Measurement of heavy-flavor electron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at STAR

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Abstract

Studying heavy-flavor quarks helps to probe parton interactions with the Quark-Gluon Plasma (QGP). Due to their large mass, charm and bottom quarks are mainly produced in the early stages of high-energy heavy-ion collisions, where hard scatterings dominate, allowing them to experience the full QGP evolution. Heavy-flavor electrons (HFE), originating from semi-leptonic decays of heavy-flavor hadrons, offer a way to study heavy-quark transport properties. We present HFE measurements at low transverse momentum (p_T) in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV, using 2017 STAR data. Strong HFE suppression observed at $\sqrt{s_{NN}}$ = 200 GeV [1] motivates this study at lower energy, providing new insights into the dependence of heavy-quark transport on QGP temperature and baryon chemical potential. These results complement earlier measurements at $\sqrt{s_{NN}}$ = 200 GeV [1] and recent HFE elliptic flow results at $\sqrt{s_{NN}}$ = 54.4 GeV [2].

Heavy-flavor electrons

- Heavy-flavor electrons are electrons from semi-leptonic decays of open heavy-flavor hadrons.
- Semi-leptonic decays BR > hadronic decays BR ⟶ wide usage in studying heavy quark production.
- The yield of **heavy-flavor electrons**, N^{HFE}, is

$$N^{\mathrm{HFE}} = \frac{N^{\mathrm{incl}} \cdot purity - N^{\mathrm{PE}}/\varepsilon^{\mathrm{PE}}}{\varepsilon^{\mathrm{total}}} - N^{\mathrm{HDE}}, \quad (1)$$

where N^{incl} is the inclusive electron candidate yield, N^{PE} is the photonic electron yield, $\varepsilon^{\mathrm{PE}}$ is the photonic electron tagging efficiency, $\varepsilon^{\mathrm{total}}$ is the total efficiency of electron identification and reconstruction, N^{HDE} is the yield of hadron-decayed electrons from ρ, ω, ϕ, J/ψ, Υ, Drell-Yan and K_{e3} [2].

- **N^{PE} sources:**
  - Dalitz decays: $\pi^0 \to \gamma e^+ e^-$, $\eta \to \gamma e^+ e^-$
  - Photon conversions in detector material: $\gamma \to e^+ e^-$
- The main goal is: **central-to-peripheral nuclear modification factor**

$$R_{\mathrm{CP}} = \frac{1}{N_{\mathrm{bin}}^{\mathrm{central}}} \cdot \frac{d^2 N^{\mathrm{HFE}}_{\mathrm{central}}}{2\pi p_{\mathrm{T}} dp_{\mathrm{T}} dy} \Bigg/ \frac{1}{N_{\mathrm{bin}}^{\mathrm{periph}}} \cdot \frac{d^2 N^{\mathrm{HFE}}_{\mathrm{periph}}}{2\pi p_{\mathrm{T}} dp_{\mathrm{T}} dy} \quad (2)$$

where $N_{\mathrm{bin}}^{\mathrm{central}}$ ($N_{\mathrm{bin}}^{\mathrm{periph}}$) and $d^2N^{\mathrm{HFE}}_{\mathrm{central}}$ ($d^2N^{\mathrm{HFE}}_{\mathrm{periph}}$) are the average binary nucleon-nucleon collisions and invariant HFE yields in central (peripheral) collisions, respectively.

Done, Work in progress, To be done

Inclusive electron selection

- Inclusive electron candidates are identified using the TPC, TOF, and BEMC.
- **TPC:** momentum-dependent $n\sigma_e$ cut at low momentum ($2.25p - 3 < n\sigma_e < 2$) and a constant cut at high momentum ($-1.2 < n\sigma_e < 2$).
- **TOF:** the inverse particle velocity, $1/\beta$, cut ($|1/\beta - 1| < 0.25$) in TOF hybrid mode (for $p_{\mathrm{T}} > 1.5$ GeV/c).
- **BEMC:** the ratio of the energy deposited by an electron in the BEMC to its momentum, E/p, for $p_{\mathrm{T}} > 1.5$ GeV/c ($0.6 \leq E/p \leq 1.5$) ⟶ suppress hadrons at high p_{T}.

Photonic electrons

- **Photonic electrons** are identified using the invariant mass method and statistically subtracted from the inclusive electron sample [3].

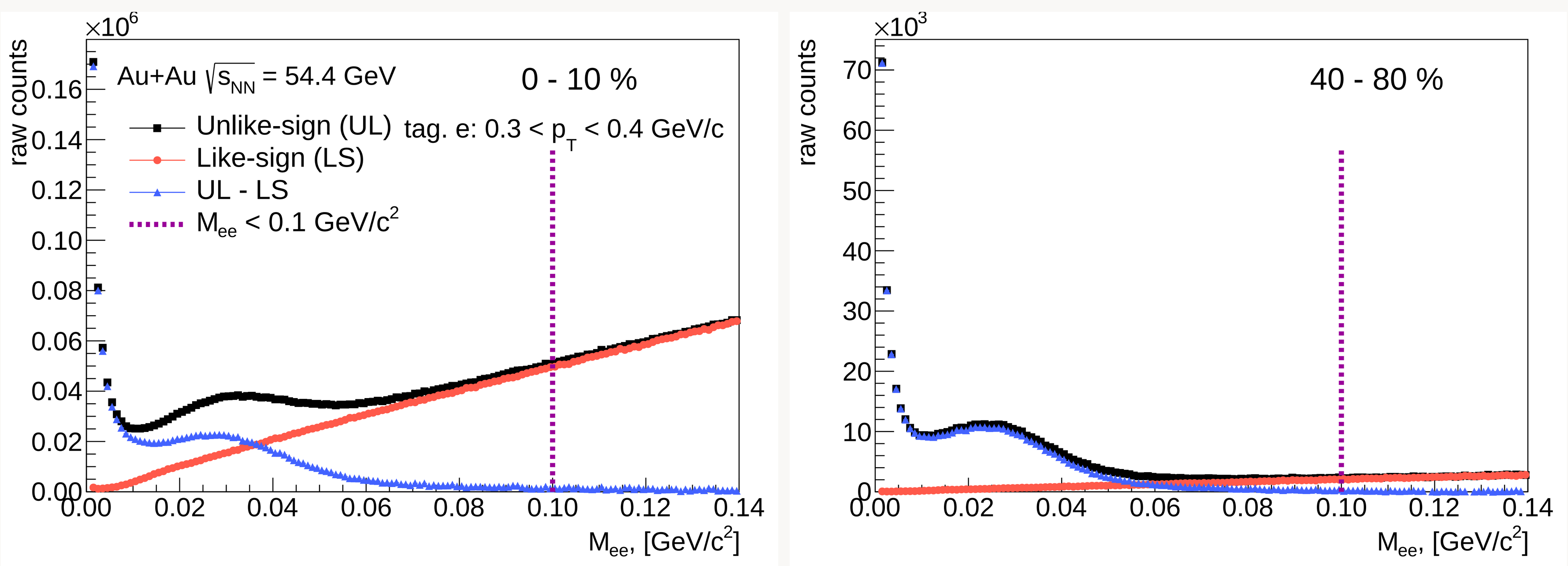

Figure 1: Invariant mass selection of photonic electrons in central (left) and peripheral (right) collisions.

- The **photonic electron identification efficiency**, $\varepsilon^{\mathrm{PE}}$, is calculated by propagating γ conversions, π^0 and η decays through the GEANT simulation of the STAR detector [2] before embedding them into real events.

STAR detector

STAR is a versatile detector designed to study the formation and properties of the QGP, as well as the spin structure of the proton.

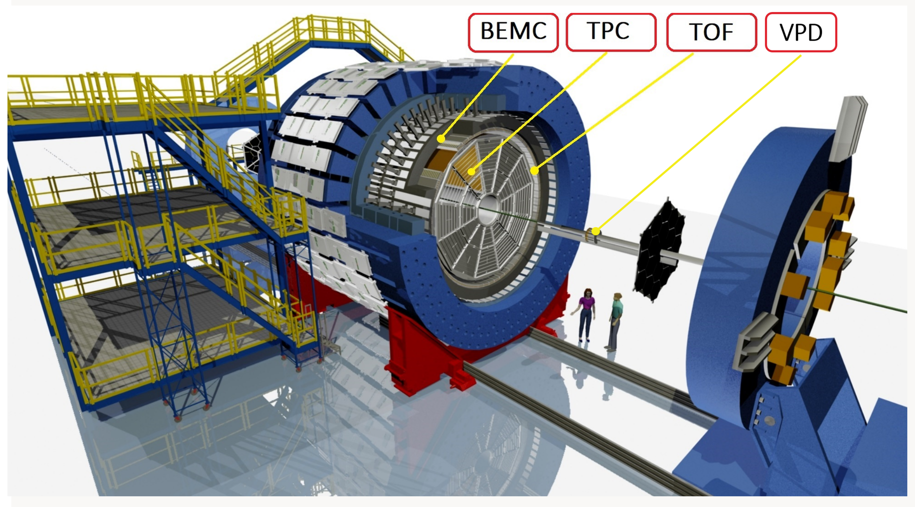

Figure 2: The STAR experiment.

- **V**ertex **P**osistion **D**etector (VPD):
  - Minimum-bias trigger.
- **T**ime **O**f **F**light (TOF):
  - Particle identification ($1/\beta$).
- **T**ime **P**rojection **C**hamber (TPC):
  - Particle momentum reconstruction and identification (dE/dx, **p**).
- **B**arrel **E**lectro**M**agnetic **C**alorimeter (BEMC):
  - High p_{T} electron identification and triggering.
- Centrality is determined by comparing the charged-particle multiplicity in data to the Glauber model [4].
- $3 \cdot 10^8$ events in 0–80% centrality pass trigger and event selection.

Correction and raw signal

- **Efficiencies:** $\varepsilon^{\mathrm{total}}$ combines TPC tracking, TOF matching, $1/\beta$ cut, BEMC matching, E/p, and $n\sigma_e$ cut efficiencies.
  - For $p_T < 1.5$ GeV/c, $\varepsilon^{\mathrm{total}}$ is calculated as: $\varepsilon^{\mathrm{total}} = \varepsilon^{\mathrm{TPC}} \cdot \varepsilon^{n\sigma_e} \cdot \varepsilon^{\mathrm{TOF}} \cdot \varepsilon^{1/\beta}$
  - For $p_T \geq 1.5$ GeV/c: $\varepsilon^{\mathrm{total}} = \varepsilon^{\mathrm{TPC}} \cdot \varepsilon^{n\sigma_e} \cdot \varepsilon^{\mathrm{BEMC+E}/p} \cdot (1 - \varepsilon^{\mathrm{TOF}} + \varepsilon^{\mathrm{TOF}} \cdot \varepsilon^{1/\beta})$
  - Figure 3 illustrates how the obtained efficiencies contribute to the total electron identification and reconstruction efficiency, $\varepsilon^{\mathrm{total}}$.

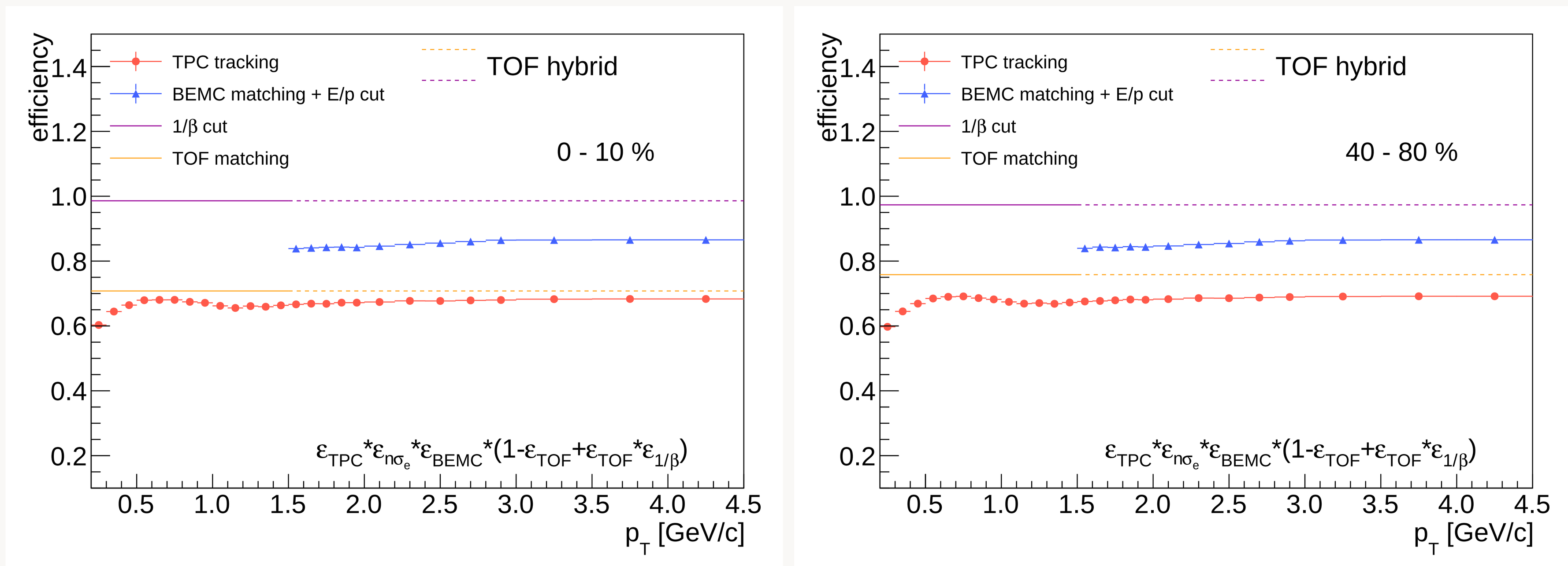

Figure 3: Efficiencies for $\varepsilon^{\mathrm{total}}$ calculation for central (left) and peripheral (right) collisions.

  - **TPC tracking**, **BEMC matching**, and **E/p cut** efficiencies are extracted from **STAR simulations**, while the others are calculated using a pure electron sample from data.
- **Raw inclusive and photonic electron yields** across centrality ranges:

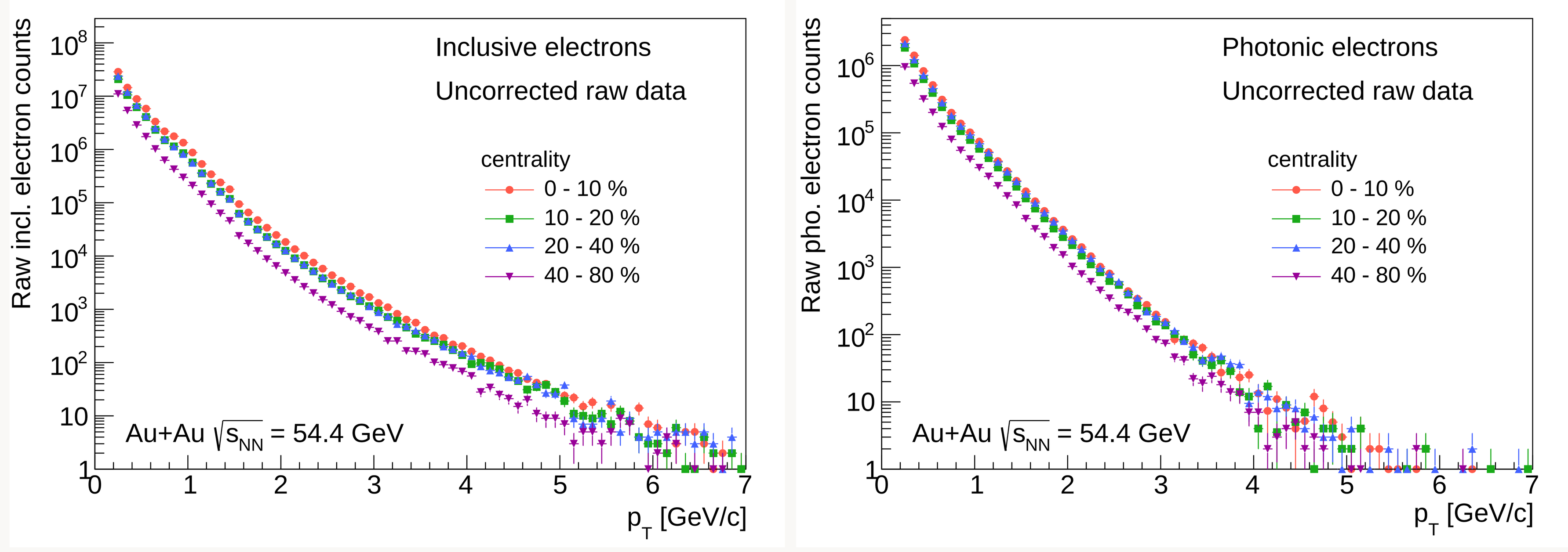

Figure 4: Inclusive and photonic electron yields, N^{incl} and N^{PE}, for different centrality ranges.

  - Drop at $p_{\mathrm{T}} > 1.5$ GeV/c is due to BEMC and TOF (in hybrid mode) in addition to TPC electron identification.

Summary and Outlook

- Technical plots illustrating the individual steps towards the evaluation of N^{HFE} are presented.
- Finalize corrections for purity, $n\sigma_e$ cut efficiency and ε^{PE} ⟶ final evaluation of N^{HFE} and R_{CP} and physics implications for heavy-quark energy loss.

References

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The STAR Collaboration

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