Heavy Flavor in PHENIX

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PHENIX has made extensive measurements at RHIC of quarkonia by studying dilepton decays and open heavy flavor through semileptonic decays.

- New silicon vertex trackers: VTX (2011) and FVTX (2012)
Outline

- **Quarkonia**
  - J/Ψ Production in Au+Au collisions at lower energy
  - J/Ψ Production in Cu+Au collisions

- **Open Heavy Flavor**
  - Bottom/Charm Ratio in p+p collisions
  - Bottom/Charm Ratio in Au+Au collisions
  - Bottom and Charm nuclear modification factor

Not covered in this talk are quarkonium and heavy flavor measurements in d+Au discussed in M. Wysocki’s talk (plenary IC on Monday)
Understanding quarkonium production in media requires disentangling the interplay between

- cold nuclear matter effects
- quark gluon plasma screening
- possible production through regeneration

J/ψ \( R_{AuAu} \) at forward rapidity

- New J/ψ \( R_{AuAu} \) at \( \sqrt{s} = 62 \text{ GeV} \) and 39 GeV

62 GeV suppression follows the trend of the 200 GeV

These data provide a strong constraint to theoretical models

\[ J/\psi \rightarrow \mu\mu, \ 1.2 < |y| < 2.2 \]

aiXrv: 1208.2251
Theory agrees with data, suggesting similarity of $R_{AA}$ from 39 to 200 GeV originates from cancellation of suppression and regeneration.

D. McGlinchey’s talk Parallel 1D on Tuesday
NEW: $J/\Psi \to \mu^+ \mu^-$ in Cu+Au Collisions

New asymmetric Collisions in Run 2012: geometry control

Cu+Au $- b=4\text{fm}$
Nuclear overlap
Density function

$\frac{dN}{d\eta}$

backward $-2.2<\eta<-1.2$
forward $1.2<\eta<2.2$
$J/\psi \rightarrow \mu^+\mu^-$ production in Cu+Au

- **Au-going** follows trend
- **Cu-going** shows stronger suppression
J/ψ→μ⁺μ⁻ production in Cu+Au

Cold nuclear matter effects have the same trend but the data show additional suppression
Open Heavy flavor Measurements

- Indirect measurement using semileptonic heavy-flavor decays
- Measure contribution of heavy flavor to lepton spectra
Extensive measurement of heavy flavor $R_{AA}$ and $v_2$.

Indirect measurement of bottom/charm ratio in p+p collisions using e–h correlations.
2011 PHENIX VTX upgrade

Front view of VTX

RUN2011: Au+Au at 200 GeV

Run 2012: p+p at 200 GeV
Inclusive electron spectra include:
- Charm semi-leptonic decays
- Bottom semi-leptonic decays
- $\pi^0$ Dalitz decays and photon conversions (photonic)

VTX provides two new capabilities:
1) Tag and reject conversion providing an independent measurement of photonic background
2) Measure distance of closest approach to separate charm and bottom components of heavy flavor spectra
Using the photonic electron estimated by the VTX, we measure the heavy flavor (HF) electron spectra consistent with previously published HF by PHENIX.
Distance of closest approach (DCA)

DCA

beam

beam

Primary Vertex

Secondary Vertex

e

p+p
200 GeV

\[ p_T > 1 \text{ GeV/c} \]

Number of Tracks

DCA (cm)
DCA decomposition uses expected DCA shapes from simulation for all known electron sources to extract bottom/charm ratio

\[
\frac{b \rightarrow e}{c \rightarrow e + b \rightarrow e} = 0.08 \pm 0.02
\]
From the fit of the DCA distributions.
First direct measurement of bottom production in p+p at RHIC

From the fit of the DCA distributions

\[
\begin{align*}
    b &\rightarrow e \\
    c &\rightarrow e + b \rightarrow e
\end{align*}
\]

FONLL agrees with our data.
First direct measurement of bottom production in p+p at RHIC

From the fit of the DCA distributions

\[ b \to e \]

\[ c \to e + b' \to e \]

From the fit of the DCA distributions

- 2012: p+p 200 GeV, |y| < 0.35
- PHENIX PRL 103, 082002 (2009)
- FONLL, y = 0
- STAR: PRL 105, 202301 (2010)

PHENIX Preliminary

FONLL agrees with our data

STAR indirect measurement consistent with our data
First direct measurement of bottom production at RHIC: Au+Au

From the fit of the DCA distributions

\[ \frac{b \rightarrow e}{c \rightarrow e + b \rightarrow e} \]

PHENIX Preliminary

- 2011: 200 GeV Au+Au MB

\(|y|< 0.35\)
First direct measurement of bottom production at RHIC: Au+Au

- From the fit of the DCA distributions

\[
\frac{b \rightarrow e}{c \rightarrow e + b \rightarrow e}
\]

Bottom in Au+Au appears more suppressed
Bottom fraction in $p+p$ and FONLL

- $p+p$ data trend is in good agreement with FONLL
- We use the FONLL shape to fit the data and determine a $p+p$ reference
Charm $R_{AA}$

$$R_{AA}(c \rightarrow e) = R_{AA}^{HF} \frac{F_{AA}^{c\rightarrow e}}{F_{pp}^{c\rightarrow e}}$$

PHENIX Preliminary

- Charm: 200 GeV Au+Au MB
- pp: $b/(b+c)$ Fitted by FONNL

Graph showing $R_{AA}(c \rightarrow e)$ dependence on Electron $p_T$ (GeV/c).
Charm $R_{AA}$

$$R_{AA}(c \rightarrow e) = R_{AA}^{HF} \frac{F_{AA}^{c \rightarrow e}}{F_{pp}^{c \rightarrow e}}$$

PHENIX Preliminary

- Charm: 200 GeV Au+Au MB
- $\pi^0$ PRL 101, 232301 (2008)

Charm less suppressed than $\pi^0$

Electron $p_T$ (GeV/c)
Bottom and Charm $R_{AA}$

$$R_{AA}(b \rightarrow e) = R^{HF}_{AA} \frac{F_{AA}^{b\rightarrow e}}{F_{pp}^{b\rightarrow e}}$$

No simple mass hierarchy in heavy flavor
Bottom and Charm $R_{AA}$

$$R_{AA}(b \rightarrow e) = R_{AA}^{HF} \frac{F_{AA}^{b \rightarrow e}}{F_{pp}^{b \rightarrow e}}$$

PHENIX Preliminary

- Charm: 200 GeV Au+Au MB
- $\pi^0$ PRL 101, 232301 (2008)
- Bottom: 200 GeV Au+Au MB
- pp: $b/(b+c)$ Fitted by FONNL

No simple mass hierarchy in heavy flavor

R. Nouicer’s talk Parallel 6A on Friday
Electrons with $2\text{GeV/c} < p_T < 2.5\text{GeV/c}$ are coming from $B$ mesons with $p_T = 2-4\text{GeV/c}$ that have $\beta\gamma = 0.4-0.8$.

PYTHIA simulation of $B^0$ decays
Charm $v_2$

Using DCA decomposition

PHENIX Preliminary

$Au+Au \sqrt{s_{NN}} = 200\text{GeV}$

10 - 60 %

Charm $v_2$ 2011 VTX-PHENIX

HF $v_2$ PR C84, 044905
More on Quarkonia and Heavy Flavor

- Plenary IC on Monday: M Wysocki – PHENIX Results on Cold Nuclear Matter
- Parallel 1D on Tuesday: D. McGlinchey – Recent Heavy Quarkonia Results from PHENIX
- Parallel 3A on Wednesday: M. Kurosawa – Higher harmonics flow measurement of charged hadrons and electrons in wide kinematic range with PHENIX VTX tracker
- Parallel 6A on Friday: R. Nouicer – Probing Hot and Dense Matter with c and b measurements with PHENIX VTX tracker
- Parallel 7D on Friday: R. Hollis – Forward/backward reaction plane dependent J/ψ production and hadron \( v_n \) in Cu +Au Collisions in PHENIX
- Poster #134: R. Akimoto – Measurement of charm and bottom yields in Au+Au collisions at PHENIX
- Poster #152: N. Apadula – Single electrons from heavy flavor decays in 200GeV Cu+Cu collisions at PHENIX
- Poster #118: C. Chen – Production of heavy flavor quark in p+p collisions
- Poster #130: L. Ding – PHENIX v2 measurement of single electron from heavy flavor decays in Au+Au at 62GeV
- Poster #131: M. Durham – A detailed study of open heavy flavor production, enhancement, and suppression at RHIC
- Poster #127: T. Hachiya – Event anisotropy from charm and bottom quark decays in 200 GeV Au+Au collisions at RHIC_PHENIX
- Poster #125: A Iordanove – Forward J/ψ production in Au+Au and CU+Au collisions at PHENIX
- Poster #133: A. Lebedev – \( x_C \) measurement in PHENIX: the present, the future
- Poster #128: K. Lee –Cold Nuclear Matter effects on \( \Upsilon(1S+@S+#S) \) production
- Poster #151: S. Lim – Heavy Quark Production at forward rapidity in d+Au Collisions at 200GeV
- Poster #121: L. Patel – Study of b\bar{b} production using correlated like sign di-muon at PHENIX
- Poster #122: A. Sen – PHENIX J/ψ measurement in Au+Au collisions at 39 and 62 GeV
- Poster #123: S. Whitaker – Measurement of \( \Upsilon R_{AA} \) at PHENIX

5 talks
13 posters
Summary

- New quarkonium results explore suppression by varying collision energy and geometry that provides stringent constraints on theoretical models.

- First direct measurement of charm and bottom separately shows that suppression pattern is complex and doesn’t follow simple mass hierarchy
Backup
Wide range of D/B meson pT’s contribute to electron DCA in a given electron pT bin. We do not know the D/B meson pT distribution a priori.
Heavy Flavor electron spectra

- Inclusive electron spectra have two major components:
  - Photonic
  - Heavy flavor

- Photonic component was estimated with two different methods:
  - Cocktail method
  - Conversion tagging in the VTX
DCA Distributions

- Raw DCA distributions for charged hadrons and electrons in Au+Au at 200 GeV

![Graphs showing DCA distributions for different centrality classes and p_T cuts for charged hadrons and electrons in Au+Au collisions at 200 GeV.](image-url)