J/ψ elliptic flow measurement in Pb-Pb collisions with the ALICE experiment

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LHC France 2013, 2-6 april, Annecy, France

Outline

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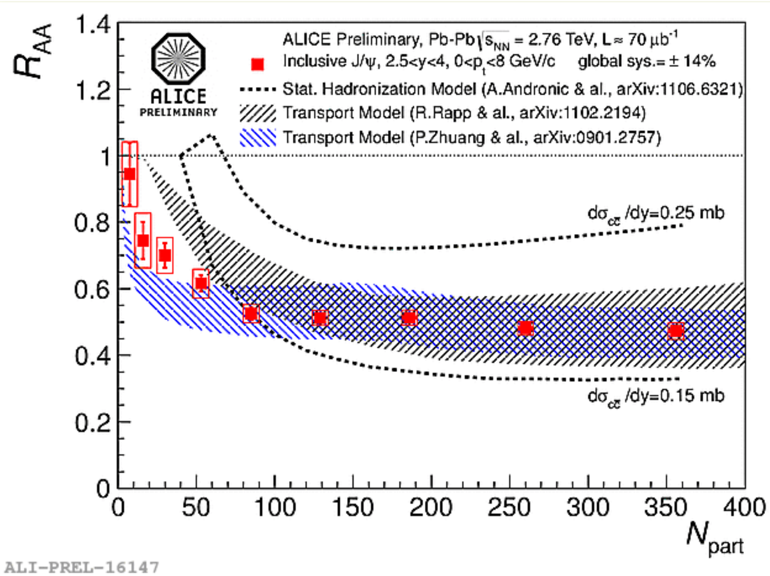
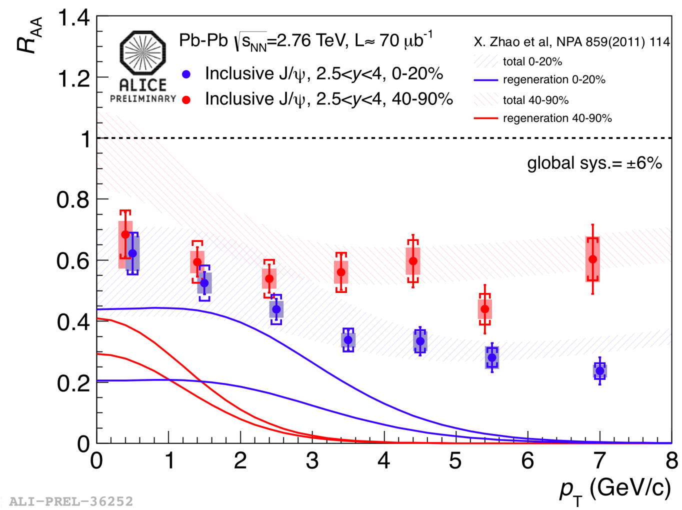
  - Comparison with STAR data
  - Comparison with theory
  - Centrality dependence of J/ψ v_2
- J/ψ elliptic flow analysis in the ALICE upgrade
- Conclusion

Motivations

- ALICE J/ψ nuclear modification factor measurement in Pb-Pb collisions at forward rapidity:
  - R_{AA} larger than at SPS and RHIC in most central collisions (all p_T)
  - Less suppression observed at low p_T
  - Statistical hadronization and transport model including a large fraction of regenerated J/ψ from charm quarks in the QGP can describe the data

see talks of H. Pereira Da Costa and M. Marchisone for details





SHM: J/ψ produced together with all hadrons, exclusively at chemical freeze-out

Transport model: continuous dissociation and regeneration of charmonium in the QGP

- **Elliptic flow to study J/ψ production mechanisms and the degree of thermalization of charmed quarks**
- **Observable sensitive on the dynamics of the early stages of heavy-ion collisions**

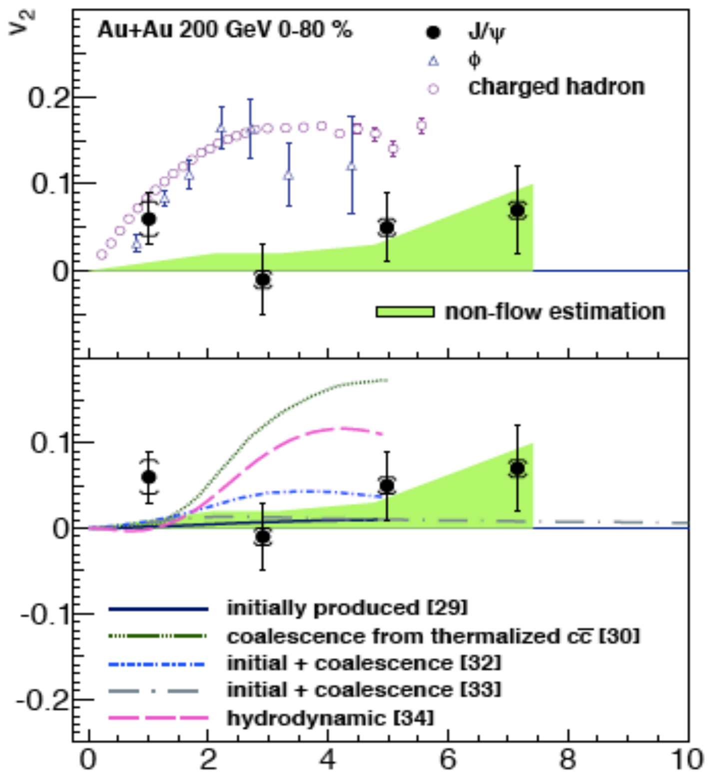
Motivations

- **J/ψ elliptic flow measurement at lower energies**

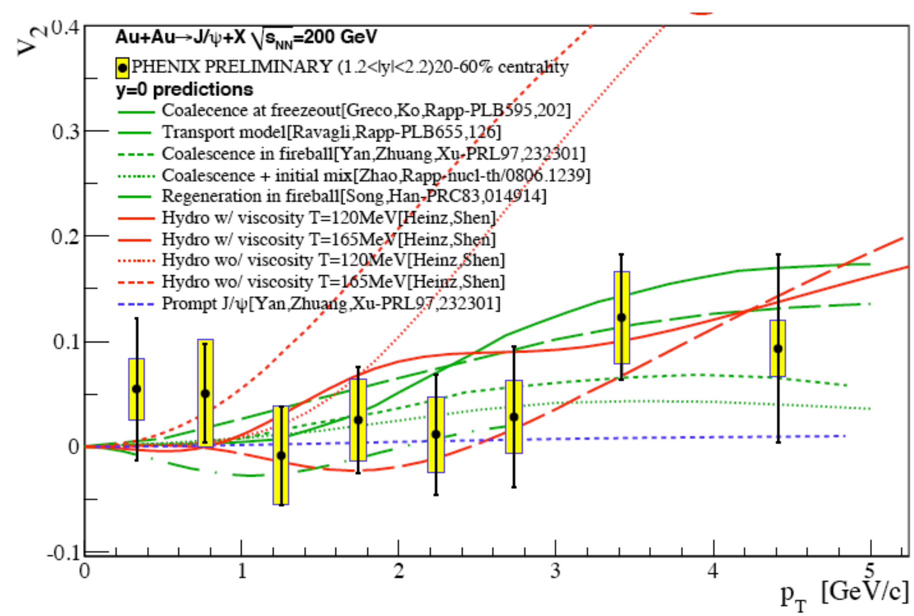
→ STAR publication
 - J/ψ v_2 consistent with zero for p_T > 2 GeV/c, unlike light flavors hadrons

Disfavors scenario in which J/ψ are produced dominantly by coalescence from charm quarks

→ PHENIX preliminary J/ψ elliptic flow measurement at forward rapidity



http://arxiv.org/abs/1212.3304



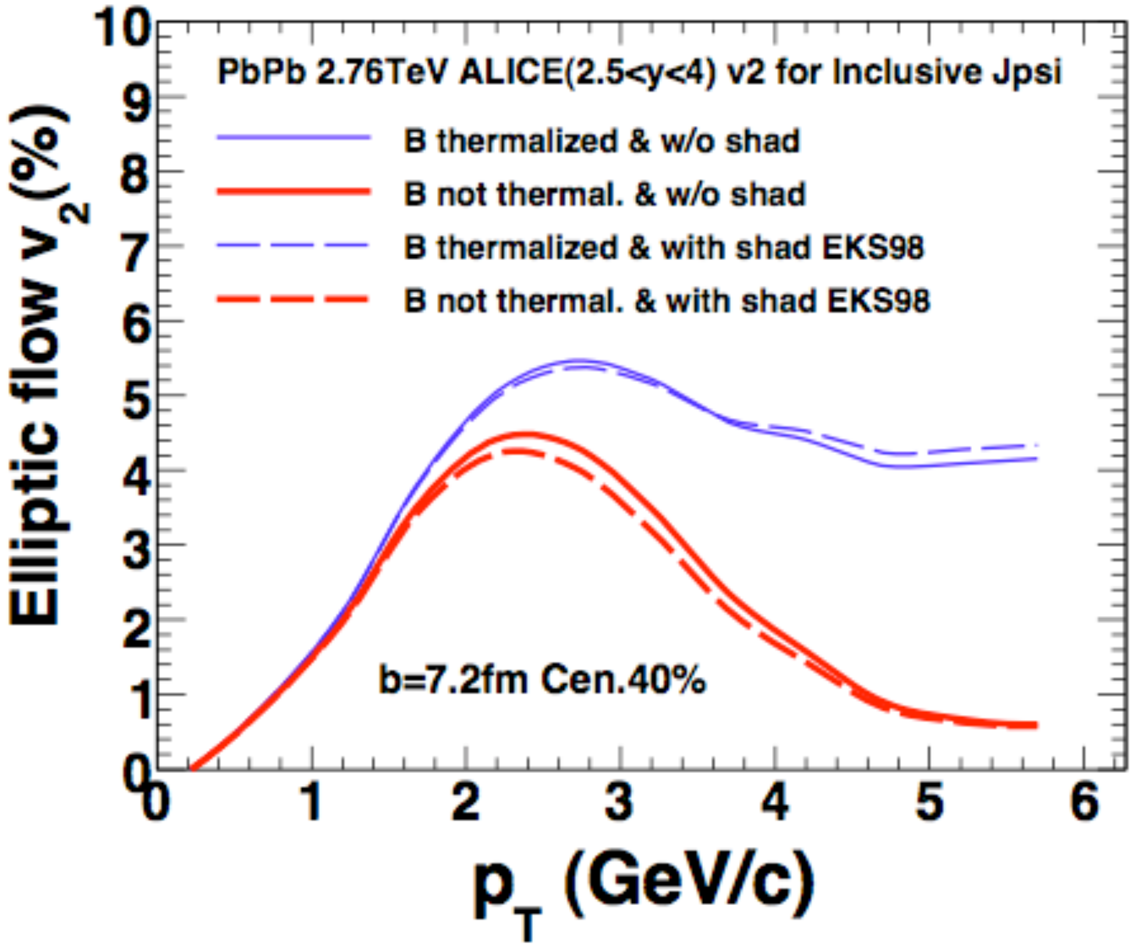
C. Da Silva, IWHQP2012

Motivations

- **J/ψ elliptic flow predictions for LHC**

Pb-Pb collisions at 2.76 TeV
forward rapidity
$d\sigma_{cc\text{-}bar}/dy = 0.38$ mb.
B feed down J/ψ.
Impact parameter b = 7.2 fm.

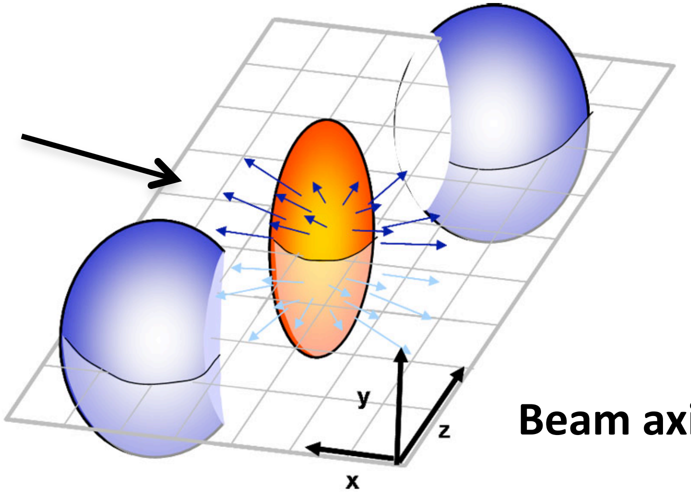
A significant elliptic flow may be expected at LHC energies due to significant contribution of regenerated J/ψ



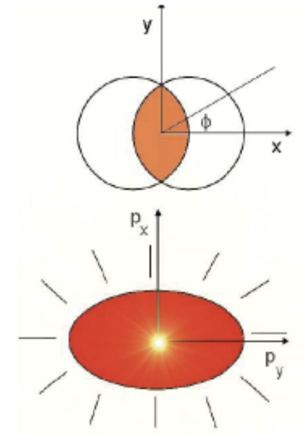
P. Zhuang et al., 2012 prediction (private communication)

Reaction plane and elliptic flow

Reaction plane



Beam axis



see talk of H. Pereira Da Costa for details

- Spatial anisotropy is converted via multiple collisions into an anisotropic momentum distribution
- reaction plane : defined by the beam axis and the impact parameter vector of the 2 colliding nuclei
- Particle azimuthal distribution measured with respect to the reaction plane can be

  expanded in **a Fourier series** : $$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty}2\mathrm{v}_n\cos\left(n\left(\phi-\Psi_{RP}\right)\right)\right)$$

  where $\mathrm{v}_2 = \; <\cos\left[2\left(\phi_i-\Psi_{RP}\right)\right]>$ quantifies elliptic flow

- Azimuthal angle of the reaction plane, Ψ_{RP}, determined via elliptic flow

ALICE setup

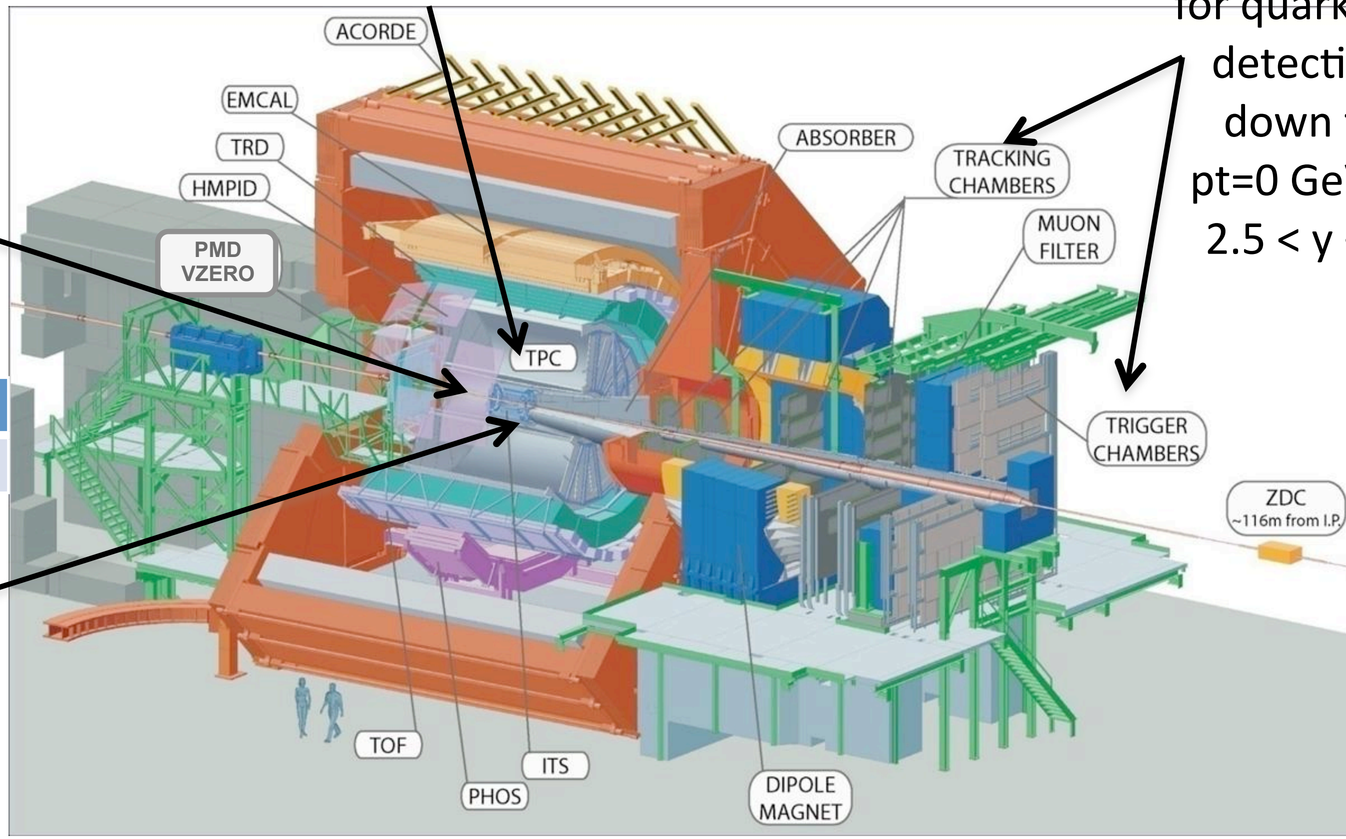
Two VZERO hodoscopes on each side of the IP to determine the event plane and the centrality of the collision. Also used as trigger

VZEROA	VZEROC
$2.8 < \eta < 5.1$	$-3.7 < \eta < -1.8$

First layers of the Inner Tracking System for vertex determination

Time Projection Chamber used for determination of the event plane resolution

Muon spectrometer for quarkonia detection down to pt=0 GeV/c, $2.5 < y < 4$



Minimum Bias trigger : Signal in VZEROA & VZEROC

$L_{int} \approx 1\ \mu b^{-1}$

Dimuon trigger : MB trigger + 2 muon tracks above a pt cut (1 GeV/c)

$L_{int} \approx 70\ \mu b^{-1}$

Pb-Pb collisions 2011

The event plane method

- The azimuthal angle ψ_2 of the second harmonic event plane is used as an estimate of the reaction plane angle
- **Event flow vector** $\vec{Q}$ (2-D vector in the transverse plane) :

$$Q_{n,x} = \frac{\sum_{i=0}^{31} S_i \cos(n\phi_i)}{\sum_{i=0}^{31} S_i} \qquad Q_{n,y} = \frac{\sum_{i=0}^{31} S_i \sin(n\phi_i)}{\sum_{i=0}^{31} S_i}$$

Where ϕ_i is the azimuthal angle of each scintillator of VZEROA detector, n = 2 for elliptic flow and S_i is a weight proportional to the elliptic flow of the primary particles crossing the scintillator

- The **event plane angle** for the 2nd harmonic obtained with VZEROA detector is expressed as :

$$\Psi_{EP,2} = \frac{\arctan 2(Q_{2,y}, Q_{2,x})}{2}$$

- **The observed v_2** is the 2nd harmonic of the azimuthal distribution of particles with respect to the event plane :

$$v_2^{obs}(p_T, y) = \; < \cos\left[2\left(\phi - \Psi_{EP,2}\right)\right] >$$

- Finite multiplicity limits the estimation of the angle of the reaction plane, v_2 is then corrected by the **event plane resolution** :

$$v_2 = v_2^{\text{obs}} / R_2$$

J/ψ signal extraction

- *Event selection*
  - Dimuon unlike sign triggered events
  - Z vertex cut : $|Z_{vertex}| < 10$ cm
- *Signal extraction*
  - **Signal shape**
    - Crystal Ball function

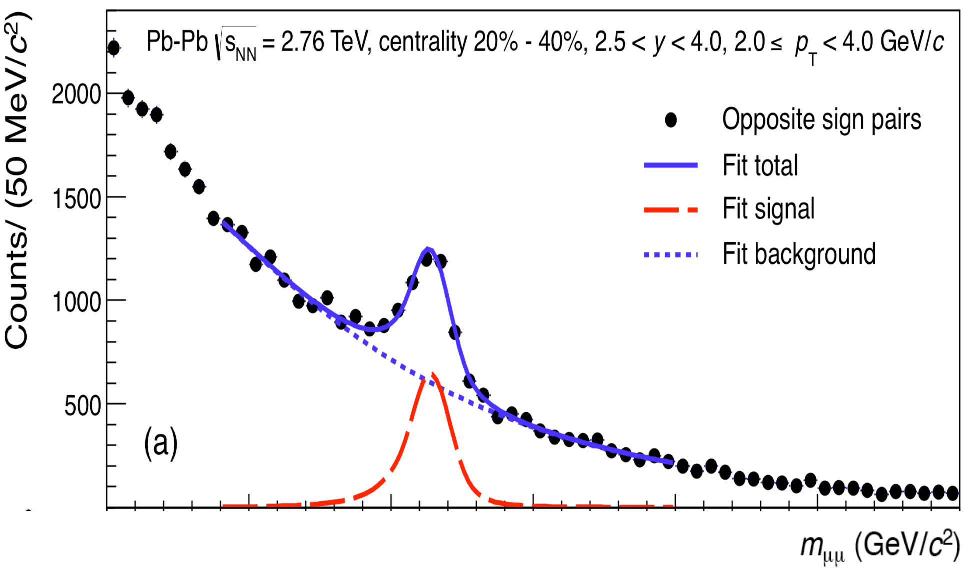
    (Gaussian core + power law tail at low masses (energy loss and radiative decays))
    - Crystal Ball extended function

    (Crystal Ball function + tail on the right (calibration biases))
  - **Background shape**
    - Variable width Gaussian (VWG)

    Gaussian with a width linearly varying with mass
    - Third order polynomial function (POL3)

- *Muon cuts*

  Standard cuts
  - Muon track matching low p_T trigger tracklet (1 GeV/c)
  - $-4 < \eta < -2.5$
  - $170^\circ < \vartheta_{abs} < 178^\circ$
  - Unlike sign dimuon with rapidity $2.5 < y < 4$



J/ψ elliptic flow analysis methods

- *2 methods using the event plane*
  - **Invariant mass fitting technique:**

→ Extract dimuon v_2^{obs} per bin of Invariant Mass where: $v_2^{obs} = \langle \cos\left(2\left(\phi_{\mu^+\mu^-} - \psi_{EP,2}\right)\right) \rangle$

→ Extract J/ψ observed elliptic flow (v_2^{sig}) by fitting the previous distribution with:

$$v_2^{obs}(total, M_{inv}) = \frac{f(signal, M_{inv}) \times v_2^{sig} + f(bkg, M_{inv}) \times v_2^{bkg}}{N_{sig+bkg}}$$

$f(signal, M_{inv})$ and $f(bkg, M_{inv})$ are the signal and background shapes obtained from the simultaneous fit of the dimuon invariant mass distribution

$N_{sig+bkg}$ is the number of dimuon pairs

v_2^{bkg} is described by a 2nd order polynomial function of the invariant mass, a first order polynomial function and its inverse for systematic studies

  - **Fit of the $dN^{J/\psi}/d\Delta\phi$ distribution (used as cross-check):**

→ Extract the J/ψ yield in 6 Δϕ bins with: $\Delta\phi = \phi_{\mu^+\mu^-} - \Psi_{EP,2}$

→ Fit the $dN^{J/\psi}/d\Delta\phi$ distribution with: $\frac{dN^{J/\psi}}{d\Delta\phi} = A \times \left(1 + 2v_2^{obs}\cos(2\Delta\phi)\right)$

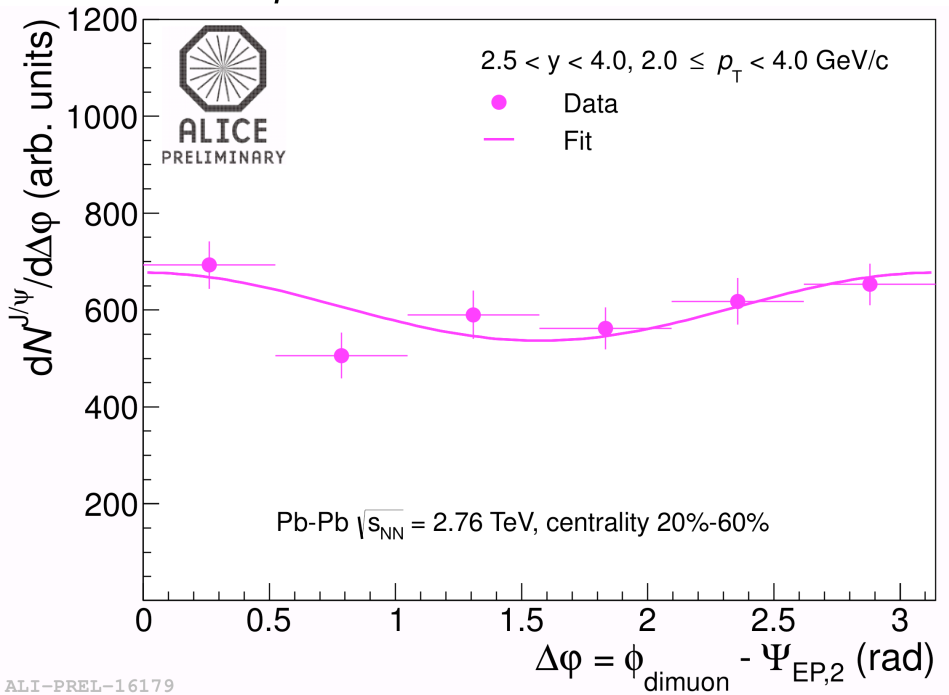
In both methods the v_2^{obs} is then corrected by the event plane resolution

Extraction of v_2^{obs}

- Example of v_2^{obs} extraction for the centrality bin 20-60% and for $2 \le p_T < 4$ GeV/c

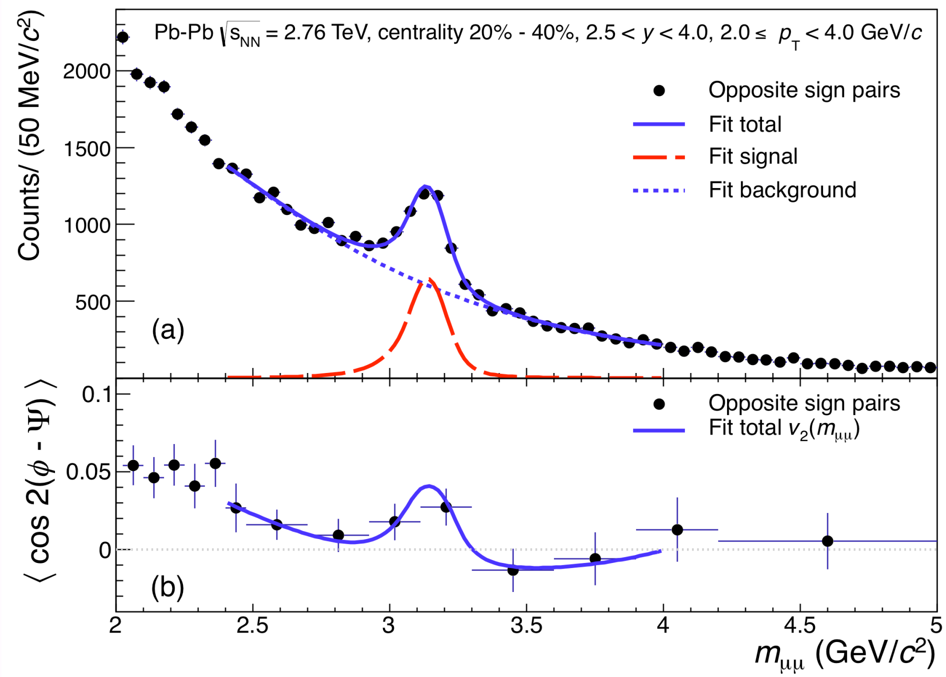
Δϕ histogram

$$\frac{dN^{J/\psi}}{d\Delta\phi} = A \times \left(1 + 2v_2^{obs}\cos(2\Delta\phi)\right)$$



Invariant mass fit technique

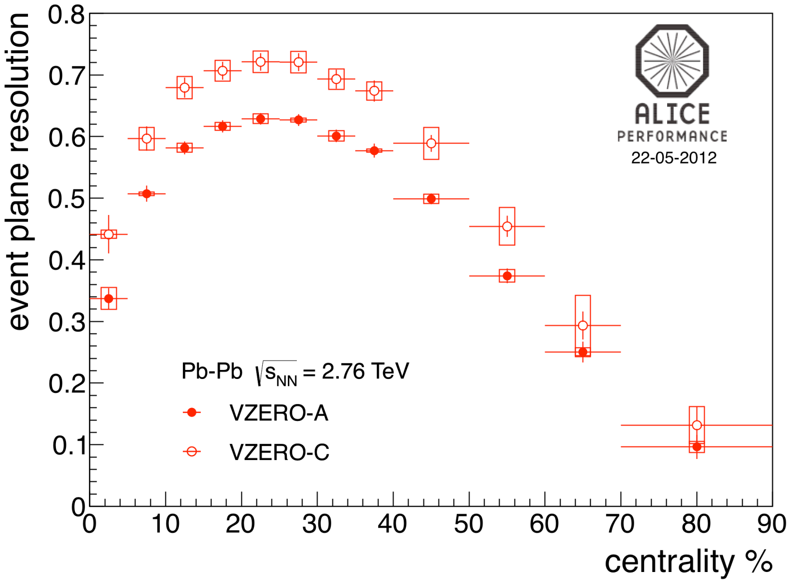
$$v_2^{obs}(total, M_{inv}) = \frac{f(signal, M_{inv}) \times v_2^{sig} + f(bkg, M_{inv}) \times v_2^{bkg}}{N_{sig+bkg}}$$



http://arxiv.org/abs/1303.5880

Event plane resolution

- **3 sub-event method** to determine the resolution of the event plane for VZEROA detector :
  - 3 independent detectors (TPC, VZEROA, VZEROC), with 3 different rapidity coverage and large η gap between each other



If the subevents are not "equal," or if you have only correlations between particles in different windows, and the resolution in each window can be different, then one needs at least three windows to determine the event plane resolution in each of them. In this case, for example, the resolution in the first window is determined as [3,4]

$$\langle\cos[n(\Psi_m^a-\Psi_r)]\rangle = \sqrt{\frac{\langle\cos[n(\Psi_m^a-\Psi_m^b)]\rangle\langle\cos[n(\Psi_m^a-\Psi_m^c)]\rangle}{\langle\cos[n(\Psi_m^b-\Psi_m^c)]\rangle}}.$$

A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C58, 1671

- Alternatively, a second set of 3 sub-event was used (VZEROA, inner ring of VZEROC, outer ring of VZEROC) → 2% difference considered as systematic uncertainty
- For wide centrality bins, the resolution obtained from narrow bins is weighted by the number of reconstructed J/ψ → resolution must reflect the distribution of events with a J/ψ within the centrality class

Results

- **J/ψ v_2 as a function of p_T in the centrality range 20-40%**

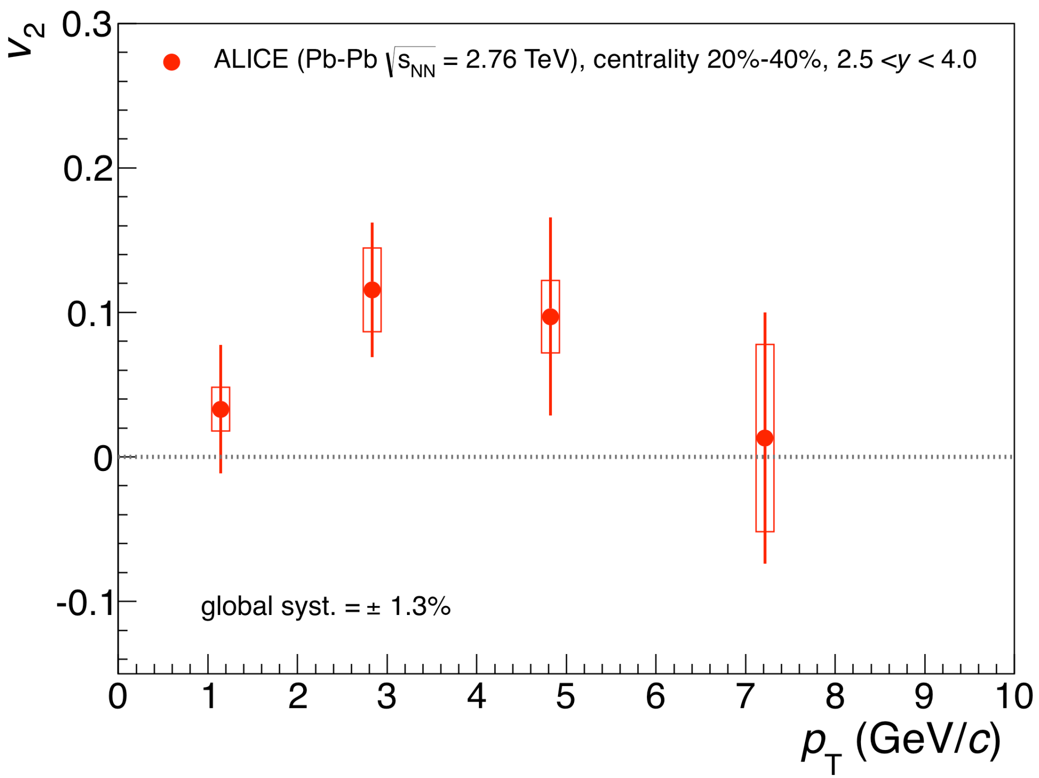
→ **Indication of non zero v_2 in the intermediate momentum range $2 \leq p_T < 6$ GeV/c with a significance of 2.7σ**

→ At lower and higher momenta, J/ ψ v_2 compatible with zero within uncertainties

http://arxiv.org/abs/1303.5880

Vertical bars : statistical uncertainties
Boxes : point to point uncorrelated systematic uncertainties
- signal extraction
- v_2^{back} shape
- reconstruction efficiency

1.3% correlated systematic uncertainty on Event Plane resolution



Results

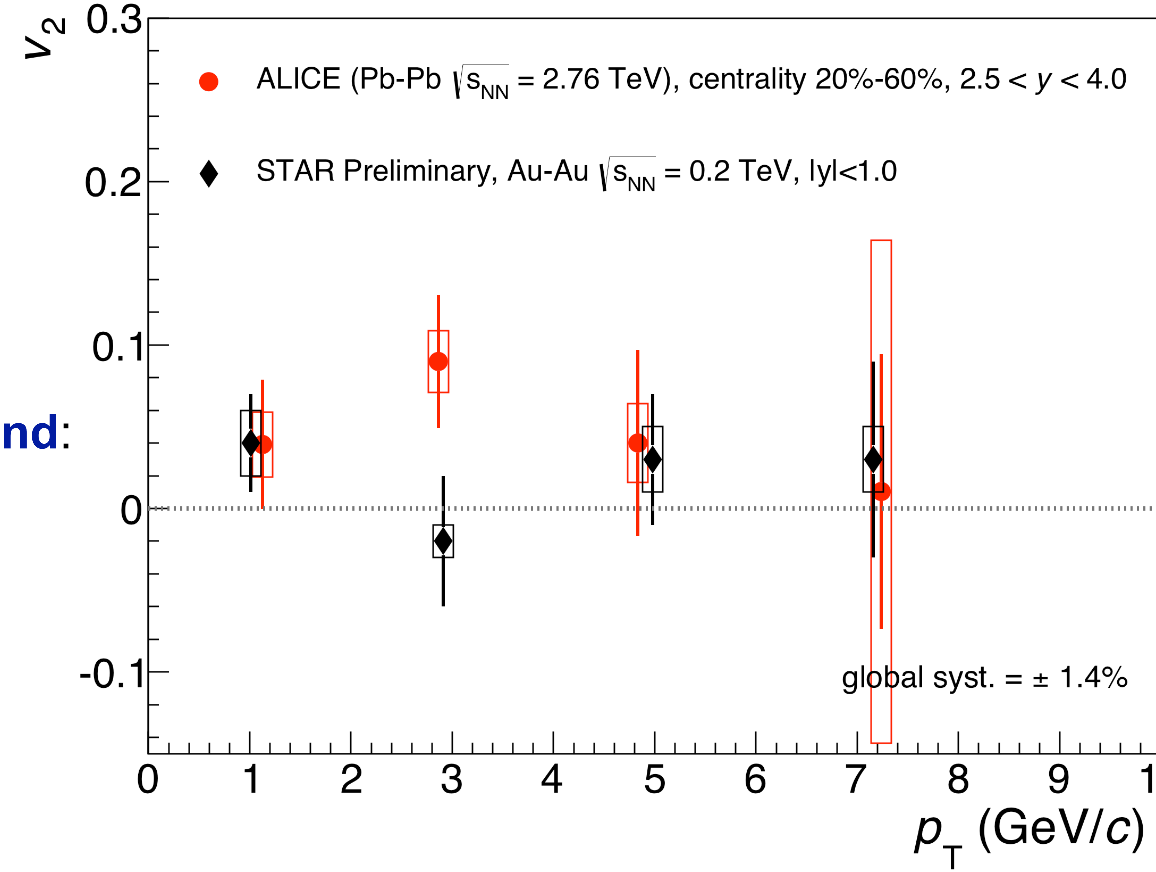
- **J/ψ v_2 as a function of p_T in the centrality range 20-60%**

→ Measurement in a broader centrality range
→ Same trend observed as in the 20-40% centrality class
→ Non zero v2 in 2 ≤ pT < 4 GeV/c with significance of 2σ

http://arxiv.org/abs/1303.5880

- Comparison with STAR preliminary data in the same centrality range at mid-rapidity and at lower energy

→ **Elliptic flow measured by STAR shows different trend**: compatible with zero for p_T ≥ 2 GeV/c (also in other centrality bins: 10-50% 0-80%)



http://arxiv.org/abs/1107.0532
http://arxiv.org/abs/1212.3304

Results

- **J/ψ v_2 as a function of p_T in the centrality range 20-60%**

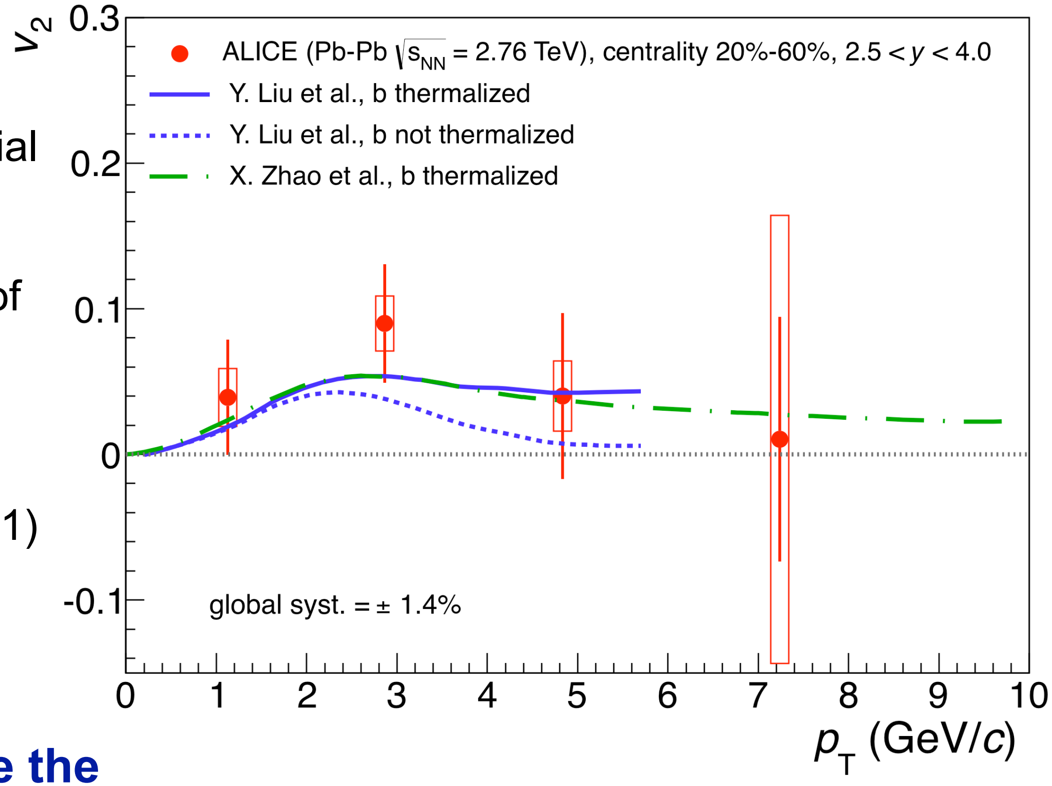
- Comparison with theoretical predictions : 2 transports model calculation including a J/ψ regeneration component from deconfined charm quarks in the medium (~ 30%)

http://arxiv.org/abs/1303.5880

→Maximum v_2 predicted at ~ 2.5 GeV/c: interplay between regeneration component dominant at low p_T and initial J/ψ production dominant at high p_T

→Different hypothesis for thermalization of b quarks

→At maximum 11% of J/ψ come from B mesons in Pb-Pb (from LHCb measurement in pp and assuming R_{AA}=1) They can inherit the flow of b quark if b is thermalized)

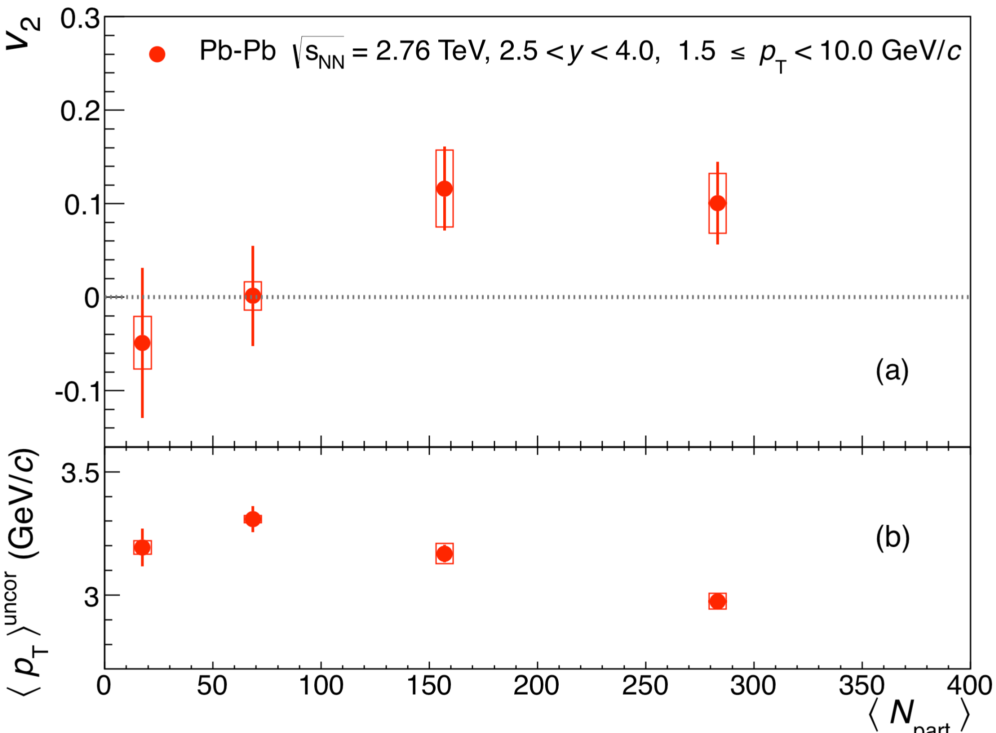


- **Both models are able to describe the p_T dependence of the v_2 and the nuclear modification factor of inclusive J/ψ**

Nucl. Phys. A. 834. 317C (2010)
arXiv:120.6583 [hep-ph]

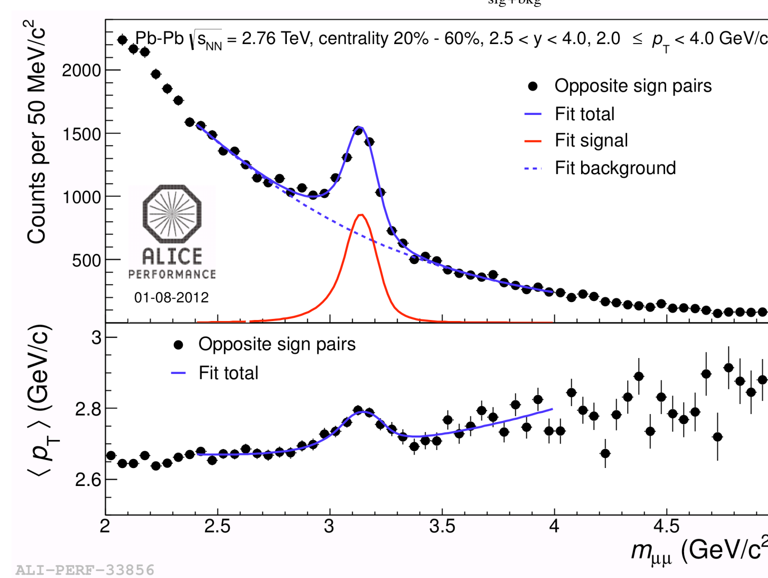
Results

- **Centrality dependence of J/ψ elliptic flow for J/ψ with $1.5 \leq p_T < 10$ GeV/c**
  - Maximize the signal/background ratio and the observed v_2
  - Exclude the 0-5% (small initial spatial anisotropy for head-on collisions)
  - Evaluation of the J/ψ mean p_T for each centrality class
  - Weak variation of the J/ψ mean p_T with the centrality (no bias in the sampled p_T distribution)
- **Indication of non-zero v_2 for centralities 5-20% and 20-40% (significance 2.9σ)**
- **for $1.5 \leq p_T < 10$ GeV/c**



J/ψ mean p_T evaluated in a similar way as the J/ψ v_2

$$< p_T(total, M_{inv}) > = \frac{f(signal, M_{inv}) \times < p_T >_{sig} + f(bkg, M_{inv}) \times < p_T >_{bkg}}{N_{sig+bkg}}$$

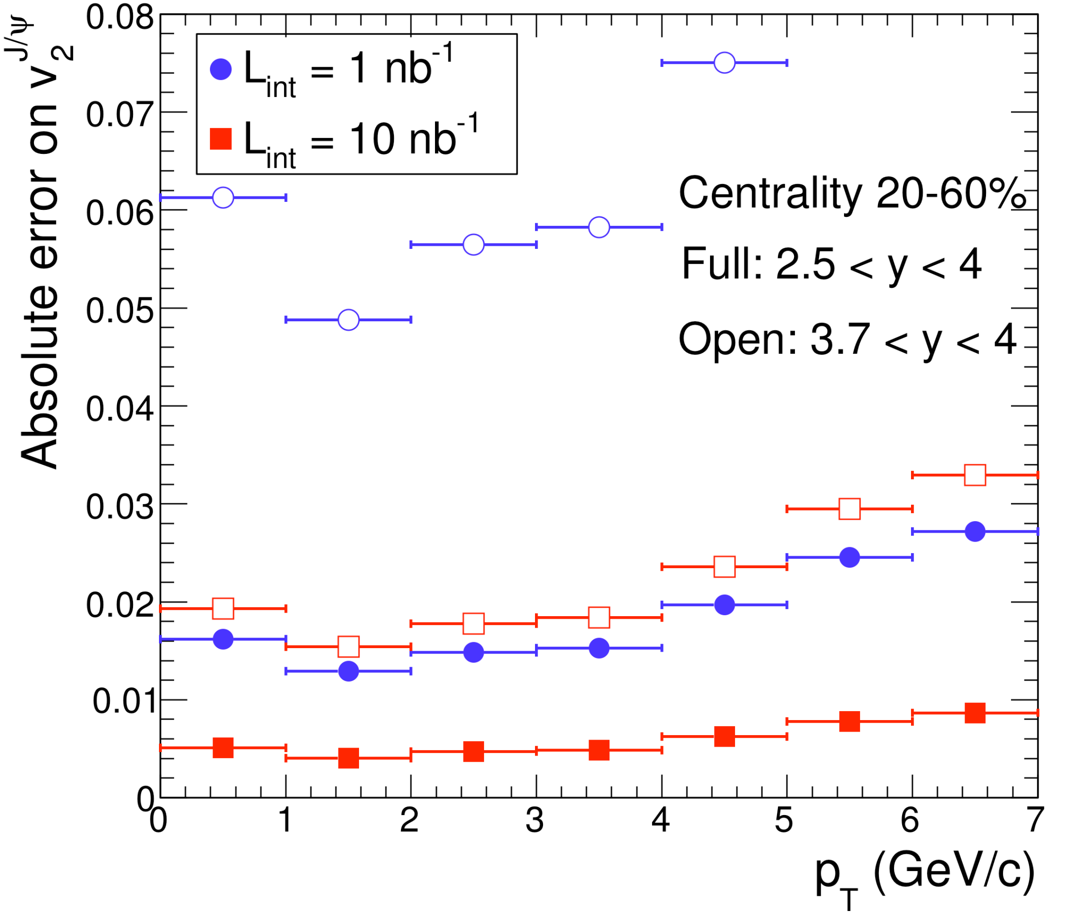


v_2 analysis in the ALICE upgrades

- ALICE data taking approved scenario: collecting Pb-Pb data up to an integrated luminosity of **L_{int} = 1 nb^{-1}**
- ALICE data taking upgrade scenario: increase the luminosity of the Pb-beam. 50kHz interaction rate. Instantaneous luminosity 6×10^{27} $cm^{-2}.s^{-1}$. **L_{int} = 10 nb^{-1}**

- L_{int} = 1 nb^{-1}:
  - Improvement of the present measurement allowing to measure a non-zero elliptic flow at **5σ significance** in the p_T bin 0-6 GeV/c

- *Lint = 10 nb^{-1}*:
  - Precise measurement of $v_2(p_T)$ **as a function of rapidity**



Conclusions

- **Summary of the results:**
  - Indication for non-zero J/ψ v_2 in the centrality range 20-40% and p_T range 2-6 GeV/c (significance 2.7σ)
  - Hint for non-zero J/ψ v_2 in the centrality range 20-60% and p_T range 2-4 GeV/c (2σ). Different trend with respect to lower energy measurements
  - Hints for non-zero v_2 in central (5-20%) and semi-central (20-40%) collisions for $p_T \geq 1.5$ GeV/c

  Indication of non-zero v_2 favors regeneration mechanisms which may contribute significantly to the production of J/ψ at LHC energies (consistent with J/ψ R_{AA} results)

  Transports models including a regeneration component from deconfined charm quarks in the medium are able to qualitatively describe the p_T dependence of the J/ψ v_2 (as well as its nuclear modification factor)

- **Future of J/ψ v_2 analysis:**
  - L_{int}= 1nb^{-1} : Improve the precision of the current measurement (5σ significance)
  - L_{int} = 10nb^{-1}: Study of $v_2(p_T)$ as a function of rapidity