Multiplicity dependence of quarkonium production

Quarkonia as Tools 2021 workshop

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Context of multiplicity differential studies

« Multiplicity » refers to the number of charged particles in the final state

- Dependent on the energy density (rising with collision energy and collision system size)
- Dominated by soft processes
- Characterizes the underlying event (UE) accompanying hard processes (e.g. quarkonia production)
- High multiplicities traditionally refers to HI collisions but also concerns smaller systems at LHC energies

Study of multiplicity dependence of quarkonium production

→ Interplay between hard and soft components of hadronic collisions

→ Role of multi-parton interactions (MPIs are necessary to describe both hard and soft components of high energy pp collisions)

Questions for quarkonia vs. multiplicity measurements

- Behavior wrt. collision energy and system size (pp/pA/AA)?

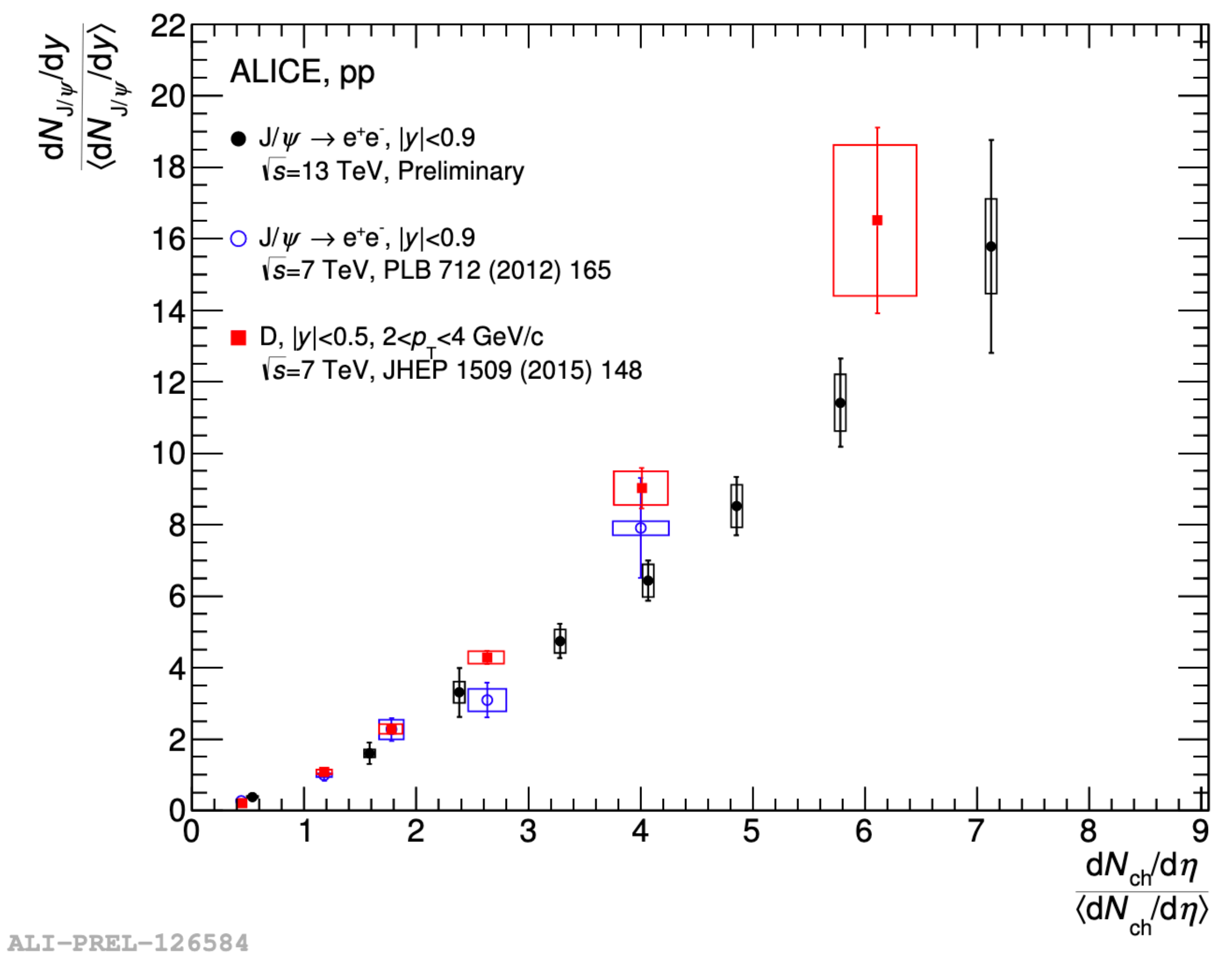
- Behavior when measuring multiplicity and quarkonia in different rapidity regions (rapidity gap or not, mid/forward)?

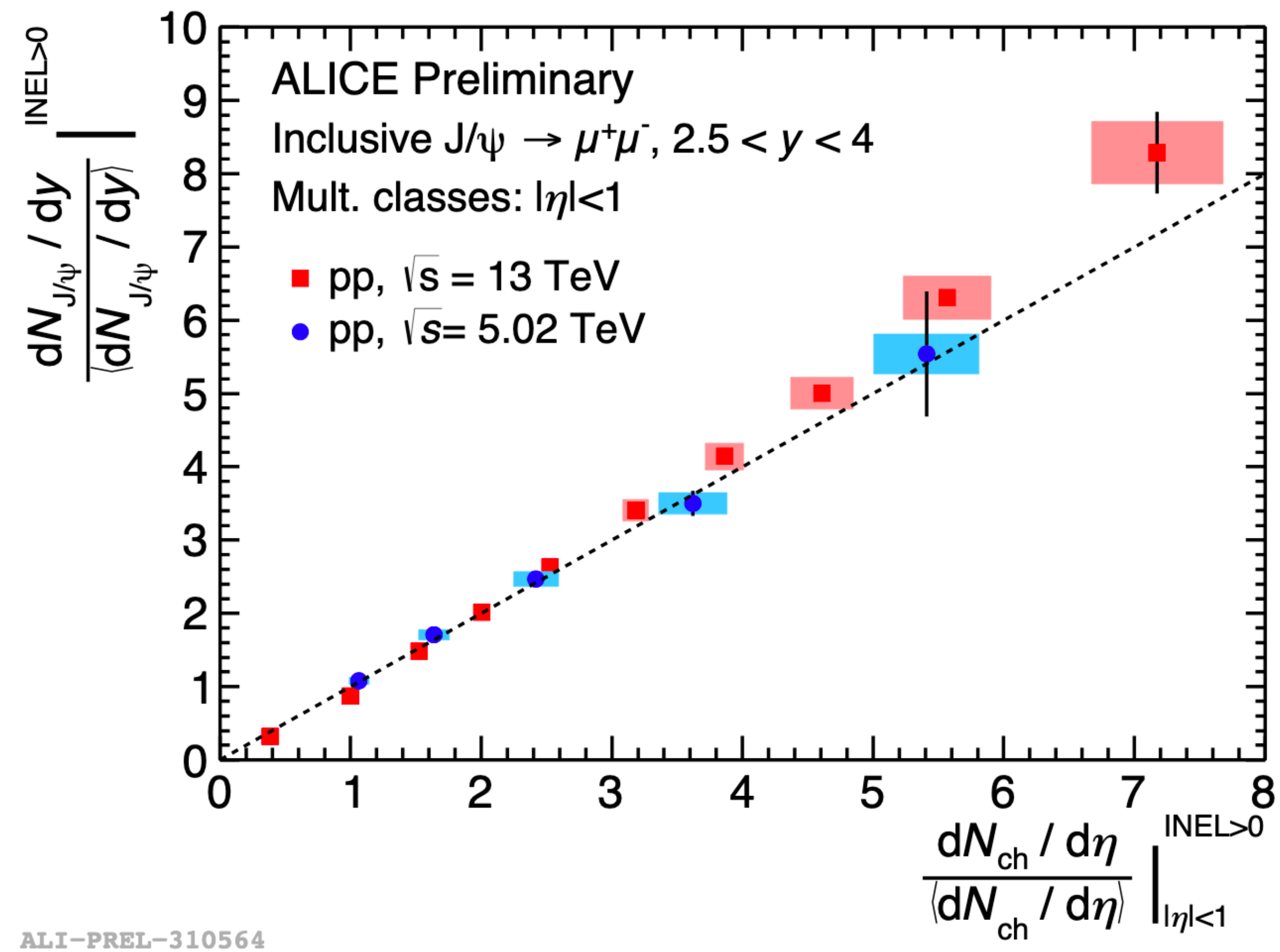
- Behavior wrt. probe's nature and hardness of production process (charm/beauty, open/closed, vs. p_T)?

Potential dissociation of quarkonia in the final state due to high multiplicity environment?

→Comparison of excited states wrt. ground state

Influence of collision energy (pp collisions)





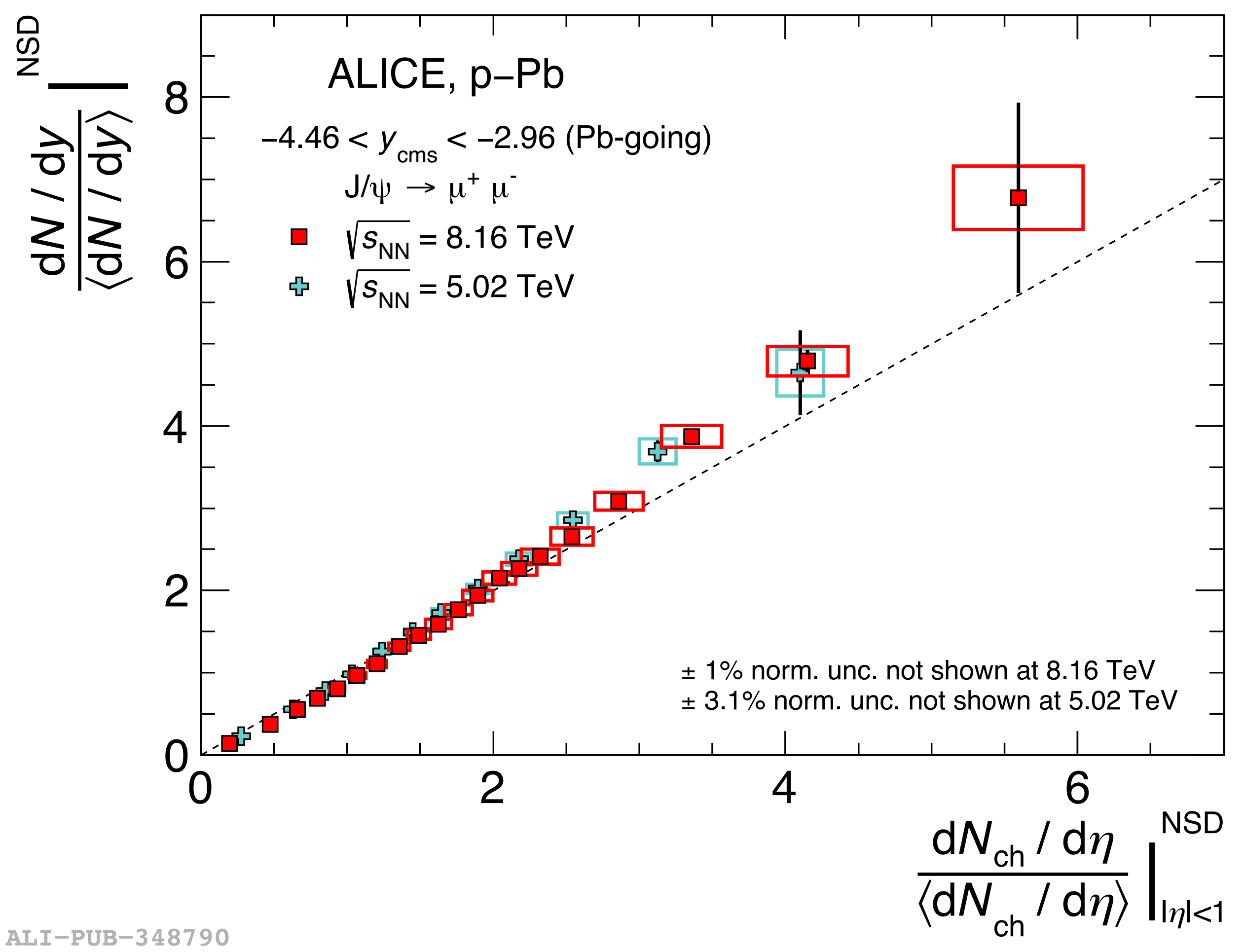
- Results compatible for J/ψ at 7 and 13TeV (without rapidity gap: J/ψ and multiplicity a mid-rapidity)
- Results compatible for J/ψ at 5.02 and 13TeV (with rapidity gap: J/ψ at forward rapidity and multiplicity at mid-rapidity)

→ No energy dependence observed for J/ψ in pp collisions

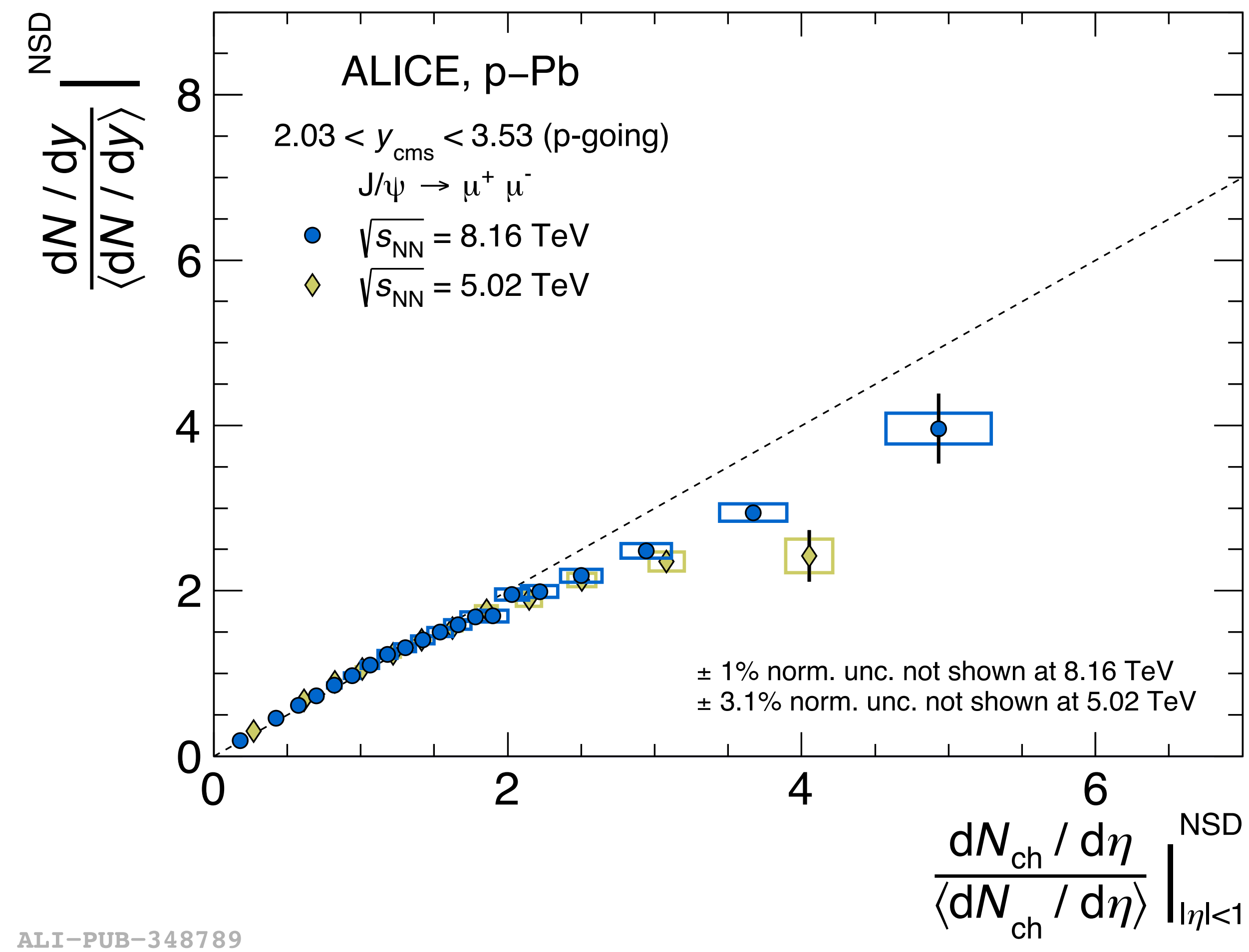
Influence of collision energy and system size (p-Pb)

JHEP09(2020)162

Backward rapidity (Pb-going)



Forward rapidity (p-going)

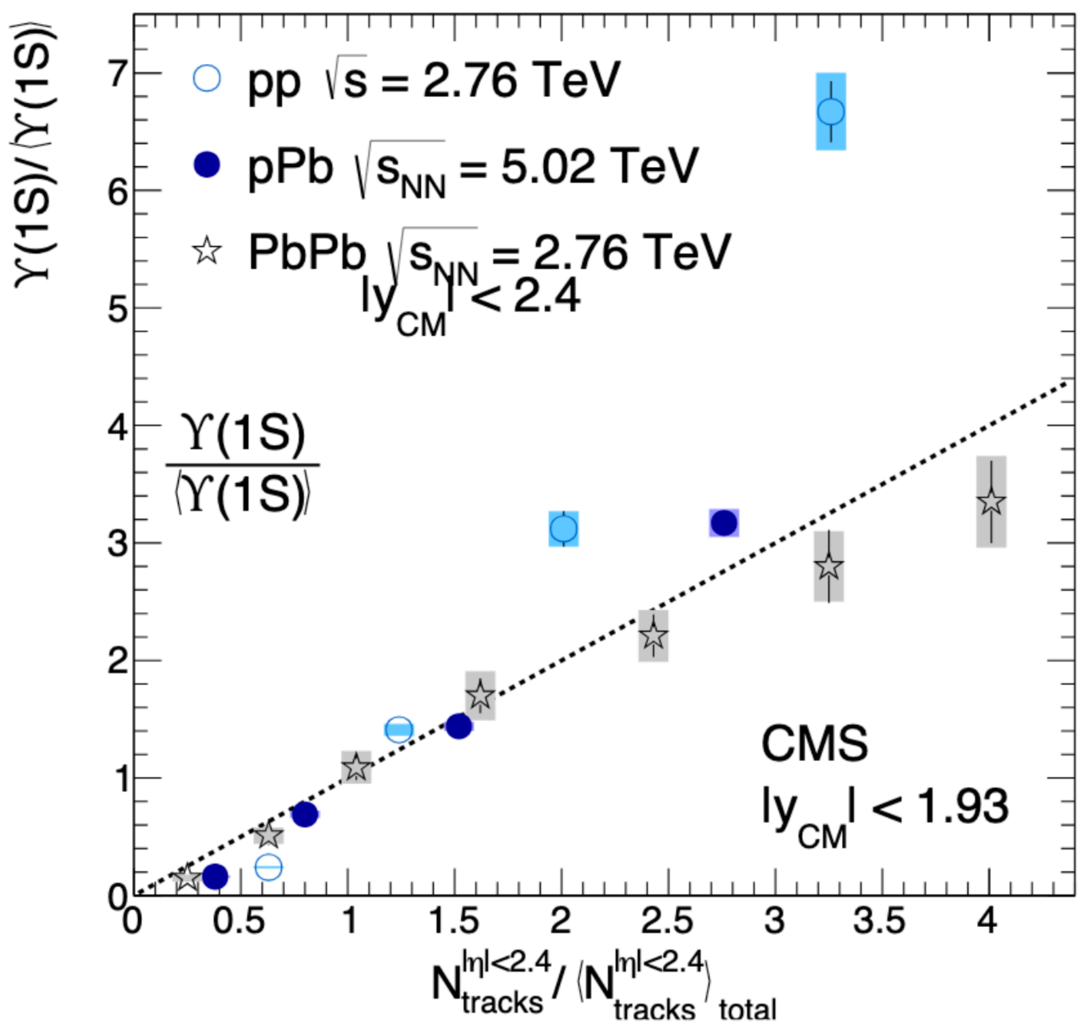


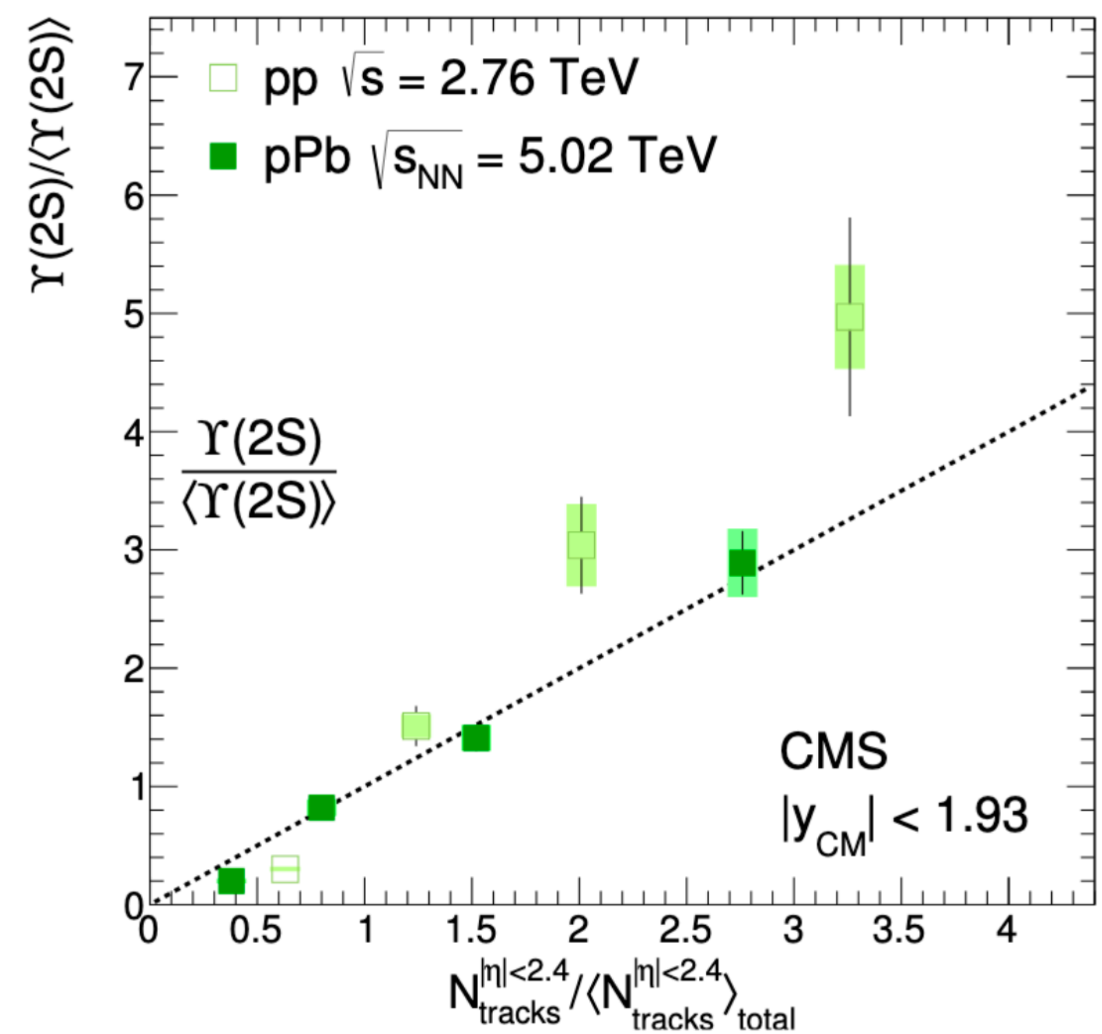
- Results compatible for J/ψ at 5.02 and 8.16 TeV → no significant energy dependence observed
- Backward rapidity: consistent with linear increase (consistent with pp results)
- Forward rapidity: suppression increases with multiplicity (consistent with Cold Nuclear Matter effect scenario i.e. modification/suppression of J/ψ)

→ No energy dependence for J/ψ in p-Pb collisions, observation of the influence of the initial state (p-Pb at backward rapidity ≠ pp)

Influence of collision system size (bottomonia)

Υ(1S) JHEP04(2014)103 Υ(2S)





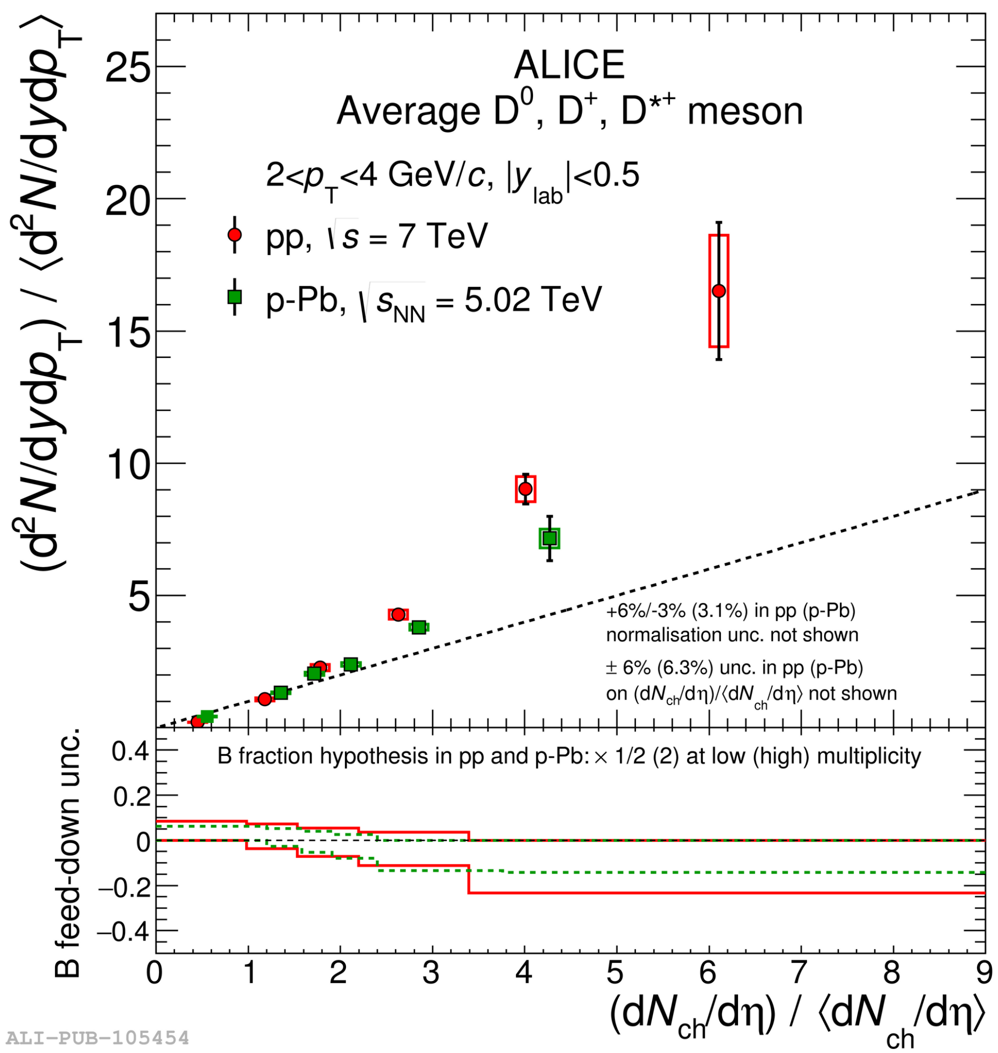
- Significantly higher increase of Υ(1S) production in pp than in p-Pb and Pb-Pb without rapidity gap (bottomonia and multiplicity measured at mid-rapidity)
- Weaker increase for Υ(2S) (larger uncertainties)

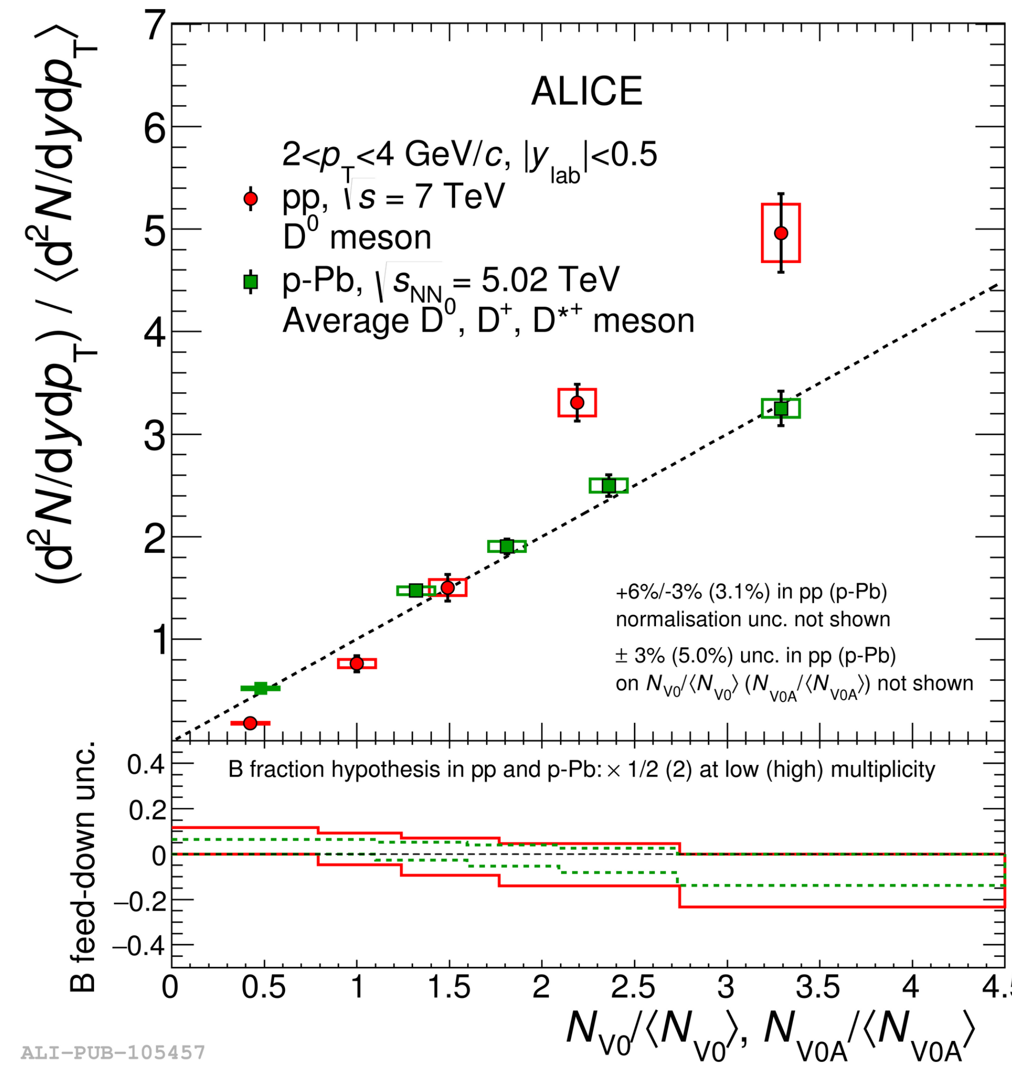
Influence of collision system size and rapidity gap

Without rapidity gap

JHEP08(2016)078

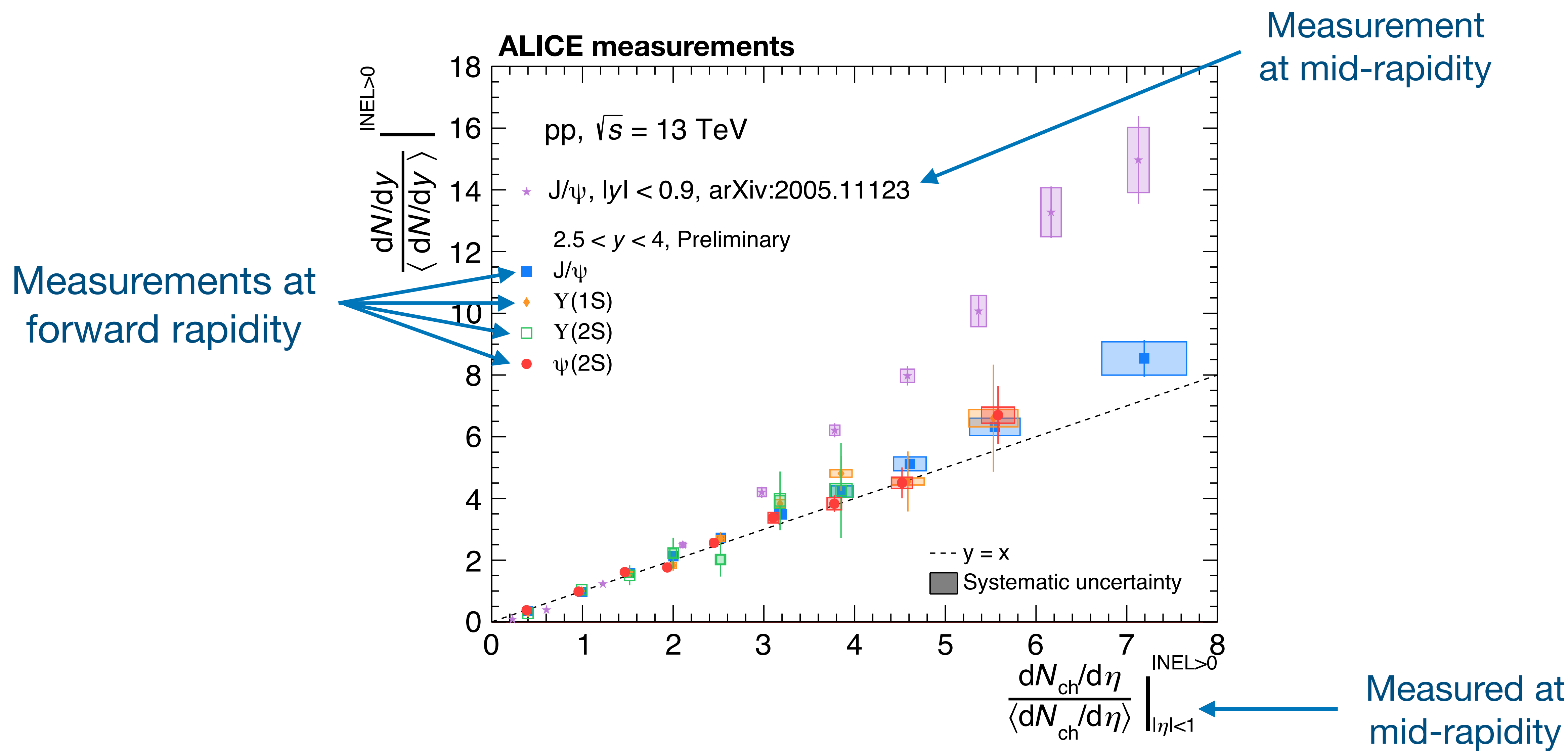
With rapidity gap





- Stronger increase of D meson production with multiplicity in pp than p-Pb in both cases
- Significant reduction of D meson production with rapidity gap (right) for pp and p-Pb collisions

Rapidity dependence (pp collisions at 13TeV)

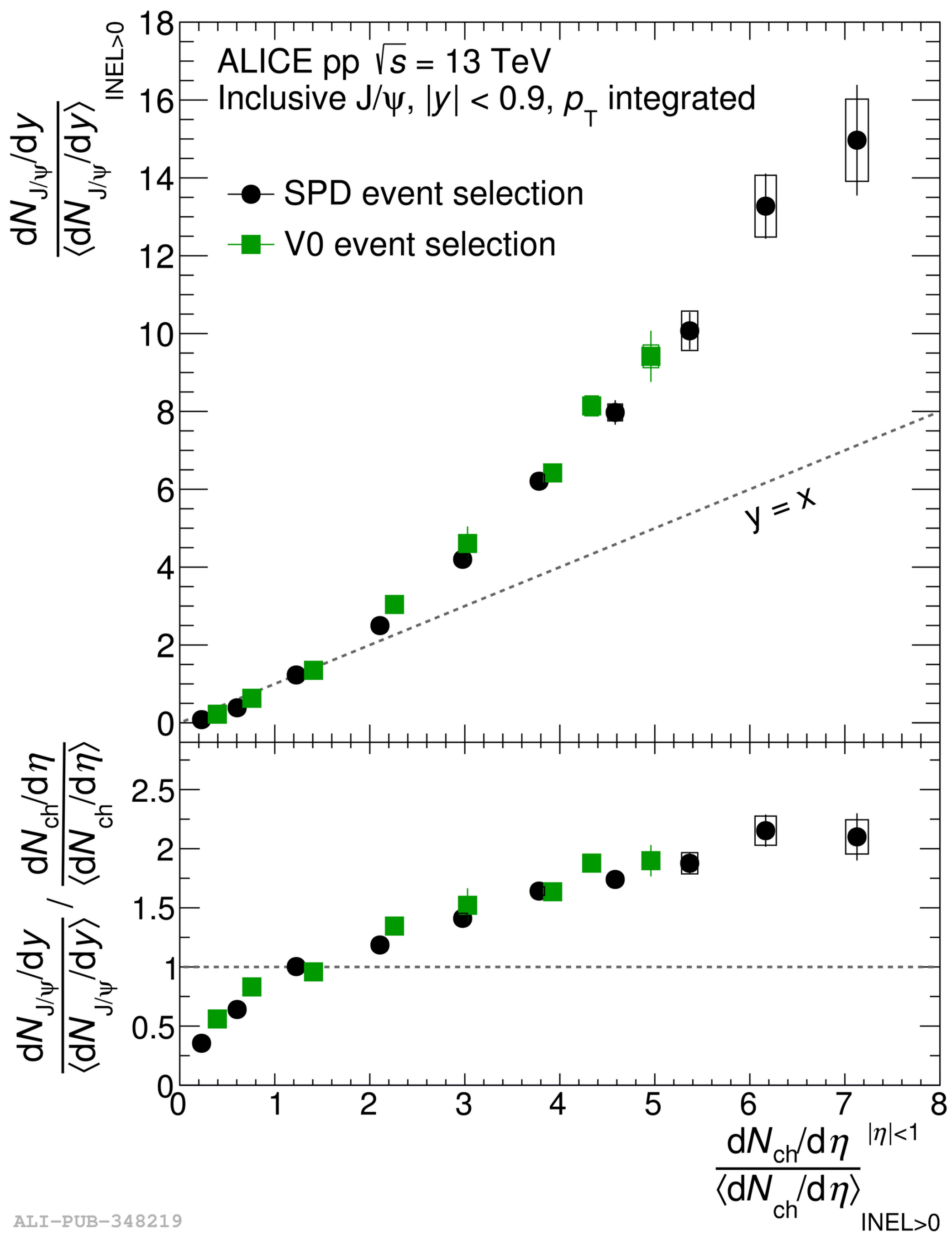


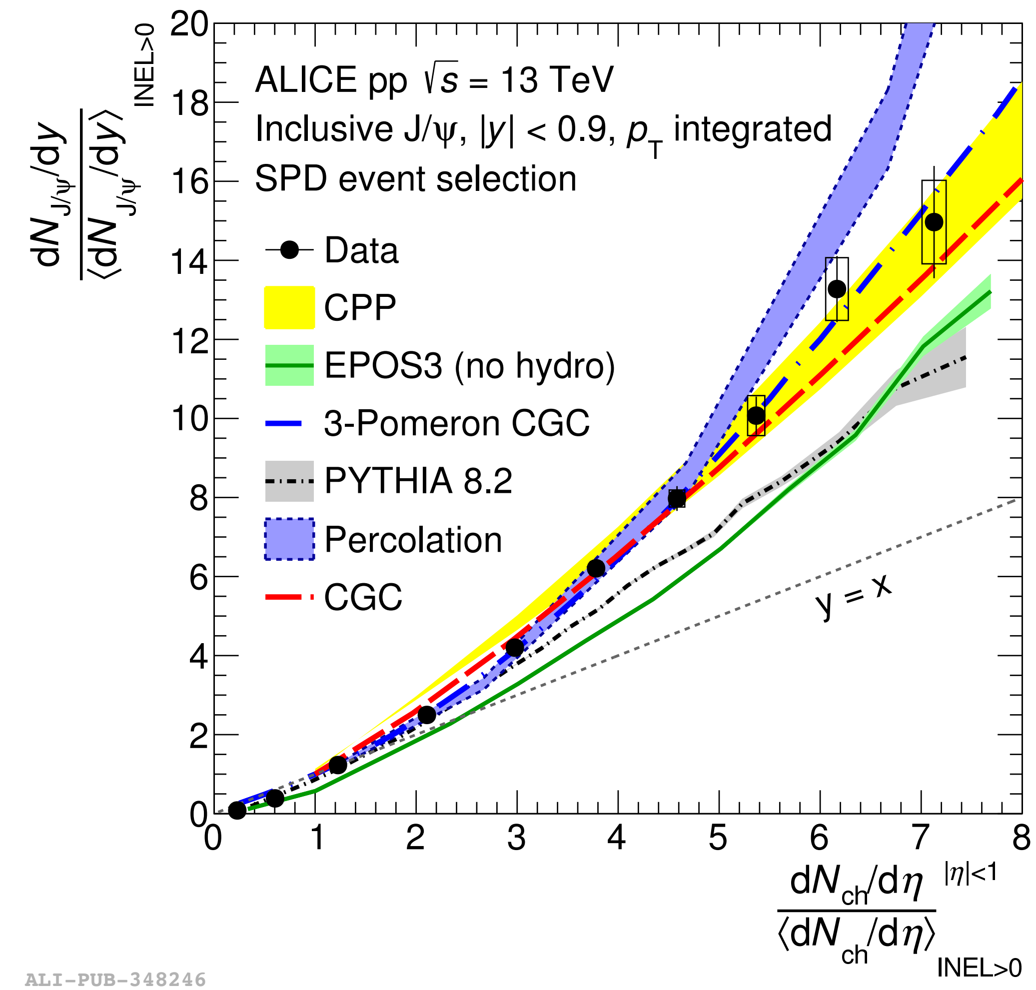
- All measurements at forward rapidity (with rapidity-gap) compatible with linear increase with multiplicity

- J/ψ at mid-rapidity (without rapidity-gap) shows stronger than linear increase with multiplicity

Rapidity dependence of J/ψ vs multiplicity

PLB810(2020)135758



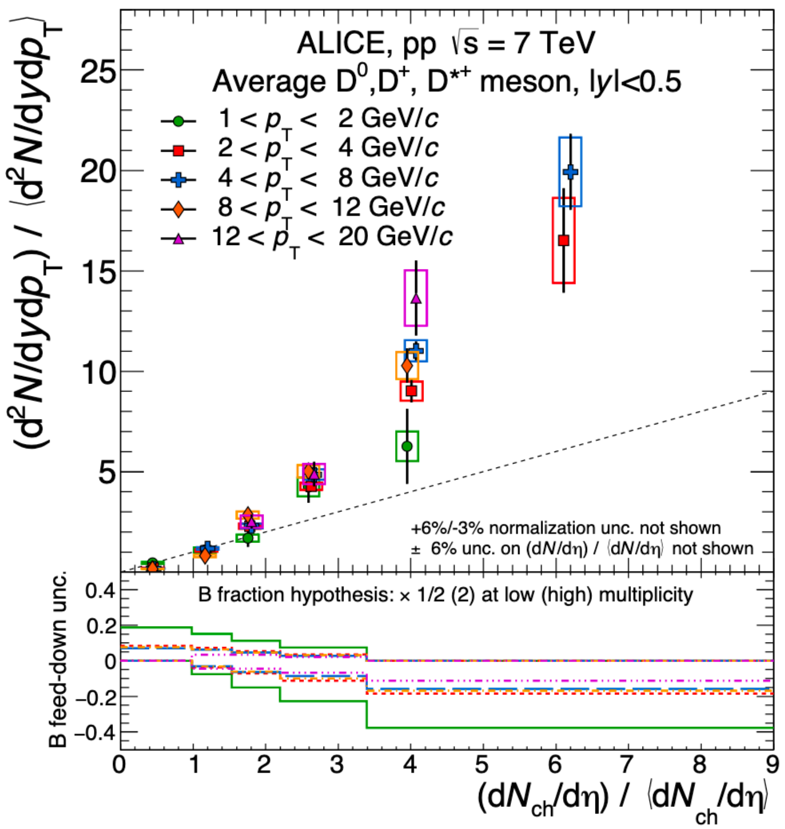


- Same behavior observed with 2 different event multiplicity classifications: SPD (mid rapidity) and V0 (forward rapidity) → excluding auto-correlation mechanisms

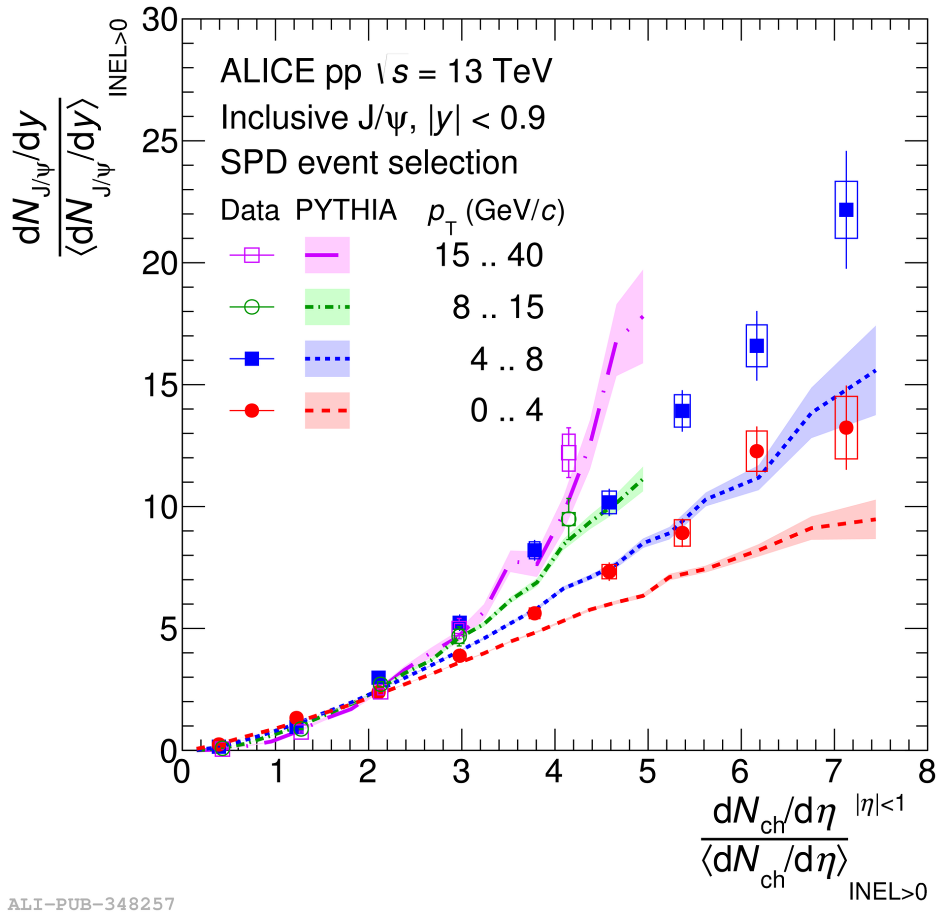
- Various mechanisms (Color string reconnection (CSR), percolation, gluon saturation, CPP, 3-gluon fusion) responsible for stronger suppression of soft processes (N_{ch}) than hard processes (J/ψ) could explain this behavior

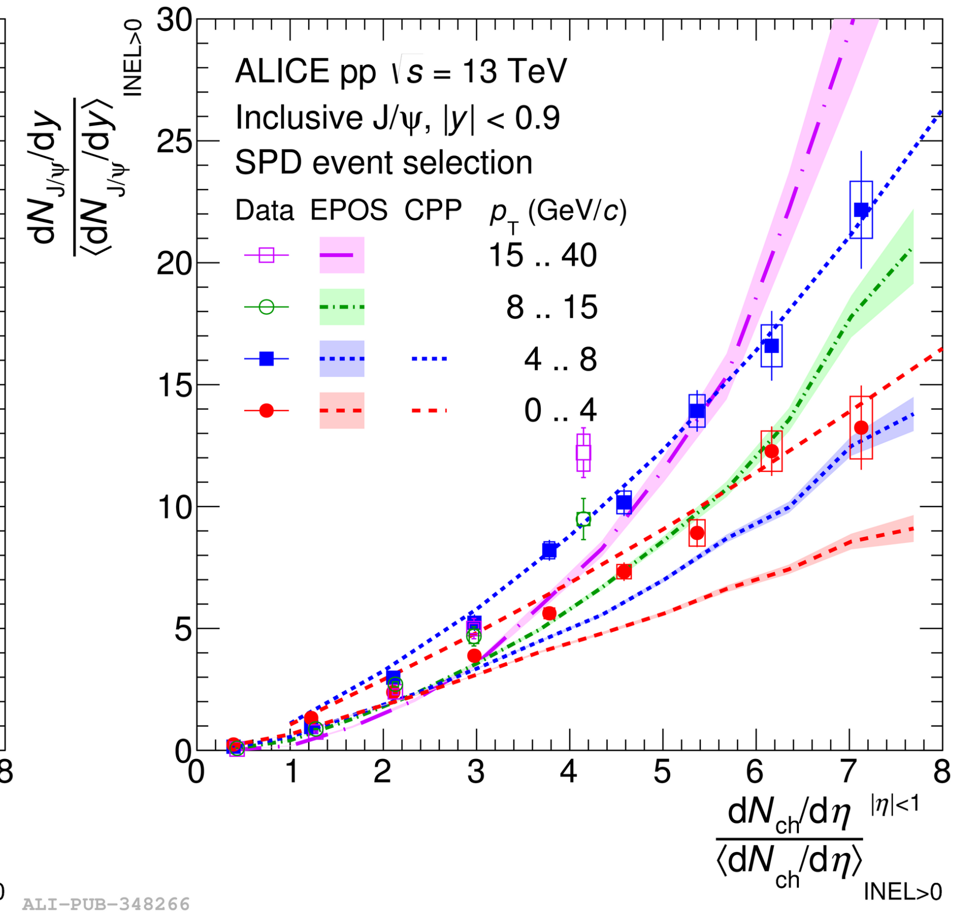
Influence of the hardness of the probe

arxiv:1505.00664



arxiv:2005.11123



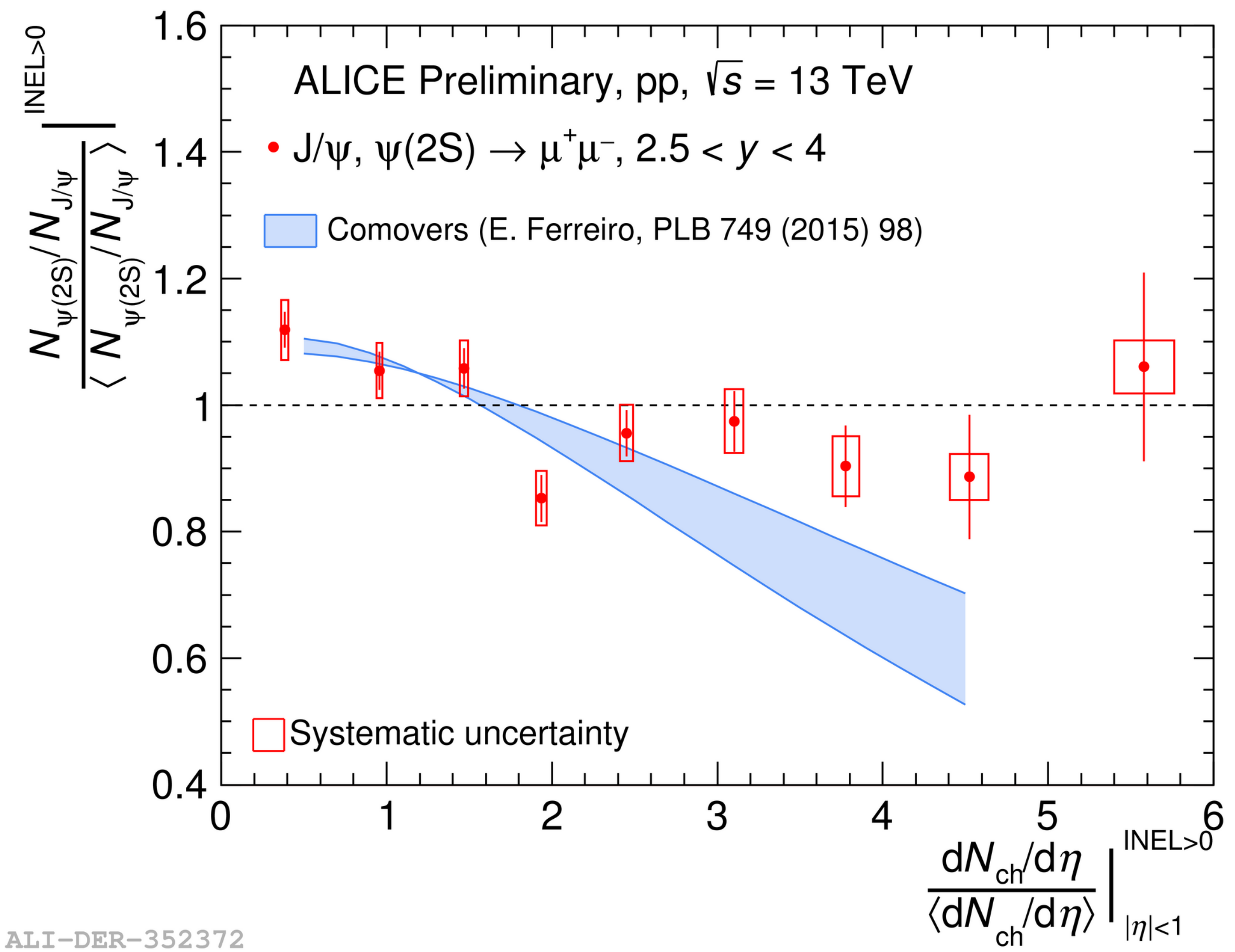


- Hints of dependence on average D mesons p_T (not significant considering uncertainties) for pp collisions at 7TeV (mid-rapidity)
- More significant dependence on J/ψ p_T observed for pp collisions at 13TeV (mid-rapidity)
- Behavior qualitatively reproduced by different models (PYTHIA, EPOS, CPP)

Excited/ground state (charmonia in pp at 13TeV)

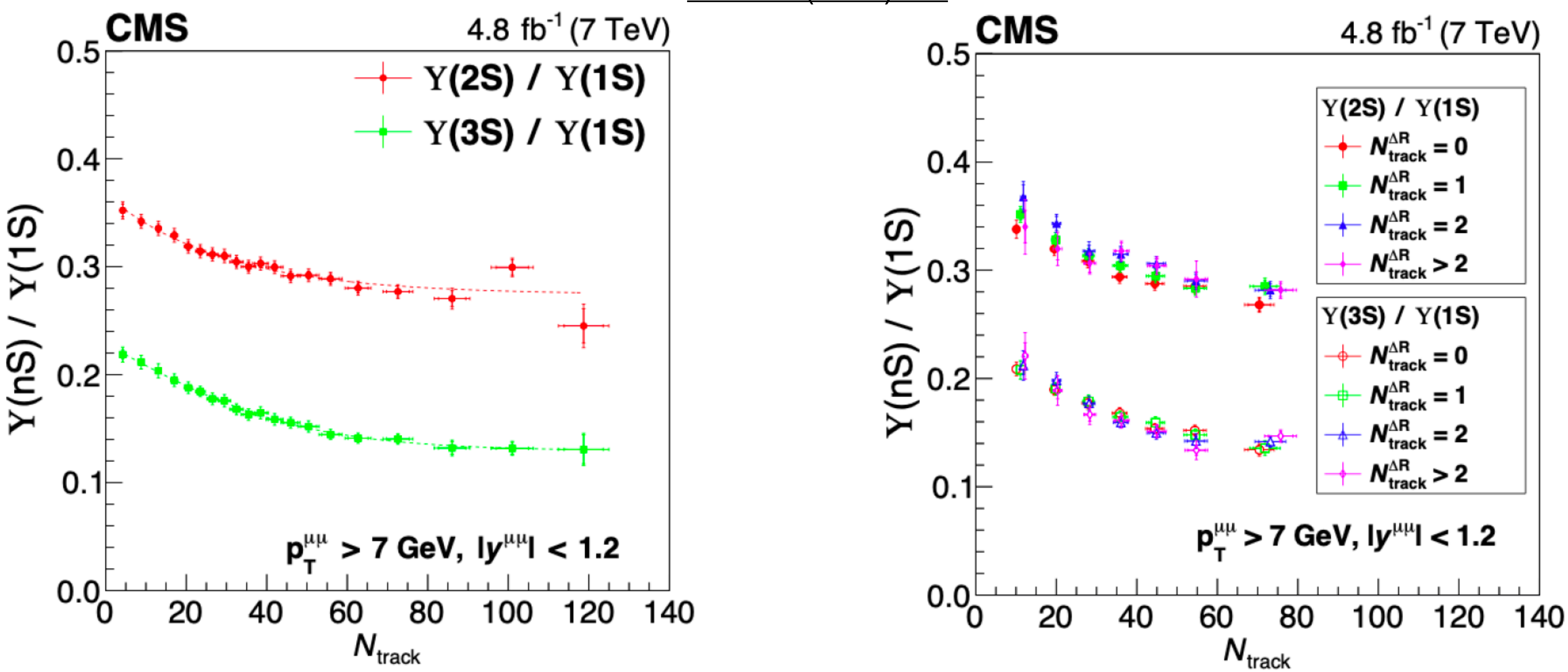
- Charmonia measured at forward rapidity, multiplicity at mid-rapidity (gap)
- No significant deviation from unity observed considering the uncertainties
- Data compatible with predictions from comovers model (~1σ) on the covered multiplicity range
- Would be interesting to perform the measurement on prompt charmonia, with and without a rapidity-gap

→ **ALICE MFT upgrade (Run3) will make it possible and reduce the uncertainties**



Excited/ground states (bottomonia in pp at 7TeV)

JHEP11(2020)001



- Relative multiplicity dependent suppression of ϒ excited states wrt the ground state reported by the CMS collaboration (without rapidity gap)

- Differential measurements as a function of the ϒ isolation (right): number of tracks in a cone around the ϒ momentum direction with $\Delta_R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.5$

→No significant difference observed in trend of the ratio from $N^{\Delta R}_{track} = 0$ to $N^{\Delta R}_{track} > 2$

→Not in good agreement with expectations from a comover dissociation scenario?

Summary

- No energy dependence on quarkonia vs multiplicity observed (with relative quantities)

- Behavior of the multiplicity dependence seems independent of the nature/mass of the probe

- Different behaviors observed in different rapidity regions

→ Possible explanation in the case of J/ψ in pp 13TeV at mid-rapidity: different mechanisms (Color string reconnection (CSR), percolation, gluon saturation, coherent particle production (CPP), 3-gluon fusion) responsible for a higher suppression of the soft processes than hard ones

- p_T dependence observed for J/ψ vs multiplicity at mid-rapidity (pp 13TeV)

Excited/ground states

- Charmonia in pp at 13TeV (ALICE): no significant relative suppression of ψ(2S) observed wrt J/ψ at high multiplicity (uncertainties: no strong conclusion)

- Bottomonia in pp at 7TeV (CMS): multiplicity dependent suppression of ϒ excited states observed wrt the ground state

→ Differential (isolation) study not in good agreement with comover scenario?

Perspectives

ALICE MFT upgrade for Run3

- Measurement of prompt charmonia at forward rapidity
- Direct multiplicity measurement at forward rapidity
- Reduction of uncertainties (improvement of S/B ratio)

LHCb

- High precision measurements of bottomonia and prompt charmonia vs multiplicity at forward rapidity accessible
- Extended p_T coverage with Magnet Tracking Stations (installation during LS3)

CMS

- Measurement of bottomonia in pp collisions at 13TeV (higher multiplicity) with differential studies at mid-rapidity

→ It would be interesting to have measurements in KNO variables (Koba-Nielsen-Olesen: relative yield and relative multiplicity) from all experiments to ease the comparisons

Thank you!

Results presented

State	Channel	System	Energy	Experiment	Reference
D^0, D^+, D^{*+}	Hadronic decay, $\|y\| < 0.5$	pp	7 TeV	ALICE	JHEP09(2015)148
D^0, D^+, D^{*+}	Hadronic decay, $-0.96 < y_{cms} < -0.04$	p-Pb	5.02 TeV	ALICE	JHEP08(2016)078
J/ψ	$\mu^+\mu^-$, $2.5 < y < 4$	pp	5.02 TeV	ALICE	Preliminary
J/ψ	- e^+e^-, $\|y\| < 0.9$ - $\mu^+\mu^-$, $2.5 < y < 4$	pp	13 TeV	ALICE	- PLB810(2020)135758 - Preliminary
J/ψ	$\mu^+\mu^-$, $-4.46 < y_{cms} < -2.96$ (Pb-going) $2.03 < y_{cms} < 3.53$ (p-going)	p-Pb	5.02 TeV	ALICE	PLB776(2018)91-104
J/ψ	$\mu^+\mu^-$, $-4.46 < y_{cms} < -2.96$ (Pb-going) $2.03 < y_{cms} < 3.53$ (p-going)	p-Pb	8.16 TeV	ALICE	JHEP09(2020)162
ψ(2S)	$\mu^+\mu^-$, $2.5 < y < 4$	pp	13 TeV	ALICE	Preliminary
ϒ(1S)/ϒ(2S)/ϒ(3S)	$\mu^+\mu^-$, $\|y\| < 1.93$	pp	2.76 TeV	CMS	JHEP04(2014)103
ϒ(1S)/ϒ(2S)/ϒ(3S)	$\mu^+\mu^-$, $\|y\| < 1.2$	pp	7 TeV	CMS	JHEP11(2020)001
ϒ(1S)/ϒ(2S)/ϒ(3S)	$\mu^+\mu^-$, $\|y\| < 1.93$	p-Pb	5.02 TeV	CMS	JHEP04(2014)103
ϒ(1S)/ϒ(2S)/ϒ(3S)	$\mu^+\mu^-$, $\|y\| < 2.4$	Pb-Pb	2.76 TeV	CMS	PRL109(2012)222301