J/ψ elliptic flow study with the ALICE detector at LHC

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Summary

What is the flow ?

Why study the elliptic flow ?

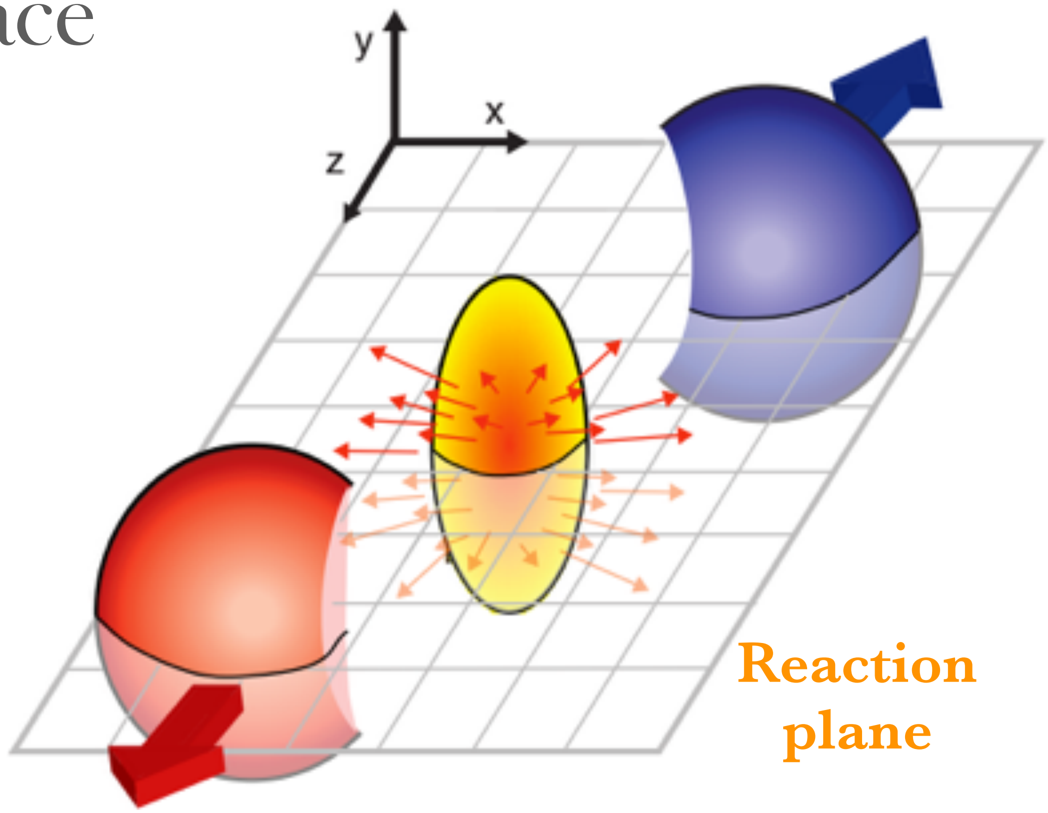
Why the J/Ψ ?

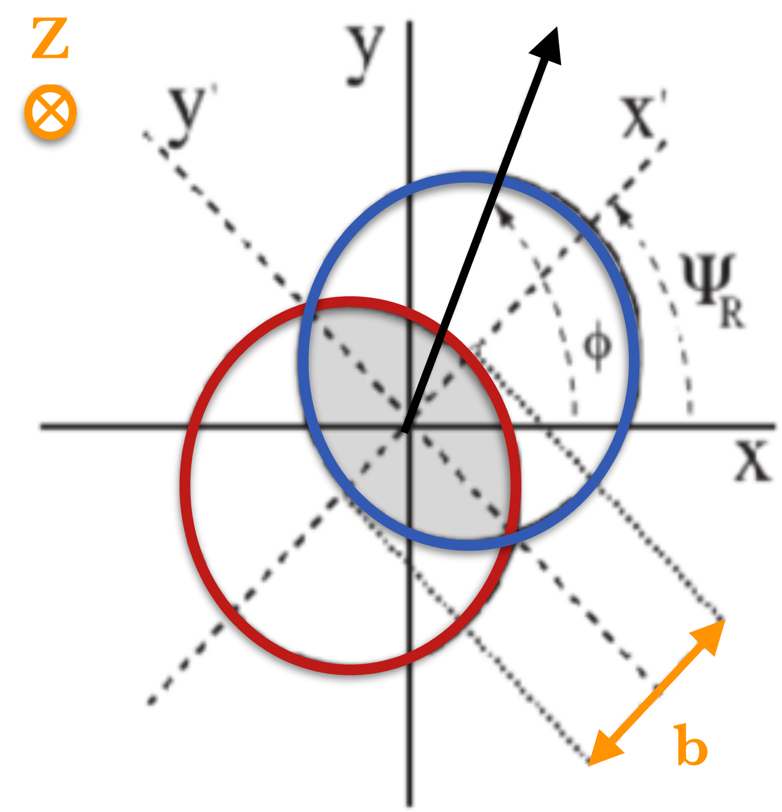
Experimental event plane methods

Results from RHIC and LHC

Anisotropic flow

- Anisotropy in particle azimuthal distribution in momentum space





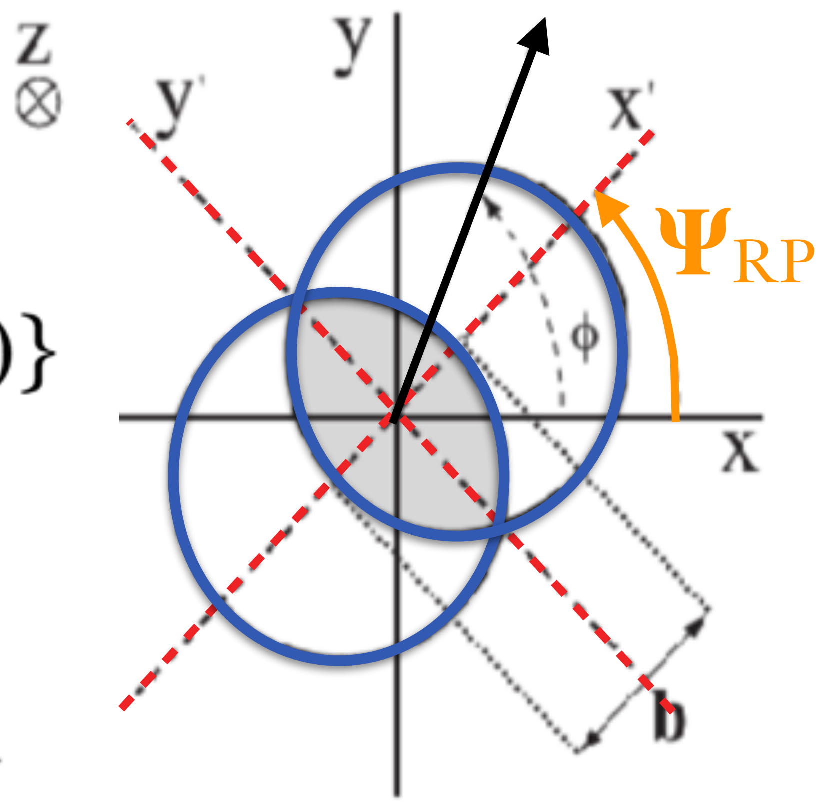
- Can be expanded into a Fourrier series :

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

Anisotropic flow

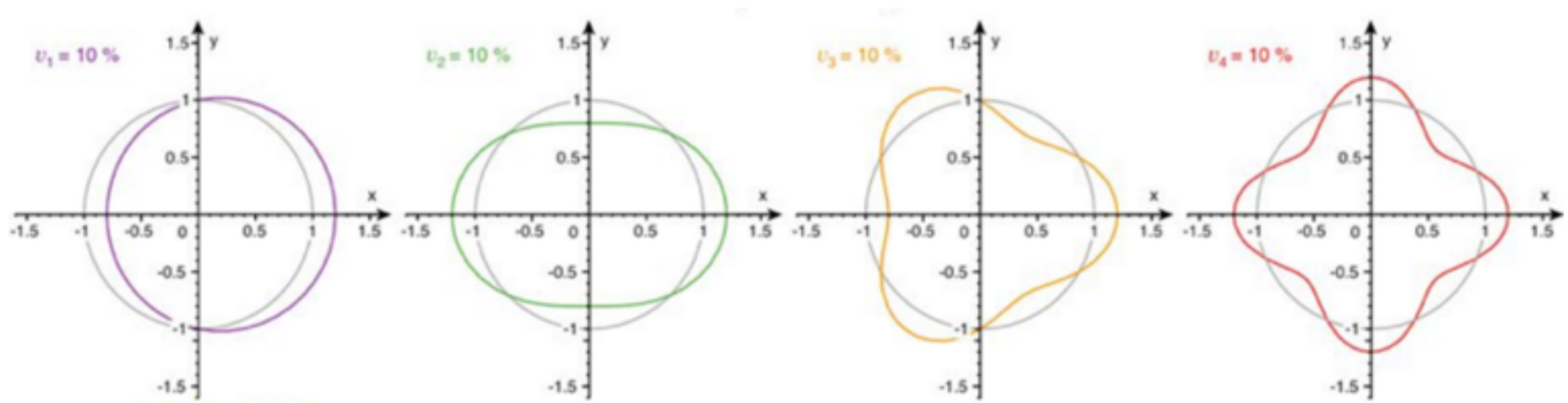
Reaction plane angle

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



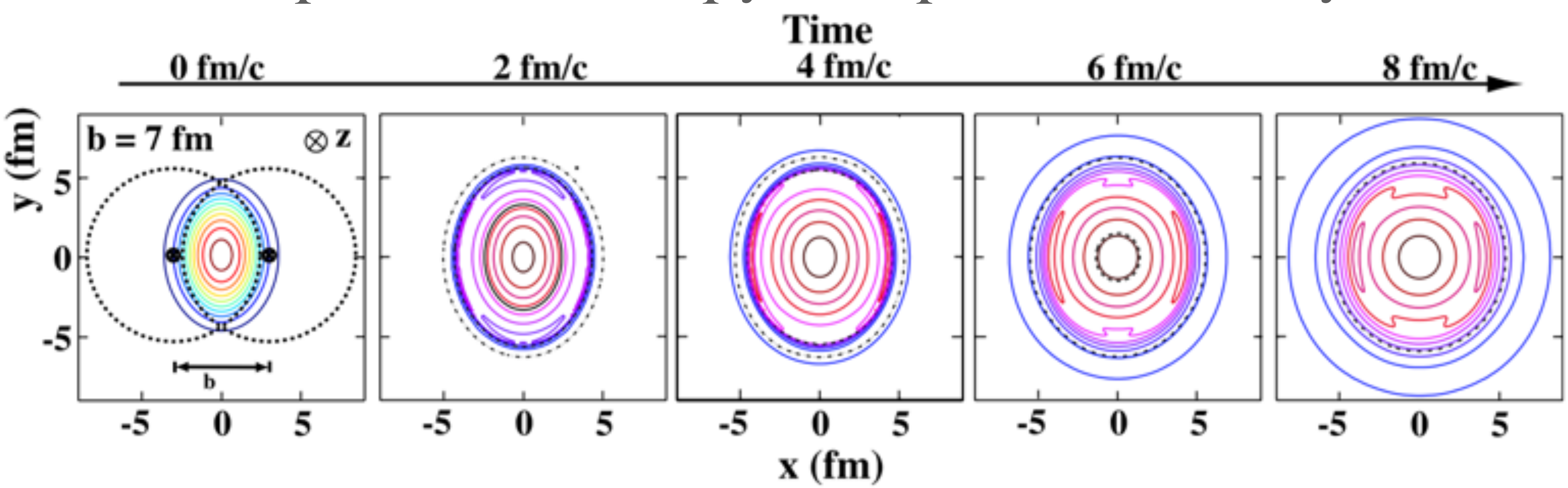
Flow coefficients : $v_n = \langle \cos\{n(\Phi_i - \Psi_{RP})\}\rangle$

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



Anisotropic flow

- Development only during the first fm/c of the system due to decrease in spatial anisotropy and particle density

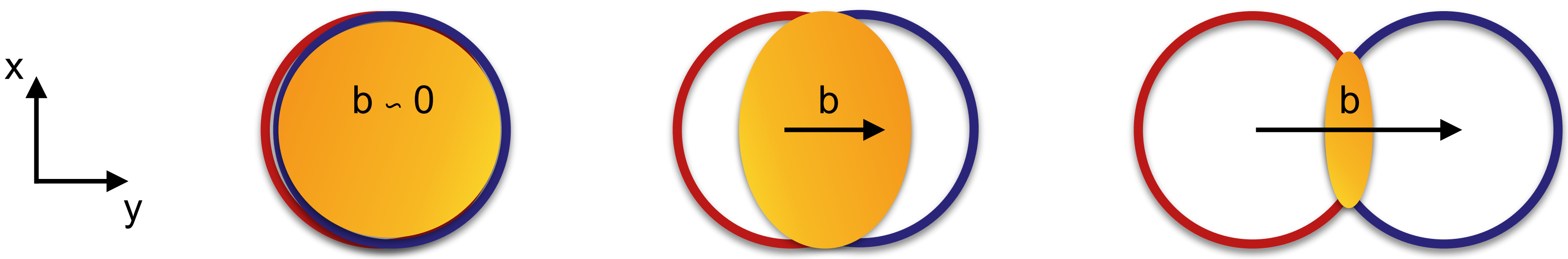


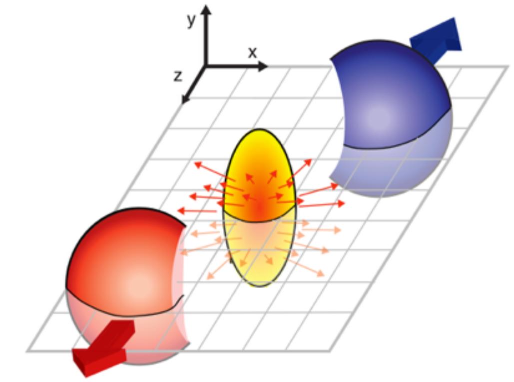
- Asymmetric initial matter distribution
  ⇒ anisotropy in the momentum space

- Response of the system to the initial geometry anisotropies

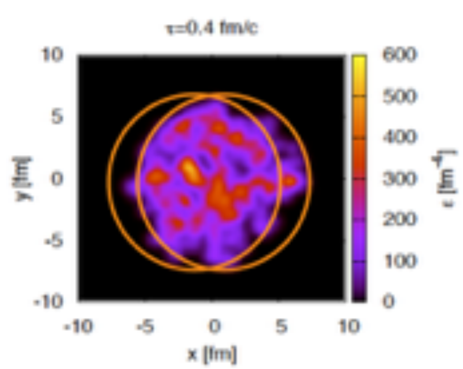
Initial anisotropies

- Collision geometry : anisotropic overlap in non central collisions





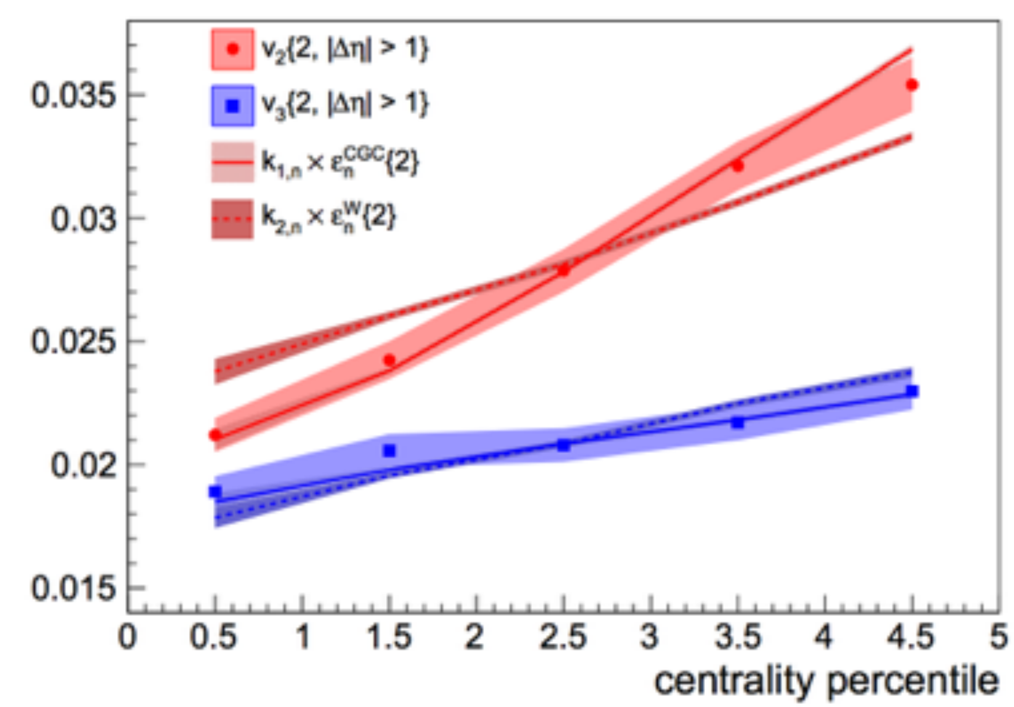
  - average shape dominated by elliptic eccentricity second Fourier coefficient v_2

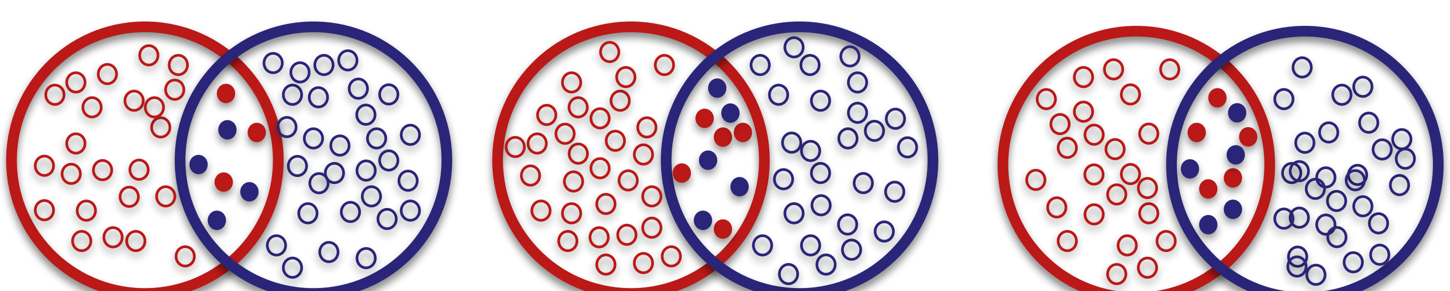


- event-by-event fluctuations

  - higher flow coefficients : v_3, v_4, …

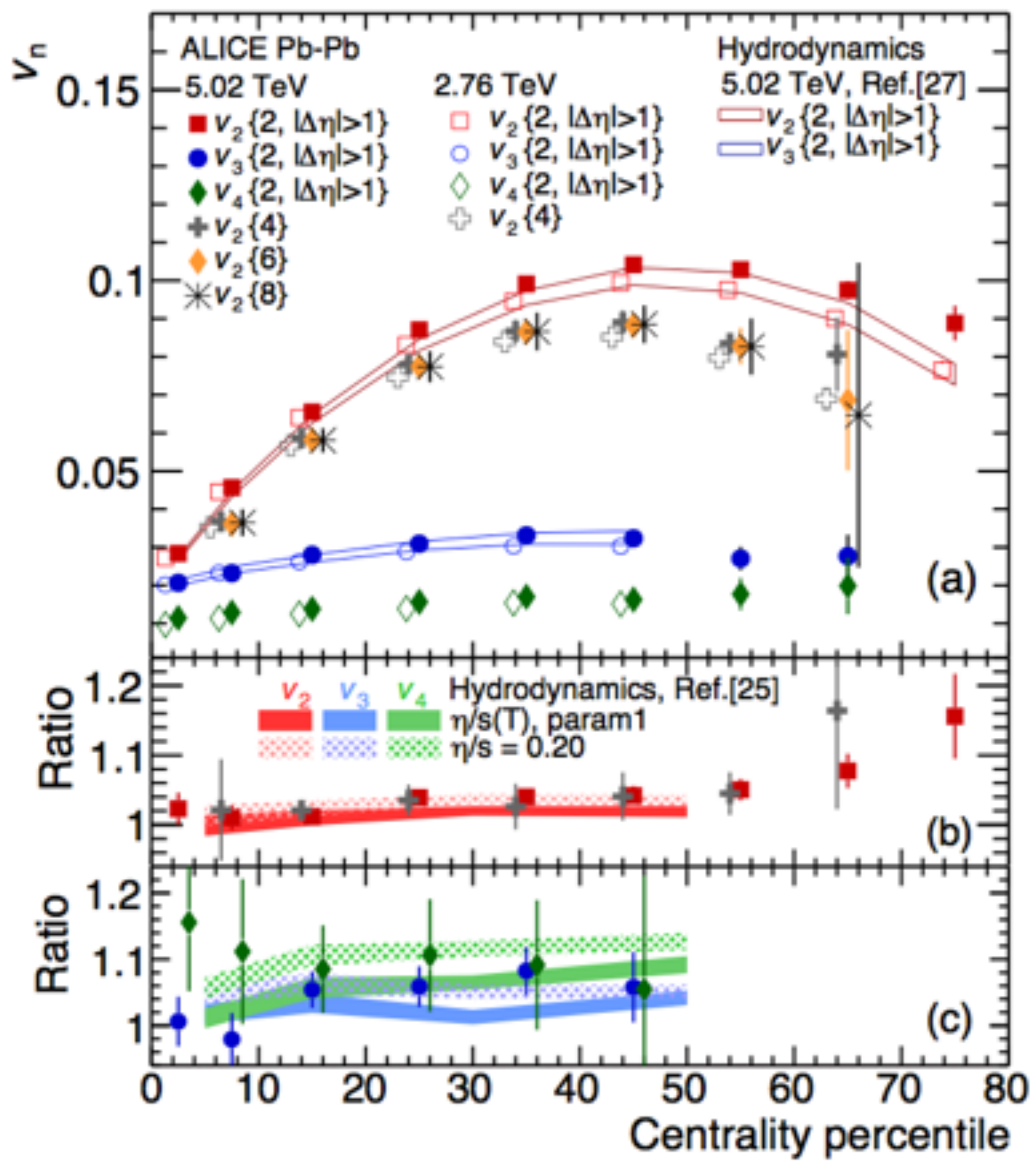
arXiv:1105.3865



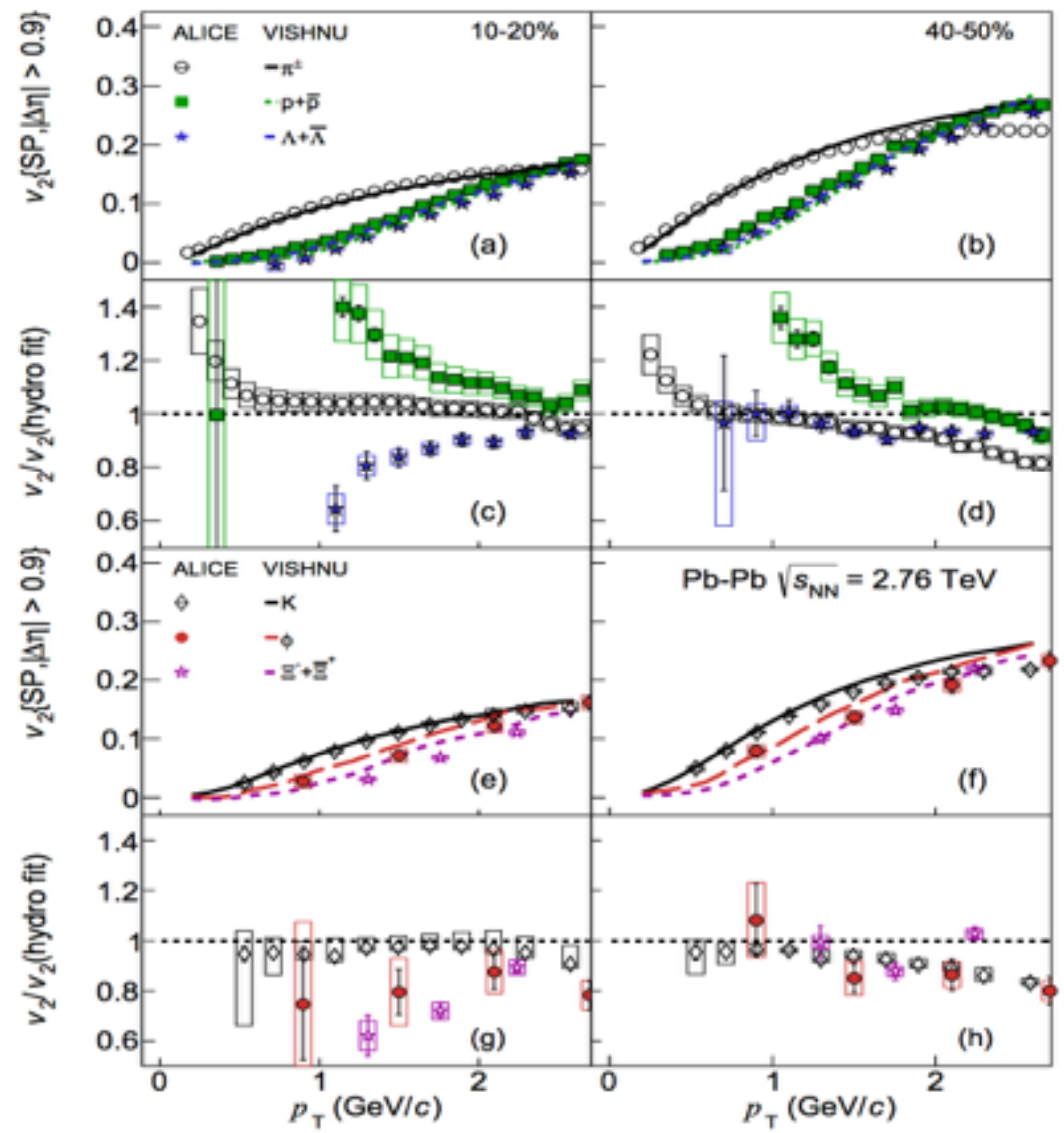


Comparison with hydrodynamics

arXiv:1609.04459



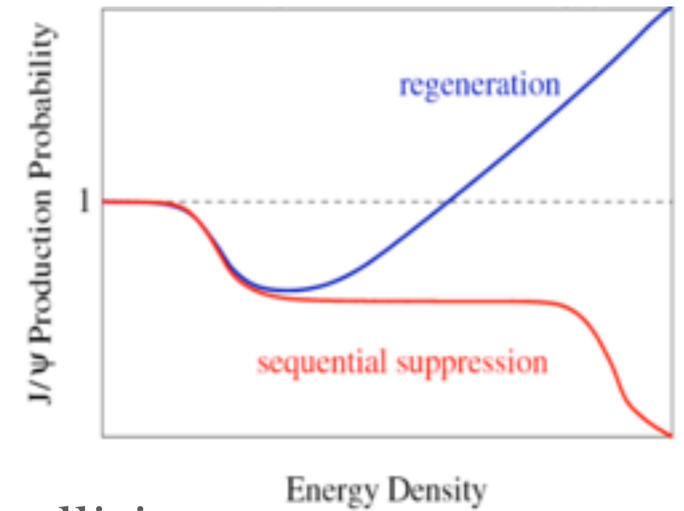
arXiv:1405.4632



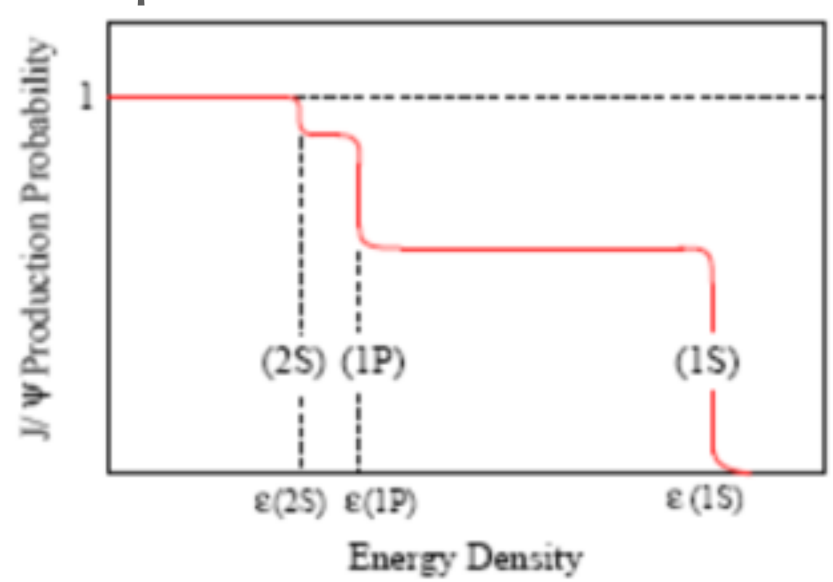
- Hydrodynamic calculations seem to reproduce fairly well the measured flow coefficients
  - Hint on QGP viscosity ⇒Needed to understand the phenomenology at RHIC and LHC
- Coupled to an hadronic cascade model : identified particle v_2

Why is it interesting for quarkonia ?

- Hot medium effects :
  - Debye screening at different T for the different quarkonia species (sequential suppression of quarkonia states)
  - Secondary source of J/Ψ through cc pair recombination
  - Good probes of deconfined state of QCD phase diagram

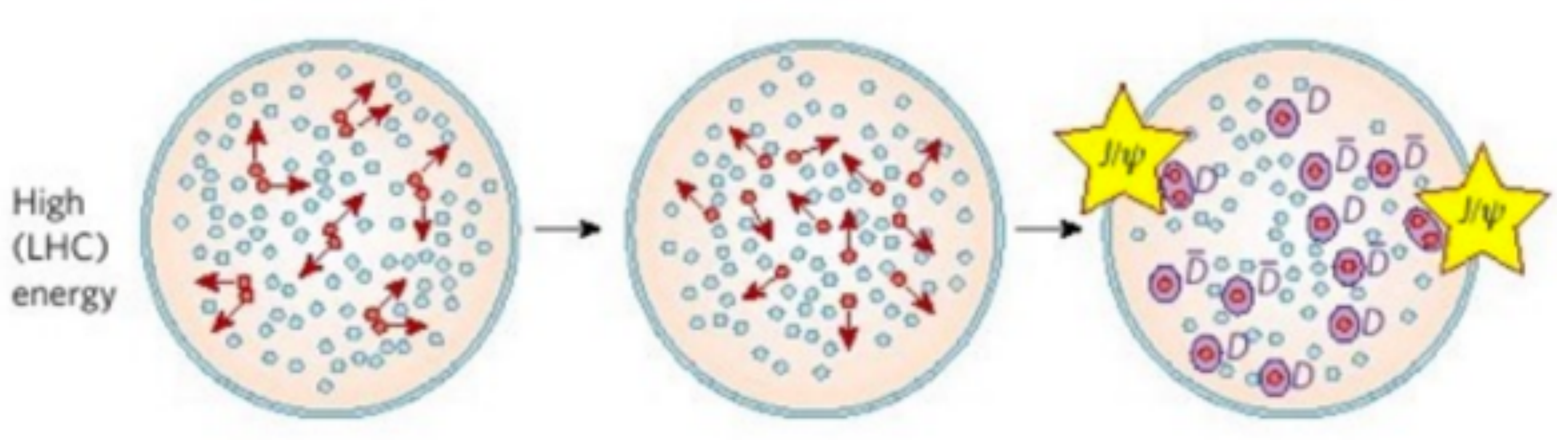


- Need to consider non QGP effects : comparison with p-p and p-Pb collisions
  - Different sources of production : observed J/Ψ = direct J/ψ(60%) + feed down (40%) from χ_c (1P) and ψ' (2S)
  - Cold matter effects (energy loss, shadowing,..)



Observable for regeneration study ?

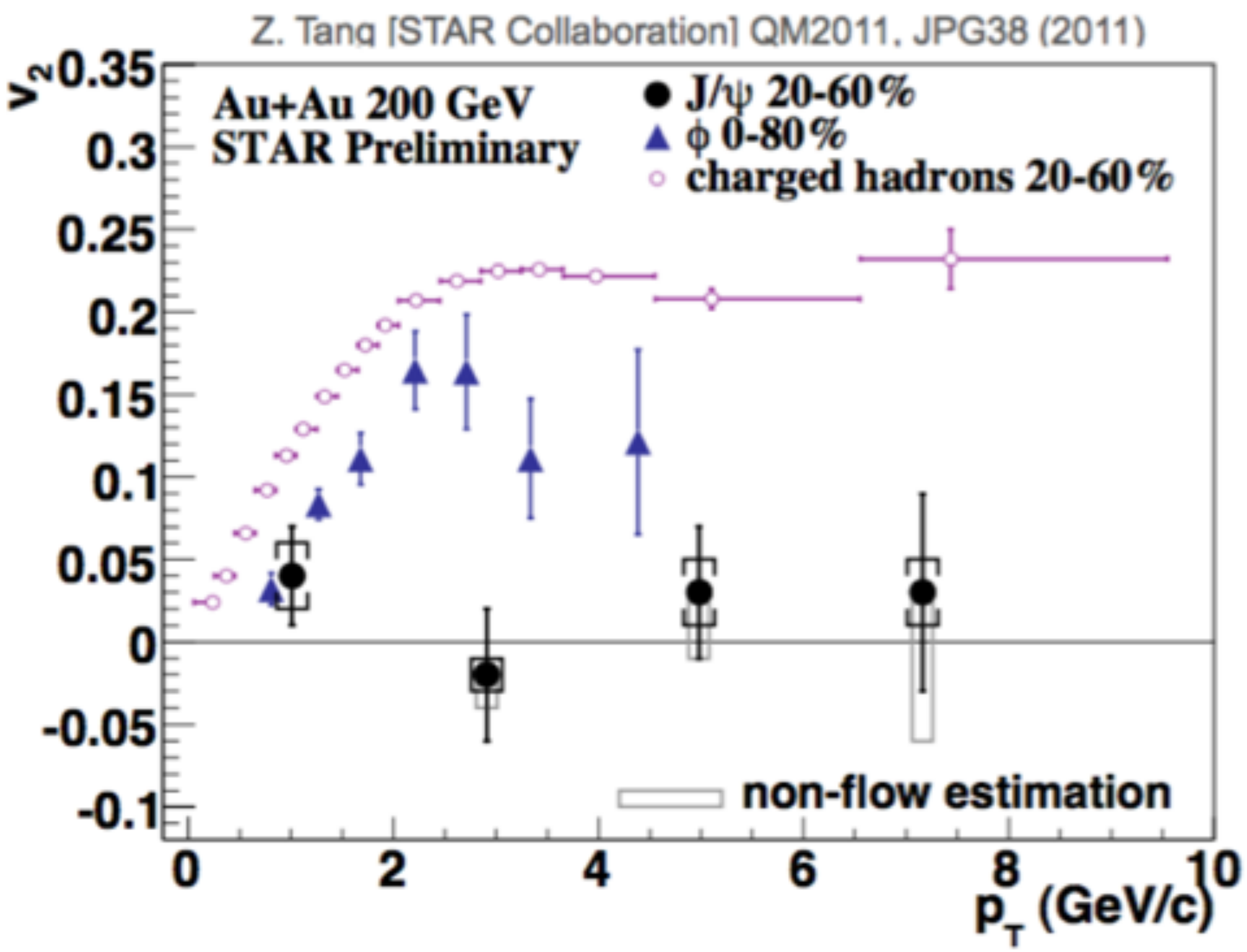
- J/ψ = hard probes, produced at early stages of the collision
  → insensitive to collective phenomena ?
  - suppression by Debye like color screening mechanism
  - recombination of $c\bar{c}$ pairs → inherit the flow of charm quarks

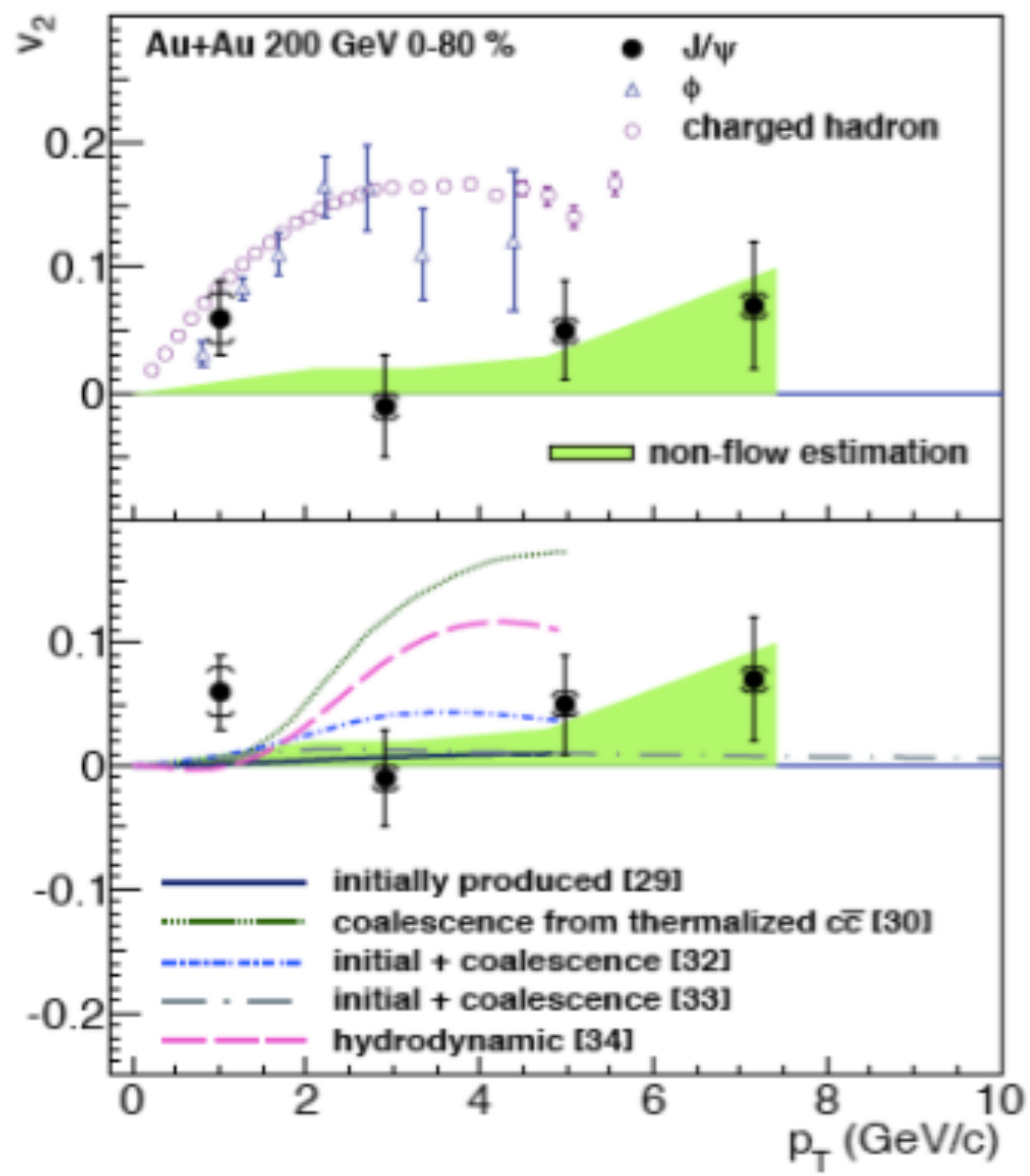


flow = relevant observable
for J/Ψ regeneration study
from $c\bar{c}$ pair recombination

STAR results

- At RHIC energy :
  J/ψ v_2 compatible very small / compatible with zero for $p_T > 2$ GeV/c

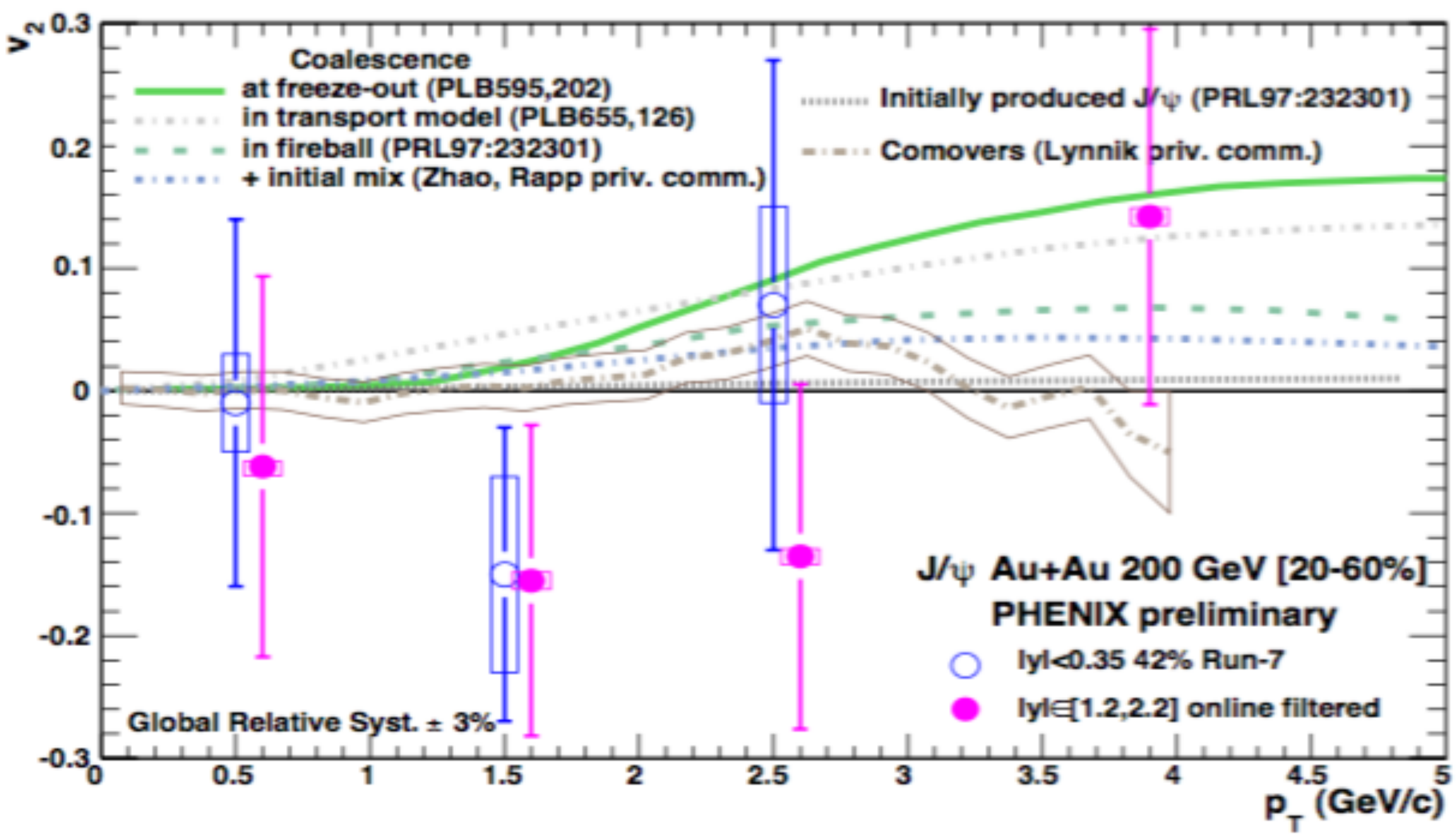




arXiv:1212.3304

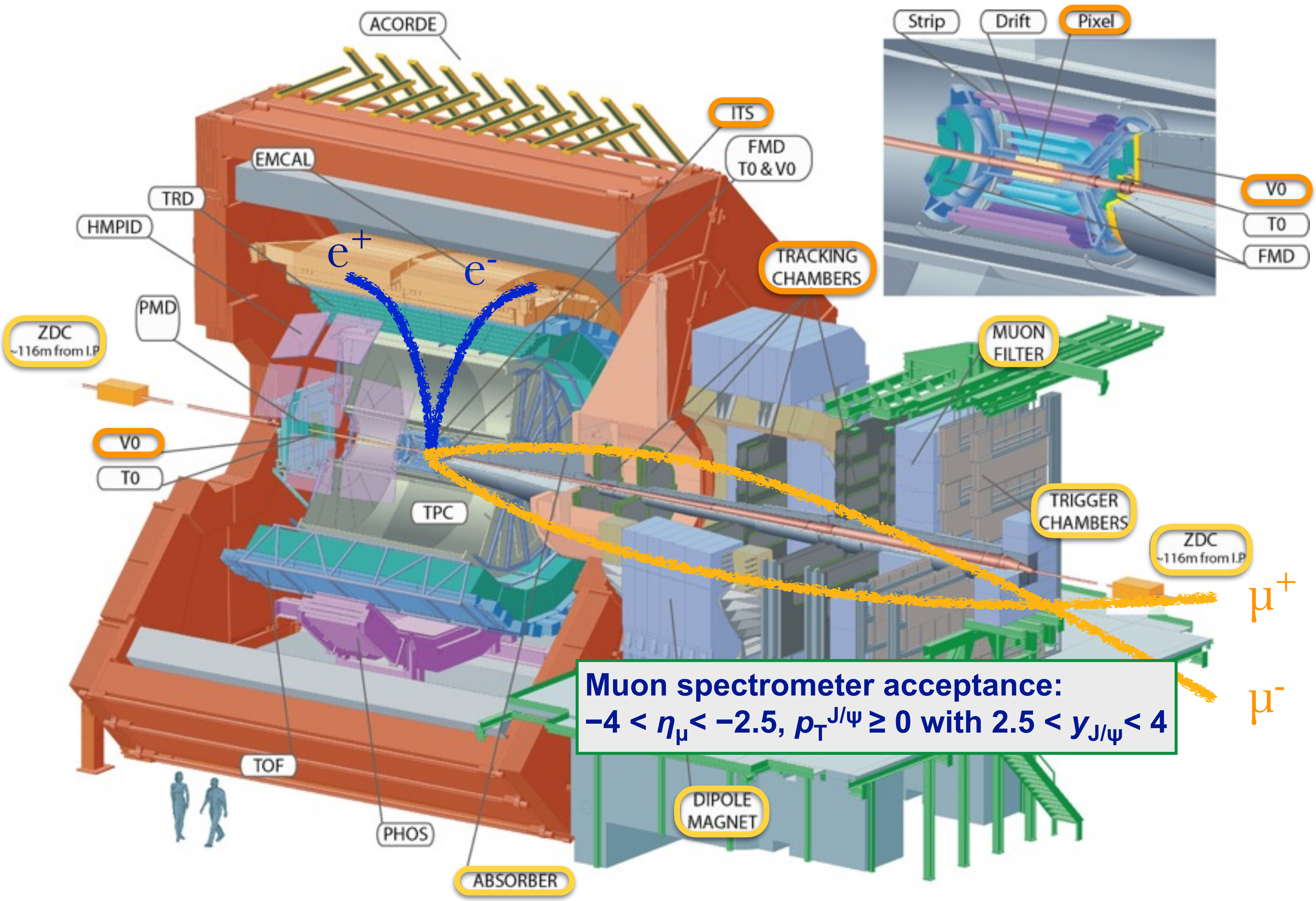
Phenix results

- Still large uncertainties
- Does not allow to distinguish between predictions



Phys.Rev.Letter 111 (2008) 104136

The ALICE detector



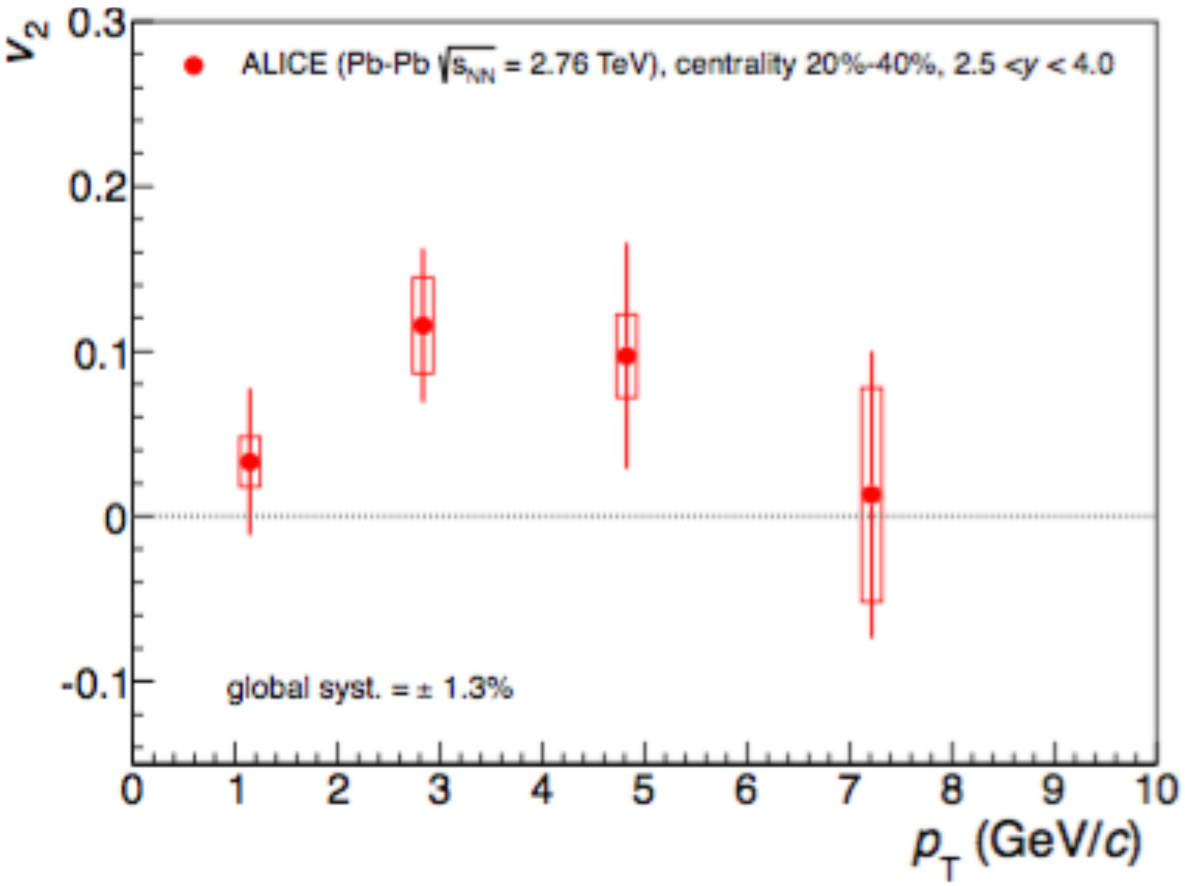
Muon spectrometer acceptance:
$-4 < \eta_{\mu} < -2.5$, $p_T^{J/\psi} \geq 0$ with $2.5 < y_{J/\psi} < 4$

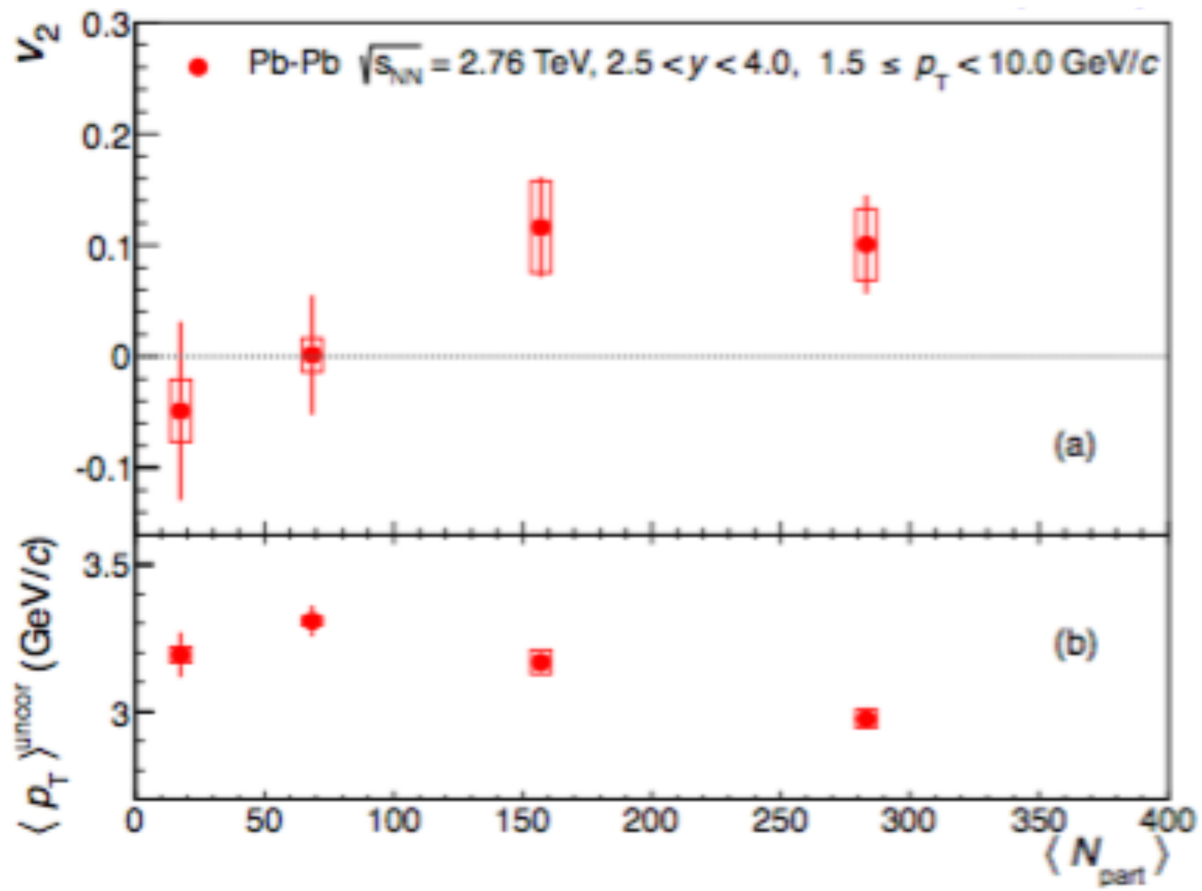
Results with ALICE à 2.76 TeV

- Hint of non-zero v_2 at intermediate p_T (2-6 GeV/c) in semi-central collisions (20-40%) with 2.7σ

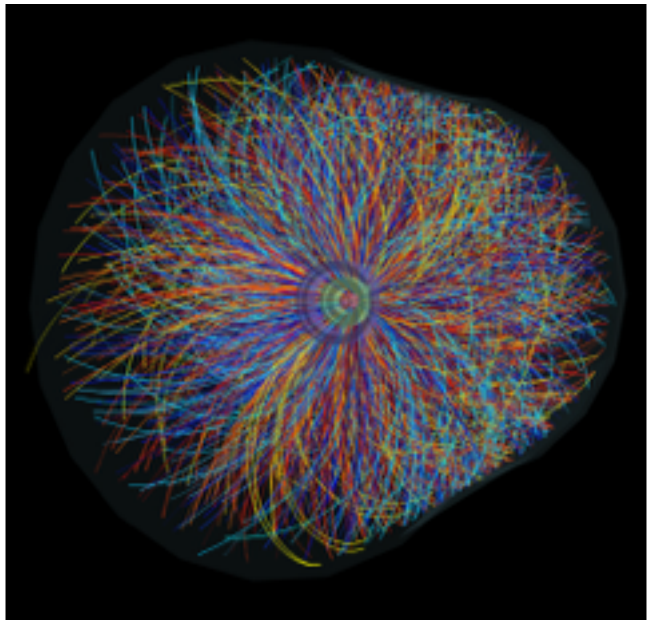
- v_2 compatible with zero in other p_T ranges

Phys.Rev.Letter 111 (2013) 162301





Motivations for run 2

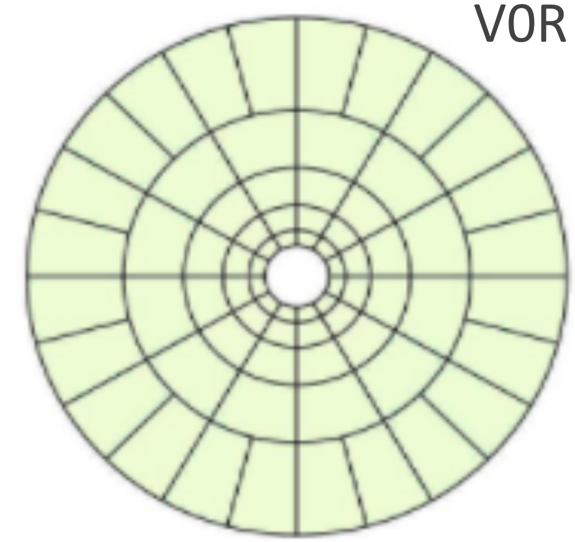


- Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - x3 integrated luminosity and x7 number of J/ψ
  - Increased number of initial c-$\bar{c}$ pairs

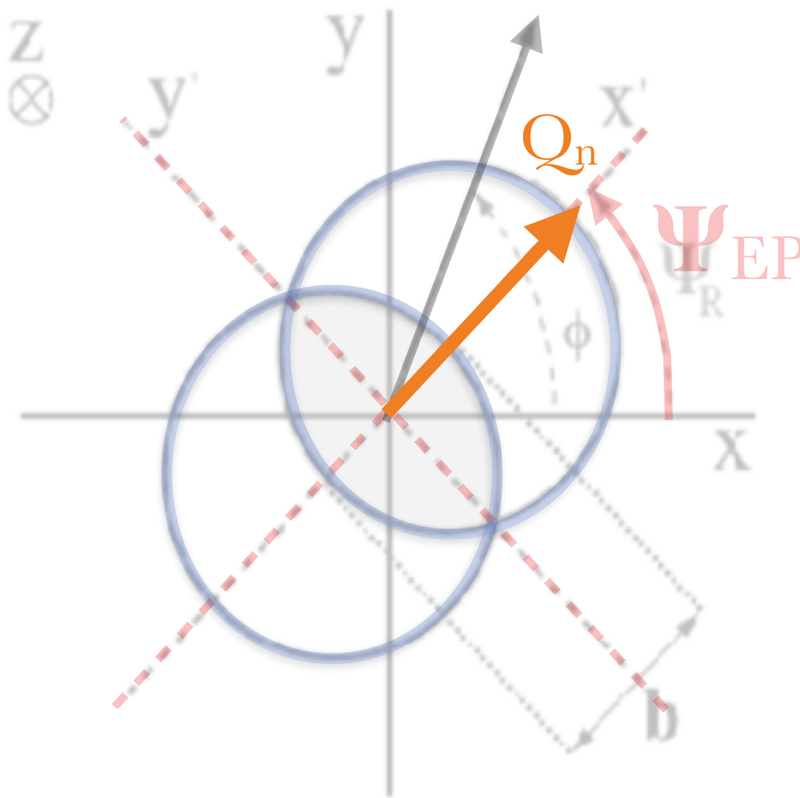
- First J/ψ v2 measurements will be done using Event Plane methods
- Standard J/ψ reconstruction and selection
- Other approaches will be followed later

How to measure the elliptic flow ?

- Focus on methods based on event plane determination



- From detector multiplicities :



$$Q_n = \sum_{i=0}^{\infty} e^{in\Phi_i} = Q_{n,x} + i\,Q_{n,y}$$

$$Q_{n,x} = \frac{\sum^{scint.} s_i \cos(n\Phi_i)}{\sum^{scint.} s_i} = |Q_n| \cos(n\Psi_n)$$

$$Q_{n,y} = \frac{\sum^{scint.} s_i \sin(n\Phi_i)}{\sum^{scint.} s_i} = |Q_n| \sin(n\Psi_n)$$

$$\Psi_n = \frac{1}{n} \arctan(Q_{n,x}, Q_{n,y})$$

- Correct for detector resolution : using 3 sub-event method

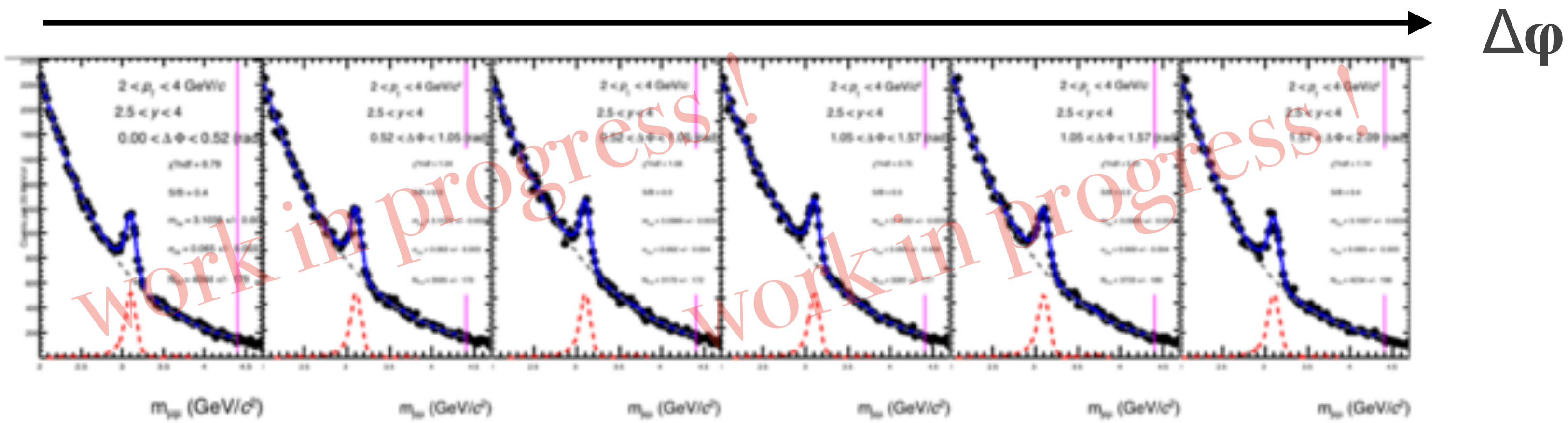
$$< \cos\{n(\Psi_2^a - \Psi_R)\} > = \sqrt{\frac{<\cos\{n(\Psi_2^a - \Psi_2^b)\}><\cos\{n(\Psi_2^a - \Psi_2^c)\}>}{<\cos\{n(\Psi_2^b - \Psi_2^c)\}>}}$$

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

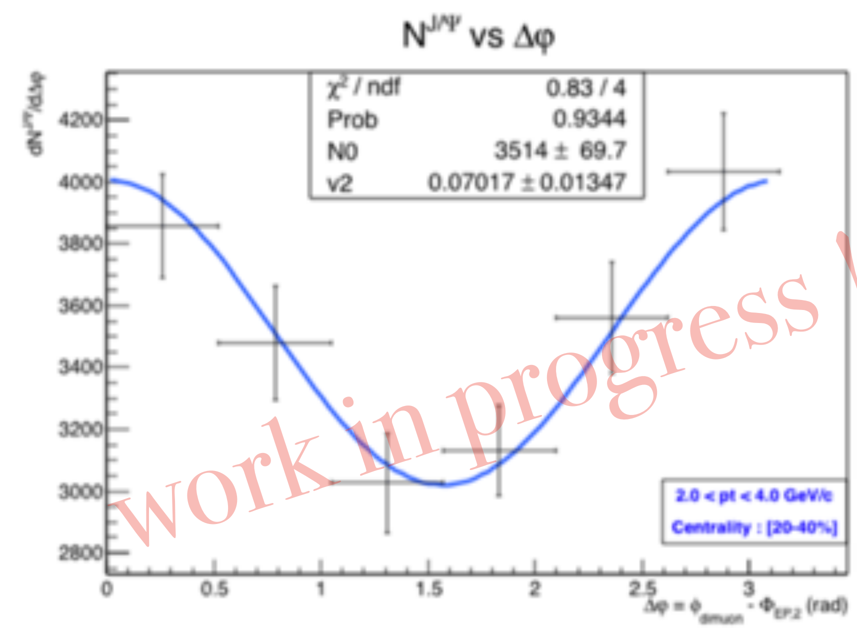
- Deal with non-uniform acceptance

Event plane method for v_2 extraction : n°1

- First method $dN_{J/\psi}/d\Delta\phi$ with $\Delta\phi = \phi_{\mu\mu} - \Psi_{EP}$
  - Division of $\Delta\varphi$ into 6 bins
  - $N_{J/\psi}$ extraction (Fit of the inv. mass spectra)



- Fit of $N_{J/\psi} = f(\Delta\varphi)$ with $N_0\{1+2v_2\cos(\Delta\varphi)\}$



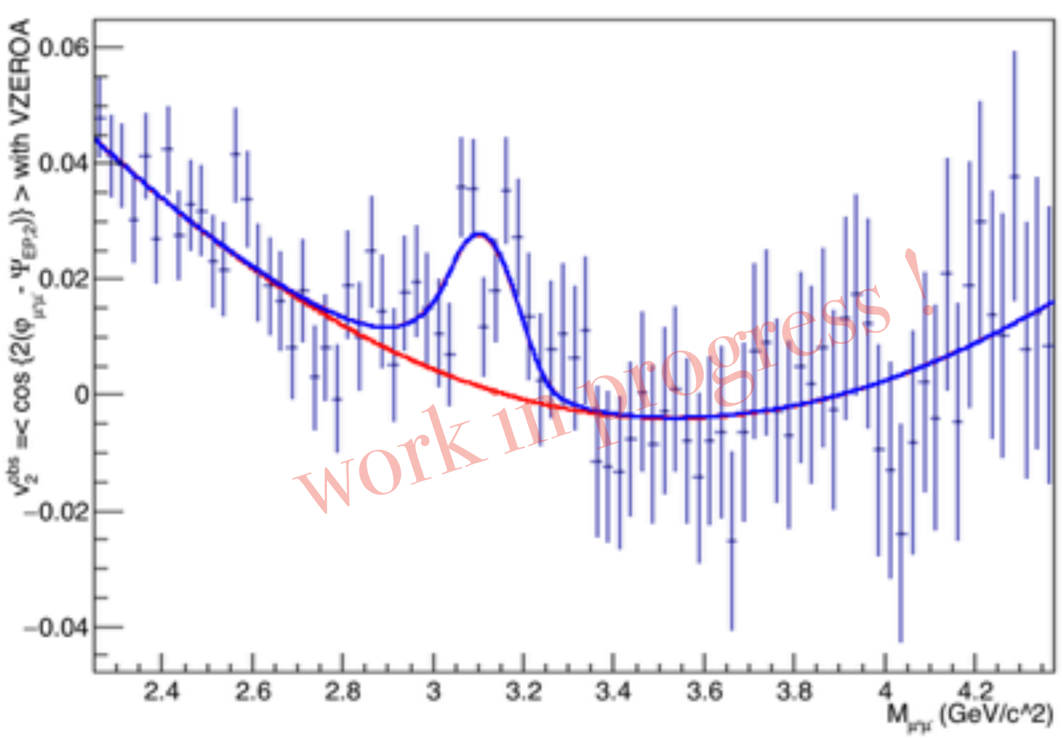
Event plane method for v_2 extraction : n° 2

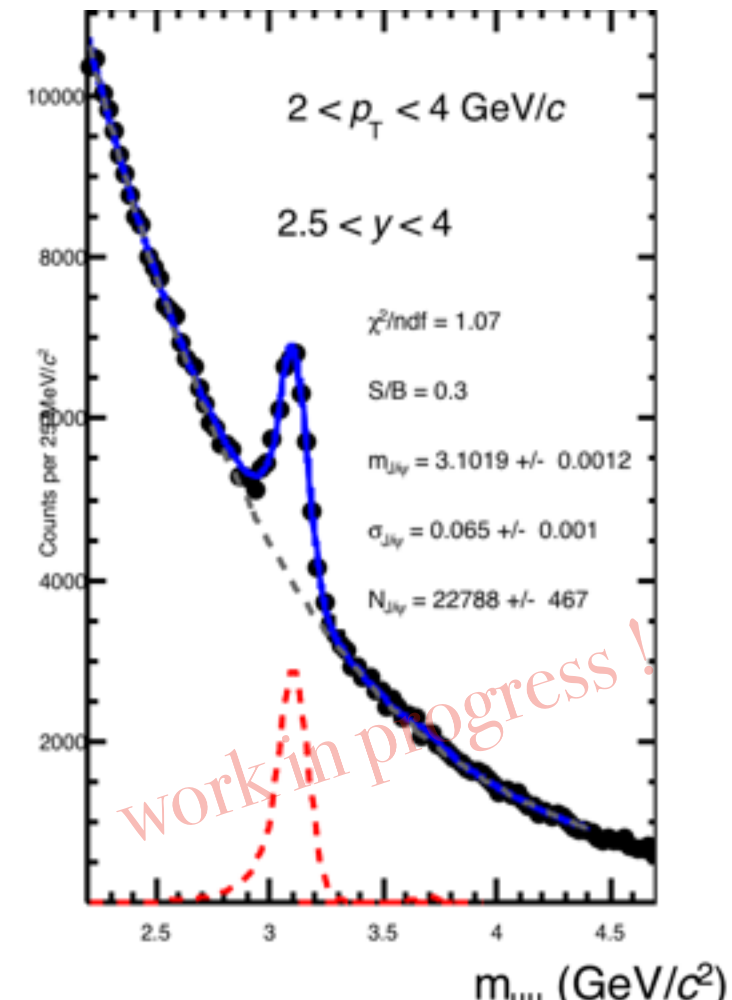
- Second method $\langle \cos(2\,\Delta\phi) \rangle$ vs inv. mass with $\Delta\phi = \phi_{\mu\mu} - \Psi_{EP}$

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

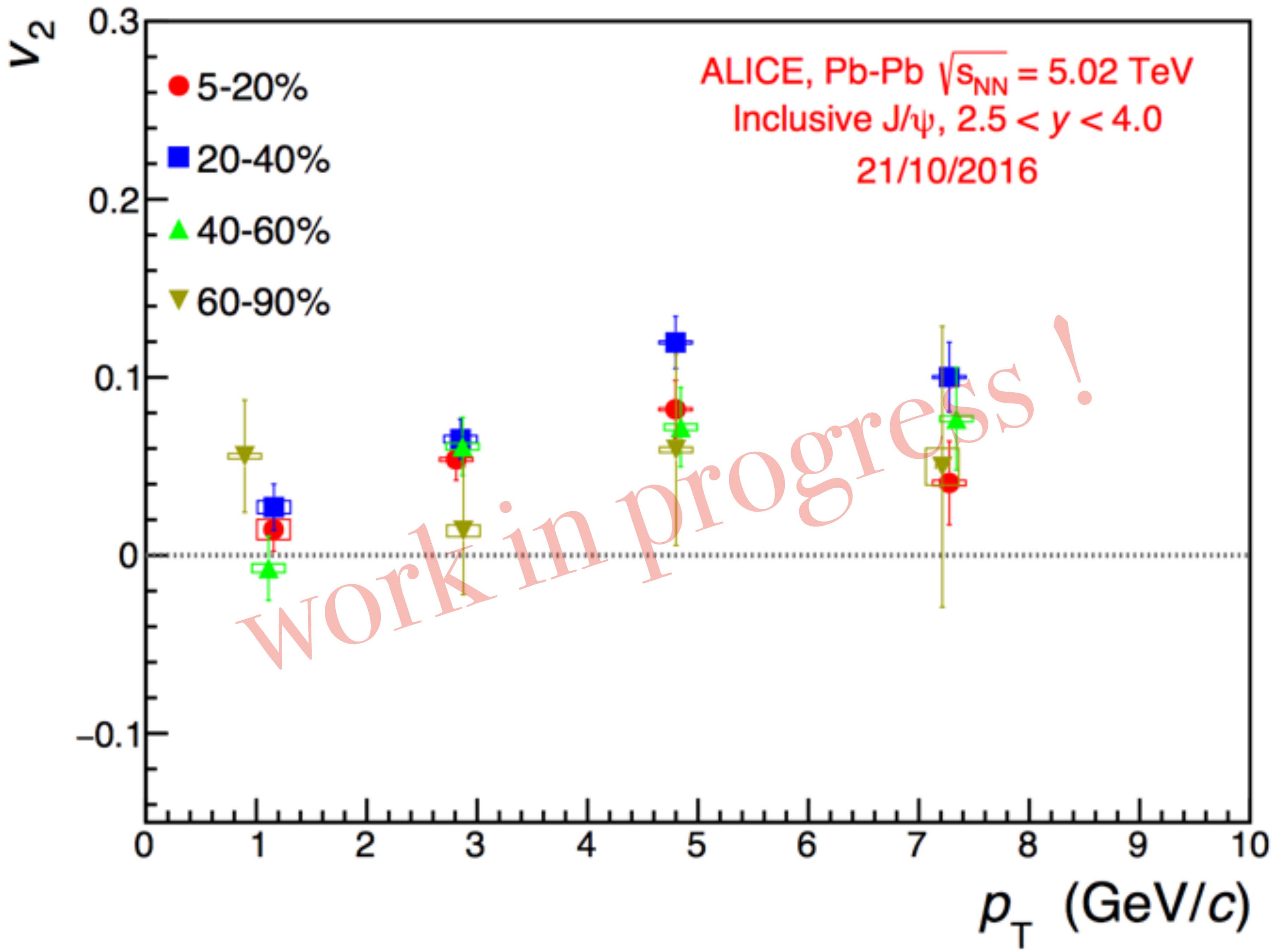
  - with $\alpha(m_{\mu\mu})$ signal shape extracted from M_{inv} fit

  - v_2^{bck} background : e.g. polynomial function





Preliminary results à 5.02 TeV



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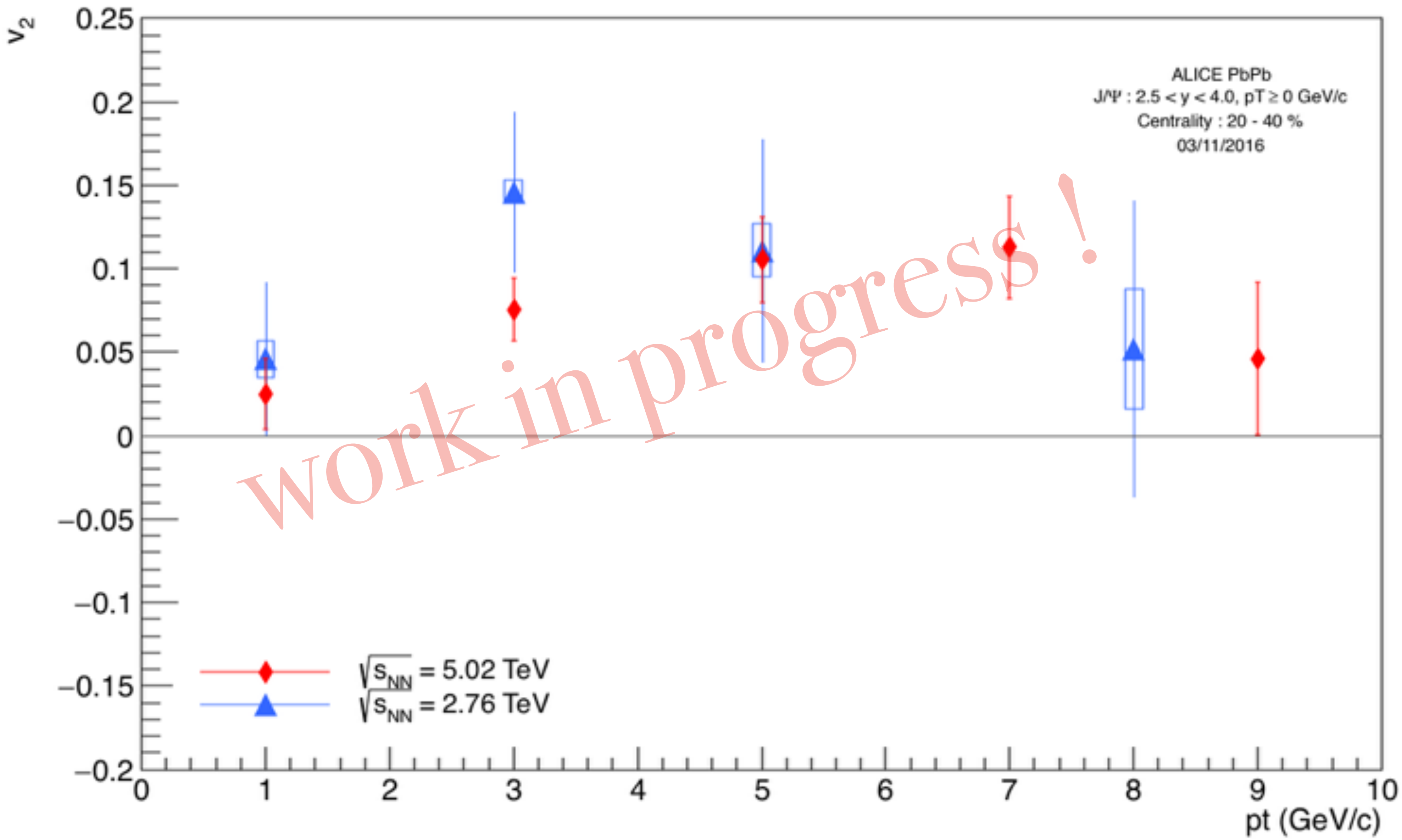


Summary

- Measure J/ψ elliptic flow would allow to study J/ψ regeneration by recombination of charm quarks

- Experimental results

  - At low energy : very low J/ψ v_2

  - At 2.76 TeV : Hint of non-zero v_2 at intermediate pT (2-6 GeV/c) in semi-central collisions

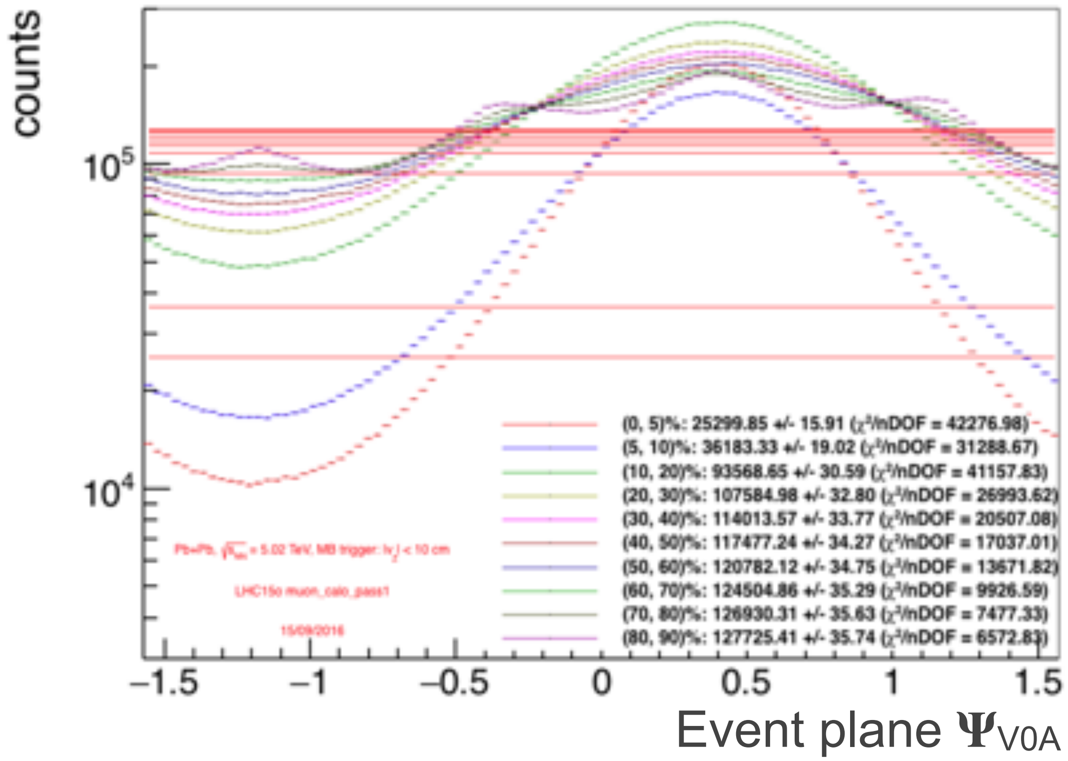
  - First results à 5.02 TeV : A significant J/psi v2 signal is observed at various centrality and p_T bins

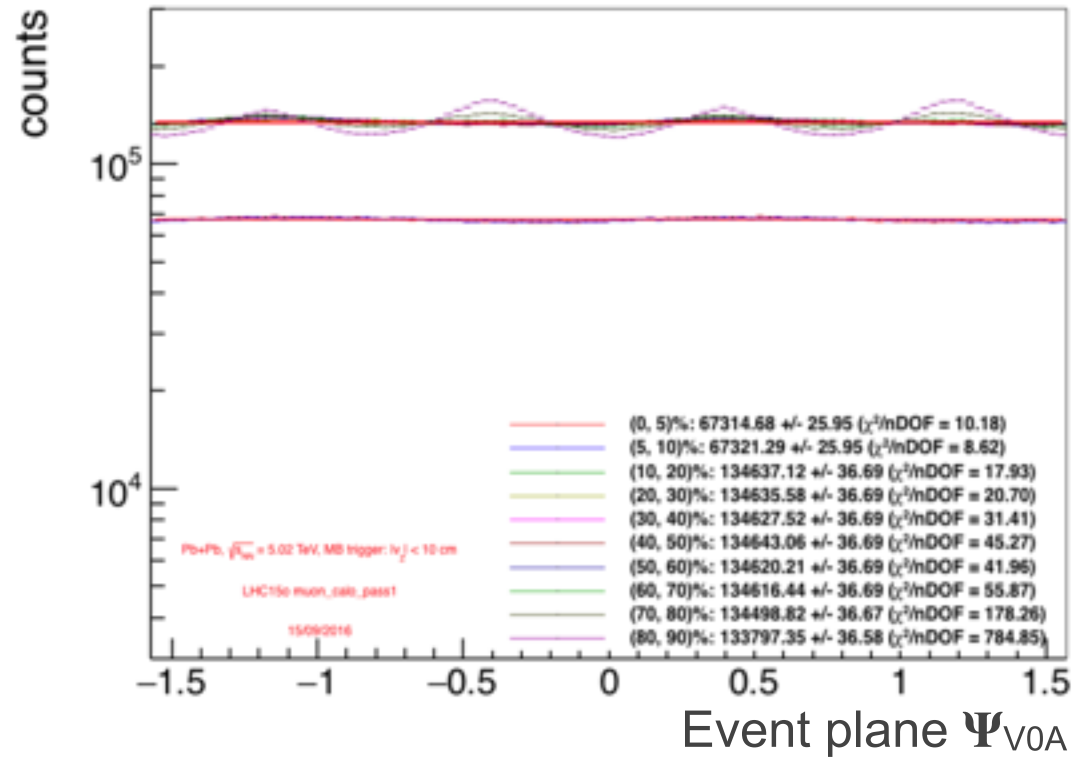
Thank you for your attention !

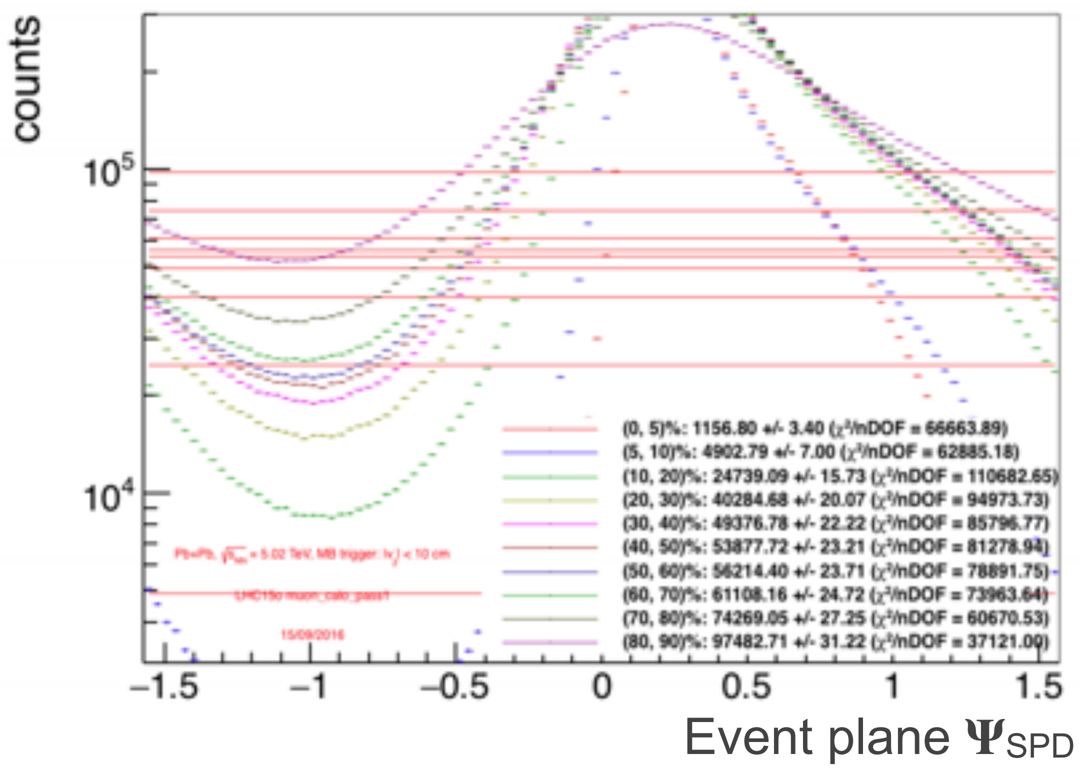
Backup

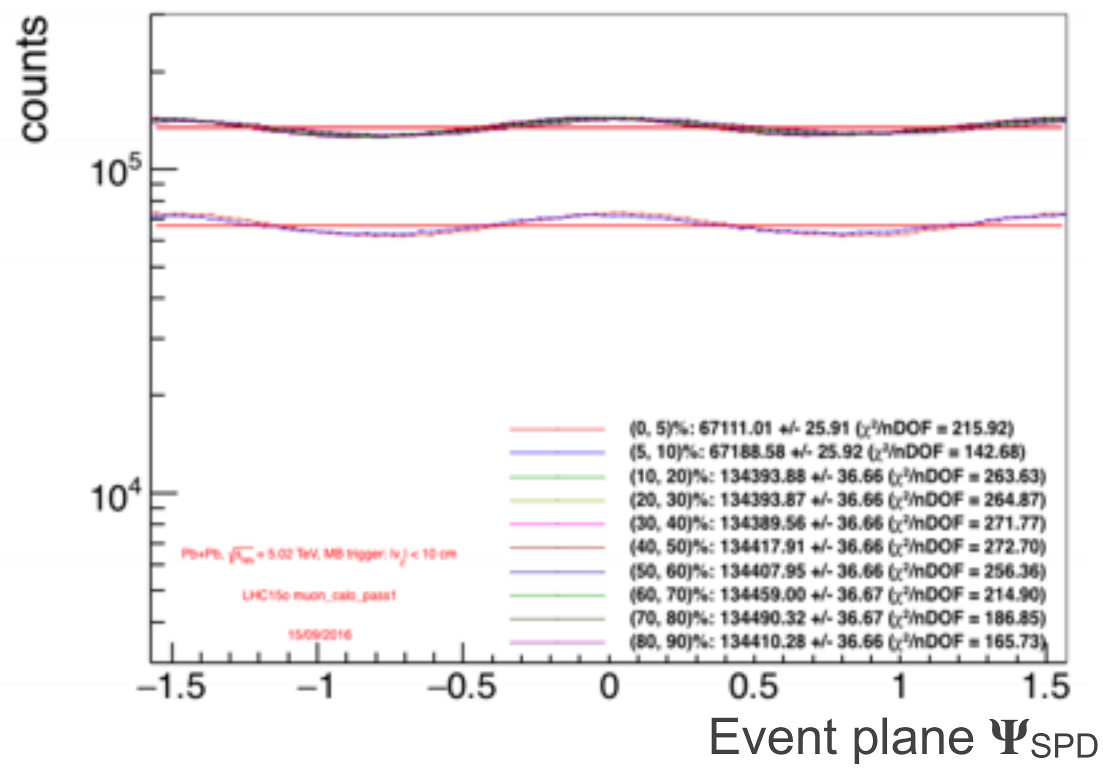
Event plane equalization results by centrality bins

Raw distribution (no correction) | After correction (step 3)







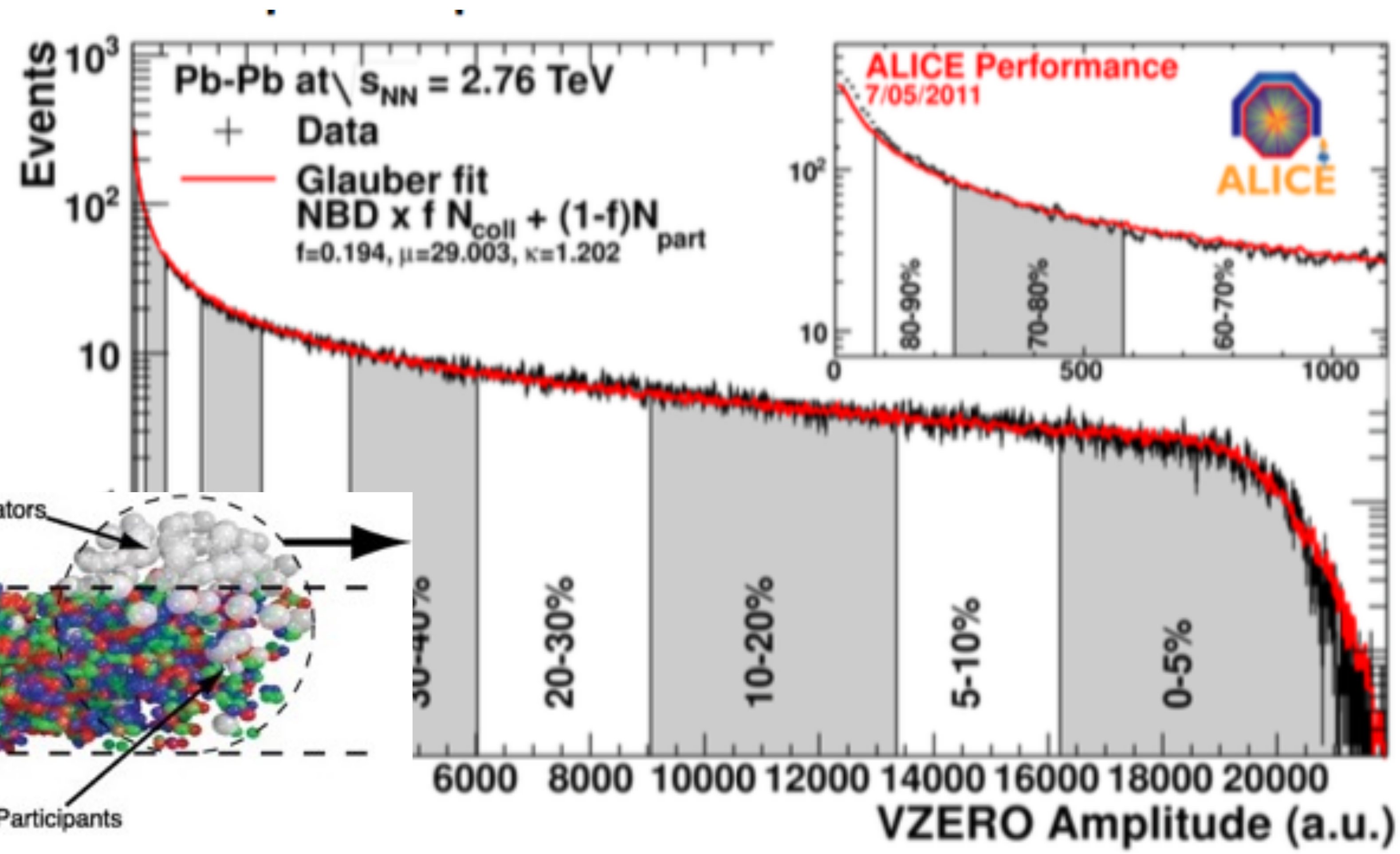


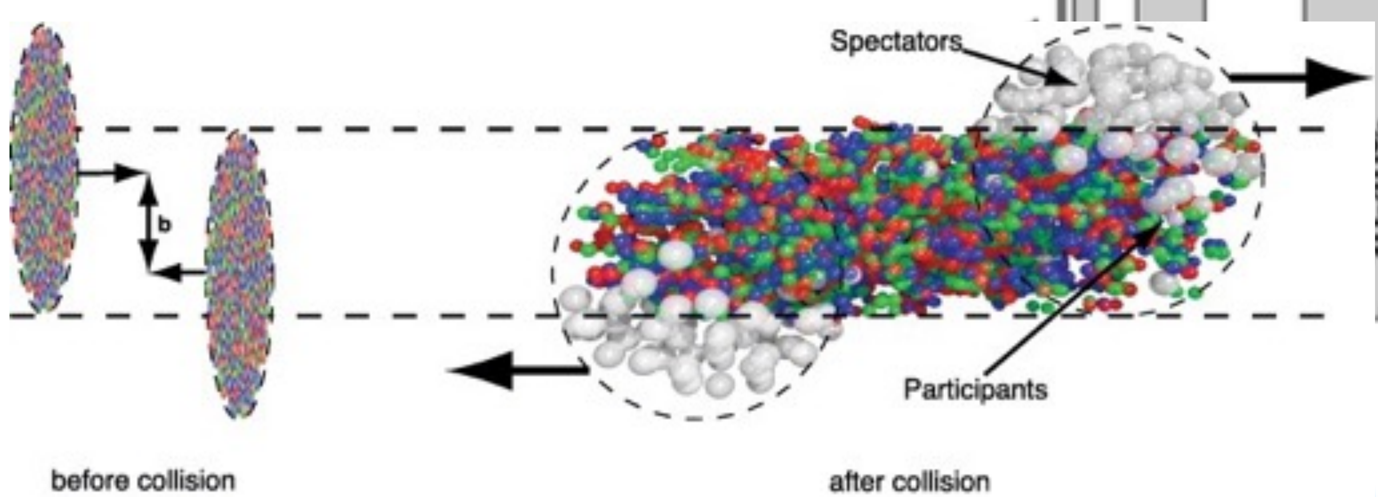
Collision centrality determination

Centrality is a key quantity because it is related to the initial overlap region of the colliding nuclei

Collision geometry determines the num

Many quantities scale with N_{part}: particl





Phys. Rev. C. 88 (2013) 044909

Detector equalization

1. Gain equalization of individual detector channels

$$M'_c = M_c/\langle M_c\rangle$$

2. Recentering

$$\boldsymbol{q}'_n = \boldsymbol{q}_n - \langle \boldsymbol{q}_n\rangle$$

3. Width equalization

$$\boldsymbol{q}''_n = \boldsymbol{q}'_n/\sigma_{\boldsymbol{q}_n}$$

4. Alignment

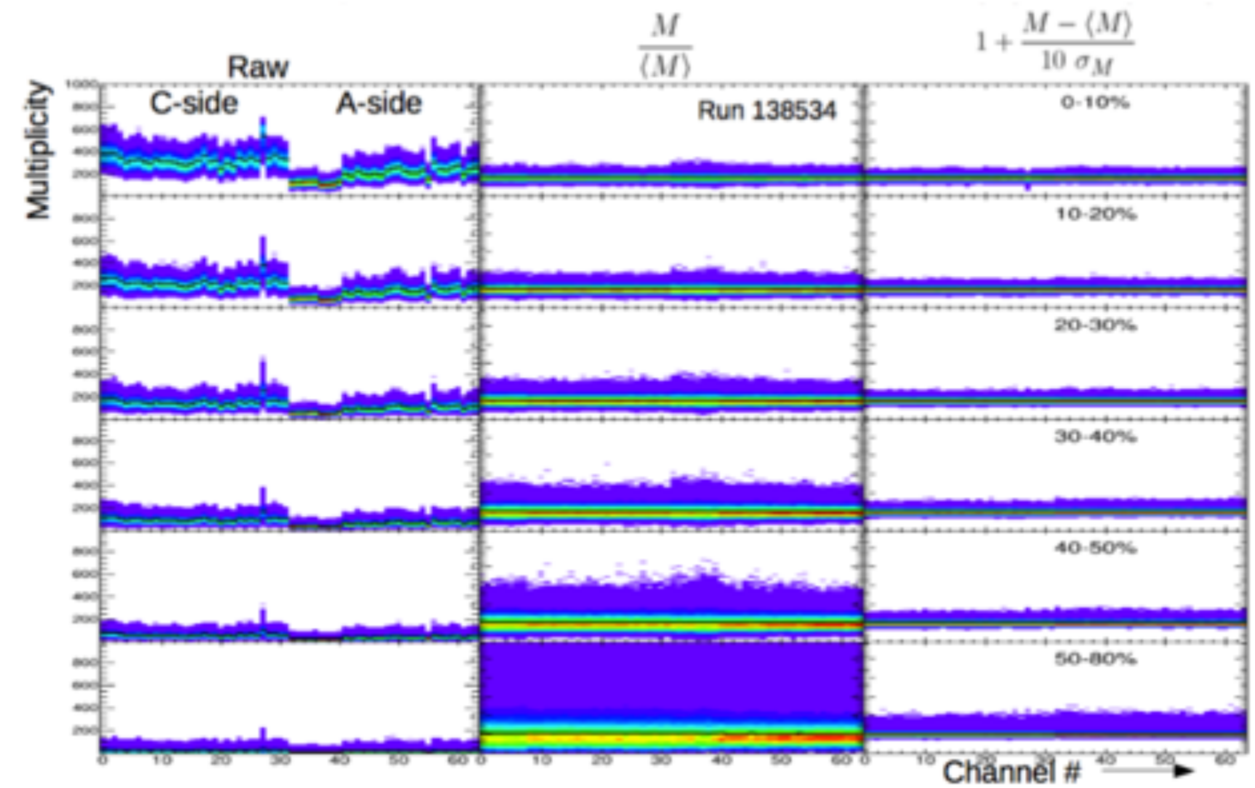
$$\boldsymbol{q}'''_n = \boldsymbol{q}''_n + \boldsymbol{q}''_{n,\phi}$$

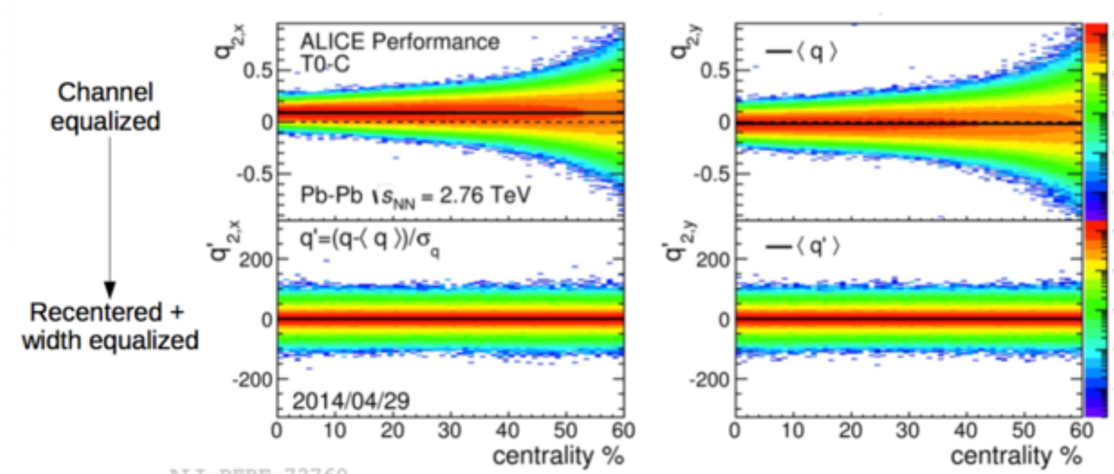
5. Twist

$$q''''_{n,(x,y)} = (q'''_{n,(x,y)} - \Lambda^{s(+,-)}_{2n} q'''_{n,(y,x)})/(1 - \Lambda^{s-}_{2n}\Lambda^{s+}_{2n})$$

6. Rescaling

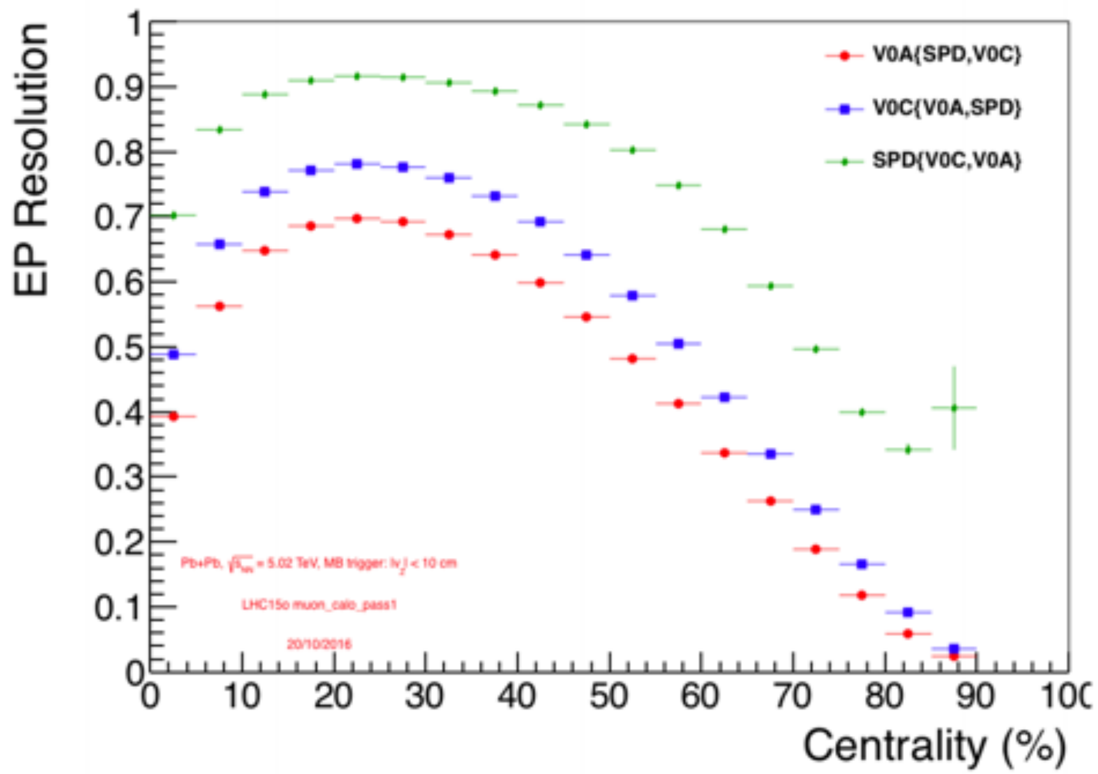
$$q'''''_{n,(x,y)} = q''''_{n,(x,y)}/A^{(+,-)}_{2n}$$

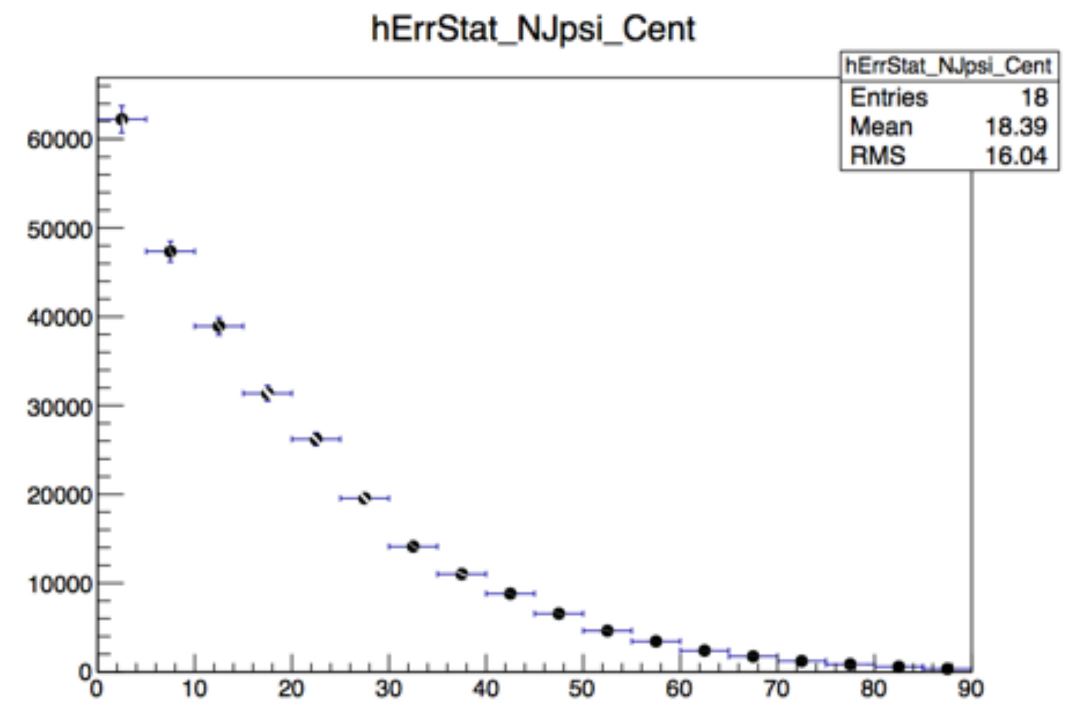




Event plane resolution

- Resolution calculated using the 3 sub-events method with V0A, V0C and SPD
- Centrality bins used for J/ψ v2 analysis are large
- Non uniform distribution of the number of J/ψ





→ Calculate a $N_{J/\psi}$-weighted resolution

	5-20%	20-40%	40-60%	60-90%
V0A	0.62472±0.00014	0.68256±0.00010	0.5333±0.00014	0.22955±0.00033
SPD	0.87297±0.00019	0.91031±0.00014	0.83192±0.00022	0.55432±0.00333

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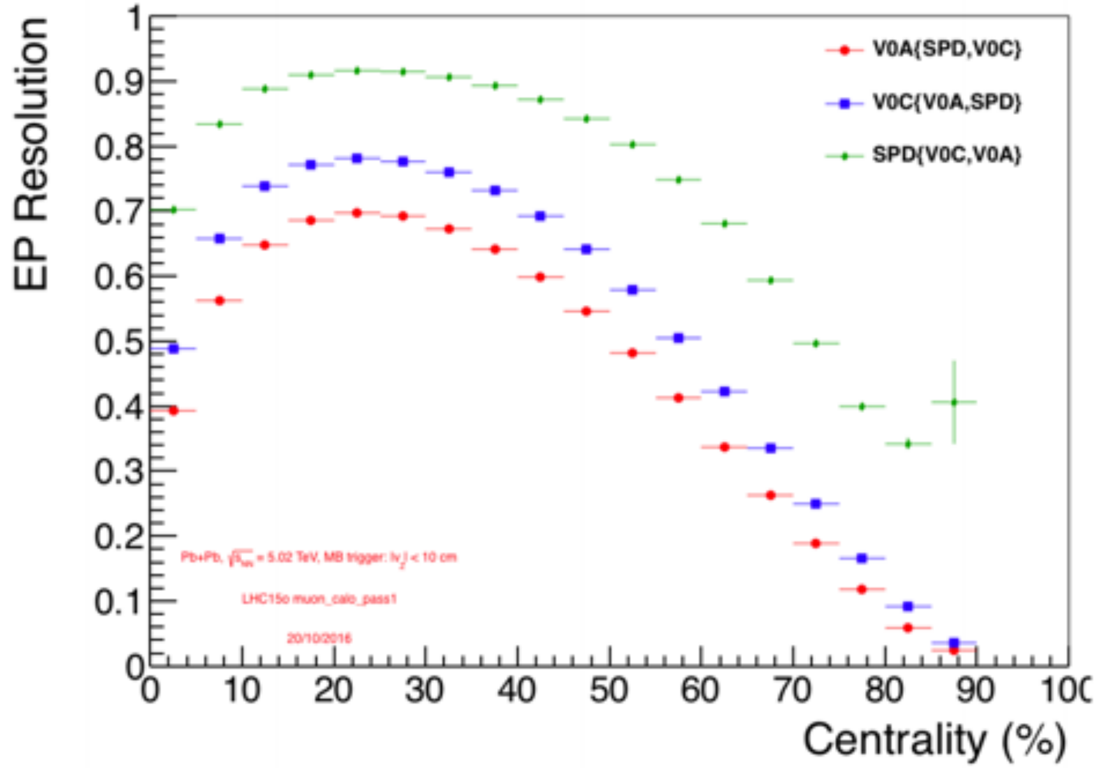

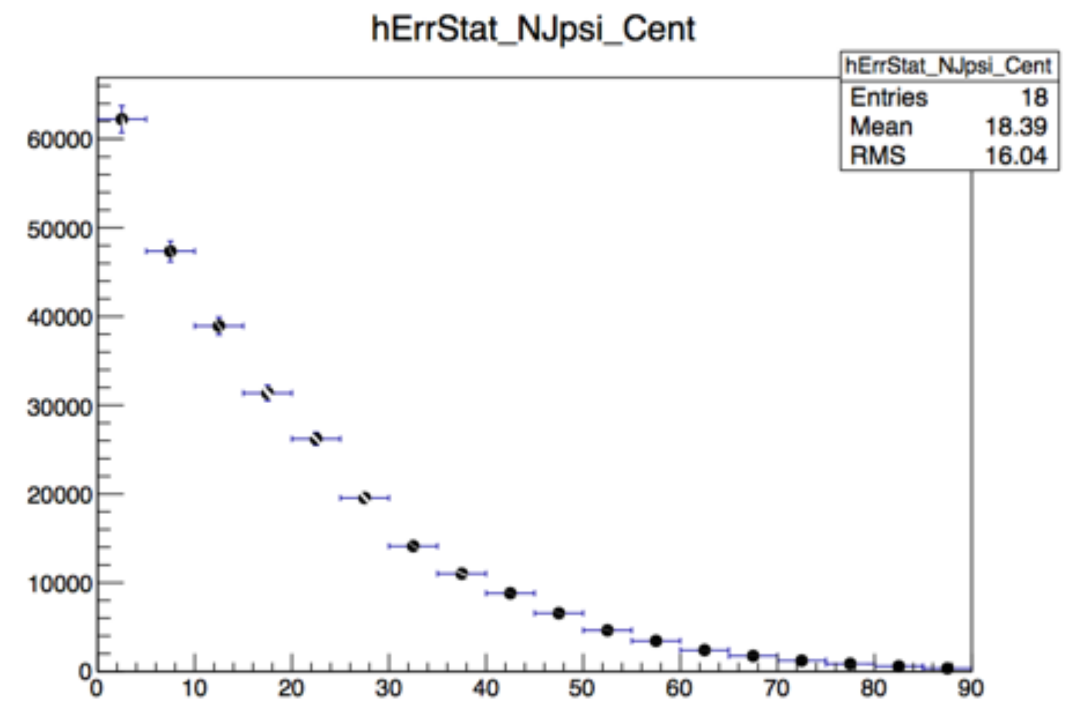

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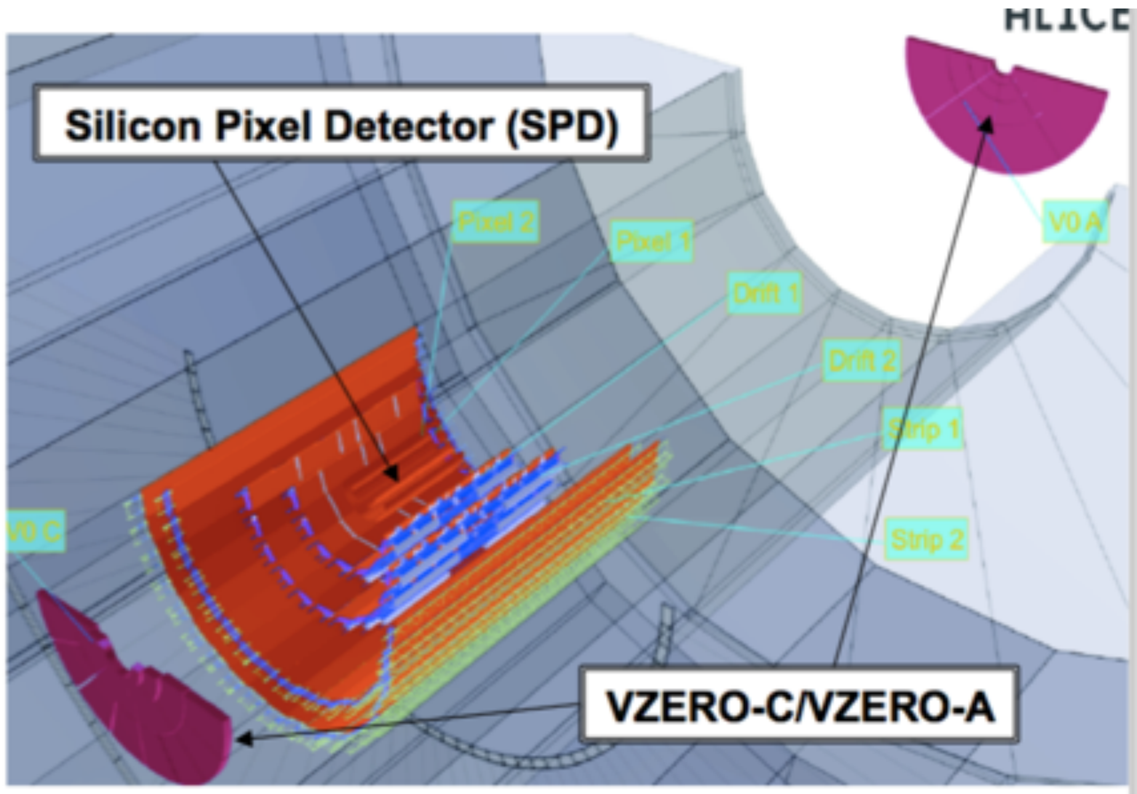
How dare you using the event plane method ?!

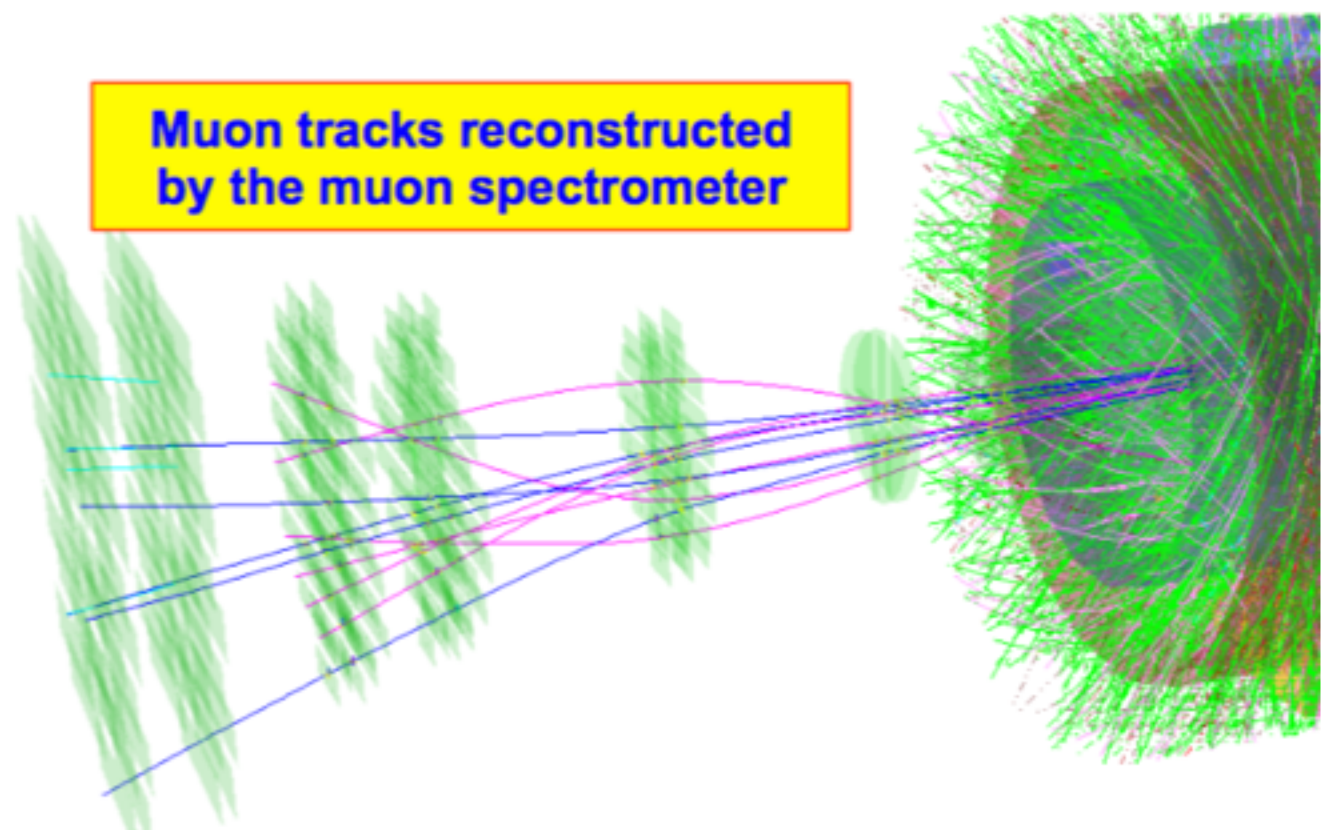
Biased method !

- Non flow effects : dominant at high p_T
- Event-by-event fluctuations
- Difficult to compare results between different experimental setups (ambiguous measurement)

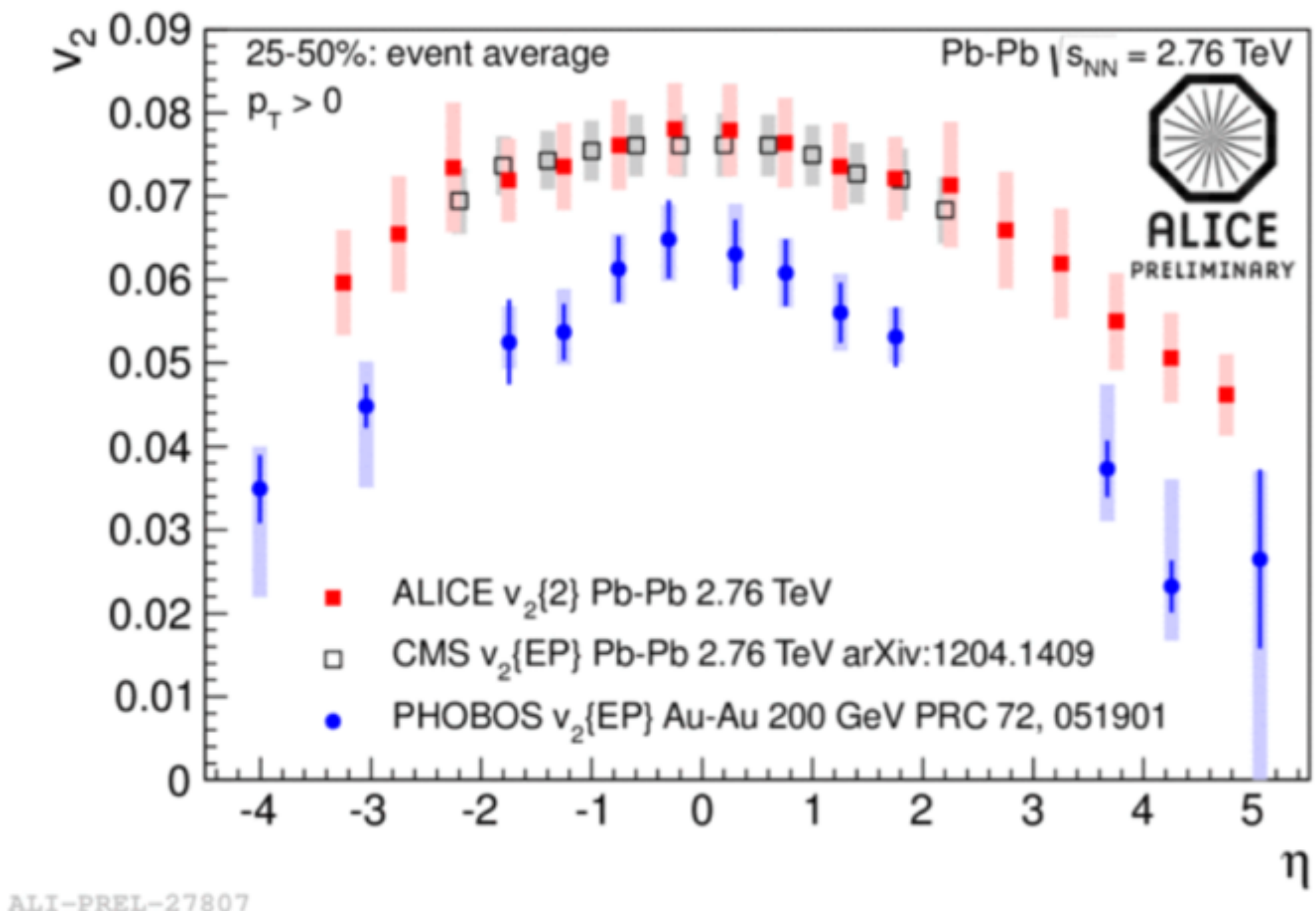
- BUT :
  - Not so precise **J/Ψ** v_2 measurement by ALICE
  - Large Δη gap (1.9) between V0A (event plane detector) and muon spectrometer (signal) : reduces sources of auto-correlations

- Yes we will check with other methods : Cumulants, Lee-Yang zeros


Silicon Pixel Detector (SPD)
Pixel 2
Pixel 1
Drift 1
Drift 2
Strip 1
Strip 2
V0 A
V0 C
VZERO-C/VZERO-A

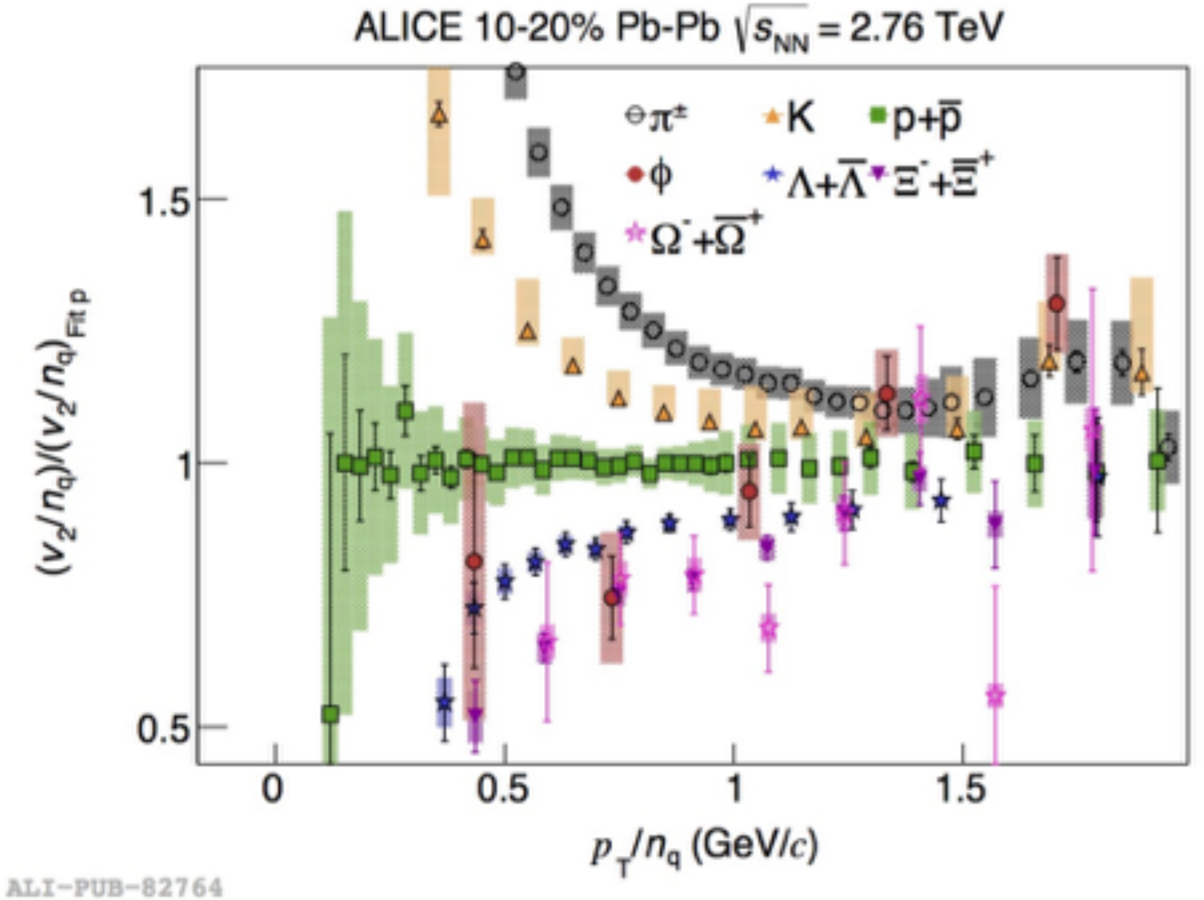

Muon tracks reconstructed by the muon spectrometer

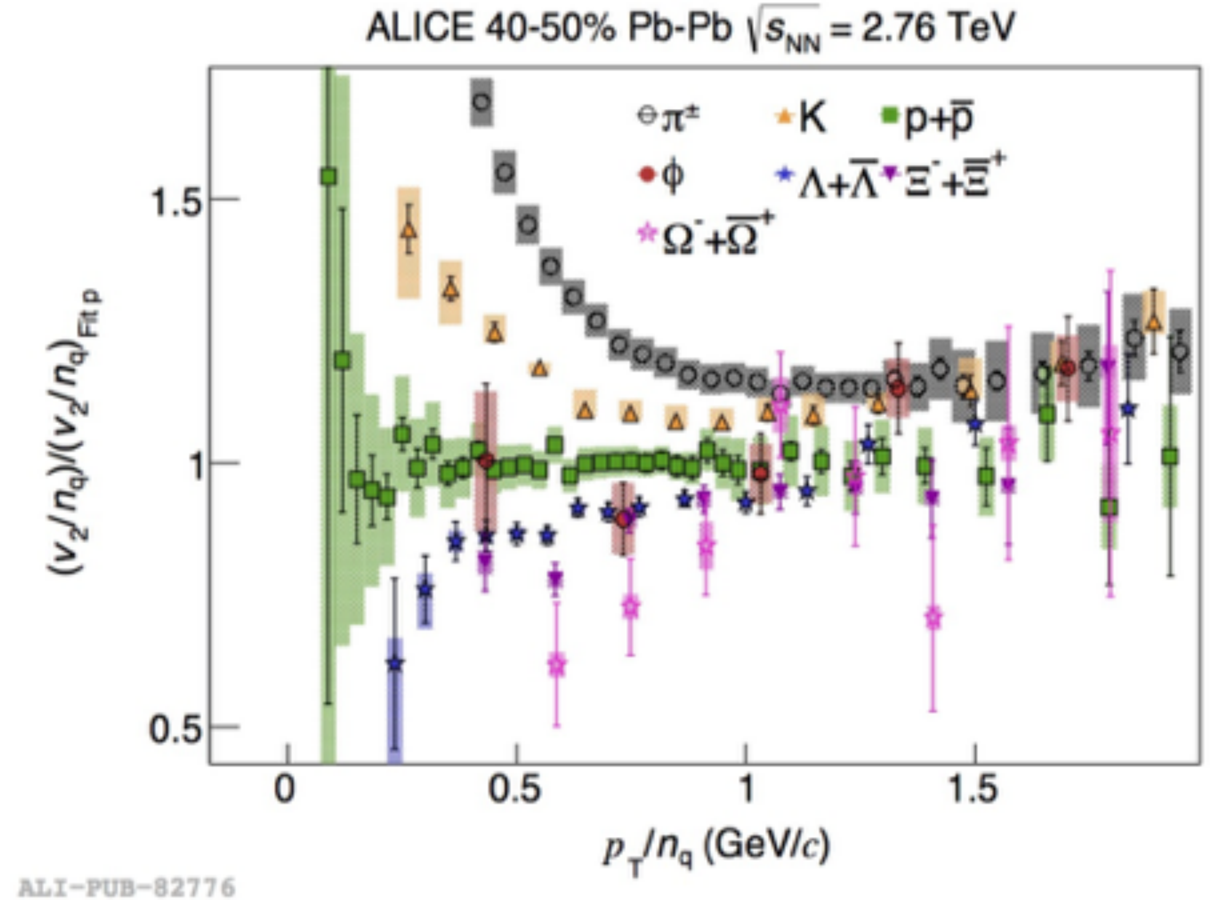
Pseudo-rapidity dependency



- depends on particle multiplicity

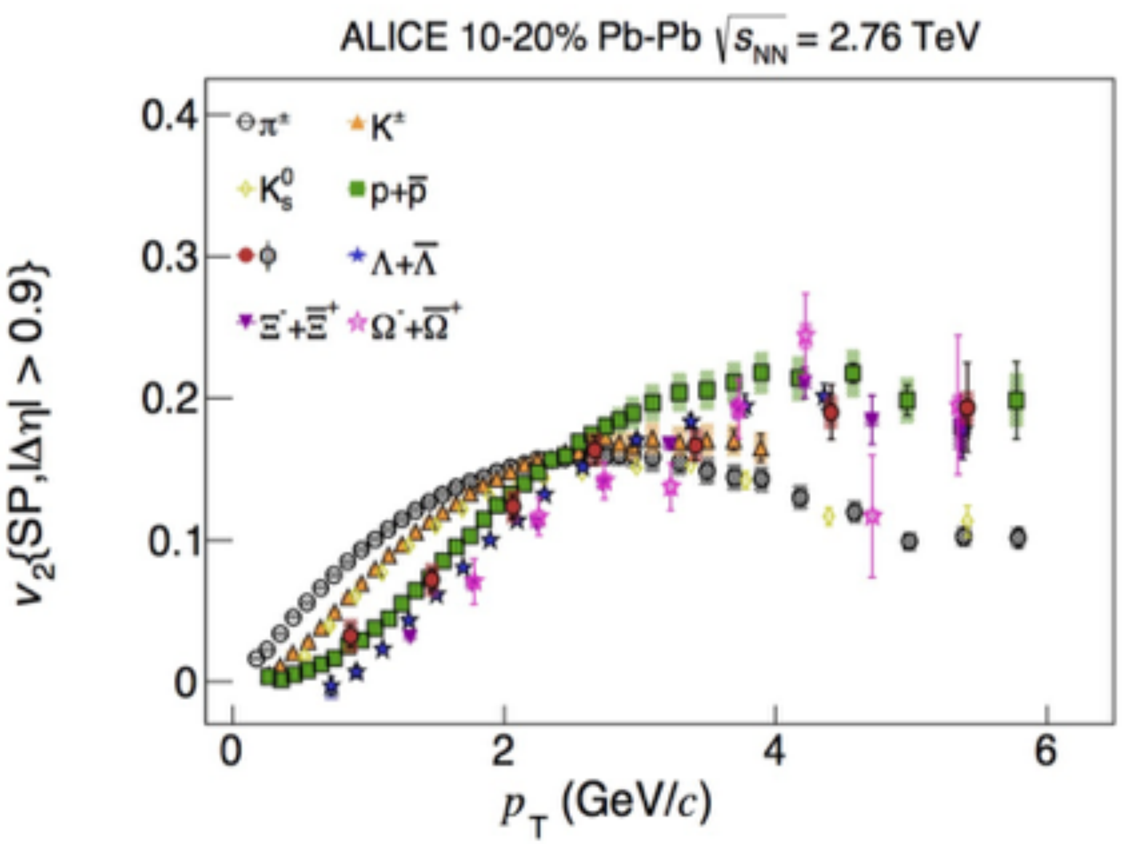
pT/nq scaling ?



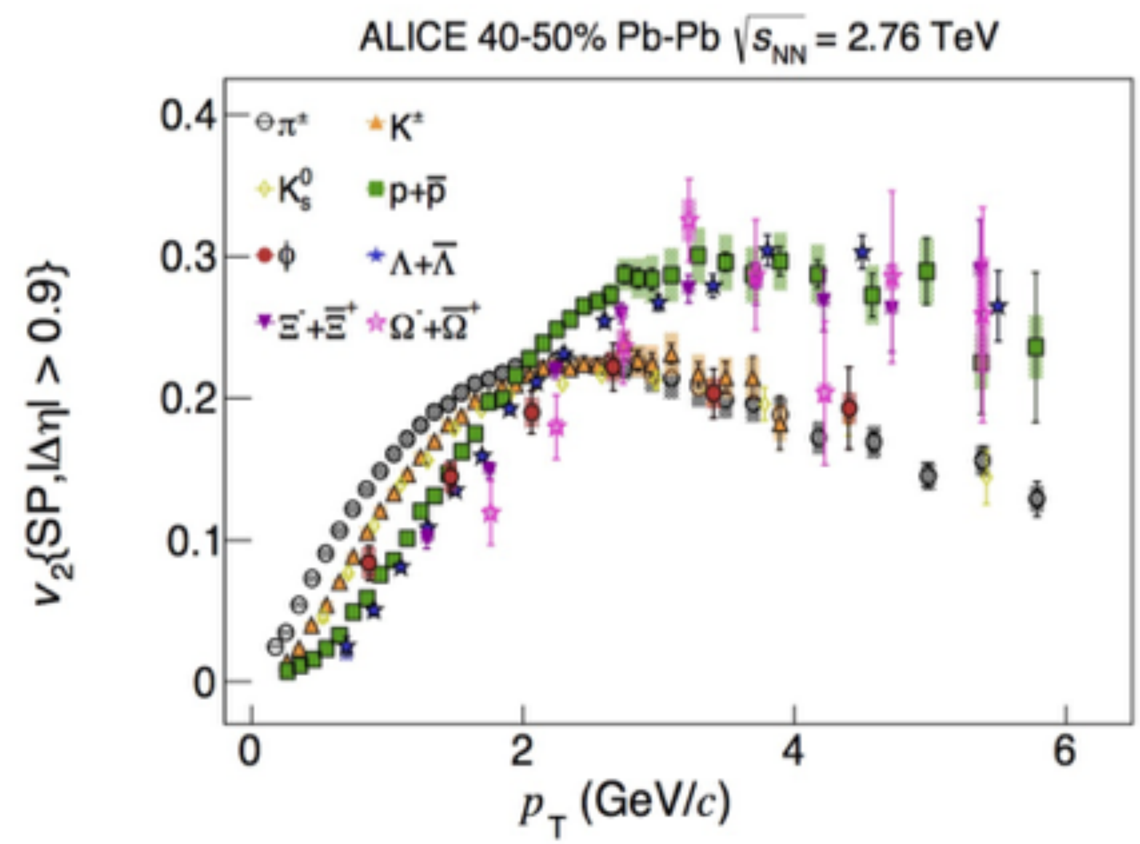


- below 1 GeV/c : ok
- then : 20% variations in both centralities

Flow of identified particles



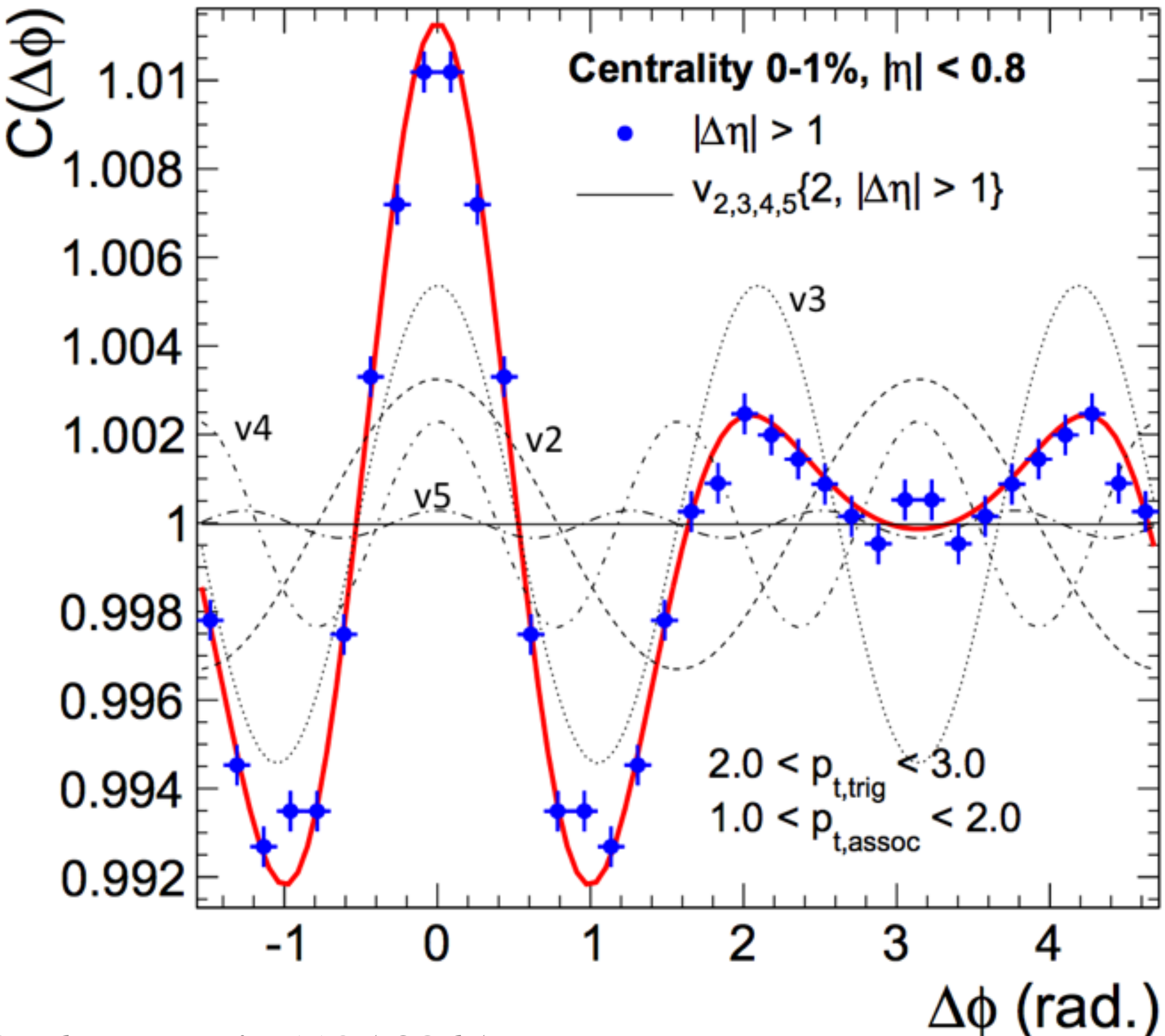
ALI-PUB-82653



ALI-PUB-82660

- For p_T<2 GeV/c: observe mass ordering indicative of radial flow
- For p_T~2-3.5 GeV/c: crossing between v_2 of p and $\pi^{\pm}$
- For p_T>3 GeV/c: particles tend to group into mesons and baryons

Flow coefficients for most central collisions

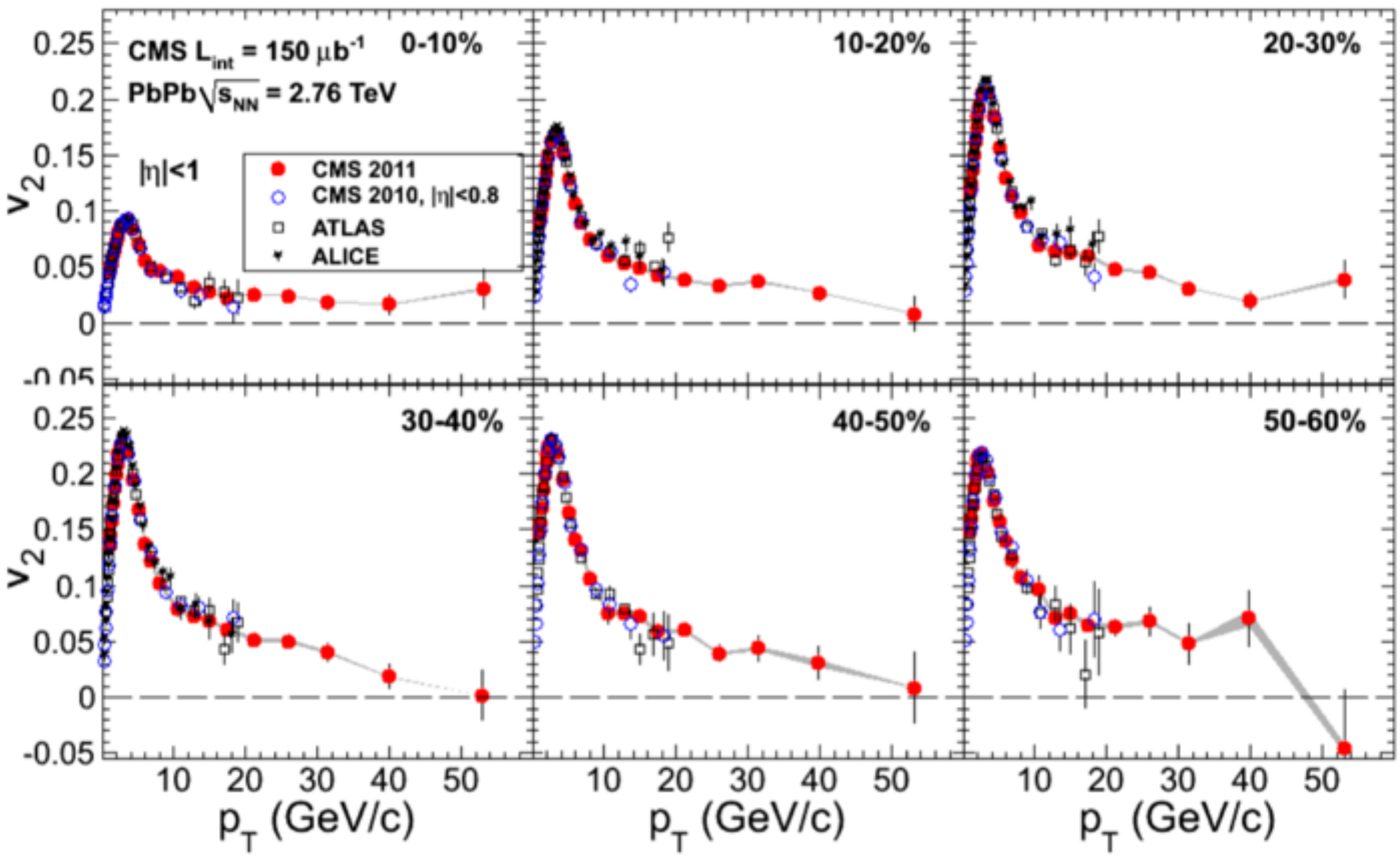


ALICE 2.76TeV arXiv 1105.3865

Parameters defining flow behavior

- Equation of state : T, P, density
- viscosity : bulk and shear
- final state interactions

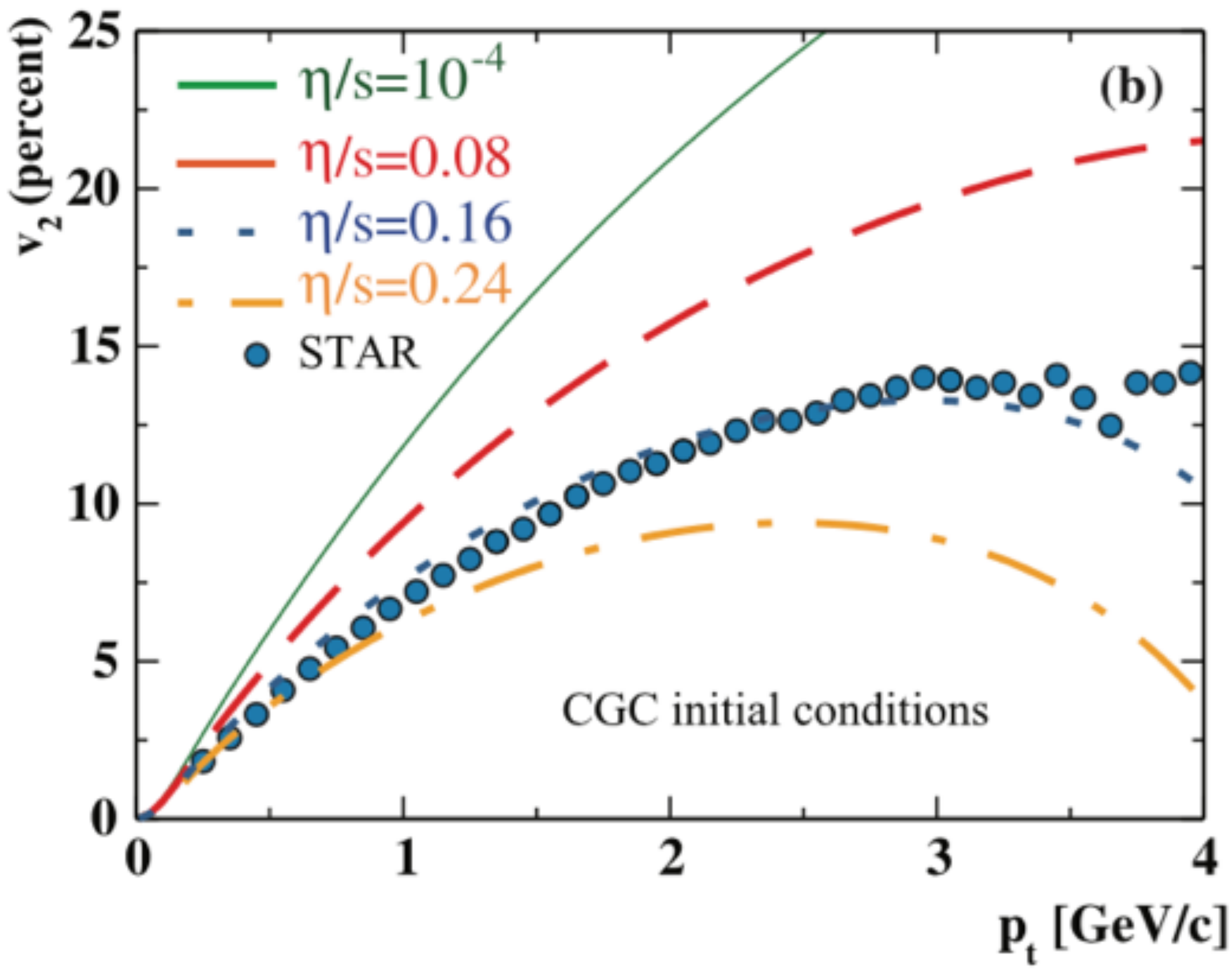
High p_T flow



High-p_T v_n dominated by energy loss mechanism

Useful to constrain models, complementary to R_{AA}

Can flow measure medium viscosity ?



from a CGC-inspired calculation, it is seen that both the centrality and transverse momentum dependence are well described with an η/s that is two times the KSS bound. These calculations are performed on the assumption that the value of η/s is constant during the entire evolution. The value used in these calculations should be considered as an effective average of η/s, because we know from other fluids that η/s depends on temperature. In addition, we also know that part of the elliptic flow originates from the hadronic phase. Therefore, a knowledge of the temperature dependence *and* a knowledge of the relative contributions from the partonic and hadronic phases are required in order to quantify η/s of the partonic fluid.

Event plane calibration : FlowVectorCorrections framework

- Event plane from detector multiplicities

$$Q_{n,x} = \sum w_i \cos(n\phi_i) = |Q_n| \cos(n\Psi_n)$$
$$Q_{n,y} = \sum w_i \sin(n\phi_i) = |Q_n| \sin(n\Psi_n)$$

$$\Psi_n = 1/n \arctan(Q_{n,y}, Q_{n,x})$$

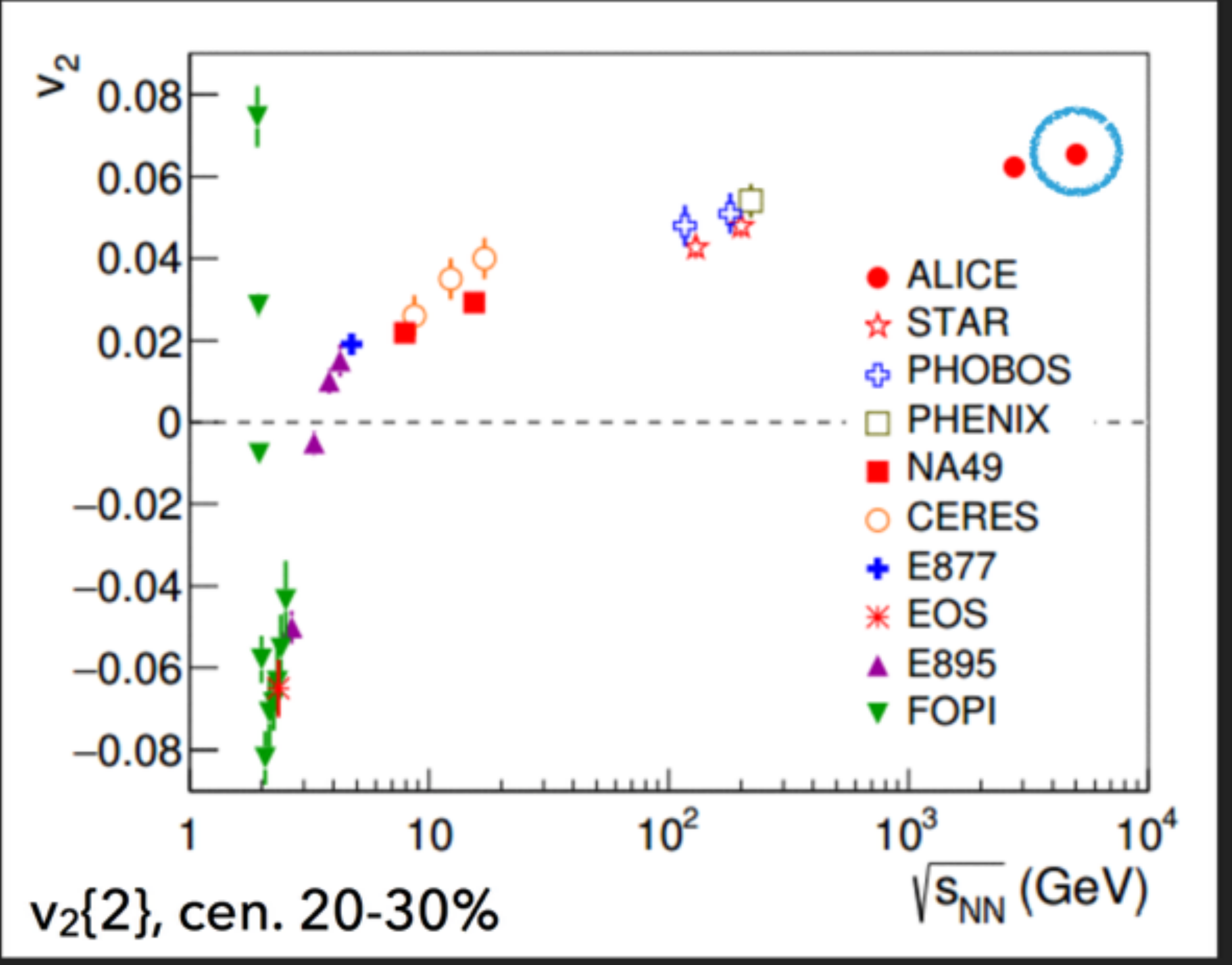
- General framework providing event plane values correcting Q-vector measurements for effects of non-uniform detector acceptance (Phys. Rev. C 77, 034904 (2008))

- Iterative corrections :
  Gain equalization/Recentering/Alignment/Twist and rescaling

- Framework ran on :
  - 137 (MUON) QA validated runs of LHC15o muon_calo_pass1 (RCT)
  - Included detectors: SPD, V0A, V0C, T0A, T0C, ZDCA, ZDCC
  - Event Selection :
    Centrality: V0M 00:90%; zvertex: -10.0:10.0cm; kMB | kMUSPB
    (CINT7-BNOPF-CENT|C0V0L7-B-NOPF-CENT|CMUL7-B-NOPF-MUFAST)
  - Run by run basis

Results: energy dependence

one step forward!



Phys. Rev. Lett. 116, 132302 (2016)