PHENIX results on heavy flavor production in p+p and Au+Au collisions at RHIC

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Introduction

Motivations:

• Probe medium properties (energy loss mechanism) in complement to light quarks studies
• Input/cross-check for di-lepton spectrum studies
• Input for some heavy quarkonia production models (recombination)

Outline:

• Heavy flavor production in p+p collisions at mid and forward rapidity
• Charm/bottom separation in p+p collisions
• Nuclear modification factor and elliptic flow in Au+Au collisions
• Perspectives
p+p collisions
Heavy flavor measurement at mid-rapidity

Measure inclusive single electron spectrum

• tracking with drift and pad chambers

• particle identification by matching tracks with RICH and EMCal

Subtract all known sources of background using *cocktail*

• $\pi$ and $\eta$ Dalitz decay

• $\gamma$ conversion

• $\omega$, $\varphi$, direct $\gamma$, etc.

Normalize cocktail to the data using a *converter* measurement:

Insert known amount of additional material, look at how the spectra are modified.
Heavy flavor measurement at mid-rapidity


Ratio to FONLL calculations are on the high side of theoretical uncertainties.

About a factor 2 discrepancy with STAR measurement (being worked on)
Heavy flavor measurement at forward rapidity

Measure inclusive single muon spectrum

- Front absorber to reject hadrons
- Cathode strip chambers to track muons
- Iarocci tubes + absorbers for identification and trigger

Subtract background sources using simulated hadron cocktail

- Muons from hadron decay
- Punch-through hadrons

Tune the cocktail on real data to reproduce:

- Stopped hadrons distributions in MuID gap 2 and 3
- Decay muons stopping at gap 3, (estimated using vertex z distribution)
Heavy flavors in p+p collisions at forward rapidity

Result using 2005 p+p data (blue).

Statistics is larger than earlier 2002 result (red), and method is different.

Forward and backward measurements are in good agreement and statistically combined.

Ratio to FONLL calculations vary from 4 at low $p_T$ to 2 at high $p_T$ (>3.5 GeV/c).
Charm and bottom separation (mid-rapidity)

D/B semi-leptonic decay

- Study the invariant mass of unlike-sign electron+hadron pairs
- Use PYTHIA to simulate these distributions for D and B mesons separately
- Fit the resulting shapes to the data using absolute scale and B/D ratio as free parameters
Measured ratios are in good agreement with FONLL calculations, but both experimental and theoretical uncertainties are large.
Di-electron spectra

Open charm and beauty cross-sections can be used as inputs to fit di-electron invariant mass distributions.

Alternatively one can fit the D and B contribution to these spectra and get an independent heavy flavor measurement.

single-electron measurement: \( \sigma_{cc} = 567 \pm 57 \pm 224 \ \text{\(\mu\)b} \)  

di-electron measurement: \( \sigma_{cc} = 544 \pm 39 \pm 142 \ \text{\(\mu\)b} \)  
arXiv:0802.005v2 [hep-ex]
Au-Au collisions
Nuclear modification factor at mid-rapidity

\[ R_{AA} = \frac{\text{yield in AA}}{N_{\text{col}} \cdot \text{yield in pp}} \]

Same method as for p+p (at mid-rapidity)

Binary scaling observed at low \( p_T \)

Large suppression for high \( p_T (>4 \text{ GeV/c}) \)
High $p_T$ suppression is similar to light mesons measurements.

Unexpected in terms of radiative energy loss, due to dead-cone effect

Possible explanations include:

- Elastic (collisional) energy loss
- sQGP effect
- in-medium D and B dissociation
Elliptic flow - principle

The elliptic flow, \( v_2 \), is the second Fourier transform of the azimuthal distribution of the probe. It characterizes the azimuthal anisotropy of particle emission with respect to the collision reaction plane.

A positive \( v_2 \) for non-central collisions corresponds to particles being emitted preferentially along the reaction plane. This is interpreted as a consequence of an anisotropic pressure gradient in the overlapping region of the colliding nuclei.
Results for light and heavy quarks

Large positive elliptic flow observed for light particles.

This requires an early thermalization of the medium.

Scaling properties suggest pre-hadronic degrees of freedom.

Large positive elliptic flow also observed for D and B.

Heavy quarks are also thermalized.

→ sQGP

This triggers similar measurement for heavy quarkonia (J/ψ) to test recombination mechanism.
This is a first measurement, at both mid and forward rapidity.

Very limited statistics so that no strong conclusion can be drawn.

Need more data, and detector upgrades.
Summary

In p+p collisions:
• mid rapidity measurement in reasonable agreement with FONLL and validated by di-electron measurement.
• Factor 2 discrepancy with STAR
• First measurement at forward rapidity
• D and B separation is available (but limited statistics)

In Au+Au collisions:
• Binary scaling observed at low $p_T$
• High $p_T$ suppression (similar to light mesons) and positive elliptic flow pose a challenge for theoretical models in terms of radiative energy loss

What’s missing:
• d+Au and Cu+Cu collisions to study cold nuclear matter effects and system size dependence
• Forward rapidity measurement in heavier systems
• Direct measurement of D and B (via e.g. hadronic decay)
Future heavy flavor program with the silicon vertex upgrade

Displaced vertex measurement should allow

- direct measurement of $D \rightarrow K\pi$ (at mid rapidity), $B \rightarrow J/\psi + X$
- event by event separation of background sources (e.g. leptons from hadron decays) at both mid and forward rapidity

Scheduled for 2010 - 2011