New approach of charmonium medium response using elliptic and triangular flow of J/ψ and ψ(2S) with CMS

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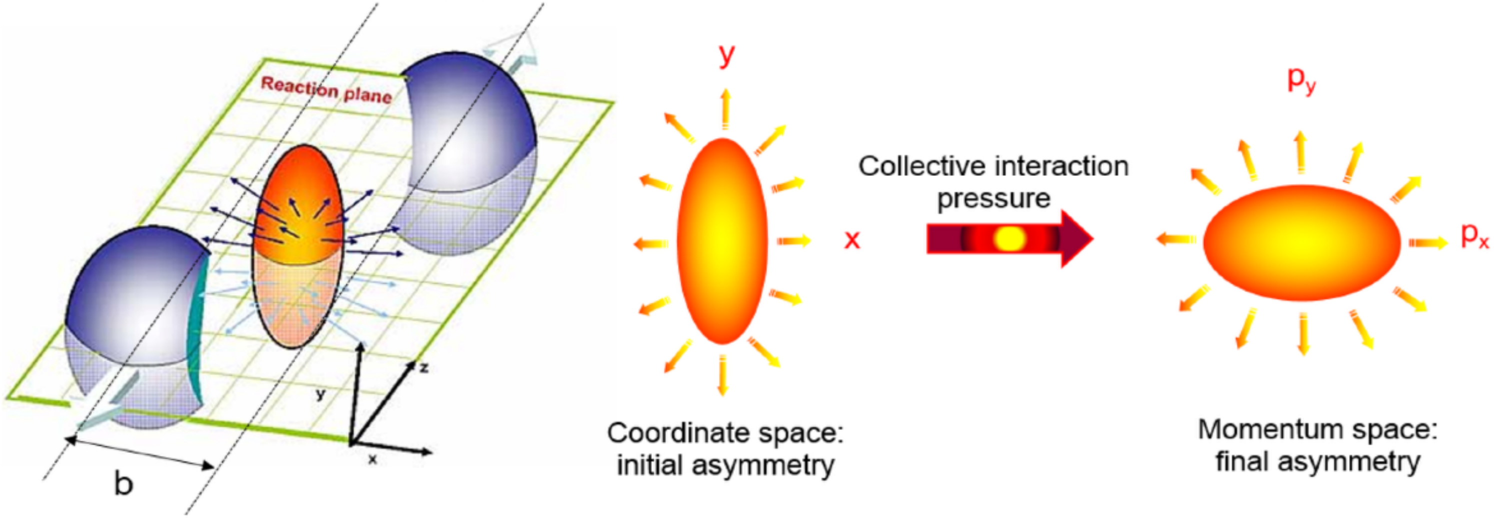
Introduction

- Quarkonia (J/ψ, ψ(2S), and ϒ), heavy quarks produced at the early stages
- Azimuthal (ϕ) distribution of particles: another effective way to probe QGP dynamics.
- Sensitive to initial collision geometry and event-by-event fluctuations
- QGP's anisotropic shape: quarkonia more suppressed in longer path directions



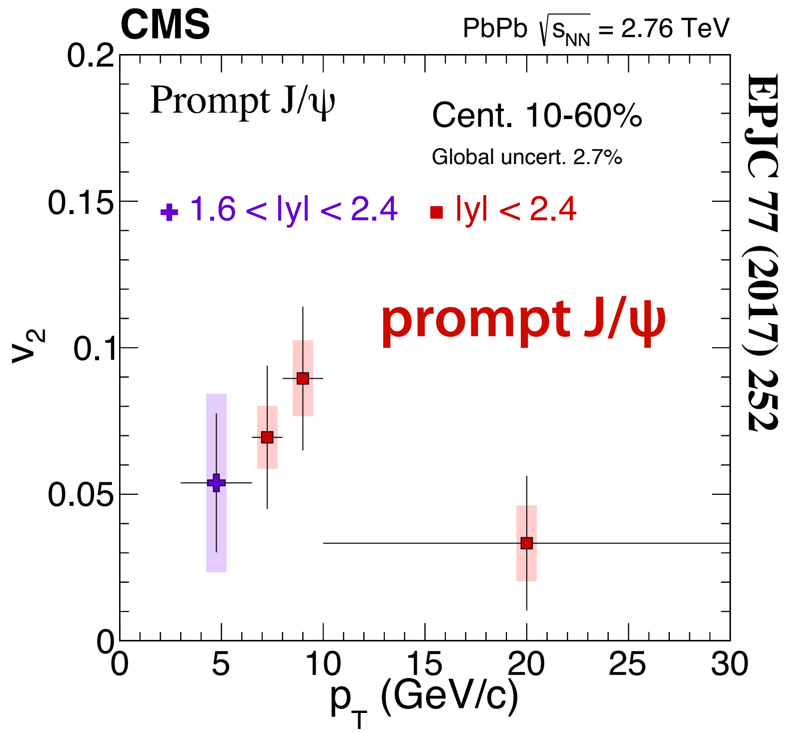
- Fourier coefficients (v_n) of the ϕ distribution can characterize azimuthal correlations

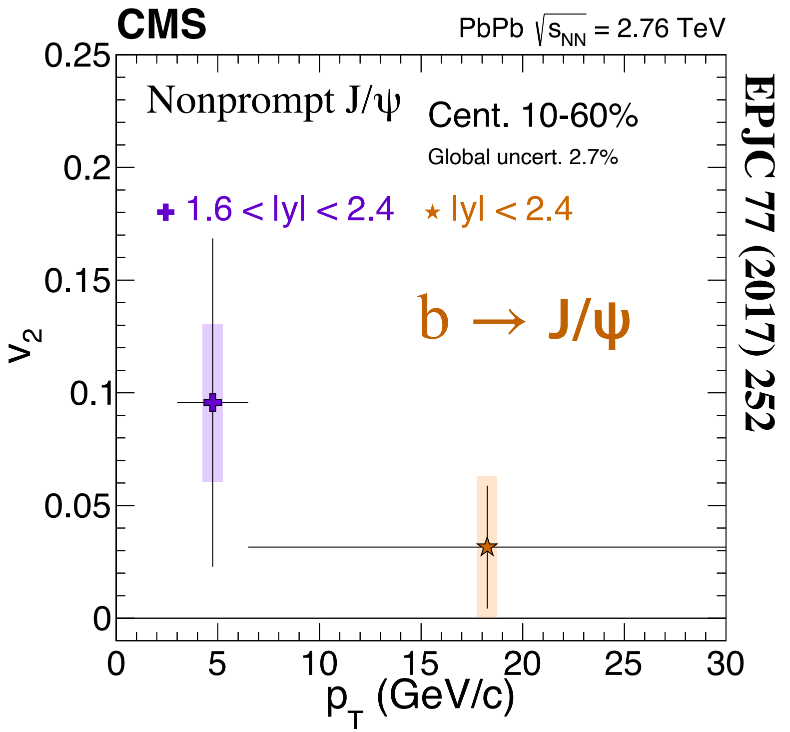
$$\frac{dN}{d\phi} \sim [1 + 2v_2\cos 2(\phi - \psi_2) + 2v_3\cos 3(\phi - \psi_3) \ldots]$$

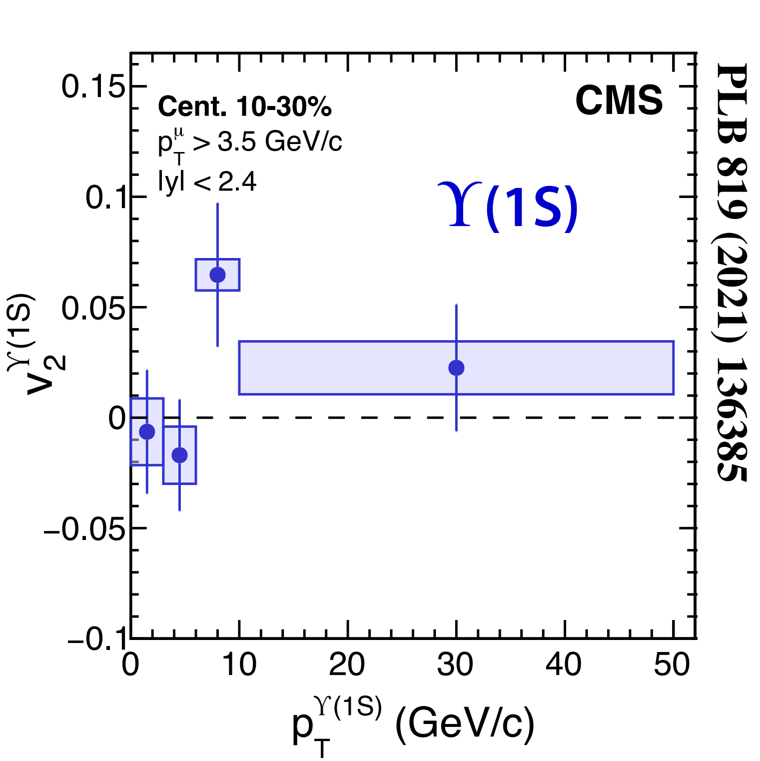
v_2: Elliptic flow

v_3: Triangular flow

Motivation J/ψ flow



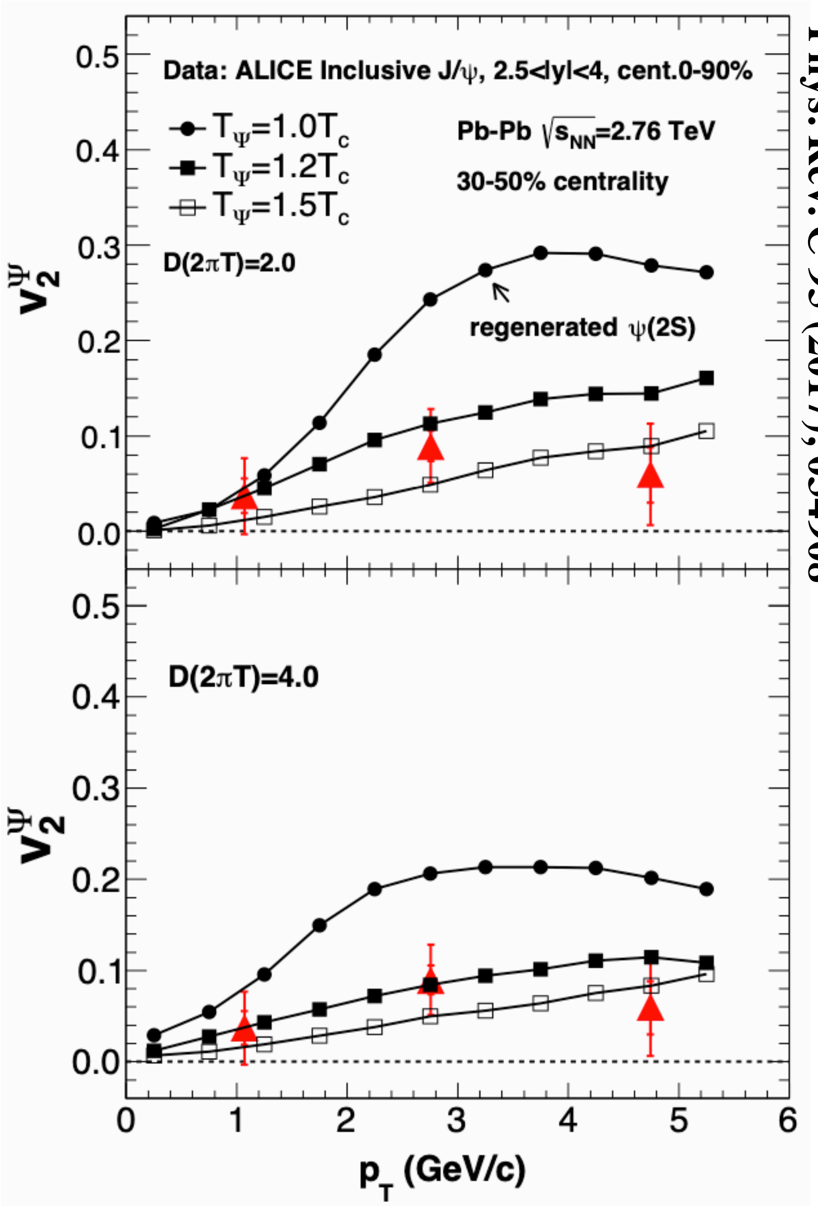




- **Precise measurement at 5.02 TeV with 2018 data (L_{int} ~1.6 nb^{-1})**
- **Low p_T: probe of the charm quark collective**
- **High p_T: study of the path length dependence of quarkonium suppression**
- **Contribution from b hadron decays (b → J/ψ)**
- **No measurement of prompt and b → J/ψ v_3**

Motivation ψ(2S) flow

- Not been measured yet
- Potential larger v_2 of ψ(2S)
  - Sensitive to temperature and diffusion coefficient?
  - Different regeneration for 1S and 2S states?

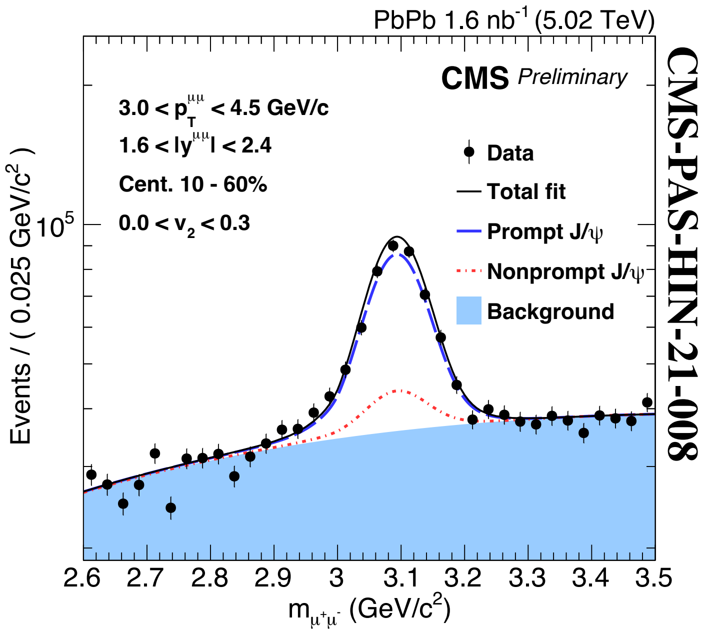


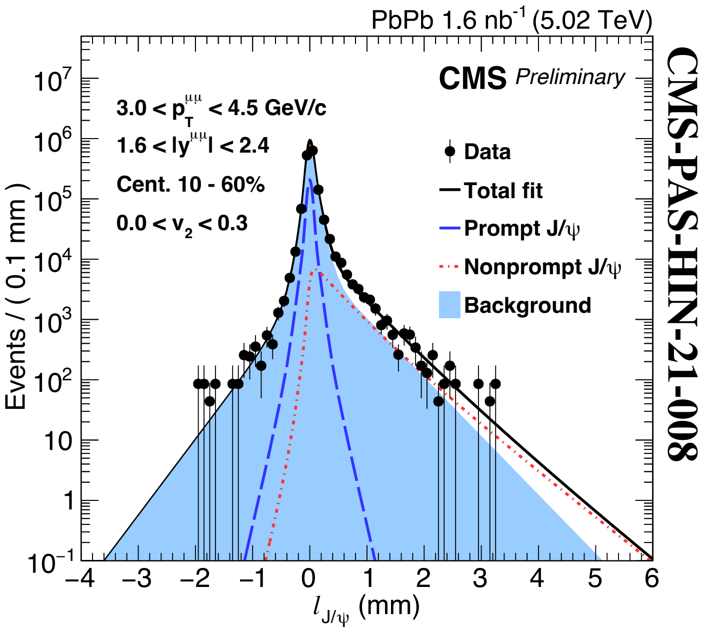
Phys. Rev. C 95 (2017), 034908

Prompt and B to Charmonia

Two techniques to separate components

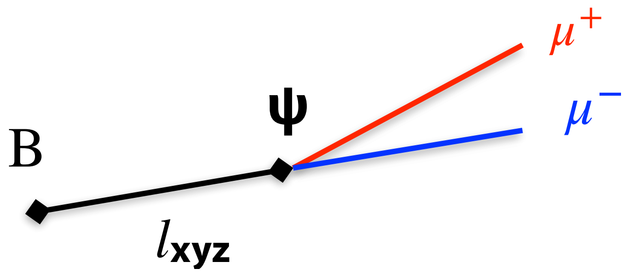
1. 2D fit to dimuon mass and decay length





Prompt J/ψ, $b \rightarrow J/\psi$

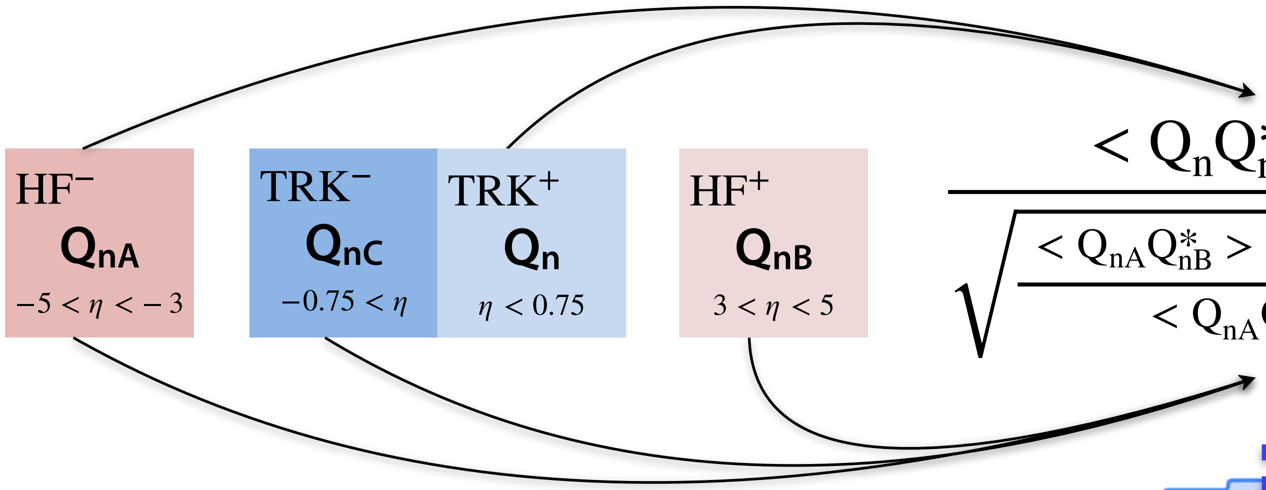
2. Reject b-contamination by constraints on decay length



$$l_\psi = l_{xyz} * m_\psi \, c \, / \, |p_{\mu\mu}|$$

Prompt ψ(2S)

v_n extraction for J/ψ

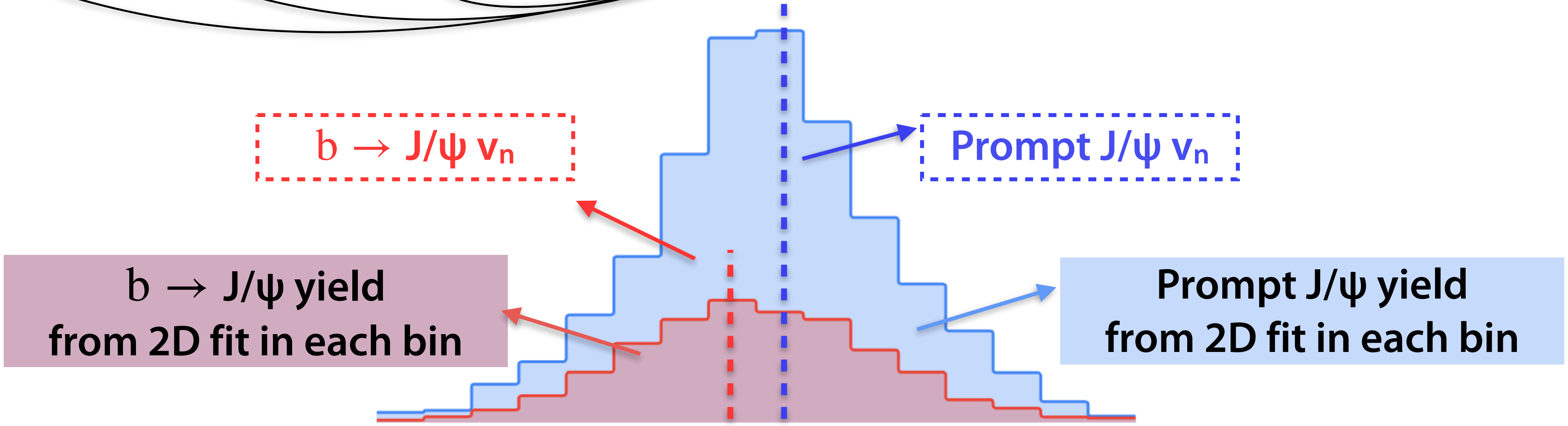


$$\frac{< Q_n Q^*_{nA} >}{\sqrt{\frac{< Q_{nA} Q^*_{nB} > < Q_{nB} Q^*_{nC} >}{< Q_{nA} Q^*_{nC} >}}}$$

Scalar product method using Q-vectors

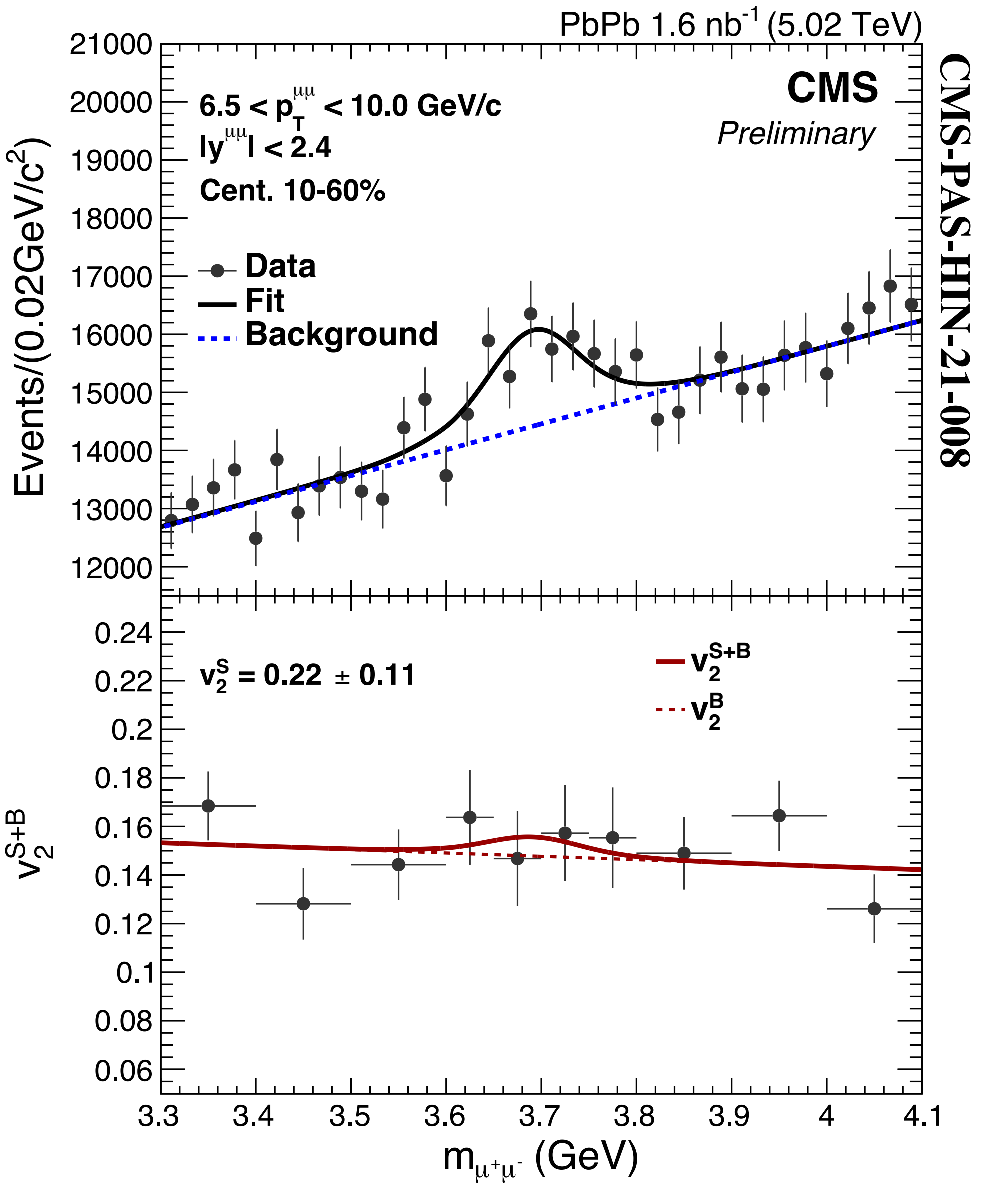
Q_n: **J/ψ candidate flow vector**

Q_{nA}, Q_{nB}, Q_{nC}: **from subevents**



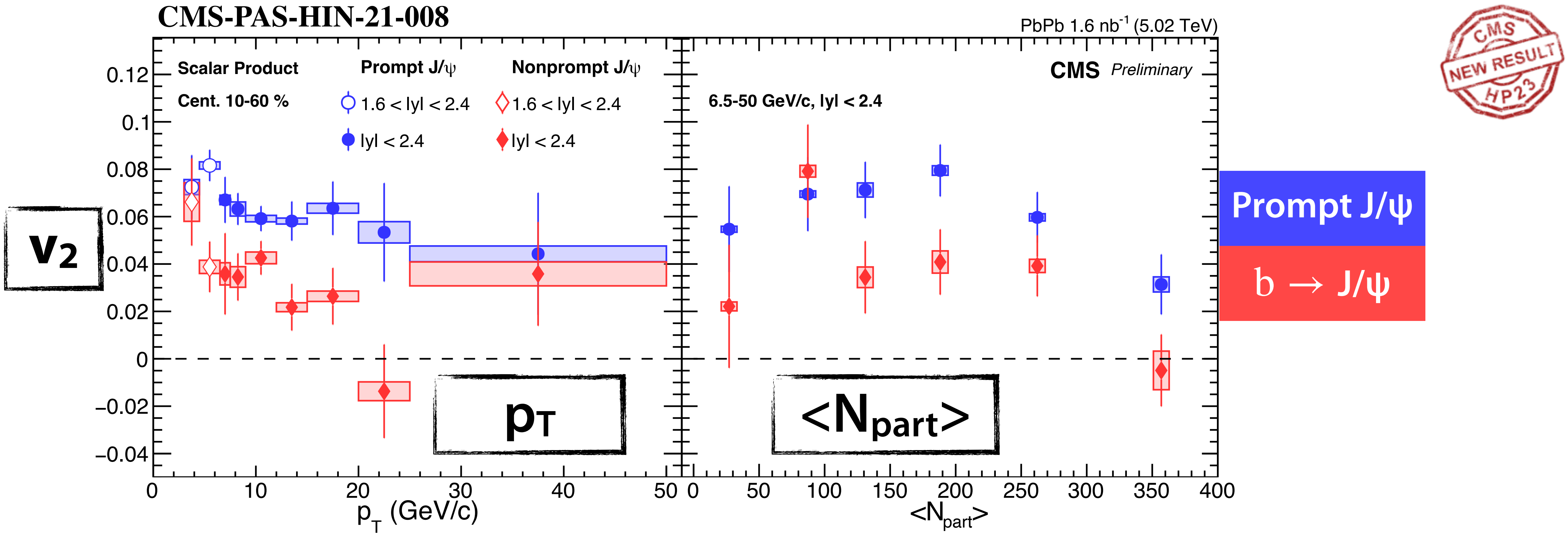
$$\frac{Q_n Q^*_{nA}}{\sqrt{\frac{< Q_{nA} Q^*_{nB} > < Q_{nB} Q^*_{nC} >}{< Q_{nA} Q^*_{nC} >}}}$$

v_n extraction for prompt ψ(2S)



- Prompt sample enriched by constraints decay length
- Mass and v_n simultaneous fit
- $$\frac{< Q_n Q_{nA}^* >}{\sqrt{\frac{< Q_{nA} Q_{nB}^* > < Q_{nB} Q_{nC}^* >}{< Q_{nA} Q_{nC}^* >}}}$$
- $$v_n^{Sig+Bkg}(m_{inv}) = \alpha(m_{inv}) v_n^{Sig} + [1 - \alpha(m_{inv})] v_n^{Bkg}(m_{inv})$$
- $$\alpha(m_{inv}) = \frac{Sig(m_{inv})}{Sig(m_{inv}) + Bkg(m_{inv})}$$

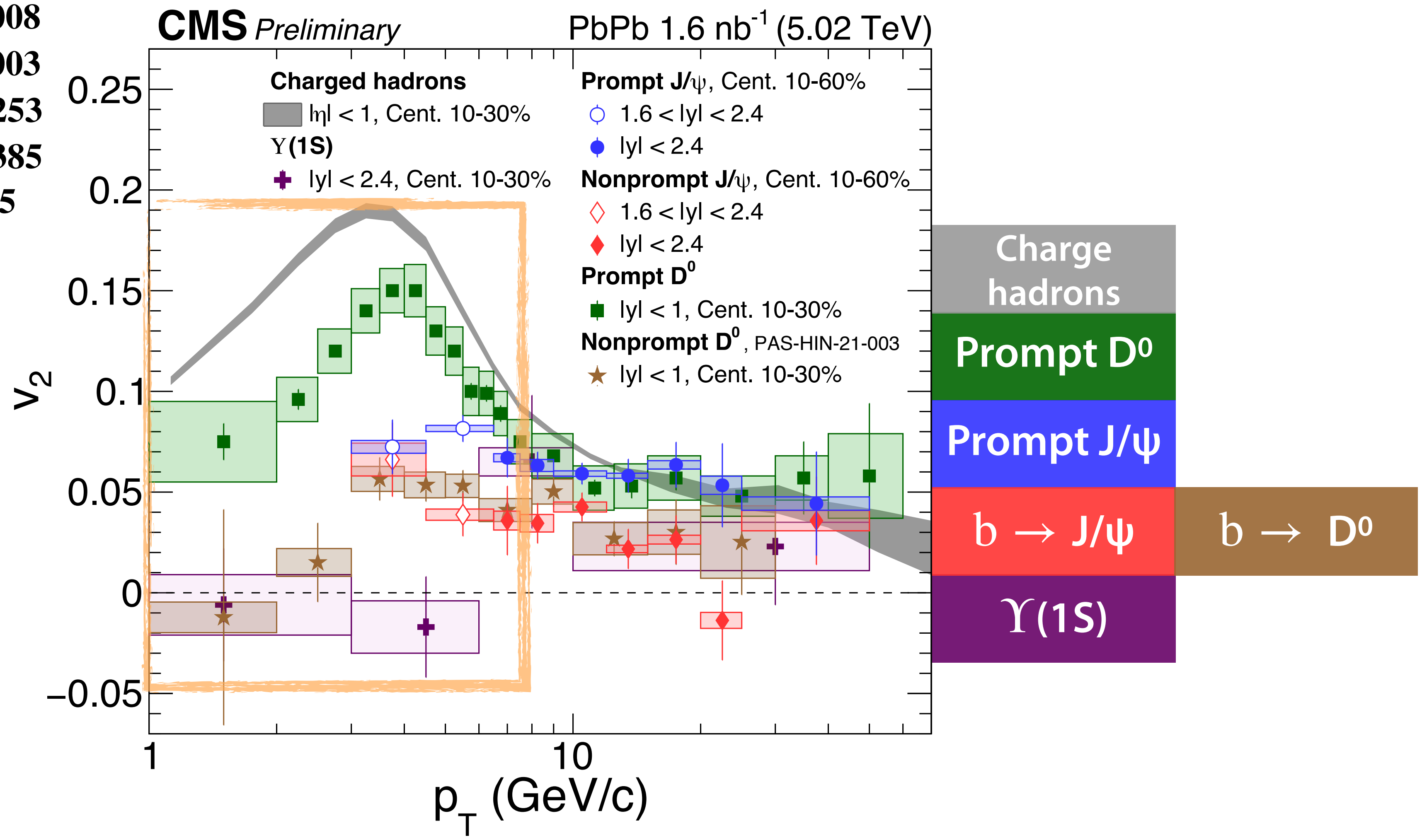
Result: J/ψ v_2



- Large v_2 up to 50 GeV/c
- Smallest v_2 in most central collision event
- prompt J/ψ v_2 > b → J/ψ
  - No clear p_T dependence
  - different collectivity may be attributed to various factors

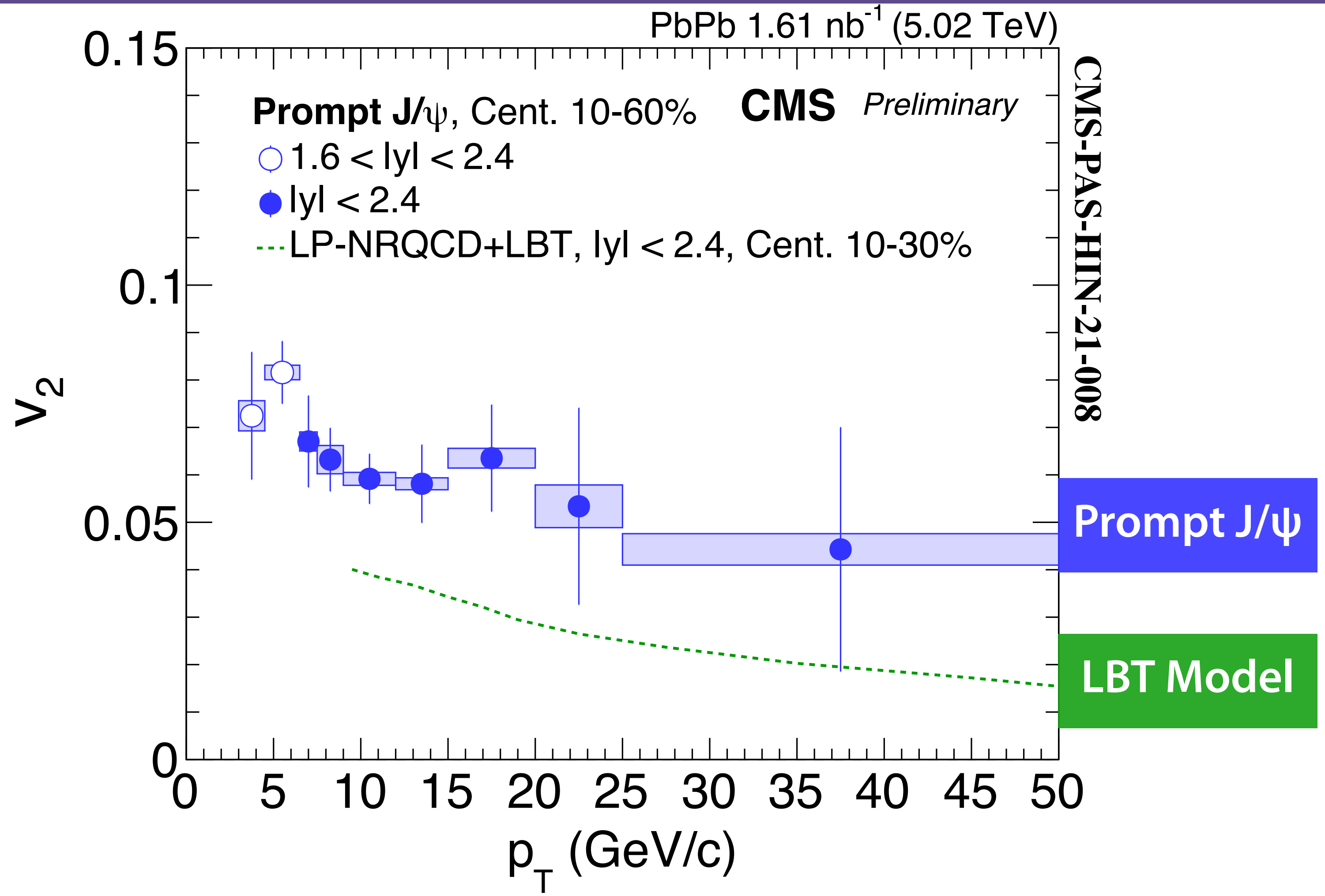
Comparison: CMS v_2

CMS-PAS-HIN-21-008
CMS-PAS-HIN-21-003
PLB 816 (2021) 136253
PLB 819 (2021) 136385
PLB 776 (2017) 195



- Low p_T: light > charm > beauty (mass ordering)
- High p_T: converged v_2 for all species

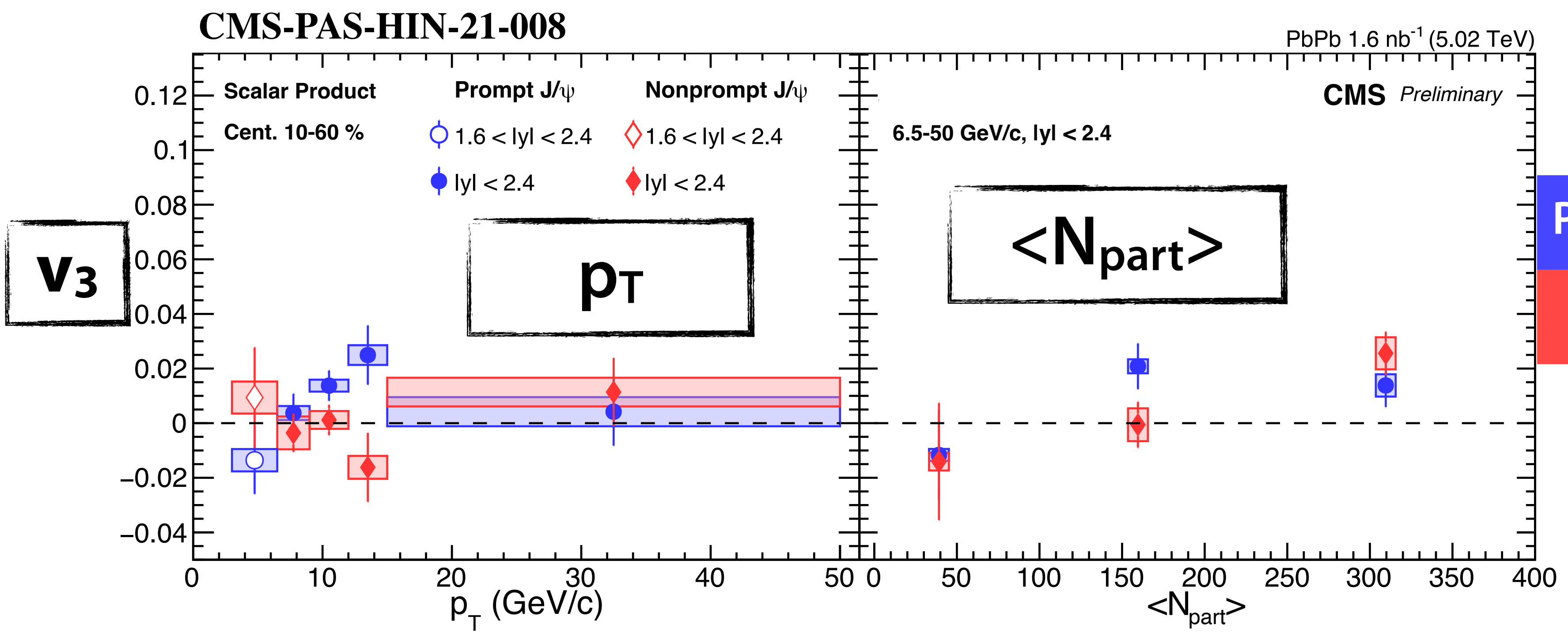
Result: prompt J/ψ v_2 vs. Model



CMS NEW RESULT HP23

- LBT is used for the medium response of jets in PbPb collisions
- v_2 in the data underpredicted by the model
- Additional contributions required to describe prompt J/ψ at high-p_T

Result: J/ψ v_3



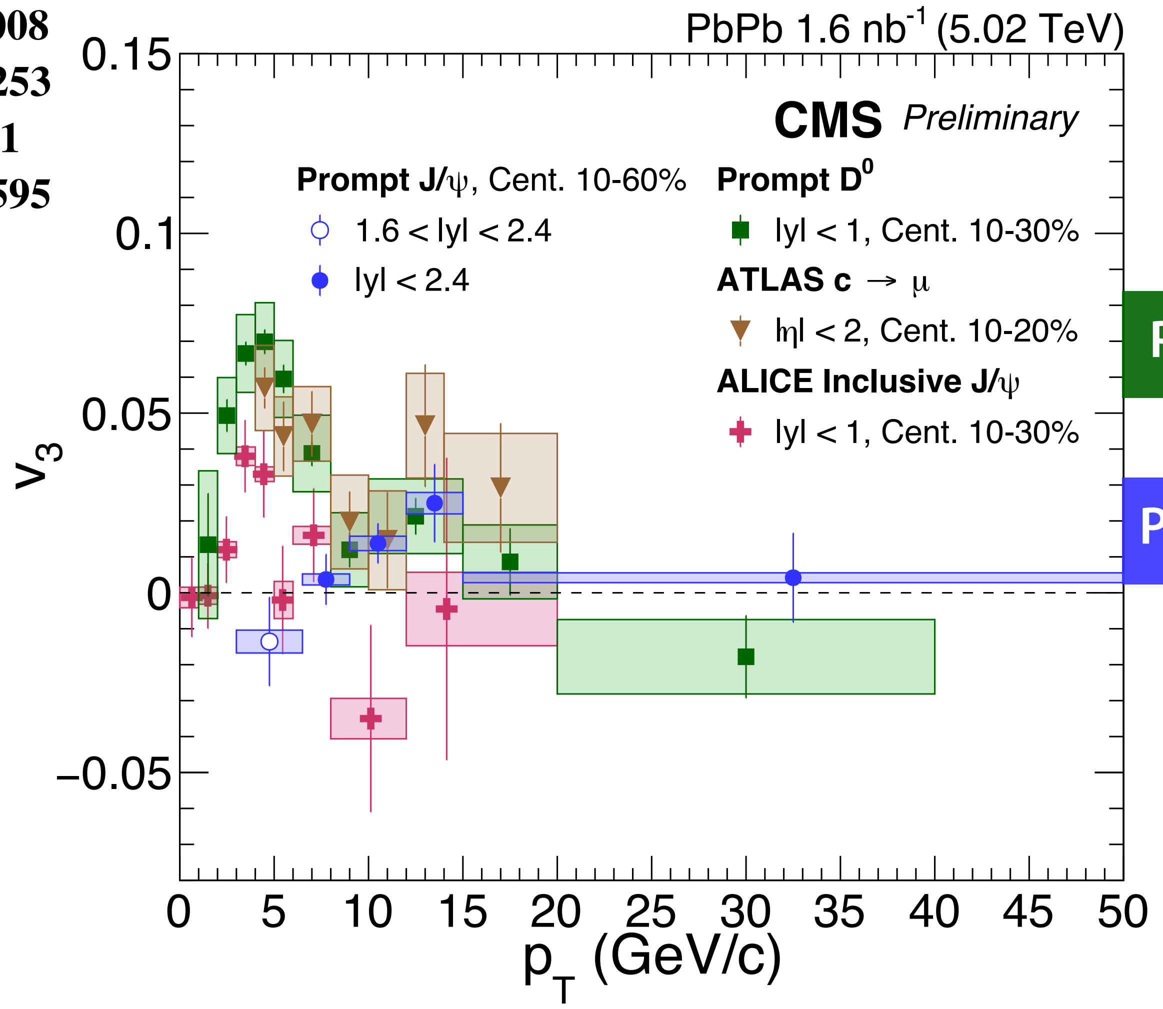
Prompt J/ψ

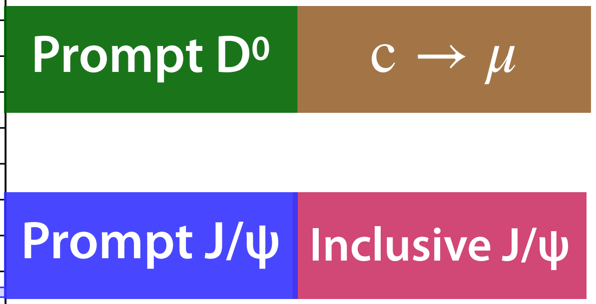
b → J/ψ

- v_3 measurement for PR and NP
- results consistent with zero

Comparison: Charm v_3

CMS-PAS-HIN-21-008
PLB 816 (2021) 136253
JHEP 10 (2020) 141
PLB 807 (2020) 135595

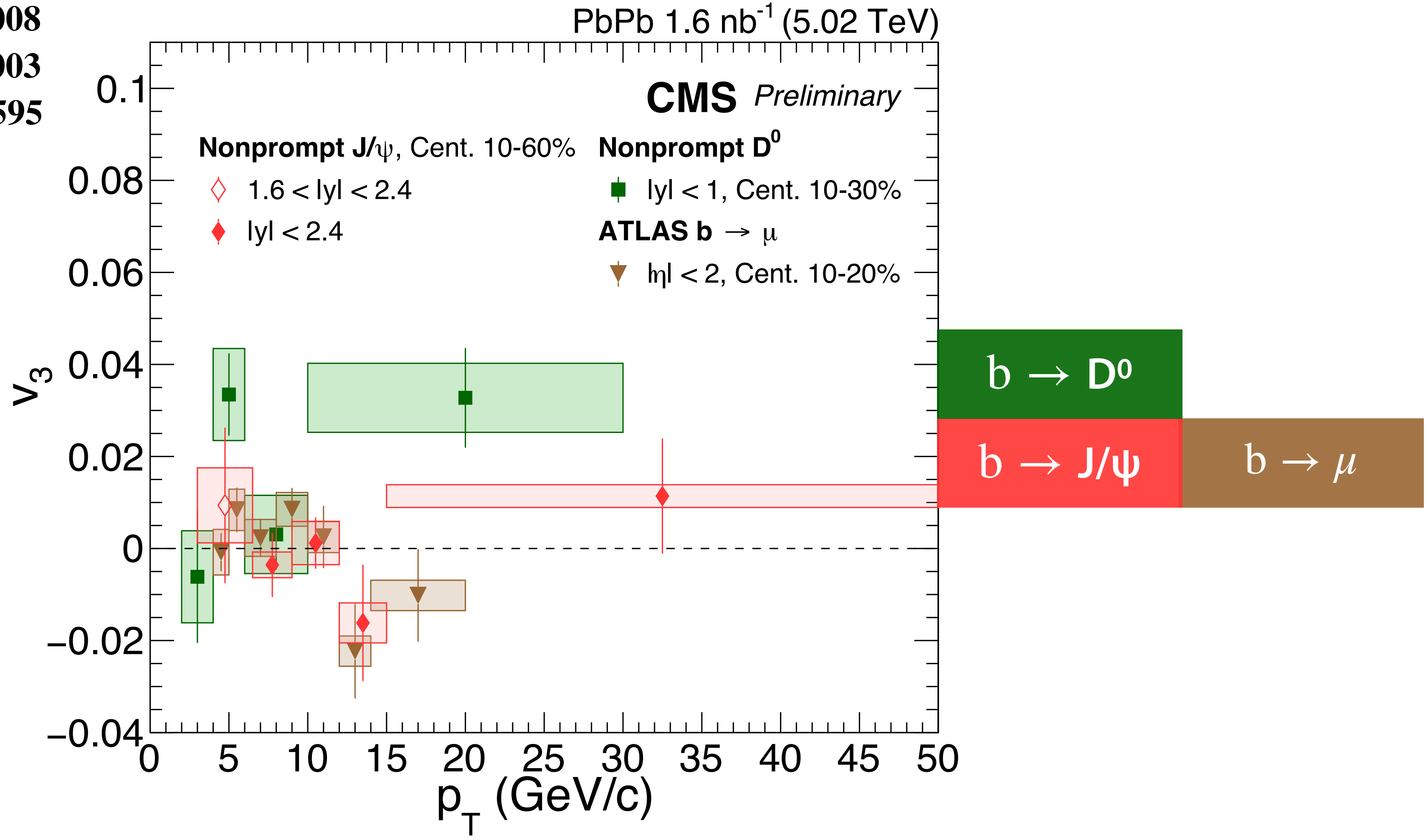




- Low p_T: Prompt D^0 v_3 > Prompt J/ψ v_3
- Open charm is more sensitive to initial geometry than hidden charm

Comparison: b hadrons v_3

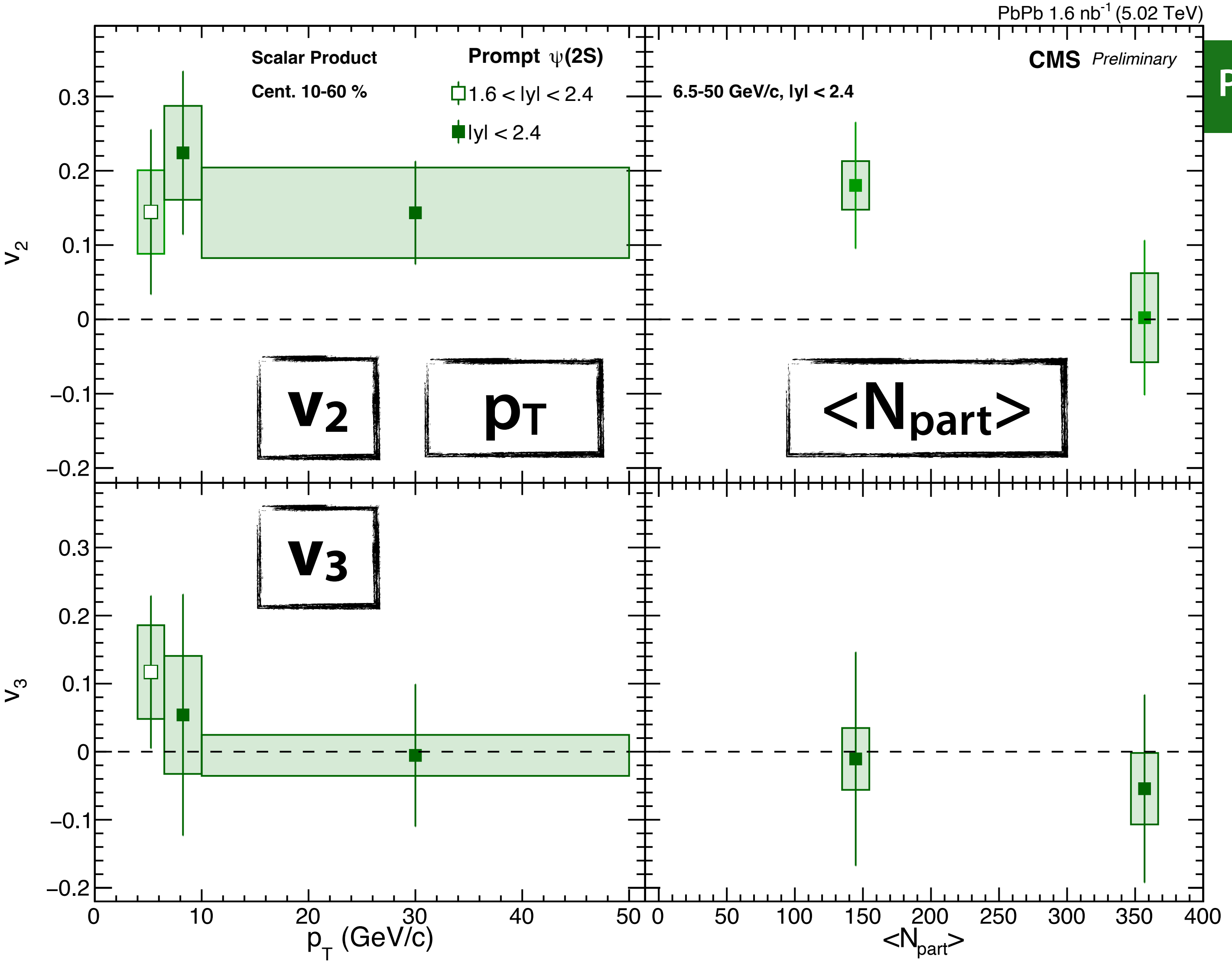
CMS-PAS-HIN-21-008
CMS-PAS-HIN-21-003
PLB 807 (2020) 135595



- v_3 of b hadrons are consistent

Result: prompt ψ(2S) v_n

CMS-PAS-HIN-21-008

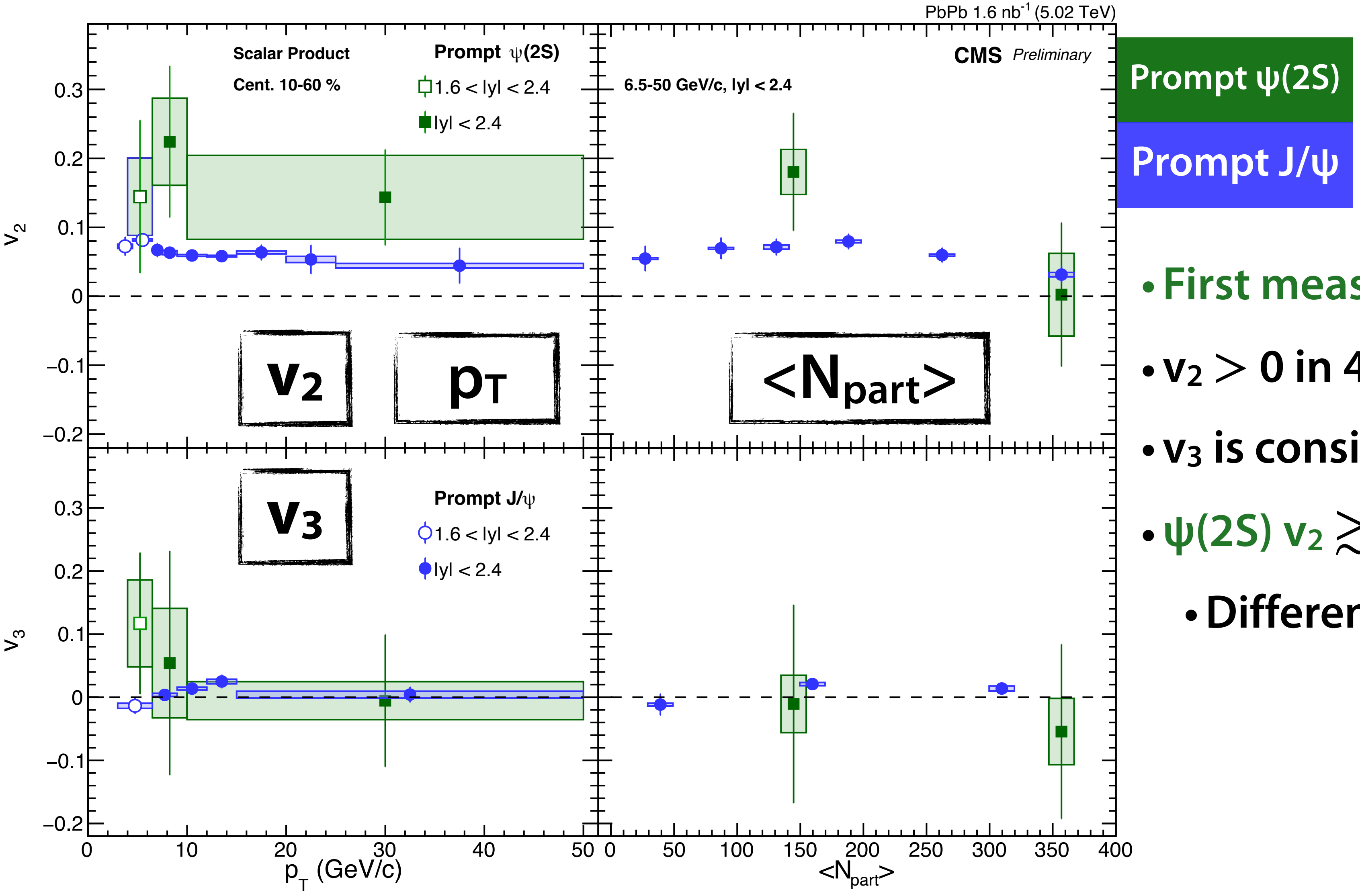


Prompt ψ(2S)

- First measurement in heavy ion collisions
- $v_2 > 0$ in $4 < p_T < 50$ GeV/c
- v_3 is consistent with zero

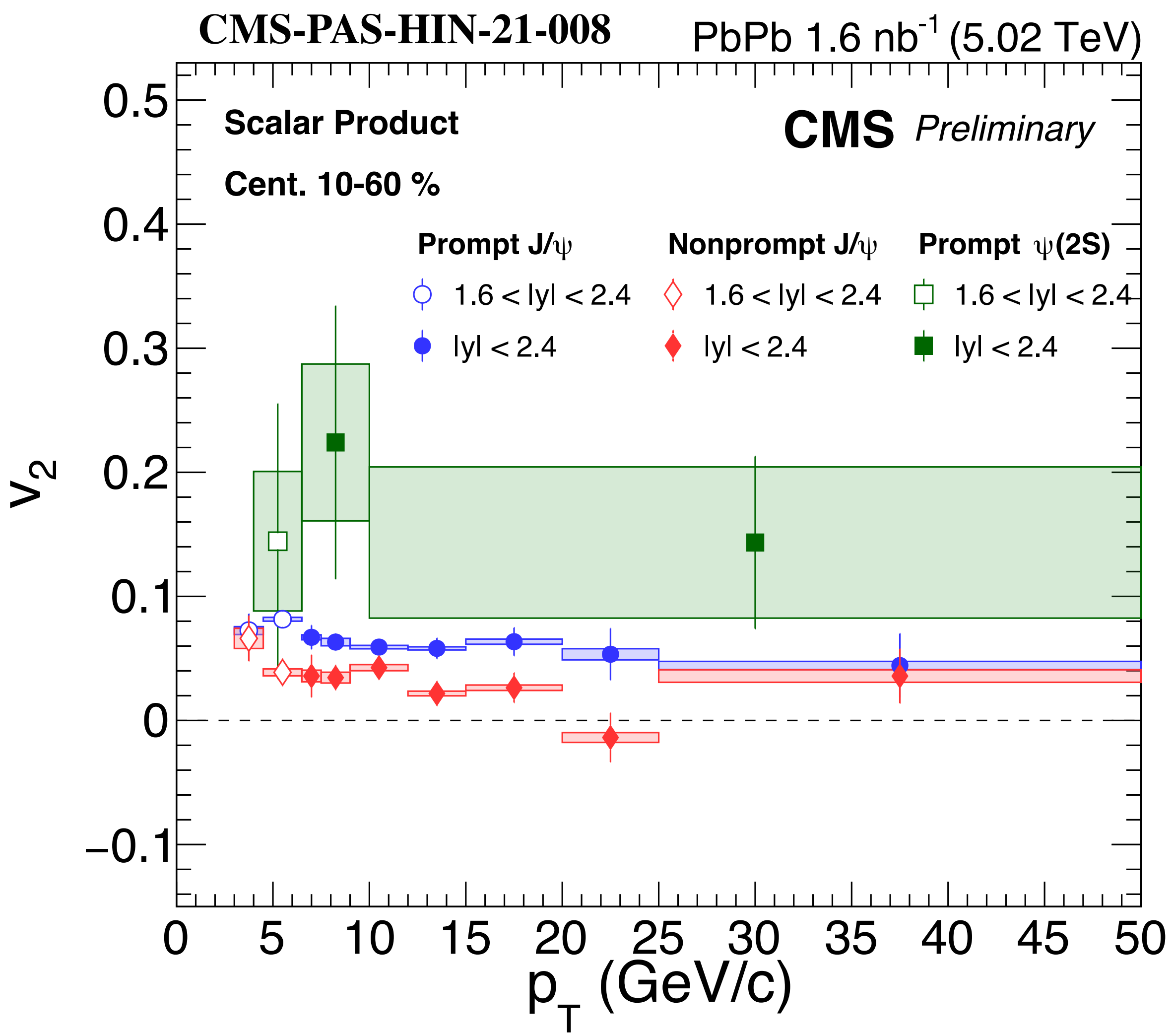
Comparison: ψ(2S) v_n vs J/ψ v_n

CMS-PAS-HIN-21-008



- First measurement in heavy ion collisions
- $v_2 > 0$ in $4 < p_T < 50$ GeV/c
- v_3 is consistent with zero
- ψ(2S) $v_2 \gtrsim$ J/ψ v_2 in mid-p_T
  - Different contribution of recombination?

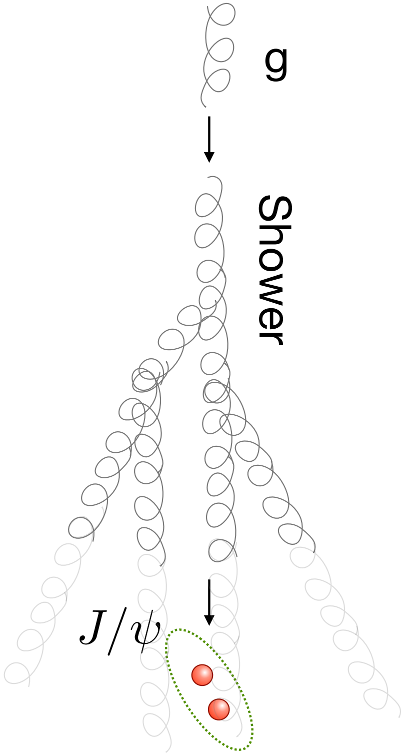
Summary

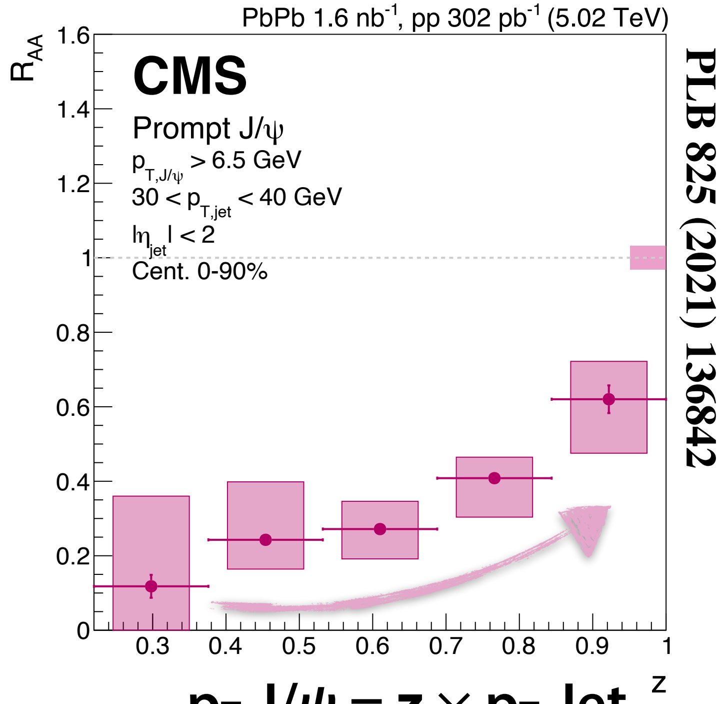


- Study of azimuthal anisotropy for charmonia
- Prompt J/ψ v_2 > b → J/ψ v_2
  → in-medium effect for c and b quarks flow
- Large prompt J/ψ v_2 at high-p_T
  → J/ψ production: jet frag. + additional contribution
- prompt, b → J/ψ v_3 consistent with zero
- ψ(2S) v_2, v_3
  - Indication of ψ(2S) v_2 > prompt J/ψ v_2
    → different hadronization time
  - v_3 consistent with zero

Thank you for your attention

Motivation

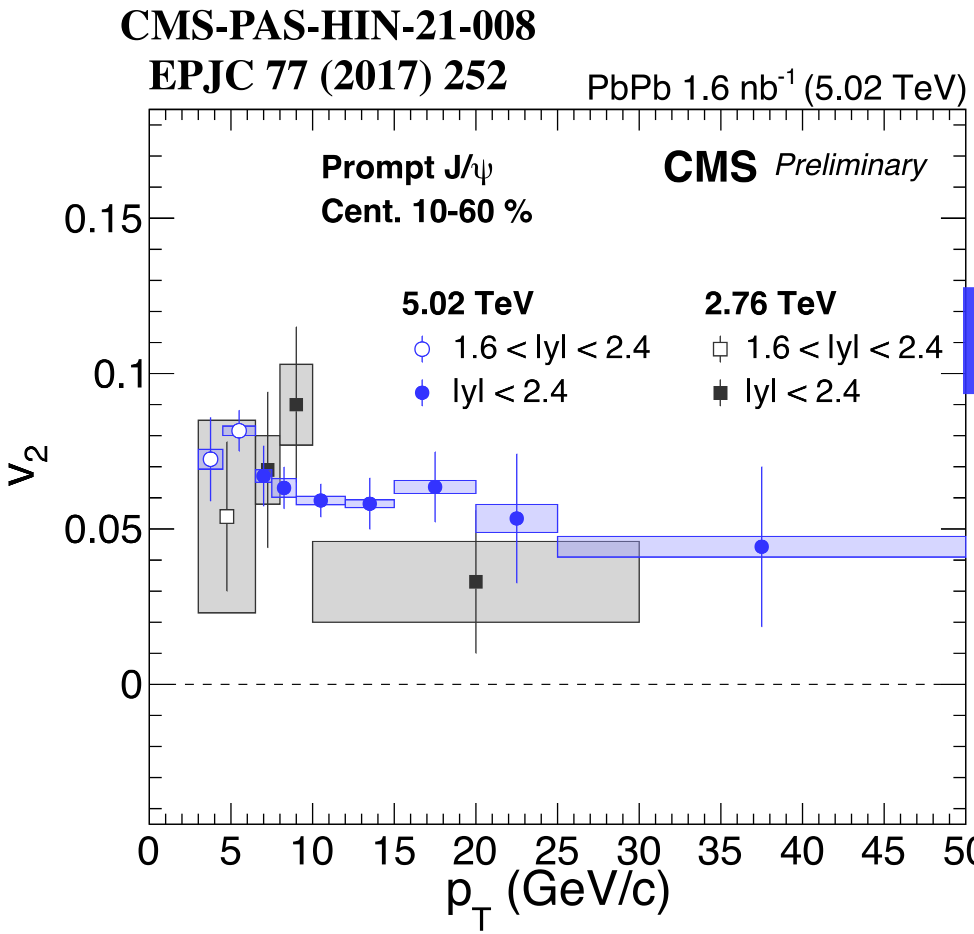




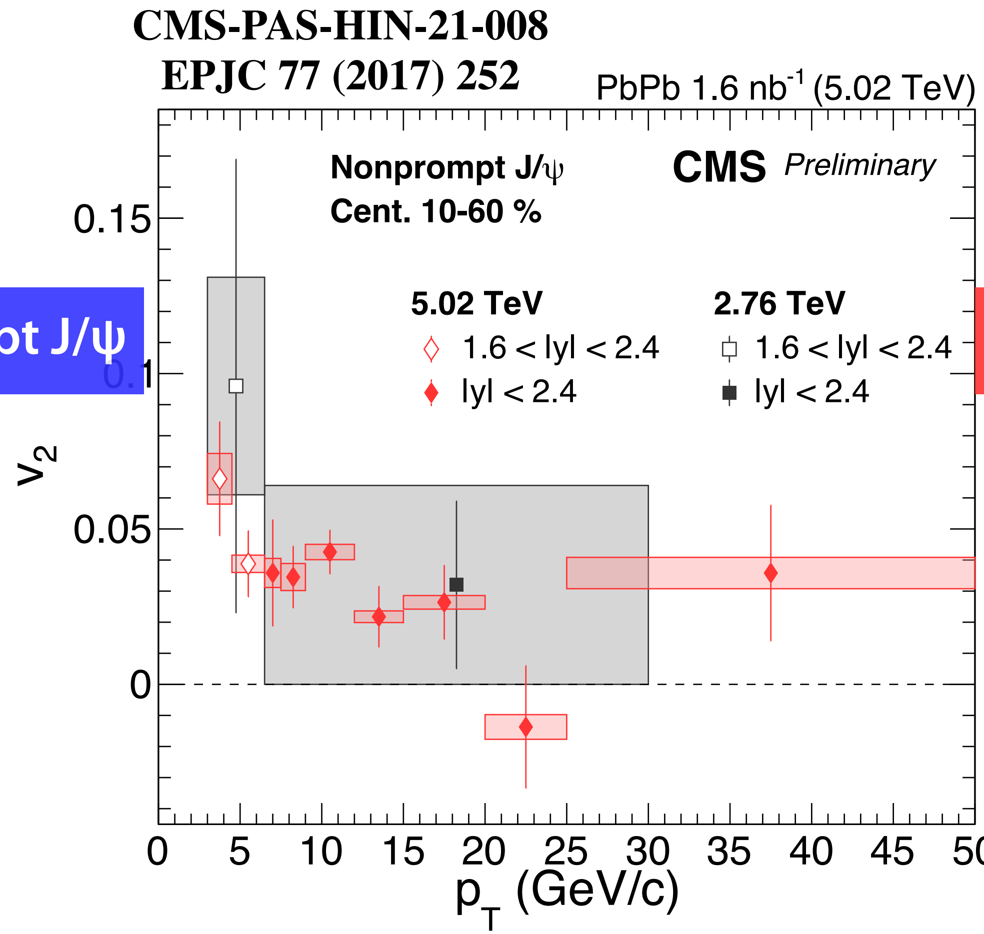
$p_{T,J/\psi} = z \times p_{T,Jet}$

- **Less suppression for isolated J/ψ compared to J/ψ with larger jet activity**
- **Jet quenching : important role for J/ψ suppression at high-p_T**
- **Investigate J/ψ flow at high-p_T**

Comparison: CMS 2.76 vs 5.02 TeV



Prompt J/ψ

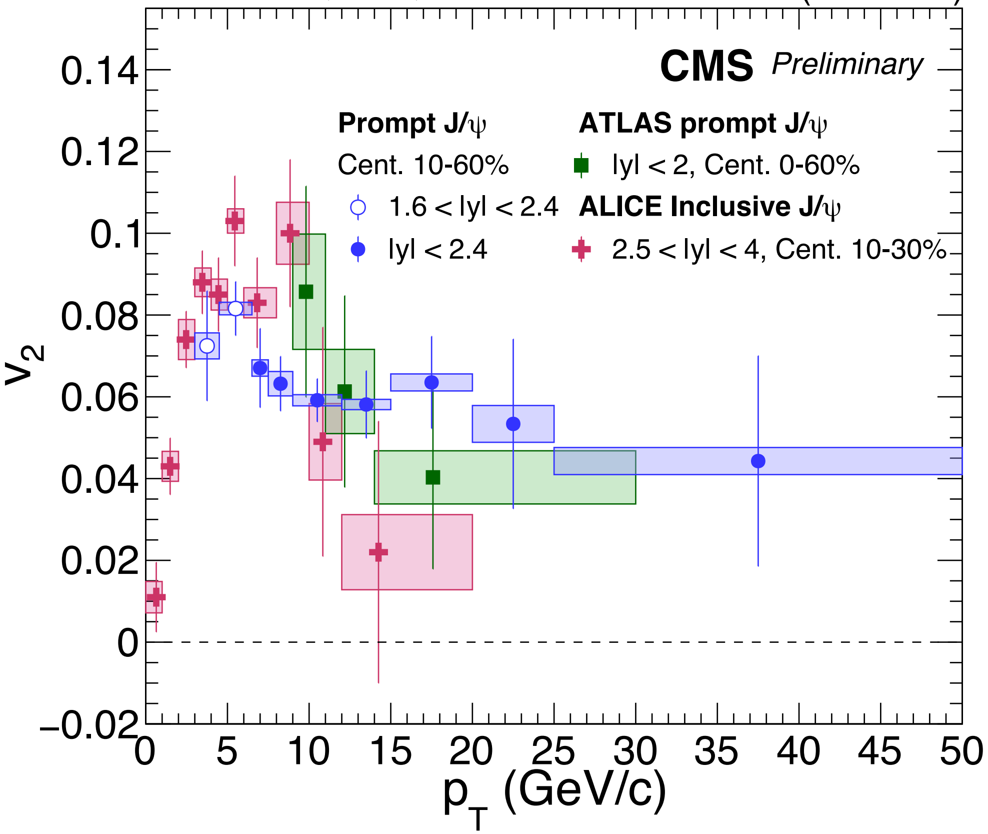


b → J/ψ

- Prompt and b → J/ψ at 2.76 vs 5.02 TeV
- High-precision with larger samples (x10)

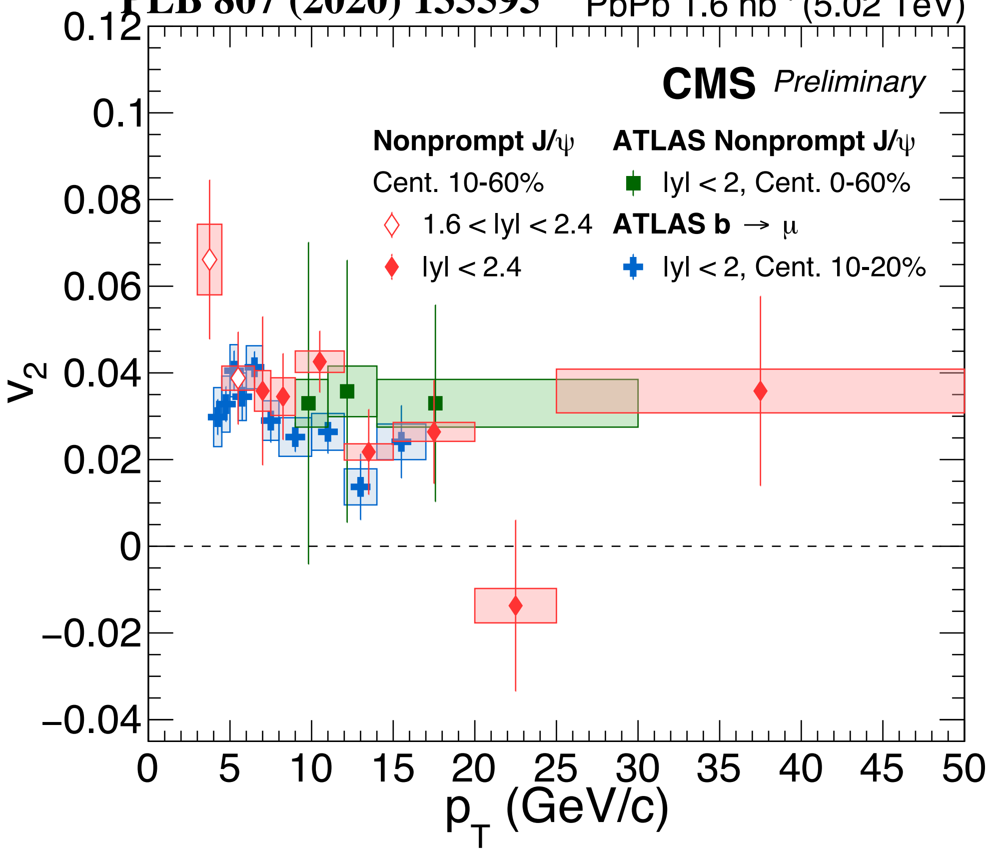
Comparison: v_2 with ATLAS, ALICE

CMS-PAS-HIN-21-008
EPJC 78 (2018) 784
JHEP 10 (2020) 141



- Flow of inclusive and prompt J/ψ
- Flat to high p_T

CMS-PAS-HIN-21-008
EPJC 78 (2018) 784
PLB 807 (2020) 135595



- Flow of b quark
- Compatible within uncertainty