Studying the interplay of medium effects on heavy quarks and quarkonia using high-precision charmonium measurements in PbPb collisions with CMS

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Abstract

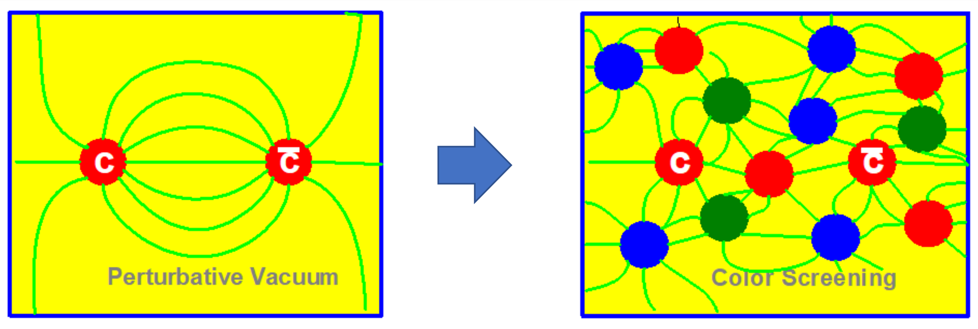
Charmonia, such as the J/ψ and $\psi(2S)$ mesons, are important probes of the quark-gluon plasma (QGP). The measurement of their nuclear modification factor, elliptic and triangular flow can provide strong constraints for the mechanism of in-medium energy loss. In this talk, results on the relative J/ψ and $\psi(2S)$ modification, based on the pp and PbPb data collected at $\sqrt{s_{NN}}$ = 5.02 TeV by CMS, will be reported. Also we present the second-order and third-order Fourier coefficients, v_2 and v_3 for prompt and nonprompt J/ψ and prompt $\psi(2S)$ mesons. In addition, the nuclear modification factor of charmonia in PbPb collisions will be reported.

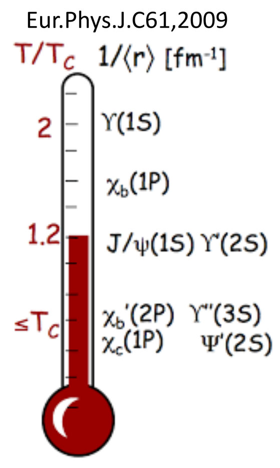
Introduction

Quarkonia in heavy ion collisions

- One of the most promising way to understand the quark-gluon plasma (QGP)[1]
- Charm quarks are produced during the early stage of collisions from hard parton scattering
- Color screening of the heavy quark potential can cause the sequential suppression of quarkonium states[2]
  - Quarkonia can be used as thermometer of the medium

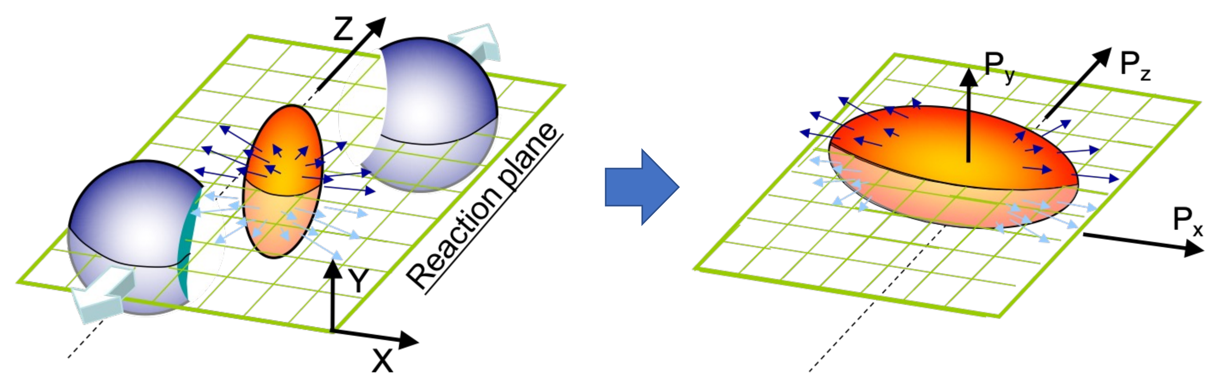
state	J/ψ (1S)	χ_c(1P)	Ψ' (2S)	Υ (1S)	χ_b(1P)	Υ (2S)	χ_b'(1P)	Υ (3S)
m(GeV/c^2)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
r_0(fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78





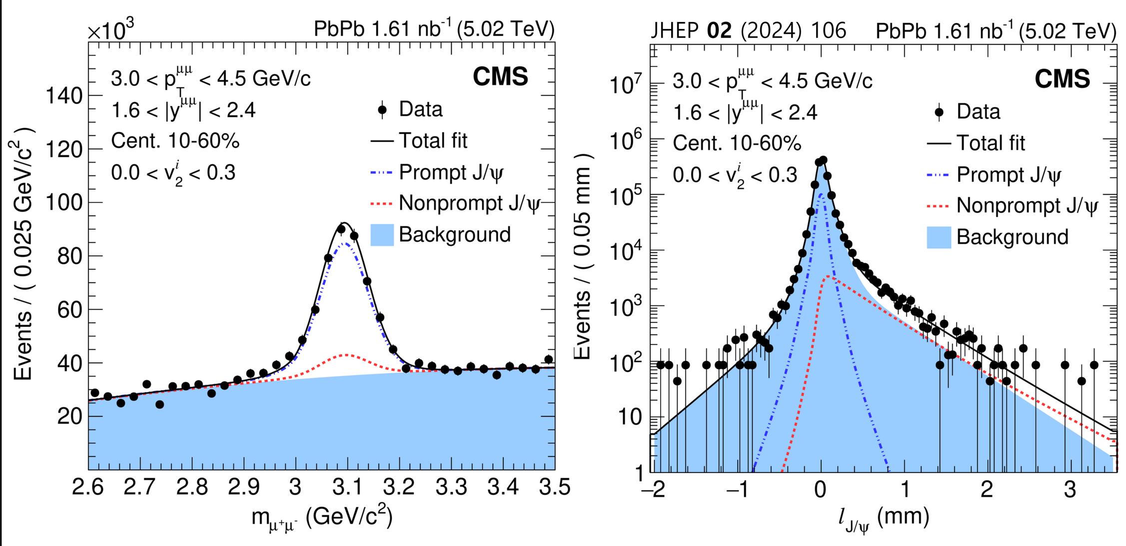
- Azimuthal anisotropy (Flow)
  - Collectivity (low-p_T), path-length dependent Energy loss (High-p_T)
  - Sensitive to initial collision geometry[3]

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

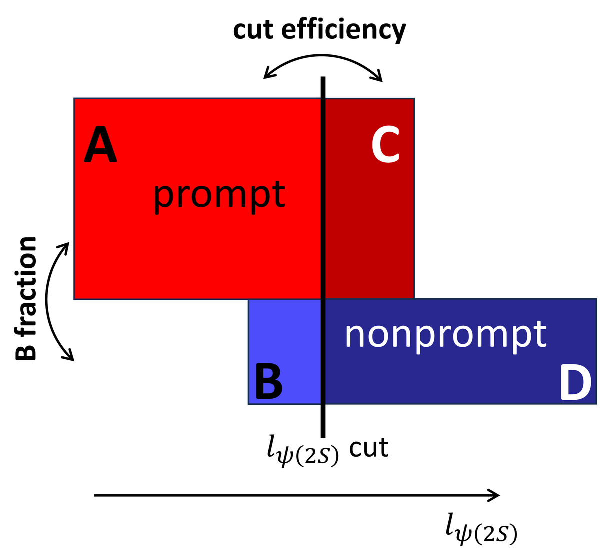


Signal extraction

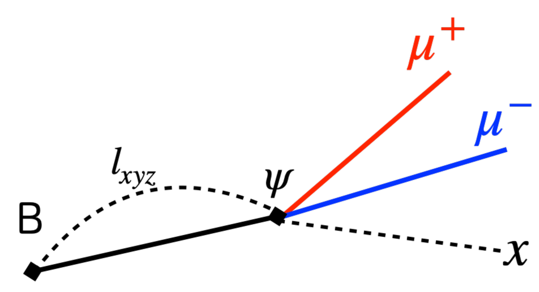
J/ψ : 2D fit on mass & decay length



$\psi(2S)$: cut on decay length



- Two method for separation prompt and nonprompt:
- J/ψ
  - 2-dimensional fit to dimuon mass $m_{\mu\mu}$ & lifetime $l_{J/\psi}$
  - Signal : double Crystal Ball
  - Background : Chebyshev function
- $\psi(2S)$
  - Rejecting nonprompt component using lifetime due to statistical issue



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

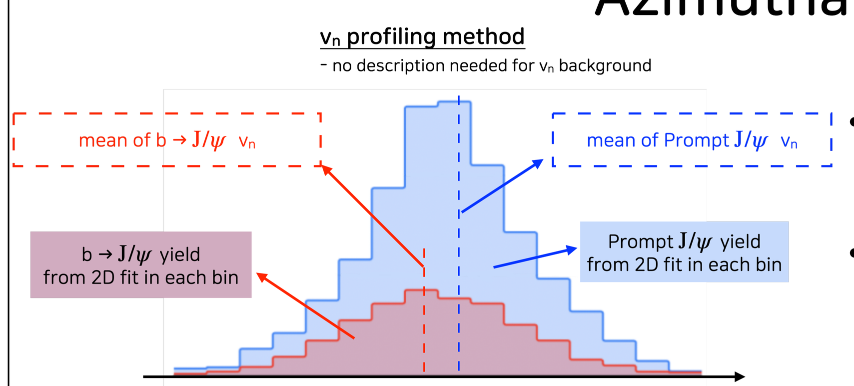
Analysis Method

Nuclear Modification factor

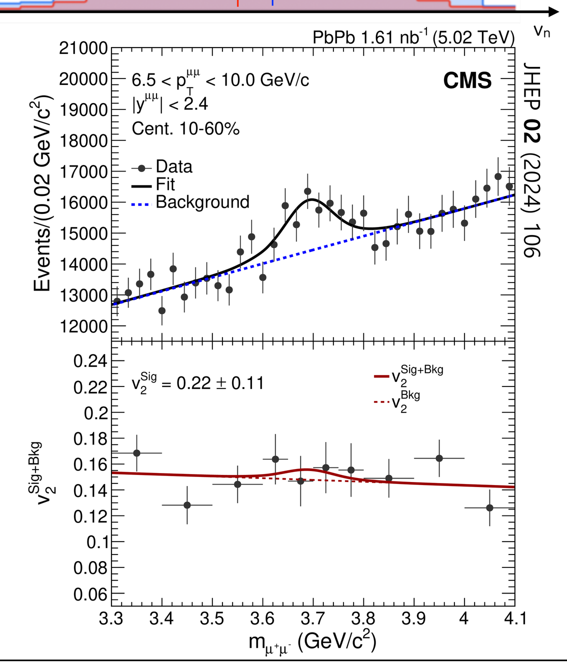
- $R_{AA} = \frac{N_\psi^{PbPb}}{N_\psi^{pp}} \cdot \frac{acc^{pp}\times\epsilon^{pp}}{acc^{PbPb}\times\epsilon^{PbPb}} \cdot \frac{\mathcal{L}^{pp}}{N_{MB}\times\langle T_{AA}\rangle\times(\text{centrality bin fraction})}$

$\psi(2S)$ R_{AA} obtained from the combination of the double ratio results of *Phys. Rev. Lett.* **118** (2017) 162301

Azimuthal anisotropy



- $v_n\{SP\} \equiv \frac{\langle Q_n^{J/\psi,\psi(2S)} Q_{nA}^*\rangle}{\sqrt{\frac{\langle Q_{nA}Q_{nB}^*\rangle\langle Q_{nA}Q_{nC}^*\rangle}{\langle Q_{nB}Q_{nC}^*\rangle}}}$
- The J/ψ candidates are classified into fine v_n bins



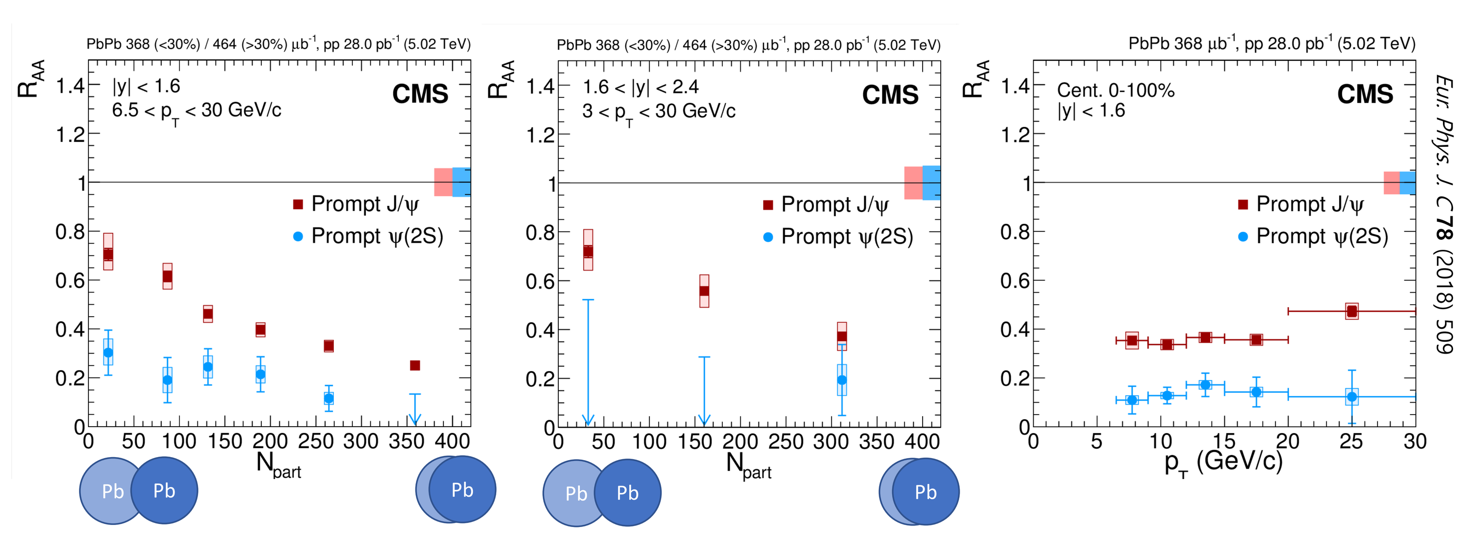
- Signal v_2 of $\psi(2S)$ extracted from simultaneous fit of the dimuon mass and v_2

$$v_n^{Sig+Bkg}(m_{inv}) = \alpha(m_{inv})v_n^{\psi} + (1-\alpha(m_{inv}))v_n^{Bkg}(m_{inv})$$

where $\alpha(m_{inv}) = \frac{Sig(m_{inv})}{Sig(m_{inv})+Bkg(m_{inv})}$

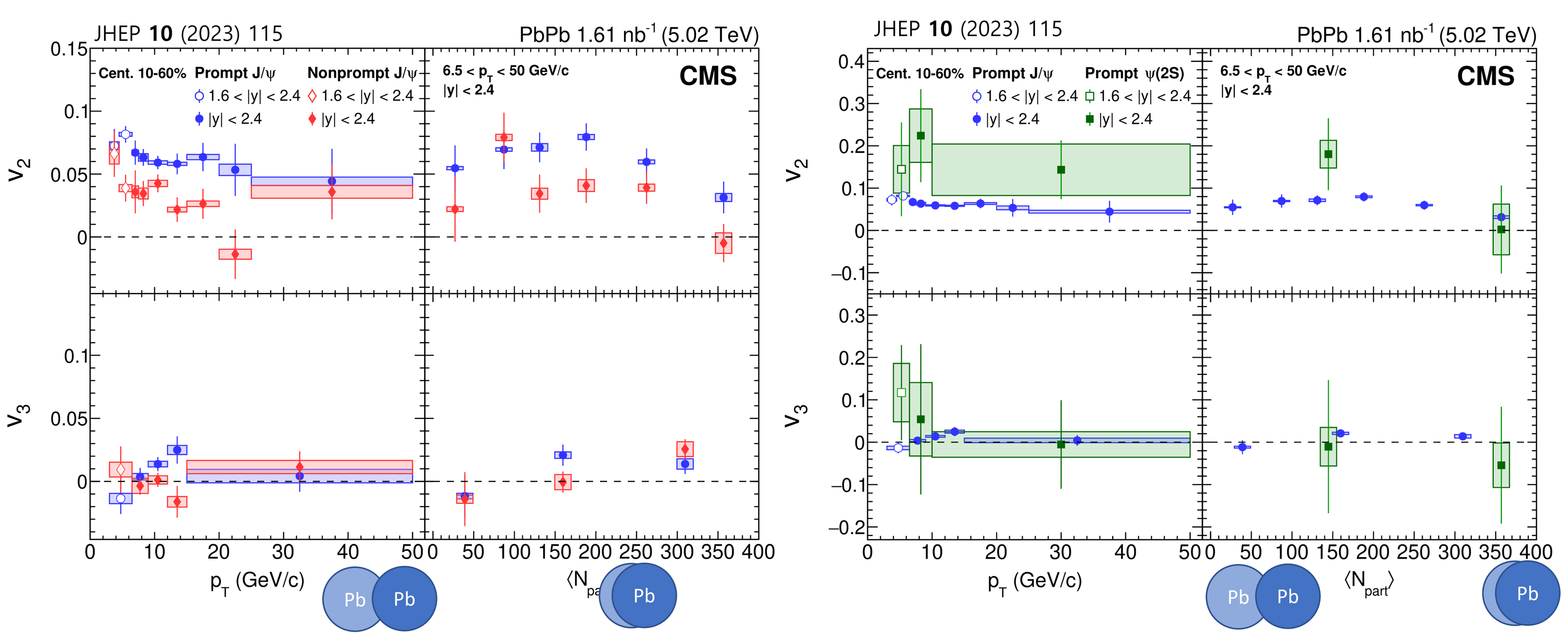
Results

Nuclear Modification factor



- The vertical arrows represent 95% confidence intervals in the bins where the double ratio measurement is consistent with 0
- Increasing suppression of $\psi(2S)$ towards central events
- No clear p_T dependence of $\psi(2S)$ suppression
- Stronger suppression $\psi(2S)$ than J/ψ in for all centralities and p_T

Azimuthal anisotropy



- For the J/ψ, the results for p_T 3-6.5 and 6.5-50 GeV/c are studied in the rapidity range $1.6 < |y| < 2.4$ and $|y| < 2.4$, respectively (left panel) and the p_T range for the right panel is p_T 6.5-50 GeV/c and rapidity of $|y| < 2.4$
- Non-zero v_2 for prompt J/ψ and $\psi(2S)$ mesons at high-p_T is measured
- J/ψ and $\psi(2S)$ v_3 values are consistent with zero

Summary

- No clear p_T dependence of $\psi(2S)$ suppression
- Stronger suppression of $\psi(2S)$ than J/ψ for all p_T

- Sizable prompt J/ψ v_2 at high- p_T
- Prompt J/ψ v_2 is larger than nonprompt J/ψ v_2
- First measurement $\psi(2S)$ v_2 in heavy ion
- $\psi(2S)$ v_2 seems to be larger than J/ψ v_2

- Larger recombination effects? Path-length dependent E.Loss? etc?
  → **Need to revealed with precision data in the future**

Reference

[1] Heavy ion collisions: The big picture, and the big questions (*Ann. Rev. Nucl. Part. Sci.* **68** (2018) 339)
[2] Qurakonium feed down and sequential suppression (*Phys. Rev. D* **64** (2001) 094015)
[3] J/ψ elliptic flow in relativistic heavy ion collsions (*Nucl. Phys. A* **834** (2010) 317C)
[4] Measurement of prompt and nonprompt charmonium suppression in PbPb collisions at 5.02 TeV (*Eur. Phys. J. C* **78** (2018) 509)
[5] Measurements of the azimuthal anisotropy of prompt and nonprompt charmonia in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (JHEP **10** (2023) 115)

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