The statistical hadronization model and beauty hadrons: a case for partial equilibration of b-quarks?

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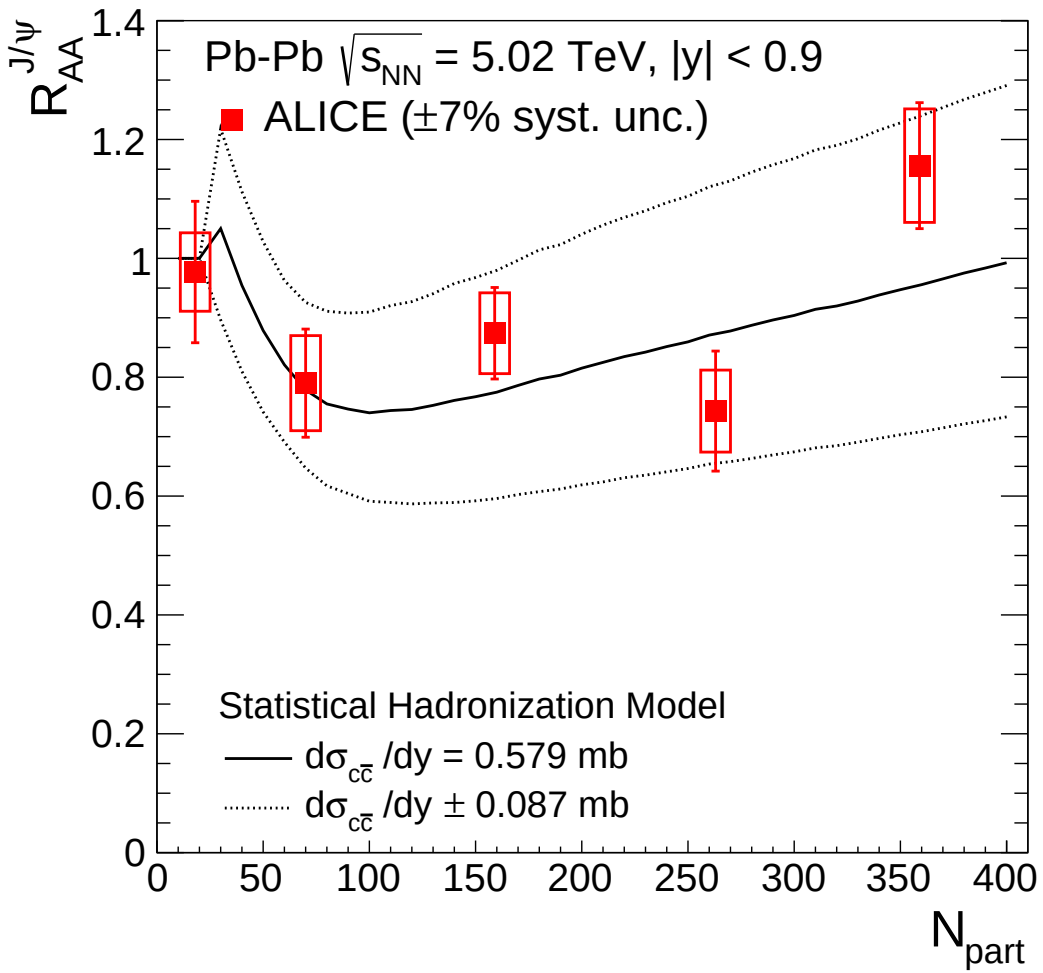
Outline

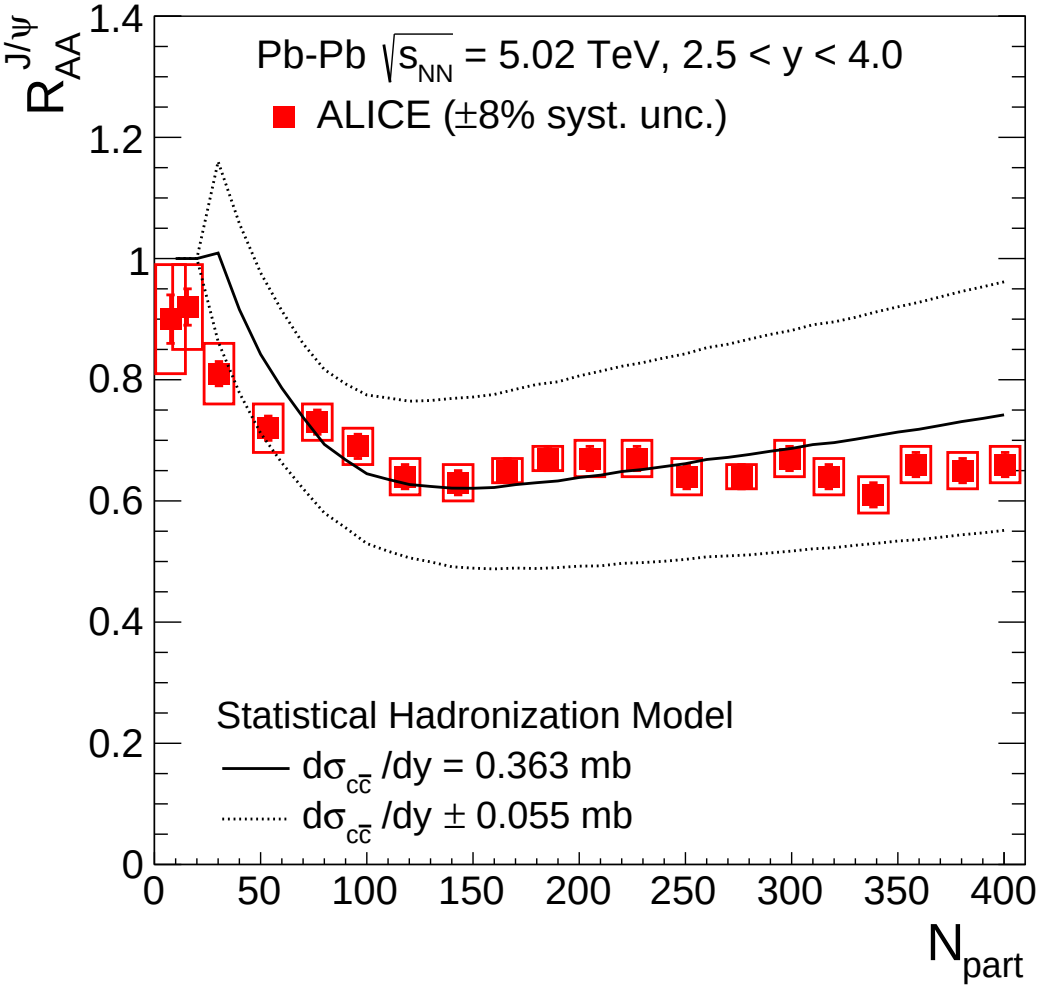
- Introduction: A brief look at charm
- The beauty model (and ingredients)
- Predictions and comparisons to data
- Summary (including the open questions)

The Statistical Hadronization Model for charm (SHMc)

A. Andronic

full thermalization of c quarks in QGP, hadronization at chemical freeze-out



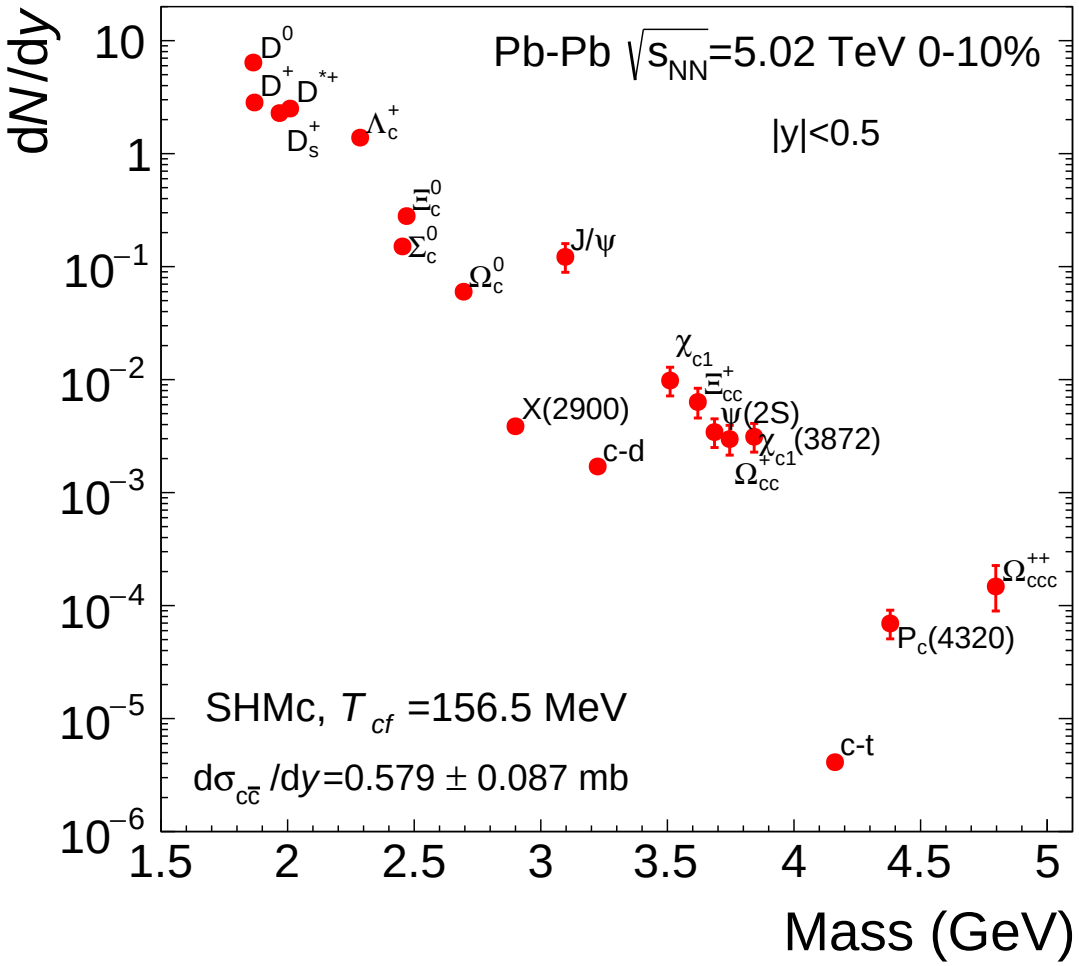


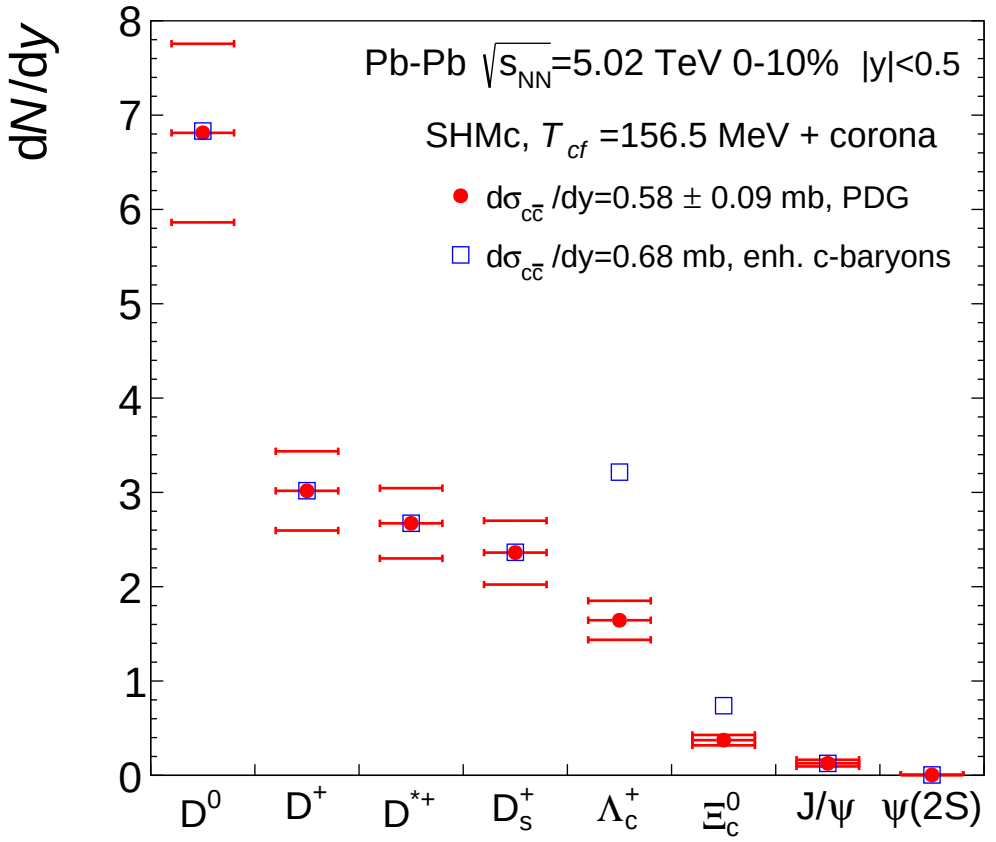
$\mathrm{d}\sigma_{c\bar{c}}/\mathrm{d}y$ via normalization to D^0 in Pb–Pb 0-10%, ALICE, arXiv:2110.09420

$\mathrm{d}N/\mathrm{d}y = 6.82 \pm 1.03$ (and assuming hadronization fractions in data as in SHMc)

SHMc: the charm zoo

The power of the model: predicting the full suite of charmed hadrons



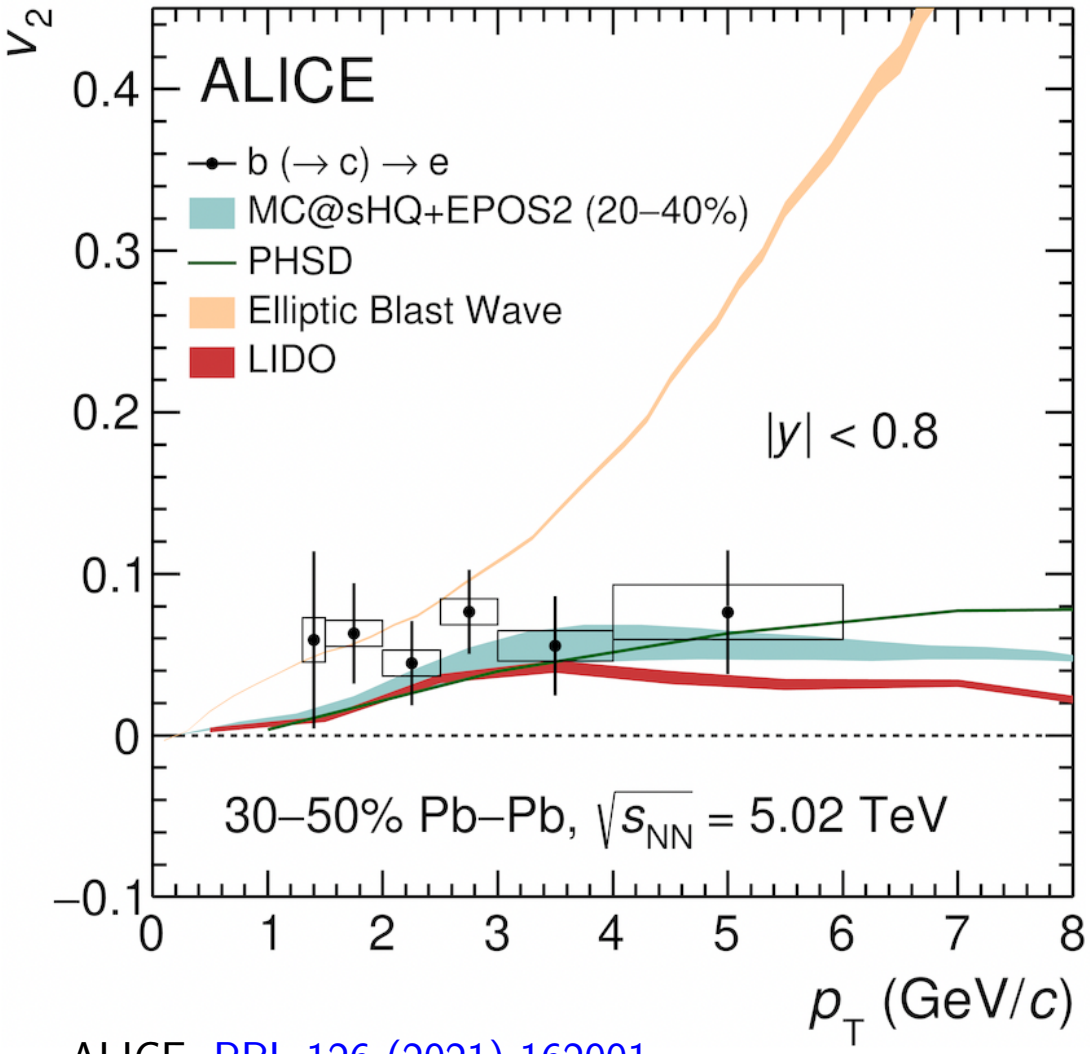


Comparison to data: talk by L. Vermunt, Friday, T11

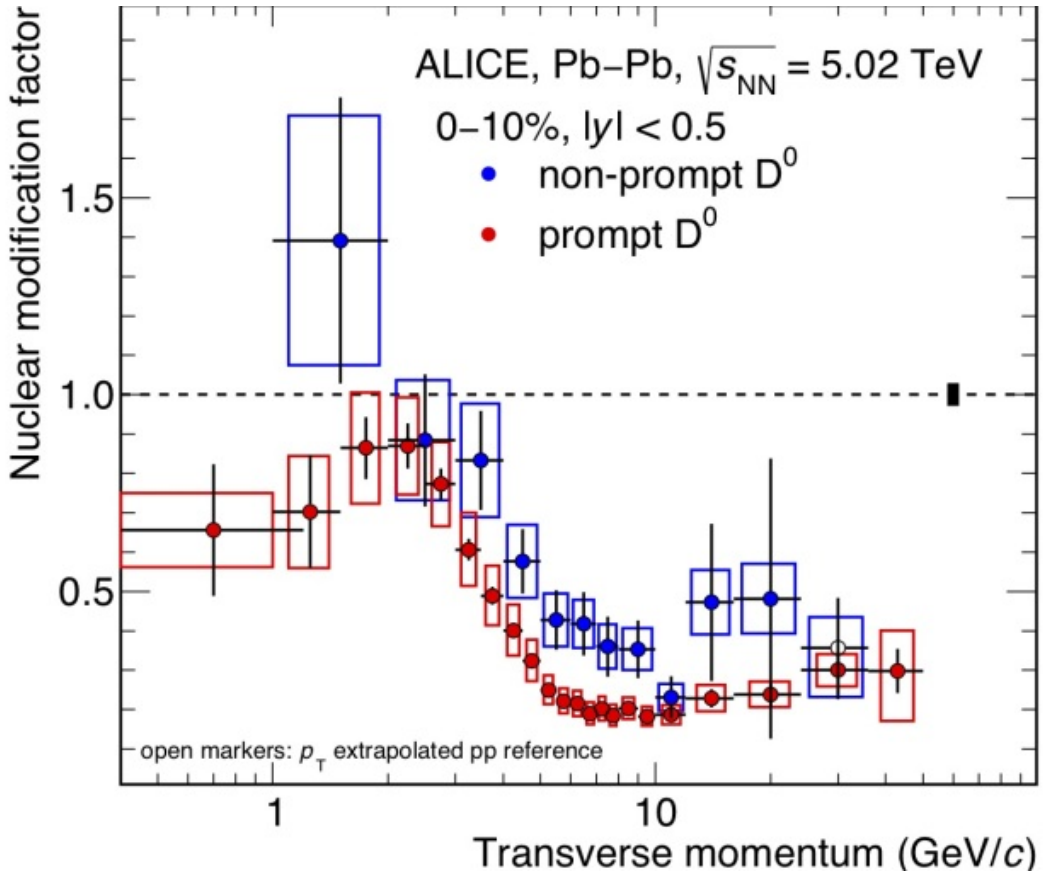
AA et al, JHEP 07 (2021) 035 (Updated slightly)

$$\frac{\mathrm{d}N_{c\bar{c}}}{\mathrm{d}y} = 13.8$$

Beauty quark thermalization?



ALICE, PRL 126 (2021) 162001



ALICE, arXiv:2202.00815, ATLAS

definitely strong flow but clearly less strong than for charm (CMS, QM'22, HIN-21-003)

...and a strong coupling with the medium (less energy loss than charm, $p_T \simeq 10$ GeV/c)

SHM for beauty (SHMb): method and inputs

- Thermal model calculation (grand canonical) T,μ_B: $\rightarrow n_X^{th}$
- $N_{b\bar{b}}^{dir} = \frac{1}{2} g_b V (\sum_i n_{B_i}^{th} + n_{\Lambda_{b,i}}^{th}) + g_b^2 V (\sum_i n_{\Upsilon_i}^{th} + n_{\chi_{b,i}}^{th})$
- $N_{b\bar{b}} \ll 1 \rightarrow$ Canonical (J.Cleymans, K.Redlich, E.Suhonen, Z. Phys. C51 (1991) 137):

$$N_{b\bar{b}}^{dir} = \frac{1}{2} g_b N_{ob}^{th} \frac{I_1(g_b N_{ob}^{th})}{I_0(g_b N_{ob}^{th})} + g_b^2 N_{b\bar{b}}^{th} \quad \rightarrow g_b \text{ (beauty fugacity)}$$

Outcome: $N_B = g_b V n_B^{th} I_1/I_0 \quad N_\Upsilon = g_b^2 V n_\Upsilon^{th}$

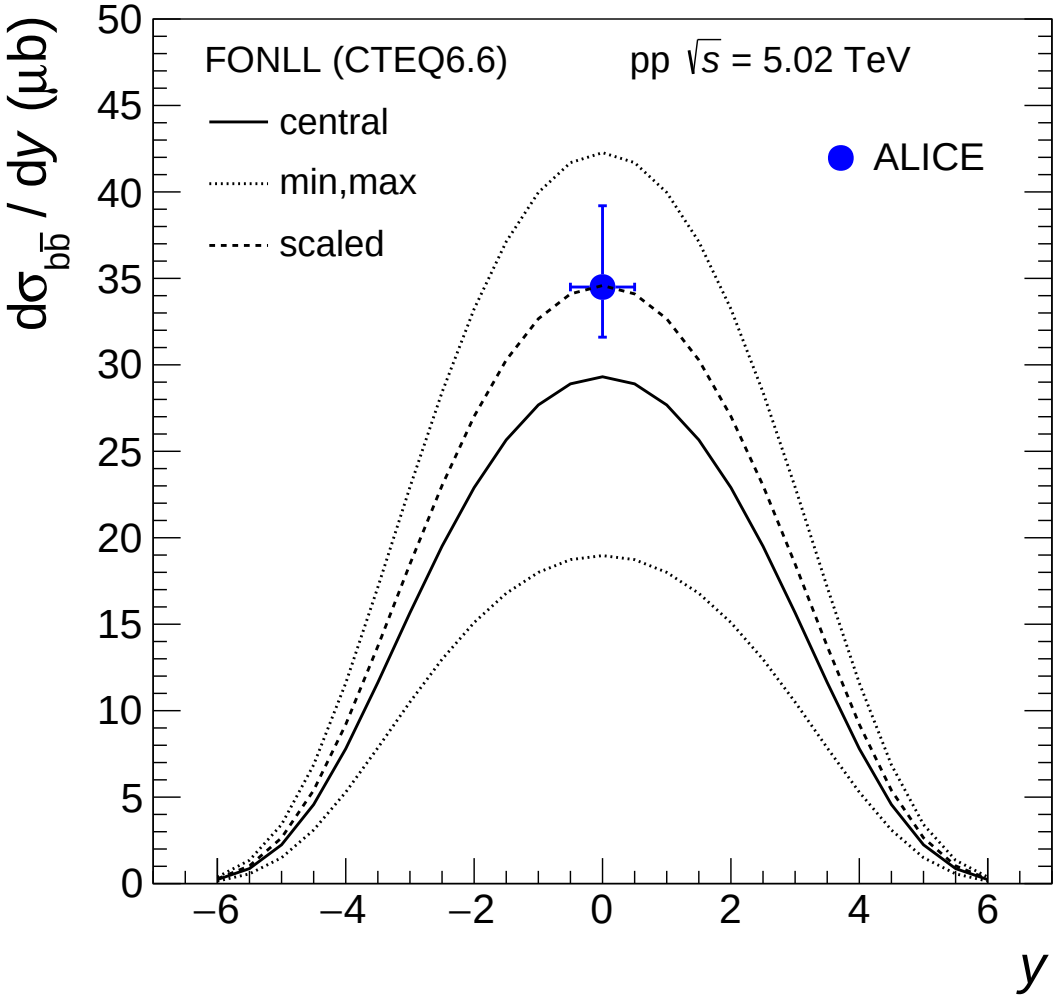
Inputs: T, μ_B, $V_{\Delta y=1} (= (\mathrm{d}N_{ch}^{exp}/\mathrm{d}y)/n_{ch}^{th})$, $N_{b\bar{b}}^{dir}$ (exp. and pQCD)

Assumed minimal volume for QGP: V_{QGP}^{min}=200 fm^3

The beauty production cross section $\mathrm{d}\sigma_{\mathrm{b\bar{b}}}/\mathrm{d}y$

A. Andronic

ALICE, JHEP 05 (2021) 220: $\frac{\mathrm{d}\sigma_{\mathrm{b\bar{b}}}}{\mathrm{d}y} = 34.5 \pm 2.4(stat)^{+4.7}_{-2.9}(tot.syst)\mu\mathrm{b}$



FONLL, Cacciari et al., JHEP 1210 (2012)

scaling for y=2.5–4

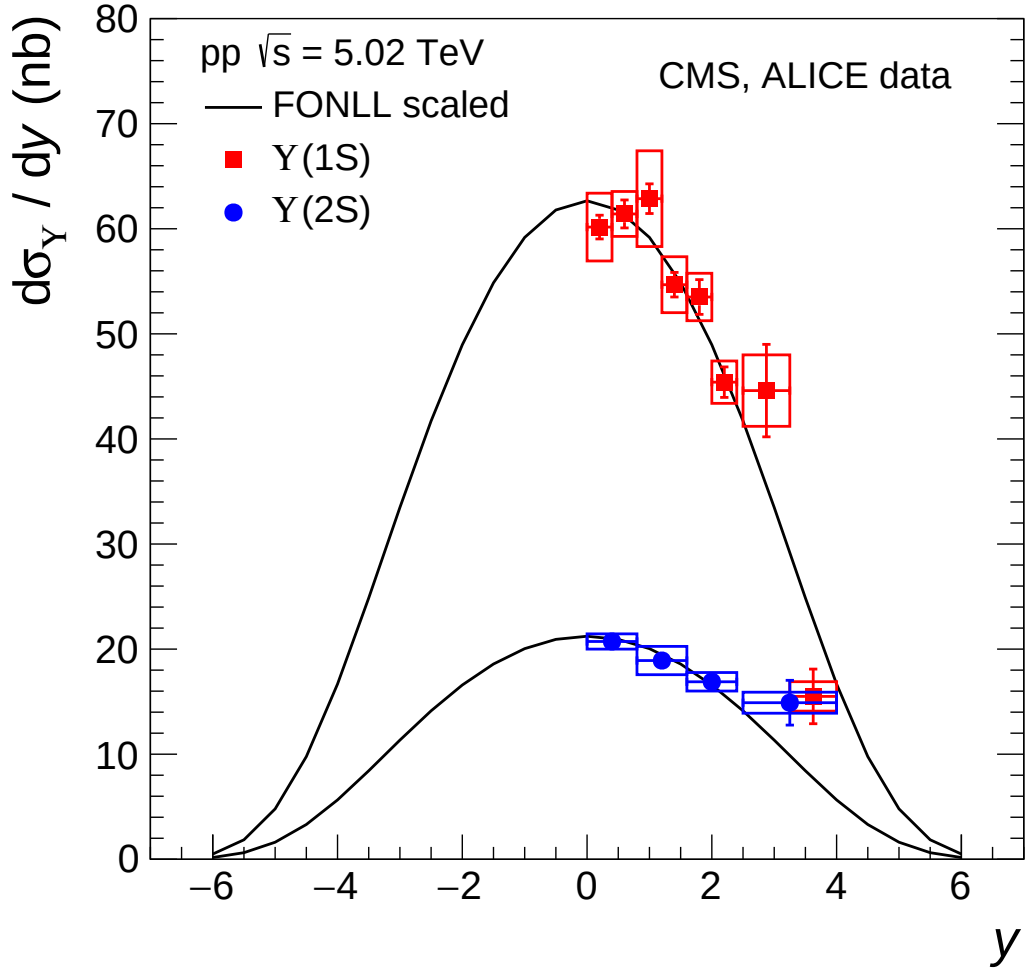
Shadowing: 0.7, independent on y

$y = 0 : \frac{\mathrm{d}N_{\mathrm{b\bar{b}}}}{\mathrm{d}y} = 0.57$

$\pm$20% total uncertainty

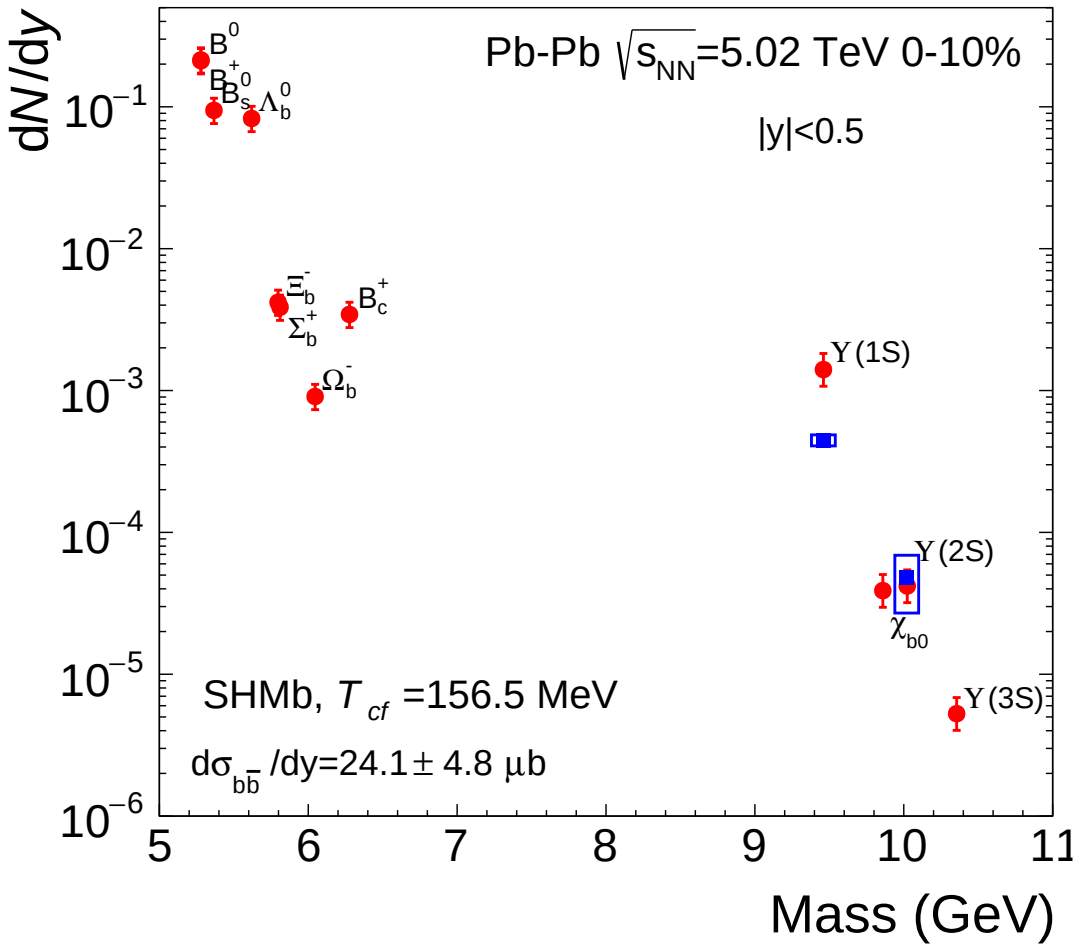
All produced anew ...no Υ state survives in QGP (extreme for $\Upsilon(1S)$?)

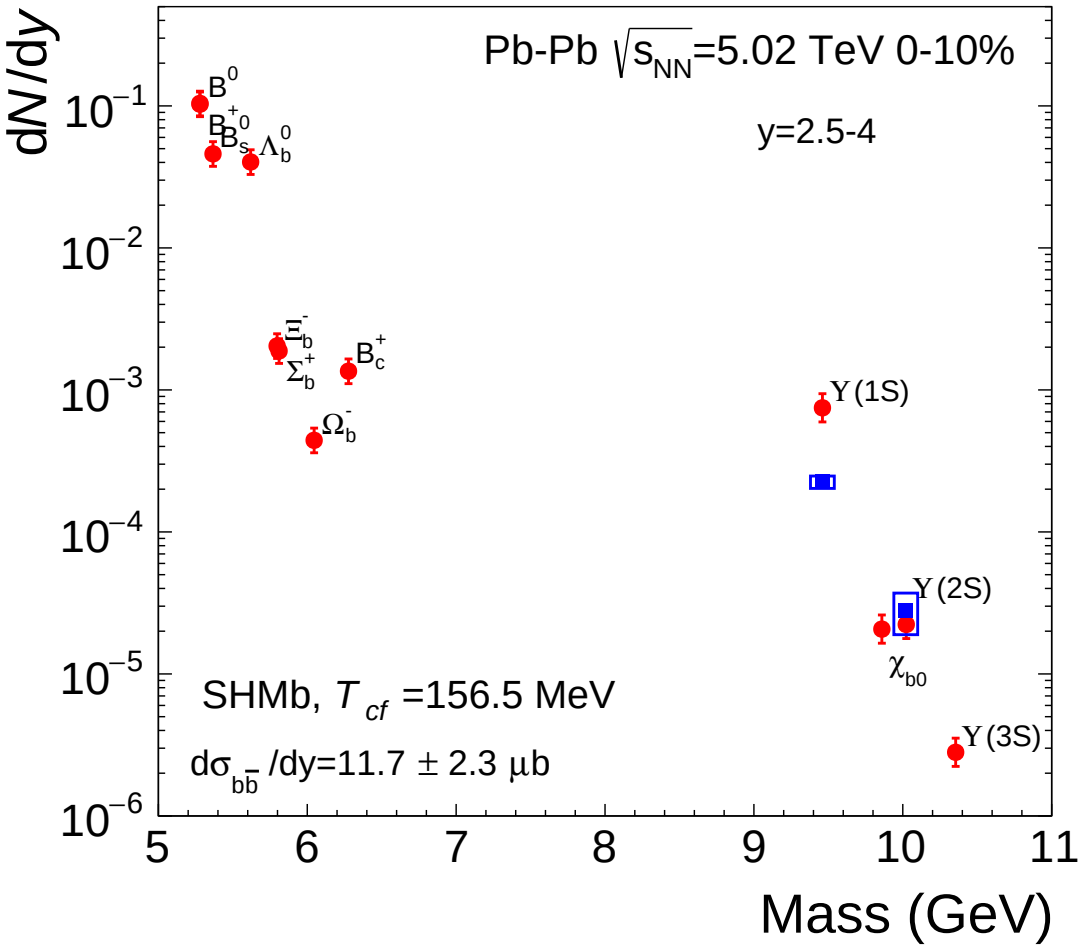
Core(SHMb)-corona with pp data input CMS, PLB 790 (2019) 270, ALICE, arXiv:2109.15240



SHMb: the beauty zoo (0-10%)

A. Andronic





$$g_b = 1.05 \cdot 10^9$$

$$B_c : \ 3.44 \cdot 10^{-3}$$

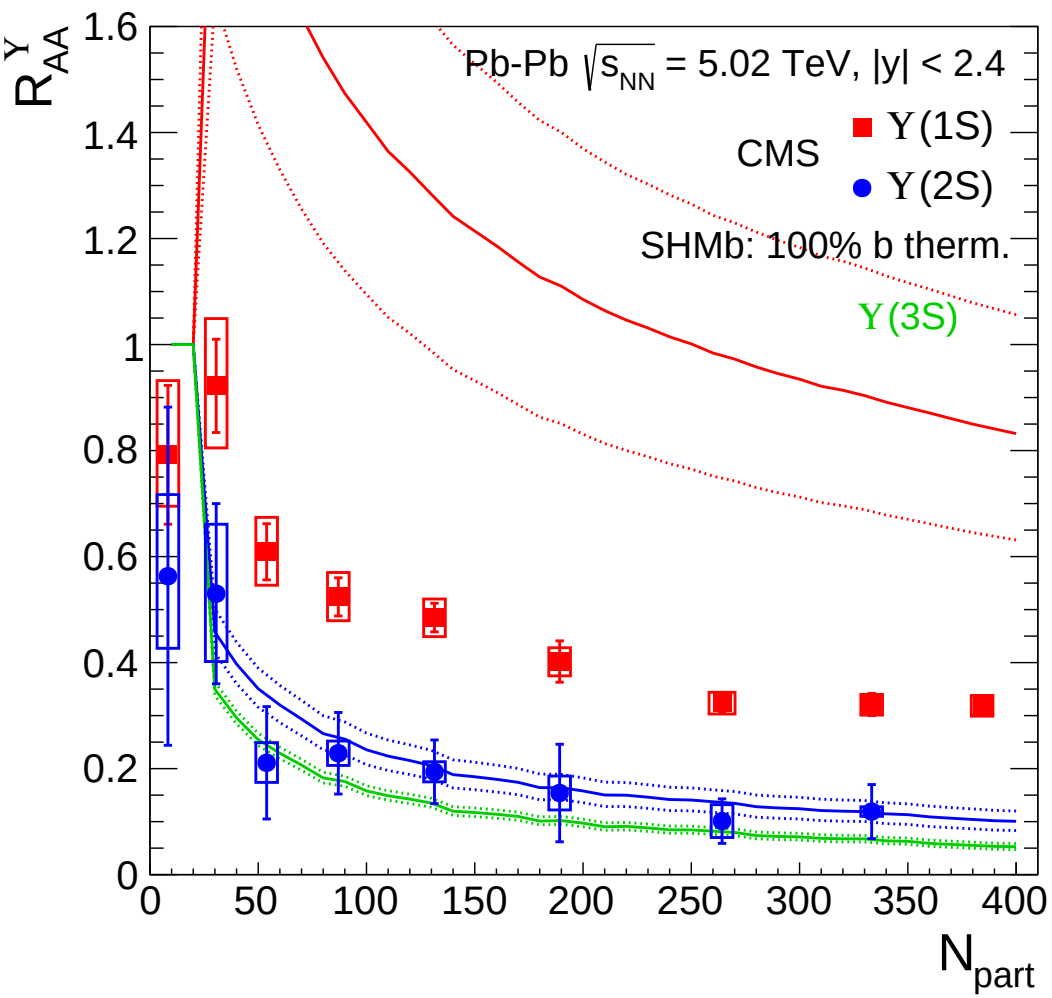
$$g_b = 0.86 \cdot 10^9$$

$$B_c : \ 1.36 \cdot 10^{-3}$$

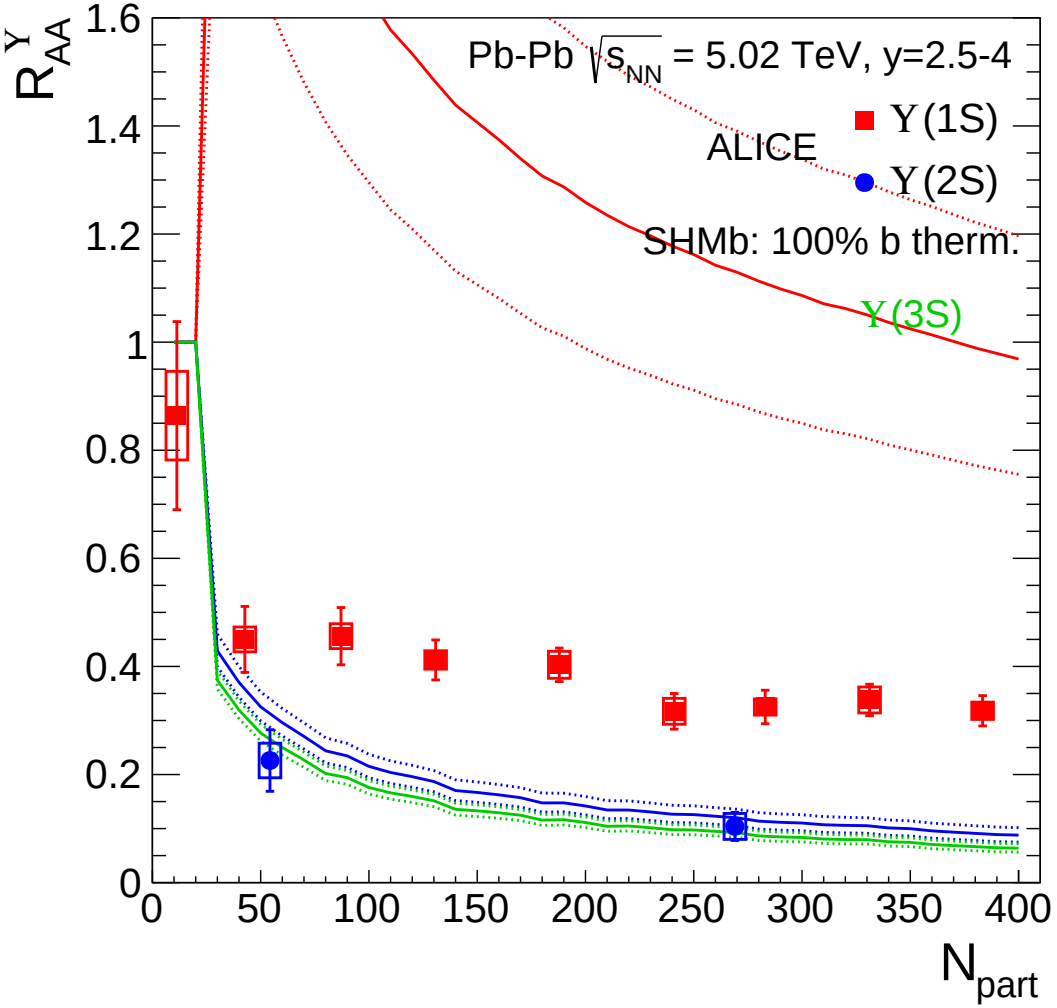
Blue: Υ data (CMS, ALICE): calc. based on R_{AA} and pp (would be nice to include in publications $\mathrm{d}N/\mathrm{d}y$)

R_{AA}, 100% $b\bar{b}$ thermalized

A. Andronic



CMS, PRL 120 (2018) 142301

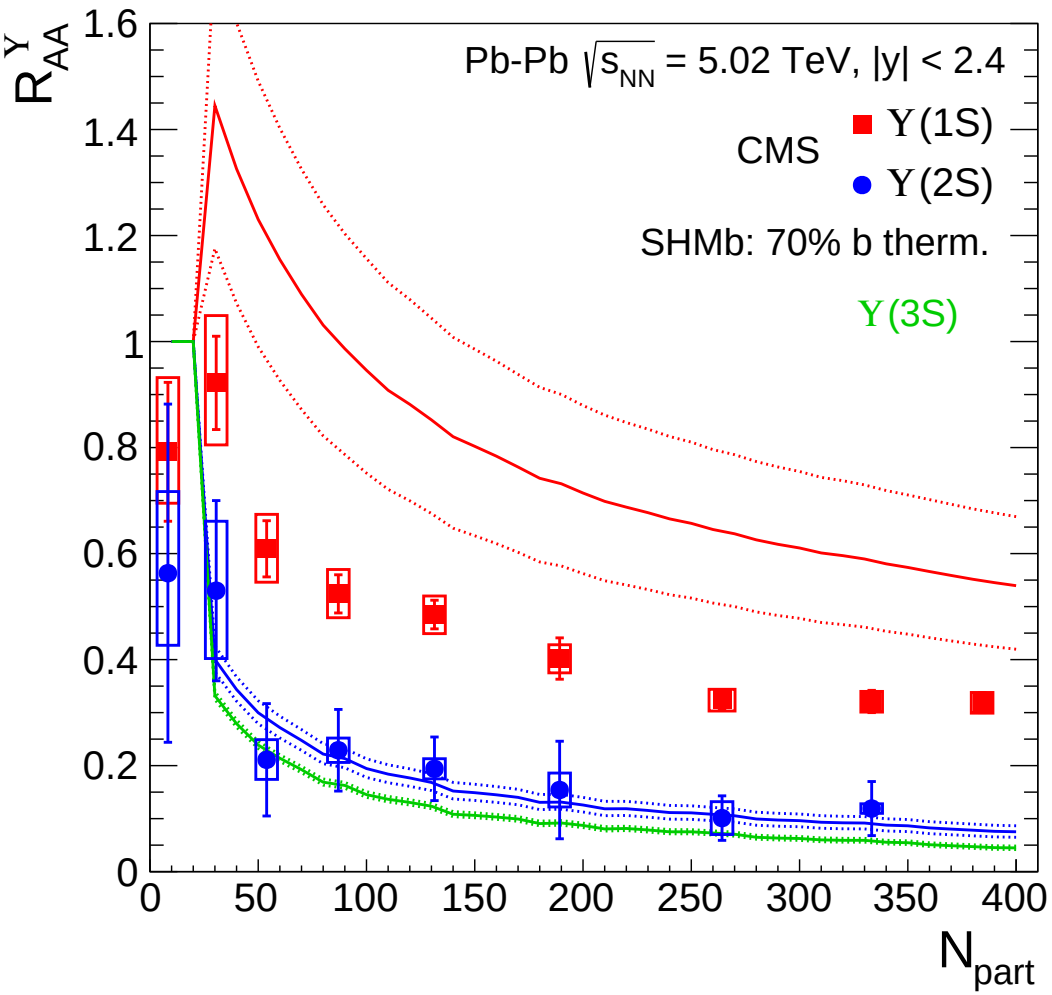


ALICE, PLB 822 (2021) 136579

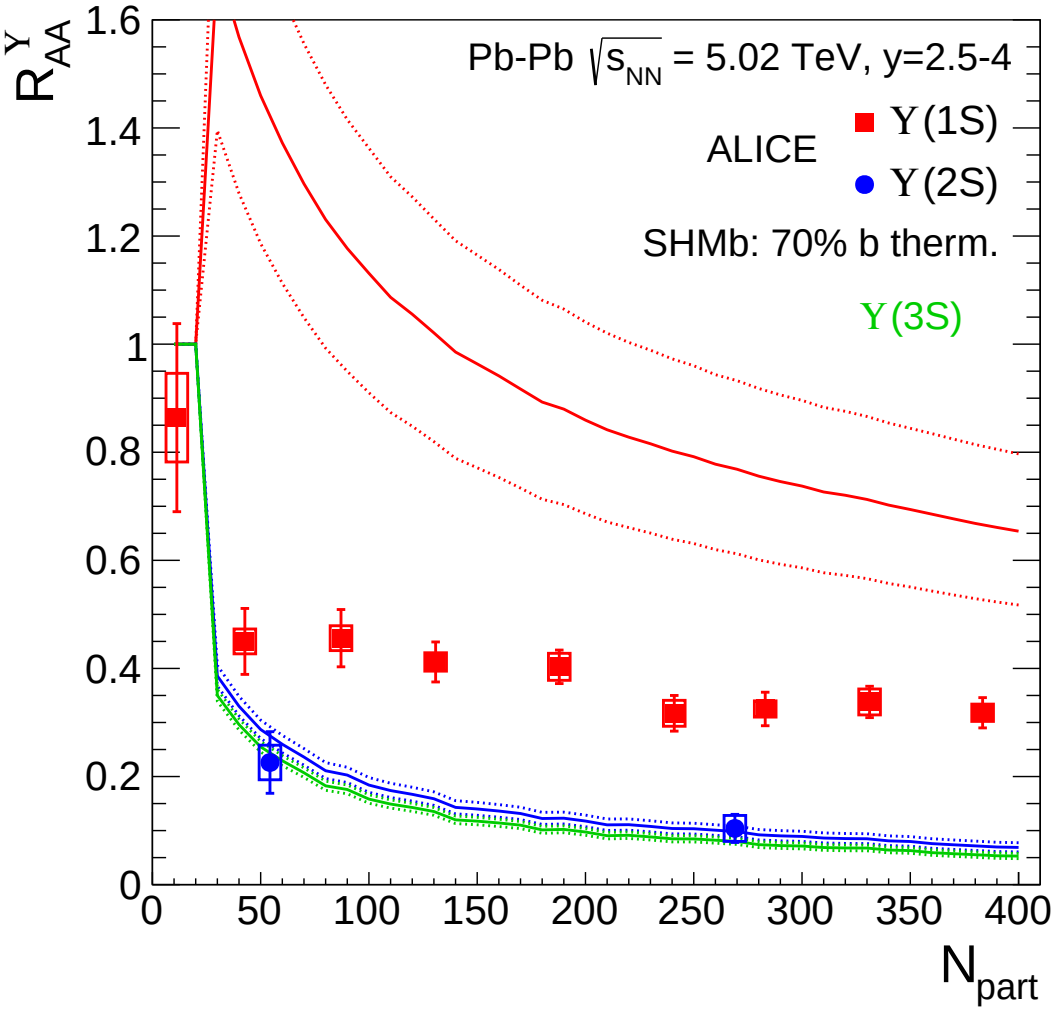
Clearly, full beauty thermalization seems not realized in nature

R_{AA}, 70% $b\bar{b}$ thermalized

A. Andronic



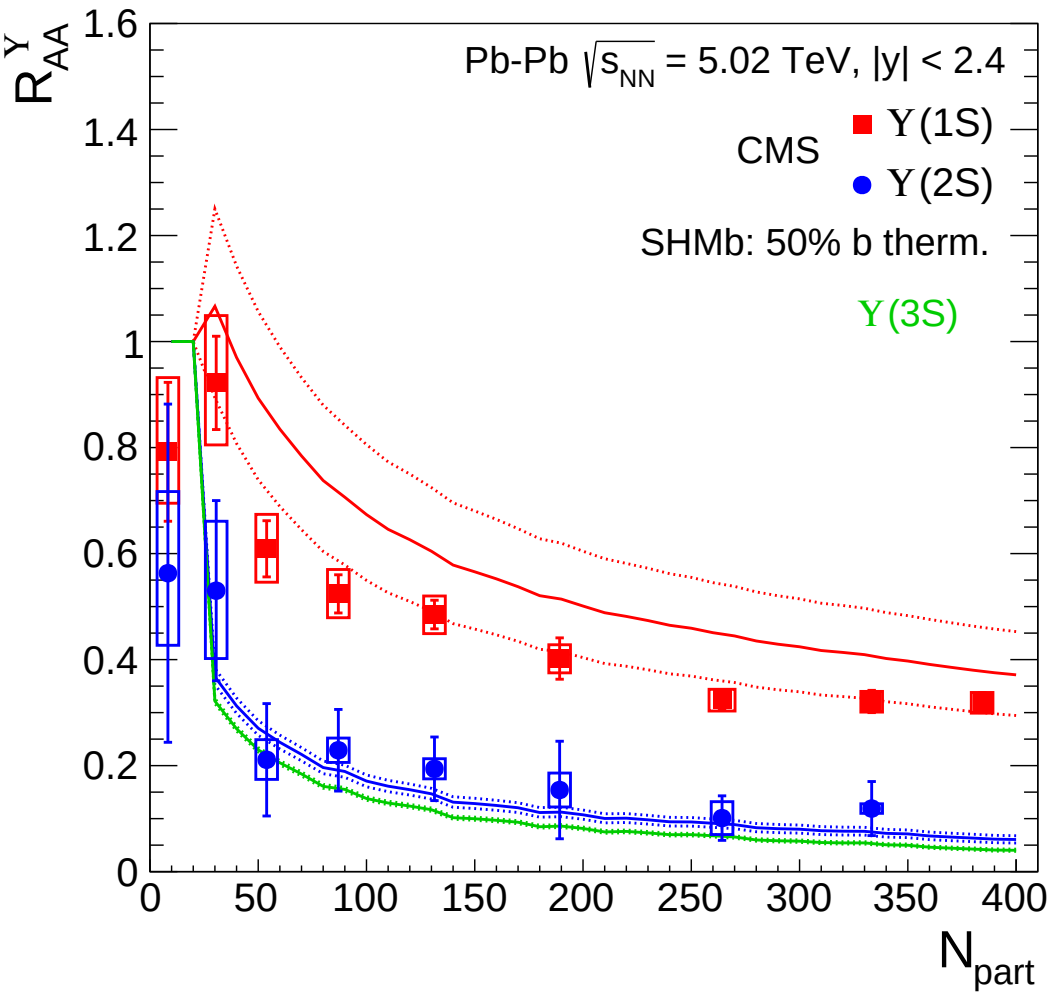
CMS, PRL 120 (2018) 142301



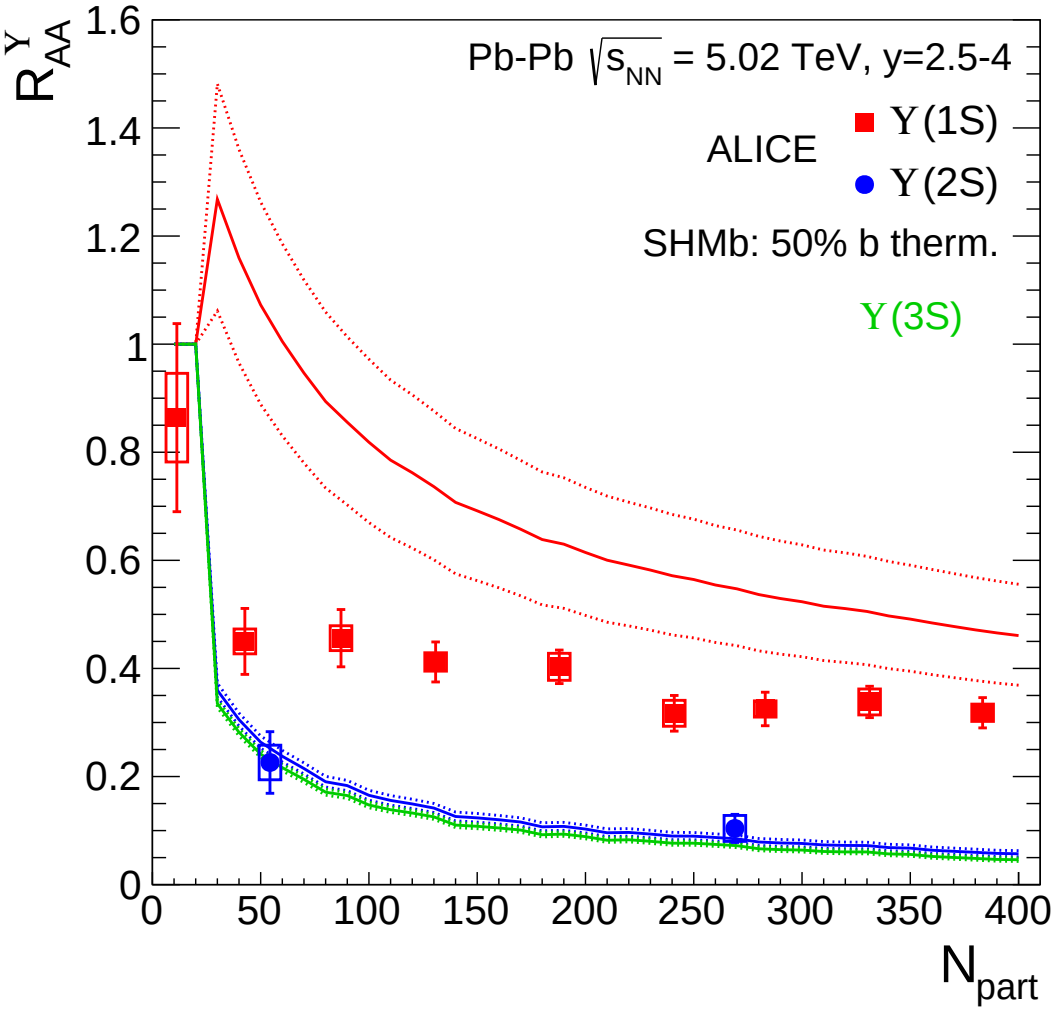
ALICE, PLB 822 (2021) 136579

R_{AA}, 50% $b\bar{b}$ thermalized

A. Andronic



CMS, PRL 120 (2018) 142301

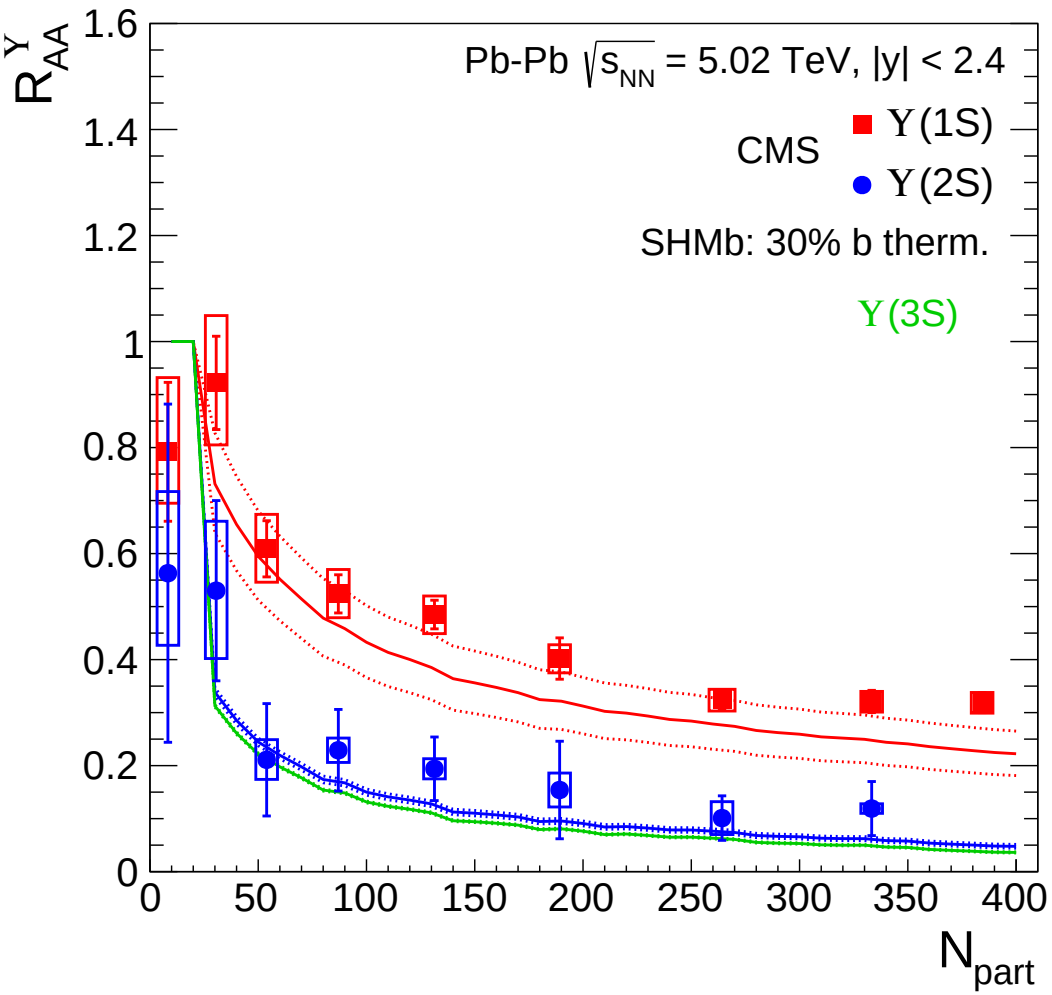


ALICE, PLB 822 (2021) 136579

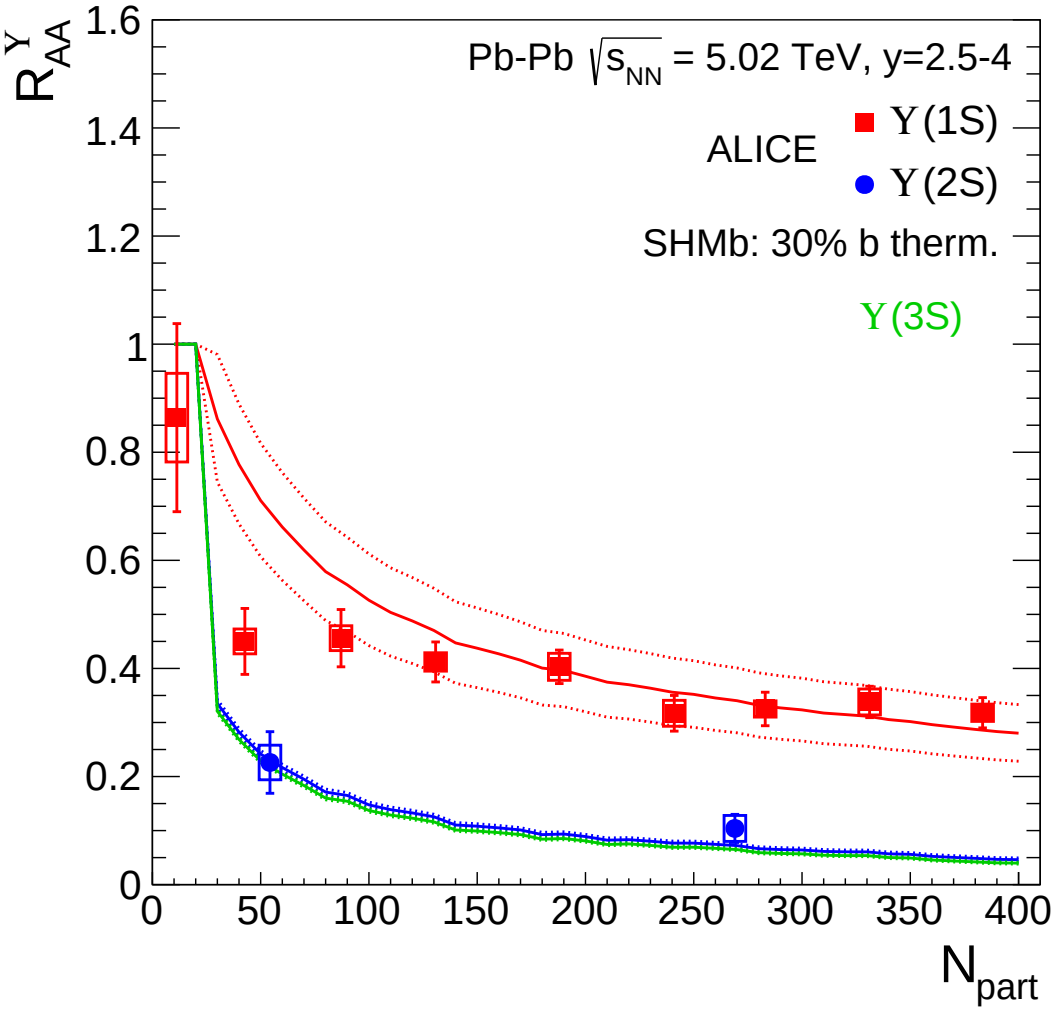
What does non-thermalized beauty produce? (no room for it in SHMb)

R_{AA}, 30% $b\bar{b}$ thermalized

A. Andronic



CMS, PRL 120 (2018) 142301

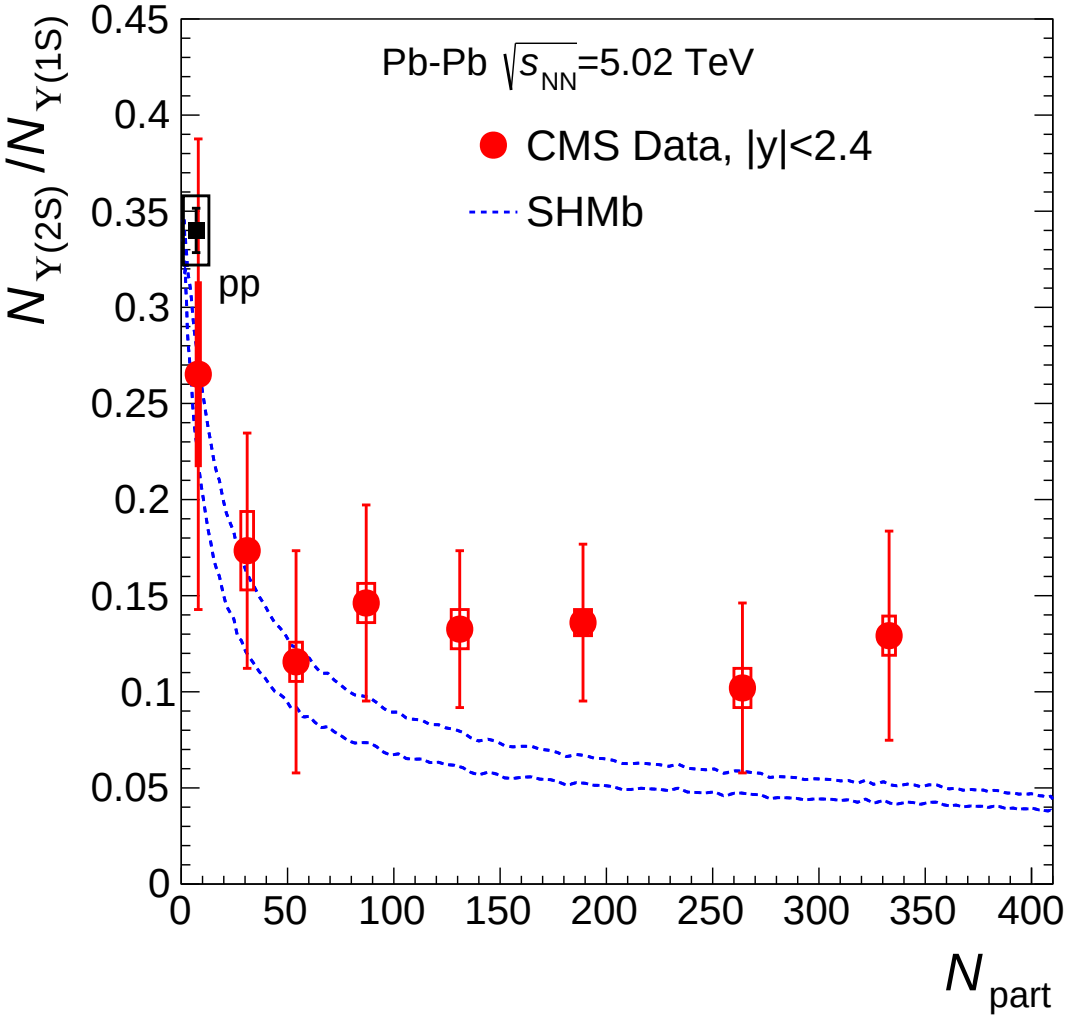


ALICE, PLB 822 (2021) 136579

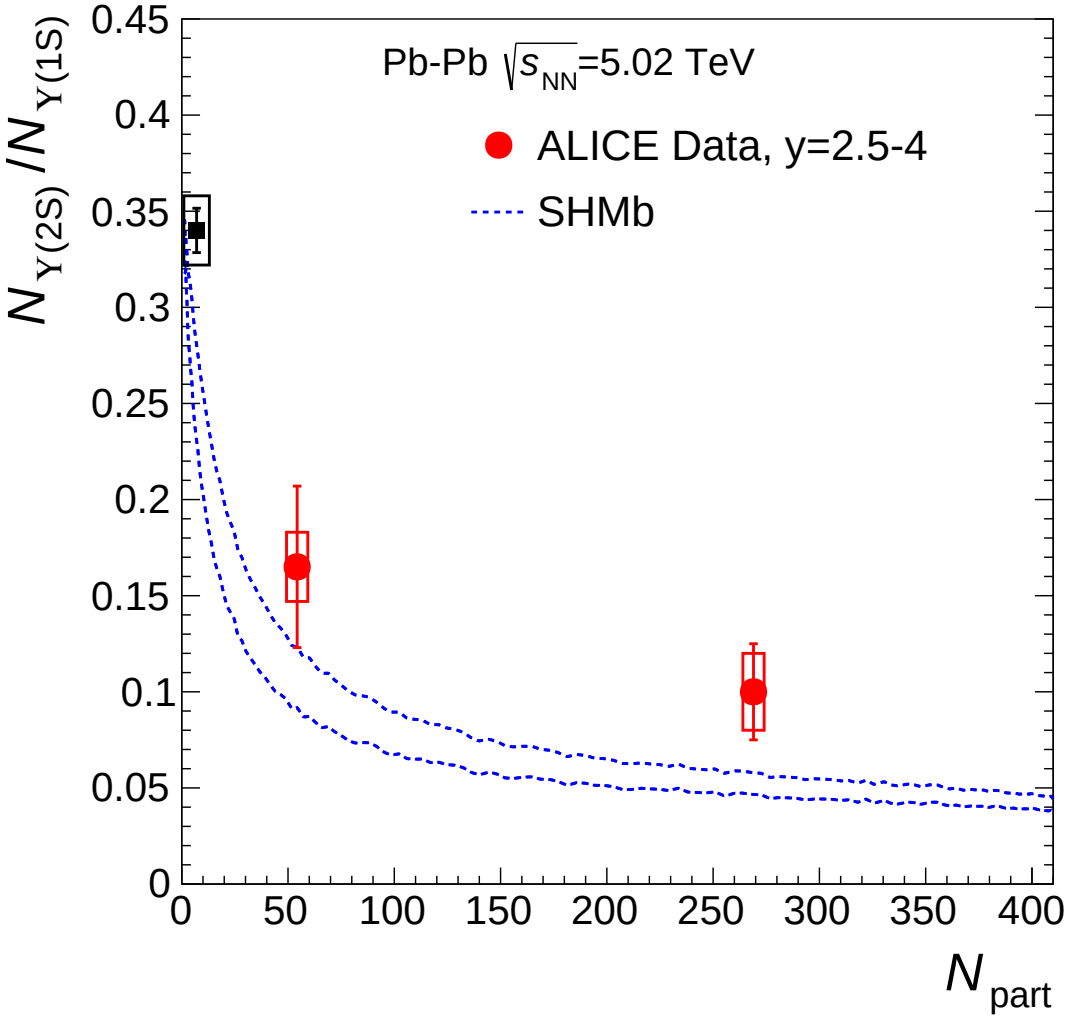
What does non-thermalized beauty produce? (no room for it in SHMb)

$\Upsilon(2S)/\Upsilon(1S)$ ratio (100% b thermalization)

A. Andronic



CMS, PRL 120 (2018) 142301



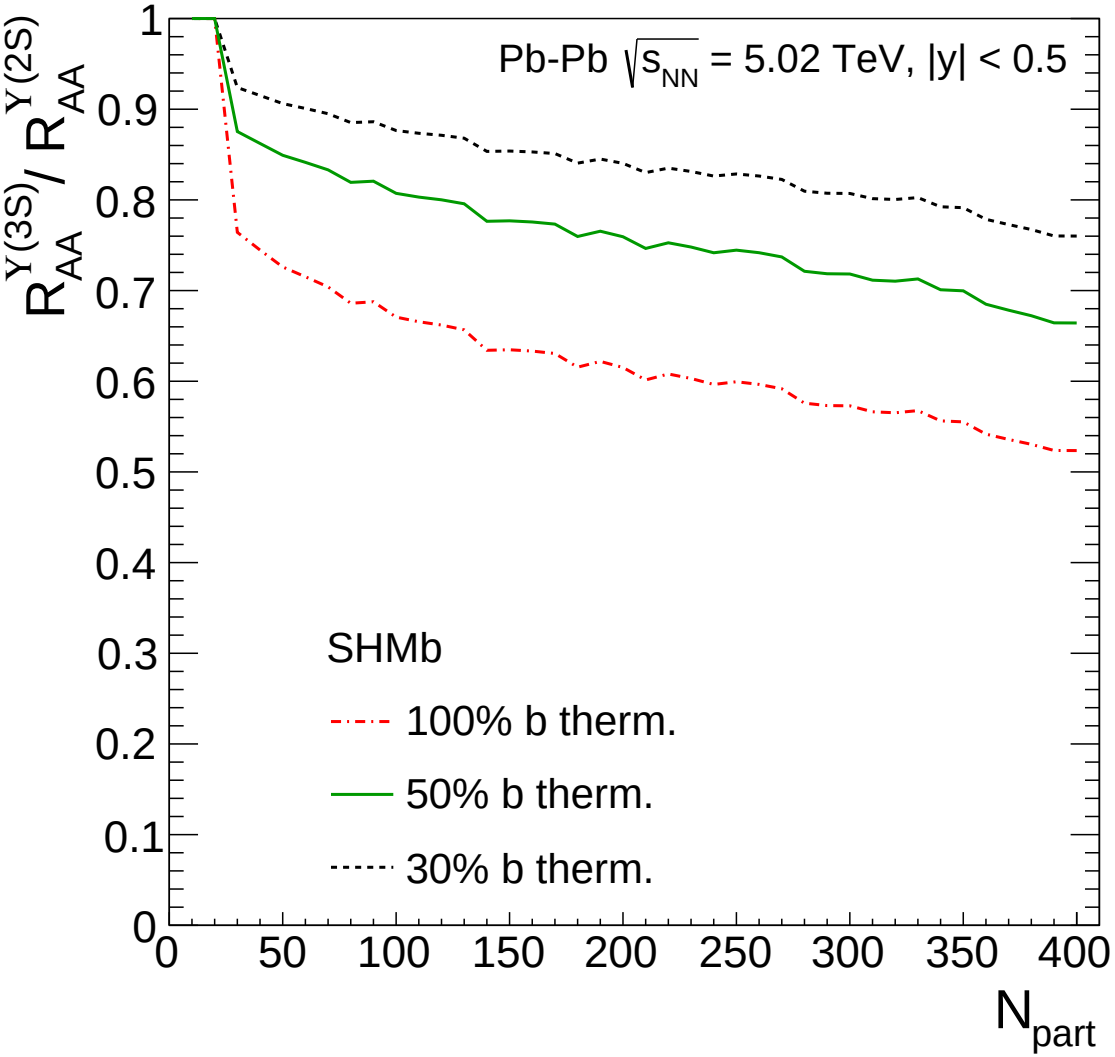
ALICE, PLB 822 (2021) 136579

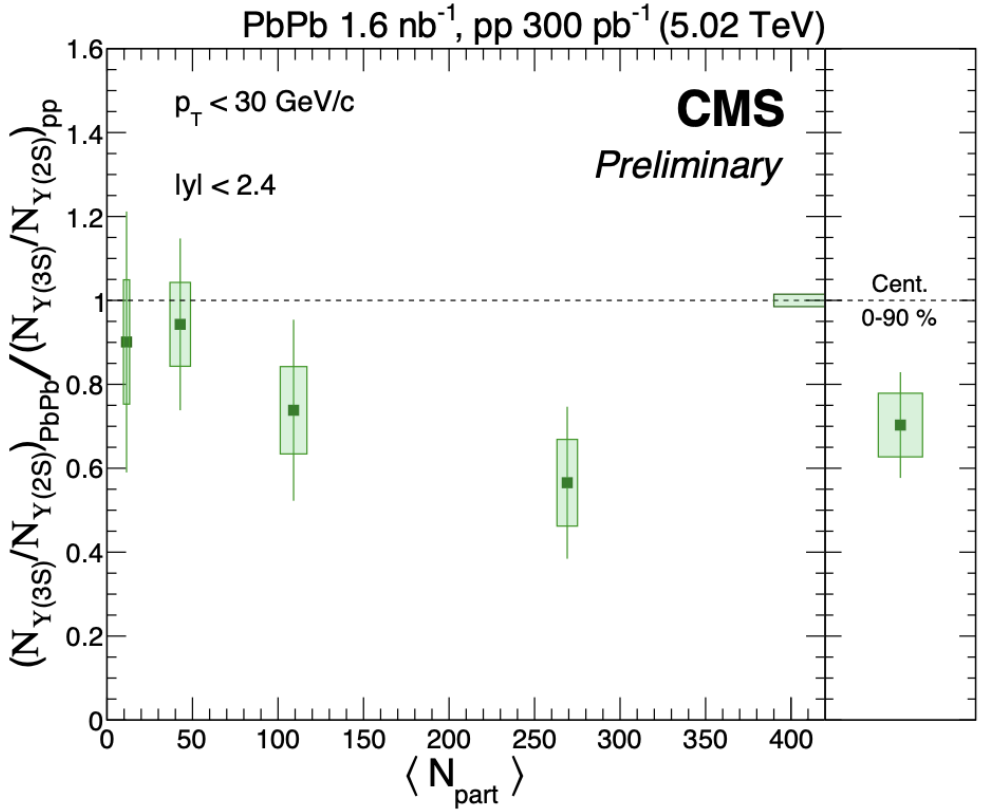
ALICE pp: $\Upsilon(2S)/\Upsilon(1S) = 0.5 \pm 0.1$, arXiv:2109.15240

SHMb uncert.: corona (fraction)

$\Upsilon(3S)/\Upsilon(2S)$ R_{AA} ratio

A. Andronic



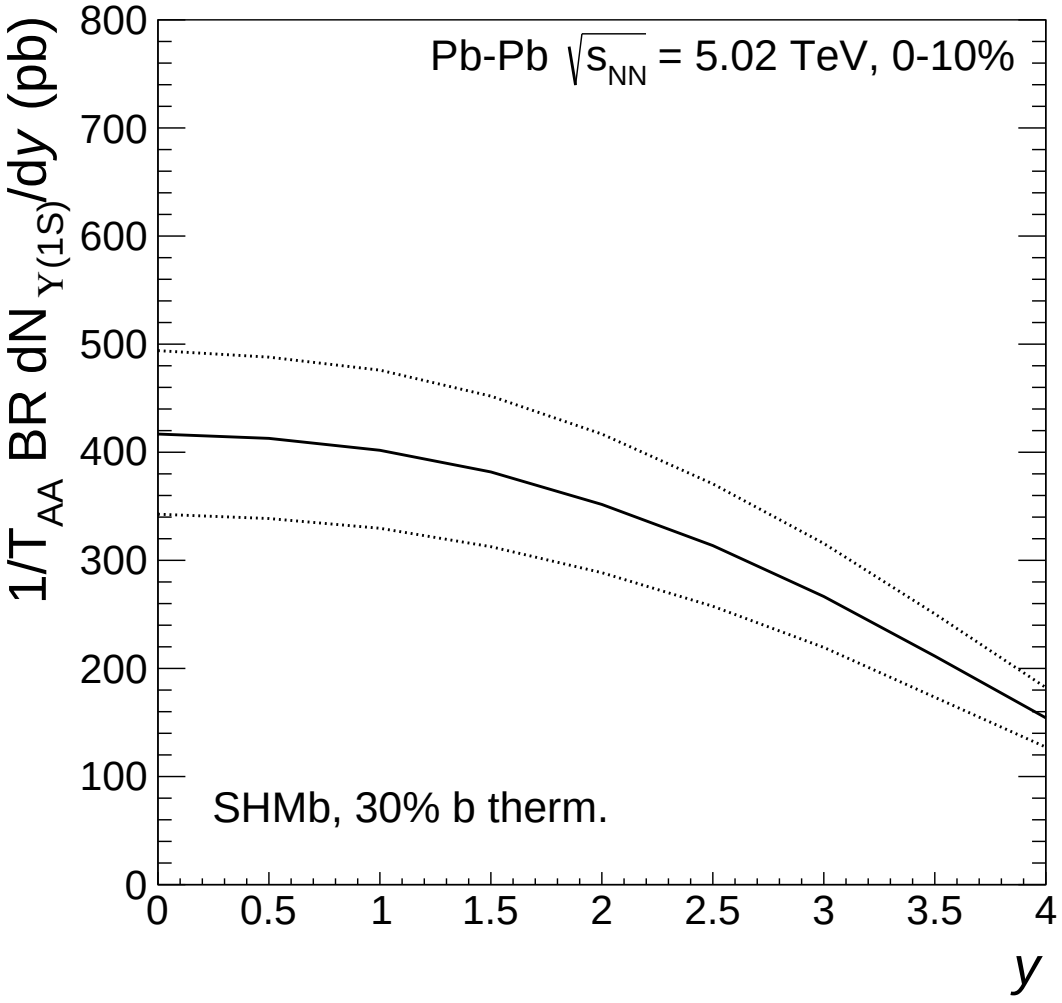


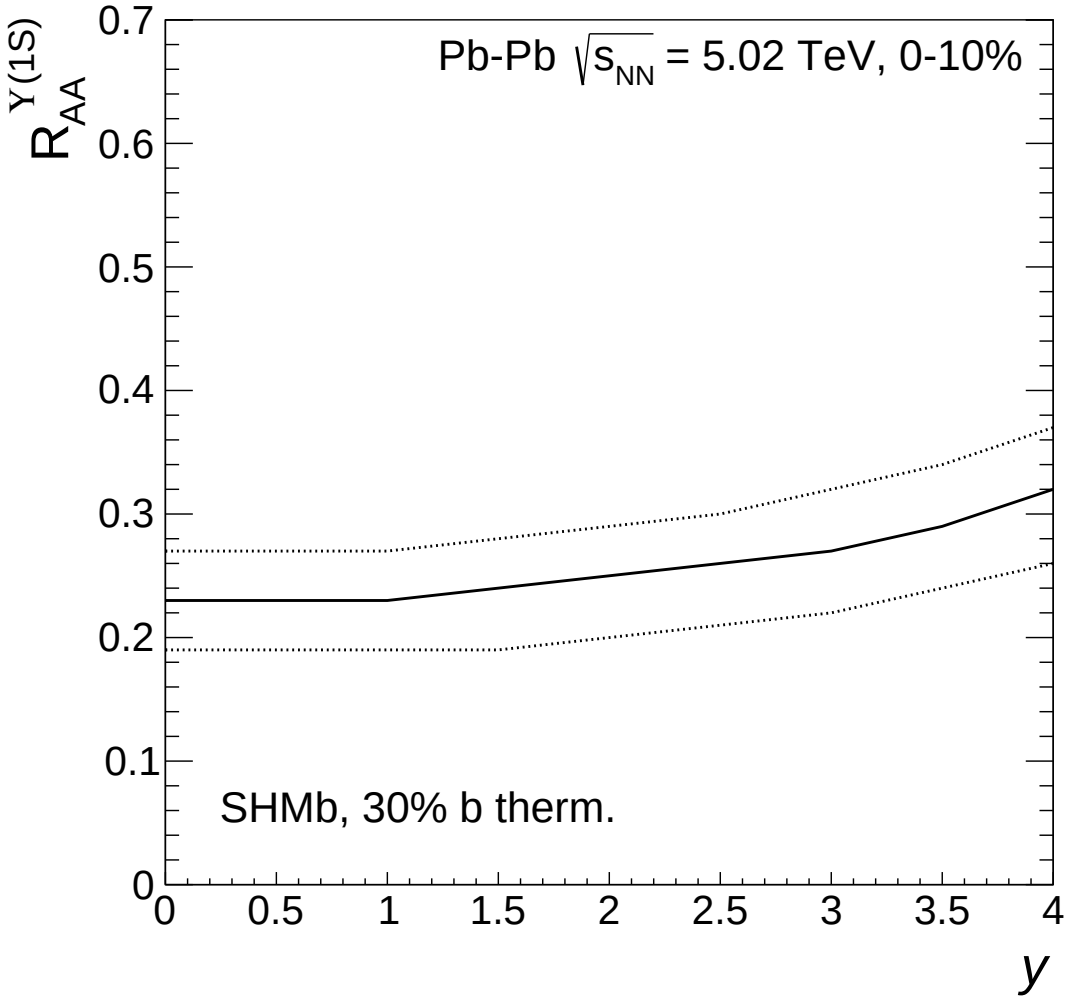
CMS, QM'22, HIN-21-007

The $\Upsilon(3S)/\Upsilon(2S)$ R_{AA} ratio is quite sensitive to the degree of b thermalization

Rapidity dependence $\Upsilon(1S)$, 30% $b\bar{b}$ thermalized

A. Andronic



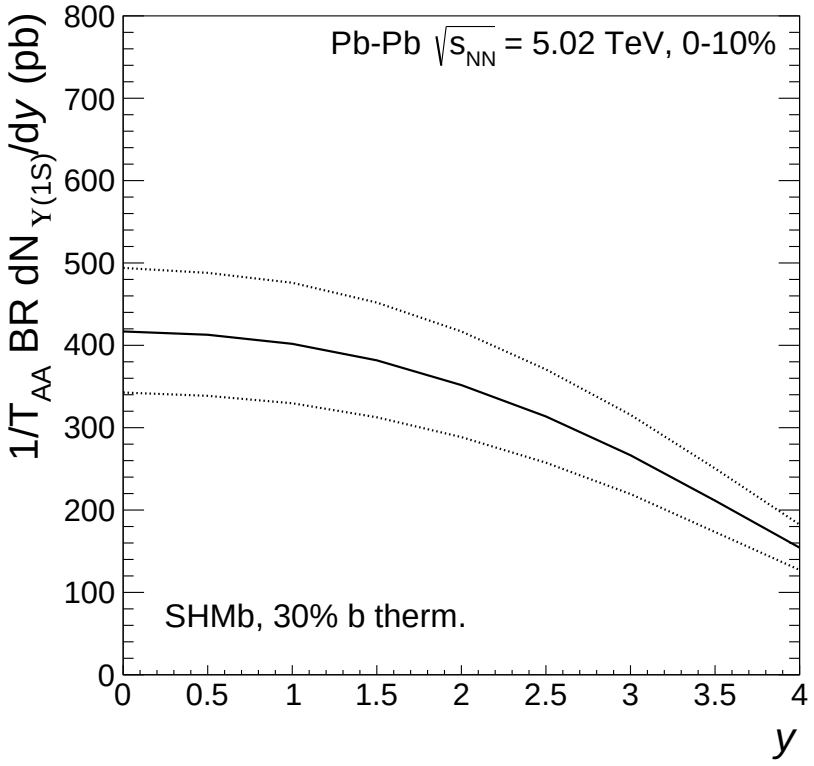


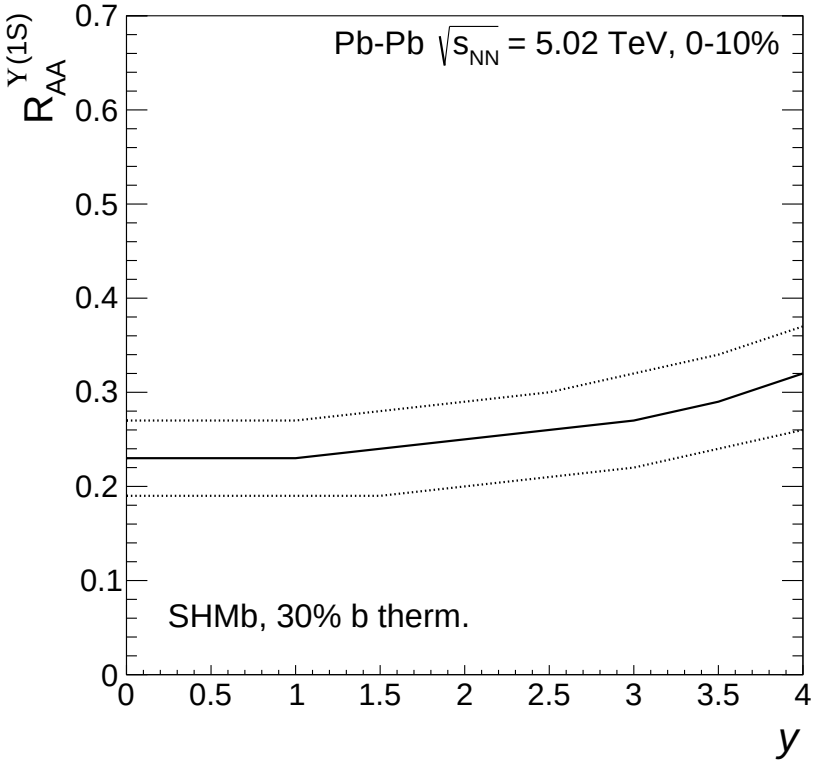
Data available only centrality-integrated ...is 0-10% (or 0-20%) doable?

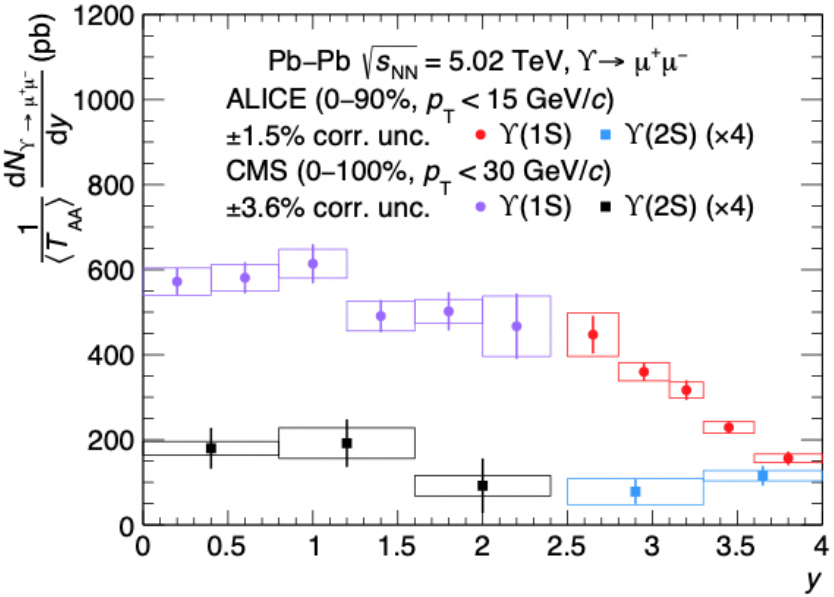
CMS, PRL 120 (2018) 142301; ALICE, PLB 822 (2021) 136579

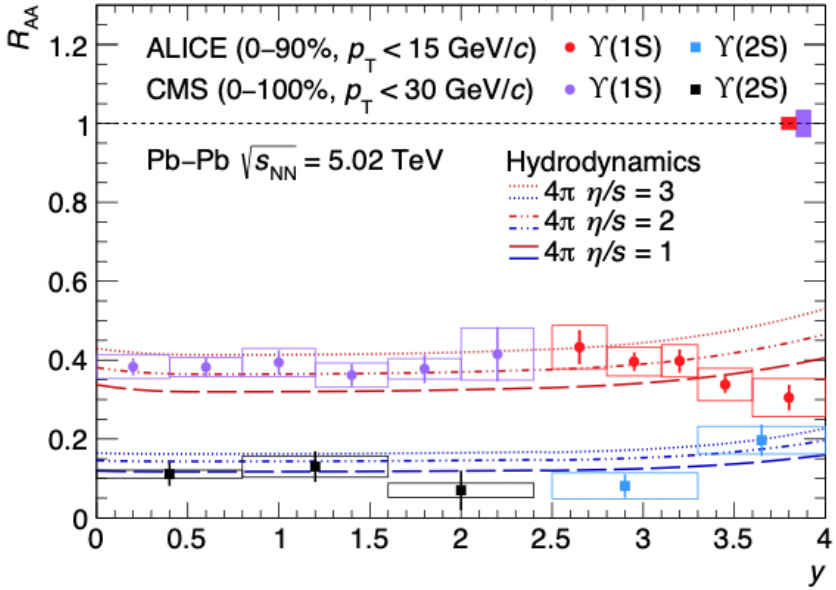
Rapidity dependence $\Upsilon(1S)$, 30% $b\bar{b}$ thermalized

A. Andronic





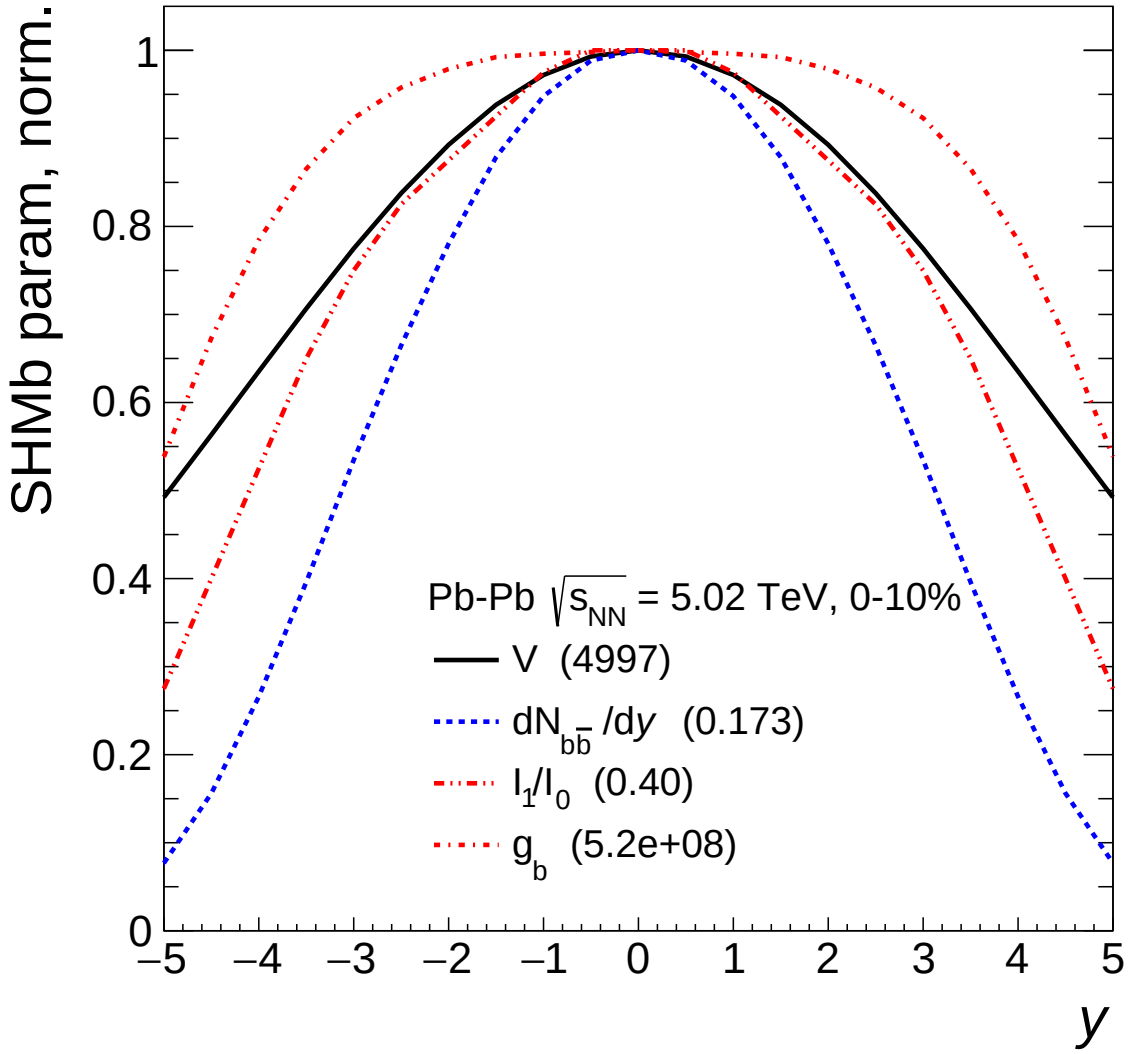




ALICE, PLB 822 (2021) 136579, CMS, PRL 120 (2018) 142301

SHMb parameters

NB: none is a free parameter, except the 30% b thermalization fraction



Summary and conclusions

- SHMb can predict the full suite of beauty hadrons
- Full beauty thermalization seems not realized in nature
  ...with 30-50% of beauty quarks fully thermalized we can explain the Υ data
- What does non/partially-thermalized beauty produce?
  no Υ because strong coupling with the medium destroys the b-$\bar{b}$ correlation?
  ...related: is there non-screened bottomonium at all? (...or maybe just $\Upsilon(1S)$?)
- Another difficulty: $R_{AA}^{Y(1S)}(p_T)$ is flat (we would predict a bump), v_2 is small

similar to Reygers et al., PRC 101 (2020) 064905

forthcoming LHC data will (hopefully) clarify these questions (...in a while)