Recent Open Heavy Flavor Measurements in CMS

Probing initial to final stage effects with charm and beauty

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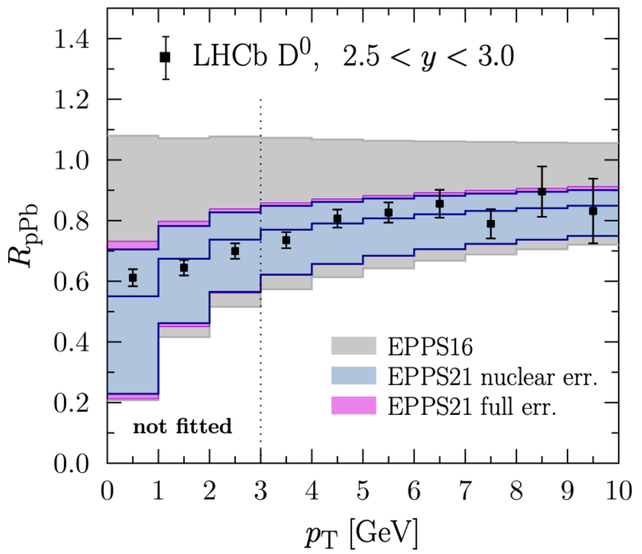
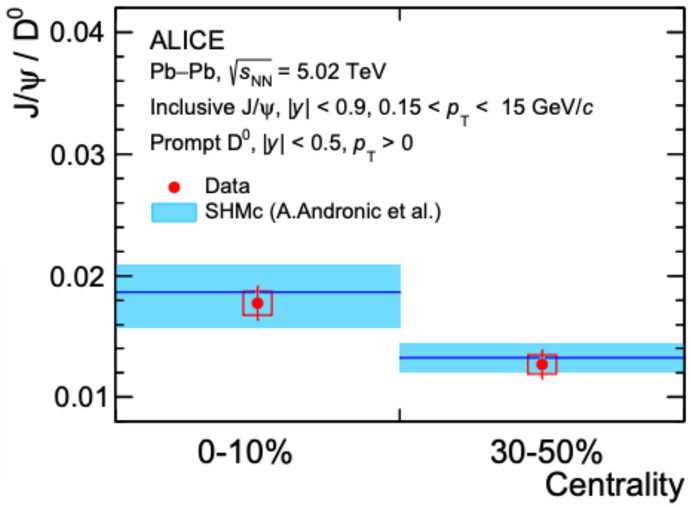
Open heavy flavor physics

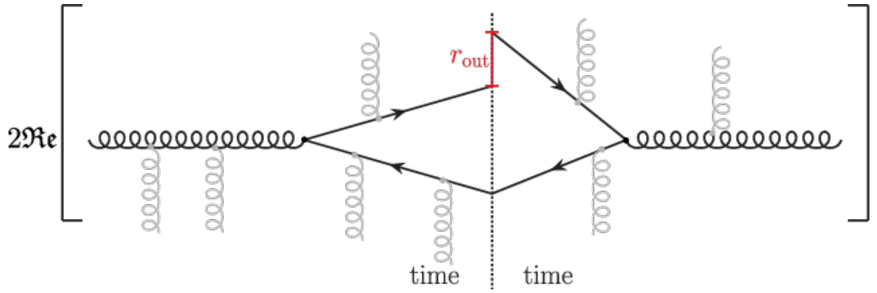
- Production of open heavy flavor well modeled via FONLL, GM-VFNS
- Measurements of heavy flavor modification in pA system used to constrain gluon nPDF
- Unique probe to investigate heavy quark energy loss mechanism in HIC
  - Unravelling the contribution of radiative and collisional energy loss
    - BDMPS-Z, GLV, higher twist approach to describe radiative loss
    - Models like heavy quark transport describe scattering in medium
- Hadronization
  - Role of coalescence of charm hadrons
  - Challenging idea of universal fragmentation in pp & heavy ion

EPJC 82 (2022) 413

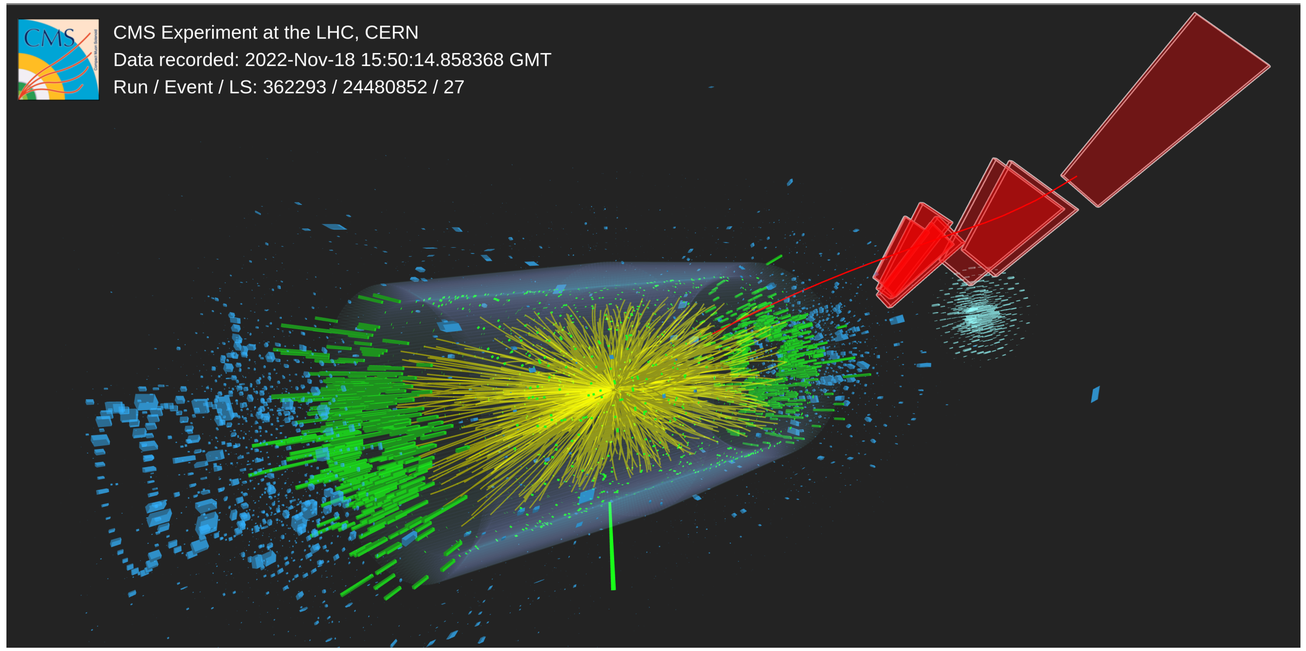


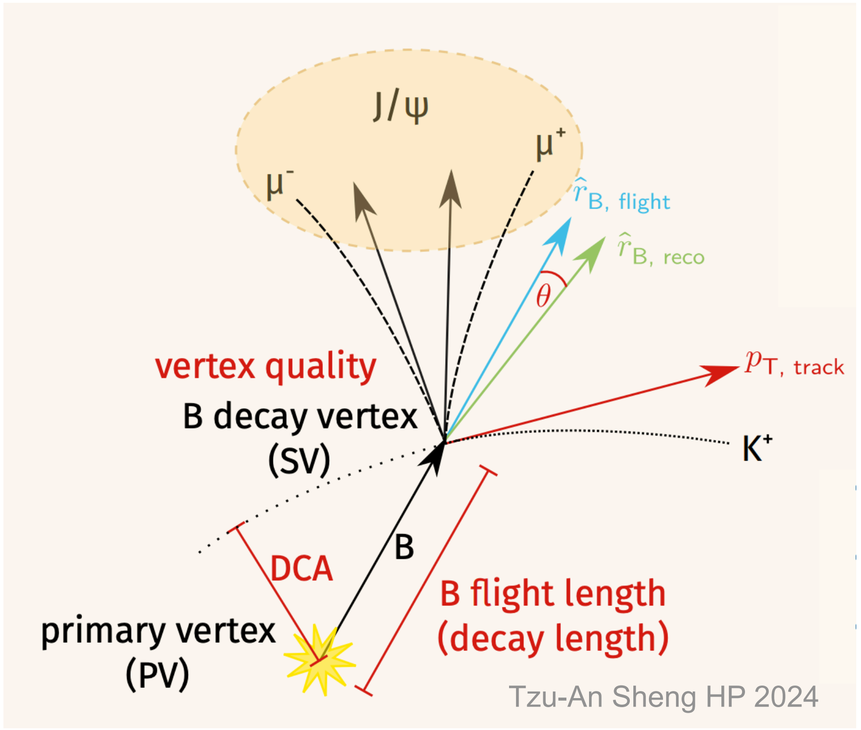
PLB 849 (2024) 138451





Heavy flavor physics in CMS heavy ion



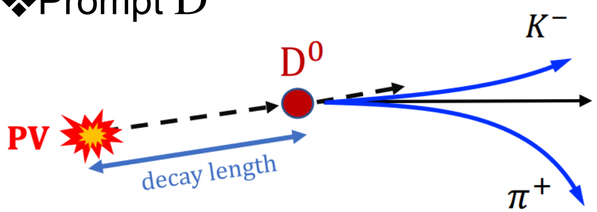


- CMS has excellent vertexing and tracking performance
  - Good resolution on decay geometry and secondary vertex finding
  - Continue evolving in run3 (see Junseok's poster)
- Muon system with good momentum resolution
  - Able to identify fully reconstructed B meson through $J/\psi(\rightarrow \mu^+\mu^-) + X$ channel

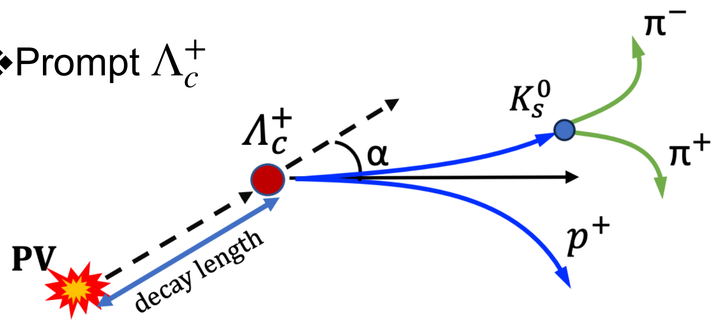
Experimental methods for HF measurement

- How does CMS reconstruct open charm and beauty?
  - Fully reconstructed charm hadrons, beauty meson
    - Partially reconstructed beauty flavor through non prompt D^0 and the B_c^+

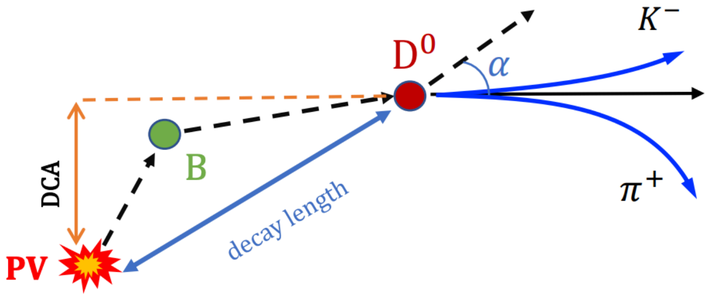
❖Prompt D^0



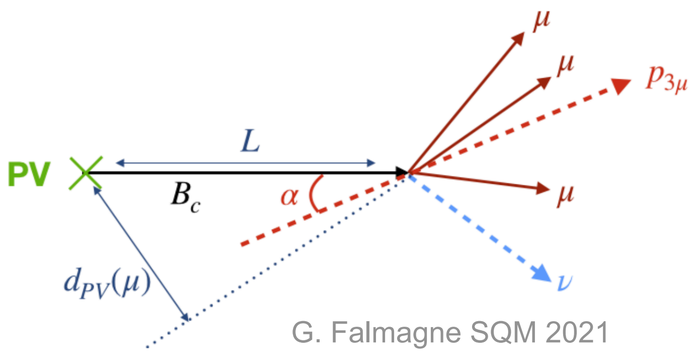
❖Prompt Λ_c^+



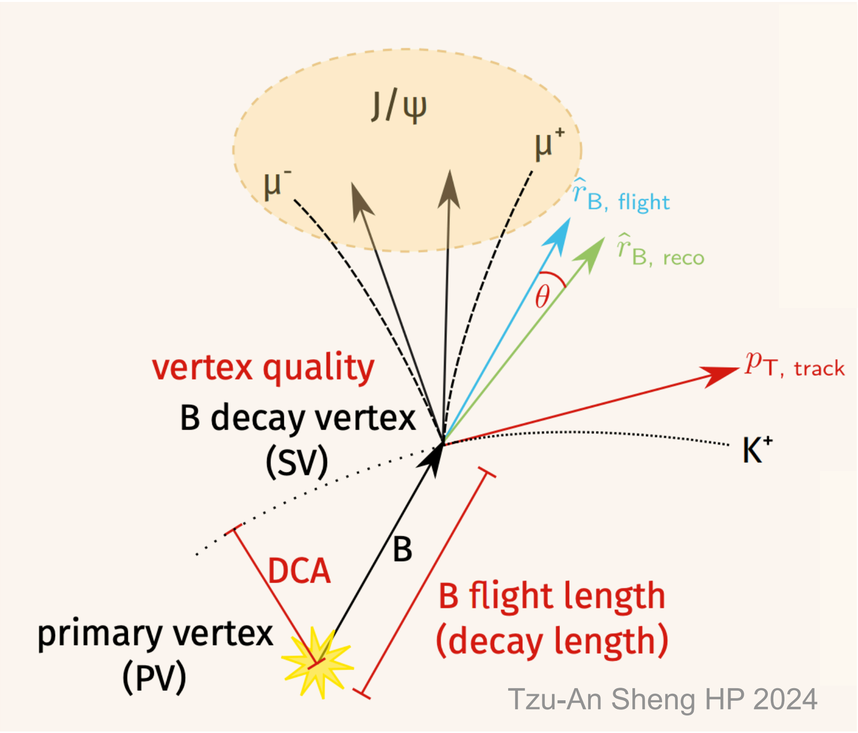
❖Non Prompt D^0



Soumik Chandra QM 2023

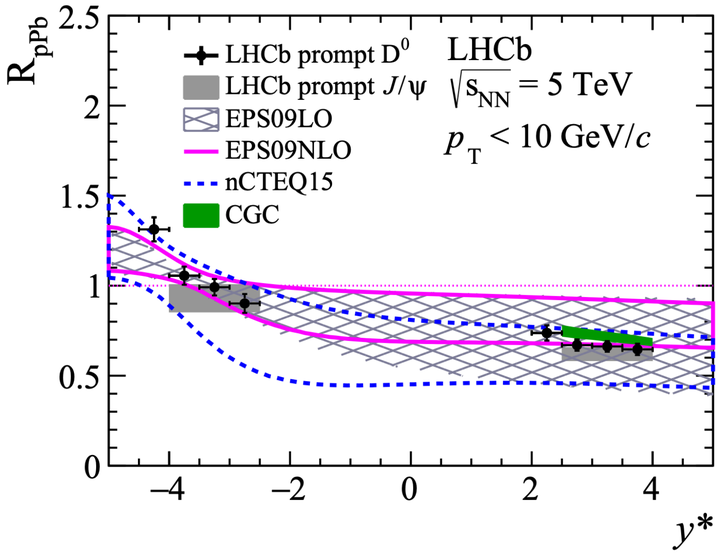


G. Falmagne SQM 2021

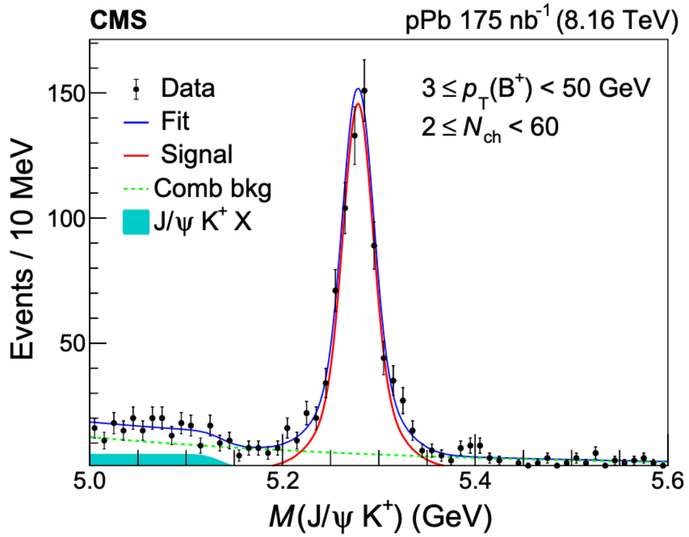


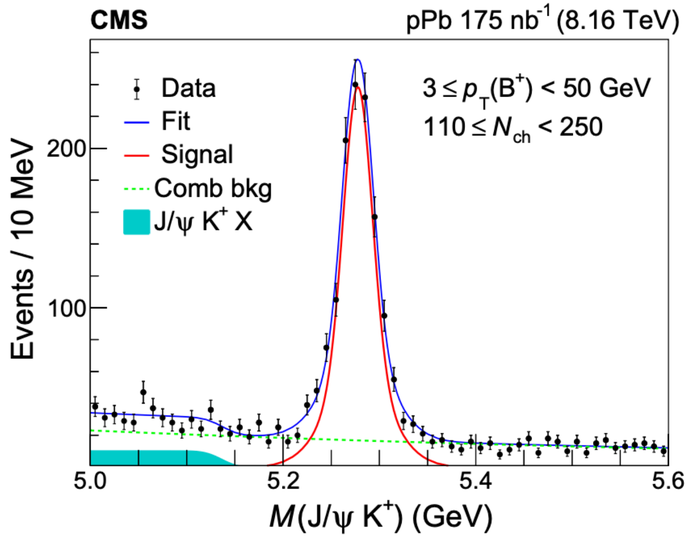
Tzu-An Sheng HP 2024

Probing the small system for b quark energy loss



PRL 134 (2025) 111903

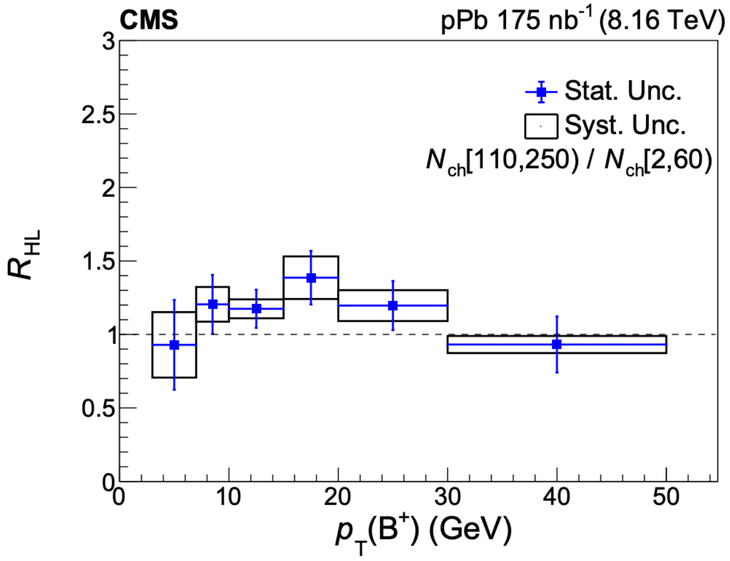


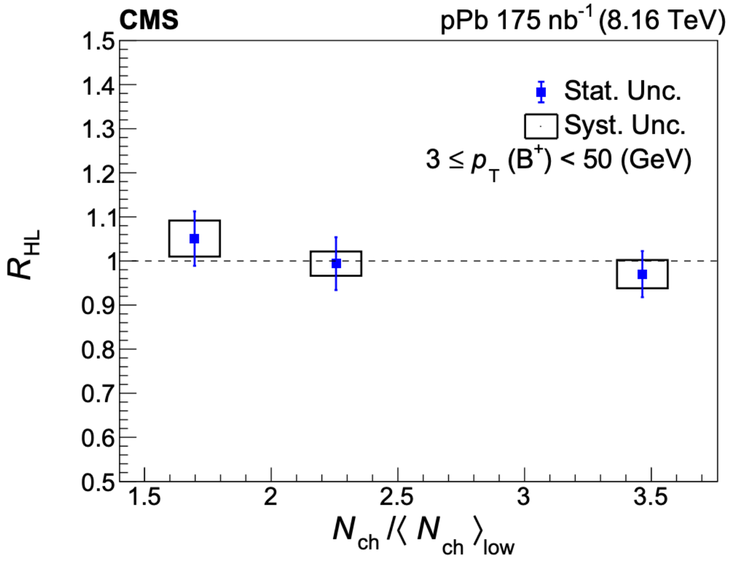


- What CNM effect influence b quark production?
  - Is there nuclear medium effect in small system, maybe in high multiplicity?
- Multiplicity dependent B meson production to understand in pPb collision with run2 data

Heavy quarks in QGP droplet?

PRL 134 (2025) 111903





$$R_{\mathrm{HL}} = \frac{(\mathrm{d}\sigma^{\mathrm{B}^+}/\mathrm{d}p_{\mathrm{T}})|_{\mathrm{high}}}{(\mathrm{d}\sigma^{\mathrm{B}^+}/\mathrm{d}p_{\mathrm{T}})|_{\mathrm{low}}} \Big/ \frac{(\mathrm{d}\sigma^{\mathrm{Z}}/\mathrm{d}p_{\mathrm{T}})|_{\mathrm{high}}}{(\mathrm{d}\sigma^{\mathrm{Z}}/\mathrm{d}p_{\mathrm{T}})|_{\mathrm{low}}}.$$

- Multiplicity dependence on B meson production ratio was measured
  - Normalized by Z boson ($\propto N_{\mathrm{coll}}$) cross section to avoid final state bias!
- R_{HL} consistent with 1, no bottom quark modification in pPb?
  - B follows similar shadowing as seen in R_{pA} vs rapidity. And no evidence of medium modification on production

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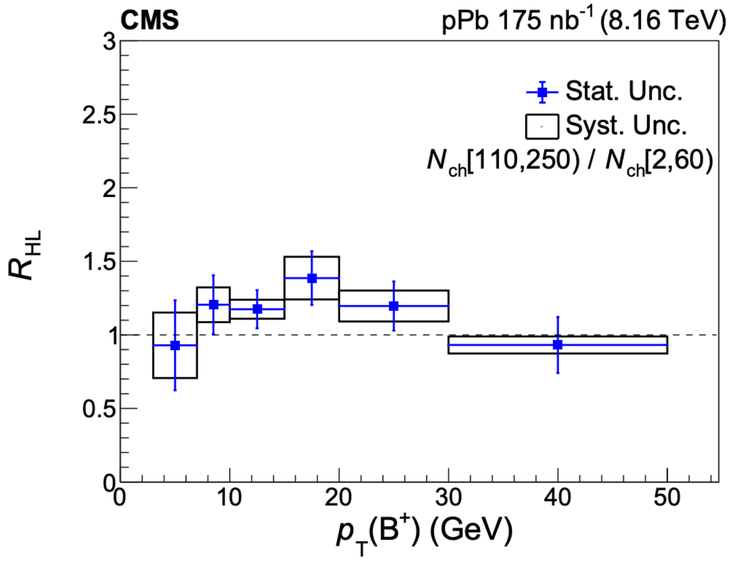

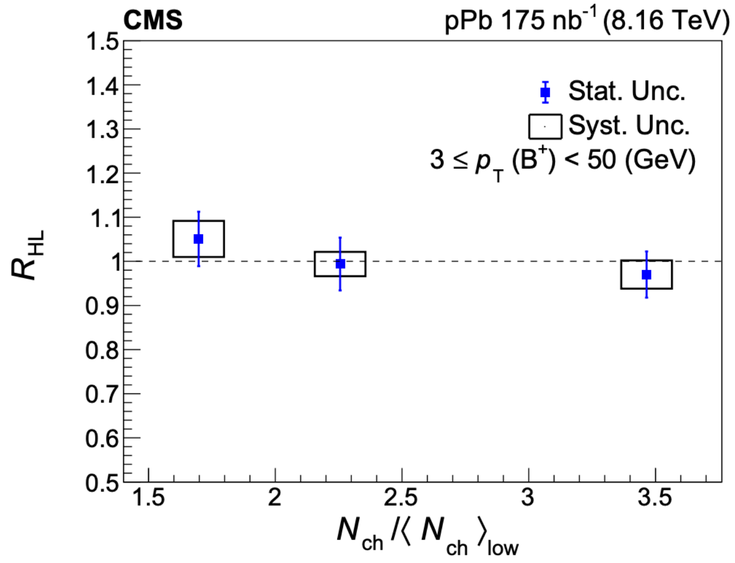

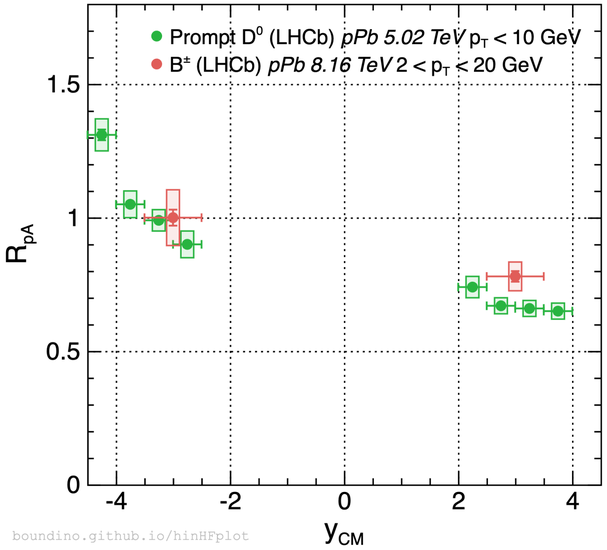

D0 JHEP 1710 (2017) 090
B+ PRD 99 (2019) 052011

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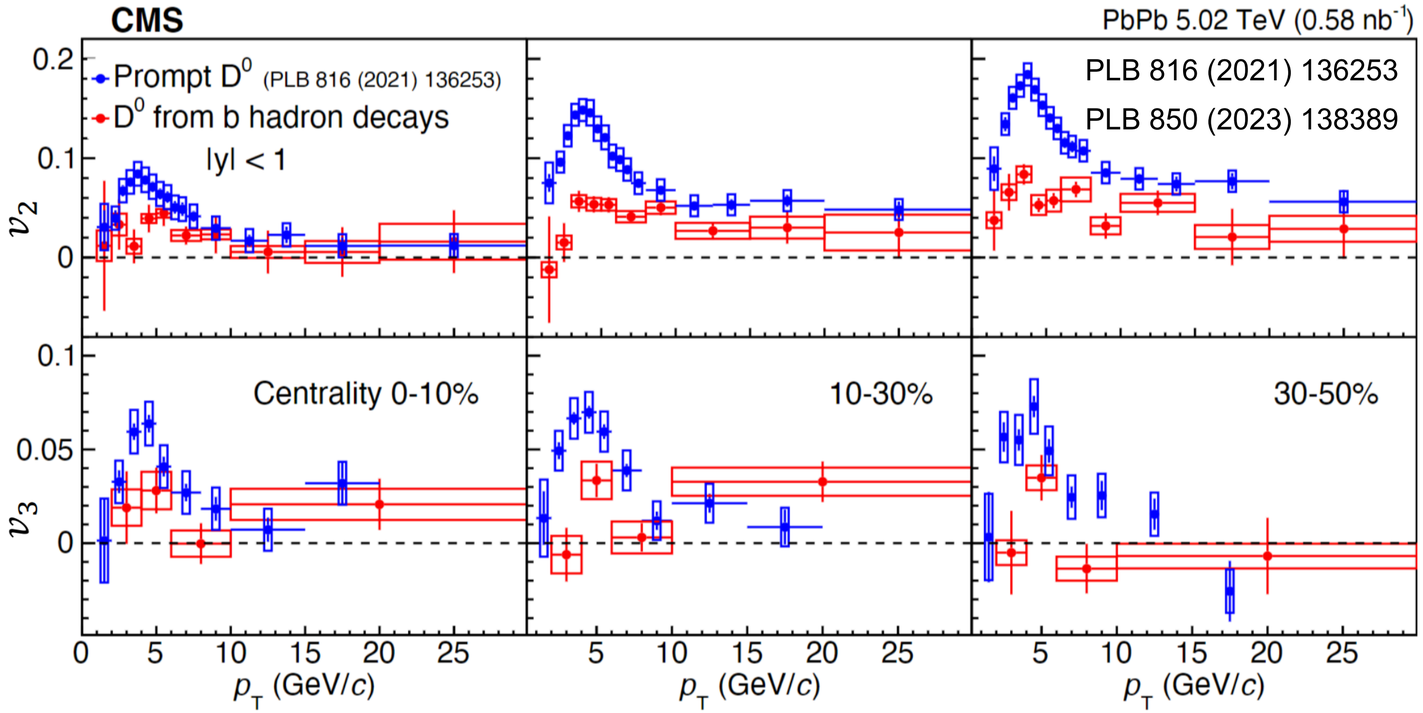
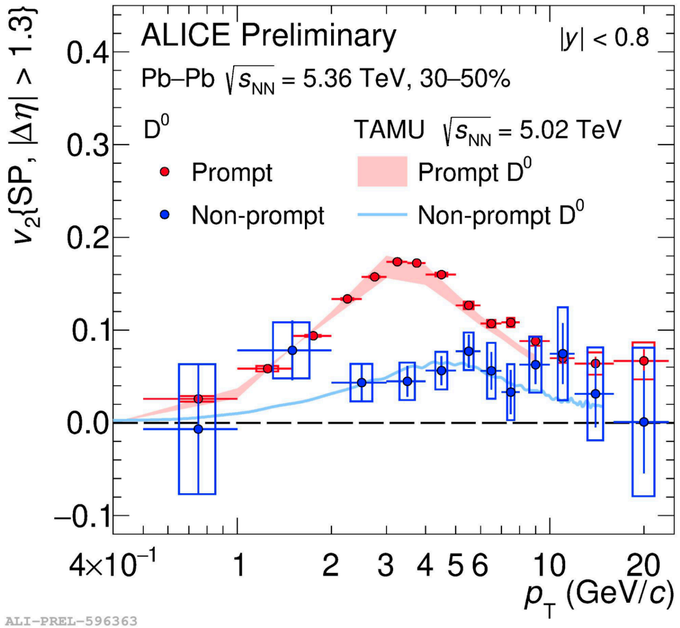
charm and beauty flow in medium



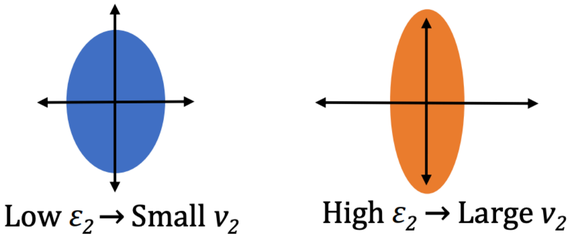


- Anisotropy on prompt and non prompt D^0 shows clear c and b mass ordering
  - Large enhancement in low pT for prompt charm from
- Significant v_3 for prompt D^0, initial geometry effect?
- Described well by quarkonia transport models on ALICE prompt and non prompt D^0 data

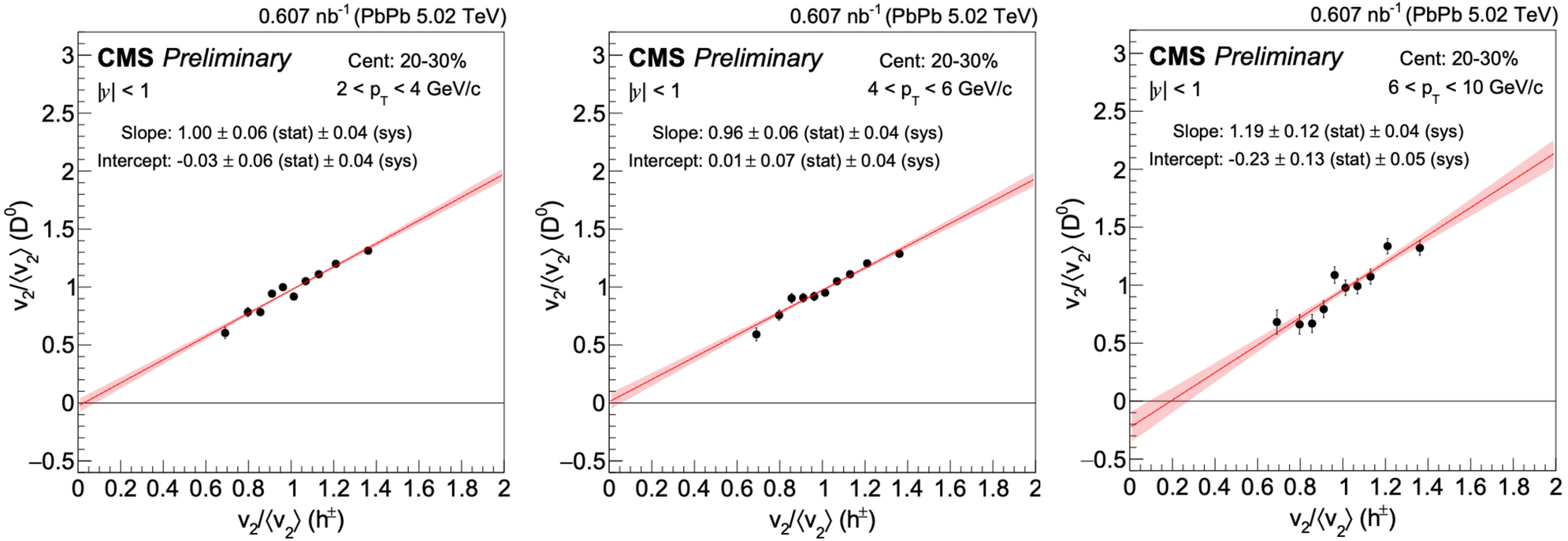
How does charm flow in medium

- A new way to look at eccentricity dependence on charm and light flow
  - Anisotropy normalized on "reduced flow vector (q_2)" using event-shape-engineering method
    - Extracting second order flow vector magnitude measured in forward detector, representing the initial geometry $\propto \epsilon$
  - Charged hadron, and D^0 v_n extracted from scalar product method from run2 PbPb data

$$q_2 = \frac{|\sum_{j=1}^{M} w_j e^{i2\phi_j}|}{\sum_{j=1}^{M} w_j}$$

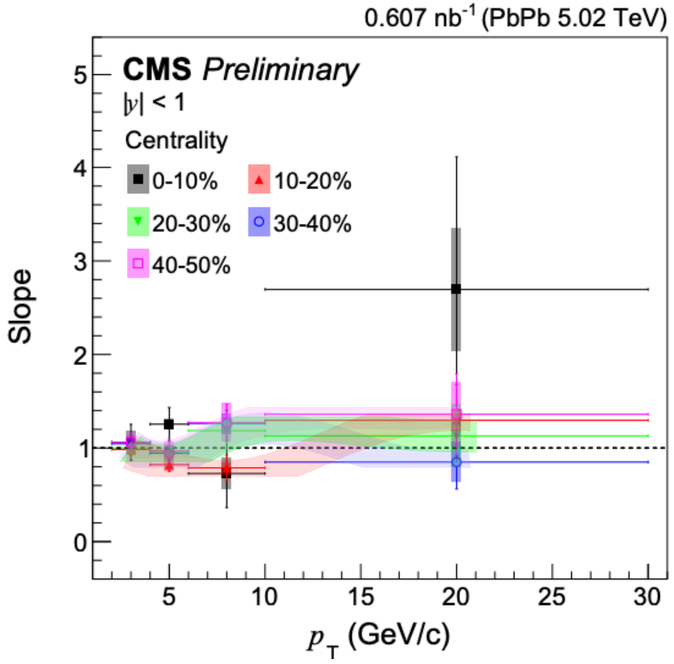


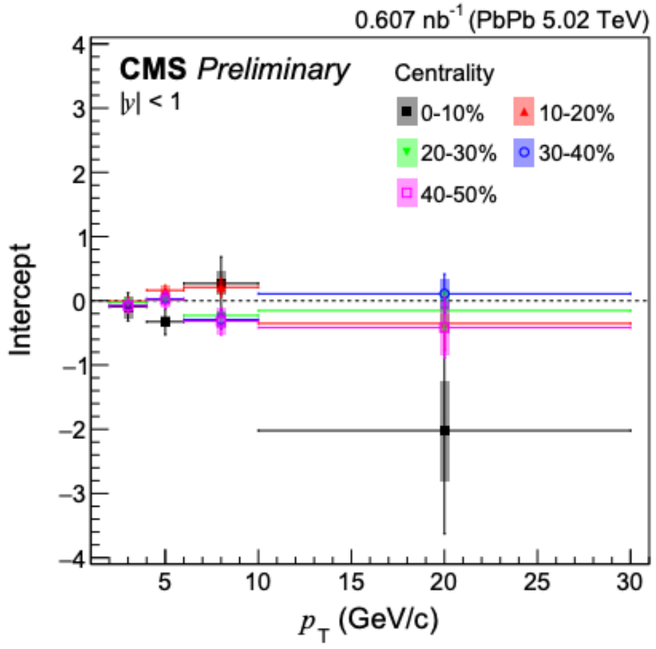
Investigating charm flow with ESE



- Data points extracted from v_2 of q_2 division, normalized on x, y with total average $\langle v_2 \rangle (\mathrm{D}^0, \mathrm{h}^\pm)$
  - Slope ~ 1, intercept ~ 0, direct correlation of D^0 with charged particles
  - D^0 flow directly inherit from light constituent in QGP

Eccentricity dependence of light and charm

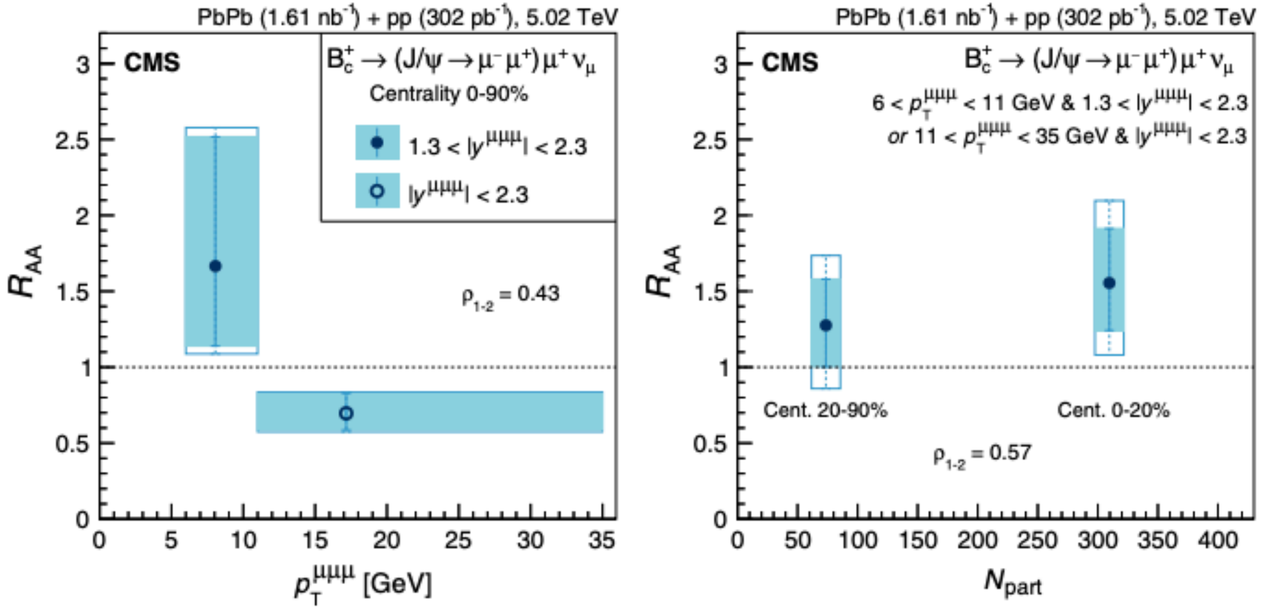




- Similar behavior seen in all centrality class
- Nonlinearity in the correlation can be interpreted to charm specific flow modification
  - So far no significant sign of deviation
- Compatible with our understanding of charm medium modification

Coalescence of c and b

PRL 128 (2022) 252301



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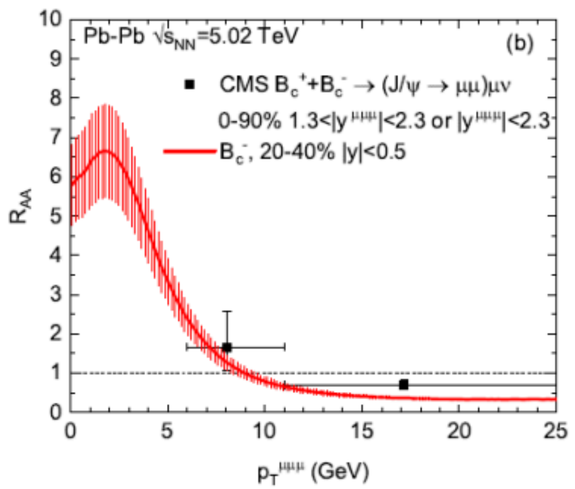
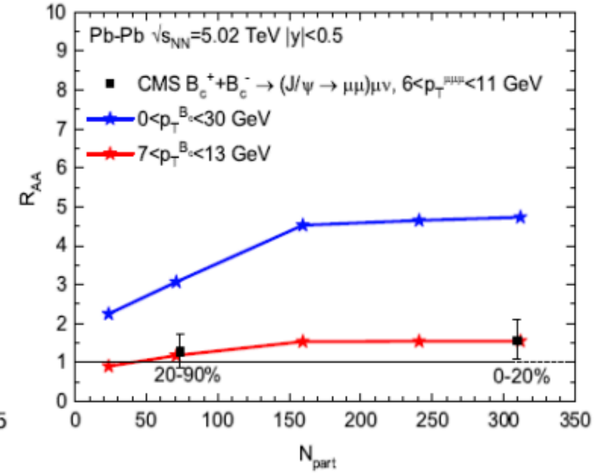
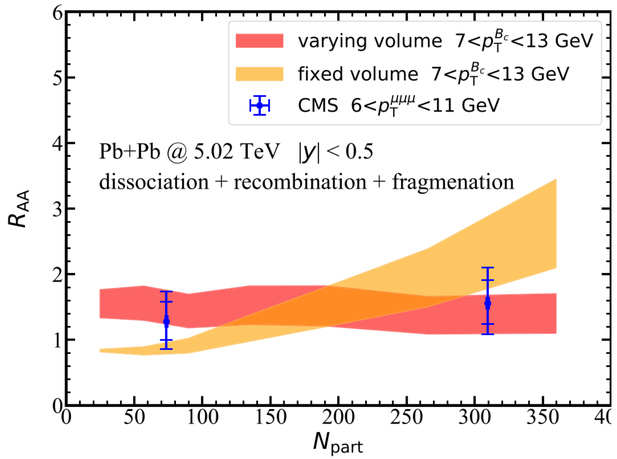
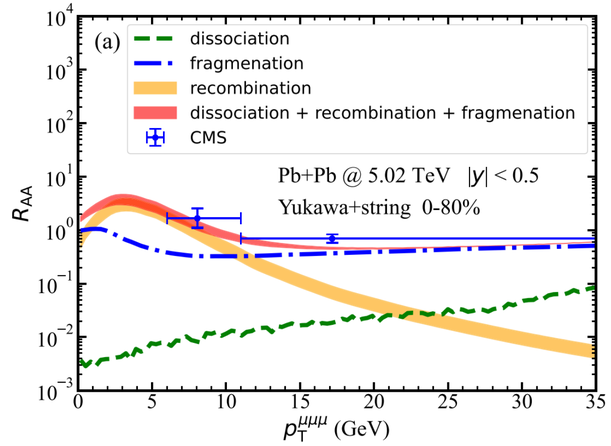




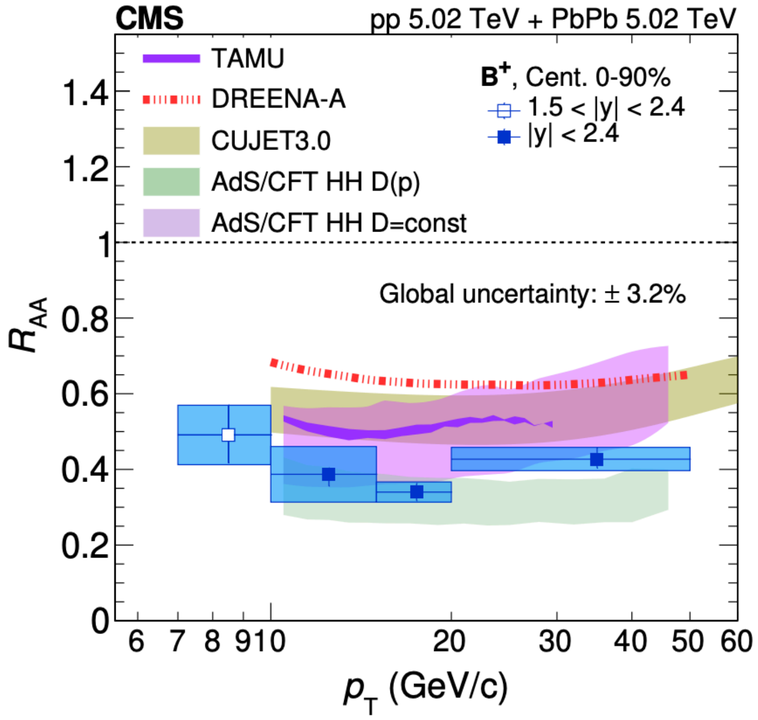


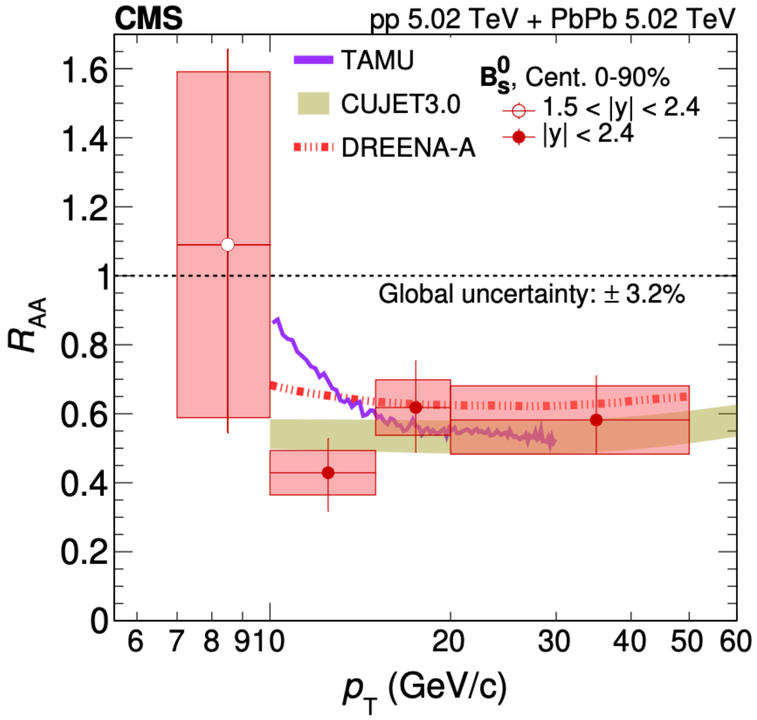


PRC 111 (2025) 054915

- Bridging the measurement gap between the charm and beauty, first and only measurement of B_c^+ in PbPb
  - Large enhancement from coalescence from on charm?
  - Better confirm with precision measurement!

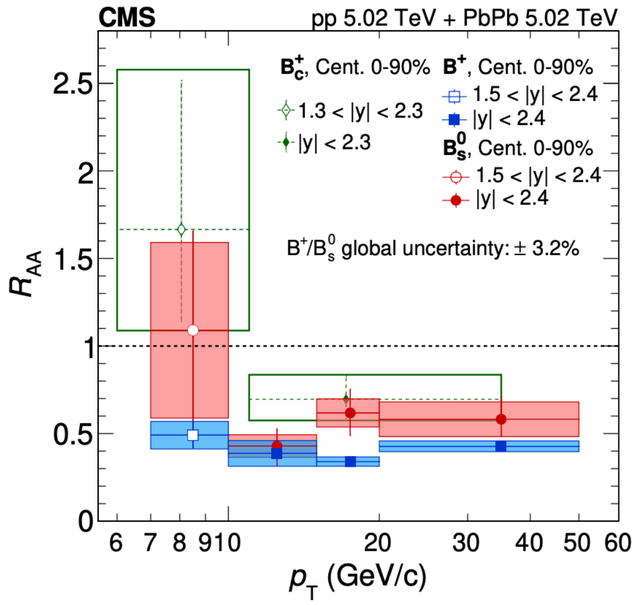
Energy loss of b quarks

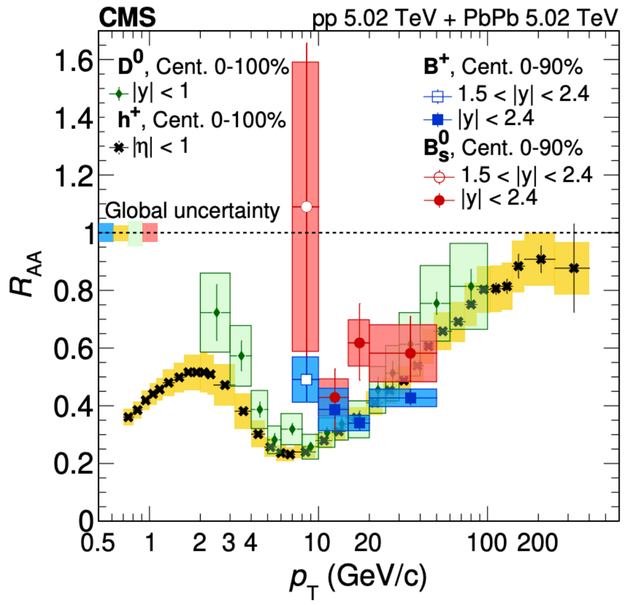




- Radiative vs. collisional energy loss
- Enhance by strangeness, large coalescence in low p_{T}
- Indication of B_{s}^{0} increase in lower p_{T} compatible with strange enhancement, coalescence

Energy loss of heavy quarks

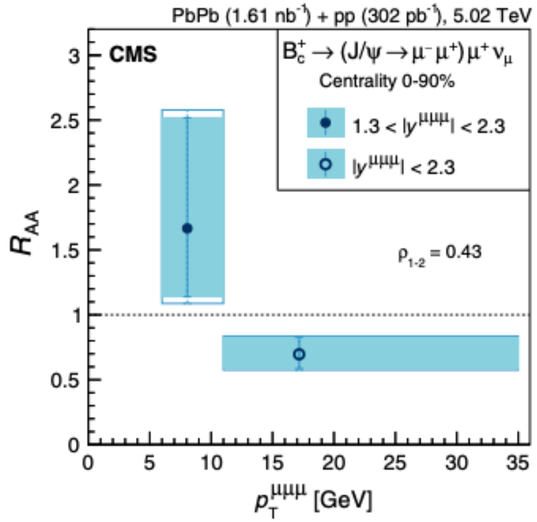


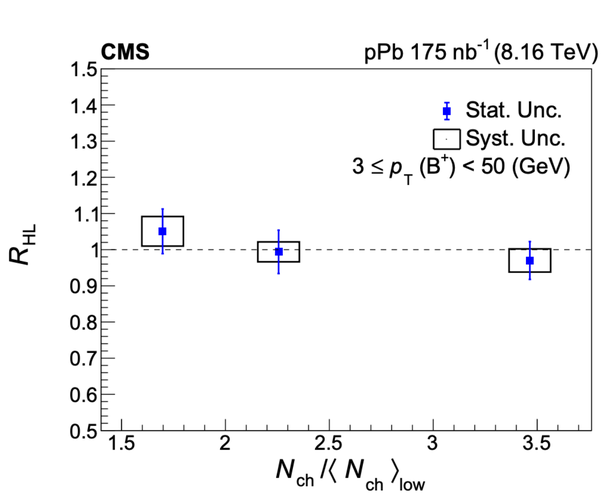


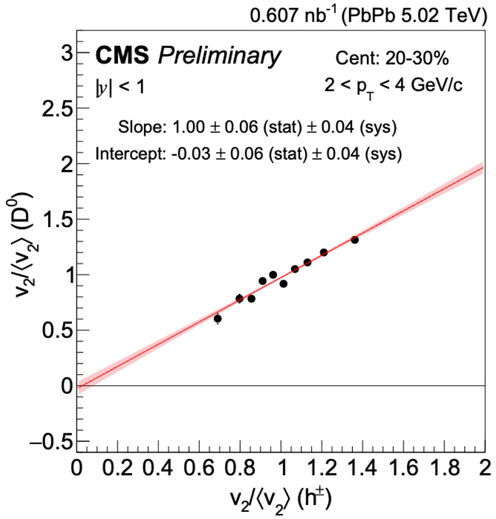
- Enhancement by charm and strange for B meson considerable? Inconclusive from uncertainty
- Low p_{T} : Quark mass dependent energy loss may qualitatively describe the h^+, D^0, B hadron suppression
- High p_{T}: All flavor converge to similar pattern

Conclusion

- CMS is capable of open heavy flavor physics in heavy ion collisions, complementary of kinematic reach with other LHC experiments
  - B measurement in small and large system allow probe b quark initial state and medium modification
  - Event shape engineering allows direct quantification of light and charm relationship in anisotropic flow in PbPb
  - Role of charm coalescence can be further constrained by the relationship of charm to beauty
    - B_c enhancement in low pT scales by the charm abundance in heavy ion? What is the actual order of enhancement?







Back up