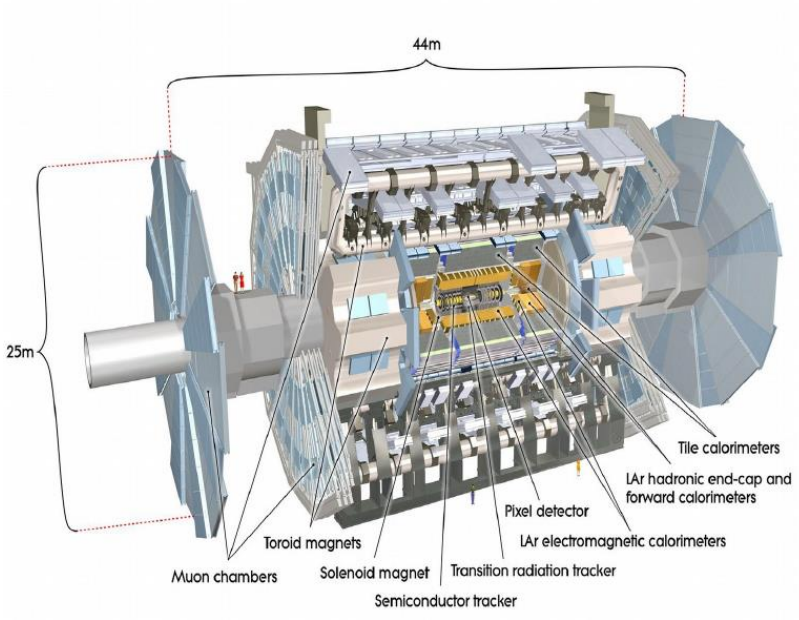
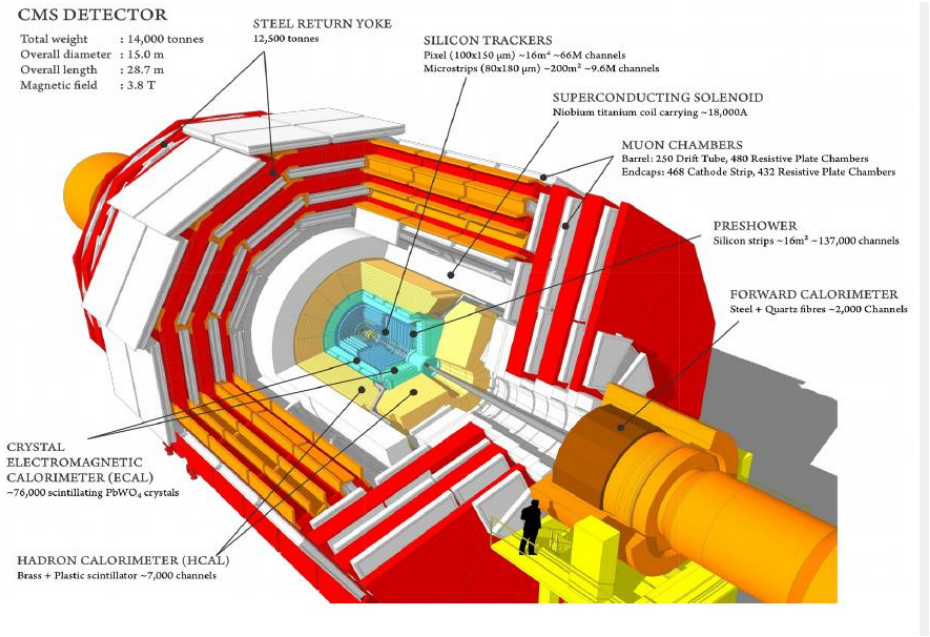
Recent results on heavy flavor in small and large systems from ATLAS and CMS

Alexandre Lebedev for the ATLAS and CMS collaborations





VIII Annual Conference on Large Hadron Collider Physics, May 25-30, 2020, Online

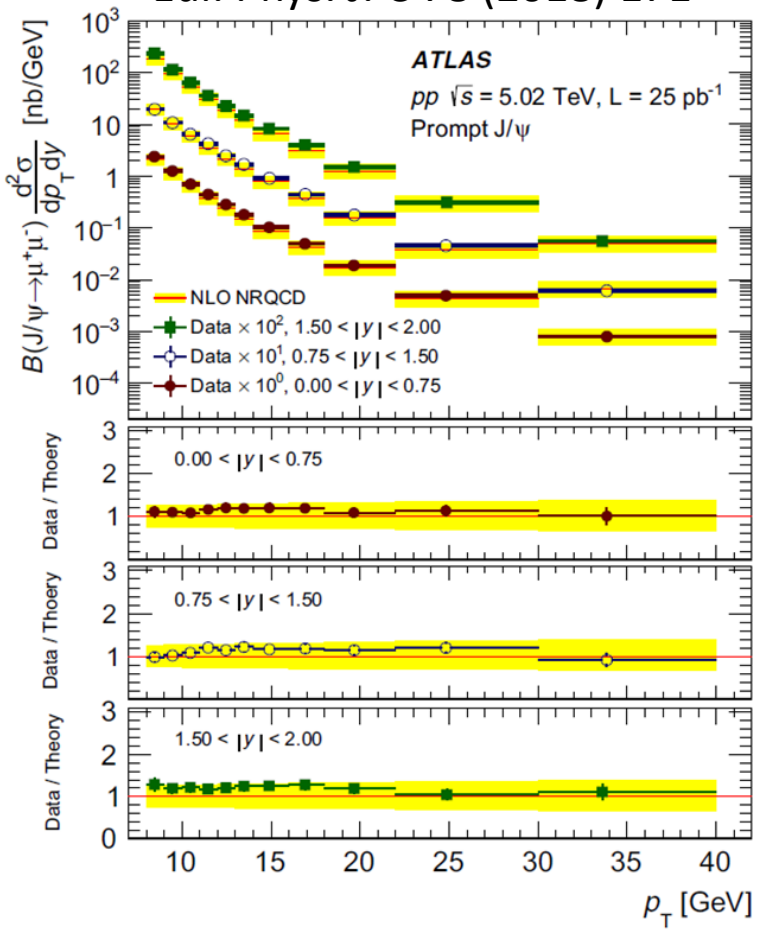
Why heavy quarks?

- Heavy quarks are produces in initial hard scatterings
  - carry information about all stages of the collision
  - production can be calculated with pQCD ($m_b > m_c > \Lambda_{QCD}$)
- Probe QGP through energy loss mechanisms
  - collisional + radiative
  - mass hierarchy, flavor dependence.
- Keep identity after hadronization
- Possible probe for strong short-lived EM field

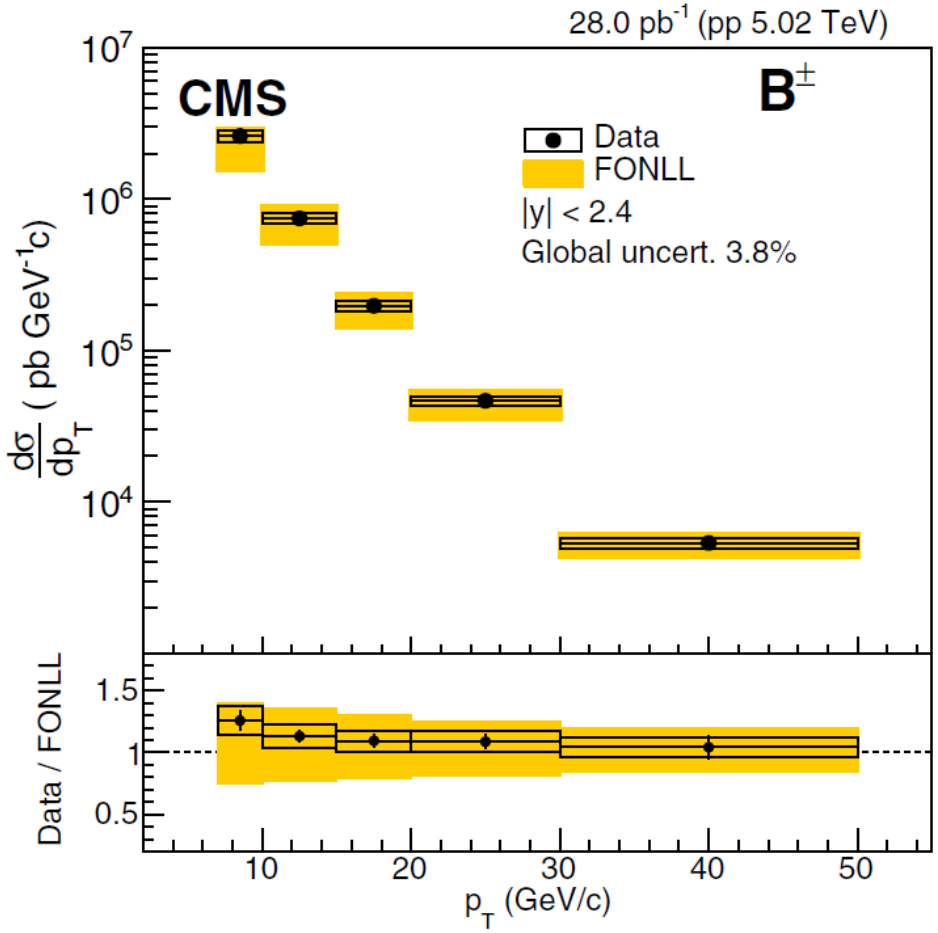
Open heavy flavor

Heavy flavor in p+p

Eur. Phys. J. C 78 (2018) 171



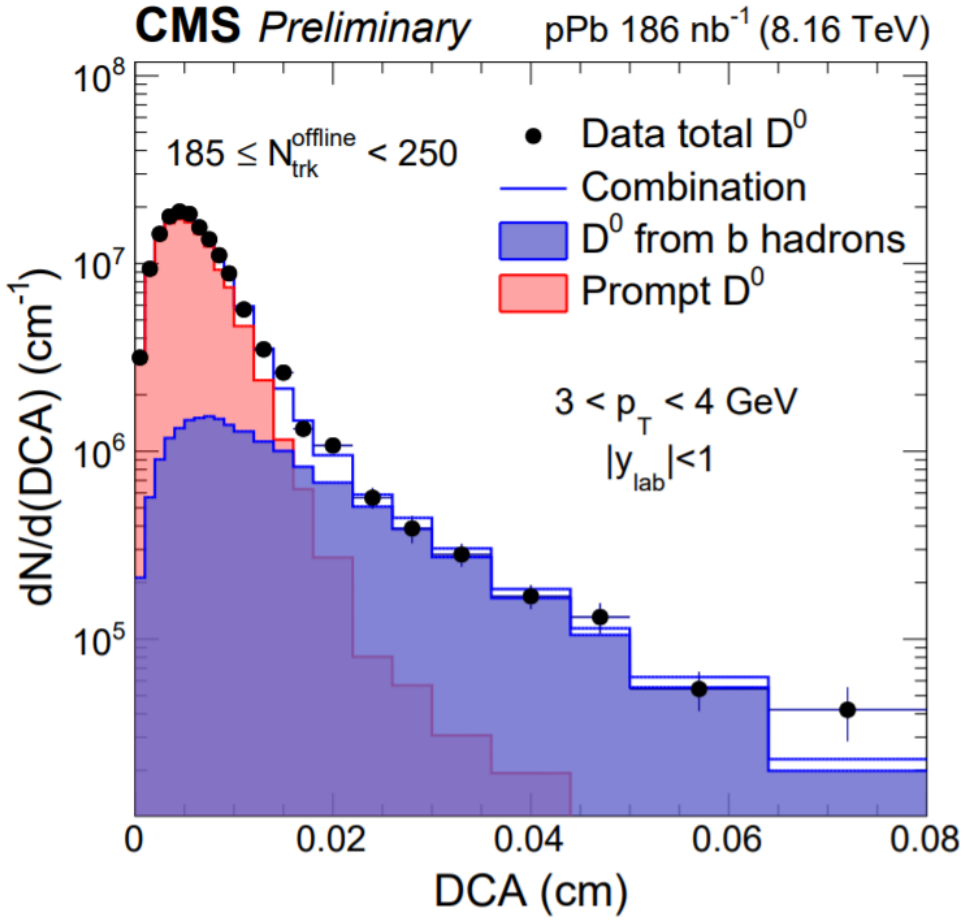
PRL 119, 152301 (2017)

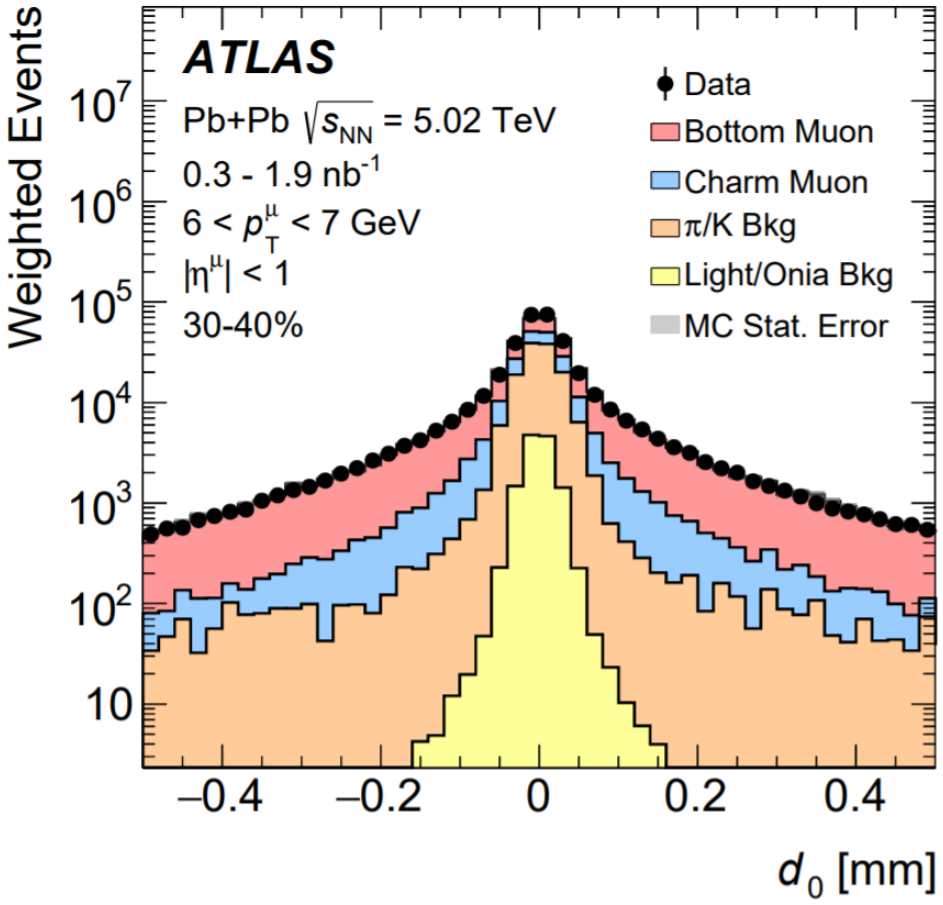


- General features of heavy flavor production are more-or-less well understood in p+p, although theory uncertainties are rather large.
- Baseline for nucleus-nucleus collisions study

Heavy flavor analysis using DCA

- Charm, beauty and light flavors are separated using Distance of Closest Approach (DCA) distribution unfolding with templates obtained from MC.
- Based on difference of lifetimes for charm and beauty mesons.

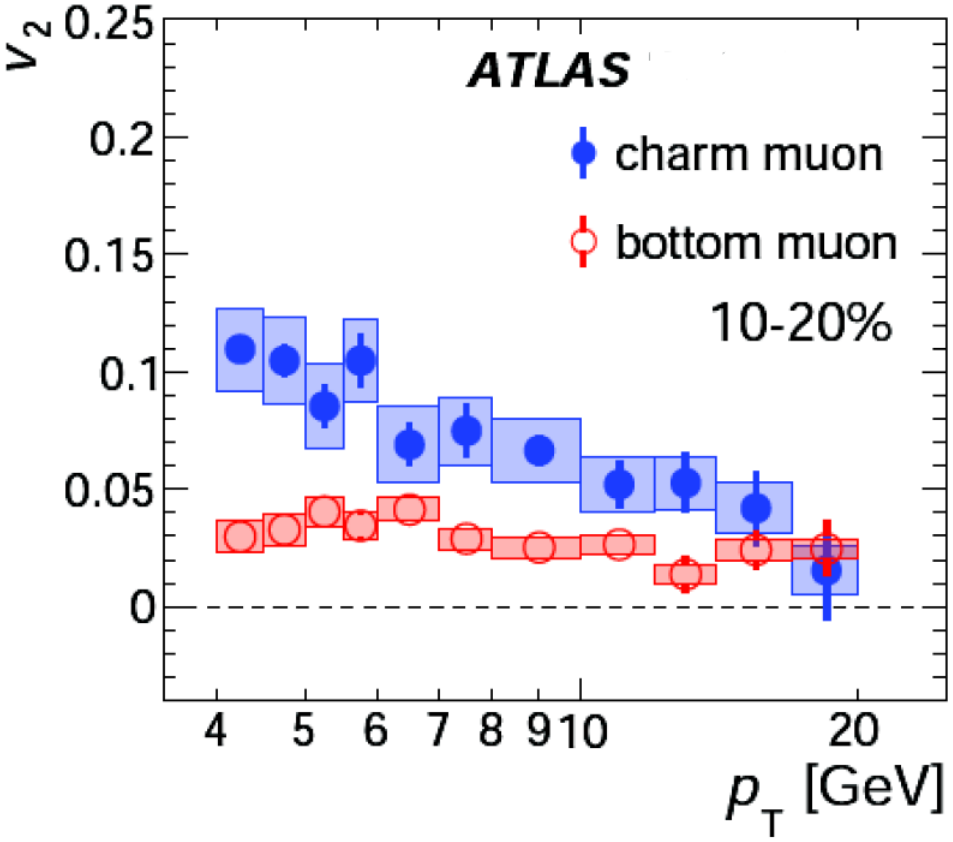


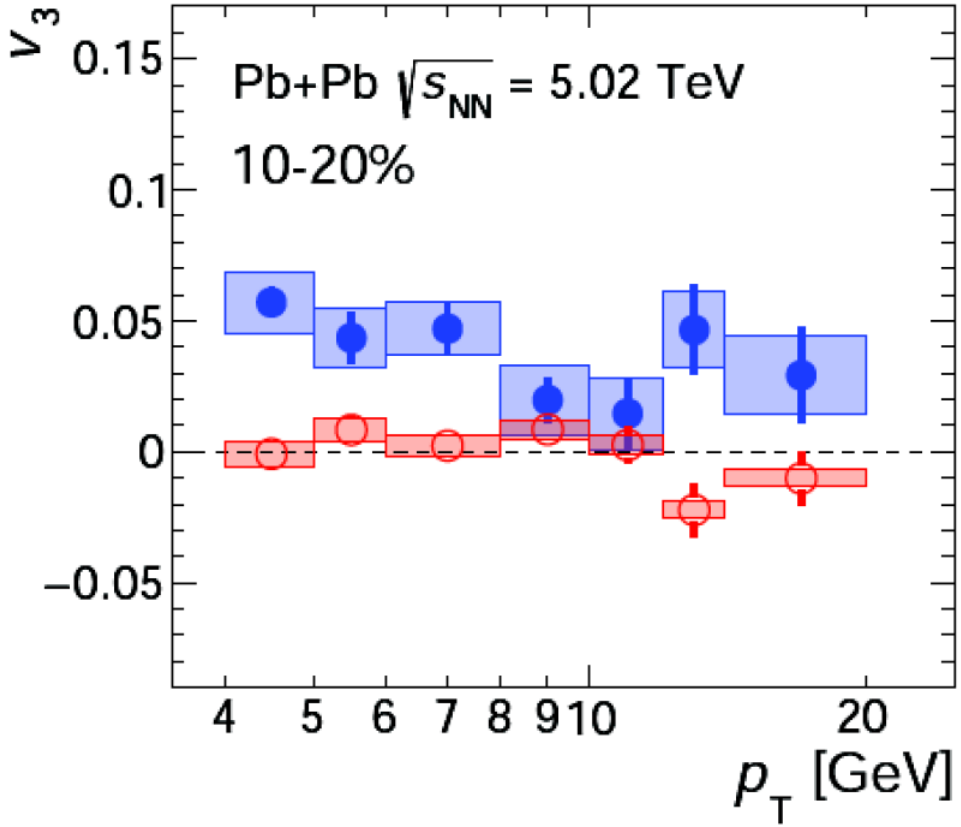


Charm and beauty flow in Pb+Pb

Muons from HF decays

arXiv:2003.03565





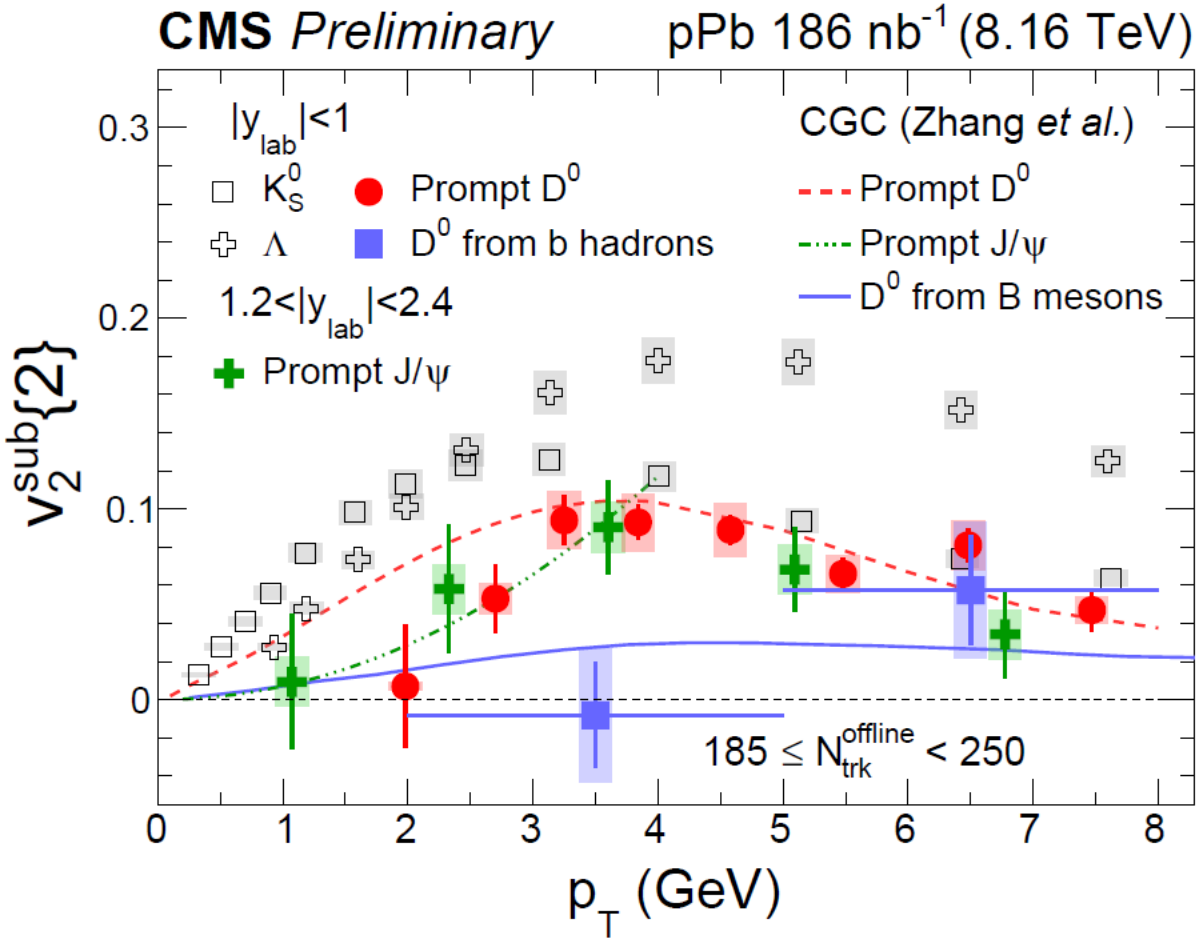
Charm: non-zero v_2 and v_3 up to 20 GeV/c

Beauty: smaller but non-zero v_2

First measurement of beauty v_3 consistent with zero at all centralities.

Heavy flavor flow in p+Pb

CMS-PAS-HIN-19-009



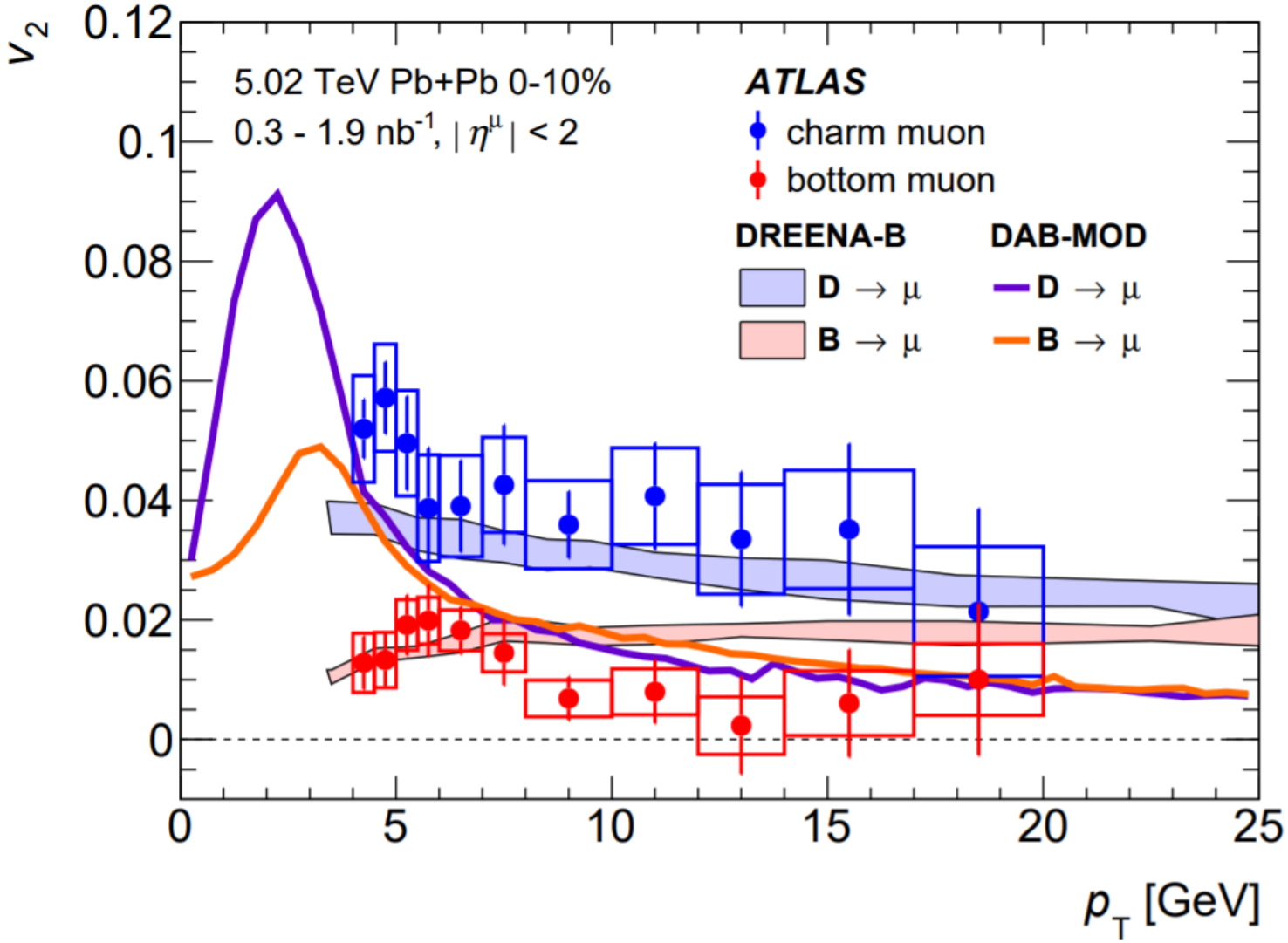
Charm flow in p+Pb (prompt D^0)
similar to that of hidden flavor (prompt J/ψ).

Beauty flow in p+Pb (non-prompt D^0):
First measurement: consistent with zero at low p_T, consistent with prompt D^0 (charm) at high p_T.

CGC model reasonably consistent with data

Theory comparison for Pb+Pb

arXiv:2003.03565

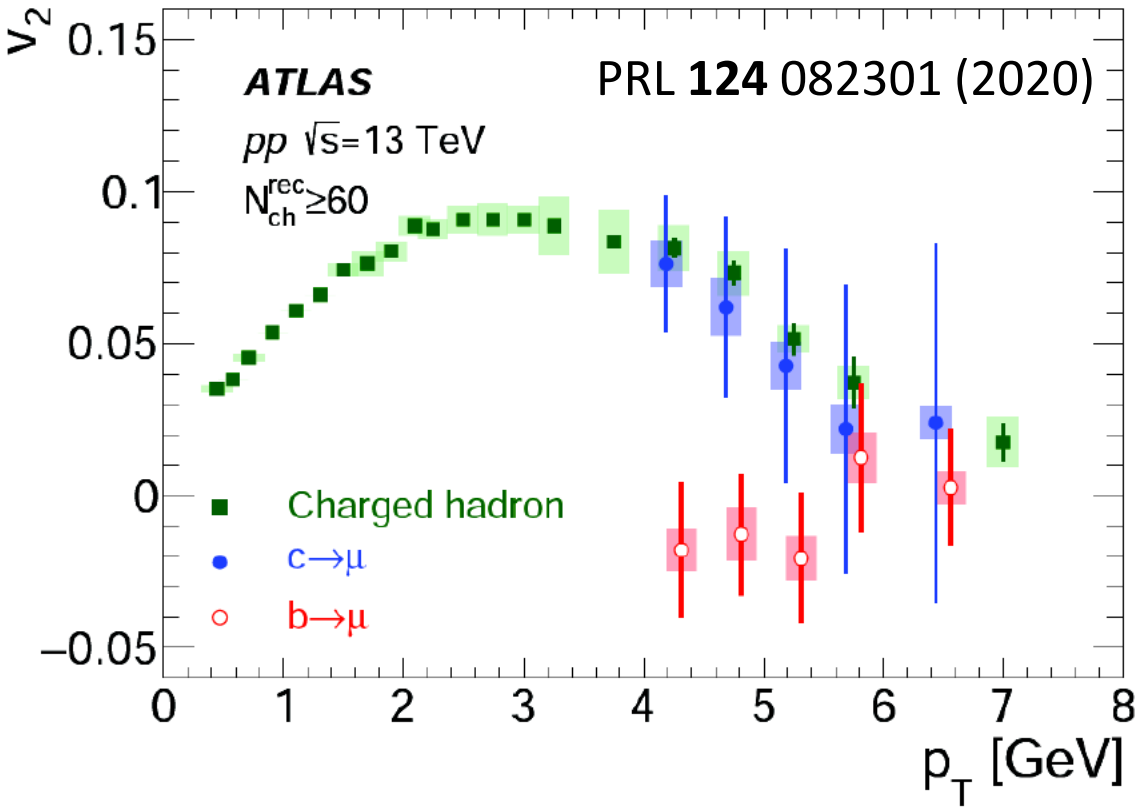


Good matching of theory to data for DREENA-B (*PLB 791 (2019) 236*). *(dynamic energy loss in 1+1D expanding QCD medium)*

Matching of DAB-MOD (*Phys. Rev. C 96, 064903*) worse for the flow from charm. *(2D+1 viscous hydrodynamic expansion with event-by-event fluctuations)*

Charm and beauty flow in p+p

Muons from HF decays



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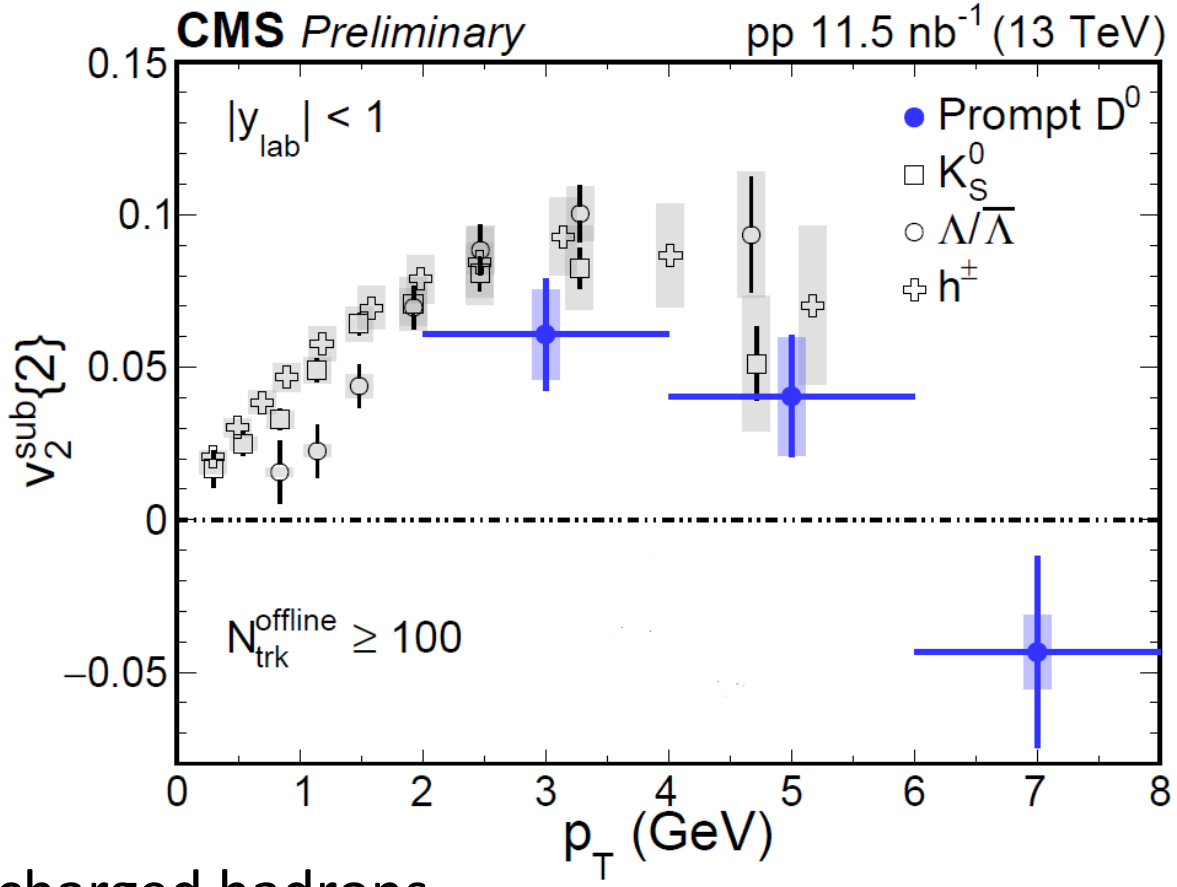
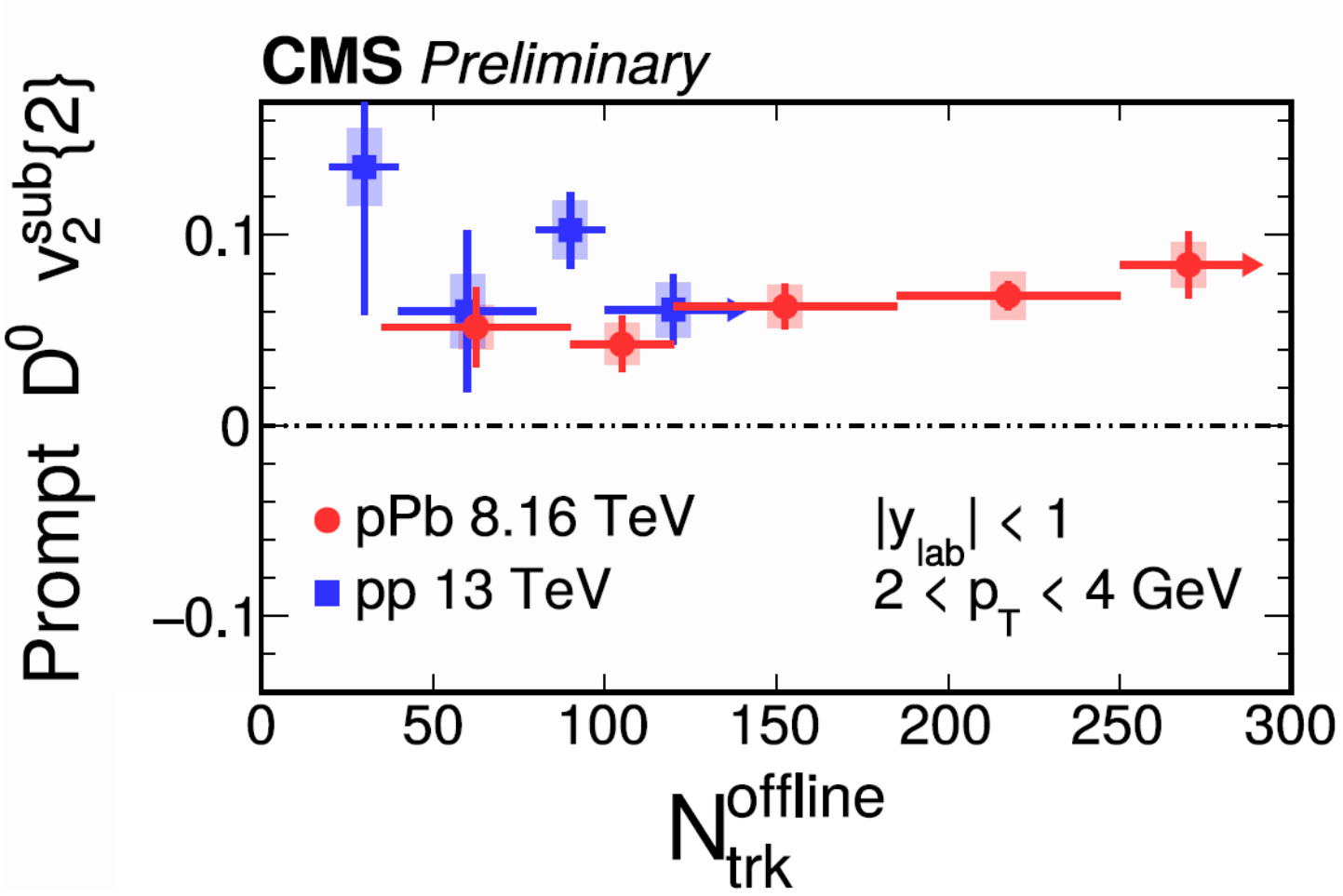


Charm: non-zero v_2, similar to inclusive charged hadrons.

Beauty: v_2 consistent with zero.

Collectivity in pp does not persist to heavy b-quarks!

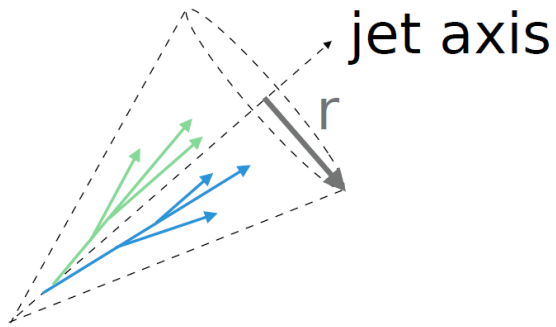
Charm flow in p+p vs. p+Pb



CMS-PAS-HIN-19-009

p+p consistent with p+Pb for similar multiplicities

Jet shape: b-jets shapes in p+p



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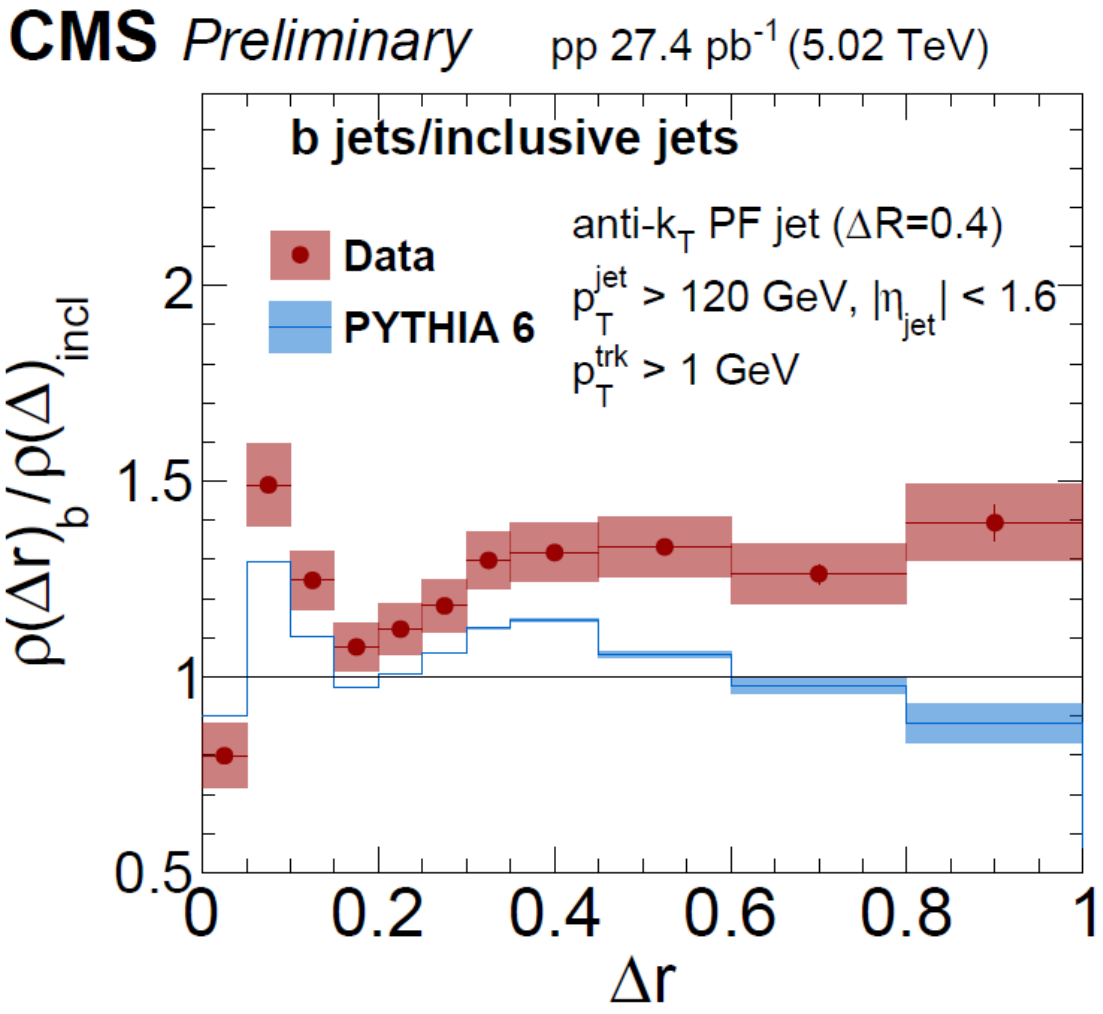


Jet shape distribution

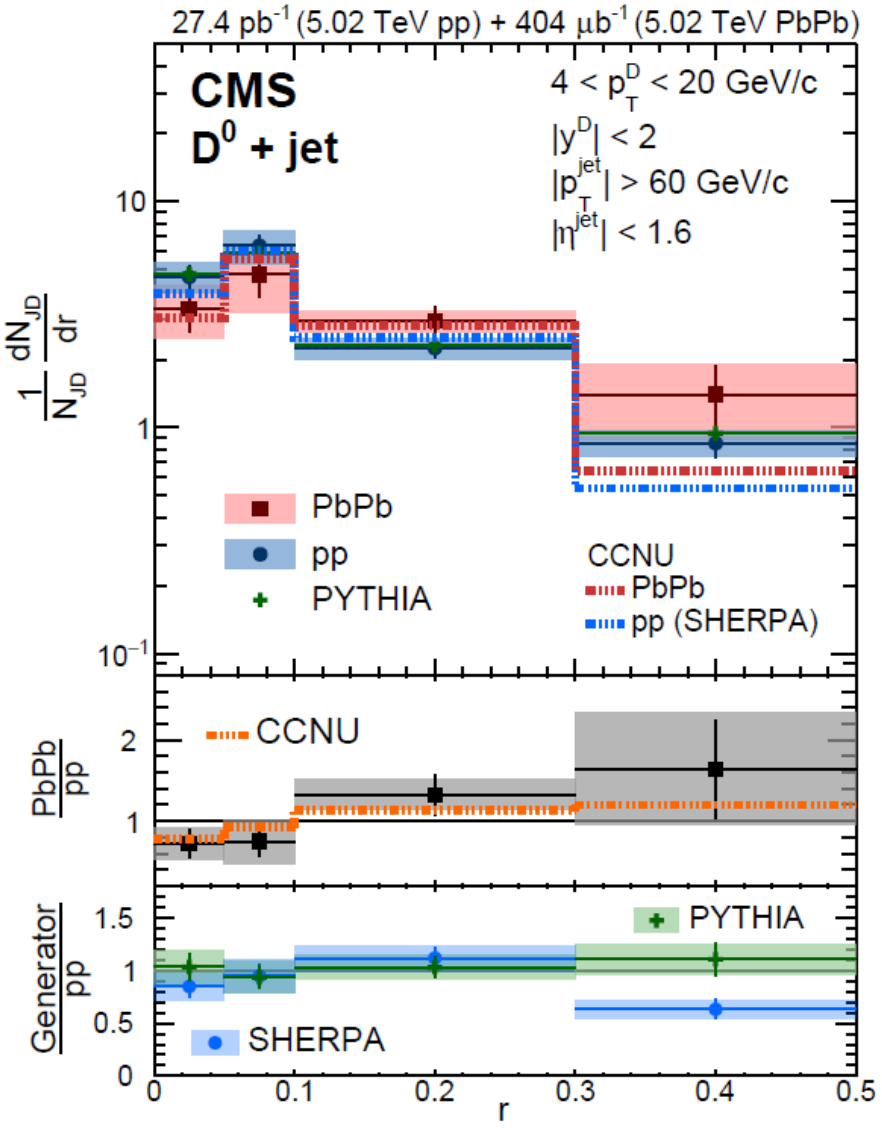
$$\rho(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\text{jets}}}\frac{\Sigma_{\text{jets}}\Sigma_{\text{trk}\in(\Delta r_a,\Delta r_b)}p_T^{\text{trk}}}{\Sigma_{\text{jets}}\Sigma_{\text{trk}}p_T^{\text{trk}}}$$

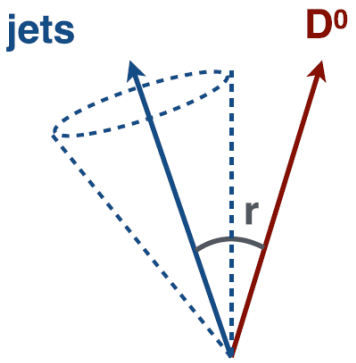
B-jets have different shape with respect to inclusive jets

Poorly reproduced in PYTHIA

⇨ Flavor dependence in parton fragmentation

Jet shape: D^0 in jets in p+p and Pb+Pb





arXiv:1911.01461

Radial profile of D^0 mesons in jets:

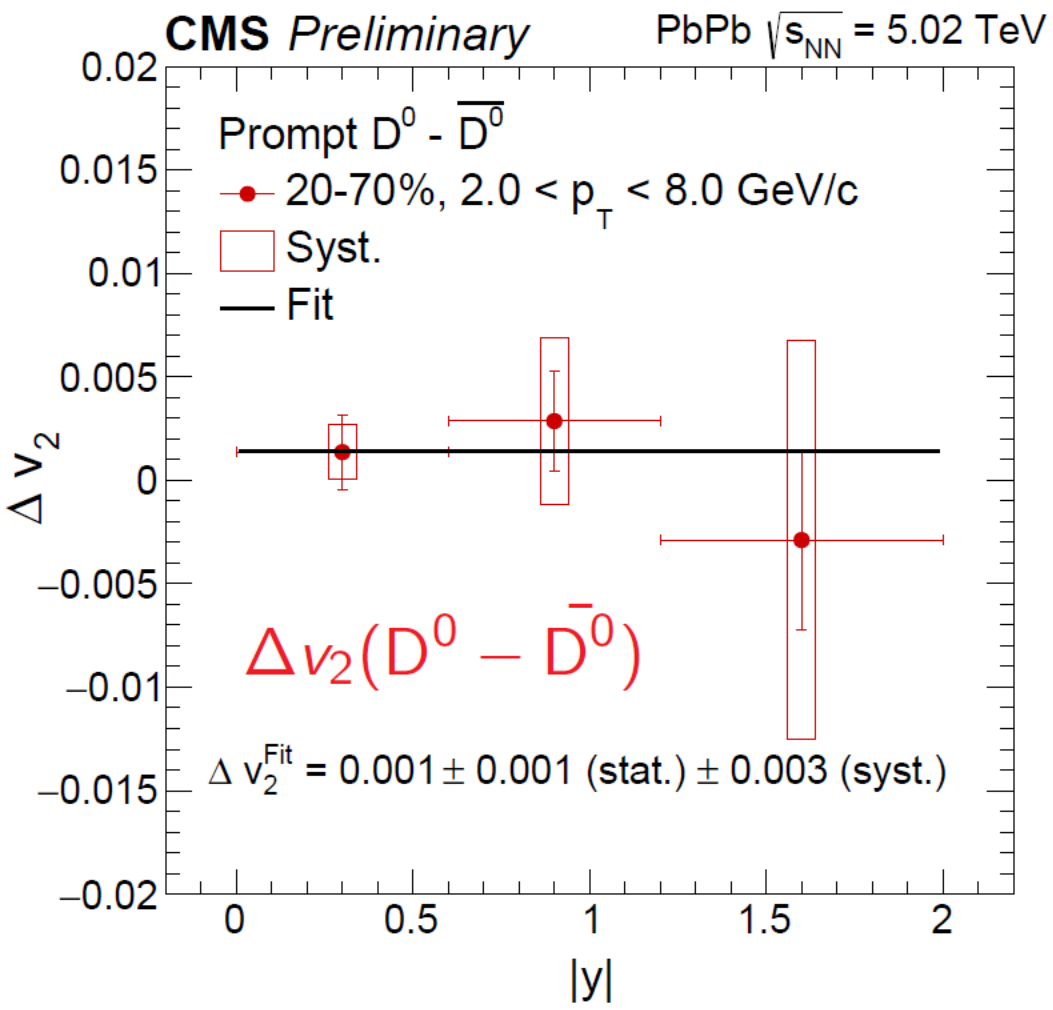
Hint of wider distribution in Pb+Pb than p+p at low p_T

⇨ Charm quark diffusion with respect to the jet axis

Energy loss CCNU model includes both elastic and inelastic collisions of all flavors (Eur. Phys. J. C 79 (2019) 789)

D^0 flow in Pb+Pb: search for strong EM effects

CMS-PAS-HIN-19-008



Theory *(e.g. Phys. Rev. C 98 (2018) 055201)* predicts creation of strong (10^{16} T) and transient (10^{-1} fm/c) EM fields in HI collisions.

Coulomb electric field will cause charge-dependent splitting of v_2 and $\langle p_T \rangle$
Heavy flavor, created early in the collision has more chances to be affected before hadronization.

Compare v_2 for prompt D^0 ($\bar{u}c$) and $\overline{D^0}$ ($u\bar{c}$)

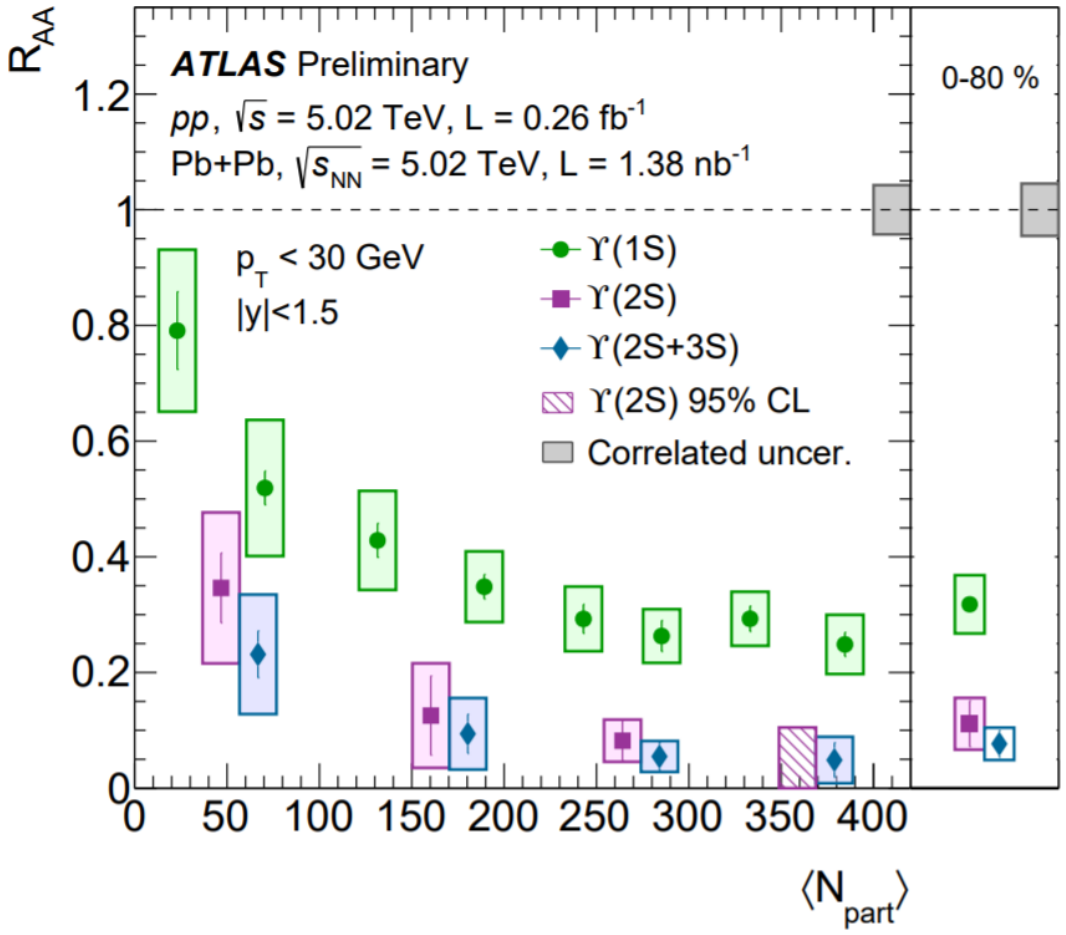
Mutli-differential analysis vs. $|y|$, p_T, centrality

Consistent with no difference

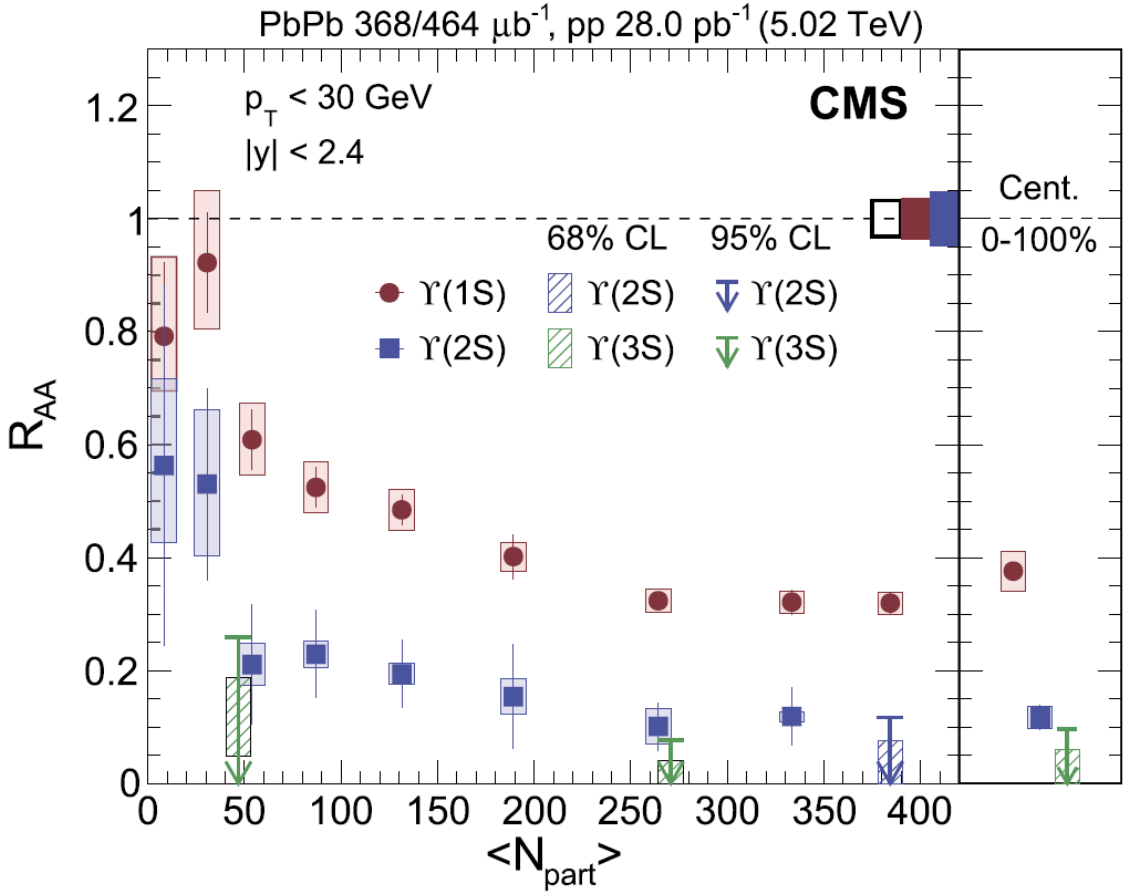
Quarkonia

Upsilon suppression in Pb+Pb

ATLAS-CONF-2019-054



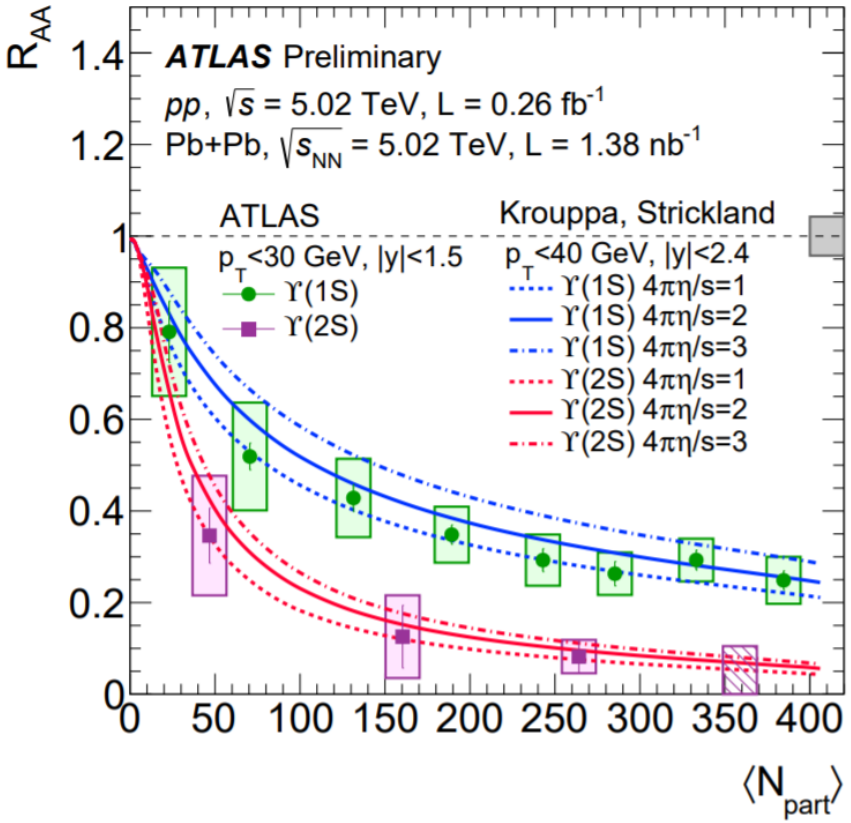
Phys. Lett. B 790 (219) 270



Expected order of suppression, larger suppression in central collisions.

Theory comparison

ATLAS-CONF-2019-054



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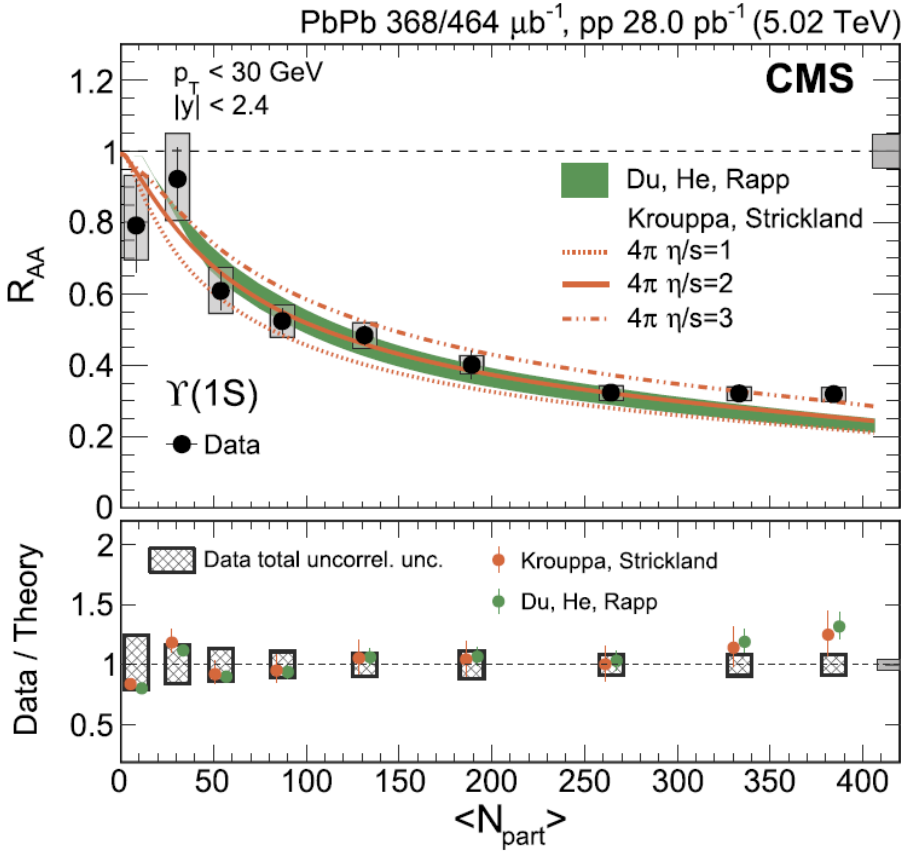
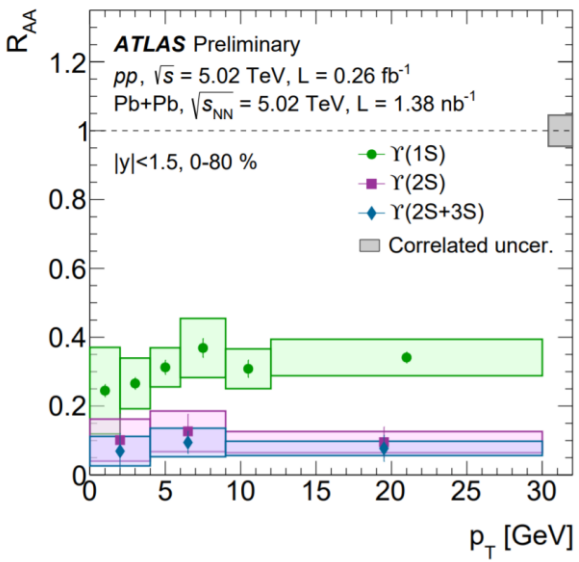
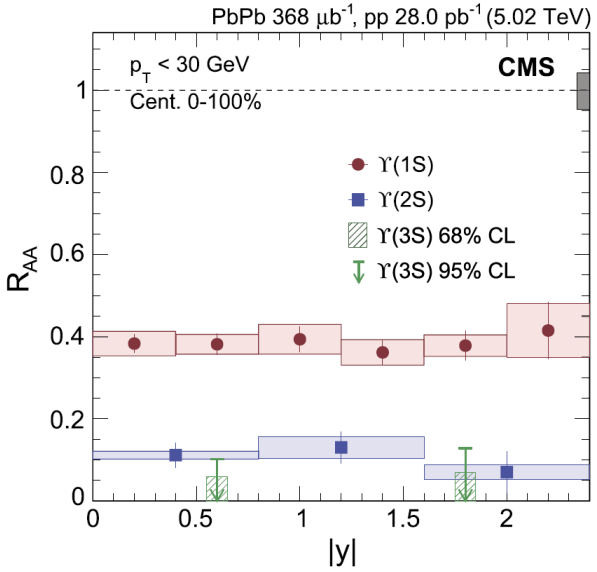


Krouppa, Strickland, (Universe 2 (2016) 16); Du, Rapp, He, (Phys. Rev. C 96 (2017) 054901)

- Both models include color screening and feed-down, Du,Rapp,He includes regeneration
- Temperature range 629-641 MeV [1] and 550-800 MeV [2]

Upsilon suppression in more details





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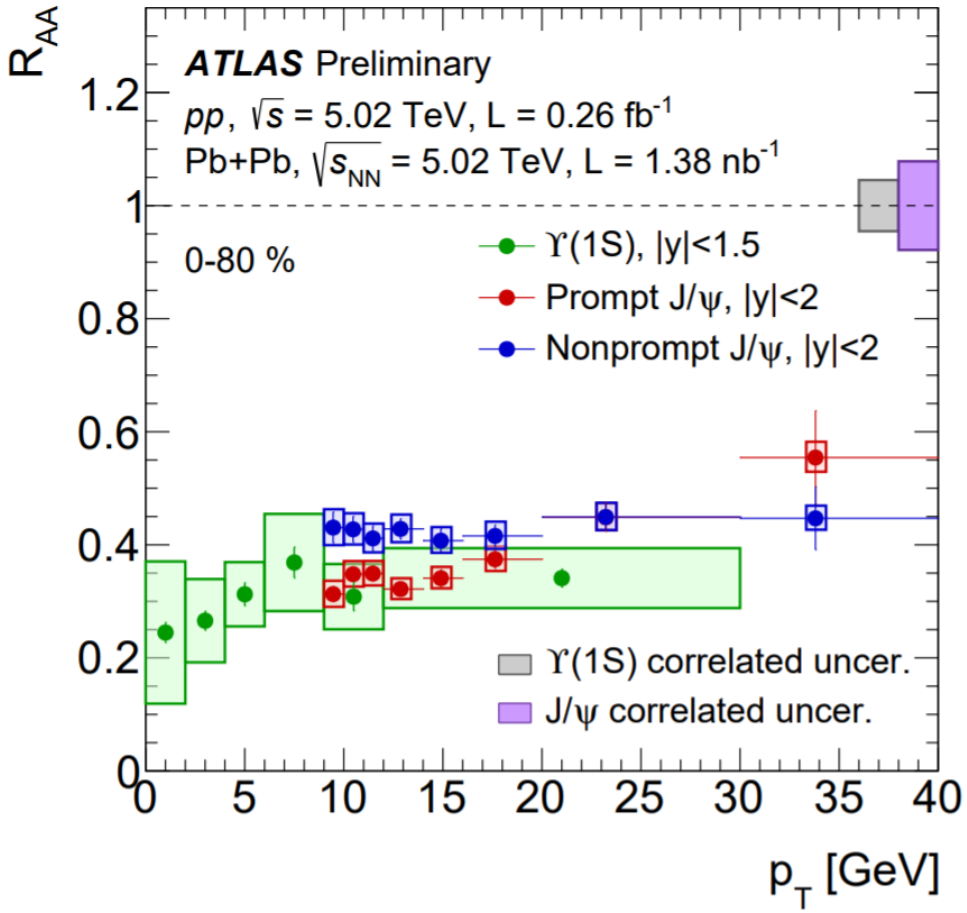


Prompt J/ψ (charm) is consistent with Y(1S) despite different binding energy

⇨ different regeneration?

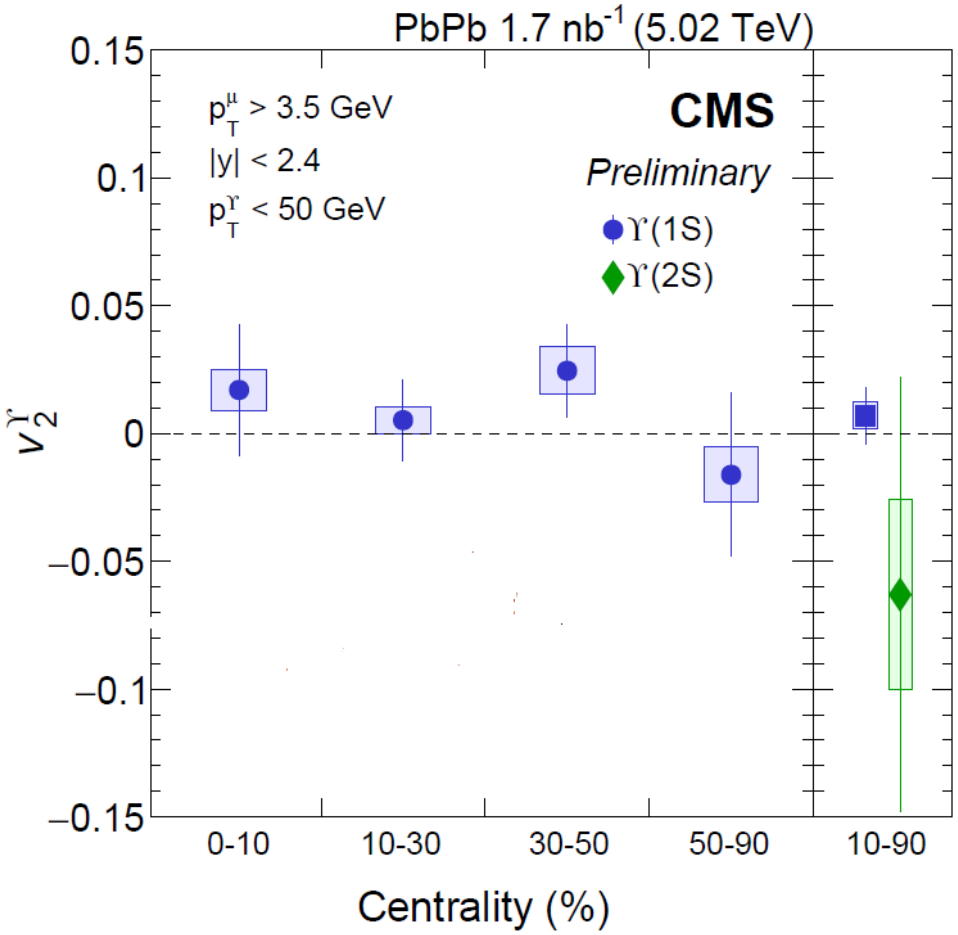
Non-prompt J/ψ (beauty) less suppressed than prompt, but still consistent with Y(1S).

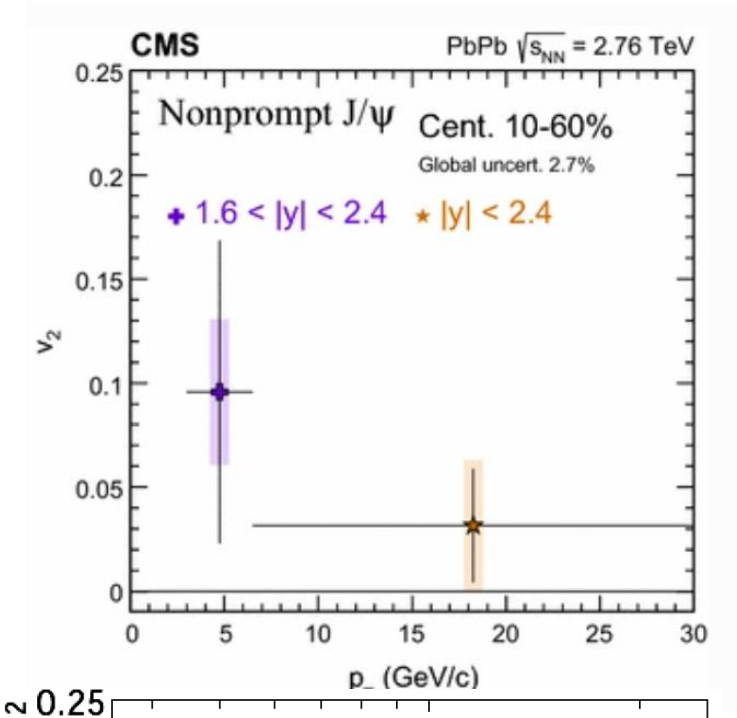
⇨ many competing mechanisms?

No p_T or rapidity dependence for suppression

Upsilon flow in Pb+Pb

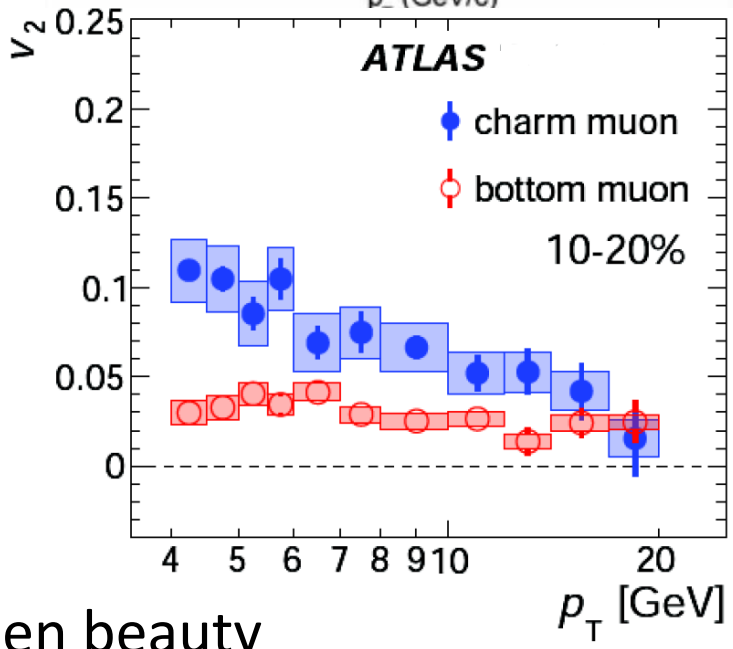
CMS-PAS-HIN-19-002





non-prompt J/ψ

Eur. Phys. J. C 77 (2017) 252



muons from beauty

arXiv:2003.03565

First measurement

Consistent with no flow, in contrast with open beauty

Conclusions

- General features of heavy flavor production in p+p collisions are reasonably well understood theoretically ans can serve as a baseline for HI studies.
- In HI collisions both charm and beauty flow, but beauty v_3 is zero.
- In high multiplicity p+p collisions open charm flow is similar to light flavors, but no beauty flow.
- Charm flow in p+p is consistent with that in p+Pb at the same multiplicity.

- B-jets are broader, D^0 have wider distribution in jets compared to light flavor.
  ⇨ flavor dependence of parton fragmentation.

- Upsilon suppression in Pb+Pb exhibits expected order, well described by theory.
- Comparison to J/ψ indicates importance of regeneration, many competing processes