Thermal Photon and Dilepton Results from STAR

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- Motivation
- STAR detector
- Physics results
  - Dielectron production results.
  - Direct photon results.
- Summary and Outlook

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Dilepton in RHIC

- **Dileptons – a bulk penetrating probe:**
  - Do not suffer strong interaction, penetrating the medium without final state effect.
  - Produced in all stages of the system evolution.
  - Provide direct information of medium.
  - Additional kinematic information (mass vs $p_T$), sensitive to different dynamics.

- **Challenges:**
  - Production rate is low, especially in higher mass region ($M_{ee} > 1\, \text{GeV}/c^2$).
  - Integrate over time and over many background sources.
Dilepton in RHIC

Interesting topics:

- **Low mass region (LMR):**
  - in-medium modifications of vector meson.
  - possible hint of chiral symmetry restoration.

- **Intermediate mass region (IMR):**
  - QGP thermal radiation.
  - semi-leptonic decays of correlated charm: possible charm de-correlation in Au+Au.

- **Direct photon:**
  - connect to dielectron through internal conversion.
  - high $p_T$ photons ($>5\text{GeV/c}$): initial hard scattering
  - low $p_T$ photons (1-5GeV/c): access QGP production
STAR detectors

Key detector used in this analysis:

➢ **Time Projection Chamber:**
   ➔ |η|<1, 0<Φ<2π
   ➔ Main tracking detector: track, momenta, ionization energy loss (dE/dx)

➢ **Time Of Flight:**
   ➔ |η|<0.9, 0<Φ<2π
   ➔ Intrinsic timing resolution ~ 75 ps
   ➔ Significant improvement for PID

➢ **Barrel Electro-Magnetic Calorimeter:**
   ➔ |η|<1, 0<Φ<2π
   ➔ Trigger and measure high-\(p_T\) particles

<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>
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<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>
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</table>
Electron identification

Clean electron PID in p+p and Au+Au collisions with a combination of TPC $dE/dx$ and TOF velocity

\[ n\sigma_e \text{ normalized } dE/dx \]

<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>Au+Au 200GeV</td>
<td>Central</td>
<td>0.2 – 2.0 GeV/c</td>
<td>~93%</td>
</tr>
<tr>
<td>Au+Au 200GeV</td>
<td>EMC trigger</td>
<td>3.5 – 6.0 GeV/c</td>
<td>~80%</td>
</tr>
<tr>
<td>p+p 200GeV</td>
<td>Min.Bias</td>
<td>0.2 – 2.0 GeV/c</td>
<td>~98%</td>
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</table>
**Background**

- **a. Low mass region**
  - **Like Sign – acceptance corrected**
    - ✓ can reproduce both the combinatorial and correlated background.
    - ✗ but lack of statistics and need correct acceptance factor
  
  \[ B_{\text{Like Sign}} = 2 \sqrt{N_{++} \cdot N_{--}} \cdot \frac{B_{\text{Mix}}^{++} \cdot B_{\text{Mix}}^{--}}{2 \cdot \sqrt{B_{\text{Mix}}^{++} \cdot B_{\text{Mix}}^{--}}} \]

  - \( N \): same Event, \( B_{\text{mix}} \): mixed Event

- **b. Mass > 0.75 GeV/c^2**
  - **Mixed Event – normalized to Like Sign in mass region [1,2] GeV/c^2**
    - ✓ large statistics and no need to correct acceptance.
    - ✗ but can't reproduce correlated background

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**PRL. 113 (2014) 22301**

\[ p_T^e > 0.2 \text{ GeV/c}, |\eta| < 1, |y_\gamma| < 1 \]

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**S/B**

\[ 0 \quad 1 \quad 2 \quad 3 \quad 4 \]

\[ \text{M}_{ee} \quad (\text{GeV/c}^2) \]

**Signal**

- \( p + p \)
- \( \text{Au + Au} \) (Central)
- \( \text{Au + Au} \) (MinBias)

**Background**

- \( \text{e}^+\text{e}^- \) same event
Cocktail simulation

Data Points:

TBW Fit:
Within uncertainty, the cocktail simulation reproduces the data very well. Greatly improved statistics ~ 7 times more than year 2009.
AuAu 200GeV results

**Enhancement w.r.t cocktail at ρ like region (0.30-0.76 GeV/c^2):**

1.77±0.11(stat.)±0.24(sys.)±0.41(cocktail) in MinBias.

Data is compared with two models both based on a ρ broadening scenario:

1) **Model I** by Rapp et al. is an effective many-body model. [R. Rapp, PoS CPOD2013, 008 (2013)]


Both models show good agreement with data within uncertainty.
The two model calculations show good agreement with data within uncertainty.
Possible charm de-correlation

Ratio\((Central/MinBias)\) shows 2.0\(\sigma\) deviation from the \(N_{bin}\) scaling in \(1.8<M_{ee}<2.8\text{GeV/c}^2\).

Possible charm de-correlation in Au+Au collision or other source from thermal radiation?

Beam Energy Scan at RHIC

**NSAC Long Range Plan 2007**
- ✔ Turn-off of the sQGP signature
- ✔ Search for the phase boundary.
- ✔ Search for the critical point.

**Dielectron production in BES:**
- **LMR:** in medium modification of vector meson. Study the chiral property of the medium.
- **IMR:** Searching for the onset of QGP thermal radiation.
Model calculations† robustly describe the data from 200 GeV to 20 GeV:

– model calculations by Rapp, based on in-medium broadening of $\rho$ spectra function, expected to depend on total baryon density.

– almost constant baryon density from 20-200 GeV.

†Model: Rapp & Wambach, priv. communication;
Acceptance corrected excess spectra

![Graph showing dielectron excess spectra](image)

**arXiv:1501.05341**

Spectra is corrected for STAR detector acceptance.

Normalized to mid-rapidity $dN_{\text{ch}}/dy$.

**NA60 Data:**

- R. Arnaldi et al., PRL. 96, 162302 (2006);
- R. Arnaldi et al., PRL. 100, 022302 (2008);

Blue line Rapp's model calculation, including a broadened spectral function and QGP thermal radiation.

**Excess spectra:**

- The model calculation from R. Rapp is consistent with acceptance corrected excess spectra of AuAu 19.6 GeV.
Low mass excess

Integrated excess yield within mass region 0.4~0.75 GeV/$c^2$:

- **AuAu 19.6 GeV:**
  - consistent with In+In 17.3 GeV.

- **AuAu 200 GeV:**
  - centrality dependence on the excess yield.
  - higher excess yield in central collision than In+In 17.3 GeVs indicates a longer life time of medium.
Dielectron from internal conversion

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

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

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

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

\[ S \sim 1 @ p_T >> M, M >> m_e \]

- Two component fit in mass region 0.1~0.3 GeV/c^2:

\[ (1 - r) f_c + r f_{dir} \]

- \( f_c \): cocktail normalized to 0~30 MeV/c^2
- \( f_{dir} \): direct virtual photon component normalized to 0~30 MeV/c^2.
- \( r \): ratio of the yield of direct virtual photon over the yield of inclusive photon
Low mass dielectron continuum

STAR, QM2014

➢ 0-5 GeV/c
Run10+Run11 MB data

➢ 5-10 GeV/c
Run11 EMC triggered data
Fraction of direct virtual photon

The curves represent NLO pQCD prediction:

\[
\frac{T_{AA}d\sigma^{NLO}_V(p_T)}{dN_{inclusive}^V(p_T)}
\]

Comparison to the p+p reference, an excess is observed up to 4GeV/c.

Direct virtual photon invariant yield

- In high $p_T$ region (5~10 GeV/c):
  - consistent with $T_{AA}$ scaled function fit to PHENIX p+p data.
- In low $p_T$ region:
  - an excess is observed in $p_T$ range 2~4 GeV/c.

Data are compared with $T_{AA}$ scaled function fit to PHENIX p+p data.

PHENIX data ref:
Low $p_T$ excess

Rapp's model prediction$^\dagger$:

$\rightarrow$ Including QGP, $\rho$, meson gas, and primordial production contributions.

$\rightarrow$ Well describing the low $p_T$ excess in our data within uncertainty.

$^\dagger$from private communication with R. Rapp for Min.Bias.

0-20%: initial temperature $\sim 320$MeV at 0.36fm/c, fireball life time $\sim 10$fm/c.

[Van Hees, Gale, and Rapp, Phys. Rev. C 84, 054906]
Summary

➢ **Dielectron production** :
  ➔ A clear excess is observed in LMR from 200 GeV to 19.6 GeV.
  ➔ The excess yields (in mass range 0.4~0.75 GeV/c²) show centrality dependence in 200 GeV Au+Au collisions.
  ➔ Within uncertainties, broadening of ρ model calculations can explain the excess in data from 200 GeV down to 19.6 GeV at RHIC.
  ➔ Comparing to In+In 17.3 GeV, higher excess yield in LMR at 200 GeV central Au+Au collisions indicates a longer life time of the medium.

➢ **Direct photon production** :
  ➔ An excess is observed in ($p_T$ range 2~4 GeV/c) when compared to p+p reference and the invariant yield is consistent with model prediction.
  ➔ For $p_T$ range 5~10 GeV/c, the invariant yield follows a $T_{AA}$ scaled p+p results.
Outlook – Measure correlated charms

- **Heave Flavor Tracker** - topologically reconstructs D mesons from hadronic decays and identifies electrons from charm decays.
- **Muon Telescope Detector** - measurement of e-μ correlation – clean to correlated charm.

STAR Upgrade HFT+MTD:
Understand the correlated charm.
Clear the way to access the thermal radiation.
Outlook - RHIC BES-II

BES Phase 2 (2018+):
➢ Revisit lower energies.
➢ Improve statistics – extend to IMR.
➢ Systematically study dielectron continuum from $\sqrt{s} = 7.7$-19.6GeV. LMR enhancement vs. increasing total baryon density.

Estimation for event statistics needed:

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</tr>
</thead>
<tbody>
<tr>
<td>MB events</td>
<td>100M</td>
<td>160M</td>
<td>230M</td>
<td>300M</td>
<td>400M</td>
</tr>
</tbody>
</table>
Thank you !!!
Backup
Photon conversion

$\gamma \to e^+e^-$

$\sqrt{s_{NN}} = 200$ GeV
Acceptance correction

positive and negative tracks: - TPC sector boundary lost in different phi region, especially in low pT region. loss Like-Sign pair in mass(<0.2 GeV/c^2), loss unLike-Sign pair in mass(0.2-0.5 GeV/c^2).
Background – photon conversion

We use $\phi_V$ angle cut method to remove the photon conversion background as described in:


Geant simulation:
– red line is the cut: remove 95% conversion electrons.

Definition of $\phi_V$ angle:

\[ \hat{u} = \frac{\vec{p}_+ + \vec{p}_-}{|\vec{p}_+ + \vec{p}_-|}, \hat{v} = \vec{p}_+ \times \vec{p}_- \]

\[ \hat{w} = \hat{u} \times \hat{v}, \hat{w}_c = \hat{u} \times \hat{z} \]

\[ \cos \phi_V = \hat{w} \cdot \hat{w}_c \]