(Anti-)deuteron production and anisotropic flow measured with ALICE at the LHC

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For the ALICE Collaboration

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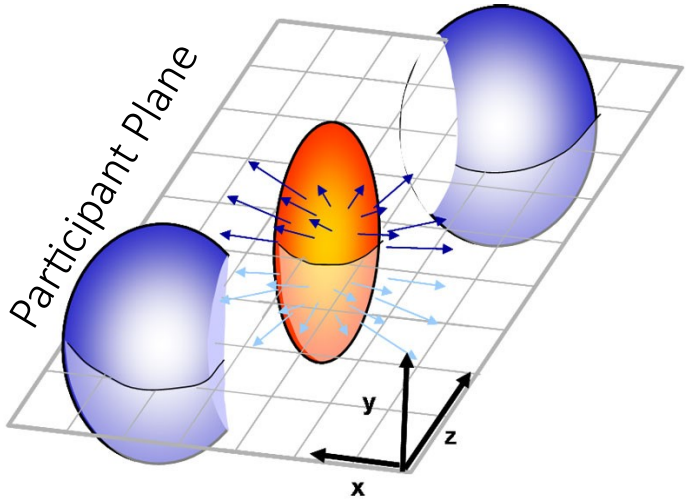
Overview

- Motivation
- Deuteron identification with the ALICE detector
- Deuteron elliptic flow measurement
- Comparison of the measured deuteron v_2 with other identified particles and scaling tests

Results from (anti-)(hyper-)Nuclei Production and Searches for Exotic Bound States with ALICE at the LHC
N. Sharma
28/09/15

Motivation



Angular distribution of reconstructed charged particles can be expanded into a Fourier series w.r.t. symmetry plane $\Psi_{\{n\}}$:

$$E\frac{d^3N}{dp^3}=\frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n\left(\varphi-\Psi_{\{n\}}\right)\right)\right)$$

$$v_n=\left\langle\cos\left(n\left(\varphi-\Psi_{\{n\}}\right)\right)\right\rangle$$

- Elliptic flow (v_2) is sensitive to the system evolution:
  - Constrains initial conditions and particle production mechanisms
- Identified particle v_2 vs transverse momentum allows for the study of:
  - rate of hydrodynamic radial expansion (mass dependence of v_n vs. p_T)
  - properties of the deconfined phase (e.g. viscosity)
  - details of hadronization mechanism (e.g. coalescence)

Motivation – Deuteron

- The measurement of light nuclei v_2 will help in the understanding of particle production mechanisms

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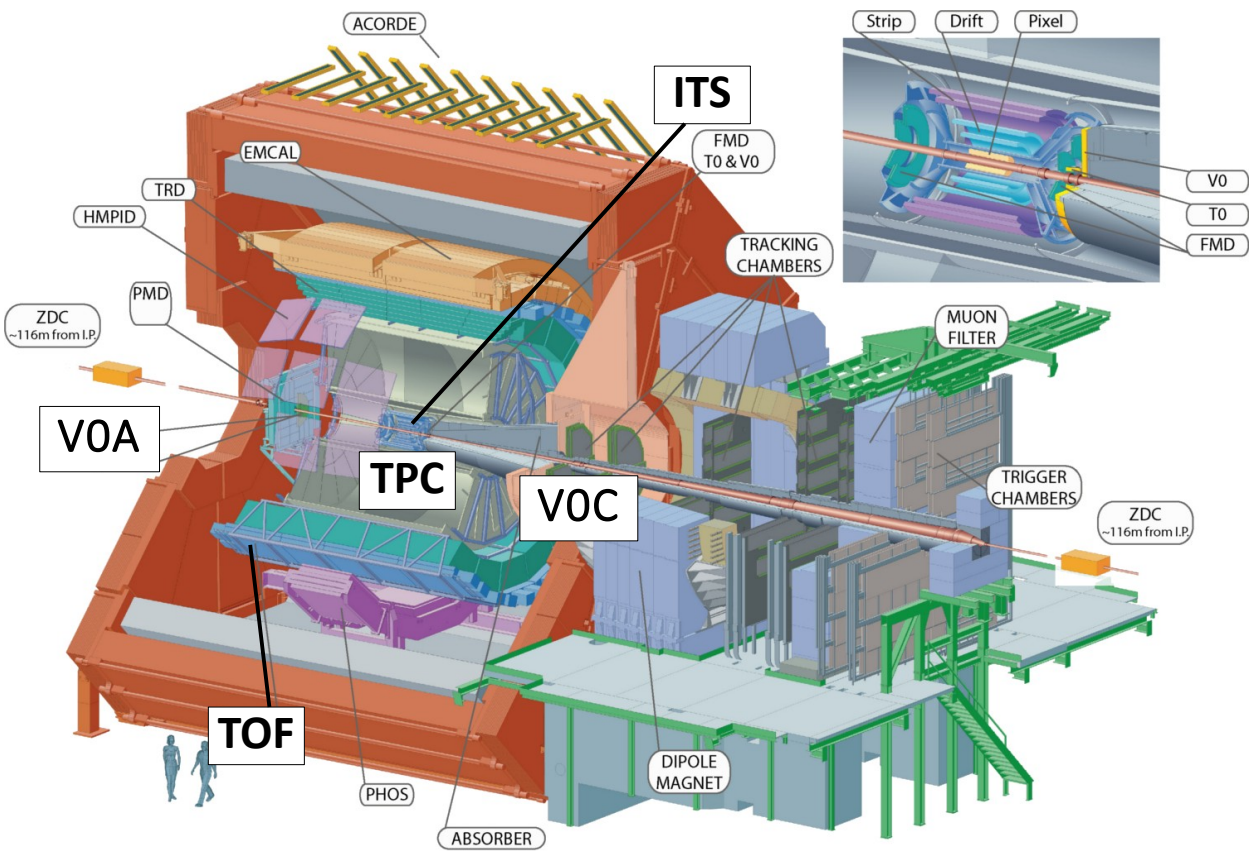
- The measurement of light nuclei v_2 will help in the understanding of particle production mechanisms

- Do deuterons follow the mass ordering observed for lighter particles?
- Do deuterons follow a mass scaling or are better described by hydrodynamical based models?

ALICE Detector



Inner Tracking System (ITS) :
- Primary vertex
- Tracking
- Particle identification via d*E*/d*x*

Time Projection Chamber (TPC):
- Tracking
- Particle identification via d*E*/dx

Time Of Flight (TOF):
- Particle identification via velocity measurement

V0A and V0C:
- Centrality classes
- Symmetry plane determination

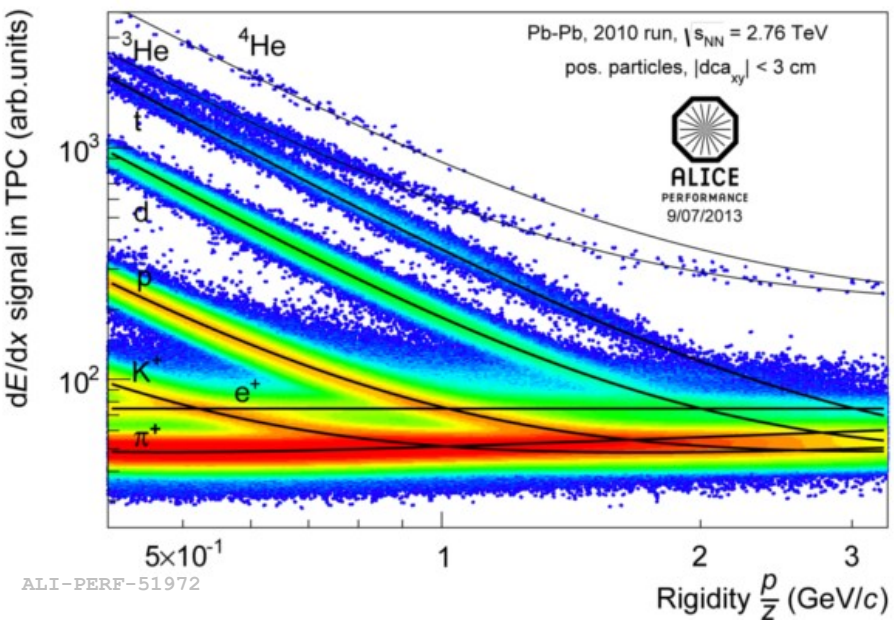
JHEP 06(2015) 190; arXiv:1405.4632

Deuteron identification

Low momenta

Nuclei identification via dE/dx measurement in the TPC:

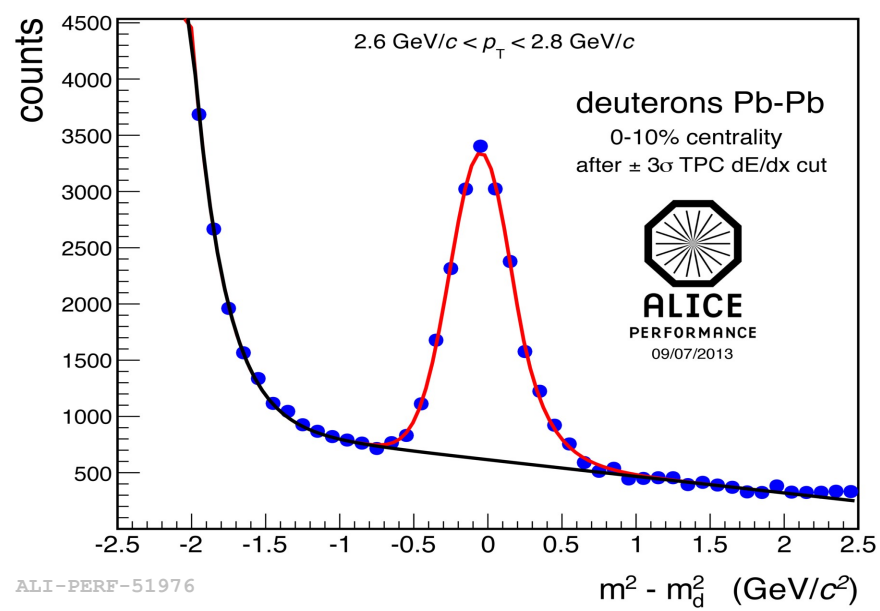
- dE/dx resolution in central Pb-Pb collisions: 7%
- Excellent separation of (anti-)nuclei from other particles over a wide range of momentum



Higher Momenta

Velocity measurement with the Time Of Flight detector is used to evaluate the m^2 distribution.

- Excellent TOF performance: $\sigma_{TOF} \approx 85$ ps in Pb-Pb collisions.
- ±3σ-cut around expected TPC dE/dx for deuterons reduces drastically the background from TPC and TOF mismatch



Flow analysis details

Analyzed data samples

- Pb - Pb at $\sqrt{s_{NN}}$ = 2.76 TeV (~ 35M events)
- Events are classified into 6 different centrality intervals

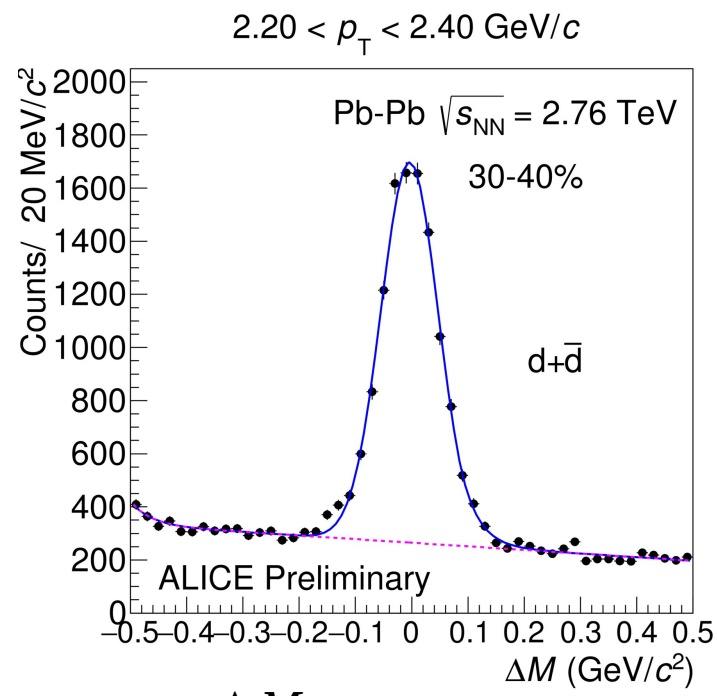
Deuteron identification

Identical to spectra analyses:

1) Energy loss in TPC: require dE/dx signal to be within 3σ of expected value for all p_T
2) Time of flight: fit to mass signal of TOF for p_T>1 GeV/c

Track selections:

- 0.5 < p_T < 5 GeV/c
- -0.8 < η < 0.8



$$\Delta M = m_{TOF} - m_{d_{PDG}}$$

Fit function: Total : Gauss + Exponential tail + Exponential

Flow analysis method

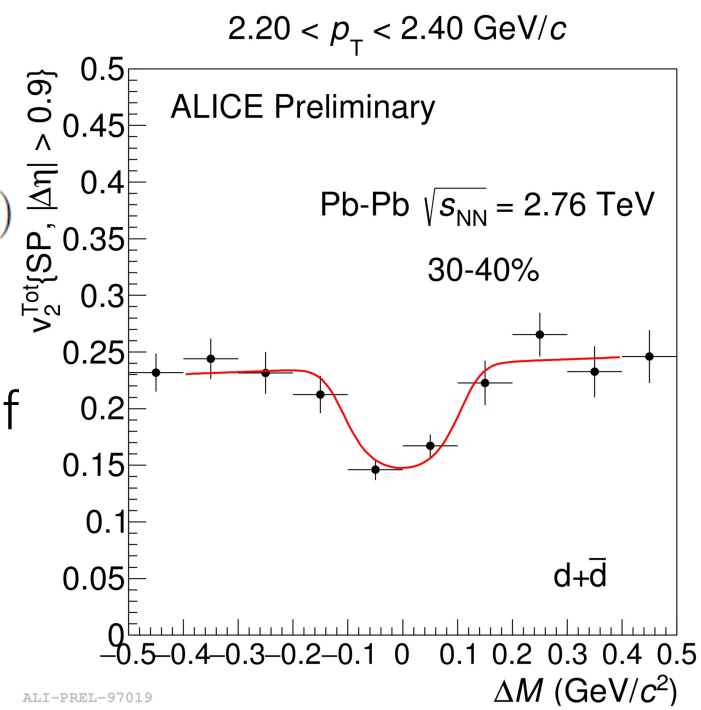
- v_2 is measured using the scalar product method
  - Hits measured by V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$) are used as reference particles
  - Deuteron candidates are the particles of interest ($|\eta|<0.8$)

$$v_n\{\mathrm{SP}\} = \frac{\left\langle u_{n,i}(p_T,\eta)\cdot\frac{Q_n^*}{M}\right\rangle}{\sqrt{\left\langle\frac{Q_{n,A}^*}{M_A}\cdot\frac{Q_{n,B}^*}{M_B}\right\rangle}}$$

- The contribution to the measured elliptic flow (v_2^{Tot}) due to misidentified deuterons (v_2^{Bkg}) was removed by studying the azimuthal correlations versus ΔM ($\Delta M = m_{TOF} - m_d$)

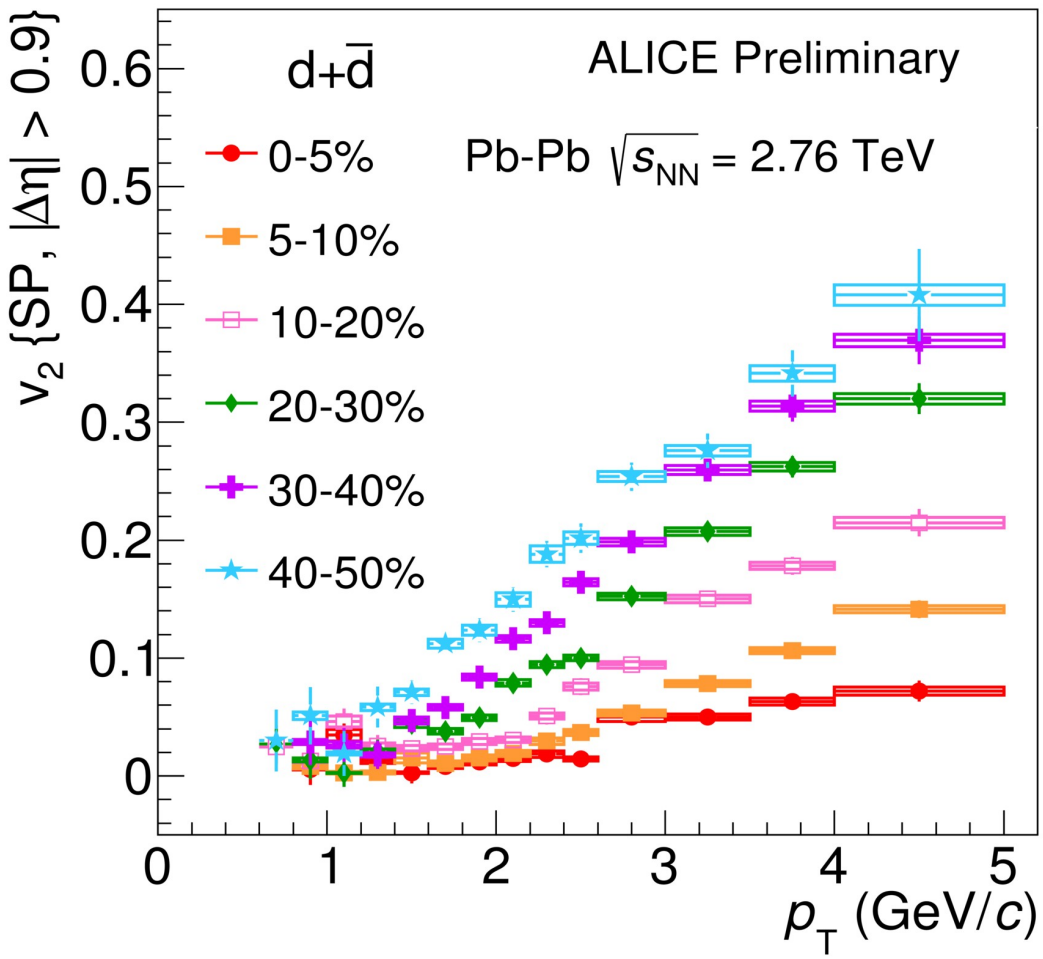
$$v_2^{Tot}(\Delta M) = v_2^{Sig}(\Delta M)\frac{N^{Sig}}{N^{Tot}}(\Delta M) + v_2^{Bkg}(\Delta M)\frac{N^{Bkg}}{N^{Tot}}(\Delta M)$$

- The yields N^{Sig} and N^{Bkg} are extracted from fits of the invariant mass distribution obtained with the TOF detector



Deuteron v_2 for different centralities

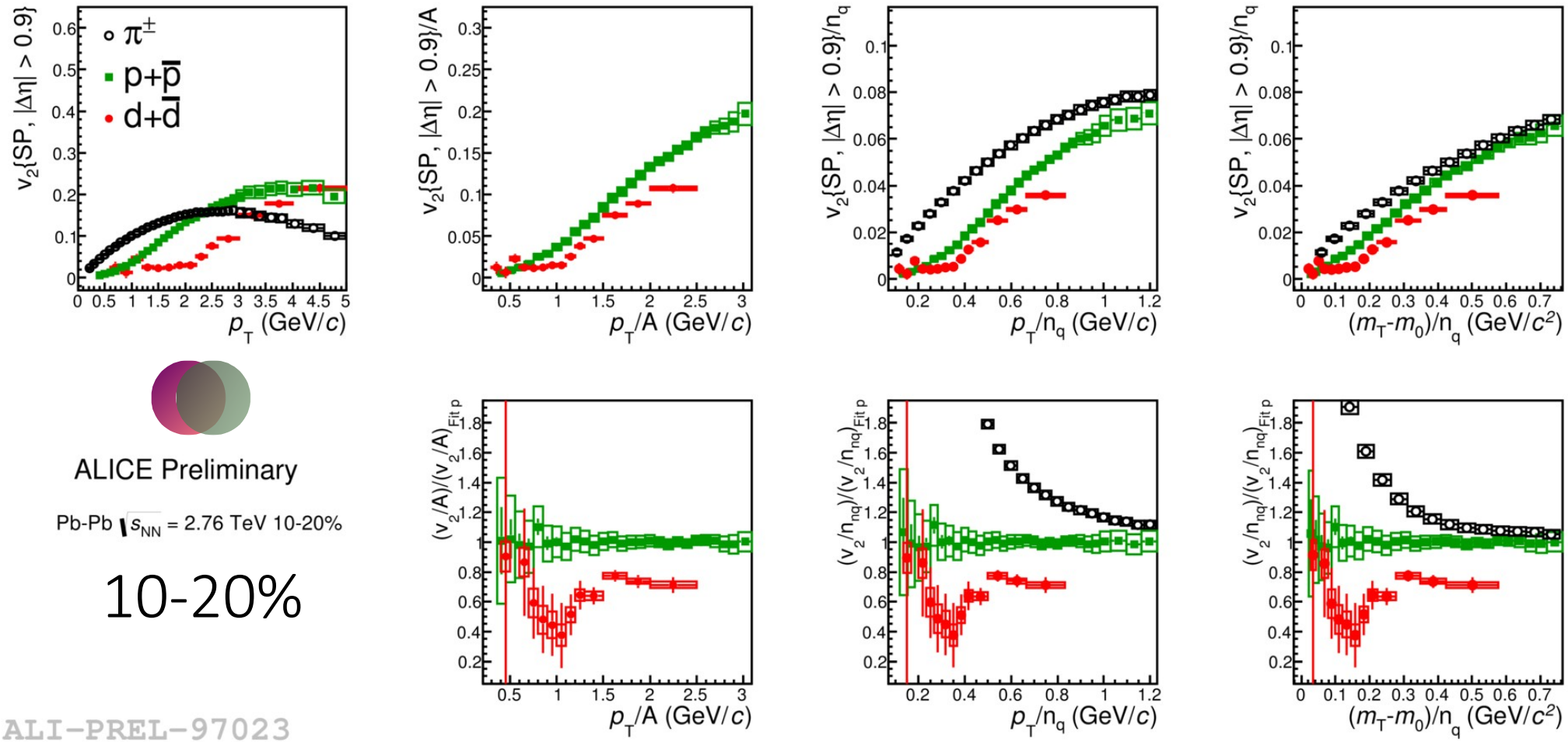
Stat. Unc.: lines
Syst. Unc.: boxes



The value of v_2 (p_T) increases progressively from central to semi-central collisions

Comparison with π and p

$\pi^{\pm}$ and (p+$\bar{p}$) from : JHEP 06 (2015) 190 (arXiv:1405.4632)



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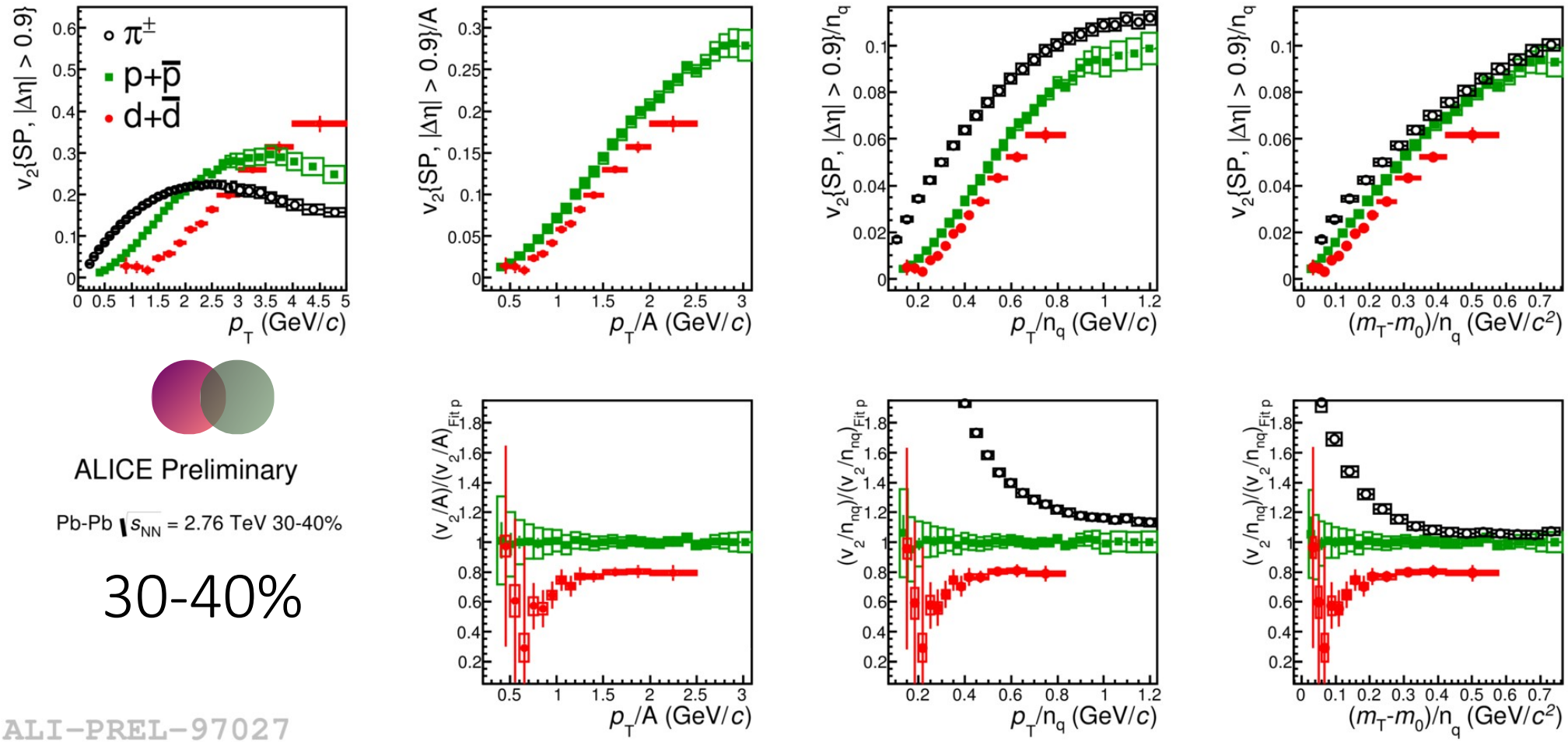

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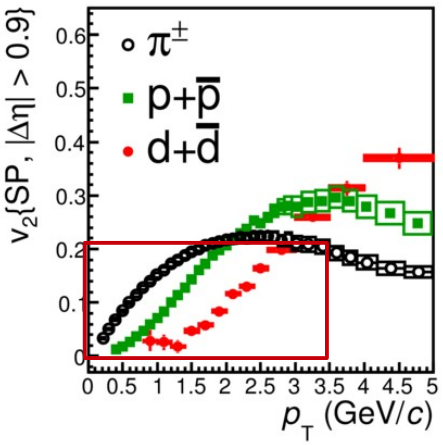

30-40%

ALICE Preliminary

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 30-40%

Low p_T: deuterons follow mass ordering → Radial Flow

ALI-PREL-97027

p_T/A scaling

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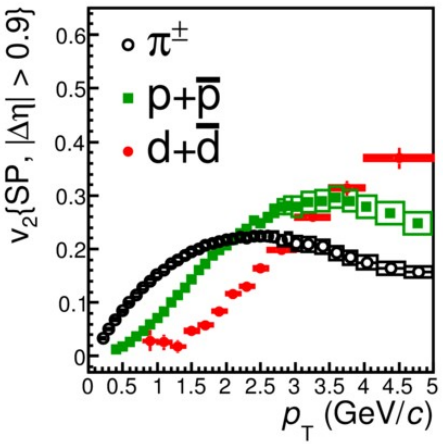

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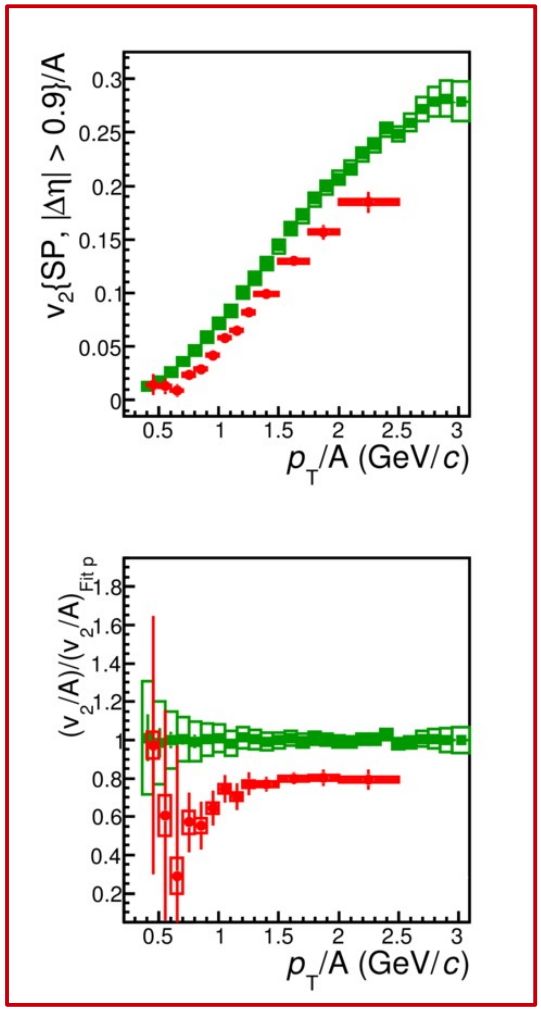

<u>Compare deuteron and proton</u>: p_T/A scaling

- For p_T /A >1 GeV/c: A scaling deviations of the order of ~20%
  - Similar magnitude for all measured centrality classes

p_T/n_q scaling

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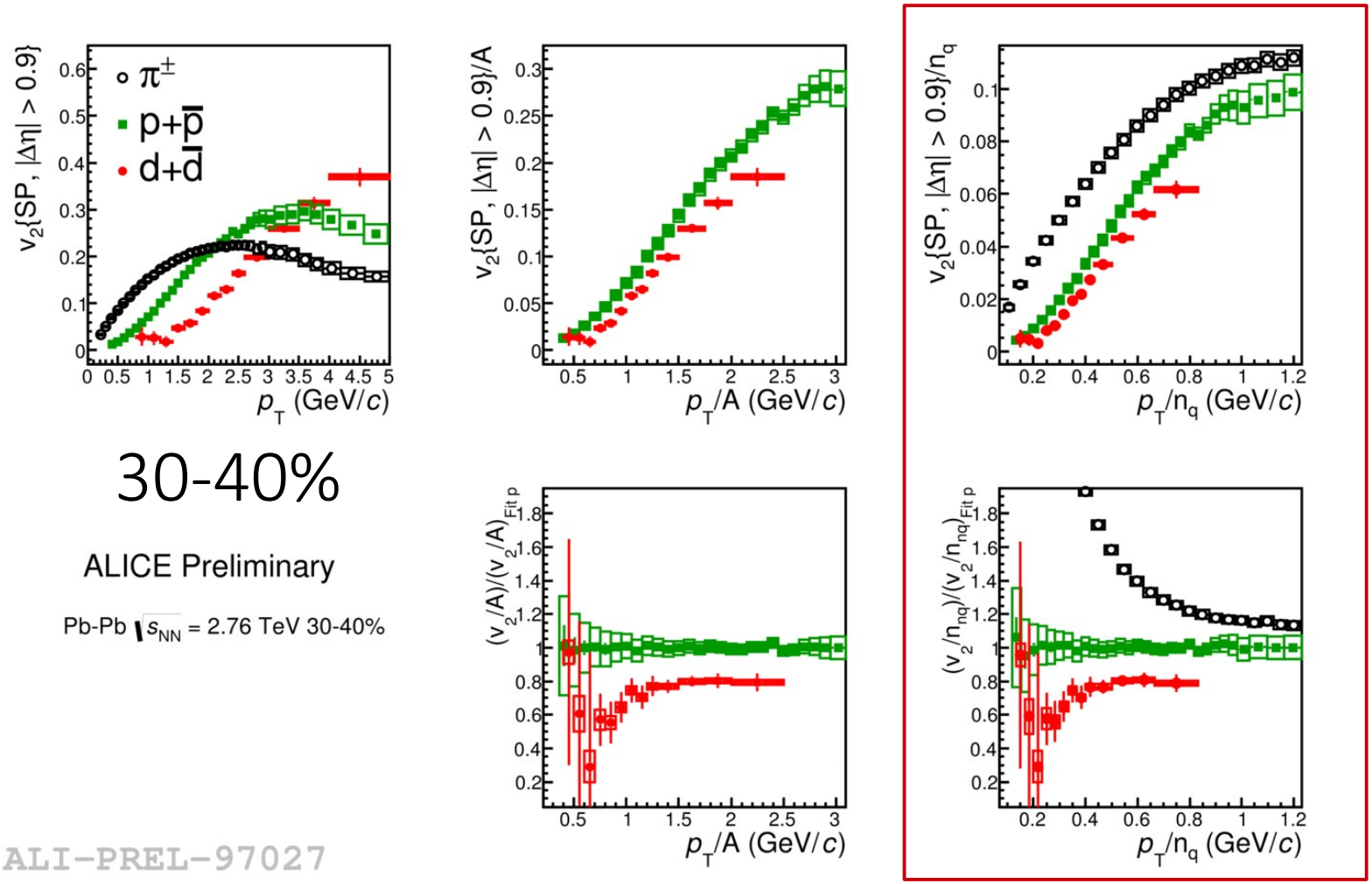

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ALI-PREL-97027

<u>Compare deuteron with π and protons</u>: p_T/n_q scaling

- For p_T/n_q >~ 0.5 GeV/c: n_q scaling deviations of the order of ~20%
  - Similar magnitude for all measured centrality classes

KE_T/n_q scaling

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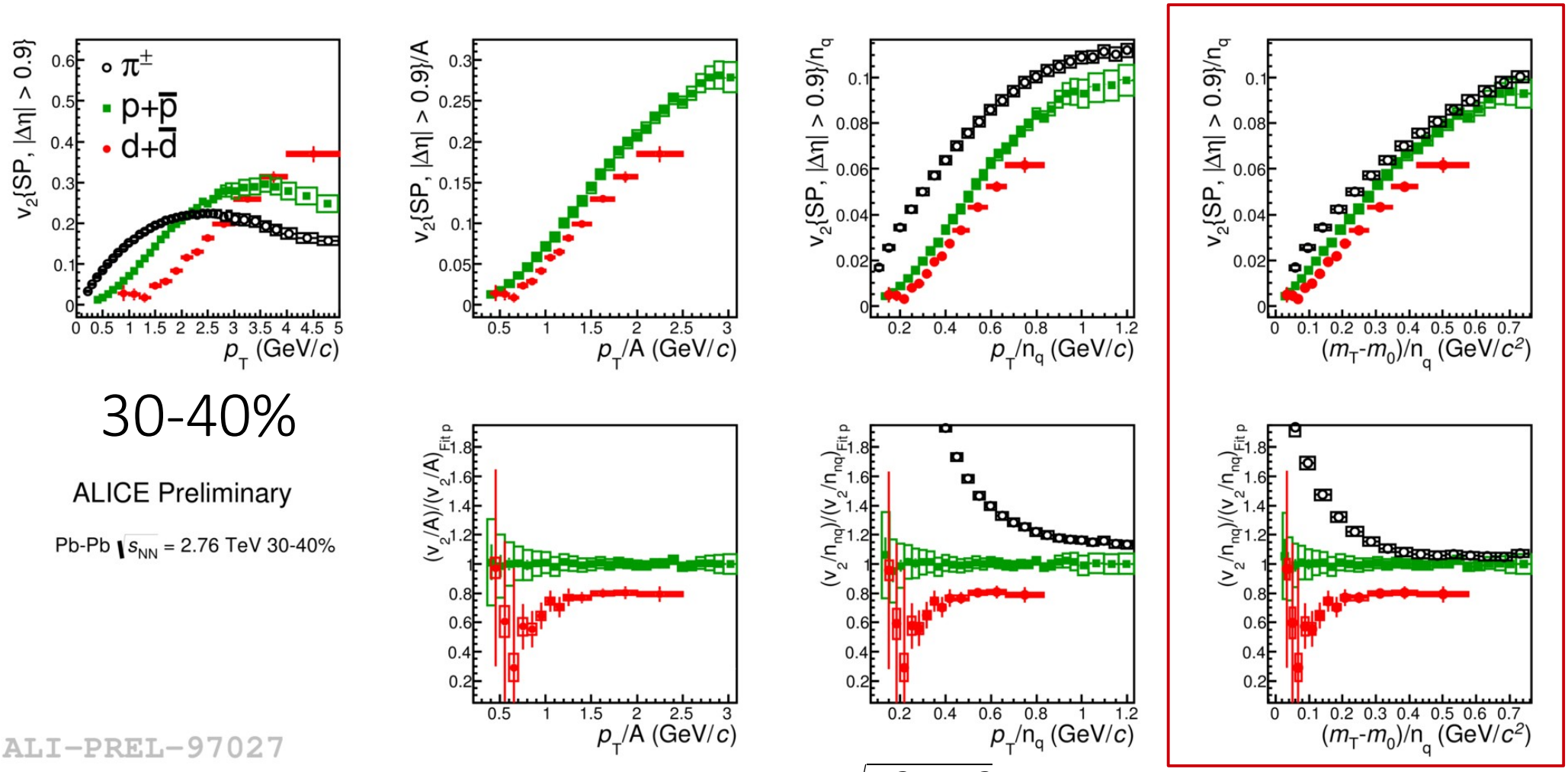


$$KE_T = m_T - m_0 \qquad m_T = \sqrt{p_T^2 + m_0^2}$$

For $KE_T/n_q < 0.6$ GeV/c^2:significant deviations from NCQ scaling are seen in data for d

- Similar magnitude for all measured centrality classes

Blast-Wave model

- Hydrodynamical calculations are able reproduce the main features of v_2 for p_T<2 GeV/c
- A simple model based on hydrodynamics is the Blast-Wave model [1,2]:

$$v_2(p_t) = \frac{\int_0^{2\pi} d\phi_s \cos(2\phi_s) I_2[\alpha_t(\phi_s)] K_1[\beta_t(\phi_s)][1 + 2s_2 \cos(2\phi_s)]}{\int_0^{2\pi} d\phi_s I_0[\alpha_t(\phi_s)] K_1[\beta_t(\phi_s)][1 + 2s_2 \cos(2\phi_s)]}.$$

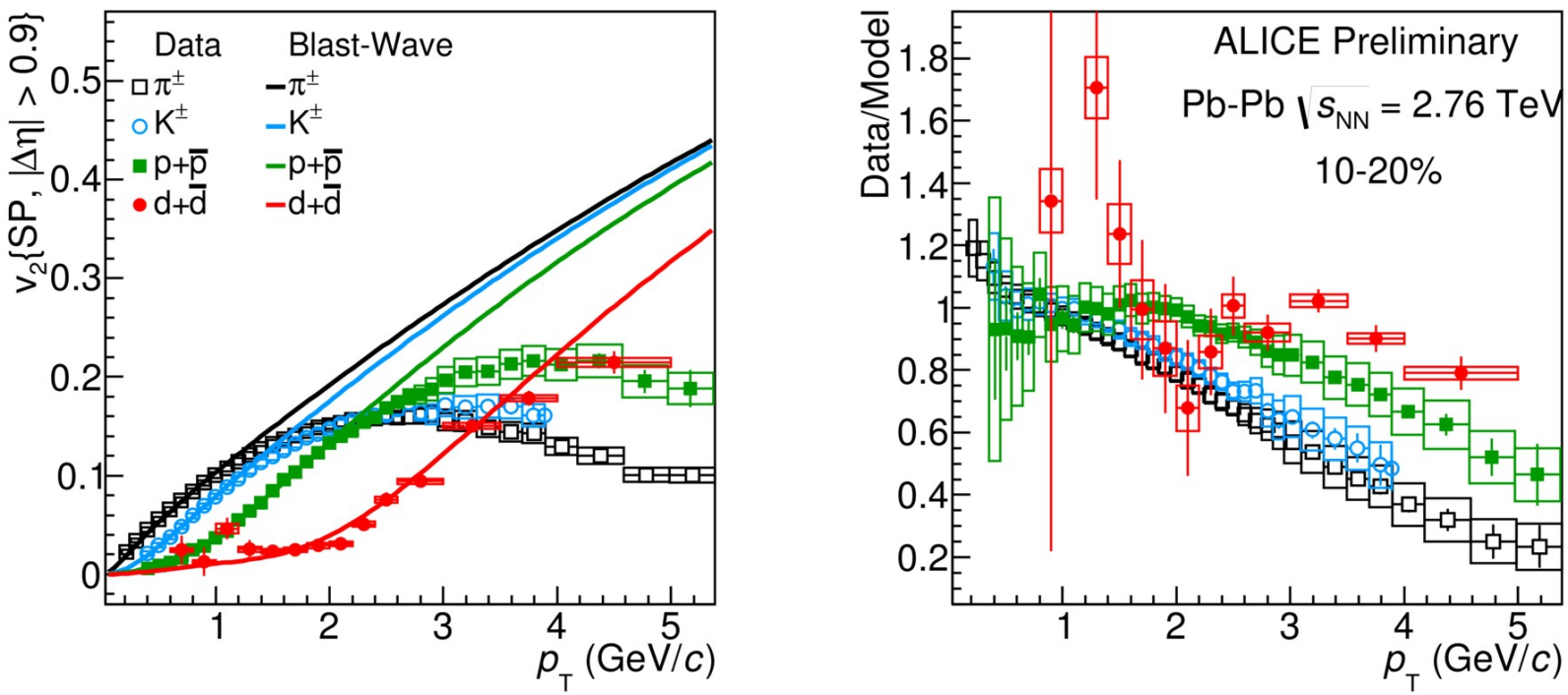
Where I_0, K_1 and I_2 are modified Bessel function, and the function has 4 free parameters + the mass of the particle

- Measured π,K,p p_T spectra and $v_2(p_T)$ were fitted, and the parameters were used to predict deuteron $v_2(p_T)$

Blast-Wave model:
[1] P. Huovinen et al. Phys. Lett. B 503, 58-64 (2001)
[2] STAR Collaboration, Phys. Rev. Lett. 87, 182301 (2001)

Blast-Wave model

10-20%

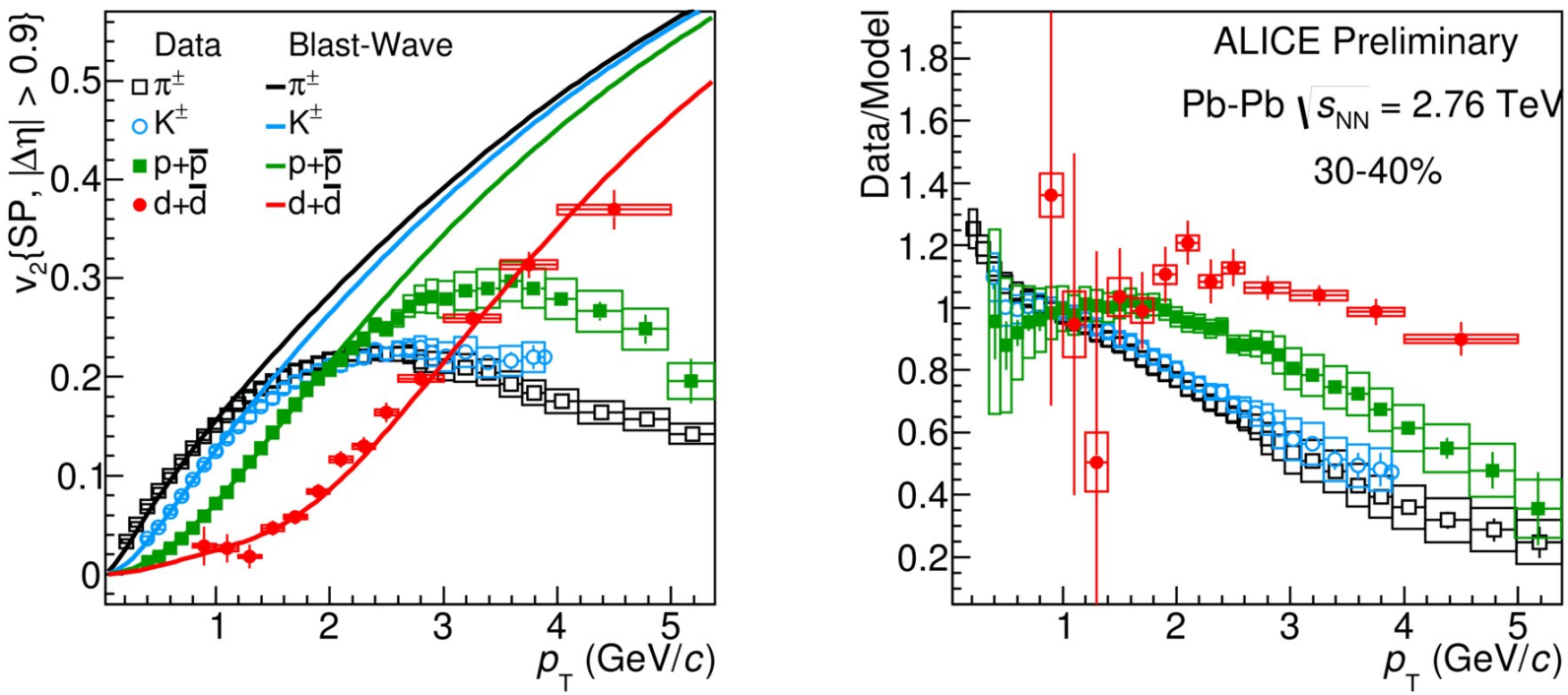


v_2 Blast-Wave curve for deuteron is predicted from combined fit of π,K,p p_T spectra and $v_2(p_T)$

- Good description of the data in the measured p_T range

Blast-Wave model

30-40%

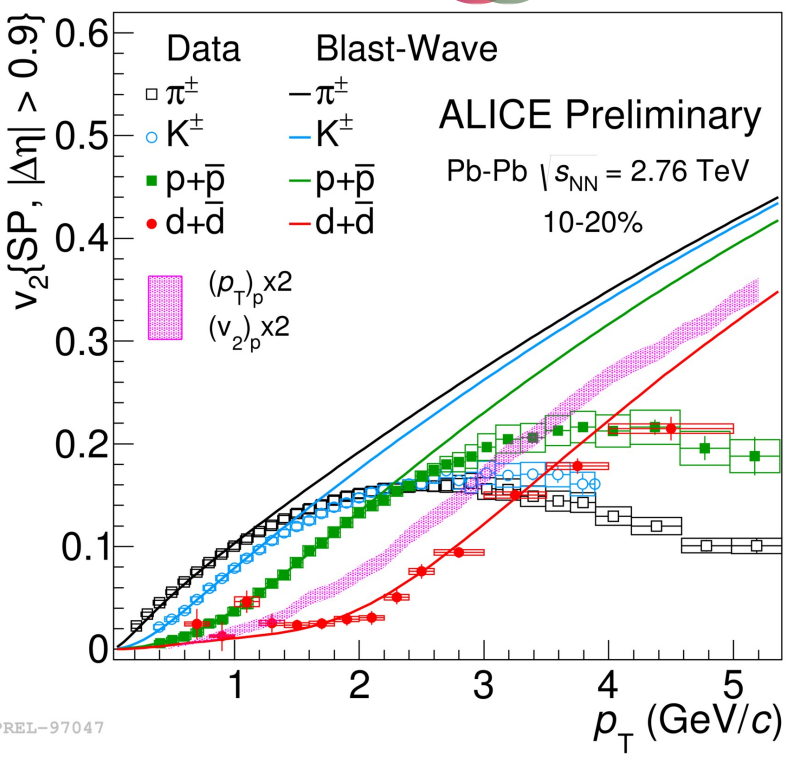


v_2 Blast-Wave curve for deuteron is predicted from combined fit of π,K,p p_T spectra and $v_2(p_T)$

- Good description of the data in the measured p_T range and for all the measured centralities

Blast-wave vs Coalescence

10-20%



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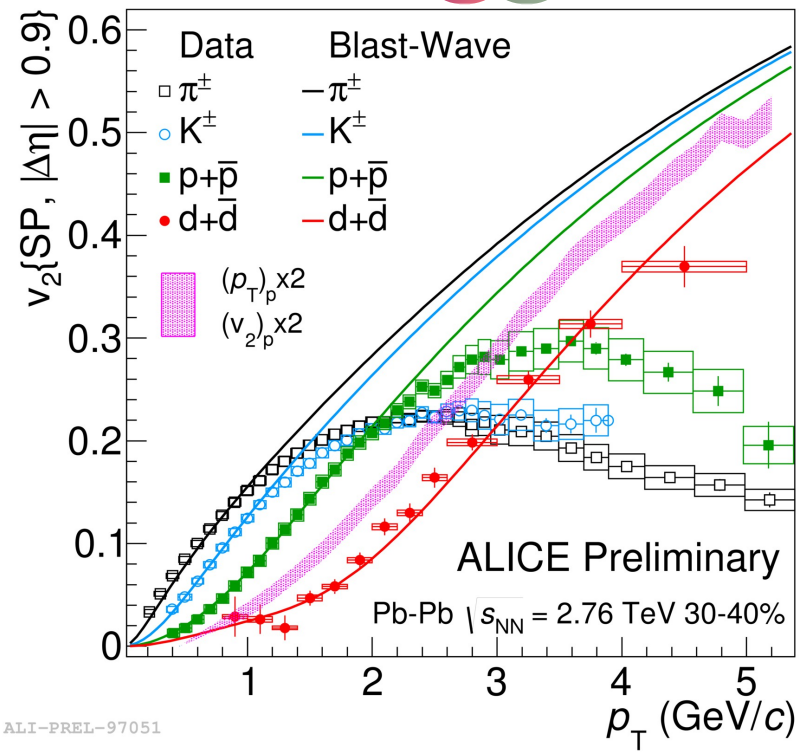
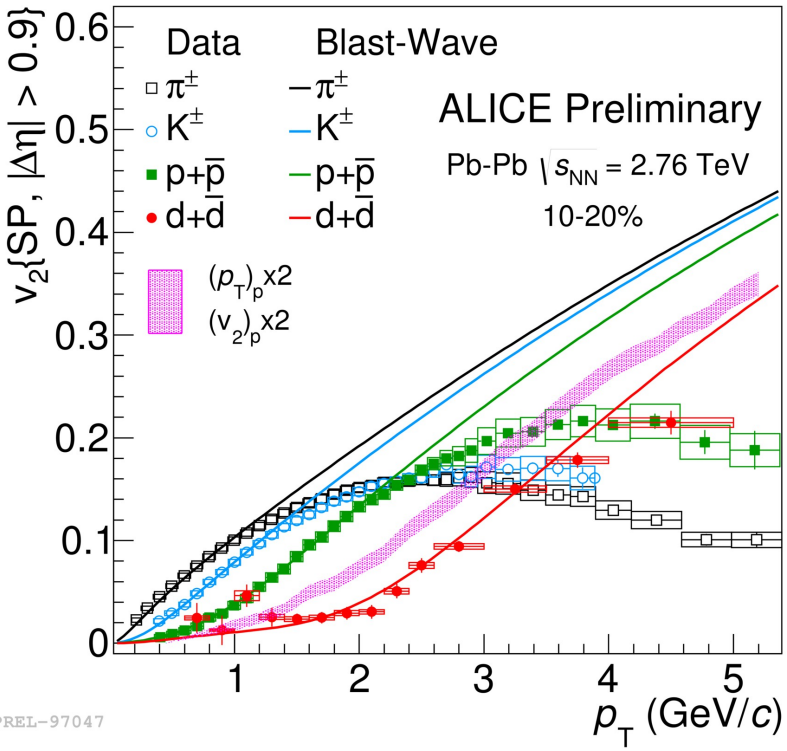


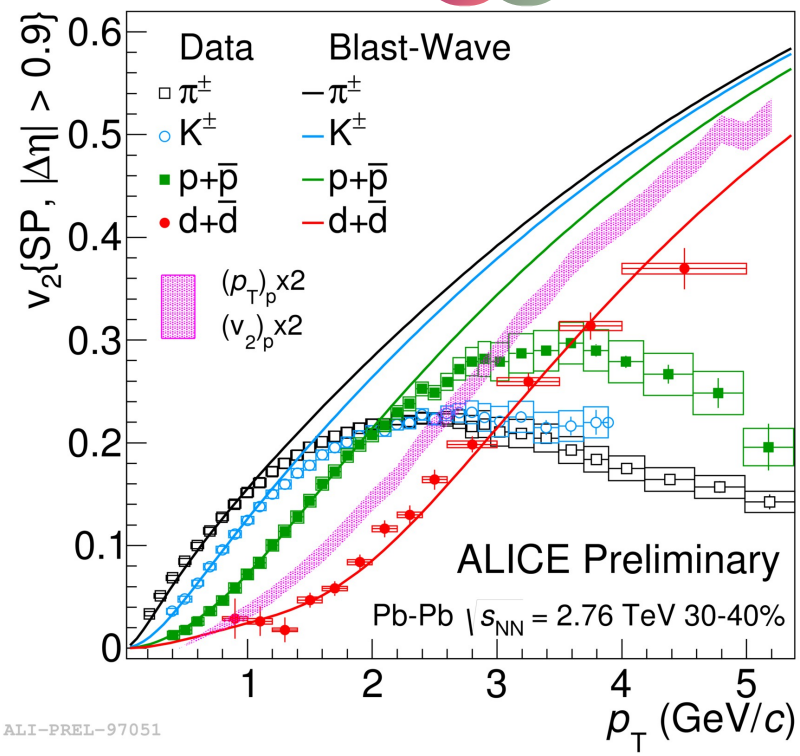
- How does the Blast-Wave prediction differ from expectations from coalescence?
  - The measured v_2 of protons was used to compute the expected v_2 of deuterons (reverse n_q scaling = both p_T and v_2 of measured p was multiplied by 2) and the results were compared to data and Blast-Wave curves:

Blast-wave vs Coalescence

10-20%



30-40%



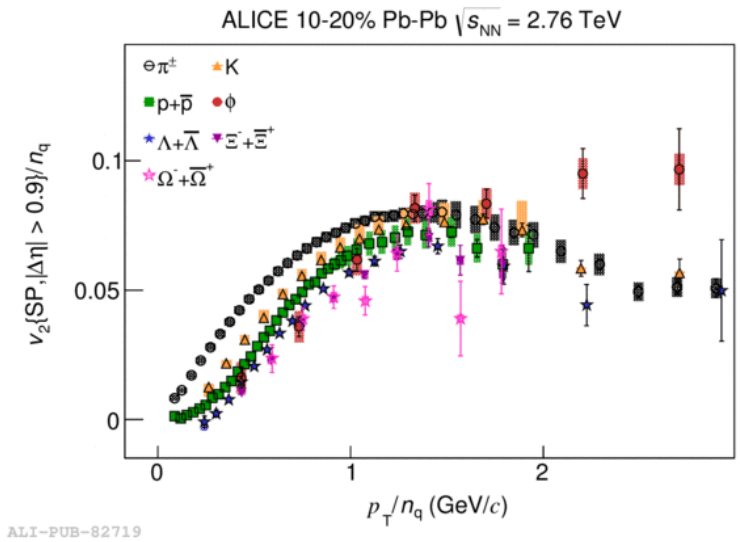
- How does the Blast-Wave prediction differ from expectations from coalescence?
  - The measured v_2 of protons was used to compute the expected v_2 of deuterons (reverse n_q scaling = both p_T and v_2 of measured p was multiplied by 2) and the results were compared to data and Blast-Wave curves:
    - simple coalescence model does not describe deuteron v_2, while the Blast-Wave model gives a good description of the measured elliptic flow of deuterons

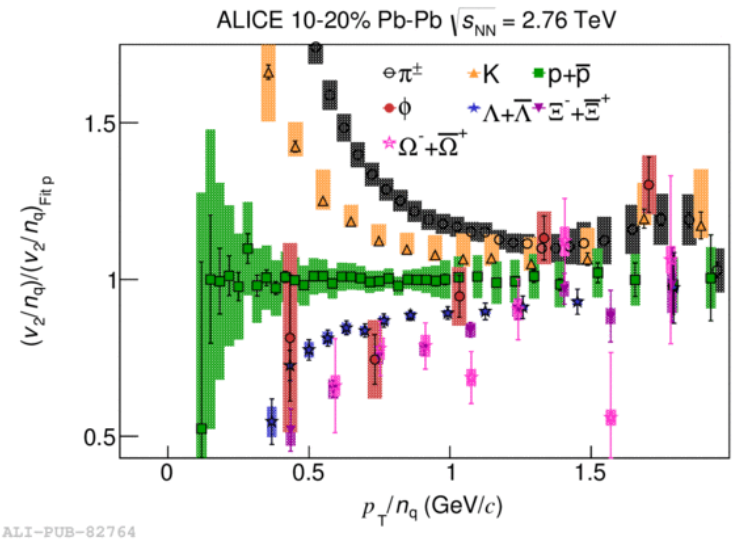
Conclusions

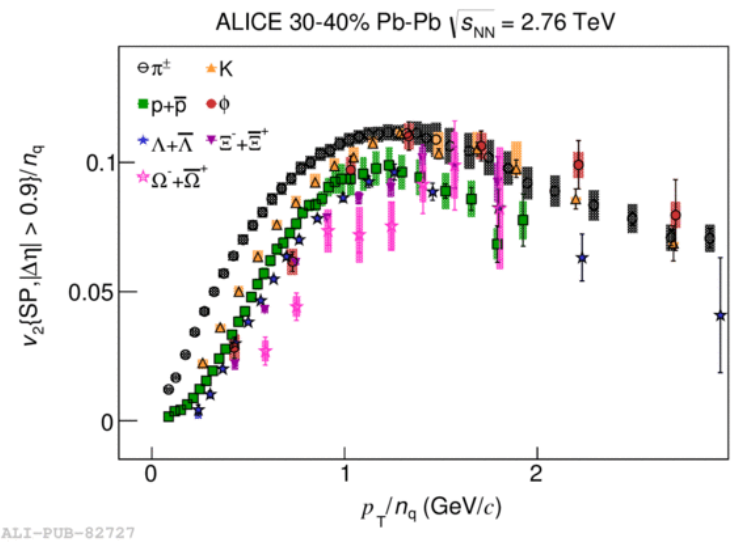
- Deuteron v_2 was measured up to 5 GeV/*c* using the scalar product technique:
  - At low p_T, deuteron v_2 follows mass ordering, indicating a more pronounced radial flow in most central collisions, as observed also for lighter particles
  - A deviation from A (number of mass) and NCQ scaling at the level of ±20% was observed
  - The Blast-Wave model gives a good description of the measured elliptic flow of deuterons

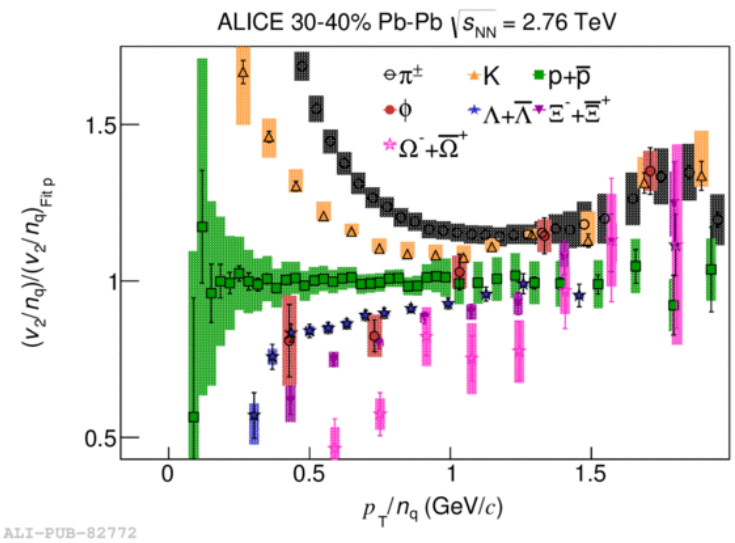
BACKUP

p_T/n_q scaling: measured identified particle

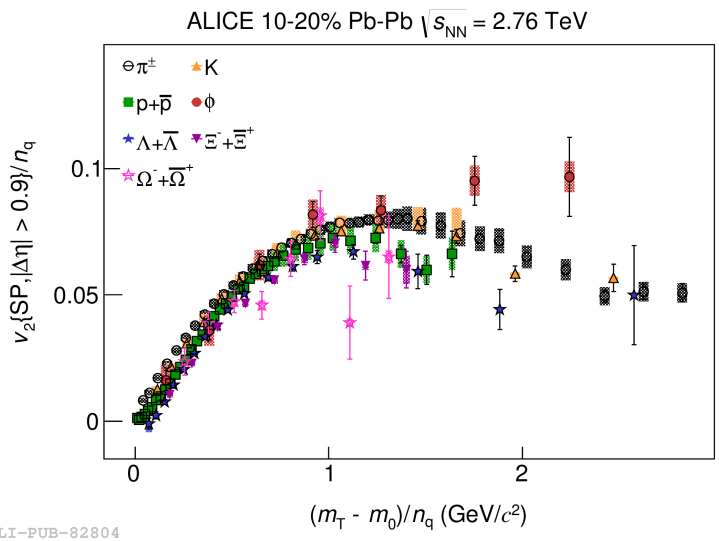


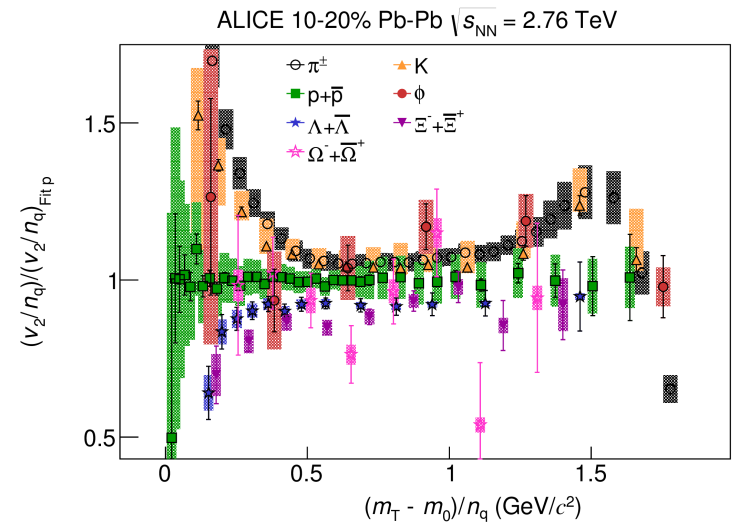


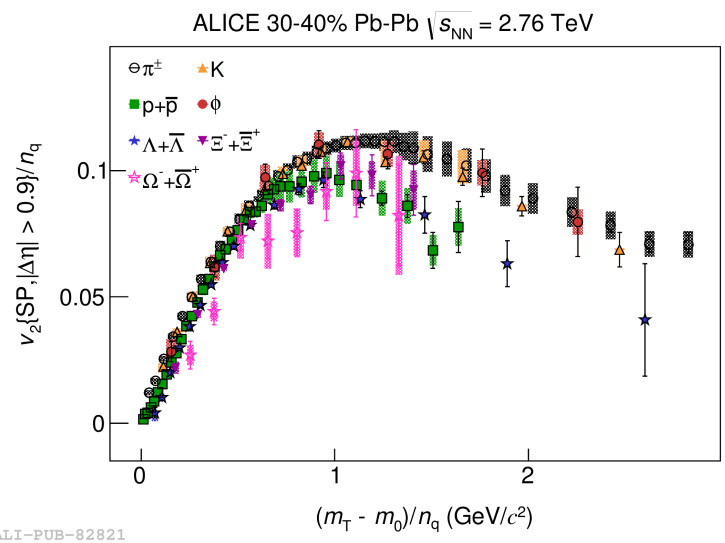


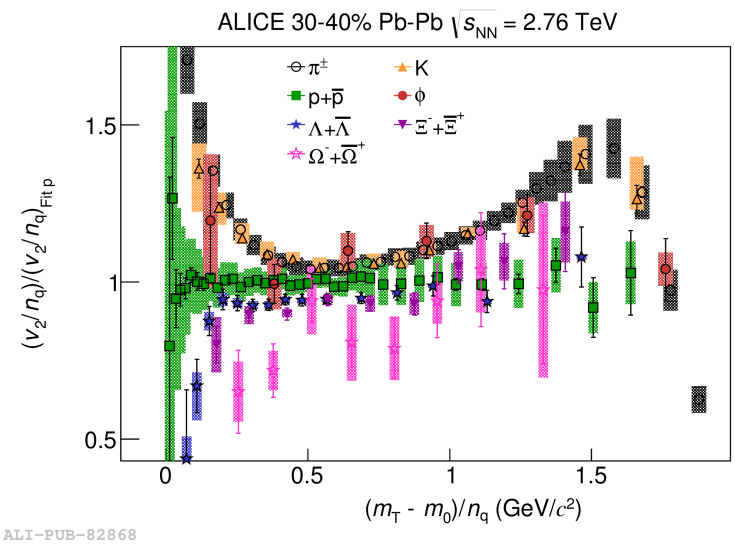


KE_T/n_q scaling: measured identified particle

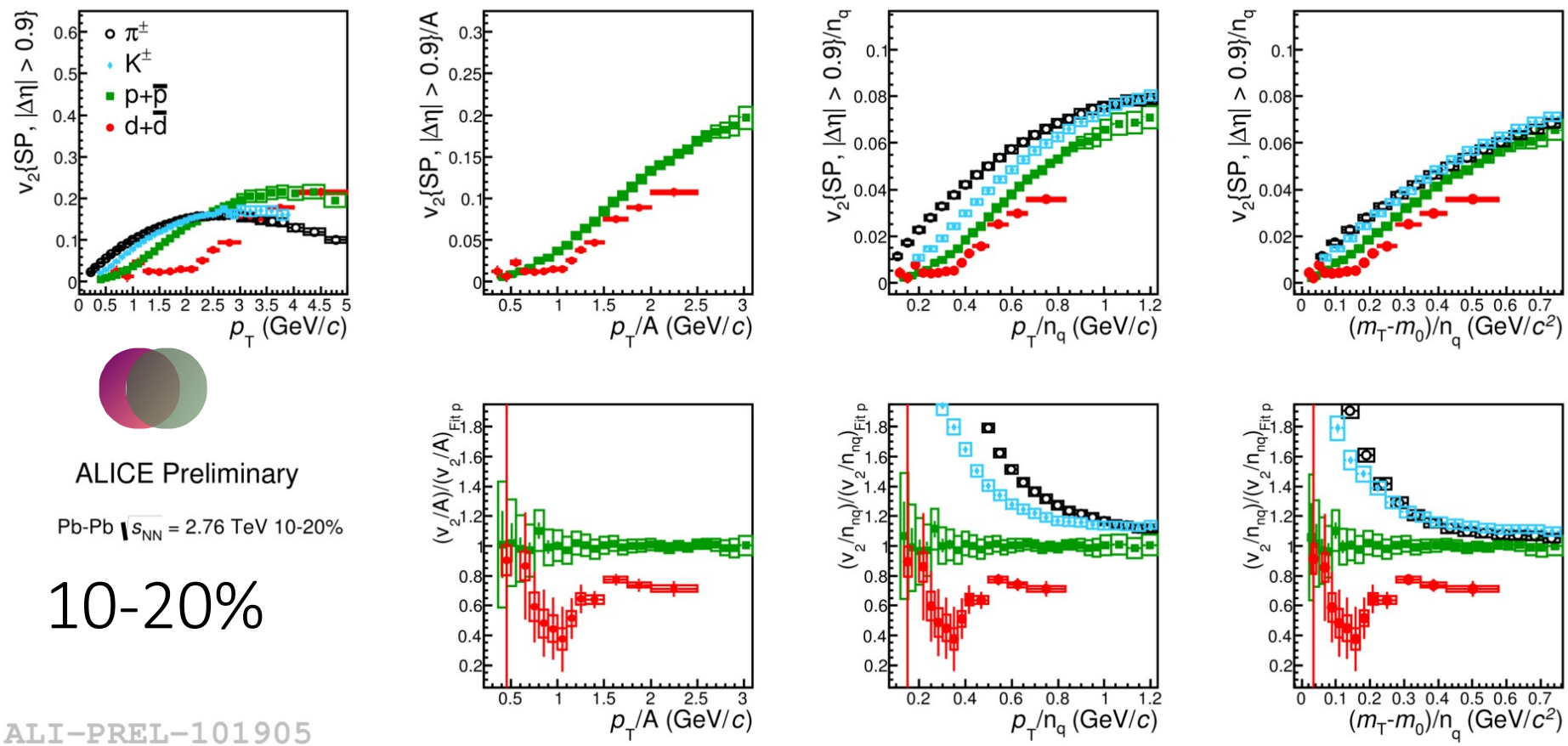






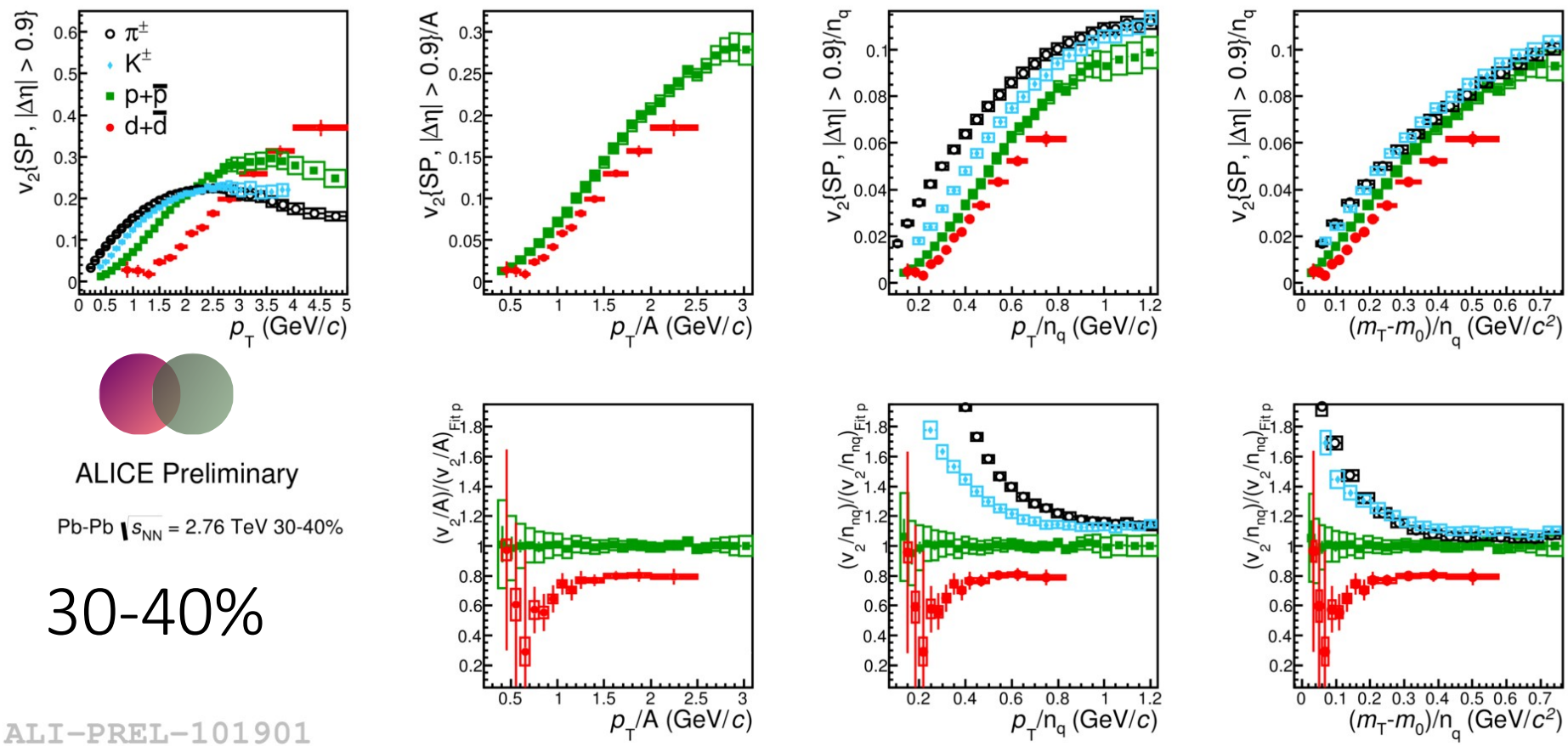


Comparison with π, k and p

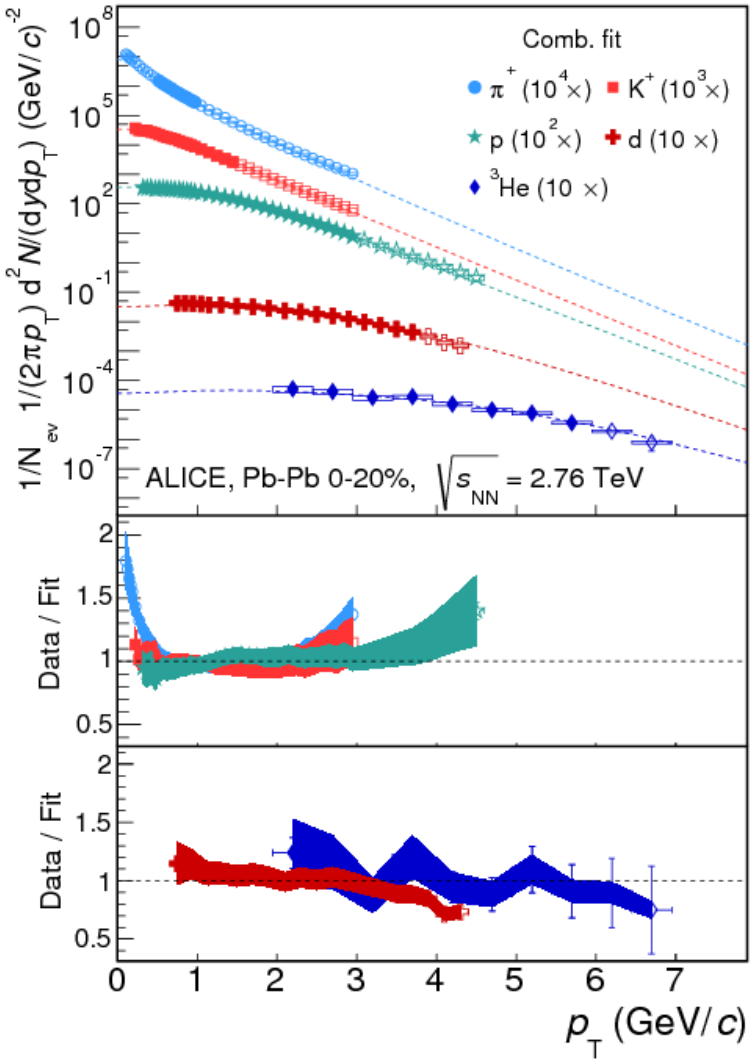


10-20%

Comparison with π, k and p



Combined Blast-Wave



ALICE Coll.: arXiv:1506.08951 [nucl-ex]

All particle spectra are described well with the BW fit.

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