Beam energy and collision species dependences of photon-induced lepton pair production at STAR

Xiaofeng Wang (王晓凤)
For the STAR Collaboration
Shandong University (山东大学)
\( \gamma \gamma \rightarrow l^+ l^- \) Process

- Highly Lorentz-contracted charged nuclei produce electromagnetic fields (EM)

- Equivalent Photon Approximation (EPA): EM fields \( \rightarrow \) a flux of quasi-real photons
  

- 1934 Breit & Wheeler: “Collision of two Light Quanta”
  

- High photon density with highly charged nuclei \( (\propto Z^2) \)
\[ \gamma \gamma \rightarrow l^+ l^- \] in Peripheral Collisions


Observation of \( \gamma \gamma \rightarrow e^+ e^- \) in hadronic heavy ion collisions at STAR

- Energy dependence?
- Centrality dependence?
- Di-muon?
- Collision species dependence?
The Solenoid Tracker At RHIC (STAR) and PID

Time Projection Chamber (TPC): momentum and energy loss

Time Of Flight (TOF): velocity

TOF selection

Centrality: 80-100%

$\sigma_n = 54.4\text{GeV}$

Au+Au

$\Delta \beta (\mu)$

Au+Au 200GeV @STAR
Excesses above hadronic production are observed at low-$p_T$.

Lowest order EPA-QED predictions are consistent with observed excesses.

Energy dependence
54.4 GeV, 200 GeV

Centrality dependence
40-60%, 60-80%, 80-100%

Transverse Momentum Distribution

$\mu^+ \mu^-$ pairs

Similar excesses at low-$p_T$ observed in the $\mu^+ \mu^-$ channel
Excesses (Data - Cocktail) are extracted

No vector meson observed ($\gamma\gamma \rightarrow e^+e^-$)

Excesses are well described by lowest order EPA-QED predictions
**Invariant Mass Distribution at Low-$$p_T$$**

$$\gamma\gamma \rightarrow \mu^+\mu^-$$

**EPA-QED predicts different cross sections due to electron and muon mass difference**

**Excesses (Data - Cocktail) are extracted**

**Excesses are well described by lowest order EPA-QED predictions**

---

**0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7**

**10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}**

**Au+Au 200GeV @STAR**

0<$$p_T^{\mu\mu}$$<0.10 GeV/c  l$$y^{\mu\mu}$$l<0.8
0.18 $$p_\mu$$<0.30 GeV/c  l$$p_\mu$$l<0.8

**STAR Preliminary**
Excess yield increase with beam energy

EPA-QED predicts similar energy dependence

\[ \gamma \gamma \rightarrow e^+ e^- \]
Energy and Centrality Dependence of $\sqrt{\langle p_T^2 \rangle}$

$\gamma\gamma \rightarrow e^+e^-$

\[ \sqrt{\langle p_T^2 \rangle} \] is sensitive to $p_T$ broadening

$\sqrt{\langle p_T^2 \rangle}$ decreases from semi-peripheral to peripheral collisions

Initial state effect: Impact parameter dependence

Energy dependence(3.7σ compared to 200 GeV QED) and/or final state effect(1.8σ)

\[ \sqrt{\langle p_T^2 \rangle} \] is sensitive to $p_T$ broadening

Initial state effect: Impact parameter dependence

Energy dependence(3.7σ compared to 200 GeV QED) and/or final state effect(1.8σ)
Application: Constrain Charge Distribution

\[ \gamma \gamma \rightarrow \ell^+ \ell^- \] can be used to constrain nucleus charge distribution at RHIC energy

STAR data compared to EPA-QED

Low energy scattering: R=6.38 fm, d=0.535 fm
R. C. Barrett and D. F. Jackson, Nuclear Sizes and Structure (Oxford University Press, 1977)

200 GeV vs 54.4 GeV: maybe due to energy dependence of charge distribution

Low-energy vs RHIC (3\sigma difference): maybe due to energy dependence of charge distribution and/or final state effect

Collision Species Dependence \((^9_{44}\text{Ru} + ^9_{44}\text{Ru}, ^{96}_{40}\text{Zr} + ^{96}_{40}\text{Zr})\)

\[\gamma\gamma \rightarrow e^+e^-\]

At very low \(p_T\) (< 0.15 GeV/c), \(e^+e^-\) pairs dominated by \(\gamma\gamma \rightarrow e^+e^-\)

Ratio is consistent with \(\left(\frac{44}{40}\right)^4\) at very low \(p_T\)

Initial EM field is different in Ru + Ru and Zr + Zr (~3\(\sigma\))

At \(p_T > 0.15\) GeV/c, hadronic production contributions to \(e^+e^-\) pairs are similar in Ru + Ru and Zr + Zr

Poster by Kaifeng Shen (04/06/22 6:30-7:30)
Collision Species Dependence \((^{96}\text{Ru} + ^{96}\text{Ru}, ^{94}\text{Zr} + ^{96}\text{Zr})\)

- At very low \(p_T\), \(J/\psi\) dominated by \(\gamma A \rightarrow J/\psi\)
- Ratio is consistent with \((\frac{44}{40})^2\) at very low \(p_T\)
- Initial EM field is different in \(\text{Ru} + \text{Ru}\) and \(\text{Zr} + \text{Zr}\) \((\sim 1.7\sigma)\)
- At \(p_T > 0.2\) GeV/c, hadronic production contributions to \(J/\psi\) are similar in \(\text{Ru} + \text{Ru}\) and \(\text{Zr} + \text{Zr}\)

\[\text{STAR Preliminary}\]
\[\text{Isobar (Ru+Ru)/(Zr+Zr), } \sqrt{s_{\text{NN}}}=200\text{ GeV}\]
\[\gamma + A \rightarrow J/\psi + X, |y|<1.0\]
\[J/\psi \rightarrow e^+e^- (M_{ee}: 3.0 - 3.2\text{ GeV/c}^2)\]

Data: 40-80%

\[\frac{44}{40}^2\text{ scaling}\]

Poster by Kaifeng Shen (04/06/22 6:30-7:30)
Collision Species Dependence \((^{96}_{44}\text{Ru} + ^{96}_{44}\text{Ru}, ^{96}_{40}\text{Zr} + ^{96}_{40}\text{Zr})\)

\[ \gamma A \rightarrow J/\psi \]

\[ J/\psi \text{ excess yield} \propto Z^2 \]

Photoproduced \(J/\psi\) yields seem to be independent of form factor and impact parameter.


Poster by Kaifeng Shen (04/06/22 6:30-7:30)
**Summary**

- Beam energy and centrality dependences of $\gamma \gamma \rightarrow l^+ l^-$ have been measured at STAR
  - Excess yield: **Increases with beam energy**
  - $\sqrt\langle p_T^2 \rangle$: Decreases with increasing impact parameter
  - $\sqrt\langle p_T^2 \rangle$: **Energy dependence** (3.7σ compared to 200 GeV QED)
  - Application: $\gamma \gamma \rightarrow l^+ l^-$ can be used to **constrain nuclei charge distribution at RHIC energy**

- Collision species dependence of $\gamma \gamma \rightarrow l^+ l^-$ and $\gamma A \rightarrow J/\psi$ have been measured at STAR
  - **Initial EM field is different** in Ru + Ru and Zr + Zr ($\sim3\sigma$ in $e^+ e^-$ ⊕ $\sim1.7\sigma$ in $J/\psi$)
  - Photon-induced $J/\psi$ yield $\propto Z^2$