Charmonium production measurements in small systems at LHCb

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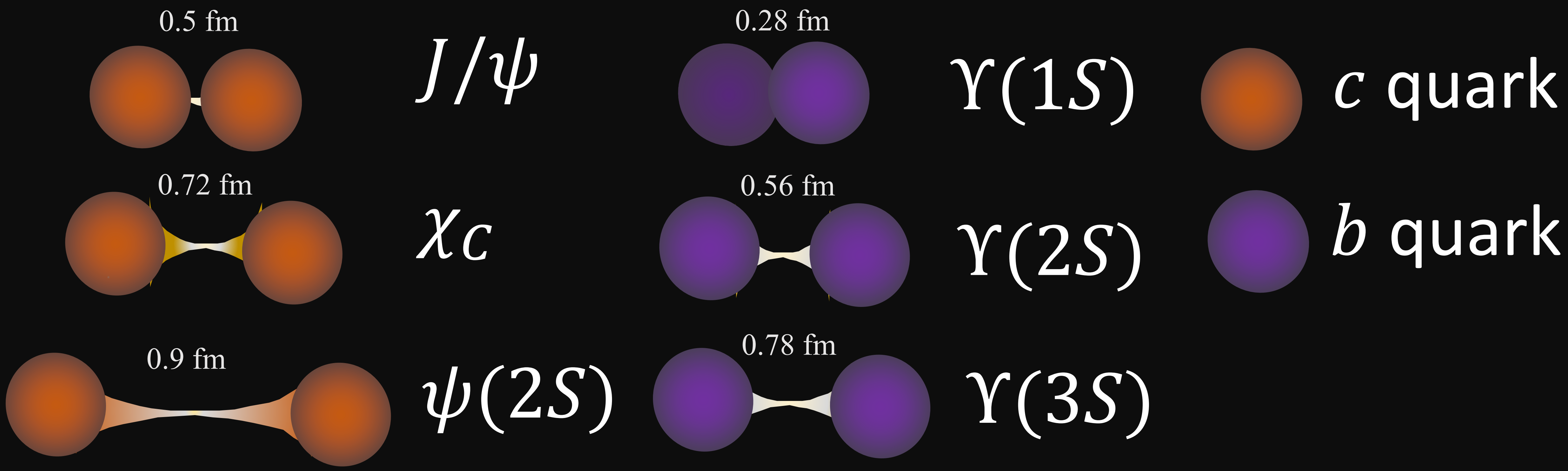
Los Alamos National Lab

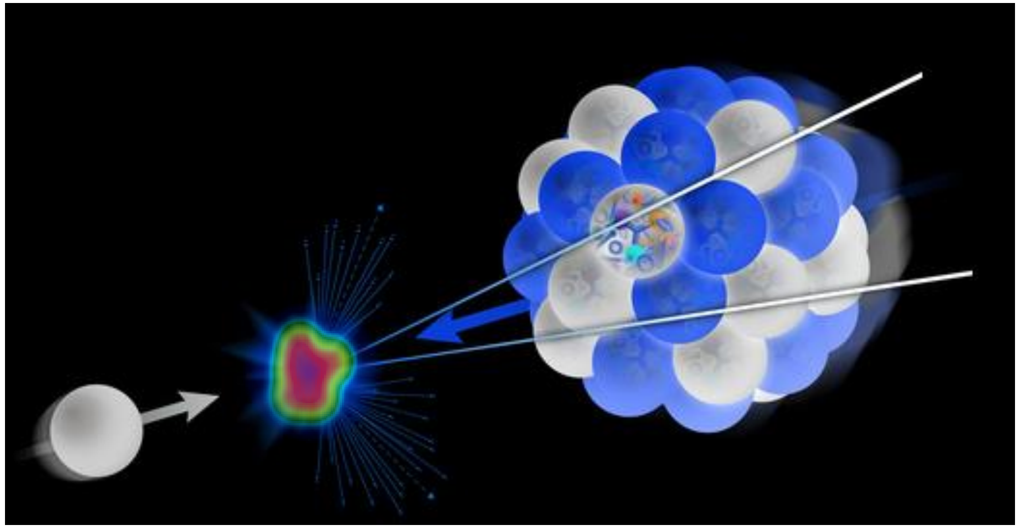
Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
Nagasaki 2024

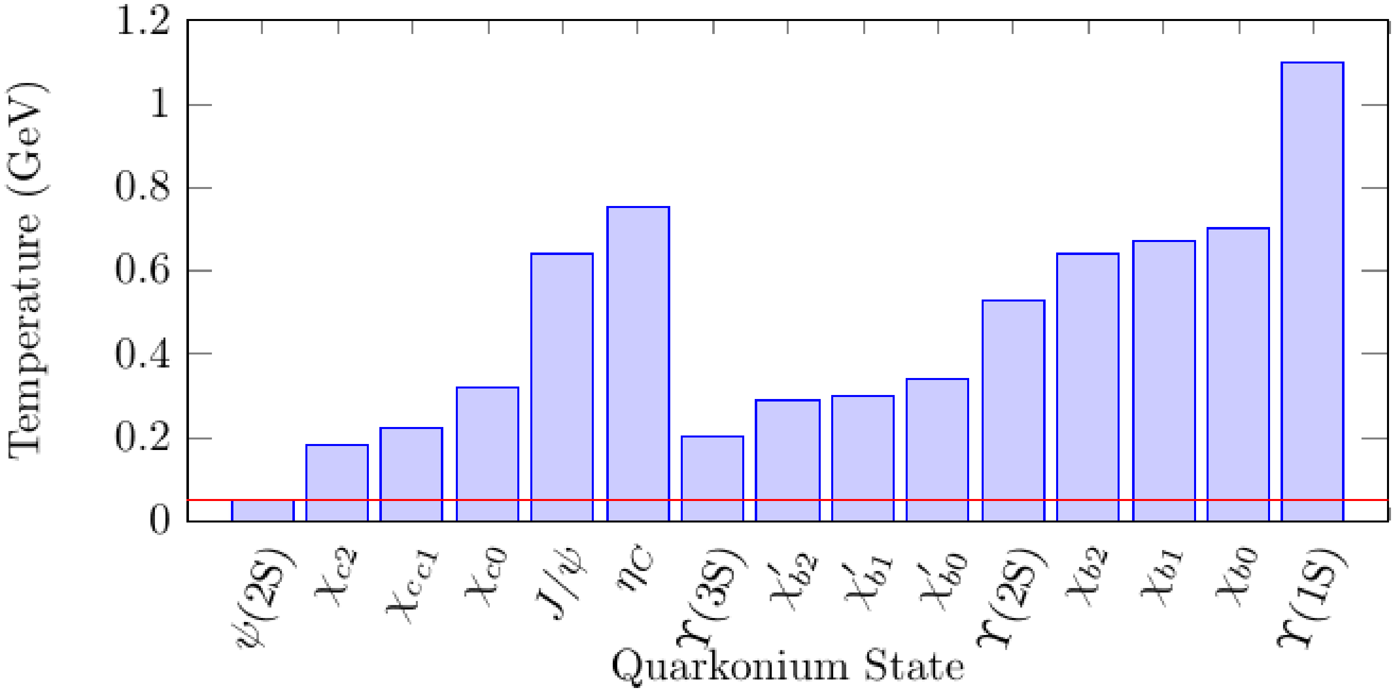
Quarkonium states



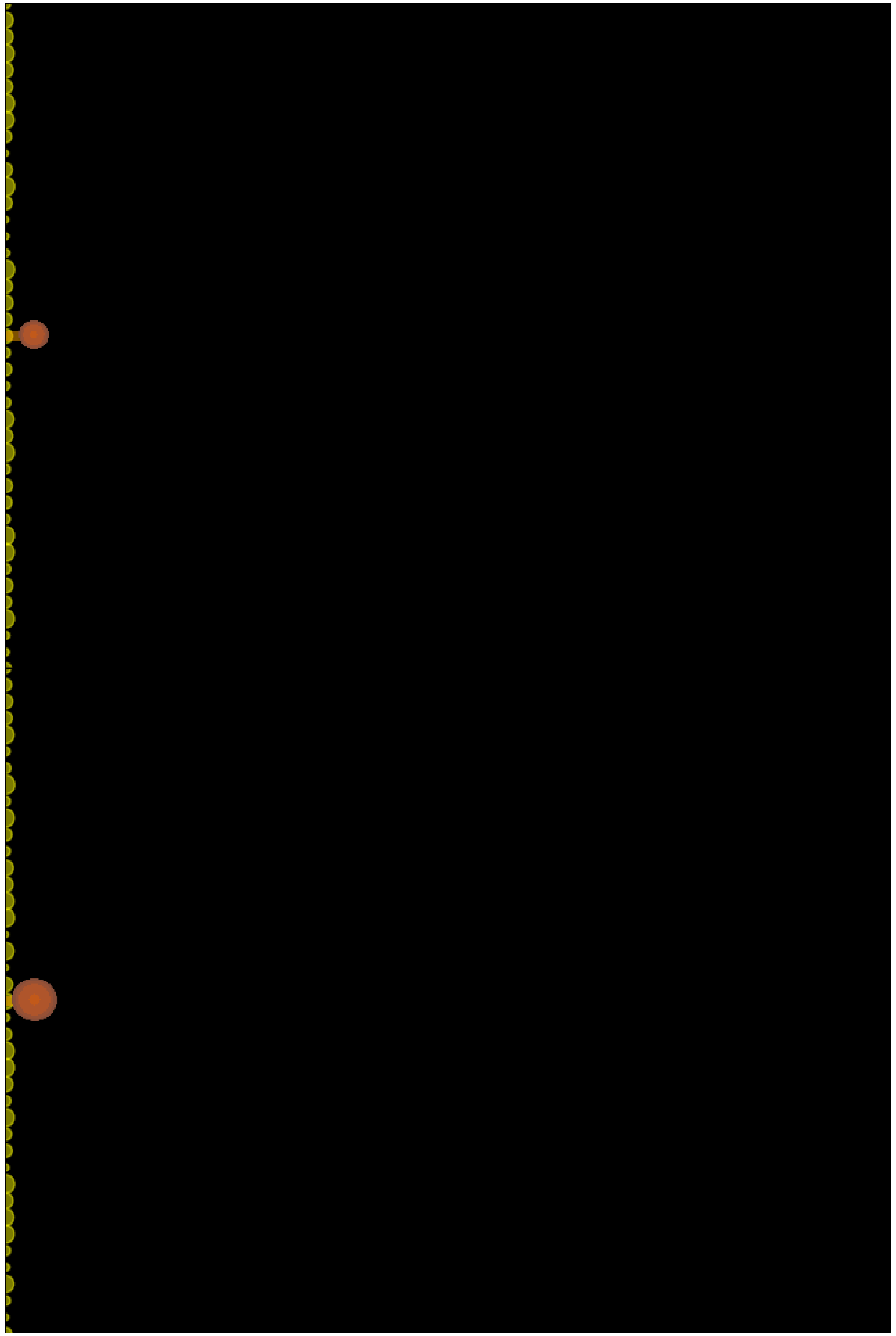
Comes in different sizes and binding energies

Quarkonium as a Hot Spot Thermometer



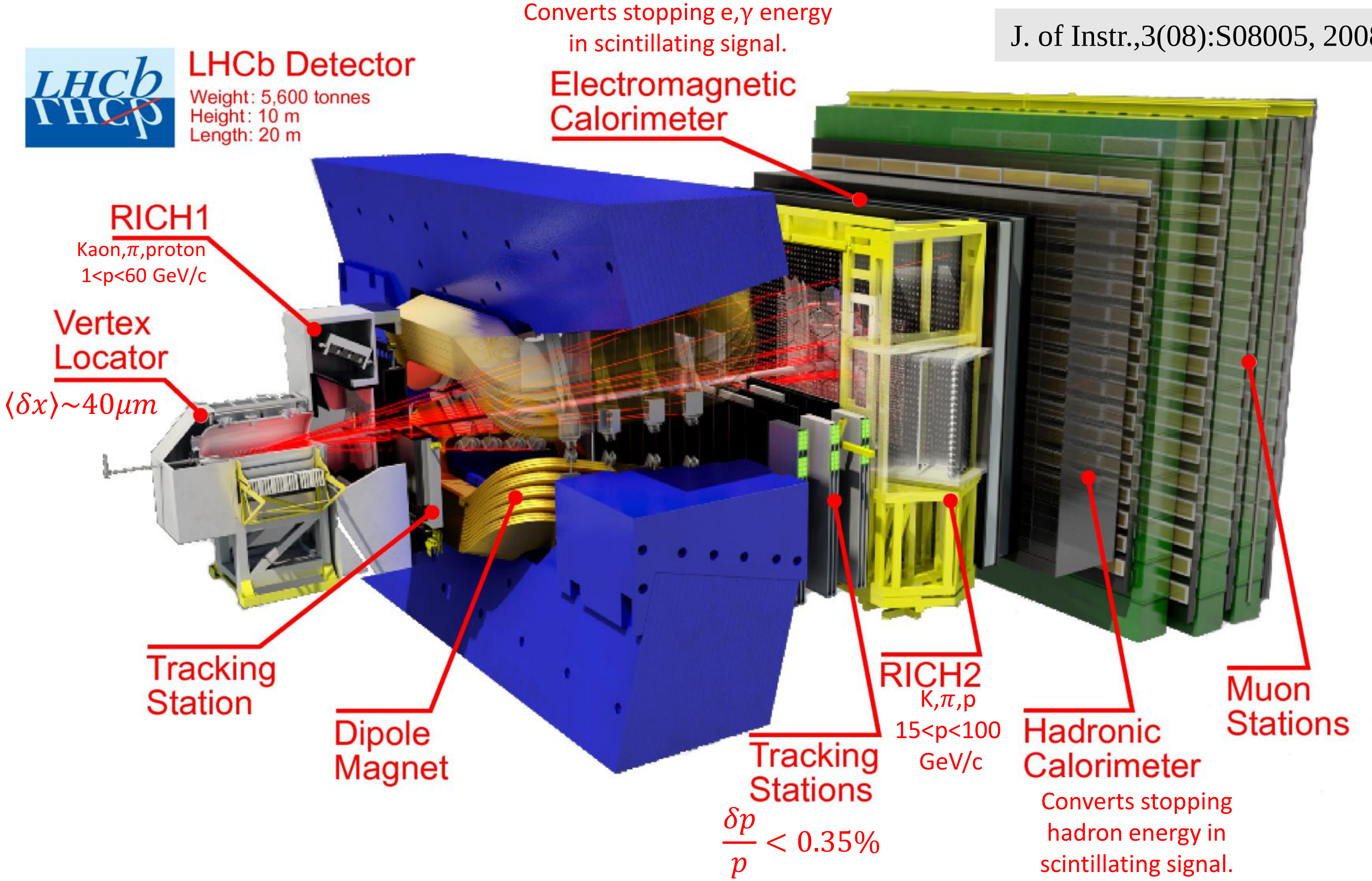


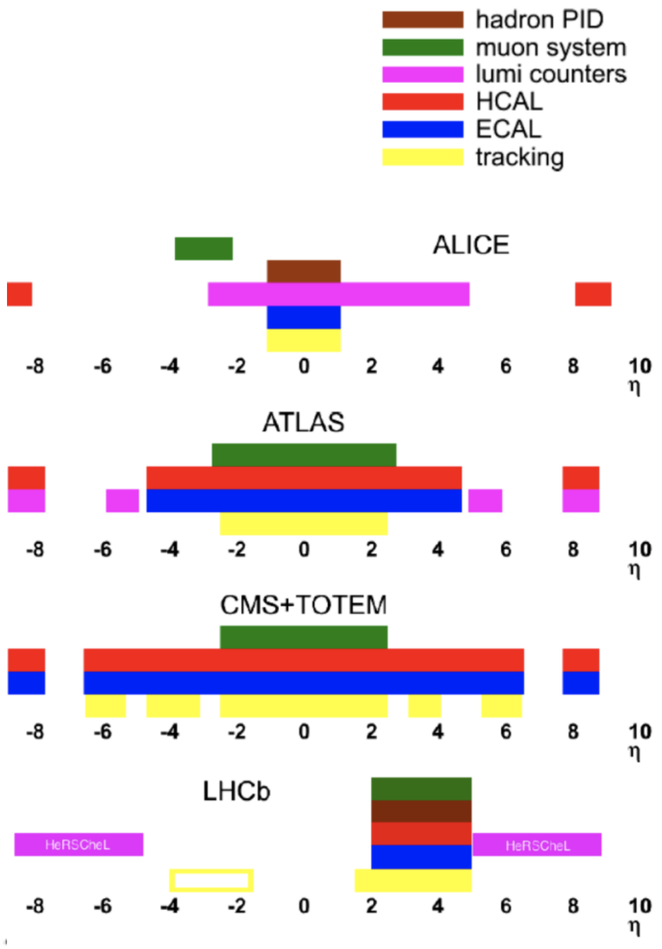
The quarkonium state is only produced if the local temperature is lower than its binding energy.



The quarkonium state can also break by encounters with comoving hadrons in high multiplicity environments.

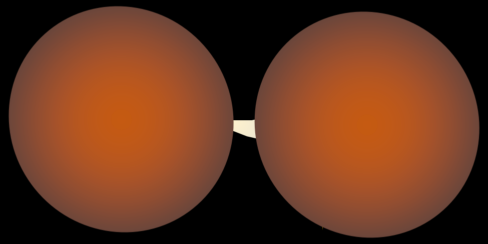
The LHC beauty detector





- General purpose forward detector at LHC
- $e, \mu, \pi, K, p, \gamma,$ particle and jet identification
- Unique forward instrumentation for heavy ion physics

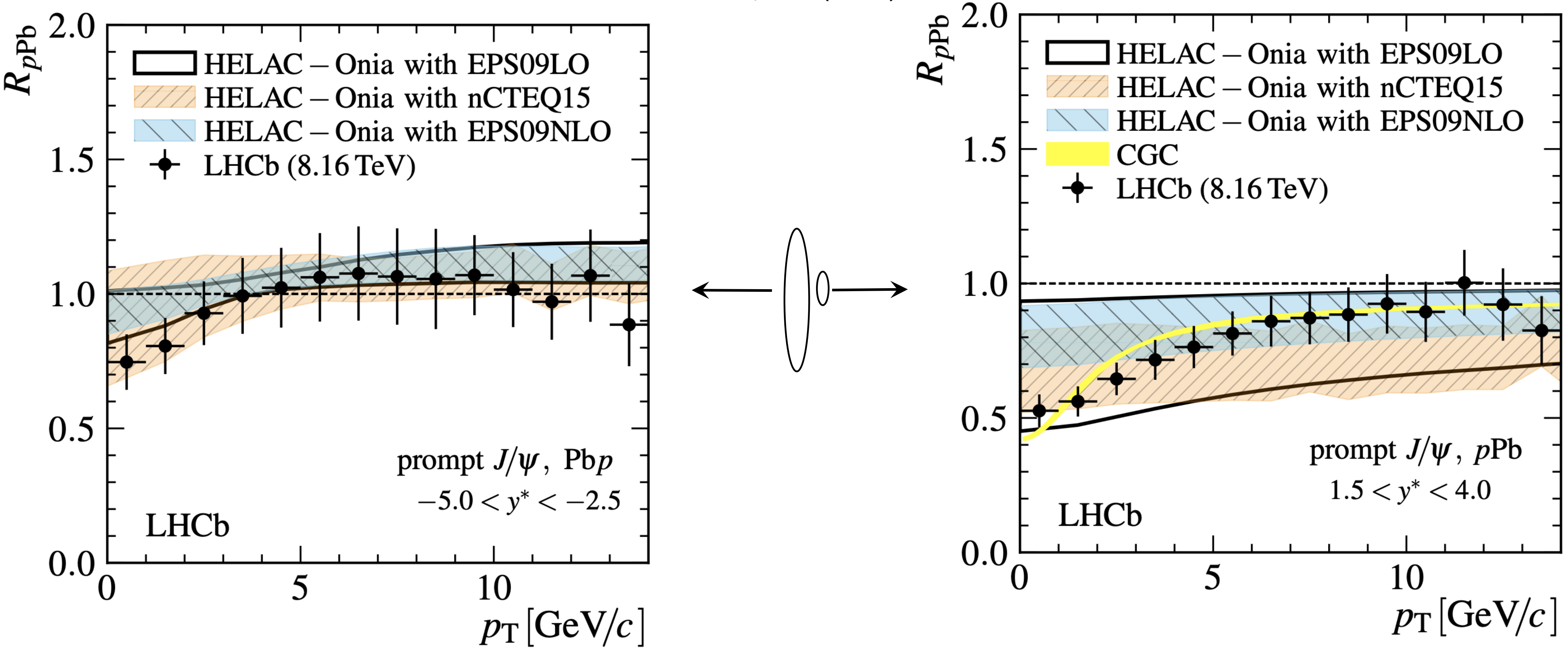
0.5 fm



Binding energy : 640 MeV

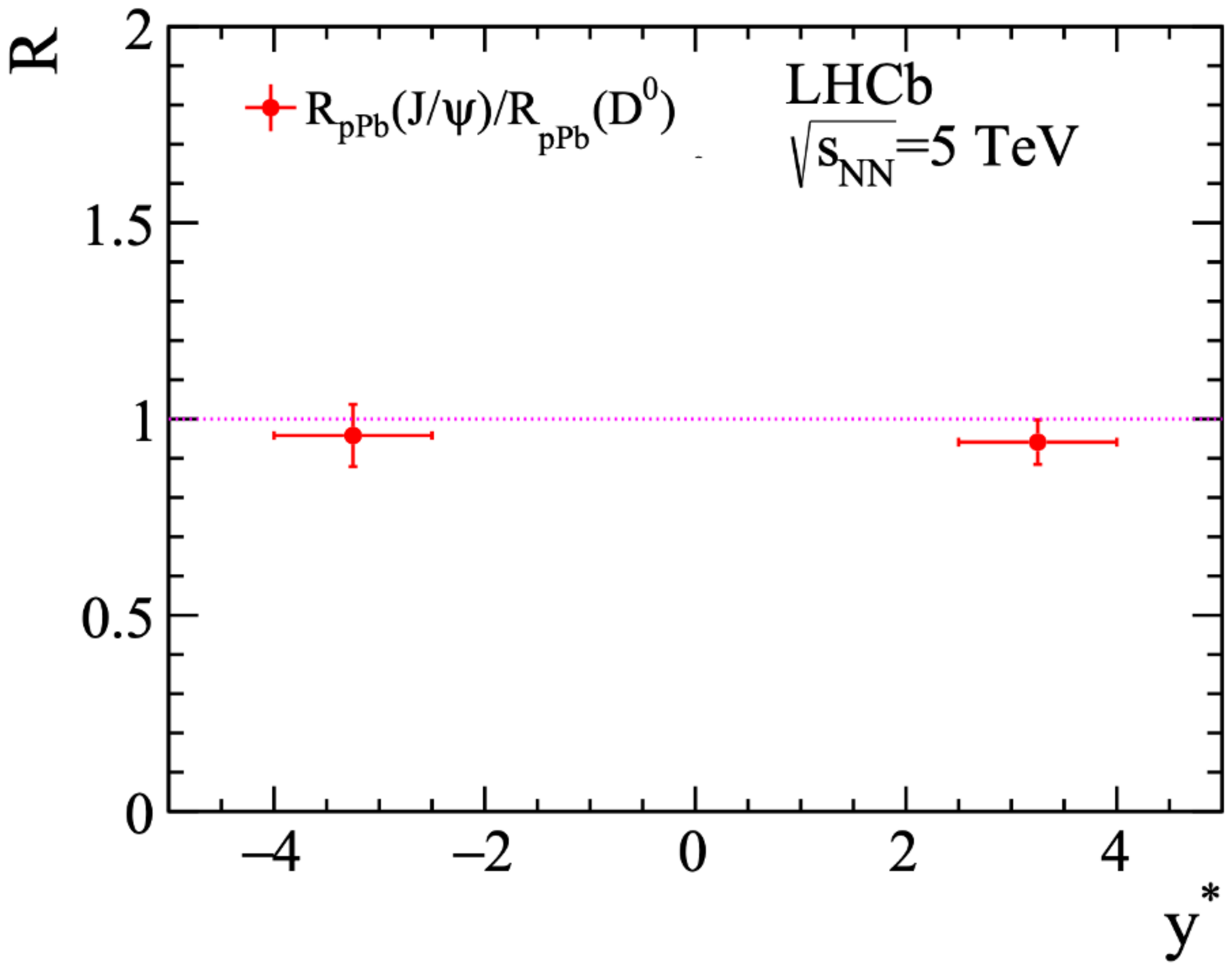
J/ψ

PLB774, 159 (2017)

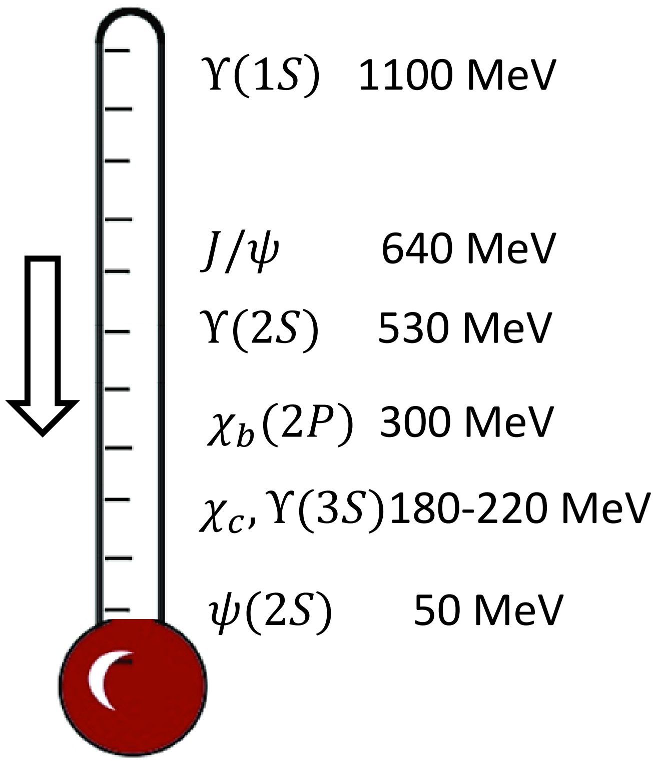


Significant J/ψ nuclear modification in pPb forward rapidity, not much in the backward rapidity.

JHEP 1710 (2017) 090

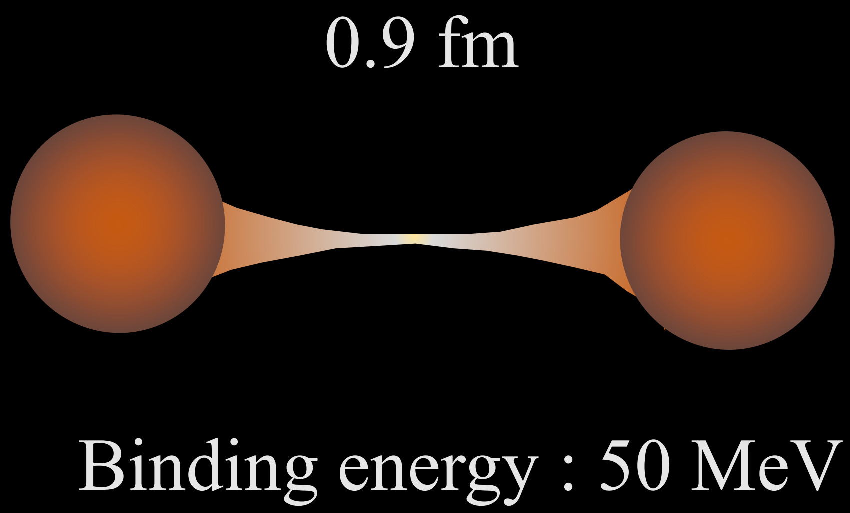


Agnes Mocsy's thermometer



J/ψ R_{pA} is affected by the same Initial-State Effects seen in D^0 yields.

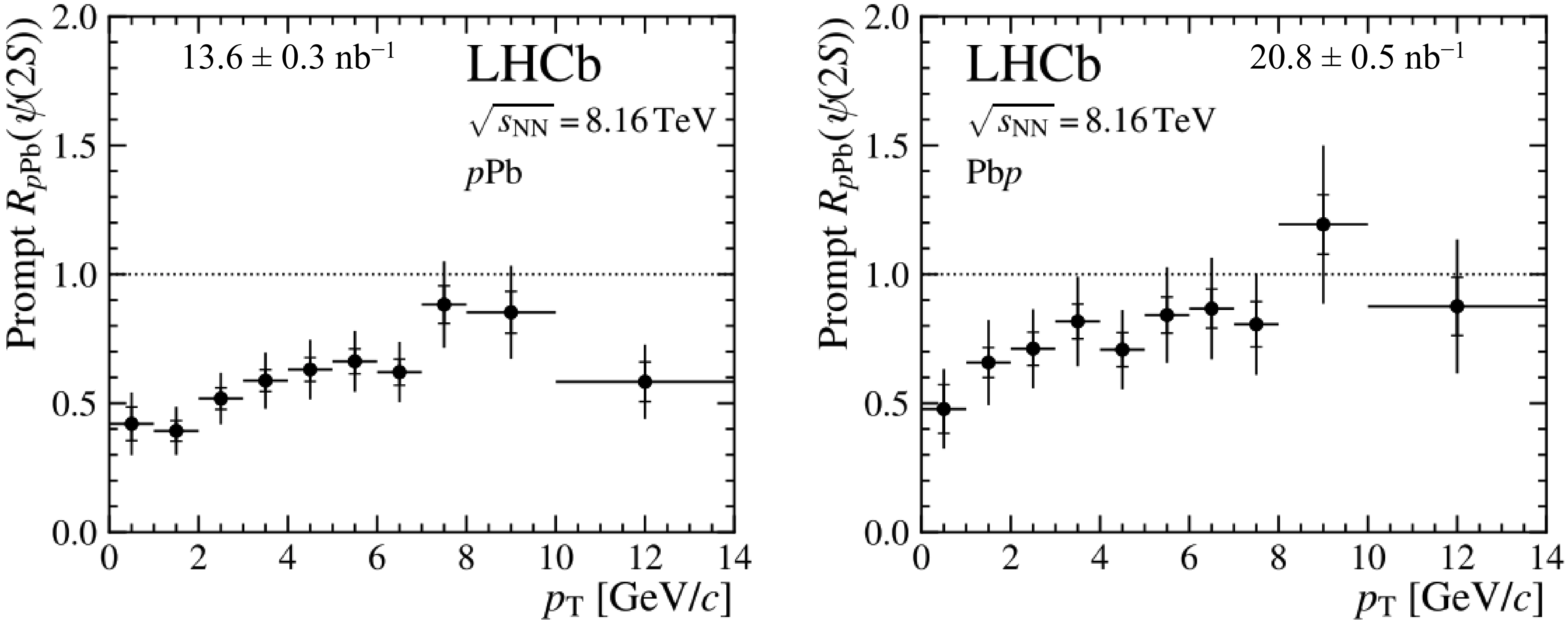
See my poster on the Initial-State studies in LHCb.



$\psi(2S)$

New ψ(2S) Result

JHEP 04 (2024) 111



A larger suppression seen in $\psi(2S)$ yield. Better quantify it with a double ratio with J/ψ.

$$R^{p\mathrm{Pb}\,(\mathrm{Pb}p)}_{\psi(2S)/J/\psi} = \frac{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(\psi(2S))}{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(J/\psi)} = \frac{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{p\mathrm{Pb}\,(\mathrm{Pb}p)}}{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{pp}}$$

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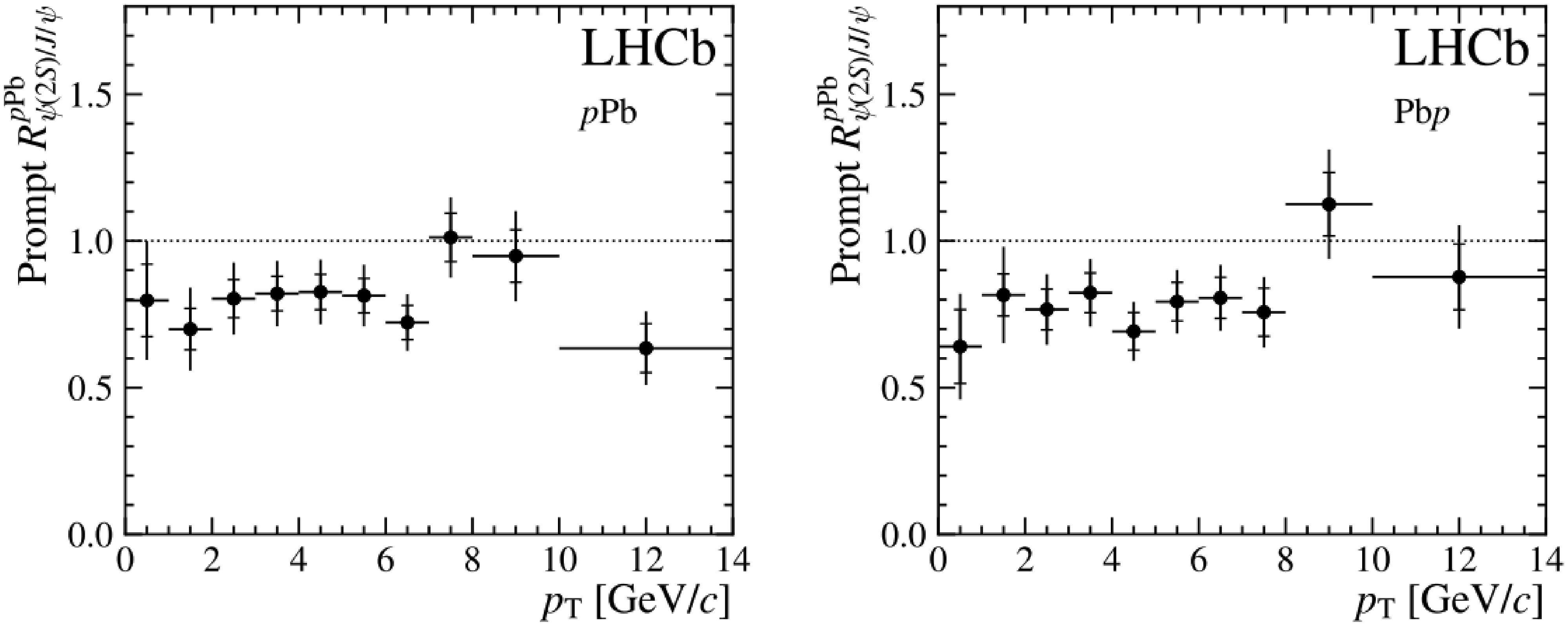

$\psi(2S)$ has stronger suppression independent of p_{T}.

$$R^{p\mathrm{Pb}\,(\mathrm{Pb}p)}_{\psi(2S)/J/\psi} = \frac{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(\psi(2S))}{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(J/\psi)} = \frac{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{p\mathrm{Pb}\,(\mathrm{Pb}p)}}{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{pp}}$$

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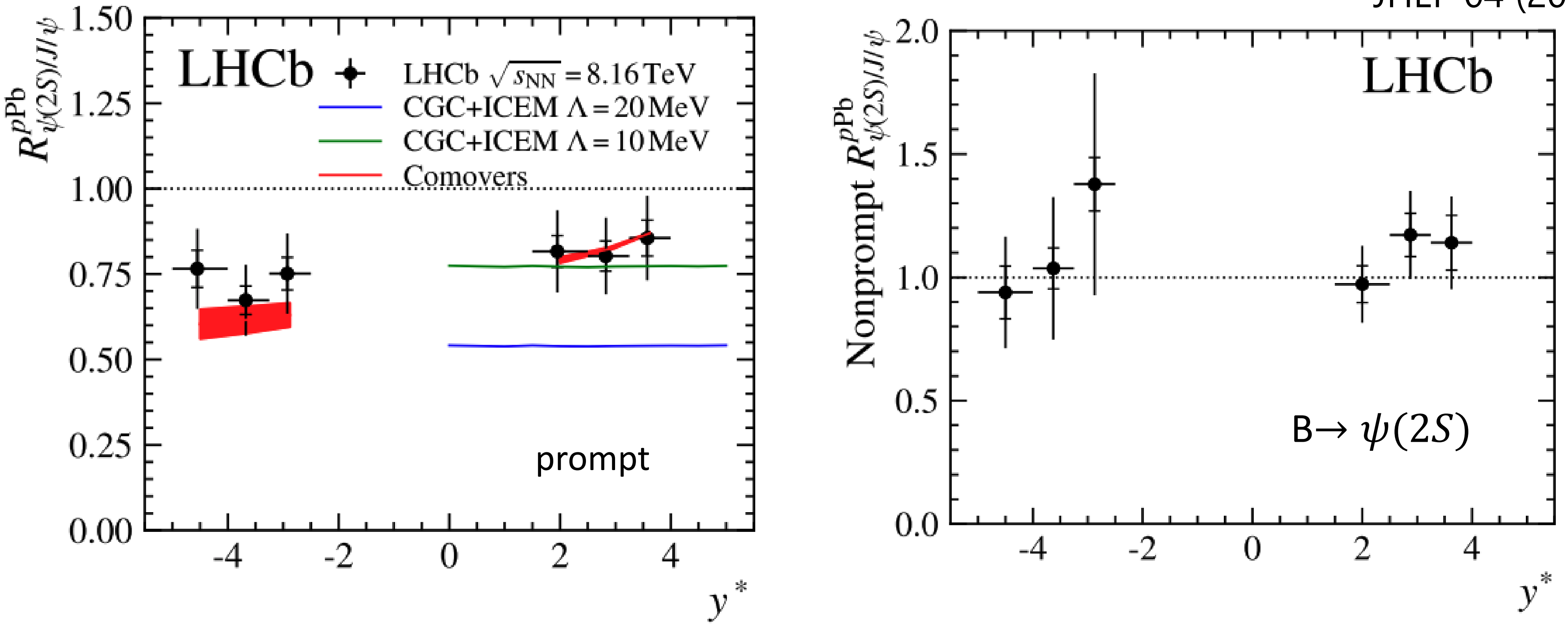
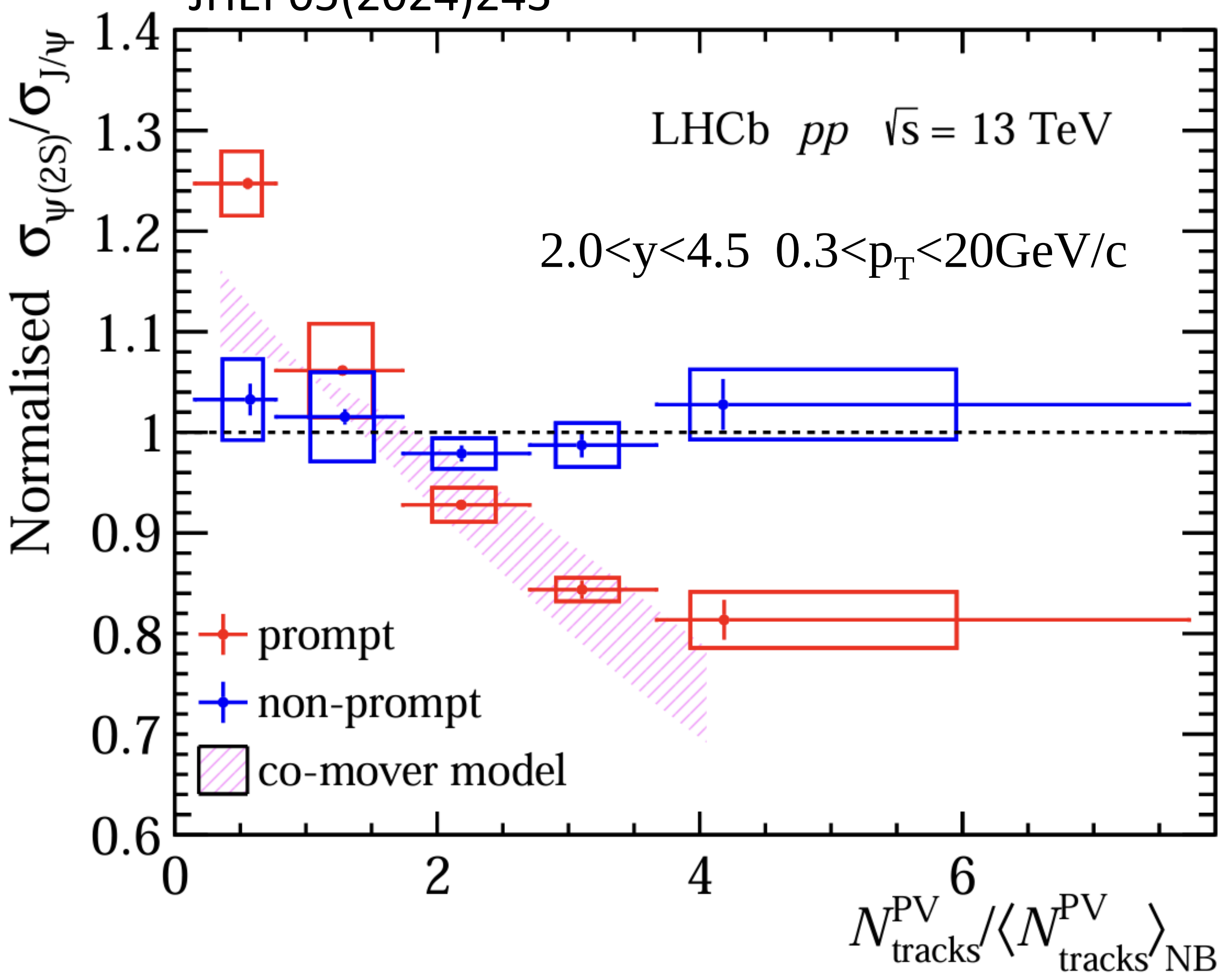


Additional $\psi(2S)$ suppression only present in the prompt component, consistent with comover particle interactions [PLB749, 98 (2015)]

CGC : Factorization violating soft gluon exchanges PRC97, 014909 (2018)

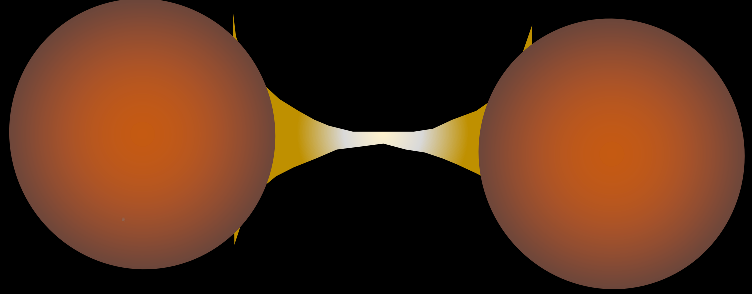
ψ(2S) dissociation in *pp* collisions

JHEP05(2024)243



- Prompt $\psi(2S)$ states are broken when particle multiplicities are larger than ~3x the average multiplicity
- $\psi(2S)$ from B-decays, produced away from the early high-density environment are intact
- **Results consistent with pPb observations**

0.72 fm

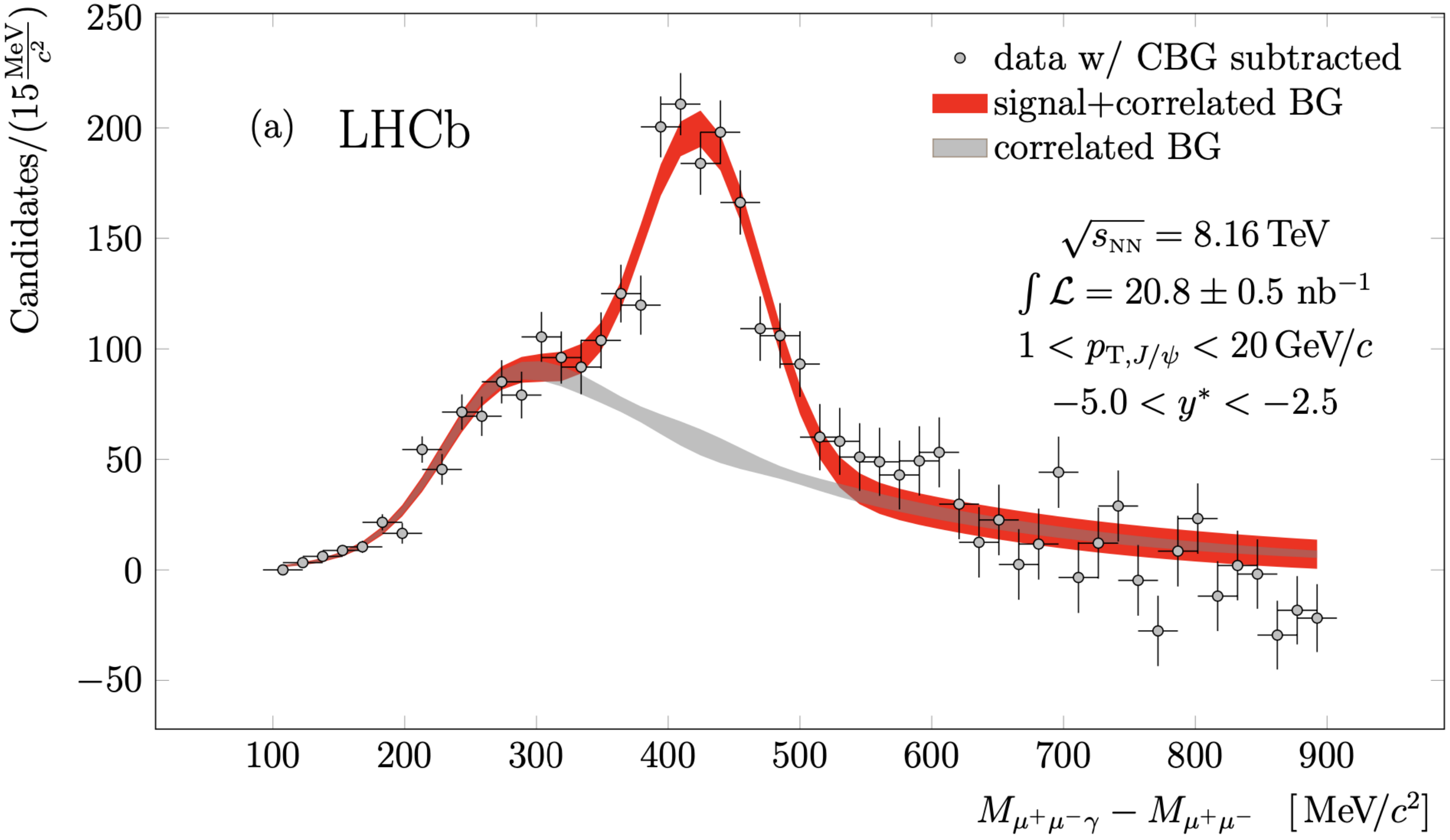


$\chi_{c1,2}$

Binding energy : 180 and 220 MeV

pPb -> χ_c Result

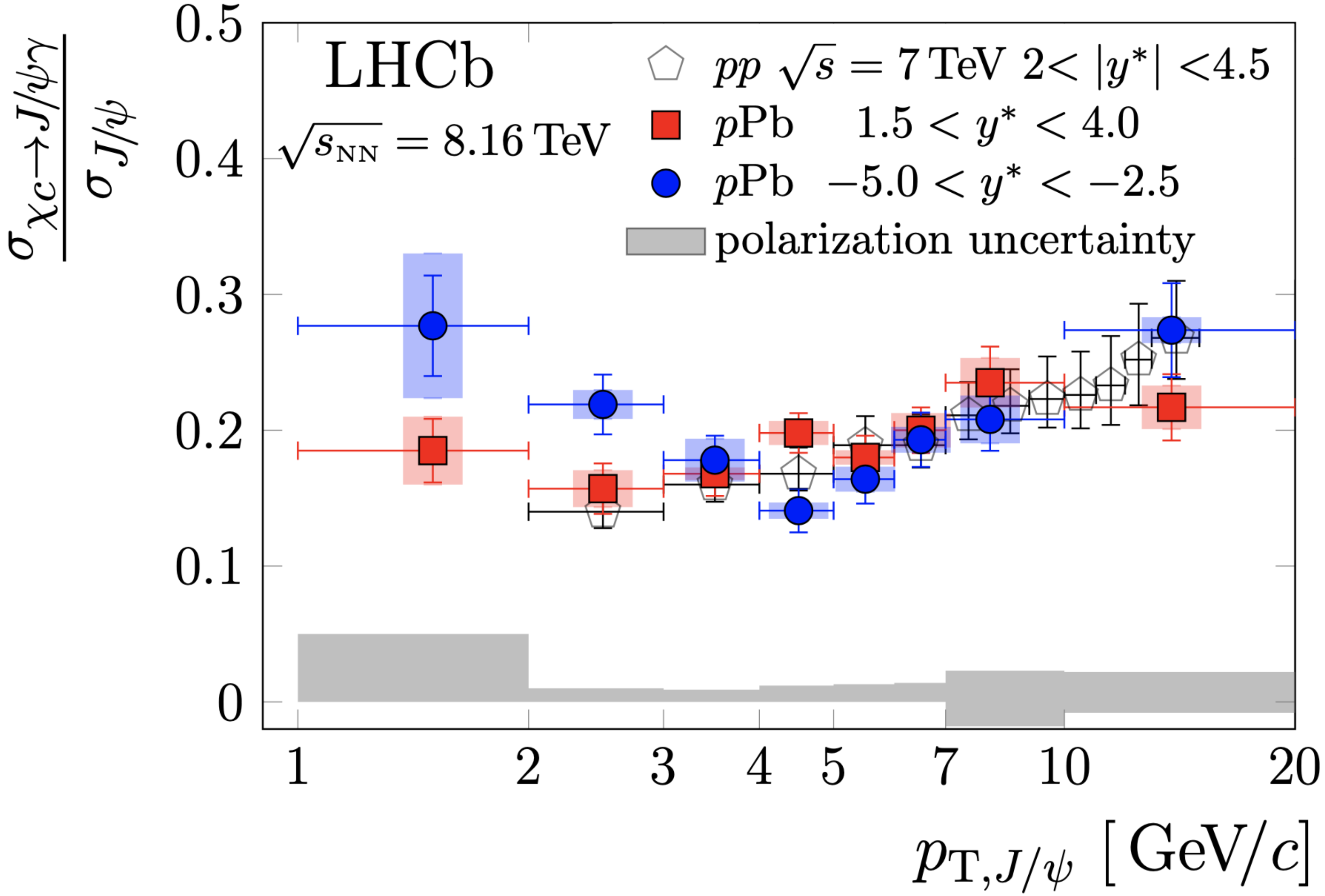
PRL 132 (2024) 102302



$\chi_{c1} + \chi_{c2}$ measured in the $J/\psi\,\gamma$ decay channel, where the photon ($p_{T,\gamma}$>400 MeV/c) is measured by the ECAL.

Fraction of χ_c decays in prompt J/ψ.

PRL 132 (2024) 102302



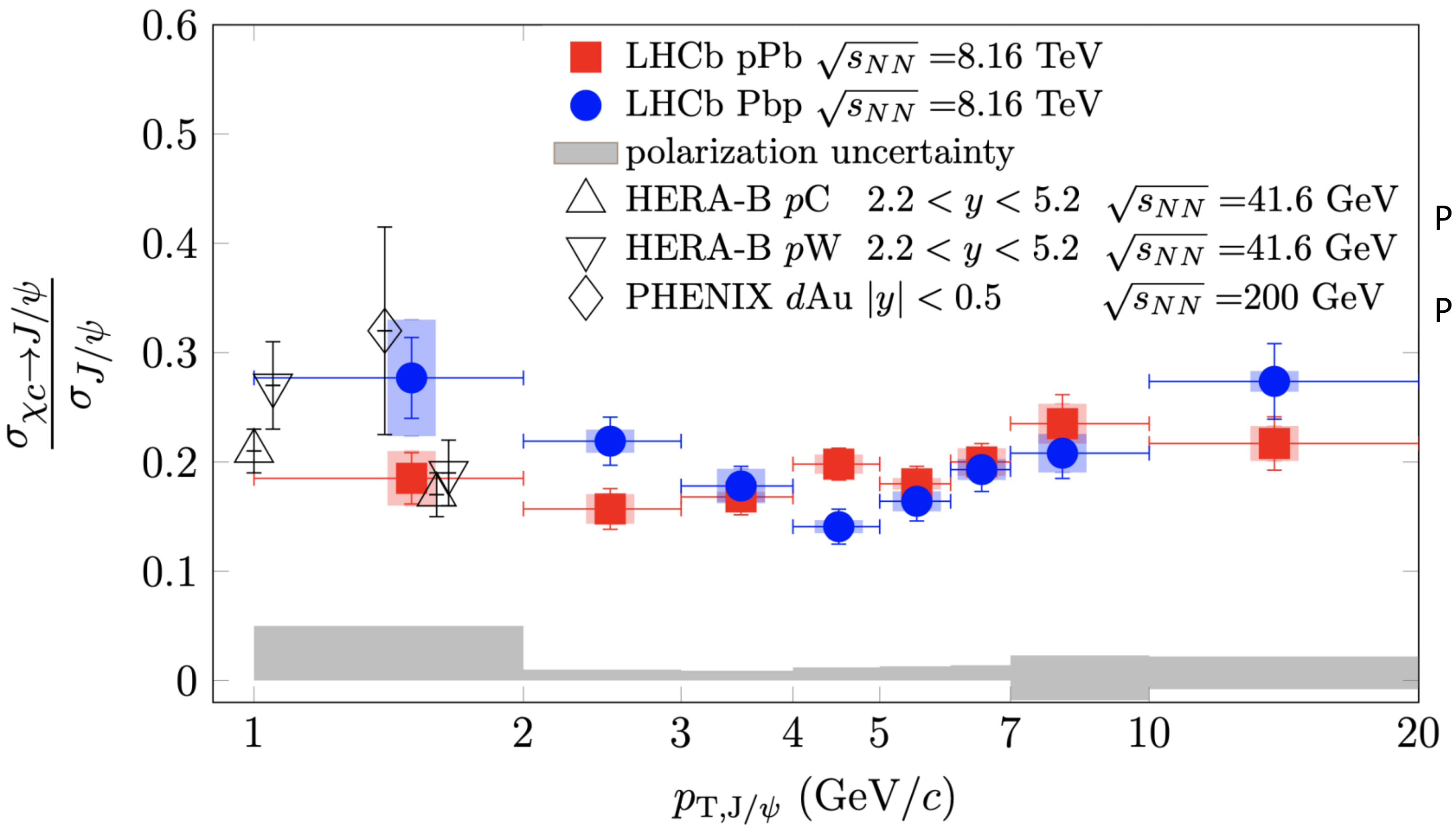
First result of this kind in LHC.

Forward rapidity consistent with pp results

Backward rapidity has a fraction 2.4 σ higher than forward for $p_{T,J/\psi}$<3 GeV/c

Fraction of χ_c decays in prompt J/ψ.

PRL 132 (2024) 102302



PRD79, 012001 (2009)

PRL111, 202301 (2013)

Result consistent with lower energy measurements from HERA-B and PHENIX.

Double ratio $\chi_c/(J/\psi)$

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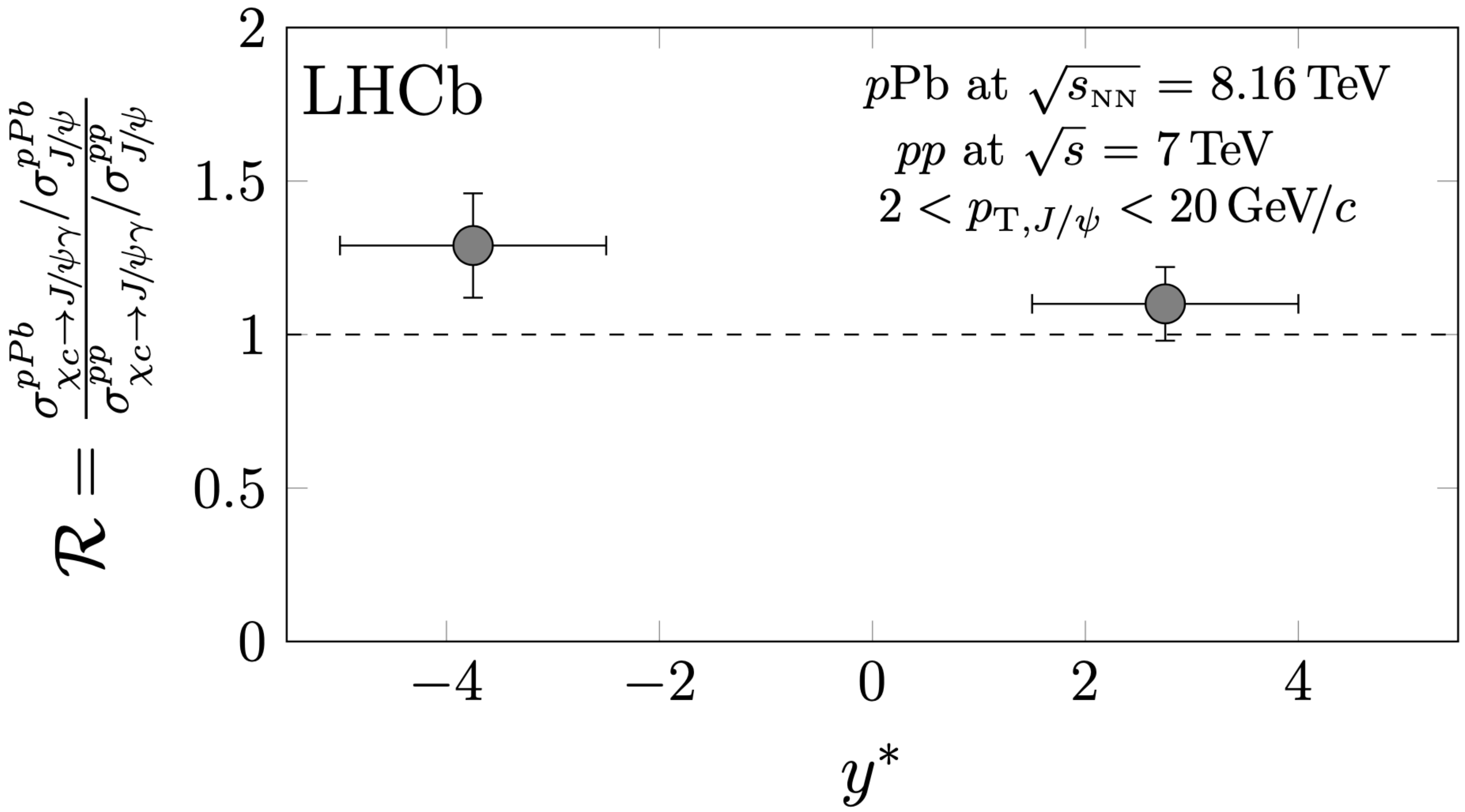
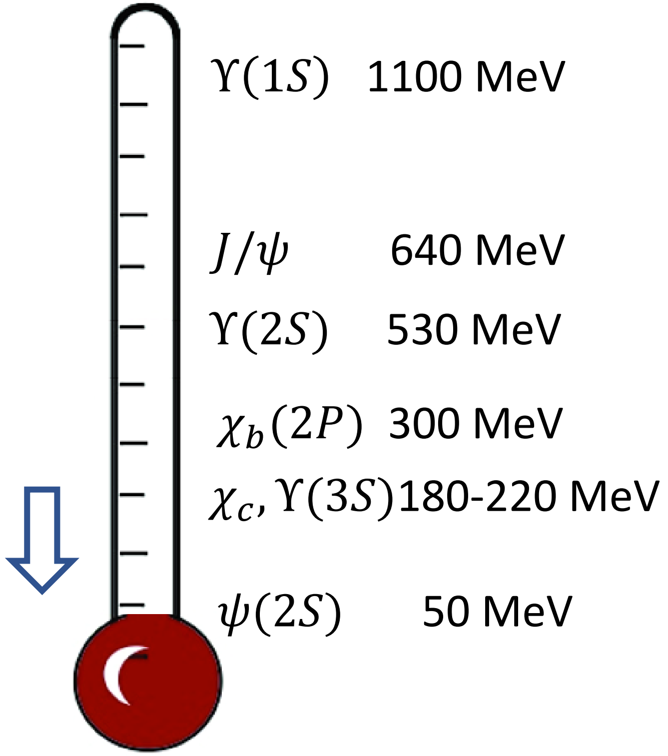
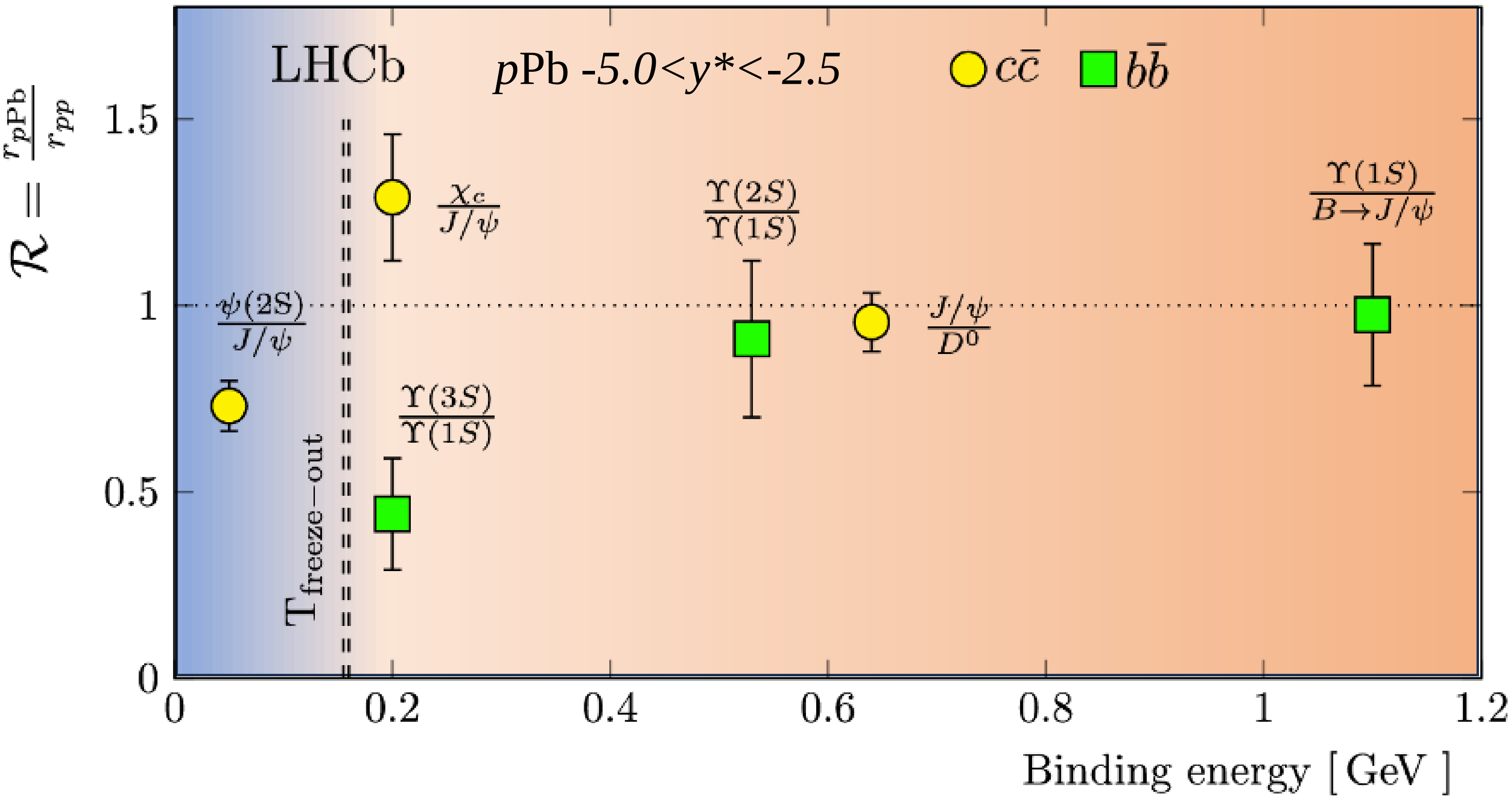
Supplementary material :
https://cds.cern.ch/record/2878991/files/Fraction_of_chi_c_decays_in_prompt_Jpsi_yields_in_pPb_and_Pbp_collisions_at_8_16_TeV.pdf?version=2





χ_c double ratio consistent with **NO final-state dissociation of χ_c states in pPb collisions**.

Quarkonium states in pPb collisions.



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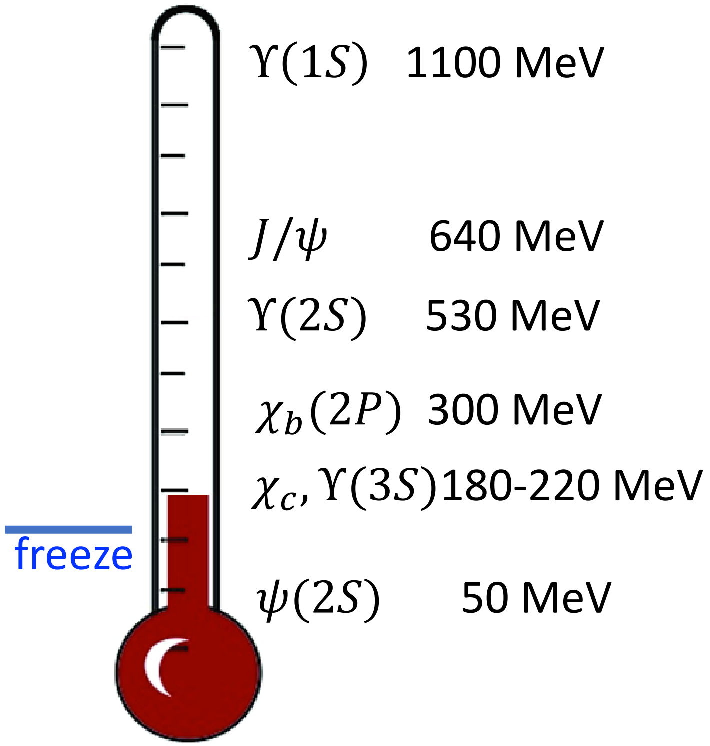
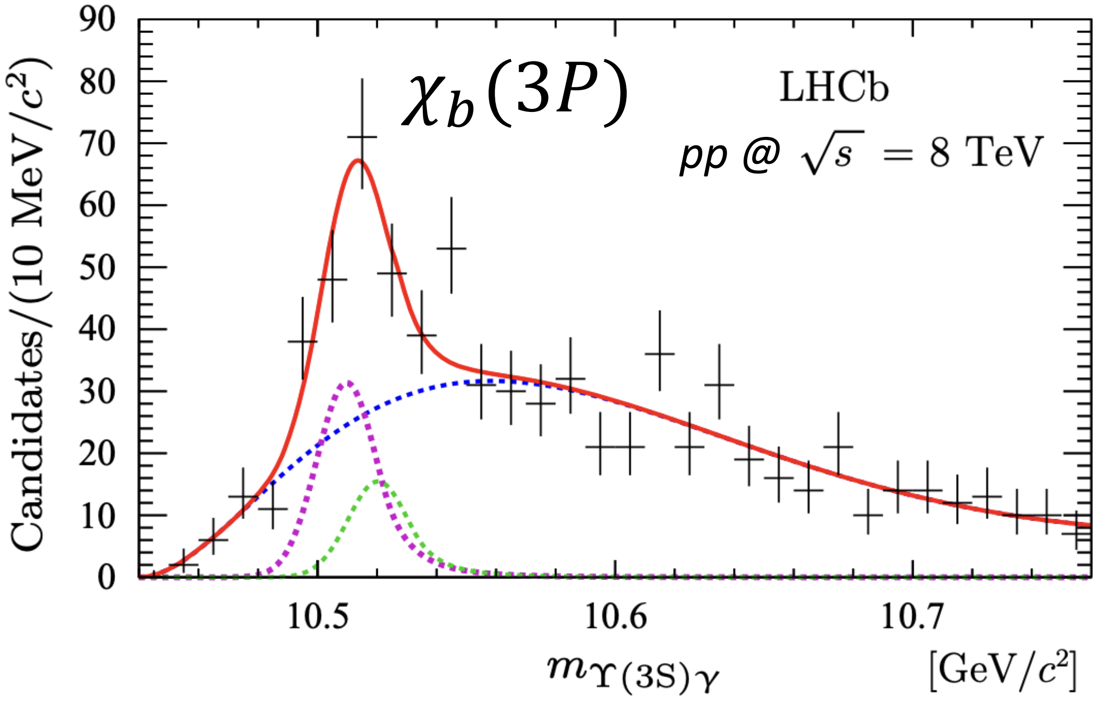


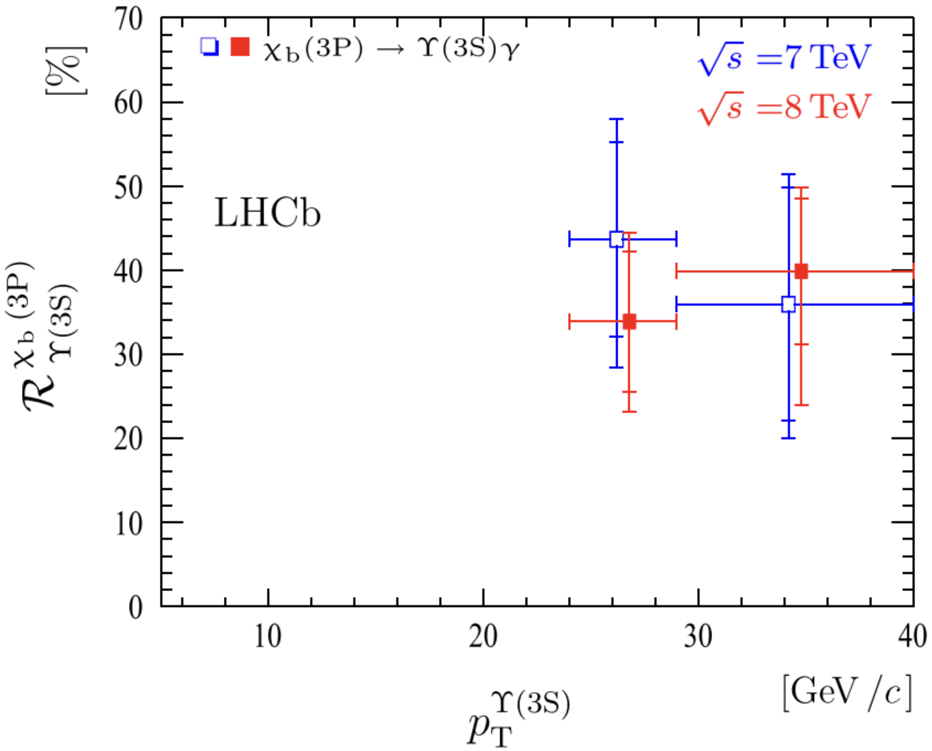
Freeze-out temperature
PLB 795, 15 (2019)
PRC 99, 044914 (2019)
PLB 834, 137473 (2022).

Doubled ratios btw. quarkonium states and corresponding HQ consistent with a hadronic medium in small system.
Except $\Upsilon(3S)$ state which seems to break in pPb collisions.

Why $\Upsilon(3S)$ is dissociate and χ_c is not ?

Eur. Phys. J. C (2014) 74:3092



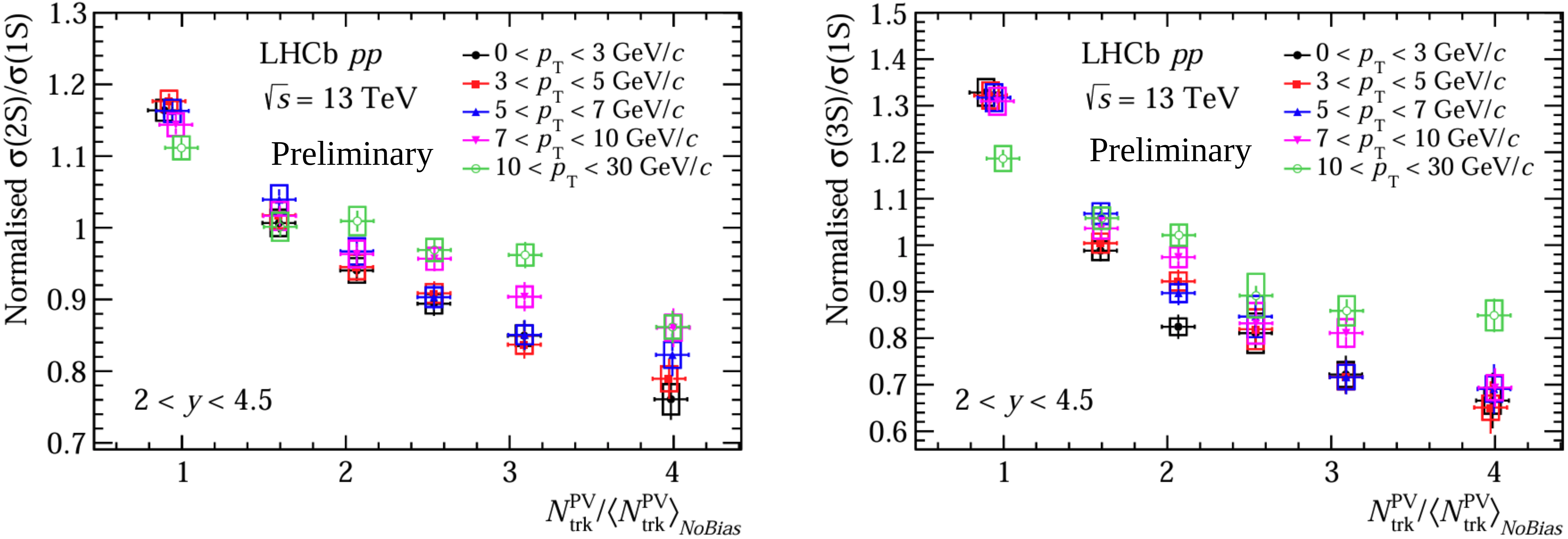


~ 40% of $\Upsilon(3S)$ comes from $\chi_b(3P)$ feed-down.

$\chi_b(3P)$ binding energy is M($B\bar{B}$)-M($\chi_b(3P)$) = 47 MeV, similar to $\psi(2S)$

$\Upsilon(3S)$ relative suppression consistent with the dissociation of the feed-down source from $\chi_b(3P)$ decays.

Υ dissociation in *pp* collisions

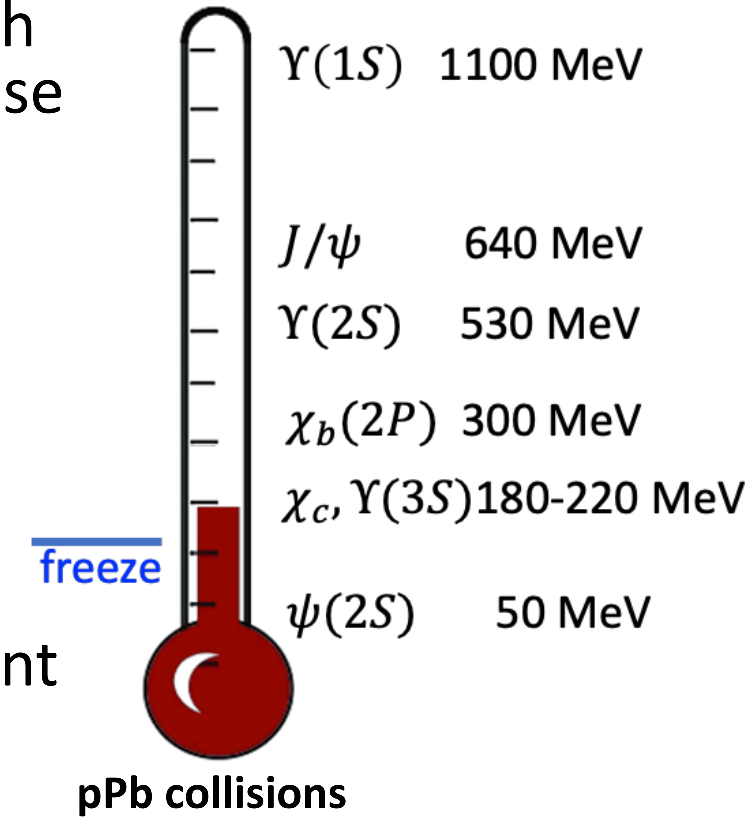


- About 35% of $\Upsilon(2S)$ and 60% of $\Upsilon(3S)$ are broken in the highest multiplicity pp collisions, consistent to what is observed in pPb collisions, when considering uncertainties
- Coincidently, 35% of $\Upsilon(2S)$ comes from $\chi_b(2P)$ (see Eur. Phys. J. C (2014) 74:3092 and backup slide)
- The high-p_T $\Upsilon(3S)$ has about 35% dissociation, also consistent with the high-p_T $\chi_b(3P)$ feed-down fraction

See Chenzhi Dong poster for more details.

Take away

- New $\psi(2S)$ and χ_c measurements in pPb collisions along with previous results sets the limit of temperature achieved in these collisions
- The temperature achieved in pPb collisions at LHC does not inhibit the production of χ_c states with its 180 MeV average binding energy
- $\psi(2S)$ is dissociated in pPb and high-multiplicity *pp*, consistent with its breaking in hadronic environment
- Dissociation of $\Upsilon(2S)$ and $\Upsilon(3S)$ are consistent between *pp* and pPb collisions and are consistent with the feed-down contribution from $\chi_b(2P)$ and $\chi_b(3P)$ decays respectively



ありがとう ございました

EXTRAS

$$R^{p\mathrm{Pb}\,(\mathrm{Pb}p)}_{\psi(2S)/J/\psi} = \frac{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(\psi(2S))}{R_{p\mathrm{Pb}\,(\mathrm{Pb}p)}(J/\psi)} = \frac{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{p\mathrm{Pb}\,(\mathrm{Pb}p)}}{\left[\frac{\sigma(\psi(2S))}{\sigma(J/\psi)}\right]_{pp}}$$

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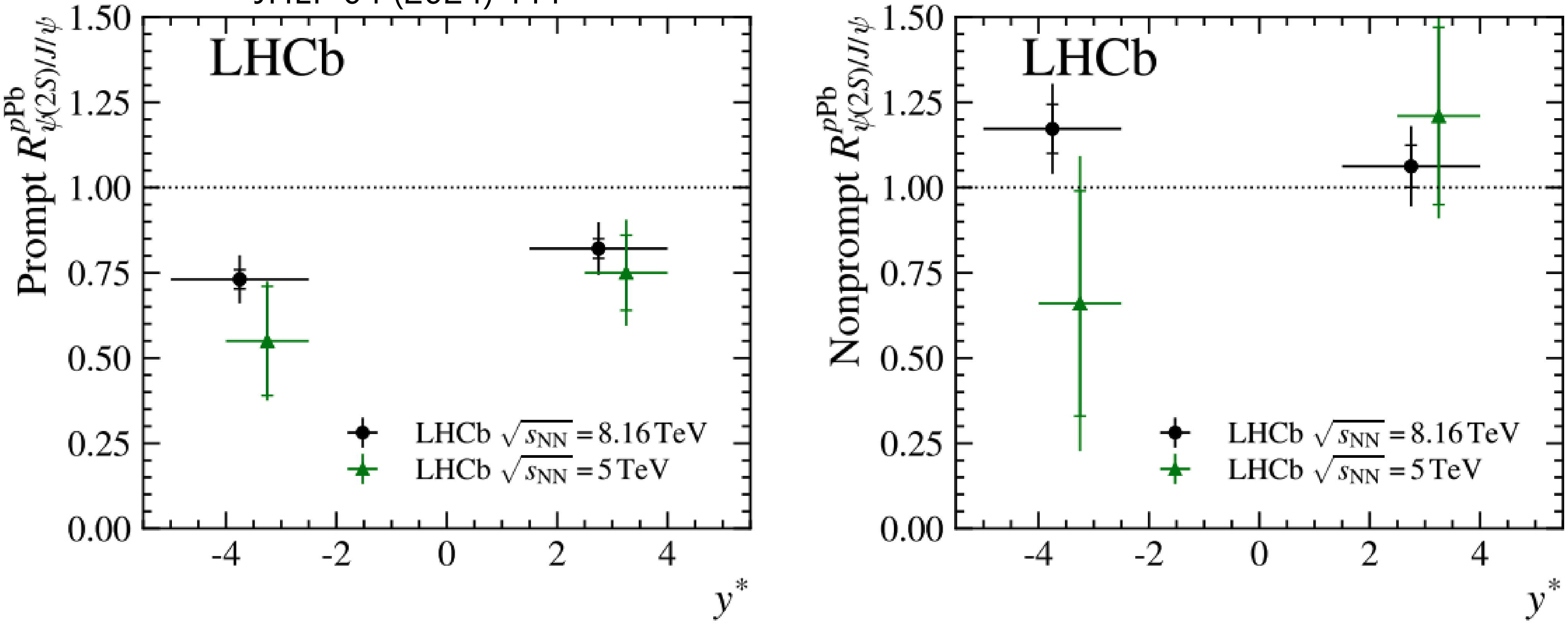

8.16 TeV result more precise and consistent with 5 TeV.

Confirming the existence of final-state effects on the $\psi(2S)$ yields.

pPb->χ_c Result

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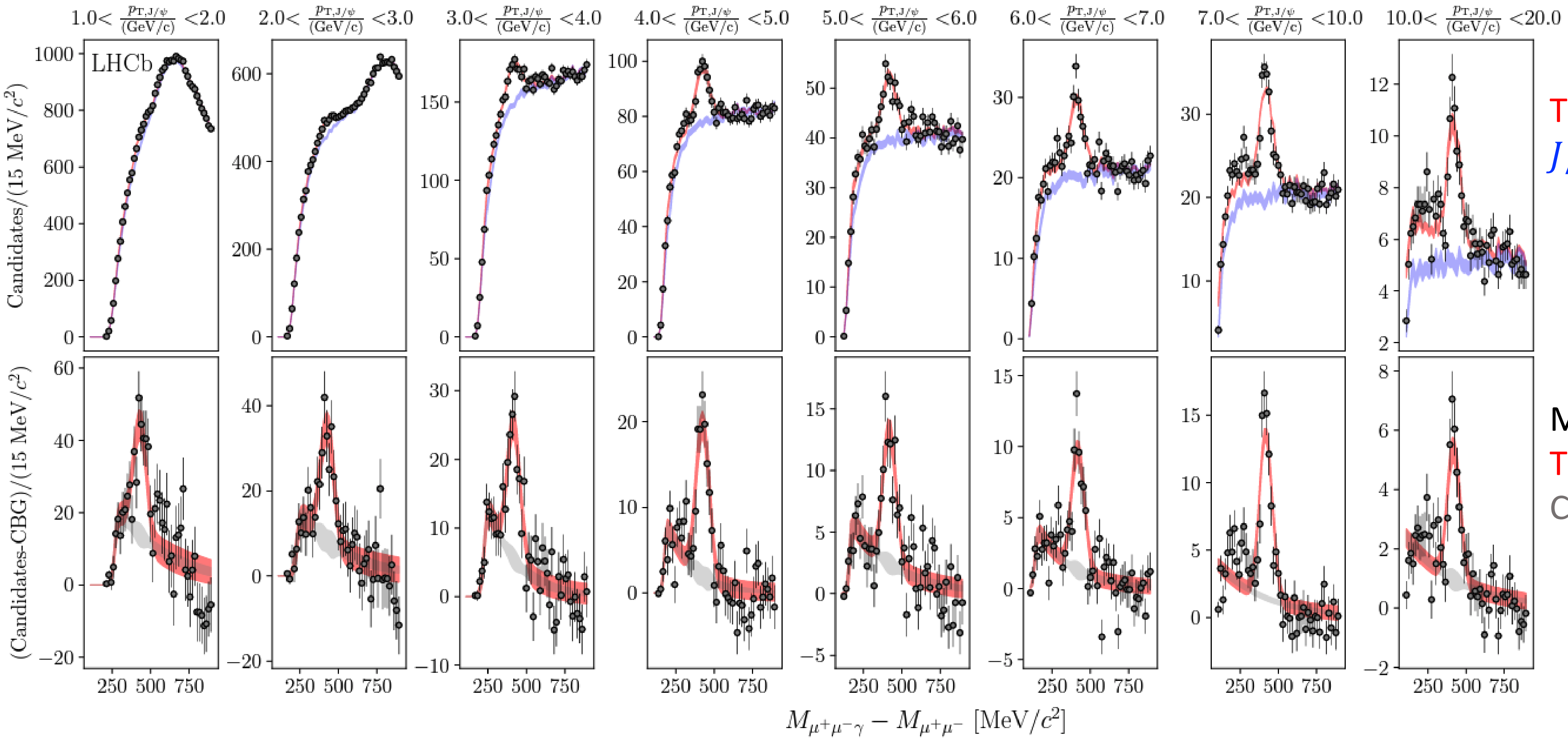


TOTAL fit

J/ψ and γ in mixed events

Mixed event subtracted

TOTAL-CB fit

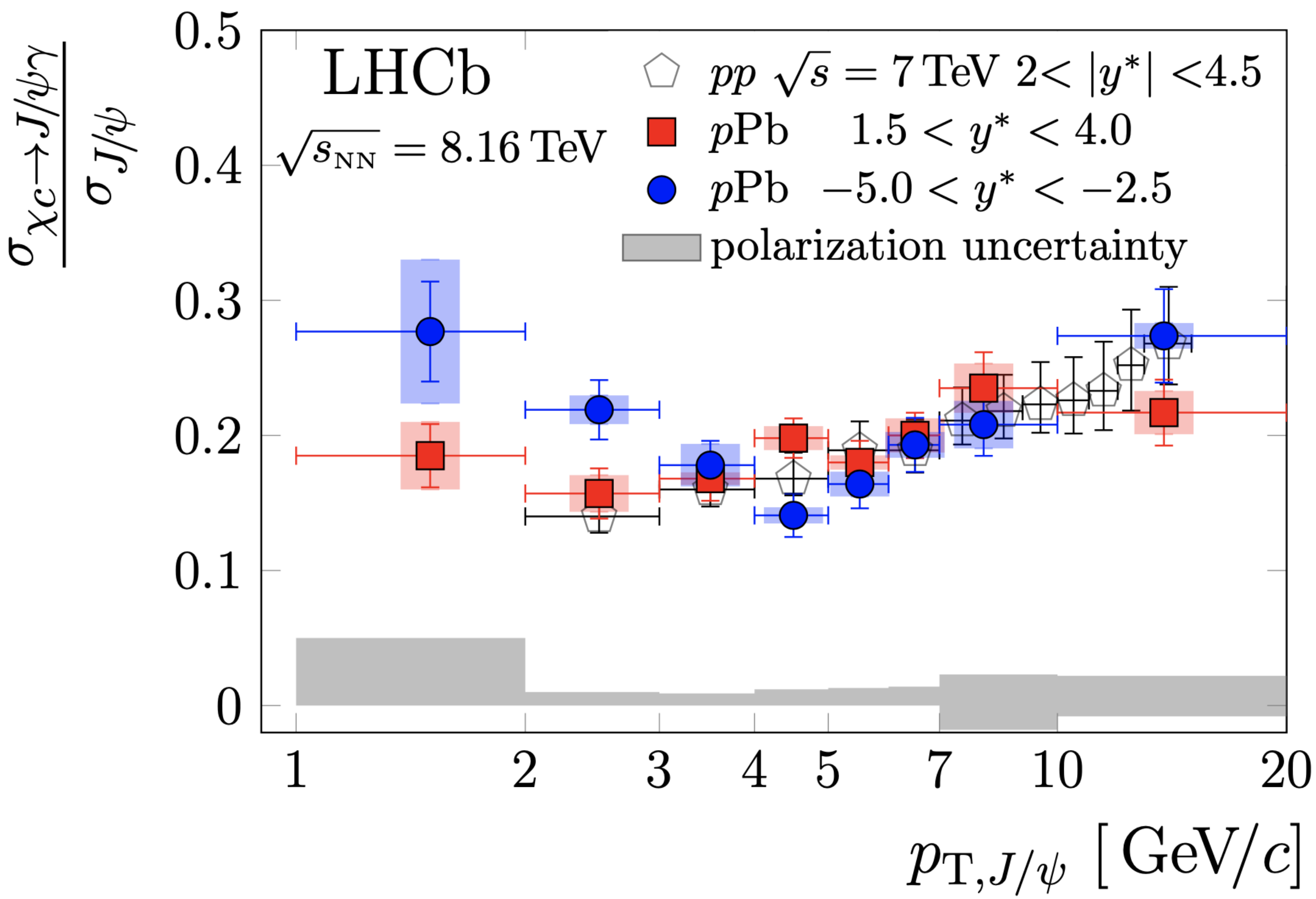
Correlated BG

Figure from the supplementary material :

https://cds.cern.ch/record/2878991/files/Fraction_of_chi_c_decays_in_prompt_Jpsi_yields_in_pPb_and_Pbp_collisions_at_8_16_TeV.pdf?version=2

Fraction of χ_c decays in prompt J/ψ.

PRL 132 (2024) 102302



Prompt J/ψ composition:

- Direct J/ψ
- $\chi_c \to J/\psi\,\gamma$ decays
- $\psi(2S) \to J/\psi + X$ decays
- exotics

Apparent larger fraction at backward rapidity consistent with the slightly larger suppression of the $\psi(2S)$ contribution to the prompt J/ψ.

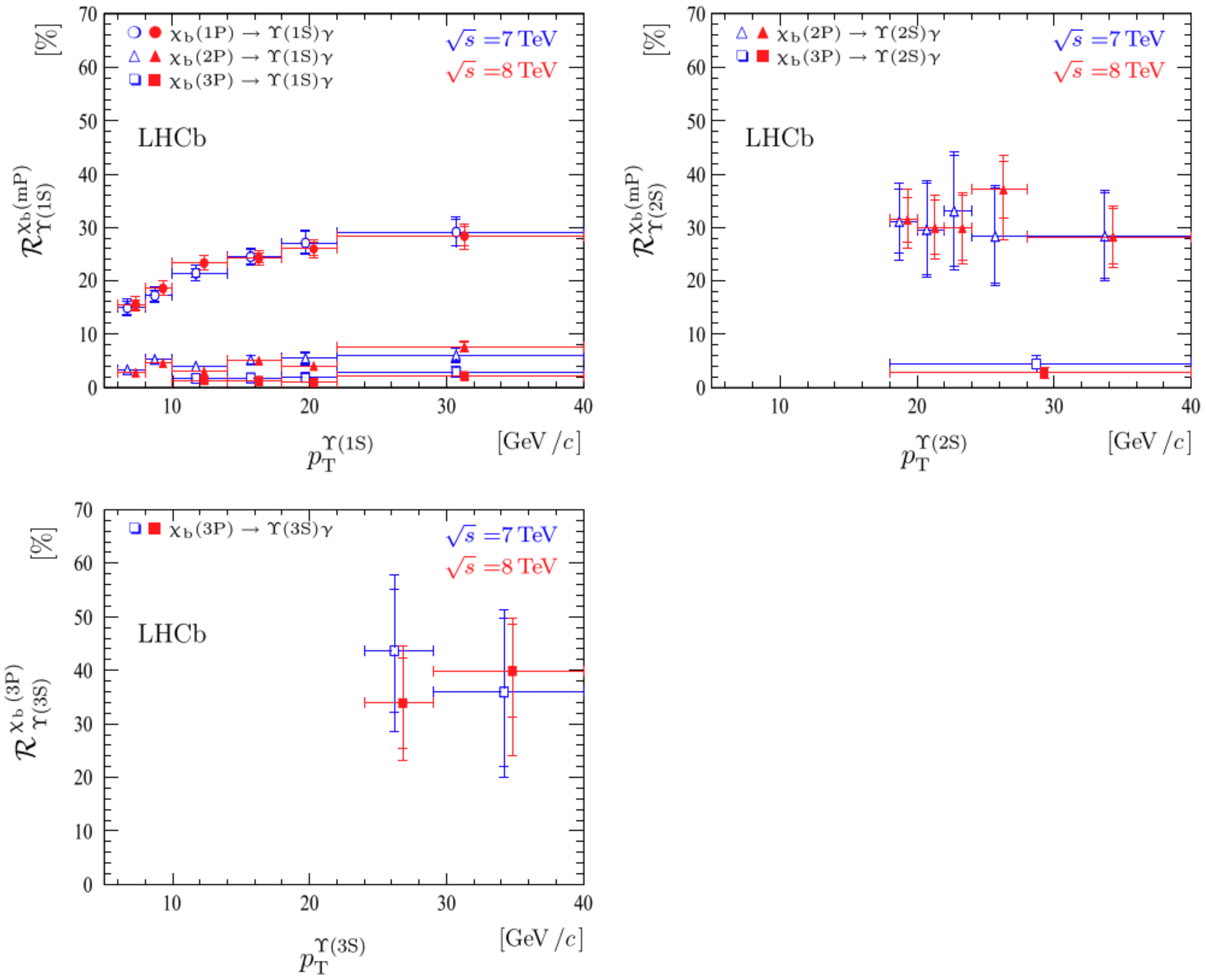


Fig. 3 Fractions $\mathcal{R}^{\chi_b(mP)}_{\Upsilon(nS)}$ as functions of p_T^{Υ}. Points with blue open (red solid) symbols correspond to data collected at $\sqrt{s} = 7(8)$ TeV, respectively. For better visualization the data points are slightly displaced from the bin centres. The inner error bars represent statistical uncertainties, while the outer error bars indicate statistical and systematic uncertainties added in quadrature