



# Elliptic flow of heavy flavor electrons in 27 and 54.4 GeV Au+Au collisions with STAR

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for the STAR collaboration

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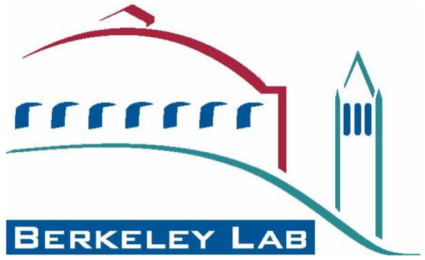


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# *Outline*

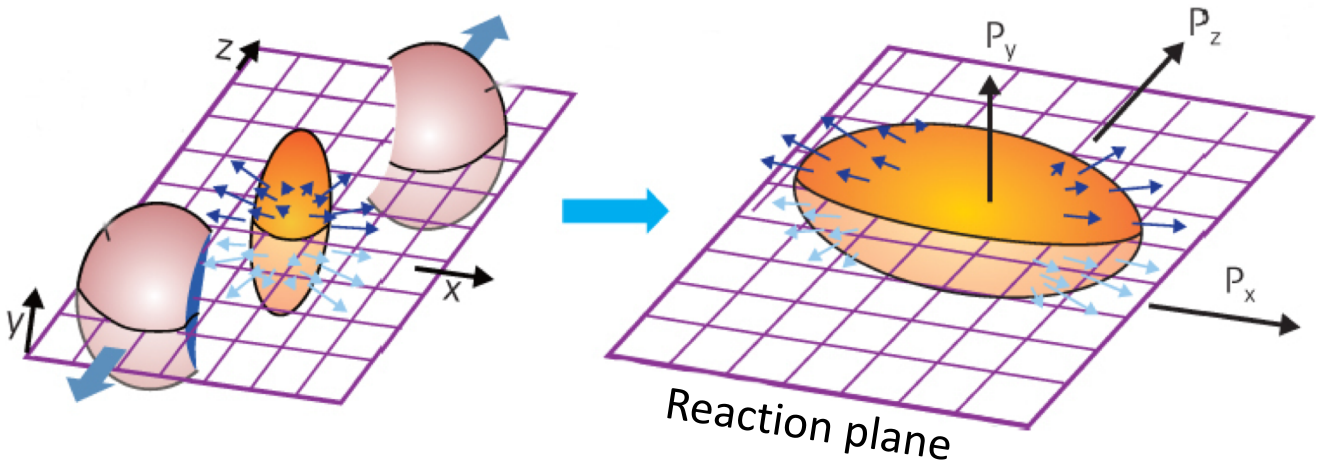
- Introduction
- STAR detector
- Analysis method
- Results and summary

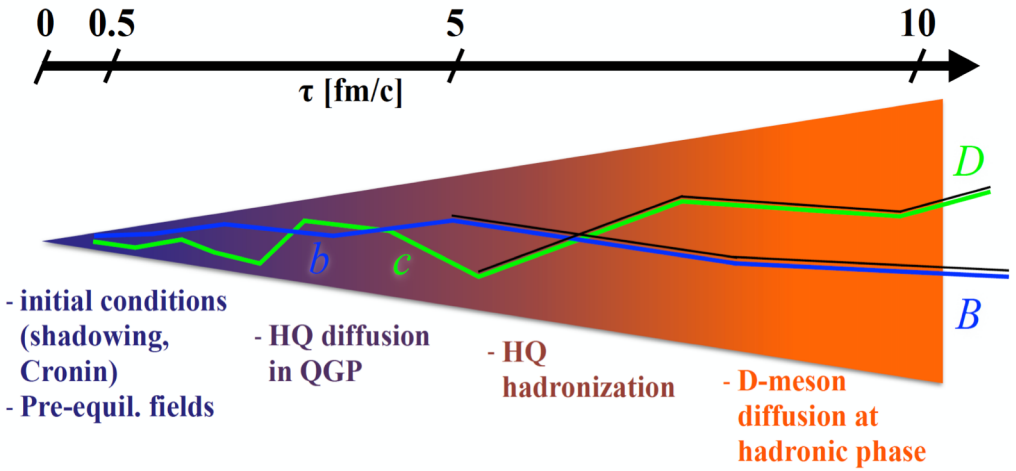
# Heavy quarks and elliptic flow

- Elliptic flow

$$E\frac{d^3N}{d^3\vec{p}} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Phi_n)])$$

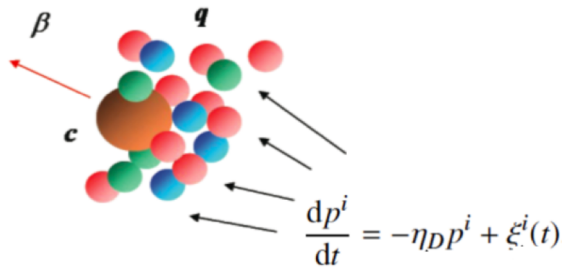
$$v_2 = < \cos 2(\phi - \Phi_2) >$$



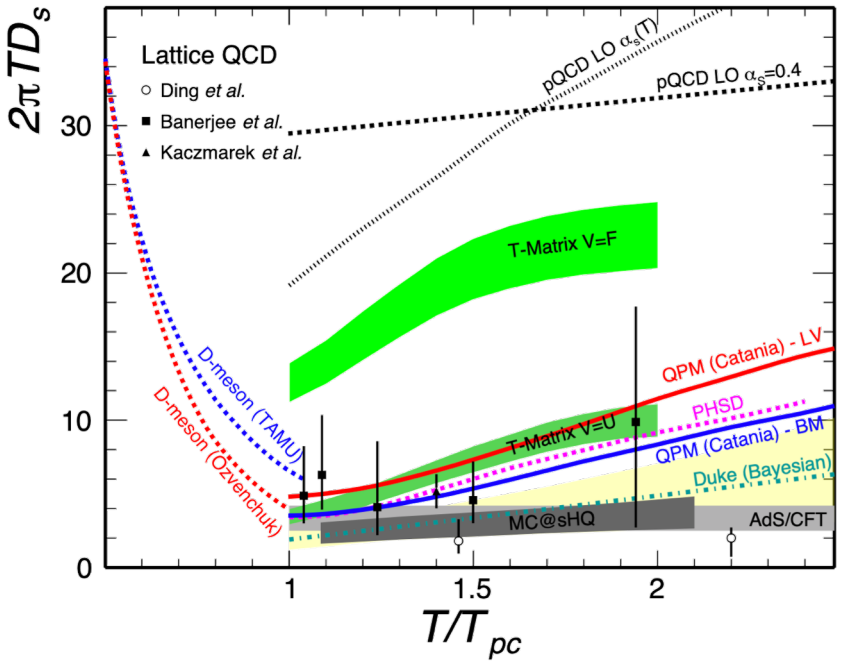

- Heavy flavor hadron $v_2$

  - Spatial diffusion coefficient ($2\pi TDs$) of heavy quarks in QGP.

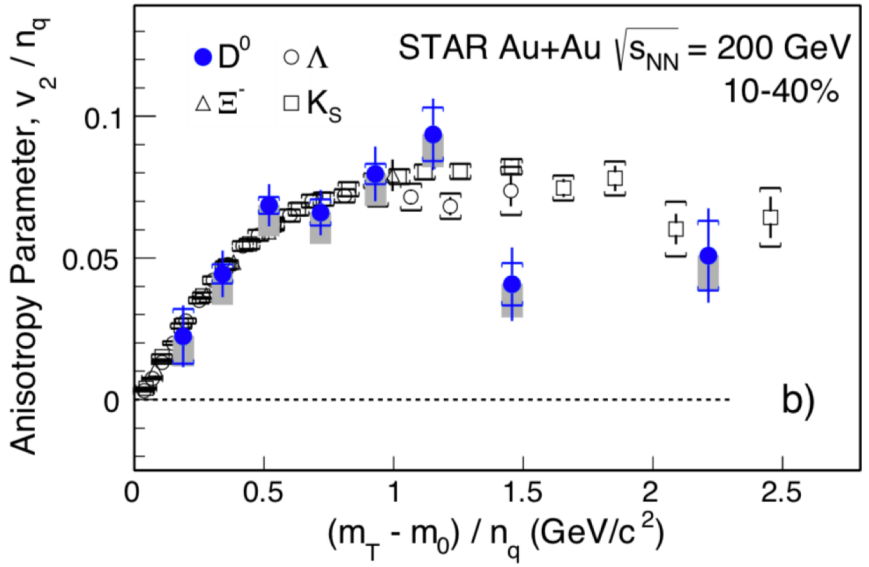


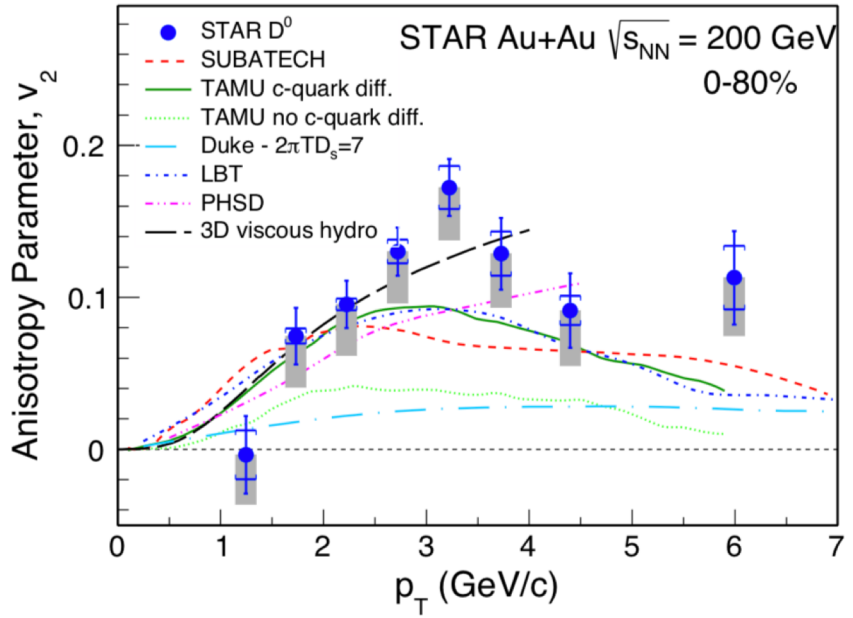
# Temperature dependence

- Charm quark $v_2$ similar to the light hadrons in Au+Au 200 GeV collisions
  - Charm attain thermal equilibrium in the QGP?
- Model calculations with T-dependent charm quark $2\pi TDs$ can qualitatively reproduce $D^0$ $v_2$
- What's charm quarks flow at lower energies?




X. Dong et al. PPNP 104, 97-141 (2019)



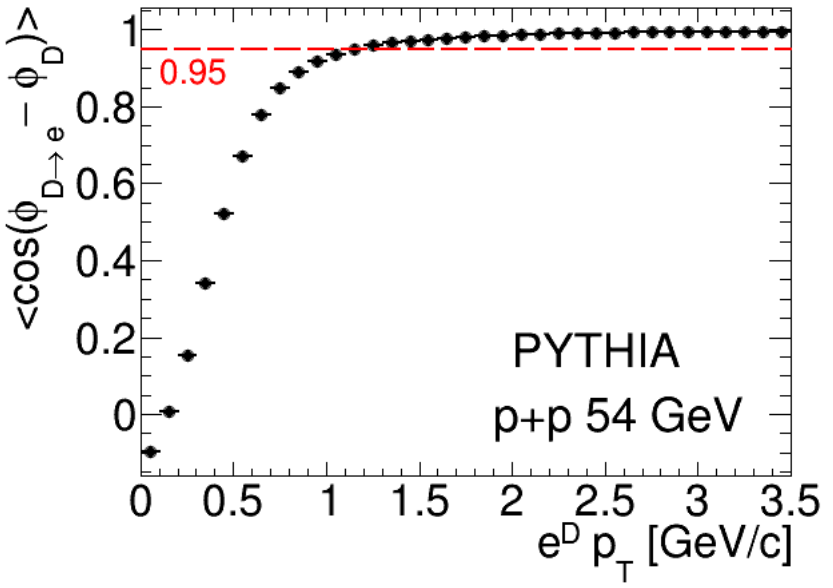



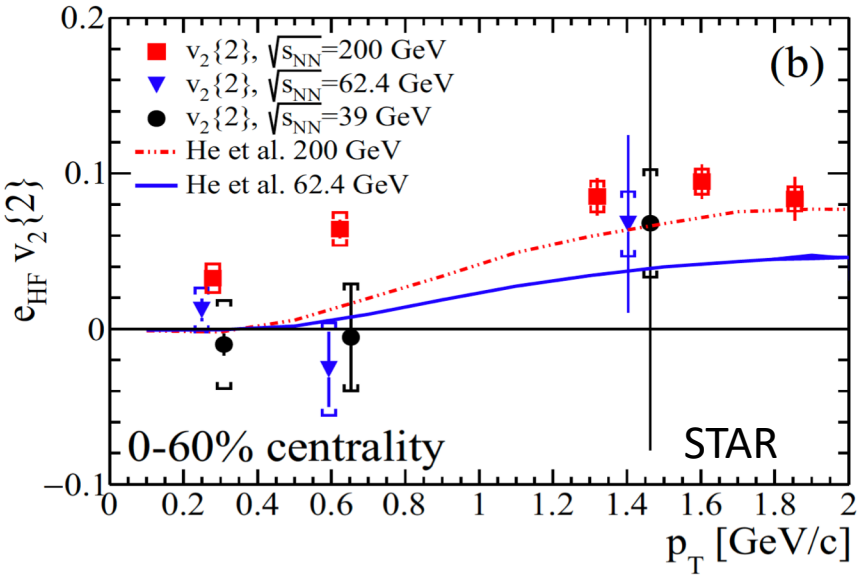

STAR. PRL 118 (2017) 212301

# *Why heavy flavor electrons?*

- Direct reconstruction is challenging
  - Charm cross section decreases rapidly at low energy
  - Low energy runs: no silicon-based tracker for precise secondary vertex reconstruction
- Semi-leptonic decays of heavy flavor hadrons
  - Larger branching ratio compared to typical hadronic channel

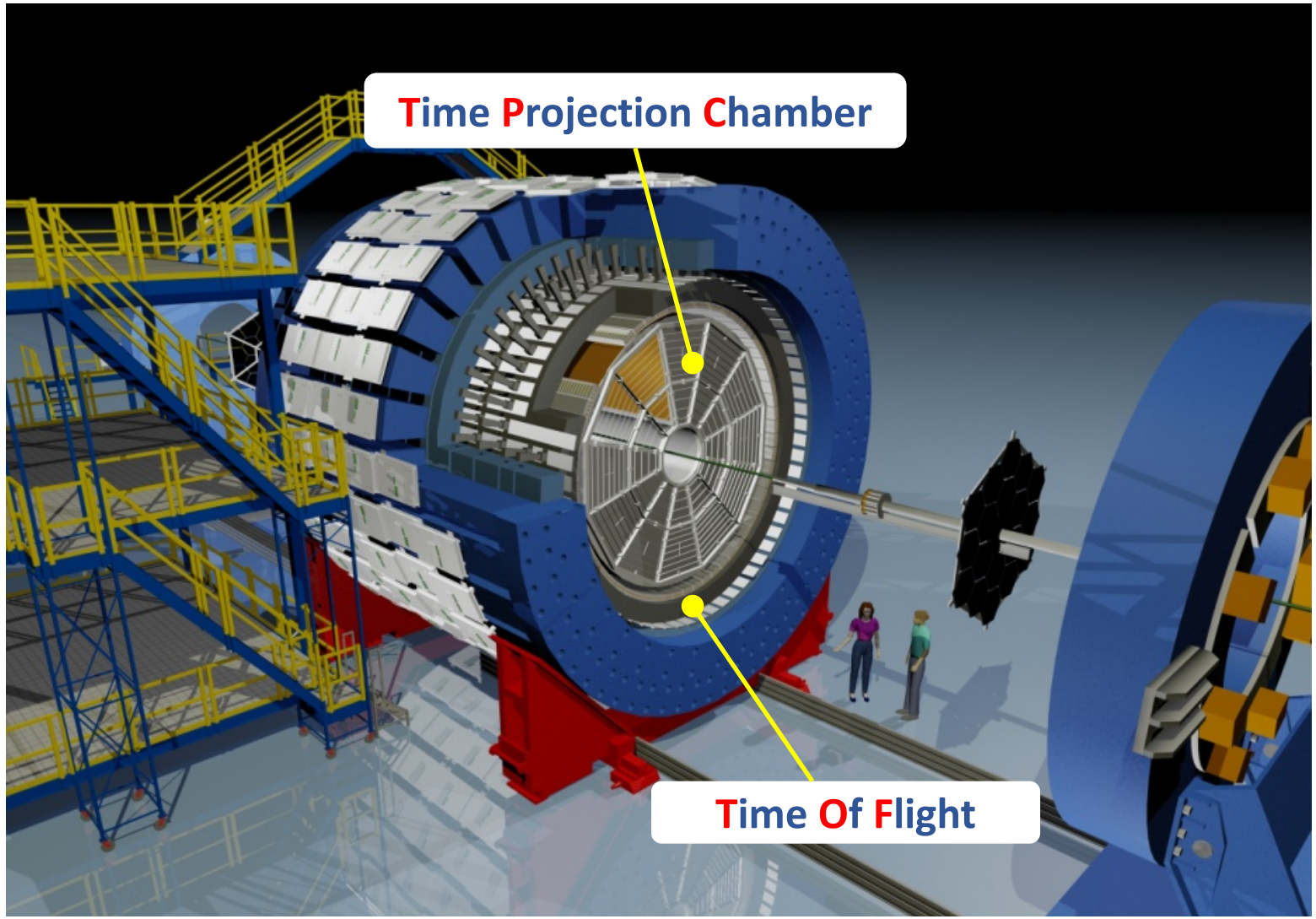
    - c→e + anything (B.R. 9.6%), PDG, PRD 98, 030001 (2018)
  - Carry information of the direction of the parent D (B) hadron.
- Large data samples of 27 and 54.4 GeV Au+Au collisions collected in 2017-2018
  - 10× more statistics compared to 62.4 GeV
  - Significantly improve the precision




STAR. PRC 95, 34907 (2017)

# The STAR detector

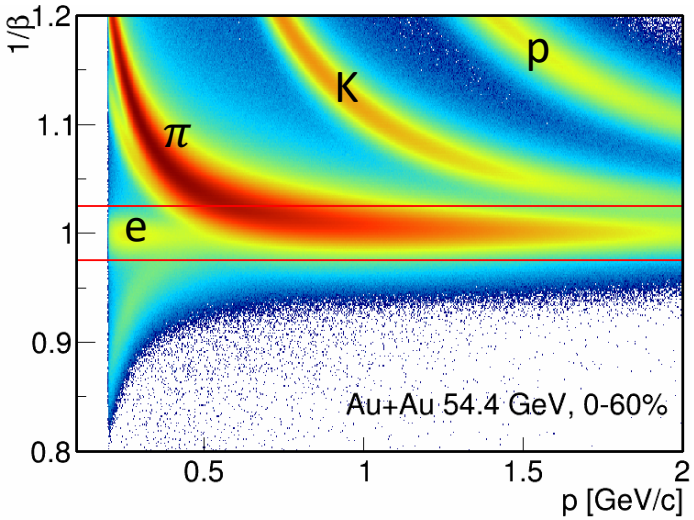



## TPC

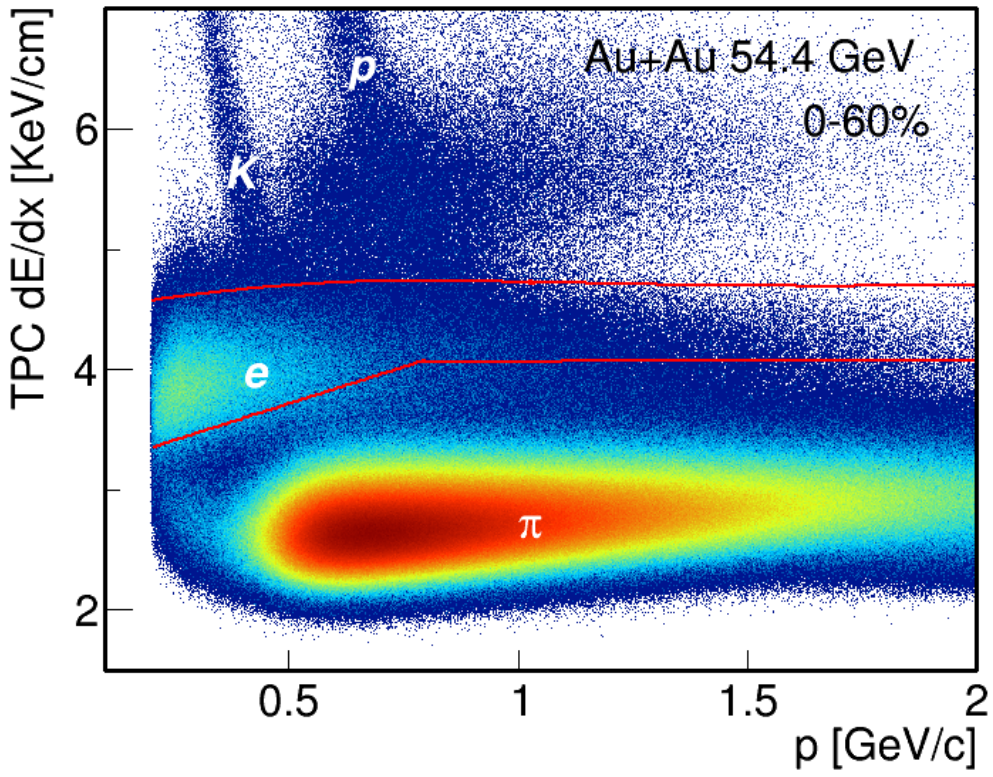
Tracking
Momentum measurement
Event plane reconstruction
$|\eta|<1$, $0<\varphi<2\pi$
Electron identification (PID)

## TOF

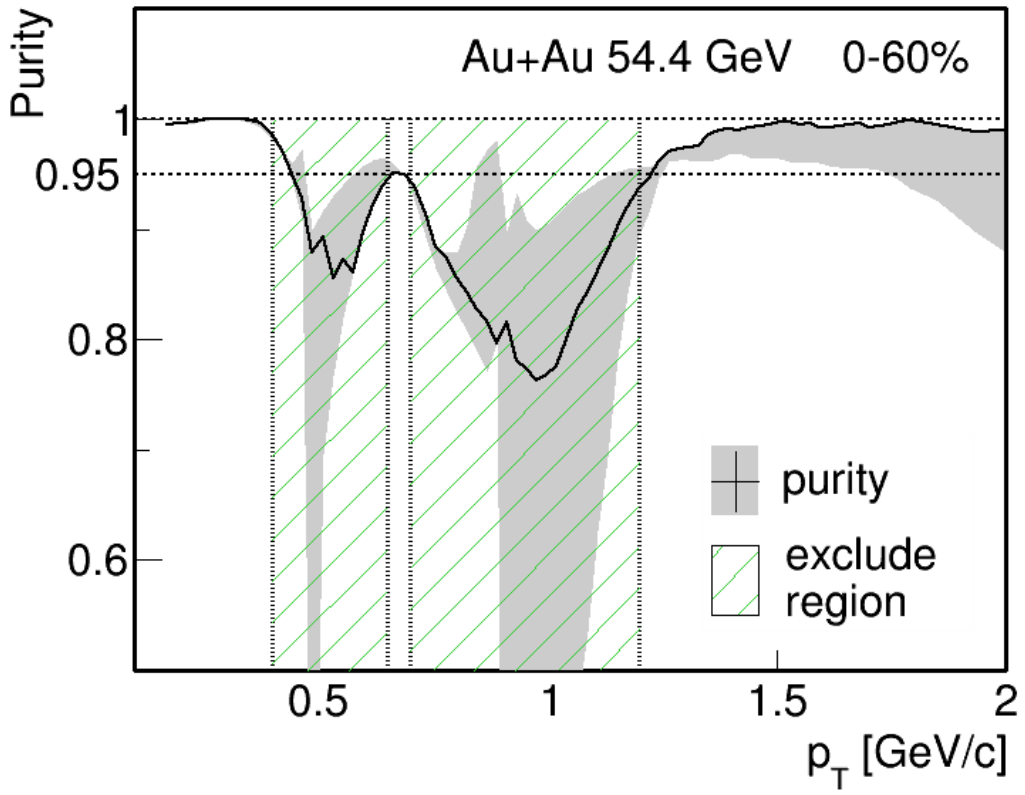
Electron identification
$|\eta|<1$, $0<\varphi<2\pi$



# Electron identification




TPC dE/dx after TOF selection




Electron purity after dE/dx

$e^{Inc} = purity \times e^{PID}$

Choose the high purity region for analysis.

# Photonic electron

- Main background for $e^{HF}$

  Photonic electron:

  $\pi^0 \rightarrow \gamma ee$ Dalitz decay

  $\eta \rightarrow \gamma ee$ Dalitz decay

  $\gamma \rightarrow ee$ gamma conversion

  - $\pi^0 \rightarrow \gamma\gamma$
  - $\eta \rightarrow \gamma\gamma$
  - direct photon

  $e^{HF} = e^{Inc} - e^{pho} = e^{Inc} - e^{reco}/eff$

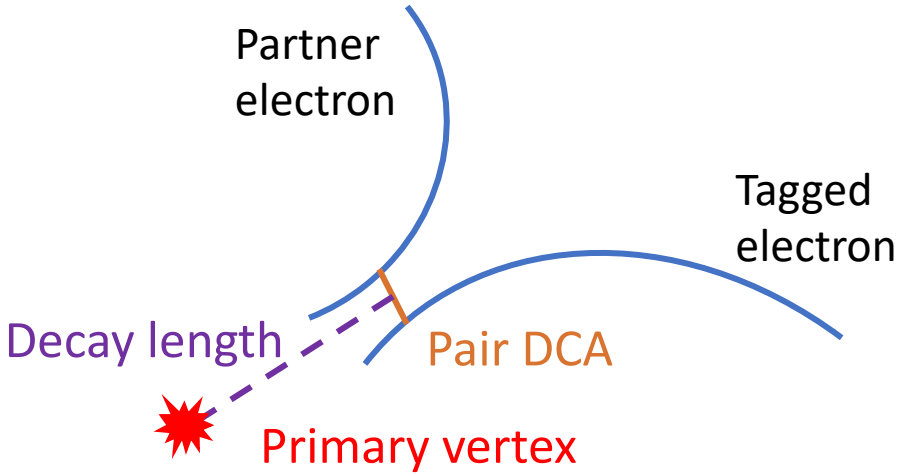
- Photonic electron tagging:

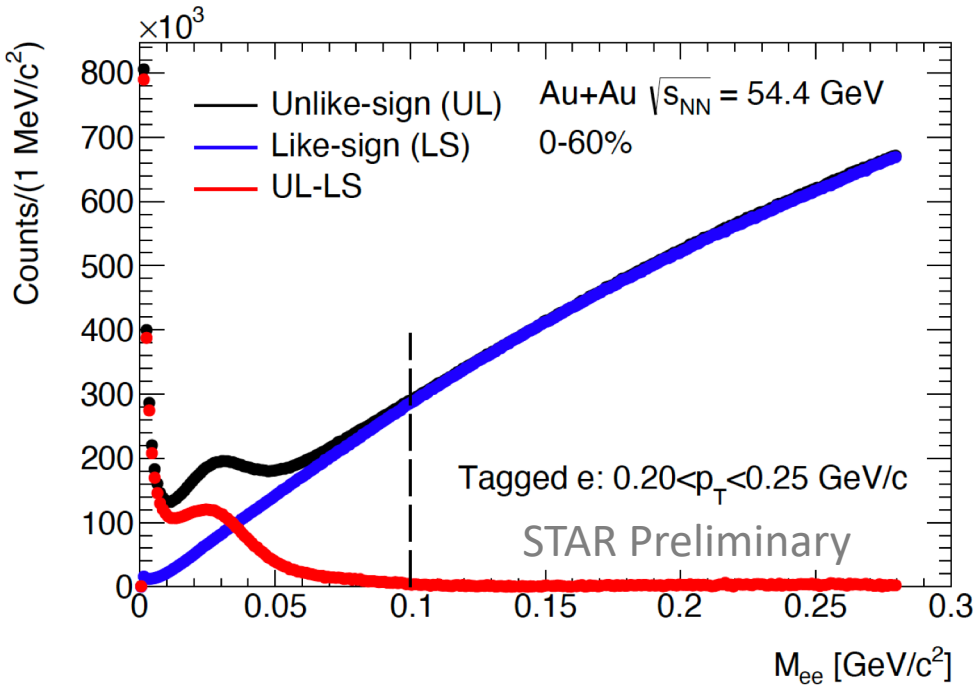
  Reconstruction method

  - pair tagged electron with partner electrons

- Reconstruction efficiency:

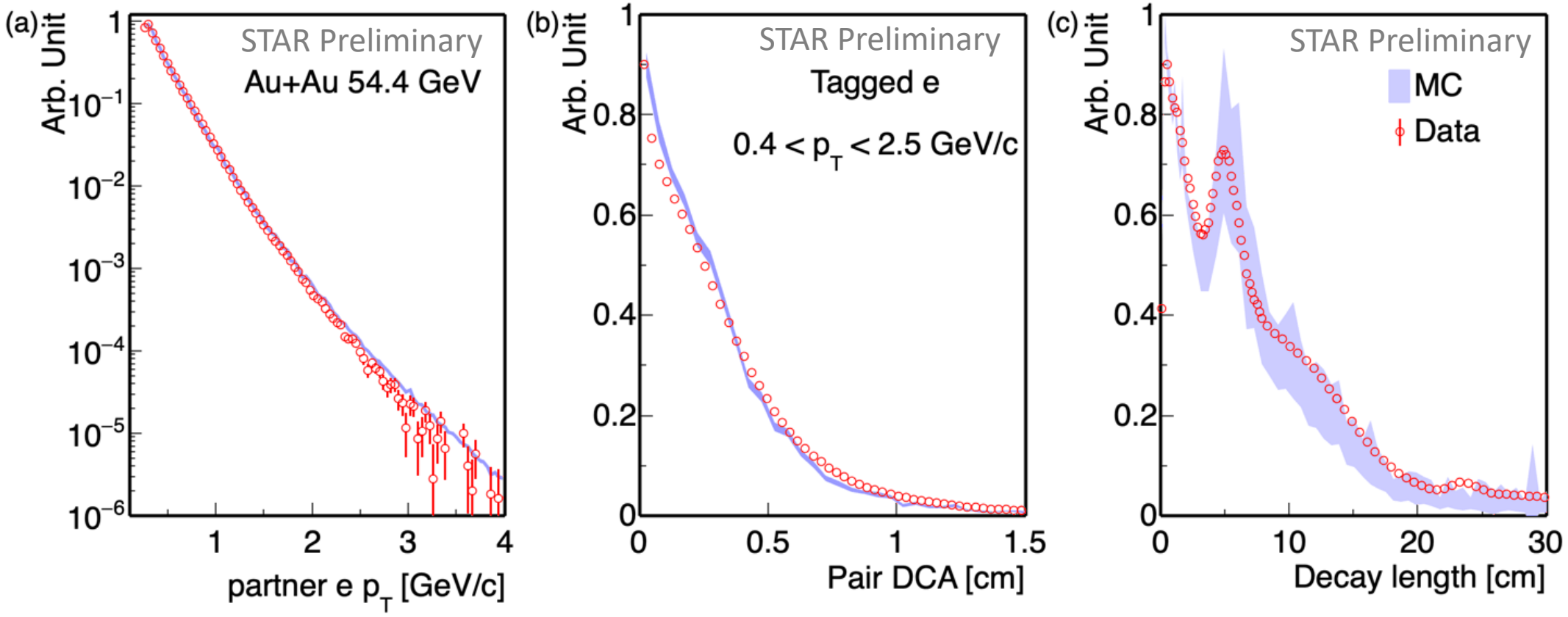
  embedding method



# Reconstruction efficiency extraction

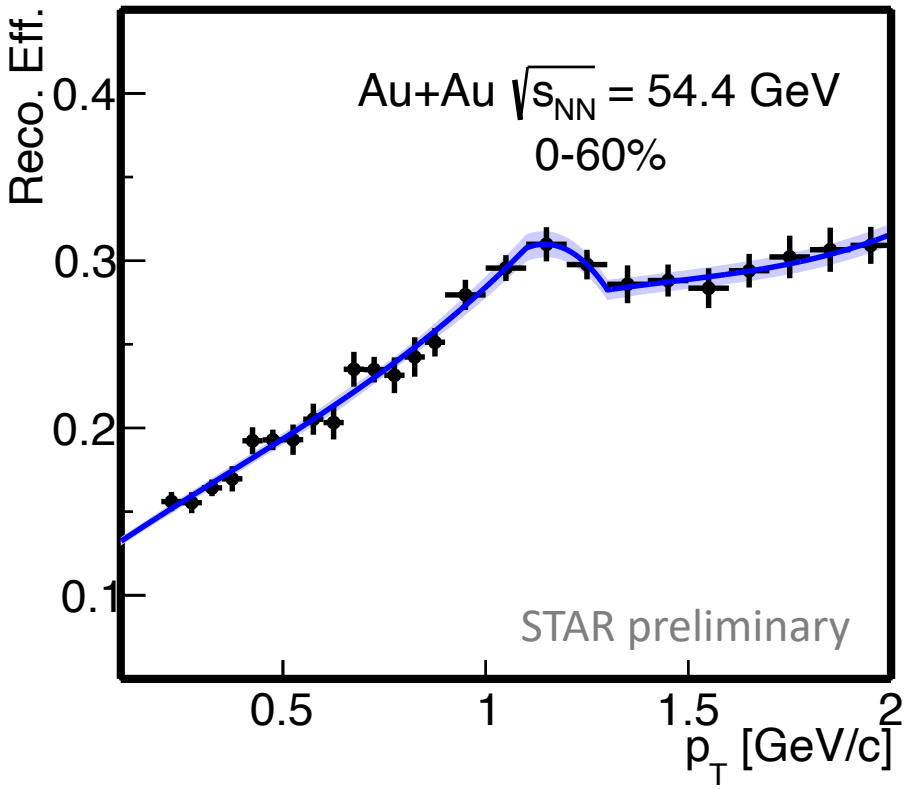
$\pi^0/\eta/\gamma$ $p_T$ weight → Full detector simulation → Tagging electrons by reconstruction method → Reconstructed electron; Partner electron; Electron pair DCA and decay length.



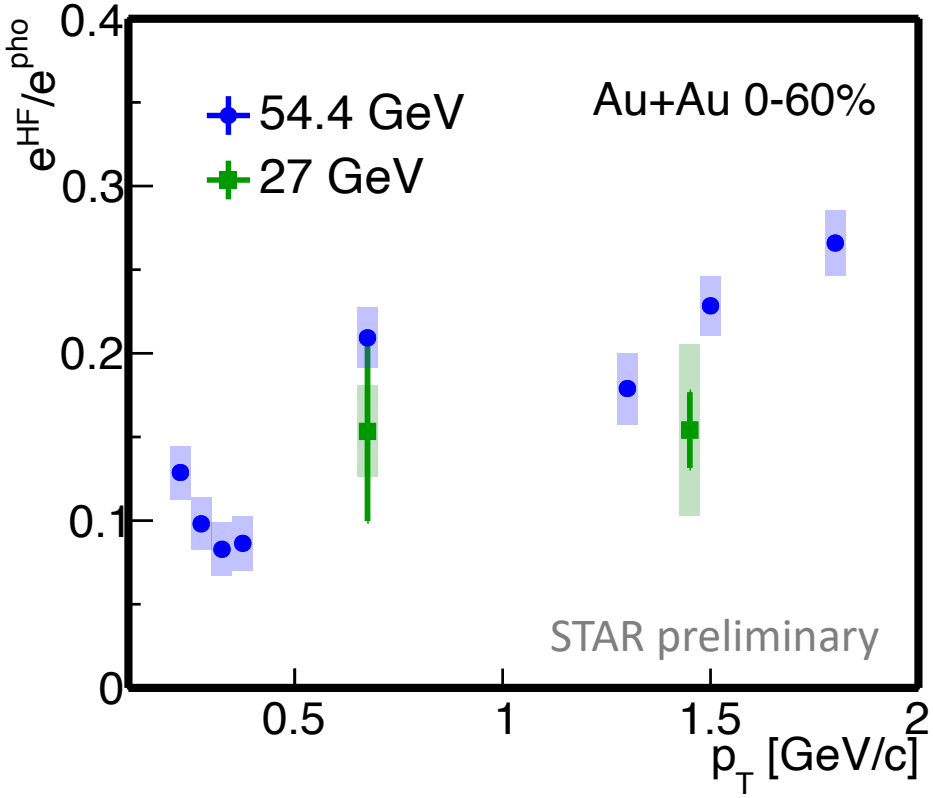

Simulations can well describe the data.

# Reconstruction efficiency extraction

$\pi^0/\eta/\gamma$ $p_T$ weight → Full detector simulation → Tagging electrons by reconstruction method → Reconstructed electron; Partner electron; Electron pair DCA and decay length.

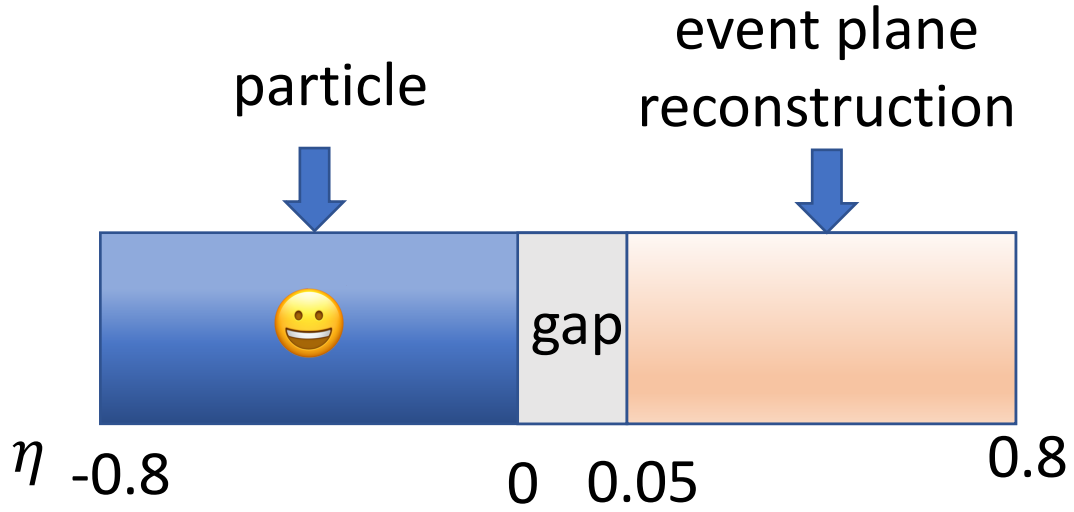



Photonic electron reconstruction efficiency




Heavy flavor electron to photonic electron ratio

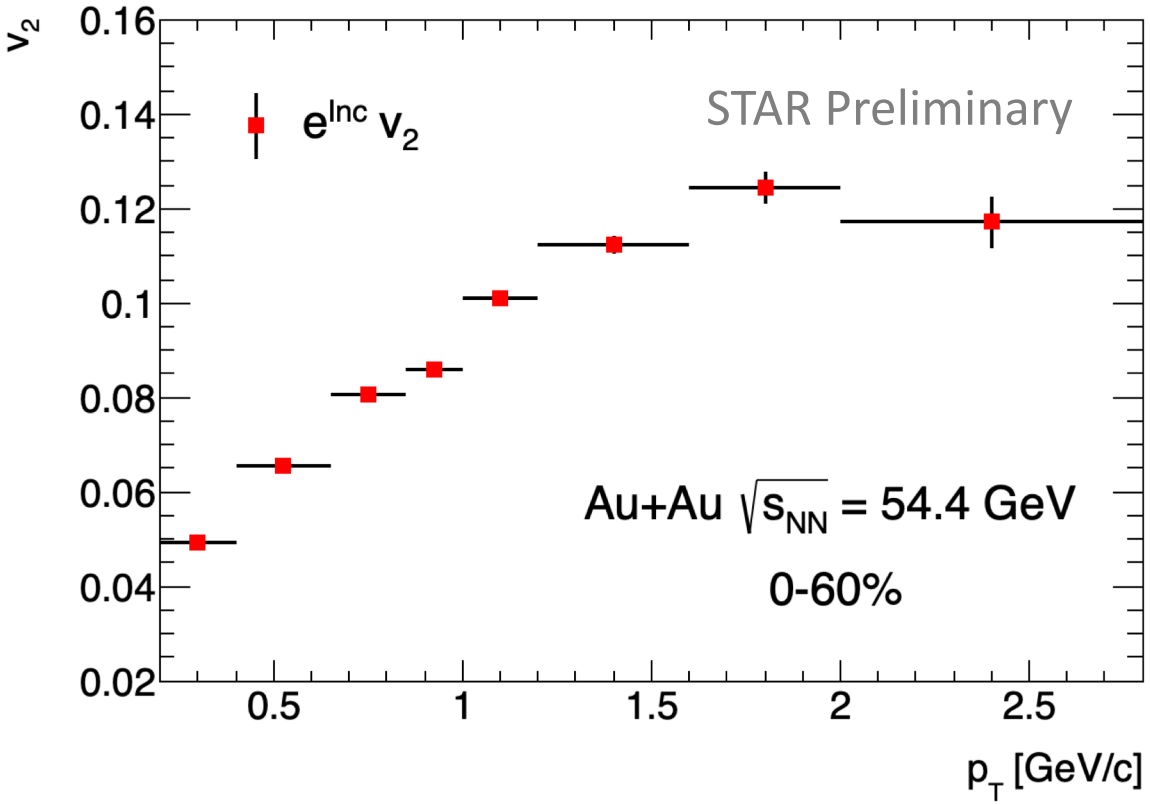
# Inclusive electron $v_2$




Event plane η-sub method

$$v_2 = < \frac{\cos 2(\phi - \Psi_{EP})}{R} >$$

*R*: event plane resolution




Inclusive electron $v_2^{inc}$

# Photonic electron $v_2$ simulation

$\pi^0/\eta/\gamma$
$p_T$ weight;
$\phi$ weight:
$1 + 2v_2 \cos 2(\phi - \Phi_2)$

Sample random event plane

Full detector simulation

Electrons passing track quality cut

Pink band

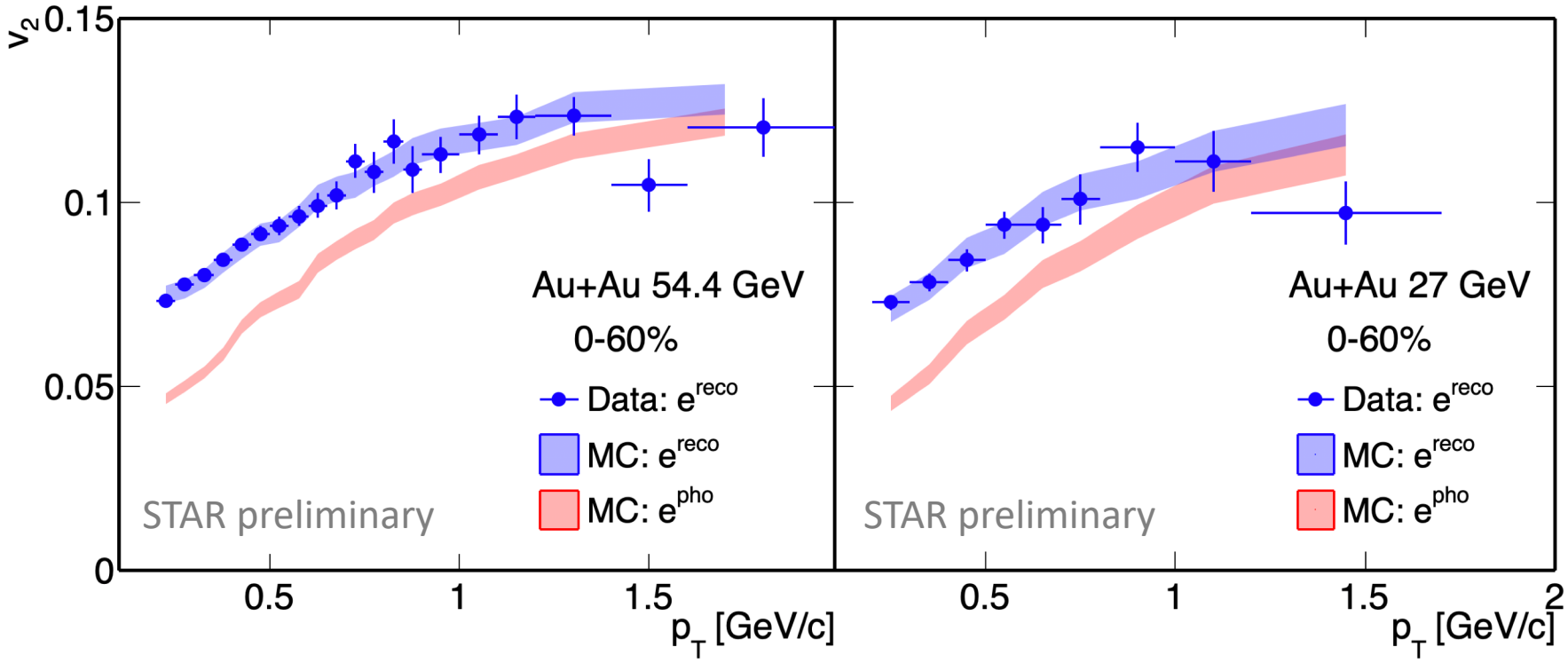
Photonic electron $v_2$

Tagging electrons by reconstruction method

Blue band

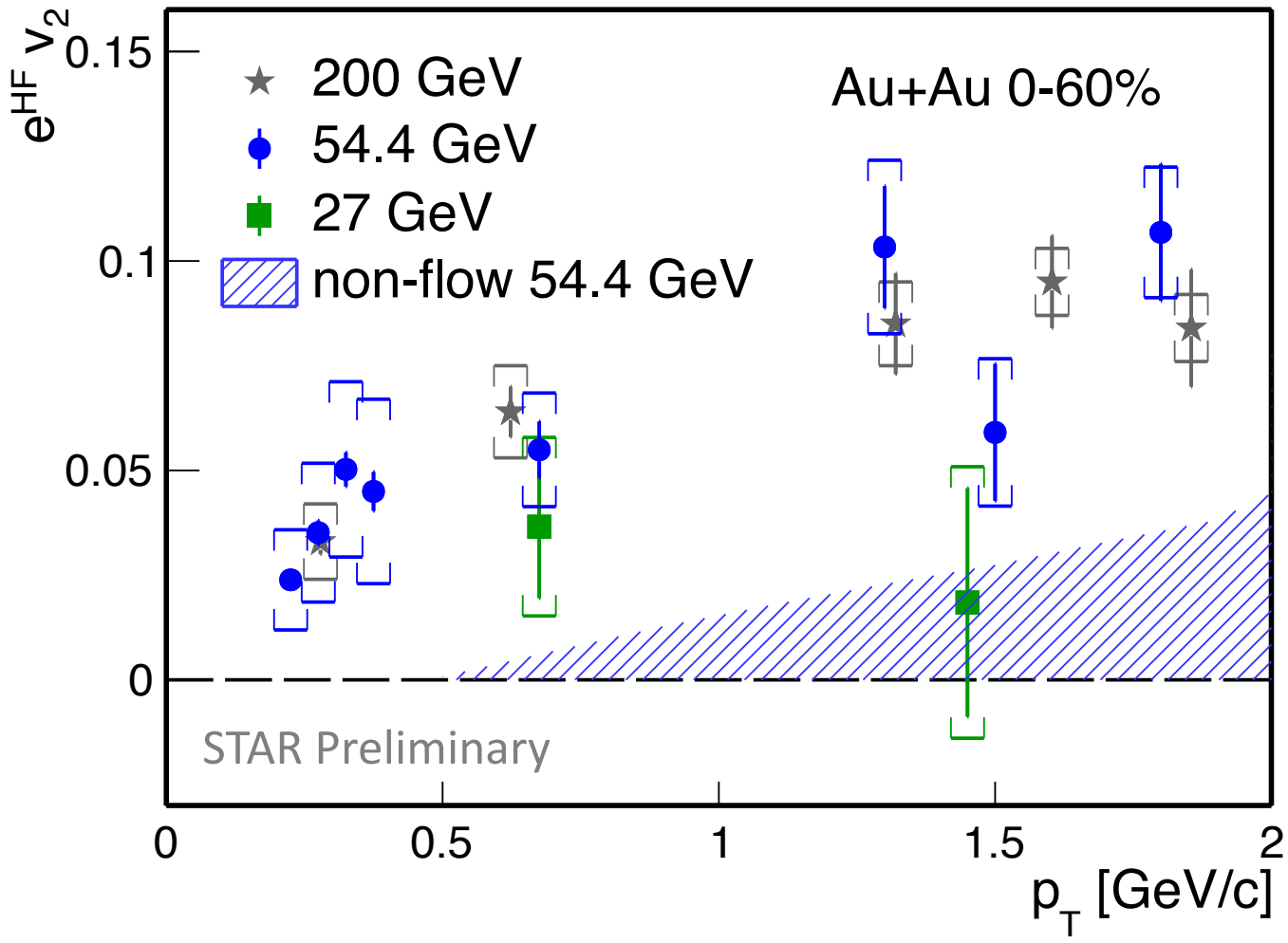
reconstructed electron $v_2$

Reconstructed electron $v_2$ from simulation is consistent with data.



# $e^{HF}$ $v_2$ at Au+Au 27, 54.4 and 200 GeV

$$N^{HF}v_2^{HF} = N^{Inc}v_2^{Inc} - N^{pho}v_2^{pho} - \sum_h f_h \cdot N^{Inc}v_2^h$$

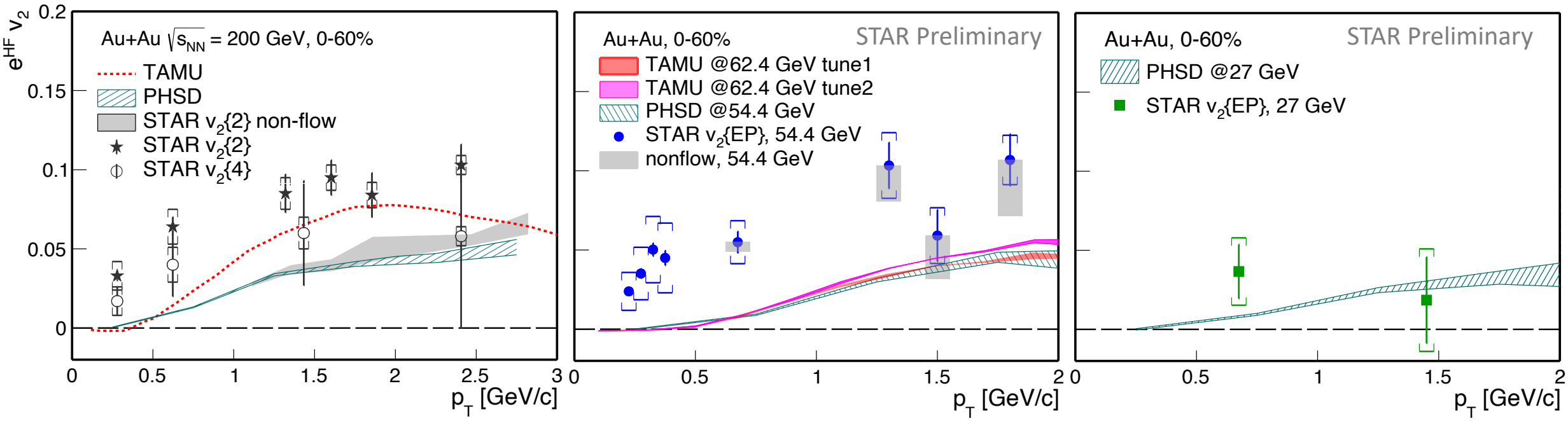



- $e^{HF}$ in Au+Au 54.4 GeV have non-zero $v_2$ comparable to that in 200 GeV;
- Hint for lower $e^{HF}$ $v_2$ in Au+Au 27 GeV than that in 54.4 and 200 GeV.

Au+Au 200 GeV data:
Phys. Rev. C 95, 034907 (2017)

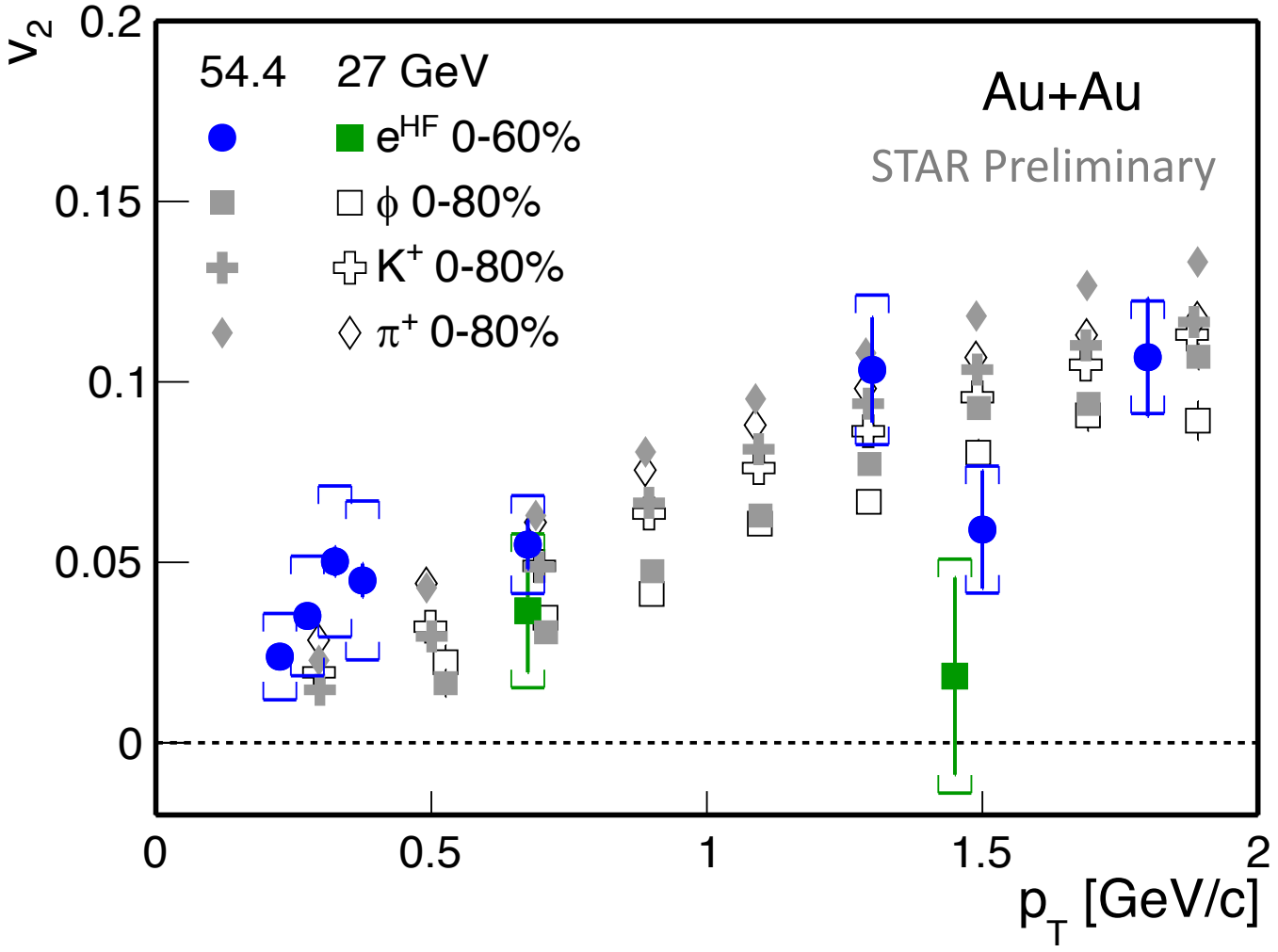
# $e^{HF}$ $v_2$: compare to models

M. He et al. PRC 91,024904 (2015)
T. Song et al. PRC 92, 014910 (2015)
T. Song et al. PRC 96, 014905 (2017)




- TAMU and PHSD calculations are lower than $v_2${EP} at 54.4 and 200 GeV below 1 GeV/c;
- Data and model calculations are comparable at $p_T$>1 GeV/c considering the upper limit of estimated non-flow contribution and uncertainties.

# $v_2$: $e^{HF}$ and identified particles



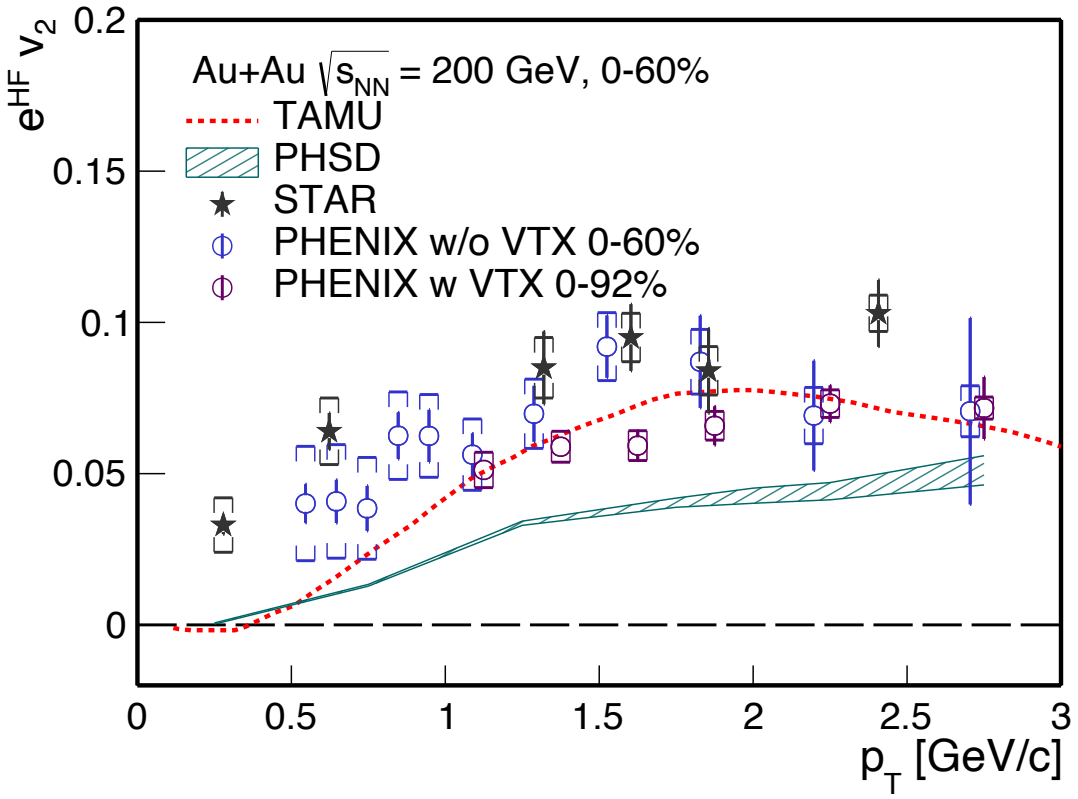

- Comparable elliptic flow as light flavor mesons at 54.4 GeV.

# *Summary*

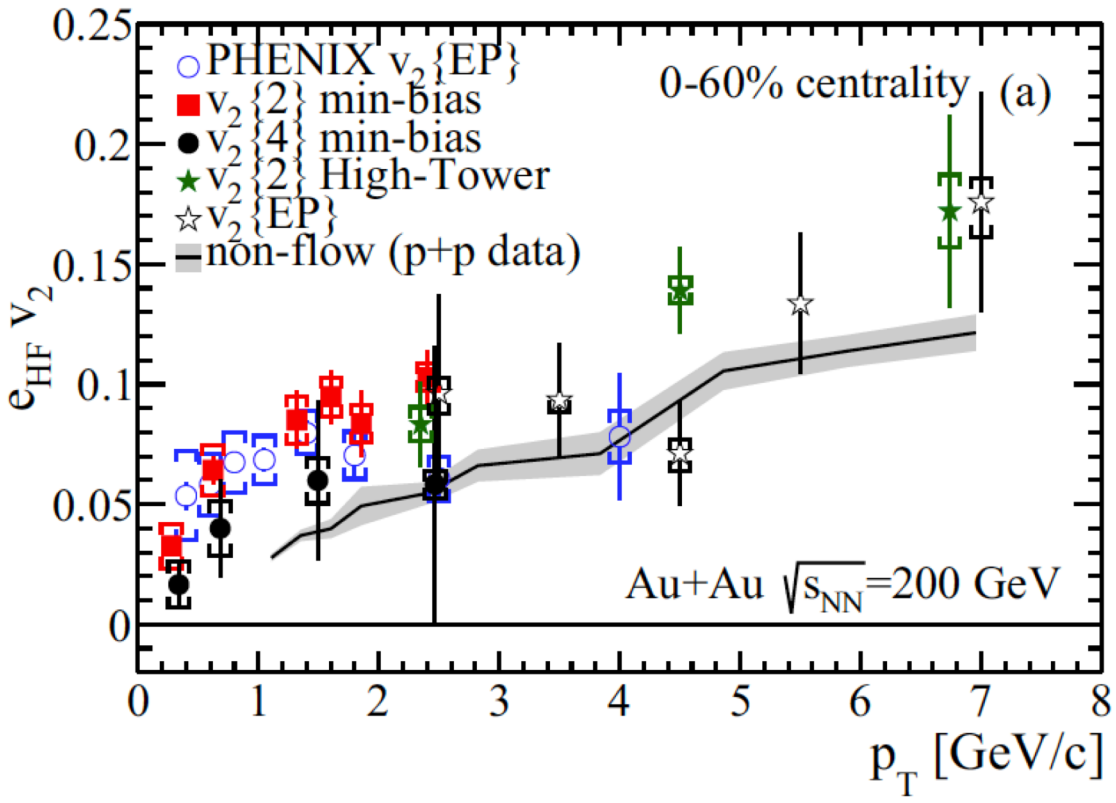
- Heavy flavor electron ($e^{HF}$) $v_2$ in Au+Au 27 and 54.4 GeV collisions are measured;
- $e^{HF}$ $v_2$ in Au+Au 54.4 GeV is comparable to that in 200 GeV, while a hint of smaller $e^{HF}$ $v_2$ in Au+Au 27 GeV;
- TAMU and PHSD models versus data:
  - Model calculations are systematically lower than measured $e^{HF}$ $v_2${EP} in 54.4 and 200 GeV Au+Au collisions below 1 GeV/c;
  - Model calculations are compatible with data above 1 GeV/c considering non-flow contribution and uncertainties.

- Back ups

# Au+Au 200 GeV NPE




M. He et al. PRC 91,024904 (2015)
T. Song et al. PRC 92, 014910 (2015)
T. Song et al. PRC 96, 014905 (2017)
PHENIX. PRL 98, 172301 (2007)
T. Hachiya, Nucl. Phys. A, 982, 663-666 (2019)




STAR. PRC 95, 34907 (2017)