Production of identified and unidentified charged hadrons in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Nicolò Jacazio on behalf of the ALICE collaboration

University and INFN – Bologna

6-11 February – Quark Matter 2017

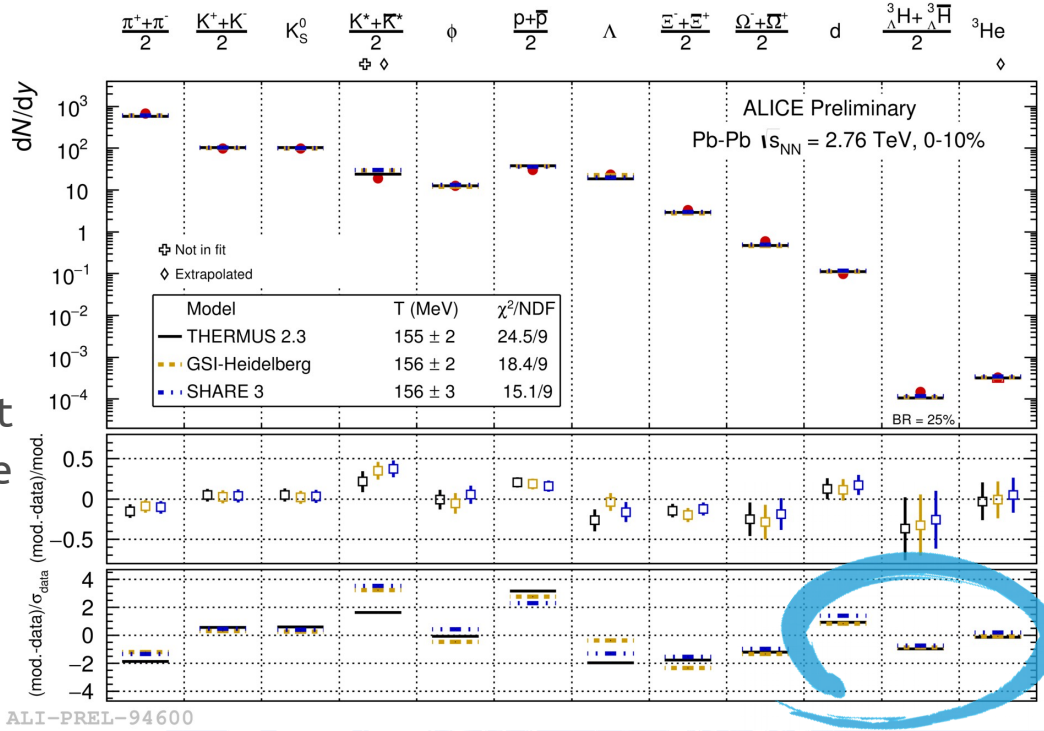
Quark Matter 2017

ALICE

INFN Istituto Nazionale di Fisica Nucleare

From Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV …

- Importance of radial flow and collective evolution in the p_T dependence of particle ratios
- Thermal model is in remarkable agreement with measured particle yields
  - » **Light-nuclei** production is well described
  - » Deviations from measured **p** (2.5 σ) and **Ξ** (2 σ) yields



» Measurements of **resonances** in central Pb–Pb collisions suggest elastic rescattering in the late hadronic phase

Posters on resonances by N. Agrawal, F. Bellini, J.Song

Poster on nuclei by S. Trogolo

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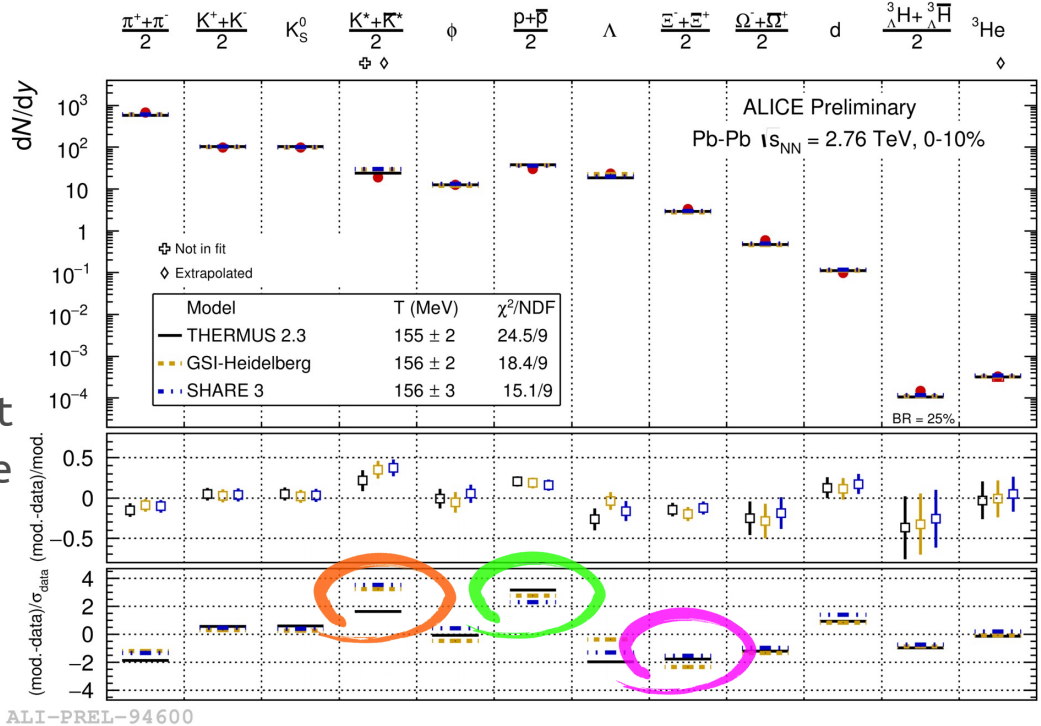

» Measurements of **resonances** in central Pb–Pb collisions suggest elastic rescattering in the late hadronic phase

Posters on resonances by N. Agrawal, F. Bellini, J.Song

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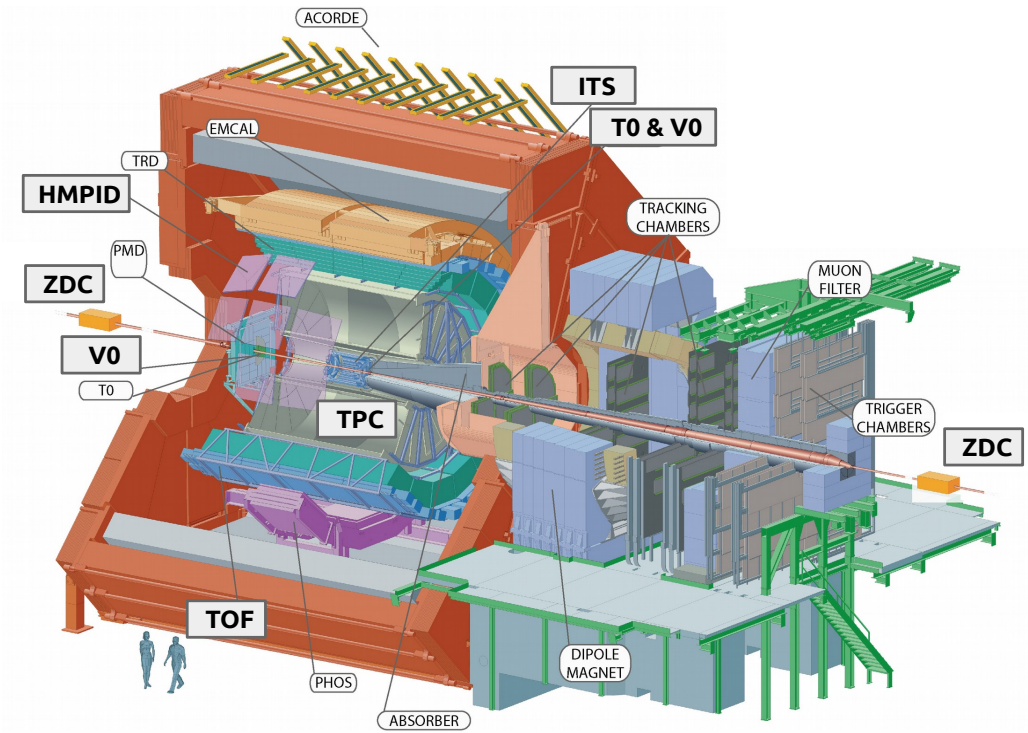
… to Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Measure the effects of the radial flow
  - Does radial flow increase from 2.76 to 5.02 TeV?
- Study the energy dependence of relative particle abundances
- Measure strangeness production in Pb–Pb collisions
- Test the thermal model with measurements
- Study the energy dependence of the nuclear modification factor

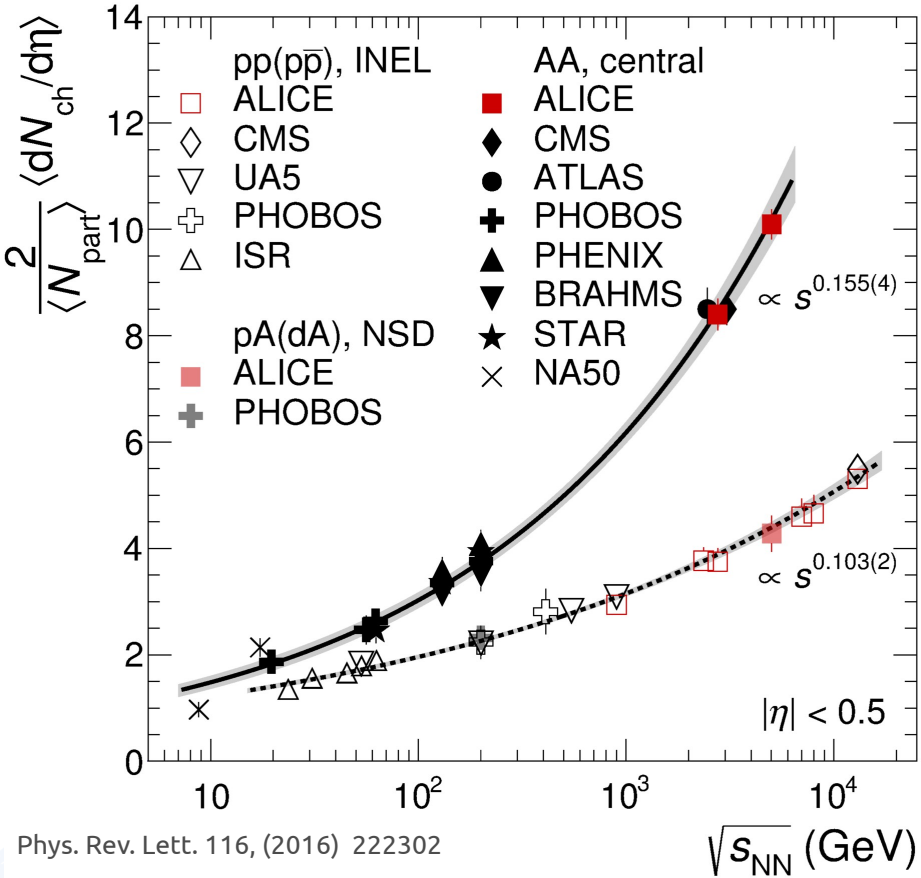
ALICE detector

- Moderate magnetic field (B = 0.5 T) in the mid-rapidity region $|\eta| < 0.9$
- Tracking down to $p_T \sim 100$ MeV/c
- High granularity to cope with the high occupancy present in Pb-Pb collisions
- Extensive particle identification (PID) by several techniques



Int. J. Mod. Phys. A 29 (2014) 1430044

$\langle dN_{ch}/d\eta \rangle$ in Pb–Pb at 5.02 TeV



Phys. Rev. Lett. 116, (2016) 222302

ALI-PUB-104920

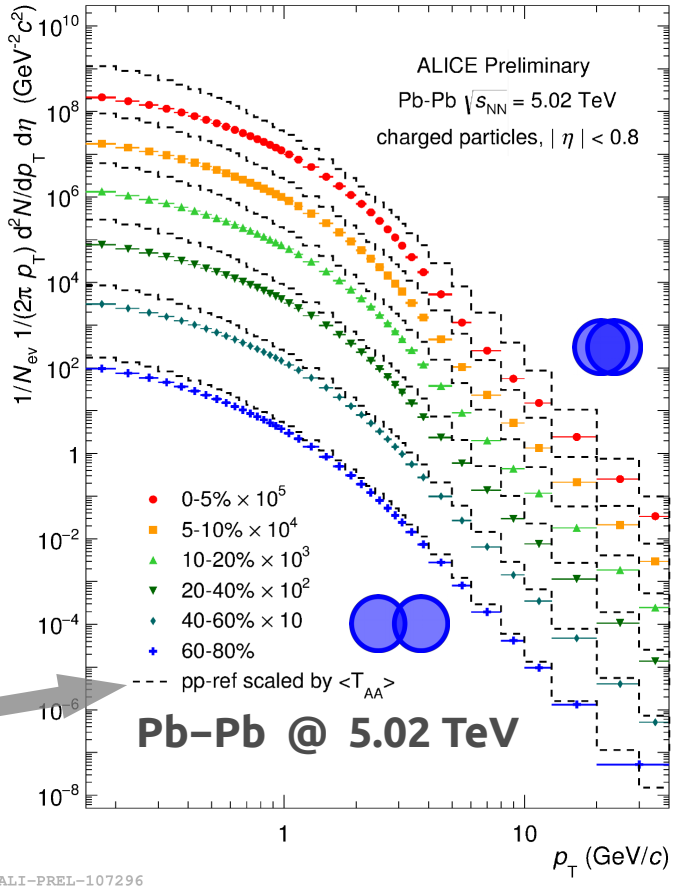
- Charged particle density measured in central collisions (0-5%) follows trends expected from lower energies
- At $\sqrt{s_{NN}}$ = 5.02 TeV increase of ~ 20% with respect to $\sqrt{s_{NN}}$ = 2.76 TeV

Talk 07/02/2017, 12:00

C. Holm Christensen

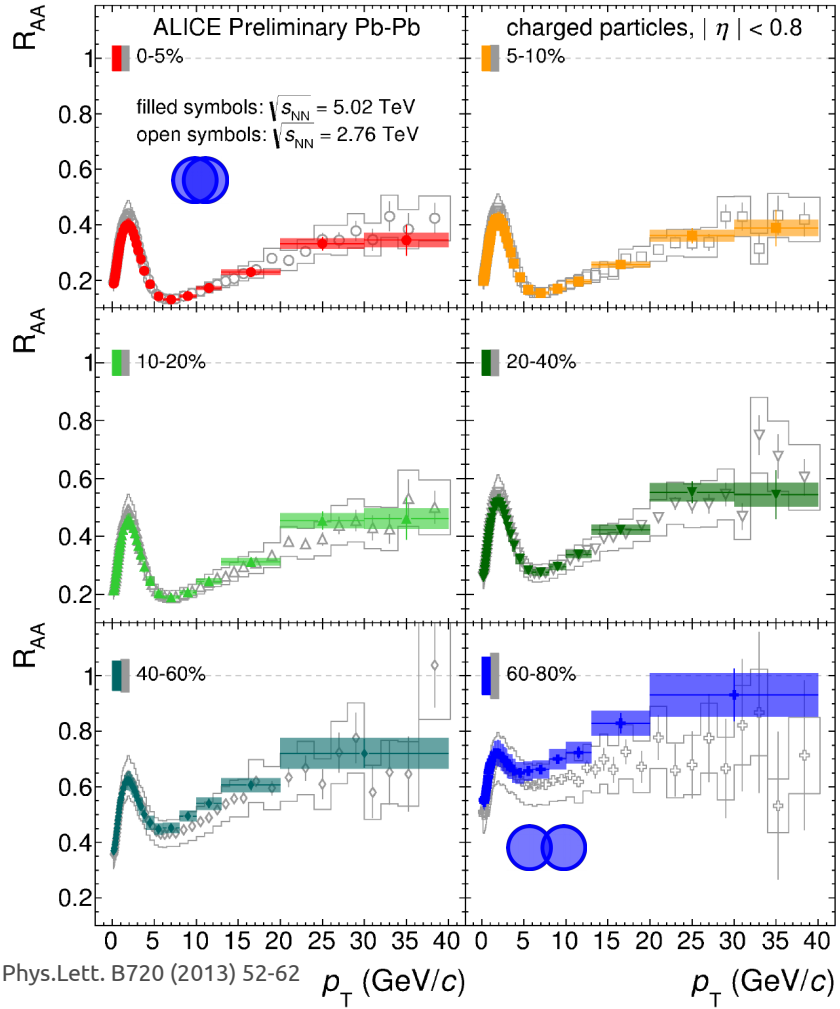
Unidentified particle spectra

- Measurement of primary unidentified particles in Pb–Pb collisions as a function of centrality
- Significant increase in the precision of the measurement
  - » Reduced systematic uncertainties with respect to lower energies
    - › Data driven correction for species dependent efficiencies and feed-down
    - › Improved detector description
- Comparison to pp measurements scaled by $\langle T_{AA} \rangle$ values



Posters by J. M. Gronefeld, E. Perez Lezama, P. Huhn

Nuclear Modification Factor R_{AA}



Phys.Lett. B720 (2013) 52-62

- Nuclear modification factor of primary charged particles

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

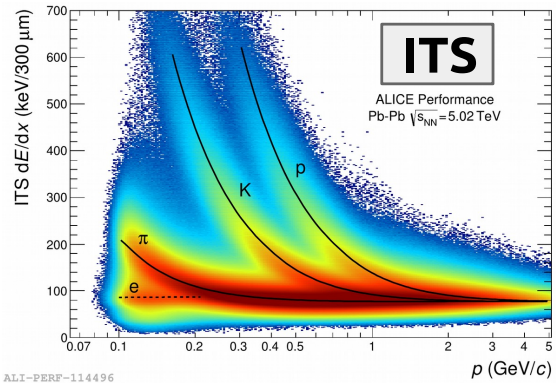
- Compared with values from Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV (gray markers)
- Reduced systematic uncertainties with respect to lower energies
- **No significant evolution with collision energy is found**

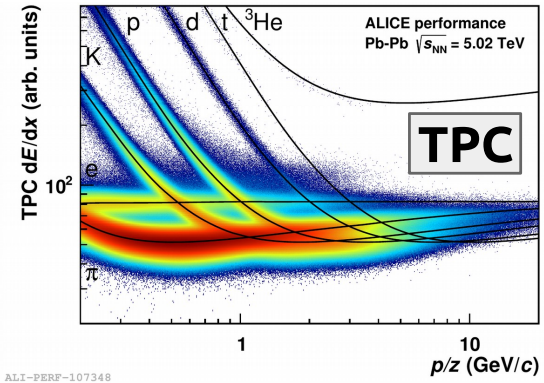
Particle identification in ALICE

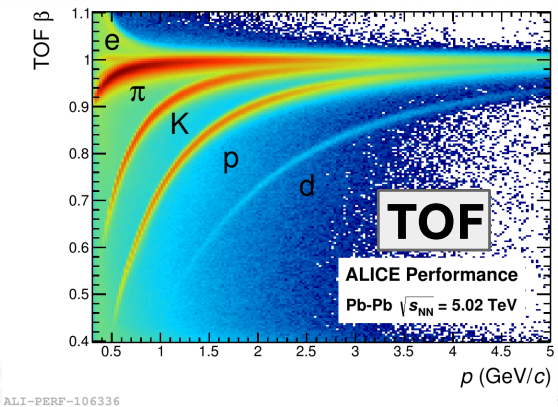
Multiple PID techniques

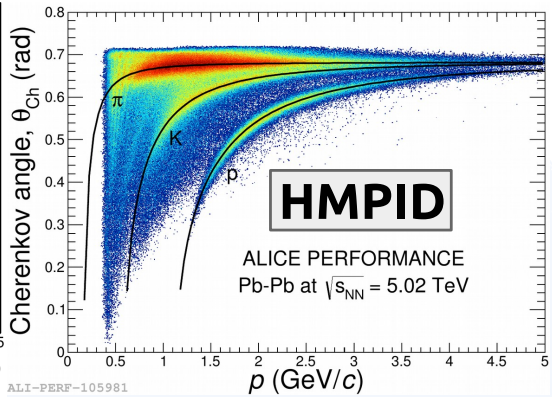
- **ITS**
  - » dE/dx in silicon
  - » Sampling in 4 layers with analogue readout
- **TPC**
  - » dE/dx in gas (Ar–CO_2)
  - » $\sigma_{dE/dx}$ ~ 5%
- **TOF**
  - » Time-of-flight measurement
  - » σ_{TOF} ~ 80 ps
- **HMPID**
  - » Cherenkov angle measurement

Excellent Particle Identification

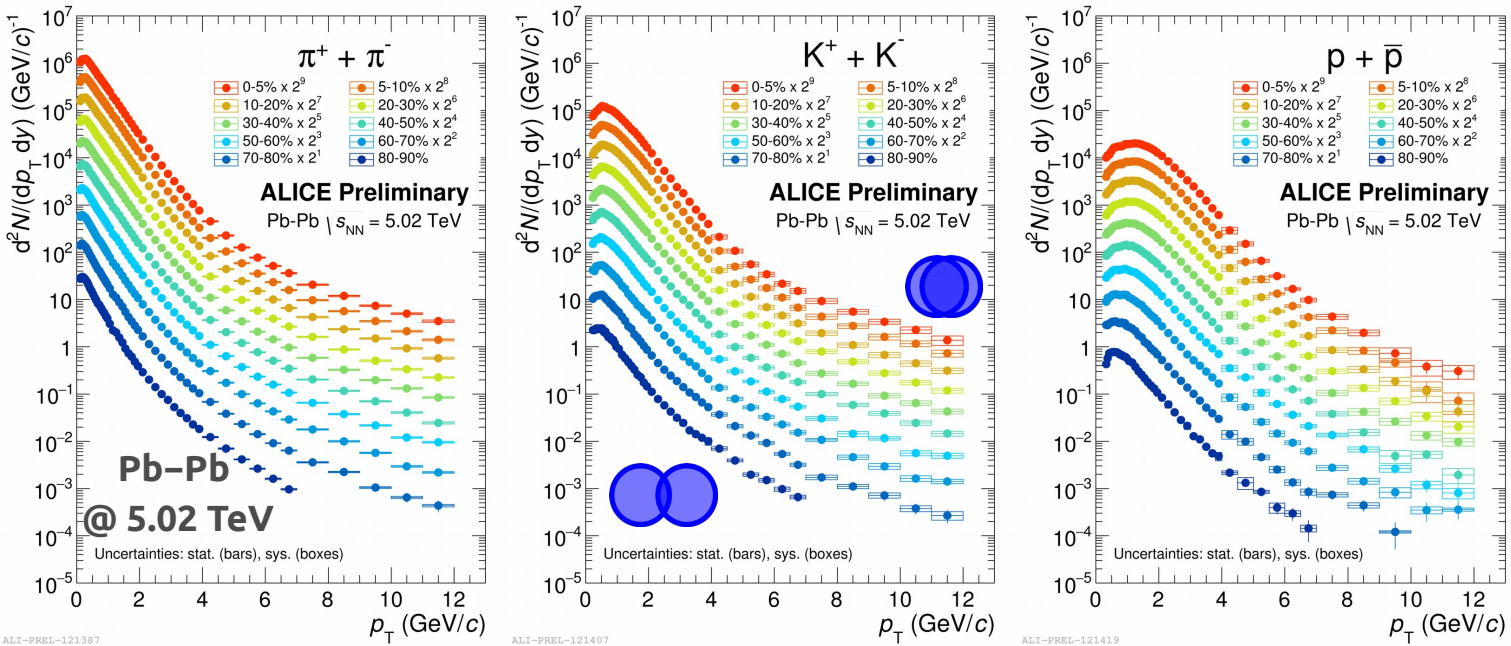






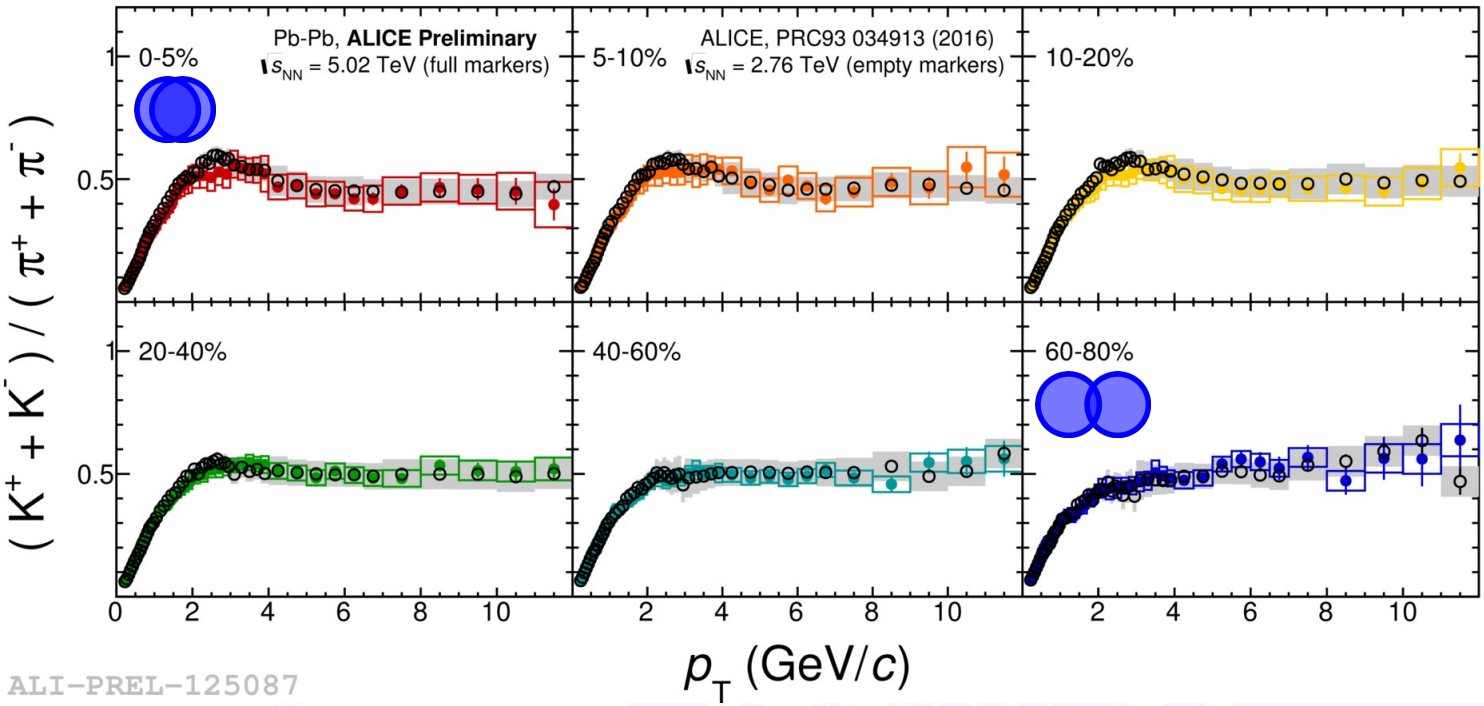


Identified particle spectra



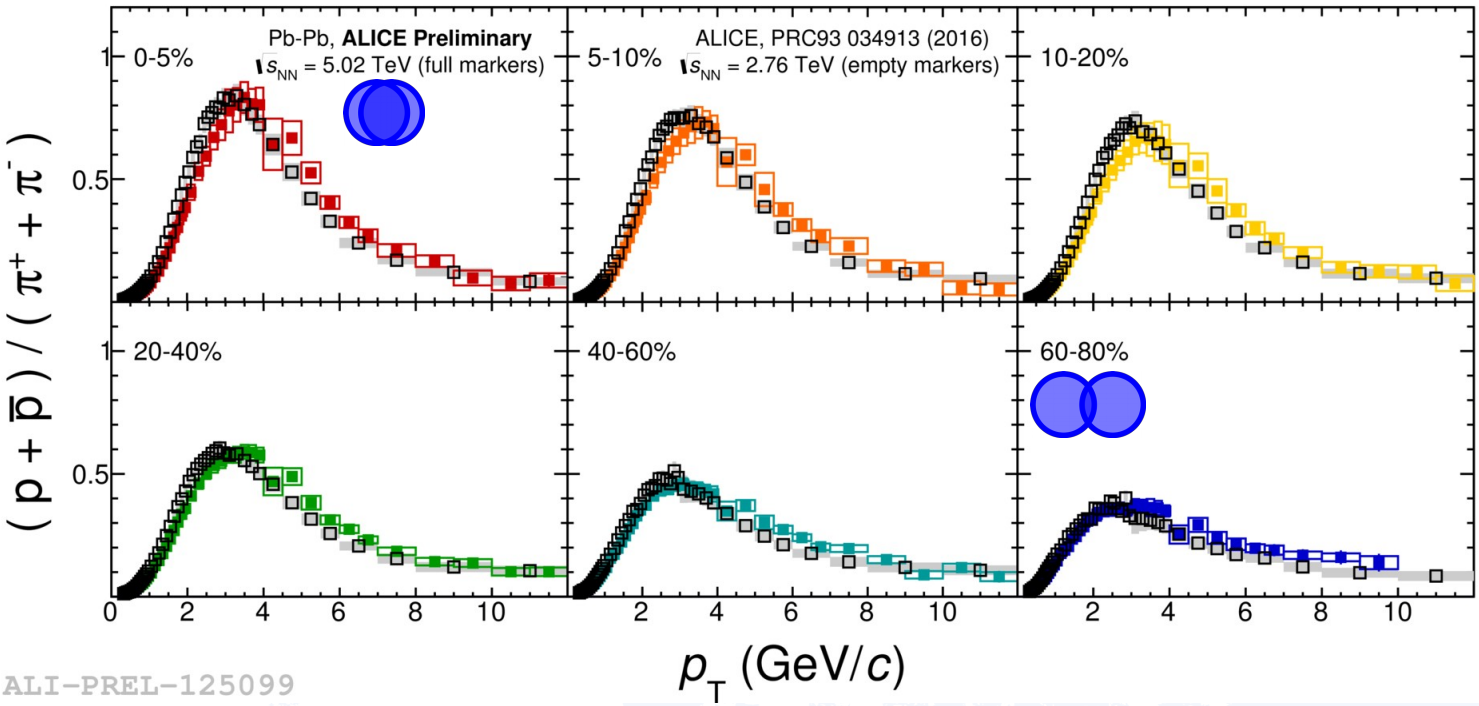
- Measured with different analysis techniques: ITS, TPC, TOF, HMPID and topological identification of K from kinks covering different p_T intervals
- **Mass dependent hardening of the spectra with increasing centrality**

Particle ratios: K/π



- Compared with values from Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV (gray markers)
- **No significant change between the two energies**

Particle ratios: p/π



- Compared with values from Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV (gray markers)
- **Shift of the maximum of p/π to higher p_T with respect to lower energies**

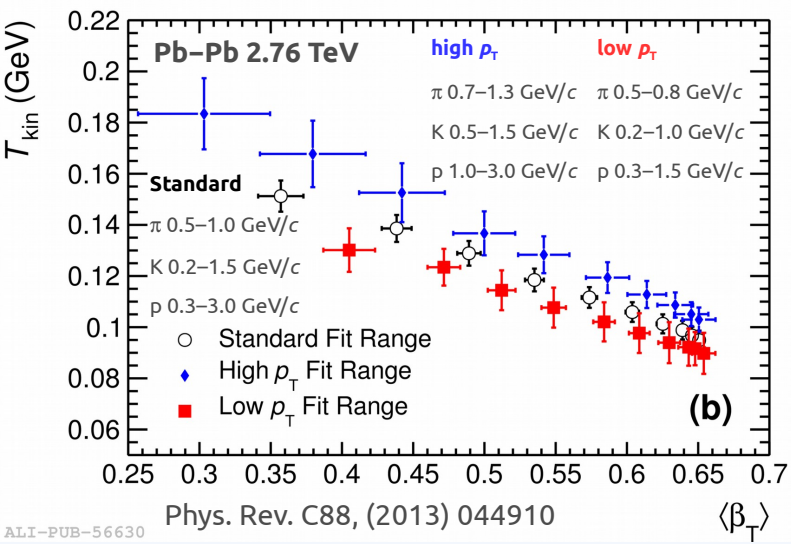
Blast-Wave model

- Simultaneous fit to the π, K, p spectra with the Boltzmann–Gibbs Blast-Wave model
- Simplified hydrodynamics model with 3 parameters
  - » β_T → radial expansion velocity
  - » T_{Kin} → kinetic freeze-out
  - » n → velocity profile

$$E\frac{d^3N}{dp^3} \propto \int_0^R m_T I_0\left(\frac{p_T \sinh(\rho)}{T_{Kin}}\right) K_1\left(\frac{m_T \cosh(\rho)}{T_{Kin}}\right) r\,dr$$

$$m_T = \sqrt{m^2 + p_T^2} \qquad \rho = \tanh^{-1}(\beta_T) \qquad \beta_T = \beta_s\left(\frac{r}{R}\right)^n$$

Schnedermann, Sollfrank and Heinz Phys. Rev. C 48, 2462



Phys. Rev. C88, (2013) 044910

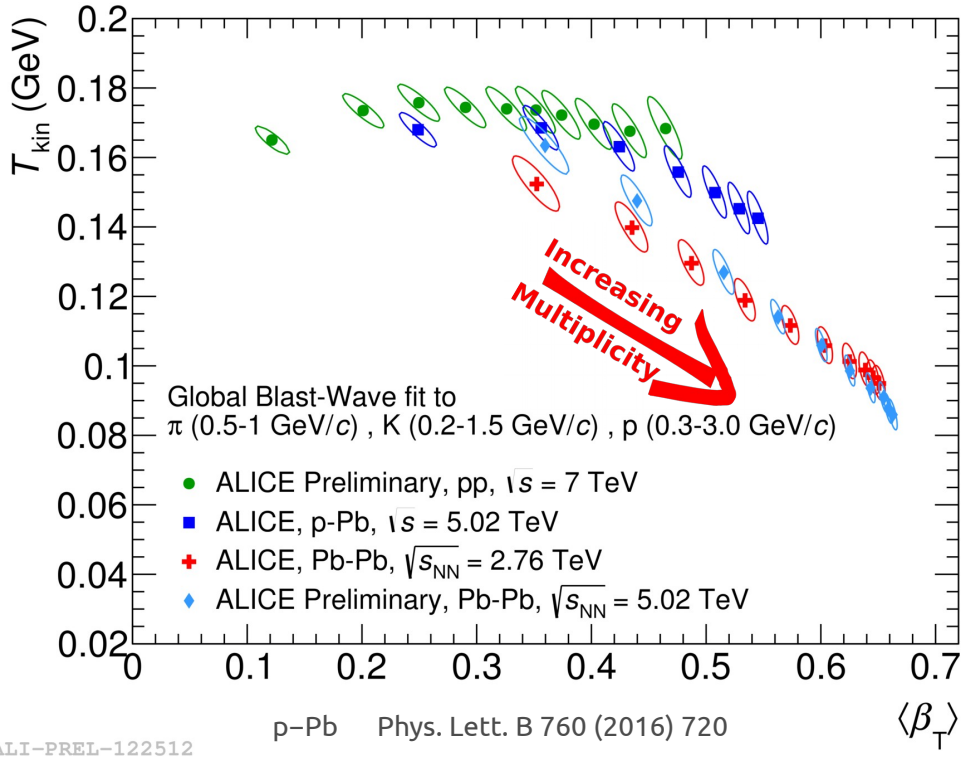
Caveats

Values of extracted Blast-Wave parameters depend on the fit range, particle species included in the fit and uncertainties considered

→ Same fitting range as used in Pb–Pb collisions at 2.76 TeV

Blast-Wave fit parameters

- Fit quality at $\sqrt{s_{NN}}$ = 5.02 TeV similar to that at 2.76 TeV
- Blast-Wave parameters follow trends obtained at lower energy

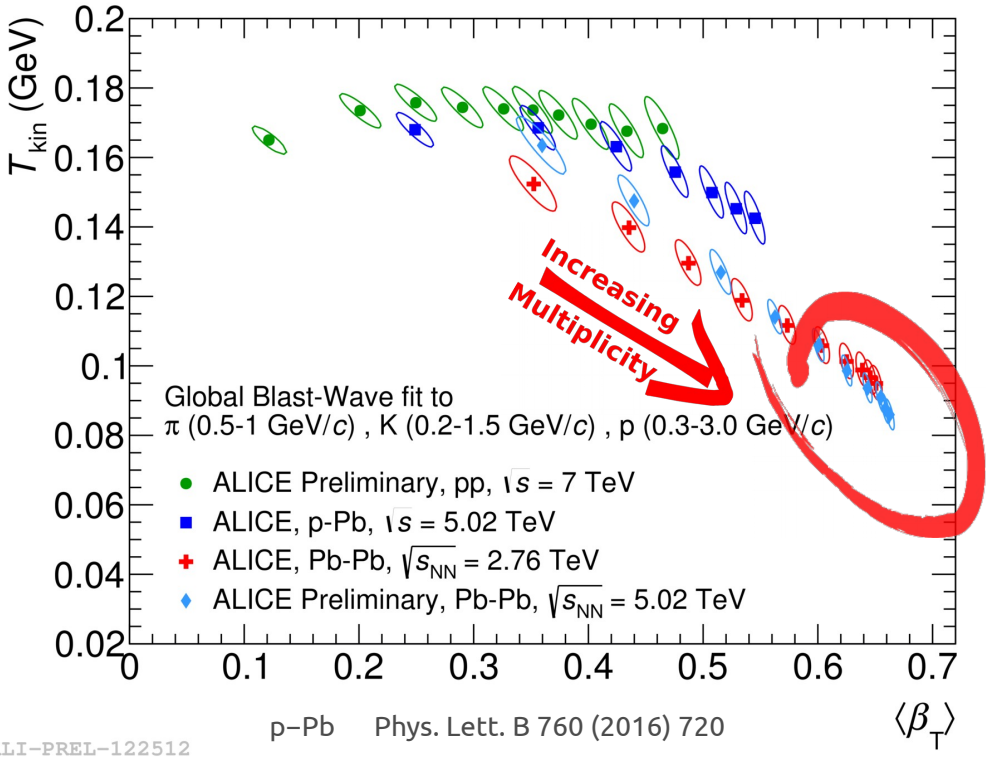


p–Pb Phys. Lett. B 760 (2016) 720

Pb–Pb Phys. Rev. C88, (2013) 044910

Blast-Wave fit parameters

- Fit quality at $\sqrt{s_{NN}}$ = 5.02 TeV similar to that at 2.76 TeV
- Blast-Wave parameters follow trends obtained at lower energy
- Largest expansion velocity for central Pb–Pb collisions

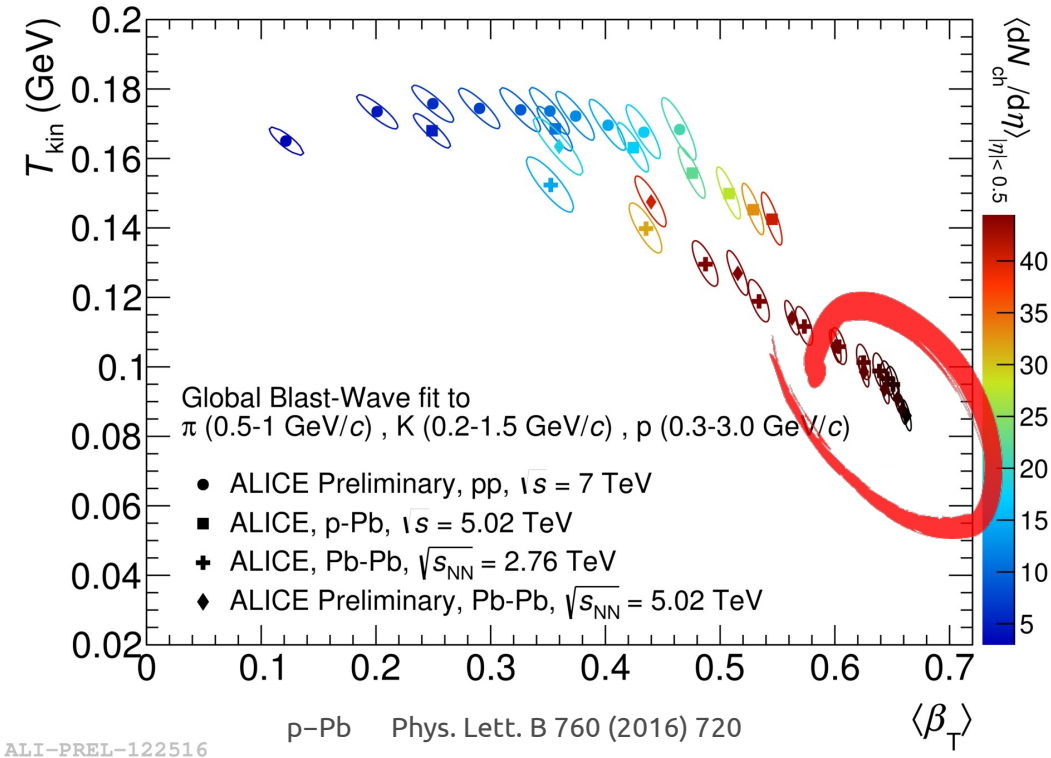


p–Pb Phys. Lett. B 760 (2016) 720

Pb–Pb Phys. Rev. C88, (2013) 044910

Blast-Wave fit parameters

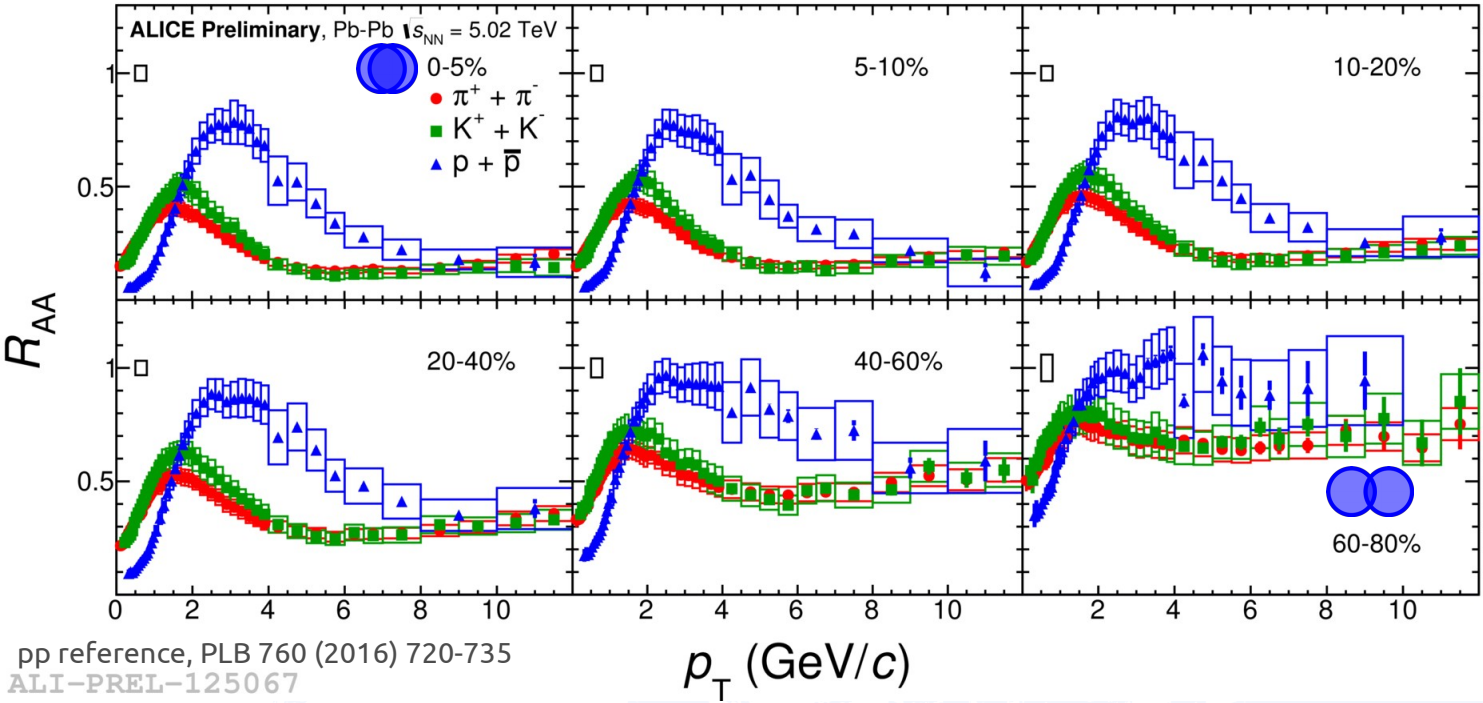
- In Pb–Pb at the two energies parameters are similar at comparable multiplicities
- Higher <β_T> for smaller collision systems at comparable multiplicities



p–Pb Phys. Lett. B 760 (2016) 720

Pb–Pb Phys. Rev. C88, (2013) 044910

R_{AA} of π, K, p

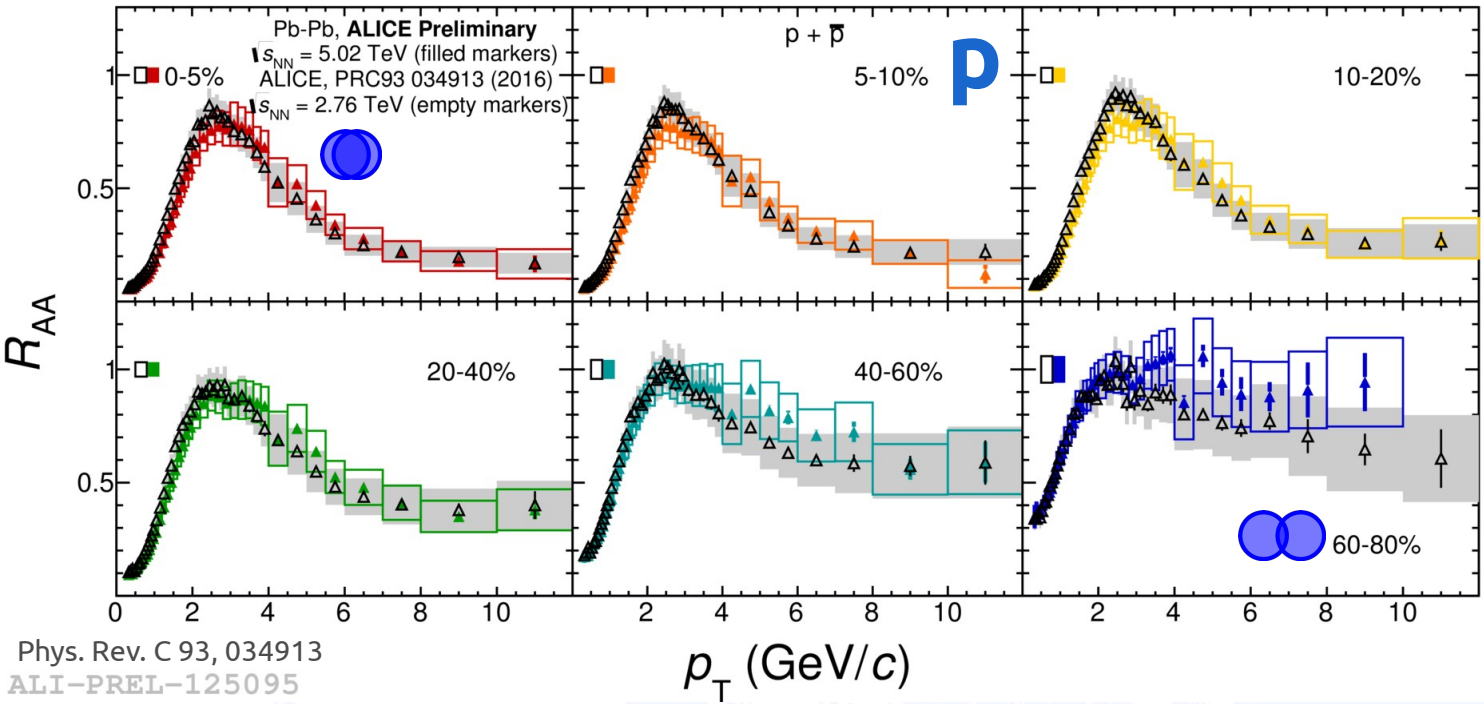


pp reference, PLB 760 (2016) 720-735

ALI-PREL-125067

- In Pb–Pb collisions all three species are equally suppressed for all centralities at high p_T (> 8 GeV/c)
- (Light–)flavor independent energy loss at high p_T as observed at $\sqrt{s_{NN}}$ = 2.76 TeV

Energy dependence of the R_{AA}

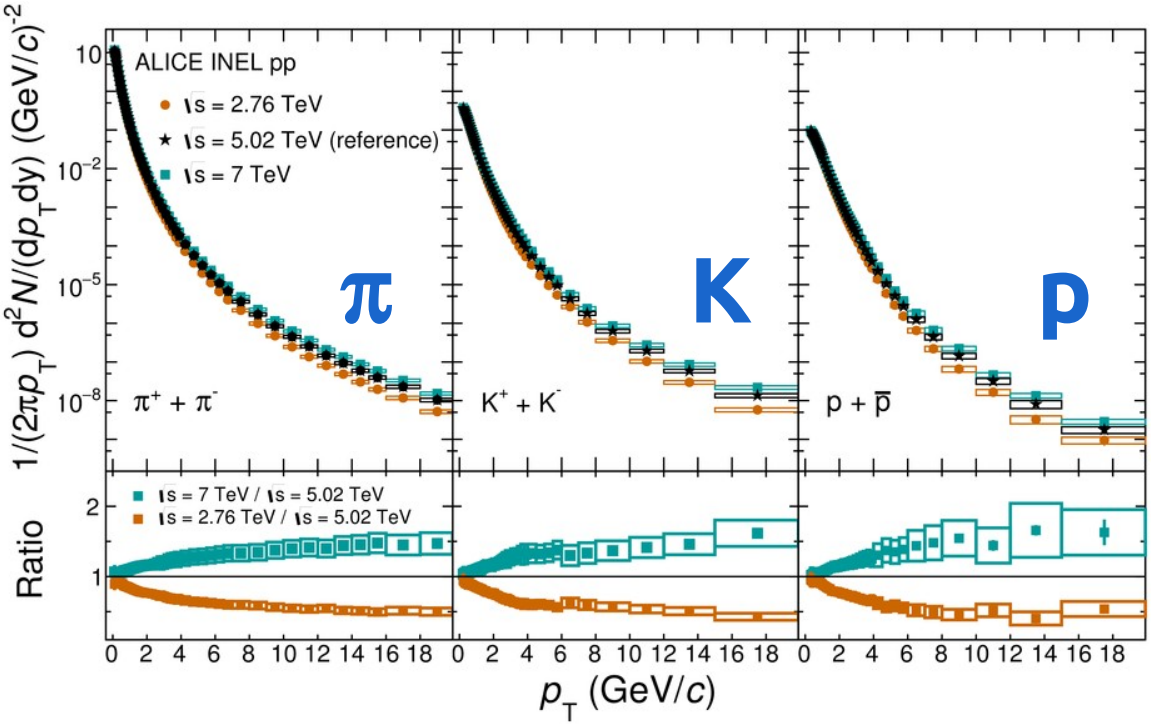


Phys. Rev. C 93, 034913

ALI-PREL-125095

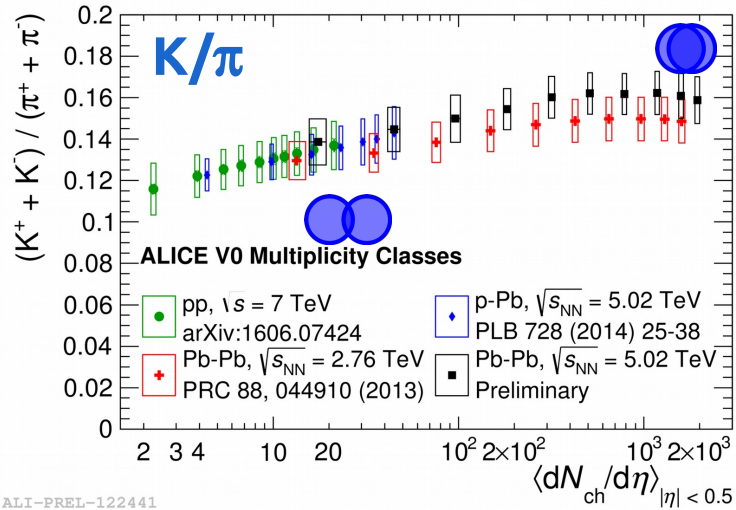
- **No significant evolution with collision energy is found**
- Similar observations for π and K

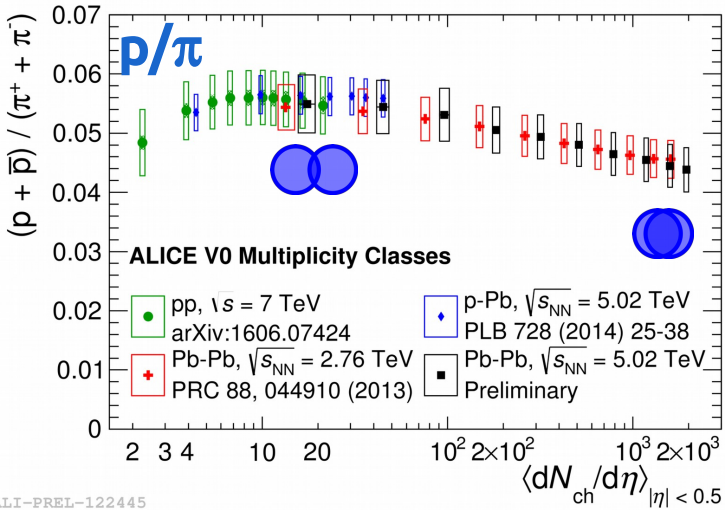
proton-proton reference for R_{AA}



- Significant hardening of the reference spectra with respect to $\sqrt{s} = 2.76$ TeV

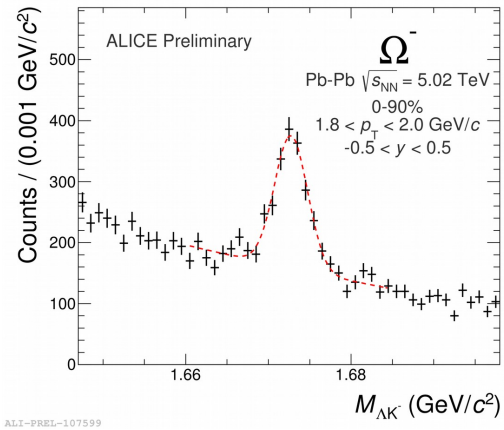
Ratios of integrated yields

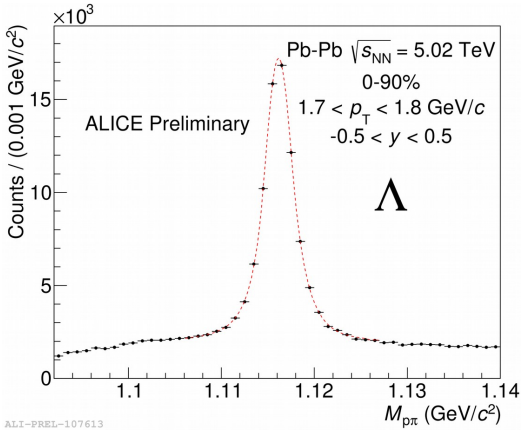




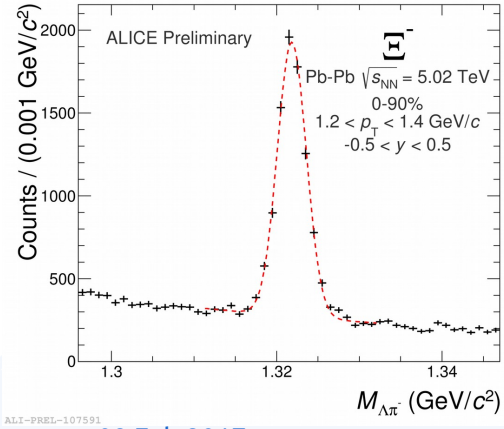
- **No significant energy dependence is observed** for p/π and K/π, as they follow the trends observed at 2.76 TeV
  - » Hint of increase in the K/π ratio not significant given the present uncertainties
- K/π and p/π measured in **peripheral Pb–Pb collisions are consistent with the high-multiplicity pp and p–Pb values**

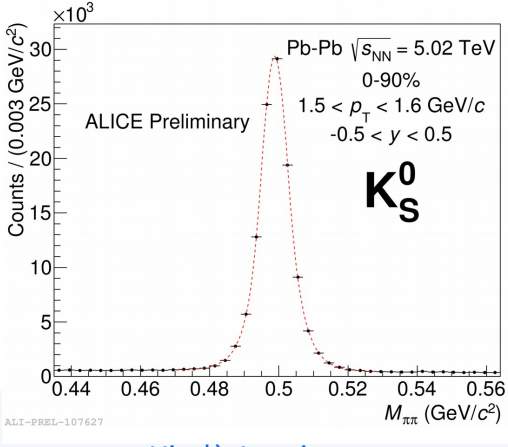
Outlook on strangeness production

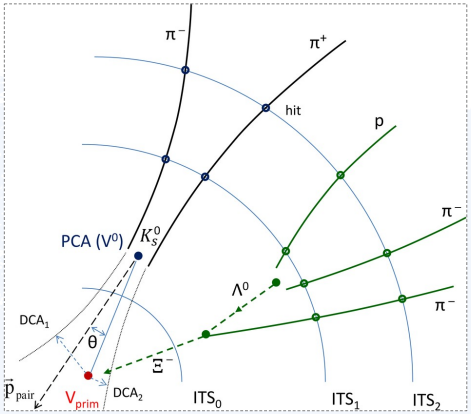




- Work is ongoing in the analysis of strangeness production
- Reconstruction of strange particle weak-decay topology







Conclusions

- The ALICE collaboration measured the spectra of unidentified particles and of π, K, p in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
  - » **Improved precision** in the measurement of inclusive charged particle production thanks to improved detector performance and analysis techniques
- Significant hardening of particle spectra with centrality
  - » Blast-Wave model fit result indicates a **higher expansion velocity** in central collisions at 5.02 TeV than at 2.76 TeV

    → **Stronger radial flow** at the higher energy
- **Nuclear modification factor has no significant evolution** with the collision energy
- p/π and and K/π **relative abundances exhibit no significant energy dependence**

  → Follows the trend with multiplicity established at 2.76 TeV

Many more results – Posters:

Charged particle spectra in Pb-Pb collisions at 5.02 TeV measured with ALICE **J. Maximilian Gronefeld**	Transverse momentum spectra of primary charged particles in pp collisions measured by ALICE at the LHC **E. Perez Lezama**	Data-driven particle composition correction of tracking efficiency for charged particles with ALICE **P. Huhn**
Transverse energy in Pb-Pb collisions with ALICE **P. William Stankus**	Recent results on light nuclei and antinuclei from ALICE at the LHC **S. Trogolo**	Resonances in Pb-Pb, exploring the hadronic phase **F. Bellini**

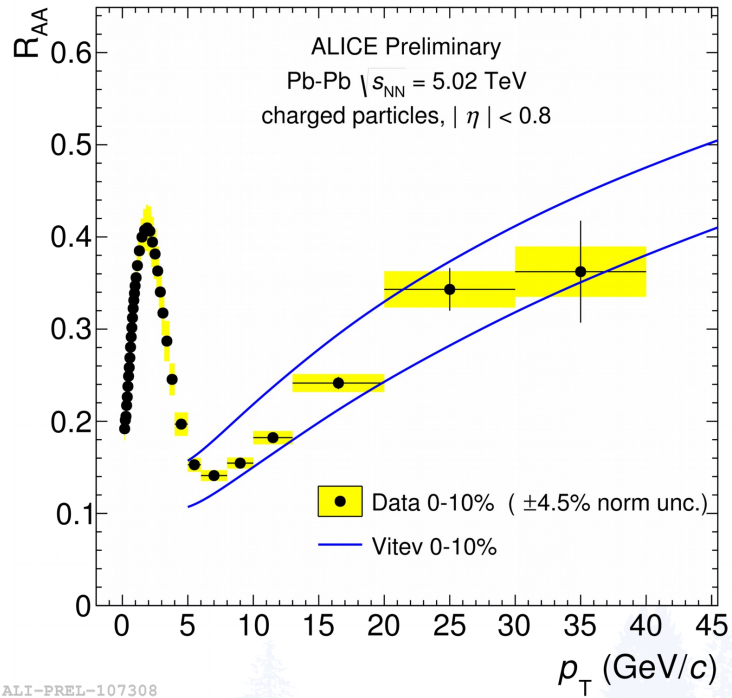
Suppression of $\Lambda(1520)$ resonance production in Pb-Pb collisions at the LHC **N. Agrawal**	Production of $\Sigma(1385)^{\pm}$ and $\Xi(1530)^{0}$ measured by ALICE in pp, p-Pb and Pb-Pb at the LHC **J. Song**

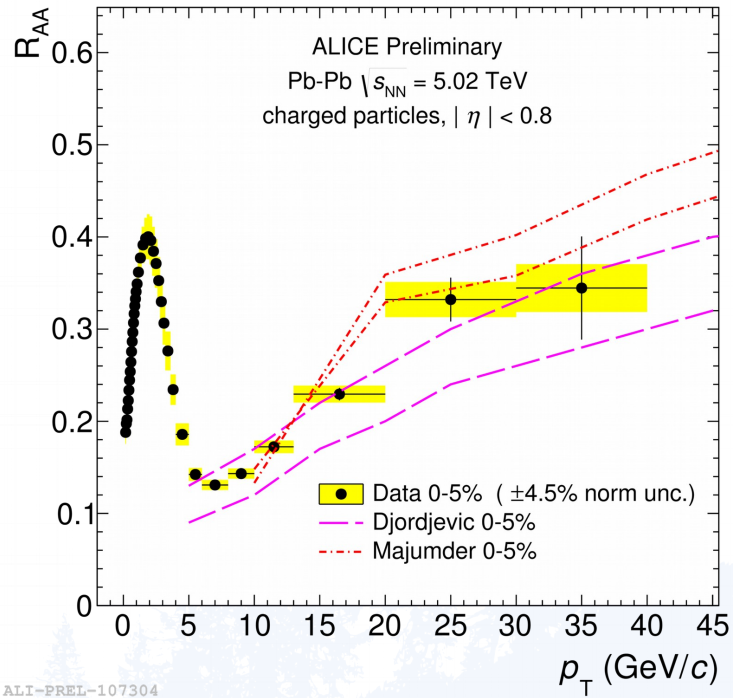
More results in pp collisions

$\varphi(1020)$ production in pp collisions with ALICE at the LHC **S. Tripanty**	Σ^{0} and $\overline{\Sigma}^{0}$ baryon production in pp collisions at $\sqrt{s}$ = 7 TeV at the LHC with ALICE **A. Borissov**

Backup

R_{AA} model comparison



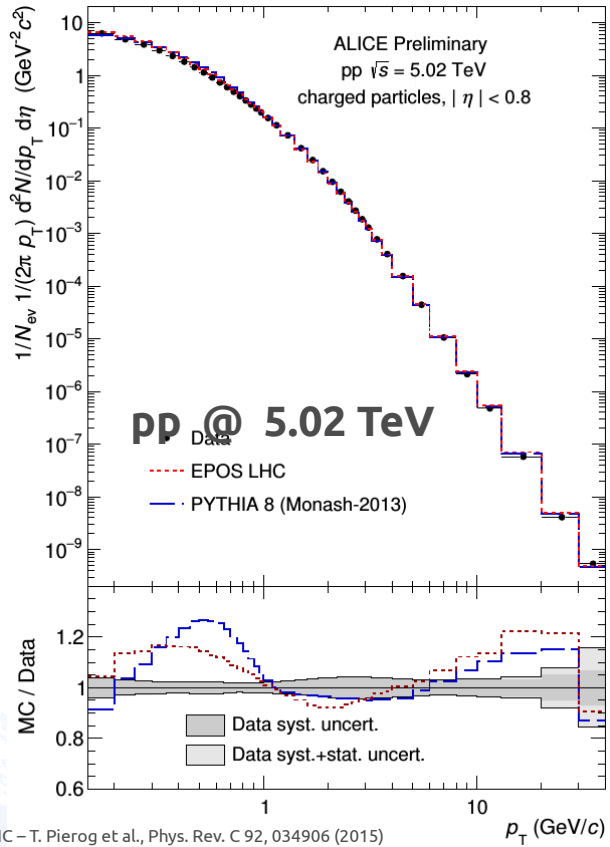


Charged particle spectra in pp at √s = 5.02 TeV

Poster by E. Perez Lezama

Poster by P. Huhn

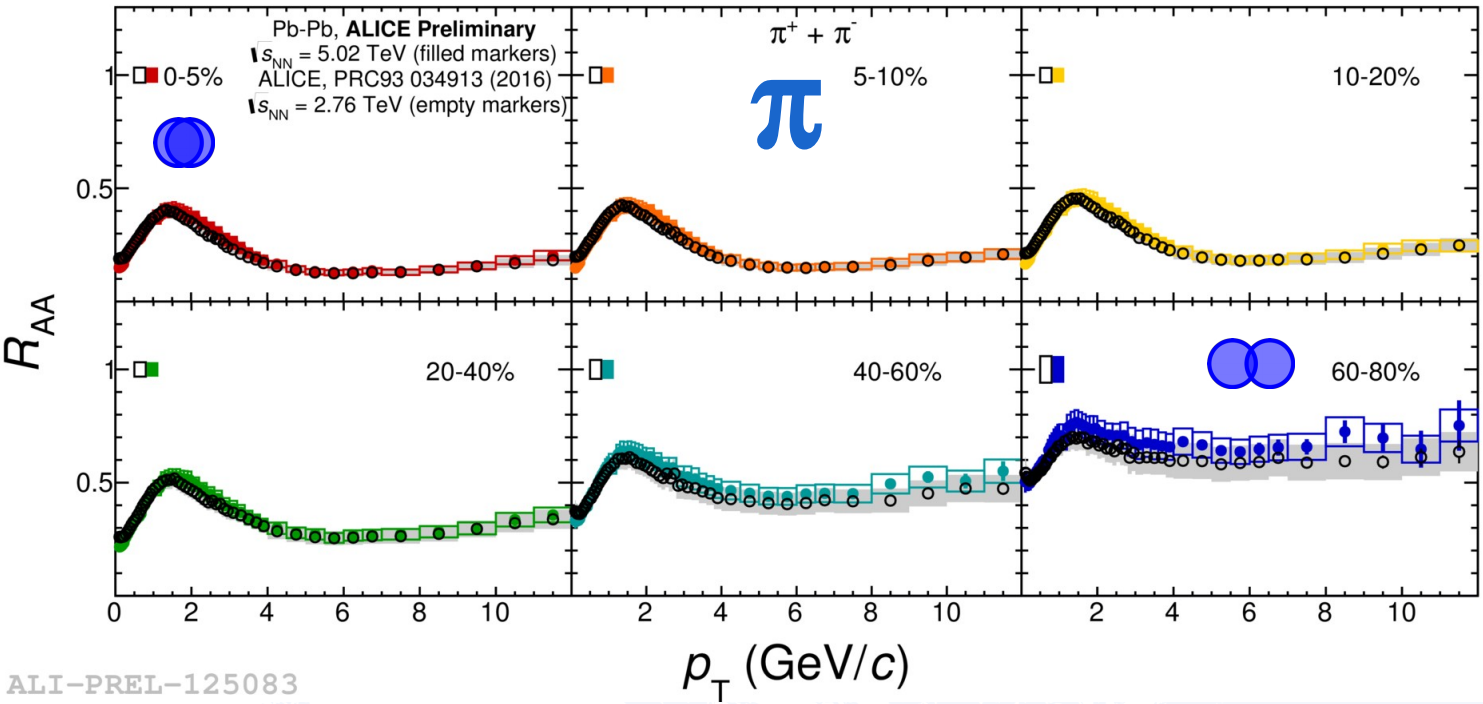
- Measurement of primary unidentified particles in Minimum Bias pp collisions
- Models predict higher values below 1 GeV/*c* and above 10 GeV/*c*
- Reweighting of the efficiency corrections by the particle composition measured in pp collisions at $\sqrt{s}$ = 7 TeV and Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV



EPOS LHC – T. Pierog et al., Phys. Rev. C 92, 034906 (2015)

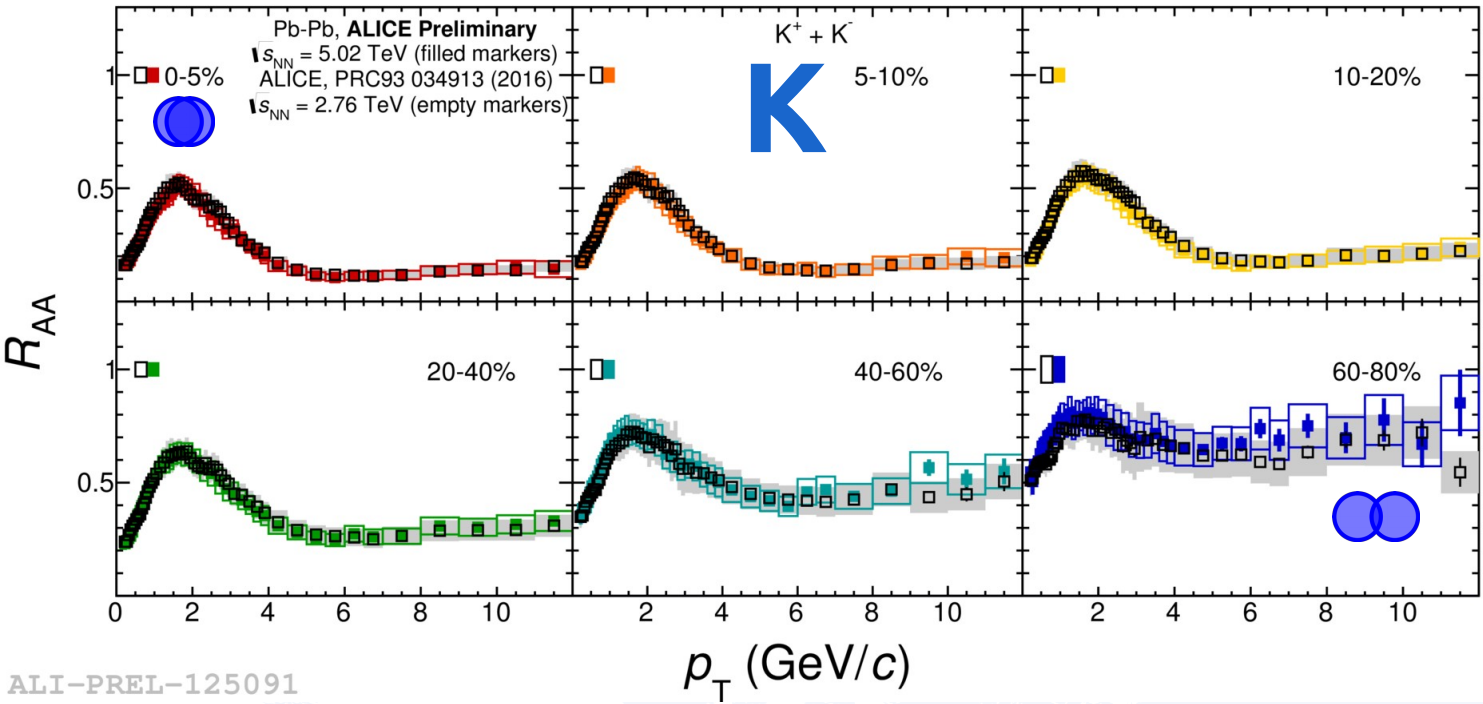
PYTHIA8 – T. Sjöstrand et al., Comput.Phys.Commun. 178 (2008) 852-867

Energy dependence of the R_{AA}



- No significant evolution with the collision energy is found

Energy dependence of the R_{AA}



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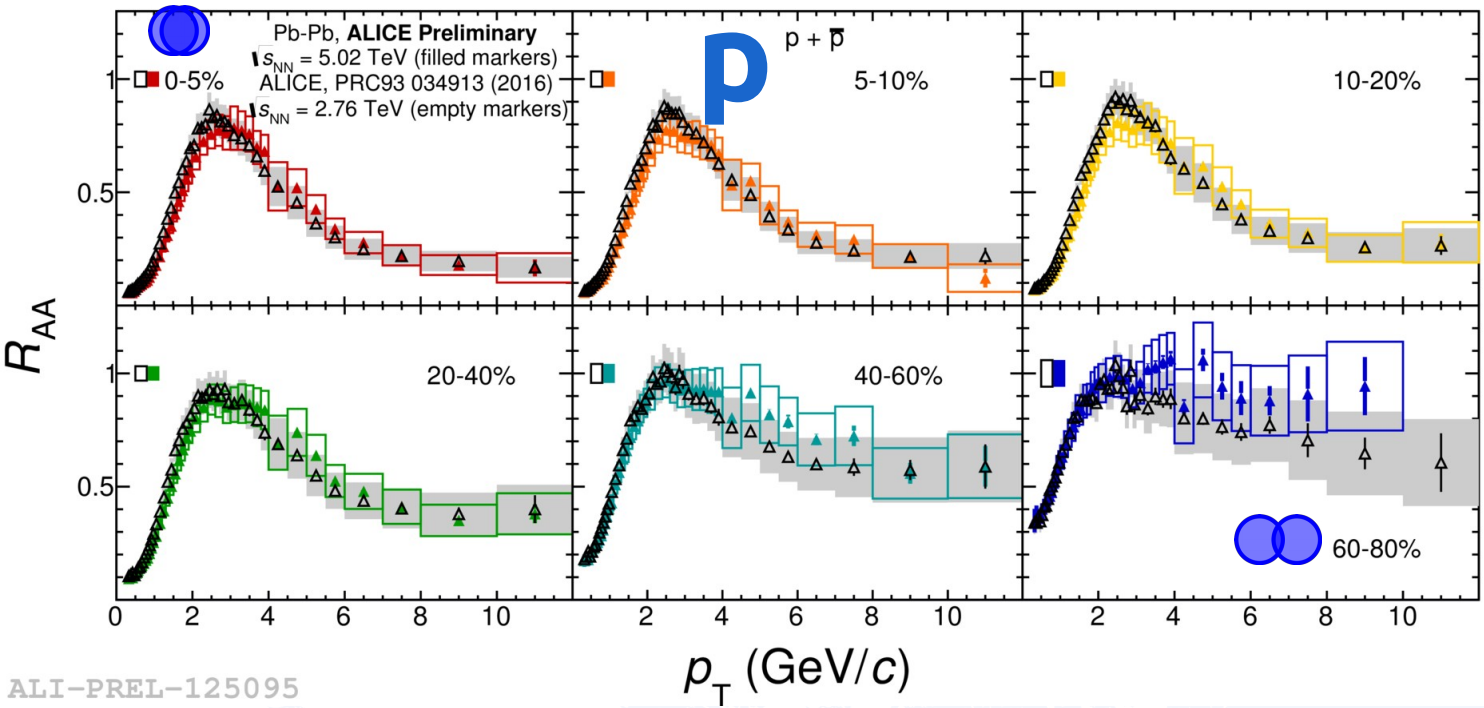
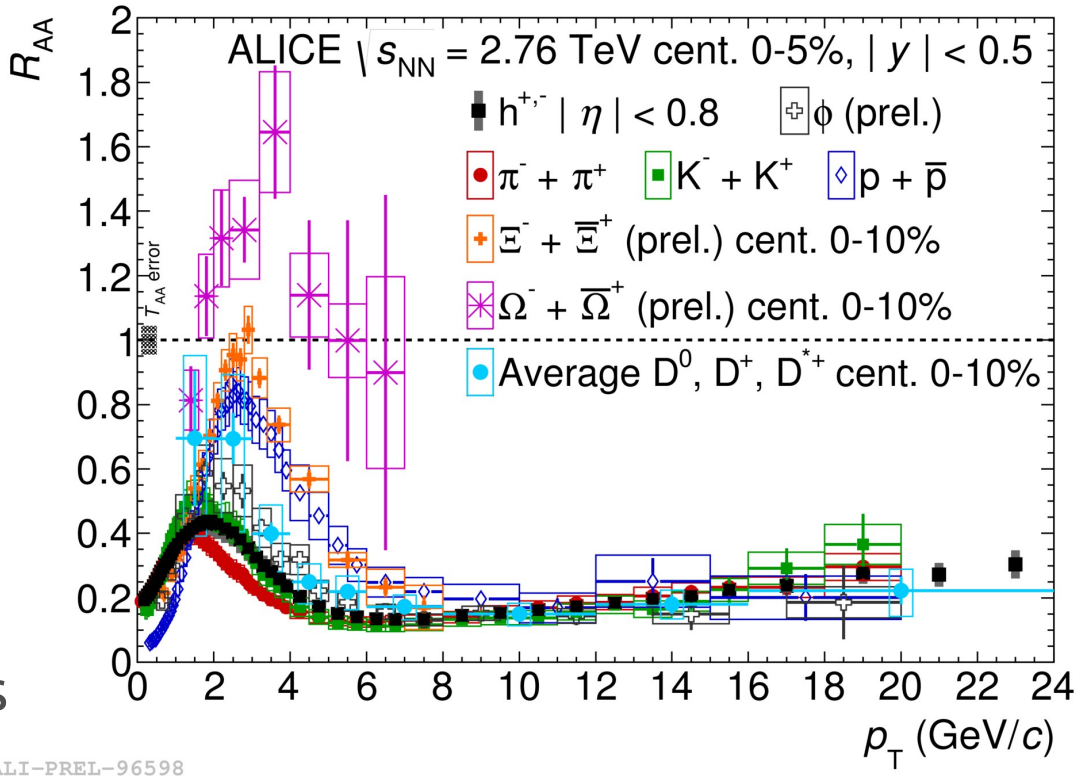
Energy dependence of the R_{AA}



- No significant evolution with the collision energy is found

R_{AA} for identified particles

- At high p_T the nuclear modification factor is in agreement among different particle species

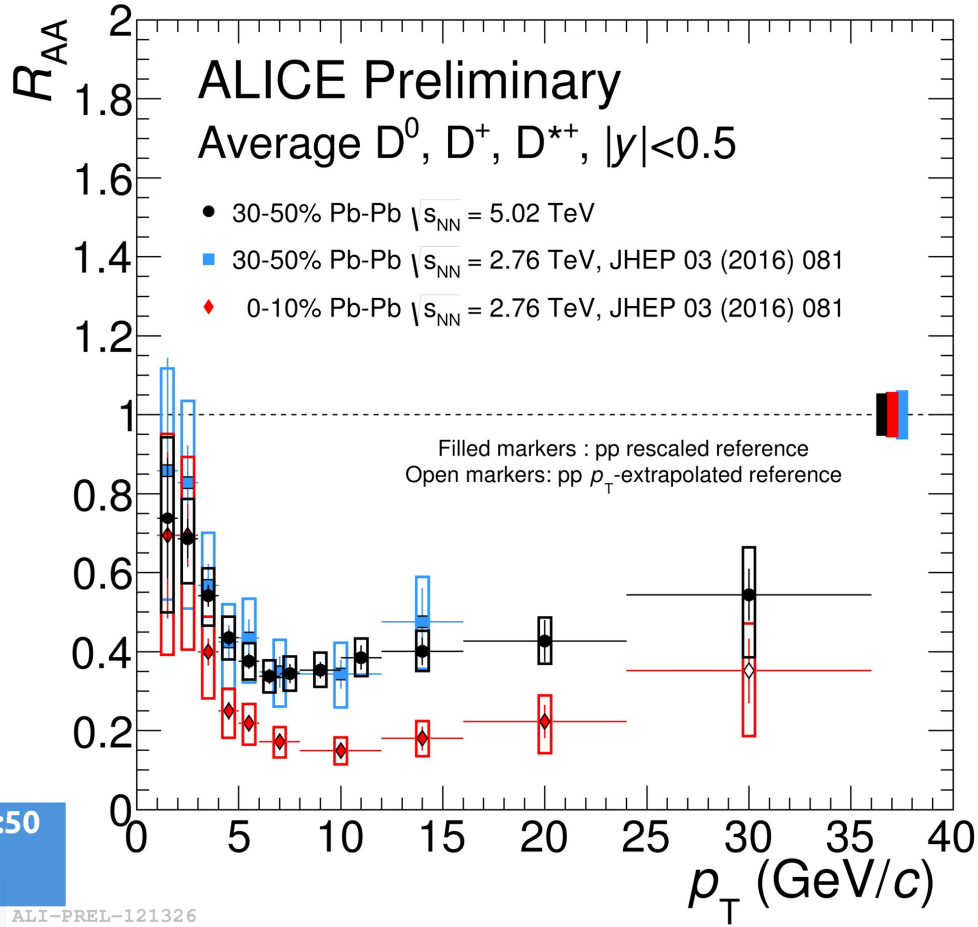


D-meson R_{AA} Talk 07/02/2017, 16:50

A. M. Barbano

R_{AA} for identified D mesons

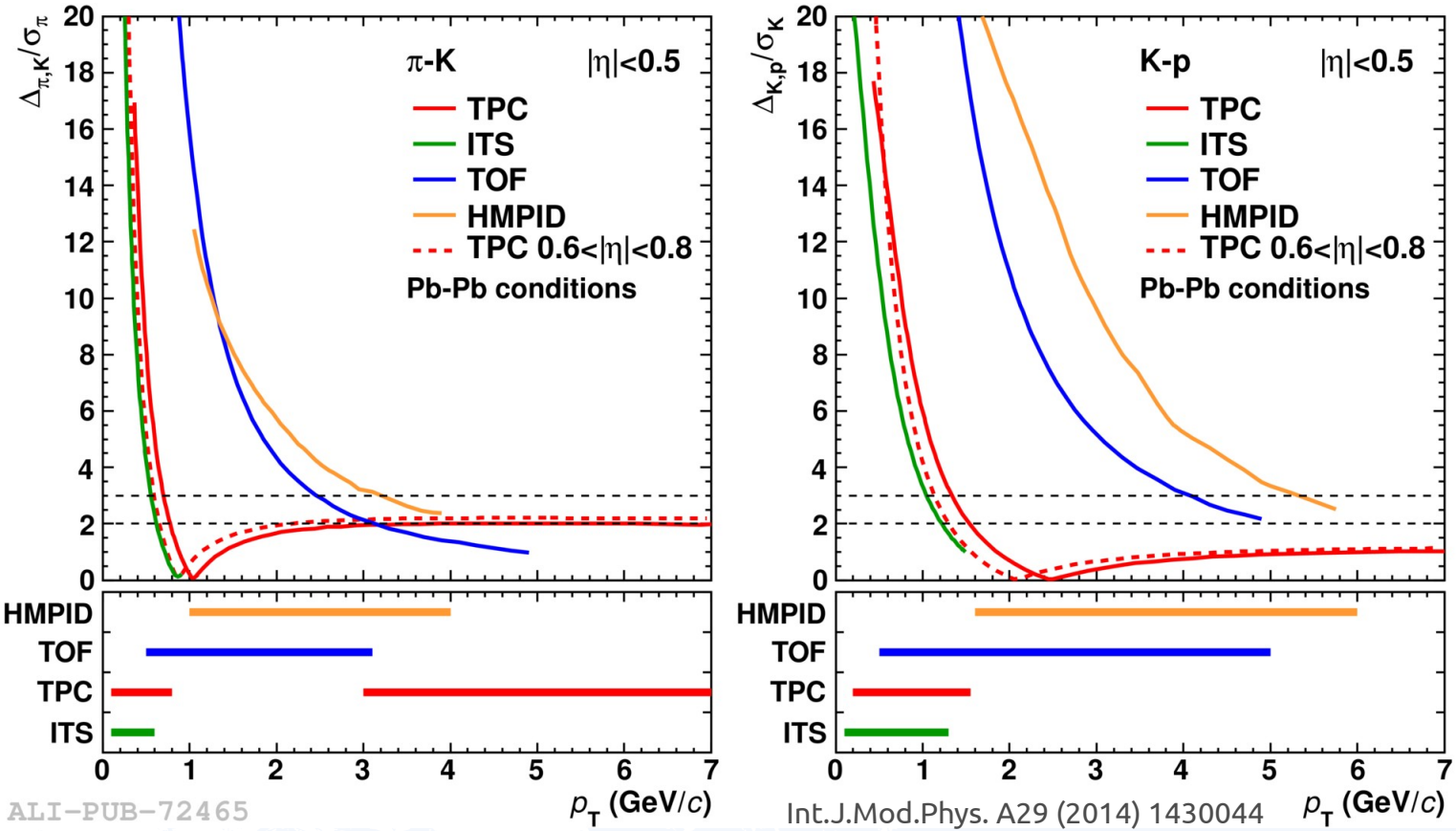
- At high p_T no significant collision energy dependence in the D meson nuclear modification factor



D-meson R_{AA} Talk 07/02/2017, 16:50

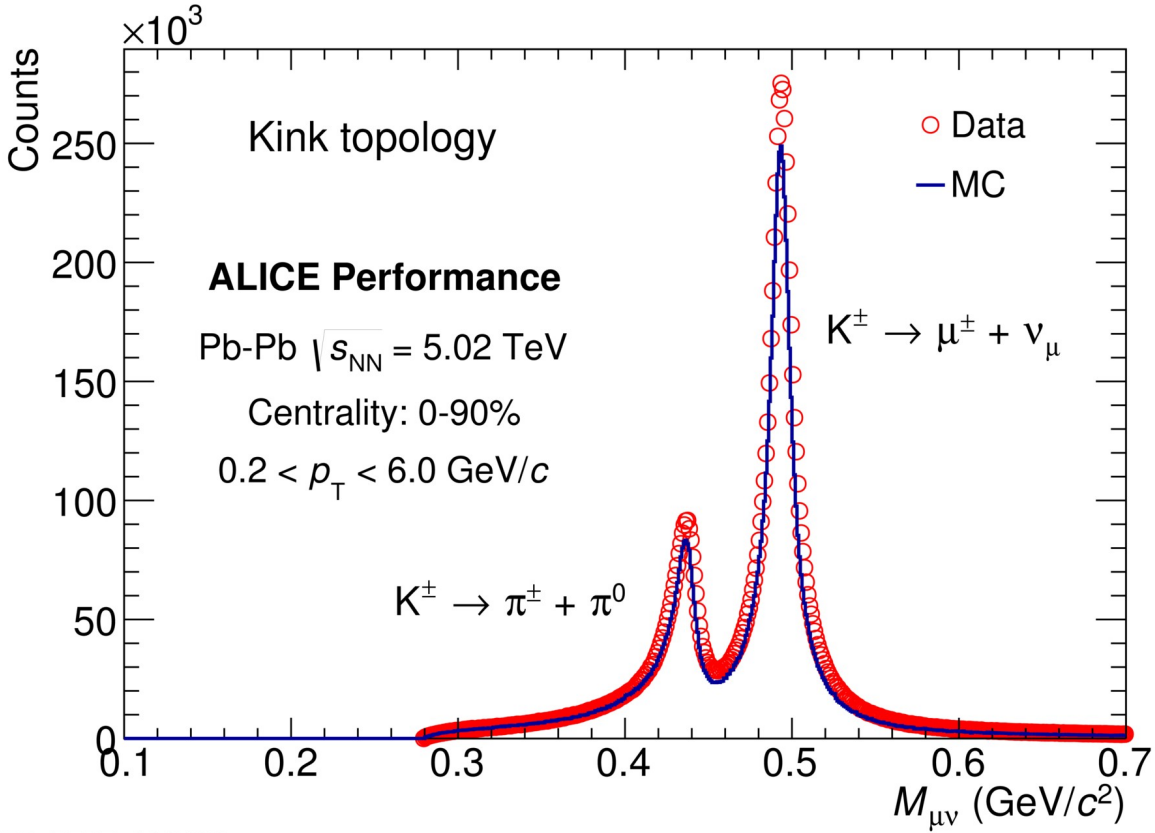
A. M. Barbano

ALICE PID capabilities

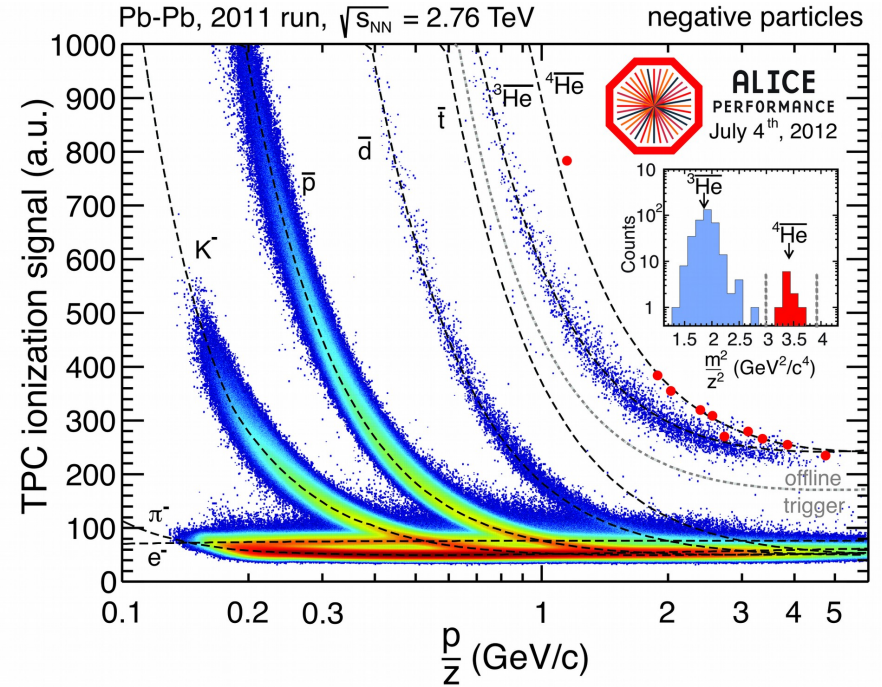


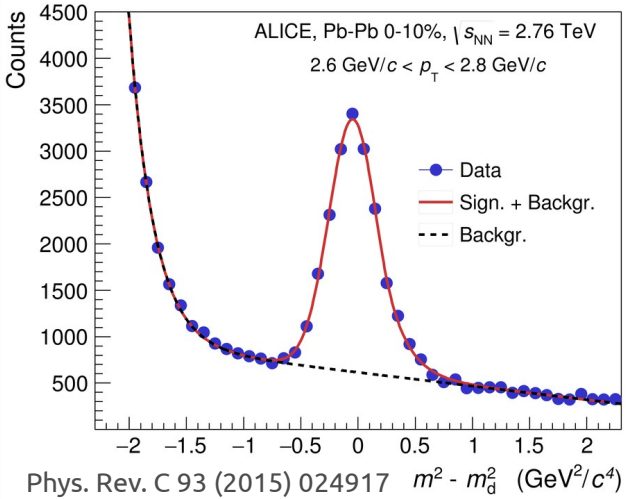
– π-K separation and K-p separation for the different detectors

Kaon identification from Kinks



Nuclei identification in ALICE

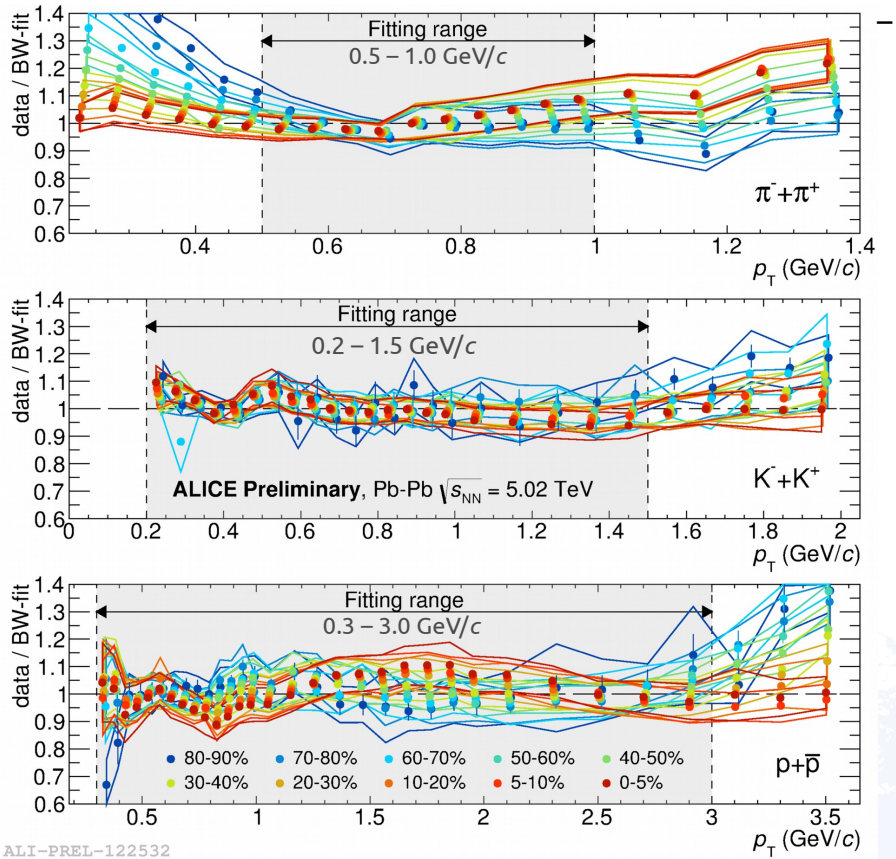




Phys. Rev. C 93 (2015) 024917

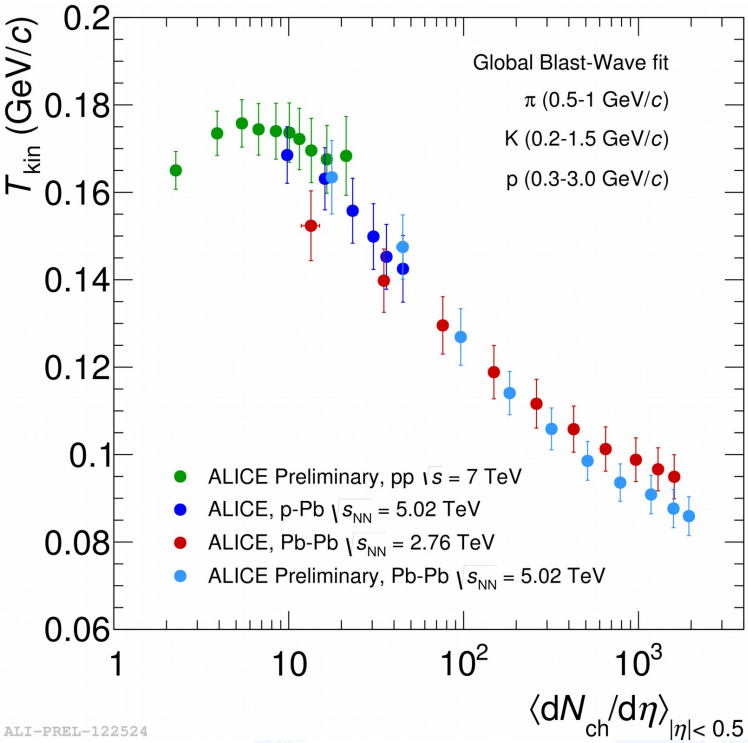
- Identification of light nuclei from specific energy loss in TPC and TOF measurements

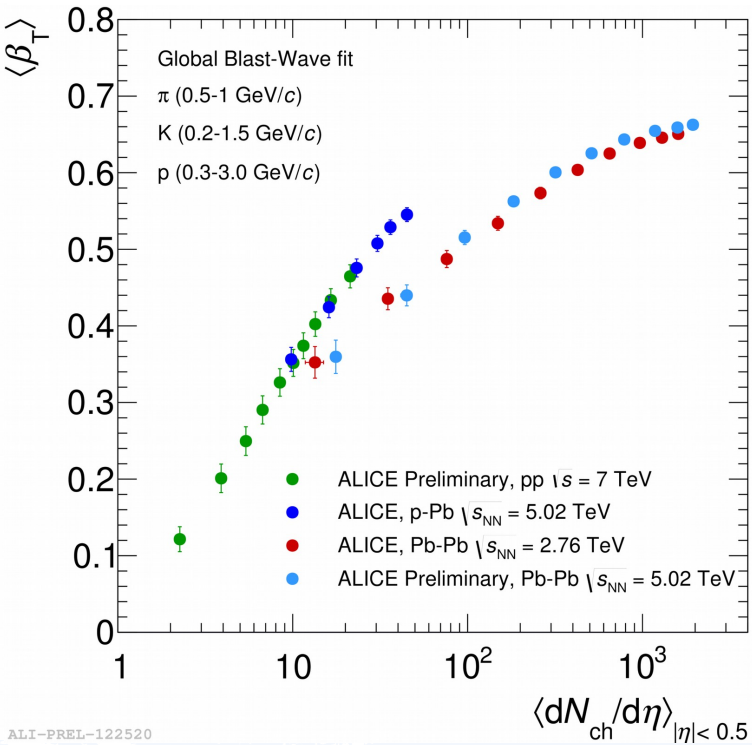
Blast-Wave fit – ratio to spectra



- Same fitting range as used in Pb–Pb collisions at 2.76 TeV Phys. Rev. C88, (2013) 044910

Blast-Wave fit parameters T_{Kin} - $\langle\beta_T\rangle$

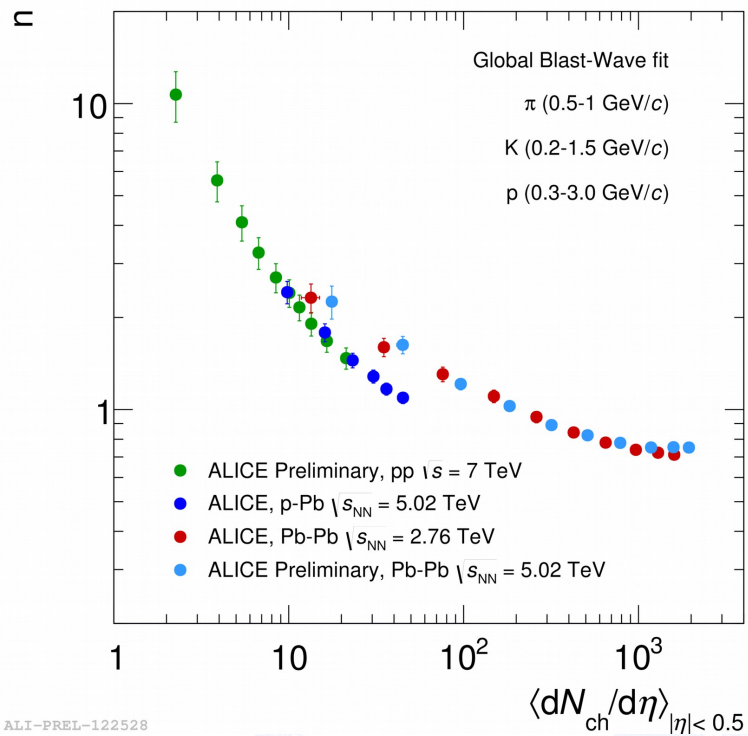


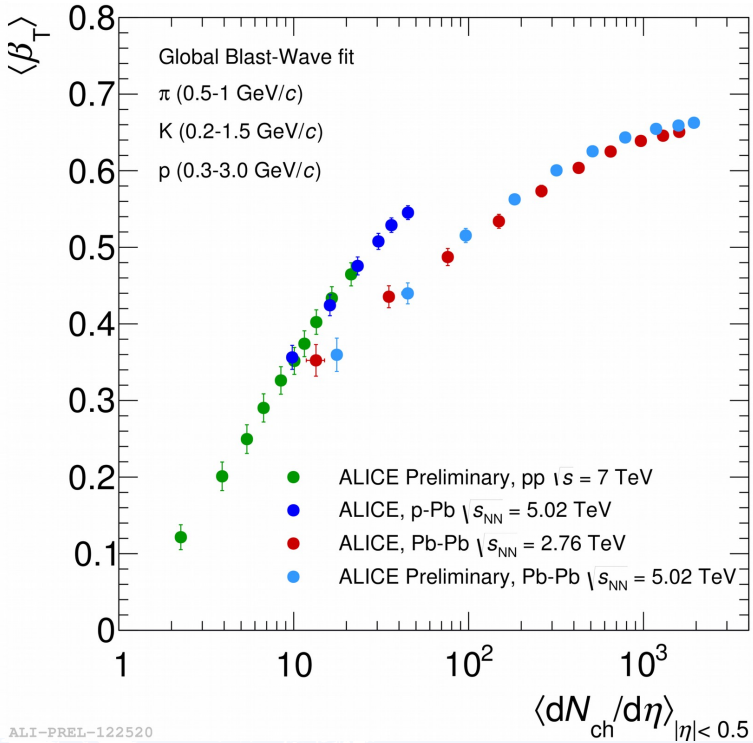


p–Pb Phys. Lett. B 760 (2016) 720

Pb–Pb Phys. Rev. C88, (2013) 044910

Blast-Wave fit parameters n - <β_T>



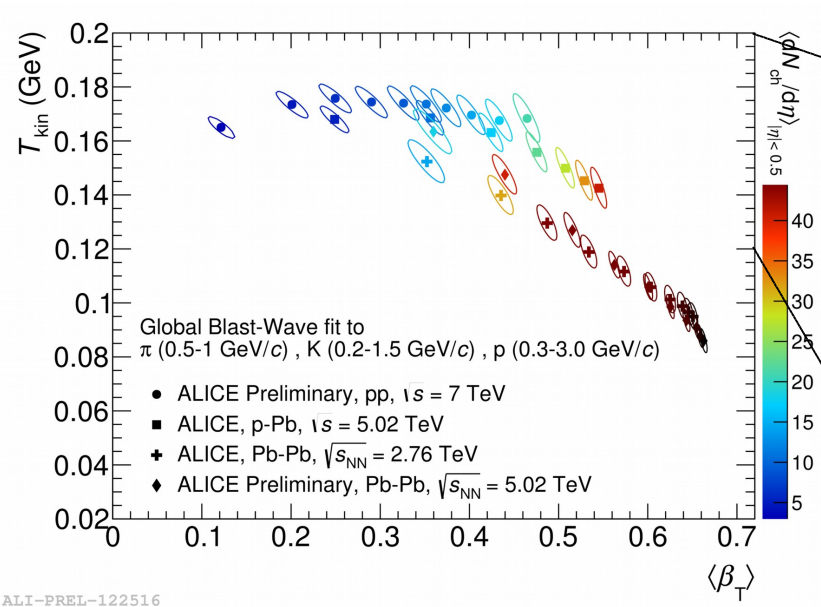


p–Pb Phys. Lett. B 760 (2016) 720

Pb–Pb Phys. Rev. C88, (2013) 044910

Blast-wave fits in small systems

	ALICE	CMS
Centrality estimators	Uses forward rapidity estimators V0A: 2.8 < η < 5.1, V0C: -3.7 < η < -1.7)	Uses central estimator in a wide η window, |η|<2.4
Rapidity	pp/Pb-Pb: |y| <0.5, p-Pb: -0.5 < y < 0	|y| < 1.0
Particle species	$\pi^{\pm}$,$K^{\pm}$, p (and K^0_S, Λ in p-Pb)	K^0_S,Λ
Uncertainties on the fitted spectra	Statistical and systematic	Statistical only
Contours	Uncertainties propagated from the fit	Fit after cut variations



CMS Coll., arXiv:1605.06699