Bottonium Measurements at Midrapidity at the STAR Experiment

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For the STAR Collaboration

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Table of contents

- Why Bottonium?

- Bottonium measurements
  - Practical considerations
  - STAR detector
  - Online and offline analysis

- Results
  - First $\gamma$ x-section in p+p at RHIC
  - Preliminary $\gamma$ x-section results from d+Au

- Summary and Outlook
Why Bottomonium?

- Investigate the properties of the Quark-Gluon Plasma (Au+Au collisions)

✓ Color screening → Deconfinement  

\( \Upsilon(nS) \) is a differential probe: sequential disappearance of states
Expectation at 200 GeV: \( \Upsilon(1S) \) not melt
\( \Upsilon(2S) \) may melt, \( \Upsilon(3S) \) will melt, J/\( \psi \) family will melt

QCD thermometer → QGP properties

- Understanding the production mechanisms of Quarkonia

  - NRQCD, Color Octet Model (COM)  
    PRD51, 1125 (1995)
  - Color Singlet Model (CSM)  
    PLB102, 364 (1981)
    • CSM w/ s-channel cut PRL100, 032006 (2008)
  - Color Evaporation Model (CEM)  
    PLB67, 217 (1977)
  - 3g-pQCD  

➢ Models have difficulties to reproduce quarkonia x-sections, pt, and polarizations simultaneously.
**Why Bottomium?**

**d+Au (Cold Nuclear Matter-CNM effect)**
- Initial state energy loss
- gluong shadowing
- Cronin
- nuclear absorption

**p+p, d+Au, Au+Au**
- Feed-down contributions from higher states represent other source of uncertainty to the x-section measurements.

**Bottomium vs. Charmonium**

Significant feed-down from higher cc states and B meson decays compared to bb.

Cleaner probe of high-temperature color screening

Co-mover absorption is very small \text{Phys. Lett. B 503, 104 (2001)}

Recombination negligible at RHIC ($\sigma_{b\bar{b}} \approx 1.9 \mu b << \sigma_{c\bar{c}}$) \text{Phys. Rev. Lett. 95, 122001 (2005)}
Practical issues with Bottomonium measurements

Branching fractions for $\Upsilon(nS) \rightarrow e^+e^-$

<table>
<thead>
<tr>
<th>$\Upsilon$ state</th>
<th>$B$ (%)</th>
<th>$\sigma$ (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Upsilon(1S)$</td>
<td>2.38±0.11</td>
<td>6.60</td>
</tr>
<tr>
<td>$\Upsilon(2S)$</td>
<td>1.91±0.16</td>
<td>2.18</td>
</tr>
<tr>
<td>$\Upsilon(3S)$</td>
<td>2.18±0.21</td>
<td>1.32</td>
</tr>
</tbody>
</table>

$\sigma_{total}$ at $\sqrt{s} = 200$ GeV (NLO CEM model)

- Extremely low rate:
  - $10^{-9}$/minimum bias pp interaction
  - 3 orders of magnitude smaller than $\sigma_{J/\psi}$

- $\Upsilon(1S+2S+3S)$ separation require high resolution

- With less radiation lengths (w/o inner tracker detectors) it is possible to separate the three states at STAR.

Run2006 p+p 200GeV
Run2007 Au+Au 200GeV

Needed: high luminosity, and acceptance, efficient triggers in p+p up to central Au+Au
As of Feb, 9th the integrated luminosity is approximately doubled.

- Stochastic cooling
- DAQ upgrade
- As of Feb, 9th the integrated luminosity is approximately doubled.
STAR detector

- Time Projection Chamber TPC – 24 sectors
  \(|\eta| < 1, \ 0 < \phi < 2\pi\)

- Barrel Electromagnetic Calorimeter BEMC – 4800 towers
  \(|\eta| < 1, \ 0 < \phi < 2\pi\)
  PID: \(p/E\)

> STAR is well-suited detector to measure \(\gamma \rightarrow e^+e^-\)

- Large acceptance
- Efficient trigger
STAR γ Online & Offline analysis

**Online:**

Trigger components: Select events with at least one candidate satisfies

- **Fast Hardware trigger – L0**
  - \( E_T \text{(tower)} > E_{\text{threshold}} \)

- **Software trigger – L2**
  - Forms clusters: \( E_{\text{cluster}-1} > E_{\text{threshold}-1} \), \( E_{\text{cluster}-2} > E_{\text{threshold}-2} \)
  - Calculates \( \cos \theta \),
  - Calculates \( m_{\text{cluster}-1\text{cluster}-2} = \sqrt{2} E_{\text{cluster}-1} * E_{\text{cluster}-2}(1-\cos\theta) \)
  - \( m_{\text{cluster}-1\text{cluster}-2} > m_{\text{threshold}} \) ?

Issue decision within ~ 5 ms for the slow detectors to continue/abort data-acquisition processes.

**Offline:**

Match TPC tracks to triggered towers

\[ p+p \, @\, 200 \, \text{GeV} \]

Geom., trigger, and tracking efficiency for reconstructing \( \gamma \rightarrow e^+e^- \) in STAR at \( |y_\gamma| < 0.5 \)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \epsilon_{\text{geo}} )</td>
<td>0.57</td>
</tr>
<tr>
<td>( \epsilon_{\text{geo}} \times \epsilon_{\text{L0}} )</td>
<td>0.25</td>
</tr>
<tr>
<td>( \epsilon_{\text{geo}} \times \epsilon_{\text{L0}} \times \epsilon_{\text{L2}} )</td>
<td>0.21</td>
</tr>
<tr>
<td>( \epsilon_{\text{geo}} \times \epsilon_{\text{L0}} \times \epsilon_{\text{L2}} \times \epsilon_{\text{track}} \times \epsilon_{R} )</td>
<td>0.13</td>
</tr>
<tr>
<td>( \epsilon_{\text{geo}} \times \epsilon_{\text{L0}} \times \epsilon_{\text{L2}} \times \epsilon_{\text{track}} \times \epsilon_{R} , (1S+2S+3S) )</td>
<td>0.14</td>
</tr>
</tbody>
</table>

BEMC: Track-blind
First $\sigma_{Y(nS)}$ measurements in $p+p$ @ 200 GeV

$\mathcal{L}dt = 7.9 \text{ pb}^{-1}$ of $p+p$ (2006)

\[ \sum_{n=1}^{3} B(nS) \times \sigma(nS) = \frac{N}{\Delta y \times \epsilon \times \mathcal{L}}, \]

\[ (\sigma_{DY} + \sigma_{b\bar{b}})|y|<0.5, 8<m<11 \text{ GeV/c}^2 = 38 \pm 24 \text{ pb} \]

\[ \sum_{n=1}^{3} B(nS) \times \sigma(nS) = 114 \pm 38^{+23}_{-24} \text{ pb} \]
STAR $\sigma_{\gamma(nS)}$ in p+p at 200 GeV at midrapidity $|y| < 0.5$ is:

- in agreement with CEM at NLO,
- inconsistent with CSM (2$\sigma$ effect),
- consistent with world data trend.
STAR Preliminary $\gamma$ measurements in d+Au @ 200 GeV

$\mathcal{L} dt = 32\ nb^{-1} \approx 12.5\ pb^{-1}\ (p+p)$

(H. Liu, QM 2009) nucle-ex 0907.4538

STAR preliminary $\sigma_{Y(nS)}$ in d+Au at 200 GeV at midrapidity $|y| < 0.5$ is:

- consistent w/ CEM calculations at NLO including anti-shadowing.

$BR \times \frac{d\sigma}{dy} \big|_{Y(1S+2S+3S)} = 35 \pm 4\,(stat.) \pm 5\,(sys.)\ nb.$

$R_{dAu} = \frac{dN_{dAu} / dy}{\langle n_{coll}^{dAu} \rangle dN_{pp} / dy}$

$R_{dAu} = 0.98 \pm 0.32\,(stat.) \pm 0.28\,(sys.).$

CNM effects are not large, need more p+p statistics in order to quantify the effect.
Summary and Outlook

- $|y|<0.5$ preliminary meas. of $\Upsilon+\Upsilon'+\Upsilon'' \rightarrow e^+e^-$ cross-section at $\sqrt{s}=200$ GeV
  - p+p $3\sigma$ Signal Significance with

  \[ \sum_{n=1}^{3} \mathcal{B}(nS) \times \sigma(nS) = 114 \pm 38 \pm 23^{+23}_{-24} \text{ pb} \]

  - o in agreement with CEM at NLO,
  - o inconsistent with CSM (2$\sigma$ effect),
  - o consistent with world data trend.

  Report the combined continuum cross-section of $(\text{Drell-Yan}+b\bar{b}\rightarrow e^+e^-)$

  \[ (\sigma_{\text{DY}} + \sigma_{b\bar{b}})|_{|y|<0.5}, \; 8<m<11 \text{ GeV}/c^2 = 38 \pm 24 \text{ pb} \]

  - d+Au $8\sigma$ Signal Significance with

  \[ \text{BR} \times \left( \frac{d\sigma}{dy} \right)_{y=0}^{Y(1S+2S+3S)} = 35 \pm 4(\text{stat.}) \pm 5(\text{sys.}) \text{ nb} \]

  - o consistent w/ CEM calculations at NLO including anti-shadowing.
  - $R_{dAu} = 0.98 \pm 0.32(\text{stat.}) \pm 0.28(\text{sys.})$.

  - o Follows Binary Scaling (in 200 GeV dAu collisions)

- Large luminosity at RHIC and full azimuth acceptance at the STAR experiment enable these measurements. Expect reduced uncertainties from further analysis and future runs, $20 \text{ pb}^{-1}$ of p+p (2009) with low $x_0$ vs. $7.9 \text{ pb}^{-1}$ (2006).
Summary and Outlook

- $\Upsilon$-hadron correlations and polarization measurements of $\Upsilon$ are underway.

- $\Upsilon$ Cross-section result in Au+Au Run (2007) is coming soon

- Projection for statistical uncertainties in $\Upsilon(1S)$ measurements.

- Muon Telescope Detector (MTD), one of STAR upgrades, will enhance its capability for the quarkonia measurements.
  - online trigger enhancement factor: 10-50
Backup slides
### Systematic uncertainties on the measurements of $\sigma_Y$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Syst. uncertainty on $d\sigma/dy$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{+-} - 2\sqrt{N_{++}N_{--}}$</td>
<td>82.7</td>
<td>$^{+10}_{-9}$</td>
</tr>
<tr>
<td>$\mathcal{L}$</td>
<td>7.9 pb$^{-1}$</td>
<td>$^{\pm7}_{\pm7}$</td>
</tr>
<tr>
<td>$\epsilon_{\text{BBC}}$</td>
<td>0.87</td>
<td>$^{\pm9}_{\pm9}$</td>
</tr>
<tr>
<td>$\epsilon_{\text{geo}}$</td>
<td>0.57</td>
<td>$^{+3.0}_{-1.7}$</td>
</tr>
<tr>
<td>$\epsilon_{\text{vertex}}$</td>
<td>0.96</td>
<td>$^{\pm1.0}_{\pm1.0}$</td>
</tr>
<tr>
<td>$\epsilon_{L0}$</td>
<td>0.43</td>
<td>$^{+7.5}_{-5.9}$</td>
</tr>
<tr>
<td>$\epsilon_{L2}$</td>
<td>0.85</td>
<td>$^{+0.7}_{-0.2}$</td>
</tr>
<tr>
<td>$\epsilon_{\text{TPC}}$</td>
<td>$0.85^2$</td>
<td>$2 \times \pm 5.8$</td>
</tr>
<tr>
<td>$\epsilon_{R}$</td>
<td>$0.93^2$</td>
<td>$2 \times ^{+1.1}_{-0.2}$</td>
</tr>
<tr>
<td>$\epsilon_{\text{dE/dx}}$</td>
<td>$0.84^2$</td>
<td>$2 \times \pm 2.4$</td>
</tr>
<tr>
<td>$\epsilon_{E/p}$</td>
<td>$0.93^2$</td>
<td>$2 \times \pm 3.0$</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td></td>
<td>$^{+22.8}_{-24.1}$</td>
</tr>
</tbody>
</table>
Obtaining the expected shape from $b\bar{b}$ simulation PHYTIA and Drell-Yan (NLO pQCD).

The continuum cross sections determined by a combined fit to bg. subtracted data.