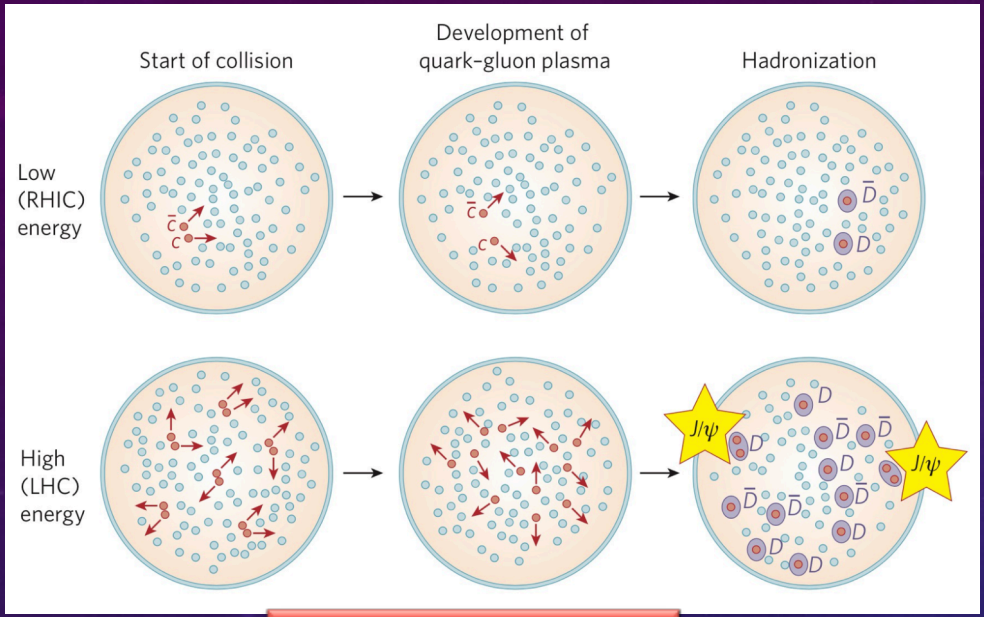
Quarkonium measurements in nucleus-nucleus collisions with ALICE

Kunal Garg
On behalf of the ALICE Collaboration

European Physical Society conference on
High Energy Physics 2021, July 26-30, 2021

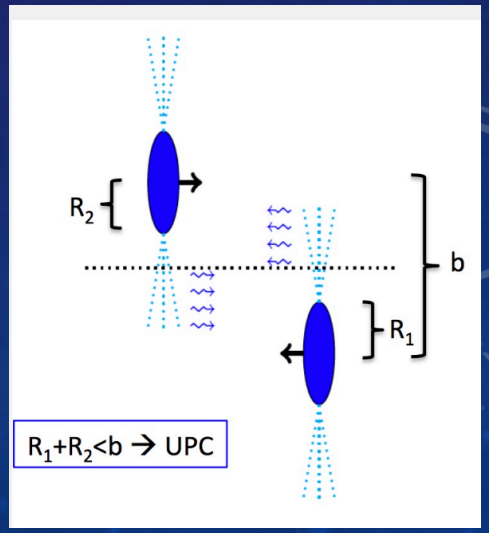
Quarkonium studies in Pb-Pb



Nature **448**, 302–309 (2007)

- Direct quarkonium production suppressed due to:
  - Color screening (static)
  - Decoherence (dynamical)
- Additional production mechanism: (re)generation of quarkonium
- Quarkonium can be used to study deconfinement of the QGP

- In ultra-peripheral collisions(UPC), hadronic interaction strongly suppressed.
- Photoproduction of vector mesons (VM) in UPC with clean experimental signature
  - Very low p_T production, large rapidity gaps
- Provides information on hadron structure of protons and nuclei at low x



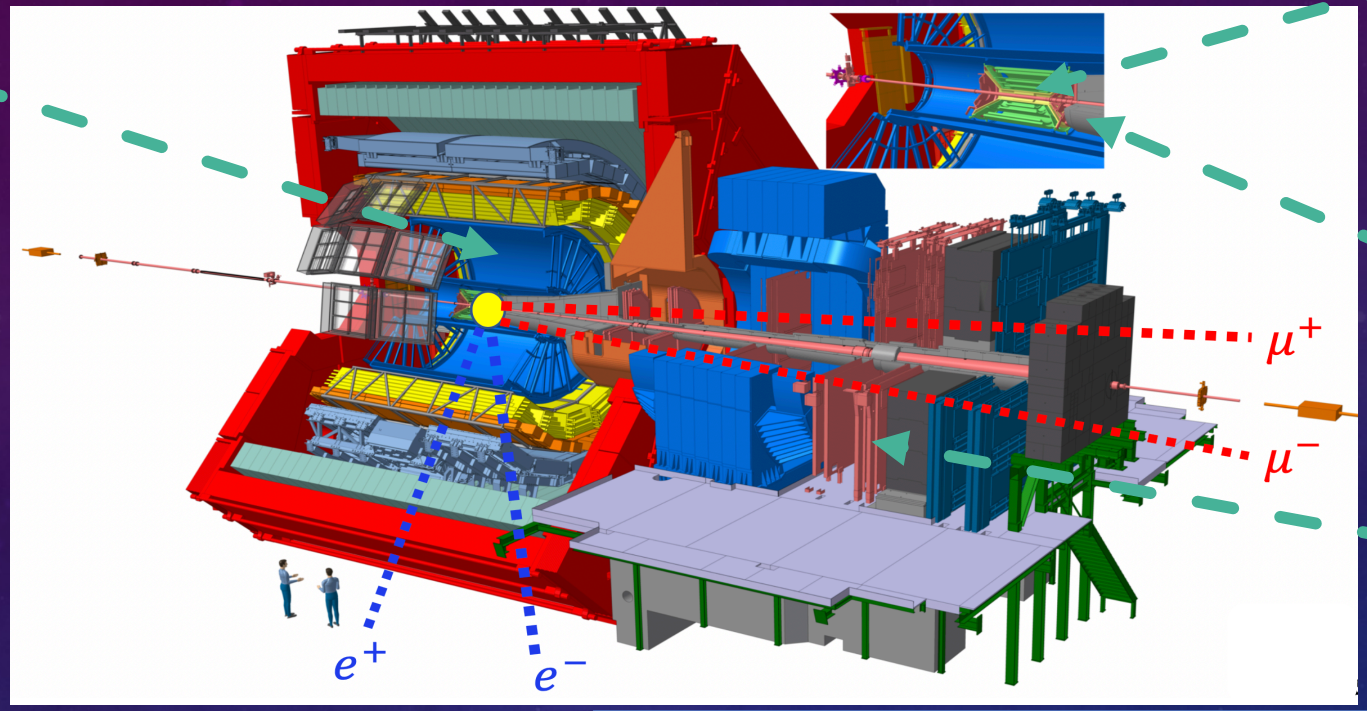
ALICE Experiment

Time Projection Chamber

Inner Tracking System

V0 Detector

Muon Spectrometer



Quarkonium detection at mid-rapidity $|y| < 0.9$
$J/\psi \rightarrow e^+e^-$,
Down to zero p_T
ITS+TPC : tracking and PID
SPD (ITS) : primary and secondary vertices
Separation of prompt and non-prompt J/ψ

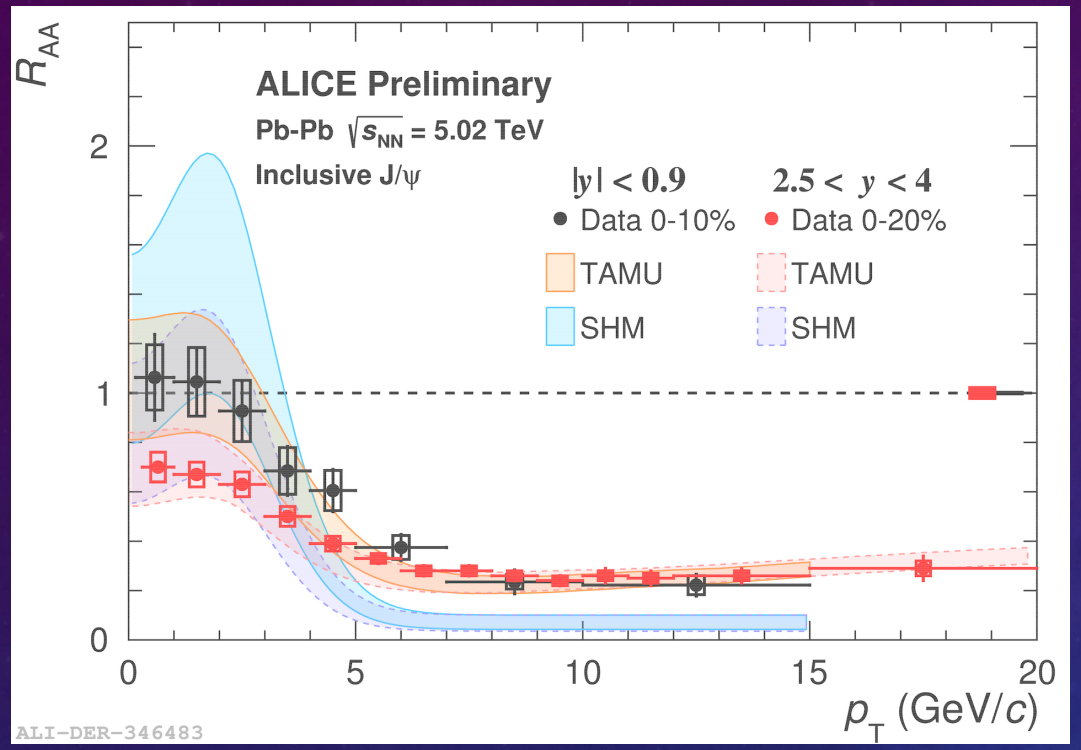
Quarkonium detection at forward rapidity $2.5 < y < 4$
$J/\psi \rightarrow \mu^+\mu^-$, $\psi(2S) \rightarrow \mu^+\mu^-$, $\Upsilon \rightarrow \mu^+\mu^-$
Down to zero p_T
MCH : tracking
MTR : trigger
ITS : primary vertex

V0: Triggering, and event characterisation

Yvonne Pachmayer 27/07 9:30 T06

J/ψ Nuclear modification factor

$$R_{AA} = \frac{Y_{PbPb}}{N_{coll} \times Y_{pp}}$$



- Suppression at forward *y* relative to mid-*y* at low p_T
- Statistical hadronization model describes the data at low p_T
- Transport model agrees with data for all p_T

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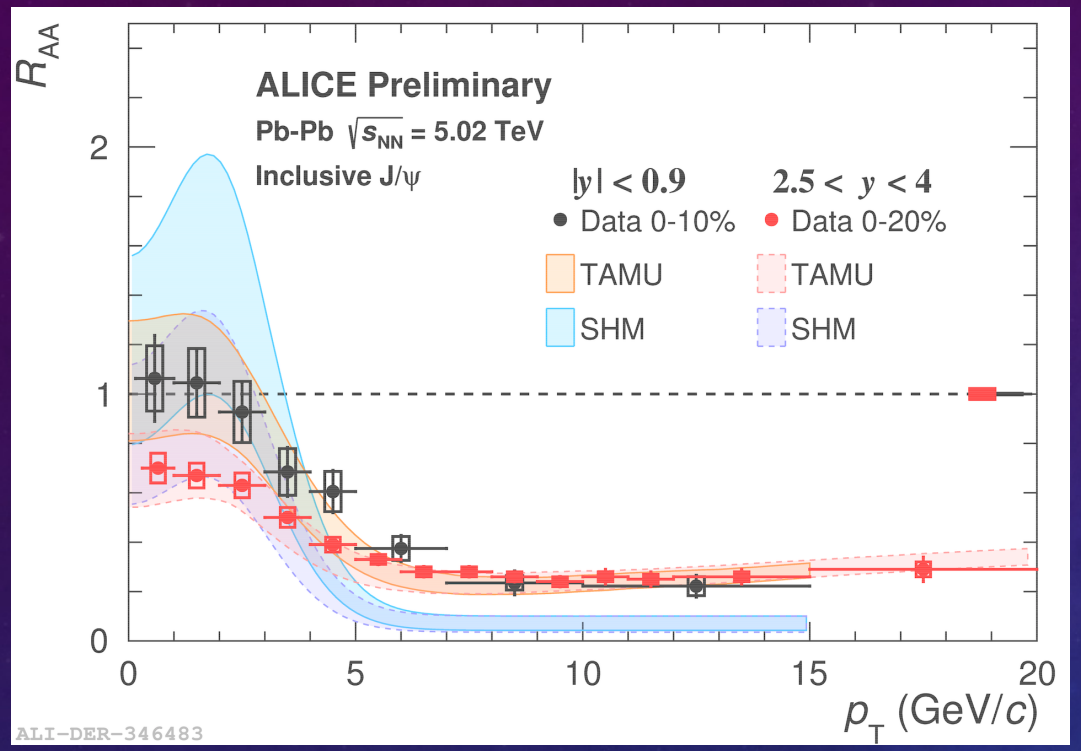
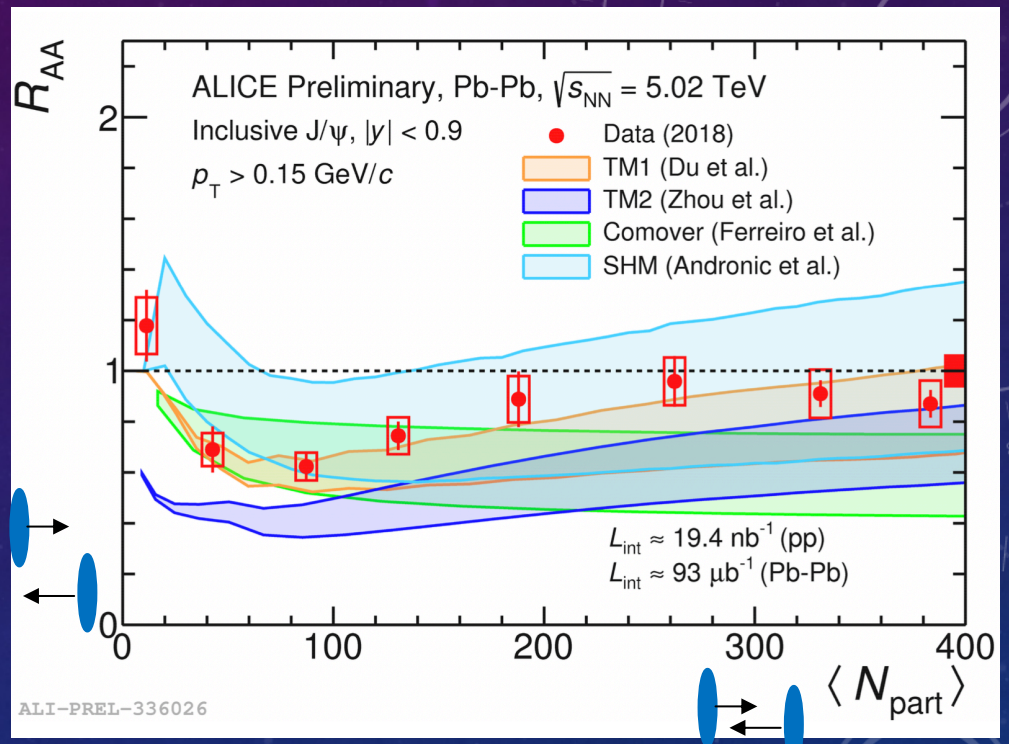
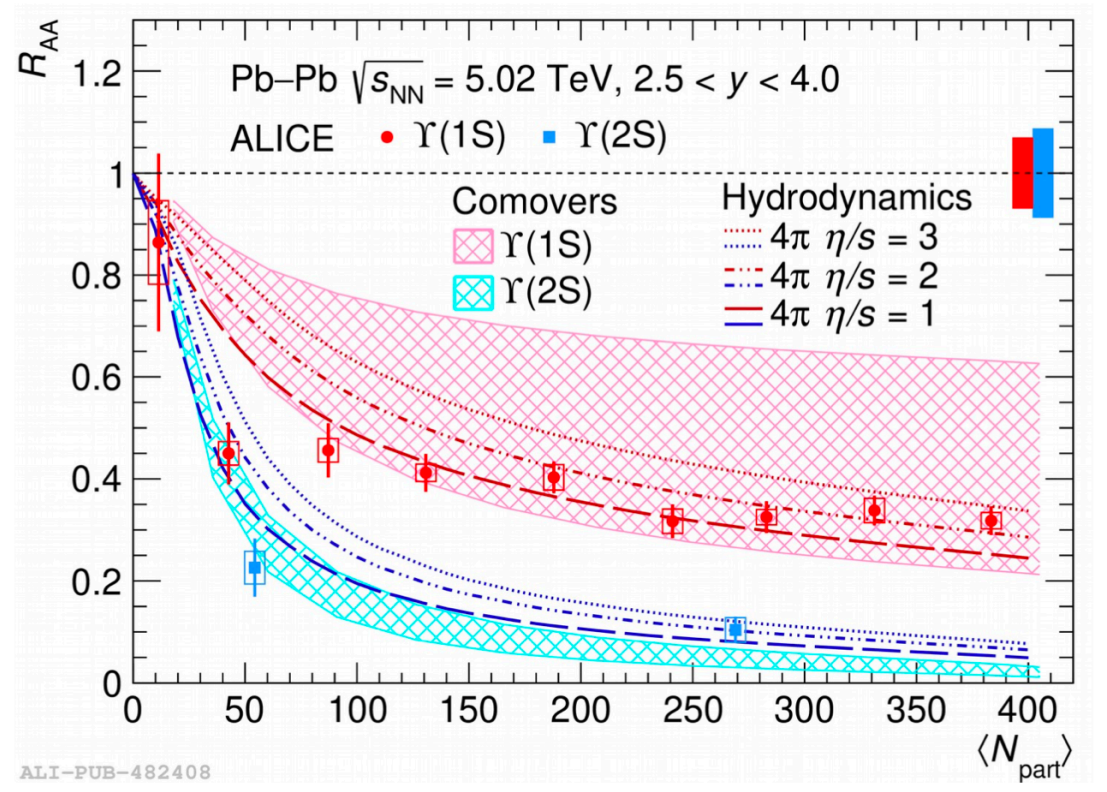




- Suppression at forward *y* relative to mid-*y* at low p_T
- Statistical hadronization model describes the data at low p_T
- Transport model agrees with data for all p_T

- The statistical hadronization model and transport model can describe the data within the uncertainties

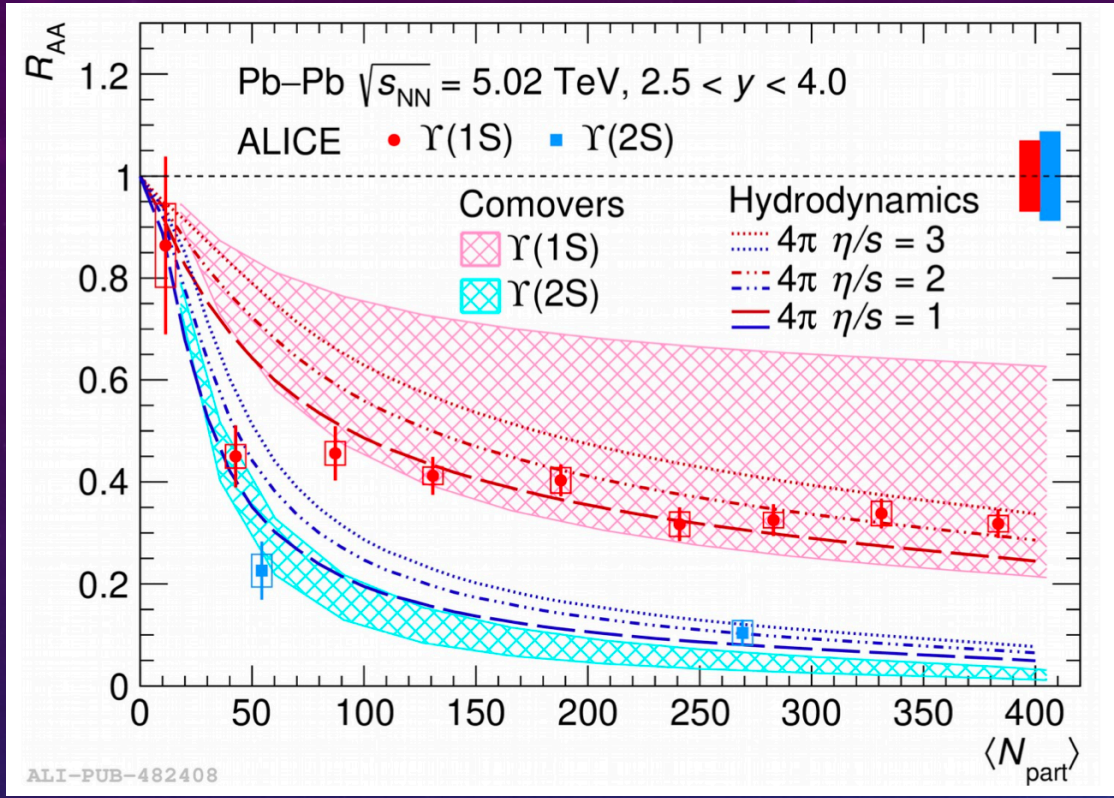
Υ(nS) Nuclear modification factor

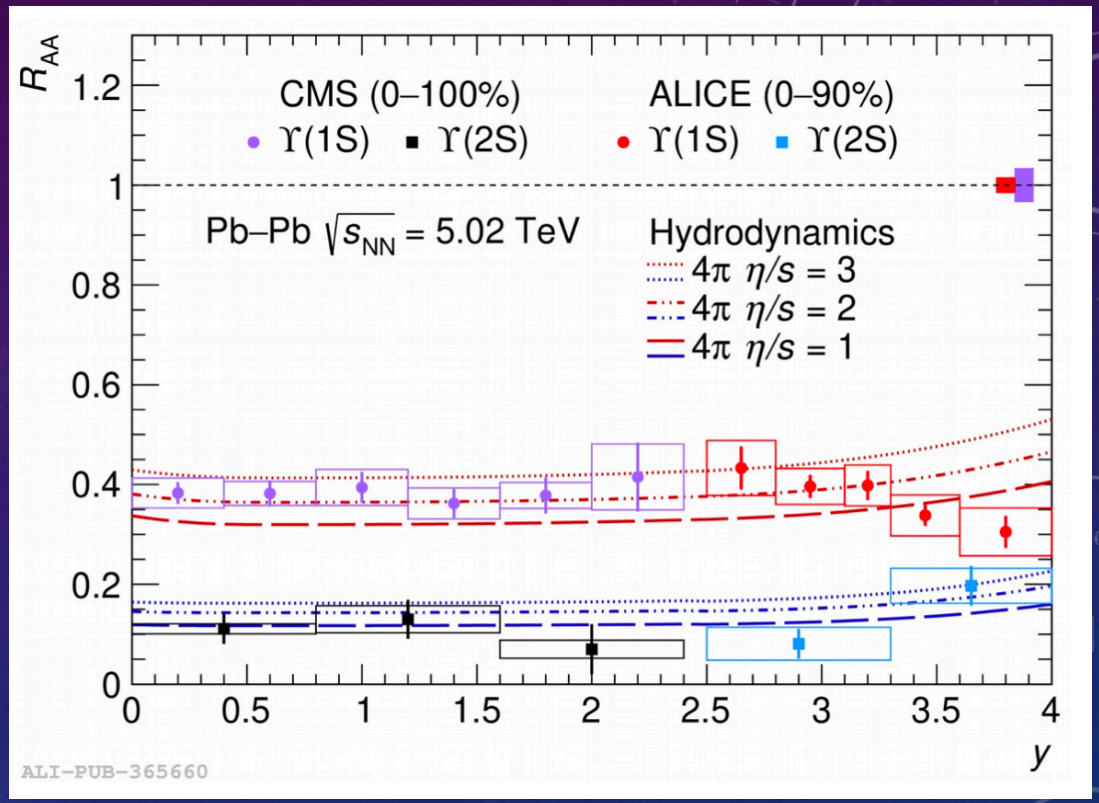


arXiv:2011.05758

- Strong suppression of Υ(1S) with respect to elementary collisions
- Comovers, Hydro models describe the data well as a function of centrality

ϒ(nS) Nuclear modification factor





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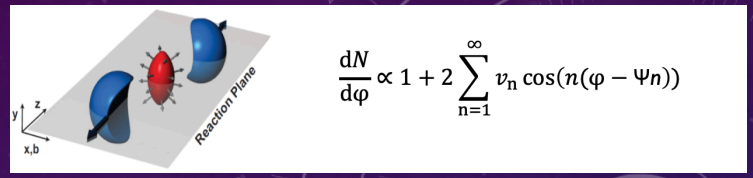
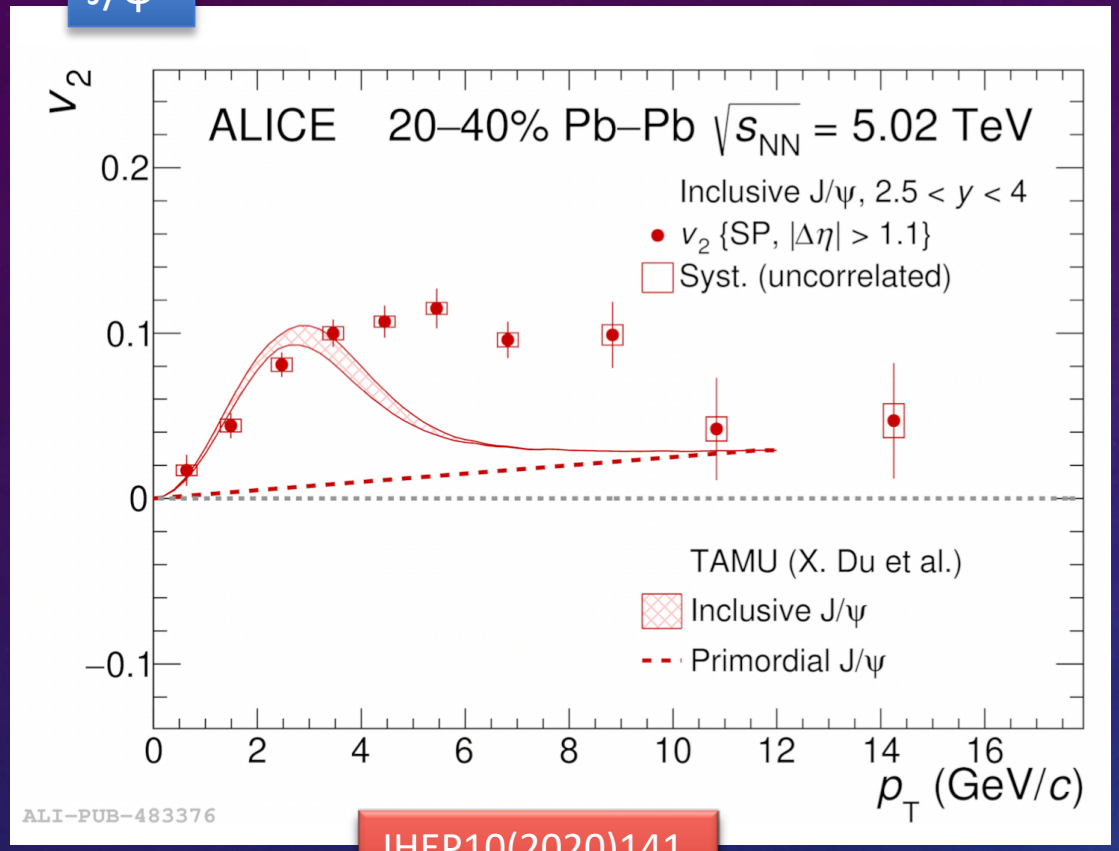
- Strong suppression of ϒ(1S) with respect to elementary collisions
- Comovers, Hydro models describe the data well as a function of centrality

- The R_{AA} of ϒ(1S) at midrapidity almost flat -> decreases at forward rapidity
- For ϒ(2S), the rapidity dependence is flat within the uncertainties

J/ψ and ϒ(1S) v_2 (Forward-y)

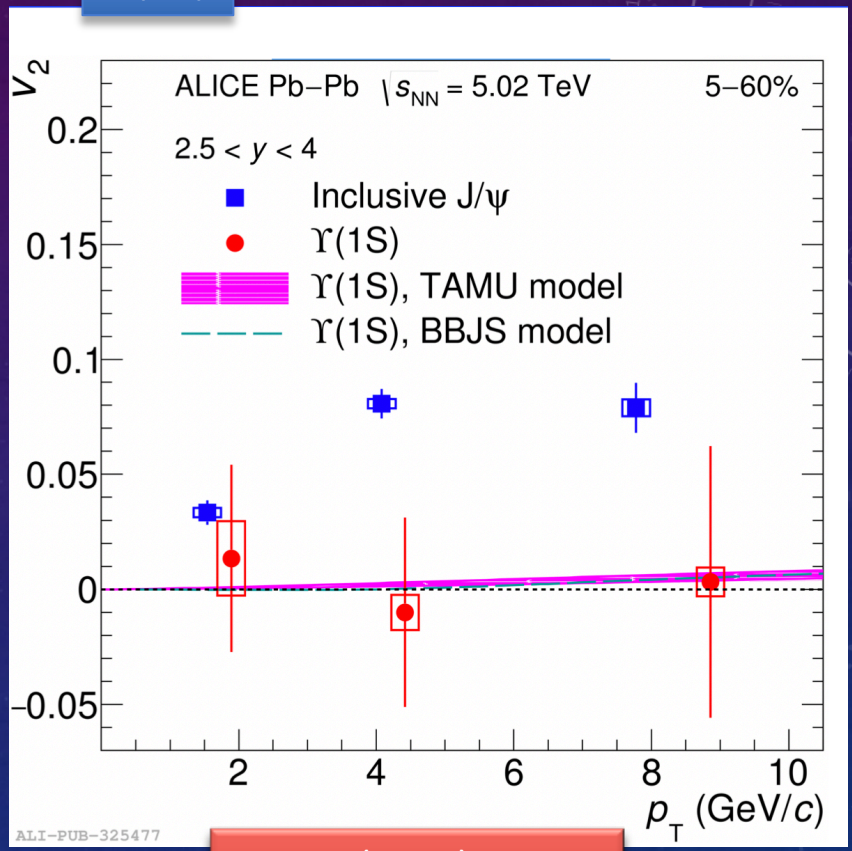


J/ψ



JHEP10(2020)141

ϒ(1S)

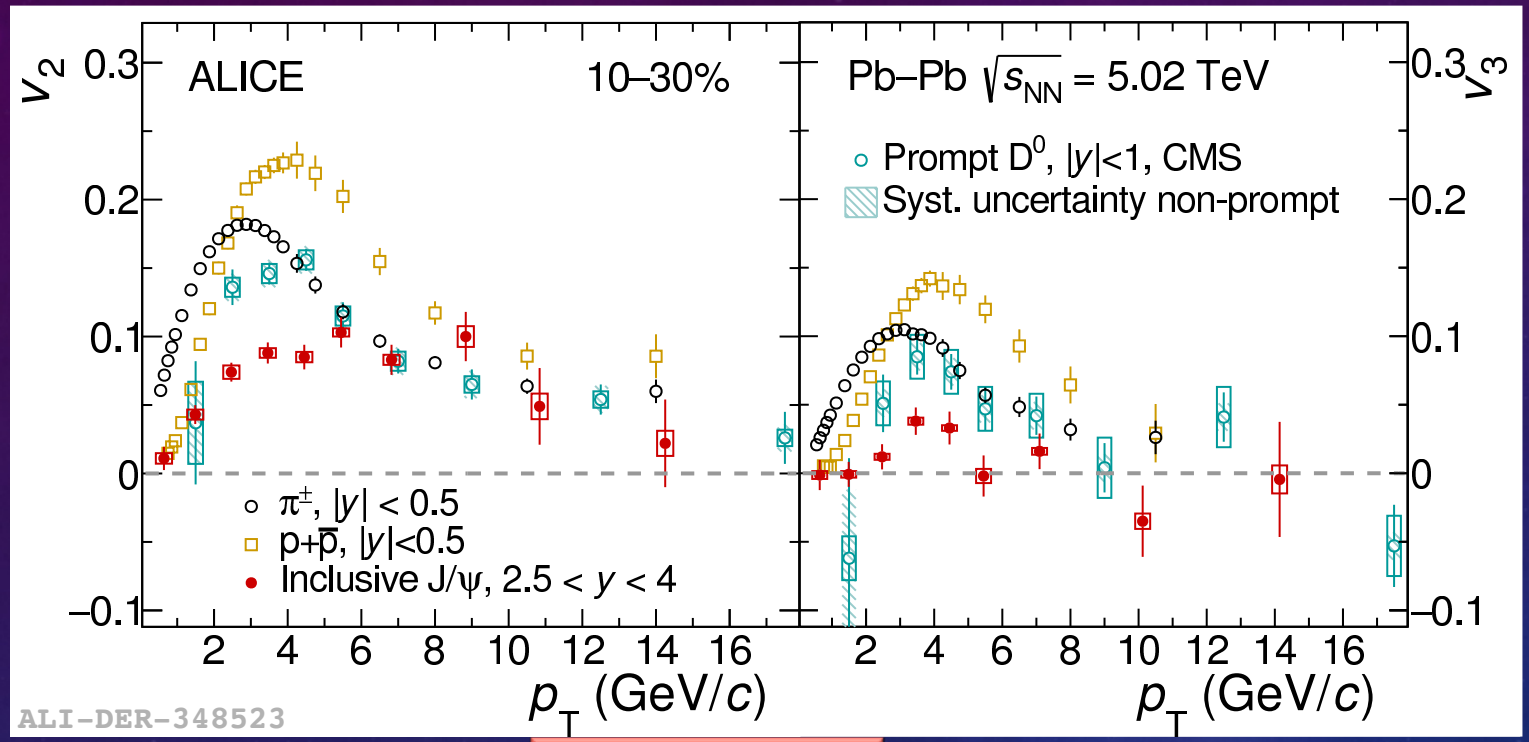


PRL123(2019)192301

- Observation of positive J/ψ v_2, agreement with transport model at low p_T, suggests charm quark thermalisation
- The ϒ(1S) v_2 is consistent with zero and lower than J/ψ v_2 by 2.6σ

TM: Nucl.Phys.A 943(2015)147-158
BBJS: Phys. Rev. C **100**, 051901(R)

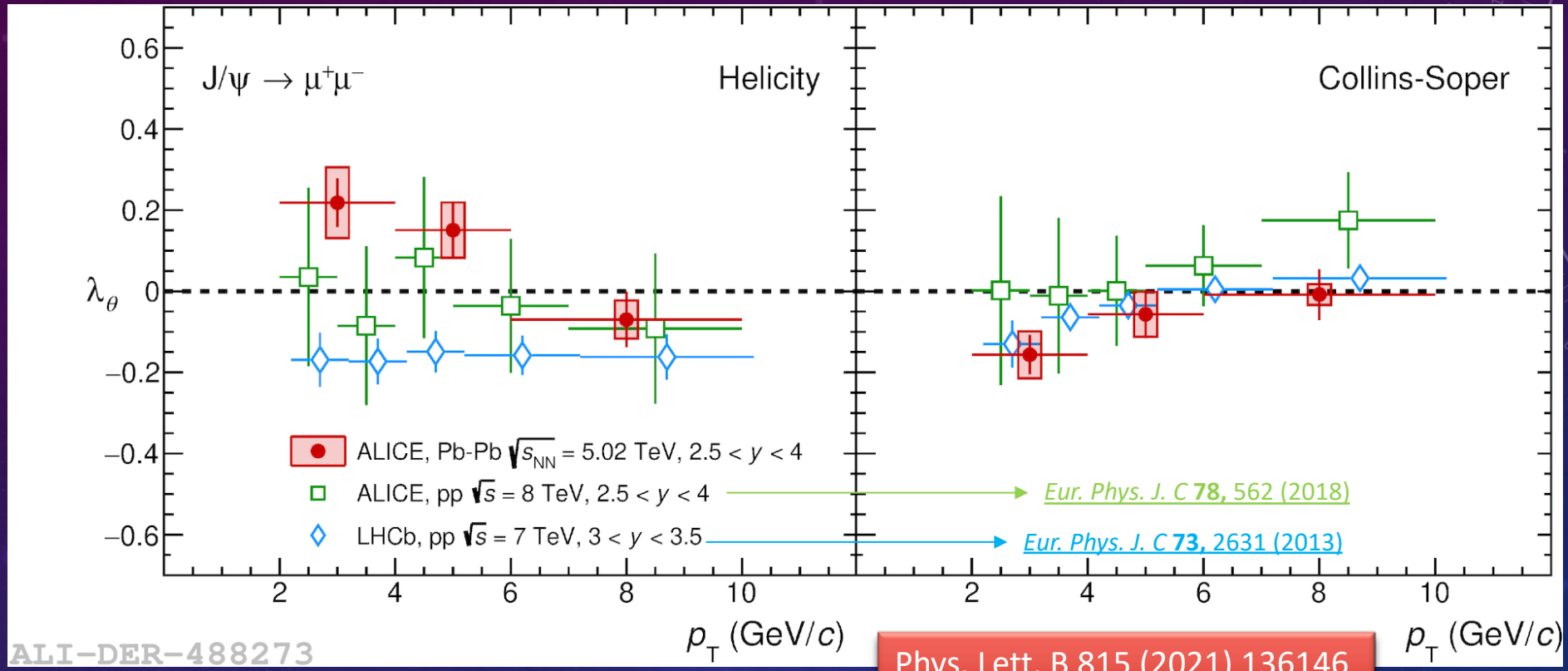
J/ψ v_2 and v_3



JHEP10(2020)141

- Clear mass hierarchy at low p_T: $v_2(\pi) > v_2(D) > v_2(J/\psi)$
- Similar behaviour for v_3
- v_2 grows from central to semi-central collisions

J/ψ Polarisation vs p_T



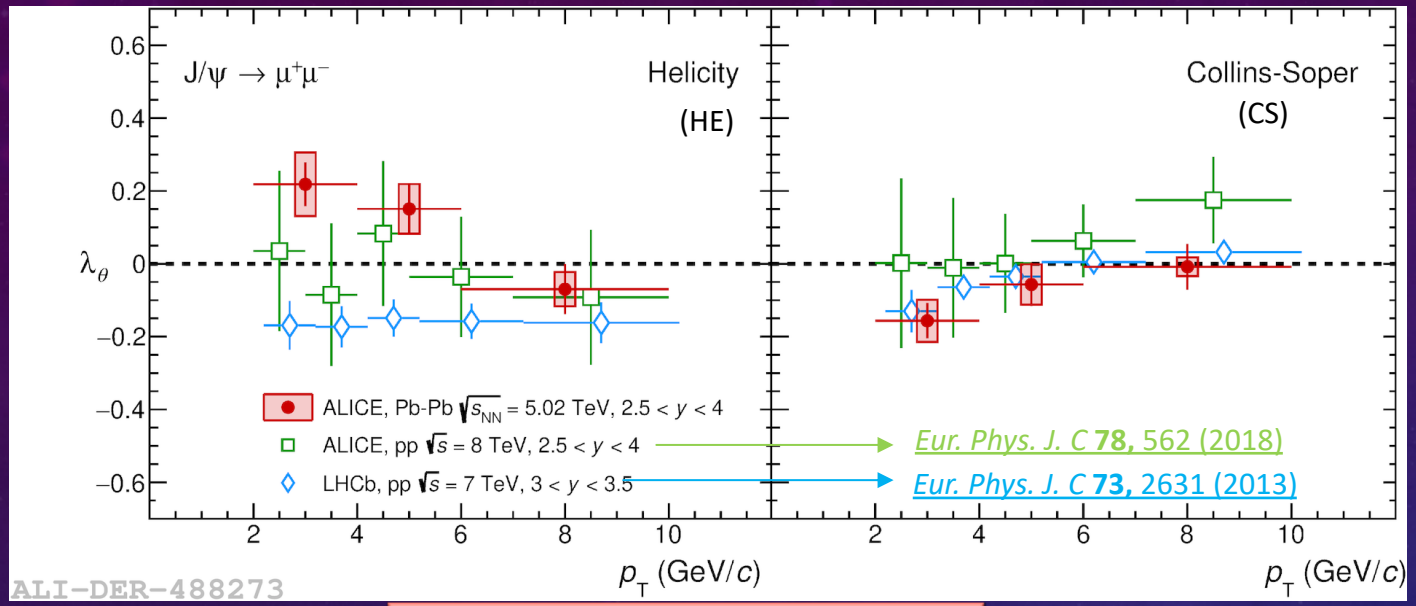
Phys. Lett. B 815 (2021) 136146

Polarisation: spin alignment w.r.t a chosen direction

$$W(cos\theta, \phi) \propto \frac{1}{3+\lambda_\theta}(1 + \lambda_\theta cos^2\theta + \lambda_\phi sin^2\theta \sin 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

- First measurement of J/ψ polarization in A–A collisions

J/ψ Polarisation vs p_T



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- λ_θ, λ_Φ, $\lambda_{\theta\Phi}$ close to zero in HE and CS frames in Pb-Pb:
  - Maximum deviation of ~ 2σ in the low-p_T bin
  - Indication of small transverse polarization in HE frame and small longitudinal polarization in CS frame for $2<p_T<4$GeV/c

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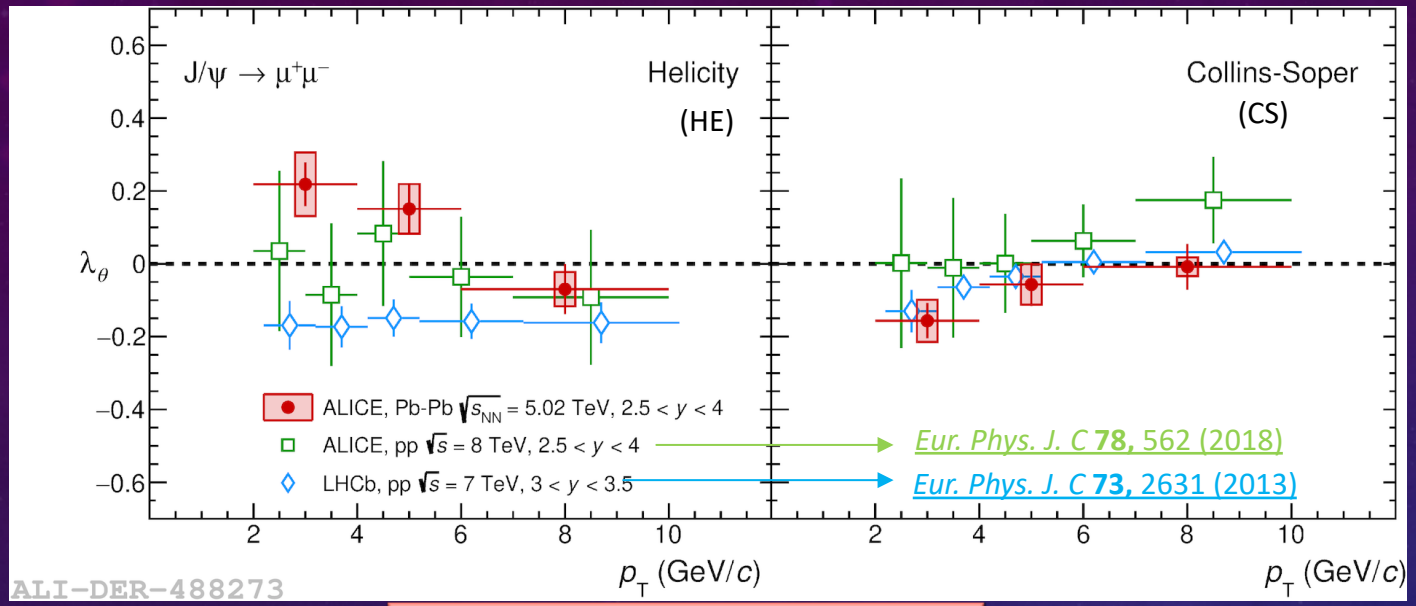

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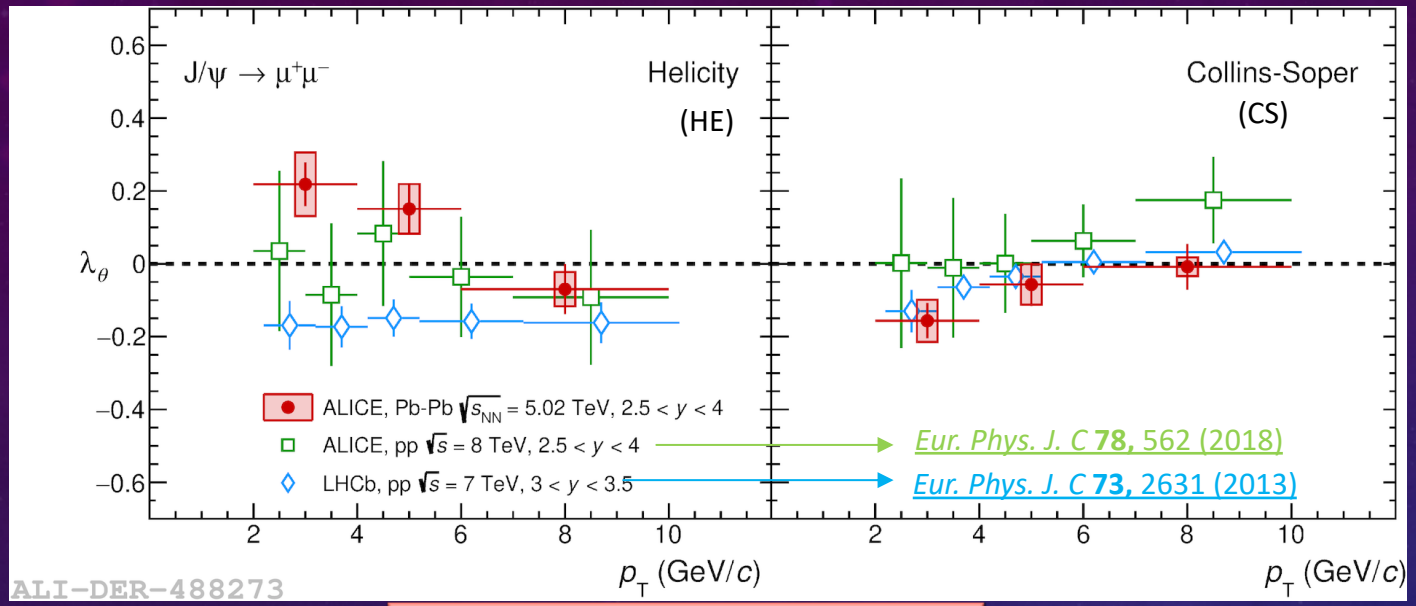
  - Significant difference for λ_θ at low p_T in HE frame with LHCb data in pp collisions at $\sqrt{s}$ = 7 TeV

J/ψ Polarisation vs p_T



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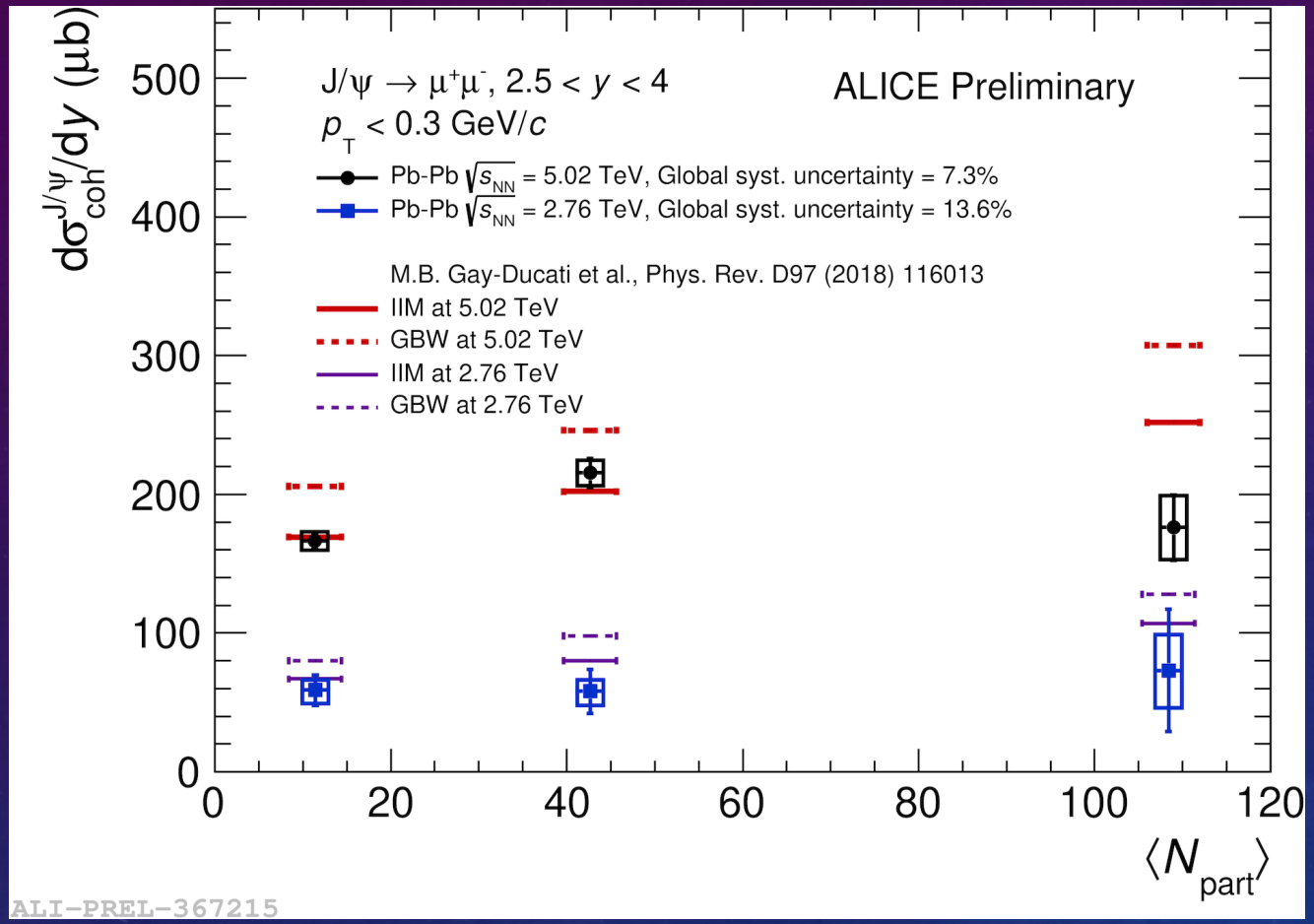
  - Significant difference for λ_θ at low p_T in HE frame with LHCb data in pp collisions at $\sqrt{s}$ = 7 TeV
- No significant centrality dependence of the J/ψ polarization
  - Polarization studies as a function of the Event Plane are ongoing

Coherent J/ψ photoproduction in Pb–Pb collision with nuclear overlap



- An excess over hadroproduction expectation in the J/ψ yield attributed to coherent photoproduction in peripheral and semicentral Pb–Pb collisions measured at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV
- Ultra peripheral collisions (UPC)-like models with modification of the photon flux can reproduce the peripheral data.
- Need to account for modification of photonuclear cross section and various coupling scenarios for semi-central events

Yvonne Pachmayer 27/07 9:30 T06

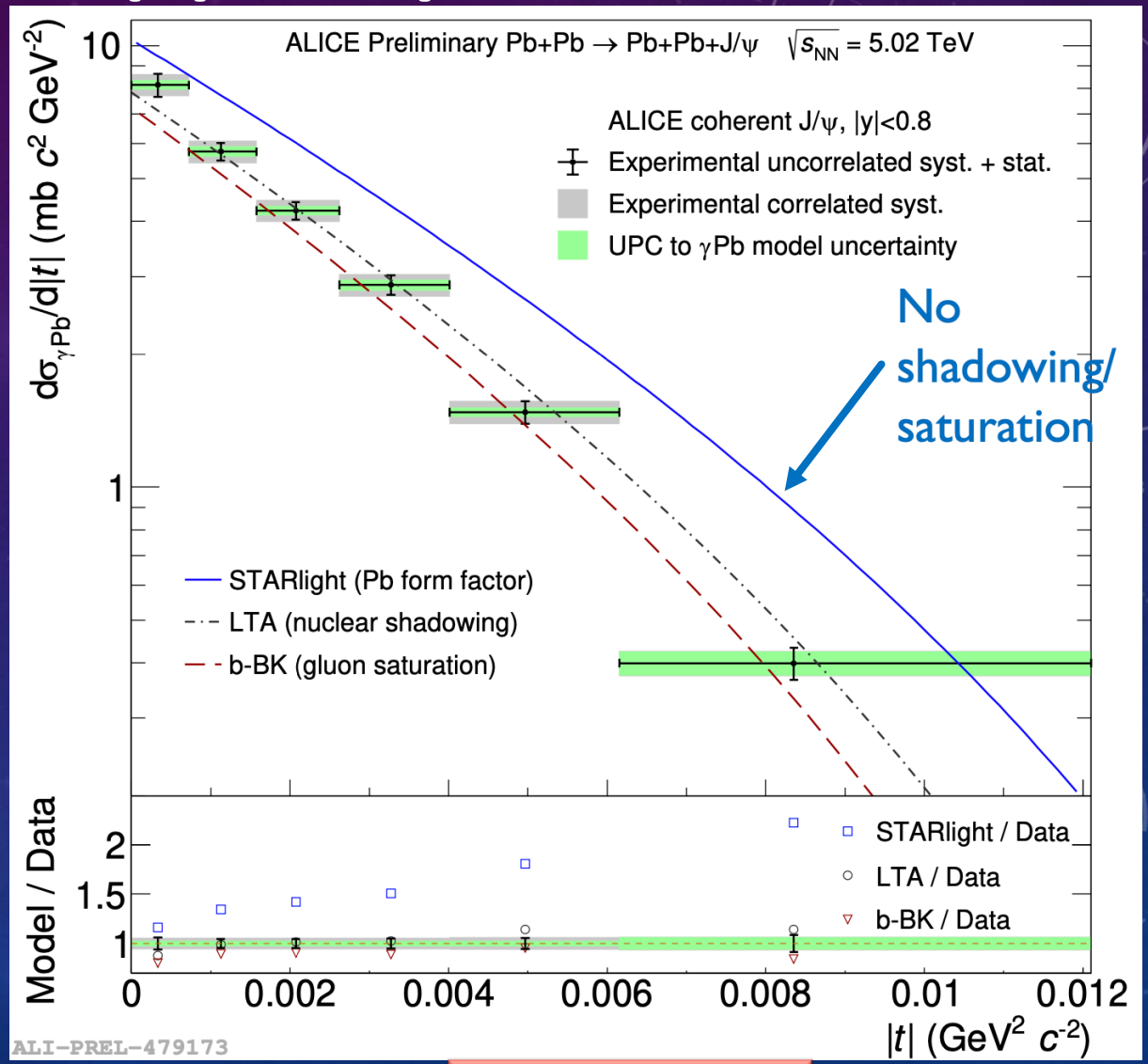
Ultra-peripheral Collisions(UPC)

$|t|$ dependence of coherent J/ψ photoproduction

- The first measurement ever of the $|t|$-dependence of the J/ψ photonuclear production cross section
- $|t|$ obtained from J/ψ p_T^2 measurement + unfolding

$$\left.\frac{\mathrm{d}^2\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}^2}\right|_{y=0} = 2n_{\gamma\mathrm{Pb}}(y=0)\frac{\mathrm{d}\sigma_{\gamma\mathrm{Pb}}}{\mathrm{d}|t|}.$$

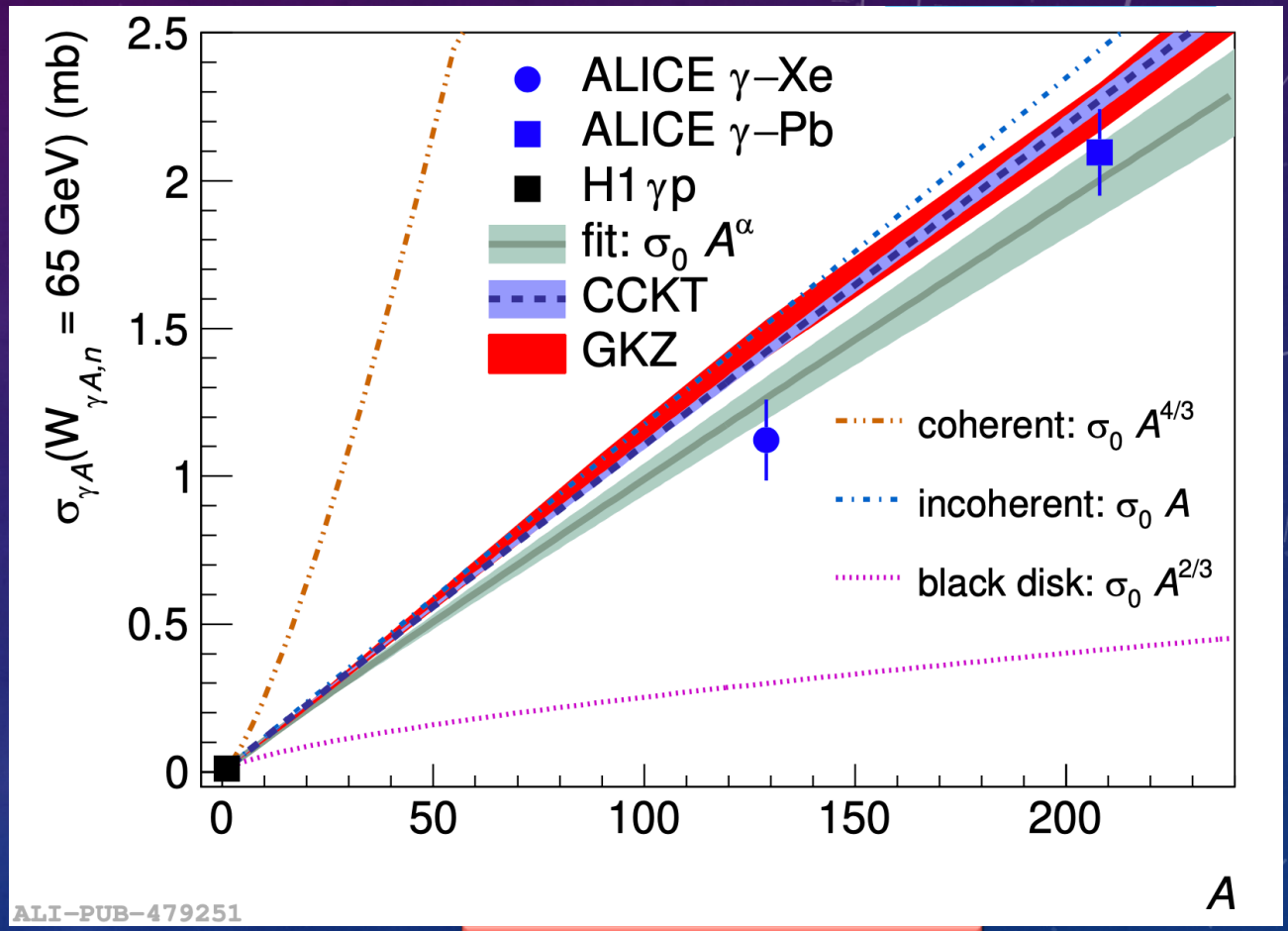
- STARLIGHT calculation (Pb form factor) without shadowing/saturation overpredicts the data
- Models incorporating nuclear shadowing (LTA) or gluon saturation (b-BK) describe well the data



arXiv:2101.04623v1

Atomic Mass Number (A) dependence of coherent ρ_0 photoproduction

- The **A** dependence of the ρ_0 photonuclear cross section explored with two collision systems: Xe–Xe and Pb–Pb
- Measured slope of cross section with A:
  - Approximately linear
  - Close to model with strong nuclear effects (GKZ, CCKT)



Phys. Lett. B (2021) 136481

Conclusions

J/ψ

- Increasing precision in measurements of R_{AA} confirming the regeneration picture
- Transport model underestimates v_2 at intermediate/high p_T
- First measurement of close to zero polarisation

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Υ(nS)

- Strong suppression for Υ(1S) and Υ(2S) in Pb–Pb collisions
- Measurements consistent with zero v_2 for Υ(1S)

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ϒ(nS)

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- Measurements consistent with zero v_2 for ϒ(1S)

Photoproduction

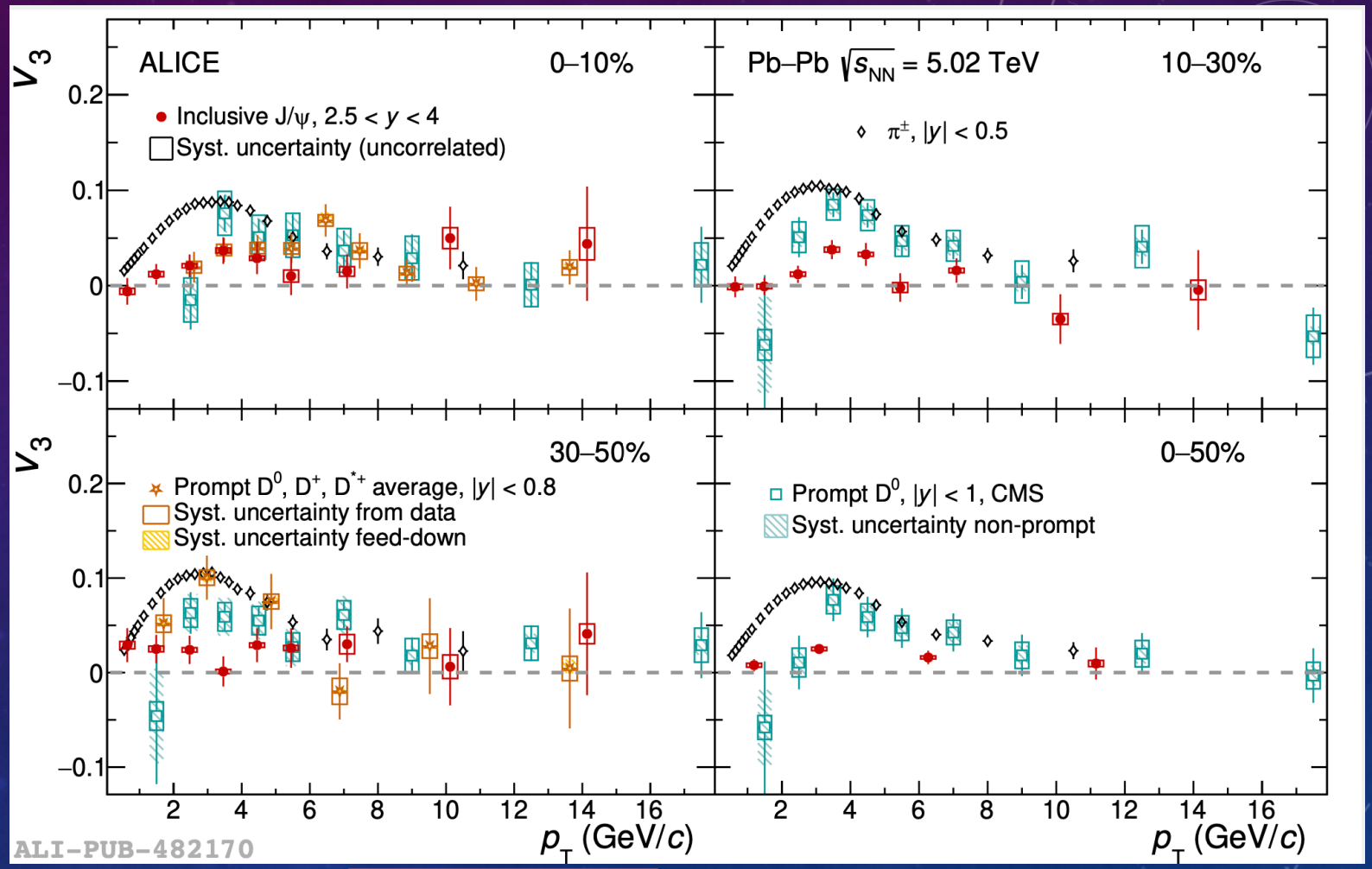
- First measurement of $|t|$ dependence of J/ψ production -> described by models with gluon saturation or nuclear shadowing
- Excess J/ψ in Pb–Pb collisions can be attributed to photoproduction
- ρ_0 production found to have linear depedendence with A

Thank You

Back-Up slides

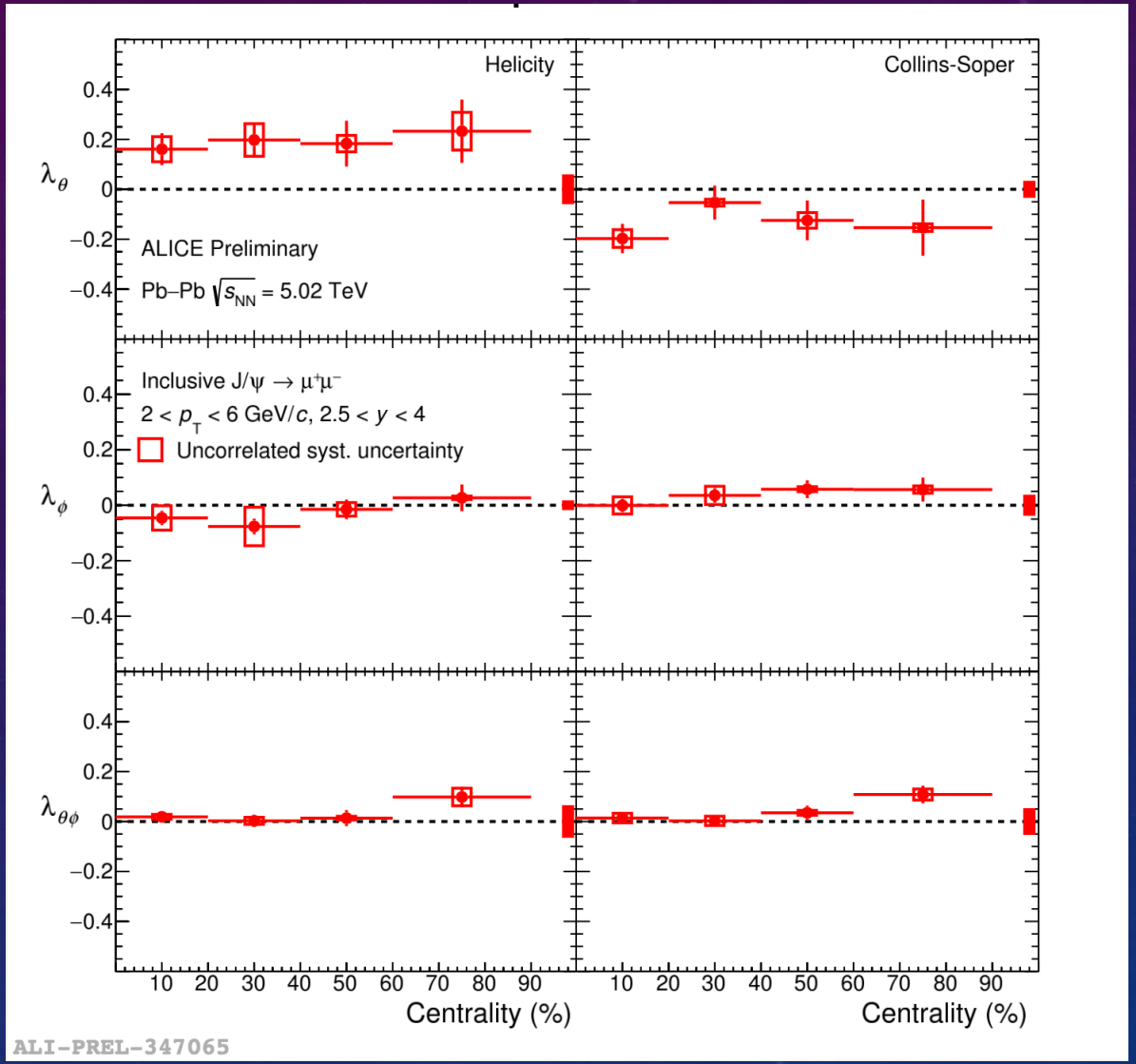
J/ψ Triangular Flow (v_3) (forward y)

- v_3 is sensitive to initial state energy-density fluctuations
- Inclusive J/ψ v_3 positive in most of the p_T and centrality intervals
- Same mass hierarchy as for v_2 :
  $v_3(\pi) > v_3(D) > v_3(J/\psi)$

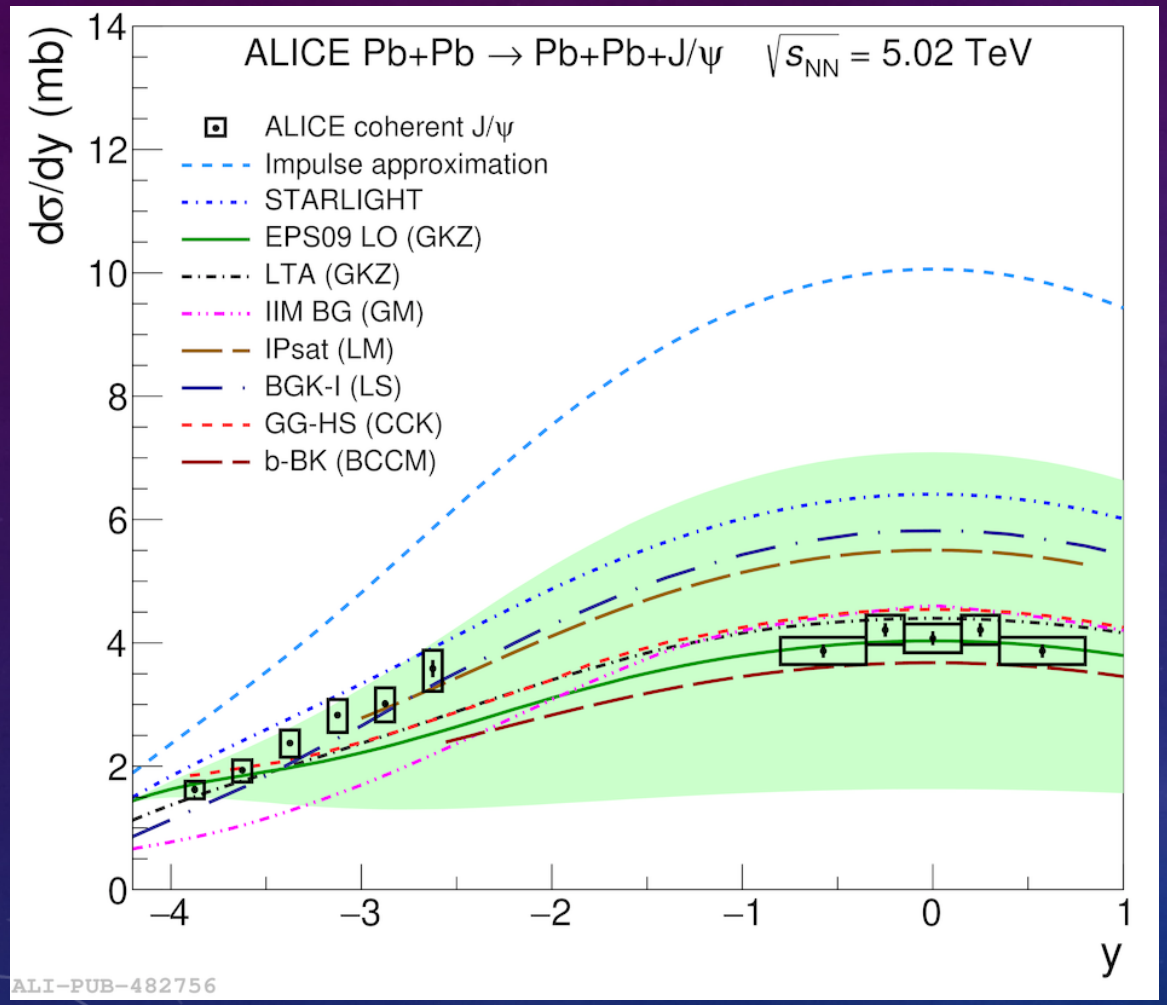


JHEP10(2020)141

J/ψ Polarisation vs Centrality



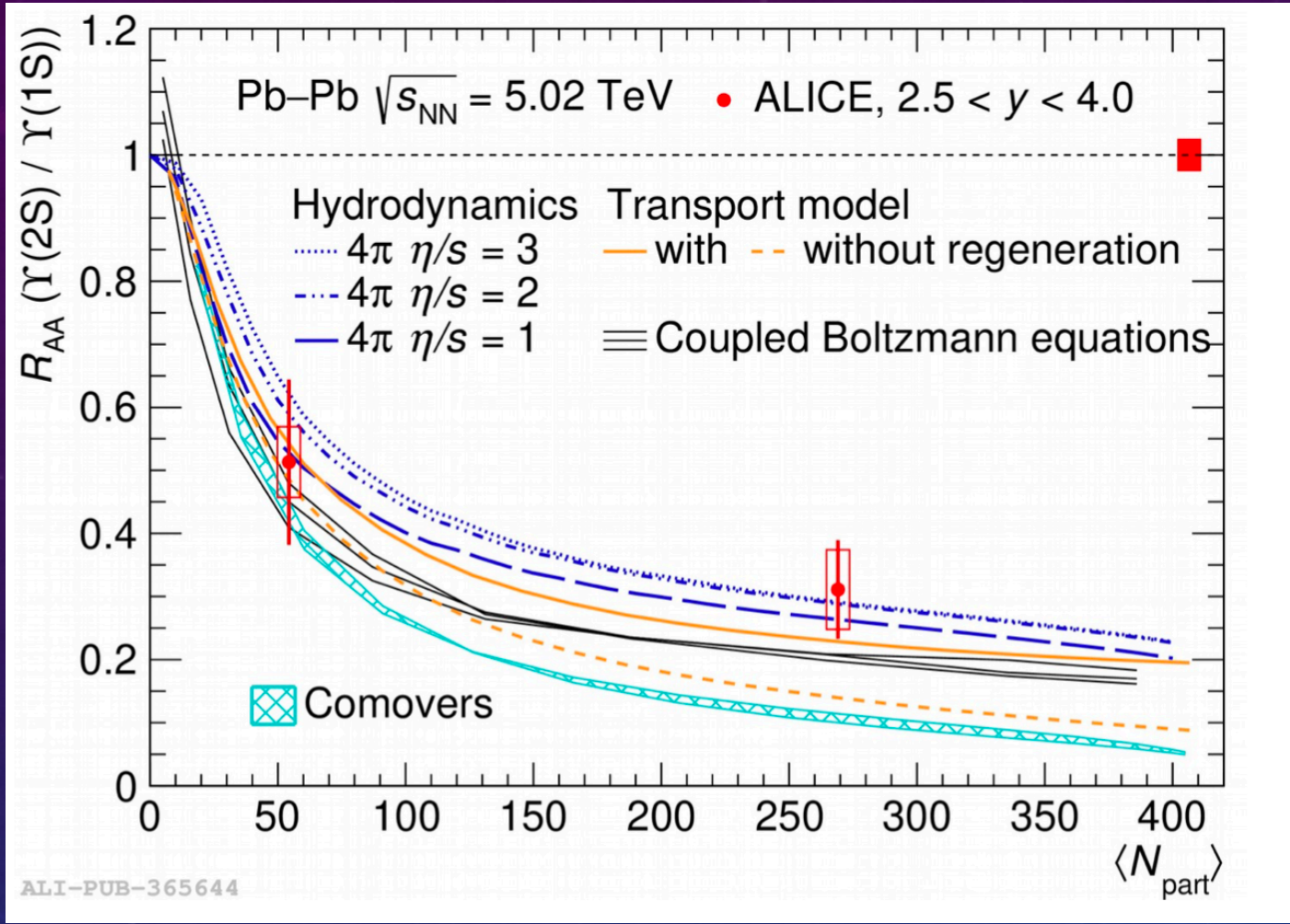
y dependence of coherent J/ψ photoproduction



- Comparison of data to impulse approximation (no nuclear effects) leads to a nuclear suppression factor S_{Pb}(x ~10-3) ~ 0.65 ± 0.03
- STARLIGHT model (no gluon shadowing) overpredicts the data
- GKZ with EPS09 shadowing and the GG-HS agree with data at forward and midrapidity, but not at semi-forward rapidity (2. 5 < *y* < 3. 5)

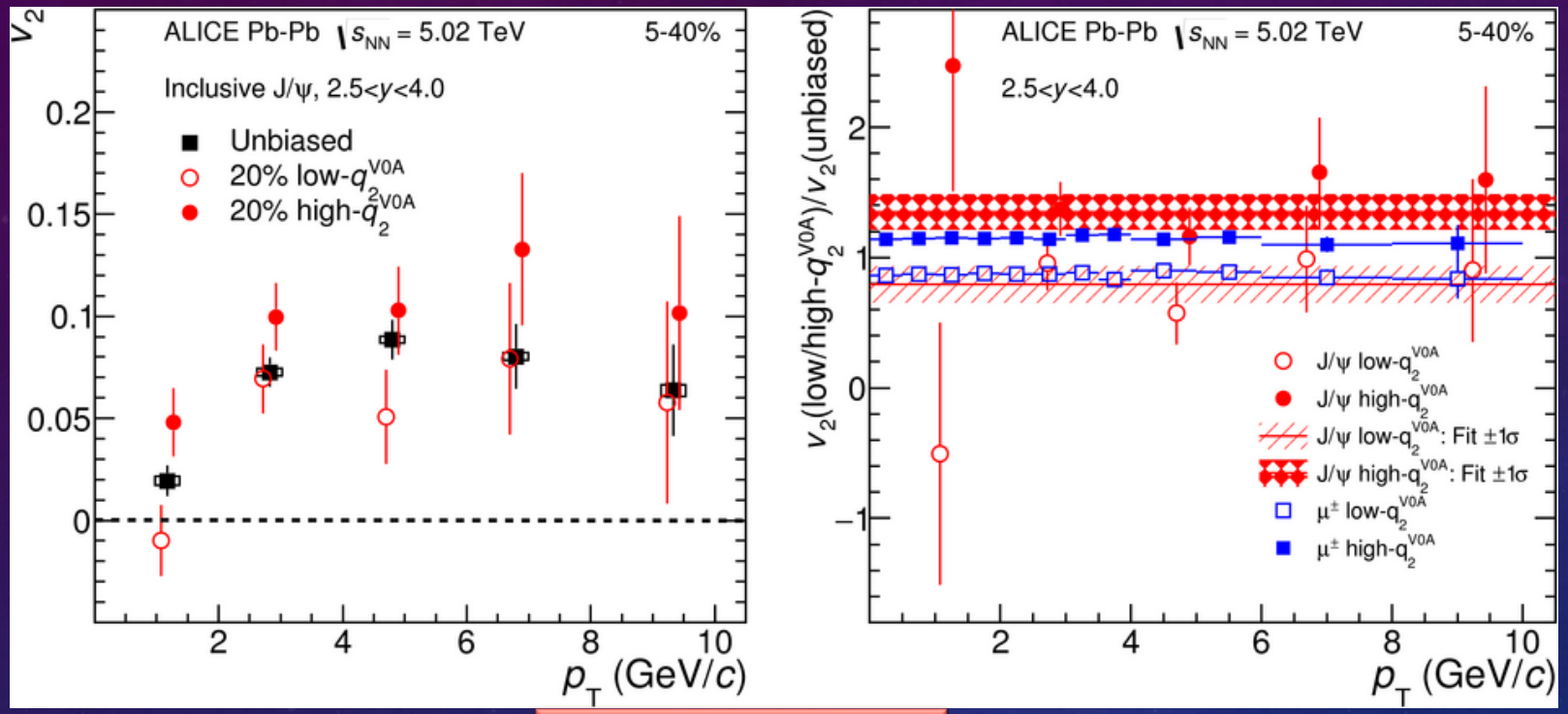
arXiv:2101.04577v1

Υ(nS) R_{AA} Ratio



- Excited-to-ground state R_{AA} ratios are in agreement with Hydro calculations, Transport model and coupled Boltzmann equations
- Underestimation by comovers model for most central collisions

J/ψ Polarisation as Event-Shape Engineering



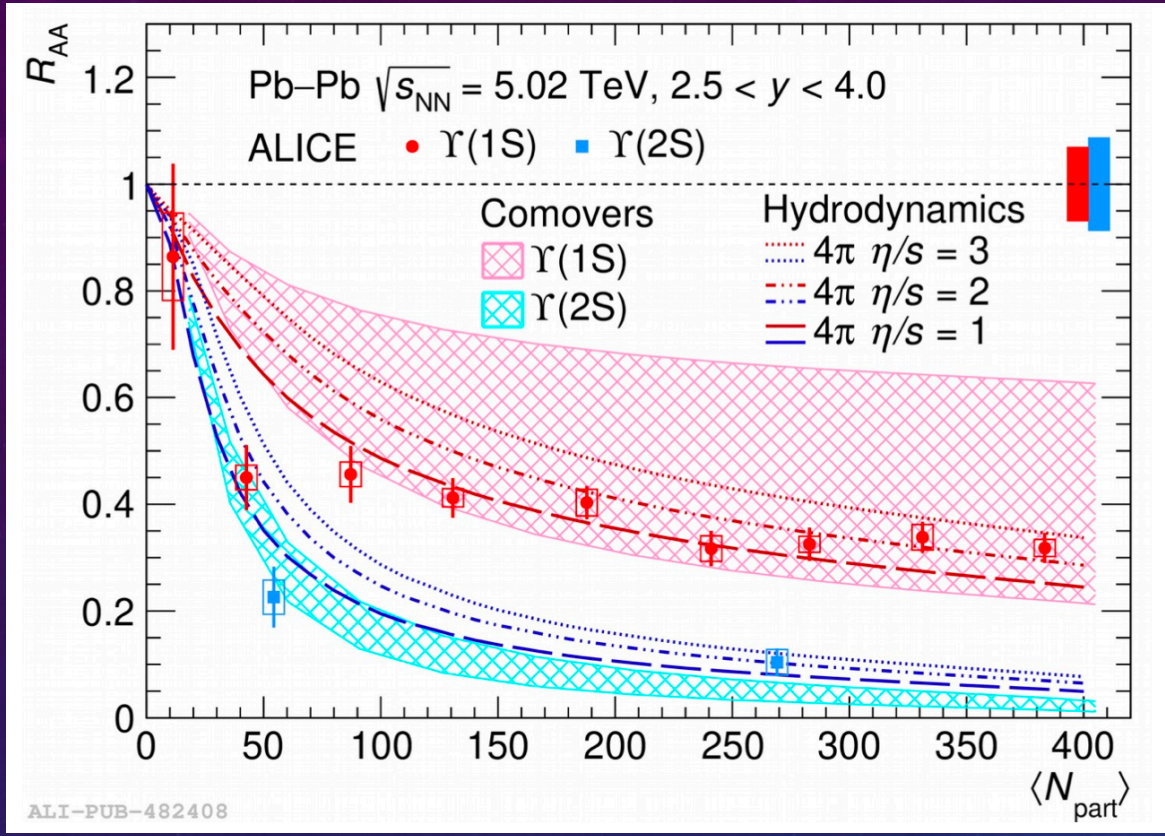
JHEP 1902 (2019) 012

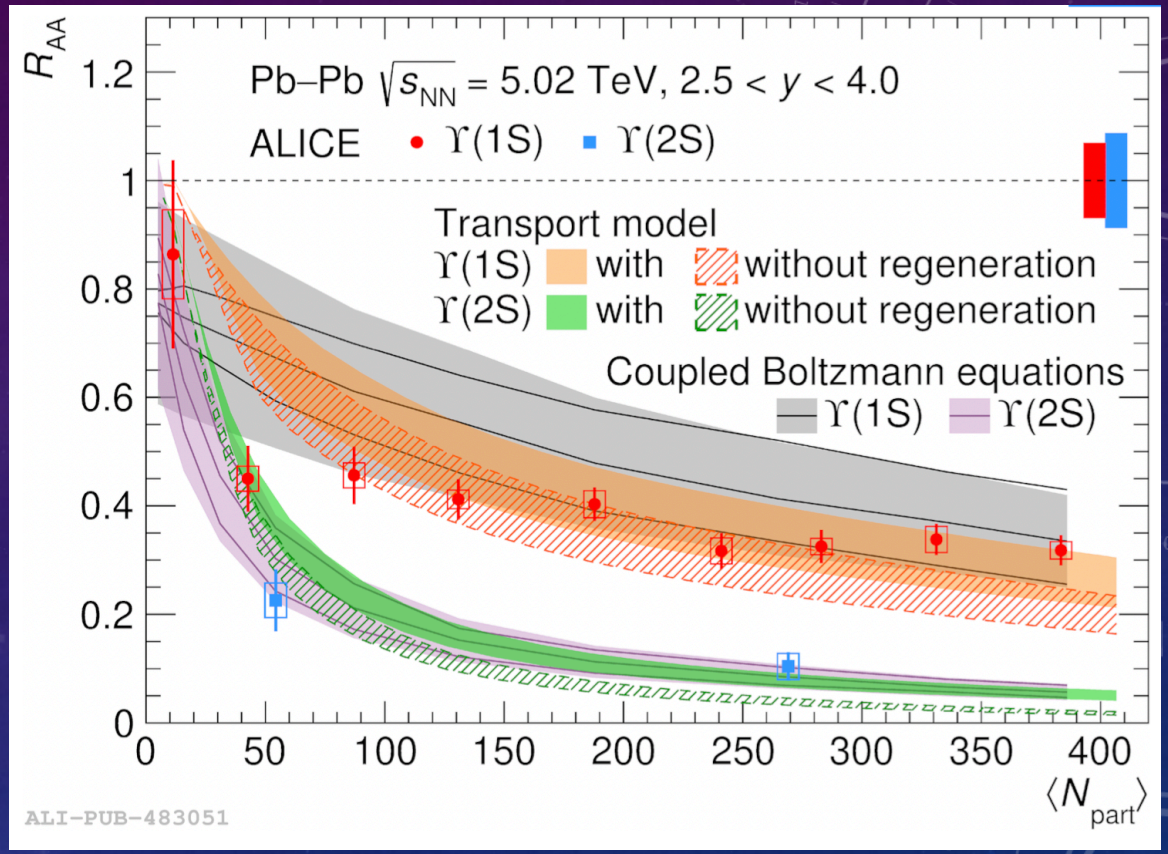
- J/ψ v_2 coefficient in low (high) q_2^{V0A} event classes are found to be lower (higher) with respect to those in the unbiased events

- Ratios in the event-shape selected and unbiased events show no p_T dependence up to 10 GeV/c

- J/ψ v_2 results compatible with the expected variations of the eccentricity of the initial-state geometry within the uncertainties.

Υ(nS) R_{AA} vs centrality





- Strong suppression of Υ(1S) in the most central collisions
- R_{AA} of Υ(2S) is smaller than Υ(1S) by a factor of 3
- Comovers, Transport, Hydro models describe the data

Υ(nS) R_{AA} vs p_T and y