Calculation of coherent and incoherent photoproduction of $\Upsilon(1S)$ in hadronic heavy-ion collisions

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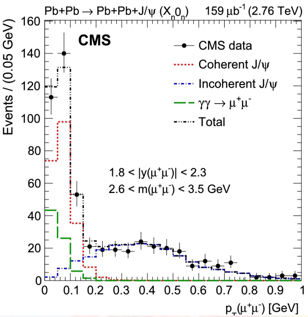
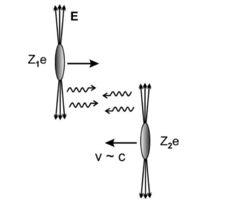
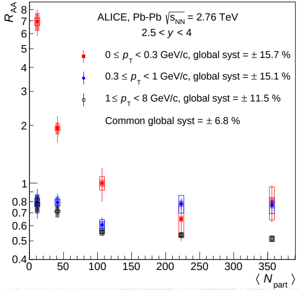
Electromagnetic Field in Heavy-ion Collisions

- Strong EM field accompanies the nuclei in relativistic heavy-ion collisions
  - $B \sim \gamma Zeb/R^3 \sim O(10^{14}\ Tesla)$ @RHIC
- The Lorentz contracted EM field can be expressed in terms of equivalent photon flux
  - Quasi-real photon flux $\propto Z^2$
- The quasi-real photons can initiate photon induced vector mesons
  - Coherent: the photon interacts with the whole nucleus
  - Incoherent: the photon interacts with a single nucleon
  - Conventionally studied in ultraperipheral collisions (UPCs) $b_{min} > R_A + R_B$

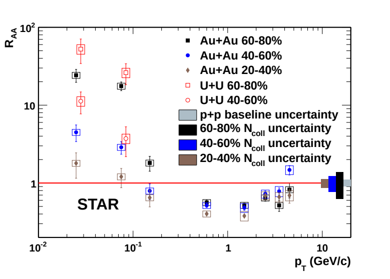




J/ψ excess in hadronic heavy-ion collisions



ALICE, PRL 116 (2016) 222301



STAR, arXiv: 1904.11658

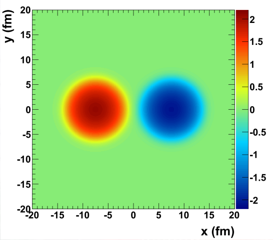
- Significant enhancement of J/ψ yield in p_T interval 0-0.3(0.2) GeV/c for peripheral heavy-ion collisions [50-90%(40-80%)] in ALICE(STAR)
  - Can not be described by hadronic production modified by the hot medium or cold nuclear matter effects → exhibit characteristics of photoproduction
- How about Υ ?

Calculate two photon process

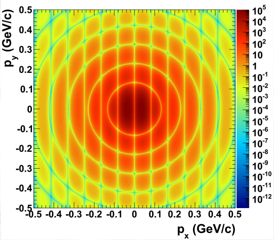
- According to the equivalent photon approximation, the photoproduction rate in heavy-ion collisions can be factorized into two parts, the photon flux and the photon-nucleus cross section:

$$\sigma(A+A\rightarrow A+A+\Upsilon)=\int d\omega n(\omega)\sigma(\gamma A\rightarrow \Upsilon A), \tag{1}$$

where ω is the photon energy, n(ω) is the photon flux at energy ω.



Amplitude density



momentum distribution in transverse plane

Interference fringes + diffraction rings

The coherent $\Upsilon(1S)$ photoproduction

- The spatial photon flux

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

$$\text{where} \quad \vec{k}_\gamma = (\vec{k}_{\gamma\perp}, \frac{\omega_\gamma}{\gamma_c}), \omega_\gamma = \frac{1}{2}M_\Upsilon e^{\pm y}$$

- Scattering amplitude with shadowing effect

$$\Gamma_{\gamma A\to\Upsilon A(r)} = \frac{f_{\gamma p\to\Upsilon N}(0)}{\sigma_{\Upsilon N}} \times 2 \times [1 - exp(-\frac{\sigma_{\Upsilon N}}{2} \times T^{'}(r))] \tag{3}$$

Using the optical theorem and vector meson dominance (VMD) relation, the total cross section for ΥN scattering is given by:

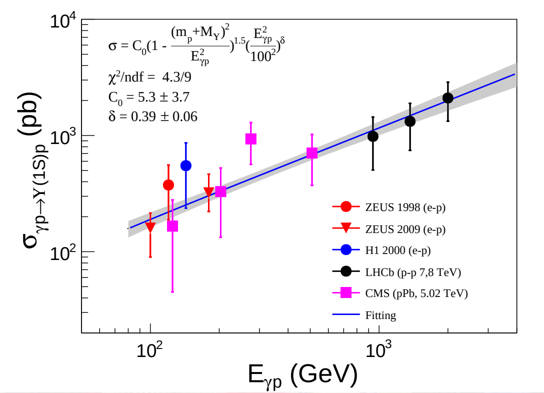
$$\sigma_{\gamma N} = \frac{f_\Upsilon}{4\sqrt{\alpha}C}f_{\gamma p\to\Upsilon N}(0), \tag{4}$$

- The coherent length effect

$$T^{'}(r) = \int_{-\infty}^{+\infty} dz\rho(\sqrt{r^2+z^2})e^{iq_L z}, \quad q_L = \frac{M_\Upsilon e^y}{2\gamma}, \tag{5}$$

The parameterization for cross section estimates

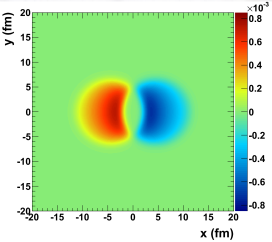
- Use world-wide experimental data on $\gamma p \to \Upsilon p$ parametrization



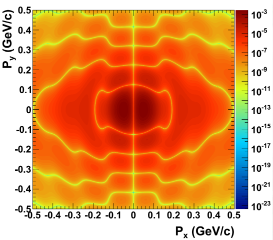
HERA: PLB 437 (1998) 432, PLB 483 (2000) 23, PLB 680 (2009) 4;
LHCb: JHEP (2015) 84
CMS: PLB 790 (2019) 270

The violent interactions in the overlap region

- The quasi-real photons are likely to be emitted before hadronic collision
  - Due to the time-retarded potential $\rightarrow \Delta t = \gamma R/c$
    γ: Lorentz factor, R: transverse distance from the colliding nuclei



Amplitude density



momentum distribution in transverse plane

The incoherent $\Upsilon(1S)$ photoproduction

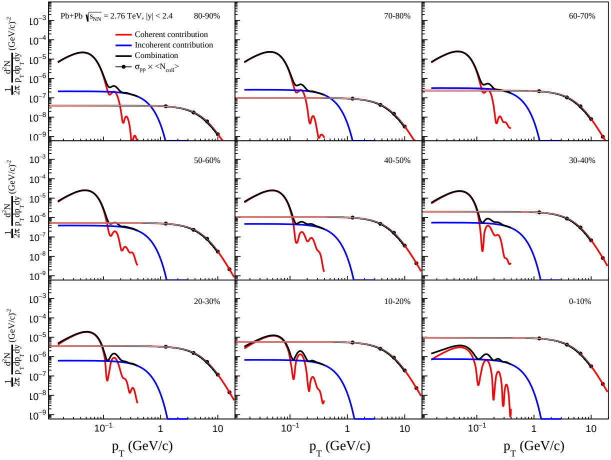
- Similarly, to the case of coherent Υ photoproduction on nuclei, the VMD model is used:

$$\frac{\sigma^{\text{VMD}}_{\gamma A\to\Upsilon A'}(W_{\gamma p})}{dt} = \frac{d\sigma_{\gamma p\to\Upsilon p}(W_{\gamma p})}{dt}\int d^2\mathbf{b}\,T_A(b)e^{-\sigma^{in}_{\Upsilon N}(W_{\gamma p})T_A(b)}, \tag{6}$$

$$\sigma^{in}_{\Upsilon N} = \sigma_{\Upsilon N} - \sigma^2_{\Upsilon N}/(16\pi B_\Upsilon) \approx \sigma_{\Upsilon N}.$$

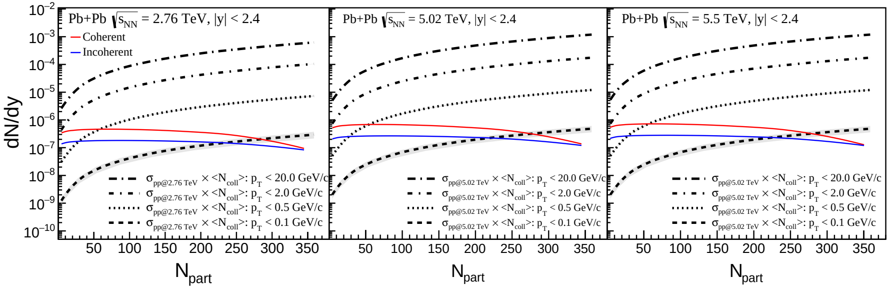
$\sigma^{in}_{\Upsilon N}$ is the inelastic Υ-nucleon cross section. BΥ is the slope of the t dependence of the γp $\to$ Υp scattering amplitude.

Υ(1S) yield vs. centrality in Pb+Pb@2.76 TeV



- The photoproduction are larger than the hadronic production at very low p_T up to ∼30% central

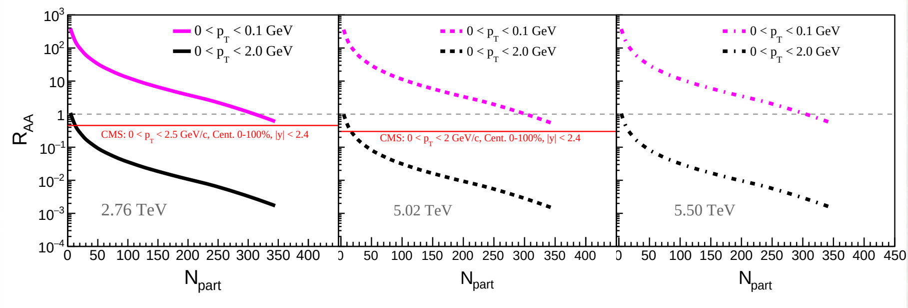
Integrated Υ(1S) yield vs. centrality @2.76, 5.02, 5.5 TeV



- Coherent and incoherent photoproduction are significant at very low p_T

Υ(1S) R_{AA} vs. centrality @2.76, 5.02, 5.5 TeV

Theoretical calculations in different low p_T region

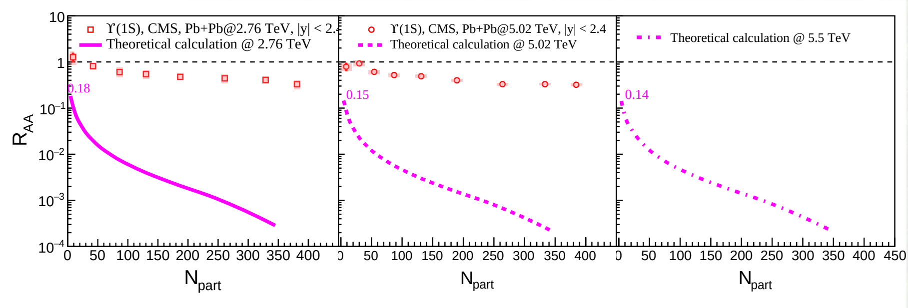


CMS@2.76 TeV: PLB 770 (2017) 357; CMS@5.02 TeV: PLB 790 (2019) 270

- Significant Υ(1S) photoproduction at low p_T

Υ(1S) R_{AA} vs. centrality @2.76, 5.02, 5.5 TeV

Theoretical calculations in $0 < p_T < 20$ GeV/c vs. experimental results



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- Υ(1S) photoproduction contribution may need to be considered

Conclusion

The coherent and incoherent photoproduction of $\Upsilon(1S)$ for Pb+Pb collisions at 2.76, 5.02 and 5.5 TeV have been calculated and are compared with the hadronic $\Upsilon(1S)$ production.

- Significant coherent and incoherent contributions at very low p_T up to $\sim$30% central

Next:

- Since only the initial production of $\Upsilon(1S)$ is considered, the medium effect will take into account

Thank You!