Probing X(3872) structure via final state interactions

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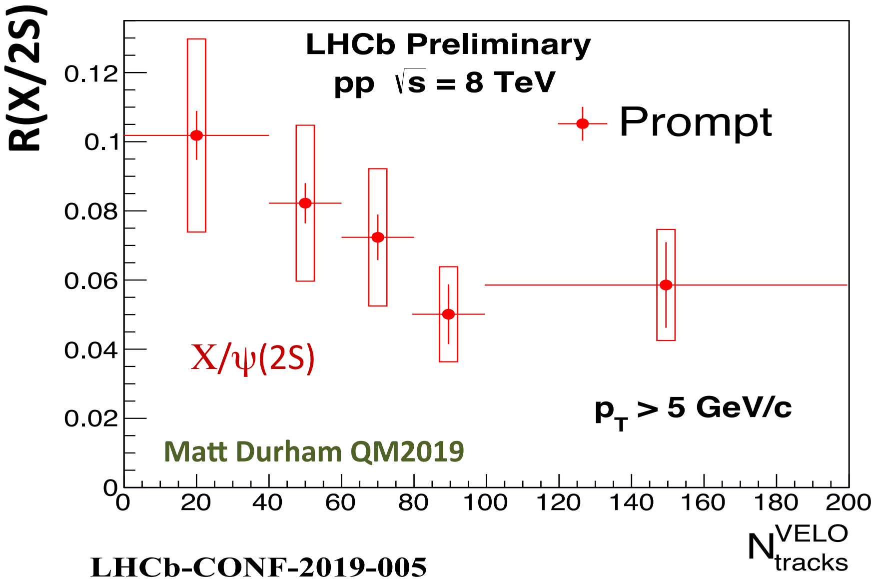
Motivation: the nature of the X(3872)

- Motivation: recent LHCb results on X(3872) versus multiplicity



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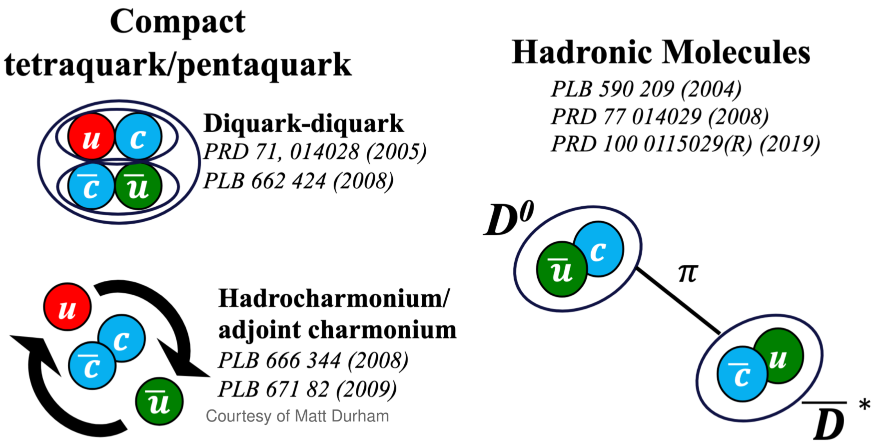
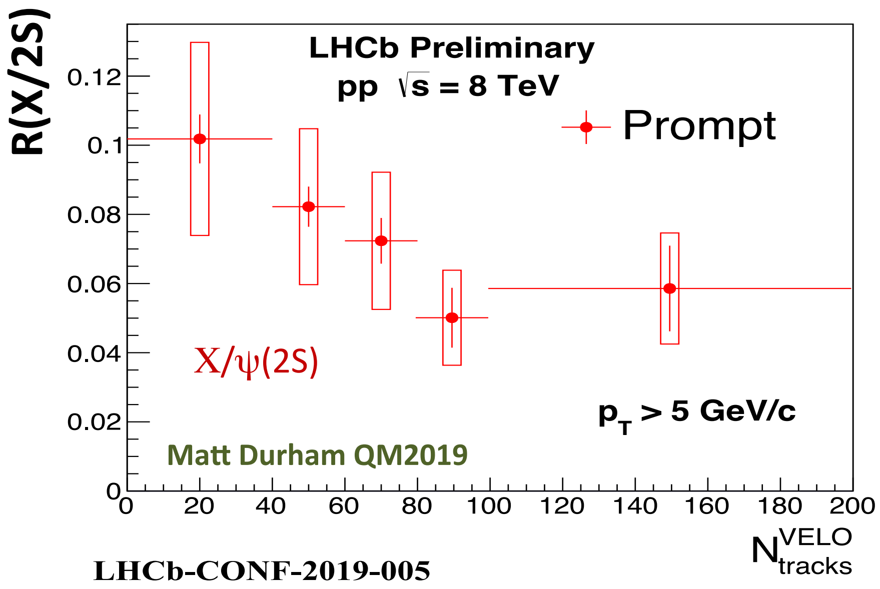
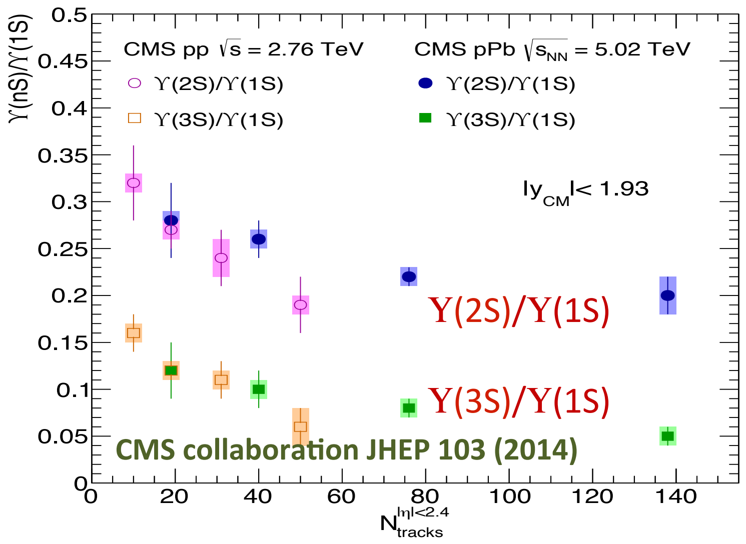


The nature of the X(3872): comparison with Υ(nS)/Υ(1S)

- In fact, the effect found by LHCb is similar to the one previously found for Υ by CMS





The nature of the X(3872): comparison with ψ(2S)/J/ψ

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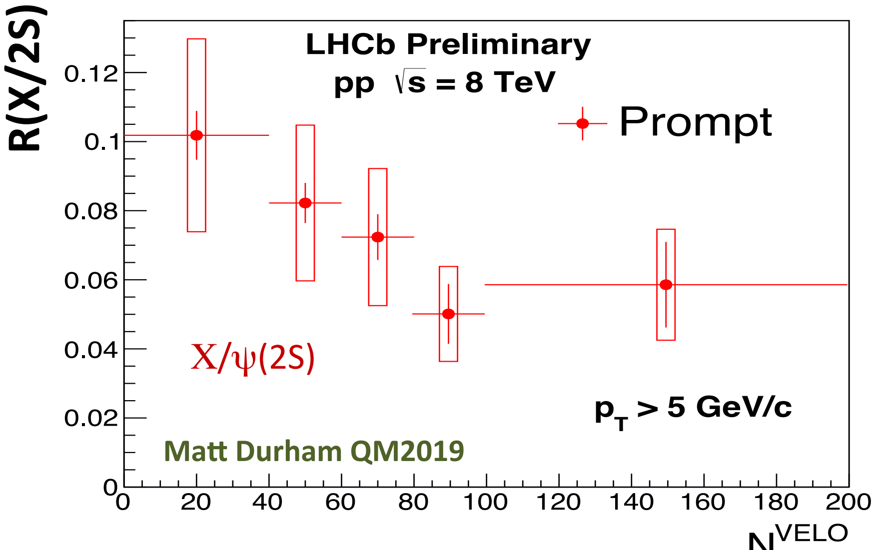

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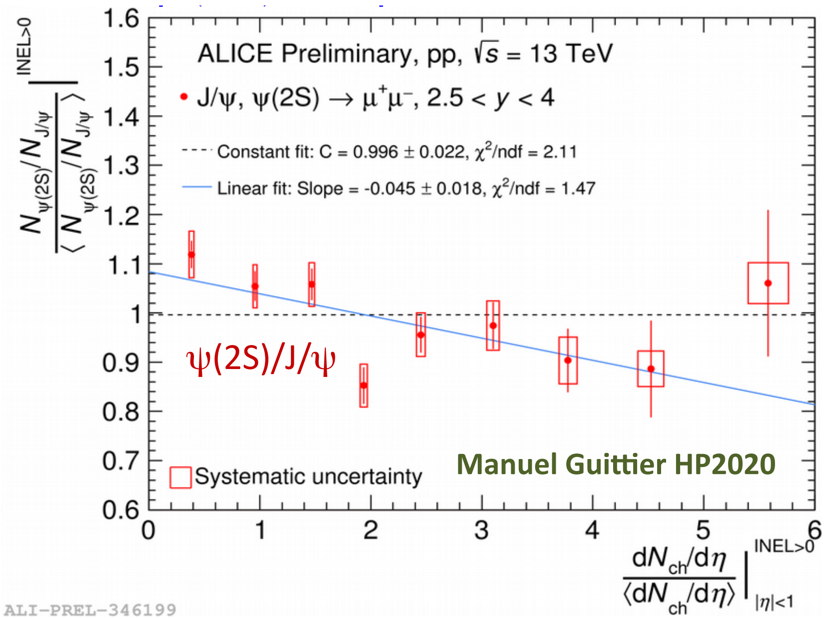

The nature of the X(3872): comparison with $\psi(2S)/J/\psi$

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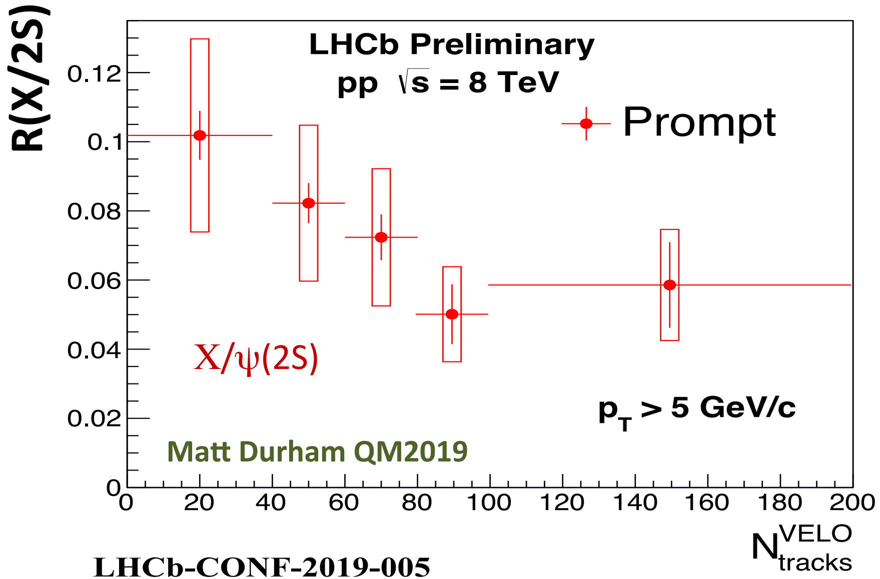

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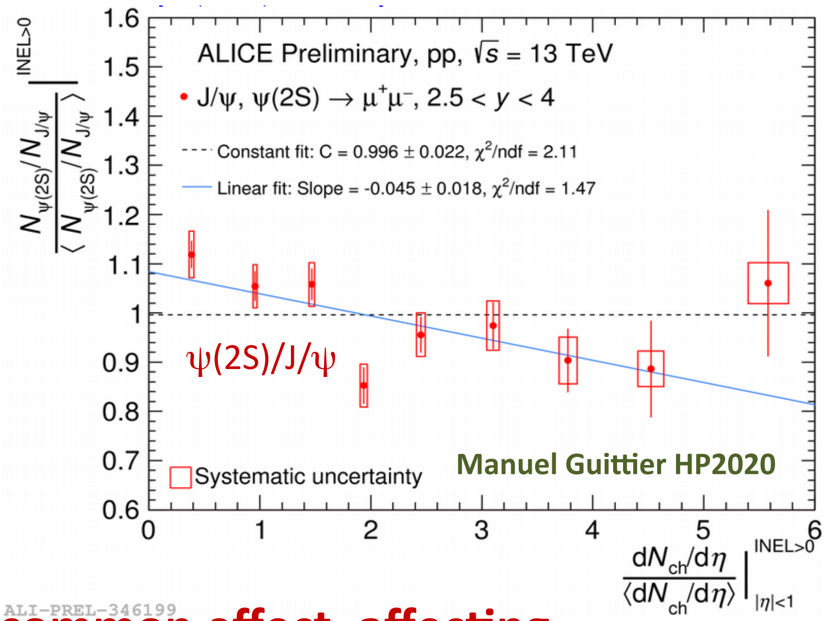


In other words, it seems to be a **common effect, affecting excited-over-ground quarkonium states vs multiplicity in pp collisions**

The intriguing suppression of excited states in pA

Suppression of weakly-bound quarkonia states has been studied for decades in pA:

Relative suppression $\psi(2S)/J/\psi$, $\Upsilon(nS)/\Upsilon(1S)$ in pA @ SPS, dAu @ RHIC, pPb @ LHC

- **Initial-state** effects identical for the family
- Any difference among the states should be due to **final-state** effects

- At low E: relative suppression explained by nuclear absorption $\sigma_{breakup} \alpha\, r^2_{meson}$
- At high E: too long formation times $t_f = \gamma\, \tau_f >> R$

Consensus: nuclear $\sigma_{breakup}$ is getting small at high energies and is the same for ground and excited states

A natural explanation would be a final-state effect acting over sufficiently long time
$\Rightarrow$ **interaction with a comoving medium**

Comover-interaction model CIM

- In a comover model: suppression from scatterings of the nascent $\mathcal{Q}$ with comoving medium constituted by particles with similar rapidities Gavin, Vogt, Capella, Armesto, Ferreiro … (1997)

- Stronger suppression where the comover densities (multiplicities) are large

  For asymmetric collisions as p-nucleus, stronger in the nucleus-going direction

- Boltzman equation governing the quarkonium density:

$$\tau \frac{\mathrm{d}\rho^{\mathcal{Q}}}{\mathrm{d}\tau}(b,s,y) = -\sigma^{co-\mathcal{Q}}\, \rho^{co}(b,s,y)\, \rho^{\mathcal{Q}}(b,s,y)$$

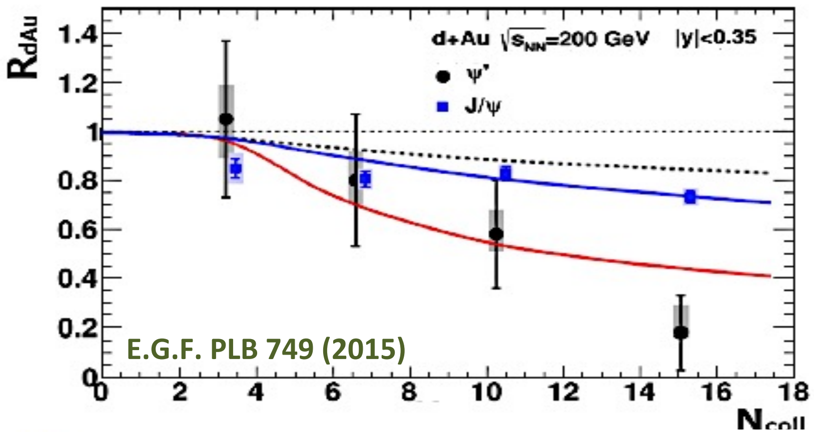
$\sigma^{co-\mathcal{Q}}$: cross section of quarkonium dissociation due to interactions with comoving medium

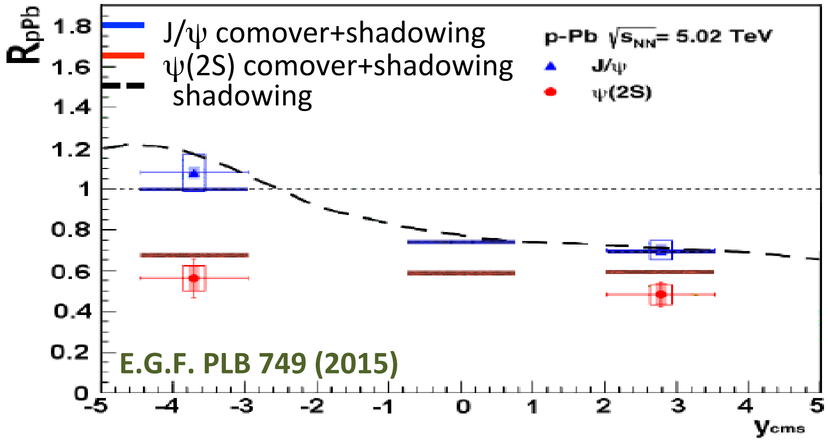
- Survival probability from integration over time:

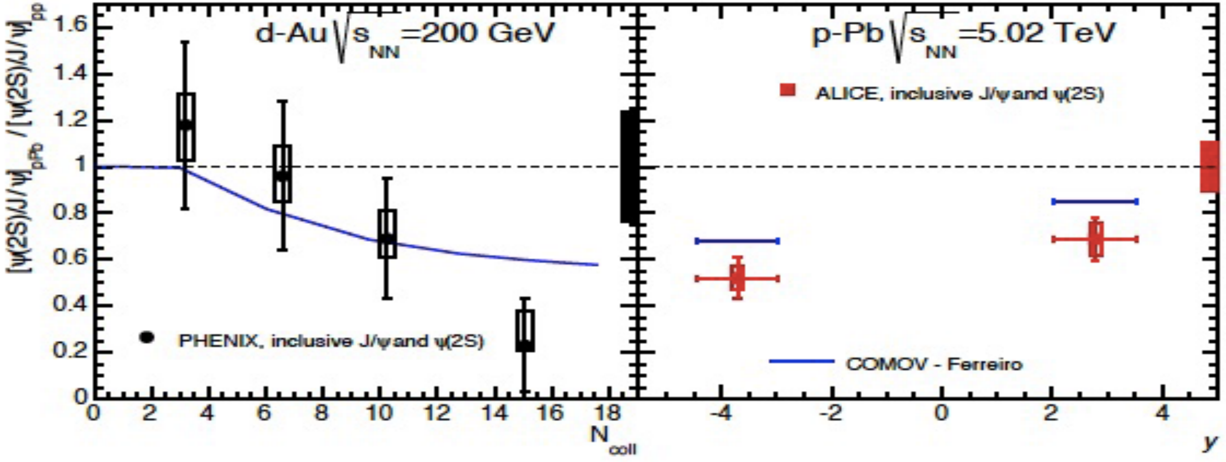
$$S^{co}_{\mathcal{Q}}(b,s,y) = \exp\left\{-\sigma^{co-\mathcal{Q}}\, \rho^{co}(b,s,y)\, \ln\left[\frac{\rho^{co}(b,s,y)}{\rho_{pp}(y)}\right]\right\}$$

$\tau_f/\tau_0 = \rho^{co}(b,s,y)/\rho_{pp}(y)$

Past CIM results for charmonia at RHIC and LHC







$\sigma^{co-\psi}$ originally fitted from SPS data: 0.65 mb for J/ψ and 6 mb for ψ(2S)

Pretty encouraging since the data were not refitted

CIM for bottomonium: the interaction cross sections

- Relative suppression of excited Υ: cleanest observable to fix the comover suppression
- Caveat: not enough data to fit all the 6 $\sigma^{co-\mathcal{Q}_{b\bar{b}}}$ [the feed-downs are taken into account]
- New strategy: going to a microscopic level

E.G.F., J.P. Lansberg JHEP 10 (2018)

$$\sigma^{\text{co}-\mathcal{Q}}(E^{\text{co}}) = \sigma_{\text{geo}}^{\mathcal{Q}} \times \left(1 - \frac{E_{\text{thr}}^{\mathcal{Q}}}{E^{\text{co}}}\right)^n$$

$$\langle\sigma^{\text{co}-\mathcal{Q}}\rangle(T_{\text{eff}}, n) = \frac{\int_0^\infty dE^{\text{co}}\,\mathcal{P}(E^{\text{co}};T_{\text{eff}})\,\sigma^{\text{co}-\mathcal{Q}}(E^{\text{co}})}{\int_0^\infty dE^{\text{co}}\,\mathcal{P}(E^{\text{co}};T_{\text{eff}})}$$

$\sigma_{\text{geo}}^{\mathcal{Q}} \simeq \pi r_{\mathcal{Q}}^2$, where $r_{\mathcal{Q}}$ is the quarkonium Bohr radius

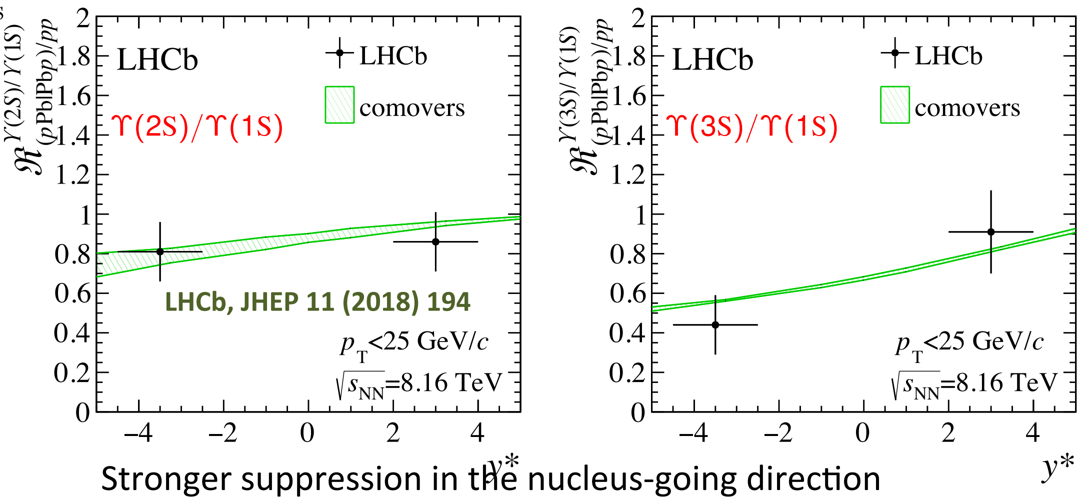
$E_{\text{thr}}^{\mathcal{Q}} = 2M_B - M_{\mathcal{Q}_{b\bar{b}}}$, *i.e.* the threshold energy

$E^{co} = \sqrt{p^2 + m_{co}^2}$ energy of the comovers

Bose-Einstein distribution

$$\mathcal{P}(E^{\text{co}};T_{\text{eff}}) \propto \frac{1}{e^{E^{\text{co}}/T_{\text{eff}}} - 1}$$

- Succesfully reproduces the excited-over-ground relative suppression versus rapidity

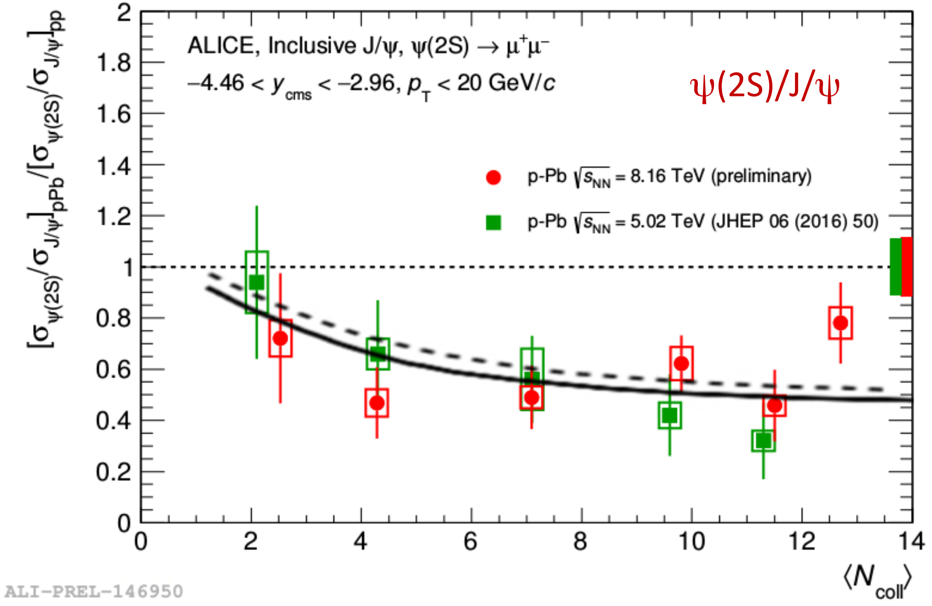


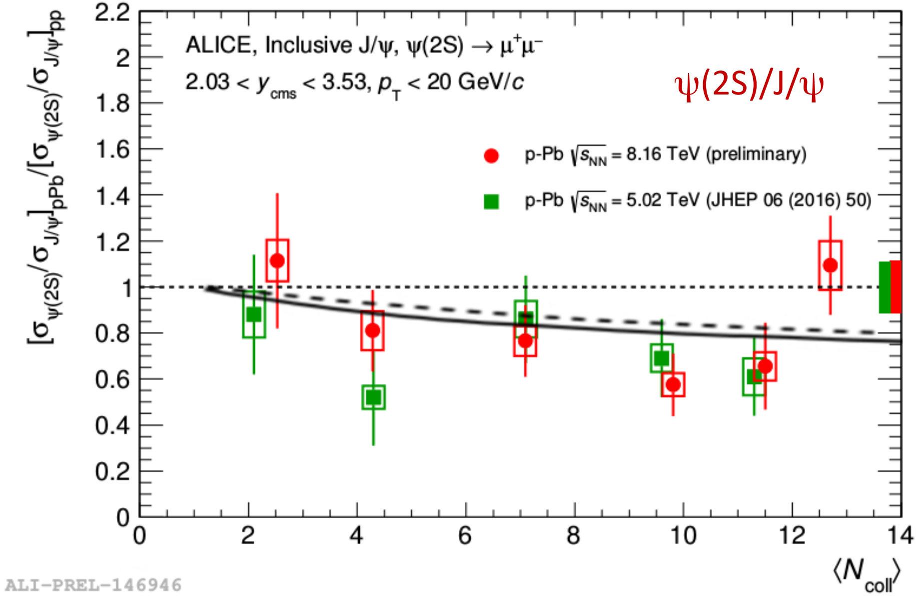
Stronger suppression in the nucleus-going direction

Suppression by comovers increases with multiplicity in pA

- Double ratios enables us to study the effect of final states alone
- The comover effect should increase with multiplicity:

stronger in central collisions & in backward y region





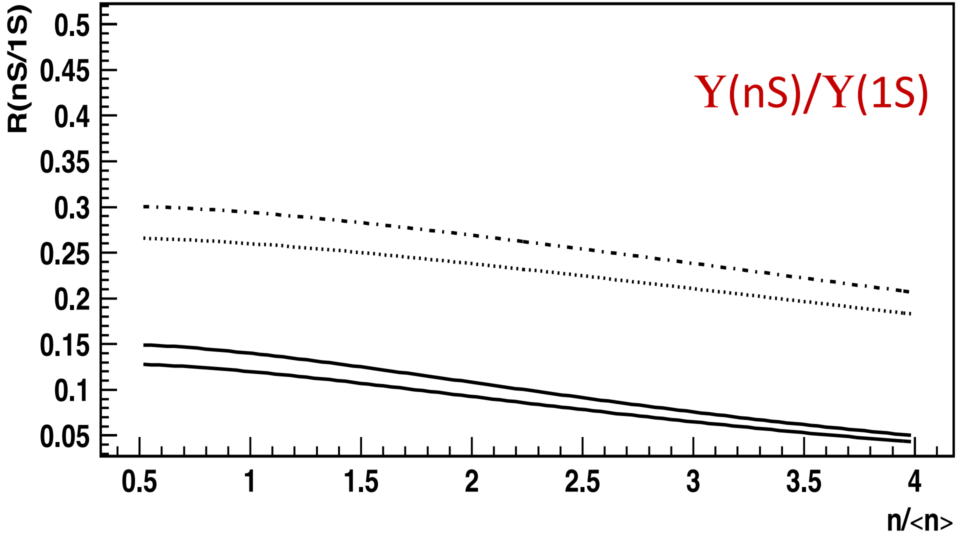
Suppression by comovers increases with multiplicity in pp

- In order to measure the effects of the comovers with increasing multiplicity, we calculate the rate **nS/1S** *vs* **n/<n>** being <n> the mean pp multiplicity

$$\tau \frac{d\rho^{\mathcal{Q}}}{d\tau}(b,s,y) = -\sigma^{co-\mathcal{Q}}\, \rho^{co}(b,s,y)\, \rho^{\mathcal{Q}}(b,s,y)$$

=> $\exp\left\{-\sigma^{co-Q}\rho^{co}(b,s,y)\ln\left(\rho^{co}(b,s,y)/\rho_{pp}(y)\right)\right\}$

n   n/<n>



- No new parameters
- Identical feed downs and interaction cross section as the previously used in pPb collisions
- Our results are normalized to the experimental value obtained for $\langle n_{ch}\rangle$

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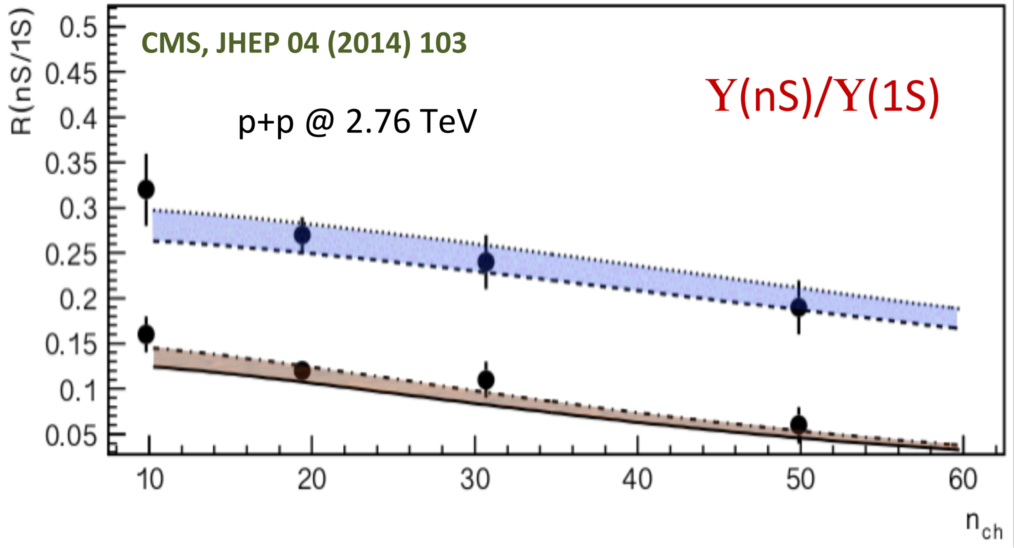

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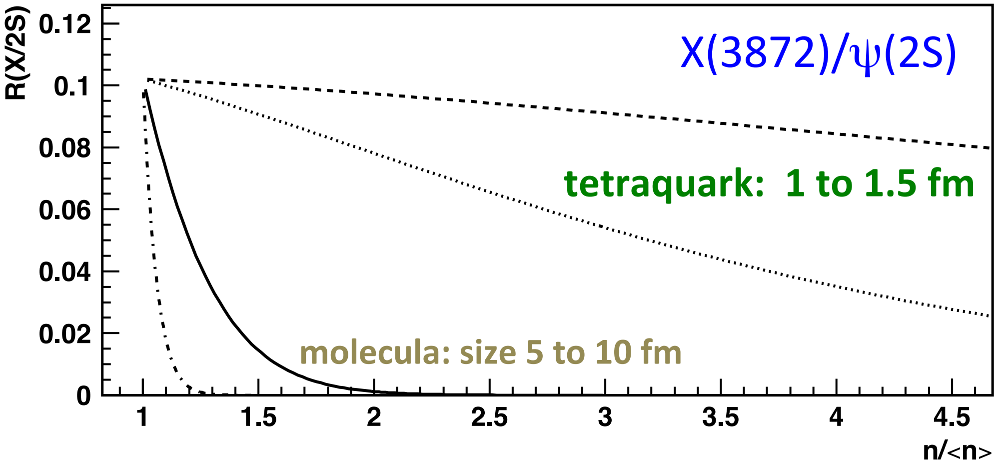
Behaviour of X(3872)/ψ(2S) with multiplicity

- Let's consider X(3872) as a compact object => interaction cross sections can be calculated

	$E_{\rm thr}^{\mathcal{Q}}$	$r_{\mathcal{Q}}$	$\sigma_{\rm geo}^{\mathcal{Q}}$	$\sigma^{\rm co-\mathcal{Q}}$
$\psi(2S)$	50 MeV	0.45 fm	6.36 mb	5.15 ± 0.84 mb
$X(3872)$ tetraquark	200 keV	0.65 fm	13.3 mb	11.61 ± 1.69 mb
$X(3872)$ molecule	200 keV	5.0 fm	785 mb	687 ± 98 mb

For the 2S: Satz 0512217
For the X tetraquark:
Esposito,Polosa 1807.06040
Maiani et al. 0412098
For X molecular: Beveren & Rupp

Cross sections very close to their geometrical value due to small binding energies involved



- Cross sections calculated as for Υ
- Parameters involved: size & binding E
- Our results are normalized to the experimental value obtained for the first bin

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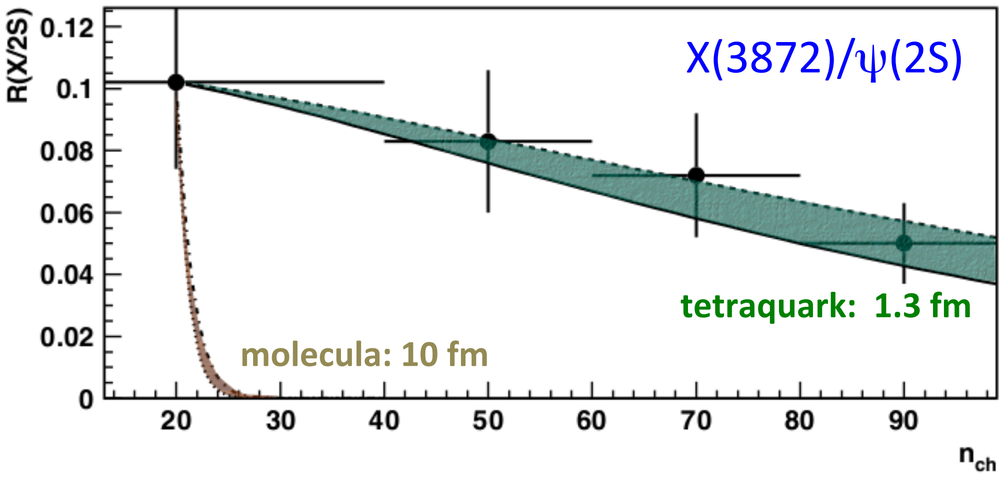

- LHCb results strongly supports the idea of X(3872) of typical hadronic size
- A molecular state disappears very quickly by interaction with comovers
- Our conclusion: tetraquark of 1.3 fm

Coalescence is not the solution

- Accoding to quarkonium data, no secondary charmonium production has been considered for a X(3872) of typical hadronic size
- In case of a X(3872) of molecular nature, coalescence effects, similar to the ones applied to reproduce d/p ratio in pp, can be at play

$$\tau \frac{dN_m}{d\tau} = \langle v\sigma \rangle_m \, \rho_c \, N_{12} - \left(\langle v\sigma \rangle_m + \langle v\sigma \rangle_{hh} \right) \rho_c \, N_m$$

N_m # of molecules
N_{12} # of constituent pairs (constant in time)

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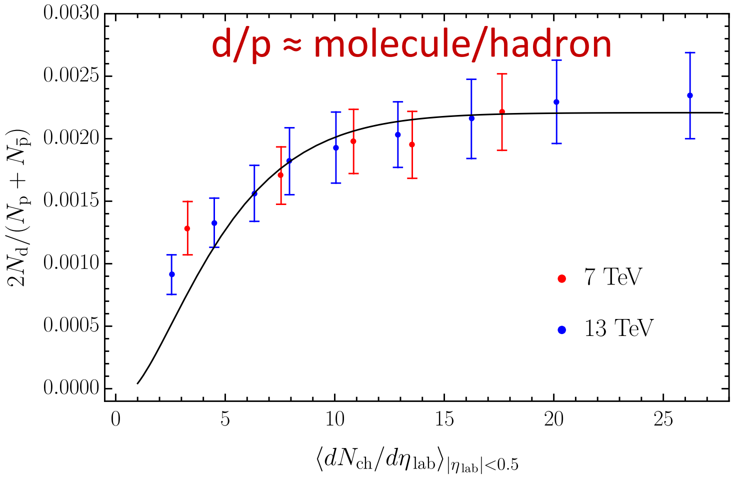

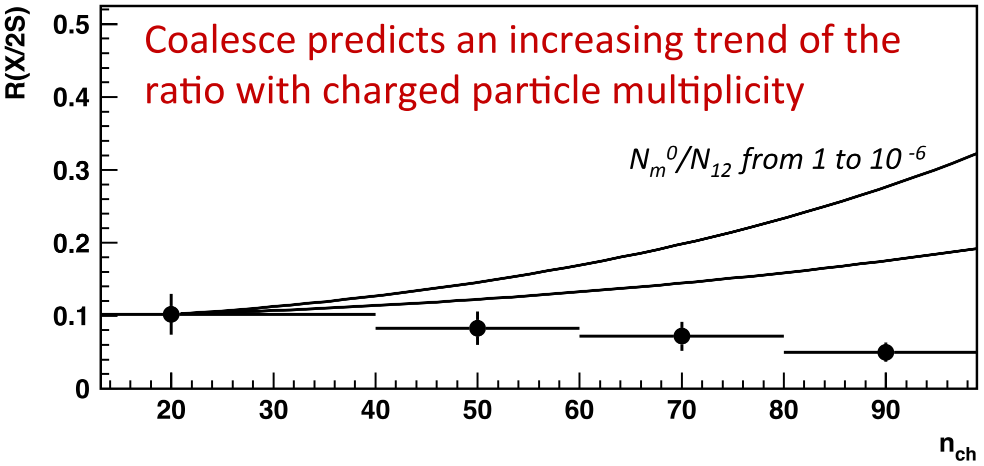

Conclusion

The new data from the LHCb collaboration on the relative X(3872) to ψ(2S) abundance can only be understood if both systems have only slightly different sizes, *i.e.* if the X(3872) has a typical hadronic size, strongly disfavouring the molecular interpretation