Measurements of Electrons from Semi-leptonic Heavy Flavor Decays in p+p and Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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Outline

• Motivation

• STAR Experiment at RHIC

• Non-Photonic Electron (NPE) Measurements
  - NPE production in p+p, Au+Au and U+U collisions
  - Separate D/B-decayed electrons in p+p and Au+Au collisions

• Summary and Outlook
Motivation

Heavy quarks (charm and bottom)

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

Non-Photonic Electrons (NPE)

- Produced from semi-leptonic decays of open heavy flavor hadrons
- A good proxy to measure heavy flavor quark production
STAR Experiment at RHIC – STAR Detector

Large acceptance
Excellent PID
Fast DAQ
Broad collision energy range
NPE Measurements – Data Analysis Methodology

Non-photonic electrons
From D/B hadron decays

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

γ conversion $\gamma \rightarrow e^+e^-$
π₀ Dalitz decay $\pi^0 \rightarrow \gamma e^+e^-$
η Dalitz decay $\eta \rightarrow \gamma e^+e^-$

Inclusive electrons
After electron ID

Photonic electrons

Hadron contamination
Statistically subtracted

NPE yield after background correction:

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

NPE invariant cross-section:

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

$$\varepsilon_{Total} = \varepsilon_{dE/dx} \varepsilon_{BEMC} \varepsilon_{Trigger} \varepsilon_{Tracking}$$

p_T > 1.5 GeV/c
p_T < 1.5 GeV/c

HP2016, Wuhan, Yaping Wang
Run12 200 GeV p+p collisions

Fit dE/dx distribution to extract purity

\[ w/o \text{dE/dx cut} \]

-1 < nσ_e < 3

Purity and Photonic Electron Eff.

Electron Reconstruction Eff.
Spectrum was extended to both lower and higher $p_T$ regions.

Consistent with pQCD calculation and previous STAR result. There is tension at low $p_T$ between data and pQCD calculation.

Significantly better precision, leading to a reduction in the uncertainty of $R_{AA}$ measurements in heavy-ion collisions.
In central collisions, significant differences were observed between Au+Au measurements and the scaled FONLL calculation, indicating existence of hot medium effects.

From central to peripheral collisions, the difference decreases. This is consistent with the expectation that peripheral collisions should have smaller QGP effects.

The analysis with Run14 200 GeV Au+Au collisions is ongoing.
In the low $p_T$ region, an enhancement shows up that is consistent with electrons from tagged $D^0$ decays. The large systematic uncertainties are dominated by that from the $p+p$ reference.

For $p_T > 4$ GeV/c, significant suppression is seen in the most central Au+Au collisions. The suppression decreases gradually toward more peripheral collisions.
NPE Measurements – NPE $R_{AA}$ in 200 GeV Au+Au collisions

U+U and Au+Au systems use the same improved Run12 p+p reference

• NPE $R_{AA}$ in the 0-5% most central 200 GeV Au+Au and 193 GeV U+U collisions are consistent within uncertainties.

• NPE suppression at high $p_T$ in 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.
Prominent correlation signals on both near-side and away-side

PYTHIA 8.1 combined with STAR-HF-Tune Version 1.1 to generate $e(D)-h$ and $e(B)-h$ correlations in 200 GeV $p+p$ collisions

Significant difference on the near-side of correlation distributions between D and B decays due to different decay kinematics
NPE Measurements – Separate D/B-decayed Electrons

- Fit function: \((R \cdot \text{PYTHIA}_B + (1-R) \cdot \text{PYTHIA}_D) \cdot \text{Norm}\)
- \(R\) is B contribution, i.e. \(B/(B+D)\), as a free parameter in fit function.

- \(B \rightarrow e\) contributions in 200 GeV p+p collisions are obtained from e-h correlations, and consistent with FONLL calculation.
- Agree with previous STAR analysis for \(p_T < 8.5\) GeV/c with significantly reduced systematics.
NPE Measurements – Separate D/B-decayed Electrons

B→e $R_{AA}$

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

$N_{c\to e}$: 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.

1) In peripheral collisions, $B\to e$ $R_{AA}$ consistent with no suppression.

2) In mini. bias and 0-10% central collisions, $B\to e$ $R_{AA}$ shows an indication of suppression ($\sim D^0 R_{AA}$ within large uncertainties).
• First application of Monolithic Active Pixel Sensor (MAPS) technology in collider experiments. DCA resolution <50 µm for Kaons at $p_T=750$ MeV/c.
• Recorded about 3B Minimum-Bias 200 GeV Au+Au events for $D^0$, $D^\pm$, $D_s$, $\Lambda_c$, and 1 nb$^{-1}$ high $p_T$ electron and dimuon samples for $D/ B \rightarrow e$ and $B \rightarrow J/\psi$ studies in 2014 and 2016.
• HFT will allow the separation of B and D decayed electrons for the first time at the STAR experiment using the impact parameter method.
Summary and Outlook

• **NPE cross-section in p+p collisions at \( \sqrt{s} = 200 \text{ GeV} \)**
  1. Measured over a broad \( p_T \) range 0.3-12 GeV/c with significantly improved precision than previous measurements.
  2. Consistent with pQCD calculation except that there is tension at low \( p_T \).

• **NPE \( R_{AA} \) in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)**
  1. Strong suppression at high \( p_T \) in central collisions, which is consistent with substantial energy loss of heavy quarks in dense matter.
  2. Likely enhancement at low \( p_T \), which is consistent with \( D^0 \ R_{AA} \), suggesting that charm quarks may recombine with light quarks in the medium.
  3. Consistent results between 0-5% central Au+Au and U+U collisions within uncertainties.

• **Separate D/B-decayed electrons**
  1. Bottom contribution to NPE is extracted using NPE-h correlations in p+p collisions at \( \sqrt{s} = 200 \text{ GeV} \) with extended \( p_T \) range and reduced systematics than previous measurements.
  2. Looking forward to a separation of charm and bottom contributions to NPE in Au +Au collisions with HFT.
Thanks for your attention!