Measurement of bottomonium nuclear modification factor and elliptic flow in PbPb and pPb collisions with the CMS detector

Gyeonghwan Bak, Chonnam National University
on behalf of the CMS Collaboration
*gyeonghwan.bak@cern.ch

Abstract

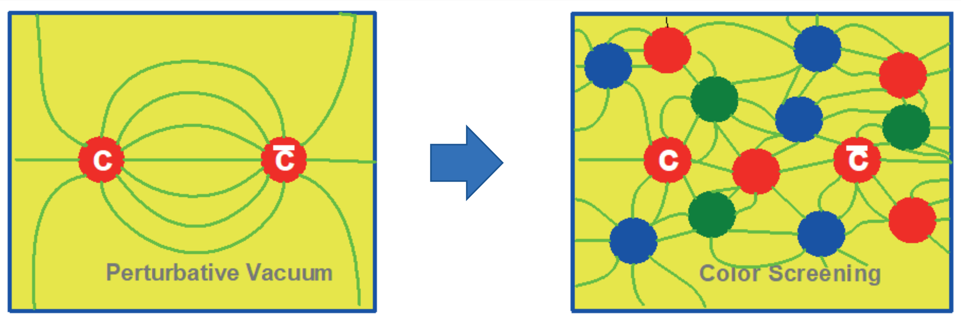
Early CMS data showed that the yields of the Υ (1S), Υ(2S), and Υ (3S) mesons are suppressed in PbPb relative to those in pp collisions. In order to interpret the results in PbPb collision unambiguously, the cold nuclear matter effects need to be quantitatively estimated using pPb collisions data. Additionally, the measurement of the azimuthal anisotropy of bottomonium states has been suggested as a powerful tool to study the different in-medium effects such as dissociation and regeneration. This presentation reports the bottomonium results for pPb and PbPb collisions data with the CMS detector. First, the nuclear modification factors of the Υ(1S), Υ(2S), and Υ (3S) mesons are presented in PbPb collisions as functions of transverse momentum and collision centrality. Then, the measurements of the azimuthal anisotropy (v_2) of the Υ (1S) meson are reported using pPb and PbPb collisions data.

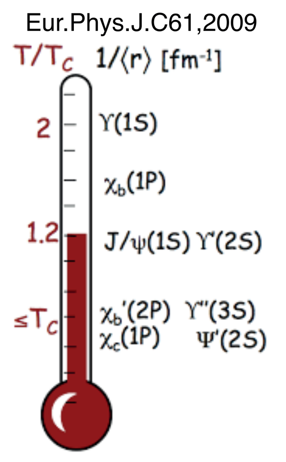
Introduction

Quarkonia in heavy ion collisions

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

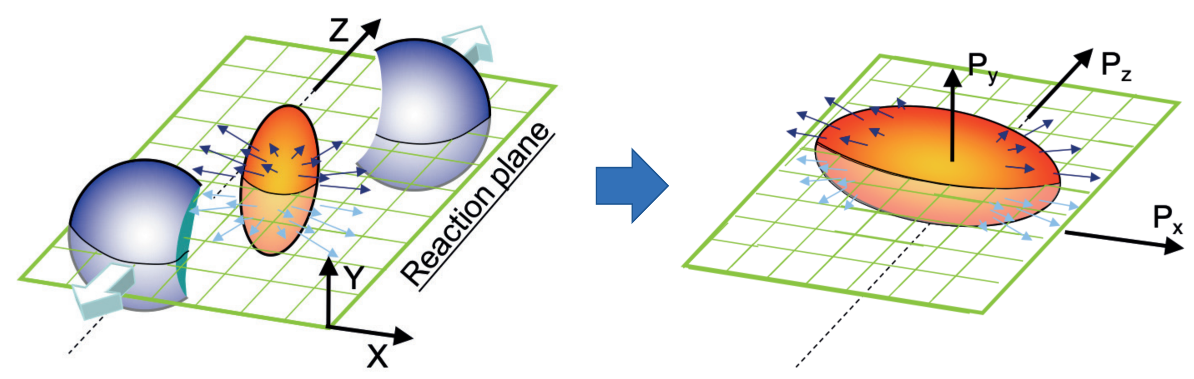
state	J/ψ (1S)	χ_c(1P)	Ψ' (2S)	Υ (1S)	χ_b(1P)	Υ (2S)	χ_b'(1P)	Υ (3S)
m(GeV/c^2)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
r_0(fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78



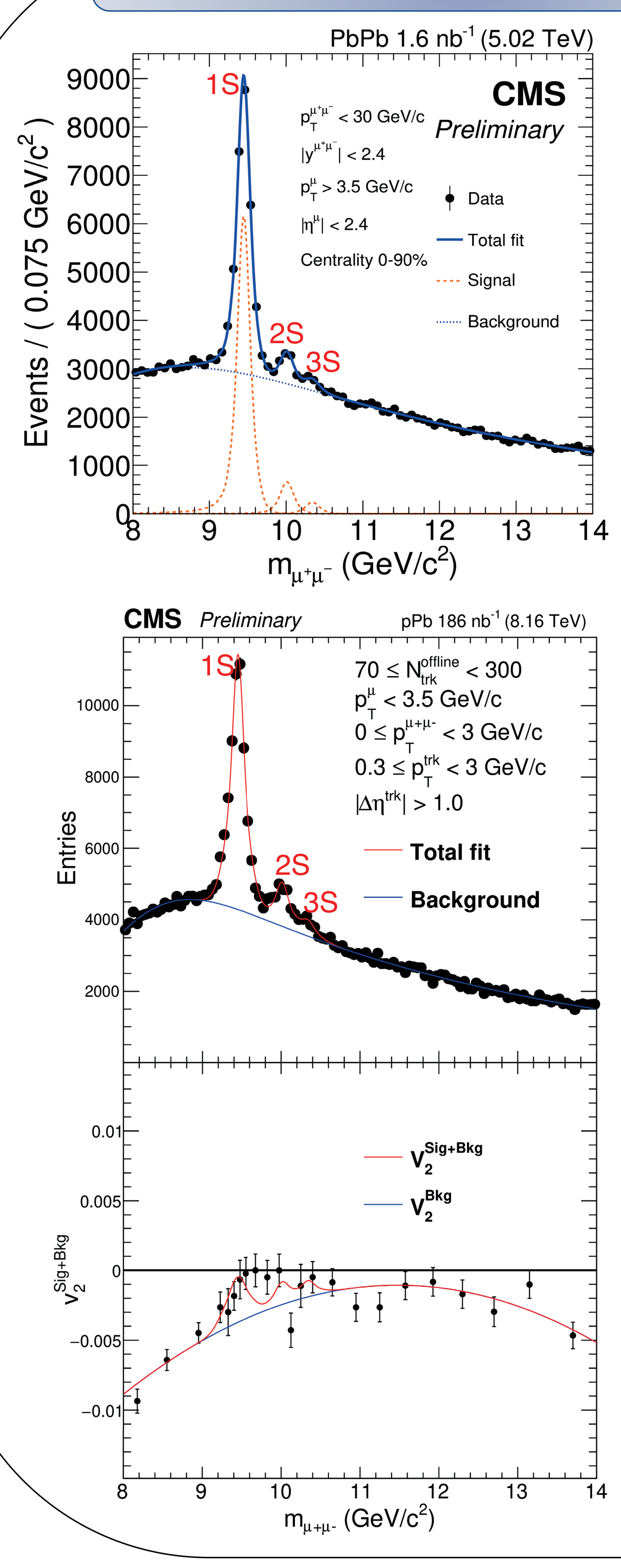


- Azimuthal anisotropy (Flow)
  - Collectivity (low-p_T), path-length dependent Energy loss (High-p_T)
  - Sensitive to initial collision geometry

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



Signal extraction

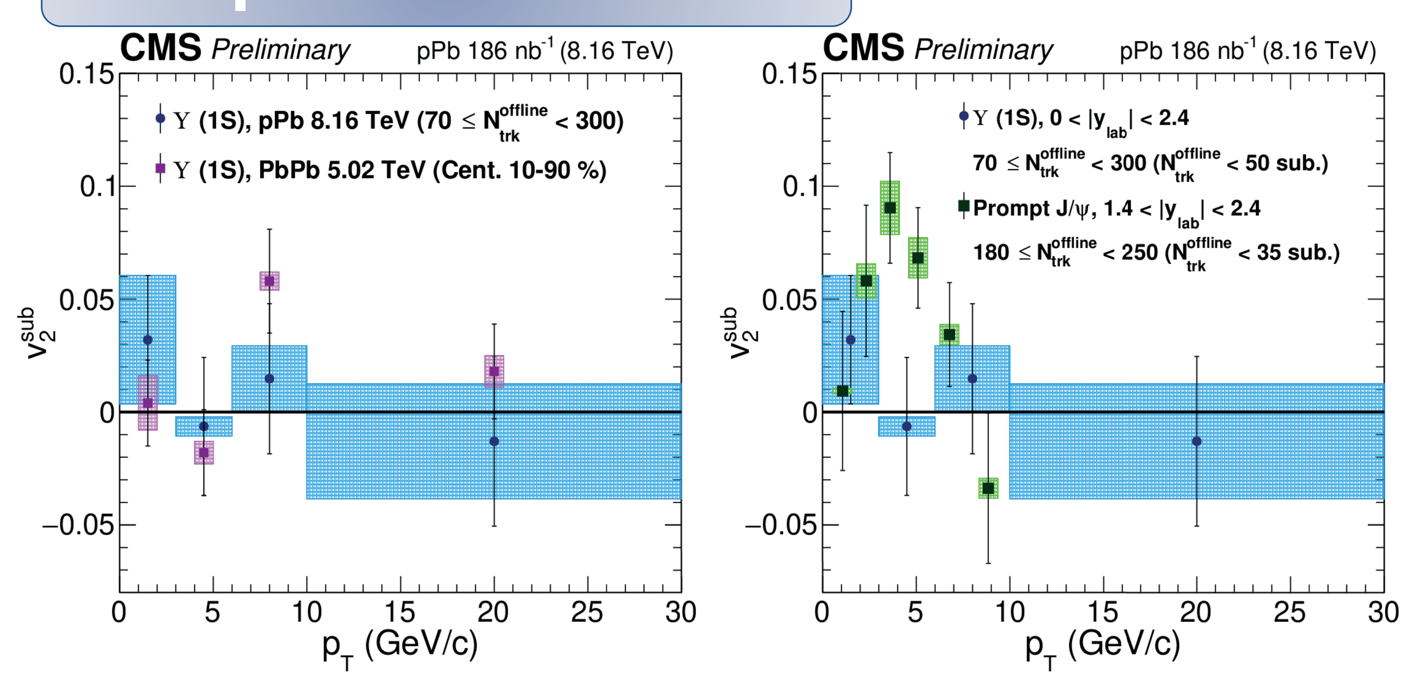


- Invariant mass distribution of muon pairs in PbPb (top) and high multiplicity pPb (bottom) collisions
- Candidate selection for PbPb data optimized by employing a BDT method for background reduction
- Unbinned maximum likelihood fit to the dimuon distribution with signal+background model
- Signal v_2 extracted from simultaneous fit of the dimuon mass and v_2

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

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

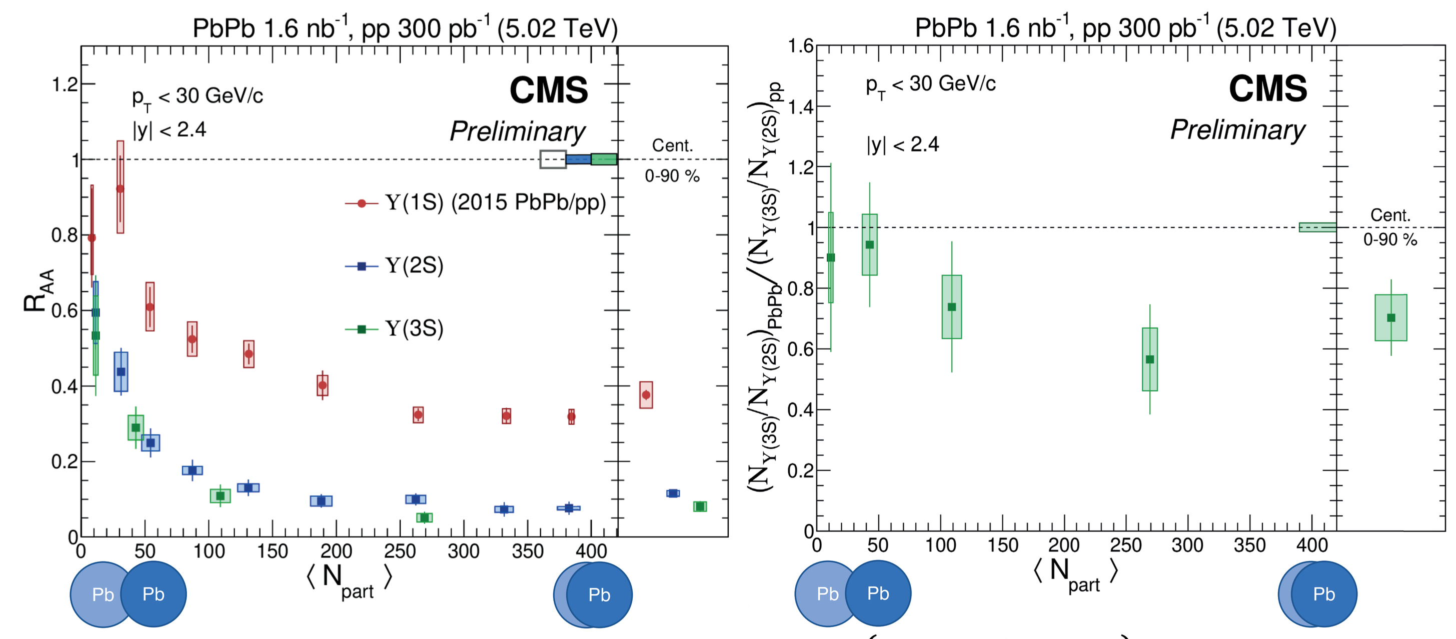
pPb Results



- The pPb Υ(1S) results, after subtracting the correlations obtained from low-multiplicity events, are denoted as $v_2^{\rm sub}$
- Left : The p_T dependent $v_2^{\rm sub}$ values for Υ(1S) mesons in pPb vs PbPb collisions
- Right : The same distribution is also compared with the $v_2^{\rm sub}$ values for prompt J/ψ mesons

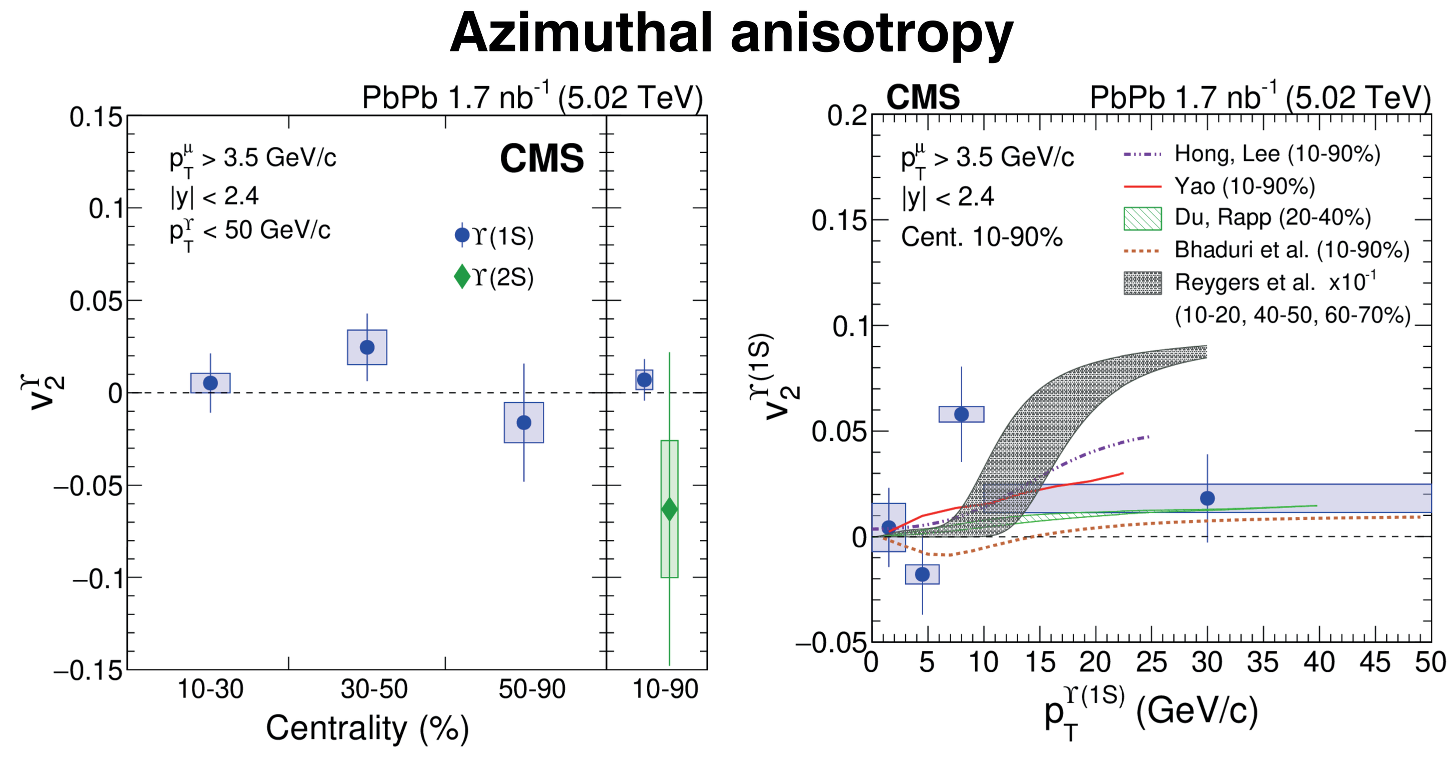
PbPb Results

Nuclear Modification factor



- $R_{AA}(p_T, y) = \frac{N^{AA}(p_T,y)}{\langle T_{AA}\rangle \sigma^{pp}(p_T,y)}$, Double ratio = $\frac{(N_{\Upsilon(3S)}/N_{\Upsilon(2S)})_{\rm PbPb}}{(N_{\Upsilon(3S)}/N_{\Upsilon(2S)})_{\rm pp}}$
- Measured R_{AA} for Υ states (left) and the double ratio of Υ(3S)/Υ(2S) (right) as function of $\langle N_{\rm part}\rangle$
- A gradual decrease of R_{AA} is observed towards more central collisions
- No dependence is found for $\Upsilon(2S)$ and $\Upsilon(3S)$ as function of p_T

Azimuthal anisotropy



- Left : p_T integrated v_2 values for $\Upsilon(1S)$ mesons measured in four centrality bins and for the $\Upsilon(2S)$ meson in the 10-90% centrality range.
- Right : v_2 of $\Upsilon(1S)$ meson as a function of p_T in the 10-90% centrality range compared with models
- The $\Upsilon(1S)$ v_2 values are consistent with zero in the centrality bins within the statistical uncertainties
- The $\Upsilon(1S)$ meson v_2 values are consistent with zero in the measured p_T range, except for the $6 < p_T < 10$ GeV/c with difference of 2.5 σ
- Many models predict small v_2 values, which is quantitatively compatible with result in the measured p_T range

Summary

1. Nuclear modification factor of Υ(nS) mesons is measured
2. Sequential suppression : R_{AA} (Υ(3S)) < R_{AA} (Υ(2S)) < R_{AA} (Υ(1S))
3. Azimuthal anisotropy studied with bottomonia in pPb and PbPb collisions
4. Υ(1S) v_2 is consistent with zero regardless of the system size

References

[1] Measurement of the azimuthal anisotropy of Υ(1S) and Υ(2S) mesons in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (Phys. Lett. B 819, 136385 (2021))

[2] Azimuthal anisotropy of Υ(1S) mesons in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV (CMS-PAS-HIN-21-001 (2022))

[3] Observation of the Υ(3S) meson and sequential suppression of Υ states in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (CMS-PAS-HIN-21-007 (2022))

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