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

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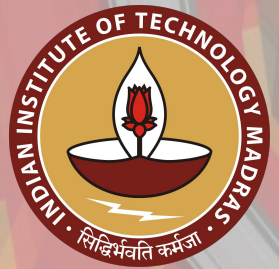
(On behalf of CMS Collaboration)

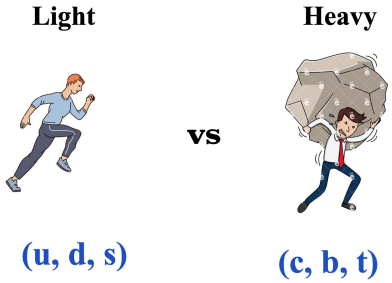
September 22-27, 2024



HP2024
NAGASAKI

Heavy flavor and QGP

- **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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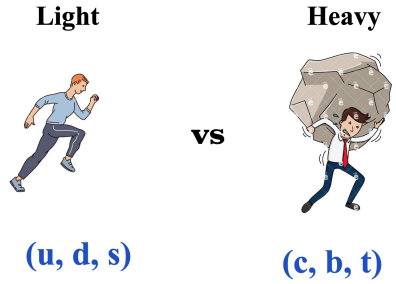
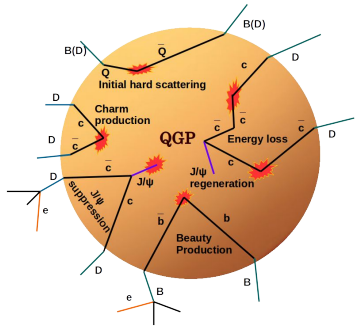


❖ Energy loss mechanism:

- ➢ **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.



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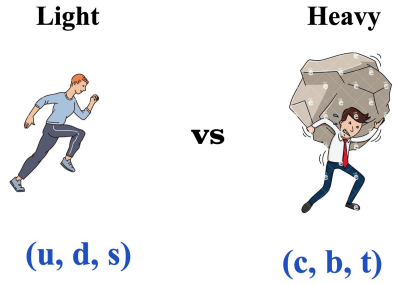

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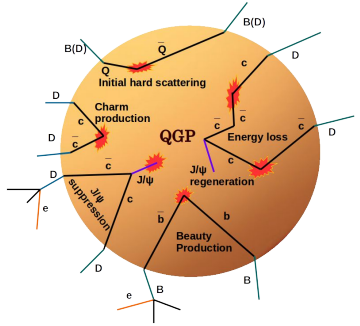
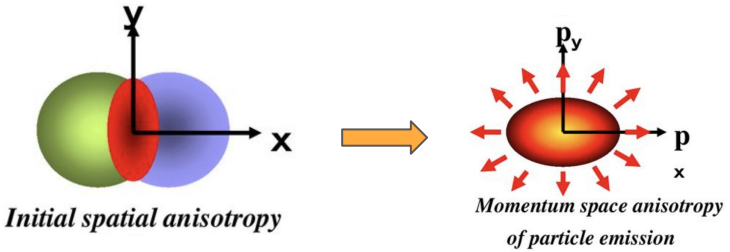


❖ Azimuthal anisotropy (collective flow):

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



Why D^0 meson?

- **Prompt D^0**
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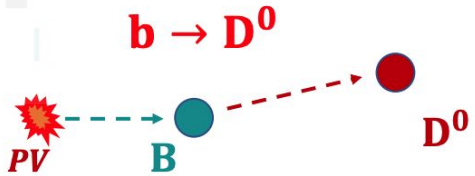
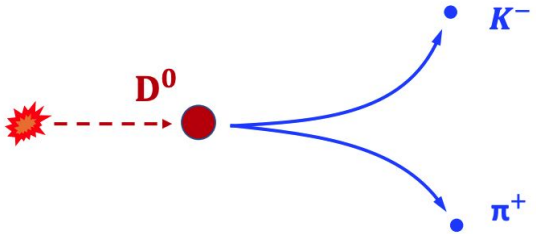
- **Non-Prompt D^0**
  - ~60% of all b hadrons decay to D^0 mesons.
  - Great possibilities for b quark studies.



Signal extraction of D^0

❖ Reconstruction

- ➢ Used PbPb data at $\sqrt{S_{NN}}$= 5.02 TeV.
- ➢ Inclusive D^0 reconstruction $D^0 \rightarrow K^- \pi^+$
- ➢ No hadron identification.
- ➢ All opposite charge track pairs combinations.
- ➢ Boosted Decision Tree (BDT) for background suppression.



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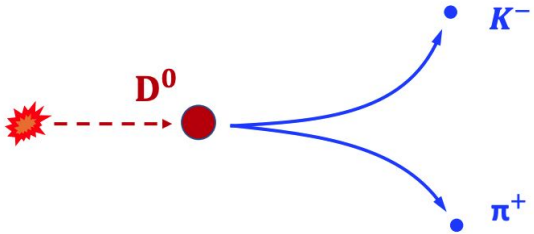
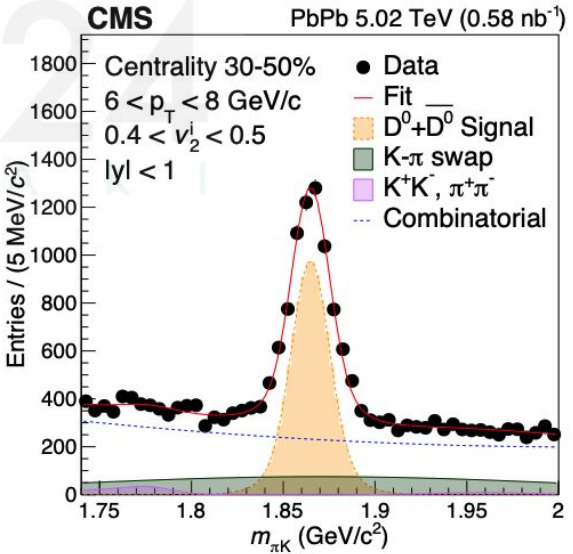


❖ Inclusive D^0 yield

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



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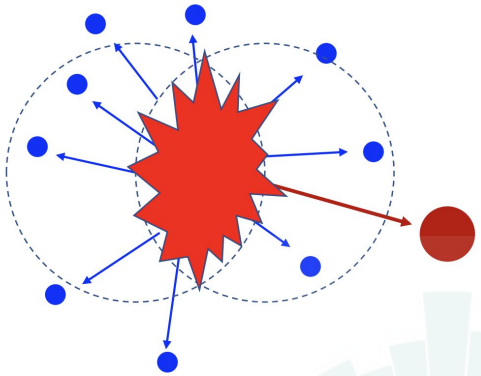
Anisotropy of D^0

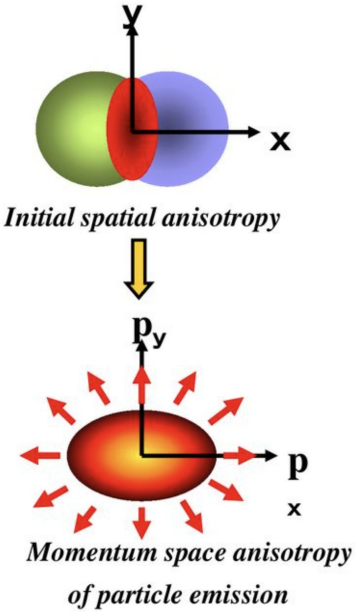


❖ **Anisotropy coefficient, v_n**

$$v_n = < 2cos\, n(\phi - \psi_n) >$$

$\phi \rightarrow$ D^0 azimuthal angle

$\psi_n \rightarrow$ Symmetry plane



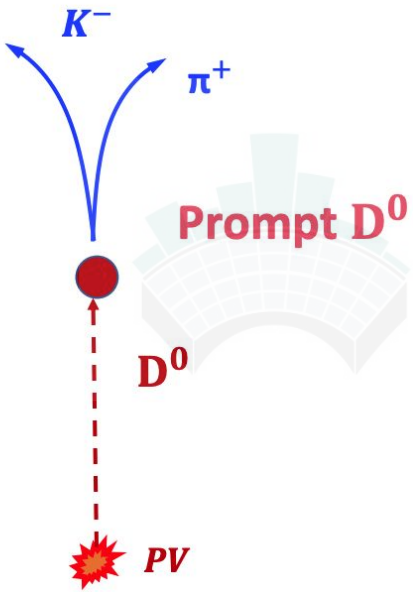
$v_2 \rightarrow$ Elliptic flow $\rightarrow$ Initial state geometry

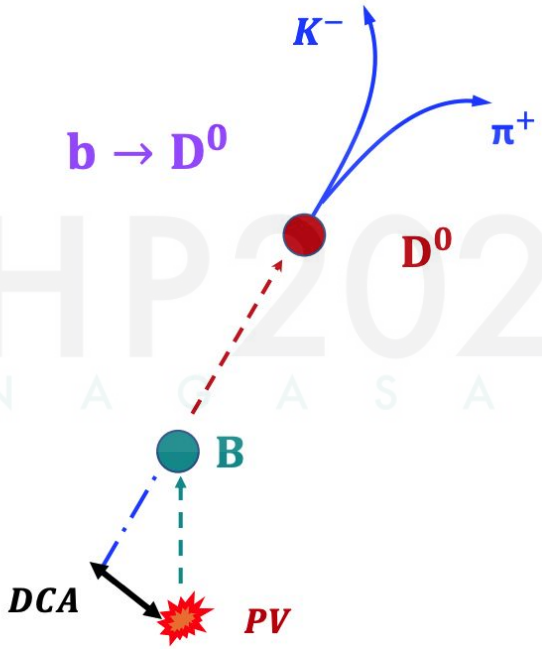
$v_3 \rightarrow$ Triangular flow $\rightarrow$ Initial state fluctuation

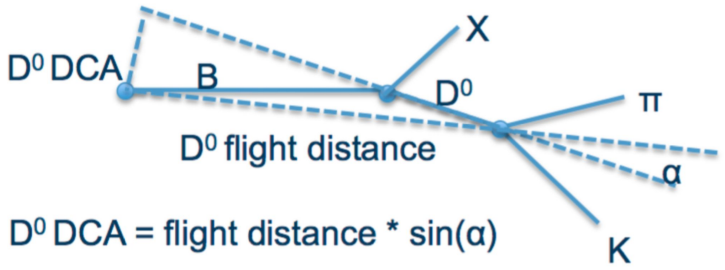
We can probe:

- Collectivity
- Diffusion
- Hadronization
- Path dependent parton energy loss

Prompt fraction estimation

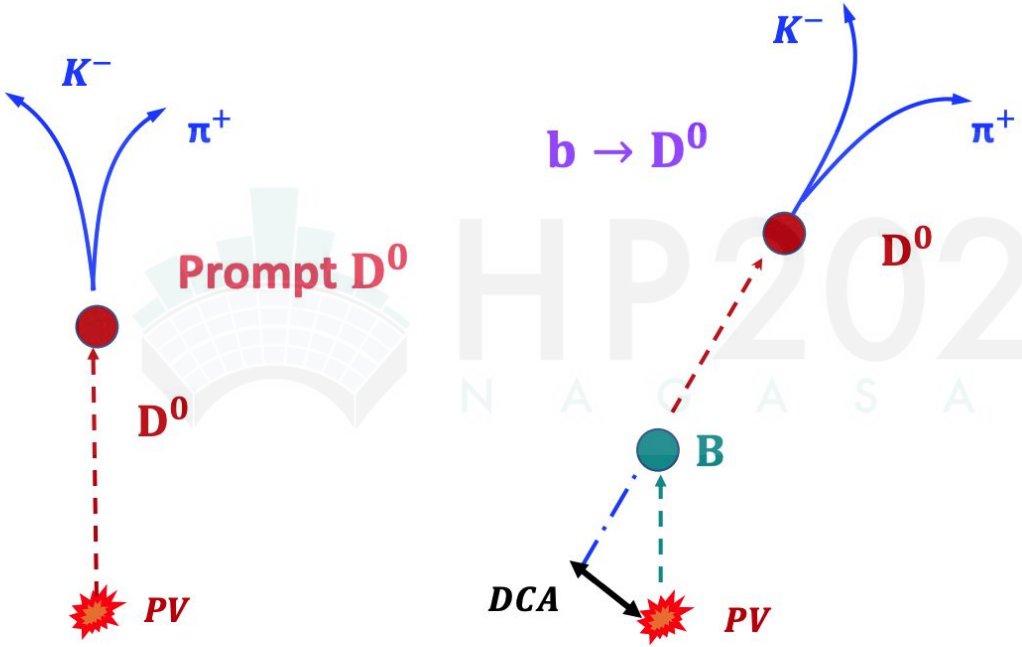


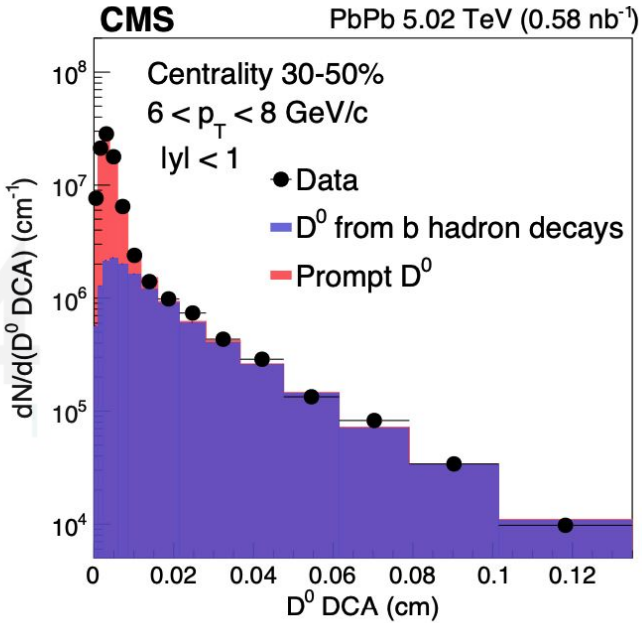




DCA (distance of closest approach)

Prompt fraction estimation





DCA (distance of closest approach)

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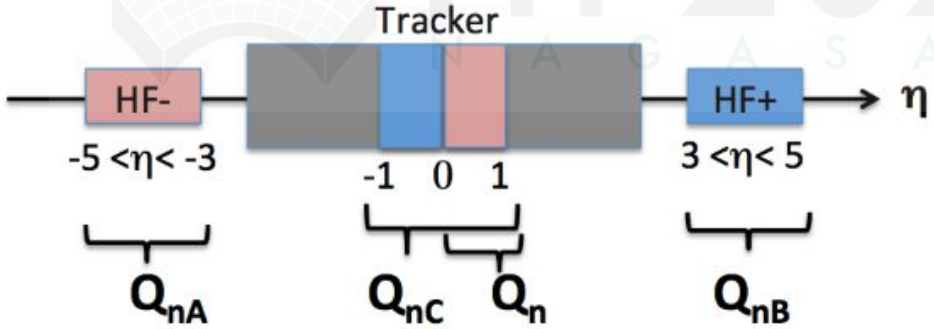
Analysis method: Scalar product

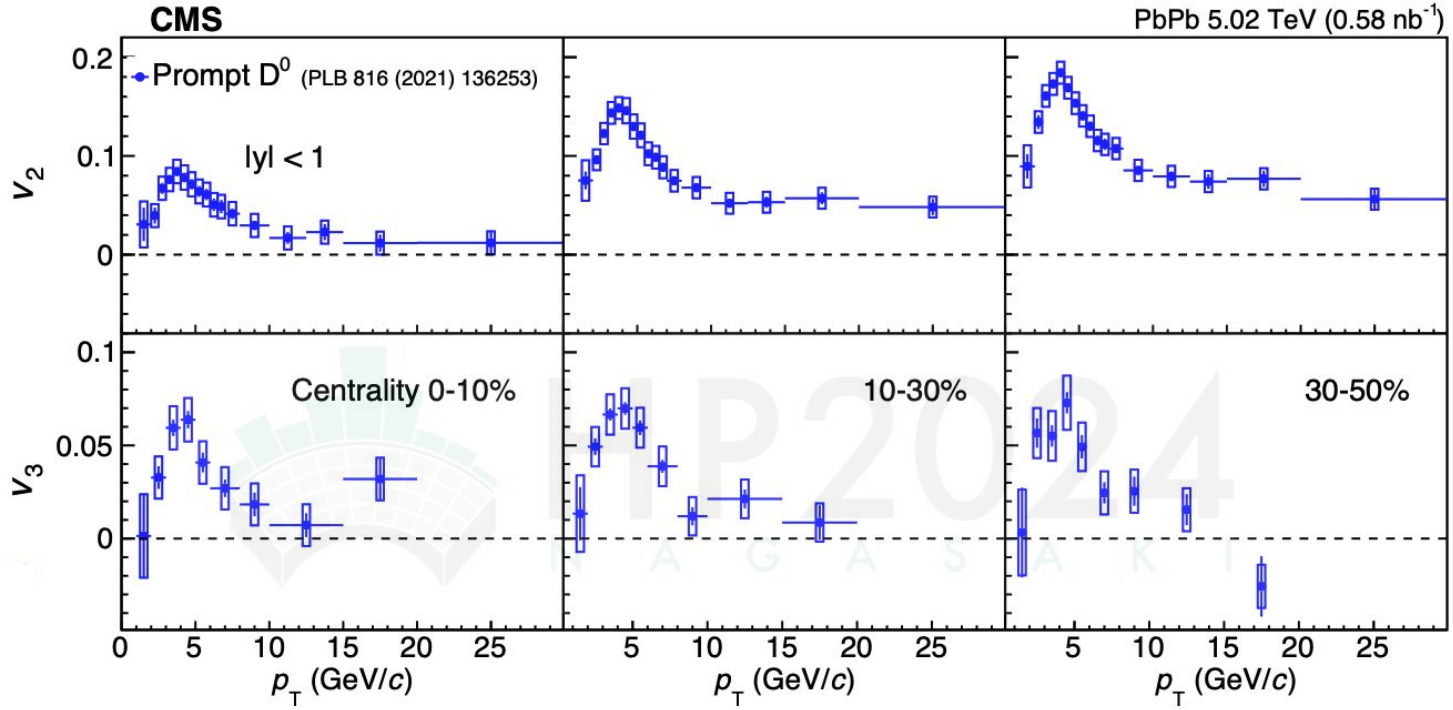
- **Q- vector:** $\vec{Q}_m = \left(\sum_i^M w_i \cos(m\phi_i) - \left\langle \sum_i^M w_i \cos(m\phi_i) \right\rangle, \sum_i^M w_i \sin(m\phi_i) - \left\langle \sum_i^M w_i \sin(m\phi_i) \right\rangle \right)$

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



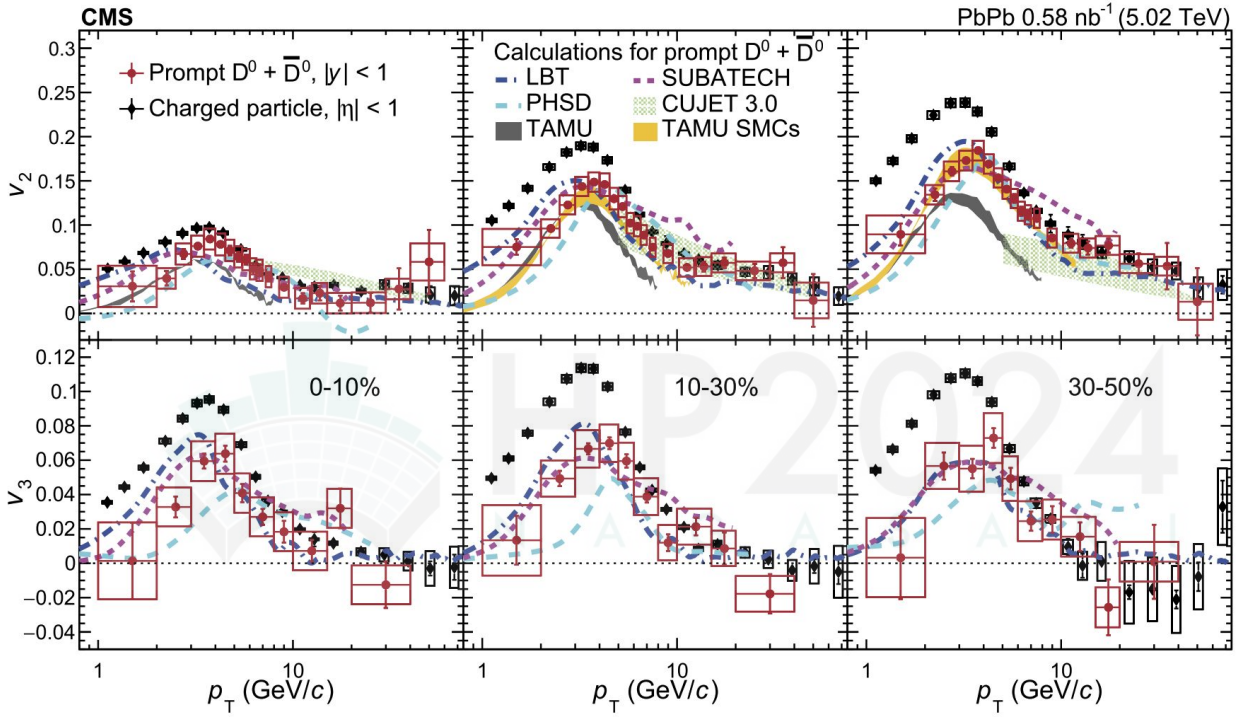
- Large η gap $|\Delta\eta| > 3.0$ applied to remove non-flow effects.

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.

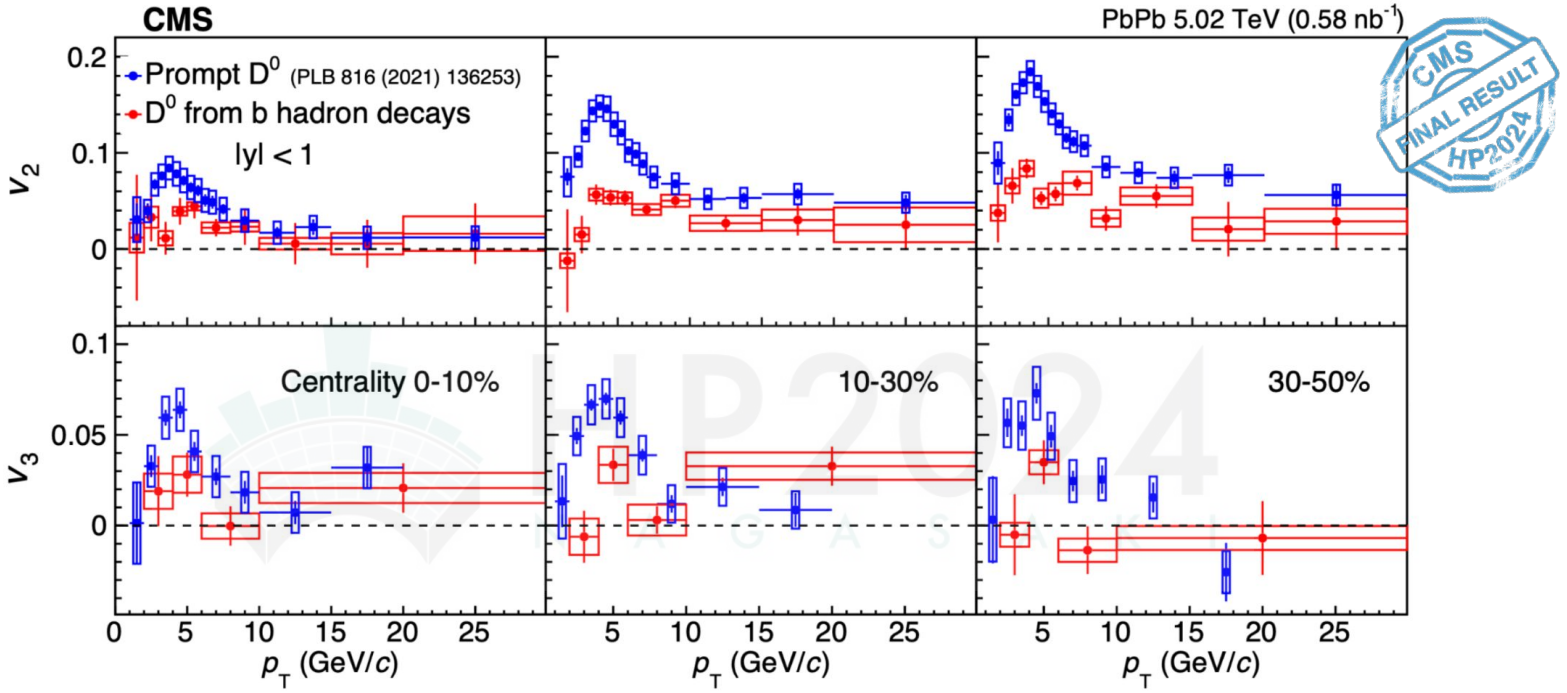
Results: Model comparison



PLB 816 (2021) 136253

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

Results: Non-prompt D^0 v_n



First measurement of b→D^0 anisotropy in PbPb collisions

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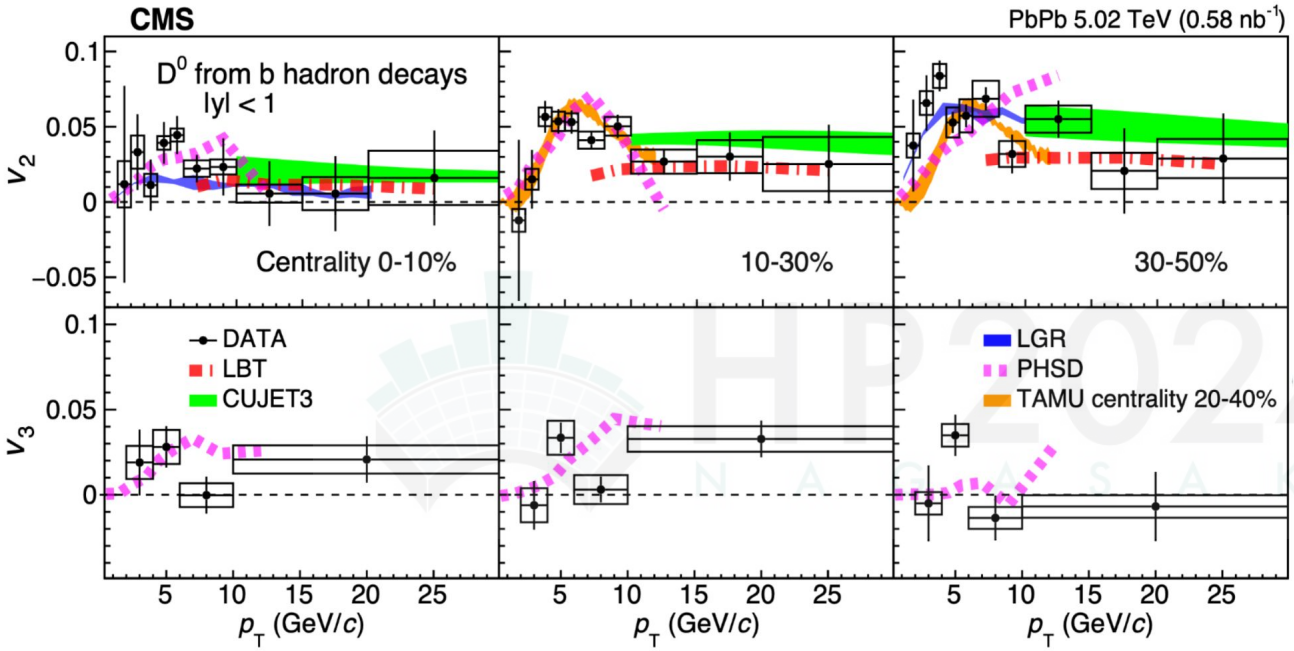
- Mass ordering of flow magnitudes.
- Weak p_T and centrality dependence for v_2.
- Indication of non-zero v_3

Results: Model comparison



High p_T

CUJET3 CPC 43 4 (2019) 044101

LBT PRC 94 (2016) 014909

Low p_T

PHSD: PRC 92 (2015) 014910

TAMU PLB 735 (2014) 445

LGR EPJ C 80 7 (2020) 671

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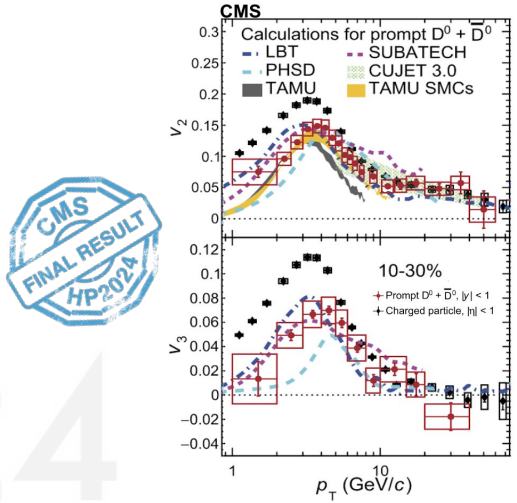
- Qualitatively good agreement between theory and data.
- Different models describe data for different p_T ranges.

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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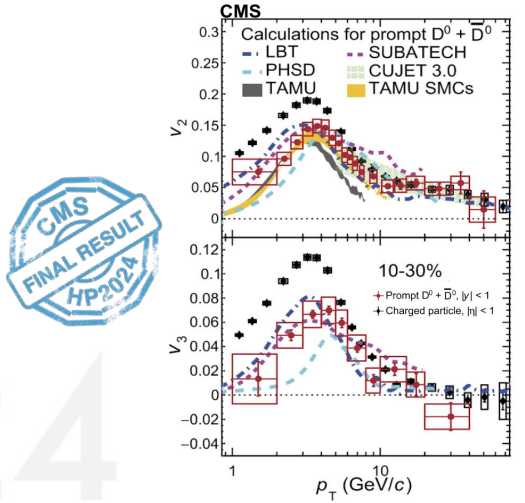

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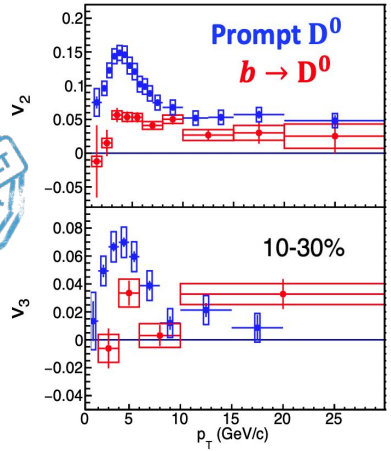
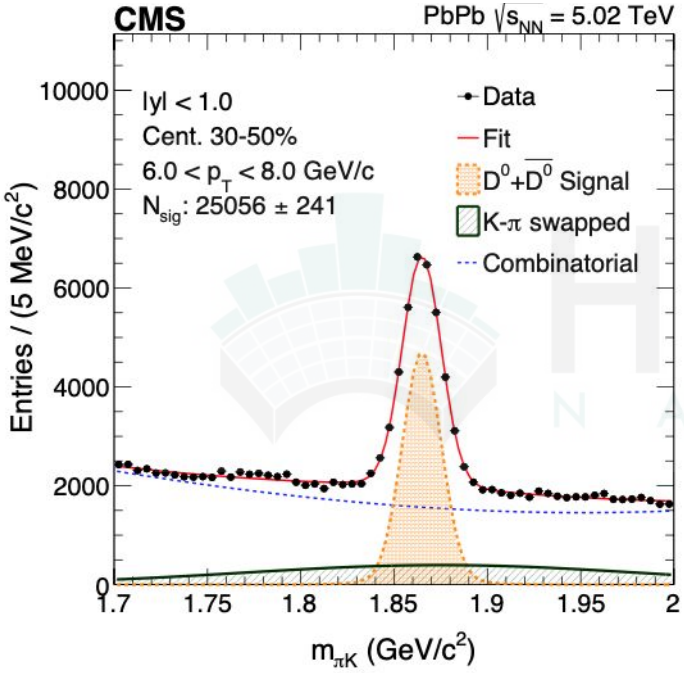
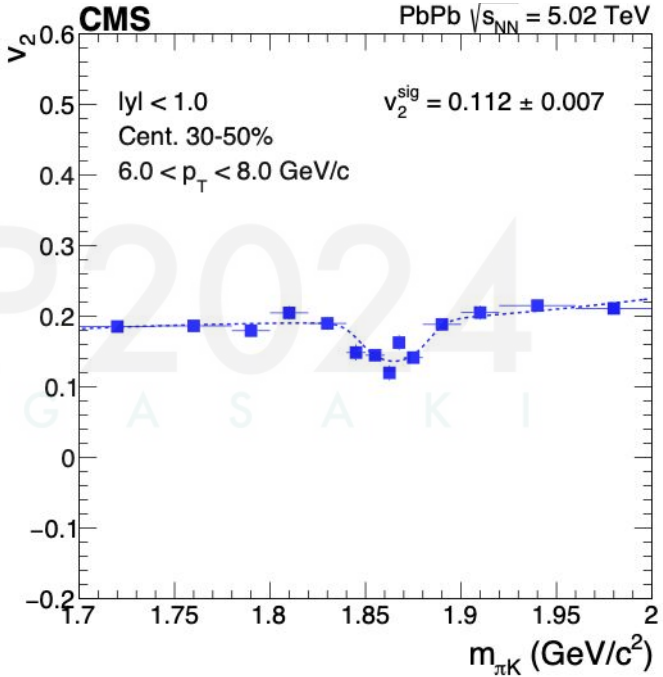



Thank You!

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.

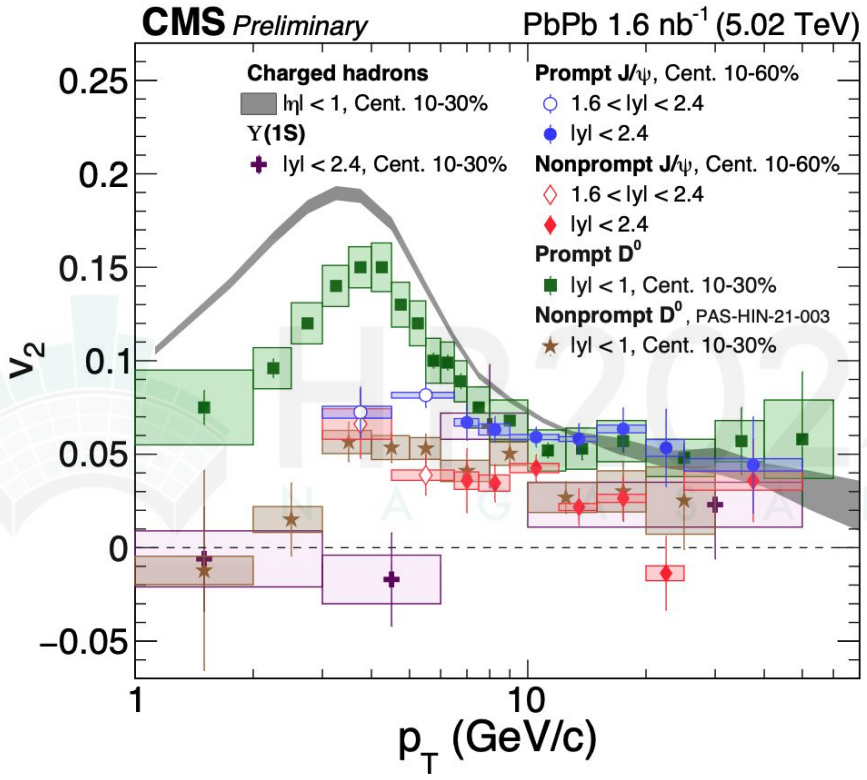
TAMU: A non-perturbative T-matrix model describing heavy quark diffusion via strong interactions in QGP.

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.

CMS v_n comparison



v_2 of Charged hadron > Charm hadron > Beauty hadron