Four things they tell you about heavy flavor flow

… that aren't true

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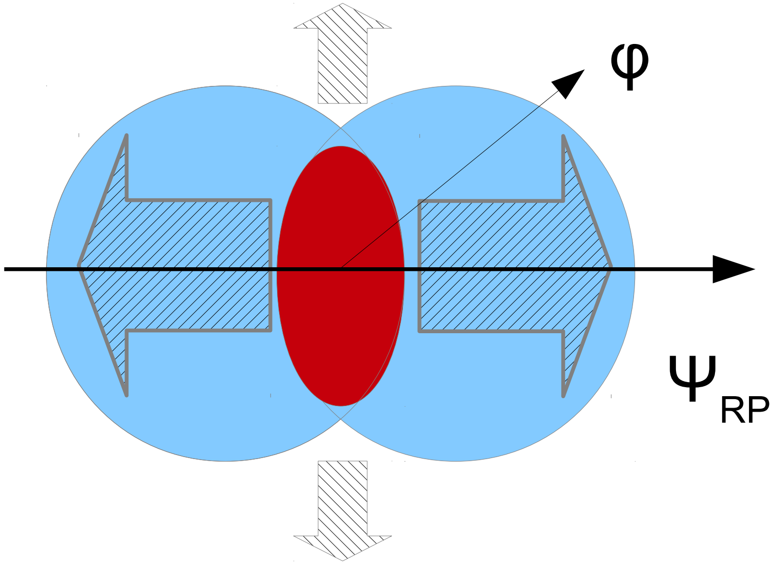
Heavy Flavor ≡ charm and beauty quarks

Flow ≡ hydro-like flow



$$\frac{dN}{d\left(\phi-\Psi_{RP}\right)} \propto 1+2v_2\cos 2\left(\phi-\Psi_{RP}\right)$$

1. We measure Heavy Flavor flow

2. We measure flow

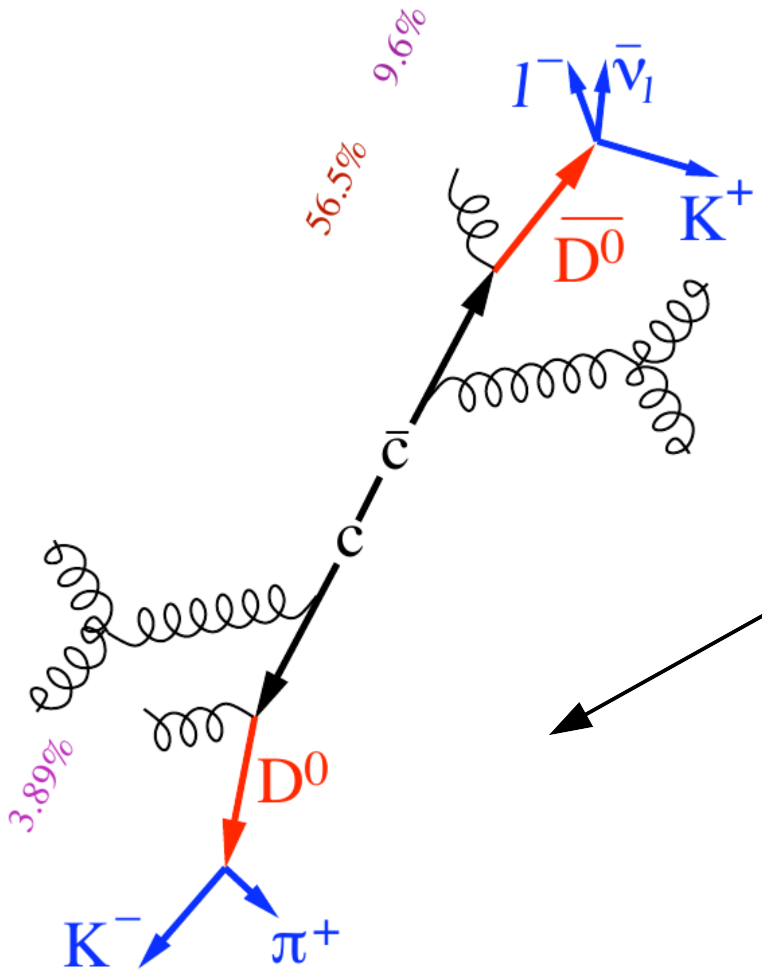
3. Finite v_2 of Heavy Flavor electron indicates heavy flavor flow

4. Heavy Flavor electron v_2 at low p_T indicates charm flow

1. We measure

Heavy Flavor flow

In the experiment:



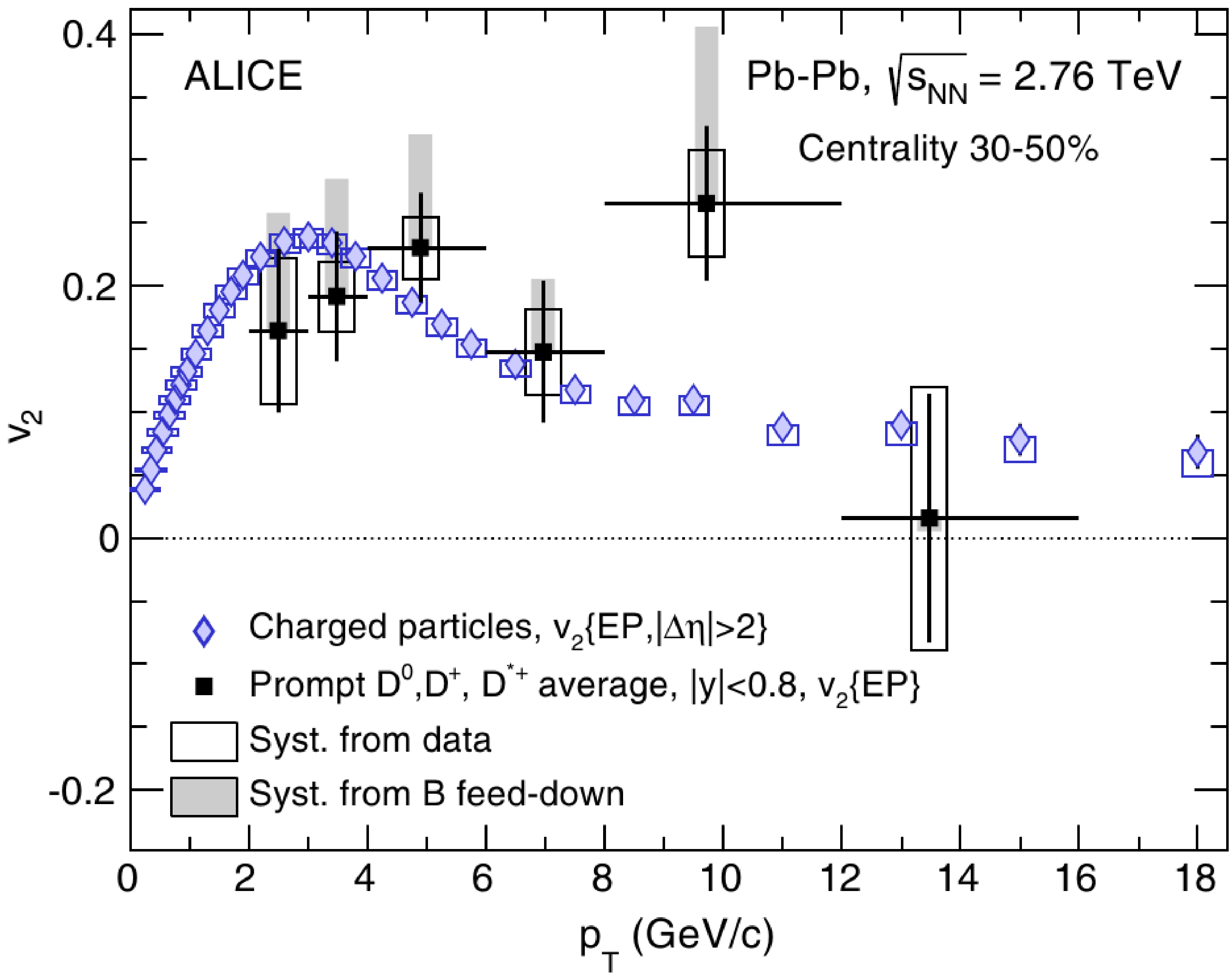
Electrons from semi-leptonic heavy flavor hadrons decay

(Non-photonic electrons)

Direct open charm reconstruction

Courtesy of David Tlusty

How much charm v_2 in D-meson v_2?

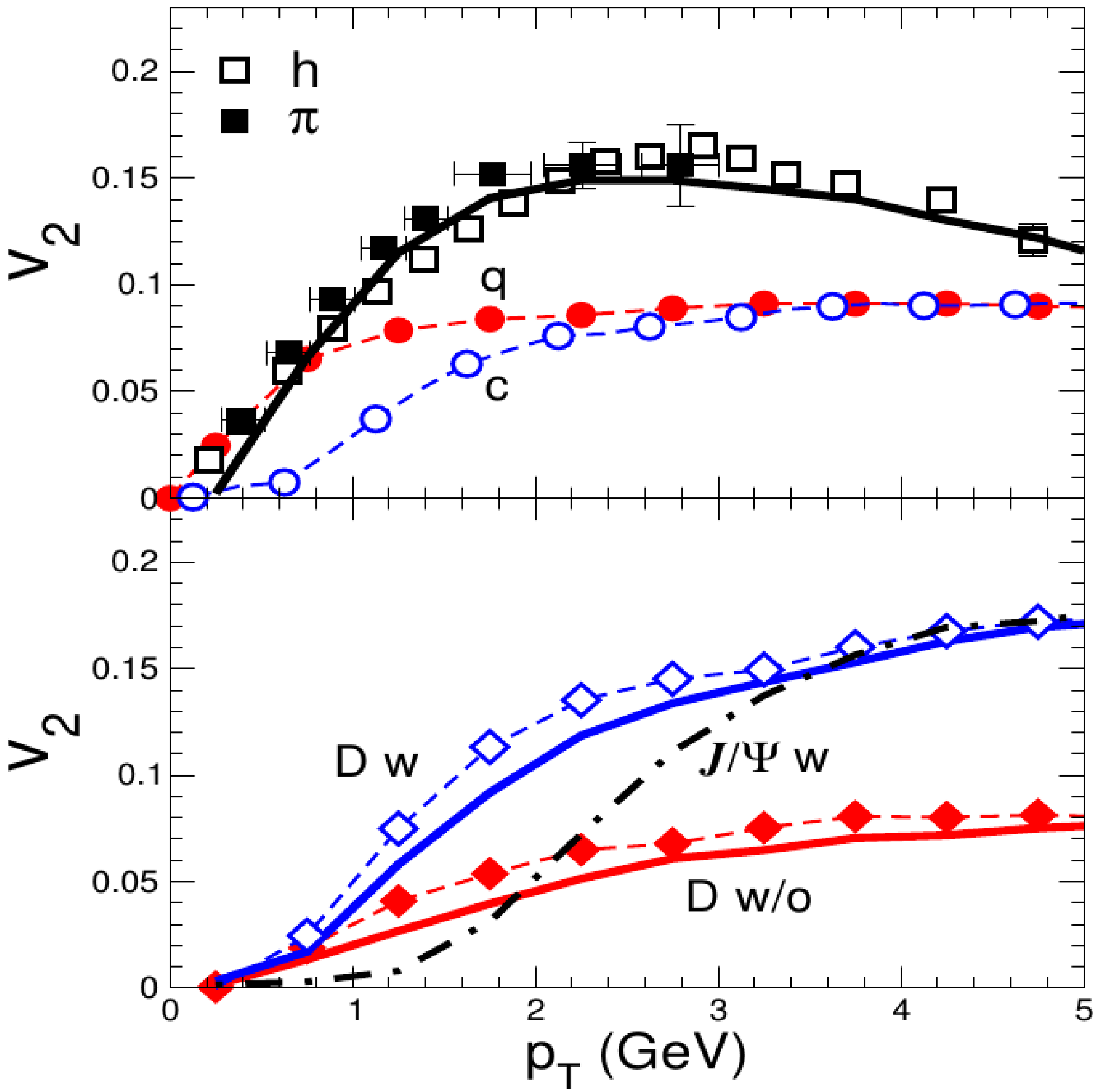


PRL 111, 102301 (2013)

v_2 should depend on production mechanism

- Naive expectation:
  - Coalescence with light quark → larger v_2 due to light quark v_2
  - Fragmentation – closer relation to parent v_2 → smaller v_2

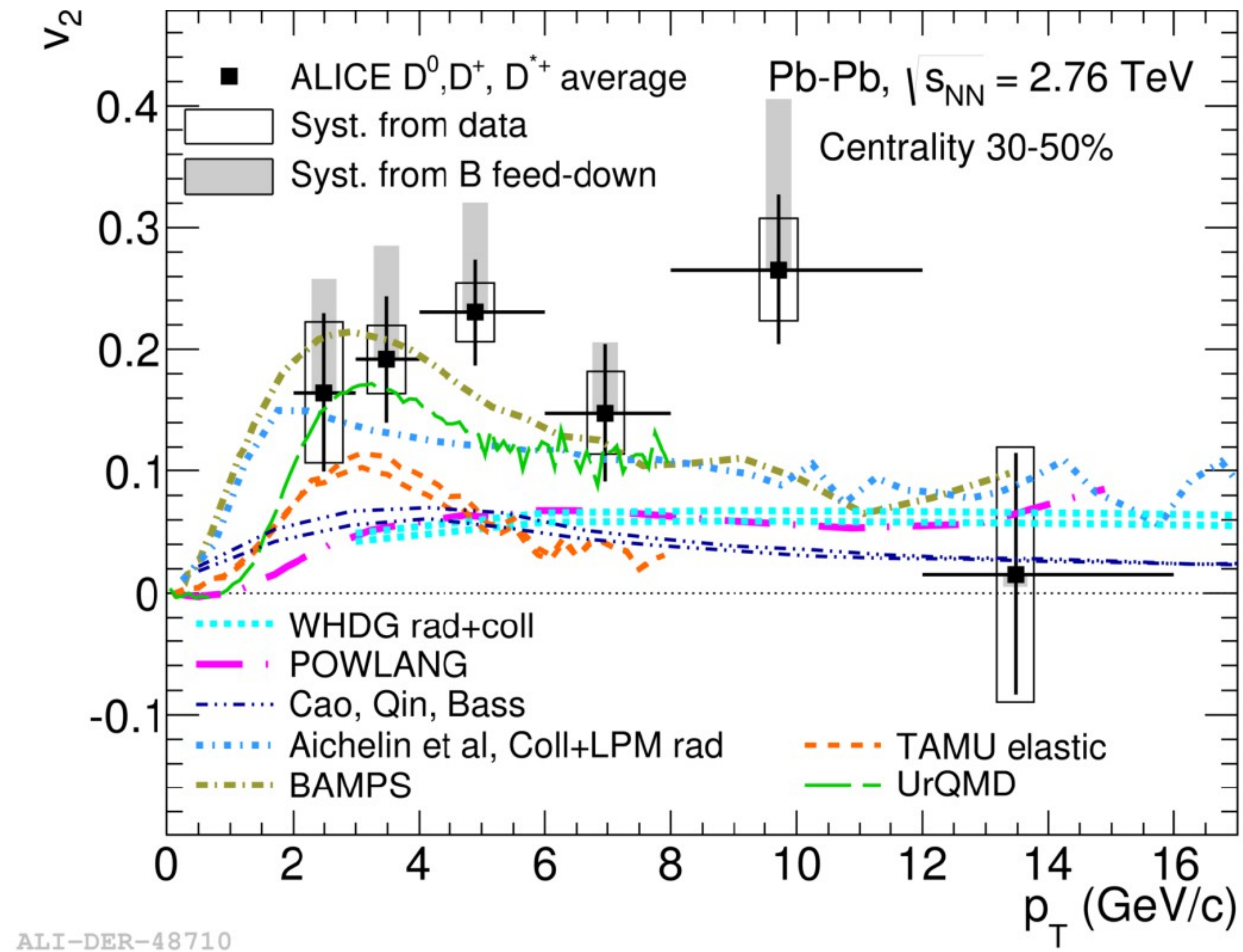
Coalescence with light quark



Phys.Lett. B595 (2004)

Min-bias Au+Au 200 GeV

50% of D meson v_2 could be from light quark



BAMPS → fragmentation → large v_2

TAMU → coalescence (at low p_T) → smaller v_2

→ results depend on details of interaction mechanism

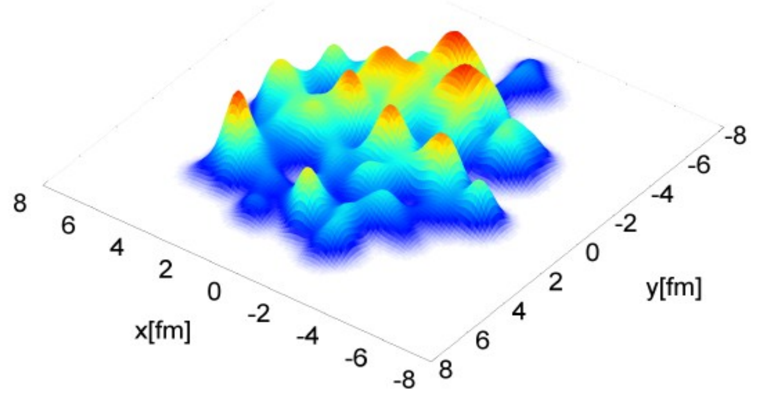
1. “We measure Heavy Flavor flow”

Reality: no direct access to heavy quarks → charmed/beauty meson (with light quark contribution) is the closest we can get

2. We measure flow

- Experiment:
  - $v_2 \rightarrow$ final state momentum anisotropy
  - $v_2\{EP\}$, $v_2\{2\}$, $v_2\{4\}$
  - Other effects than flow → jet-like correlations, decay kinematics

- Flow (v_2) is not uniquely defined
  - reaction vs participants plane
  - How to define that plane?
    - integrate over gluon density?
    - count participant nucleons?



Phys. Rev. Lett. 108, 252301

1. “We measure Heavy Flavor flow”

   Reality: no direct access to heavy quarks → charmed/beauty meson (with light quark contribution) is the closest we can get

2. “We measure flow”

   Reality: we measure final state anisotropy, flow is not even uniquely defined in theory

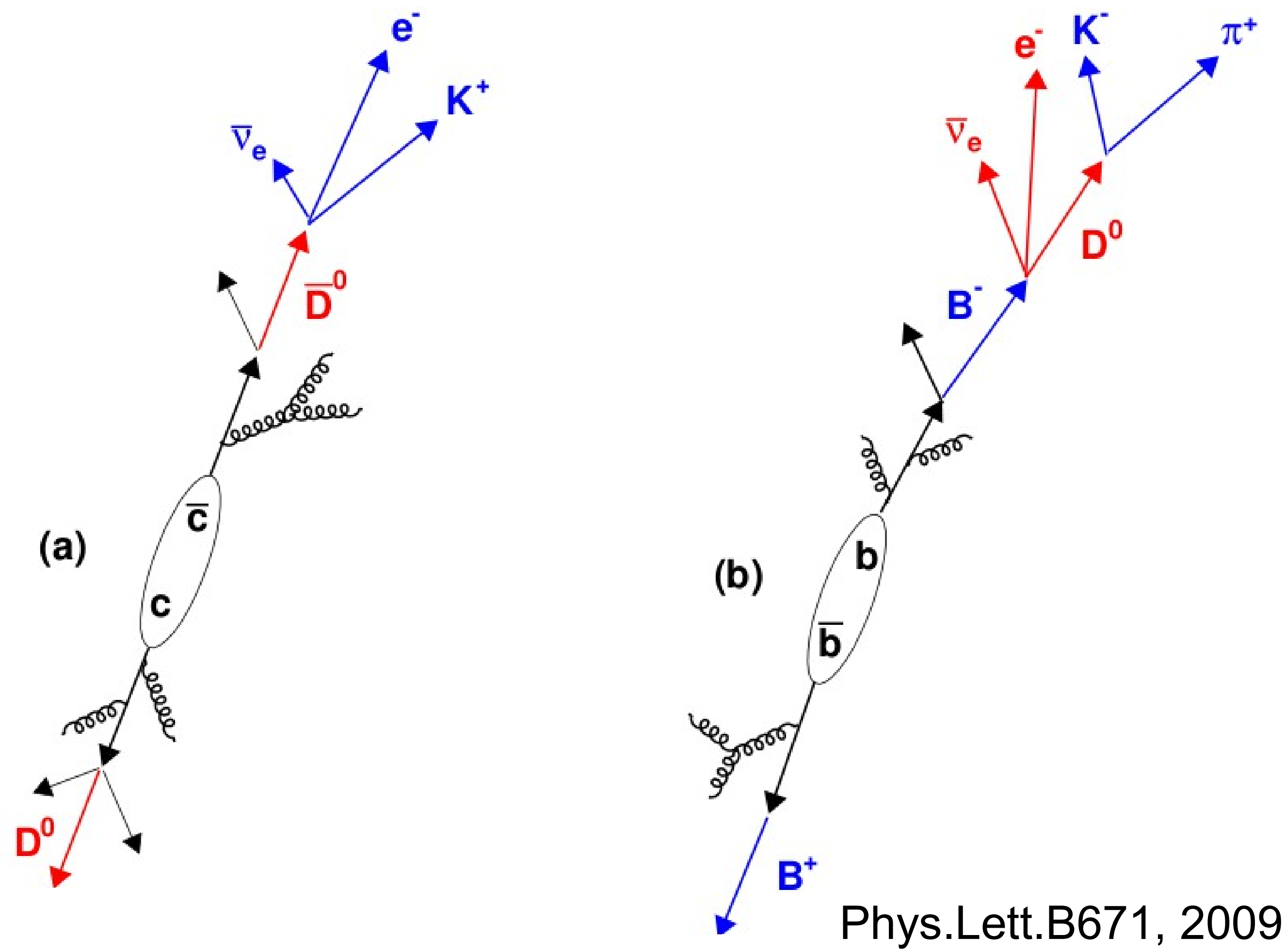
3. Finite v_2 of heavy flavor electron indicates heavy flavor flow

Non-photonic electrons

Proxies for heavy flavor quarks

p_T shift compared to parent quark

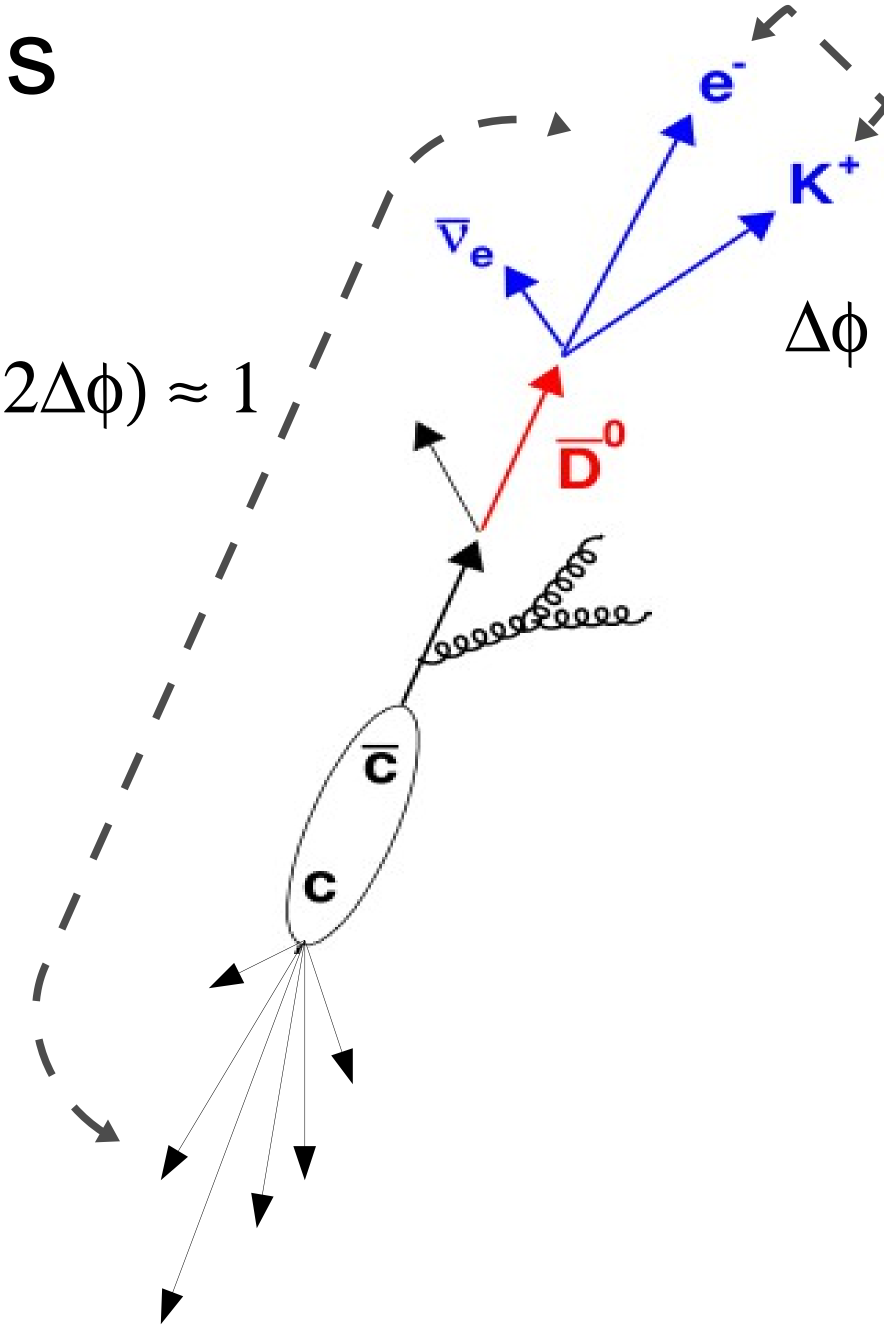
ϕ angle smeared



Phys.Lett.B671, 2009

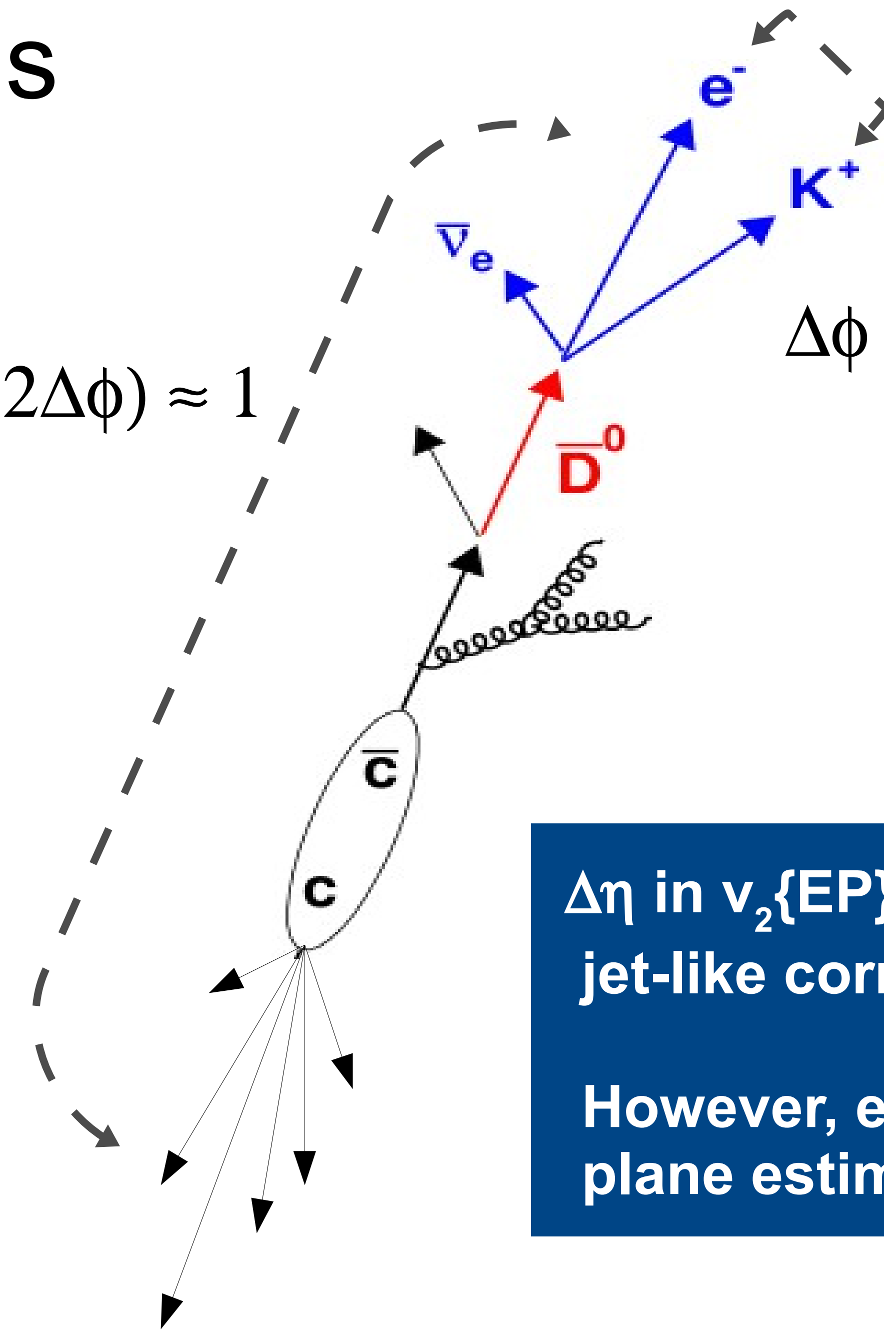
Jet-like correlations

$\Delta\phi \approx \pi \rightarrow \cos(2\Delta\phi) \approx 1$



$\Delta\phi \approx 0 \rightarrow \cos(2\Delta\phi) \approx 1$

Jet-like correlations



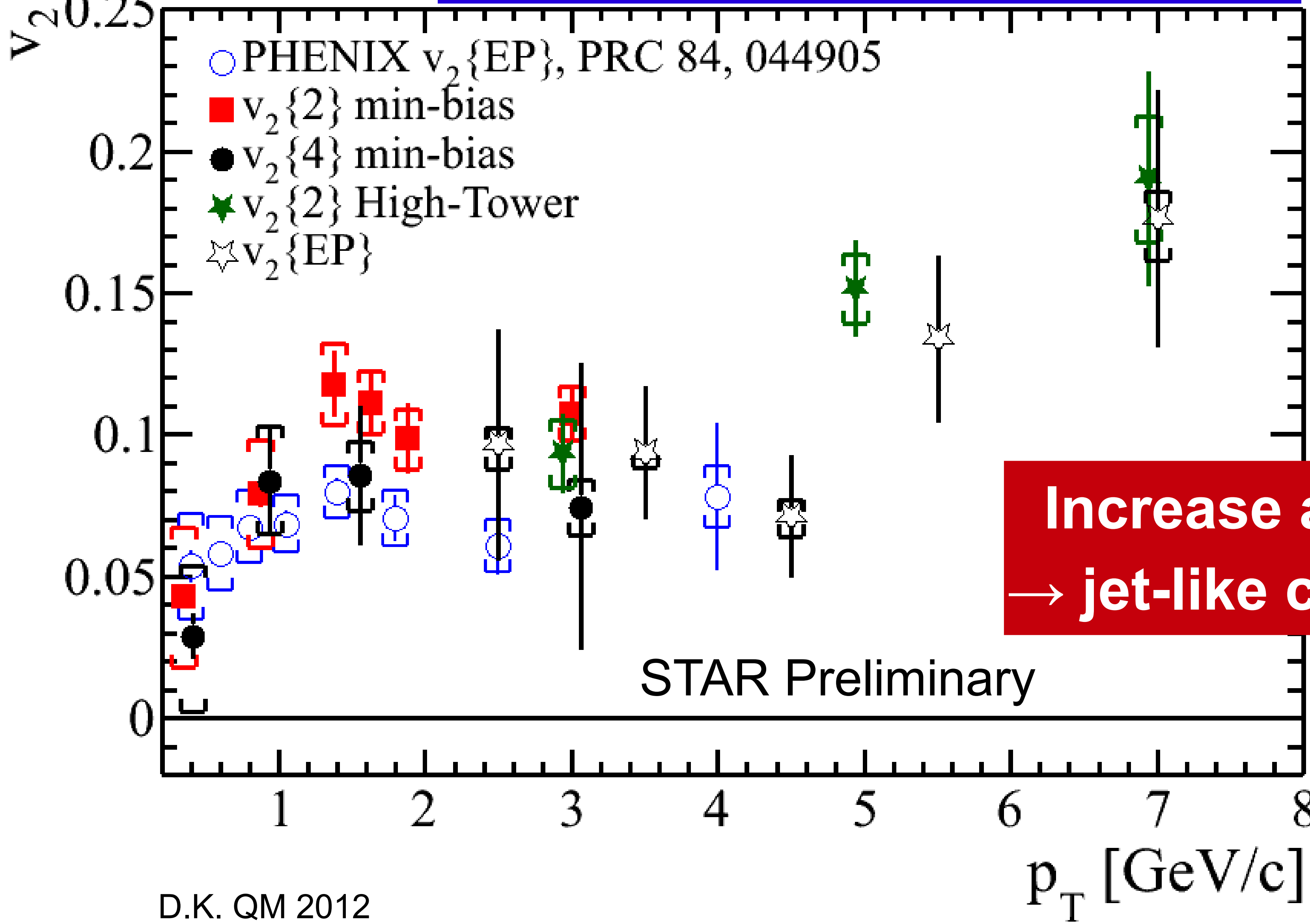
$\Delta\phi \approx \pi \rightarrow \cos(2\Delta\phi) \approx 1$

$\Delta\phi \approx 0 \rightarrow \cos(2\Delta\phi) \approx 1$

$\Delta\eta$ in $v_2\{EP\}$ supposes to reduce jet-like correlations

However, effect of jets on event plane estimation not really known

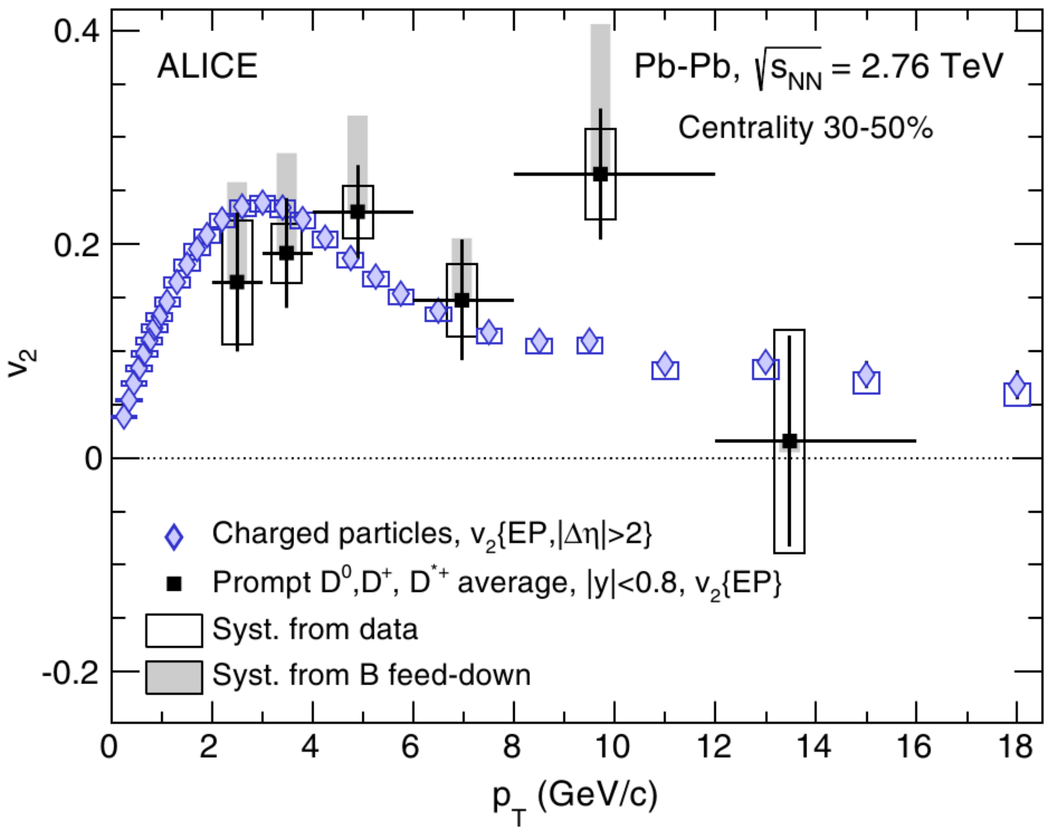
Au+Au 200 GeV, 0 - 60%



Increase at high-p_T
→ jet-like correlations

D.K. QM 2012

How much “nonflow” in D-meson v_2?



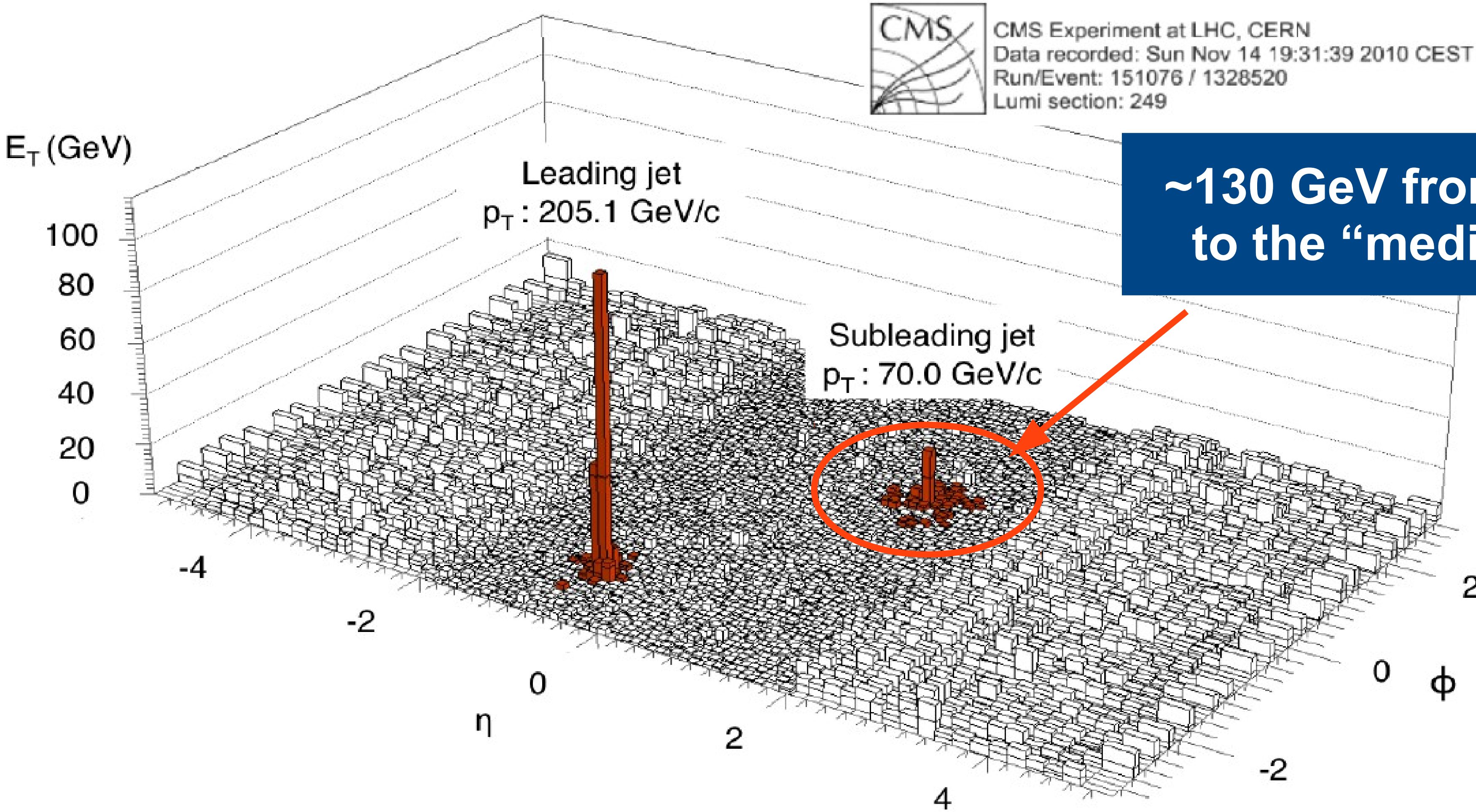
ALICE:

“...[non-flow] effect was estimated to be small with respect to the other uncertainties by repeating the analysis using the event plane determined in a different η region with the VZERO detector.”

PRL 111, 102301 (2013)

LHC:

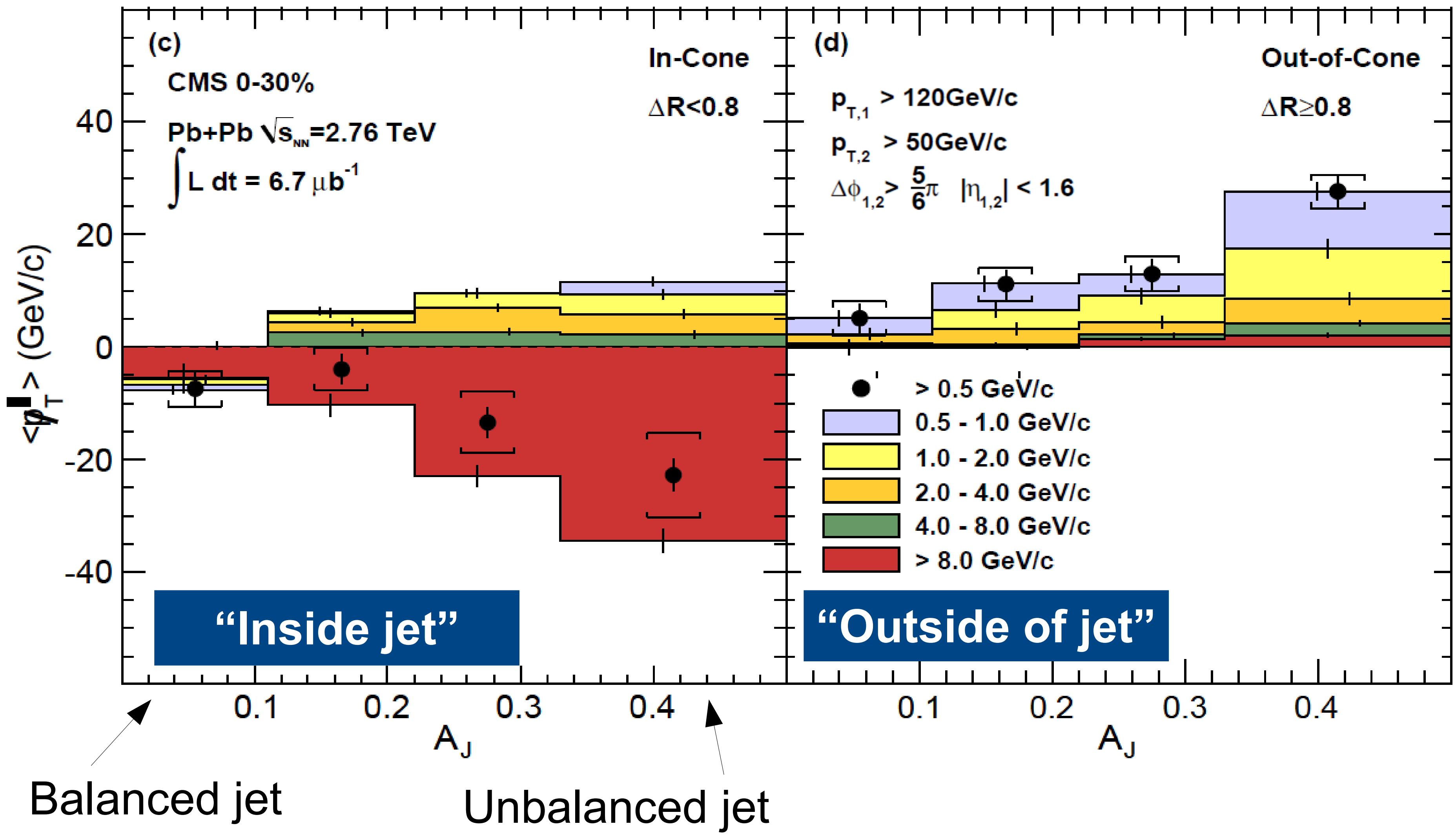
- large jet production
- large di-jet imbalance



~130 GeV from jet goes to the "medium"

CERN-PH-EP/2011-001

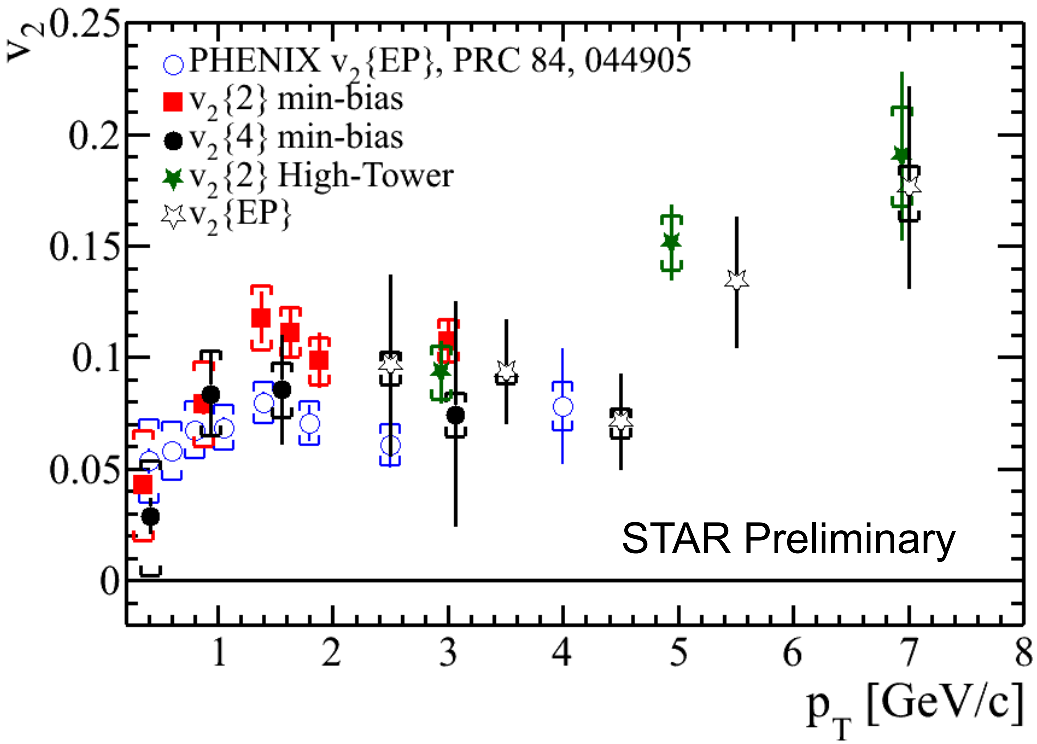
LHC – large di-jet imbalance

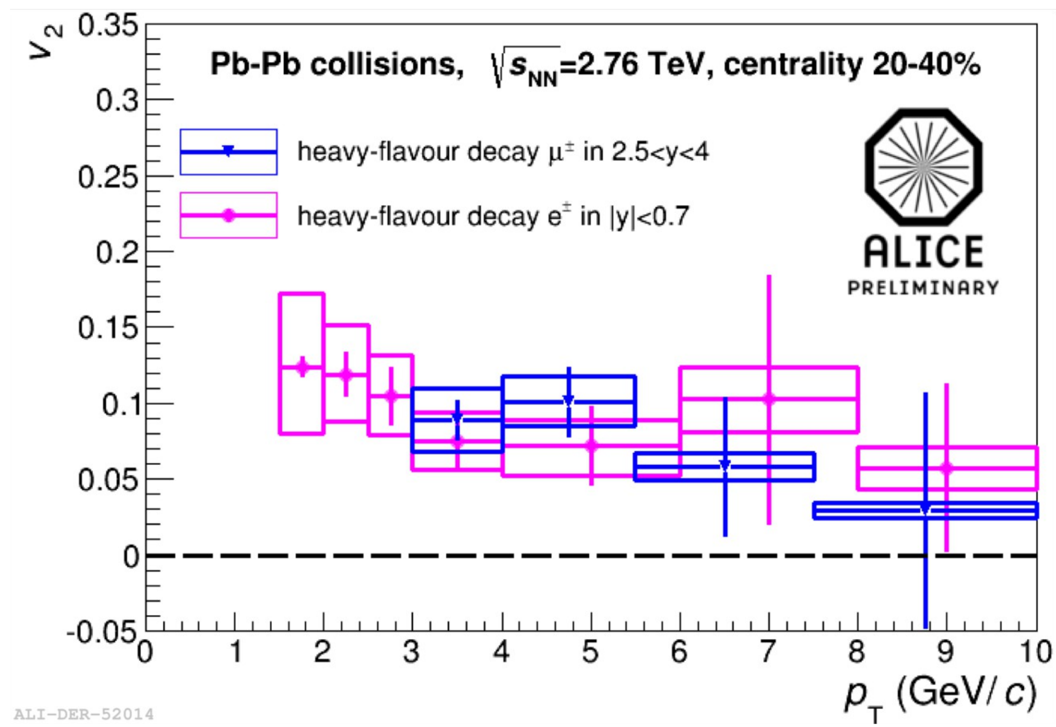


Really, ALICE? No jet effect on D v_2 measurement?

Phys.Rev.C84:024906

RHIC vs LHC





Positive v_2 at p_T > 1 GeV/c for heavy flavor leptons

No energy dependence within uncertainties

1. “We measure Heavy Flavor flow”

Reality: no direct access to heavy quarks → charmed/beauty meson (with light quark contribution) is the closest we can get

2. “We measure flow”

Reality: we measure final state anisotropy, flow is not even uniquely defined in models

3. “Finite v_2 of HF electron indicates heavy flavor flow”

- **Reality:** need to be very careful about correlations due to jets and decay kinematics

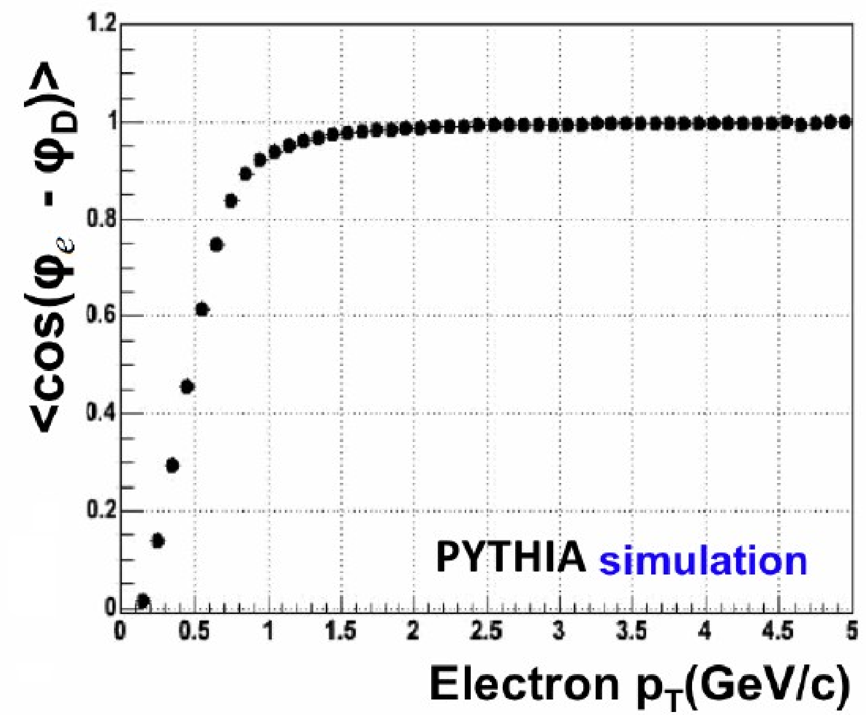
4. Heavy flavor electron v_2 at low p_T indicates charm flow

NPE represents parent momentum direction well when:

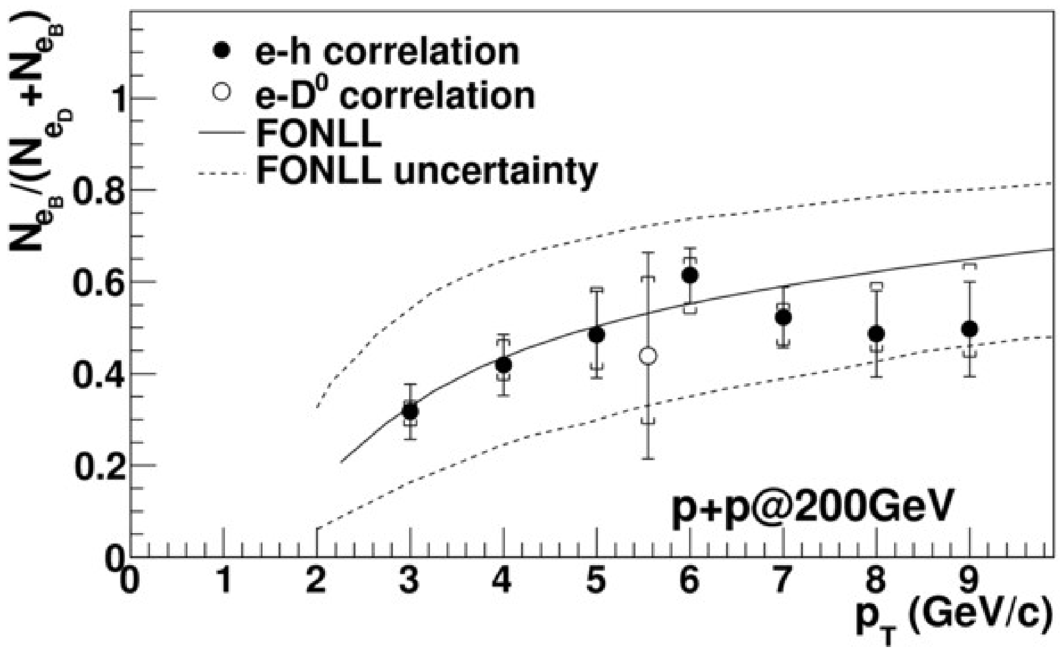
p^e_T >1.5 GeV/c for D

p^e_T > 3 GeV/c for B

→ p^e_T ~1.5 – 2 GeV/c for charm v_2 study



W. Xu, QM 2011



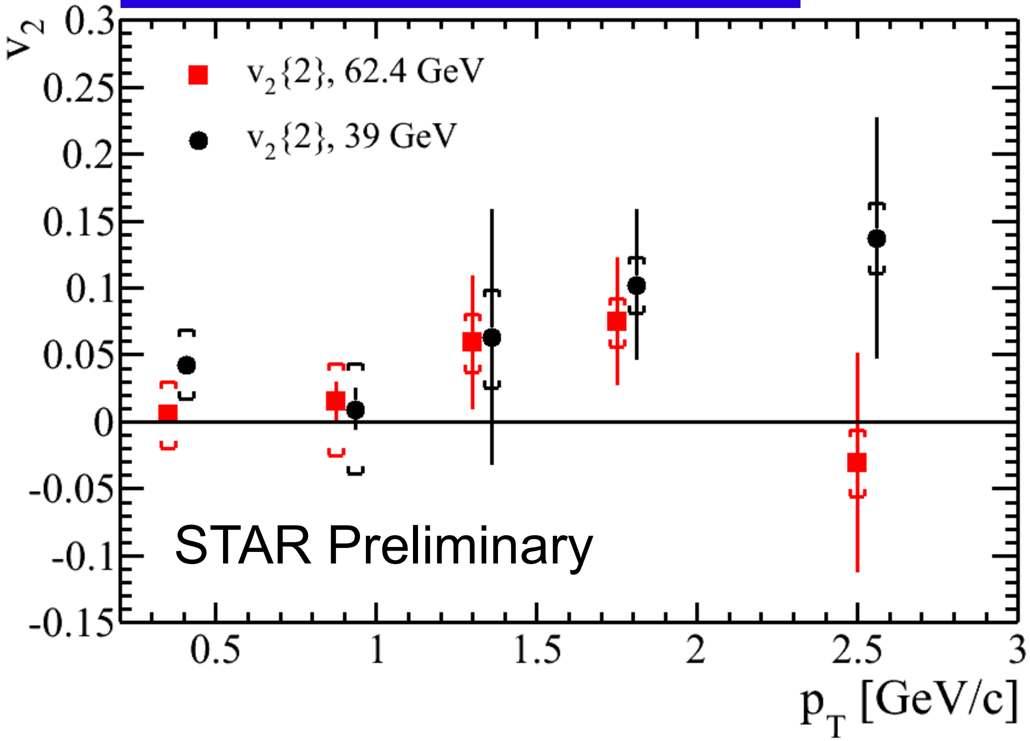
At p_T ~2 GeV, up to 40% from B → p_T shift and v_2 smearing

What about D/B suppression?

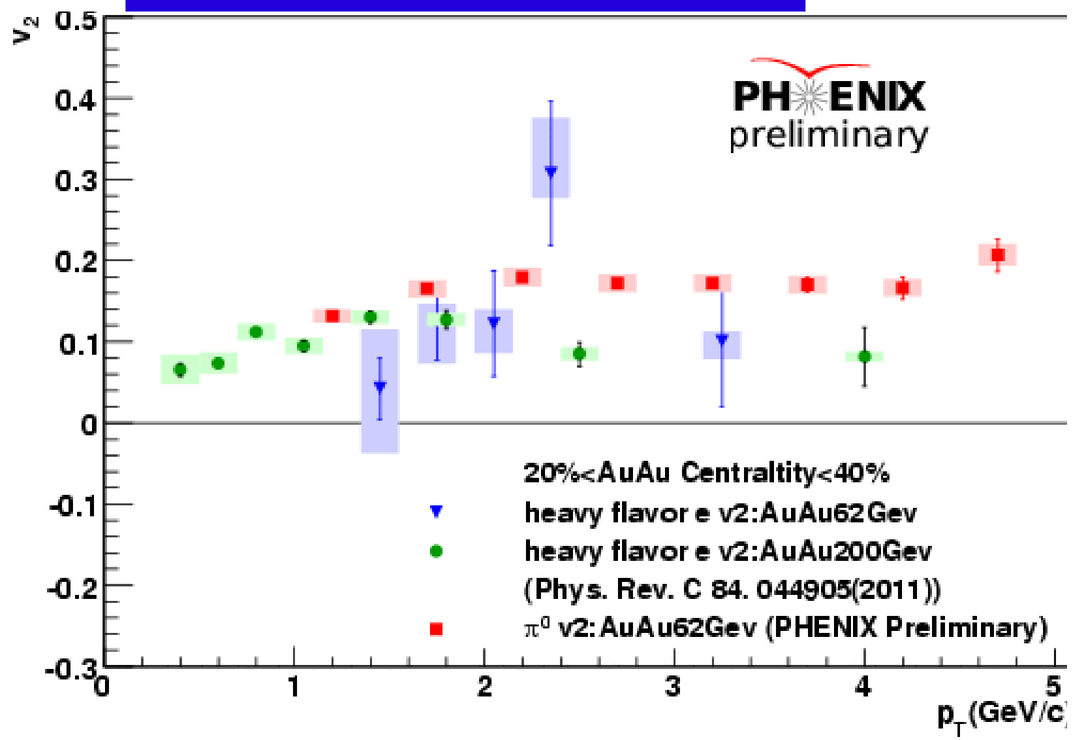
NPE v_2 in Beam Energy Scan

Lower energy → less issues with bottom

39 and 62 GeV, 0 - 60%



62 GeV, 20 - 40%



Unfortunately issues with statistics as well

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3. “Finite v_2 of HF electron indicates heavy flavor flow”

   - **Reality:** need to be very careful about correlations due to jets and decay kinematics

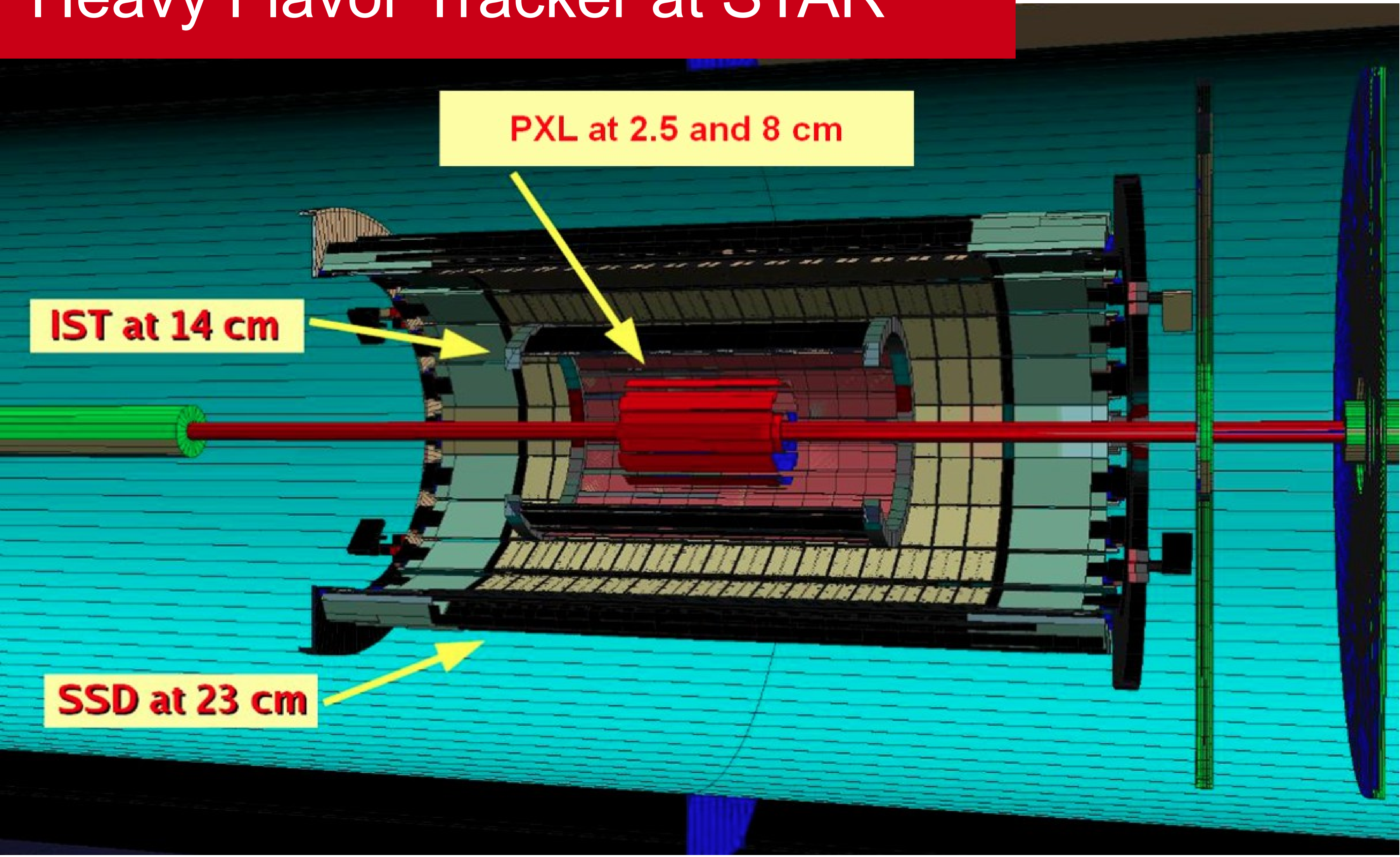
4. HF electron v_2 at low p_T indicates charm flow

   - **Reality:** need charm/beauty separation in Au+Au to claim that

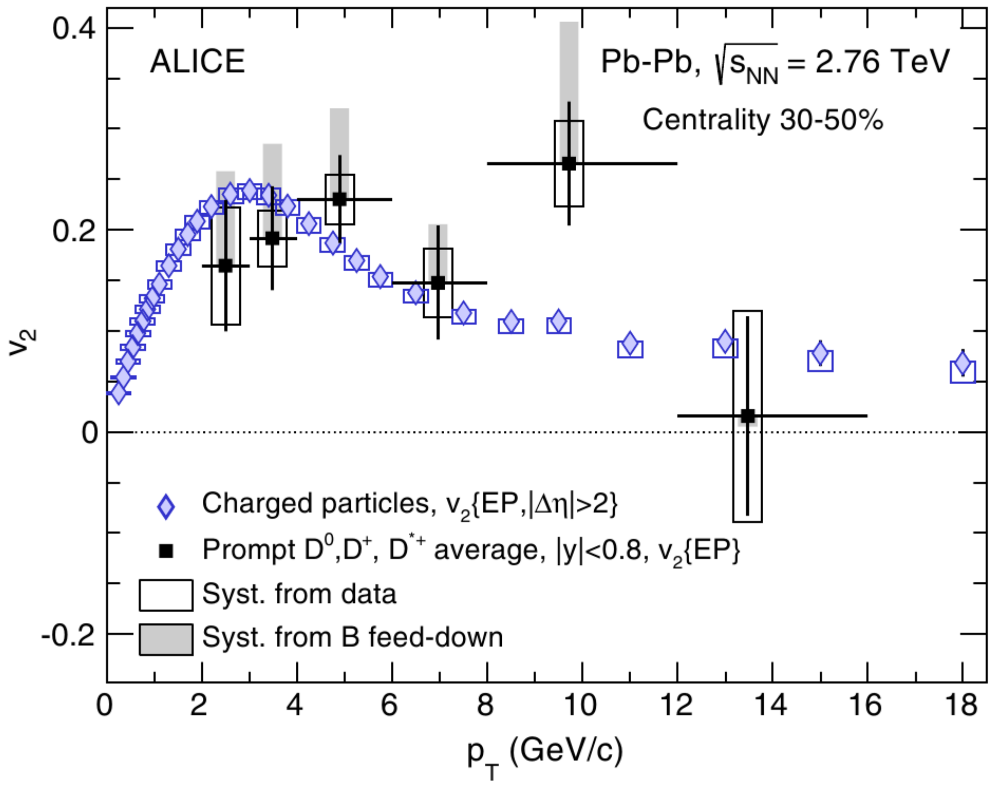
Path forward:

provide as much precise **data** as possible and ask **theory** to describe **all** of them

Heavy Flavor Tracker at STAR

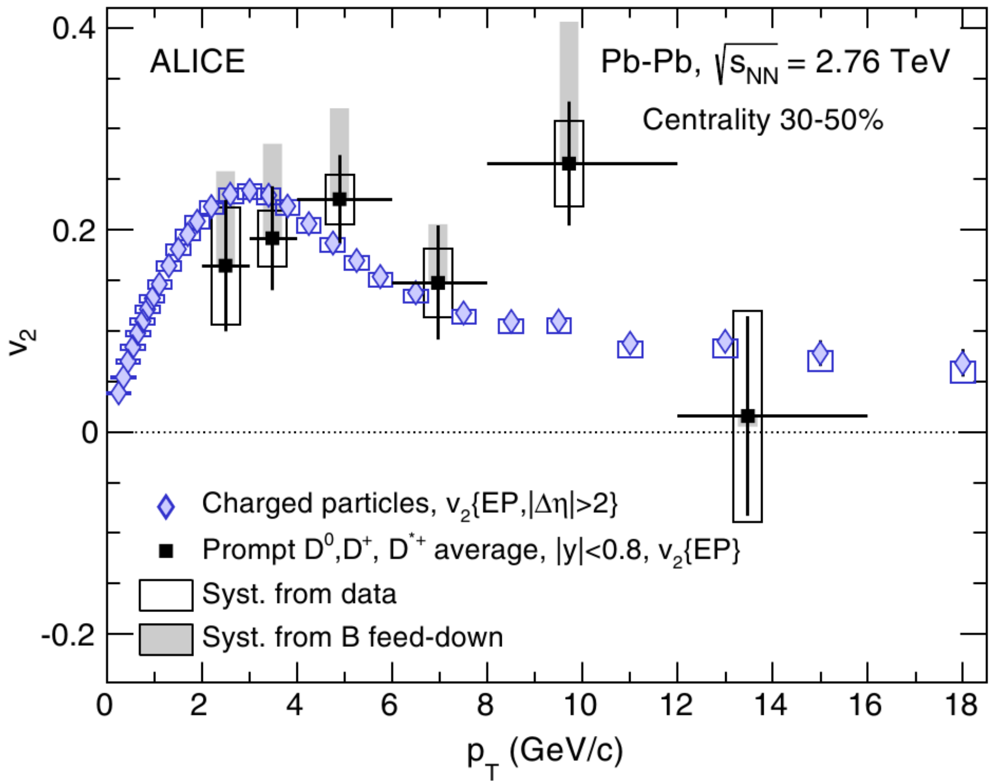


Best data so far ...



PRL 111, 102301 (2013)

STAR data with Heavy Flavor Tracker



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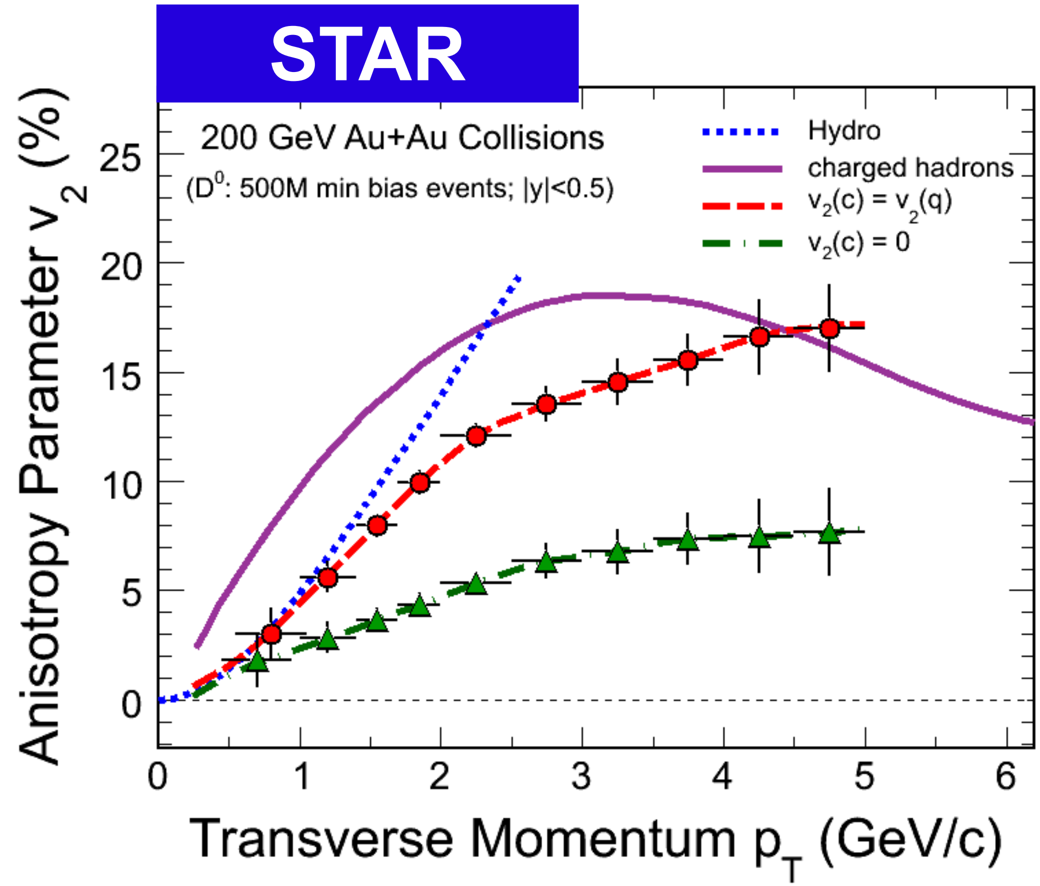
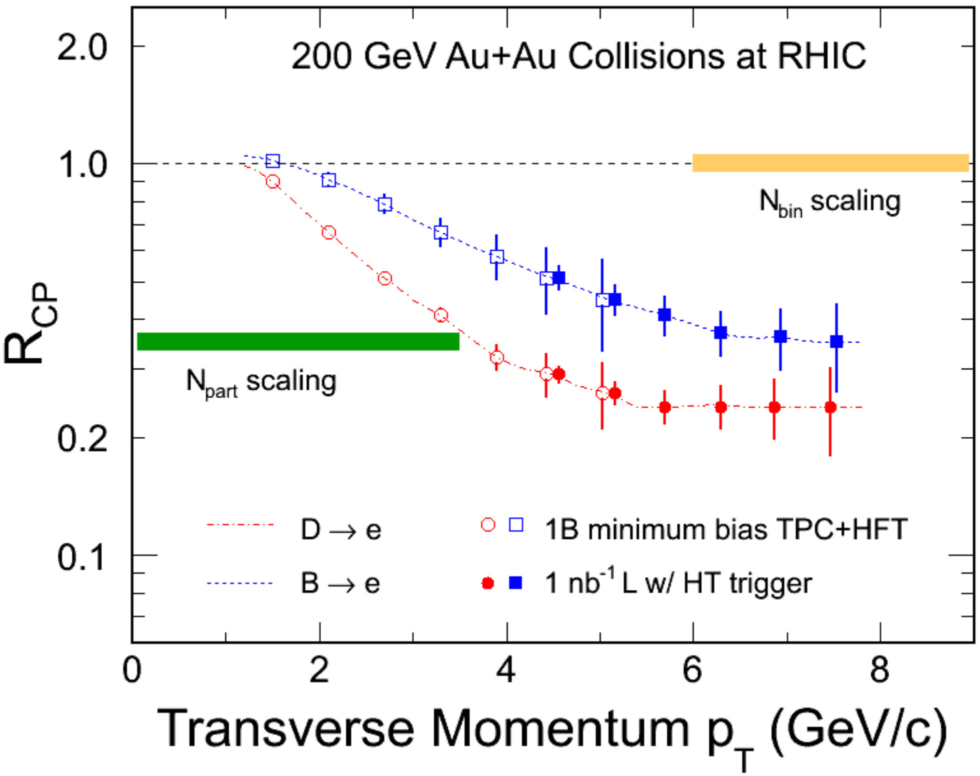
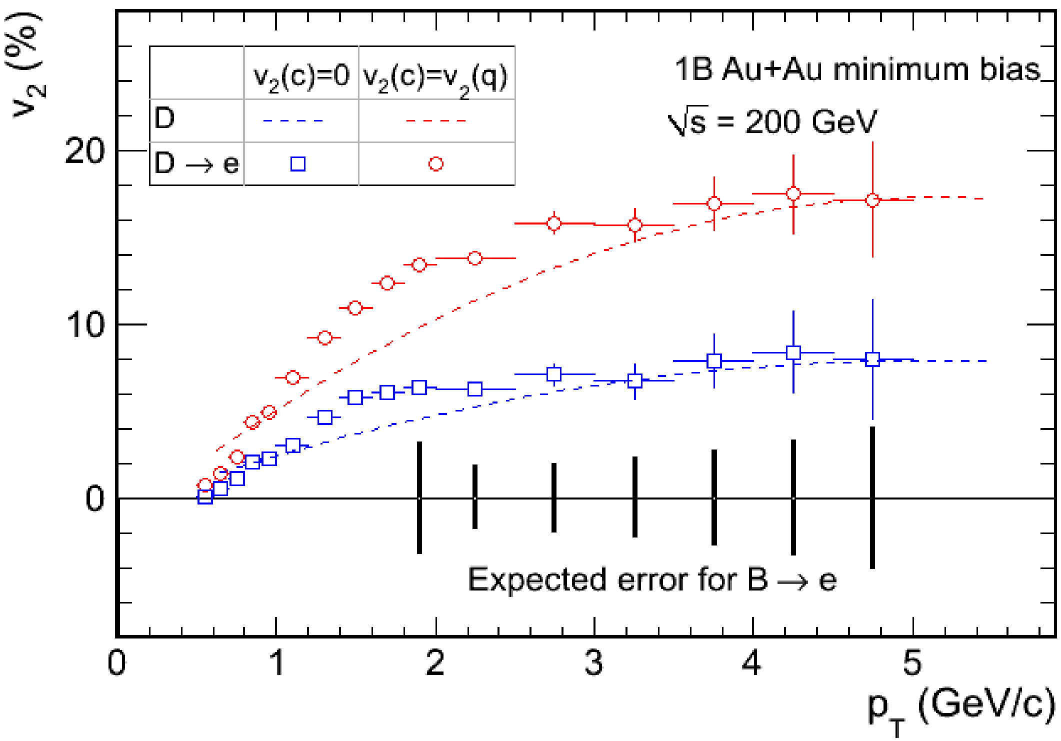


HFT Conceptual Design Report

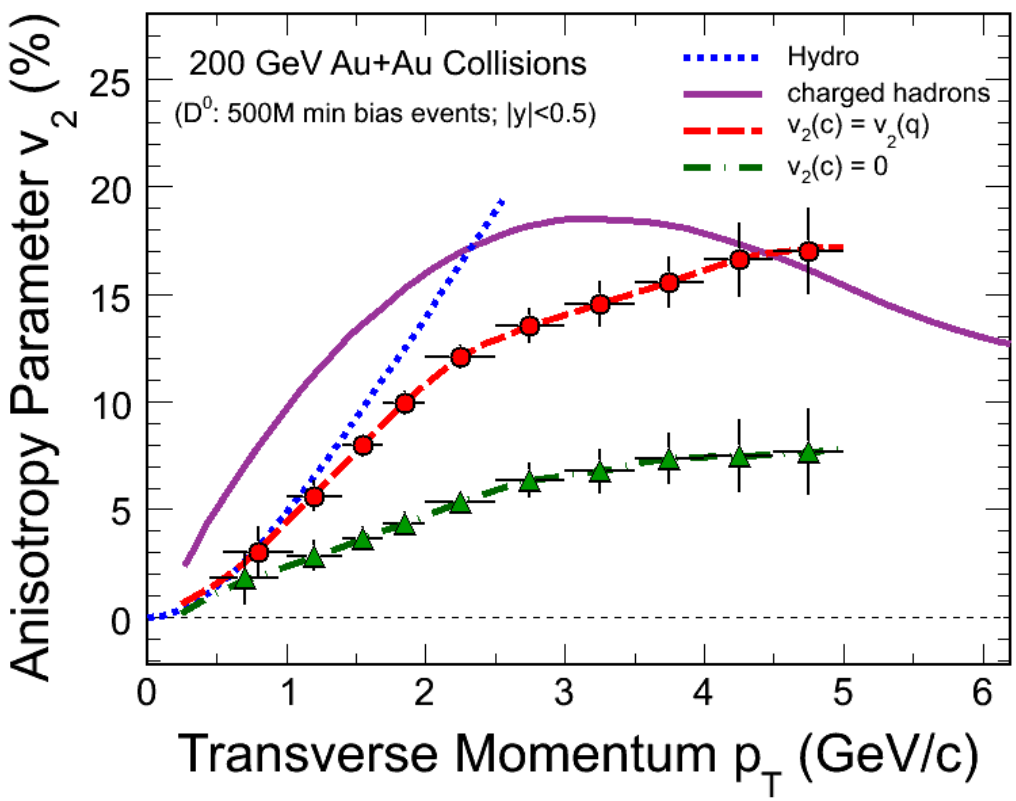
STAR data with Heavy Flavor Tracker

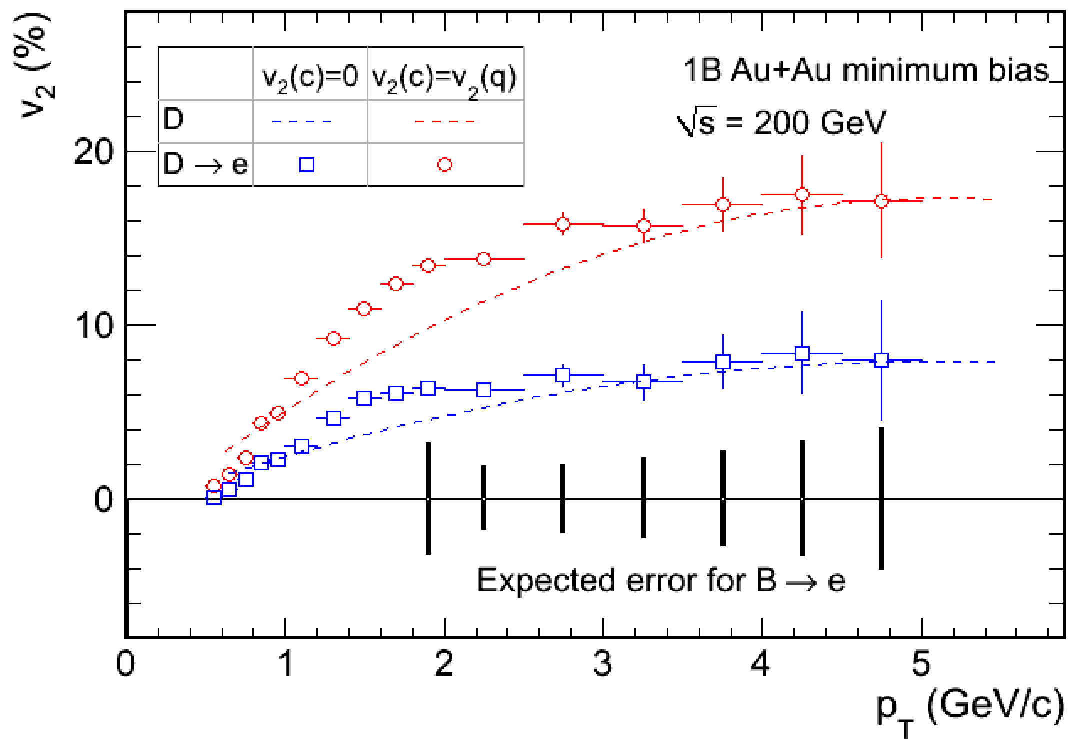




HFT Conceptual Design Report

Best data yet to come from STAR





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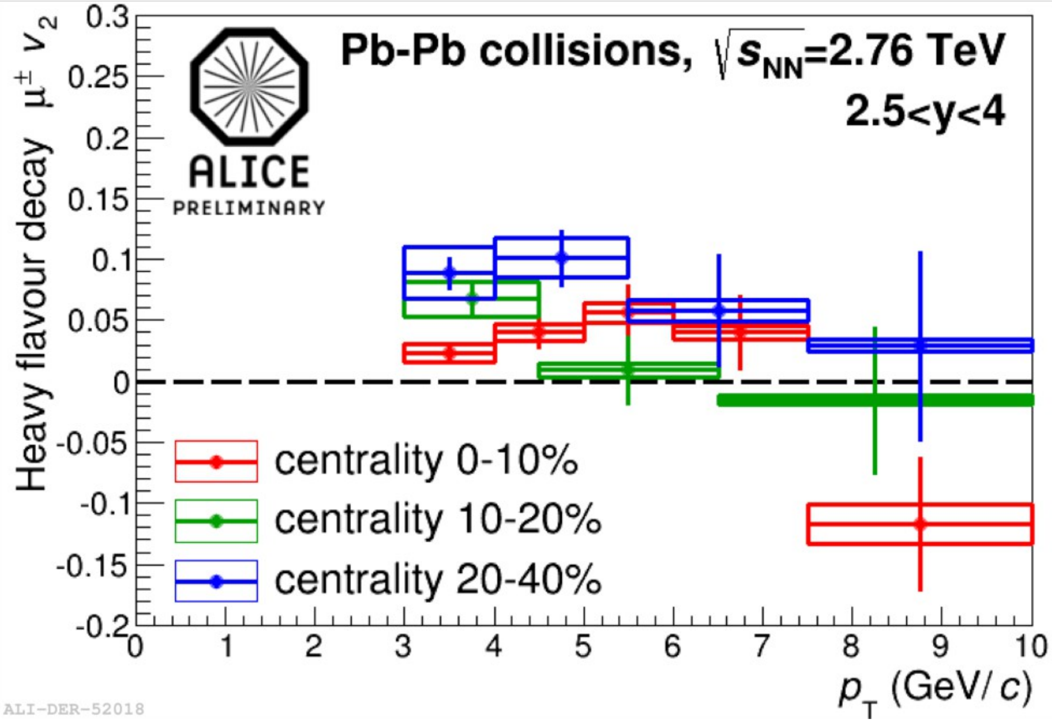
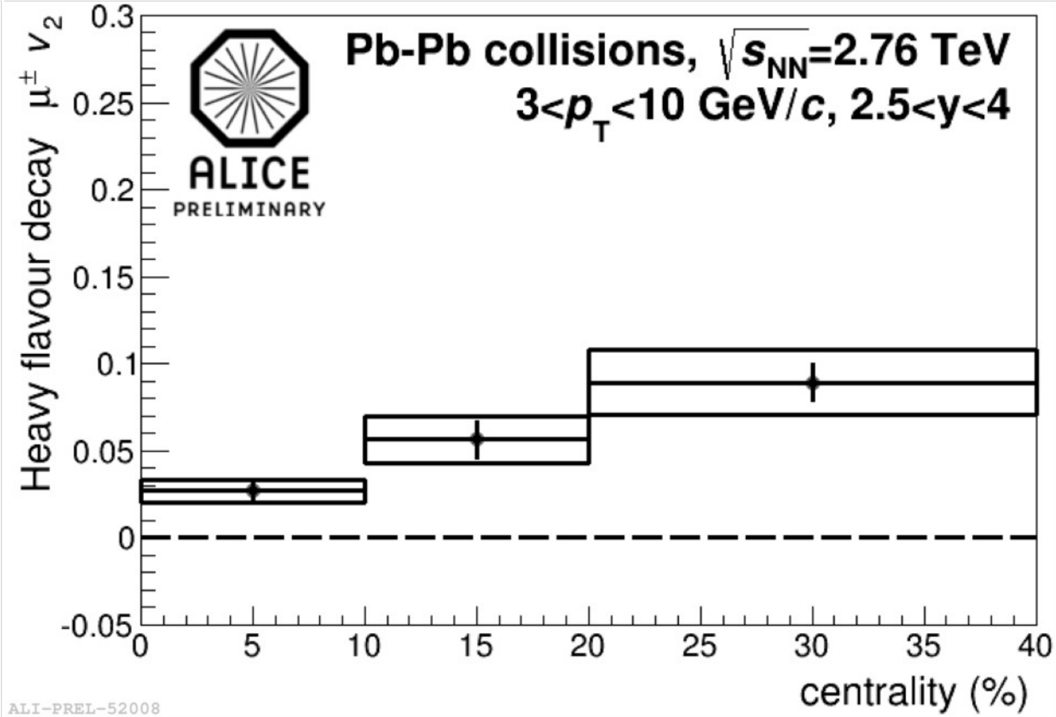
Backup

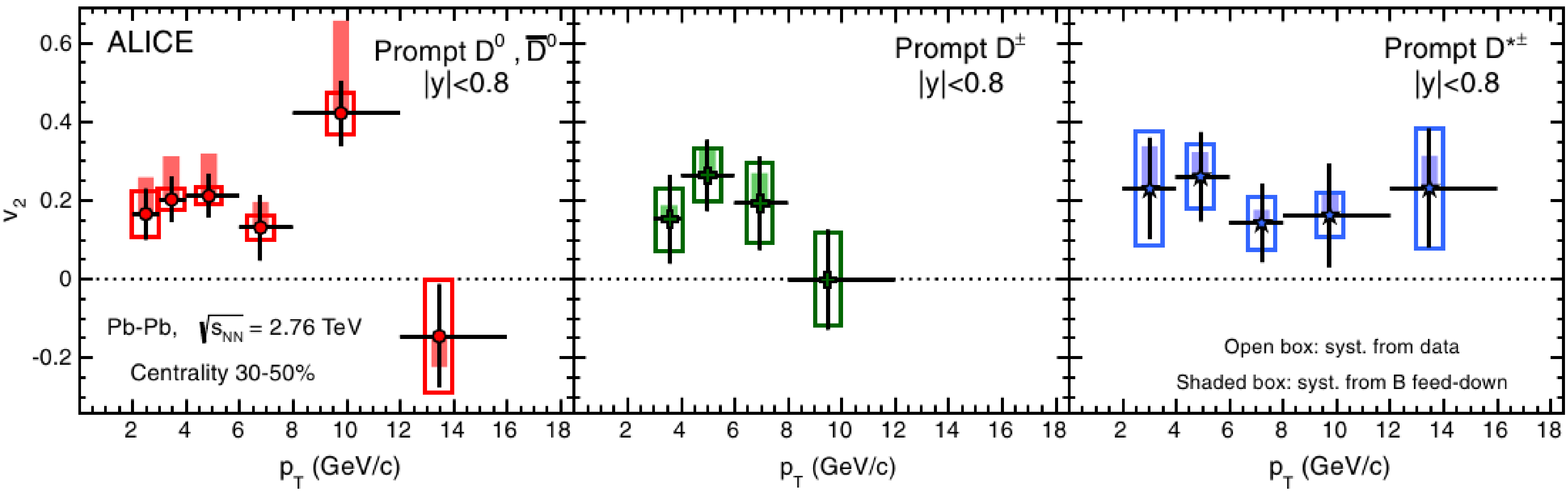
Elliptic flow of HF muons





Increase of v_2 from central to semi-central collisions

Positive v_2 in semi-central collisions at intermediate p_T (3σ effect)



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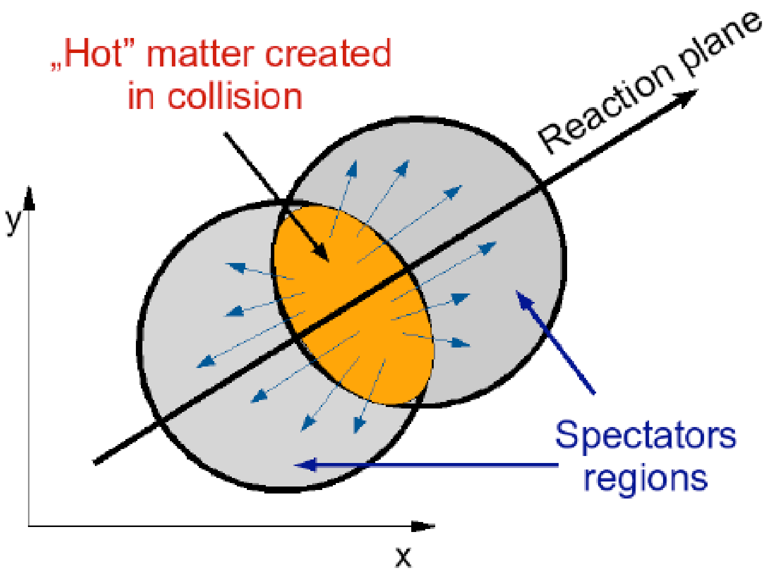


$$v_n \equiv \langle \cos n\phi \rangle = \frac{\int_0^{2\pi} \cos n\phi \frac{dN_j}{d^3\mathbf{p}} d\phi}{\int_0^{2\pi} \frac{dN_j}{d^3\mathbf{p}} d\phi}$$

Two-particle distribution = sum of an uncorrelated distribution and two-particle (direct) correlations

$$\frac{dN_{jk}}{d^3\mathbf{p_1} d^3\mathbf{p_2}} = \frac{dN_j}{d^3\mathbf{p_1}} \frac{dN_k}{d^3\mathbf{p_2}} (1 + C_{jk}(\mathbf{p}_1, \mathbf{p}_2))$$

$$\langle \cos n(\phi_1 - \phi_2) \rangle = v_n^2 + nonflow$$

nonflow: jets, resonance decays, HBT ..

If nonflow $\delta \approx 0$ and negligible fluctuations ($\sigma \approx 0$):

Using 2-particle correlations: $\upsilon_n\{2\}^2 = \langle \cos n(\phi_1 - \phi_2) \rangle = \langle \upsilon_n \rangle^2$

Using 4-particle correlations:

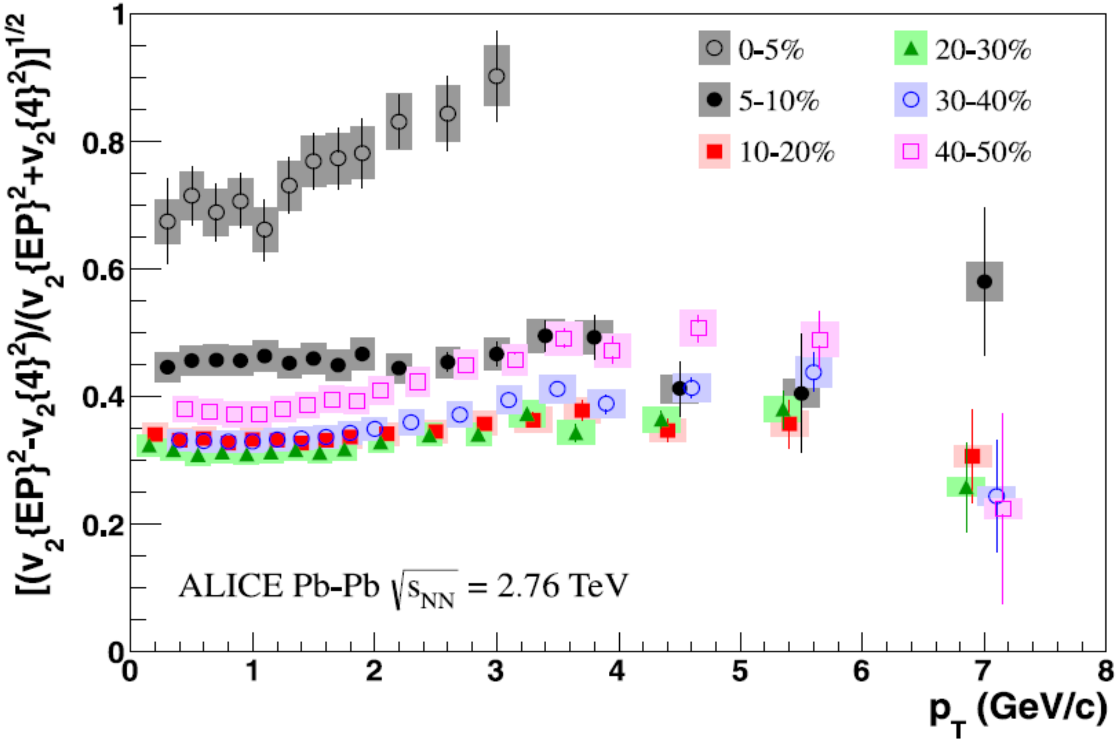
$$\upsilon_n\{4\}^4 = 2\langle \cos n(\phi_1 - \phi_2) \rangle - \langle \cos n(\phi_1 + \phi_2 - \phi_3 - \phi_4) \rangle$$
$$= 2\langle \upsilon_n^2 \rangle^2 - \langle \upsilon_n \rangle^4 = \langle \upsilon_n \rangle^4$$

If nonflow $\delta \neq 0$ and non-negligible fluctuations ($\sigma \neq 0$):

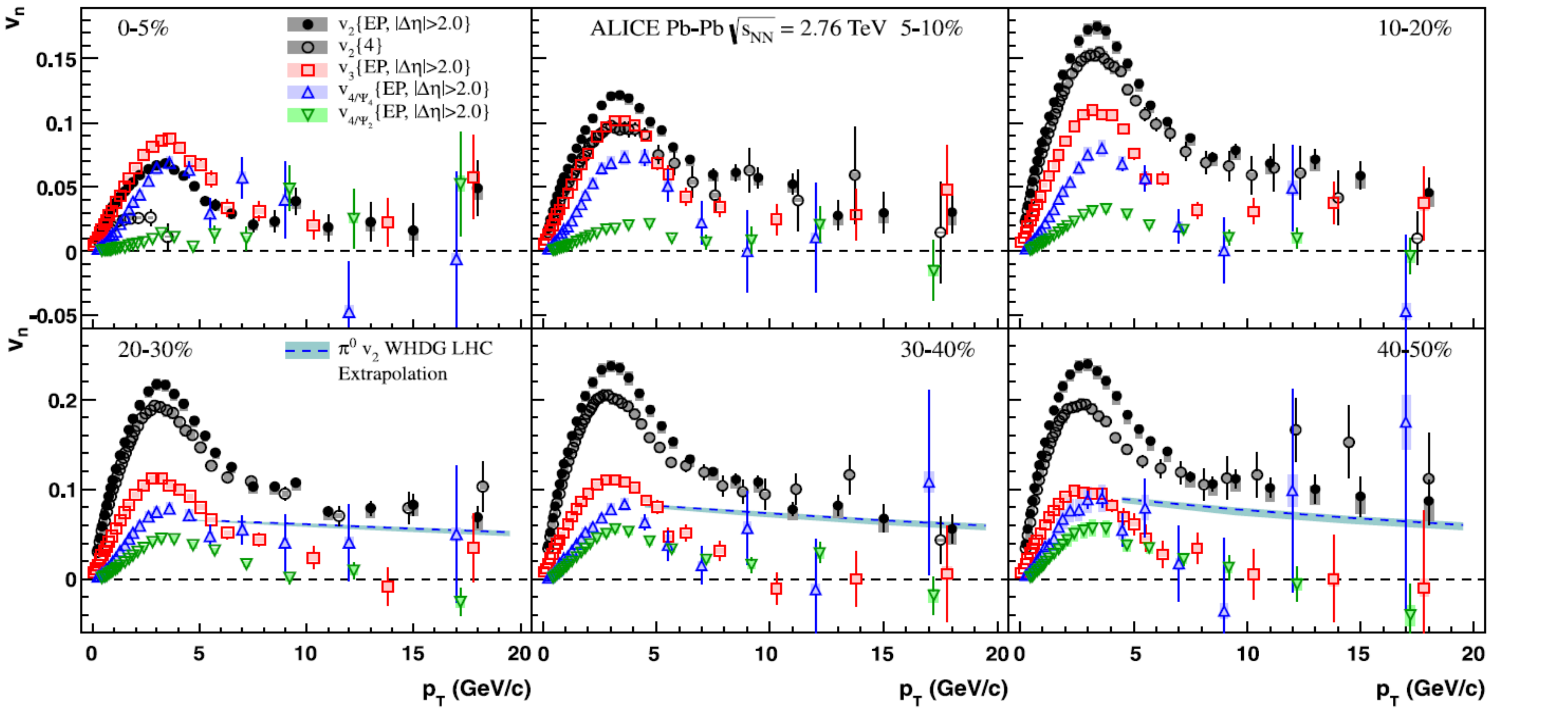
$$\upsilon_n\{2\}^2 = \langle \upsilon_n^2 \rangle + \sigma^2 + \delta$$
$$\upsilon_n\{4\}^4 = (\langle \upsilon_n \rangle^2 + \sigma^2)^2 - 2\sigma^4$$

L. Yi, et al. arxiv: 1101.4646
(assuming Gaussian fluctuations)

→ upper and lower limit on elliptic flow

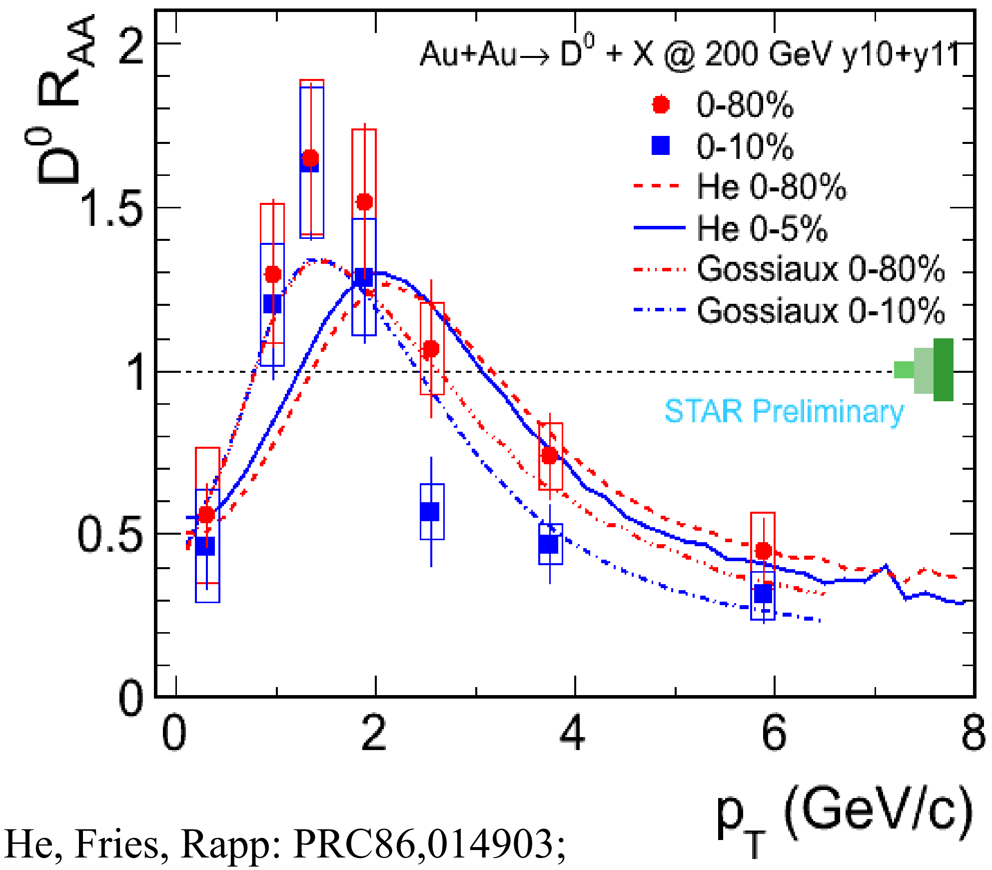


Physics Letters B 719 (2013) 18–28



Physics Letters B 719 (2013) 18–28

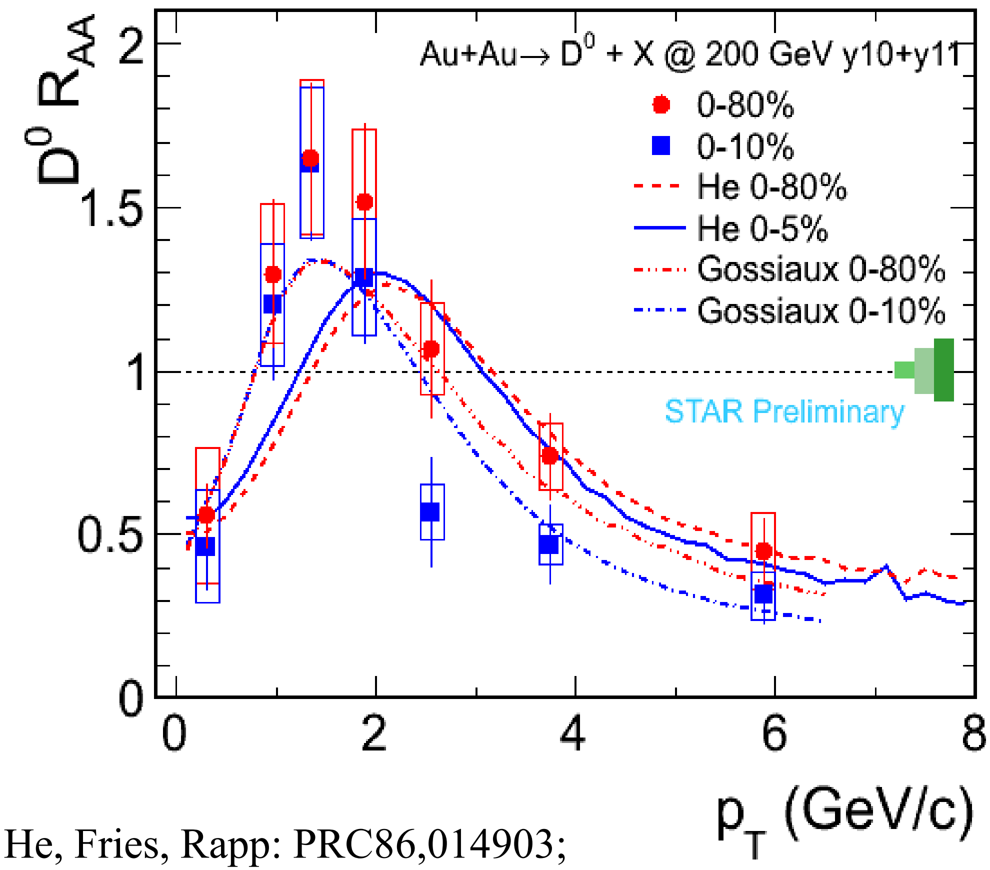
Flow should affect spectra ...



He, Fries, Rapp: PRC86,014903; arXiv:1204.4442; private comm.
P. Gossiaux: arXiv: 1207.5445

Enhancement at intermediate p_T due to radial flow?

Flow should affect spectra ...



He, Fries, Rapp: PRC86,014903; arXiv:1204.4442; private comm.
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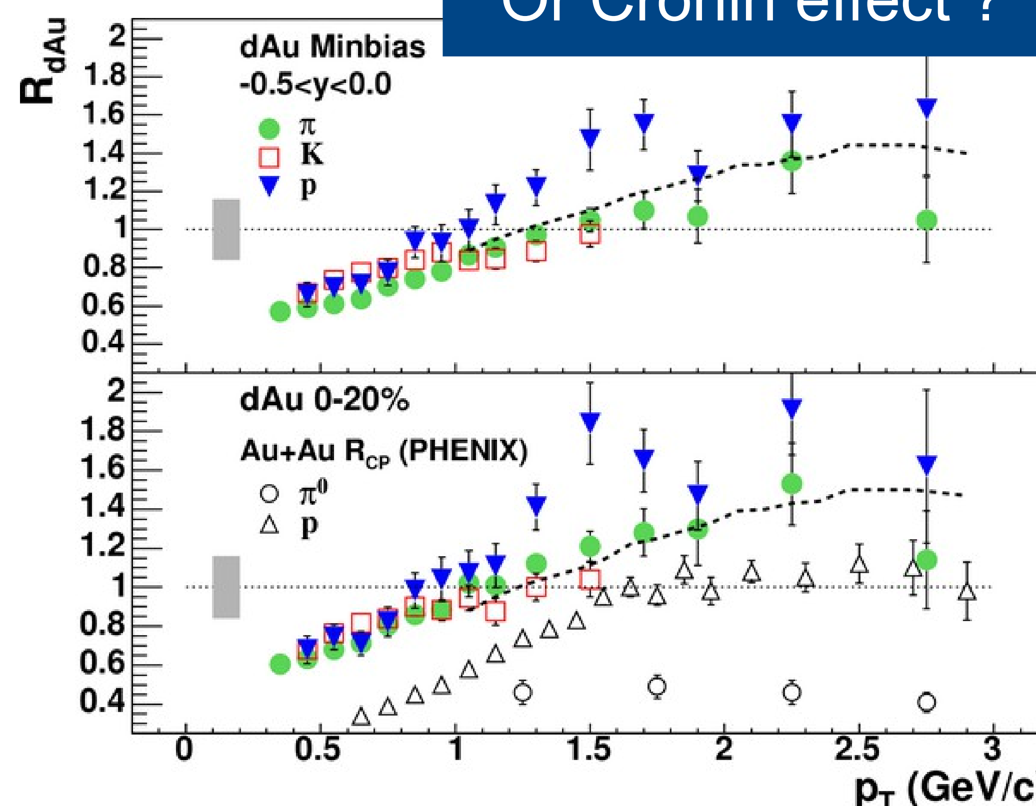
Enhancement at intermediate p_T due to radial flow?

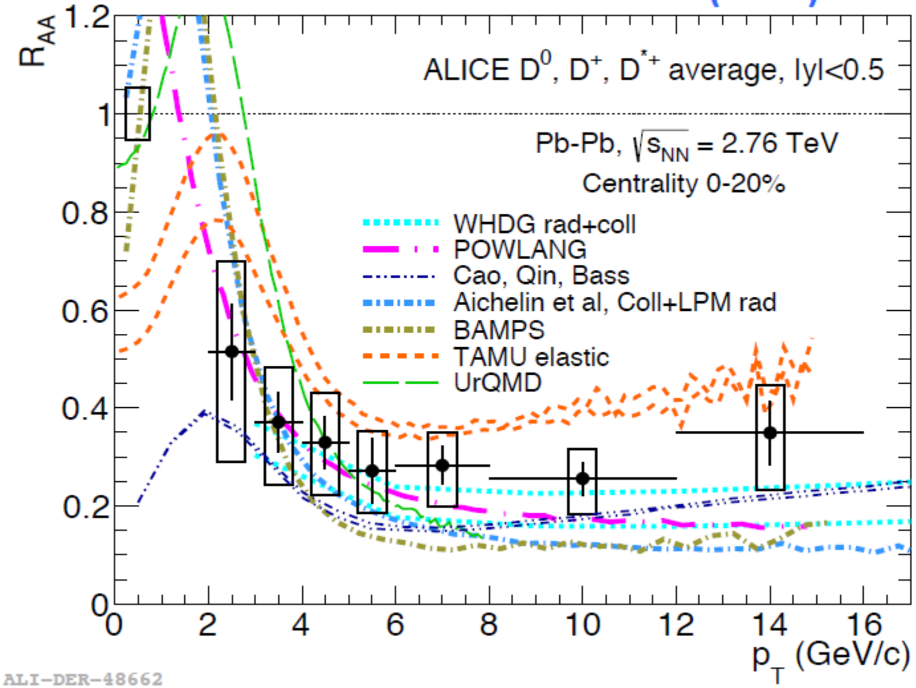
Or Cronin effect ?



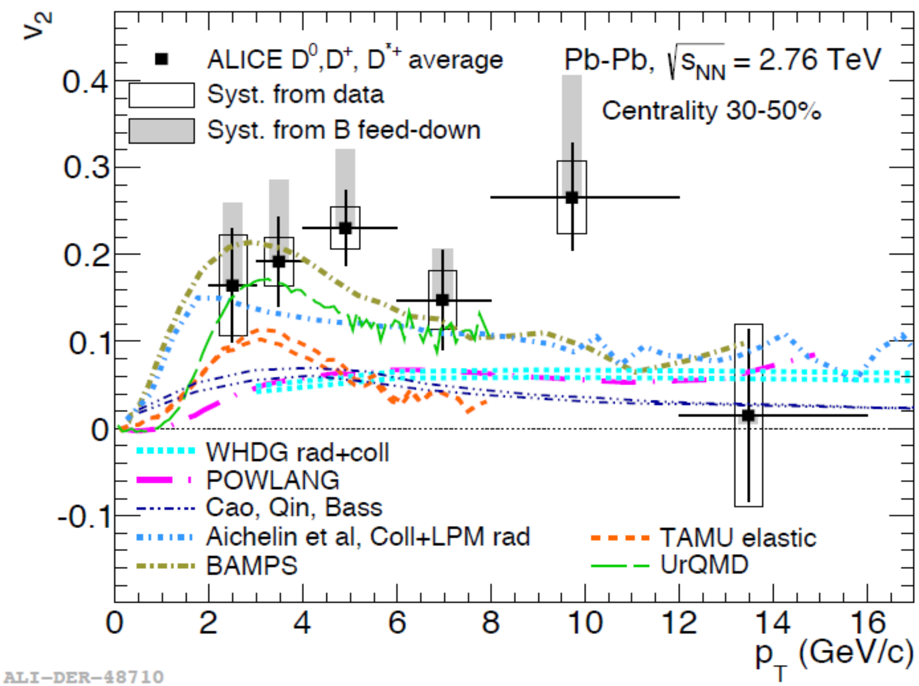
Phys. Lett. B 616 (2005) 8

D mesons

JHEP 09 (2012) 112



Phys. Rev. Lett. 111, 102301 (2013)



BAMPS Uphoff et al. arXiv: 1112.1559, Aichelin et al. Aichelin et al. Phys. Rev. C 79 (2009) 044906, WHDG W. A. Horowitz et al. J. Phys. G38, 124064 (2011), POWLANG W. M. Alberico et al. Eur. Phyis J. C 71, 1666 (2011), TAMU M. He, R. J. Fries and R. Rapp, arXiv:1204.4442[nucl-th], UrQMD arXiv:1211.6912, J. Phys. Conf. Ser. 426, 012032 (2013), Cao, Quin, Bass arXiv:1308.0617