Measurements of Non-photonic Electrons Production and Elliptic Flow in $\sqrt{s_{NN}}$ = 39, 62 and 200 GeV in Au+Au Collisions

Outline:

- NPE spectra measurements:
  - New Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.
  - Nuclear Modification Factor at $\sqrt{s_{NN}}$ = 200 GeV.
  - Au + Au at $\sqrt{s_{NN}}$ = 62.4 GeV.

- NPE Azimuthal Anisotropy measurement:
  - $\mathbf{v_2}$ Au + Au at $\sqrt{s_{NN}}$ = 200 GeV.
  - $\mathbf{v_2\{2\}}$ Au + Au at $\sqrt{s_{NN}}$ =39 GeV and 62.4GeV.

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for the STAR Collaboration

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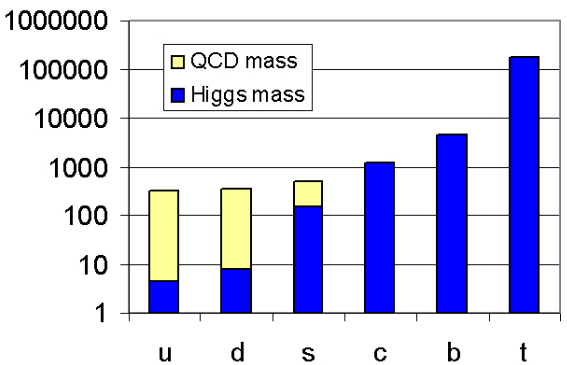
Why Heavy Flavor? Why NPE?

Heavy Flavor:

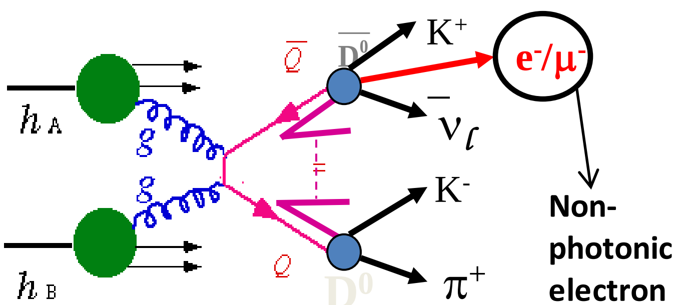
- Created at the early stages through initial hard scattering, thus:
  - experience full medium evolution.
  - scale by $N_{bin.}$
- Their masses are external to QCD.
- Study flavor dependence of parton energy loss mechanisms.
- Low $\mathbf{p_T}$ v_2 → degree of thermalization.
- High $\mathbf{p_T}$ v_2 → path length dependence of energy loss.



B. Müller, Nucl. Phys. A, 750(2005), p. 84–97

Non-photonic electrons (NPE)

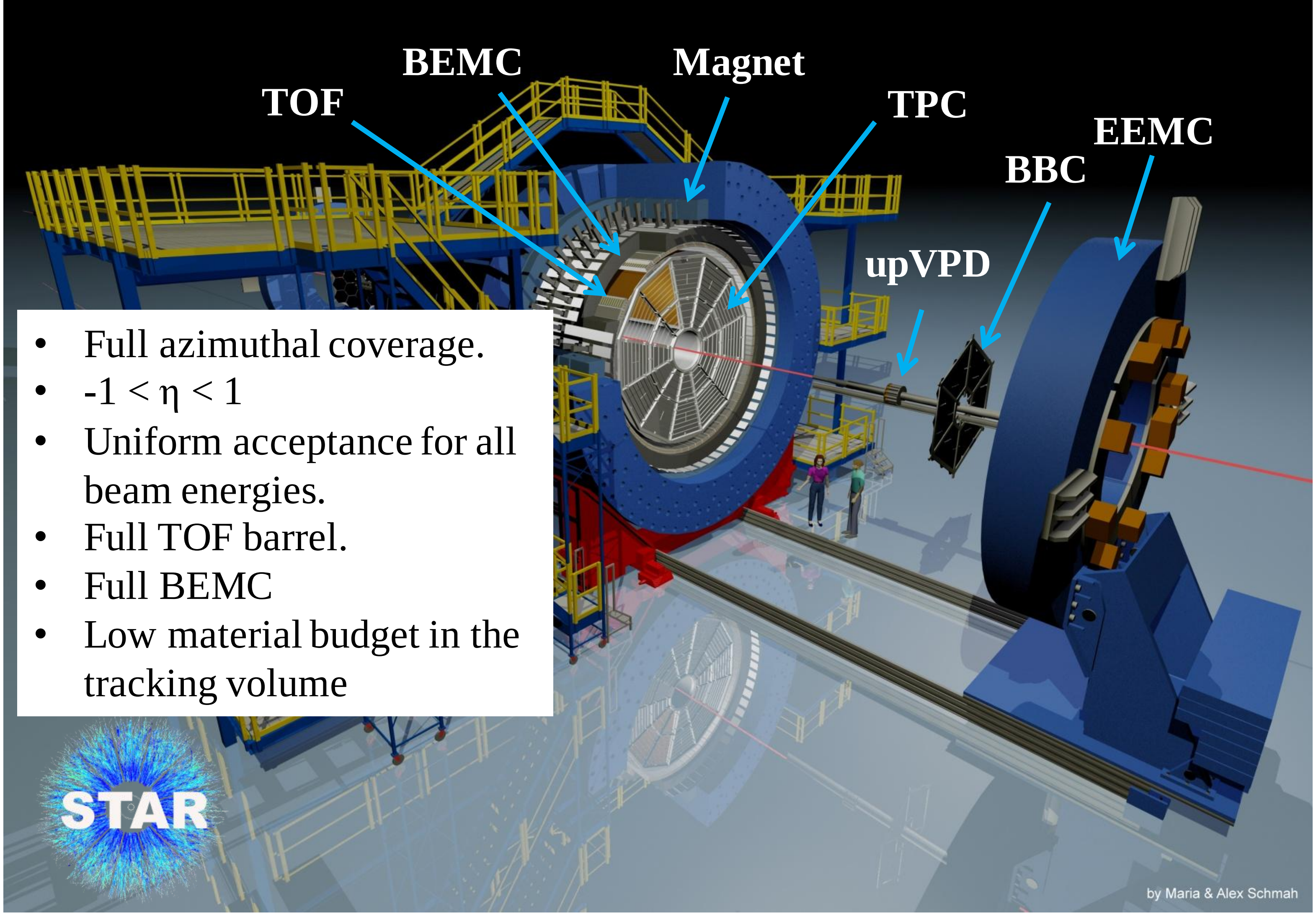
1) Semileptonic channel have higher branching ratios than hadronic channels of open heavy flavor mesons.
2) Easy to trigger on high $\mathbf{p_T}$ electrons.



Open heavy flavor

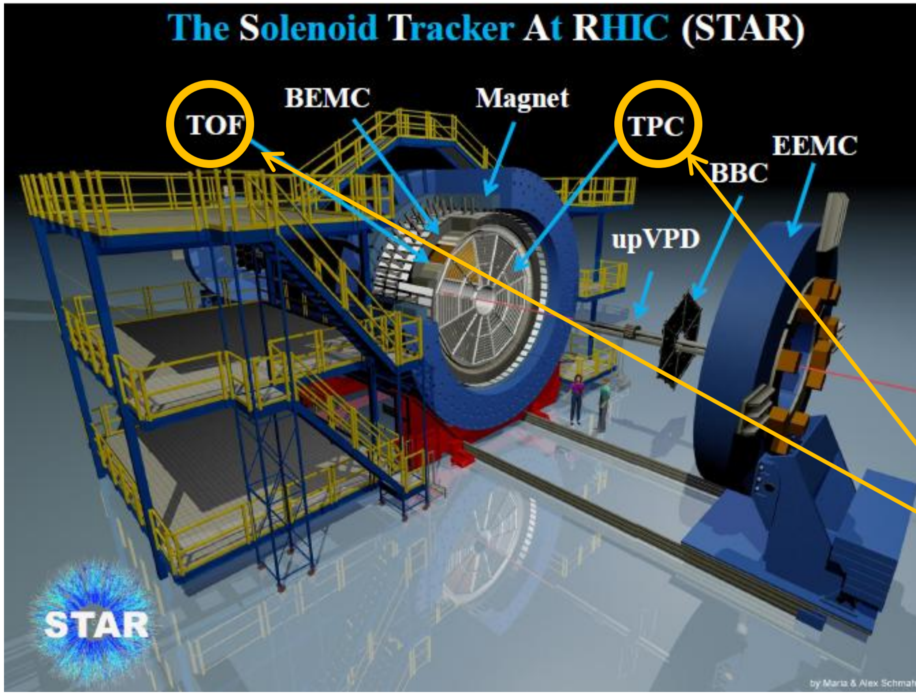
Experimental Setup

The Solenoid Tracker At RHIC (STAR)



- Full azimuthal coverage.
- $-1 < \eta < 1$
- Uniform acceptance for all beam energies.
- Full TOF barrel.
- Full BEMC
- Low material budget in the tracking volume

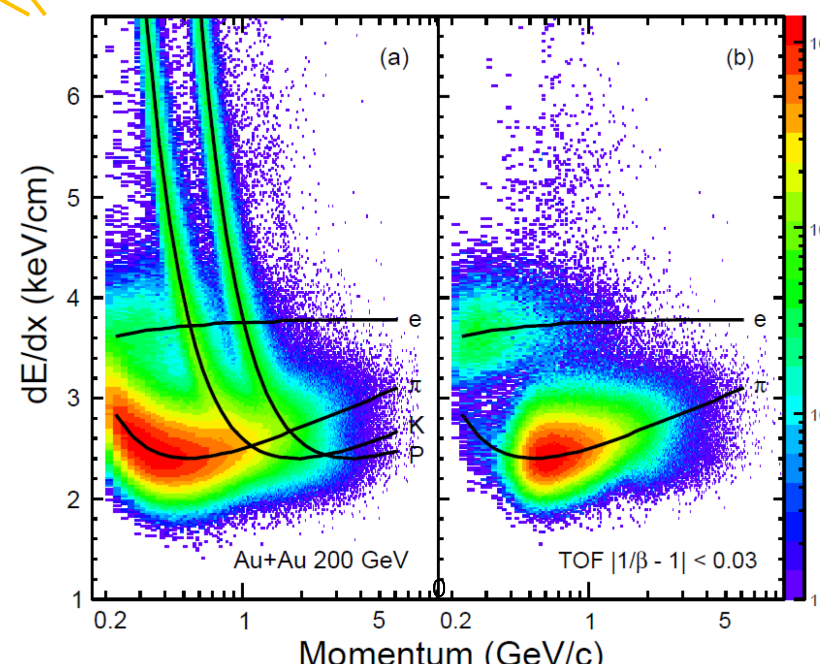
Electrons Identification



TPC dEdx +
Time Of Flight (TOF):

Low $\mathbf{p_T}$ (0.2-2.0 GeV/c)

The combination of TPC dEdx and β from TOF provides +95% purity down to the lowest reachable $\mathbf{p_T}$ at STAR (0.2GeV/c) .



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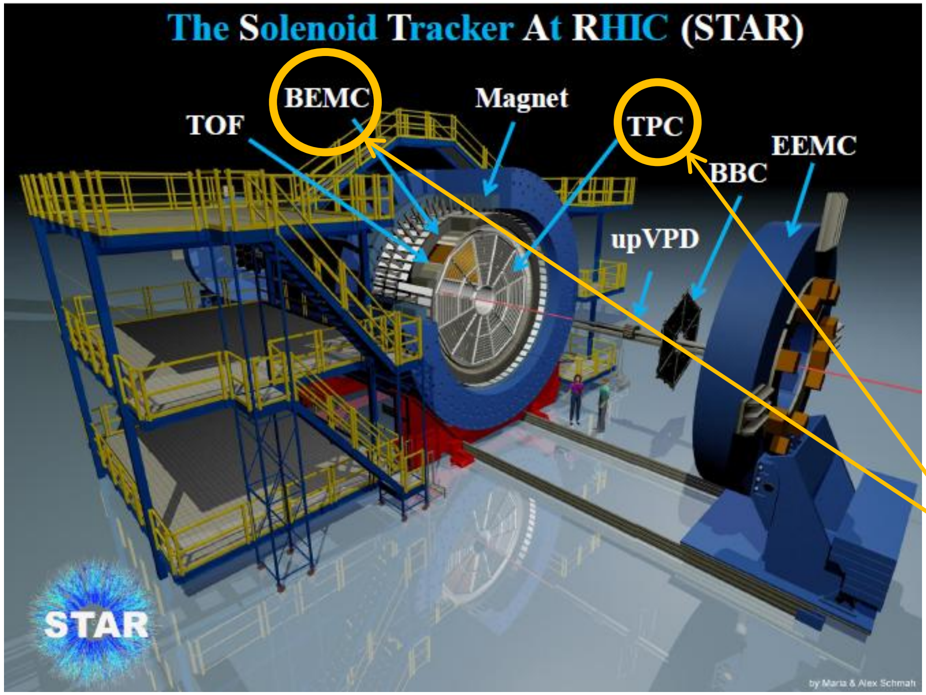
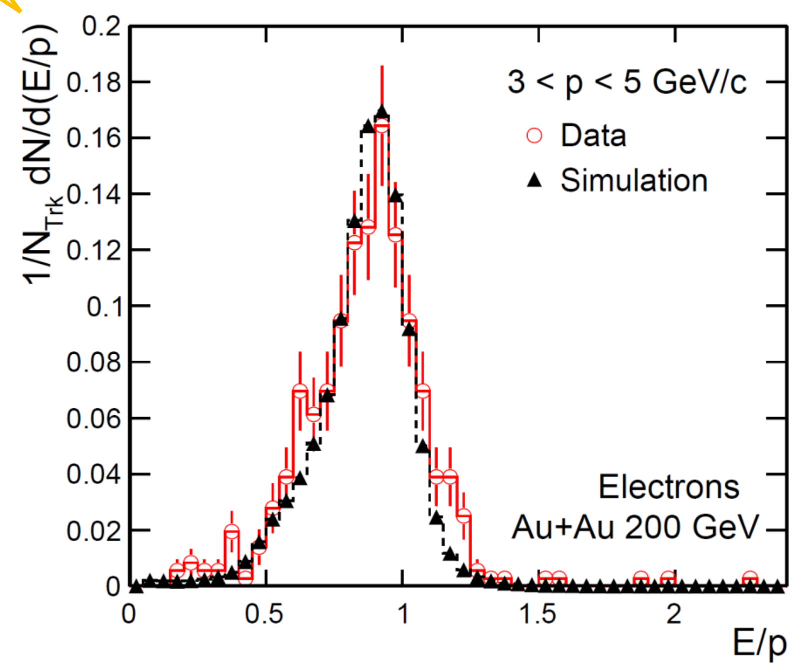


TPC dEdx +
Barrel ElectorMagnetic Calorimeter (BEMC):
High $\mathbf{p_T}$ (> 1 GeV/c)

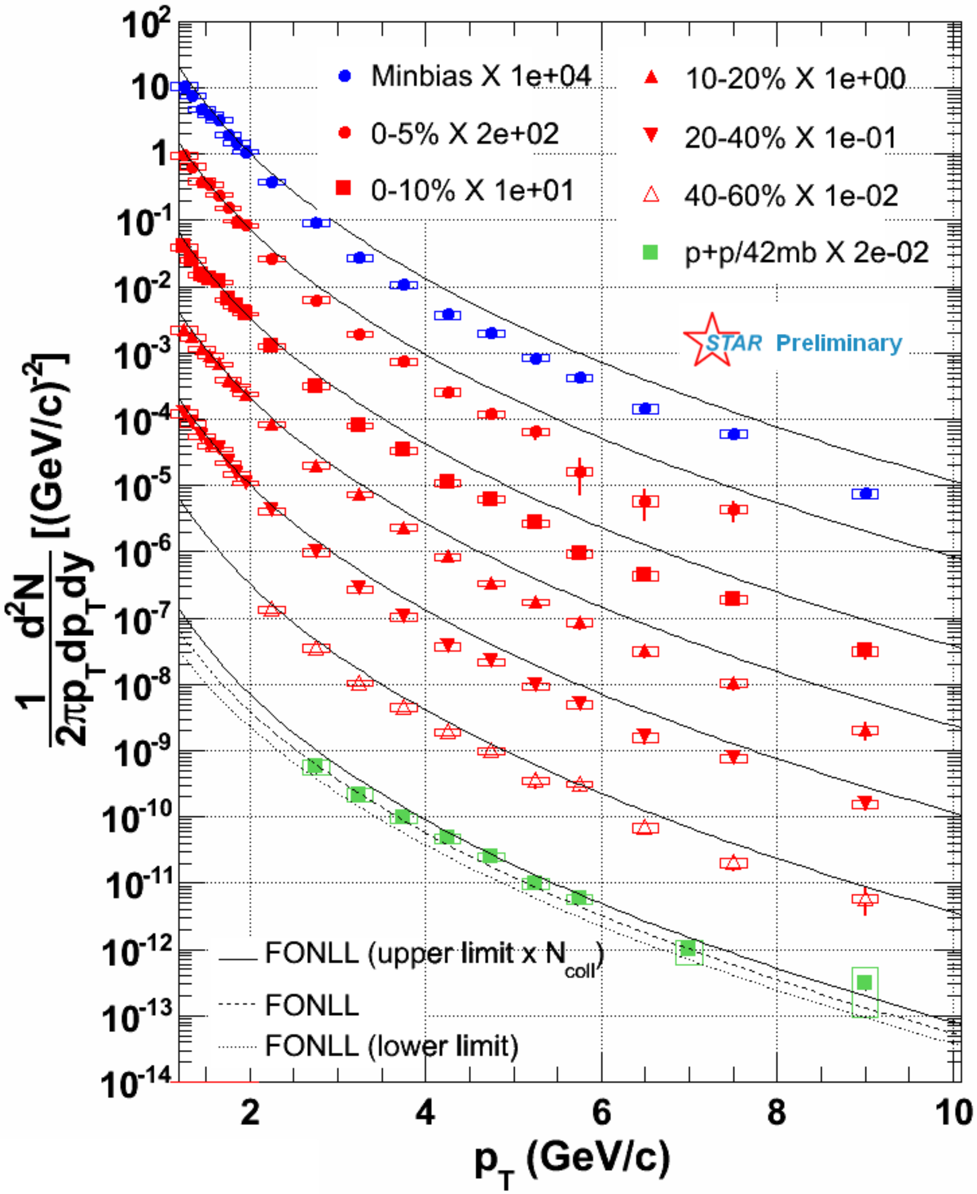
1- Associating TPC tracks with BTOW and BSMD clusters.

2- E/P cuts. (Due to their negligible mass, electrons have E/P ~ 1).



Spectra in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

- With ~1 nb^{-1} sampled luminosity in Run2010 Au+Au collisions, STAR provides a new measurement of NPE with a highly improved result at high $\mathbf{p_T}$.
- < (5-10)% statistical errors in all 4 centralities.
- An independent central trigger provides 0-5% centrality.



p+p NPE STAR Phys. Rev. D 83 (2011) 052006

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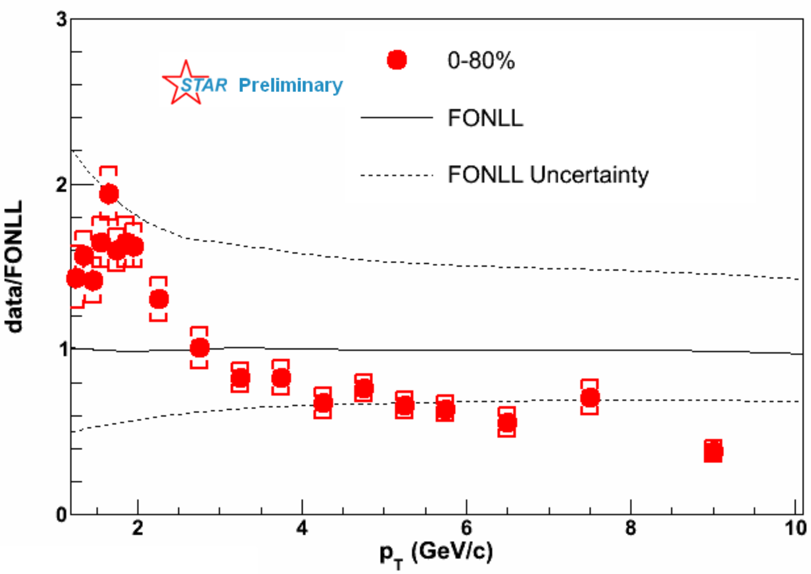
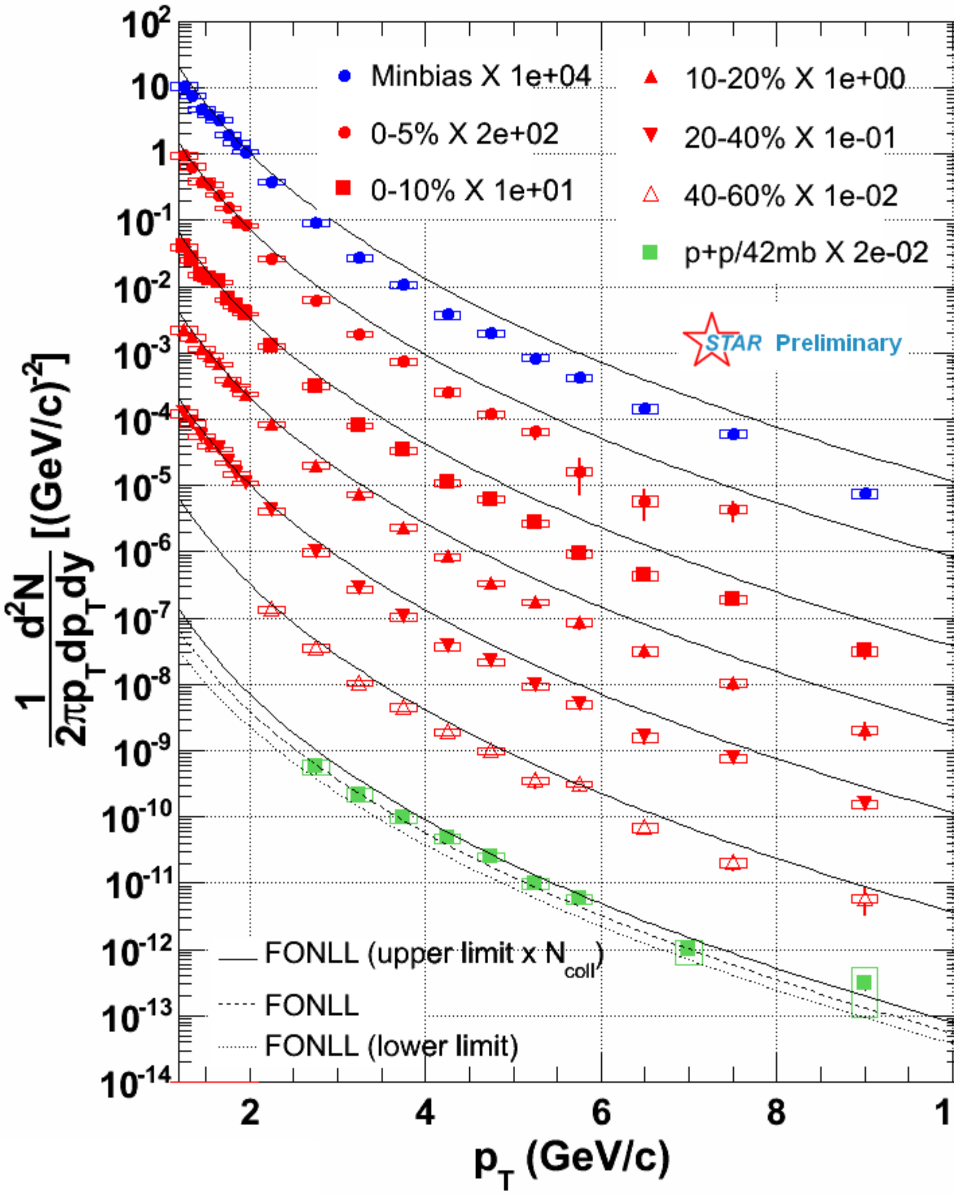
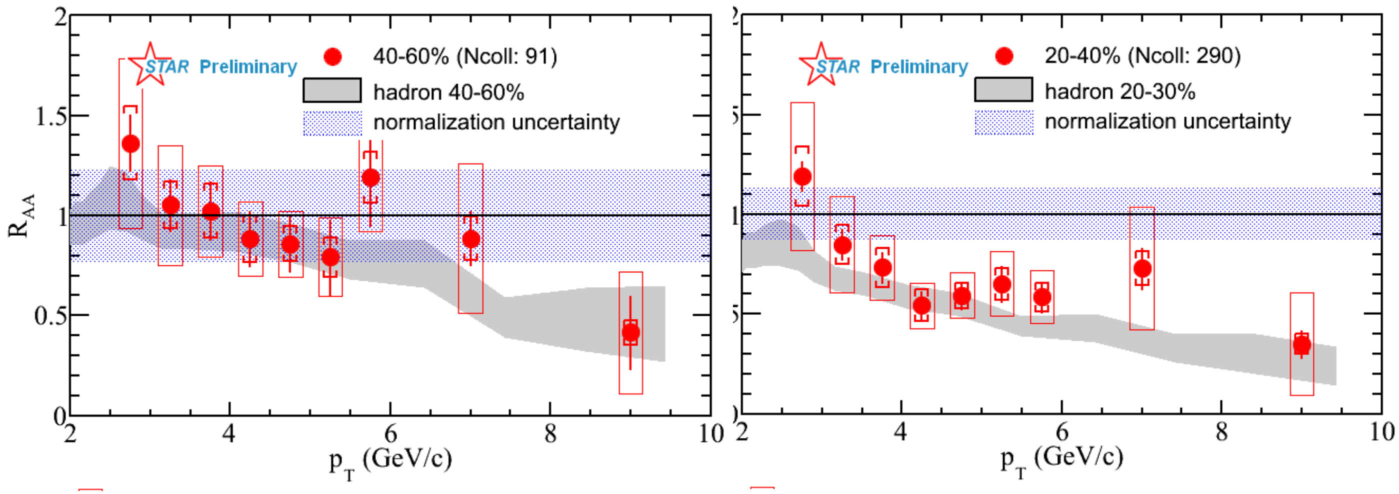




p+p NPE STAR Phys. Rev. D 83 (2011) 052006

Nuclear Modification Factor (R_{AA}) in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV



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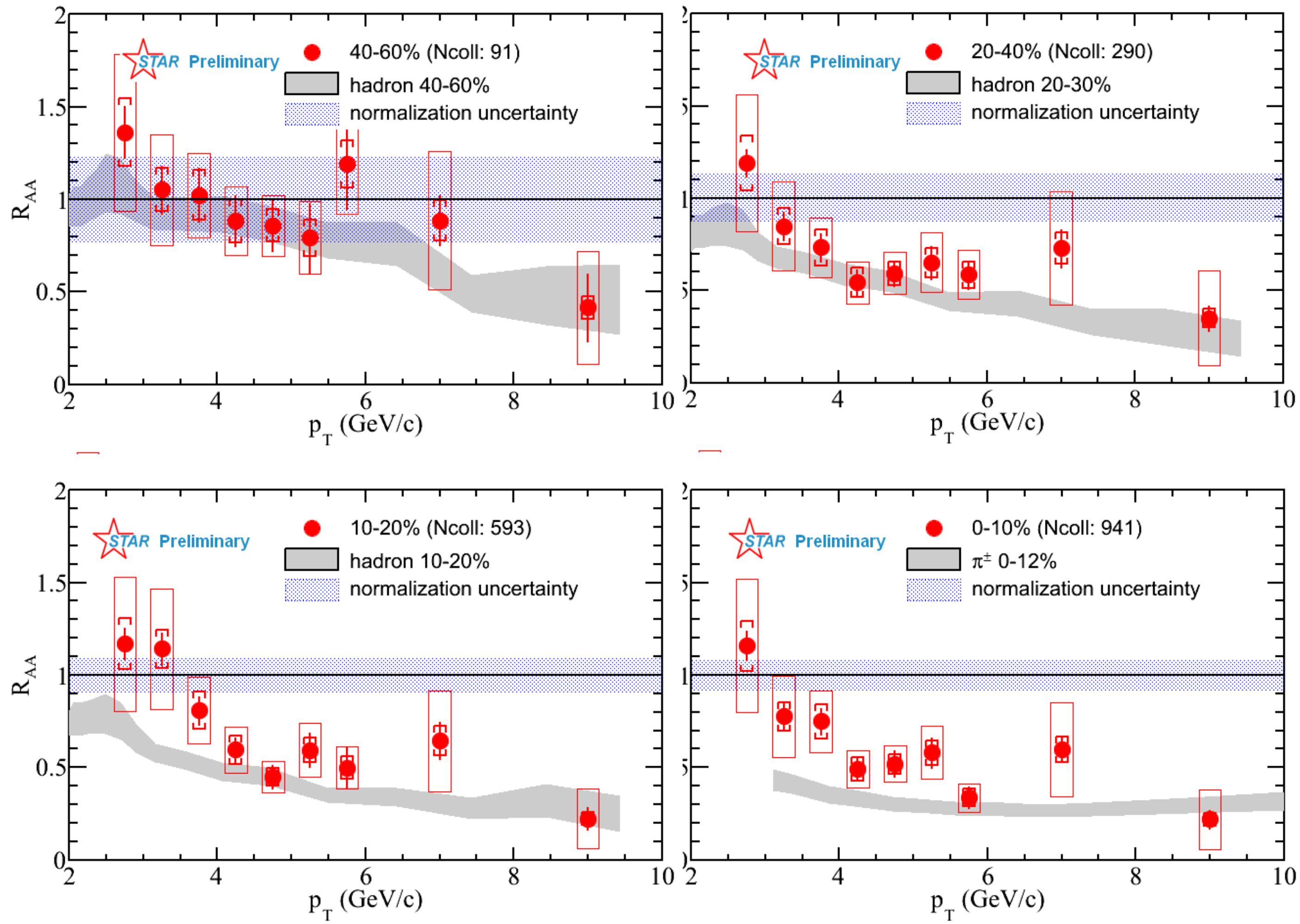
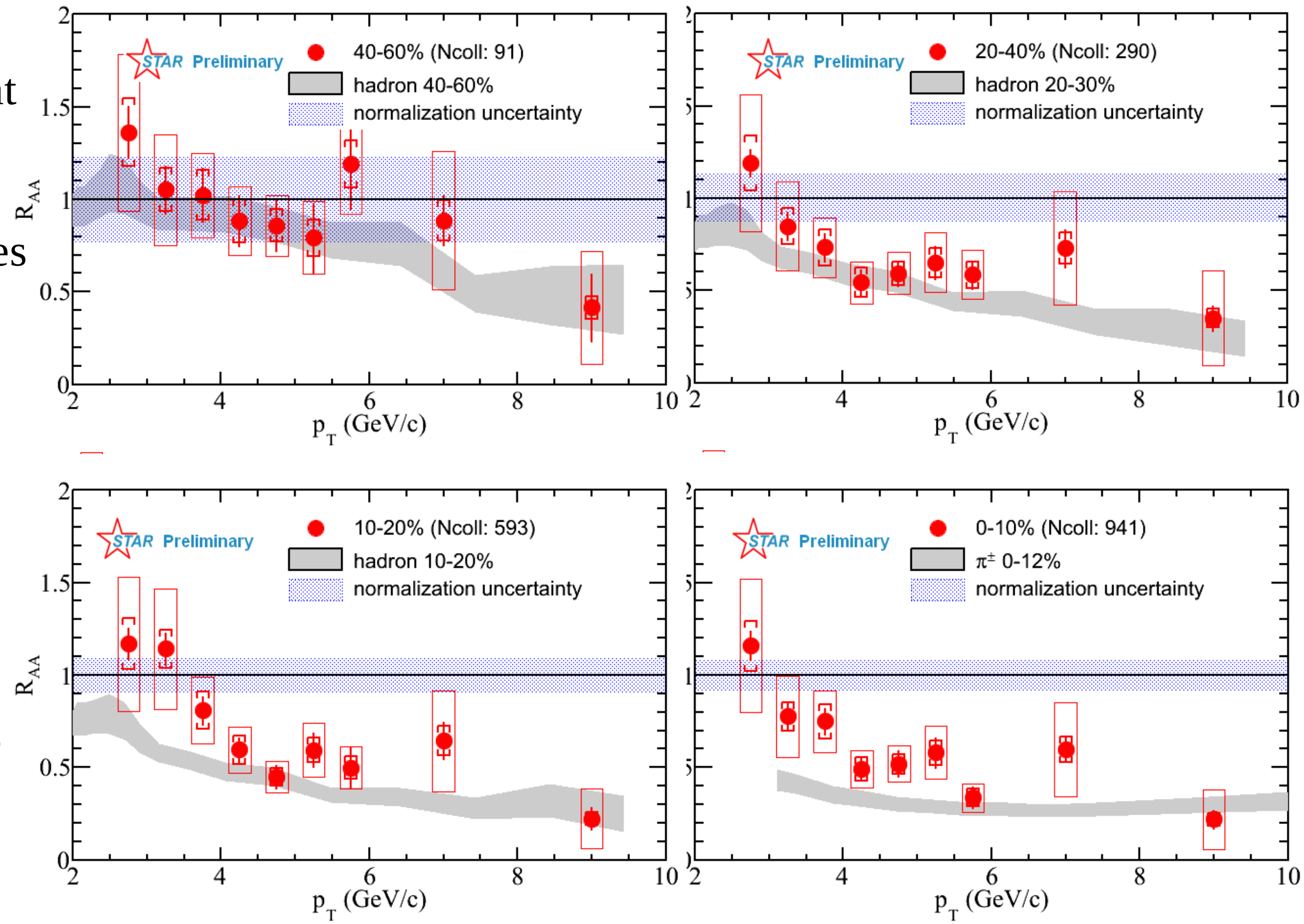


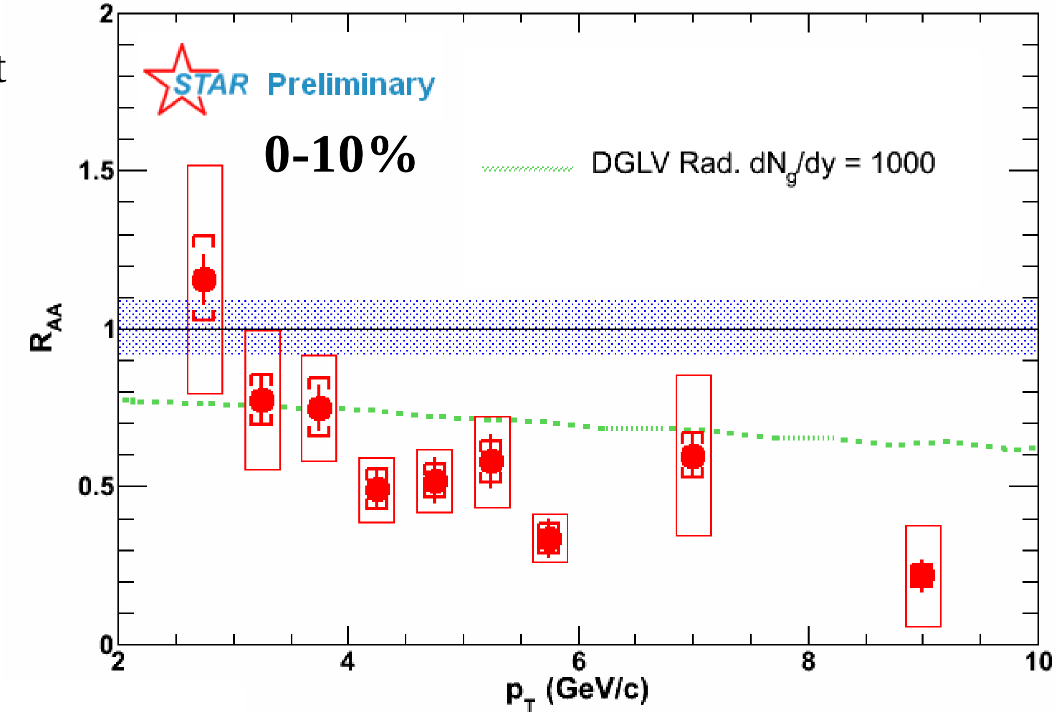
Nuclear Modification Factor (R_{AA}) in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

- Strong suppression at high $\mathbf{p_T}$.
- Suppression increases as a function of $\mathbf{p_T}$.
- $\mathbf{R_{AA}}$ uncertainty is dominated by Run2005+Run2008 p+p uncertainty.
- Should be improved with Run2009+2012 large statistics high quality p+p data.



Nuclear Modification Factor (R_{AA}) in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

- This high precision measurement at high $\mathbf{p_T}$ clearly disfavors radiative energy loss as the only mechanism.



DGLV:
Djordjevic, PLB632, 81 (2006) and references within.

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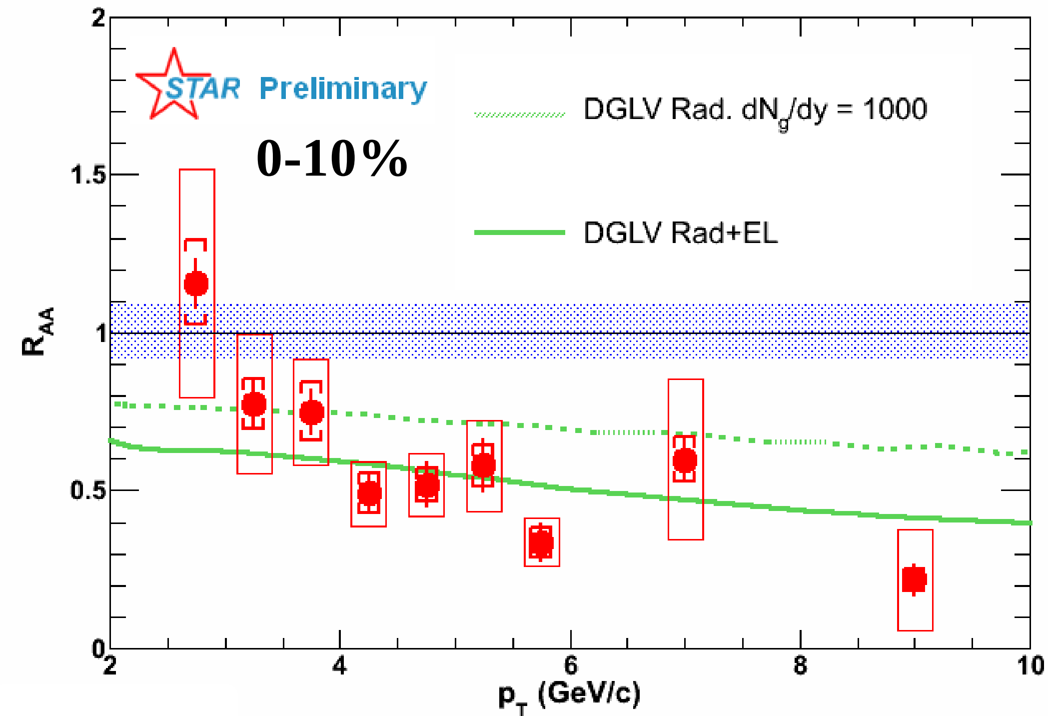
- More precision is needed on the p+p baseline to decide on the DGLV+EL.



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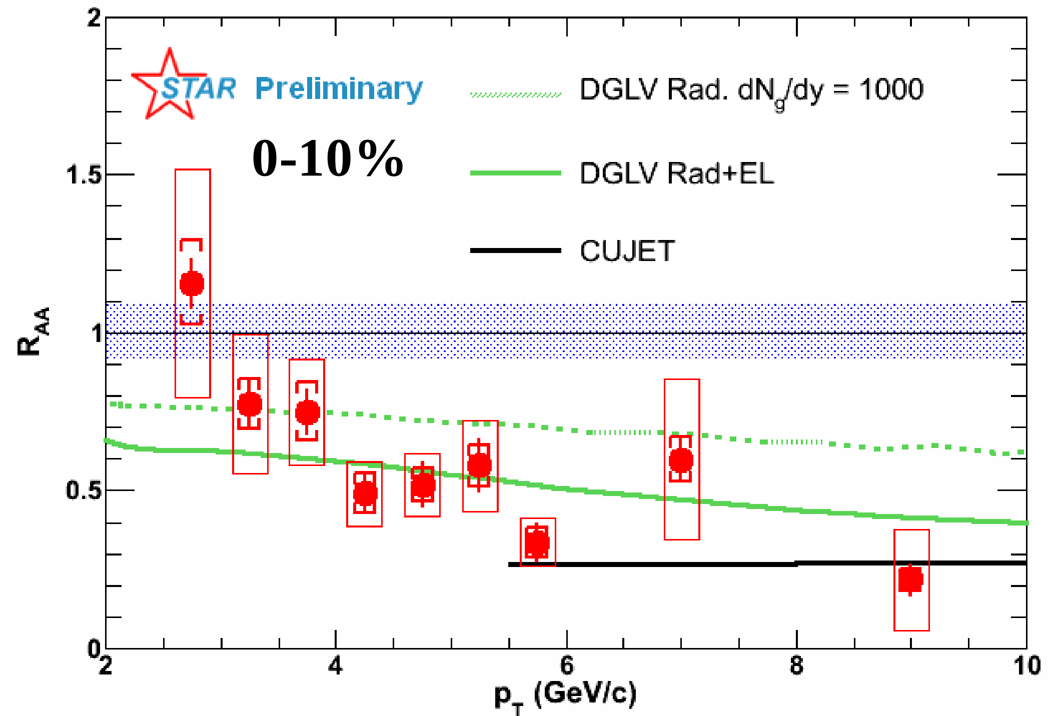
- CUJET is the new improvement over the DGLV/DGLV+EL efforts. It is consistent with our measurement.



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CUJET:
Buzzatti, arXiv:1207.6020

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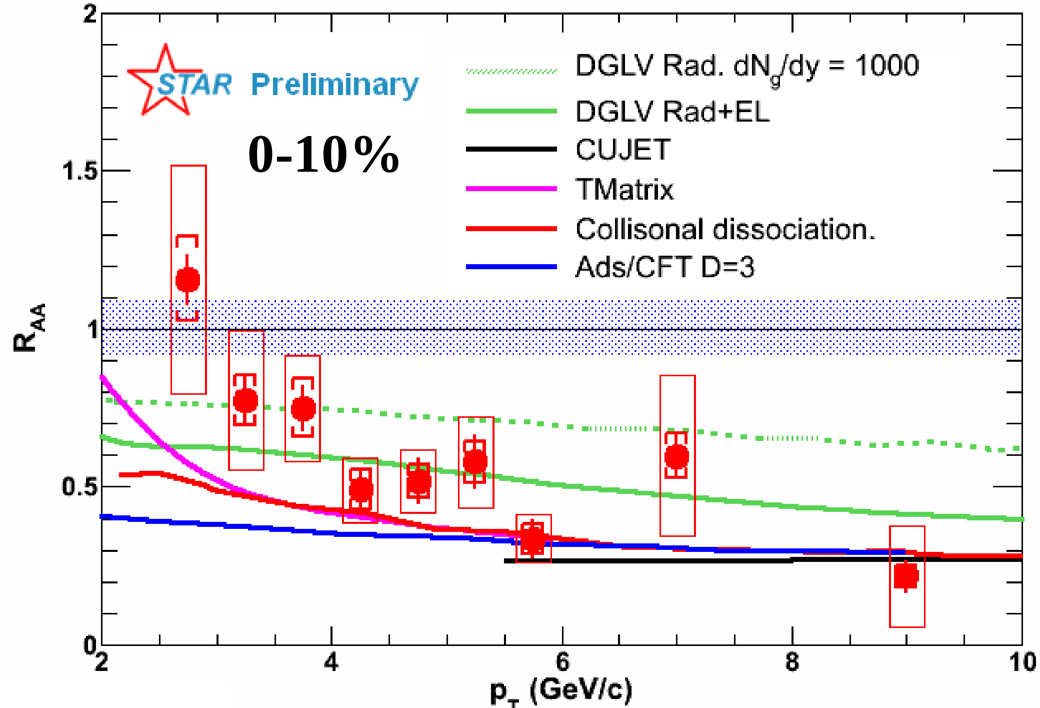
- More precision is needed on the p+p baseline to decide on the DGLV+EL.
- CUJET is the new improvement over the DGLV/DGLV+EL efforts. It is consistent with our measurement.
- Other proposed energy loss mechanisms also agree with our measurement:
  - T-Matrix.
  - Collisional Dissociation.
  - Ads/CFT.



DGLV:
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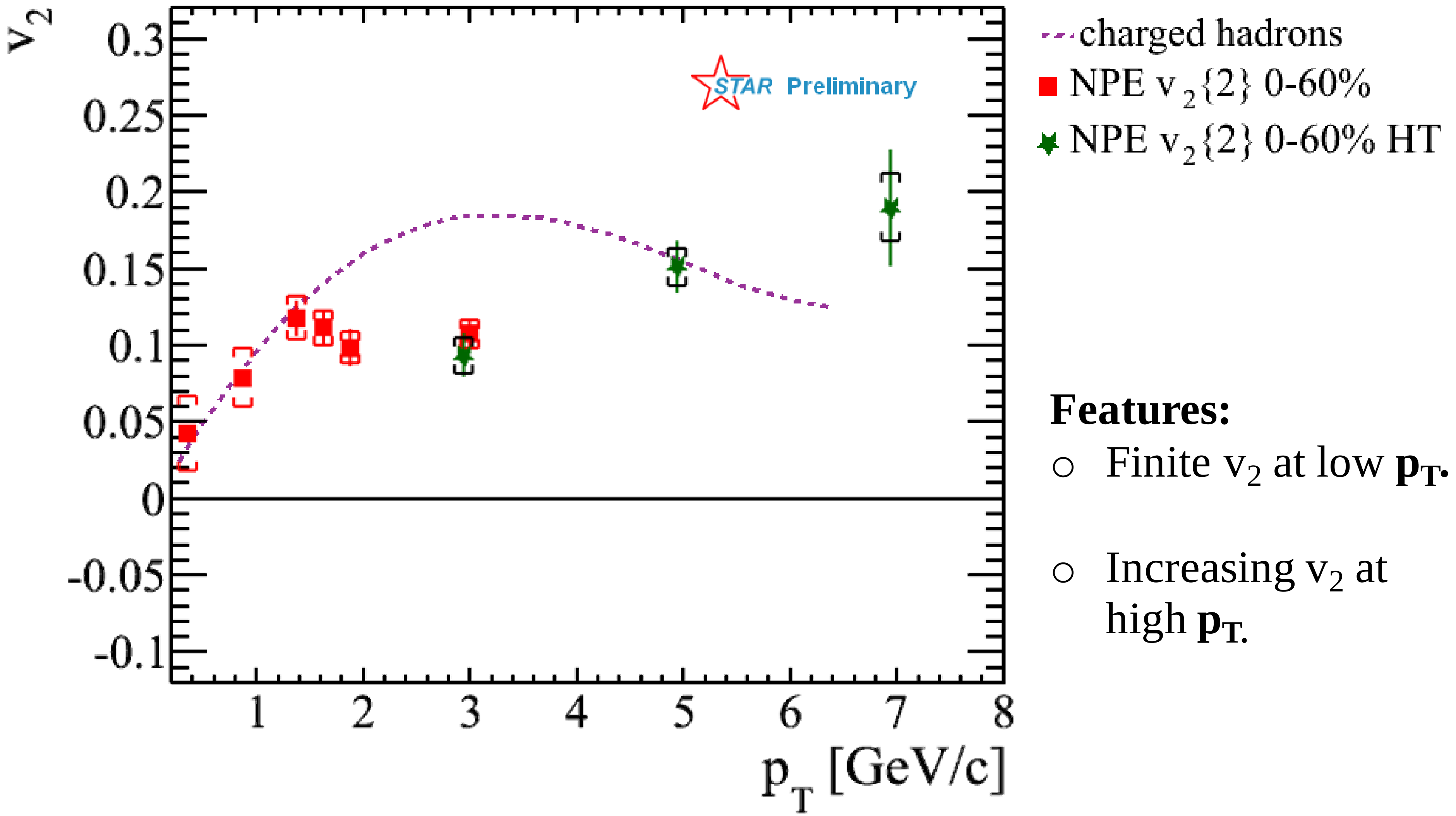
CUJET:
Buzzatti, arXiv:1207.6020

T-Matrix:
Van Hees et al., PRL100,192301(2008).

Coll. Dissoc.
R. Sharma et al., PRC 80, 054902(2009).

Ads/CFT:
W. Horowitz Ph.D thesis.

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

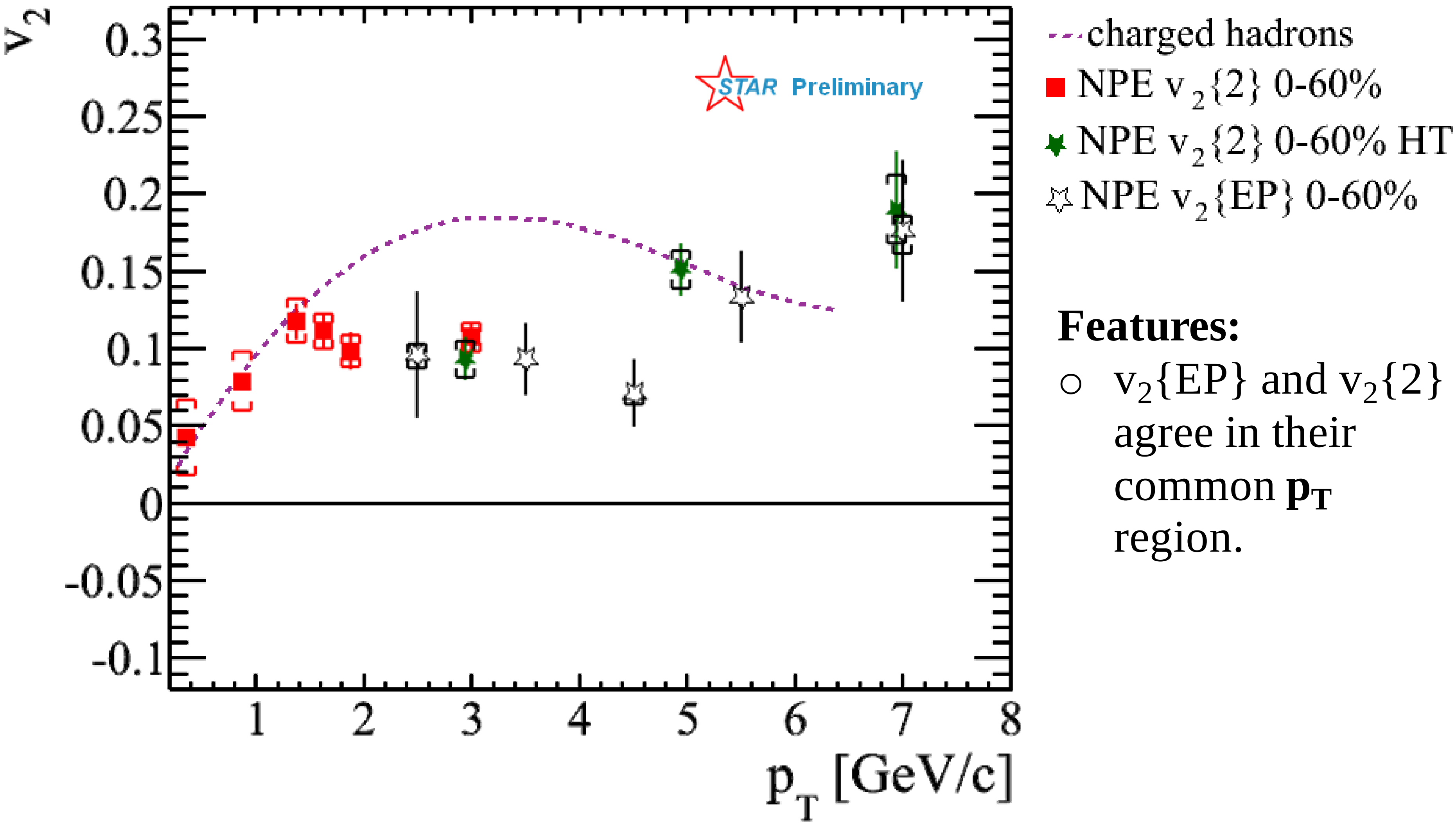


Features:

- Finite v_2 at low $\mathbf{p_T}$.
- Increasing v_2 at high $\mathbf{p_T}$.

For more details see D. Kikoła poster

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

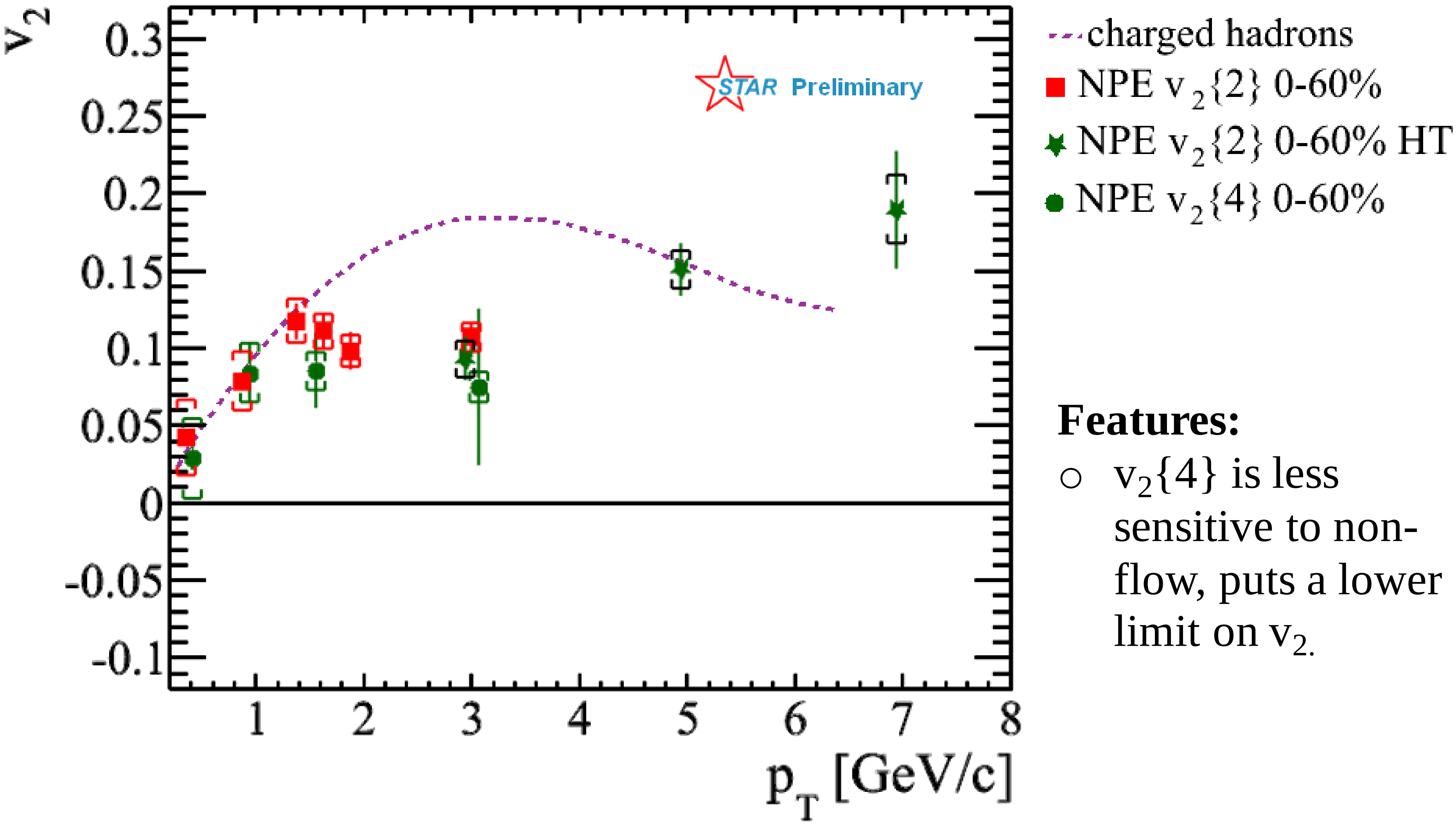


Features:

- $v_2\{EP\}$ and $v_2\{2\}$ agree in their common $\mathbf{p_T}$ region.

For more details see D. Kikoła poster

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

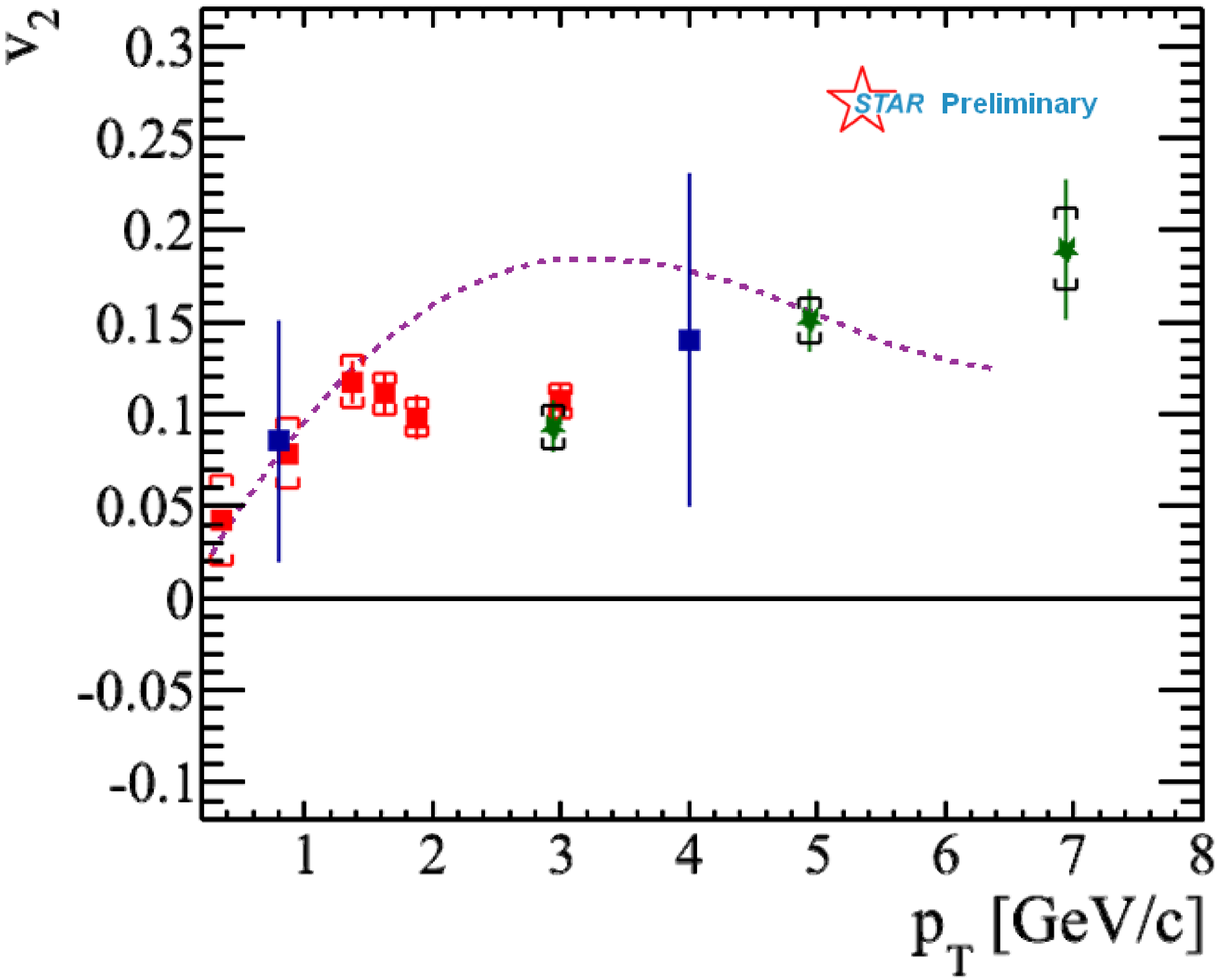


Features:

- v_2{4} is less sensitive to non-flow, puts a lower limit on v_2.

For more details see D. Kikoła poster

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

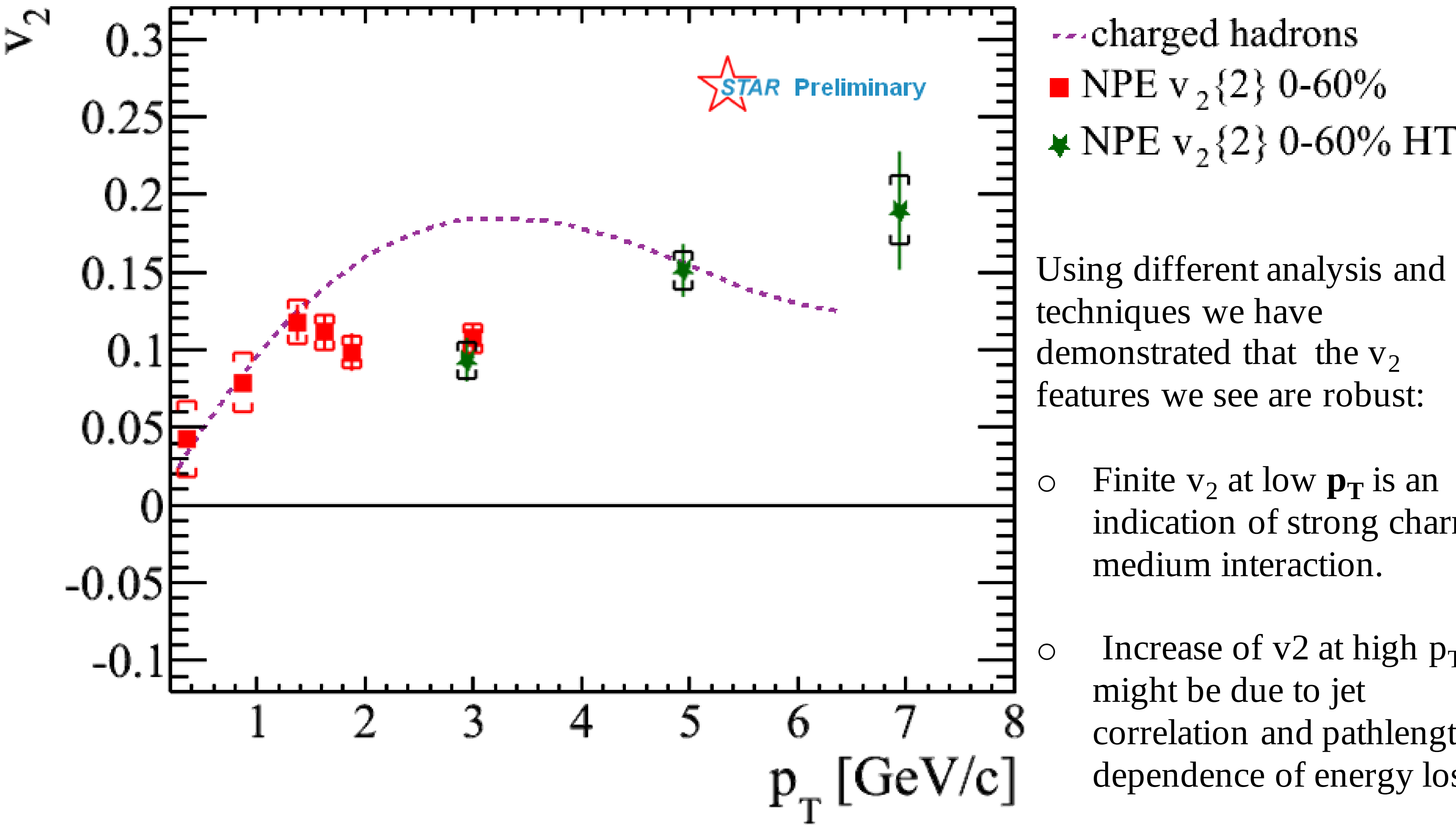


Features:

- D0 v_2 measurement also agrees with a finite v_2 at low $\mathbf{p_T}$.

For more details see D. Kikoła poster

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

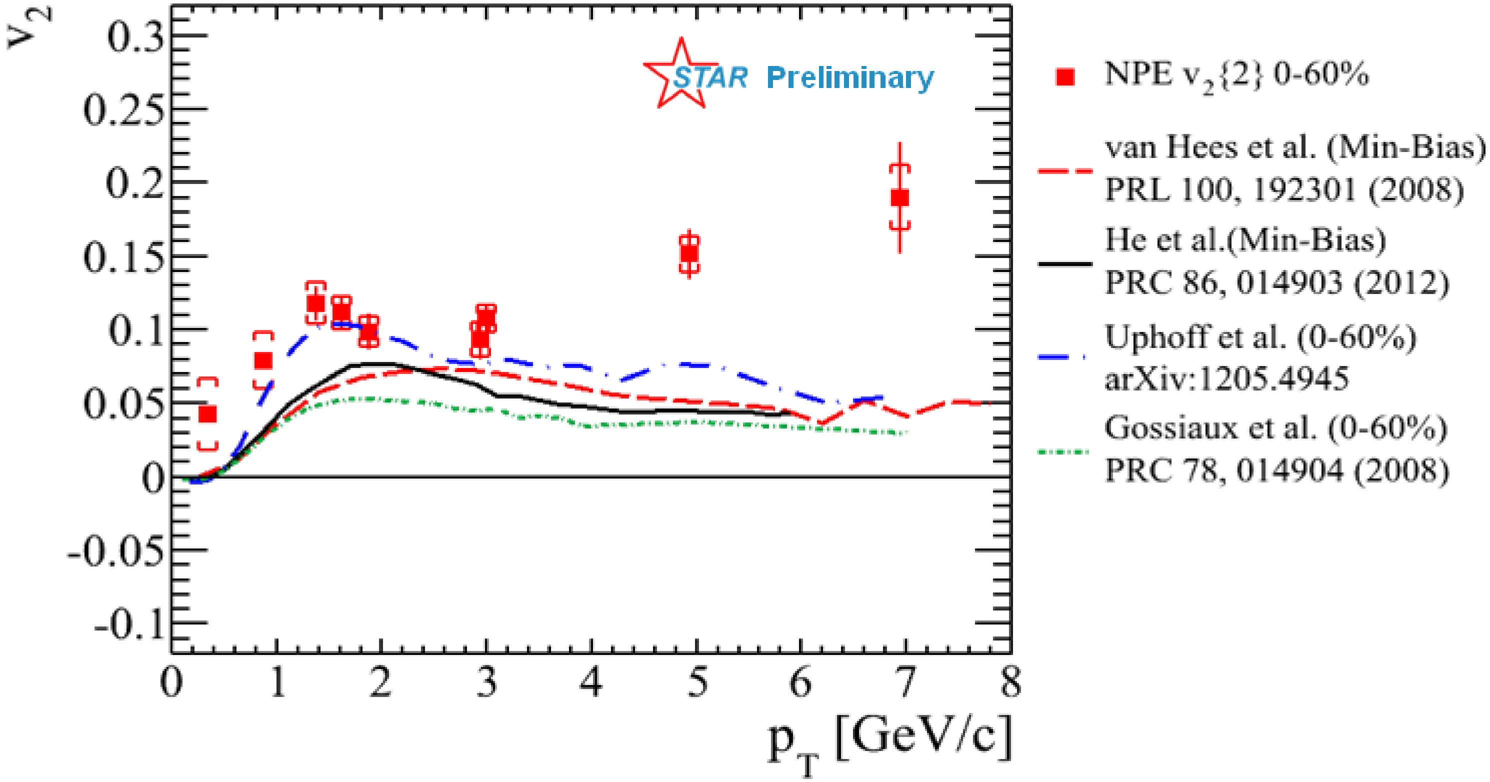


Using different analysis and techniques we have demonstrated that the v_2 features we see are robust:

- Finite v_2 at low $\mathbf{p_T}$ is an indication of strong charm-medium interaction.
- Increase of v2 at high p_T might be due to jet correlation and pathlength dependence of energy loss.

For more details see D. Kikoła poster

NPE v_2 in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV



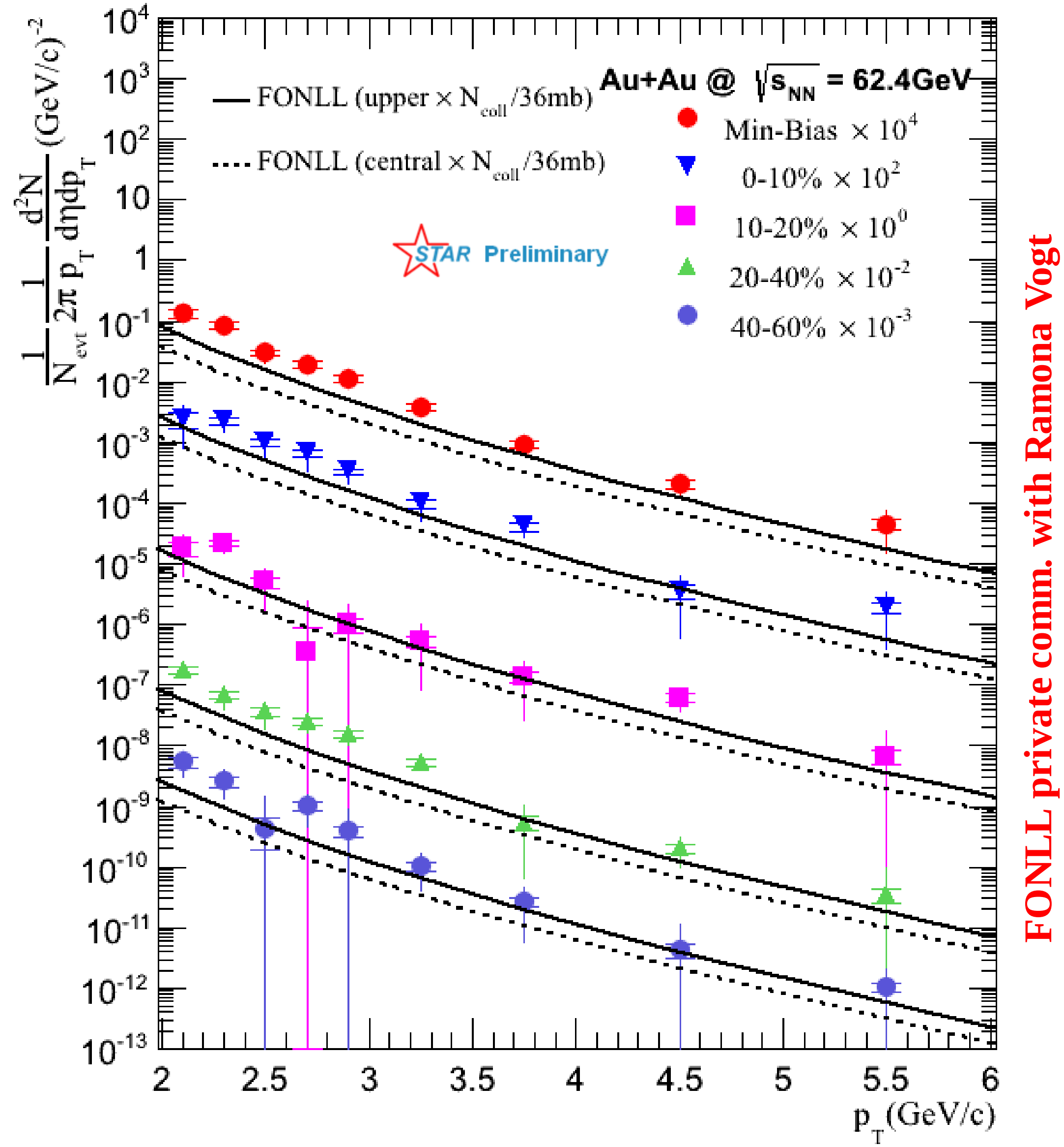
- With the contribution of non-flow (jet correlations) at high $\mathbf{p_T}$ it is difficult to directly compare to models.
- It is interesting that the BAMPS approach can reproduce the bump-feature we see at $\mathbf{p_T}$ 1-2 GeV/c. Nevertheless, more precision is needed for decisive comparison to models.

For more details see D. Kikoła poster

Spectra in Au + Au at $\sqrt{s_{NN}}$ = 62.4 GeV

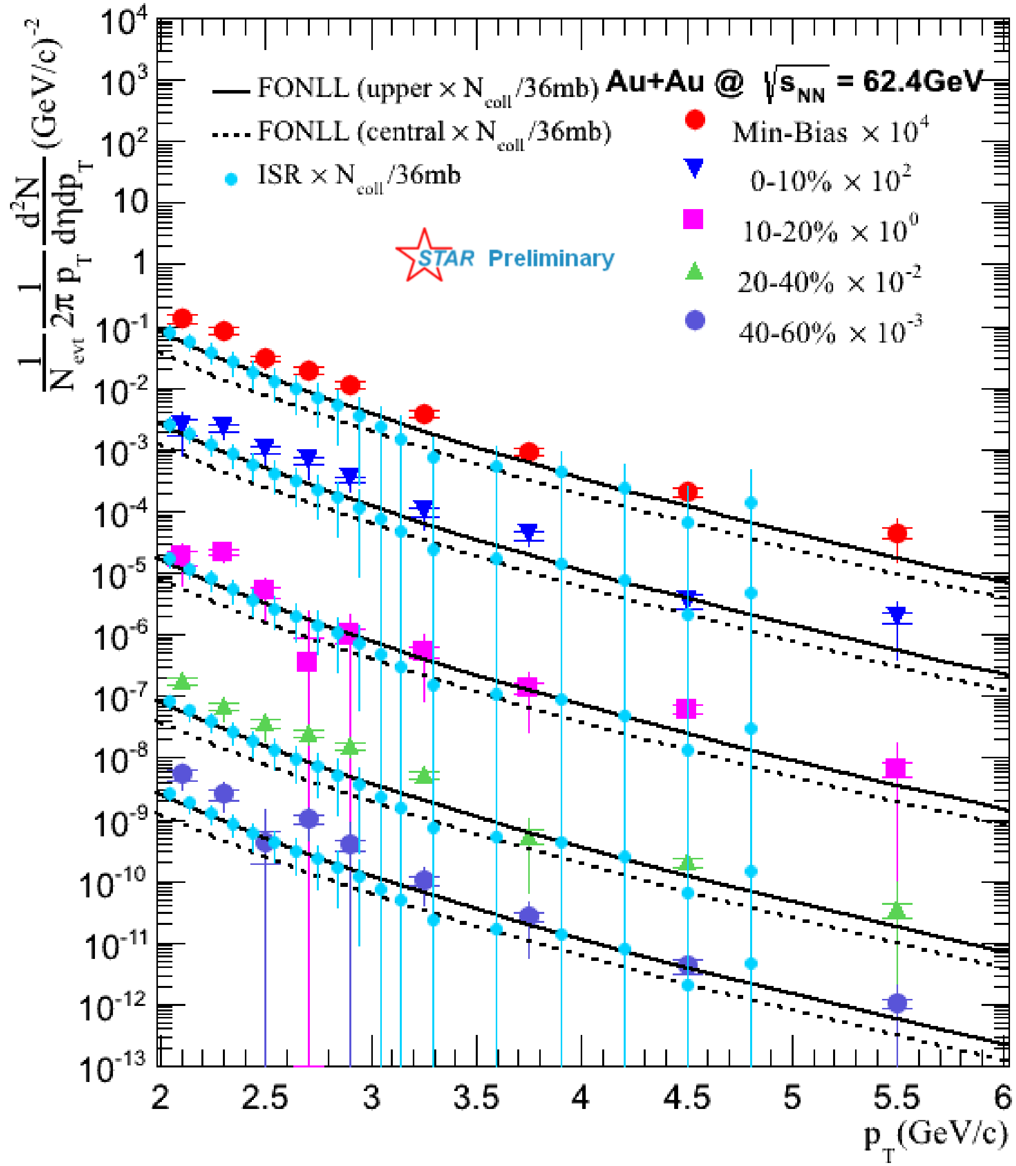
STAR NPE studies are being extended to lower collision energies in search for possible indications of similarities to, or, differences from the suppression effects we observe at $\sqrt{s_{NN}}$ = 200GeV.

- J/ψ not subtracted.



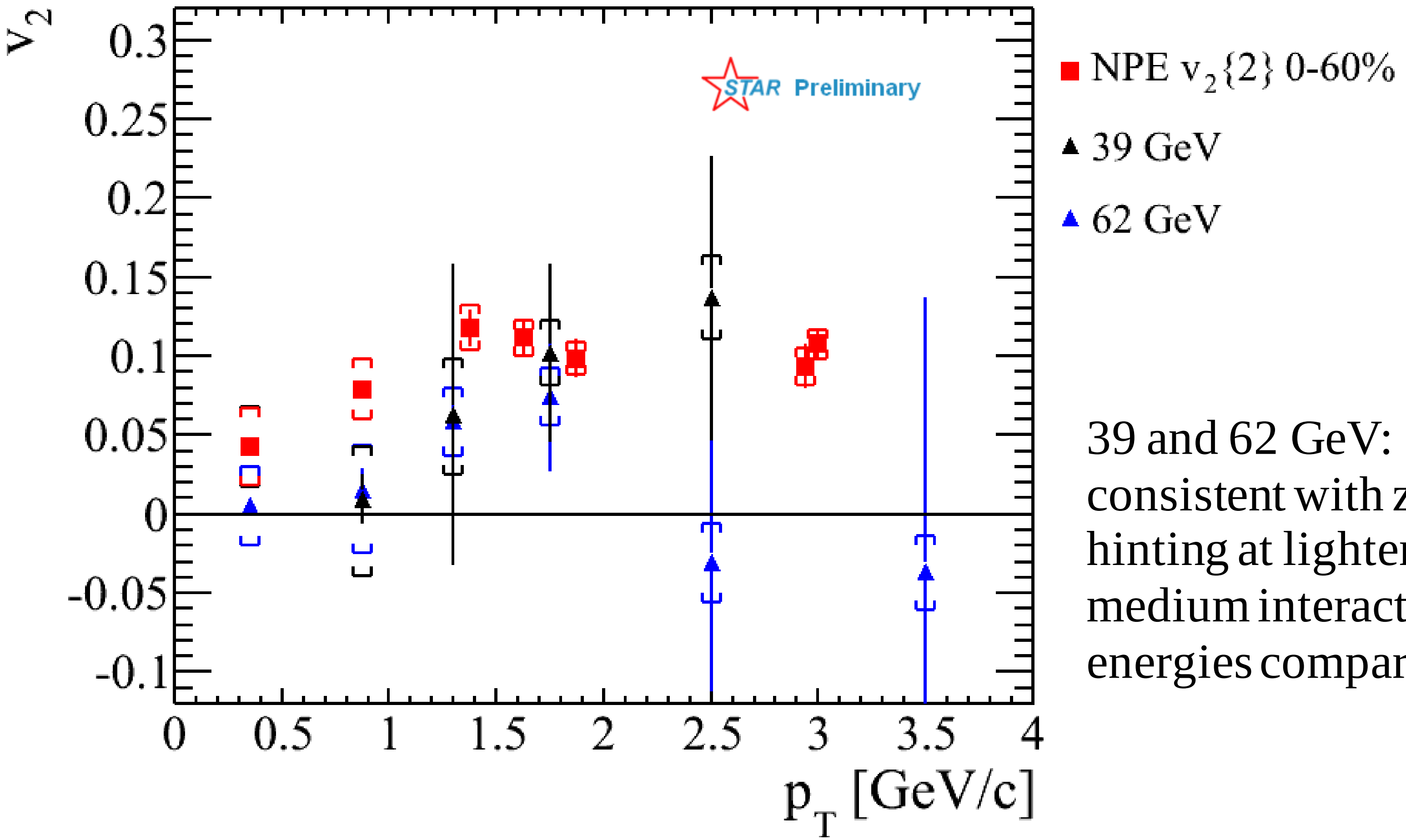
Spectra in Au + Au at $\sqrt{s_{NN}}$ = 62.4 GeV

- Measurement is systematically higher than FONLL upper limit.
- ISR measurement is consistent with FONLL upper limit.
  IL NUOVO CIMENTO (1981), 65A, N4, 421-456



FONLL private comm. with Ramona Vogt

NPE $v_2\{2\}$ in Au + Au at $\sqrt{s_{NN}}$ = 62.4 and 39 GeV



39 and 62 GeV: $v_2\{2\}$ consistent with zero at low-$\mathbf{p_T}$ hinting at lighter charm-medium interaction at lower energies compared to 200GeV.

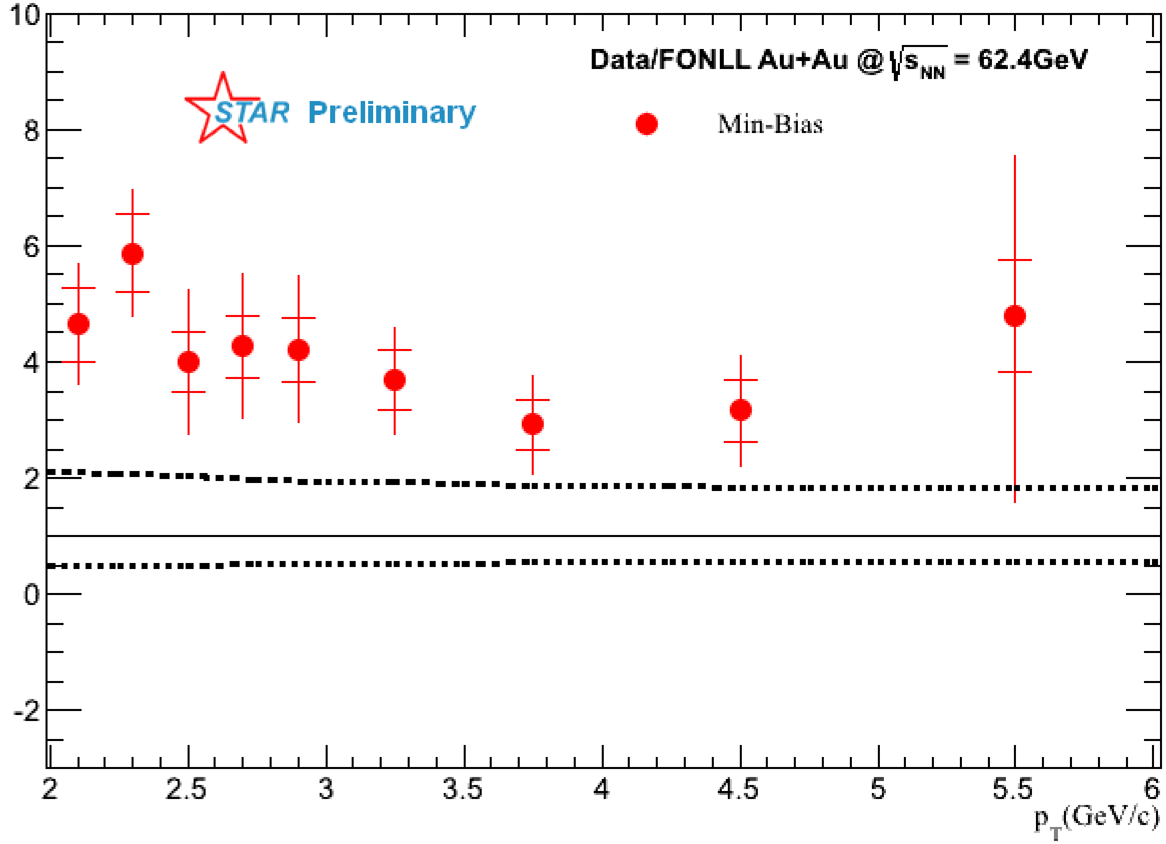
For more details see D. Kikoła poster

Summary

- **New measurement of NPE in Au+Au at $\sqrt{s_{NN}}$ = 200GeV:**
  - High precision at high $\mathbf{p_T}$.
  - R_{AA} indicates strong suppression of heavy quarks, and disfavors radiative energy loss as the only energy loss mechanism for heavy quarks.
  - NPE Azimuthal Anisotropy shows a finite v_2 at low $\mathbf{p_T}$ this is an important indication of strong charm-medium interaction.
  - Due to jet correlations and likely path-length dependence of energy loss, we see an increase in $\mathbf{v_2}$ at high $\mathbf{p_T}$.
- **NPE at lower energies:**
  - NPE spectra in Au+Au $\sqrt{s_{NN}}$ = 62.4 GeV is systematically higher than FONLL.
  - Measurement of NPE V2{2} at √sNN = 62.4 and 39GeV is consistent with zero at low pT which might indicate a difference in the degree of charmed-medium interaction compared to 200GeV.

Backup Slides

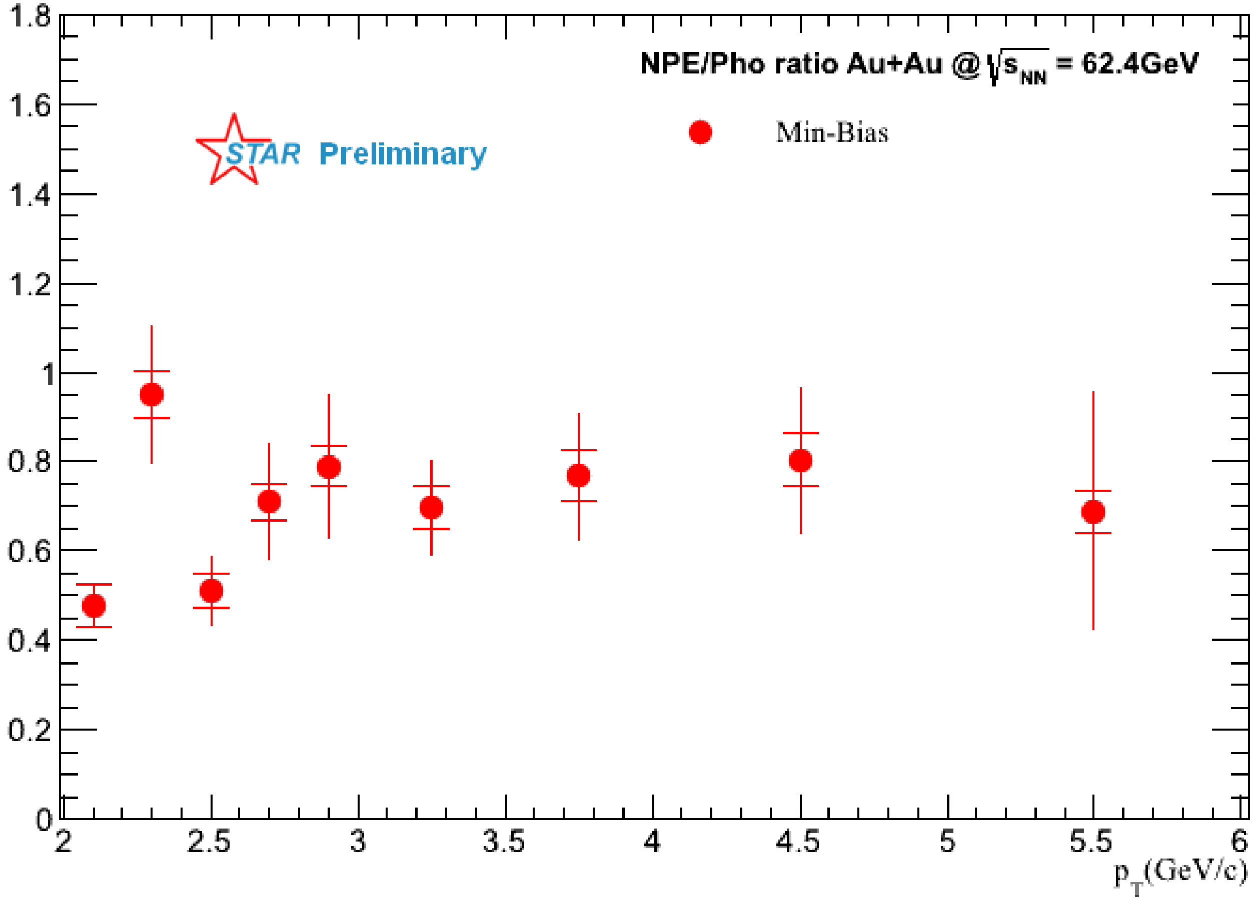
Spectra in Au + Au at $\sqrt{s_{NN}}$ = 62.4 GeV



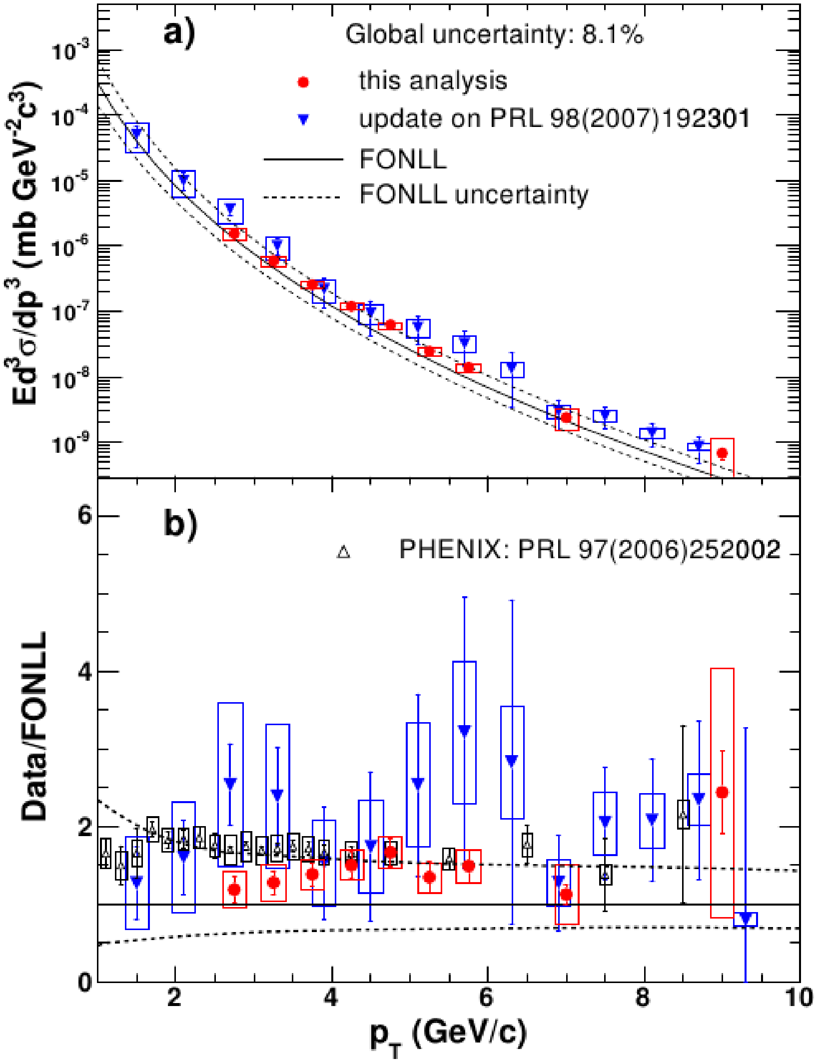
FONLL private comm. with Ramona Vogt

- Measurement is systematically higher than FONLL upper limit.

Spectra in Au + Au at $\sqrt{s_{NN}}$ = 62.4 GeV – NPE/Photonic Ratio



NPE p + p at $\sqrt{s}$ = 200 GeV



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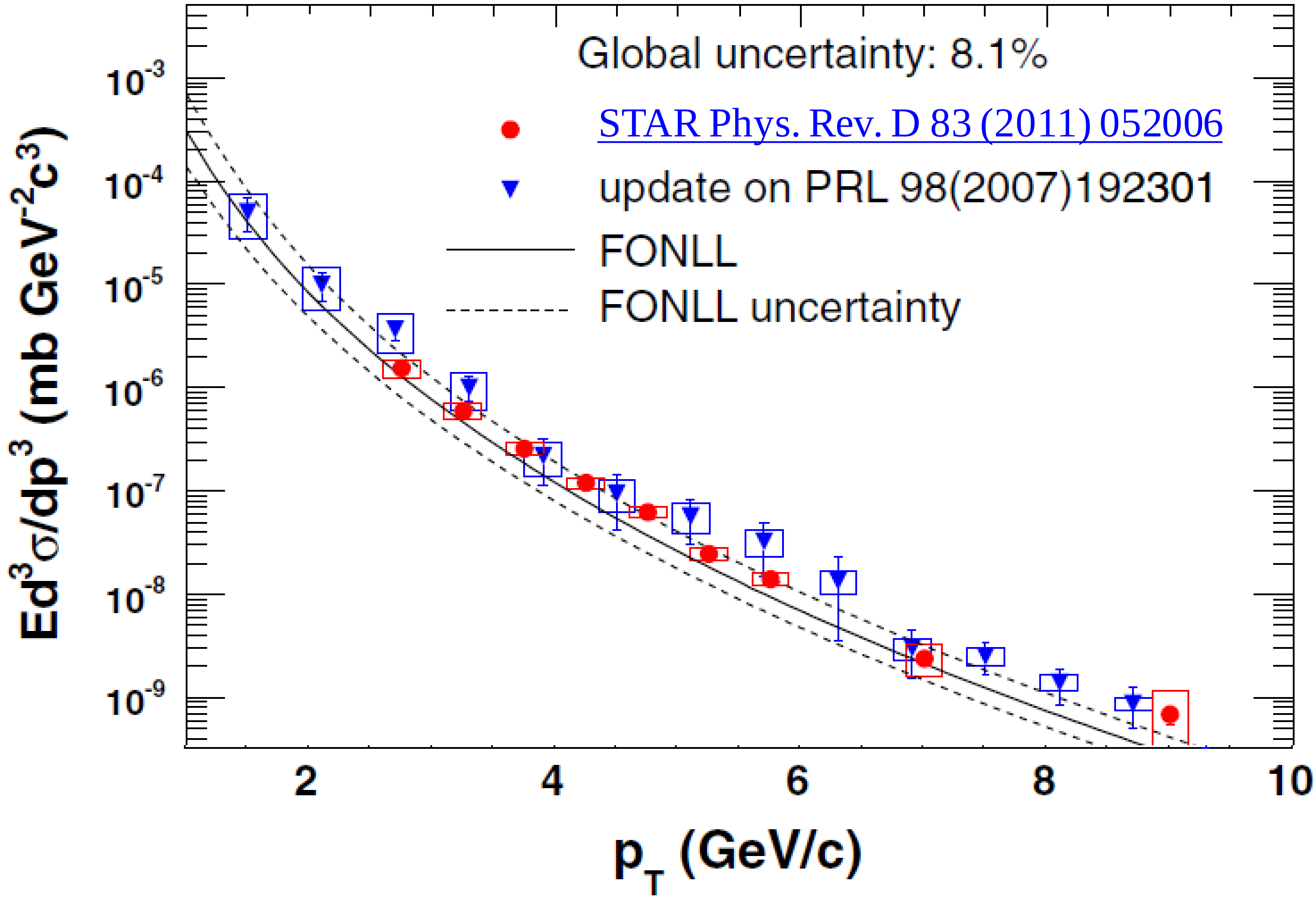


Analysis Technique

Primary background sources:

$\pi^0 \rightarrow \gamma + e^+ + e^-$ BR: 1.2%.

$\eta \rightarrow \gamma + e^+ + e^-$ BR: 0.7%.

$\gamma \rightarrow e^+ + e^-$

- Mostly from $\pi^0(\eta) \rightarrow \gamma + \gamma$

Secondary contributions:

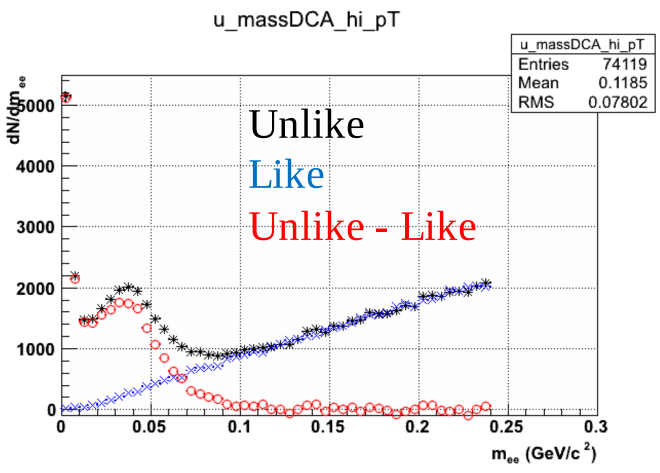
ρ,ω,Φ Dalitz decays , Drell-Yan, Charmonium, etc…

We use the "Reconstruction Method" to statistically subtract the contribution of photonic electrons to inclusive electrons.

$$\frac{dN(NPE)}{dp_T} = \epsilon_{purity} * \frac{dN(Inclusive)}{dp_T} - \frac{1}{\epsilon_{pho}} * \frac{dN(Photonic)}{dp_T}$$

ϵ_{purity} : purity of inclusive electrons sample. Calculated from data.

ϵ_{pho} : photonic electrons reconstruction efficiency. Calculated from embedding.



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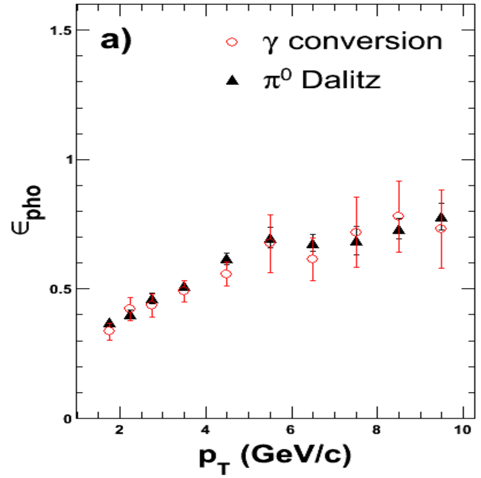

NPE $v_2\{2\}$ and $v_2\{4\}$: Analysis Technique

$$v_2^{\mathrm{Npe}} = \frac{N^I v_2^I - N^{\mathrm{Pho}} v_2^{\mathrm{Pho}} - N^I(1-p)v_2^H}{N^{\mathrm{Npe}}}$$

v^{Pho}_2 from simulations of $\pi^0 \rightarrow e$ and $\gamma \rightarrow e$ in STAR

Simulations are based on $v_2\{EP\}$

v_{2H} – $v_2\{2\}$ or $v_2\{4\}$ for all charged hadrons in |h|<0.7

p - purity