Bottomonium elliptic flow from anisotropic escape

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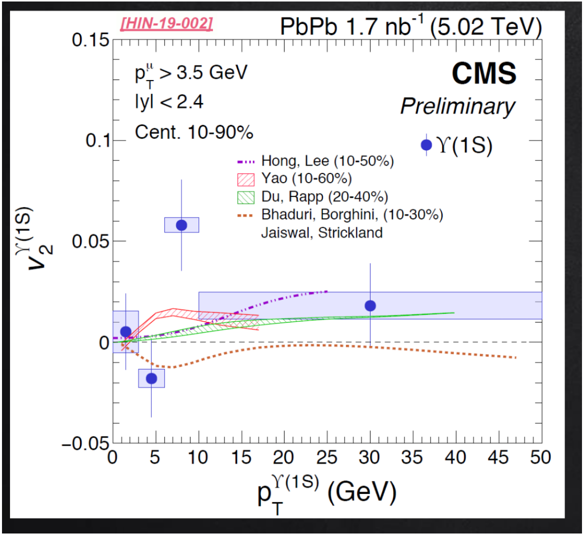
Recent results from CMS



The model

- aHydro output for 5.02 TeV Pb+Pb collisions from KSU.
- We use Optical Glauber model for spatial initialization of the fireball energy density profile.
- The spatial distribution of the bottomonium production points in the transverse plane is assumed to follow the number of binary collisions.
- We consider transverse momentum (p_T) distribution of the Υ's obtained from PYTHIA simulations for $p + p$ collisions, scaled by the mass number of the colliding nuclei [K. Zhou, N. Xu and P. Zhuang, Nucl. Phys. A 931, 654.].
- We adopt the isotropic thermal decay widths $\Gamma(T)$ of the bottomonium states from: [M. Strickland and D. Bazow, Nucl. Phys. A 879, 25]
- Then we allow the bottomonium states to propagate through the medium and decay/survive according to their widths.

Formation time of bottomonium states

- The formation of each bound bottomonium state requires a finite formation time $\tau_{\rm form}$.
- The value $\tau^0_{\rm form}$ of the latter in the bottomonium rest frame is assumed to be proportional to the inverse of the vacuum binding energy for each state.
- For the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, $\chi_b(1P)$ and $\chi_b(2P)$ states we use $\tau^0_{\rm form} = 0.2, 0.4, 0.6, 0.4, 0.6$ fm$/c$, respectively [B. Krouppa and M. Strickland, arXiv:1605.03561].
- In the laboratory frame, relative to which a bottomonium state with mass M has transverse momentum p_T, the formation time becomes $\tau_{\rm form} = E_T \tau^0_{\rm form}/M$ with $E_T = \sqrt{p_T^2 + M^2}$.

Propagation through the medium [P. P. Bhadury, N. Borghini, AJ and M. Strickland, PRC 100, 051901 (2019)].

- We assume that the bottomonium states propagate quasi freely following nearly straight-line trajectories.
- They are either dissociated (absorbed) or survive, no elastic scattering.
- If (x_0, y_0) denotes the position in the transverse plane where a bottomonium with momentum p_T is at time τ_i, it will at a later time $\tau = \tau_i + \tau'$ be at

$$x' = x_0 + v_T \tau' \cos\phi \quad , \quad y' = y_0 + v_T \tau' \sin\phi,$$

where $v_T = p_T/E_T$ is the bottomonium transverse velocity and ϕ the azimuthal angle of its transverse momentum.

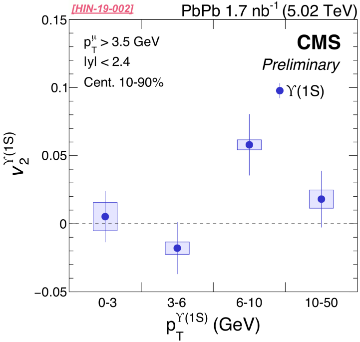
Dissociation and width of bottomonium

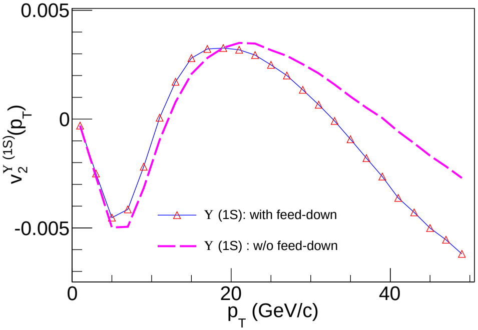
- From hydro output we can get the temperature experienced by the $b\bar{b}$ pair at (x', y') at τ'.
- For this temperature, we obtain the thermal decay widths $\Gamma(T(x', y', \tau'))$ of the bottomonium states, adopting the recent state-of-the-art results of in-medium dissociation of different bound $b\bar{b}$ states [M. Strickland and D. Bazow, Nucl. Phys. A 879, 25].
- The final transmittance for a $b\bar{b}$ bound state labelled by j is given by

$$\mathcal{T}_j(x, y, p_T, \phi) = \exp\left[-\Theta(\tau_f - \tau_j^{\rm form})\int_{\max(\tau_j^{\rm form}, \tau_i)}^{\tau_f} d\tau' \, \Gamma_j\left(T(x', y'; \tau')\right)\right],$$

where Θ is the usual step function.

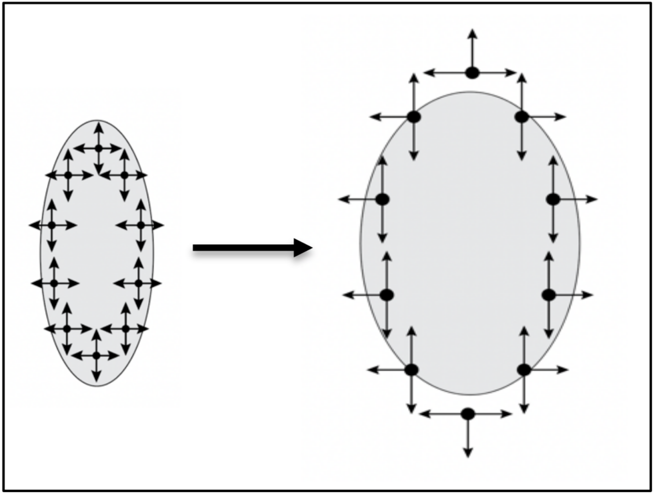
Estimation of $R_{AA}(p_T)$ and $v_2(p_T)$ for $\Upsilon(1S)$ states



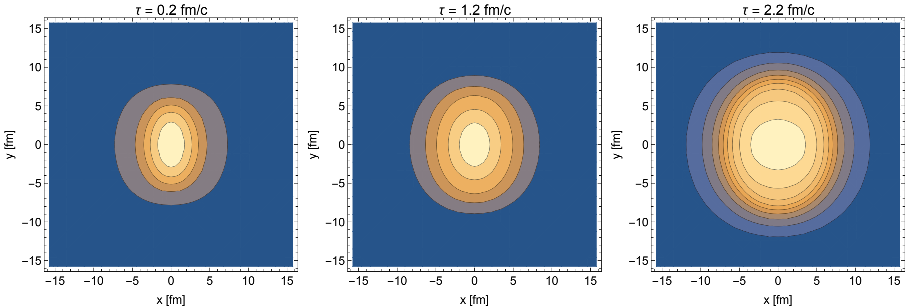


- Feed down from excited states is included.
- Excited states are produced late in the plasma frame.

Expansion geometry



Hydrodynamic evolution



Effect of time dilation

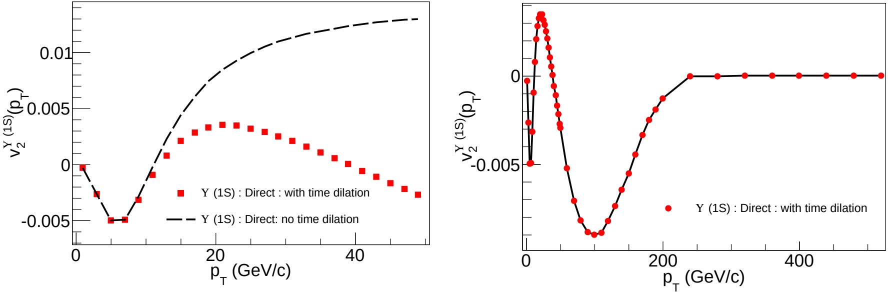
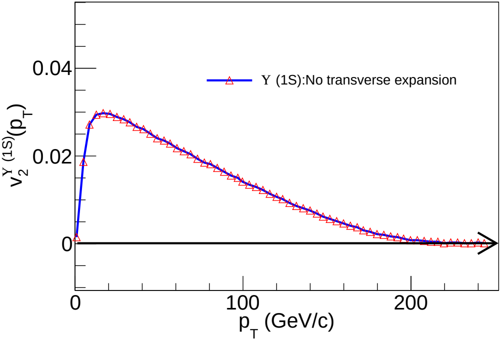
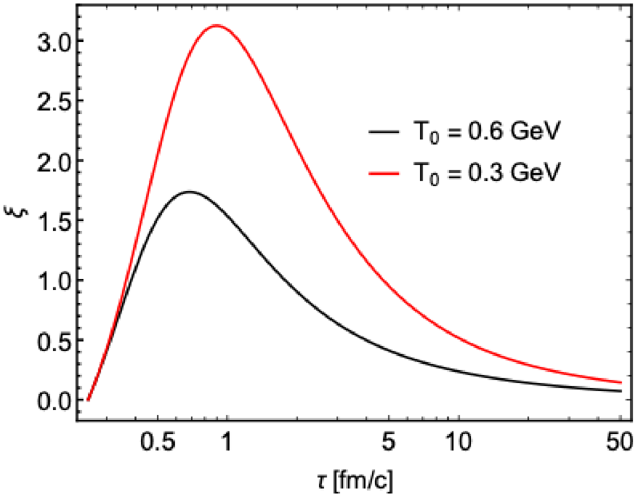


Figure: p_T dependence of v_2 for directly produced $\Upsilon(1S)$ states with and w/o time dilation effect. Feed down correction not included.

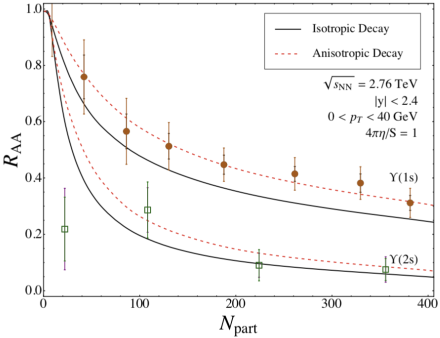


- Transverse expansion is turned off; initial profile from aHydro.
- No negative v_2 observed. At very high p_T bottomonia are formed late in the plasma frame, and eventually $v_2 \to 0$.
- Temperature is scaled by time dependent central temperature: $T(\tau, x, y, z = 0) = T(\tau_0, x, y) \times \frac{T(\tau,0,0,0)}{T_0}$

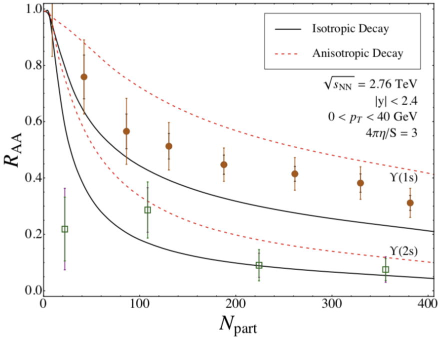
Backup 1



Backup 2



1.0
0.8
0.6
0.4
0.2
0.0
R_{AA}
0
100
200
300
400
N_{part}
Isotropic Decay
Anisotropic Decay
$\sqrt{s_{NN}}$ = 2.76 TeV
|y| < 2.4
0 < p_T < 40 GeV
$4\pi\eta/S$ = 1
Υ(1s)
Υ(2s)



1.0
0.8
0.6
0.4
0.2
0.0
R_{AA}
0
100
200
300
400
N_{part}
Isotropic Decay
Anisotropic Decay
$\sqrt{s_{NN}}$ = 2.76 TeV
|y| < 2.4
0 < p_T < 40 GeV
$4\pi\eta/S$ = 3
Υ(1s)
Υ(2s)