Quarkonium anisotropic flow in heavy-ion collisions with ALICE

Journées Rencontres Jeunes Chercheurs 2019

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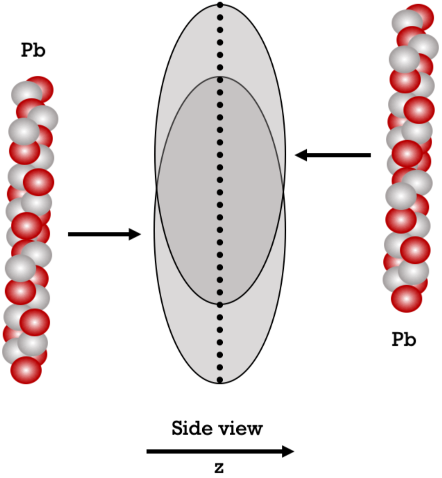
December 2, 2019

Outline

1. Physics motivation
2. Detectors used and data set
3. Quarkonium flow measurements
4. Conclusion

Why study the flow of quarkonia in heavy ion collisions?



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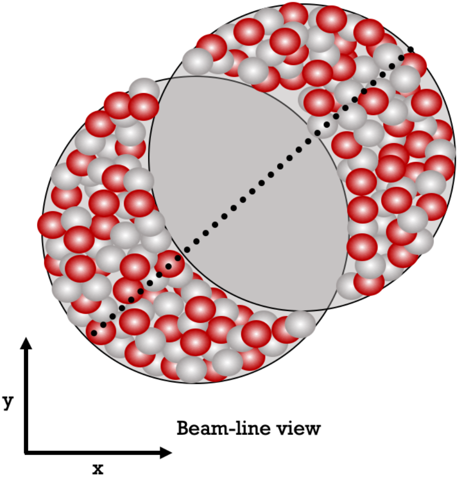

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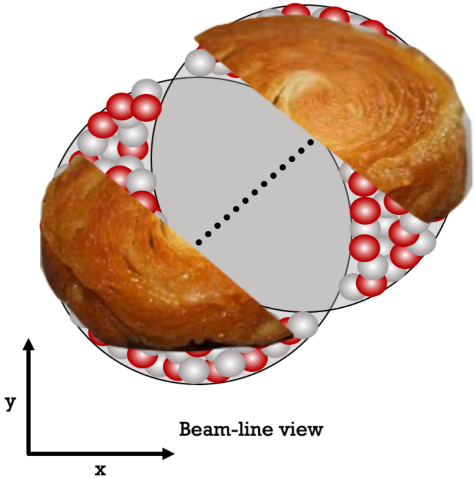

"Que fit un breton lorsqu'il se morda la langue ?? Il couina, man"

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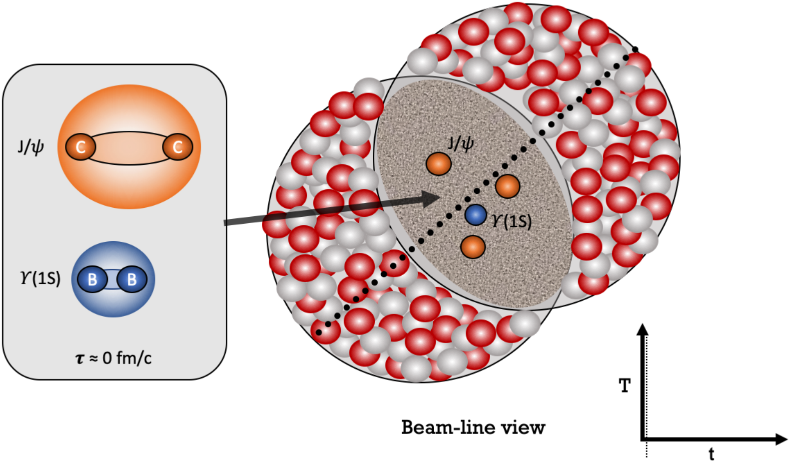

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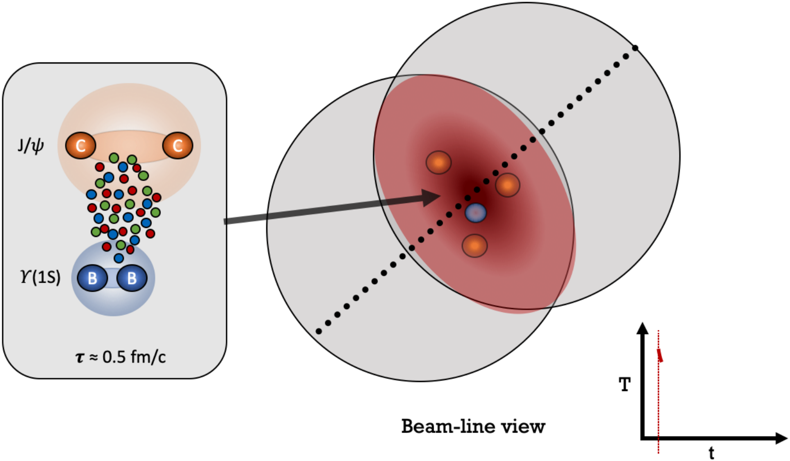

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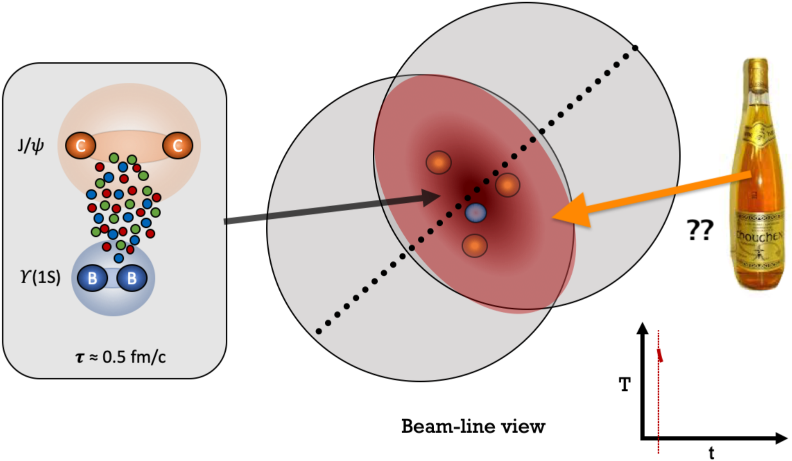

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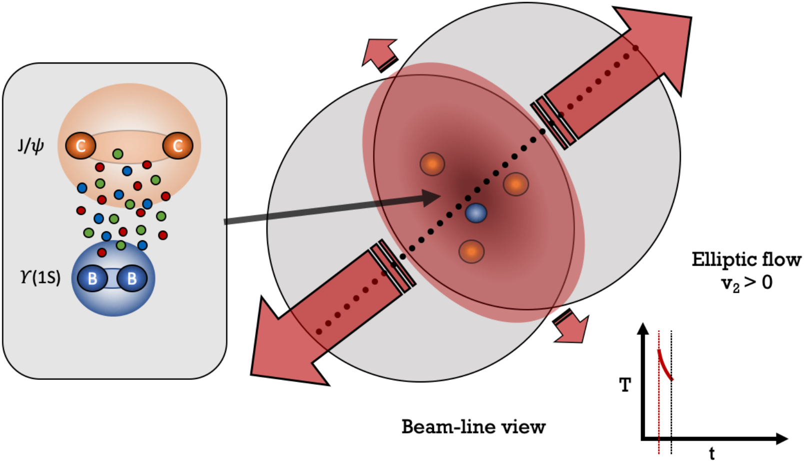

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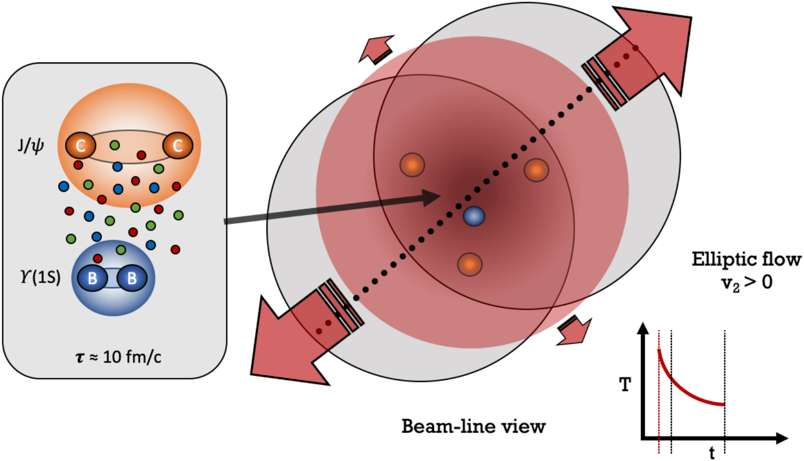

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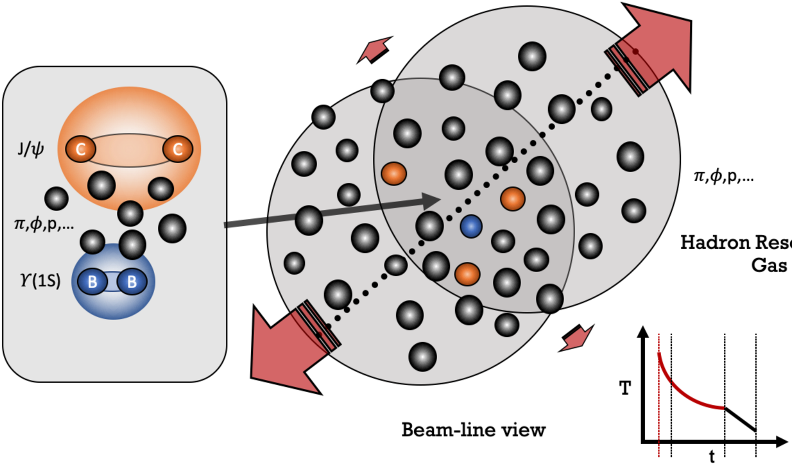

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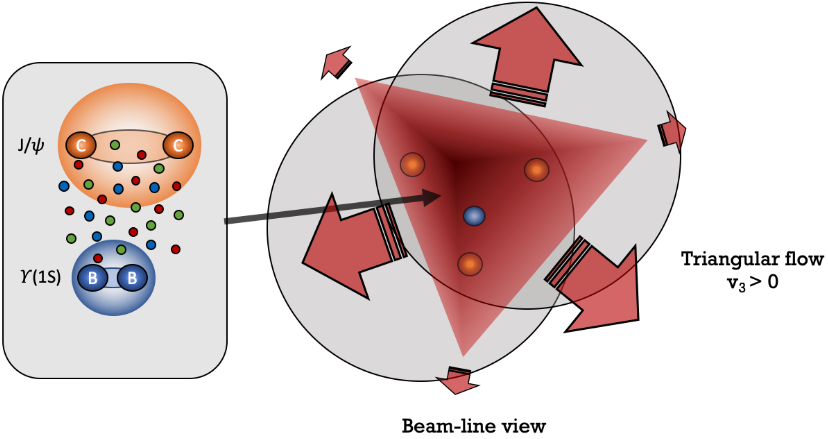
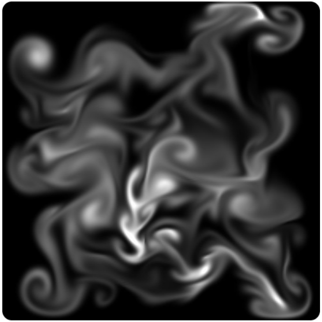
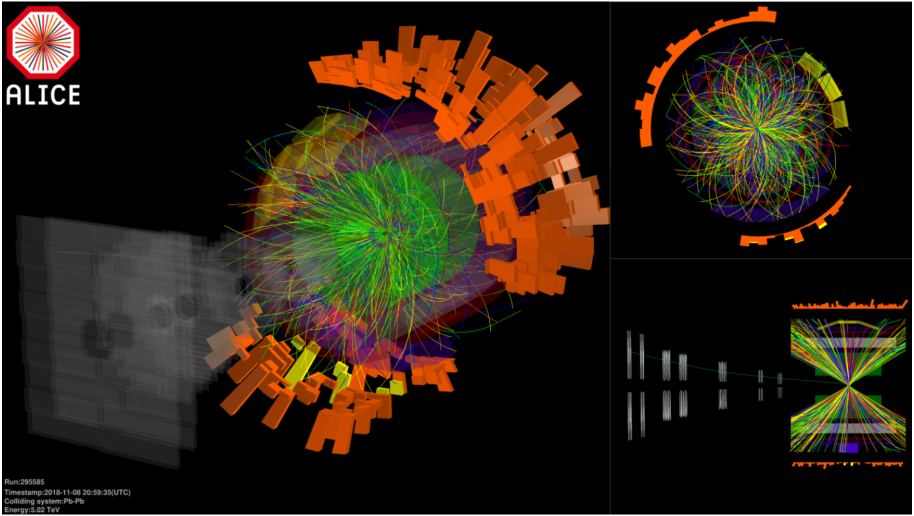


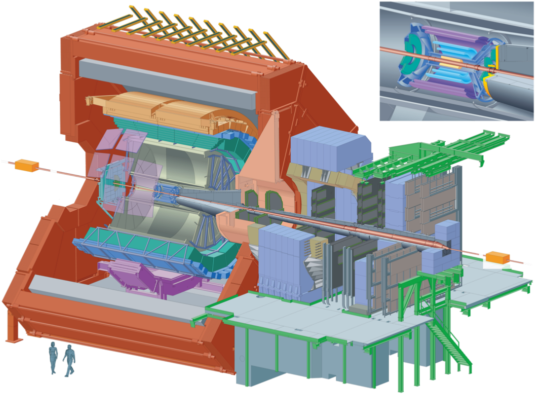
The question is, does everything flow ?



Event display : a Pb-Pb collision



ALICE Experiment



- Silicon Pixel Detector, $|\eta| < 1.4$: tracklets reconstruction + primary vertex
- V0 (2 scintillators $-3.7 < \eta < -1.7$ & $2.8 < \eta < 5.1$: trigger + centrality estimator
- Forward Muon Spectrometer used to reconstruct quarkonia : $J/\psi, \Upsilon \to \mu^+\mu^-$
- Full LHC Run 2 Pb-Pb dataset equivalent to $L \approx 0.75$ nb^{-1}

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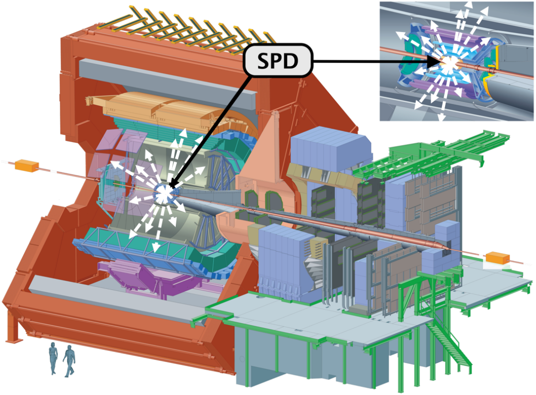

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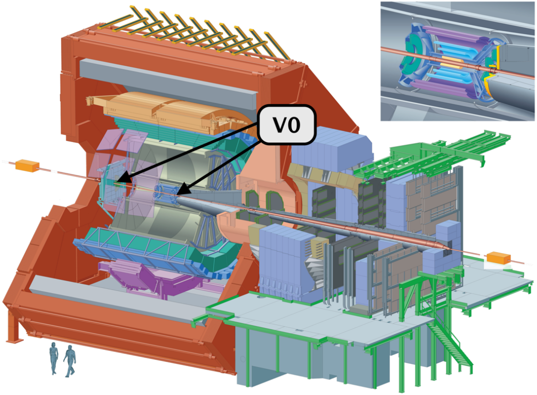

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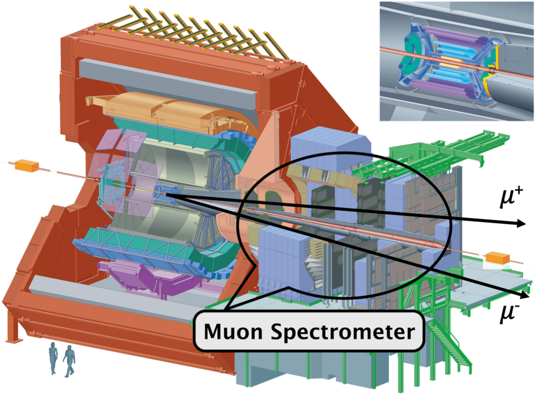

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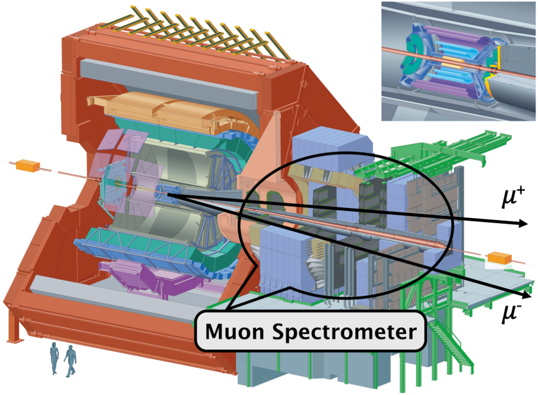

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Light flavor sector

- Light quark (u, d, s) flow & energy loss in the medium

Heavy flavor sector

- c quark much heavier, produce before QGP formation
- Does the charm interact with the medium ?
  - does it flow with it ?
  - charm quark energy loss ?
  - if yes, indicate strong coupling with the medium

Does the charm quark flow ?

Extraction of J/ψ v_n

Filling the histograms with $\mu\mu$

1. Invariant mass $m_{\mu\mu}$
2. $v_n = \langle\langle \cos n(\phi_{\mu\mu} - \Psi_n)\rangle\rangle$
3. Transverse momentum p_T

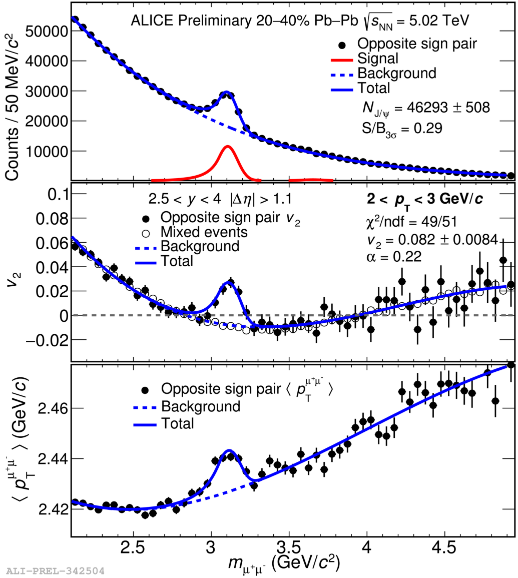
Fitting procedure

v_n^{sig} : is extracted by fitting the total dimuon v_n :

$$v_n = v_n^{bkg}(1-\alpha) + v_n^{sig}\alpha \quad (1)$$

Parameters

- $\alpha = \frac{S}{S+B}$
- v_n^{bkg} : polynomial functions (order 2, 3)

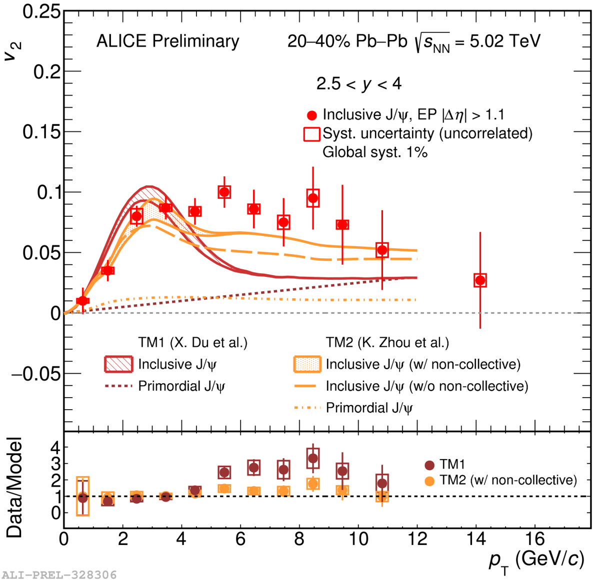


Comparison of J/ψ v_2 with model predictions

The transport model interpretations :

1. **- Regenerated J/ψ v_2** from (partially) thermalized c quarks
   - Primordial J/ψ v_2 from path-length dependent suppression
   - Non-prompt J/ψ v_2 from path-length dependent e-loss of B

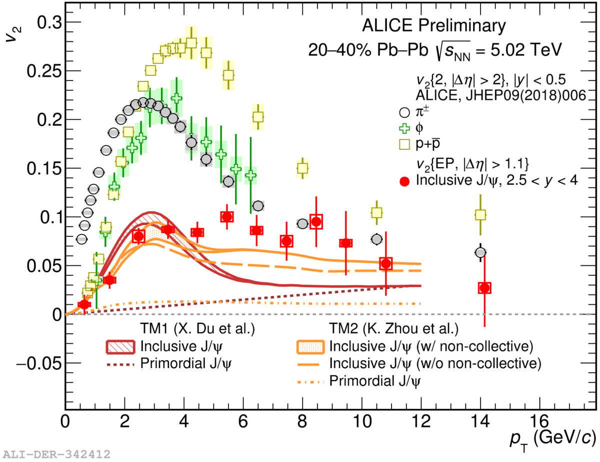
2. Only TM2, additional **initial strong magnetic field effect** on heavy quark v_2



Comparison between light flavor and heavy flavor

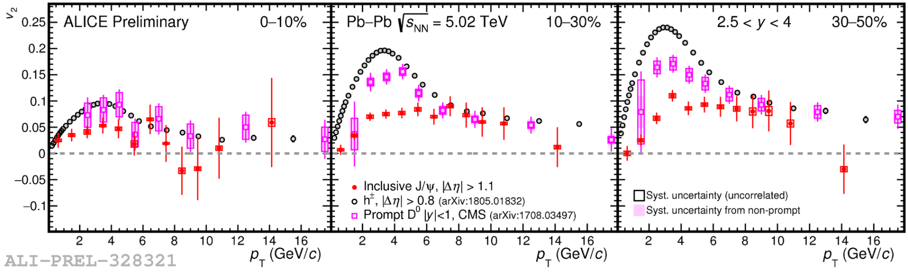
Hadrons compared to J/ψ

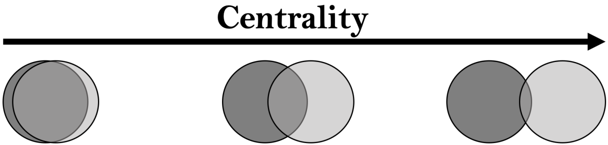
- π, p, ϕ inherit their v_2 at phase boundary from the medium (hadronization process)
- **Mass ordering** between light/heavy flavor particles for $p_T < 2$ GeV/c



J/ψ v_2 in Pb-Pb collisions

- v_2 comparison between charged particles, and D meson, and J/ψ
  - Clear ordering between light and heavy flavor particles at low-p_T
  - Converge to same values at high-p_T (similar conclusions with R_{AA})
    - ★ Radiative/collisionnal energy loss of partons inside QGP ?





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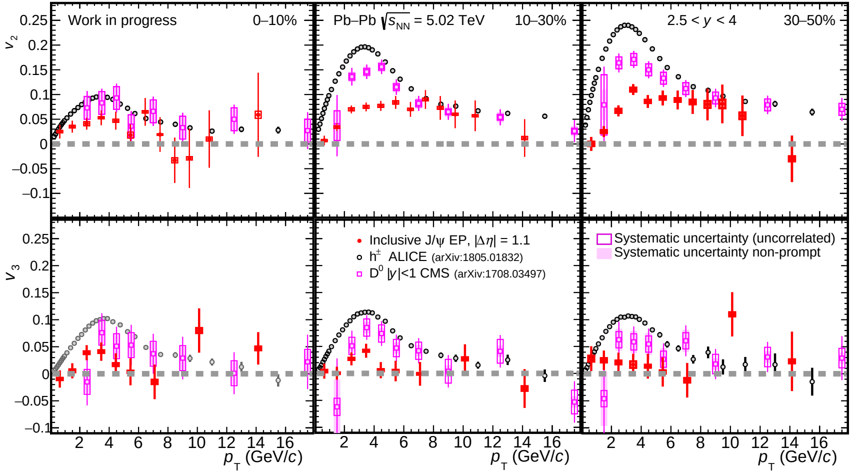
    - ★ Radiative/collisionnal energy loss of partons inside QGP ?
- v_3 comparison gives similar conclusions with **mass ordering at low-p_T**



Does the beauty quark flow ?

Beauty quark flow ?

Model (TAMU, PRC.96.054901) implement a kinetic-rate equation

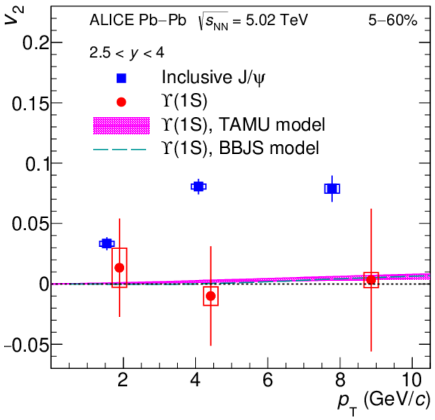
- Predict a very low $\Upsilon(1S)$ v_2 (large binding energy)
- T dependent binding energy
- Medium effect from lattice-QCD (based equation of state for bulk evolution)
  - Dissociation at higher T
  - Limited to earlier stages of QGP evolution (beginning of expansion)

Small number of produced $b\bar{b}$ pairs in Pb-Pb collisions

- Very small regeneration component
- v_2 mostly driven by primordial $\Upsilon(1S)$ up to higher-p_T

Beauty quark not flow

- **First measurement** of $\Upsilon(1S)$ v_2 with full Run 2 (PRL.123.192301)
- $\Upsilon(1S)$ v_2 compatible with 0 and models (confirmed by CMS):
  - ⋆ Production dominated by dissociation limited to early stage of collision



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- $\Upsilon(1S)$ v_2 compatible with 0 and models (confirmed by CMS):
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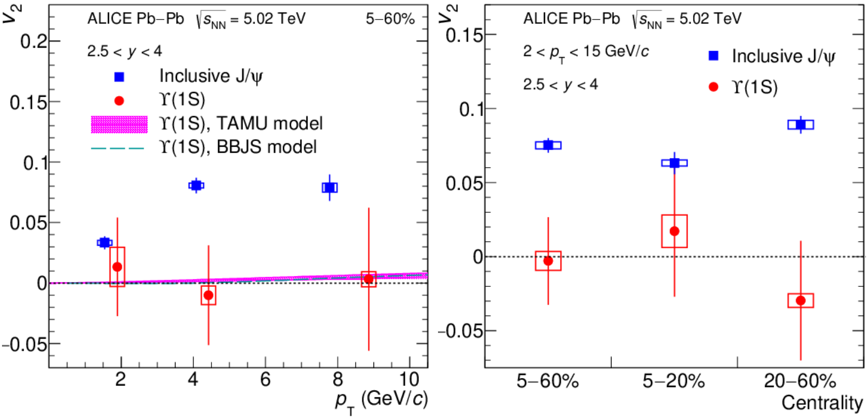
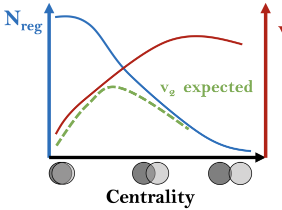
- v_2 lower than J/ψ v_2 (by 2.6 σ) measured in same p_T and centrality intervals



Centrality dependence

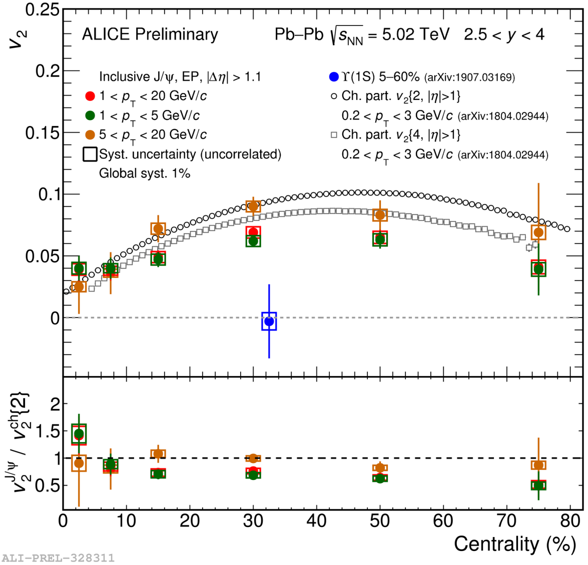
J/ψ production mechanisms

low-p_T : regeneration $N_{reg}^{J/\psi}$
high-p_T : path-length

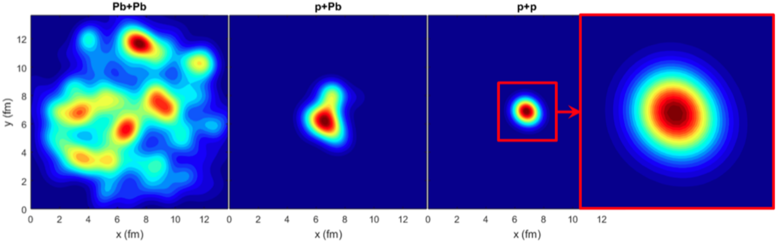


Initial collision geometry

- v_2 (J/ψ reg.) $\approx v_2^{ch}$
- v_2^{max} shifted to central collisions



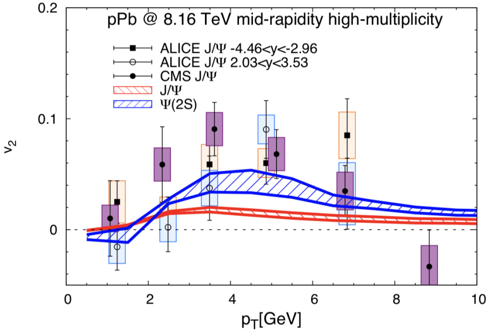
What about quarkonium flow in p-Pb or even in pp collisions ?



arXiv:1701.07145

Charm quark flow in p-Pb

- Initially used to quantified Cold Nuclear Matter (CNM) effects
- Discover that collective effects play a important role for light flavor (LF)
  Also present for heavy flavor (HF), J/ψ v_2 measurement in p-Pb by ALICE
  - LF: Interpreted as sign of QGP fluid dynamics HF: Initial-state effects?
- Transport models (arXiv:1808.10014) challenges for a small system size :
  - Negligible path-length dependent effects & regeneration



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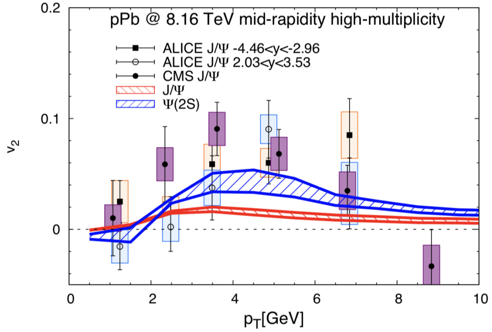


Conclusion

Does the charm quark flow ? Yes

- Significant J/ψ v_2 and mass ordering of v_n with charged particles and D meson at low-p_T
- At high-p_T ($p_T > 6$ GeV/c), similar values of v_2 for light and heavy flavor
- Hint of different centrality dependence of v_2 according to the type of J/ψ production mechanisms
- No clear rapidity dependence of J/ψ v_2

Does the beauty quark flow ? It seems no, may be differently

- First measurement of $\Upsilon(1S)$ v_2 compatible with 0 and models predictions, also lower than J/ψ by 2.6 σ
- Favors a production of $\Upsilon(1S)$ dominated by dissociation limited to early stage of collision

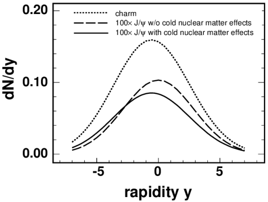
Thank you for your attention !

"Centre Moulin Mer (avant tempête)"

Rapidity dependence

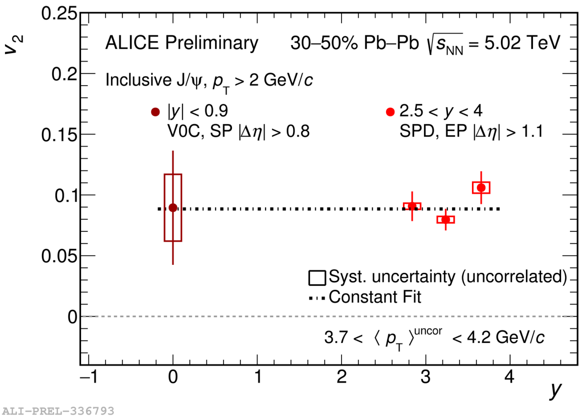
Sensitive to energy density

At mid-rapidity : higher energy density and larger $c\bar{c}$ pairs produced



What we expect ?

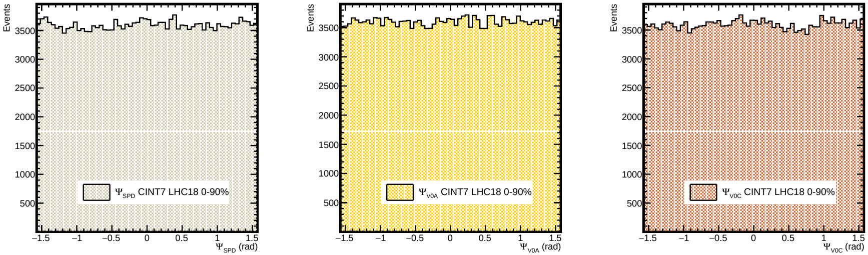
Epected to have a higher J/ψ v_2 at mid-rapidity from regenerated/primordial J/ψ



Ψ_n calibration

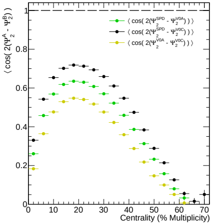
Calibration steps on flow vector $\mathbf{Q_n}$ (run-by-run basis, as function of z vertex and centrality), based on the article : arxiv0707.4672

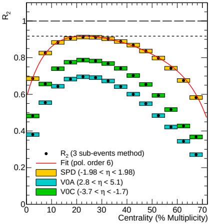
1. **Gain equalization** for channels in V0A, V0C
2. **Re-centering and width equalization** for SPD, V0A, V0C
3. **Alignment** only for V0A, V0C
4. **Twist and re-scale** correction for non-uniform acceptance

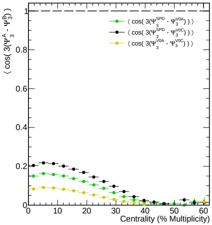


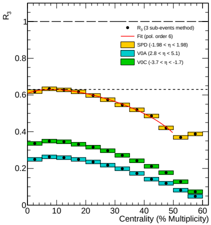
Event plane resolution R_n

$$R_n(\Psi_n^{SPD}) = \sqrt{\frac{\langle \cos n(\Psi_n^{SPD} - \Psi_n^{V0A})\rangle \langle \cos n(\Psi_n^{SPD} - \Psi_n^{V0C})\rangle}{\langle \cos n(\Psi_n^{V0A} - \Psi_n^{V0C})\rangle}} \quad (2)$$









Projection for quarkonium flow after Run 3

- Huge sample of p-p collisions at 13 TeV
  - First measurement of J/ψ v_2 in p-p ?
- Statistics $\times 10$ for J/ψ and $\Upsilon(1S)$ in dimuon decay channel
  - Separation of prompt and non-prompt J/ψ from b using MFT
- Statistics $\times 100$ for J/ψ in dielectron decay channel
  - New ITS and upgrade TPC : better tracking + PID