Global view on coupled dynamics of heavy and light flavor observables from EPOSHQ

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with

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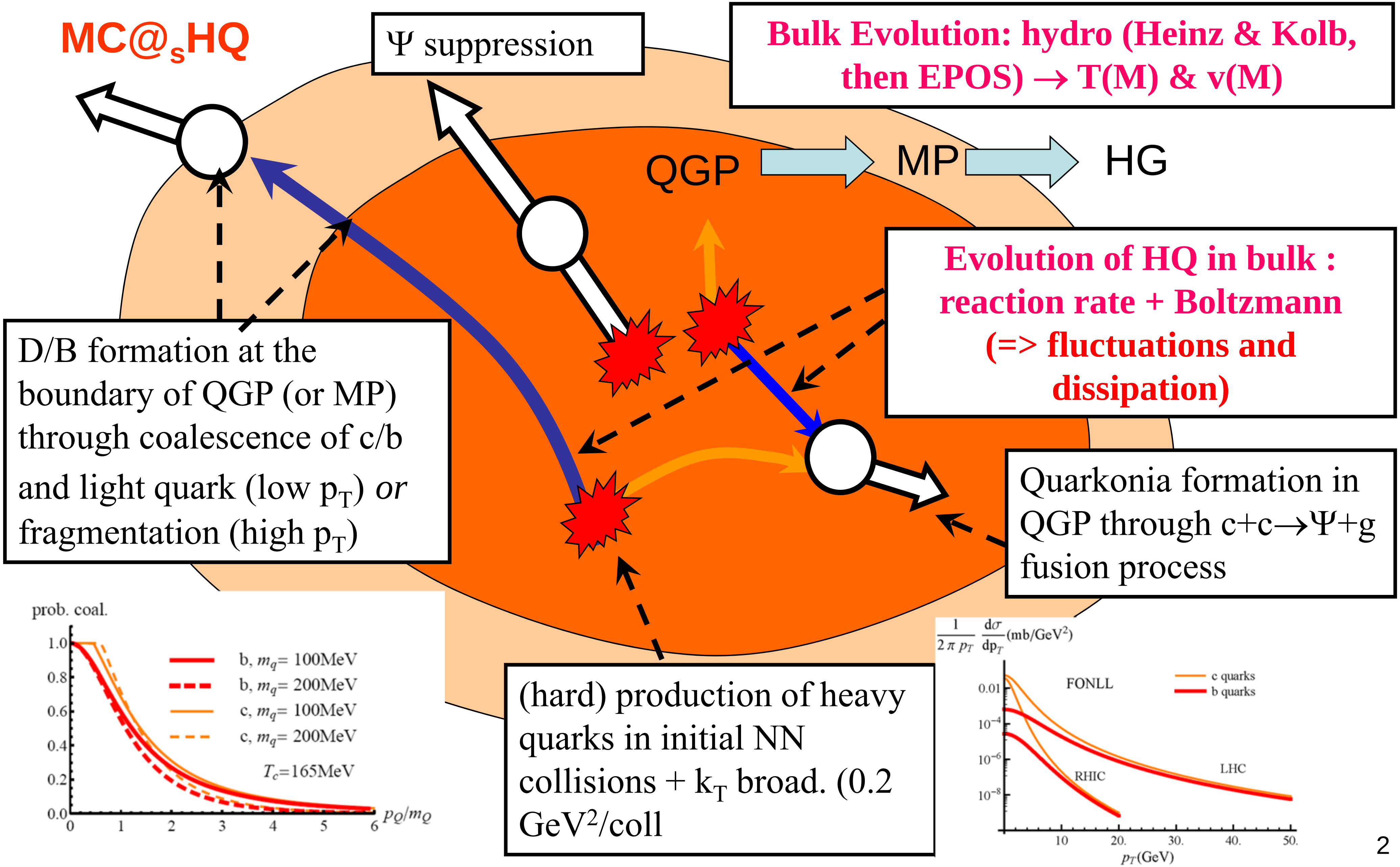
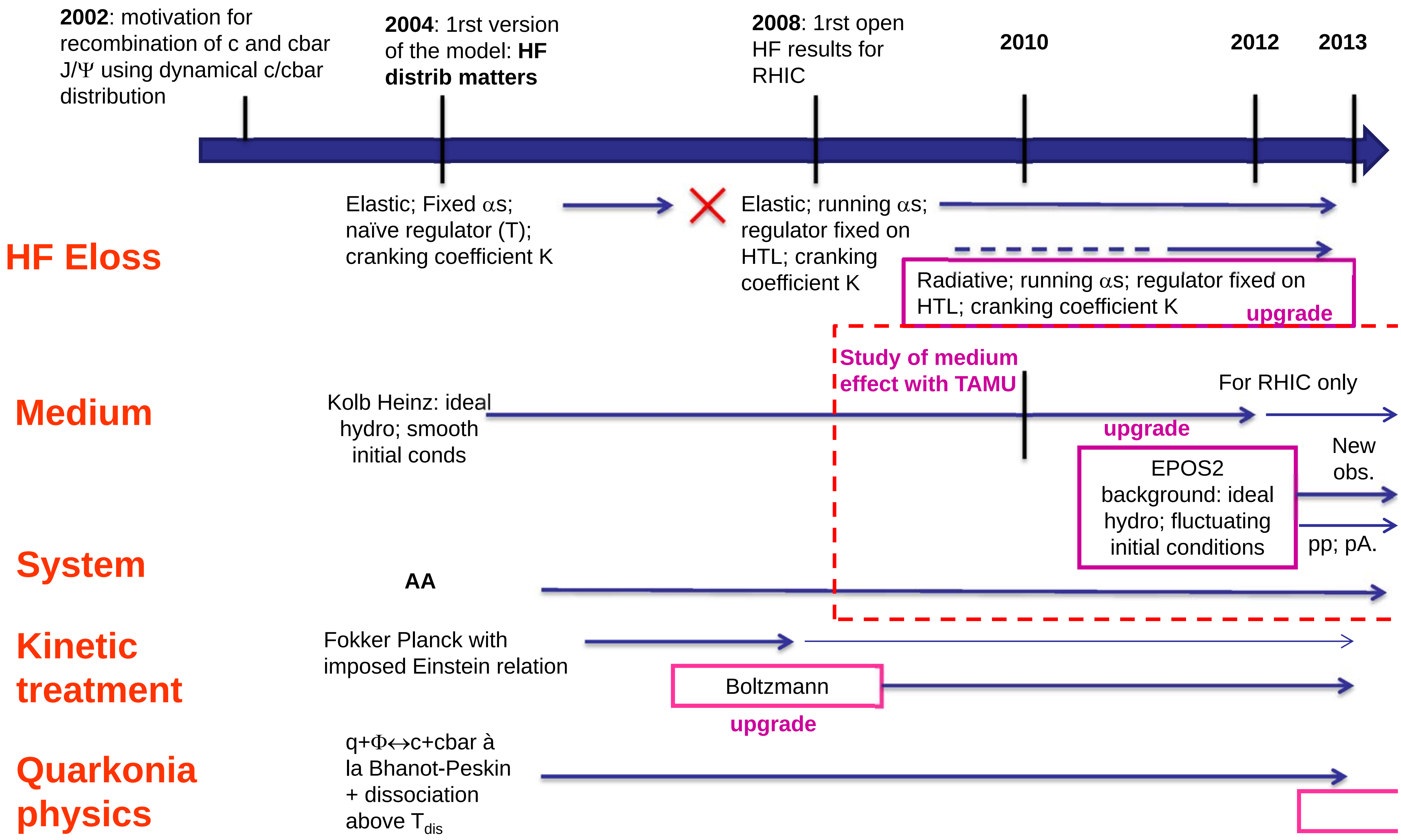
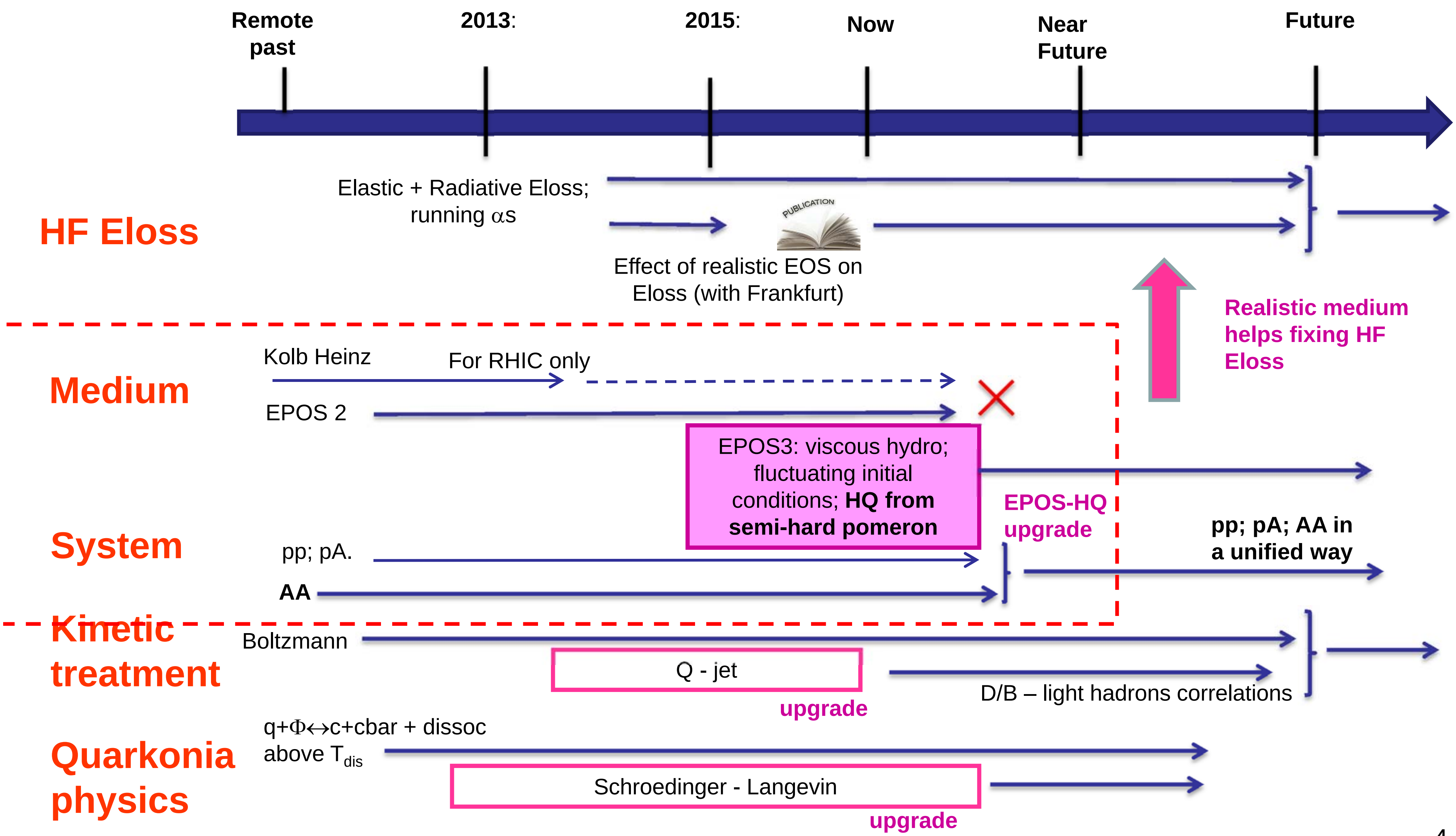
Schematic view of the global MC@HQ framework



Some global view of our model development

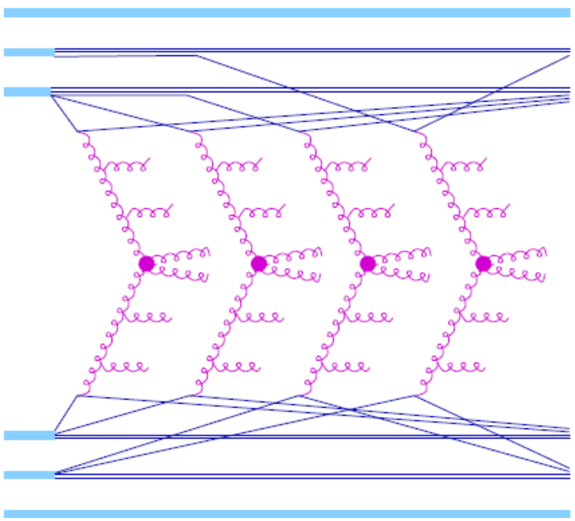


Some global view of our model development



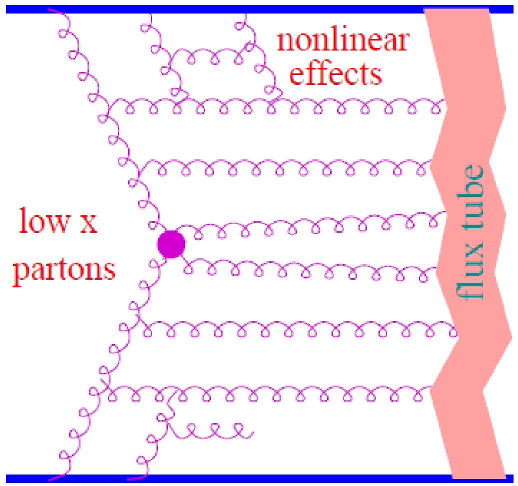
EPOS + Hydro as a background for MC@sHQ

EPOS + Hydro : state of the art framework that encompass pp, pA and AA collisions



EPOS (initial conditions):

- Model based on Gribov-Regge multiple pomeron interactions
- Particle production in cut (semi-hard) pomerons, seen as partons ladder
- Soft particles form a flux tube (string, with its own dynamics, incl. string breaking)… lots of them in A-A
- Slow string segments, far from the surface, are mapped to fluid dynamic fields (-> hydro -> Freeze out)
- Hard particles -> jets

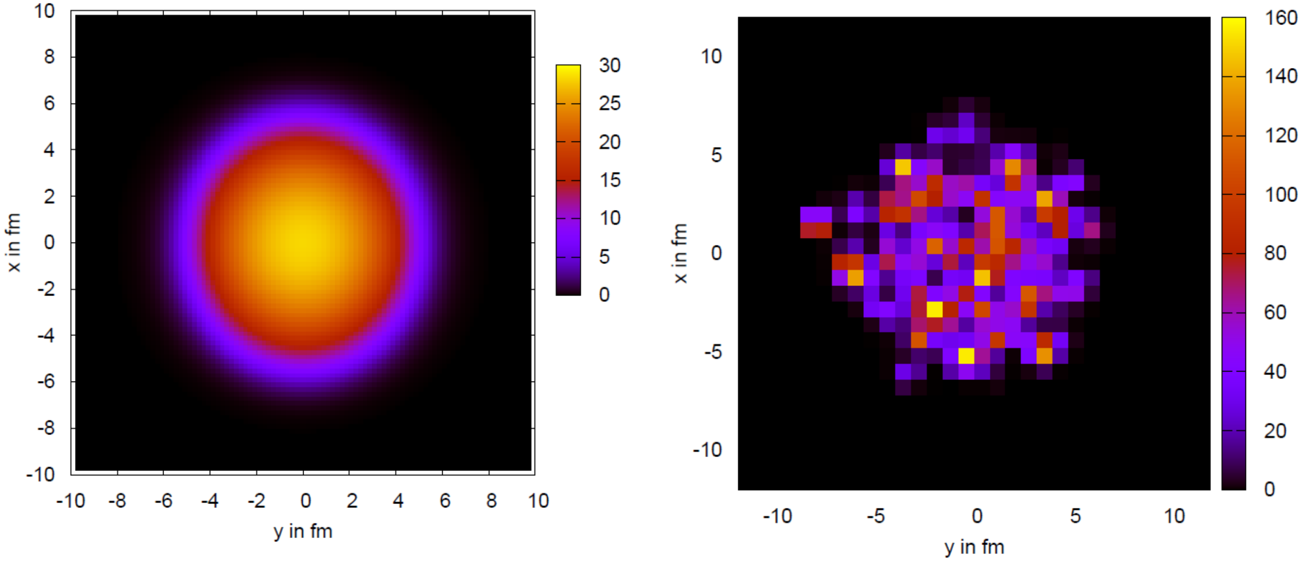


Ref: K. Werner, Iu. Karpenko, M. Bleicher, T. Pierog, and S. Porteboeuf-Houssais Phys. Rev. C 85 (2012), 064907

EPOS as a background for MC@sHQ

EPOS: state of the art framework that encompass pp, pA and AA collisions

Initial energy density



Kolb Heinz (used previously) EPOS

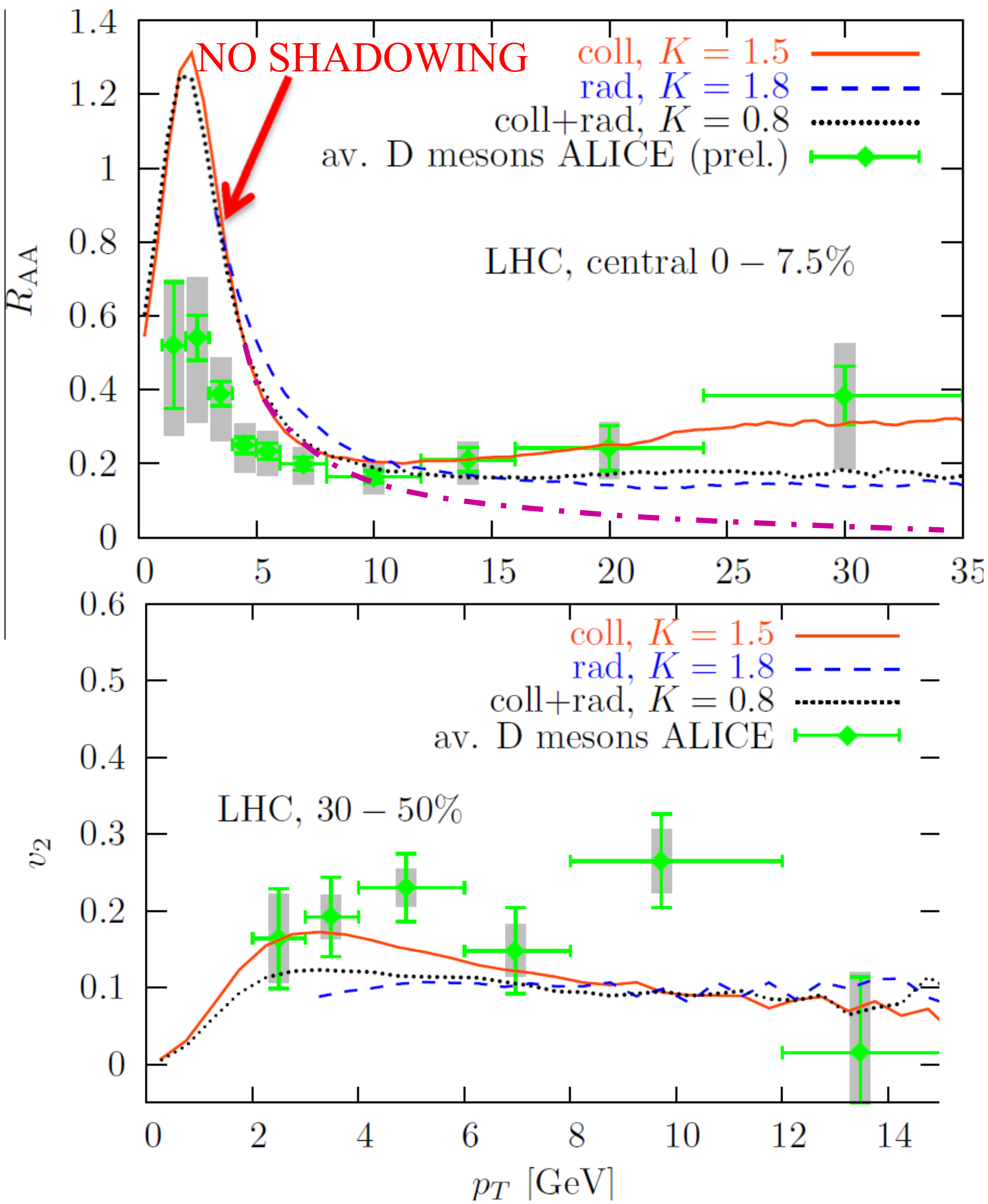
Beware: ≠ color scales

More realistic hydro and initial conditions => original HQ studies such as:

1) fluctuations in HQ observables (some HQ might « leak » through the « holes » in the QGP)

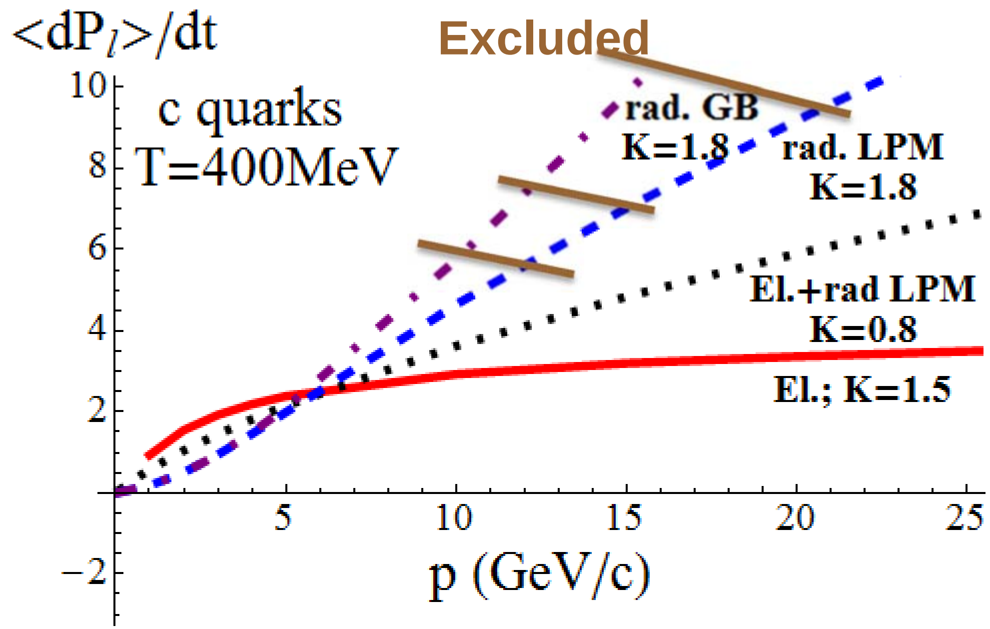
2) correlations between HF and light hadrons

LHC: EPOS2 as a background for MC@sHQ



Same microscopic ingredients as for RHIC (ΔE α L);

N.B.: K values: slightly smaller then what obtained from RHIC



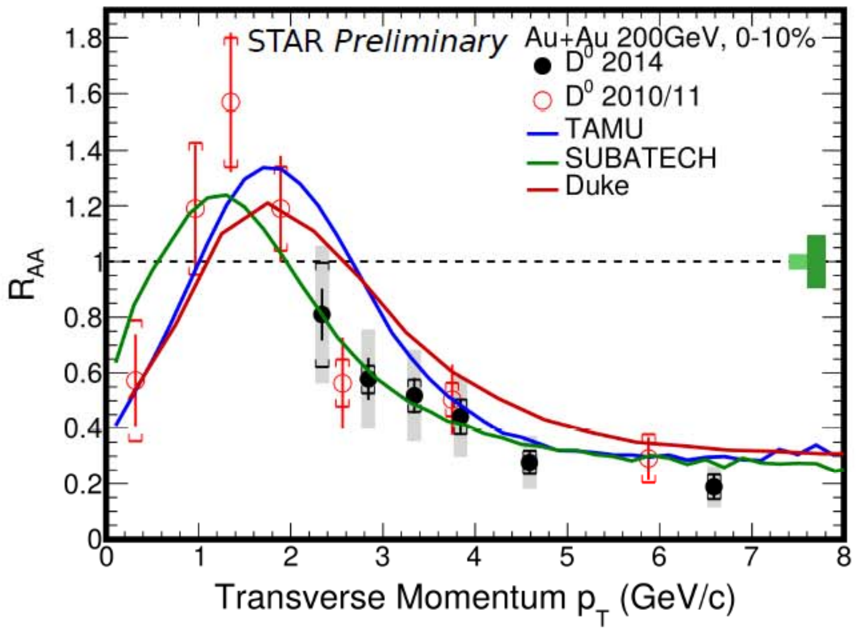
Data at large p_T seems to favor « Collisional only » - like average momentum loss

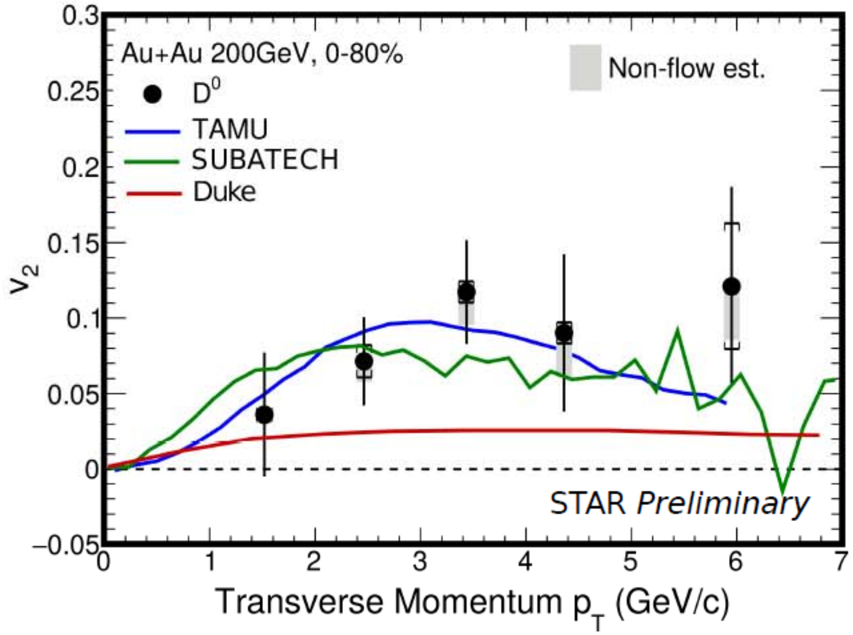
RHIC: EPOS 3 as a background for MC@sHQ

Comparison to Theory

Sept 2015

NEW





- Data favors models with charm diffusion
  → charm exhibits collectivity with the medium

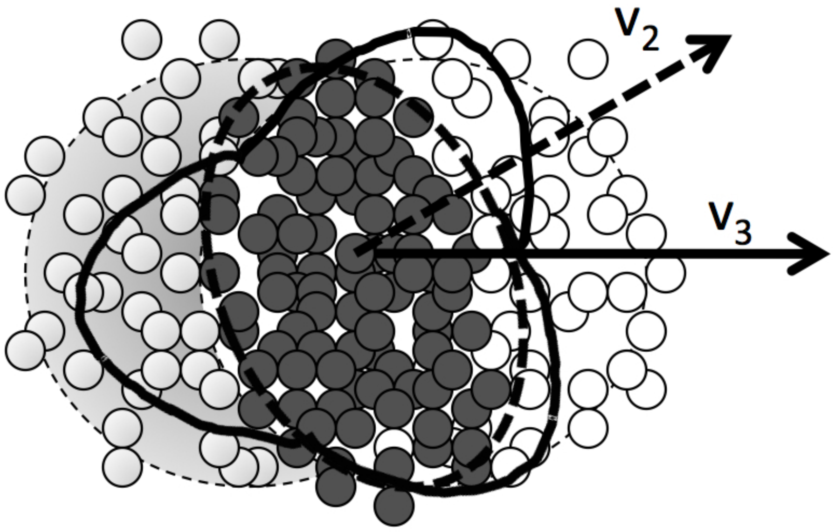
	D × 2πT	Diff. Calculation
TAMU	2-11	T-Matrix
SUBATECH	2-4	pQCD+HTL
Duke	7	Free parameter

arXiv:1506.03981 (2015) & private comm.

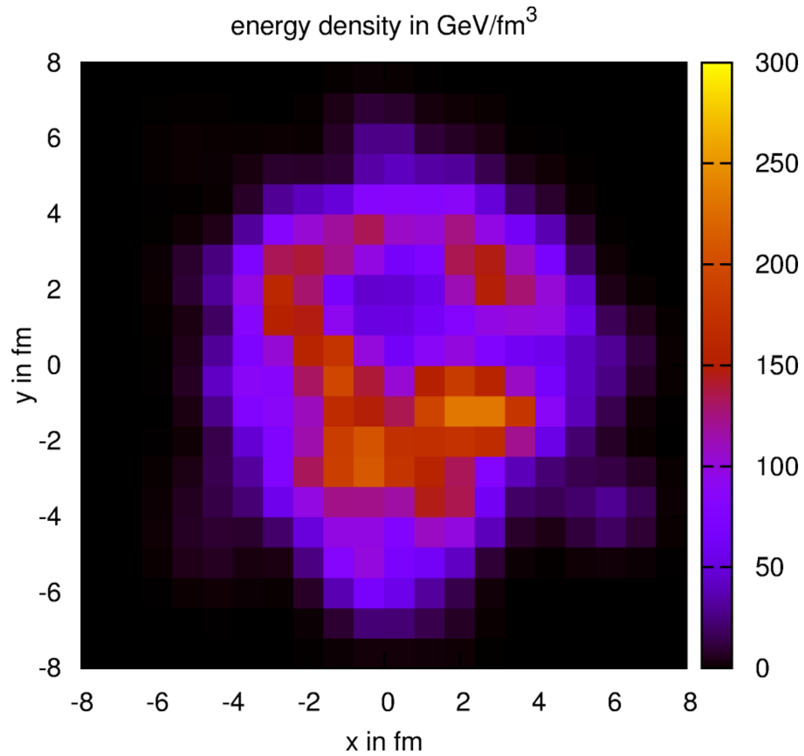
Subatech: same Eloss model as previously

More recent observables: Higher HQ flow components

Fluctuations in the Initial energy-density profile => odd components of the flow: v_3, v_5, … (seen indeed in the light particle spectra)



sketch

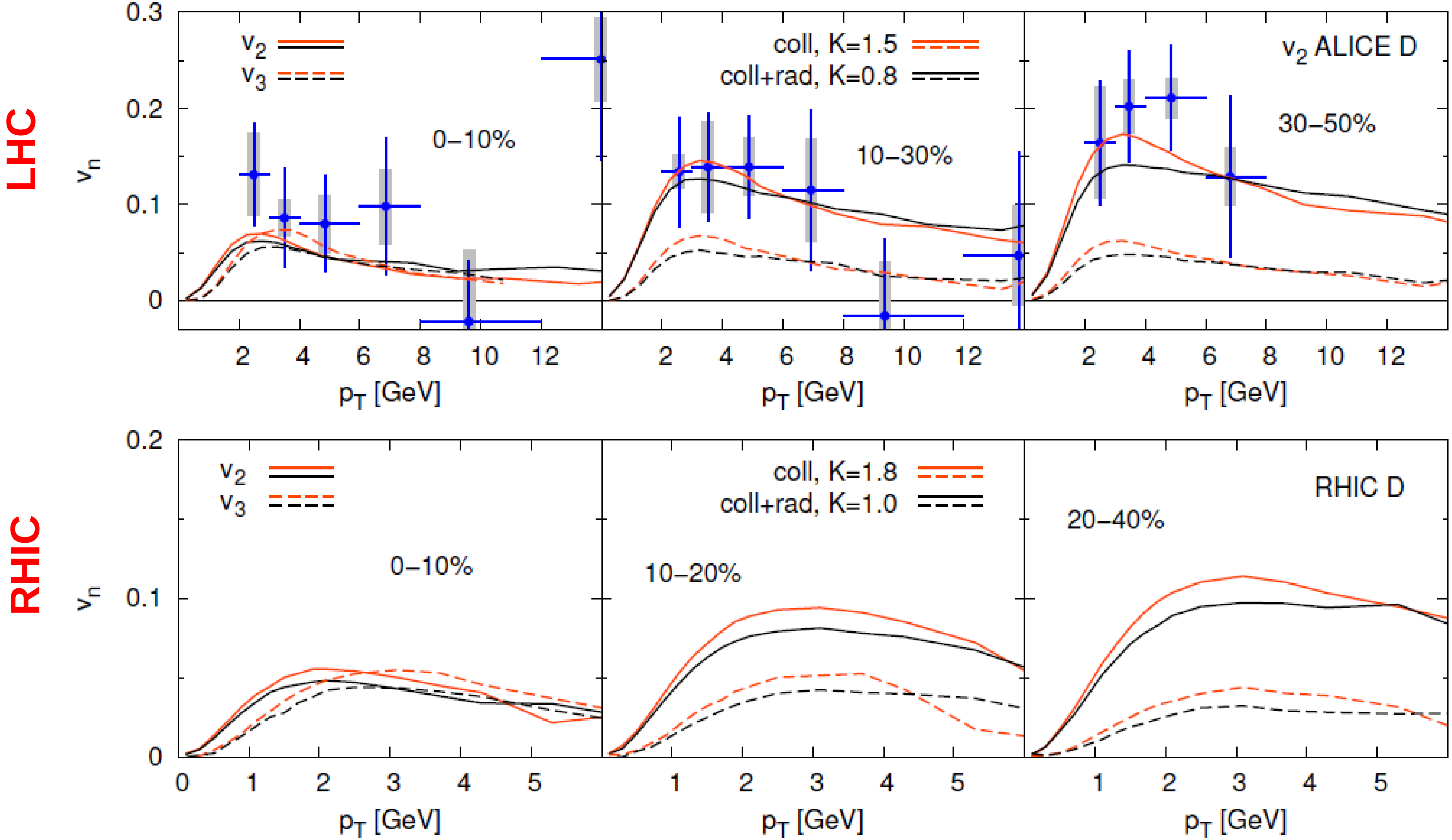


EPOS initial conditions

As heavy quarks couple to the expending QGP, same trend should be observed

More recent observables: Higher HQ flow components

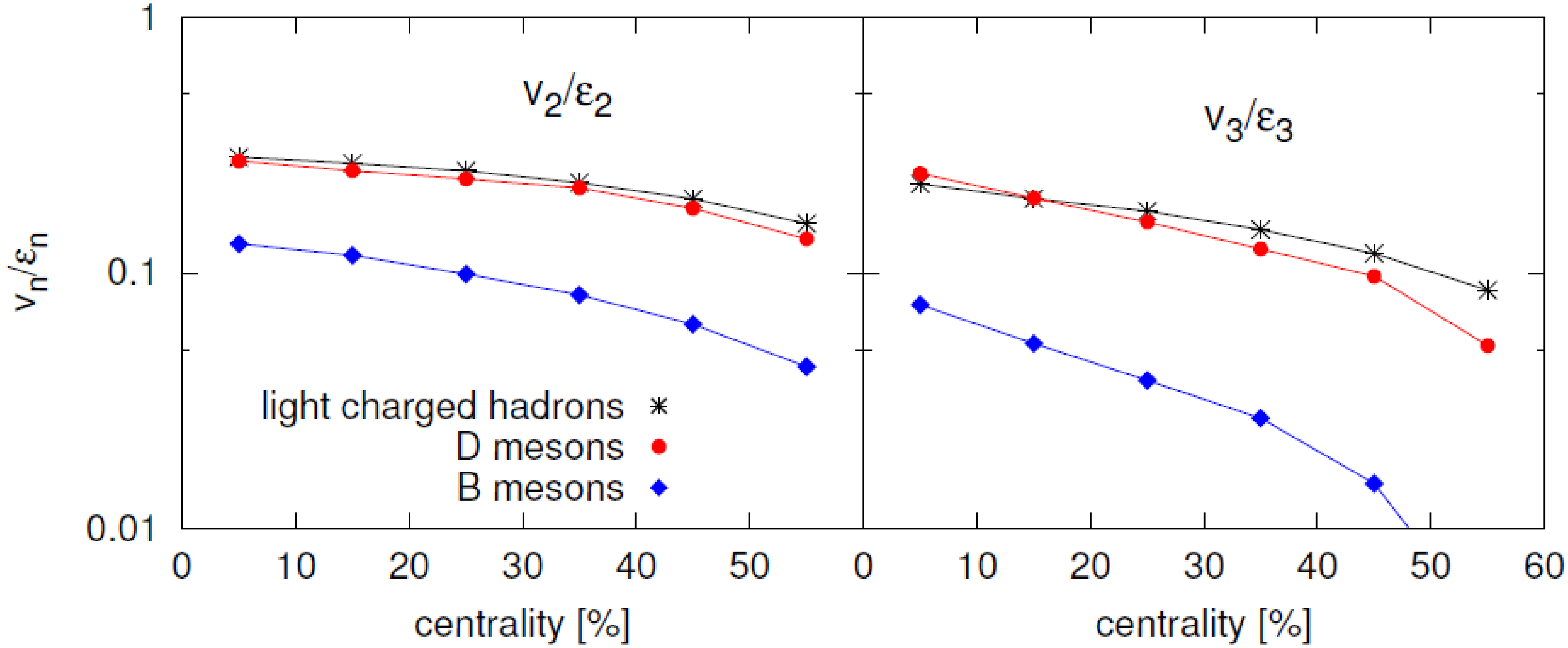
Nahrgang et al, Phys. Rev. C 91 (2015), 014904



Indeed finite v3 observed at all centralities, both at RHIC and LHC

More recent observables: Higher HQ flow components

In 1rst approximation: $v_n \alpha$ eccentricity ε_n => look at the ratio for less trivial effects **LHC**



More detailed analysis reveals that HQ benefit less and less from the flow of the bulk at large centrality, especially for higher harmonics.

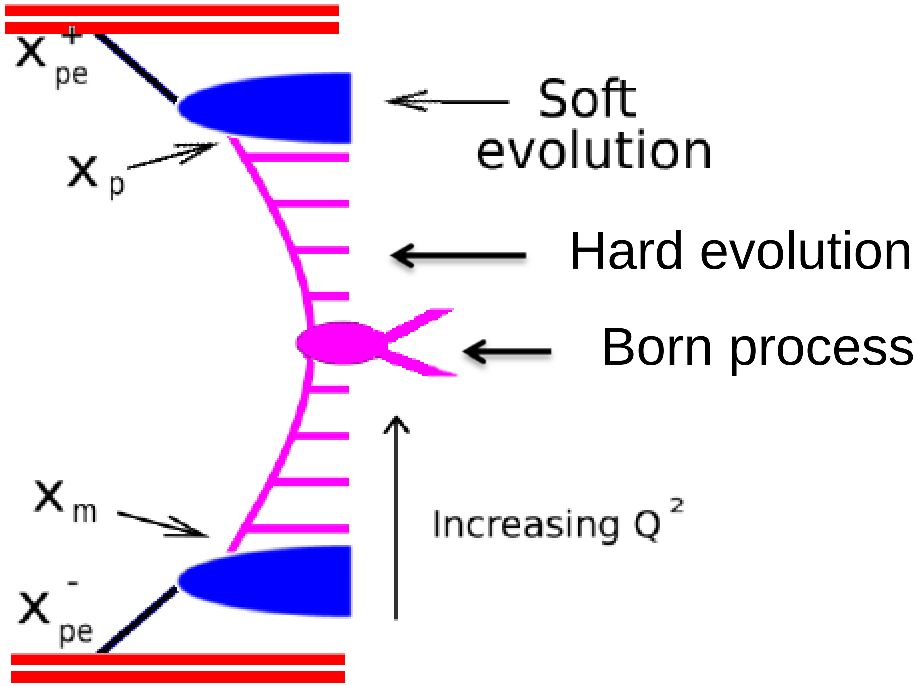
Possible inertia effect: HQ need a longer time to develop their flow => earlier freeze out at larger centrality prevents the v_n to develop fully.

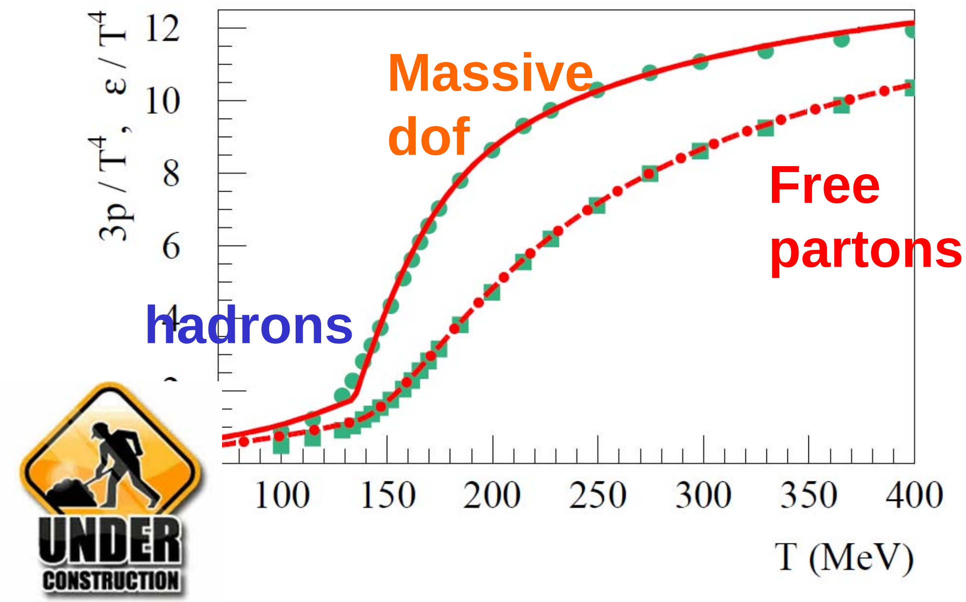
This may offer a different perspective on the probing of the system evolution (ESE)

EPOS-HQ: Coupling EPOS3 and MC@sHQ

Two main (physical) issues:

1) Generating initial HQ consistently with the multi-partonic approach in EPOS (done in EPOS3; B. Guiot)





2) Dealing properly with the underlying degrees of freedom in a crossover evolution btwn hadronic phase and QGP.

Concrete goal of this talk: address EBE v_n in EPOS-HQ

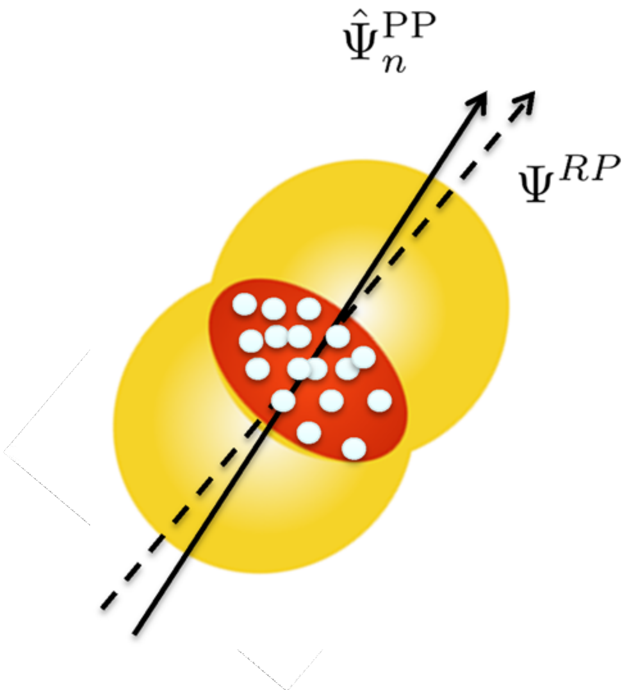
Main investigation: How well do HQ flow with the bulk ?

Some key features of our analysis:

- HQ-QGP interaction: pure ellastic with K=1.5 cranking of the cross section
- c -> D through pure fragmentation (easier analysis)
- V_n (nucleons from coalescence at FO) will be studied in // (as a corner stone)
- Not aimed to be quantitative as EPOSHQ still under calibration for Pb-Pb
- Main Focus: LHC energies, but RHIC will follow
- HQ over sampling x 50 in order to reduce computing time

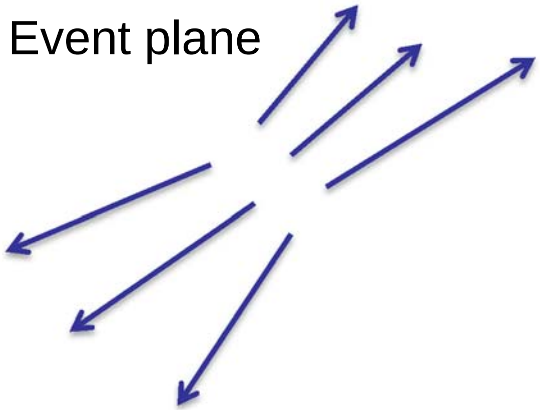
Event plane method

Initial (theorical)



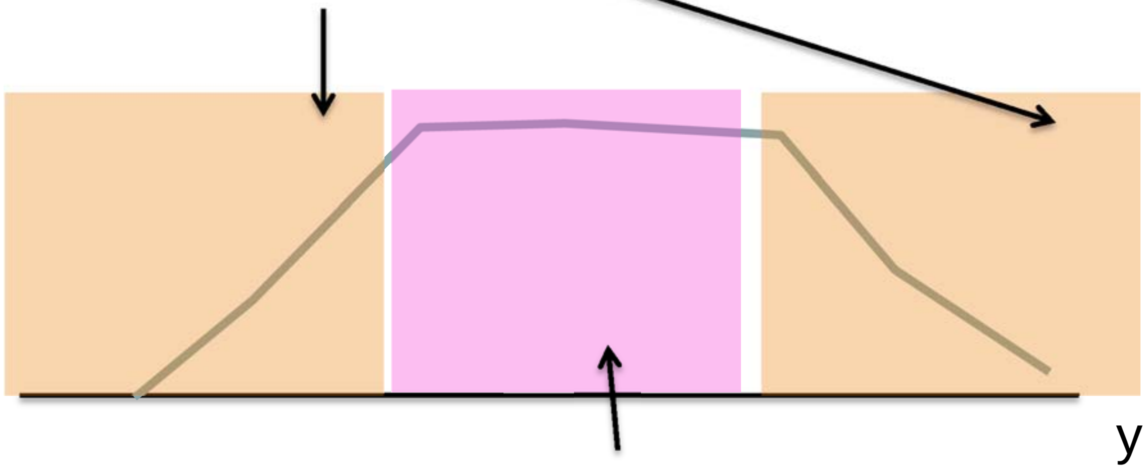
Time evolution

Event plane



$$\hat{\Psi}_n^{EP} = \frac{1}{n} \tan^{-1} \left(\frac{\sum_i w_i \sin n\phi_i}{\sum_i w_i \cos n\phi_i} \right)$$

EP (|y|>2)

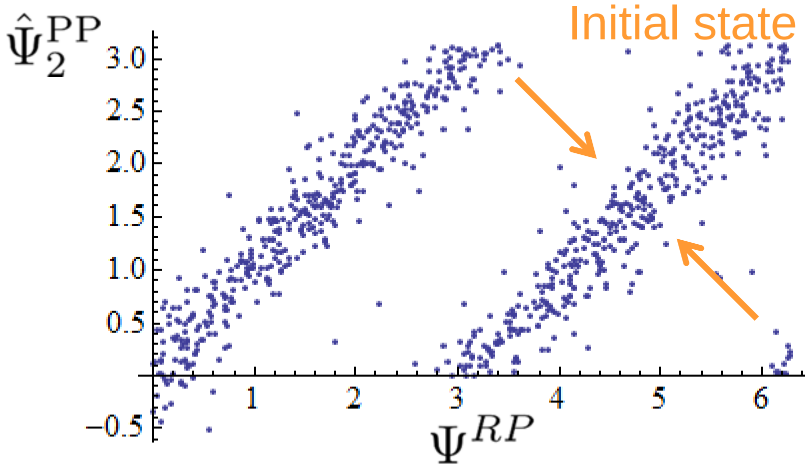


« observables» (|y|<2)

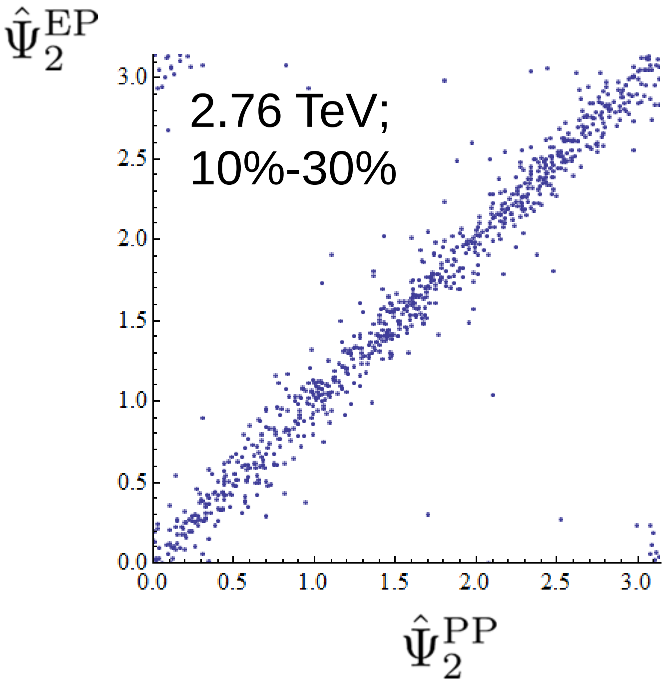
In our simulations:

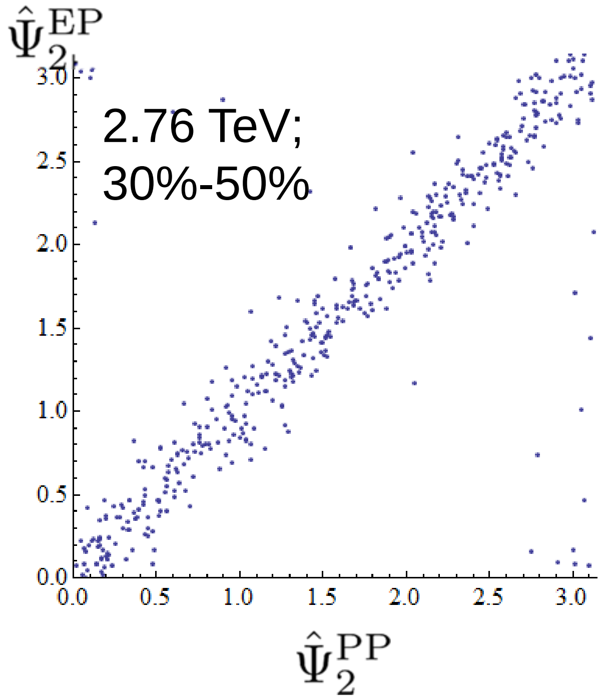
- RP is extracted from the EBE initial pomeron distribution
- EP is extracted from pions at |y|>2 (for this study)

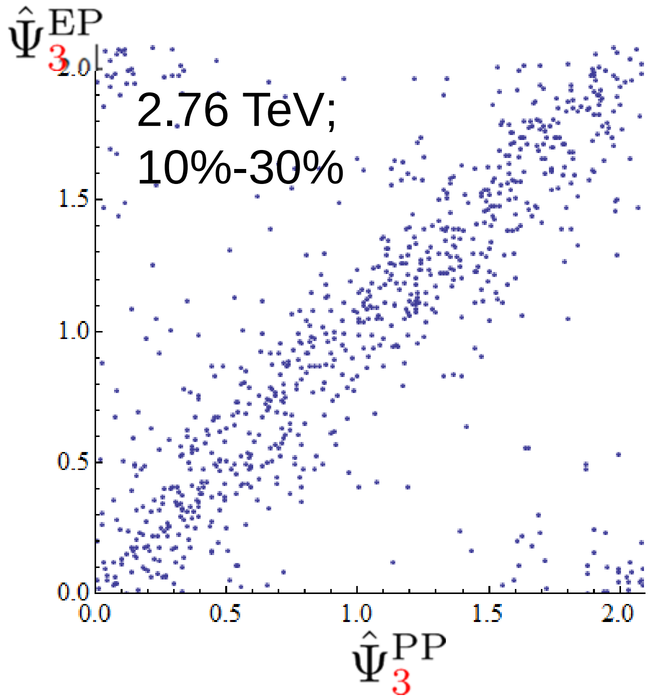
Correlations between X-Planes



Good extraction of PP plane for n=2,3;
would need slight correction for n=3







Event plane method

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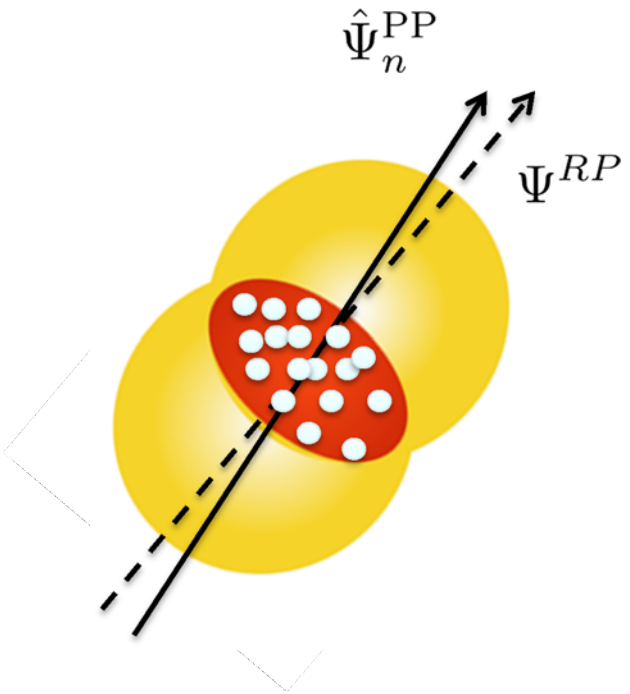

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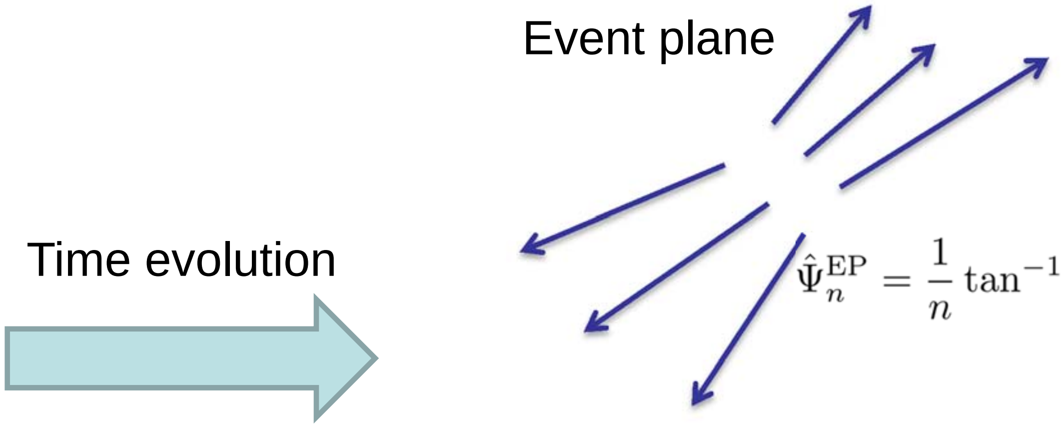

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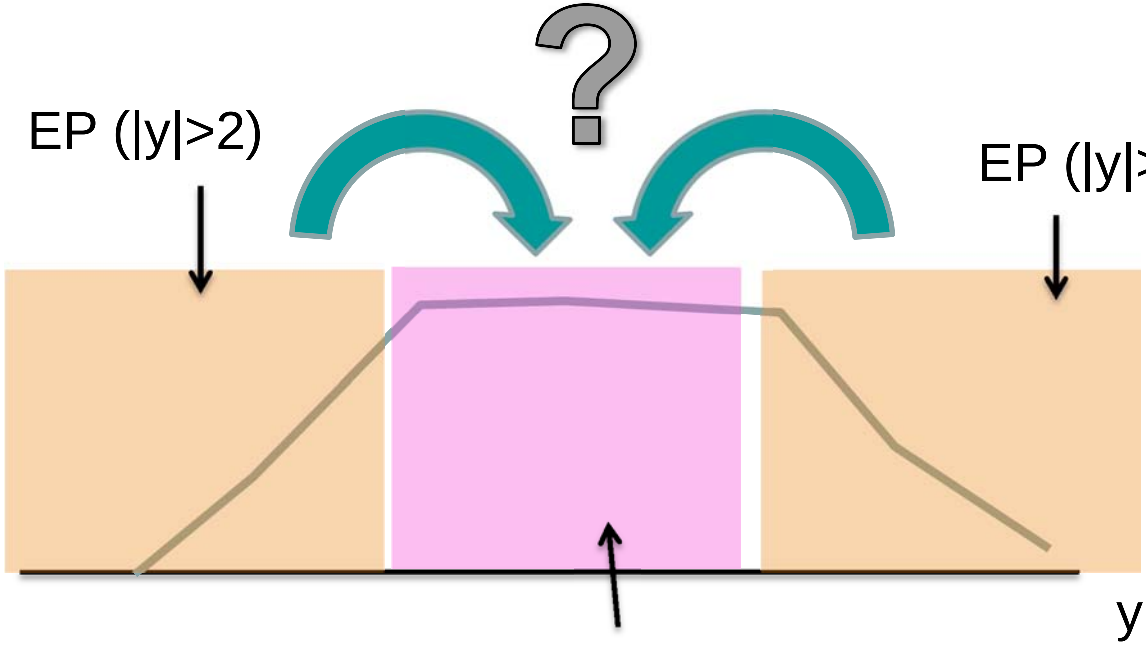

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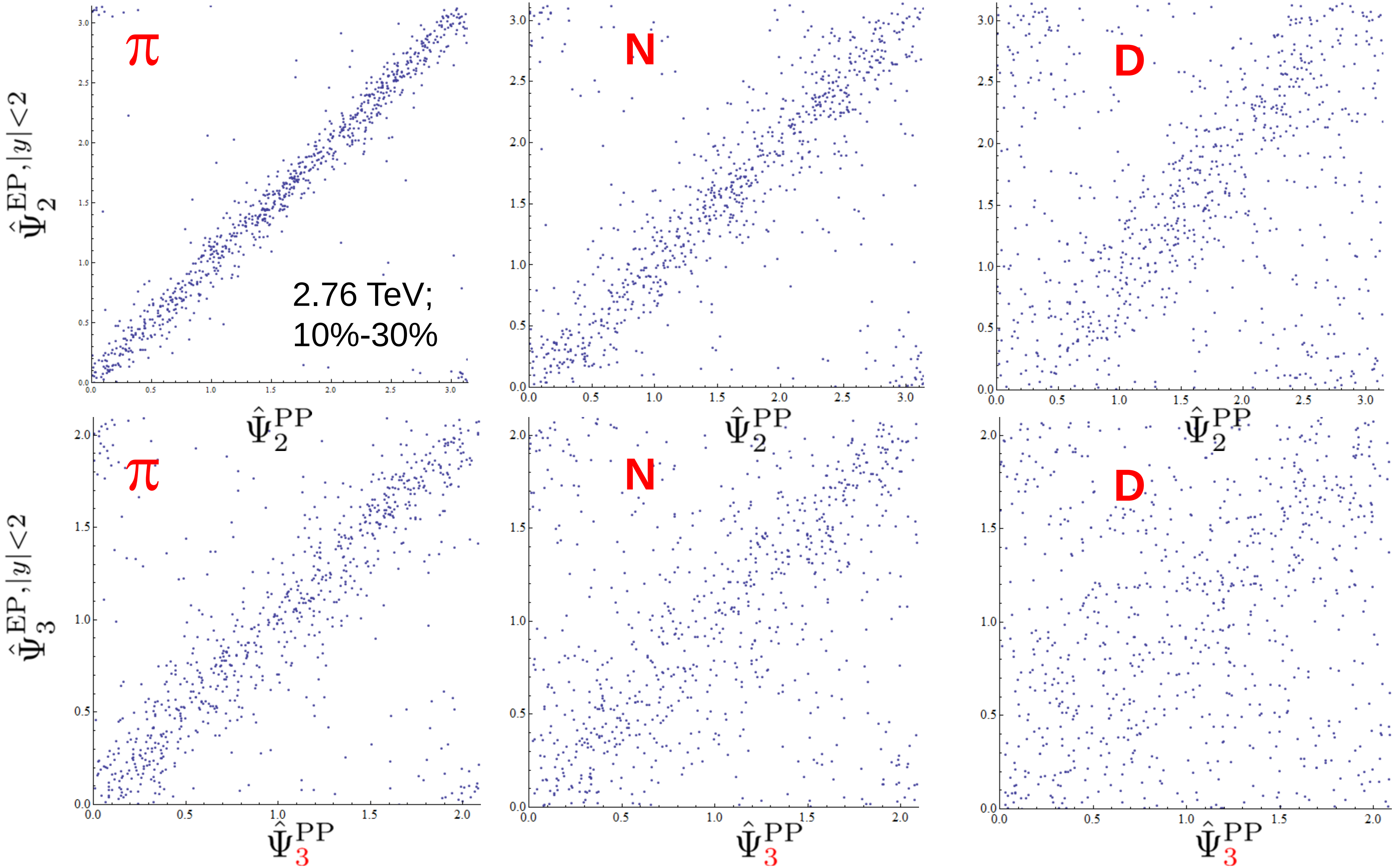

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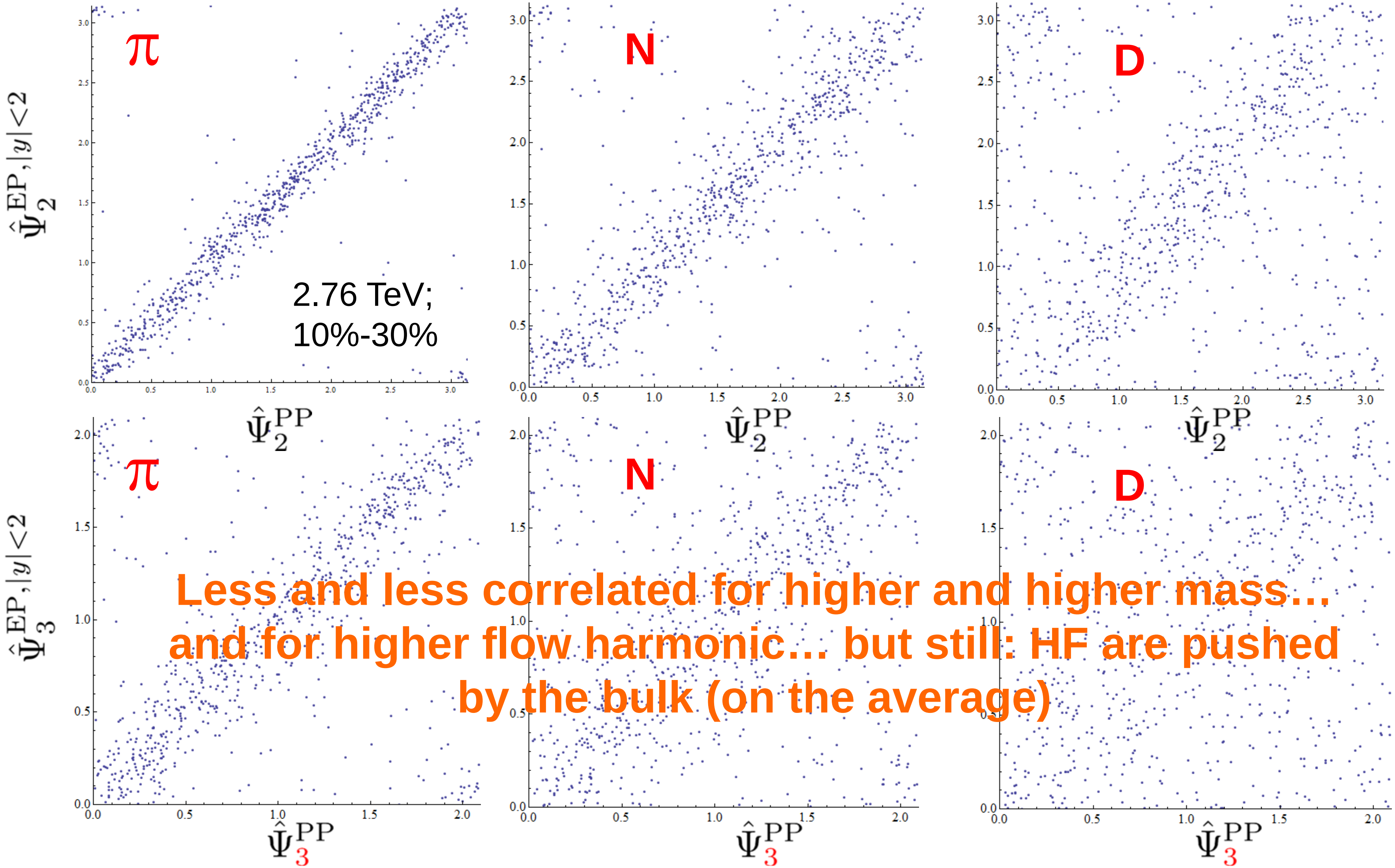
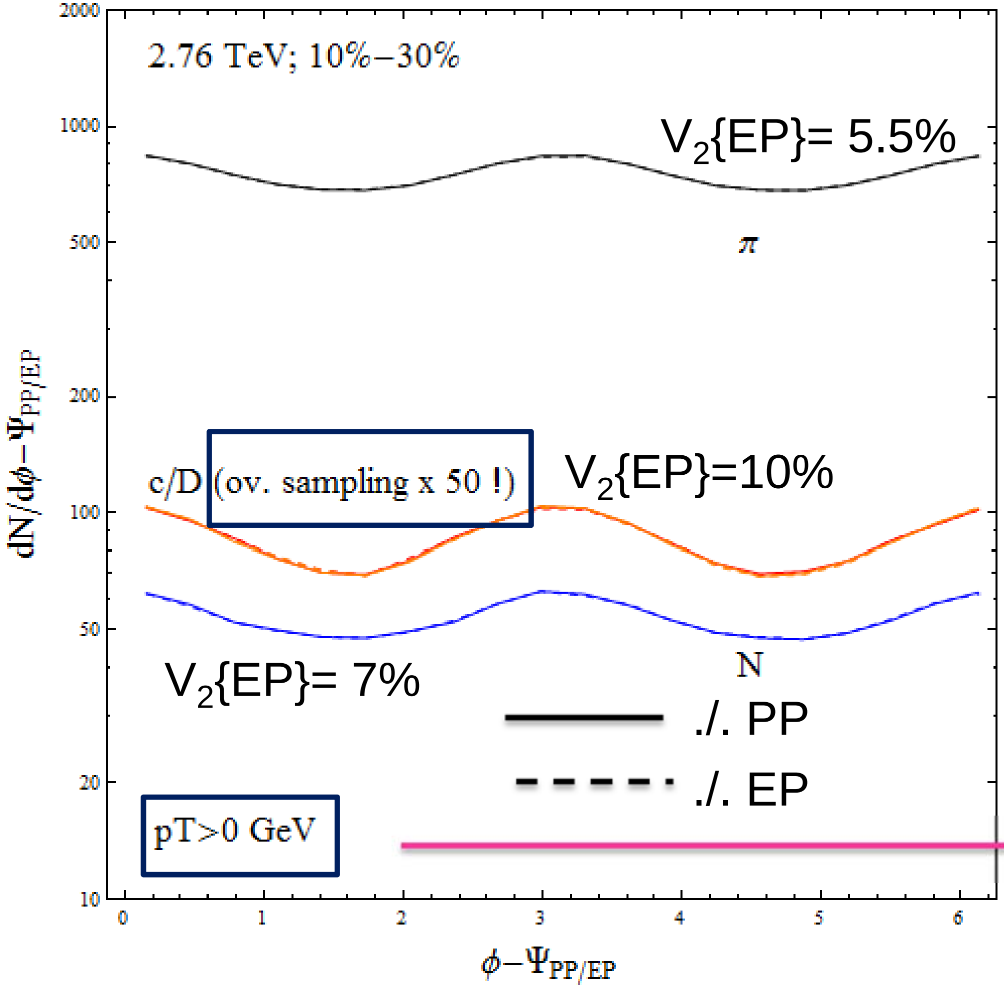
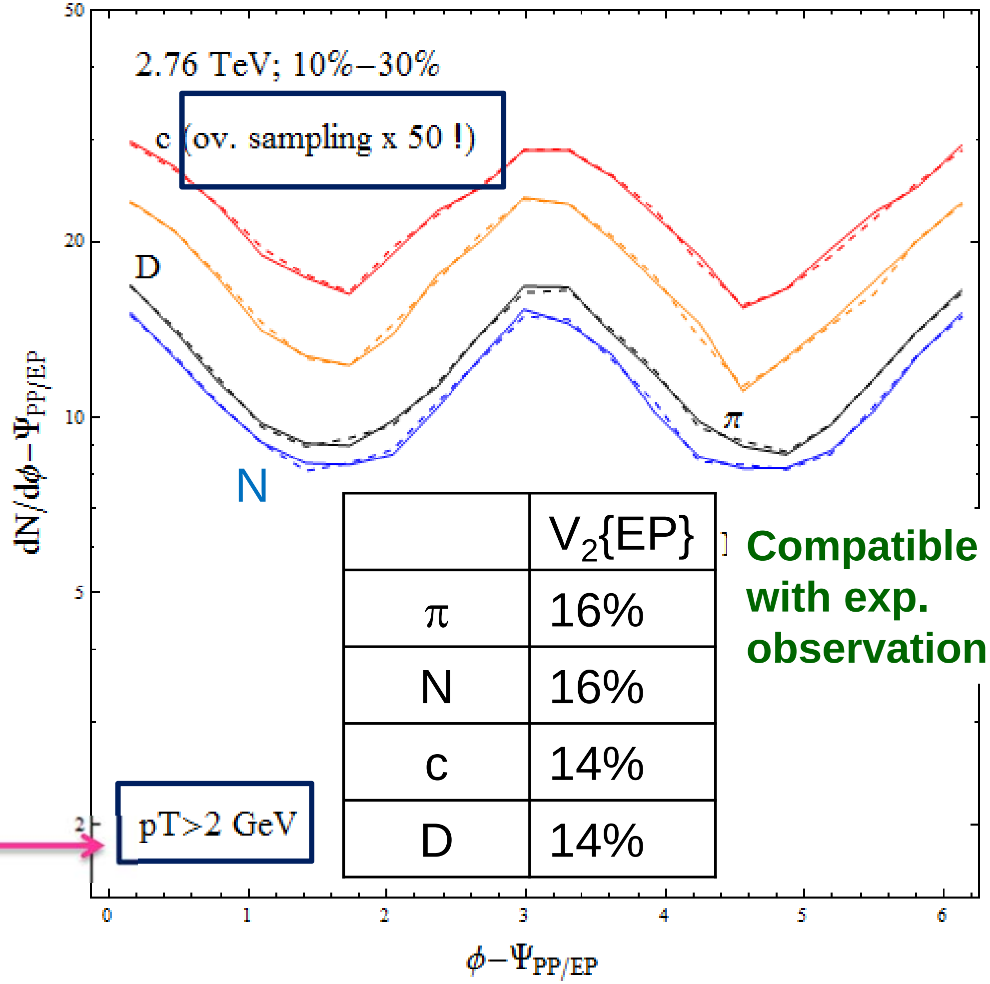


Less and less correlated for higher and higher mass… and for higher flow harmonic… but still: HF are pushed by the bulk (on the average)

Average distribution and $v_n\{EP\}$

Ensemble averaging (1000 EPOS3 events)



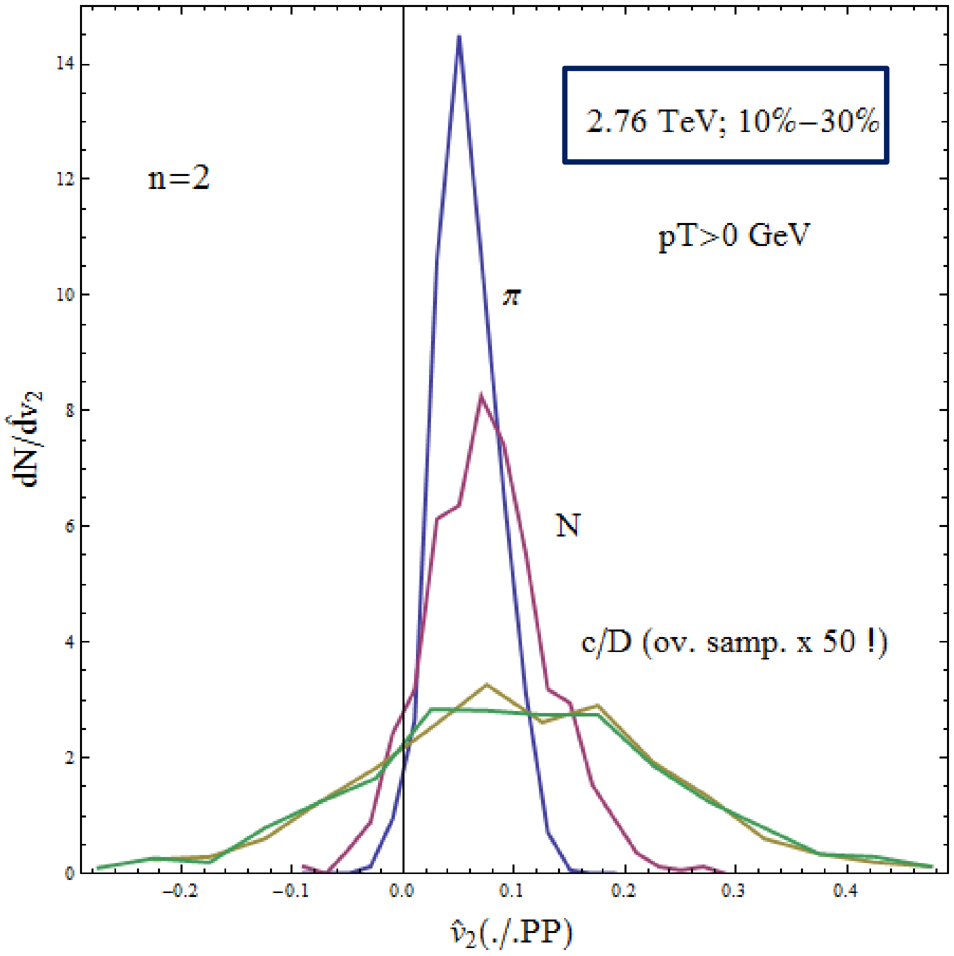


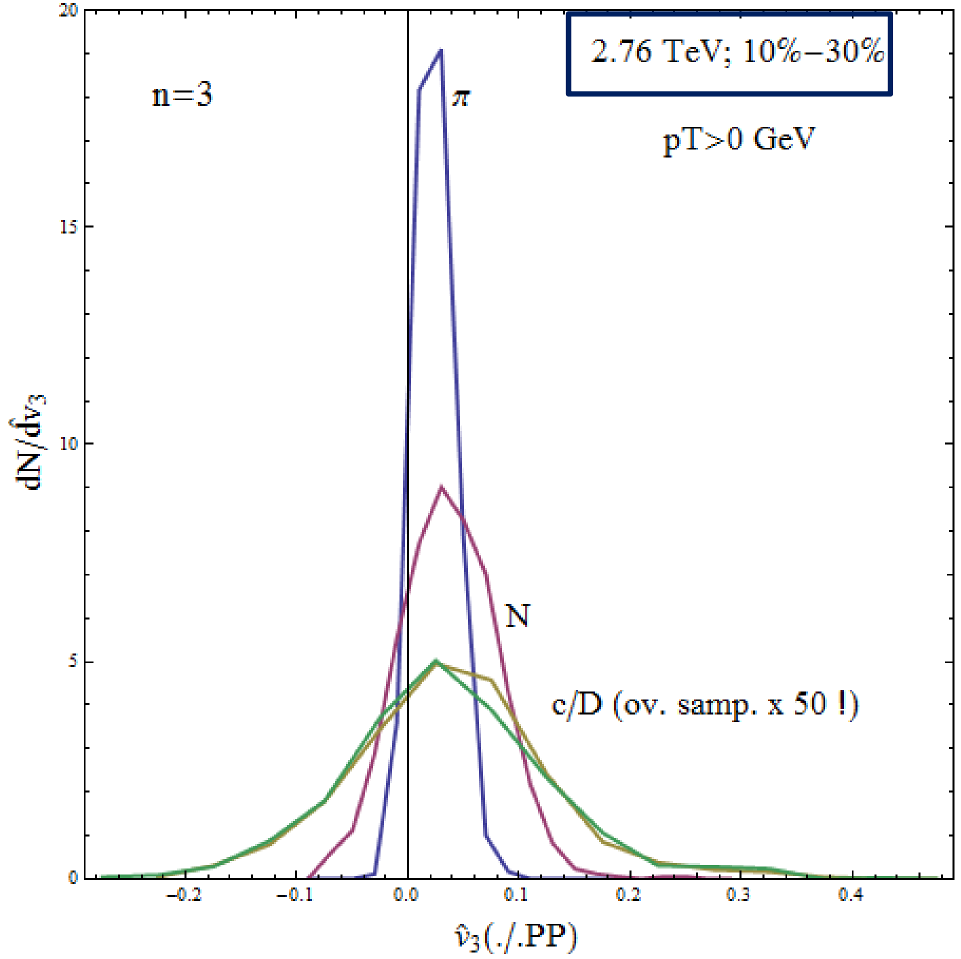
	$V_2\{EP\}$
π	16%
N	16%
c	14%
D	14%

Compatible with exp. observation

Oversampling => 2 x more Ds' than nucleons !!!

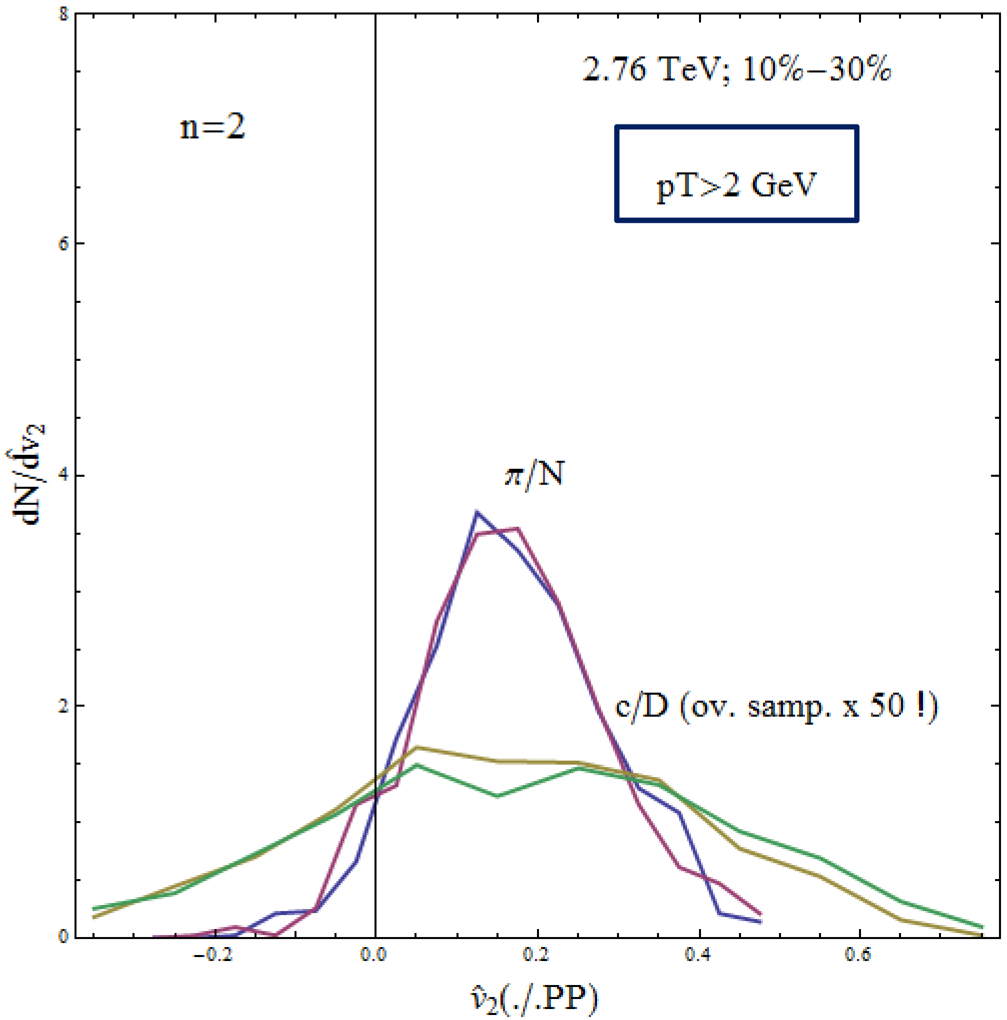
EBE flow distributions for n=2 & n=3

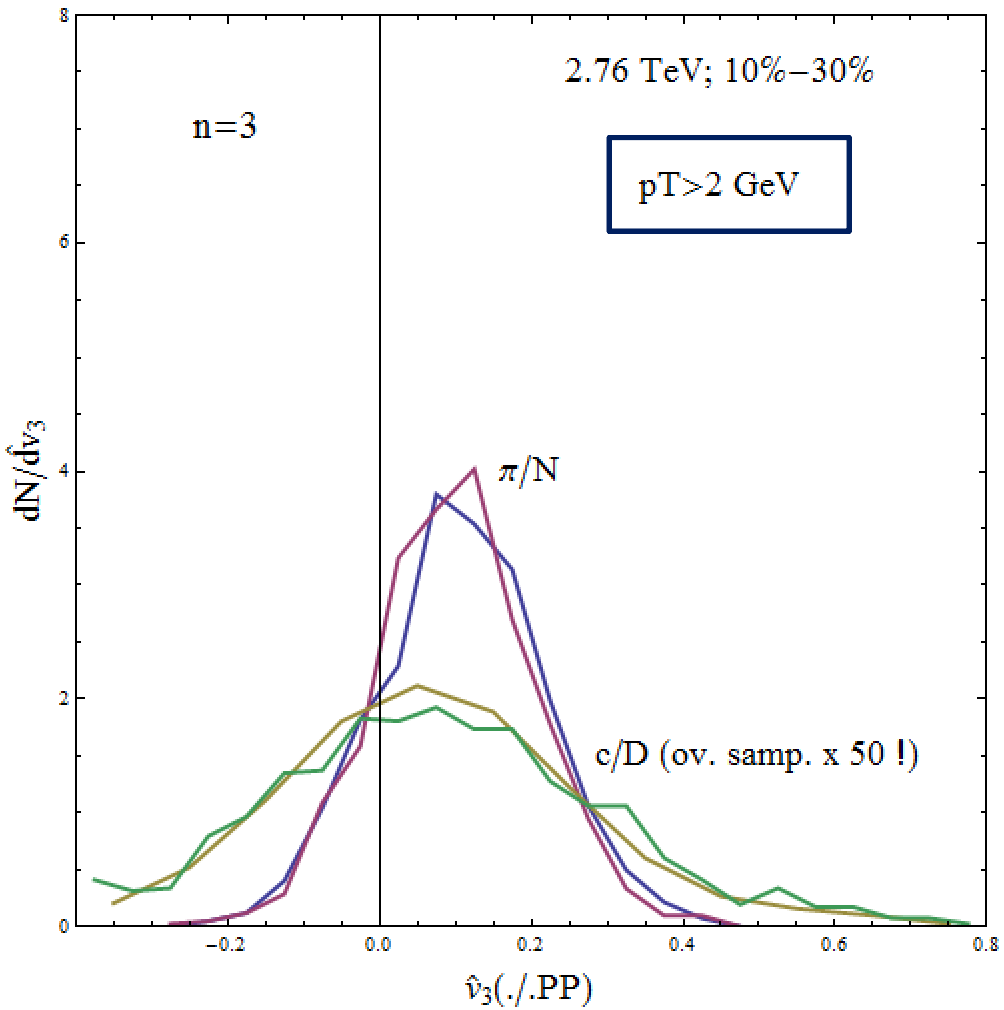




Large variance for c quarks & D mesons

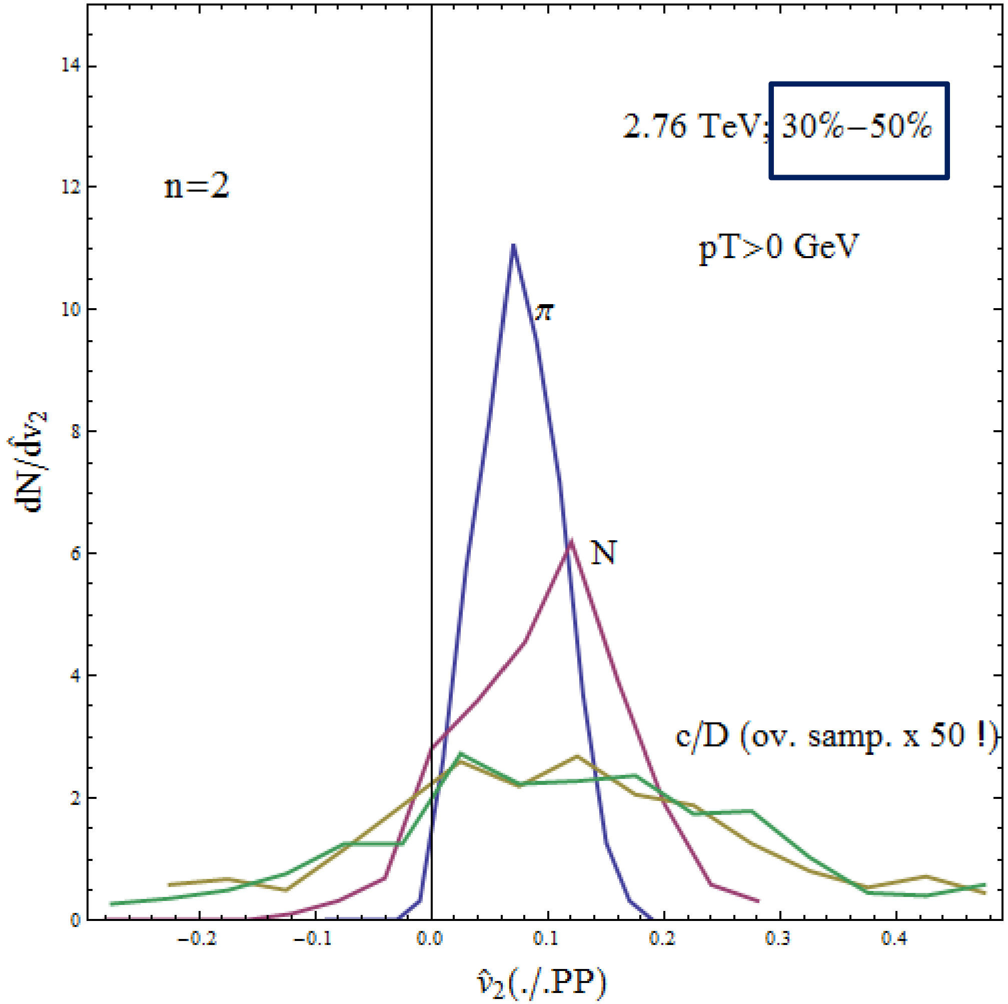
EBE flow distributions for n=2 & n=3

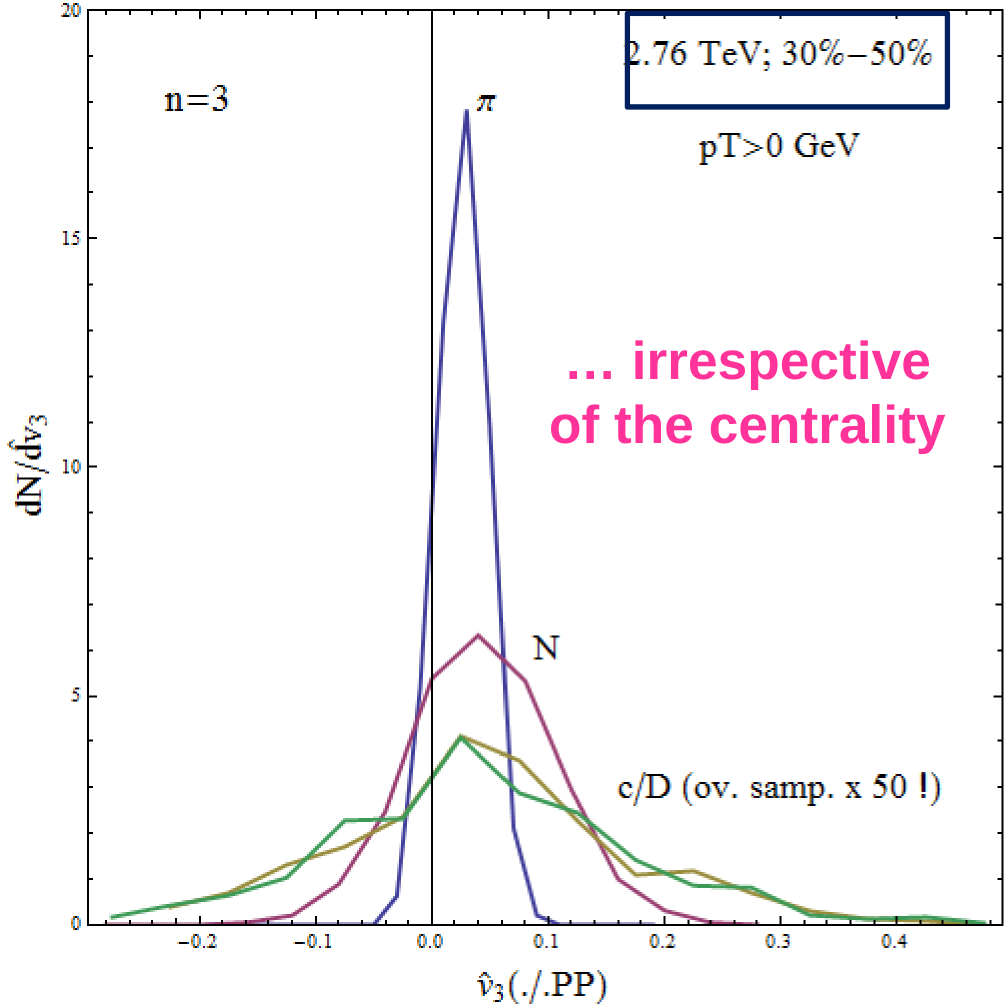




… irrespective of the p_T cut

EBE flow distributions for n=2 & n=3





… irrespective of the centrality

However $\sigma^2 = \frac{1}{2N}(1+2c)$

Contradicts n(N)<n(D) in sample !!!

Poskanzer & Voloshin (98)

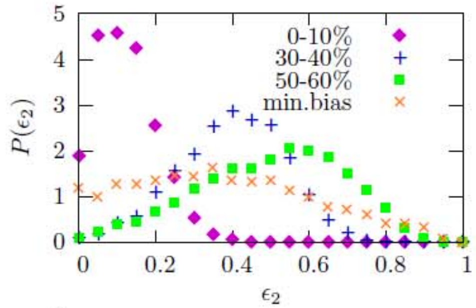
Non flow (seems rather small from {D} vs {D,Dbar} analysis

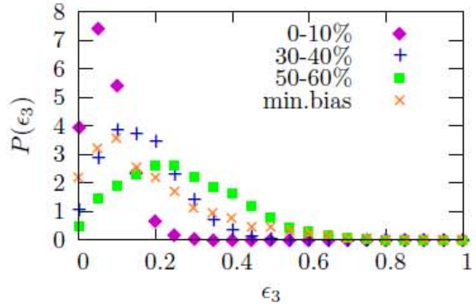
What makes the flow ? Theory view point

- Bulk flow is driven by the initial elliptic or triangular eccentricity ϵ_2 and ϵ_3

$$\epsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$

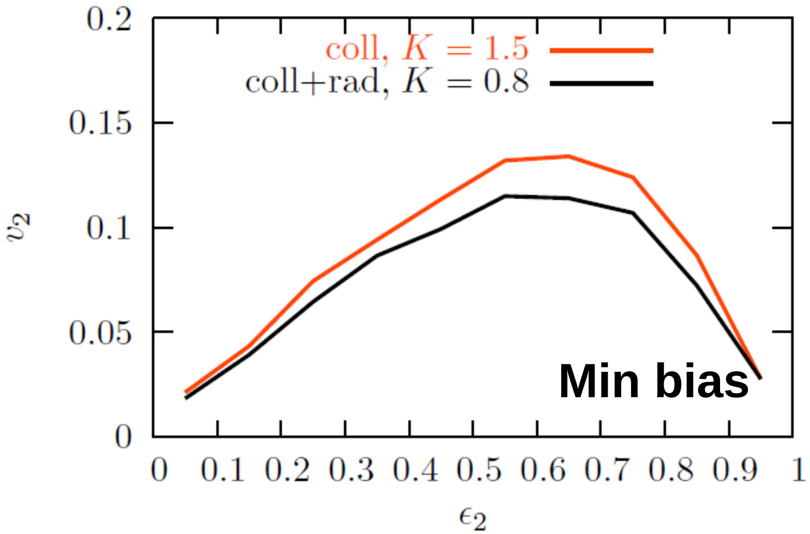
- In the light hadron sector the final $v_2 \propto \epsilon_2$ and $v_3 \propto \epsilon_3$, proportionality depends on viscosity.
- v_n distributions have been measured!

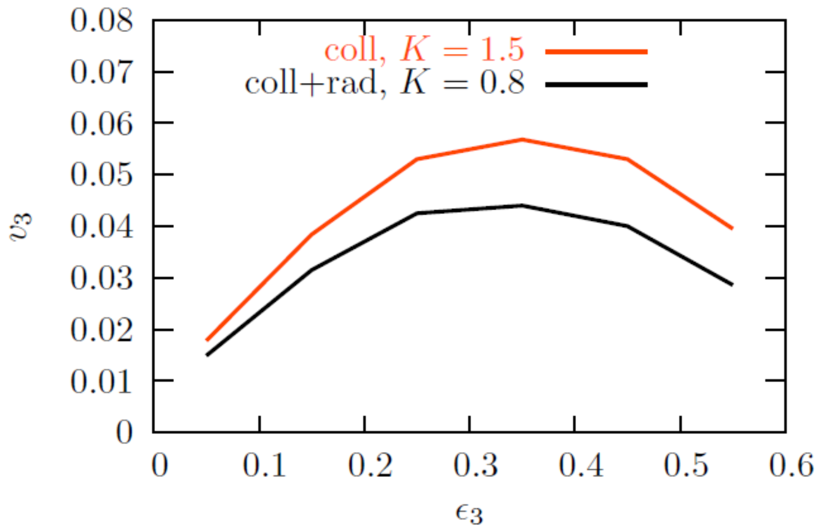




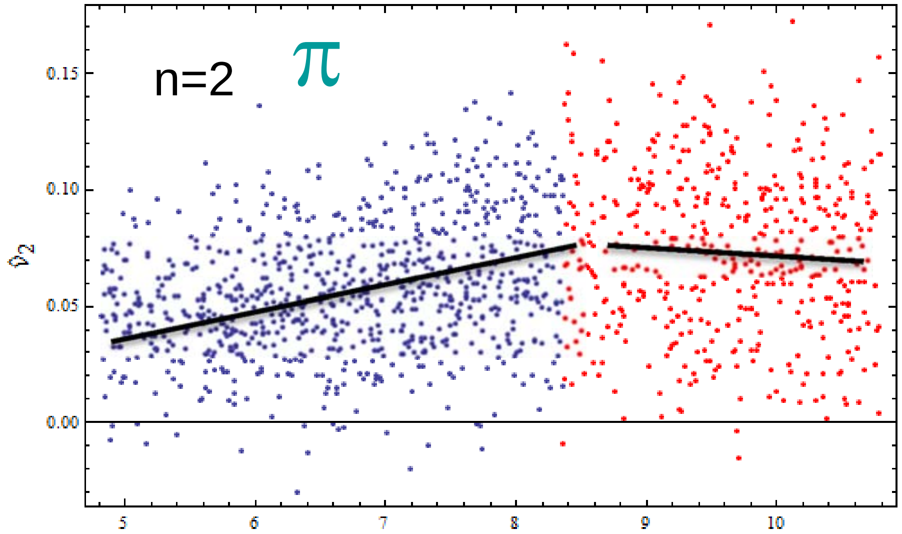
M. Nahrgang QM 2014

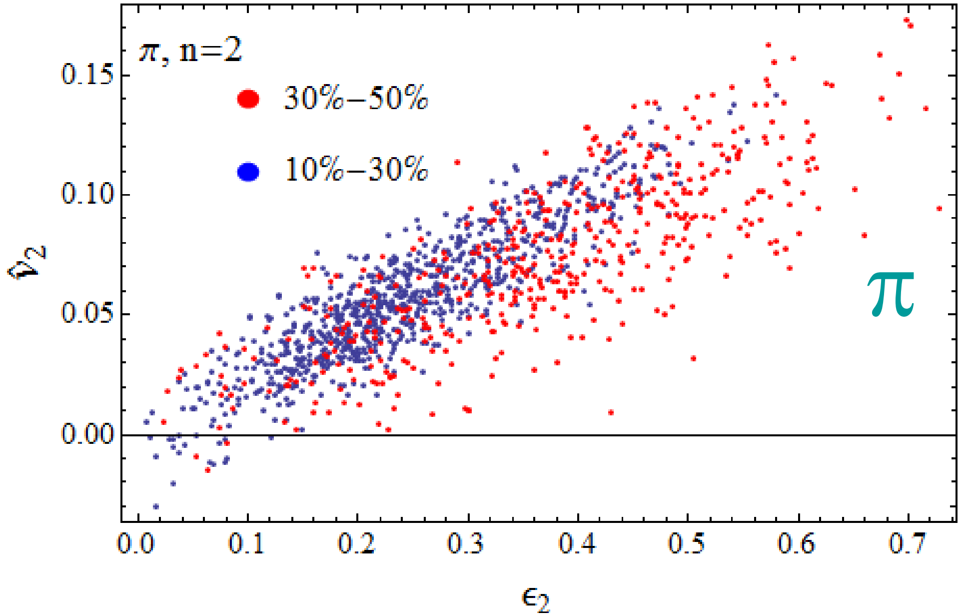
With EPOS 2

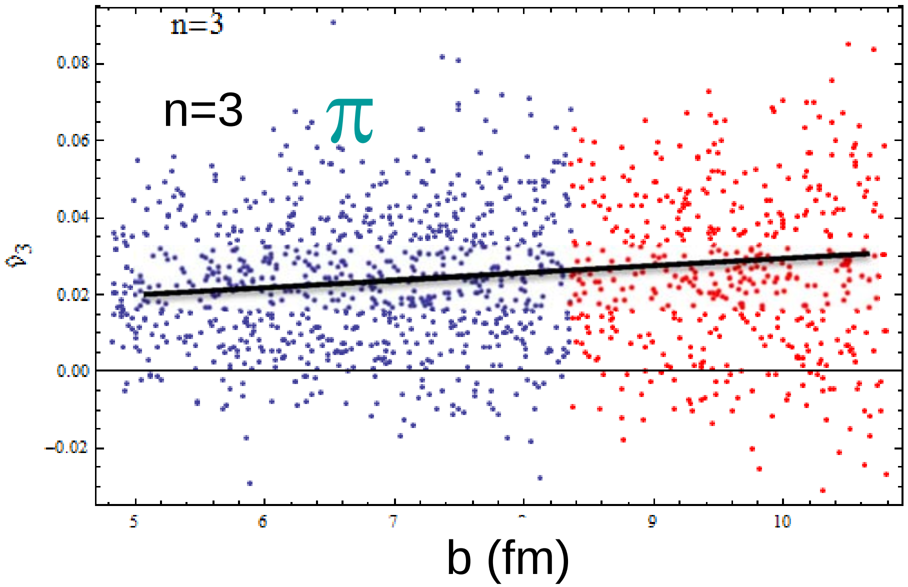


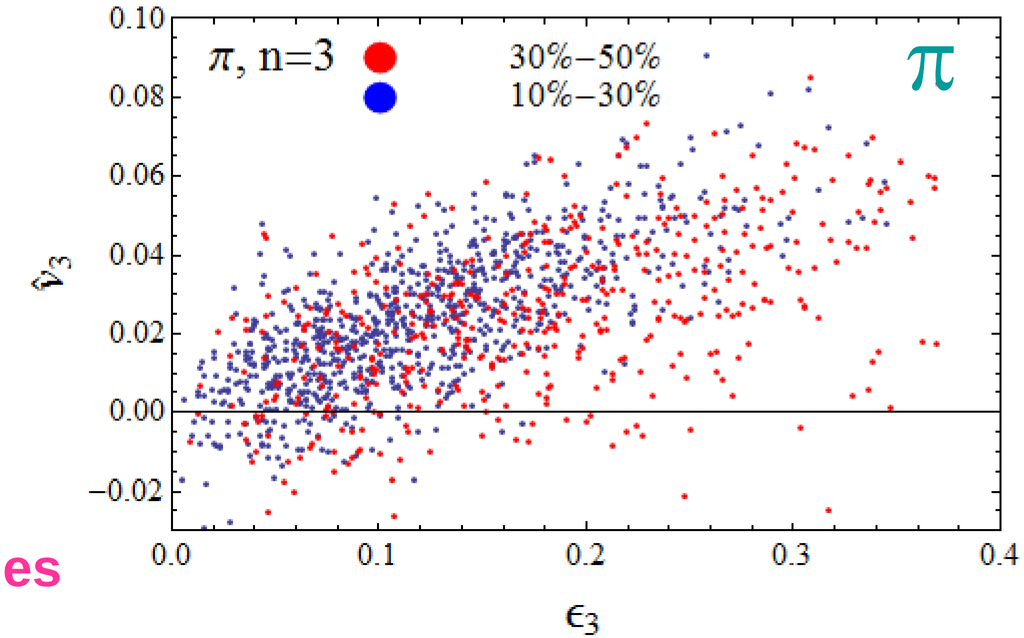


What makes the flow ? Theory view point



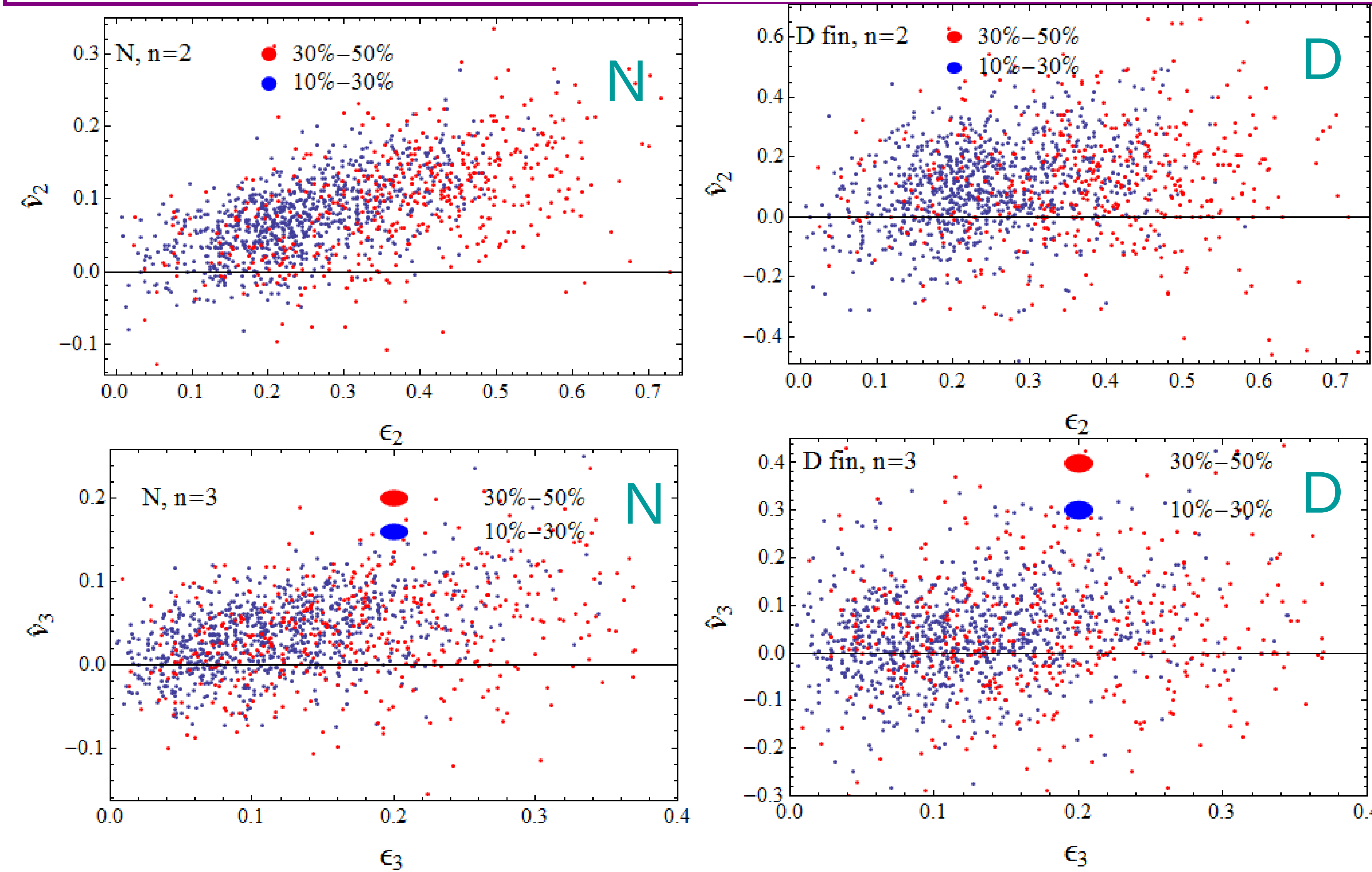






Better correlations with eccentricities

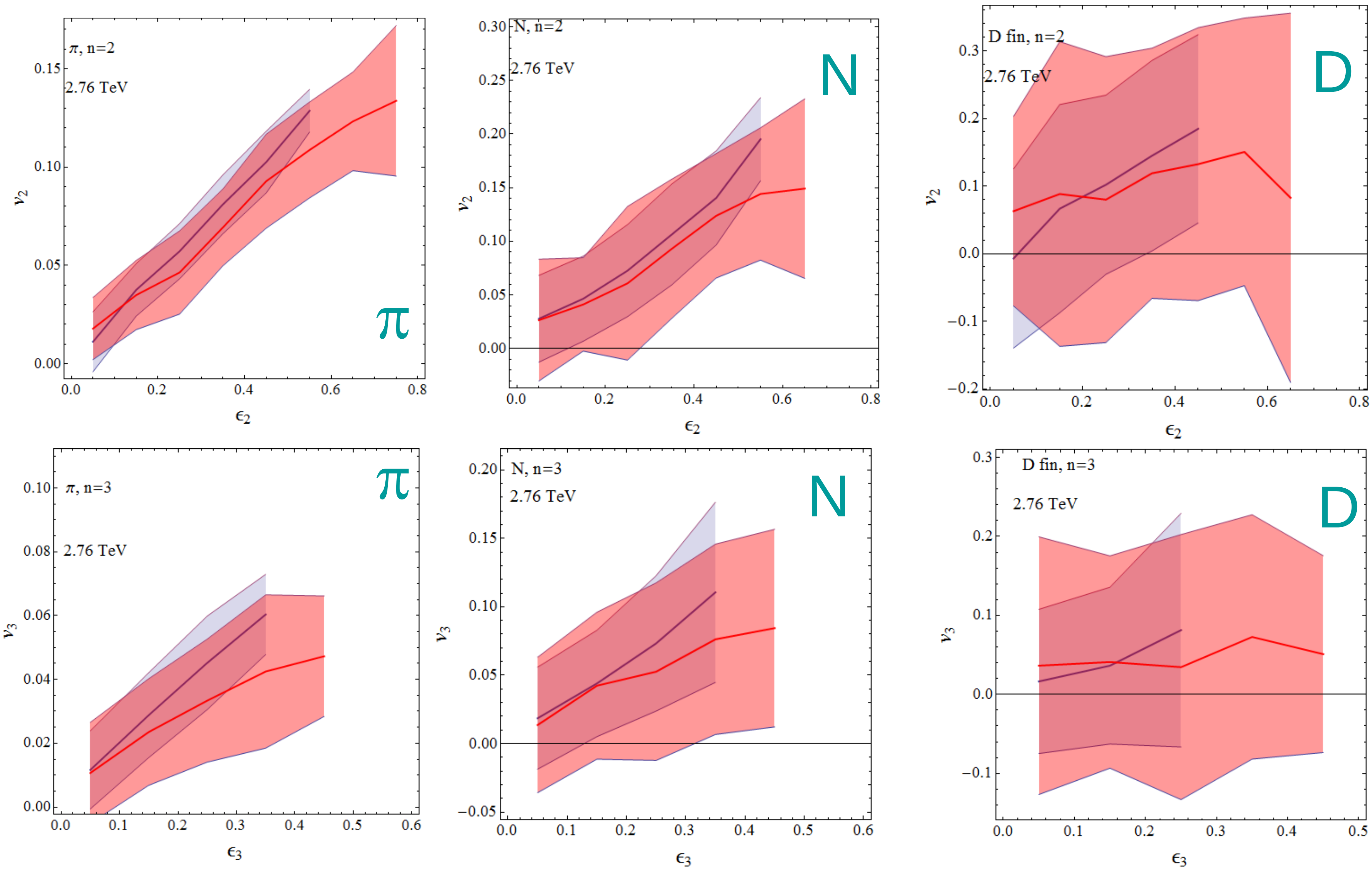
What makes the flow ? Theory view point



What makes the flow ? Theory view point

- Scattered plots are more and more scattered from
  - π -> N -> D
  - n=2 -> n=3 -> …
- Variance seems roughly independent of the « explanatory » quantity
- Picture compatible with previous study in EPOS2

What makes the flow ? Theory view point



What makes the flow ? Theory view point

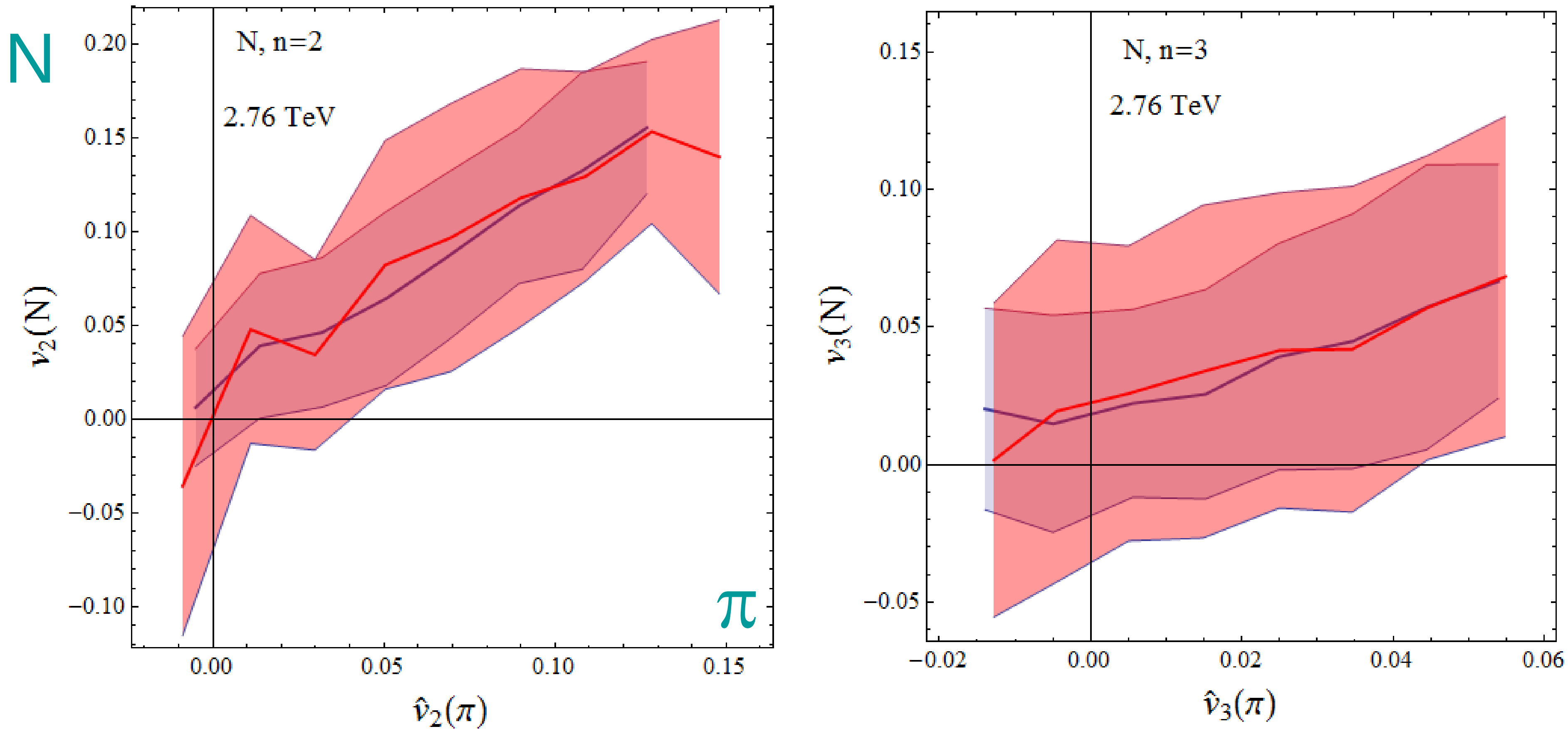
- Confirms results found in PHYSICAL REVIEW C **91**, 014904 (2015) by Nahrgang et al: non linearity of v_n vs ε_n for HF

- HF benefit less from the bulk flow than lF… especially for larger impact parameter (and a given ε_n)

- EBE Fluctuations have a slight tendency to grow with ε_n

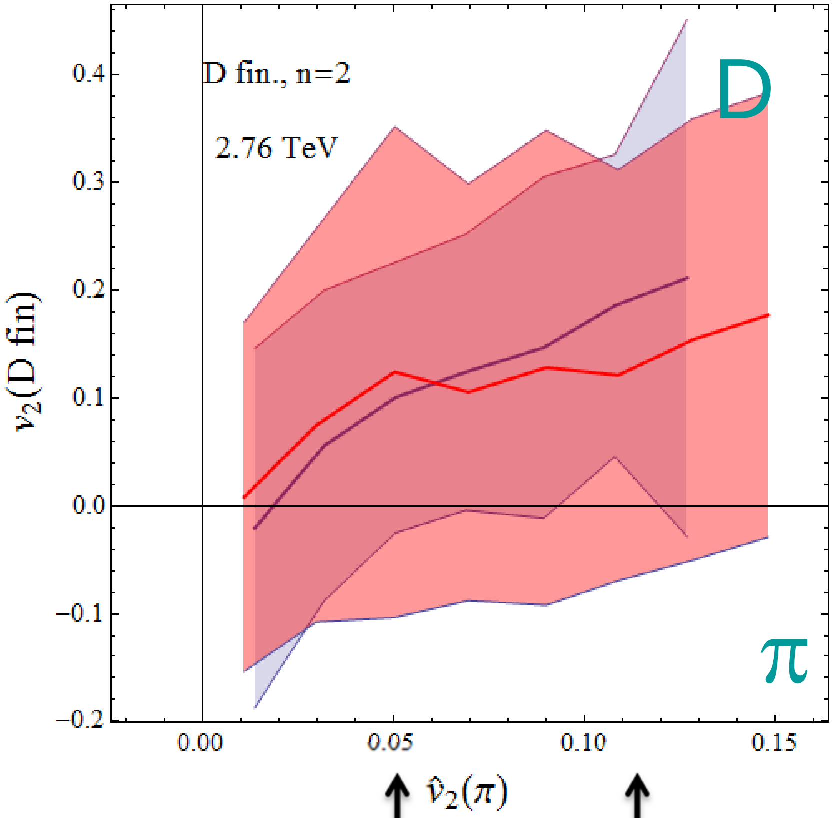
What makes the flow ? Getting closer to experiment

Natural correlation to explore is v_n(HF) vs v_n(IF)

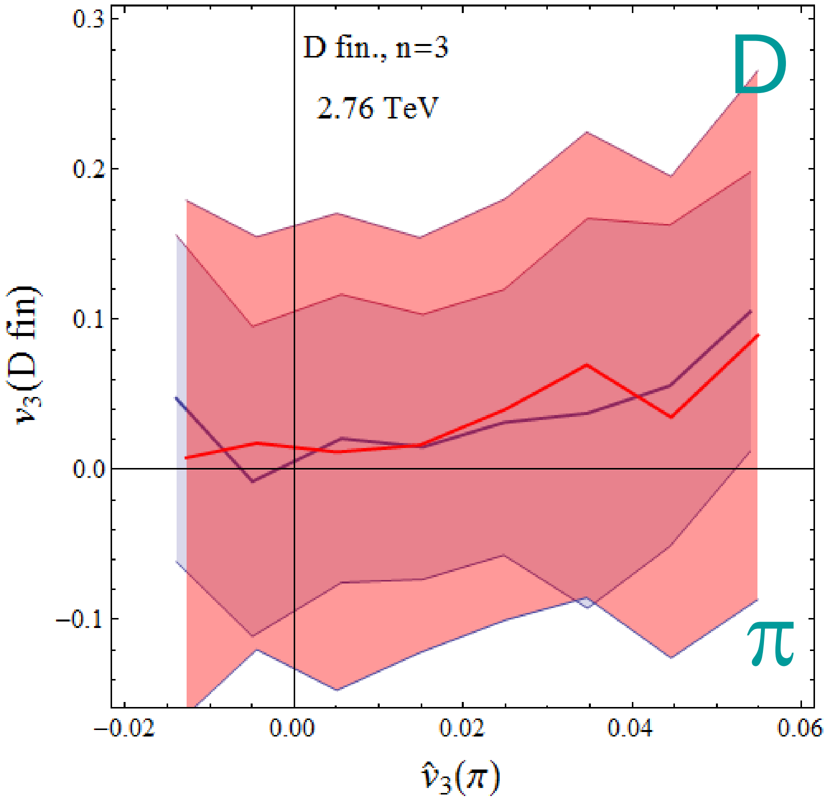


Good correlation for {π,N} (common freeze out surface), less dependence on the centrality

What makes the flow ? Getting closer to experiment



<60% low q_2> <20% high q_2>



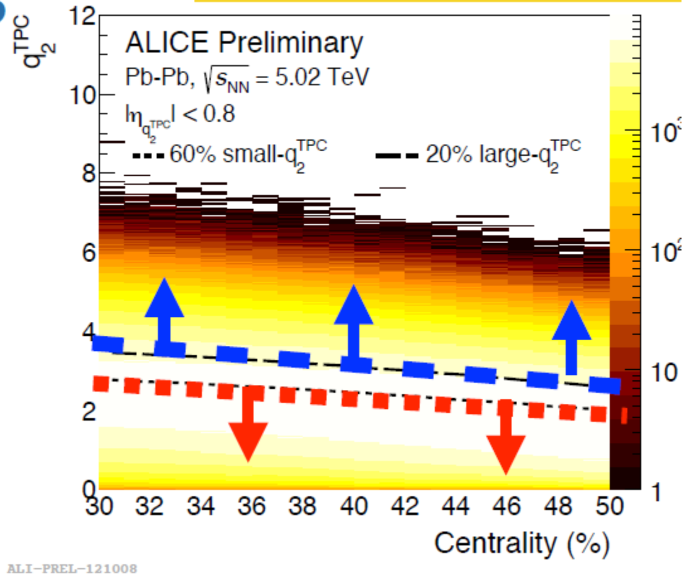
Good correlation for {π,N} (common freeze out surface), less dependence on the centrality… still large fluctuations

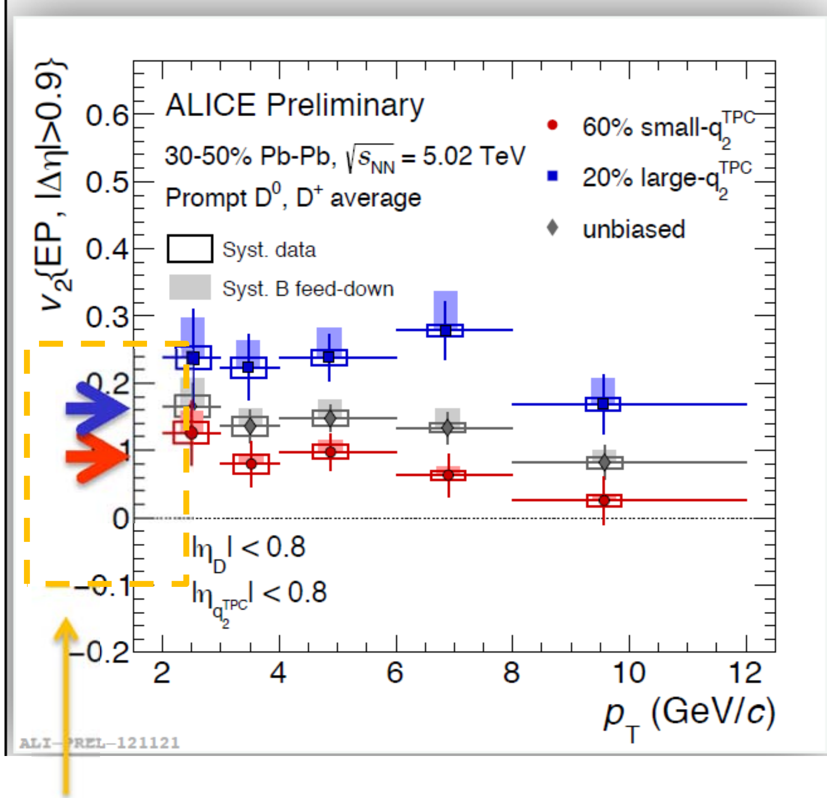
What makes the flow ? Getting closer to experiment

Event-shape engineering analysis

- q_2 measured with TPC tracks:
  - **20%** of the events with **large q_2**
  - **60%** of the events with **small q_2**
- v_2 measured with event plane method (with V0)

q_2 vs centrality





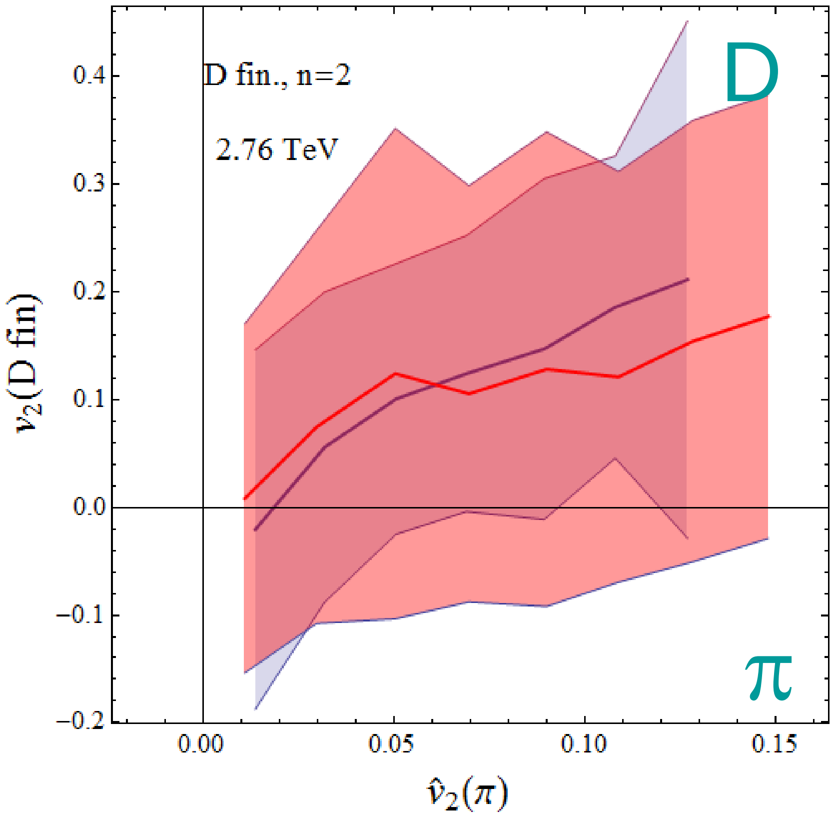
- **Significant separation** of D-meson v_2 in events with **large and small q_2**
- Autocorrelation and non-flow effects between q_2-determination and D-meson reconstruction are present
- **Charm** quarks **sensitive** to the light-hadron bulk **collectivity** and **event-by-event initial condition fluctuations**

28

Own predictions (@2.76 TeV)

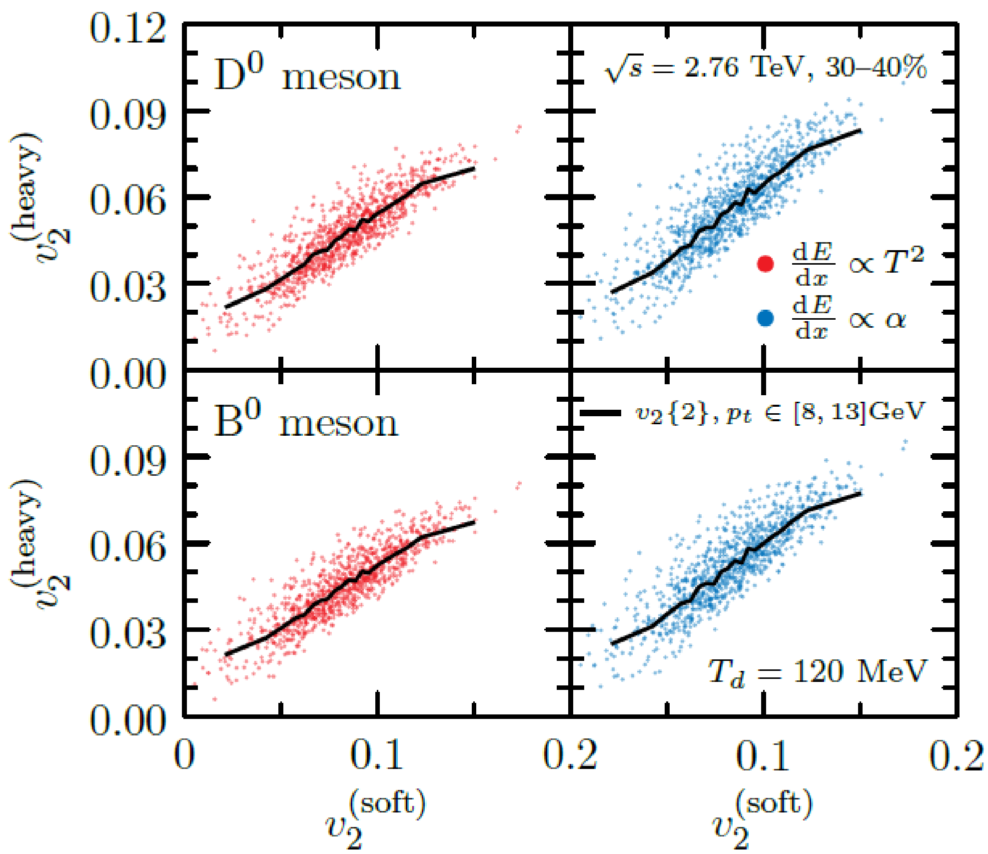
From A. Barbano (//OHF 1, Tuesday)

What makes the flow ? Comparison with recent work



p_T (D) range: >0 GeV

Prado et al. arXiv:1611.02965v1



p_T (D/B) range 8–13 GeV

Trends are compatible for the averages, but fluctuations differ

Oversampling: 50x for HF

In this work, an event-by-event analysis is possible by oversampling each individual hydro event with millions of heavy quarks. Thus, from each individual event the nu-

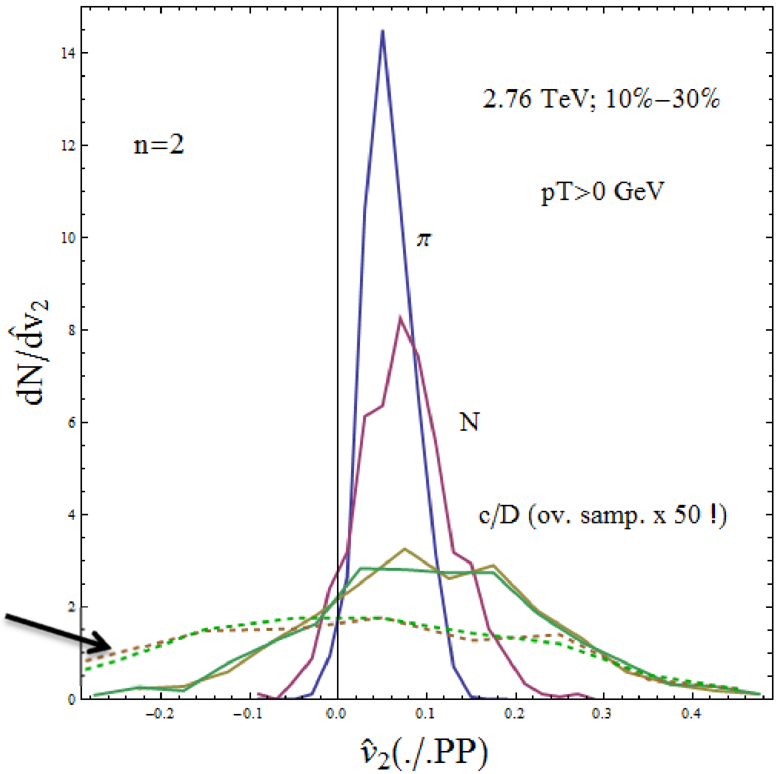
An insight on the D-mesons v_n fluctuations

- For light particles: produced from a common underlying distribution dN/d^3p on the freeze out hypersurface. Their fluctuations mostly translate the way this distribution is sampled
- For Heavy Flavors: created at QGP creation point and subject to transport calculation through the QGP => fluctuations might not stem from the same origin.

Why $\sigma(v_2(D)) > \sigma(v_2(N))$ although $n(N) < n(D)$ (with oversampling) ?

New postulate: for HF, initial state fluctuations are LARGE and dominate until coupling with QGP can possibly tame them => Not the same framework as for hadrons produced through fluid dynamics evolution

No E loss, no coupling with QGP



Conclusions and perspectives

C1: We confirm the main conclusion of our previous study for <v_n(HF)>: deviations from linear scaling with ε_n, especially for higher n value and more pheripheral reactions

C2: Study of the light – heavy v_n (positive) correlations offers a new play ground for model comparison (consistent with ALICE most recent results).

C3: Study EBE flow harmonics in EPOSHQ, large fluctuations observed, which seems to go beyond standard flow analysis results; possible reminder of EBE fluctuations in the initial state => signature for thermalization ?

C4: Yes, c-quarks flow with the bulk… but on the average only

P1: Other methods under exploration (SP, Cumulants) + p_T dependent analysis

P2: Need to explore better the time evolution of v_n(HF) fluctuations until decoupling from the QGP… Consequences for the v_n of other hard probes ?