
10th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

# STAR Highlights at HP2020

**Zaochen Ye (Rice University) for the STAR Collaboration**

In part supported by U.S. DEPARTMENT OF ENERGY | Office of Science

RICE

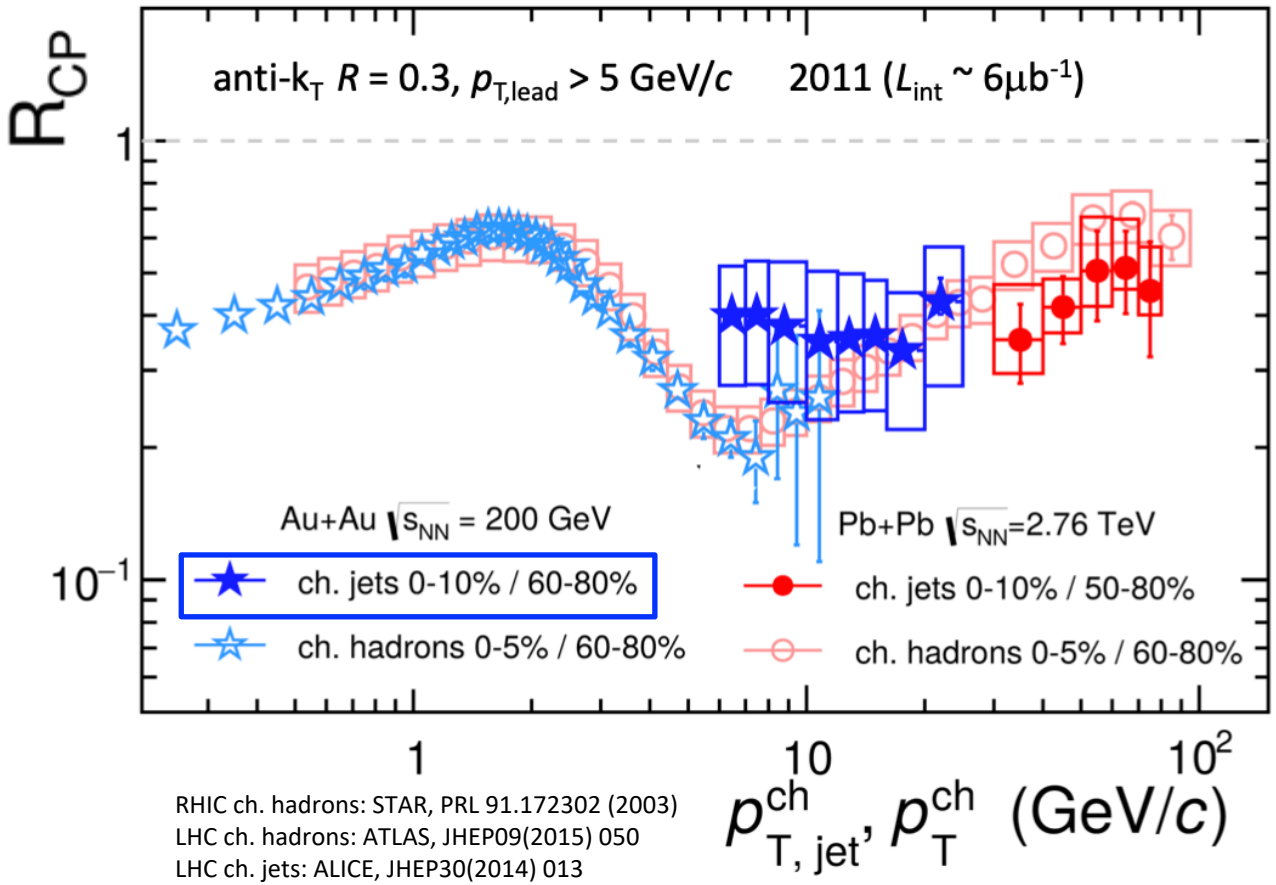
# STAR Highlights at HP2020

- Jet
- Heavy Flavor
- Electroweak Probe
- Beyond BES-II

Selected results out of **15** Parallel Talks + **4** Posters

# Jet Suppression: Inclusive Charged Jet

R. Licenik, 1 June, 12:20, A1



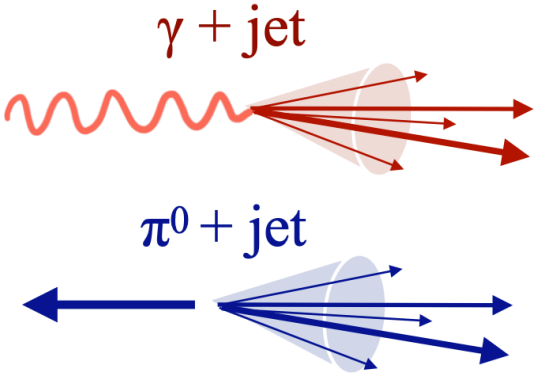

RHIC ch. hadrons: STAR, PRL 91.172302 (2003)
LHC ch. hadrons: ATLAS, JHEP09(2015) 050
LHC ch. jets: ALICE, JHEP30(2014) 013

First inclusive charged jet $R_{CP}$ and $R_{AA}$ at RHIC:

- Significant suppression in central collisions w.r.t peripheral collisions
- Suppression level is similar as inclusive hadrons (RHIC & LHC) and jets (LHC), with a possibly different $p_T$-dependence

# Jet Suppression: $\gamma^{dir}$+jet and $\pi^0$+jet

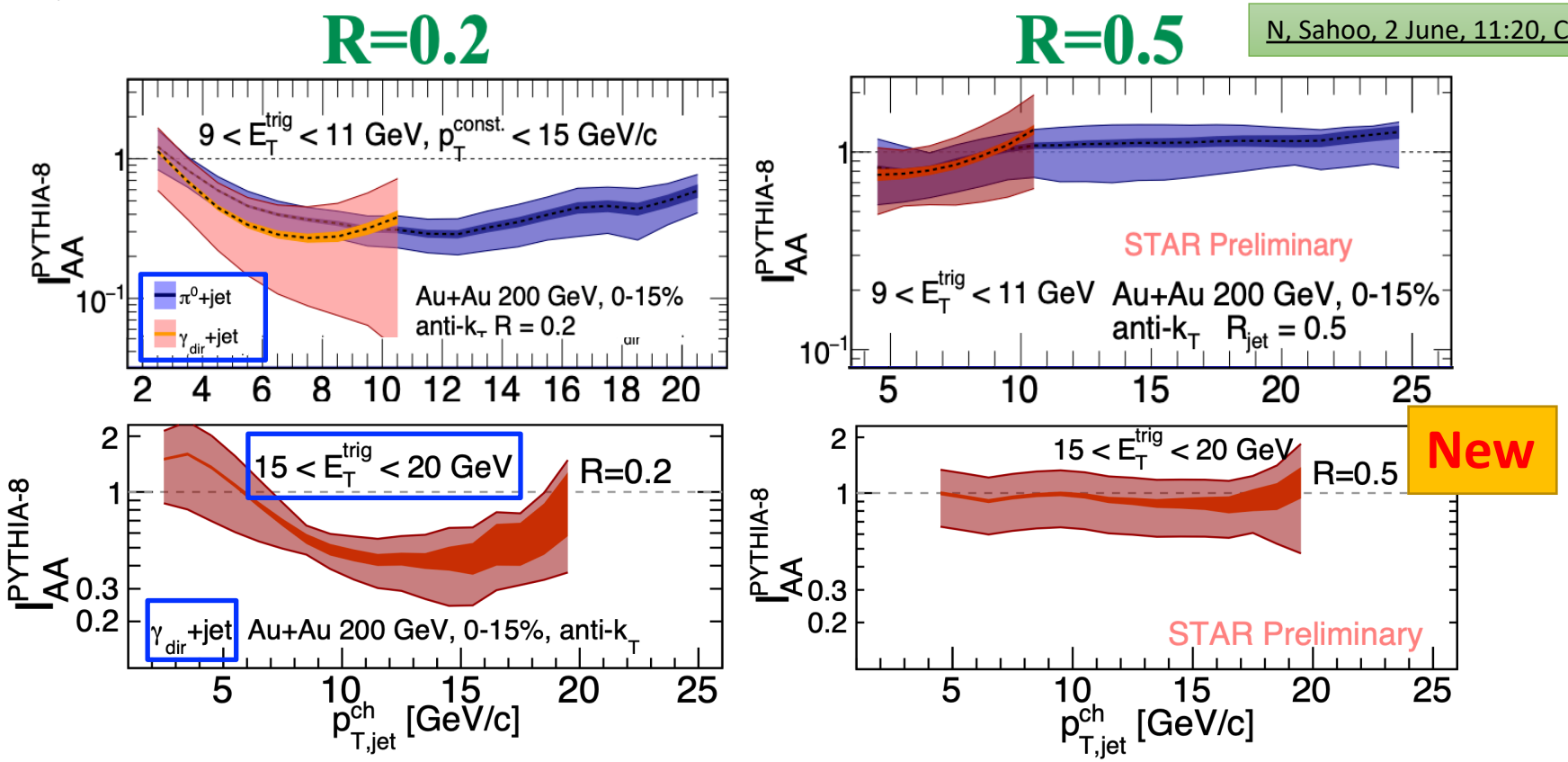
N, Sahoo, 2 June, 11:20, C1




Vary:

- quark vs. gluon of recoil jets
- <path length>

$$I_{AA}(p_{T,jet}^{ch}) = \frac{Y(p_{T,jet}^{ch})^{Au+Au}}{Y(p_{T,jet}^{ch})^{p+p}}$$



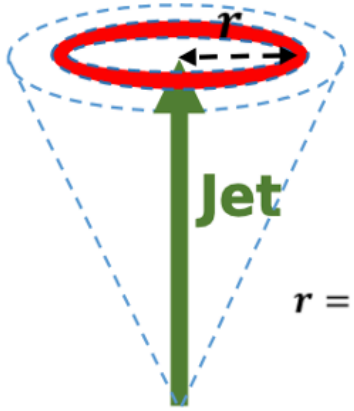

## First $\gamma^{dir}$+jet and $\pi^0$+jet in Au+Au at RHIC:

- $\gamma^{dir}$+jet and $\pi^0$+jet show similar level of suppression, no significant trigger $E_T$ dependence
- R dependence of suppression sensitive to reference used (PYTHIA 6 STAR tune vs. PYTHIA8); will be resolved with p+p measurements

# Jet Shape in Au+Au

J. Mazer, 4 June, 13:50, H1

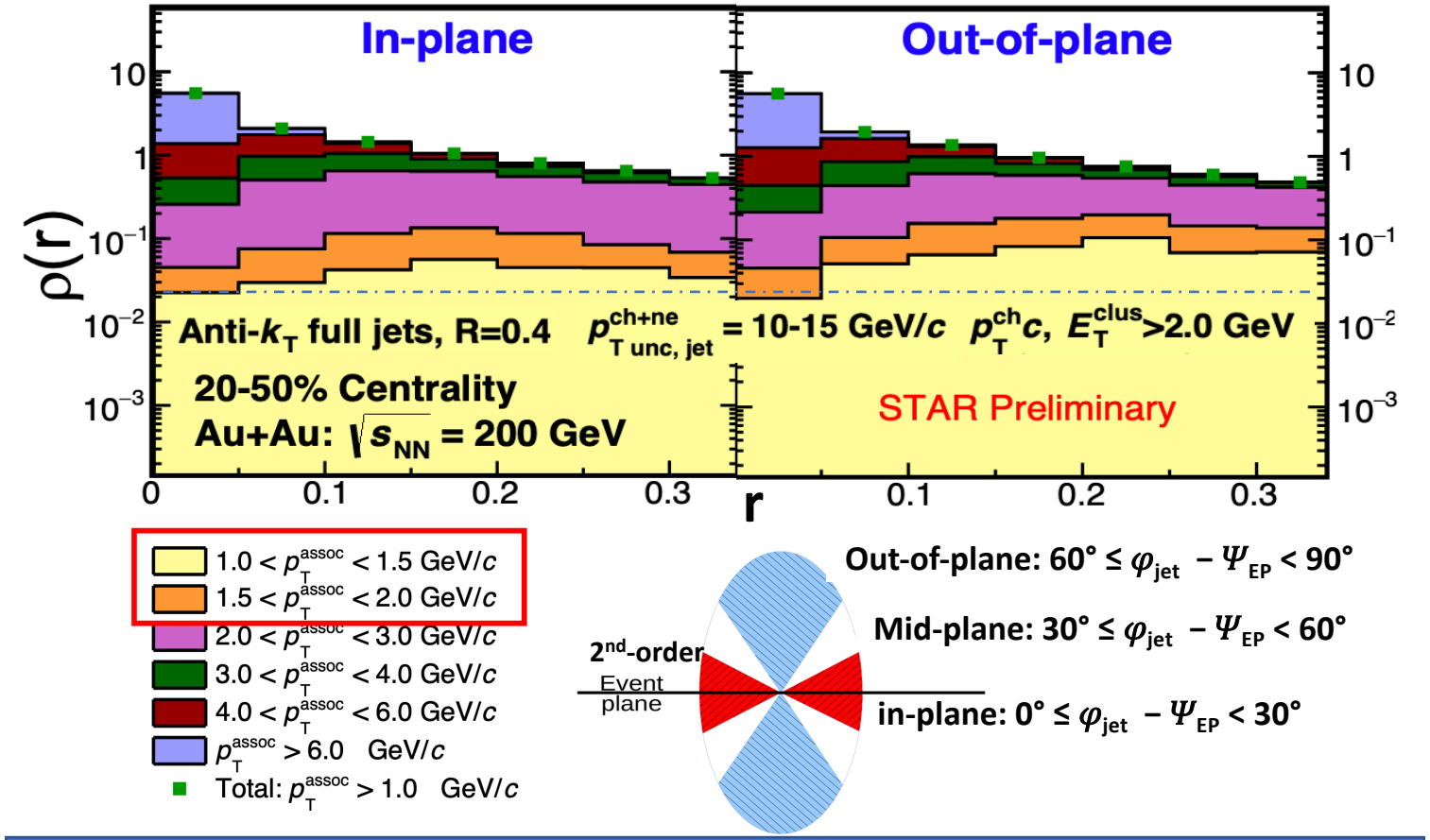
## Jet Shapes




$$r = \sqrt{(\Delta\varphi)^2+(\Delta\eta)^2}$$

$$\rho(r) = \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jet}}\frac{\sum_{\text{track}\in(r-\delta r/2,r+\delta r/2)} p_{\text{T,track}}}{p_{\text{T,jet}}}$$

- Provides information about the radial distribution of momentum carried by the jet constituents (fragments)

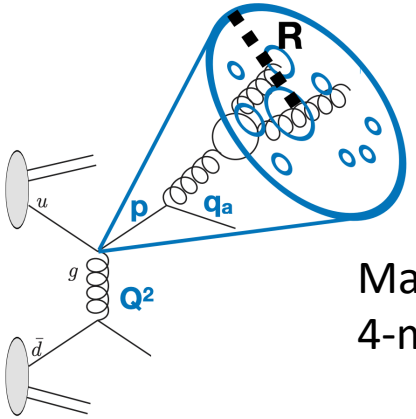



**First full-jet (charged+neutral) shapes in Au+Au at RHIC:**

- Low-$p_T$ particles have larger yields, and are pushed toward larger $r$ in the out-of-plane direction
  → Hint of path-length dependent jet quenching

# Jet (groomed) Mass in p+p and p+Au

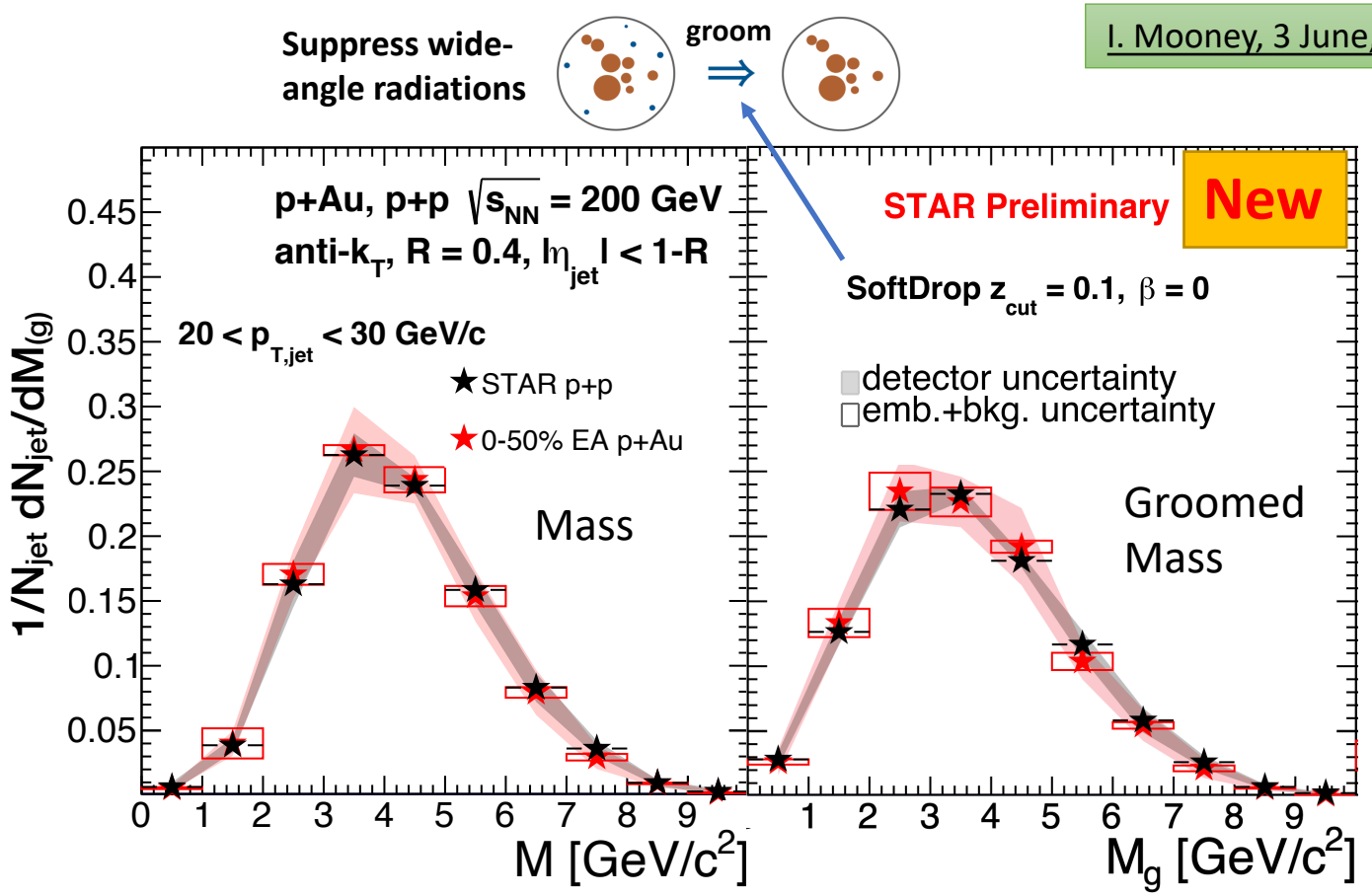
I. Mooney, 3 June, 11:50, E1




$$M_{\text{jet}} = \left| \sum_{i \in J} p_i \right| = \sqrt{E^2 - \mathbf{p}^2}$$

Magnitude of constituents 4-momentum sum within R

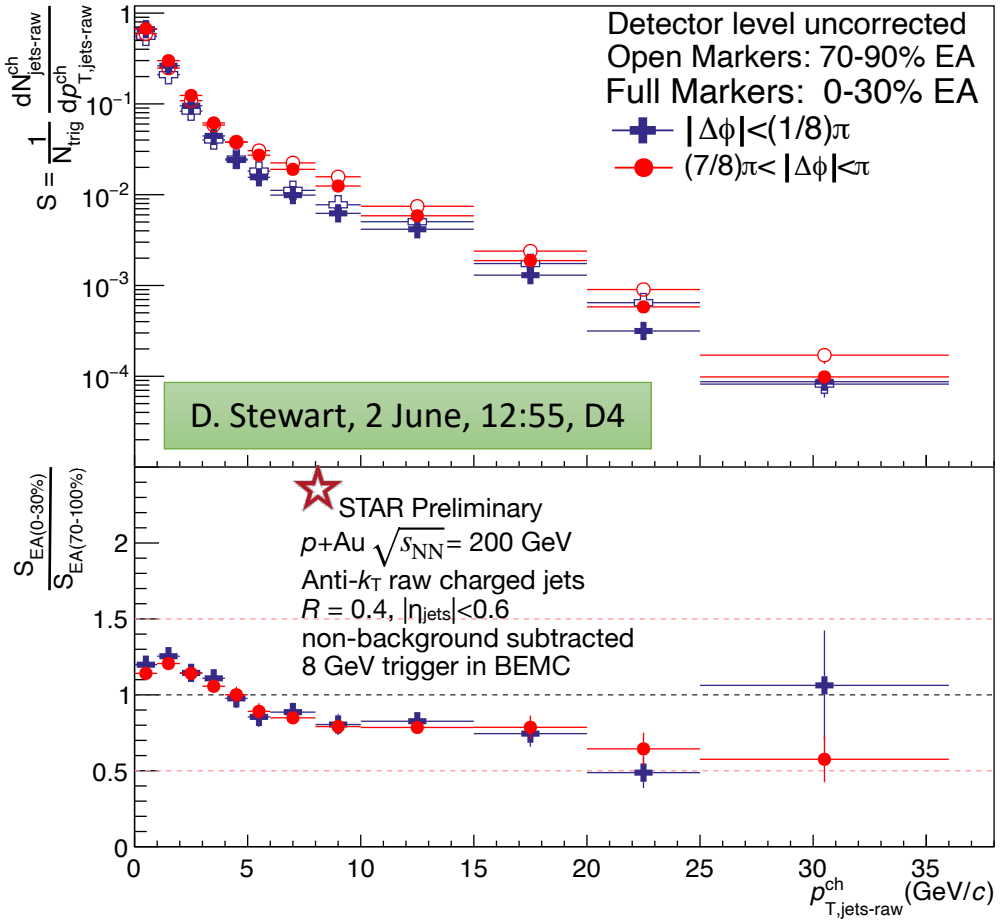
- Jet mass is sensitive to how parton loses energy in medium
- Jets with different masses resolve medium at different scales

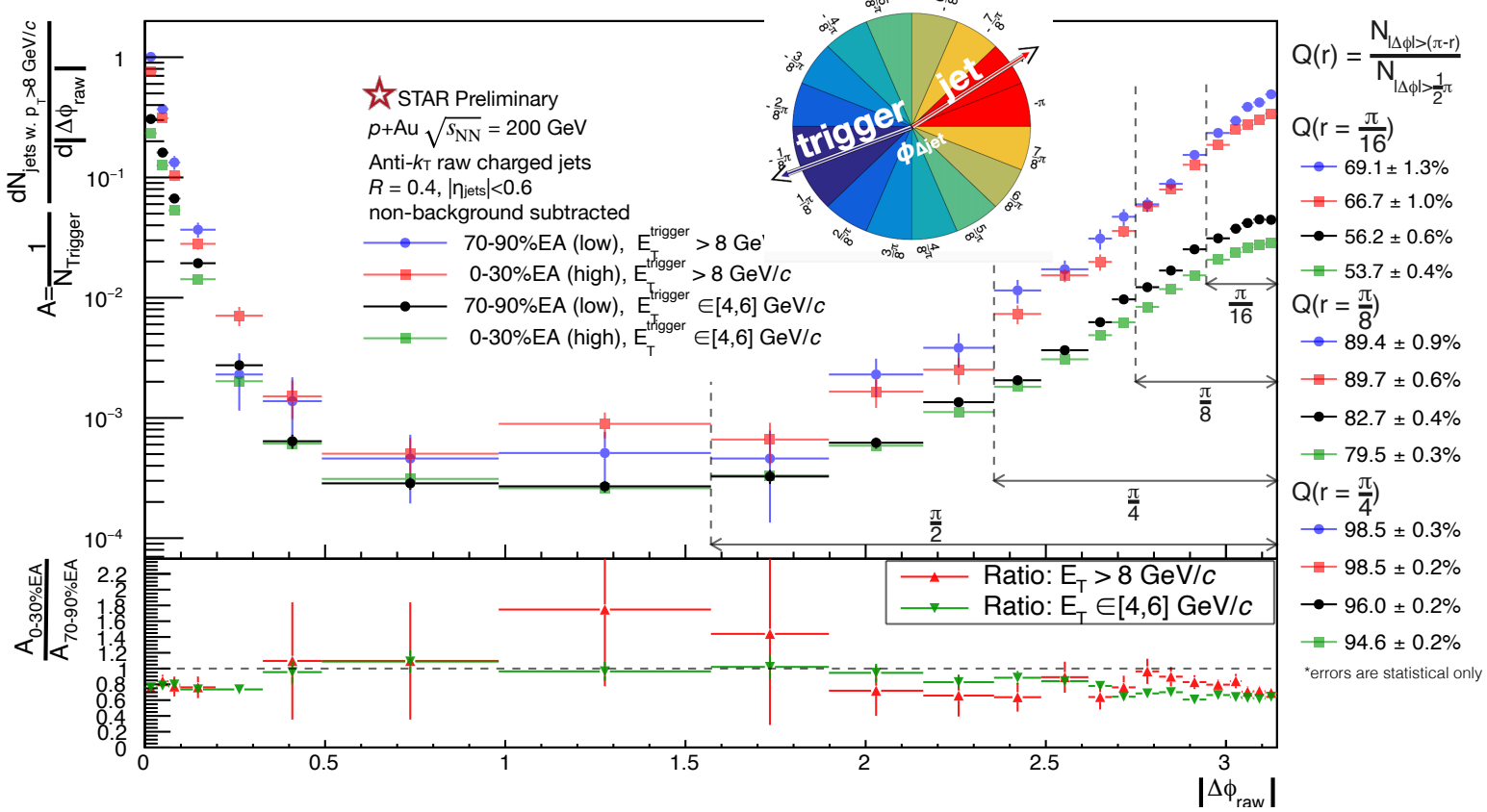



**First inclusive jet (groomed) mass measurements in p+p and p+Au at RHIC:**

- High event activity p+Au consistent with p+p, suggesting p+p-like fragmentation
- No significant modification on jet mass due to the CNM effects

# Event Activity Dependent Jet Study in p+Au



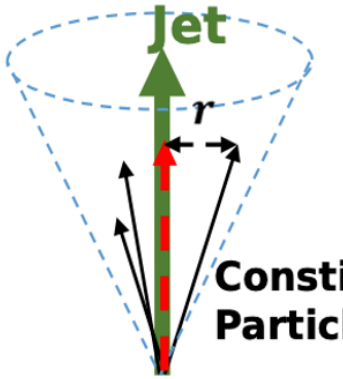

**EA is defined with the BBC activity in the Au-going direction**

- High-EA vs. low-EA: spectra clearly suppressed, but acoplanarity minimally modified
- Consistent with phase-space correlation; qualitatively reproduced by PYTHIA (details in Dave's talk)

# Jet Fragmentation Function in Au+Au

J. Mazer, 4 June, 13:50, H1

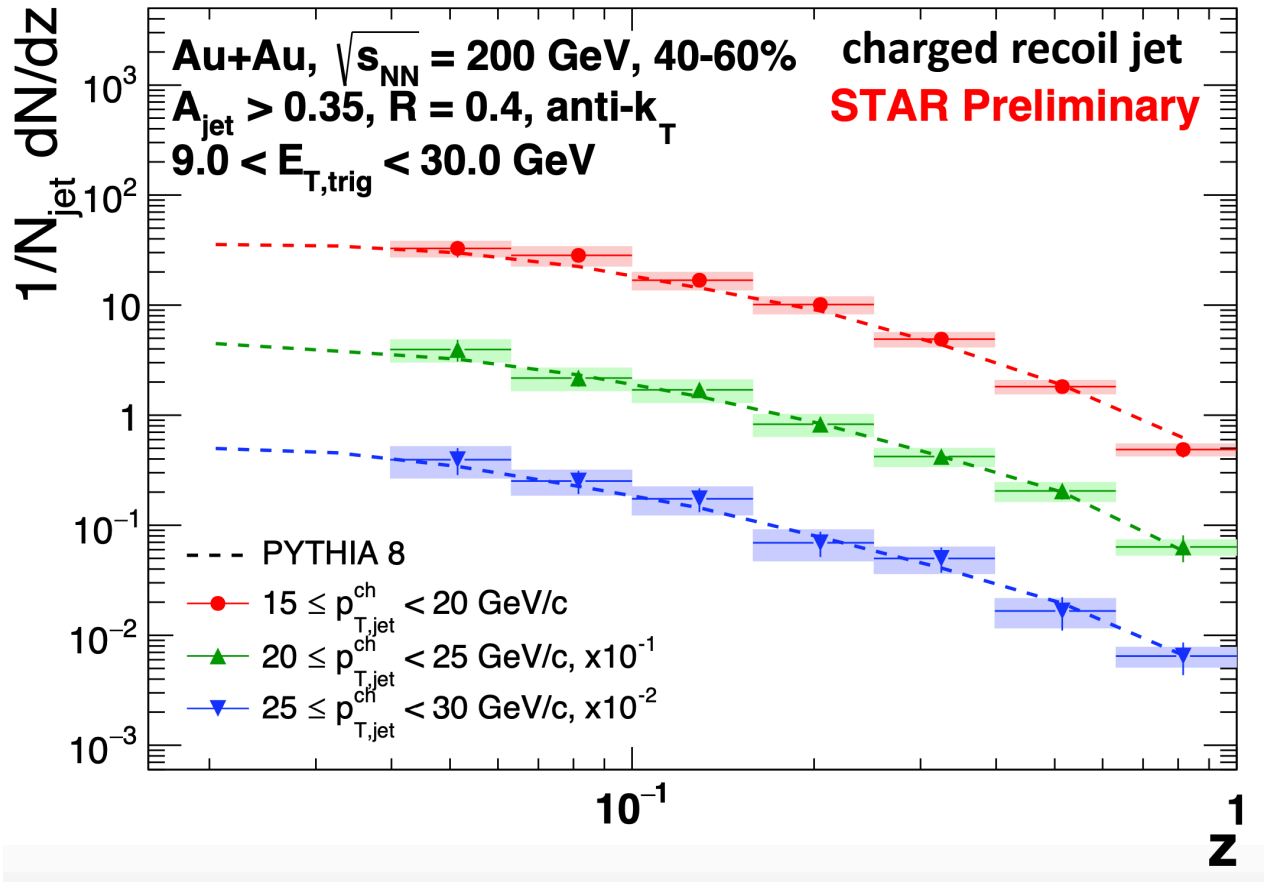
## Jet Fragmentation Functions




$$z = \frac{p_{T,track}\cos(r)}{p_{T,jet}}$$

$$\text{Fragmentation Function} = \frac{1}{N_{jet}}\frac{dN}{dz}$$

- Provides information of the longitudinal momentum fraction of particles with respect to the jet




Semi-inclusive jet fragmentation functions in 15 <= $p_{T,jet}^{ch}$ < 30 GeV/c:

- Unfolded results (40-60%) are comparable to PYTHIA8 predictions

# $J/\psi$ Production in Jet in p+p

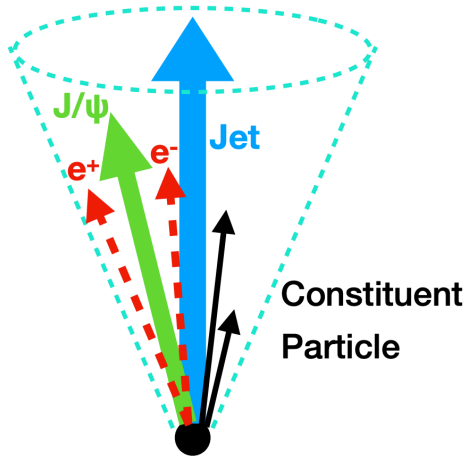
Q. Yang, 2 June, 12:55, D2

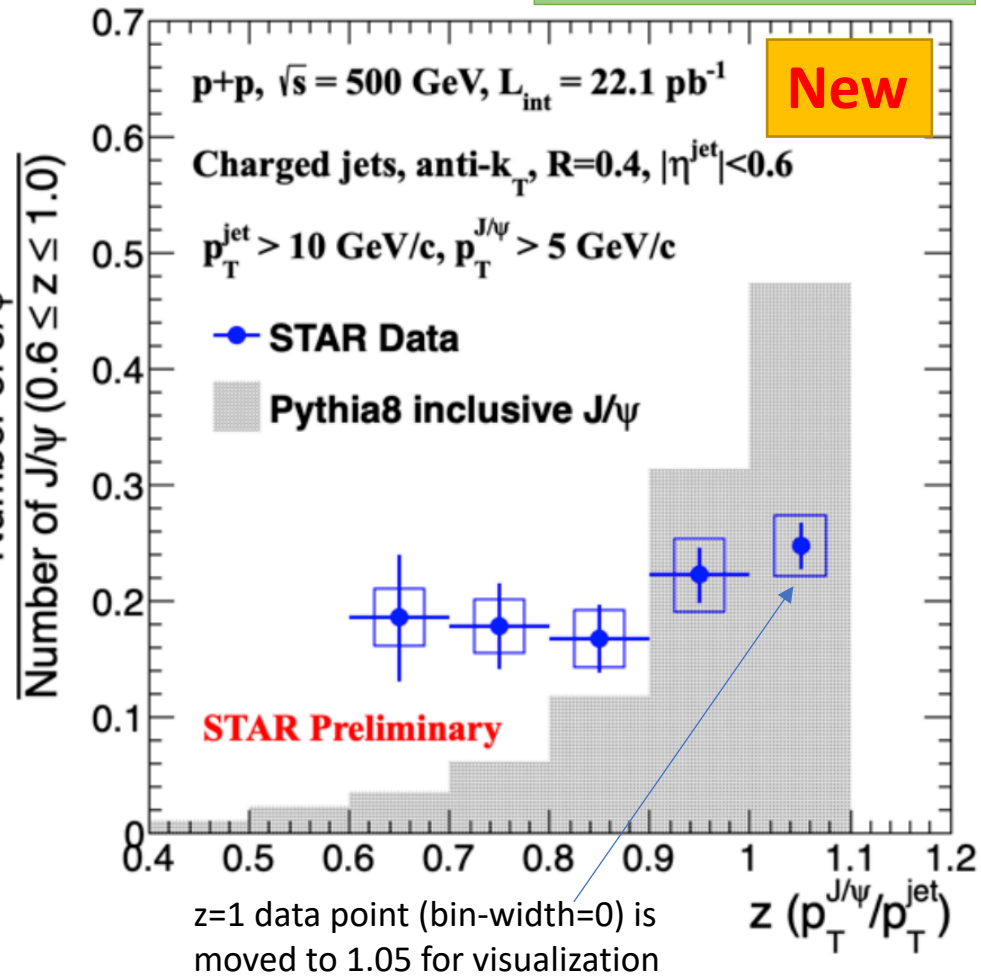
**$J/\psi$ as a probe of QGP, its production mechanism is still unclear**

- The non-pQCD transition ($c\bar{c} \rightarrow J/\psi$ ) can be characterized through the universal NRQCD long-distance matrix elements (LDMEs)

- Calculations with different LMDEs could well describe the inclusive $J/\psi$ $p_T$ spectrum, but give significantly different predictions on $J/\psi$ distribution inside jets

Zhong-Bo, Kang et.al, PRL 119, 032001(2017)




**First $J/\psi$-jet fragmentation function at RHIC:**

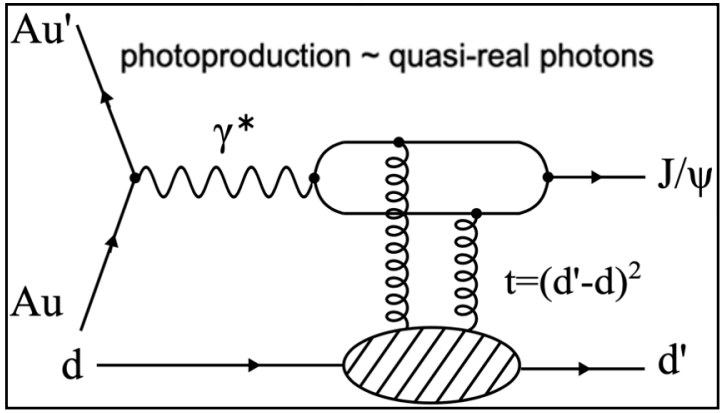
- Data indicate different trend and less isolated production than PYTHIA8

- **Welcome theoretical calculations for RHIC**

# Photoproduction of $J/\psi$ in d+Au UPC

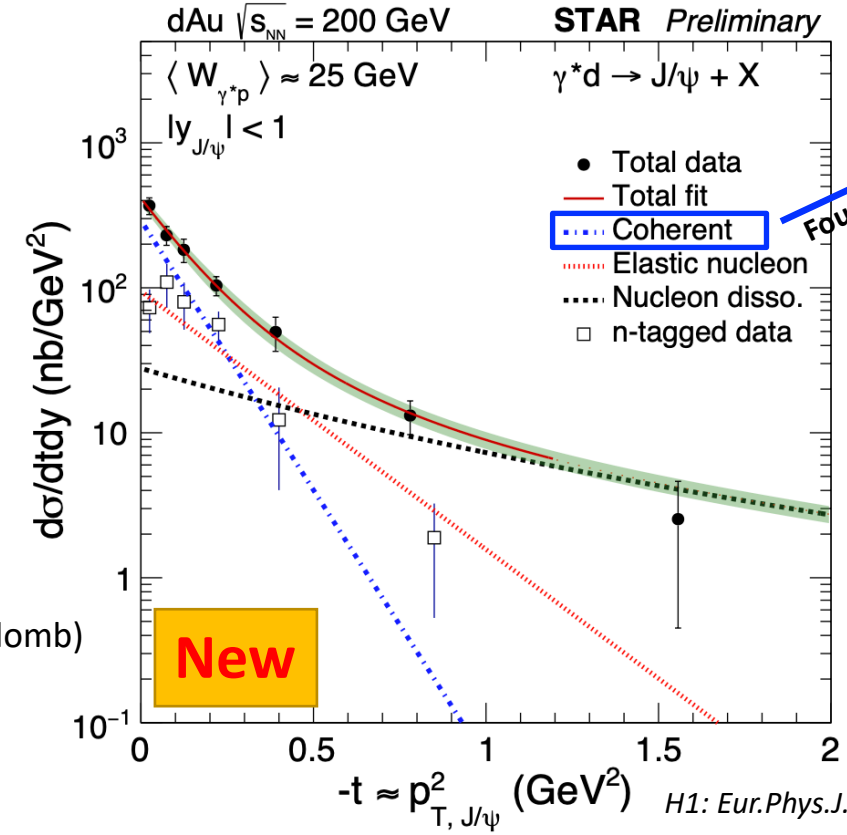
Z. Tu, 1 June, 11:20, A4

**Photoproduction of J/ψ is a good tool to study the gluon density distributions inside nucleons and nucleus**

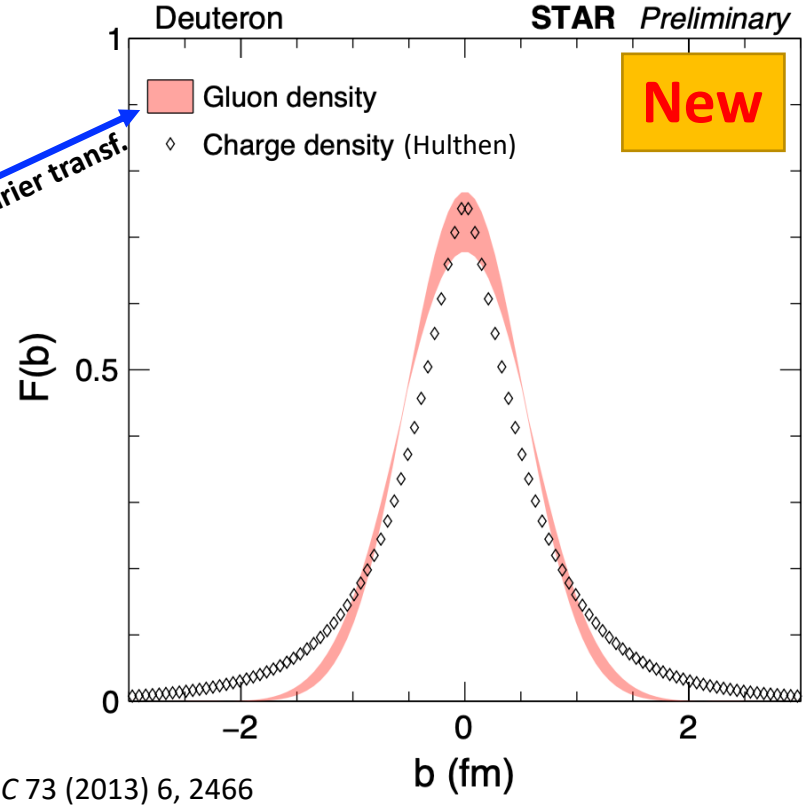



**Au + d → J/ ψ + Au' + X**

- X = d' (coherent) or d'→ p'+n' (coherent + coulomb)
- X = p'+n' (elastic nucleon)
- X = p'+X or n'+X (nucleon dissoc.)




Fourier transf.




*H1: Eur.Phys.J.C* 73 (2013) 6, 2466

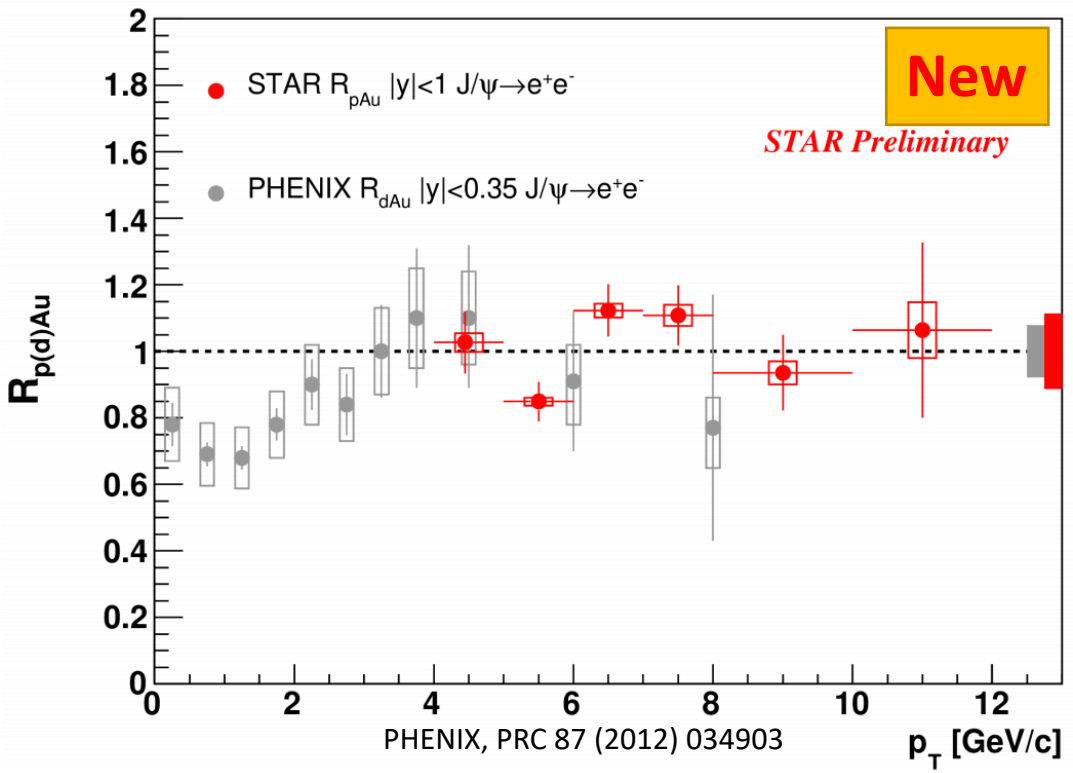
First coherent $J/\psi$ photoproduction off deuteron:

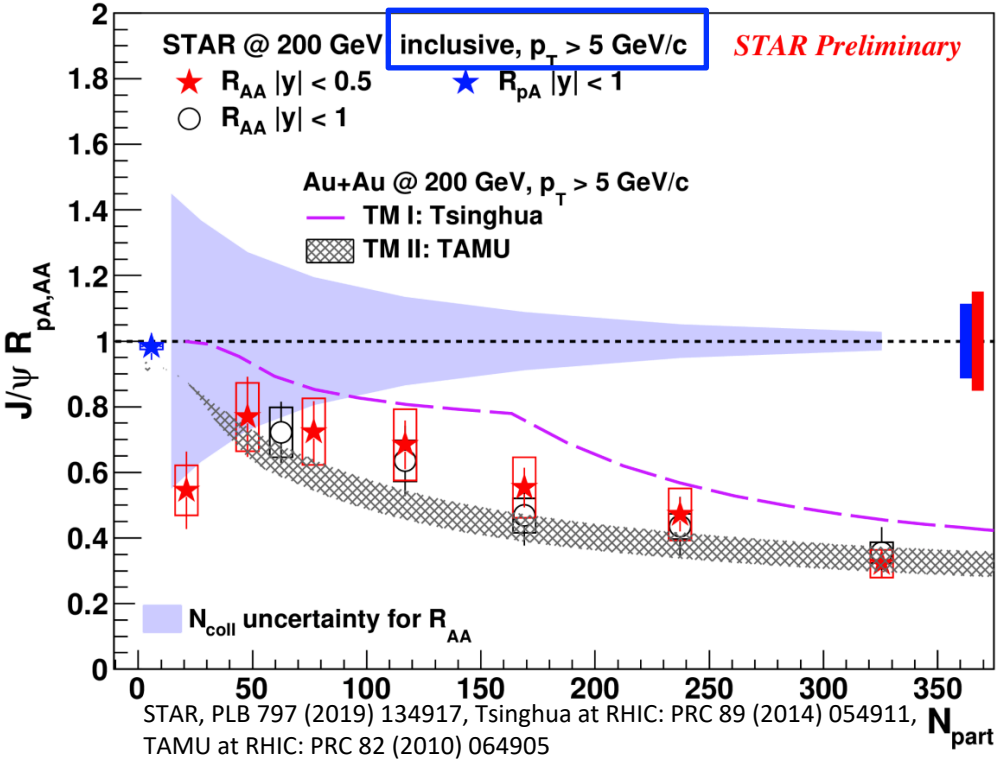
- Cross sections of different physics processes are extracted
- Hint: gluon distribution is different to the charge distribution

# $J/\psi$ Suppression in p+Au w.r.t. p+p

ZY Zhang, 1 June, 12:20, A3

**CNM effects on J/ψ production are important to interpret J/ψ suppression in AA**

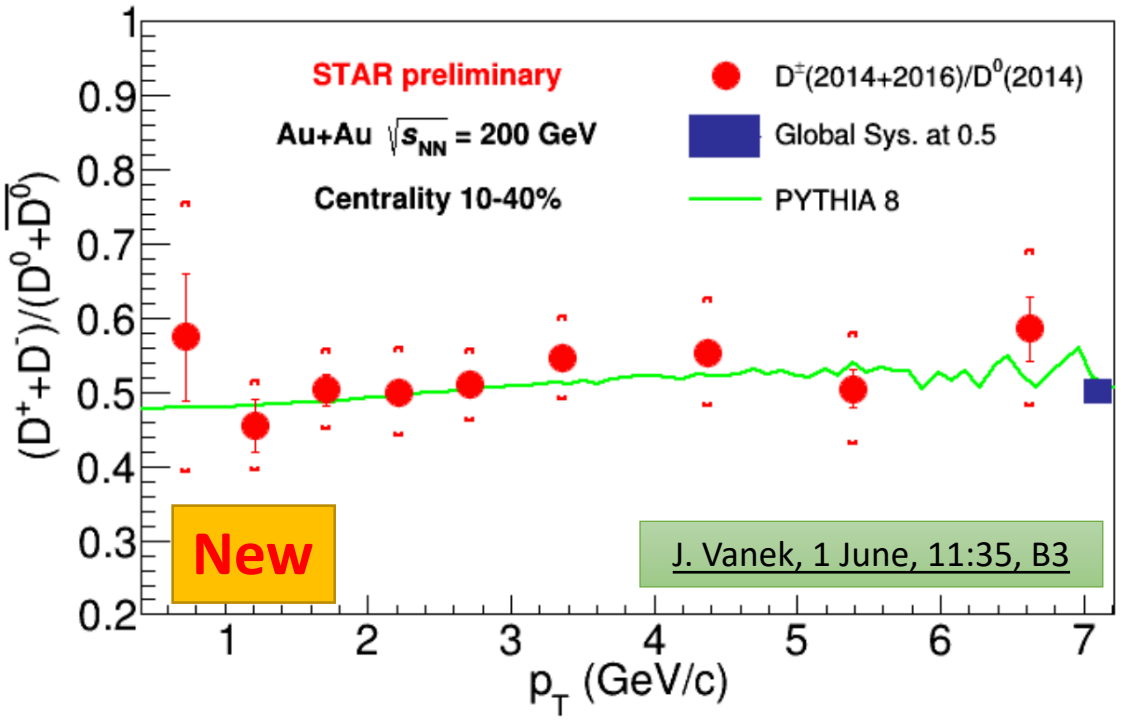



The new $J/\psi$ $R_{pA}$ measurements:

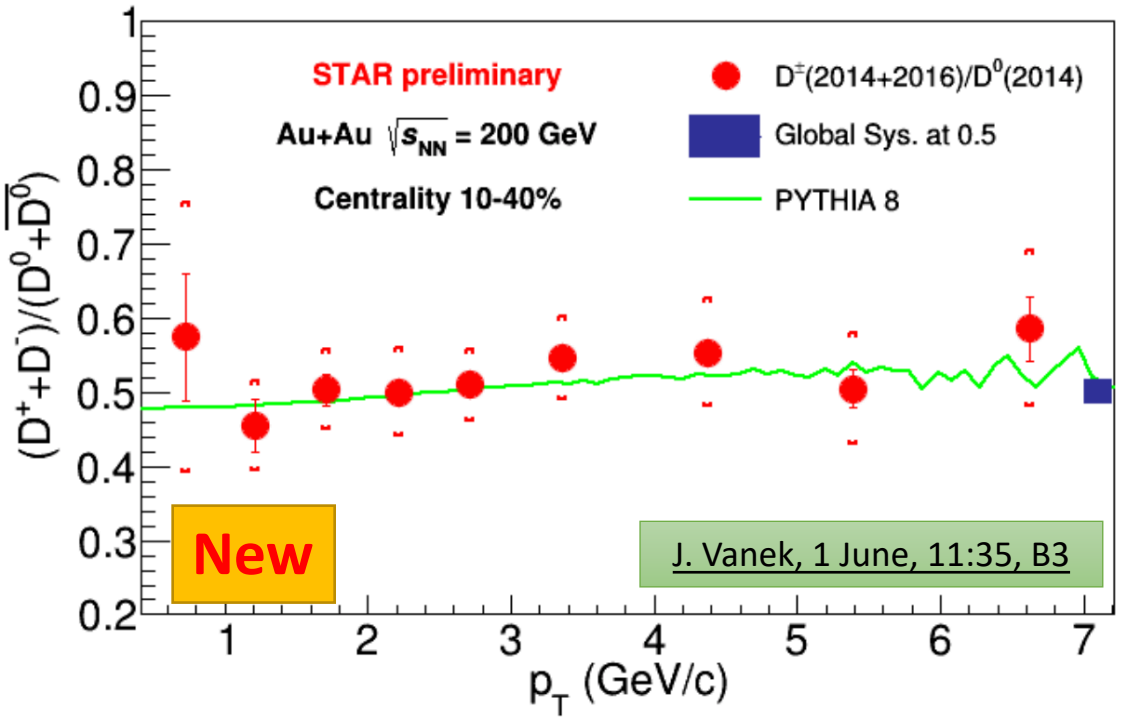
- Consistent with unity, suggesting no suppression at high $p_T$ due to the CNM effects
- Suppression of high $p_T$ $J/\psi$ in Au+Au are dominantly due to the hot medium effect

# $D^{\pm}$ and $D_s^{\pm}$ vs $D^0$ in Au+Au




- $D^{\pm}$ show similar level of suppression as $D^0$, as expected

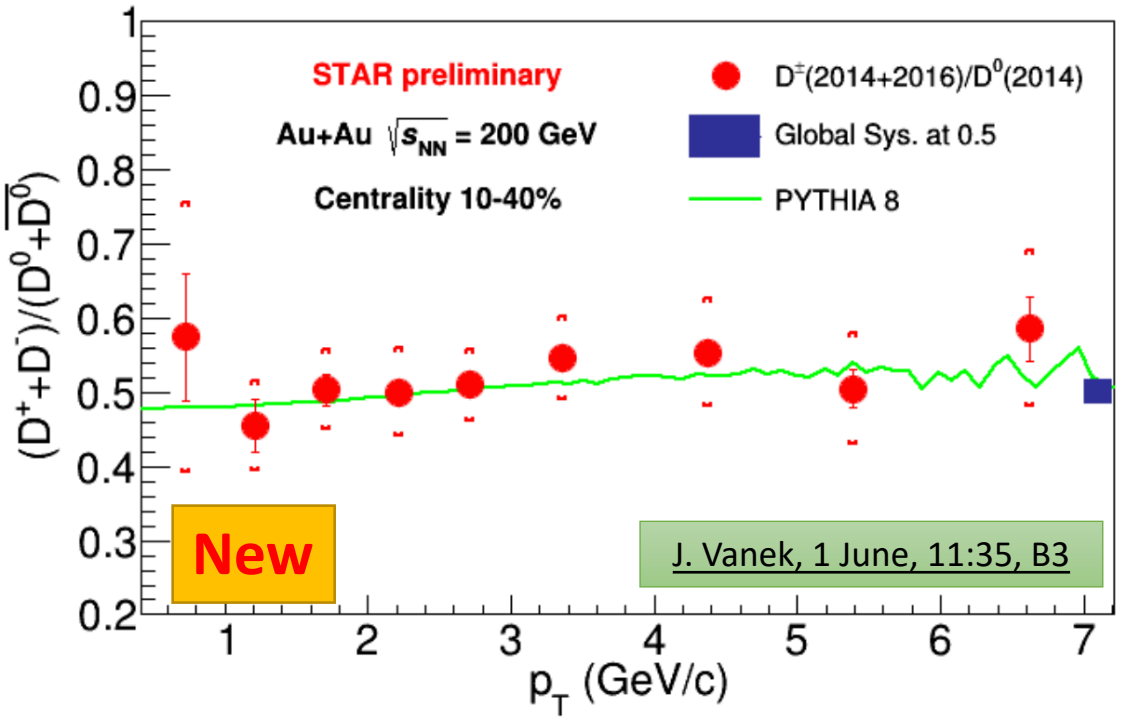
# $D^{\pm}$ and $D_s^{\pm}$ vs $D^0$ in Au+Au

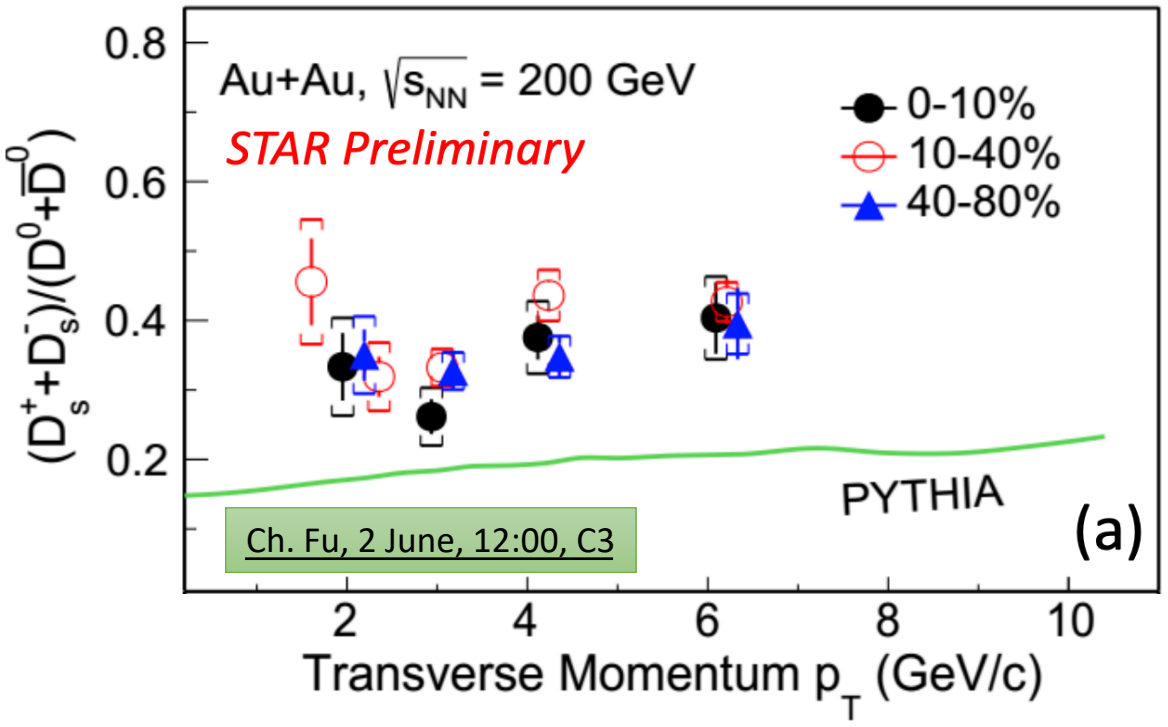



- Will the enhanced strangeness production observed in A-A collisions be reflected in $D_s$ production ?

- $D^{\pm}$ show similar level of suppression as $D^0$, as expected

# $D^{\pm}$ and $D_s^{\pm}$ vs $D^0$ in Au+Au

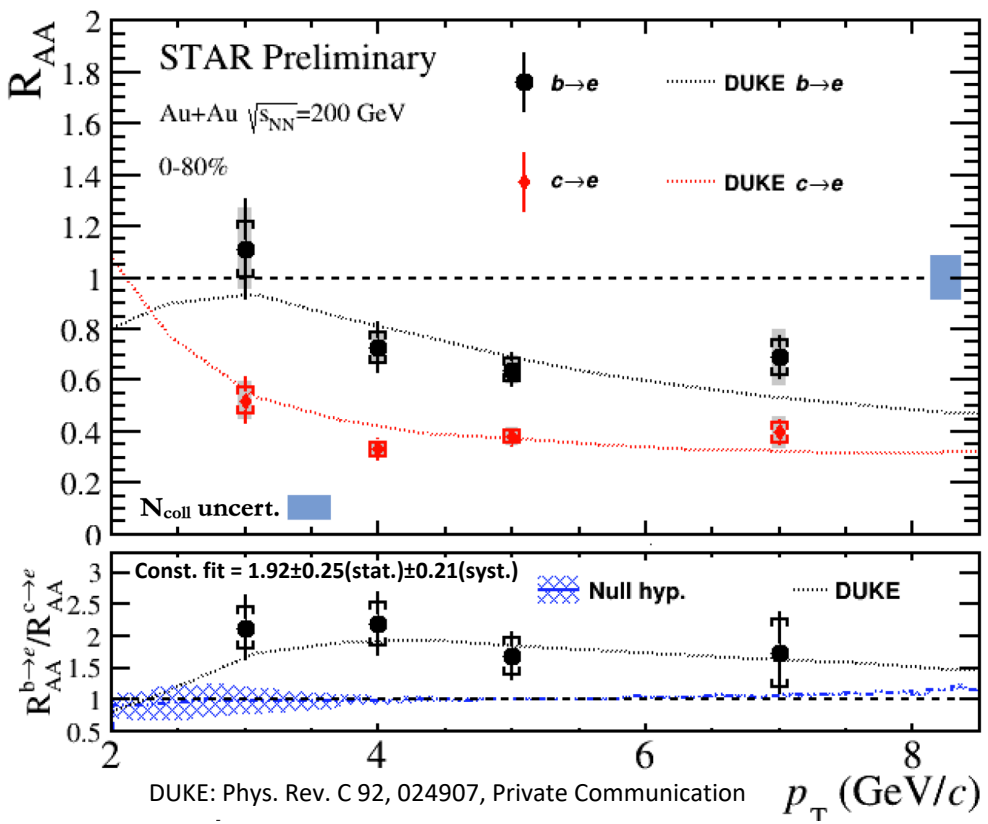


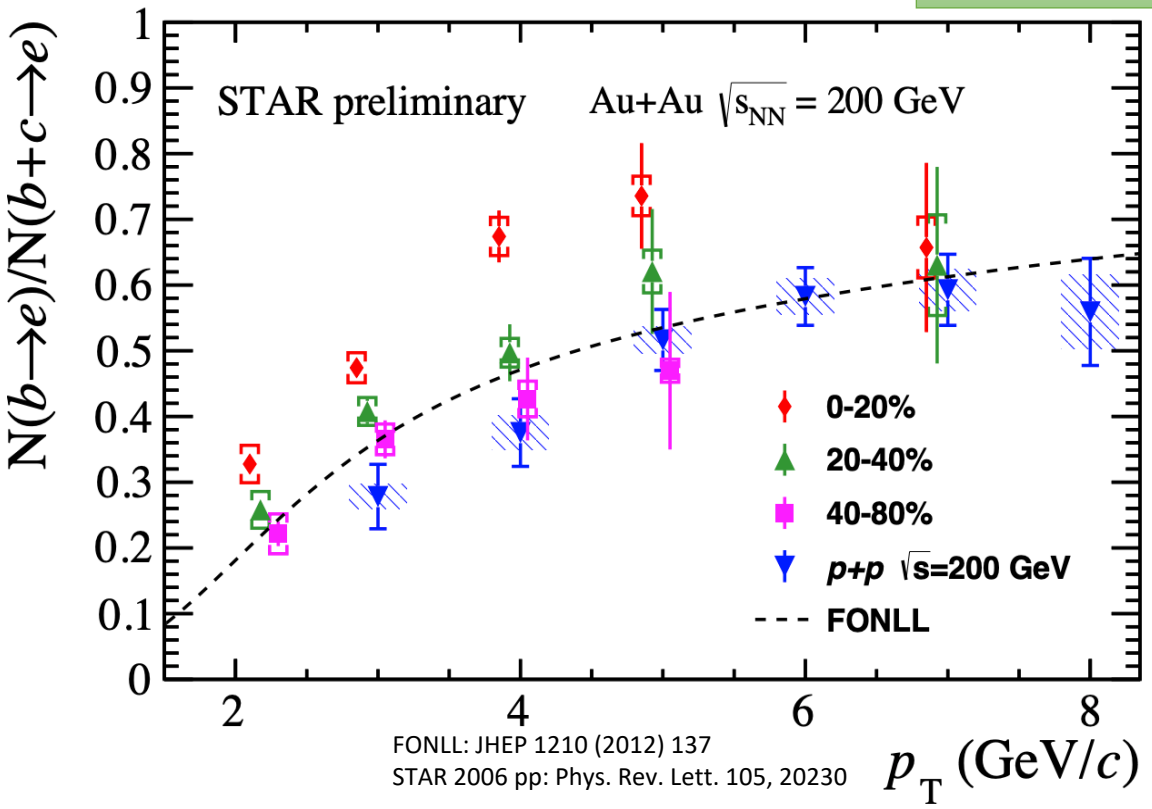

- $D^{\pm}$ show similar level of suppression as $D^0$, as expected
- $(D_s^+ + D_s^-)/(D^0 + \overline{D}^0)$: larger than the PYTHIA calculation (1.5~2 times), consistent with the expectation of coalescence hadronization of *c* with enhanced *s* quarks

# $c \rightarrow e$ and $b \rightarrow e$ with Heavy Flavor Tracker

YJ Zhou, 4 June, 11:35, G3




DUKE: Phys. Rev. C 92, 024907, Private Communication



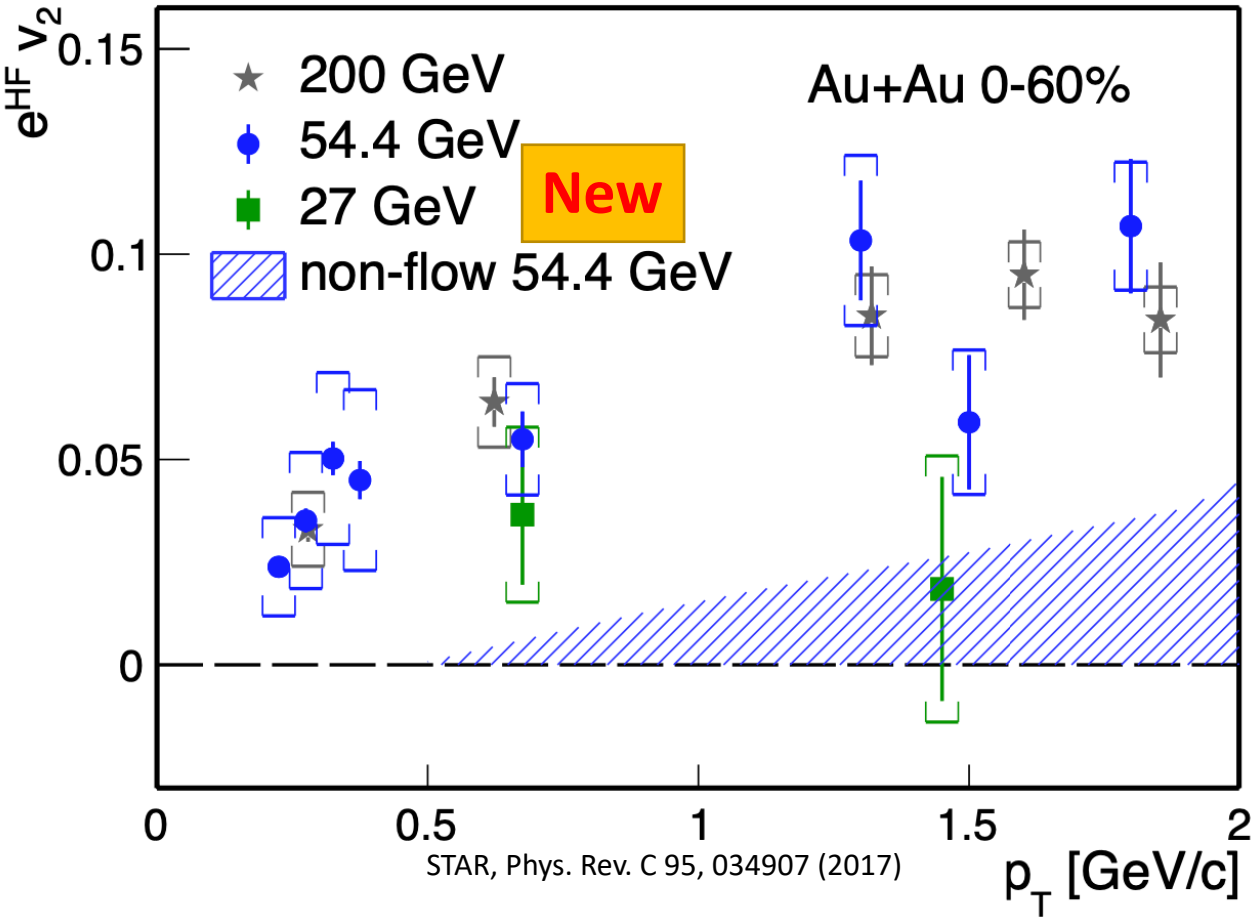

FONLL: JHEP 1210 (2012) 137
STAR 2006 pp: Phys. Rev. Lett. 105, 20230

- $R_{AA}(b \rightarrow e) > R_{AA}(c \rightarrow e)$ (>3σ): bottom is less suppressed than charm
- Bottom fraction significantly enhanced in central collisions, approach p+p data towards peripheral
- Consistent with $\Delta E(b) < \Delta E(c)$ in the QGP

# HF ($c$+$b$)→ e $v_2$ at Lower Energies

YJ Ji, 4 June, 11:15, G3

Do heavy flavor quarks show similar collectivity at lower energies?




**Large datasets ~10x BES-I allow measuring HF decayed electron $v_2$ at lower energies**

- $e^{HF}$ in 54.4 GeV: non-zero $v_2$, comparable to $e^{HF}$ at 200 GeV as well as light hadrons at 54.4 GeV
  - Indication of strong charm-medium interactions at 54.4 GeV
- $e^{HF}$ in 27 GeV: hint of a smaller $v_2$ than 54.4 and 200 GeV

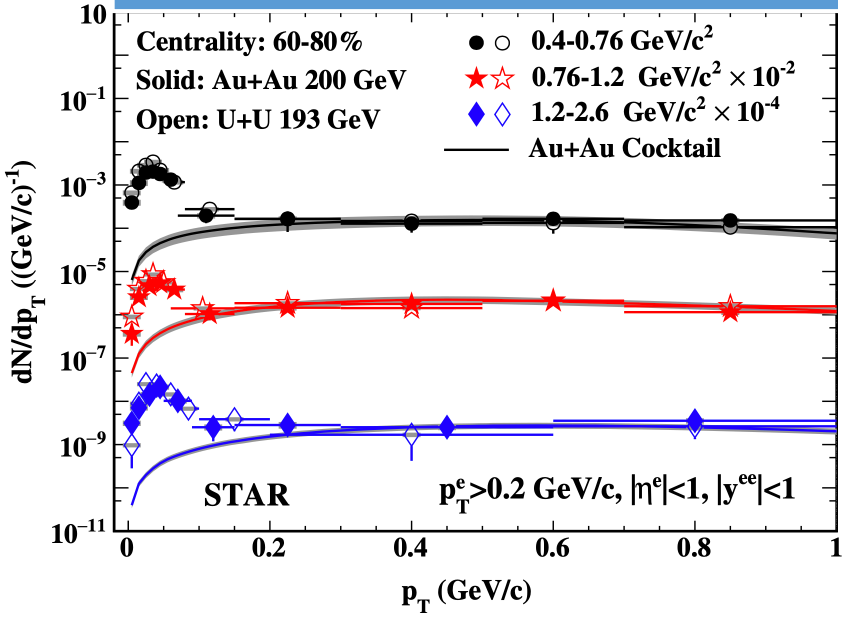
# $\mu^+\mu^-$ pairs Enhancement in Peripheral Au+Au

Z. Liu, 2 June, 11:00, C2

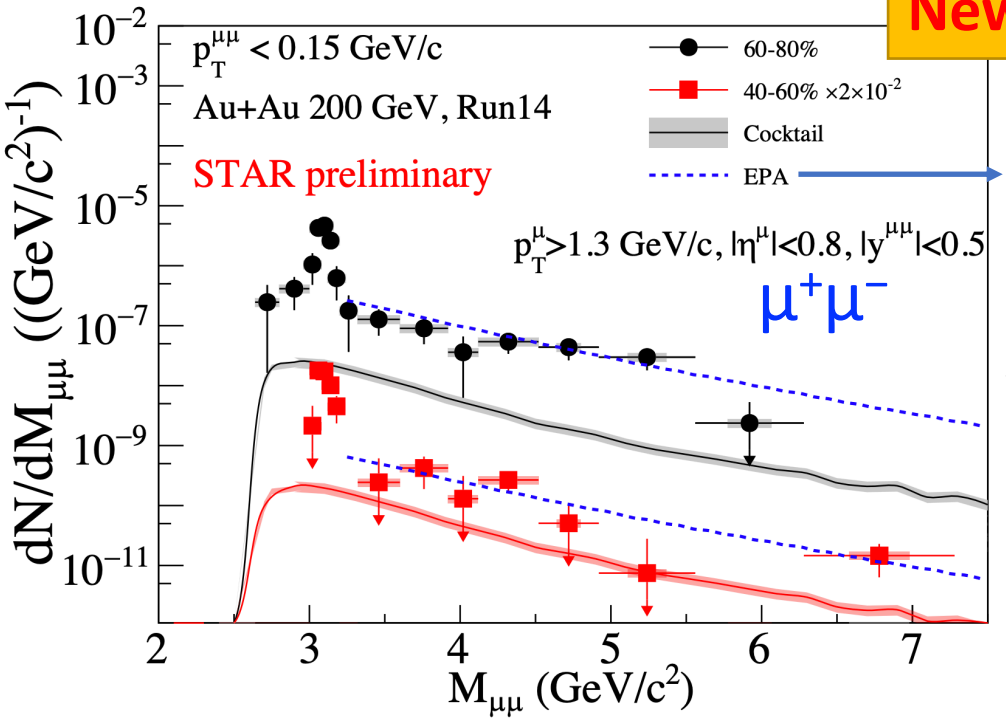
**Significant enhancement of the very low-$p_T$ $J/\psi$ and low mass $e^+e^-$ pairs observed in peripheral A+A collisions at STAR**

STAR, Phys. Rev. Lett. 123 (2019)132302, STAR, Phys. Rev. Lett. 121 (2018) 132301

STAR published $e^+e^-$ enhancement




New




**E**quivalent **P**hoton **A**pproximation
- Photon as real
- Weizsacker–Williams method to estimate photon flux

W.M. Zha et al., Phys. Lett. B 800 (2020) 135089

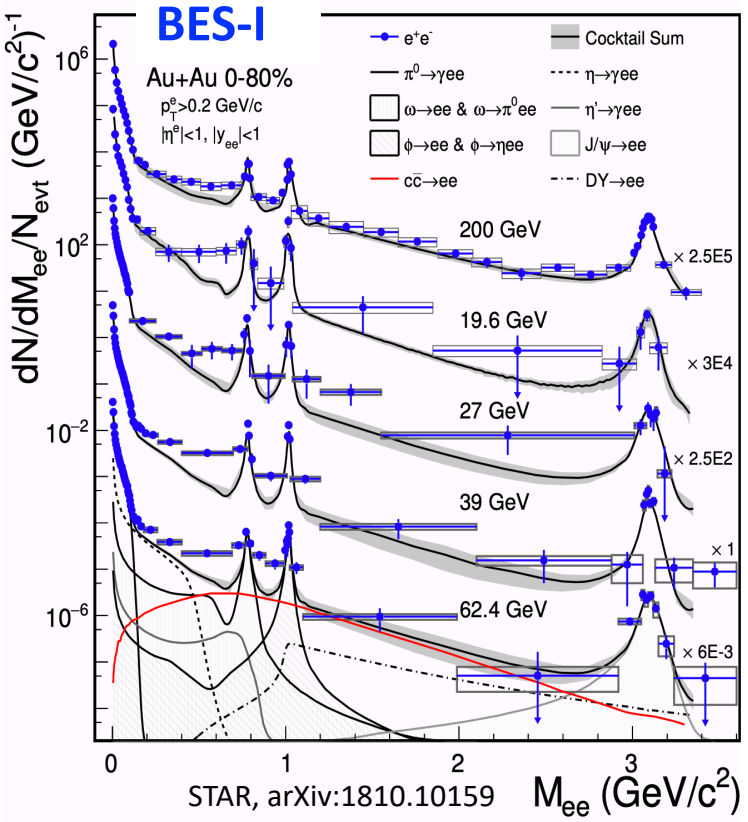
**First dimuon** enhancement from STAR:
- Similar as in previous dielectron measurements at $M_{ee}$<3.2 GeV/$c^2$, extend to the higher mass region
- Consistent with EPA model calculations

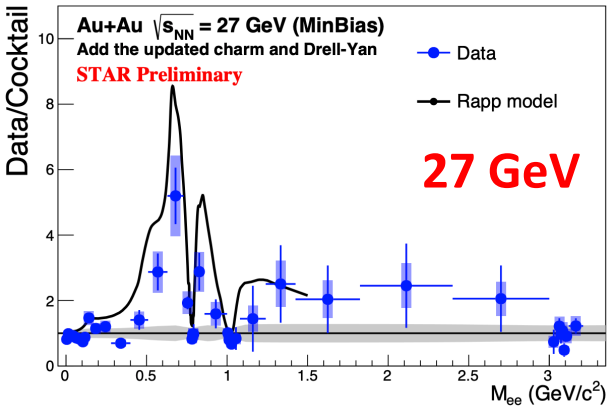
# Dielectron Production in Au+Au

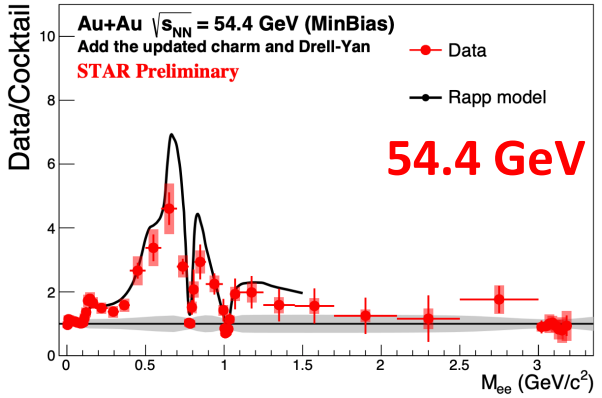
**Excellent penetrating probe, created throughout evolution of medium**

Z. Wang, 2 June, 11:40, C2

- LMR ($M_{ee} < M_{\phi}$): in-medium modifications linked to the chiral symmetry restoration
- IMR ($M_{\phi} < M_{ee} < M_{J/\psi}$): excess from thermal radiation → medium temperature




New 54.4 GeV and improved 27 GeV (~x10 BES-I):

- Consistent with published data with greatly improved data precision
- Hint of more enhancement at IMR in 27 GeV than 54 GeV → lower energy 7.7-19.6 GeV (BES-II) could further explore

# STAR Beyond BES-II (2021+)

D. Brandenburg, 4 June, 11:55, G4

STAR

- The forward ($2.5 < \eta < 4$) upgrade includes **Trackers (**silicon microstrip tracker **& s**mall-strip **Thin Gap Chamber)** and **Calorimeters (ECAL & HCAL)** dedicated to study nuclear structure, QGP (details will be in Daniel's talk).

**Forward-rapidity 2.5 < h < 4.0**

**A+A**

**Beam**:
Full Energy AuAu

Physics Topics:
- Temperature dependence of viscosity through flow harmonics up to h~4
- Longitudinal decorrelation up to h~4
- Global Lambda Polarization → strong rapidity dependence predicted

**p+p & p+A**

**Beam**:
500 GeV: p+p
200 GeV: p+p and p+A

Physics Topics:
- TMD measurements at high x transversity → tensor charge
- Improve statistical precision for Sivers through DY
- $Dg(x,Q^2)$ at low x through Di-jets
- Gluon PDFs for nuclei
- ➢ $R_{pA}$ for direct photons & DY
- Test of Saturation predictions through di-hadrons, g-Jets

Observables:
- Inclusive jets and di-jets
- Hadrons in jets
- Direct photons
- Drell-Yan *e+e-*
- Lambda's
- Mid-forward & forward-forward
- rapidity correlations

Requirements:
- Good *e*/*h* separation
- Hadrons, photons, $\pi^0$ identification

2021/22: 500 GeV polarized pp run

Additional pp, pA, and AA data taking in parallel to the sPHENIX campaign

# Summary: Enjoy All STAR Talks and Posters !!!

Click for contributions

## Initial State

234. **Dependence of jet and high-$p_T$ charged particle production on event activity at high rapidity in sqrt(sNN) = 200 GeV p+Au collisions** — David Stewart, 2 June, 12:55, D4
315. **Photoproduction of J/psi -mesons off deuteron in d+Au Ultra-Peripheral Collisions using the STAR detector** — Zhoudunming Tu, 1 June, 11:20, A4

## Jets and High Momentum Hadrons

235. **Jet substructure in p+p and p+Au collisions at sqrt(sNN) = 200 GeV at STAR** — Isaac Mooney, 3 June, 11:50, E1
236. **Evolution of jet shapes and fragmentation functions in Au+Au collisions at sqrt(sNN) = 200 GeV with the STAR experiment at RHIC** — Joel Mazer, 4 June, 13:50, H1
237. **Measurement of fully-reconstructed inclusive jet production in Au+Au collisions at sqrt(sNN) = 200 GeV by the STAR experiment** — Robert Licenik, 1 June, 11:20, A1
238. **$\gamma$+jet and $\pi^0$+jet Measurements in Au+Au Collisions at sqrt(sNN) = 200 GeV with the STAR Experiment** — Nihar Sahoo, 2 June, 11:20, C1
247. **Measuring the groomed shared momentum fraction ($z_g$) in Au+Au collisions at sqrt(sNN) = 200 GeV at STAR** — Daniel Nemes
248. **Measurement of semi-inclusive jet fragmentation functions in Au+Au collisions at sqrt(sNN) = 200 GeV in STAR** — Saehanseul Oh
249. **Jet and Di-jet Underlying Event in p+Au collisions at sqrt(sNN) = 200 GeV at STAR** — Veronica Verkest
253. **Transverse Momentum Imbalance for Jets Recoiling from Direct-photon and $\pi^0$ Triggers in Au+Au Collisions at sqrt(sNN) = 200 GeV** — Annika Ewigleben

## Heavy Flavor and Quarkonia

223. **Elliptic flow of electrons from heavy-flavor decays in 54.4 and 27 GeV Au+Au collisions from the STAR experiment at RHIC** — Yuanjing Ji, 4 June, 11:15, G3
225. **Measurements of electron production from heavy flavor decays in p+p and Au+Au collisions at sqrt(sNN) = 200 GeV at STAR** — Yingjie Zhou, 4 June, 11:35, G3
227. **Measurement of $D^{\pm}$ meson production in Au+Au collisions at sqrt(sNN) = 200 GeV with the STAR experiment** — Jan Vanek, 1 June, 11:35, B3
229. **Production of $D_s^{\pm}$ mesons in Au+Au collisions at sqrt(sNN) = 200 GeV by STAR** — Chuan Fu, 2 June, 12:00, C3
232. **J/psi production in jets in p+p collisions at sqrt(s) = 500 GeV by STAR** — Qian Yang, 2 June, 12:55, D2
233. **Cold Nuclear Matter Effects on J/psi and Upsilon Productions at RHIC with the STAR Experiment** — Ziyue Zhang, 1 June, 12:20, A3

## Electroweak Probes

240. **Measurements of dielectron production in Au+Au collisions at sqrt(sNN) = 27 and 54.4 GeV with the STAR experiment** — Zhen Wang, 2 June, 11:40, C2
245. **Low-$p_T$ $\mu^+$ $\mu^-$ pair production in Au+Au collisions at sqrt(sNN) = 200 GeV at STAR** — Zhen Liu, 2 June, 11:00, C2

## New Experimental Developments

288. **The Forward Rapidity Upgrade for the STAR Detector** — D. Brandenburg, 4 June, 11:55, G4

The STAR Collaboration: https://drupal.star.bnl.gov/STAR/presentations/

# THANK YOU

# STAR is composed of 68 institutions from 14 countries and region, with a total of 722 collaborators


## STAR Collaboration Acknowledgements

We thank the RHIC Operations Group and RCF at BNL, the NERSC Center at LBNL, and the Open Science Grid consortium for providing resources and support. This work was supported in part by the Office of Nuclear Physics within the U.S. DOE Office of Science, the U.S. National Science Foundation, the Ministry of Education and Science of the Russian Federation, National Natural Science Foundation of China, Chinese Academy of Science, the Ministry of Science and Technology of China and the Chinese Ministry of Education, the National Research Foundation of Korea, Czech Science Foundation and Ministry of Education, Youth and Sports of the Czech Republic, Hungarian National Research, Development and Innovation Office, New National Excellency Programme of the Hungarian Ministry of Human Capacities, Department of Atomic Energy and Department of Science and Technology of the Government of India, the National Science Centre of Poland, the Ministry of Science, Education and Sports of the Republic of Croatia, RosAtom of Russia and German Bundesministerium fur Bildung, Wissenschaft, Forschung and Technologie (BMBF) and the Helmholtz Association.

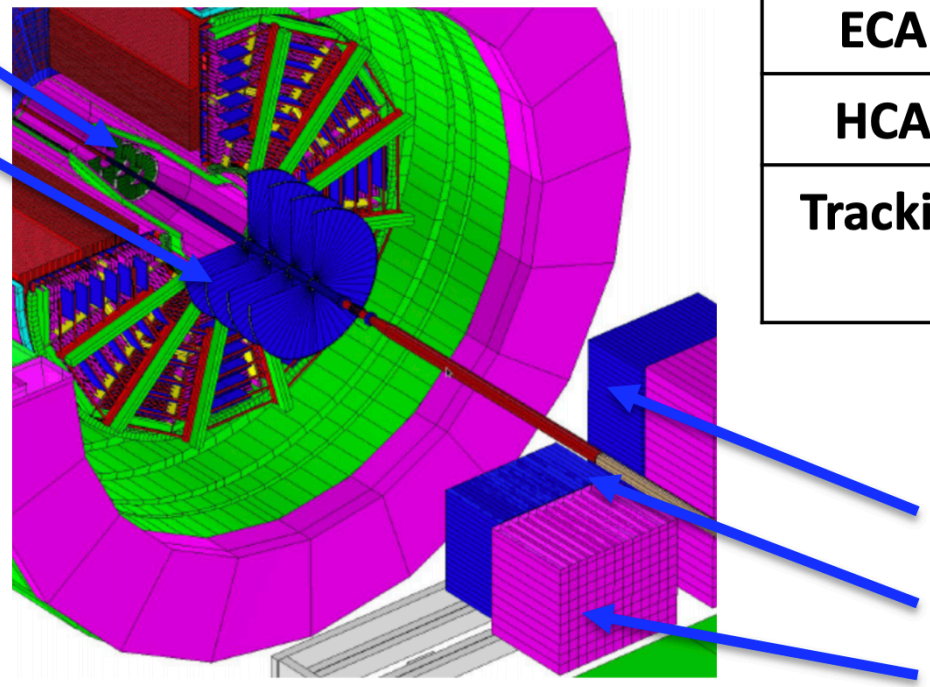

STAR official webpage: https://www.star.bnl.gov/

# STAR Beyond BES-II

D. Brandenburg, 4 June, 11:55, G4

- **Detectors from BES-II upgrade (iTPC and EPD) will keep going**
- The forward ($2.5 < \eta < 4$) upgrade includes **Trackers** (silicon microstrip tracker **&** small-strip **Thin Gap Chamber)** and **Calorimeters (ECAL & HCAL)** dedicated to study nuclear structure, QGP.

Forward Tracker
- 3 silicon disks
- 4 sTGC layers



| Detector | pp and pA | AA |
|---|---|---|
| ECAL | ~10%/√E | ~20%/√E |
| HCAL | ~60%/√E | --- |
| Tracking | Charge separation<br>Photon suppression | $0.2 < p_T < 2$ GeV/c<br>with 20 – 30% $1/p_T$ |

Preparing for data-taking from **2021+**

Forward Calorimeters
- Pre/post-shower: scintillator
- ECAL: PbSc towers (18 $X_0$)
- HCAL: FeSc plates (4.5 λ)