Measurements of Open Heavy Flavor Production in Semi-leptonic Channels at the STAR experiment

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Outline

- **Motivation**

- **STAR experiment**

- **Non-Photonic Electron (NPE) measurements:**
  - Reference from p+p collisions at $\sqrt{s} = 200$ GeV
  - Nuclear modification factor ($R_{AA}$) in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

- **Heavy Flavor Tracker prospects**

- **Summary**
The time evolution of a high energy heavy-ion collision.
Motivation

Heavy quarks (charm and bottom)

- Large masses, dominantly produced in hard scatterings at the early stage
- Probe to the QCD medium properties
  - energy loss ($R_{AA}$)
  - thermalization (elliptic flow $v_2$)
- Test the validity of pQCD and provide the reference for heavy-ion collisions

Non-Photonic Electrons (NPE)

- Produced from semi-leptonic decays of open heavy flavor hadrons
- A good proxy to measure heavy flavor quark production
Time Projection Chamber (TPC)
• Tracking, momentum.
• PID through dE/dx

Time of Flight (TOF)
• PID through time-of-flight
• Timing resolution: ~85 ps.

Barrel Electromagnetic Calorimeter (BEMC)
• PID through p/E
• Fast online trigger
Electron identification

- **Time Projection Chamber**
  - $|\eta|<1.8$, full azimuth
  - Tracking, momentum
  - PID through $dE/dx$

- **Time of Flight**
  - $|\eta|<0.9$, full azimuth
  - PID through TOF
  - Timing resolution: $\sim 85$ ps

- **Barrel Electromagnetic Calorimeter**
  - $|\eta|<1$, full azimuth
  - $p/E$ for electron ID
  - Fast online trigger
Inclusive electrons
After electron ID

Non-photonic electrons
From D/B hadron decays

Photonic electrons
Partially reconstructed through $e^+e^-$ pairs

Hadron contamination
Statistically subtracted

Methodology

NPE yield after background subtraction

$$N_{npe} = N_{inclusive} \times purity - N_{photonic}/\varepsilon_{photonic}$$

NPE invariant cross section:

$$E \frac{d^3\sigma}{dp^3} = \frac{1}{L} \frac{1}{2\pi p_T dp_T dy} \frac{N_{npe}}{\varepsilon_{Total}}$$

$$\varepsilon_{total} = \frac{\varepsilon_{dE/dx} \varepsilon_{BEMC} \varepsilon_{trigger} \varepsilon_{tracking}}{p_T > 1.5 GeV/c} \varepsilon_{dE/dx} \varepsilon_{TOF} \varepsilon_{tracking}$$

p_T < 1.5 GeV/c
Low $p_T$ measurements from Run12 200 GeV $p+p$ collisions
NPE cross section from Run12 200 GeV p+p collisions

- Spectrum was extended to the low $p_t$ region.
- Consistent with pQCD calculation and previous STAR result.
- Greatly reduced uncertainty, leading to a reduction in the uncertainty of $R_{AA}$ measurements in heavy-ion collisions.
In central collisions, there are significant differences between Au+Au measurements and the scaled FONLL calculation, indicating existence of hot medium effects.

From central to peripheral collisions, the difference is getting smaller, which is consistent with less QGP effects in peripheral collisions.

The analysis with Run14 200 GeV Au+Au collisions is ongoing.
NPE $R_{AA}$ in 200 GeV Au+Au collisions

$R_{AA} = \frac{1}{<N_{\text{coll}}>} \times \frac{dN_{AA}/dy}{dN_{pp}/dy}$

- Enhancement at low $p_T$, with large systematic uncertainties from pp reference, is consistent with $D^0$ decayed electron $R_{AA}$.
- Strong suppression is observed at high $p_T$ in central collisions.
Compare NPE $R_{AA}$ with $D^0$ and light hadrons $R_{AA}$ in different heavy-ion collision systems.

Suppression at high $p_T$ in central Au+Au collisions is similar to $D^0$ mesons and light hadrons in Au+Au collisions as well as NPE and $D^0$ mesons in central U+U collisions.
1) In peripheral collisions, $b \rightarrow e R_{AA}$ consistent with no suppression.
2) In min-bias and 0-10% central collisions, $b \rightarrow e R_{AA}$ consistent with indication of suppression ($\sim D^0 R_{AA}$ within large uncertainties).
3) We expect more precise impact parameter method measurement with Heavy Flavor Tracker (HFT).

$N_{b \rightarrow e} = N_{NPE} - N_{c \rightarrow e}$

$N_{c \rightarrow e}$: extract the charm quark cross-section from the measured $D^0 p_T$ spectrum by STAR, and decay the charm quarks into electrons through PYTHIA.

Two different functions, i.e. Levy and Power-law, are used to fit $D^0 p_T$ spectrum, and the difference from these two fits is taken as the uncertainty.
HFT will allow a direct measurement of $B \rightarrow e$ spectrum in Au+Au collisions via displaced decay vertices.

- Help understand the interactions between partons and the medium.
Summary

◆ **NPE cross section in p+p collisions at $\sqrt{s} = 200$ GeV**
  1) measured over a broad $p_T$ range 0.3-12 GeV/c with significantly improved precision than previous measurements.
  2) is consistent with pQCD calculation.

◆ **NPE $R_{AA}$ in Au+Au collisions at $\sqrt{s} = 200$ GeV**
  1) observed large suppression at high-$p_T$ in central collisions, which is consistent with substantial energy loss of heavy quarks in dense matter.
  2) observed an enhancement at low $p_T$, which is consistent with $D^0$ decay electron $R_{AA}$, suggesting the scenario that charm quarks recombine with light quarks in the medium with strong radial flow.

◆ **Look forward to separation of charm and bottom contributions to NPE in Au+Au collisions with HFT data.**
Back up
### HFT Design

- HFT consists of 3 sub-detector systems inside the STAR Inner Field Cage

<table>
<thead>
<tr>
<th>Detector</th>
<th>Radius (cm)</th>
<th>Hit Resolution R/φ - Z (μm - μm)</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td>22</td>
<td>30 / 860</td>
<td>1% X₀</td>
</tr>
<tr>
<td>IST</td>
<td>14</td>
<td>170 / 1800</td>
<td>1.32 %X₀</td>
</tr>
<tr>
<td>PIXEL</td>
<td>8</td>
<td>6.2 / 6.2</td>
<td>~0.52 %X₀</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>6.2 / 6.2</td>
<td>~0.39% X₀</td>
</tr>
</tbody>
</table>

- **SSD** existing single layer detector, double side strips (electronic upgrade)
- **IST** one layer of silicon strips along beam direction, guiding tracks from the SSD through PIXEL detector - **proven pad technology**
- **PIXEL** double layers, 20.7x20.7 mm pixel pitch, 2 cm x 20 cm each ladder, 10 ladders, delivering ultimate pointing resolution. - **new active pixel technology**
Background from hadron decays

Study background by simulations

1) $K \rightarrow e\pi\nu(K_{e3})$:

\[ K^+ \rightarrow e^+\pi^0\nu \quad K_L^0 \rightarrow e^\pm\pi^\mp\nu \]

2) dielectron decays of vector mesons:

\[ \omega \rightarrow e^+e^-/\omega \rightarrow \pi^0e^+e^- \quad \phi \rightarrow e^+e^-/\phi \rightarrow \eta e^+e^- \]