Heavy Quarkonium production at LHCb

Cesar Luiz da Silva for the LHCb Collaboration
Los Alamos National Lab

U.S. DEPARTMENT OF
ENERGY
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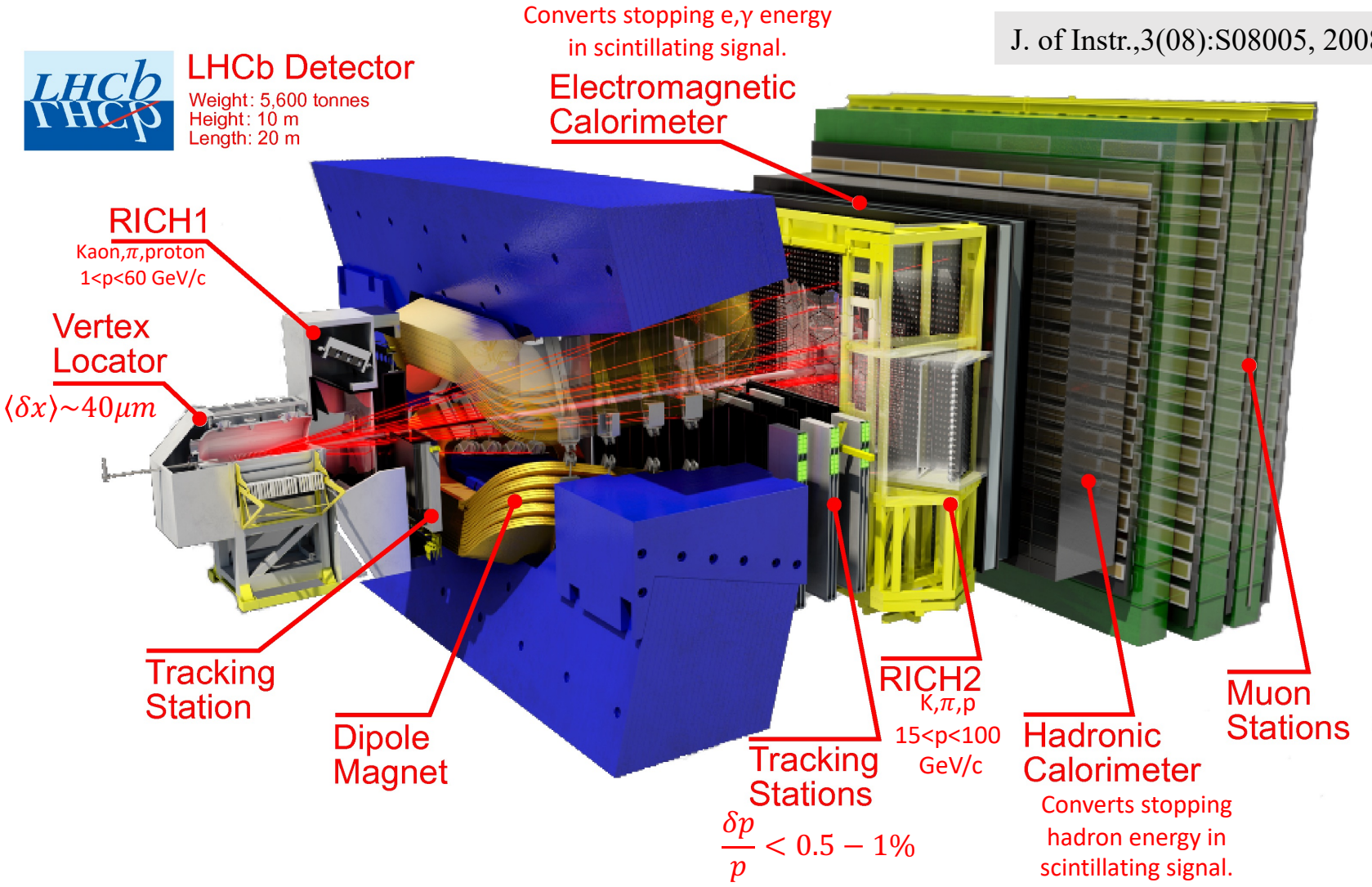
Topics to be Covered in this Talk

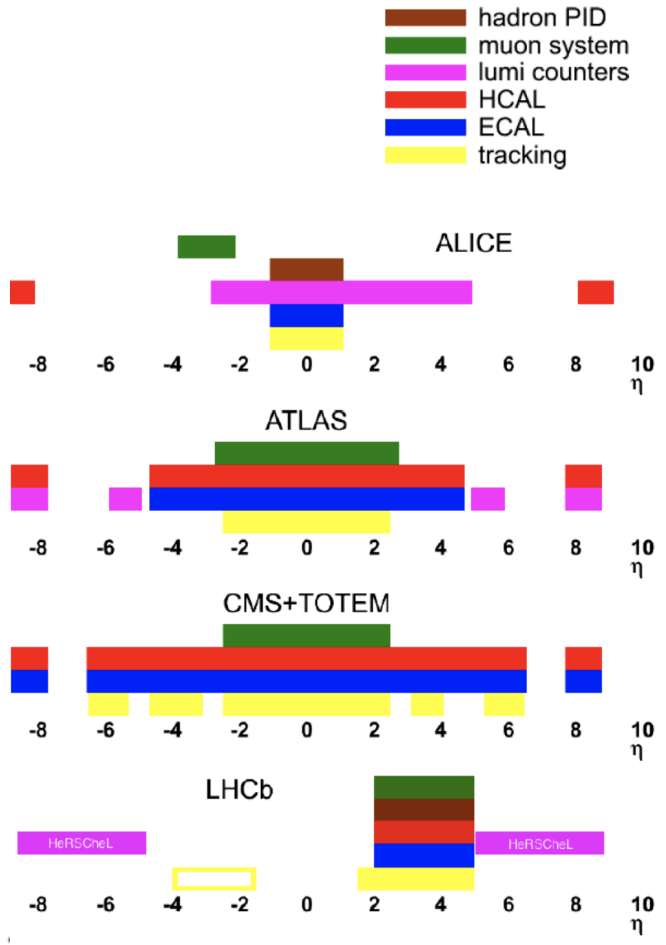
- Multiplicity Dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in *pp* collision at $\sqrt{s}$=13TeV arXiv:2312.15201

- Measurement of J/ψ-pair production in *pp* collisions at $\sqrt{s}$ =13TeV and study of gluon transverse-momentum dependent PDFs arXiv:2311.14085

- Measurement of associated J/ψ-ψ(2S) production cross-section in *pp* collisions at $\sqrt{s}$ =13TeV arXiv:2311.15921

The LHC beauty detector

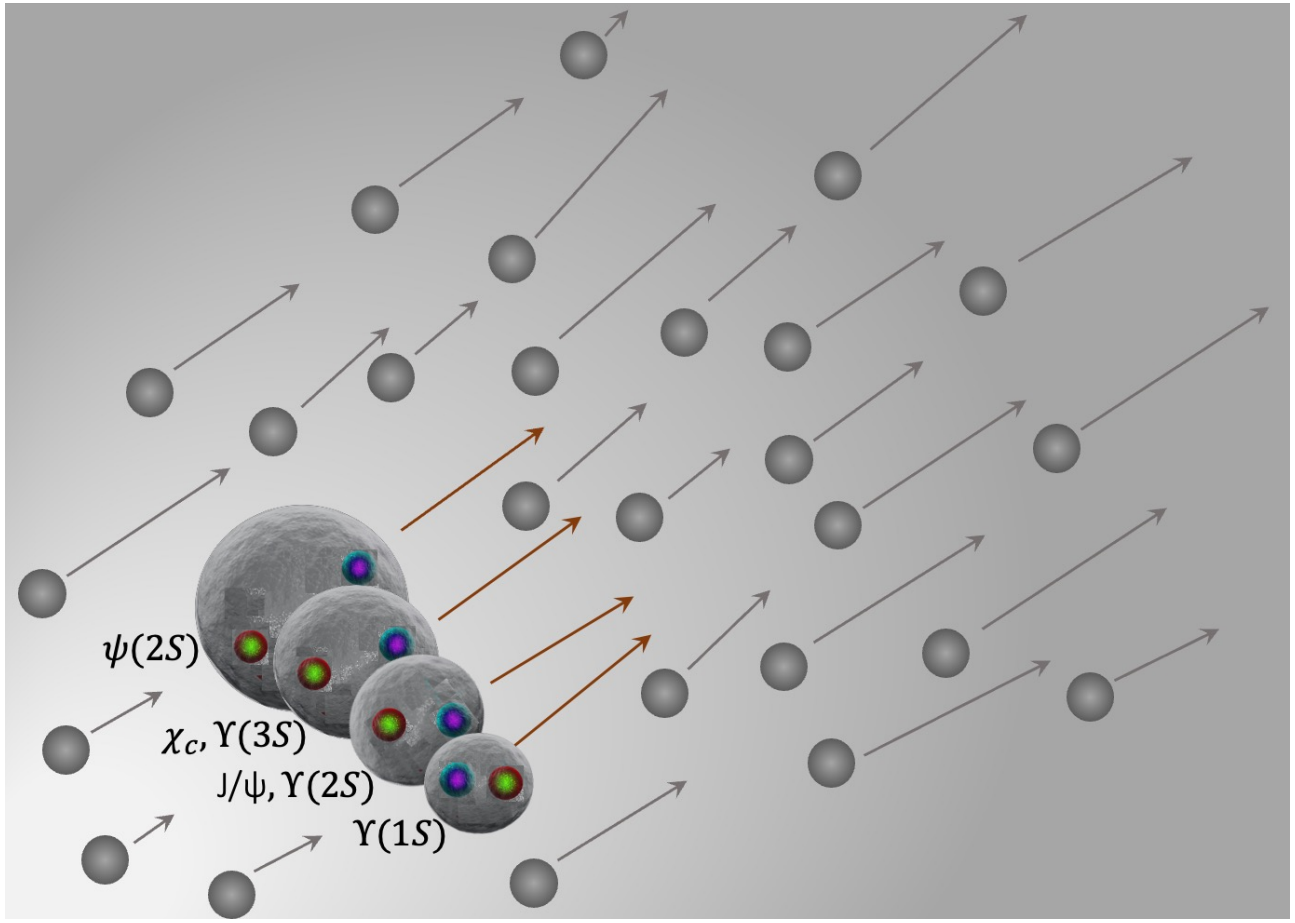




- Dedicated to Flavor Physics
- $e, \mu, \pi, K, p, \gamma$, particle jet identification in 1<p<100 GeV/c
- Unique forward instrumentation for heavy ion physics

Multiplicity Dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in *pp* collision at $\sqrt{s}$=13TeV

arXiv:2312.15201

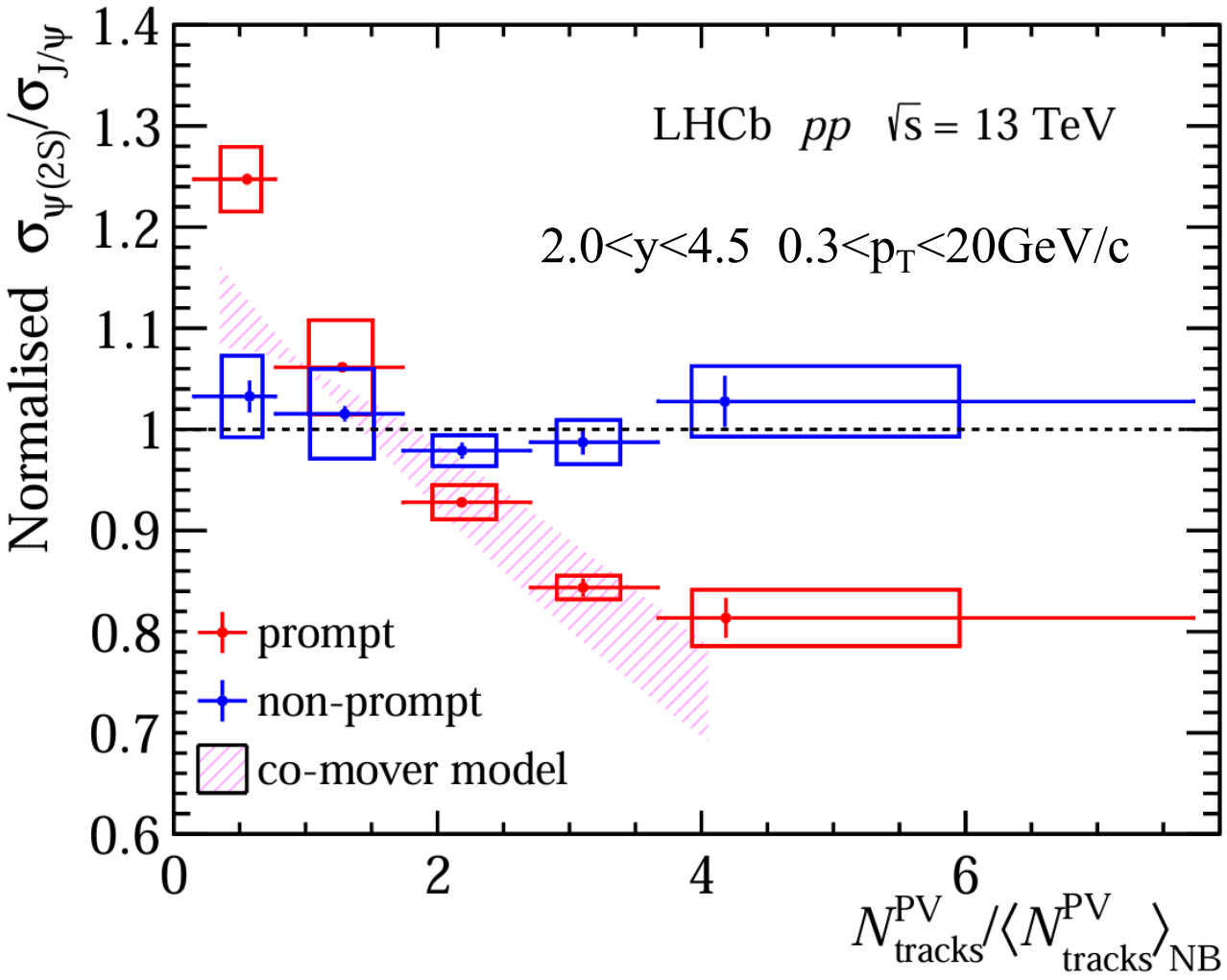


	$r(fm)$
J/ψ	0.50
χ_c	0.72
$\psi(2S)$	0.90
$\Upsilon(1S)$	0.28
χ_b	0.44
$\Upsilon(2S)$	0.56
$\chi_b(2P)$	0.68
$\Upsilon(3S)$	0.78

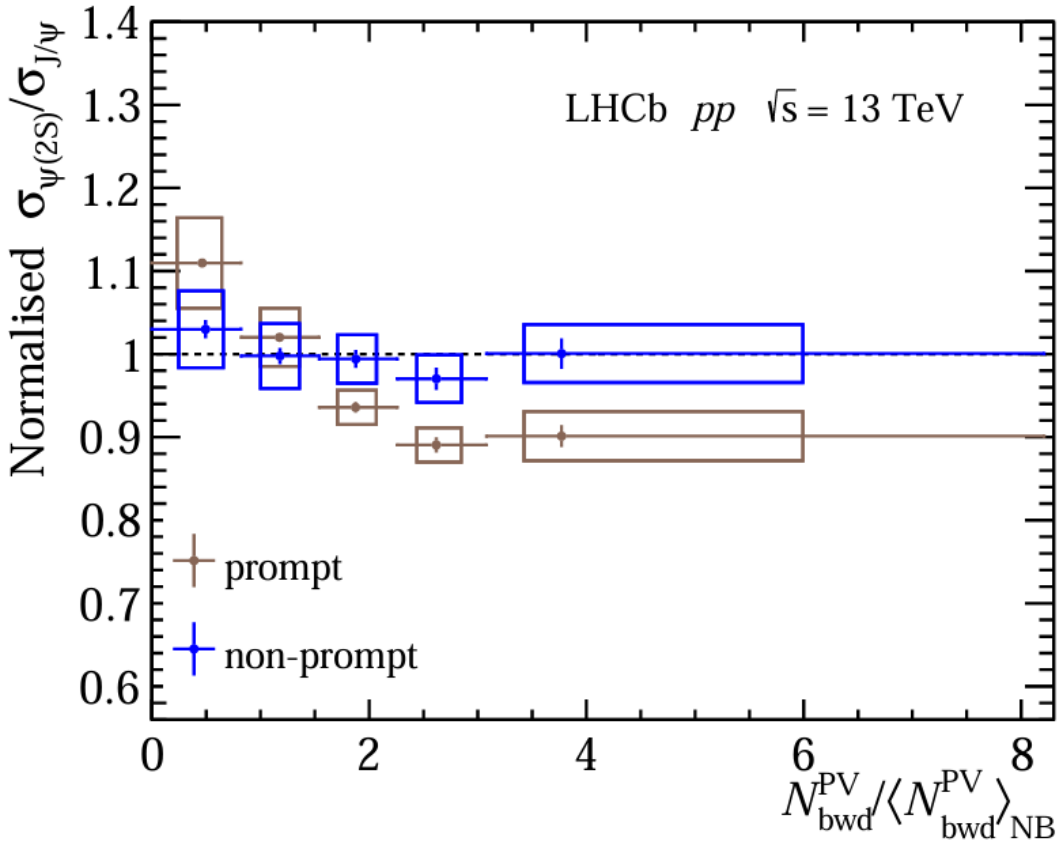
Non-Relativistic Potential Theory:
Satz, J.Phys.G32:R25 (2006)

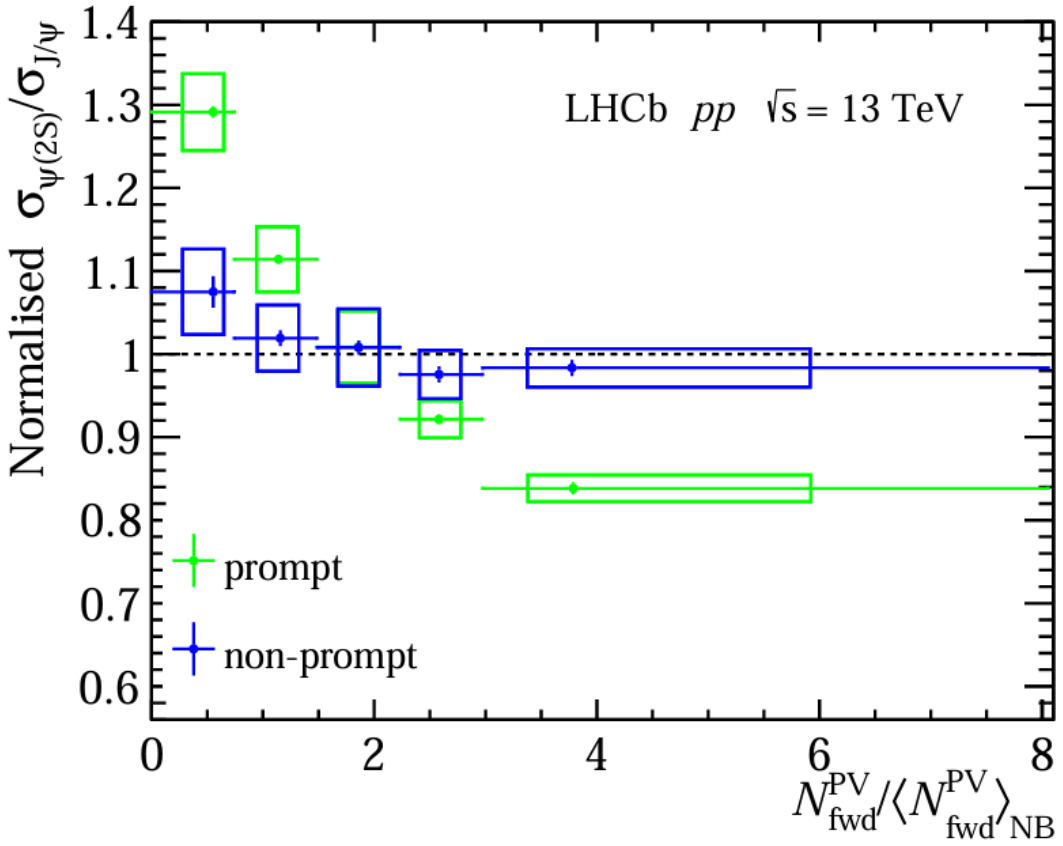
Quarkonium states can break by co-moving particles. The breaking depends on

- Event multiplicity
- Size of the quarkonium state
- How fast the quarkonium state moves through other particles



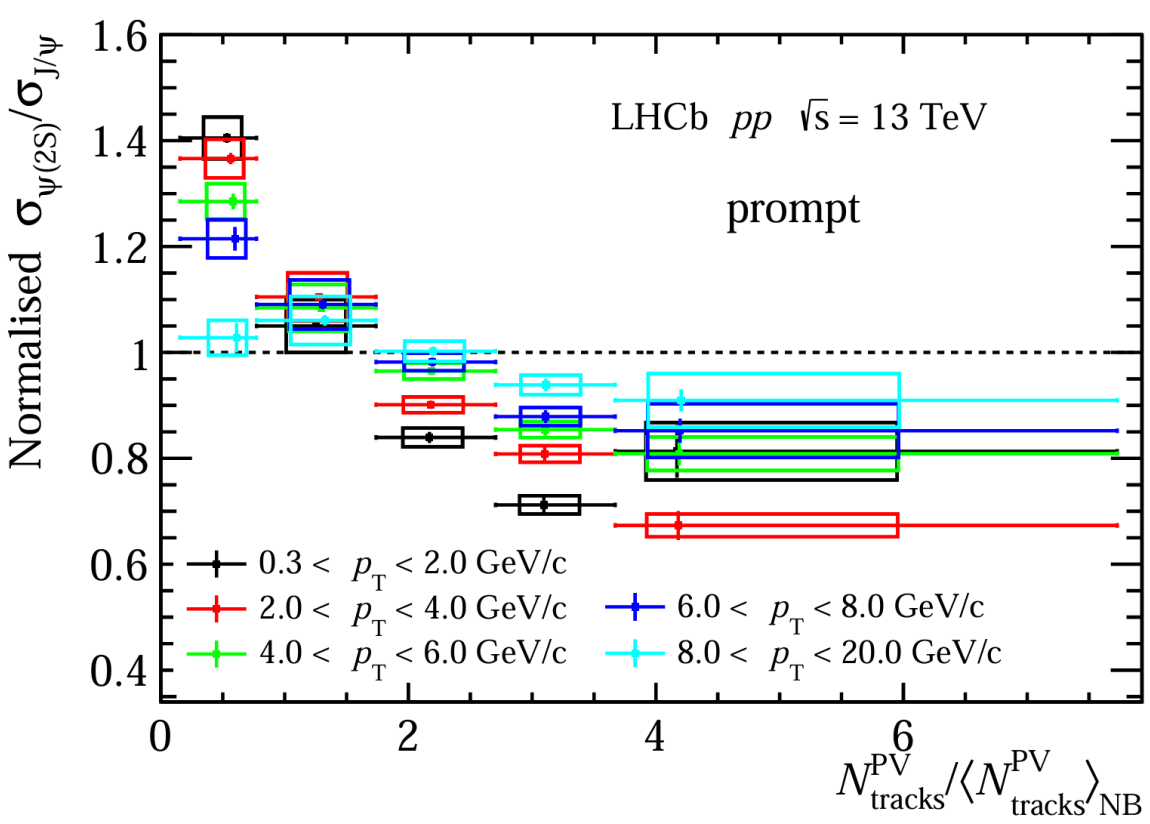
- Prompt $\psi(2S)$ states are broken when particle multiplicities are larger than ~3x the average multiplicity
- $\psi(2S)$ from B-decays, produced away from the early high-density environment are intact

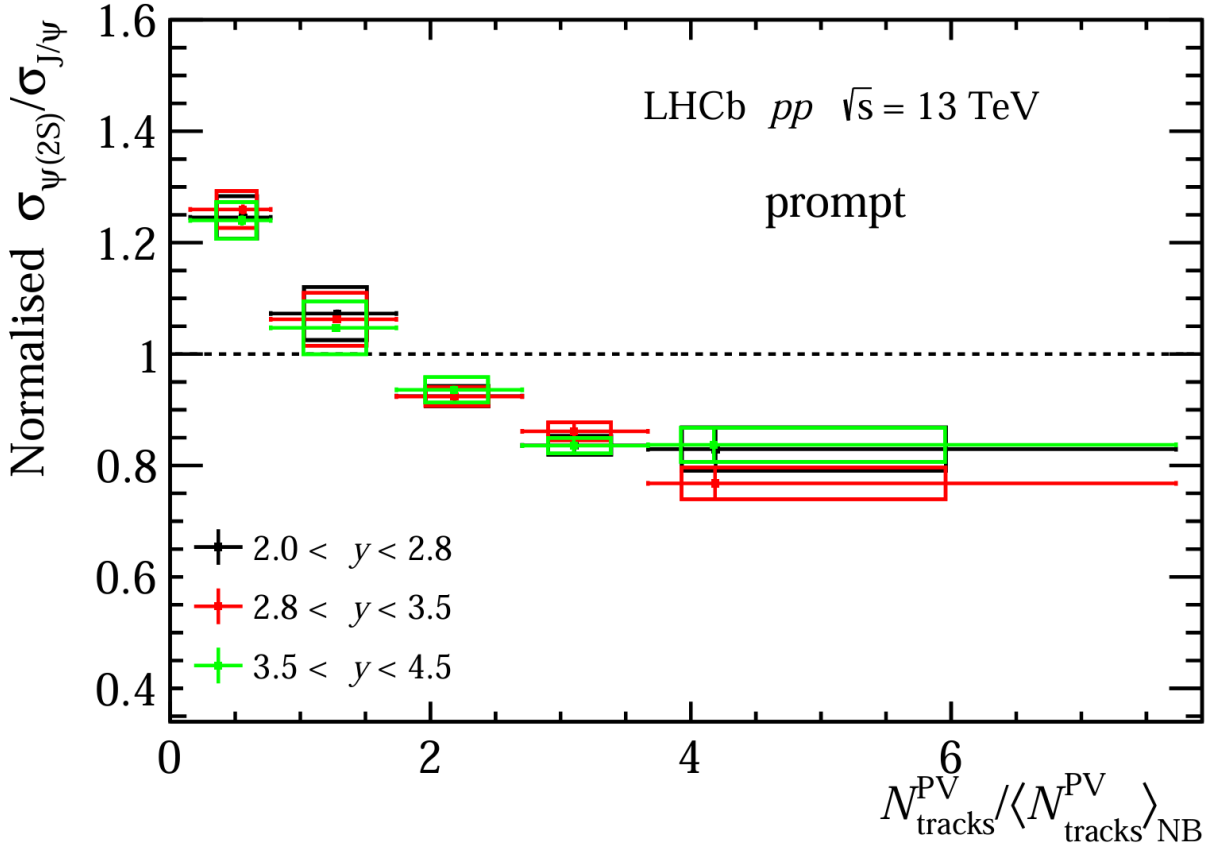




Dependency with multiplicity is stronger when quarkonium states and charged particles are measured at the same rapidity, indicating a dependence with local activity.

Small dependence in the backward multiplicity caused by a correlation btw. Backward and forward multiplicities. Detailed study in the paper.





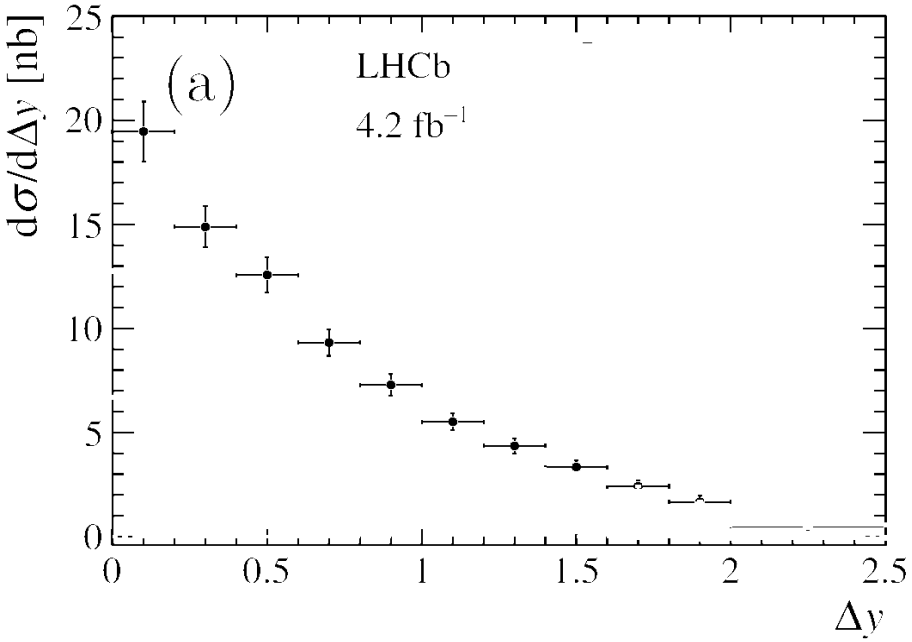
High p_T (fast) $\psi(2S)$ seems to scape from being broken by co-moving particles.

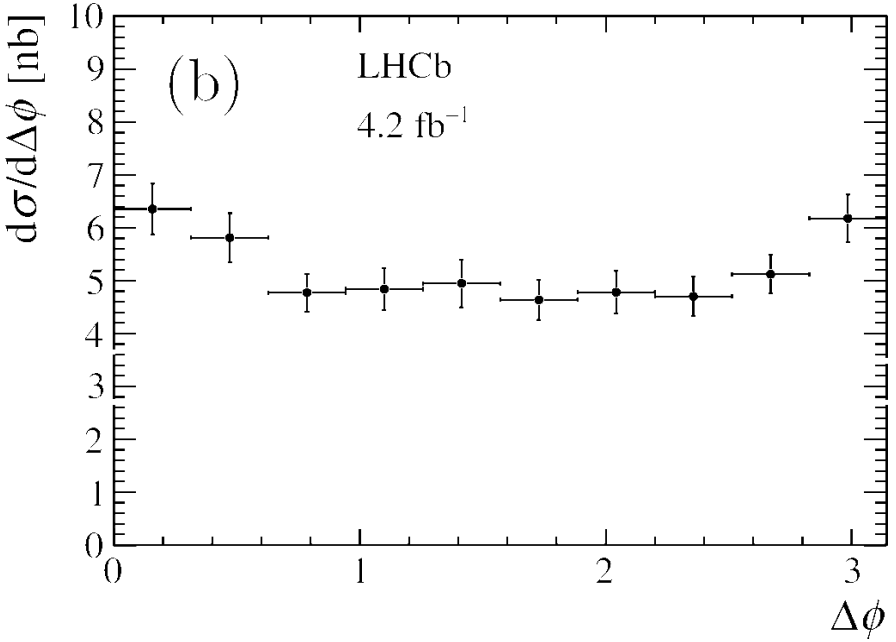
No dependency with the quarkonium rapidity.

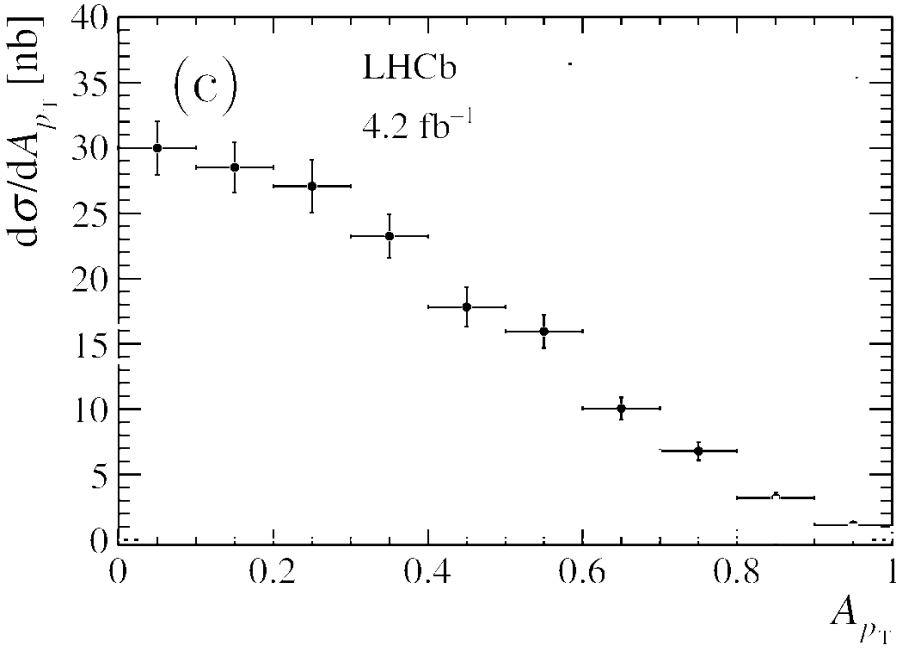
Measurement of J/ψ-pair and J/ψ-ψ(2S) production in *pp* collisions at $\sqrt{s}$ =13TeV

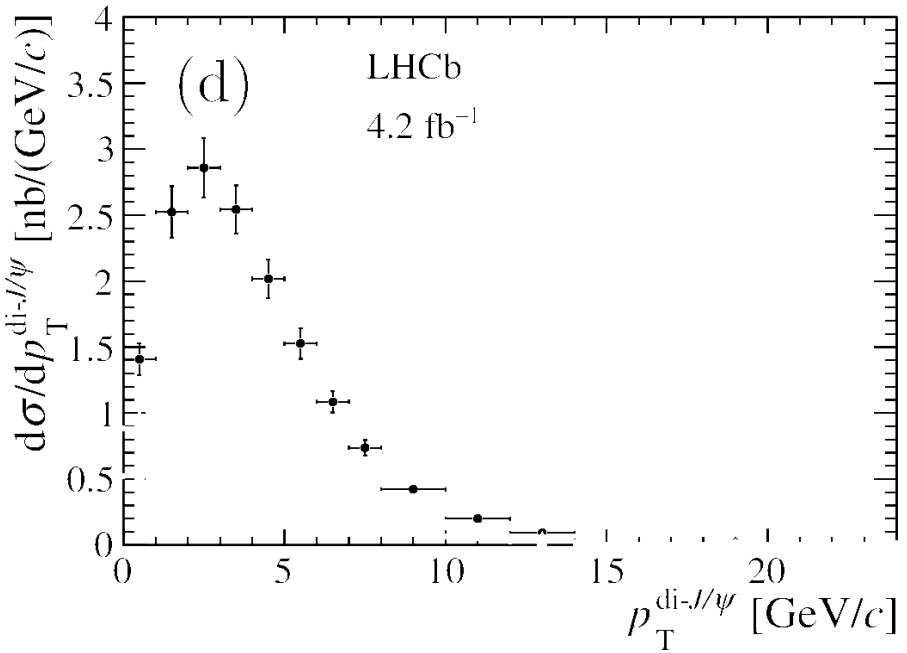
J/ψ pair production : arXiv:2311.14085
J/ψ-ψ(2S) pair production : arXiv:2311.15921

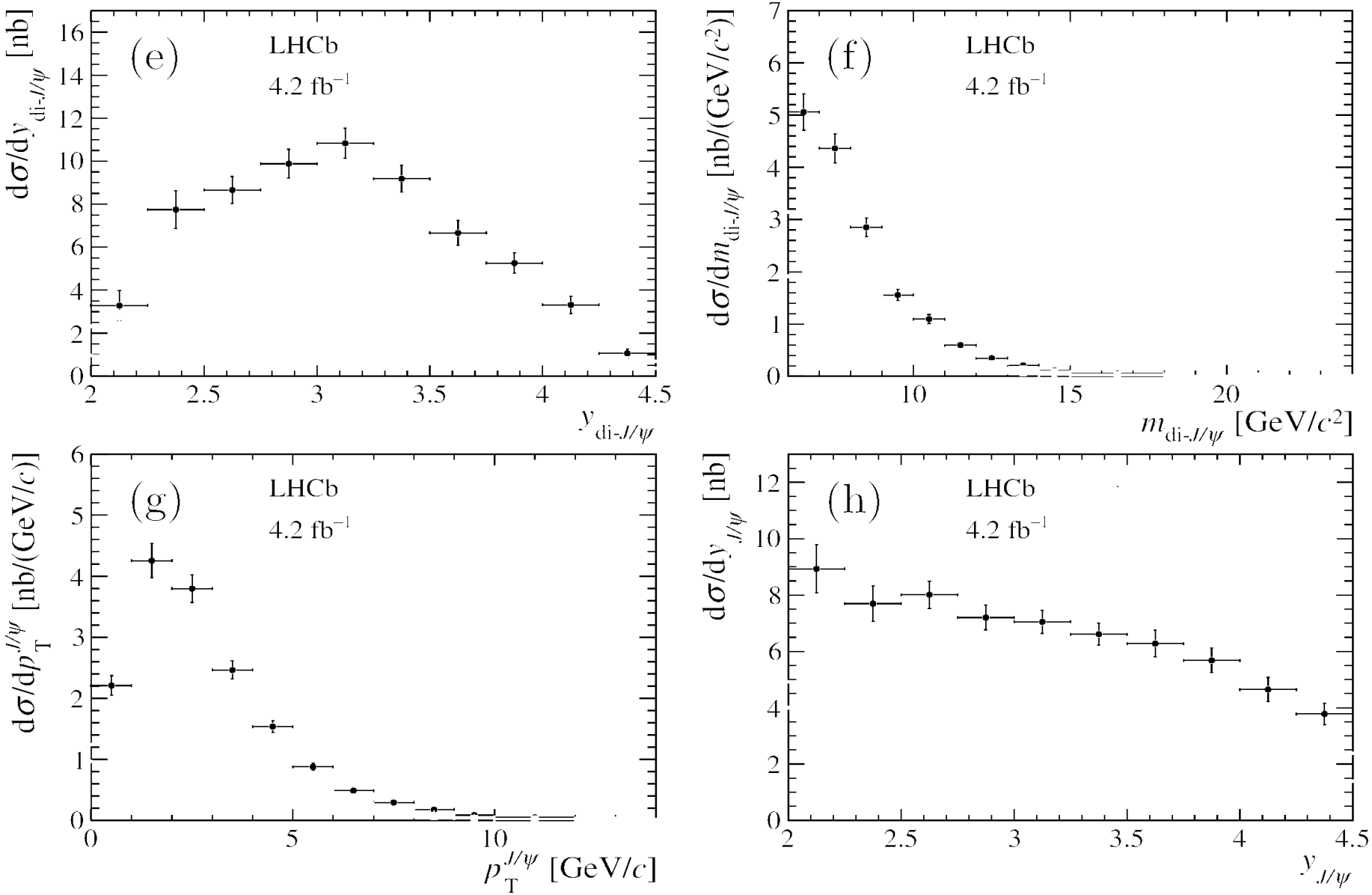
$$\mathcal{A}_{p_{\mathrm{T}}} = \left| \frac{p_{\mathrm{T}}^{J/\psi_1} - p_{\mathrm{T}}^{J/\psi_2}}{p_{\mathrm{T}}^{J/\psi_1} + p_{\mathrm{T}}^{J/\psi_2}} \right|$$





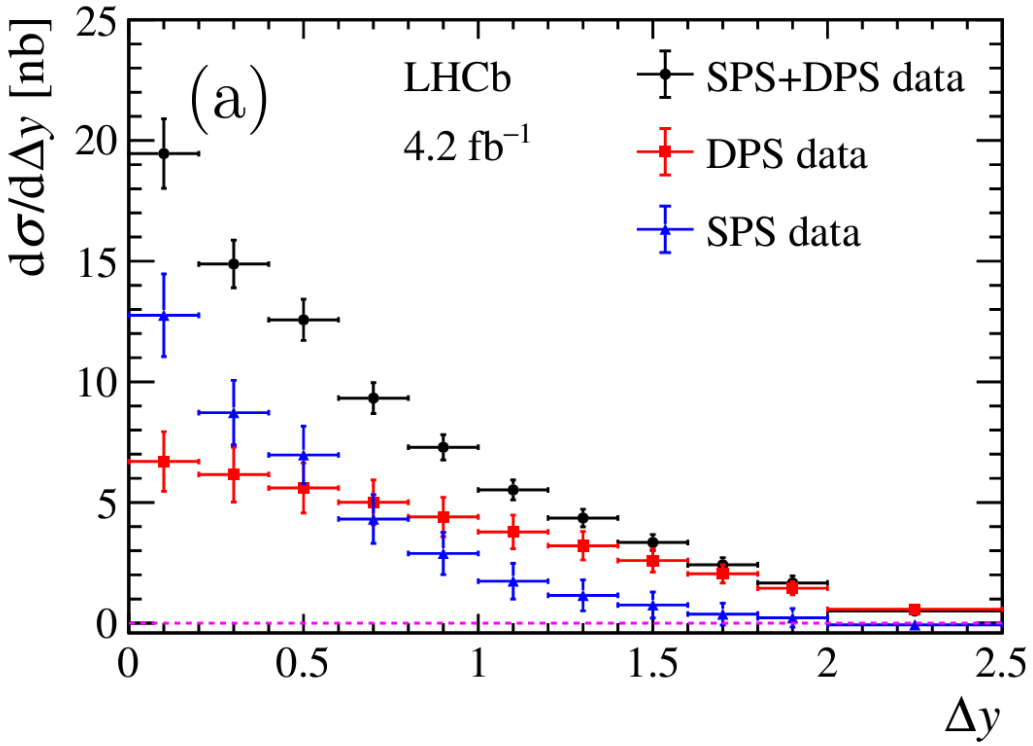


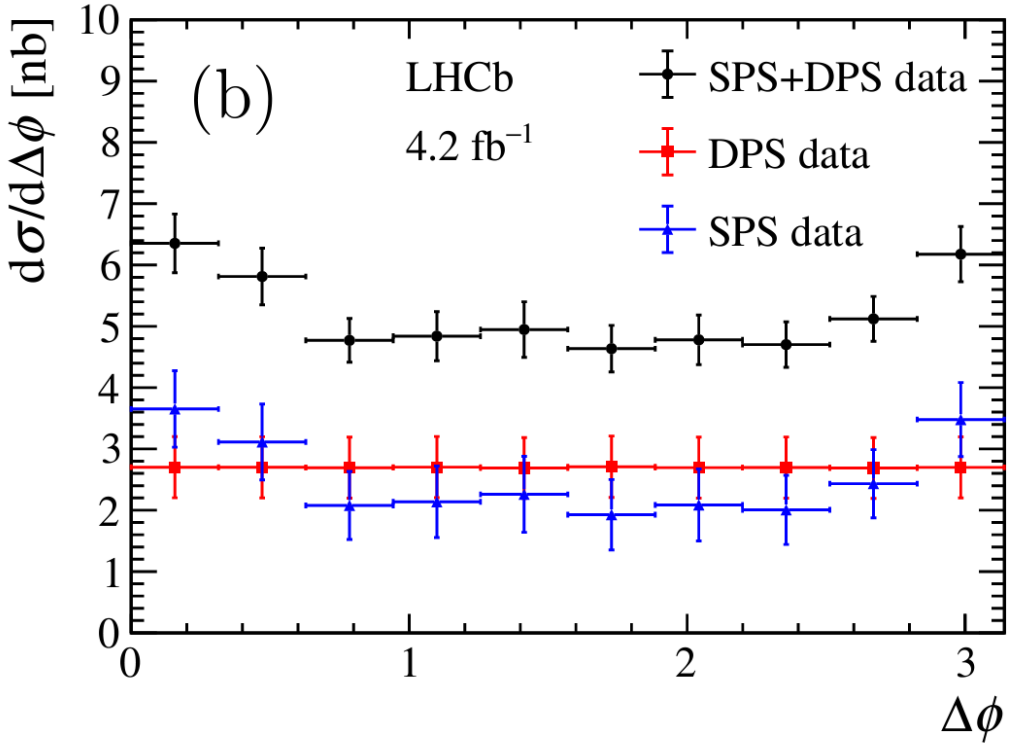



(e)
LHCb
4.2 fb^{-1}
$d\sigma/dy_{\text{di-}J/\psi}$ [nb]
$y_{\text{di-}J/\psi}$
(f)
LHCb
4.2 fb^{-1}
$d\sigma/dm_{\text{di-}J/\psi}$ [nb/(GeV/c^2)]
$m_{\text{di-}J/\psi}$ [GeV/c^2]
(g)
LHCb
4.2 fb^{-1}
$d\sigma/dp_{\text{T}}^{J/\psi}$ [nb/(GeV/c)]
$p_{\text{T}}^{J/\psi}$ [GeV/c]
(h)
LHCb
4.2 fb^{-1}
$d\sigma/dy_{J/\psi}$ [nb]
$y_{J/\psi}$

Separating di-J/ψ from Double Parton Scattering

- Δy distributions between the two J/ψmesons have different shapes for the SPS and DPS processes
- DPS component shape obtained by using p_T of single J/ψ and uniformly $\Delta\phi$ between the pair
- According to NRQCD estimations SPS is negligible for 1.8<Δy<2.5, this region is used as a DPS normalization





DPS and effective cross-section

p_T<14GeV/c 2.0<y<4.5

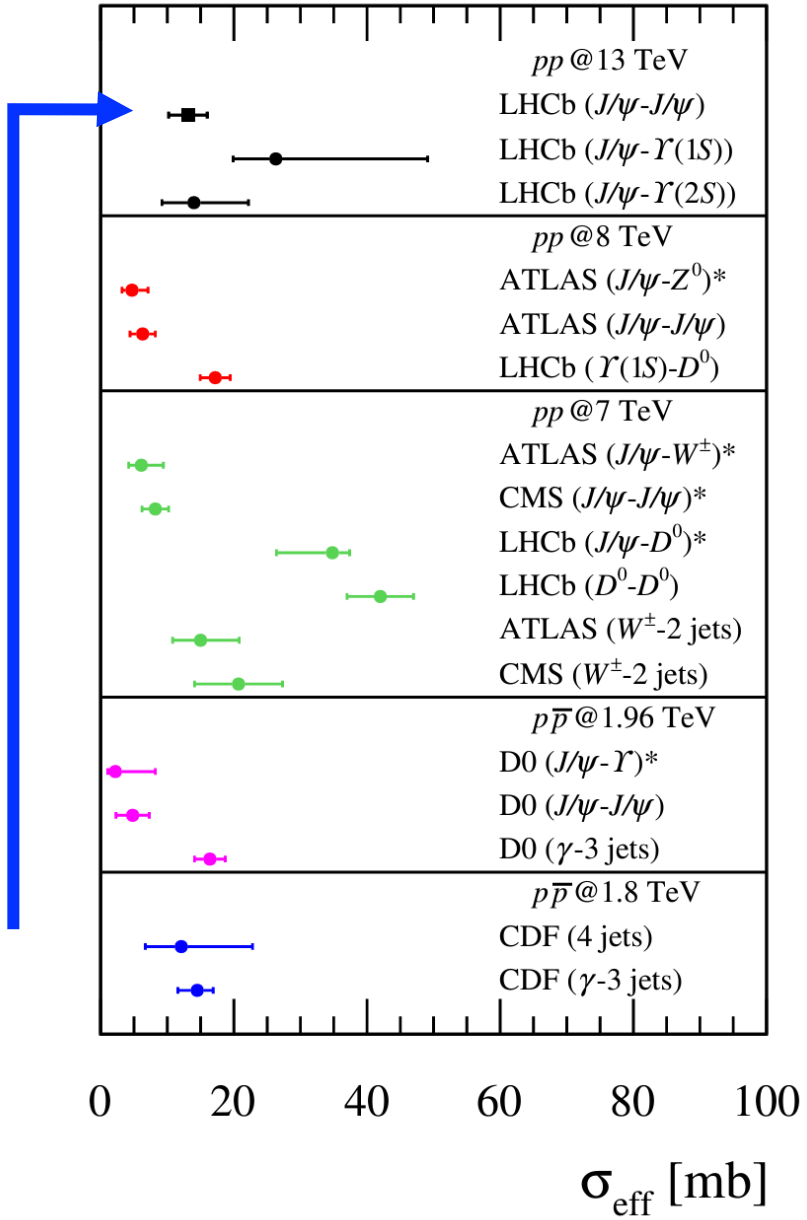
$$\sigma^{\mathrm{DPS}}_{\text{di-}J/\psi} = 8.6 \pm 1.2\ (\mathrm{stat}) \pm 1.0\ (\mathrm{syst})\ \mathrm{nb}.$$

The DPS cross-section is related on the profile and correlation between the partons inside the proton.

Quantified by the effective cross-section σ_{eff}

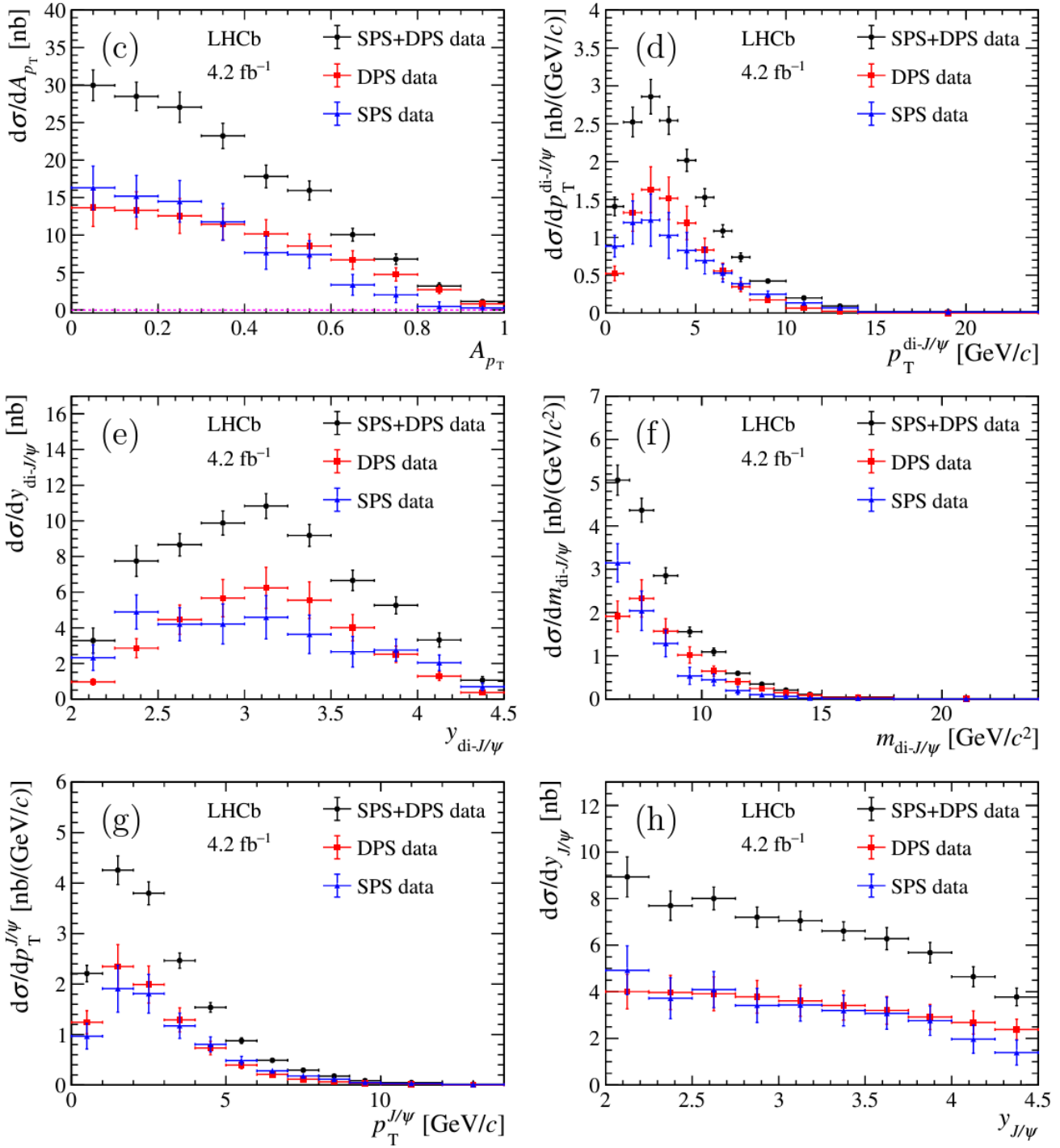
$$\sigma^{\mathrm{DPS}}_{\mathcal{Q}_1\mathcal{Q}_2} = \frac{1}{1+\delta_{\mathcal{Q}_1\mathcal{Q}_2}} \frac{\sigma_{\mathcal{Q}_1}\sigma_{\mathcal{Q}_2}}{\sigma_{\mathrm{eff}}}$$

$$\sigma_{\mathrm{eff}} = \frac{1}{2}\frac{\sigma^2_{J/\psi}}{\sigma^{\mathrm{DPS}}_{\text{di-}J/\psi}} = 13.1 \pm 1.8\ (\mathrm{stat}) \pm 2.3\ (\mathrm{syst})\ \mathrm{mb}$$



SPS and DSP distributions

$$\sigma^{\mathrm{SPS}}_{\text{di-}J/\psi} = 7.9 \pm 1.2\ (\mathrm{stat}) \pm 1.1\ (\mathrm{syst})\ \mathrm{nb}.$$



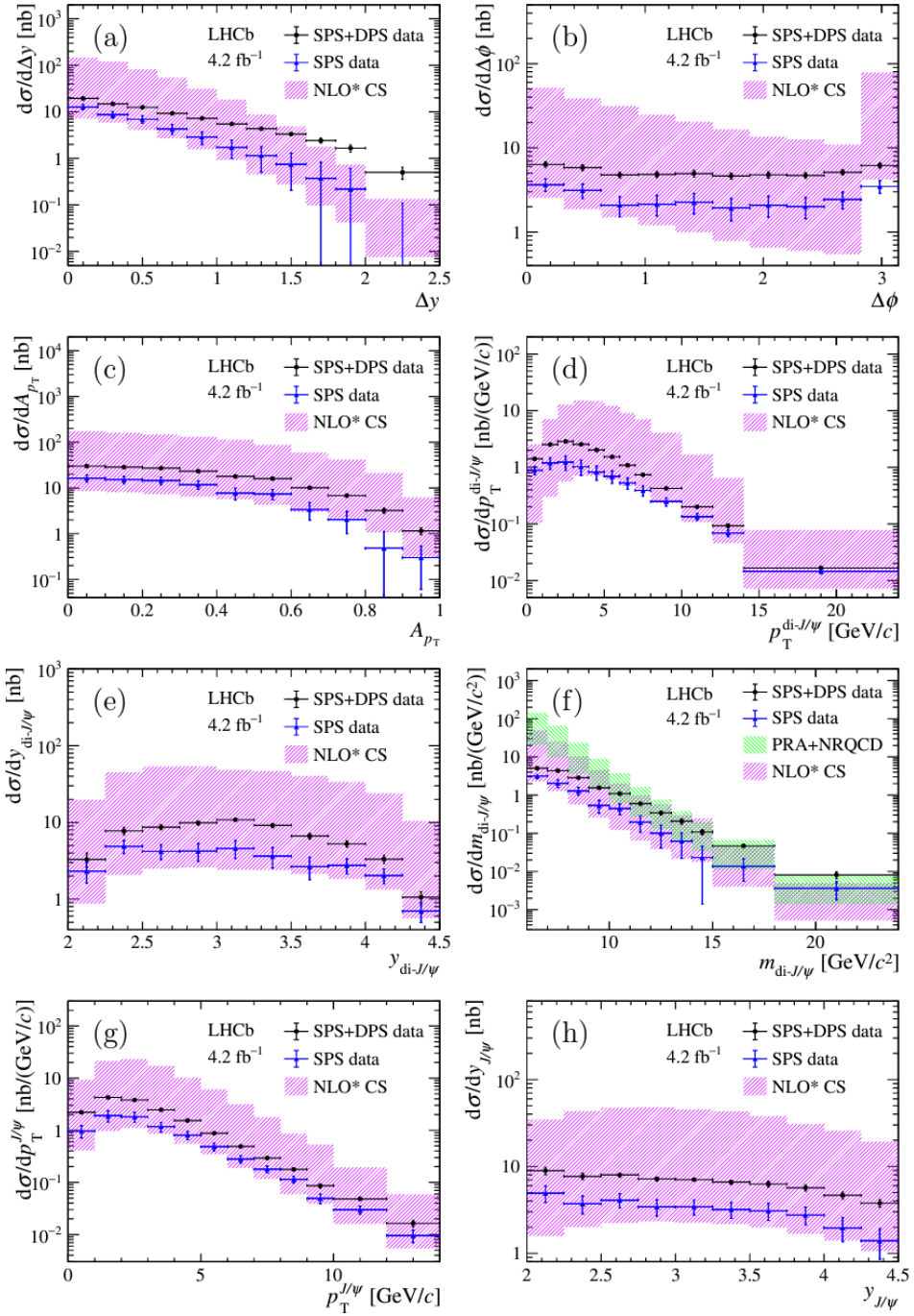
Comparison with Color Singlet and NRQCD estimations

NLO+CS :

- PRL111 (2013) 122001
- HELAC-Onia Comp.Phys.Com.184(2013)2562, Comp.Phys. Com. 198 (2016) 238

PRA+NRQCD :

- PRL123 (2019) 162002



Comparison with Color Singlet and NRQCD estimations for $J/\psi + \psi(2S)$ pairs

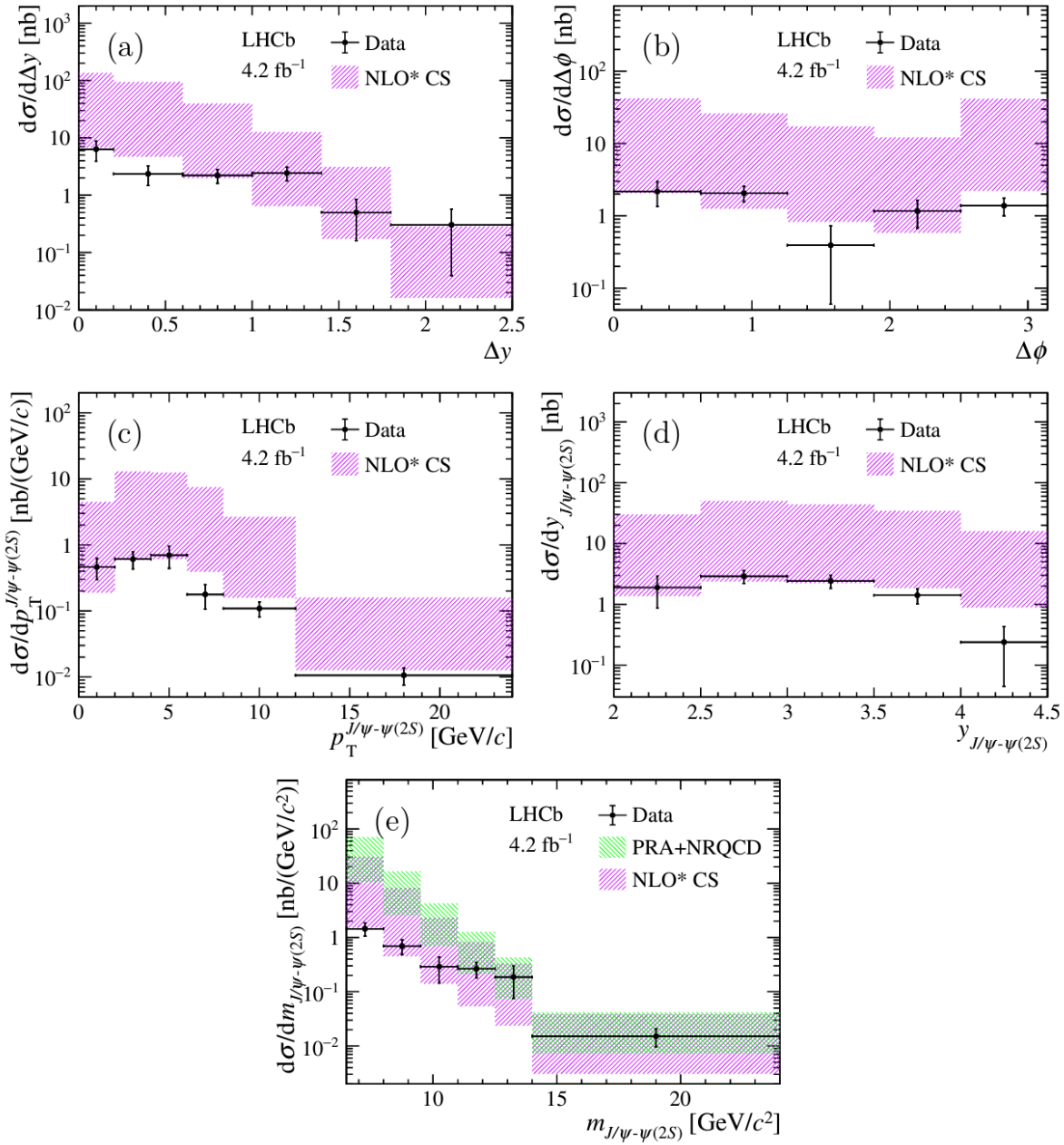
DPS not subtracted in data

NLO+CS :

- PRL111 (2013) 122001
- HELAC-Onia Comp.Phys.Com.184(2013)2562, Comp.Phys. Com. 198 (2016) 238

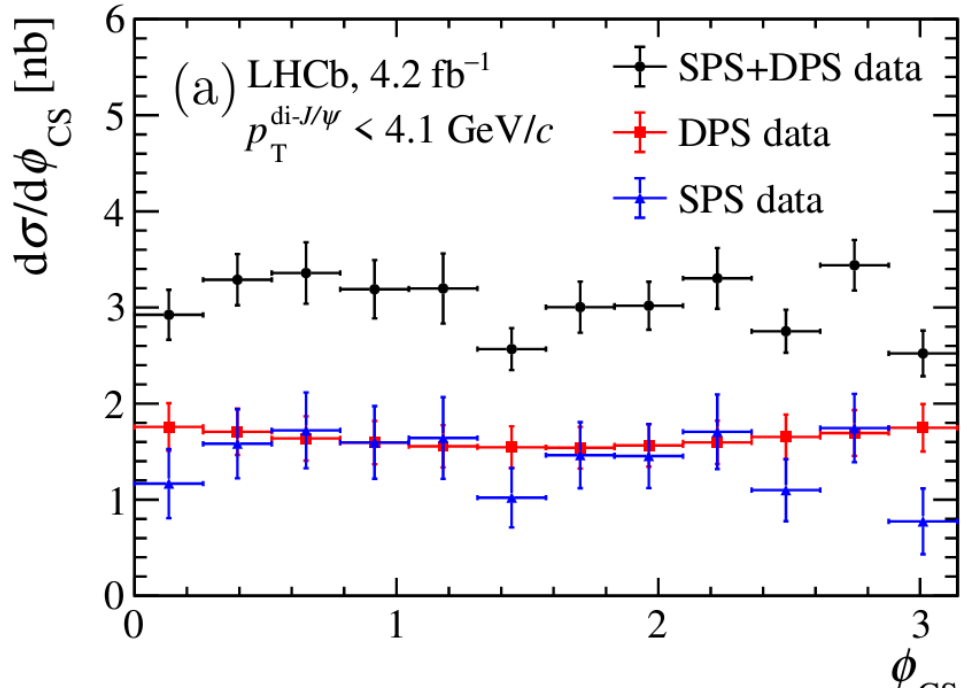
PRA+NRQCD :

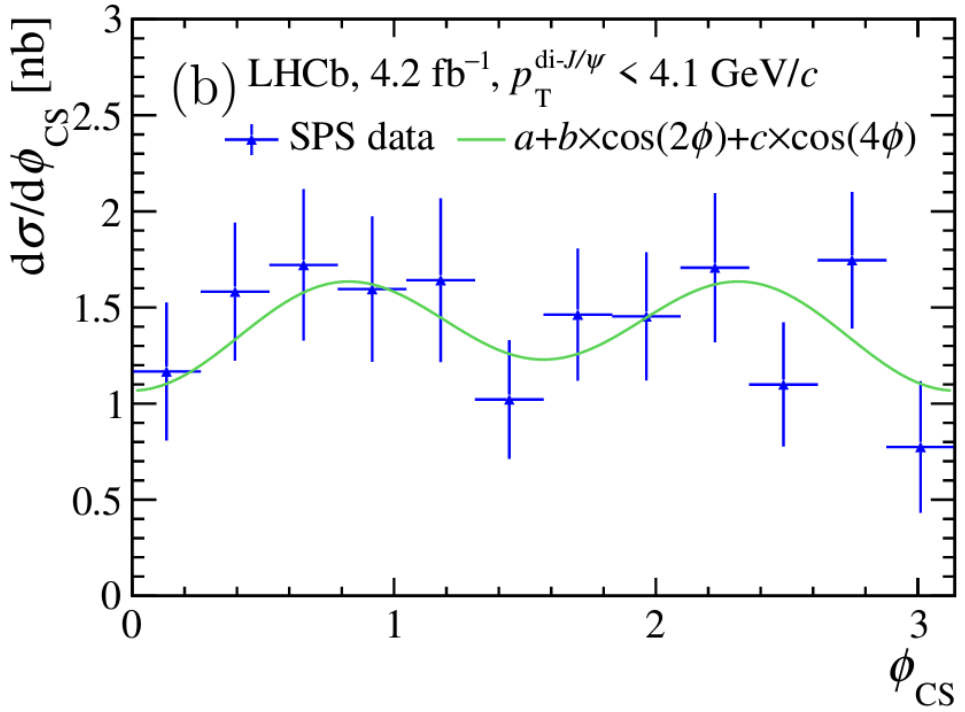
- PRL123 (2019) 162002



Gluon TMD

- Take the di-J/ψ azimuthal angle in the Collins Soper frame ϕ_{CS}
- The differential SPS cross-section relates with ϕ_{CS} as $a + b\cos(2\phi_{CS}) + c\cos(4\phi_{CS})$ where parameters a, b, c encode information from the gluon TMD [PLB 784(2018)217, PLB791(2019)420]





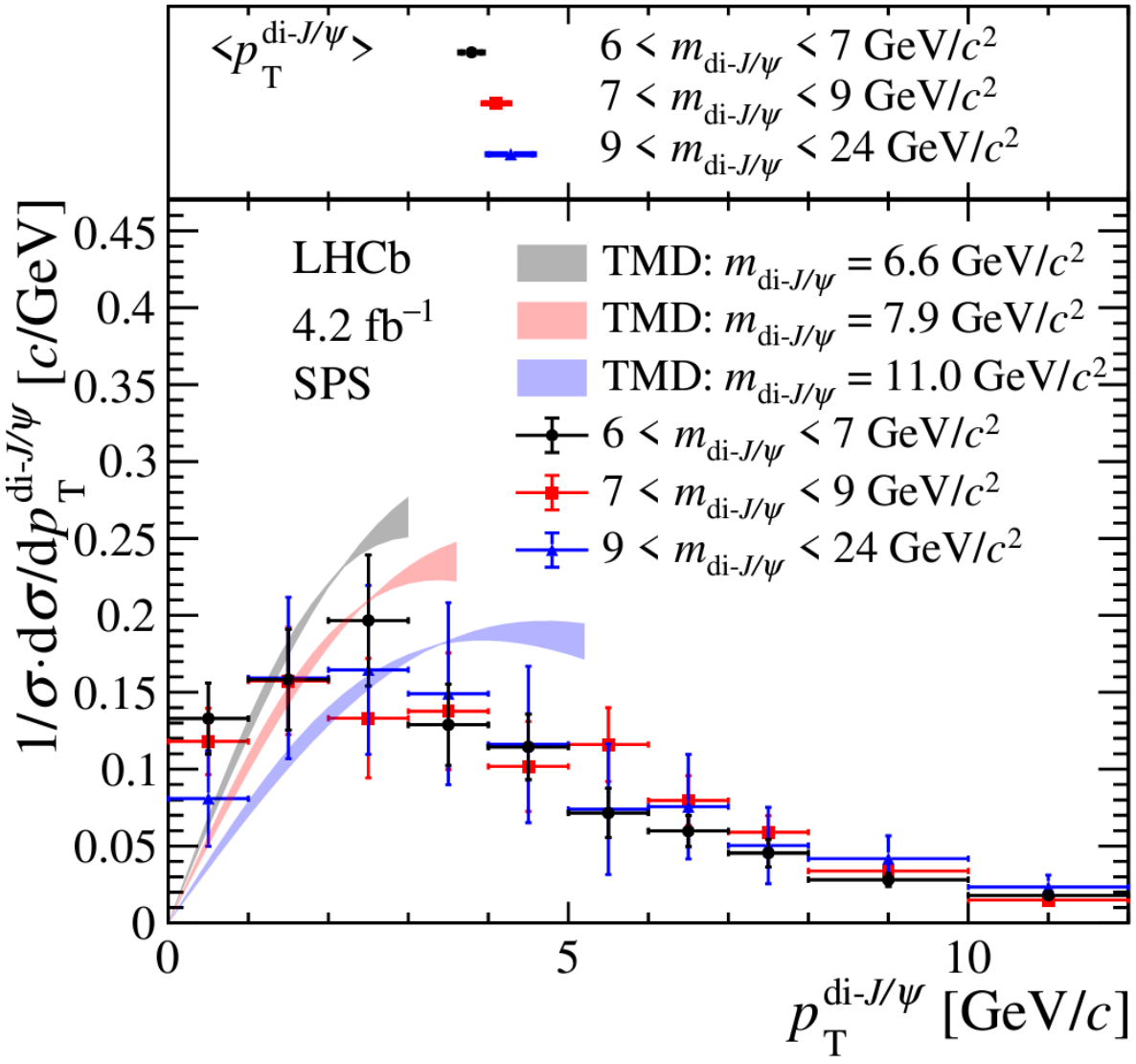
$$\langle \cos 2\phi_{\rm CS} \rangle = -0.029 \pm 0.050\ (\text{stat}) \pm 0.009\ (\text{syst}),$$
$$\langle \cos 4\phi_{\rm CS} \rangle = -0.087 \pm 0.052\ (\text{stat}) \pm 0.013\ (\text{syst}),$$

TMD prediction :

$< cos2\phi_{CS} >$ ~ 0.009-0.016

EPJ.C80(2020)87

Gluon TMD



TMD: EPJ.C80(2020)87

p_T spectrum would broaden with $m_{di-J/\psi}$ according to the prediction

But p_T broadening is not observed given the current uncertainties

Take Away

- About 20% of the low p_T $\psi(2S)$ state are broken by co-moving particles when the particle multiplicity is larger than three times the average in *pp* collisions

- Effective cross-section extracted from charmonium pairs consistent with world data

- SPS contribution to di-J/ψ distributions consistent with Color Singlet production, given the large theoretical uncertainties

- Data still not precise to be compared with gluon TMD predictions, Run3+4 may be conclusive