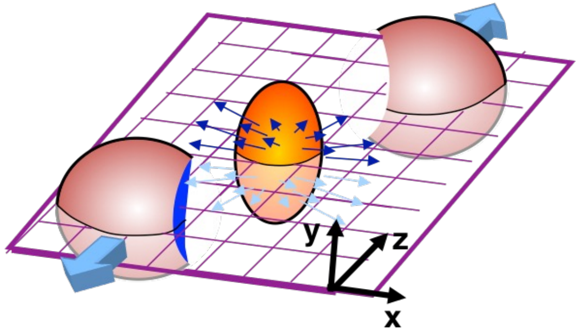
Measurements of D^0 mesons production and collective flow with CMS at 5.02 TeV

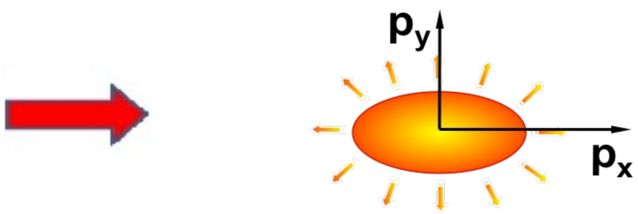
Milan Stojanovic
Purdue University
on behalf of the CMS collaboration

Hard Probes 2023, Aschaffenburg, Germany

Anisotropy in heavy ion collisions

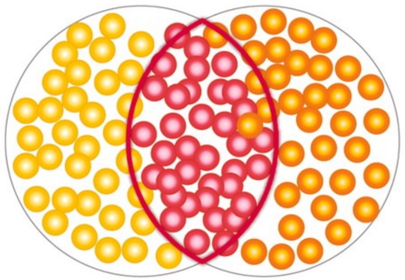


Space anisotropy

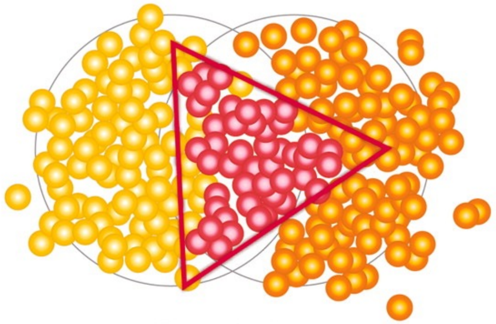


momentum space anisotropy

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



System symmetry → elliptic flow, v_2



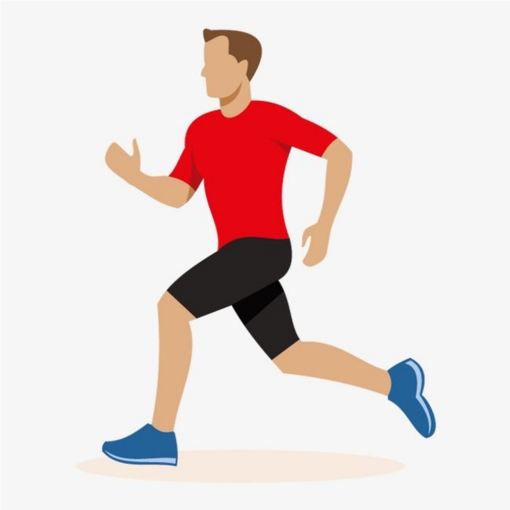
Fluctuations → triangular flow, v_3

Flow mechanism (light hadrons):

- **low p_T → hydrodynamics**
- **medium p_T → coalescence**
- **high p_T → path-dependent parton energy loss**

Heavy quark anisotropy

Traveling light vs **carrying a heavy luggage**



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

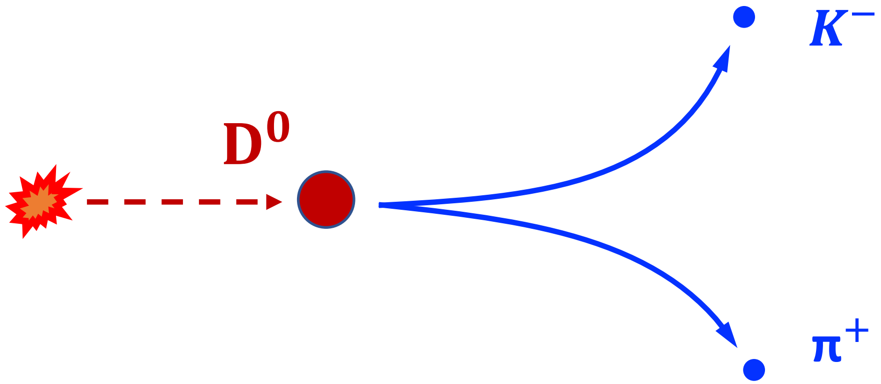
Flow mechanism (heavy quarks):

- **low p_T → hydrodynamics + collisional energy loss**
- **~~medium~~ all p_T → coalescence**
- **high p_T → path-dependent parton energy loss**

D^0 signal extraction

Reconstruction

- Data from 2018 Run:
  - PbPb @ 5 TeV ~ 4B Minimum Bias events
- Inclusive D^0 reconstruction
  - $D^0 \rightarrow K^-\pi^+$
- No particle identification → All possible combinations of pairs with opposite charge track in an event are taken into account
- Additional selection performed with Boosted Decision Tree



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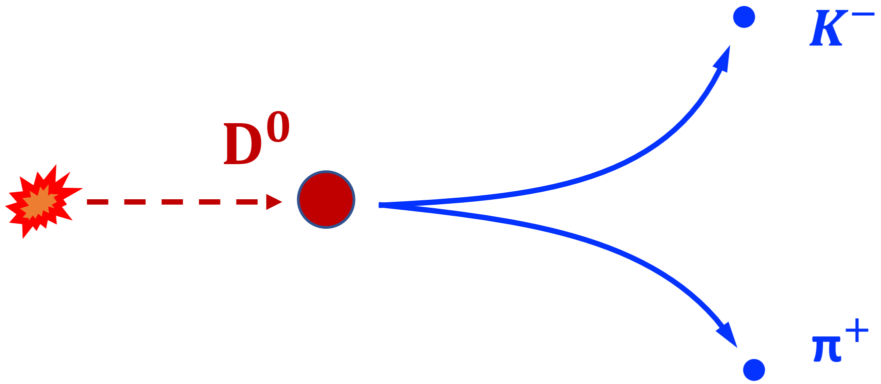
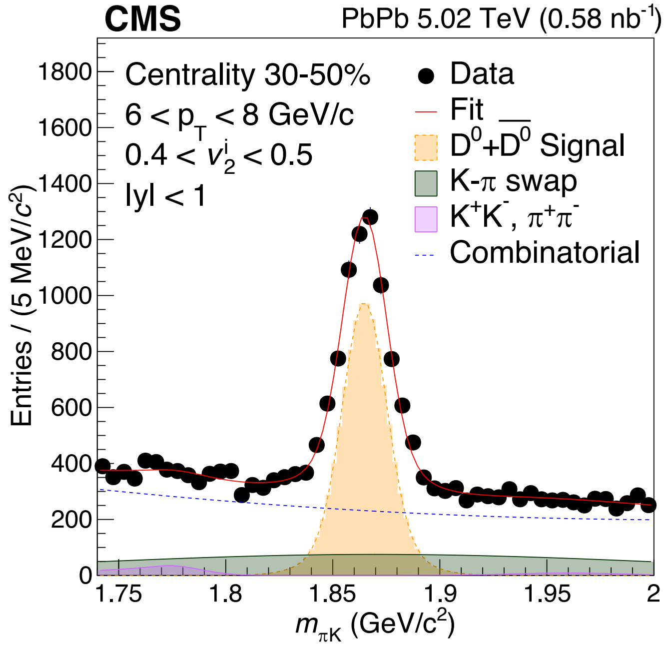


Inclusive D^0 Yield

- Signal mass spectrum – double gaussian
- Swap component – gaussian
- K^+K^- & $\pi^+\pi^-$ – Crystal ball functions
- Combinatorial – polynomial 3rd order



arXiv:2212.01636

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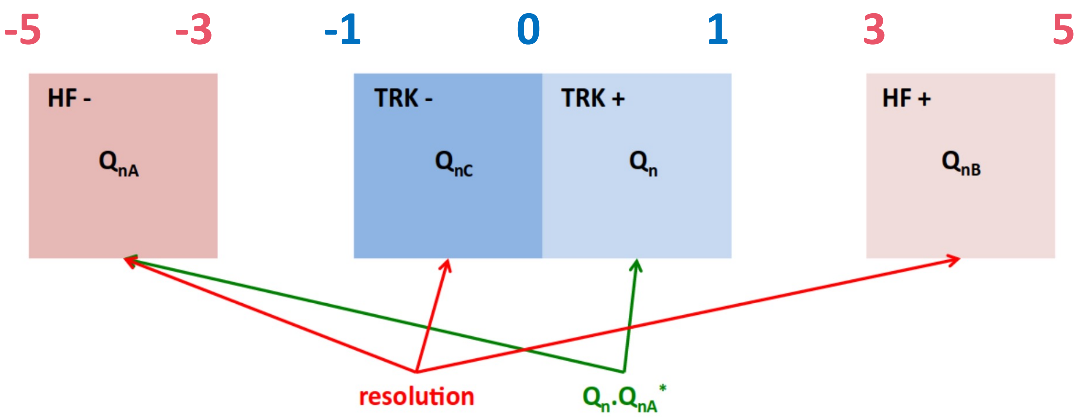
D^0 meson anisotropy

Charm anisotropy via D^0

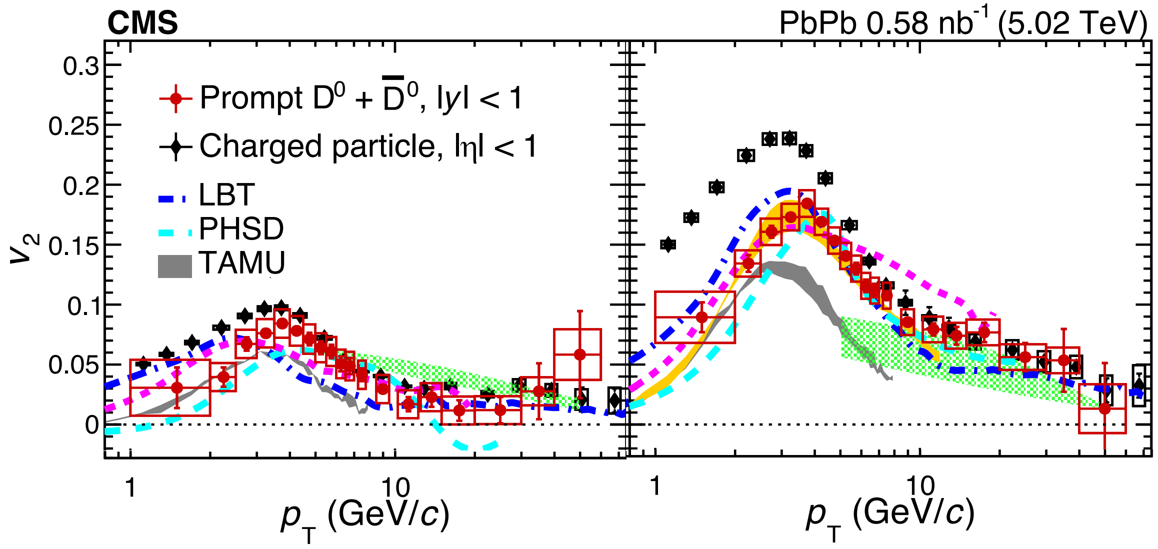
Scalar Product method



Q_n – D^0 candidate flow vector

Q_{nA}, Q_{nB}, Q_{nC} – event plane vectors from subevents

$$v_n\{SP\} \equiv \frac{\langle Q_n Q_{nA}^* \rangle}{\sqrt{\frac{\langle Q_{nA} Q_{nB}^* \rangle \langle Q_{nA} Q_{nC}^* \rangle}{\langle Q_{nB} Q_{nC}^* \rangle}}}$$

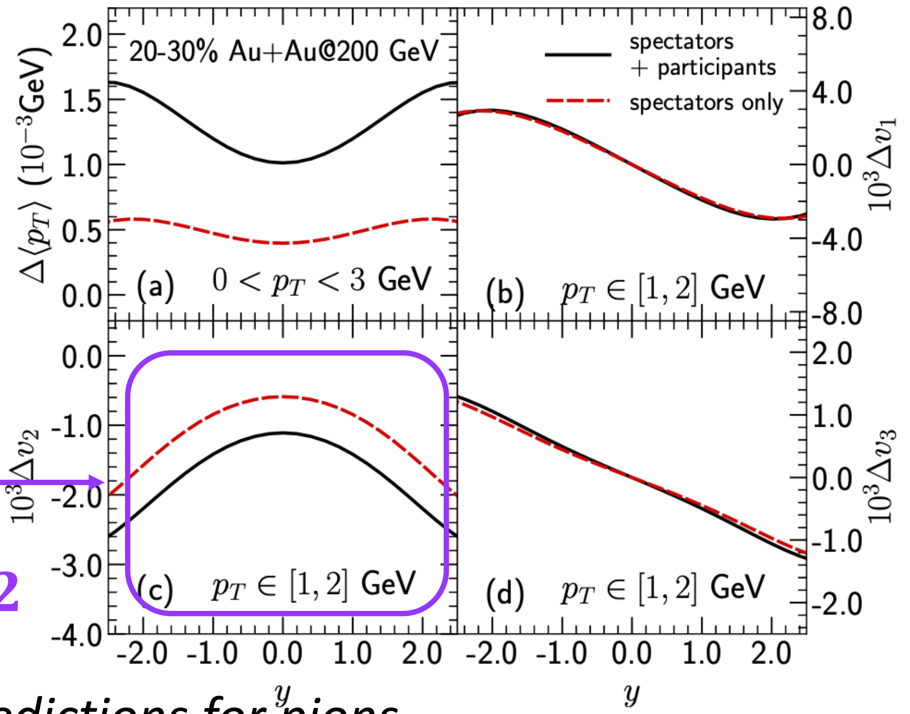


- Similar p_T dependence as for charged hadrons
- Small p_T – mass ordering
  - D^0 $v_2 < h^{\pm}$ v_2
- Higher p_T – v_n converges
  - D^0 $v_2 \approx h^{\pm}$ v_2

PLB 816 (2021) 136253

Search for EM field in PbPb

EM field from participant can affect v2 signal



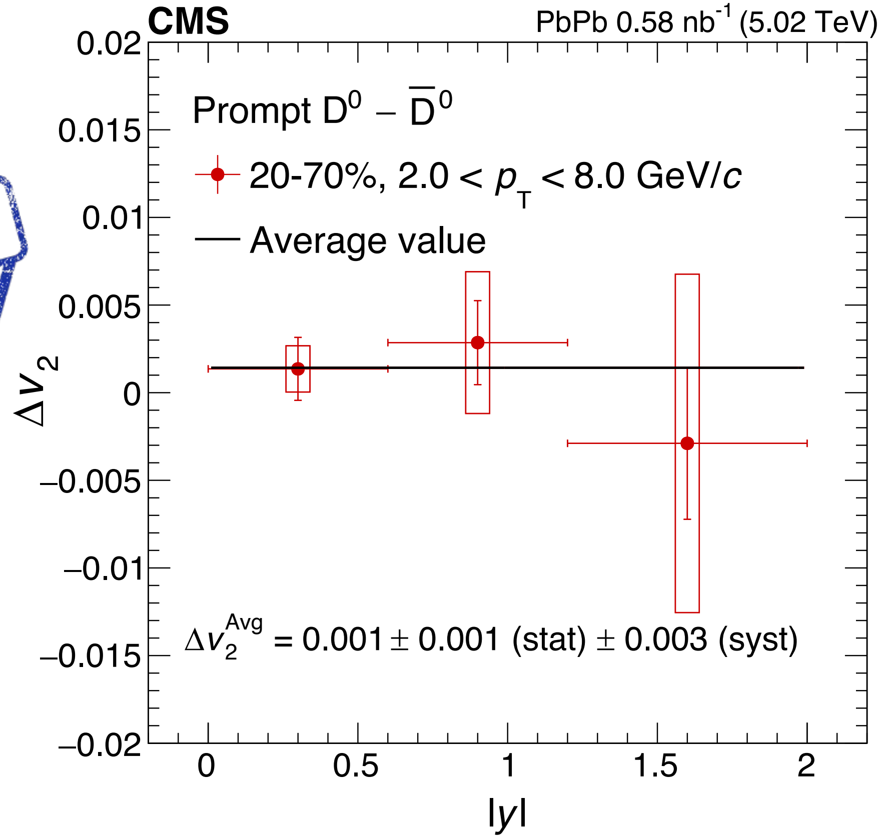
Δv_2

Predictions for pions

$$\Delta \equiv \pi^+ - \pi^-$$

Phys. Rev. C 98, 055201 (2018)

CMS FINAL HP23



Average value extracted with a fit to data:

$$\Delta v_2 \equiv v_2(D^0) - v_2(\overline{D^0}) = 0.001 \pm 0.001\ (stat) \pm 0.003\ (syst)$$

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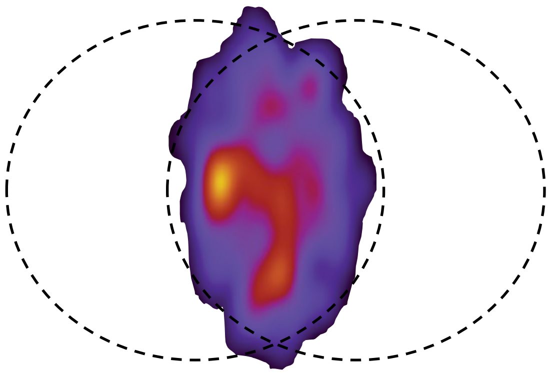
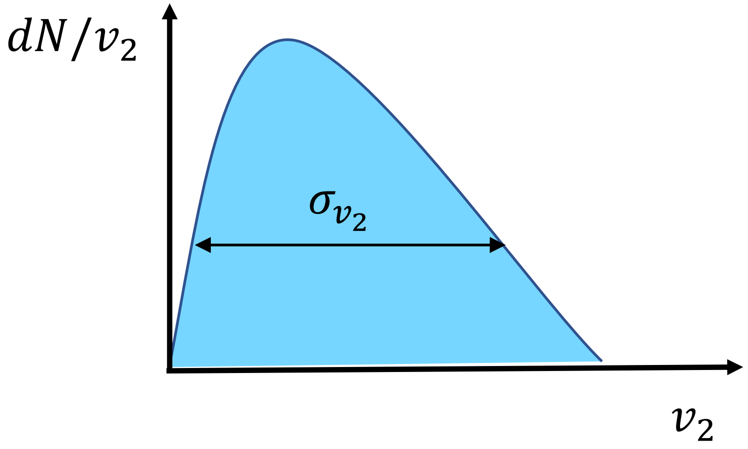
Event-by-event fluctuations

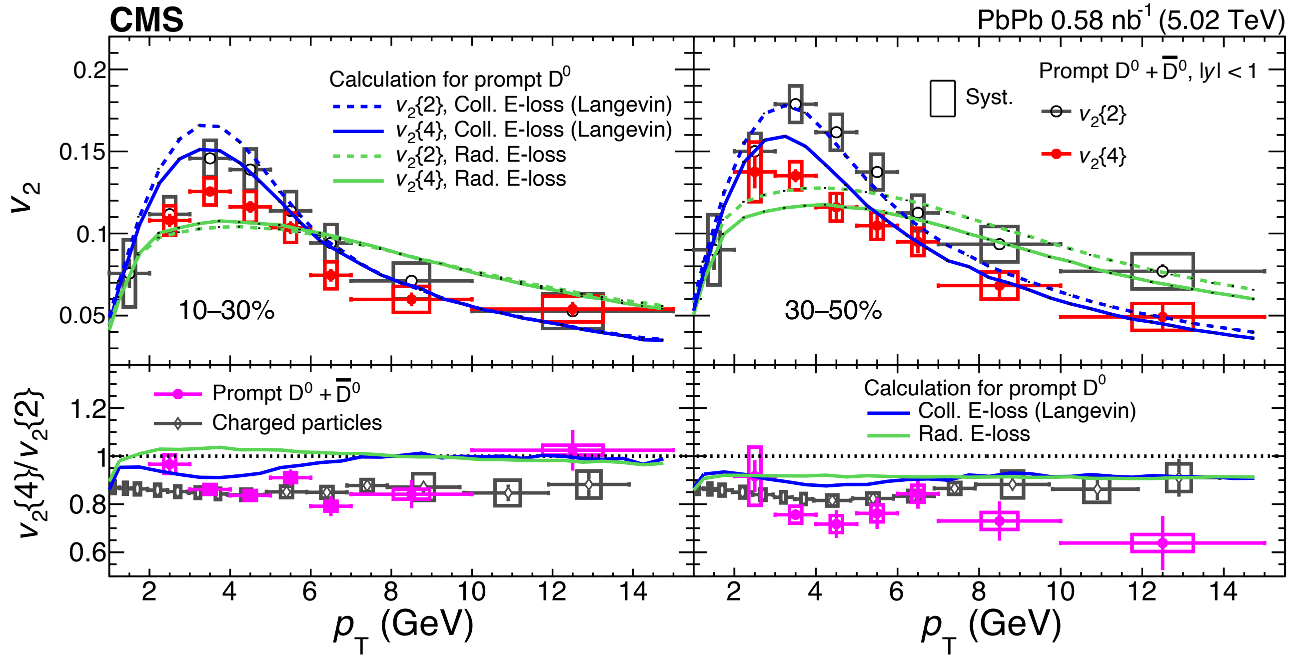
Event by event fluctuations:
- ❑ Initial geometry fluctuations – event property
- ❑ Final state effects – can show difference between D^0 and charged particles

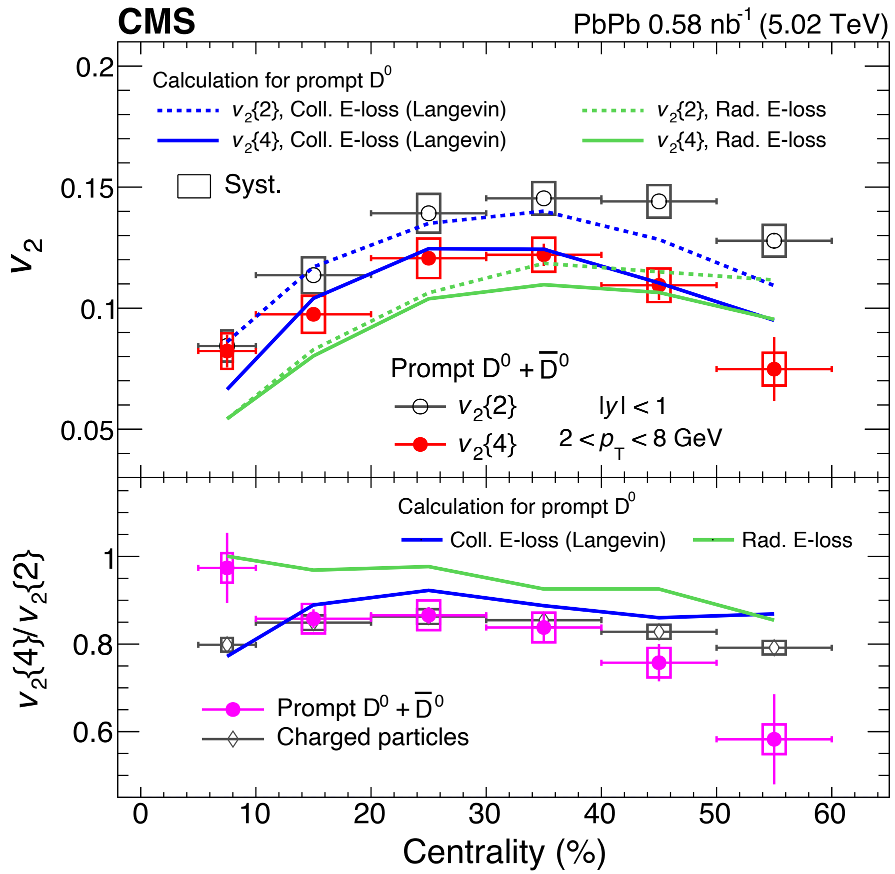




- ➢ Two-particle correlations: $v_2\{2\} \simeq \langle v_2 \rangle + \frac{1}{2}\frac{\sigma_{v_n}^2}{\langle v_2 \rangle}$
- ➢ Four-particle correlations: $v_2\{4\} \simeq \langle v_2 \rangle - \frac{1}{2}\frac{\sigma_{v_n}^2}{\langle v_2 \rangle}$

Event-by-event fluctuations



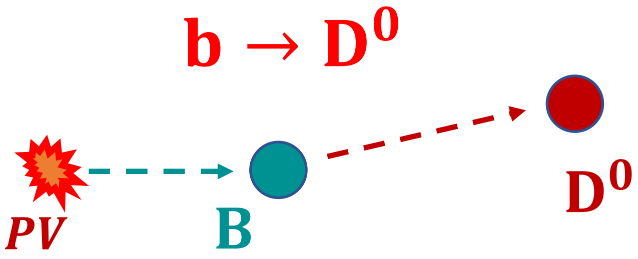


$v_2\{4\}/v_2\{2\}$:

- ❑ D^0 compatible with charged hadrons in 10-40% centrality
  - ○ Suggesting that initial fluctuations are dominant
- ❑ Indication of discrepancies in more peripheral collisions
  - ○ potential final state effects

PRL 129 (2022) 022001

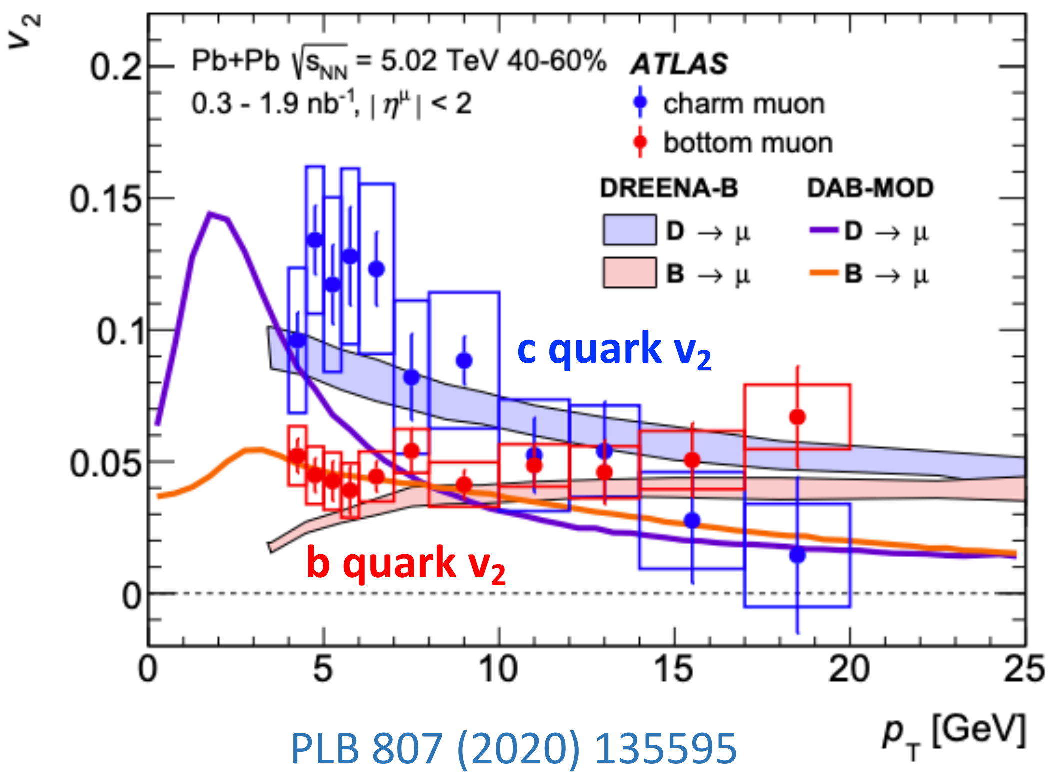
Bottom anisotropy via D^0



b quark anisotropy

- ATLAS
  $b \rightarrow \mu$
  PLB 807 (2020) 135595
- ALICE
  $b \rightarrow e$
  PRL 126 (2021) 162001
- CMS
  $b \rightarrow J/\psi$
  CMS-PAS-HIN-21-008

❖ Non-zero v_2!



PLB 807 (2020) 135595

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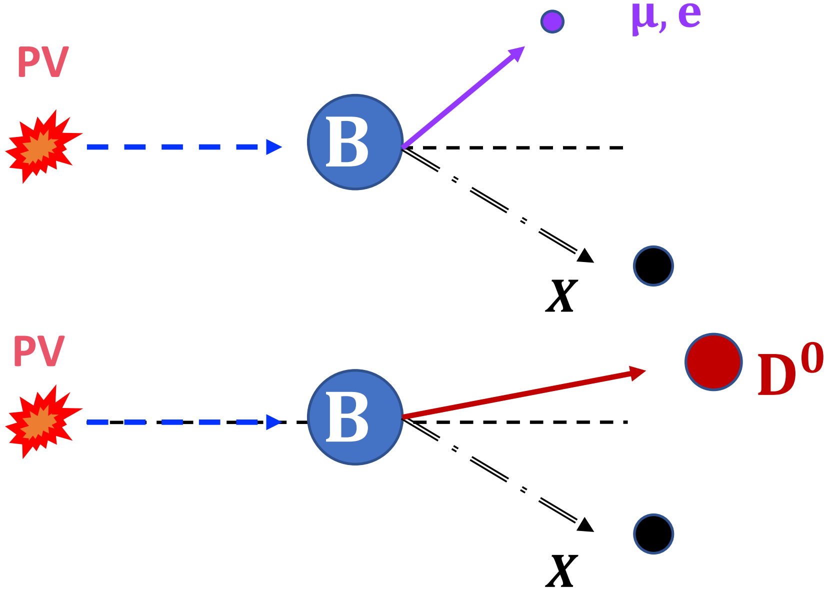
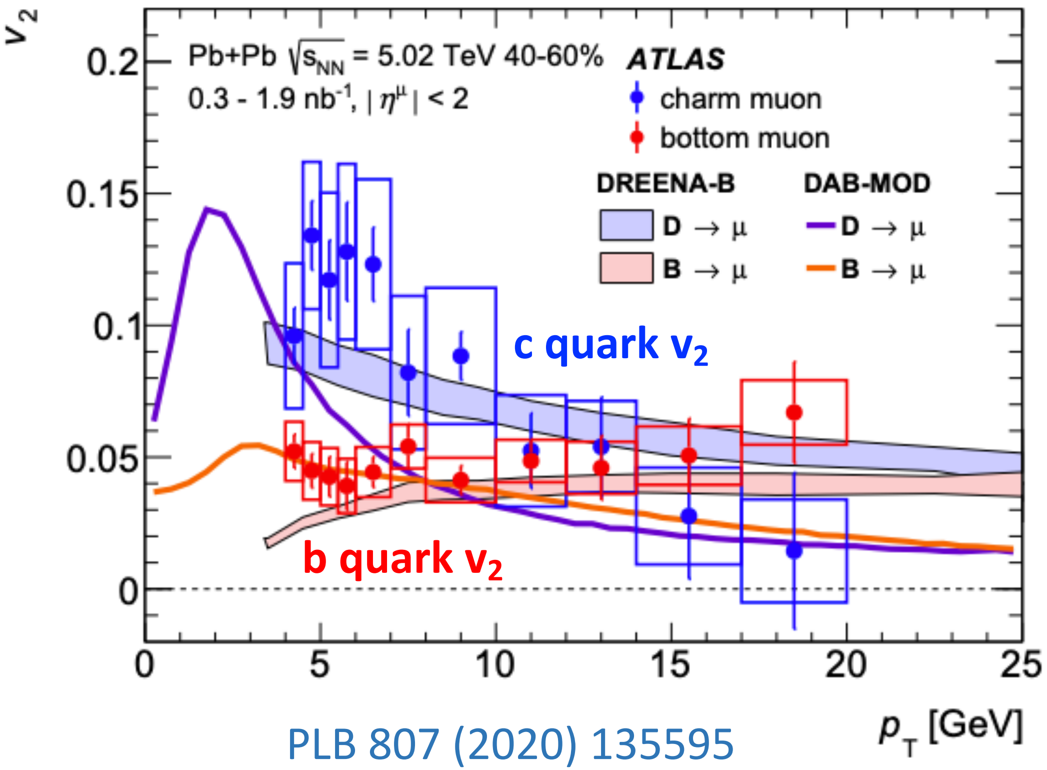
❖ Non-zero v_2!

❑ Advantages of $b \rightarrow D^0$ channel

✓ Larger branching ratio wrt $b \rightarrow J/\psi$

✓ Higher D^0 mass than leptons: higher correlation between D^0 and b momentum



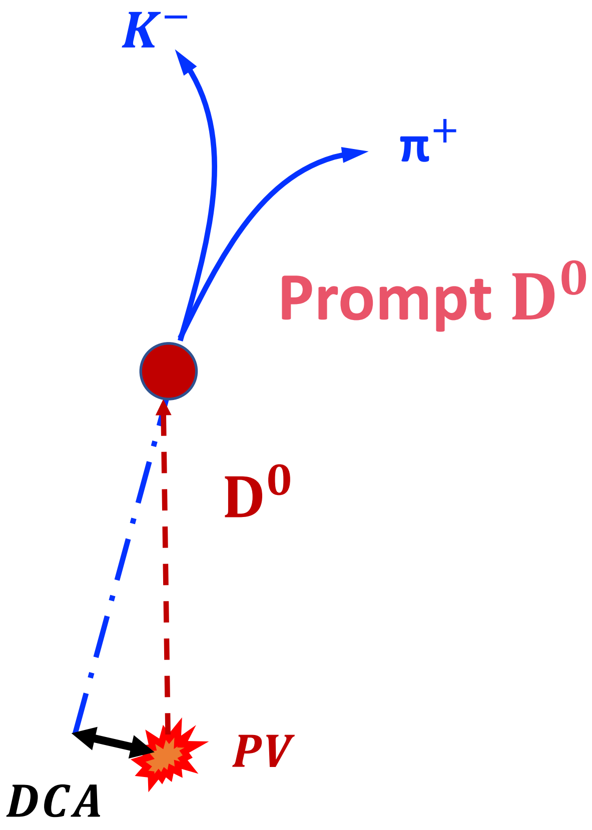


PLB 807 (2020) 135595

Potential for precise measurement in wide kinematic range!

$b \rightarrow \mathrm{D}^0$ fraction

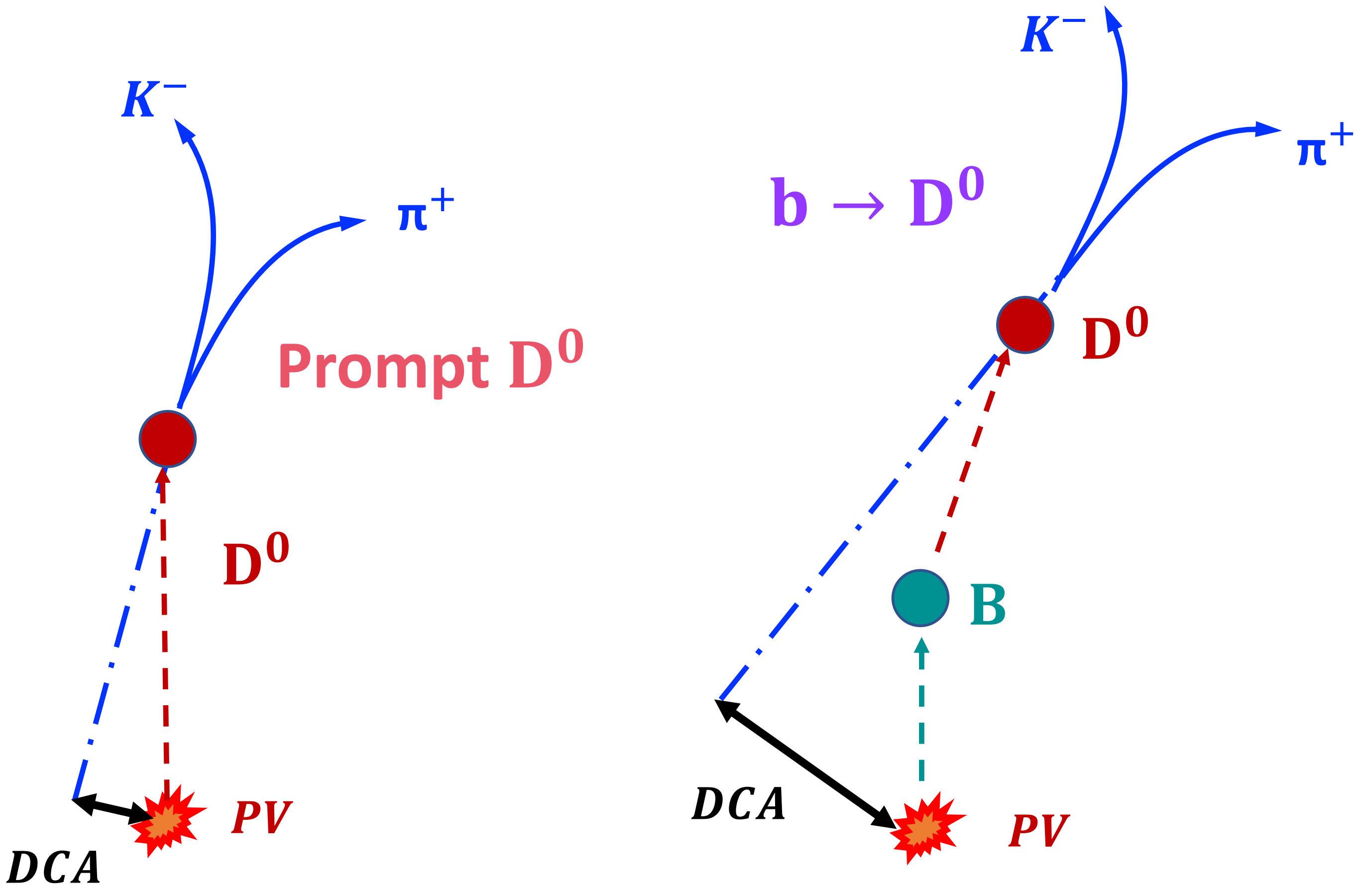
Two component template fit to extract $b \rightarrow \mathrm{D}^0$ fraction



DCA (distance of closest approach)

$b \rightarrow D^0$ fraction

Two component template fit to extract $b \rightarrow D^0$ fraction



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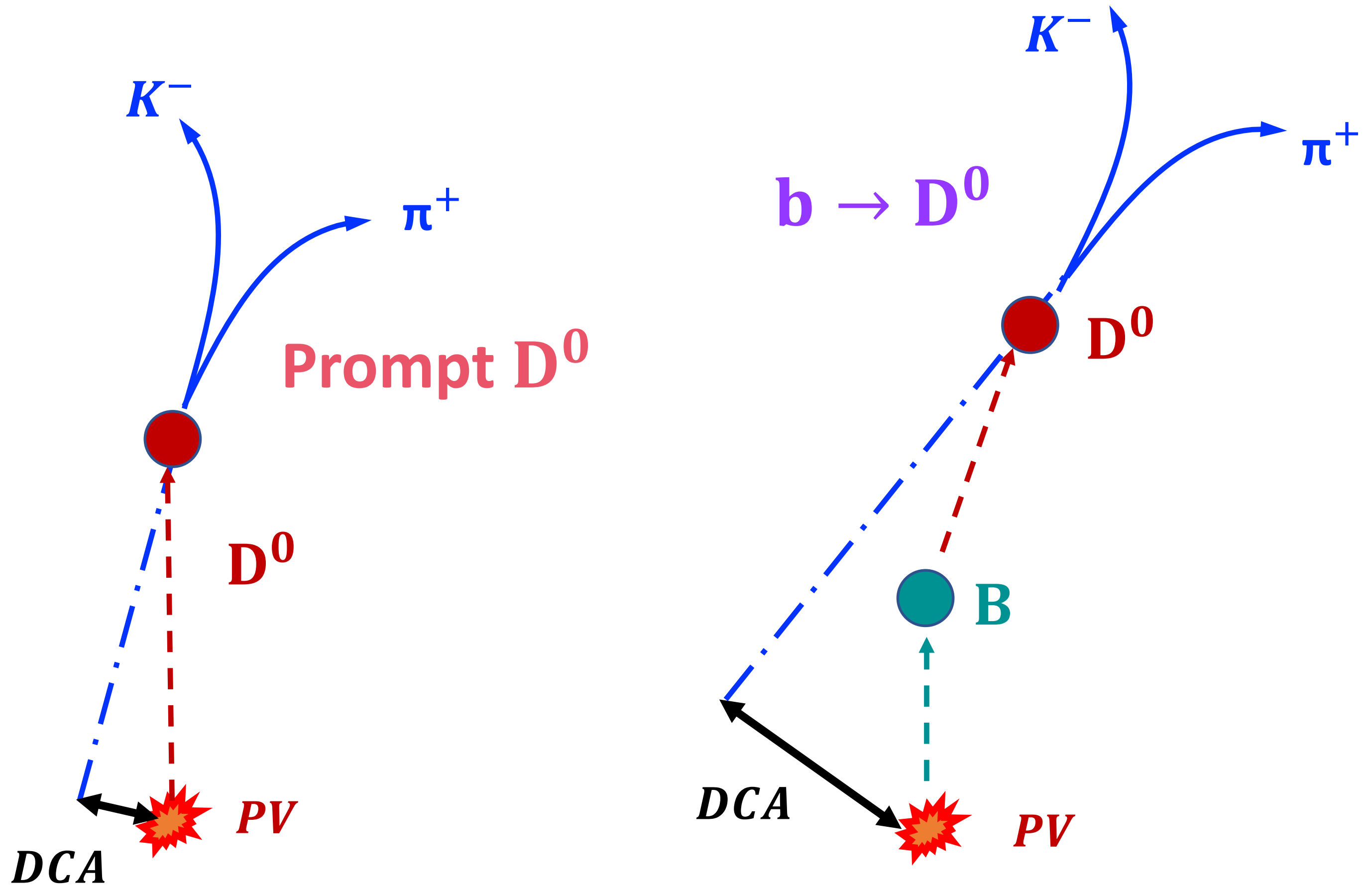
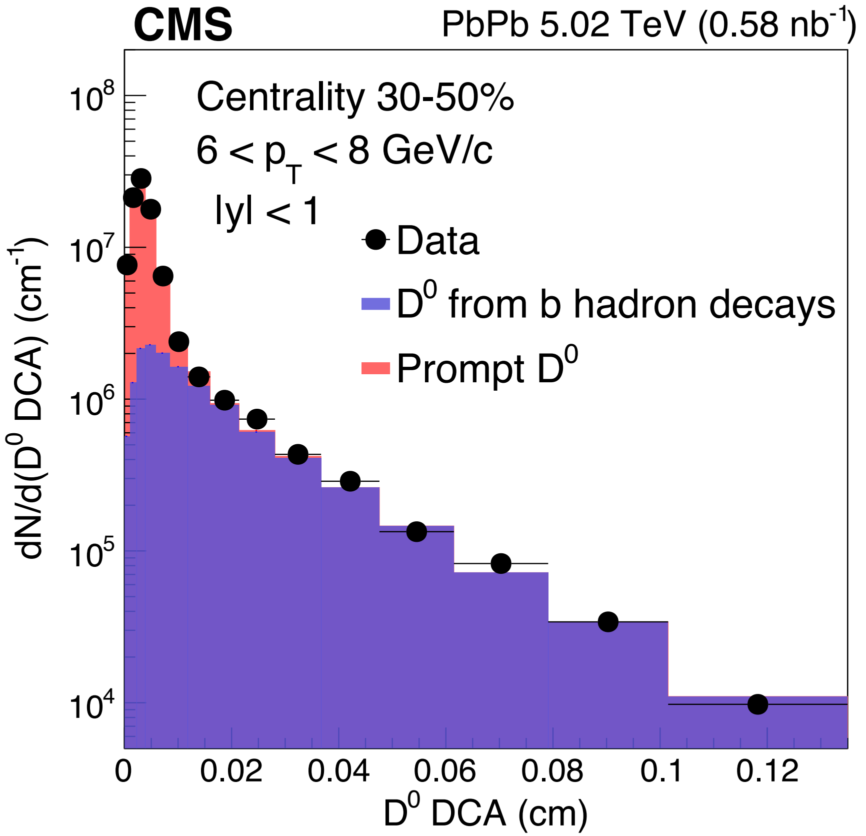
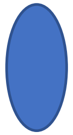




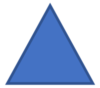
arXiv:2212.01636
submitted to PLB

DCA (distance of closest approach)

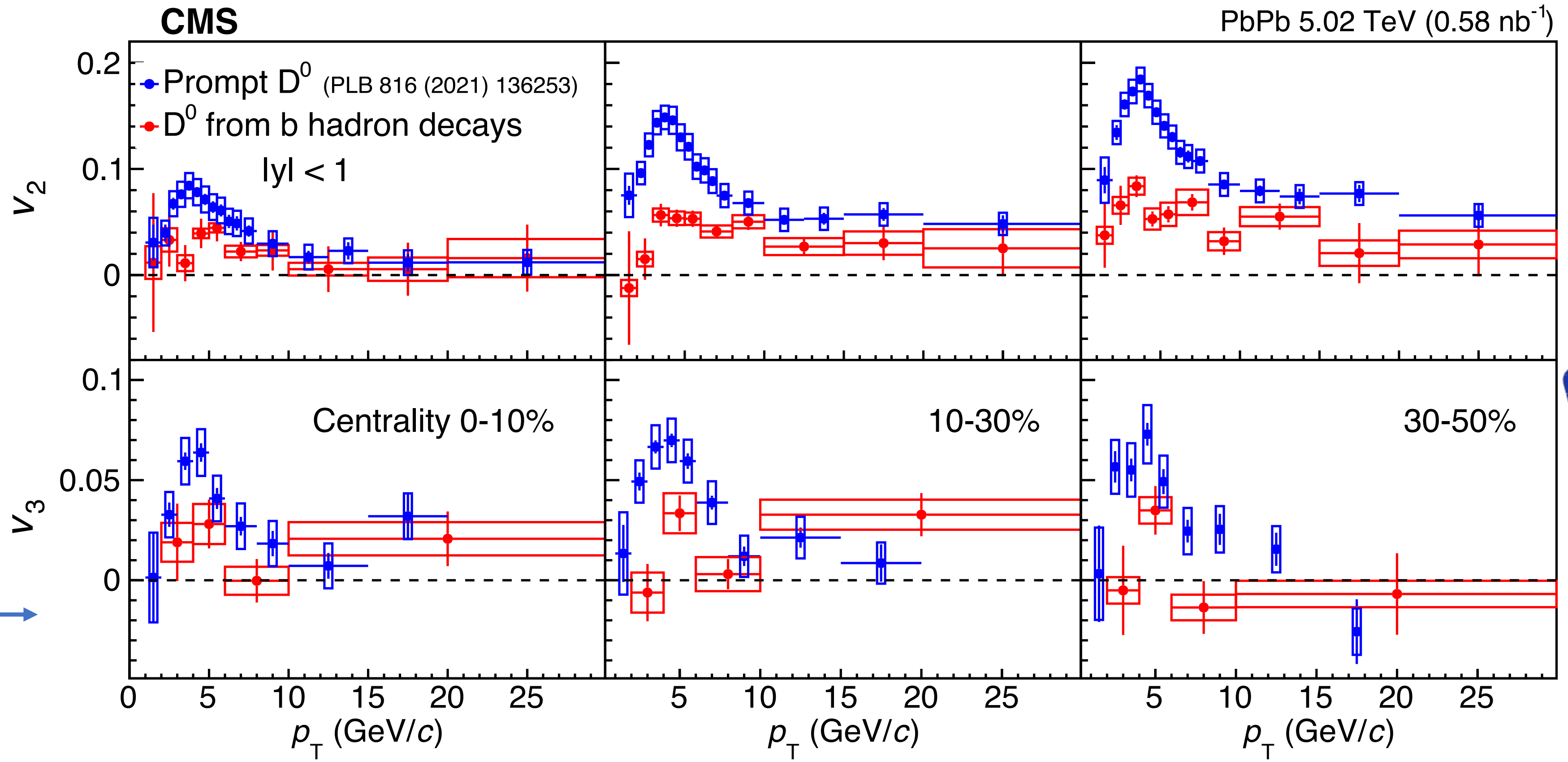
$b \to D^0$ anisotropy



Elliptic flow



Triangular flow



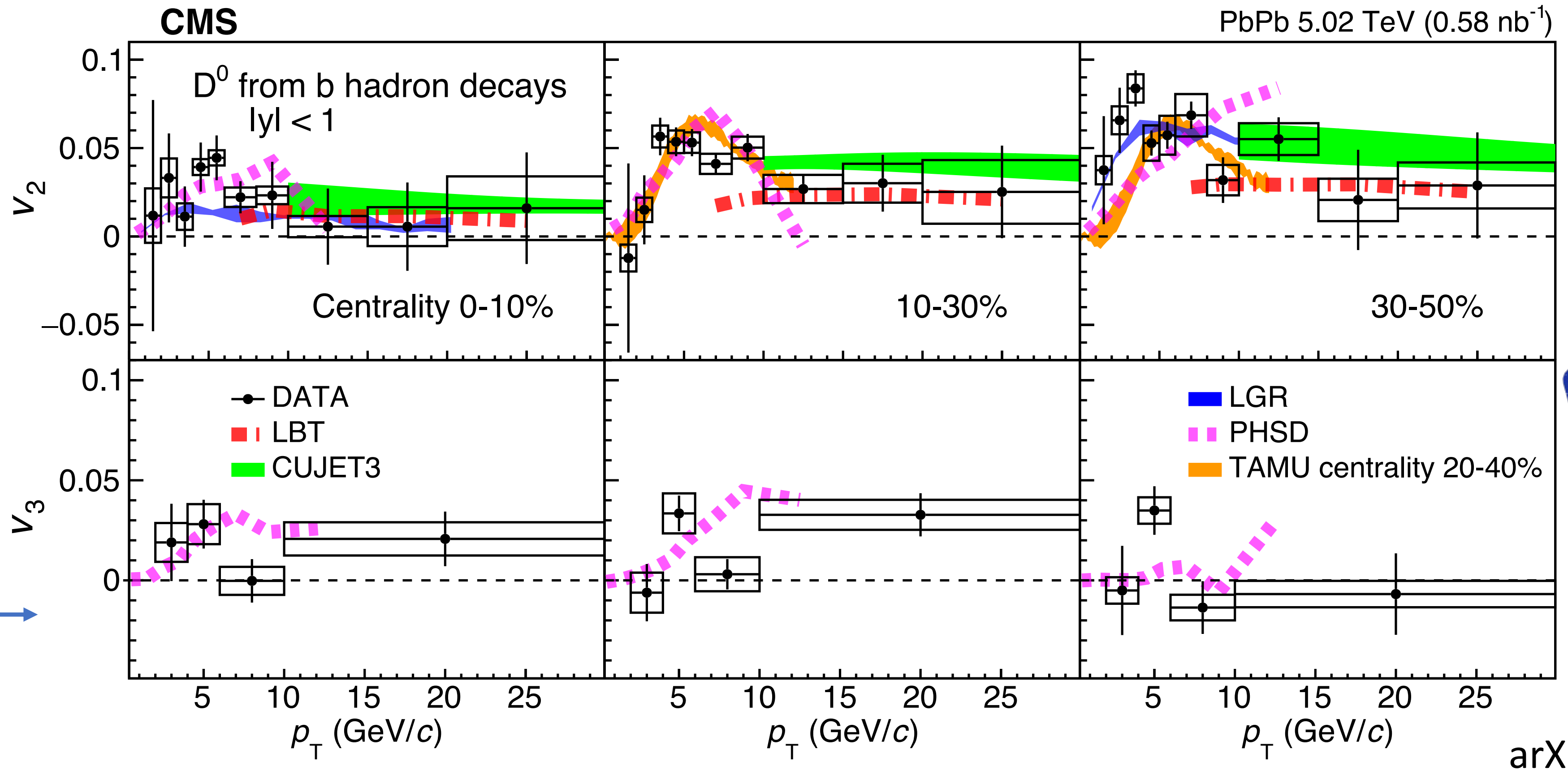
First measurement of b → D^0 anisotropy in PbPb collisions

arXiv:2212.01636
submitted to PLB

- ❑ Mass ordering of flow magnitudes
- ❑ Weak p_T and centrality dependence
- ❑ Nonzero v_3

PURDUE UNIVERSITY

$b \rightarrow D^0$ anisotropy



Elliptic flow →

Triangular flow →

arXiv:2212.01636

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

- ❑ Qualitatively good agreement between theory and data
- ❑ No model can describe whole p_T range

high-p_T

CUJET3 CPC **43 4** (2019) 044101

LBT PRC **94** (2016) 014909

low-p_T

PHSD: PRC **92** (2015) 014910

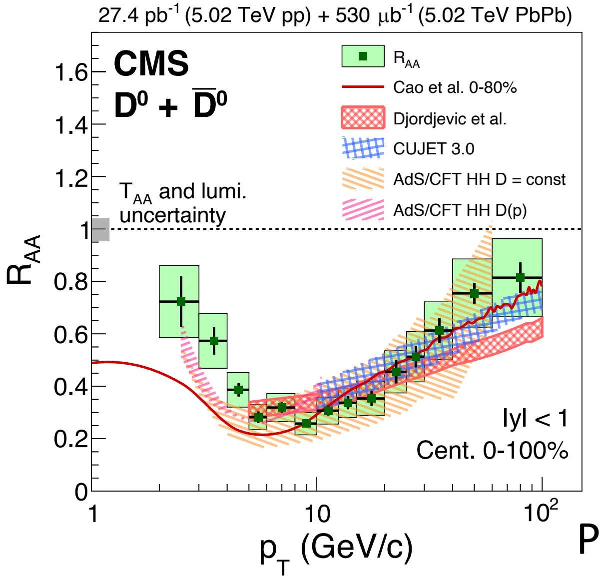
TAMU PLB **735** (2014) 445

LGR EPJ C **80 7** (2020) 671

D^0 production

- Simultaneous measurement of R_{AA} and v_n essential for understanding heavy flavor in QGP
- 2015 results:
  - Hint of mass ordering at low p_T
  - Unexpected suppression at low p_T

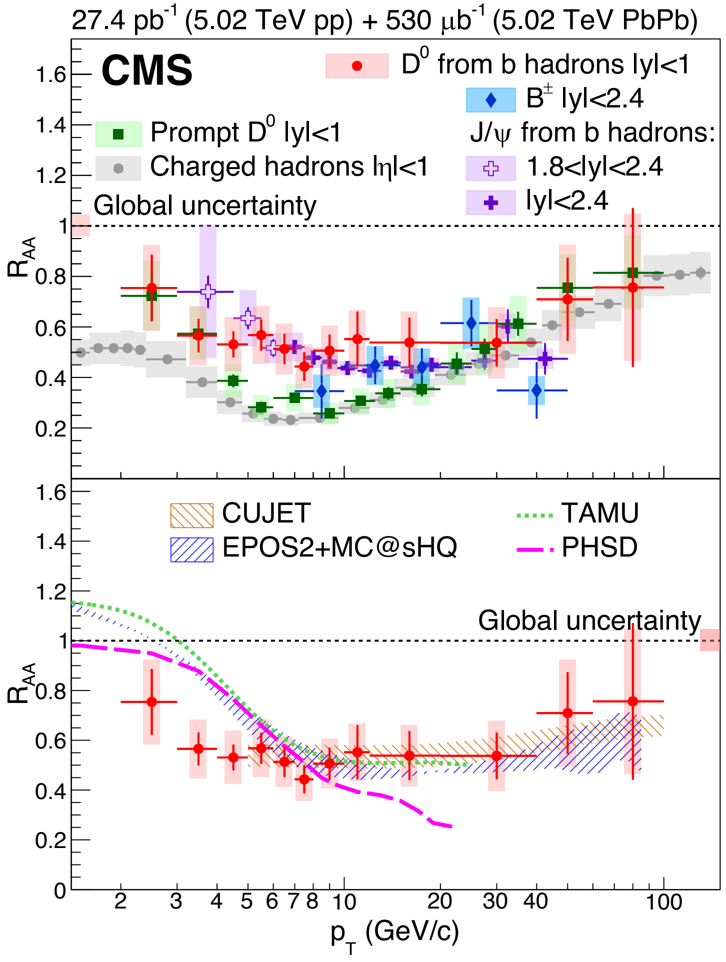
More precise measurement needed



Prompt D^0

PLB 782 (2018) 474

$b \rightarrow D^0$

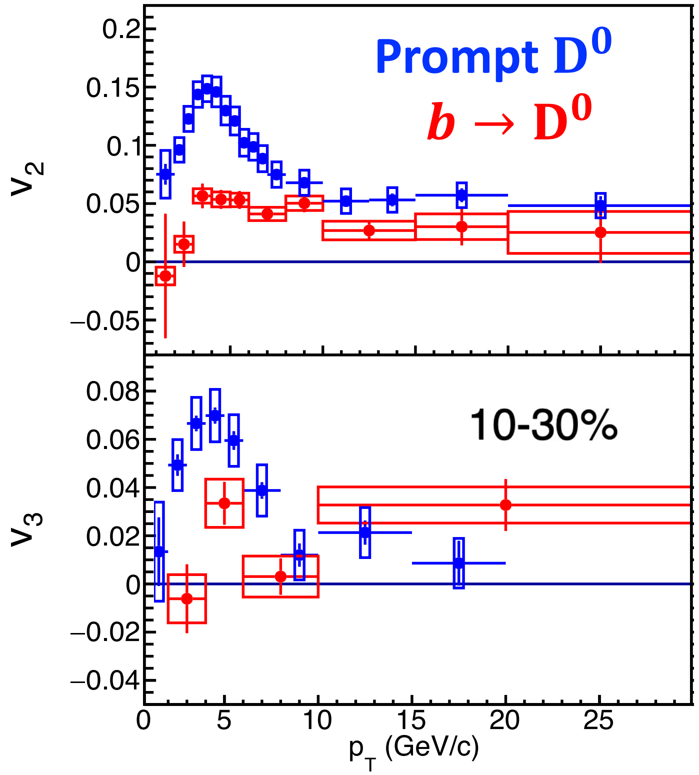


PRL 123, 022001 (2019)

Summary

- Prompt $\mathbf{D^0}$ azimuthal anisotropy
  - E-by-E fluctuations indicate different final state effects in peripheral collisions
  - No sign of strong Coulomb field in PbPb

- First measurement of $\mathbf{b} \rightarrow \mathbf{D^0}$ azimuthal anisotropy in PbPb collisions
  - Covered both high p_{T} and low p_{T} range
  - Mass ordering of flow observed



arXiv:2212.01636

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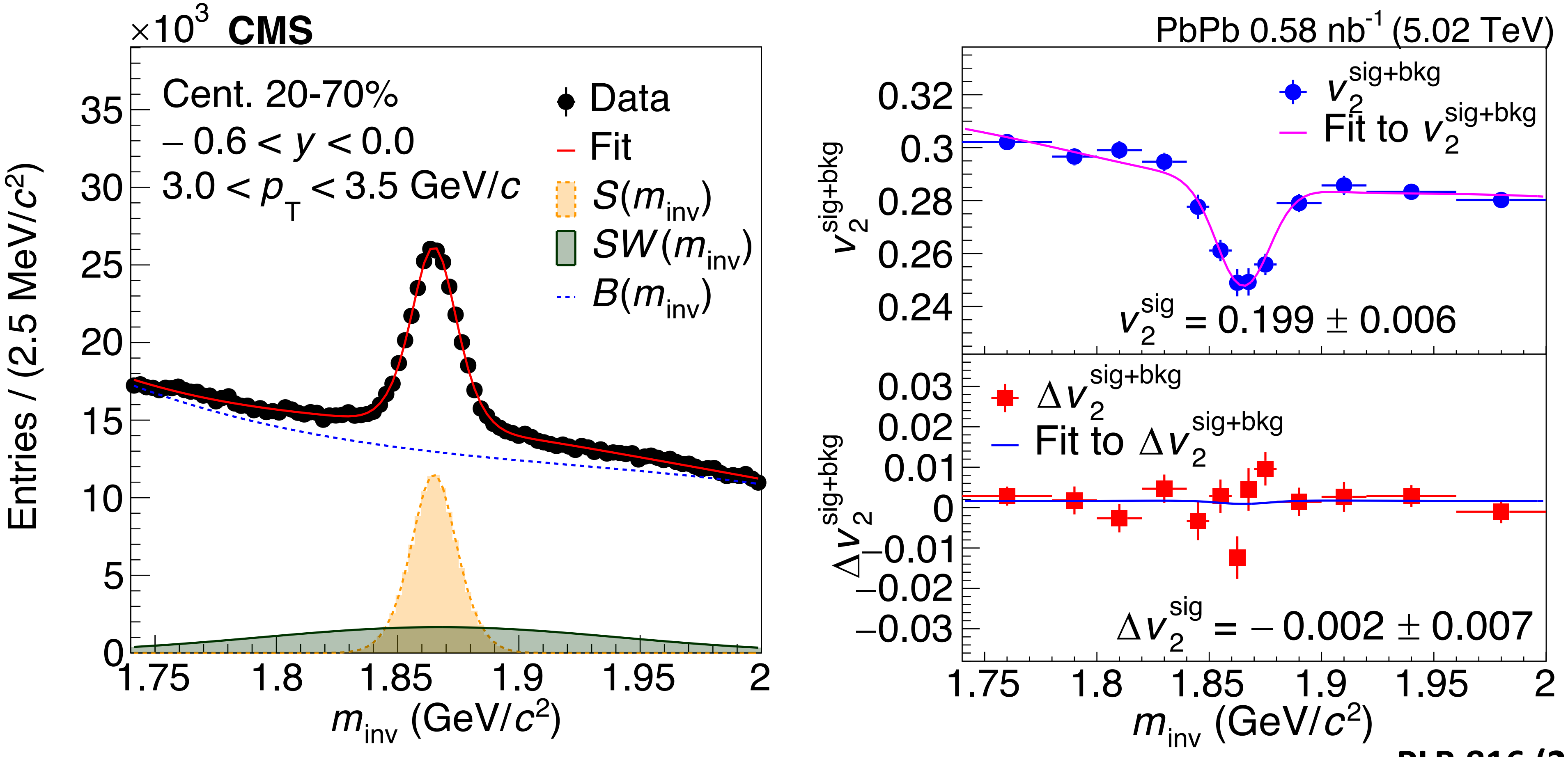
Backup

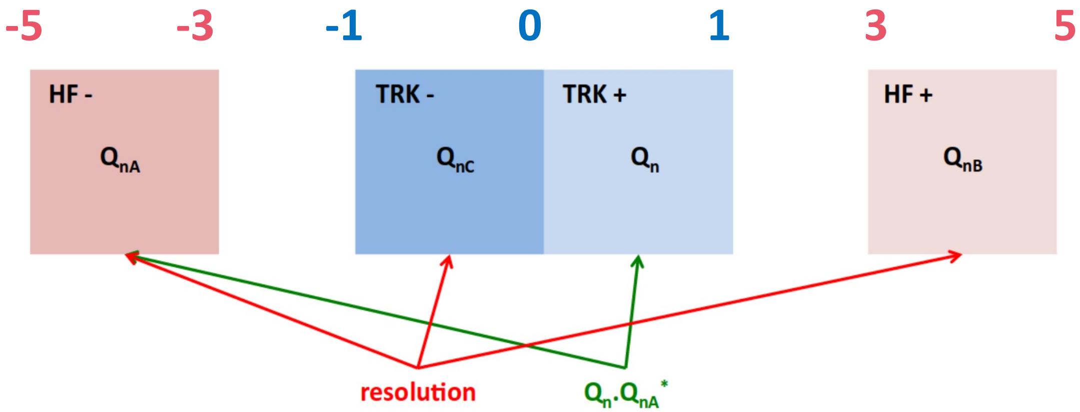
Δv_2 extraction: simultaneous fit

Simultaneous fit on invariant mass distribution and vn (delta vn) versus mas



PLB 816 (2021) 136253

$b \to D^0\ v_n$ extraction



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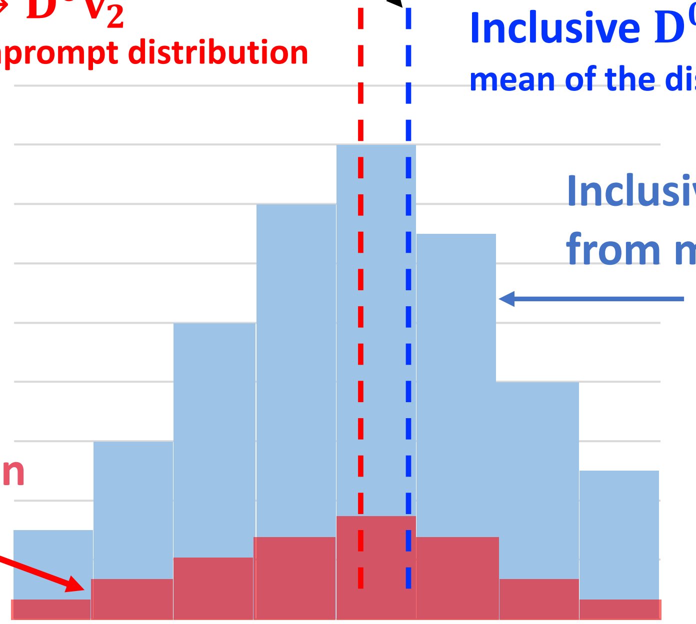
mean value

$b \to D^0 v_2$
mean of the nonprompt distribution

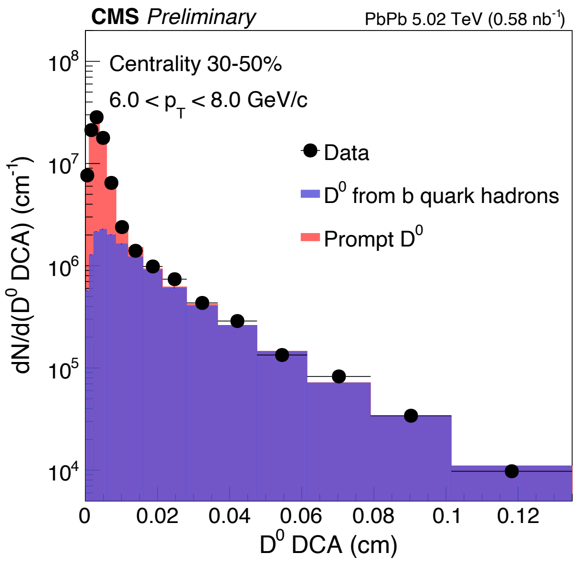
Inclusive $D^0 v_2$
mean of the distribution

Inclusive D^0 yield
from mass fit in each bin

$b \to D^0$ yield
From mass + DCA fit in each bin



$$\frac{Q_2 Q_{2A}^*}{\sqrt{\frac{\langle Q_{2A} Q_{2B}^* \rangle \langle Q_{2A} Q_{2C}^* \rangle}{\langle Q_{2B} Q_{2C}^* \rangle}}}$$



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Heavy flavor v_2 from CMS

Charged hadrons
Phys. Lett. B 776 (2017) 195

Prompt D^0
Phys. Lett. B 816 (2021) 136253

Nonprompt D^0
CMS–PAS–HIN–21–003

Prompt J/ψ
CMS–PAS–HIN–21–008

Nonprompt J/ψ
CMS–PAS–HIN–21–008

Υ(1S)
CMS–PAS–HIN–21–008