Direct Photon Production from measurements of the low-mass $e^+e^-$ excess at STAR

Chi Yang$^1$

for the STAR Collaboration

1. University of Science and Technology of China

Hard Probes 2016, Sep. 23-27, 2016, Wuhan, China
Outline

- Motivation
- STAR detector
- Electron identification
- $e^+e^-$ production
- Direct photon production
- Summary and outlook
Motivation

Direct photon and e+e- pairs
------ ideal electroweak probes
✓ suffer no strong interaction, traverse the medium with minimum interaction
✓ produced throughout all stages of the evolution of the system

Direct photon:
✓ high $p_T$ photons (>5GeV/c) : initial hard scattering
✓ low $p_T$ photons (1-5GeV/c) : access QGP production

Similar process for virtual photon production, which could convert into e+e- pair.

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

e^+e^- pairs:
• higher invariant mass => earlier production

- Low Mass Region
  ✓ In-medium modification of vector mesons

- Intermediate Mass Region
  ✓ QGP thermal radiation
  ✓ Semi-leptonic decay of correlated charm: charm modification in Au+Au

- High Mass Region
  ✓ Heavy quarkonia
  ✓ Drell-Yan process

Cocktail simulation in Au+Au 200GeV
STAR detectors

Key detectors used in the analysis:

**Time Projection Chamber:**
- $|\eta| < 1 \quad 0<\Phi<2\pi$
- Main tracking detector: track, momenta, ionization energy loss (dE/dx)

**Time Of Flight:**
- $|\eta| < 0.9 \quad 0<\Phi<2\pi$
- Intrinsic timing resolution ~ 75 ps
- Time-of-flight measurement

**Barrel Electro-Magnetic Calorimeter:**
- $|\eta| < 1 \quad 0<\Phi<2\pi$
- Trigger on and measure high-$p_T$ processes

<table>
<thead>
<tr>
<th>Type</th>
<th>Year</th>
<th>Central</th>
<th>Min.Bias</th>
<th>EMC trigger (energy threshold 4.3GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au+Au 200GeV</td>
<td>2010</td>
<td>220M</td>
<td>240M</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>490M</td>
<td>39M</td>
<td></td>
</tr>
<tr>
<td>p+p 200GeV</td>
<td>2012</td>
<td>375M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Electron identification

Time-Of-Flight provides clean electron identification from low to intermediate $p_T$ which enables the dielectron measurements.

<table>
<thead>
<tr>
<th>Collision system</th>
<th>Trigger</th>
<th>Momentum range</th>
<th>Purity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au+Au 200GeV</td>
<td>Min.Bias</td>
<td>0.2 – 2.0 GeV/c</td>
<td>~95%</td>
</tr>
<tr>
<td></td>
<td>Central</td>
<td>0.2 – 2.0 GeV/c</td>
<td>~93%</td>
</tr>
<tr>
<td></td>
<td>EMC trigger</td>
<td>3.5 – 6.0 GeV/c</td>
<td>Up to 80%</td>
</tr>
<tr>
<td>p+p 200GeV</td>
<td>Min.Bias</td>
<td>0.2 – 2.0 GeV/c</td>
<td>~98%</td>
</tr>
</tbody>
</table>

Require $\beta$ close to speed of light
Invariant mass distribution and cocktail input for Au+Au at $\sqrt{s_{NN}} = 200\text{GeV}$

**Input $p_T$ spectra**

- $\pi^+$
- $\pi^-$
- $K^+$
- $K^-$
- $\phi$
- $\eta$
- $J/\psi$
- $\psi'$

$M_{ee} < 1 \text{ GeV}/c^2$ Like sign background

$M_{ee} \geq 1 \text{ GeV}/c^2$ Mixed event background

**References**


$\pi$ low $p_T$

$\eta$ (scaling)

Tsallis

$K_{PHENIX}$

$K^+$

$K^-$

$\phi$

$J/\psi_{PHENIX}$

$\psi'$

$\eta_{PHENIX}$

$\omega$

$\eta$

$J/\psi_{PHENIX}$

$\psi'$

Chi Yang, Hard Probes 2016, Sep. 22-27, Wuhan, China
Au+Au at $\sqrt{s_{NN}} = 200$GeV results

The measured enhancement factor at $\rho$-like region (0.30-0.76 GeV/c$^2$) is $1.77 \pm 0.11$ (stat.) $\pm 0.24$ (sys.) $\pm 0.33$ (cocktail) in Min.Bias.

Comparison with models based on a $\rho$-broadening scenario:

1) Model I: effective many-body model
   [R. Rapp, PoS CPOD2013, 008 (2013)]

2) Model II: Parton-Hadron String Dynamics (PHSD)

Models show good agreement with data within uncertainty.
e^+e^- pairs from internal conversion

- Relation between real photon yield and the associated e^+e^- pairs:

\[
\frac{d^2N_{ee}}{dM} = \frac{2\alpha}{3\pi} \frac{L(M)}{M} S(M, q) dN_{\gamma}
\]

- \(\checkmark\) pass STAR acceptance
- \(\checkmark\) normalize to 0-30MeV/c^2

\[
S(M, q) = \frac{dN_{\gamma}^*}{dN_{\gamma}}
\]

\[
L(M) = \sqrt{1 - \frac{4m_e^2}{M^2}} (1 + \frac{2m_e^2}{M^2})
\]

Direct photons can be measured by the associated e^+e^- production.

\(S = 1 \Rightarrow\) direct photon \((p_T \gg M, M \gg m_e)\)

- : two-component fit to e^+e^- continuum.

\[
r = \frac{\text{yield of direct photon}}{\text{yield of inclusive photon}}
\]
Low mass $e^+e^-$ continuum

- 1-3 GeV/c
  Run10+Run11 MB data

- 5-10 GeV/c
  Run11 EMC triggered data

The statistical and systematic uncertainties are shown by the bars and bands, respectively.
Two component fit and fraction of direct photon

The curves represent NLO pQCD prediction:

\[ T_A d\sigma^{NLO}_{\gamma}(p_T) dN_{\text{inclusive}}^{\gamma}(p_T) \]


Compared to p+p reference, an excess is observed in low p_T
Direct photon invariant yield
Direct photon invariant yield

No $\eta$ measurement for cocktail simulation input
Large uncertainty (>100%)

$d^2N/(2\pi p_T \, dp_T \, dy)$ (GeV/c)^2

$3 < p_T < 5$ GeV/c
Low purity and statistics
Direct photon invariant yield

In the high $p_T$ range above 6 GeV/c
- the yield is consistent with a $T_{AA}$ scaled fit function to PHENIX pp data.

In the $p_T$ range 1~3 GeV/c
- Compared to the pp reference, an excess is observed in 10-40% and 40-80%.
- [arXiv:1607.01447]
Compared to model prediction

**Rapp calculation:**
elliptic thermal fireball evolution
(consistent with their (2+1)-D hydrodynamic evolution (beam-direction independent))

**Paquet calculation:**
(2+1)-D hydrodynamic evolution

both models include:
- QGP thermal radiation
- in-medium meson
- mesonic interactions in the hadronic gas
- primordial contributions from the initial hard parton scattering

---

H. van Hees, C. Gale, and R. Rapp

H. van Hees, M. He, and R. Rapp
[Nucl. Phys. A 933, 256 (2015)]

J.-F. Paquet et al.,
[Phys. Rev. C 93, 044906 (2016)]
private communications
Compared to model prediction

\( p_T \) 1-3 GeV/c: 
thermal radiation dominant

\( p_T > 6 \) GeV/c: 
initial hard-parton scattering dominant

The comparison shows consistency between both model calculations and measurements within uncertainties for all the other centralities except 40-80% centrality.

40-80% includes peripheral collisions, where hydrodynamic calculations might not be applicable.

H. van Hees, C. Gale, and R. Rapp

H. van Hees, M. He, and R. Rapp
[Nucl. Phys. A 933, 256 (2015)]

J.-F. Paquet et al.,
[Phys. Rev. C 93, 044906 (2016)]
private communications

[arXiv:1607.01447]
Total yield and excess yield

The model calculations are consistent with our measurements within uncertainties in central and semi-central for both excess and total direct photon yield.

H. van Hees, C. Gale, and R. Rapp

H. van Hees, M. He, and R. Rapp
[Nucl. Phys. A 933, 256 (2015)]

J.-F. Paquet et al.,
[Phys. Rev. C 93, 044906 (2016)]
private communications

[arXiv:1607.01447]
Total yield and excess yield

<table>
<thead>
<tr>
<th>Comparison</th>
<th>$\chi^2/NDF$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAR data to Rapp</td>
<td>4.26/2</td>
<td>0.119</td>
</tr>
<tr>
<td>STAR data to Paquet</td>
<td>2.81/2</td>
<td>0.245</td>
</tr>
<tr>
<td>PHENIX data to Rapp</td>
<td>11.1/2</td>
<td>0.0038</td>
</tr>
<tr>
<td>PHENIX data to Paquet</td>
<td>16.9/2</td>
<td>2.2e-04</td>
</tr>
<tr>
<td>Total yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAR data to Rapp</td>
<td>3.98/2</td>
<td>0.137</td>
</tr>
<tr>
<td>STAR data to Paquet</td>
<td>2.78/2</td>
<td>0.249</td>
</tr>
<tr>
<td>PHENIX data to Rapp</td>
<td>12.8/2</td>
<td>0.0017</td>
</tr>
<tr>
<td>PHENIX data to Paquet</td>
<td>15.0/2</td>
<td>5.6e-04</td>
</tr>
</tbody>
</table>

PHENIX collaboration

H. van Hees, C. Gale, and R. Rapp

H. van Hees, M. He, and R. Rapp
[Nucl. Phys. A 933, 256 (2015)]

J.-F. Paquet et al.,
[Phys. Rev. C 93, 044906 (2016)]

private communications

[arXiv:1607.01447]
Summary

- Presented the *direct photon measurement* (1-3 and 5-10 GeV/c) from low-mass $e^+e^-$ excess in Au+Au collisions at STAR at $\sqrt{s_{NN}} = 200$GeV

- An enhancement compared with PHENIX p+p results is observed for 1-3 GeV/c in 10-40% and 40-80%

- In the $p_T$ range above 6 GeV/c there is no clear enhancement observed for all the centralities

- Model predictions including the contributions from thermal radiation and initial hard-processes are consistent with our direct photon yield within uncertainties in central and mid-central collisions

- In 40-80% centrality bin, the model calculation results are systematically lower than our data for 1<$p_T<$3 GeV/c

**Outlook:**

Direct photon in 62 GeV Au+Au collisions to study its behavior close to critical temperature
May have enough statistics from future RHIC run