Dilepton production in p+p, Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV

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In This Talk

Part I
• Very low \( p_T e^+e^- \) invariant mass spectra in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) and U+U collisions at \( \sqrt{s_{NN}} = 193 \text{ GeV} \)

See Shuai Yang’s Poster : Poster ID 340

Part II
• First look at \( \mu^+\mu^- \) invariant mass spectra with the Muon Telescope Detector at STAR in p+p collisions at \( \sqrt{s} = 200 \text{ GeV} \) and peripheral Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)
Motivation: Low $p_T$ J/$\psi$ Enhancement

→ STAR and ALICE have observed significant excess production of J/$\psi$ in peripheral A+A collisions at low $p_T$ ($p_T < 300$ MeV/c)

→ Cannot be described by hadronic production modified by medium / cold nuclear matter effects

→ May be due to coherent photoproduction?

→ Observed in collisions with impact parameter $b < 2$ R

Motivation to measure $e^+e^-$ pair production over a wider invariant mass range

J/$\psi$ $R_{AA}$ in Au+Au and U+U Collisions via J/$\psi \rightarrow e^+e^-$

STAR Preliminary

- Au+Au 200 GeV
- U+U 193 GeV
- $p+p$ baseline uncertainty
- $N_{col}$ uncertainty

centrality: 60 - 80%

See Wangmei Zha’s poster
Poster ID 258
**Time Projection Chamber (TPC)**
- Charged particle tracking
- Momentum measurement
- Particle identification via ionization energy loss (dE/dx)

**Time-Of-Flight (TOF) Detector**
- Used in $e^+e^-$ analysis to reject slow hadrons
- Enables clean electron identification up to $p_T \sim 3$ GeV/c
→ Significant excess in 60-80% central Au+Au and U+U collisions for $M_{ee} < 4$ GeV/$c^2$

→ Excess becomes less significant in more central collisions
STAR $e^+e^-$ in Au+Au & U+U

Data - Cocktail
Centrality: 60-80%
$0 < p_T < 0.15$ GeV/c

$STAR$ Preliminary
$p_T > 0.2$ GeV/c, $|η|<1$, $|y_{ee}|<1$

- AuAu@200 GeV
- UU@193 GeV
- Sum
- In_Med
- QGP

→ Excess is consistent in Au+Au and U+U

→ Excess cannot be explained by hadronic contributions modified by medium

→ Can this excess be explained by coherent photoproduction?
→ Good agreement with hadronic cocktail contributions for $p_T > 0.2$ GeV/c

→ Excess is found entirely below $p_T < 0.2$ GeV/c
STAR $e^+e^-$ in Au+Au & U+U

→ Low $p_T$ shape very similar to that from coherent photoproduction in Ultra Peripheral Collisions

→ Can this excess in $e^+e^-$ be explained by coherent photoproduction?
What is coherent photoproduction?

Photoproduction in Ultra Peripheral Collisions (UPC)

Coherent:

→ Emitted photon/pomeron interacts with the nucleus as a whole
→ Strong coupling \((z\alpha_{EM} \sim 0.6)\) results in large cross sections
→ Photon wavelength \(\lambda = h/p > R_A\)
→ \(p_T < h/R_A \sim 30\) MeV/c for heavy ions

Photon Interactions in A+A Collisions

• We can gain insight into the production mechanism through the $t = p_T^2$ distribution due to interference effects

Coherent photon-nucleus interaction:

→ Photon can be emitted from $A_1$ or $A_2$, ie. two indistinguishable processes

→ For a vector meson, the amplitudes from each process have opposite signs

→ Results in strong destructive interference at very low $p_T$

• Experimentally distinguish by looking at $dN/dp_T^2$ distribution at very low $p_T$

Coherent Photoproduction in UPCs

→ What does this look like in the UPC case?

→ Coherent production characterized by large slope parameter for small \(|t|\)

\[
\text{SLOPE} = 426 \pm 2 \text{ (GeV/c)}^{-2}
\]

→ Interference visible as downturn for very low values of \(|t|\)

See Spencer Klein’s Talk
Ultra-peripheral collisions and hadronic structure, 10 Feb 2017, 18:00
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**Photon Interactions in 60-80% A+A?**

**AuAu@200 GeV, 0.4 < M_{ee} < 0.76 GeV/c^2**
\[ \chi^2/\text{ndf}: 3.07/4 \]
Slope: 371 ± 31 (GeV/c)^2

**AuAu@200 GeV, 1.2 < M_{ee} < 2.6 GeV/c^2**
\[ \chi^2/\text{ndf}: 0.55/3 \]
Slope: 287 ± 37 (GeV/c)^2

**STAR preliminary**

**UU@193 GeV, 0.4 < M_{ee} < 0.76 GeV/c^2**
\[ \chi^2/\text{ndf}: 5.08/4 \]
Slope: 506 ± 53 (GeV/c)^2

**UU@193 GeV, 1.2 < M_{ee} < 2.6 GeV/c^2**
\[ \chi^2/\text{ndf}: 1.26/4 \]
Slope: 411 ± 81 (GeV/c)^2

**Centrality: 60-80%**

Daniel Brandenburg | Quark Matter 2017
Photon Interactions in 60-80% A+A?

Large slope parameter is similar to that in UPC case.

STAR preliminary
Photon Interactions in 60-80% A+A?

Possible evidence of interference?
More data needed for definitive answer

STAR preliminary
→ Vector meson ($\rho^0, J/\psi$) is coherently produced with very low $p_T$
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→ Medium is produced by strong interaction
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→ Medium is produced by strong interaction

→ Meson has very low $p_T$ → it remains in the medium until it decays to an $l^+l^-$ pair
→ Vector meson ($\rho^0$, J/$\psi$) is coherently produced with very low $p_T$

→ Medium is produced by strong interaction

→ Meson has very low $p_T$ → it remains in the medium until it decays to an $l^+l^-$ pair

→ Since leptons are unaffected by the strong force, they carry information to the final state

→ Provide a clean probe of medium
Part I

• Very low $p_T e^+e^-$ invariant mass spectra in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV

Part II

• First look at $\mu^+\mu^-$ invariant mass spectra with the Muon Telescope Detector at STAR in p+p collisions at $\sqrt{s} = 200$ GeV and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
Muon Telescope Detector (MTD)

- $|\eta| < 0.5$
- Azimuthal coverage ~ 45%
- Precise timing $\sigma \sim 100$ picoseconds
- Precise spatial resolution ~1 cm
• STAR’s Muon Telescope Detector allows for new studies of the dimuon continuum at RHIC energies with STAR.

<table>
<thead>
<tr>
<th>Species</th>
<th>Energy (GeV)</th>
<th>~Sampled Luminosity</th>
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</thead>
<tbody>
<tr>
<td>p+p (63% MTD)</td>
<td>500</td>
<td>28 pb⁻¹</td>
</tr>
<tr>
<td>p+p</td>
<td>200</td>
<td>122 pb⁻¹</td>
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<tr>
<td>p+Au</td>
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<td>Au+Au 2014</td>
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<td>14 nb⁻¹</td>
</tr>
<tr>
<td>Au+Au 2016</td>
<td>200</td>
<td>13 nb⁻¹</td>
</tr>
</tbody>
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Why measure $\mu^+\mu^-$ in central heavy ion collisions?
→ Low mass excess is sensitive to the lifetime of the medium
→ Rho meson broadening may be a probe of chiral symmetry restoration
→ Intermediate mass region is sensitive to QGP thermal radiation.

Measurements of $\mu^+\mu^-$ in p+p collisions:
→ Baseline for Au+Au measurements
$\mu^+ \mu^-$ in Run15 p+p @ $\sqrt{s} = 200$ GeV

STAR Preliminary

2015 p+p at $\sqrt{s} = 200$ GeV
$p_T^\mu > 1.0$ GeV/c, $|\eta^\mu| < 0.5$
$|y_{\mu\mu}| < 0.5$

- Raw Unlike-Sign
- Like-Sign Background
- Signal

$J/\psi$
$\omega$
$\phi$
$\psi(2S)$

$dN/dM$ (GeV/c$^2$)$^{-1}$ vs. $M_{\mu\mu}$ (GeV/c$^2$)
Data Triggered by dedicated Dimuon Trigger

In 60-80% Au+Au:
→ Clear $\phi$ and $J/\psi$ peaks
→ $S/B > \sim 1/10$
   ($\sim 1/100$ to $1/250$ in $e^+e^-$)

Significantly more data in semi-central and central collisions

→ Expect exciting new $\mu^+\mu^-$ results from STAR
Summary

Low $p_T e^+e^-$ measurements in Au+Au and U+U

- Significant excess yield with respect to hadronic sources observed across wide invariant mass range ($M_{ee}<4$ GeV/$c^2$)
- Shape and slope of $t$ distribution show evidence of interference
- Large slope parameter is evidence for UPC-like coherent photoproduction mechanism
- Future studies will help clarify production mechanism
- May provide a novel probe of the medium

First look at $\mu^+\mu^-$ invariant mass spectra from the Muon Telescope Detector at STAR

- New measurements possible at STAR with MTD
- Clear $\omega, \phi, J/\psi, \psi(2S)$ signal in p+p collisions @ $\sqrt{s}=200$ GeV
- Expect exciting new $\mu^+\mu^-$ results from STAR
Thank you
$J/\psi$ dN/dt distribution for Au+Au @ $\sqrt{s_{NN}} = 200$ GeV (40-80%)
J/ψ \( R_{AA} \) for Au+Au collisions @ \( \sqrt{s_{NN}} = 200 \) GeV and U+U collisions @ \( \sqrt{s_{NN}} = 193 \) GeV

See Wangmei Zha’s poster: Poster ID 258
ALICE, Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV
$2.5 < y < 4$

$0 \leq p_T < 0.3$ GeV/c, global syst = ±15.7 %

$0.3 \leq p_T < 1$ GeV/c, global syst = ±15.1 %

$1 \leq p_T < 8$ GeV/c, global syst = ±11.5 %

Common global syst = ±6.8 %

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