Quarkonium azimuthal anisotropy at forward rapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ALICE

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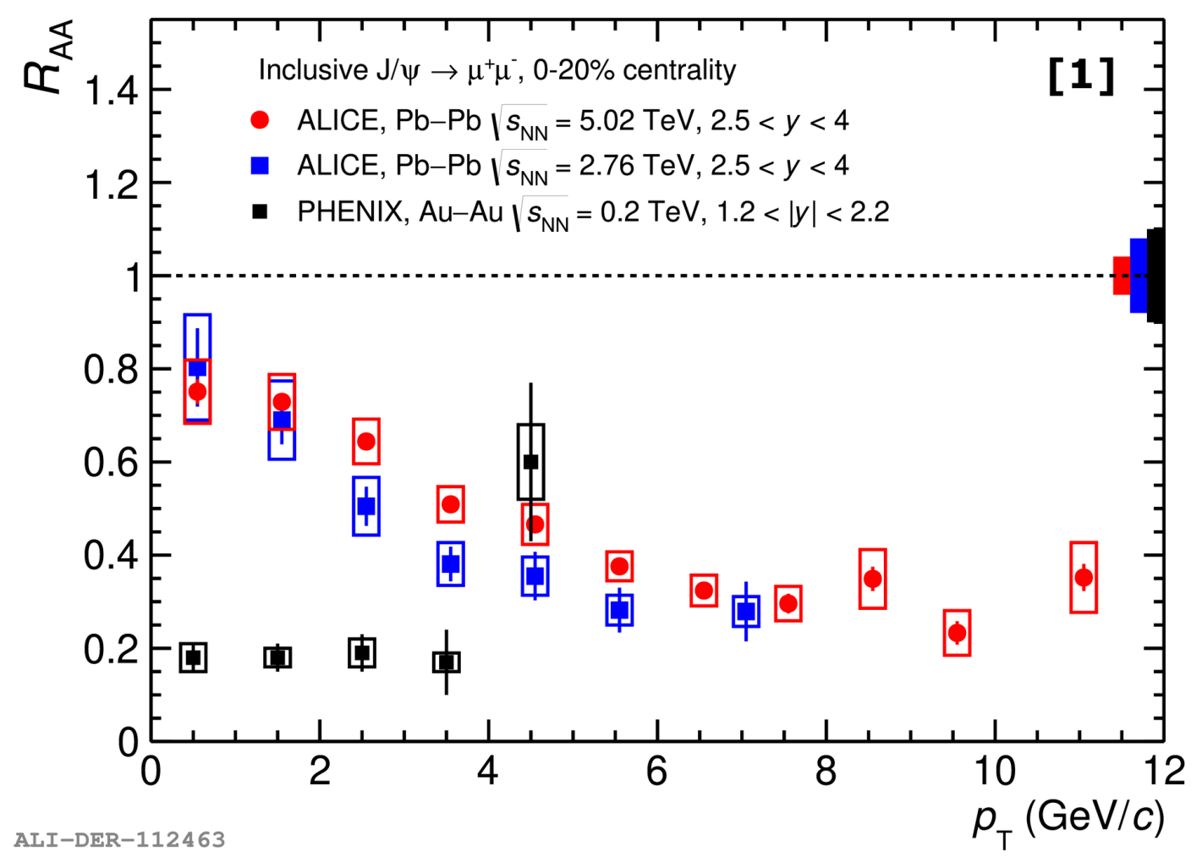
1 – Physics motivations

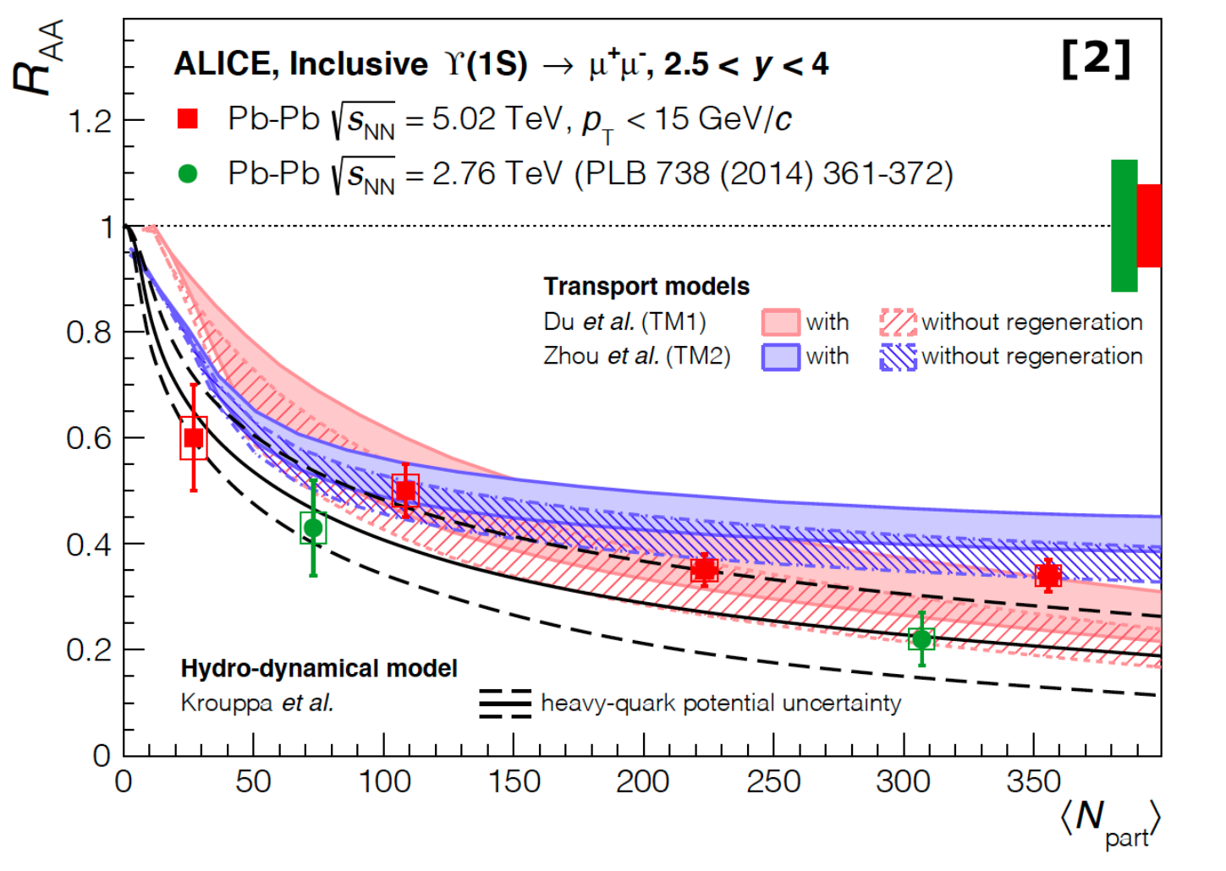
Charm and beauty created early in collisions: excellent probes of the deconfined medium. **Quarkonium** states (like J/ψ : $c\bar{c}$, or $\Upsilon(1\mathrm{S})$: $b\bar{b}$) undergo:

- **suppression**, originally due to color screening with surrounding charges
- **regeneration**, recombination of thermalized heavy quarks in the medium

Quantify by R_{AA} (> 1 enhancement, < 1 suppression, Pb–Pb w.r.t. pp collisions)

- Inclusive J/ψ mainly regenerated at low p_{T} while strongly suppressed at high p_{T} [1]

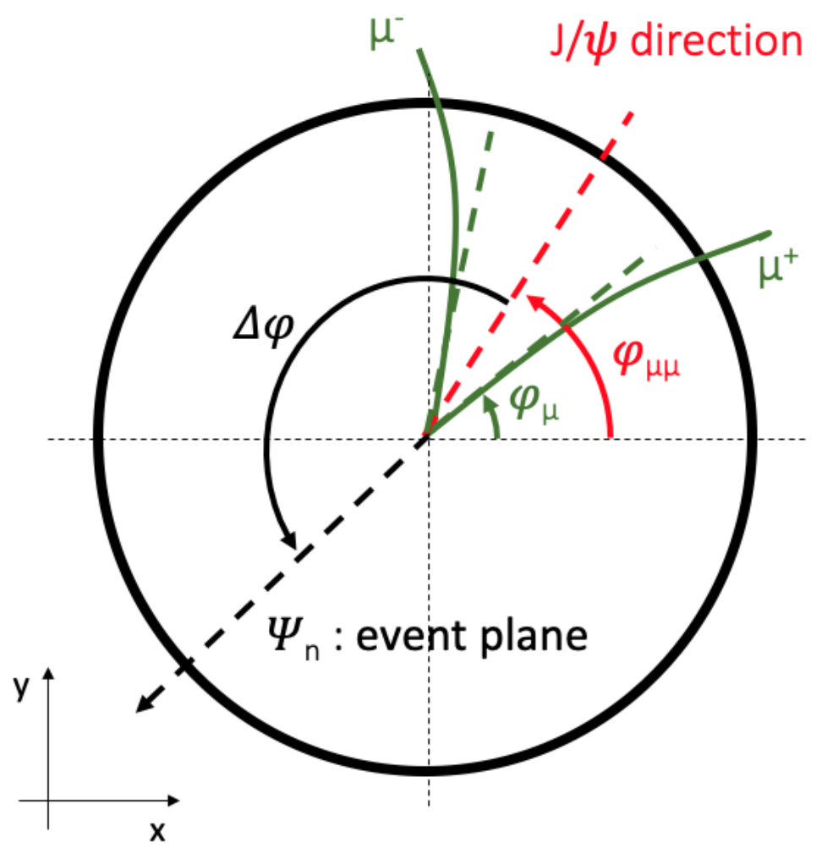


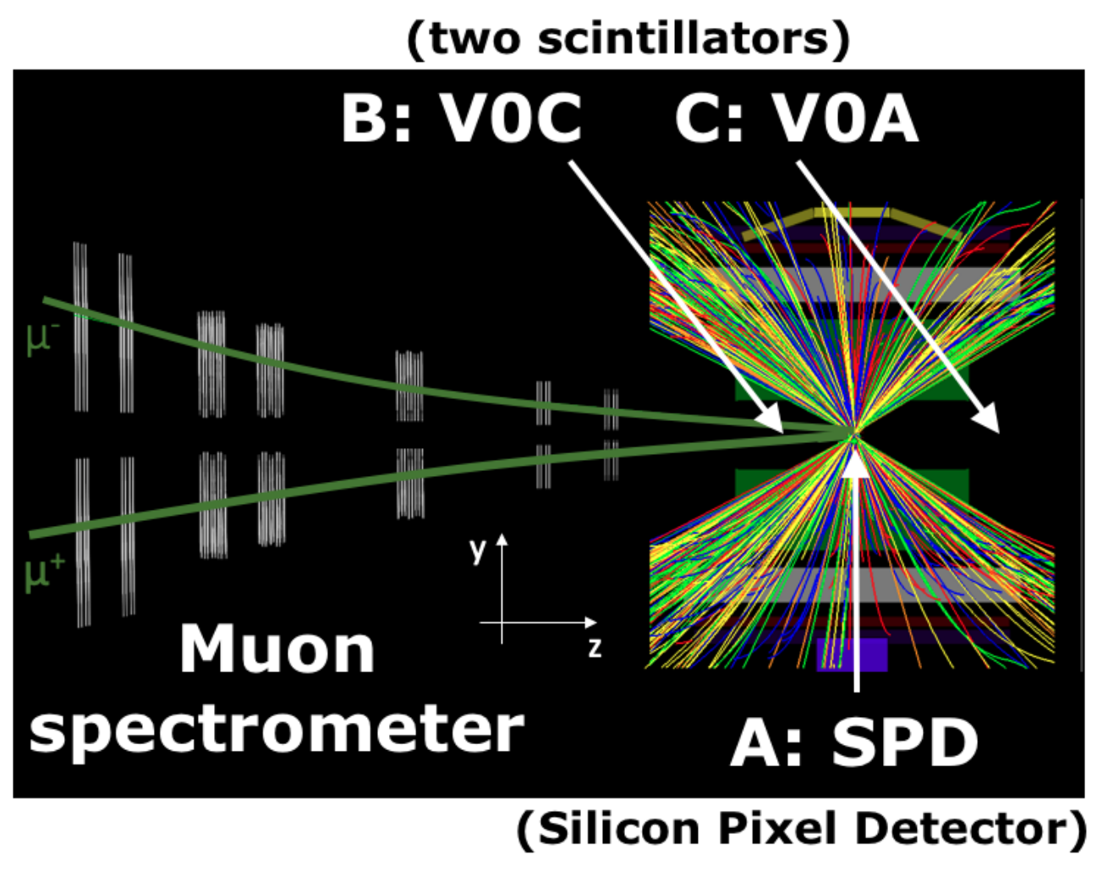


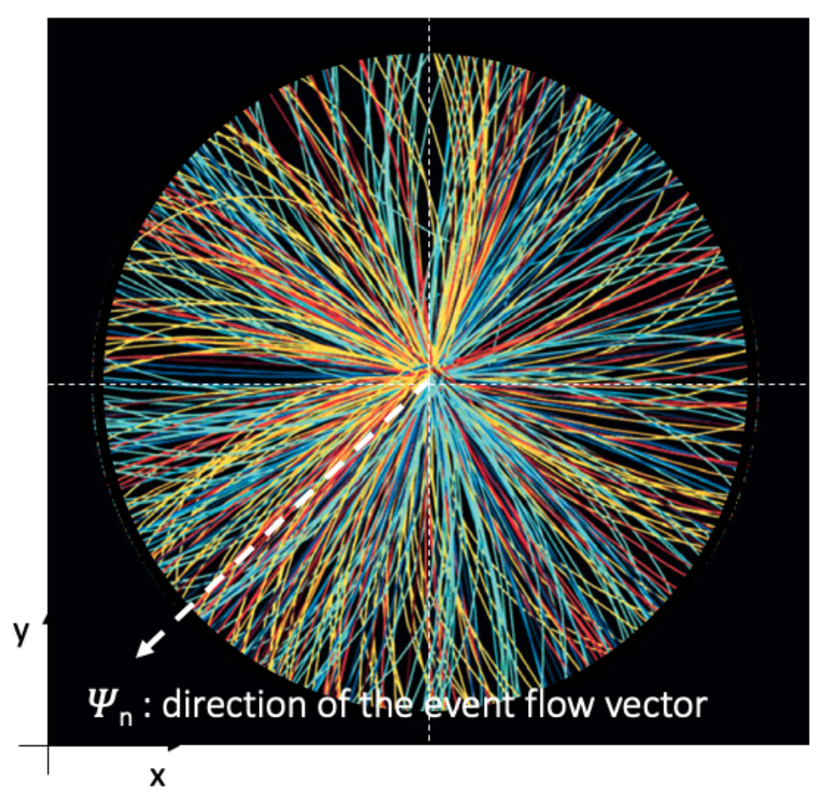
- $\Upsilon(1\mathrm{S})$ suppressed in Pb–Pb (but large fraction from feed-down) [2]

3 – ALICE experimental setup, muon and dimuon tracks reconstruction

- V0A, V0C, SPD: multiplicity, event flow vector $\mathbf{Q_n} = \sum_j e^{in\varphi_j}$, vertex
- **muon spectrometer**: quarkonia via dimuon decay channel (forward rapidity)







4 – Analysis details, signal extraction and v_n measurement

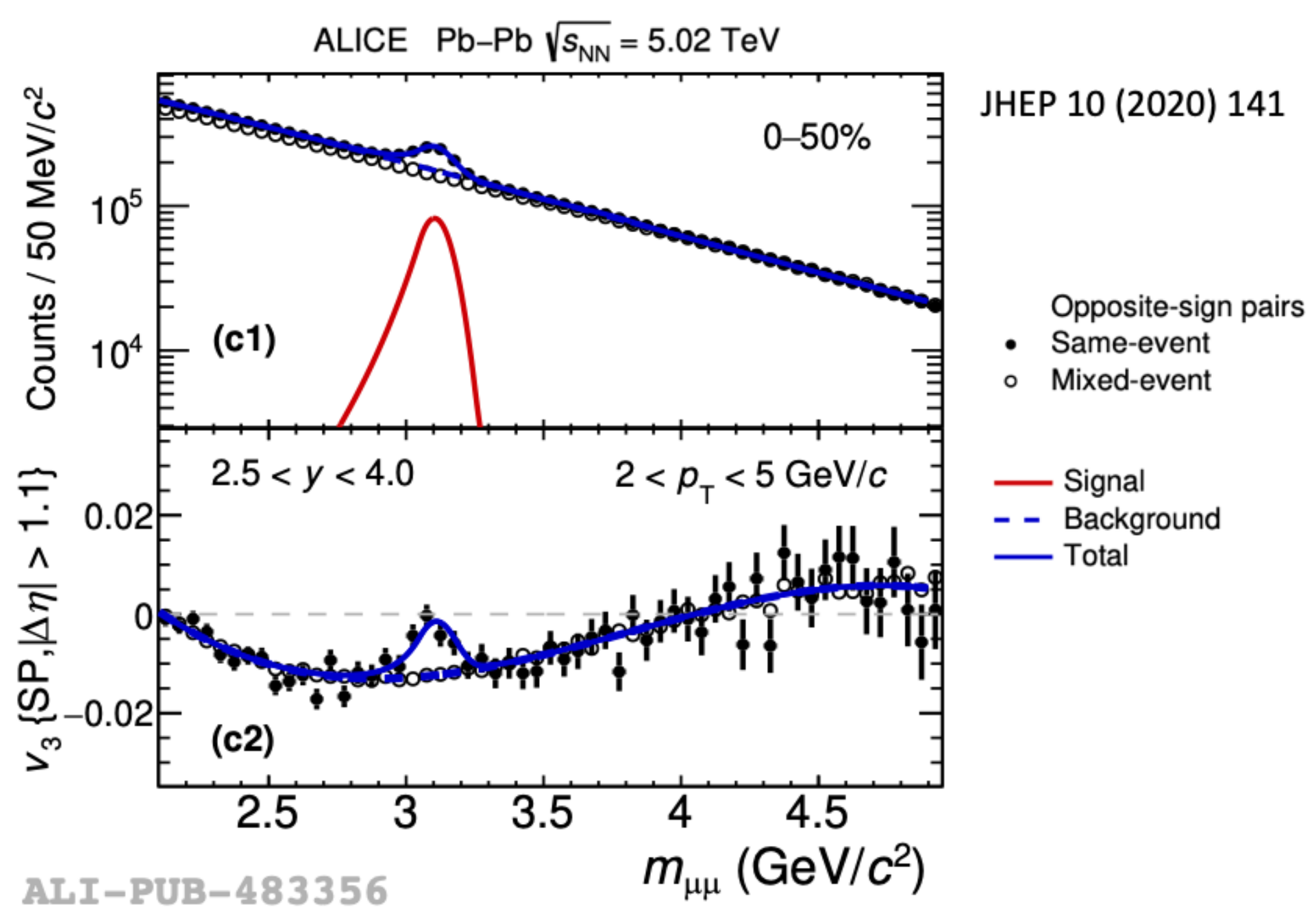
Scalar product (SP) method, three sub-event technique (A,B,C sub-detectors: SPD, V0A, V0C): suppress non-flow effects [4]:

$$v_{\mathrm{n}}\{\mathrm{SP}\} = \left\langle \mathbf{u_n Q_n^{A*}} \bigg/ \sqrt{\frac{\langle \mathbf{Q_n^A Q_n^{B*}}\rangle\langle \mathbf{Q_n^A Q_n^{C*}}\rangle}{\langle \mathbf{Q_n^B Q_n^{C*}}\rangle}} \right\rangle_{\mu\mu},$$

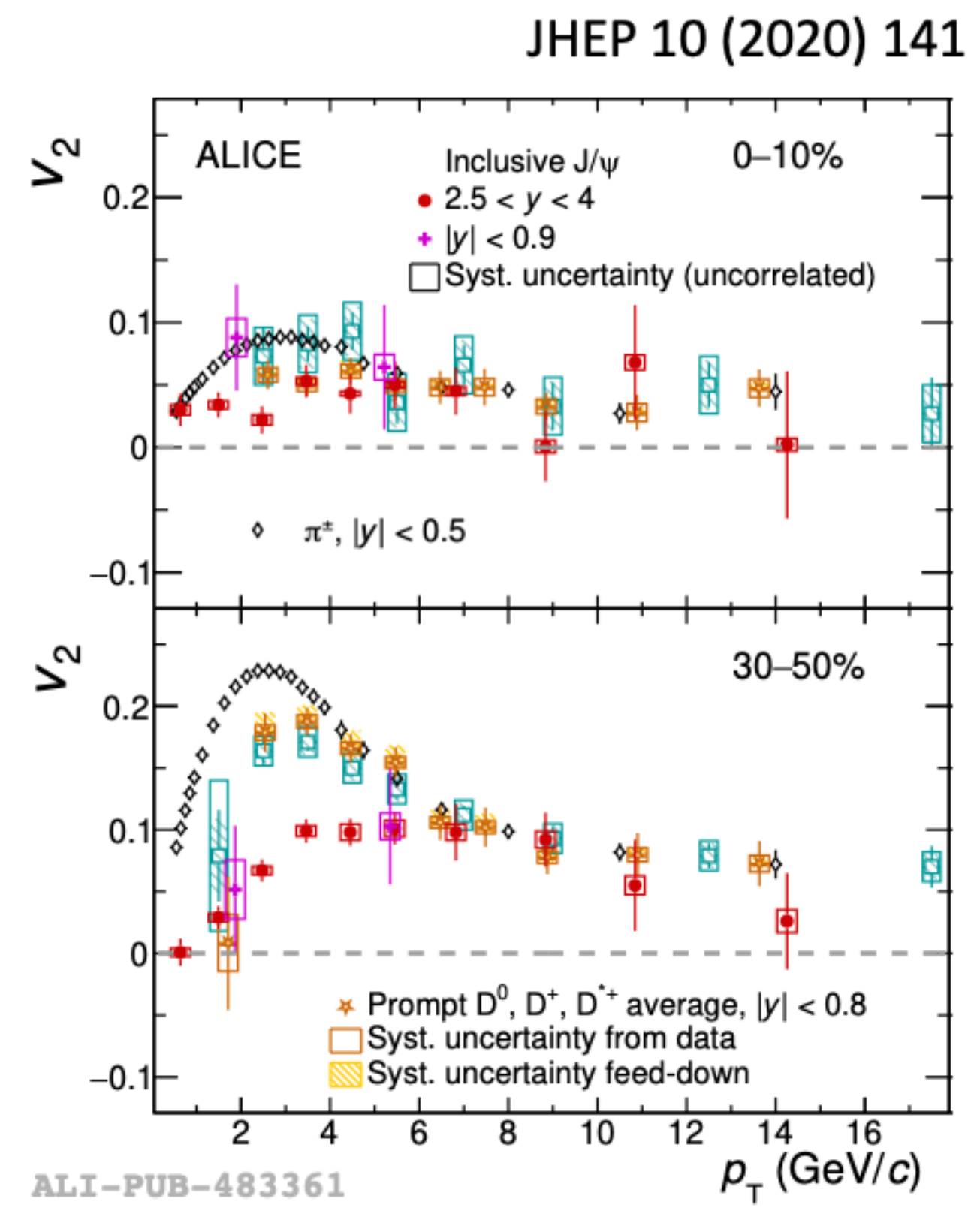
$\mathbf{u_n} = e^{in\varphi}$, $\langle ... \rangle$: average over dimuons from all events. signal + background (dashed blue): extracted from invariant mass distribution, through $\alpha = \mathrm{S/(S+B)}$.

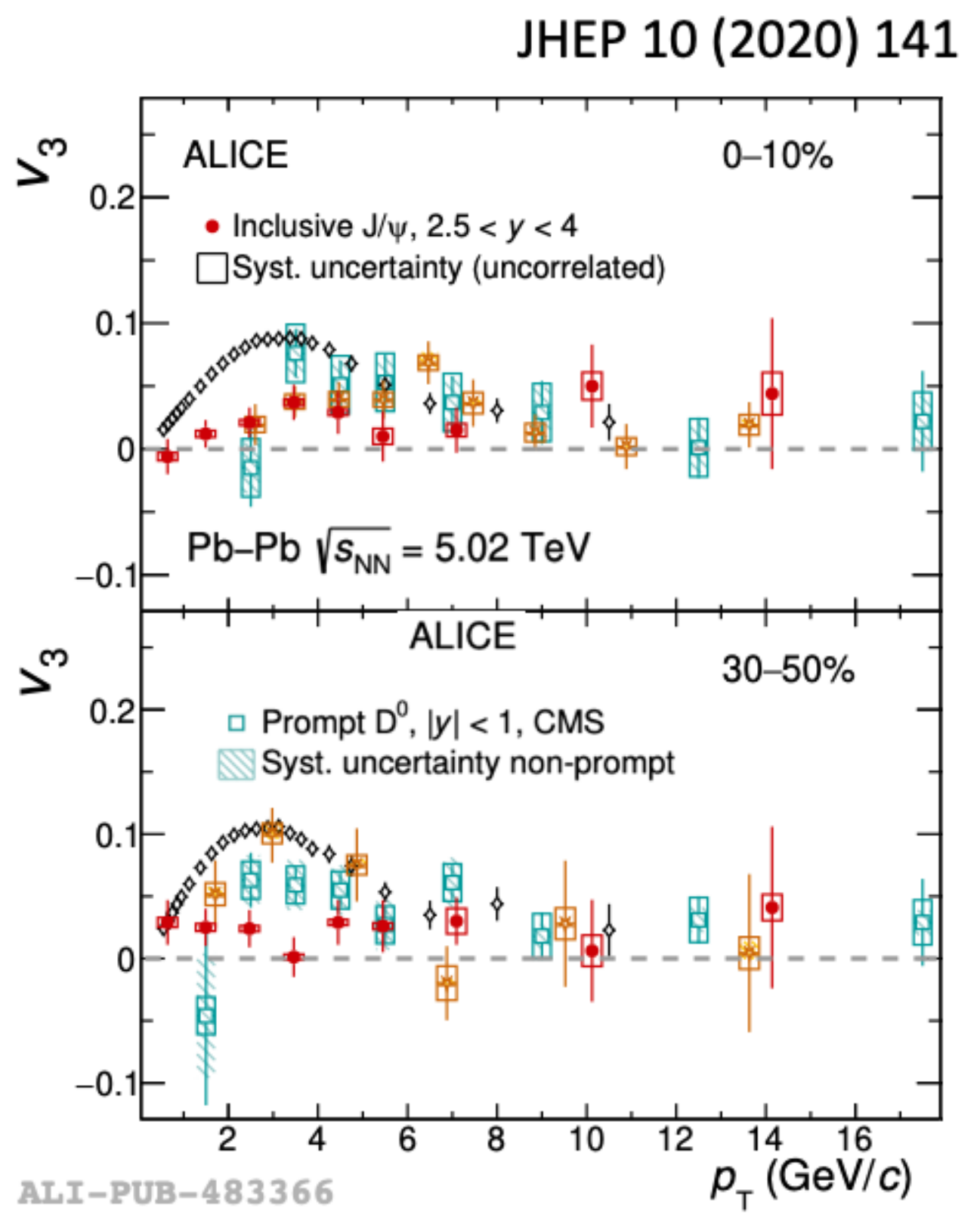
v_n^{sig} ($v_n^{\mathrm{J}/\psi}$ or $v_n^{\Upsilon(1\mathrm{S})}$): obtained from dimuon $v_n(m_{\mu\mu})$ fit

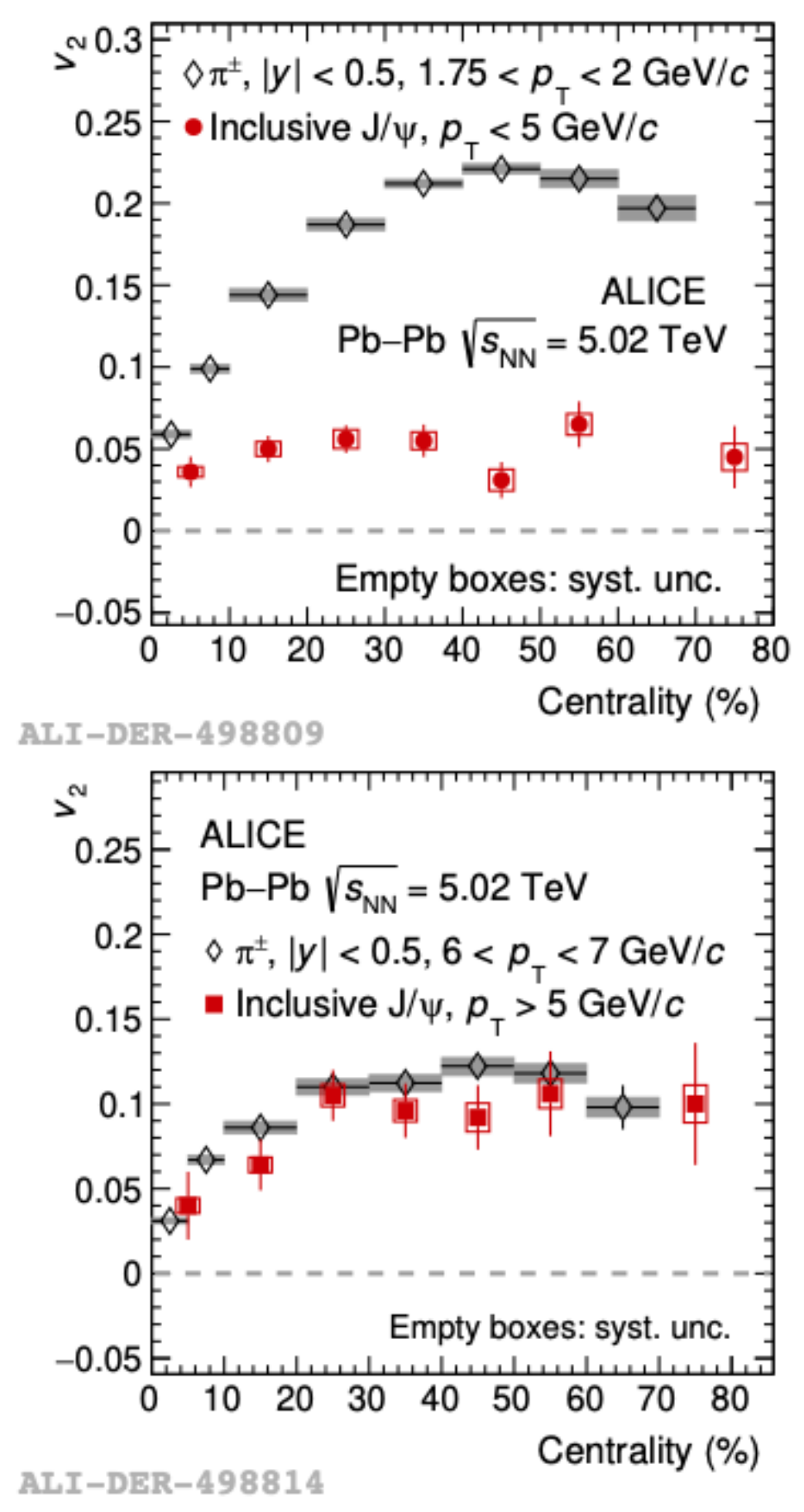
$$v_n(m_{\mu\mu}) = \alpha(m_{\mu\mu})\; v_n^{\mathrm{sig}} + [1 - \alpha(m_{\mu\mu})]\; v_n^{\mathrm{bkg}}(m_{\mu\mu}).$$

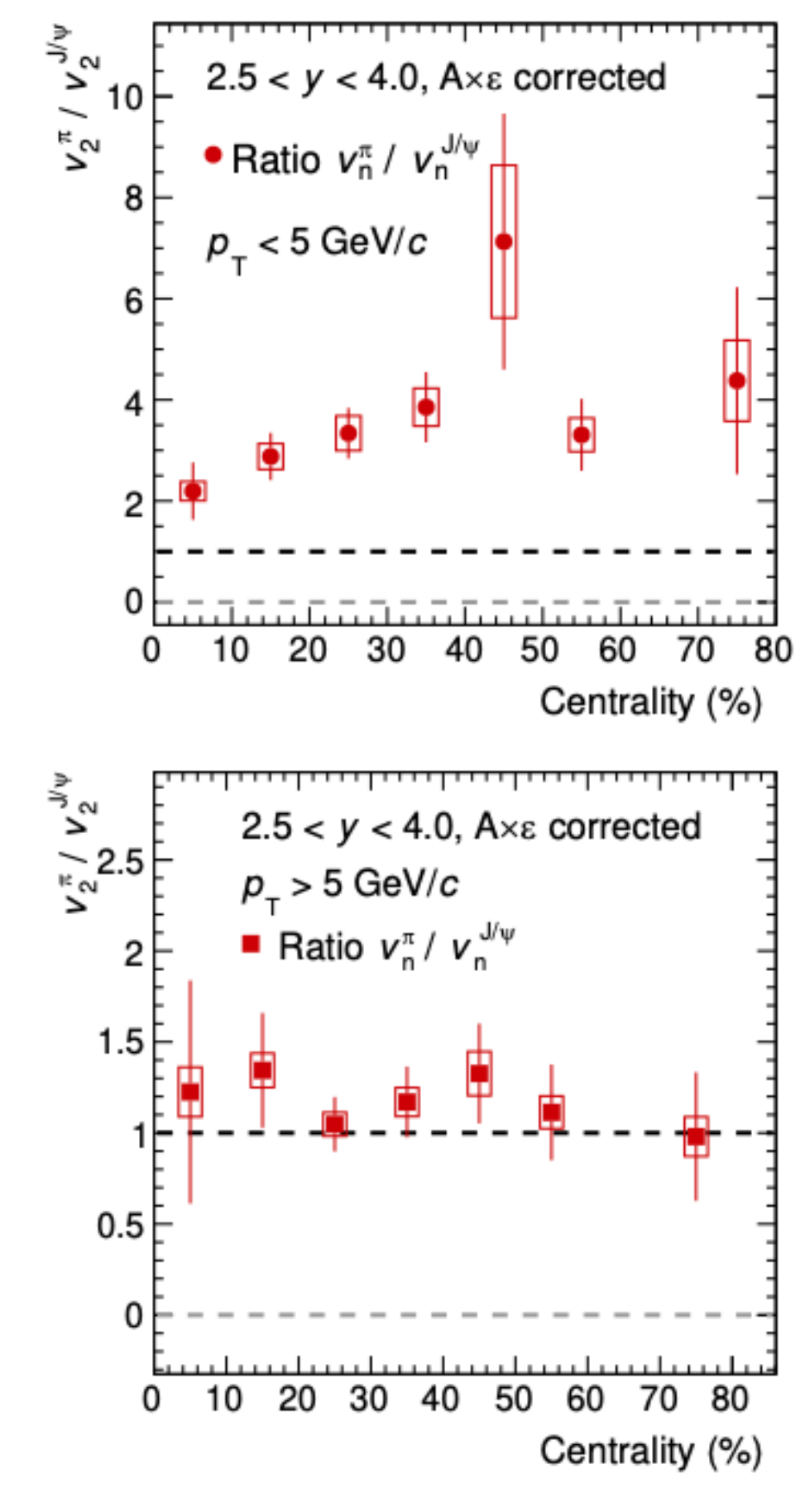


5 – Results: p_{T} and centrality dependence



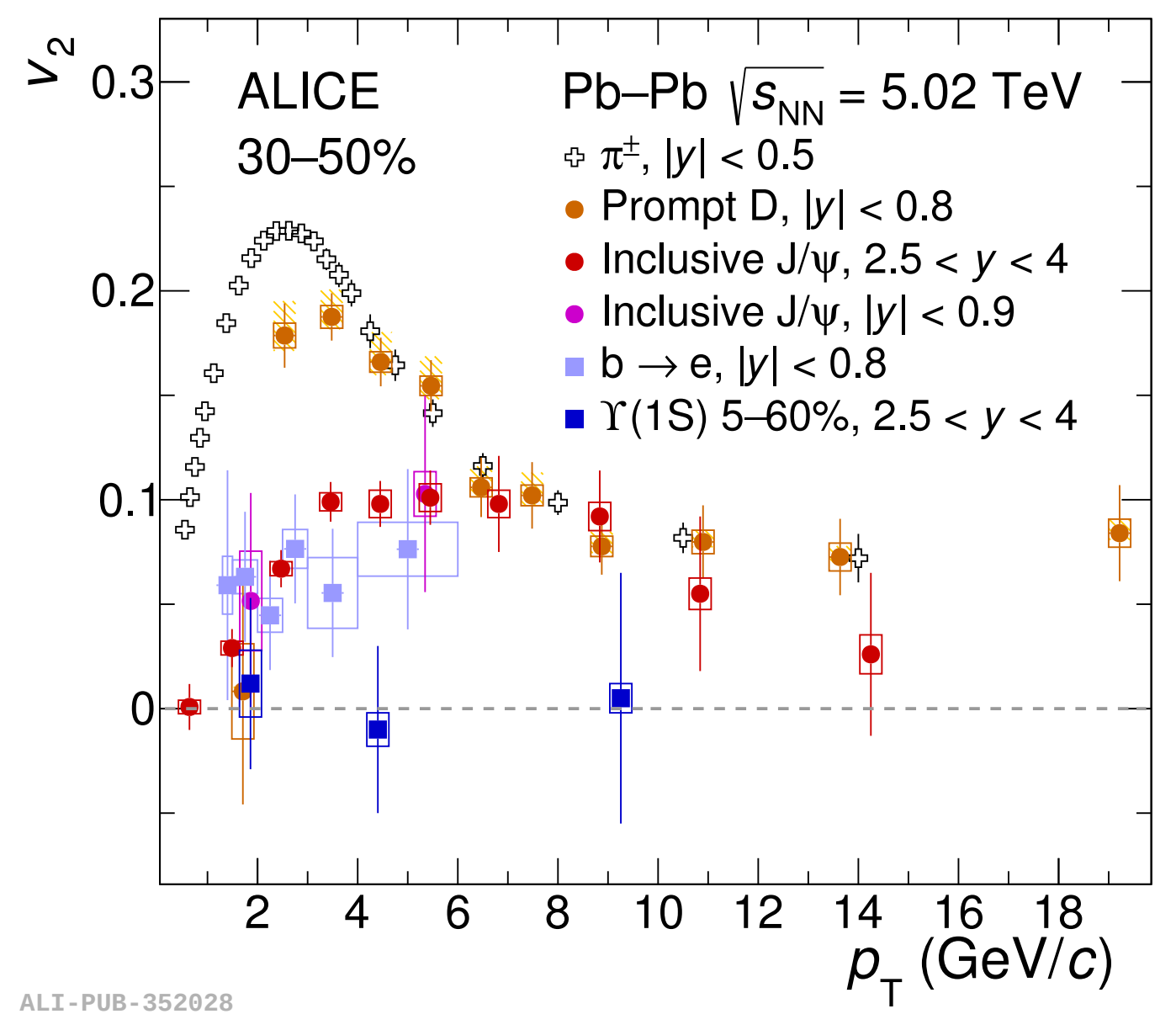






- Mass hierarchy at low p_{T} for π, D, and J/ψ v_n, while path-length dependent effects dominate at high p_{T}
- Low p_{T} $v_2^{\pi}/v_2^{\mathrm{J}/\psi}$ increases from unity toward peripheral collisions, while at high p_{T} it is compatible with 1

6 – Global picture: from light, to charm, to beauty flavor, and summary



$\rightarrow$ $v_2^{\mathrm{J}/\psi}$ favors scenario that all initially created J/ψ dissociate in the medium, recombination of charm quarks dominates the J/ψ production [5]

$\rightarrow$ $v_3^{\mathrm{J}/\psi} > 0$ in 0–50%, $2 < p_{\mathrm{T}} < 5$ GeV/c (5.1σ), no centrality dependence

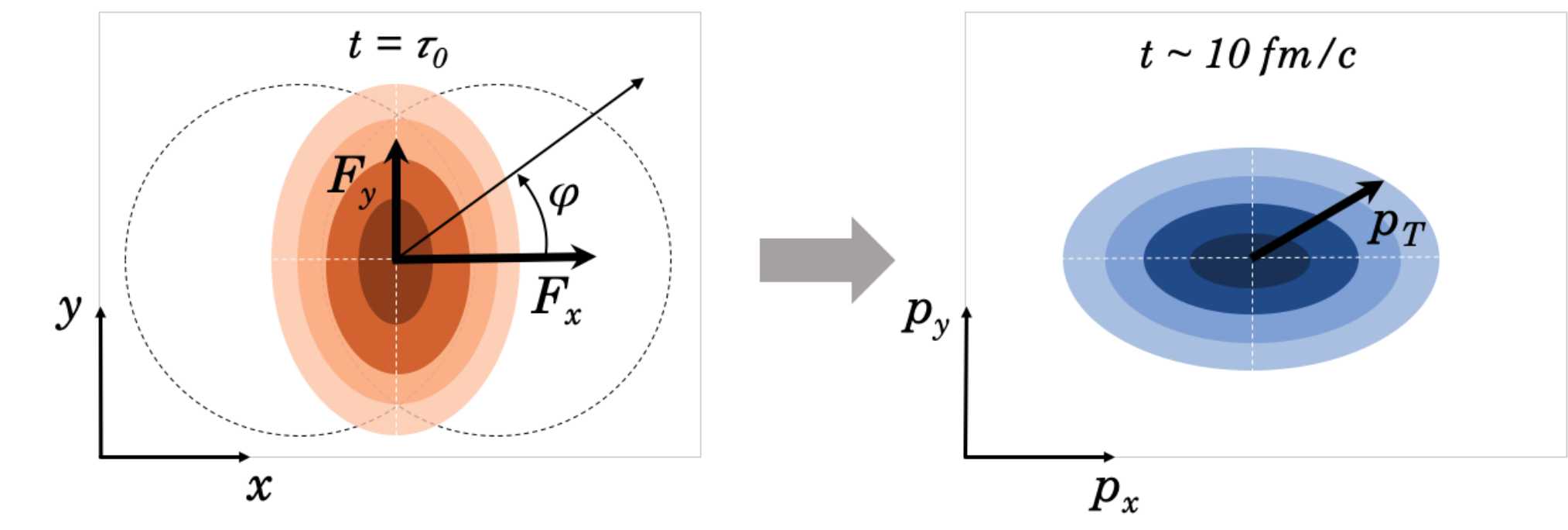
$\rightarrow$ Low p_{T} $v_2^{\pi}/v_2^{\mathrm{J}/\psi}$ increases from central to peripheral collisions, compatible with the scenario where c quarks thermalize later than the light ones

$\rightarrow$ $v_2^{\Upsilon(1\mathrm{S})}$: agreement with all scenarios: $b\bar{b}$ bound state formation limited to first stages (transport [6]), anisotropic escape mechanism (hydro [7]), or based from a full thermalization (statistical hadronization model [8])

$\rightarrow$ Global ordering at low p_{T} : $v_2^{\pi} > v_2^{D} > v_2^{\mathrm{J}/\psi} \gtrsim v_2^{b\rightarrow e} > v_2^{\Upsilon(1\mathrm{S})}$

2 – Azimuthal anisotropy

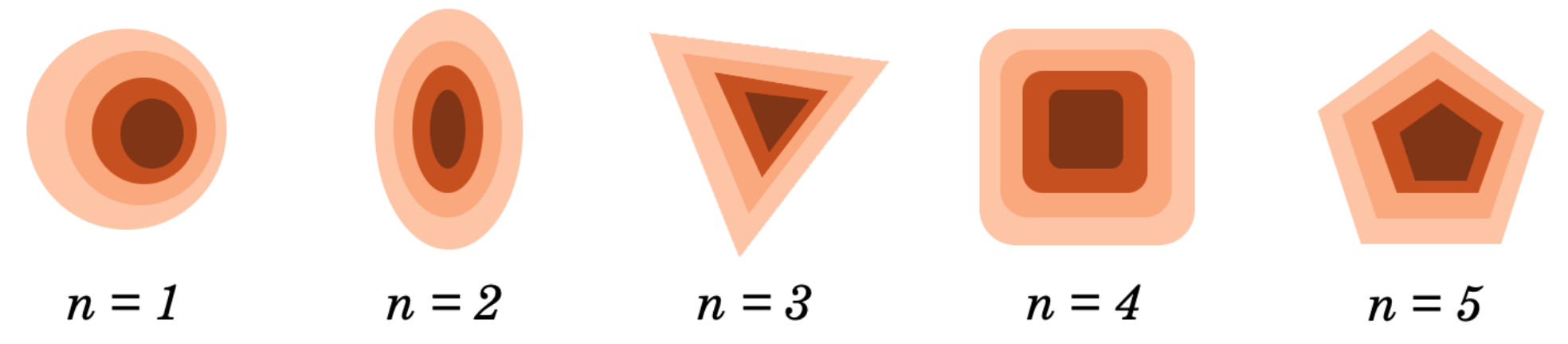
In non-central heavy-ion collisions, the nuclear overlap region has a **spatial anisotropy**. During system expansion, pressure gradients generated by parton interactions, transform the spatial anisotropy into a **momentum space anisotropy** of produced particles [3].



Azimuthal distributions of final state particles can be decomposed by Fourier series (with n: harmonics):

$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} \propto 1 + 2\sum_{n=1}^{+\infty} v_n \cos\left[n(\varphi - \Psi_{\mathrm{n}})\right],$$

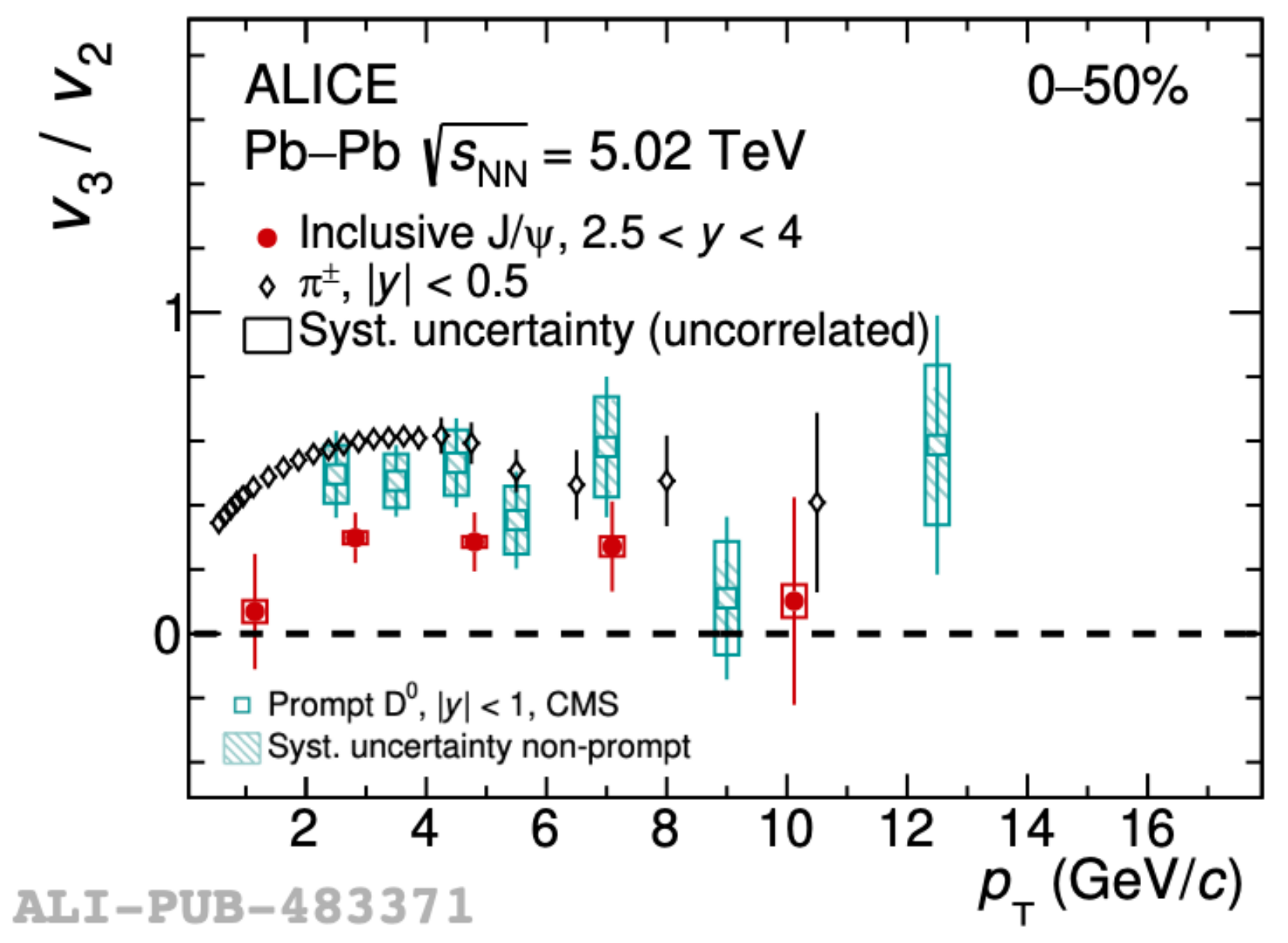
where φ: azimuthal angle, and Ψ_n: symmetry planes. v_n coefficients: sensitive to initial conditions, equation of state, and medium transport properties.



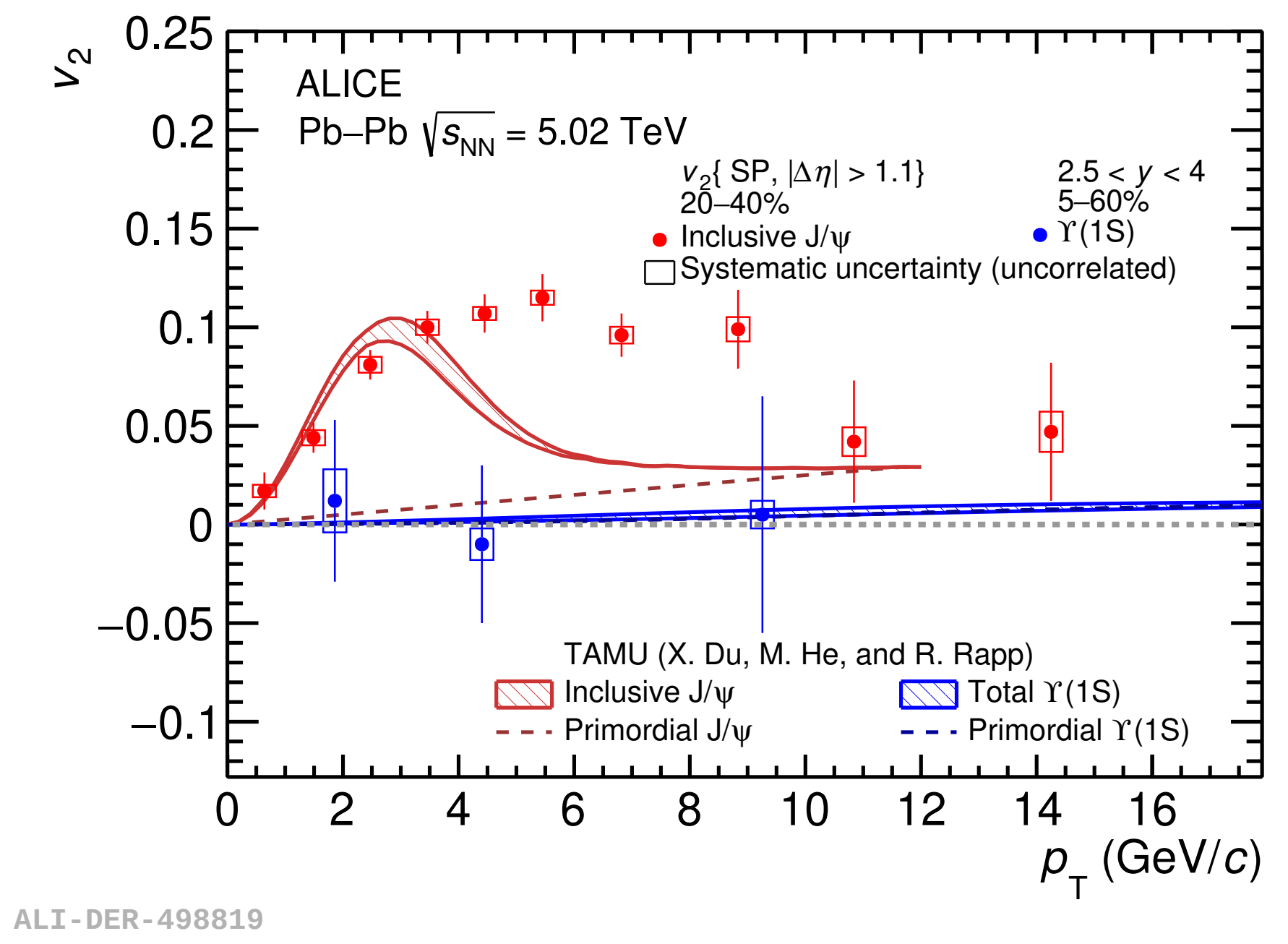
v_2 is called **elliptic flow**, and v_3 **triangular flow**,...

5 – Results: v_3/v_2 and comparison with models

v_3/v_2 exhibits the same hierarchy than single flow coefficients indicating that higher harmonics are damped for charmonia compared to lighter particles



Precise $v_2^{\mathrm{J}/\psi}$ measurement which extend p_{T} coverage (w.r.t. previous data) and first $v_2^{\Upsilon(1\mathrm{S})}$ measurement. Low p_{T}: agreement with microscopic transport models (strong regeneration for J/ψ [5], while small for $\Upsilon(1\mathrm{S})$ [6]), missing mechanisms for J/ψ at intermediate p_{T}



$v_2^{\Upsilon(1\mathrm{S})}$: compatible with 0 and model predictions [6-8]

References

[1] Phys. Lett. B 766 (2017) 212-224
[2] Phys. Lett. B 790 (2019) 89
[3] Phys. Rev. D 46 (1992) 229
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[5] Nuclear Physics A, 943 (2015) 147-158
[6] Phys. Rev. C 96 (2017) 054901
[7] Phys. Rev. C 100 (2019) 051901
[8] Phys. Rev. C 101 (2020) 064905