Measurements of Bottom to Charm Ratio and Heavy Quark Interaction with the QCD Medium through Non-Photonic Electron-Hadron Correlations

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1: Introduction
2: Analysis methods for Non-Photonic Electrons (NPE)
3: Updates on NPE spectrum in p+p collisions at 200GeV
4: NPE-hadron correlation in p+p collisions:
   a handle on bottom contributions
5: NPE-hadron correlation in Au+Au collisions:
   heavy flavor tagged jet-medium interaction
6: Summary
Motivation for NPE studies

NPE: semi-leptonic decays of open heavy flavor hadrons

\[ c \rightarrow e^+ + \text{anything}(9.6\%) \]

\[ B \rightarrow e^+ + \text{anything}(10.86\%) \quad \text{PDG2010} \]

- Initial gluon fusion (hard process) dominates heavy flavor production – pQCD applicable.
- Study the interactions of heavy quarks with the hot and dense medium.
- Access to high \( p_T \) regime of heavy flavor quarks

Picture courtesy of Wei Xie @ HP2010
**Concrete STAR Detector**

**Large acceptance:**
\[-1 < \eta < 1, \ 0 < \phi < 2\pi\]

**BSMD:** embedded in BEMC.

**Detectors in these NPE analyses:**
- Time Projection Chamber (TPC)
- Barrel Electromagnetic Calorimeter (BEMC)
- Barrel Shower Maximum Detector (BSMD)

**Data Sample:**
- Run05, Run08 p+p collisions at $\sqrt{s_{NN}} = 200$ GeV
- Run09 p+p collisions at $\sqrt{s_{NN}} = 500$ GeV
- Run10 Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
Analysis principle

\[ \Delta \phi_{\text{NPE}} = \Delta \phi_{\text{inclusive}} - \left( \Delta \phi_{\text{Opposite Sign}} - \Delta \phi_{\text{Same Sign}} \right)/\varepsilon - \Delta \phi_{\text{hadron}} \]

\( \Delta \phi \) could be other variables, e.g. yield, elliptic flow \((v_2)\), etc
Electron identification: shower profile

Electron showers are widely developed, firing several BSMD strips.

Hadron showers are much less developed, firing mostly one or zero strip.

Example from the NPE-hadron correlation in Au+Au 200GeV study, where we apply number of bsmd $\eta$ strips $\geq 2$ and number of bsmd $\phi$ strips $\geq 2$
Electron identification: energy loss $n\sigma_{\text{electron}}$

$$n\sigma_e = \frac{\log\left(\frac{dE}{dx}\right)}{B_e}$$

$B_e$ is the expected mean electron $dE/dx$ from Bichsel[1] function, and $\sigma_e$ is TPC resolution of $\log\left((dE/dx)/B_e\right)$

Hadron contamination < 1%

$n\sigma_e$ for $3<p_T<4\text{GeV}$

$n\sigma_e$ for $4<p_T<6\text{GeV}$

Example from the NPE in Au+Au 200GeV study

We found an error in the previous analysis based on Run03 data.
An Erratum was published.

Run05, Run08 have very different material budgets.
\( p_T > 2.5 \text{GeV/c} \) agree with each other.

See Xin Li’s poster (#44, session 2) for more details.

**FONLL:** M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. 95, 122001 (2005);
M. Cacciari, R. Vogt, private communications.
Heavy flavor daughter electrons represent parent momentum directions well, when $p_T^{e}>1.5$ GeV/$c$ for D case, and when $p_T^{e}>3$ GeV/$c$ for B case.

Away Side in medium:
How does B/D lose energy?
Any pattern like what seen in di-hadron?

Near Side:
Decay
Kinematics
B/D separation

A proxy to b/c quark-hadron correlation

trigger $e^-$
Near side correlation in p+p 200 GeV

Different decay kinematics for charm and bottom hadrons → Crucial for charm and bottom discrimination.

Bottom quark contributes significantly in interested $p_T$ ranges

Apply to NPE $R_{AA}$: Bottom suppressed

STAR: PRL 105, 202301 (2010)
Separated Bottom/Charm decay electrons

Apply the ratios to NPE spectrum in p+p @ 200GeV, with J/ψ, Y, Drell-Yan feeddown subtracted.

![Graph showing Bottom and Charm decay electrons]

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

- $\sigma_{bb}^- = 1.34 \mu b$ (PYTHIA, MiniBias Mode)
- $\sigma_{bb}^- = 1.83 \mu b$ (PYTHIA, MSEL=5 Mode)

Results bear 12.5% (stat.) and 27.5% (sys.) experimental uncertainties.

FONLL calculation: $\sigma_{bb}^- = 1.87^{+0.99}_{-0.67} \mu b$

FONLL is consistent with data within the uncertainties.

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*STAR Phys. Rev. D 83 (2011) 052006*

FONLL: M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. 95, 122001 (2005);
M. Cacciari, R. Vogt, private communications.
HT3 triggered events with max $E_T > 7.4$GeV.
Trigger tracks are NPE at different $p_T$.

Associated $p_T > 0.3$ GeV/c

See Wei Li’s poster (#43, session 2) for more details
Bottom/Charm contributions to their decay electrons are obtained by comparison against PYTHIA

The extracted $e_B/(e_B+e_D)$ ratio is higher than 60% within the current statistics.

Error bars are statistical only.

Fit function:

$$r_B f_{e_B}(\Delta \phi) + (1 - r_B) f_{e_D}(\Delta \phi) + \text{const}.$$  

$r_B$ is relative B contribution  

$f_{e_B}, f_{e_D}$ are the correlations from PYTHIA
Away side correlation: d+Au vs Au+Au

Vertical error bars are statistical only. The open star data points are reflected points.
Red dashed curves: $v_2$ background range set with NPE $v_2$ being zero and hadron $v_2$.

Very large uncertainties associated with the background, currently under study, not subtracted.
**Associated tracks with higher $p_T$**

Horizontal error bars are statistical only. The open star data points are reflected points.

Red dashed curves: $v_2$ background range with by NPE $v_2$ being zero and hadron $v_2$.

- We see both near side and away side correlations
- Background studies are in progress
- ~half statistics in Run10
We corrected the NPE spectrum in p+p 200GeV.

Bottom and Charm contributions to NPE in p+p 200GeV are disentangled.

Bottom decay electron spectrum and extrapolated Bottom cross-section in p+p 200GeV are consistent with FONLL calculations.

\[ \sigma_{b\bar{b}} : 1.34 \sim 1.83 \mu b \]

We can study the heavy flavor tagged jet-medium interactions by using the NPE-h correlations in Au+Au 200GeV. More studies are required. Higher statistics are forthcoming.
Backup
PHENIX NPE-hadron corr

arXiv:1011.1477

FIG. 4: (color online) $e_{inc} - h$, $e_{bkg} - h$ and $e_{HF} - h$ (solid circles) for p+p (top panel) and Au+Au (bottom panel) collisions for $2.0 < p_{T,e} < 3.0 \text{ GeV}/c$ and $1.5 < p_{T,h} < 2.0 \text{ GeV}/c$. The overall normalization uncertain of 7.9% in p+p and 9.4% in Au+Au is not shown.

eHF – h jet functions for Au+Au (solid blue circles) and p+p collisions for 3.0–4.0 GeV/c
Electron triggers and the hadron-pT bins indicated.
Photonic electron (PE) reconstruction

Example from the NPE in P+P 500GeV study

Example from the NPE in AuAu 200GeV study
STAR NPE-h correlation mixing event backgrounds

Inclusive trigger tracks-hadron (asso p_T 0.15~0.5GeV) correlations from mixed events
The background for NPE-h correlation.

4 centrality bins:
Black dots: 0~5%
Red dots: 5~10%
Green dots: 10~20%
Blue dots: 20~30%