

Strangeness in Quark Matter 2016

27 June to 1 July – UC Berkeley



ALICE

Identified particle production in pp collisions
at 7 and 13 TeV measured with ALICE

Rafael Derradi de Souza

for the ALICE Collaboration

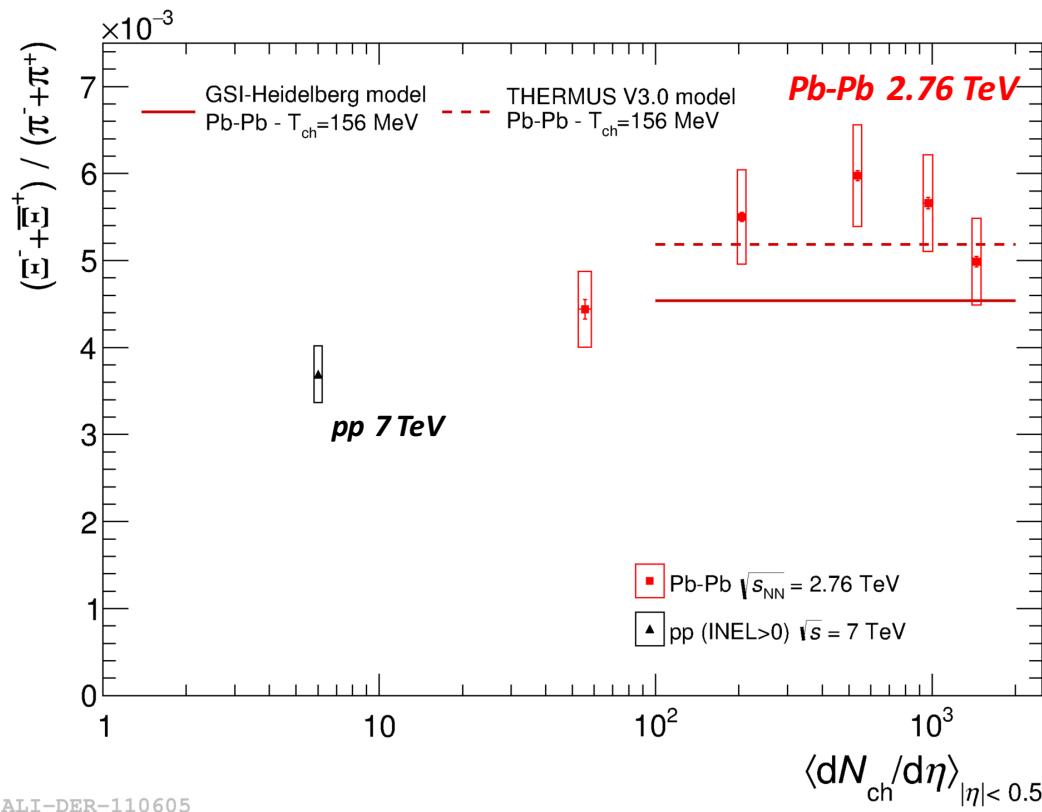
IFGW – UNICAMP - Brazil



Outline

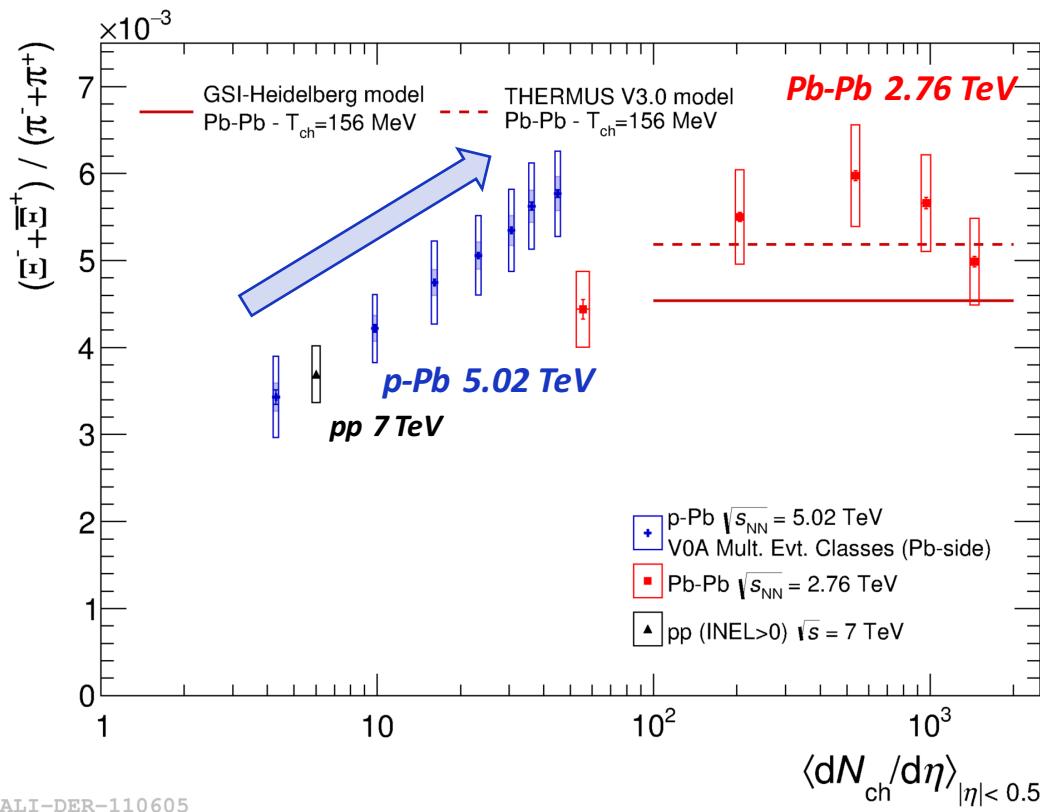
- ▶ **Introduction and Motivation**
- ▶ **The ALICE Experiment**
- ▶ **Light Flavor Hadron Measurements:**
 - $\pi, K, p, K_S^0, \Lambda, \Xi, \Omega, K^{*0}$
- ▶ **Results:**
 - *Identified particle production as a function of multiplicity in pp at 7 TeV*
 - *Preliminary results from pp collisions at 13 TeV*
- ▶ **Summary and Conclusions**

Introduction and Motivation



Hyperon-to-pion ratio as a function of the average charged multiplicity density $\langle dN_{ch}/d\eta \rangle$ at midrapidity ($|\eta| < 0.5$)

Introduction and Motivation



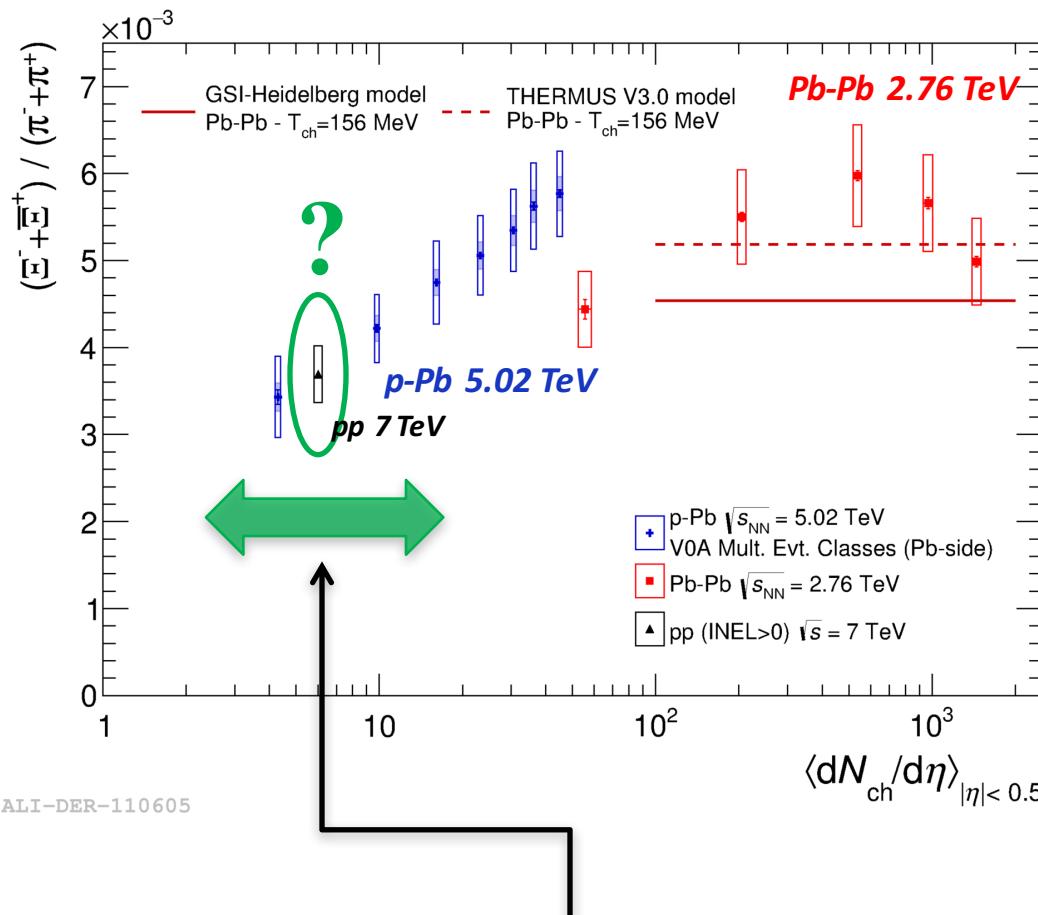
Hyperon-to-pion ratio as a function of the average charged multiplicity density $\langle dN_{ch}/d\eta \rangle$ at midrapidity ($|\eta| < 0.5$)

■ **p-Pb results:** ([arXiv:1512.07227](https://arxiv.org/abs/1512.07227))

- *Consistent with pp at low multiplicities and with central Pb-Pb at high multiplicities*

→ see Domenico Colella's talk
Strangeness Production Session
28 Jun, 14:40

Introduction and Motivation



Hyperon-to-pion ratio as a function of the average charged multiplicity density $\langle dN_{ch}/d\eta \rangle$ at midrapidity ($|\eta| < 0.5$)

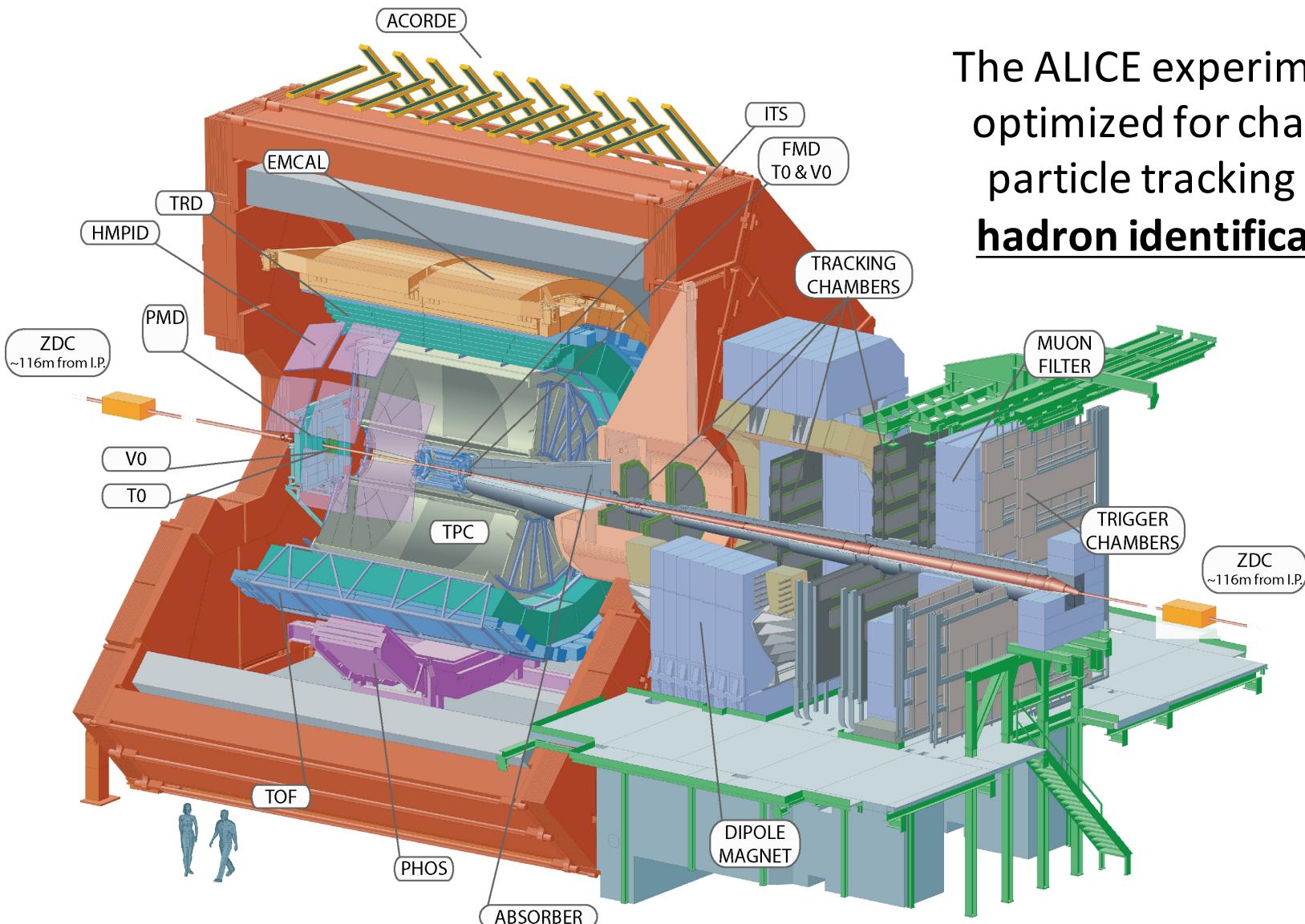
■ **p-Pb results:** ([arXiv:1512.07227](https://arxiv.org/abs/1512.07227))

- Consistent with **pp** at low multiplicities and with **central Pb-Pb** at high multiplicities

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**What about multiplicity dependence in pp?
Is hadrochemistry independent of \sqrt{s} ?**

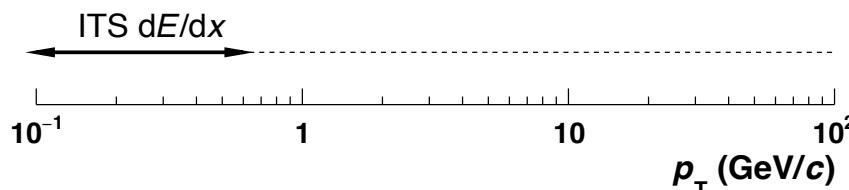
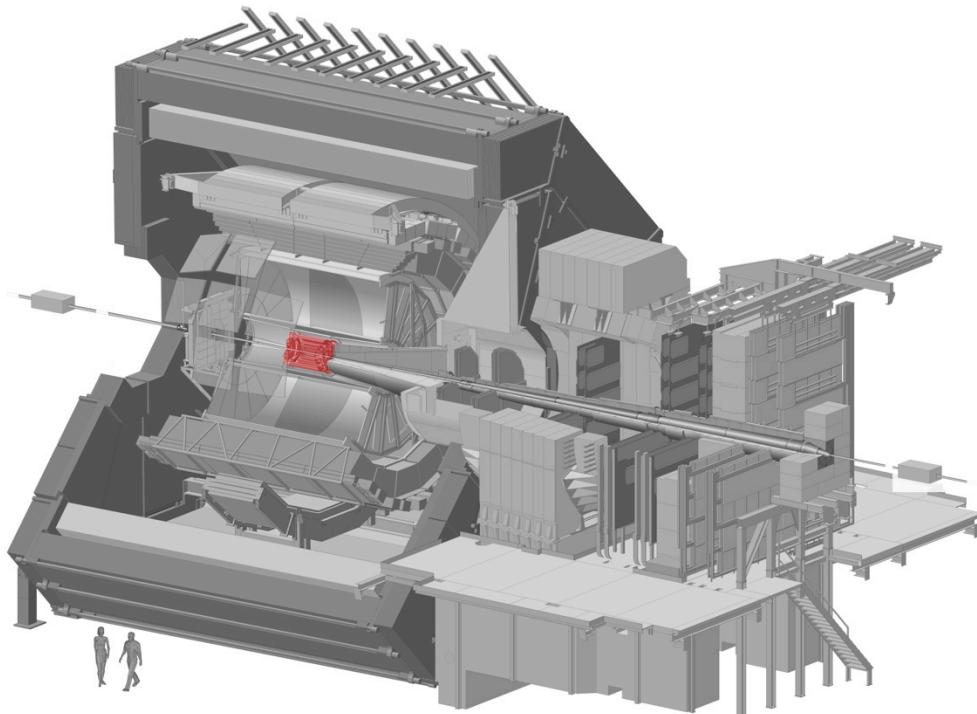
The ALICE Experiment



The ALICE experiment is optimized for charged particle tracking and **hadron identification**

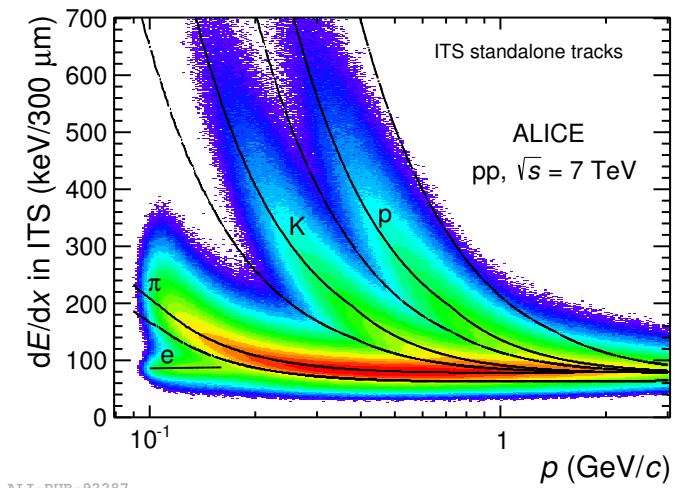
The ALICE Experiment

→ Particle Identification: π , K and p



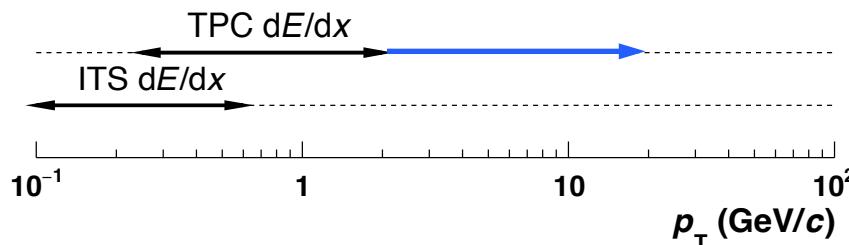
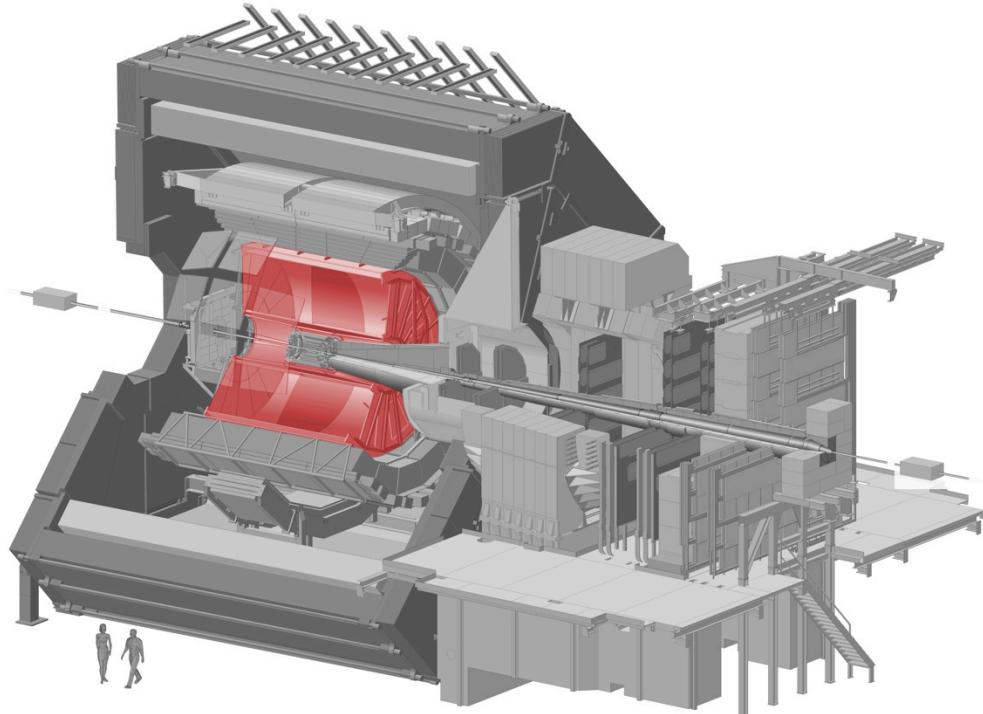
ITS ($|\eta| < 0.9$)

- 6 Layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)



The ALICE Experiment

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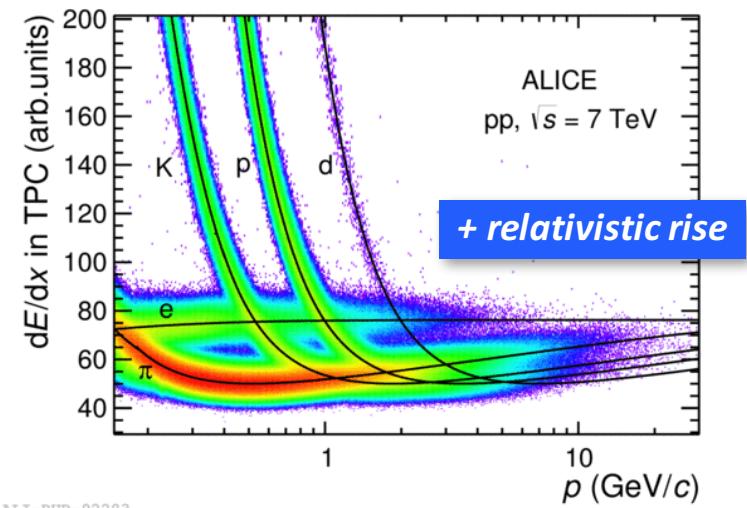


ITS ($|\eta| < 0.9$)

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- Trigger, tracking, vertex, PID (dE/dx)

TPC ($|\eta| < 0.9$)

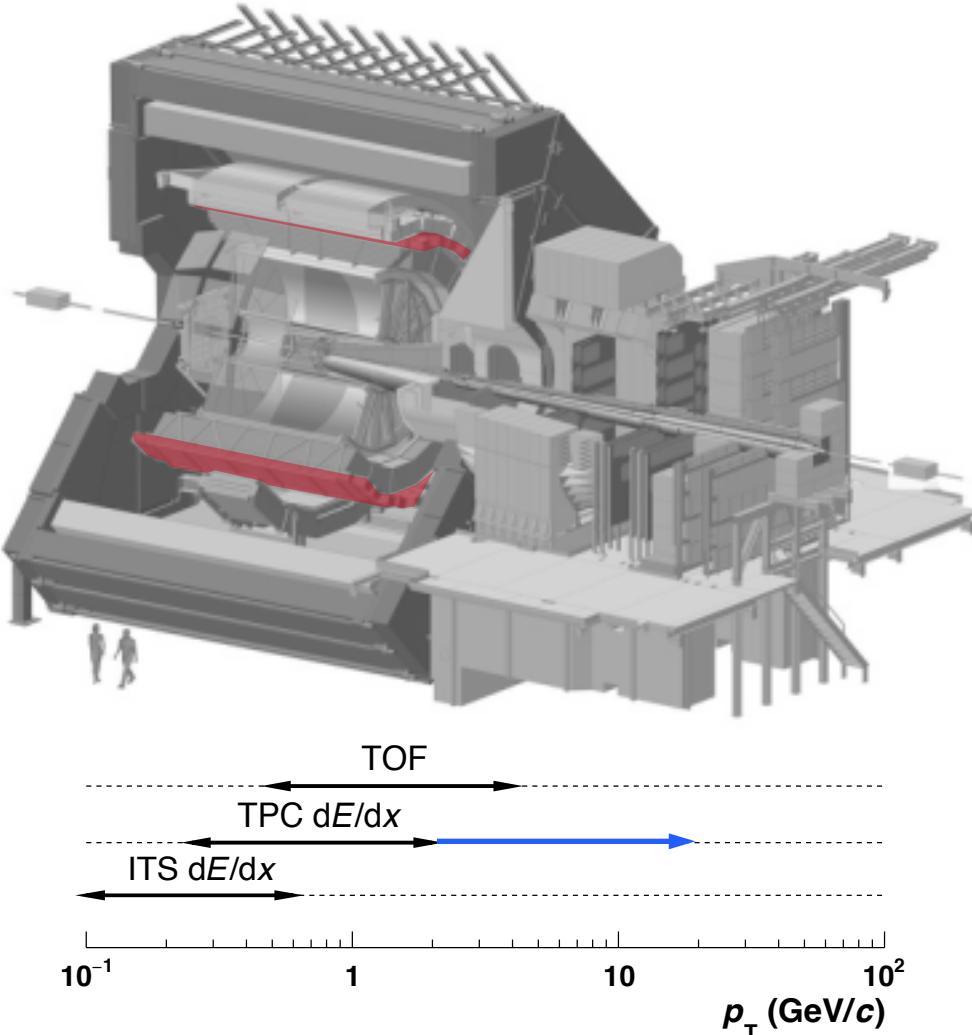
- Gas-filled ionization detection volume
- Tracking, vertex, PID (dE/dx)



ALI-PUB-92283

The ALICE Experiment

→ Particle Identification: π , K and p



ITS ($|\eta| < 0.9$)

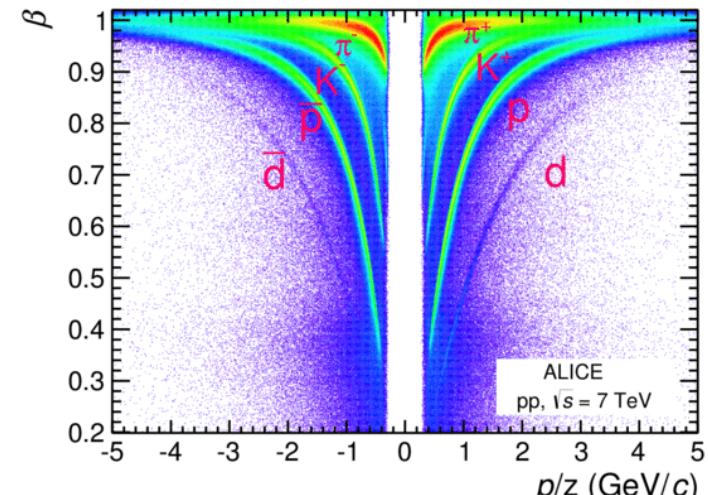
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TPC ($|\eta| < 0.9$)

- Gas-filled ionization detection volume
- Tracking, vertex, PID (dE/dx)

TOF ($|\eta| < 0.9$)

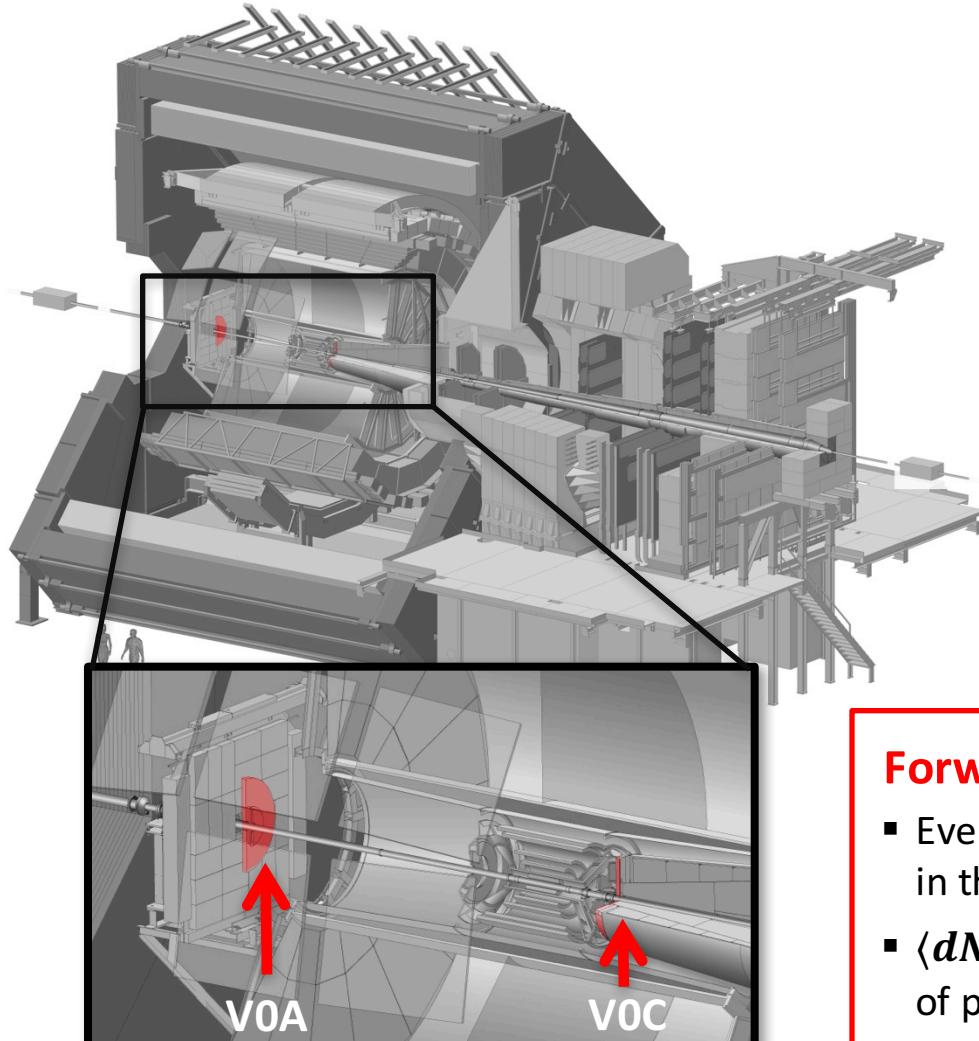
- Multi-gap resistive plate chambers
- PID



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The ALICE Experiment

→ Multiplicity Selection



ITS ($|\eta| < 0.9$)

- 6 Layers of silicon detectors
- Trigger, tracking, vertex, PID (dE/dx)

TPC ($|\eta| < 0.9$)

- Gas-filled ionization detection volume
- Tracking, vertex, PID (dE/dx)

TOF ($|\eta| < 0.9$)

- Multi-gap resistive plate chambers
- PID

V0 [$V0A (2.8 < \eta < 5.1) \& V0C (-3.7 < \eta < -1.7)$]

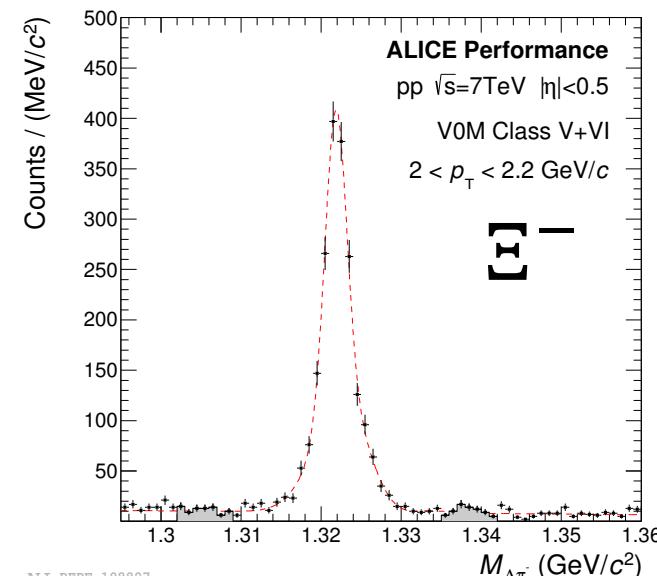
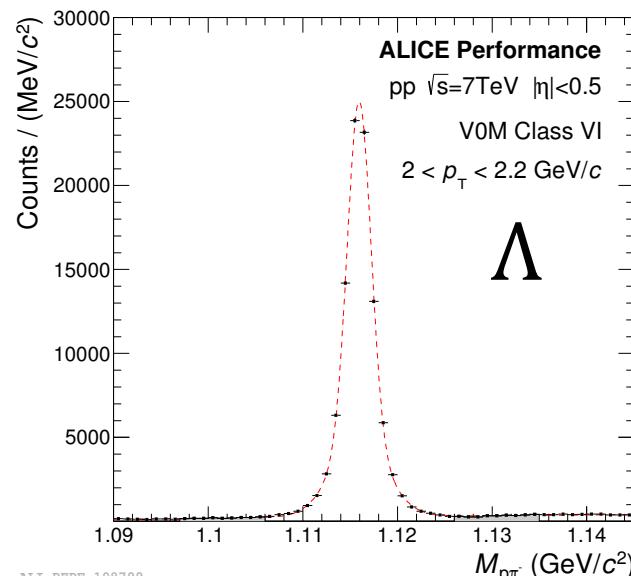
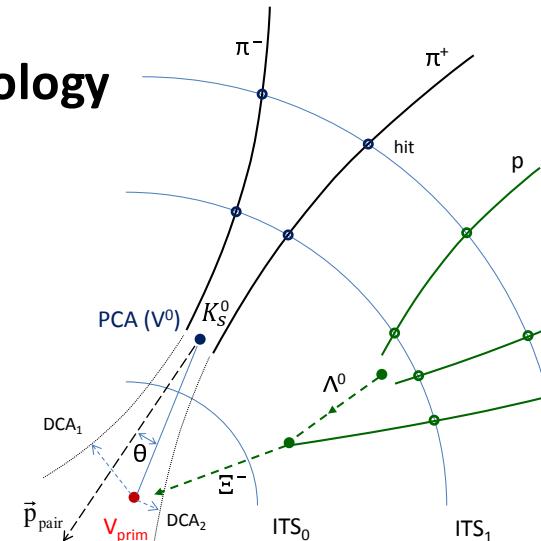
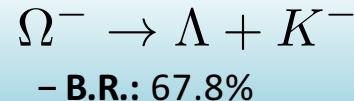
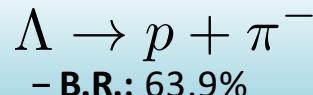
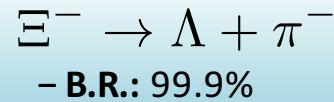
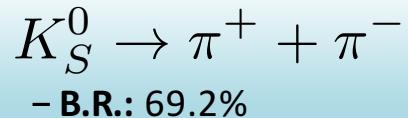
- Forward arrays of scintillators
- Trigger, beam gas rejection
- Multiplicity estimator ←

Forward Multiplicity Estimator

- Event selection based on total charge deposited in the **V0A** and **V0C** detectors ("V0M")
- $\langle dN_{\text{ch}}/d\eta \rangle$ estimated as the average number of primary charged tracks in $|\eta| < 0.5$

Invariant Mass Reconstruction

V^0 's and Cascades reconstruction via decay topology



Invariant Mass Reconstruction

V^0 's and Cascades reconstruction via decay topology

$$K_S^0 \rightarrow \pi^+ + \pi^-$$

- B.R.: 69.2%

$$\Xi^- \rightarrow \Lambda + \pi^-$$

- B.R.: 99.9%

$$\Lambda \rightarrow p + \pi^-$$

- B.R.: 63.9%

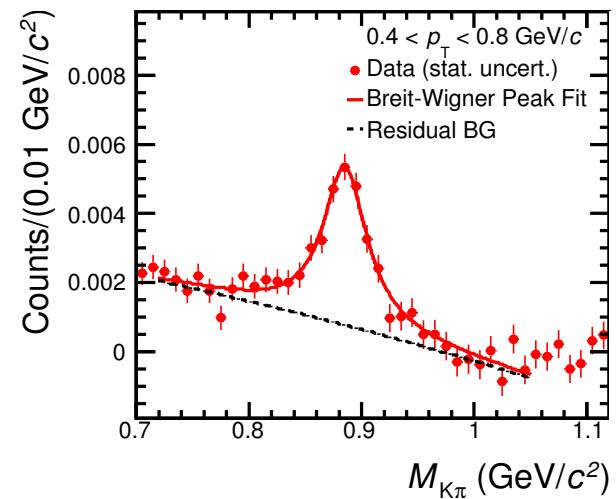
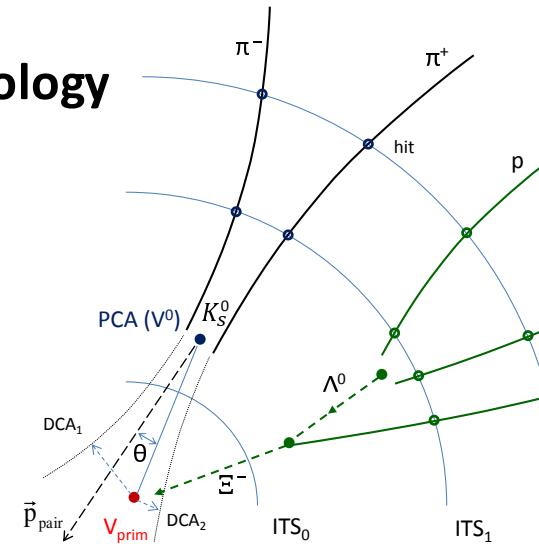
$$\Omega^- \rightarrow \Lambda + K^-$$

- B.R.: 67.8%

$$K^{*0} \rightarrow K^+ + \pi^-$$

- B.R.: ~66.6%

- *Combinatorial background estimated using event mixing technique*
- *Polynomial residual background*
- *Signal extraction performed using bin counting method*

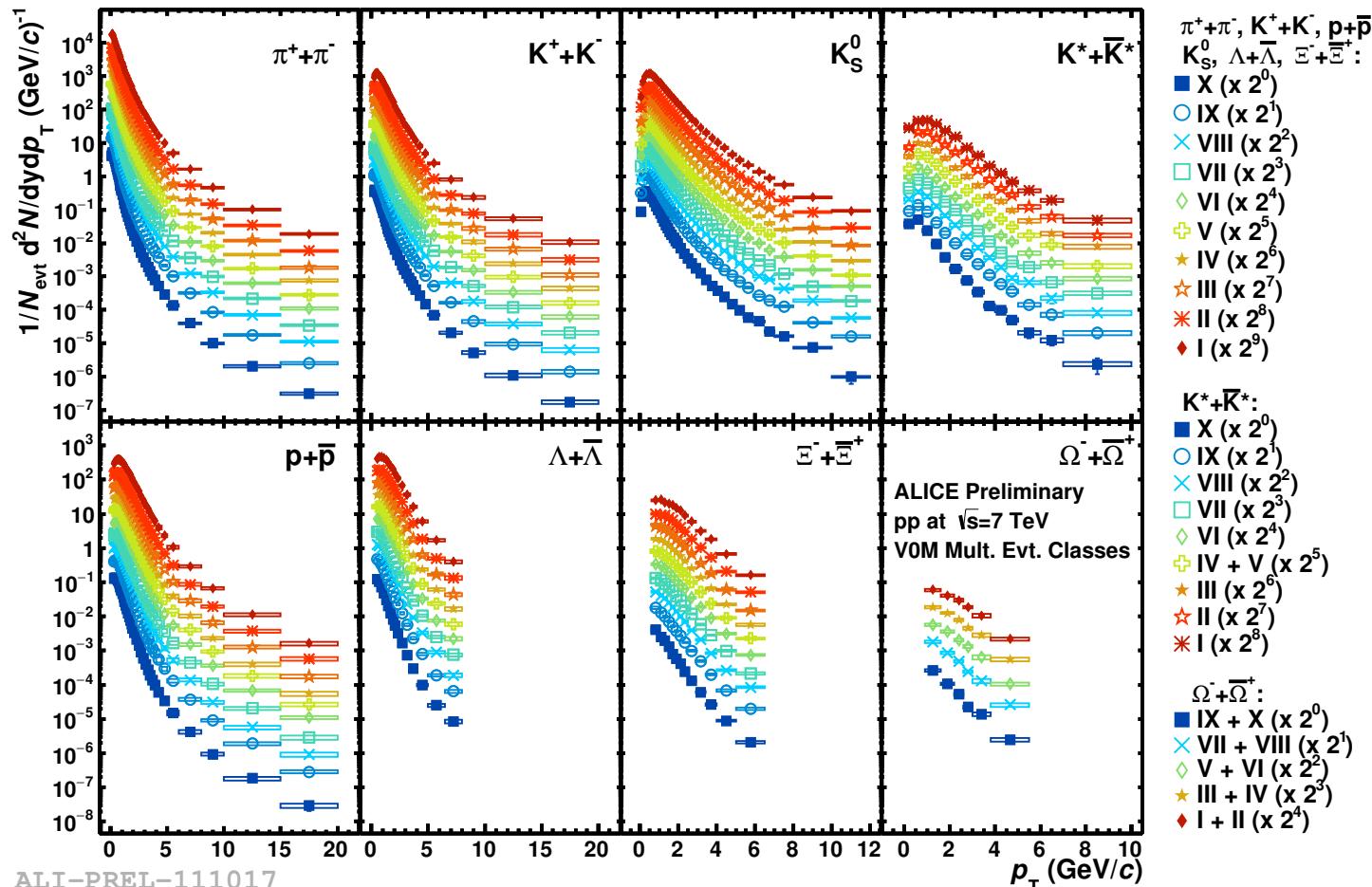


ALI-PREL-107495

Transverse momentum spectra

- *pp at 7 TeV vs multiplicity*

- **V0M Multiplicity Classes:** $\left\{ \begin{array}{l} I \rightarrow \langle dN_{ch}/d\eta \rangle \approx 3.5 \times \langle dN_{ch}/d\eta \rangle^{INEL>0} \\ \vdots \\ X \rightarrow \langle dN_{ch}/d\eta \rangle \approx 0.4 \times \langle dN_{ch}/d\eta \rangle^{INEL>0} \\ \langle dN_{ch}/d\eta \rangle^{INEL>0} \approx 6.0 \end{array} \right\}$



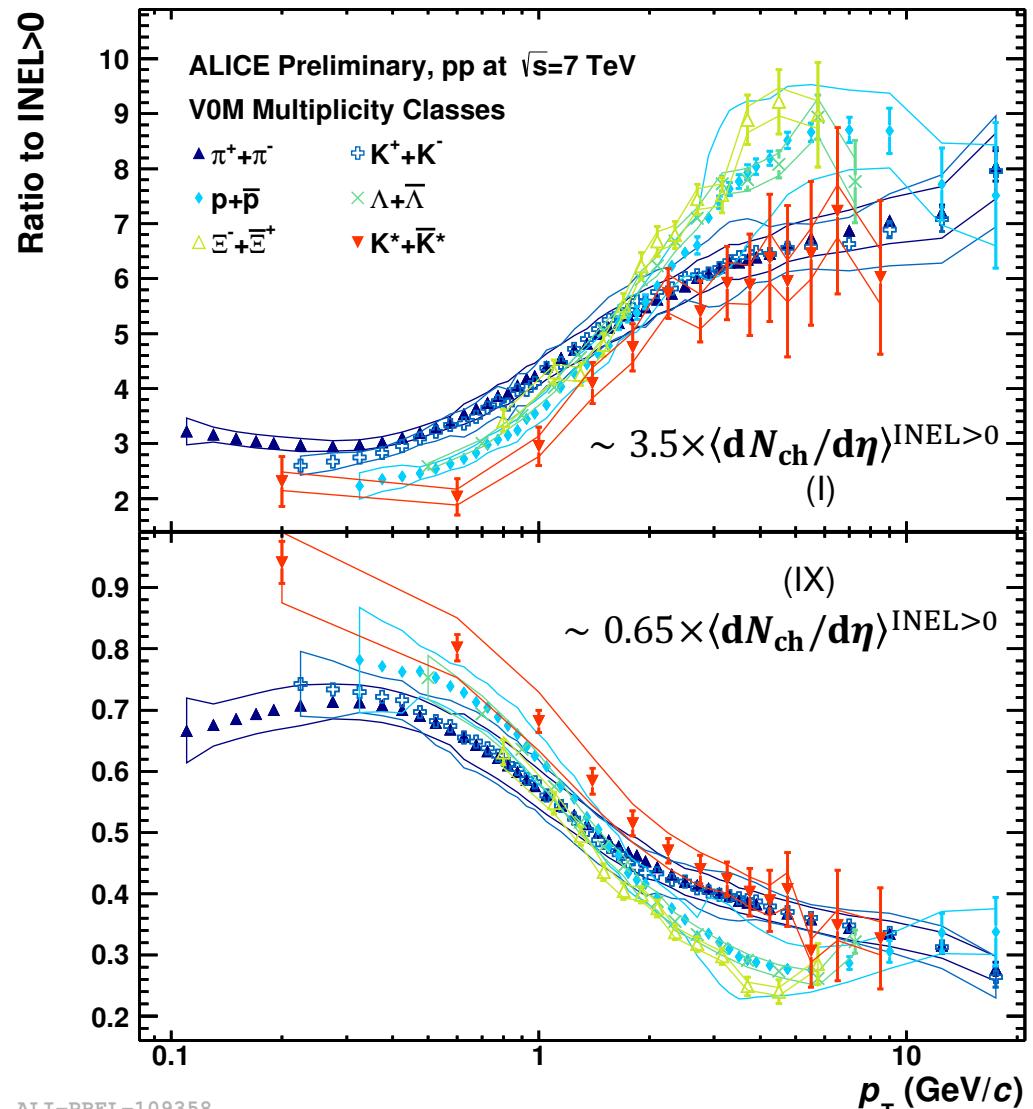
Transverse momentum spectra

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Spectral Modification

- Spectra become ***harder*** at ***higher multiplicities***
- The ***hardening*** is more pronounced for **baryons** than for **mesons**

$$\langle dN_{ch}/d\eta \rangle^{INEL>0} \approx 6.0$$

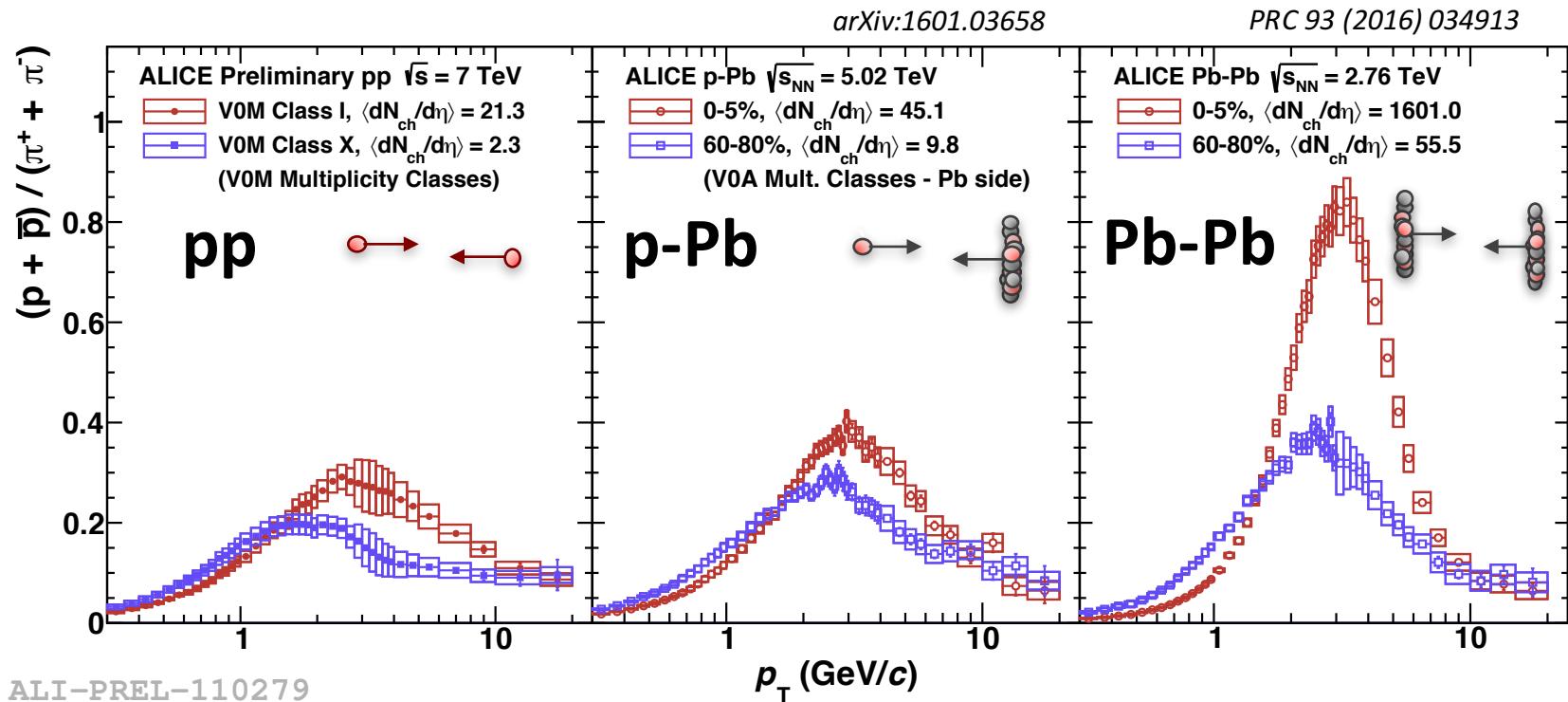


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Spectra Ratios in pp, p-Pb and Pb-Pb

- *pp at 7 TeV vs multiplicity*

Baryon-to-meson ratio

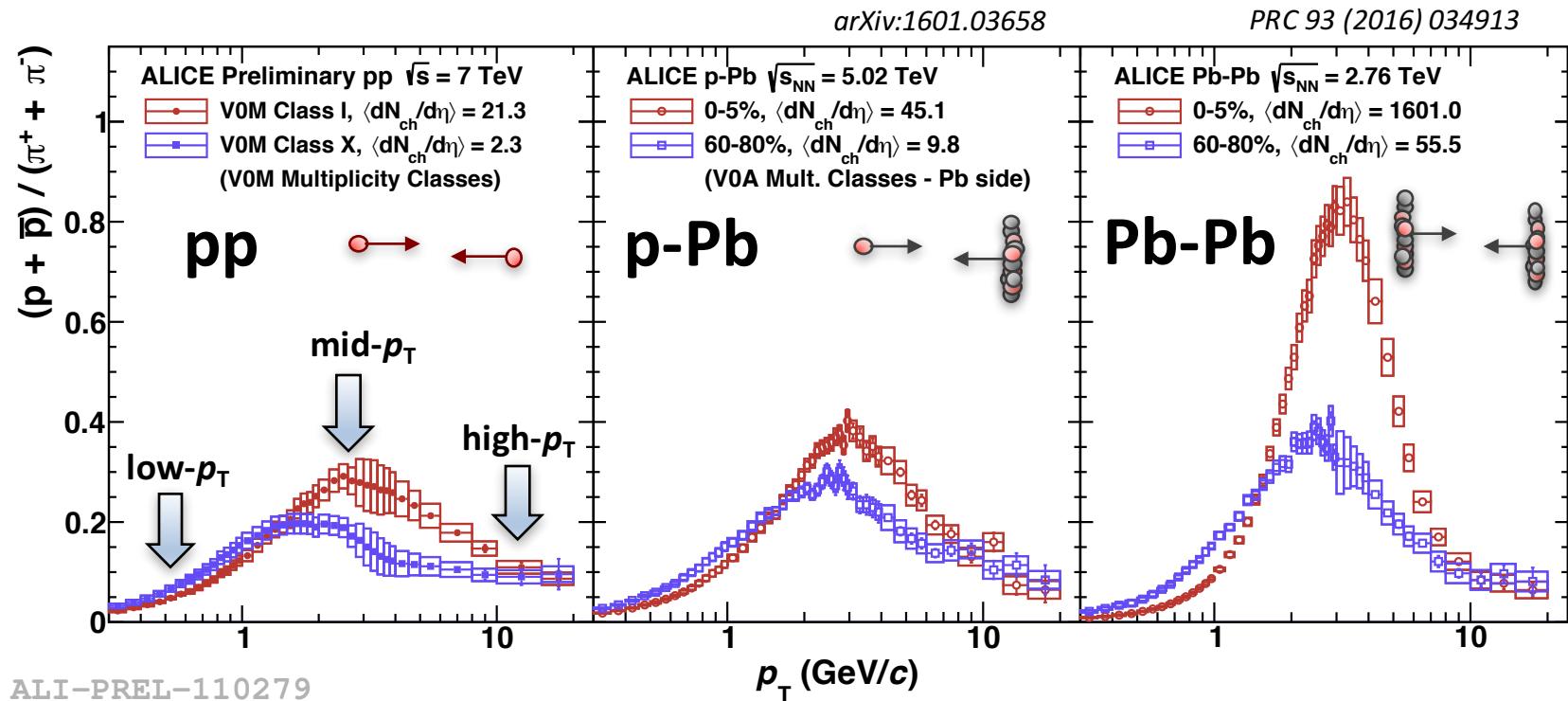


*Dependence with the event multiplicity in pp
qualitatively similar to p-Pb and Pb-Pb*

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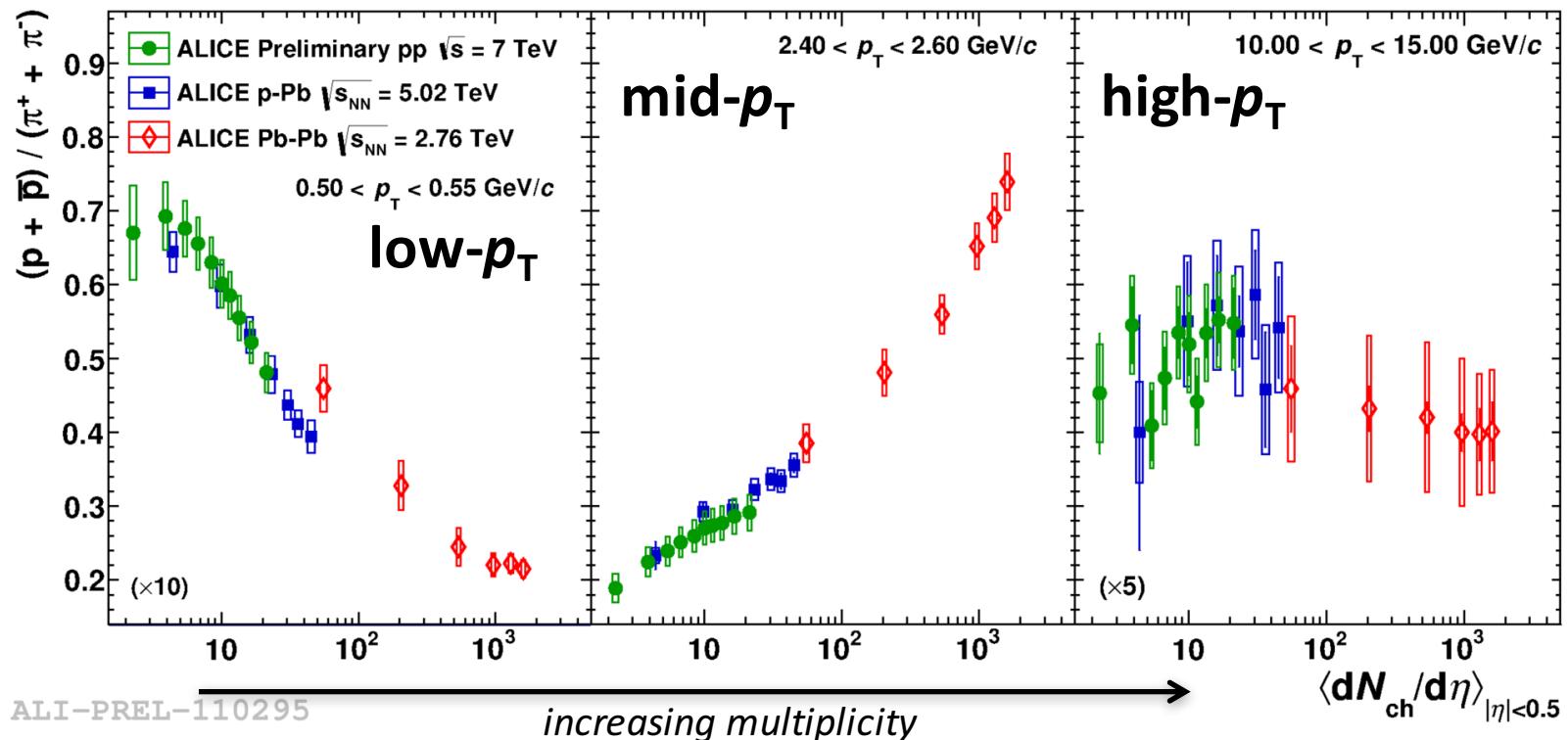


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Spectra Ratios in pp, p-Pb and Pb-Pb

- *pp at 7 TeV vs multiplicity*

Low-, mid- and high- p_T vs multiplicity for pp, p-Pb and Pb-Pb



Remarkable consistency across systems as a function of multiplicity
Radial flow? Color reconnection?...

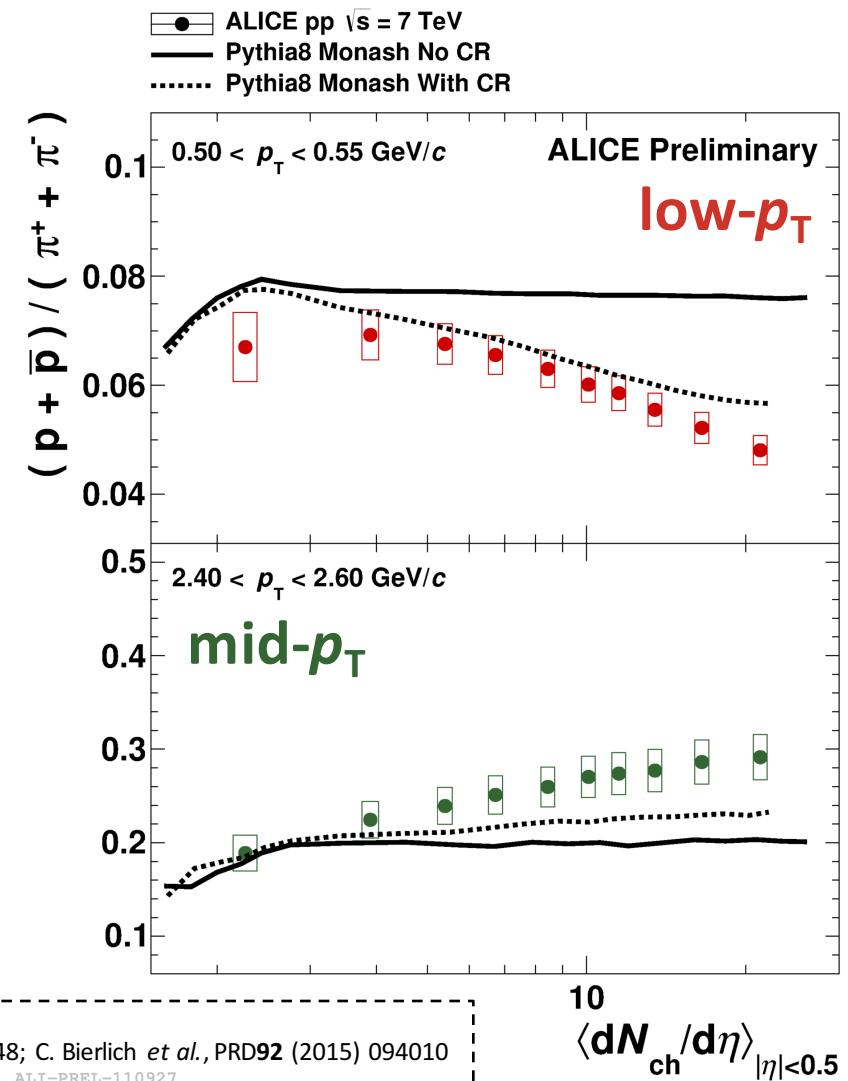
Spectra Ratios in pp compared to MC



- *pp at 7 TeV vs multiplicity*

MC predictions in pp collisions

- Color Reconnection:
 - Implemented in PYTHIA8 Monash
 - Qualitative agreement with the behavior of the data



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

DIPSY – C. Flensburg *et al.*, JHEP **08** (2011) 103; C. Bierlich *et al.*, JHEP **03** (2015) 148; C. Bierlich *et al.*, PRD **92** (2015) 094010

EPOS LHC – T. Pierog *et al.*, arXiv:1306.0121

HERWIG7 – M. Bahr *et al.*, EPJC **58** (2008) 639-707; J. Bellm *et al.*, EPJC **76** no.4 (2016) 196

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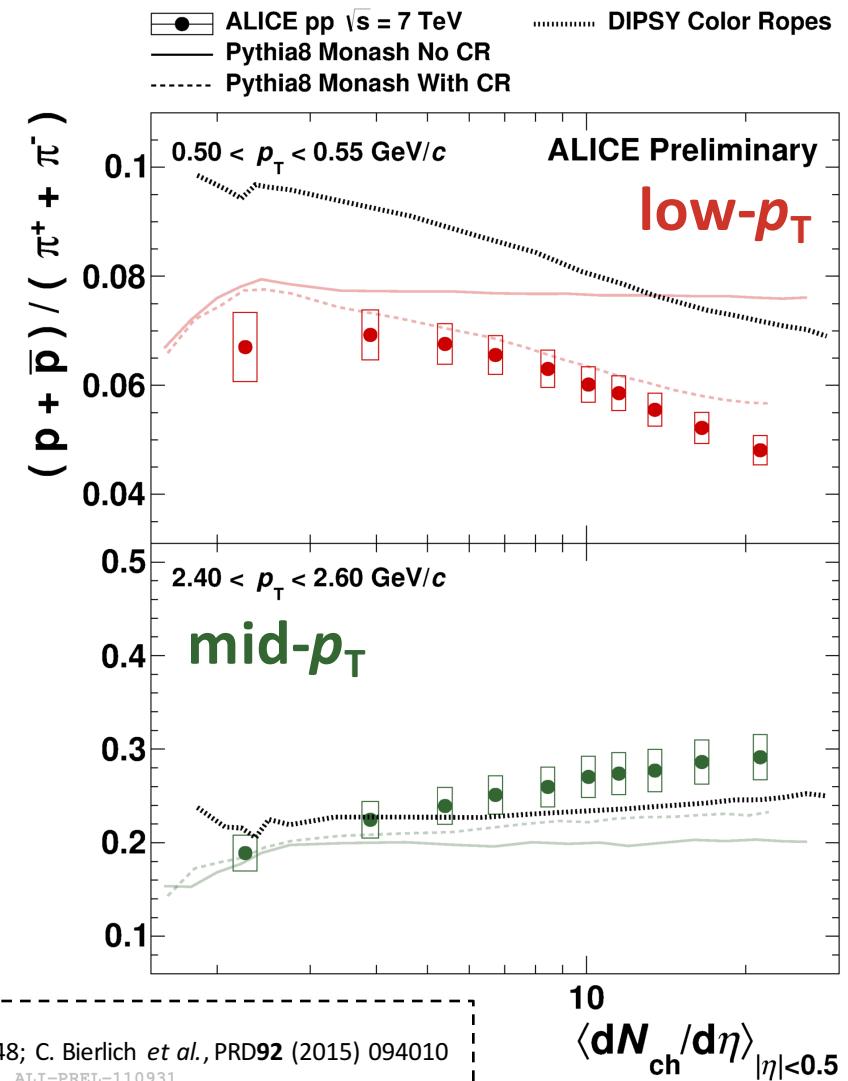
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ALICE-PREL-110931

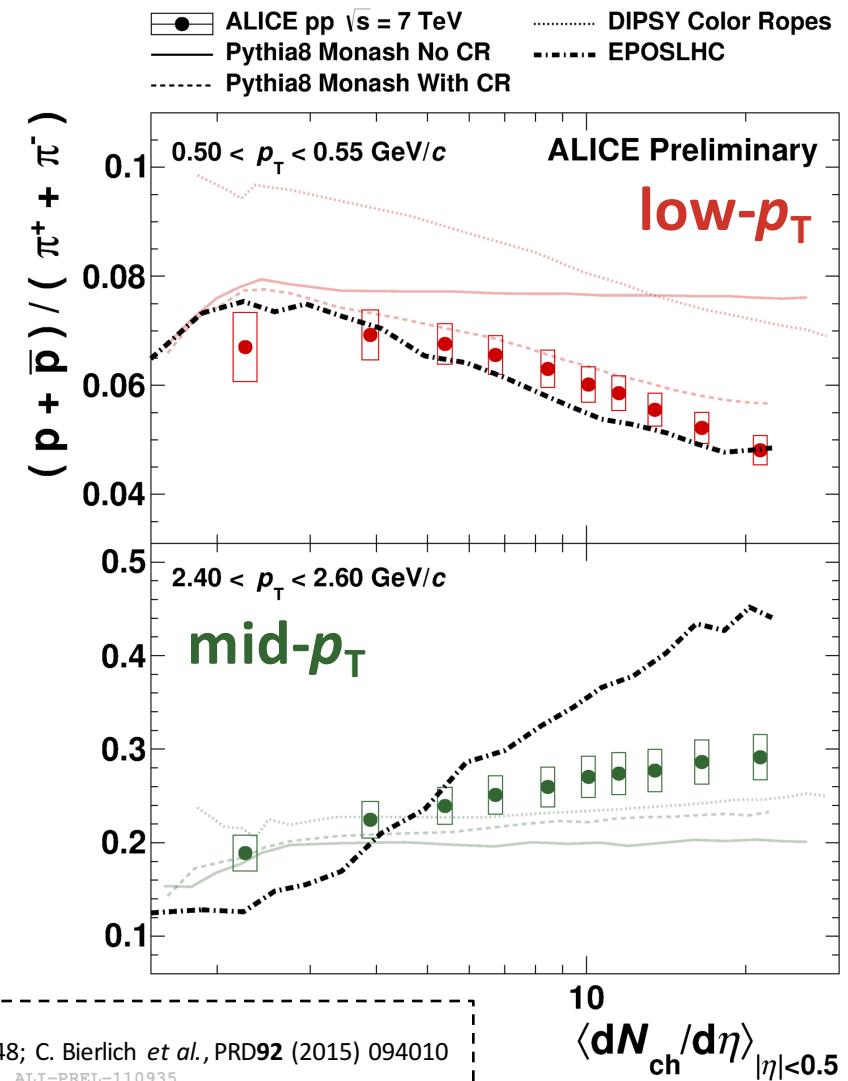
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- Collective Radial Expansion:
 - Present in EPOS LHC
 - viable explanation but effect is overestimated



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ALICE-PREL-110935

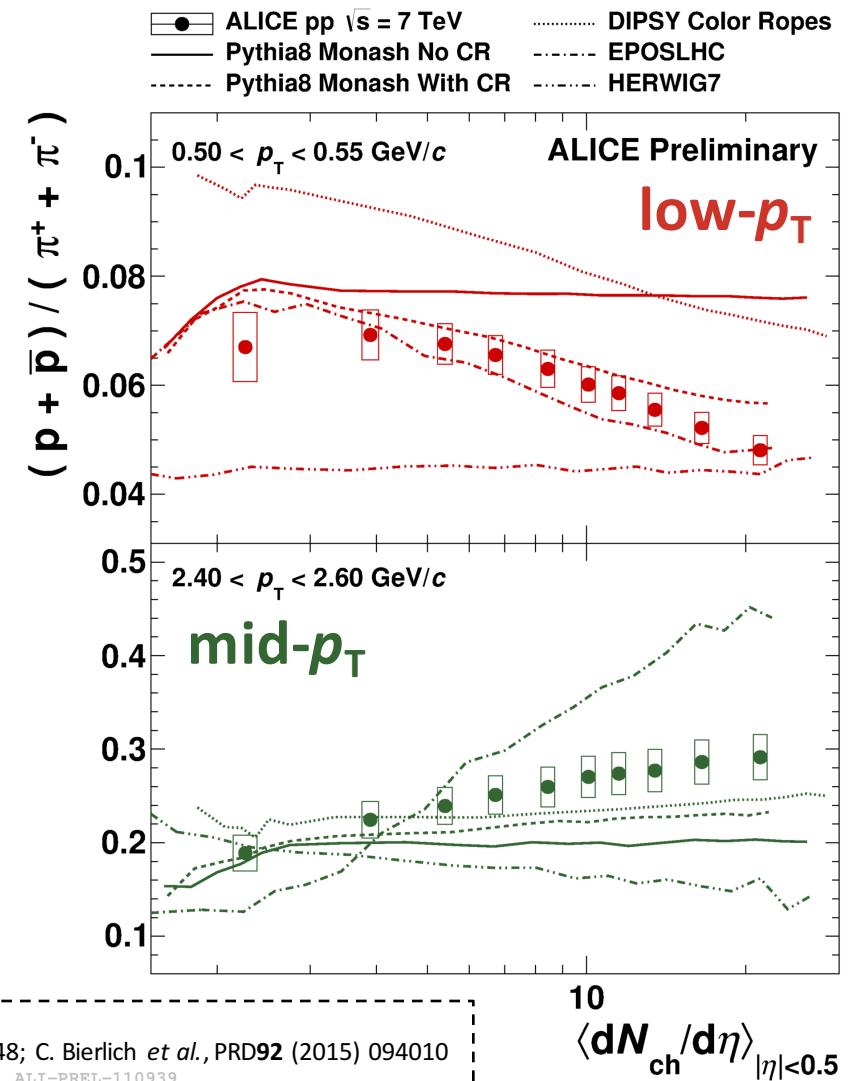
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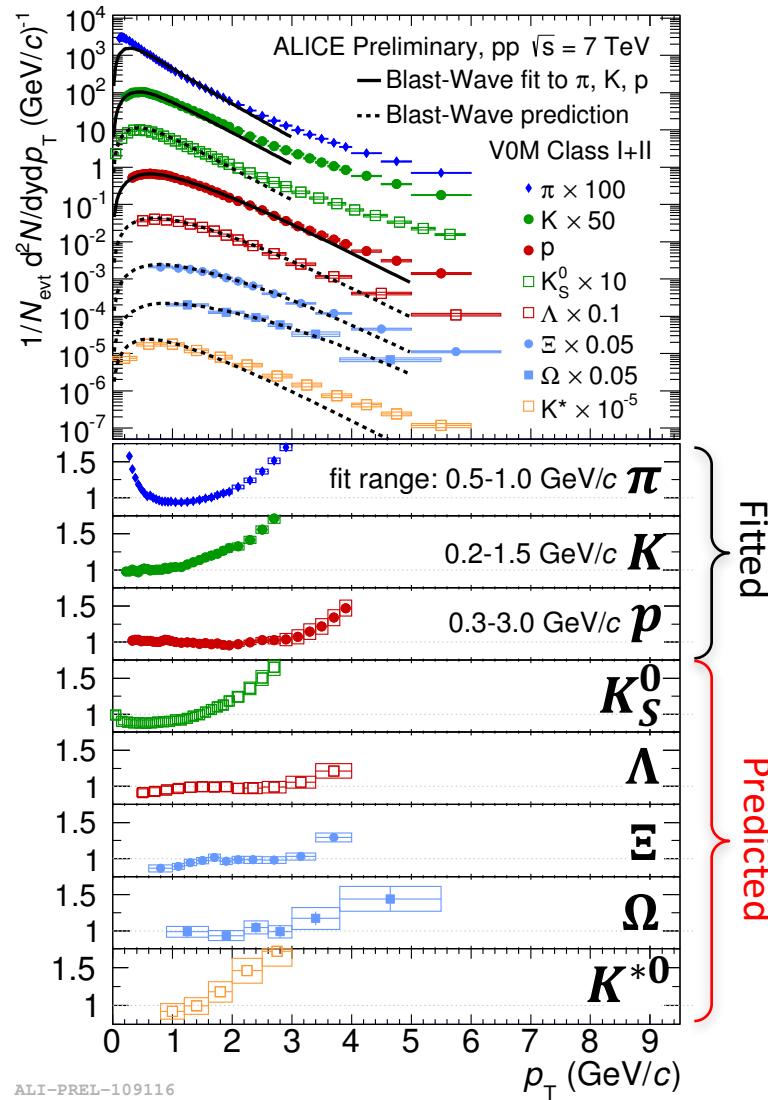
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HERWIG7 – M. Bahr *et al.*, EPJC **58** (2008) 639-707; J. Bellm *et al.*, EPJC **76** no.4 (2016) 196

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Blast-Wave Model Fits

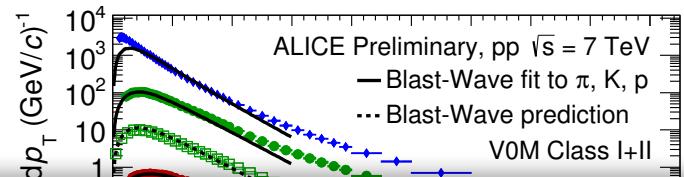
- *pp at 7 TeV vs multiplicity*
- Fit performed over π , K and p spectra for the highest multiplicity selection



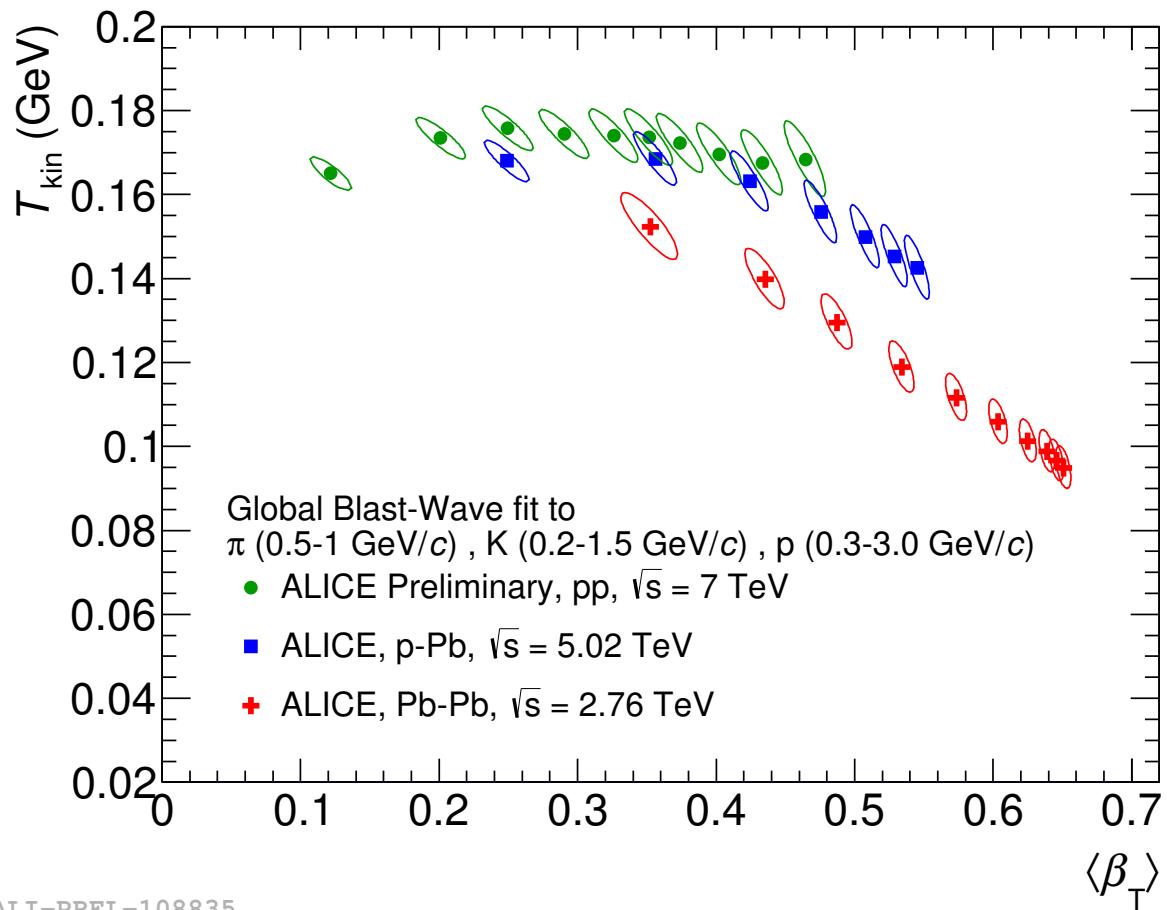
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- $\beta_T - T_{kin}$ plot:
 - *Similar behavior between pp and p-Pb*
 - *Clear separation with respect to Pb-Pb*



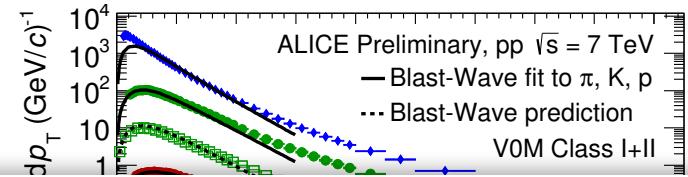
ALI-PREL-108835

Blast-Wave Model Fits



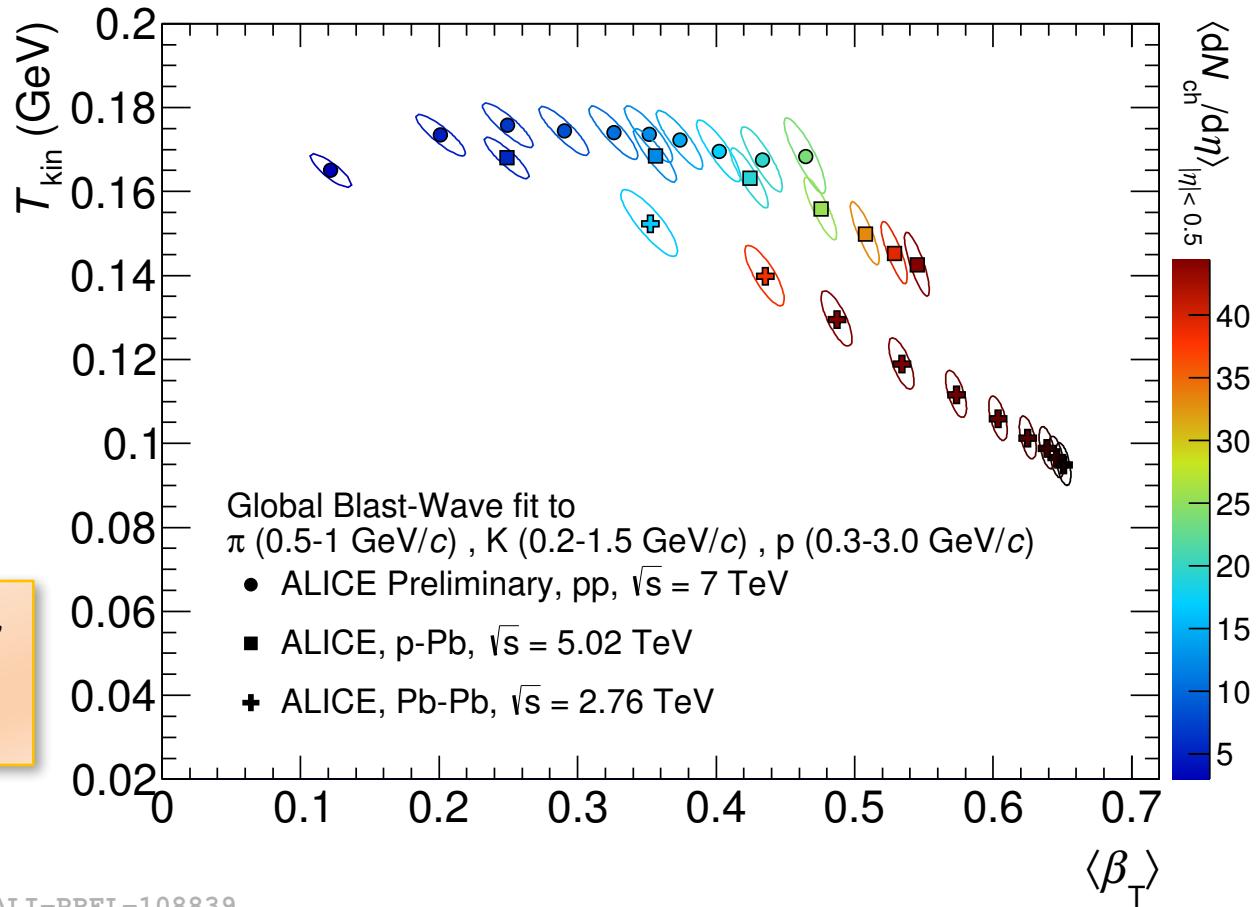
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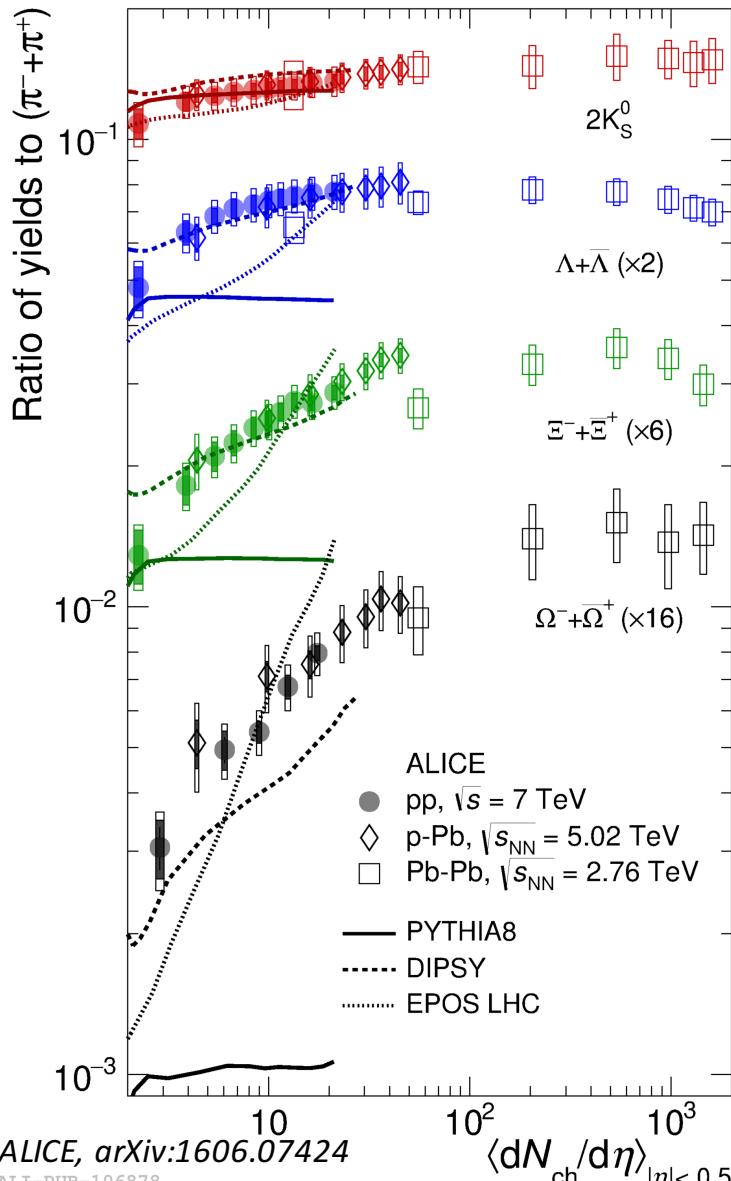
- $\beta_T - T_{kin}$ plot:
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**at similar multiplicities,
smaller systems have
stronger β_T**



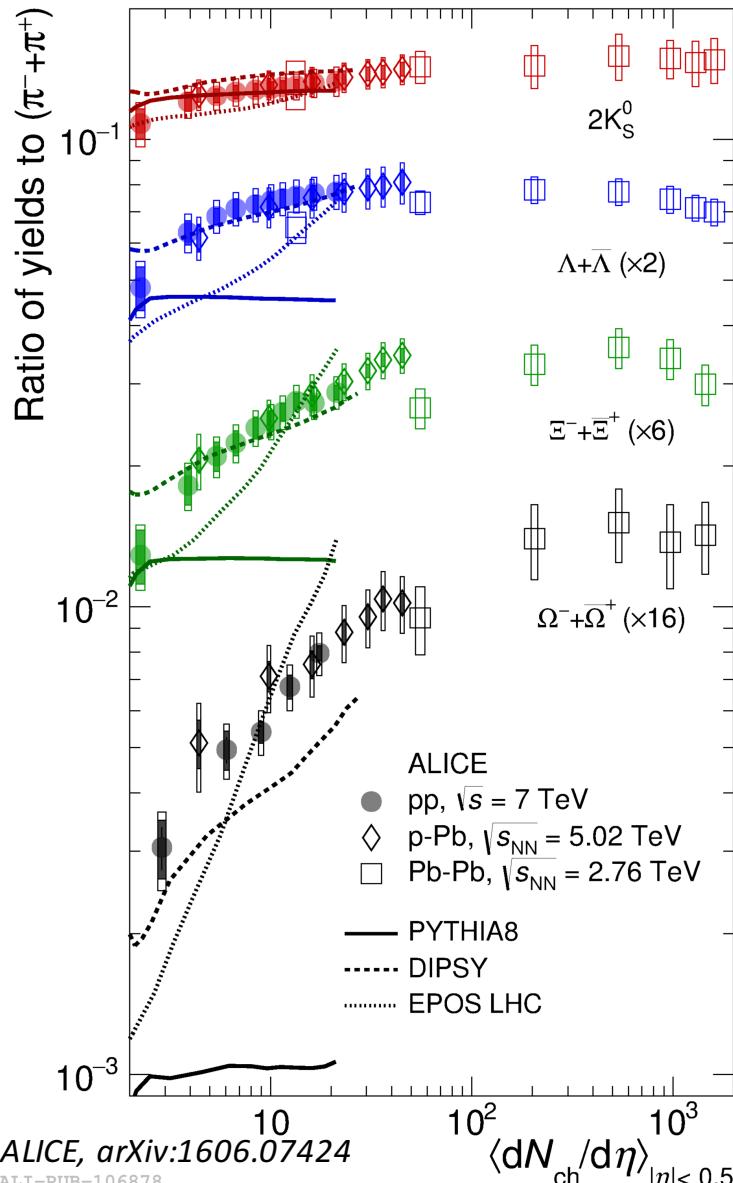
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Strangeness Enhancement

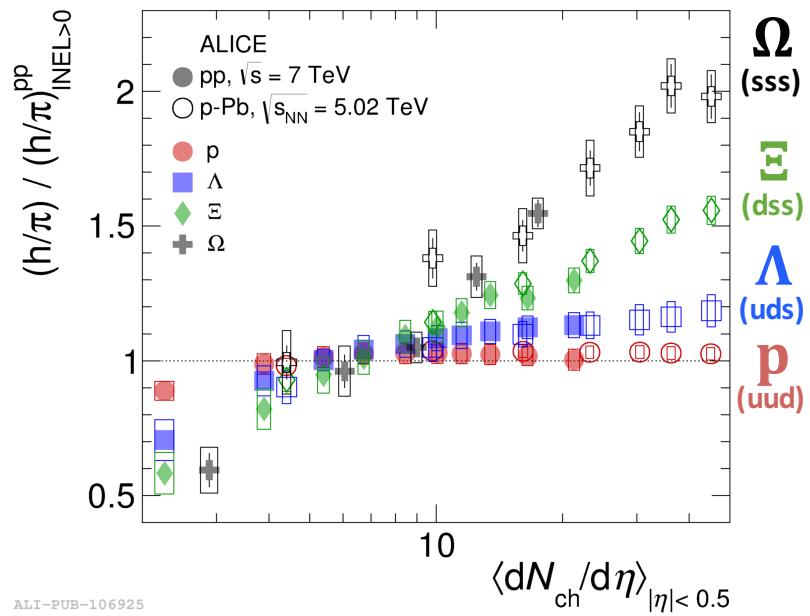


- *pp at 7 TeV vs multiplicity*
- ▶ *Significant enhancement* of strange to non-strange hadron production
- ▶ *MC model* predictions *do not* describe satisfactorily the behavior of the data

Strangeness Enhancement



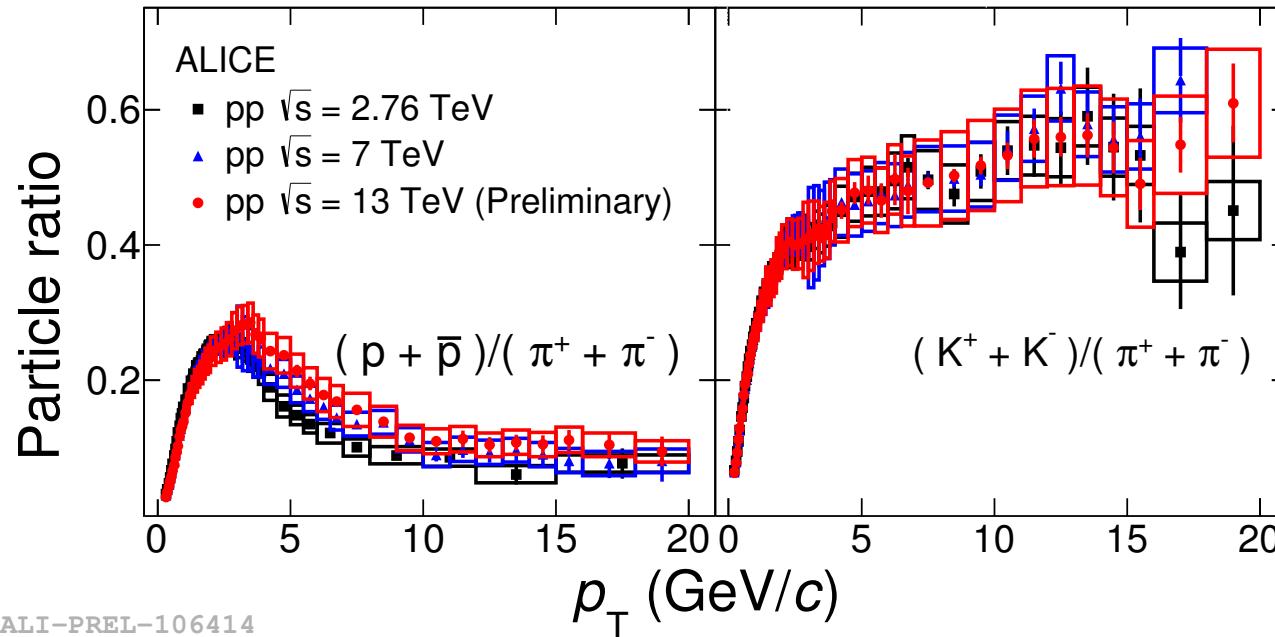
- *pp at 7 TeV vs multiplicity*
- ▶ *Significant enhancement* of strange to non-strange hadron production
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Observed increase is more pronounced for baryons with higher strangeness content

Spectra Ratios at 13 TeV

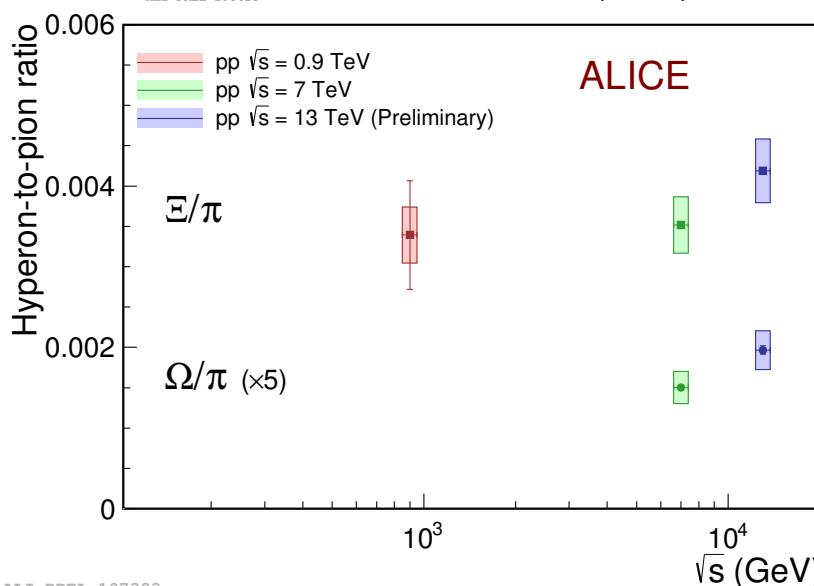
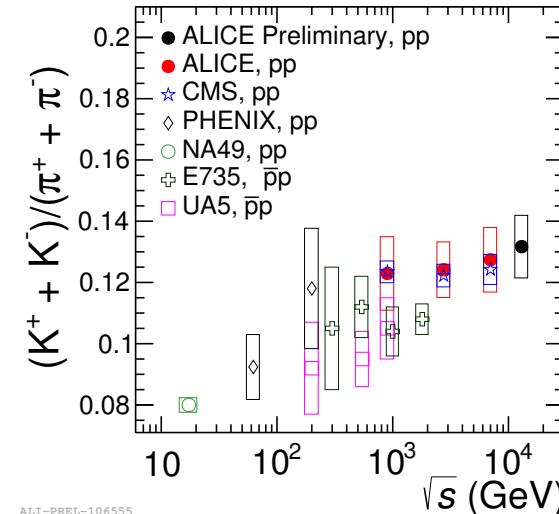
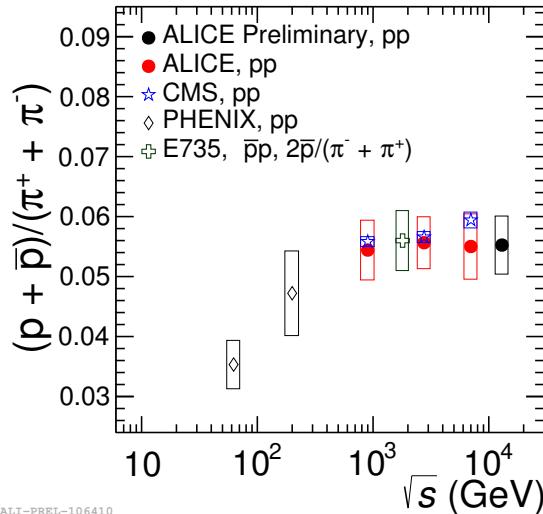
- *pp at 13 TeV minimum bias*



- Spectra ratio shape shifts towards higher p_T for higher \sqrt{s} for p/π
- No significant modification observed for K/π

Integrated-Yield Ratios at 13 TeV

- *pp at 13 TeV minimum bias*



- **p/π and K/π ratios:**
 - flat at LHC energies
 - **Hyperon-to-pion ratios:**
 - Slightly increased at 13 TeV
 - Is it due to higher \sqrt{s} or $\langle N_{ch} \rangle$?
- to be further investigated in the multiplicity dependence studies in pp at 13 TeV*

→ See talk by Anders G. Knospe for resonances
This session, 28 Jun, 16:00

Conclusions and Outlook



- ▶ **Multiplicity dependence** studies of identified particles in **pp collisions** at 7 TeV show **enhancement** of strange and multi-strange hadron production towards **high multiplicity events**.
- ▶ ***QCD inspired MC generators*** fail to describe the observed **multiplicity dependence** of strange hadron production.
- ▶ **pp collisions at 13 TeV** will provide **crucial input** to understand the contribution of **collision energy** and **charged-particle multiplicity** to particle production.

Conclusions and Outlook



- ▶ **Multiplicity dependence** studies of identified particles in **pp collisions** at 7 TeV show **enhancement** of strange and multi-strange hadron production towards **high multiplicity events**.
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Thank you!

Backup

VOM Multiplicity Classes

- *pp at 7 TeV vs multiplicity*

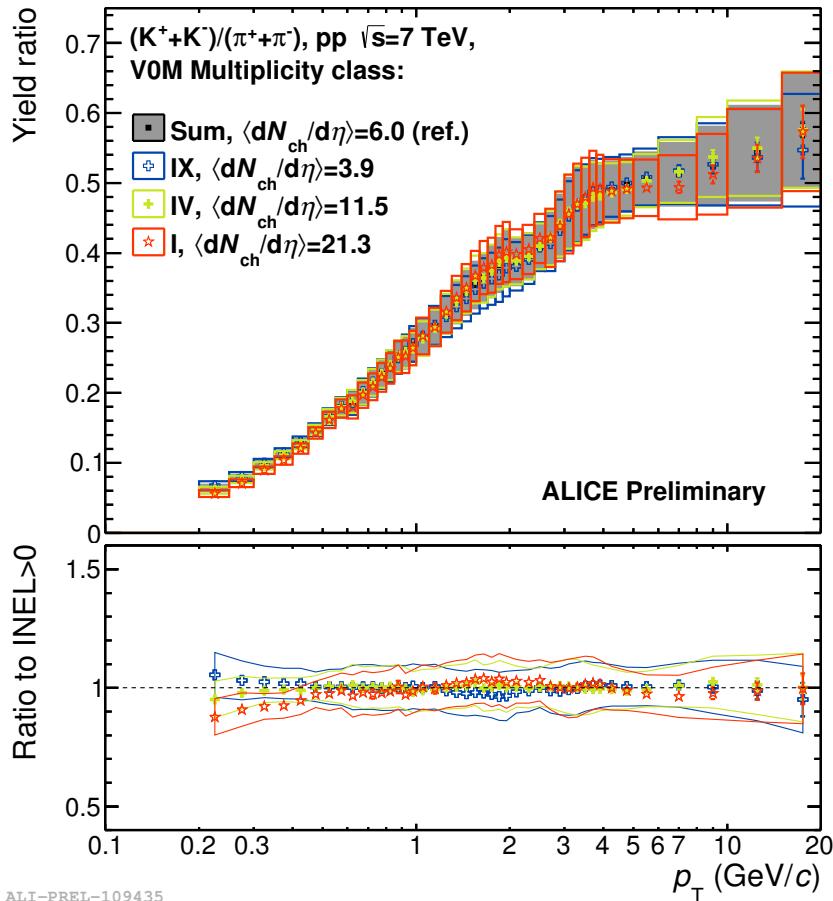
Fractions of the INEL>0 cross-section:

| $\pi, K, K_S^0, p, \Lambda, \Xi$ | | | K^* | | | Ω | | |
|----------------------------------|-----------------------------------------|-----------------------------------------------------------|-----------|-----------------------------------------|-----------------------------------------------------------|-----------|-----------------------------------------|-----------------------------------------------------------|
| VOM Class | $\frac{\sigma}{\sigma_{\text{INEL}>0}}$ | $\left\langle \frac{dN_{\text{ch}}}{d\eta} \right\rangle$ | VOM Class | $\frac{\sigma}{\sigma_{\text{INEL}>0}}$ | $\left\langle \frac{dN_{\text{ch}}}{d\eta} \right\rangle$ | VOM Class | $\frac{\sigma}{\sigma_{\text{INEL}>0}}$ | $\left\langle \frac{dN_{\text{ch}}}{d\eta} \right\rangle$ |
| I | 0-0.95% | 21.3 ± 0.6 | I | 0-0.95% | 21.3 ± 0.6 | I+II | 0.0-4.7% | 17.5 ± 0.5 |
| II | 0.95-4.7% | 16.5 ± 0.5 | II | 0.95-4.7% | 16.5 ± 0.5 | III+IV | 4.7-14% | 12.5 ± 0.4 |
| III | 4.7-9.5% | 13.5 ± 0.4 | III | 4.7-9.5% | 13.5 ± 0.4 | V+VI | 14-28% | 8.99 ± 0.27 |
| IV | 9.5-14% | 11.5 ± 0.3 | IV+V | 9.5-19% | 10.8 ± 0.3 | VII+VIII | 28-48% | 6.06 ± 0.19 |
| V | 14-19% | 10.1 ± 0.3 | VI | 19-28% | 8.45 ± 0.25 | IX+X | 48-100% | 2.89 ± 0.14 |
| VI | 19-28% | 8.45 ± 0.25 | VII | 28-38% | 6.72 ± 0.21 | | | |
| VII | 28-38% | 6.72 ± 0.21 | VIII | 38-48% | 5.40 ± 0.17 | | | |
| VIII | 38-48% | 5.40 ± 0.17 | IX | 48-68% | 3.90 ± 0.14 | | | |
| IX | 48-68% | 3.90 ± 0.14 | X | 68-100% | 2.26 ± 0.12 | | | |
| X | 68-100% | 2.26 ± 0.12 | | | | | | |

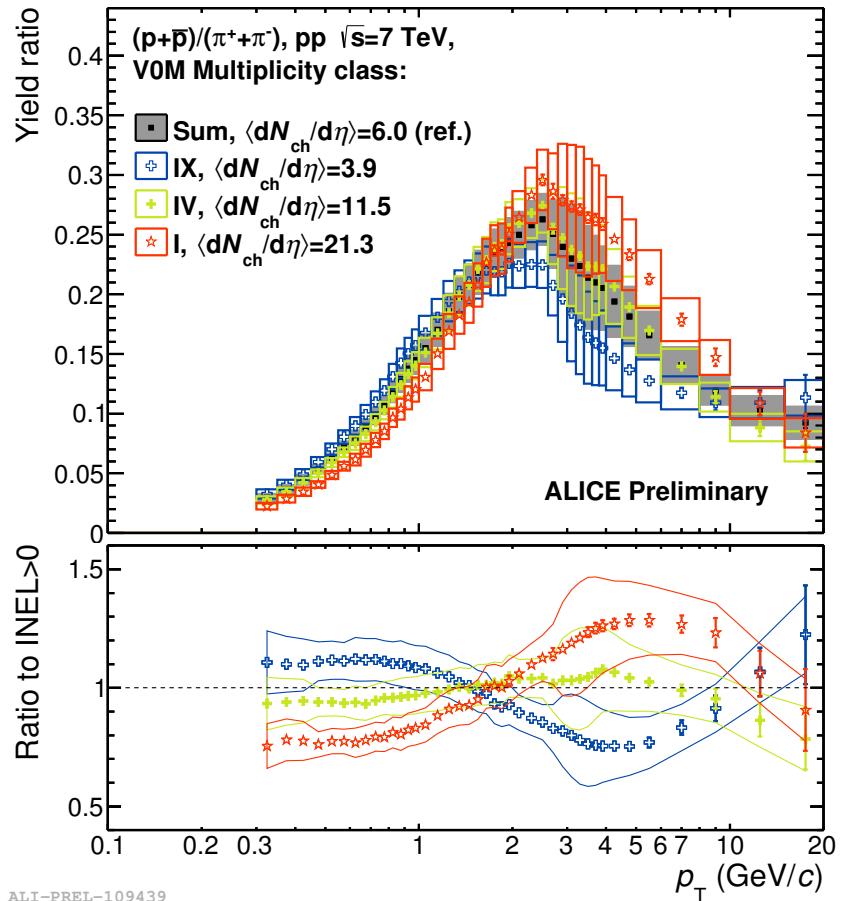
Multiplicity Dependence of Spectra Ratios



- *pp at 7 TeV vs multiplicity*



$K/\pi \rightarrow$ no dependence with multiplicity

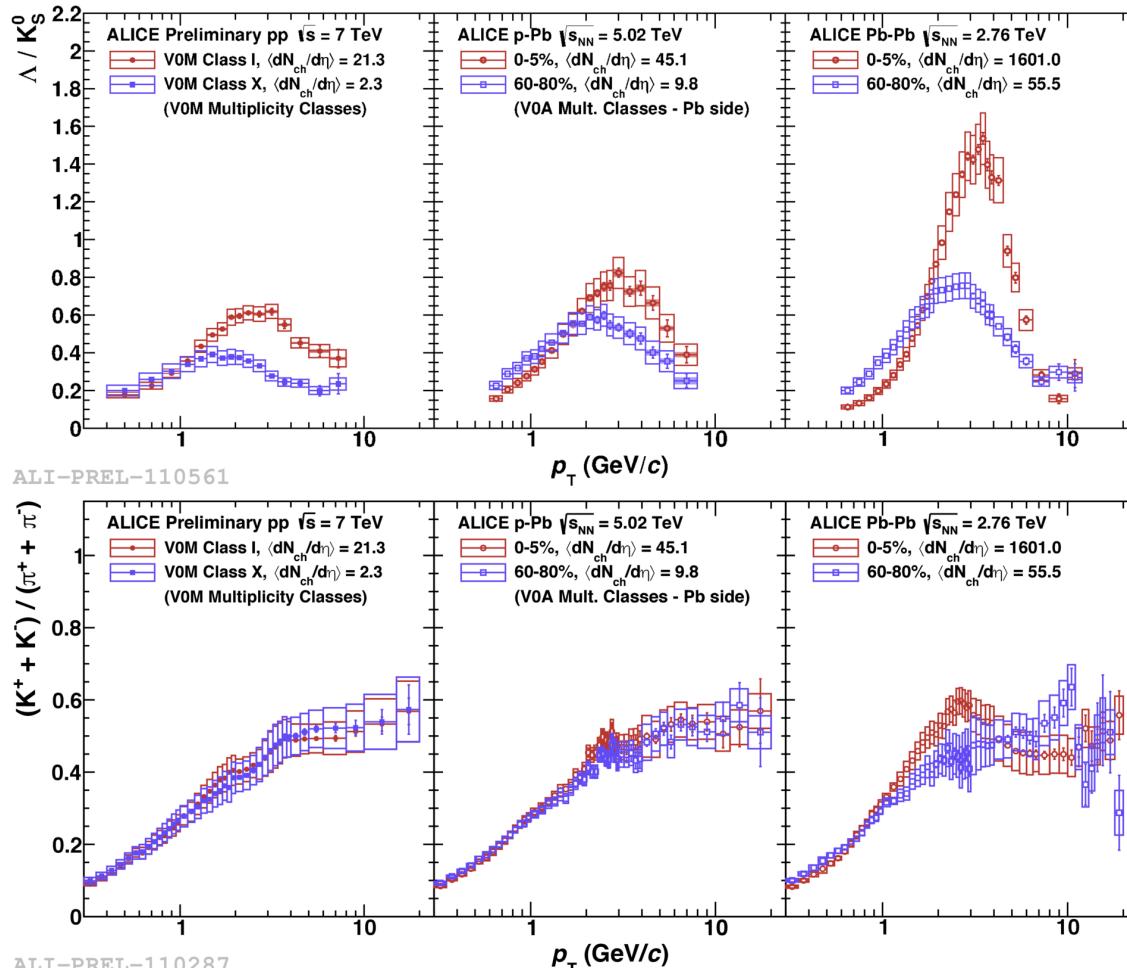


$p/\pi \rightarrow$ clear variation with multiplicity

(backup) Spectra Ratios

- *pp at 7 TeV vs multiplicity*

Baryon/Meson and Meson/Meson



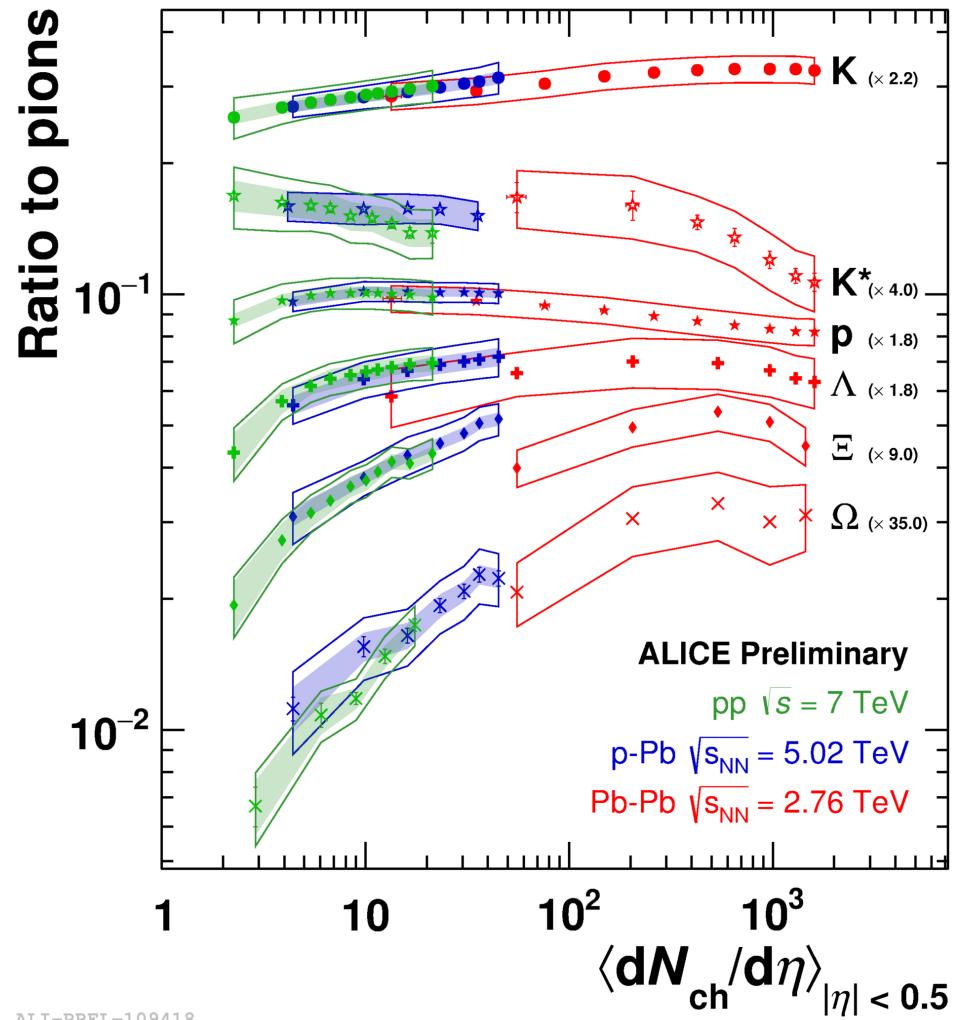
- Similarly to p/π ratio, Λ/K_S^0 in pp collisions also shows qualitatively ***similar evolution as seen in p-Pb and Pb-Pb***
- K/π , on the other hand, ***does not show any dependence*** with multiplicity in ***pp and p-Pb collisions***

Integrated-Yield Ratios

- *pp at 7 TeV vs multiplicity*

Evolution of ratios across systems

- **Small systems:**
 - Strangeness enhancement
 - Relative decrease of K^{*0}
 - No multiplicity dependence of baryon/meson ratio
- **Towards central Pb-Pb:**
 - Strangeness abundance constant
 - K^{*0} abundance decreases further
 - Baryon/meson decreases

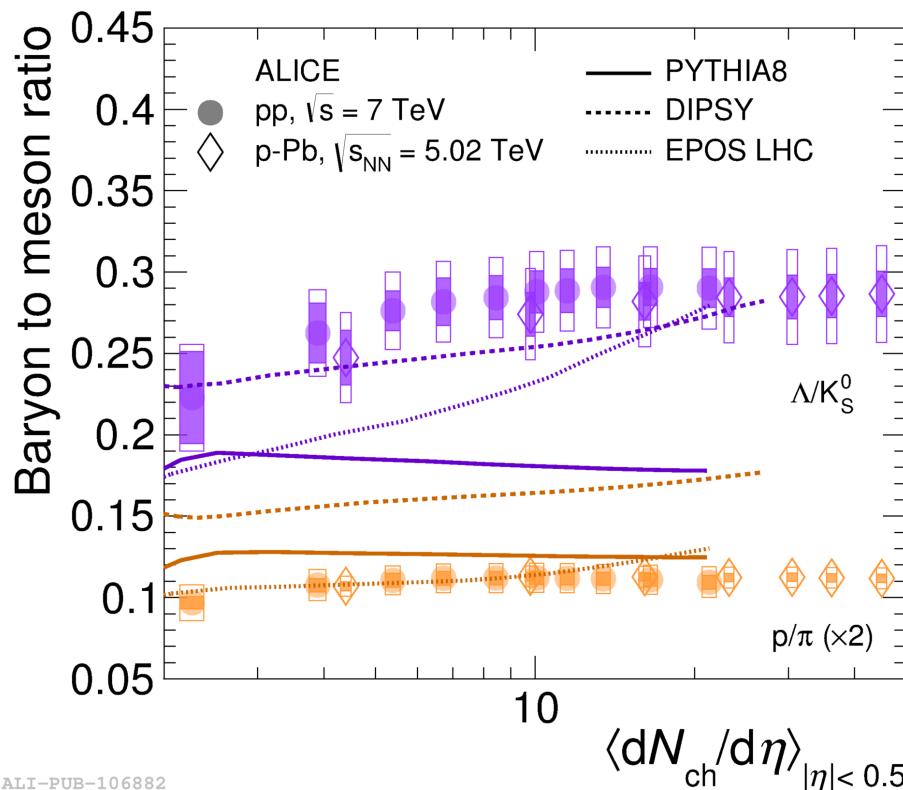


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Strangeness Enhancement

- *pp at 7 TeV vs multiplicity*

Baryon to meson ratio vs multiplicity



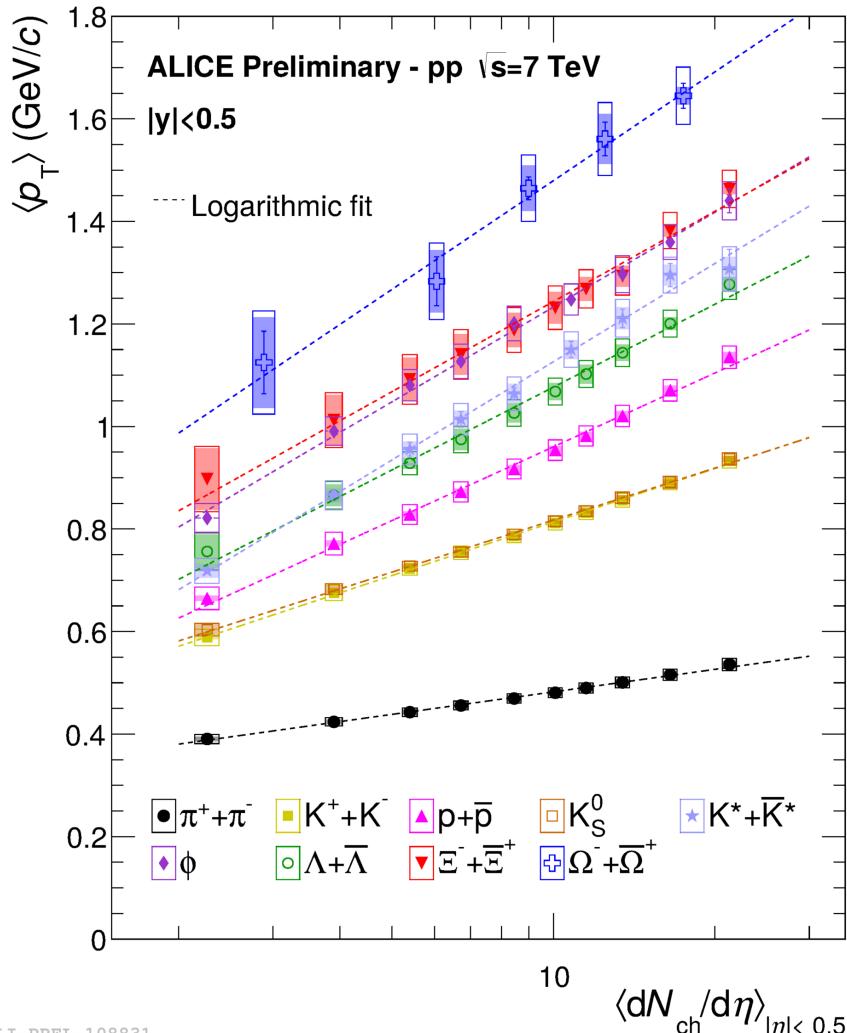
p/π and Λ/K_S^0
ratios are flat



enhancement is
strangeness rather than mass related

Average Transverse Momentum

- *pp at 7 TeV vs multiplicity*



Mass-dependent hardening of the spectra

- Rising trend similar to what is observed in p-Pb collisions

