Measurements of non-photonic electrons in STAR

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Outline

• Motivation

• Non-photonic electron (NPE) analysis method

• NPE results:
  → p+p at 200 GeV
  → Au+Au – nuclear modification factor $R_{AA}$ at 200 GeV
    – elliptic flow $v_2$ in Au+Au at 39, 62.4, and 200 GeV
Heavy-ion collisions

- Heavy-ion collisions:
  - → hot and dense nuclear matter formation - Quark-Gluon Plasma
  - → hot and cold nuclear matter effects

- p+p collisions:
  - → baseline

- Medium effects quantified by nuclear modification factor:
  - $R_{dA}$ – cold nuclear matter effects
  - $R_{AA}$ – hot nuclear matter effects

$$R_{AA} = \frac{1}{<N_{\text{coll}}>} \ast \frac{dN_{AA}/dy}{dN_{pp}/dy}$$
Non-photonic electrons

Semi-leptonic decay of bottom and charm hadrons → non-photonic electrons.
\[ b \rightarrow e^\pm + \text{anything} (10.86\%) \]
\[ c \rightarrow e^\pm + \text{anything} (9.6\%) \]

- **Heavy quarks:**
  - large masses
  - early production
  - p+p collisions - test of the validity of the pQCD

- **Heavy ion collisions:**
  - energy loss
    (nuclear modification factor \( R_{AA} \))
  - thermalization (elliptic flow \( v_2 \))
STAR detector at RHIC

Solenoidal Tracker At RHIC: \(-1 < \eta < 1, \ 0 < \phi < 2\pi\)

- **Time Projection Chamber (TPC)** – tracking, particle identification, momentum

- **Time of Flight detector (ToF)** – particle identification at low \(p_T\) region

- **Barrel Electromagnetic Calorimeter (BEMC)** – electron identification at high \(p_T\) region, triggering (High Tower triggers)

- **Barrel Shower Maximum Detector (BSMD)** – electron identification at high \(p_T\)
STAR detector at RHIC

Solenoidal Tracker At RHIC: \(-1 < \eta < 1, 0 < \phi < 2\pi\)

Electron identification with only TPC at low \(p_T\) region is difficult.
TPC and TOF together are great tool to distinguish electrons and hadrons at low $p_T$ region ($p_T < 2\text{GeV/c}$).
STAR detector at RHIC

**Solenoidal Tracker At RHIC**: $-1 < \eta < 1$, $0 < \phi < 2\pi$

TPC and BEMC together are used for electron identification at high $p_T$ region ($p_T > 2\text{GeV}/c$).

![Graph of $E/p$ vs. $E$ for Au+Au collisions at 200 GeV](image)
Analysis method

\[ NPE = N_{\text{Inclusive}} \times \text{purity}_{\text{Inclusive}} - \frac{N_{\text{Photonic}}}{\epsilon_{\text{Photonic}}} \]

- **Inclusive electrons** – identification with TPC, TOF, BEMC.

- **Main background** - photonic electrons
  
  Dalitz decay: \( \pi^0 \rightarrow \gamma + e^+ + e^- \) (BR: \( \sim 1.2\% \))
  
  Gamma conversions: \( \gamma \rightarrow e^+ + e^- \)
  
  → identified via small \( e^+e^- \) invariant mass
  
  → statistically reconstructed
  
  → corrected for reconstruction efficiency via simulation
NPE in p+p collisions at $\sqrt{s}=200\text{GeV}$

- **p+p at 200GeV data** (year 2009 and year 2012)

- Spectrum is reconstructed at wide $p_T$ range.

- Results are compared with FONLL pQCD. (Fixed Order plus Next-to-Leading Logarithms).

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Data to FONLL ratio

- Results compared with FONLL calculation.
- Results are consistent with FONLL and with other RHIC NPE results.

NPE in Au+Au collisions at $\sqrt{s_{NN}} = 200\text{GeV}$

- Au+Au at 200GeV (year 2010 data):
  - suppression at high $p_T$ compared with FONLL calculations
Strong suppression is observed at high $p_T$. Strong suppression is similar as for $D^0$ mesons and light hadrons.

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dy}{dN_{pp}/dy}$$

Elliptic flow in Au+Au collisions

- Elliptic flow $v_2$ describes the collective evolution of the system.

- Initial geometry asymmetry $\rightarrow$ final momentum anisotropy

- NPE $v_2$ measurement serves as a proxy for heavy quark $v_2$.

\[
\frac{dN}{d\varphi} \propto \left( 1 + 2 \sum_n \nu_n \cos[n(\varphi - \psi_n)] \right)
\]

\[
\nu_n = \langle \cos n(\varphi - \psi_n) \rangle
\]
NPE elliptic flow in Au+Au collisions at \( \sqrt{s_{\text{NN}}} = 200 \text{ GeV} \)

- Results obtained using 2-particle and 4-particle correlations.
- With different contributions from fluctuations and non-flow contribution, \( v_2^2 \) gives upper and \( v_2^4 \) gives lower limit on elliptic flow.
- We observed finite \( v_2^2 \) and \( v_2^4 \) for \( p_T > 0.5 \text{ GeV/c} \) at \( \sqrt{s_{\text{NN}}} = 200 \text{ GeV} \).

arXiv:1405.6348 [nucl-ex]

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NPE elliptic flow in Au+Au collisions at $\sqrt{s_{NN}} = 39$ and 62.4 GeV

- $v_2^2$ Beam Energy Scan results

- Energy dependance of the strength of heavy quarks interaction with hot and dense medium.

- Inclusive charged hadron $v_2$ approximatelly independent of beam energy.

- NPE $v_2^2$ at 39 and 62.4 GeV is consistent with zero.

arXiv:1405.6348 [nucl-ex]
Gluon radiation scenario alone fails to explain large NPE suppression at high $p_T$.

Finite elliptic flow together with large suppression at high $p_T$ at $\sqrt{s_{NN}} = 200$ GeV indicates that heavy quarks interact strongly with the surrounding partonic medium.

It's challenging for model calculations to describe the suppression and $v_2$ simultaneously.
Heavy flavor tracker (HFT)

- HFT allows measurement of $\text{B} \rightarrow \text{e}$ and $\text{D} \rightarrow \text{e}$ spectrum separately in Au+Au.
Conclusions

- Measurement of the NPE spectrum in p+p collisions at $\sqrt{s}=200$ GeV was extended to the low $p_T$ region.

- We observed strong suppression of NPE in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV.

- NPE $v_2$ at $\sqrt{s_{NN}}=200$ GeV in Au+Au collisions: finite $v_2$ at low $p_T$ together with strong suppression at high $p_T$ indicates a strong charm-medium interaction.

- NPE $v_2$ at $\sqrt{s_{NN}}=39$ and 62.4 GeV in Au+Au collisions: $v_2$ consistent with zero.

- The new HFT detector will allow measurement of $B \to e$ and $D \to e$ spectra separately.
Thank you!