The High Transverse Momentum Non-Photonic Electron (NPE) Measurements in Au+Au Collisions at √s=200GeV at RHIC/STAR

Wenqin Xu
University of California, Los Angeles
For the STAR collaboration
At PANIC 2011
MIT - Boston
1: Introduction
2: Analysis methods for Non-Photonic Electrons (NPE)
3: NPE spectrum
4: NPE elliptic flow ($v_2$)
5: NPE-hadron azimuthal correlation:
   heavy flavor tagged jet-medium interaction
6: Summary
Motivation for NPE studies

NPE: semi-leptonic decays of open heavy flavor hadrons

\[ c \rightarrow e^+ + \text{anything}(9.6\%) \quad B \rightarrow e^+ + \text{anything}(10.86\%) \]

NPE is the proxy of heavy flavor quarks

- Initial gluon fusion (hard process) dominates heavy flavor production – pQCD applicable.
- Study the interactions of heavy quarks with the hot and dense medium.
  - NPE yield and nuclear modification factor \( R_{AA} \)
  - NPE elliptic flow \( v_2 \)
  - NPE-hadron correlation
- Access to high \( p_T \) regime of heavy flavor quarks

Cartoons of dynamical models
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:**
- Run10 Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
  - Mini-Bias Triggered Events (NPE spectrum, $v_2$)
  - High-Tower Triggered Events (NPE-h correlation)
Analysis principle

Inclusive Electrons (particles after EID cut)

Non-photonic electrons (NPE)

Photonic electrons (PE)

Hadron contamination

Reconstructed Photonic electrons = Opposite Sign – Same Sign.
Efficiency from embedding: $\varepsilon$

Not reconstructed Photonic Electrons

$\Delta \phi_{NPE} = \Delta \phi_{\text{inclusive}} - (\Delta \phi_{\text{OppoSign}} - \Delta \phi_{\text{SameSign}})/\varepsilon - \Delta \phi_{\text{hadron}}$

$\Delta \phi$ could be other variables, e.g. yield, elliptic flow ($v_2$), etc
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 $n\sigma_{\text{electron}}$

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

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

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

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

Examples from the NPE-hadron correlation study, where hadron contamination is $<1\%$ with tight $\sigma_e$ cuts.

NPE production in Mini-Bias triggered events collected by STAR. 
~38 Million events analyzed here. 
~10% of the entire data sample.

Low photonic electron background.

Measurements of NPE $R_{AA}$ will follow.
NPE elliptic flow

NPE elliptic flow ($v_2$) in Mini-Bias triggered events obtained by fitting electron-event plane correlations

Non-Photonic Electrons

STAR Preliminary

Counts

Counts

10~40% central events

2.0 < $p_T$ < 4.0 GeV/c

$\chi^2$/ndf = 7.501/8.0

NPE $v_2$ = 0.067 +/- 0.049

$\Delta \phi$

$\Delta \phi$

10~40% central events

2.0 < $p_T$ < 4.0 GeV/c

$\chi^2$/ndf = 3.402/8.0

PE $v_2$ = 0.139 +/- 0.043

Photonic Electrons

STAR Preliminary
Compare to charged hadrons

- NPE $v_2$ in Run10 is **finite** and consistent with Run07
- Lower than $v_2$ of charged hadrons (or $K^0_S$, $\Lambda$) at the same $p_T$

This analysis of NPE $v_2$ in Run10

STAR Preliminary results shown in Hard Probes 2010, arxiv: 1011.5543

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?
Away side correlation: d+Au vs Au+Au

Asso. tracks $p_T$ 0.15 ~ 0.5GeV/c, $|\eta|<1$

NPE $p_T$ 3~6GeV/c, based on High Tower triggered events in Run10. 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 \( p_T \)

- **Associated tracks** \( p_T \ 0.15 \sim 0.5 \text{GeV/c}, \ |\eta|<1 \)
- **Associated tracks** \( p_T \ 0.5 \sim 1 \text{GeV/c}, \ |\eta|<1 \)

Vertical error bars are statistical only. The open star data points are reflected points. Red dashed curves: \( \nu_2 \) background range with by NPE \( \nu_2 \) being zero and hadron \( \nu_2 \).

- **We see both near side and away side correlations**
- **Background studies are in progress**
- **\sim half statistics of High Tower triggered events in Run10**

arXiv:1106.6020
Summary

We presented NPE spectrum in 0 - 60% central Au+Au collisions at $\sqrt{s} = 200\text{GeV}$. Measurements of NPE $R_{AA}$ are also forthcoming.

NPE has finite elliptic flow in 10% - 40% centrality ➞ possible heavy quark coupling to the QCD medium. Need more precise measurements.

There is a NPE-h correlation beyond statistical uncertainties ➞ heavy flavor tagged jets do interact with the QCD medium. Quantitative measurements yet to emerge and theoretical comparisons are required to understand the physical picture.

We are exploring heavy flavor quark-medium interactions. The centrality dependence of these measurements will reflect properties of the QCD medium and provide strong constrains on dynamical models.
Backup
PHENIX NPE production

\[
\frac{d^2N_{npe}}{N_{evt} 2\pi P_T d\eta dP_T}
\]

- 0-60% STAR Preliminary

- PHENIX

\[((0-10%)+(10-20%)+(20-40%)*2+(40-60%)*2)/6\]

PhysRevLett.96.032301

http://www.phenix.bnl.gov/phenix/WWW/info/data/ppg056/non_photonic_electrons.txt
PHENIX NPE v2

FIG. 38: (Color online) $v_2^{HF}$ for the indicated centralities.
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.

$Y_{e_{HF} - h}(\Delta \phi)$

$e_{HF} - h$ 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 AuAu 200GeV study
Nsigma electrons in Mini-Bias triggered events
Event plane resolution for sub-event plane method

3 centrality bins will be used for NPE v2.

- 0.387 for 0~10%
- 0.568 for 10~40%
- 0.472 for 40~60%
Break up of npe v2, 10~40%

Oppo-sign

same-sign

inclusive

Photonic, i.e. oppo-same

Hadrons
With BEMC matching

TPC hadrons
don’t care about BEMC matching

Inclusive - scaled hadron

NPE, before folding
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%