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Recent J/ψ results in p+p and Au+Au collisions from STAR

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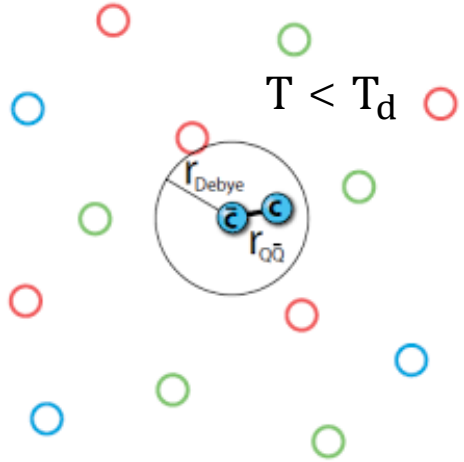
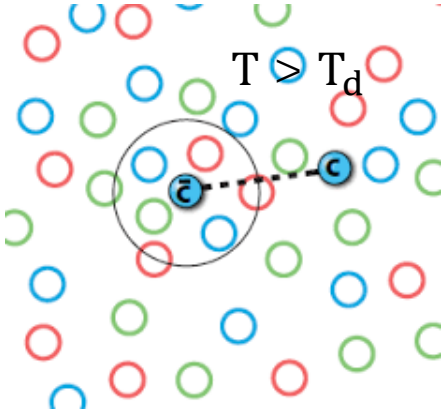
Outline

- Motivation and detector
- J/ψ suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV
- J/ψ production in jets in p+p collisions at $\sqrt{s}$ = 500 GeV
- Summary

J/ψ production in heavy ion collisions

Heavy quarkonia are ideal probes of the Quark-Gluon Plasma (QGP)



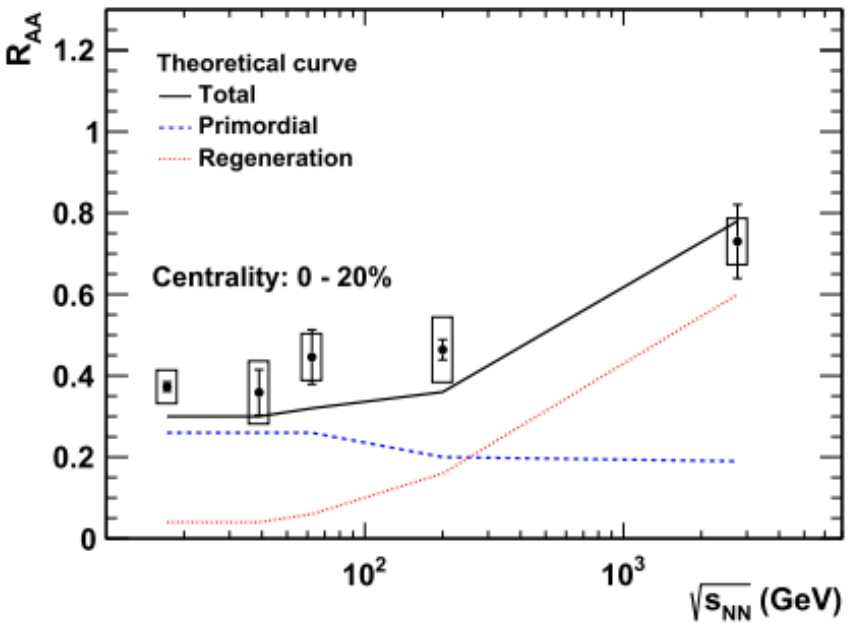


J/ψ has been suggested as a signature of the formation of the QGP

Modification of J/ψ yield

- **Color screening effect**
- **Regeneration**
- Cold nuclear matter effects (like nPDF, coherent energy loss, nuclear absorption)
- Other final state effects

J/ψ production in heavy ion collisions



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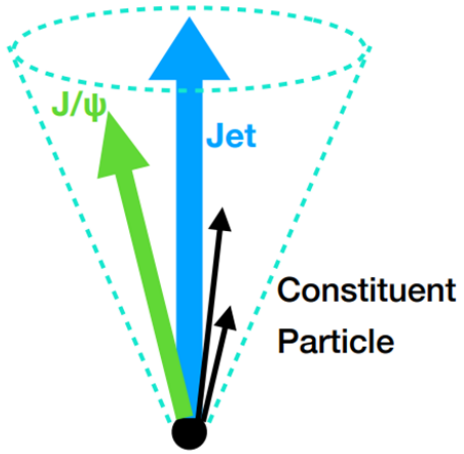
- The J/ψ production has been measured in Au+Au collisions at 39, 62.4 and 200 GeV and in Pb+Pb collisions at 17.2 GeV, 2.76 and 5.02 TeV
- No significant energy dependence of nuclear modification factor within uncertainties at $\sqrt{S_{NN}} \leq 200\ GeV$
  - Interplay of color screening, cold nuclear matter effects and regeneration
- ~10x more statistics in 54 GeV compared to 62.4 GeV, and this will help better understand the energy dependence of J/ψ suppression

J/ψ production in p+p collisions

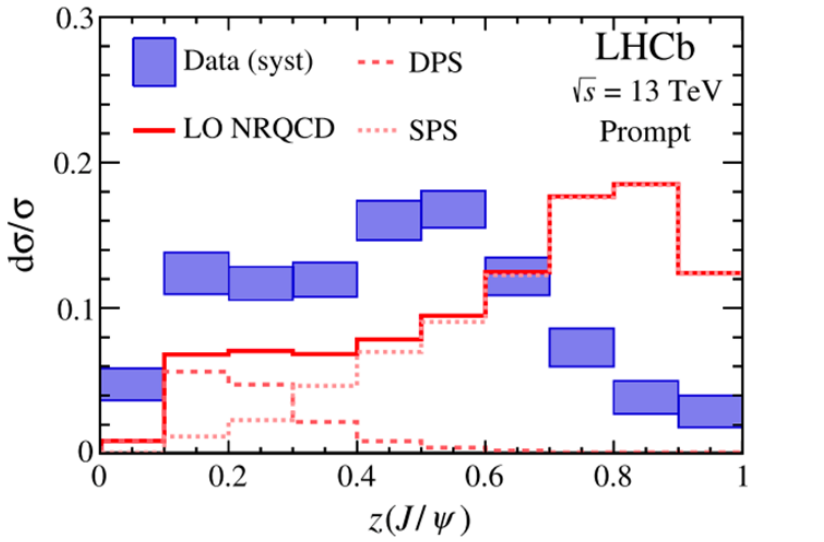
Production of the $c\bar{c}$
(large momentum transfer, pQCD)

Evolution of the $c\bar{c}$ pair into J/ψ
(small dynamical scale, non-pQCD)

Difficult for models to account for the hadronization:
- Color Singlet Model
- NRQCD approach(CGC+NRQCD)
  Long distance matrix elements(LDMEs)
- Improved Color Evaporation Model

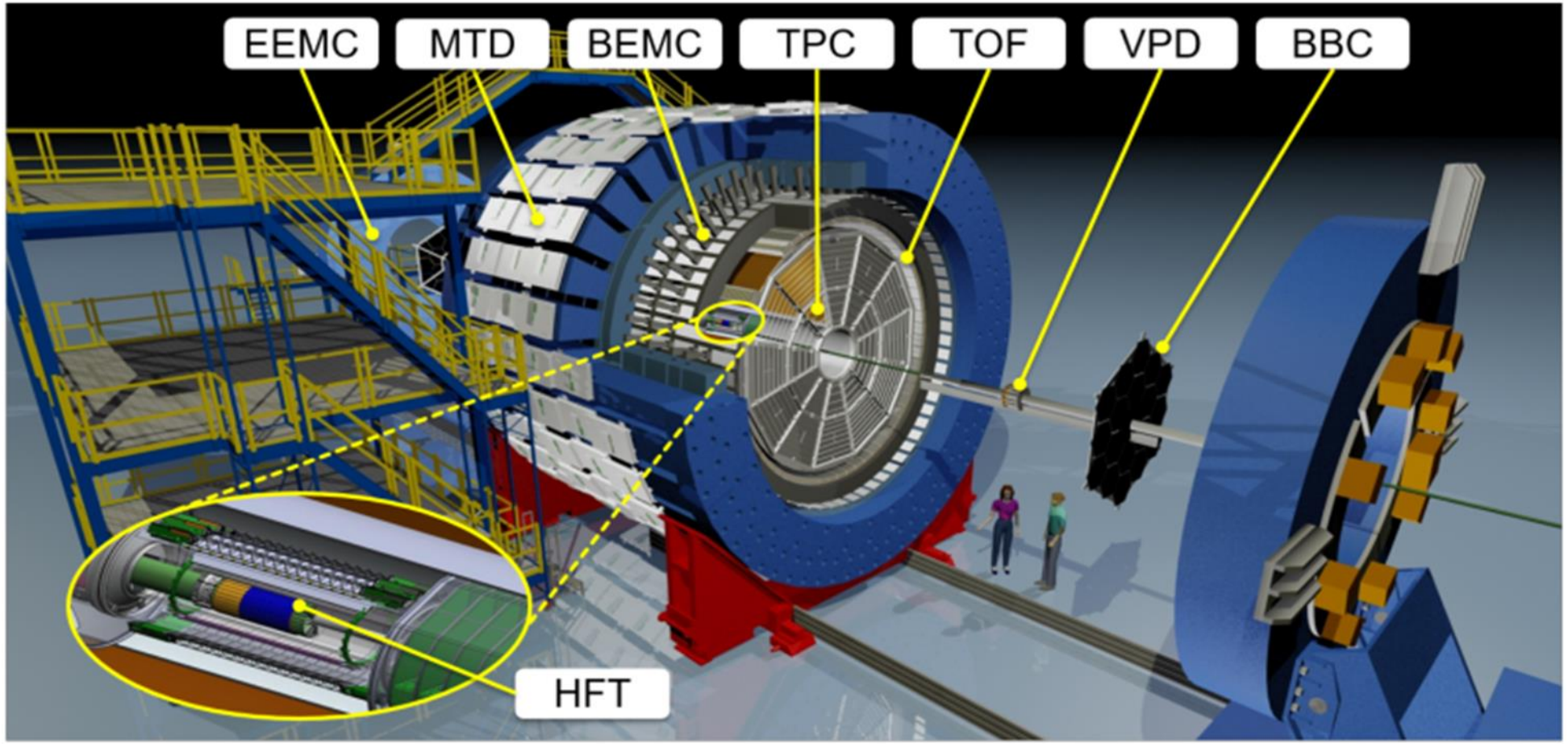


LHCb, PRL 118, (2017) 192001



J/ψ production in jets:
- Difference between LHCb measurement and Pythia8 prediction
- What is the case at RHIC energies?
  Different collision energy, jet energy and kinematic range

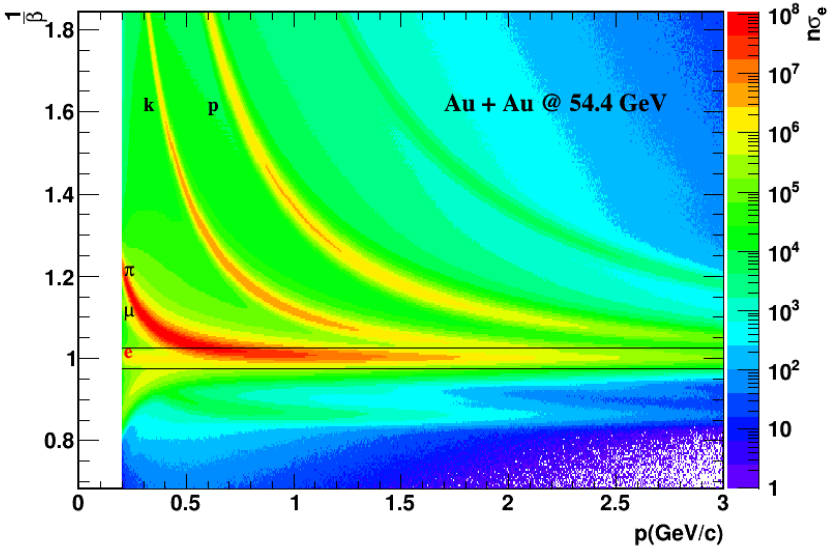
The Solenoidal Tracker At RHIC

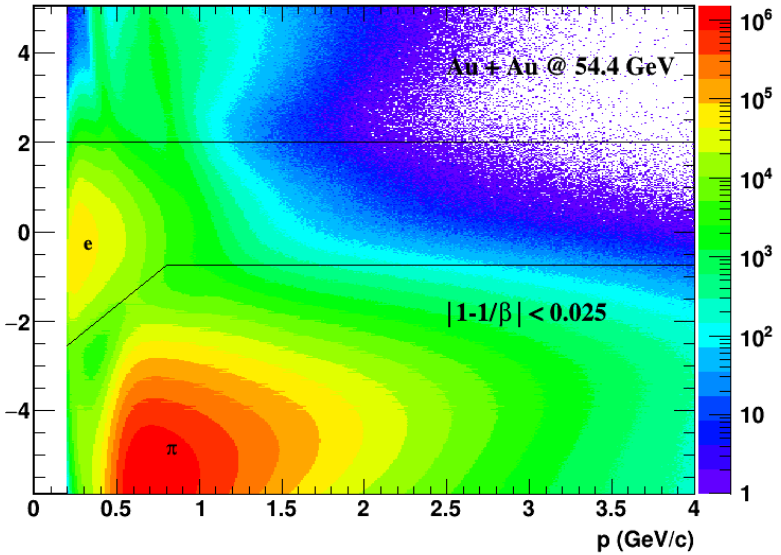


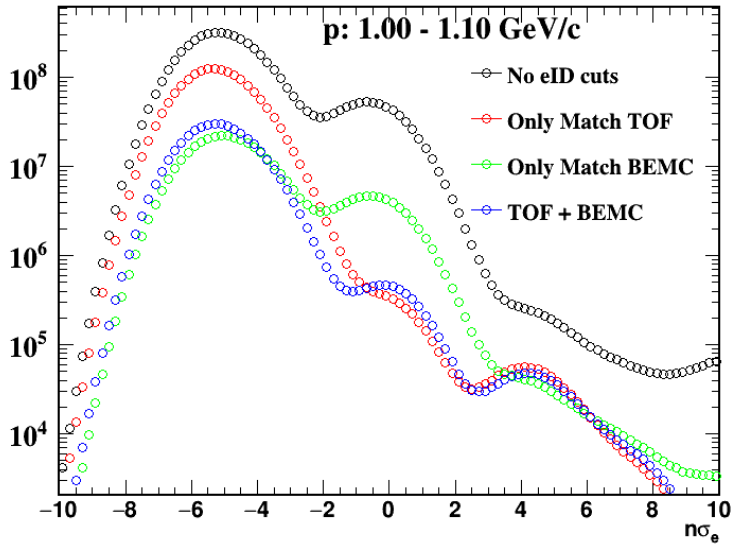
- ✓ TPC: Tracking, momentum and energy loss
- ✓ TOF: Time of flight, particle identification
- ✓ BEMC: trigger and identification of high-$\mathbf{p_T}$ electrons

J/ψ suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV

Electron identification







$p_T \leq 1$ GeV/c

$|\vec{P}| \leq 0.8$
- $3\times|\vec{P}|-3.15< n\sigma_e < 2$
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

$|\vec{P}| > 0.8$
- $-0.75< n\sigma_e < 2$
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

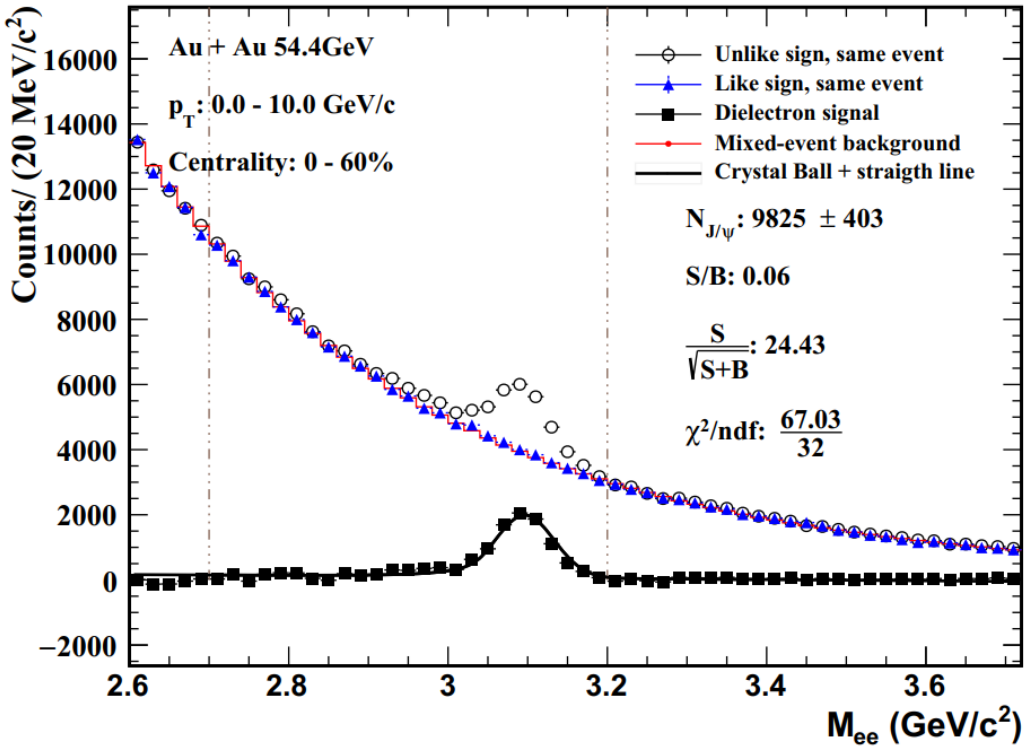
$p_T > 1$ GeV/c

TOF&BEMC
- $-1.5 < n\sigma_e < 2$
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$
- $0.5 < E_0/p < 1.5$

TOF
- $-0.75< n\sigma_e < 2$
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

BEMC
- $-1 < n\sigma_e < 2$
- $0.5 < E_0/p < 1.5$

J/ψ raw signal in Au+Au collisions



- J/ψ raw signal are reconstructed through dielectron channel
- J/ψ signal shape from embedding with additional momentum smearing
- Residual background described by a straight line
- Raw counts extracted by bin counting in $2.7 < M_{ee} < 3.2$ GeV/c^2
- There is no BSMD information at 54.4 and 200 GeV
  - ◆ BSMD detector can further improve electron purity

$\sqrt{s_{NN}}$	39 GeV	54.4 GeV	62.4 GeV	200 GeV
S/B	0.34	0.06	0.19	0.03
Significance	10	24	9	22

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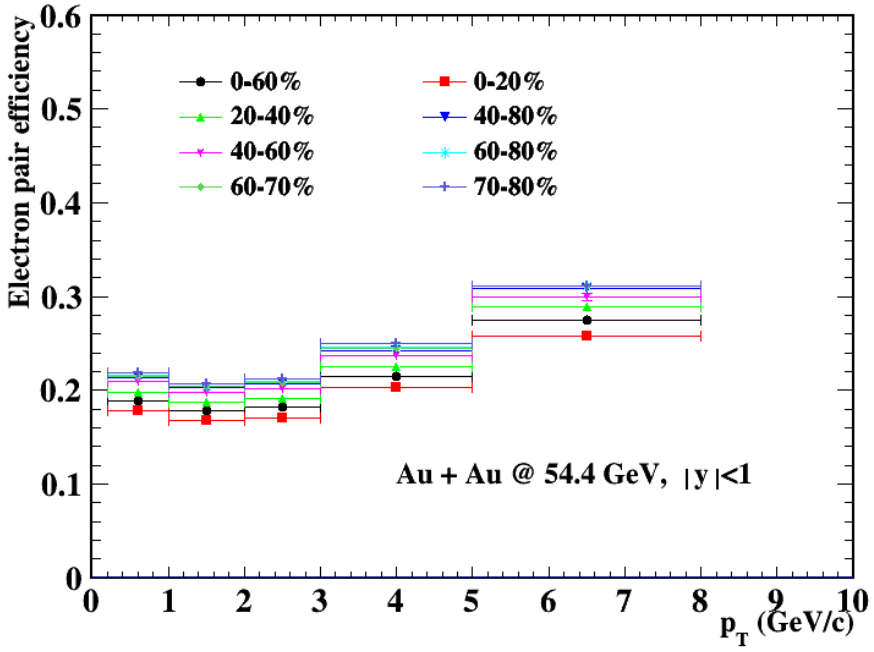
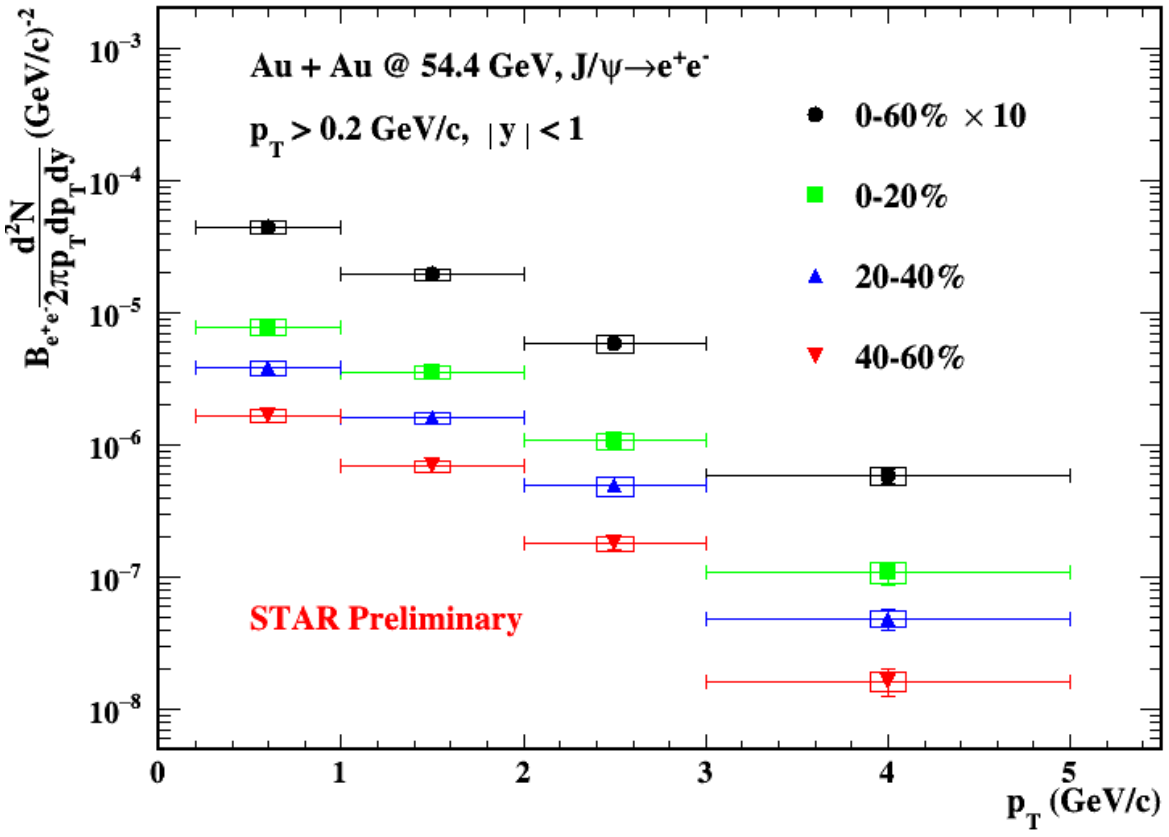
Efficiency and invariant yield

- The pair efficiency is evaluated by folding the single track efficiency
- The acceptance is showed below: $p_T^e \geq 0.2$ GeV/c, $|\eta_e| \leq 1$, $|y_{ee}| \leq 1$,



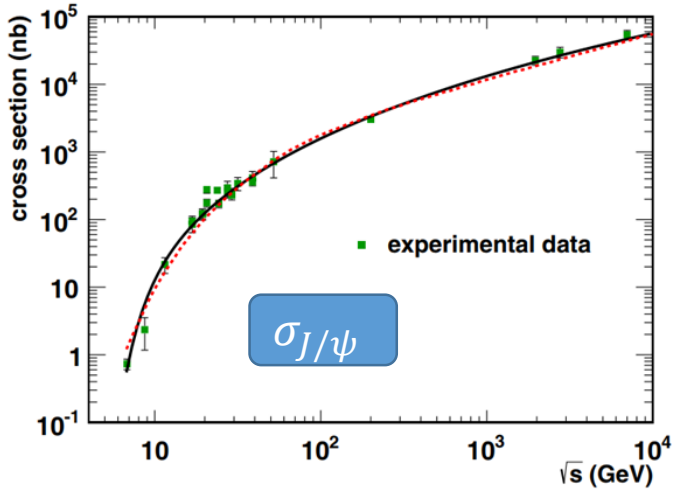


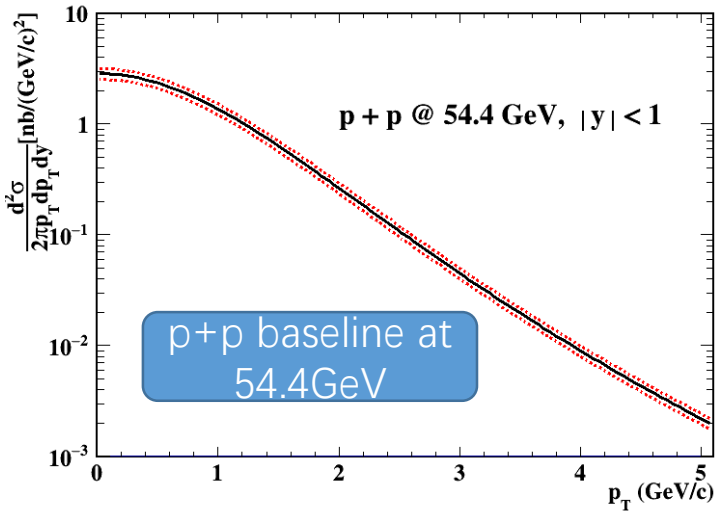
$p_T > 0.2$ GeV/c to exclude coherent photon induced production

p+p baseline

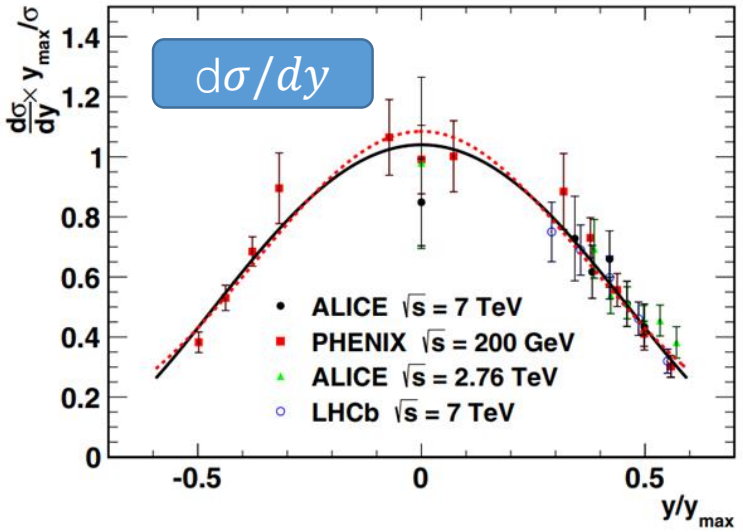
- **For p+p baseline at 39, 54.4, and 62.4 GeV, they are extracted from phenomenological calculations**

W. Zha, et al., Phys. Rev. C 93 (2016) 024919.



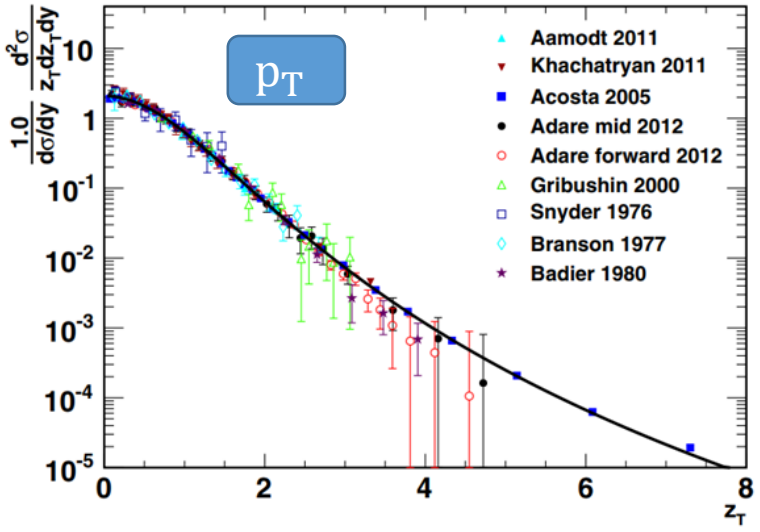


- Energy interpolation from the existing total J/ψ cross section measurements
- Energy evolution of the rapidity distribution
- Energy evolution of J/ψ transverse momentum distribution



$$\frac{1}{\sigma}\frac{d\sigma}{d(y/y_{max})} = ae^{-\frac{1}{2}(\frac{y/y_{max}}{b})^2}$$

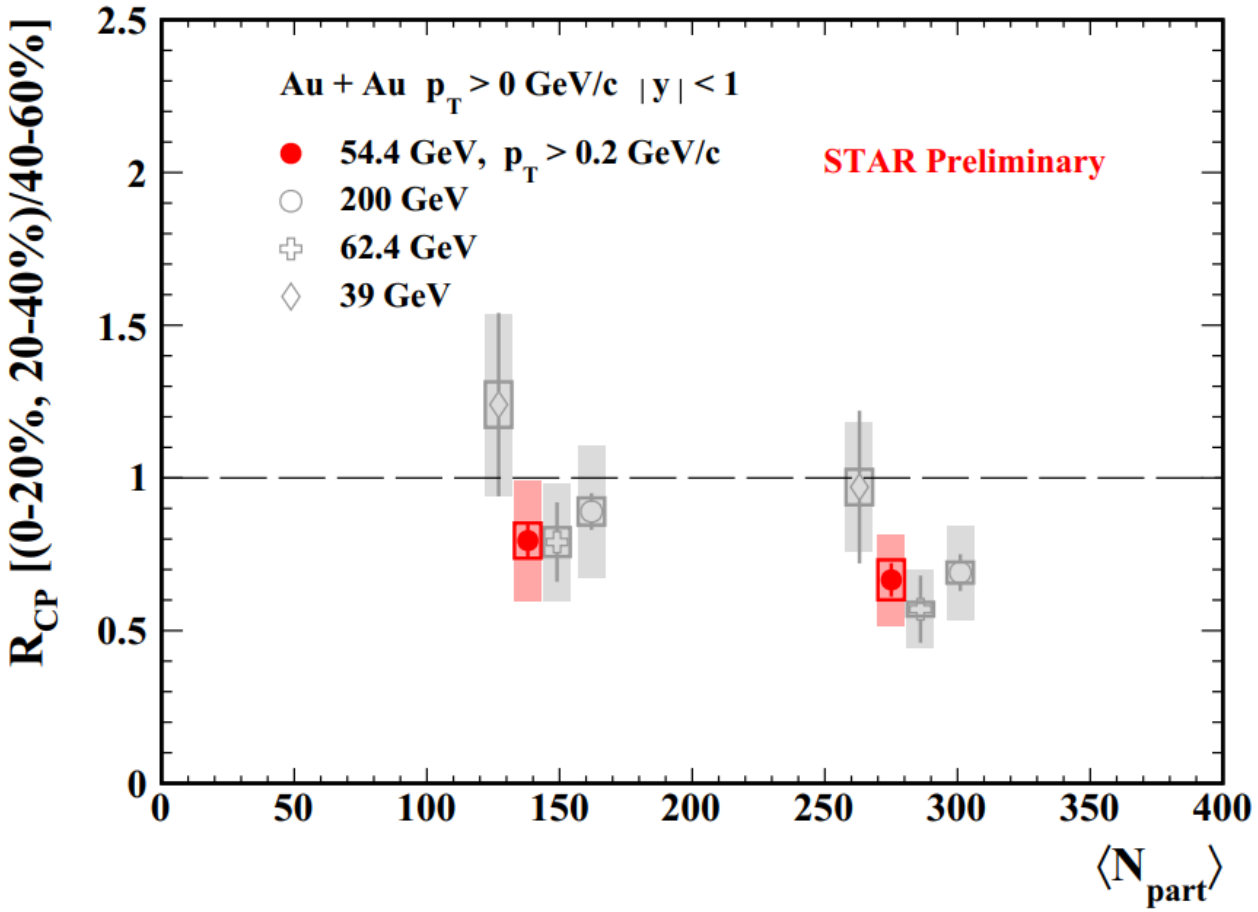
where $y_{max} = \ln(\frac{\sqrt{s}}{m_{J/\psi}})$



$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

where $z_T = p_T/\langle p_T \rangle$

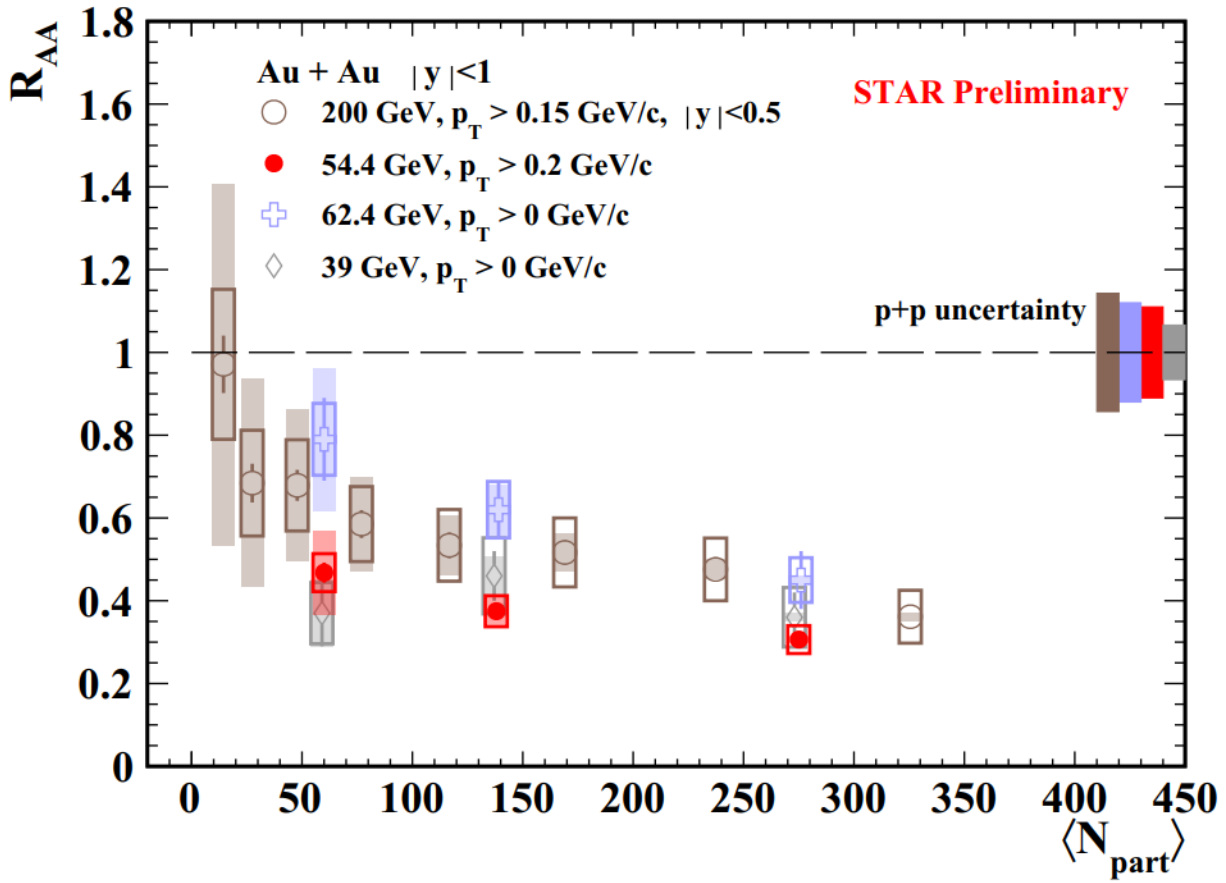
R_{CP} vs $\langle N_{part} \rangle$



$$R_{CP} = \frac{\frac{dN/dy}{\langle N_{coll} \rangle}(\text{central})}{\frac{dN/dy}{\langle N_{coll} \rangle}(\text{peripheral})}$$

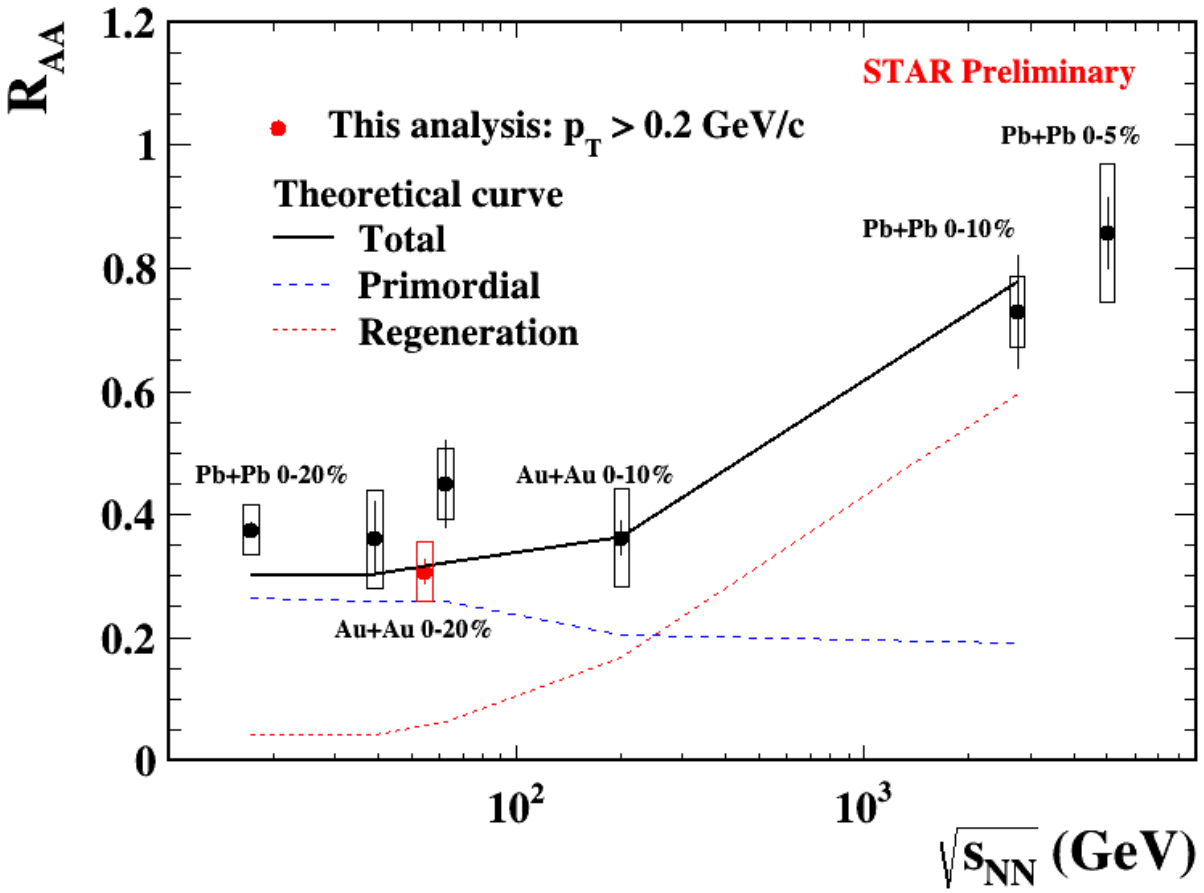
- Peripheral 40 – 60 % centrality is used as reference
- A suppression is observed in central Au+Au collisions at 54.4 GeV, similar to that at 62.4 and 200 GeV

R_{AA} vs $\langle N_{part} \rangle$



- Suppression of J/ψ production is observed in Au + Au collisions at 54.4 GeV with better precision
- No significant energy dependence is observed among 39, 54.4, 62.4 and 200 GeV, as a function of $\langle N_{part} \rangle$

R_{AA} vs $\sqrt{s_{NN}}$

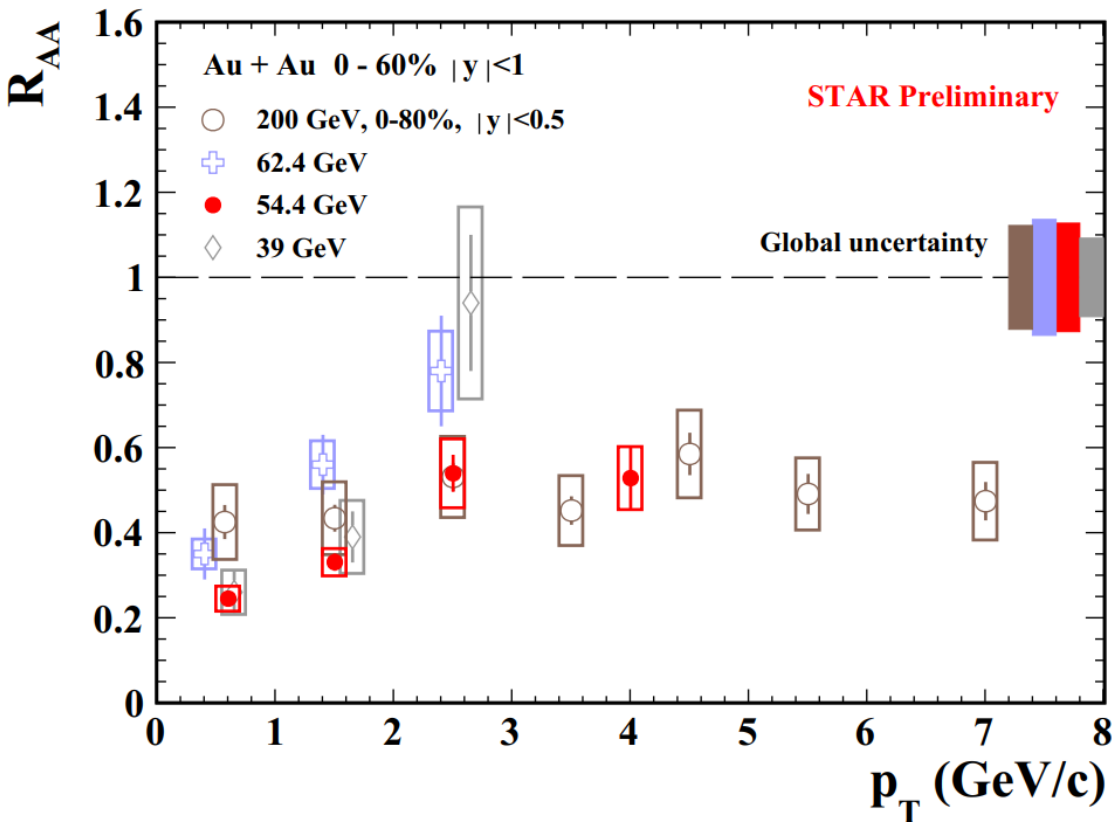


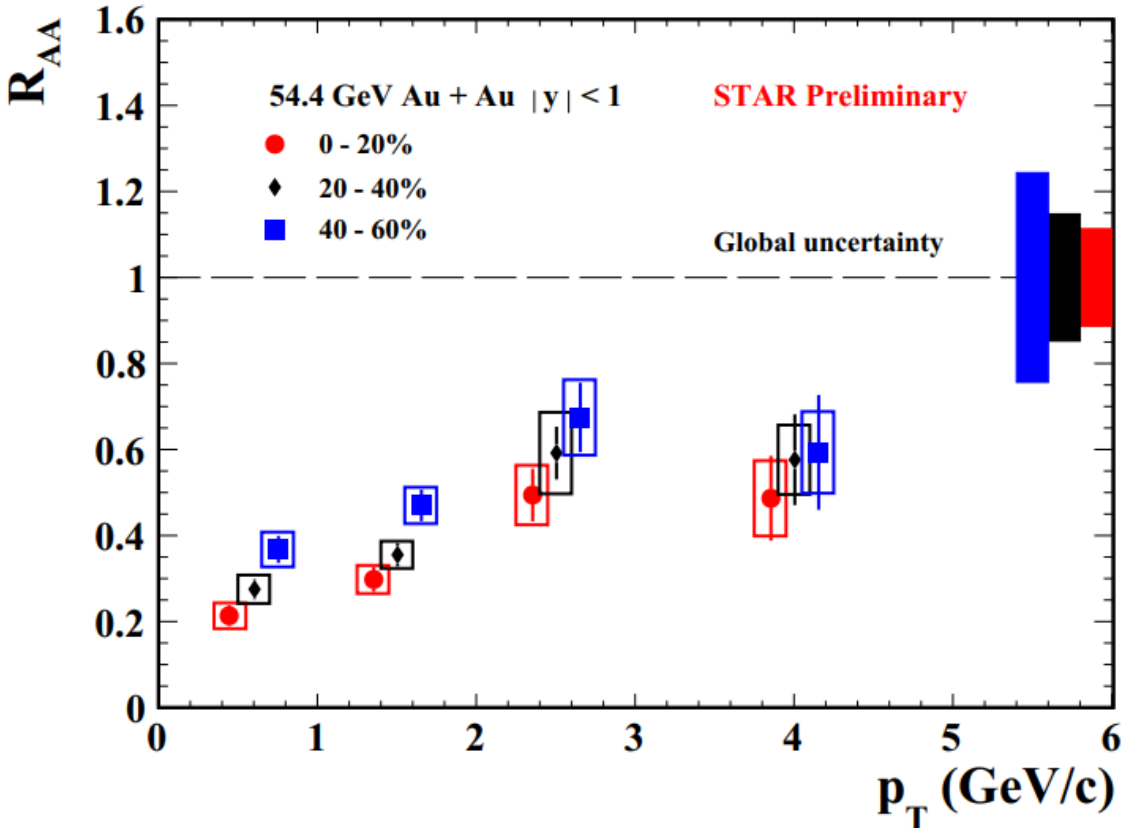
- R_{AA} as a function of $\sqrt{s_{NN}}$, in central A+A collisions
- 54.4 GeV data follow the trend with improved precision
- No significant energy dependence is observed within uncertainties up to 200 GeV
- Model calculations are consistent with the observed energy dependence

Calculations are for the same system as data points and in 0-20% centrality

- X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905 (private communication).
- L. Kluberg, Eur. Phys. J. C 43 (2005) 145.
- NA50 Collaboration, Phys. Lett. B 477 (2000) 28.
- ALICE Collaboration, Phys. Lett. B 734 (2014) 314
- STAR Collaboration, Phys. Lett. B 771 (2017) 13-20
- STAR Collaboration, Phys. Lett. B 797 (2019) 134917
- ALICE Collaboration, Nucl. Phys. A 1005 (2021) 121769

R_{AA} vs p_T

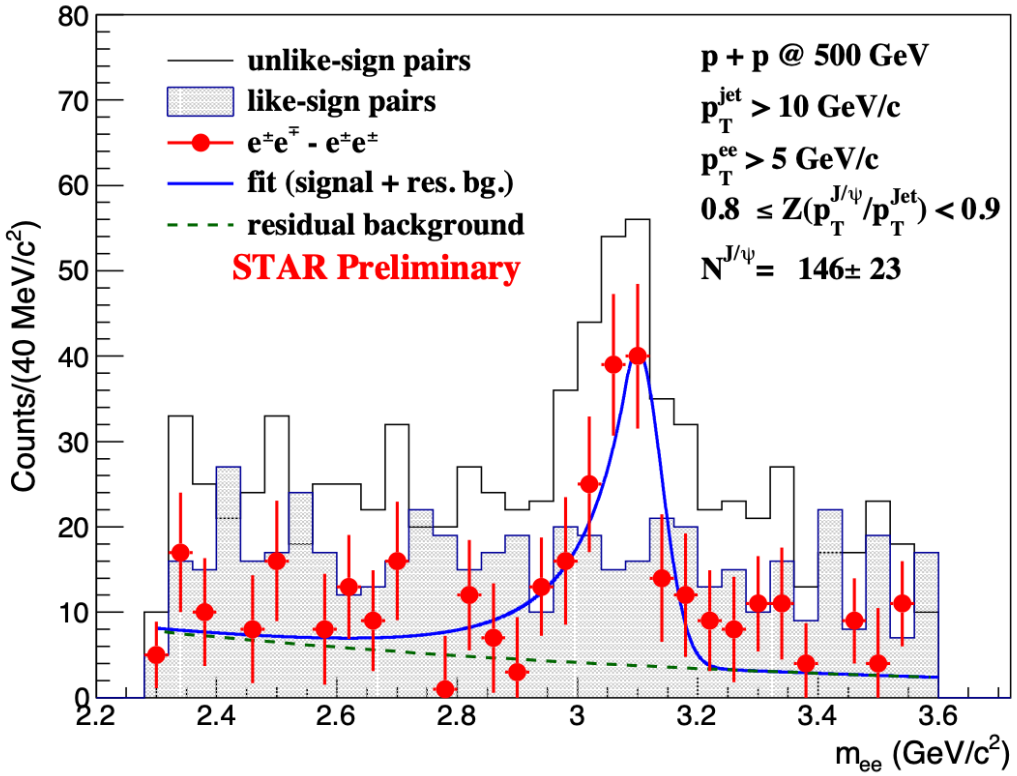


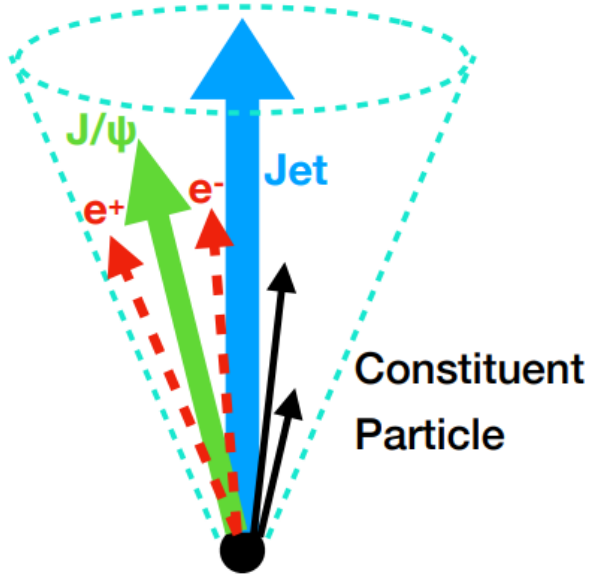


- R_{AA} increases with increasing p_T for 39, 54.4 and 62.4 GeV
- More suppression towards central collisions

J/ψ production in jets in p+p collisions at $\sqrt{s}$ = 500 GeV

J/ψ and jet reconstruction

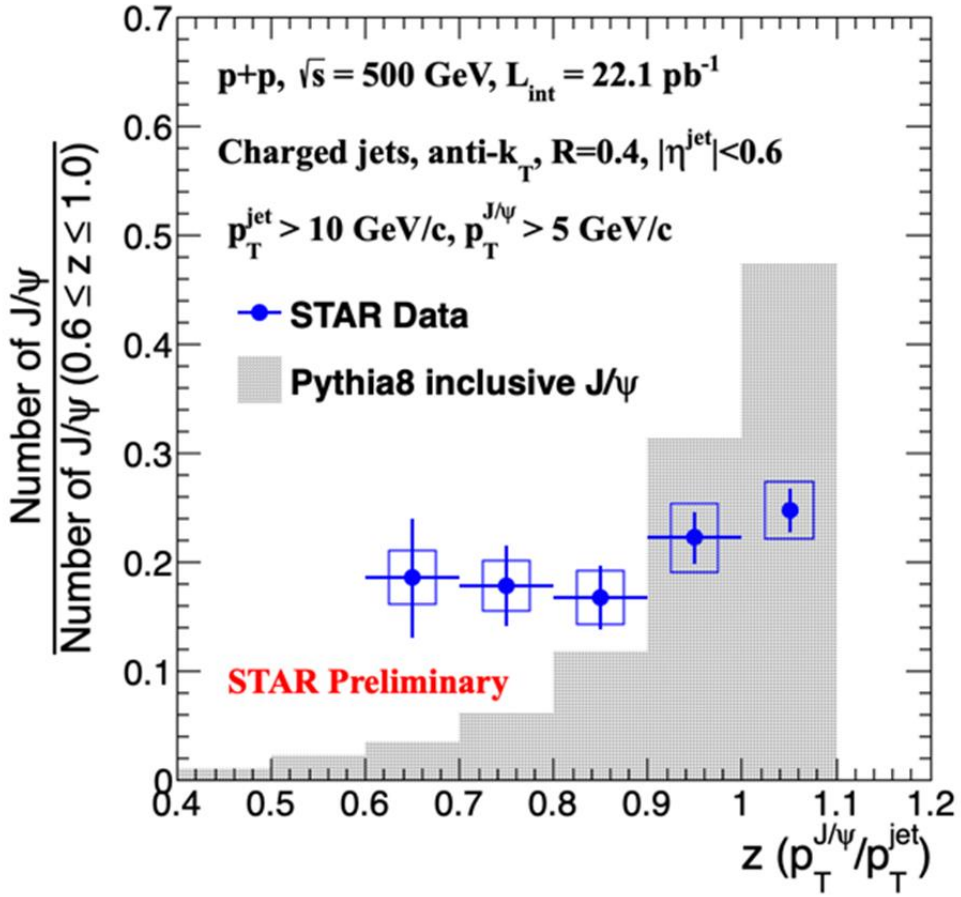




- Jet: charged particles + J/ψ candidates
- Anti-k_T, R = 0.4

- Combinatorial background: like-sign method
- Residual background (Drell-Yan, $c\bar{c}$, $b\bar{b}$): exponential function
- Signal: Crystal-Ball function

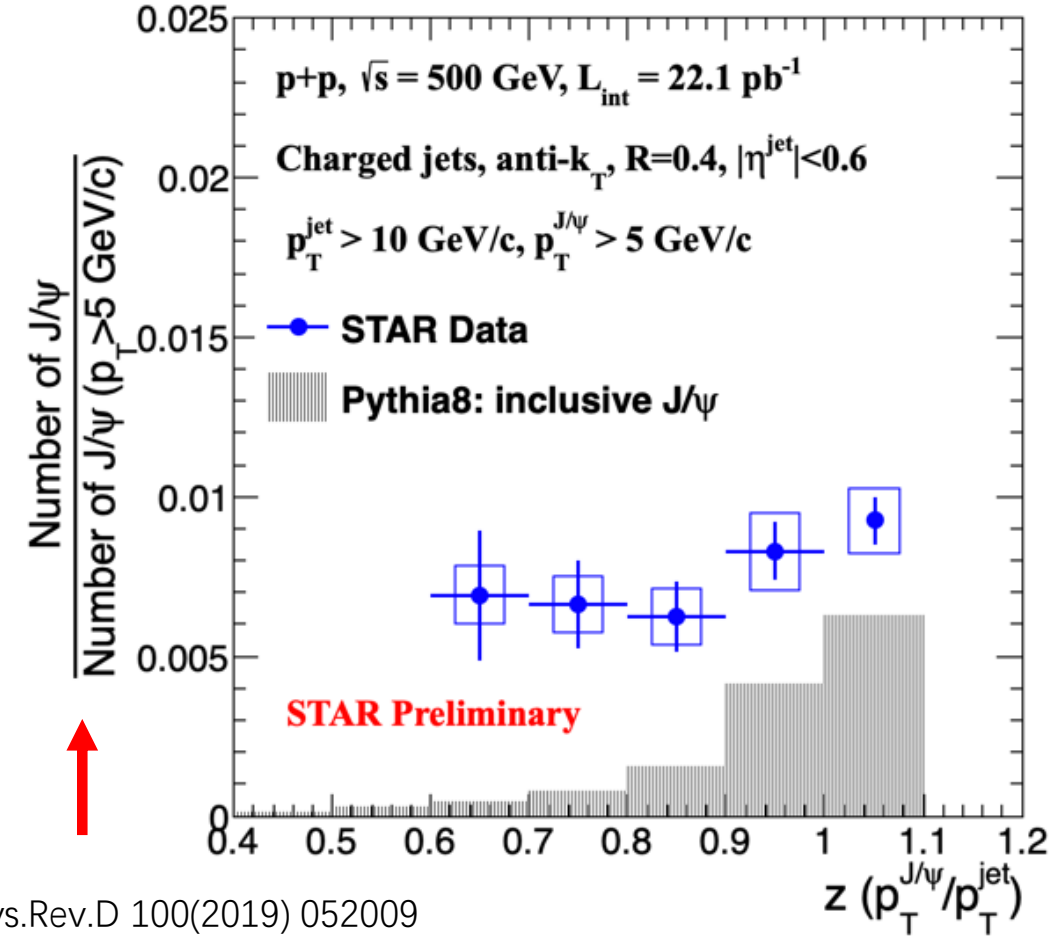
Fragmentation of J/ψ in jets



- First measurement of J/ψ production in jets at RHIC
- No significant z dependence is observed within uncertainties
- Compared to Pythia8: less isolated production in data

Major systematic uncertainty sources:
- Pile-up tracks (~8%)
- Min-bias vs J/ψ PYTHIA events used for response matrix (~5%)
- Tracking efficiency (~12%)

Fraction of J/ψ produced in jets



STAR, Phys.Rev.D 100(2019) 052009
for p_T > 5 GeV/c J/ψ cross section

- The fraction of J/ψ with $p_T > 5$ GeV/c produced in jets with $p_T > 10$ GeV/c is 3.7% $\pm$ 0.3% (stat.) $\pm$ 0.2% (sys.)
- The probability of producing a J/ψ in charged jet is systematically higher in data than in Pythia8 for the measured kinematics

Summary

Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV

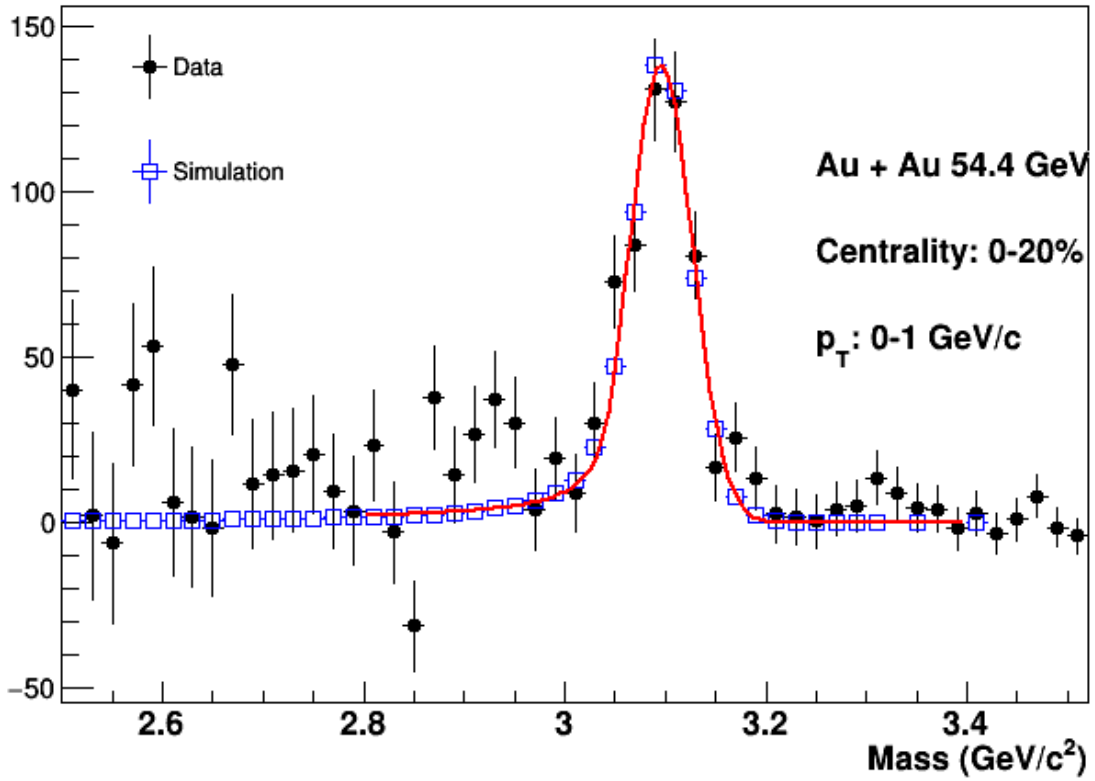
- Suppression of J/ψ at 54.4 GeV has been observed
- The suppression is more significant at lower $\mathrm{p_T}$ and central collisions
- No significant energy dependence of $\mathrm{R_{AA}}$ has been observed in central collisions from 17.2 to 200 GeV

p+p collisions at $\sqrt{s}$ = 500 GeV

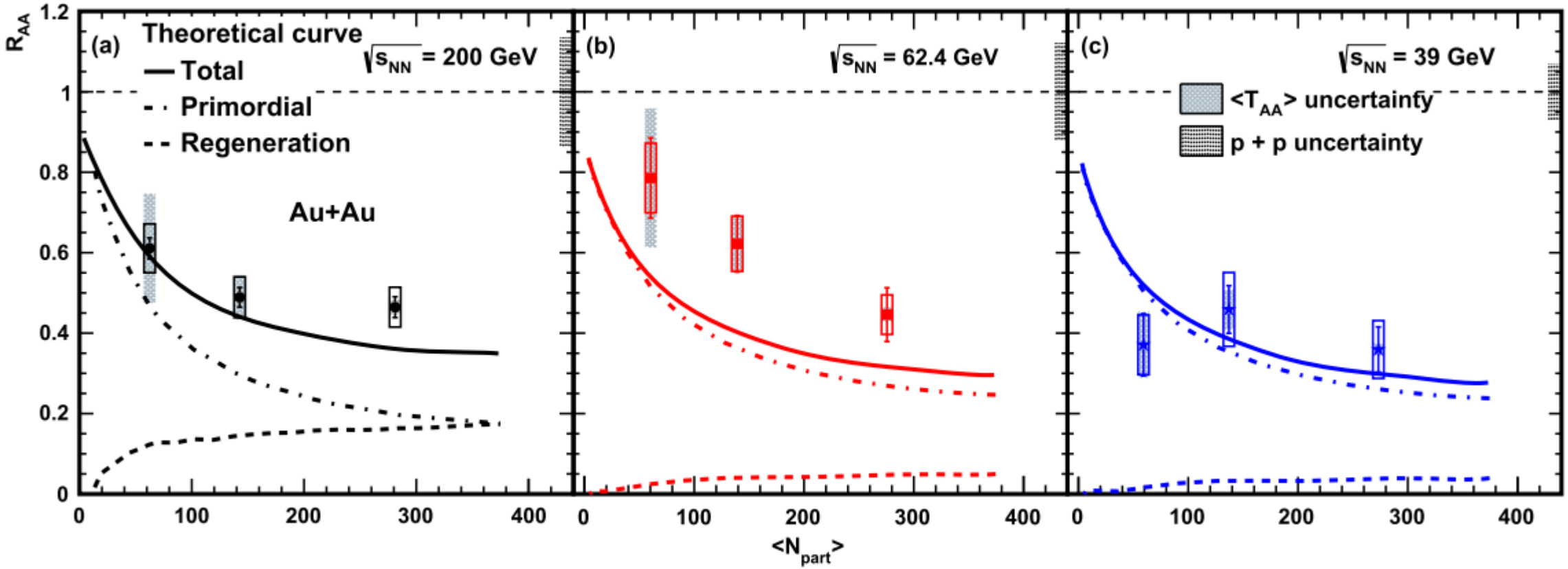
- First measurement of J/ψ production in charged jets at RHIC
- No significant z dependence of J/ψ production in jets is observed, for J/ψ $\mathrm{p_T} > 5$ GeV/c and jet $\mathrm{p_T} > 10$ GeV/c

Back up

J/ψ signal templates



- The J/ψ line-shape from embedding and additional momentum smearing matches data well
- The distribution is fitted by Crystal-ball function
- Fix the shape of the Crystal-ball function from simulation when fitting the J/ψ raw signal from real data



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P18ic; AuAu54_production_2017; St_physics

MB	Events
580001	201179346
580021	1132925521
580011	1040074

P10ik; AuAu62_production_2017; St_physics

MB	Events
270001	6158445
270021	126783290
270011	20692702