QCD与夸克物质物理研讨会

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Coherent Photoproduction in Heavy-Ion Collisions

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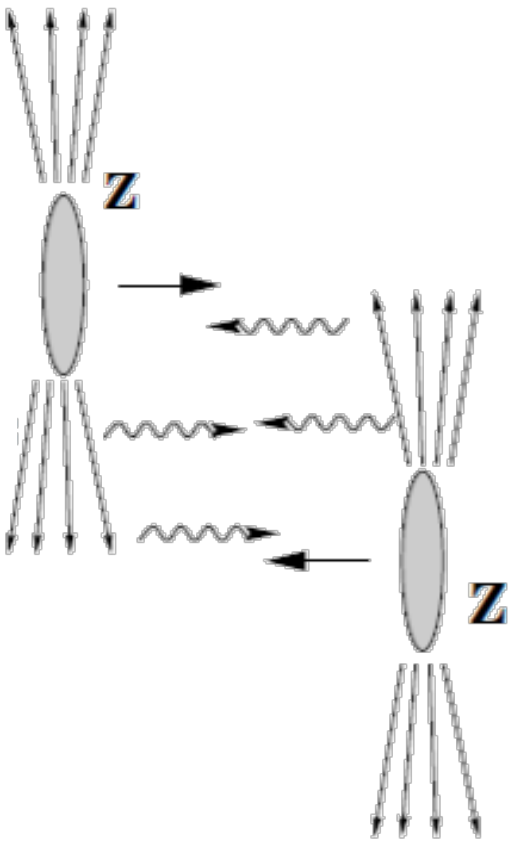
Electromagnetic Field in Heavy-Ion Collisions

- Strong EM field accompanies the nuclei in relativistic heavy-ion collisions

$$B \sim \gamma Zeb/R^3 \sim O(10^{18}\ Gauss)\ @\text{RHIC}$$

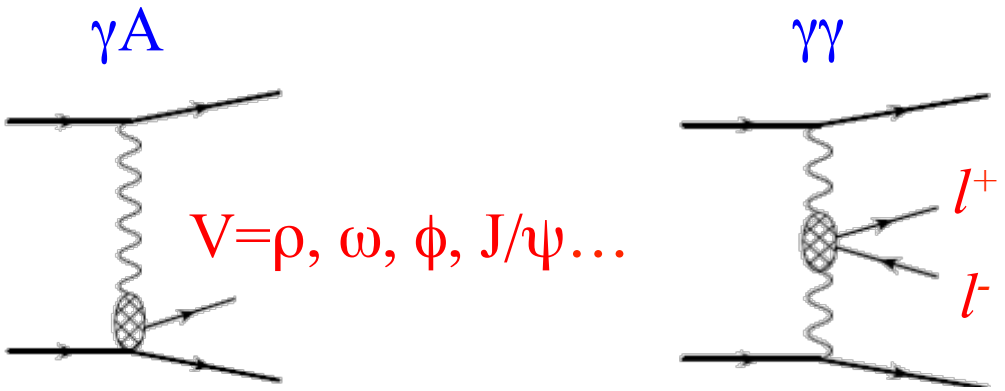
- The Lorentz contracted EM field can be expressed in terms of equivalent photon flux *E. Fermi, Z. Phys. 29, 315 (1924)*

$$k_T <\sim 1/R \sim 0.03\ GeV\ @\text{RHIC/LHC}$$
$$k_0 <\sim \gamma/R \sim \quad 3 \quad GeV\ @\text{RHIC}$$
$$\quad\quad\quad\quad\quad\quad 80 \quad GeV\ @\text{LHC}$$
$$n(\vec{k}, \vec{x}_T) \propto Z^2 \alpha_{em}$$



- The quasi-real photons can initiate γA or γγ collisions in relativistic heavy-ion collisions

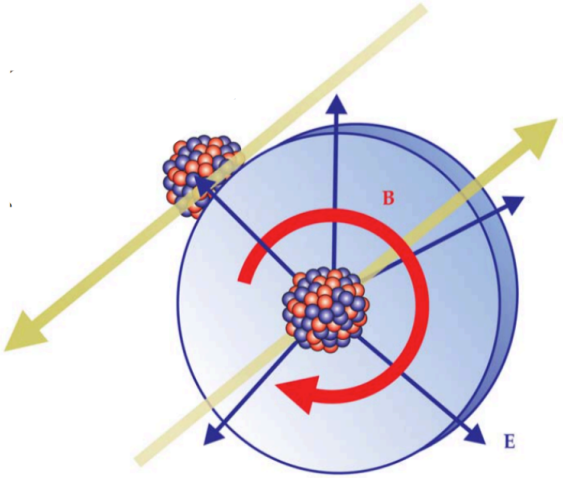
Coherent Photoproduction



Traditionally studied in Ultra-Peripheral Collisions (UPC, $b > R_A+R_B$)

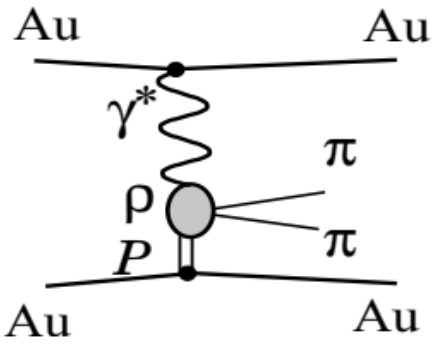
$\langle R_\rho \rangle \sim 40$ fm in Au+Au @ 200 GeV

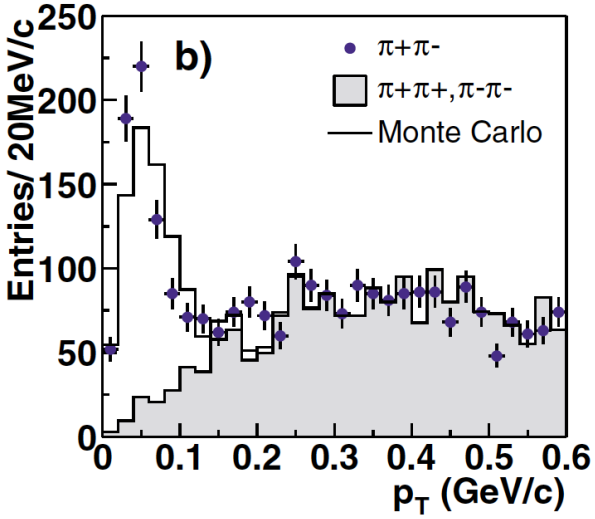
No hadronic interaction

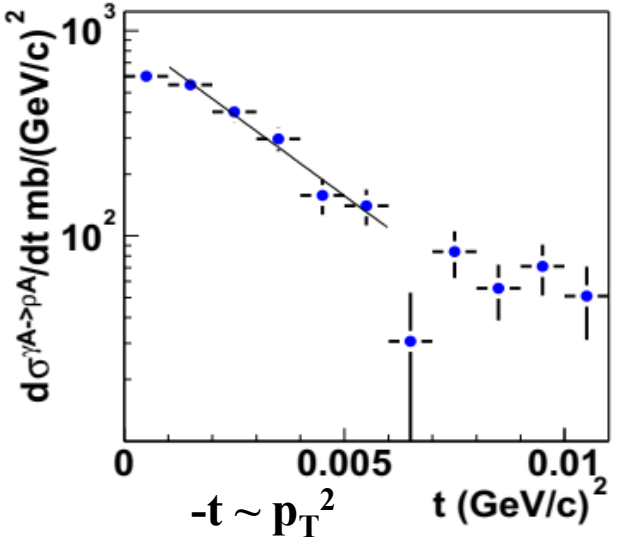


Physics Today **70**, 10, 40 (2017)

Vector Meson Photoproduction



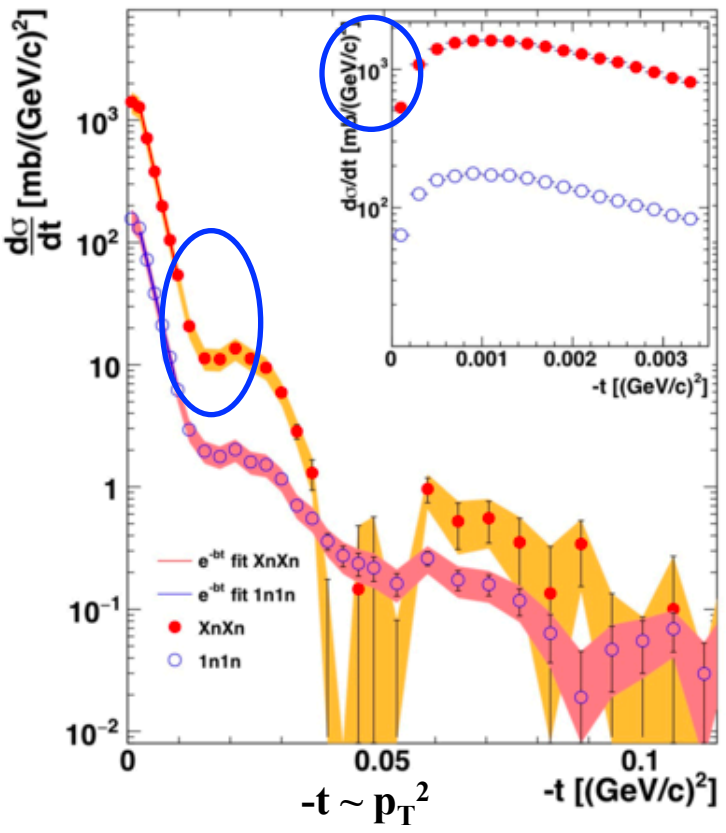




STAR, PRL89, 272302 (2002)

- Colorless "Pomeron" exchange
- Dominantly produced at very-low p_T (p_T<~ 0.1 GeV/c)
- *t* slope reflects nucleus form factor (radius)

Vector Meson Photoproduction

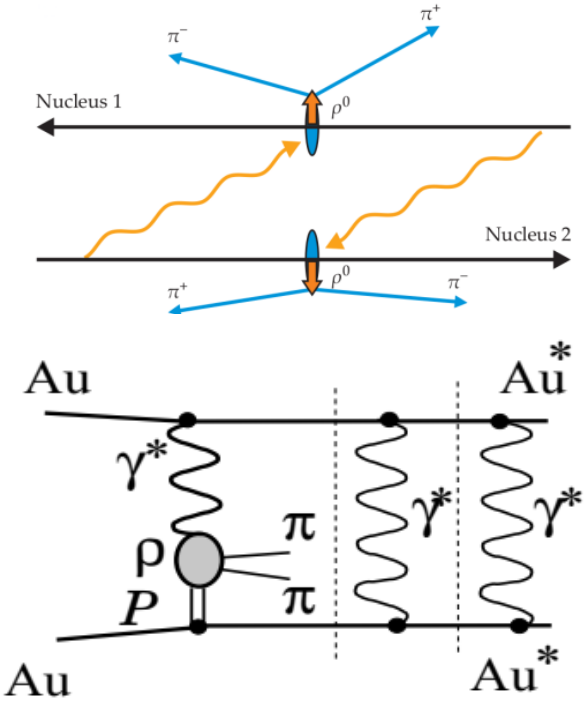


STAR, PRC96, 054904 (2017)

t distribution tells more

- Diffraction
- Destructive interference

  Even w/ nucleus breakup



Photon-photon Interaction in UPC

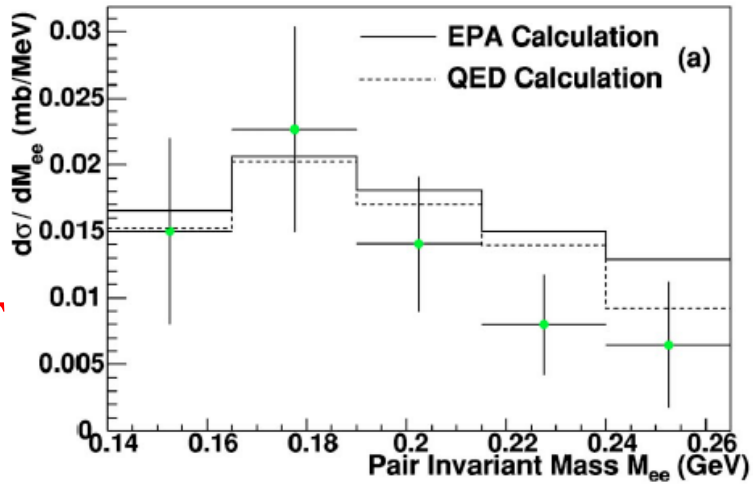
- Dilepton production measured by STAR

  Mass range limited by electron ID

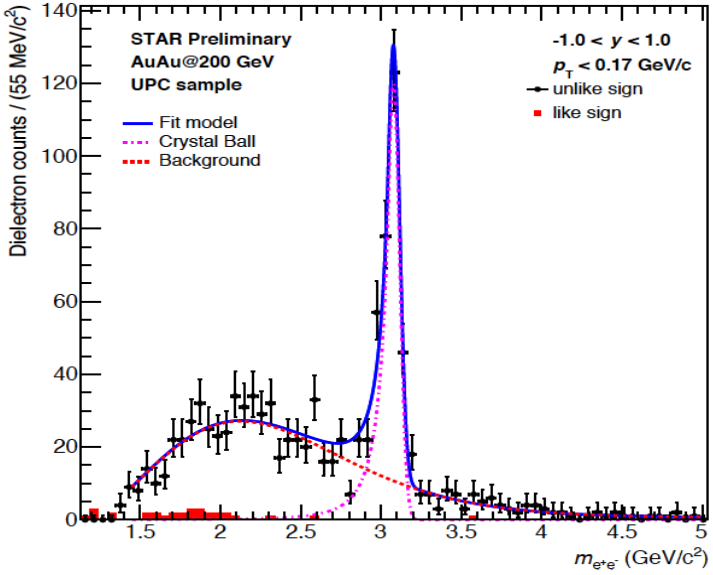
  Being (sig.ly) improved by EMC/TOF

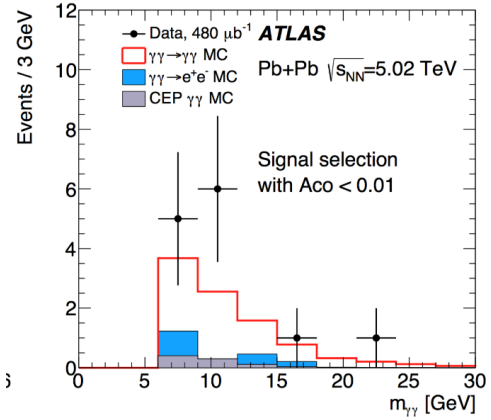
- Meson production also possible

- γγ production observed by ATLAS



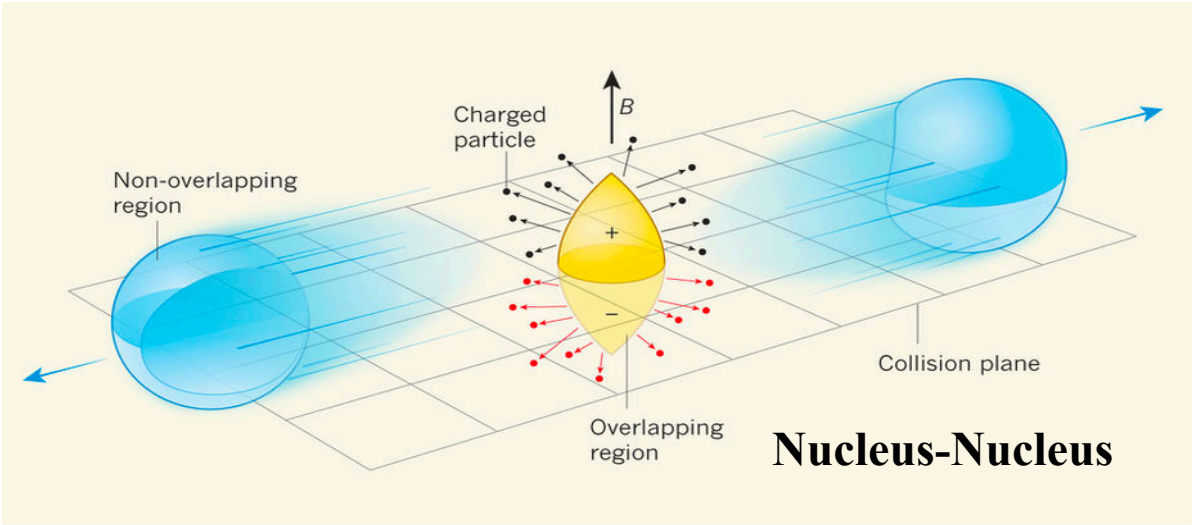
STAR, PRC70, 031902 (2004)

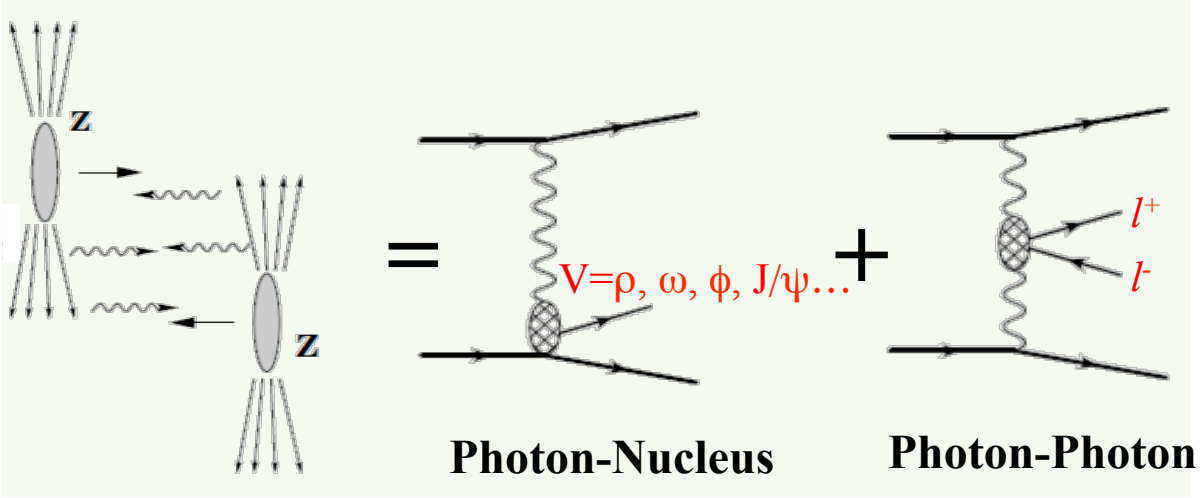




Nature Phys. 13, 852 (2017)

Coherent Photoproducts in QGP





Novel probe of QGP:

- J/ψ: Deconfinement
- e^+e^-: EM field
- …

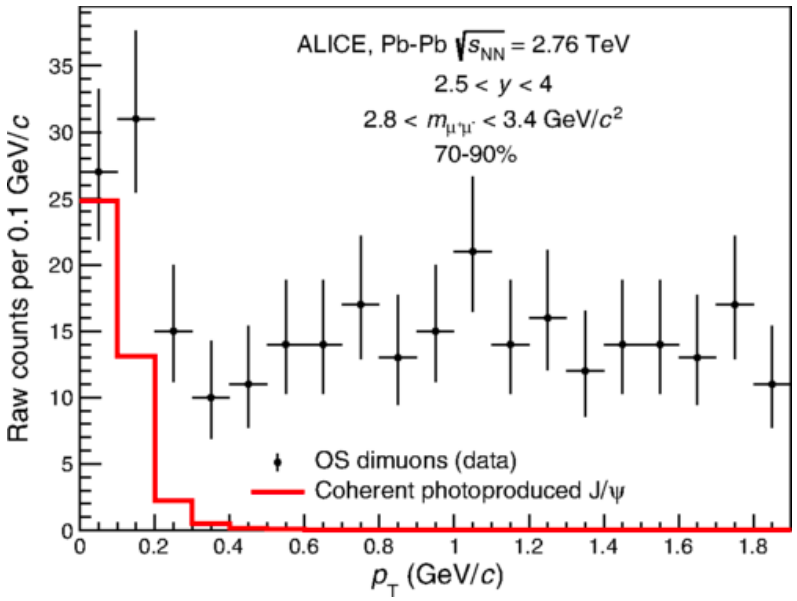
EM+QGP:

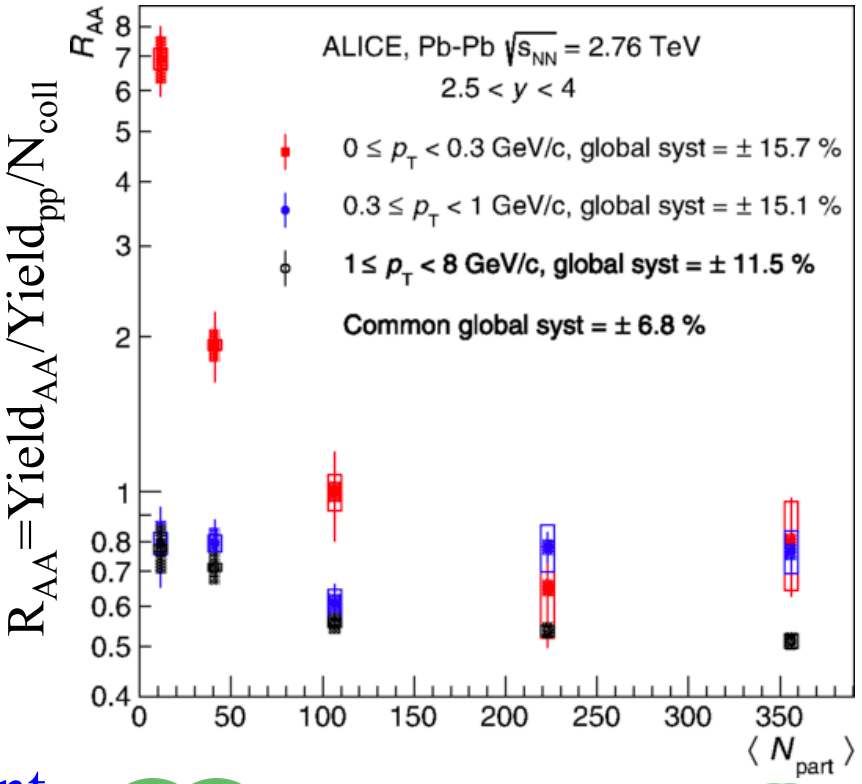
Chiral Magnetic Effect

…

Very-low-p_T J/ψ Enhancement at ALICE

ALICE, PRL116, 222301 (2016)

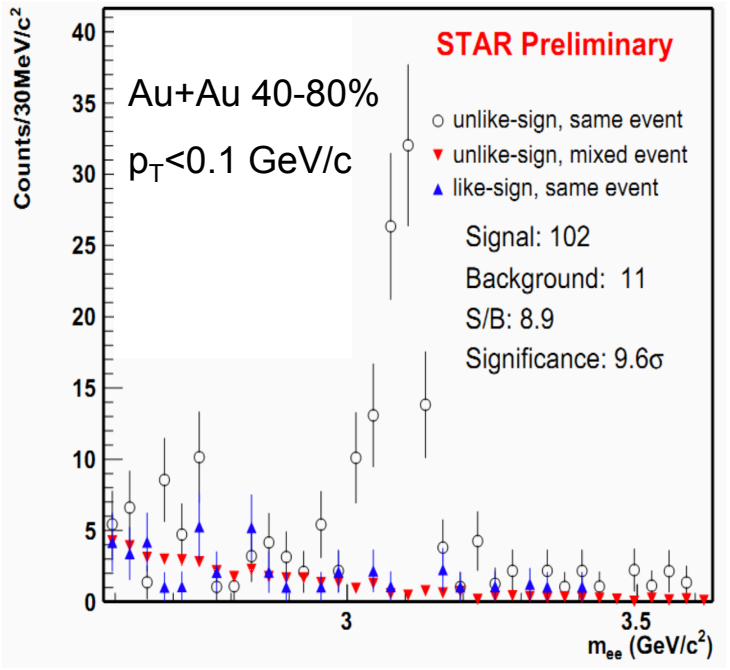


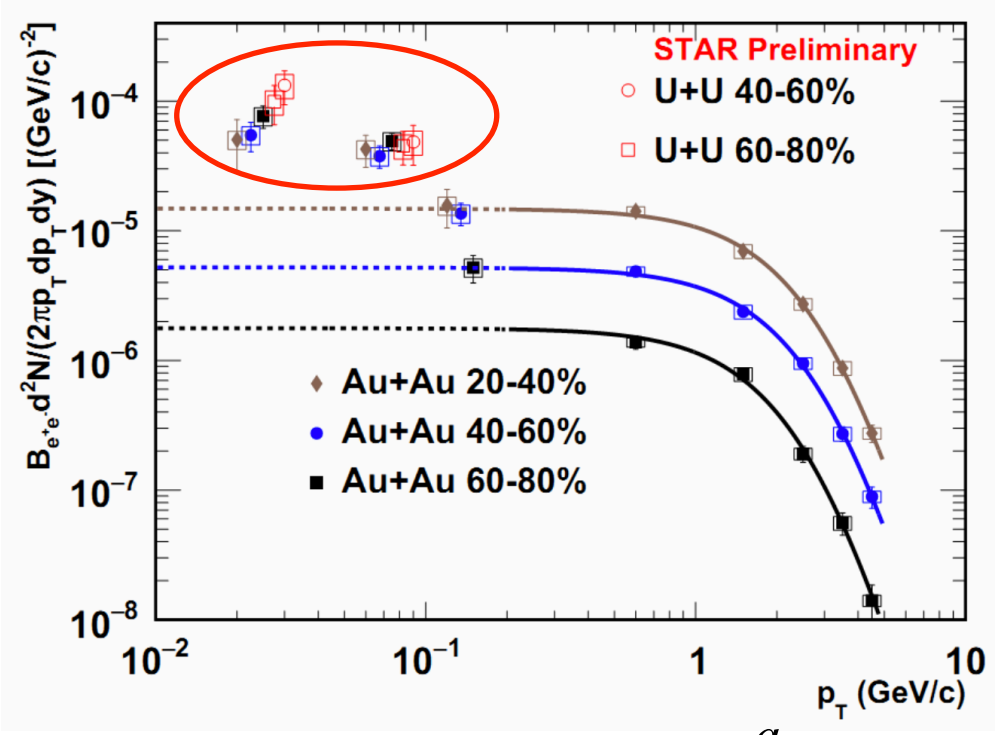


ALICE observed strong enhancement of J/ψ at very low-p_T in peri. collisions

Originate from coherent photoproduction in non-UPC?

Very-low-p_T J/ψ Enhancement at STAR



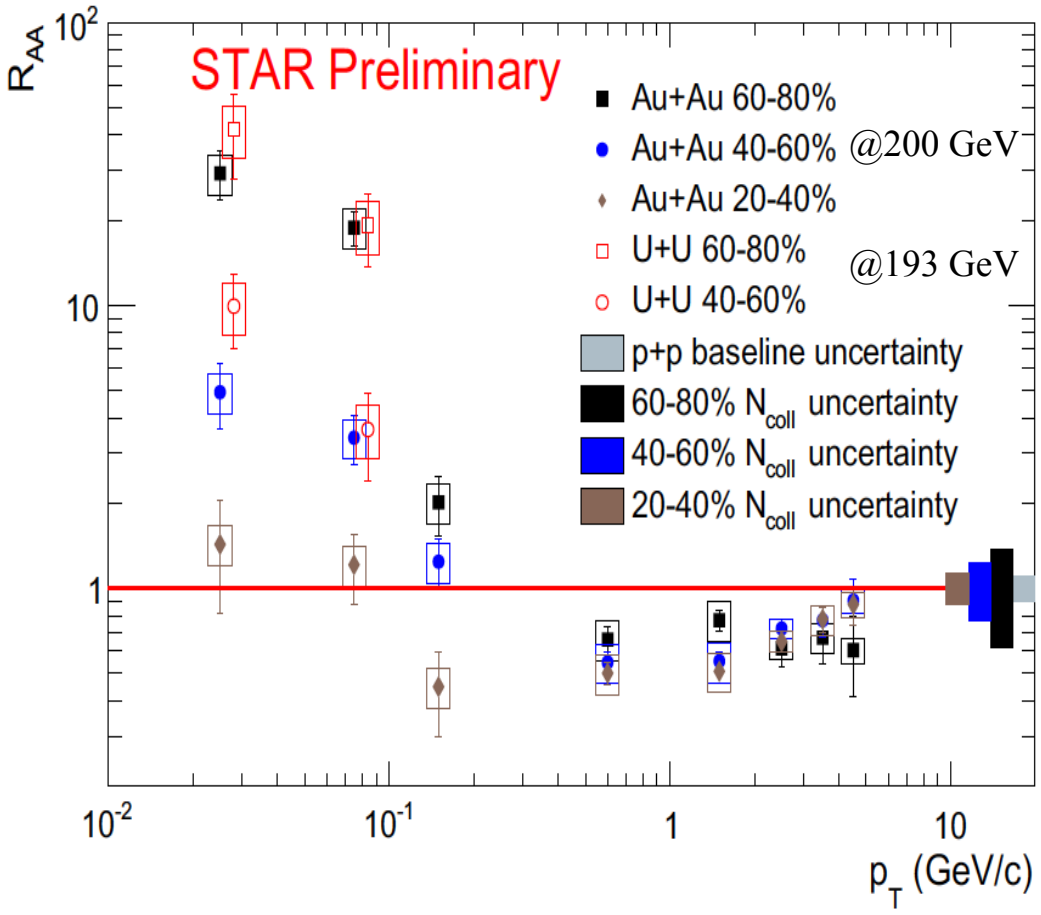


Clear signal at very low p_T

Fit fun. (empirical): $\dfrac{a}{\left(1+b^2 p_T^2\right)^n}$

Significant enhancement of J/ψ yield at p_T<0.2 GeV/c in (semi-)peripheral Au+Au and U+U collisions

$R_{AA}(p_T)$ in Au+Au and U+U Collisions



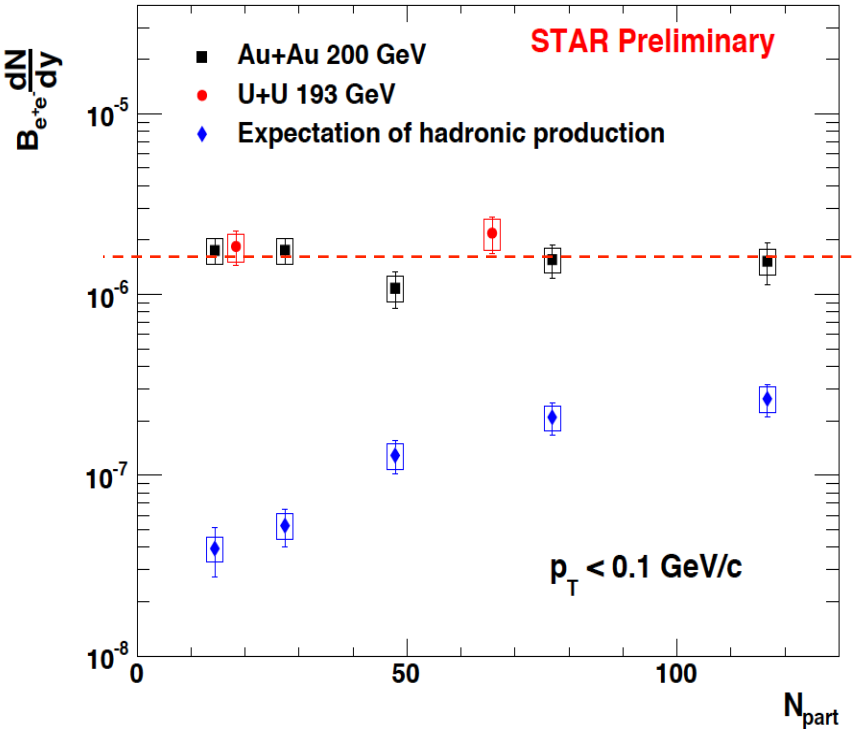
R_{AA} ~ 30-40

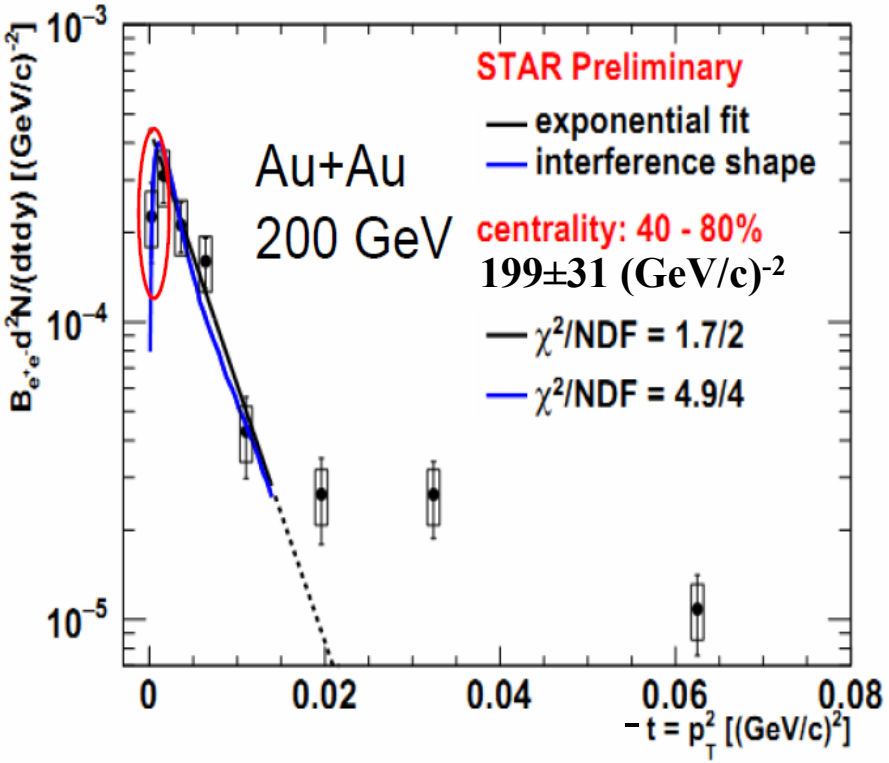
at $p_T < 0.05$ GeV/c

in 60-80% central

Au+Au and U+U

Centrality and $-t$ Dependence





Excess yield has no obvious centrality dependence

t distribution consistent with interference

slope similar to that from UPC

Modeling Coh. J/ψ Photo-prod. in Non-UPC

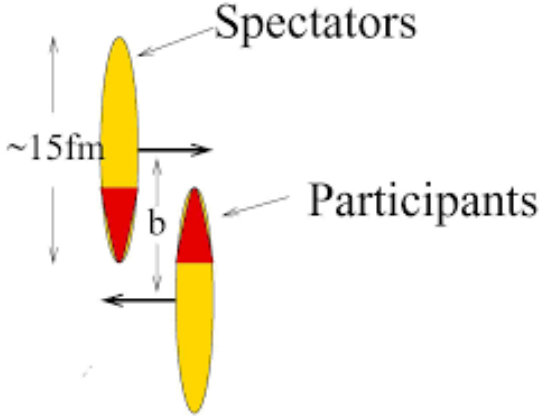
$$\sigma(AA \to AAJ/\psi) = \int d\omega_\gamma \frac{dN_\gamma(\omega_\gamma)}{d\omega_\gamma} \sigma(\gamma A \to J/\psi A)$$

Photon flux:

$$\frac{d^3N_\gamma(\omega_\gamma, \vec{x}_\perp)}{d\omega_\gamma d\vec{x}_\perp} = \frac{4Z^2\alpha}{\omega_\gamma} \left| \int \frac{d^2\vec{k}_{\gamma\perp}}{(2\pi)^2} \vec{k}_{\gamma\perp} \frac{F_\gamma(\vec{k}_\gamma)}{|\vec{k}_\gamma|^2} e^{i\vec{x}_\perp \cdot \vec{k}_{\gamma\perp}} \right|^2$$

EM form factor ← Woods-Saxon distribution

From entire nucleus or spectator?



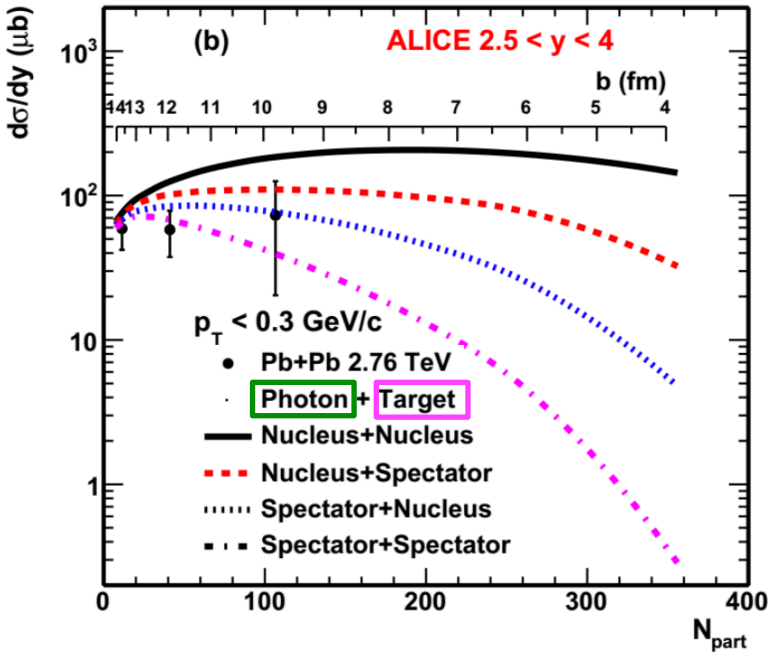
Photonuclear scattering:

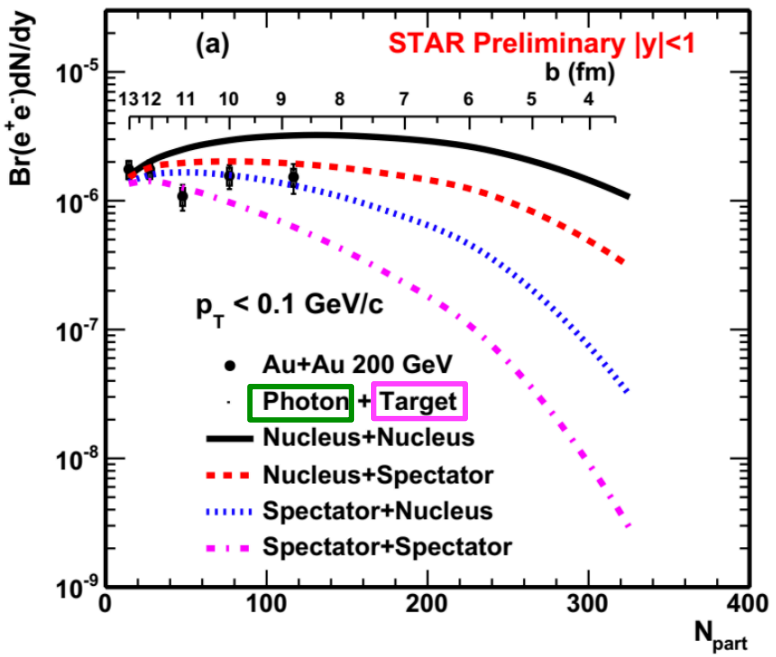
$$\sigma(\gamma A \to J/\psi A) = \left. \frac{d\sigma(\gamma A \to J/\psi A)}{dt} \right|_{t=0} \times \int |F_P(\vec{k}_P)|^2 d^2\vec{k}_{P\perp}$$

Form factor for Pomeron ← Nuclear density distribution

From entire nucleus or spectator?

Data vs. Model

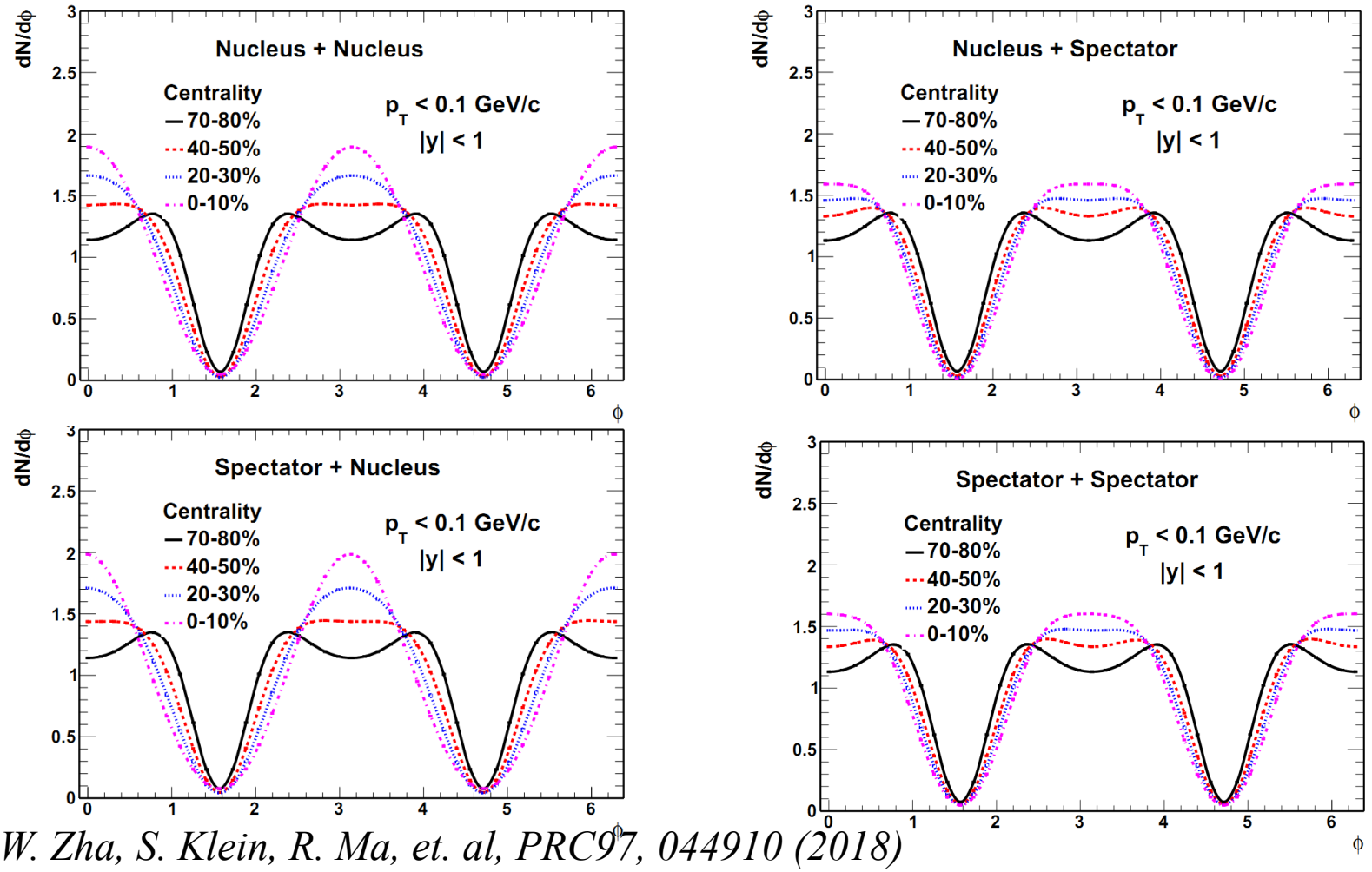




W. Zha, S. Klein, R. Ma, et. al, PRC97, 044910 (2018)

- All scenarios describe data at b~2R
- "Nucleus+Spectator" and "Spectator+Nucleus" are favored
- Extending to more central collisions is crucial

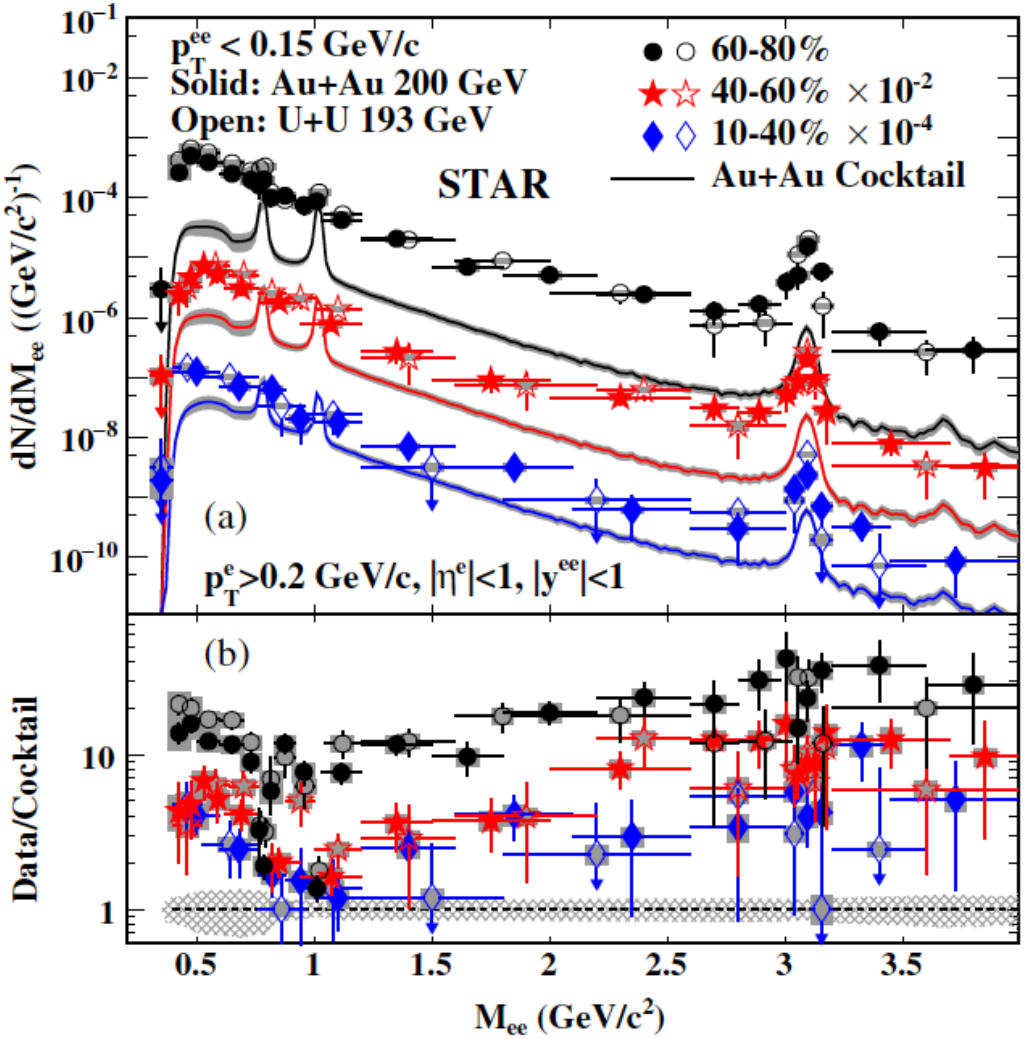
Azimuthal Angular Distribution



W. Zha, S. Klein, R. Ma, et. al, PRC97, 044910 (2018)

Significant anisotropy for coherent photoproduced J/ψ

Very-low-p_T ee Enhancement at STAR

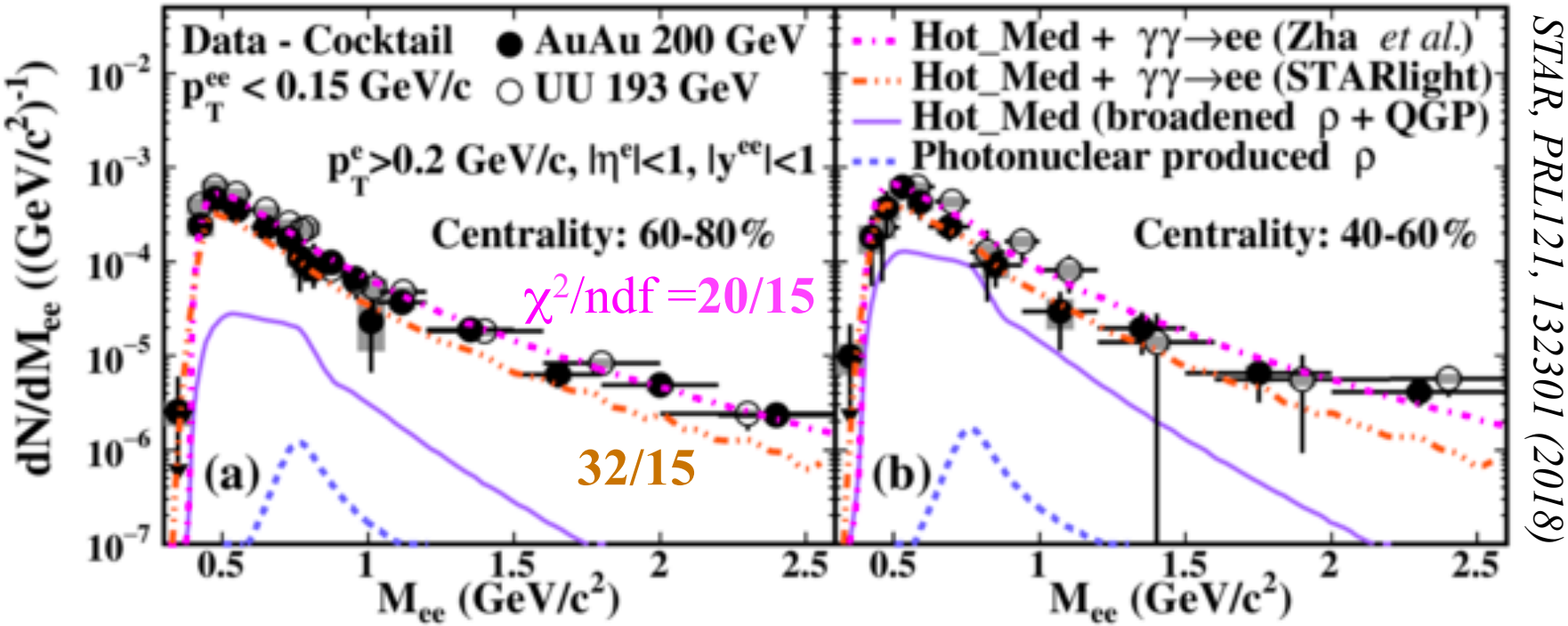


STAR, PRL121, 132301 (2018)

Significant enhancement of dilepton yield at p_T<0.15 GeV/c in (semi-)peripheral Au+Au and U+U collisions

Enhancement factor increases from semi-central to peripheral collisions

Excess Yield vs. Invariant Mass



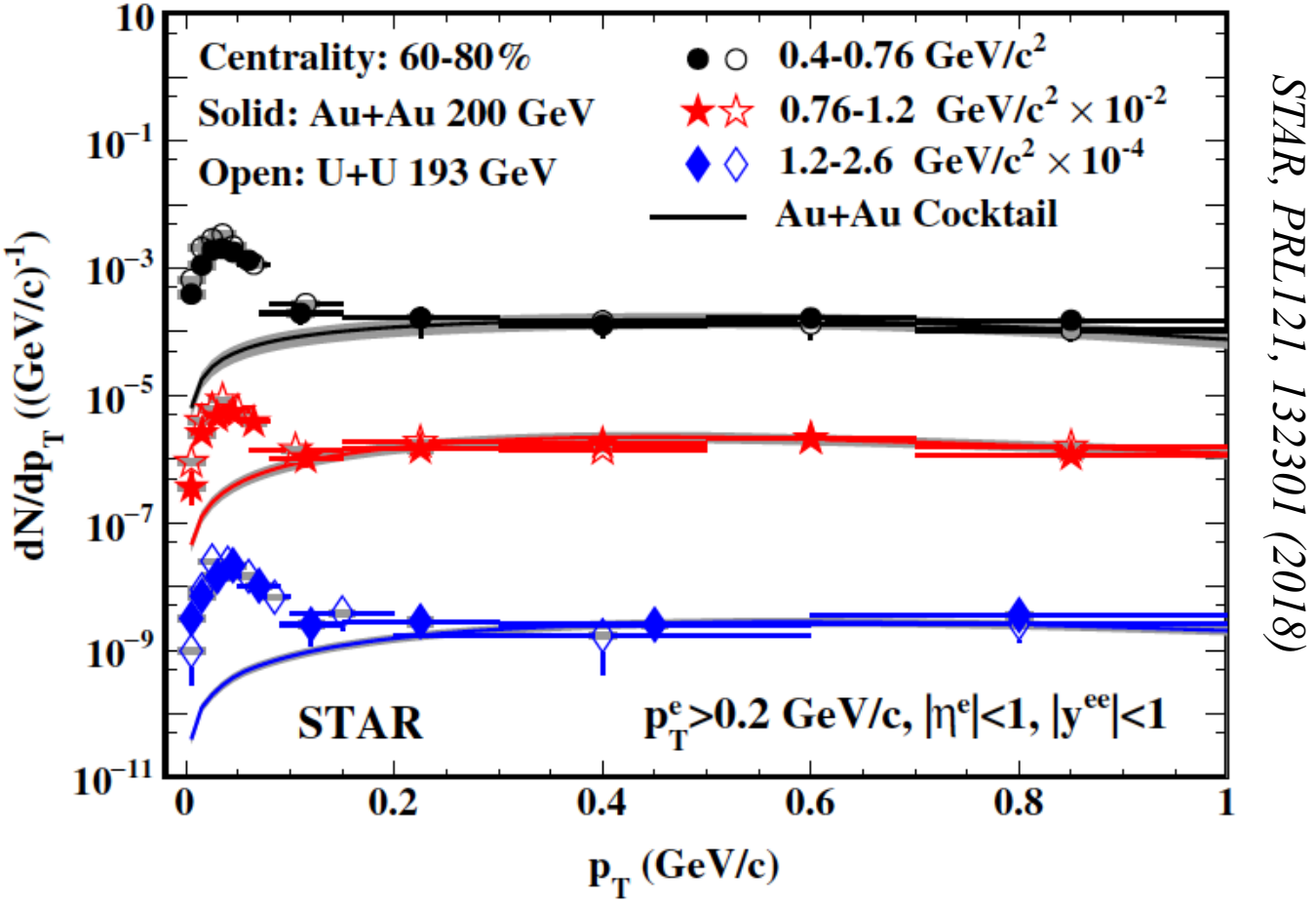
Well described by theoretical calculations

Zha et al.: Woods-Saxon, entire nucleus as emitter *W. Zha et al, PLB 781, 182 (2018)*

STARlight: point-like charge, ignore x_T>R *S. Klein, PRC97, 054903 (2018)*

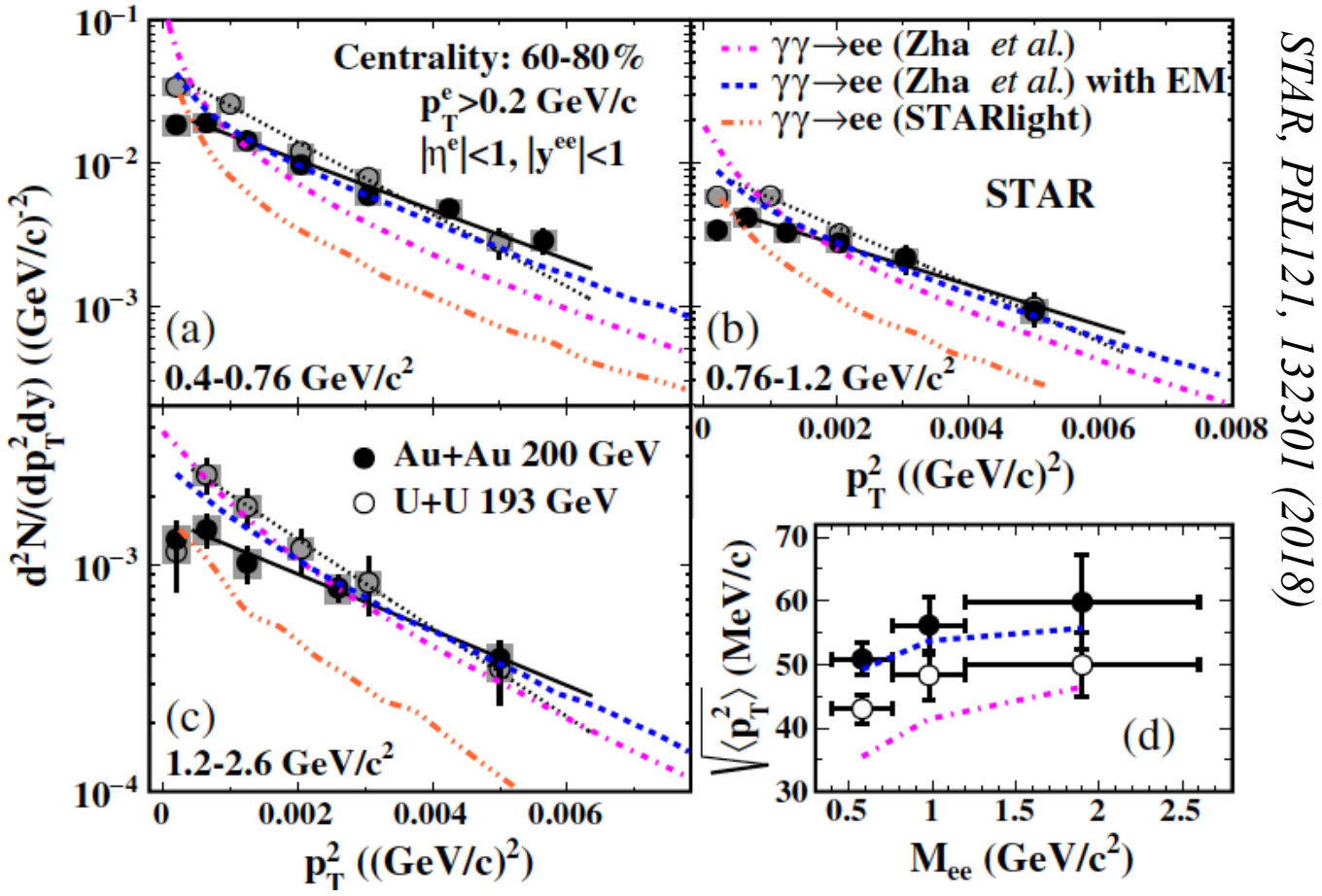
Very-low-p_T dilepton dominantly produced by γγ in peri. collisions

ee p_T Distribution



- Significant excesses at p_T<~0.15 GeV/c
- Consistent with hadronic cocktail above 0.15 GeV/c

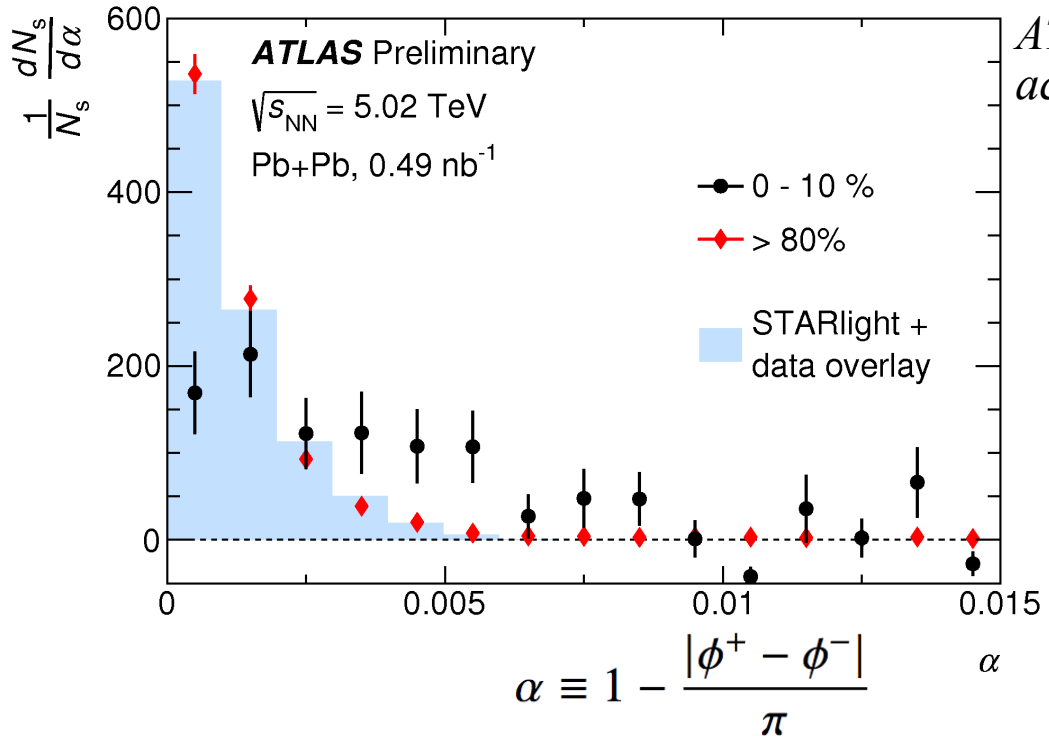
Transverse Momentum Broadening



p_T^2 in data broader than in both models

Bending by the magnetic field in QGP?

Acoplanarity of Very-low-p_T Di-muon



ATLAS, arXiv:1806.08708, accepted by PRL

Acoplanarity of high-mass muon pair

Broadening in central collisions compared to peripheral collisions

QGP effect?

Summary

- Significant enhancement of very-low-p_T J/ψ and ee observed in hadronic heavy-ion collisions
- Consistent with expectation of coherent photoproduction
- Broadening of p_T and angular correlation of dilepton
- Provide novel probes of QGP

Outlook:

- $_{44}^{96}Ru+_{44}^{96}Ru$, $_{40}^{96}Zr+_{40}^{96}Zr$ vs. $_{79}^{197}Au+_{79}^{197}Au$
- Beam energy dependence
- UPC
- Other photoproducts
- …

Thanks!