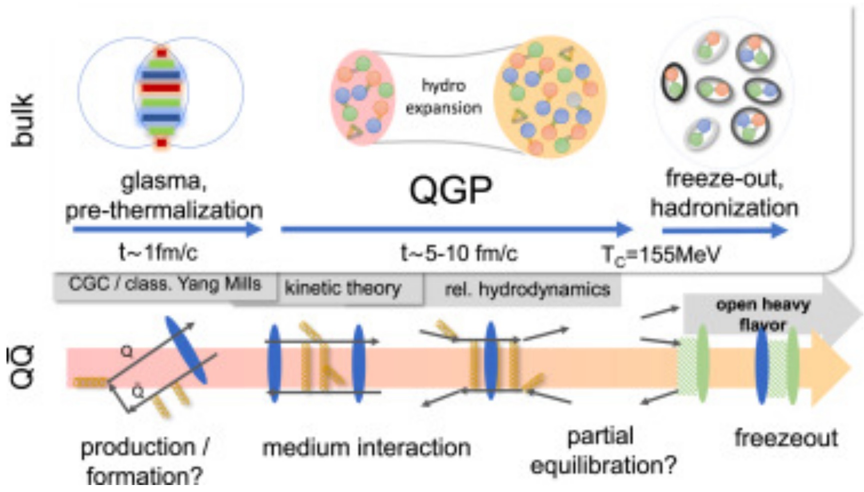
# Investigation of in-medium effects of charmonia using azimuthal anisotropy and jet fragmentation function in PbPb at 5.02 TeV with CMS

**Geonhee Oh (UIC)**
**On Behalf of the CMS Collaboration**

QUARK MATTER
KRAKÓW
2022

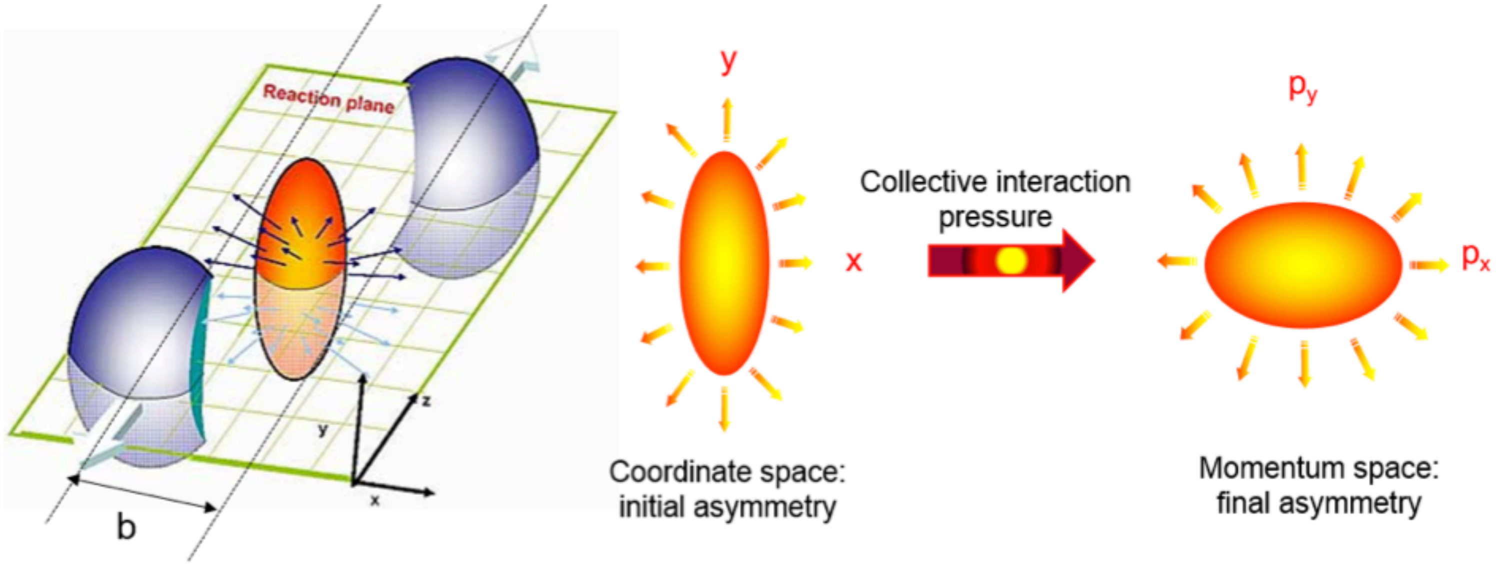
# Introduction

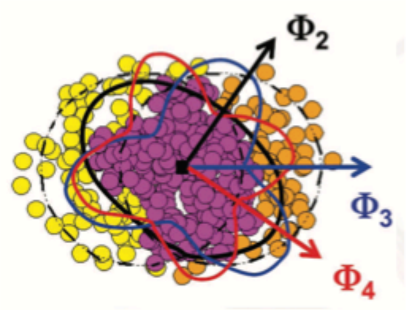
- A medium of deconfined quarks and gluons (QGP) in heavy ion collisions.
- Quarkonia: one of the classic probes of the QGP.
  - Experience whole medium evolution
- Effects on Quarkonium Production in heavy ion collisions:
  - Debye screening + Dissociation
  - Recombination
  - Cold Nuclear Matter (CNM) effects



# Introduction

- Immediately after a heavy ion collision, the overlap region defined by the nuclear geometry is almond shaped, with shortest axis along the impact parameter vector.
- Multiple interactions between particles in the **evolving system** change the initial coordinate space asymmetry into final momentum space asymmetry.



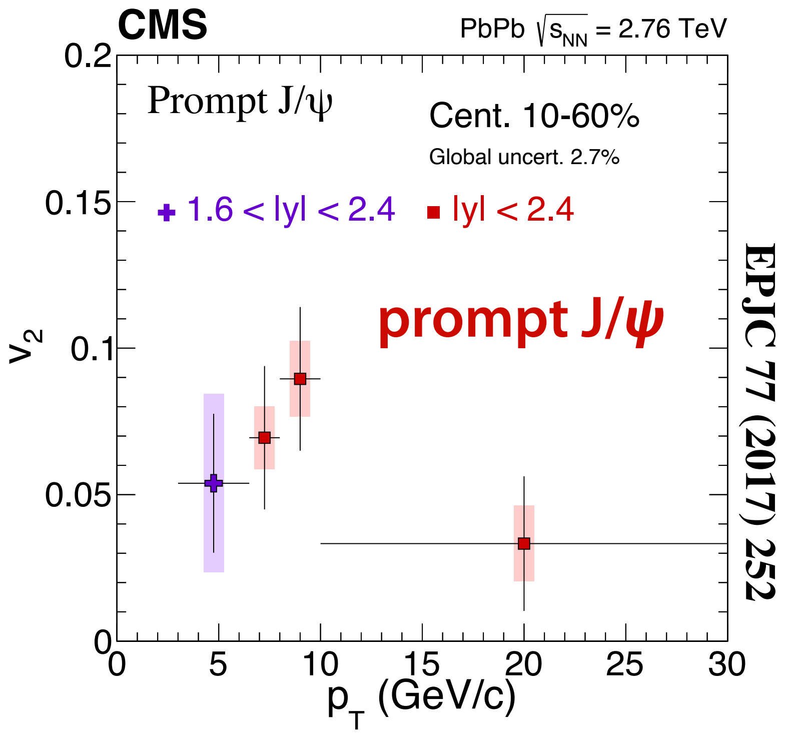



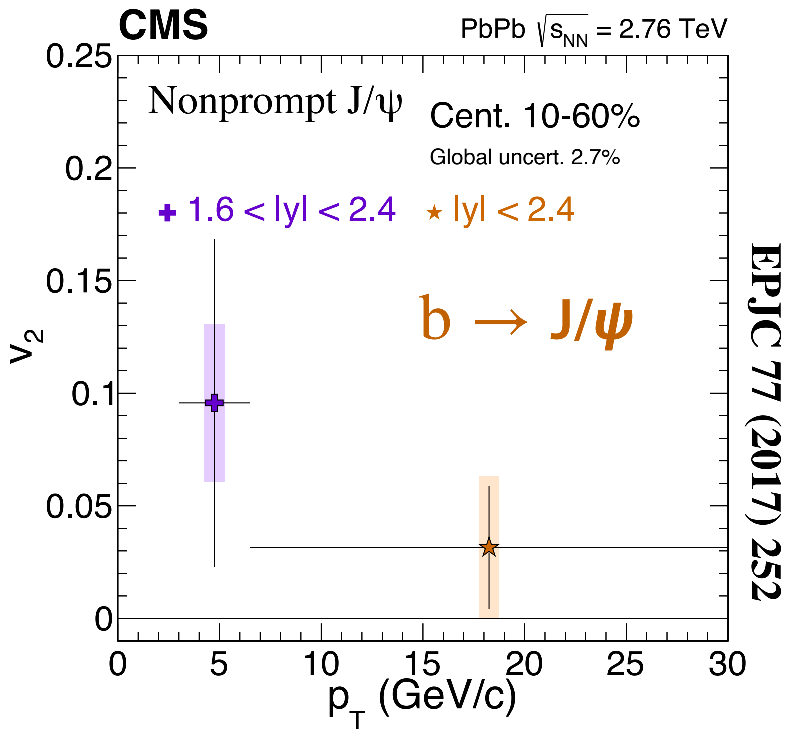

$$\frac{dN}{d\phi} \sim [1 + 2v_2\cos2(\phi - \psi_2) + 2v_3\cos3(\phi - \psi_3)\ldots]$$

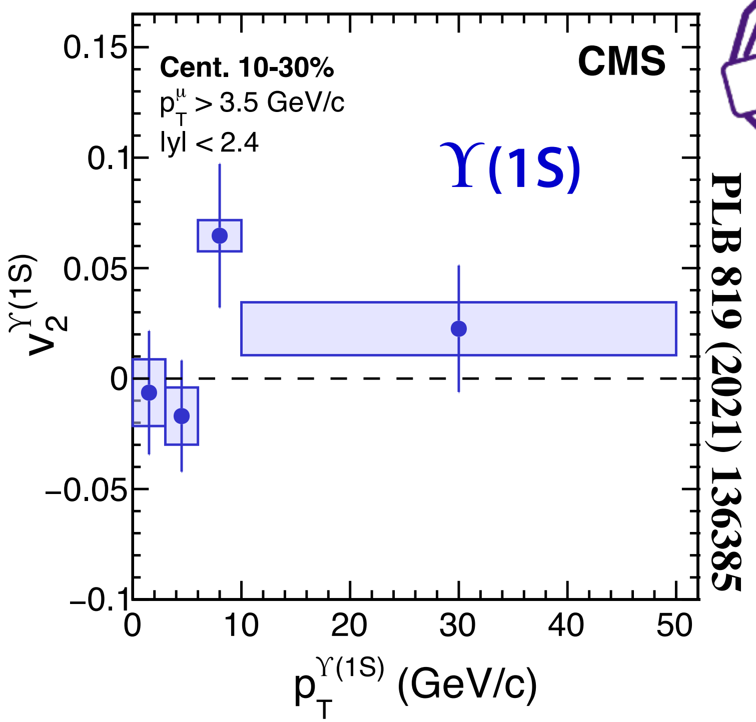
$v_2$: Elliptic flow

$v_3$: Triangular flow

# Motivation



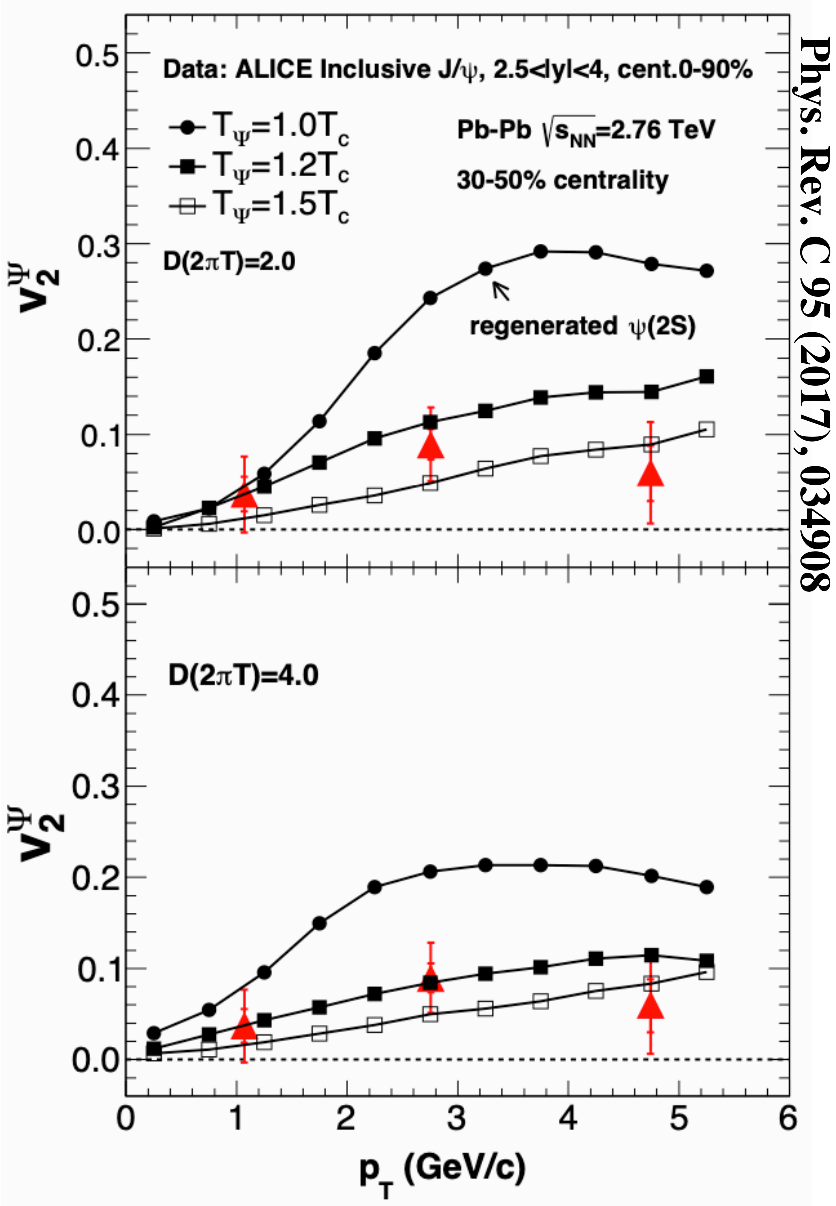




CMS FINAL QM22

- **J/ψ flow**
  - **Low $p_T$: collective behavior**
  - **High $p_T$: path length dependence of energy loss**
  - **J/ψ $v_2 > 0 \Leftrightarrow$ ϒ(1S) $v_2 \approx 0$**
  - **Contribution from b hadron decays (b → J/ψ)**

# Motivation

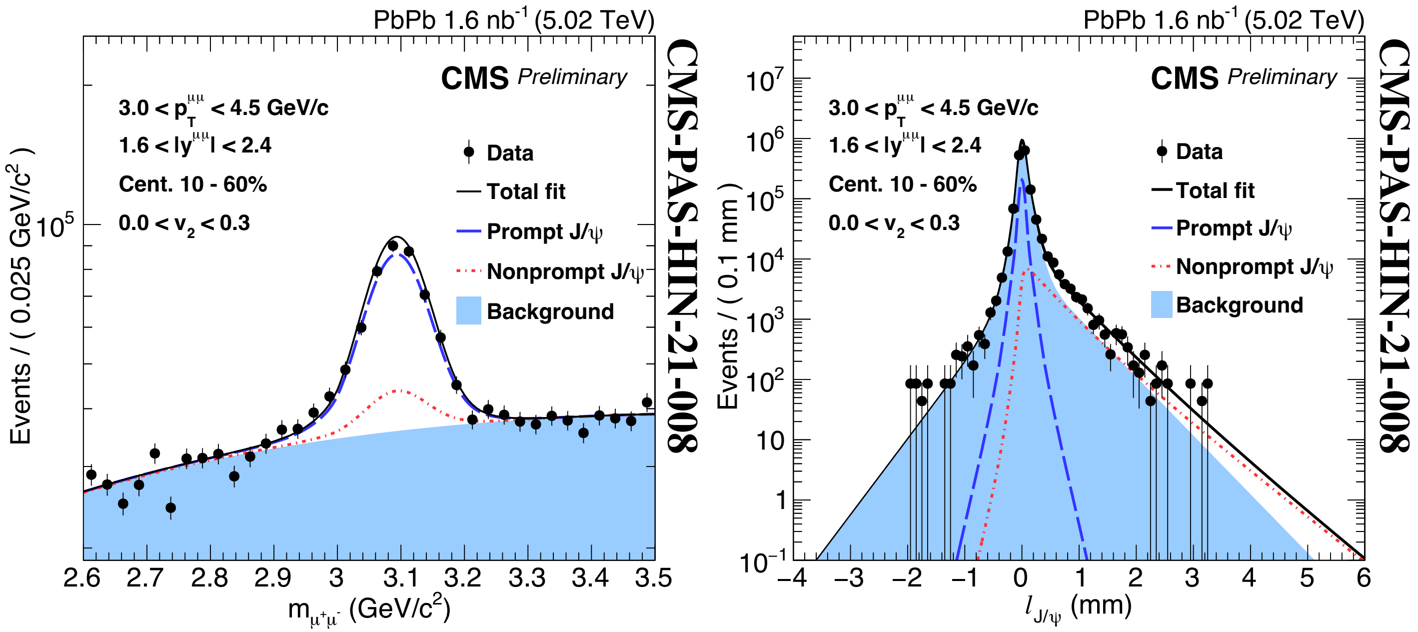
- $\psi(2S)$ flow
  - Not been measured yet
  - Different regeneration for 1S and 2S states?




Phys. Rev. C 95 (2017), 034908

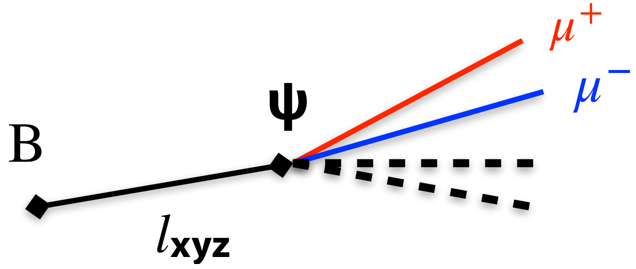
**Two techniques to separate components**

## 1. 2D fit to dimuon mass and decay length




Prompt J/$\psi$, b → J/$\psi$

## 2. Reject b-contamination by decay length cut
## : prompt enriched sampling




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

Prompt ψ(2S)

# $v_n$ extraction for J/$\psi$

HF$^-$ $Q_{nA}$ $-5 < \eta < -3$

TRK$^-$ $Q_{nC}$ $-0.75 < \eta$

TRK$^+$ $Q_n$ $\eta < 0.75$

HF$^+$ $Q_{nB}$ $3 < \eta < 5$

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

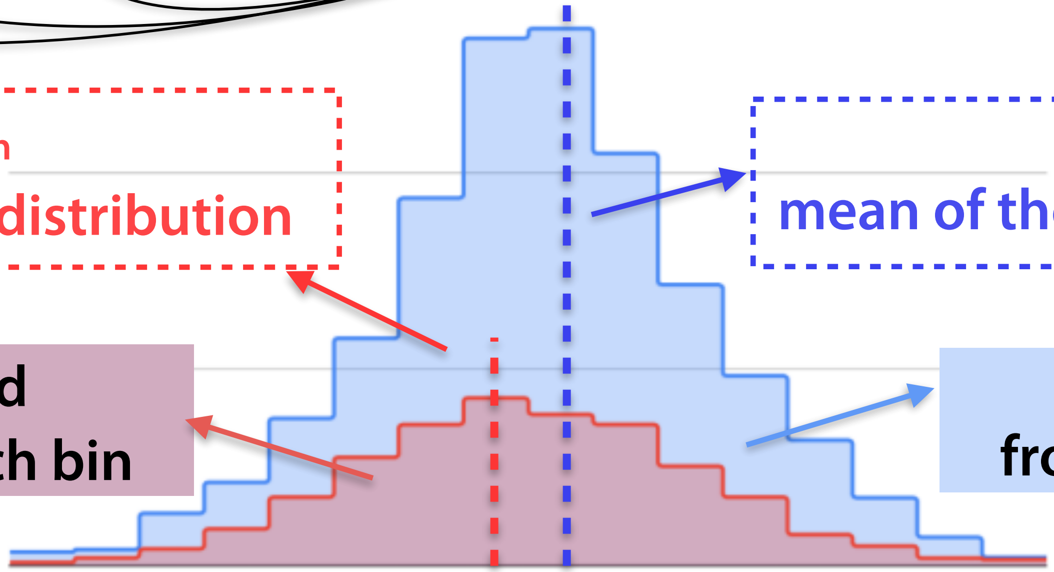
**Scalar product method using Q-vectors**

$Q_n$: J/$\psi$ candidate flow vector

$Q_{nA}, Q_{nB}, Q_{nC}$:
Event plane vectors from subevent

$b \rightarrow$ J/$\psi$ $v_n$
mean of the $b \rightarrow$ J/$\psi$ distribution

Prompt J/$\psi$ $v_n$
mean of the prompt J/$\psi$ distribution

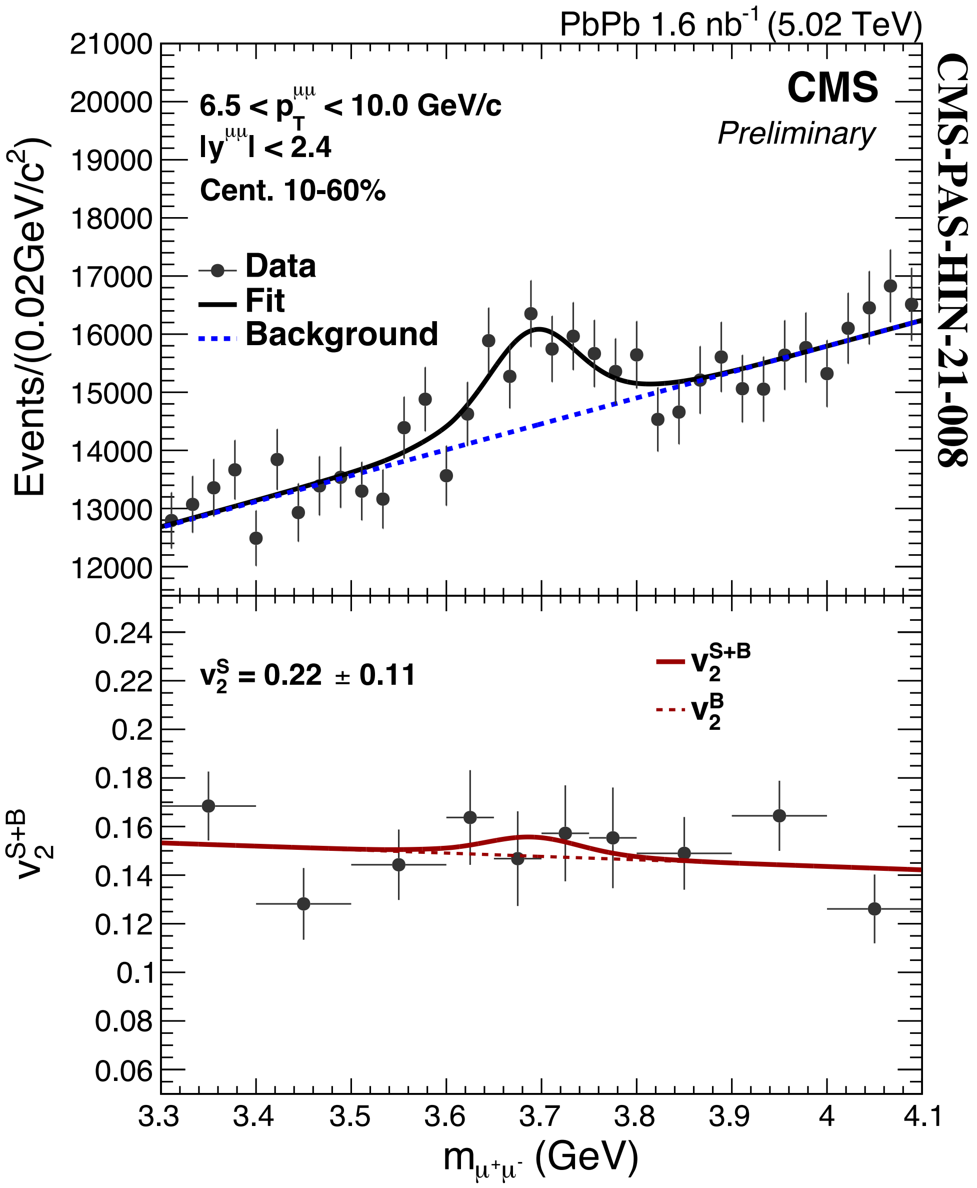


$b \rightarrow$ J/$\psi$ yield
from 2D fit in each bin

Prompt J/$\psi$ yield
from 2D fit in each bin

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

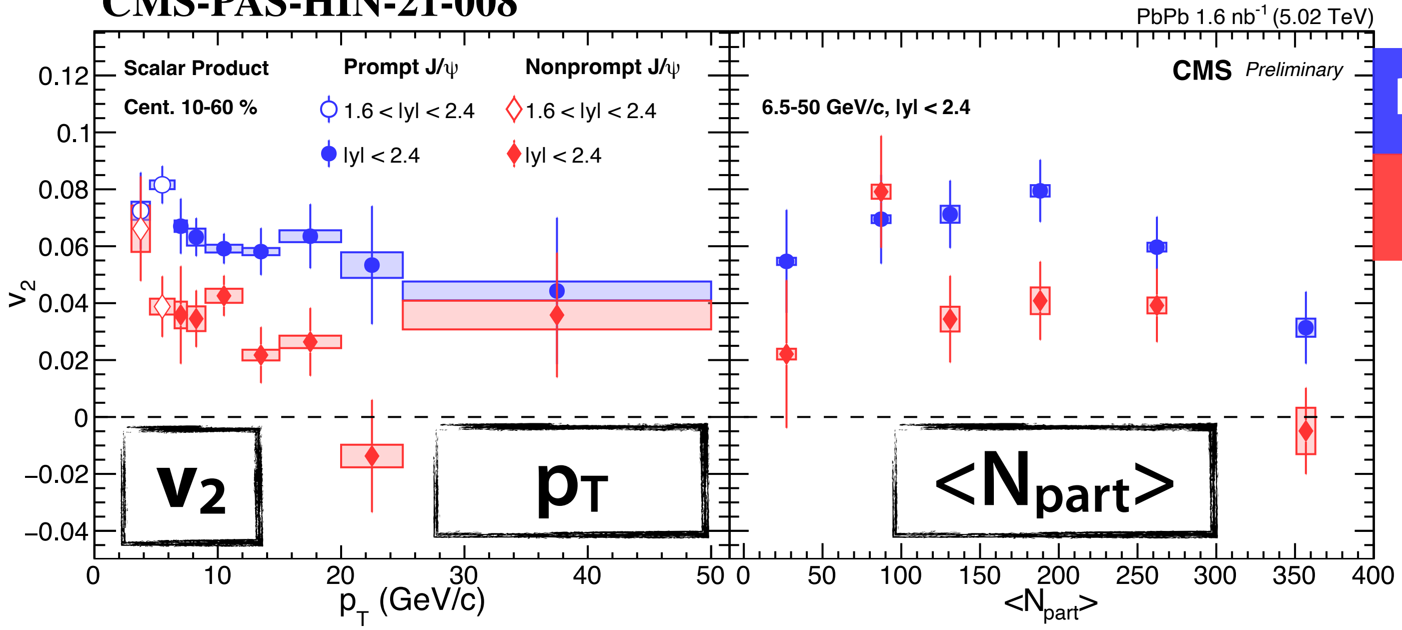
# $v_n$ extraction for prompt ψ(2S)

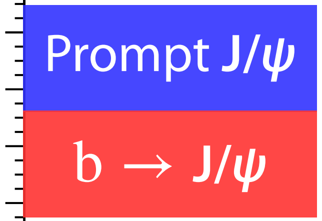



- Prompt enriched sample by decay length cut
- Mass and $v_n$ simultaneous fit
- $v_n^{Sig+Bkg}(m_{inv}) = \alpha(m_{inv})v_n^{Sig} + (1 - \alpha(m_{inv}))v_n^{Bkg}(m_{inv})$
- $\alpha(m_{inv}) = \frac{Sig(m_{inv})}{Sig(m_{inv}) + Bkg(m_{inv})}$

# Result J/ψ $v_n$

CMS-PAS-HIN-21-008

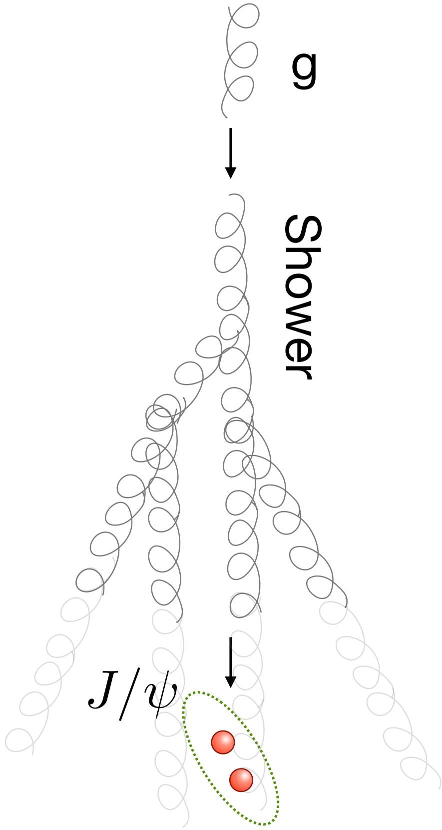


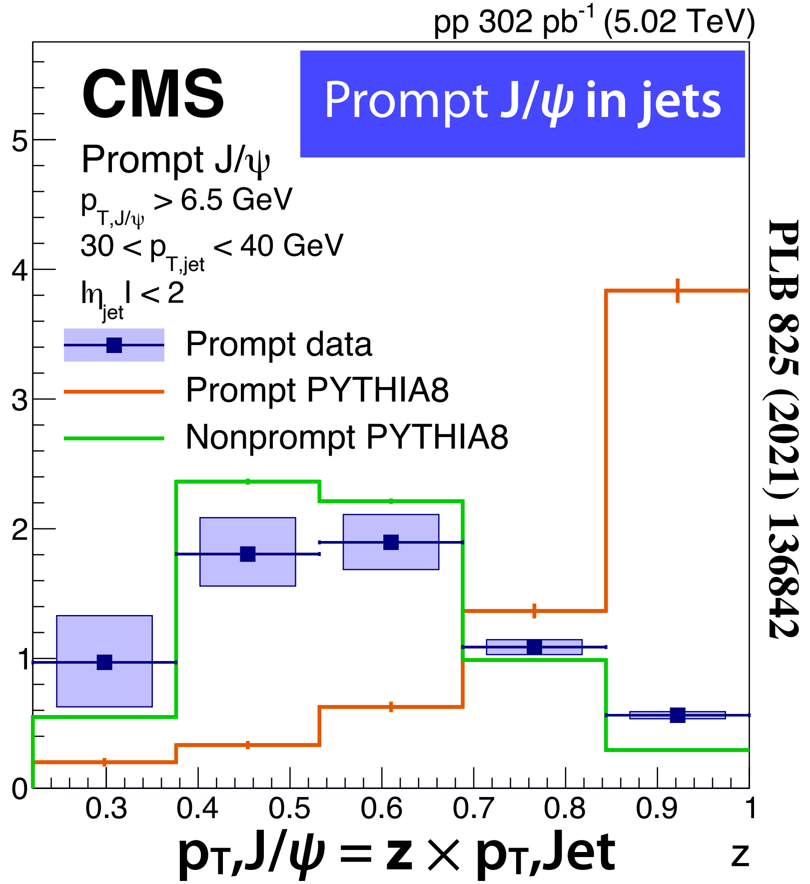



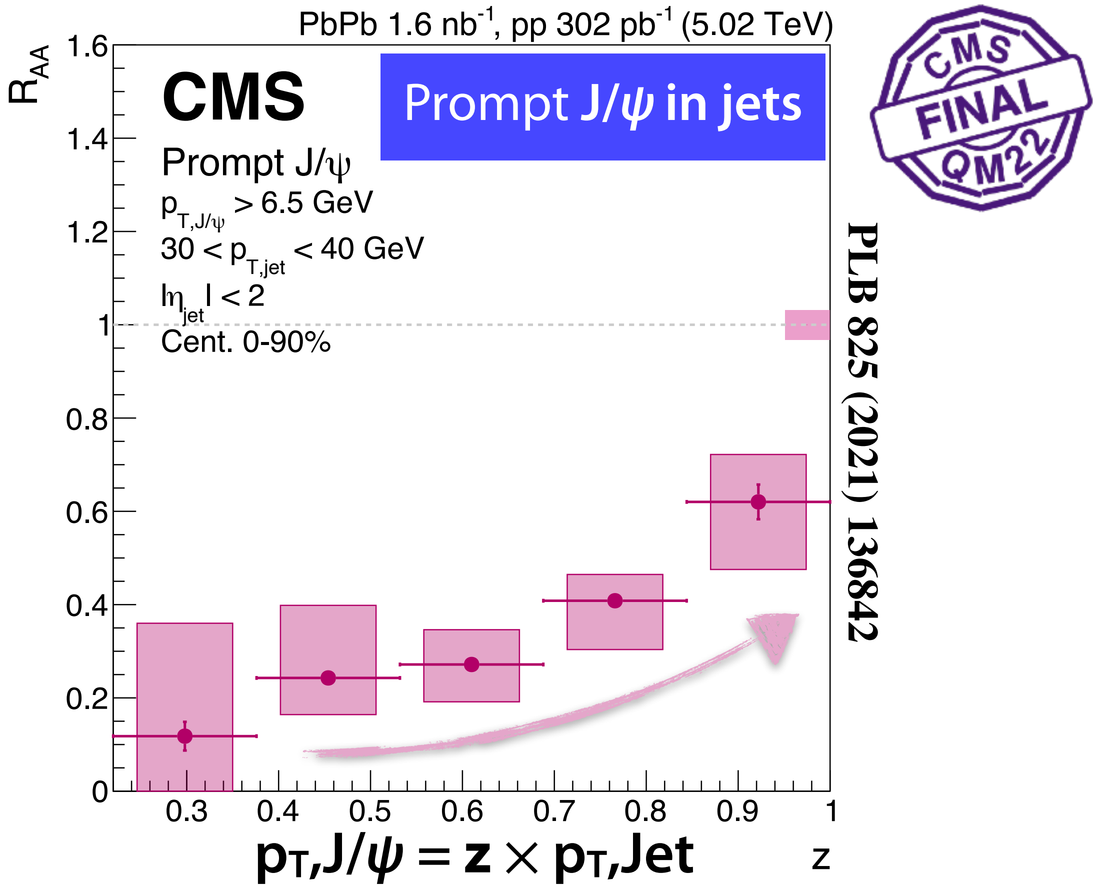


- Large $v_2$ up to 50 GeV/c
- b → J/ψ < prompt J/ψ $v_2$
  - different collectivity for c and b quark
- Smaller $v_2$ in most central collision event

# $R_{AA}$ of J/ψ and J/ψ in jets

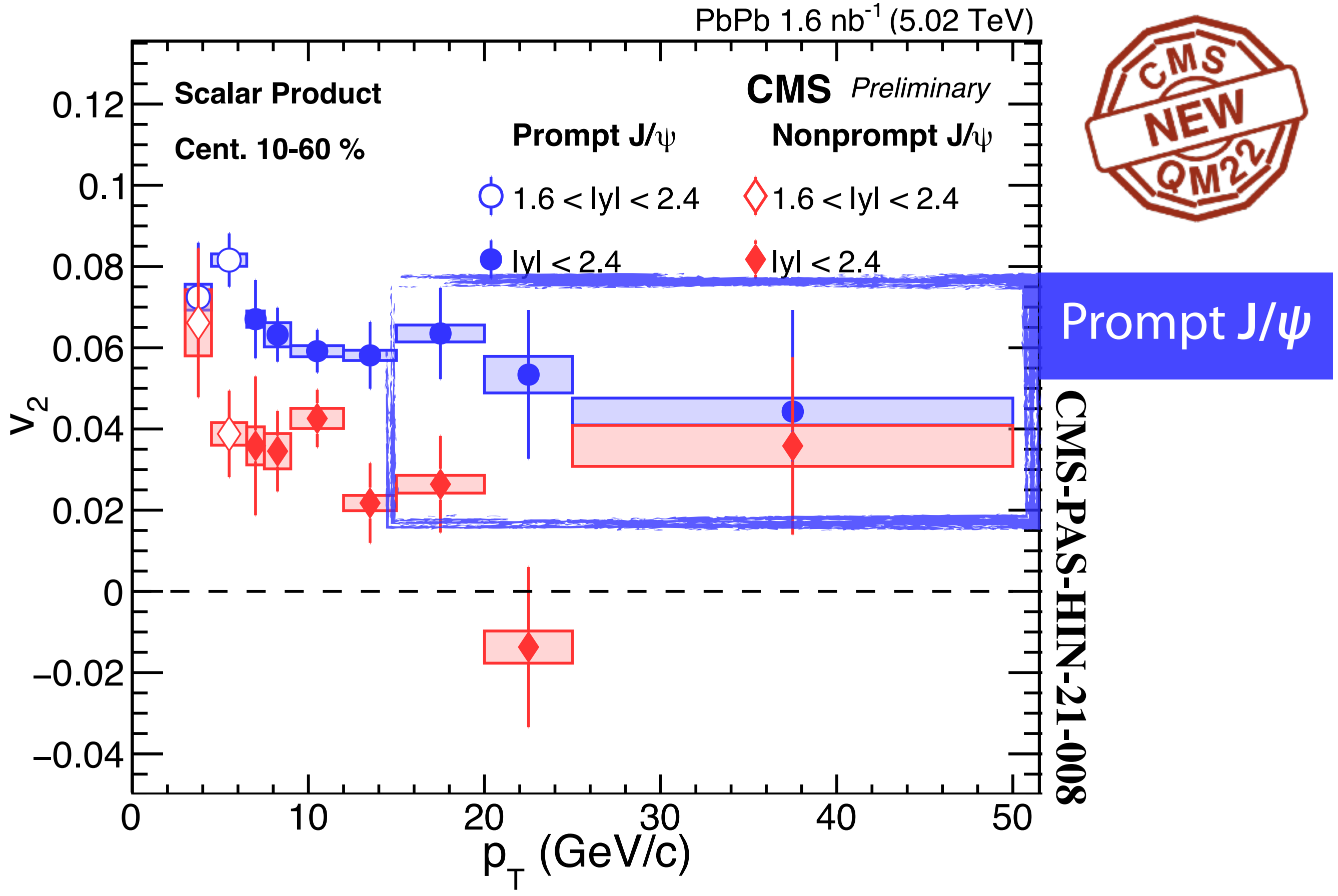


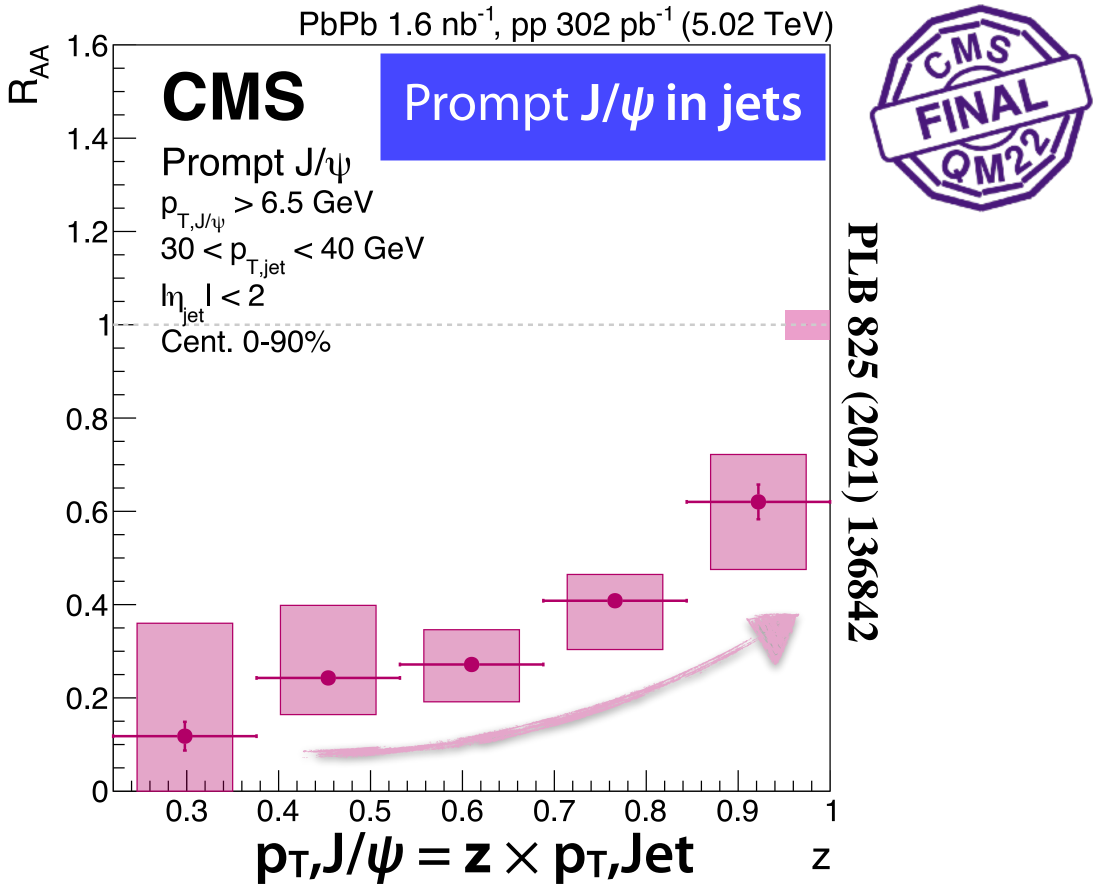




- Prompt J/ψ produced in much larger jet-activity than PYTHIA
- Less suppression for isolated J/ψ compared to J/ψ with larger jet activity
- Jet quenching : important role for J/ψ suppression at high-$p_T$

# $R_{AA}$ of J/ψ in jets

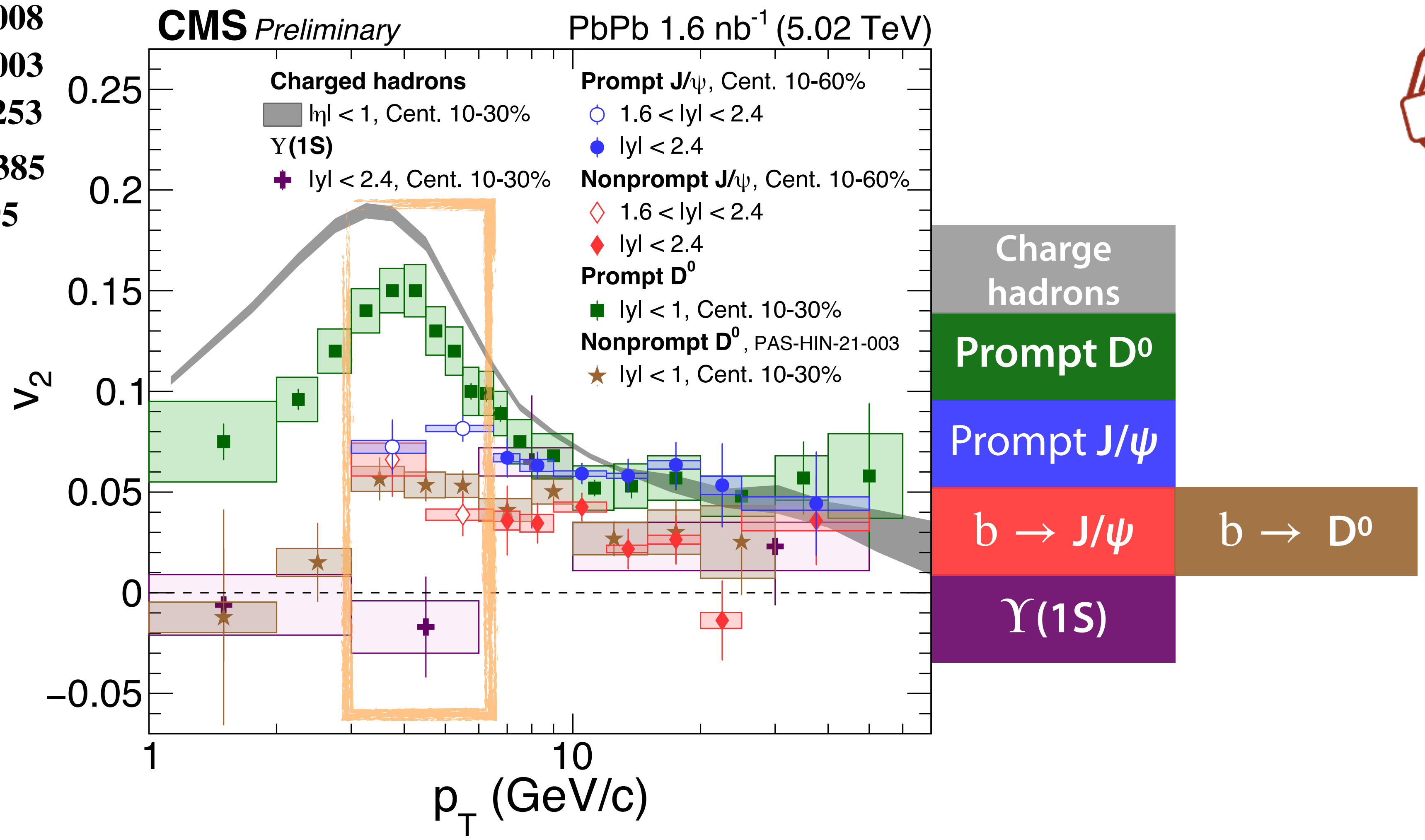



- Large $v_2$ up to 50 GeV/c → Connection to jet quenching?

# Comparison for $v_2$

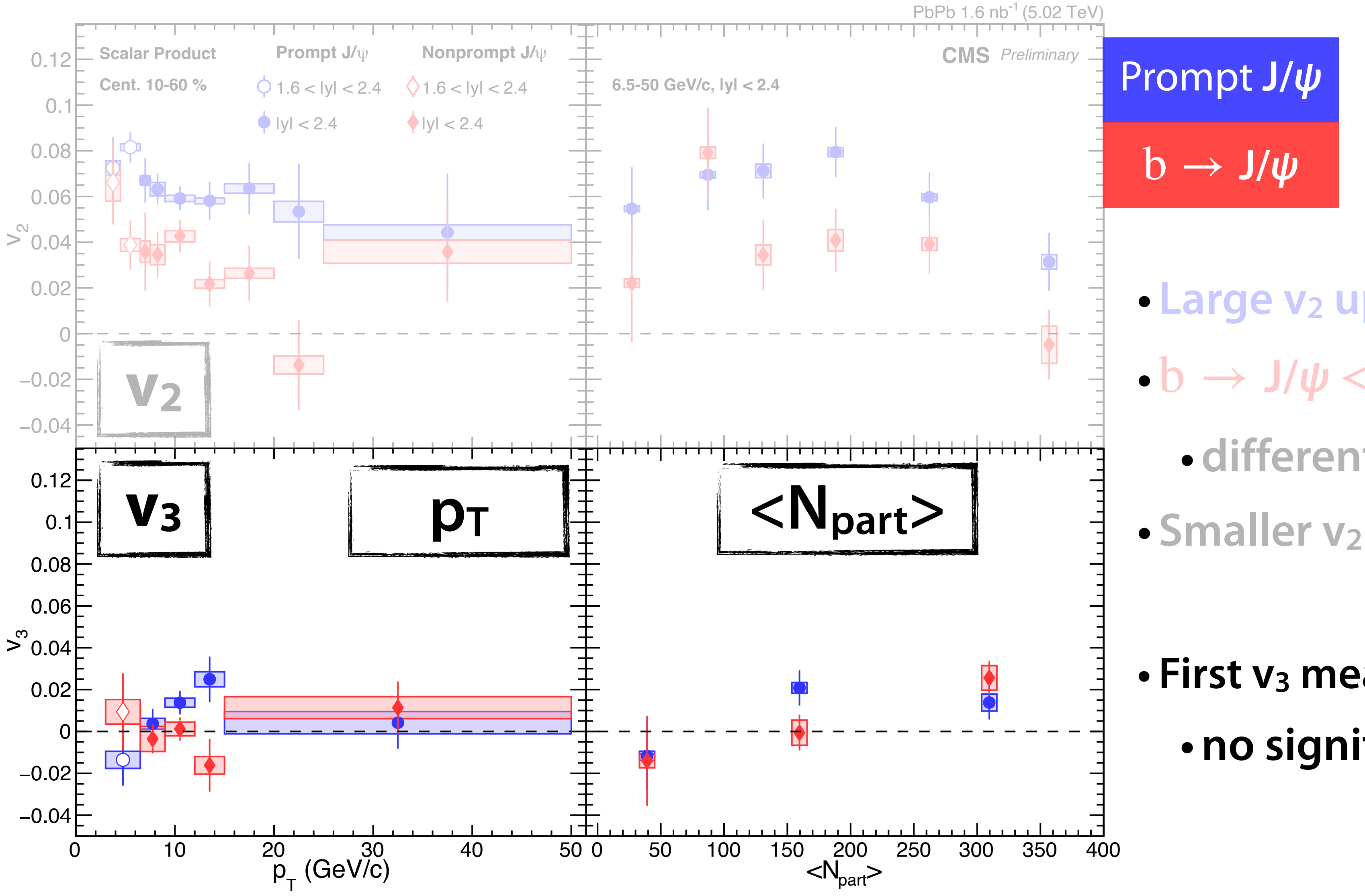
CMS-PAS-HIN-21-008
CMS-PAS-HIN-21-003
PLB 816 (2021) 136253
PLB 819 (2021) 136385
PLB 776 (2017) 195




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

# Result J/ψ $v_n$

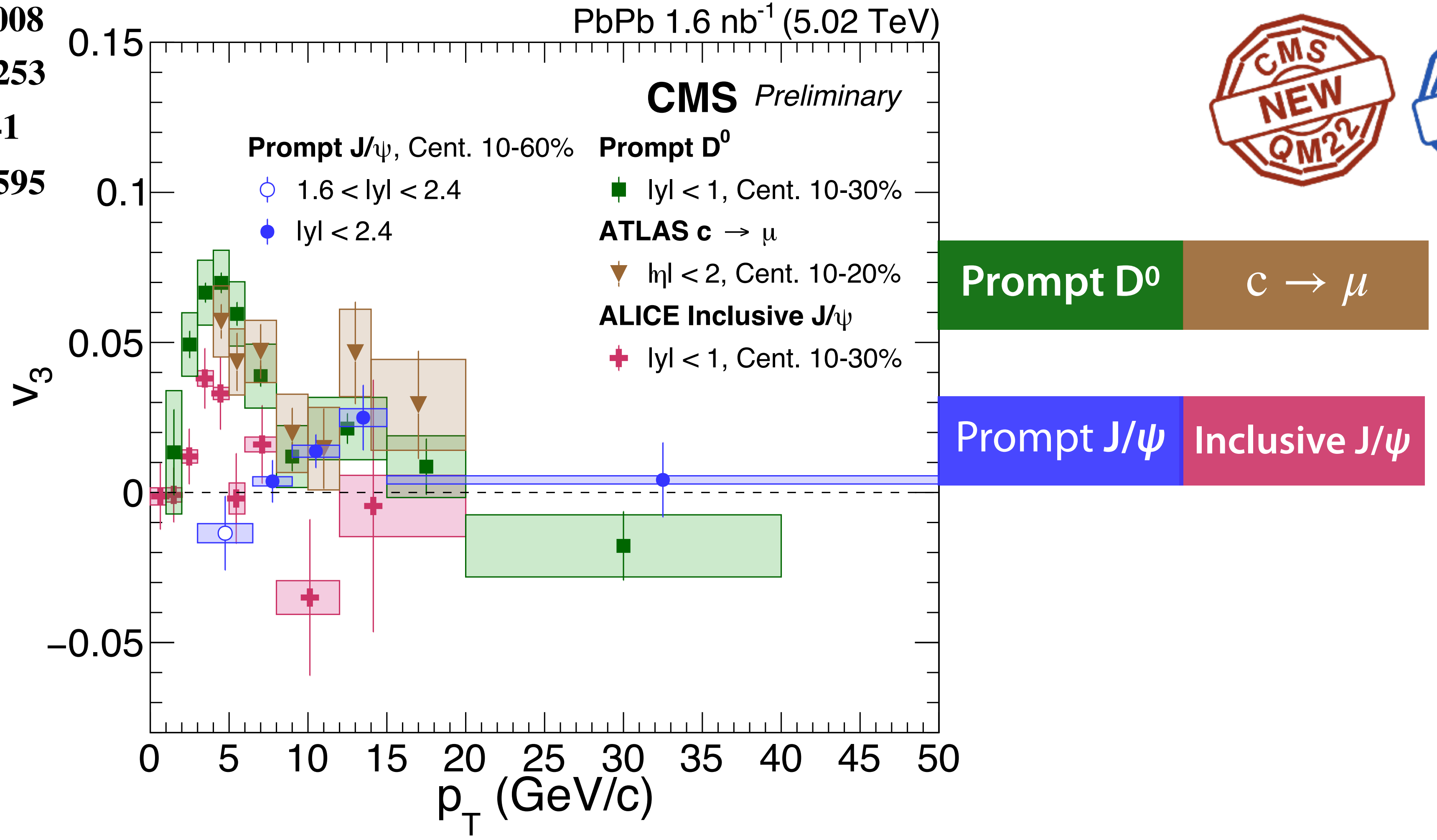
CMS-PAS-HIN-21-008




- Large $v_2$ up to 50 GeV/c
- b → J/ψ < prompt J/ψ $v_2$
  - different collectivity for c and b quark
- Smaller $v_2$ in most central collision event
- First $v_3$ measurement for separate PR and NP
  - no significant non-zero $v_3$

# Comparison for $v_3$

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



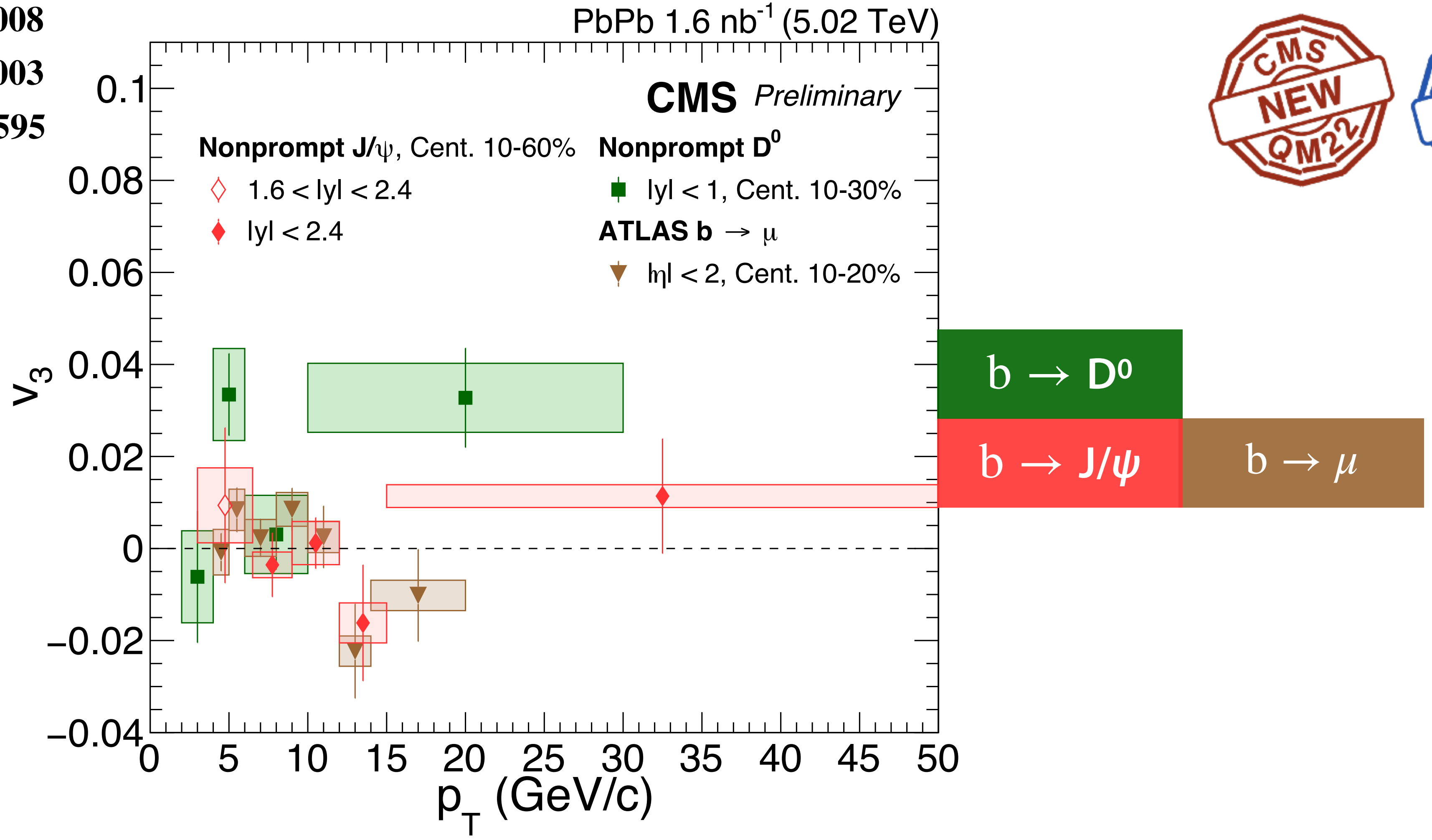

- Low $p_T$: Prompt $D^0$ $v_3$ > Prompt $J/\psi$ $v_3$
- Open charm is more sensitive to initial geometry than hidden charm

# Comparison for $v_3$

CMS-PAS-HIN-21-008

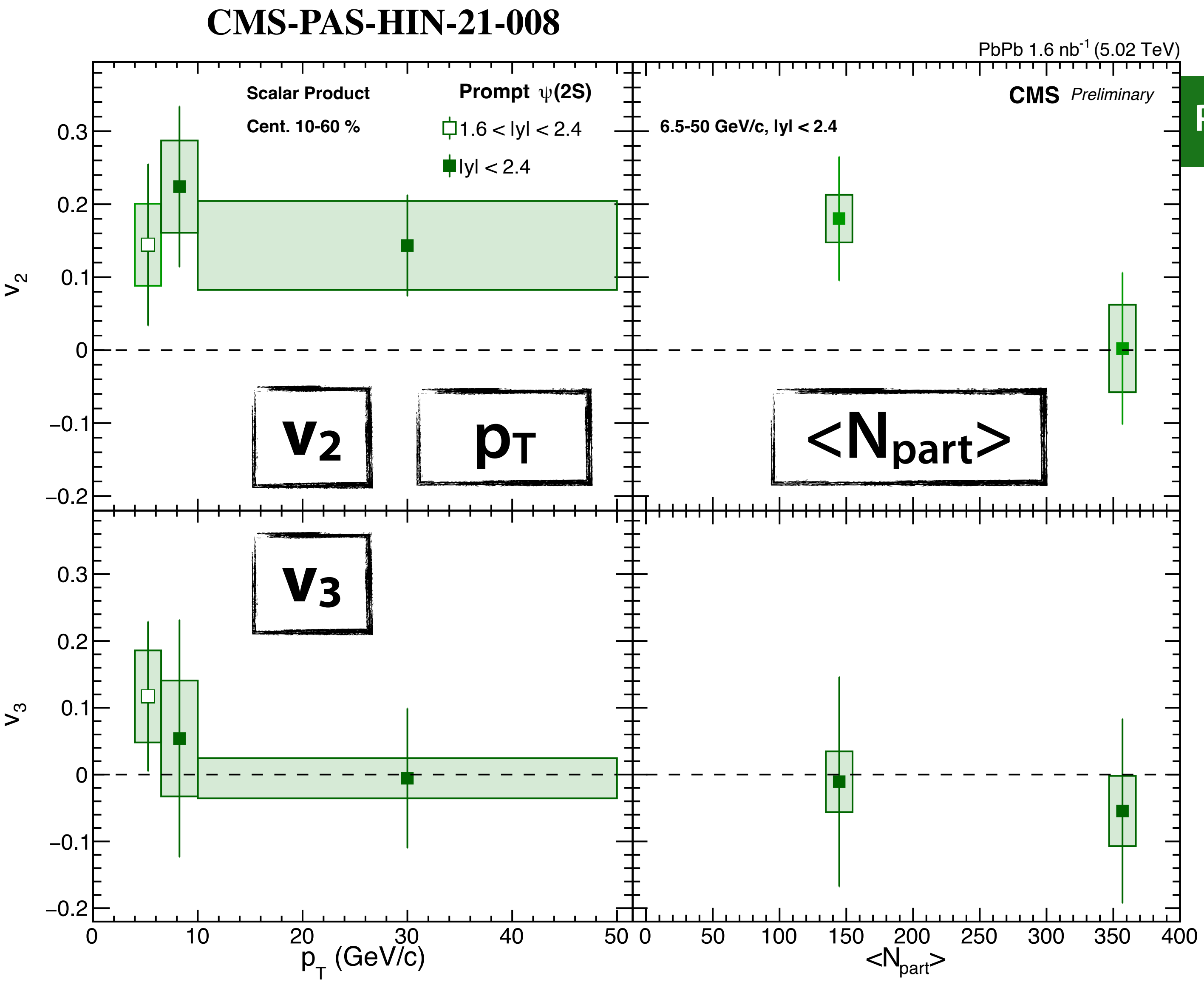
CMS-PAS-HIN-21-003

PLB 807 (2020) 135595




- $v_3$ of b hadrons are consistent

# Result ψ(2S) $v_n$

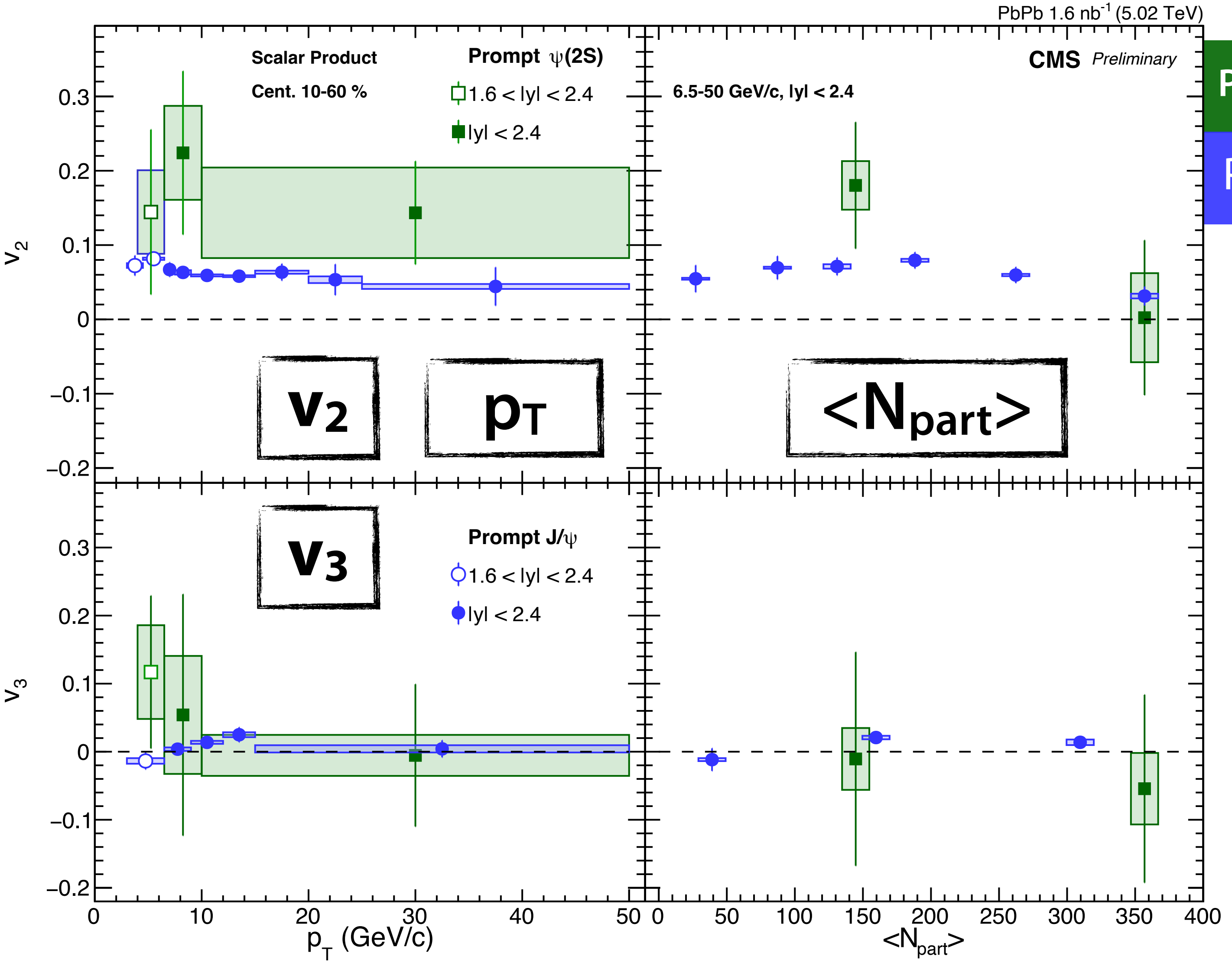



Prompt ψ(2S)


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

# Result ψ(2S) $v_n$ vs J/ψ $v_n$

CMS-PAS-HIN-21-008

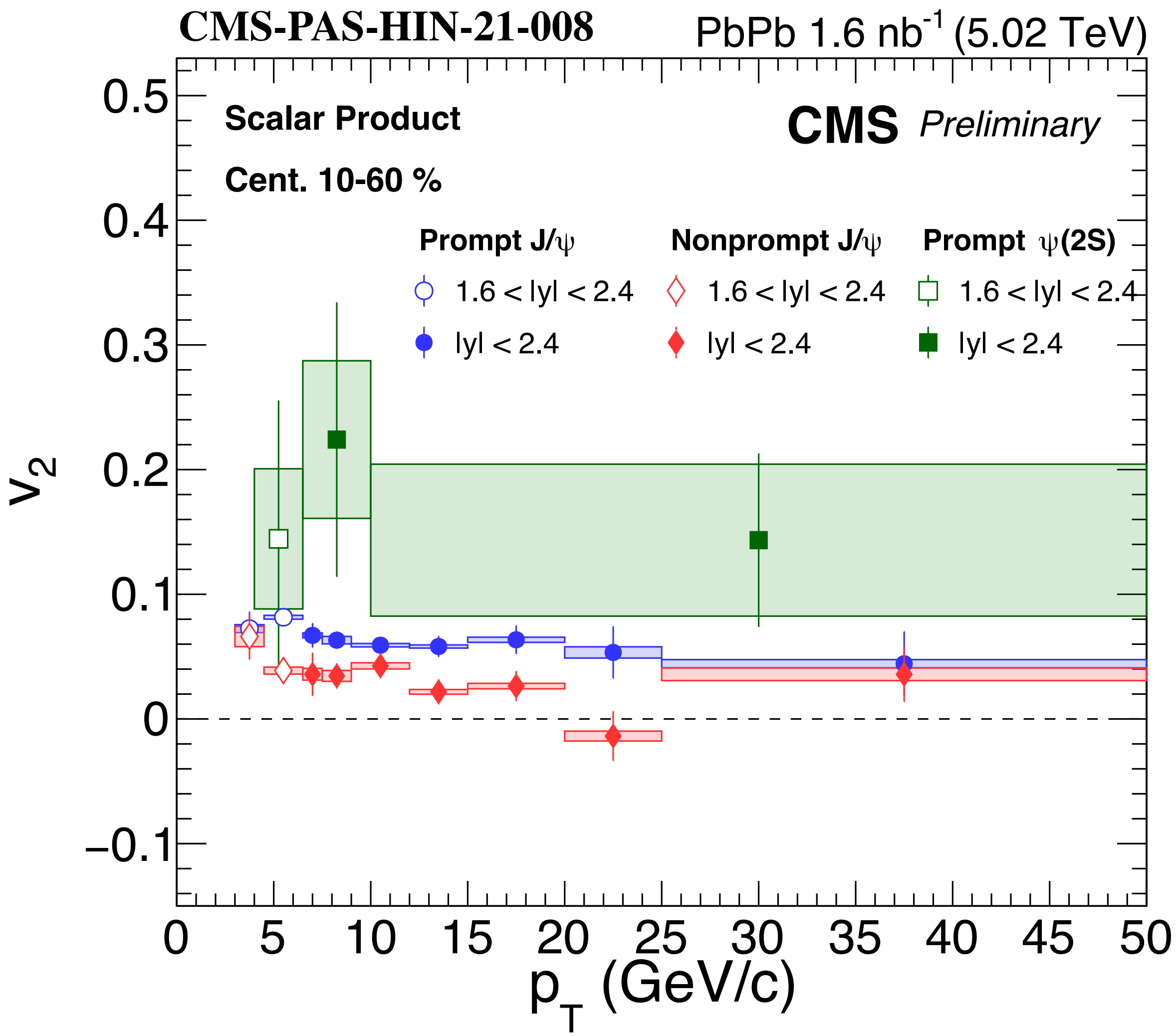



Prompt ψ(2S)

Prompt J/ψ

- **First measurement in heavy ion!!**
- $v_2 > 0$ in $p_T$ 4-50 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?

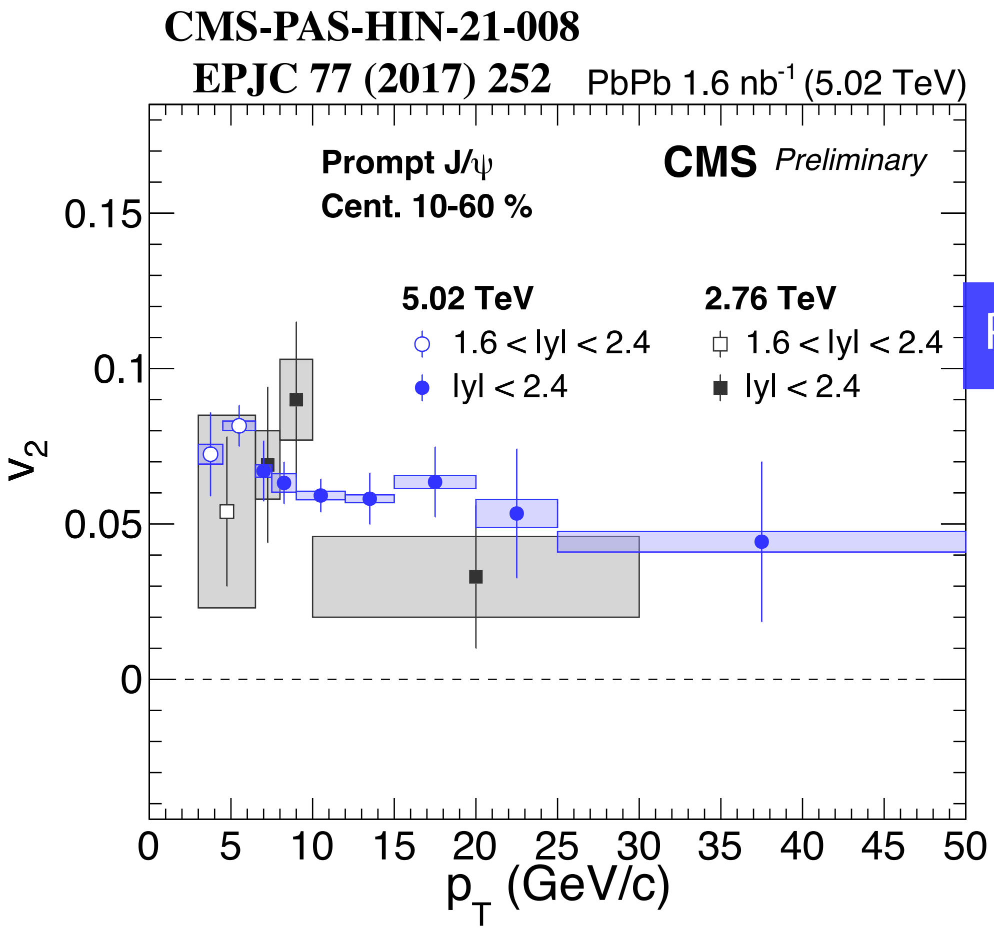
# Summary



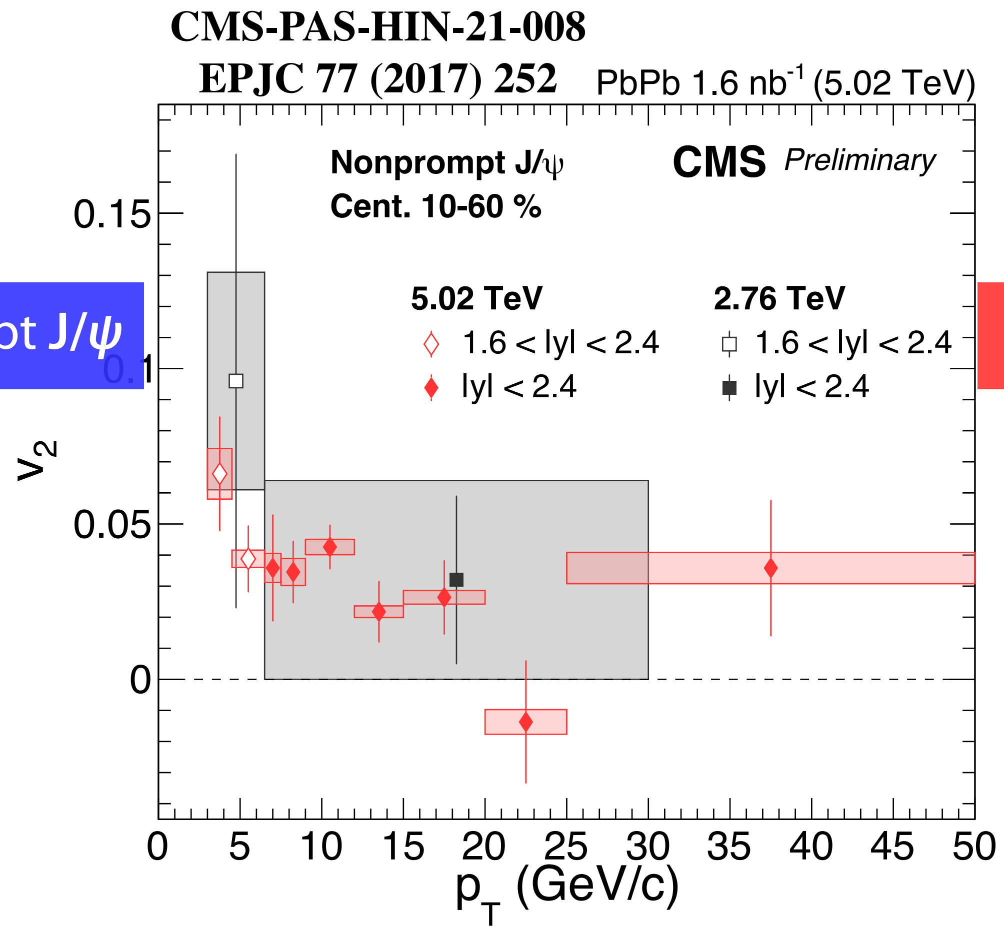

- Study of azimuthal anisotropy for charmonia
- Prompt $J/\psi$ $v_2$ > $b \rightarrow J/\psi$ $v_2$
  - → different in-medium effect for c and b quarks flow
- Large prompt $J/\psi$ $v_2$ at high-$p_T$
  - → hint for the role of jet quenching
- $\psi(2S)$ $v_2$ first measured!
- $\psi(2S)$ $v_2 \gtrsim J/\psi$ $v_2$
  - → hint for different recombination contributions

# Thank you for your attention

# CMS 2.76 vs 5.02 TeV




Prompt J/ψ

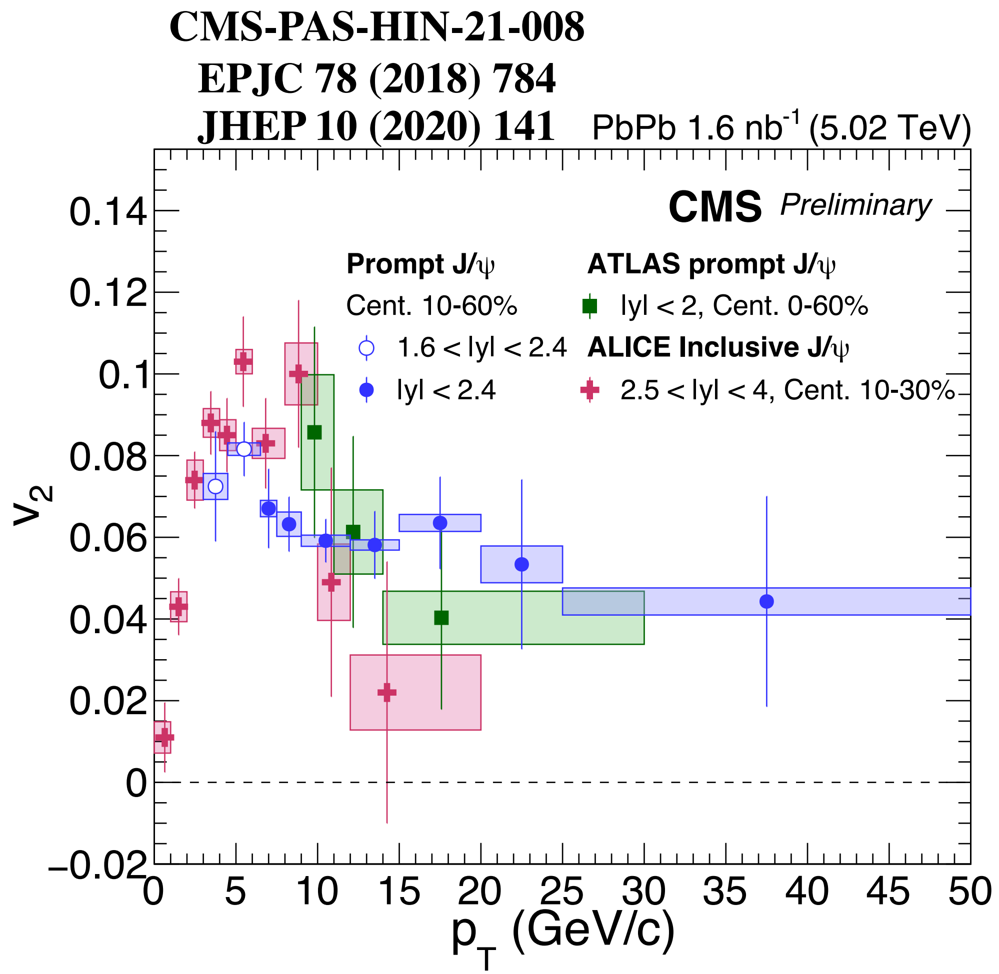


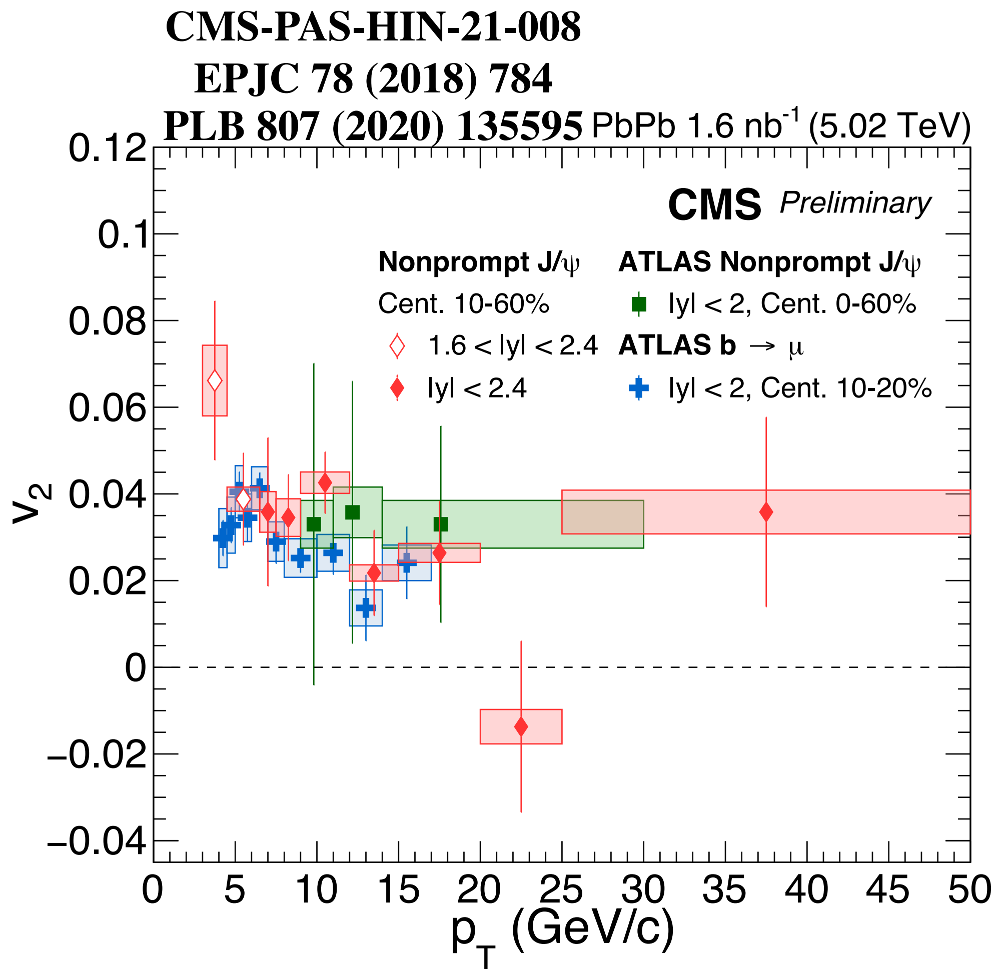

CMS NEW QM22

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 NEW QM22

- Flow of inclusive and prompt $J/\psi$
- Flat to high $p_T$

- Flow of b quark
- Compatible within uncertainty