Prompt J/ψ and ψ(2S) production in pp, pPb and PbPb collisions

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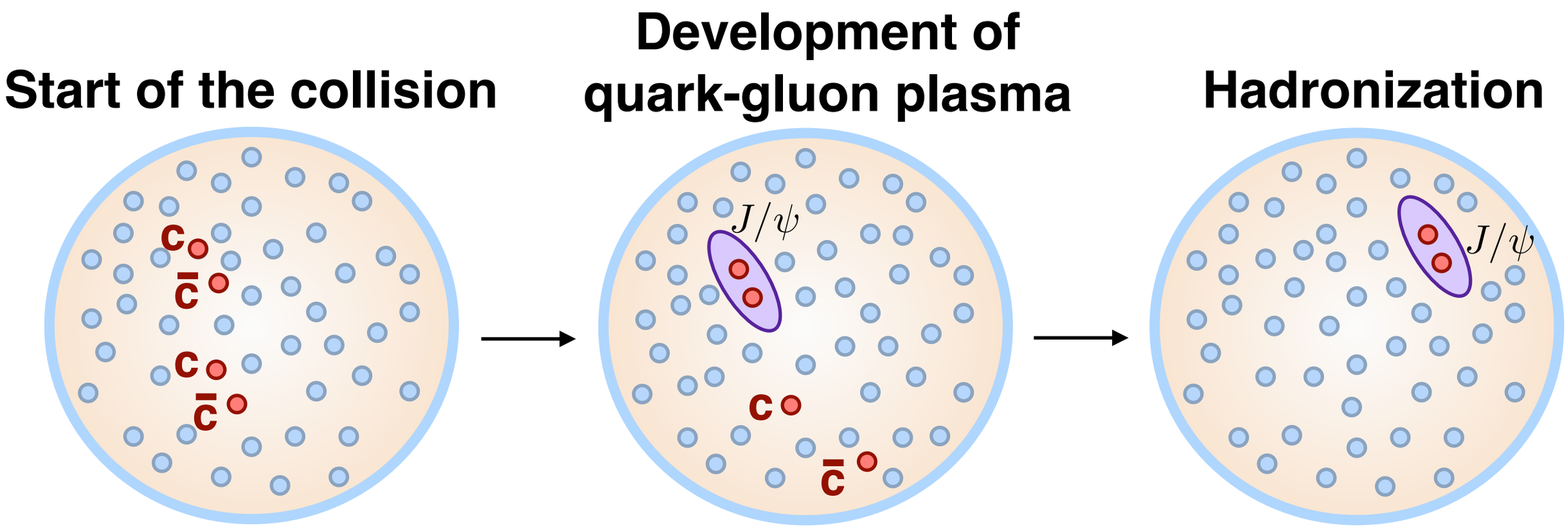
On behalf of the CMS Collaboration

Laboratoire Leprince-Ringuet, École Polytechnique, France

03/10/2018

Charmonia in Heavy Ion collisions

Charmonia are bound states of $c\bar{c}$



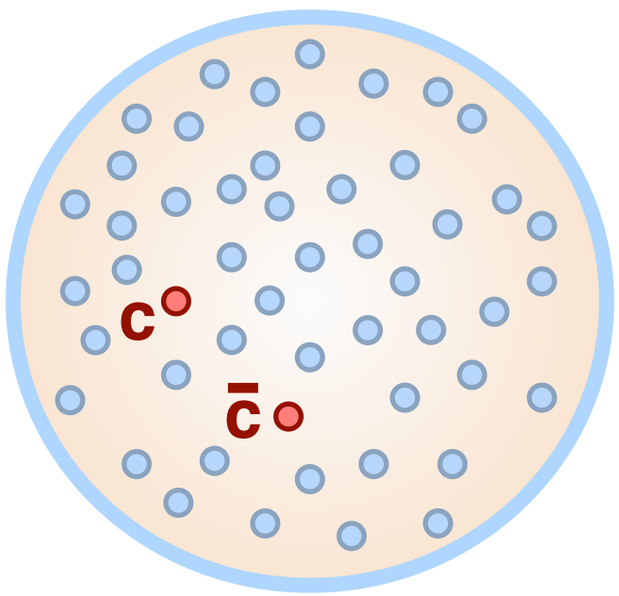
$$\tau^{c\bar{c}}_{formation} < \tau^{QGP}_{formation} < \tau^{freeze-out} < \tau^{J/\psi}_{decay}$$

→ Expected to experience the whole QGP evolution

Charmonia in the QGP

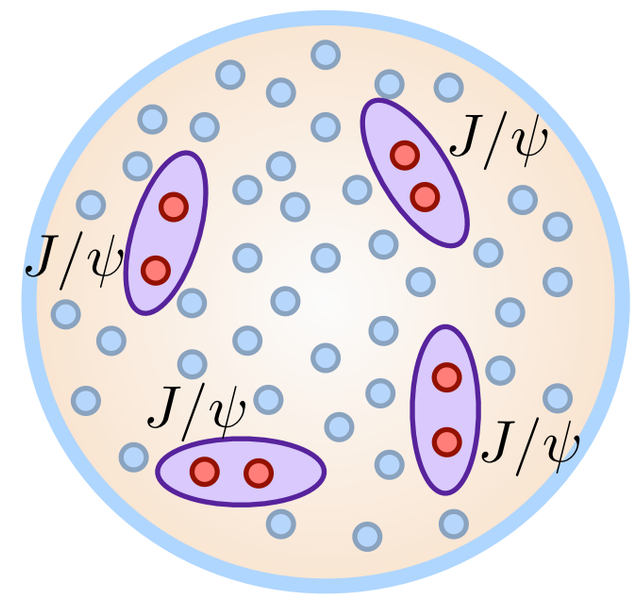
The effect of QGP on charmonia: two scenarios

QGP



Suppression

QGP + high $\sqrt{s_{NN}}$



+ Enhancement

Charmonia in the QGP

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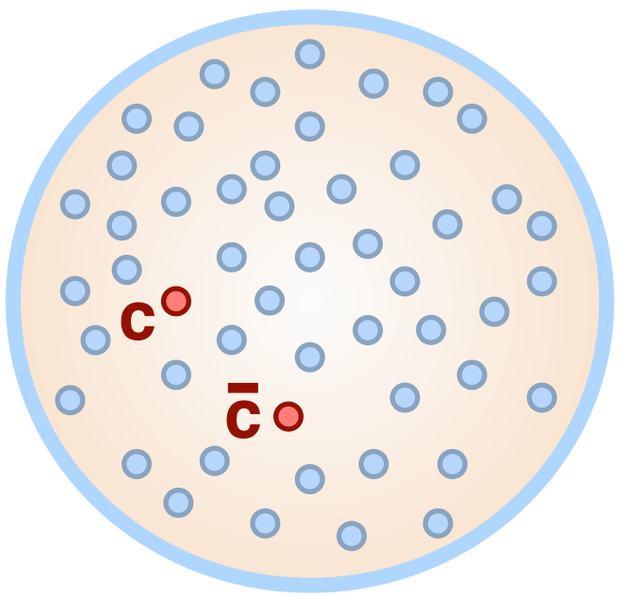
QGP



Suppression

QGP + high $\sqrt{s_{NN}}$

Debye screening:
Color deconfinement

Energy loss:
Parton propagation in QGP

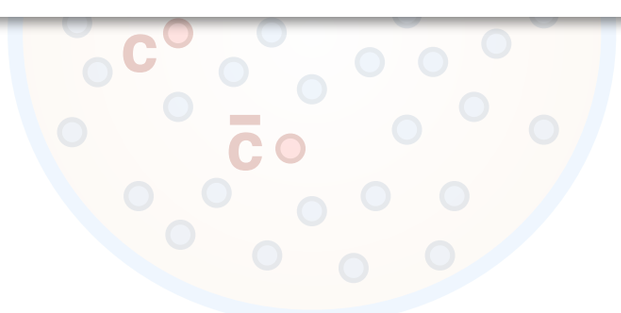
+ Enhancement

Charmonia in the QGP

The effect of QGP on charmonia: two scenarios

QGP

Regeneration:
High charm density



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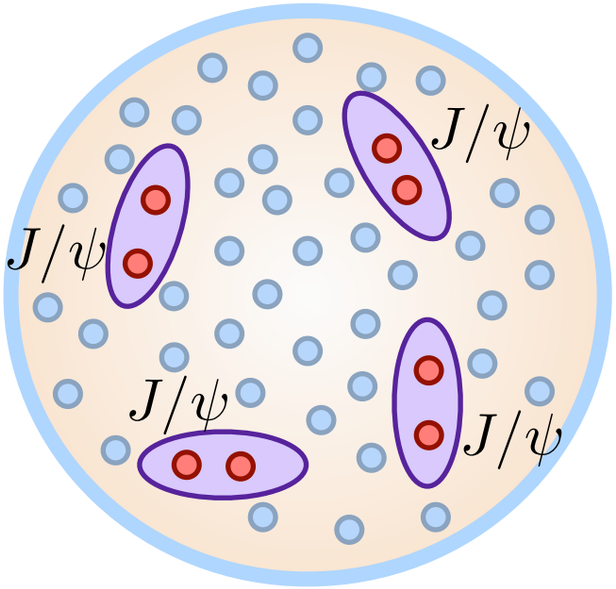

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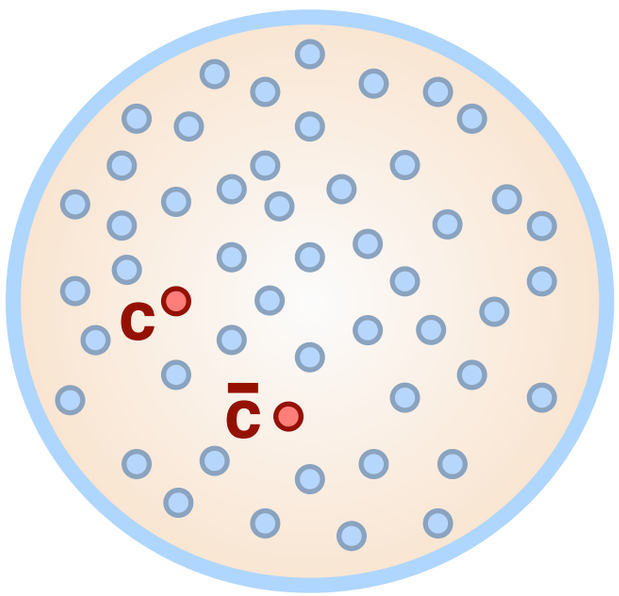

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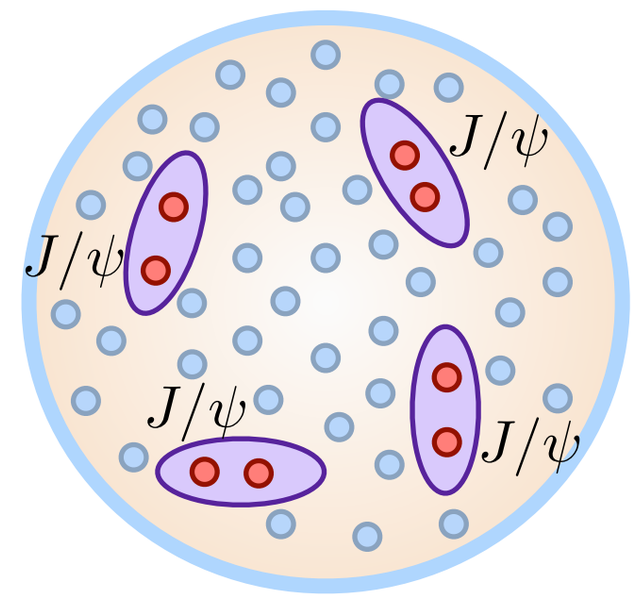
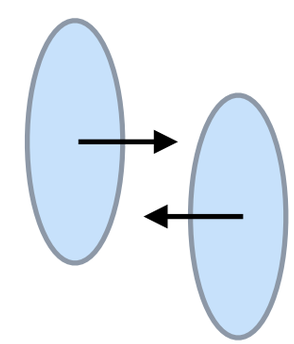


+ Enhancement

Tool: PbPb collisions



Cold Nuclear Matter

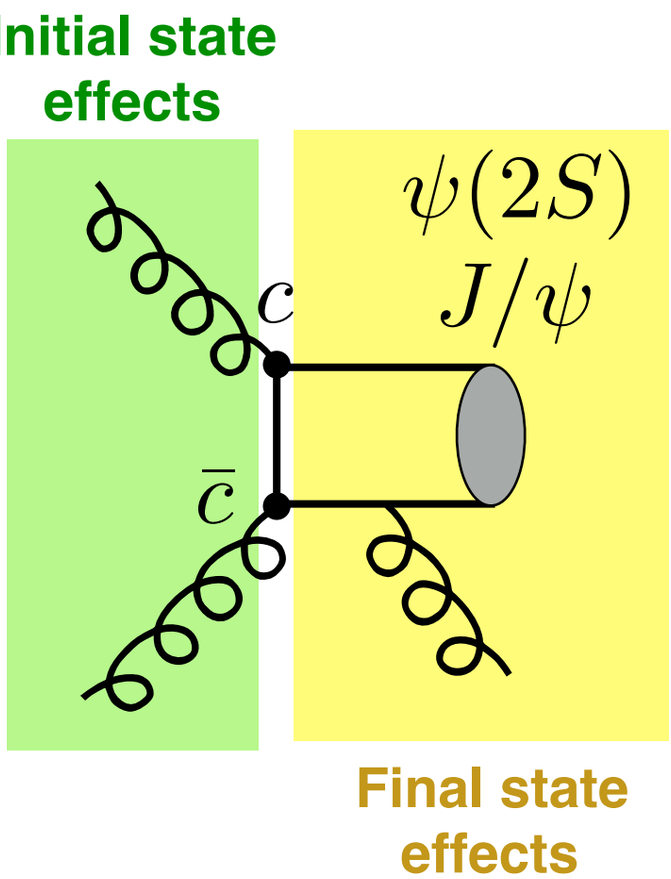
Charmonia as a probe of Cold Nuclear Matter effects:

Initial state: Shadowing due to modification of nuclear PDFs

Initial-final: Energy loss due to parton propagation in medium

Final state: Nuclear absorption

Interaction with comoving particles



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Predict similar suppression for J/ψ and ψ(2S)

~~**Final state:** Nuclear absorption~~ → Negligible at LHC

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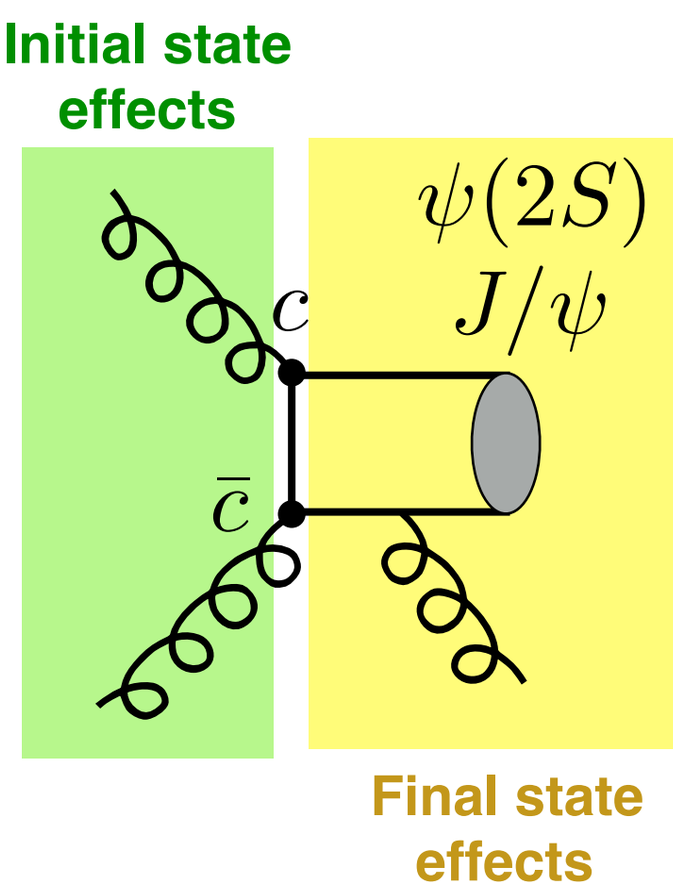

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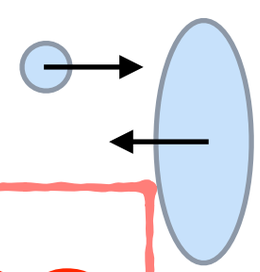
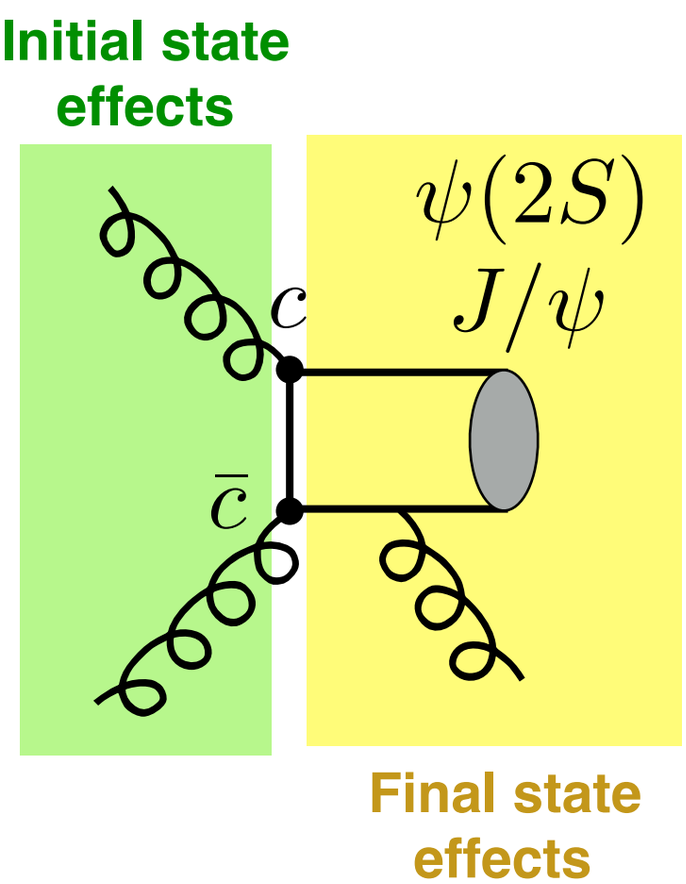


Tool: pPb collisions

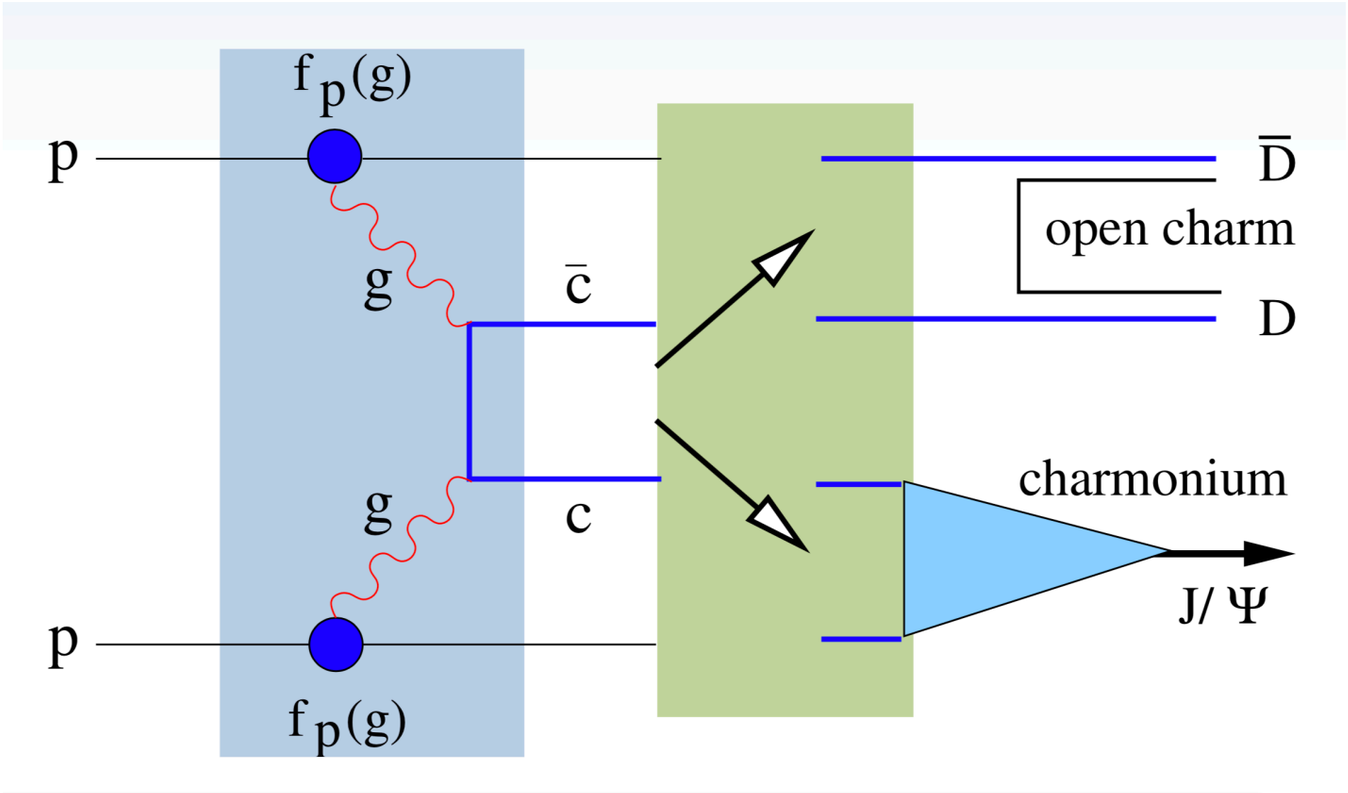


Charmonia production

$$d\sigma[pp \to c\bar{c}(n)X] \approx \sum_{n,X'} f_g^p(Q^2) \otimes f_g^p(Q^2) \otimes d\sigma[gg \to c\bar{c}(n)X']$$

cc production cross section — **Parton distribution functions** — **gg→cc cross section**

Perturbative



Non-perturbative

$$d\sigma(pp \to J/\psi X) = \sum_n d\sigma[pp \to c\bar{c}(n)X] \otimes \langle O^{J/\psi}(n)\rangle$$

cc production cross section — **Matrix elements for transition to bound state**

Charmonia production

$$d\sigma[pp \to c\bar{c}(n)X] \approx \sum_{n,X'} f_g^p(Q^2) \otimes f_g^p(Q^2) \otimes d\sigma[gg \to c\bar{c}(n)X']$$

cc production cross section

Parton distribution functions

gg→cc cross section

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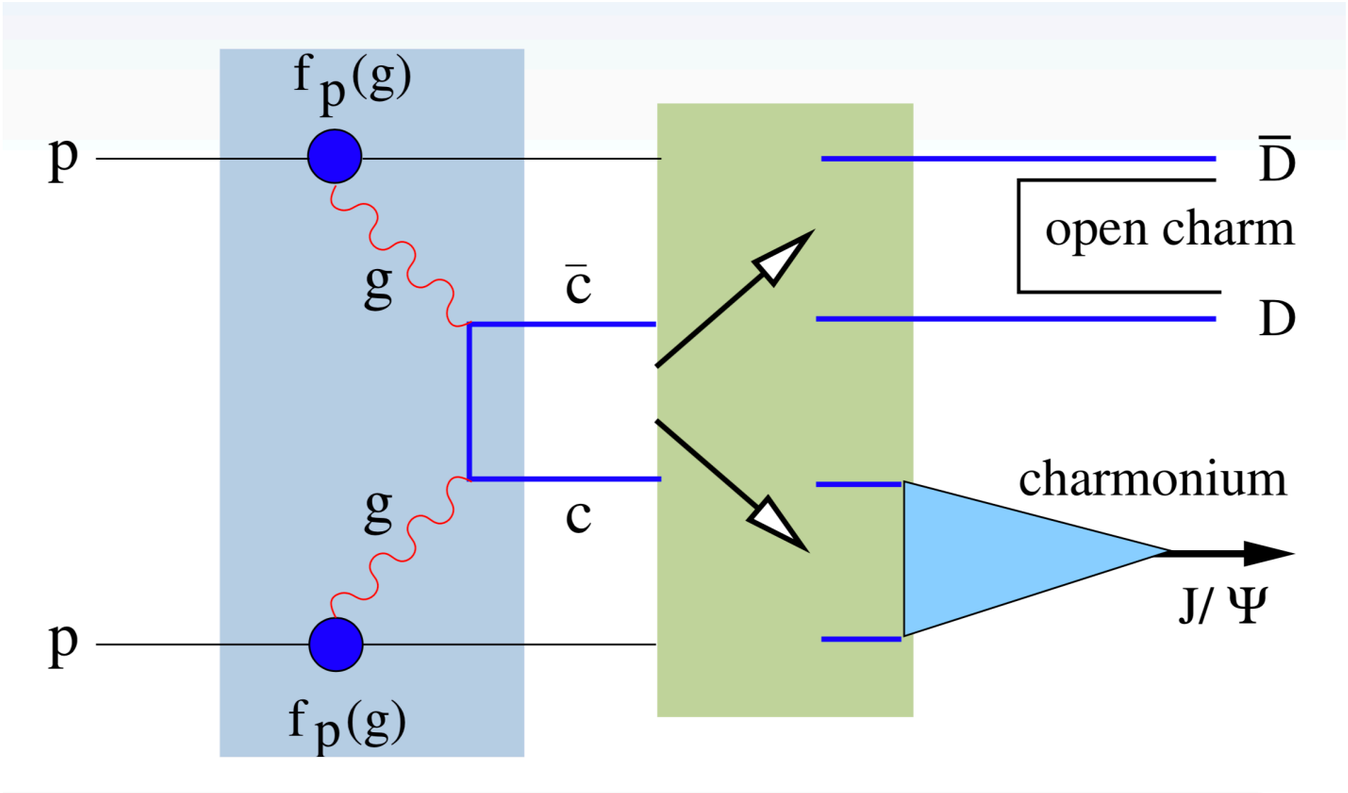


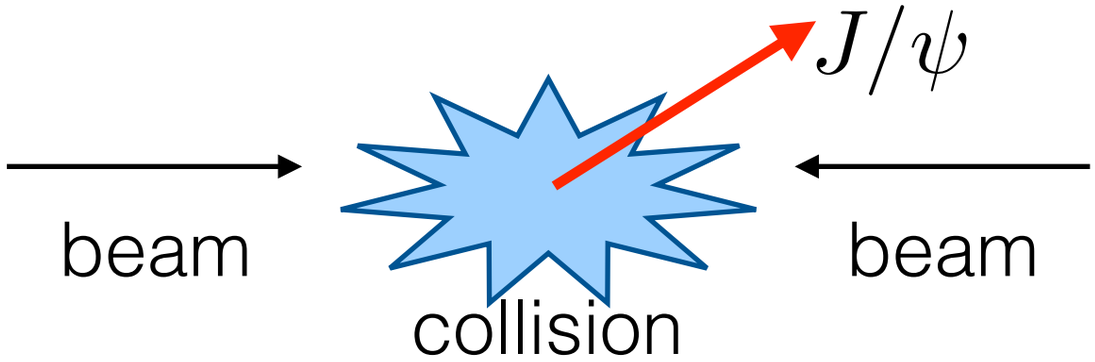
Non-perturbative

$$d\sigma(pp \to J/\psi X) = \sum_n d\sigma[pp \to c\bar{c}(n)X] \otimes \langle O^{J/\psi}(n)\rangle$$

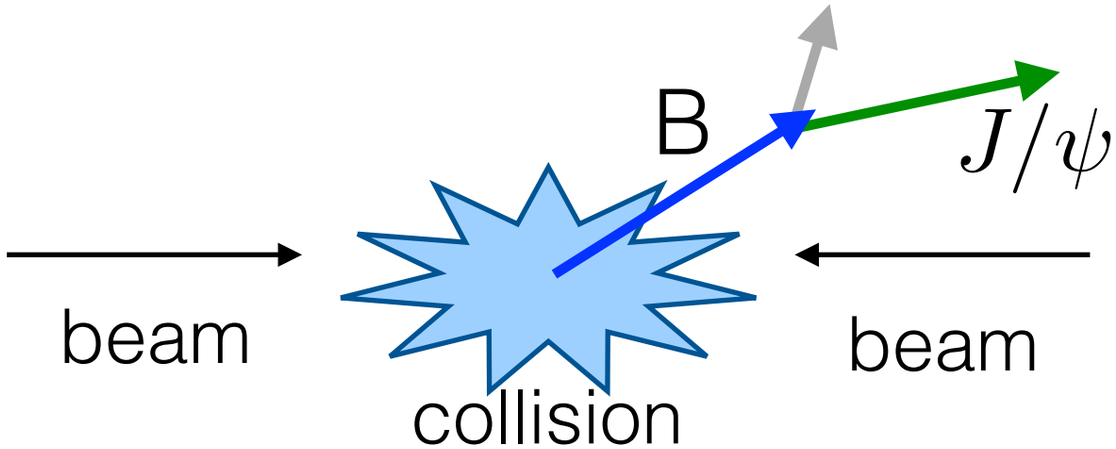
Tool: pp collisions

Prompt vs nonprompt charmonia

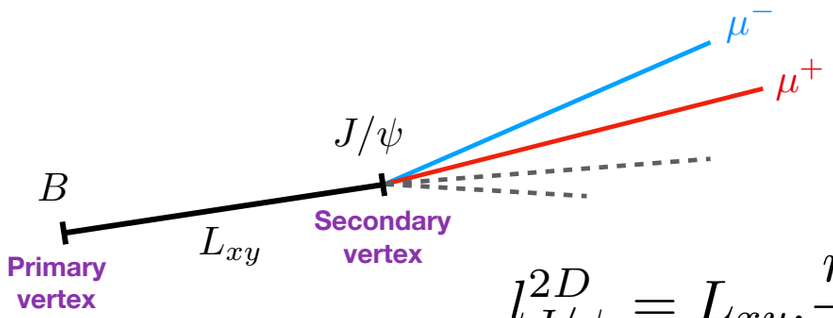
Prompt:
Directly in the collision
Decay of heavier Charmonium states



Nonprompt:
Decay of b hadrons



Separation based on the
pseudo-proper decay length $l_{J/\psi}$



$$l^{2D}_{J/\psi} = L_{xy} . \frac{m}{p_T}$$

Prompt vs nonprompt charmonia

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Directly in the collision
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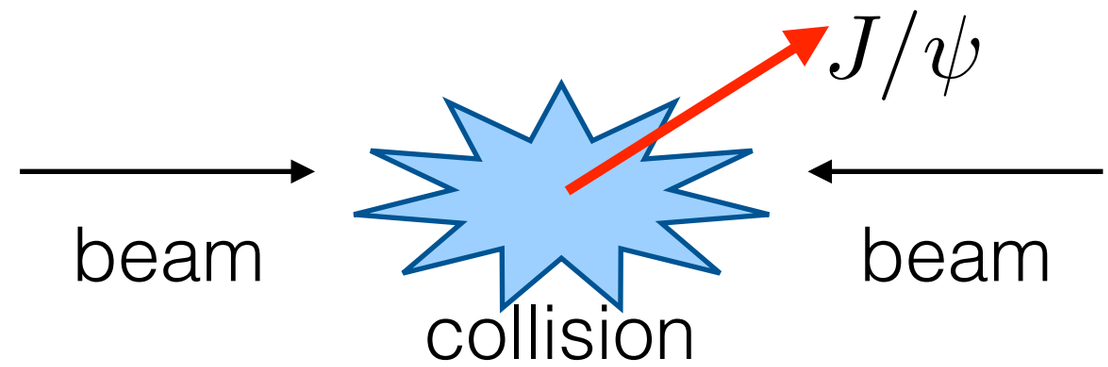

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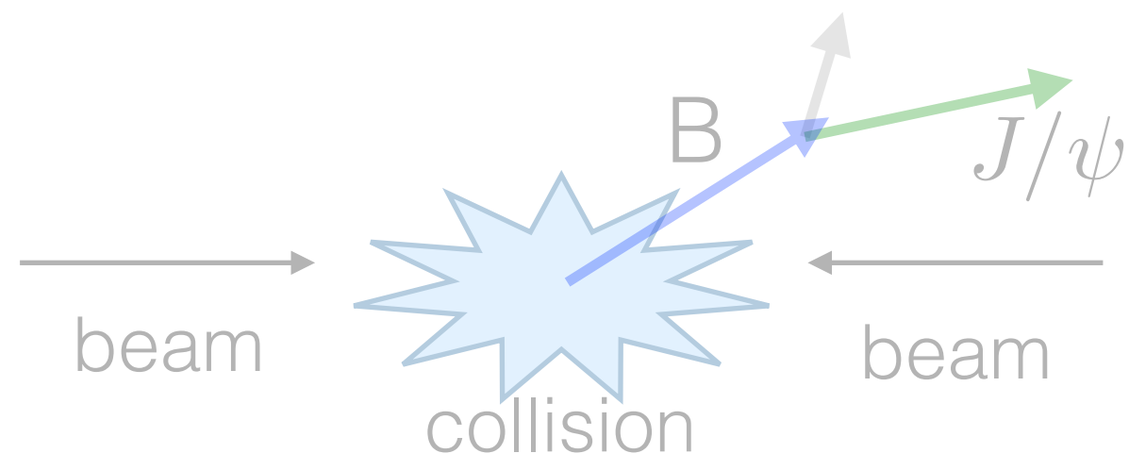

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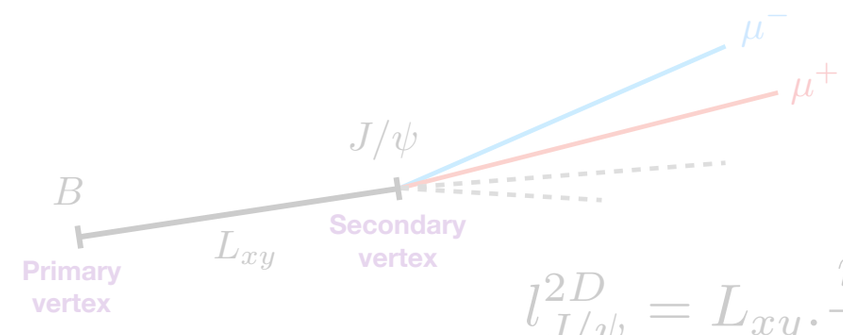
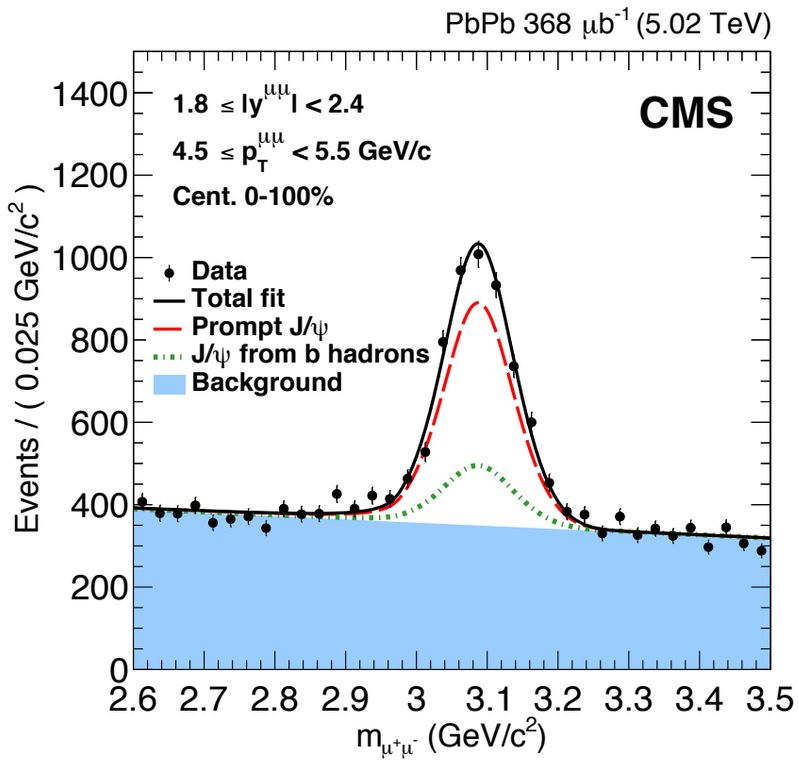


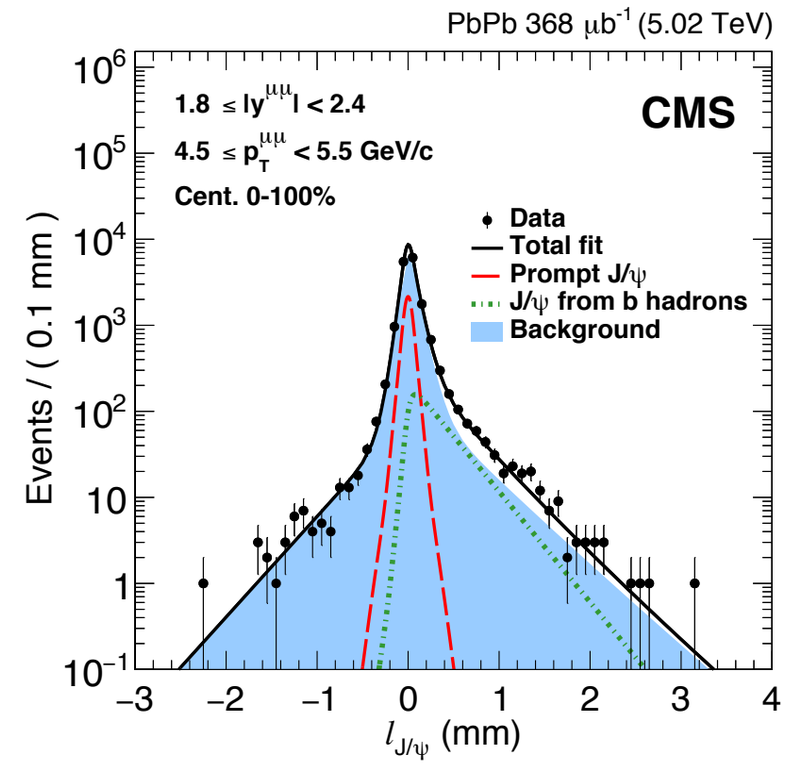
$$l^{2D}_{J/\psi} = L_{xy} \cdot \frac{m}{p_T}$$

Prompt vs nonprompt charmonia

Two techniques to separate the two components:

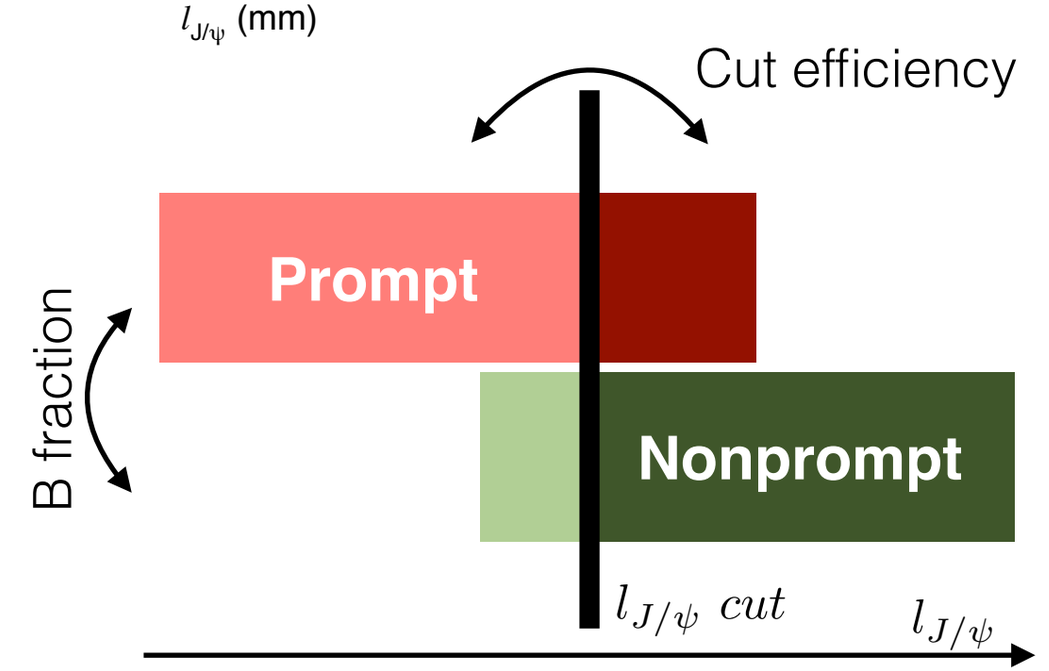
- 2D fits of dimuon mass and pseudo-proper decay length



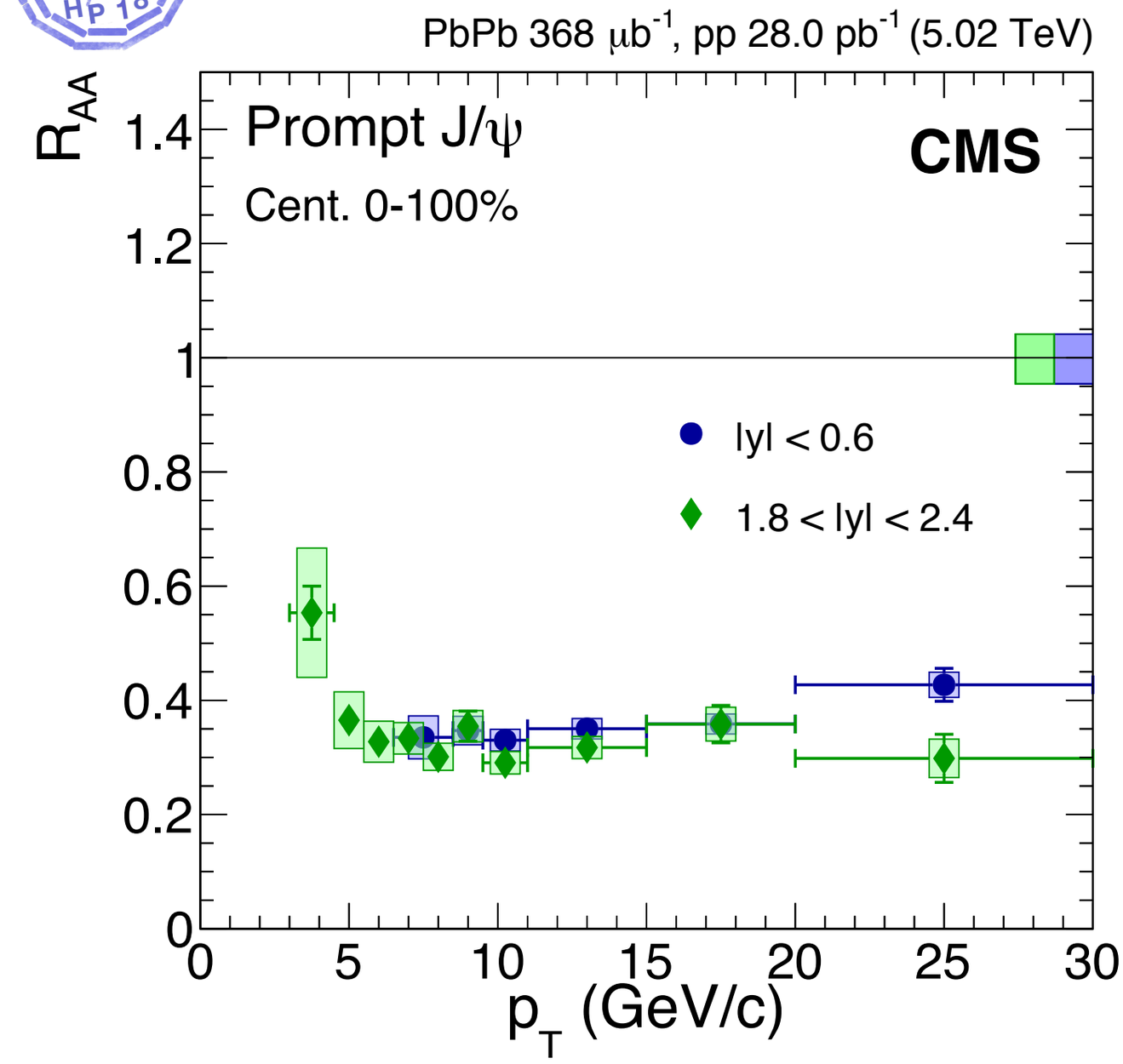


- Rejecting nonprompt using a cut on $l_{J/\psi}$

+ corrections to account for remaining nonprompt contamination



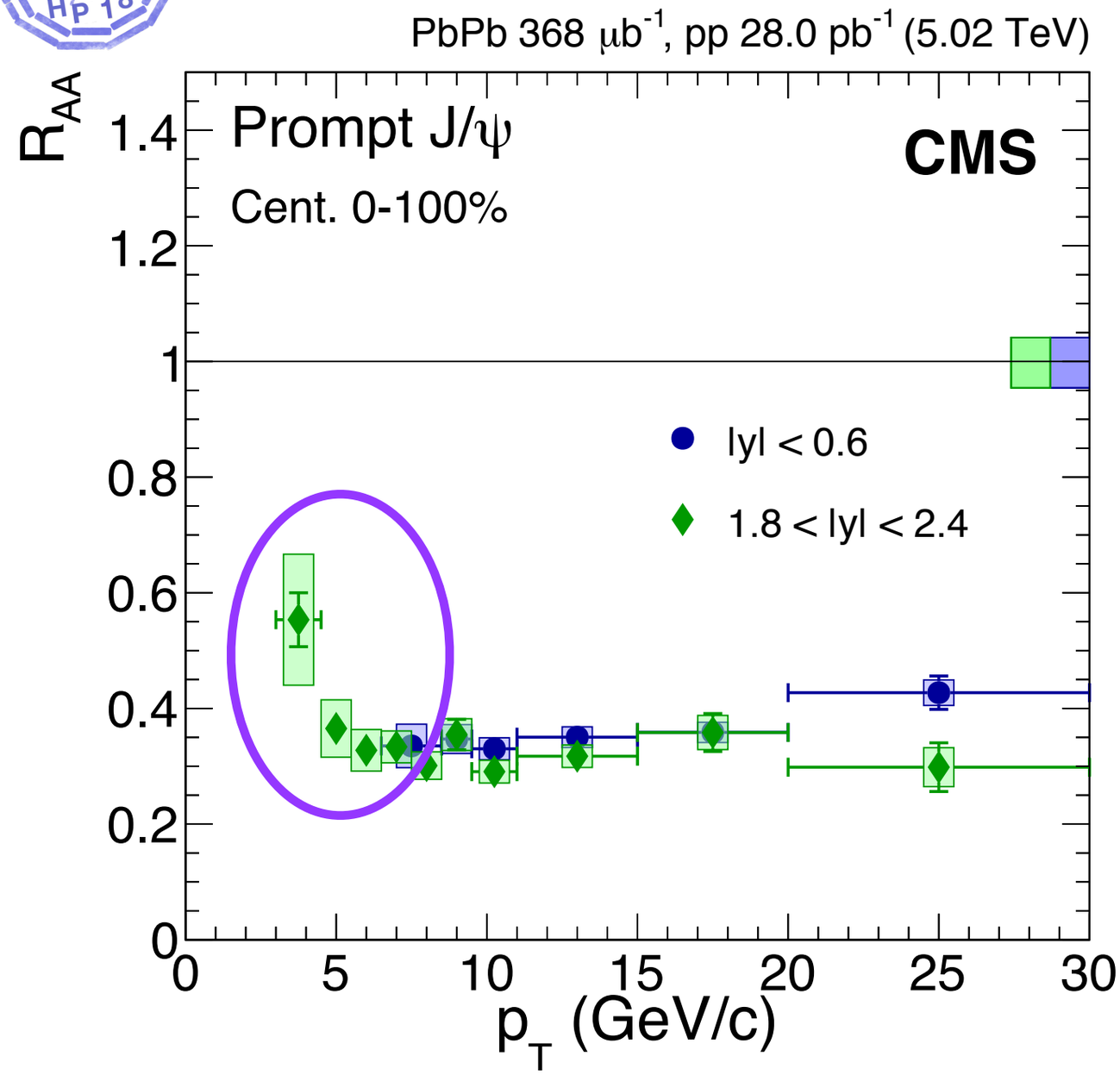
J/ψ in PbPb

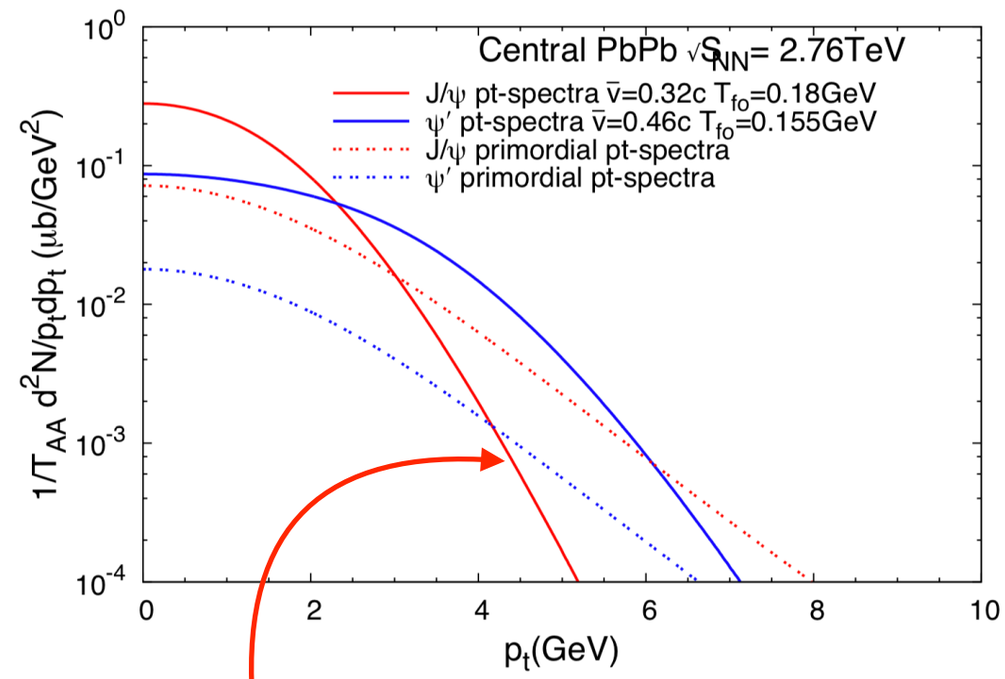


$R_{AA}<1$ → J/ψ is suppressed

Eur. Phys. J. C 78 (2018) 509

J/ψ in PbPb





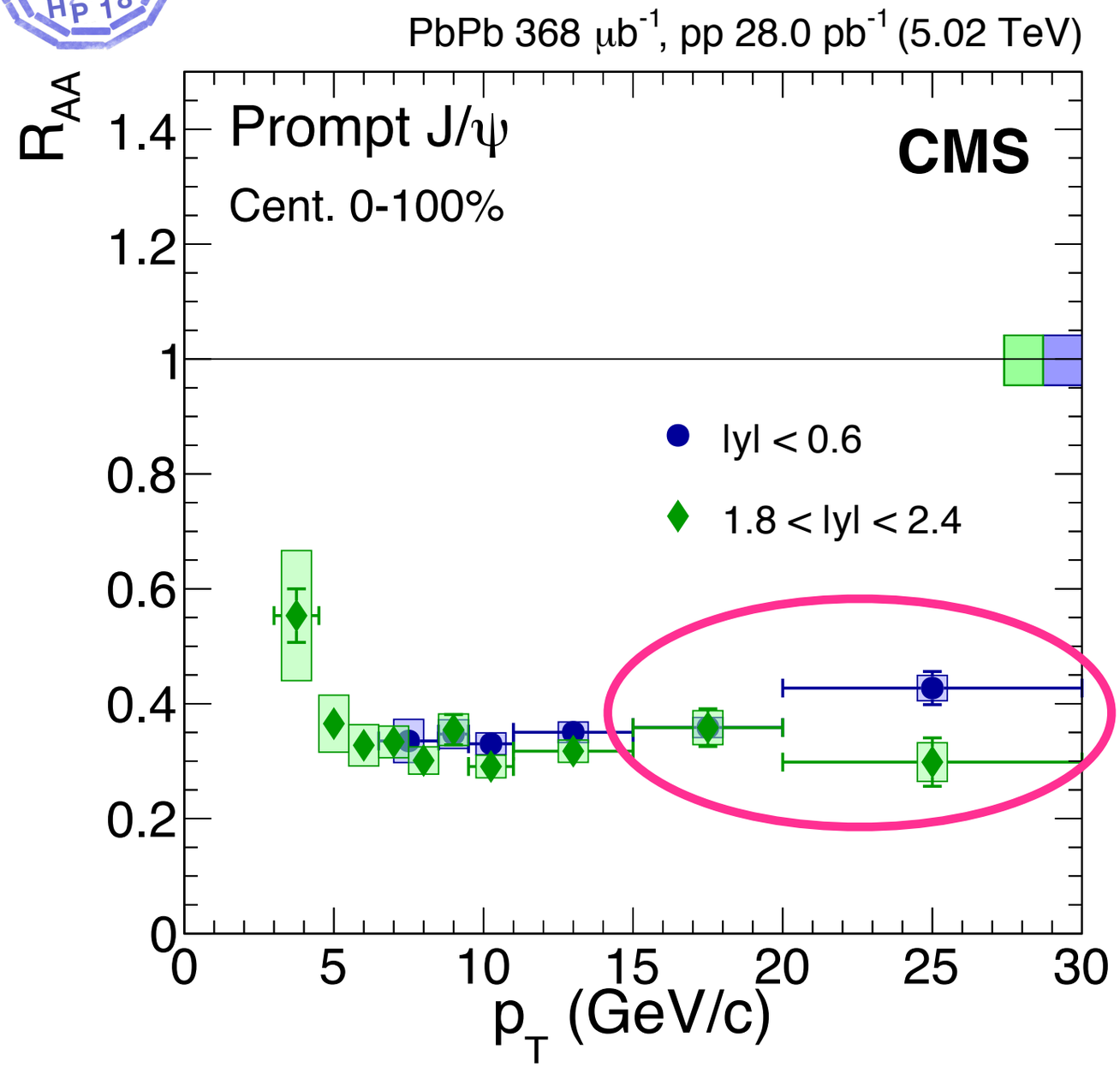
Regeneration of J/ψ

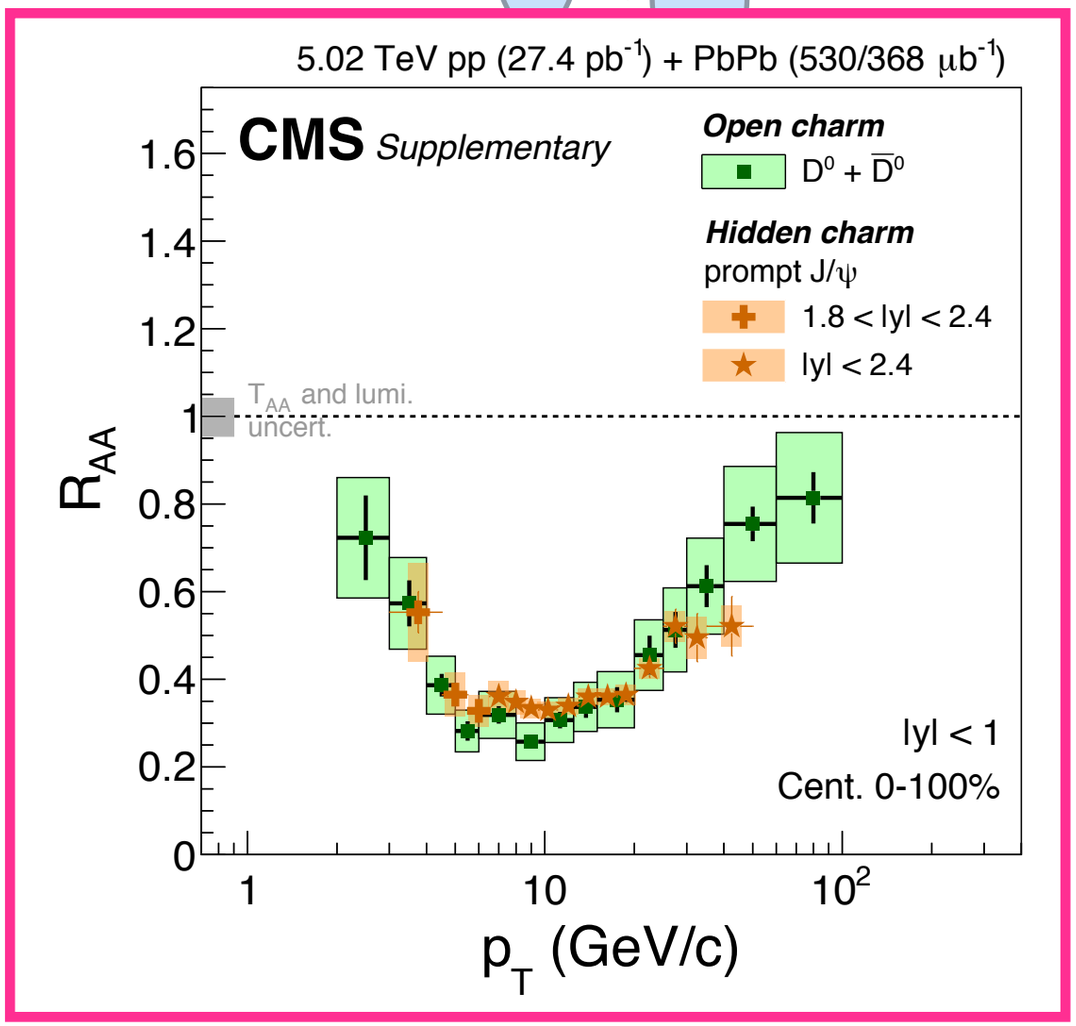
Lower suppression at low p_T
Regeneration effect is largest at low p_T

→ Regeneration

Nucl. Phys. A 09 (2015) 006
Eur. Phys. J. C 78 (2018) 509

J/ψ in PbPb





Lower suppression at high p_T
Similar R_{AA} for hidden and open charm

→ **E_{Loss}**

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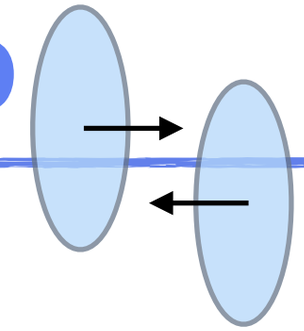
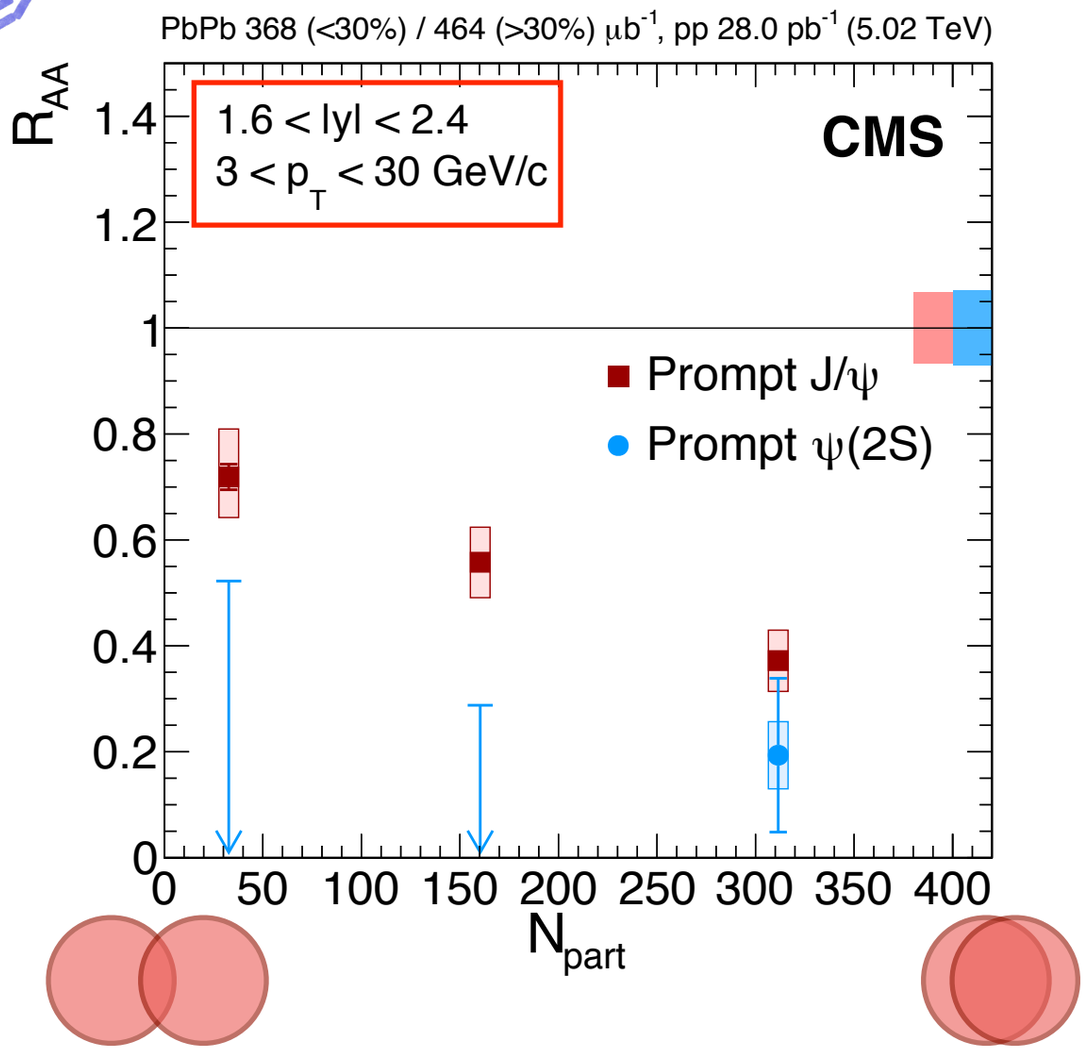
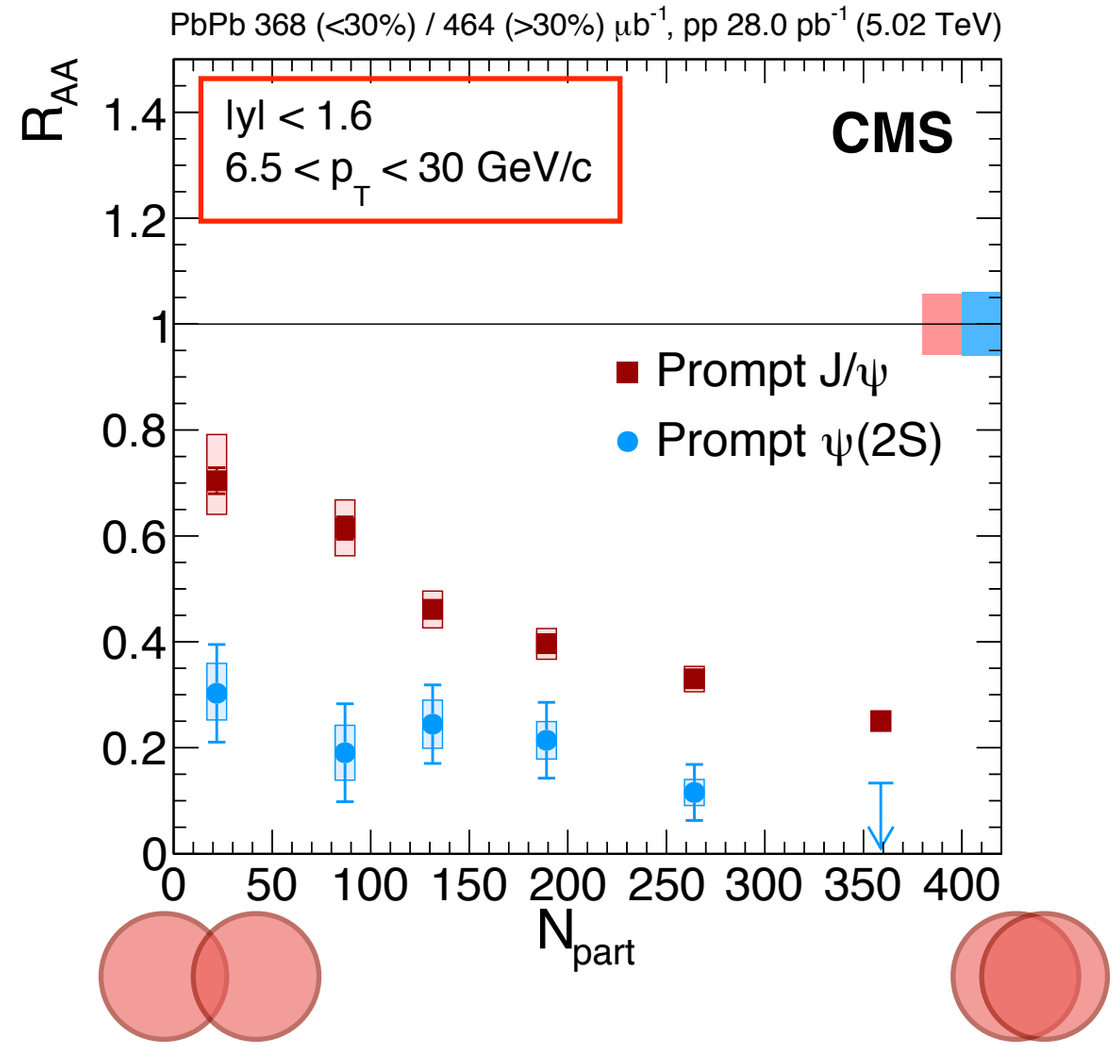
J/ψ and ψ(2S) in PbPb







Increasing suppression towards central events

Larger suppression for ψ(2S) than J/ψ

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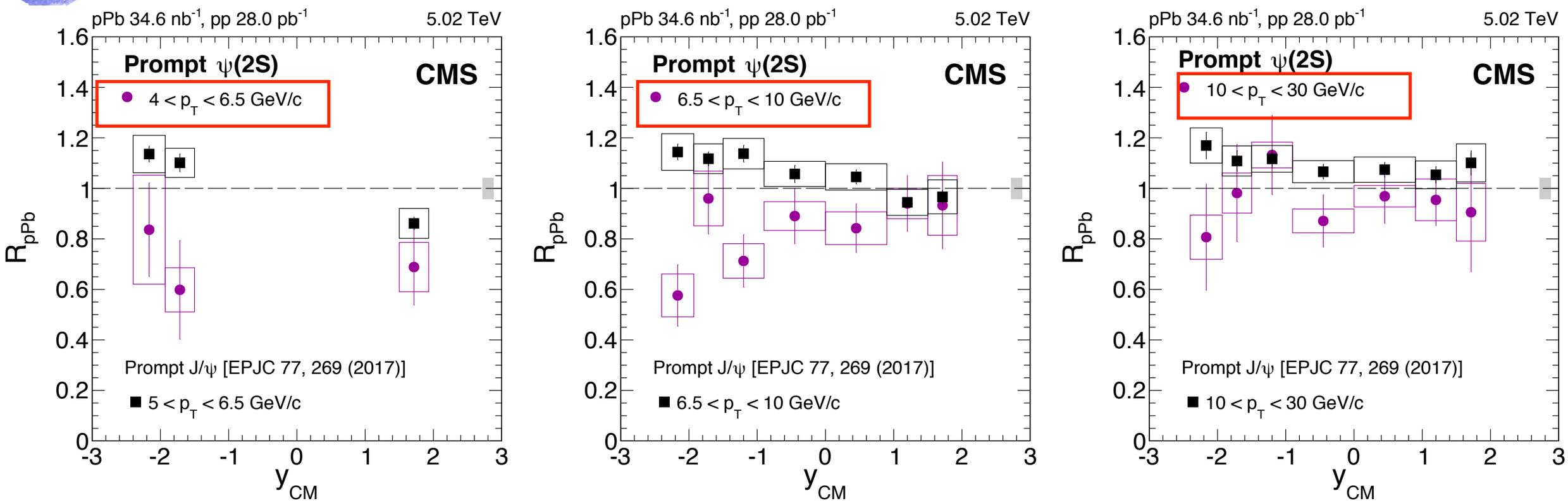
Charmonia in pPb



$R_{pPb}(2S) < R_{pPb}(1S)$ for all bins

$R_{pPb}(2S)<1 \rightarrow \psi(2S)$ is suppressed

Expect same modification of J/ψ and ψ(2S) from nPDF and E_{Loss}

Indication of final state effect: **interactions with comovers**?

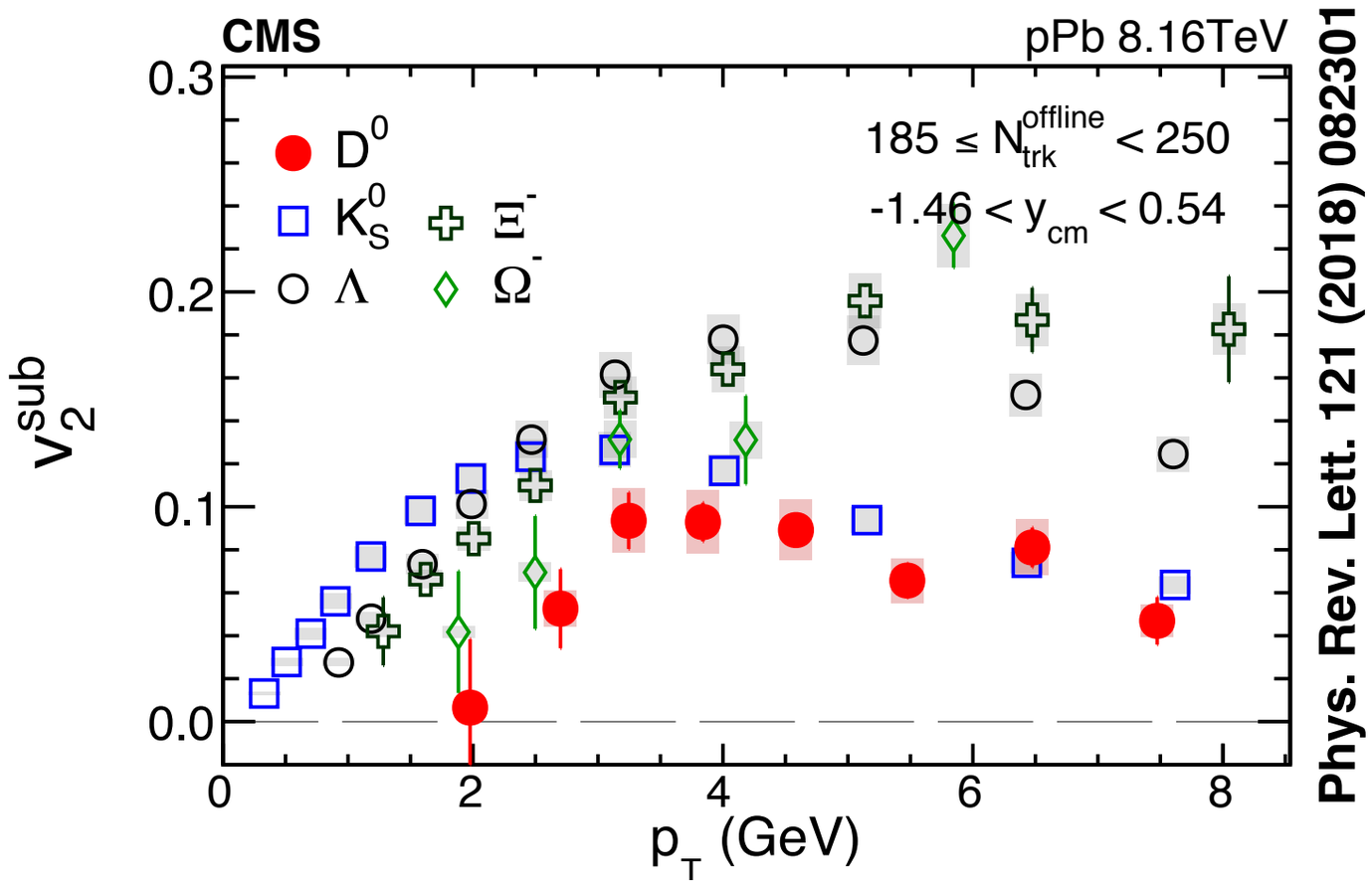
arXiv:1805.02248

Charm dynamics in pPb

- In PbPb: Collectivity reflects the QGP response to the initial collision geometry
- In pPb: Observation of collective behaviour

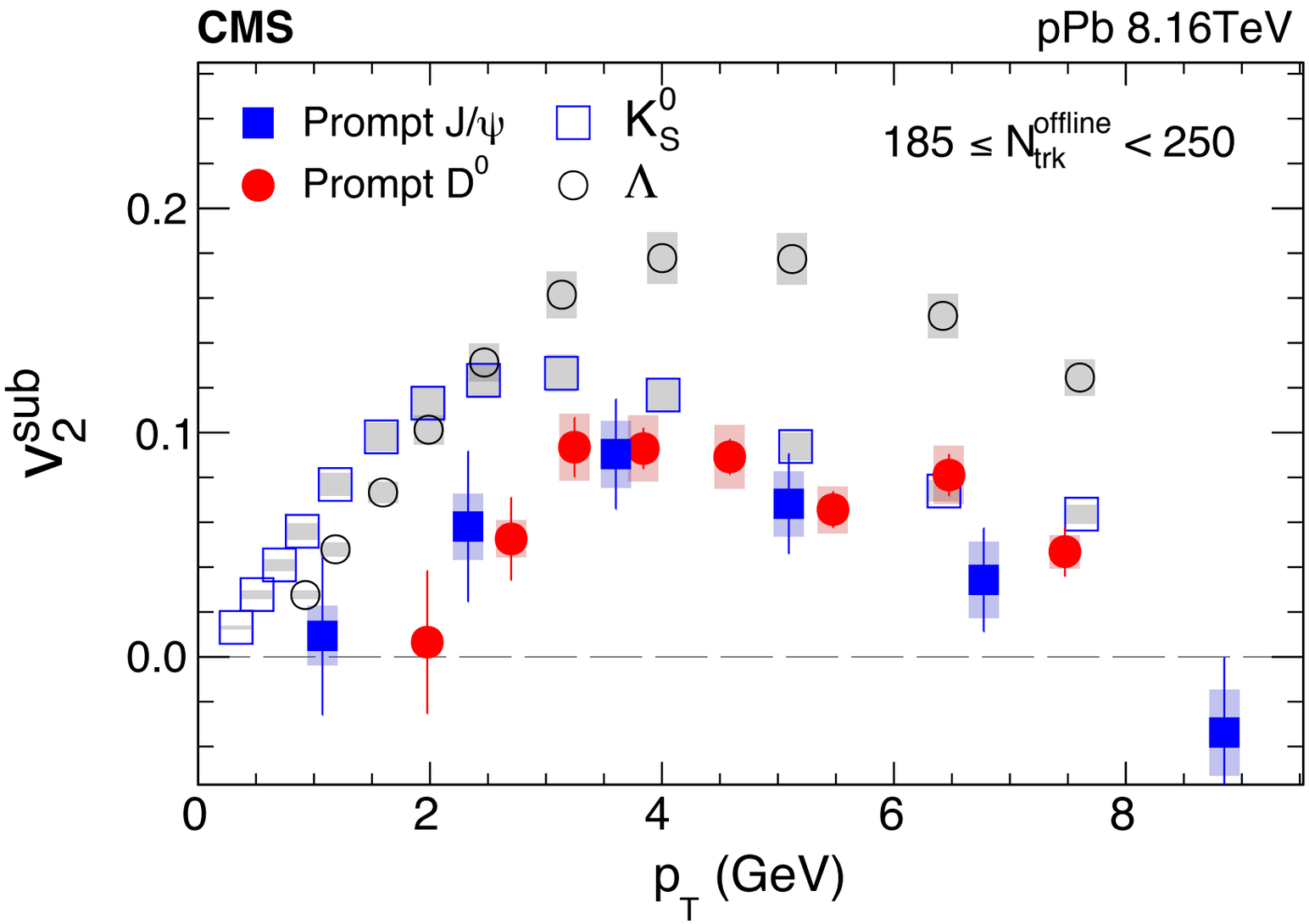
D_0 $v_2 > 0$ in pPb

D_0: charm quark + light quark flow from u or c quark?



J/ψ v_2 needed to complete the picture of charm dynamics

J/ψ v_2 in pPb



Clear observation of prompt J/ψ v_2 in pPb collisions

→ **Direct evidence of charm collectivity**

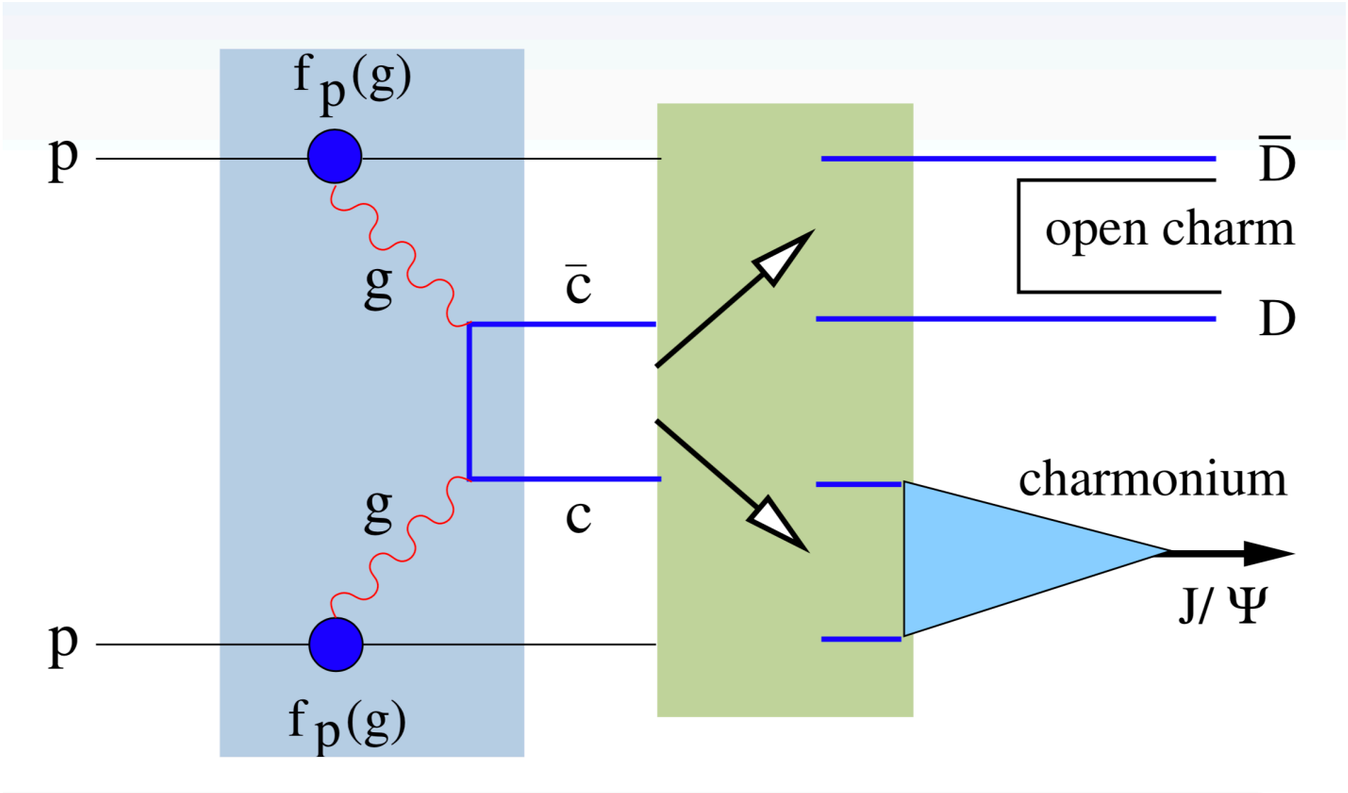
QGP in pPb collisions?

CMS PAS HIN-18-010

Charmonia production

Color Singlet Model?

Color Evaporation Model?



Non-Relativistic QCD?

Charmonia production

Color Singlet Model?

?

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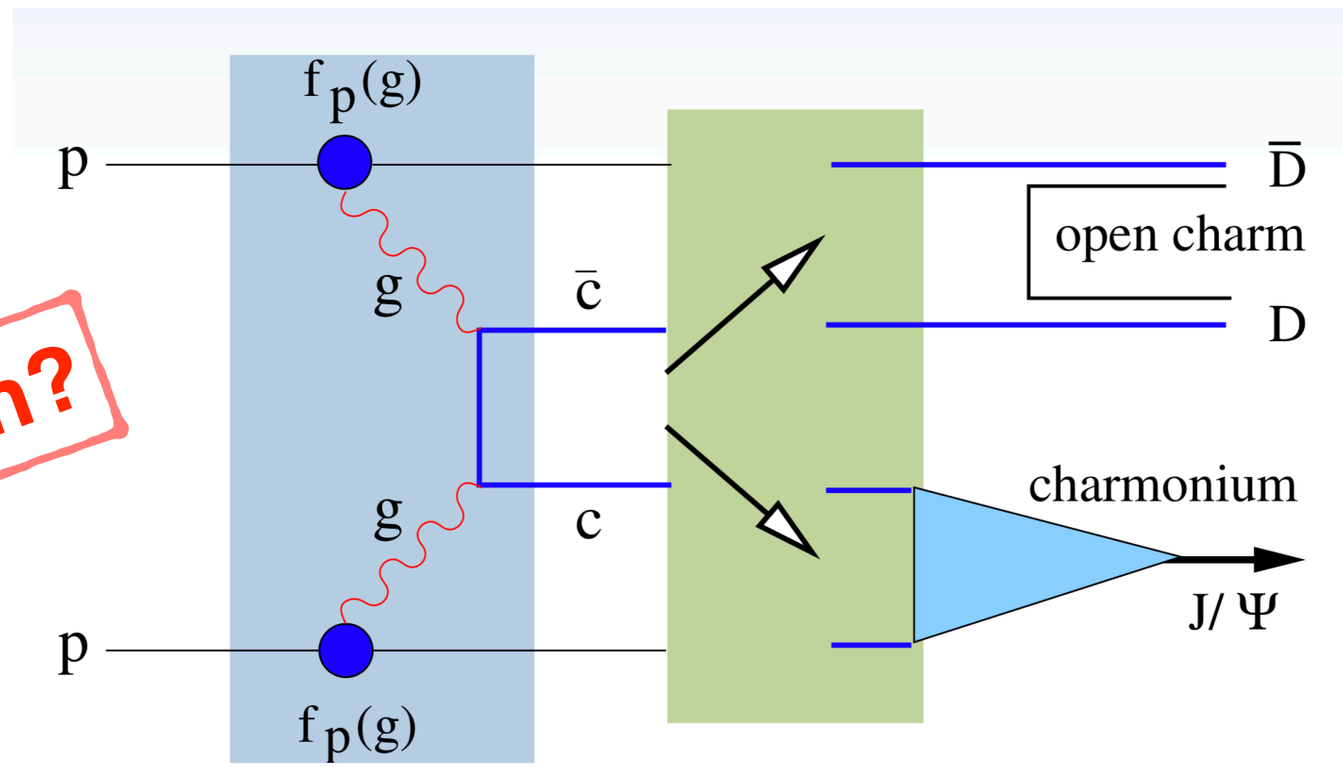


?

Isolation?

Singlet? Octet?

?

?

?

Polarisation?

Non-Relativistic QCD?

?

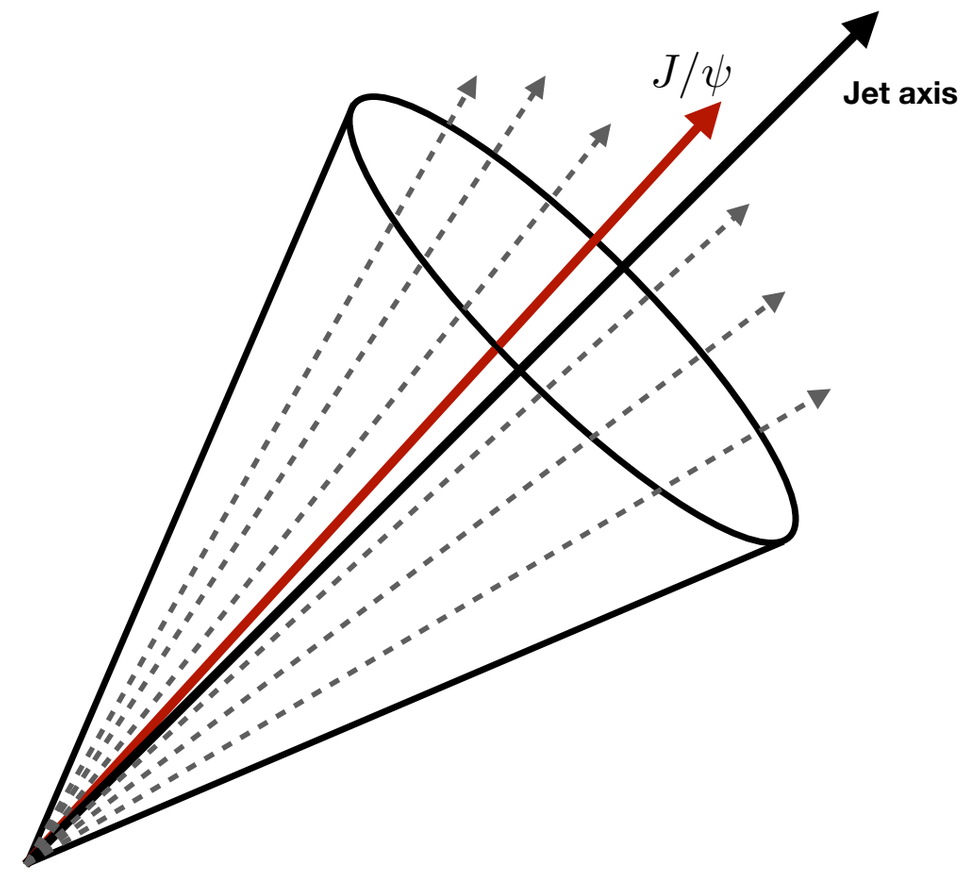
?

J/ψ in jets

Isolation? → **J/ψ in jets**

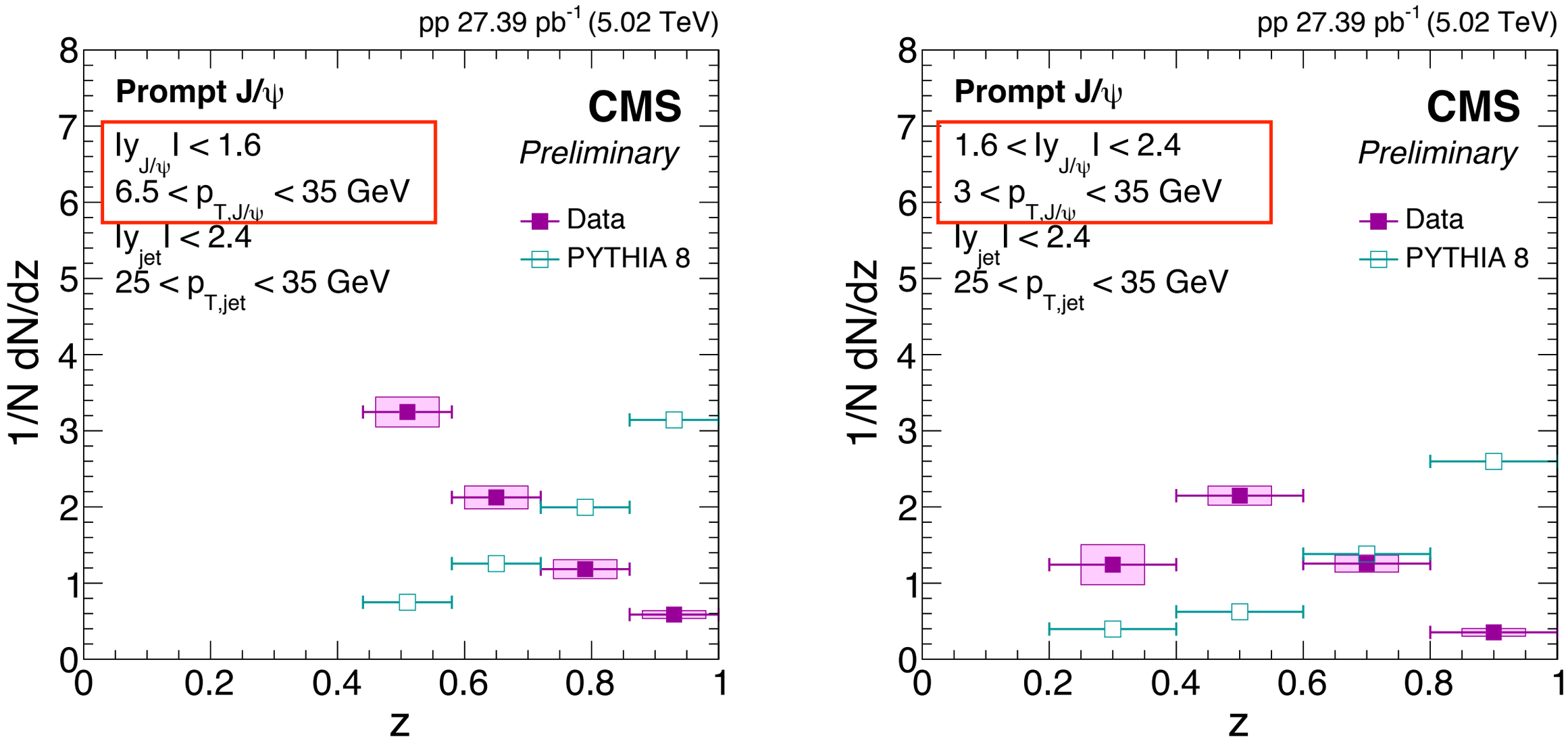
- Fragmentation function?

$$z = \frac{p_{T,J/\psi}}{p_{T,jet}}$$



- Fraction of J/ψ produced in jets?

J/ψ in jets in pp



Different behaviour in data and Pythia

J/ψ are less isolated in data

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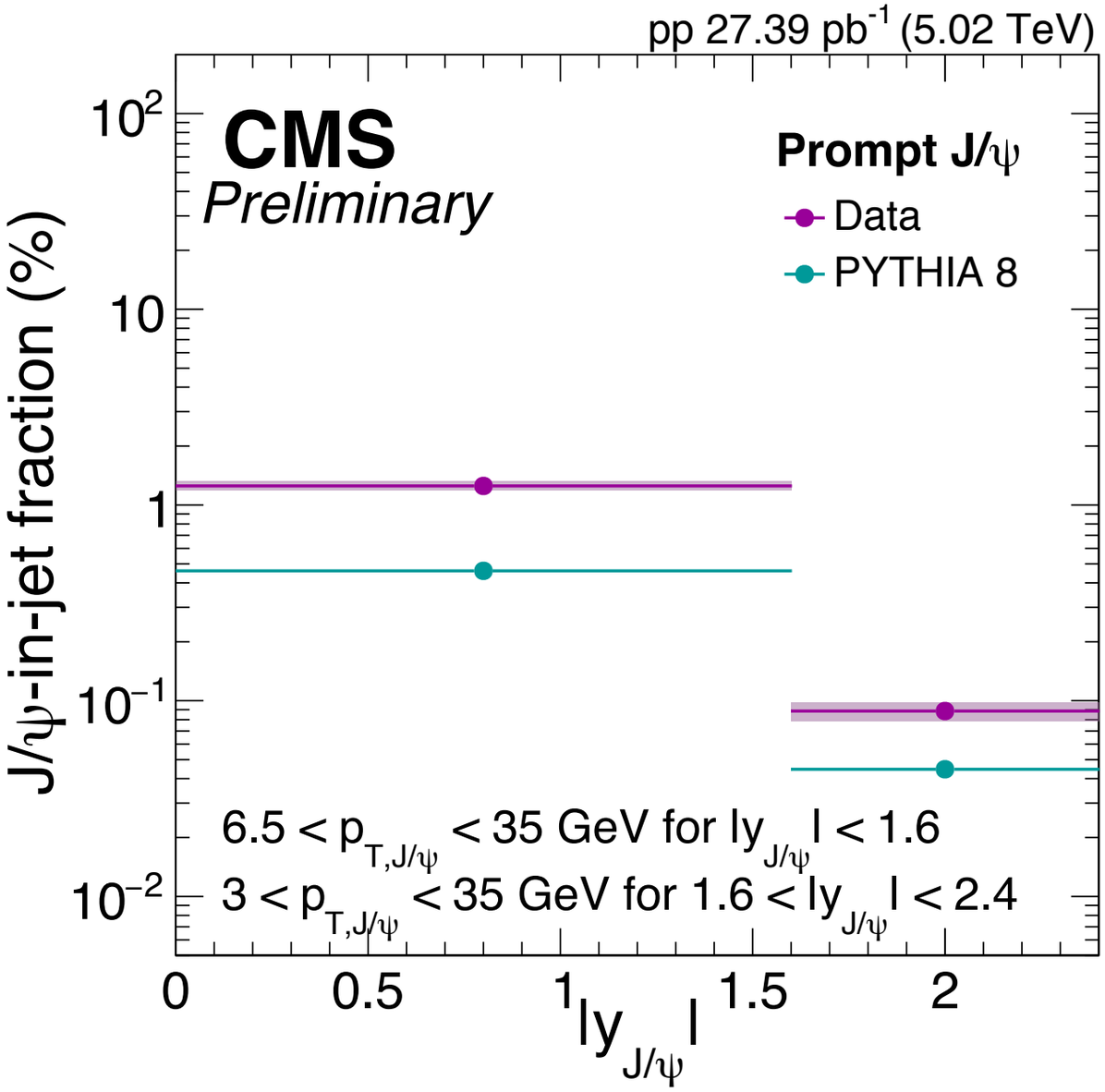
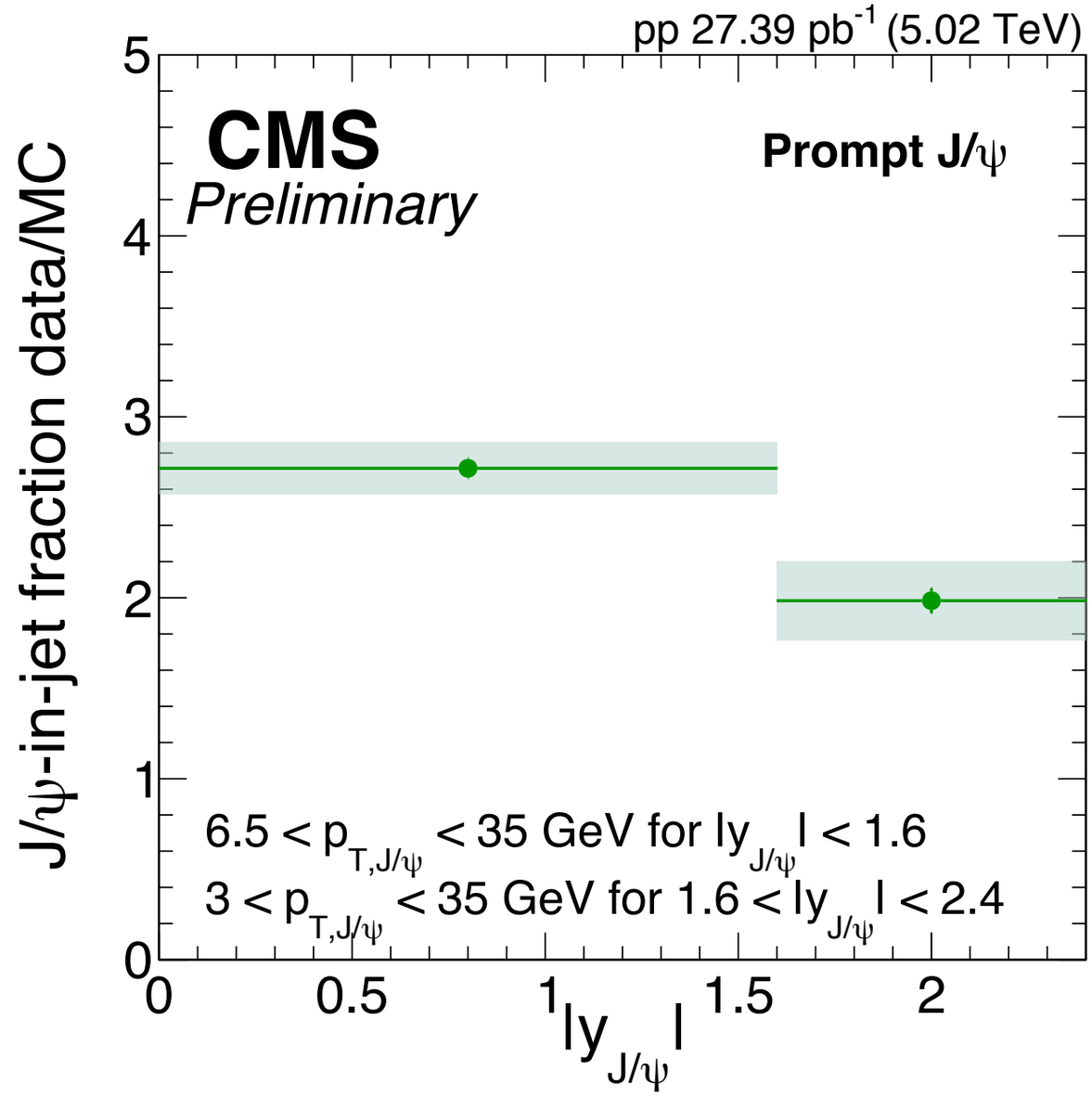
J/ψ-in-jet fraction





Under-predicted in Pythia: 2 times more J/ψ in jets in data than PYTHIA8

Less than 2% due to the kinematic range selected

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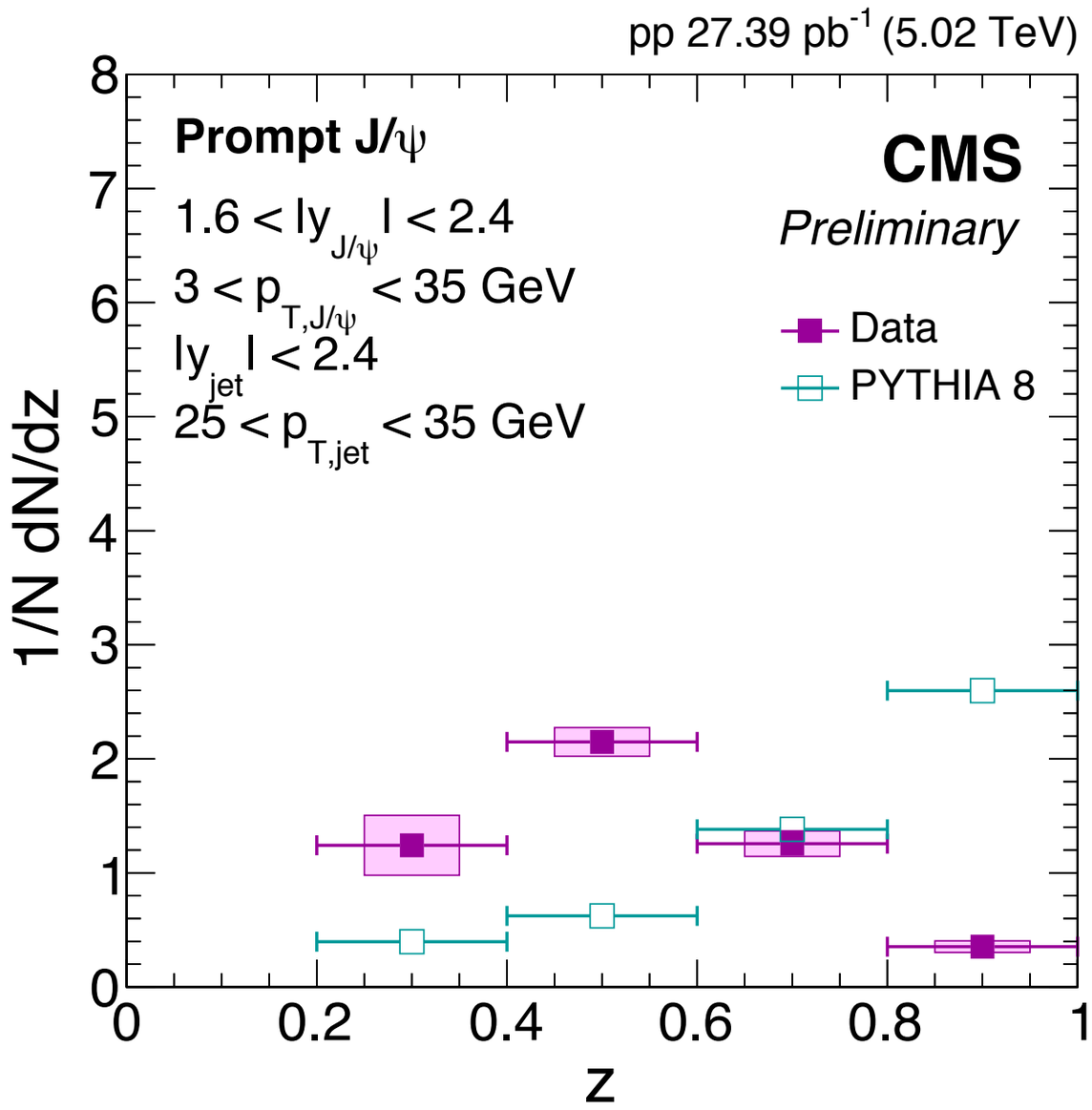
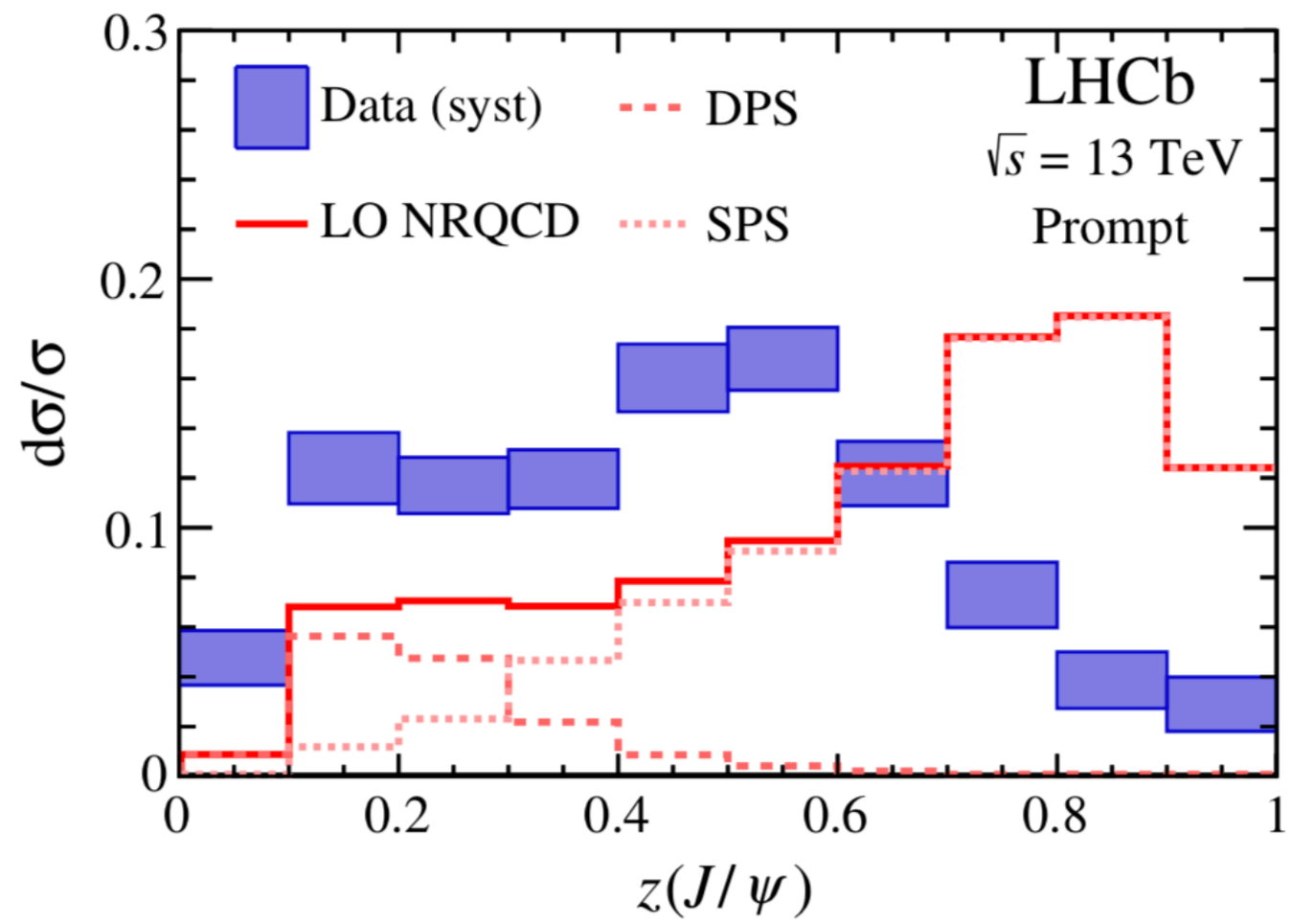
CMS vs LHCb

Similar results in CMS and LHCb in different kinematic regions





Phys. Rev. Lett. 118 (2017) 192001

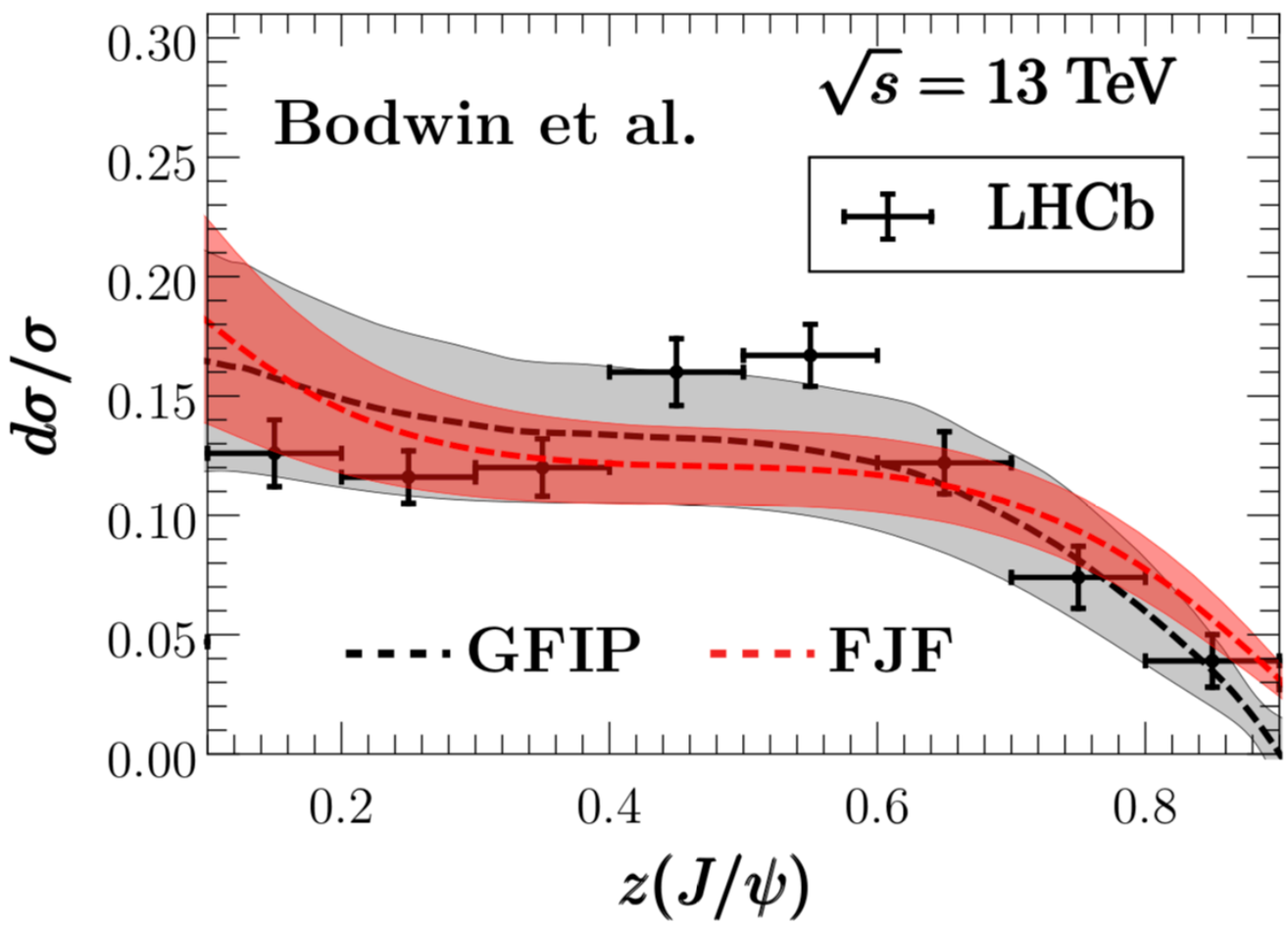
CMS PAS HIN-18-012

NRQCD on J/ψ in jets

Recent theoretical approach: J/ψ could be produced in parton showers

Hard gluon→ shower → gluon of virtuality $2m_c$→ **J/ψ**

Better agreement with LHCb results than Pythia



GFIP: Gluon Fragmentation Improved Pythia

FJF: Fragmentation Jet Functions

Phys. Rev. Lett. 119 (2017) 032002

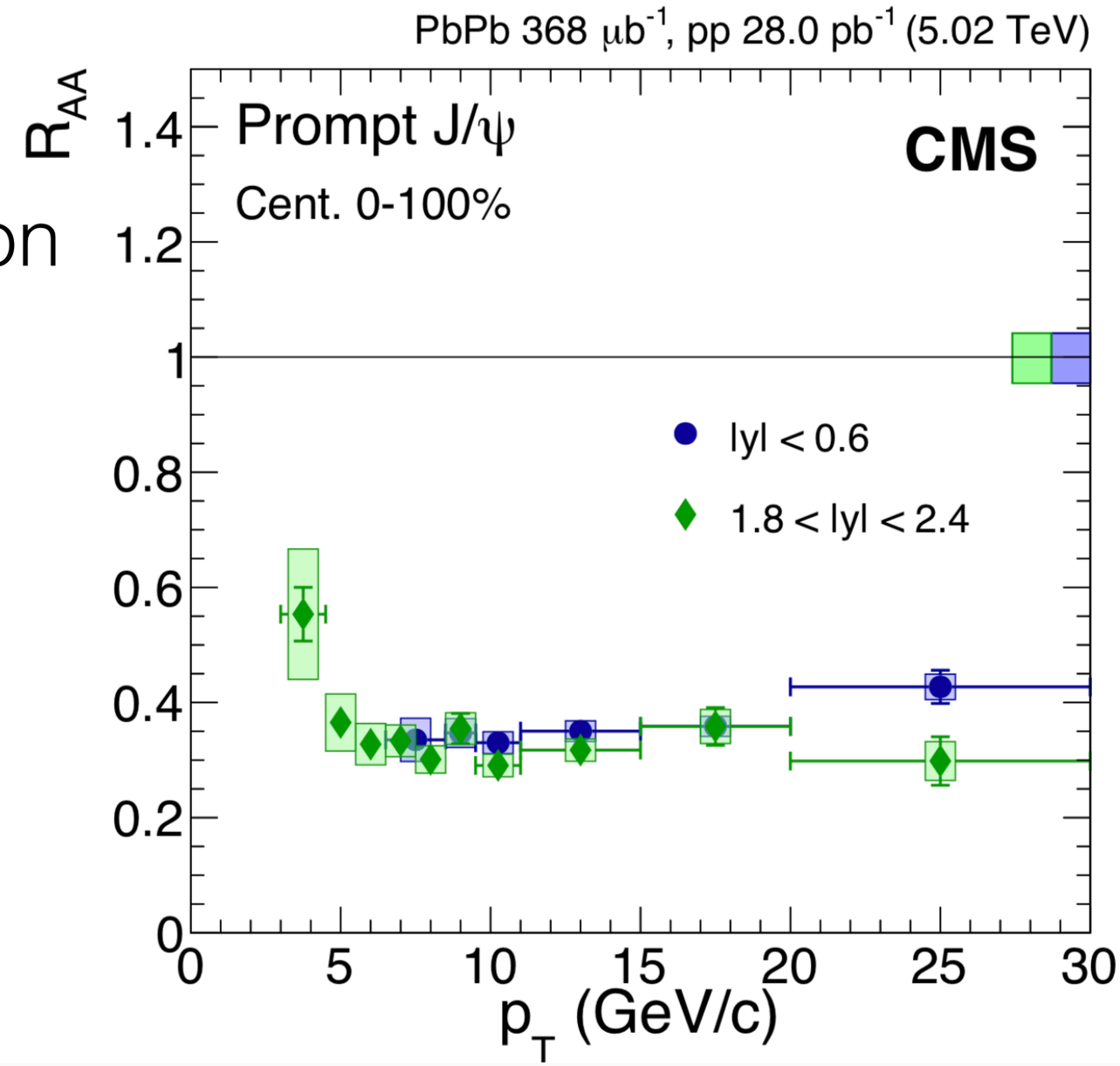
And back to PbPb

Might change the interpretation of J/ψ results in HI

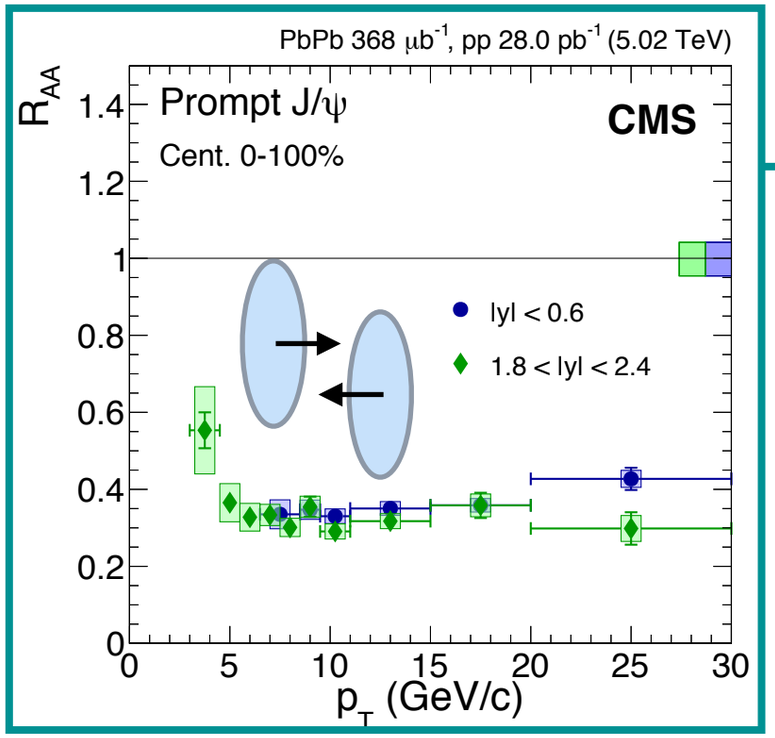
J/ψ suppression in PbPb:

- Role of jet quenching?

→ **J/ψ in jets in PbPb**

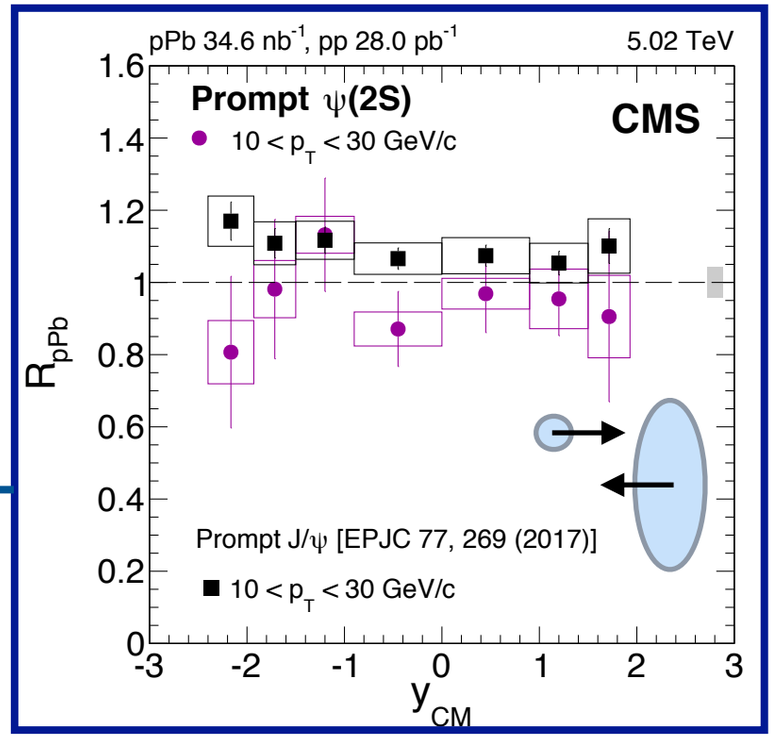


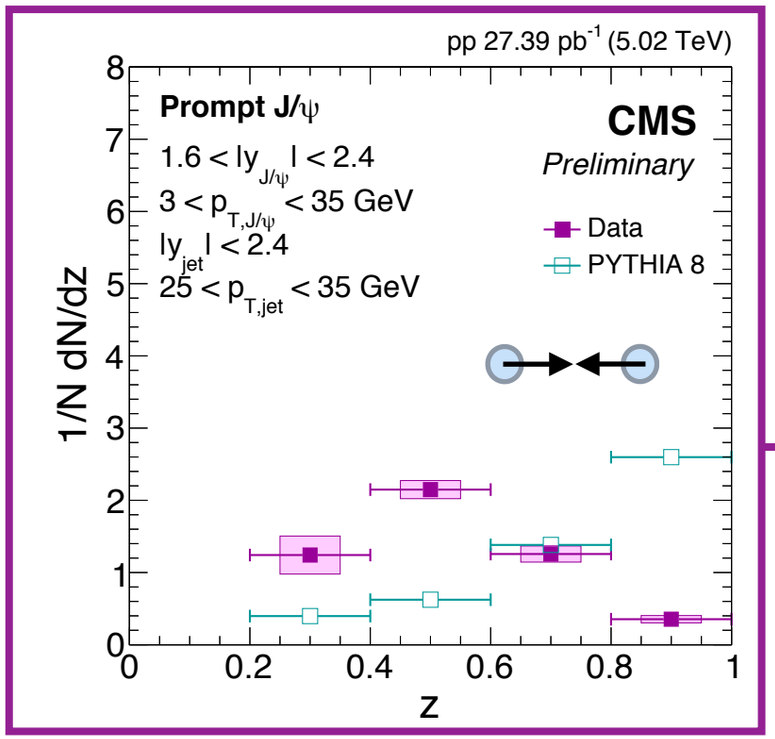
Summary



- **Regeneration**
- **E_{Loss}**

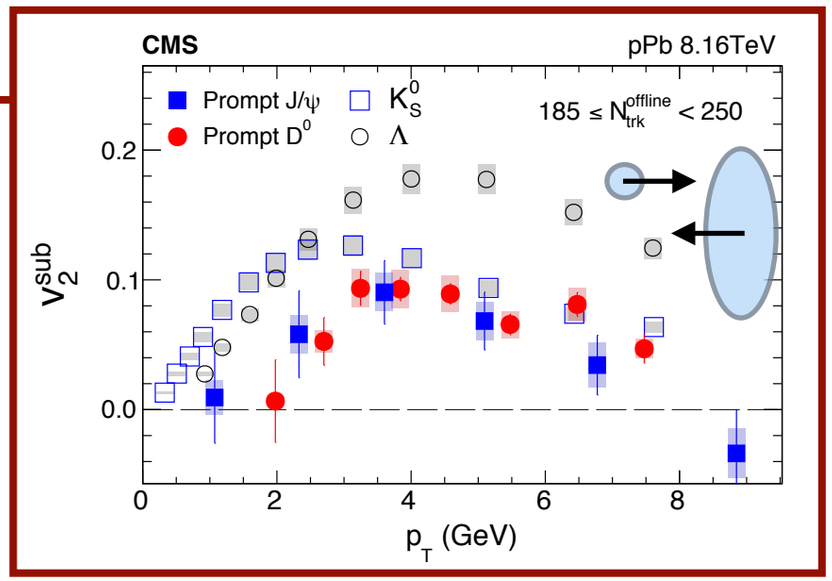
- **Interaction with comovers?**





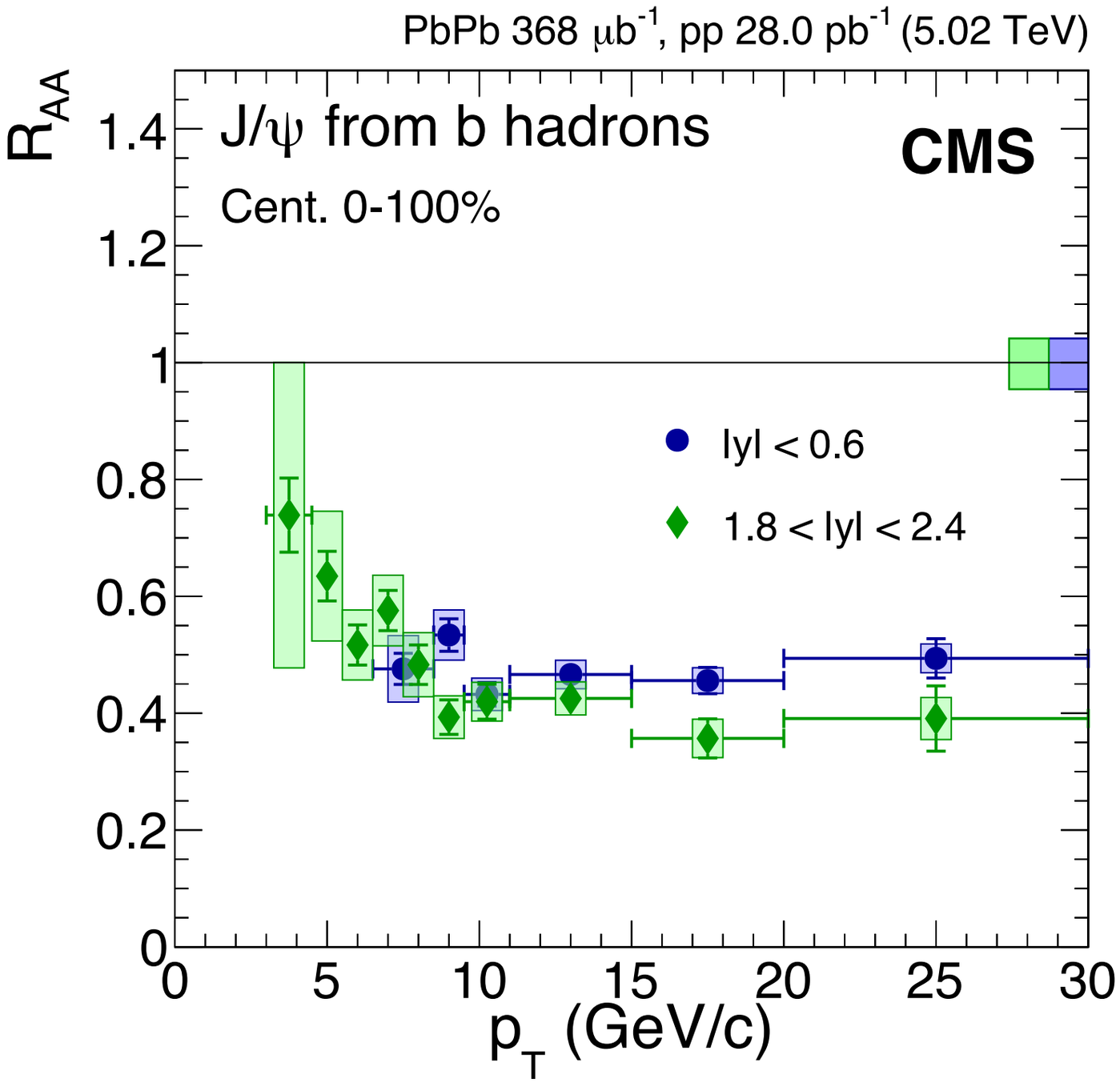
- **QGP in pPb?**

- **Production in parton showers?**

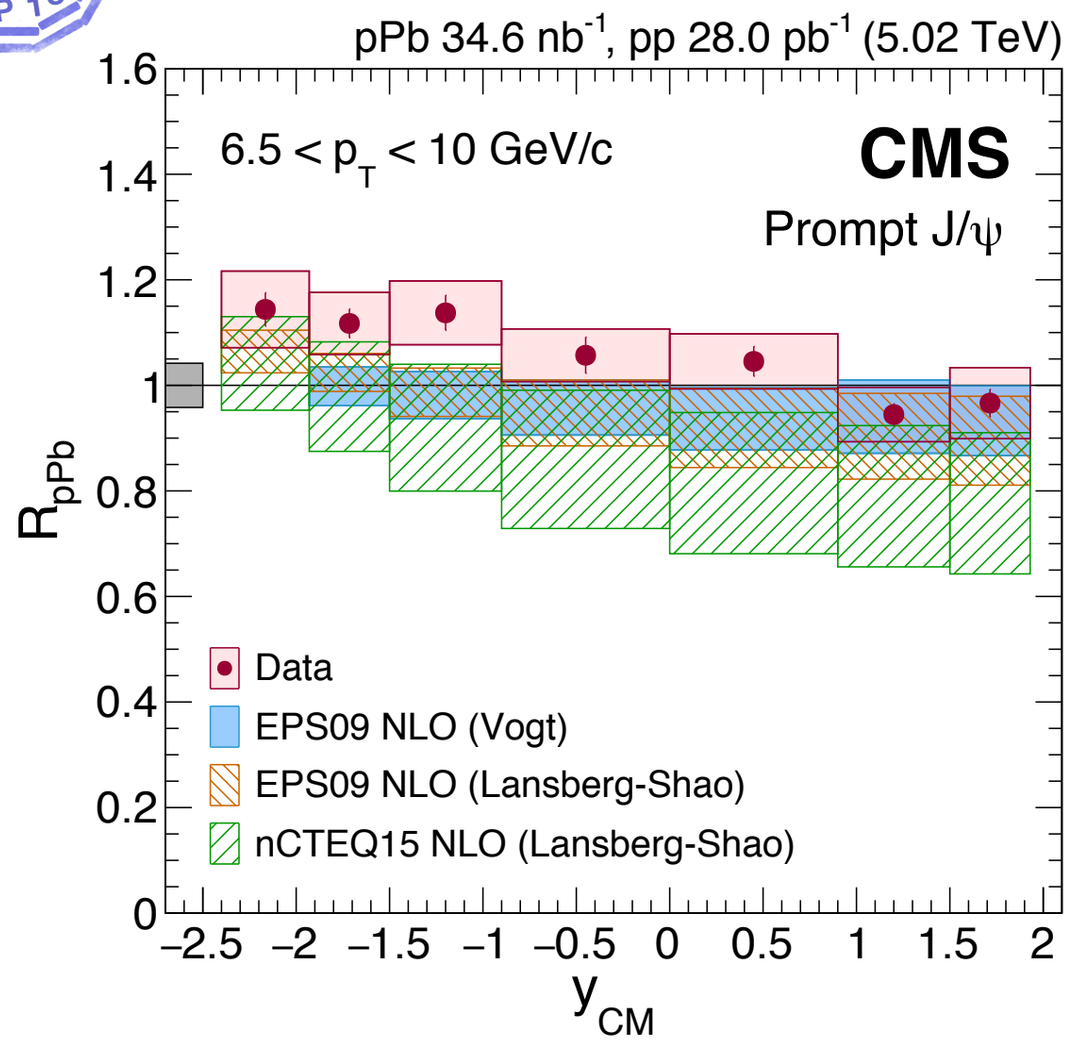


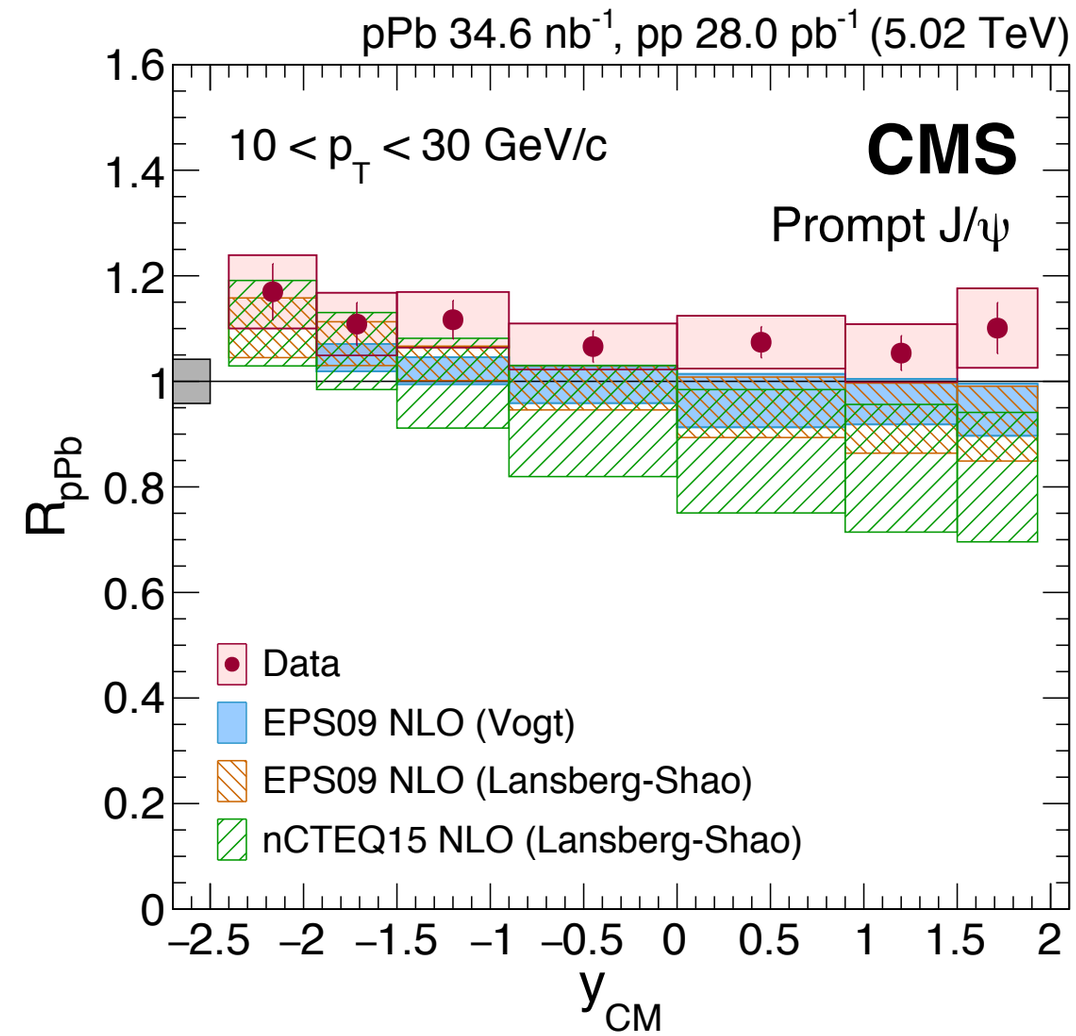
Backup

Backup


PbPb 368 μb-1, pp 28.0 pb-1 (5.02 TeV)
J/ψ from b hadrons
Cent. 0-100%
CMS
|y| < 0.6
1.8 < |y| < 2.4
RAA
pT (GeV/c)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
5
10
15
20
25
30

Backup





R_{pPb} decreasing with rapidity

Models predict lower R_{pPb}

R_{pPb}>1 at high p_T for all rapidity range

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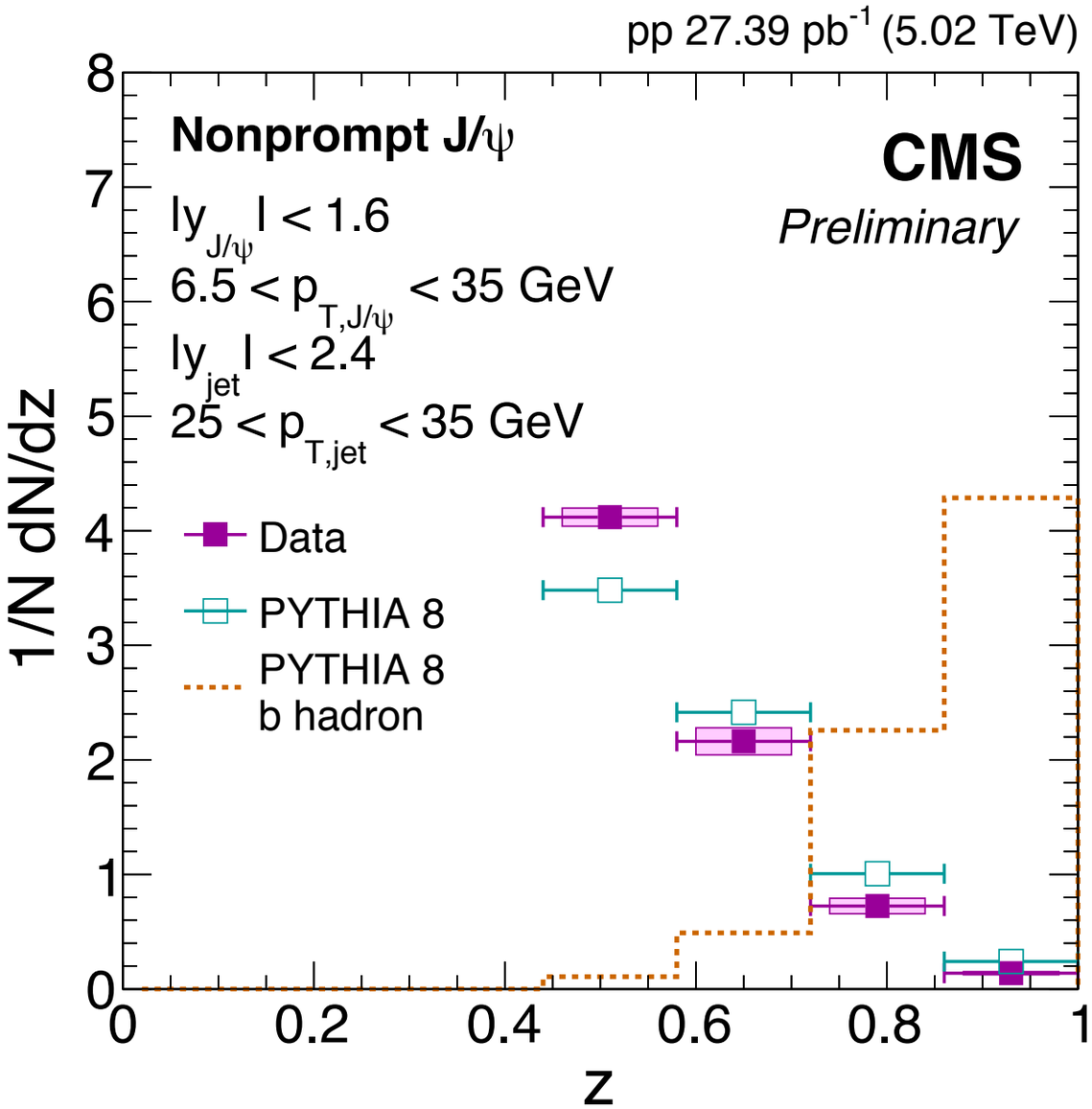
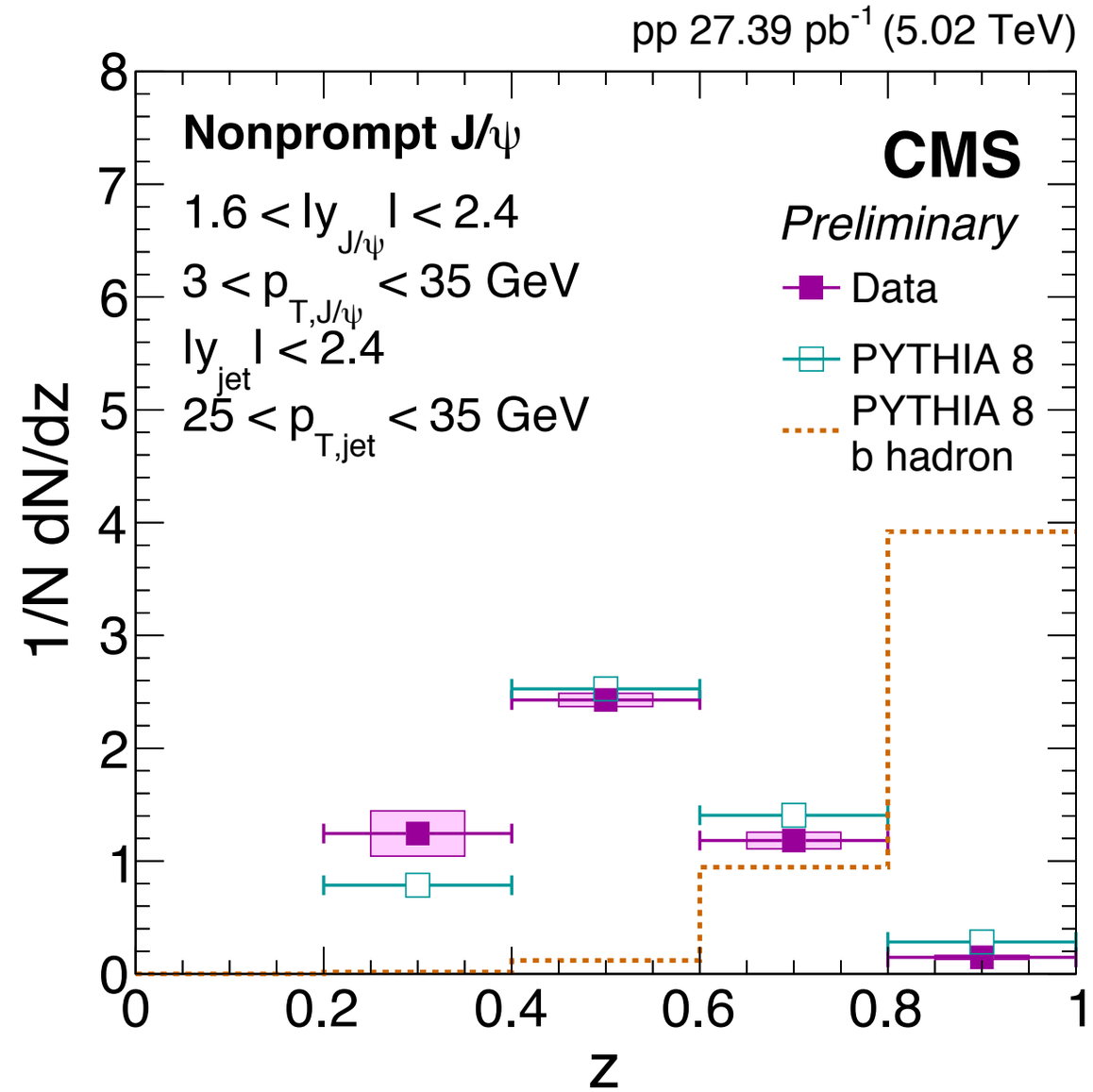
Backup

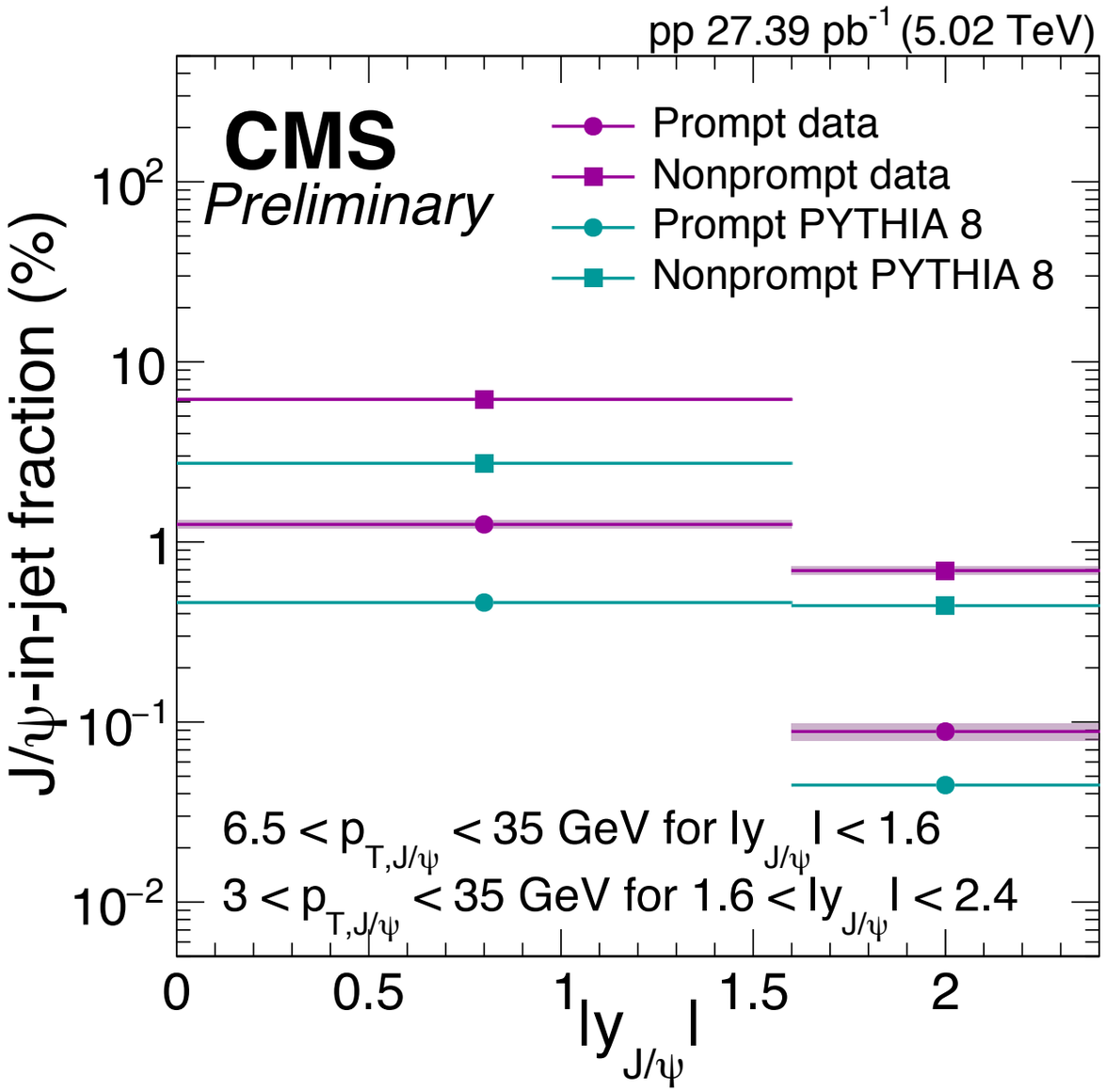


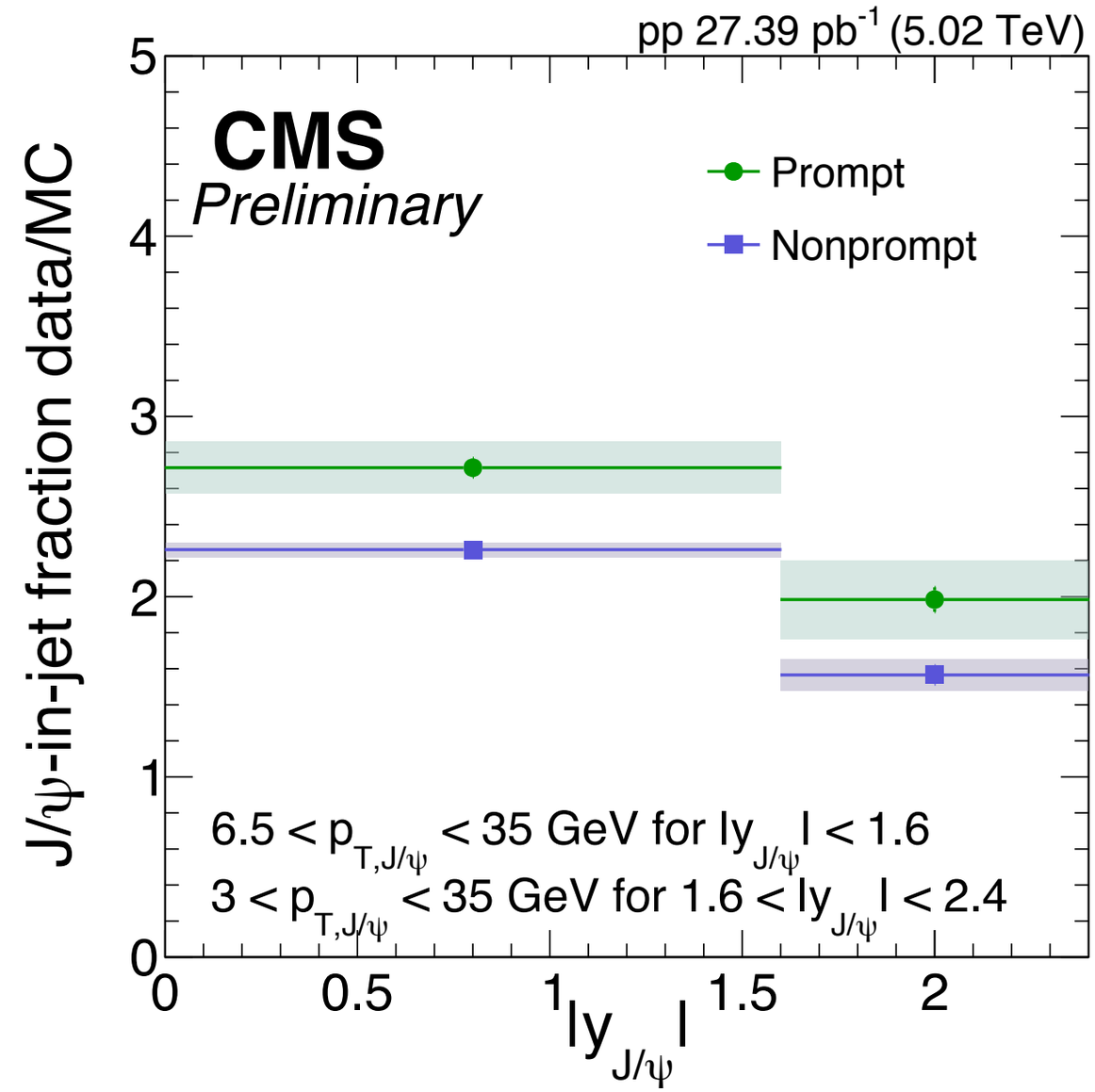


Similar behaviour in data and Pythia

Expected due to the decay kinematics

Backup





Less than 7% of J/ψ produced in jets

Under-predicted in Pythia