Recent jet measurements from STAR

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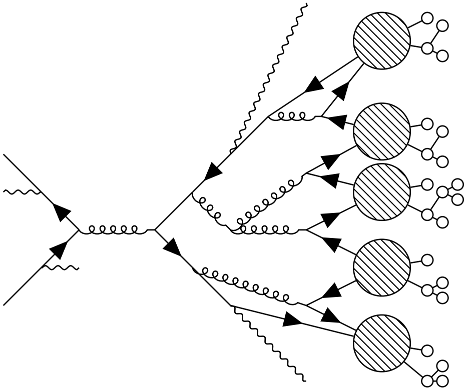
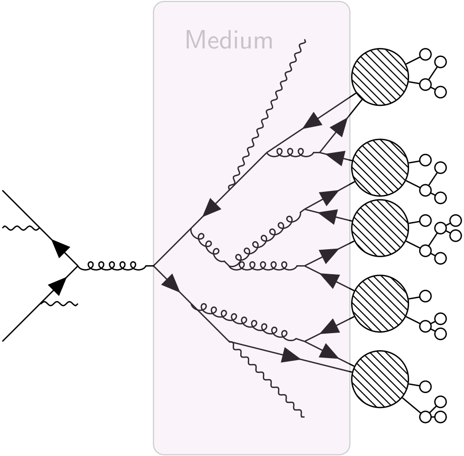
Supported in part by U.S. DEPARTMENT OF ENERGY | Office of Science

Jets in vacuum



- Collimated sprays of particles, proxies for hard scattered partons
- Produced by parton showering explained by perturbative QCD
- Reconstructed by clustering final state particles after hadronization (non-perturbative)

Jets in medium



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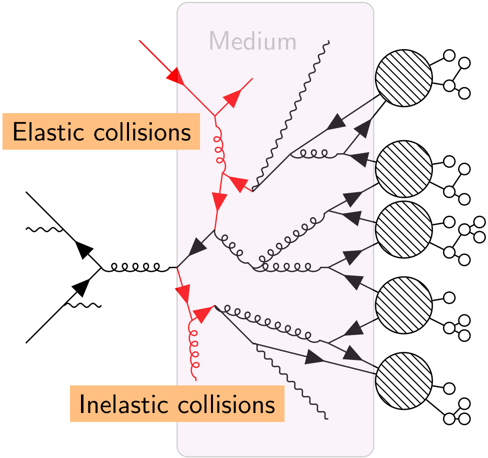
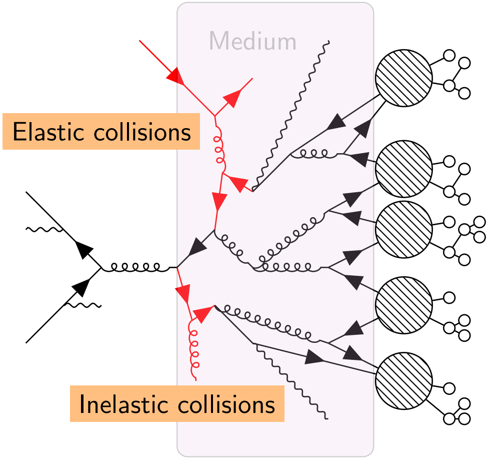
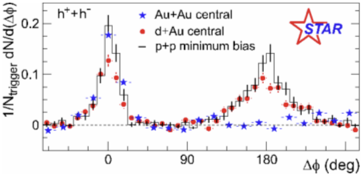


- Elastic and inelastic collisions with medium particles leads to modification of jet properties

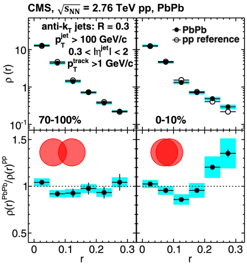
Jets in medium



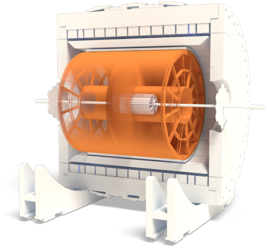
- Energy loss: STAR, Phys.Rev.C 102 (2020) 5



- Jet broadening: CMS, Phys. Lett. B 730 (2014) 243



The STAR detector



- Time Projection Chamber (TPC)
  - Reconstructs charged particle tracks
  - $|\eta| < 1, 0 < \phi < 2\pi$
  - PID using dE/dx

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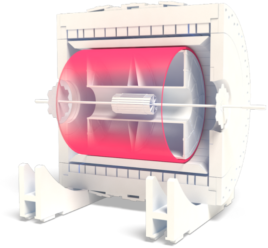

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  - PID using TOF measurements
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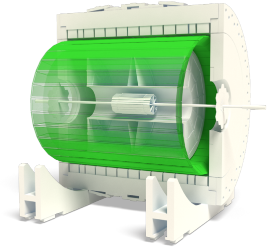

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  - Measures neutral component of jet energy
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  - Used to trigger high energy events

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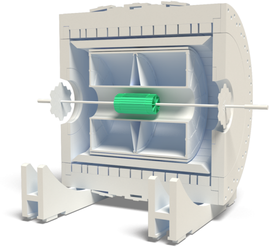

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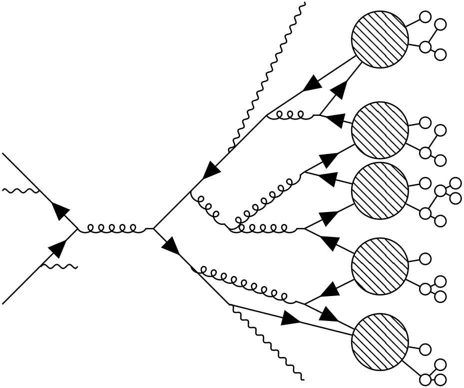
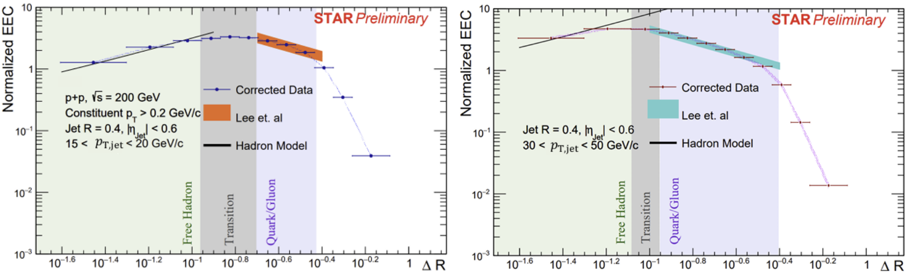
- Heavy Flavor Tracker (HFT, 2014-2016)
  - Improves position resolution for secondary vertices

Jets in vacuum



Time evolution of jets, from partons to hadrons

- Normalized EEC $= \frac{1}{\sum_{\text{Jets}} \sum_{i \neq j} \frac{E_i E_j}{{p_{T,Jet}}^2}} \frac{d\left(\sum_{\text{Jets}} \sum_{i \neq j} \frac{E_i E_j}{{p_{T,Jet}}^2}\right)}{d(\Delta R)}$
- Formation time: $t_f \propto \frac{1}{(\Delta R)^2}$ *(Apolinário, Cordeiro, & Zapp EPJC 81 (2021))*

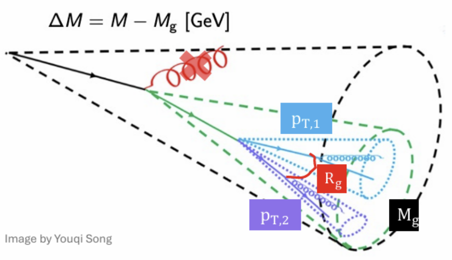


$\Delta R_{Turnover} \times p_{\mathrm{T,Jet}} \approx 2-3$ GeV, independent of $p_{\mathrm{T,Jet}}$

Universal energy scale for hadronization

In perturbative (Quark/Gluon) region, next-to-leading log pQCD calculations explain EECs

Separating pQCD and npQCD in vacuum

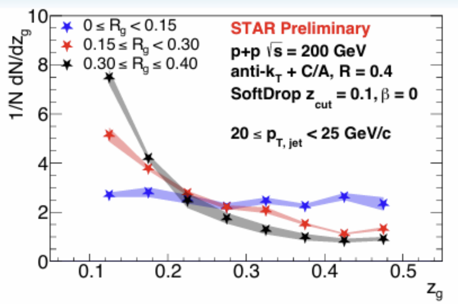


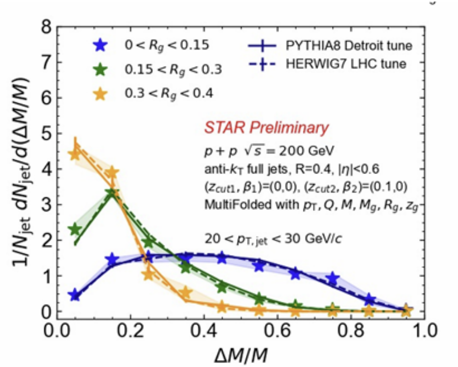
$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut} \left(R_g / R_{jet}\right)^{\beta}$$

for $z_{cut} = 0.1$ and $\beta = 0$, $z_g > 0.1$ and R_g is the distance of subjets at split

- **SoftDrop:** Reduce wide-angle, soft radiation from reconstructed jets (Larkoski, A.J., Marzani, S., Soyez, G. et al. Soft drop. J. High Energ. Phys. 2014, 146 (2014))
- **CollinearDrop:** Soft component of given jet observable ($\mathcal{O}$). $\Delta\mathcal{O} = \mathcal{O} - \mathcal{O}_g$ (Chien, YT., Stewart, I.W. Collinear drop. J. High Energ. Phys. 2020, 64 (2020))

Separating pQCD and npQCD in vacuum



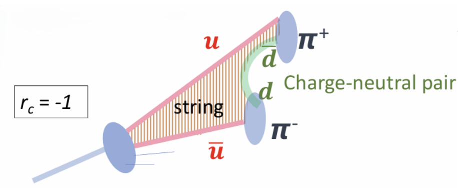


- **Perturbative:** Larger R_g $\implies$ Smaller $\langle \Delta M/M \rangle$ $\implies$ Steeper z_g
- **Non-perturbative:** Smaller R_g $\implies$ Larger $\langle \Delta M/M \rangle$ $\implies$ Flatter z_g
- PYTHIA8 Detriot tune and HERWIG7 LHC tune explain $\Delta M/M$ distributions from data

Probing npQCD region in vacuum

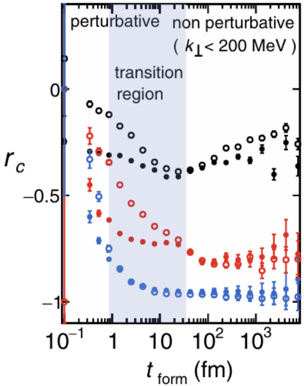
$$r_c(X) = \frac{\mathrm{d}\sigma_{h_1 h_2}/\mathrm{d}X - \mathrm{d}\sigma_{h_{h_1}\overline{h_2}}/\mathrm{d}X}{\mathrm{d}\sigma_{h_1 h_2}/\mathrm{d}X + \mathrm{d}\sigma_{h_1\overline{h_2}}/\mathrm{d}X}$$

$h_1 h_2$: same charge hadrons, $h_1\overline{h_2}$: opposite charge hadrons



- r_c measures fraction of "string-like hadronization"
- baseline for studying medium modification of hadronization

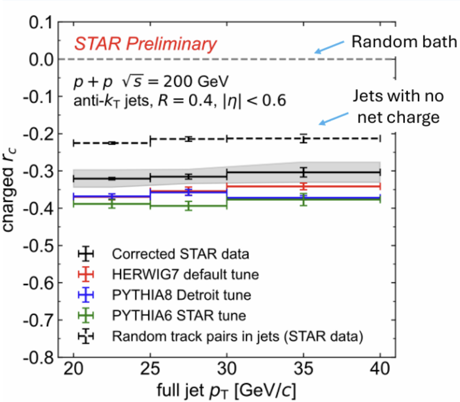
Chien, Deshpande, Mondal, Sterman, PRD 105 (2022) 5, L051502



$$t_{\text{form}} = z(1-z)p/k_{\text{T}}^2$$

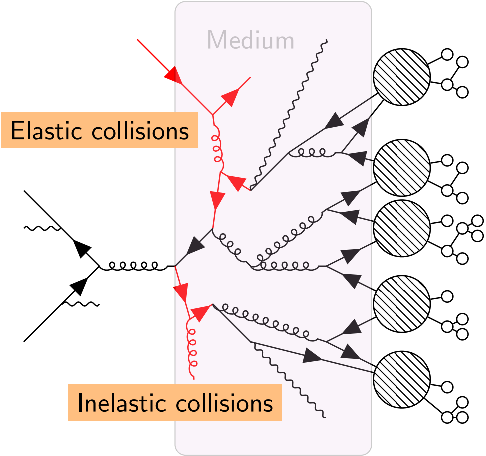
where, $p = p^{h_1} + p^{h_2}$, and $z = p^{h_2}/p$

Probing npQCD region in vacuum



- **First measurement in p+p:** Both string-like and cluster hadronization underpredict STAR data
- More model tuning required

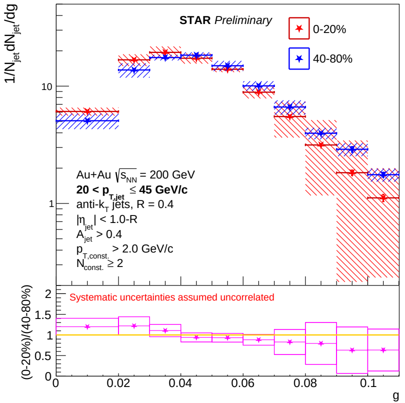
Jets in medium



Jet substructure in medium

$$\lambda^\kappa_\beta = \sum_{\text{const}\in\text{jet}} \overbrace{\left(\frac{p_{\text{T,const}}}{p_{\text{T,jet}}}\right)^\kappa}^{\text{soft/hard radiation}} \times \overbrace{r(\text{const},\text{jet})^\beta}^{\text{collinearity sensitive}}$$

- $\lambda^0_0 = N_{\text{constit.}}$, $\lambda^1_1 = g$ (girth), $\lambda^1_2 =$ thrust, $\sqrt{\lambda^2_0} = p_T^D$
- β, κ control sensitivity to energy and angular scales
- Probe modification of radiation pattern in medium



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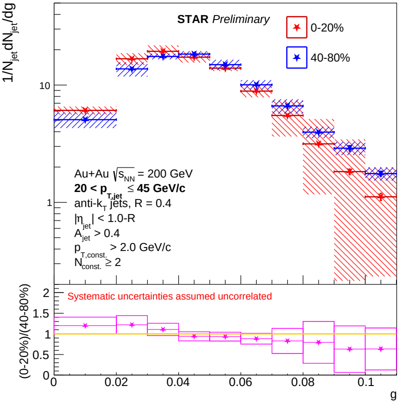
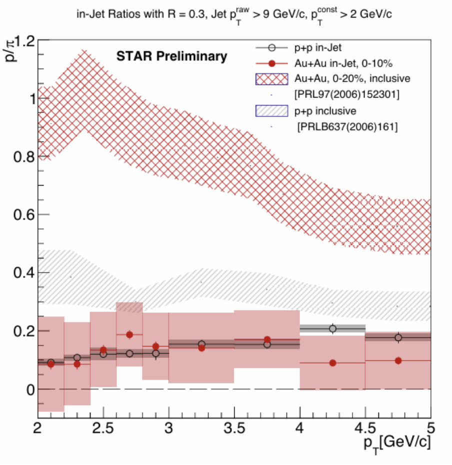
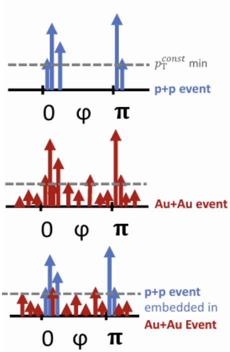


- **Girth consistent within systematic uncertainties between central, peripheral collisions**
- Better estimates of systematic uncertainties ongoing

Hadron chemistry in jet cones



Correlated backgrounds:
Upward fluctuation into real jets removed using "pseudo-embedding" $p+p$ events into a random central Au+Au events



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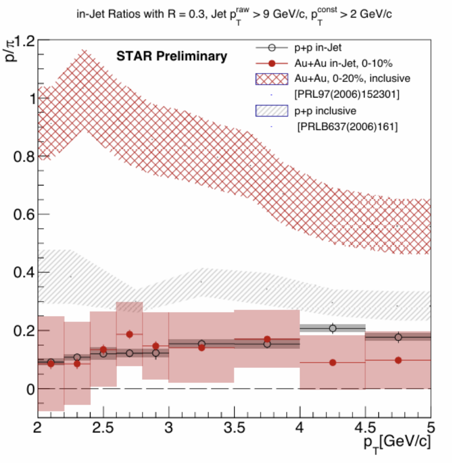
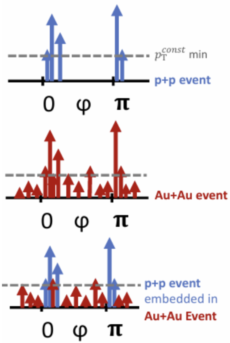


Correlated backgrounds:
Any residual jet - Au+Au hadron correlation → bias towards upward fluctuation



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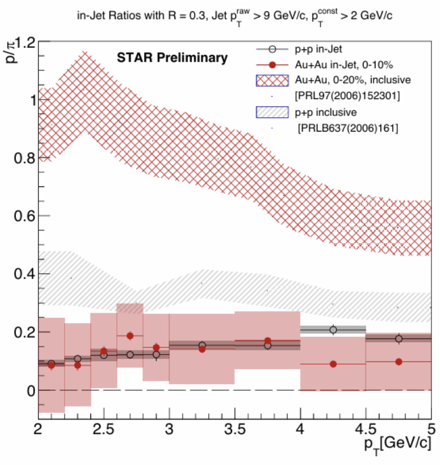
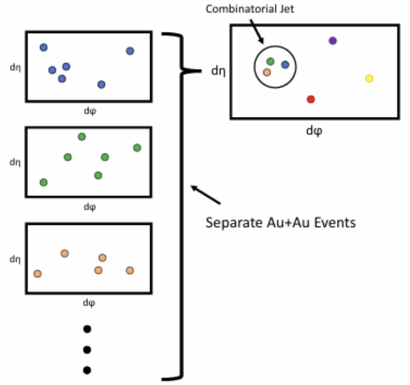


Correlated backgrounds:
Combinatorial jets (jets clustered from low p_T tracks, no hard processes)



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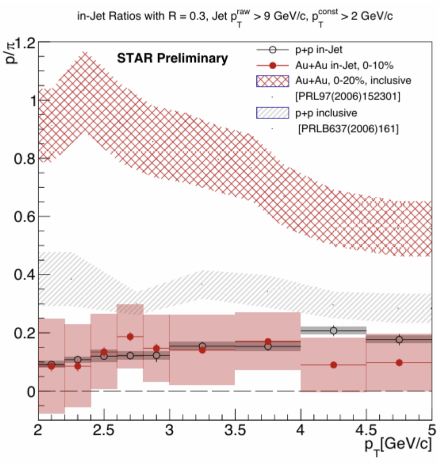
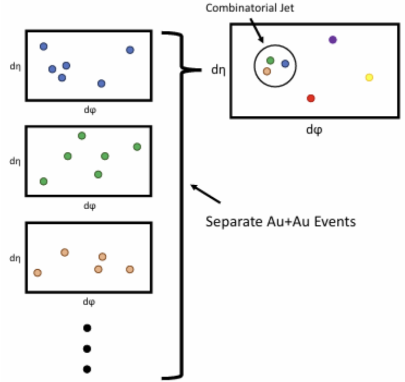


Correlated backgrounds:
Simulated by clustering randomly sampled tracks from separate events (Mixed Constituent Event)



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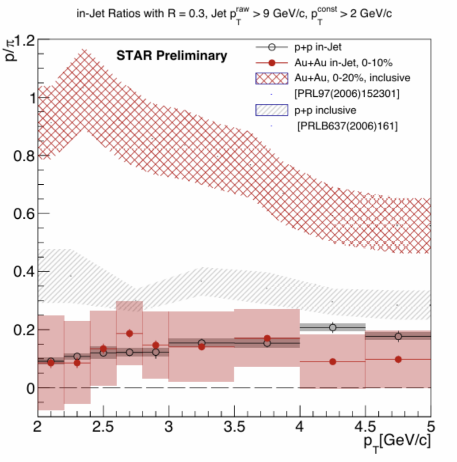
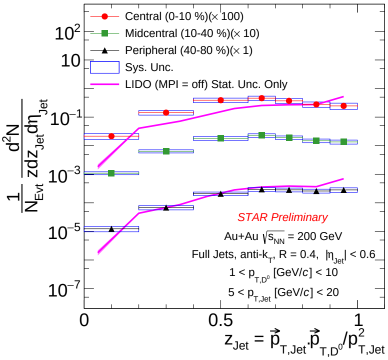
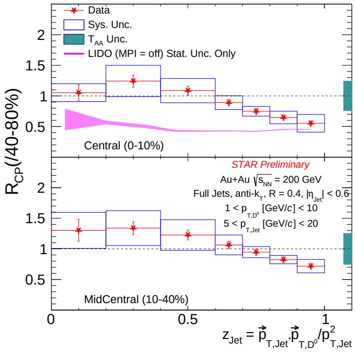


- p/π ratio suppressed inside jet cones compared to inclusive $p+p$
- No significant difference in Au+Au p/π ratio compared to $p+p$

Flavour dependence - D^0 jets

$$z_{\text{Jet}} = \frac{\vec{p}_{\text{T,Jet}} \cdot \vec{p}_{\text{T,D}^0}}{|\vec{p}_{\text{T,Jet}}|^2}$$, Low/High z_{Jet} $\rightarrow$ soft/hard-fragmented D^0 jet





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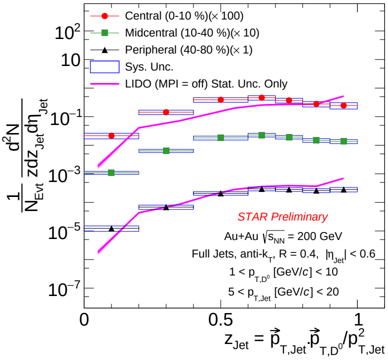
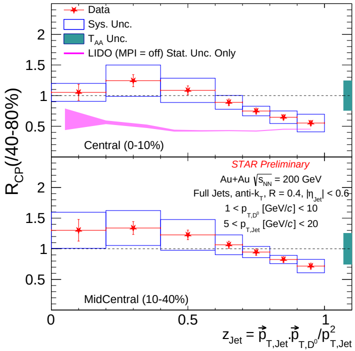


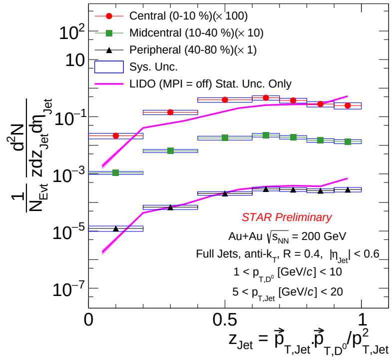


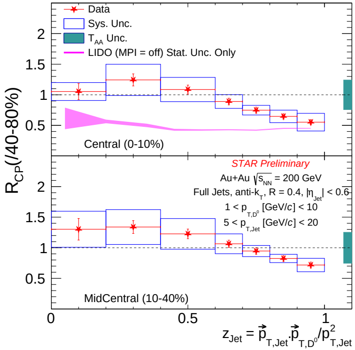
Hard fragmented D^0 jet R_{CP} suppressed in central and midcentral events

Soft fragmented D0 jet R_{CP} consistent with 1 in central and midcentral events

Flavour dependence - D^0 jets

LIDO, Phys. Rev. C 98, 064901





LIDO underpredicts soft-fragmented D^0 jets in central events, overpredicts hard-fragmented D^0 jets

LIDO predicts flat R_{CP}, which agrees with data for D^0 jets with highest z_{Jet} (hardest-fragmented)

Outlook

$\sqrt{s_{NN}}$ (GeV)	Species	Sampled Luminosity	Year
200	Au+Au&p+Au	AuAu 32.7 nb^{-1} / pAu 0.69 pb^{-1}	2023+2025
200	p+p	142 pb^{-1}	2024

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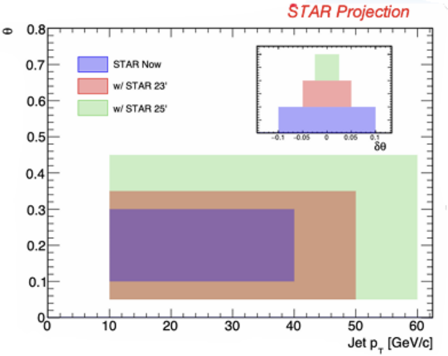
- Increased statistics for jet substructure measurements
- Access to high p_{T} jets and wide angle radiation
- Increased angular resolution



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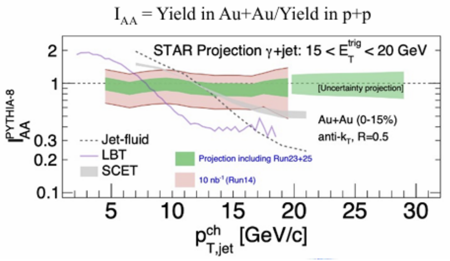
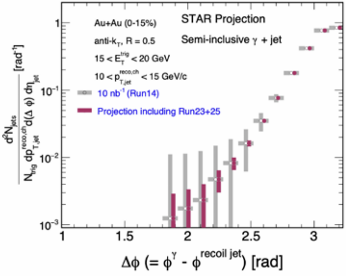
- Wider kinematic range for I_{AA} (current results: https://arxiv.org/abs/2309.00156) and acoplanarity measurements
- Larger statistics → Improved uncertainty



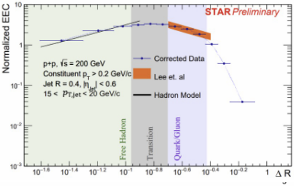


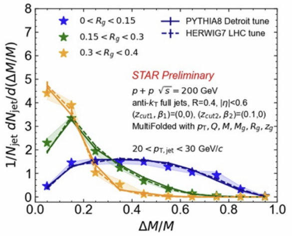
Outlook

- HERWIG tune to RHIC kinematics ongoing
- Jet chemistry in unbiased sample (constituent $\mathrm{p_T}$ dependence)
- Generalized angularities for $\mathrm{D^0}$-jets
- Higher order EECs, charge dependence, medium modifications

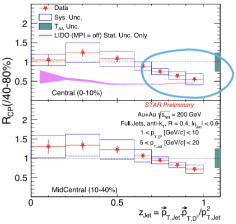
Summary

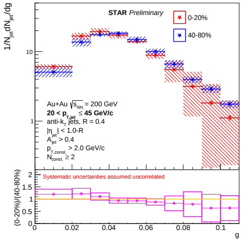
Precision era of jet substructure



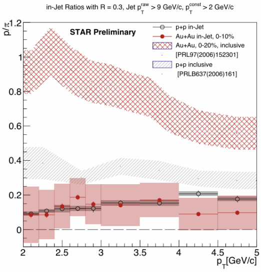


Medium modification of jets





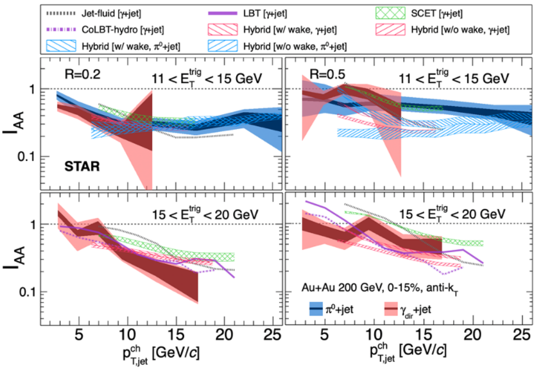
Differential jet yeild modifications



Backups

γ+jet and π^0 + jet measurements

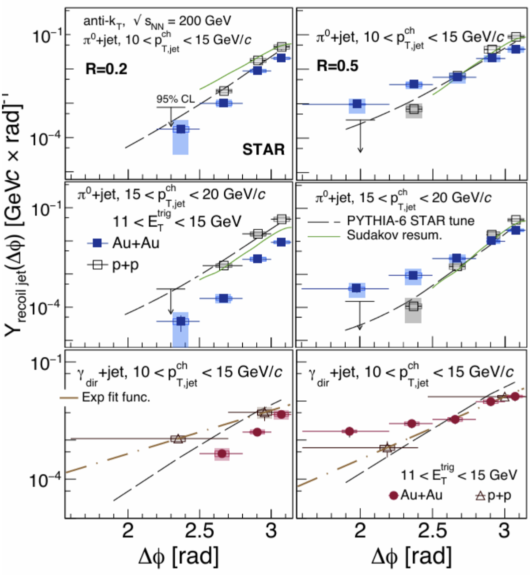
How does the jet energy move around during propagation in medium?



- Significant medium-induced recoil jet yield suppression for $R = 0.2$ compared to 0.5
- Evidence of significant medium-induced intra-jet broadening at angular scales less than 0.5 radians

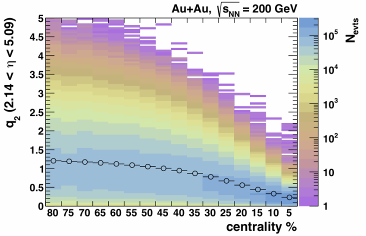
Short paper arXiv: 2309.00156 [nucl-ex] Long paper arXiv: 2309.00145 [nucl-ex]

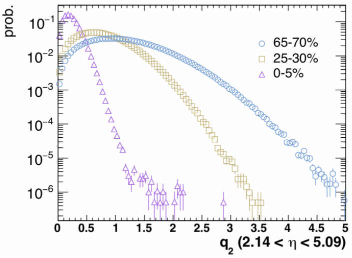
γ+jet and π^0 + jet acoplanarity



- For R=0.5, observed excess yield toward $\Delta\phi \approx \pi/2$ in AuAu
- For R=0.2, observed jet yield suppression at all $\Delta\phi$

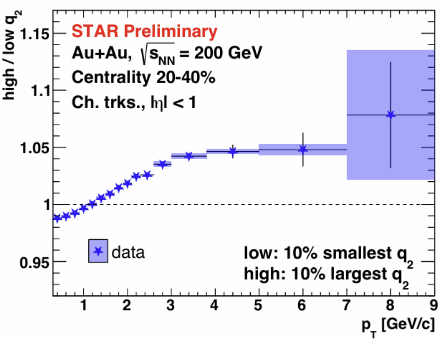
Event shape engineering





- Charged particle spectra from TPC, q2 from EPD-W to avoid autocorrelation
- Correlation between q_2 and centrality, but broad distribution of q2 in each centrality bin

Event shape engineering



- Charged particle spectra harder in high-q_2 events, flattened at high p_T
- Consistent with ALICE results at 2.76 TeV