Low-$p_T$ $\mu^+\mu^-$ production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

Zhen Liu (for the STAR Collaboration)
State Key Laboratory of Particle Detection and Electronics,
University of Science and Technology of China
Dileptons – penetrating probe of QGP

- Do not suffer strong interactions
- Bring direct information of the medium created in heavy-ion collisions
Dileptons from photon interactions

- Boosted nuclei have intense electromagnetic field $\Rightarrow$ treated as quasi-real photons in the Weizsacker-Williams equivalent photon approximation
  - Photon flux increases with $Z^2$
  - Photoproduction is distinctly peaked at low $p_T$

- Conventionally studied in ultraperipheral collisions (UPCs)

G. Breit and John A. Wheeler, Phys. Rev. 46 (1934) 1087
Photons in hadronic heavy-ion collisions

• Photons interact at the very beginning
• The dileptons can bring the information from the nuclear overlap region

Example of dilepton spatial distributions at z=0 in 50-60% Au+Au collisions

Photoproduction with nuclear overlap

- Excess $e^+e^-$ pair $p_T$ distribution concentrates below $p_T \sim 0.15$ GeV/c
  - Evidence of photon interactions in hadronic heavy ion collisions


ALICE, S. Scheid, QM2019
Sensitivity to electromagnetic field trapped in QGP?

• Calculated $p_T^2$ spectra with EM effects can describe the Au+Au data much better than the same model without incorporating EM effects.

  □ The level of $p_T$ broadening may indicate the existence of strong magnetic field trapped in a conducting QGP?

  □ Or due to the QED scattering between the lepton pair and the medium?


Sensitivity to electromagnetic field trapped in QGP?

The broadening originates predominantly from the initial electromagnetic field strength that varies significantly with impact parameter.

An additional small broadening may be due to final-state interaction.

Data:
Theoretical calculations:
More studies are needed to understand the modification of coherent photoproduction with nuclear overlap.

Low-$p_T$ muon pairs production measurements provide a complementary channel and will help to further improve our understanding of photon-induced processes.
The Solenoid Tracker At RHIC (STAR)

• Mid-rapidity detector: $|\eta| < 1$, $0 < \varphi < 2\pi$

Muon Telescope Detector

($\sim 45\%$ in $\varphi$, $|\eta| < 0.5$): trigger on and identify muons

Time Projection Chamber:
measure momentum and energy loss
Muon PID with TPC+MTD

Data set: 2014 Au+Au 200 GeV, full luminosity ~ 14.2 nb⁻¹

MTD system:
• fully installed in 2014, behind magnet backlegs (~ 5 interaction length)
  • $p_T^\mu > 1.3$ GeV/c could hit MTD
  • Precise timing measurement ($\sigma \sim 100$ ps)
    • Arrive time: $\Delta$tof cut
  • Spatial resolution (~ 1 cm)
    • Hit position: $\Delta y$ and $\Delta z$ cut

TPC:
• measure energy loss
  • $dE/dx$ cut: muons are expected to lose about $0.5\sigma$ more energy compared to pions; $-1 < n\sigma_\pi < 3$ (2.5$\sigma$)

MTD system provides the possibility of muon pair measurement in the high mass region
Signal Extraction

- The $\mu^+\mu^-$ invariant mass distribution for $p_T < 0.15$ GeV/c in peripheral collisions
  - The mixed-event technique is used to estimate the combinatorial background
  - Focused on the high mass region $3.2 < M_{\mu\mu} < 10$ GeV/c$^2$
In invariant mass spectra in peripheral collisions

- Significant enhancement with respect to the cocktail in 60-80% centrality collisions
- Consistent with the theoretical calculation

Equivalent Photon Approximation (EPA) method
- Photon is treated as real
- Weizsacker–Williams method to estimate photon flux

Calculations based on EPA method by W.M. Zha et al.
- Use Woods-Saxon charge distribution in nucleus for photon flux estimation
- Consider dilepton production inside nucleus

$p_T$ distributions in peripheral collisions

- Excesses concentrate below $p_T \approx 0.15$ GeV/c
- Data are consistent with hadronic expectation when $p_T > 0.15$ GeV/c
- Theoretical calculation is compatible with data

Dimuon in low mass region

- TPC+TOF: dimuon measurement in low mass region ($0.4 < M_{\mu\mu} < 0.65$ GeV/c$^2$) is ongoing
  - Provide a complementary mass range
  - Help to further improve our understanding of photon induced processes


$m^2 = \frac{(p/(\beta\gamma))^2}{m^2}$
Isobaric collisions in 2018

- $^{96}_{44}\text{Ru}$ vs. $^{96}_{40}\text{Zr}$
  - Charge differs by 10%, everything else is almost the same
  - Huge statistics: 3.1B minimum-bias events for each

- 60-80% Au+Au vs. 47-75% Ru+Ru
  - Similar hadronic contribution
  - Different yields from two photon interactions

- Statistics
  - 60-80% Au+Au: ~180M
  - 47-75% Ru+Ru (Zr+Zr): ~840M

- Yield ratio in 0.4-0.76 GeV/c$^2$
  - Au : Ru : Zr $\approx 8.11 : 1.46 : 1$
  - Difference between Ru+Ru and Zr+Zr: 3.7σ
  - Help to verify and constrain the possible trapped magnetic field
Summary

• A significant $\mu^+\mu^-$ enhancement w.r.t. cocktail is observed at very low $p_T$ in peripheral Au+Au collisions at 200 GeV
  • Measured in high mass region $3.2 < M_{\mu\mu} < 10 \text{ GeV}/c^2$
  • Excess entirely happens below $p_T \approx 0.15 \text{ GeV}/c$
  • Compatible with the theoretical calculation

• Outlook
  • The low-$p_T$ dimuon measurement in low mass region and using the isobaric data could further improve our understanding of photon induced processes
Thanks for your attention!