Measurements of proton-antiproton pairs from QED vacuum excitation in Au+Au ultra-peripheral collisions at $\sqrt{s_{NN}}$ = 200 GeV from STAR

Xin Wu (Email: wuxinust@ustc.edu.cn), *for the STAR Collaboration*
University of Science and Technology of China

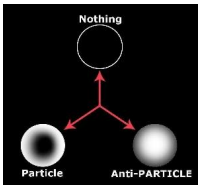
Quark Matter 2025

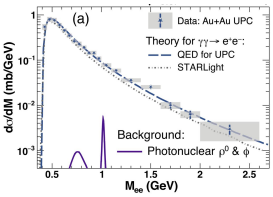
Abstract

Relativistic heavy-ion collisions generate extremely strong electromagnetic fields, providing an ideal environment to study the electromagnetic excitation of the vacuum. This poster shows the first measurements of baryon-antibaryon pair production from QED vacuum excitation in Au+Au ultra-peripheral collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR experiment. These measurements will shed new lights on the understanding of the QED vacuum.

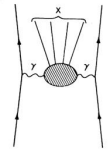
Motivation

- The ground state of quantum system is characterized by zero-point motion, and consequentially the creation and annihilation of virtual matter and antimatter particle pairs occur all the time in QED vacuum.
- An electromagnetic field which reaches the Schwinger limit would separate the virtual particle pairs. These virtual particle pairs will evolve to real particle pairs in a dynamic environment and be observed.
- The Breit-Wheeler process has been observed by STAR[1], however, higher excitation mode of QED vacuum from pure electromagnetic fields has never been observed.





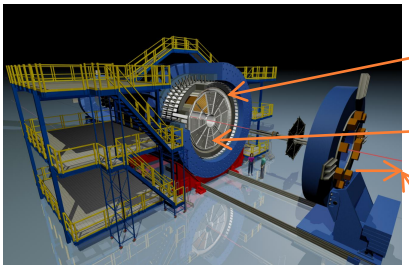
Breit-Wheeler process



$\gamma\gamma \rightarrow h\bar{h}$?

[1] STAR Collaboration, Phys.Rev.Lett. 121 (2018) 13, 132301

The Solenoidal Tracker At RHIC (STAR)



Time of Flight: particle identification

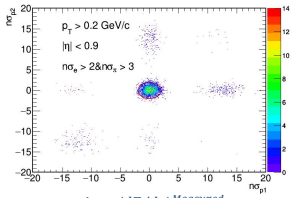
Time Projection Chamber: track reconstruction, particle identification

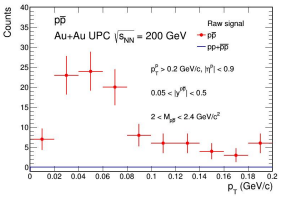
Zero Degree Calorimeter: neutron detection

Event Selection

- Dataset: Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV taken in 2010, 2011 and 2014
- Triggered events: ultra-peripheral collisions with Coulomb excitation in both sides
- Luminosity: 679 μb^{-1} (2010), 621 μb^{-1} (2011), 1270 μb^{-1} (2014)

PID and Raw $p\bar{p}$ Signal

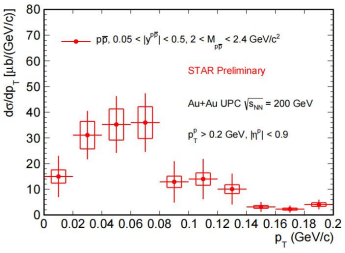


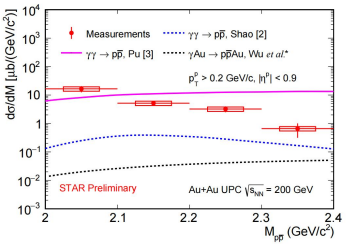


$$n\sigma_x = \frac{1}{\sigma}\log\frac{(dE/dx)^{Measured}}{(dE/dx)_x^{Theory}},\quad \chi^2_{x_1x_2} = n\sigma_{x_1}{}^2 + n\sigma_{x_2}{}^2$$

- PID: $\chi^2_{p\bar{p}}$ <4 & $n\sigma_e$ > 2 & $n\sigma_\pi$ > 3, pairs with |y|<0.05 are rejected to remove cosmic rays.
- Significant $p\bar{p}$ signals are observed at p_T < 0.1 GeV/c.

Cross Section





- $\sigma_{AuAu\rightarrow AuAup\bar{p}}$ = 2.6 ± 0.4($stat$) ± 0.5(sys) μb.
- The $p\bar{p}$ pairs located at very low p_T region.
- The $\gamma\gamma\rightarrow p\bar{p}$ theoretical calculation (within the measured acceptance) from different models vary considerably. The measured cross section has the potential to constrain parameters within these models. $\gamma Au \rightarrow p\bar{p}Au$ contribution is negligible.

[2] Shao, arXiv:2406.05618
[3] Pu, arXiv:2407.06091
* Private communication

Summary and Outlook

- The vacuum excitation $p\bar{p}$ pairs has been observed, and the invariant mass spectra are compared to theoretical calculations.
- Next to do: Measure the angular modulation to extract the polarization information.

Supported in part by the U.S. DEPARTMENT OF ENERGY Office of Science

University of Science and Technology of China

The STAR Collaboration