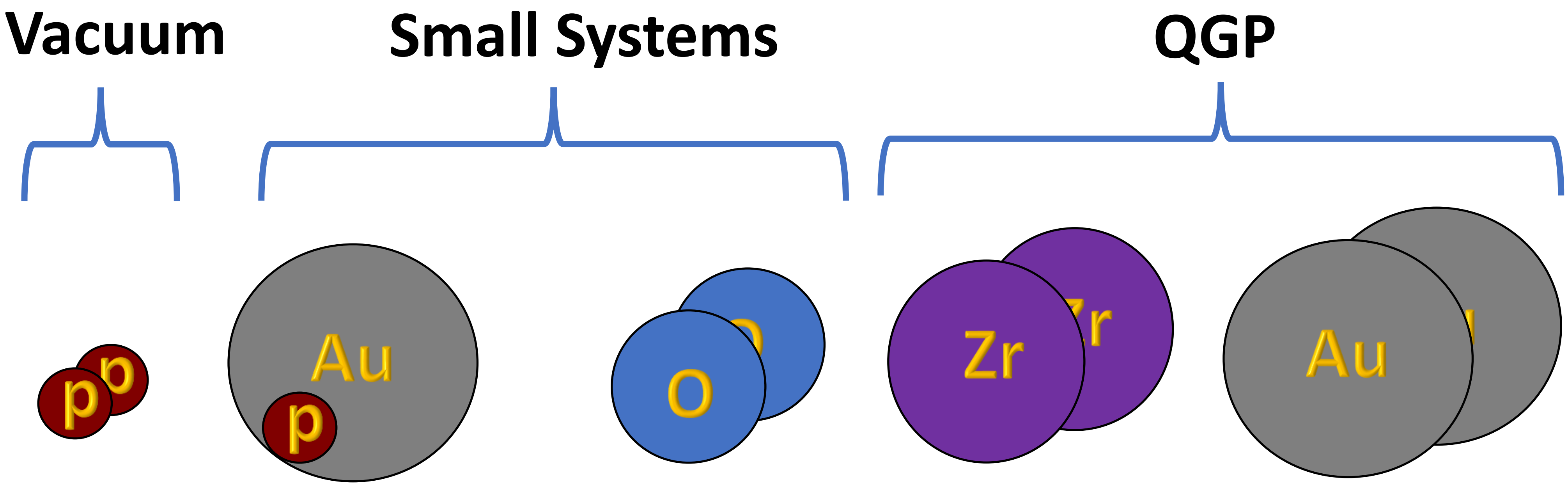
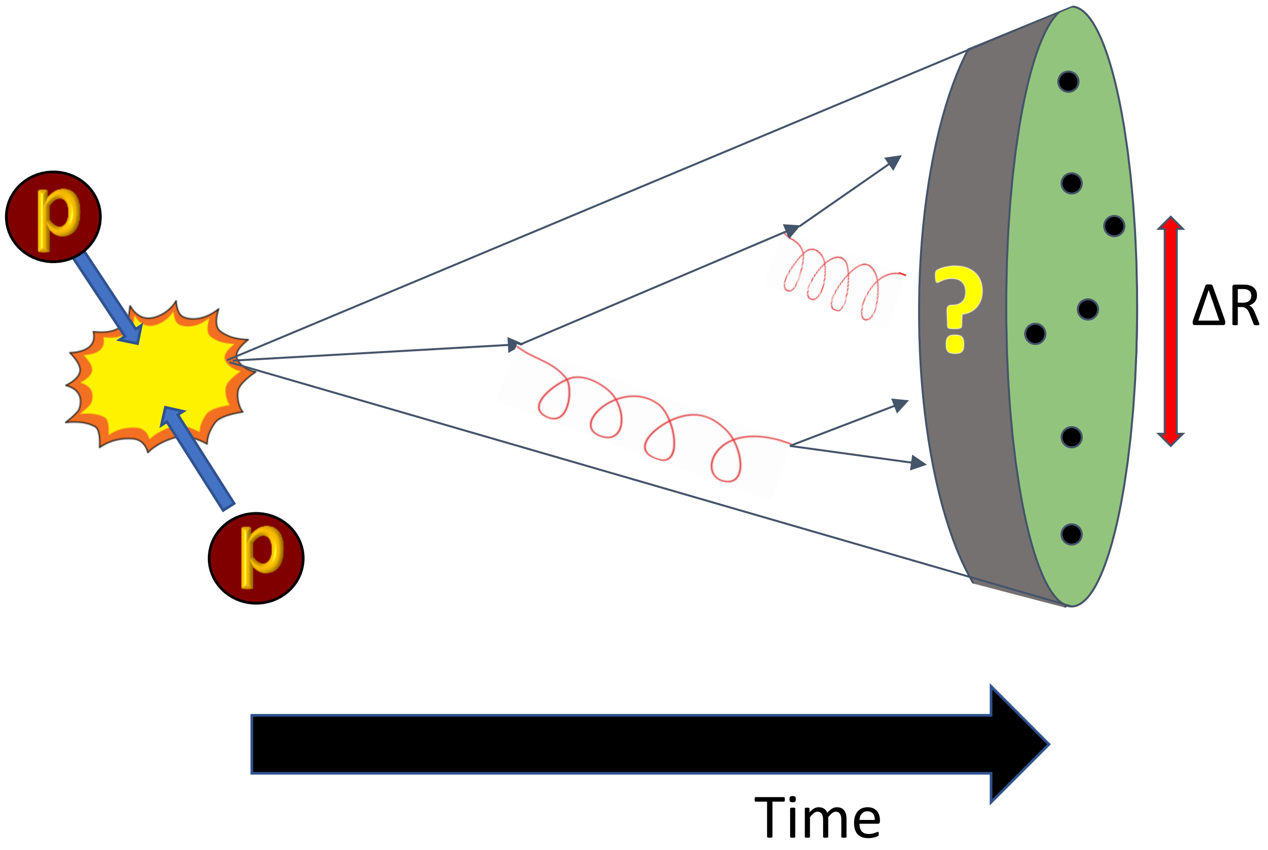


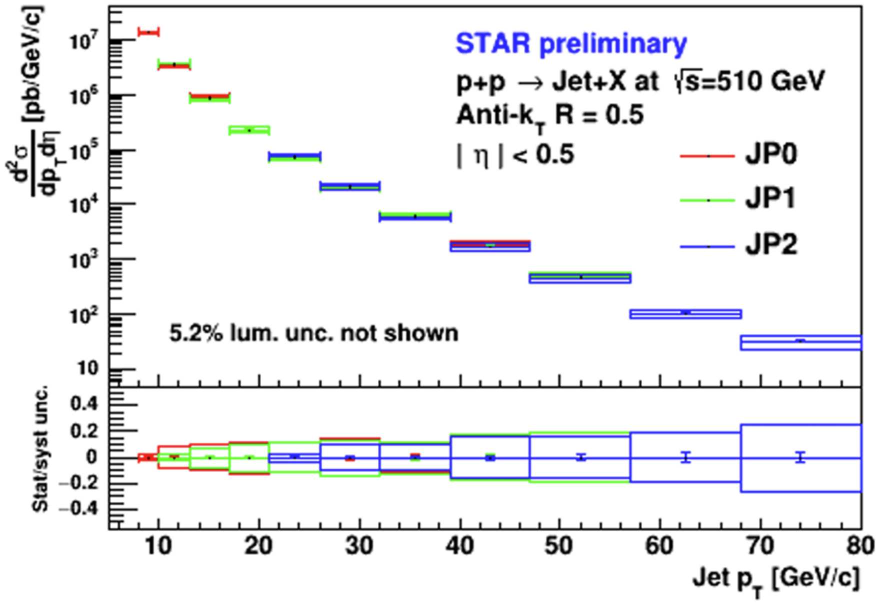
Jets in p+p

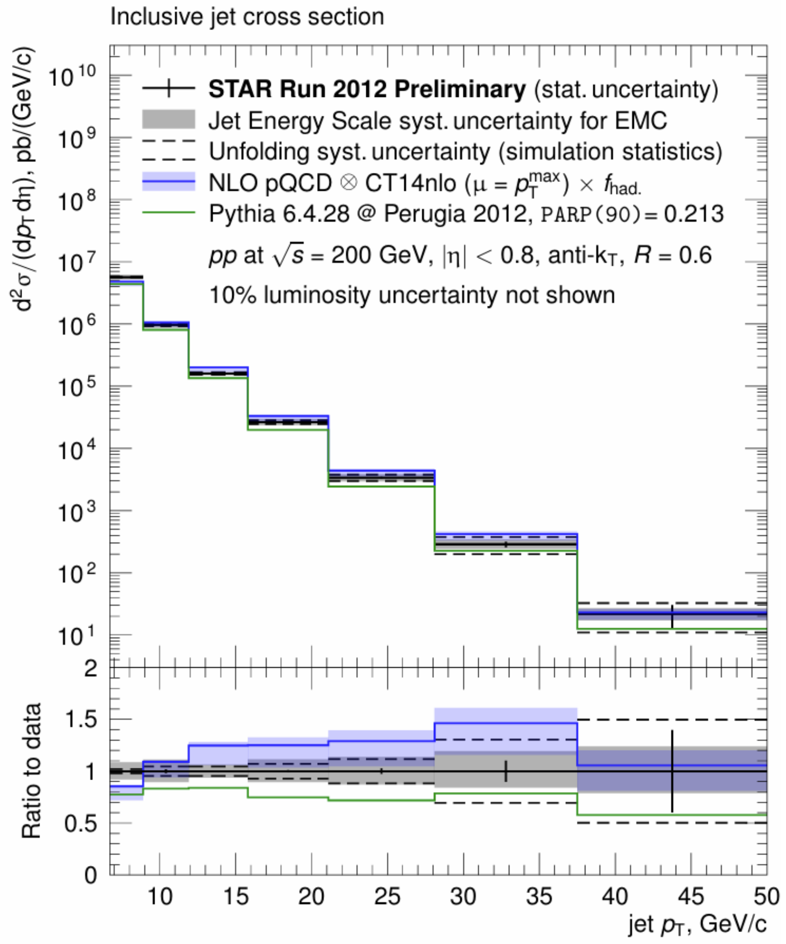


- **Jets are proxies for hard-scattered partons**
- Clustered from final state particles using a jet finding algorithm
- In vacuum, substructure analyses further understanding of both perturbative and non-perturbative physics

Inclusive Jet Spectra

- First jet spectrum measurement using anti-k_T jet algorithm at STAR at both $\sqrt{s}$ = 200 GeV and 500 GeV
- An off-axis cone method is applied to correct the underlying event contribution



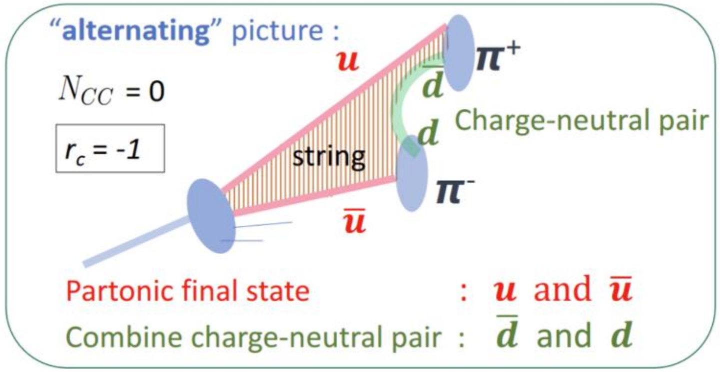


Hadronization in p+p

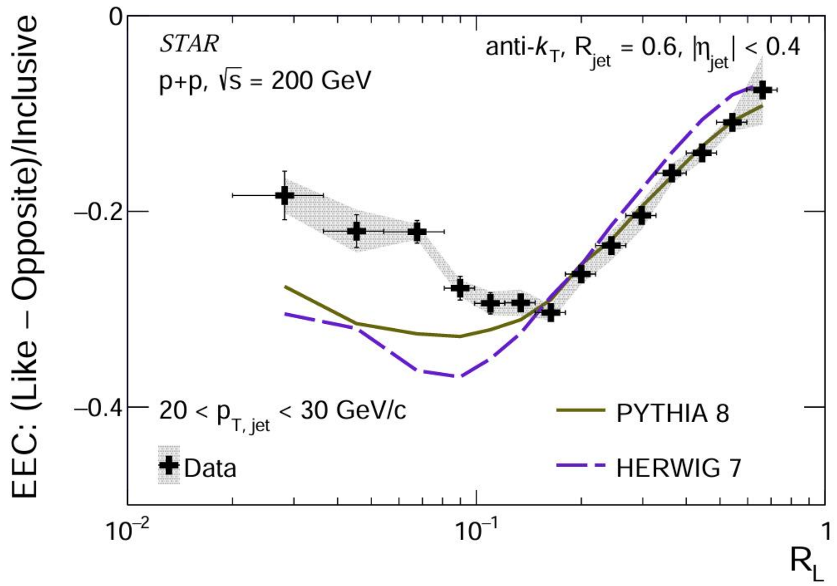
- Charged EEC and r_c **probe hadronization** via charge conservation
- Both PYTHIA and HERWIG fail to capture data

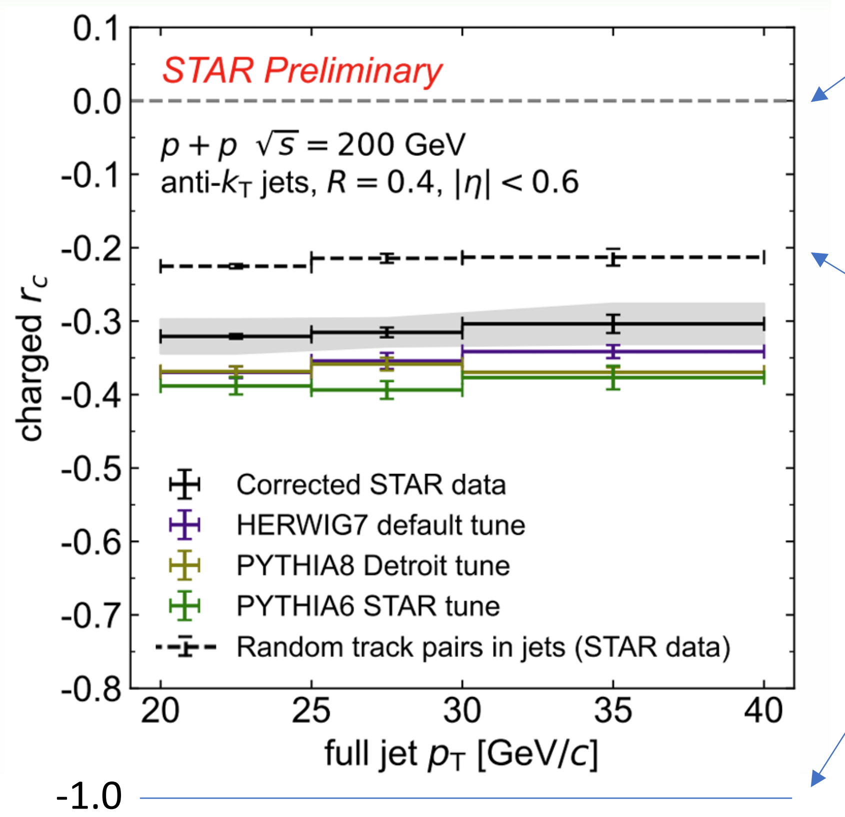
$$\frac{\boldsymbol{Like - Opposite}}{\boldsymbol{Like + Opposite}}$$

Figure: Mriganka Mouli Mondal



STAR: ArXiv: 2502.15925



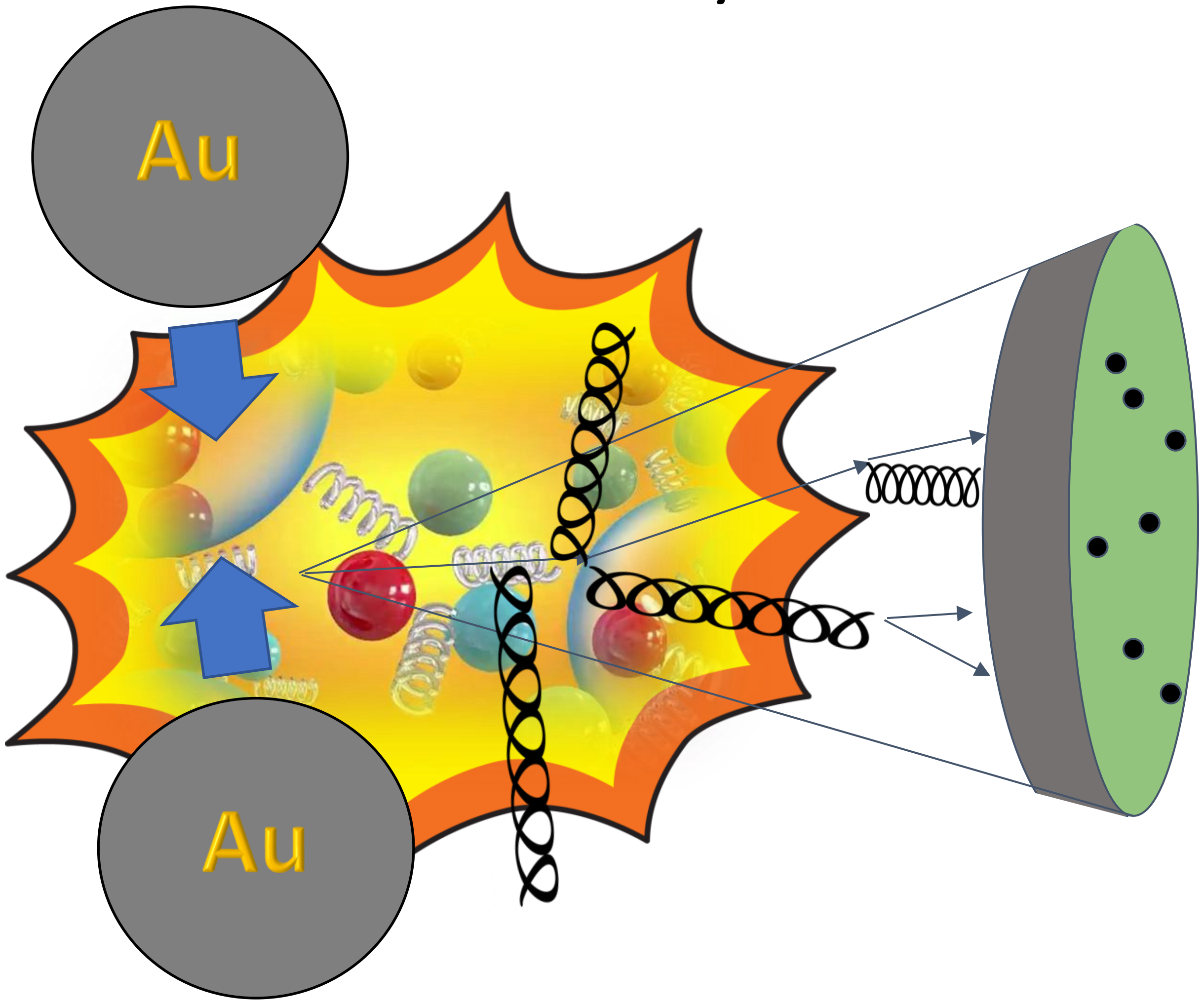


Infinite bath of charges

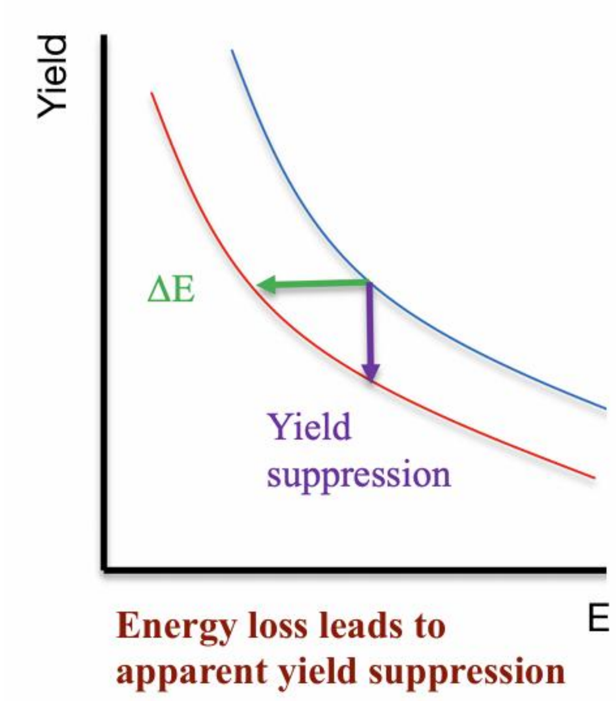
Randomly-sampled jet particles

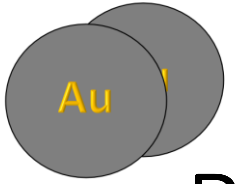
Perfect correlation

Jets in Heavy-Ion



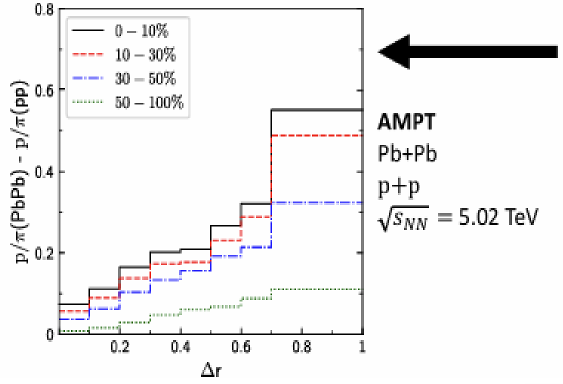
- Both overall production and substructure serve as excellent probes of the medium





Baryon/Meson Ratio

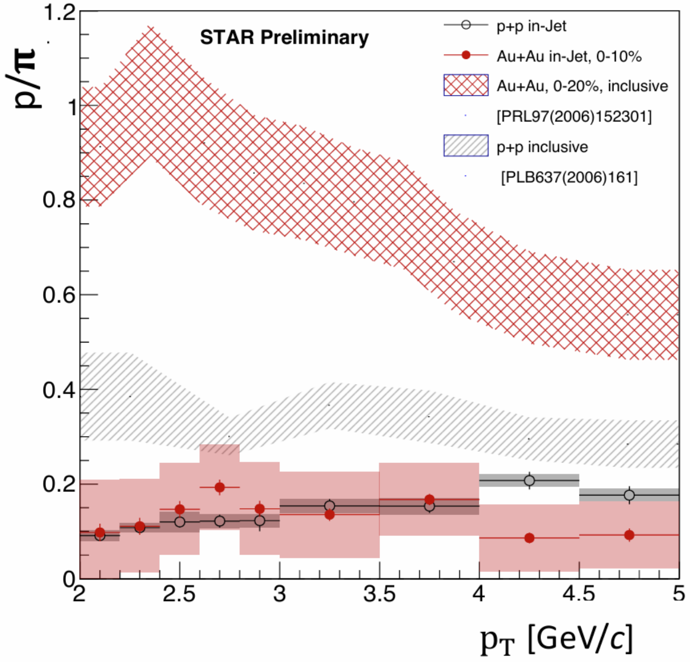
[Gabe Dale-Gau](): QM2025

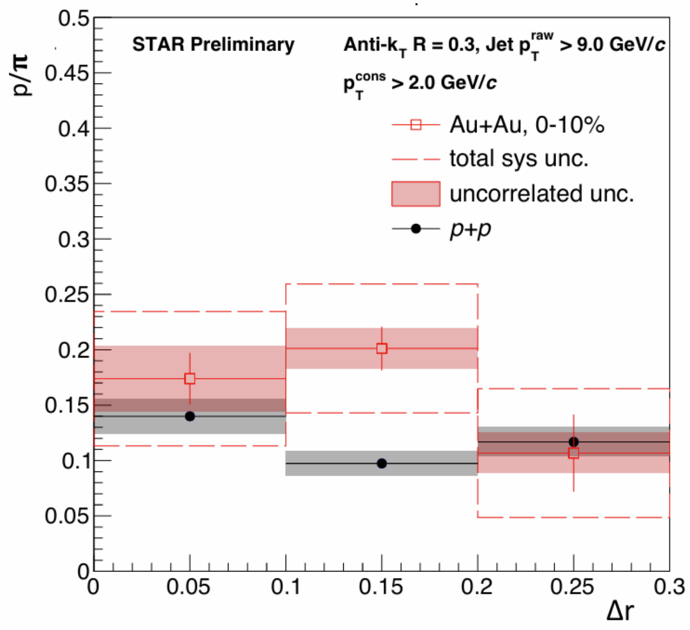


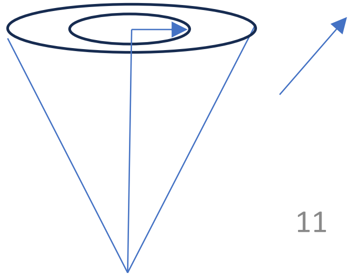
- AMPT simulations: p/π is modified for jets in QGP

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

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





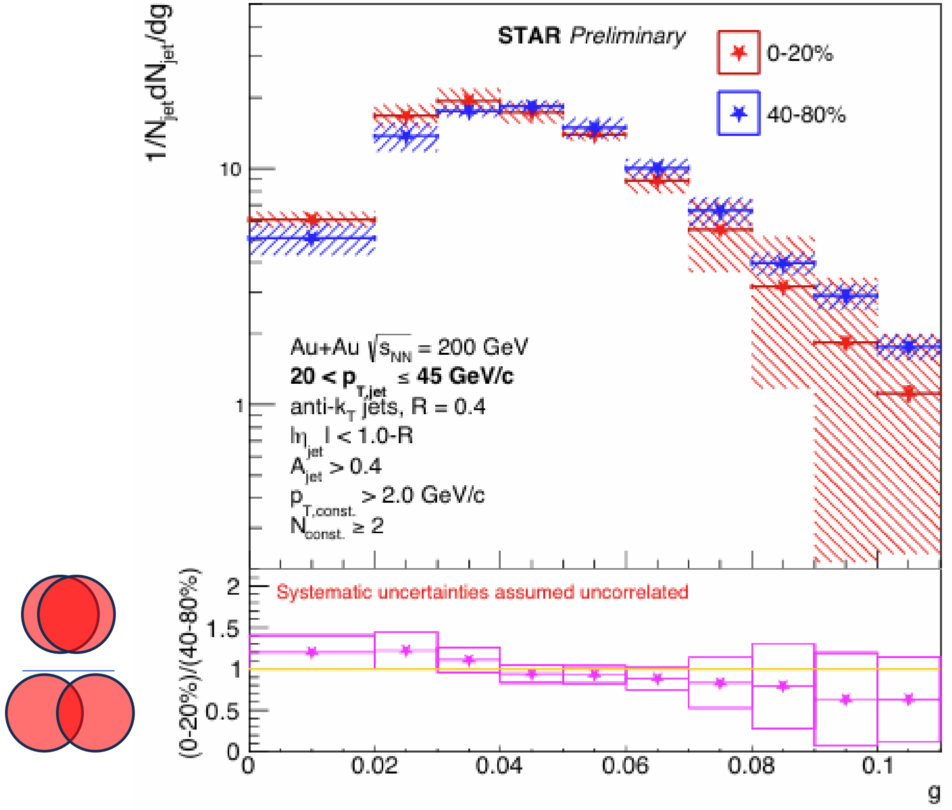


Generalized Angularities: Girth

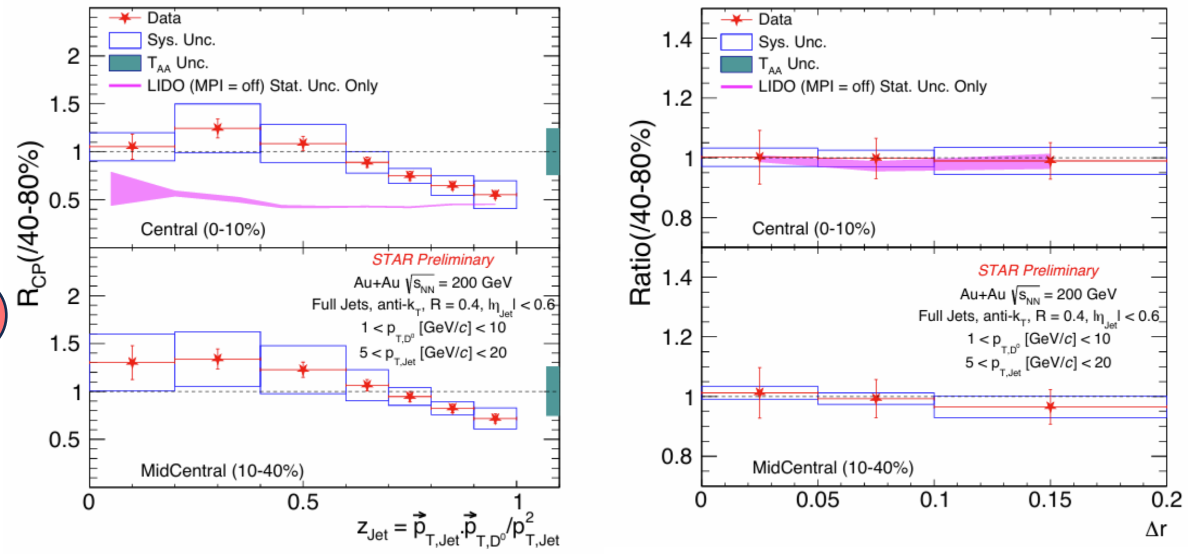
$$\lambda_{\beta}^{\kappa} = \sum_{\mathrm{cons}\in\mathrm{jet}} \left(\frac{p_{\mathrm{T,cons}}}{p_{\mathrm{T,jet}}}\right)^{\kappa} \Delta R\,(\mathrm{cons,jet})^{\beta}$$

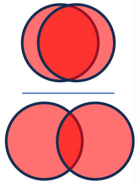
$$g = \lambda_1^1 = \frac{\sum_{\mathrm{trk}\in\mathrm{jet}} p_{\mathrm{T,trk}} \Delta R}{p_{\mathrm{T,jet}}}$$

- Generalized angularities, an adjustable subset of substructure observables
- Girth allows study of jet broadening in medium
- No change resolved, work being done to reduce uncertainties and create p+p baseline

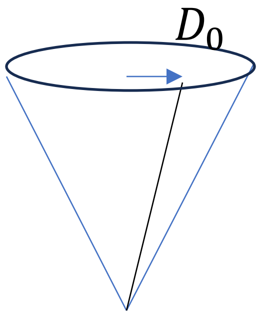


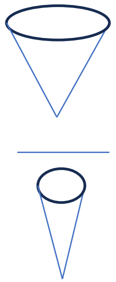
Charm Jets in Heavy Ion



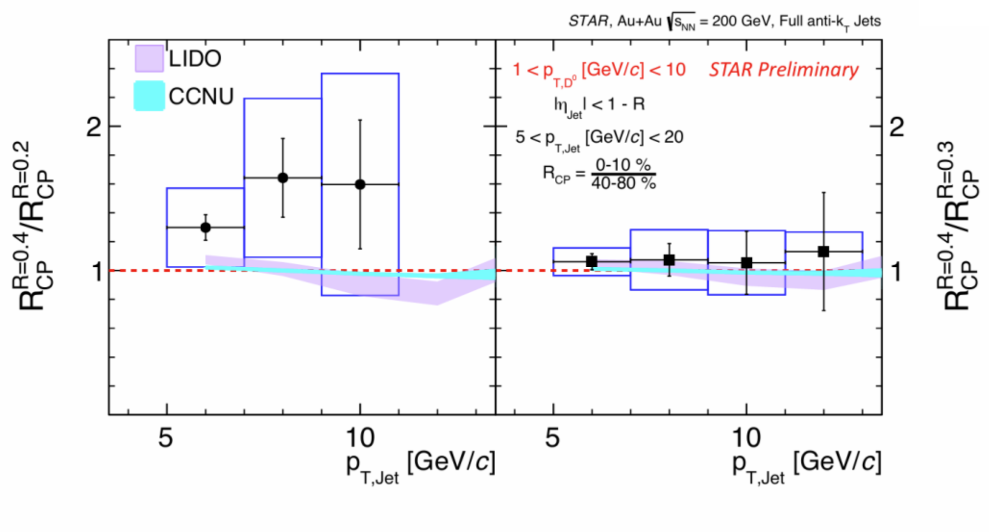


$$z_{jet} = \frac{\vec{p}_{T,Jet} \cdot \vec{p}_{T,D^0}}{|\vec{p}_{T,Jet}|^2}$$





- Suppression of hard fragmented D_0 **-> Medium induced radiation**
- No observed radial dependence

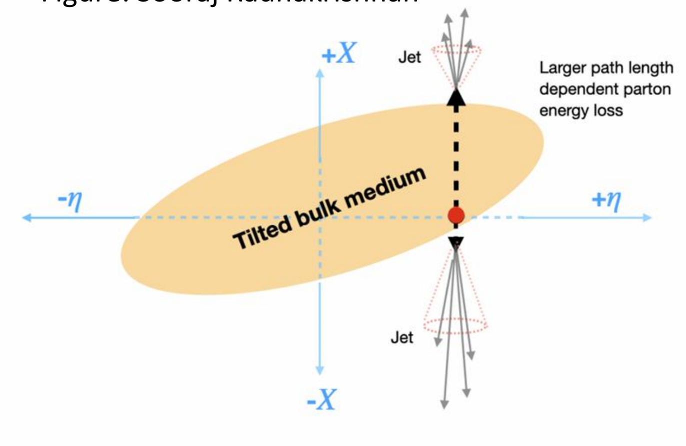


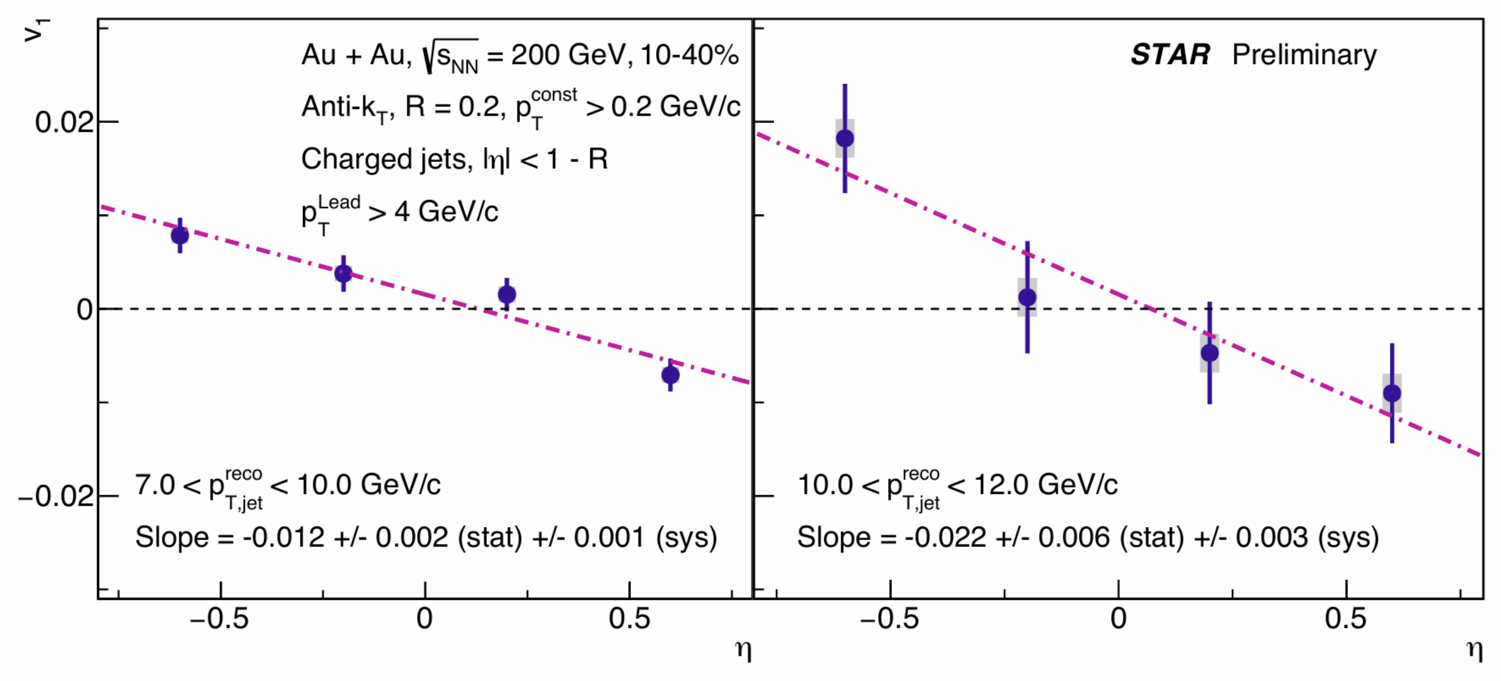
Two Competing effects:
Large R increases gluon fraction, resulting in more quenching, but also recovers more energy
- Neither effect dominates

Jet v_1

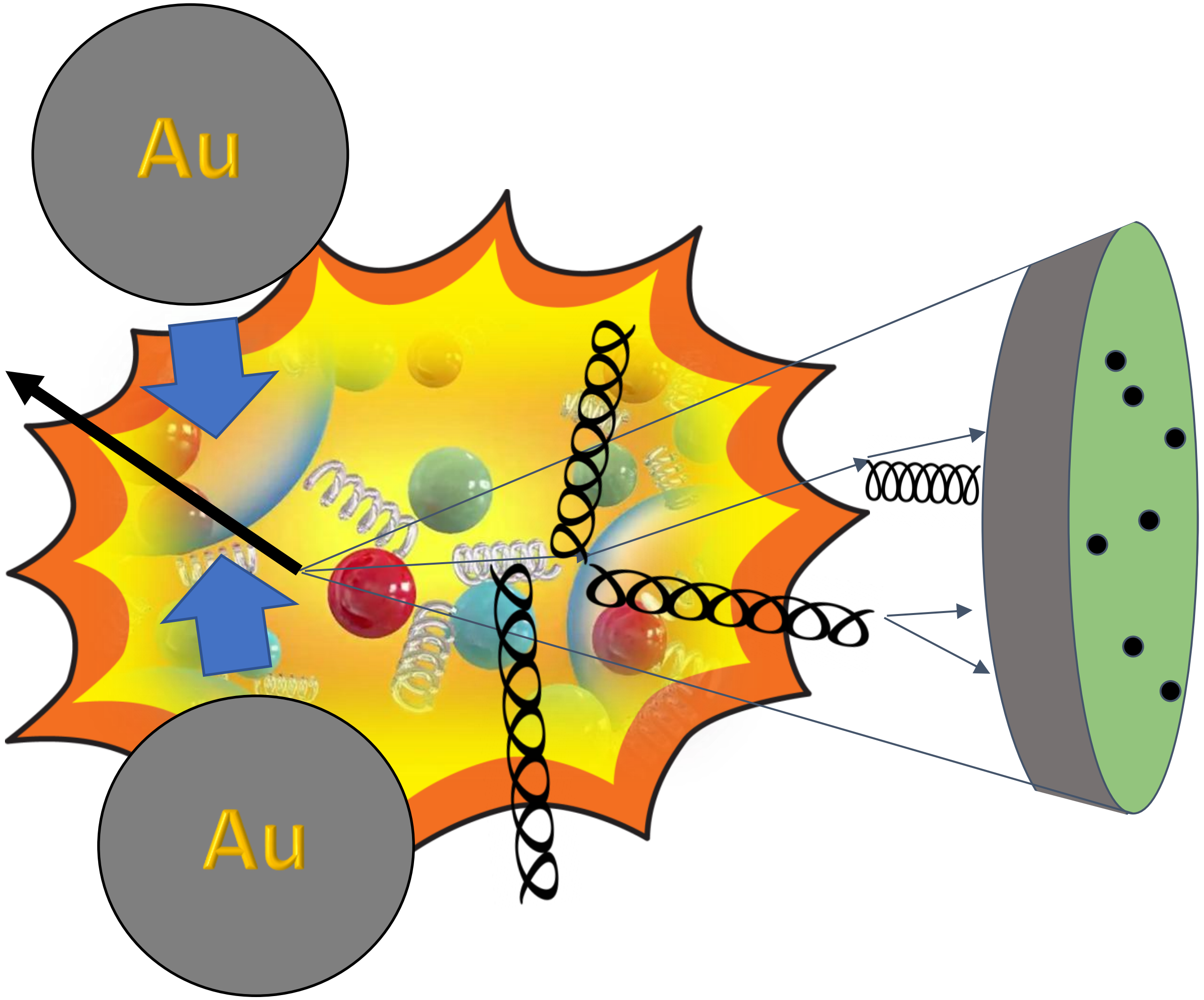
- Asymmetry in bulk production will cause jets to experience different path lengths in medium
- Probe of path-length dependent quenching
- **Clear signal observed in Au+Au**
- Event-Shape engineering will allow for finer tuning of path-length dependence

Figure: Sooraj Radhakrishnan





Semi-Inclusive Jet Measurements in Au+Au and Isobar

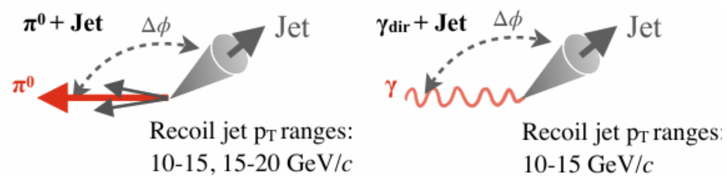


- Back-scattered charged hadron or photon gives us reference for hard scattering
- In systems where we know there is QGP, gives additional parameters to study quenching in reference to

Medium-Induced Acoplanarity

STAR: [ArXiv: 2505.05789]

Figure: Nihar Ranjan Sahoo



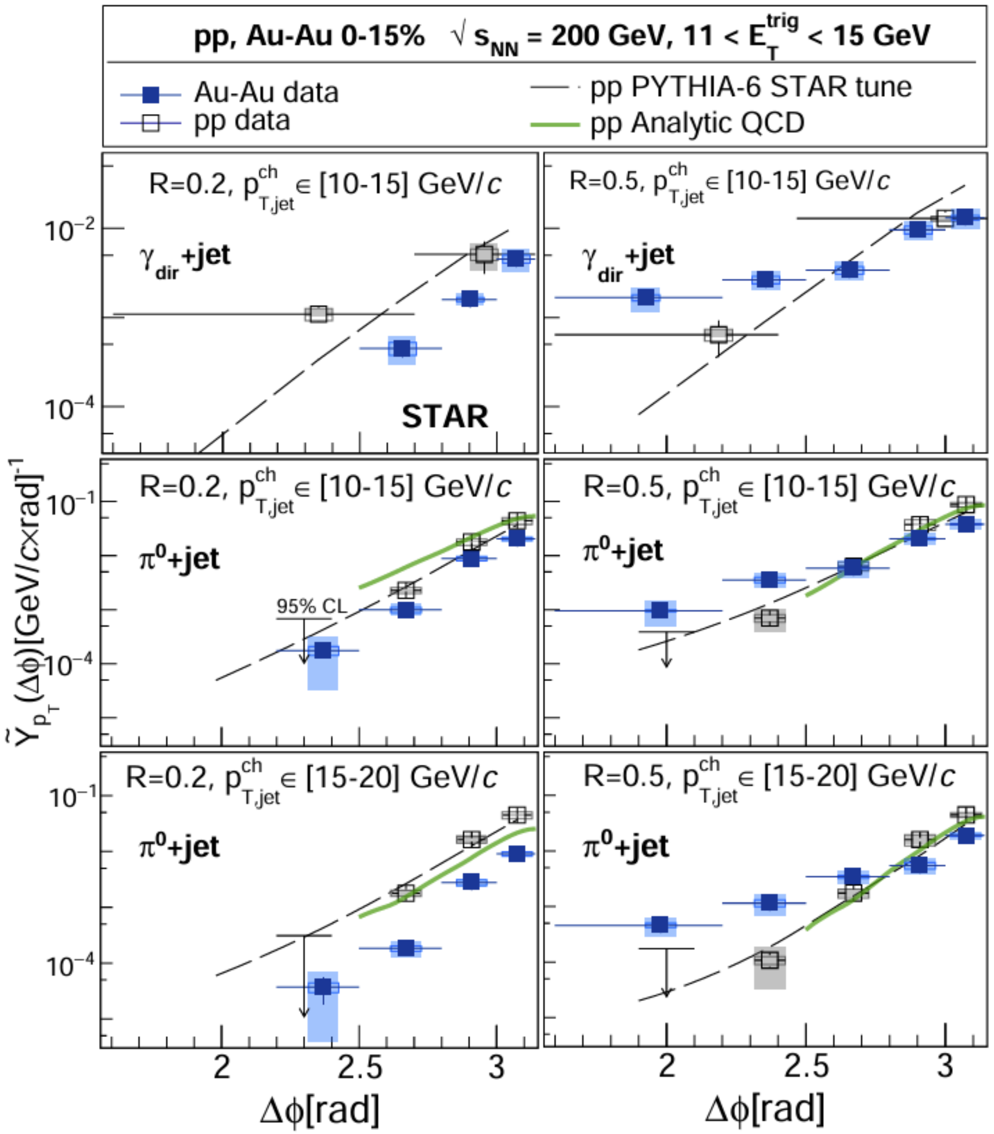
- **Significant R-dependent acoplanarity observed in Au+Au**
- Most likely due to medium/wake response

$$\tilde{\mathbf{Y}}_{\Delta\phi}(\mathbf{p}_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}}) = \mathbf{Y}_{\mathrm{SE}}(\mathbf{p}_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}}) - \mathbf{Y}_{\mathrm{MEnorm}}(\mathbf{p}_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}})$$

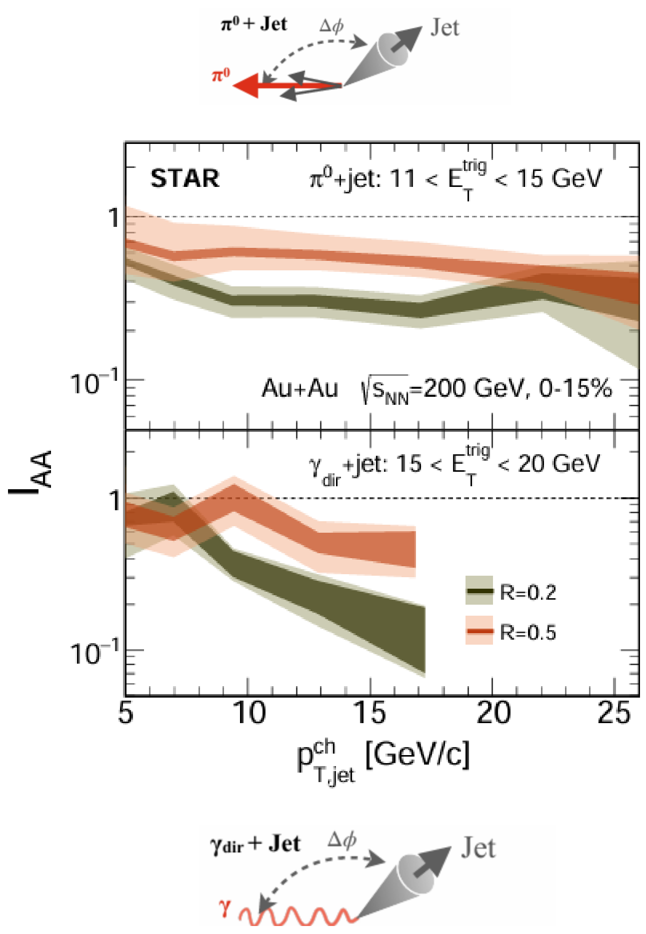
$\tilde{Y}_{\Delta\phi}(p_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}})$: Normalised ME subtracted jet distributions

$Y_{\mathrm{SE}}(p_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}})$: Recoil jet distributions of Same Event (SE)

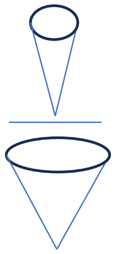
$Y_{\mathrm{MEnorm}}(p_{\mathrm{T,\,jet}}^{\mathrm{reco,ch}})$: Normalised ME distributions



Semi-Inclusive Jet Modification

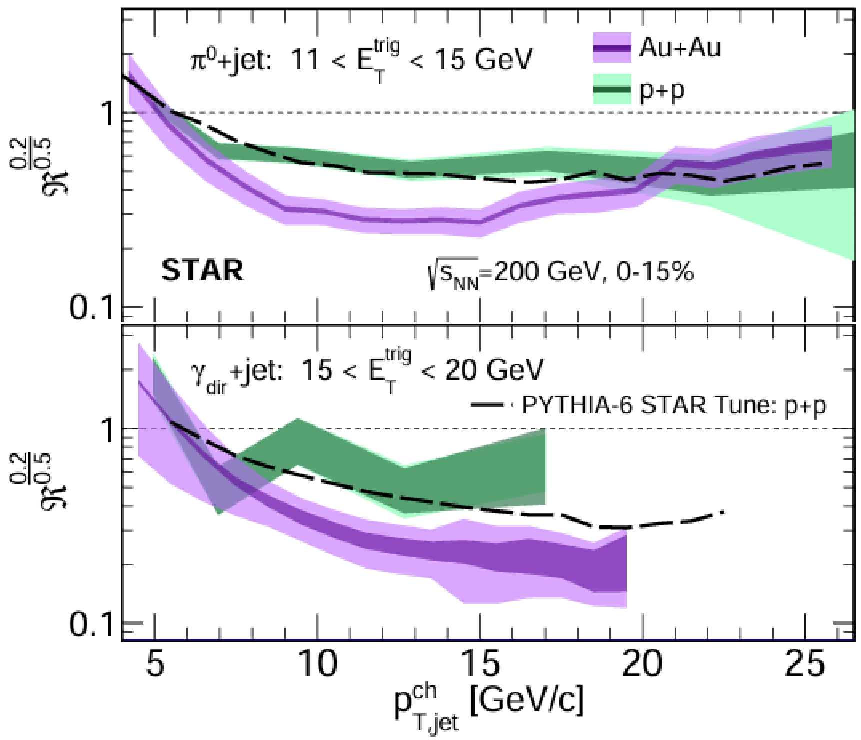


- Accepted for PRC and PRL
- Suppression of small R relative to large R, suggests in-medium broadening

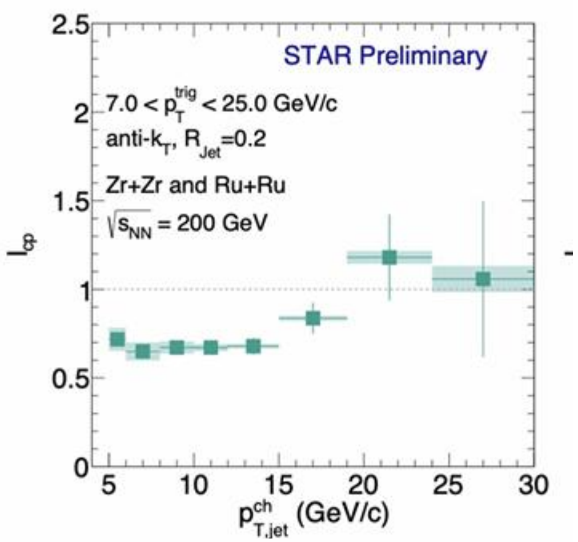


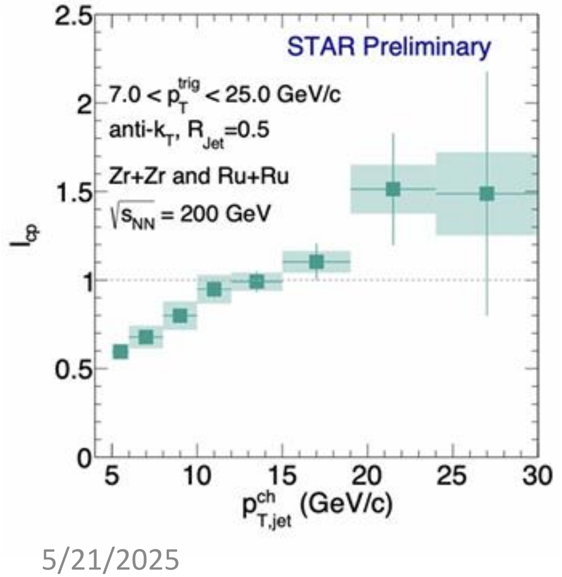
STAR: ArXiv: 2309.00145

STAR: ArXiv: 2309.00156

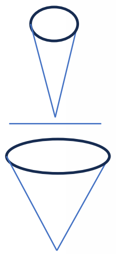


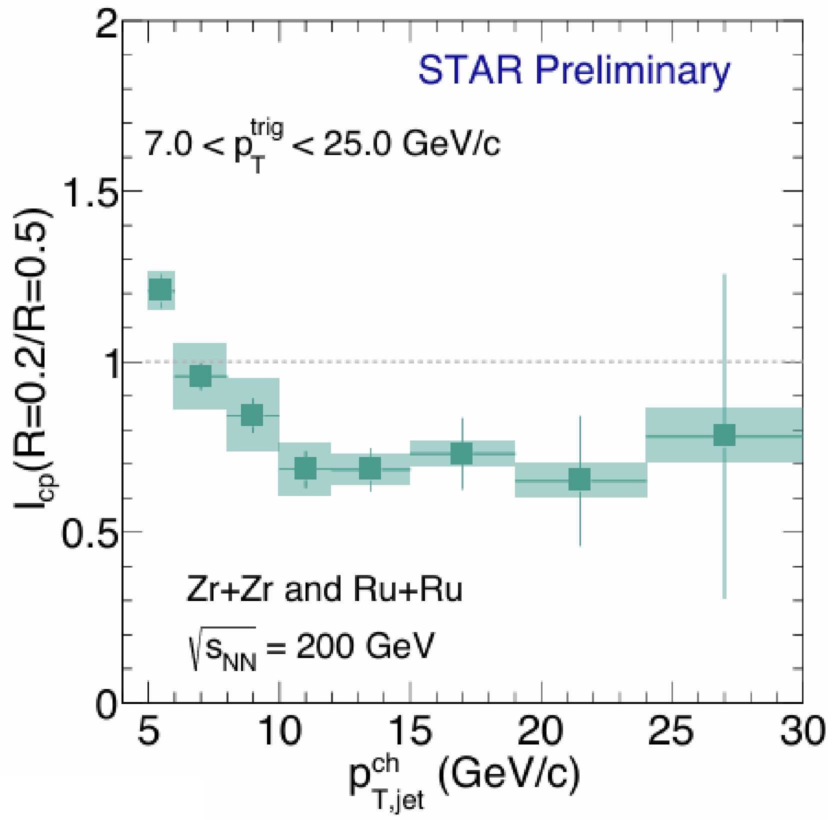
Semi-Inclusive Hadron+Jet in Isobar (Zr+Zr and Ru+Ru) Collisions





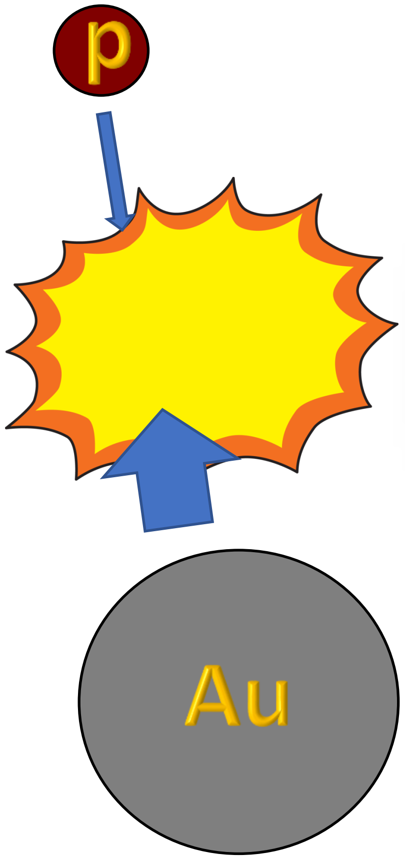
- Extends measurement to Isobar collisions at higher jet momentum
- In-medium broadening of shower persists to smaller system
- Trigger bias causes $I_{cp} > 1$ for high $p_{T,jet}^{ch}$

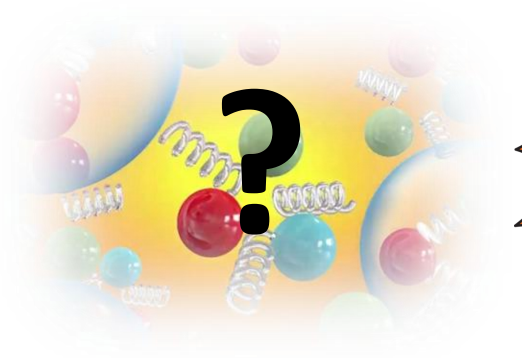


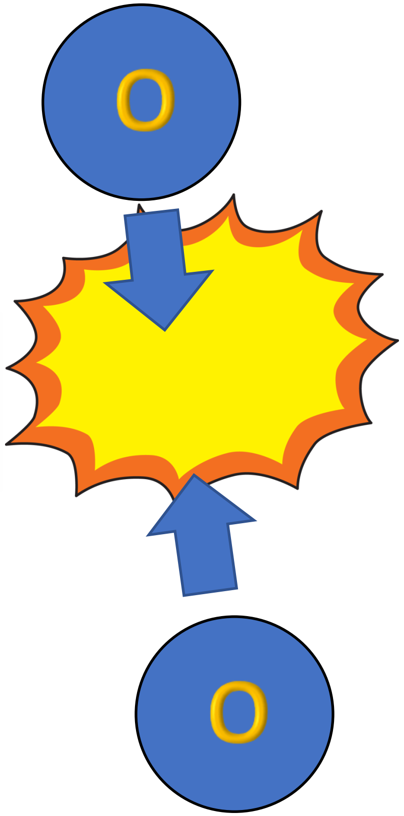


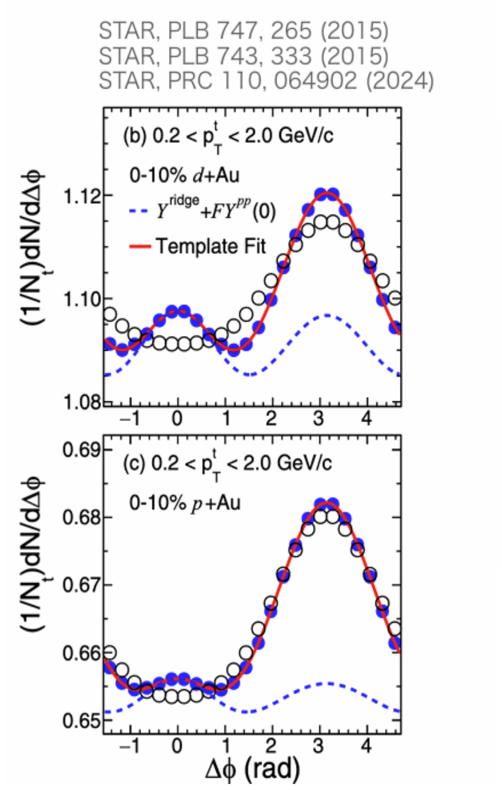
Small Systems

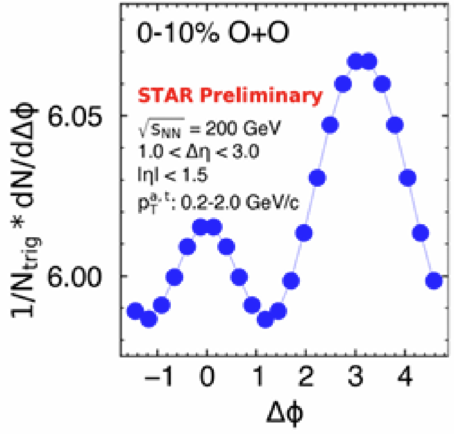
- Small systems have shown signs of collectivity, but do they exhibit jet quenching?





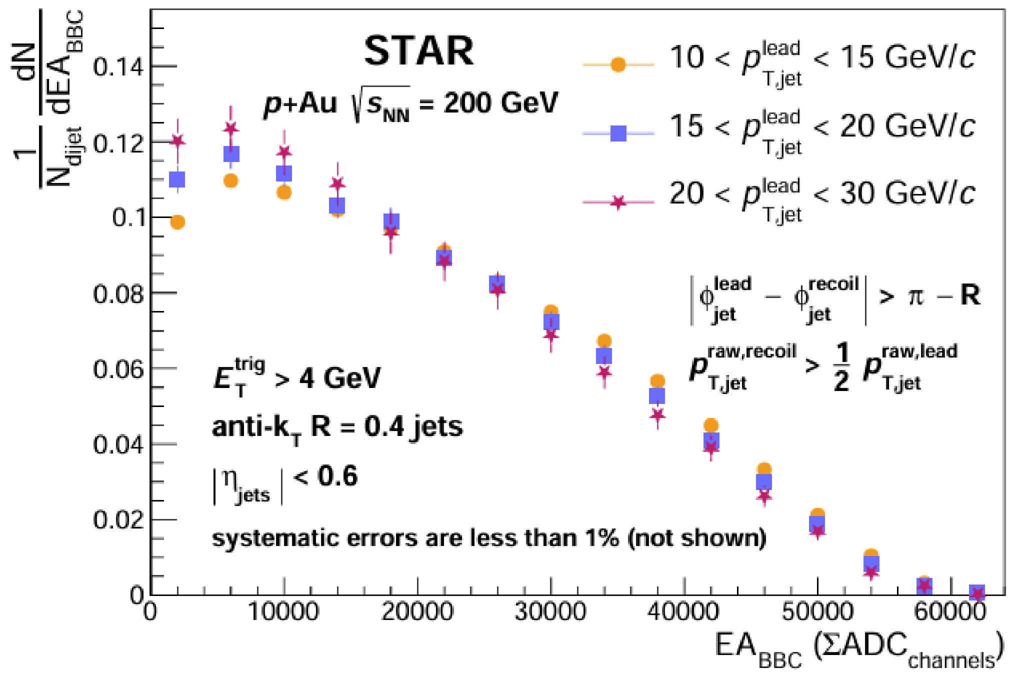




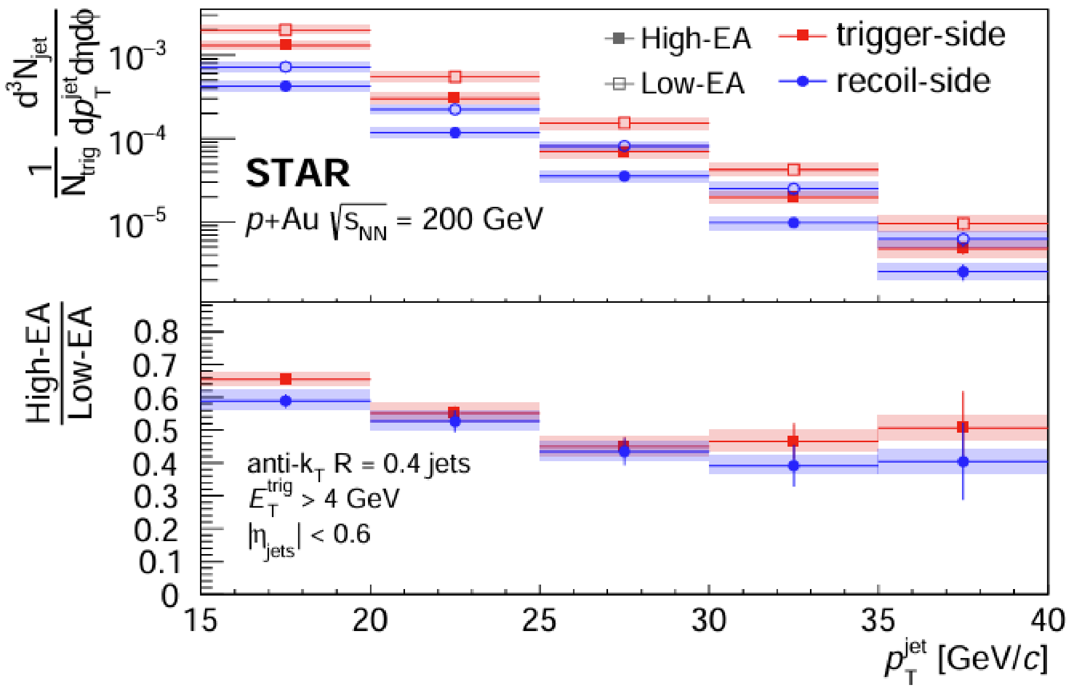


Quenching Disfavored in p+Au

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

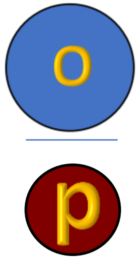


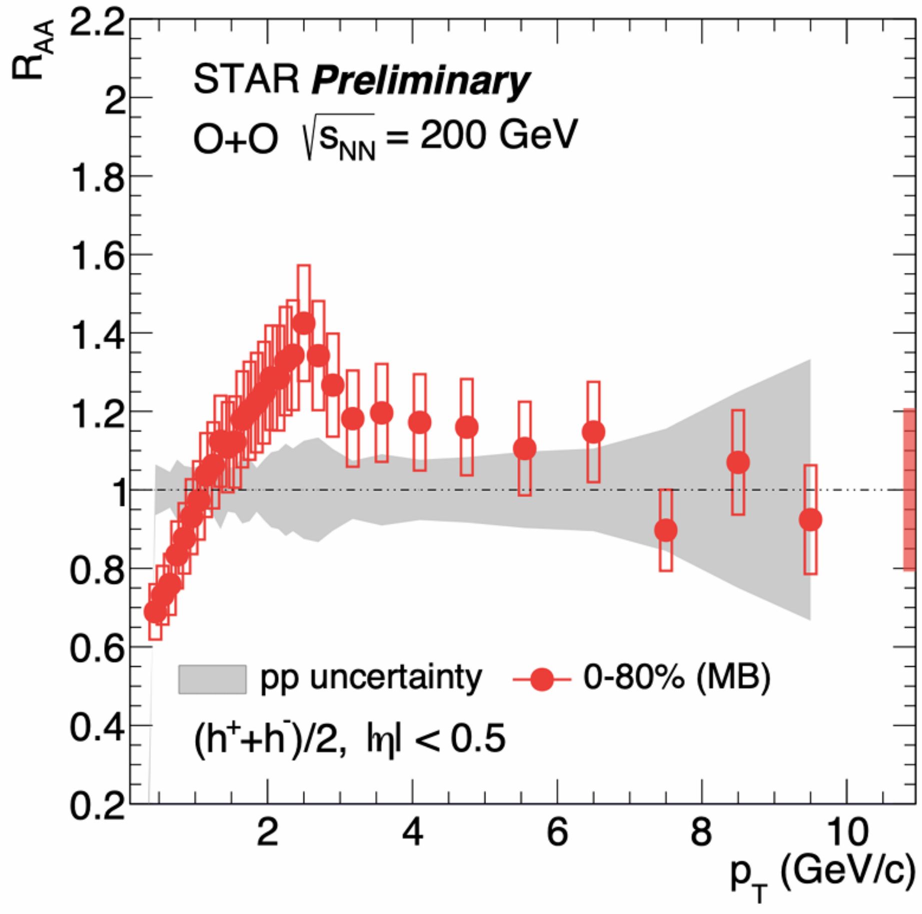
STAR: PRC 110 (2024) 4, 044908



O+O Hadron R_{AA}

- Charged hadron R_{AA} consistent with unity at large momentum

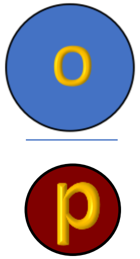


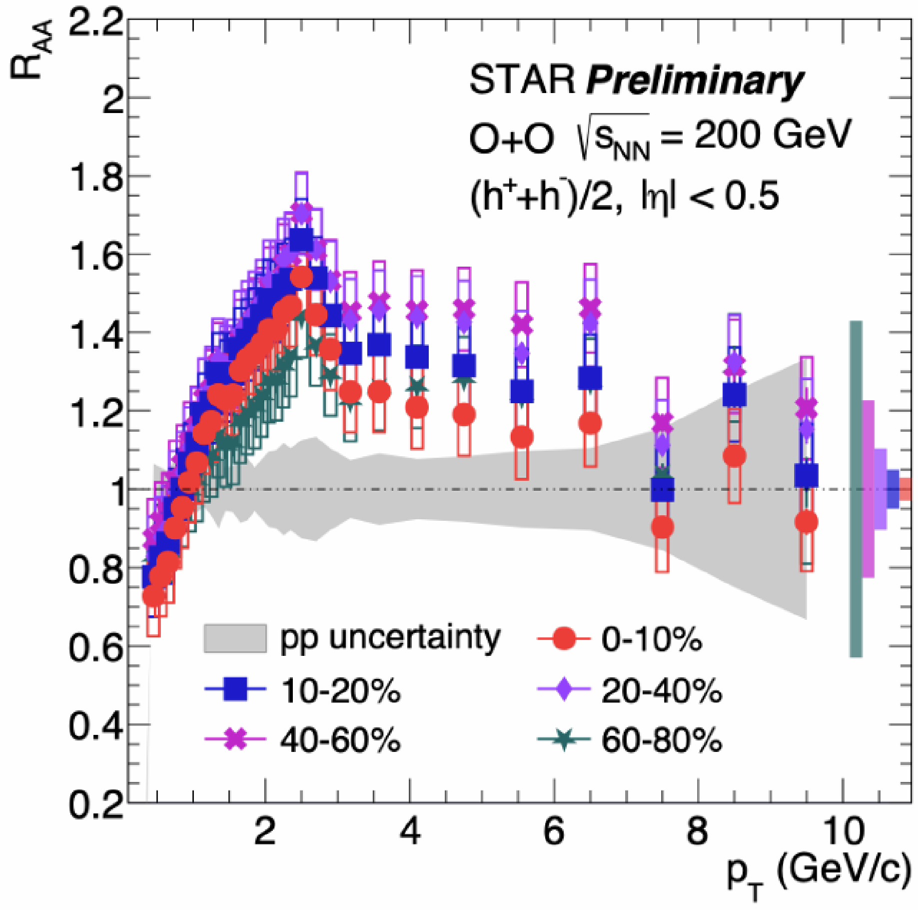


- Work is being done on p+p baseline for jet R_{AA} comparison

O+O Hadron R_{AA}

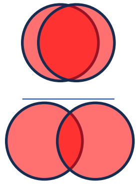
- Charged hadron R_{AA} consistent with unity at large momentum
- In multiple centrality ranges
- Work is being done on p+p baseline for jet R_{AA} comparison

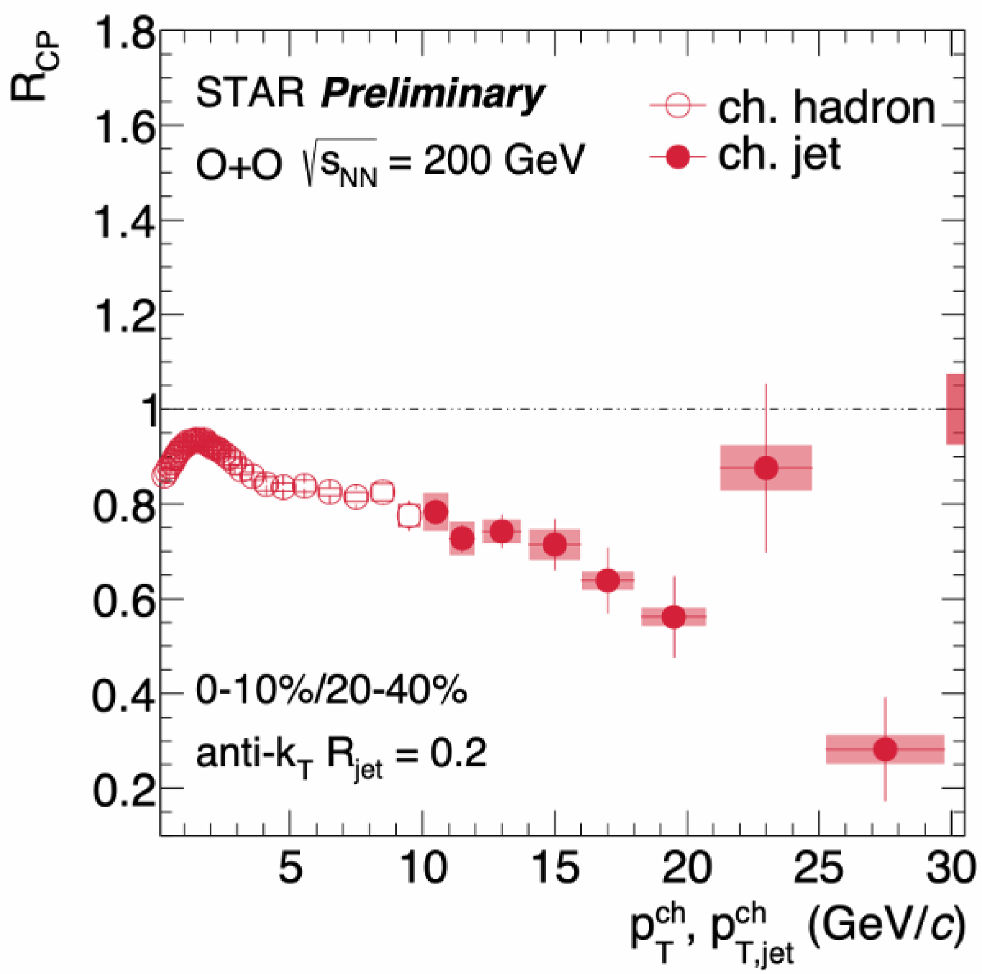




R_{cp} for hadrons and jets

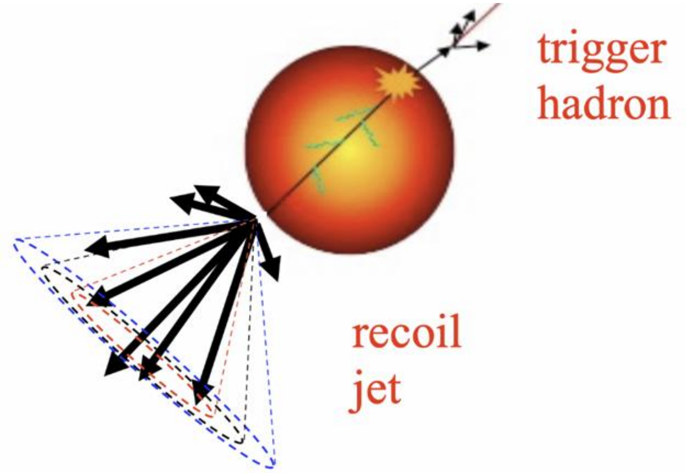
- **Signs of suppression for high p_T jets** in central O+O collisions
- Effects other than quenching may be present
  - Early-time dynamics
  - EA-Q^2 anti-correlation
  - α-clustering

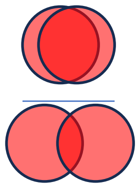


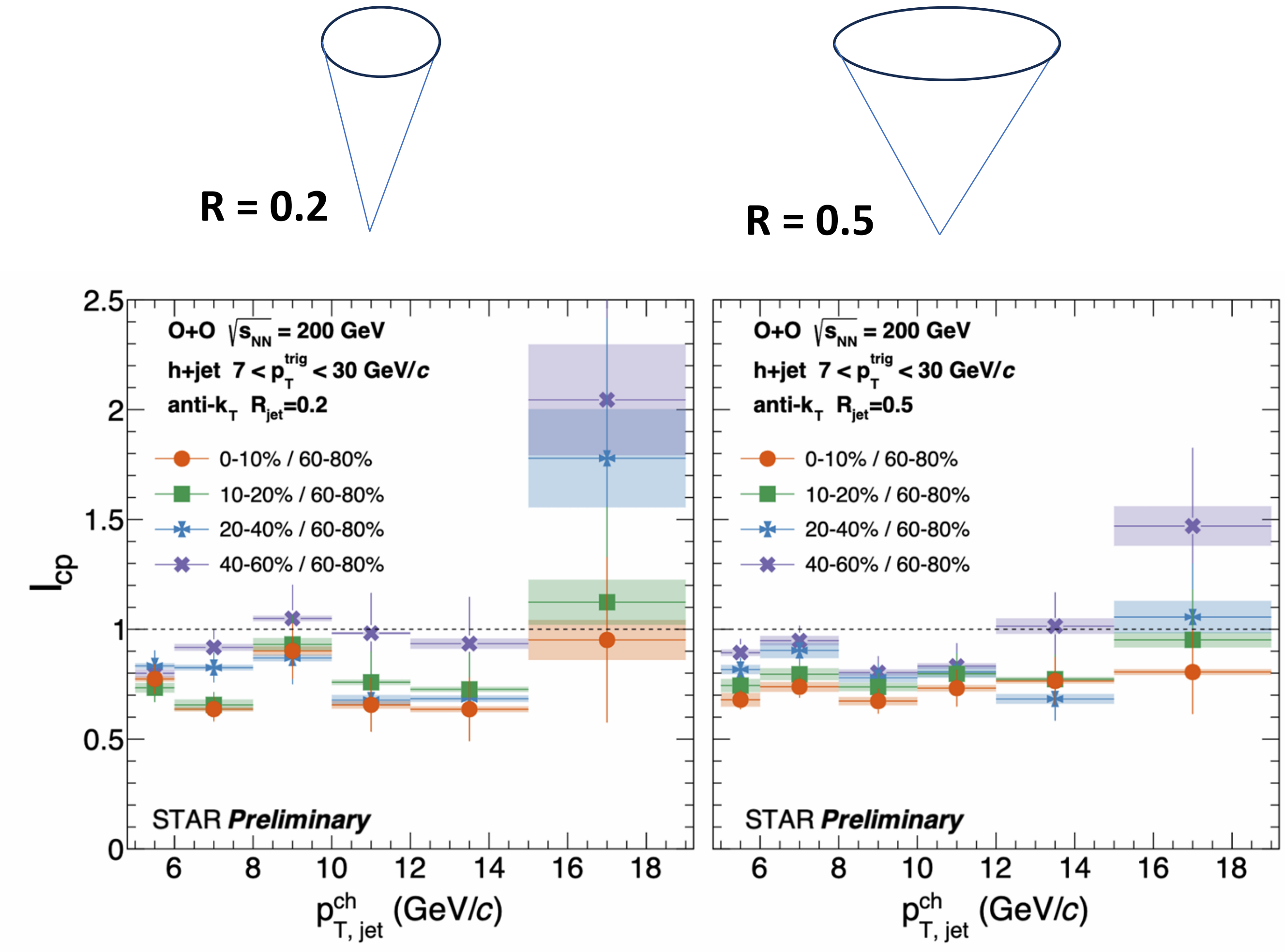


I_{CP} for jets

- No Significant Radial Dependence
- **Consistent yield suppression observed**







Many Exciting Analyses on the Horizon!

- Further jet substructure studies in p+p and heavy-ion
- Energy Correlators in heavy-ion
- Improved Jet Measurements from Run 22 onward with STAR upgrades
- Jet spectra and substructure in p+Au
- Further O+O analyses