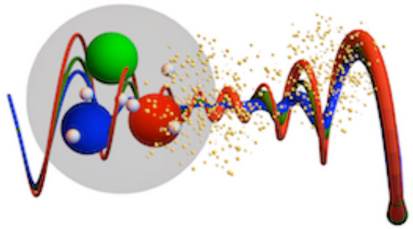
CMS results on Heavy Flavor Flow

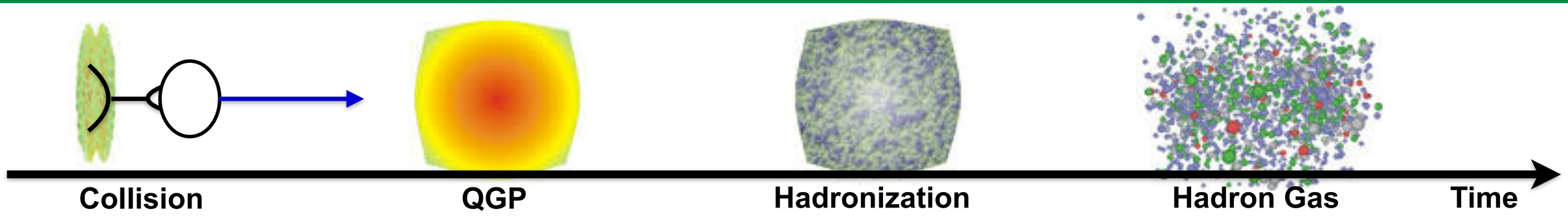
Andre Ståhl
on behalf of the CMS Collaboration

European Organisation for Nuclear Research

13th International workshop on Multiple Partonic Interactions at the LHC

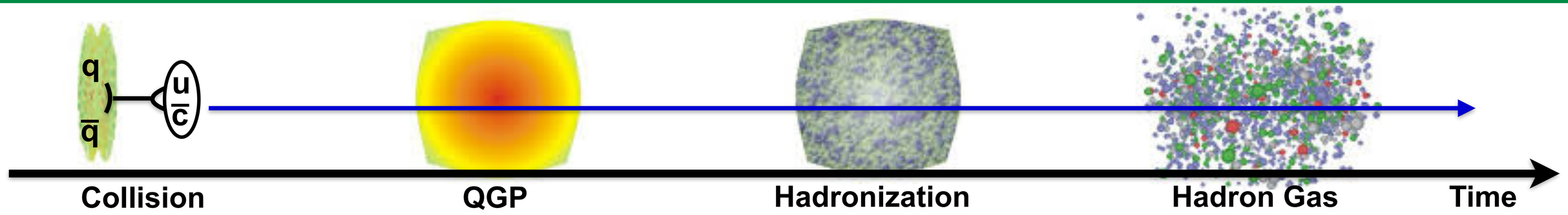


Heavy Quarks in HI collisions



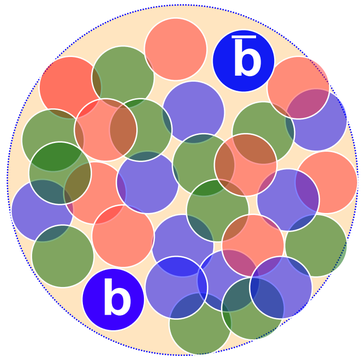
- Heavy quarks ($m_{c,b} >> \Lambda_{QCD}$): high Q^2 processes → production well understood in pQCD.
- Produced in the initial hard scattering → experience the full space-time evolution of the QGP.

Heavy Quarks in HI collisions



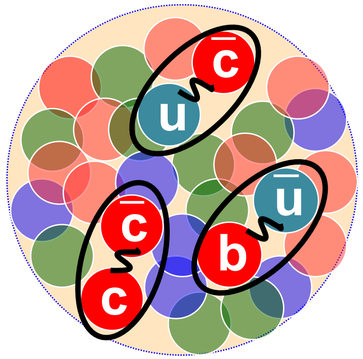
- Heavy quarks ($m_{c,b} >> \Lambda_{QCD}$): high Q^2 processes → production well understood in pQCD.
- Produced in the initial hard scattering → experience the full space-time evolution of the QGP.
- The QGP is expected to modify the HF hadron production.

Quarkonia



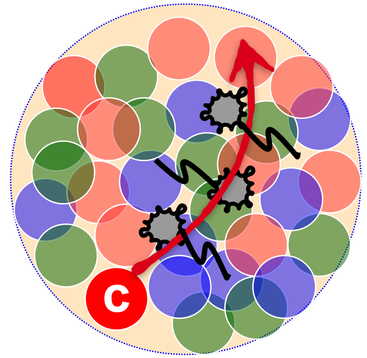
+Suppression
Medium-induced dissociation

HF hadrons



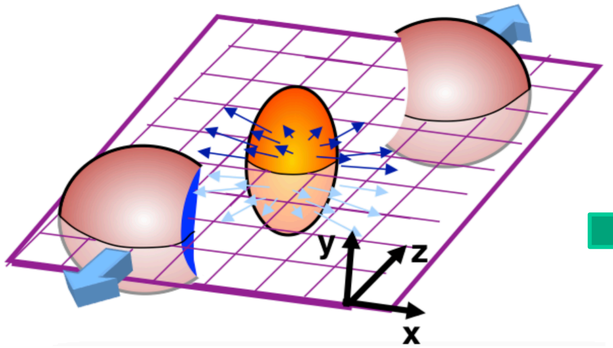
+Enhancement
Regeneration
Coalescence

HF quarks

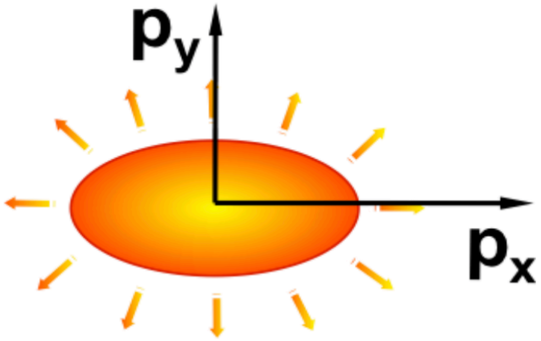


+Parton energy loss
via collisional and radiative interactions

Heavy Quarks anisotropy in HI collisions

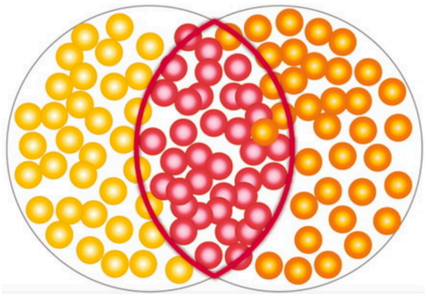


Space anisotropy

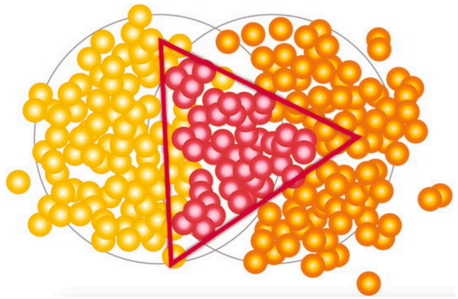


Momentum anisotropy

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



System symmetry
Elliptic flow (v_2)

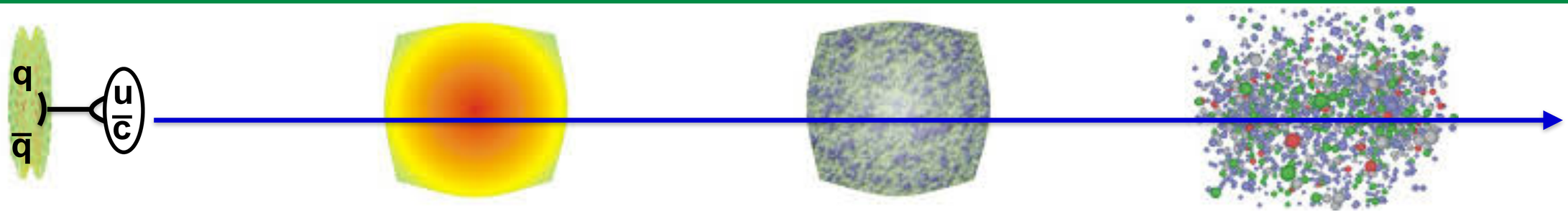


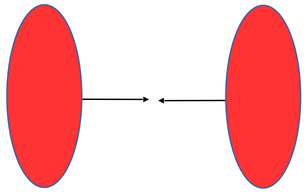
Fluctuations
Triangular flow (v_3)

HF flow mechanism:

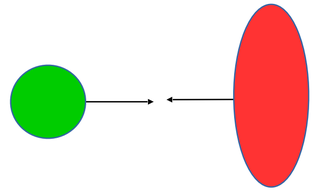
- Coalescence/regeneration.
- Low p_T: hydrodynamics + coll. E. loss.
- High p_T: path-dependent parton E. loss.

OUTLINE



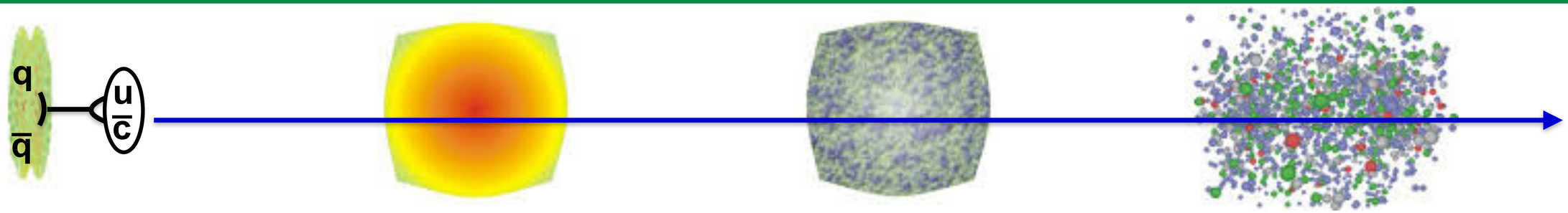


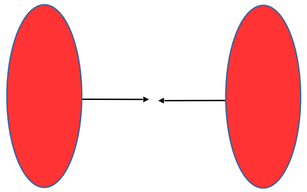
- HF flow in large systems
  - D^0 v_2{N} in PbPb.
  - (b→)D^0 v_n in PbPb.
  - Quarkonium v_n in PbPb.



- HF flow in small systems
  - D^0 in pp.
  - (b→)D^0 in pPb.
  - Y(1S) in pPb.

OUTLINE





- HF flow in large systems
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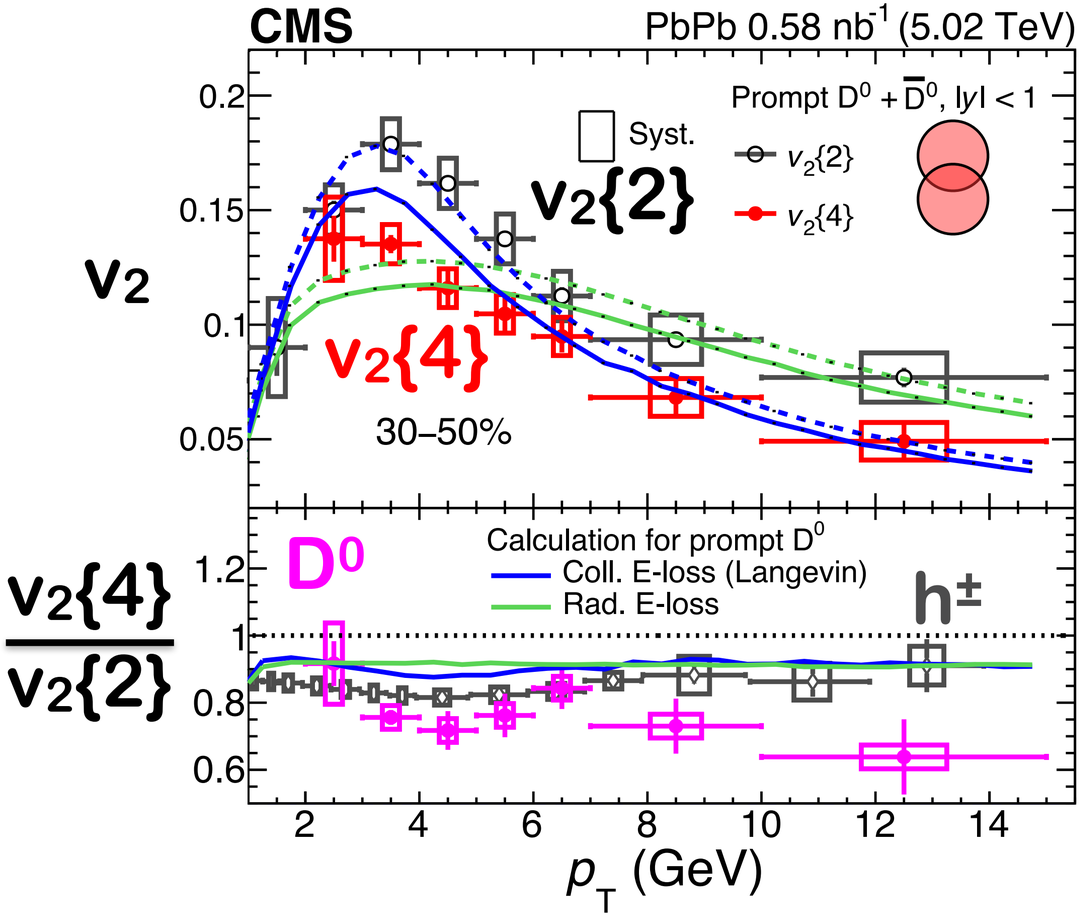
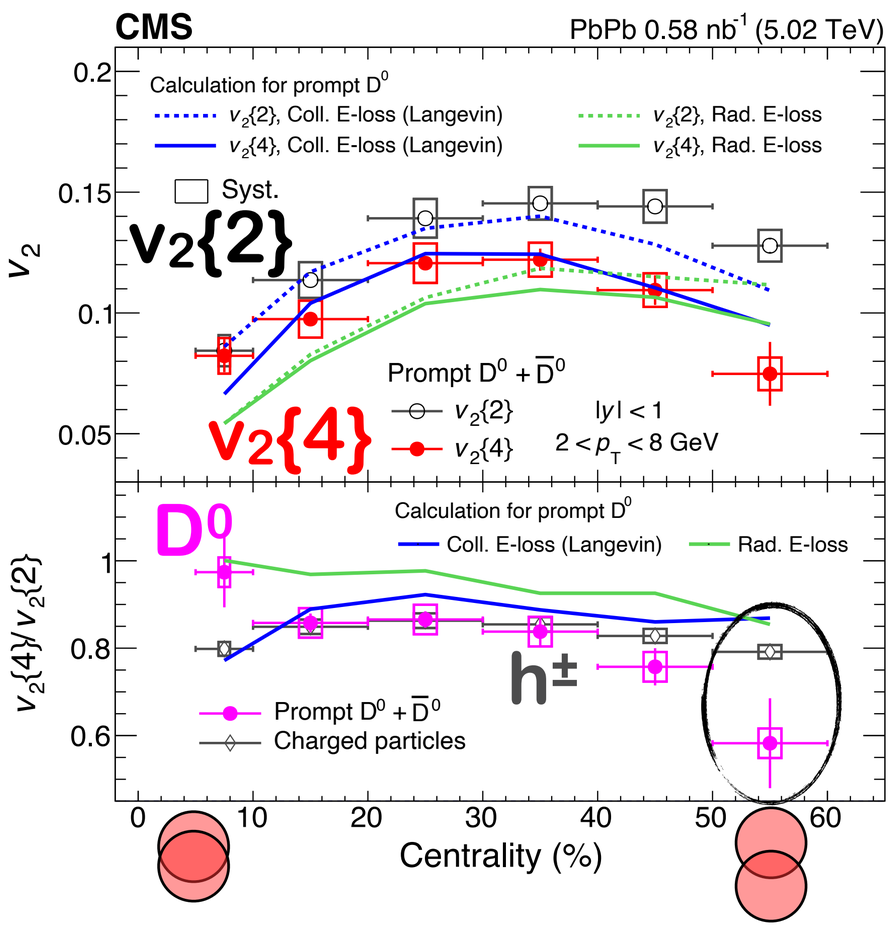
- HF flow in small systems
  - D^0 in pp.
  - (b→)D^0 in pPb.
  - Y(1S) in pPb.

D^0 flow fluctuations in PbPb

PRL 129 (2022) 022001 **FINAL**





2-particle correlation

$$v_2\{2\}^2 \approx \langle v_2 \rangle^2 + \sigma^2 \quad \text{(mean)}$$

$$v_2\{4\}^2 \approx \langle v_2 \rangle^2 - \sigma^2 \quad \text{(fluctuation)}$$

4-particle correlation

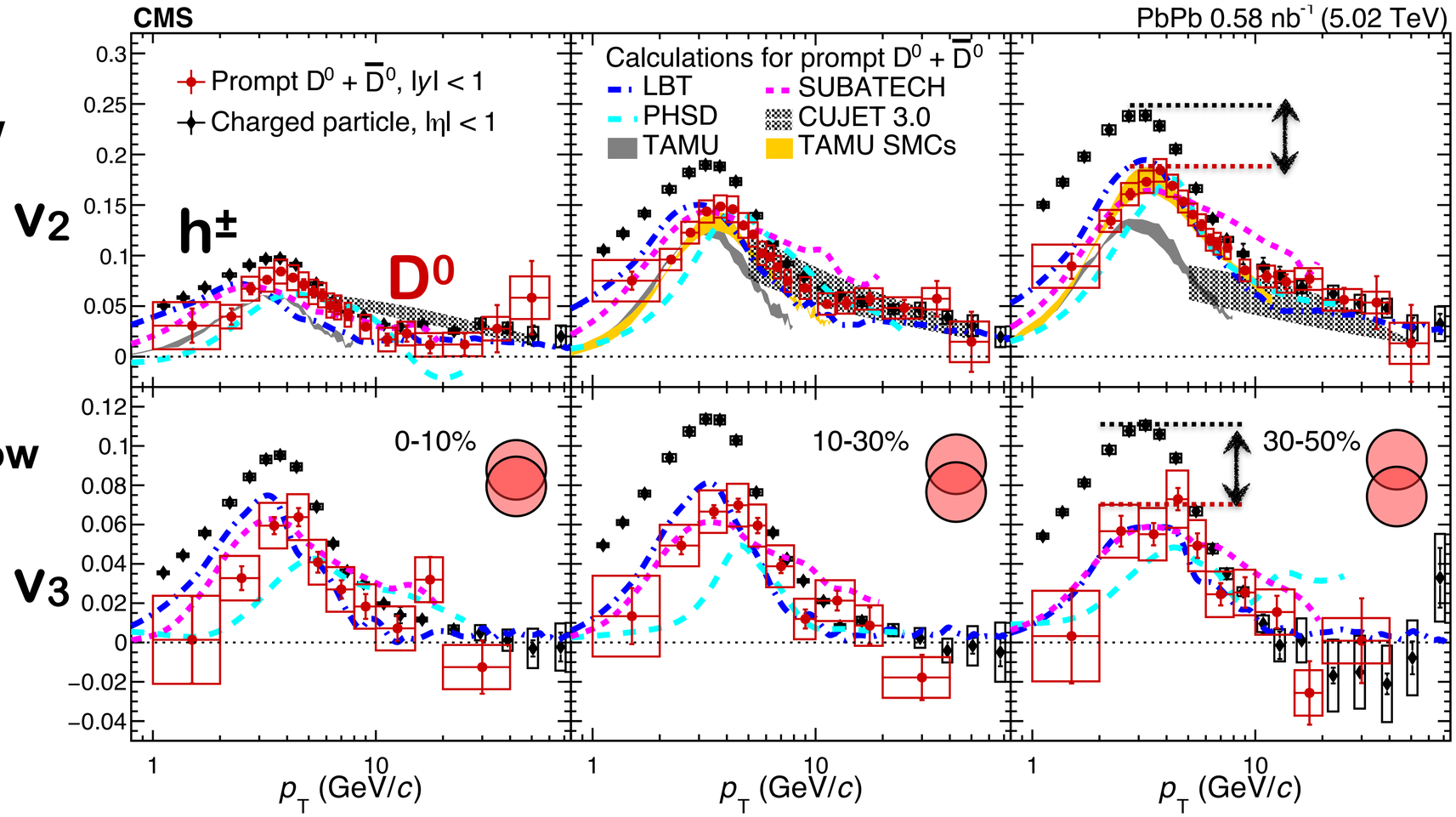
- $v_2\{n\}$ probe event-by-event fluctuations from initial geometry and final state effects.
- $h^\pm$ ~ D^0 **$v_2\{4\}/v_2\{2\}$** at cent < 40%→ suggest initial state fluctuations are dominant.
- Hint of larger charm quark final state fluctuations at peripheral collisions.

D^0 flow in PbPb

PLB 816 (2021) 136253 **FINAL**

Elliptic flow

Triangular flow

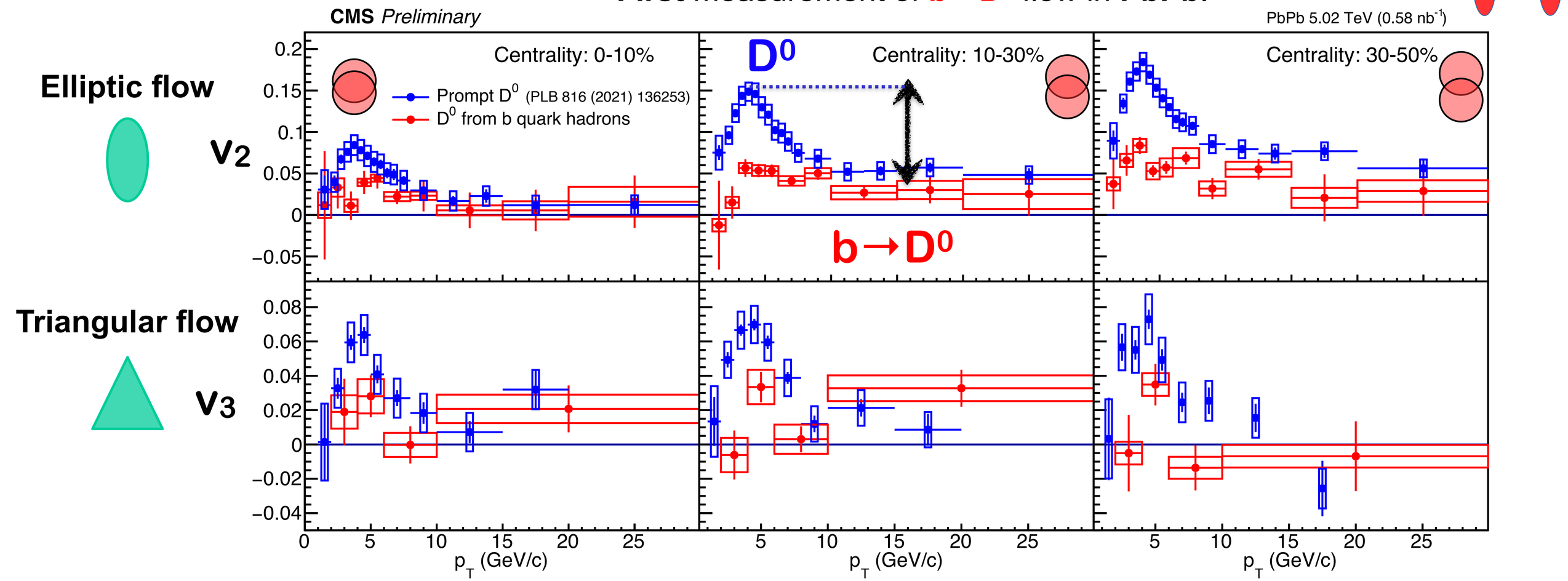


- **$h^\pm$ v_n > D^0 v_n > 0** at p_T < 6 GeV → collective motion of light quarks larger than charm quarks.
- **D^0** and **$h^\pm$** flow converges at high p_T→ path-dependent energy loss.
- No model is able to describe the data over the full centrality and p_T ranges.

b→D⁰ flow in PbPb

CMS-PAS-HIN-21-003 **NEW!**

First measurement of **b→D⁰** flow in **PbPb**.

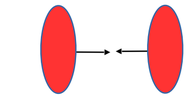


- **D⁰ v_2 > b→D⁰ v_2 > 0** → mass ordering of heavy flavour elliptic flow.
- **D⁰ v_3 > 0** → initial geometry fluctuations probed by charm quarks.

b→D⁰ flow in PbPb

CMS-PAS-HIN-21-003 **NEW!**

First measurement of **b→D⁰** flow in **PbPb**.

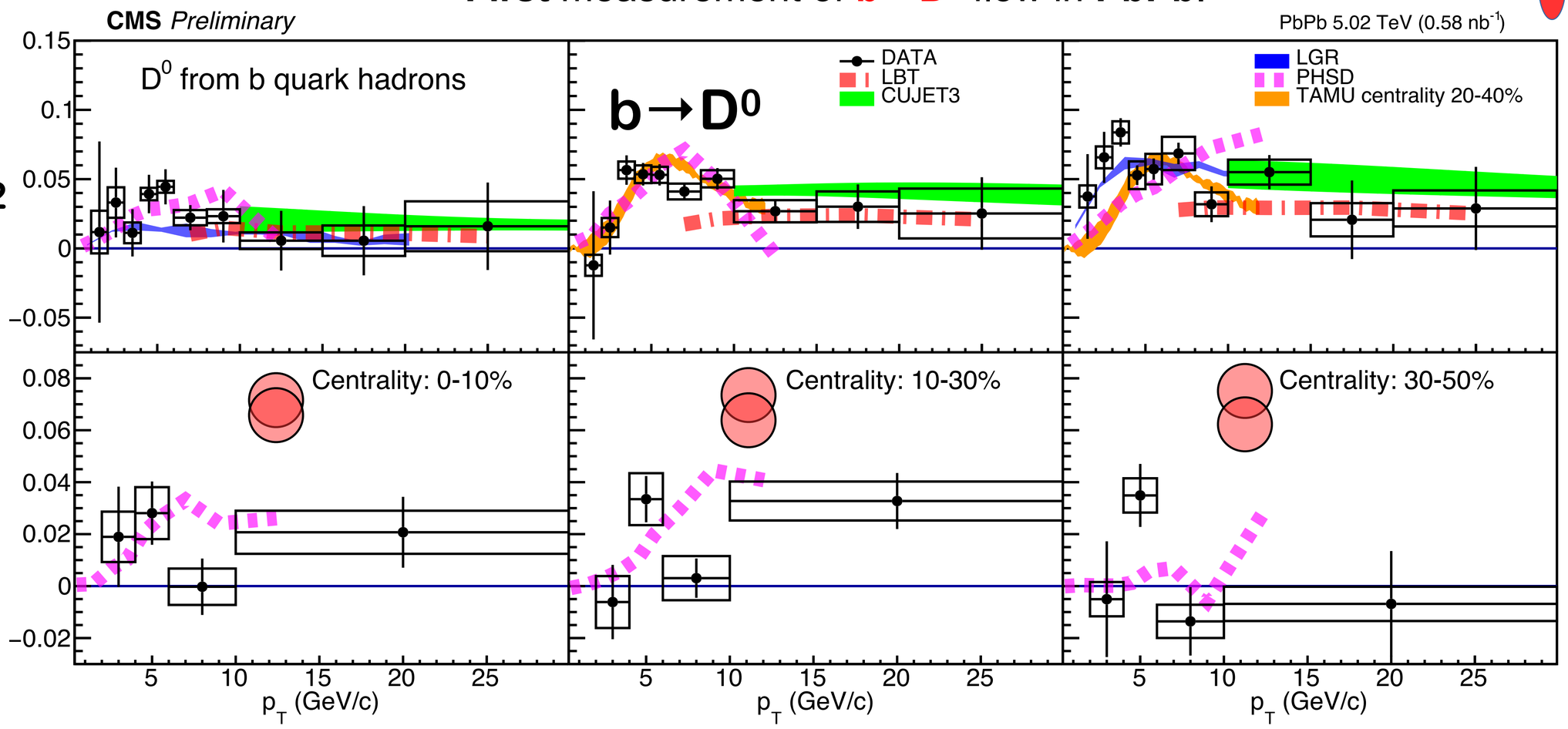


Elliptic flow

v_2

Triangular flow

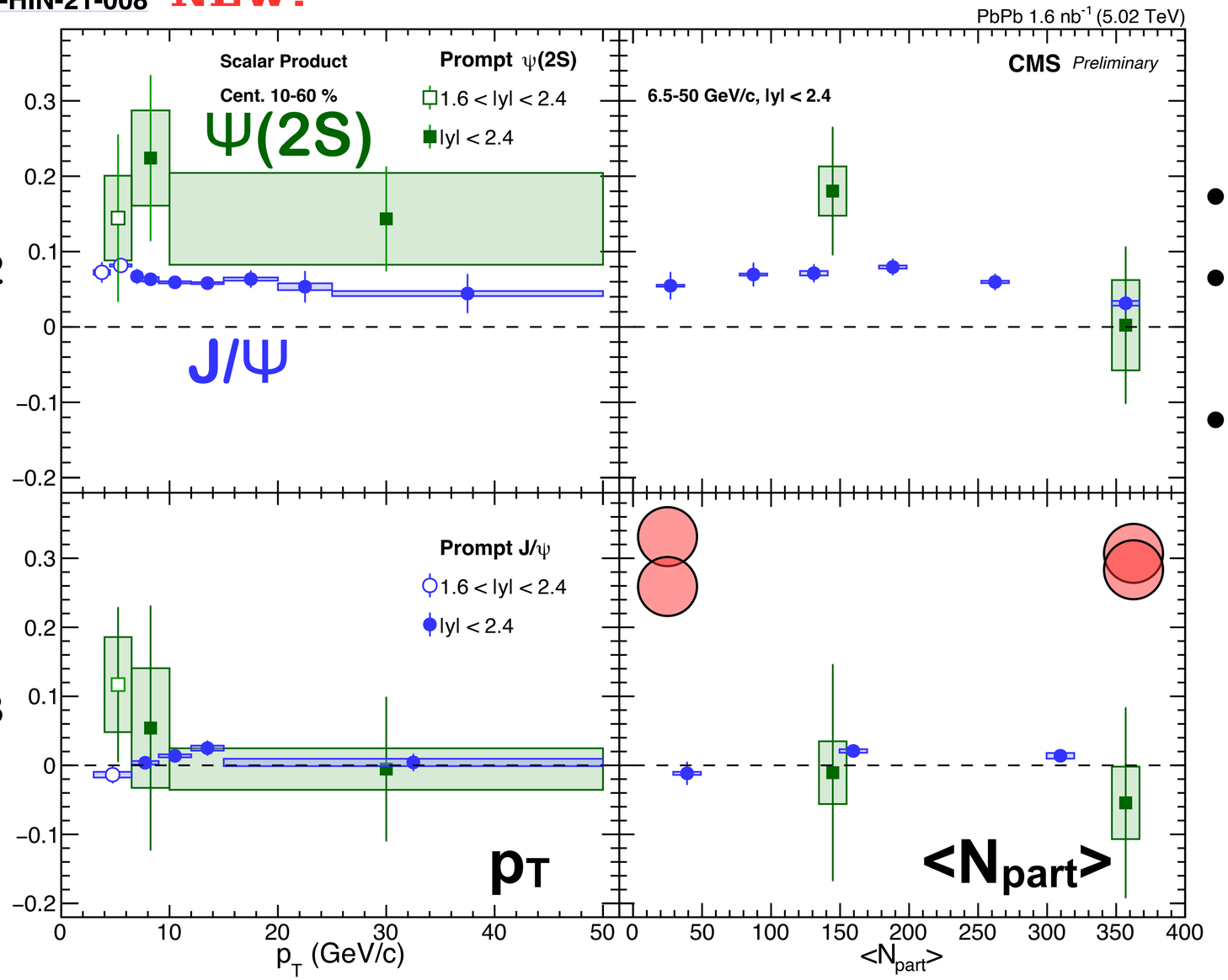
v_3



- **D^0 v_2 > b→D^0 v_2 > 0** → mass ordering of heavy flavour elliptic flow.
- **D^0 v_3 > 0** → initial geometry fluctuations probed by charm quarks.
- Weak centrality dependence of **b→D^0** flow → qualitatively described by models.

Charmonium flow in PbPb

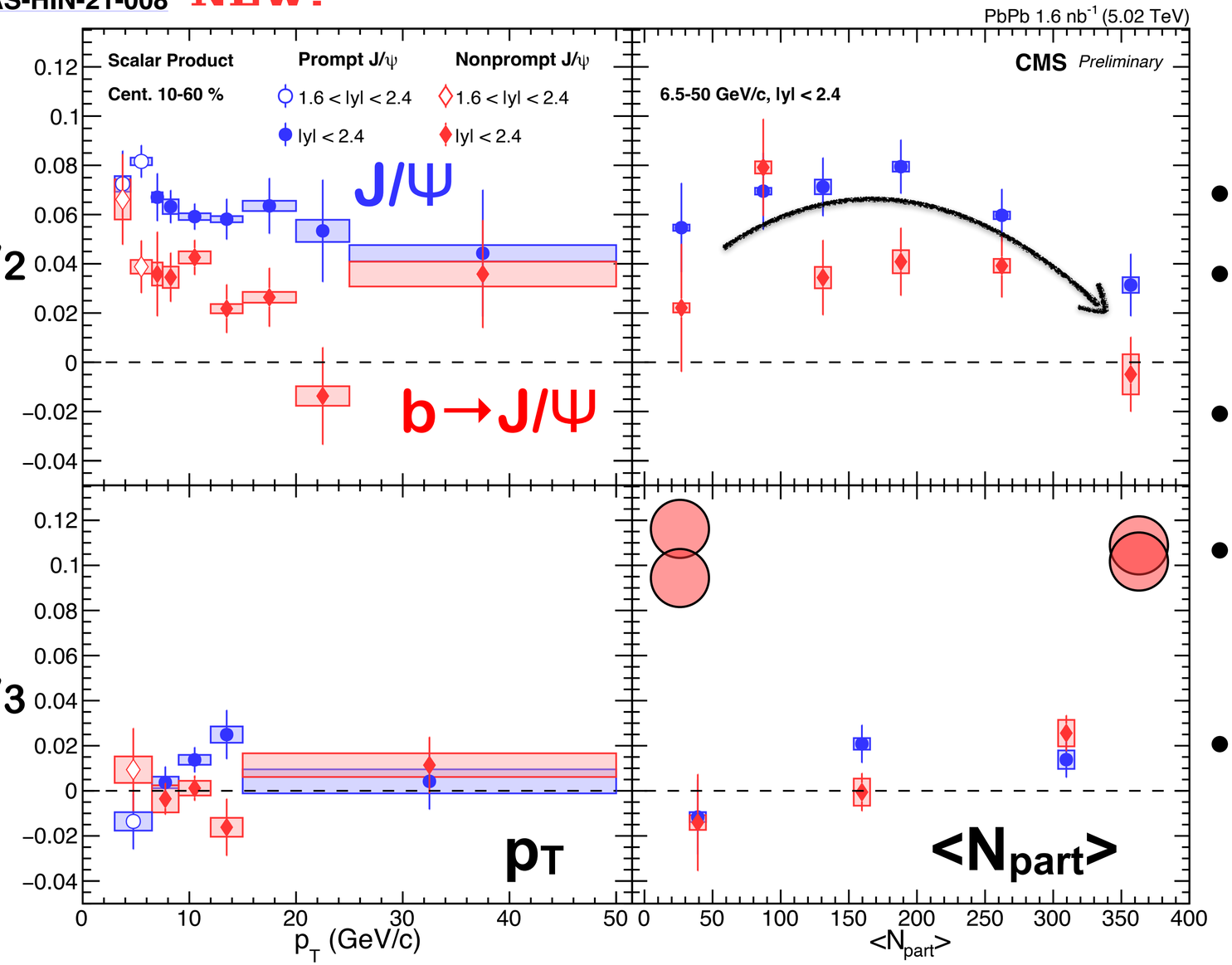
CMS-PAS-HIN-21-008 **NEW!**



- **First** measurement of **Ψ(2S)** flow.
- **Ψ(2S) v_2 ≳ J/Ψ v_2 > 0** → hint of larger v_2 for excited states.
- **Ψ(2S) v_3 ~ J/Ψ v_3** ~ 0.

Charmonium flow in PbPb

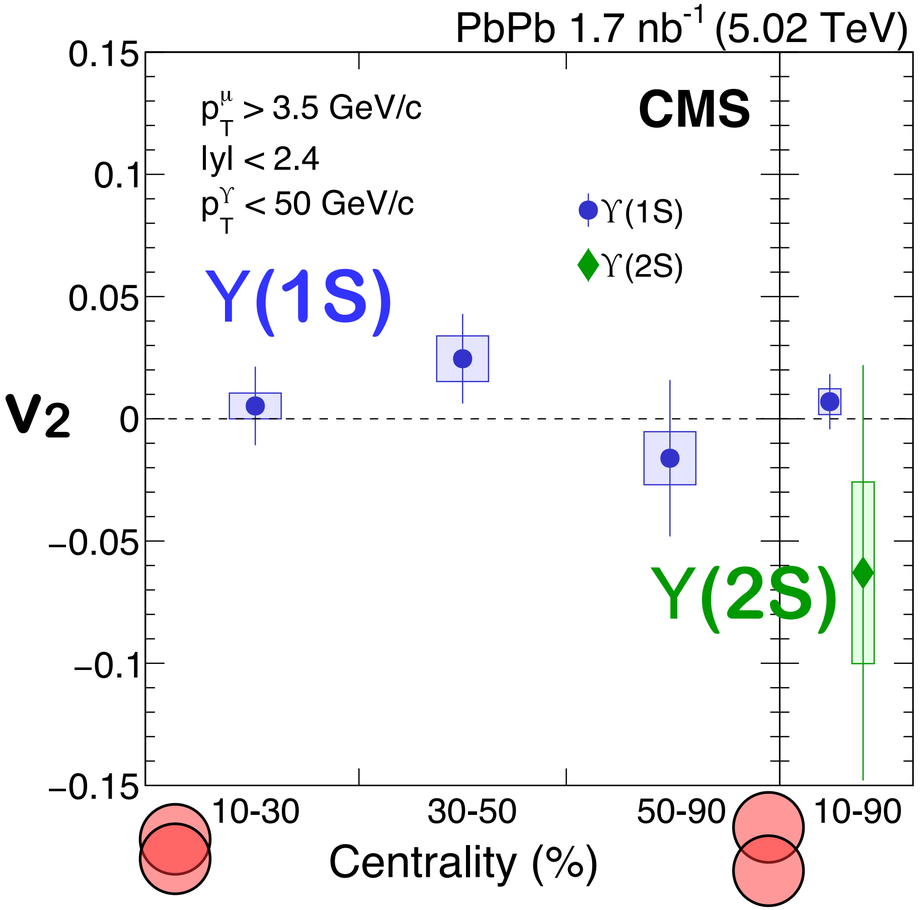
CMS-PAS-HIN-21-008 **NEW!**

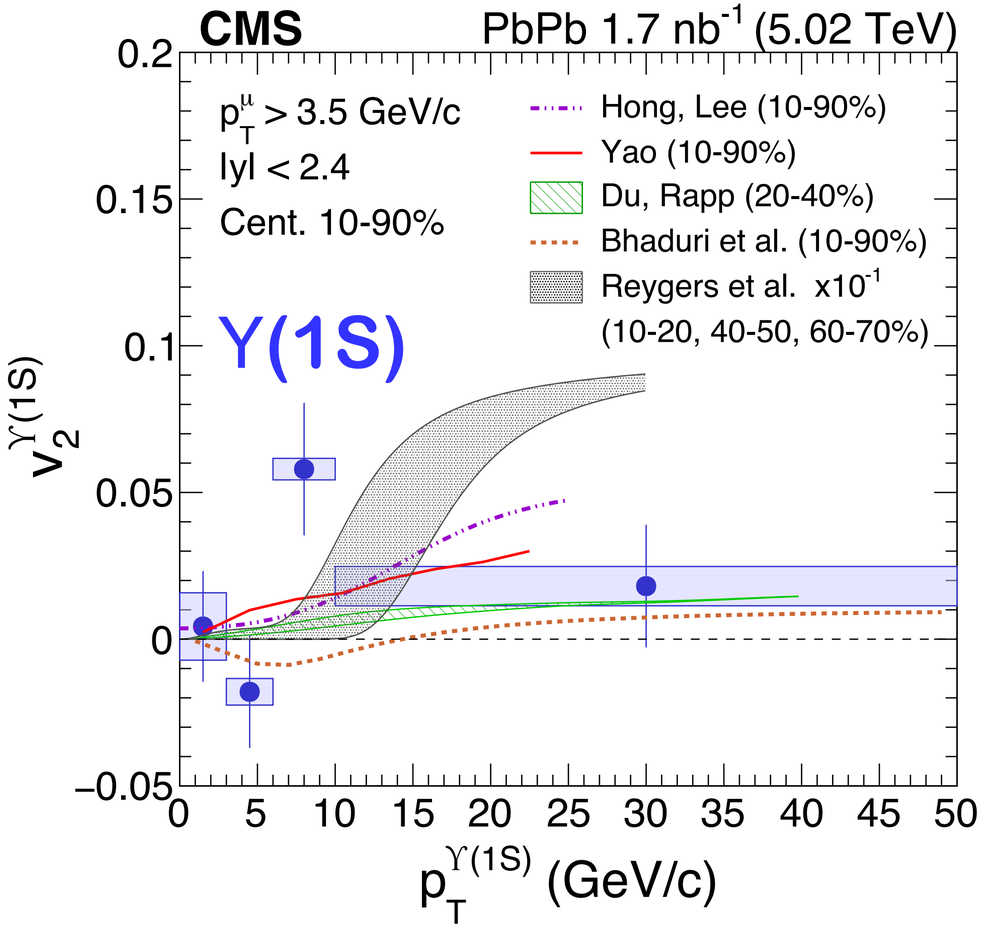


- **First** measurement of **Ψ(2S)** flow.
- **Ψ(2S) v_2 ≳ J/Ψ v_2 > 0** → hint of larger v_2 for excited states.
- **J/Ψ v_2 > b→J/Ψ v_2 > 0** → different flow for charm and beauty quarks.
- v_2 increase and then decrease from central to peripheral events → as expected by hydrodynamics.
- **Ψ(2S) v_3 ~ J/Ψ v_3 ~ b→J/Ψ v_3 ~ 0.**

Bottomonium flow in PbPb

PLB 819 (2021) 136385 **FINAL**

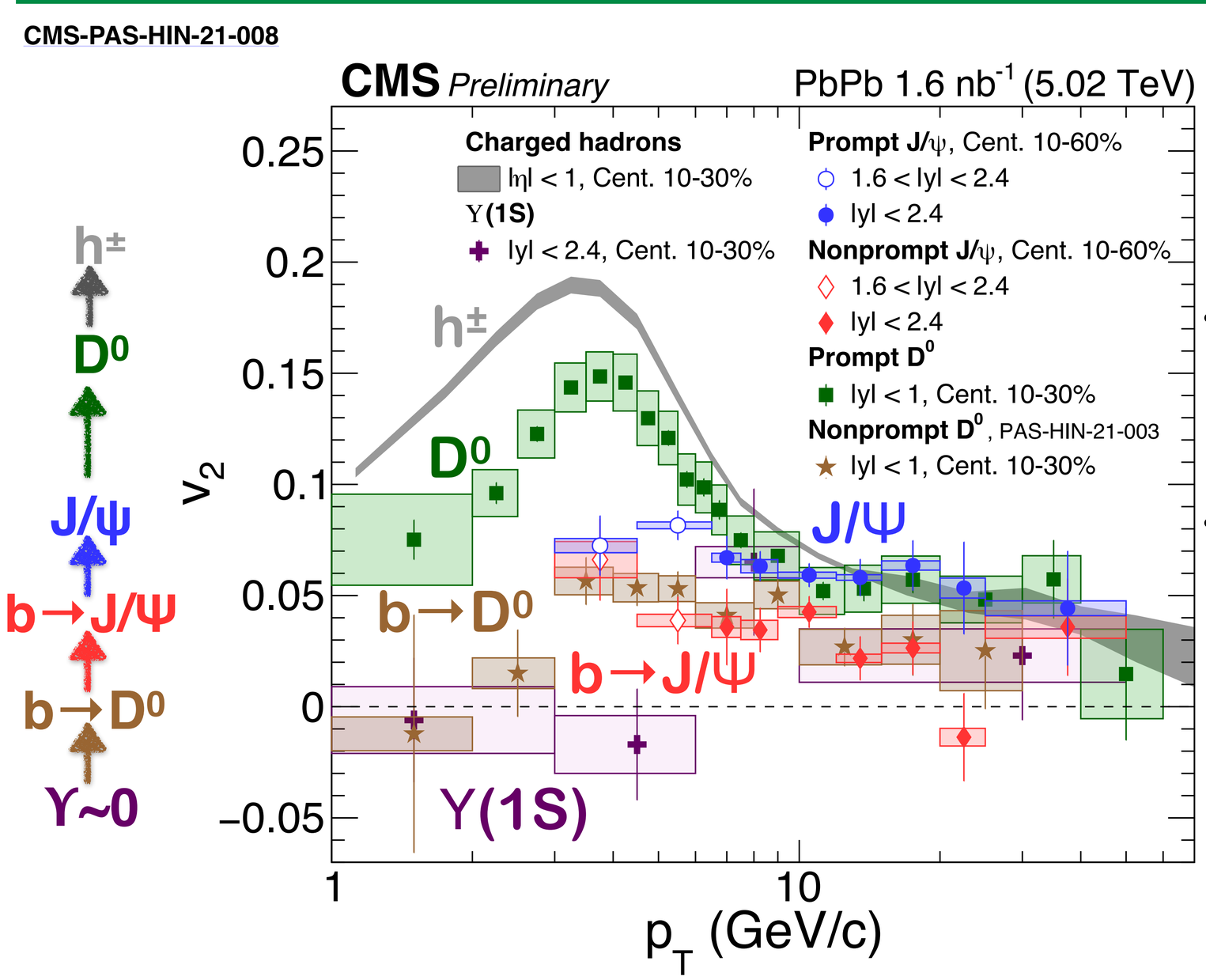




- Y(1S) v_2 consistent with 0 → no significant bottomonium collectivity.
- Current precision will be improved with future LHC Run 3/4 data → help constrain models.

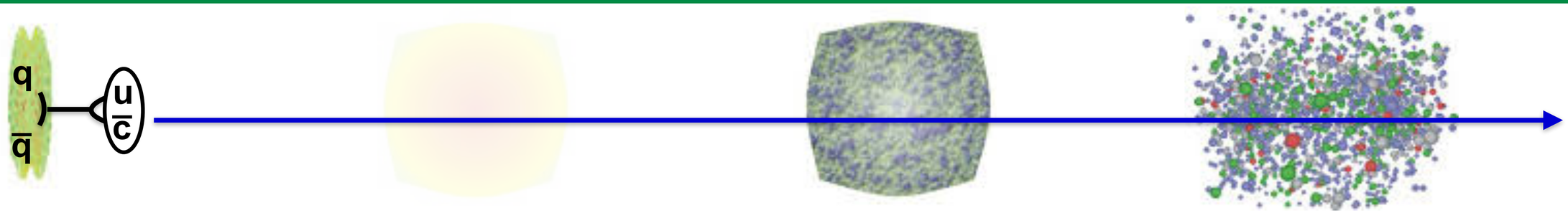
Summary of HF v_2 in PbPb

CMS-PAS-HIN-21-008

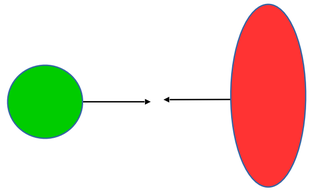


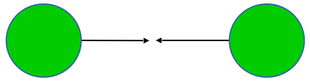
- **Low p_T:**
  - $v_2(h) > v_2(D) > v_2(J/\Psi) > v_2(b) > v_2(\Upsilon) \sim 0$
  - Thermalization → mass ordering
- **High p_T:**
  - $v_2(h) \sim v_2(D) \sim v_2(J/\Psi) \sim v_2(b)$
  - Energy loss

OUTLINE



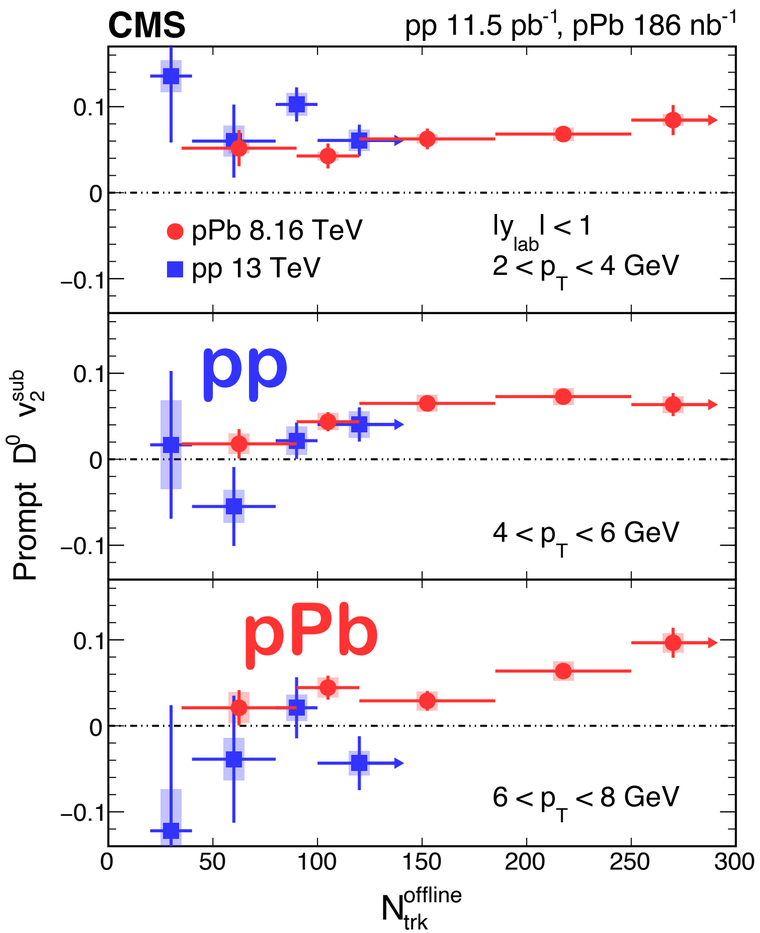
- HF flow in large systems
  - D^0 $v_2\{N\}$ in PbPb.
  - $(b\rightarrow)D^0$ v_n in PbPb.
  - Quarkonium v_n in PbPb.

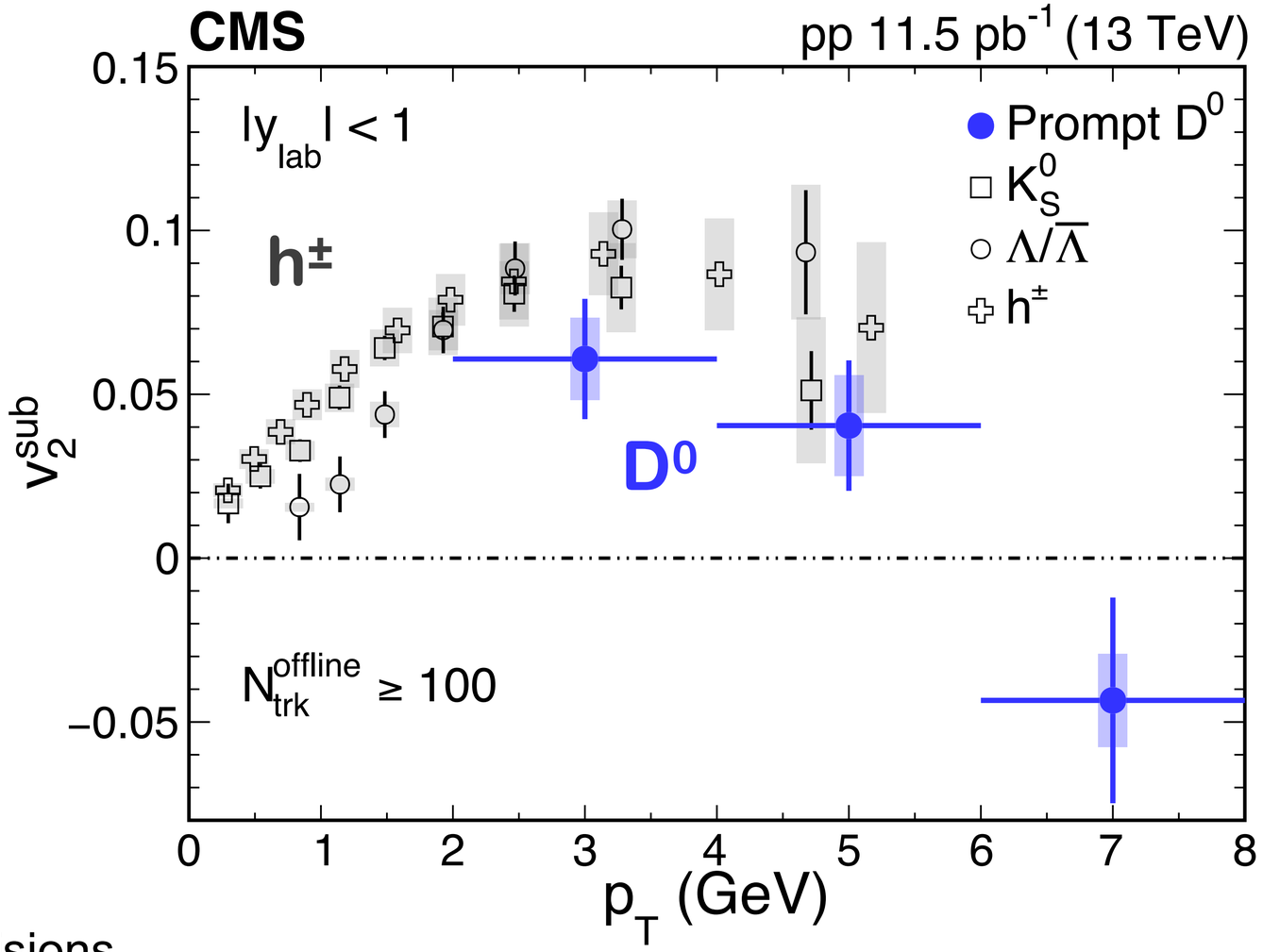


- **HF flow in small systems**
  - **D^0 in pp.** 
  - **$(b\rightarrow)D^0$ in pPb.**
  - **Y(1S) in pPb.**

D^0 elliptic flow in small systems

PLB 813 (2021) 136036 **FINAL**

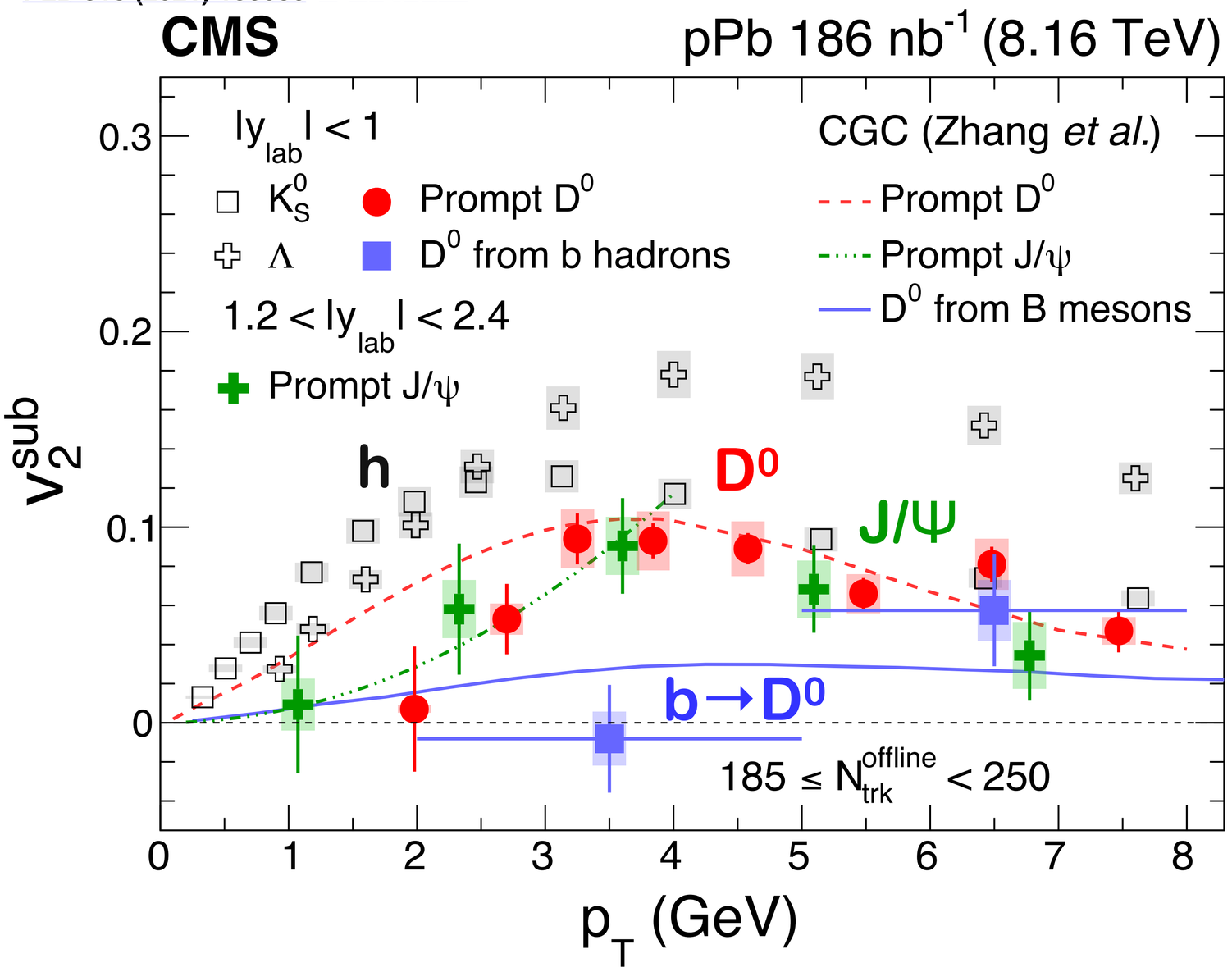




- First measurement of D^0 v2 in pp collisions.
- Indication of nonzero charm flow → comparable with light hadrons.
- Positive D^0 v_2 of observed at high multiplicities → diminish towards lower multiplicities.

b→D⁰ elliptic flow in pPb

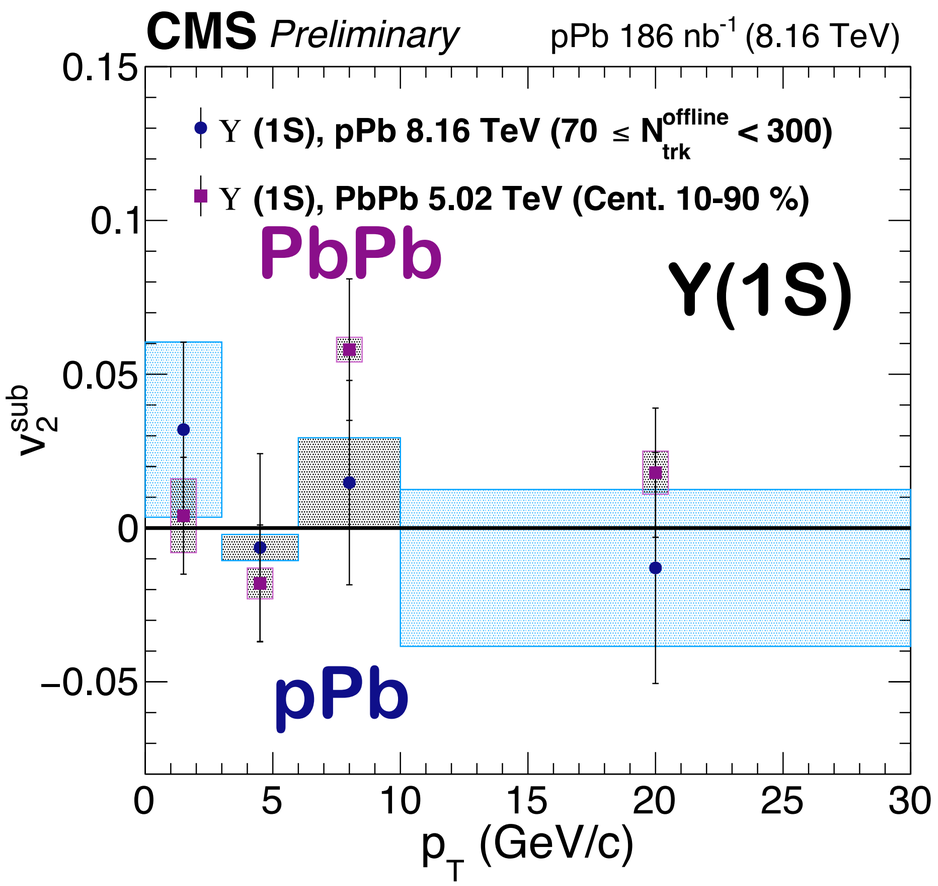
PLB 813 (2021) 136036 **FINAL**

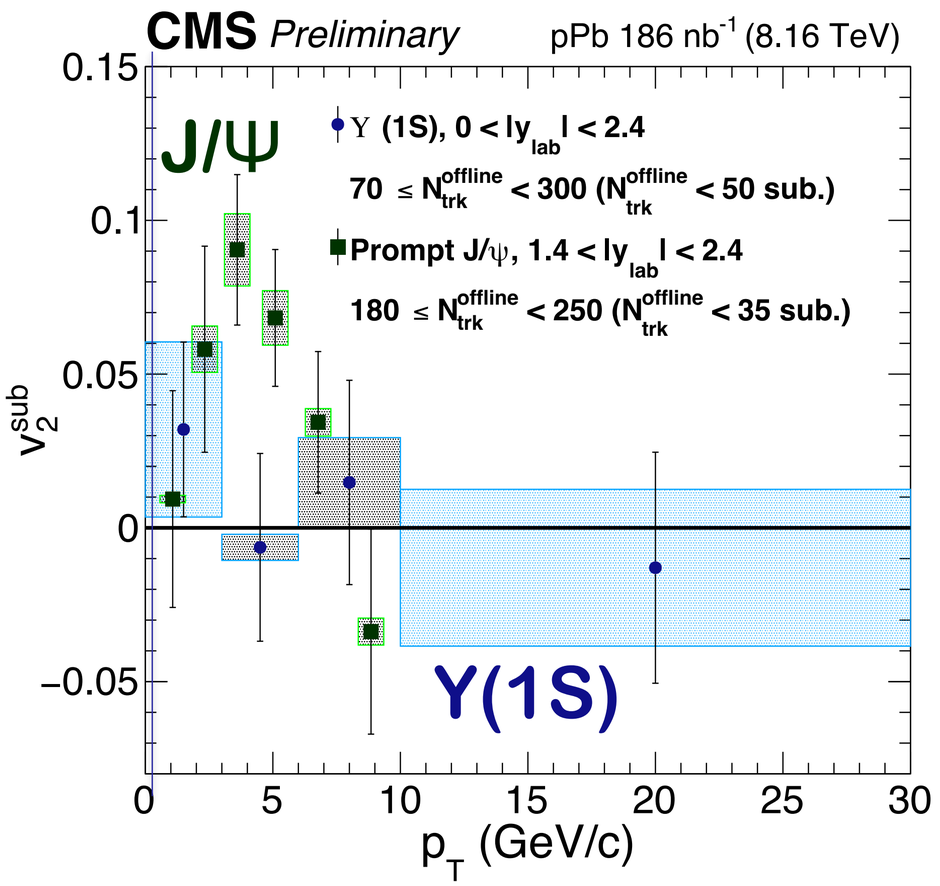


- First measurement of **b → D⁰ v_2** in pPb.
  - v_2 consistent with 0.
- Mass hierarchy at lower p_T.
- CGC model consistent with data.
  - Although with large uncertainties

Y(1S) v_2 in pPb

CMS-PAS-HIN-21-001 **NEW!**

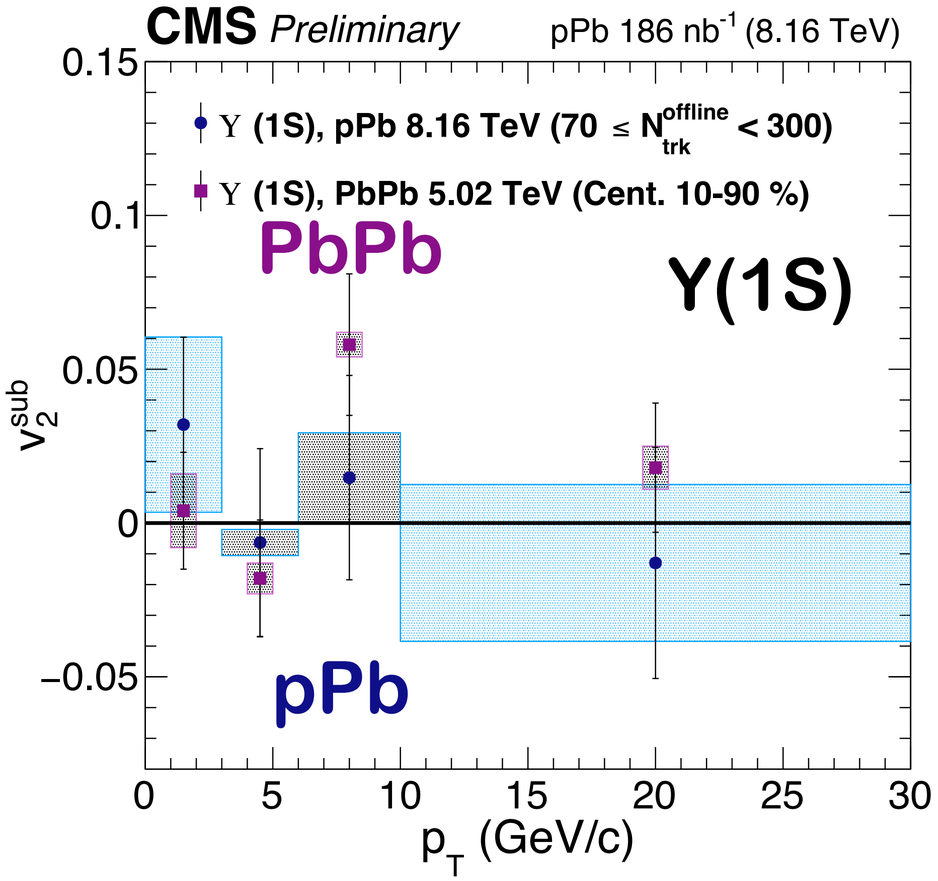


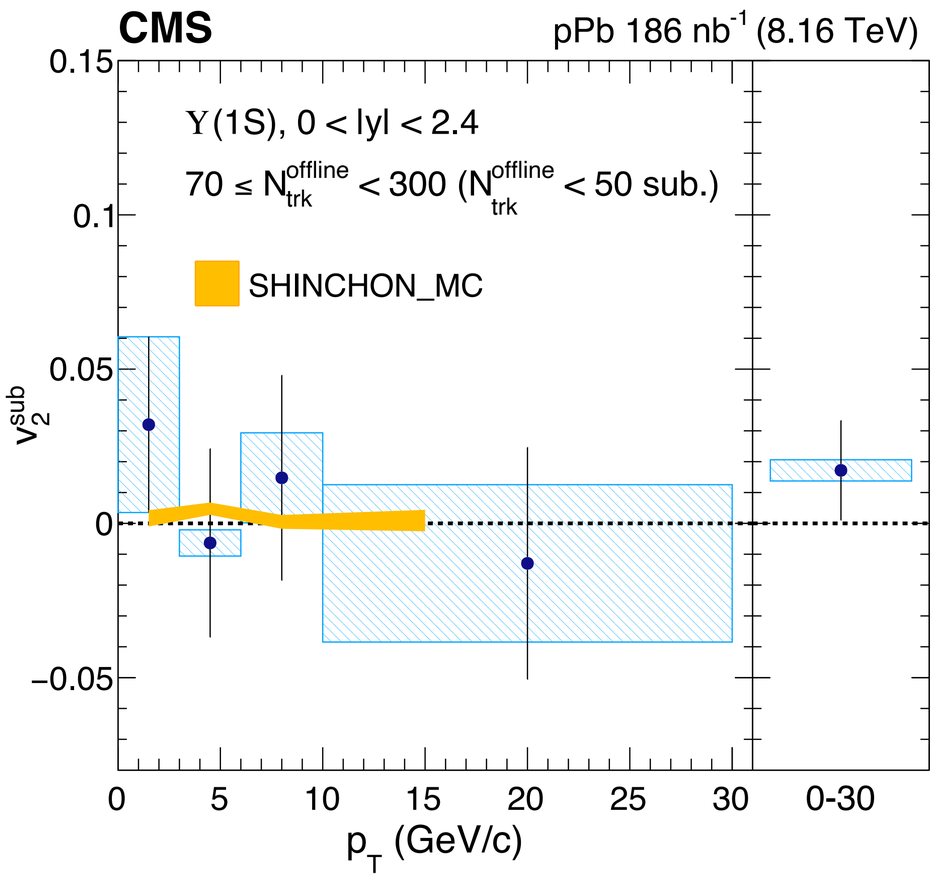


- **Y(1S) v_2** measured for the **first** time in **pPb** → **v_2~0** regardless of system size.
- Hint of different behaviour between **charmonia** and **bottomonia**.

Y(1S) v_2 in pPb

CMS-PAS-HIN-21-001 **NEW!**

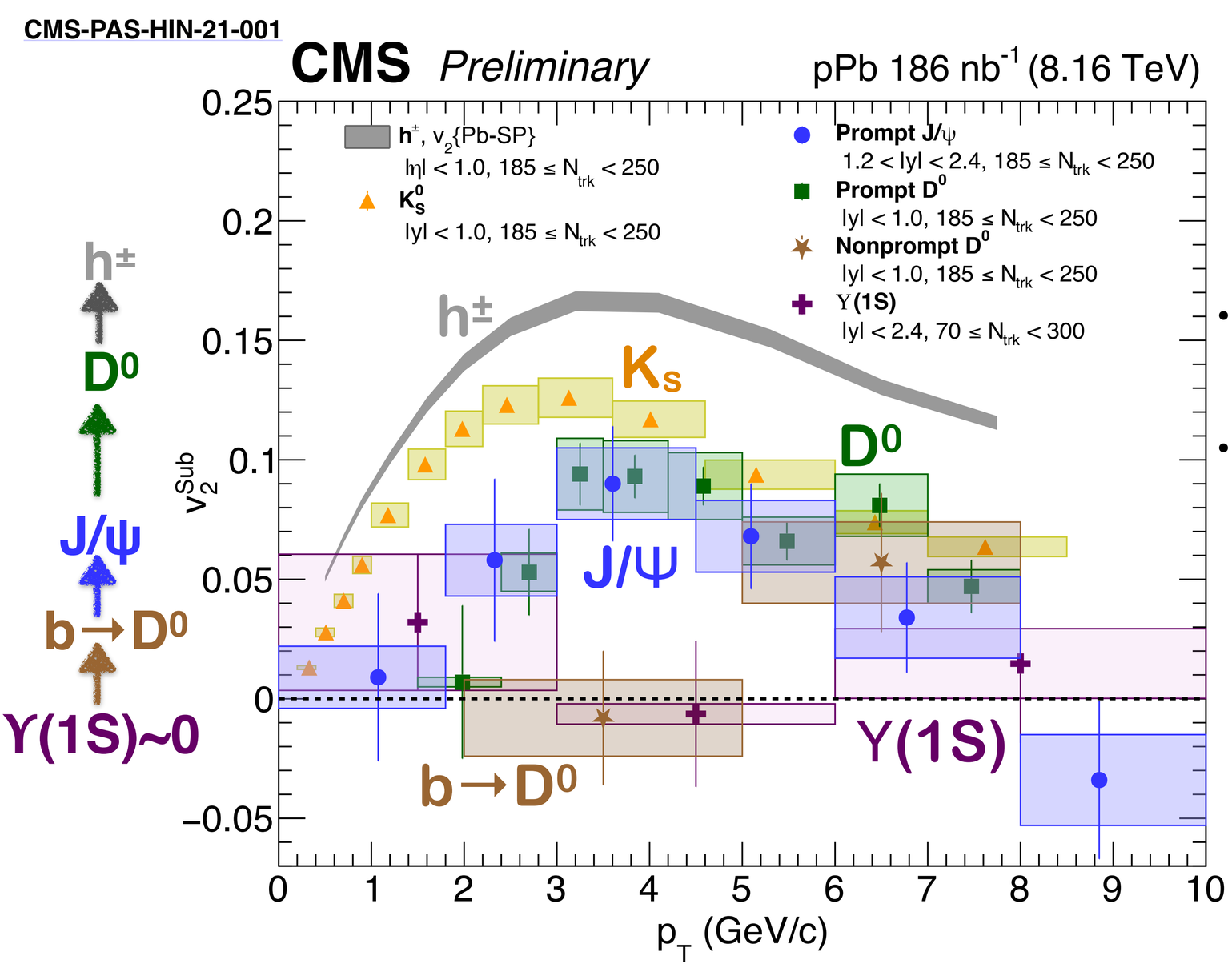




- **Y(1S) v_2** measured for the **first** time in **pPb** → **v_2~0** regardless of system size.
- Hint of different behaviour between **charmonia** and **bottomonia**.
- Results described by MC model (medium response + no Y regeneration).

Summary of HF v_2 in pPb

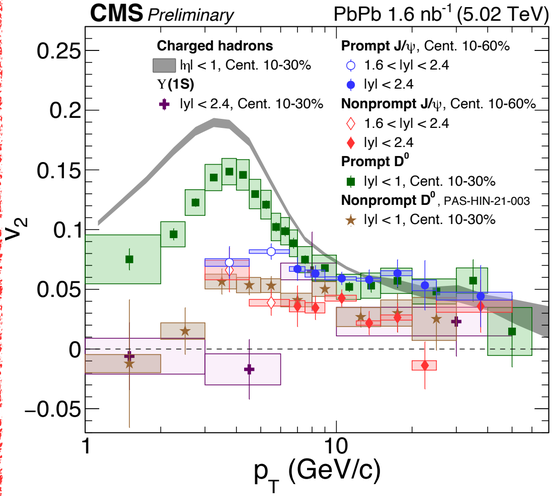
CMS-PAS-HIN-21-001



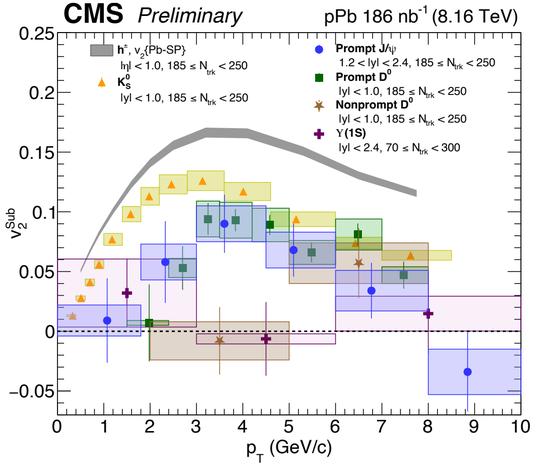
- **Low p_T:**
  - $v_2(h) > v_2(D) \sim v_2(J/\Psi) > v_2(b \rightarrow D) \sim v_2(\Upsilon) \sim 0$
- **High p_T:**
  - $v_2(h)$? $v_2(D) \sim v_2(J/\Psi) \sim v_2(b \rightarrow D) \sim v_2(\Upsilon) \sim 0$

SUMMARY

Several exciting HF flow results published by CMS (link).



- **HF flow in PbPb collisions:**
  - D^0 flow fluctuations compatible with light hadrons but hint of larger charm quark final state fluctuations in peripheral events.
  - Significant collectivity measured for charm quarks.
  - Υ(nS) flow consistent with 0 but b→D^0 and b→J/Ψ v_2 > 0.



- **HF flow in small systems at high multiplicity:**
  - Hint of nonzero charm flow in pp comparable to light hadrons.
  - Mass hierarchy of HF flow seen in small and large systems.
  - Υ(1S) v_2~0 regardless of system size.

Thank you for your attention!

BACKUP