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

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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 ⇒ 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)

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G. Breit and John A. Wheeler, Phys. Rev. 46 (1934) 1087

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PHENIX, PLB 679 (2009) 321
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
### 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?


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Sensitivity to electromagnetic field trapped in QGP?

Data:

\[ \frac{d^2N}{dp_T^2 dy} \] ((GeV/c)^2)

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

Muon Telescope Detector
(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: \(\Delta\text{tof}\) 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$^2$
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

$p_T$ 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 ($0.4 < M_{\mu\mu} < 0.65 \text{ GeV}/c^2$) is ongoing
  - Provide a complementary mass range
  - Help to further improve our understanding of photon induced processes

$0.17 < p_T < 0.25 \text{ GeV}/c$

$m^2 = (p/(\beta\gamma))^2$

Isobaric collisions in 2018

• $^{96}_{44}\text{Ru} \text{ vs. } ^{96}_{40}\text{Zr}$
  • 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

W.M. Zha et. al., PLB 789 (2019) 238-242
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 $3.2 < M_{\mu\mu} < 10$ GeV/c$^2$
  • Excess entirely happens below $p_T \approx 0.15$ 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!