



Excess of J/ ψ yield at very low p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV with STAR

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Collaboration

Hard Probes 2016

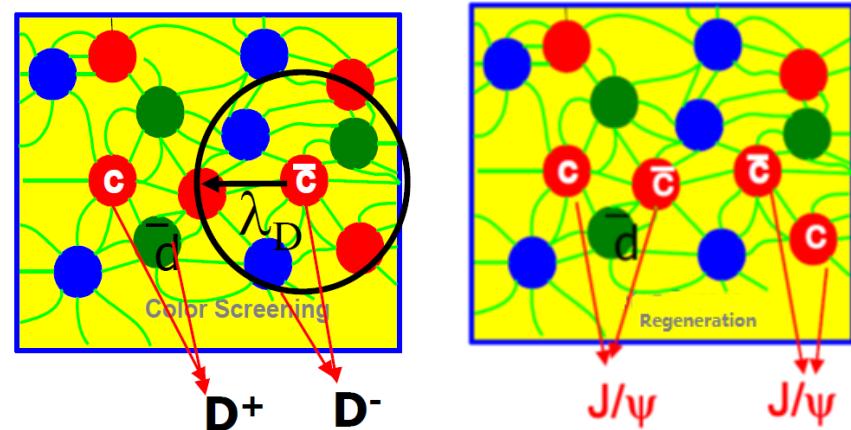
8th International Conference on Hard and Electromagnetic
Probes of High-Energy Nuclear Collisions

September 23–27, 2016
Wuhan, China

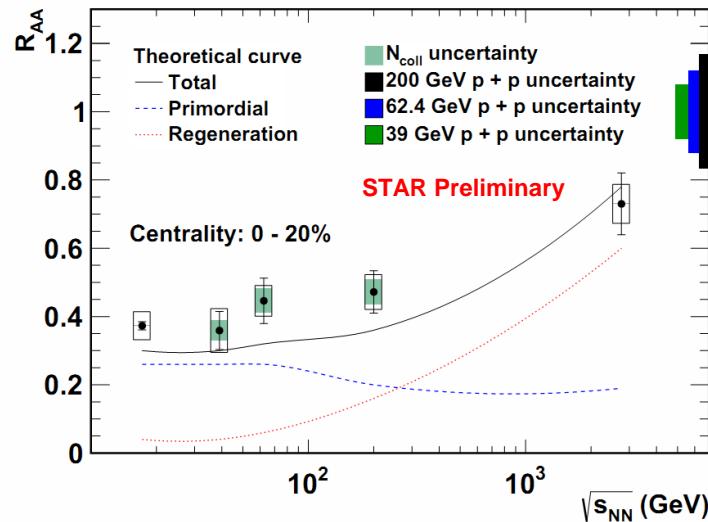
Wuhan
HP2016

J/ ψ production modification in hadronic A+A collisions

- Hot medium effects:
 - ✓ Color Screening
 - “Smoking gun” signature for QGP
 - ✓ Regeneration
 - Recombination of charm quarks



- Cold Nuclear Matter effects:
 - ✓ PDF modification in nucleus
 - ✓ Initial-state energy loss
 - ✓ Cronin effect
 - ✓

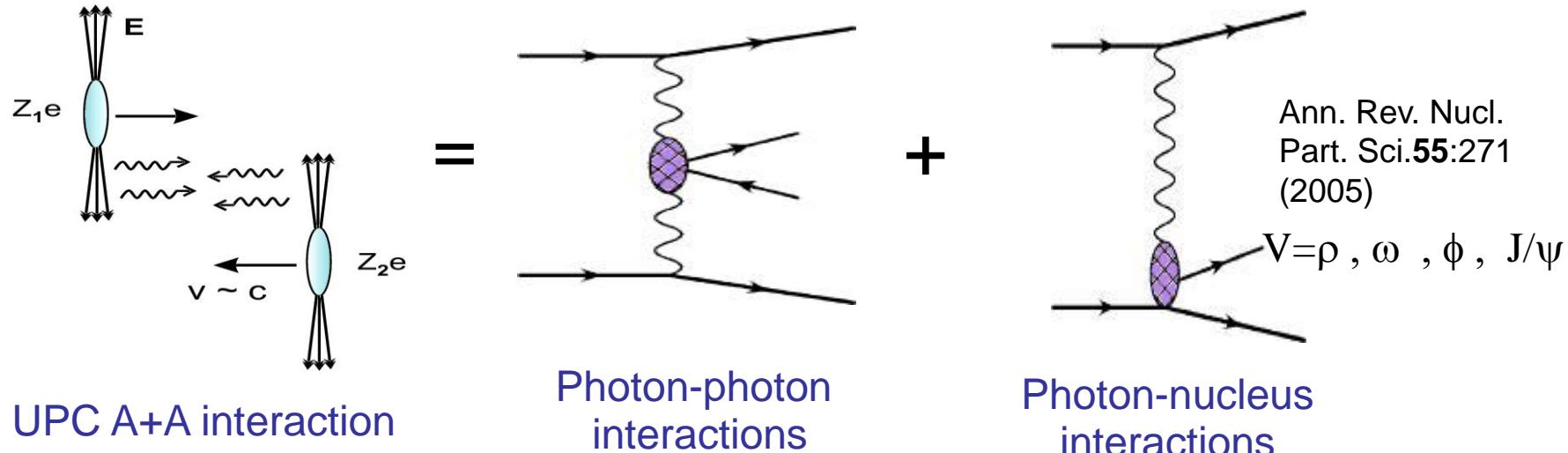


The interplay of these effects can explain the results from SPS to LHC!

Introduction to photon interactions in A+A

- Studied in detail for Ultra-Peripheral Collisions (UPC)

- ✓ UPC conditions: $b > 2R_A$, no hadronic interactions



- This large flux of quasi-real photons makes a hadron collider also a photon collider!

- Photon-nucleus interactions:

- Coherent: emitted photon interacts with the entire target nucleus.
 - Incoherent: emitted photon interacts with nucleon or parton individually.

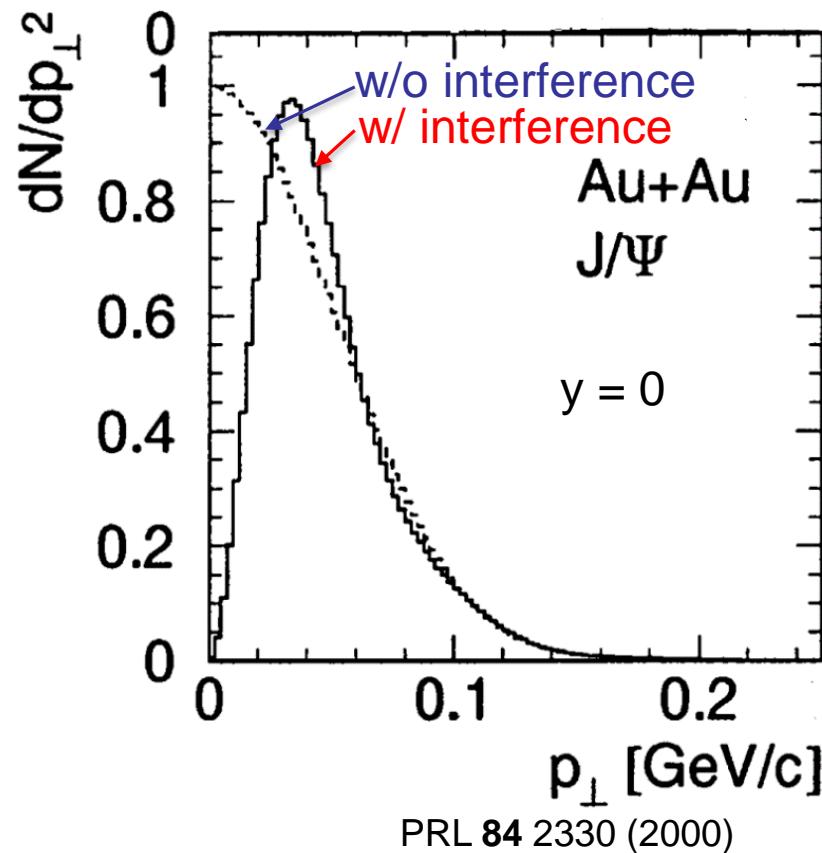
Features of coherent photon-nucleus interaction

● Coherently:

- ✓ Both nuclei remain intact
- ✓ Photon/Pomeron wavelength $\lambda = \frac{h}{p} > R_A$
- ✓ $p_T < h/R_A \sim 30 \text{ MeV}/c$ for heavy ions
- ✓ Strong couplings ($Z\alpha_{EM} \sim 0.6$) → large cross sections

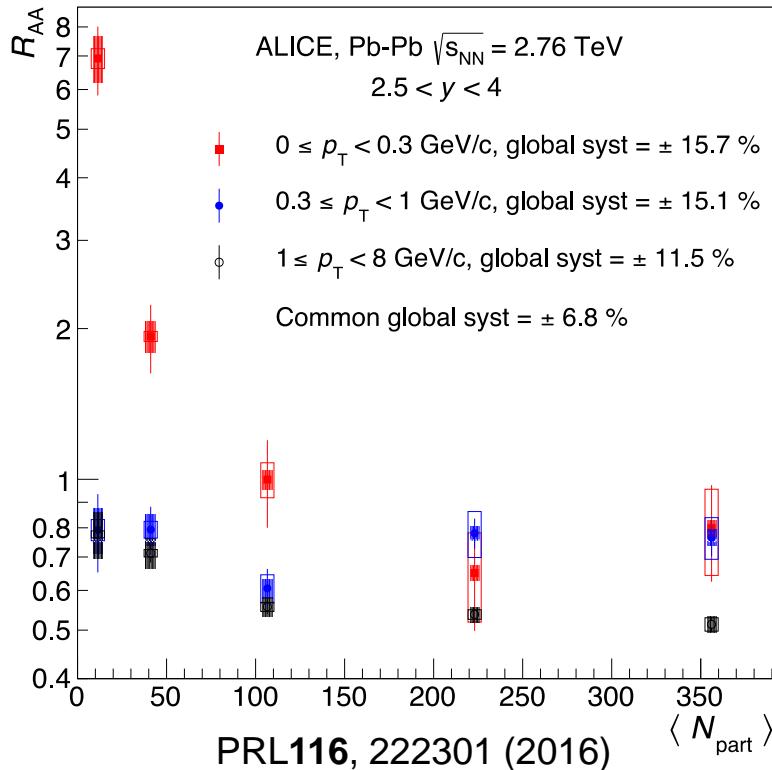
● Interference:

- ✓ Two indistinguishable processes (photon from A_1 or A_2)
- ✓ Vector meson → opposite signs in amplitude
- ✓ Significant destructive interference for $p_T \ll 1/\langle b \rangle$



PRL 84 2330 (2000)

Excess of J/ ψ production at very low p_T with ALICE

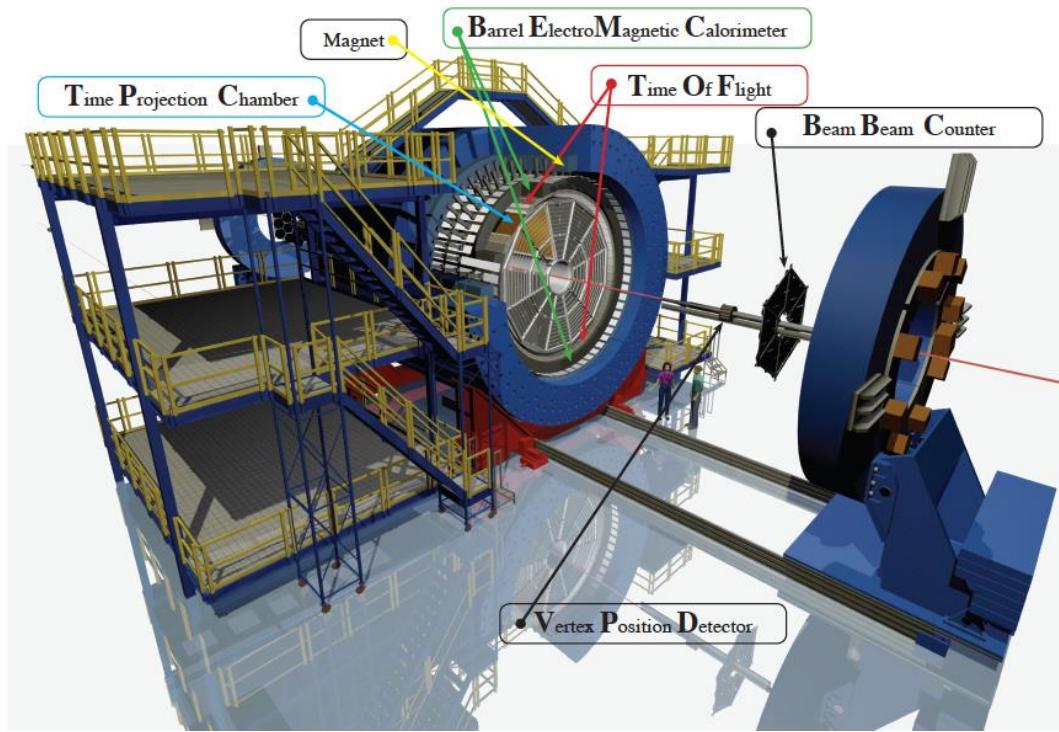


- ✓ Significant enhancement of J/ ψ yield observed in p_T interval 0 – 0.3 GeV/c for peripheral collisions (50 – 90%).
- ✓ Can not be described by hadronic production modified by the hot medium or cold nuclear matter effects!
- ✓ Origin from coherent photon-nucleus interactions?

- Measurement of J/ ψ yield at very low p_T in hadronic collisions (U+U and Au+Au):
 - Enhancement of J/ ψ yield at very low p_T ?
 - If so, what are the properties and origin of the excess?
 - p_T , centrality and system size dependence of the excess; t distribution.

STAR detector

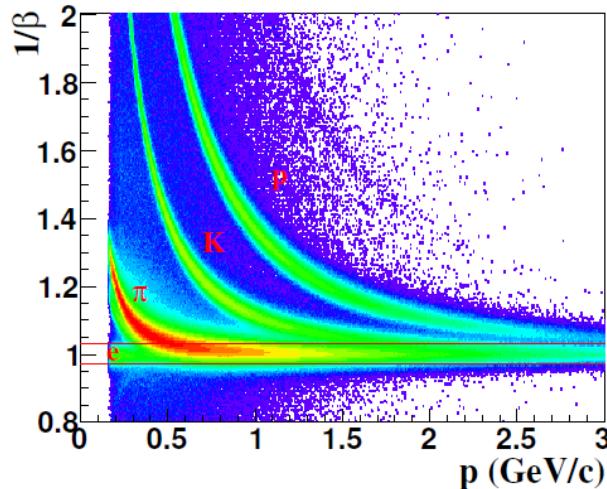
Solenoidal T racker A t R HIC : $-1 < \eta < 1, 0 < \phi < 2\pi$



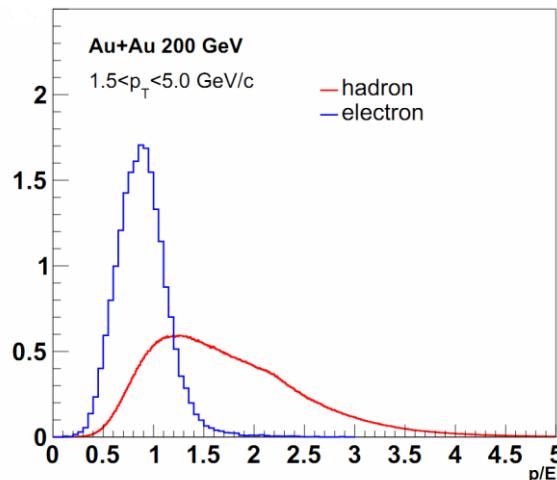
- Large acceptance:
 $|\eta| < 1, 0 < \phi < 2\pi$
- Time Projection Chamber (TPC) – tracking, particle identification, momentum
- Time of Flight detector (TOF) – particle identification
- Barrel ElectroMagnetic Calorimeter (BEMC) – electron identification, triggering

Electron Identification

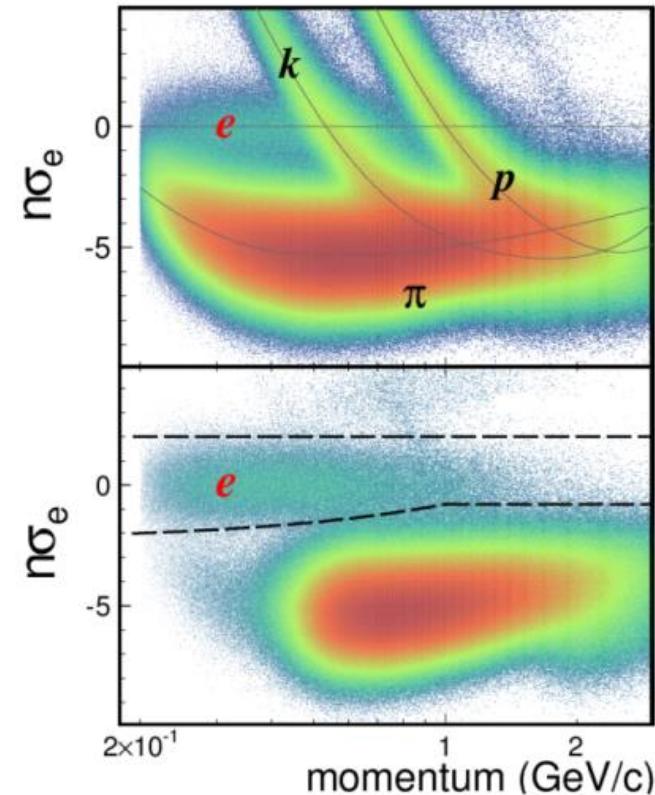
1/ β distribution for electrons and hadrons from TOF



p/E distribution for electrons and hadrons from BEMC

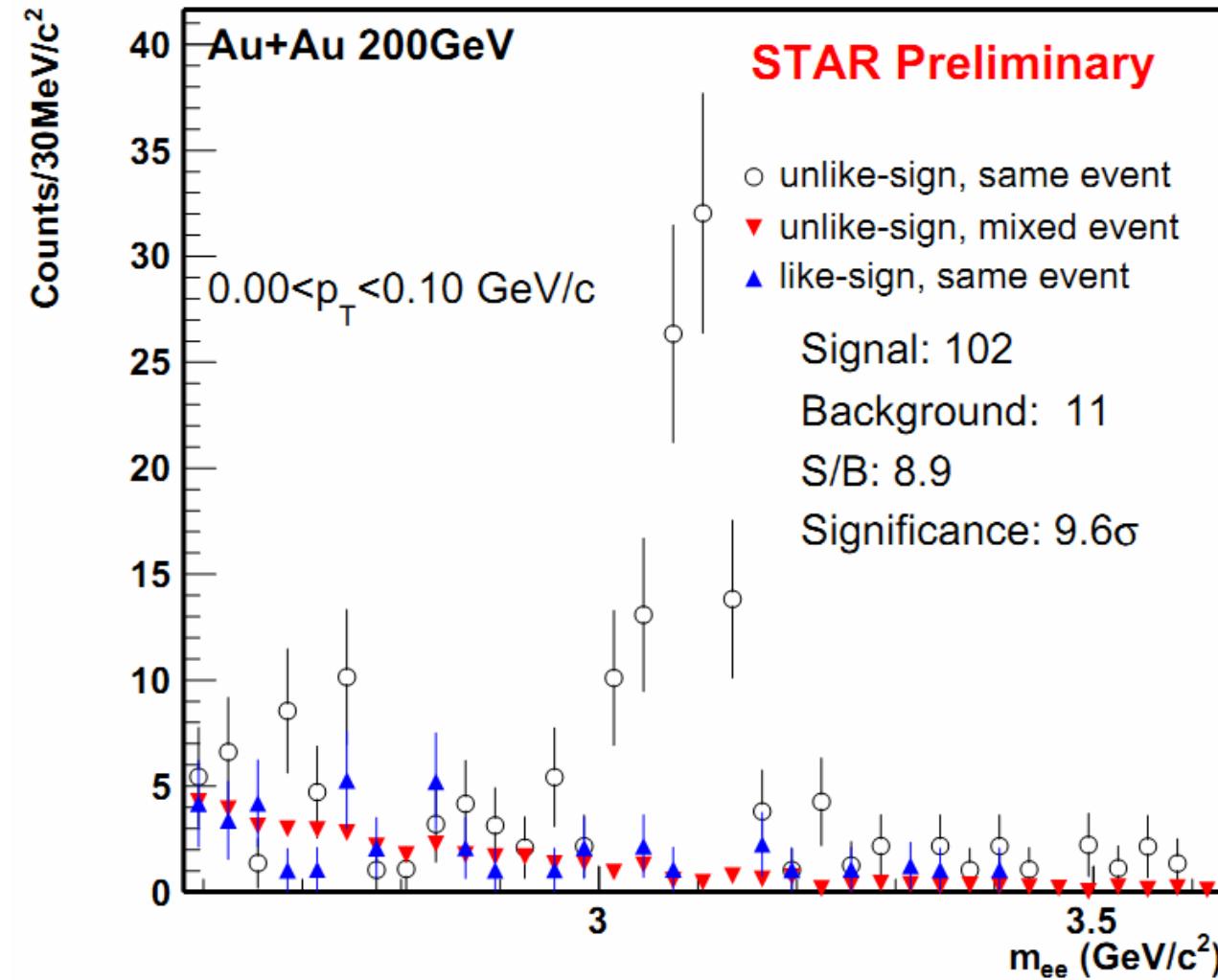


Normalized dE/dx ($n\sigma_e$) distribution before and after TOF cuts



Phys. Rev. C92 (2015) 24912

J/ ψ signal

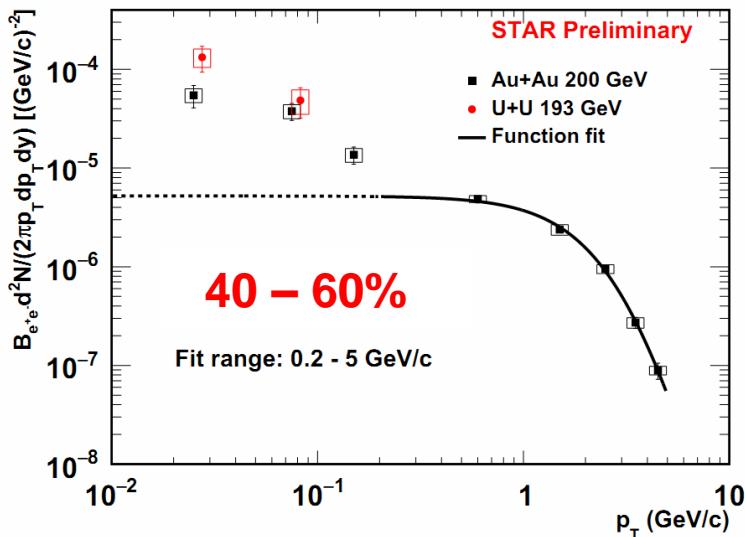
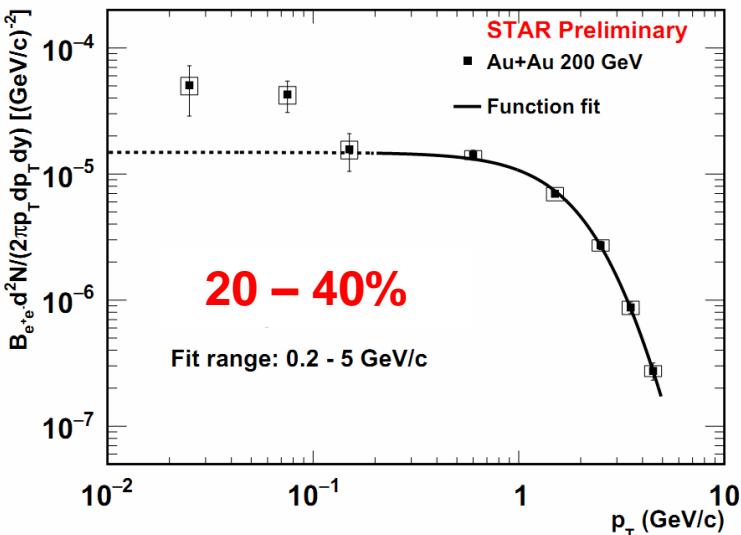
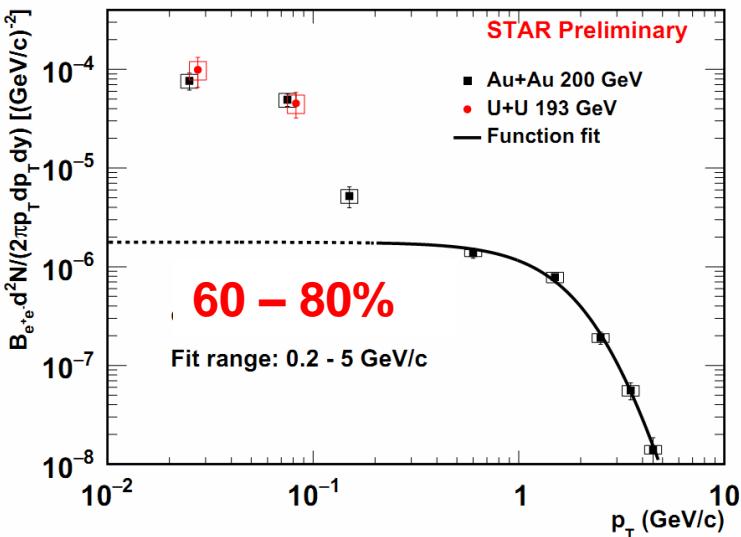


Centrality: 40 – 80%

The signal is extracted by subtracting the mixed event background from the unlike-sign pairs.

Good signal over background ratio!

J/ ψ invariant yield in Au+Au and U+U Collisions

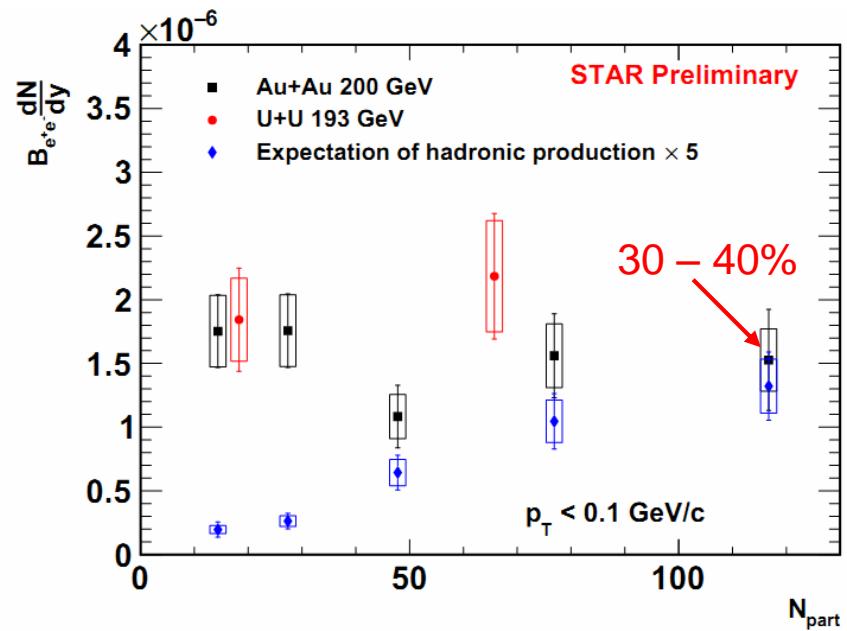
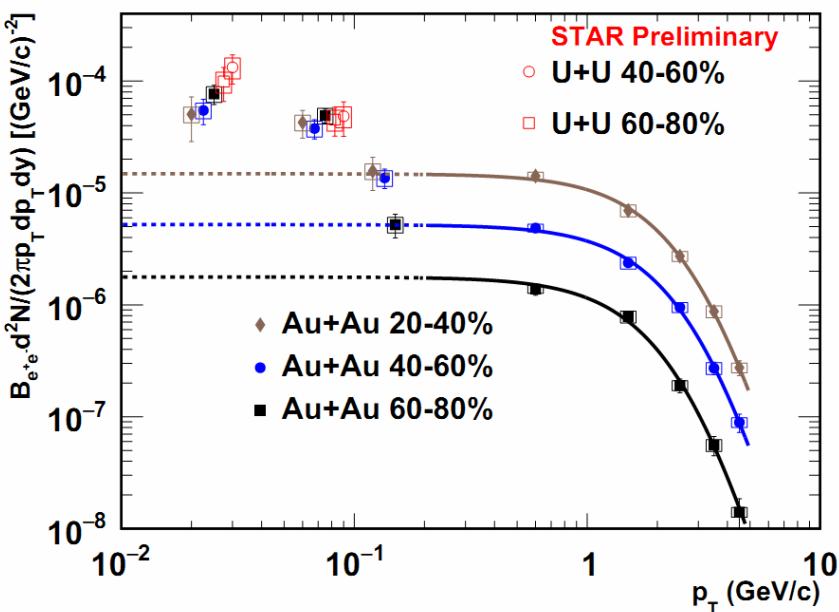


Function to describe hadronic production:

$$\frac{d^2N}{p_T dp_T} = a \times \frac{1}{(1 + b^2 p_T^2)^n}$$

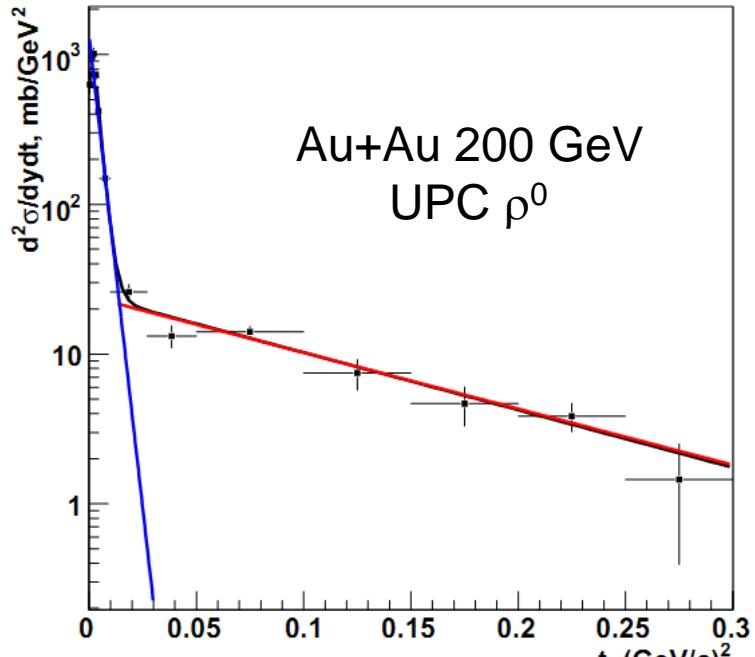
- Significant enhancement of J/ ψ yield observed at p_T interval 0 – 0.2 GeV/c for peripheral collisions (40 – 80 %)!
- The yield of J/ ψ at very low p_T in Au+Au is similar to that in U+U within uncertainties.

J/ ψ yield at very low p_T versus centrality



- ✓ Low p_T J/ ψ from hadronic production is expected to increase dramatically with N_{part} .
- ✓ No significant centrality dependence of the excess yield!
- ✓ No significant difference between Au+Au and U+U collisions.

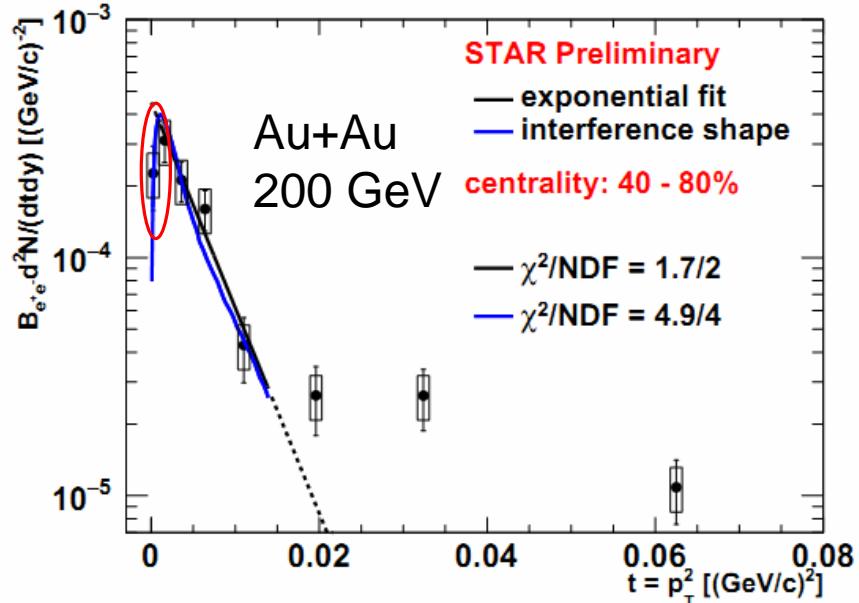
J/ ψ dN/dt distribution for Au+Au 40-80%



Phys. Rev. C 77 4910 (2008)

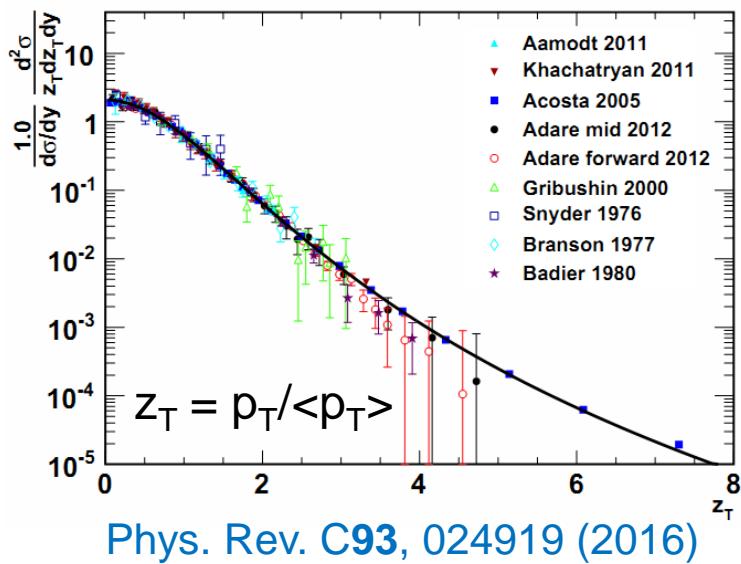
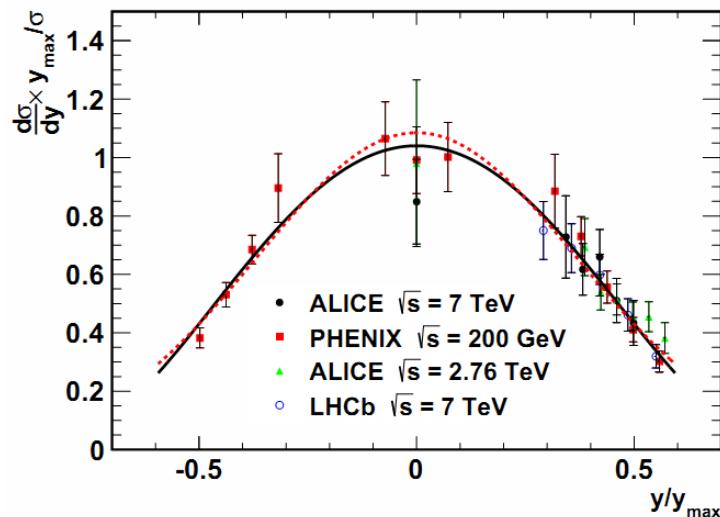
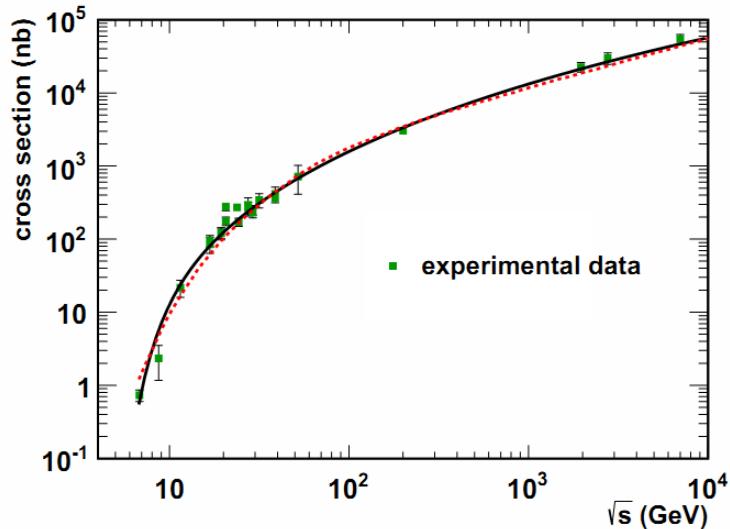
ρ^0 cross-section as a function of the momentum transfer squared ($t \approx p_T^2$) from STAR UPC measurements.

- The slope from the exponential fit reflects the size and shape of target.



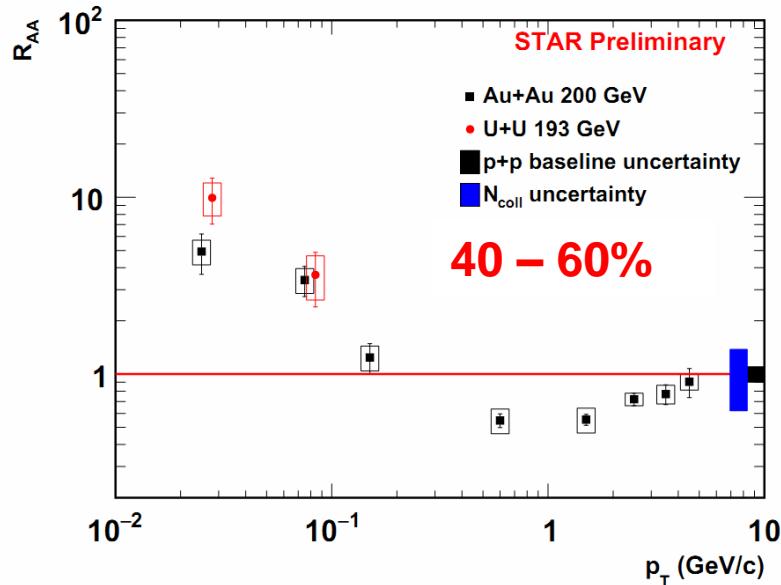
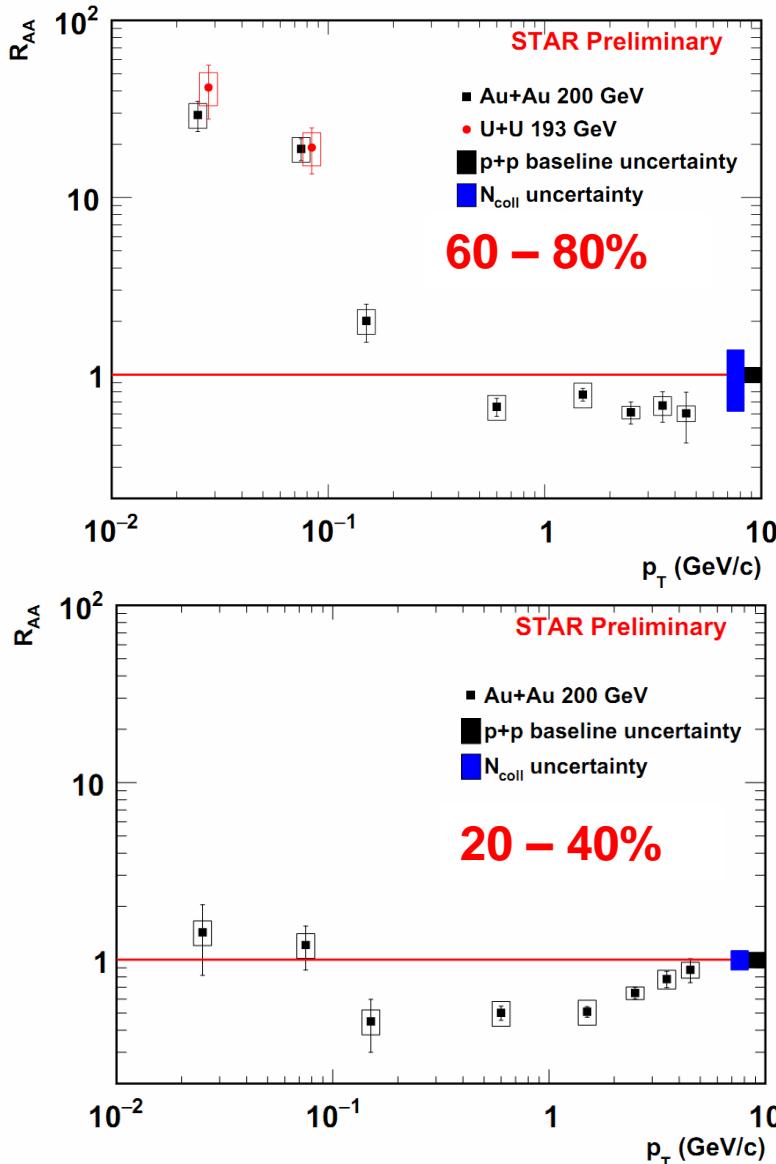
- ✓ Similar structure to that in UPC case!
- ✓ Indication of interference!
 - ✓ Interference shape from calculation for UPC case PRL 84 2330 (2000)
- ✓ Similar slope parameter!
 - ✓ Slope from STARLIGHT prediction in UPC case – 196 (GeV/c) 2
 - ✓ Slope w/o the first point: 199 ± 31 (GeV/c) 2
 $\chi^2/NDF = 1.7/2$
 - ✓ Slope w/ the first point: 164 ± 24 (GeV/c) 2
 $\chi^2/NDF = 5.9/3$

J/ ψ p+p baseline extraction from world-wide data



- ✓ The scaled rapidity and p_T distributions follow a universal trend.
- ✓ pp baseline at very low p_T is interpolated from the world-wide experimental data.

J/ ψ R_{AA} for Au+Au and U+U collisions



- ◆ R_{AA} ~ 20 in 60 – 80% centrality at p_T interval 0 – 0.1 GeV/c
- ◆ R_{AA} ~ 4 for 40 – 60% centrality at p_T interval 0 – 0.1 GeV/c

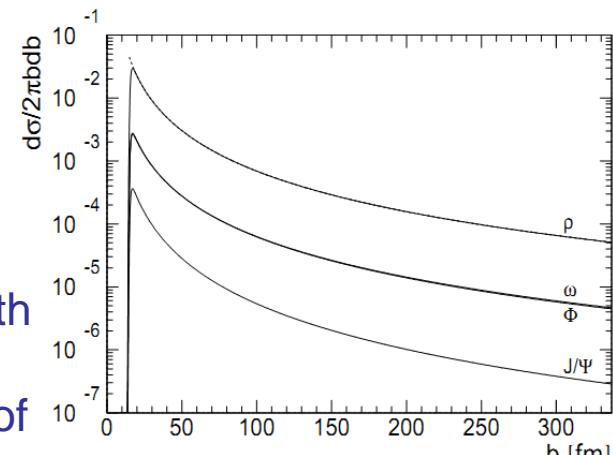
Summary

- Significant excess of J/ψ yield at p_T interval $0 - 0.2 \text{ GeV}/c$ is observed for peripheral collisions (40 – 80%).
- The excess trend shows no significant centrality dependence (30 – 80%) within uncertainties, which is beyond the expectation from hadronic production.
- The properties of the excess are consistent with the physical picture of coherent photon-nucleus interactions.
 - ✓ Similar dN/dt distribution to that in UPC case.
 - ✓ Indication of interference at p_T interval $0 - 0.03 \text{ GeV}/c$.
 - ✓ The extracted nuclear form factor slope is consistent with nucleus size.

Discussion and outlook

➤ Challenges for theoretical calculations in hadronic peripheral collisions:

- How do the broken nucleus satisfy the condition of coherence?
- No significant dependence of production on impact parameter?
 - The coherent cross section increases dramatically with decreasing impact parameter in UPC collisions.
 - Cancellation of photon flux in the overlapping region of colliding nuclei for hadronic peripheral collisions.
- How large is incoherent contribution?
- Can the products of coherent photon-nucleus interactions serve as a probe to test the cold and hot medium effects?



Phys. Rev. C60, 014903 (1999)

➤ Future experimental measurements:

- More differential measurements for J/ψ .
- The excess of other vector meson (ρ , ω , ϕ , Υ ...) in hadronic collisions?
- The excess of photon-photon process (π^0, η, η' , $f_2(1270)$, $a_2(1320)$, $\pi^+ + \pi^-$, $e^+ + e^-$, $\mu^+ + \mu^-$...)?