ALICE Overview

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Heavy Ion Meeting 2011-06

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Korea University, Seoul, Korea

2.76 TeV/N **Pb-Pb Results**

Most are extracted from ALICE talks presented at QM2011 (23-28 May 2011, Annecy)

- ⇨ **Spectra & Particle Ratios**
- ⇨ **Flow & Correlations & Fluctuations**
- ⇨ **R_{AA} of inclusive particles**
- ⇨ **Heavy open Flavour**
- ⇨ **J/Ψ**

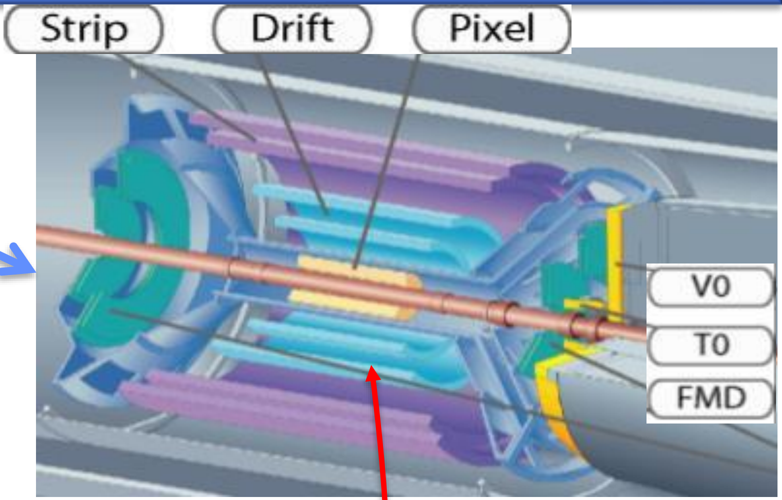
PID in ALICE

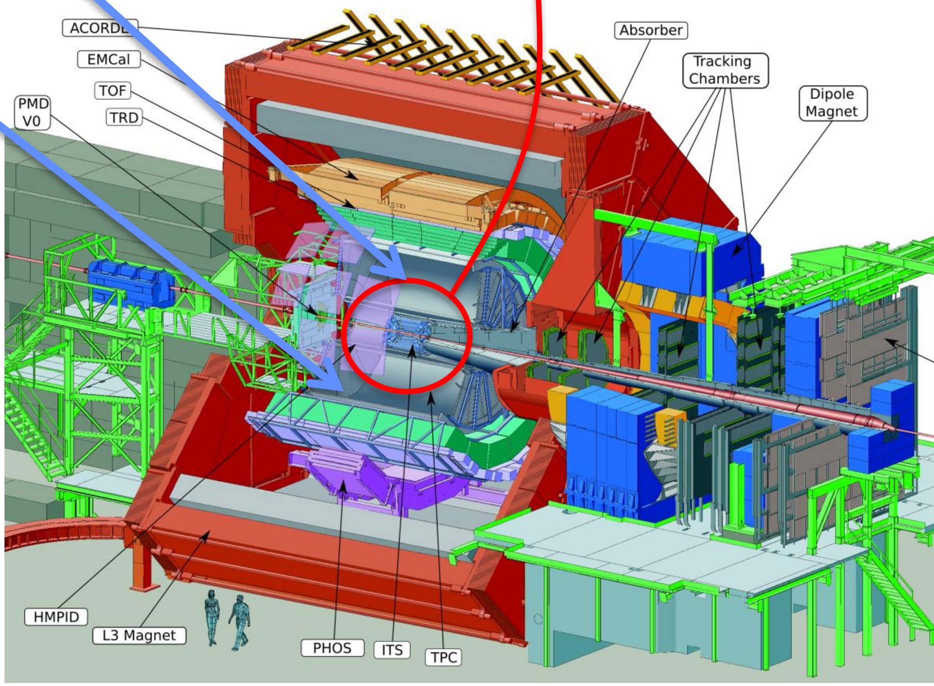
Inner tracking system
- Low p_T standalone tracker
- PID: dE/dx in the silicon (up to 4 samples)

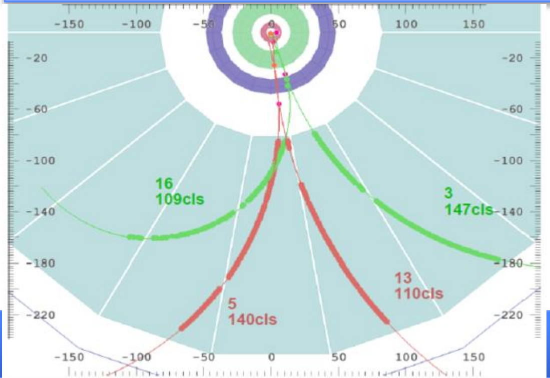
TPC
- Standalone and global (+ITS) tracks
- PID: dE/dx in the gas (up to 159 samples)

Time of Flight
- Matching of tracks extrapolated from TPC
- PID: TOF, σ_{TOT} ~ 85ps(PbPb) – 120ps(pp)

Topological ID + Invariant Mass
- Resonances, Cascades, V0s, Kinks
- PID: indirect cuts to improve S/B



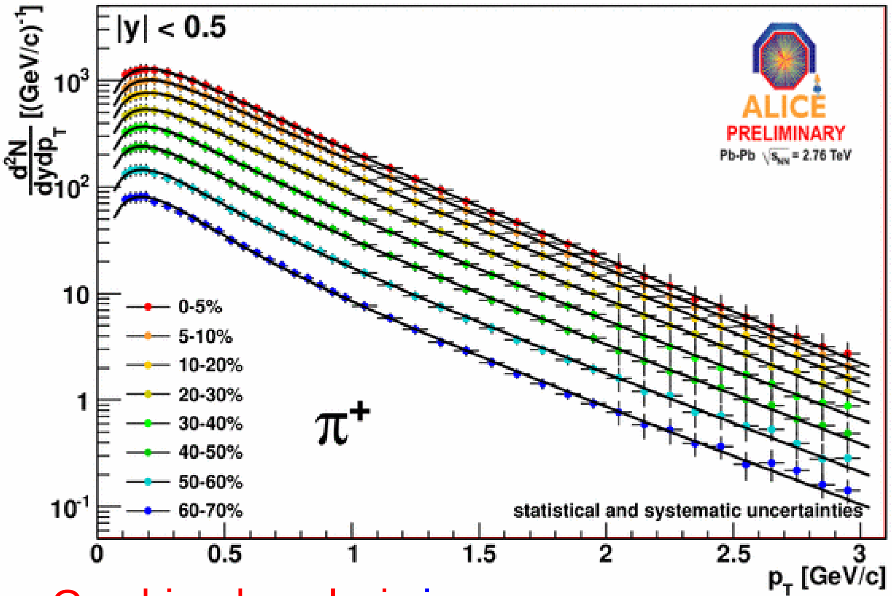


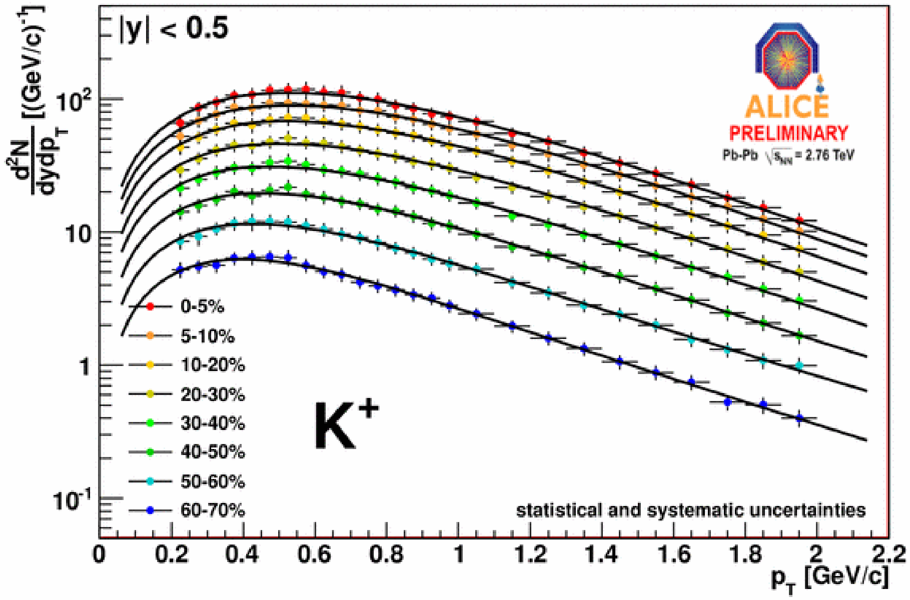


$\pi^0 \to \gamma+\gamma \to e^+e^-e^+e^-$

similarly K0, Λ, Ξ, Ω,...

π/K/p Spectra





Combined analysis in

- Inner Tracking System
- Time Projection Chamber
- TOF

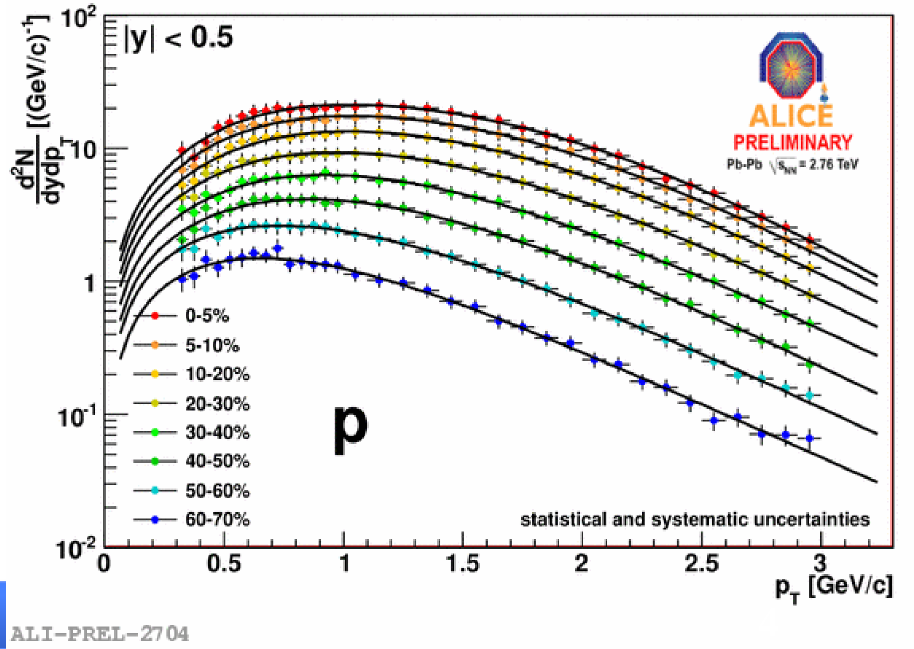
p_T Range:

0.1 – 3 GeV/c (π)

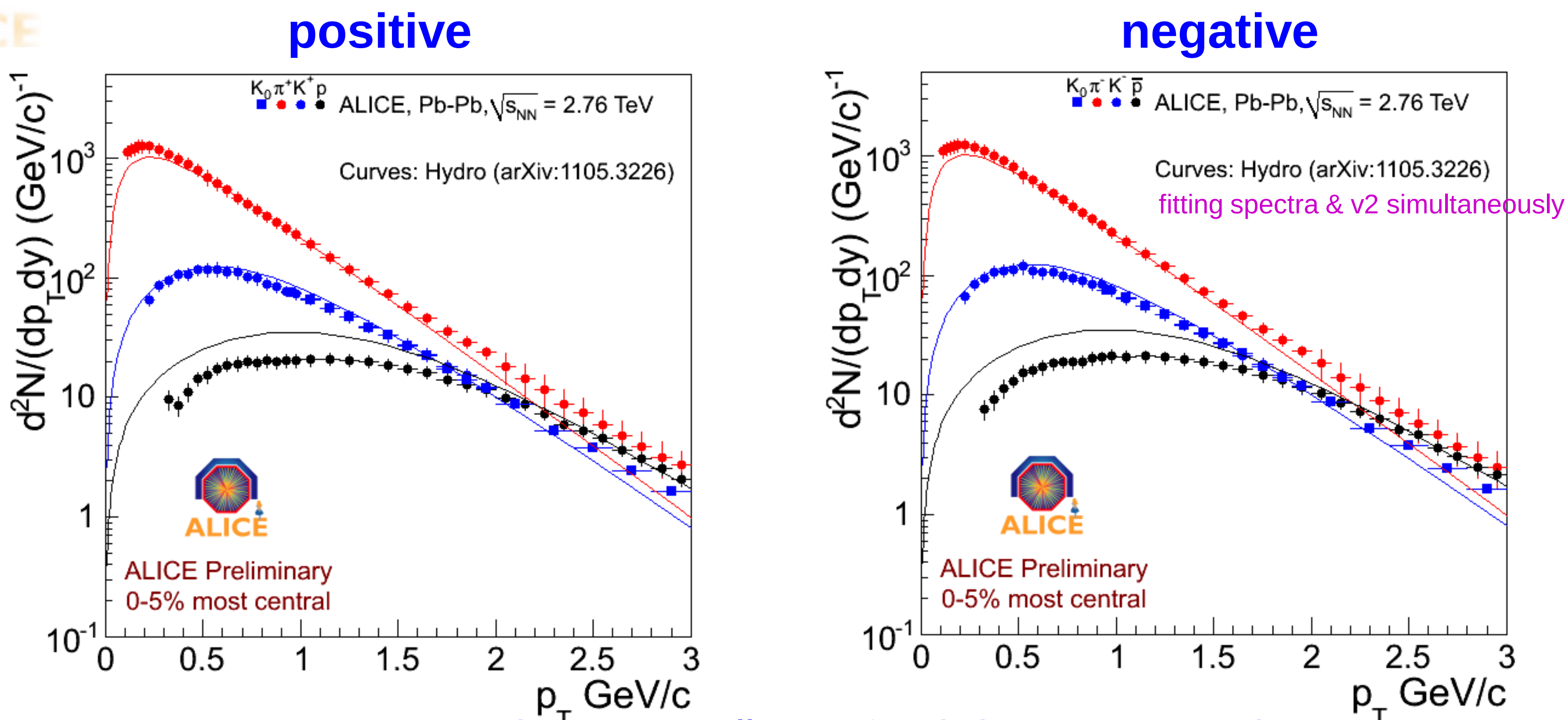
0.2 – 2 GeV/c (K)

0.3 – 3 GeV/c (p)

Blast wave fits to individual particles to extract yields



Comparison to RHIC (0-5% Central)



At RHIC: STAR proton data generally not feed-down corrected.

Large feed down correction

➔ Consistent picture with feed-down corrected spectra

At LHC: ALICE spectra are feed-down corrected

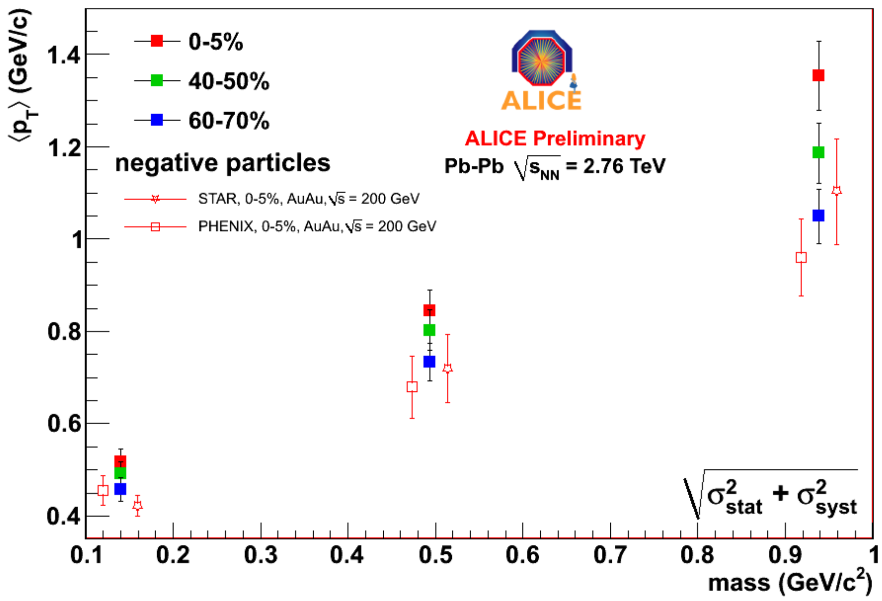
- Harder spectra, flatter p at low pt
- Strong push on the p due to radial flow?

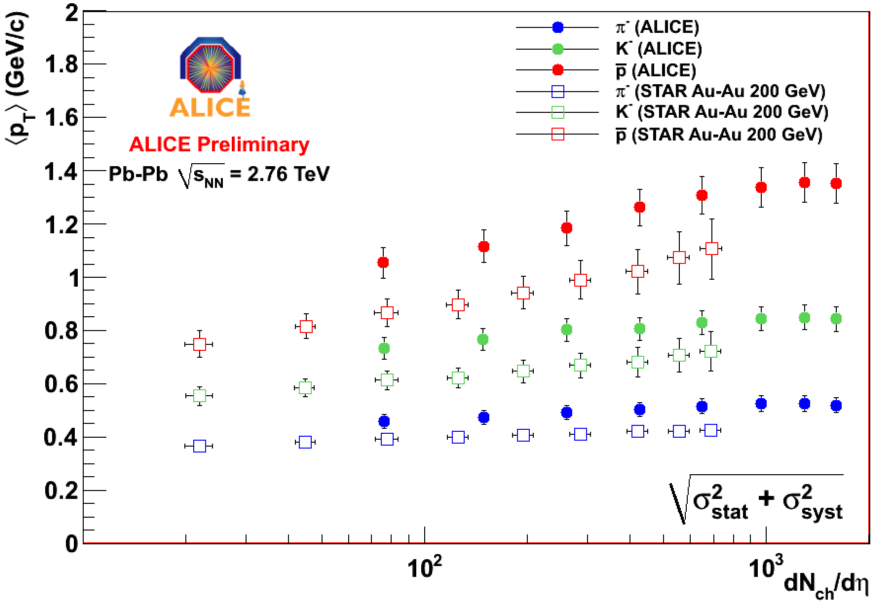
STAR, PRL97, 152301 (2006)

STAR, PRC 79 , 034909 (2009)

PHENIX, PRC69, 03409 (2004)

Mean p_T





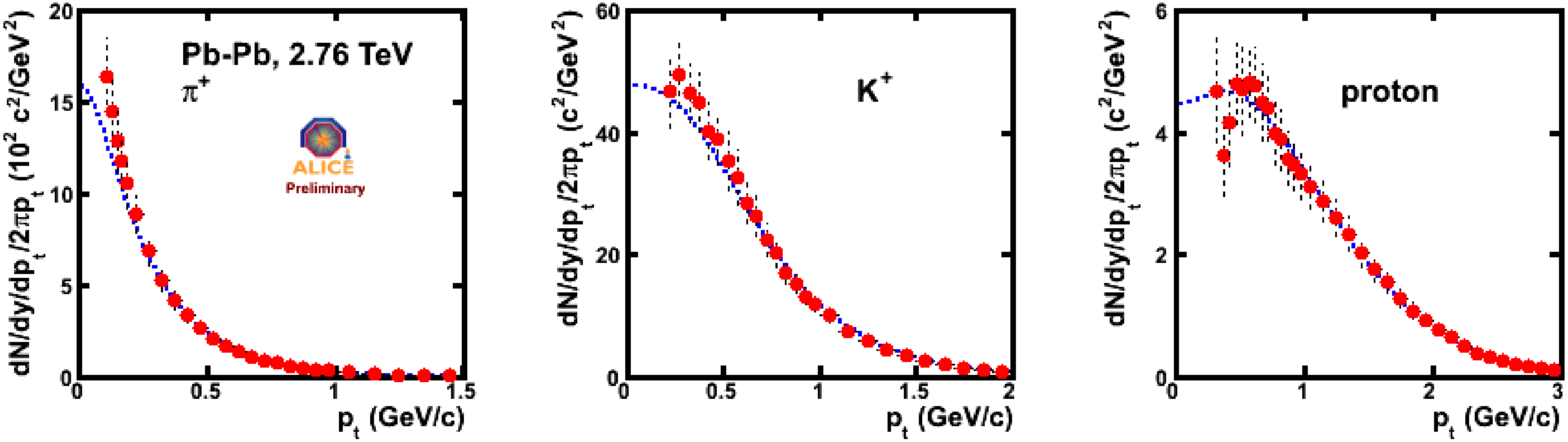
Mean p_T increases linearly with mass

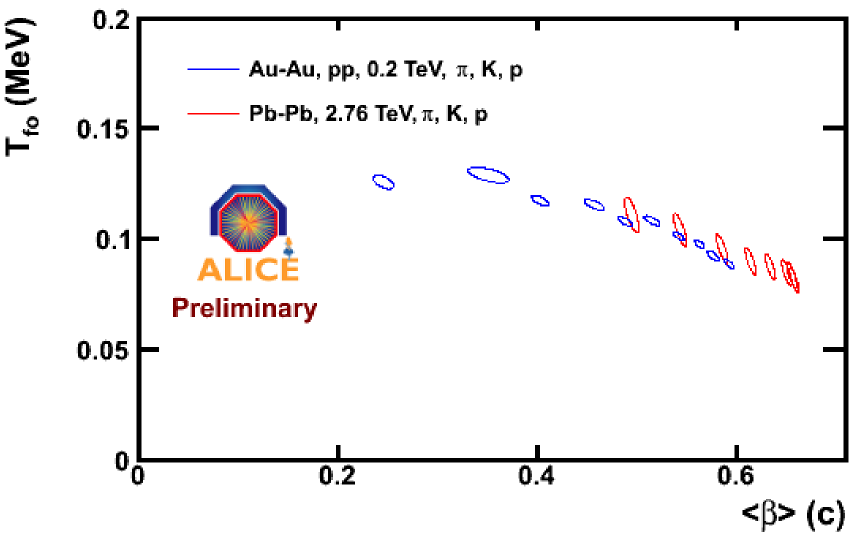
Higher than at RHIC (harder spectra, more radial flow?)

For the same dN/dη higher mean p_T than at RHIC

Blast wave fits

PRC48, 2462 (1993).





Blast wave fits → radial flow ~ 10% higher than at RHIC

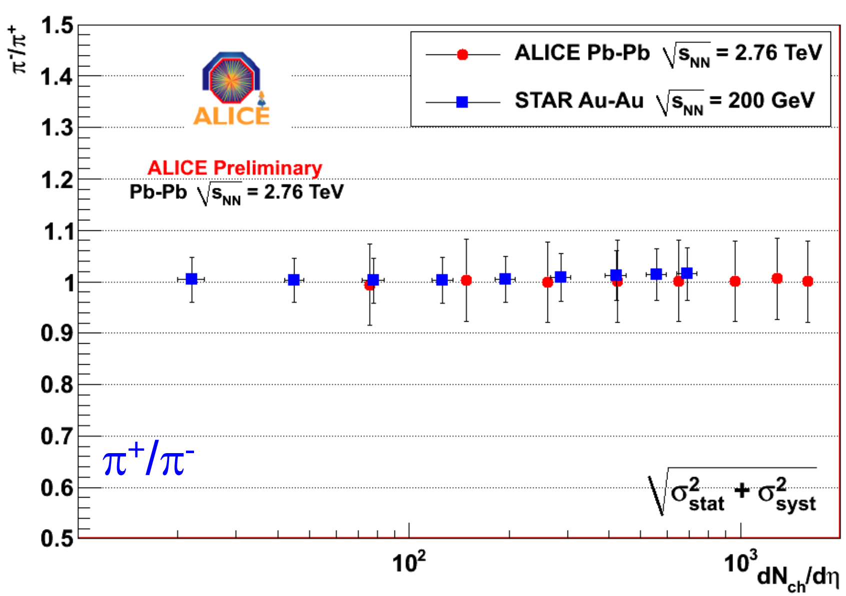
Fit Range:

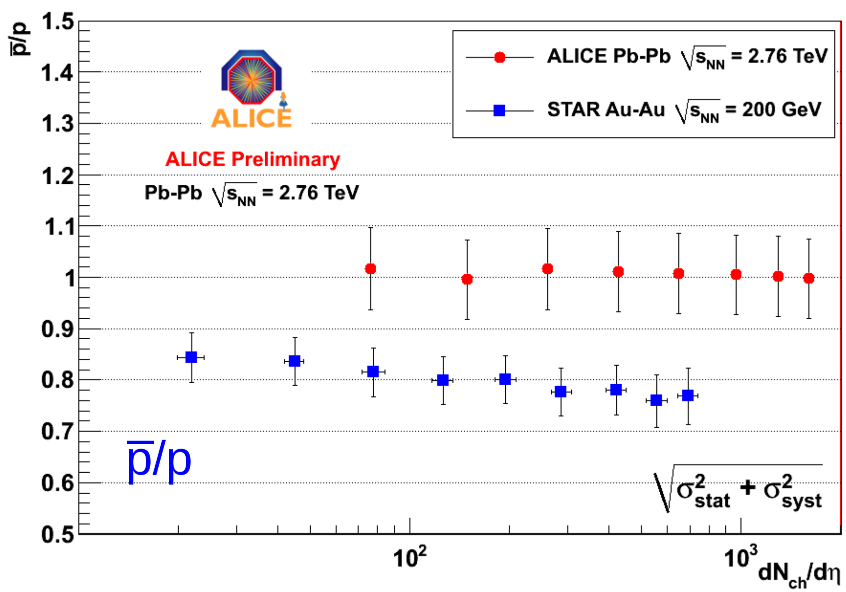
- pions 0.3 – 1 GeV
- kaons 0.2 – 1.5 GeV
- protons 0.3 – 3 GeV

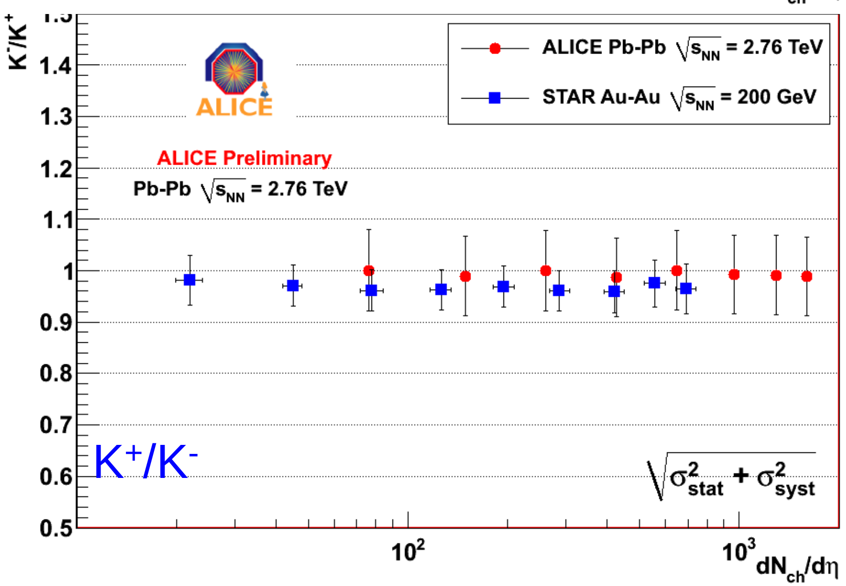
T depends on the pions and fit-range

(effect of resonances to be investigated)

Integrated yields ratios



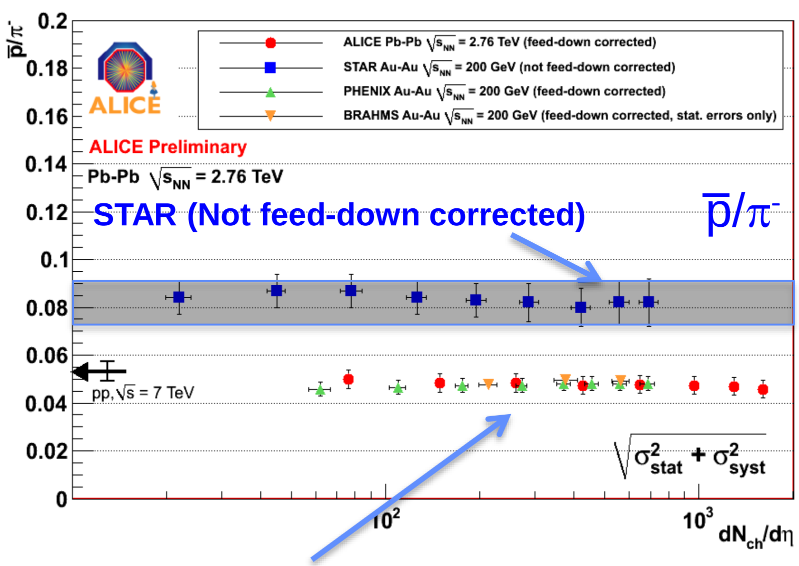


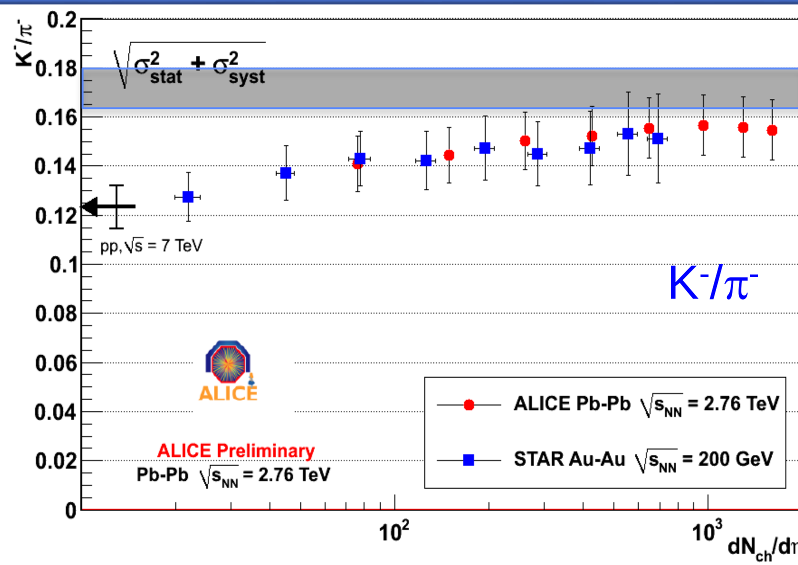


All +/- ratios are compatible with 1 at all centralities, as expected at LHC energies

STAR, PRC 79 , 034909 (2009)

Integrated ratios vs Centrality





ALICE, BRAHMS, PHENIX (feed-down corrected)

STAR, PRC 79 , 034909 (2009)
PHENIX, PRC69, 03409 (2004)
BRAHMS, PRC72, 014908 (2005)

Predictions for the LHC

p/π: lower than thermal model predictions

Ratio	Data	(1)	(2)
p/π^+	0.0454+-0.0036	0.072	0.090
p/π^-	0.0458+-0.0036	0.071	0.091+0.009-0.007
K/π^+	0.156 +- 0.012	0.164	0.180+0.001-0.001
K/π^-	0.154 +- 0.012	0.163	0.179+0.001-0.001

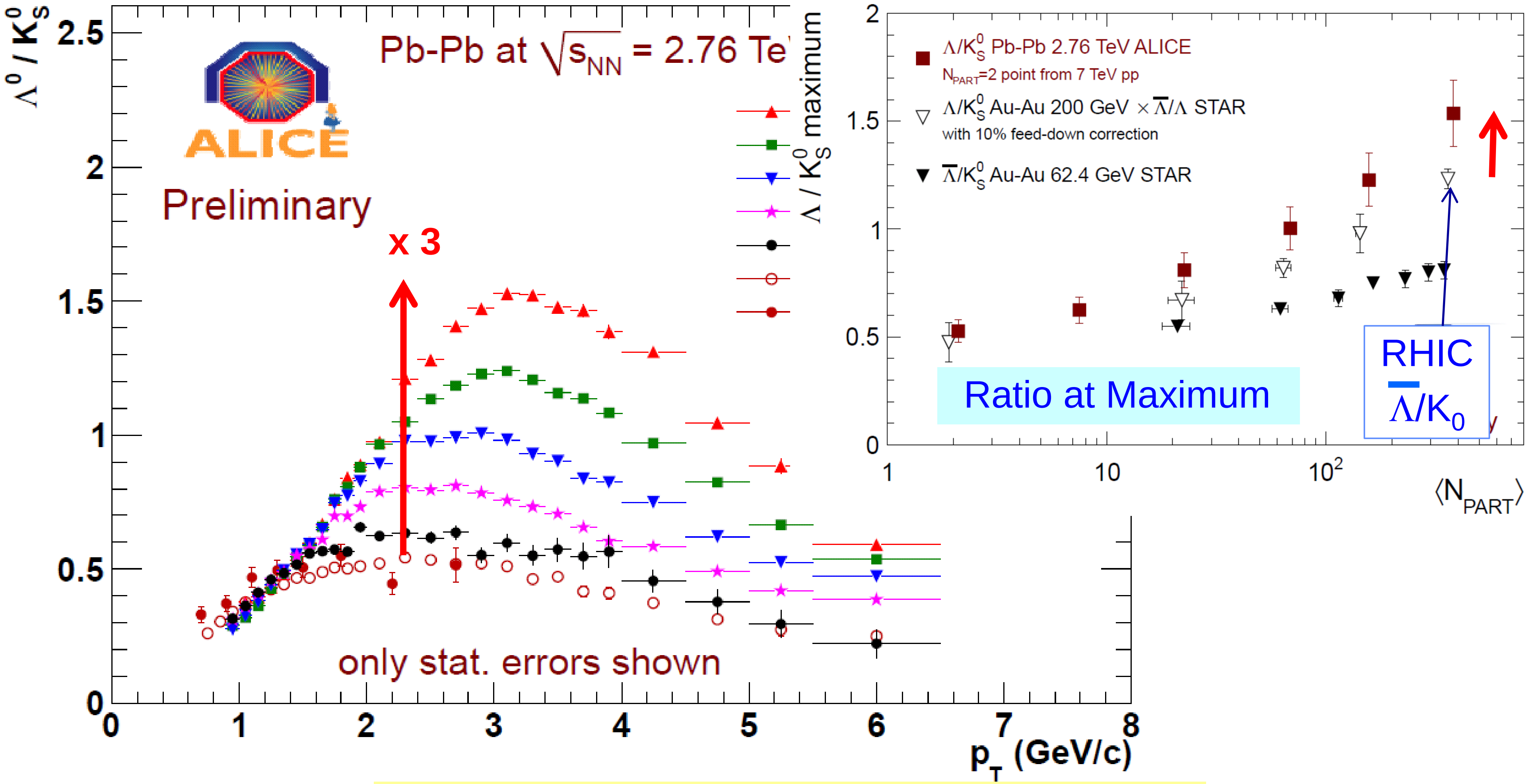
(1) A. *Andronic et al, Nucl. Phys. A772 167 (2006)*

T = 164 MeV, μ_B = 1 MeV

(2) *J. Cleymans et al, PRC74, 034903 (2006)*

T = (170±5) MeV and μ_B =1+4 MeV

'Baryon anomaly': Λ/K_0



Baryon/Meson ratio still strongly enhanced

x 3 compared to pp at 3 GeV

- Enhancement slightly larger than at RHIC 200 GeV
- Maximum shift very little in p_T compared to RHIC

despite large change in underlying spectra !

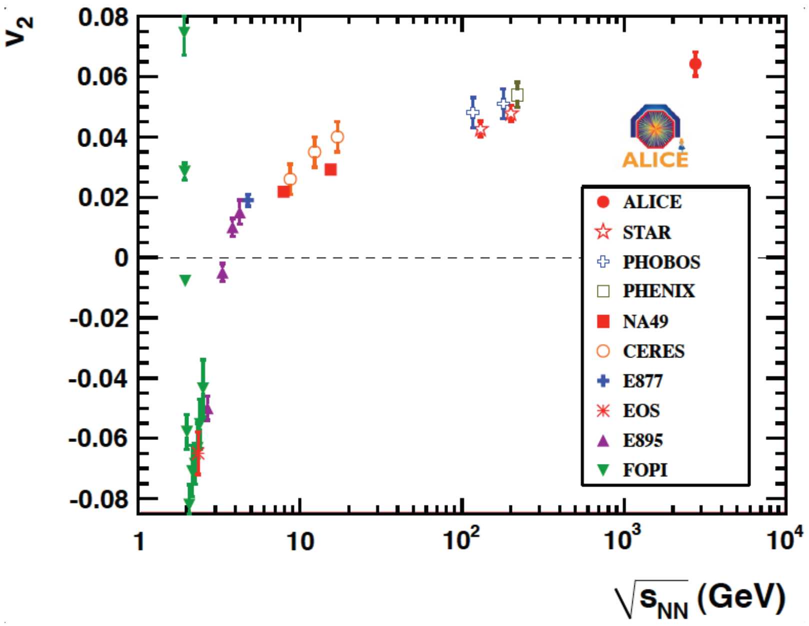
Summary – spectra/particle ratio

- ALICE has very good capabilities for the measurement of identified particles
- PbPb Collision
  - ⇨ Spectral shapes show much stronger radial flow than at RHIC
  - ⇨ p_bar/p ≈ 1.0 (the state of zero net baryon number)
  - ⇨ p/π ≈ 0.05 (lower than thermal model predictions with T = 160-170 MeV)
  - ⇨ Baryon/meson anomaly: enhancement slightly higher and pushed to higher p_T than at RHIC

Azimuthal Flow: What next ?

- Elliptic flow (v_2) and perfect fluid:
  - ⇨ large v_2 => strongly interacting "perfect" fluid
  - ⇨ from hydro: large v_2 => low η => large σ
  - ⇨ $\eta/s = 1/4\pi$ => conjectured AdS/CFT limit
  - ⇨ current RHIC limit: $\eta/s < (2\text{-}5) \times 1/4\pi$
  - ⇨ need precision measurement of η/s

shear viscosity: $$\eta = \frac{\sqrt{2mkT}}{\sigma}$$



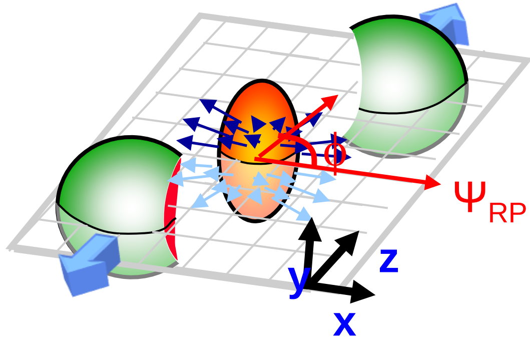
- To get precision measurement of η/s *(parameters in hydro)* using flow v_n *(experimental data)*:
  - ⇨ fix **initial conditions** (geometrical shape is model dependent, eg Glauber, CGC)
  - ⇨ quantify **flow fluctuations** σ (influence measured v_2, depending on method)
  - ⇨ measure **non-flow correlations** δ (eg jets)
  - ⇨ **improve theory** precision (3D hydro, 'hadronic afterburner', ...)
  - ⇨ ....

Experimental methods

- Event plane (EP) method:

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_t dp_t\, dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos(n(\varphi-\Psi_{RP}))\right)$$

$$v_n=\langle\cos(n(\varphi_i-\Psi_{RP}))\rangle$$



- Cumulants:
  - 2- and 4-particle azimuthal correlations for an event:

$$\langle 2\rangle\equiv\langle\cos(n(\varphi_i-\varphi_j))\rangle,\ \varphi_i\neq\varphi_j$$

$$\langle 4\rangle\equiv\langle\cos(n(\varphi_i+\varphi_j-\varphi_k-\varphi_l))\rangle,\ \varphi_i\neq\varphi_j\neq\varphi_k\neq\varphi_l$$

  - Averaging over all events, the 2nd and 4th order cumulants are given:

$$c_2\{n\}=\langle\langle 2\rangle\rangle=v_n^2+\delta_n$$

$$c_4\{n\}=\langle\langle 4\rangle\rangle-2\langle\langle 2\rangle\rangle^2=-v_n^4$$

v_n : reference_flow
$\langle\rangle$: average_particles
$\langle\langle\rangle\rangle$: average_events

$$v_n\{2\}\equiv\sqrt{c_n\{2\}}$$

$$v_n\{4\}\equiv\sqrt[4]{-c_n\{4\}}$$

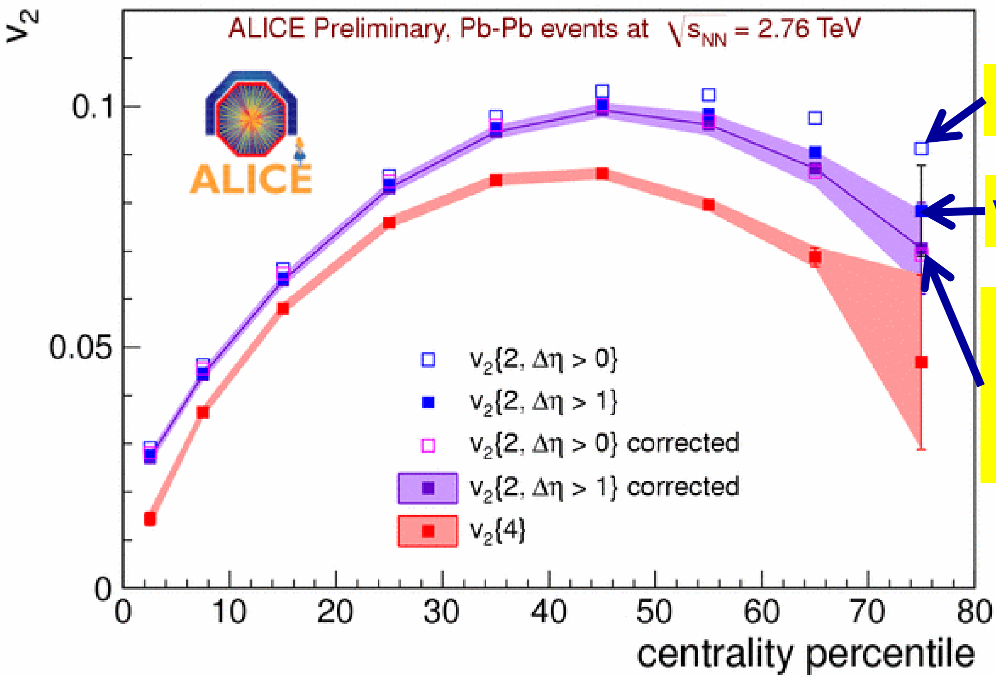
$$v_n\{2\}\cong v_n^2+\sigma_n^2+\delta$$

$$v_n\{4\}\cong v_n^2-\sigma_n^2$$

v_2 {2} and v_2{4} have different sensitivity to flow fluctuations (σ_n) and non-flow (δ)

Non-Flow corrections

Elliptic Flow v_2



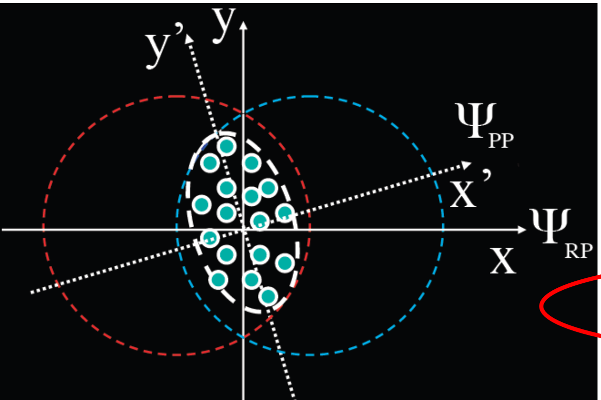
v_2 no eta gap between particles

v_2 $|\eta|>1$ to reduce non-flow such as jets

both v_2 corrected for remaining non-flow using Hijing or scaled pp

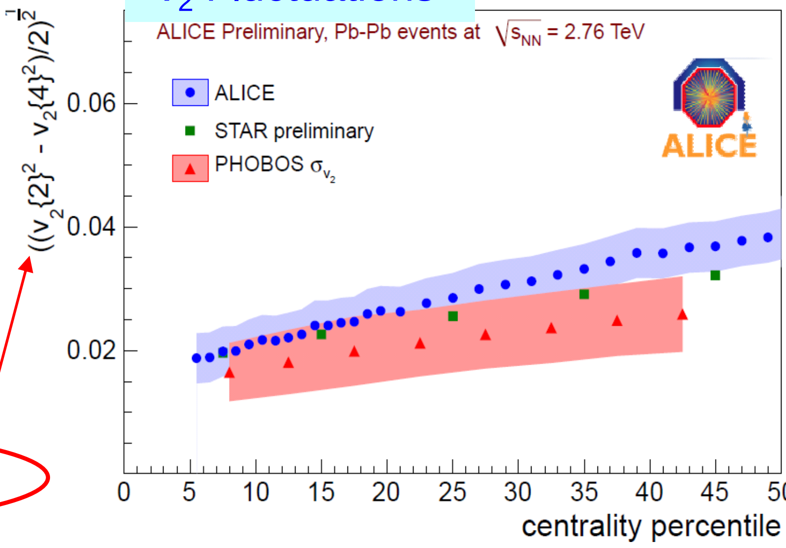
With this, we can remove most of non-flow (δ)

Plane of symmetry (Ψ_{PP}) fluctuate event-by-event around reaction plane (Ψ_{RP}) => flow fluctuation (σ_n)

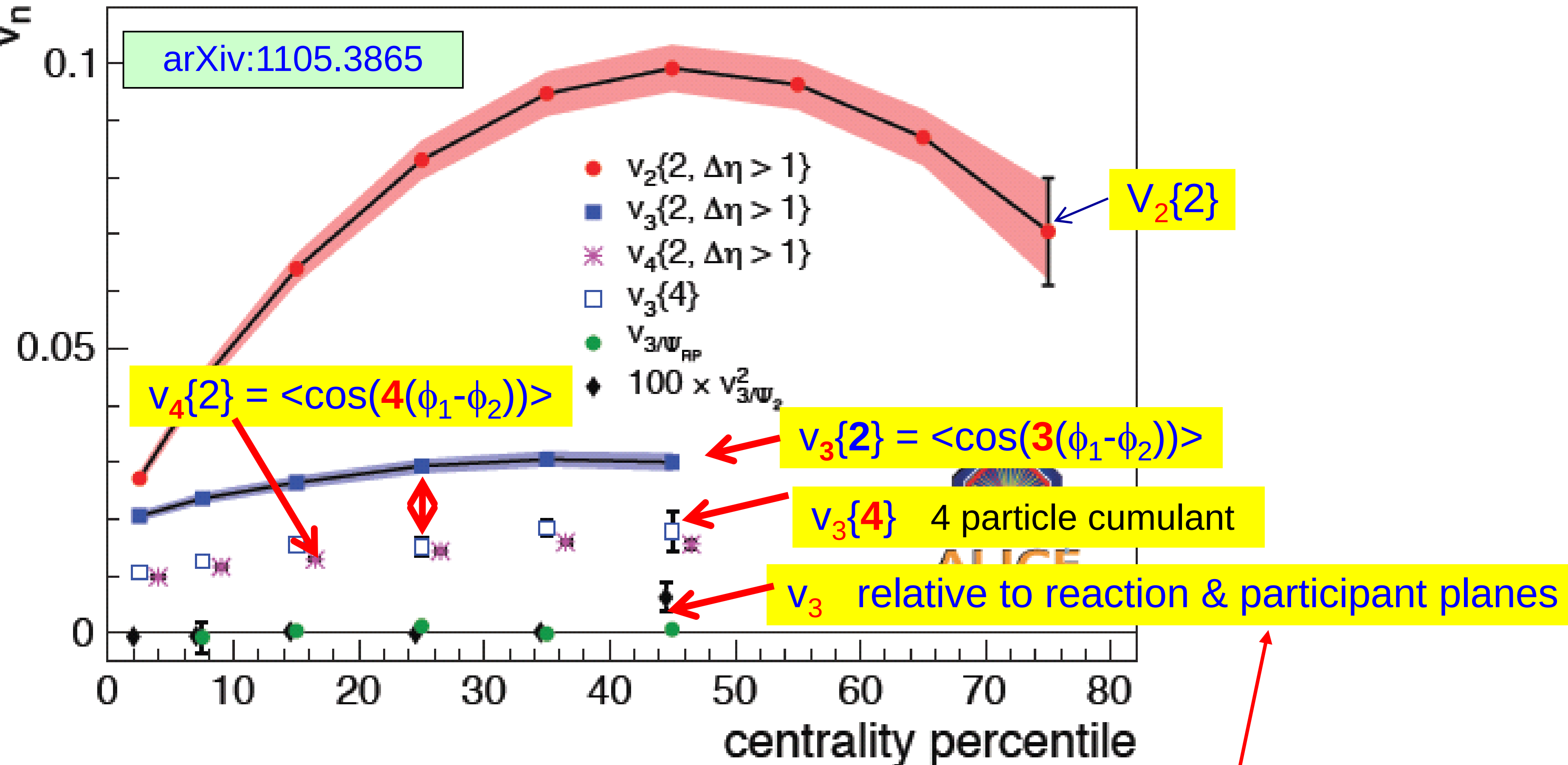


$$v_n^2\{2\} = \bar{v}_n^2 + \sigma_v^2$$
$$v_n^2\{4\} = \bar{v}_n^2 - \sigma_v^2$$
$$v_n^2\{2\} + v_n^2\{4\} = 2\bar{v}_n^2$$
$$v_n^2\{2\} - v_n^2\{4\} = 2\sigma_v^2$$

v_2 Fluctuations



Higher Order Flow v_3, v_4,..



V_3:

small dependence on centrality

$v_3\{4\} > 0$ => not non-flow

$v_3\{4\} < v_3\{2\}$ => fluctuations !

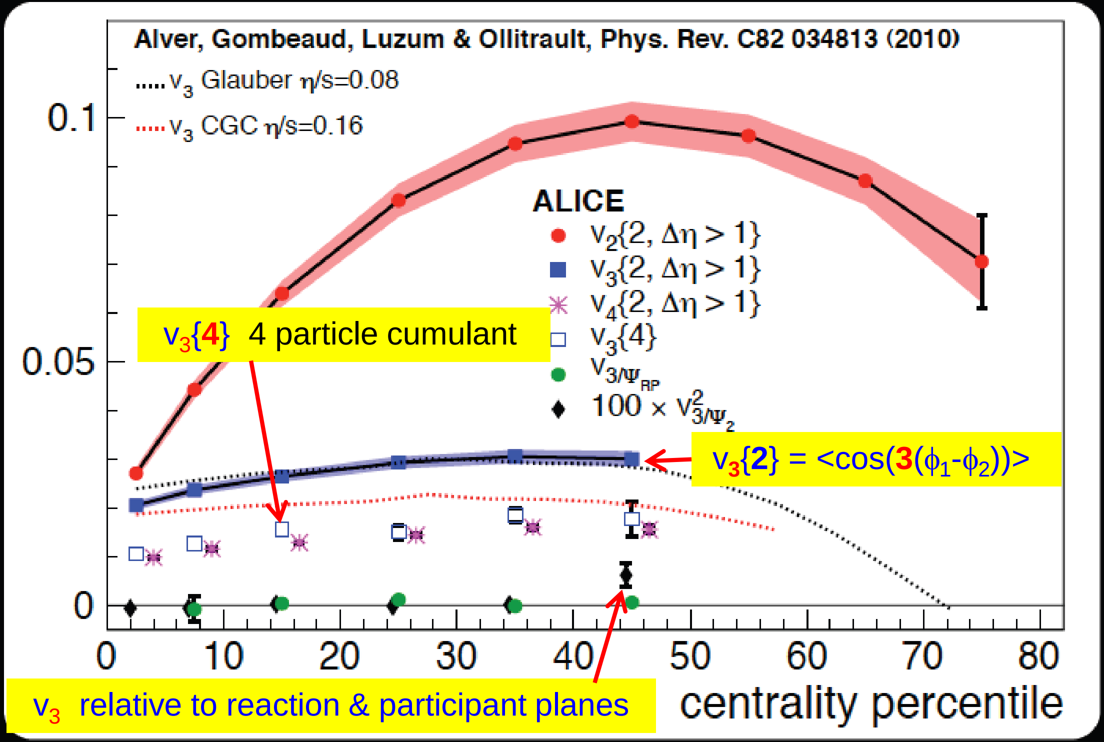
$v_3\{RP\} \approx 0$

there should be no "intrinsic" triangular flow, unlike the elliptic flow due to the almond shape of overlapping region

Triangular flow (v_3) – models

We observe significant v_3 which compared to v_2 has a different centrality dependence

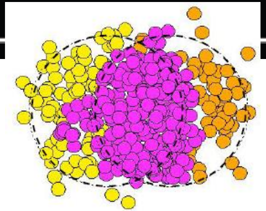
The centrality dependence and magnitude are similar to predictions for MC Glauber with η/s=0.08 but above MC-KLN CGC with η/s=0.16



ALICE Collaboration, arXiv:1105.3865

The v_3 with respect to the reaction plane determined in the ZDC and with the v_2 participant plane is consistent with zero as expected if v_3 is due to fluctuations of the initial eccentricity

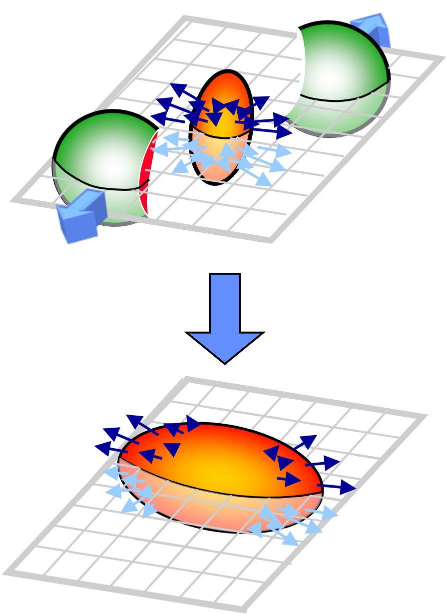
The $v_3\{2\}$ is about two times larger than $v_3\{4\}$ which is also consistent with expectations based on initial eccentricity fluctuations

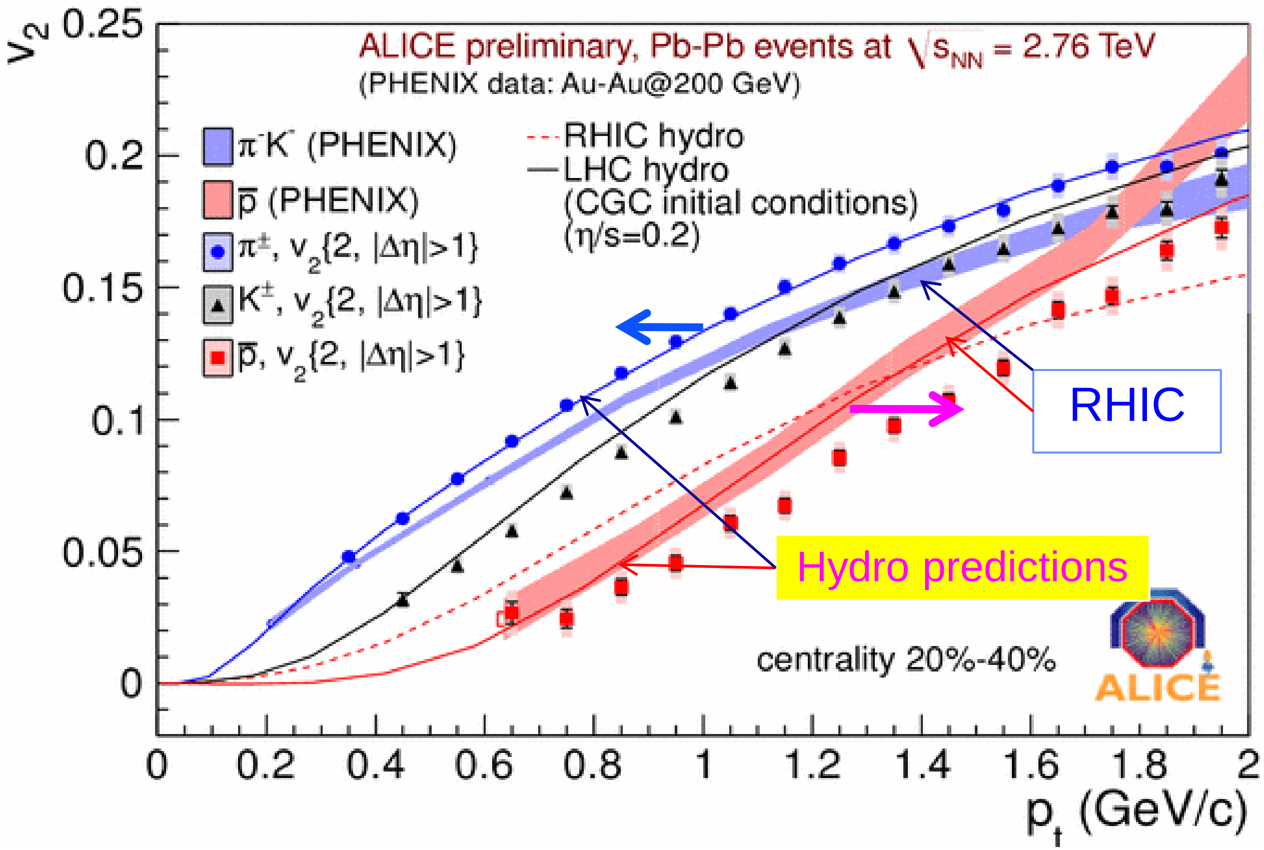


V_3 measurements are consistent with initial eccentricity fluctuation and similar to predictions for MC Glauber with η=0.08

Elliptic Flow v_2 – PID and p_t

π/K/p v_2





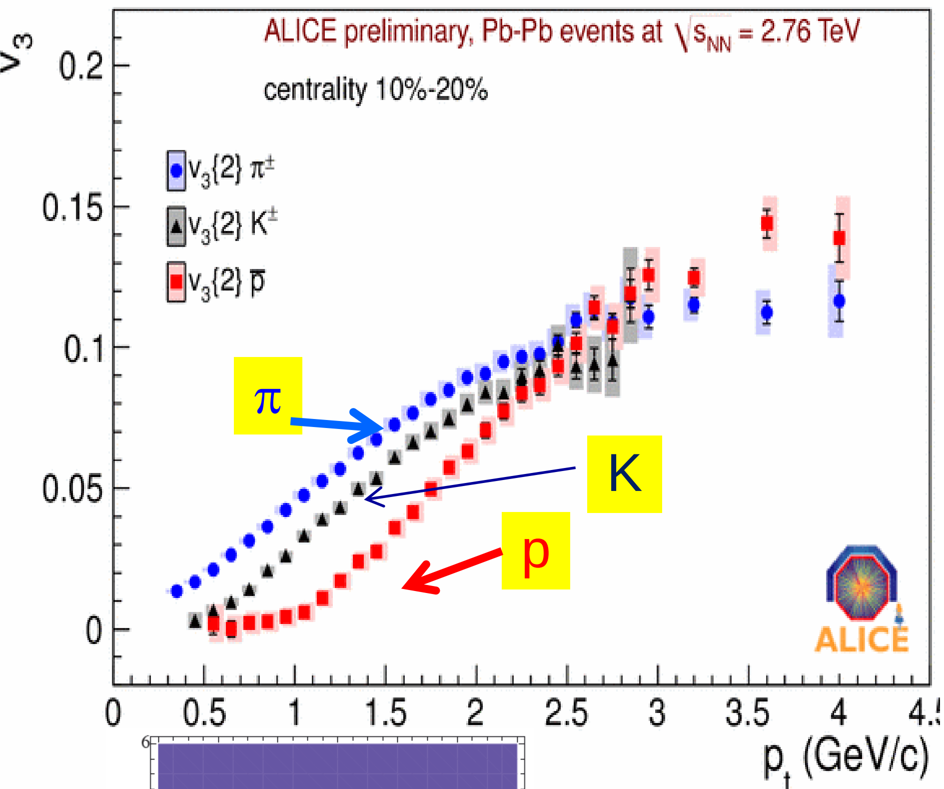
PID flow:

–π and p are 'pushed' further compared to RHIC

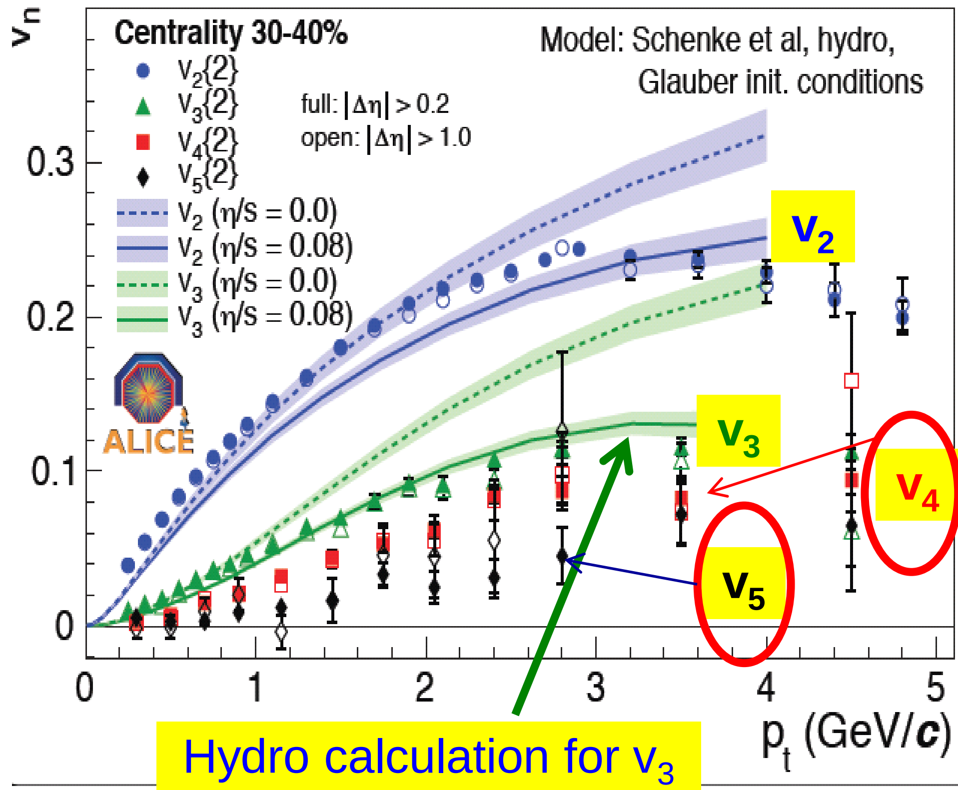
- v_2 shows mass splitting expected from hydro

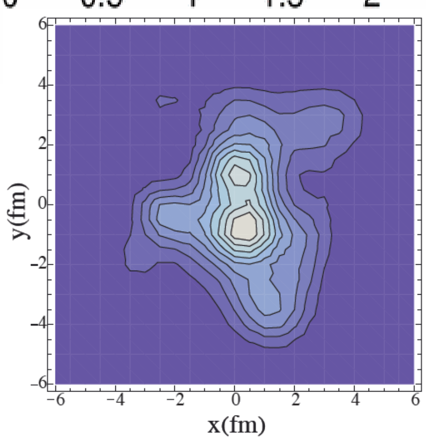
Triangular Flow v_3 – PID and p_t

v_3 for π/K/p



v_3 v_4 v_5 versus p_T





energy momentum tensor components for 1 event with b=8fm
(MC Glauber by G. Qin, H. Peterson, S. Bass. and B. Muller)

v_3 shows mass splitting expected from hydro
(shows different sensitivity to η/s than v_2)

also possible to have initial eccentricity fluctuations for square flow v_4 and pentagonal flow v_5

Summary – flow

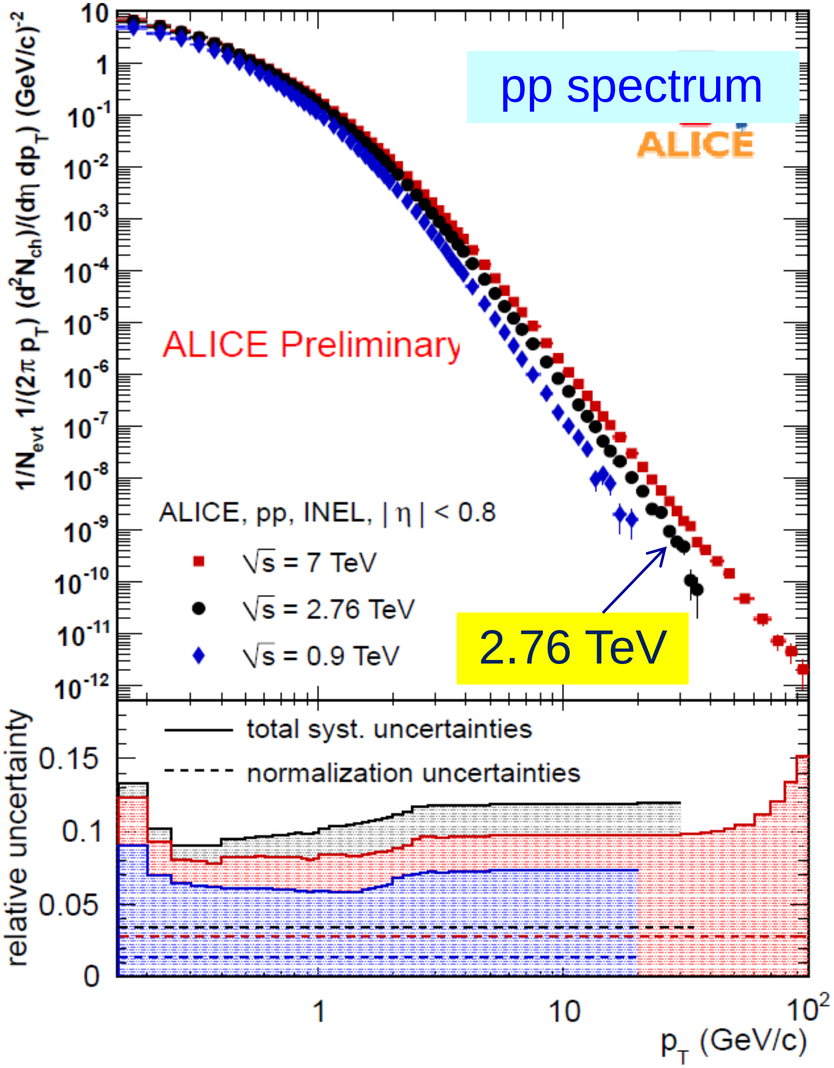
- Stronger flow than at RHIC which is expected for almost perfect fluid behavior

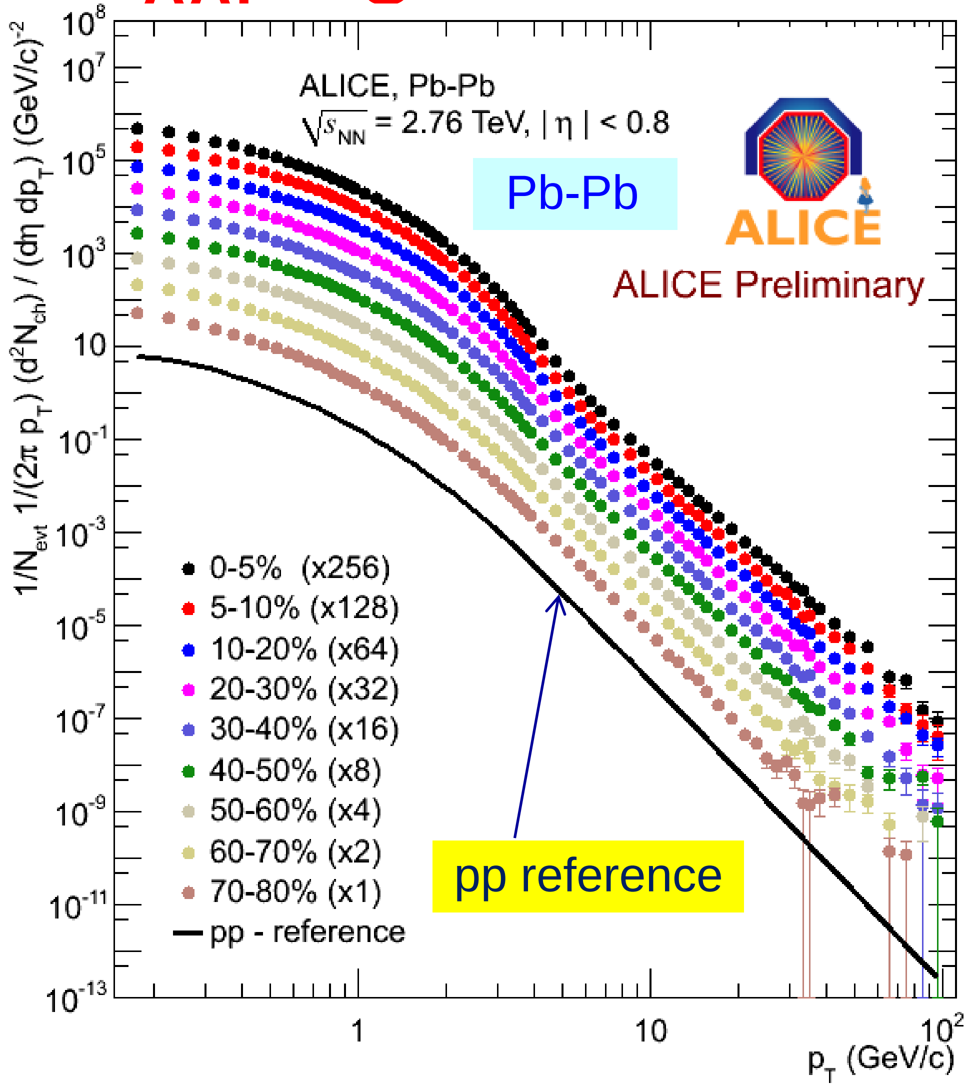
- First measurements of v3, v4 and v5, and have shown that these flow coefficients behave as expected from fluctuations of the initial spatial eccentricity

- New strong experimental constraints on η/s and initial conditions

- Flow coefficients at lower p_t showing mass splitting are in agreement with expectations from viscous hydrodynamic calculations

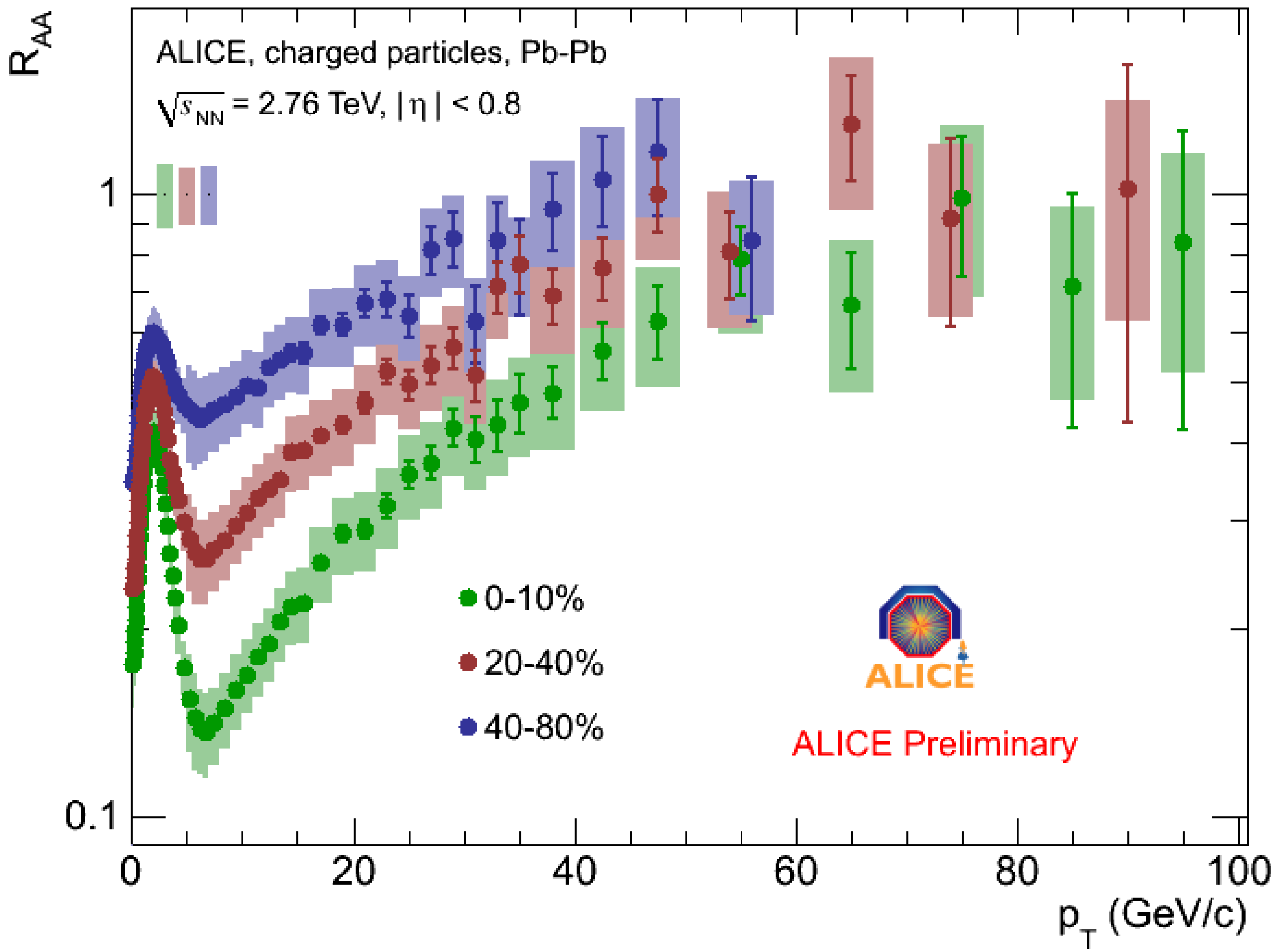
Charged Particle R_{AA}: Ingredients





Measured reference, still needs extrapolation for p_T> 30 GeV

charged particle R_{AA}

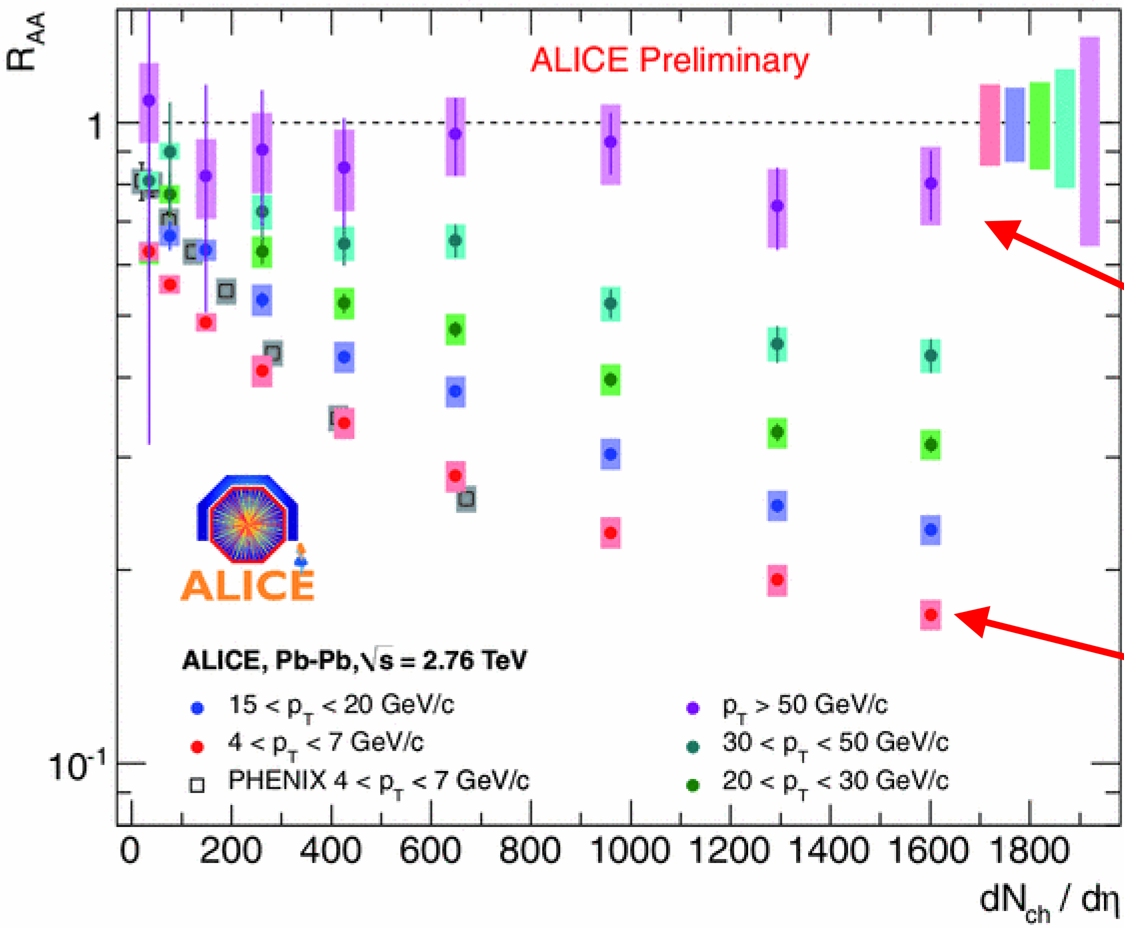


$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle N_{coll}\rangle d^2N^{pp}/dp_T d\eta}$$

$$\langle N_{coll}\rangle = \langle T_{AA}\rangle \cdot \sigma_{pp}^{INEL}$$

- pronounced centrality dependence below p_T = 50 GeV/c
- minimum at $p_T \approx$ 6-7 GeV/c
- strong rise in 6 < p_T < 50 GeV/c
- no significant centrality and p_T dependence at p_T > 50 GeV/c

charged particle R_{AA} - centrality dependence



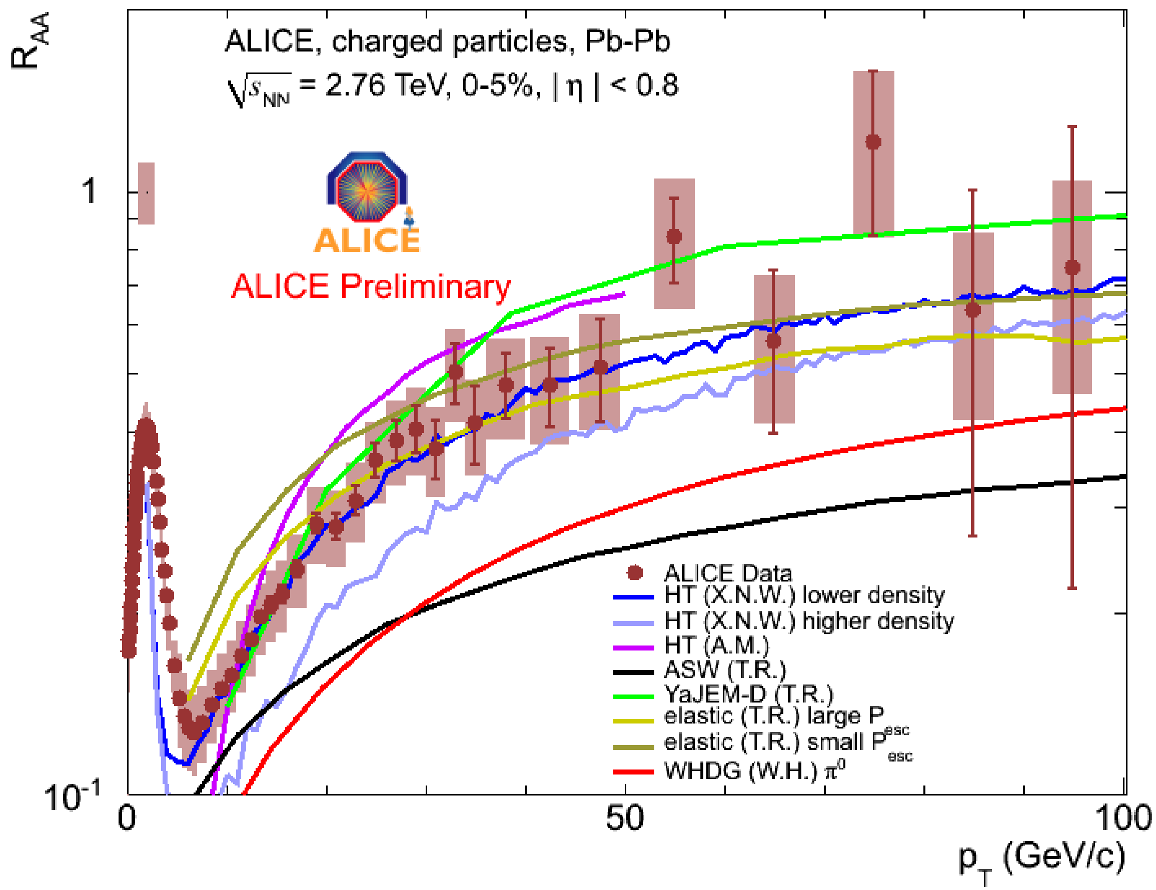
high p_T:

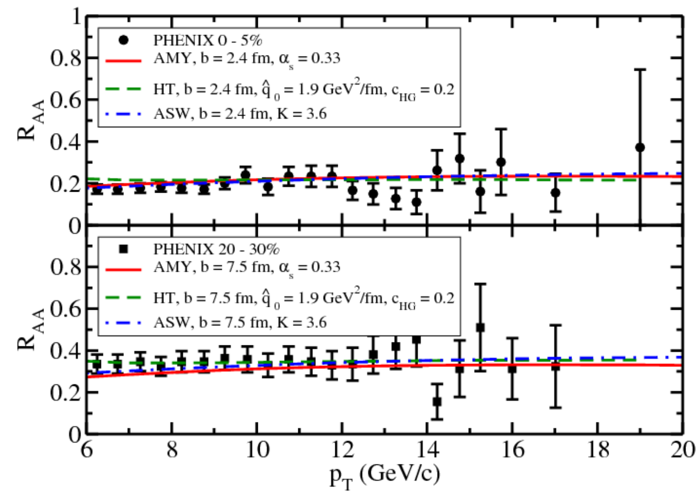
- weak suppression, no significant centrality dependence

low p_T:

- approximate scaling with multiplicity density,
- matching also RHIC results

charged particle R_{AA} - models

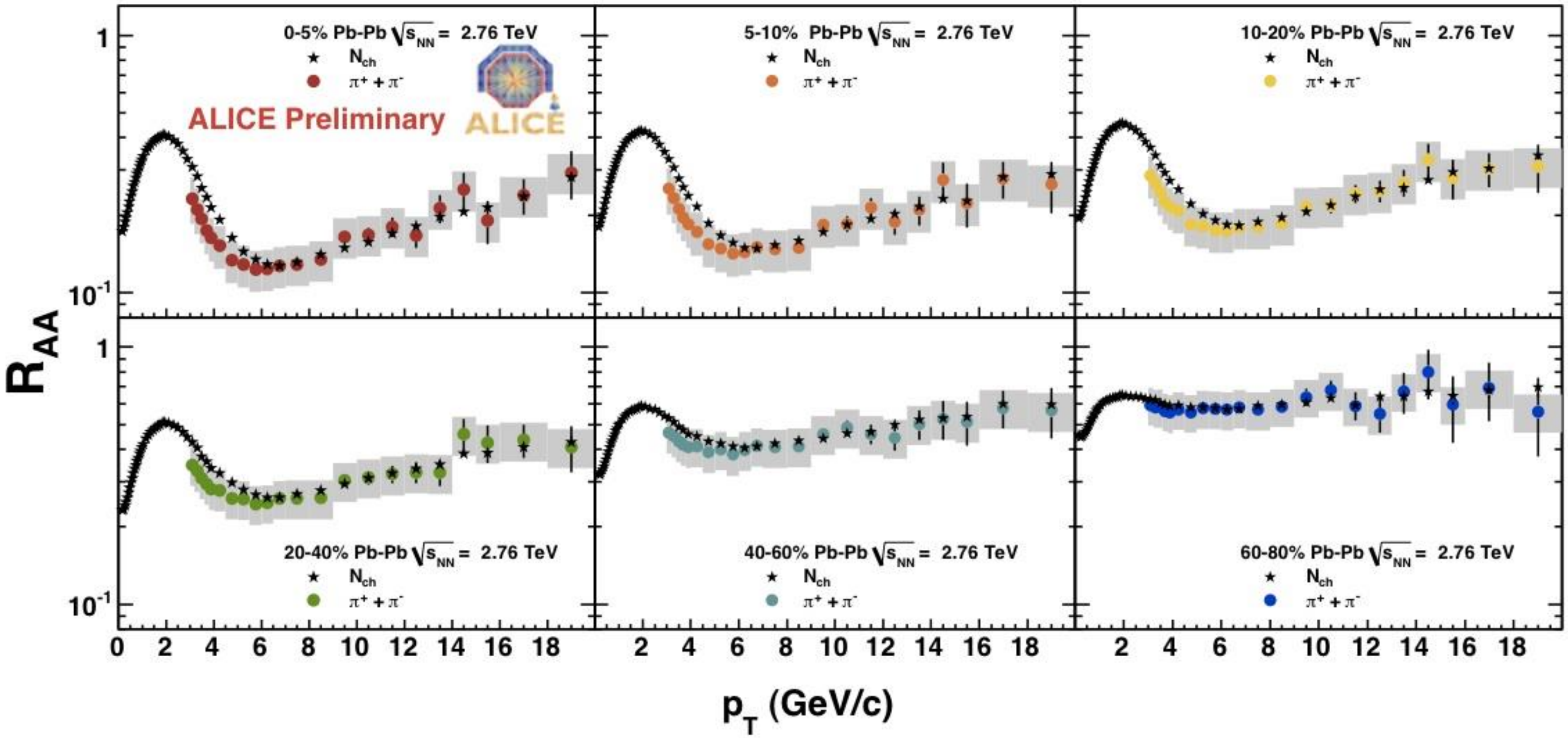




- pronounced p_T dependence of R_{AA} at LHC

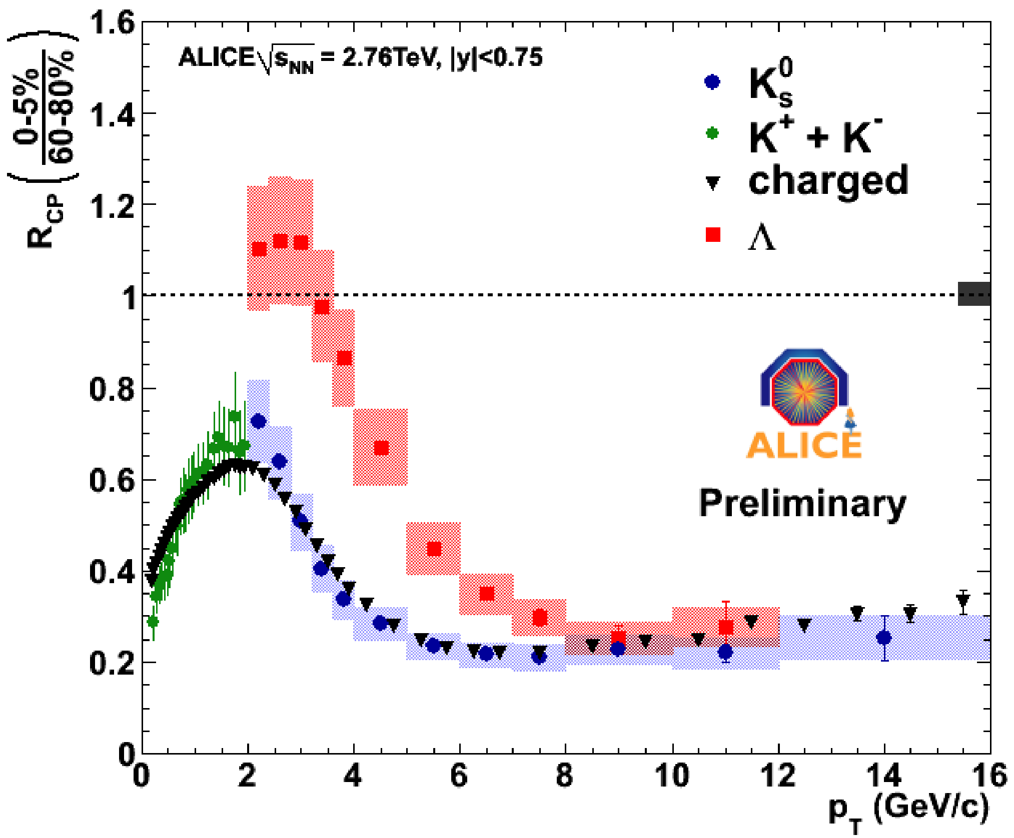
→ sensitivity to details of the energy loss distribution

charged pion R_{AA}



- agrees with charged particle R_{AA}
  - in peripheral events
  - for p_T > 6 GeV/c
- is smaller than charged particle R_{AA} for p_T < 6 GeV/c

Λ and K^0_s - R_{CP}



- K^0_s - R_{AA} very similar to that of charged particles:
  strong suppression of K^0_s at high p_T
- Λ - R_{AA} significantly larger than charged at intermediate p_T:
  enhanced hyperon production counteracting suppression
- for p_T > 8 GeV/c, Λ and K^0_s - R_{AA} similar to charged particle R_{AA}:
  strong high-p_T suppression also of Λ

Summary – R_{AA}

- Charged particle p_T spectra in Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV measured with ALICE at the LHC

- Pronounced p_T dependence of R_{AA} at LHC

- Comparison to RHIC data suggests that suppression scales with the charged particle density for a given p_T window

- At p_T > 50 GeV/c, no strong centrality dependence of charged particle production is observed

- Results on identified particles will allow to disentangle the interplay between quark and gluon energy loss, and recombination mechanisms at intermediate p_T