Heavy flavour R_{AA}:
mass dependence of energy loss and recombination

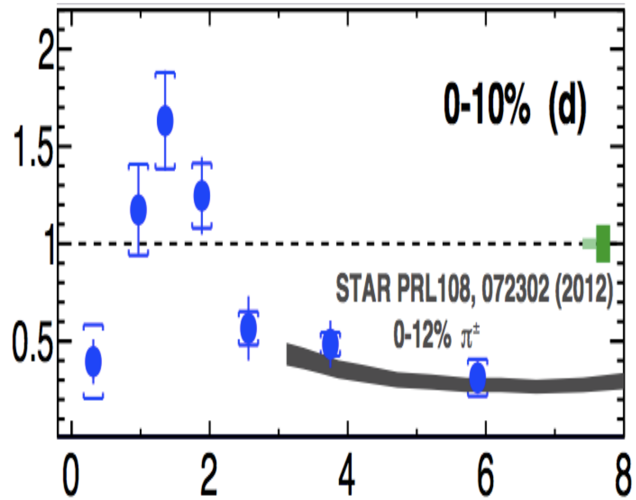
Andrea Dainese (Padova), Francesco Scardina (Catania)

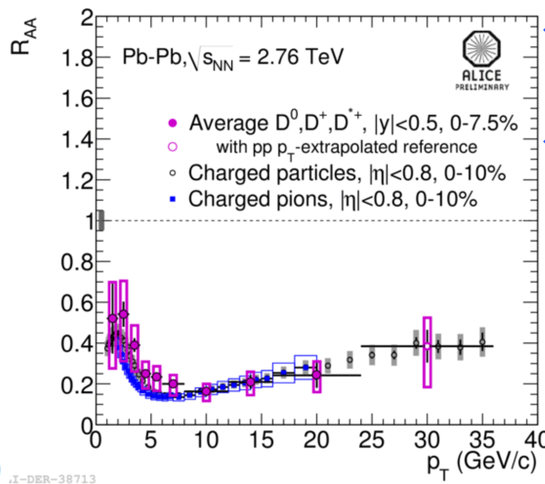
What do we learn from existing data? What can future measurements provide?

- Energy loss / interaction mechanisms:
  - Colour charge dependence of radiative E loss?
  - Mass dependence of E loss?
  - Radiative vs. collisional E loss?
  - Collisional E loss: Brownian motion?

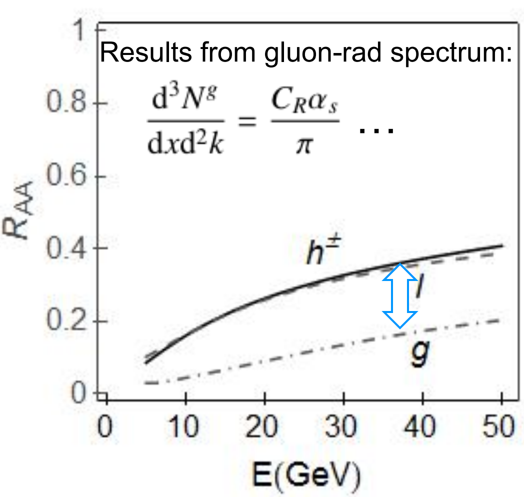
- Collectivity and hadronization:
  - Radial flow?
  - HQ coalescence?

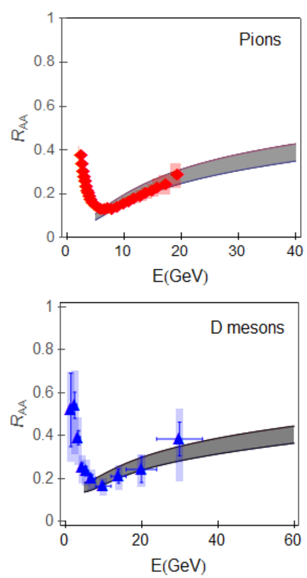
Energy loss mechanisms: Colour charge dependence





- D consistent with pions for p_T>5-6 GeV
- Many other effects below 5 GeV
  - Flow, Coal, Shad, Soft pions, …





M. Djordjevic and M. Djordjevic, PRL112 (2014) 042302

- Calculation by M. Djordjevic (rad+coll energy loss) can describe both R_{AA}
- And shows strong colour charge effect in partonic R_{AA} (g vs. light and c)
- Conclusive?

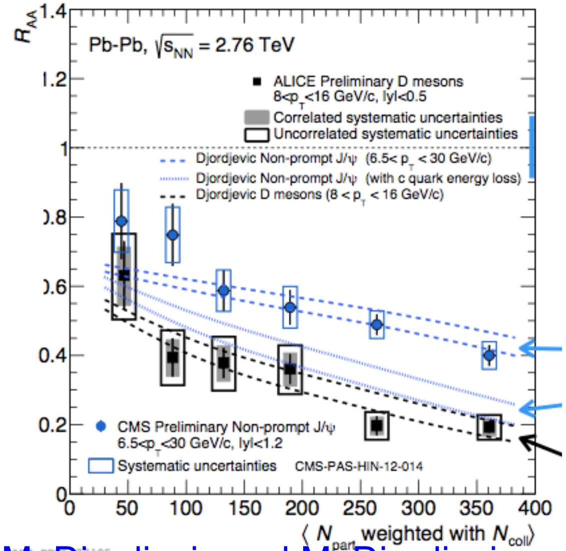
Outlook/Questions:

- LHC Run-2 and RHIC vtx dets will provide better measurements, but there may not be a "data-only" evidence
- can we just "assume" that gluon-rad is prop to C_R?
- can it be seen in LF R_{AA} (e.g. π vs p)?

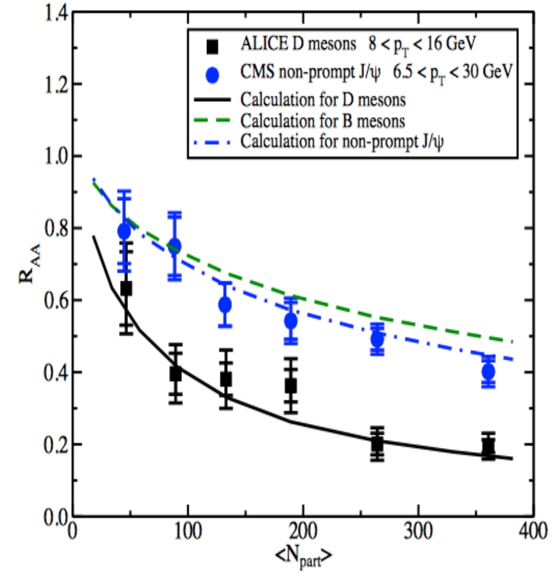
Energy loss mechanisms: Mass dependence

Similar <p_T> for B and D:

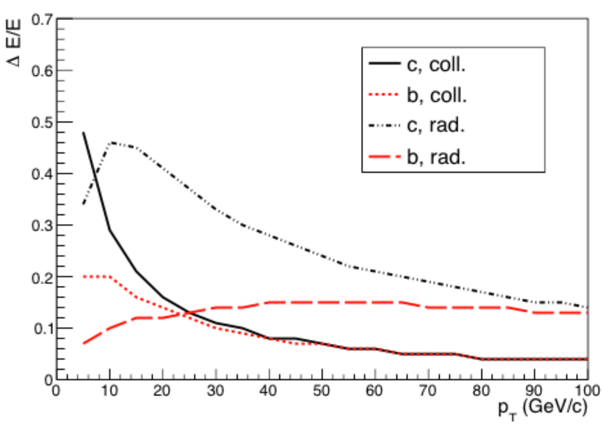
- B <p_T> ~ 11 GeV (FONLL+EvGen)
- D <p_T> ~ 10 GeV



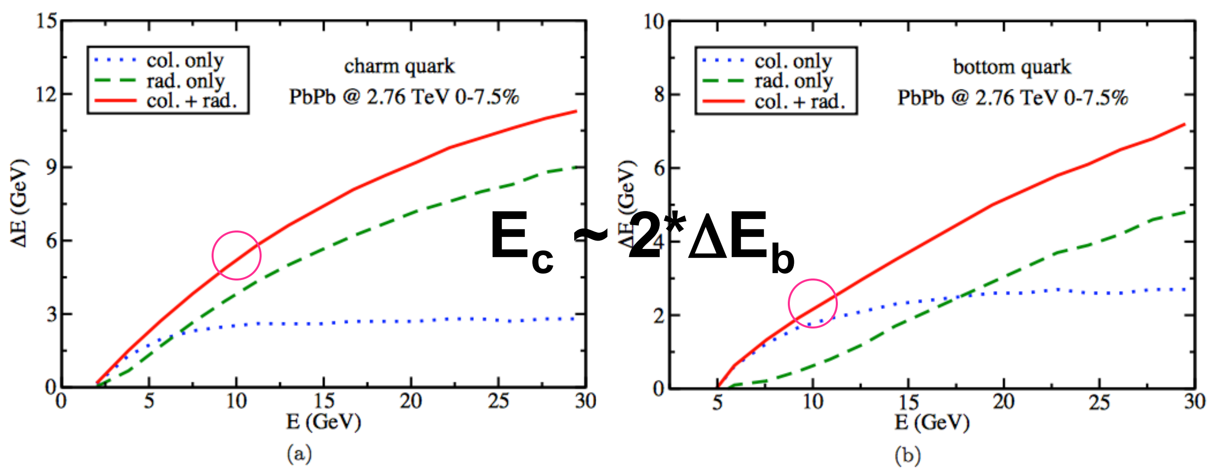
M. Djordjevic and M. Djordjevic, PRL112 (2014) 042302



Cao et al. 1505.01413



M. Djordjevic



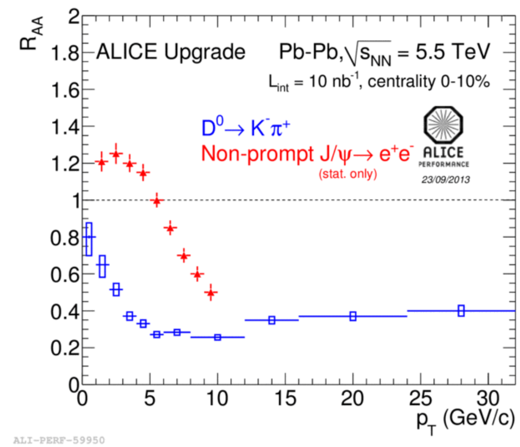
$E_c \sim 2^*\Delta E_b$

Cao et al. 1505.01413

Energy loss mechanisms: Mass dependence

Outlook/Questions:

- Future LHC and RHIC runs will allow to study p_T-dependence down $p_T \sim 0$.
- What can a precise measurement tell us about the gluon-radiation mechanism? Info on formation time and angular distr. of radiated gluons?



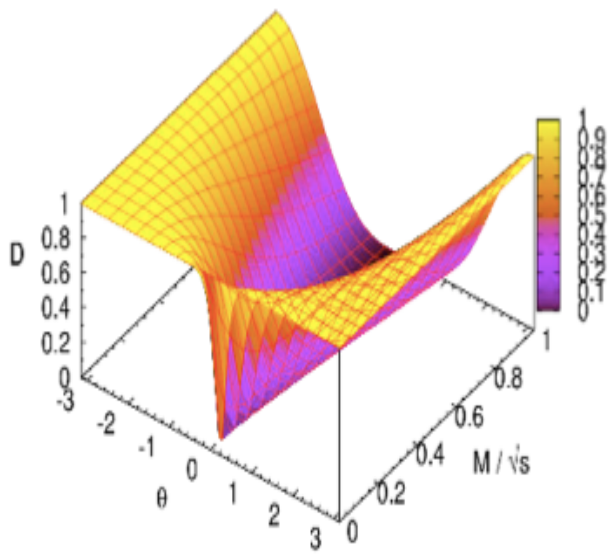
Is there a "dead cone"?

More accurate: valid for all order of mass M and also for large angles

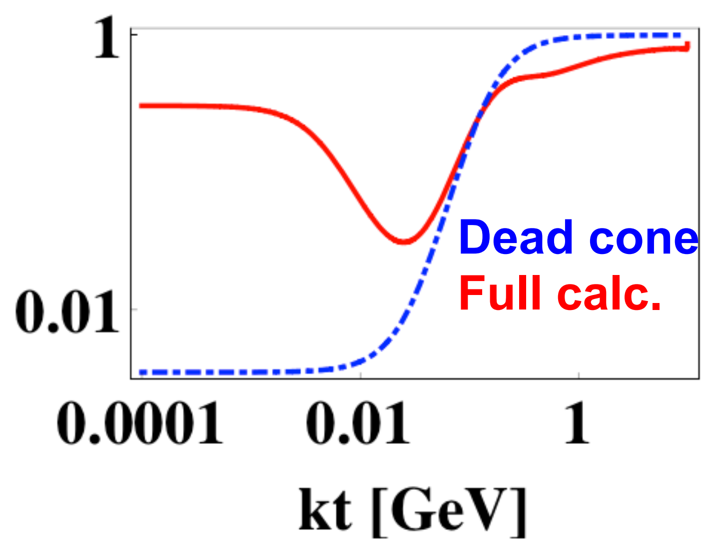
$$\mathcal{D} = \frac{1}{1 + \frac{M^2}{s \tan^2(\frac{\theta}{2})}}$$

Abir, Greiner, Martinez, Mustafa, JU, Phys.Rev. D85 (2012)

Uphoff (QM14)



Or is it partially "filled"?



J. Aichelin et al. PRD89 (2014)

R_{AA} gives information on the strength of the interaction and on the mass dependence of the energy loss but does not give information on the microscopical details of the interaction:

- ✓ **HQ undergone to a Brownian motion?**
- ✓ **Temperature dependence of the energy loss? (see Greco's Talk)**
- ✓ **Collisional vs radiative?**

HQ undergone to a Brownian motion?

Boltzmann Eq. $$\left(\frac{\partial}{\partial t}+\frac{P}{E}\frac{\partial}{\partial x}\right)f(x,p,t)=C_{22}$$

$$C_{22}=\int d^3k\left[\omega(p+k,k)f(p+k)-\omega(p,k)f(p)\right]$$

K momentum transfered
P momentum of the charm

If |k|<< |P| <-> (the motion is Brownian)

C_{22} can be expandend in terms of k up to 2° order

$$\omega(p+k,k)f(p+k)\approx\omega(p,k)f(p)+k.\frac{\partial}{\partial p}(\omega f)+\frac{1}{2}k_ik_j\frac{\partial^2}{\partial p_i\partial p_j}(\omega f)$$

One gets the Fokker Plank equation

We have done a systematic comparison between F-P and BM approach

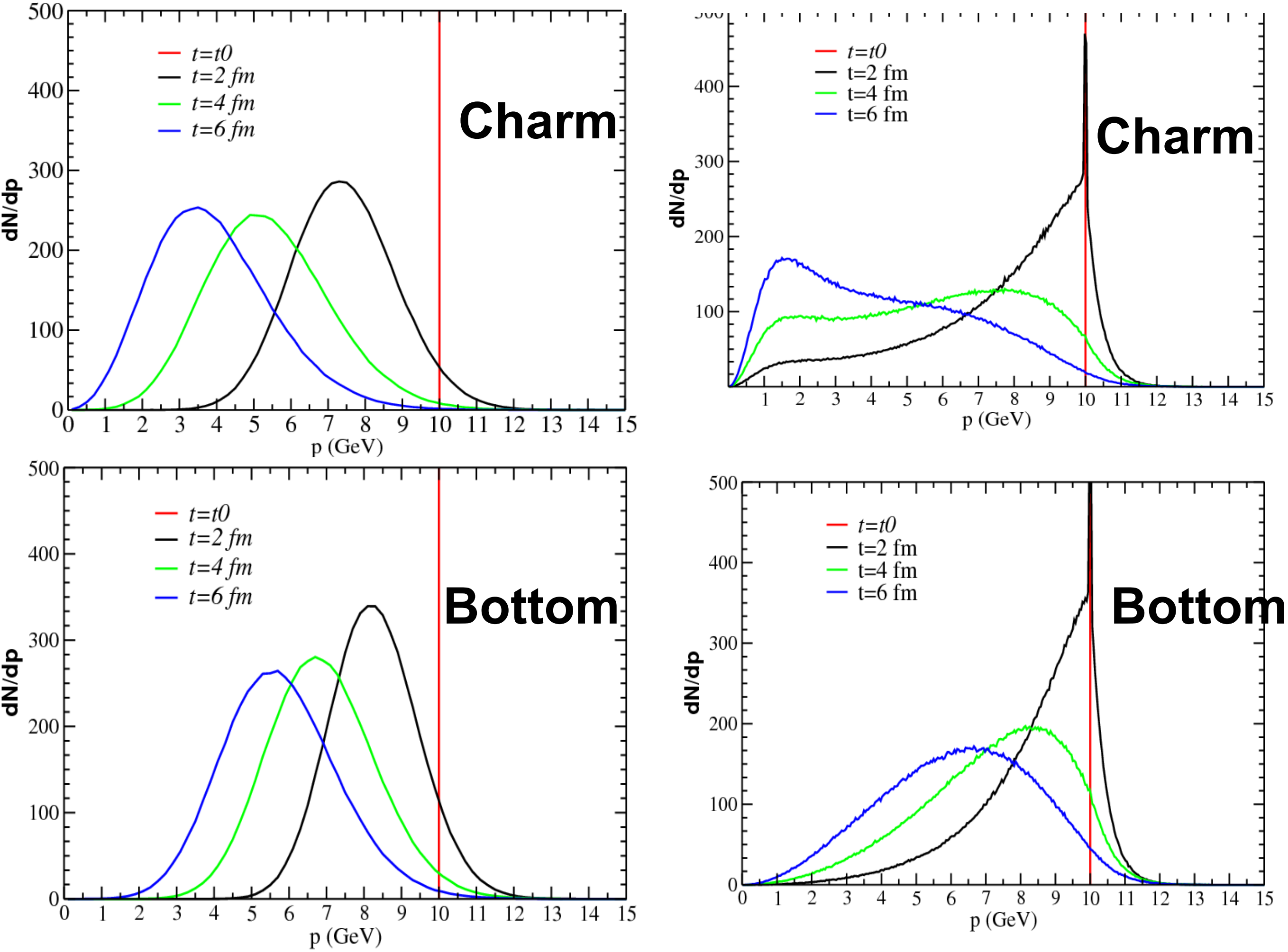
The more one looks at differential observables the larger is the difference between the two approaches

[S. K. Das , F. Scardina, V. Greco PRC90 044901 (2014)]

[F. ScardinaJ.Phys.Conf.Ser. 535 (2014) 012019]

Energy loss of a single HQ

Langevin **Boltzmann**



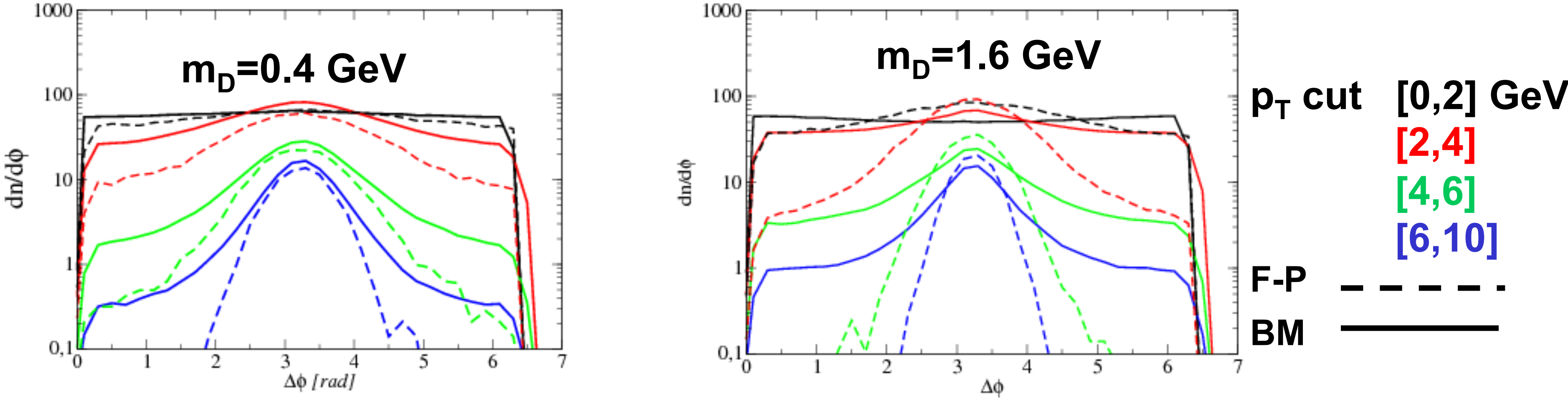
T=400 MeV
Mc/T≈3 Mb/T≈10

Charm motion -> No Brownian
Bottom motion -> Brownian

Back to back correlation observable could be sensitive to such a detail

cc angular correlations

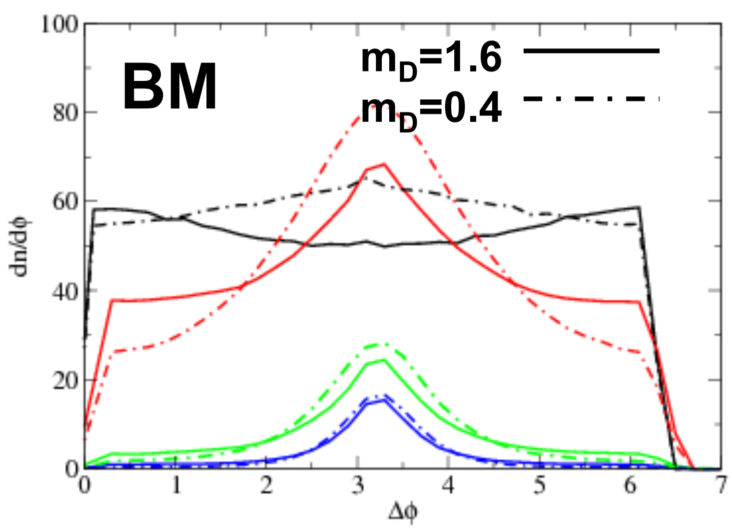
Same R_{AA} for the two cases



cc angular correlations are sensitive to the microscopic detail of the interactions

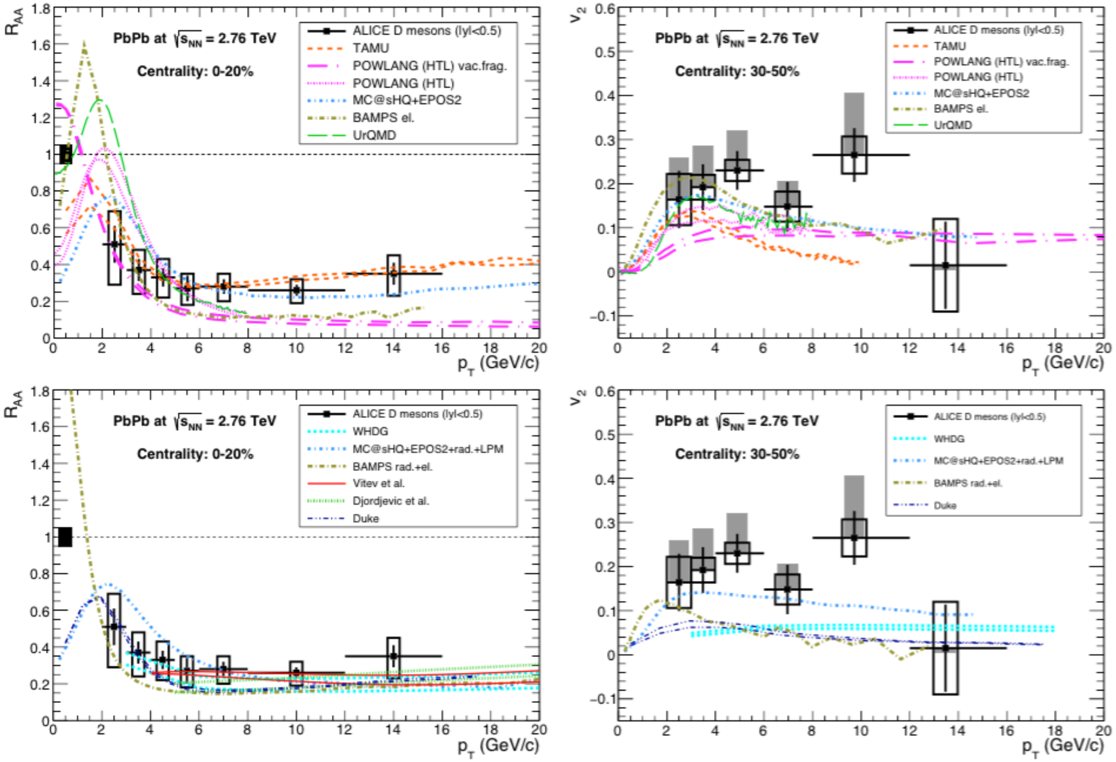
- HQ motion is Brownian?
- Debye screening mass
- Radiative vs coll energy loss

For m_D=1.6 we observe the partonic wind effect (enhancement of the azimuthal correlations in the region of $\Delta\phi$=0) with the BM and not with the LV.
[X. Zhu et al PRL 100, 152301 (2008)]



In which momentum range measures of c-c angular correlations can be done?

Energy loss mechanisms: Radiative vs Collisional



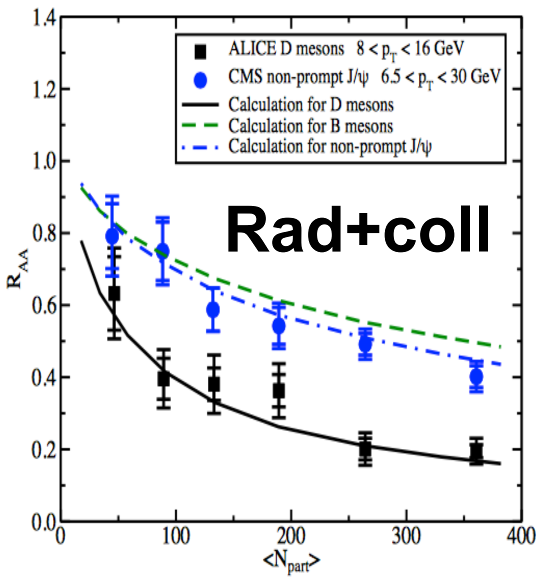
Coll. only

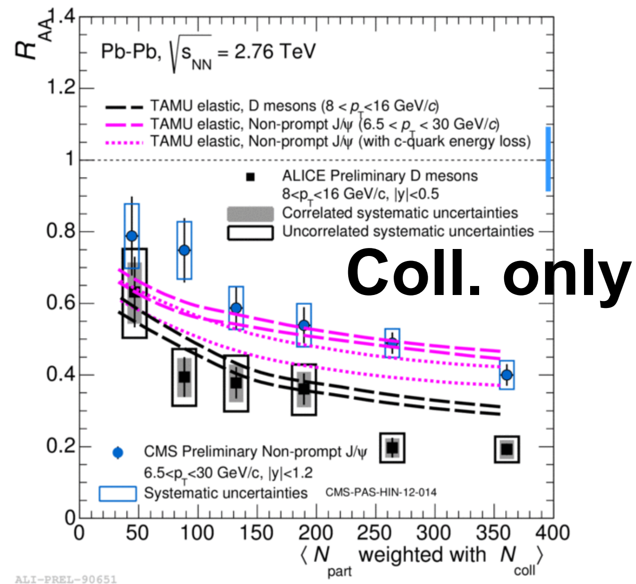
Rad+Coll

- Current R_{AA} and v_2 measurements: models with rad+coll have more difficulties to get a large v_2, but current exp. unc. on v_2 prevent a strong conclusion
- Run2: expect to reduce uncertainties on v_2 by a factor about 2
- High precision measurements in Run3 after upgrade

Energy loss mechanisms: Radiative vs Collisional

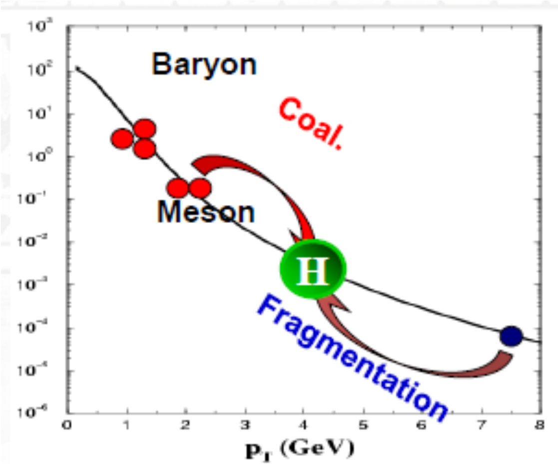
- Can the models with only collisional describe the difference between R_{AA}^{D} and $R_{AA}^{npJ/\psi}$?

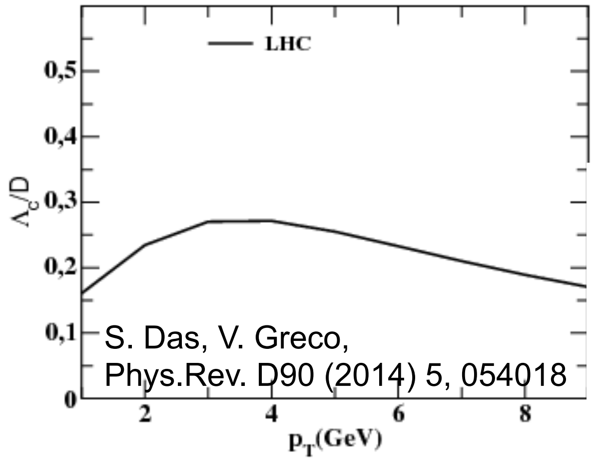




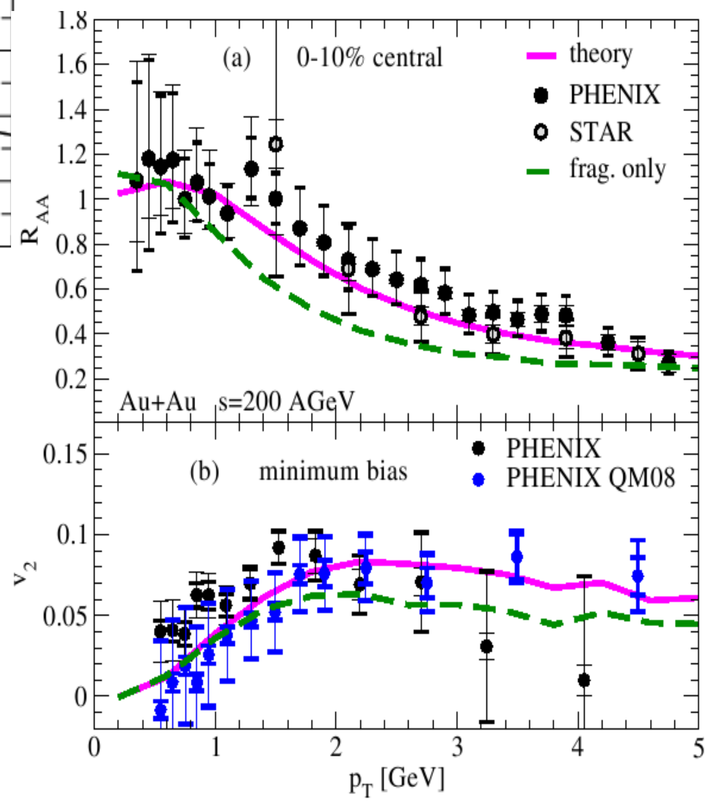
- Run2, Run3: Precise measurements over extended p_T range for R_{AA} and v_2 of charm and beauty → can this constrain the pT-dependent role of rad and coll E loss?
- HQ correlations expected to be sensitive
  → See talk by Rossi & Nardi

Coalescence





$$\frac{d^3N_{D,B}}{d^3P} = C_{D,B}\int_{\Sigma} f_{c,b}\otimes f_{\bar{q}}\otimes \Phi_M + \int_{\Sigma} f_{c,b}\otimes D_{c,b\to D,B}$$



The difference with light quark

Coalescence occurs between particles with equal velocities: for light quarks equal v means equal p_T; that's not true for coalescence between light and HQ.

$$v_{2,M}(p_T) = 2v_{2,q}(p_T/2) \qquad v_{2,B}(p_T) = 3v_{2,q}(p_T/3)$$

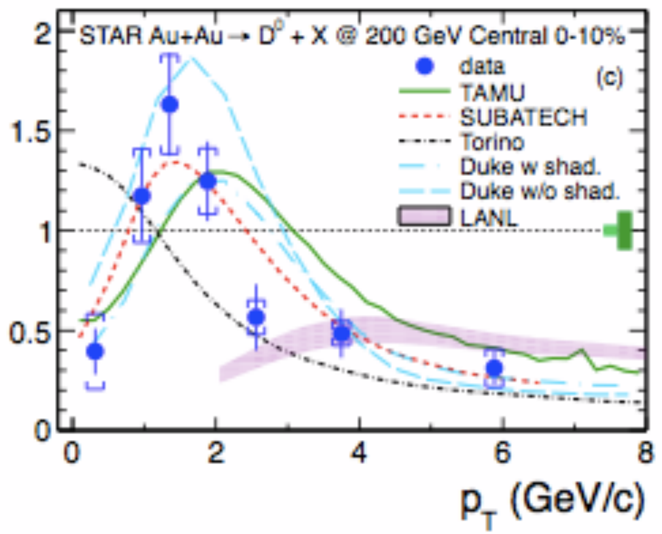
$$v_{2,D}(p_T) = v_{2,C}(5p_T/6) + 2v_{2,q}(p_T/6)$$

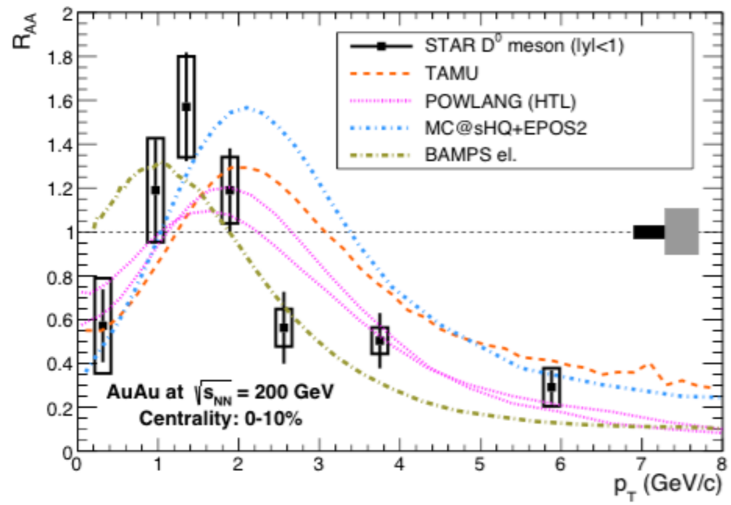
$$v_{2,D}(p_T) = v_{2,C}(5p_T/7) + 2v_{2,q}(p_T/7)$$

Coalescence increases both R_{AA} and v_2 toward agreement with data

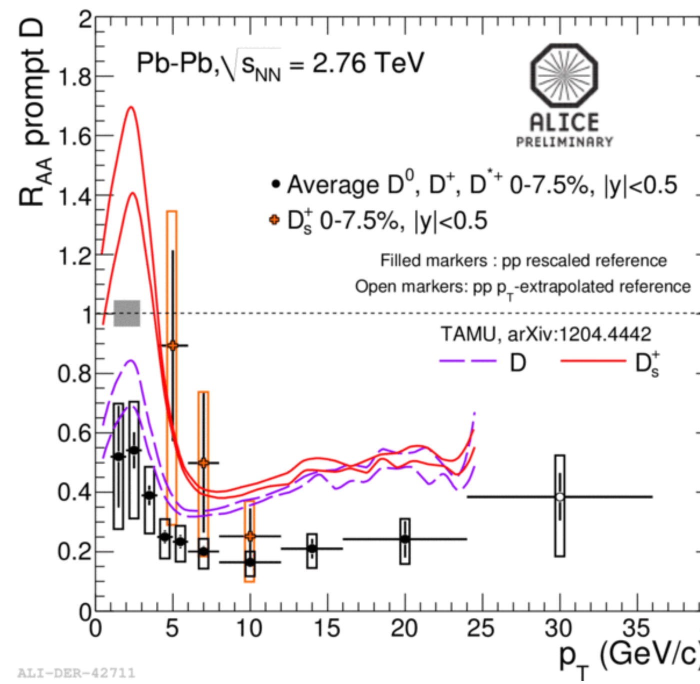
Is it possible to measure v_n for HQ?

HF R_{AA}: Radial Flow? Coalescence?





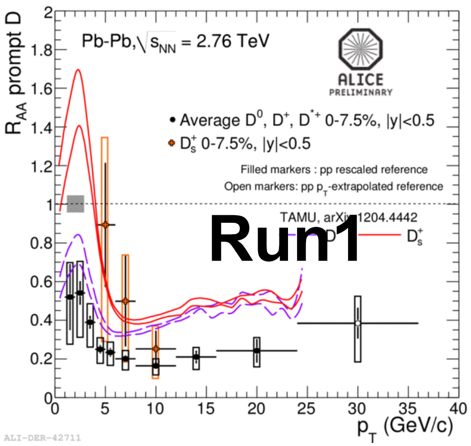
- Is the "R_{AA} bump" at RHIC due to flow and coalescence?
- Does it require both effects?
  - Models without coalescence don't get a bump? BAMPS doesn't have coalescence…
  - POWLANG gets a better description after including coalescence
  - Check by switching off coalescence in the other models?
- Is the ALICE D_s a hint for coalescence?



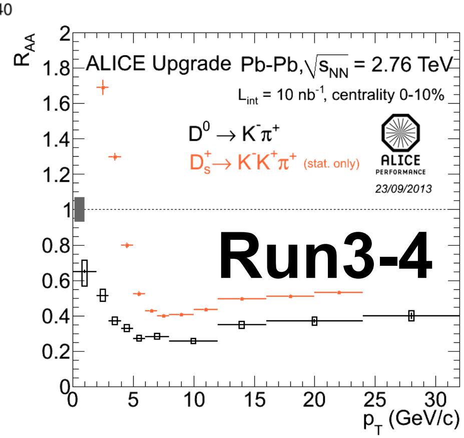
HF R_{AA}: Radial Flow? Coalescence?

- Future LHC and RHIC runs: add beauty, D_s, Λ_c
- e.g. D, D_s, Λ_c: relatively close mass (1.7-2.2), very different quark content; same for B and B_s
- Need model calculations: e.g. can the D_s and Λ_c measurements discriminate between flow (c and uds contributions) and coalescence?

D_s



Run2:
Errors reduced by factor 2-3



Λ_c/D