Measurement of collective flow D^0 meson in heavy ion collisions at CMS

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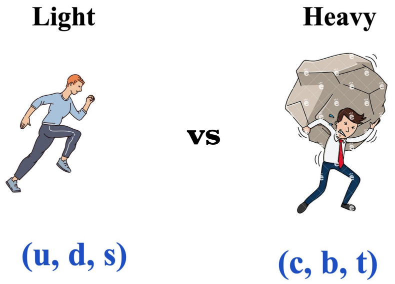
THIC 2025

Why heavy flavor?

- **Production:**
  - Heavy quarks are produced via hard scattering in the initial stage of the collisions (~0.1 fm/c).
  - Production rates can be calculated by pQCD
  - Higher penetrating power: $m_Q >> T_c, \Lambda_{QCD}$



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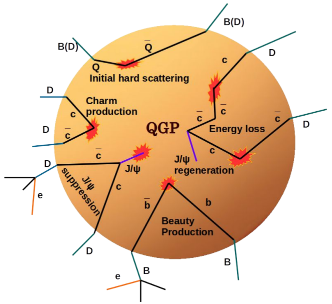
- **Energy loss mechanism:**
  - **Radiative:** Loss energy by via inelastic $Q \rightarrow Qg$ process. Significant at higher energy.
  - **Collisional:** Transfer energy via elastic $Qq \rightarrow Qq$ process. Significant at lower energy.

Light **Heavy**

vs

(u, d, s) **(c, b, t)**



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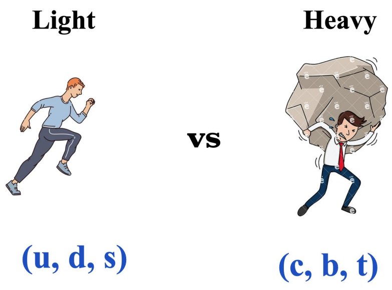

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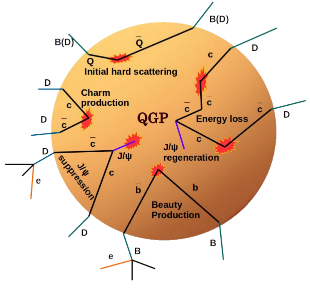
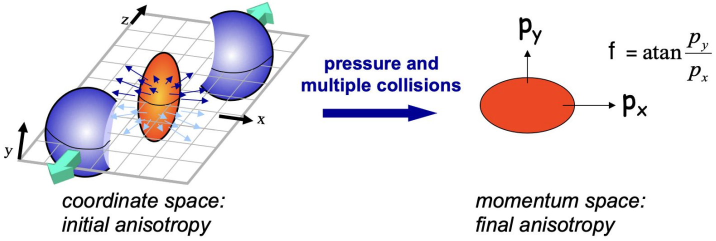
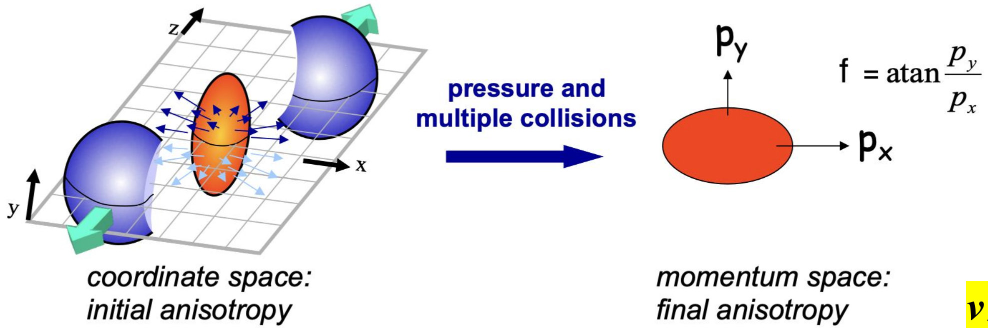


❖ Azimuthal anisotropy (collective flow):

- ➢ Initial state geometry and fluctuation.
- ➢ Path-dependent parton energy loss.



Azimuthal anisotropy



- **Anisotropy coefficient, v_n**

$$\frac{dN}{d\phi} \propto 1 + \sum_n 2 v_n \cos n(\phi - \Psi_n)$$

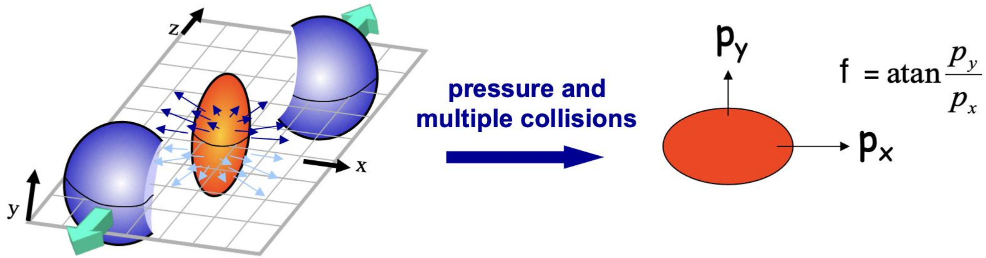
$$v_n = \langle 2\cos n(\phi - \psi_n) \rangle$$

v_2 → Elliptic flow → Initial state geometry

v_3 → Triangular flow → Initial state fluctuation

Pressure gradient generates collective flow anisotropy in momentum space!

Azimuthal anisotropy



coordinate space: initial anisotropy

momentum space: final anisotropy

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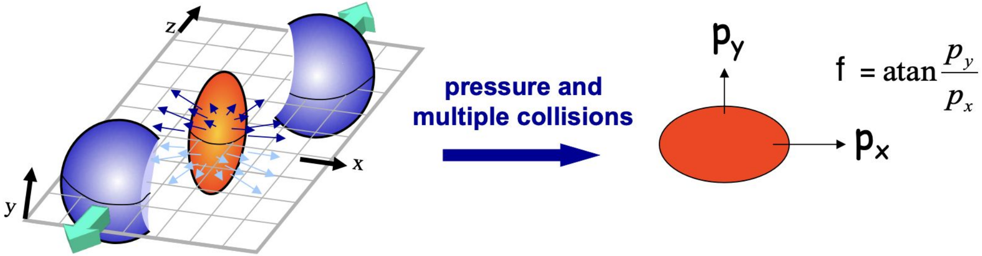
- ➔ Is it similar to that of light flavor?
- ➔ How do heavy quarks couple with the bulk medium?

Azimuthal anisotropy



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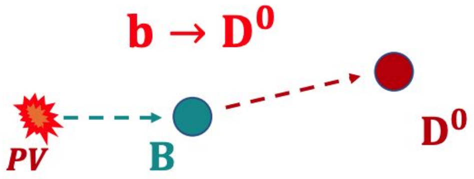
We can probe:

- ➔ Transport properties of medium
- ➔ Hadronization mechanism
- ➔ Path-length dependent parton energy loss

Why D^0 meson?

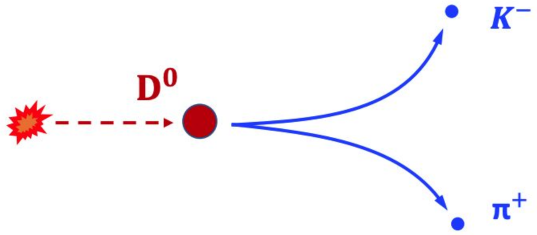
- **Prompt D^0**
  - ~40% of all prompt charm hadrons are D^0 mesons.
  - Best avenue for charm quark properties.

- **Non-Prompt D^0**
  - ~55% of all b hadrons decay to D^0 mesons.
  - Great possibilities for b quark studies.

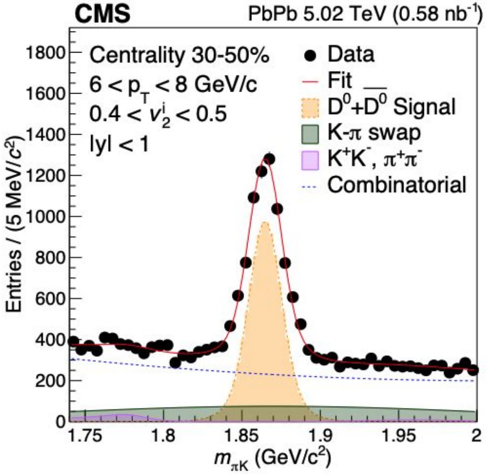


Signal extraction

- **Reconstruction**
  - Used PbPb data at $\sqrt{S_{NN}}$= 5.02 TeV.
  - Inclusive D^0 reconstruction $D^0 \rightarrow K^- \pi^+$
  - No dedicated PID.
  - All opposite charge track pairs combinations.
  - **B**oosted **D**ecision **T**ree (BDT) for background suppression.



- **Inclusive D^0 yield**
  - Signal mass → Double gaussian
  - Swap component → Gaussian
  - K^+K^- & $\pi^+ \pi^-$ → Crystal ball functions
  - Combinatorial → Polynomial 3rd order

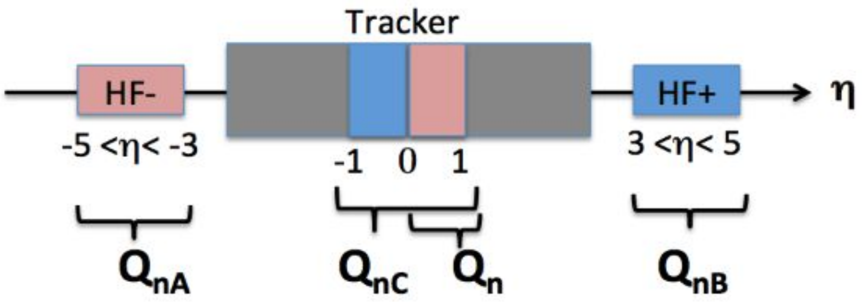


PLB 850 (2024)138389

Methodology: Scalar Product

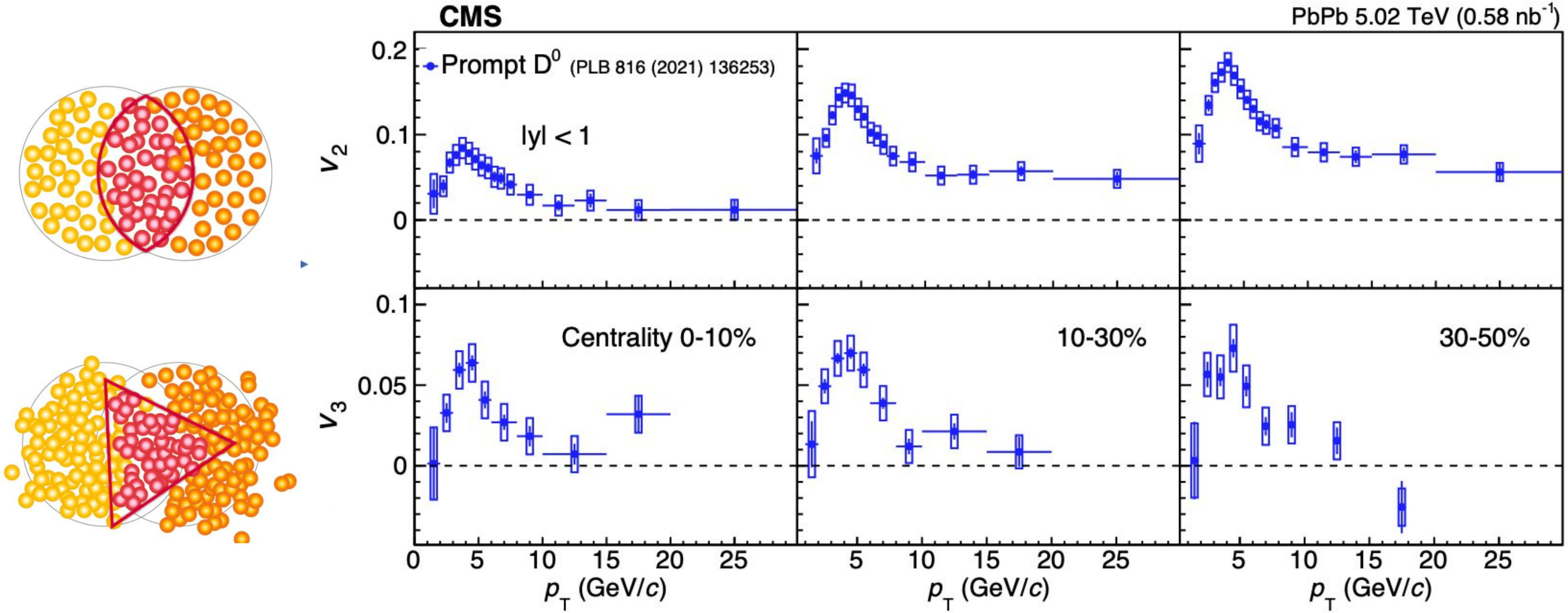
- **Q- vector:** $\vec{Q}_m = \left(\sum_{i}^{M} w_i \cos(m\phi_i) - \left\langle \sum_{i}^{M} w_i \cos(m\phi_i) \right\rangle , \sum_{i}^{M} w_i \sin(m\phi_i) - \left\langle \sum_{i}^{M} w_i \sin(m\phi_i) \right\rangle \right)$

- **Flow harmonics:** $v_n\{SP\} \equiv \frac{\langle Q_n Q_{nA}^{*} \rangle}{\sqrt{\frac{\langle Q_{nA} Q_{nB}^{*} \rangle \langle Q_{nA} Q_{nC}^{*} \rangle}{\langle Q_{nB} Q_{nC}^{*} \rangle}}},$



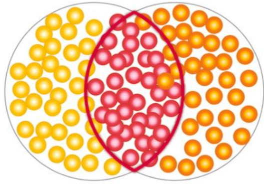
- Large η gap $|\Delta\eta| > 3.0$ applied to remove non-flow effects.

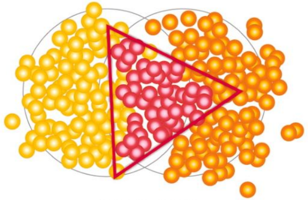
Results: Prompt D^0 v_n

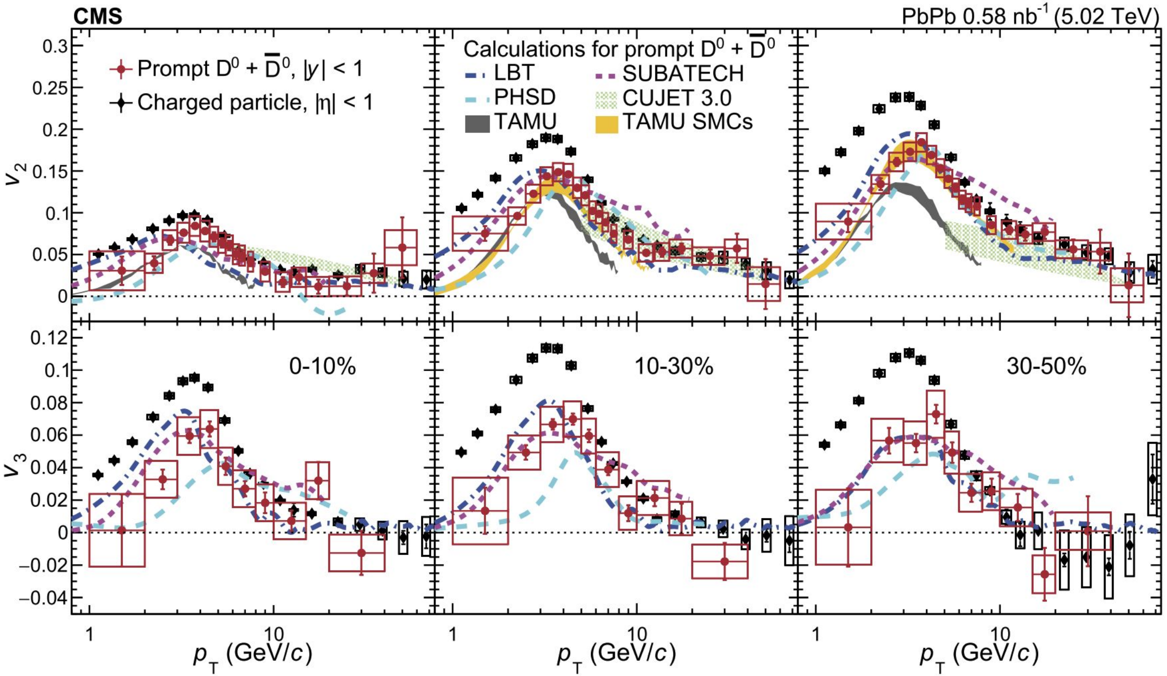


- Strong p_T and centrality dependence for v_2
- Positive v_2 at higher p_T indicates path-dependent energy loss of charm quarks.
- Significant nonzero v_3 up to ~10 GeV, indicates initial state fluctuation.

Results: Model comparison

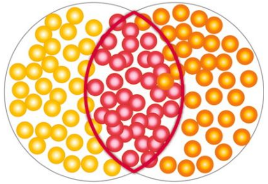


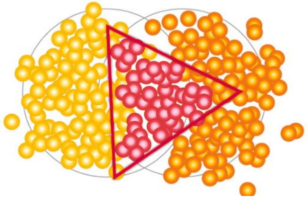


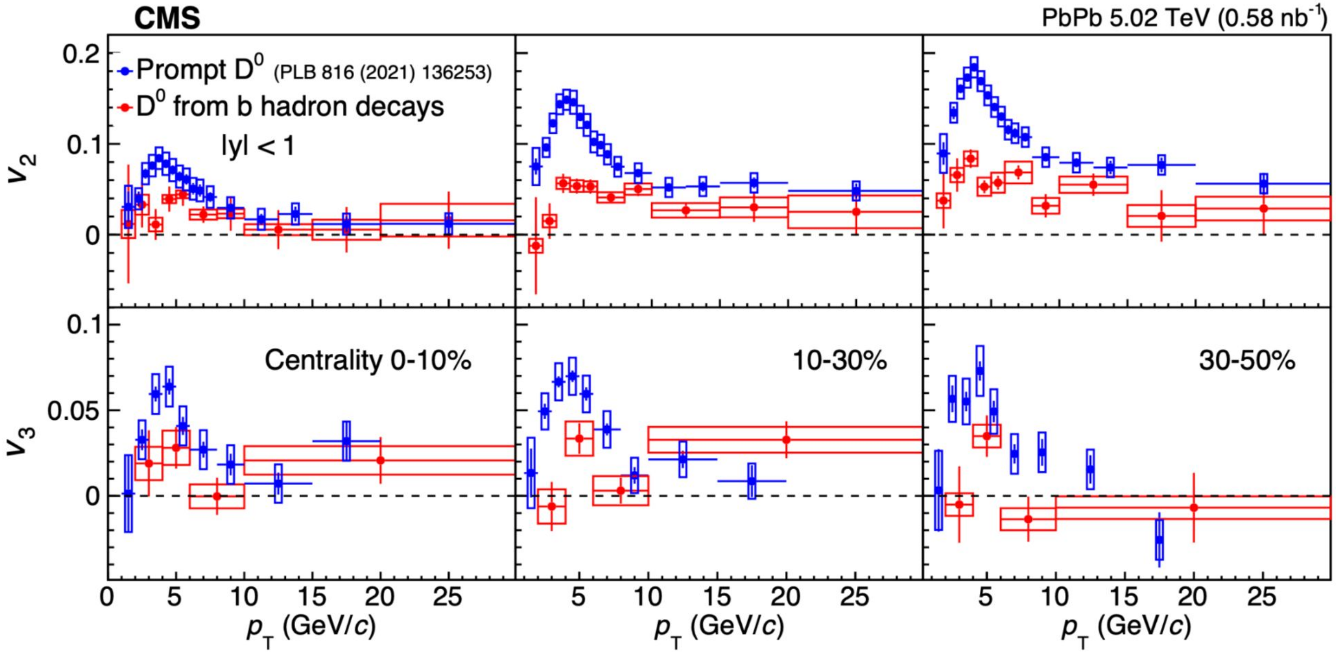


- ❖ Comparison with charge hadrons shows mass hierarchy.
- ❖ Qualitative agreement with model predictions.

Results: Non-prompt D^0 v_n



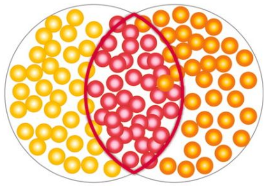


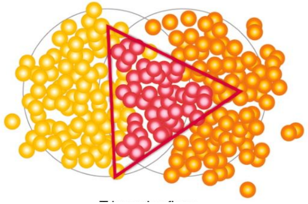


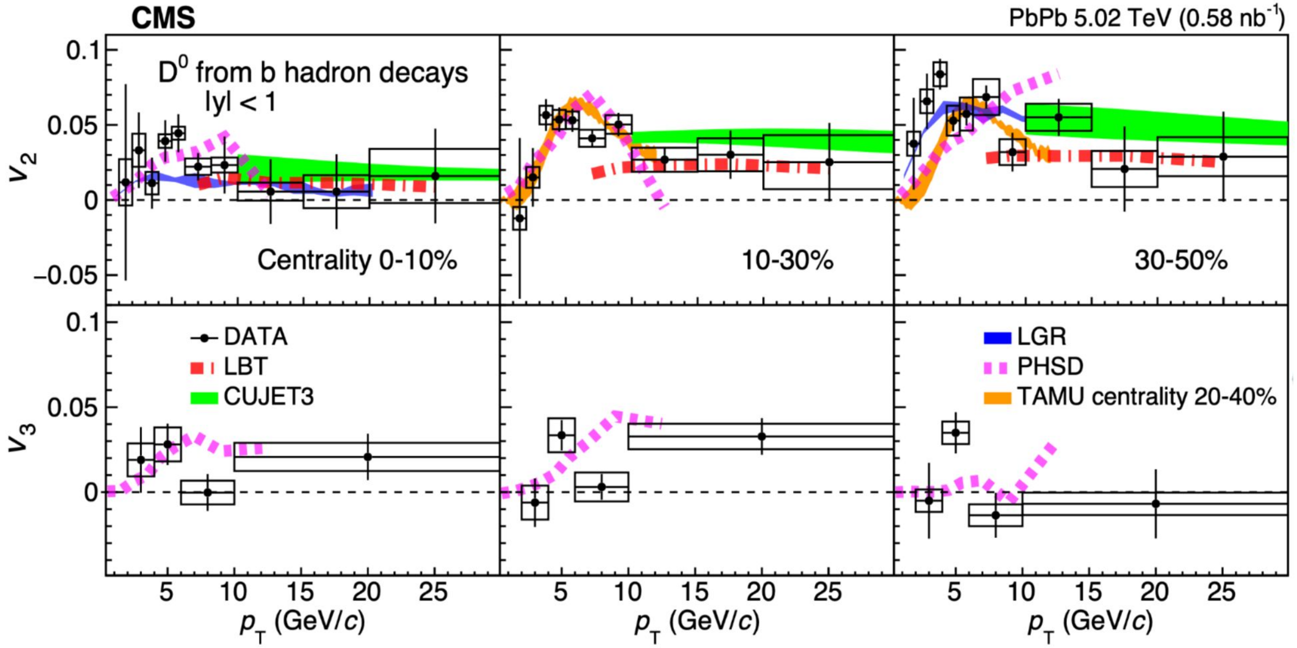
First measurement of $b \rightarrow D^0$ anisotropy in PbPb collisions

- ❖ Mass ordering of flow magnitudes.
- ❖ Weak p_T and centrality dependence for v_2.
- ❖ Indication of non-zero v_3

Results: Model comparison





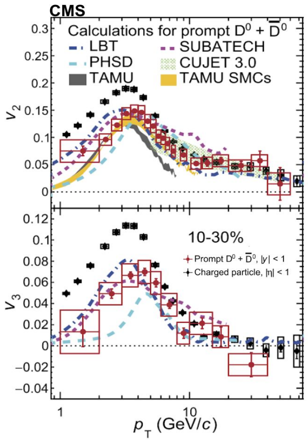


- ❖ Qualitatively good agreement between theory and data.
- ❖ Different models describe data for different p_T ranges.

Summary

❖ Measurement of prompt D^0

- ➢ We have measured elliptic flow (v_2) and triangular flow (v_3) in three different centrality ranges.
- ➢ Strong p_T and centrality dependence are observed for v_2.
- ➢ Non-zero v_3 is also observed, indicates initial state fluctuation.
- ➢ Qualitative agreement with theoretical models.



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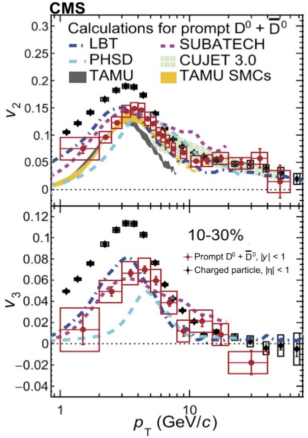

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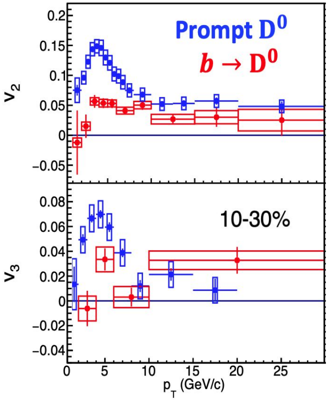


Stay tuned!

- **Ds anisotropy** ➡ Impact of hadronization on Charm flow!
- **Λ_c anisotropy** ➡ Charm flow in baryonic form!

Stay tuned!

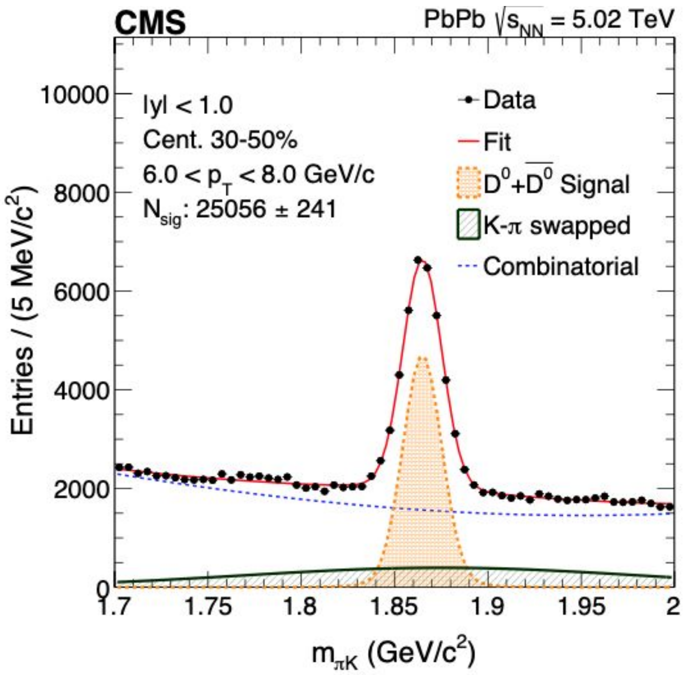
- **Ds anisotropy** ➡ Impact [illegible] hadronization on Charm flow!
- **Λ_c anisotropy** ➡ Ch[illegible]m flow in baryonic form!

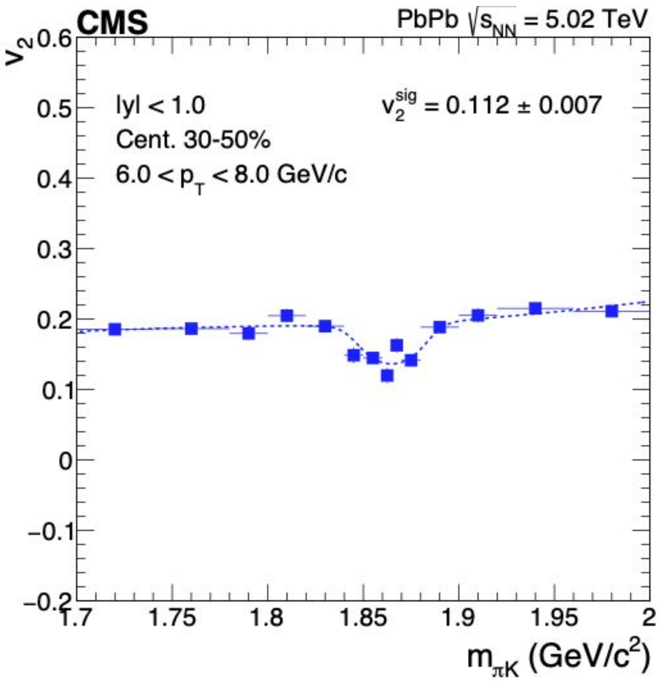
Selected for QM2025

Thank You!

Backup

Simultaneous Fit





Theoretical Models

CUJET 3.0: A pQCD-based jet energy loss model with a color-magnetic monopole medium for heavy quarks in QGP.

PHSD: An off-shell transport model with dynamical quarks and gluons for non-equilibrium heavy quark dynamics in QGP.

TAMU: A non-perturbative T-matrix model describing heavy quark diffusion via strong interactions in QGP.

LBT: A pQCD-based Boltzmann transport model simulating heavy quark scattering in QGP.

LGR: Langevin framework for heavy quark dynamics with strong coupling in a gluon-rich QGP.

SUBATECH: Hydro-kinetic or Langevin model focusing on drag and diffusion of heavy quarks in QGP.