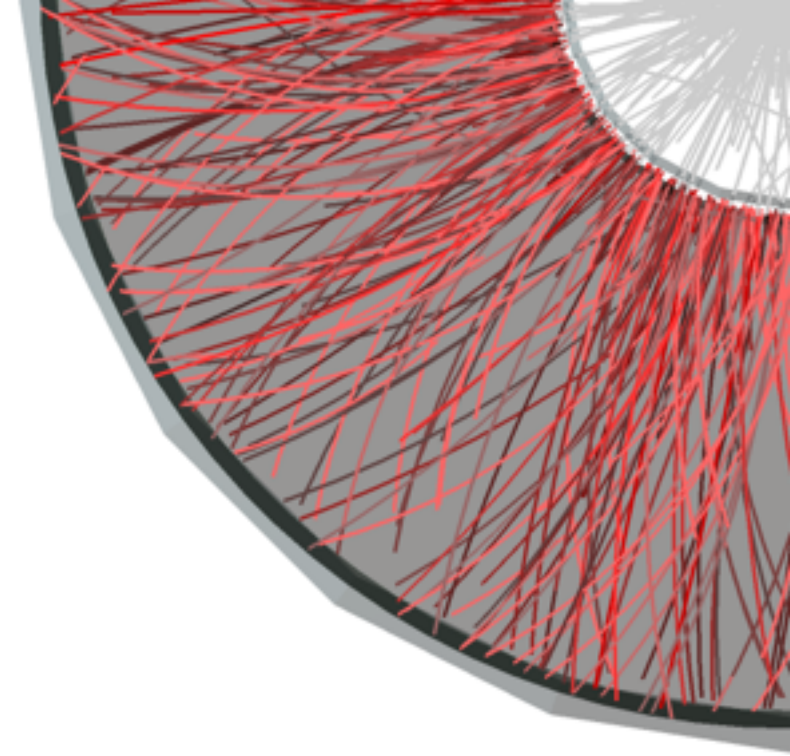
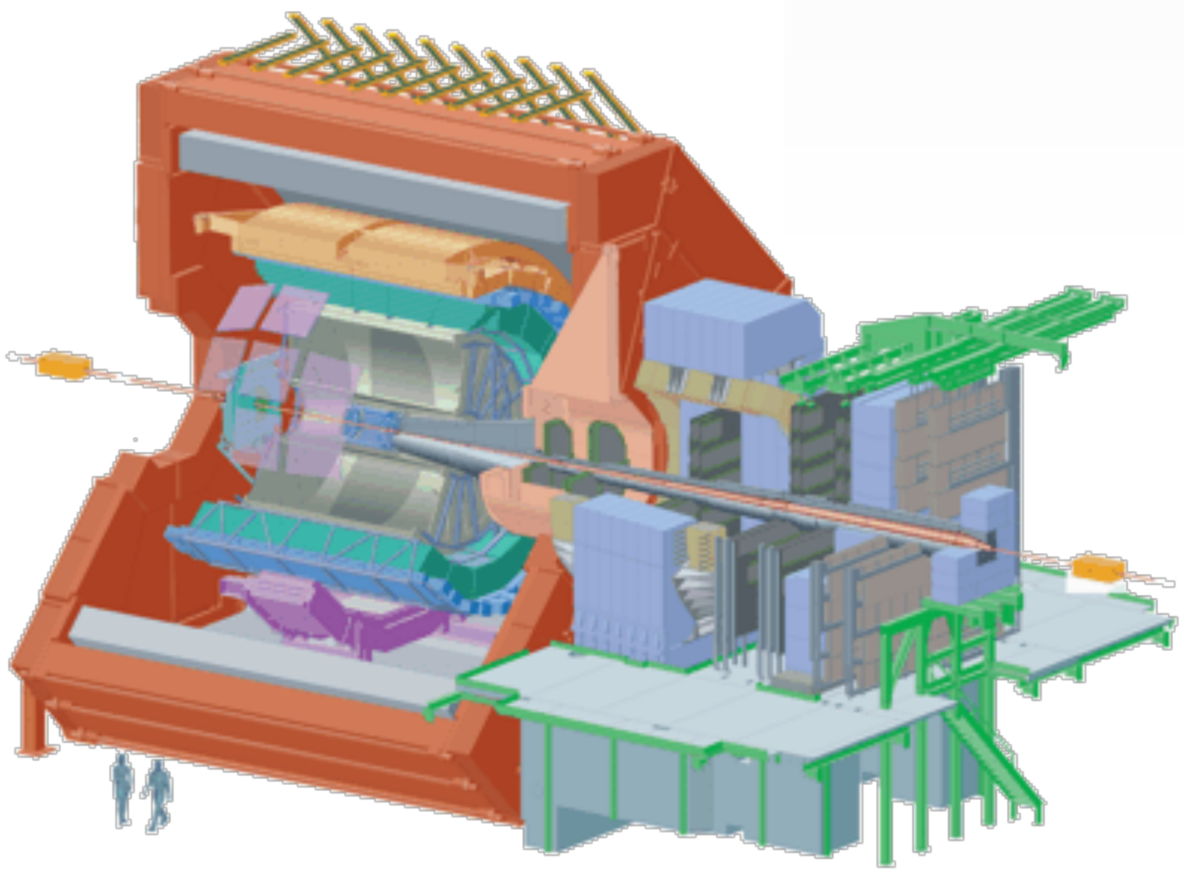
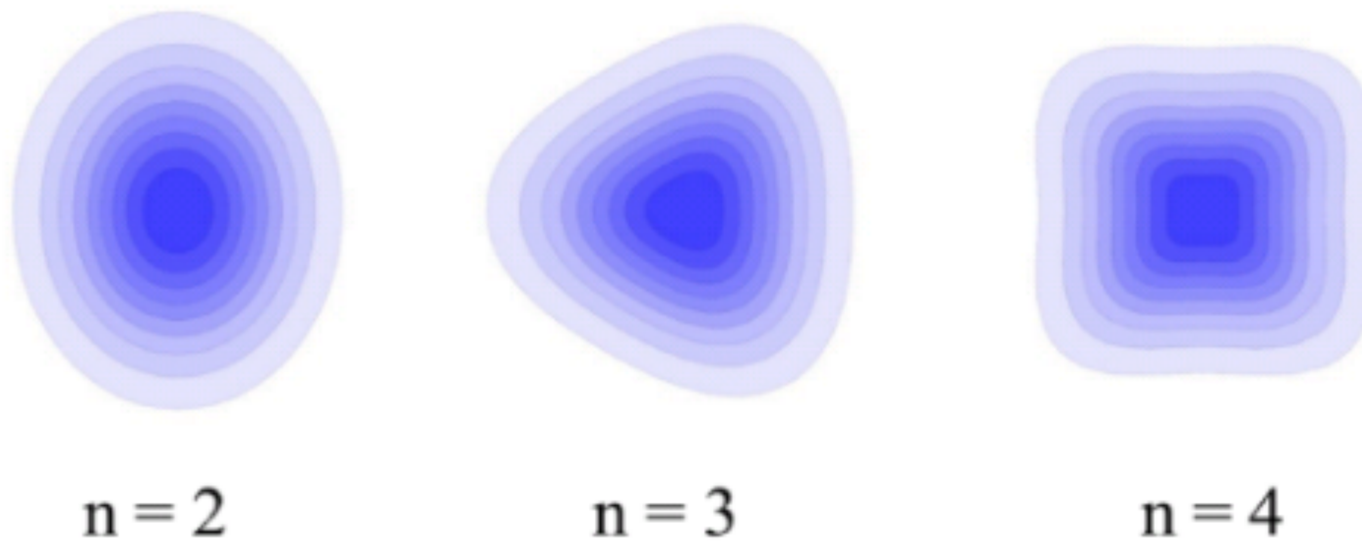
Higher harmonic anisotropic flow of identified particles in Pb-Pb collisions with the ALICE detector





Naghmeh Mohammadi
[1]NIKHEF
[2]Utrecht University
(on behalf of the ALICE Collaboration)

Flow harmonics



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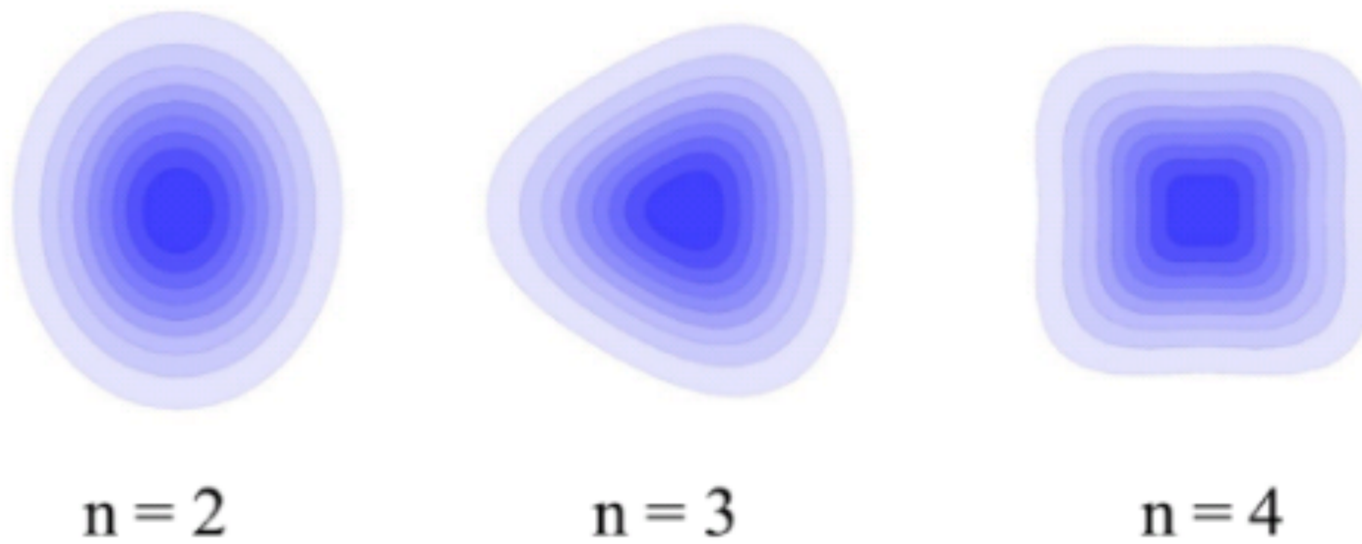
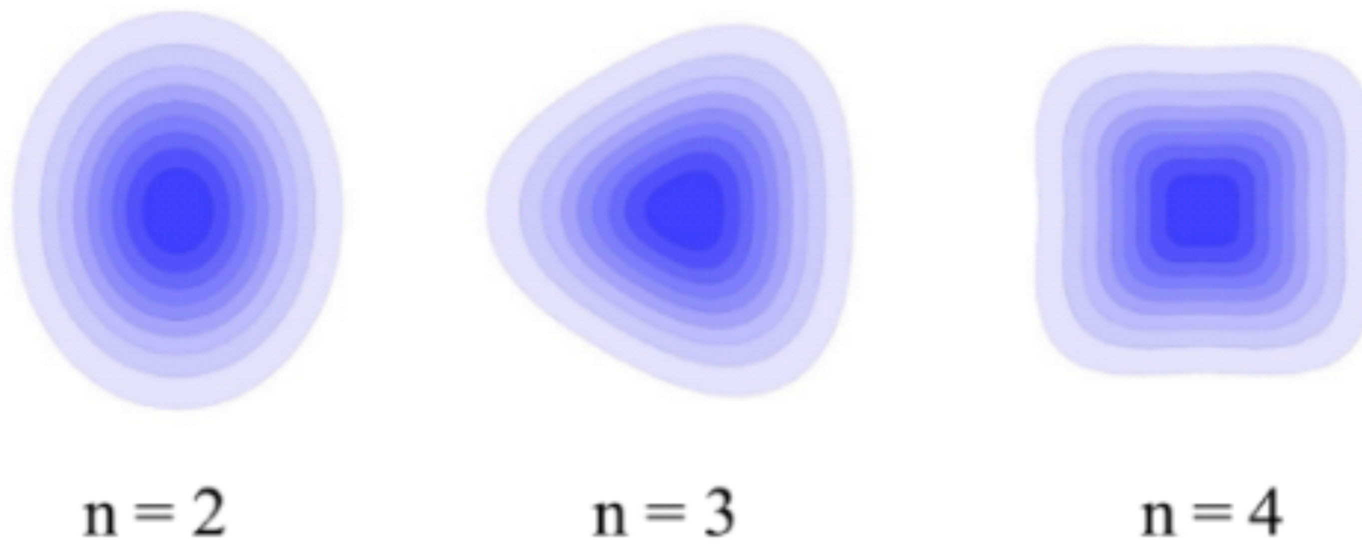


Flow harmonics driven by: 1) Geometry of the system
2) Initial state fluctuations

Flow harmonics



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flow harmonics depend on:

1) energy of the collision
2) Initial geometry
3) transverse momentum
4) η/s
5) mass of the particles
6) hadronization mechanism, e.g. via constituent quark coalescence

Flow measurement

Azimuthal particle distribution:

$dN/d(\phi-\psi_n) = N_0(1+\Sigma 2v_n \cos(n(\varphi-\psi_n)))$

$v_n = \langle \cos[n(\varphi-\psi_n)] \rangle$

flow harmonics

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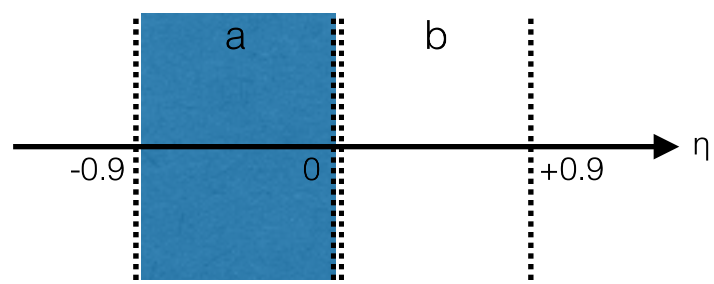
Scalar product method:

$v_n^a(\eta,p_T) = \langle Q_n^b, u^a(\eta,p_T)\rangle/\sqrt{\langle Q_n^a . Q_n^b\rangle}$

u: unit flow vector,
Q: total flow vector

$|\Delta\eta|>0$



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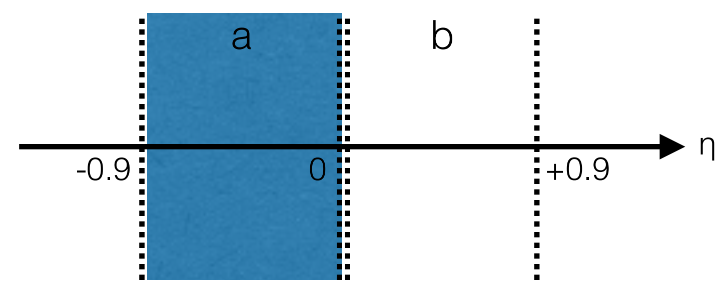

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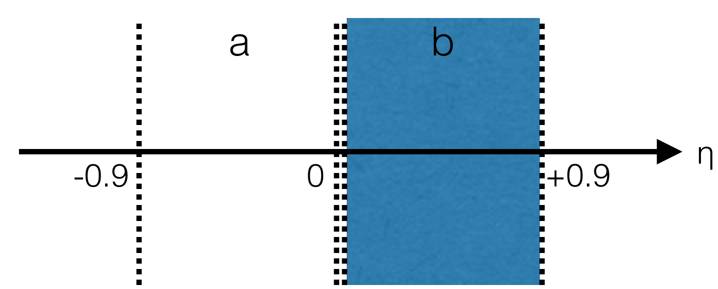

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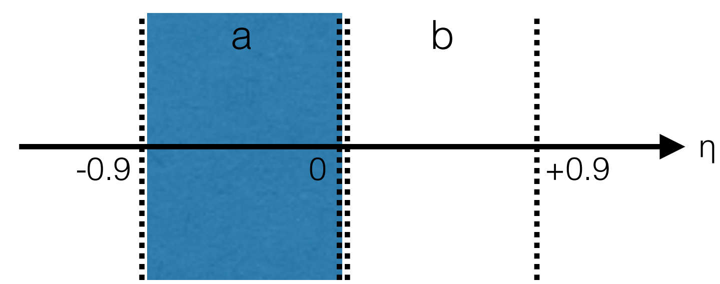

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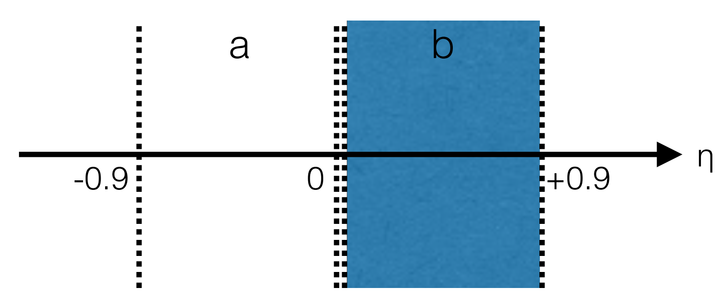

v_n= Combination of v_n^a and v_n^b

Flow measurement

2-particle azimuthal correlation {
- Anisotropic flow
- Resonance decays, jets a.k.a. non-flow

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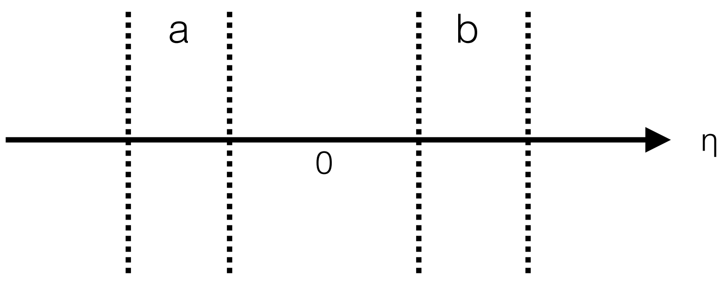
How to treat non-flow:

1) Apply large η gap between subevent a and b



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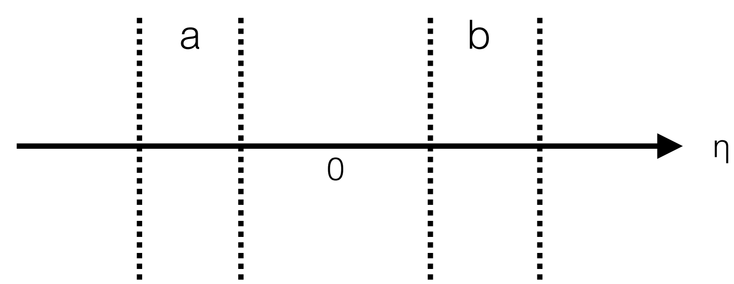

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2) subtract non-flow estimate from Monte-Carlo/pp → Used in this analysis

- $v_n^{subtracted} = v_n - \delta^{MC}$
- δ^{MC} : An estimate of non-flow → from a model (HIJING) that treats heavy-ion collisions as a superposition of independent pp collisions
- At intermediate p_T ($2<p_T<4$ GeV/c) this correction is ~0.017 for v_2, ~0.008 for v_3 and ~0.006 for v_4 in 0-1% centrality class

Analysis details

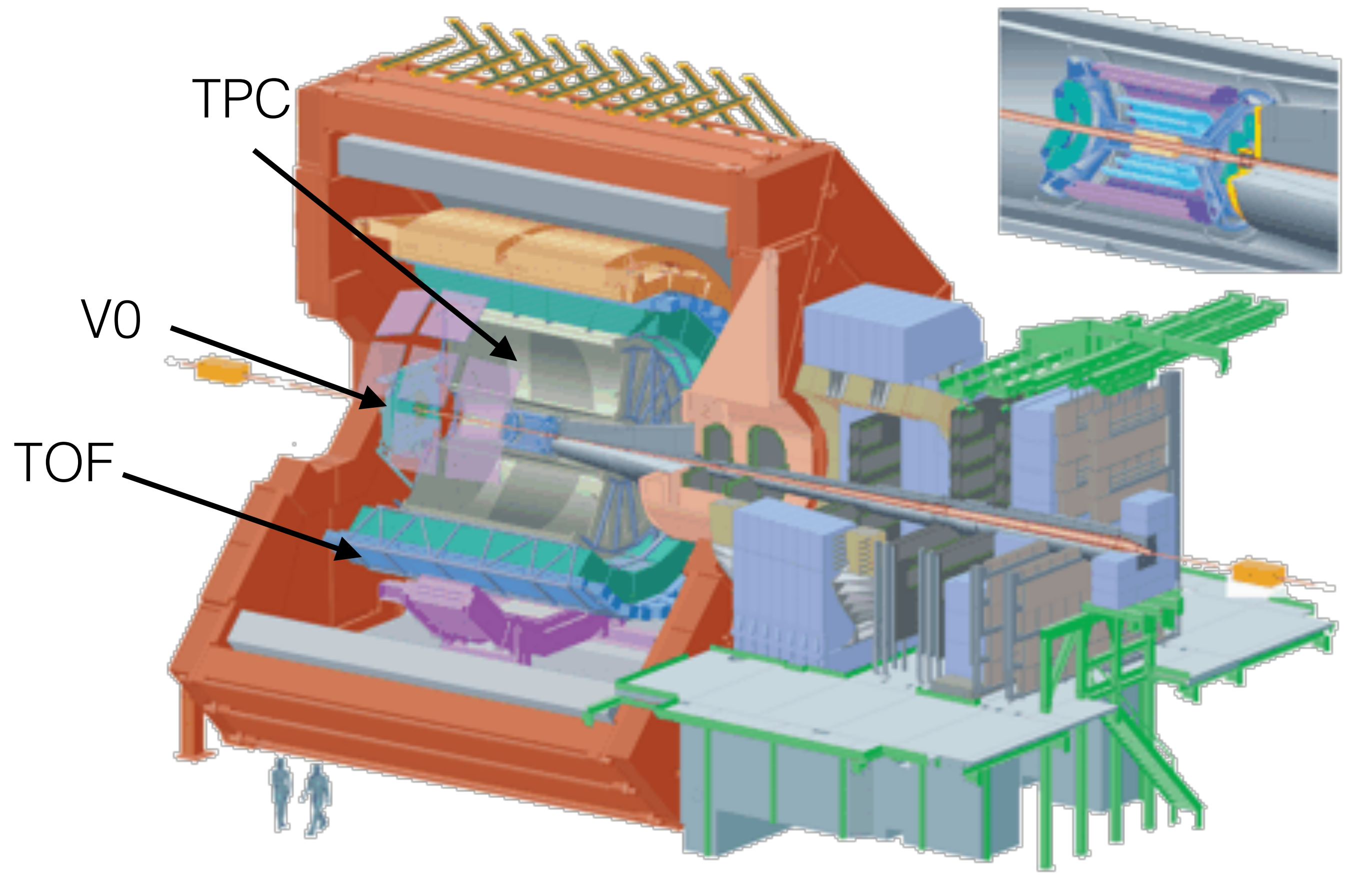
Data sample:
- Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV

Centrality trigger:
- Central (0-1%)
- SemiCentral (20-30%)

Statistics:
- 1M (0-1%),
- 2.2M (20-30%)

Particles of interest (POI):
- $\pi^{\pm}$,$K^{\pm}$,p($\bar{p}$)

Reference Particles (RP):
- All charged particles



POI p_T range:
- $\pi^{\pm}$,p($\bar{p}$): 0.3<p_T<5.5 GeV/c
- $K^{\pm}$: 0.3<p_T<4 GeV/c

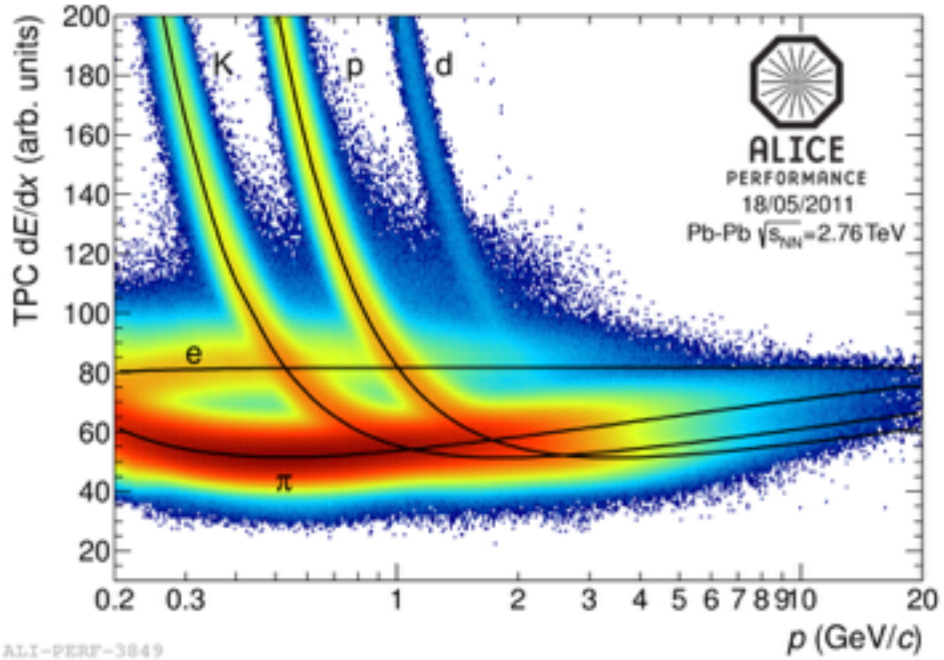
RP p_T range:
- 0.2<p_T<5 GeV/c

Particle Identification

Time Projection Chamber (TPC)

dE/dx : the deposited energy

Resolution: $\sigma_{dE/dx} \approx 5\%$



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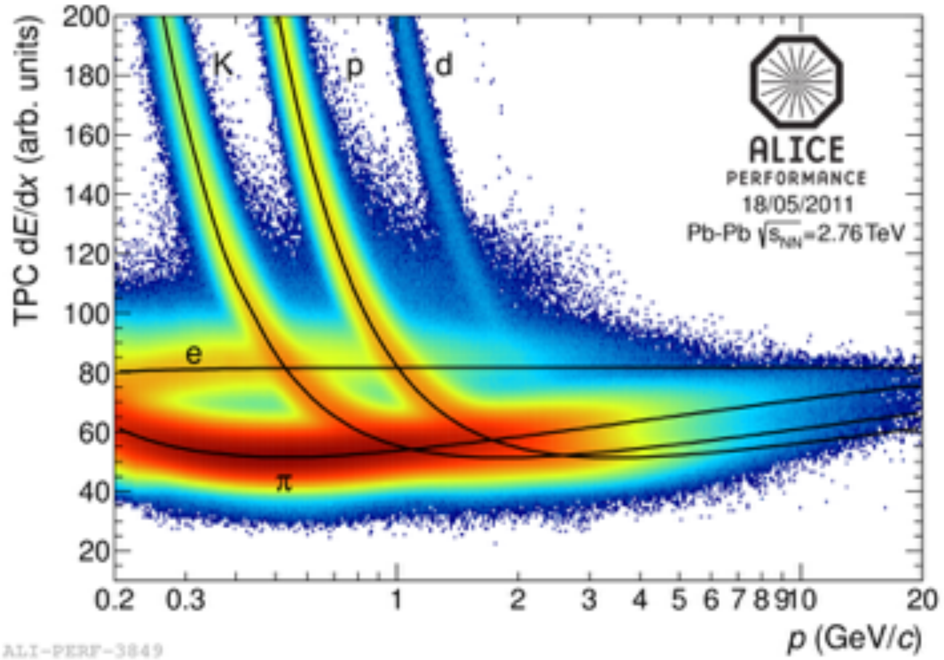
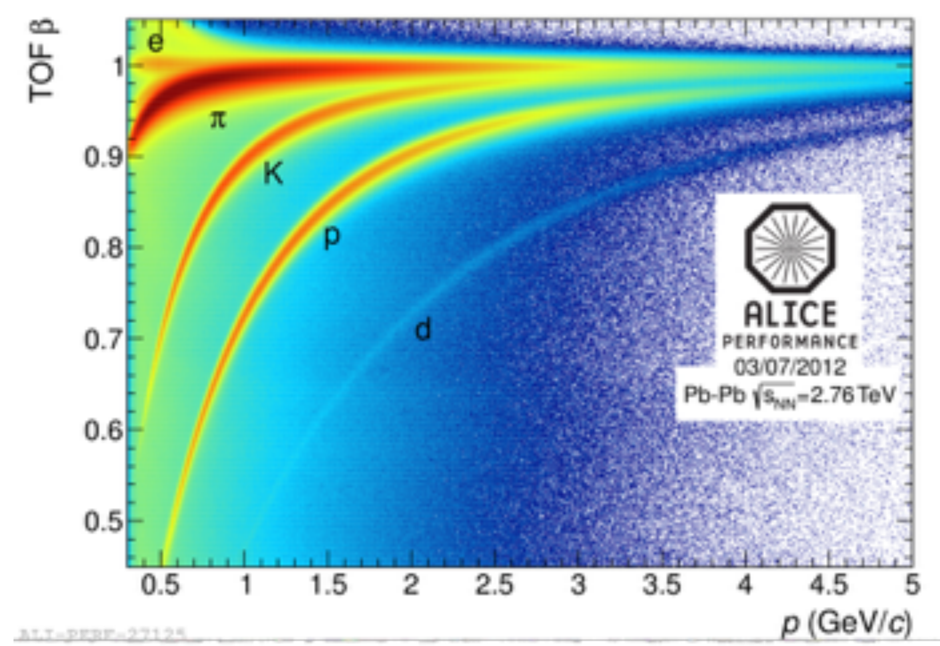


Time of Flight (TOF)

β=Track length/Time of flight

Resolution: $\sigma_{TOF} \simeq$ 86 ps for Pb-Pb collision



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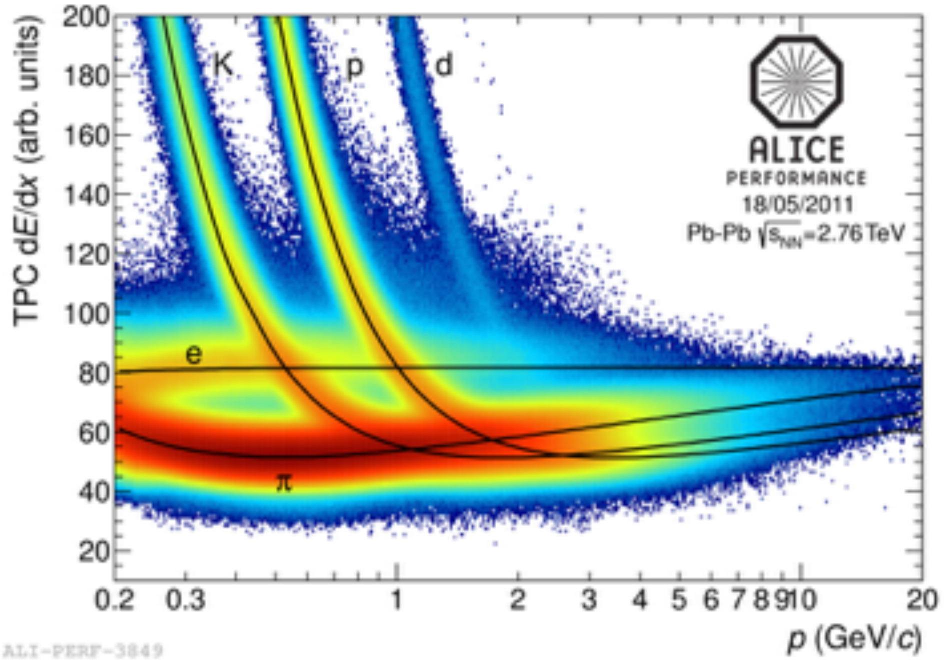

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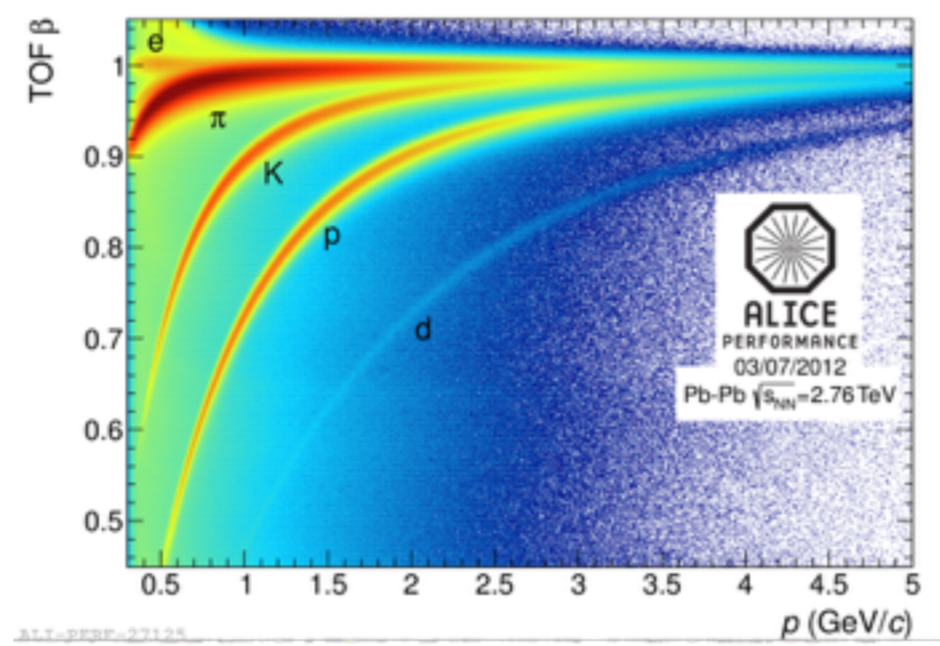
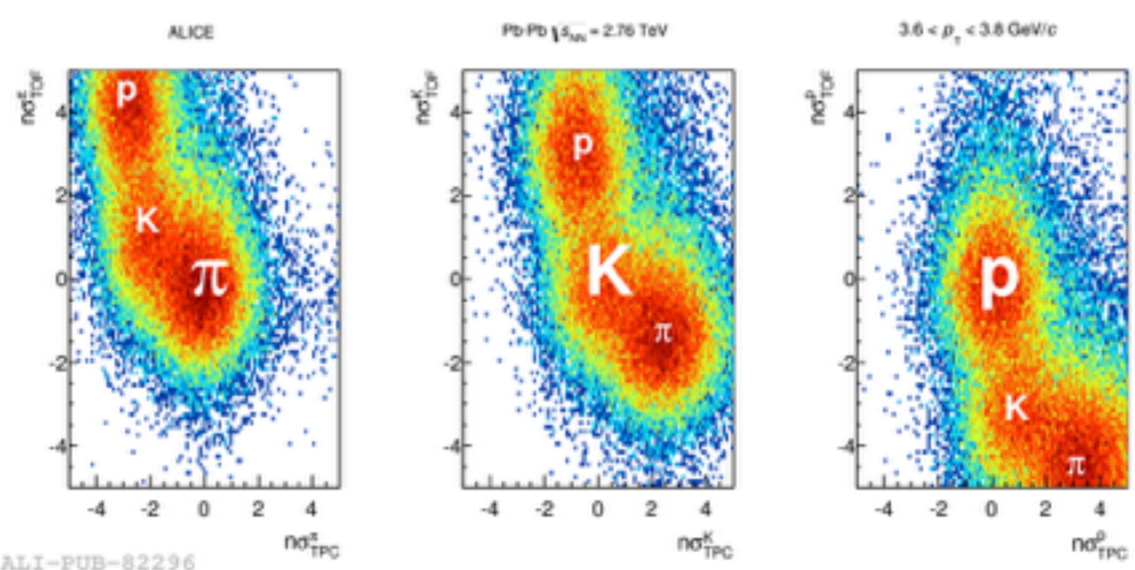


Combination of TPC and TOF used for PID to calculate purity

Purity of $\pi^{\pm}$ and $p+\bar{p}$ > 95% up to p_T<6 GeV/c

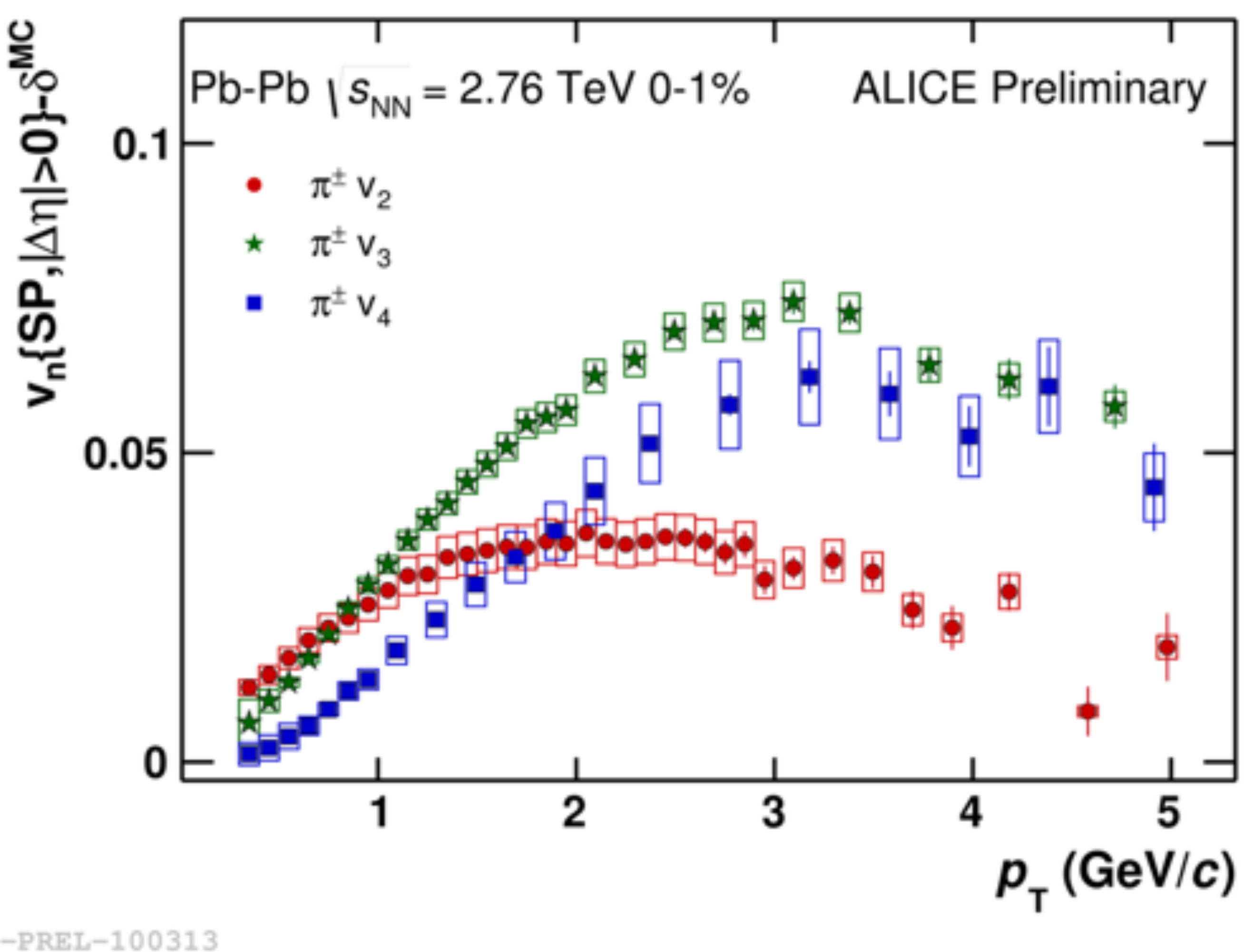
Purity of $K^{\pm}$ > 90% up to p_T<3.5 GeV/c and >80% for $3.5<p_T<4.5$ GeV/c

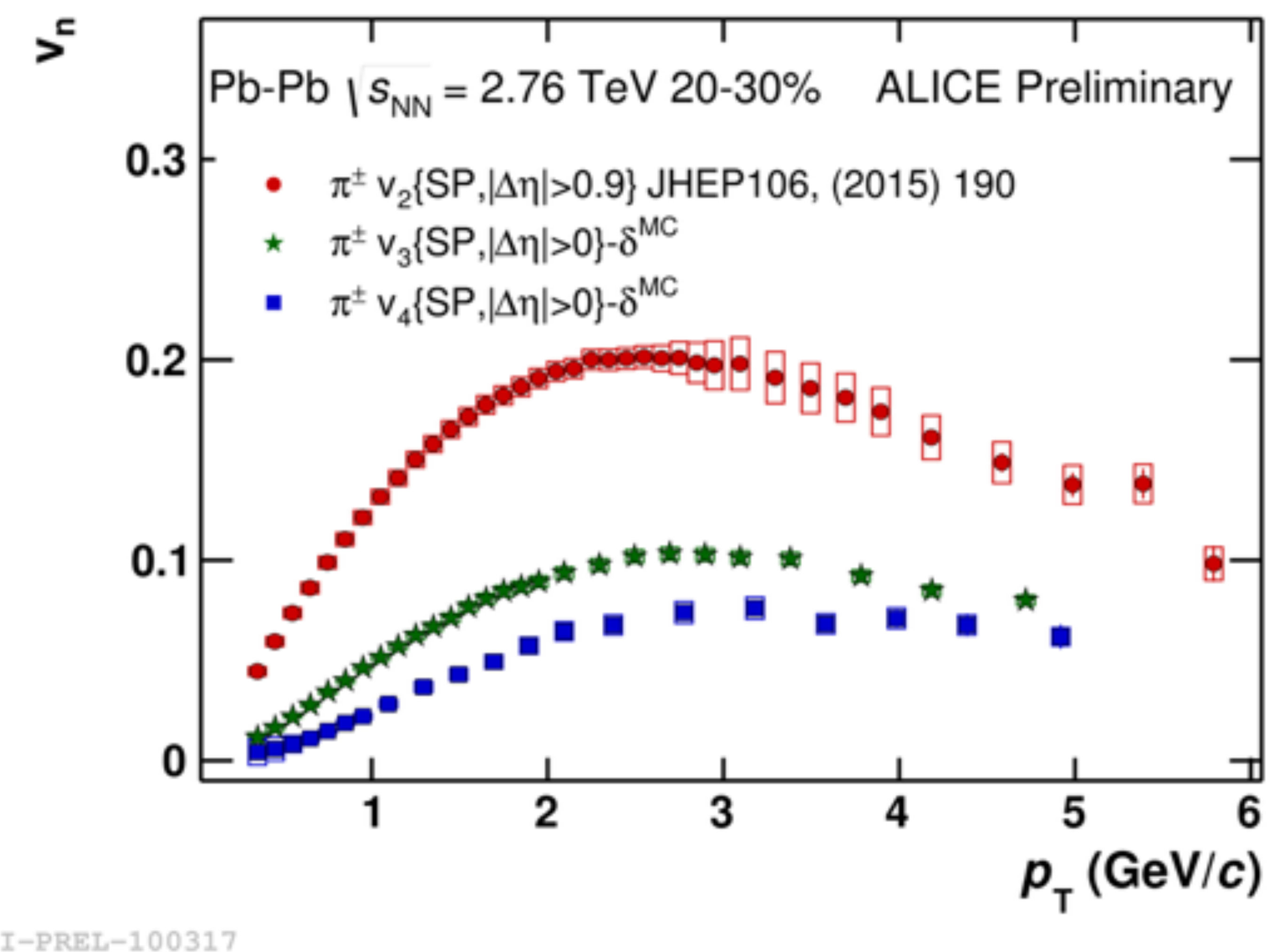


p_T evolution of flow harmonics

At intermediate p_T (p_T>2 GeV/c) { in most central (0-1% cc) $v_3 > v_4 > v_2$; in mid-central (20-30% cc) $v_2 > v_3 > v_4$

1) charged pion ($\pi^\pm$)





p_T evolution of flow harmonics

At intermediate p_T (p_T>2.5 GeV/c) {
- in most central (0-1% cc) $v_3 > v_4 > v_2$
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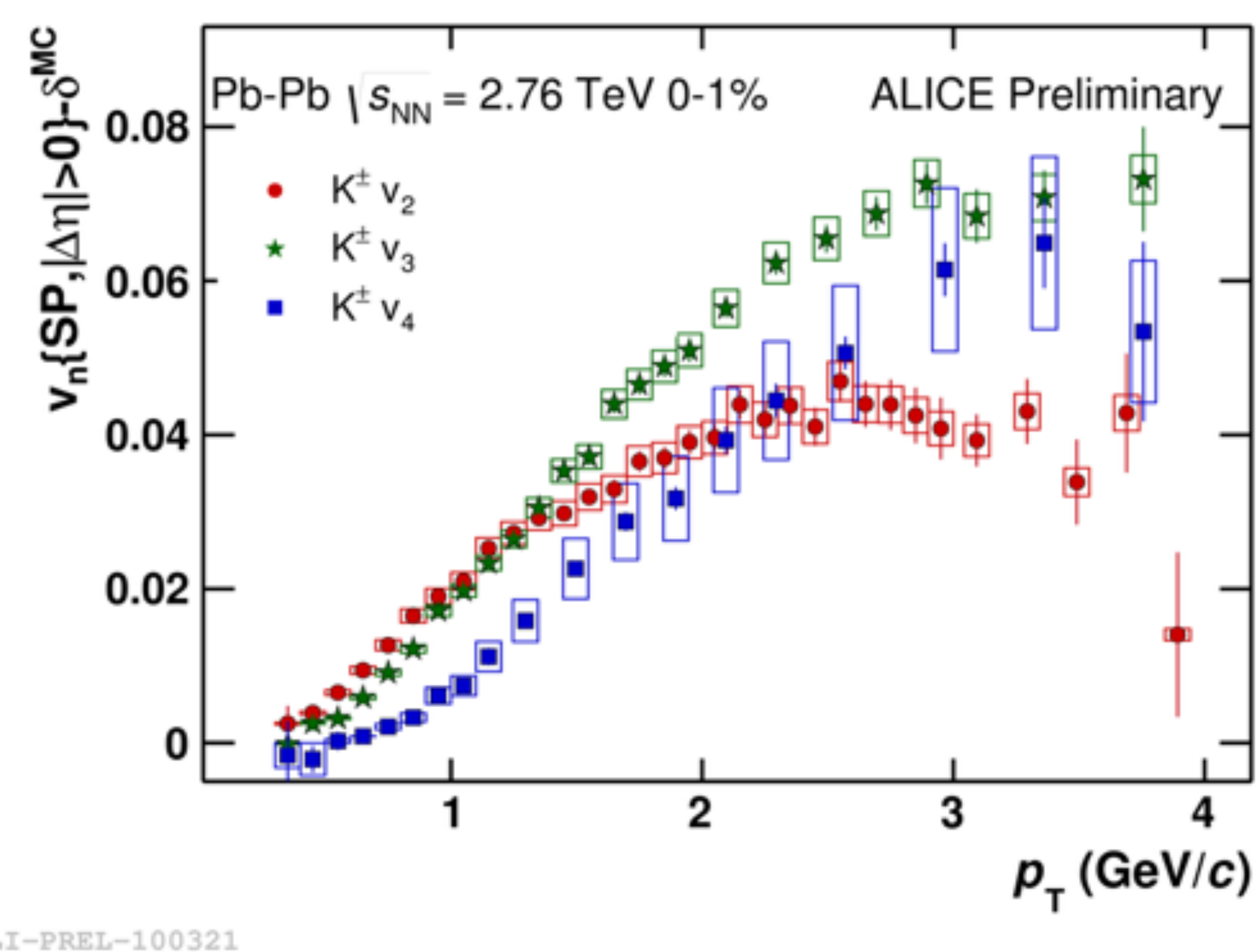
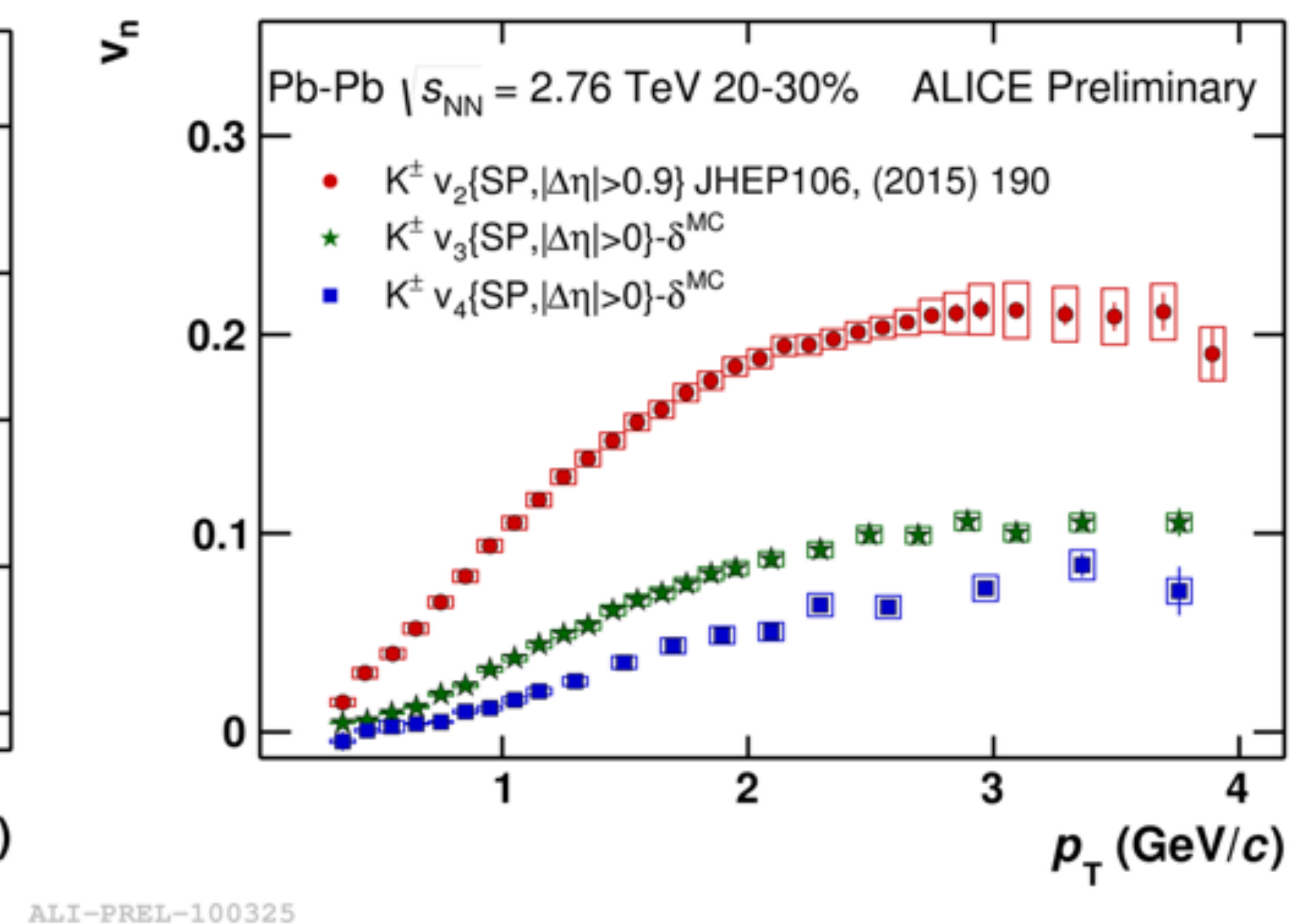
2) charged kaon ($K^{\pm}$)





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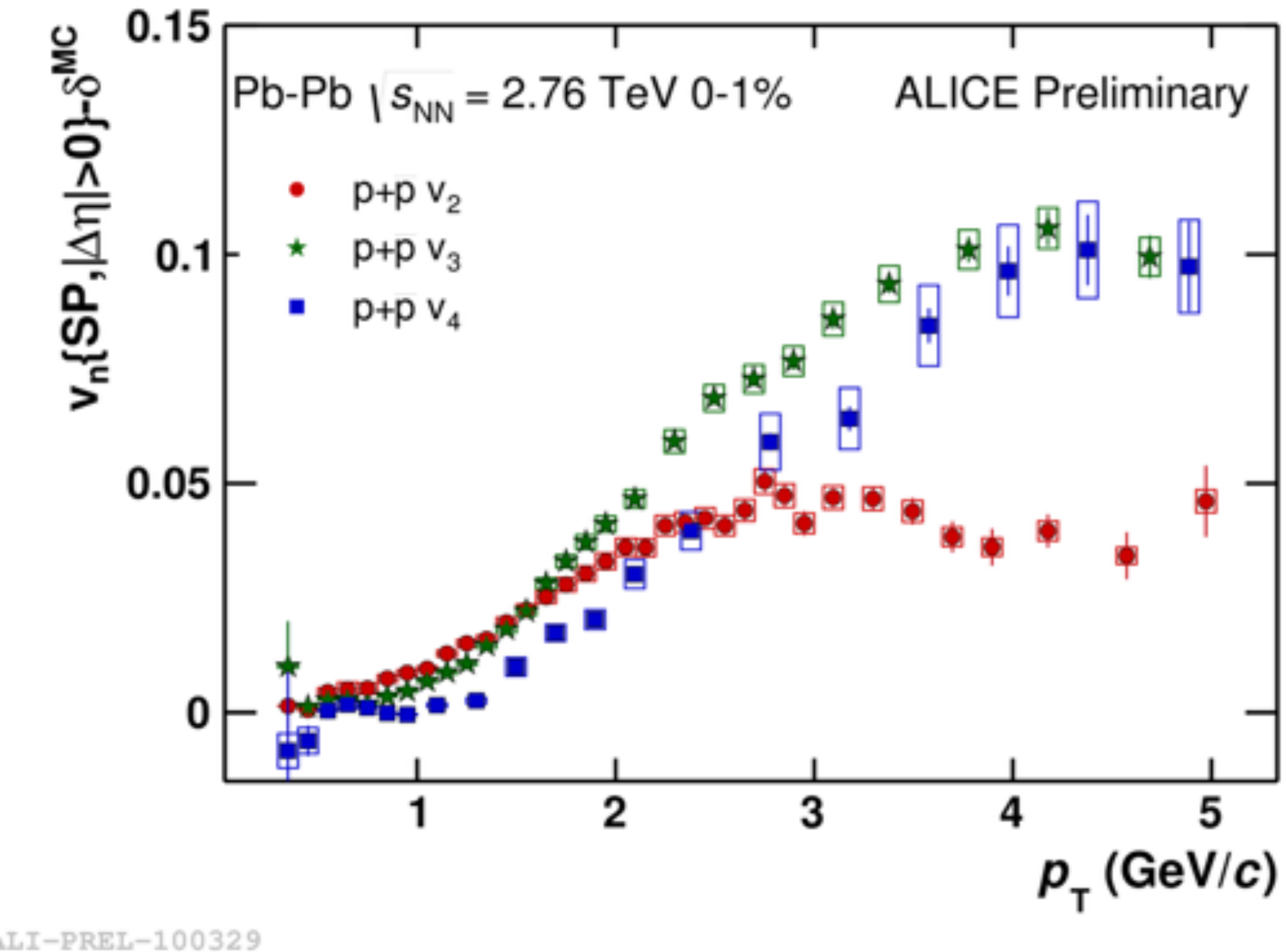
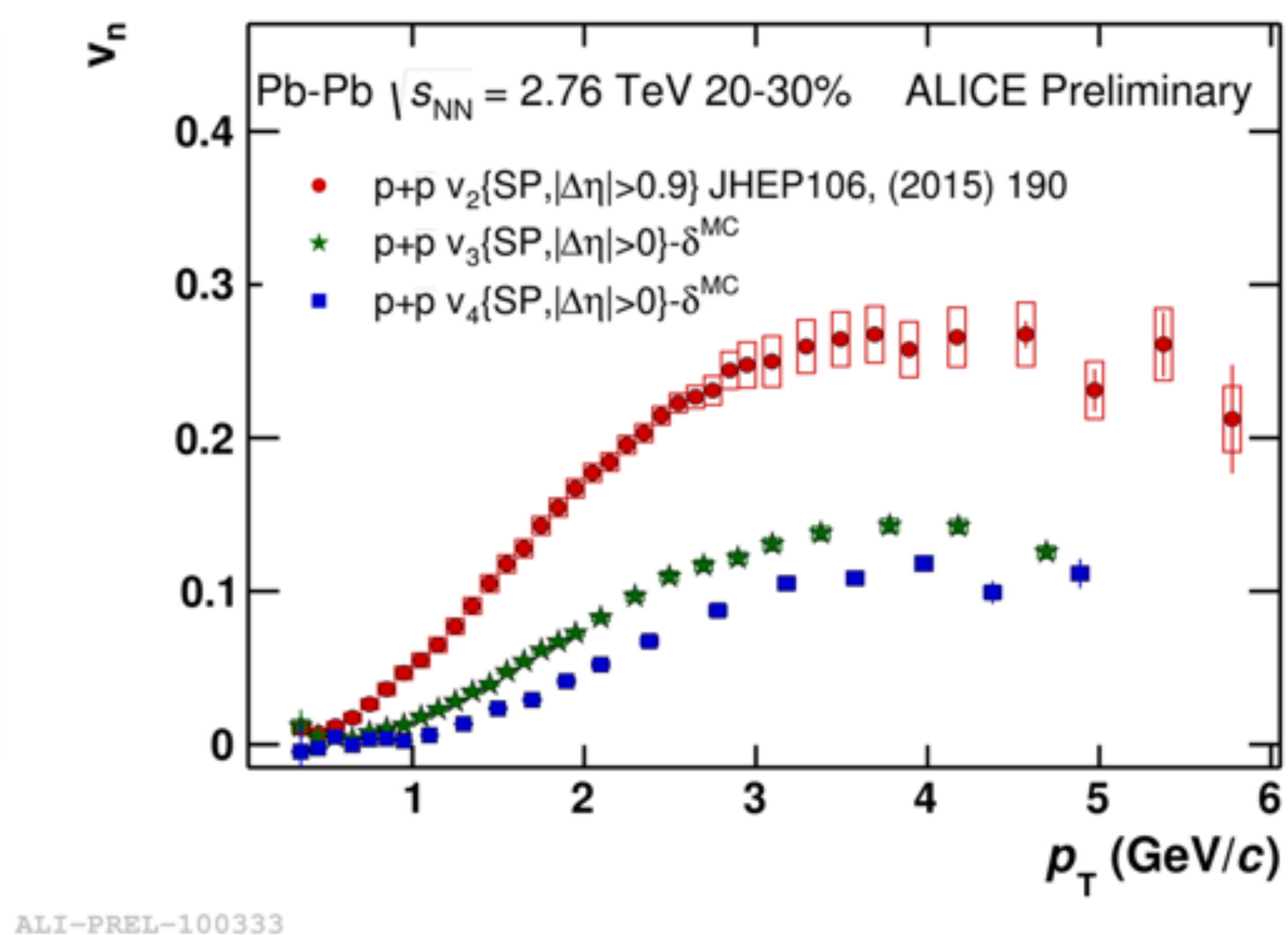
3) proton + anti-proton ($p+\bar{p}$)





Mass ordering

Density gradient of the fireball

↓

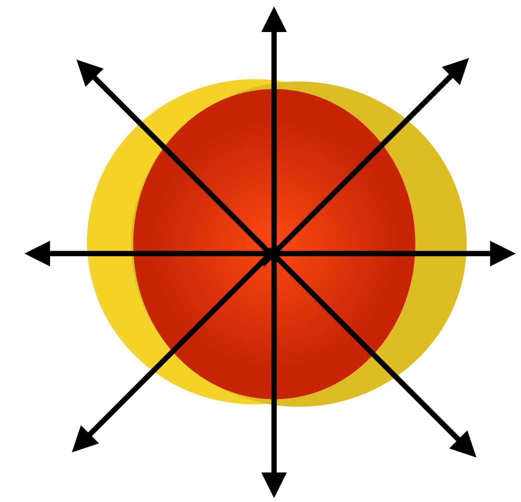
Pressure gradient

↓

Radial flow

↓

Increase of momentum for heavier particles



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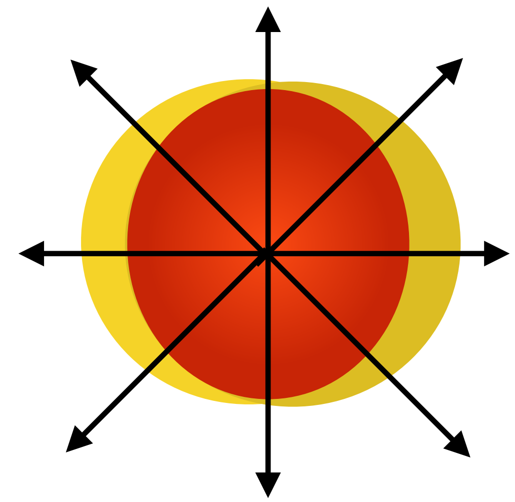

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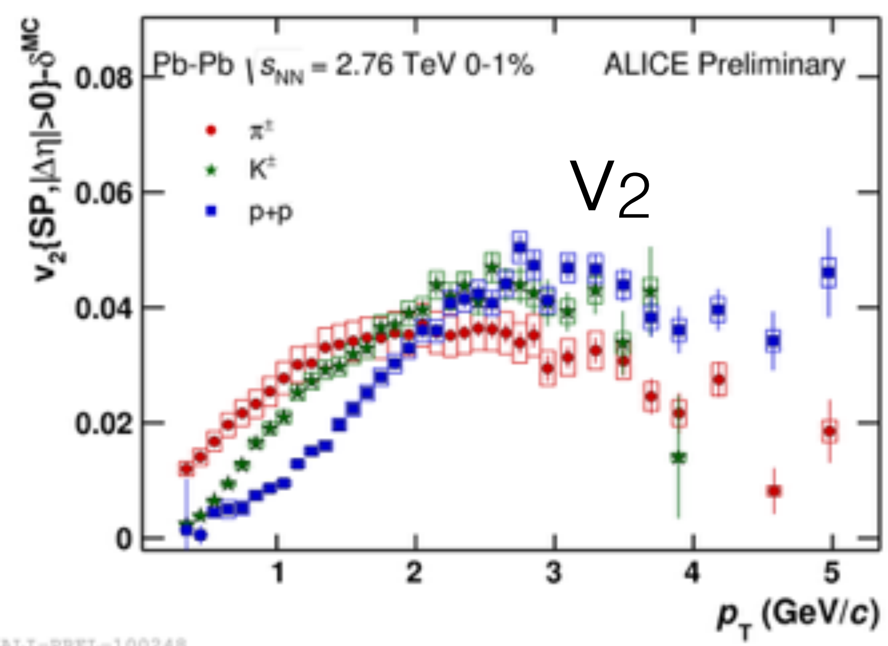

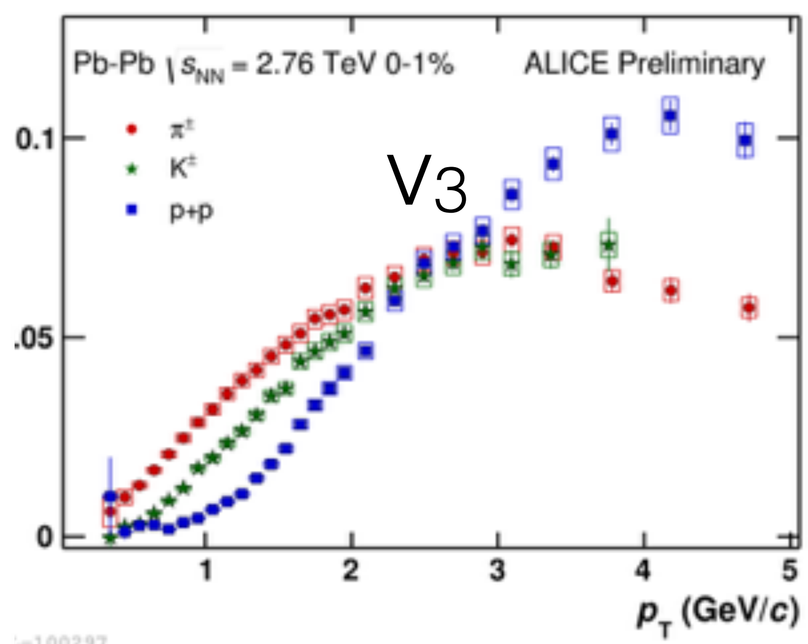

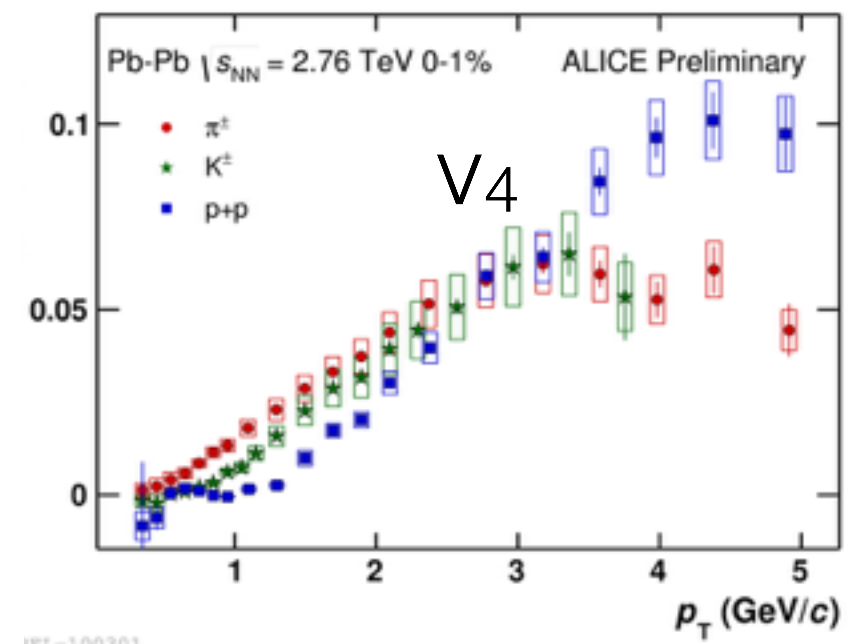

- Low p_T depleted by radial flow
- Heavier the particle lower the v_n value (p_T<3 GeV/c)
- crossing at $p_T \simeq 2.5$ GeV/c

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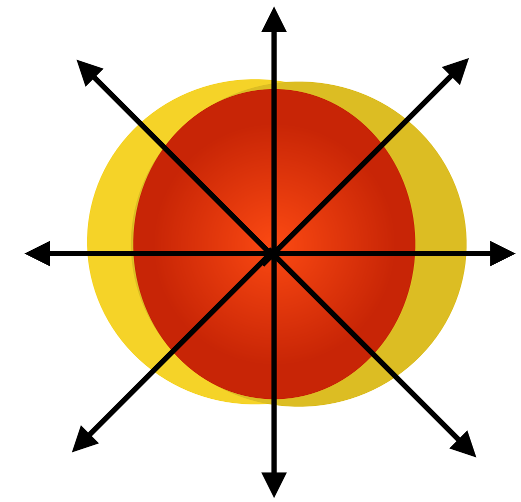
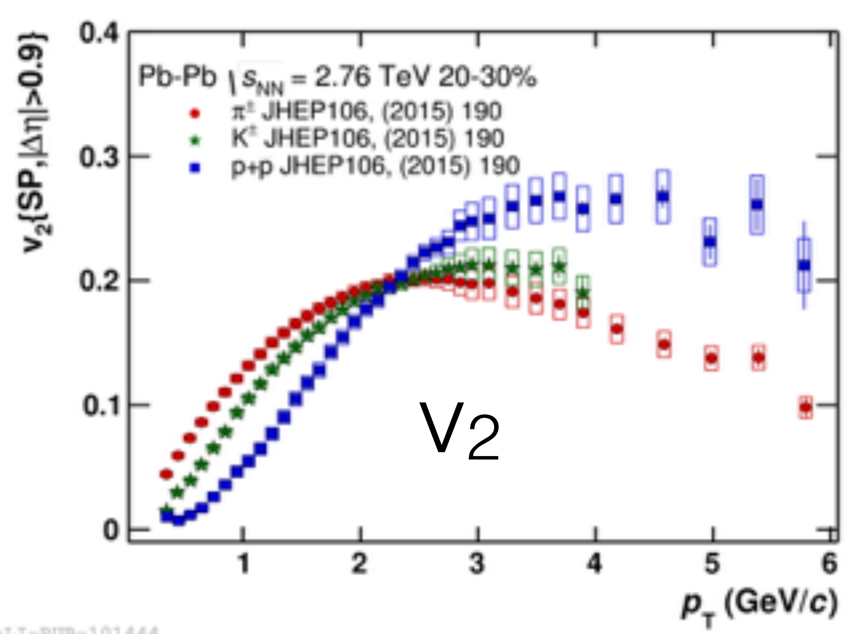
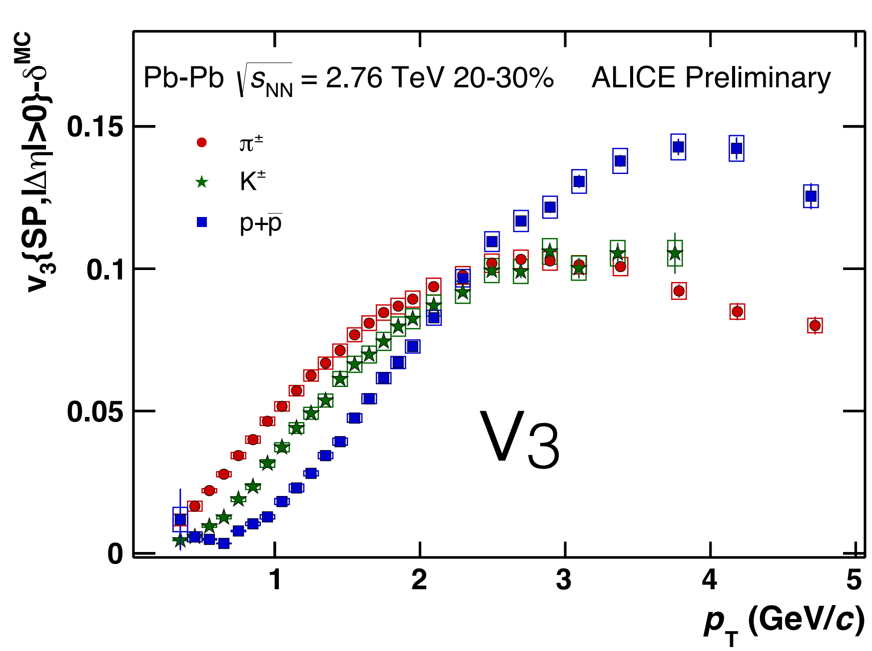
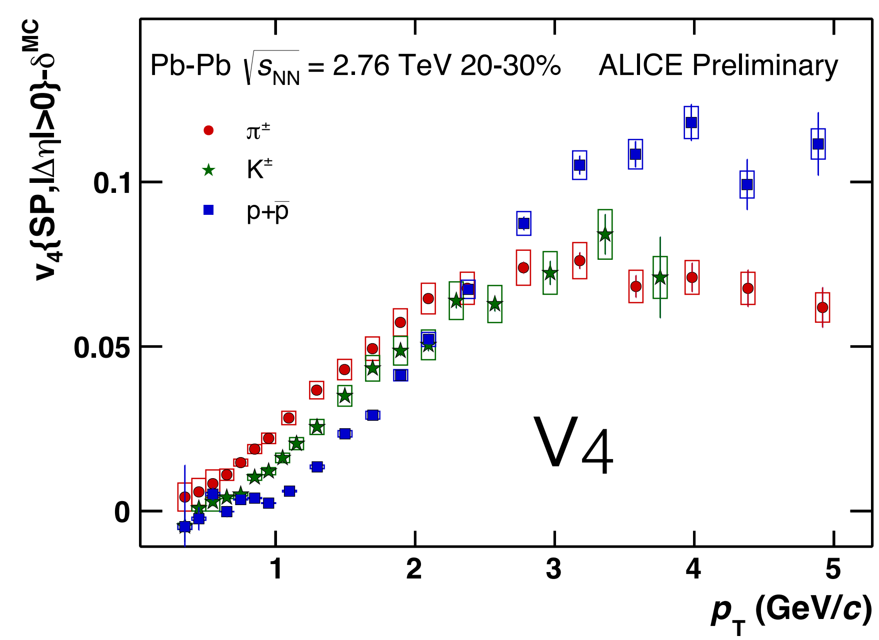


2) mid-central: 20-30% centrality class







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NCQ scaling

Intermediate p_T (p_T >3 GeV/c): v_n of baryons > v_n of mesons

- Is coalescence the driving force of particle production in this p_T range
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- NCQ scaling: p_T/n_q

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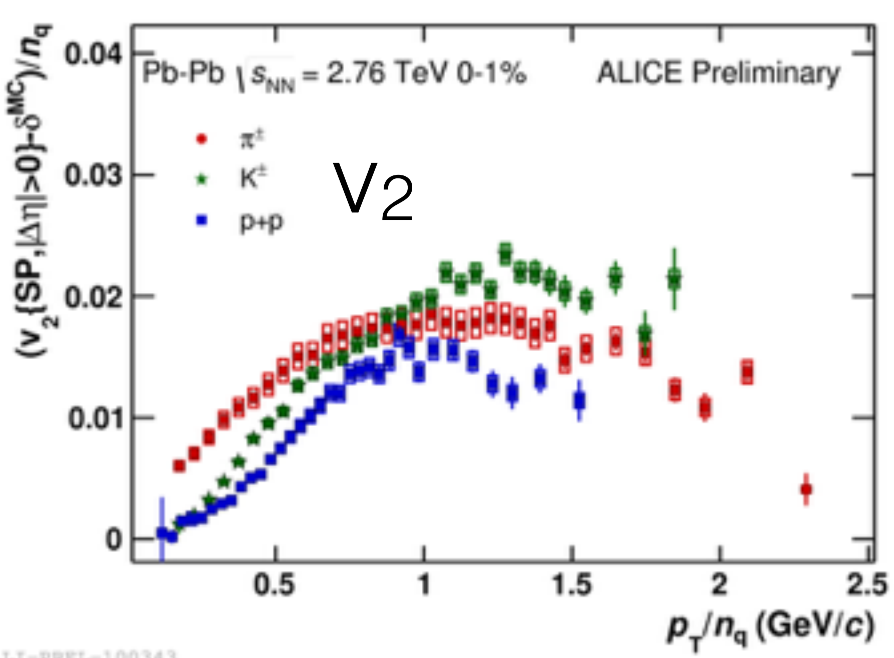

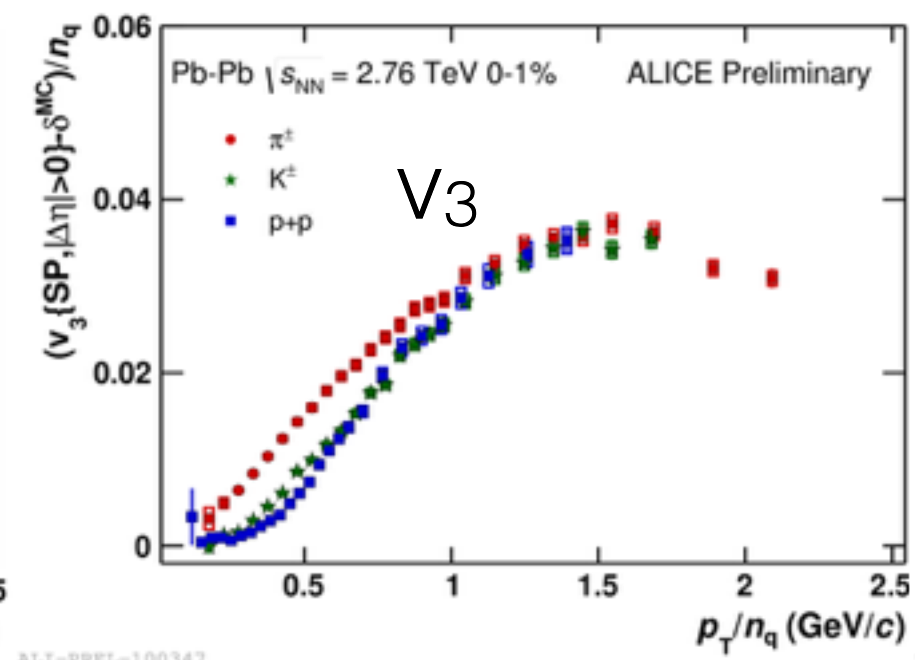

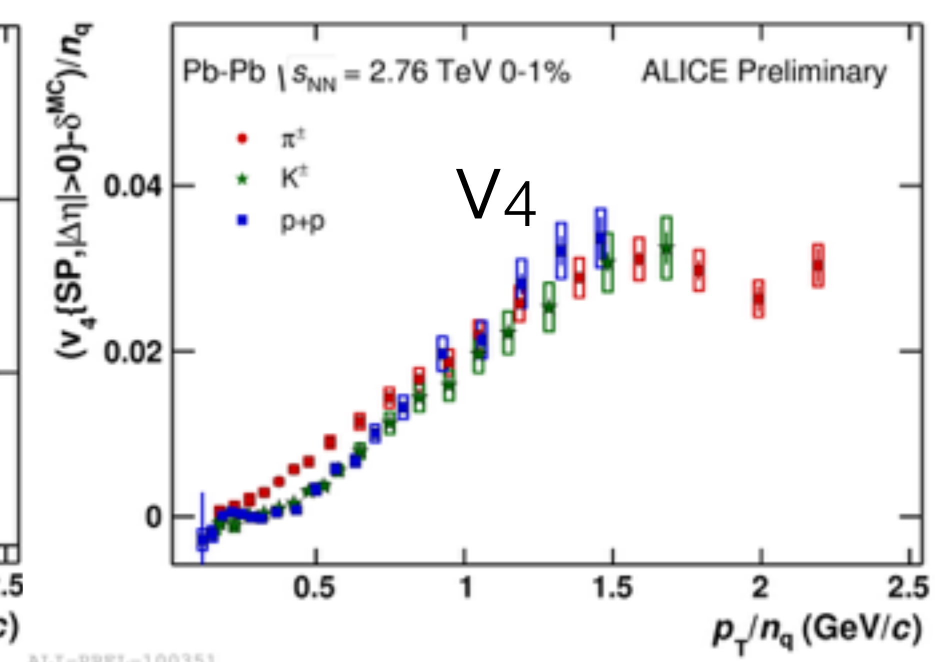

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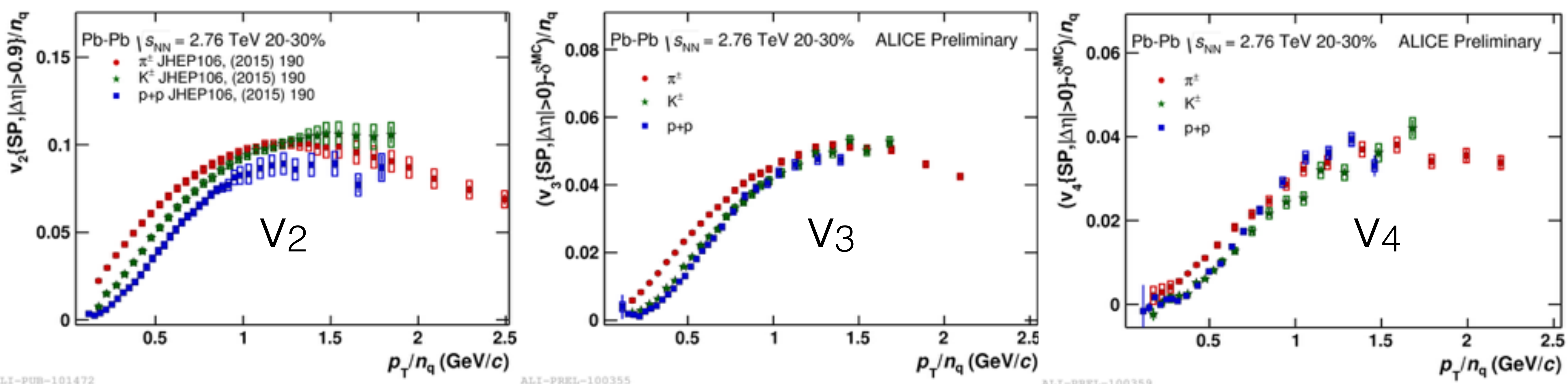

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Extend the scaling to low p_T (p_T<3 GeV/c)

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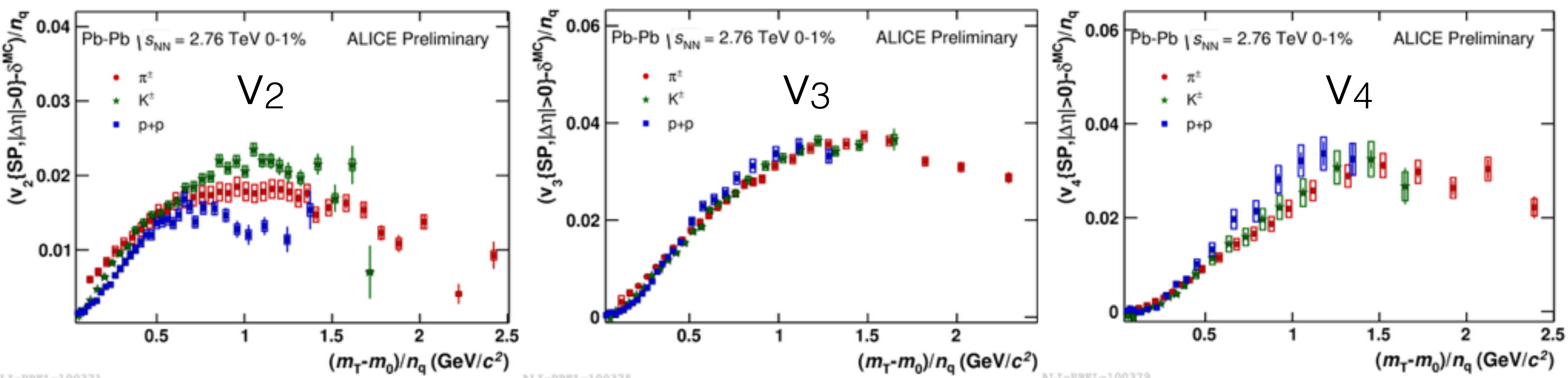

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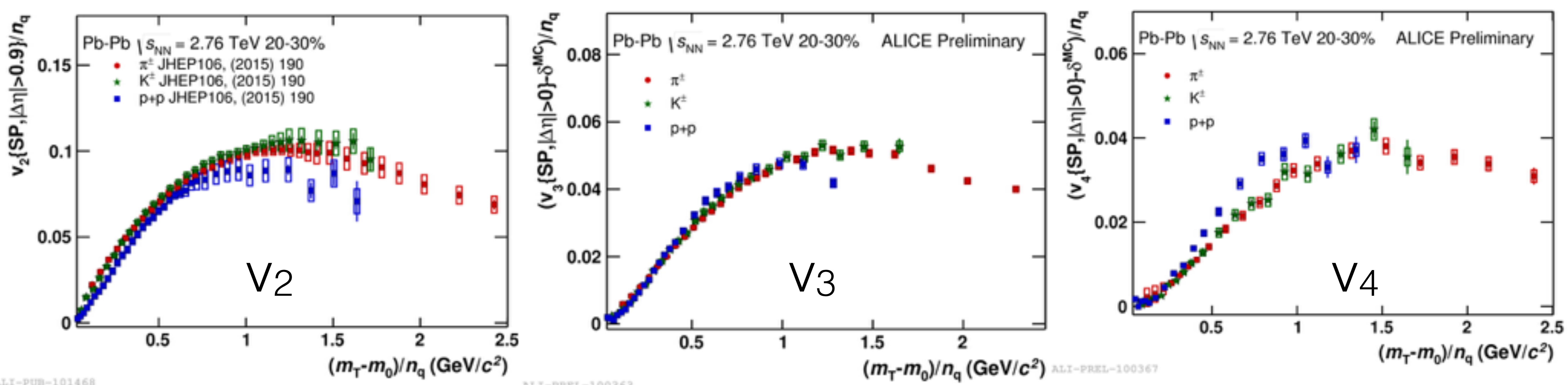


- KE_T scaling holds better for v_3

Summary

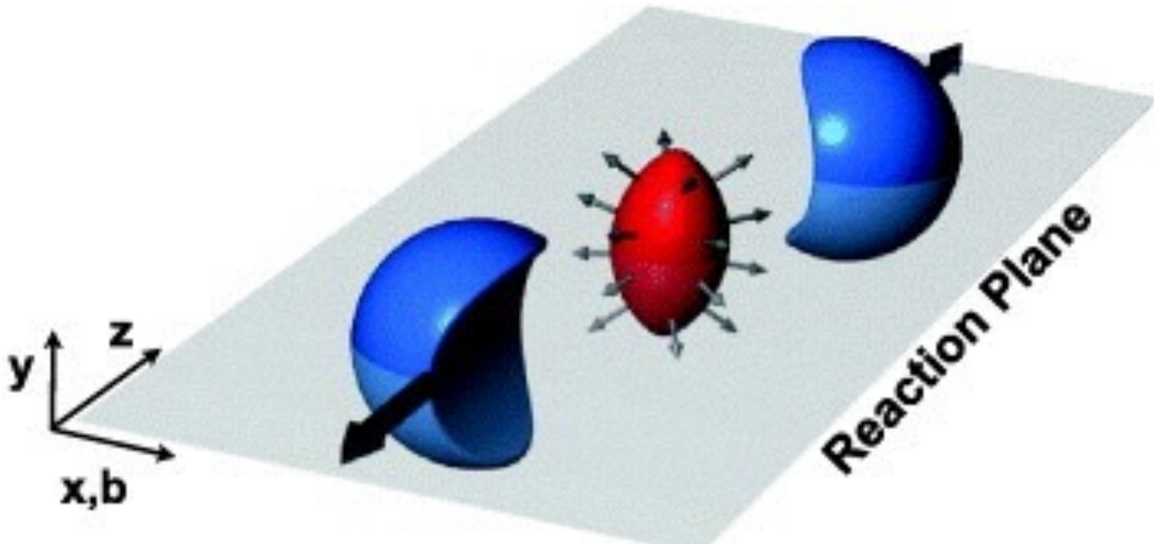
- Flow harmonics are measured for $\pi^{\pm}$,$K^{\pm}$,$p+\bar{p}$ with $|\Delta\eta|>0$ in 0-1%, 20-30% cc

Flow harmonics {
1) Centrality dependence
2) Transverse momentum
3) Mass dependence
4) Number of constituent quarks

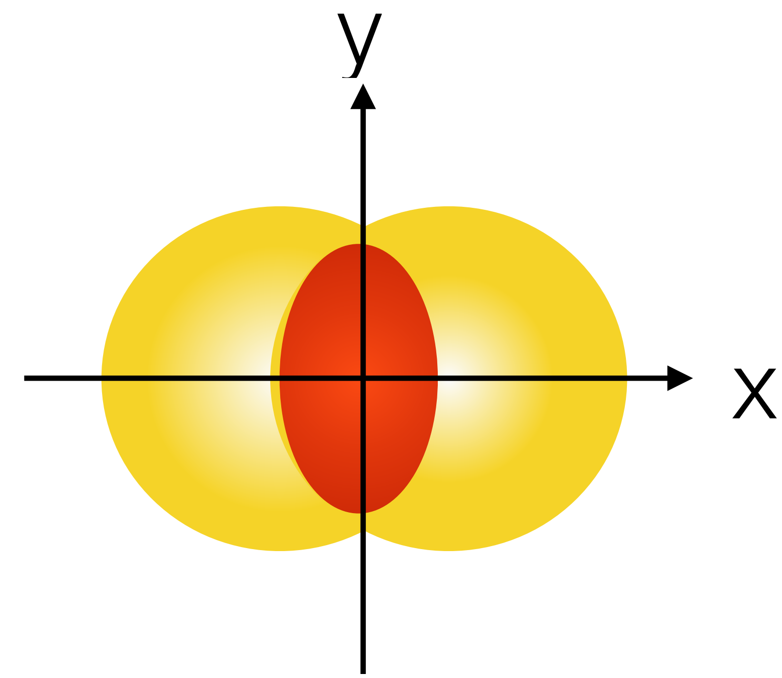
- At very central collisions where geometry is not a dominant mechanism, v_2 becomes smaller than higher harmonics (p_T >3 GeV/c)
- A clear mass ordering in flow harmonics
- Scaling representations seem to hold better for higher flow harmonics

Back-up

Asymmetric expansion

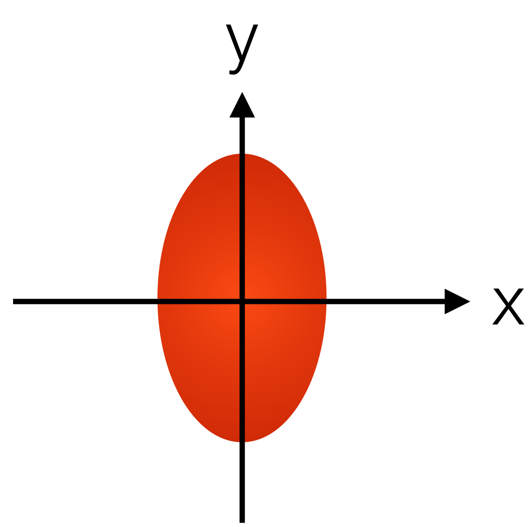


Reaction plane :
x: impact parameter
z: beam axis

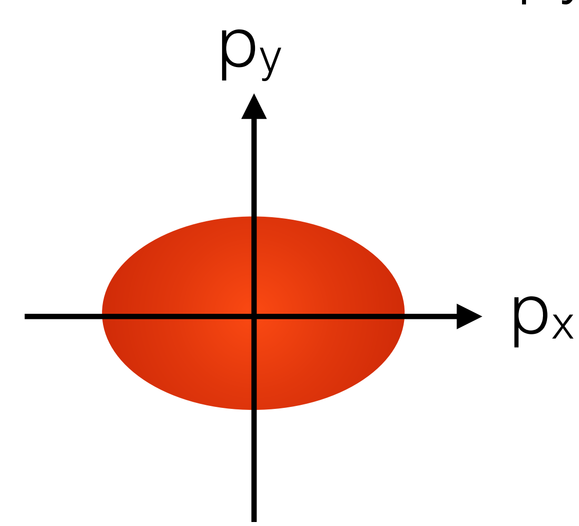


Asymmetric Overlapping region

spatial anisotropy



momentum anisotropy



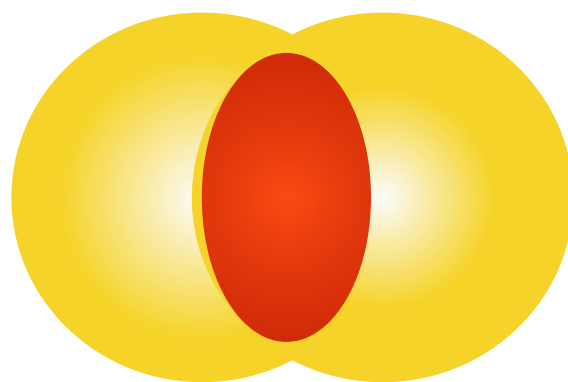
$$\epsilon = \frac{<y^2 - x^2>}{<y^2 + x^2>}$$

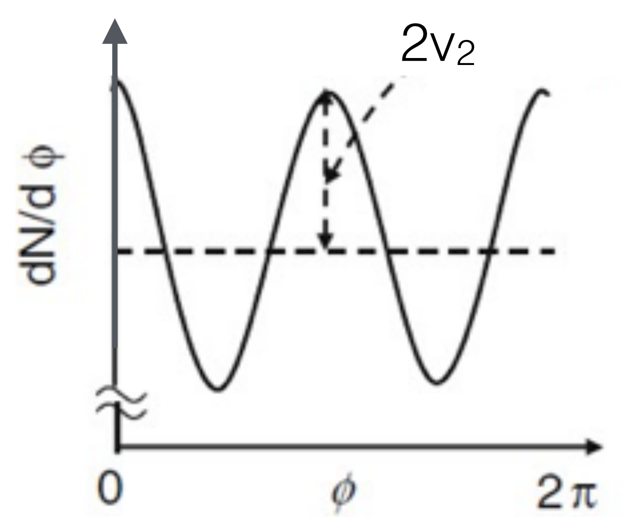
$$v_2 = \frac{<p_y^2 - p_x^2>}{<p_y^2 + p_x^2>}$$

Elliptic Flow

Medium expands collectively

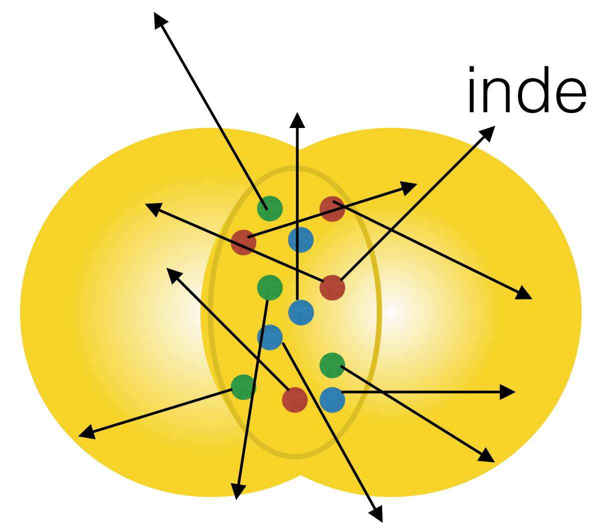
elliptic flow

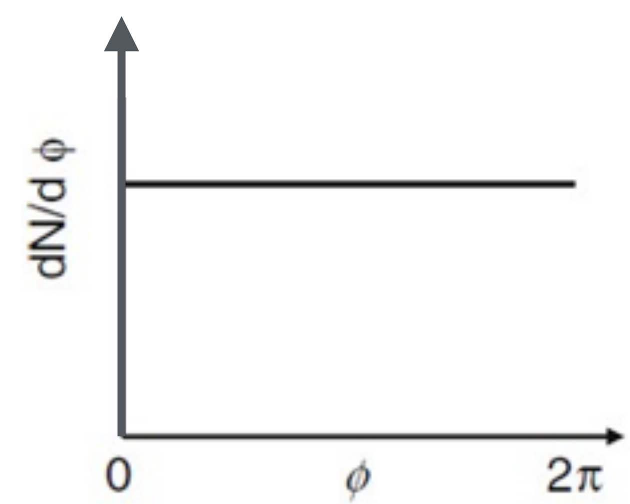




superposition of independent pp collision

no elliptic flow





$\frac{dN}{d\phi}$: azimuthal particle distribution

Analysis details

Monte Carlo:

- Hijing

Centrality trigger:

- Min. bias trigger

Centralities:

- 0-1%, 20-30%

Statistics:

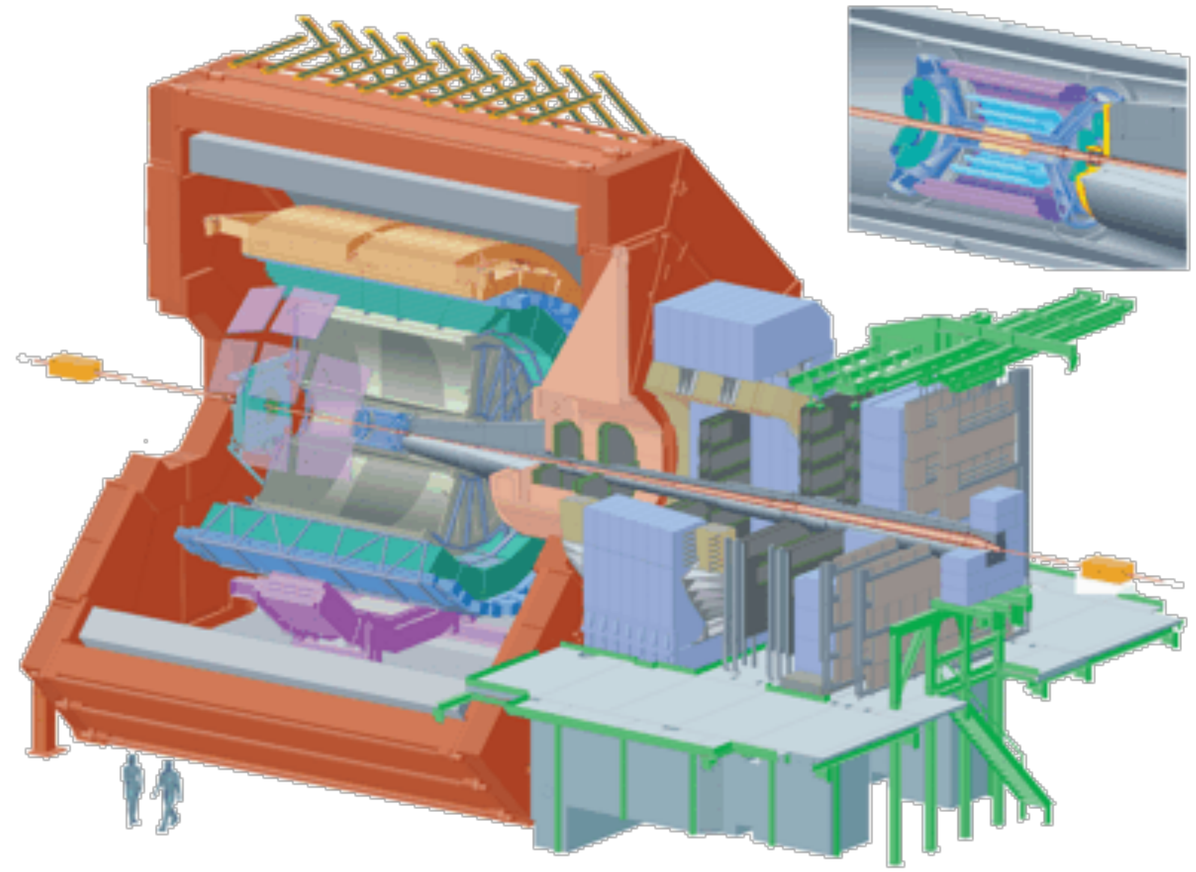
- 1.7M

Particles of interest:

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

Reference Particles:

- All charged particles



Elliptic flow: NCQ scaling

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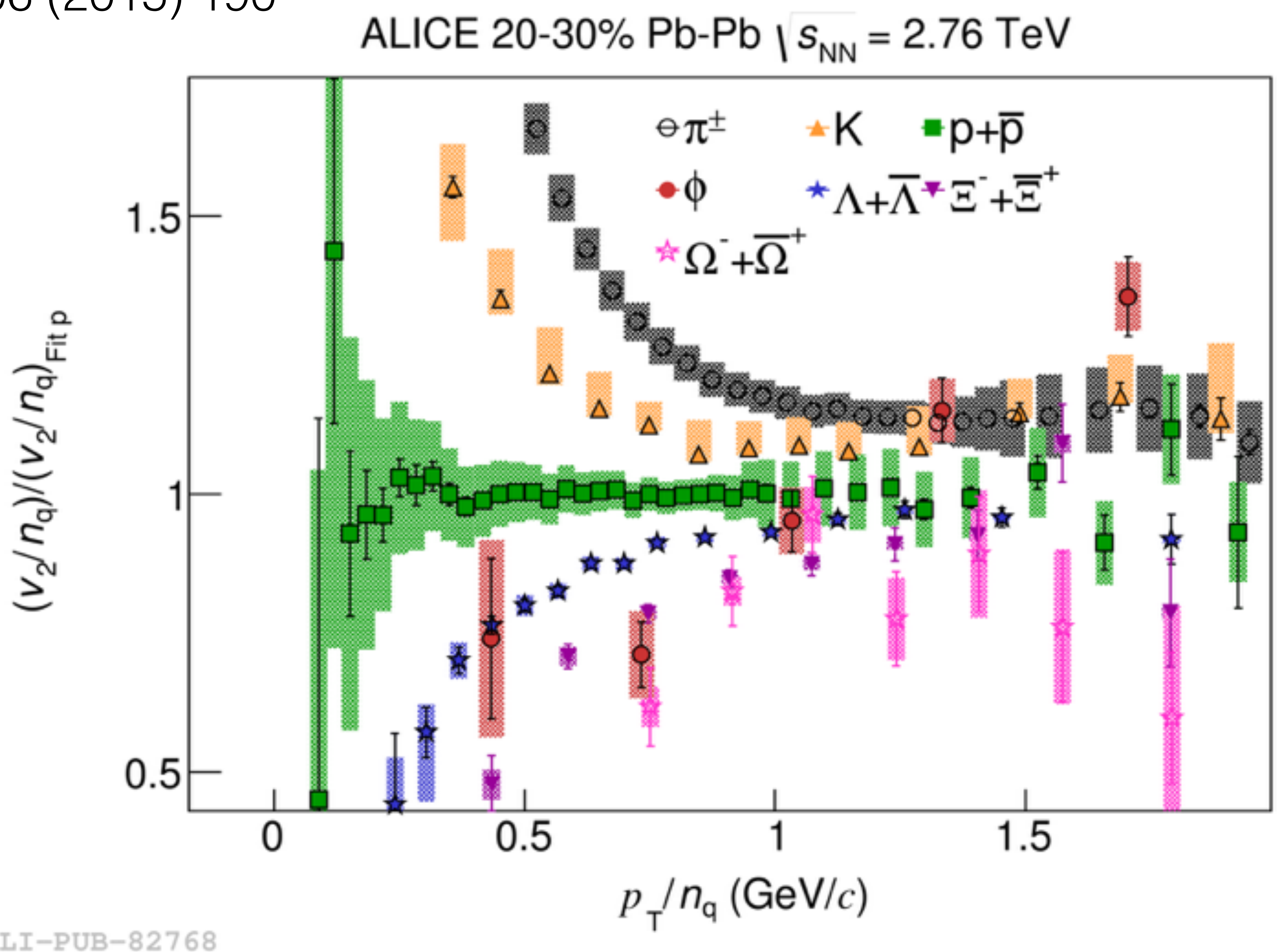

- $p_T/n_q > 1$: ±20% difference

Elliptic flow: KE_T scaling

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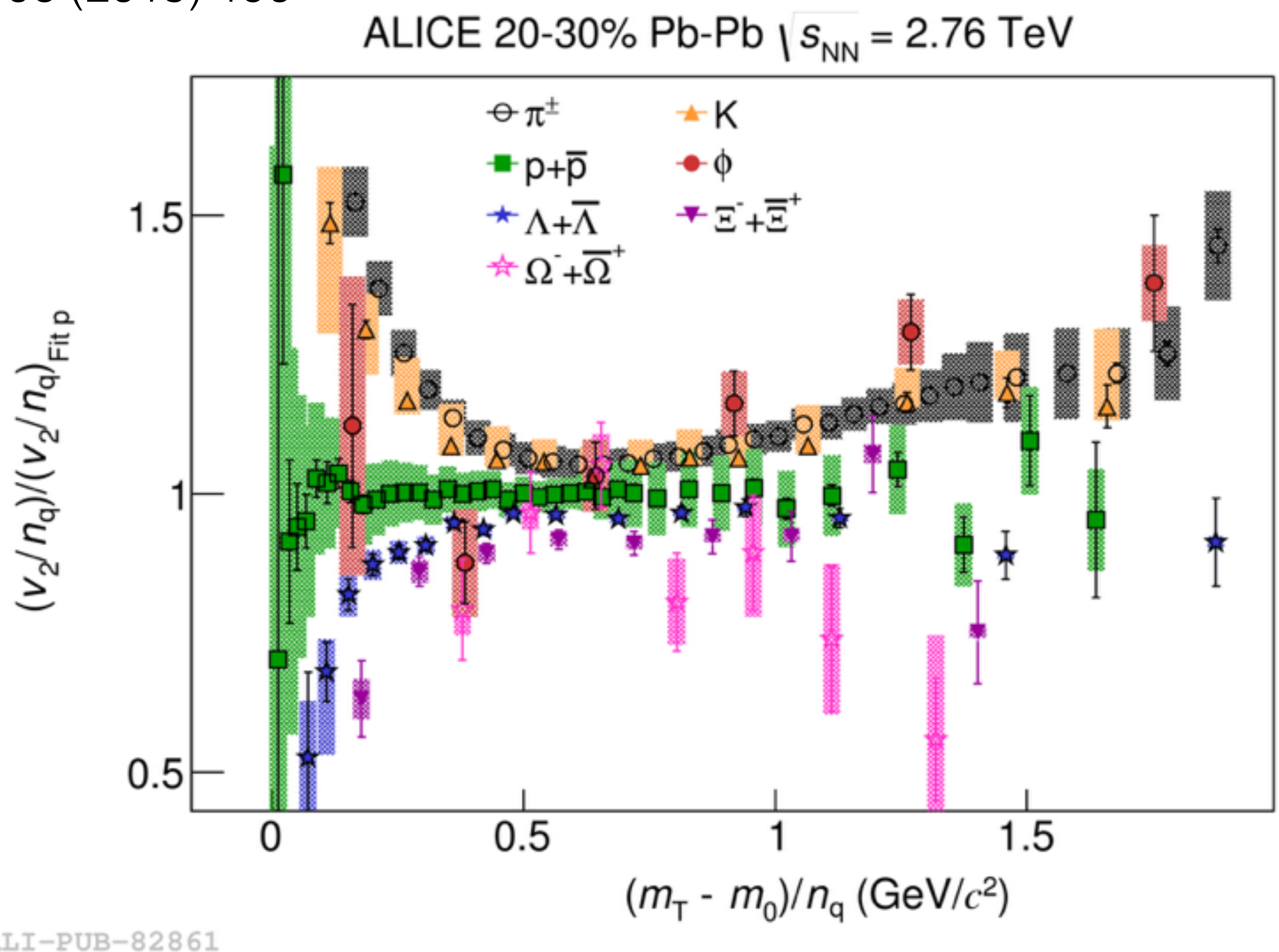

- $(m_T-m_0)/n_q > 0.8$: ±20% difference
- $(m_T-m_0)/n_q < 0.8$: No scaling