Tale of coherent photon products: from UPC to HHIC

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Abstract

The coherent photon-nucleus and photon-photon interactions has been studied in detail to probe the gluon distribution in nucleus and to test QED via relativistic heavy-ion collisions. These kind of interactions are traditionally thought to be only exist in ultra-peripheral collisions (UPC), where there is no hadronic interactions. Recently, significant excess of J/ψ yield and dielectron pair production at very low transverse momentum (p_T < 0.3 GeV/c) were observed by the ALICE and STAR collaborations in peripheral A+A collisions, which points to evidence of coherent photon products in hadronic heavy-ion collisions (HHIC). The possible survival of photoproduced J/ψ and electron pair merits theoretical investigations, which are currently absent on the market.

In this poster, we report on calculations of J/ψ yield from coherent photon-nucleus interactions and dilepton production from photon-photon interactions in HHIC at RHIC and LHC energies. The model used to calculate the cross section is discussed and the expected yield are compared with experimental results from RHIC and LHC. We predict the coherent production contribution of J/ψ and dielectron from isobaric collisions (Ru+Ru, Zr+Zr) for the further experimental test at RHIC.

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Motivation

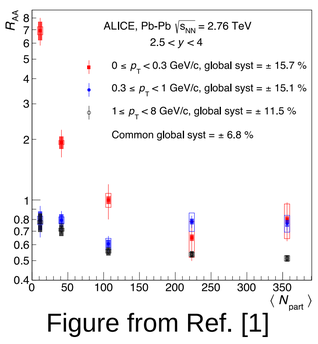


Figure from Ref. [1]

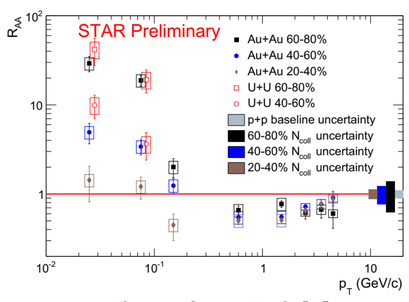


Figure from Ref. [2]

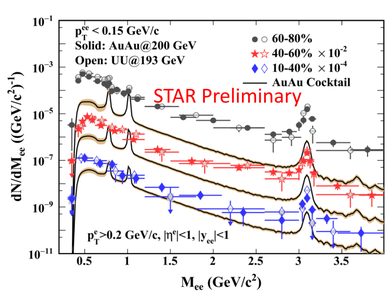
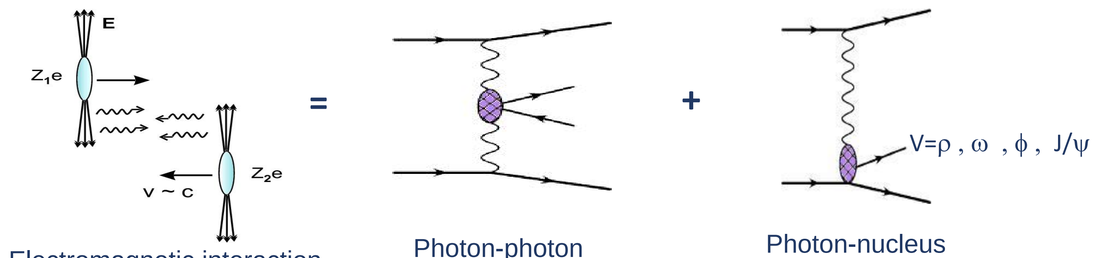


Figure from Ref. [3]

- Significant abnormal enhancement of J/ψ and dielectron production observed at very low p_T for peripheral collisions!
- Cannot be described by hadronic production modified by the hot medium or cold nuclear matter effects!
- Originate from coherent photon induced interactions?

Introduction to photon interactions in A+A collisions



Electromagnetic interaction | Photon-photon interactions | Photon-nucleus interactions

- This large flux of quasi-real photons makes a hadron collider also a photon collider!
- Photon-nucleus interactions: ρ, ω, ϕ, J/ψ...
  - ✓ Coherent: emitted photon interacts with the entire target nucleus.
  - ✓ Incoherent: emitted photon interacts with nucleon or parton individually.
- Photon-photon interactions: e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-…

Methodology in UPC

Photon-nucleus interactions

$$\sigma(AA \to AAV) = \int dk \frac{dN_\gamma(k)}{dk} \sigma(\gamma A \to VA)$$

$$= \int_0^\infty dk \frac{dN_\gamma(k)}{dk} \int_{t_{min}}^\infty dt \frac{d\sigma(\gamma A \to VA)}{dt}\Big|_{t=0} |F(t)|^2$$

$$\frac{d^3N_\gamma(k,r)}{dkd^2r} = \frac{Z^2\alpha x^2}{\pi^2 k r^2} K_1^2(x) \quad \frac{\mathrm{d}\sigma(\gamma A \to J/\psi A; t=0)}{\mathrm{d}t} = \frac{\alpha_{em}\sigma_{tot}^2(J/\psi A)}{4f_{J/\psi}^2}$$

$$\sigma_{tot}^{CM}(J/\psi A) = \int \mathrm{d}^2\mathbf{r}\left(1 - \exp\left(-\sigma_{tot}(J/\psi p)\, T_A(\mathbf{r})\right)\right)$$

$$\sigma_{tot}^2(J/\psi p) = 16\pi \frac{\mathrm{d}\sigma(J/\psi p \to J/\psi p; t=0)}{\mathrm{d}t}$$

$$\frac{\mathrm{d}\sigma(J/\psi p \to J/\psi p; t=0)}{\mathrm{d}t} = \frac{f_{J/\psi}^2}{4\pi\alpha_{em}} \frac{\mathrm{d}\sigma(\gamma p \to J/\psi p; t=0)}{\mathrm{d}t}$$

$$\frac{\mathrm{d}\sigma(\gamma p \to J/\psi p; t=0)}{\mathrm{d}t} = b_{J/\psi} X_{J/\psi} W_{\gamma p}^{\epsilon_{J/\psi}}$$

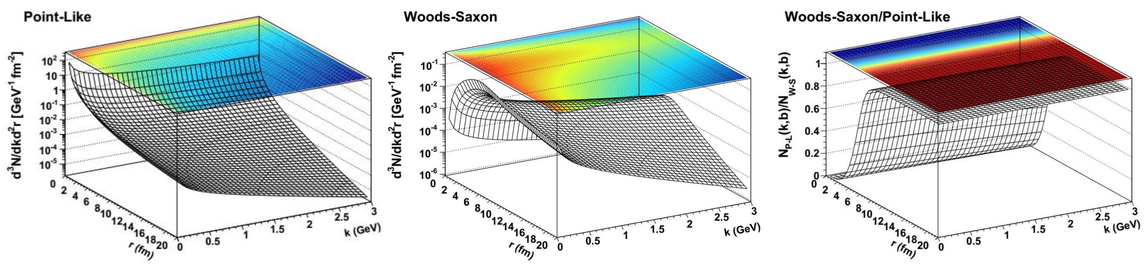
Photon-photon interactions

$$\sigma(A + A \to A + A + X) = \int dk_1 dk_2 \frac{n(k_1)}{k_1} \frac{n(k_2)}{k_2} \sigma[\gamma\gamma \to X(W)]$$

$$\sigma_{\gamma\gamma} = \frac{4\pi\alpha^2}{W^2}\left[\left(2 + \frac{8M^2}{W^2} - \frac{16M^4}{W^4}\right)\ln\frac{W + \sqrt{W^2 - 4M^2}}{2M} - \sqrt{1 - \frac{4M^2}{W^2}}\left(1 + \frac{4M^2}{W^2}\right)\right]$$

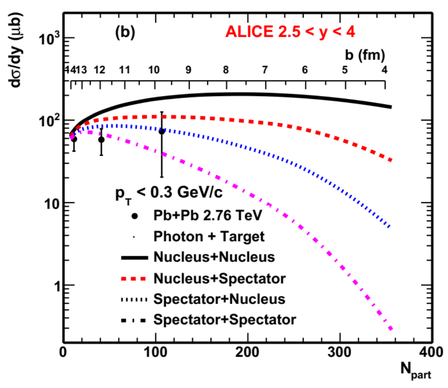
Extend to the case in HHIC

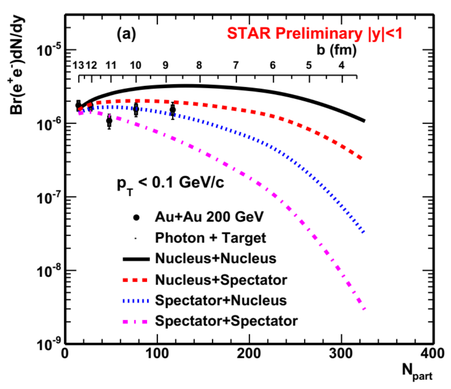
- Consider the charge distribution in nucleus

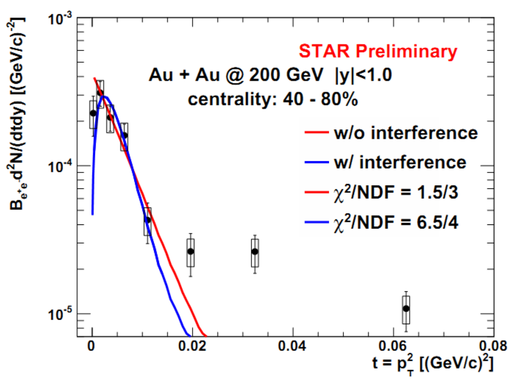


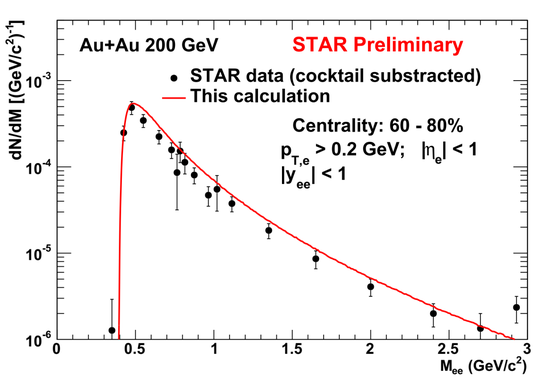
- The possible disruption from overlap region: nucleus? or spectator?

Results Ⅰ --- Can the excess be described?



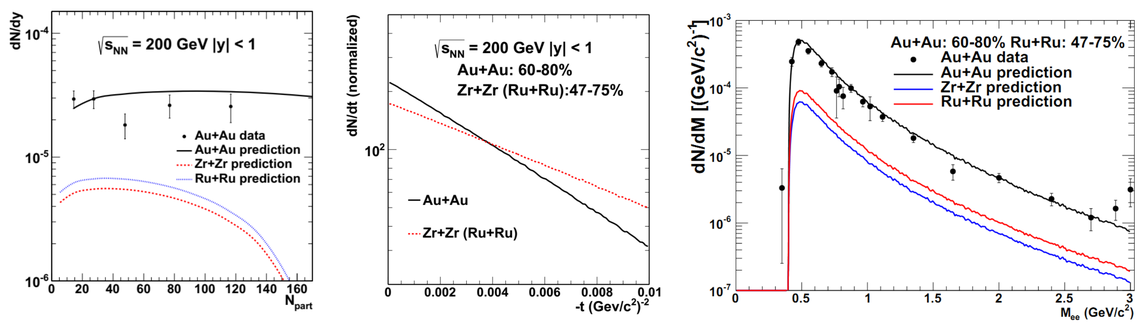






- Excess of J/ψ: reasonably described by coherent photon-nucleus interactions; favor "Nucleus + Spectator" and "Spectator +Nucleus"
- Excess of dielectron: well described by coherent photon-photon interactions

Results Ⅱ --- isobaric collisions: a perfect test!



- Cross section in isobaric collisions (Zr+Zr, Ru+Ru) is significant small than that in Au+Au collisions!
- Sizable difference between isobaric collisions!

Summary

- The excess of J/ψ and dielectron observed can be reasonably described by coherent photon-nucleus and photon-photon interactions!
- There exists possible disruption from overlap region for coherent photon-nucleus interactions!
- The isobaric collisions performed at RHIC can served as an excellent test for the coherent photon interactions in HHIC!

References

[1] J. Adam *et al.* (ALICE) 2016 *Phys. Rev. Lett.* **116** 222301
[2] W. Zha, Journal of Physics: Conference Series **779**, 012039 (2017)
[3] Shuai Yang, Int. J. Mod. Phys. Conf. Ser., 46, 1860013 (2018)