Recent ALICE results on single and double J/ψ production and on collective effects in pp collisions

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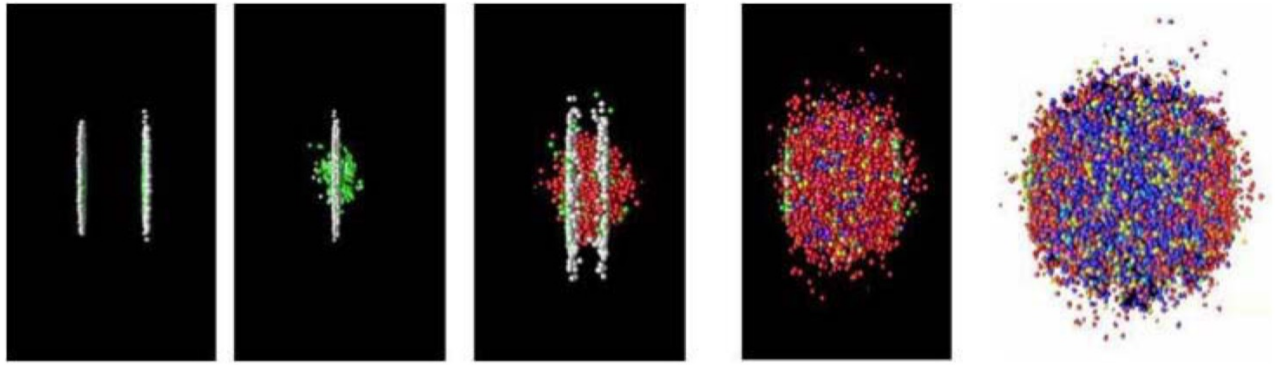
On behalf of the ALICE collaboration

QWG 2022 - The 15th International Workshop on Heavy Quarkonium
GSI Darmstadt – 27/09/22

Science Pusheen - Illustration project by Kelly Stanford

Quarkonium in small systems: physics motivations



Reference systems to study quark-gluon plasma (QGP)

Heavy flavour probes in small systems

- Heavy flavour quarks formed at early stages (hard scale)
- pp: Allows to test perturbative QCD predictions, study production mechanisms

  - J/ψ **single production** in pp at 13 TeV
  - J/ψ **pair production** in pp at 13 TeV

Investigate possible collective behaviours

- Study similarities in small systems and Pb—Pb collisions
- Use of observables directly linked to collectivity (flow)
- Multiplicity dependent analyses (behaviour accross system size)

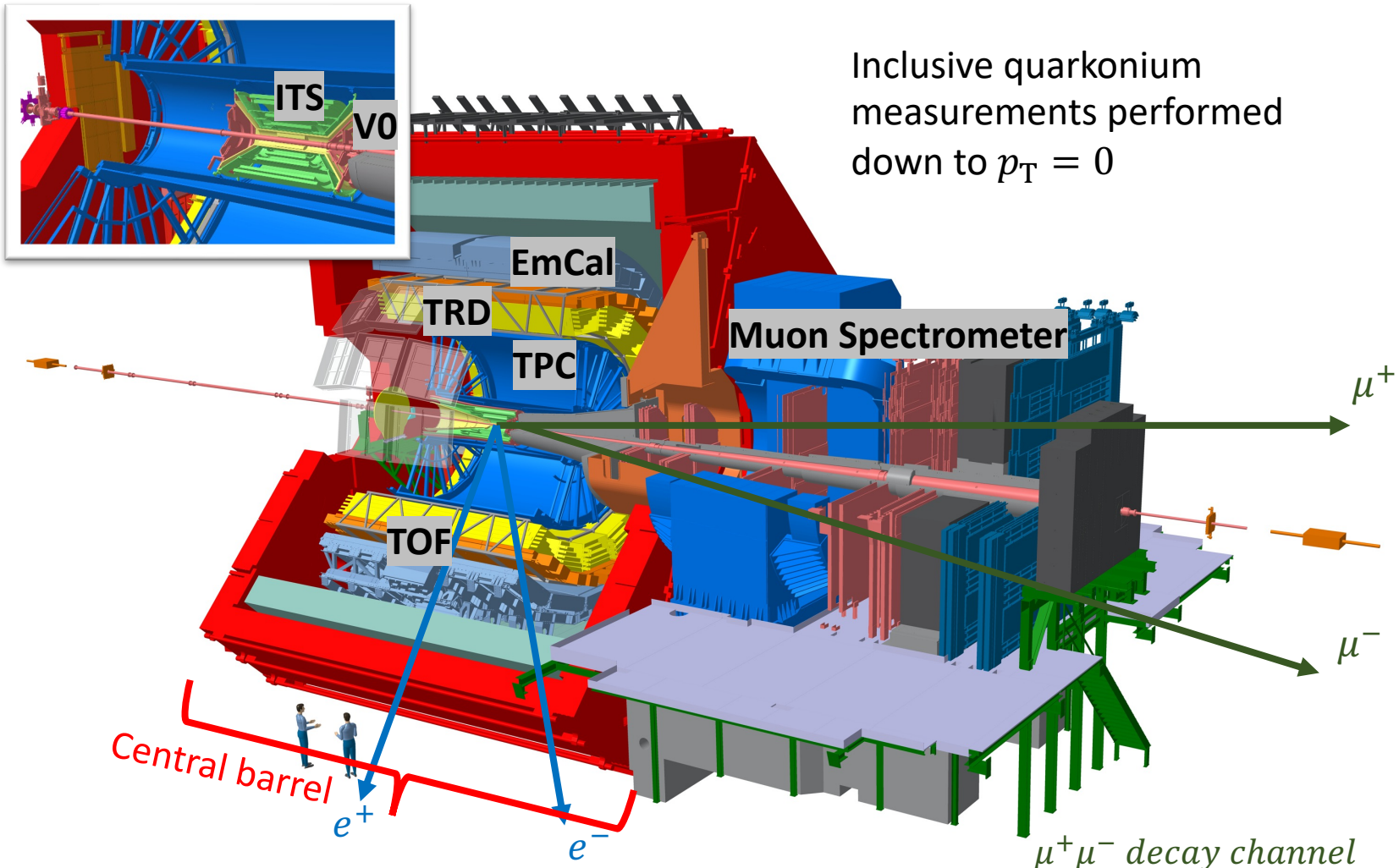
  - J/ψ **elliptic flow** in pp at 13 TeV

Anton Andronic's presentation (26/09 – 9h45)
Multiplicity dependence of quarkonium production in pp collisions

Enrico Scomparin's presentation (27/09 – 15h20)
$\psi(2S)$ in Pb—Pb collisions

Luca Micheletti's presentation (27/09 – 17h50)
Quarkonium polarization in pp and Pb—Pb collisions

A Large Ion Collider Experiment (Run 1 – Run 2 configuration)



Inclusive quarkonium measurements performed down to $p_{\mathrm{T}} = 0$

e^+e^- *decay channel* ($|y| < 0.9$)
Separation between prompt (produced at primary vertex) / non-prompt (b-hadron decays) down to very low p_{T}

$\mu^+\mu^-$ *decay channel*
($2.5 < y < 4.0$)
Inclusive measurements

ITS – Inner Tracking System
Tracking, vertex reconstruction, multiplicity estimation

V0(A and C)
Triggering, centrality and multiplicity estimation, background rejection

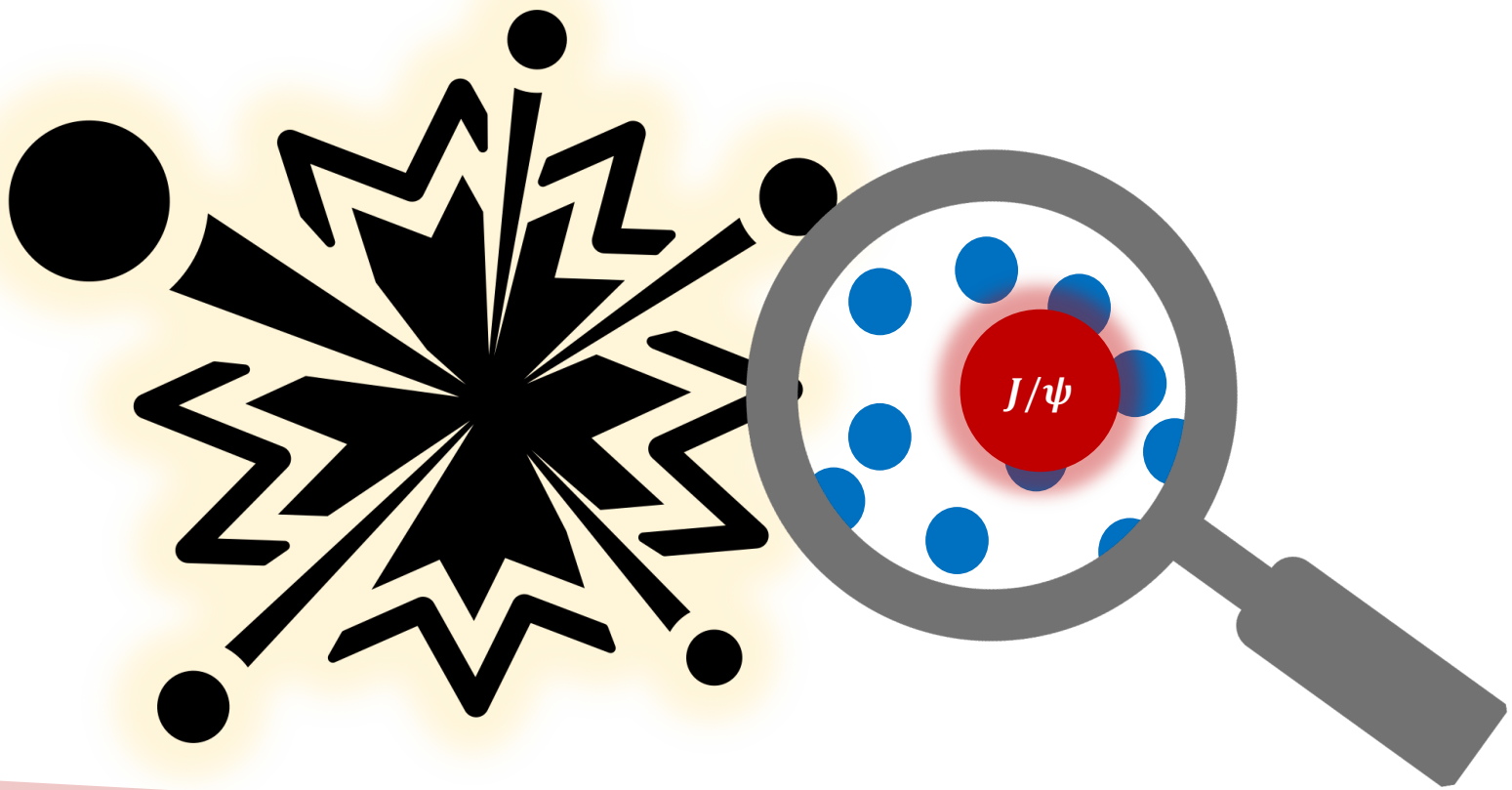
TPC – Time Projection Chamber
PID, tracking

EmCal – Electromagnetic Calorimeter
Triggering, PID

TRD – Transition Radiation Detector
Triggering, PID

TOF – Time Of Flight detector
PID

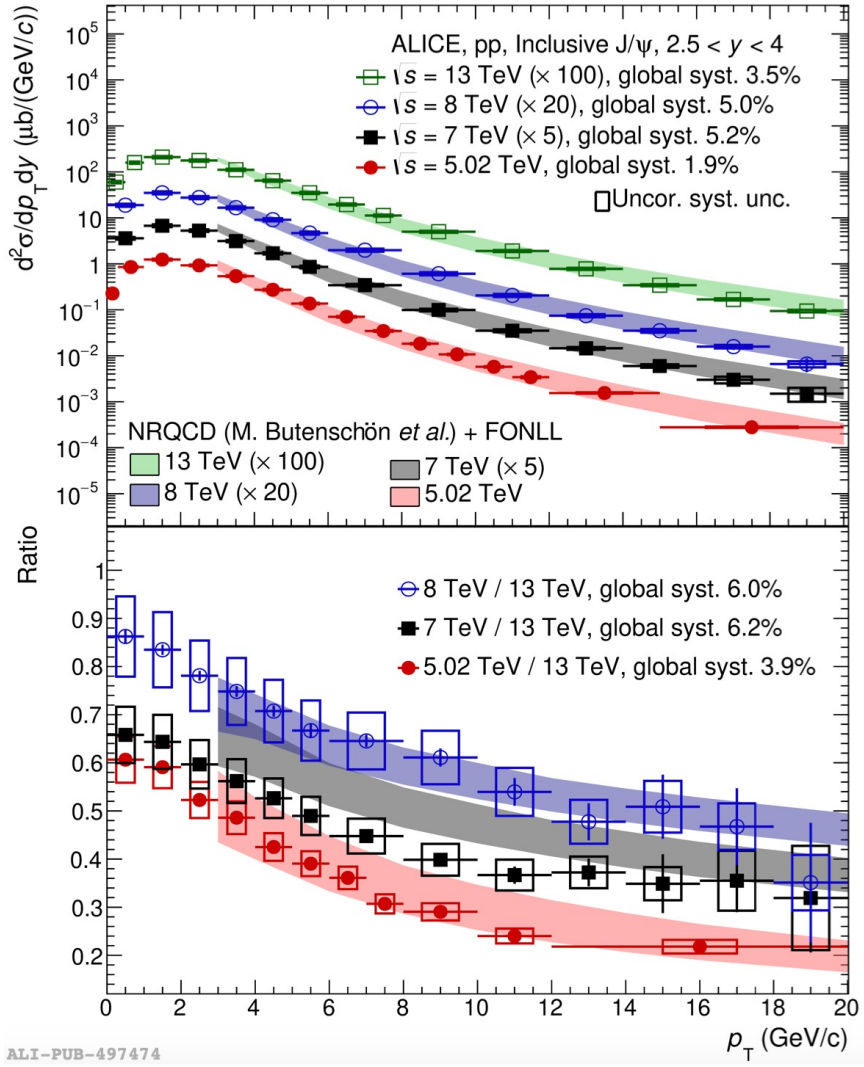
Muon Spectrometer
Forward tracking and triggering of muons



J/ψ production in pp collisions

Single J/ψ production – Forward rapidity

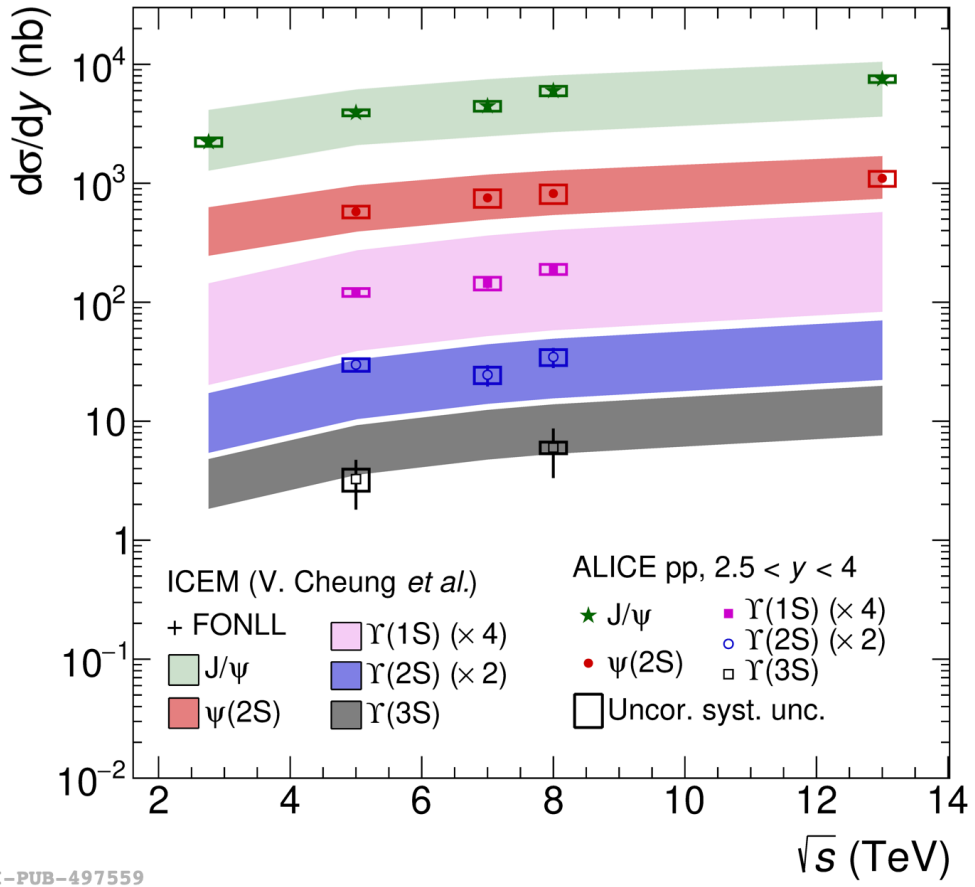
arXiv:2109.15240 New measurement done at $\sqrt{s} = 5$ TeV (10 times the statistics available in earlier publication)



Cross section ratios: additional constraints on models (partial cancellation of theoretical uncertainties)

Cross sections reproduced by both NRQCD and ICEM calculations at all energies

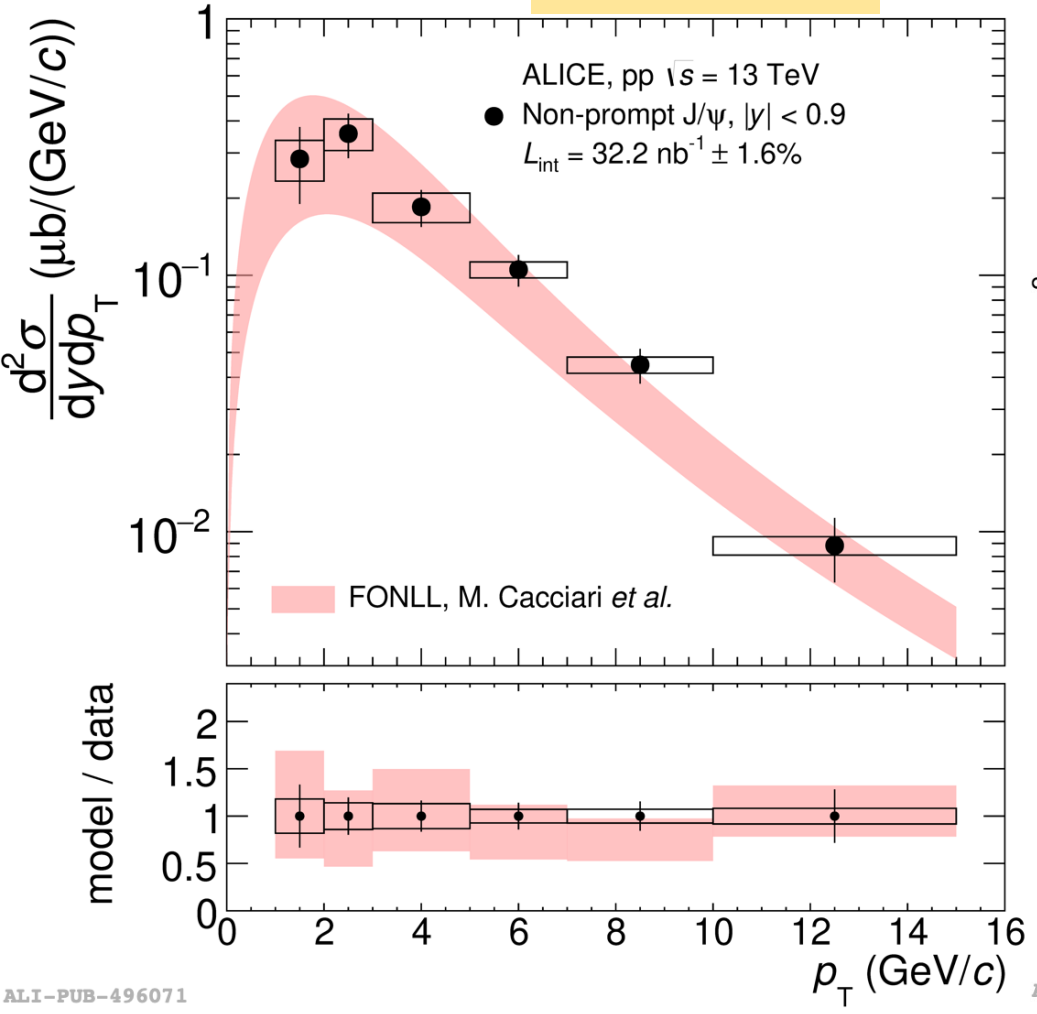
Difficulties to reproduce at the same time all the cross section ratios among energies, but compatibility within the experimental precision



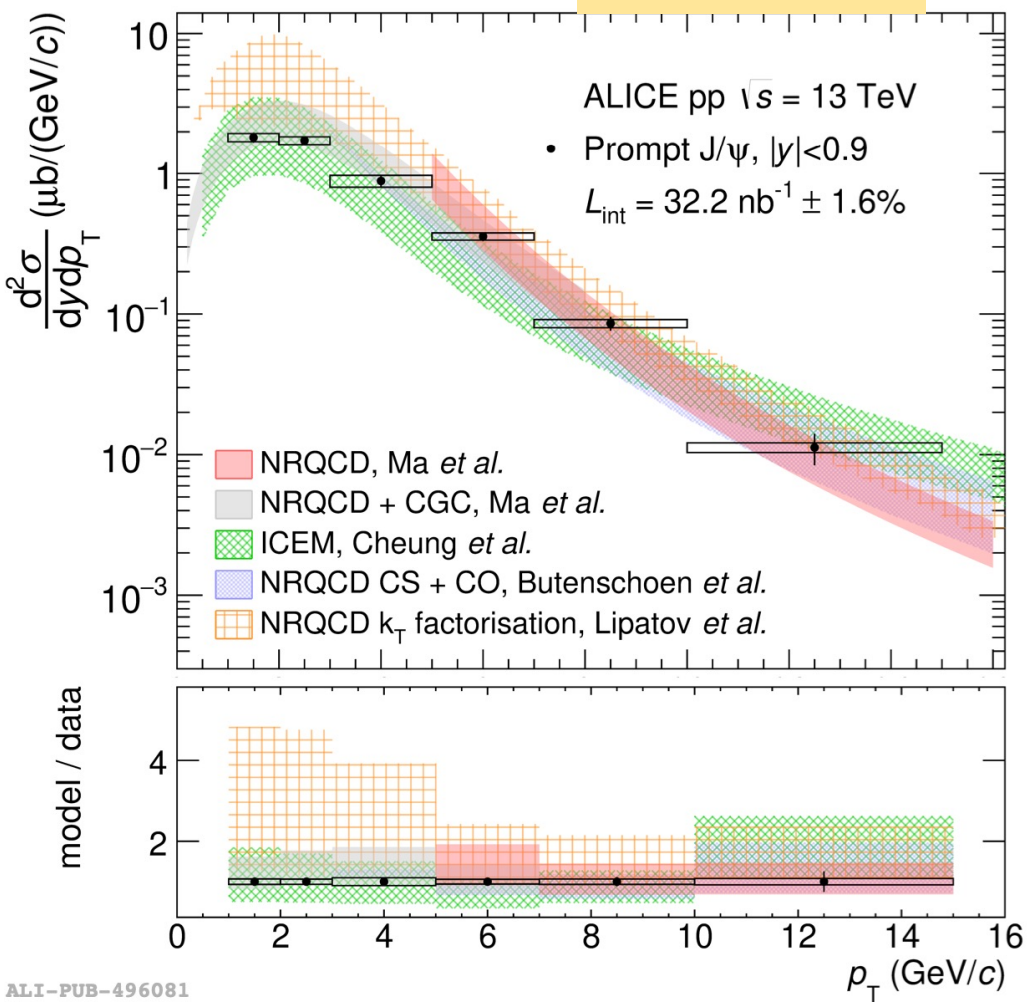
Behaviour of $q\bar{q}$ production with energy well reproduced by ICEM calculations for different species

Single J/ψ production – Midrapidity

Non-prompt



Prompt



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Models describe well the prompt (NRQCD, ICEM) and non-prompt (FONLL) differential cross sections at midrapidity, at $\sqrt{s} = 13$ TeV

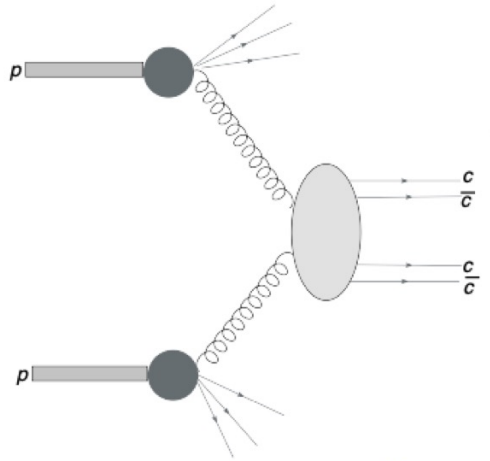
Similar agreement is found at $\sqrt{s} = 5$ TeV as well

Same models manage to describe data in both rapidity ranges and in a large range of energies

Double J/ψ production – Motivation and process

Insight on:

- Single J/ψ production
- NRQCD constraints
- Double-parton scattering

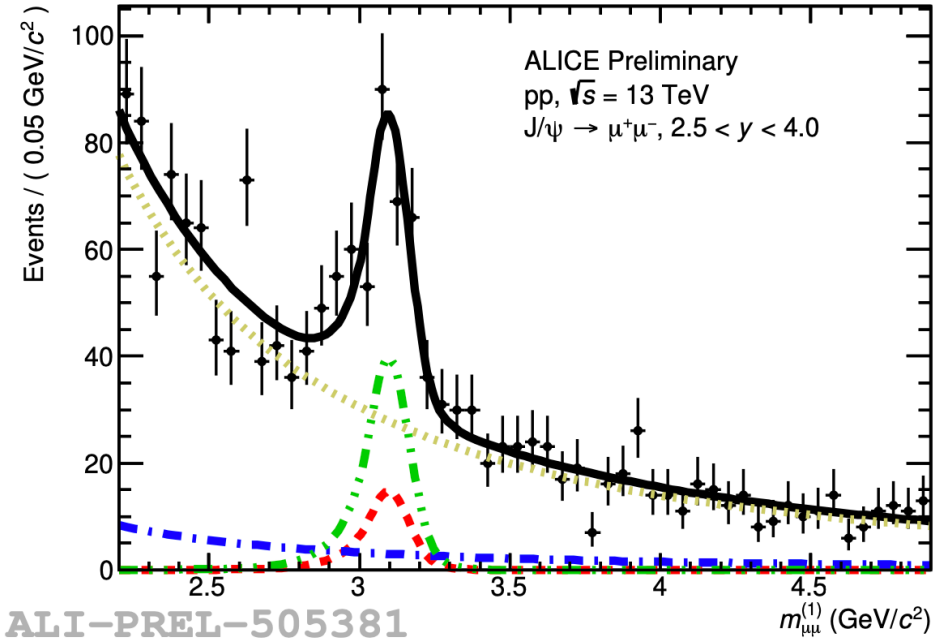


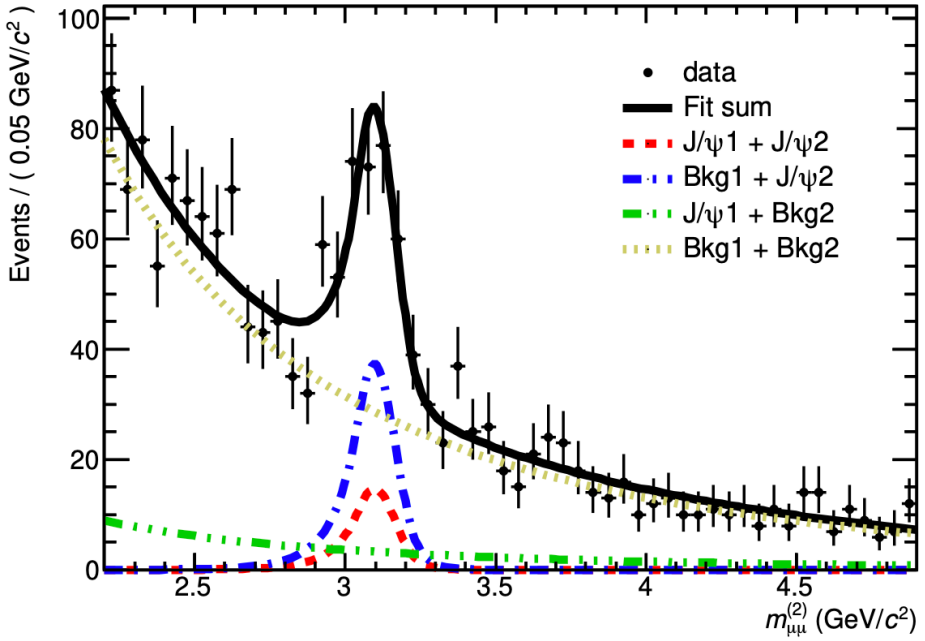
2D invariant mass fit:

Mass distributions of first $m^1_{\mu\mu}$ and second $m^2_{\mu\mu}$ reconstructed unlike-sign dimuon pairs

AIP Conf. Proc. 1523 (2013) 1, 255-259

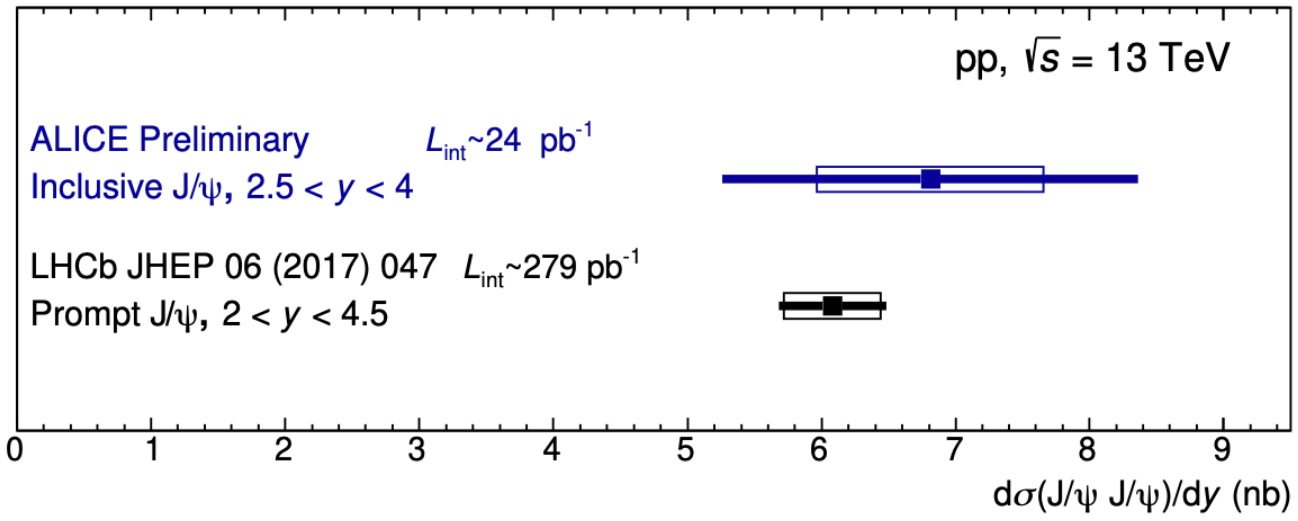
1D projections of the fit →





ALI-PREL-505381

Double J/ψ production – Results

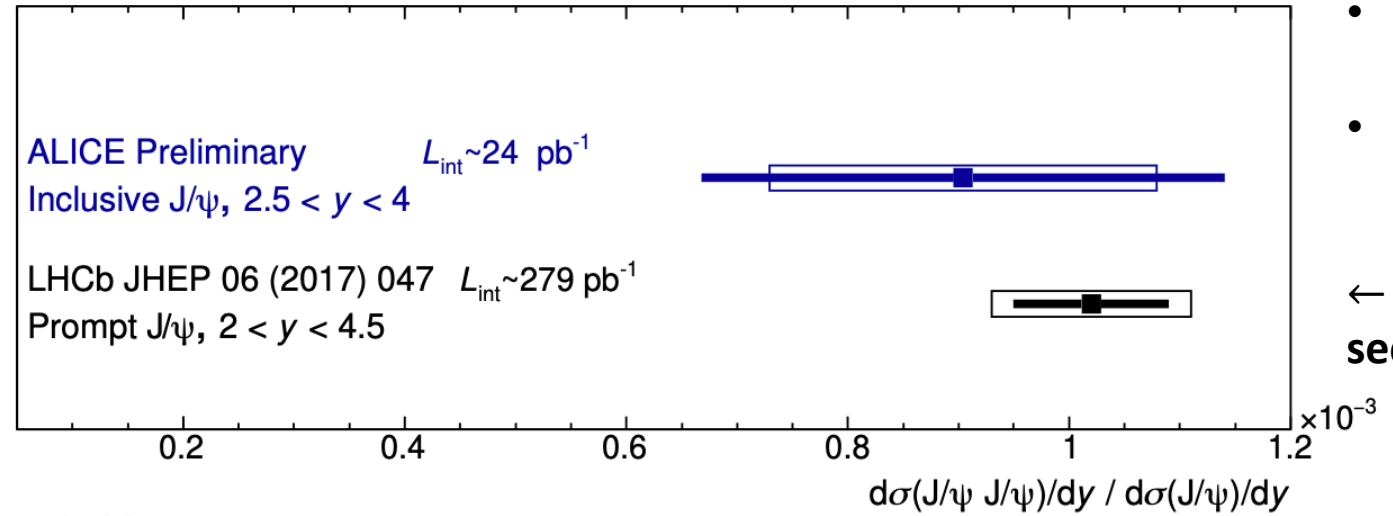


← **Di–J/ψ cross section**

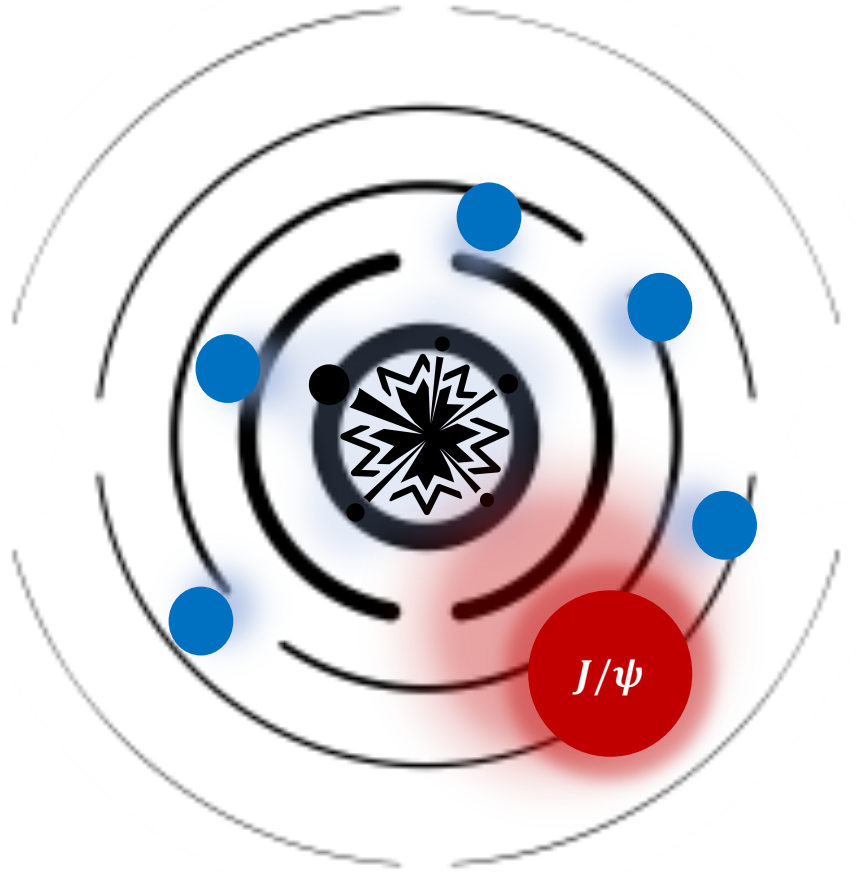
Both results on di-J/ψ cross section and di-J/ψ to single-J/ψ cross section are in good agreement with LHCb

Caveat:

- ALICE measures inclusive J/ψ and LHCb prompt J/ψ
- Slightly different rapidity ranges



← **Di–J/ψ to single–J/ψ cross section ratio**

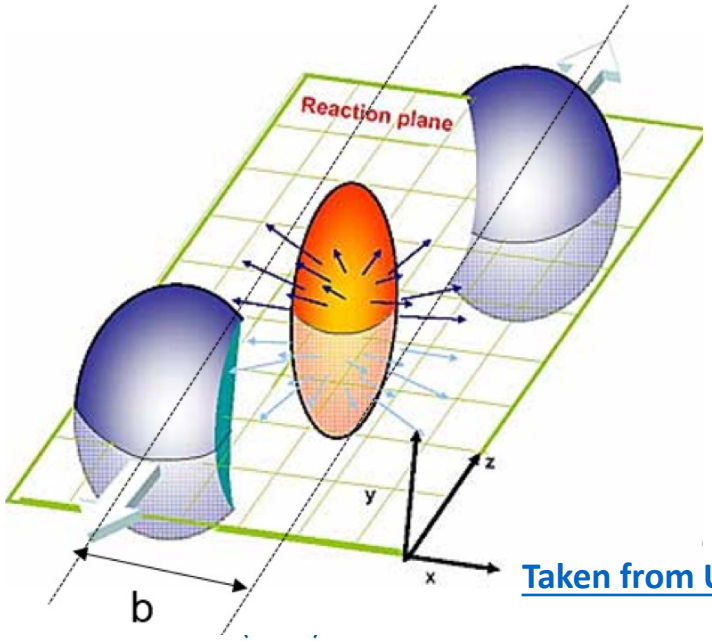


J/ψ collectivity in pp collisions

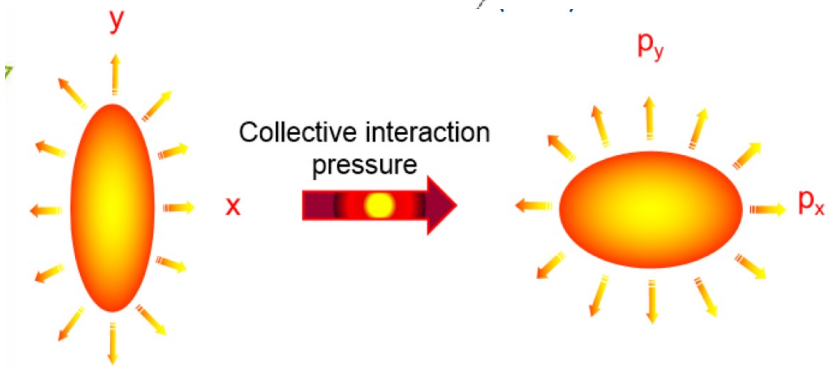
Elliptic flow: observable for collectivity

In heavy-ion collisions, **anisotropic geometry of overlapping** region for $b > 0$

- **Anisotropies in momentum** distribution
- **Long-range correlations** of produced particles



Taken from Universe, 2017



Azimuthal correlations of particles quantified by Fourier coefficients in ϕ angle distribution (wrt event plane if large multiplicity), or 2-particle correlations:

$$\frac{dN^{pairs}}{d\Delta\phi} \propto (1 + \sum_{n=1}^{\infty} 2v_n^2 \cos(n\Delta\phi)).$$

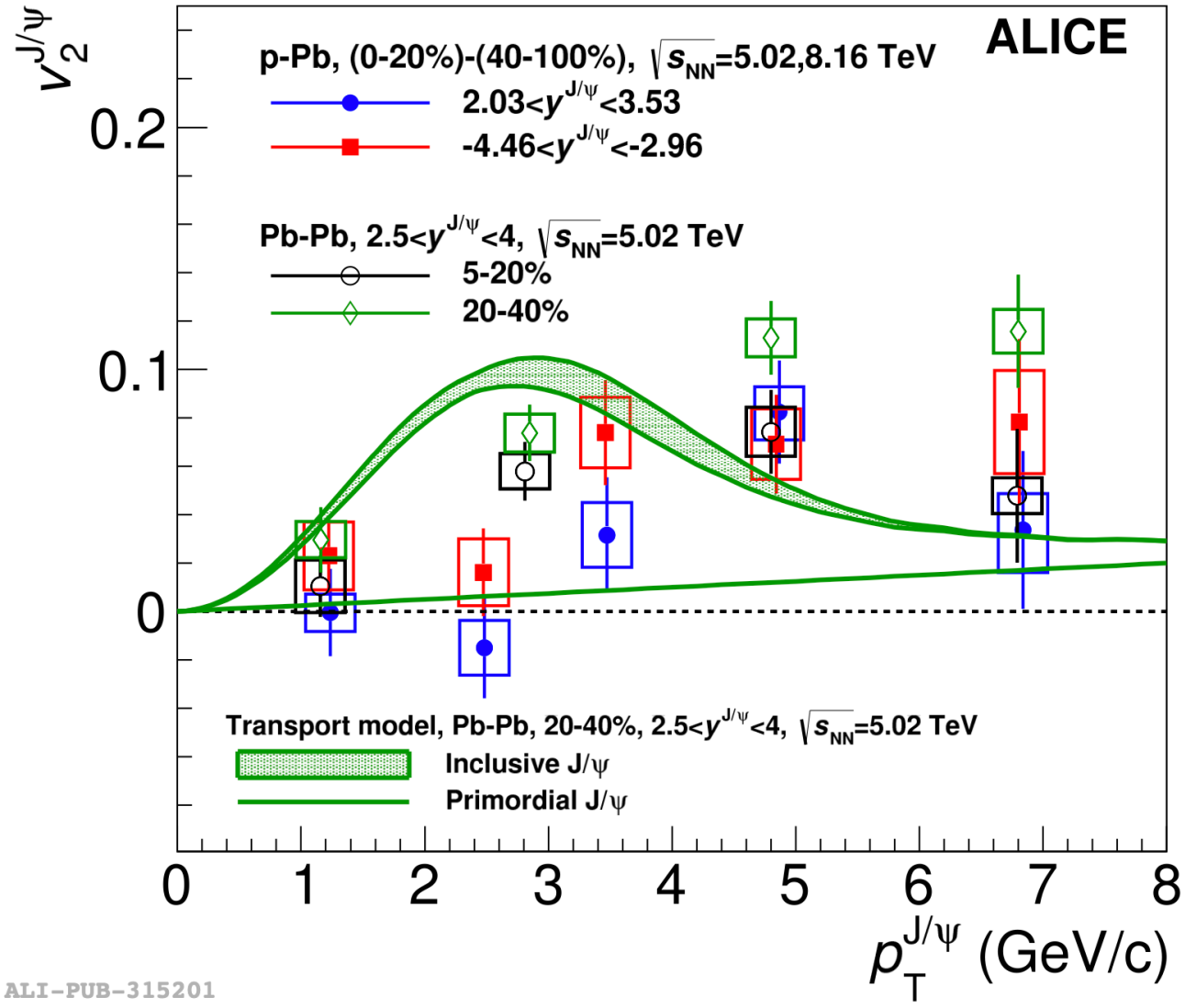
v_2 (elliptic) : sensitive to thermalization of the medium
v_3 (triangular) : sensitive to fluctuations of the initial state

In small systems, non-flow effects (e.g. dijets) suppressed by subtracting low-multiplicity distributions from high-multiplicity ones

Non-zero flow points to collective behaviours : signature of QGP

Constrains theoretical models

J/ψ elliptic flow in large systems



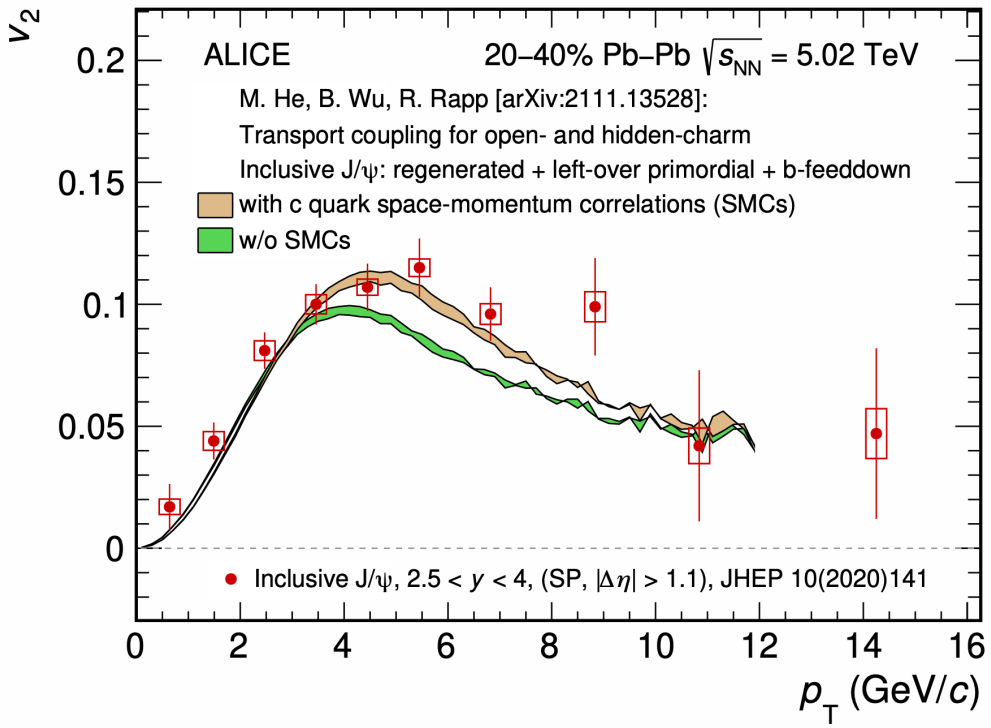
ALI-PUB-315201

Phys. Lett. B 780 (2018) 7-20

Pb–Pb: *JHEP 10 (2020) 141*

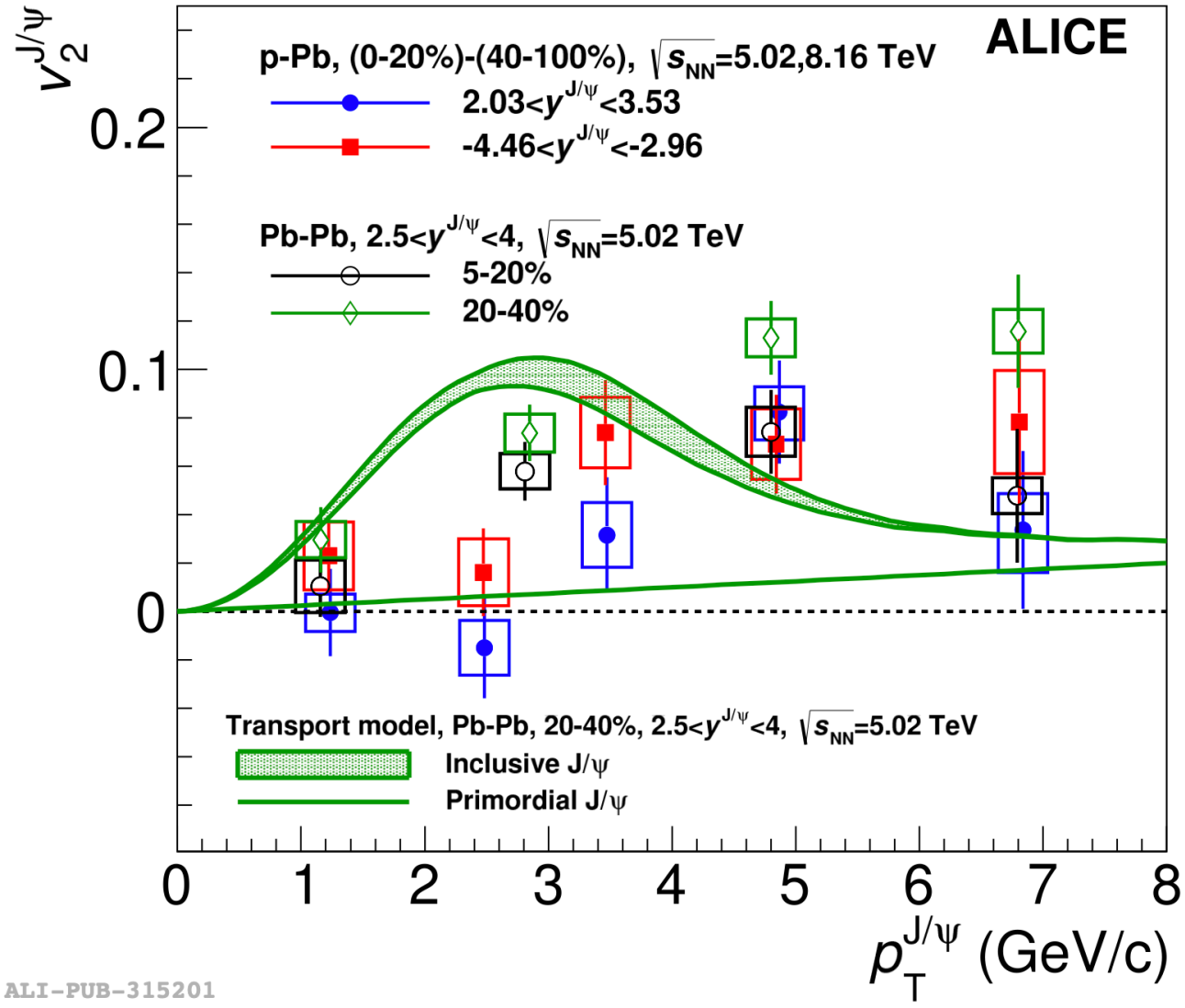
- For p_T > 1 GeV/c, significant flow (elliptic and triangular)
- Transport model description valid: originally only qualitatively, but recent tuning works better

arXiv:2204.09299 (He et al.)



ALI-PUB-500427

J/ψ elliptic flow in large systems



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p—Pb : *Phys. Lett. B 780 (2018) 7-20*

- For p_T > 3 GeV/c, significant flow
- Results close to A—A → hints at common flow mechanism regardless of system size
- Transport model does not hold in p-Pb, no explanation for p-Pb flow
- Motivates pp study

J/ψ elliptic flow in pp

Collective effects already assessed for light flavours, open question for heavy flavours
Same extraction method as in p—Pb

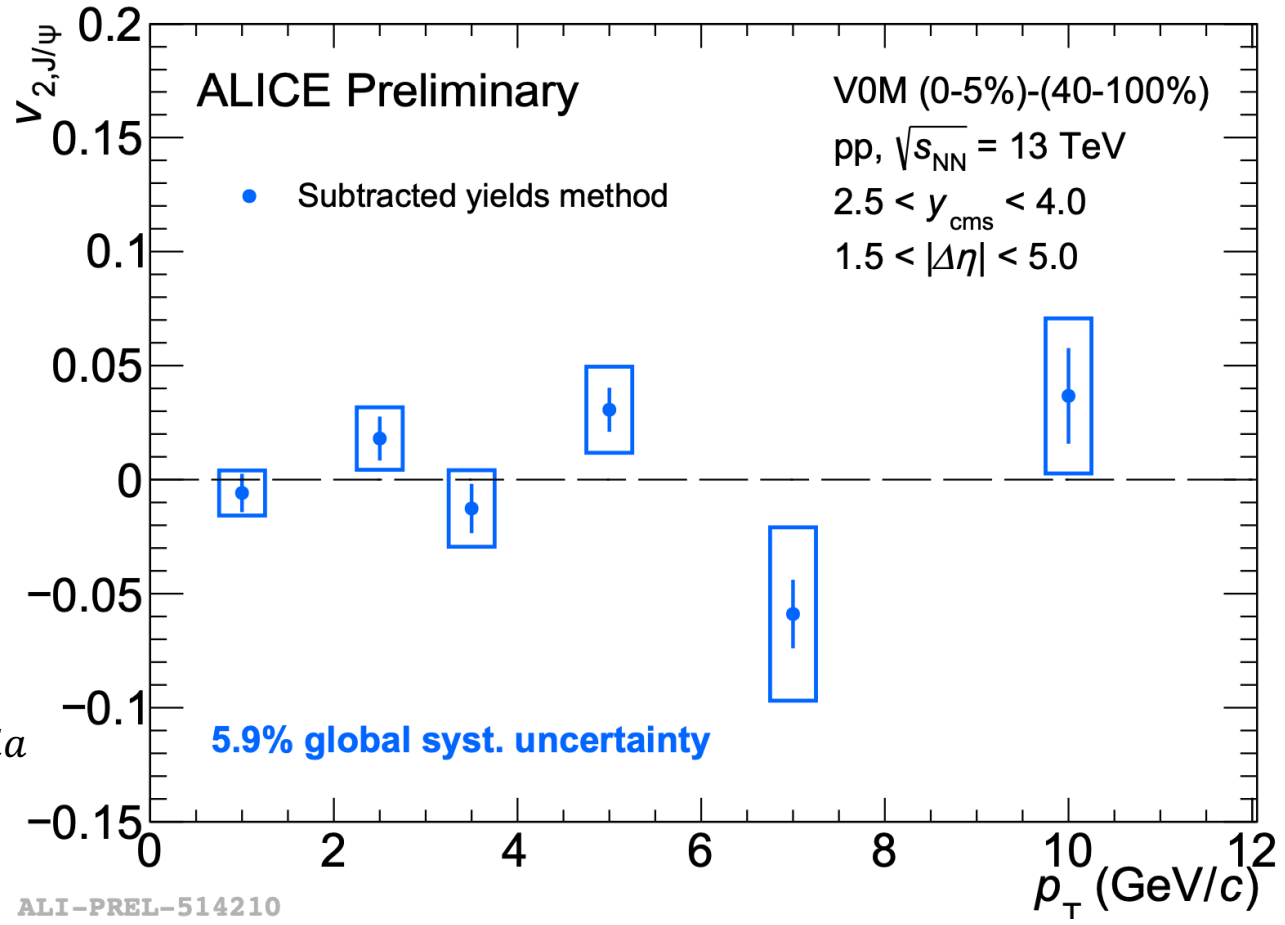
- No significant p_T dependence
- p_T-integrated v_2 compatible with 0 (within 1σ)

Remarks:

- Prediction by transport model:
no fireball expected in pp → no flow
- Hint at mass hierarchy of elliptic flow at fixed p_T :

$$Light\ flavour\ particles > Open\ heavy\ flavour > Quarkonia$$

Based on recent results by ALICE and CMS on light and open heavy flavour flow in pp, respectively.

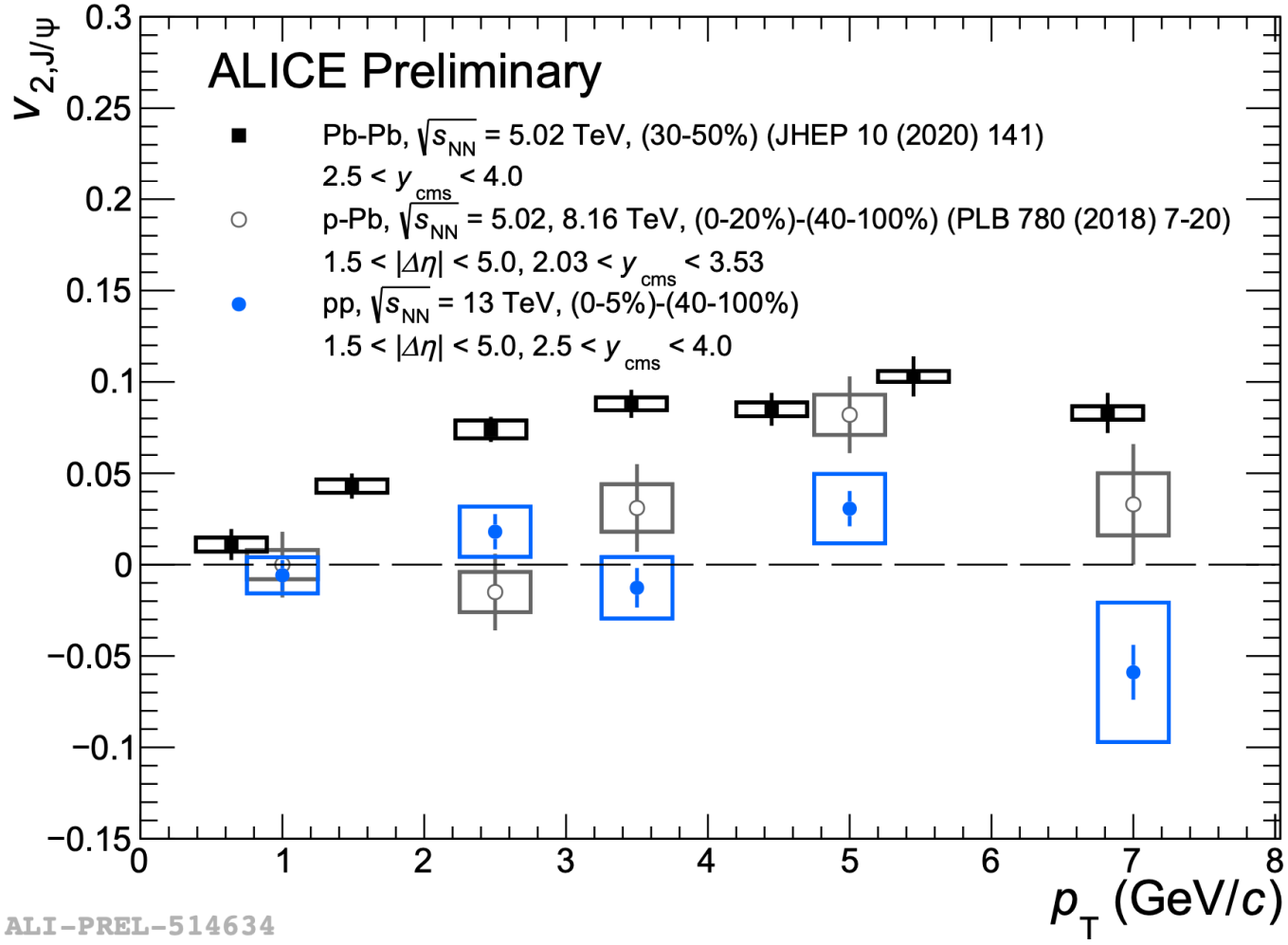


J/ψ v_2 as a function of p_T from **subtracted yields method**

ALICE contribution (QM2022)
Phys. Lett. B 813 (2021) 136036 (CMS)

J/ψ elliptic flow – Comparison with large systems

J/ψ v_2 as a function of p_T in **Pb-Pb**, **p-Pb** and **pp** systems



J/ψ v_2 in pp compatible with 0 within experimental uncertainties

Appears lower than in larger systems especially from intermediate p_T (above 3 GeV/c)

Conclusions

Multiple ALICE results give important insight on J/ψ production mechanisms and search for collectivity in pp !

J/ψ production in pp collisions

Single production of the J/ψ in pp **is well described by theory** over a wide energy, transverse momentum and rapidity range. Agreement of data with theory extends to excited states.
Double production results are in good agreement with existing LHCb measurements (although some caveats limit the comparison).

J/ψ collectivity in pp collisions

J/ψ collective flow mechanism in p-Pb still to be understood, **J/ψ in pp does not show collective flow** effects within uncertainties.

Thank you for your attention !

Backup slides