Anisotropic flow observables and how to measure them

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International School on

"Relativistic Heavy Ion Collisions, Cosmology and Dark Matter, Cancer Therapy"

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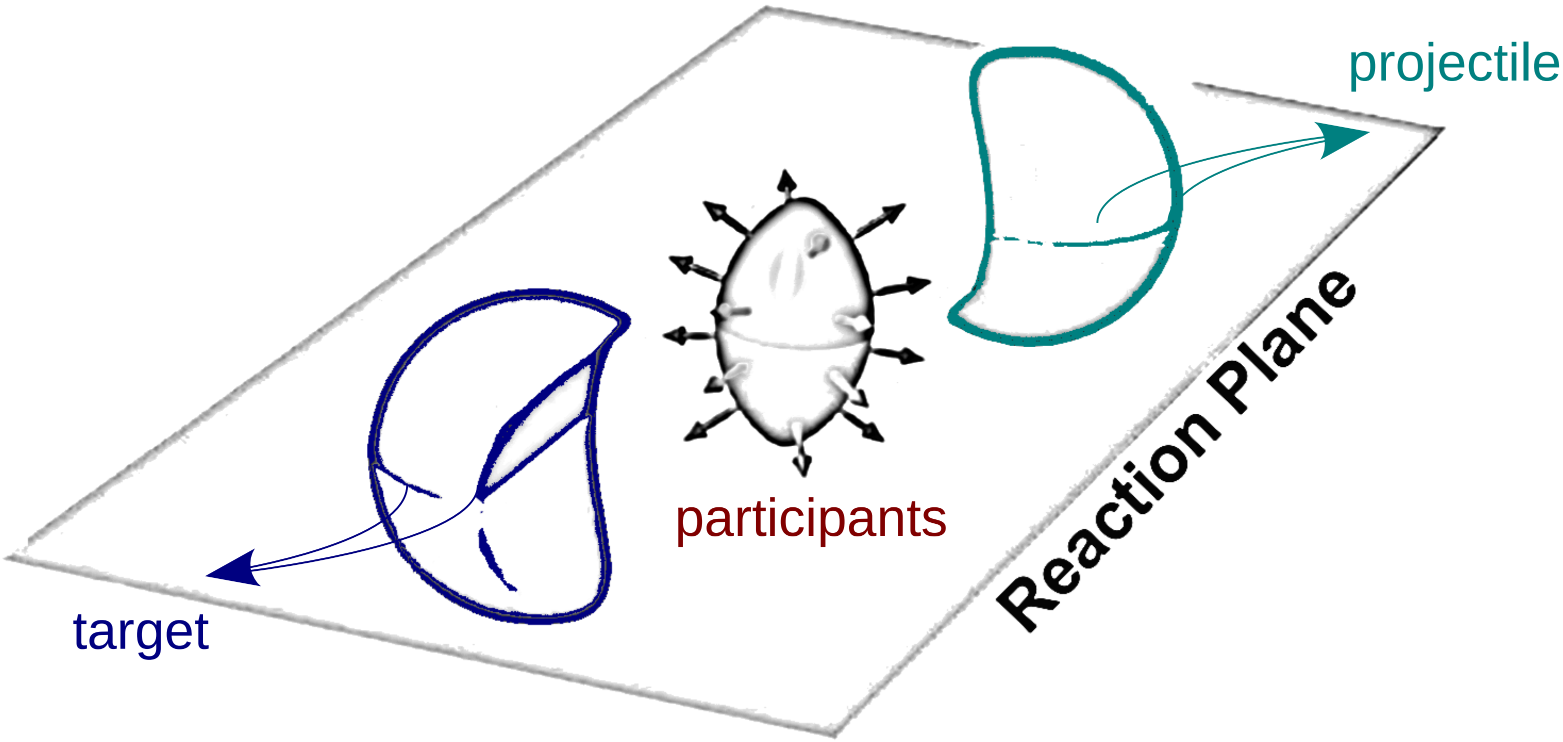
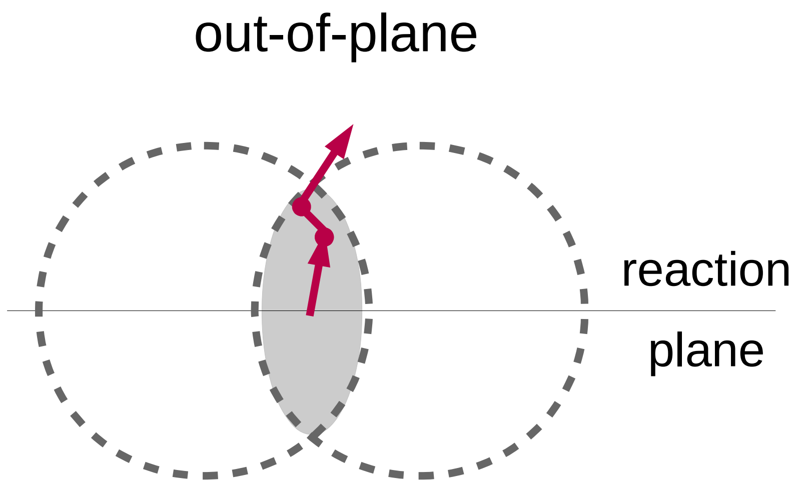
Reaction plane



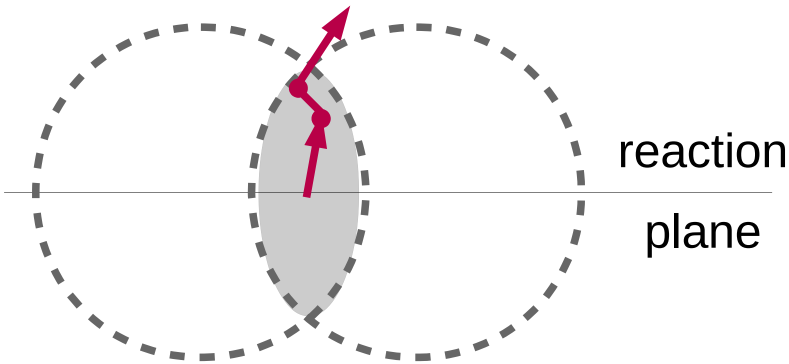
Spatial and momentum space asymmetries



Multiple interactions with medium

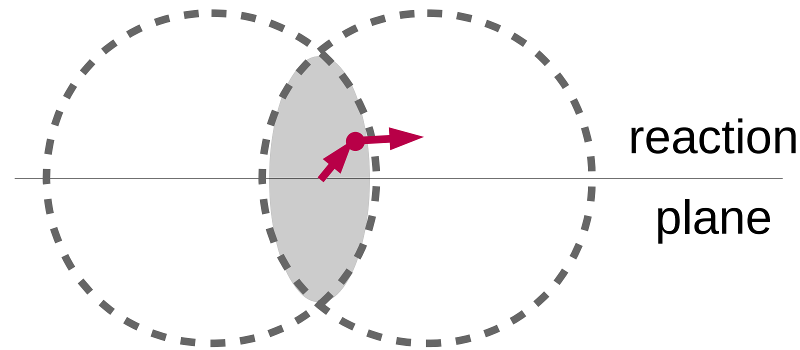
Spatial and momentum space asymmetries

out-of-plane



Multiple interactions with medium

in-plane



Less interaction - small modification

Spatial and momentum space asymmetries

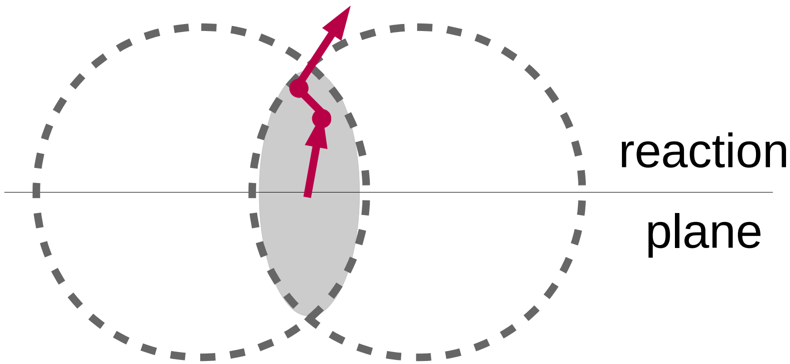
Multiple interactions with medium

Less interaction - small modification

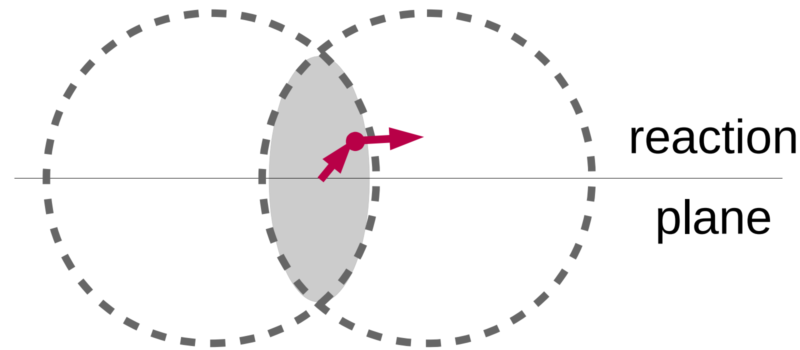
Initial spatial asymmetry converts into azimuthal anisotropy in the momentum space

Spatial and momentum space asymmetries

out-of-plane



in-plane



Multiple interactions with medium

Less interaction - small modification

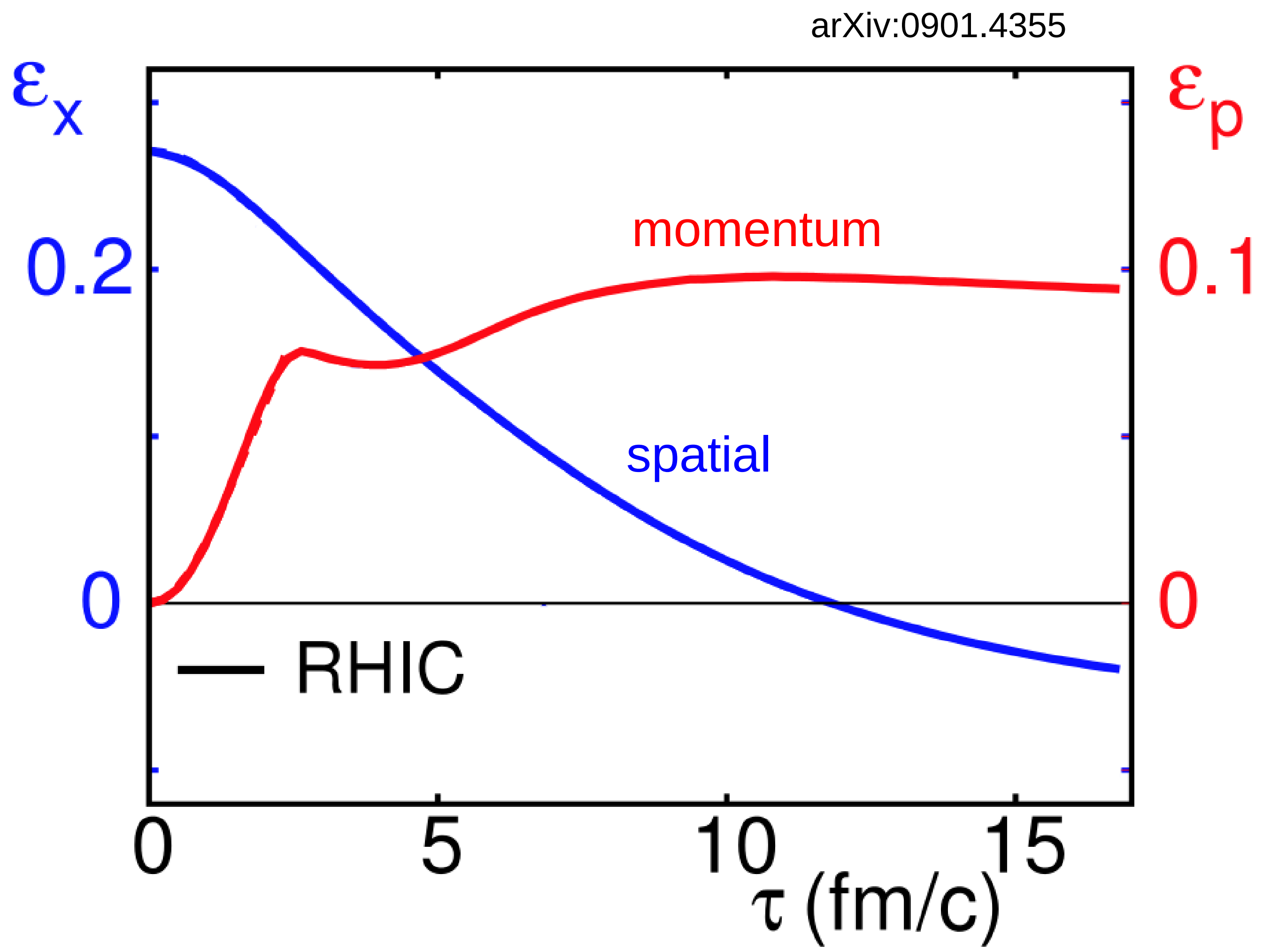
Initial spatial asymmetry converts into
azimuthal anisotropy in the momentum space

Quantified with the Fourier coefficients:

$$\frac{dN}{d(\phi_i - \Psi_n)} \sim 1 + 2 \sum_{n=1} v_n \cos[n(\phi_i - \Psi_n)]$$

v_1 - directed, v_2 - elliptic, and v_3 - triangular flow

Time evolution of the spatial and momentum asymmetries



Spatial asymmetry drops very fast → Momentum asymmetry develops very early

Anisotropic flow measurement techniques

$$\frac{dN}{d(\phi_i - \Psi_n)} \sim 1 + 2 \sum_{n=1} v_n \cos[n(\phi_i - \Psi_n)]$$

If orientation of the collision symmetry plane is known

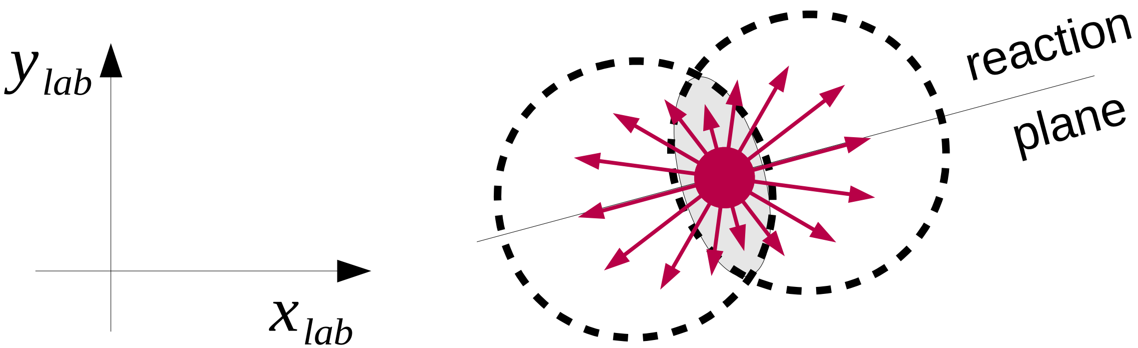
$$v_n = \langle \cos[n(\phi_i - \Psi_n)] \rangle$$

BUT: experimentally the collision symmetry plane orientation is unknown

Estimating the reaction plane angle

Reaction plane is not known experimentally
Orientating wrt. to the laboratory frame changes event-by-event

Event 1



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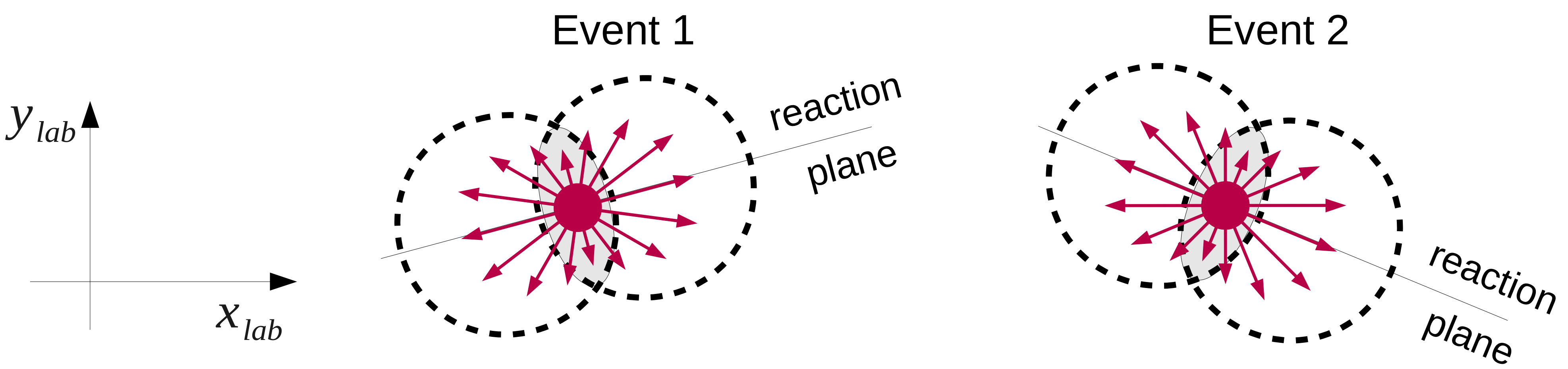

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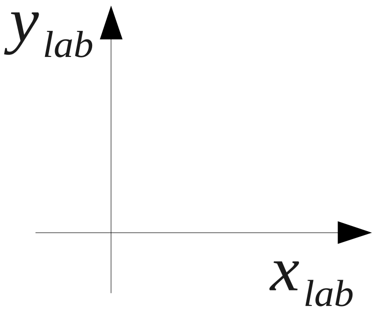

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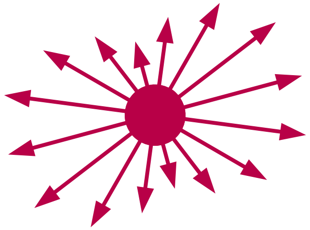
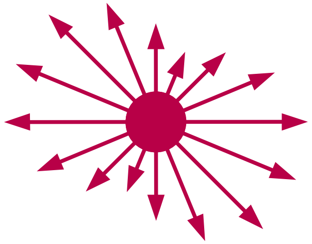


Event 2



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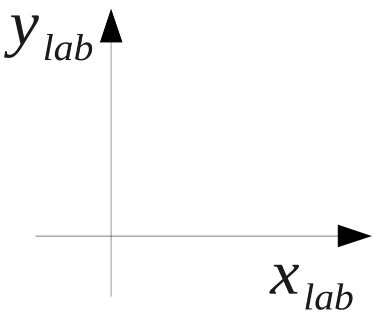

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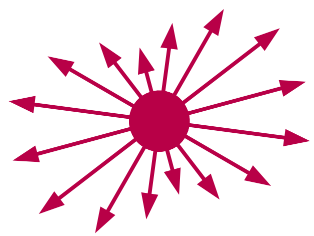
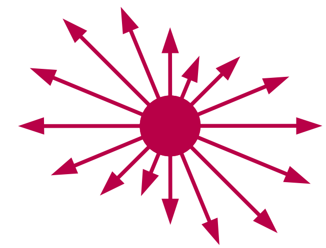


Event 2

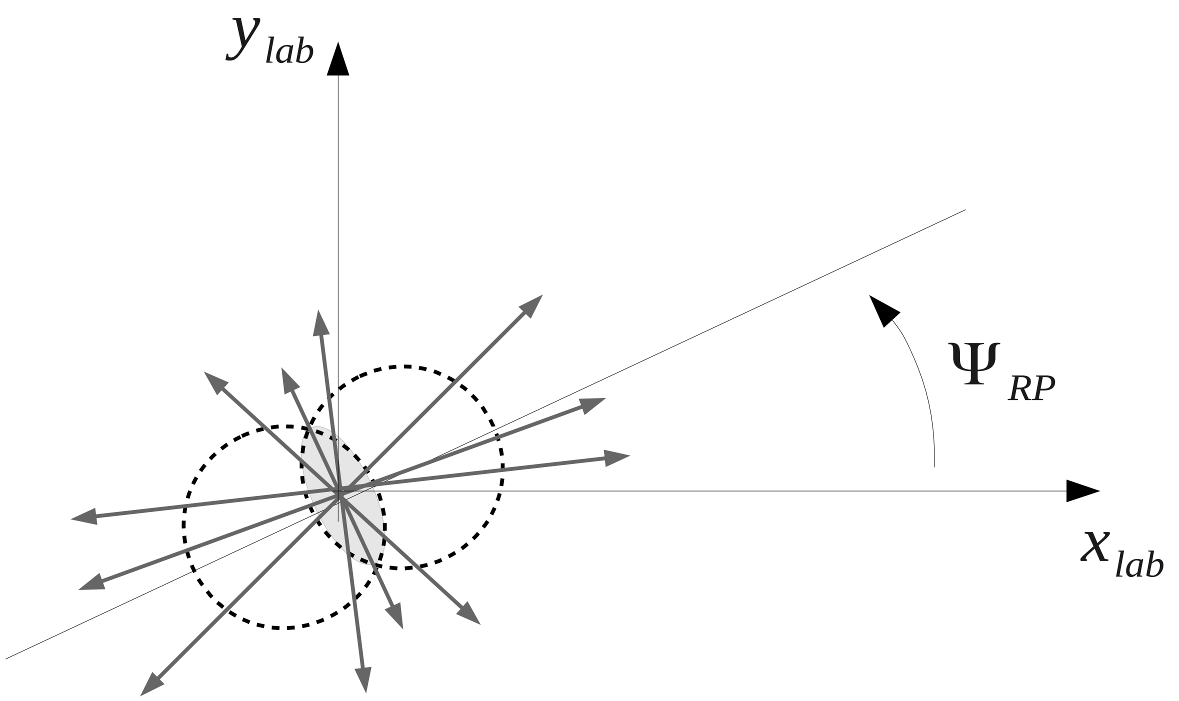


Only measuring particles distribution in the momentum space

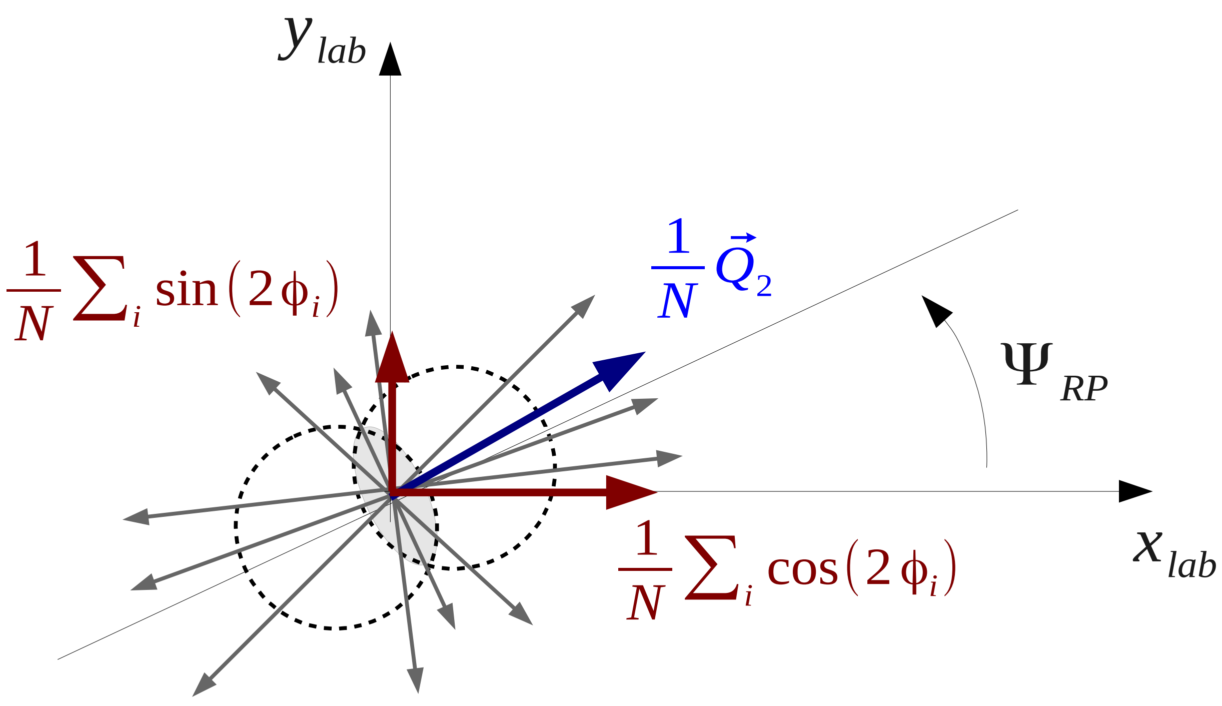
If the momentum distribution is azimuthally asymmetric due to flow,
then this asymmetry should be correlated
with the impact parameter direction (reaction plane orientation)

Use particle azimuthal distribution in the event
to estimate the reaction plane angle – event plane vector

Event plane vector



Event plane vector



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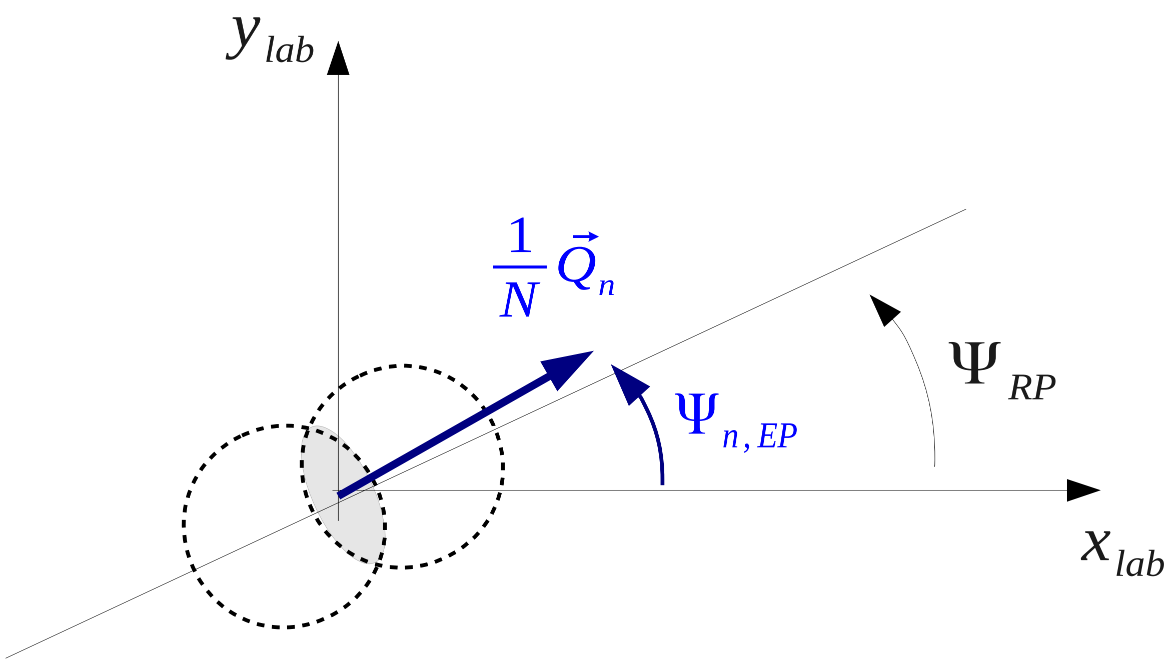
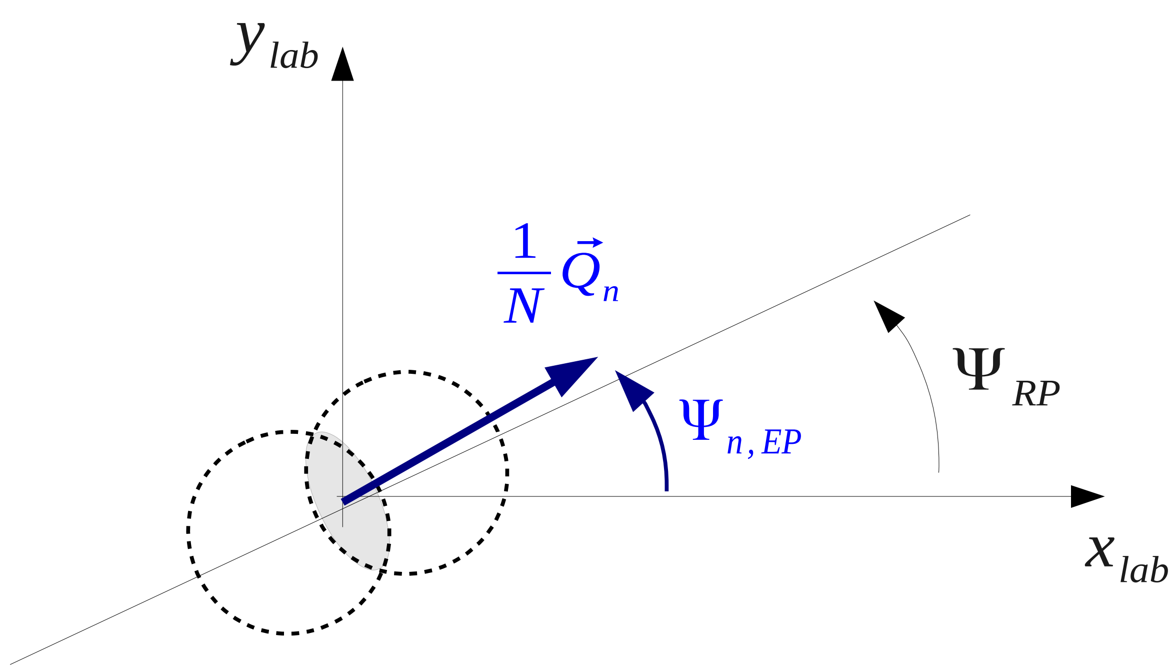


Event plane (flow) vector



Vector sum of all particles direction:

$$Q_{n,x} = \sum_i w_i \cos(n\phi_i) \qquad Q_{n,y} = \sum_i w_i \sin(n\phi_i)$$

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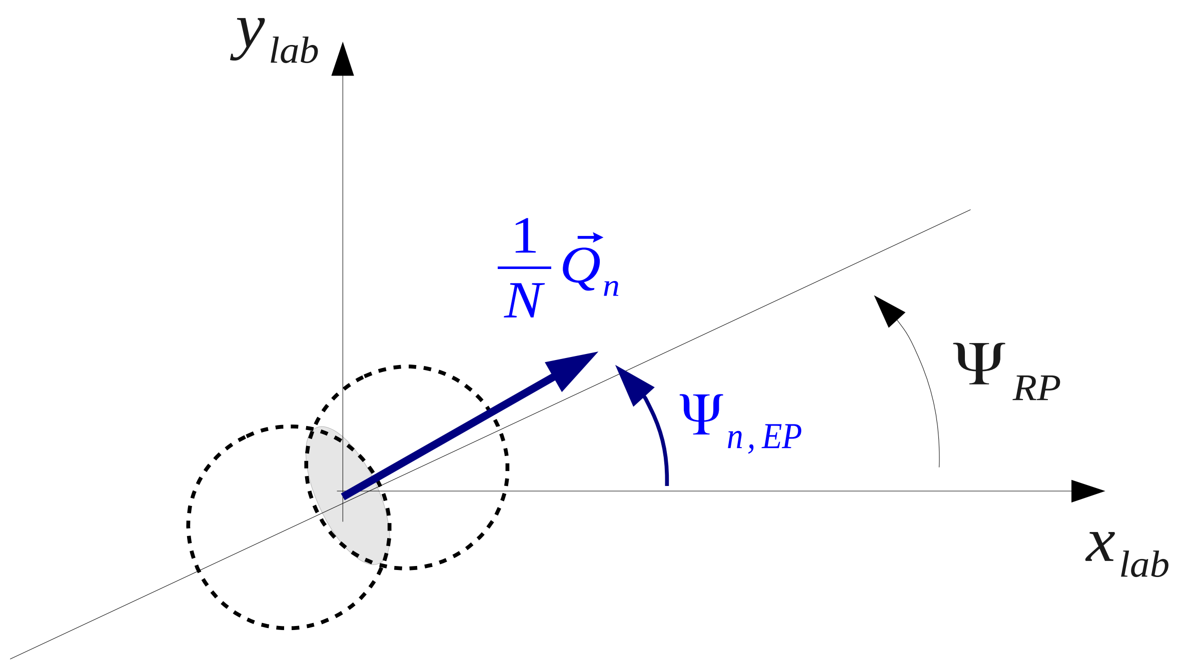

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Experimental estimate of the reaction plane:

Event plane vector: $$\Psi_{n,EP} = \frac{1}{n}\tan^{-1}\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$

Measuring flow with the event plane vector

$$\frac{dN}{d(\phi-\Psi_{RP})} \sim 1 + 2\sum_{i=1} v_n(p_t,\eta) \cos[n(\phi-\Psi_{RP})]$$

Want to measure:

$$v_n = \langle \cos[n(\phi-\Psi_{RP})] \rangle$$

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→

Measured:

$$v_n^{obs} = \langle\cos[n(\phi-\Psi_{n,EP})]\rangle$$

Measuring flow with the event plane vector

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Want to measure:

$$v_n = \langle\cos[n(\phi-\Psi_{RP})]\rangle \longrightarrow$$

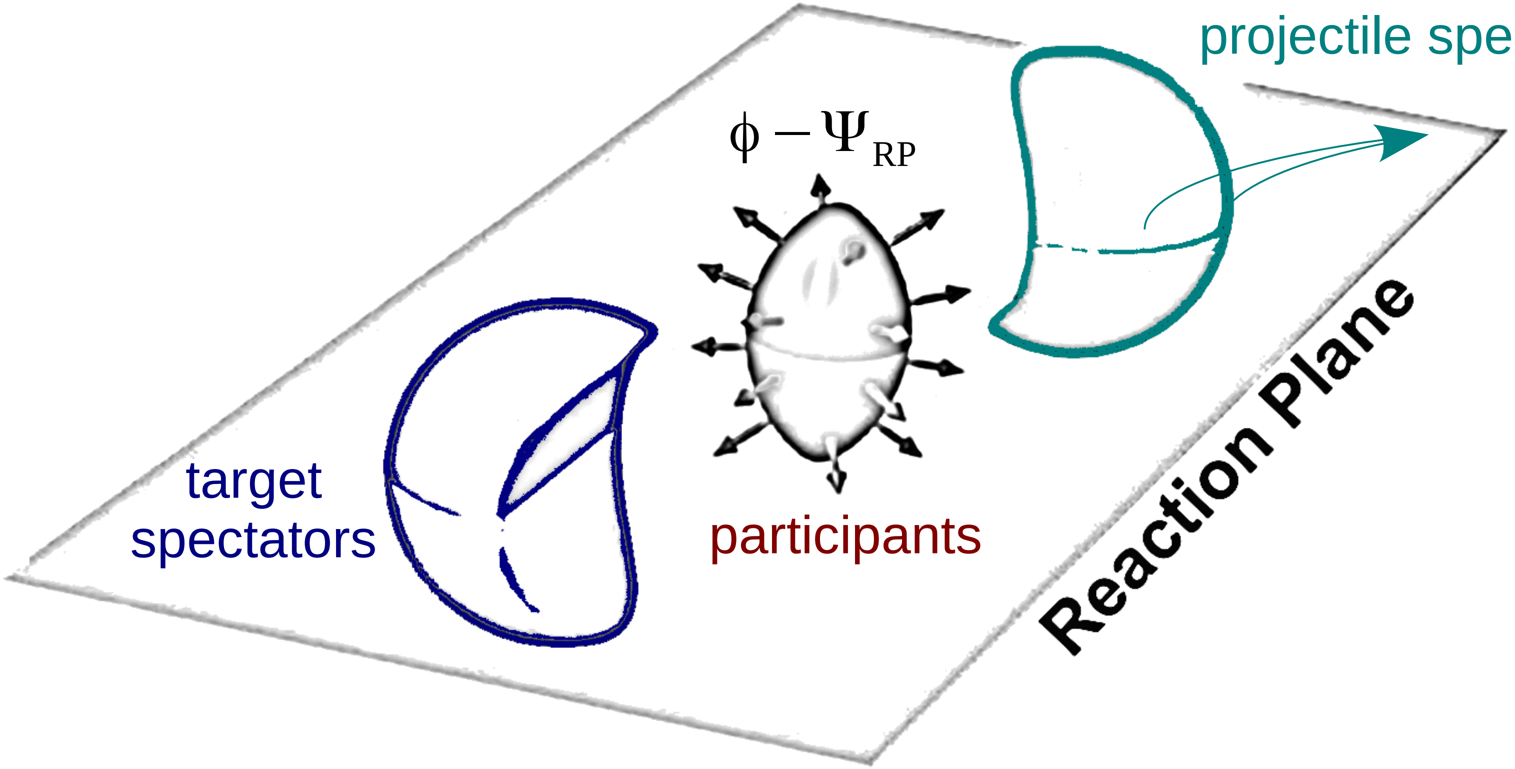
Measured:

$$v_n^{obs} = \langle\cos[n(\phi-\Psi_{n,EP})]\rangle$$

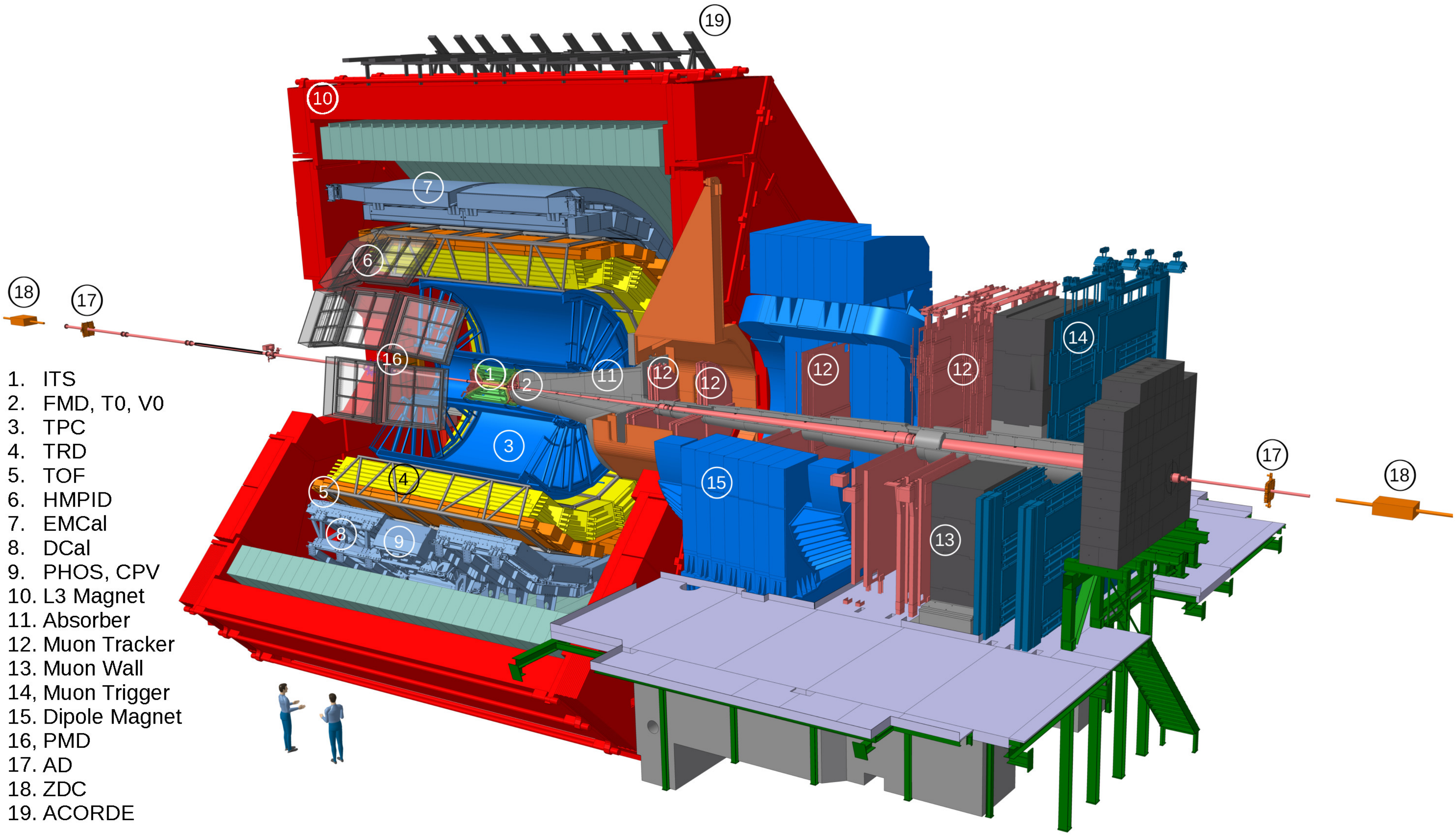
Event plane vector and the reaction plane are correlated with finite resolution:

$$v_n = \frac{\langle\cos[n(\phi-\Psi_{n,EP})]\rangle}{\langle\cos[n(\Psi_{n,EP}-\Psi_{RP})]\rangle} = \frac{v_n^{obs}}{R_n}$$

What can be used in ALICE for reaction plane estimate

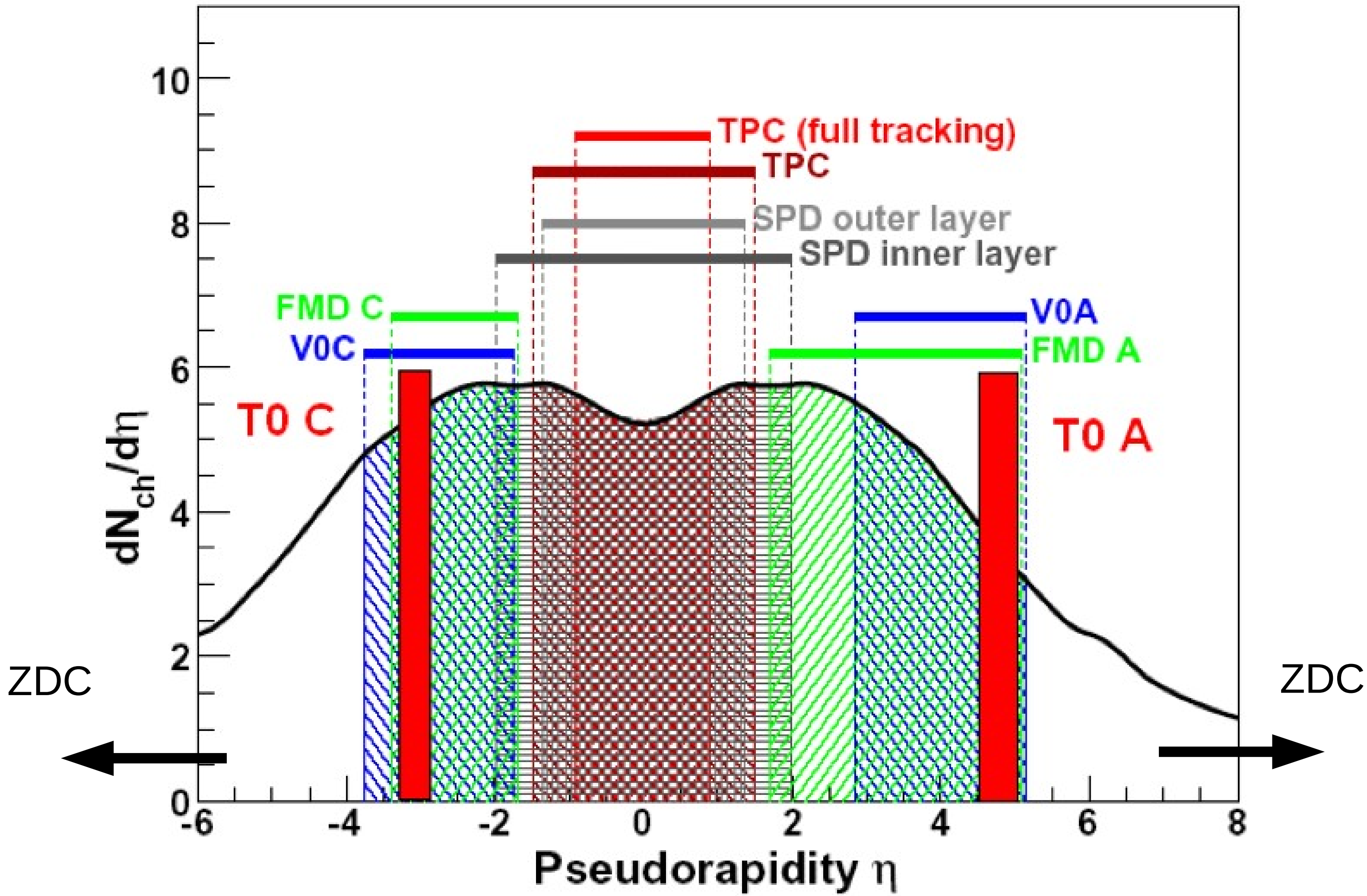


Where we can get an event plane angle in ALICE?

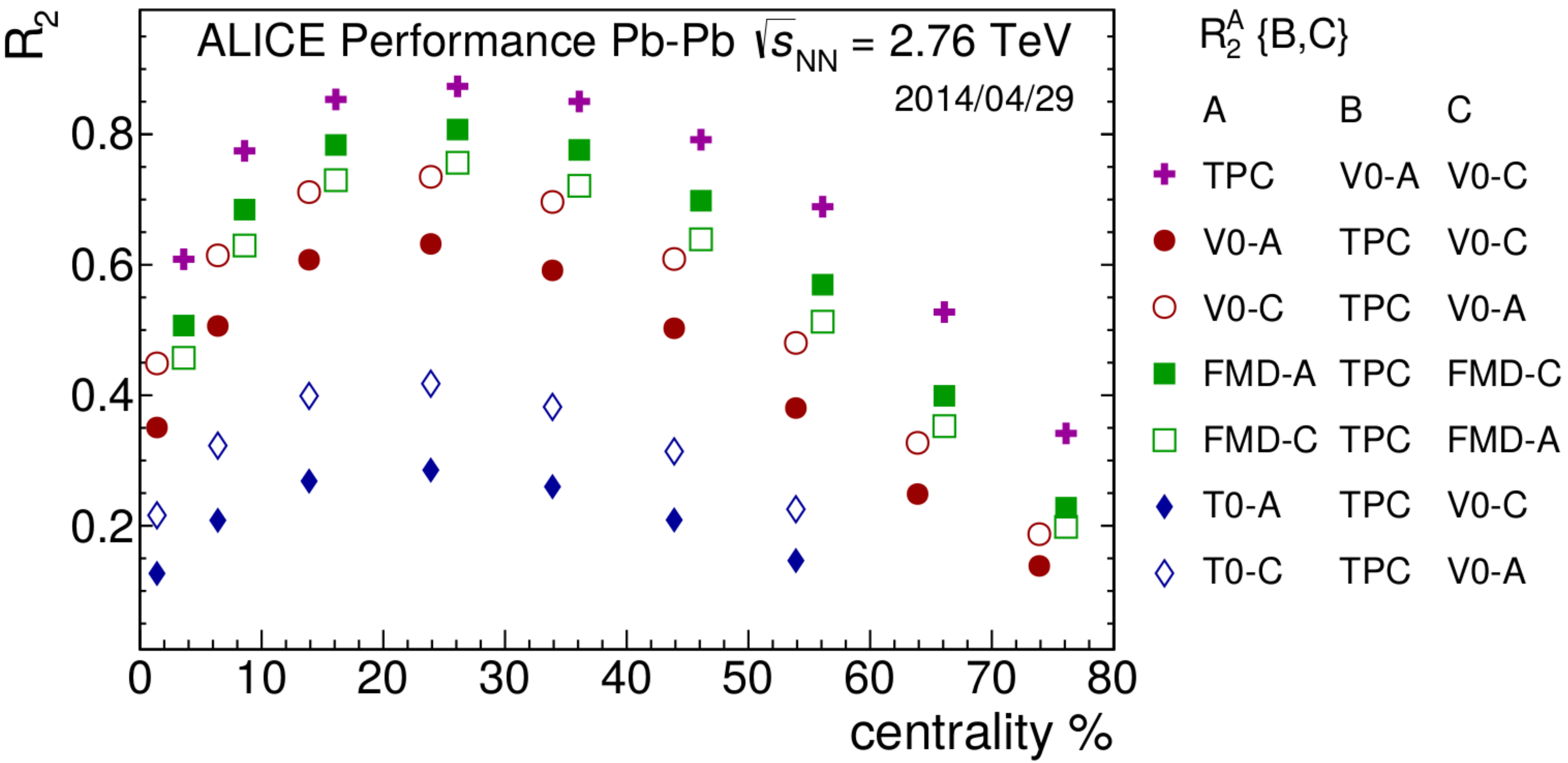


1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE

ALICE rapidity coverage

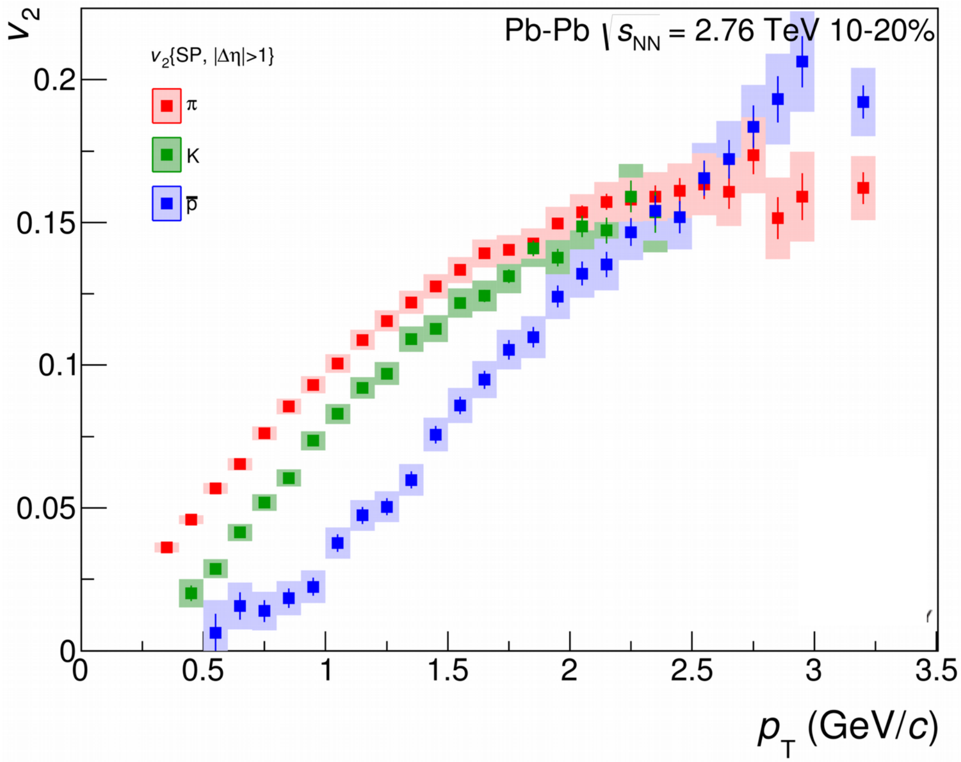


Reaction plane resolution



Particle type dependence of v_2

$\pi^{\pm}$, $K^{\pm}$, $p(\bar{p})$



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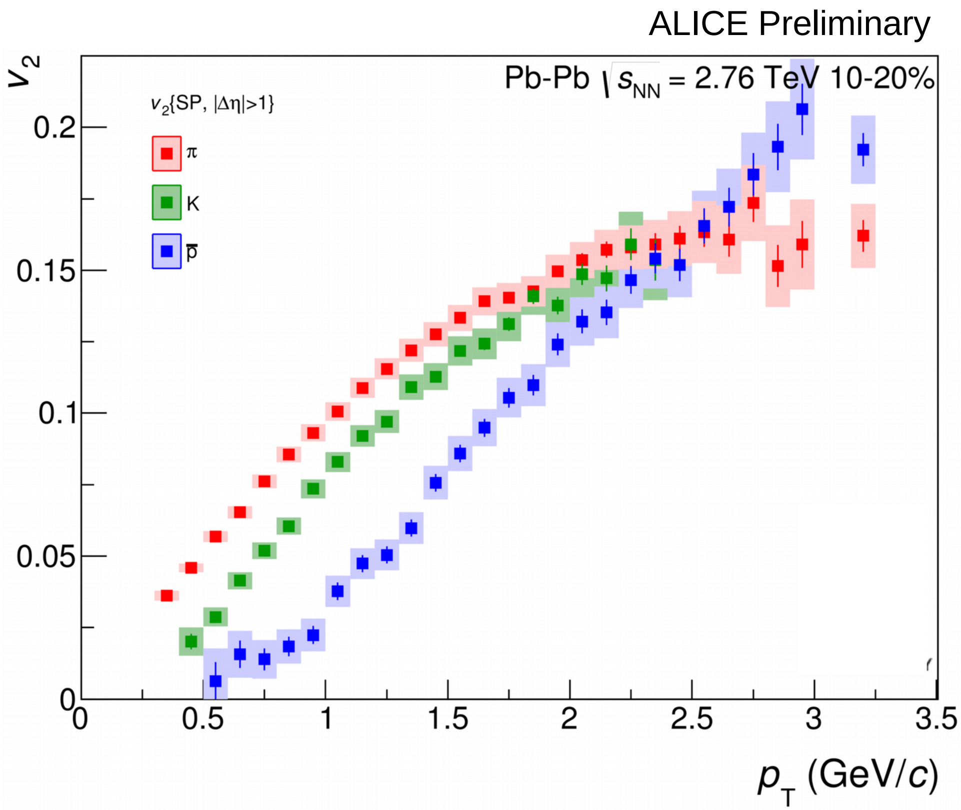
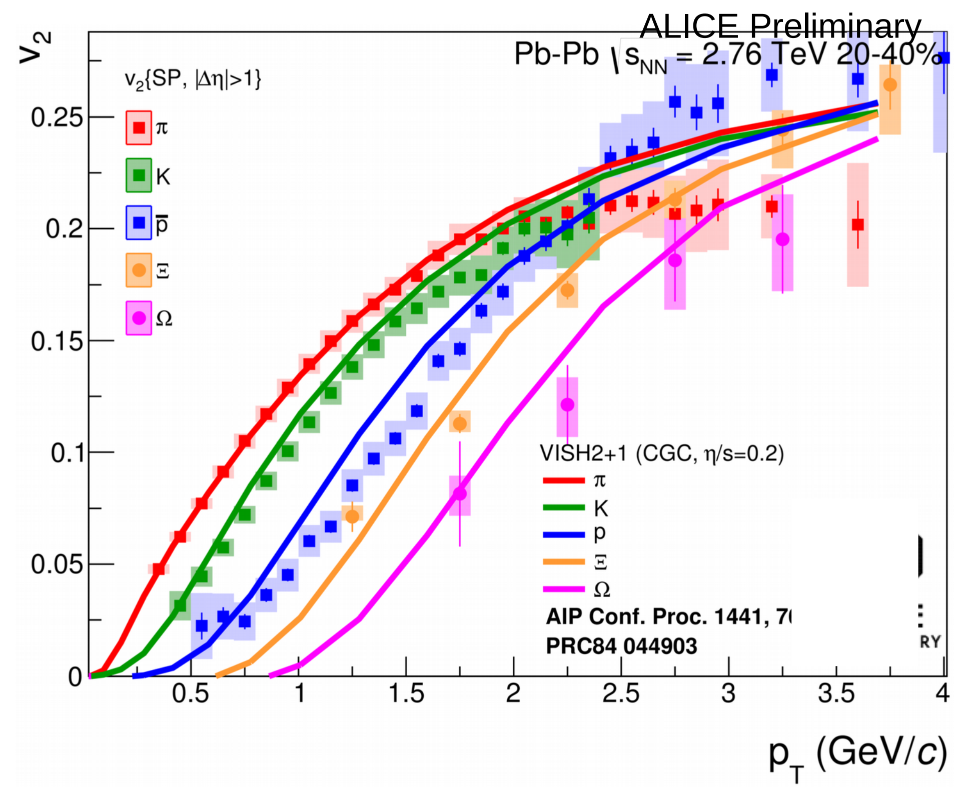


$\pi^{\pm}$, $K^{\pm}$, $p(\bar{p})$ and multi-strange (Ξ, Ω)



Viscous hydrodynamics reproduce mass dependence of v_2:

Sensitive to the initial conditions

Suggest low viscosity of the matter