Event-by-Event correlations between light and heavy mesons

J.A., PB. Gossiaux, B. Guiot, V. Ozvenchuk, K. Werner

Why?

EPOS3 – HQ (heavy quarks)

- EPOS3
- How heavy quarks interact in the plasma
- First results for RHIC
- Correlation between light and heavy particles

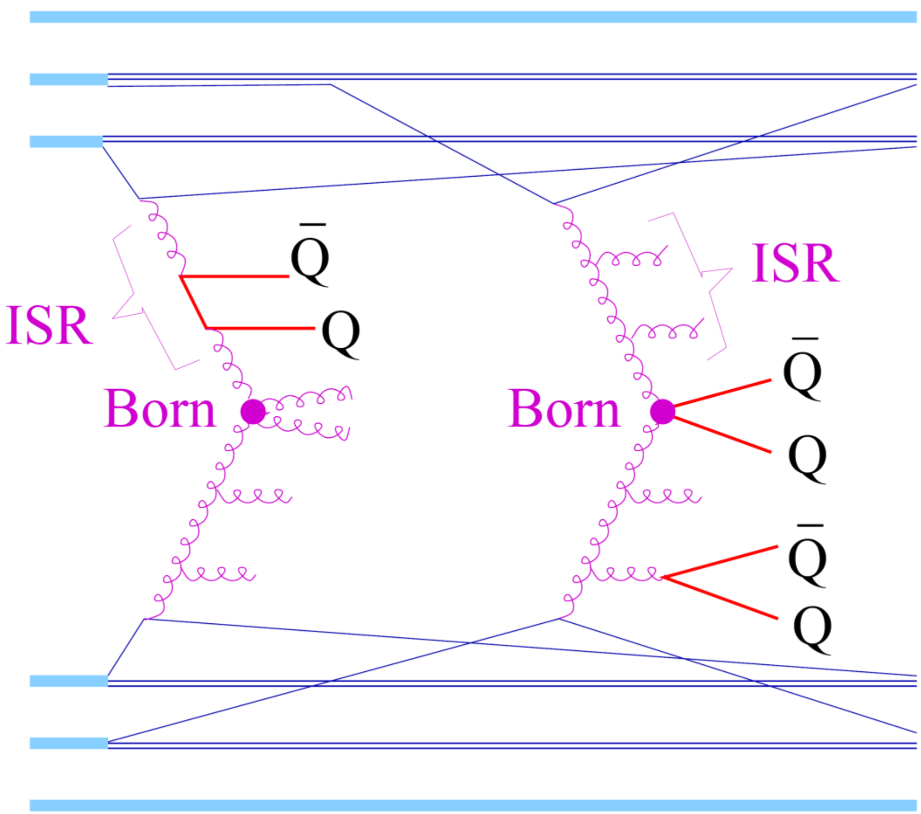
Why we should combined the heavy quark and light quark physics?

Exploratory studies (arXiv 1102.1114)
have shown that different expansion scenarios
may modify the values for R_{AA} and v_2 by a factor of 2
for an identical treatment of the HQ-light parton interactions.

To improve:
We have to combine the HQ physics with the light quark physics
➔ we have to use for the plasma expansion approaches which have been proven to describe the light hadron sector

EPOS is one of the most successful of these approaches

Heavy quark production in EPOS multiple scattering framework



as light quark production

In any of the ladders via

- ☐ **splitting during ISR**
- ☐ **splitting during FSR**
- ☐ **$Q\bar{Q}$ in Born**

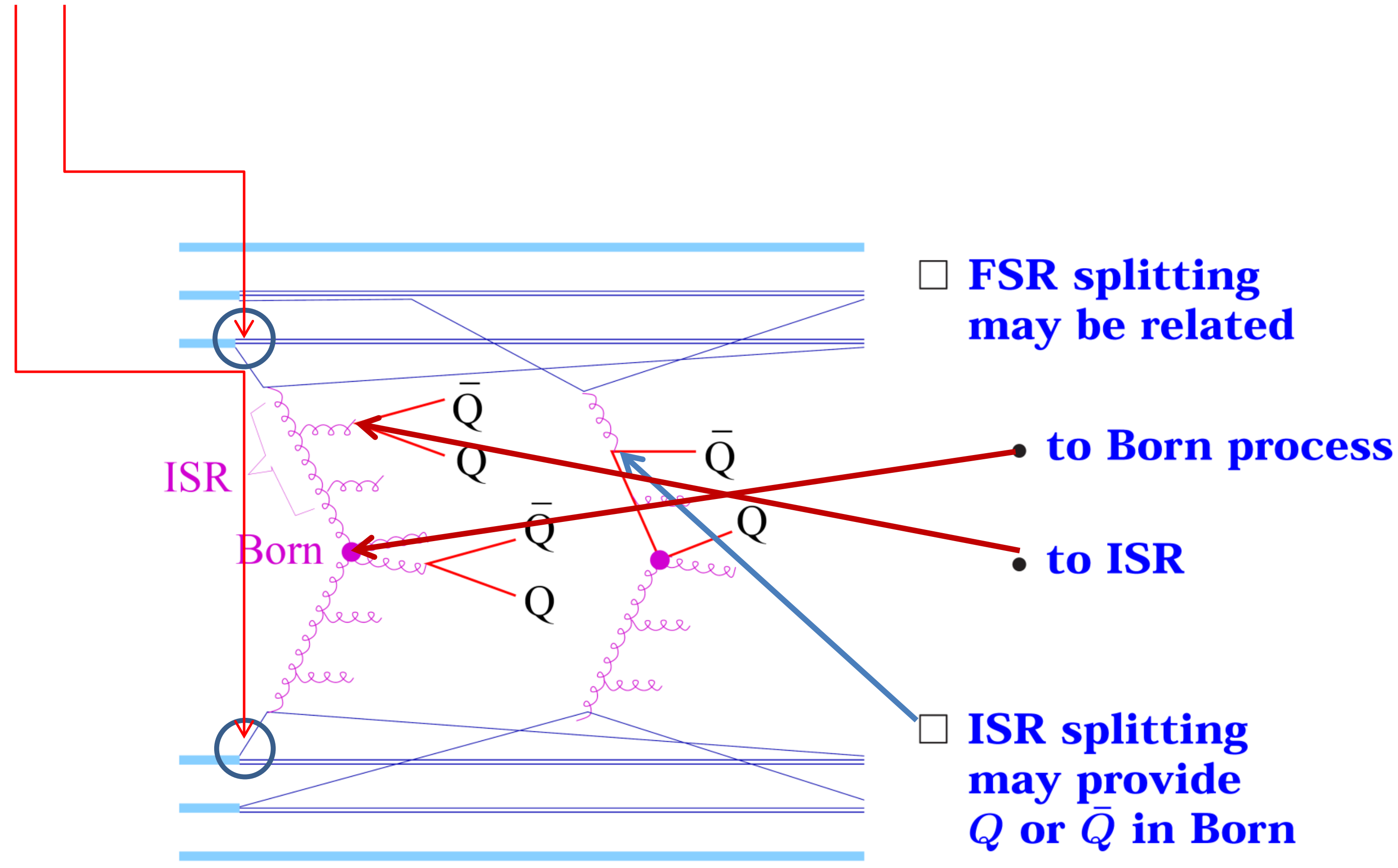
but m_Q non-zero

$(m_c = 1.3,\ m_b = 4.2)$

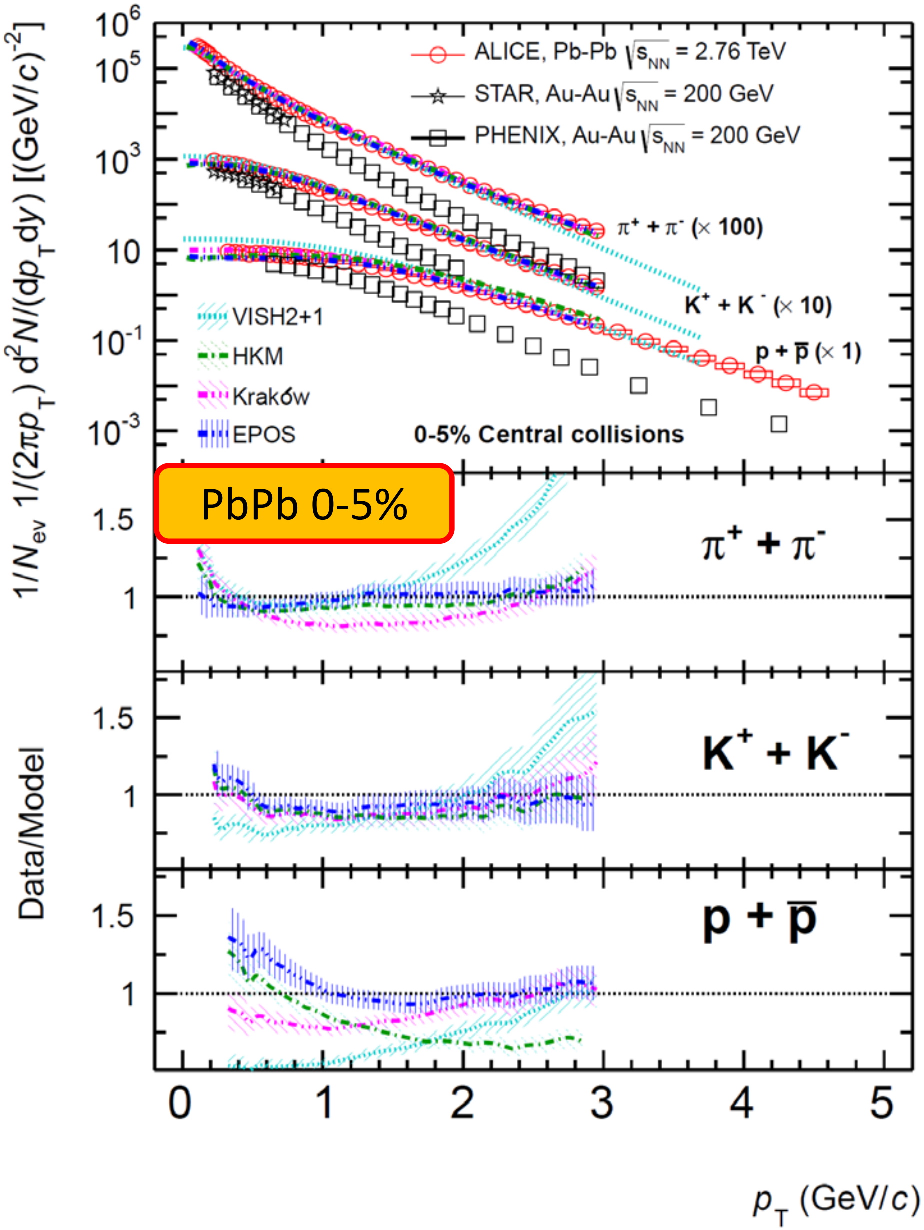
Splitting functions for light and heavy quarks identical, phase space different

In nuclear collisions the lower boundary of the integration becomes dependent on the local density

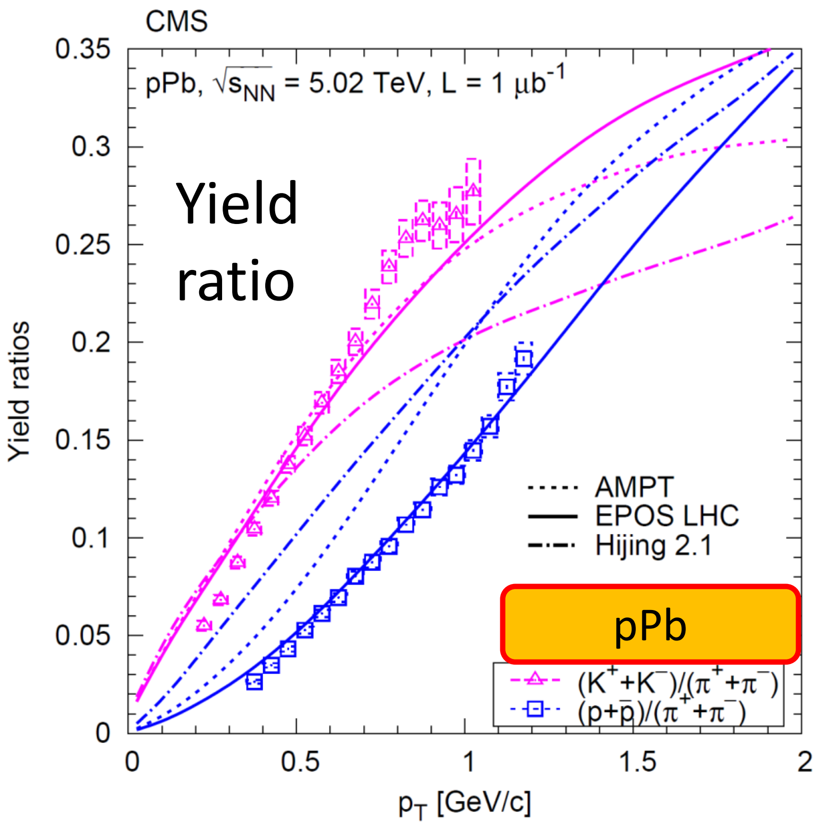
ISR very similar to the color glass condensate approach



EPOS provides a very good description of the light quark sector



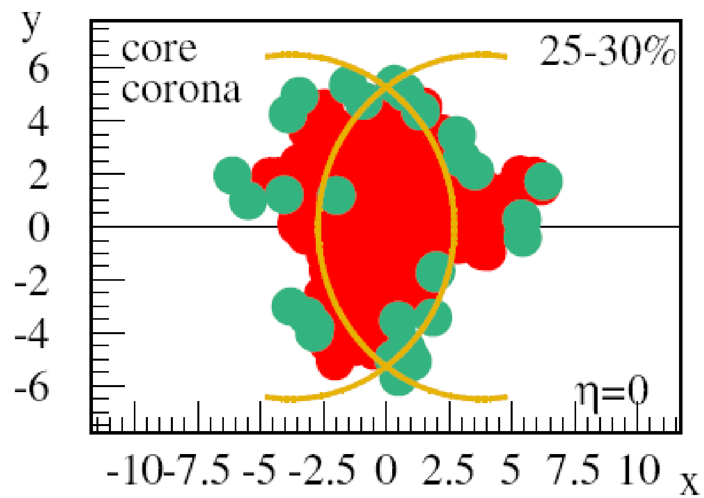
ALICE PRC88, 044910



CMS: EPJC 74 (2014) 2847

- **The steps of EPOS (event by event)**

- **Interaction using the Gribov- Regge approach**
- **Formation of strings and string decay**
- **Determination of the local energy density and velocity**
- **Formation of a QGP in regions with $E_{loss} > E$**
- **(viscous) hydrodynamical expansion of the QGP**
- **Hadronization with Cooper Frye at T_{had}**
- **Hadronic rescattering with URQMD**



Heavy quarks

- **interact with the massless plasma particles by radiative and elastic collisions**

- **form heavy mesons (p_t small) or fragment (p_t large) at T_{had}**

- **interact with hadrons (not yet implemented)**

Elastic collisions q(g)Q -> q(g)Q

$$\frac{d\sigma}{dt} = \frac{16\pi\alpha_s^2}{(s-M^2)^2}\left[\frac{(s-M^2)^2}{(t-\kappa m_D^2)^2} + \frac{s}{t-\kappa m_D^2} + \frac{1}{2}\right]$$

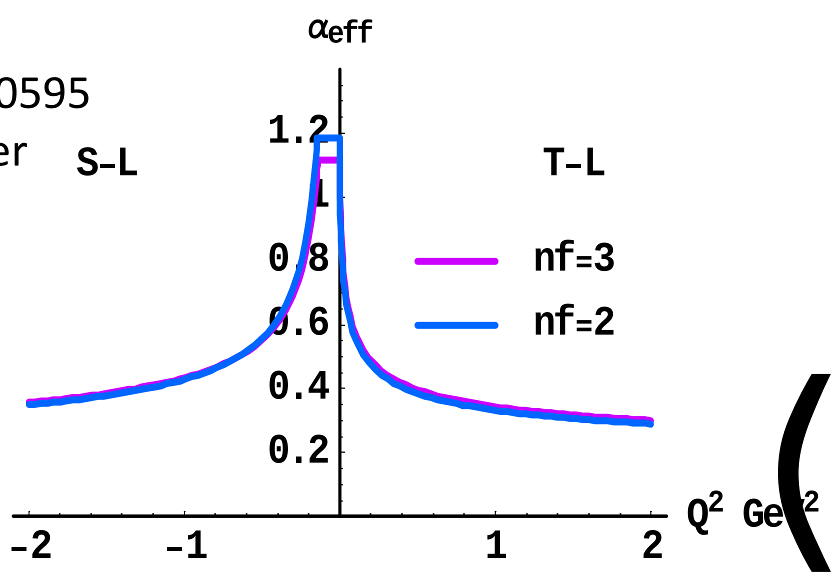
Coupling const.

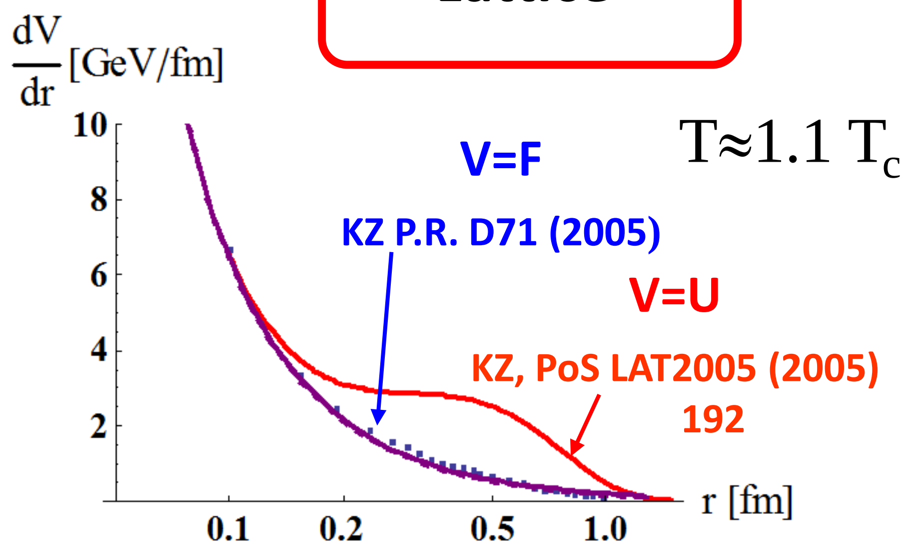
“Universality constraint”
(Dokshitzer NP A711,11)

$$\boxed{\frac{1}{Q_u}\int_{|Q^2|\le Q_u^2} dQ\,\alpha_s(Q^2) \approx 0.5}$$

Lattice

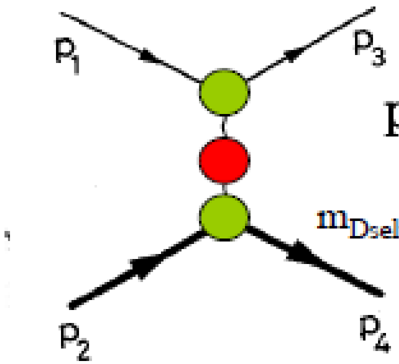
0801.0595
Peshier





Propagator

PRC78 014904， 0901.0946



$$\text{prop} \propto \frac{1}{q^2 - \kappa m^2_{\mathrm{Dself}}(T)}$$

$$m_{\mathrm{Dself}}^2(T) = (1+n_f/6)\, 4\pi\alpha_{\mathrm{eff}}(m_{\mathrm{Dself}}^2)\, T^2$$

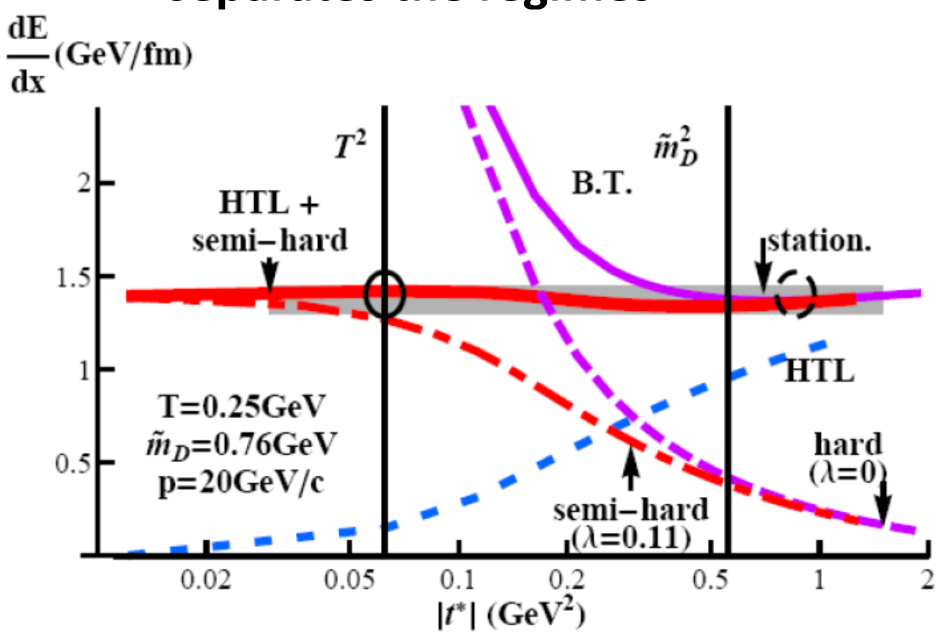
hep-ph/0607275

If t is small (<<T) : Born has to be replaced by a hard thermal loop (HTL) approach

For t>T Born approximation is (almost) ok

(Braaten and Thoma PRD44 (91) 1298,2625) for QED:

Energy loss indep. of the artificial scale t* which separates the regimes



We do the same for QCD (a bit more complicated)

Phys.Rev.C78:014904

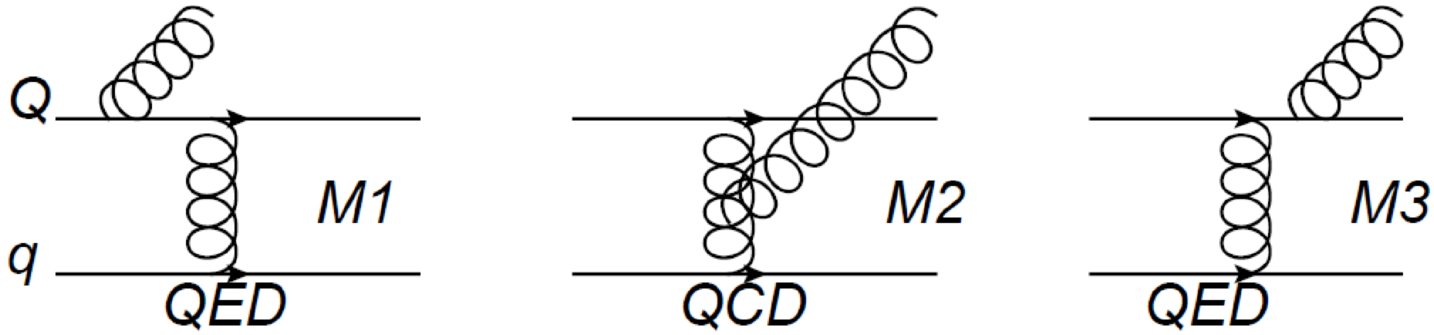
Result:

$\boxed{\kappa \approx 0.2}$

much lower than the standard value

Inelastic collisions q(g)Q -> q(g)Q+g

Three diagrams which contribute at leading order in $\sqrt{s}$



$$T^b T^a = T^a T^b - i f_{abc} T^c$$

There are two gauge invariant contrib.

$$M_{QED} = T^a T^b (M1 + M3)$$

$$M_{QCD} = i f_{abc} T^c (M1 + M2)$$

M_{QCD} dominates radiative energy loss

arXiv:1307.5270

M^{SQCD} in light cone gauge (for explanation)

In the limit $\sqrt{s} \to \infty$ the radiation matrix elements **factorize** in

$$M_{tot}^2 = M_{elast}^2 \cdot P_{rad}$$

k_t , ω = transv. mom/ energy of gluon   E = energy of the heavy quark

$$P_{rad} = C_A \Big(\frac{\vec{k}_t}{k_t^2 + (\omega/E)^2 m^2} - \frac{\vec{k}_t - \vec{q}_t}{(\vec{q}_t - \vec{k}_t)^2 + (\omega/E)^2 m^2} \Big)^2$$

Emission from heavy Q

Emission from g

leading order: no emission

from light q

heals colinear divergences

creates dead cone effect

m=0 -> Gunion Bertsch

Energy loss:

$$\frac{\omega d^4 \sigma^{rad}}{dx\, d^2 k_t\, dq_t^2} = \frac{N_c \alpha_s}{\pi^2} (1 - x) \cdot \frac{d\sigma^{el}}{dq_t^2} \cdot P_{rad}$$

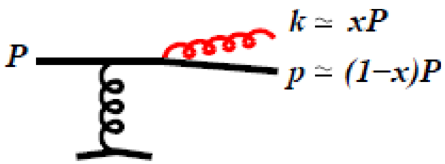
x=▯ /E

calculations without assumption $\sqrt{s} \to \infty$

$$M_{QCD} = M_{SQCD} \Big(1 - \frac{(\omega/E)^2}{(1-\omega/E)^2}\Big)$$

Landau Pomeranschuk Migdal Effekt (LPM)

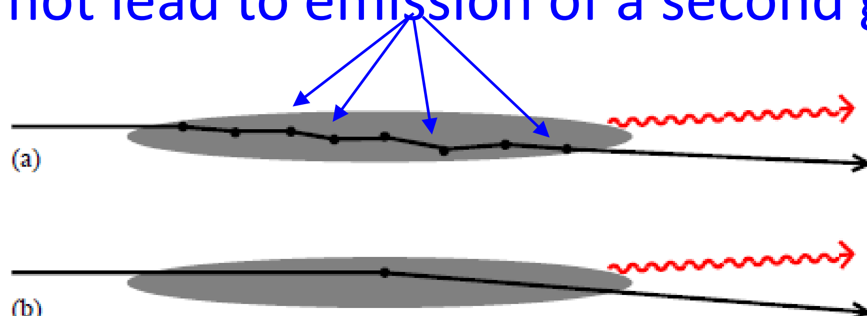
reduces energy loss by gluon radiation



Heavy quark radiates gluons

gluon needs time to be formed

Collisions during the formation time
do not lead to emission of a second gluon



emission of one gluon
(not N as Bethe Heitler)

(hep-ph/0204343)

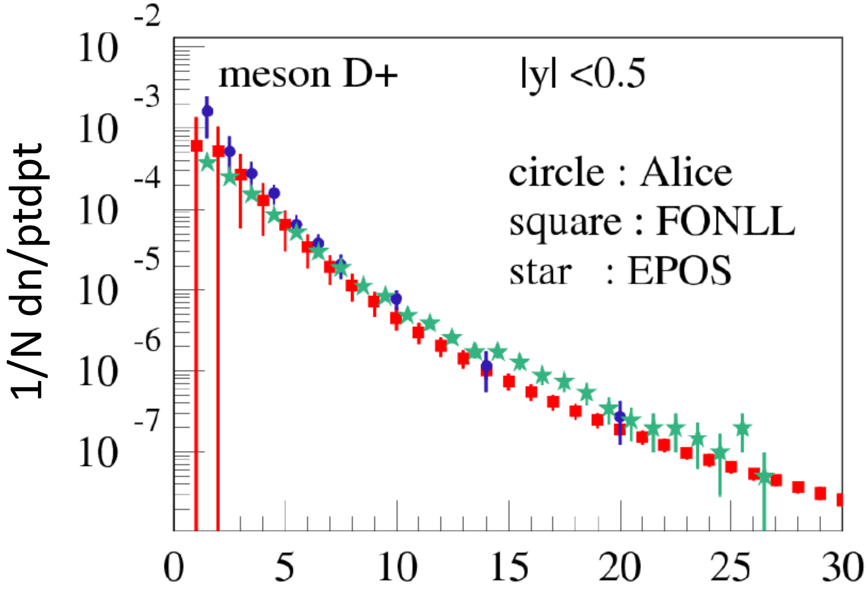
$$t_{form} = \frac{2(1-x)\omega}{\underbrace{\vec{k}_\perp^2}_{=t_{form}\hat{q}} + \underbrace{x^2m^2 + (1-x)m_g^2}_{\text{single scattering}}}$$

dominates x<1   dominates x≈1 dominates x<<1

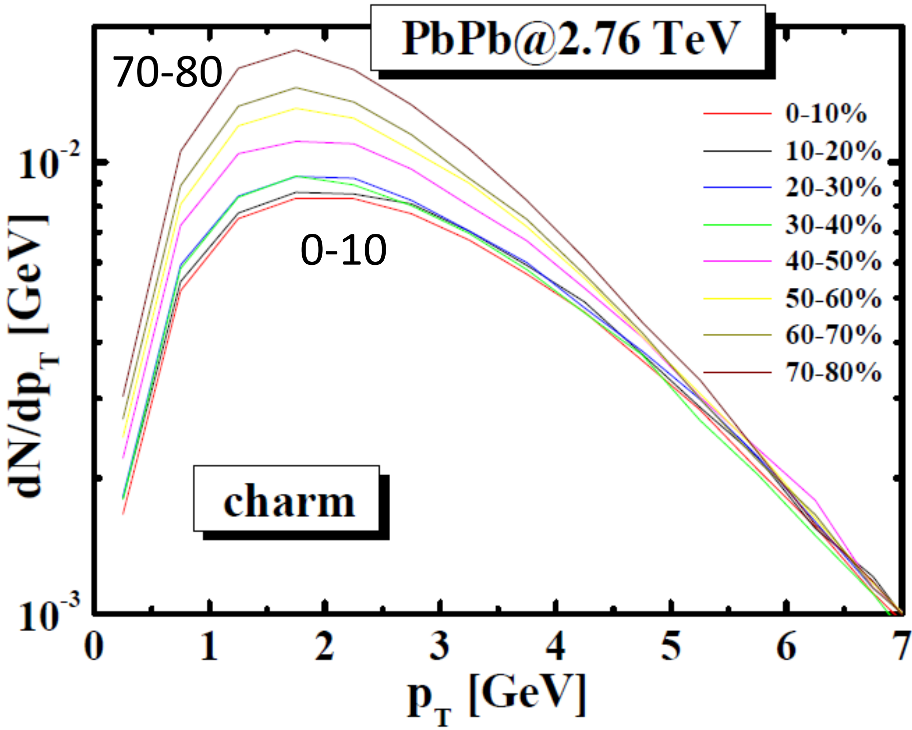
First results and comparison with data

Initial charm quark distribution

pp in comparison with Star data



centrality dependence of the p_T distribution of c-quarks



ALICE: D-meson in pp 5.07 TeV

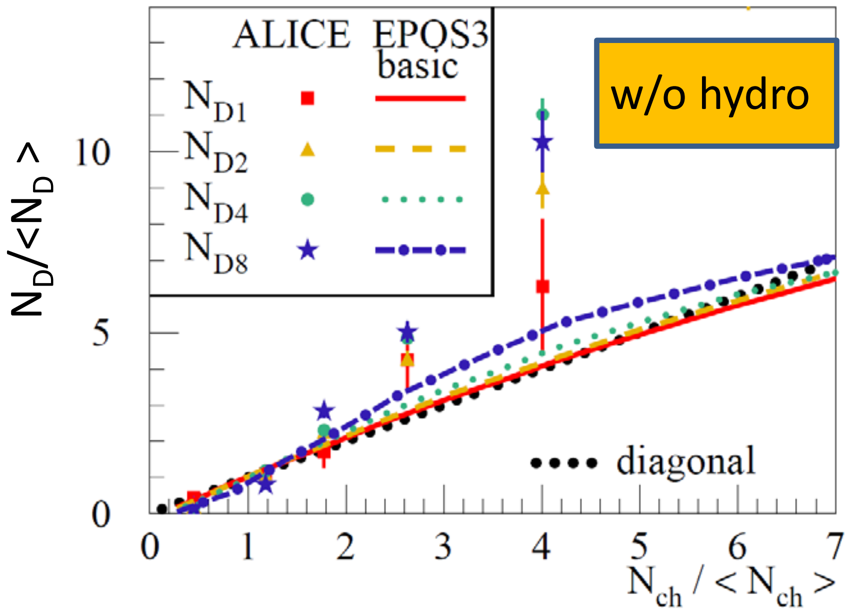
w/o hydro: linear increase

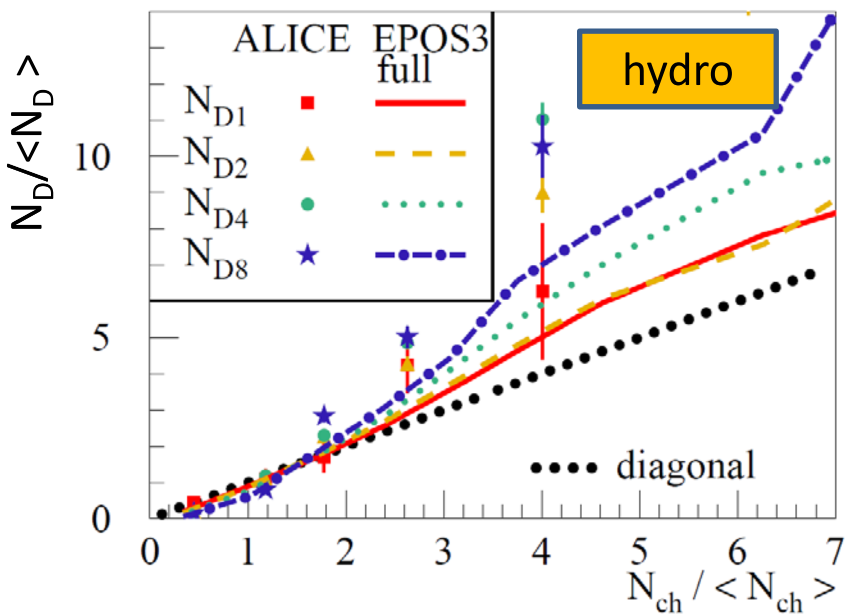
$$N_{D1} = 0 < p_t < 2\ GeV$$
$$N_{D2} = 2 < p_t < 4\ GeV$$
$$N_{D3} = 4 < p_t < 8\ GeV$$
$$N_{D4} = 8 < p_t < 12\ GeV$$

Hydro:
Significant non linear increase

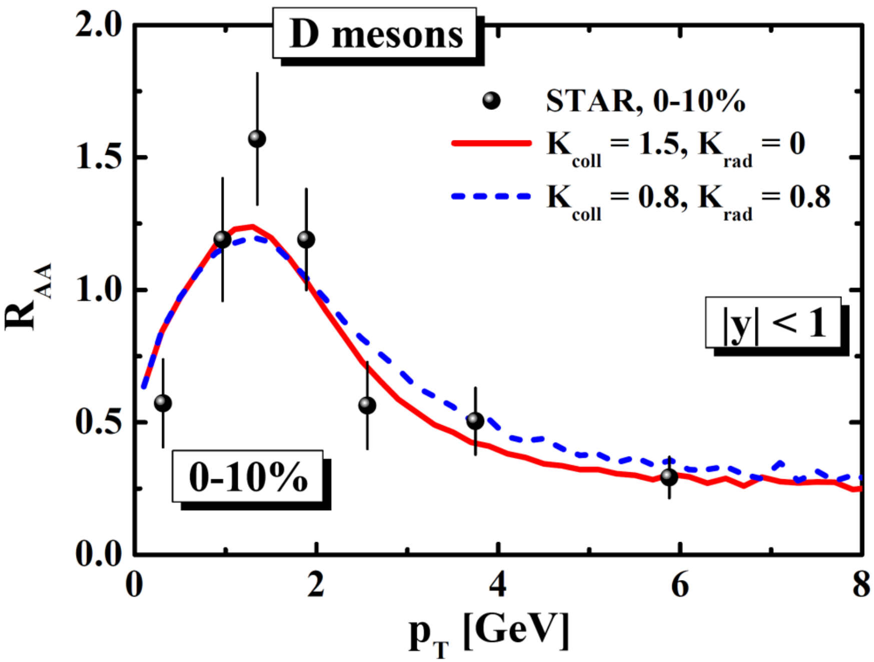
Bigger effect for high pt

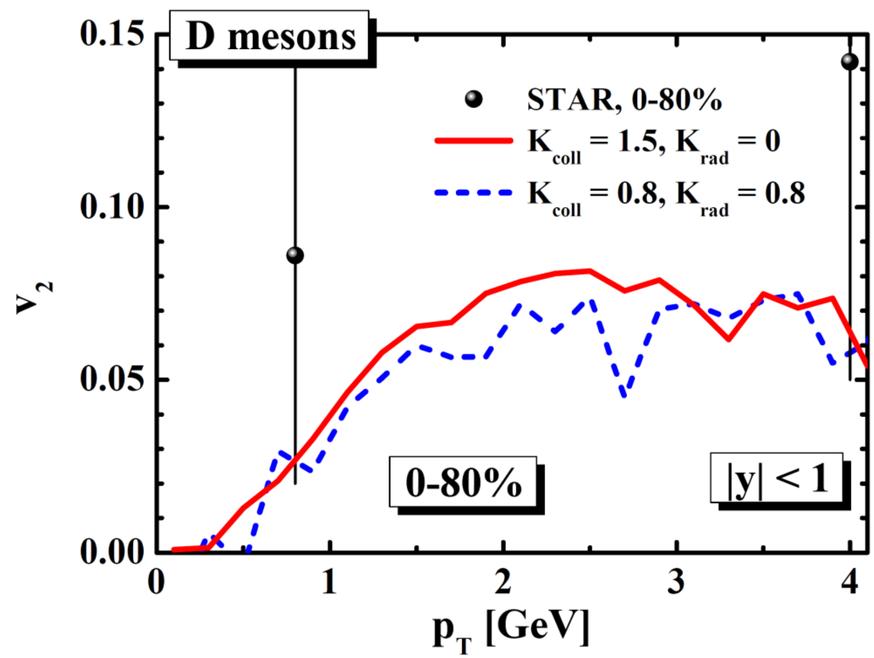
Reason: Reduction of N_{ch}





D mesons STAR collaboration





R_{AA} and v_2 simultaneously reproduced

Strong suppression of R_{AA} around 1-2 GeV due to shadowing

No form difference for

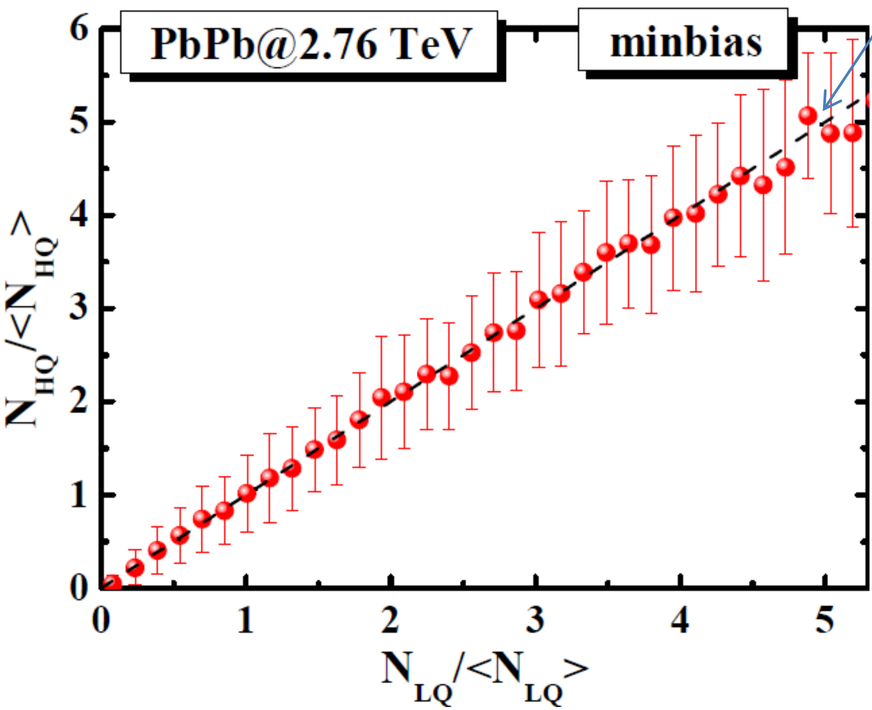
elastic or radiational energy loss

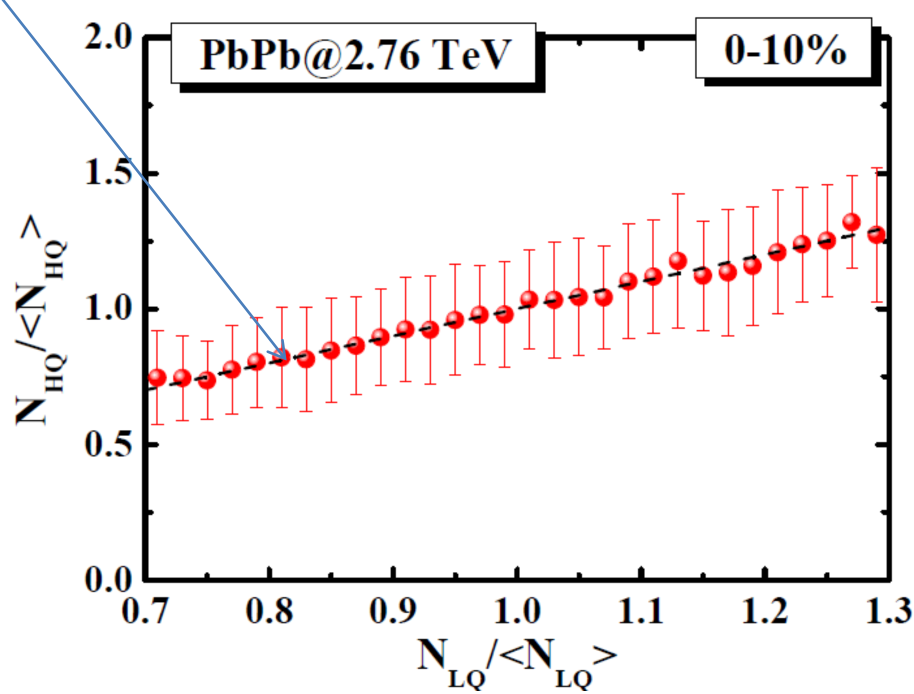
Initial correlations between light and heavy quarks?

EPOS-HQ: no initial state correlation between light and heavy mesons

no sequential scattering like in most of the other approaches

Dashed line = diagonal



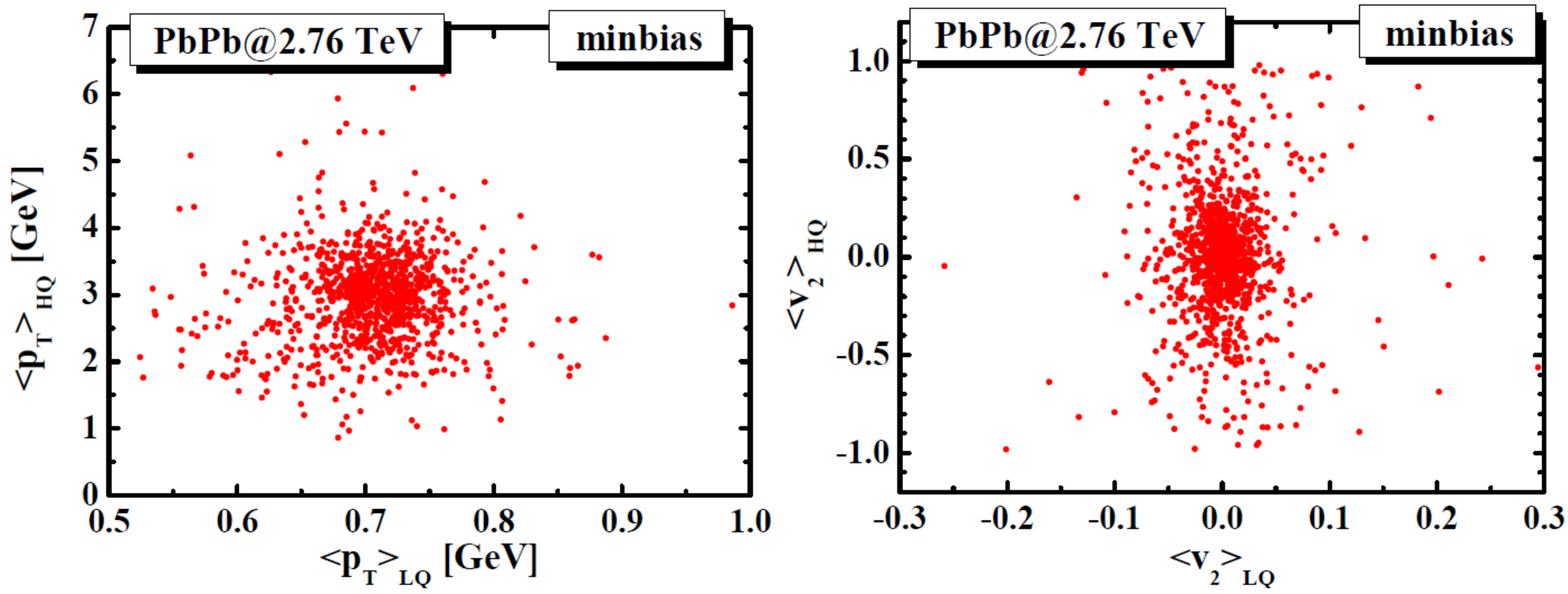


Also in momentum space (p_T or elliptic flow v_2)

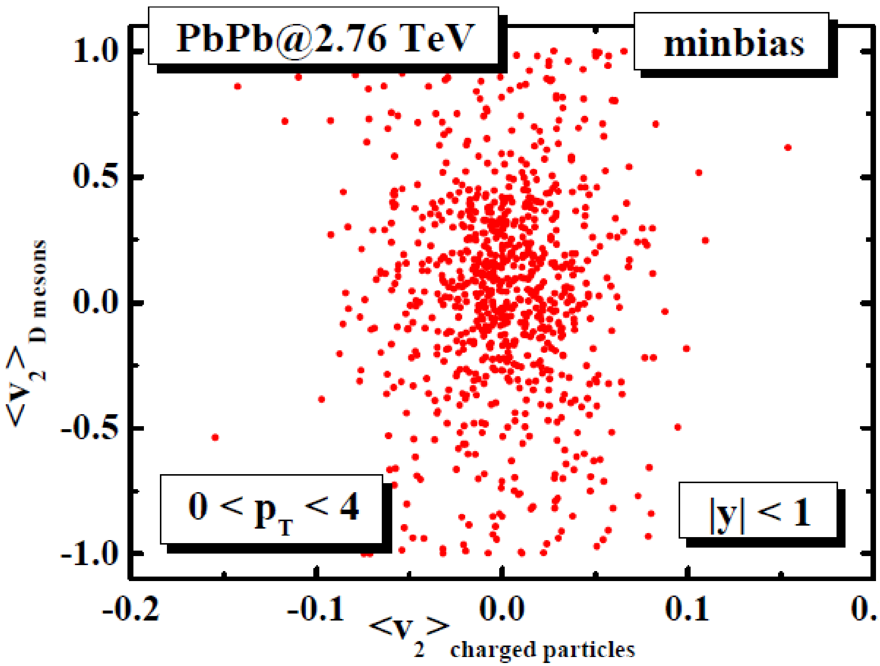
no initial state correlations

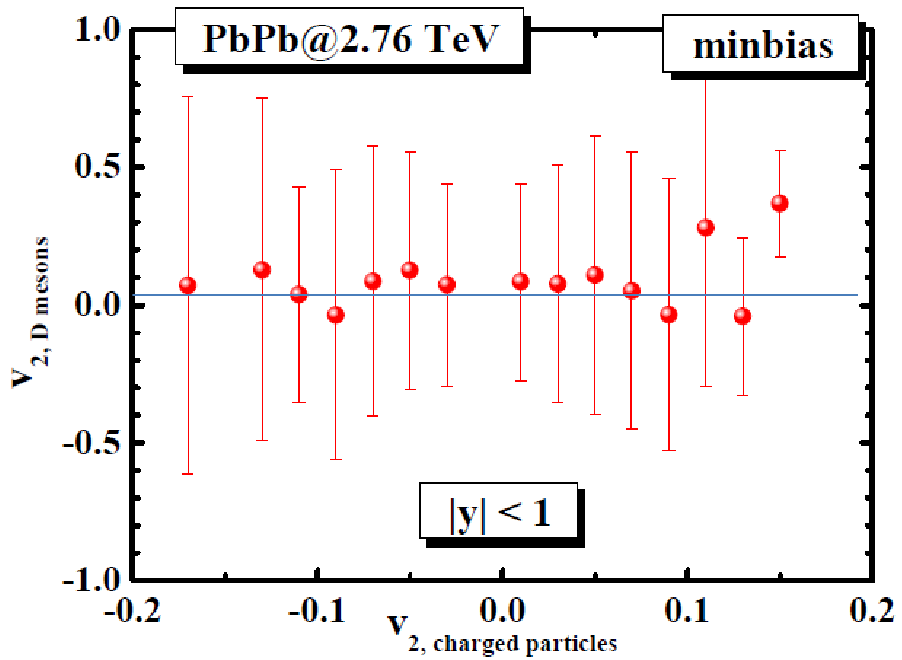
Large values of v_2 due to final particle number

$$v_2 \equiv \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2}$$



Event by event fluctuations of heavy and light meson v_2





E-by-e: v_2 of D mesons and of charged particles is not strongly correlated

but mean value of v_2 of heavy mesons equals mean value of v_2 of light mesons

Conclusions

First results from EPOS3- HQ (Heavy Quarks)

- use of an event generator which reproduces many features in the light hadron sector
- heavy quark production consistently calculated using Gribov Regge
- shadowing automatically included
- reproduces at RHIC R_{AA} and v_2 simultaneously
- v_2 , multiplicity and p_T of heavy and light quarks initially and finally not correlated

Many things remain to be done (which require very long computation time) but the foundation is laid.