Heavy flavor measurements at STAR

Outline:
- Motivation.
- HF production at STAR.
- HQ interaction with medium.
- Summary and outlook.

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RHIC & AGS Users ‘ Meeting, BNL
June 20–24th
Light flavor behavior in strong coupled medium

- **High $p_T$:**
  - Jet quenching
- **Low $p_T$:**
  - Hydrodynamics works
  - Multi-strange hadrons flow
- **Intermediate $p_T$:**
  - Number of Constituent Quark scaling flow $s \sim u,d$

Large collective flow observed.
$u, d, s$ quarks strongly interact with hot/dense medium.

What about heavier charm quark? Is the medium hot/dense enough to modify charm quark?

Why study heavy quarks?

- Higgs mass: electro-weak symmetry breaking (current quark mass).
- QCD mass: Chiral symmetry breaking (constituent quark mass).
- Strong interactions do not affect heavy quark mass.

- Study properties of the hot and dense medium at the early stage of heavy-ion collisions.
- Test pQCD at RHIC.
- Charm collectivity => Light flavor thermalization.
STAR detector and Particle ID

Large acceptance
$|\eta|<1$, $0<\phi<2\pi$

- Time Projection Chamber
dE/dx, momentum
- Time Of Flight detector
  particle velocity $\beta$
- Electro-Magnetic Calorimeter
- Shower Max Detector
Signals

**D⁰ p+p**

- $\chi^2 / \text{ndf} = 8.7 / 14$
- Yield: $(4.2 \pm 1.0) \times 10^3$
- Mean: $1.866 \pm 0.003$
- $\sigma$: $0.010 \pm 0.002$

**D⁰ Au+Au**

- $\chi^2 / \text{ndf} = 31.1 / 27$
- Yield: $(54.3 \pm 6.9) \times 10^4$
- Mean: $1.863 \pm 0.002$
- $\sigma$: $0.012 \pm 0.002$

**D* p+p**

- STAR Preliminary

**J/ψ p+p**

- STAR Preliminary

**J/ψ Au+Au**

- STAR Preliminary

**ϒ Au+Au**

- STAR Preliminary

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June 17, 11

Yifei Zhang / LBNL
D⁰ and D* pₜ spectra in p+p 200 GeV

The charm cross section at mid-rapidity in p+p 200 GeV is:
202 ± 56 (stat.) ± 40 (sys.) ± 20 (norm.) µb

D⁰ scaled by N_{cc} / N_{D⁰} = 1 / 0.56[^1]
D* scaled by N_{cc} / N_{D*} = 1 / 0.22[^1]
Xsec = dN/dy|_{y=0}^{cc} × σ_{pp}
σ_{pp}(NSD) = 30 mb

Charm cross section vs $N_{\text{bin}}$

All of the measurements are consistent.
Year 2003 d+Au : $D^0 + e$
Year 2009 p+p : $D^0 + D^*$
Year 2010 Au+Au: $D^0$

Assuming $N_{D^0}/N_{cc} = 0.56$ does not change.

Charm cross section in Au+Au 200 GeV:
Mid-rapidity:
186 ± 22 (stat.) ± 30 (sys.) ± 18 (norm.) μb


Charm cross section follows number of binary collisions scaling =>
At RHIC, charm quarks are produced via initial hard scatterings.
Compared with other experiments, provide constraint for theories.
At $p_T > 1.5$ GeV/c, STAR measurements in p+p are consistent with FONLL calculations.

Significant bottom contribution in NPE measurement.
Separate charm/bottom decay electrons

With spectrum shapes from model calculations, the production cross section of bottom in p+p collisions at 200 GeV, extrapolated to be:

\[ \sigma(b\bar{b}) = 1.34 \mu b \text{ PYTHIA, MinBias Mode} \]

\[ \sigma(b\bar{b}) = 1.83 \mu b \text{ PYTHIA, MSEL=5 Mode} \]

with 12.5% (stat.) and 27.5% (sys.) experimental uncertainties

FONLL calculation:
\[ \sigma(b\bar{b}) = 1.87^{+0.67}_{-0.67} \mu b \]

Consistent with data

$D^0 R_{AA}$

$D^0$ Au+Au 0-80% divided by p+p with $N_{\text{bin}}$ scaled.

No obvious suppression at $p_T < 3$ GeV/c.

Blast-wave predictions with light hadron parameters are different from data.

$\Rightarrow D^0$ freeze out earlier than light hadrons.

$\Rightarrow$ Small collectivity?
Does charm follow the trend of hadron mass dependence?
Smaller collectivity (charm-medium interaction)?
Data is significantly softer than Tsallis Blast-Wave prediction from light-quark hadrons.

With zero velocity TBW describes data better.

- Smaller radial flow?

No significant $v_2$ observed.

- Disfavor coalescence from thermalized charm quarks.
- Small charm flow?
Show a similar magnitude of suppression as light hadrons in Au+Au collisions.

High $p_T$ charm energy loss in medium.

Collisional dissociation of heavy quarks, in-medium heavy resonance diffusion, multi-body mechanisms might play an important role for heavy quark energy loss.

A. Adil and I. Vitev, Phys. Lett. B649, 139 (2007);
H. van Hess, V. Greco and R. Rapp, Phys. Rev. C73 034913 (2006);
W. Liu and C. M. Ko, nucl-th/0603004.
Predicted NPE $R_{AA}$ – high $p_T$ suppression

Extrapolate D-meson to high $p_T$ with a power-law function in $p+p$ collisions. Assuming high $p_T$ $D^0$ $R_{AA}$ saturates at 0.5 or 0.2. Then decay to electrons.

Assume the charm hadron fractions in Au+Au collisions are the same as in $p+p$ collisions.

Predicted NPE $R_{AA}$ shown in curves, consistent with data assuming high $p_T$ $D^0$ suppression (bottom contributes less energy-loss).

High $p_T$ charm energy loss in medium.
Charm correlation (ccbar $\rightarrow$ ee)

ccbar correlation scaled by $pp^*N_{bin}$, but it may be modified by medium in central Au+Au collisions.

Measure charm modifications to distinguish QGP thermal radiation in the future.

$\rho$ contribution not included in the cocktail.

J. Zhao, QM2011
J/ψ $R_{AA}$ increases from low to high $p_T$

- Not suppressed in peripheral Au+Au but suppressed in central Au+Au at high $p_T$
  
  System size dependent due to formation time effect? – X. Zhao and R. Rapp, PRC 82,064905(2010).
  

- $\Upsilon(1S+2S+3S)$ $R_{AA}$ suppressed in central Au+Au collisions.
  
  Comparable with high $p_T$ J/ψ $R_{AA}$, large $Q^2$, small regeneration?
  
  Feed-down? Sensitivity to temperature?
Fruitful heavy flavor production at STAR: Open charm hadrons ($D^0$, $D^*$), NPE and quarkonium ($J/\psi$, $\Upsilon$) are measured in p+p and Au+Au collisions at 200 GeV.

Charm cross sections at mid-rapidity follow number of binary collisions scaling, which indicates charm is produced via initial hard scatterings at early stage of the collisions at RHIC.

Many observations, $D^0 R_{AA}$, $D^0 m_T$ slope, low $p_T J/\psi$, $J/\psi v_2$, suggest small collectivity of charm quark.

High $p_T$ NPE suppression indicates charm energy loss in medium.

Blast-wave predictions with light hadron parameters are different from data, which may indicate $D^0$ decoupled earlier from the medium than light hadrons.

$J/\psi$ and $\Upsilon$ suppression in central Au+Au collisions at 200 GeV.
STAR Heavy Flavor Tracker Project.

- Reconstruct secondary vertex.
- Dramatically improve the precision of measurements.
- Address physics related to heavy flavor.

$v_2$: charm / bottom flow, thermalization

$R_{CP}$: charm / bottom energy loss mechanism.
Outlook – charm correlation

Z. Xu, BNL LDRD 07-007; L. Ruan et al., JPG 36 (2009) 095001

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Outlook – high mass di-muon capabilities

2. With HFT, study $B \rightarrow J/\psi X$; $J/\psi \rightarrow \mu\mu$ using displaced vertices
3. Excellent mass resolution: separate different upsilon states

Heavy flavor collectivity and color screening, quarkonia production mechanisms:
$J/\psi R_{AA}$ and $v_2$; upsilon $R_{AA}$ ...

Z. Xu, BNL LDRD 07-007; L. Ruan et al., JPG 36 (2009) 095001