Results on Breit-Wheeler Process in Heavy-Ion Collisions and its Application to Nuclear Charge Radius Measurements

Xiaofeng Wang, James Daniel Brandenburg, Lijuan Ruan, Fenglan Shao, Zhangbu Xu, Chi Yang, and Wangmei Zha

Key Laboratory of Particle Physics and Particle Irradiation (MoE), Institute of Frontier and Interdisciplinary Science, Shandong University, Qingdao, China

xiaofeng_wang@mail.sdu.edu.cn

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Abstract

- In ultra-relativistic heavy-ion collisions, strong electromagnetic fields arising from the Lorentz-contracted, highly charged nuclei can be approximated as a large flux of high-energy quasi-real photons that can interact via the Breit-Wheeler process to produce e^+e^- pairs.
- Within a given experimental kinematic acceptance, the cross section of e^+e^- pairs from the Breit-Wheeler process in heavy-ion collisions is found to increase while the pair transverse momentum ($\sqrt{\langle p_T^2\rangle}$) decreases with increasing beam energy.
- The corresponding results found to be sensitive to the nuclear charge distribution and the infrared-divergence of the ultra-Lorentz boosted Coulomb field. Following this approach we demonstrate that the experimental measurements of the Breit-Wheeler process in heavy-ion collisions can be used to quantitatively constrain the nuclear charge radius. The extracted parameters show sensitivity to the impact parameter dependence, and can be used to study the initial-state and final-state effects in hadronic interactions.

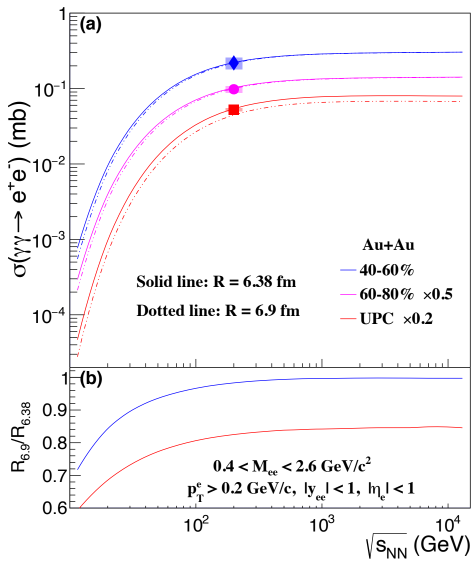
Introduction

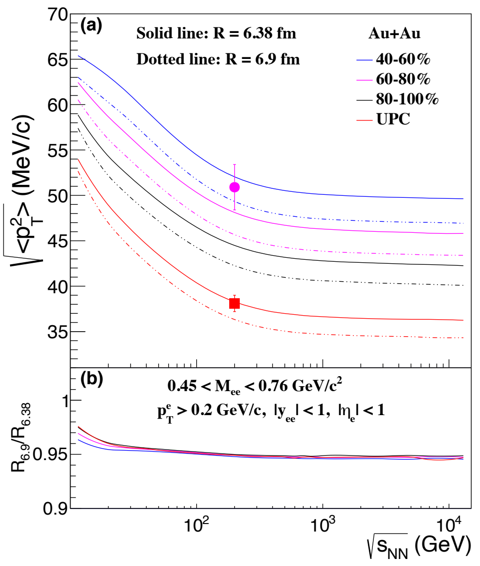
- In high-energy e^+e^- collisions, photon flux diverges at both high and low four-momentum transfer
  [P. A. Zyla *et al.* (PDG), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)]
- The photon flux does not diverge in heavy-ion collisions, which naturally regulated by the form factor at high q and finite ω/γ at low q
  [J. D. Brandenburg et al, Eur. Phys. J. A 57, 299 (2021)]
  [F. Krauss et al, Prog. Part. Nucl. Phys. 39, 503 (1997)]

$$n(\omega) = \frac{(Ze)^2}{\pi\omega}\int_0^\infty \frac{d^2k_\perp}{(2\pi)^2}\left[\frac{F\left(\left(\frac{\omega}{\gamma}\right)^2+\vec{k}_\perp^2\right)}{\left(\frac{\omega}{\gamma}\right)^2+\vec{k}_\perp^2}\right]^2$$

- The photon source from heavy-ion collisions is crucial for the discovery of the Breit-Wheeler process
- We can further test this by studying the beam energy dependence of the cross section and $\sqrt{\langle p_T^2\rangle}$

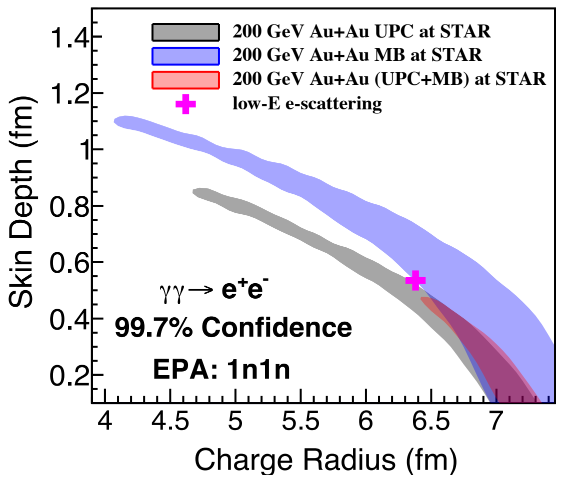
Beam Energy Dependence of Cross Section and $\sqrt{\langle p_T^2\rangle}$





- The cross section of e^+e^- pairs from Breit-Wheeler process increases with beam energy
- The $\sqrt{\langle p_T^2\rangle}$ of e^+e^- pairs from Breit-Wheeler process decreases with increasing beam energy
- The ratios which deviate from unity demonstrate that the kinematics of the Breit-Wheeler process are sensitive to the details of the nuclear charge distribution.

Application: Constrain Nuclear Charge Distribution



RMS of radius, low-E e-scattering: 5.33 fm

	UPC	MB	UPC+MB
RMS	5.39+0.14-0.21	5.67+0.08-0.12	5.53+0.10-0.02

- Using LO QED calculate Breit-Wheeler process to match data with least-χ^2
- UPC consistent with nominal nuclear geometry
- Peripheral collisions systematically larger

Summary

- Within a given experimental kinematic acceptance, the cross section is found to increase while the $\sqrt{\langle p_T^2\rangle}$ decreases with increasing beam energy.
- We demonstrate that the experimental measurements of the Breit-Wheeler process in ultra-relativistic heavy-ion collisions can be used to quantitatively constrain the nuclear charge radius.