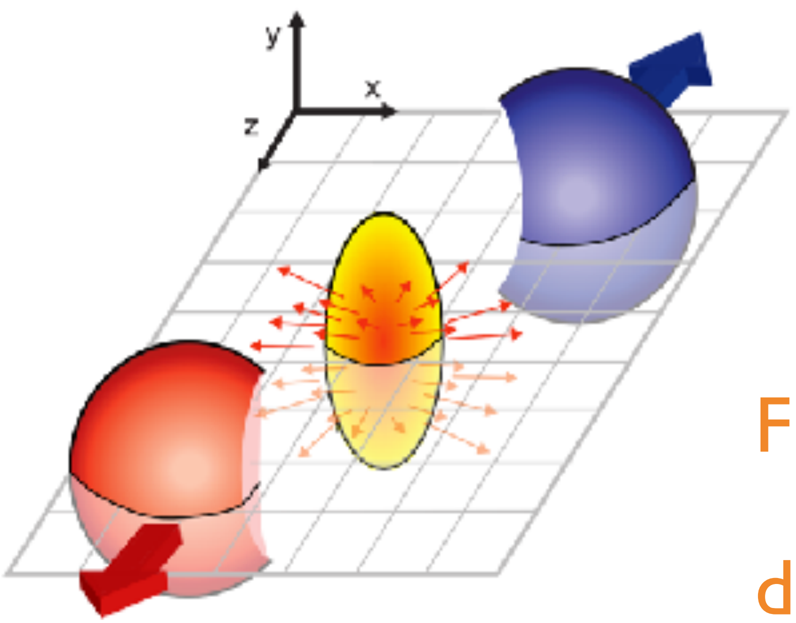
J/ψ elliptic flow

Audrey FRANCISCO
Subatech, France

Heavy-ion meeting, March 8th 2017
• IPN Orsay

Outlook

- **The flow observable**



anistropic matter distribution around the collision

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\{1+\sum_{n=1}^{\infty} 2 v_n \cos(n(\Phi-\Psi_{RP}))\}$$

Flow coefficients : $v_n = <\cos\{n(\Phi_i - \Psi_{RP})\}>$

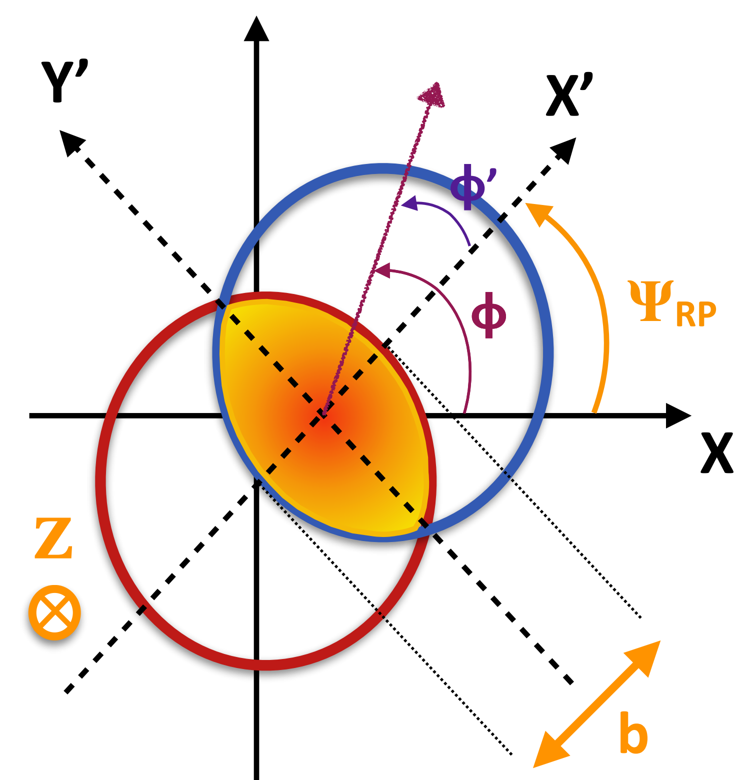
directed flow (v_1), elliptic flow (v_2), triangular flow (v_3), …

- **Motivations for charmonium flow study**

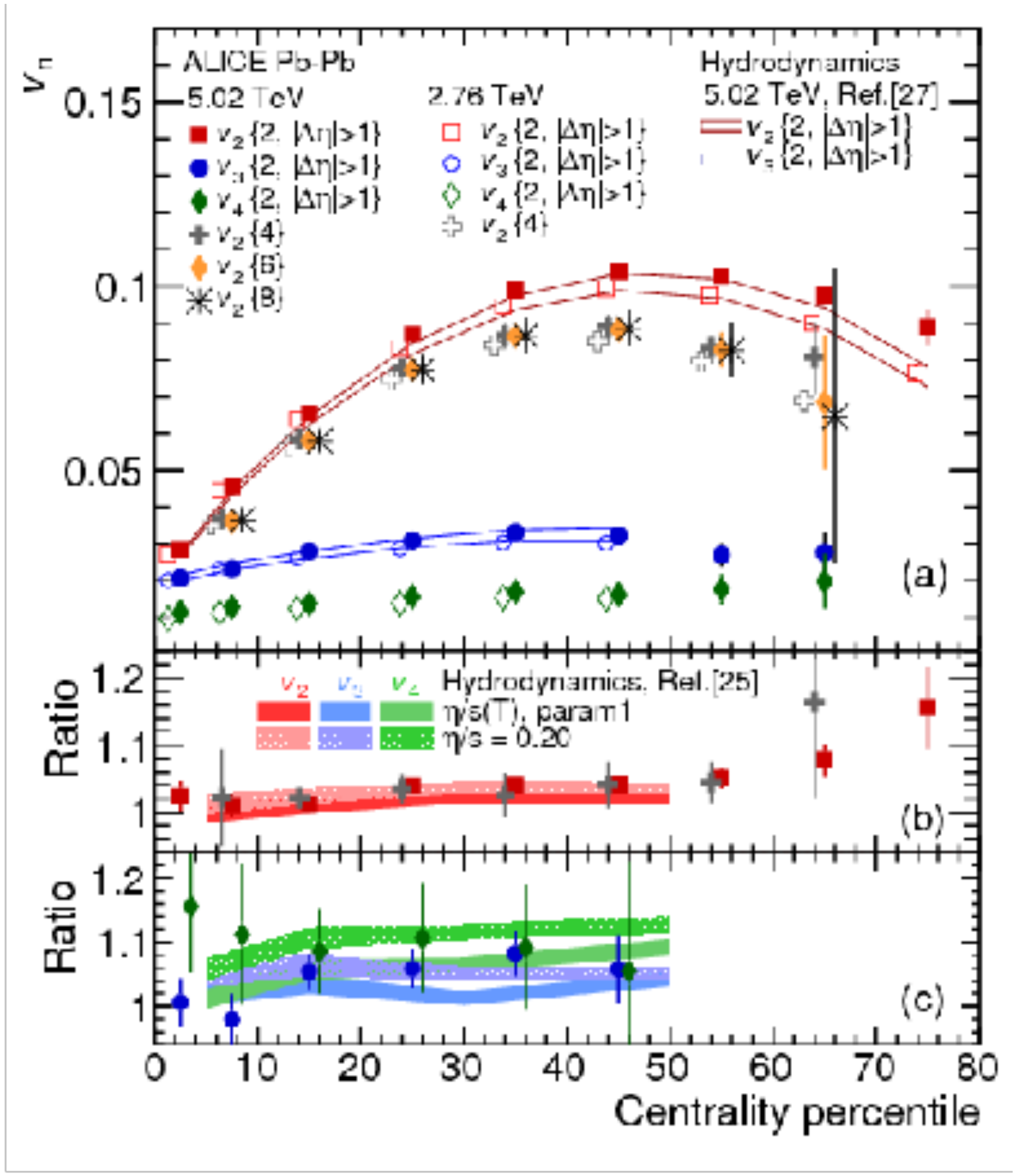
Why is it interesting ?

How to measure it ?

What are the results ?



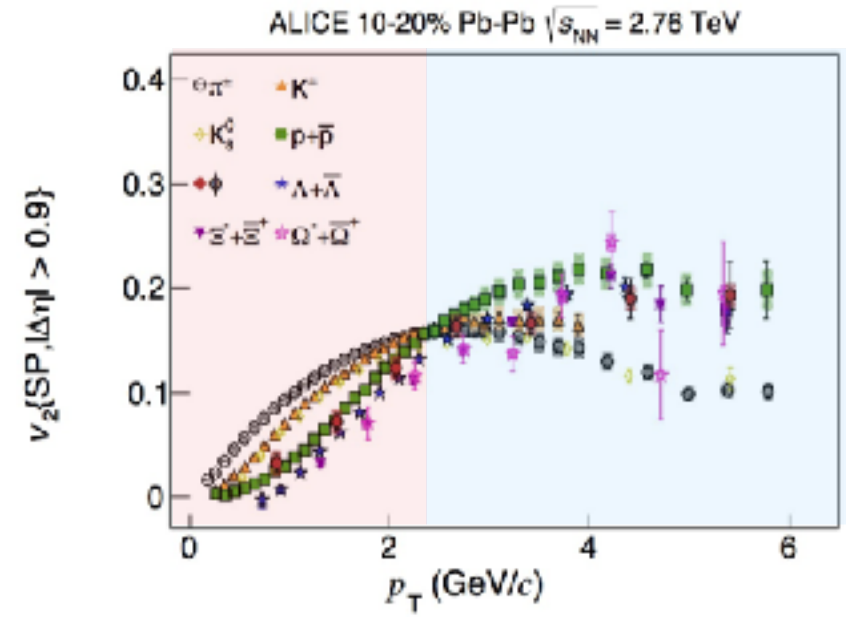
Hydrodynamics : charged hadrons with ALICE

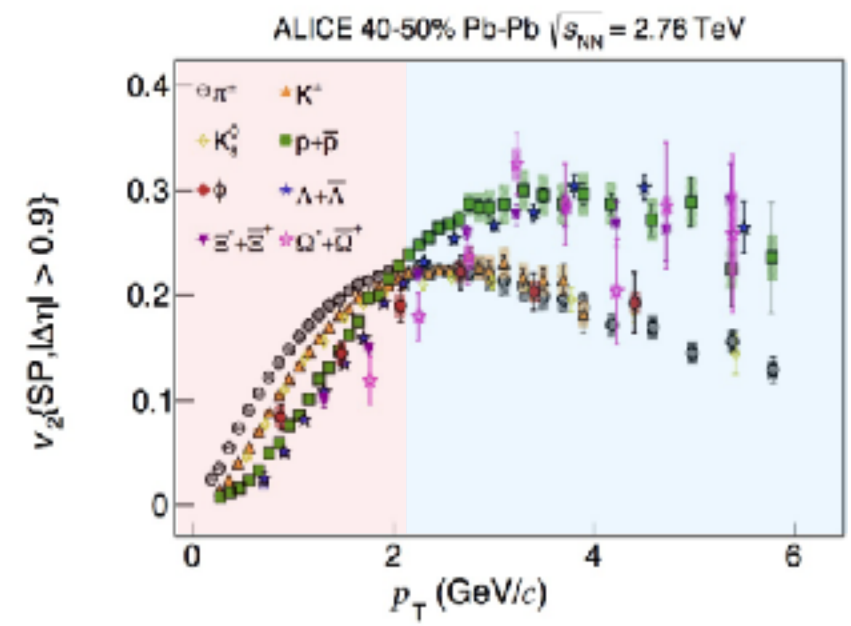


Comparison to hydro at low p_T :

- v_2 origin: early, partonic stages of the system
- v_2 governed by the QGP evolution

At low p_T (p_T < 2 GeV/c) :
mass ordering

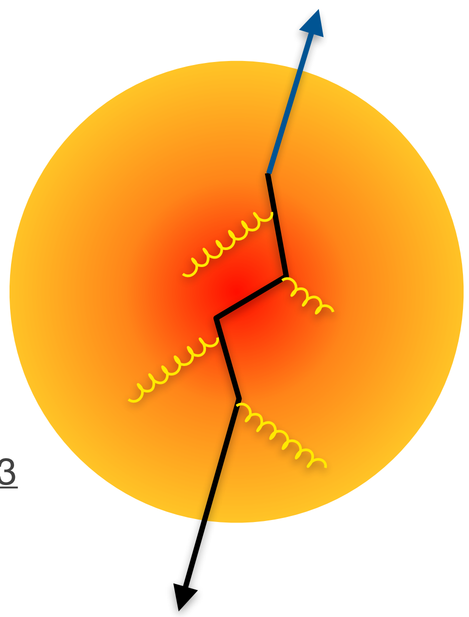




For intermediate p_T :
v_2 (Baryons) > v_2 (Mesons)

Motivations for charmonium studies

- **Heavy quarks in Pb-Pb collisions at the LHC**
  - early production (c ~ 0.1 fm/c vs. QGP ~ 0.3 fm/c)
    → experience the full system evolution Nucl.Phys. A757 (2005) 184-283
  - interact with the QGP : sensitive to the medium properties



- **Charmonium ($c\bar{c}$) in Pb-Pb collisions : hard probes of the QGP**

Open questions :

➡ Do charm quarks thermalize?

➡ Do they follow collective dynamics of bulk?

Charmonium production in the QGP

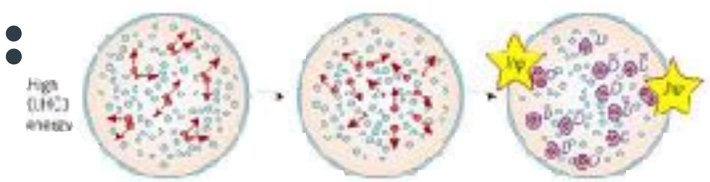
Quarkonium suppression :

- Initially : J/ψ suppression predicted by Matsui and Satz in 1986 by Debye screening mechanism Phys.Lett. B178 (1986) 416-422
- Different quarkonium binding energy : sequential suppression with increasing medium temperature Phys. Rev. D 64 (2001) 094015

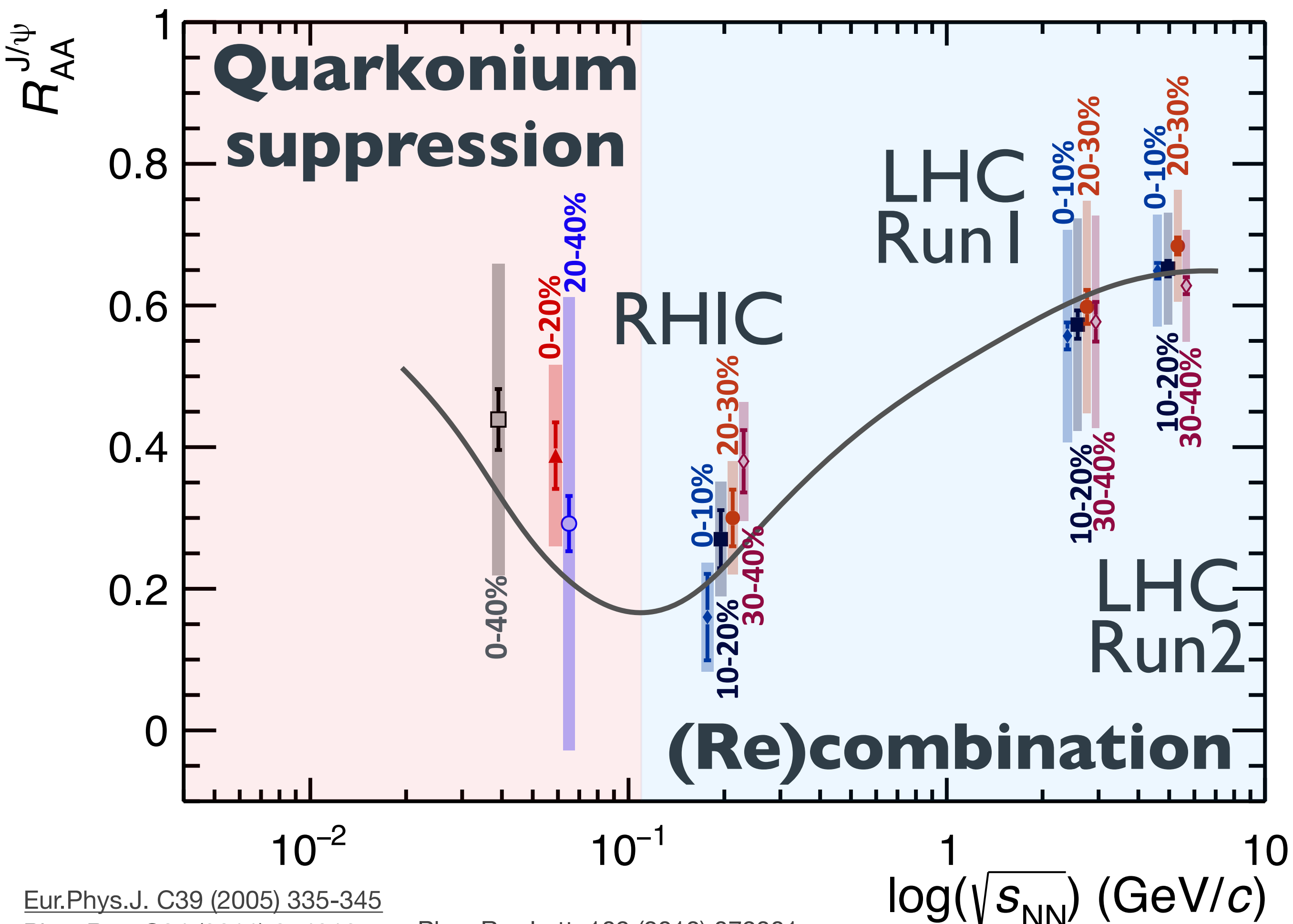
$$R_{AA} = \frac{Y_{AA}}{\langle T_{AA}\rangle \sigma_{PP}}$$

Quarkonium yield in AA compared to the pp one, scaled by the overlap factor T_{AA} (from Glauber model)

(Re)combination :

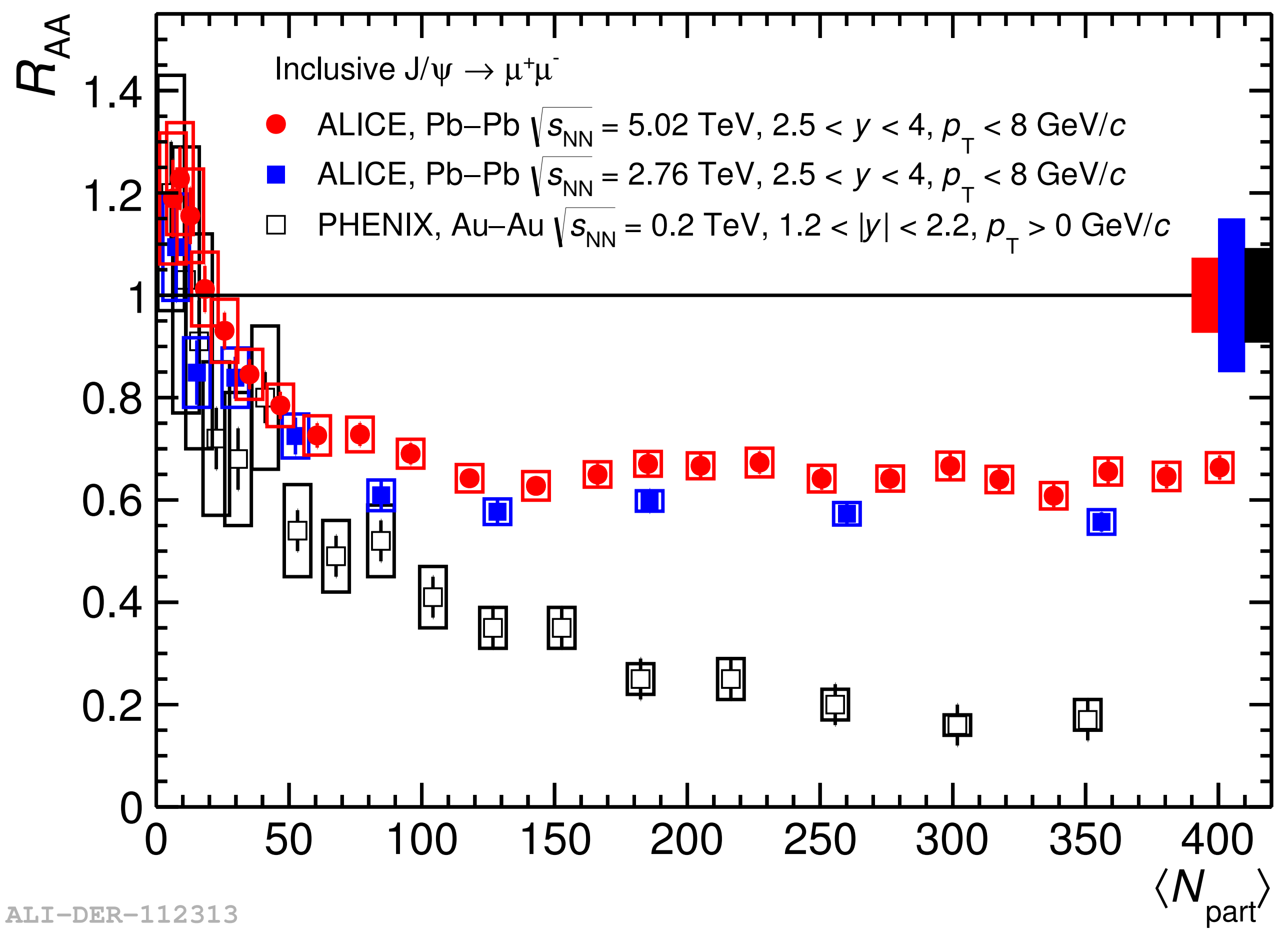


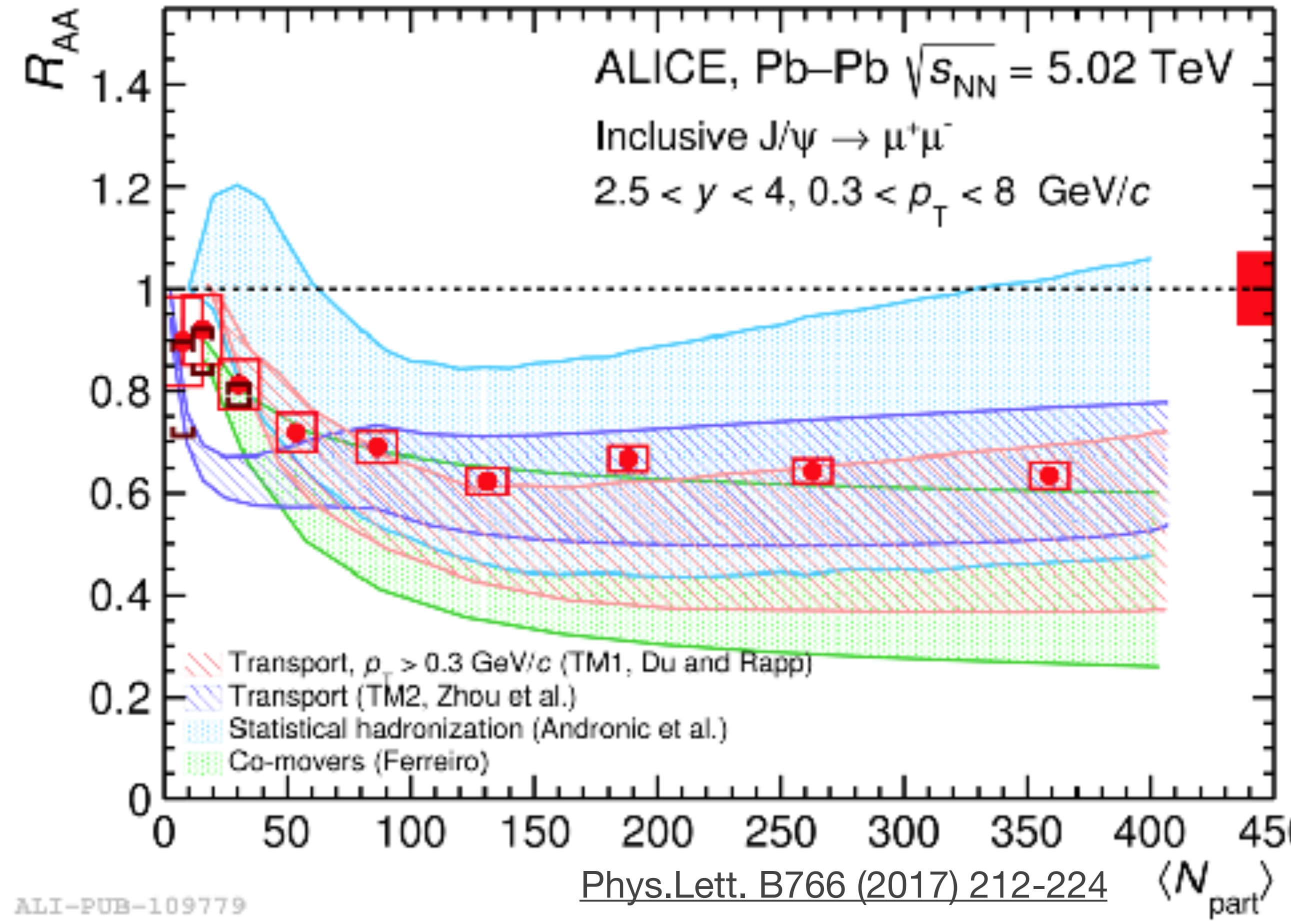
- Increased charm quark density →enhanced quarkonia production
- Less relevant for bottomonium than charmonium Phys. Rev. C 63 (2001) 054905 Phys. Lett. B 490 (2000) 196–202 J. Phys. Conf. Ser. 509 (2014) 012019



Eur.Phys.J. C39 (2005) 335-345
Phys.Rev. C84 (2011) 054912
Phys.Rev. C86 (2012) 064901
Phys.Rev.Lett. 109 (2012) 072301
Phys. Lett. B 766 (2017) 212-224

Charmonium production in the QGP





Phys.Lett. B766 (2017) 212-224

- From ⟨N_{part}⟩ > 50: no significant centrality dependence
- J/ψ suppression at $\sqrt{s_{NN}}$=5.02 TeV confirms observations at $\sqrt{s_{NN}}$=2.76 TeV with an increased precision
- p_T > 0.3 GeV/*c* to remove most of photo-production (brackets for the remaining contribution)

Transport models: TM1 and TM2

NPA 859 (2011) 114, PRC 89 no.5, 459 (2014) 054911

Statistical hadronization

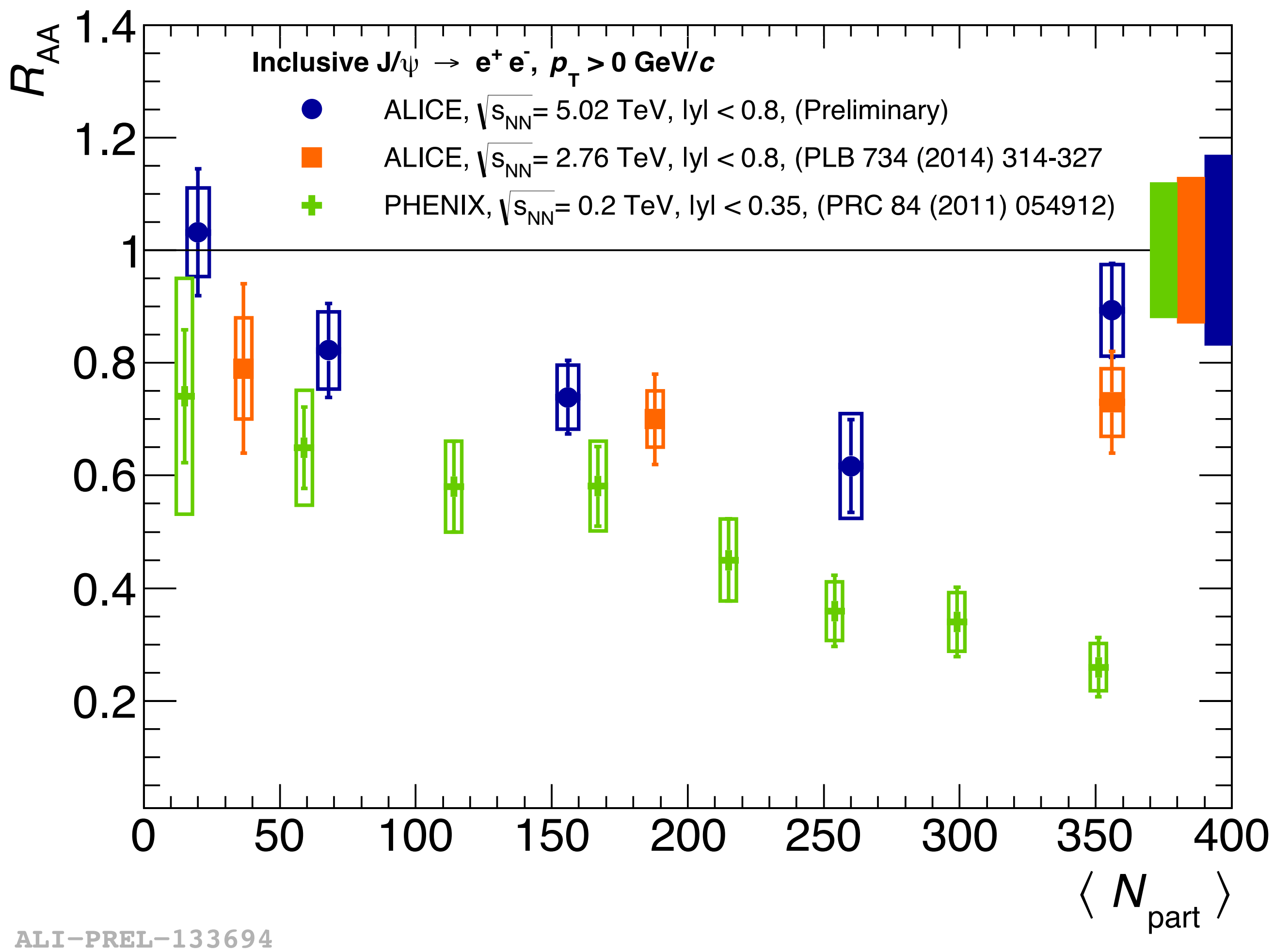
NPA 904-5 (2013) 535c

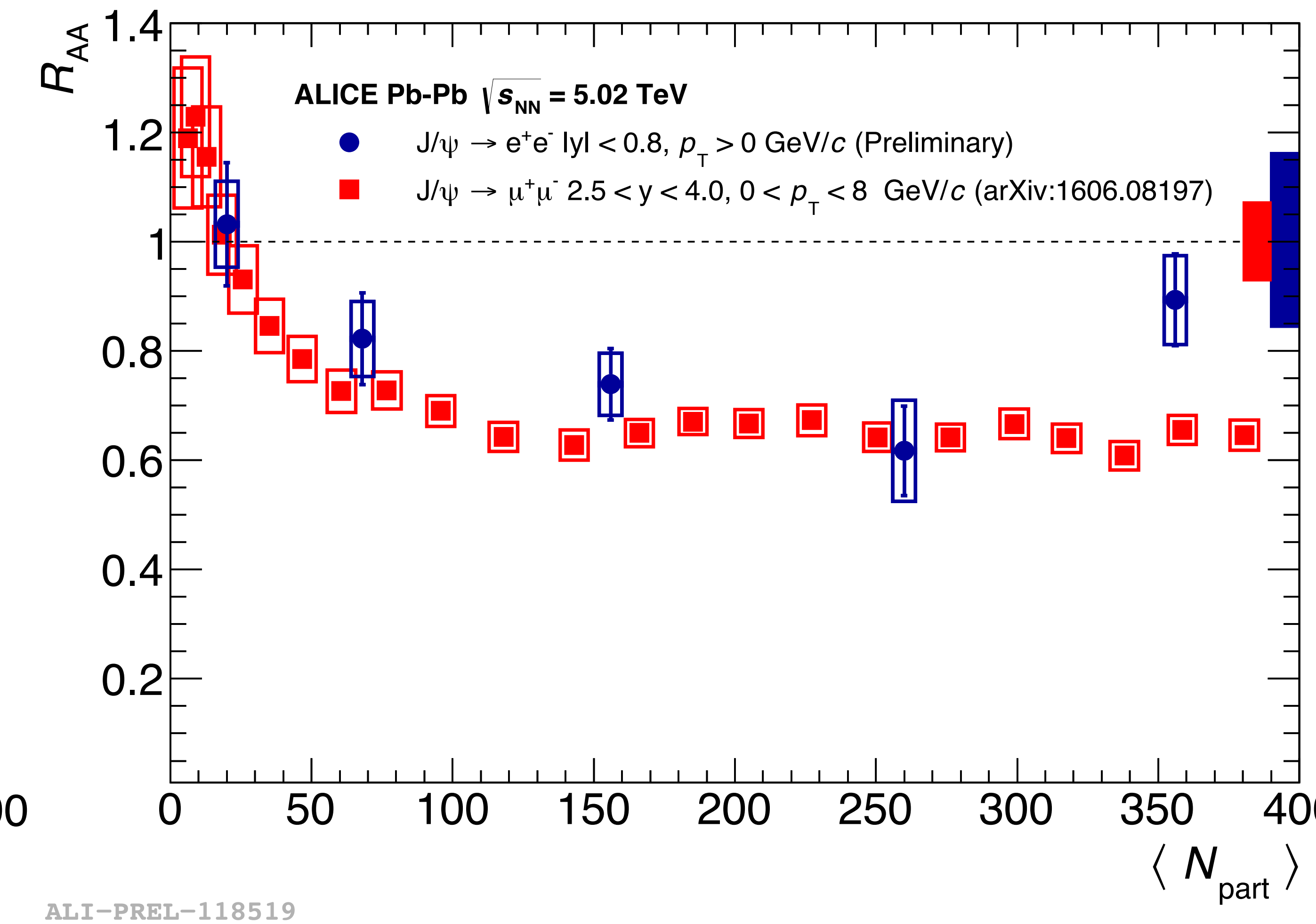
Co-movers interaction model

PLB 731 (2014) 57

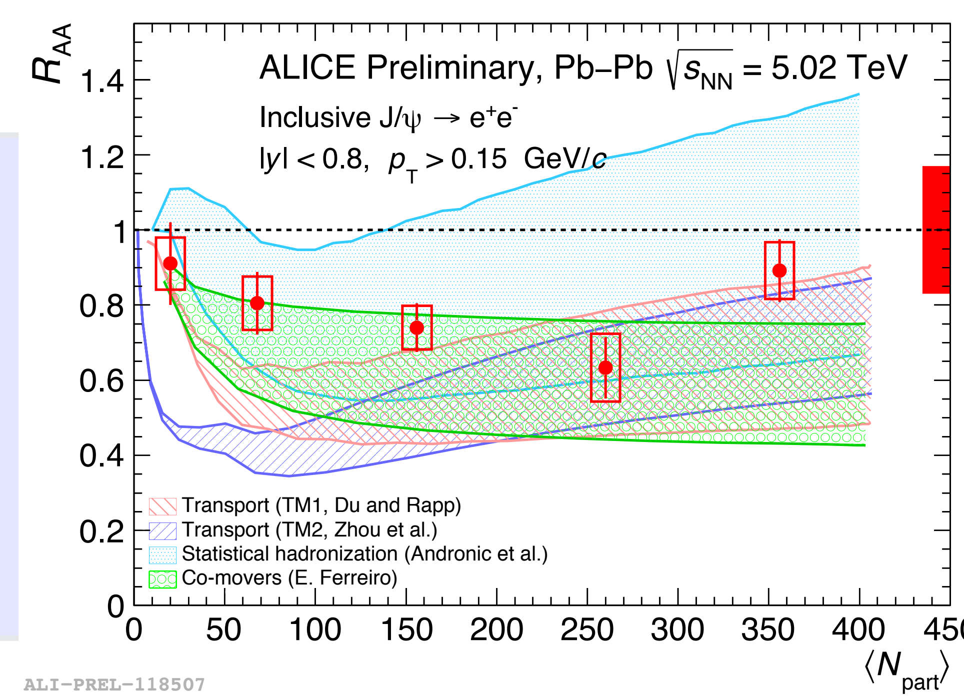
- Main sources of uncertainties
  - Feed-down from higher quarkonium resonances and b decays
  - Precise determination of open charm cross-section
  - CNM effects on quarkonium production

Charmonium production at mid-y



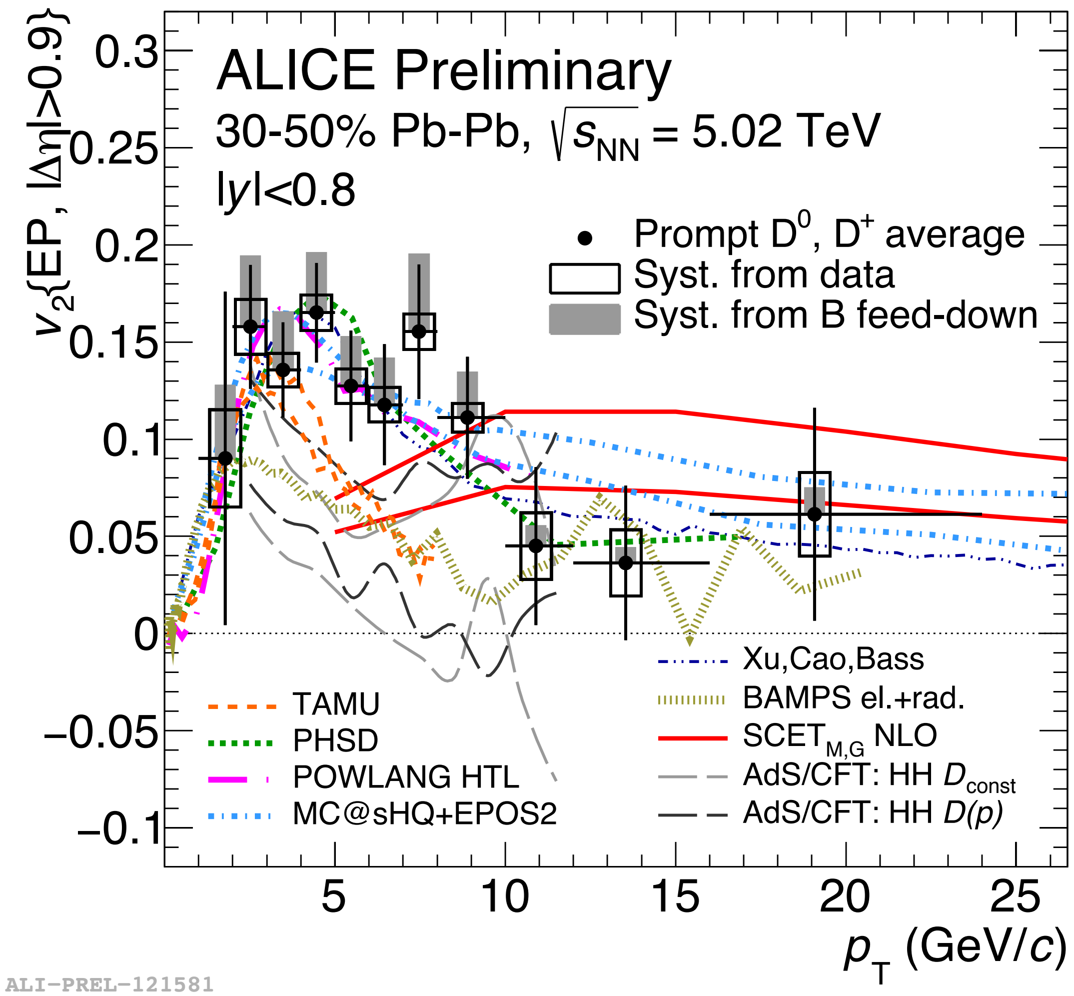


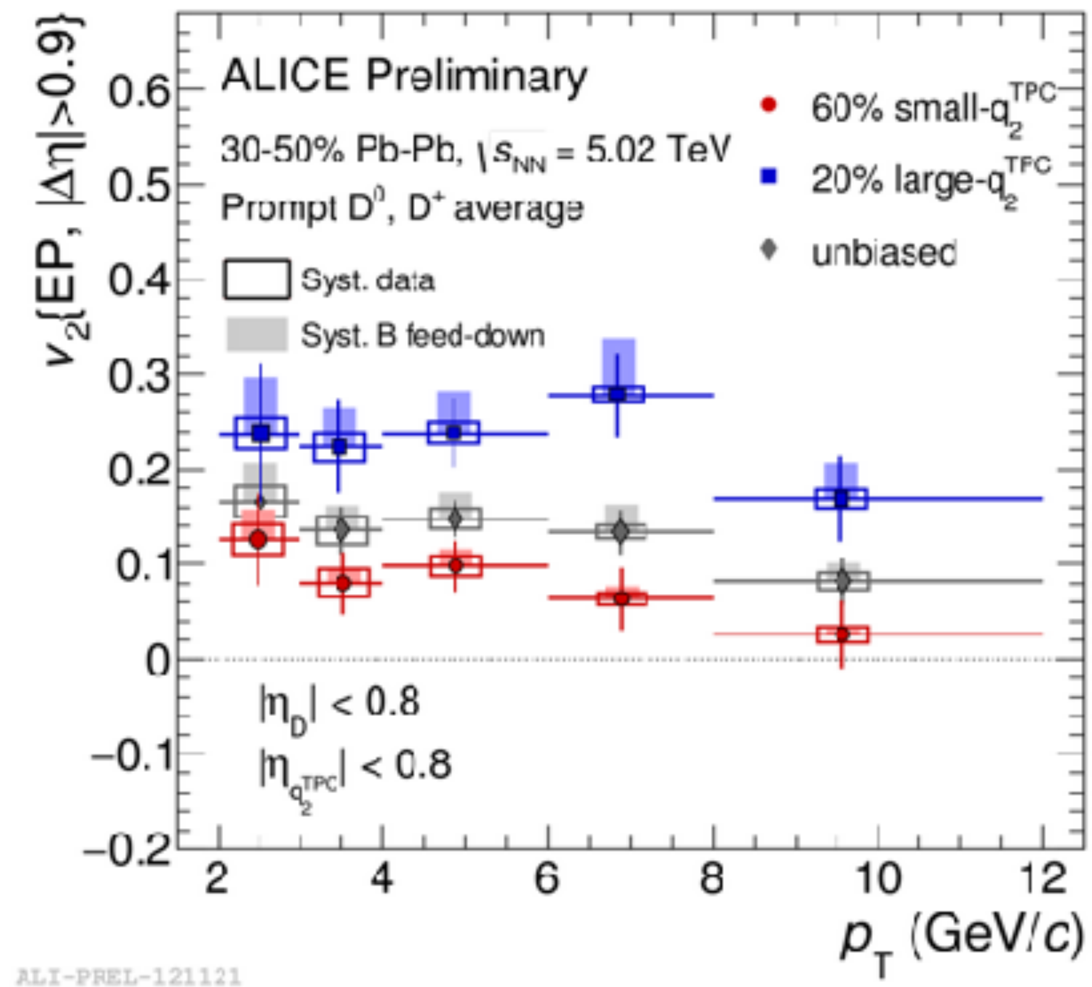
- Results at 2.76 TeV compatible with 5.02 TeV, confirming forward-y observations
- Small R_{AA} increase for most central collisions, not observed at forward-y



The elliptic flow of D mesons

- Heavy quarks participate to the collective expansion dynamics



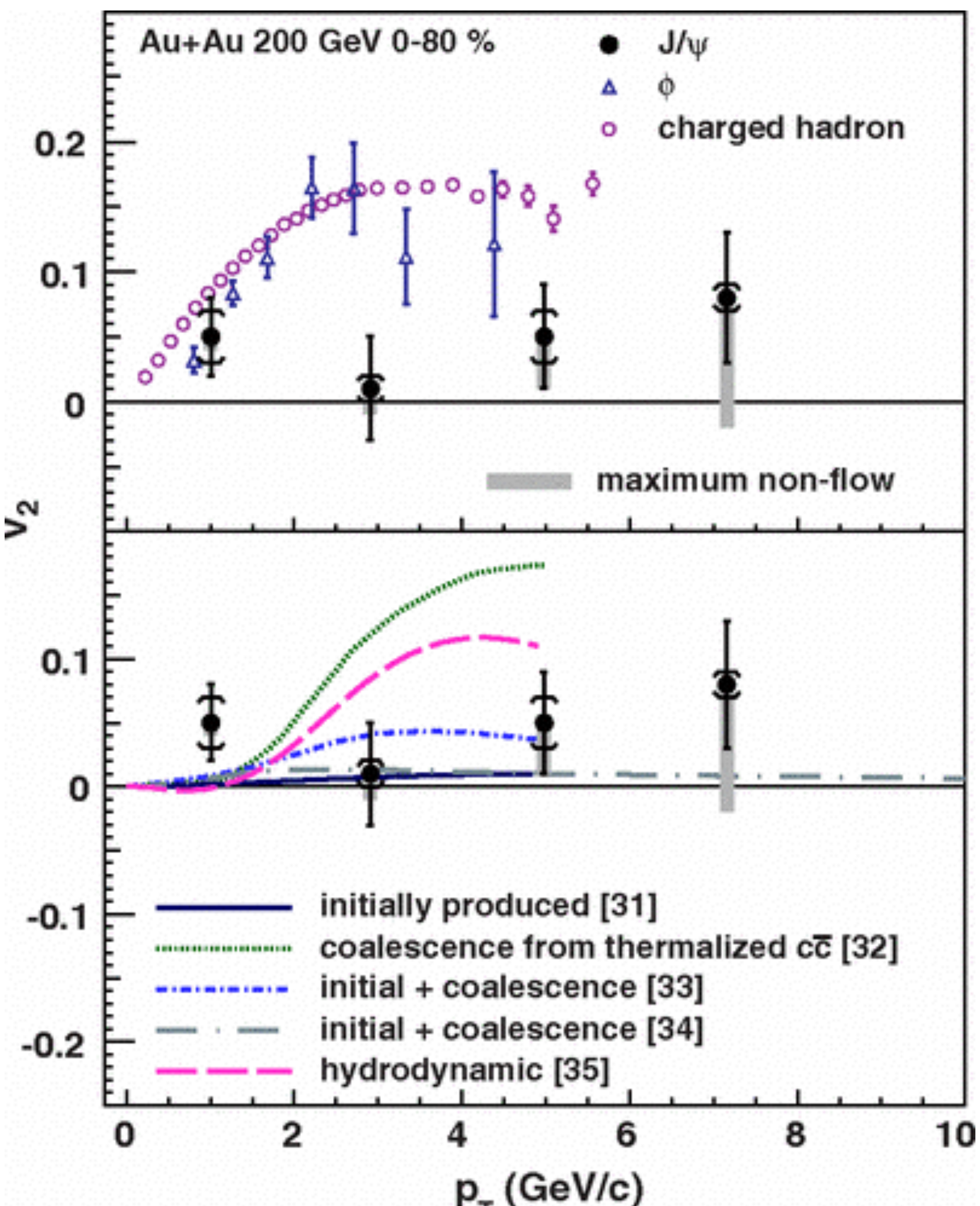


- Recombined states should inherit their flow
- Relevant observable for quarkonium (re)generation study
- Further constrain theoretical models describing quarkonium production

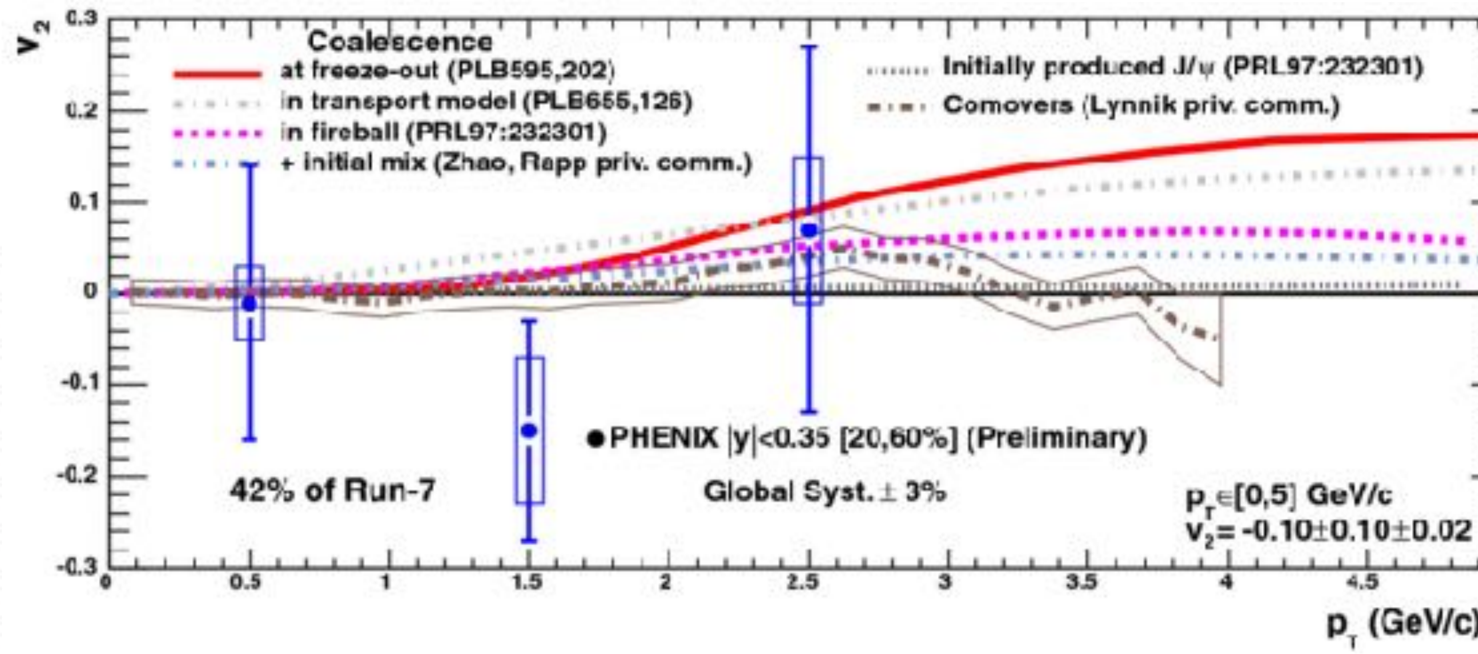
J/ψ v_2 at RHIC energies

v_2 ~0 at RHIC energies
v_2 <0 at low p_T ?

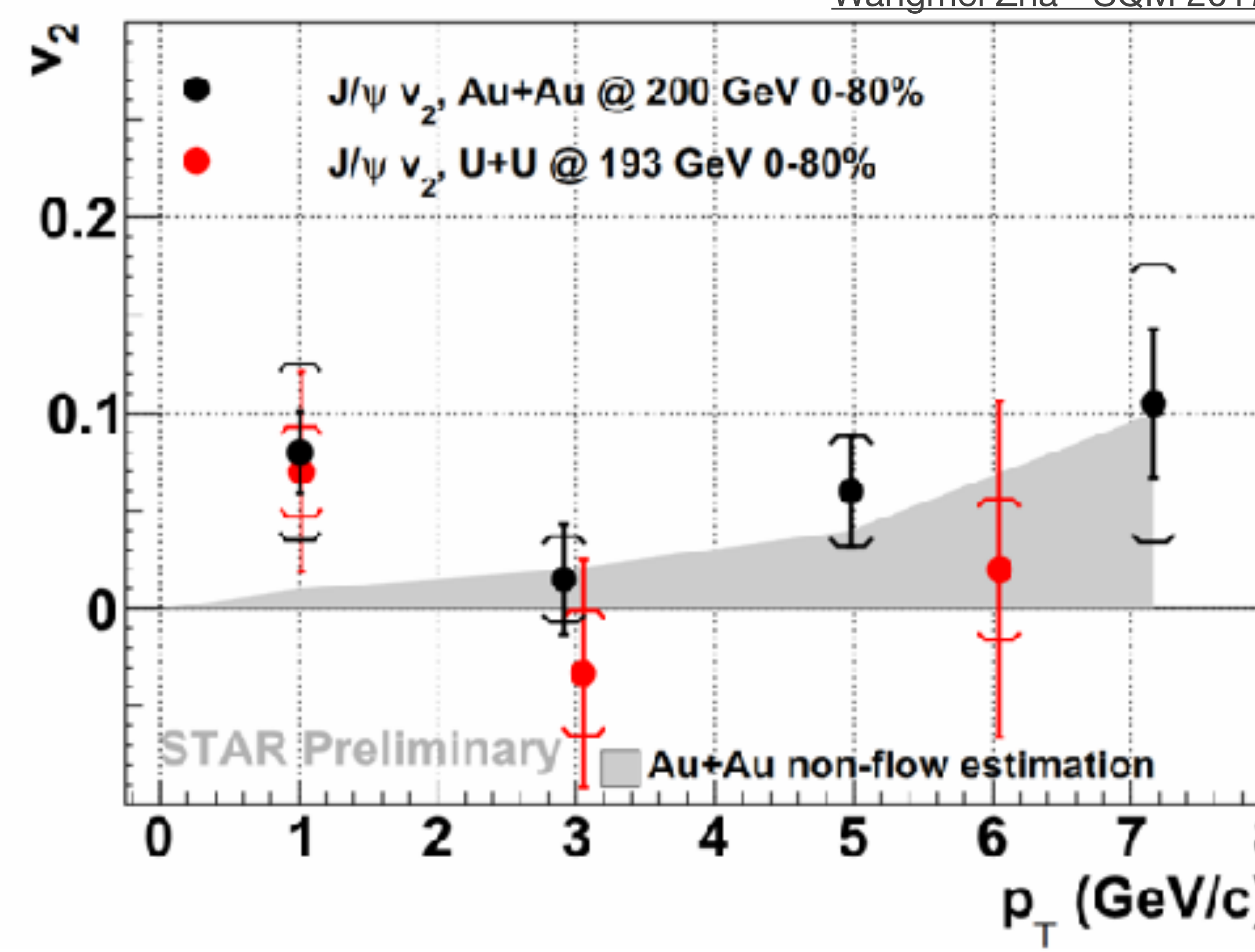
Phys. Rev. Lett. 111, 052301 (2013)



Acta Phys.Polon.Supp. 5 (2012) 323-328



Wangmei Zha - SQM 2017



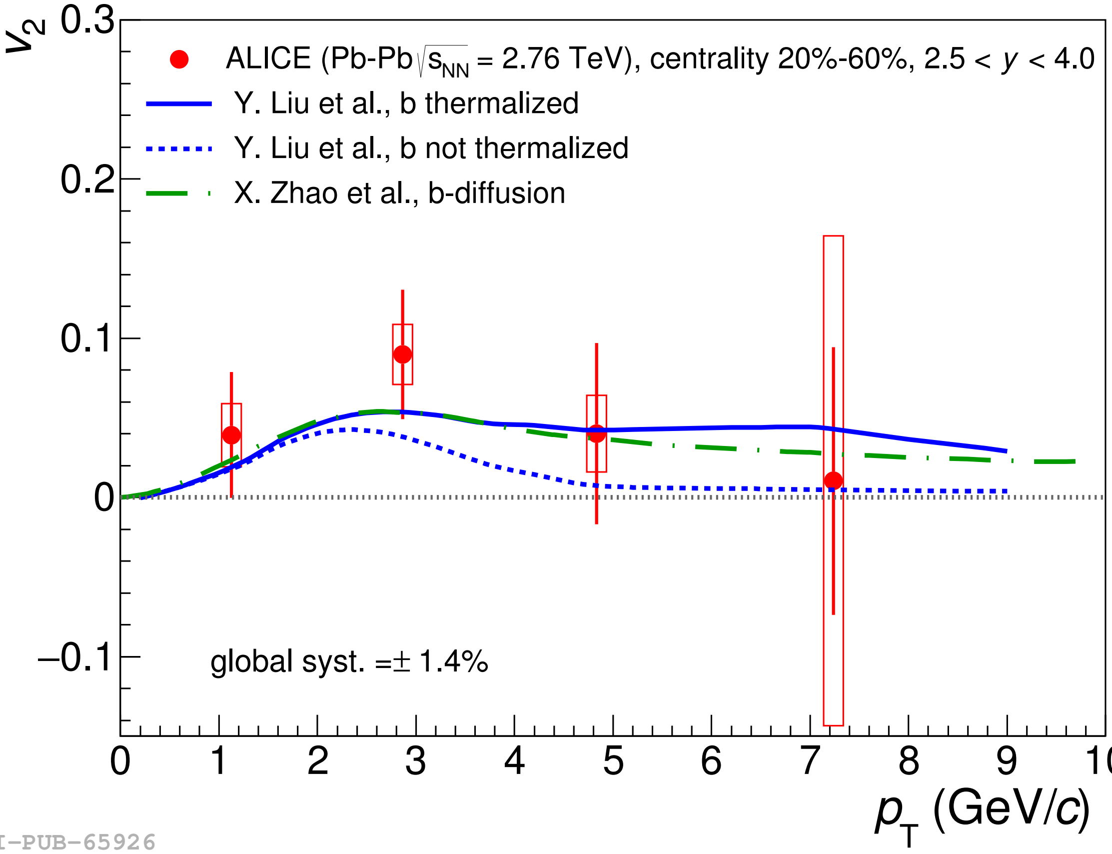
J/ψ v_2 at $\sqrt{s_{NN}}$ = 2.76TeV

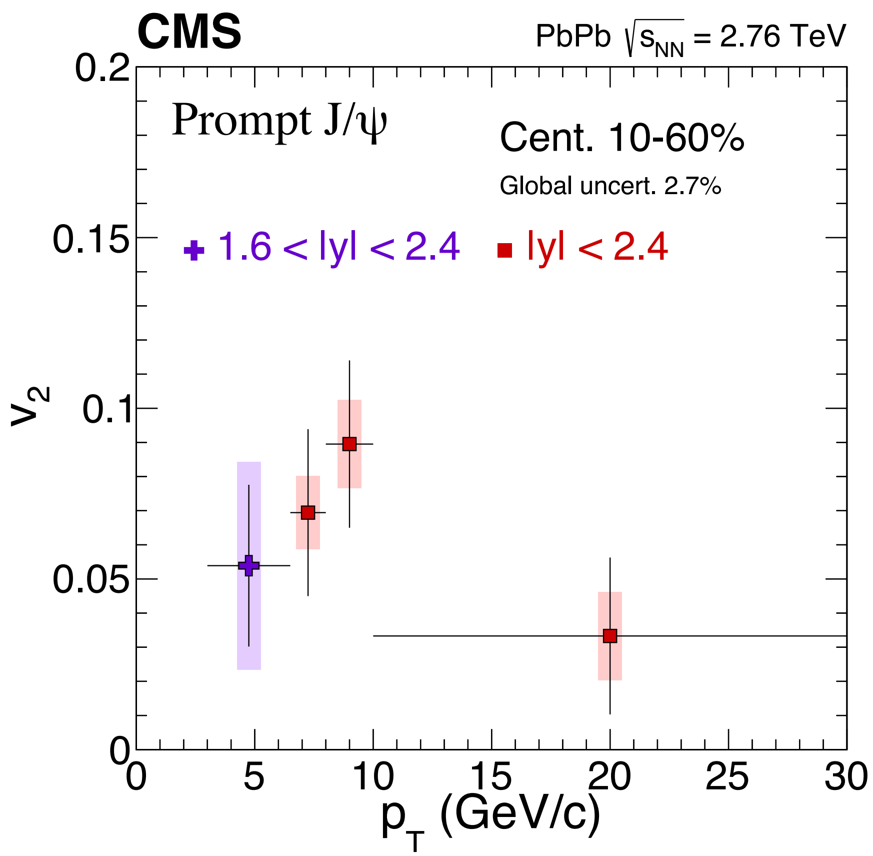
ALICE

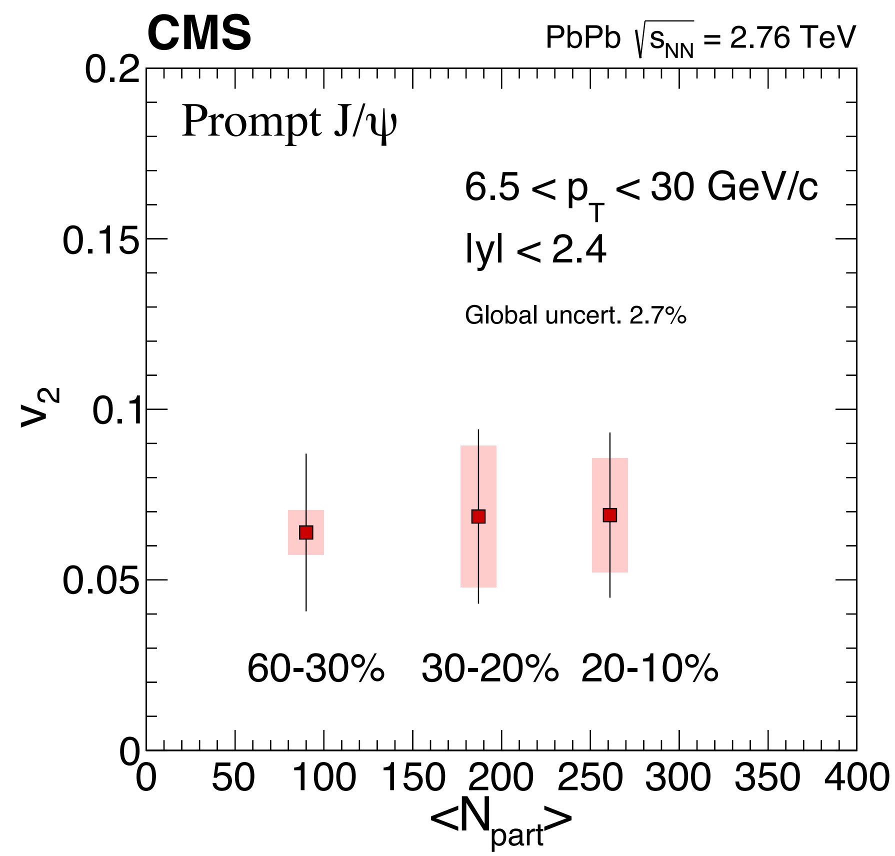
First hint of J/ψ v_2

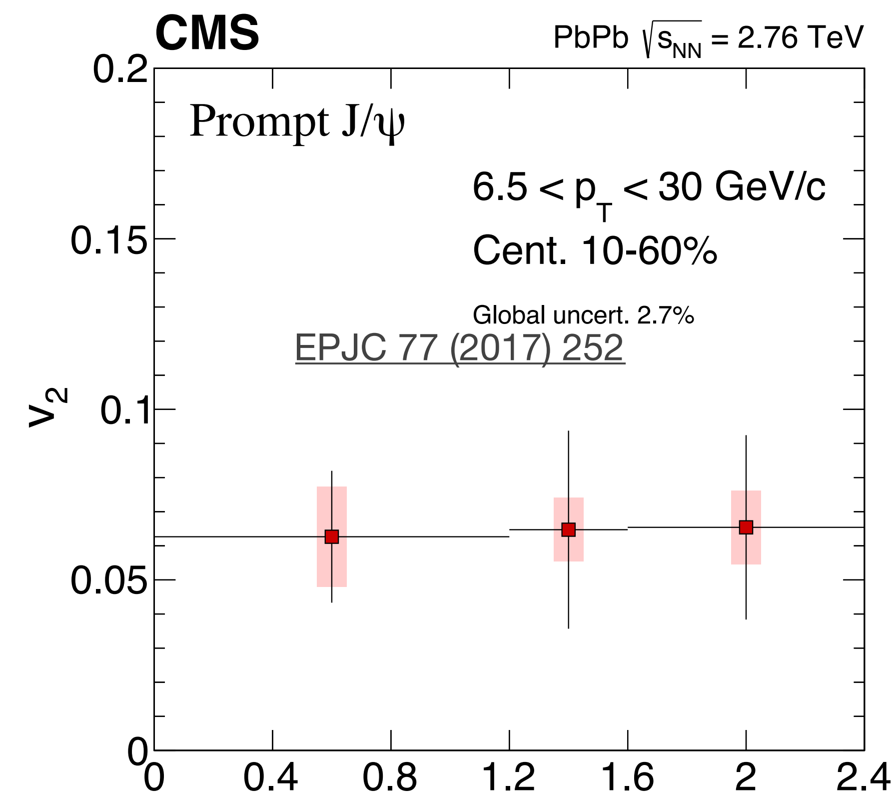
measured by both CMS and ALICE

➡ different kinematic regions !







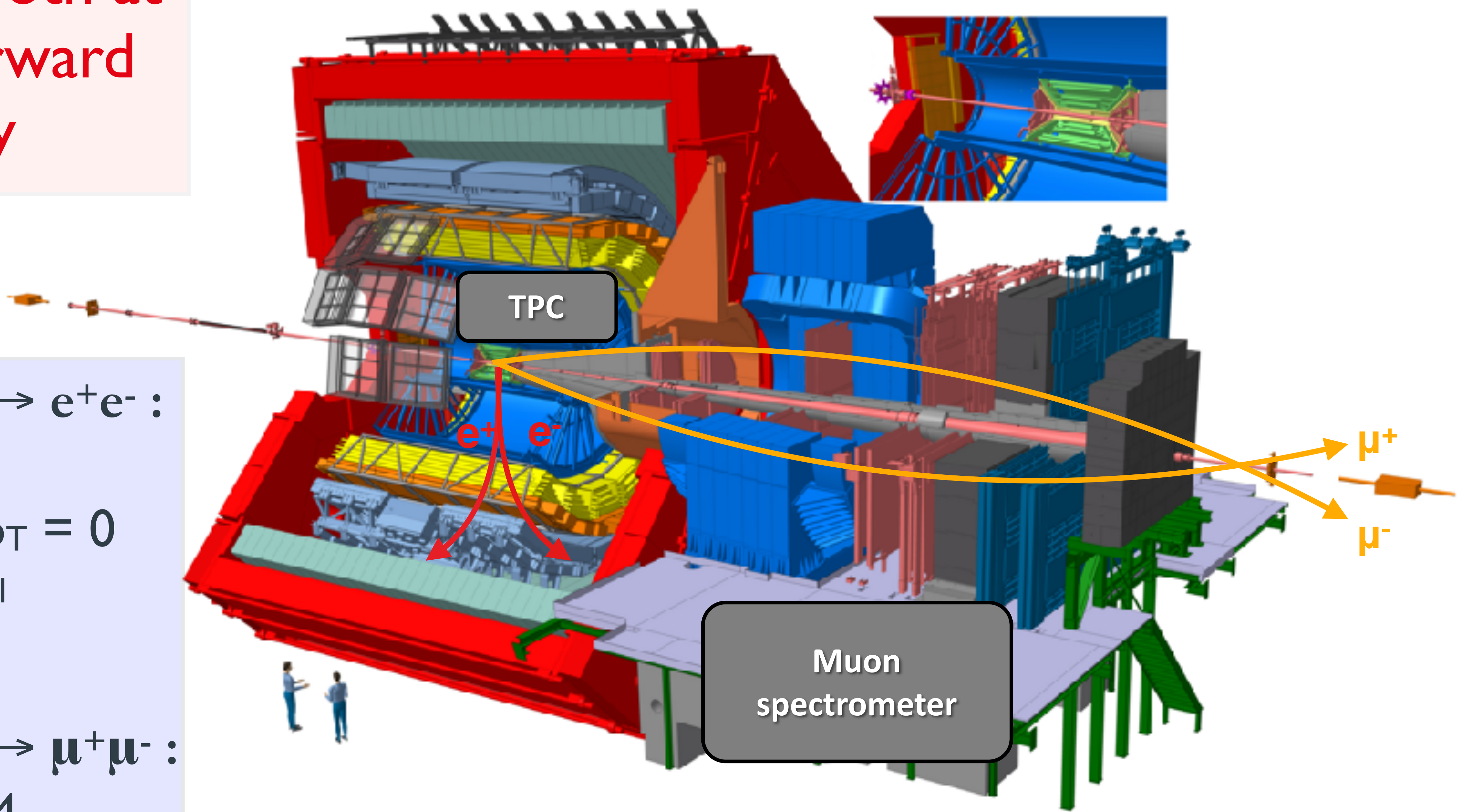


EPJC 77 (2017) 252

J/ψ v_2 measurements with ALICE in Pb-Pb

Run 2 (2015-2016) Pb-Pb at $\sqrt{s_{NN}}$=5.02 TeV

Performed both at mid and forward rapidity

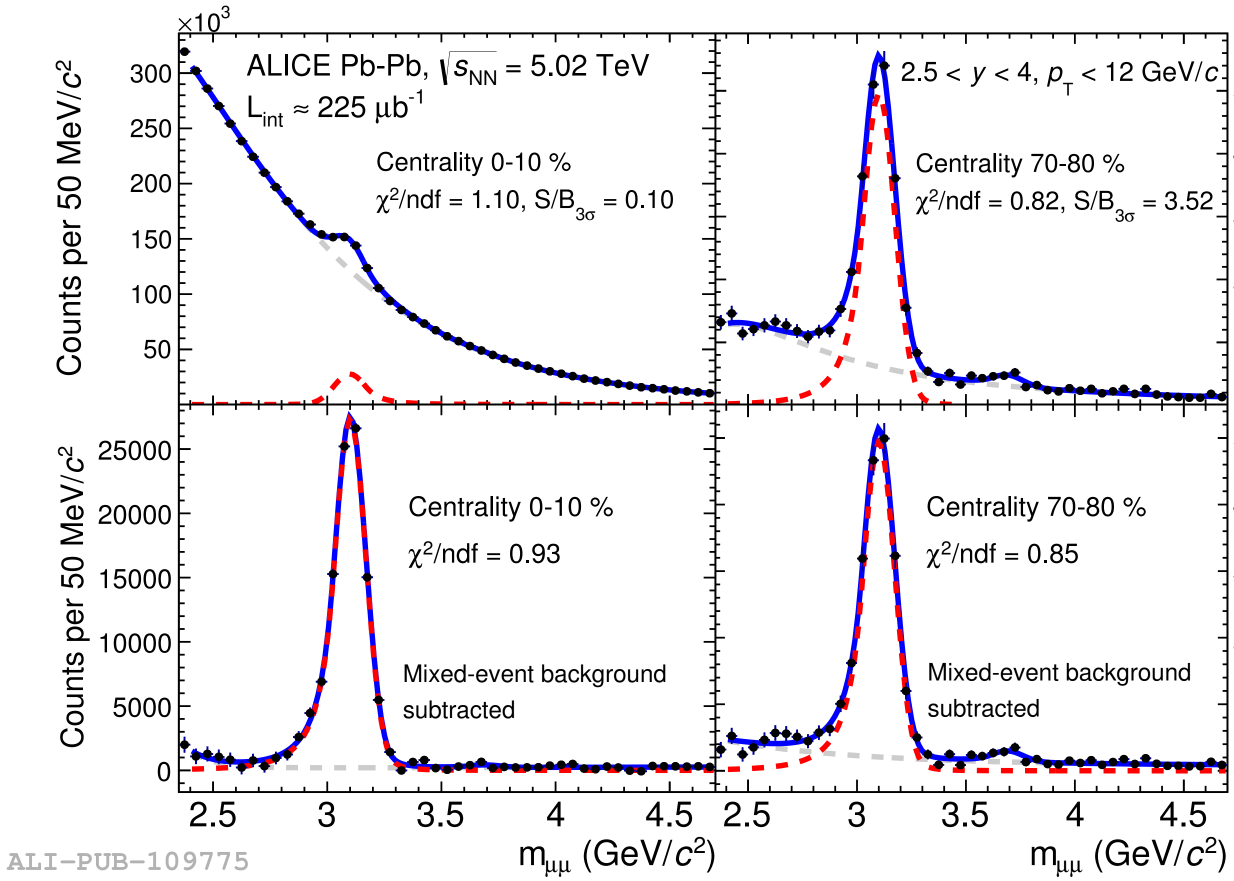


Quarkonium → e^+e^- :
- $|y| < 0.9$
- down to $p_T = 0$
- $\mathcal{L} = 13\mu b^{-1}$

Quarkonium → $\mu^+\mu^-$:
- $2.5 < y < 4$
- down to $p_T = 0$
- $\mathcal{L} = 225\mu b^{-1}$

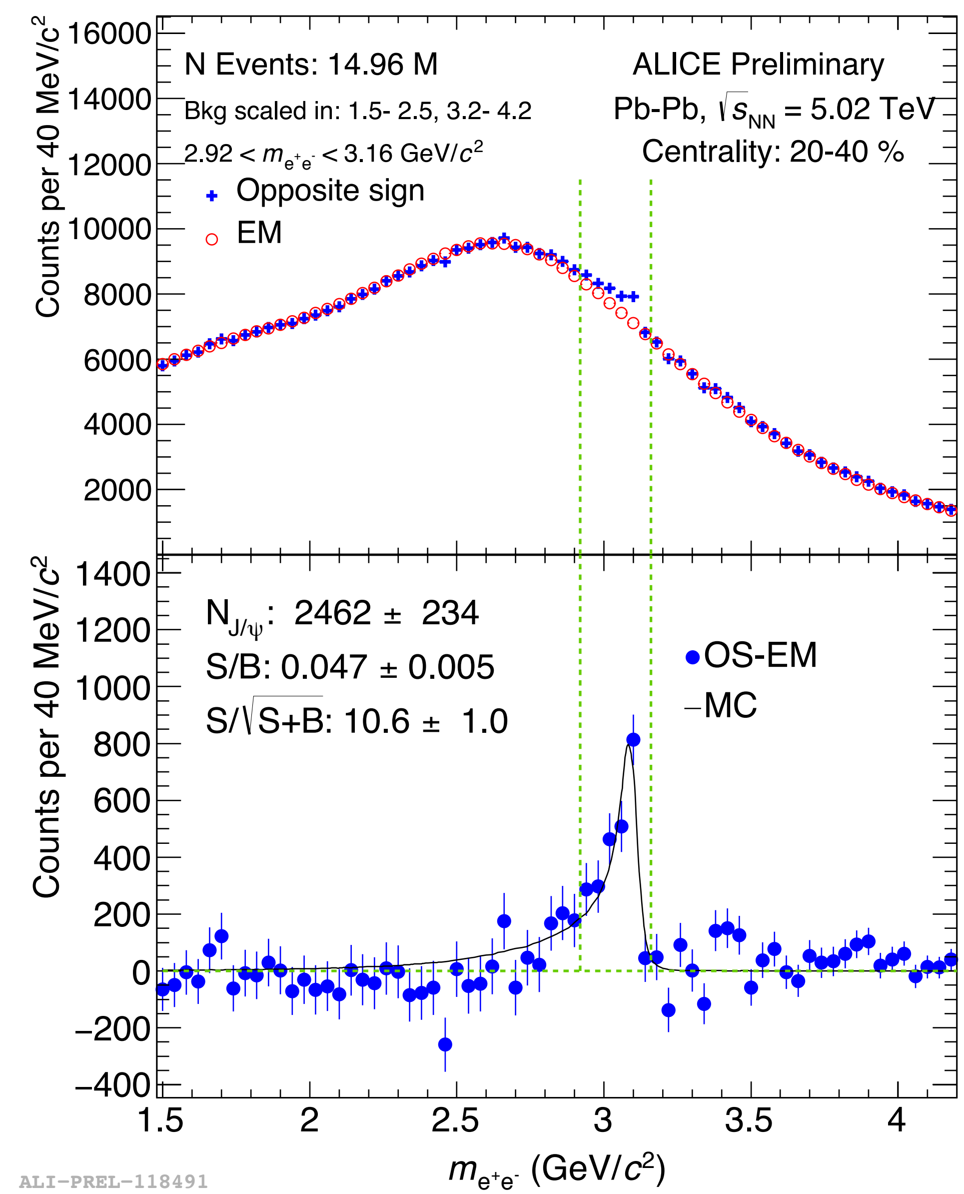
V0 : Event plane (EP) + centrality
ITS (SPD) : vertex + EP
T0 : luminosity

Charmonium reconstruction with the ALICE detector



Yield extraction :

Fit of the dimuon invariant mass distribution with several signal + background shapes



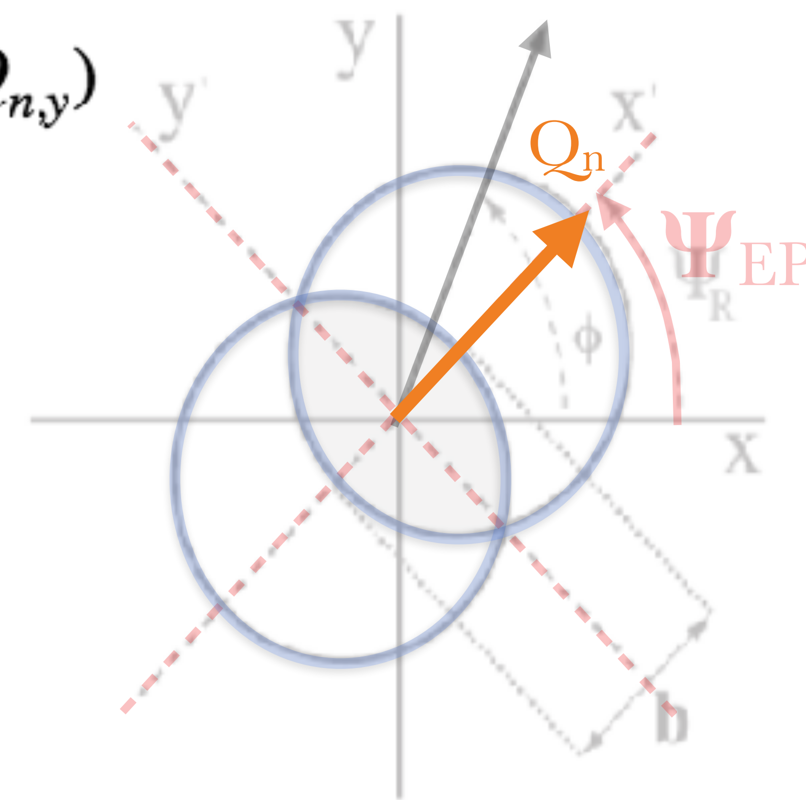
INCLUSIVE J/ψ

- **Prompt J/ψ**: Direct J/ψ + Feed-down from excited states
- **Non-prompt J/ψ**: B hadron decays

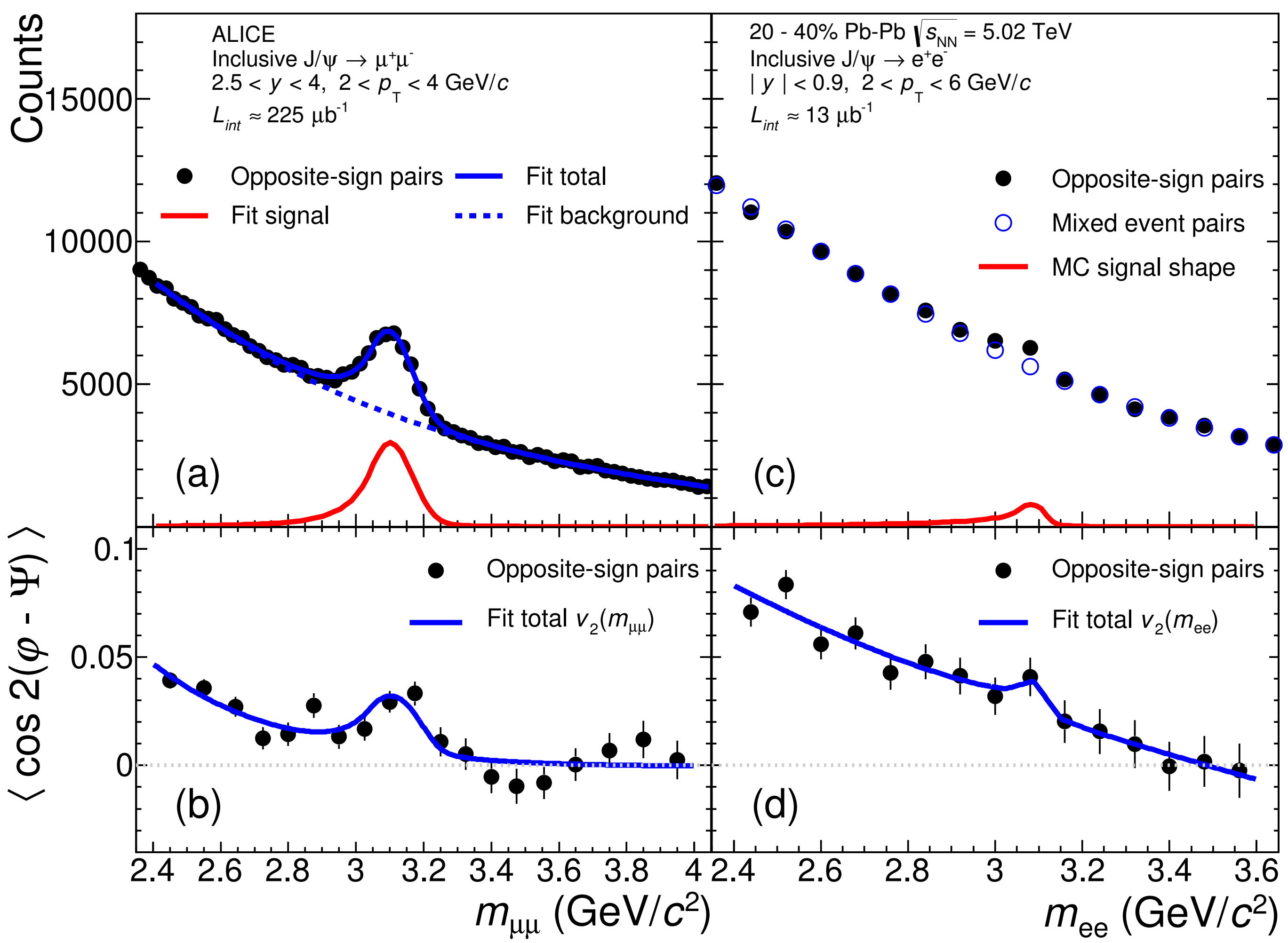
J/ψ elliptic flow: how to measure it ?

ALICE

- Methods based on event plane determination
  From detector multiplicities : $\Psi_n = \frac{1}{n} arctan(Q_{n,x}, Q_{n,y})$



- Fit of ⟨cos(2 Δφ)⟩ distribution vs inv. mass
  with $\Delta\varphi = \varphi_{\mu\mu} - \Psi_{2,EP}$



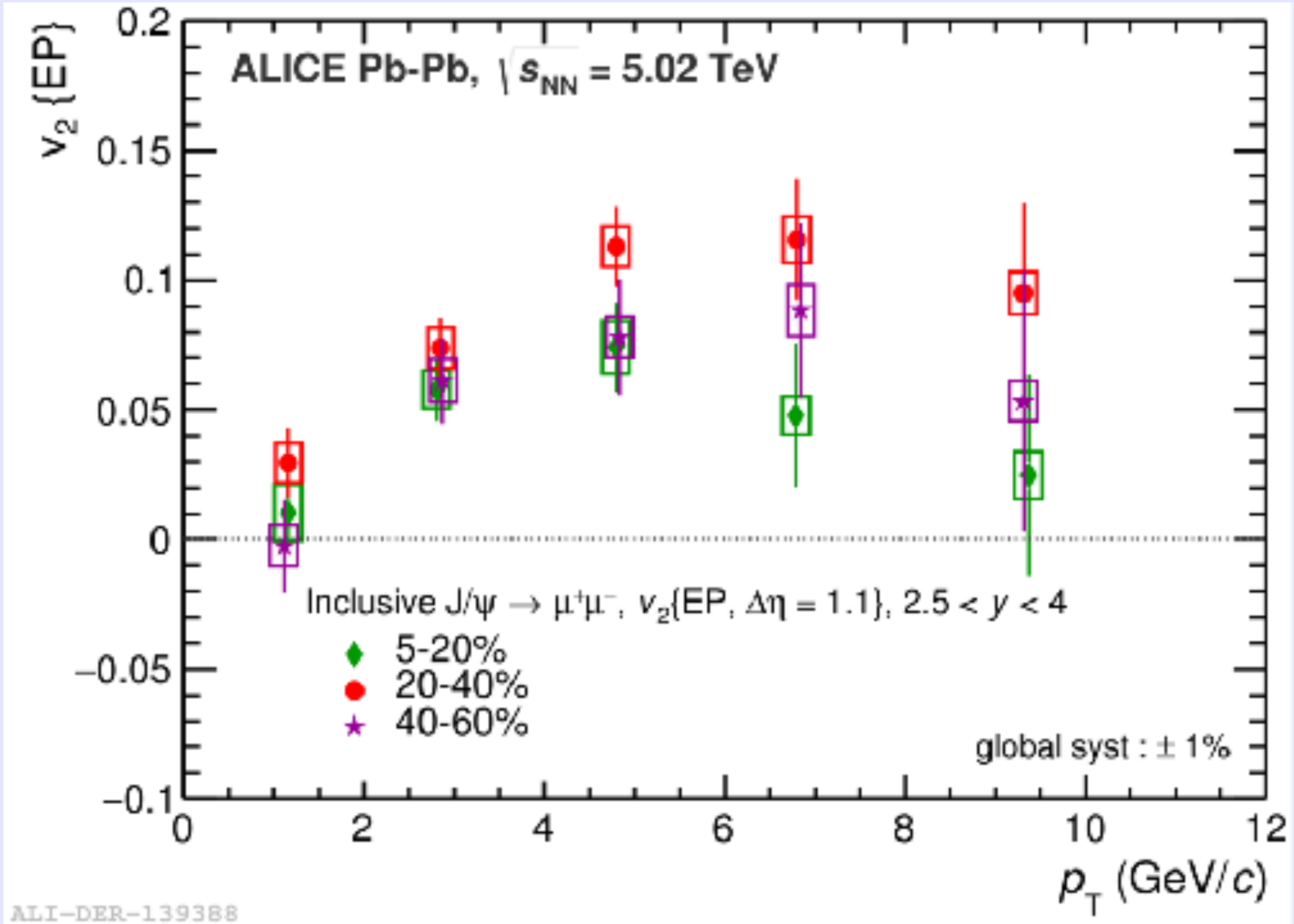
Model total flow as

$$v_2(m_{\mu\mu}) = v_2^{sig}\alpha(m_{\mu\mu}) + v_2^{bck}(1-\alpha(m_{\mu\mu}))$$

signal shape extracted from M_{inv} fit

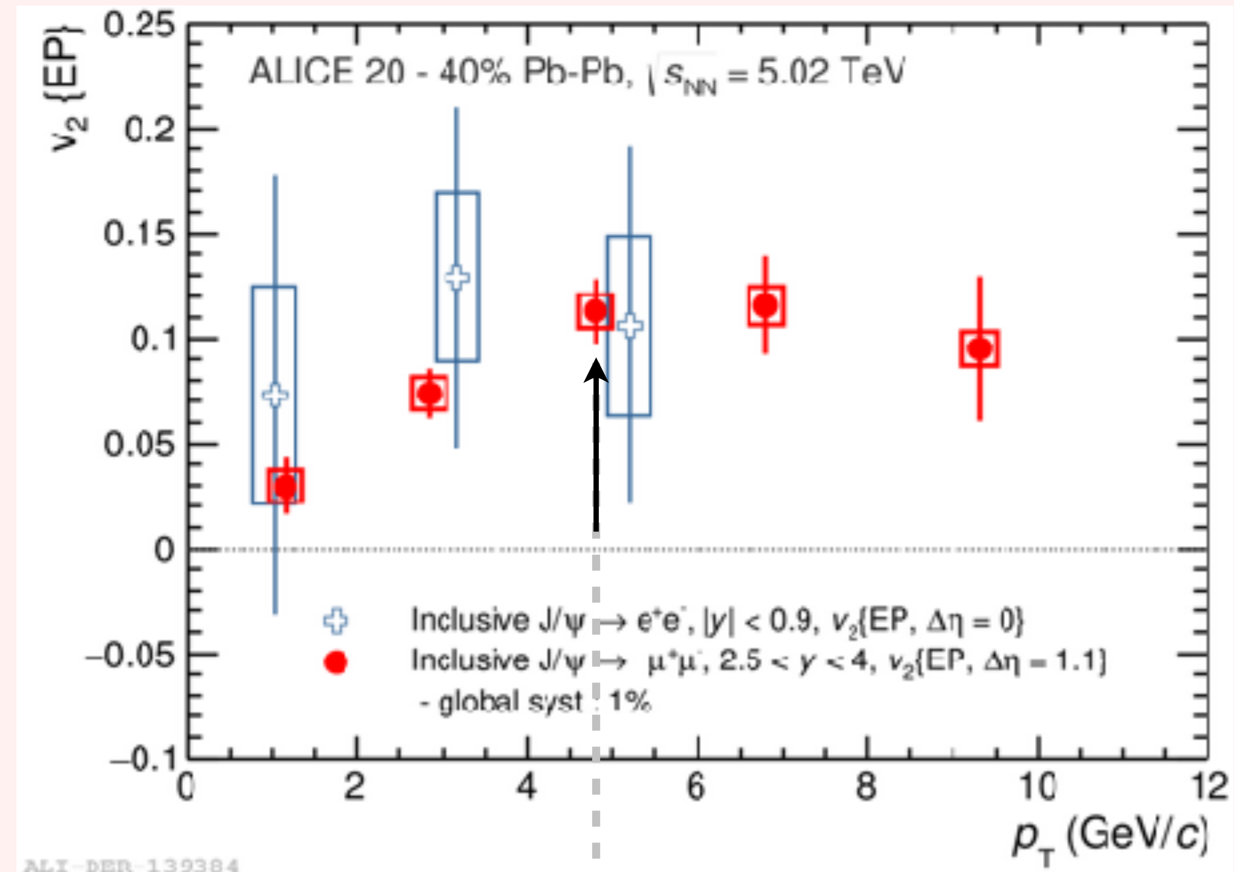
background : e.g. polynomial function

Results at $\sqrt{s_{NN}}$ = 5.02TeV



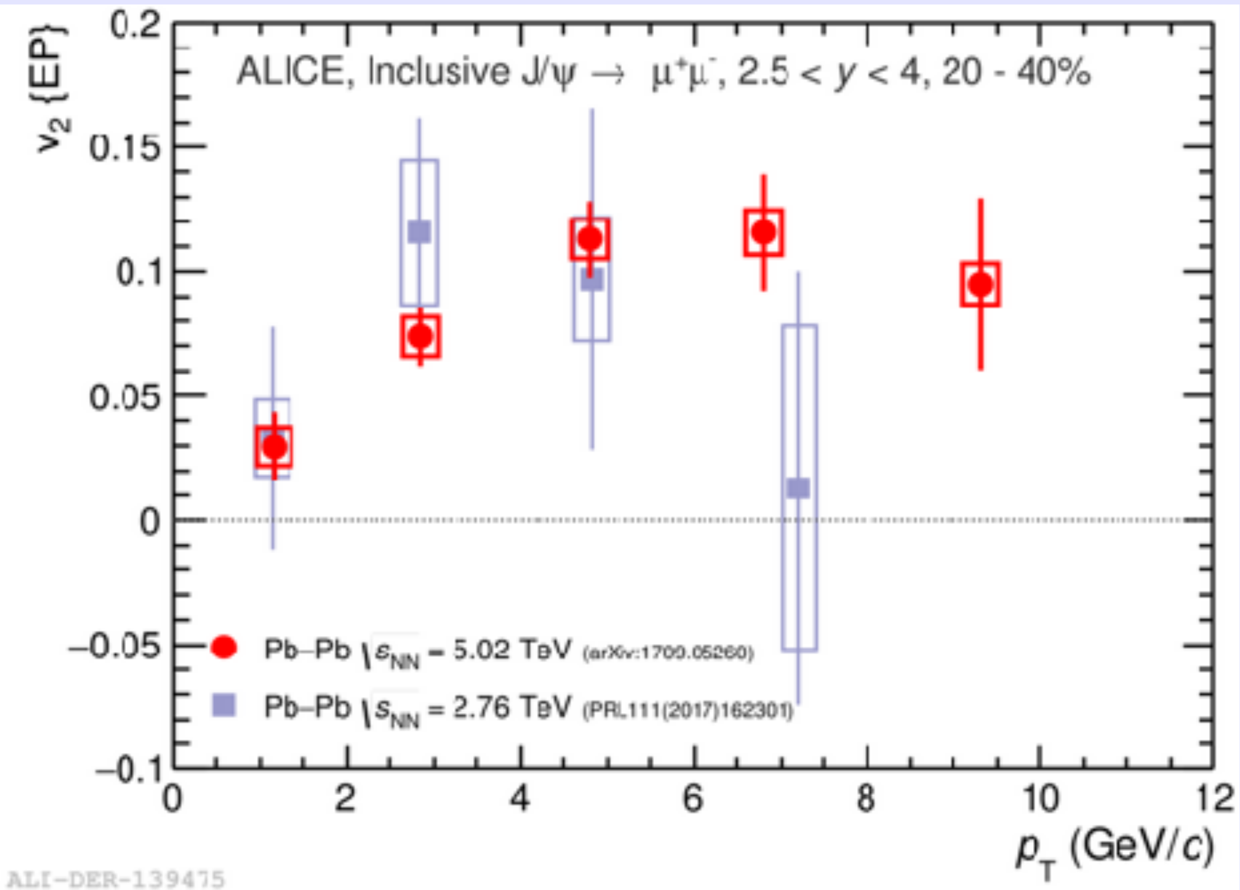
A significant v_2 is observed for various centrality and p_T bins

Compatible results between both rapidity measurements



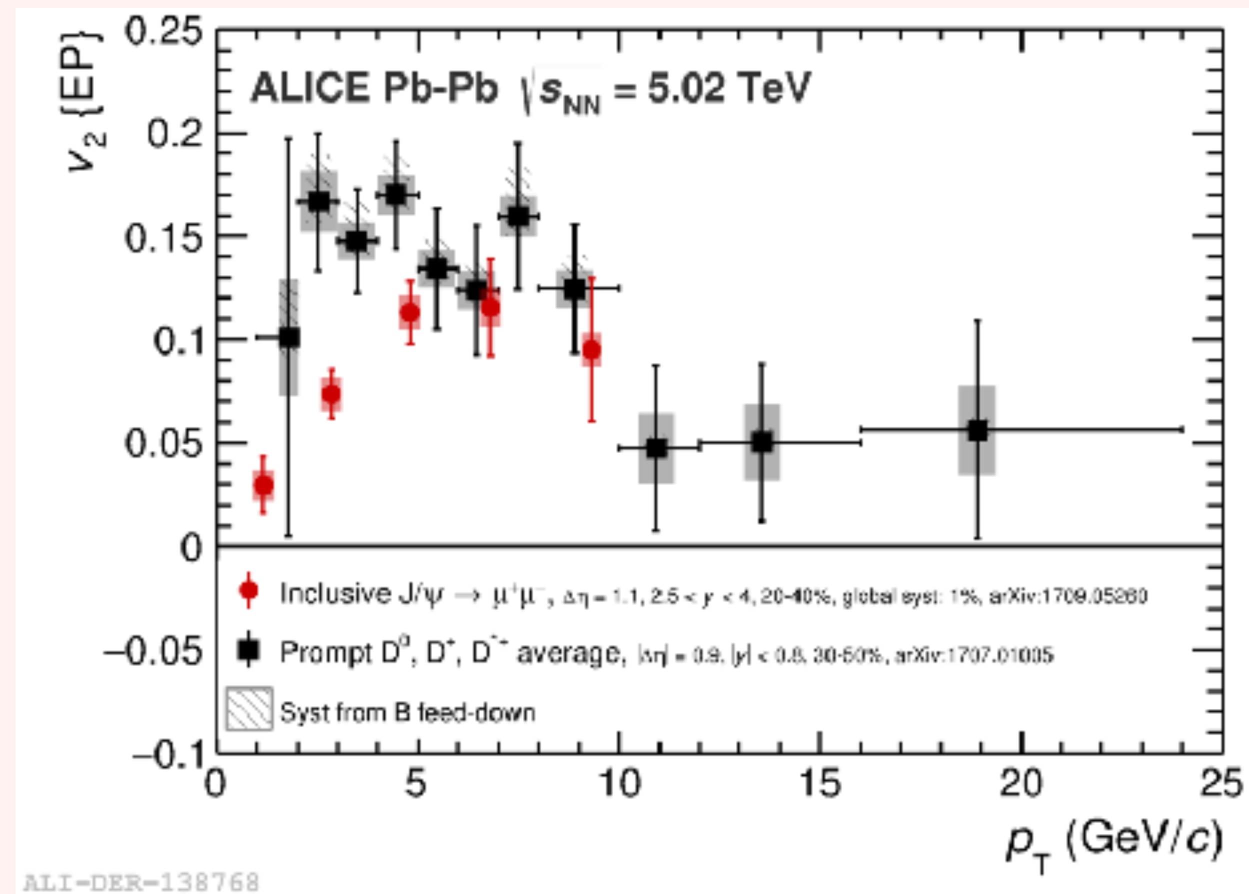
Highest significance : 6.6σ for 20-40% and 4<p_T<6 GeV/c
v_2 = 0.113 ± 0.015(stat) ± 0.008(syst)

J/ψ v_2 comparison with $\sqrt{s_{NN}}$ =2.76 TeV and D mesons

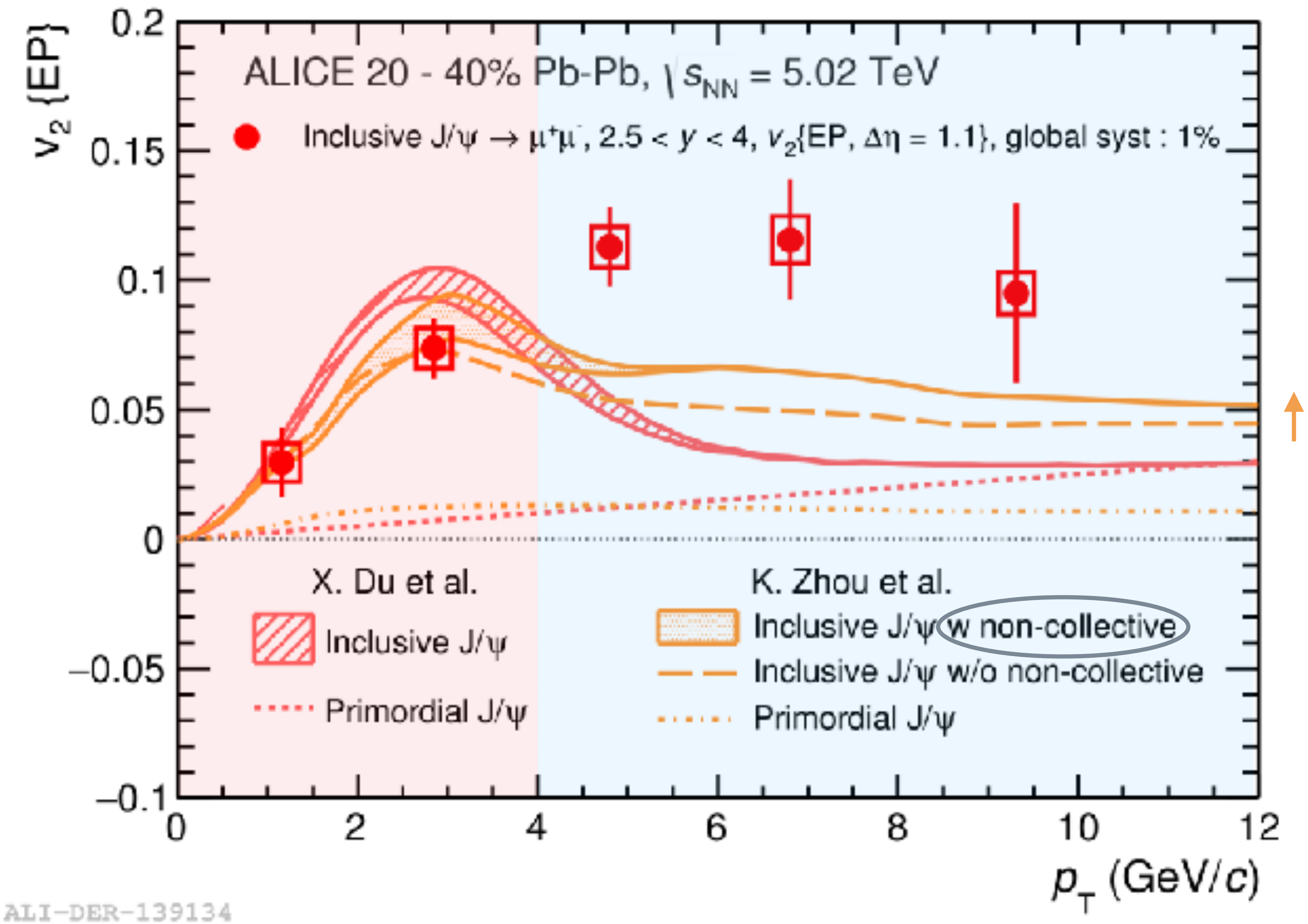


Compatible with results at $\sqrt{s_{NN}}$ = 2.76TeV with a higher precision

Comparison to open charm
→ indication of :
charm recombination and thermalization in the medium



Comparison with theory



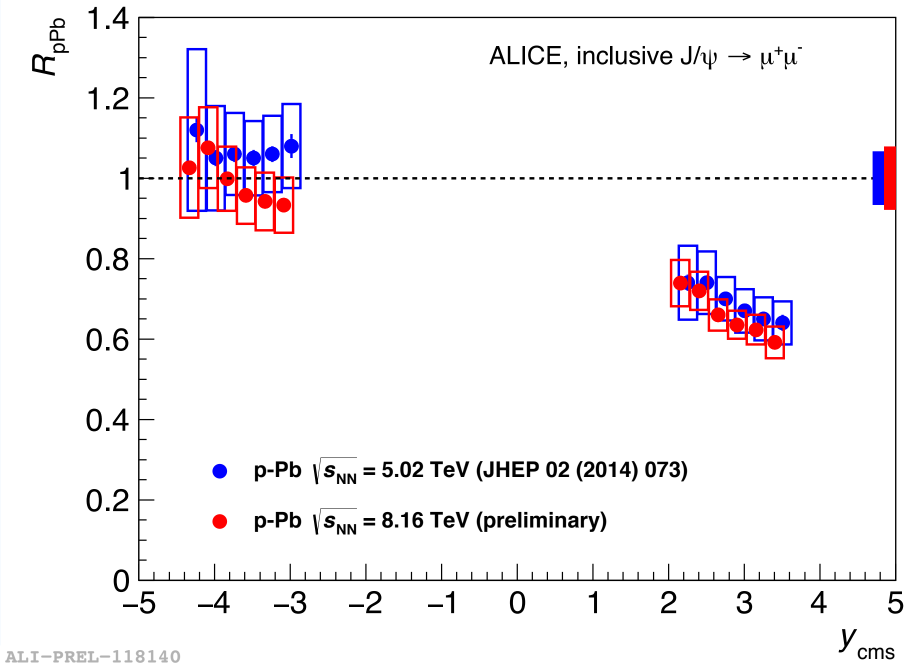
Additionnal component from initial magnetic field could help better describe high p_T anisotropy

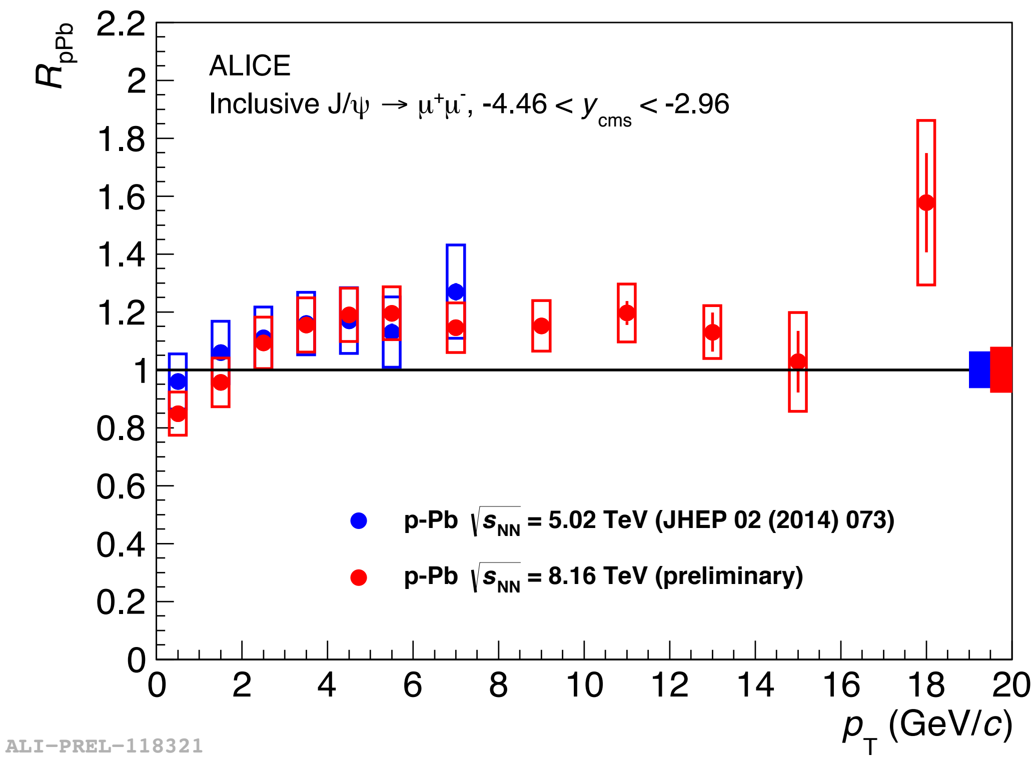
Magnitude at low p_T is reproduced by including a strong J/ψ (re)generation component

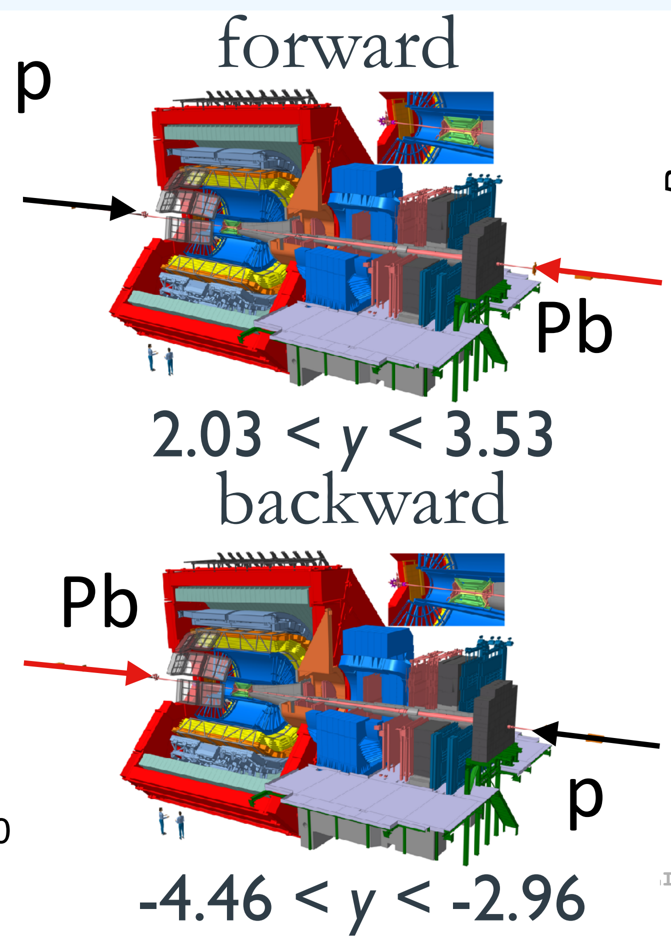
At high p_T the v_2 is underestimated (prompt J/ψ from CMS also indicate a non-zero v_2)

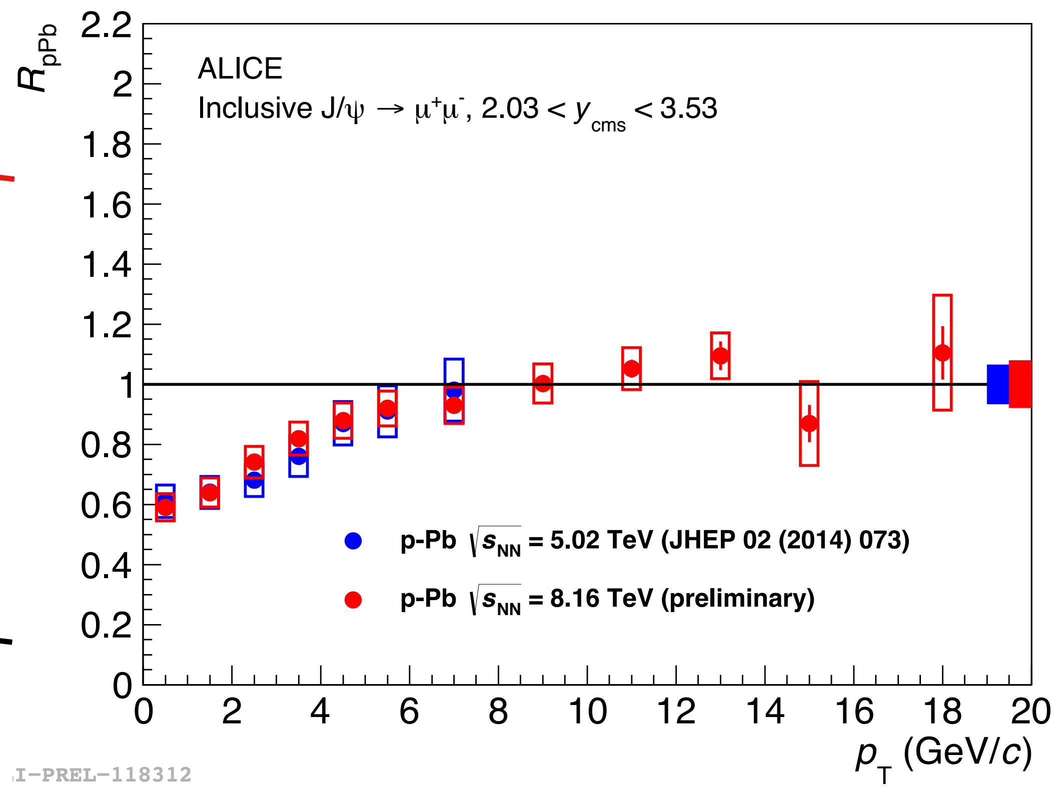
Cold nuclear matter effects

- Outside hot matter mechanisms, other effects might affect quarkonium production
  - Energy loss
  - Initial state: nuclear parton shadowing/CG condensate
  - Final state: nuclear absorption
- CNM investigated in p-A collisions

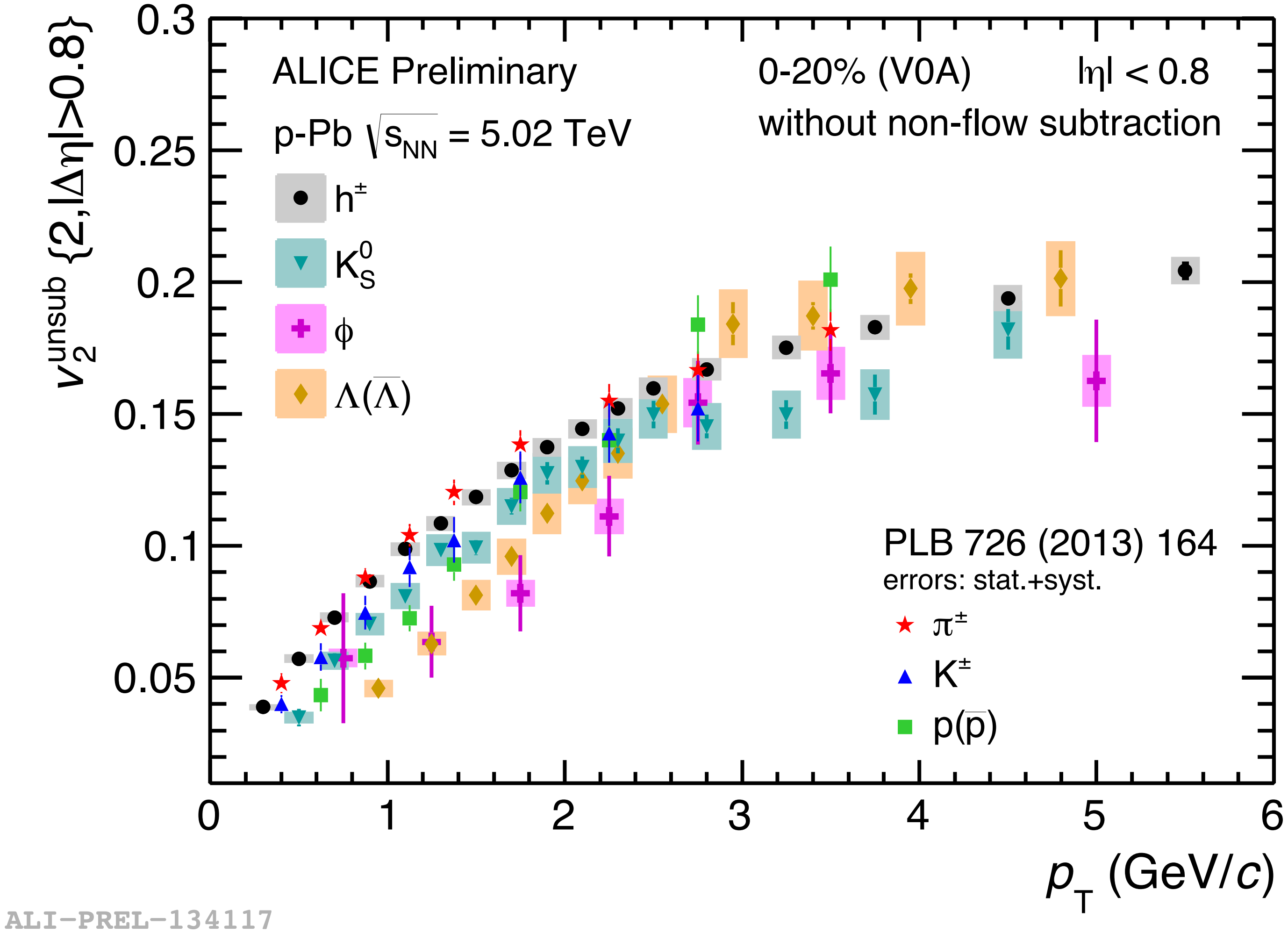


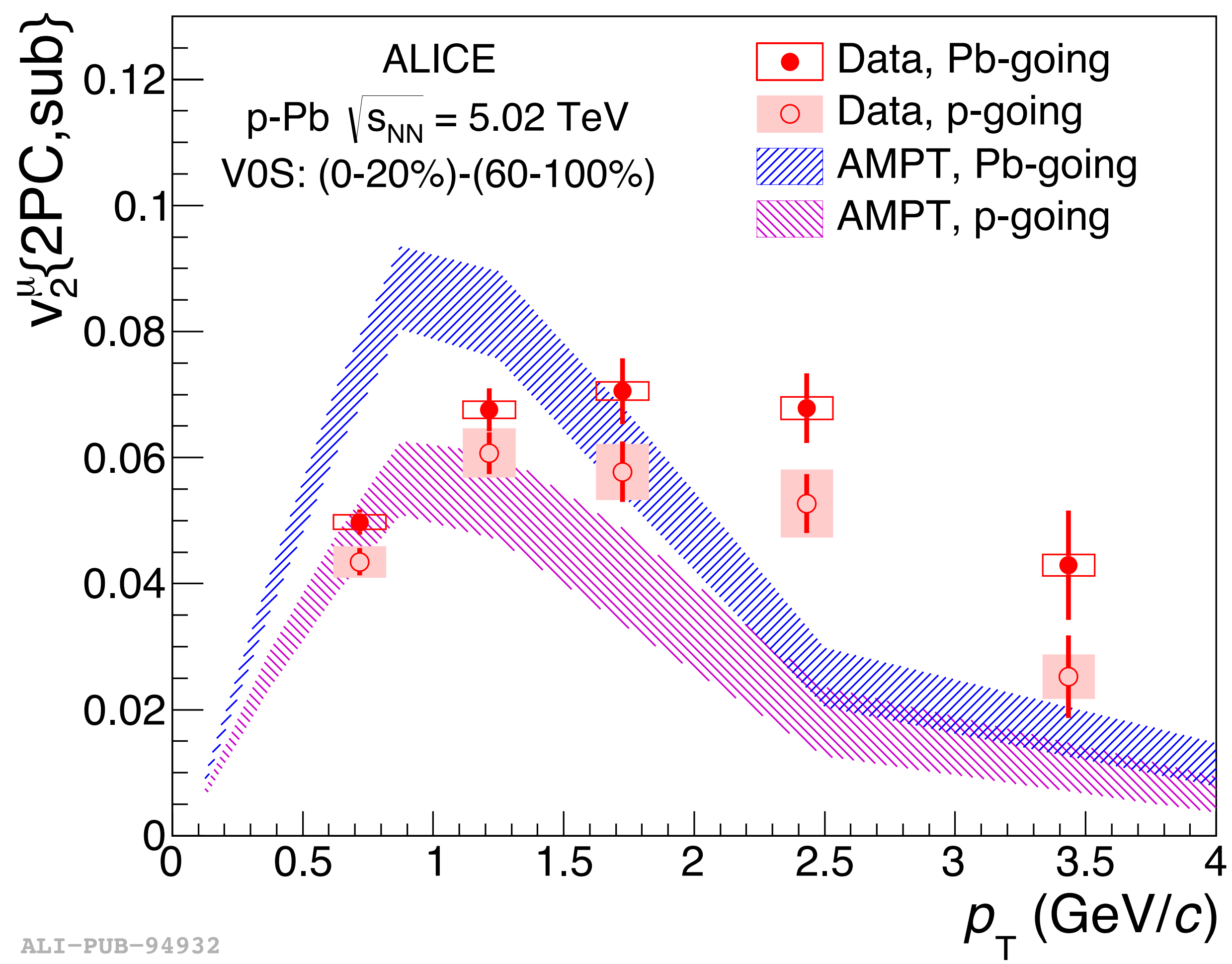






Collectivity in p-Pb collisions ?





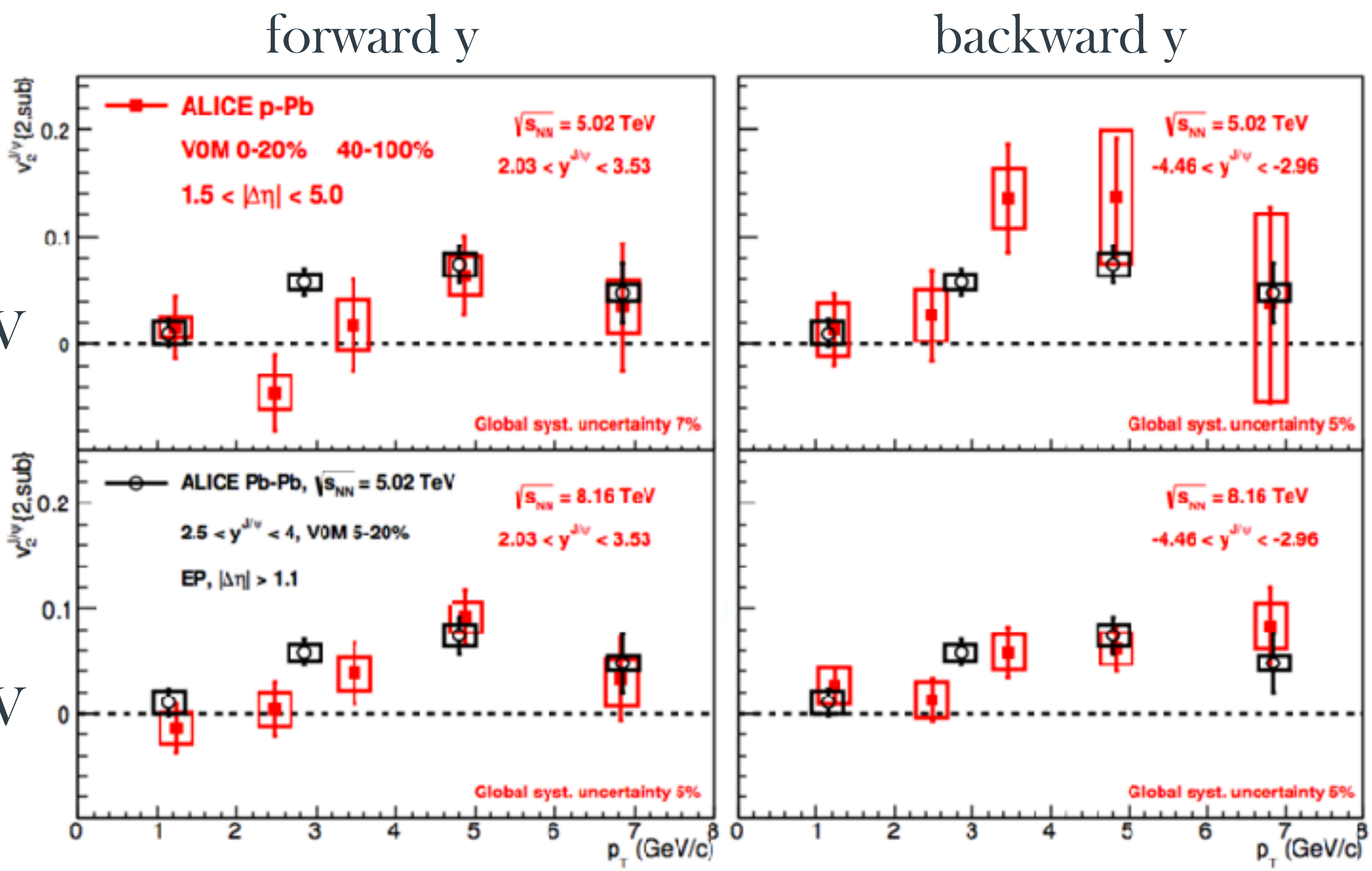
- Positive v_2 observation for charged particles
- Mass ordering for p_T < 2.5GeV/c
- At high p_T muons are dominated by HF decays

Collective effect for J/ψ in p-Pb ?

Integrated $\mathcal{L}$	p-Pb	Pb-p
5.02 TeV	~8.0nb^{-1}	~5.8nb^{-1}
8.16 TeV	~8.7nb^{-1}	~12.9nb^{-1}

Pb-Pb

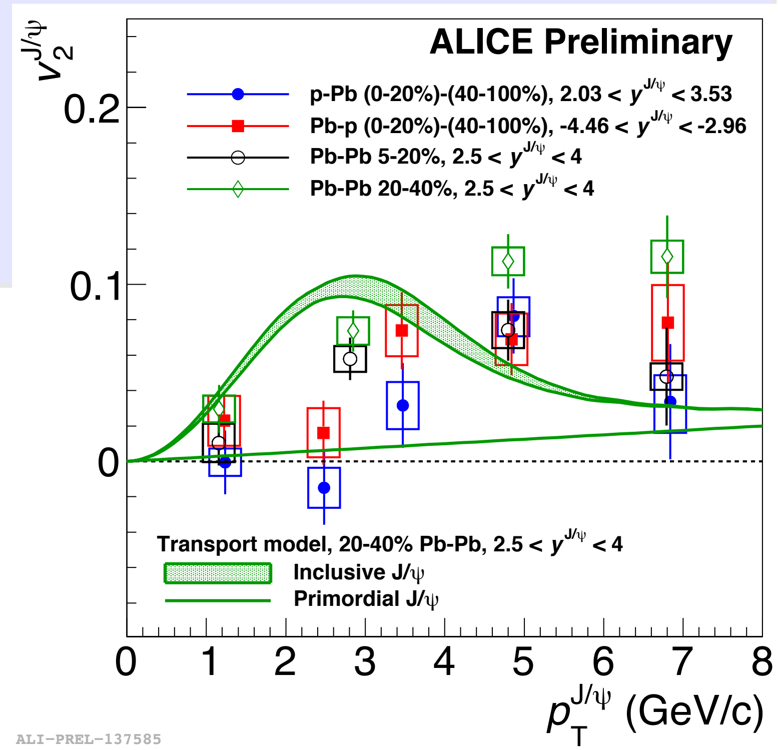
p-Pb



- Azimuthal correlations between J/ψ (in the dimuon channel) and mid-rapidity charged particles
- Sizeable v_2 measured in p-Pb collisions at 5.02 and 8.16 TeV (compatible with Pb-Pb in 5-20%)
- No significant (re)generation contribution is expected and lesser path-length effect w.r.t Pb-Pb

Summary

- The J/ψ particle flows !
  - First hints at 2.76 TeV and clear signal at 5.02TeV
  - Low energy measurements still compatible with LHC observations
- At high p_T the J/ψ v_2 in Pb-Pb is largely underestimated by theory
- The origin of J/ψ v_2 in p-Pb is not yet understood



Thank you for your attention !

Papers on arXiv :

1709.05260 : J/ψ elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

1709.06807 : Search for collectivity with azimuthal J/ψ hadron correlations in high multiplicity p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 and 8.16 TeV