Measurement of inclusive jet production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR experiment

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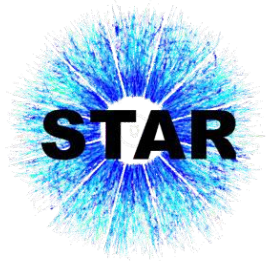
for the STAR Collaboration

Supported in part by:

U.S. DEPARTMENT OF ENERGY | Office of Science

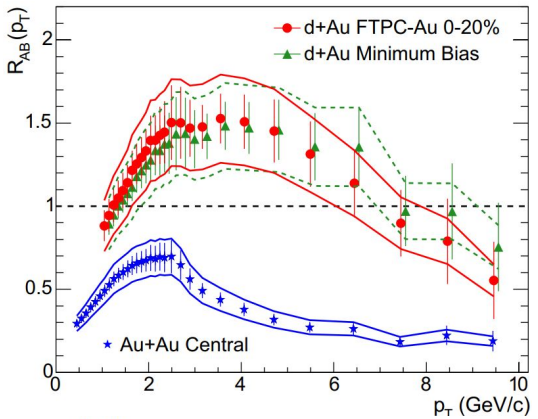


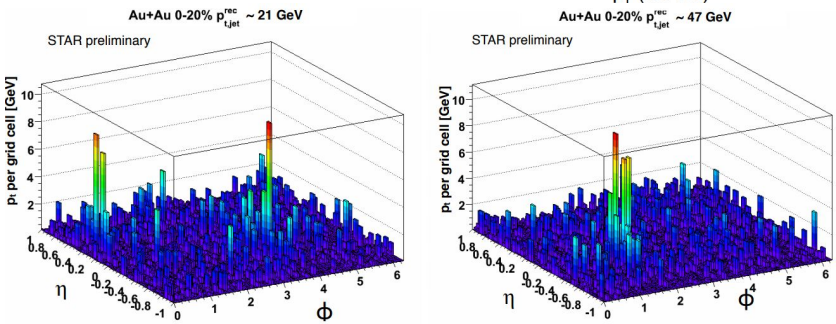
The 10th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions - June 1, 2020

Motivation

- **High-p_T hadron suppression** - extensively measured at RHIC and the LHC
- **Reconstructed jets** - broader exploration of jet quenching mechanisms
- Different jet measurement channels: **inclusive**, coincidence, heavy flavor
- RHIC vs. LHC
- This talk:
  - **First inclusive charged-jet measurements in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV** {arXiv:2006.00582}
  - **First look at fully-reconstructed inclusive jets in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV**

STAR, PRL 91.072304 (2003)

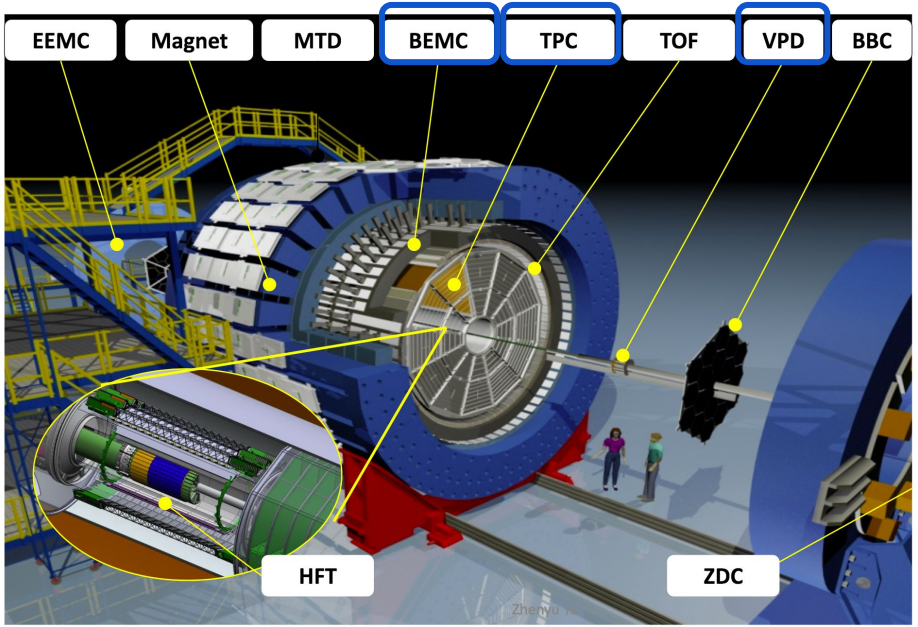




STAR Experiment

This analysis utilizes:

- **Time Projection Chamber** (TPC)
  - Charged-particle identification and precise momentum reconstruction
- **Barrel Electromagnetic Calorimeter** (BEMC)
  - Detection of neutral and charged particle energy
  - Fast detector used for triggering
- **Vertex Position Detector** (VPD)
  - Minimum-bias trigger
  - Fast detector for pile-up event rejection



Full azimuthal coverage; $|\eta| < 1$

Dataset and Analysis

Data sample: Au+Au at $\sqrt{s_{NN}}$ = 200 GeV:

- 2011 minimum-bias, L_{int} = 6 μb^{-1} (charged jets)
- 2014 minimum-bias and BEMC-triggered, L_{int} = 5.2 nb^{-1} (full jets)

Centrality: Determined from charged-track multiplicity within $|\eta_{track}| < 0.5$

- Central (0-10%)
- Peripheral (60-80%)

Event selection:

- $|V_z^{TPC}| < 30$ cm, $|V_z^{TPC} - V_z^{VPD}| < 3$ cm

Primary track selection:

- $|\eta_{track}| < 1$
- Number of TPC hits > 14; ratio of used to maximum possible TPC hits > 0.52
- DCA < 1 cm

***p+p* reference:** PYTHIA 6.428, Perugia 2012, STAR tune

Details in: STAR, PRD 100, 052005 (2019)

Jet Reconstruction

- **Charged jets**: charged tracks from TPC
- **Full jets**: charged tracks from TPC + neutral energy from BEMC clusters, corrected for hadronic energy deposition in BEMC

Details in: STAR, PRL 115.092002 (2015)

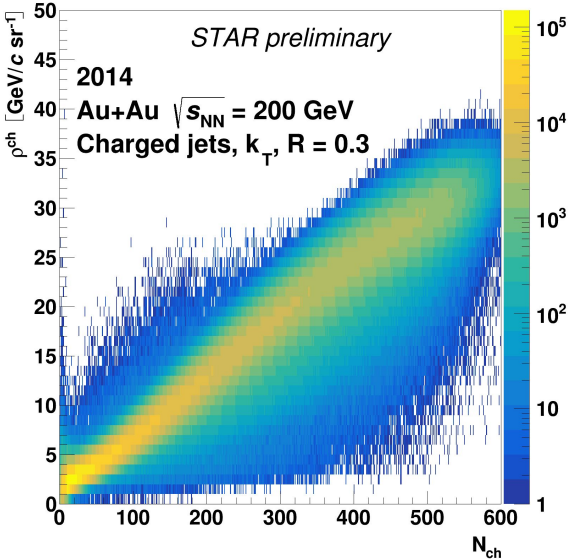
- Anti-k_T algorithm, R = 0.2, 0.3, 0.4
- Fiducial acceptance cut: $|\eta_{jet}| < 1 - R$
- Constituents:
  - charged: $0.2 < p_T < 30.0$ GeV/c
  - neutral: $0.2 < E_T < 30.0$ GeV
- **Inclusive jet analysis: two-step correction (event-by-event, ensemble)**

Inclusive Charged Jet Spectrum Analysis: Event-by-event Step

- Area cut: A_{jet} >= 0.07 / 0.2 / 0.4 sr for R = 0.2 / 0.3 / 0.4
- Approximate jet-wise **background subtraction** (FastJet)

$$p_{\mathrm{T,jet}}^{\mathrm{reco,i}} = p_{\mathrm{T,jet}}^{\mathrm{raw,i}} - \rho \cdot A_{\mathrm{jet}}^{\mathrm{i}}, \text{ where } \rho = \mathrm{median}\left\{ \frac{p_{\mathrm{T,jet}}^{\mathrm{raw,i}}}{A_{\mathrm{jet}}^{\mathrm{i}}} \right\}$$

- Combinatorial jets suppressed by imposing a cut on **leading hadron** transverse momentum ($p_{T,lead}$)
  - Imposes **bias** on jet fragmentation and breaks collinear safety
    → as low threshold as possible ($p_{T,lead}$ > 5 GeV/c)
  - Measure bias using $p_{T,lead}$ > 7 GeV/c



Inclusive Charged Jet Spectrum Analysis: Event-by-event Step

- **Raw charged jet spectra** reconstructed in central and peripheral collisions with various $p_{\mathrm{T,lead}}$ thresholds

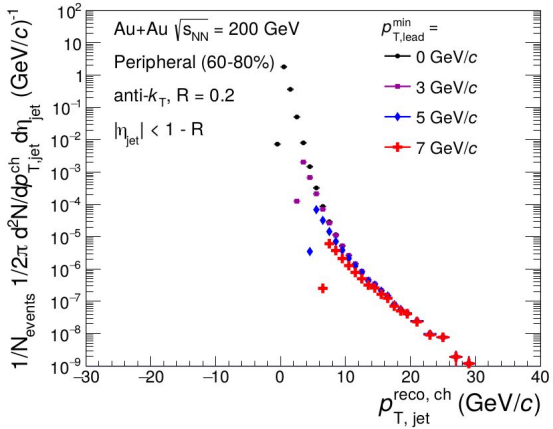
R=0.2

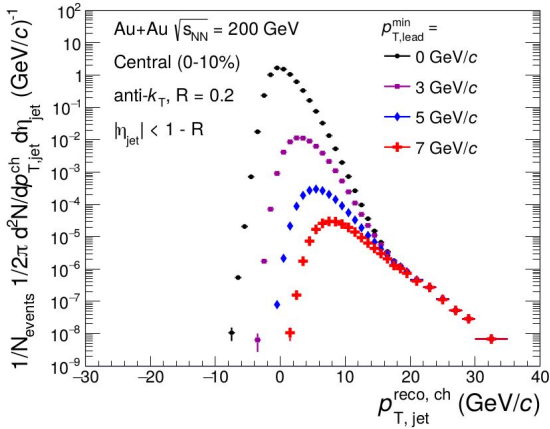
- High $p_{\mathrm{T,lead}}$ cut preferentially suppresses yield at low and negative $p_{\mathrm{T,jet}}^{\mathrm{reco,ch}}$, where combinatorial jet contribution is largest

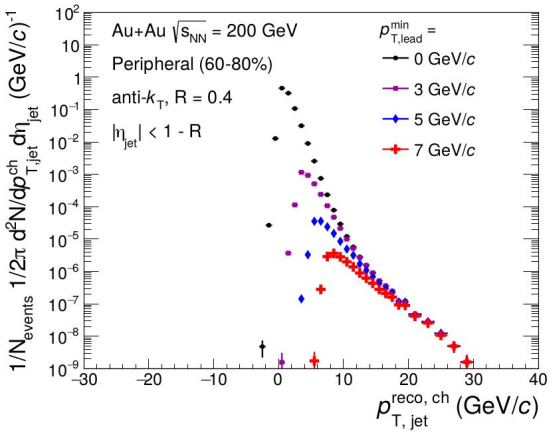
R=0.4

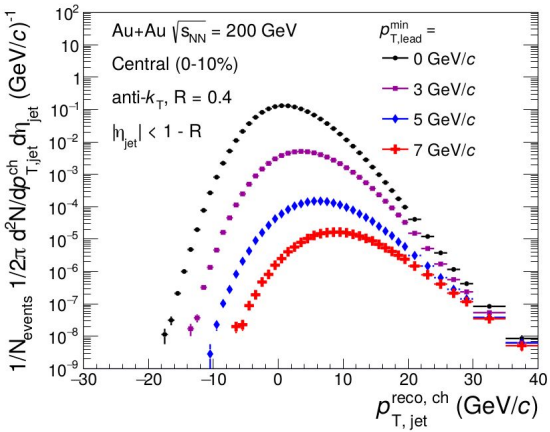
peripheral

central





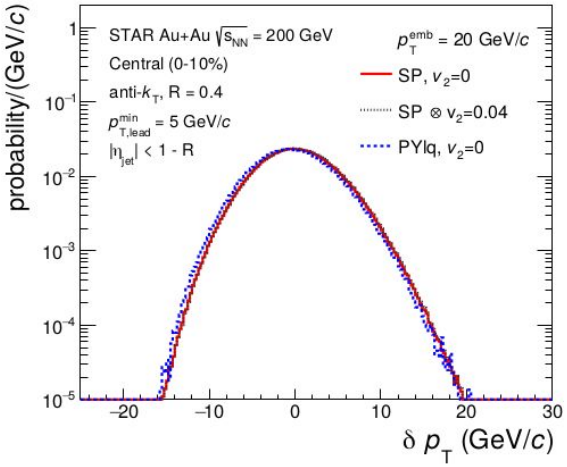


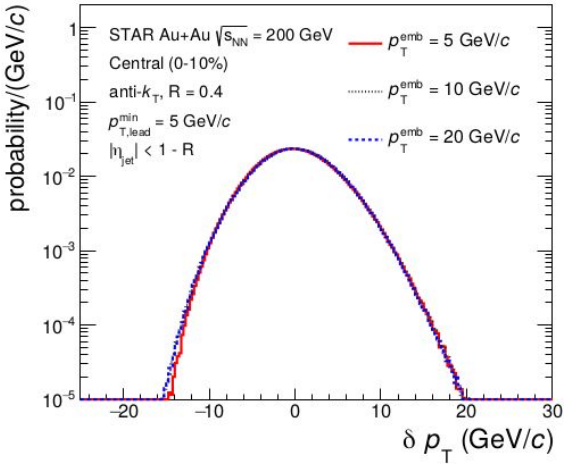


Inclusive Charged Jet Spectrum Analysis: Ensemble Step

- **Unfolding**: iterative **Bayesian** and **SVD** (systematic uncertainty estimation)
- **Factorize** background fluctuations and detector effects
- **Background fluctuations:** embed different jet-like objects
  - Variations of fragmentation pattern: Single Particle (SP), PYTHIA light-quark jet (PYlq)

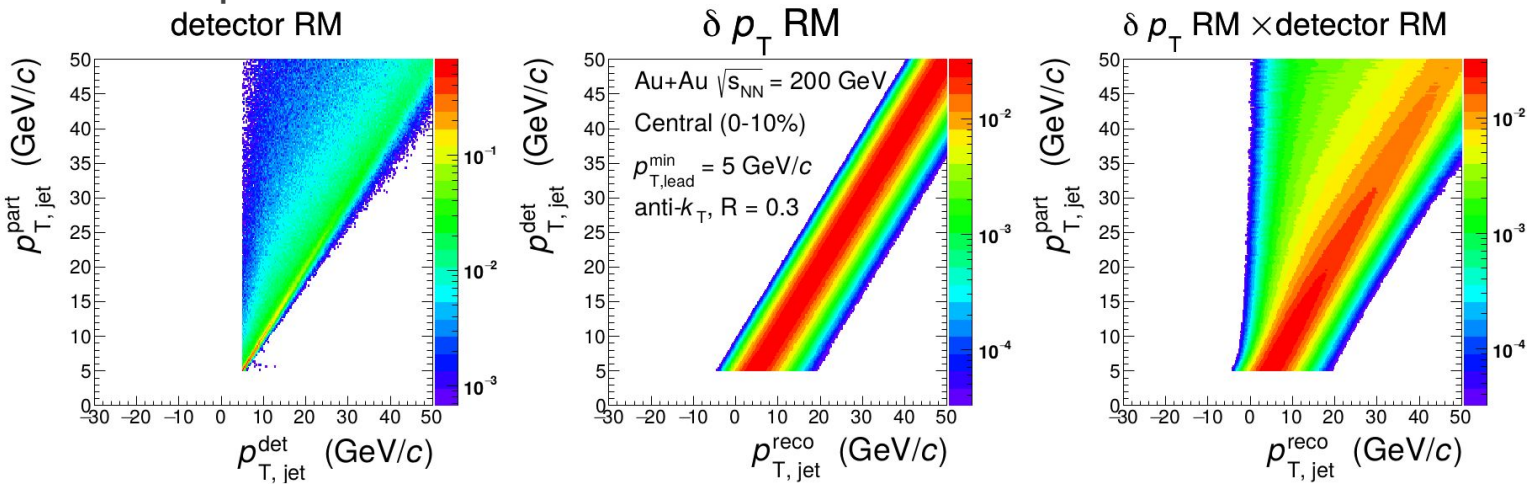
$$\delta p_{\mathrm{T}} = p_{\mathrm{T,jet}}^{\mathrm{reco,ch}} - p_{\mathrm{T}}^{\mathrm{emb}}$$





Inclusive Charged Jet Spectrum Analysis: Ensemble Step

- **Unfolding**: iterative **Bayesian** and **SVD** (systematic uncertainty estimation)
- **Factorize** background fluctuations and detector effects
- **Detector effects:** parametrized PYTHIA



Fully-corrected Inclusive Charged Jet Spectra in Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV

$p_{T,lead} > 5$ GeV/c

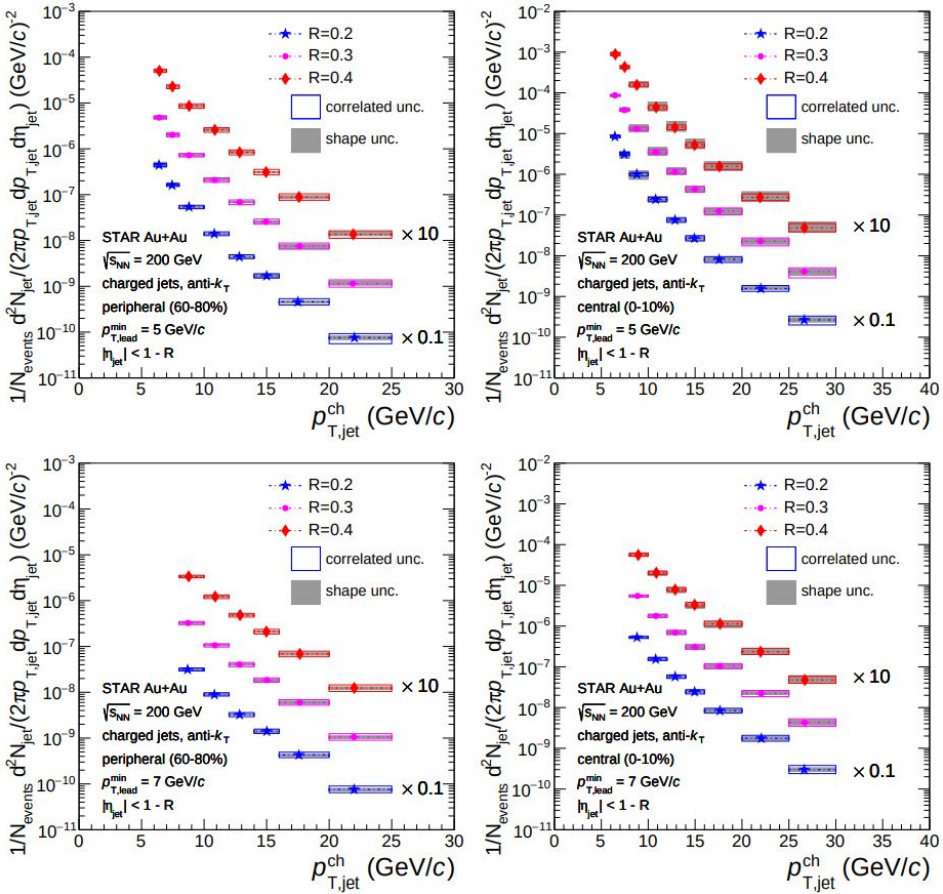
- Central (0-10%) and peripheral (60-80%) collisions

- Spectra biased by $p_{T,lead}$ cut

$p_{T,lead} > 7$ GeV/c

peripheral

central



Unbiased Region Determination

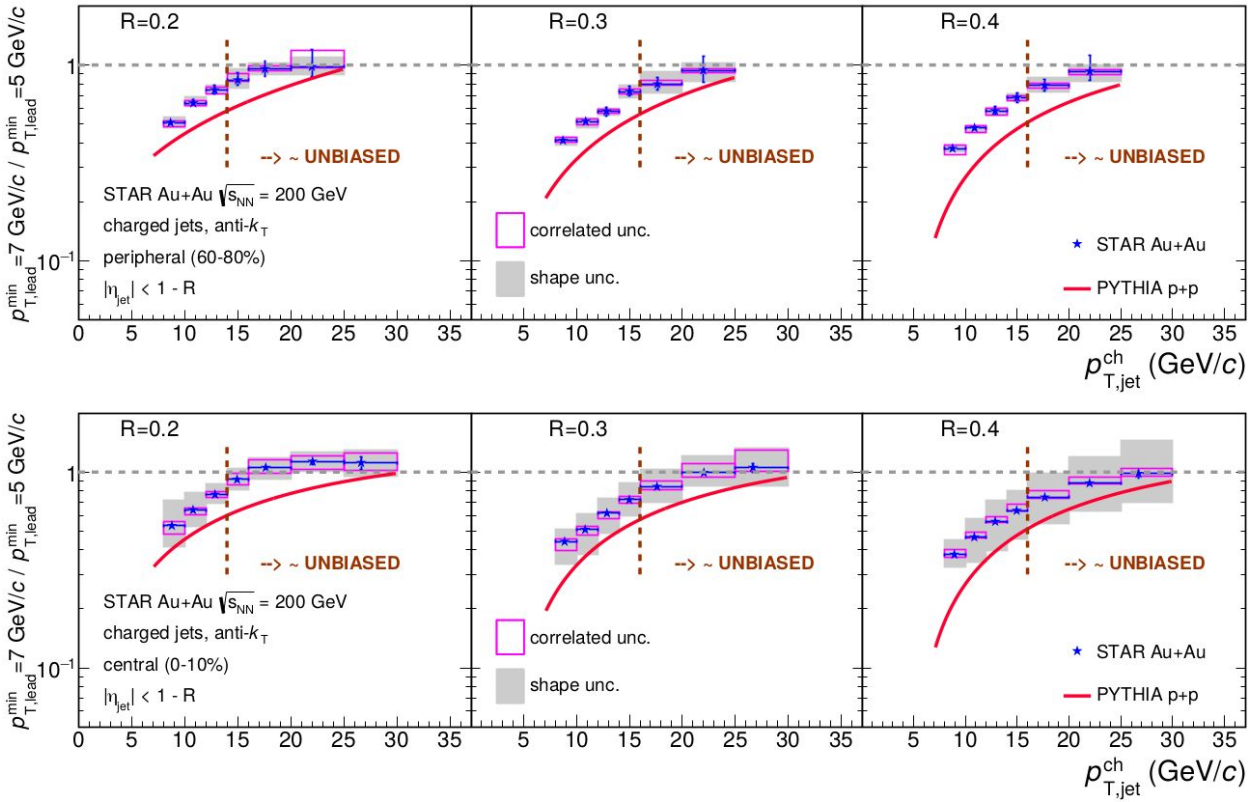
- **Unbiased region** estimated from the ratio of yields with $\frac{p_{\mathrm{T,lead}} > 7\ \mathrm{GeV}/c}{p_{\mathrm{T,lead}} > 5\ \mathrm{GeV}/c}$

peripheral

- **~unbiased** = ratio > 0.9

- Physics comparisons in **~unbiased** region only

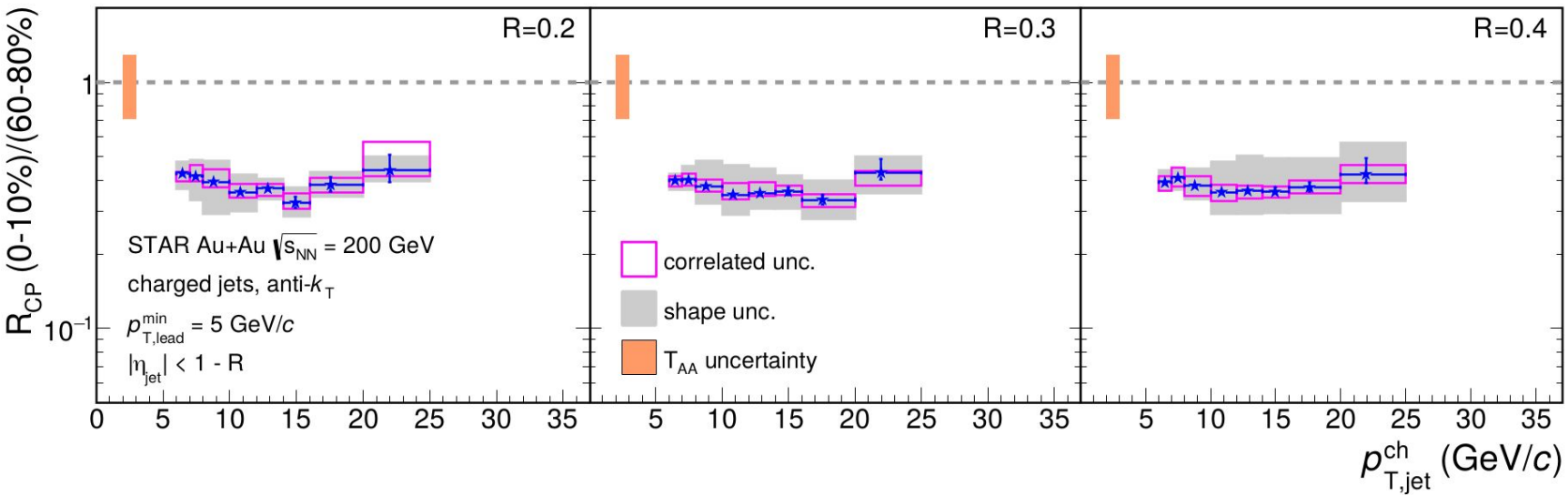
central



Charged Jet R_{CP}

- **Strong suppression** of central vs peripheral, **weak p_T-dependence**
- Weak R dependence

R = 0.2 | R = 0.3 | R = 0.4

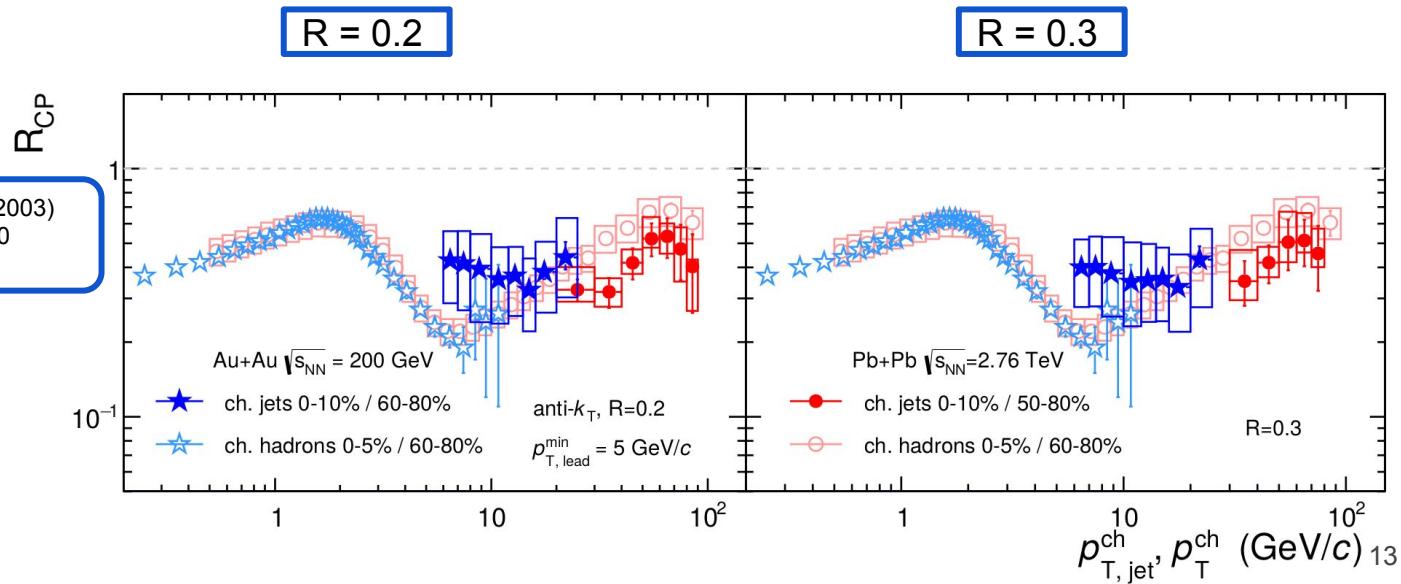


Charged Jet R_{CP}: Comparison with LHC

- **Strong suppression** of central vs peripheral, **weak p_T-dependence**
- Similar level of suppression as RHIC & LHC inclusive hadron R_{CP} in the same p_T region, possibly different p_T-dependence
- Suppression level and p_T-dependence consistent with LHC jet measurements at higher $p_{T,jet}$

RHIC ch. hadrons: STAR, PRL 91.172302 (2003)
LHC ch. hadrons: ATLAS, JHEP09(2015)050
LHC ch. jets: ALICE, JHEP30(2014)013

Centrality selection different for different measurements

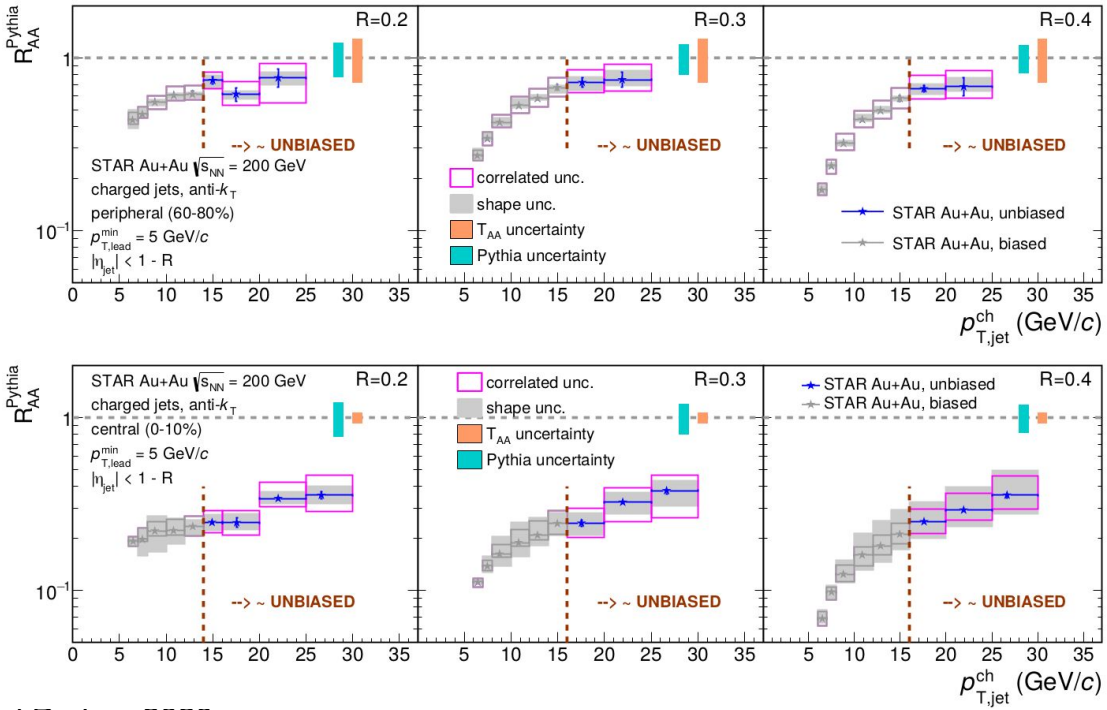


Charged Jet R_{AA}

- *p+p* baseline: PYTHIA 6.428, Perugia 2012, STAR tune

Details in: STAR, PRD 100, 052005 (2019)

- Significant **jet yield suppression** in central collisions

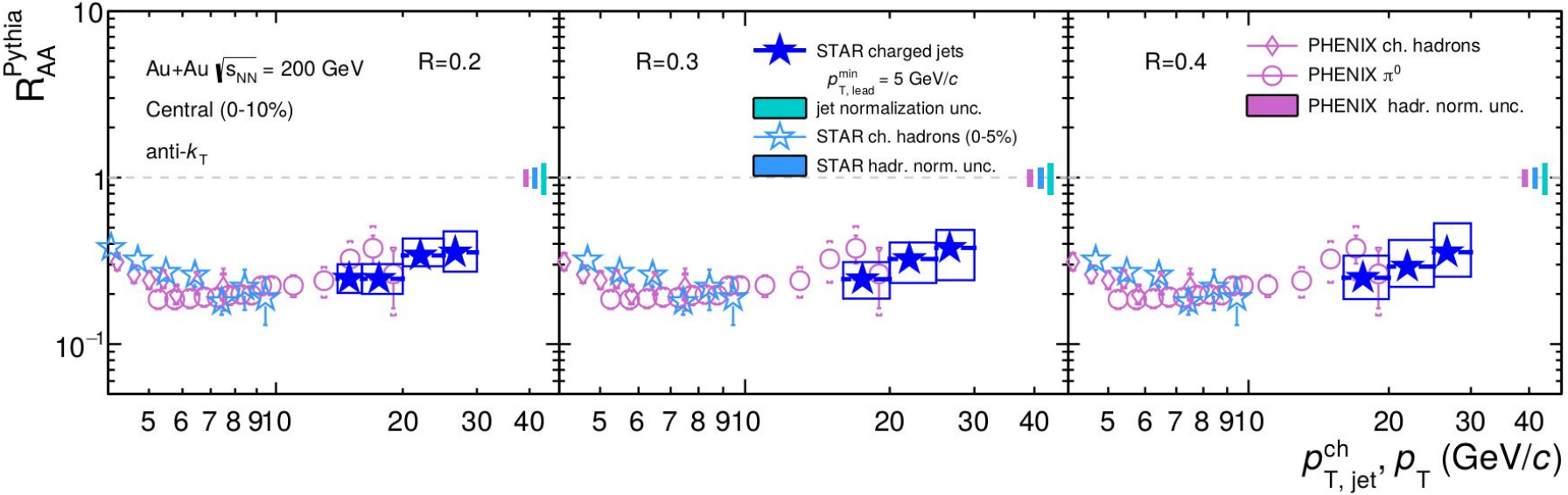


peripheral

central

Charged Jet R_{AA}: Comparison to Inclusive Hadrons

Only **~unbiased** data points shown

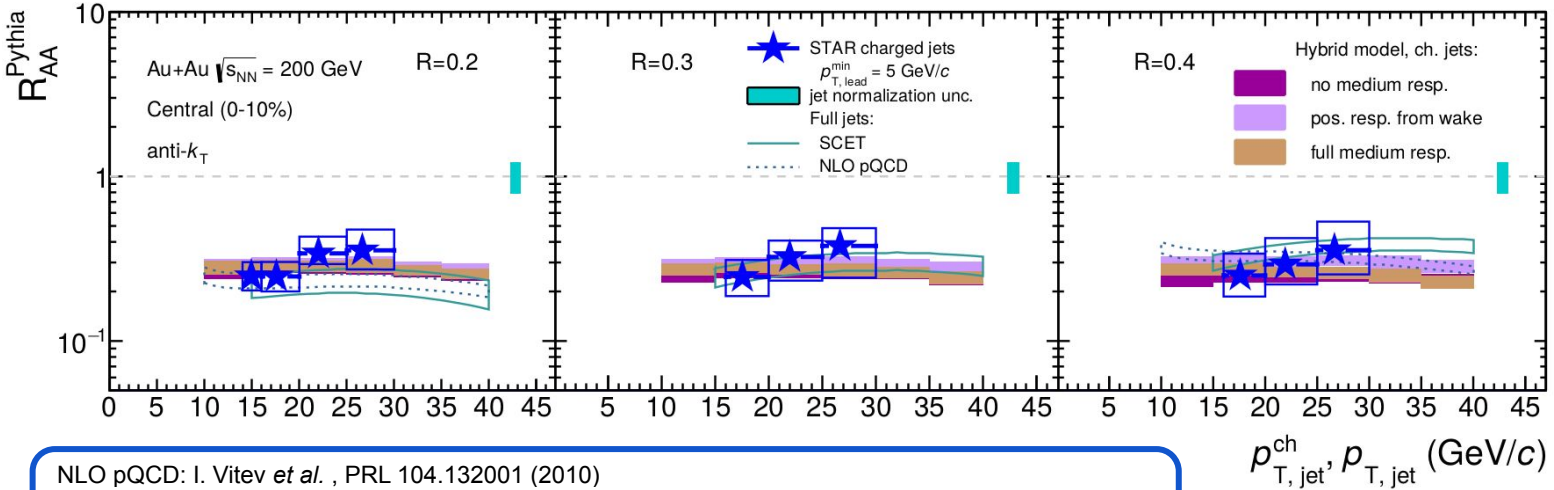


- Yield suppression **consistent with inclusive hadron** suppression in central Au+Au collisions at RHIC

STAR ch. hadrons: PRL 91.172302 (2003)
PHENIX ch. hadrons: PRC 69, 034910 (2004)
PHENIX π^0: PRC 87, 034911 (2013)

Charged Jet R_{AA}: Model Comparison

Only **~unbiased** data points shown

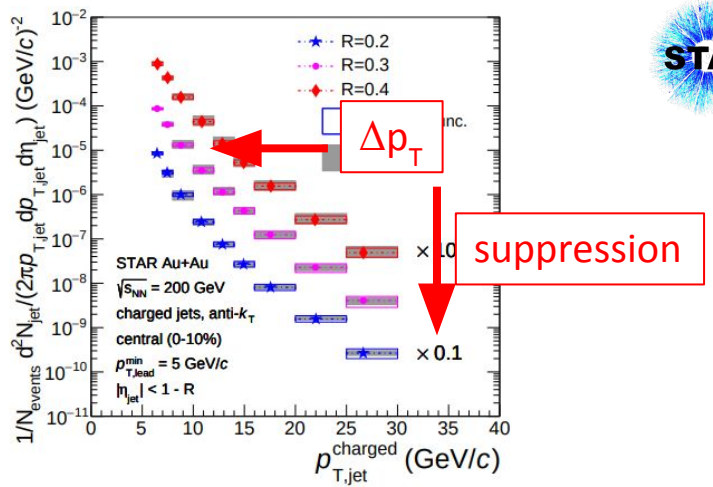


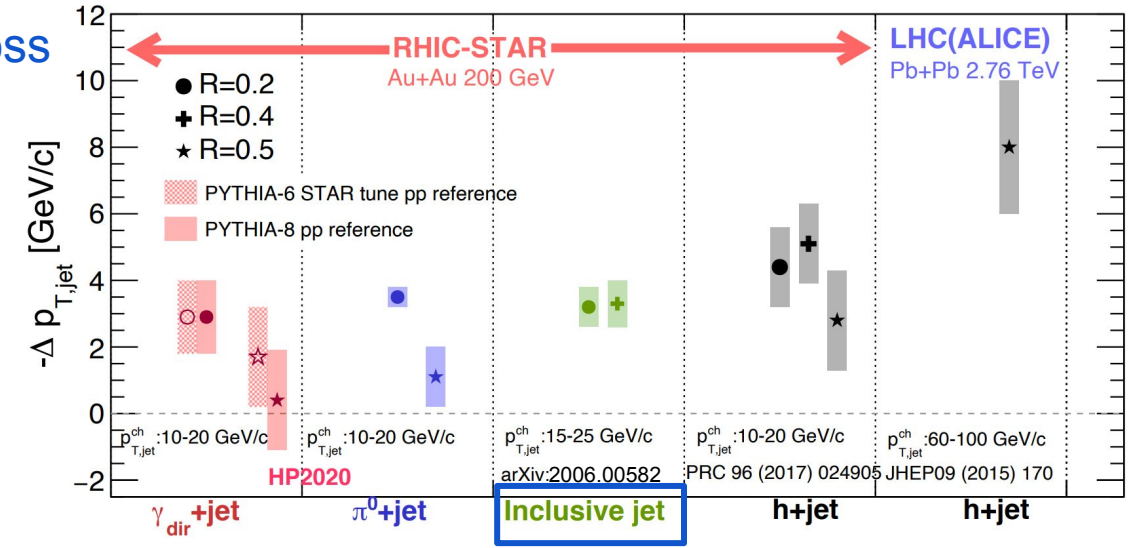
NLO pQCD: I. Vitev *et al.* , PRL 104.132001 (2010)
Soft-Collinear Effective Theory (SCET): Y-T. Chien *et al.*, PRD 93, 074030 (2016),
Y-T. Chien *et al.*, JHEP05(2016)023
Hybrid strong/weak coupling model of jet quenching: J. Casalderrey-Solana *et al.*, JHEP03(2017)135

- All **calculations consistent** with our measurement
- Models predict similar R_{AA}: current precision does not enable us to discriminate between models

Transverse Momentum Shift

- No R-dependence observed in inclusive jet production
- Energy loss consistent with semi-inclusive results at RHIC
- Indication of smaller energy loss at RHIC than the LHC
- See also talk by Nihar Sahoo tomorrow (June 2, 11:20)



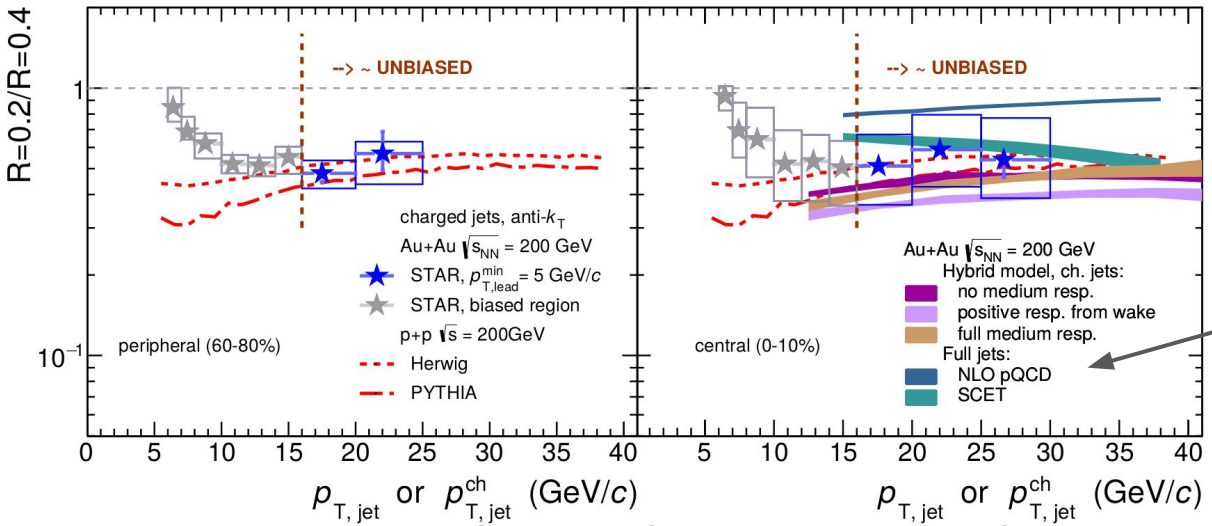


Medium-induced Jet Broadening

- Ratio of inclusive cross sections with different R at fixed $p_{T,jet}$ measures jet energy profile
  - Significant uncertainties cancel

See also talk by Joel Mazer on Thursday (June 4, 13:50)

peripheral



central

NLO pQCD and SCET calculations are for full jets

- **Peripheral**: No observed modification of transverse jet profile compared to *p+p* collision reference (< 1 for both HERWIG and PYTHIA)
- **Central**: Dispersion of models is greater in this observable than for R_{AA} - strong physical motivation to improve systematic uncertainties and study full jets

Outlook: Inclusive Full Jet p_T Spectra

- Raw inclusive **full-jet spectra** reconstructed from large-statistics BEMC-triggered dataset

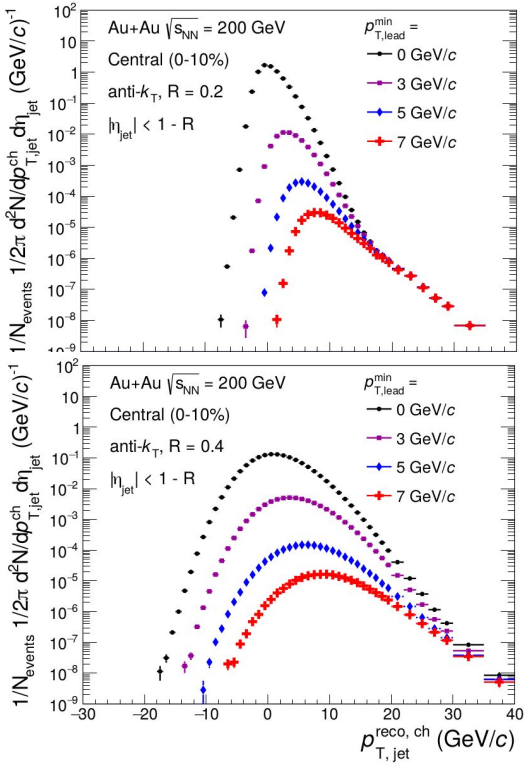
R = 0.2

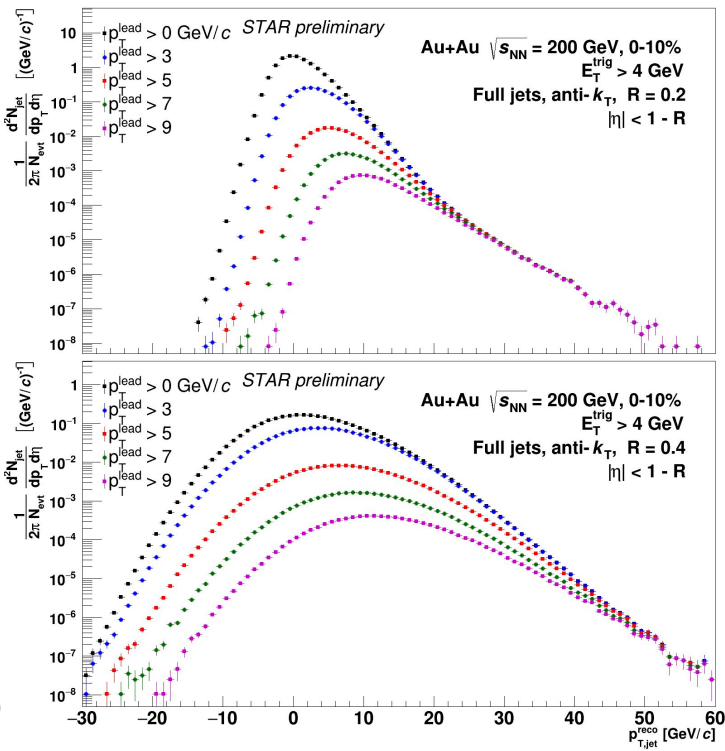
- **Increase in kinematic reach** for future STAR inclusive jet results

R = 0.4

charged jet, 2011

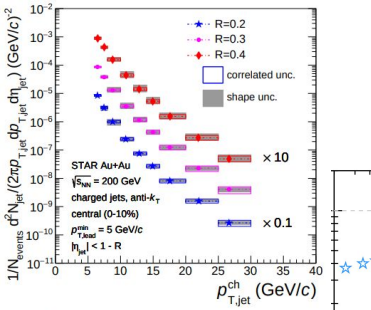
full jet, 2014

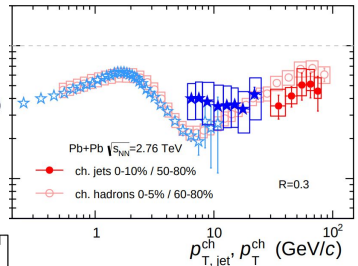


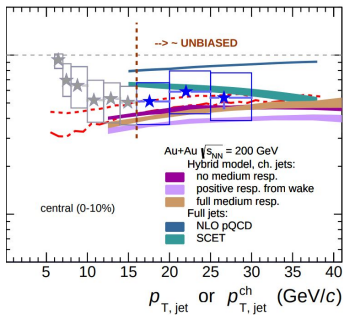


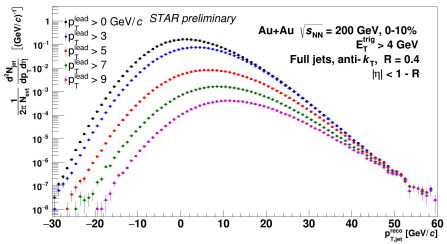
Summary

- First measurement of **inclusive charged jet** distributions in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
- **Significant yield suppression** in central Au+Au with respect to peripheral Au+Au (data) and *p*+*p* (PYTHIA) collisions
- Magnitude of **suppression similar** to inclusive hadrons (RHIC & LHC) and jets at the LHC
- **No** evidence of **medium-induced broadening** for R < 0.4
- **Quenching** models largely **consistent** with inclusive jet measurements but opportunities for higher precision
- High-statistics measurements of **fully-reconstructed jets** in Au+Au collisions **in progress**







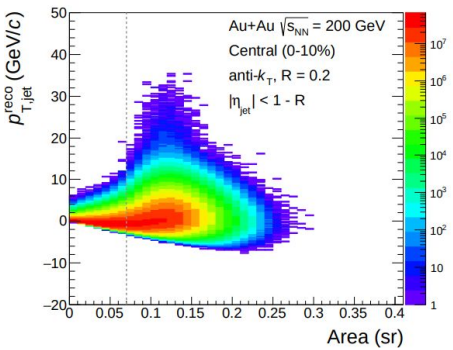


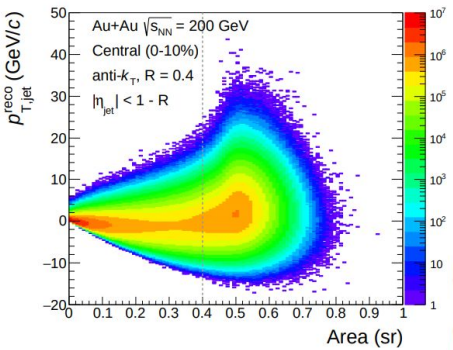
Acknowledgments: This research was funded by the project LTT18002 of the Ministry of Education, Youth, and Sport of the Czech Republic.

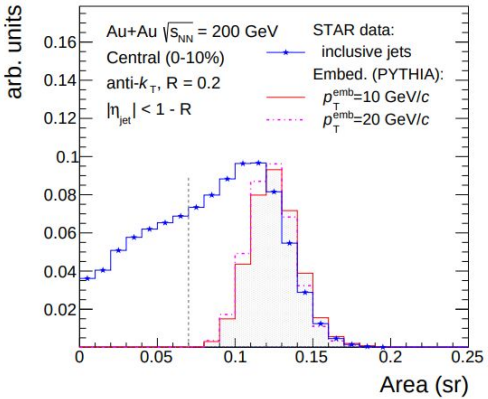
BACKUP

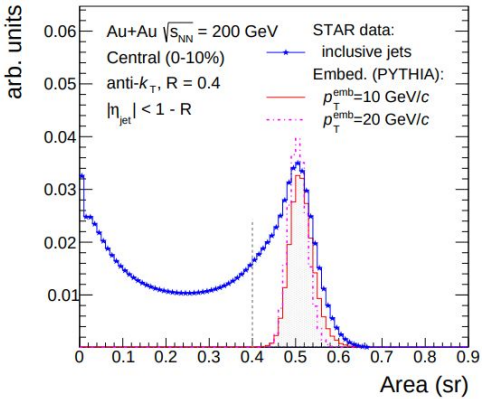
Jet Area Cut

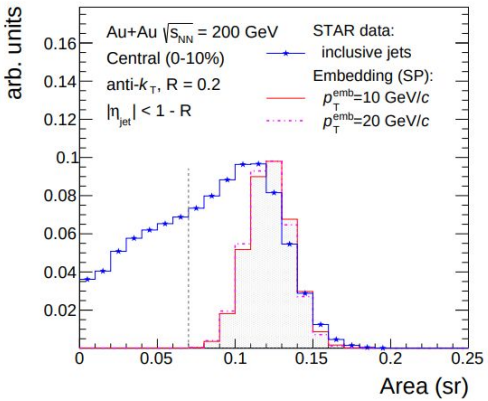
- Area >= 0.07, 0.2, 0.4

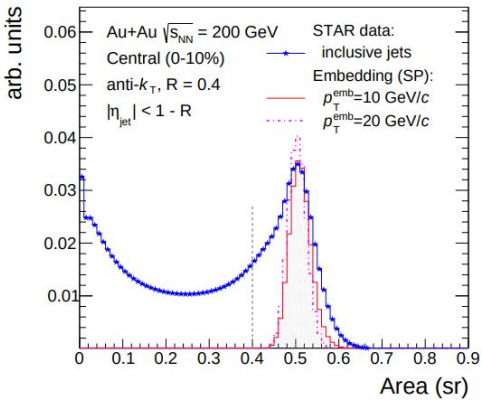






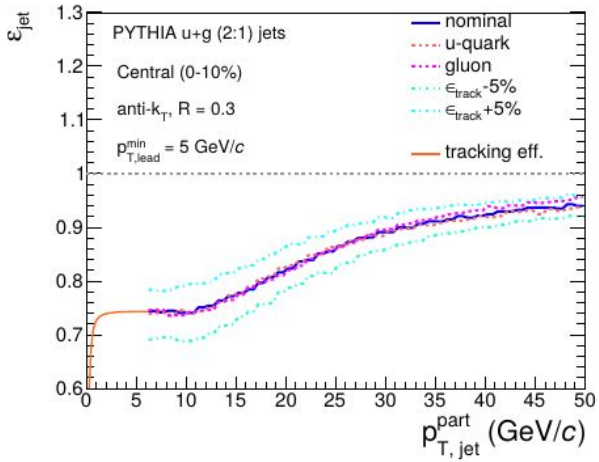


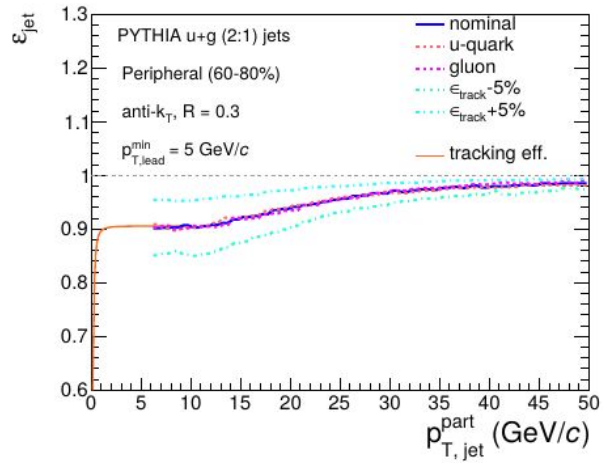




Jet Reconstruction Efficiency

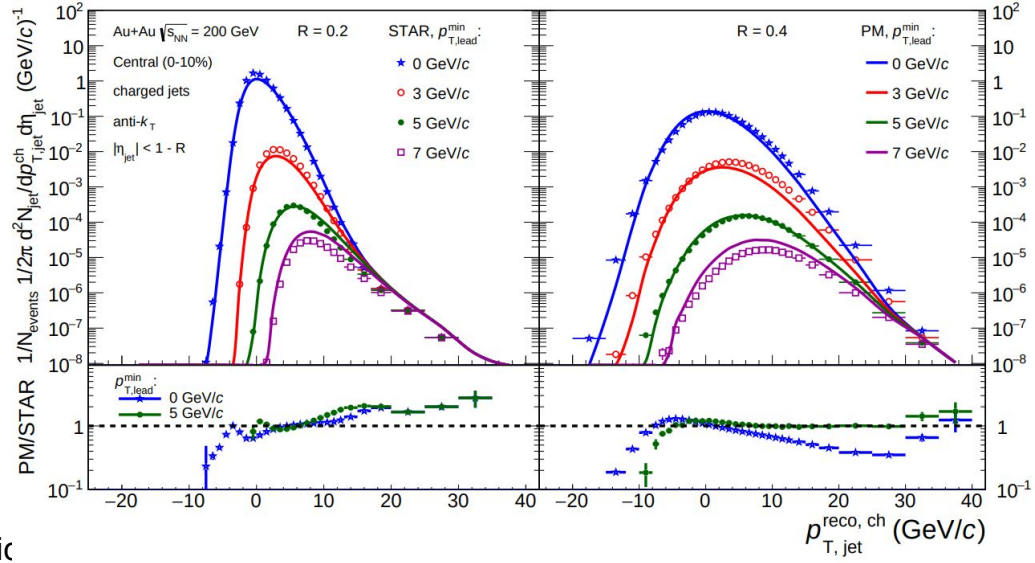
- Estimated from comparing matched parton- and detector-level jets generated by PYTHIA6
- Negligible difference on parton type (u/g)
- Dominated by TPC **tracking efficiency**
- Variations used for systematic uncertainty estimation

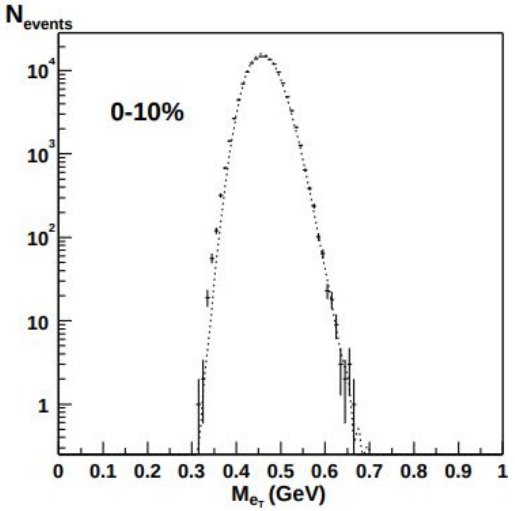




Background Description - Parametrized Model

- Combines simple Boltzmann-distributed independent emission with hard jets fragmentation based on PYTHIA simulations
- Background well-described by statistical phase space, consistent with previous event-by-event E_T fluctuation and hadron+jet mixed-event measurement





PHENIX, PRC 66 024901 (2002)

Outlook: Inclusive Full Jet p_T Spectra - peripheral

- Raw inclusive full-jet spectra reconstructed from large-statistics BEMC-triggered dataset
- Great potential for increase in kinematic reach for future STAR inclusive jet results