Do Quarkonium thermalization at LHC ?

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Motivation

- Quarkonia are the bound states of a heavy quark (Q) and it's anti-quark (Q).
- $c\bar{c}$ pair: J/ψ, $\psi(2S)$ and $b\bar{b}$ pair: $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$
- Large mass and small production cross section even at LHC, Quarkonia are not likely to be thermally produced.
- Quarkonium suppression has been since long suggested as a hard probe for the quark-gluon plasma formed in high-energy heavy-ion collisions
- The difference in the production pattern between nucleus-nucleus (A-A) collisions and p-p collisions was first seen at the (SPS).
- But important backgrounds to the signal came from the initial state via parton density effects and the final state through comover interactions.
- New experimental results at LHC show sequential suppression are not equal, $R_{PbPb}[\Upsilon(1S)] \neq R_{PbPb}[\Upsilon(2S)] \neq R_{PbPb}[\Upsilon(3S)]$.
- Nor $R_{PbPb}[J/\psi] \neq R_{PbPb}[\psi(2S)]$

Motivation

- Non-zero v2 could be an indication of charm (beauty) collective motion at low pT.

- At this situation, it is interacting to know Do the quarkonia thermalize?

- Statistical Hadronisation Model tries to explain the quarkonia production in high-energy heavy-ion collisions.

- SHM assumes that heavy quarks are produced in initial hard scatterings.

- All produced heavy-flavor quarks survive and thermalize within the QGP.

- Charmonium, together with all the other light hadrons, is formed at the phase boundary.

- What happens if we let the experimental date to decide the quarkonia freeze-out temperature (approach of S. Gupta, R. Sharma (*S. Gupta and R. Sharma, Phys. Rev. C 89 (2014), 057901.*)

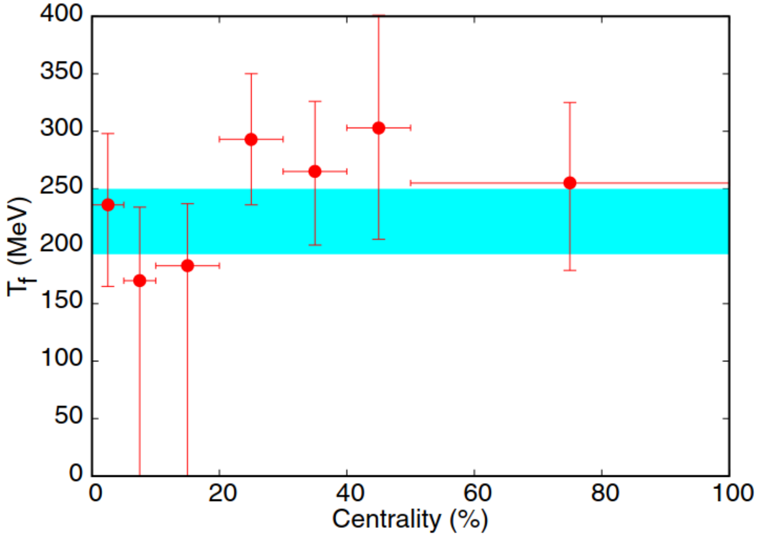
- ***Previous work [**S. Gupta and R. Sharma, Phys. Rev. C 89 (2014), 057901**].***

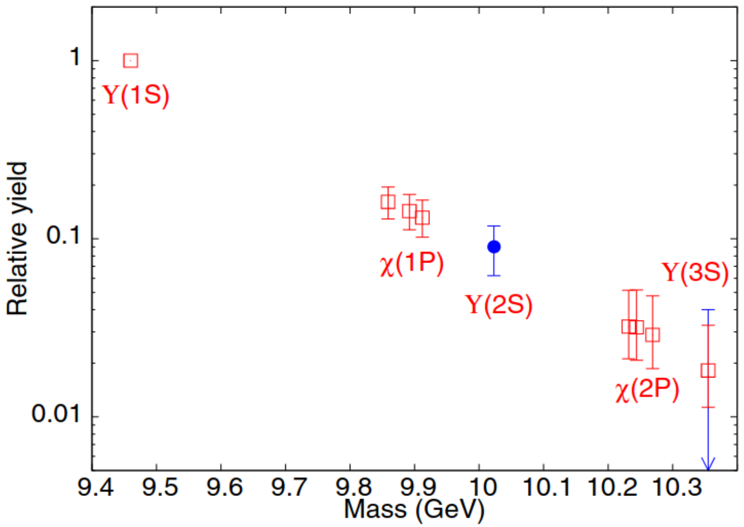
Equilibrium density of heavy quarkonia

$$n \simeq (\mathcal{M}T)^{3/2} \exp\left(-\frac{\mathcal{M}}{T}\right) z,$$

$$Y[\Upsilon(nS)] = \frac{N_{PbPb}(\Upsilon(nS))}{N_{PbPb}(\Upsilon(1S))}$$

Use Single Ratio to Extract Tf





Centrality Integrated Case:

$$T_f = 222^{+28}_{-29} \text{ MeV for } Y[\Upsilon(2S)],$$

$$T_f < 282 \text{ MeV for } Y[\Upsilon(3S)]$$

- **Investigate the centrality dependence of TF . Construct from the double ratio.**
- **Centality independence of TF supports thermalization,in the sense that the initial state information is forgotten.**
- **Premature conclusion due to large error bars.**

- ***Previous work [**S. Gupta and R. Sharma, Phys. Rev. C 89 (2014), 057901**]***

Charmonia Sector

PbPb 2.76 TeV System non prompt $r[\psi(2S)] = \frac{N_{PbPb}[\psi(2S)]}{N_{PbPb}[J/\psi]} = \begin{cases} 0.024 \pm 0.008 & (|y| \leqslant 1.6,\ 6.5 \leqslant p_T \leqslant 30), \\ 0.105 \pm 0.02 & (1.5 \leqslant |y| \leqslant 2.4,\ 3 \leqslant p_T \leqslant 30). \end{cases}$

CMS Collaboration, CMS-PAS-HIN-12-007, 201

$$r_{\text{prompt}}[\psi(2S)] = r[\psi(2S)] \left(\frac{1 - af}{1 - f} \right).$$

S. Gupta and R. Sharma, Phys. Rev. C 89 (2014), 057901]

Where, ‘f ’ and ‘af ’ are respectively the fraction of J/ψ and ψ(2S) coming from weak decay.

$T_F = 149 \pm 14$ MeV at midr-rapidity ($|y| < 1.6$) and
$T_F = 255 \pm 25$ MeV at forward rapidity ($2.5 < |y| < 4.0$)

- **Difference likely to occur from unequal pT acceptance.**
- **Higher pT of charmonia, easy escape from the fireball, without properly being thermalized in the medium.**
- **Centrality dependent analysis for midrapidity sample shows TF increases from 185 MeV to 240 MeV as Npart increases from 35 to 310. High pT charmonium goes from less to more thermalized as the system size grows.**

Previous work [S. Gupta and R. Sharma, Phys. Rev. C 89 (2014), 057901.]

- The observed sequential suppression of the Y family of mesons as measured by the CMS collaboration, was interpreted as the bottomonium states attaining thermal equilibrium in the fireball and then freezing out at a temperature Tf = 220 ± 29 MeV, much earlier than the bulk of the medium made of light hadrons.

- The near constancy of Tf across various collision centralities was considered as the evidence for thermalization.

- The results however suffered from the large uncertainty.

- Forbidding one to make any mature claim.

- Now with the availability of high-precision data at the LHC, we reinvestigated the issue of Quarkonium thermalization.

- We analyzed relative yields of different Chromium and Bottomonium states using the ideal-HRG model.

BRIEF DESCRIPTION OF THE HRG MODEL

In the ID-HRG model, the primordial yield (Np) of the ith hadron at zero chemical potential.

$$N_i^p = \frac{g_i V}{2\pi^2} \int_0^\infty dp \, \frac{p^2}{\exp\left(\sqrt{m_i^2 + p^2}/T\right) \pm 1}$$

Primordial yield

$$N_i^t = N_i^p + \sum_j N_j^p \text{ x } B.R_{j \rightarrow i}.$$

Particle yield

Branching Ratio

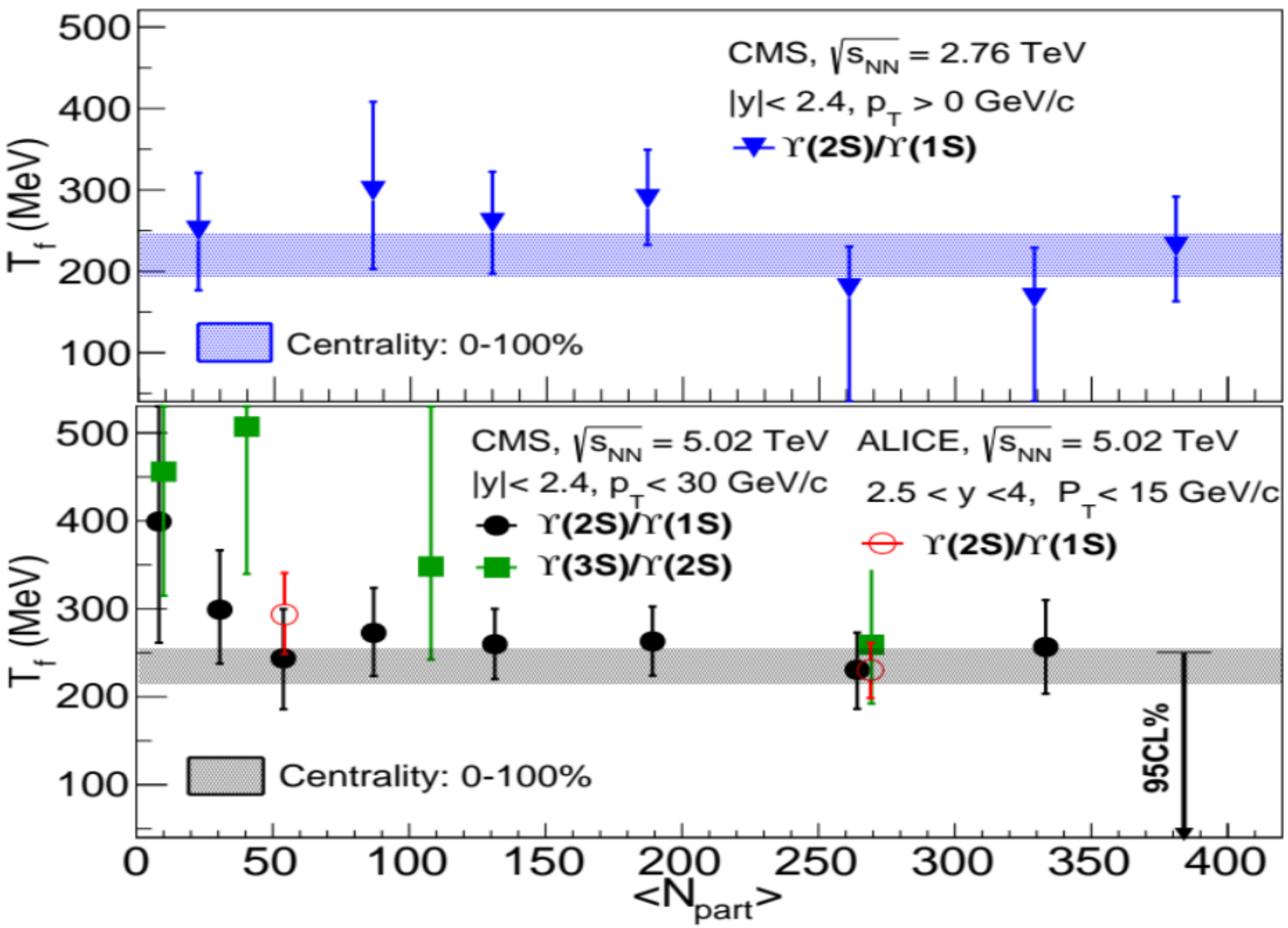
Experimental acceptance corrected primordial yield.

$$N_i^p = \frac{g_i V}{4\pi^2} \int d\eta \, dp_T \, \frac{p_T^2 \cosh \eta}{\exp\left[\sqrt{p^2 \cosh^2 \eta + m_i^2}/T\right] \pm 1}$$

P. Garg, D. et al. Phys. Lett. B, 726:691–696, 2013.
Paolo Alba. et al. Phys. Lett. B, 738:305–310, 2014.

ANALYSIS RESULTS

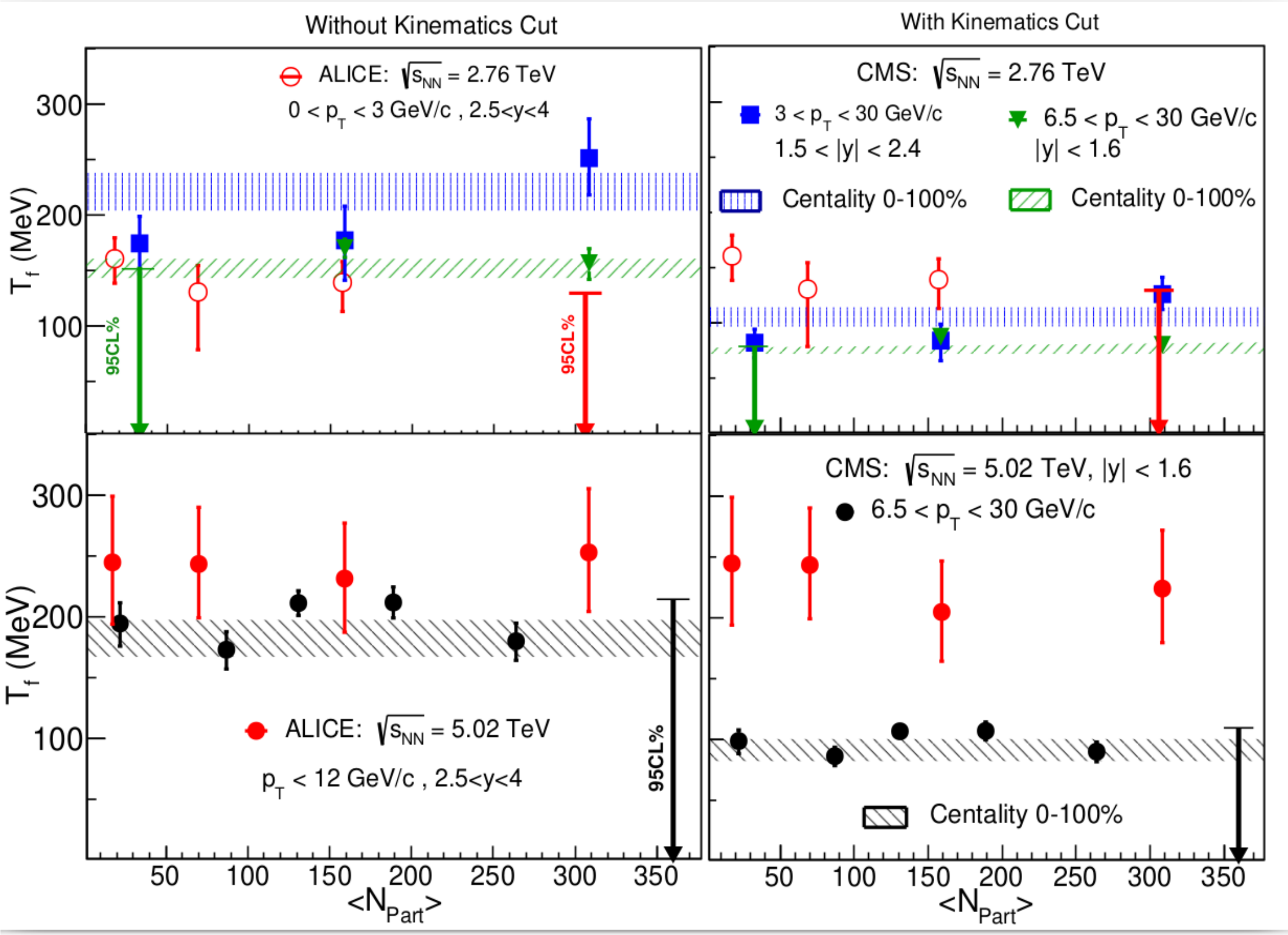
A. PbPb System



The centrality dependence freeze-out temperatures in the PbPb system were extracted using different relative yields of the bottomonium states.

- Small increase in T_f for almost all the centrality classes at higher $\sqrt{s_{NN}}$.
- Centrality independence of T_f With $\sqrt{s_{NN}}$.
- Modest decrease of T_f for the most central collisions.
- Rapidity independence of T_f
- The single freeze-out scenario of all bottomonium states for events with high N_{part}.

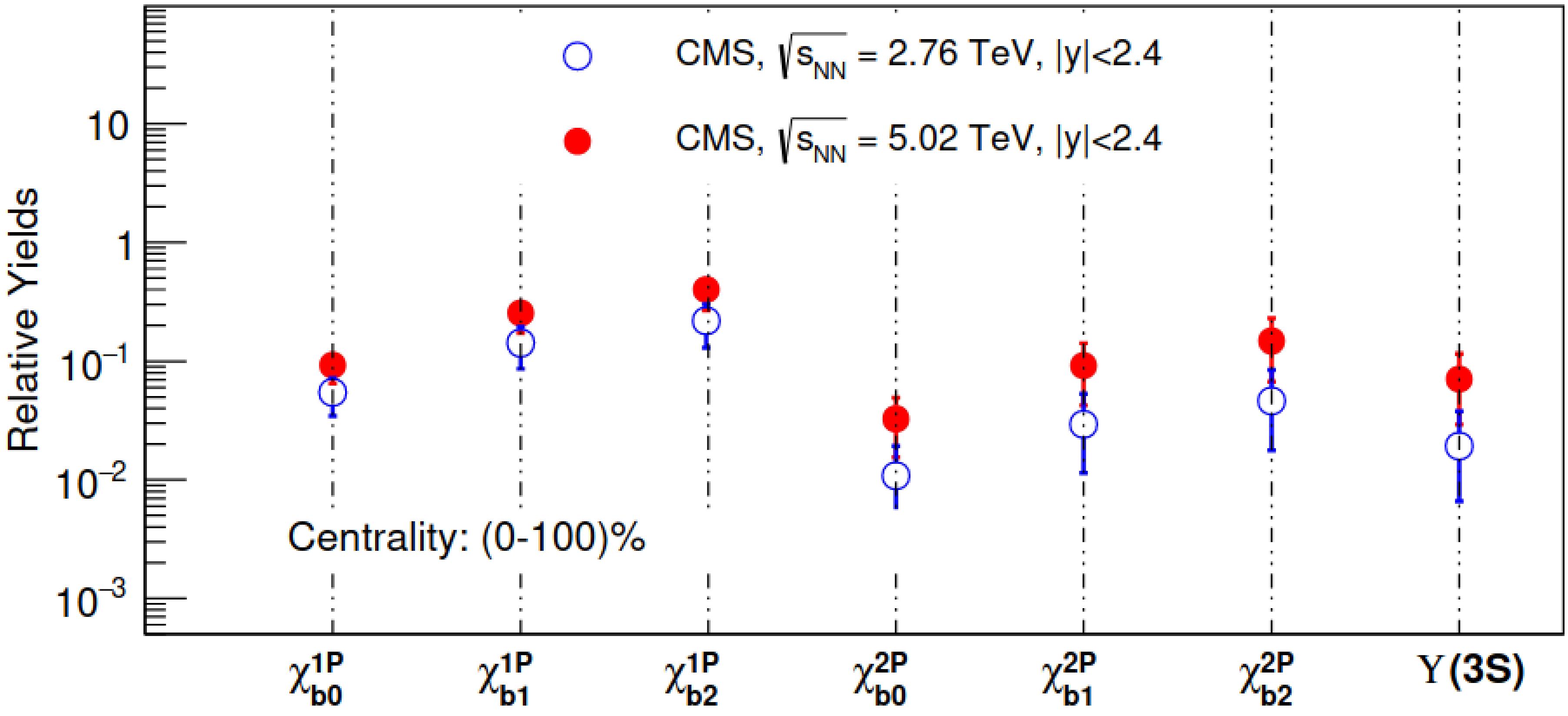
A. PbPb System



The centrality dependence freeze-out temperatures for without (left) and with (right) acceptance correction effect, extracted using prompt yields ratios of charmonium states in the PbPb system.

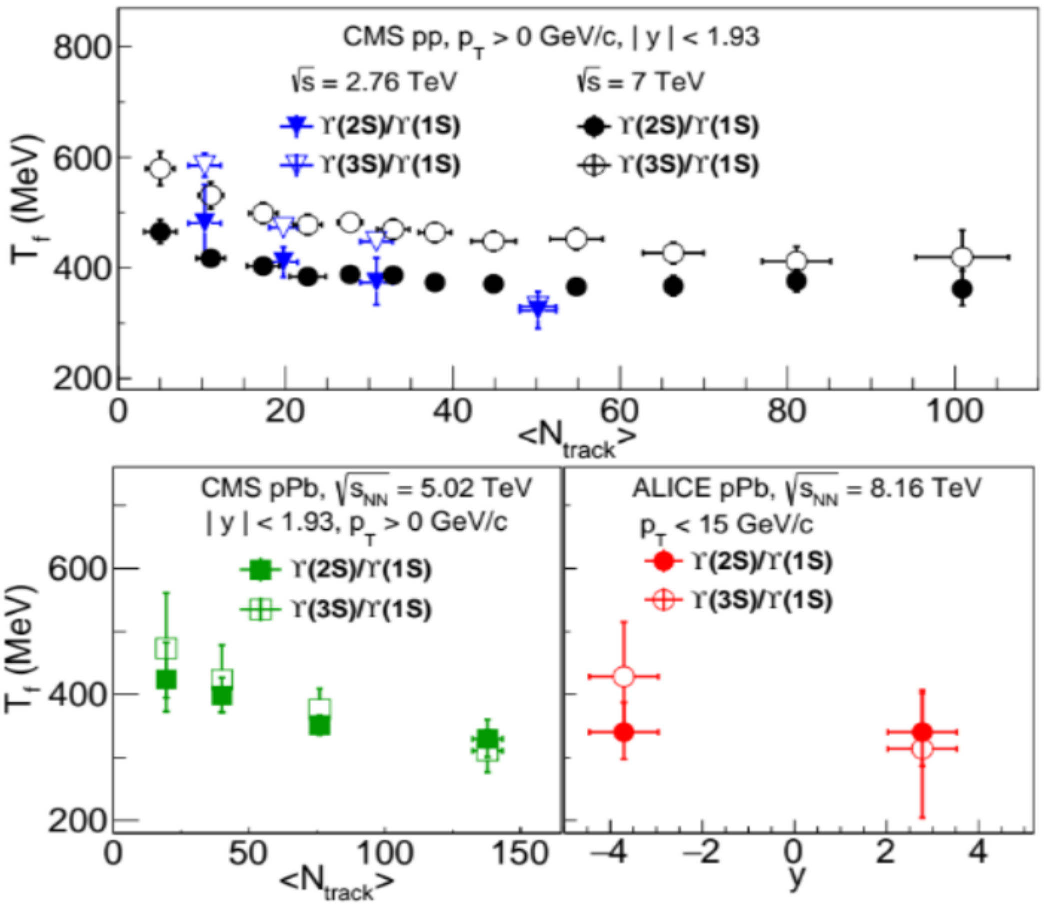
- The acceptance correction significantly decreases the T_f because of the large minimum p_T threshold of the CMS experiments.
- No such effect for ALICE data where the minimum p_T threshold is zero.

Predictiosn for different unmeasured states



Bottomonium States

B. Small Systems (pp,pPb)

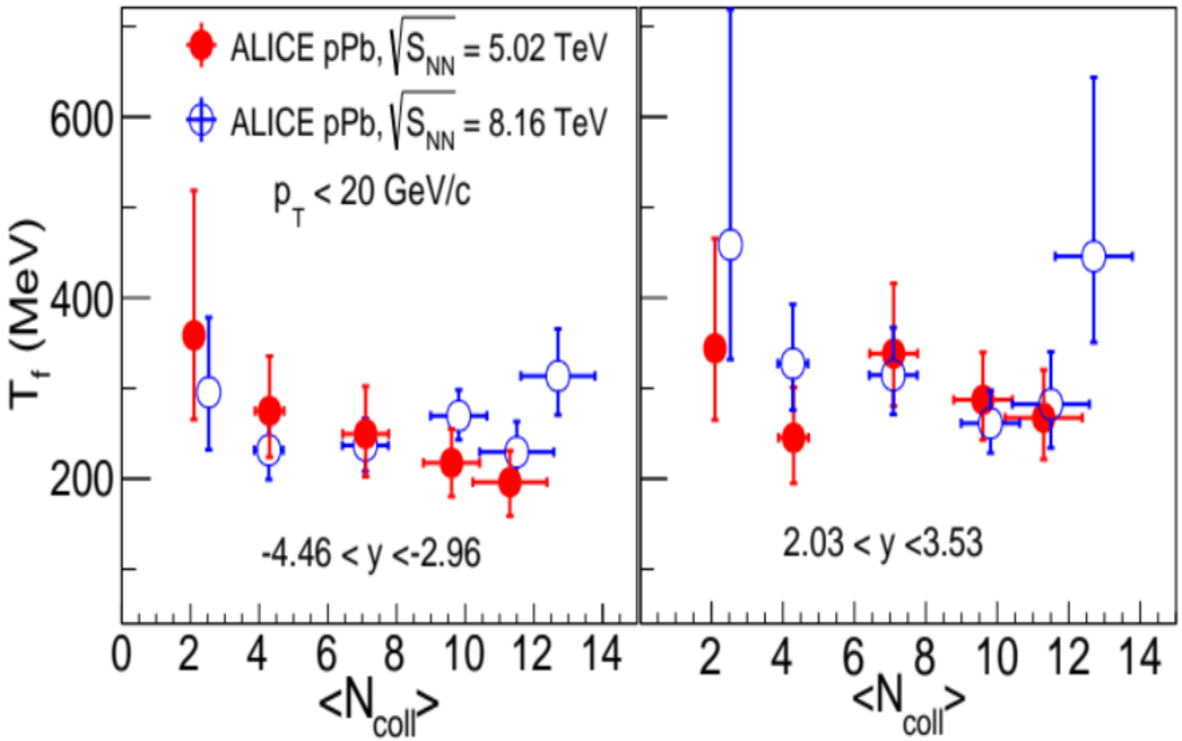


Upper plane: The multiplicity dependence freeze-out temperatures for the pp system TeV. Lower left: Same as the upper plane but for the pPb system Lower right: Tf as a function of rapidity for pPb system.

- Like the PbPb system, the indication of lowering of the T_f for higher multiplicity events for both pp and pPb system
- T_f for the high multiplicity class is almost 1.7 times larger than the T_f we obtained for the centrality integrated PbPb system.
- The most integrating feature that resembles the feature of the PbPb system is the simultaneous freeze out of all the states at higher multiplicity events for both pp and pPb system.
- For pPb system T_f for the backward rapidity is slightly higher than that of the forward-rapidity region, but it’s not completely conclusive because of the large uncertainty.

B. Small Systems (pp,pPb)

Charmonium States



Tf as a function of < Ncoll > for two different collision energy. The multiplicity- dependent T f for the forward and backward rapidity regions are presented in the right and left planes respectively.

- No significant collision energy or rapidity dependence of the T_f has been observed.
- For all the collision energies and investigated rapidity regions, there is a tendency to decrease T_f with centrality, but not so conclusive.
- The T_f of all cases (the centrality classes and for both the collision energies) are significantly larger than the T_f we obtain from analyzing the relative yield of the PbPb system at 2.76 TeV ALICE data.

Thank you