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

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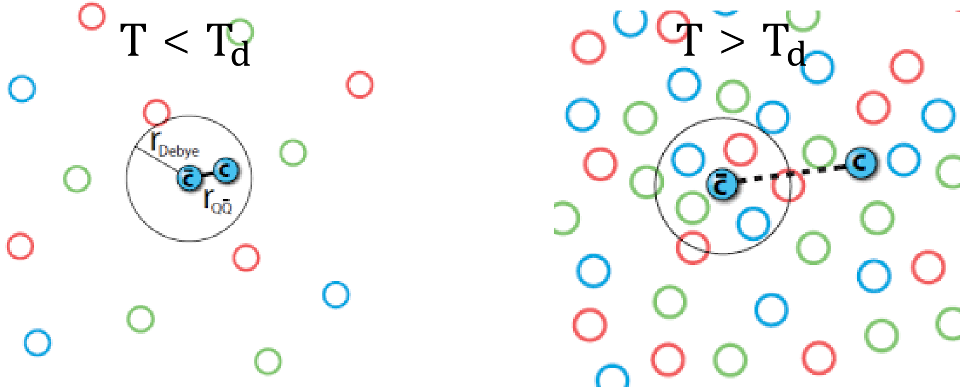
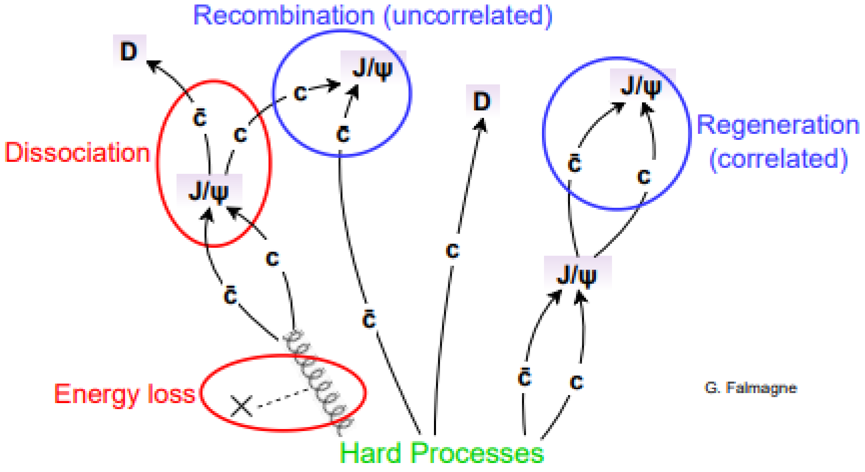
Outline

- Motivation
- J/ψ suppression in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 54.4$ GeV
  - J/ψ signal reconstruction
  - J/ψ cross section in p+p collisions at $\sqrt{s} = 54.4$ GeV
  - Nuclear modification factor distribution
- Summary

J/ψ production in heavy ion collisions

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



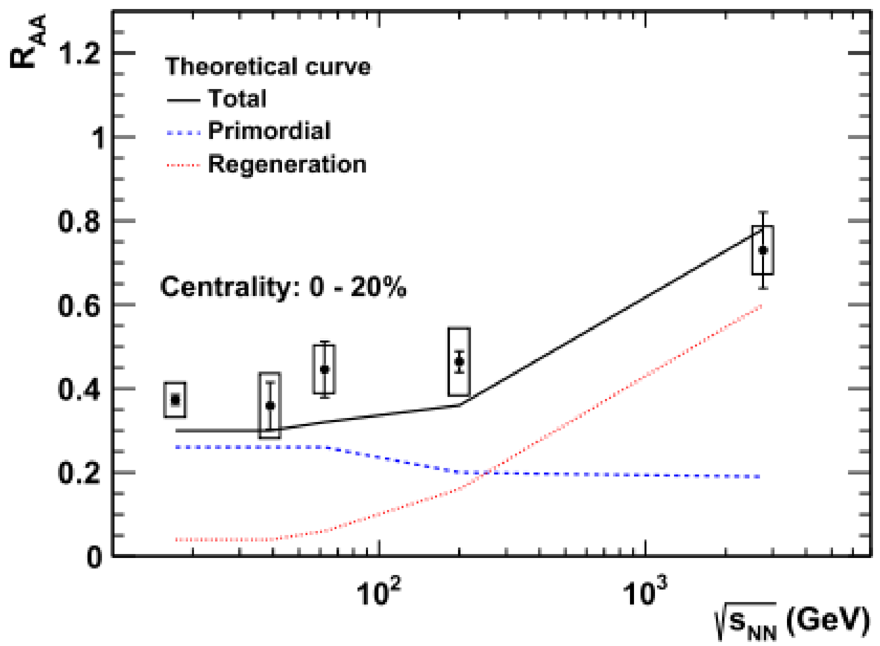


Guilaume Falmagne, SQM 2021

Modification of J/ψ yield:

- **Dissociation in QGP (like color screening effect, Dynamical screening)**
- **Regeneration**
- Cold nuclear matter effects (like nPDF, Cronin effect, Nuclear absorption)
- Other final state effects (co-mover effect)

J/ψ production in heavy ion collisions



(STAR Collaboration)
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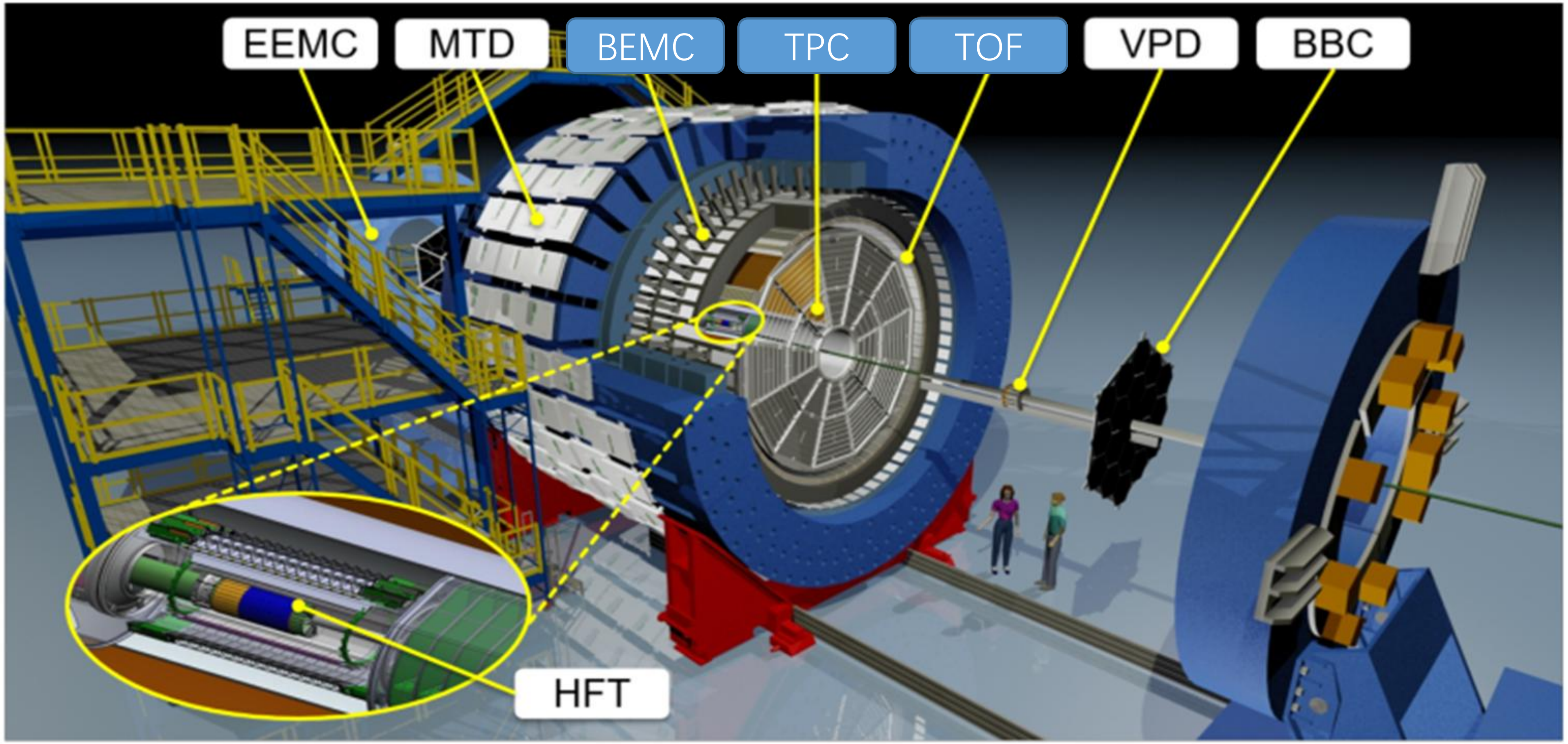
- The J/ψ production has been measured in Au+Au collisions at 39, 62.4 and 200 GeV and in Pb+Pb collisions at 17.3 GeV, 2.76 and 5.02 TeV

- No significant energy dependence of nuclear modification factor within uncertainties at $\sqrt{S_{\mathrm{NN}}} \leq 200\ GeV$

  - ➢ Interplay of melting in the QGP, cold nuclear matter effects and regeneration

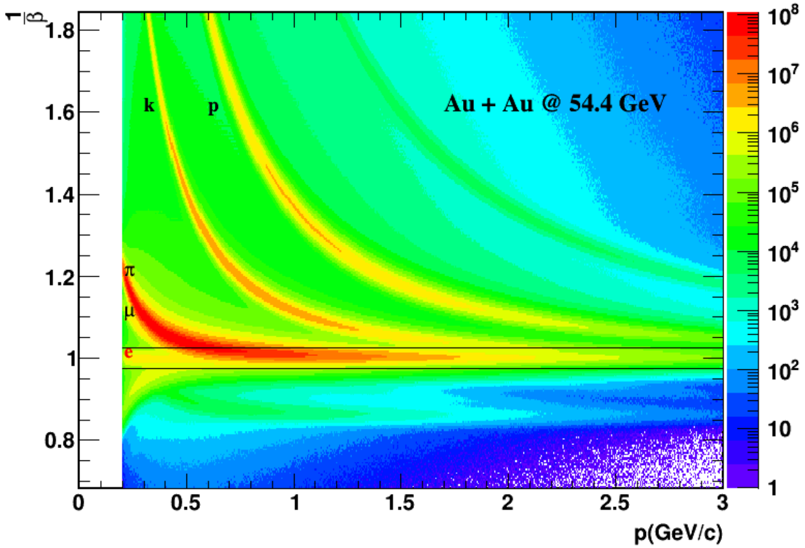
- ~10x more statistics in 54.4 GeV, and this will help better understand the energy dependence of J/ψ suppression, as well as the p_T distributions

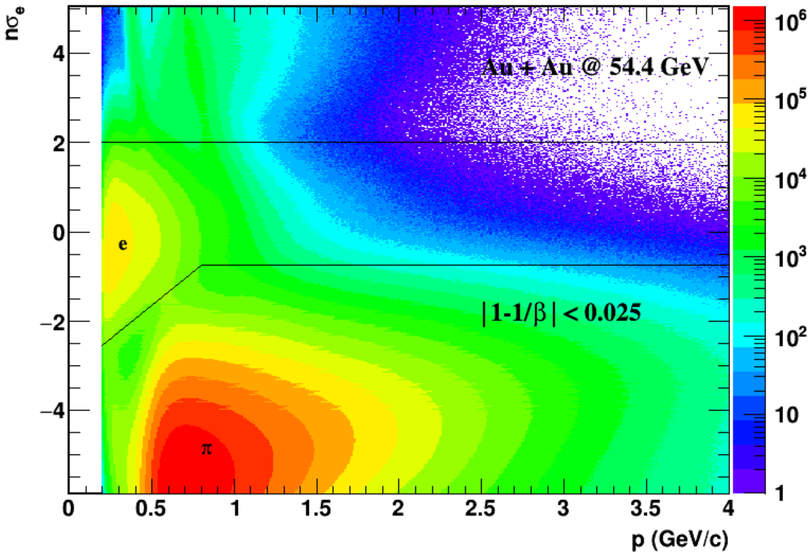
The Solenoidal Tracker At RHIC

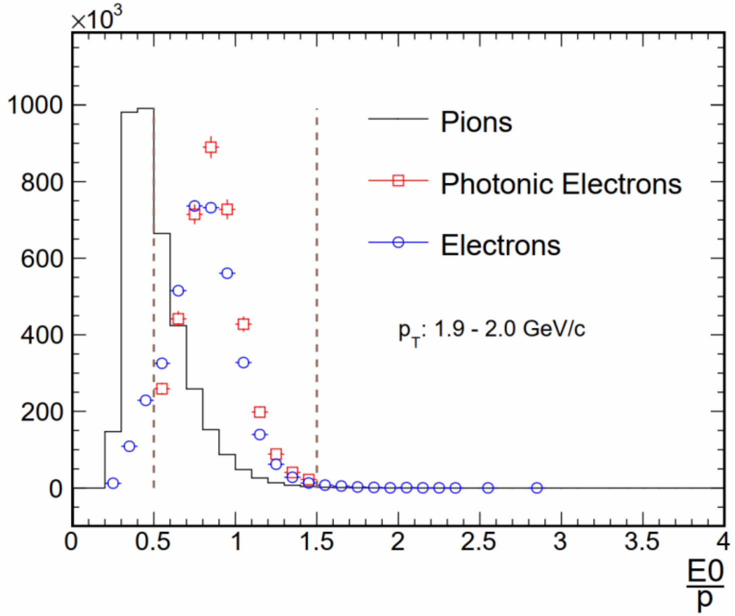


- ✓ TPC: Tracking and energy loss
- ✓ TOF: Time of flight, particle identification
- ✓ BEMC: Identification of high-p_T electrons
- ● Minimum-bias trigger (VPD or ZDC)

Electron identification







$p_T \le 1$ GeV/c

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

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

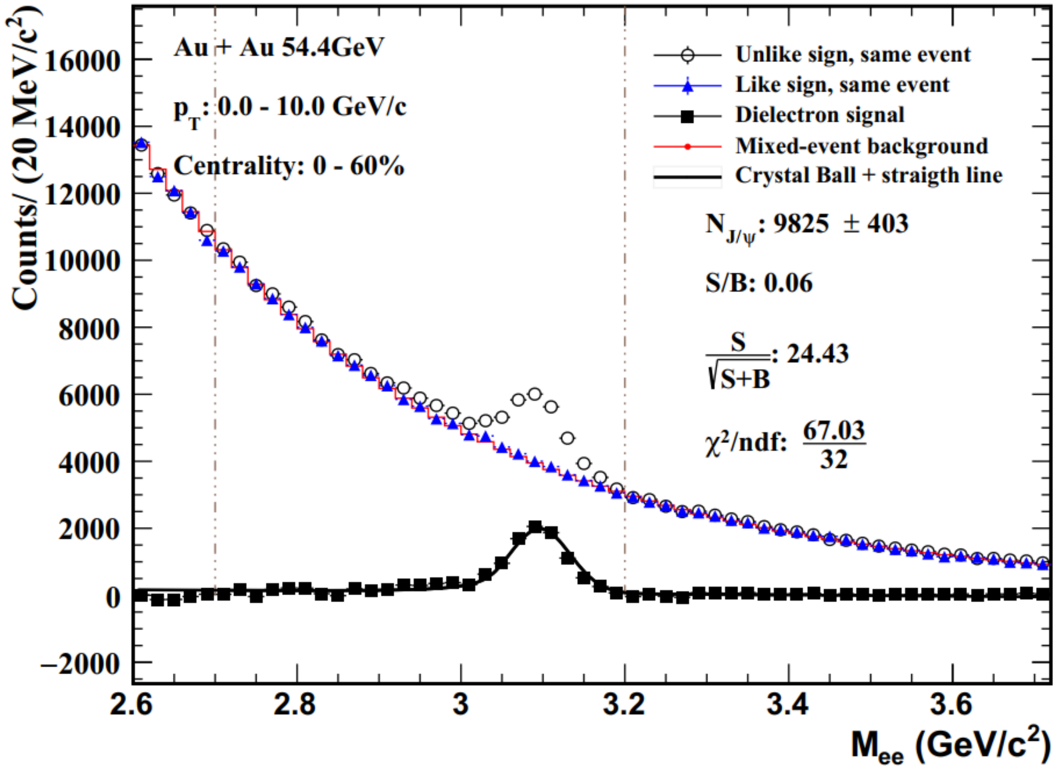
$p_T > 1$ GeV/c

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
- Not full BEMC information used at 54.4 and 200 GeV → Implementing full BEMC information can further improve the 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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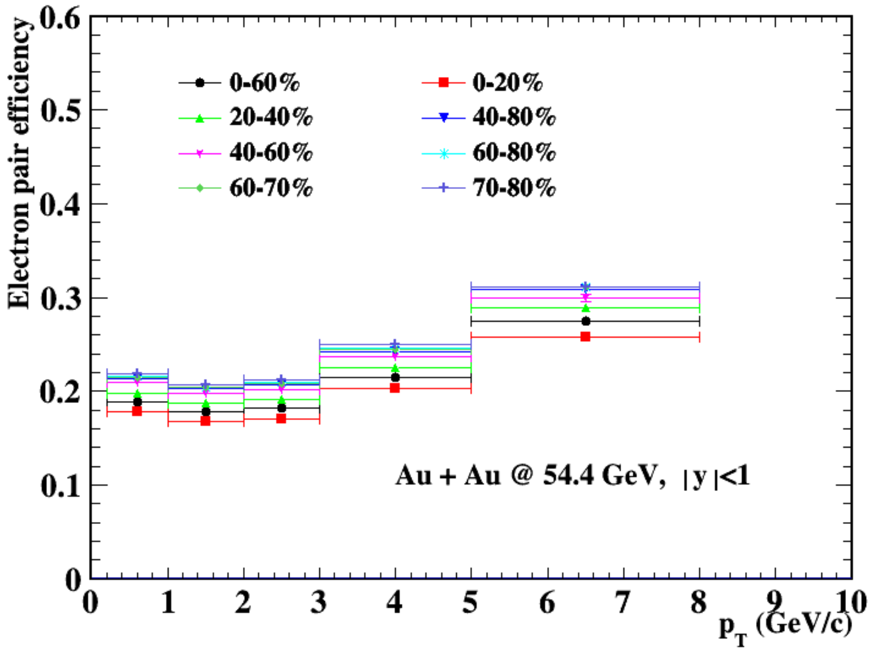
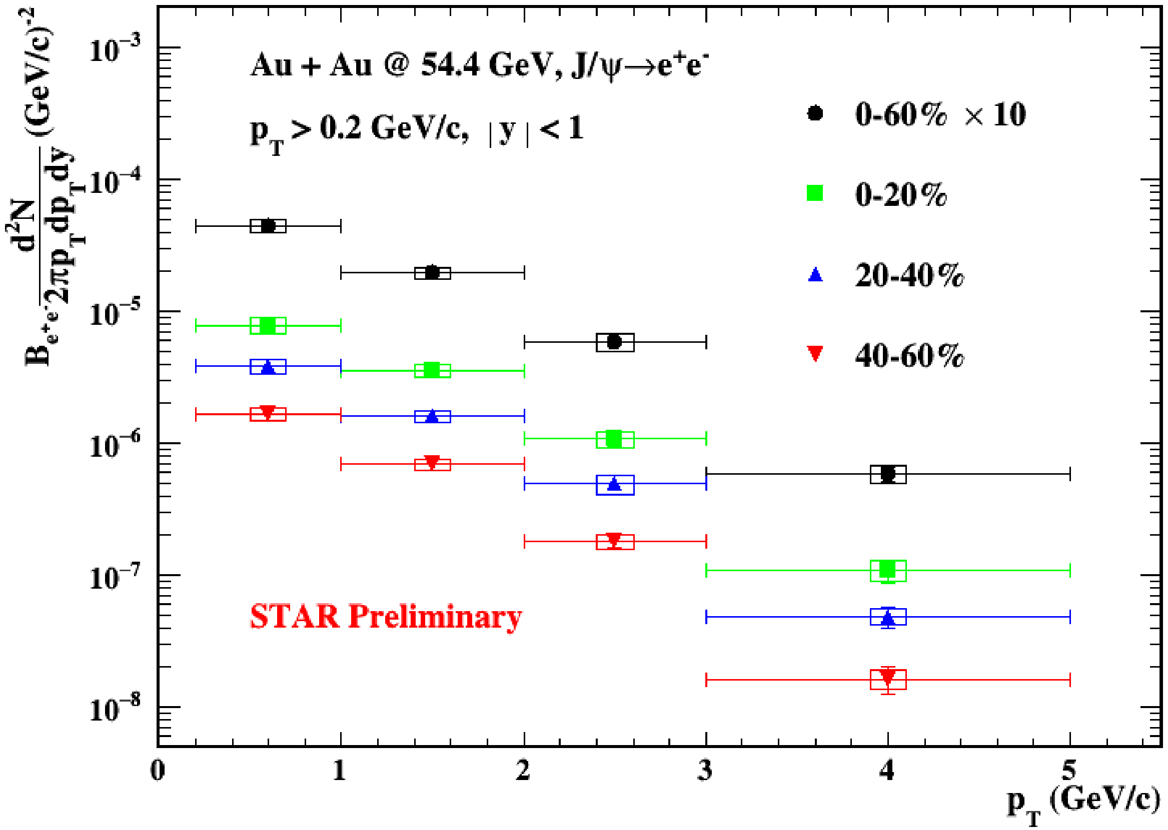
Efficiency and invariant yield

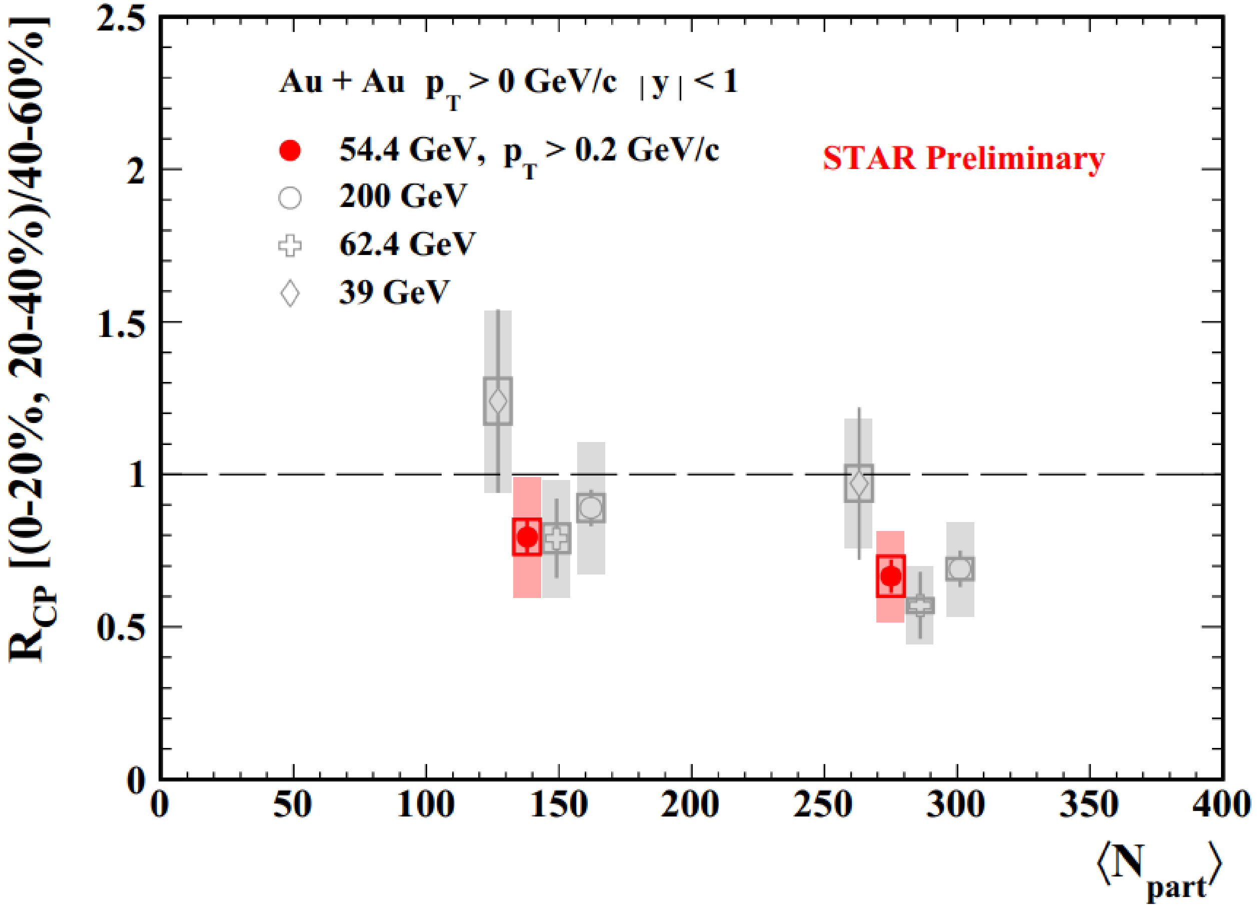
- The pair efficiency is evaluated by folding the single track efficiency
- The acceptance is showed below: $p_T^e \geq 0.2$ GeV/c, $|\eta_e| \leq 1$, $|y_{ee}| \leq 1$





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

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



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

STAR Collaboration, Phys. Lett. B 771 (2017) 13-20

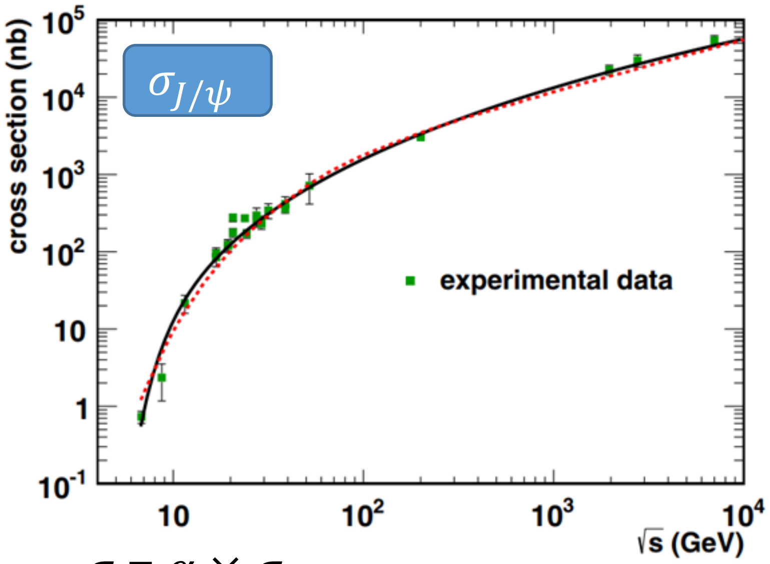
- Peripheral 40 – 60 % centrality is used as reference
- A suppression is observed in central Au+Au collisions at 54.4 GeV, similar to that at 62.4 and 200 GeV

p+p baseline

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

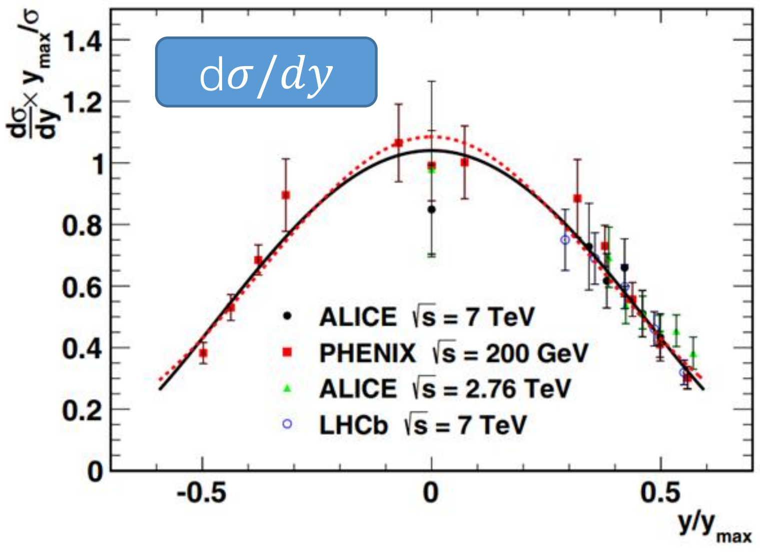
- Energy interpolation from the existing total J/ψ cross section measurements
- Energy evolution of the rapidity distribution
- Energy evolution of J/ψ transverse momentum distribution

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

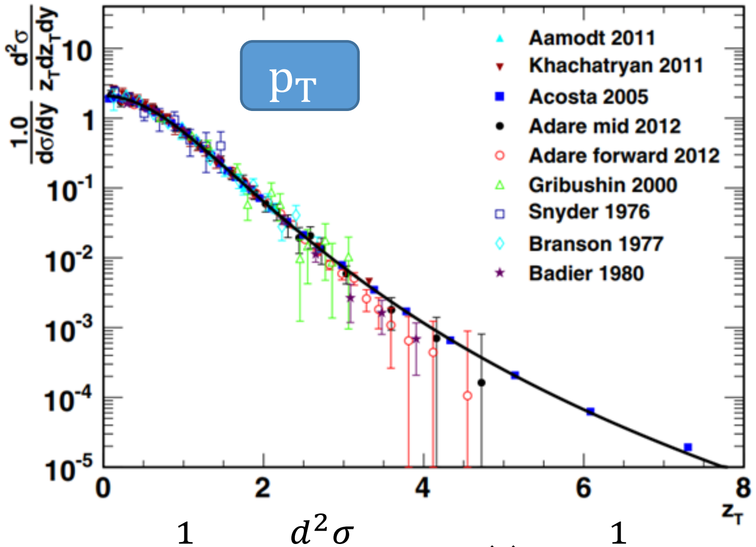


$\sigma = \alpha \times \sigma_{CEM}$

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



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

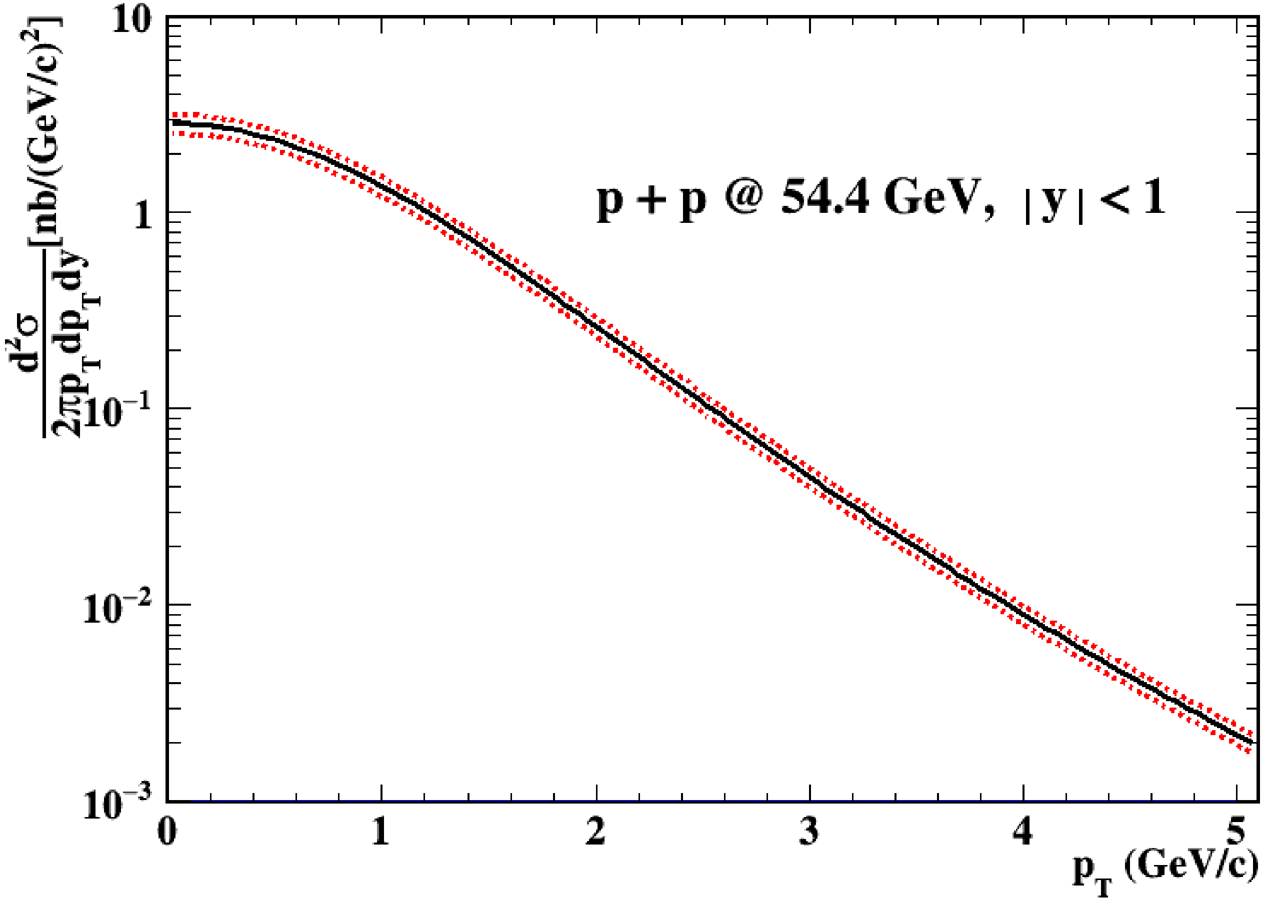


$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

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

p+p baseline at $\sqrt{s}$ = 54.4 GeV

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

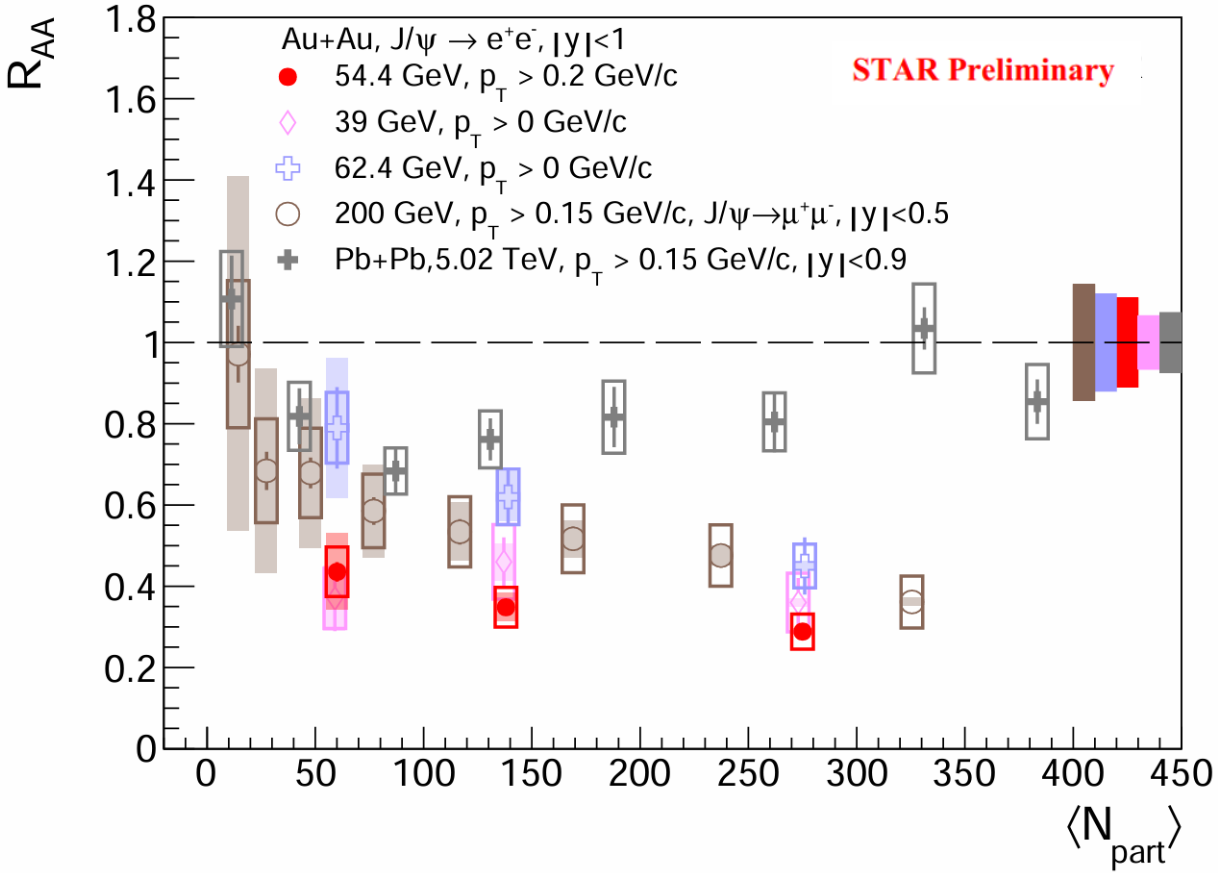


- The p_T dependence of expected J/ψ differential cross section in p+p collisions at $\sqrt{s}$ = 54.4 GeV and midrapidity

- The uncertainty from interpolation: ~ 11 %

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

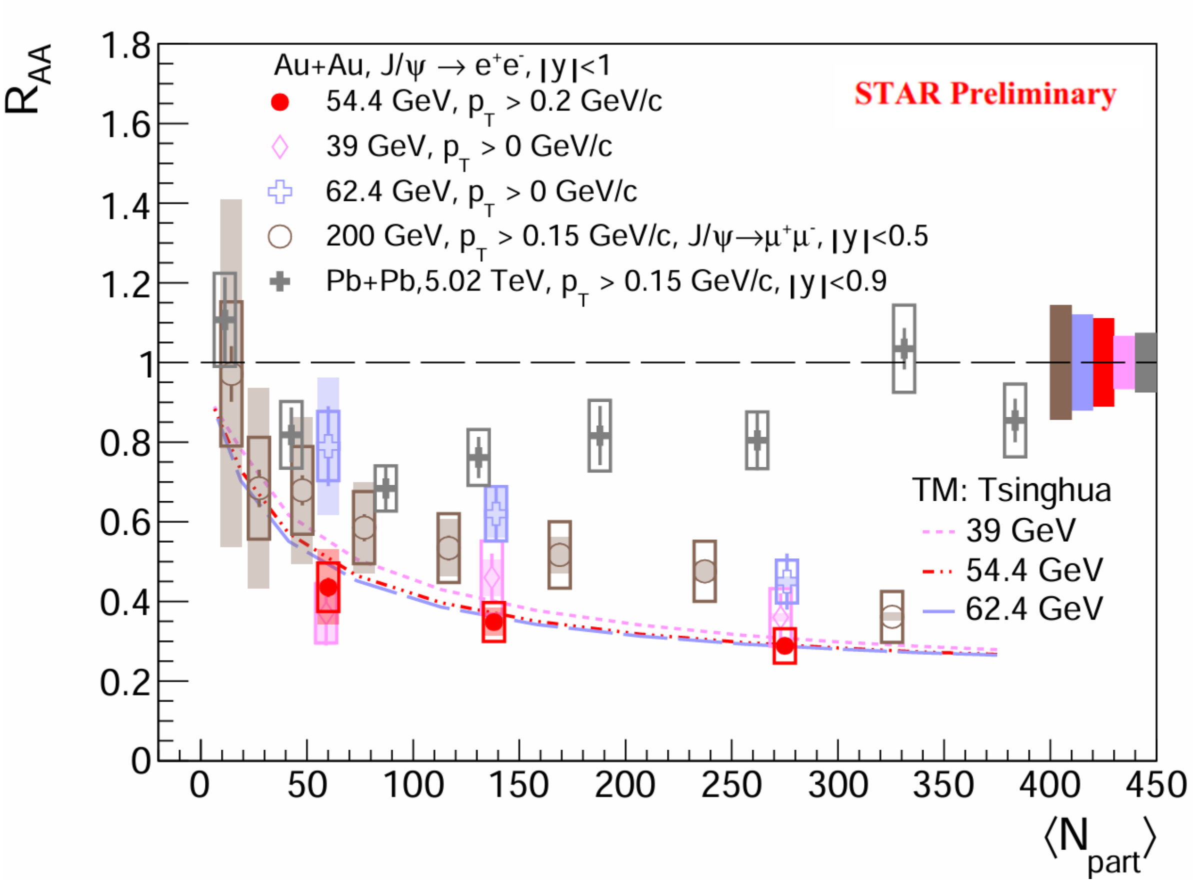
R_{AA} vs $\langle N_{part} \rangle$



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

- 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 $\langle N_{part} \rangle$
- Less regeneration contribution at RHIC energies

R_{AA} vs $\langle N_{part} \rangle$: compared with transport model calculations



Transport model

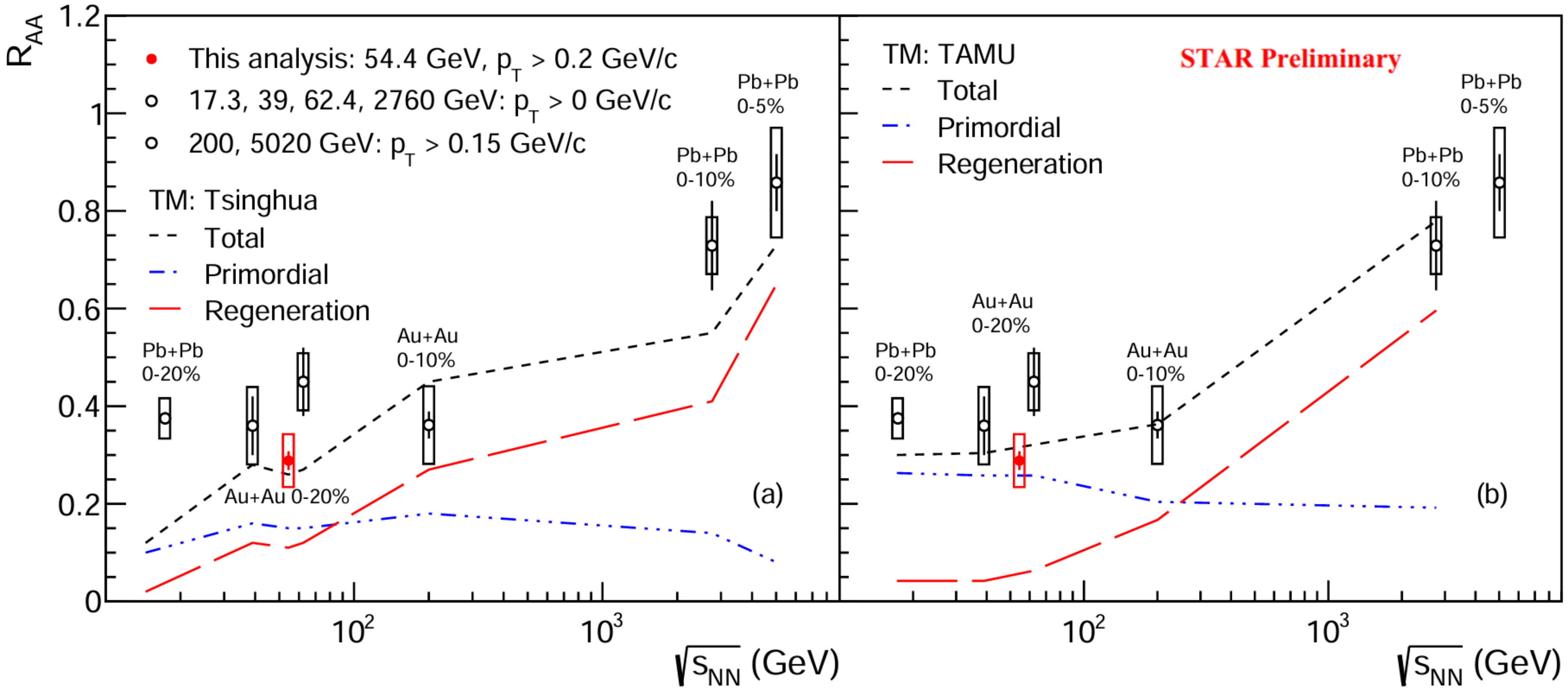
Primordial suppression, including dissociation in the hot medium and cold nuclear matter effects

Regeneration effects, the rate is proportional to the square of charm quark number, hence $\propto N_{coll}^2$

J. Zhao, S. Shi, Eur.Phys.J.C 83 (2023) 6, 511 (private communication).

- Within current uncertainties, the model calculations (Tsinghua) can described the p_T integrated R_{AA} at 39, 54.4, and 62.4, as a function of $\langle N_{part} \rangle$

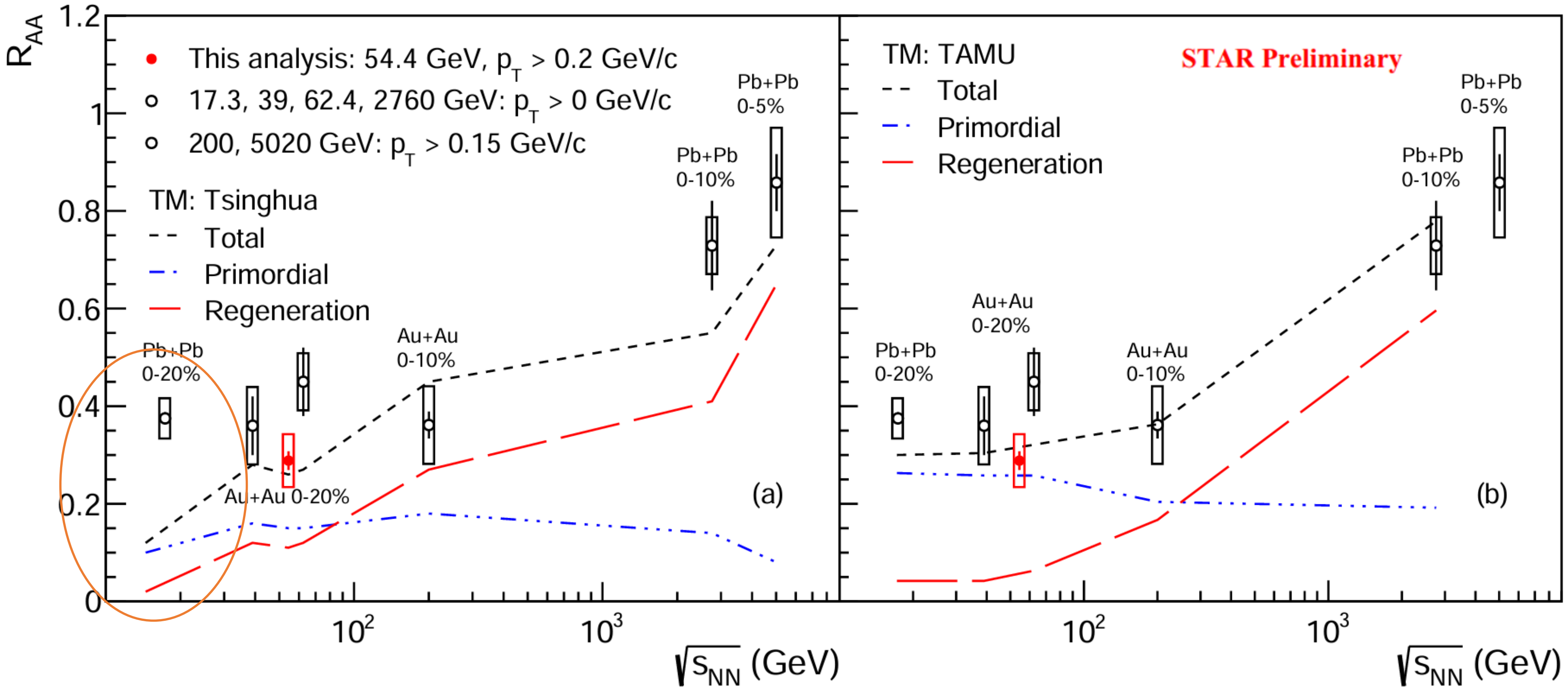
R_{AA} vs $\sqrt{s_{NN}}$



J. Zhao, S. Shi, Eur.Phys.J.C 83 (2023) 6, 511 (private communication).
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.

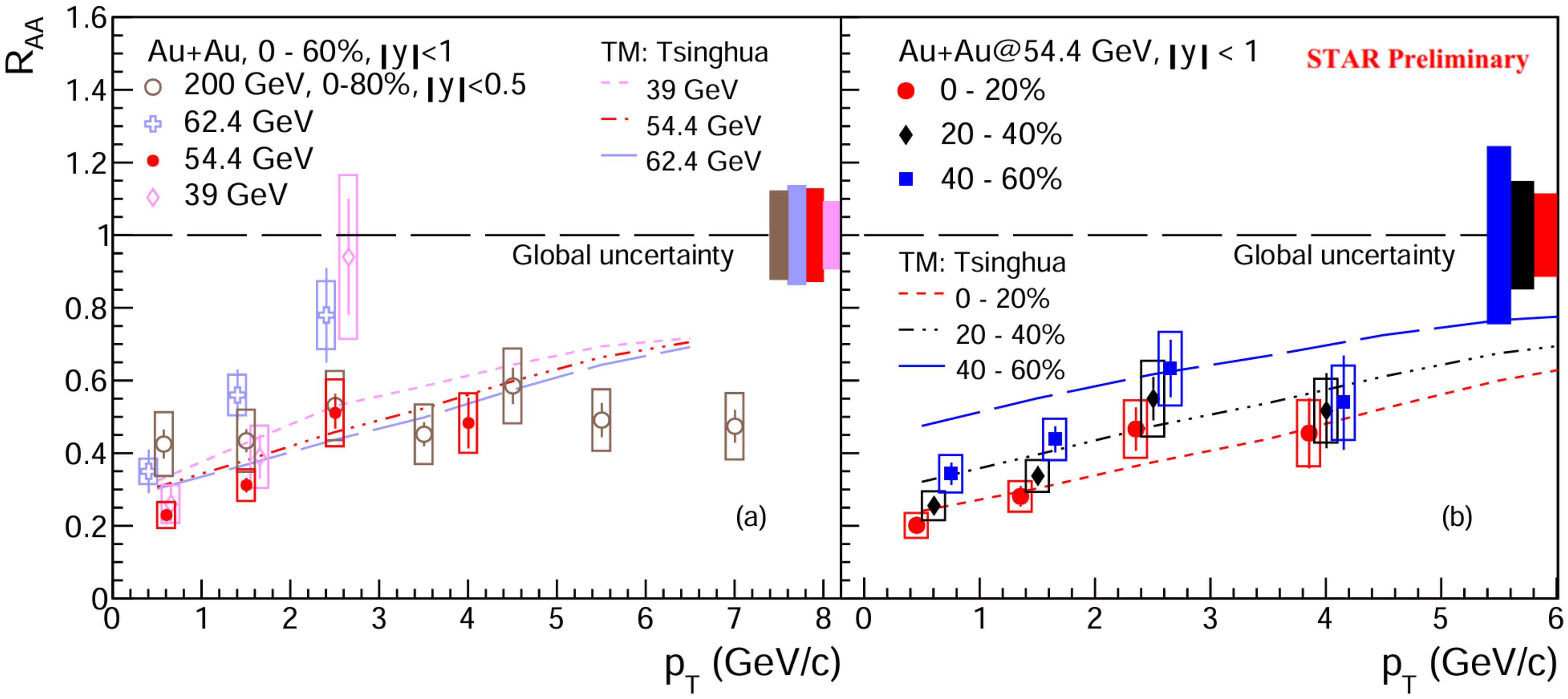
- No significant energy dependence is observed within uncertainties up to 200 GeV, interplay of hot and cold matter effects
- Model calculations are both consistent with the observed energy trend

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



- BES-2 energy regions are crucial for refining our understanding (Wei Zhang, Tuesday, last but not the least)

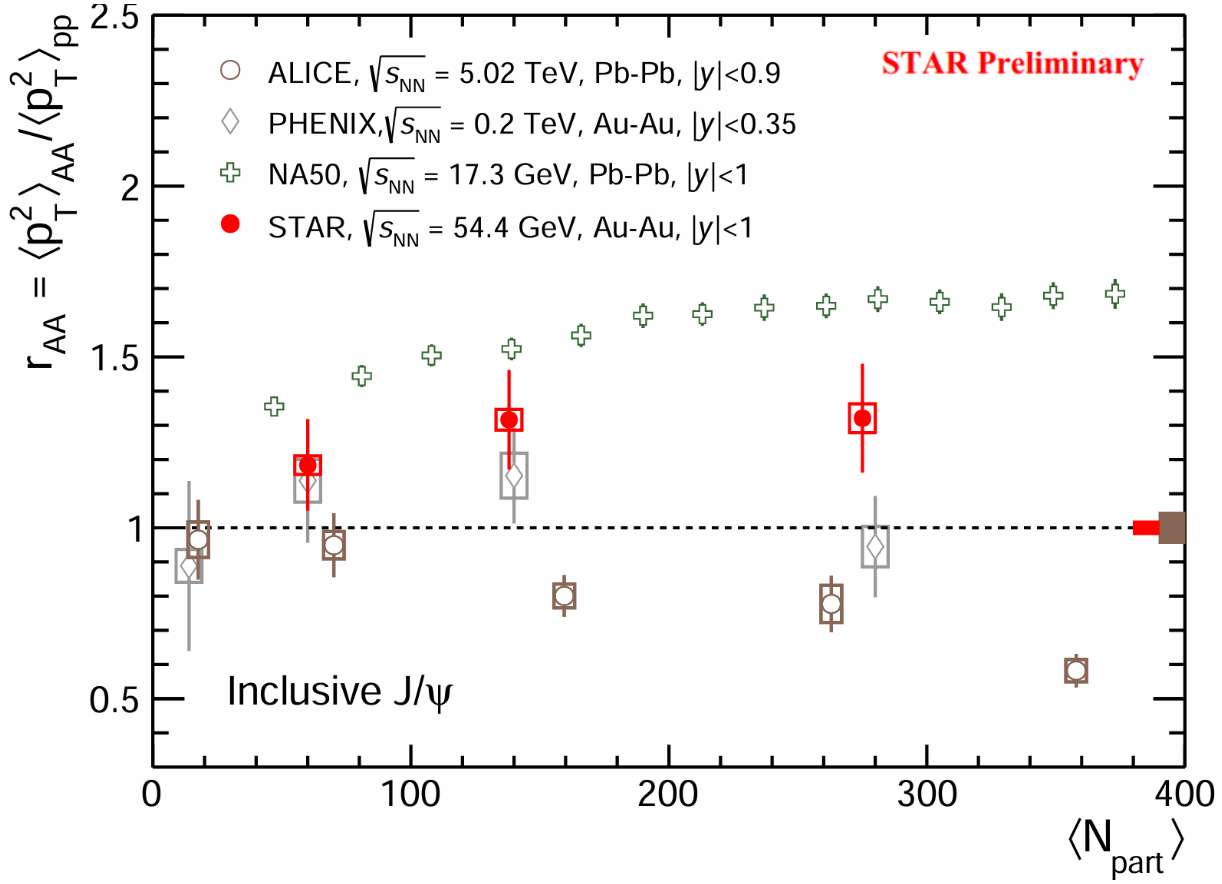
R_{AA} vs p_T



J. Zhao, S. Shi, Eur.Phys.J.C 83 (2023) 6, 511 (private communication).

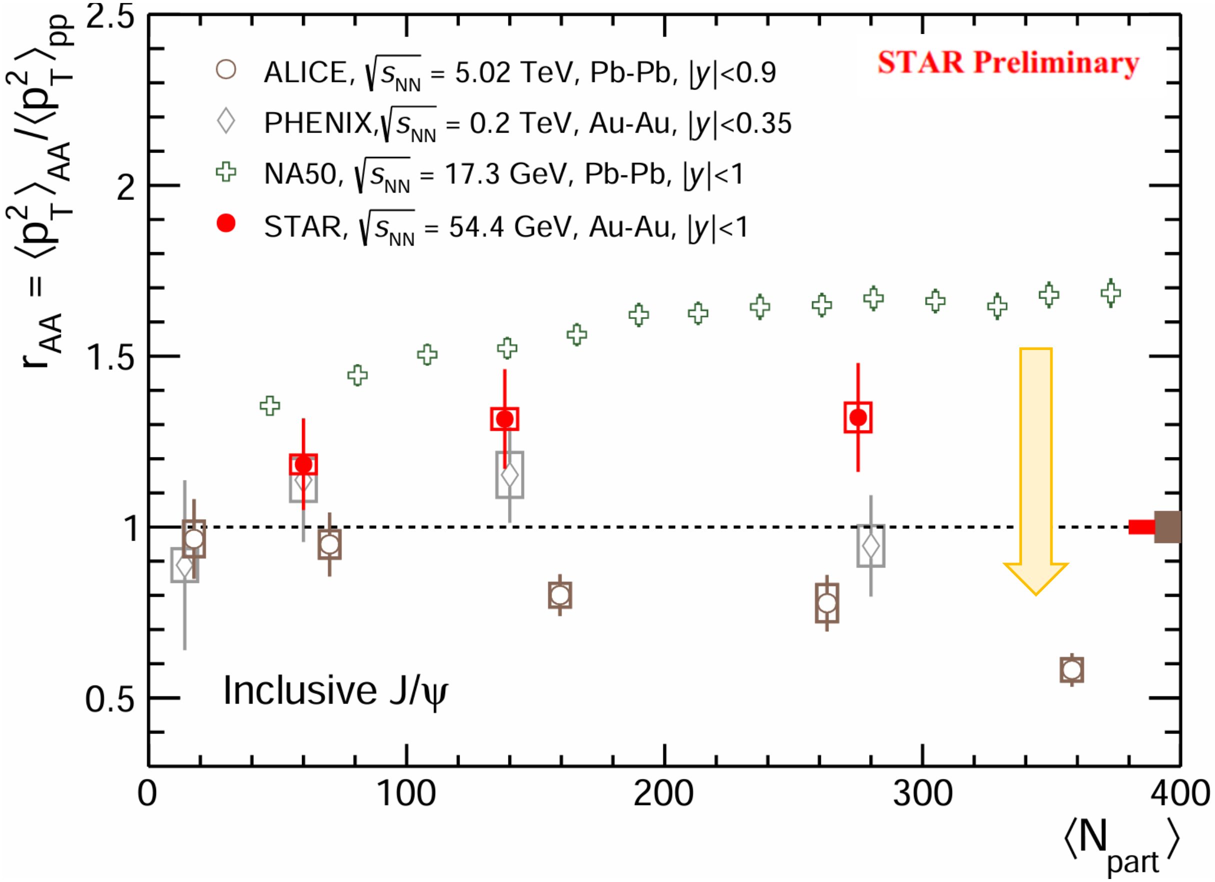
- R_{AA} seems increase with increasing p_T for 39, 54.4 and 62.4 GeV, less regeneration contributions than those at higher energies
- The p_T spectra at low energies is more complicated

r_{AA} vs N_{part}



- Each hot or cold effect is expected to be more pronounced within specific p_T ranges
- To compare the impact of the p_T distribution in heavy ion collisions at different energies, the r_{AA} is measured at 54.4 GeV
- There is no significant centrality dependence of the r_{AA} at 54.4 GeV

r_{AA} vs N_{part}



- To compare the impact of the p_T distribution in heavy ion collisions at different energies, the r_{AA} is measured at 54.4 GeV
- There is no significant centrality dependence of the r_{AA} at 54.4 GeV
- The r_{AA} at 54.4 GeV follows the energy dependence trend

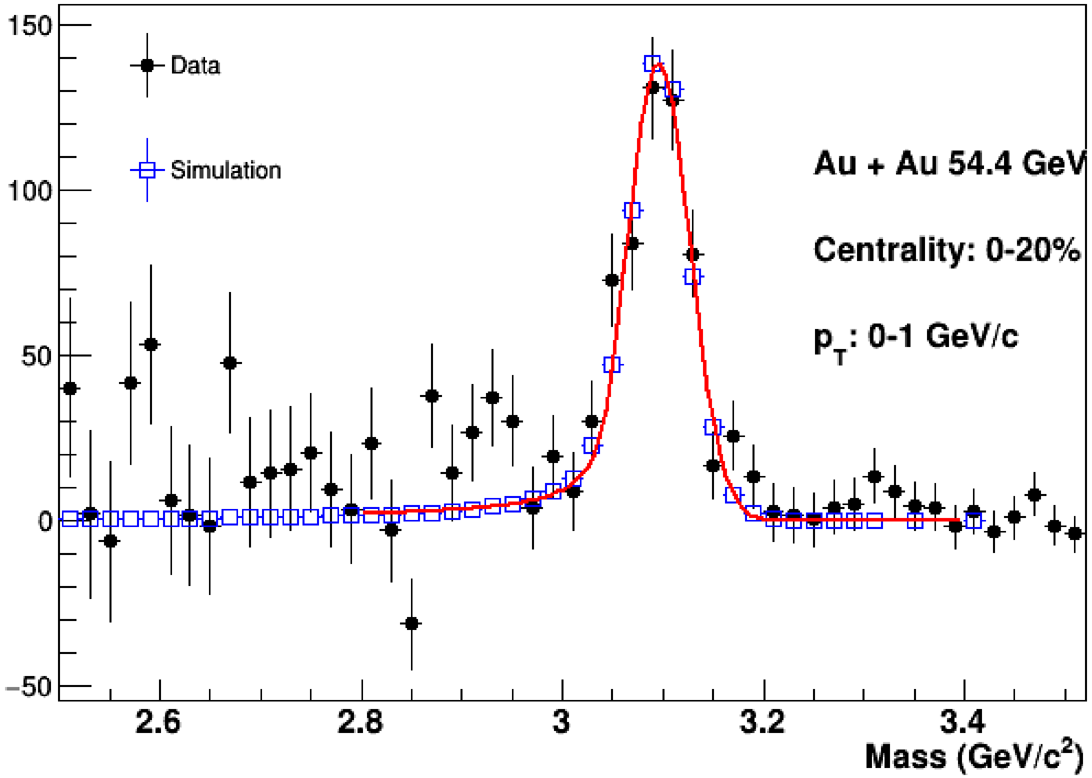
Summary

- Suppression of J/ψ in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV has been observed, with improved precision compare to the previous STAR results
- The suppression is more significant at lower p_T and central collisions
- No significant energy dependence of R_{AA} has been observed in central collisions from 17.3 to 200 GeV
- The r_{AA} at 54.4 GeV follows the energy trends

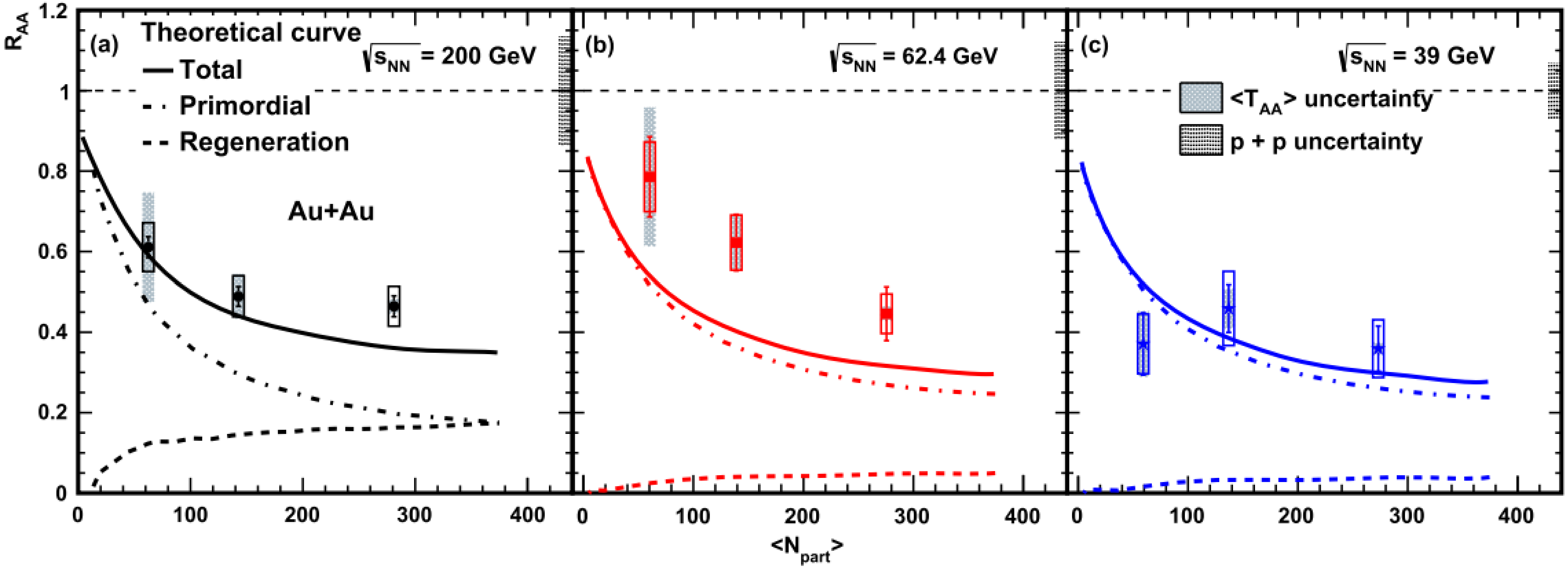
Thanks for your attention

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



(STAR Collaboration)
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P18ic; AuAu54_production_2017; St_physics

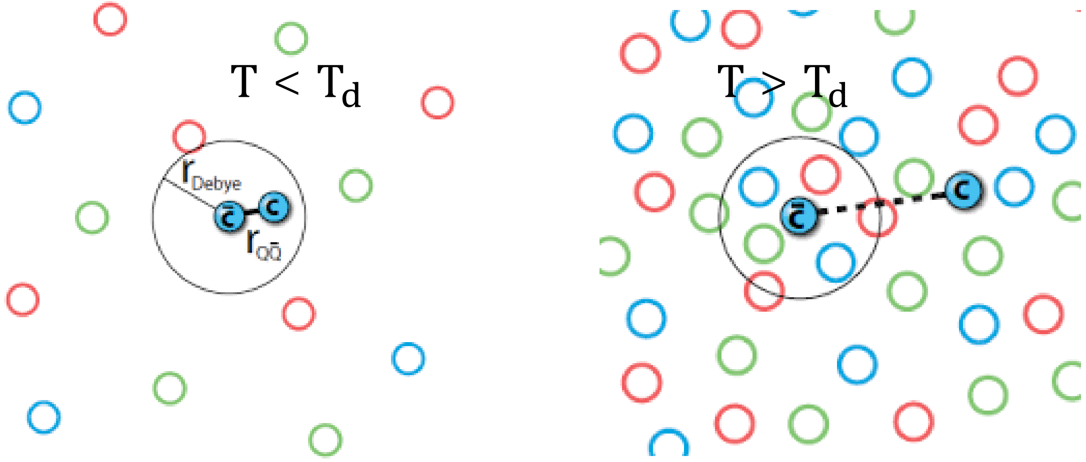
MB	Events
580001	201179346
580021	1132925521
580011	1040074

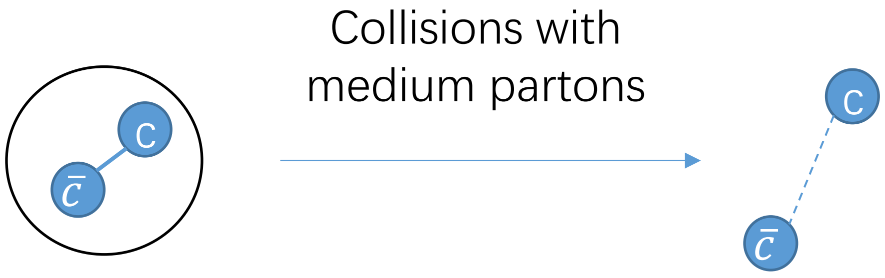
P10ik; AuAu62_production_2017; St_physics

MB	Events
270001	6158445
270021	126783290
270011	20692702

J/ψ production in heavy ion collisions

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





Modification of J/ψ yield

- **Dissociation in QGP**
- **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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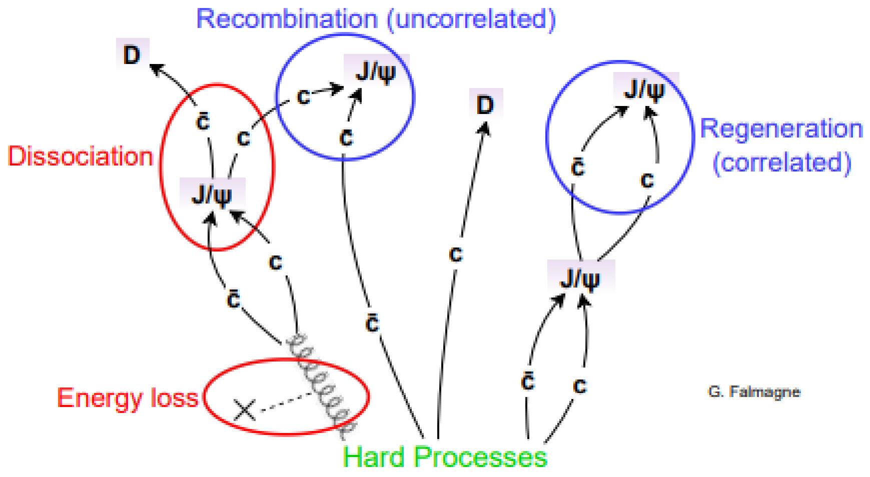

Guilaume Falmagne, SQM 2021

Modification of J/ψ yield:

- **Dissociation in QGP**
  - Color screening effect: suppression of color attraction
  - Dynamical processes: collisions with medium partons
- **Regeneration**
- Cold nuclear matter effects (like nPDF, coherent energy loss, nuclear absorption)
- Other final state effects