New LHCb results on quarkonia production (and exotic hadron) in pp and pPb collisions.

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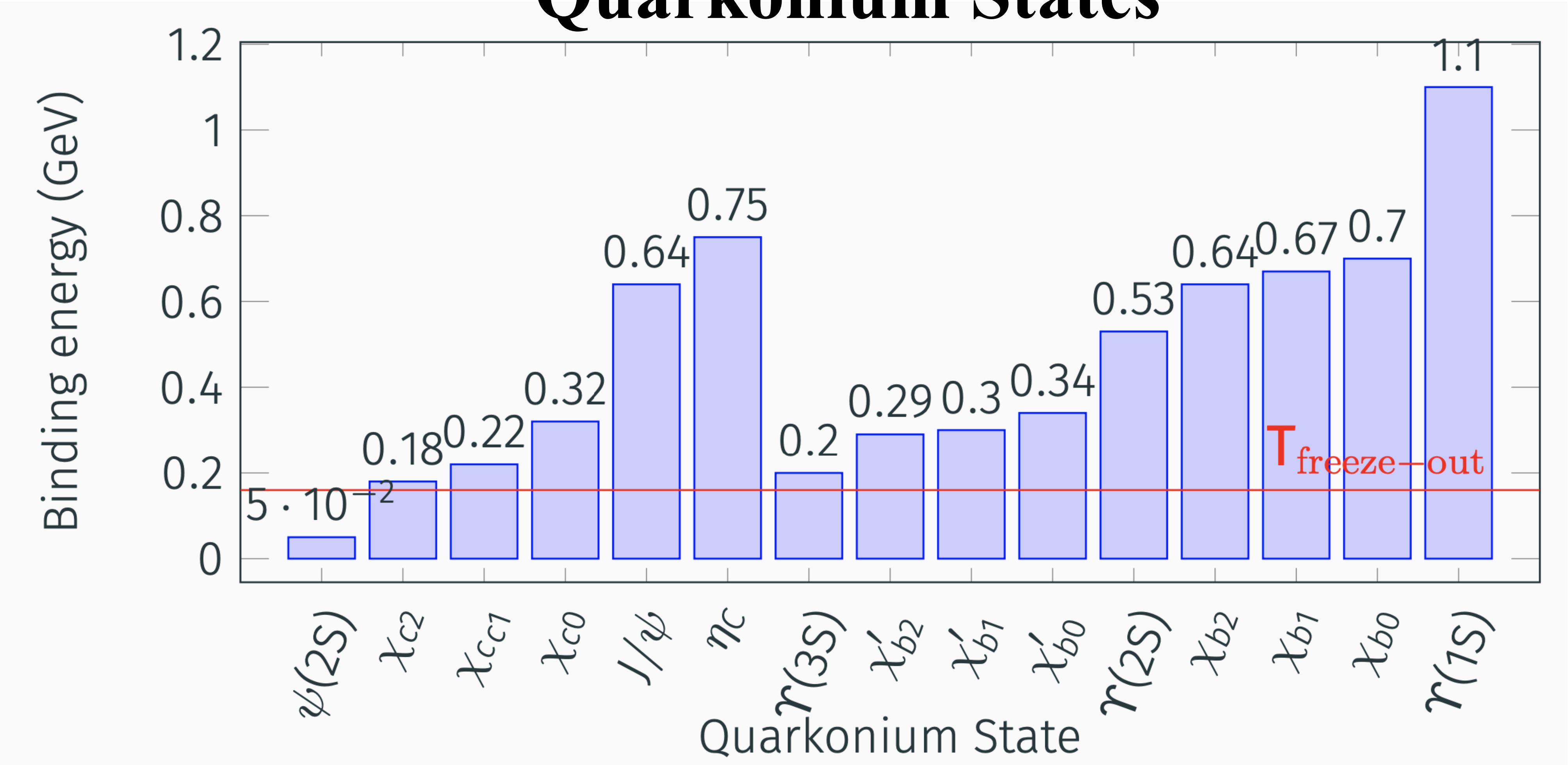
Los Alamos National Lab

LA-UR-23-30003

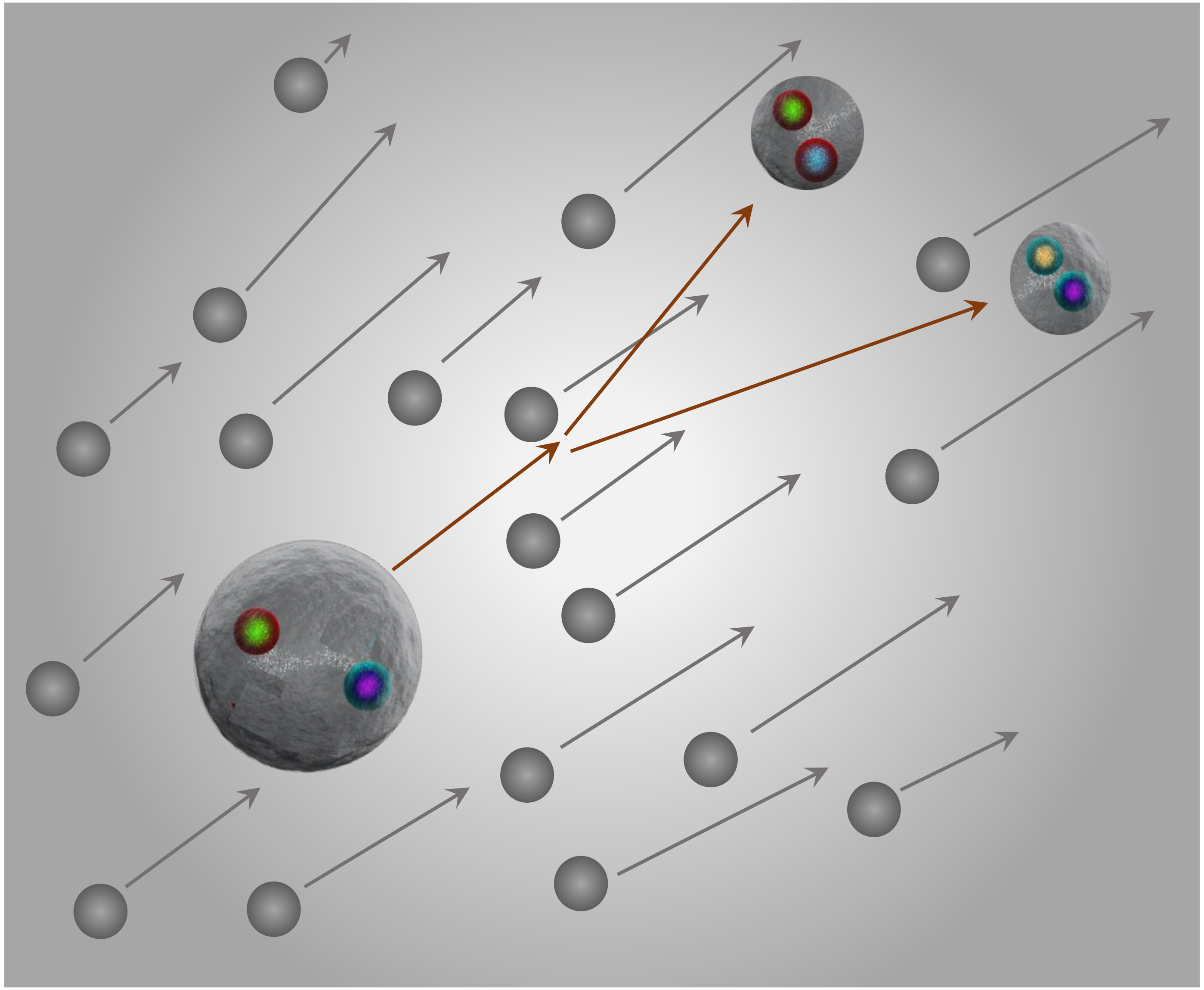
Quarkonium States



If medium is formed and temperature is above its binding energy, the quarkonium state is inhibit to be produce.

$T_{freeze-out}$ ~ 155-160 MeV

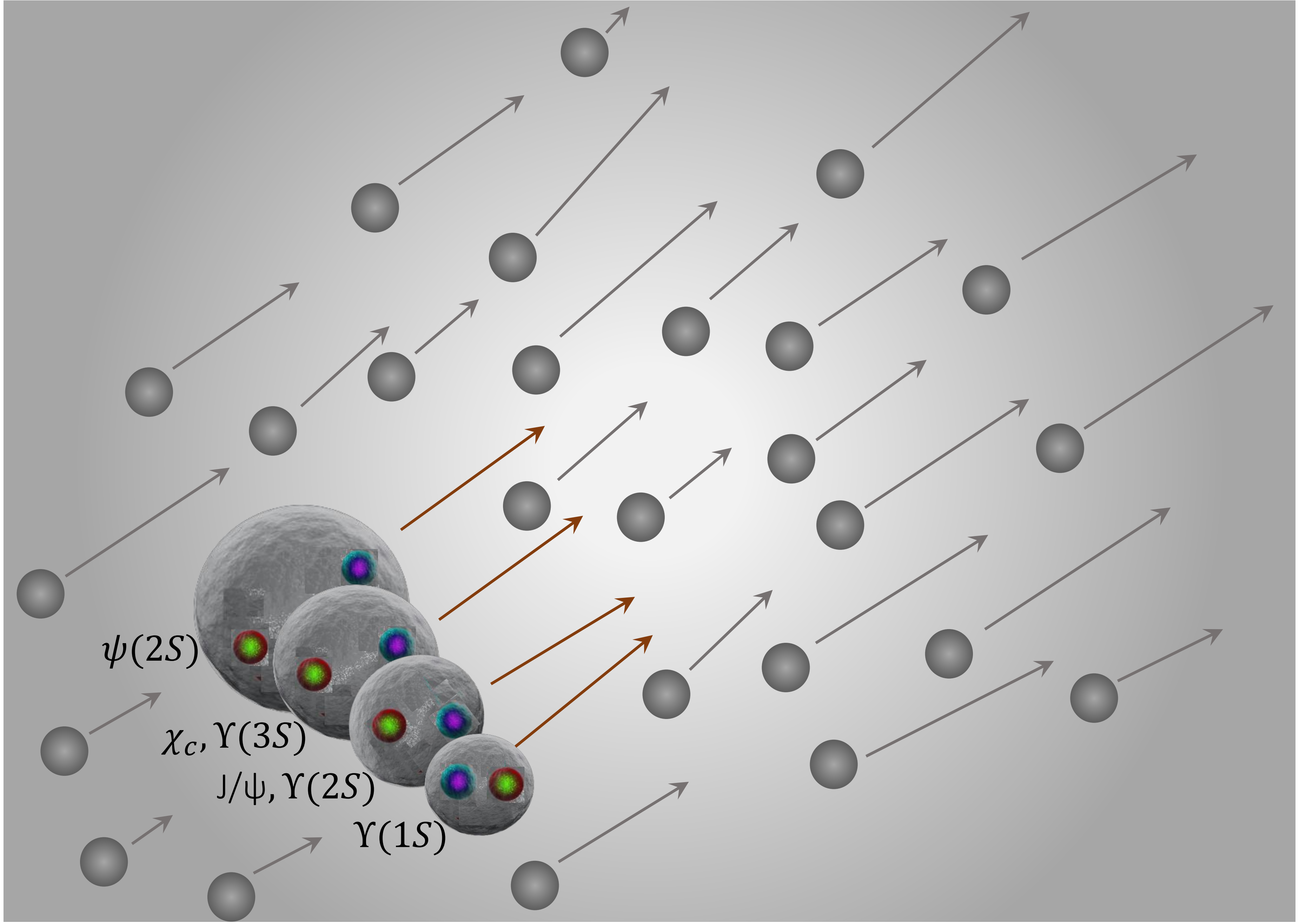
Lattice QCD A. Bazavov et al., PLB795 (2019) 15
Thermal Model N. Sharma et al. PRC 99 (2019) 044914
Thermal fits to ALICE data F. A. Flor, PLB 834 (2022) 137473



Alternative way to break quarkonium states:

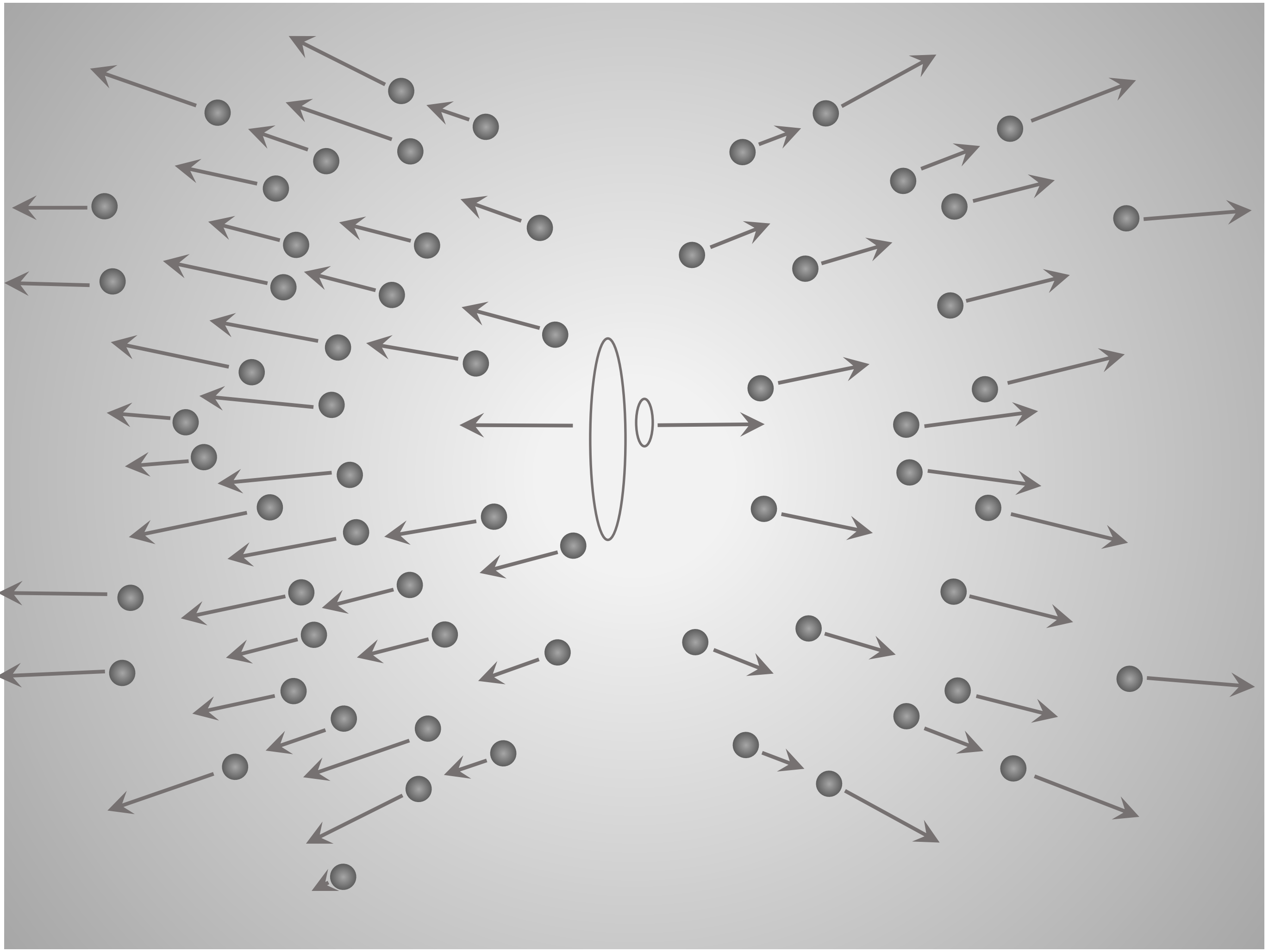
Large quarkonium states can break in high-multiplicity environment when interacting with **co-moving** particles

[Ferrero, PLB749, 98 (2015)].

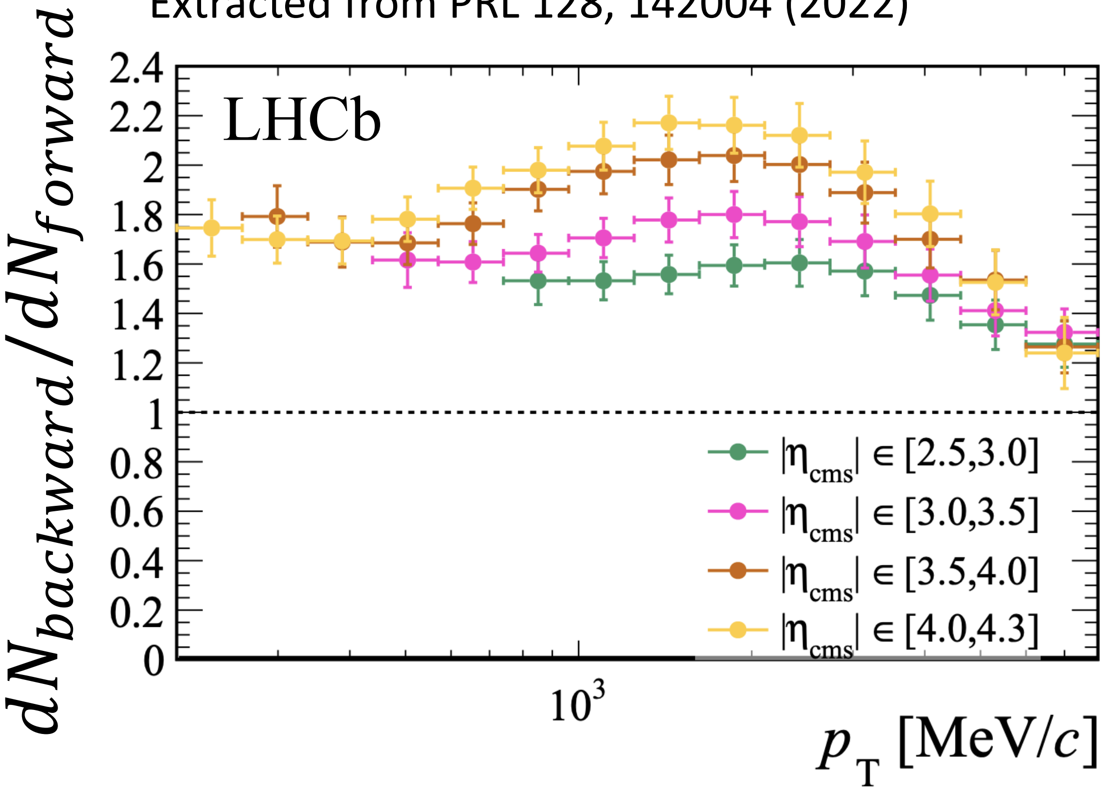


	$r(fm)$
J/ψ	0.50
χ_c	0.72
$\psi(2S)$	0.90
$\Upsilon(1S)$	0.28
χ_b	0.44
$\Upsilon(2S)$	0.56
$\chi_b(2P)$	0.68
$\Upsilon(3S)$	0.78

Non-Relativistic Potential Theory:
Satz, J.Phys.G32:R25 (2006)



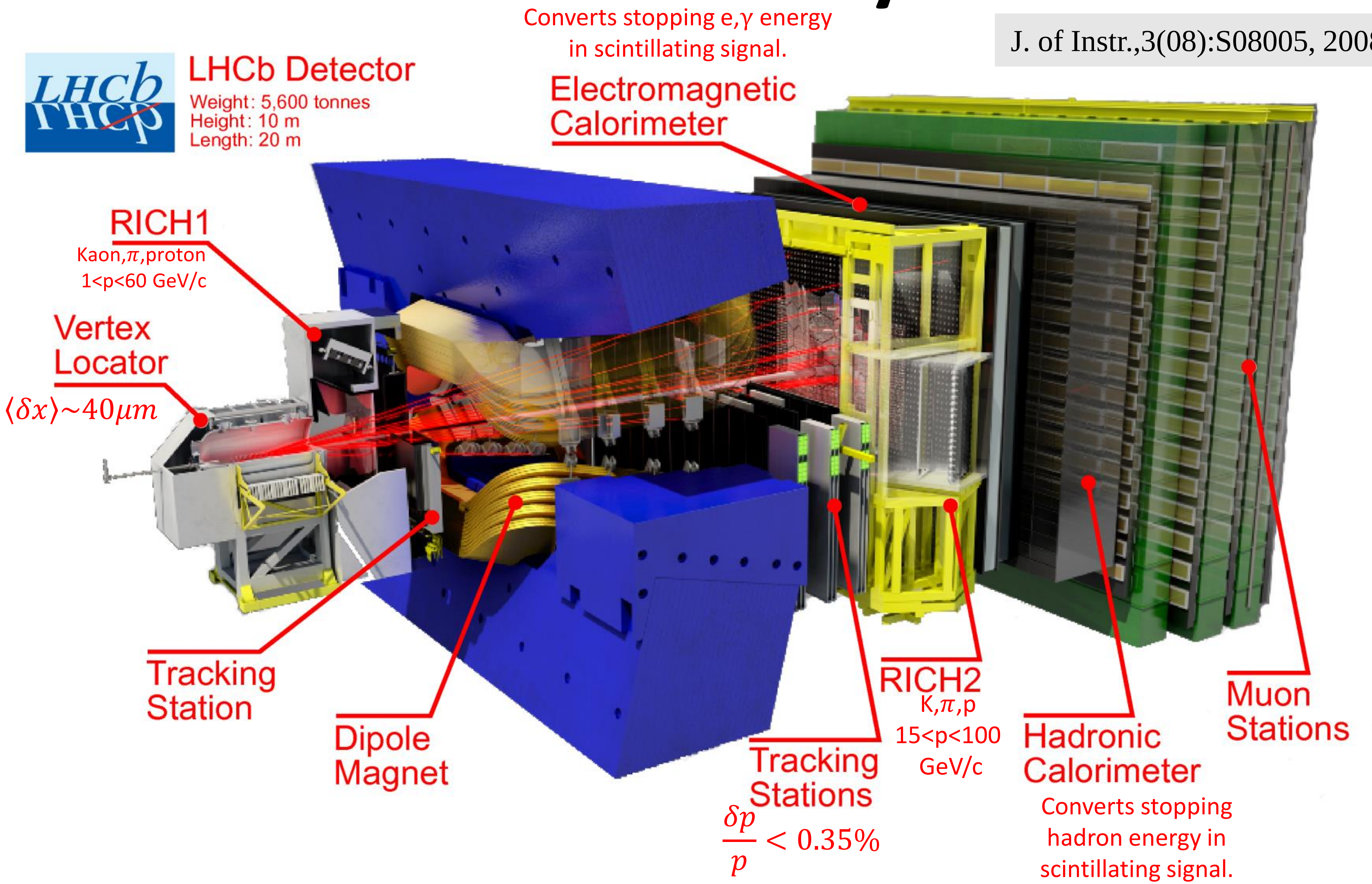
Extracted from PRL 128, 142004 (2022)

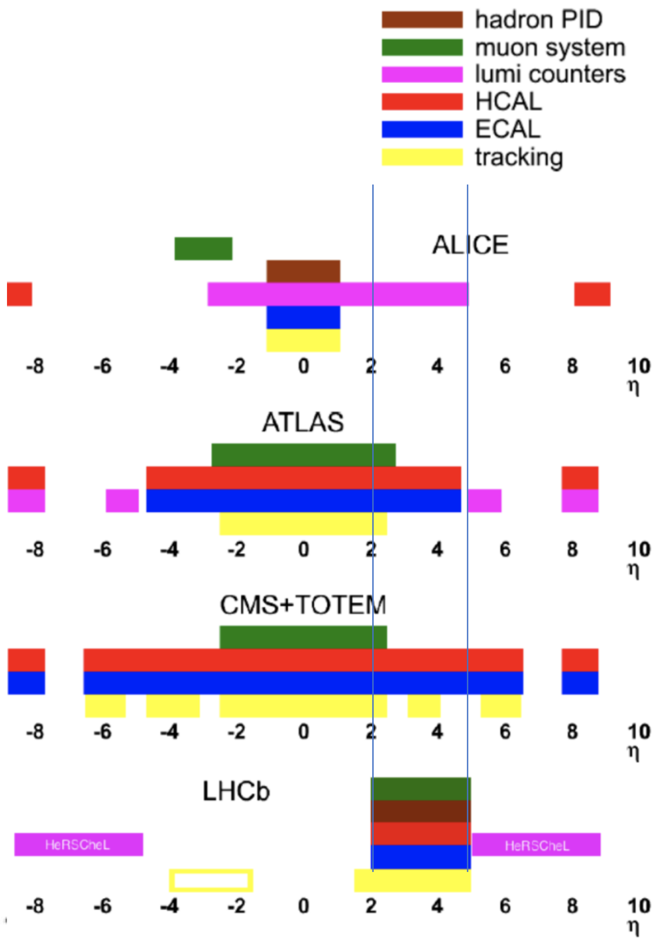


Particle multiplicities are higher at the backward rapidity (A-going direction).

The LHC beauty detector

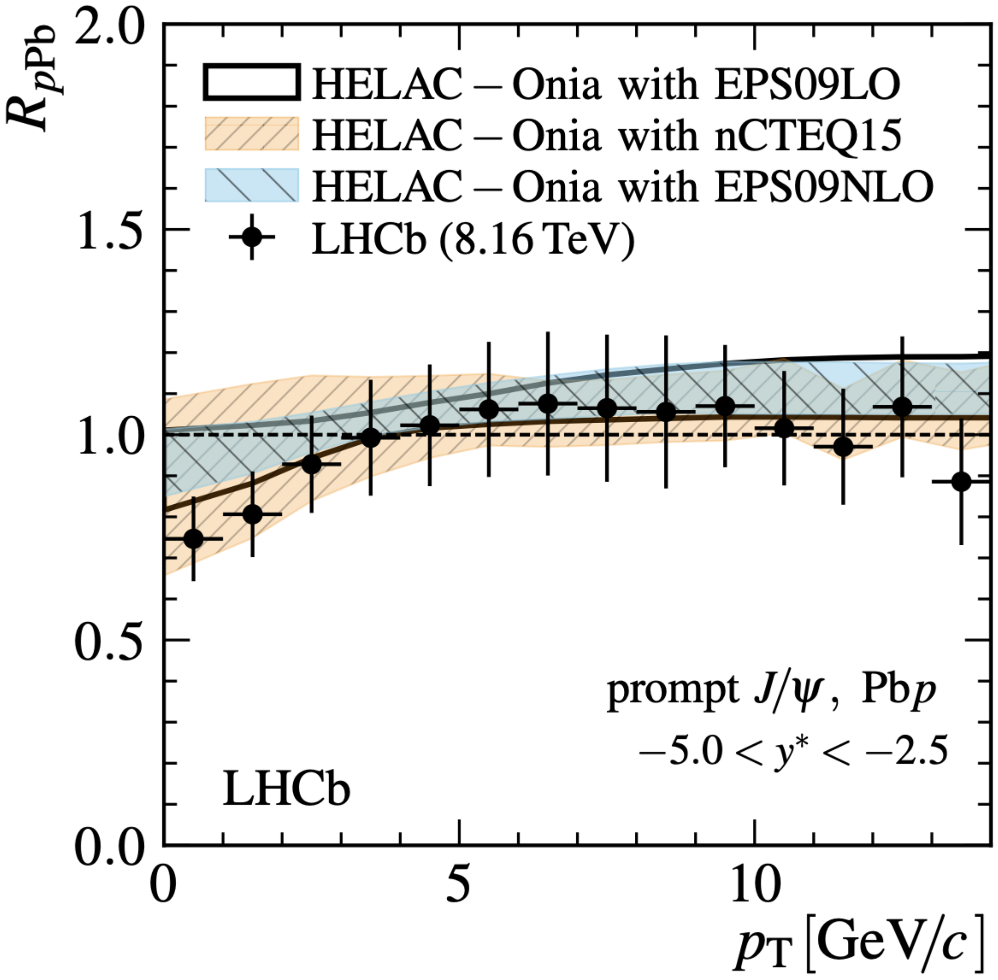
J. of Instr.,3(08):S08005, 2008

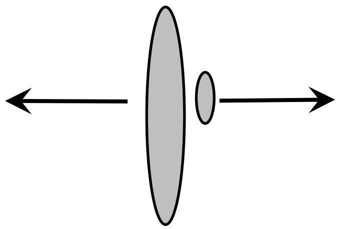


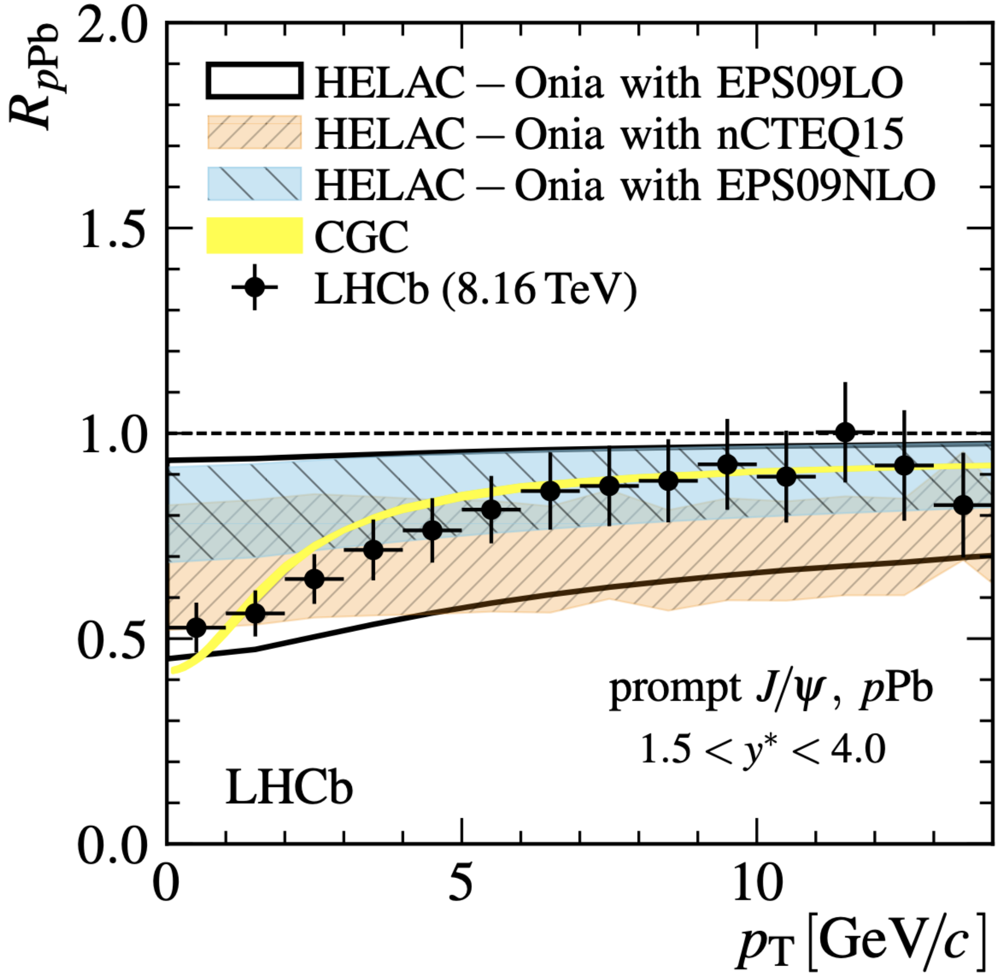


- the optimum detector for quarkonia studies
- $e, \mu, \pi, K, p, \gamma$, particle jet identification in 1<p<100 GeV/c
- Unique forward instrumentation for heavy ion physics

PLB774, 159 (2017)



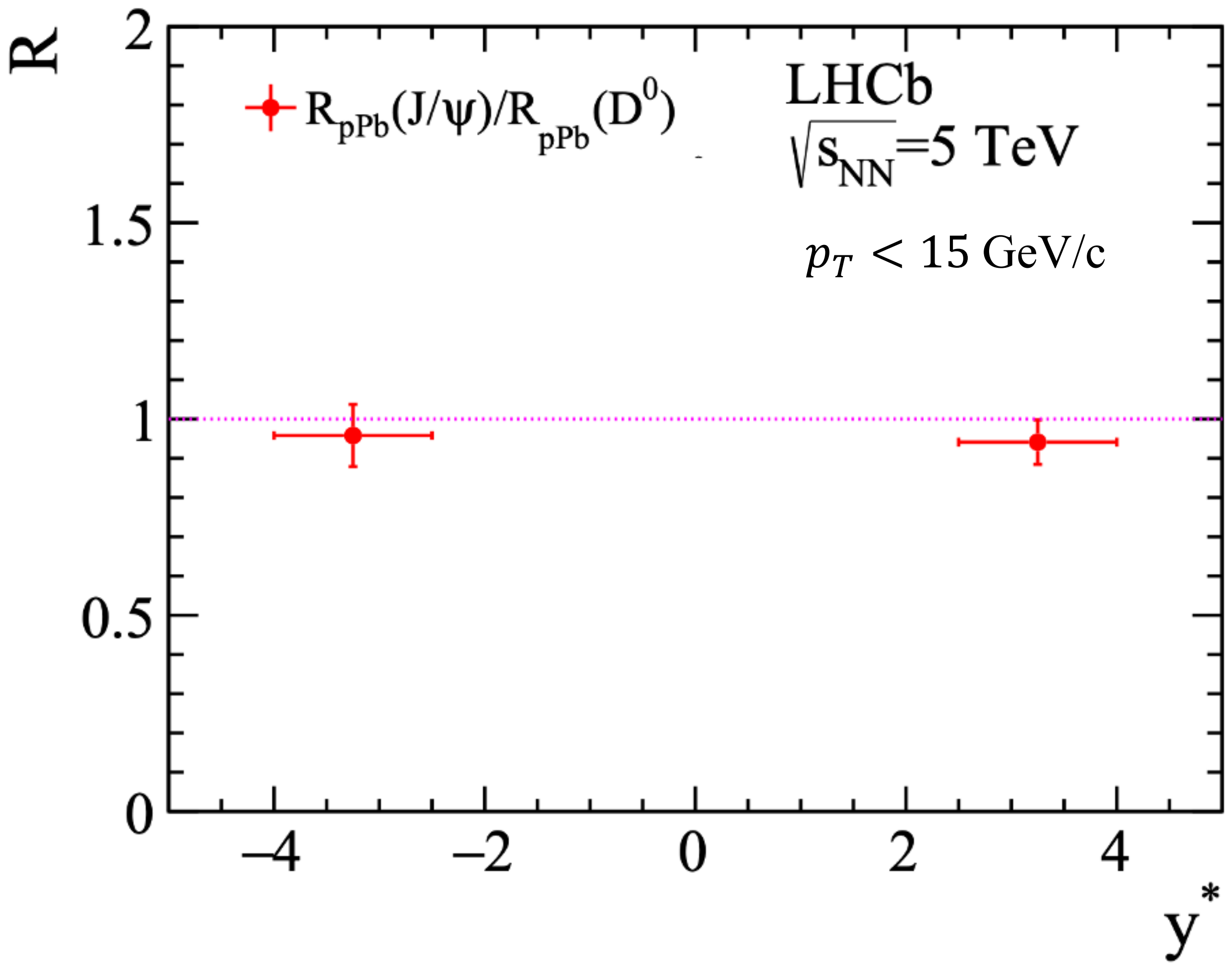


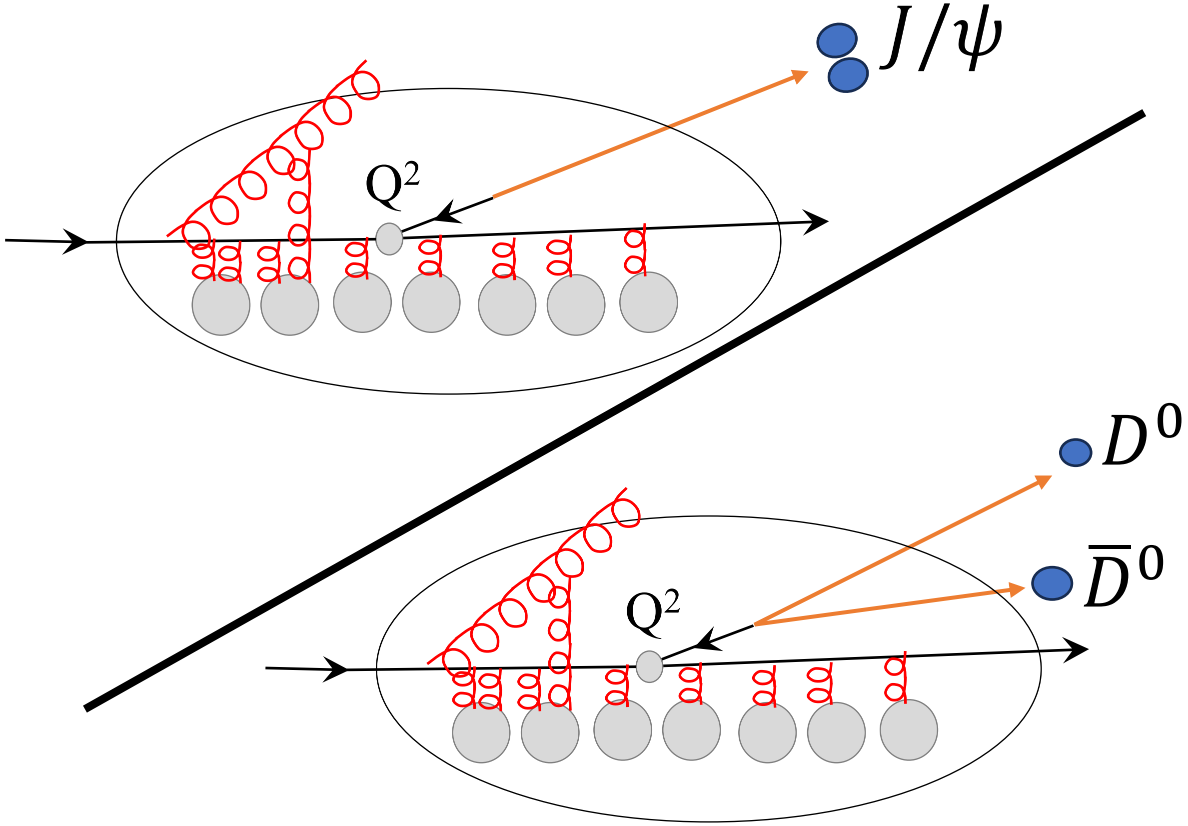


- J/ψ nuclear modification factor largely comes from Initial-State Effects.
- ISE are studied in LHCb using several probes. See Tom Boettcher's talk in the Initial state session this afternoon.

Cancelling out Initial-State Effects

JHEP 1710 (2017) 090

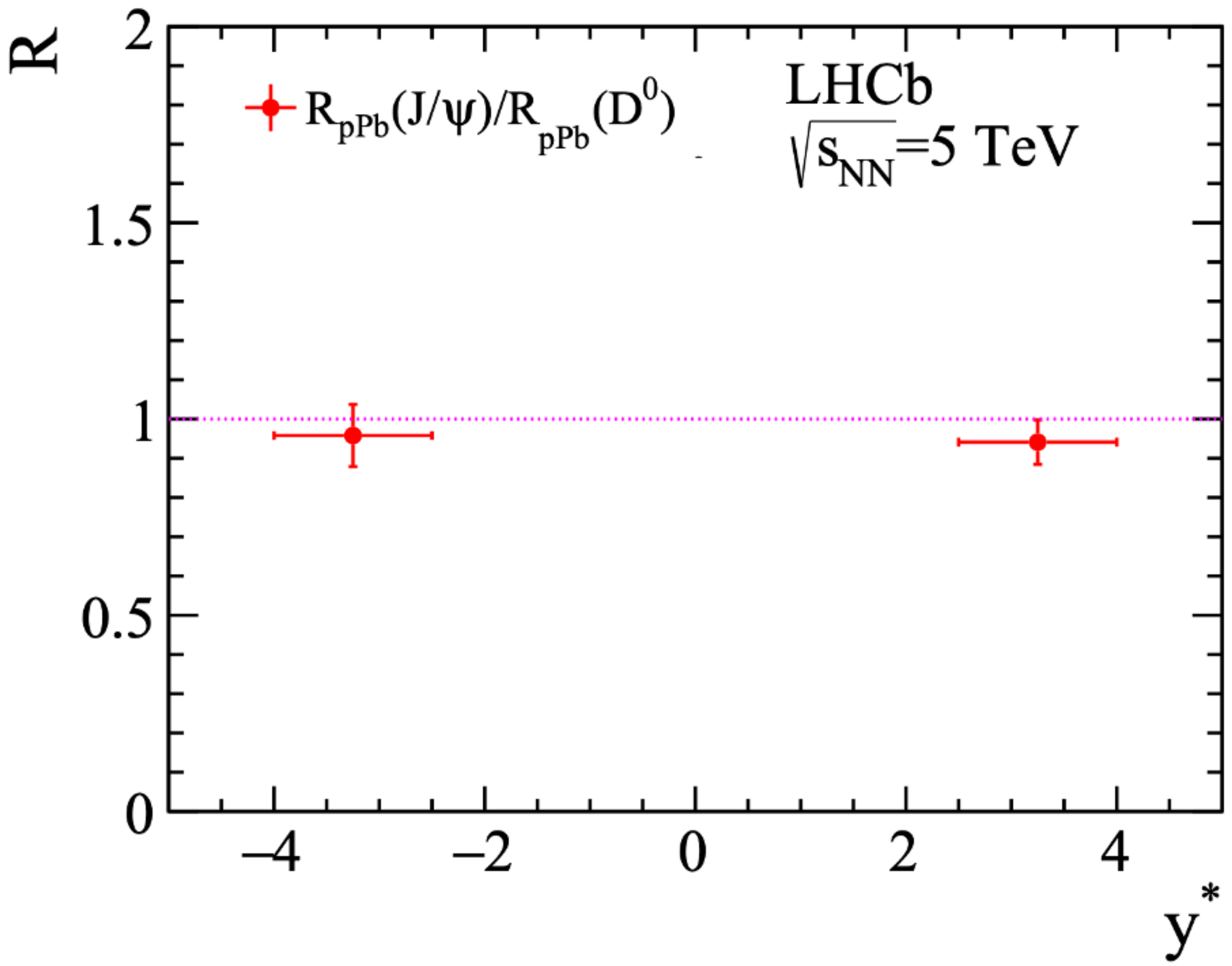




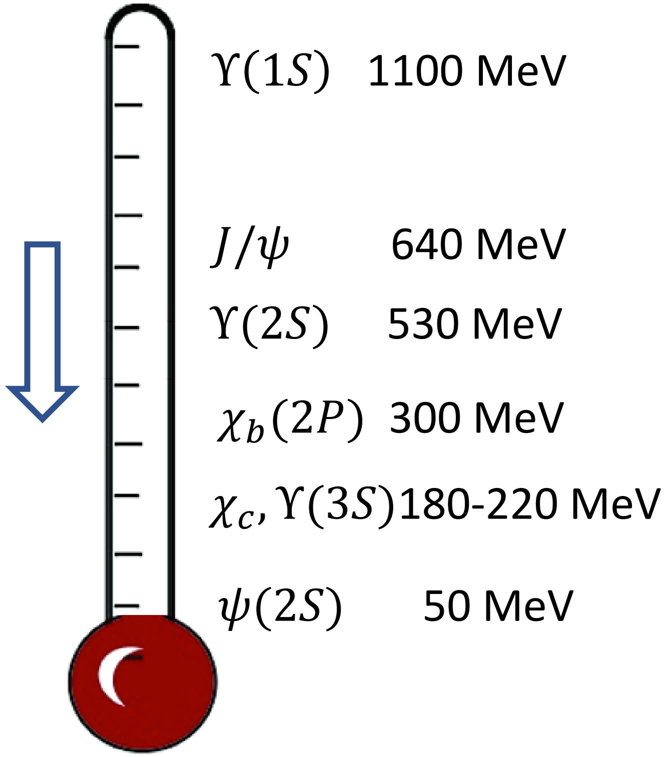
Initial-state effects are cancelled out in the $\mathrm{R}_{\mathrm{pA}}(J/\psi)/\mathrm{R}_{\mathrm{pA}}(D^0)$ ratio.

J/ψ yield is not affected by final-state effects.

JHEP 1710 (2017) 090



Agnes Mocsy's thermometer



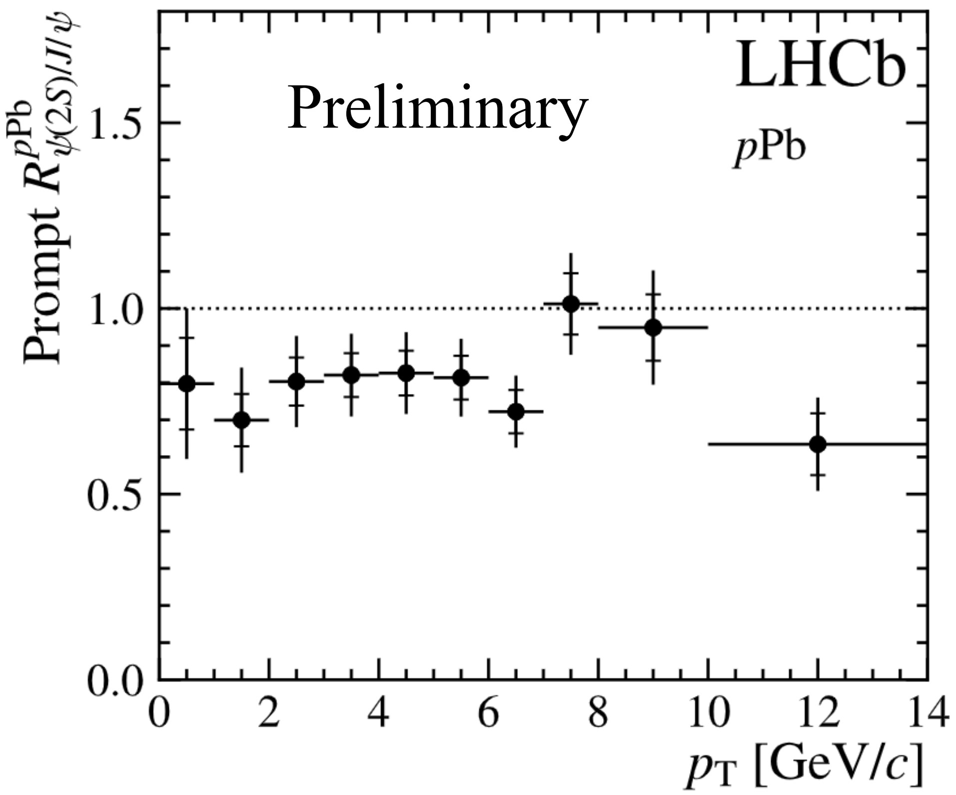
Initial-state effects are cancelled out in the $\mathrm{R_{pA}}(J/\psi)/\mathrm{R_{pA}}(D^0)$ ratio.

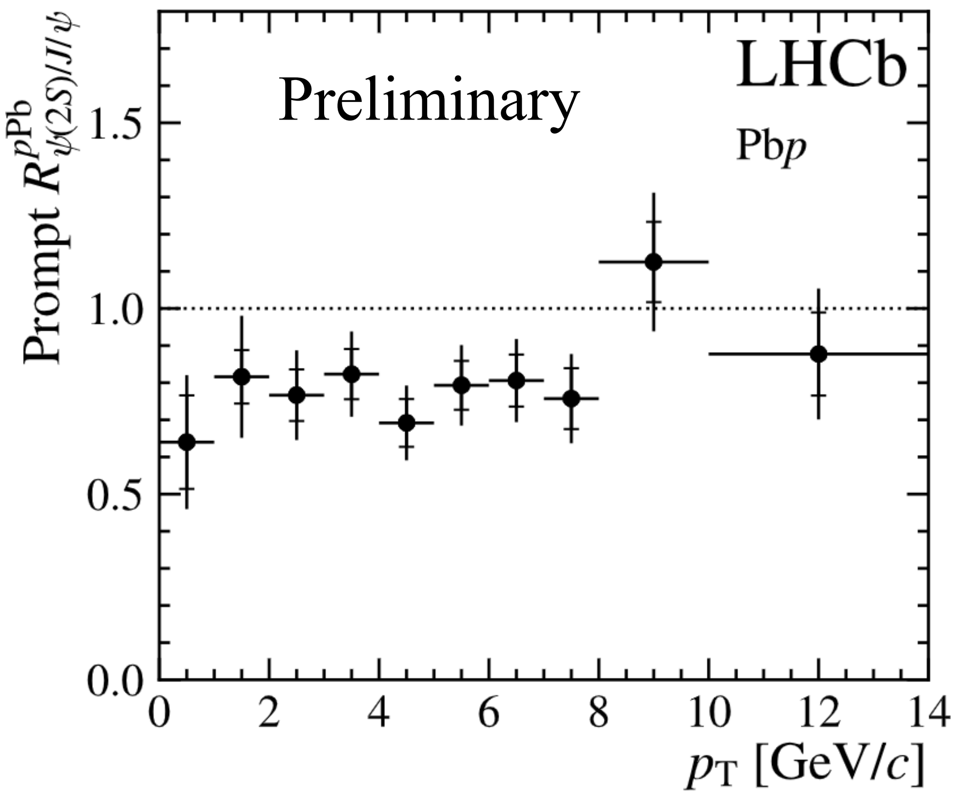
J/ψ yield is not affected by final-state effects.

New $\psi(2S)$ Result at $\sqrt{s_{NN}}$=8.16 TeV

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

LHCb-PAPER-2023-024 in preparation





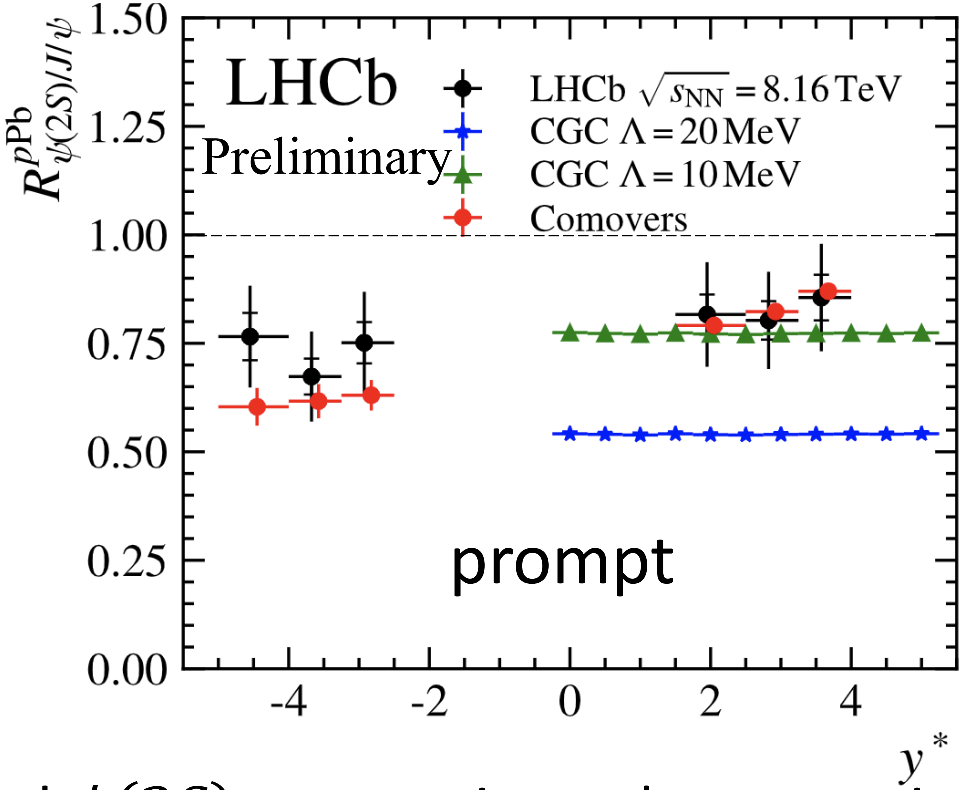
ISE cancelled out in the $\mathrm{R_{pA}}(\psi(2S))/\mathrm{R_{pA}}(J/\psi)$ ratio.

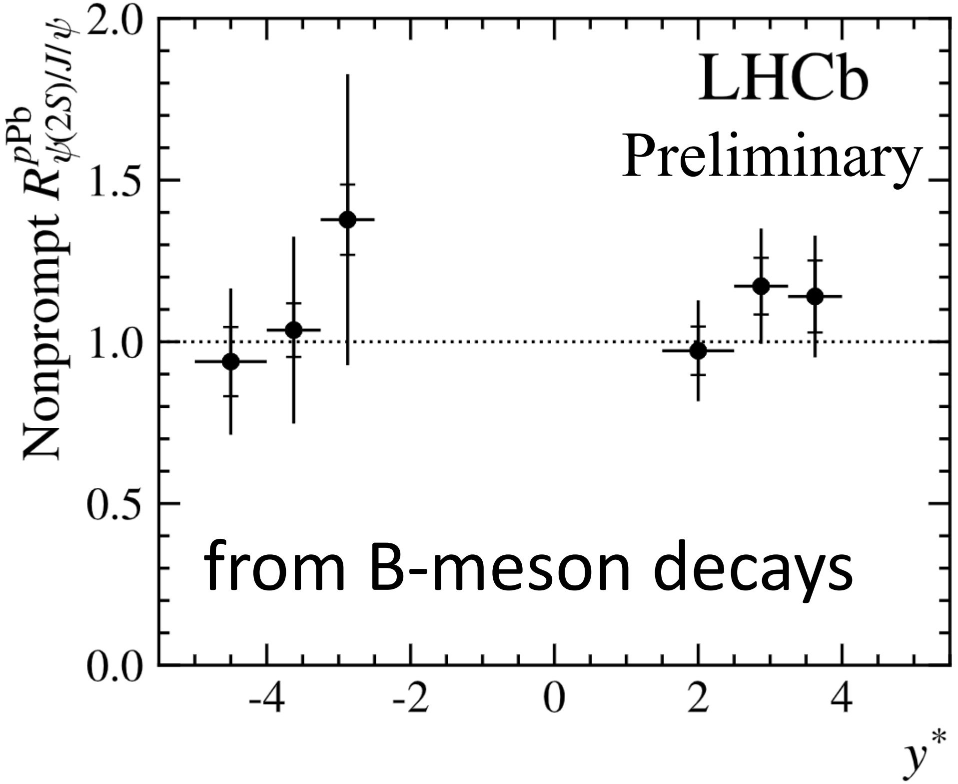
$\psi(2S)$ is affected by final-state effects.

New $\psi(2S)$ Result at $\sqrt{s_{NN}}$=8.16 TeV

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

LHCb-PAPER-2023-024 in preparation





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

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

New $\psi(2S)$ Result at $\sqrt{s_{NN}}$=8.16 TeV

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

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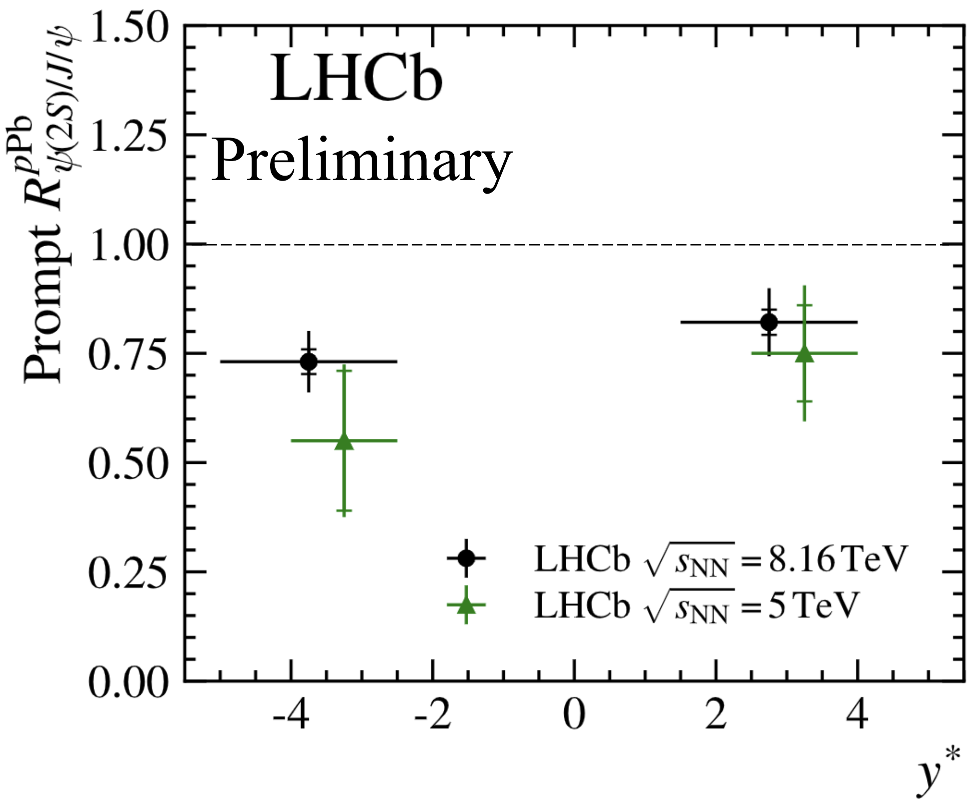
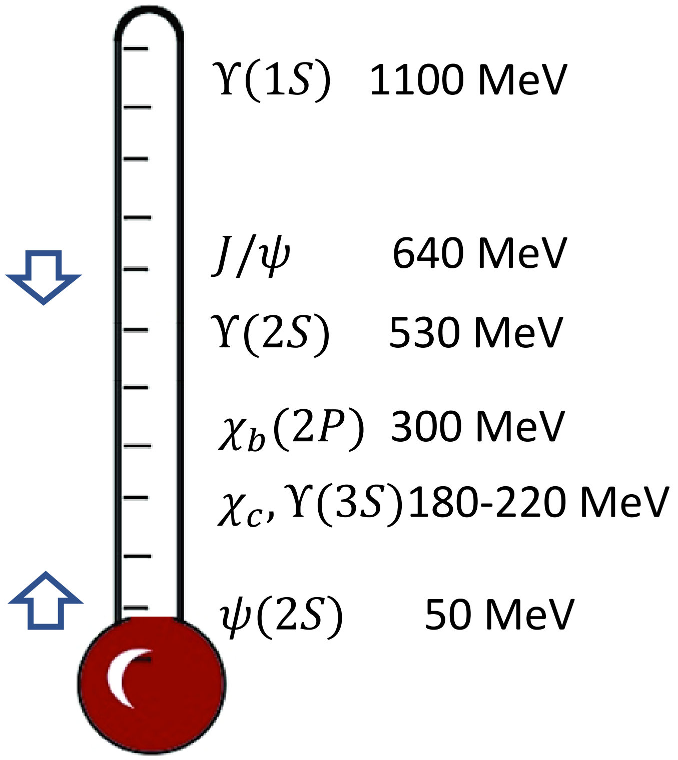
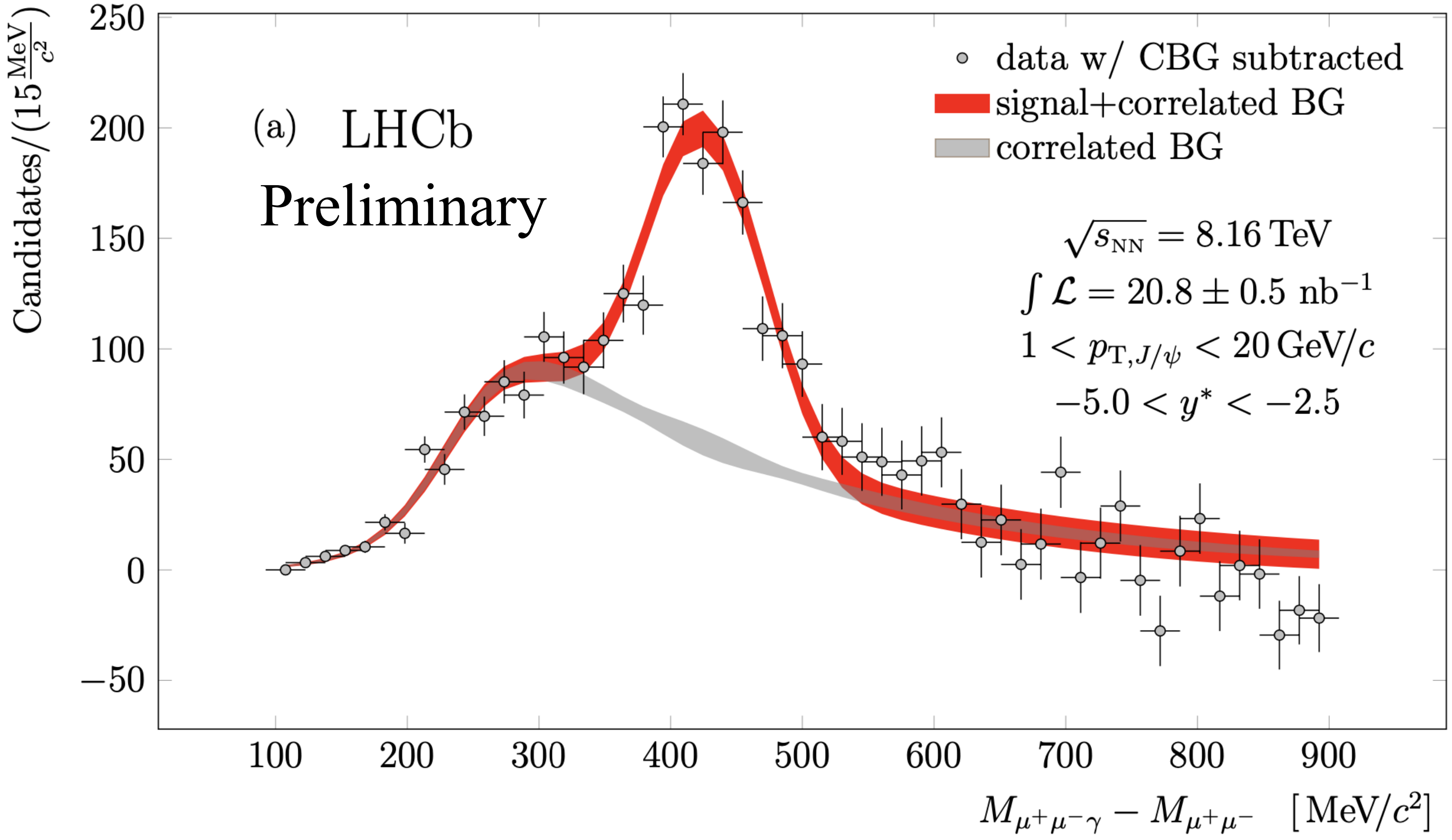




8.16 TeV result more precise and consistent with 5 TeV.

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

New χ_c Result

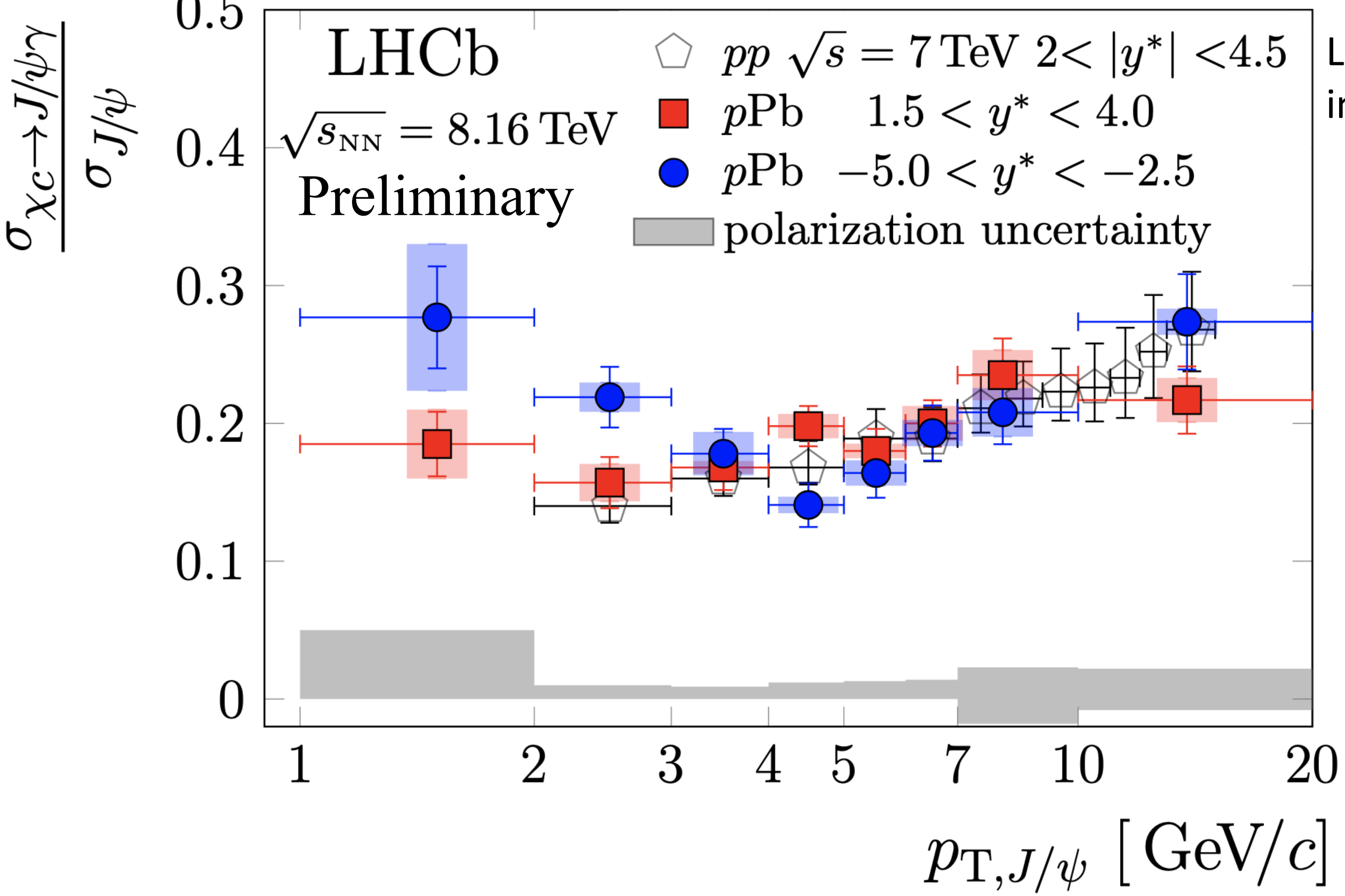


LHCb-PAPER-2023-028
in preparation

$\chi_{c1} + \chi_{c2}$ measured in the $J/\psi\ \gamma$ decay channel.

Photon ($p_{T,\gamma}$>400 MeV/c) measured by the ECAL.

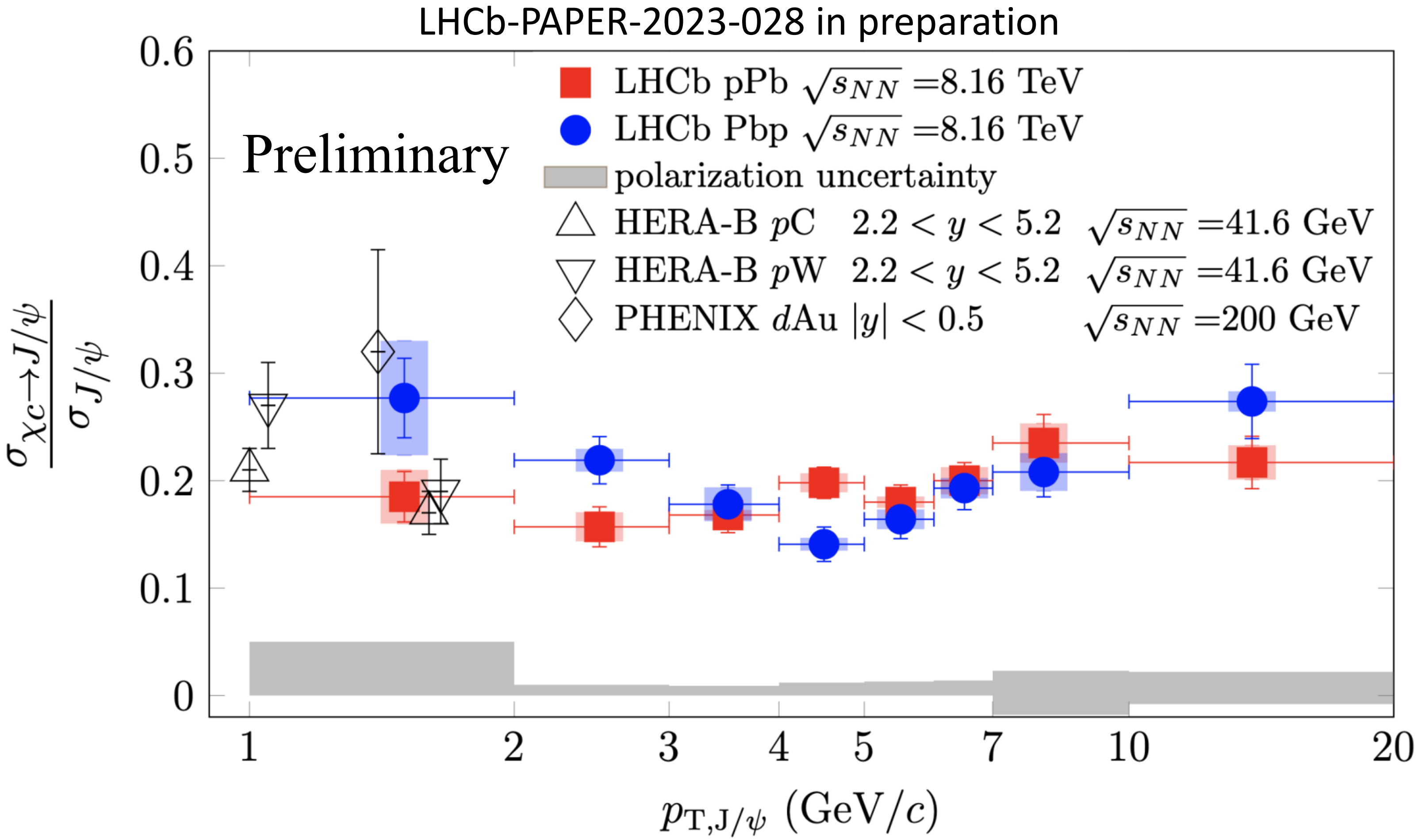
Fraction of χ_c decays in prompt J/ψ.



LHCb-PAPER-2023-028
in preparation

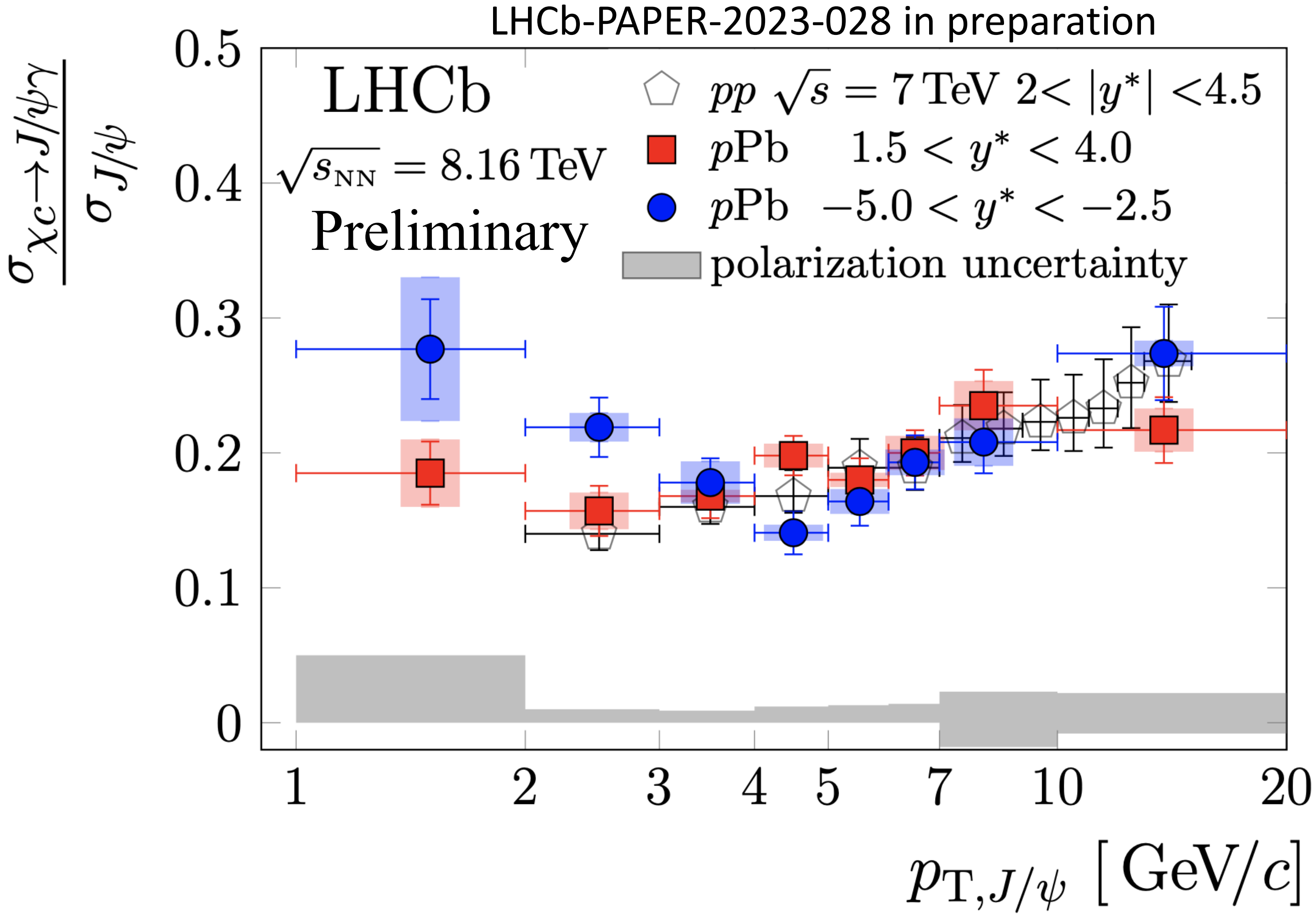
- First result of this kind in LHC. ISE does not affect the fraction.
- Forward rapidity consistent with pp results.
- Backward rapidity 2.4 σ higher than forward for $p_{T,J/\psi}$<3 GeV/c.

Fraction of χ_c decays in prompt J/ψ.



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

Fraction of χ_c decays in prompt J/ψ.



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 X-sec in the denominator.

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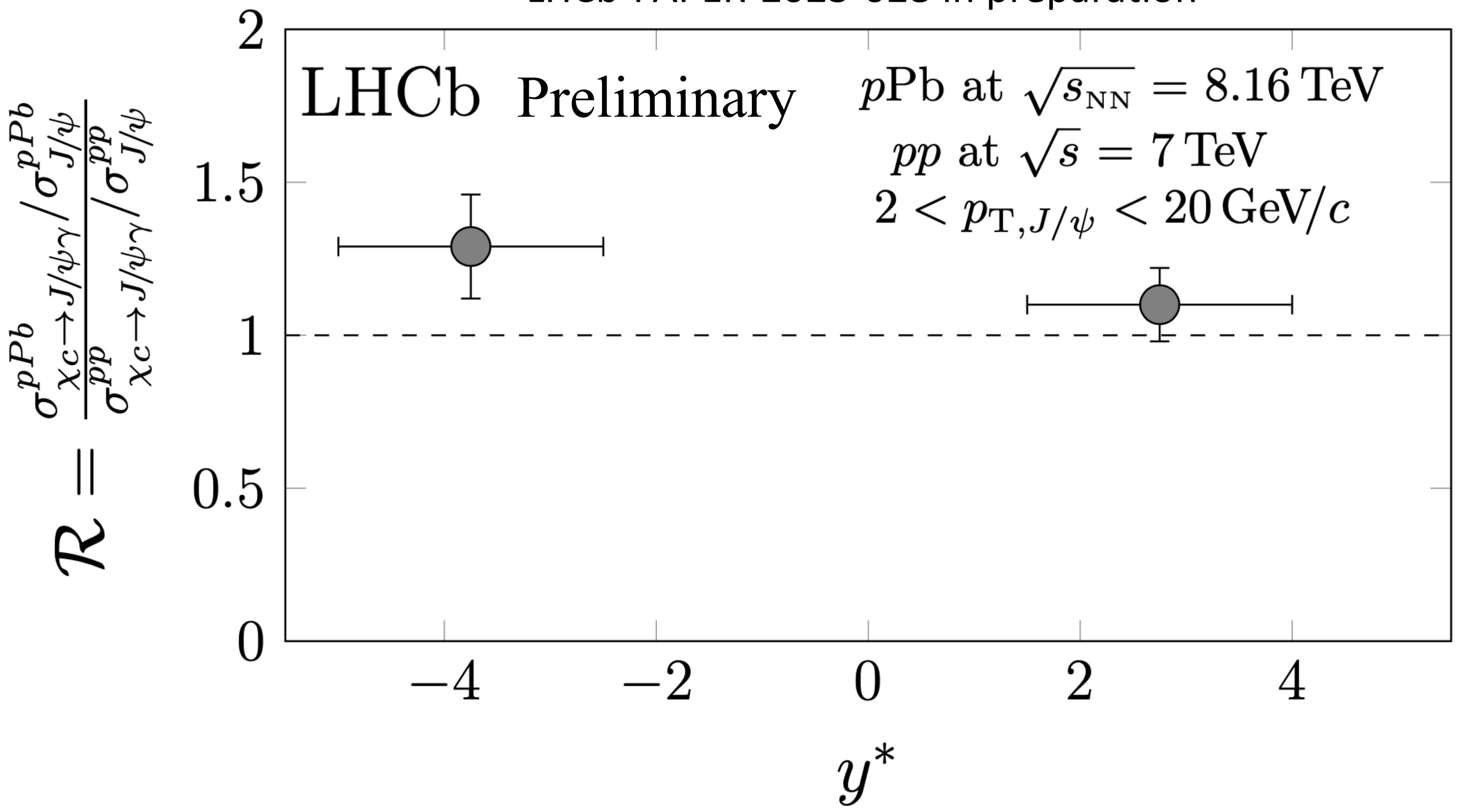

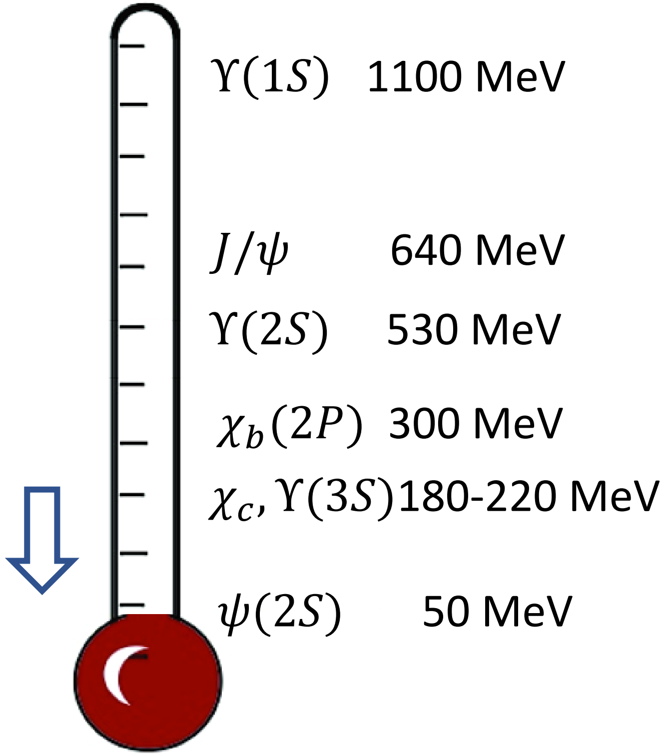

χ_c double ratio consistent with **NO final-state dissociation of χ_c states in pPb collisions**.

Constraints to maximum medium temperature in pPb collisions.

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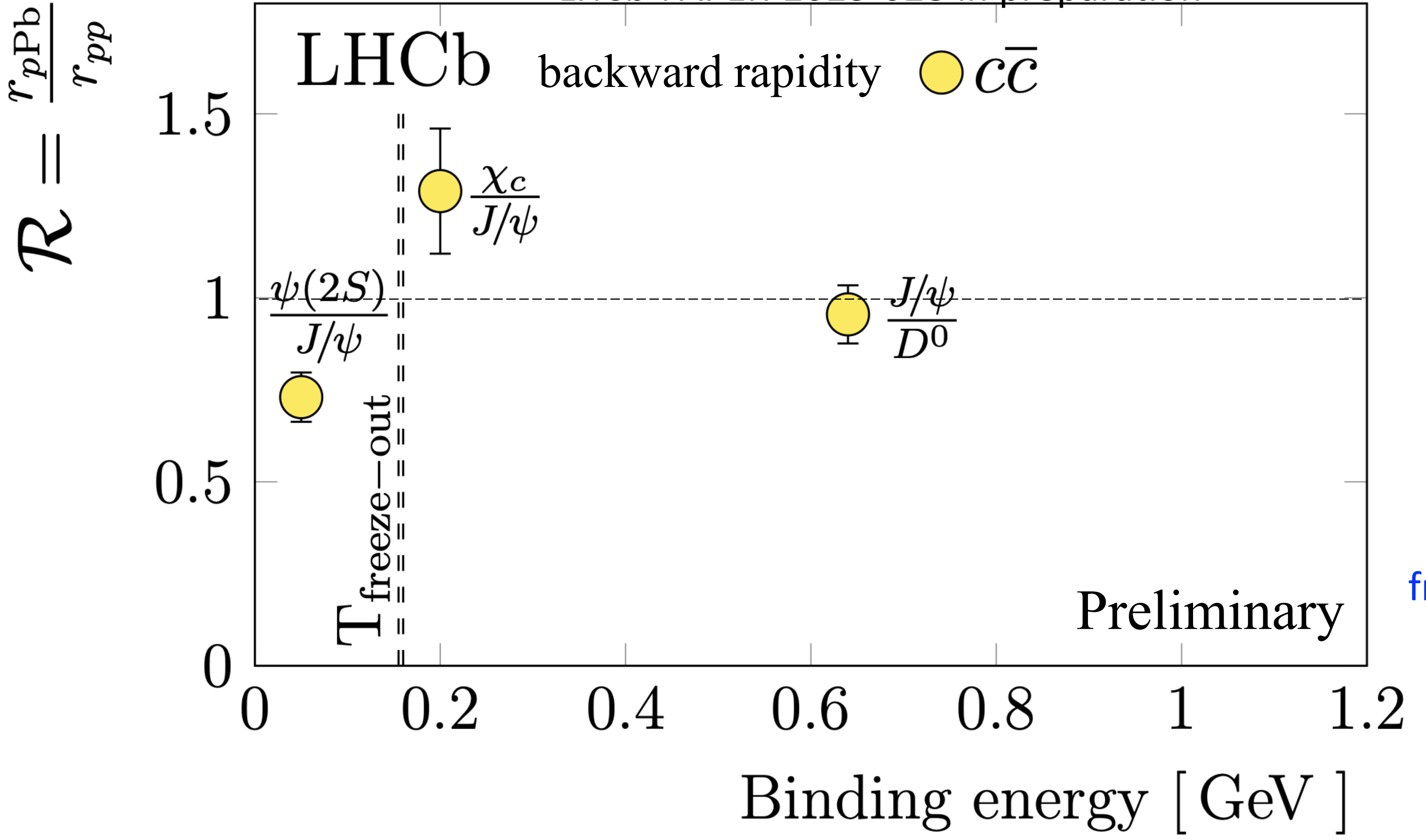
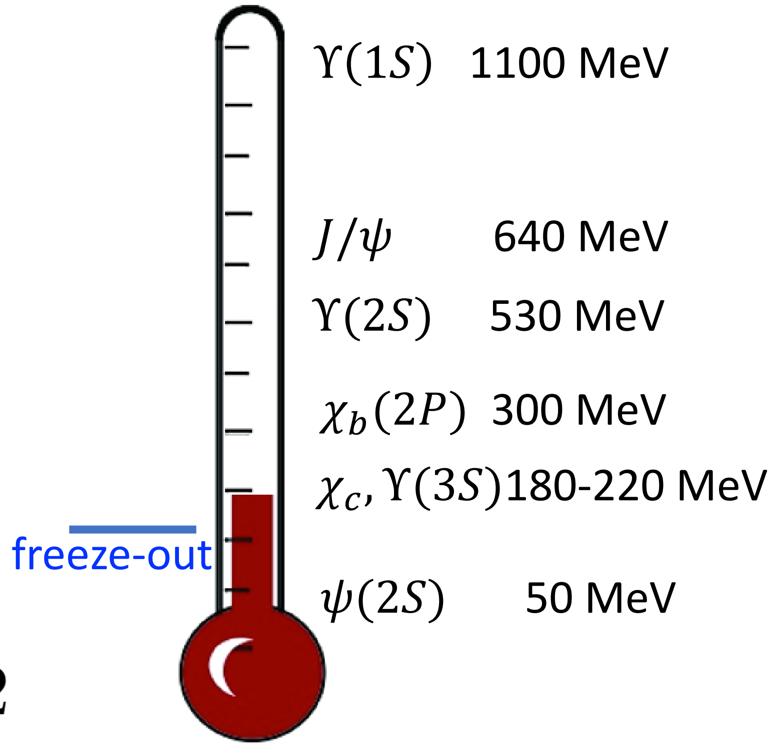
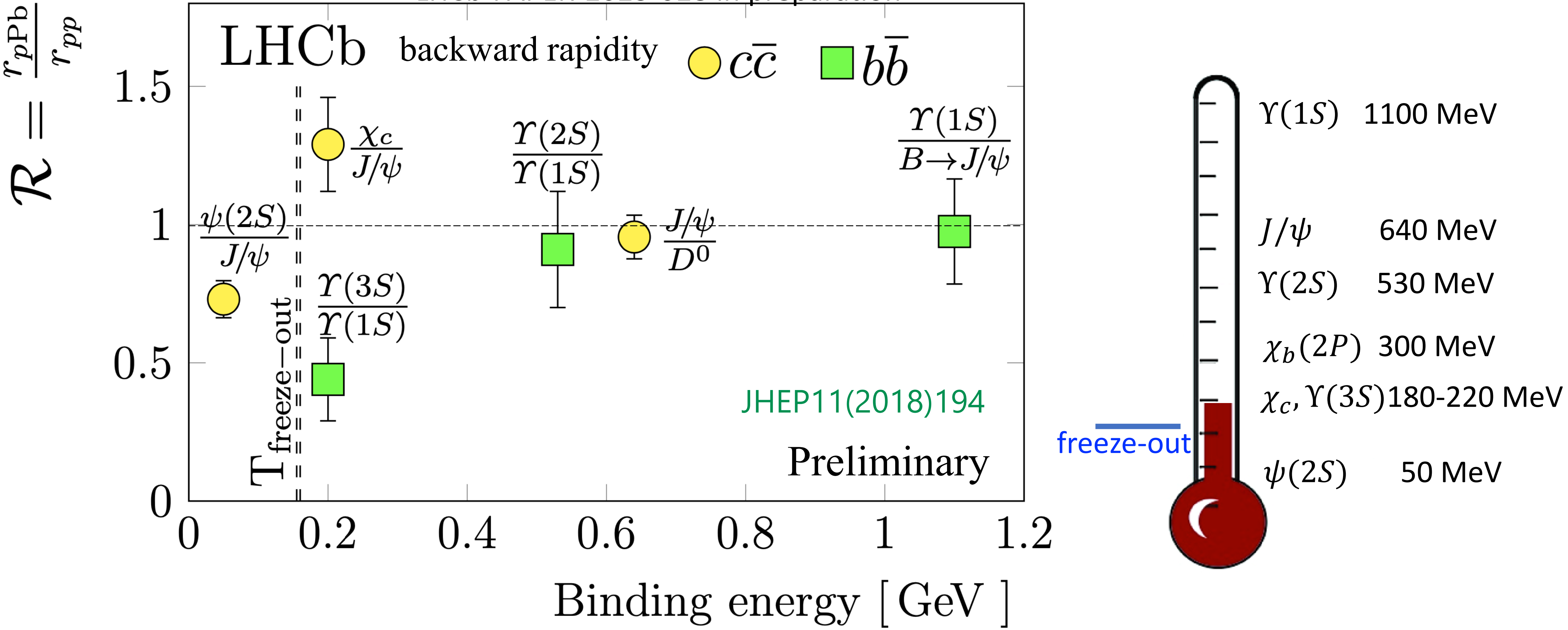




The medium temperature hypothetically formed in pPb collisions cannot inhibit the formation of charmonium states with binding energy larger than 180 MeV, just 20 MeV above the estimated freeze-out temperature.

Constraints to maximum medium temperature in pPb collisions.

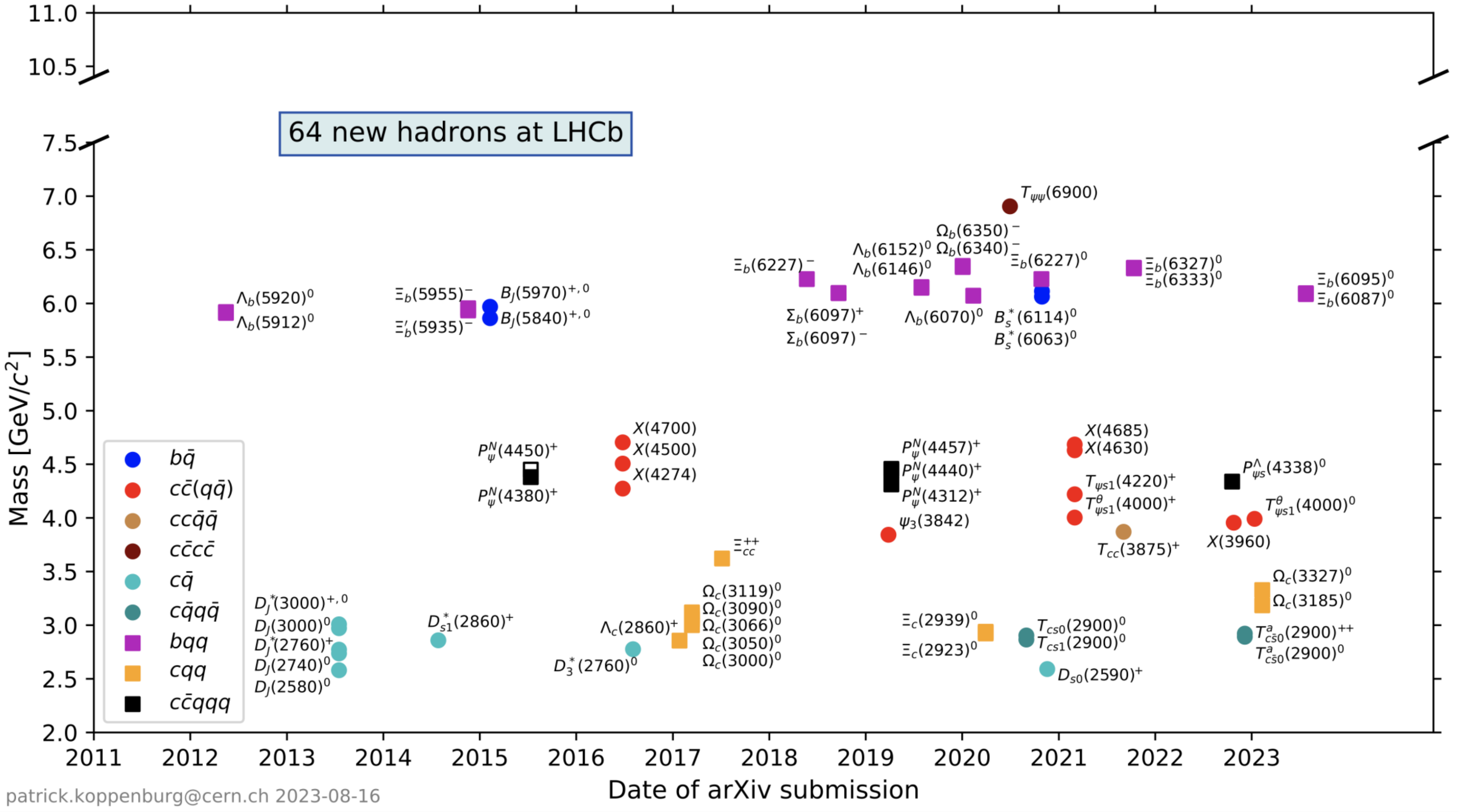
LHCb-PAPER-2023-028 in preparation



Despite the similar binding energy and size with χ_c, $\Upsilon(3S)$ is dissociated.

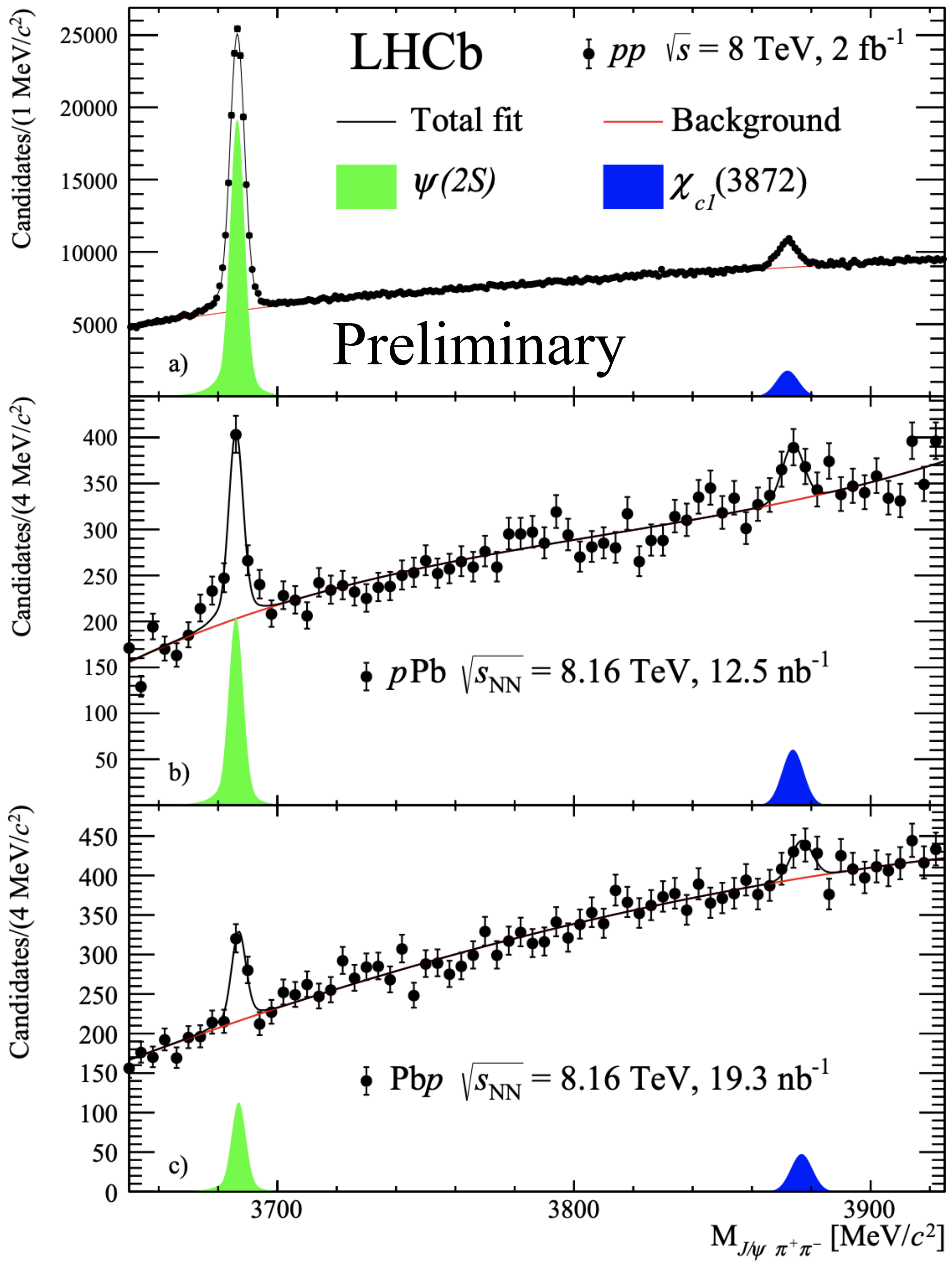
$\Upsilon(3S)$ is 2.9 x heavier and slower than χ_c, more likely to interact with comoving particles.
Theoretical input is welcome !!!

Exotic Particles



https://www.nikhef.nl/~pkoppenb/particles.html

$\chi_{c1}(3872)$



Measured in the $J/\psi\ \pi^+\pi^-$ decay

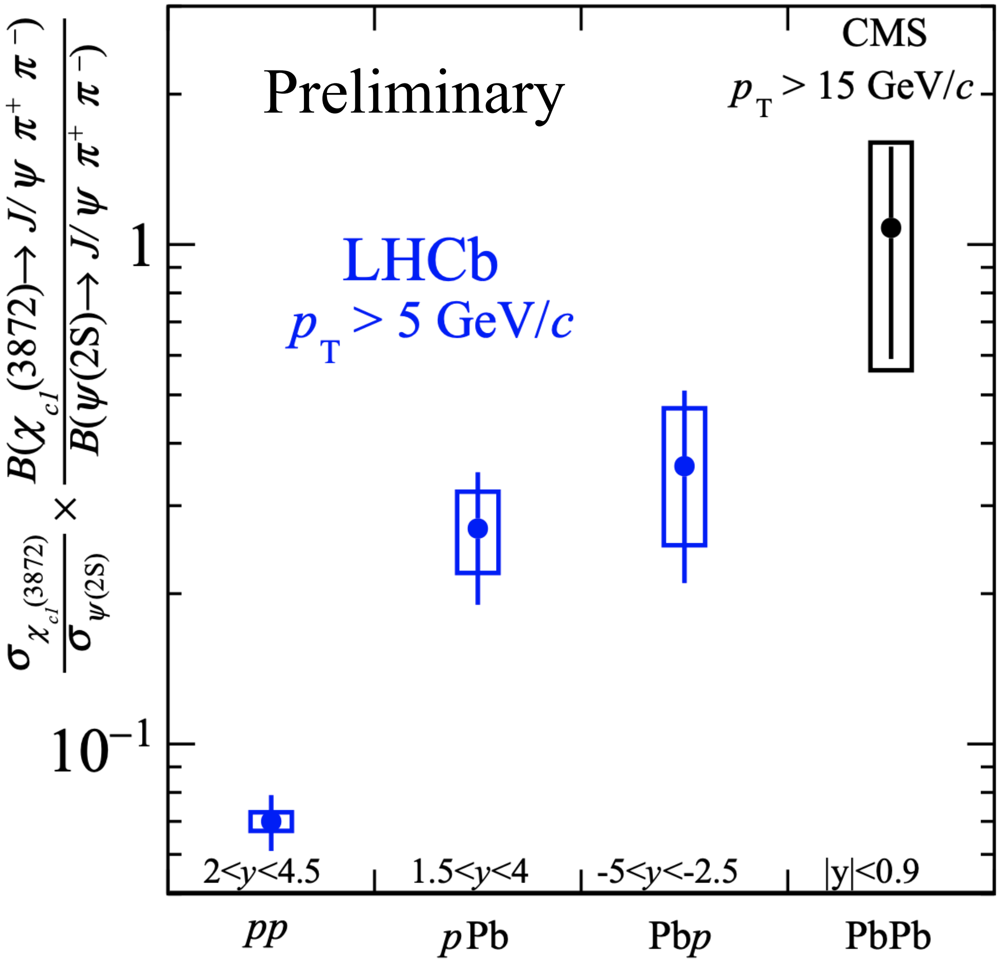
$p_T > 5$ GeV/c

$\chi_{c1}(3872)$ production measured relatively to $\psi(2S)$ in the same decay channel.

LHCB-PAPER-2023-026 in preparation

$\chi_{c1}(3872)$

LHCB-PAPER-2023-026 in preparation



Increasing relative yield in pPb and PbPb collisions.

But uncertainties are still large.

Coalescence ? Limited number of $c\bar{c}$ in the system.

Same mechanism of baryon enhancement observed in other probes ? (See Chenxi Gu talk on the latest from LHCb)

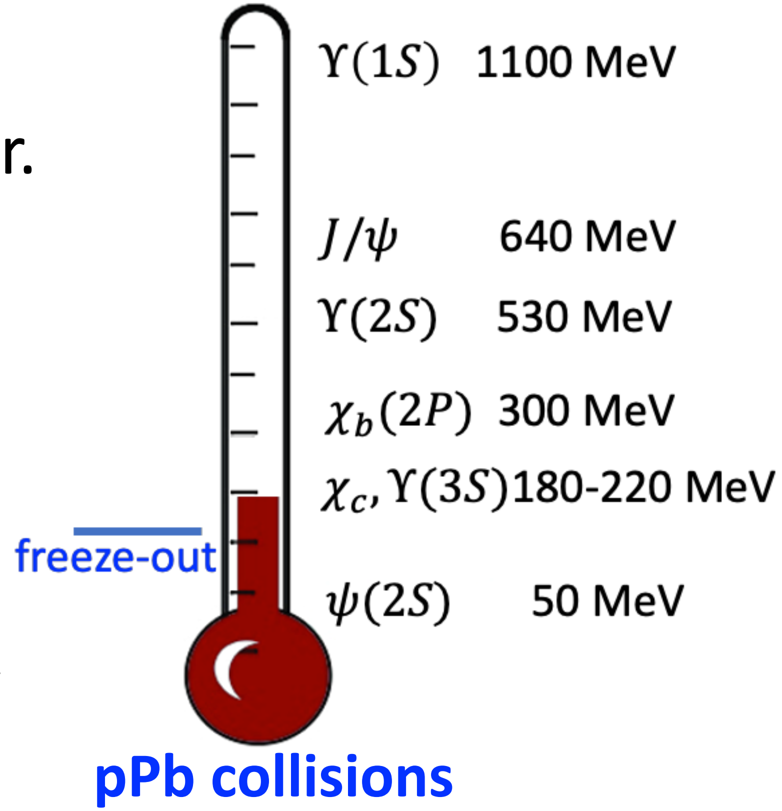
Double parton scattering [Navarra, EPJ WC137, 06004 (2017)]

Take away

- Now we know how to use the quarkonium thermometer.

- More precise measurement of $\psi(2S)$ final-state dissociation is now available.

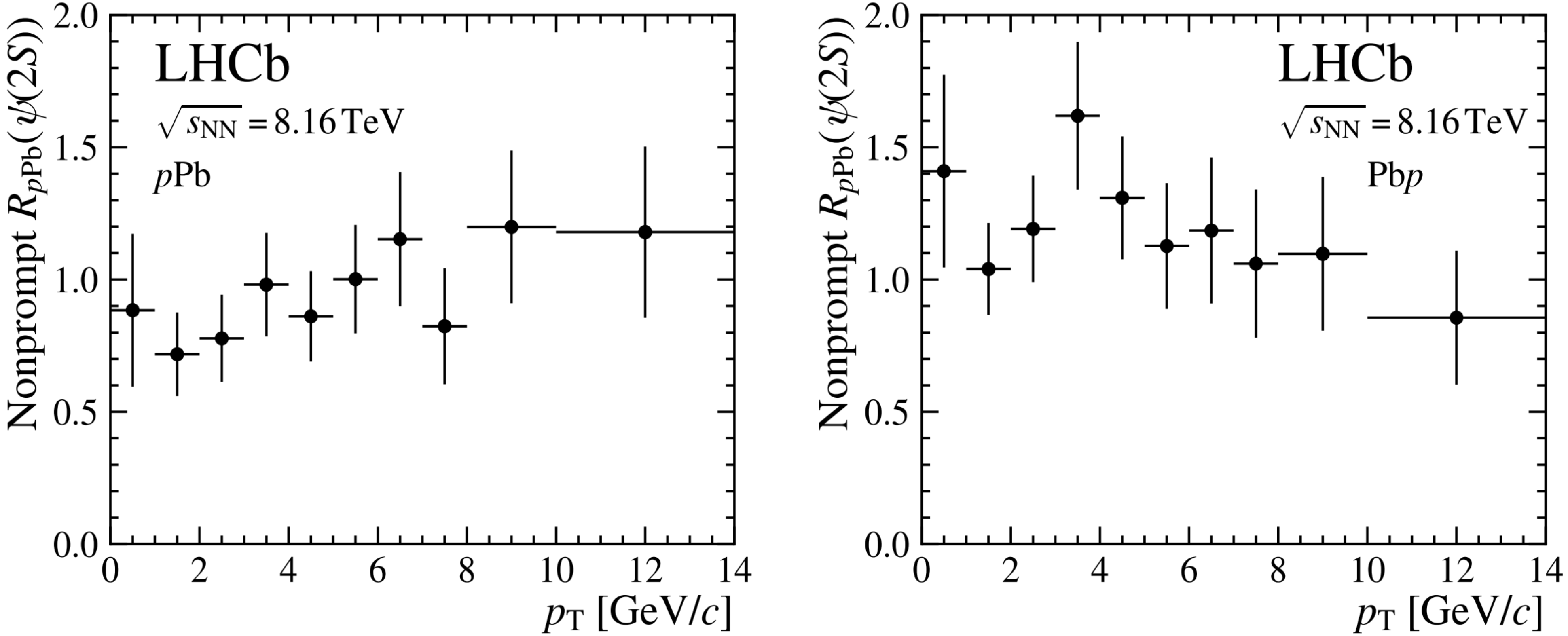
- The medium formed in pPb collisions cannot "break" χ_c states with its 180 MeV average binding energy, limiting the medium temperature in this **small system close of a hadron environment**.



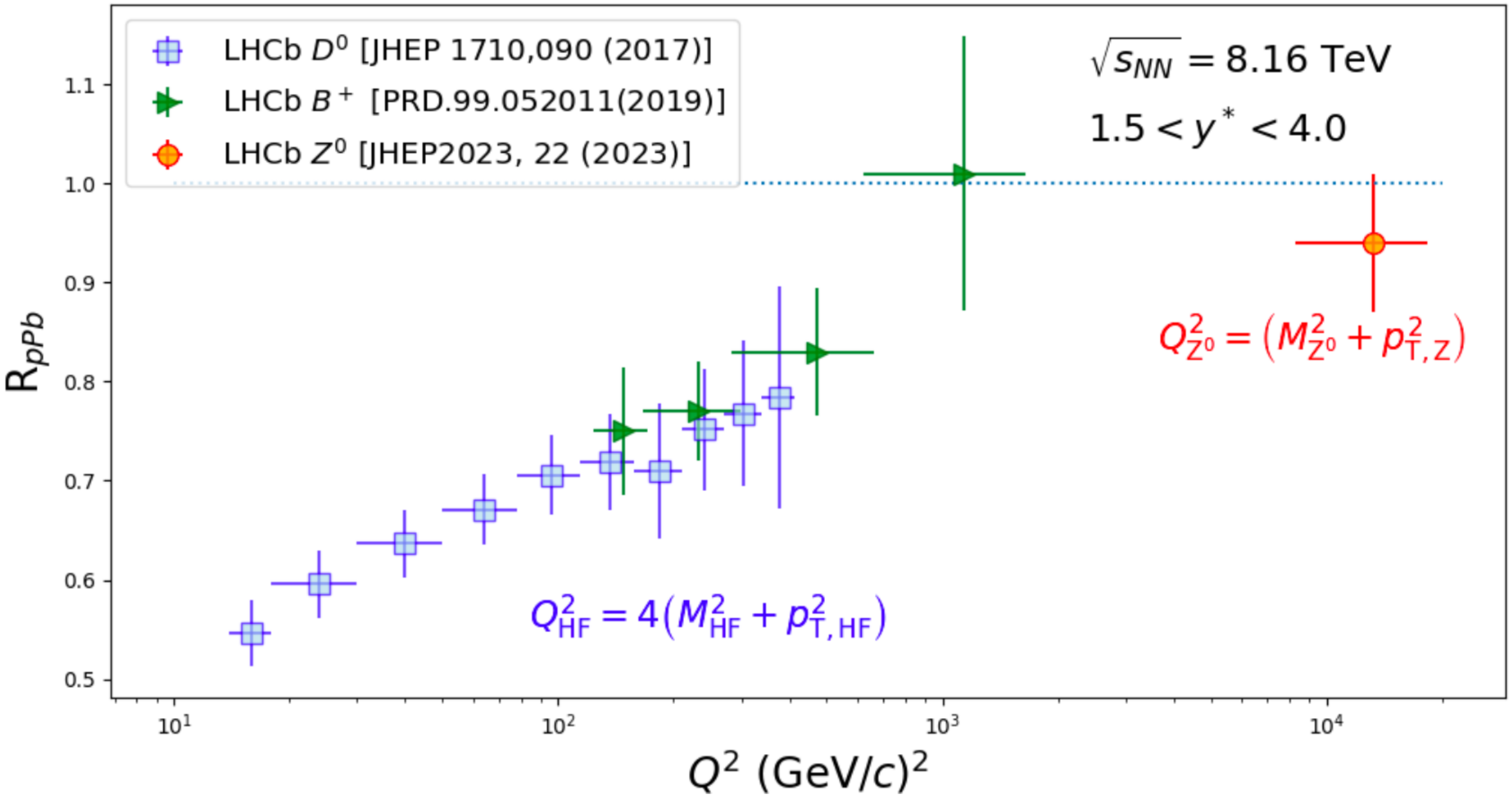
- Observed apparent $\chi_{c1}(3872)$ enhancement in pPb collisions, suggesting an **additional production mechanism of tetraquark** states in nuclear collisions.

EXTRAS

LHCb-PAPER-2023-024



Small to no-suppression of the non-prompt component from B-meson decays.


LHCb D^0 [JHEP 1710,090 (2017)]
LHCb B^+ [PRD.99.052011(2019)]
LHCb Z^0 [JHEP2023, 22 (2023)]
$\sqrt{s_{NN}} = 8.16$ TeV
$1.5 < y^* < 4.0$
$Q^2_{Z^0} = \left(M^2_{Z^0} + p^2_{T,Z}\right)$
$Q^2_{HF} = 4\left(M^2_{HF} + p^2_{T,HF}\right)$
R_{pPb}
Q^2 (GeV/c)^2

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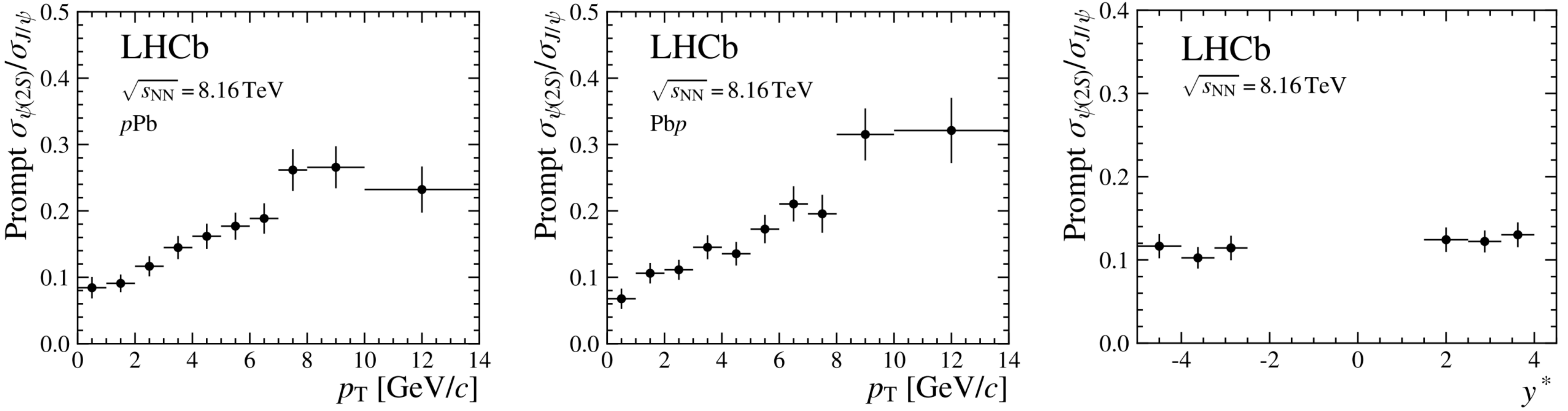

$$\frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi}}$$

- increases with p_T
- flat in rapidity

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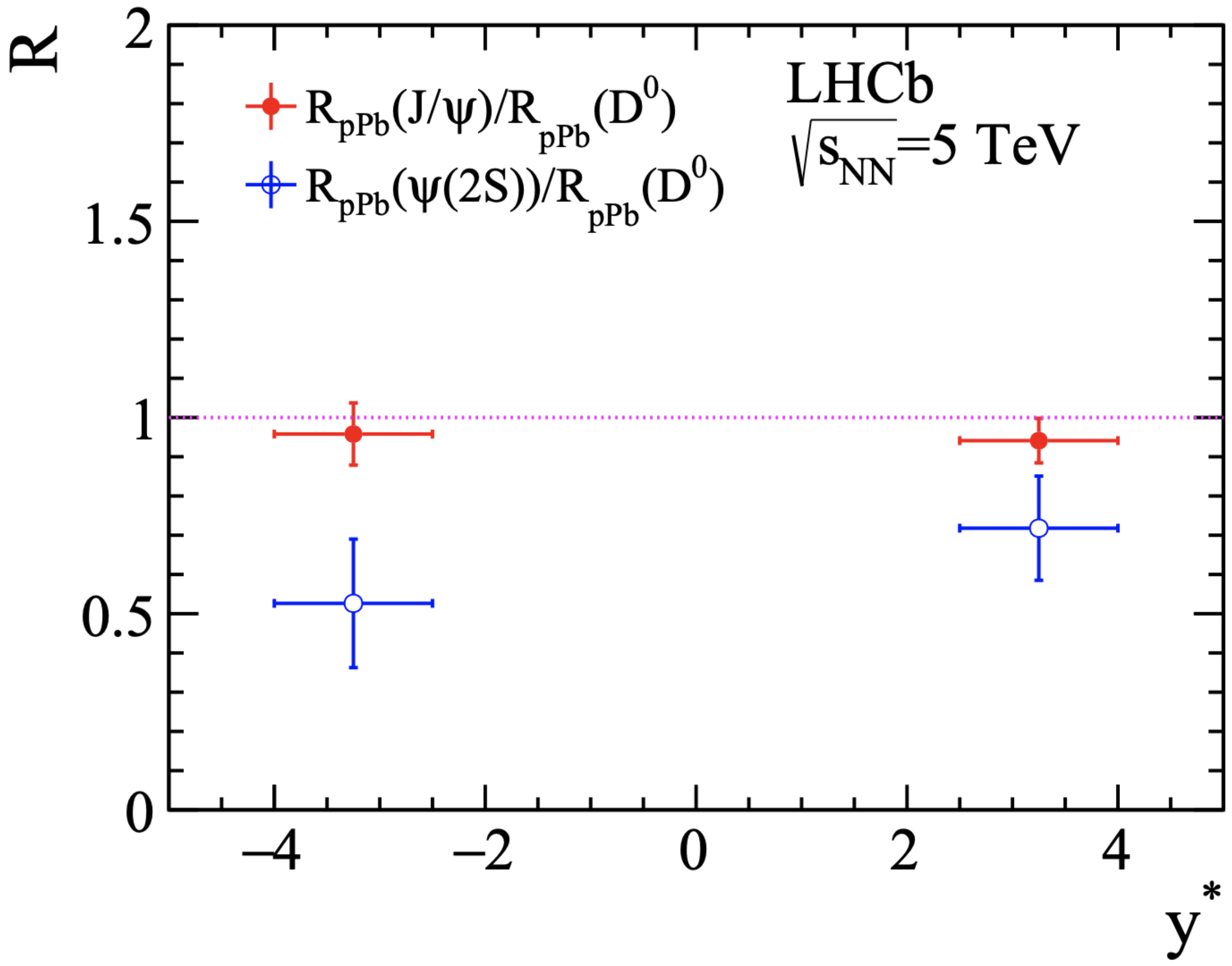
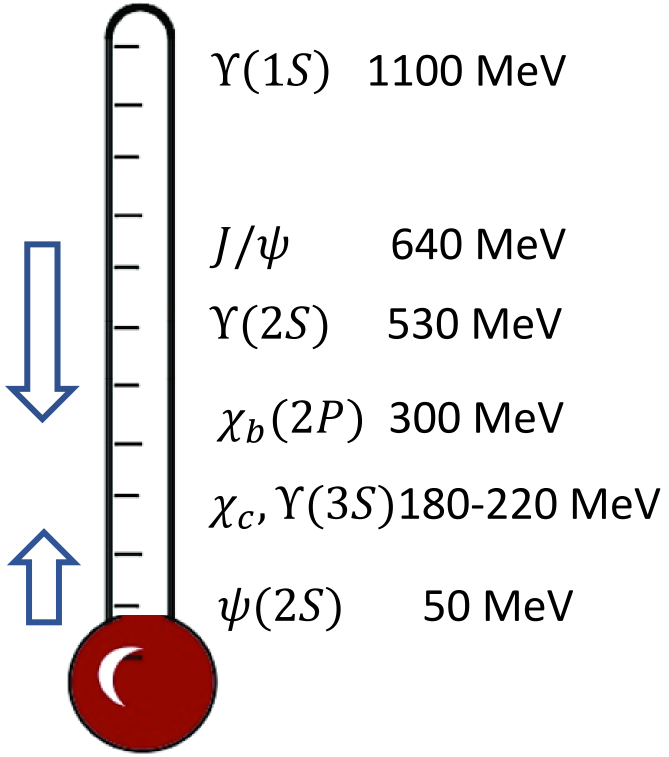


Agnes Mocsy's thermometer

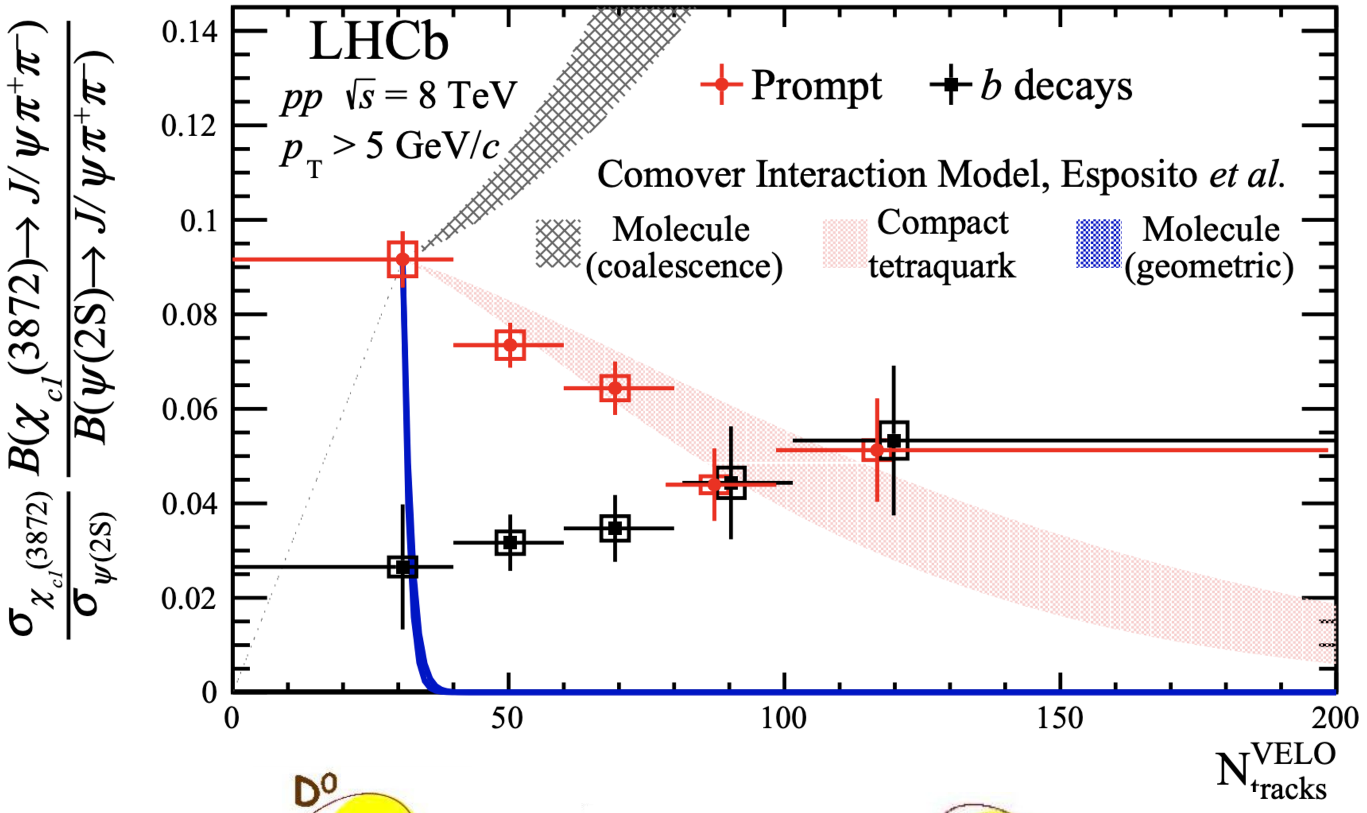


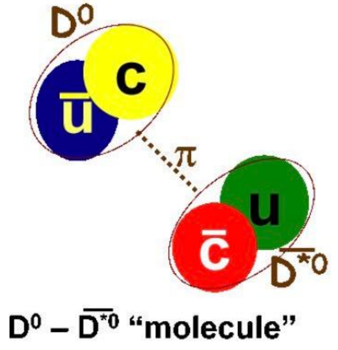
$\psi(2S)$ yield is affected by final-state effects.

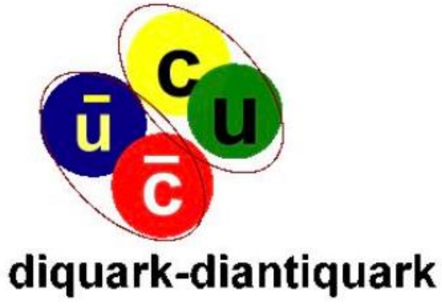
But its very weak binding and large size make it easy to break it.

$\chi_{c1}(3872)$

PRL126 (2021) 092001







Suppression of $\chi_{c1}(3872)$ relative to $\psi(2S)$ at high multiplicity pp events.

Consistent with dissociation of a compact tetraquark in comoving particles.

Molecular explanation from Bratten

New $\psi(2S)$ Result

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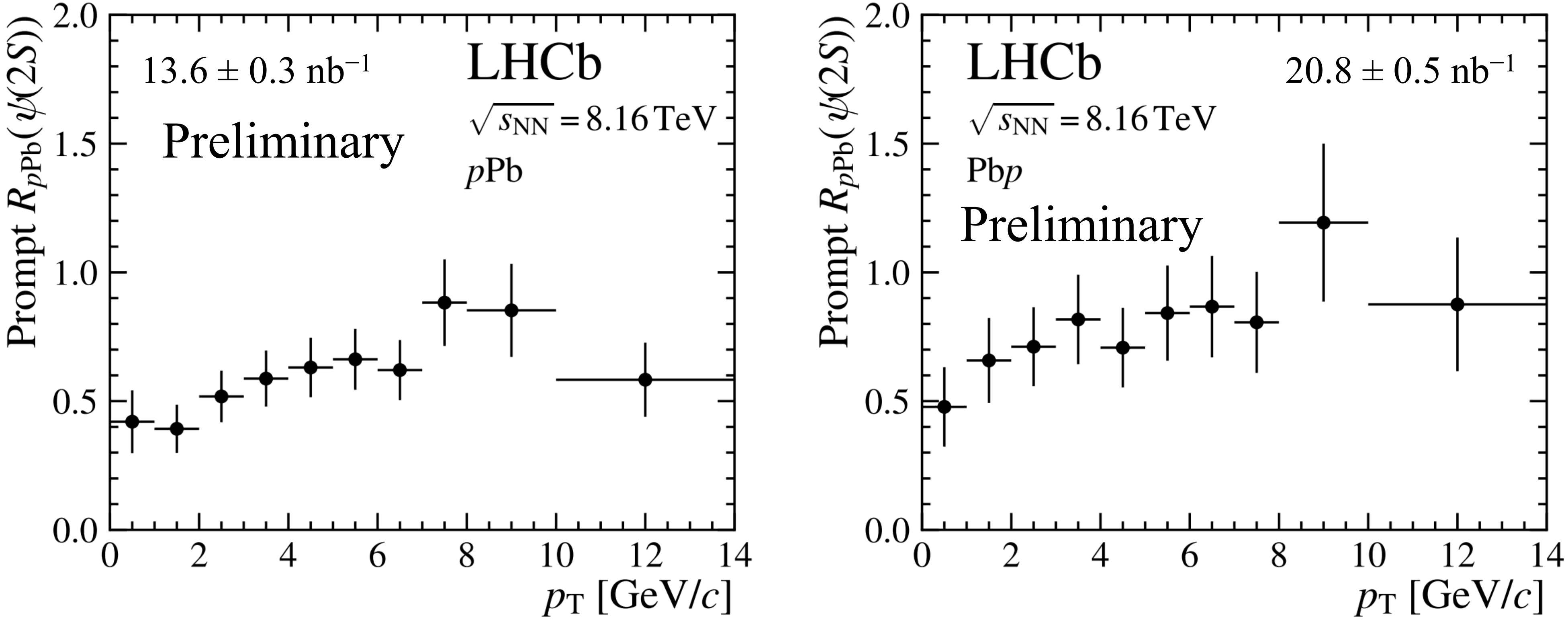
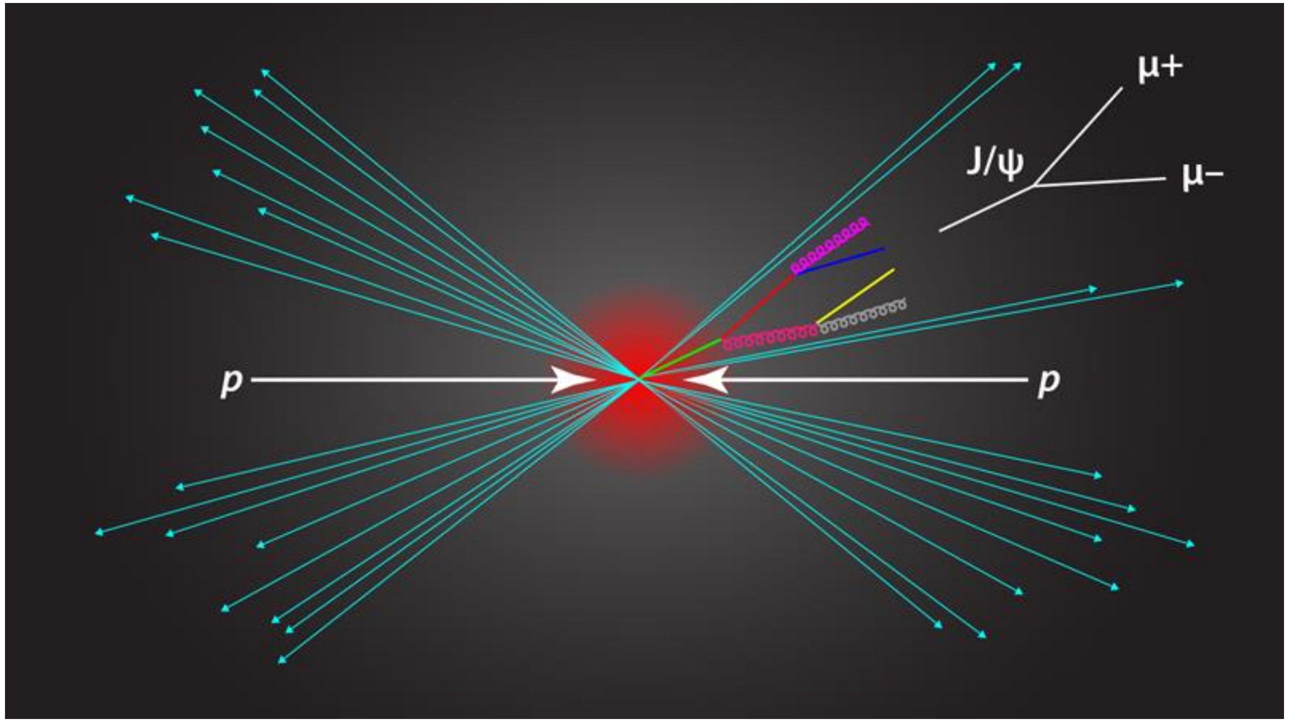


A larger suppression seen in $\psi(2S)$ yield. Better quantify it with a double ratio with J/ψ.



APS/Alan Stonebraker

PRL 118, 192001 (2017)