Strangeness production in high multiplicity pp collisions

Marek Bombara on behalf of the ALICE Collaboration

(Pavol Jozef Šafárik University, Košice, Slovakia)

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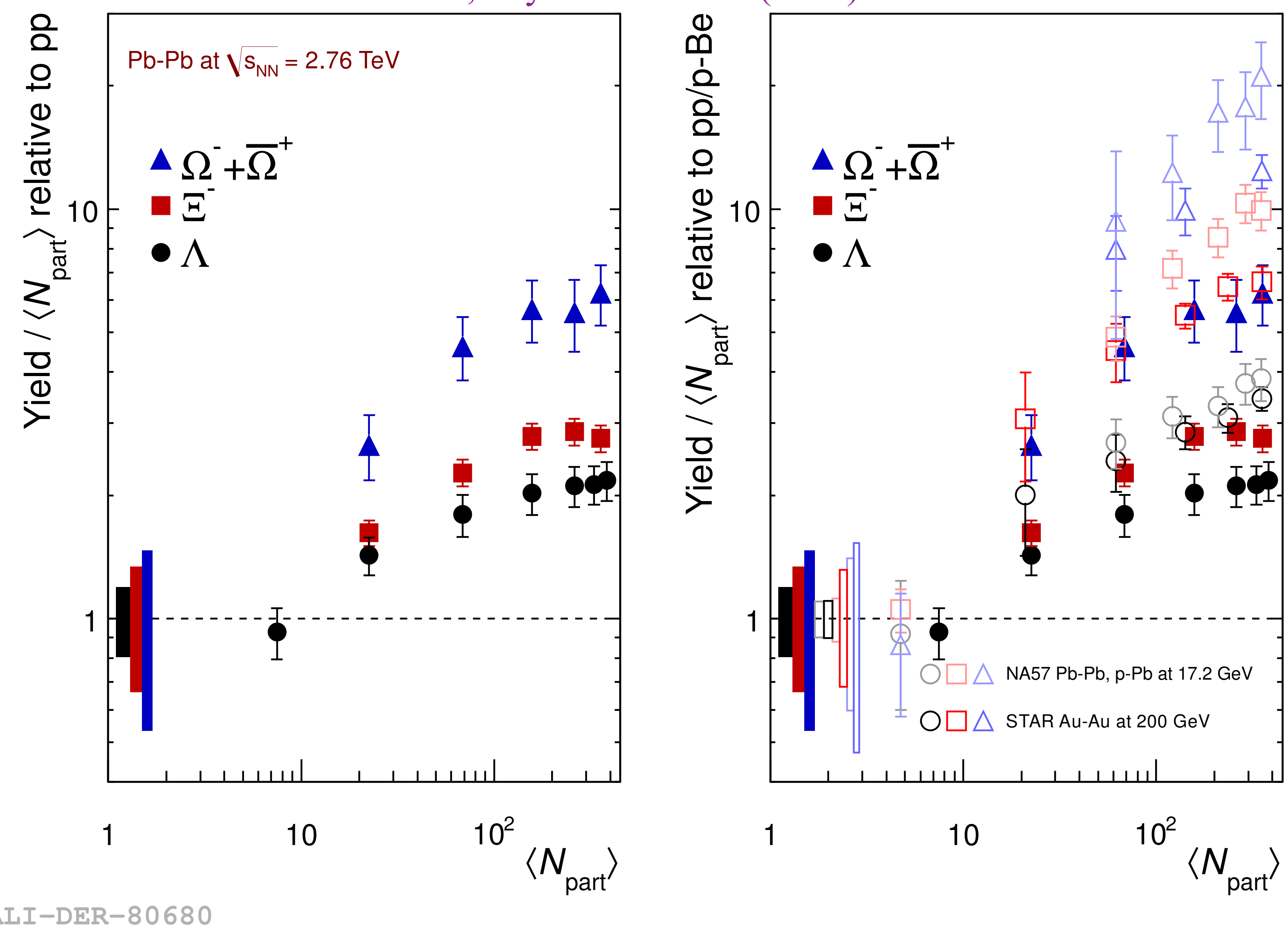
7-11 August 2017

Strangeness enhancement

- Historically, an enhanced production of strangeness was proposed as a signature of QGP in nucleus-nucleus collisions [J. Rafelski, B. Müller, Phys. Rev. Lett. 48 (1982) 1066–1069]
- However, the measured effect can be qualitatively explained as a strangeness suppression in reference sample (pp and p−A collisions)

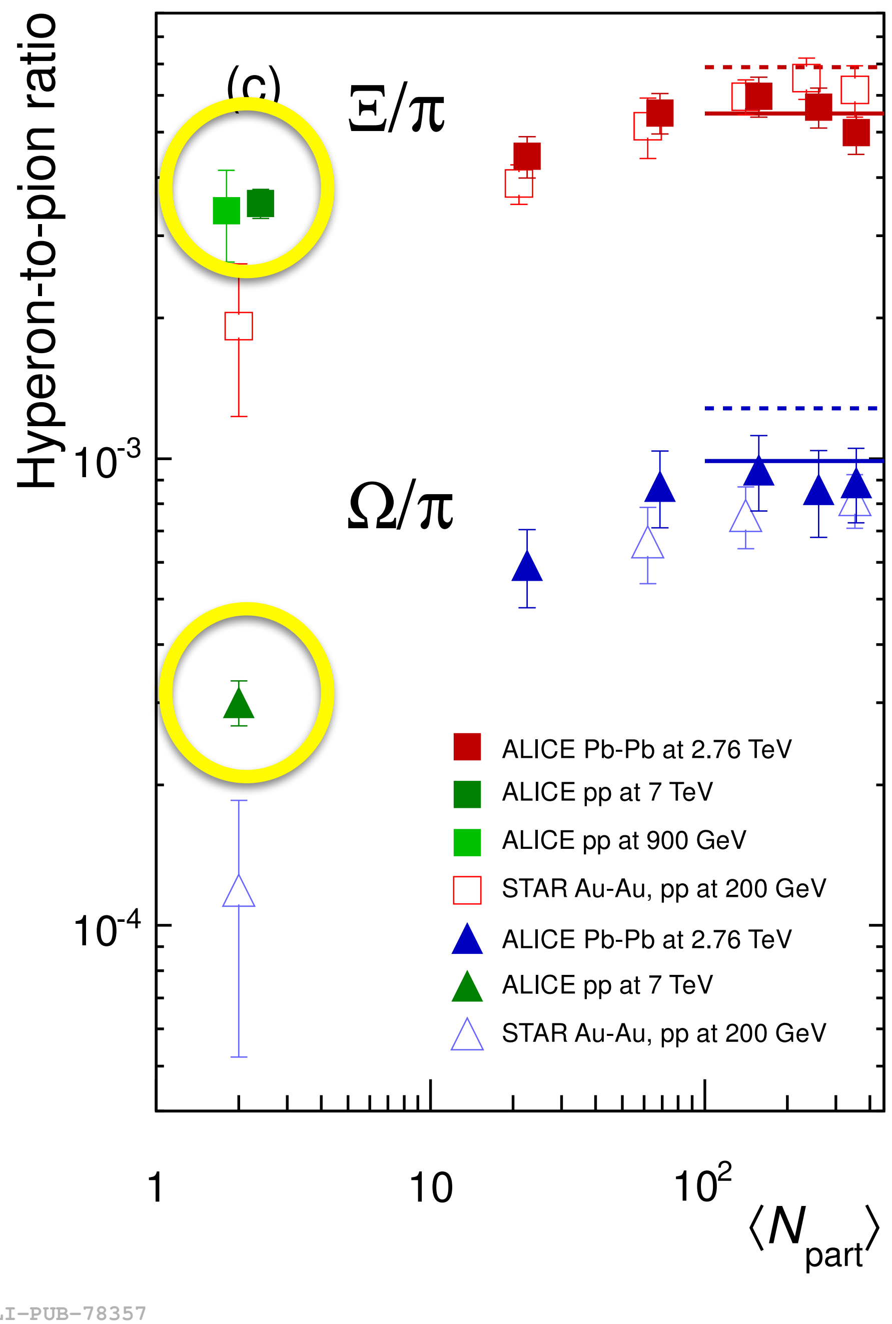
ALICE, Phys. Lett. B 728 (2014) 216



Strangeness enhancement

ALICE, Phys. Lett. B 728 (2014) 216

- N_{part}-scaling does not hold at LHC energies, ratios to pions (as the most abundant particle) are studied
- hyperon-to-pion ratios for pp higher at LHC than at RHIC energies
- for A−A - no obvious collision energy dependence

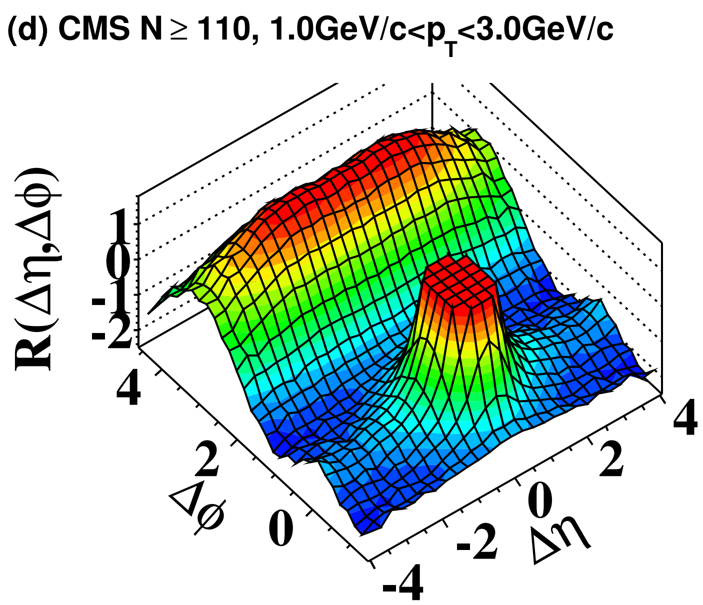


LHC offers not only unprecedented energies, but also unprecedented collision statistics in small systems ⇒ allows extensive multiplicity study of the reference samples (pp and p−Pb).

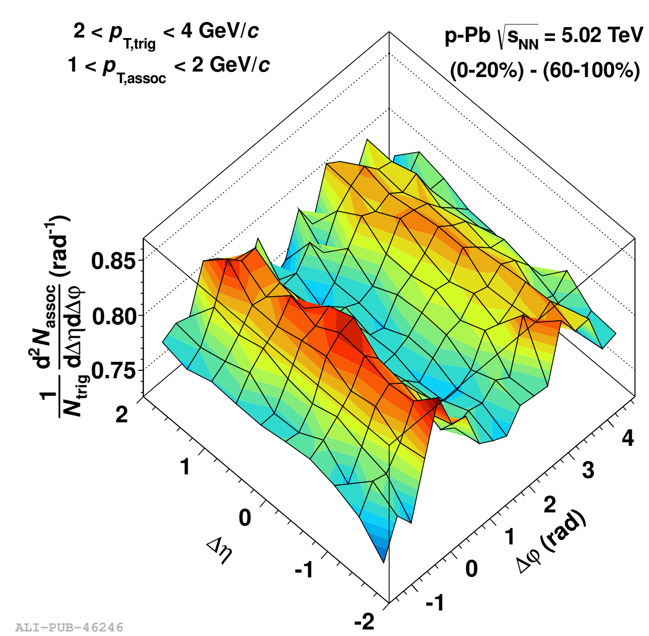
Multiplicity studies at the LHC

It all started with ridges:

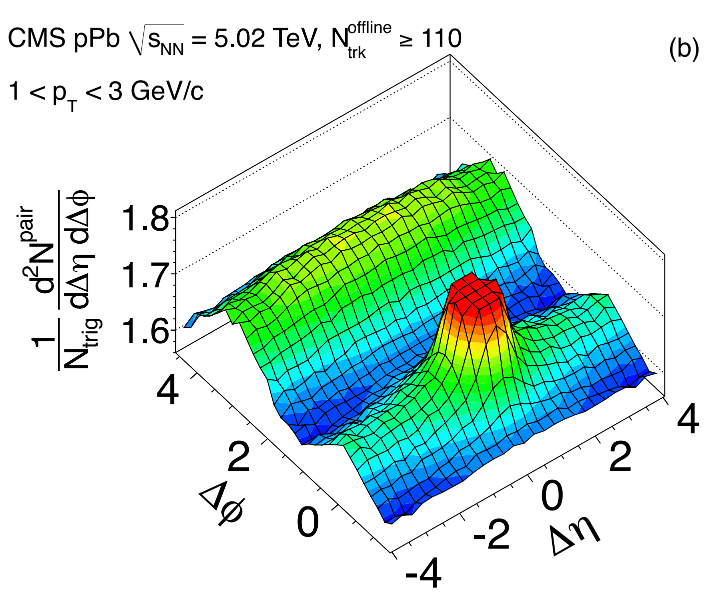
CMS, JHEP 09 (2010) 091



ALICE, PLB 719 (2013) 29



CMS, PLB 718 (2013) 795



- structures previously connected to collectivity in Pb−Pb collisions
- many other observables in high multiplicity pp and p−Pb resemble those in A−A

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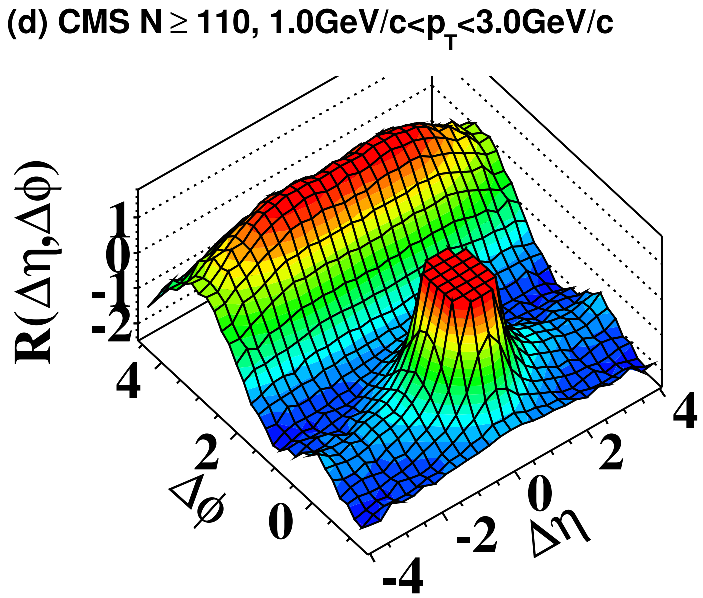

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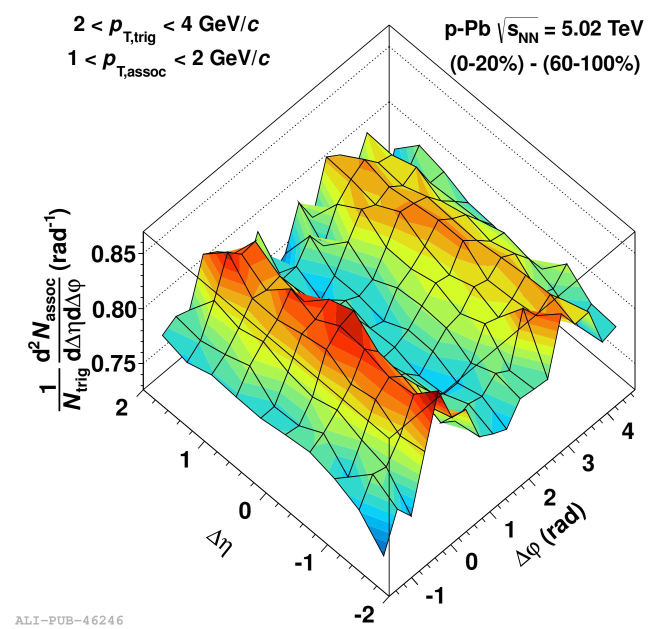

Are there any unusual trends also in strangeness production in high multiplicity pp collisions?

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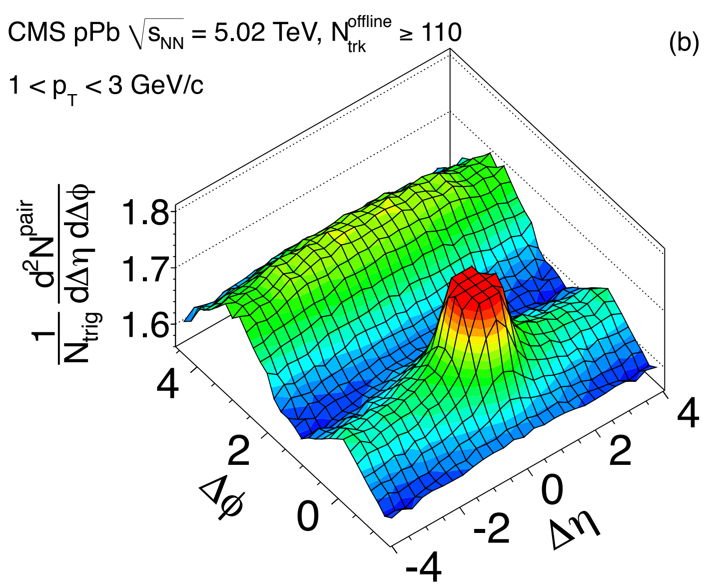

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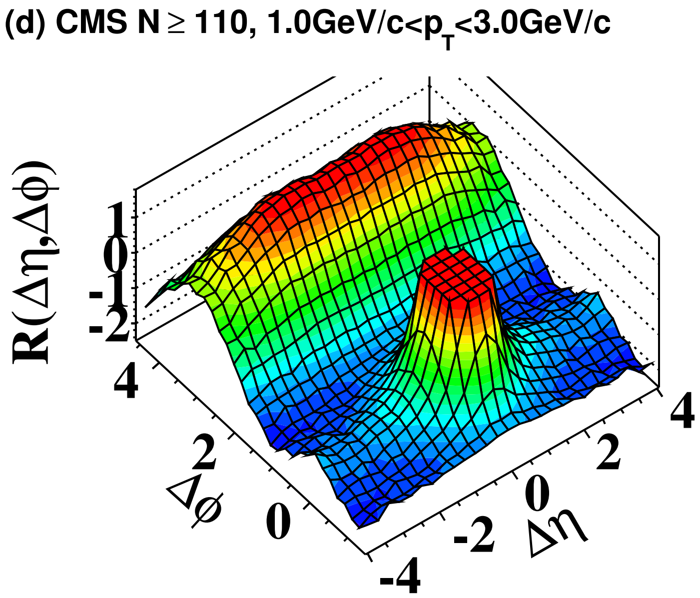

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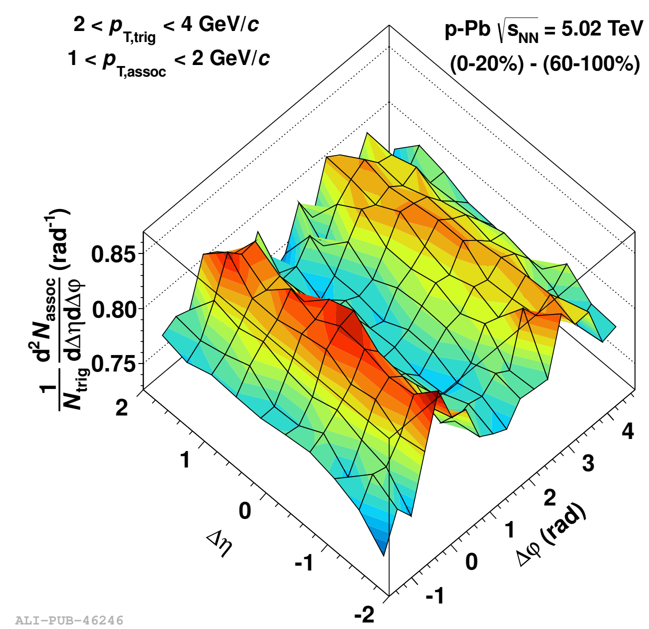

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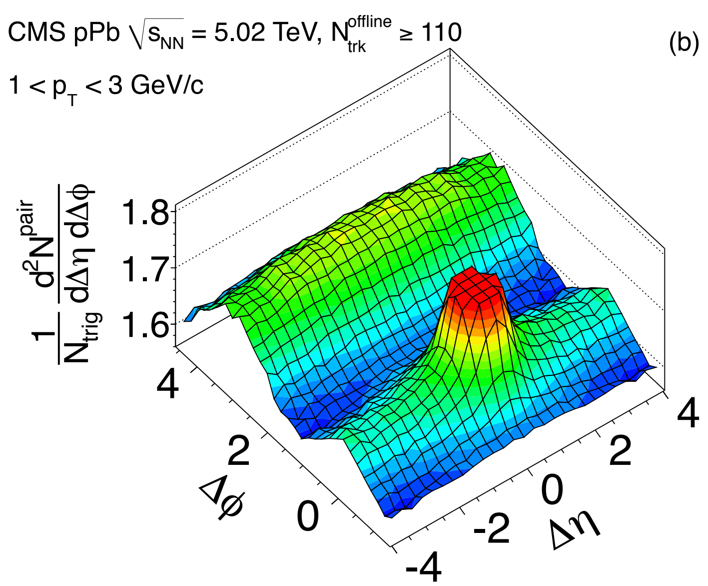

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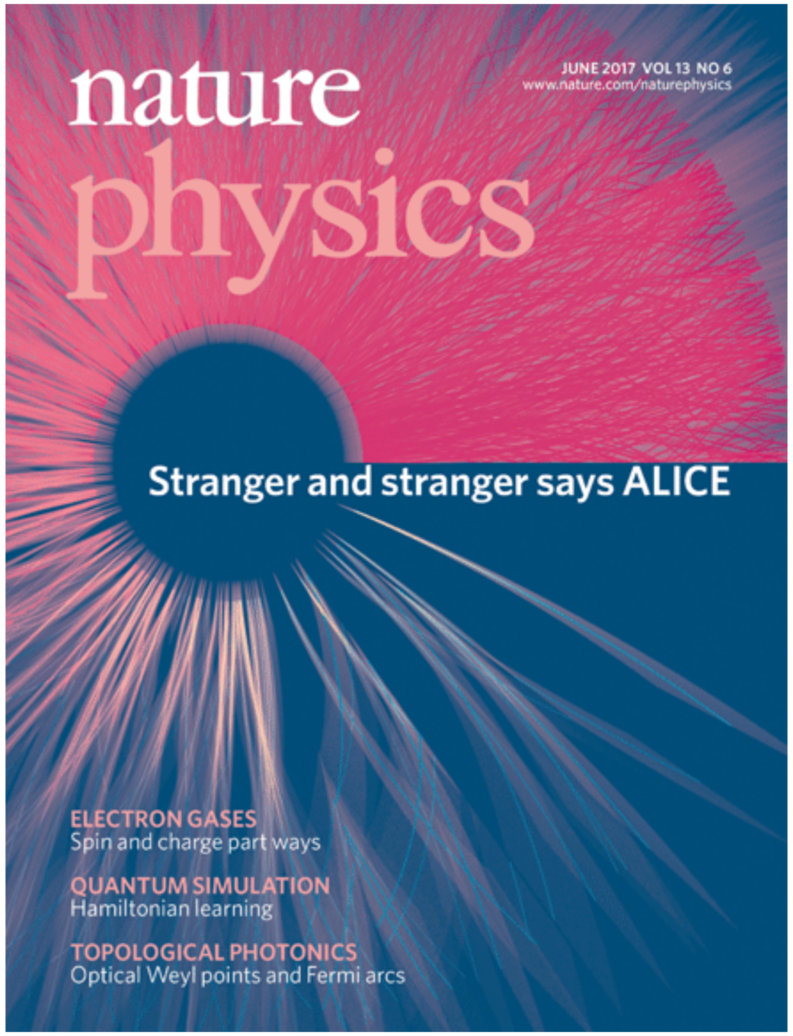

- structures previously connected to collectivity in Pb−Pb collisions
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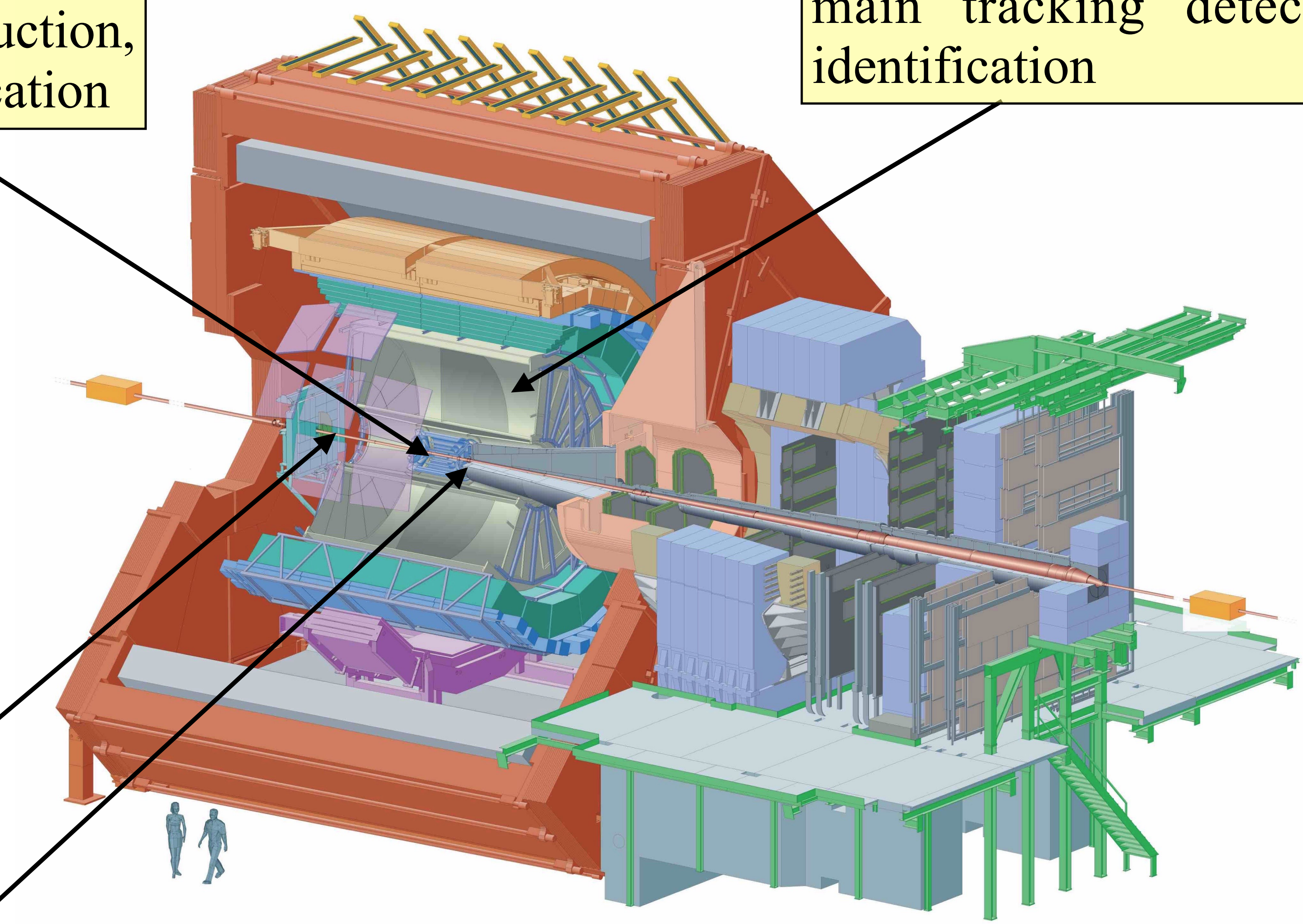
A Large Ion Collider Experiment

ITS (Inner Tracking System): primary vertex reconstruction, tracking, particle identification

TPC (Time Projection Chamber): main tracking detector, particle identification



V0: triggering, background suppression, event multiplicity determination

Data:
- pp $\sqrt{s}$ = 7 TeV, 100 M 2010
- pp $\sqrt{s}$ = 13 TeV, 50 M 2015

Multiplicity definition

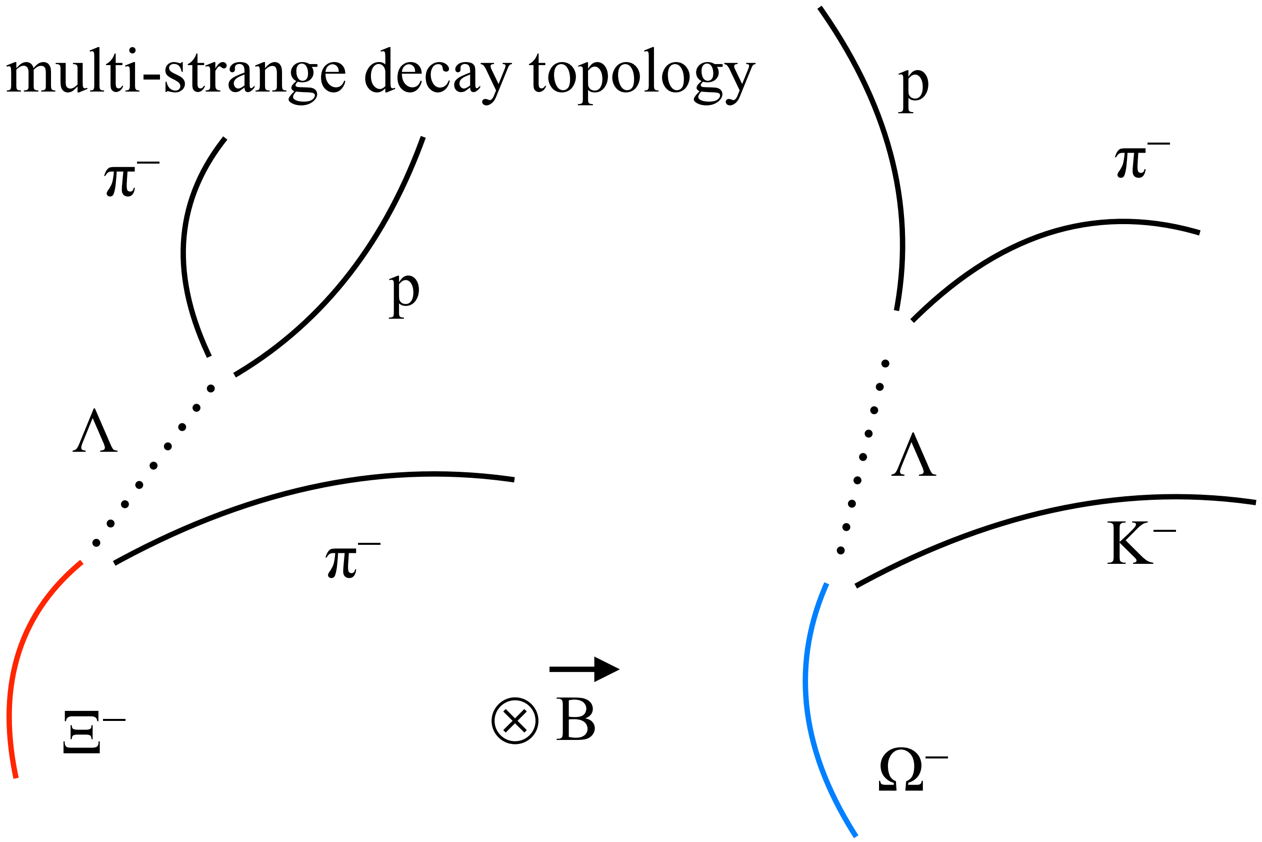
- analysed events have at least one charged particle in $|\eta|<1$ (INEL>0)
- event sample divided into 10 classes according to ionisation energy (~ proportional to the charged particle multiplicity) deposited in V0 detectors, covering the regions $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$
- $\langle dN_{ch}/d\eta \rangle$ - average pseudorapidity density of primary charged particles in $|\eta| < 0.5$

Multiplicity classes used in pp@7TeV analysis:

Class name	I	II	III	IV	V
$\sigma/\sigma_{\mathrm{INEL}>0}$	0 – 0.95%	0.95 – 4.7%	4.7 – 9.5%	9.5 – 14%	14 – 19%
$\langle dN_{ch}/d\eta \rangle$	21.3 ± 0.6	16.5 ± 0.5	$13.5 \pm 0.4\%$	11.5 ± 0.3	10.1 ± 0.3
Class name	VI	VII	VIII	IX	X
$\sigma/\sigma_{\mathrm{INEL}>0}$	19 – 28%	28 – 38%	38 – 48%	48 – 68%	68 – 100%
$\langle dN_{ch}/d\eta \rangle$	8.45 ± 0.25	6.72 ± 0.21	$5.40 \pm 0.17\%$	3.90 ± 0.14	2.26 ± 0.12

(Multi-)Strange particle identification

Example of multi-strange decay topology



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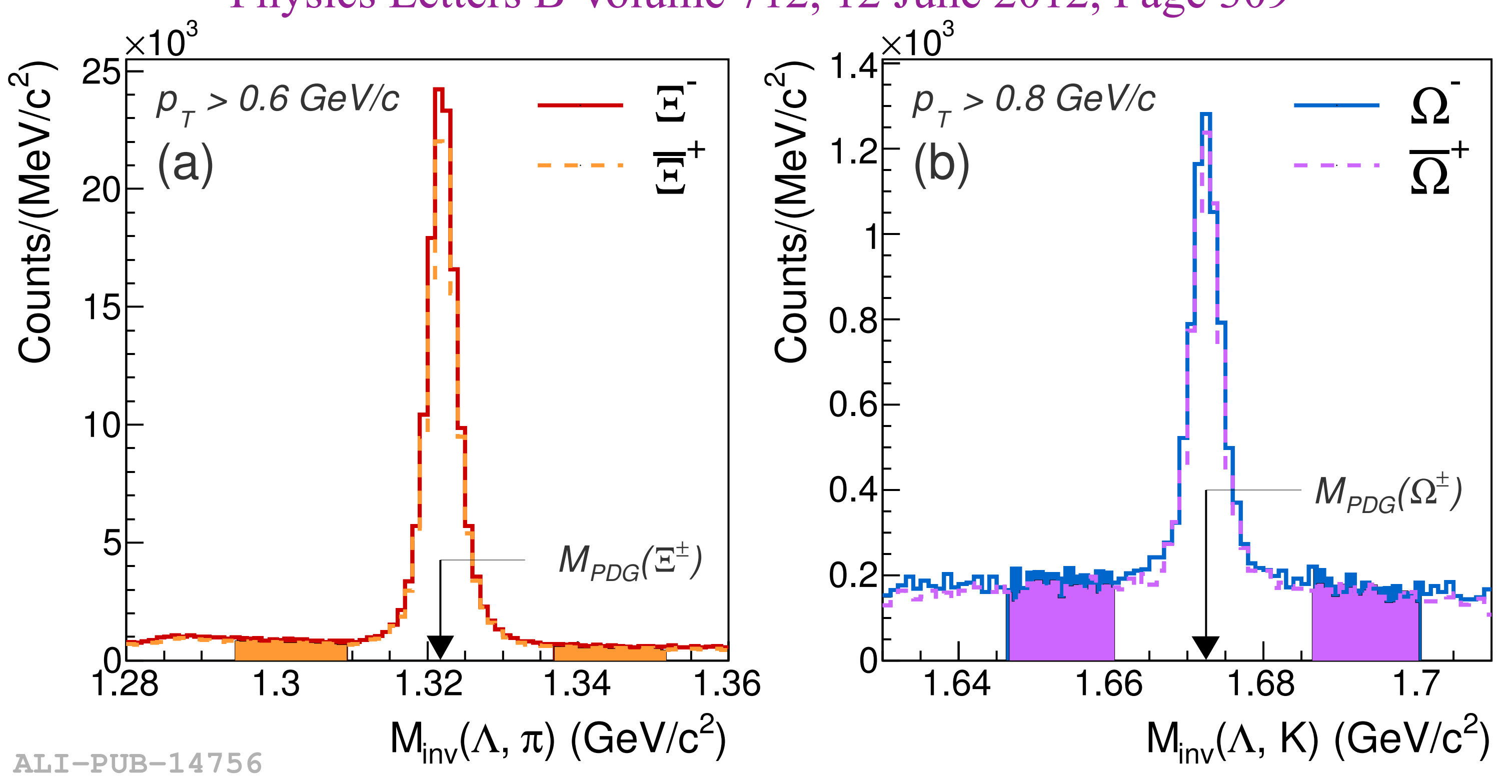
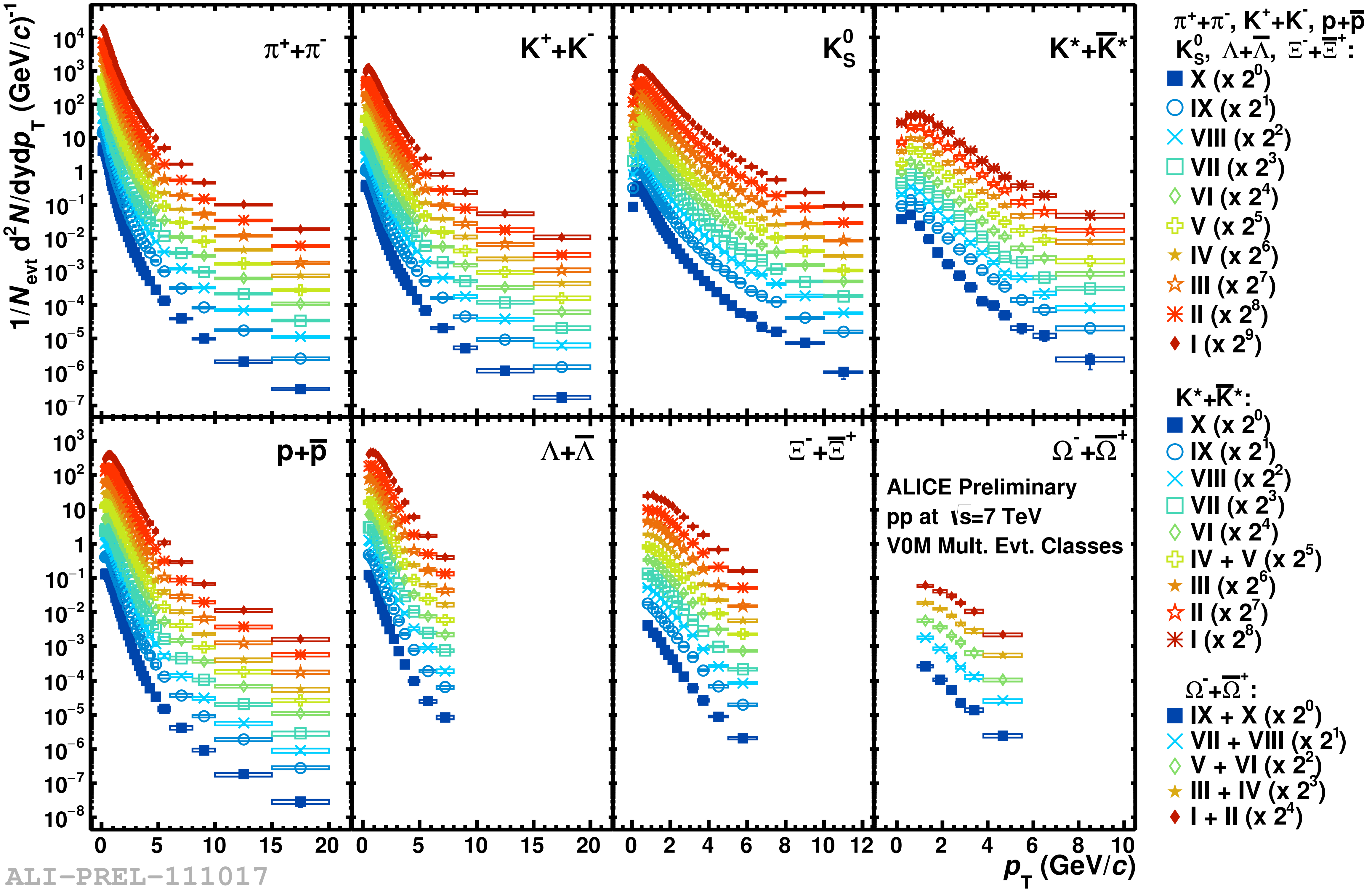


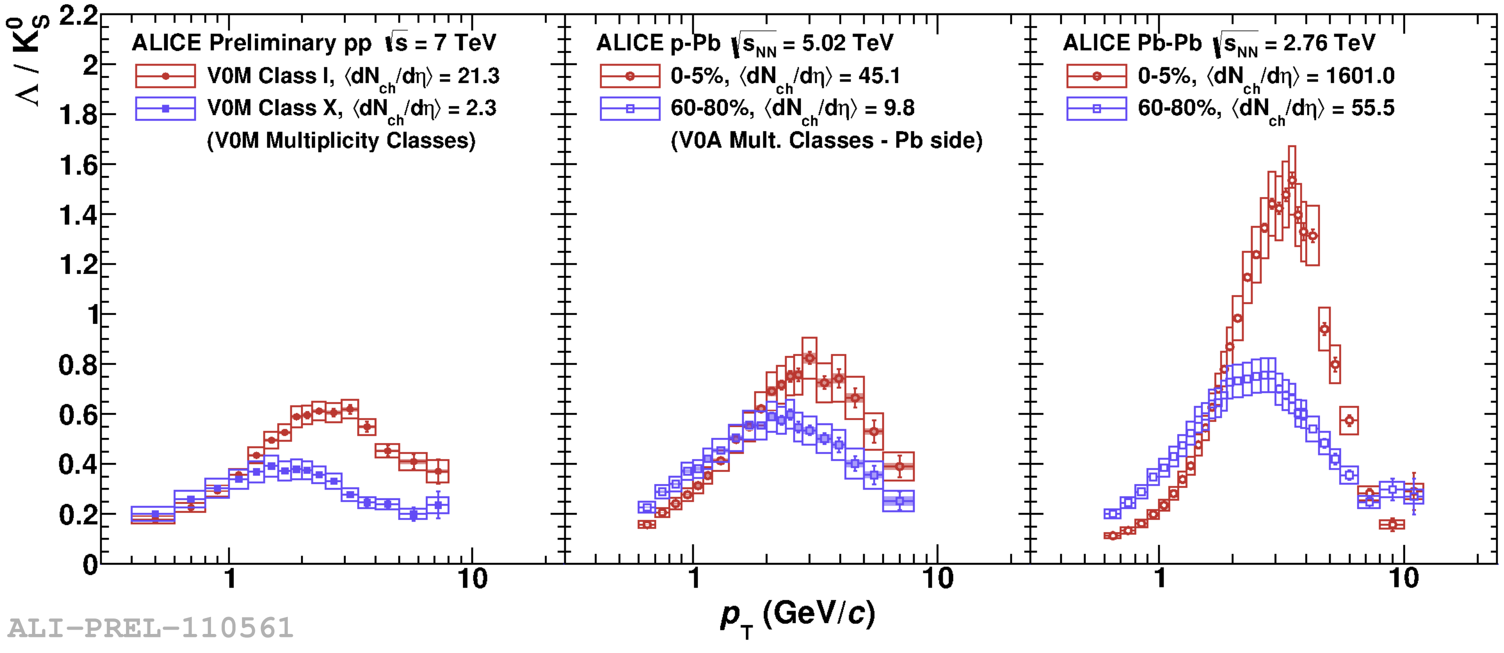
- the (multi-)strange particle candidates are identified in the ALICE detector via decay topology
- in order to distinguish between signal and background, many geometrical selection criteria were applied on the candidates
- the yield is extracted by analysing invariant mass distributions of the decay products

Identified particle p_T spectra at 7 TeV



- p_T spectra get harder as the multiplicity increases

Baryon to meson ratios



- shift + increase of the peak in most central Pb−Pb collisions ⇒ radial flow + quark recombination
- B/M qualitatively similar in all three colliding systems: depletion at low p_T, enhancement in mid p_T and no change in high p_T

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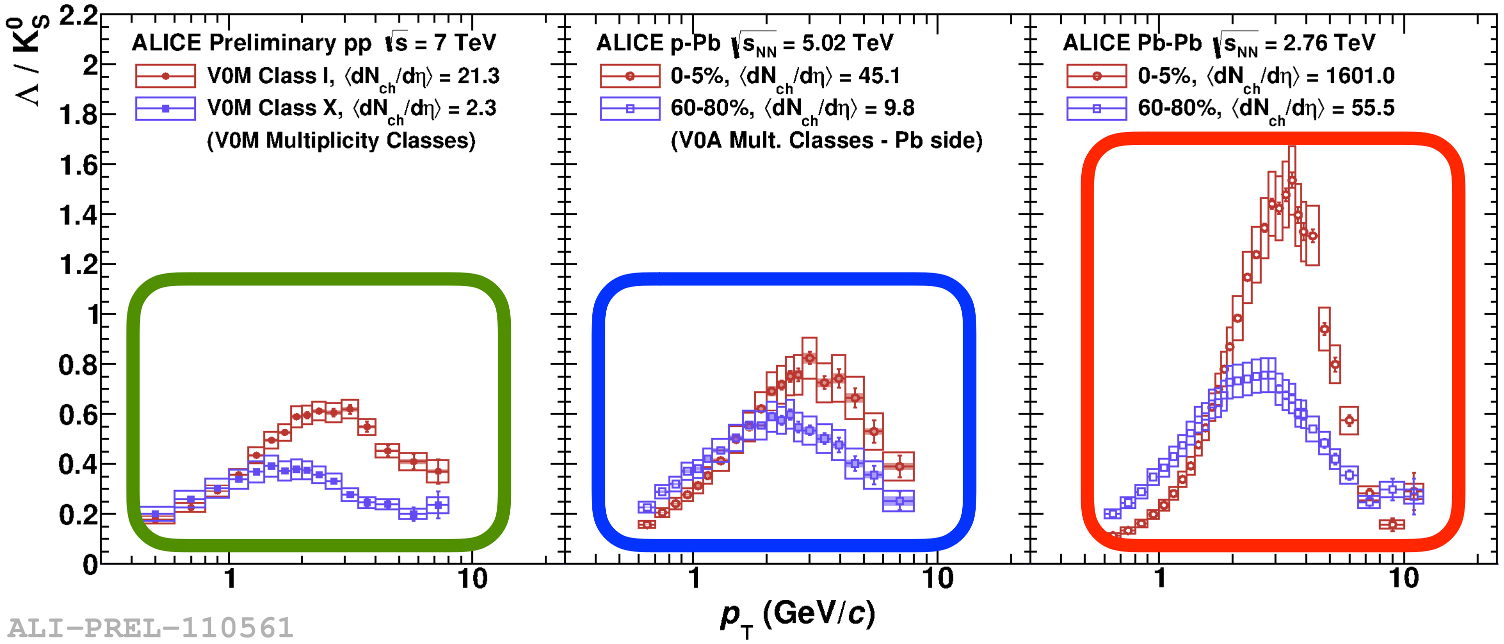
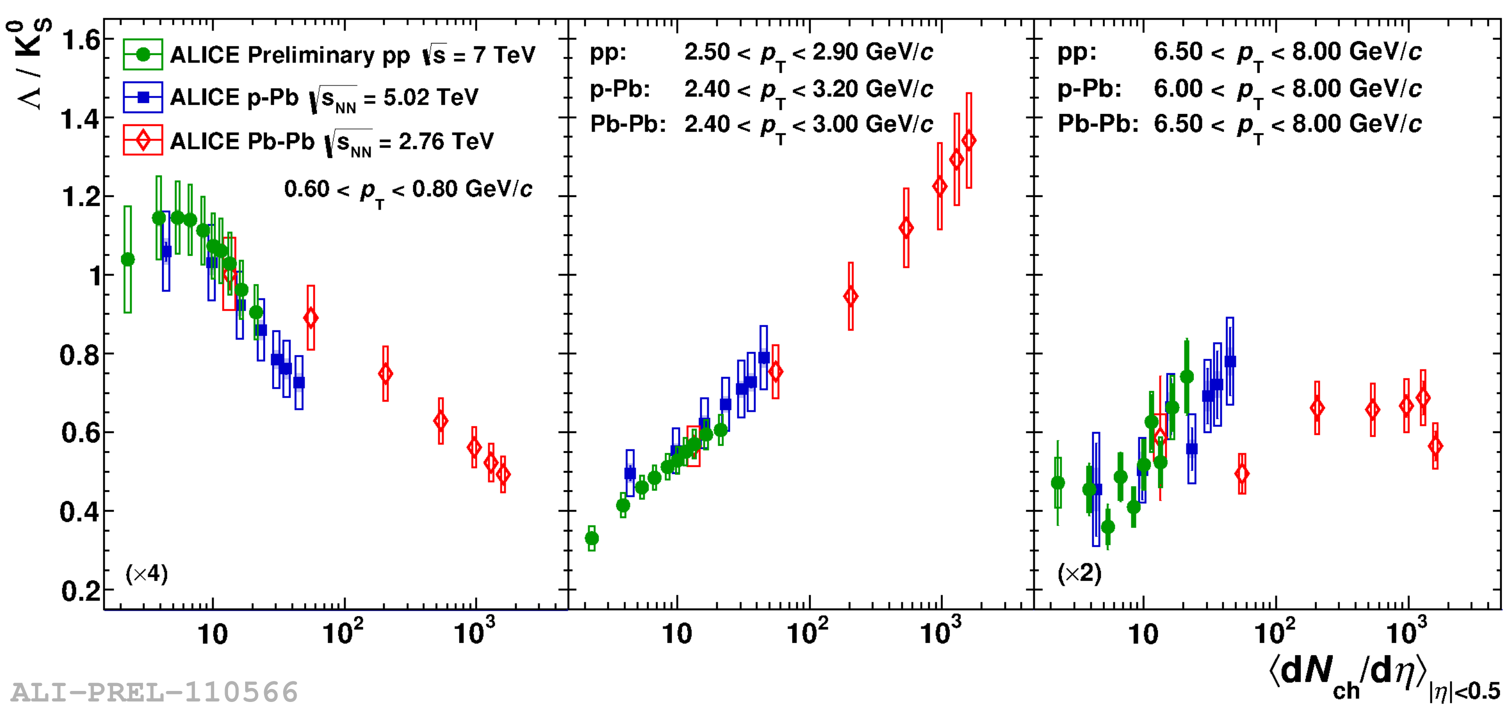


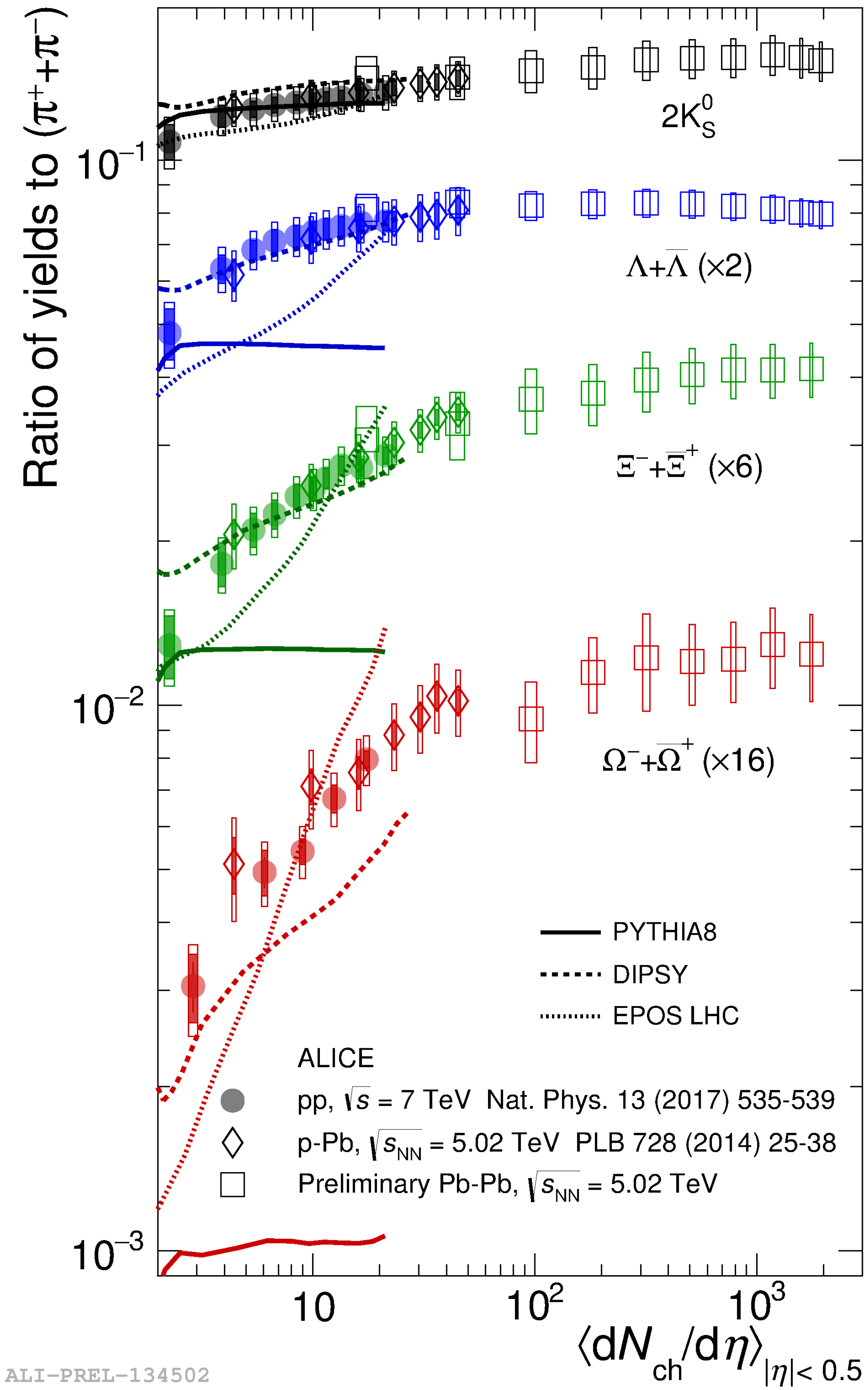


- shift + increase of the peak in most central Pb−Pb collisions ⇒ radial flow + quark recombination
- B/M qualitatively similar in all three colliding systems: depletion at low p_T, enhancement in mid p_T and no change in high p_T
- more-or-less smooth evolution across the systems in low and mid p_T region, production is driven by final multiplicity
- high p_T independent on multiplicity

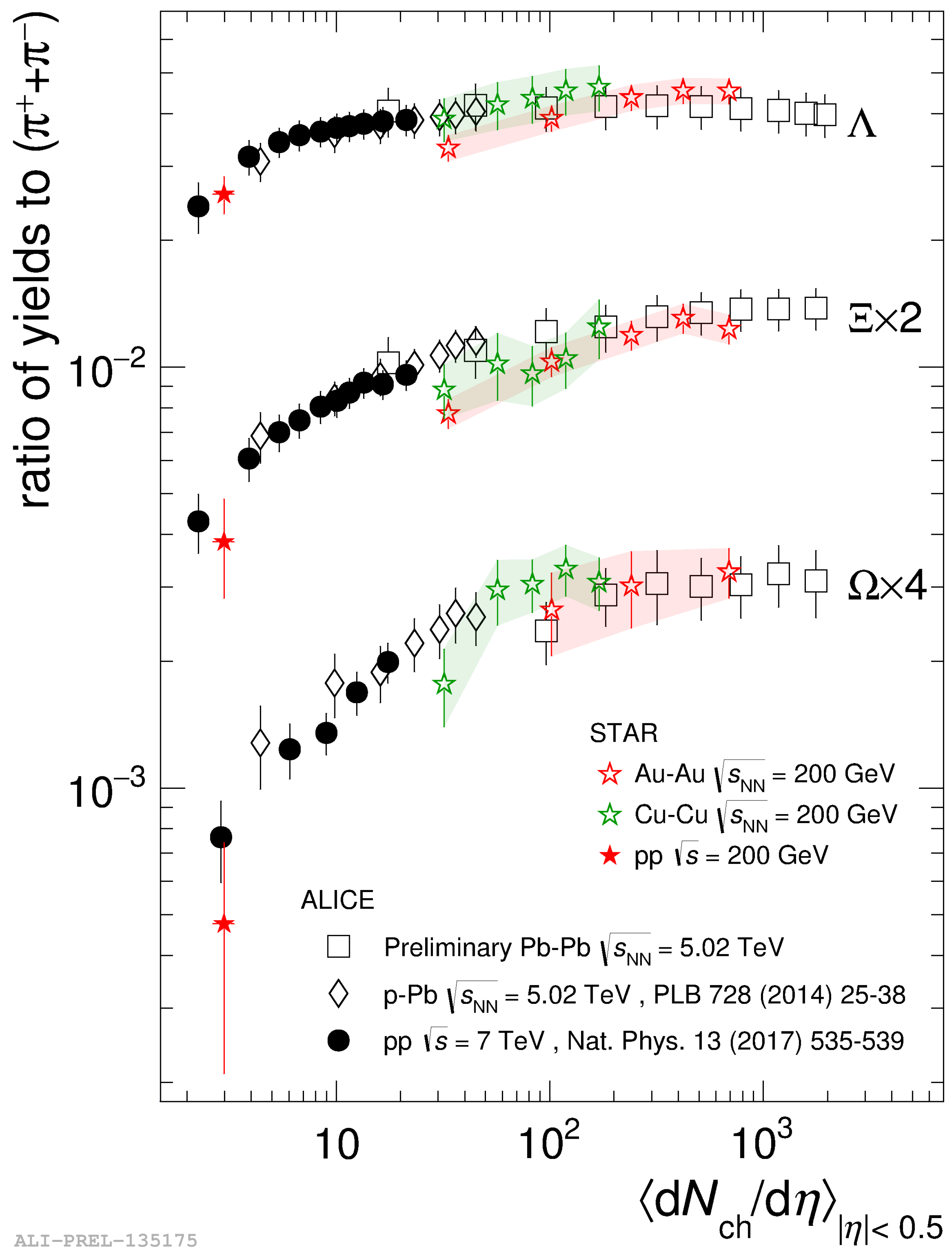
Strangeness enhancement in pp

- enhancement of strange particle w.r.t. non-strange yield clearly visible for high multiplicity pp collisions
- very nice overlap with p−Pb and Pb−Pb results

Enhancement observed as a function of $\langle dN_{ch}/d\eta \rangle$ is independent of collision type!



Is the enhancement dependent on collision energy?

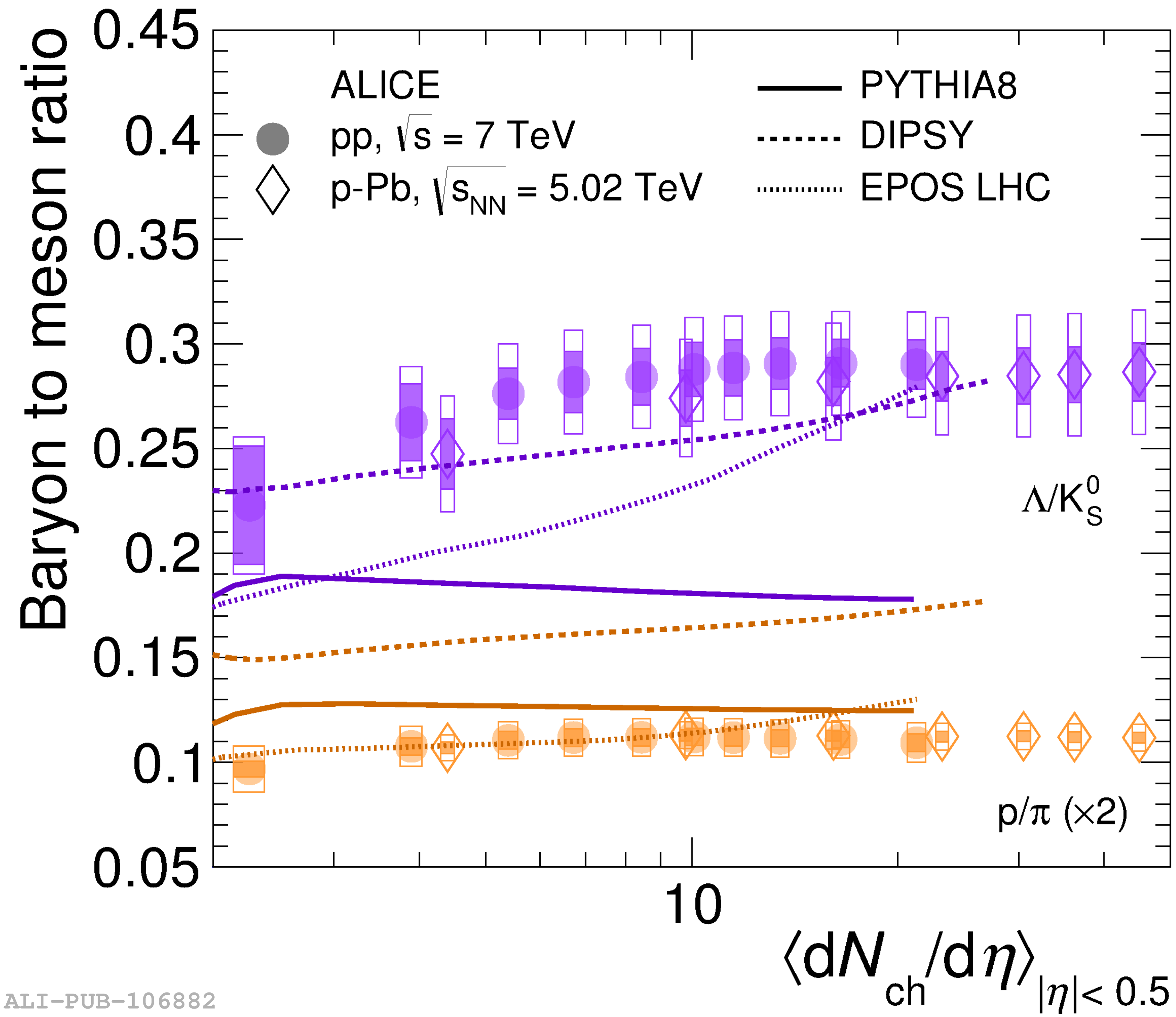


- remarkable overlap of p−Pb and peripheral Pb−Pb with Cu−Cu and Au−Au - even for 25 times smaller energy the strangeness production is similar!
- need more data for pp from RHIC (either multiplicity dependence study or from Beam Energy Scan programme)

Is the enhancement mass related?

ALICE, Nature Physics 13 (2017) 535

- The ratios of particle yields with a big mass difference do not show enhancement as a function of multiplicity
- no model* is able to reproduce the increase of the hyperon-to-pion ratios and the "flatness" baryon-to-meson ratios



* There is a very recent improvement of the DIPSY prediction for p/π ratio, see the talk of C. Bierlich at SQM'17

Strangeness enhancement in pp

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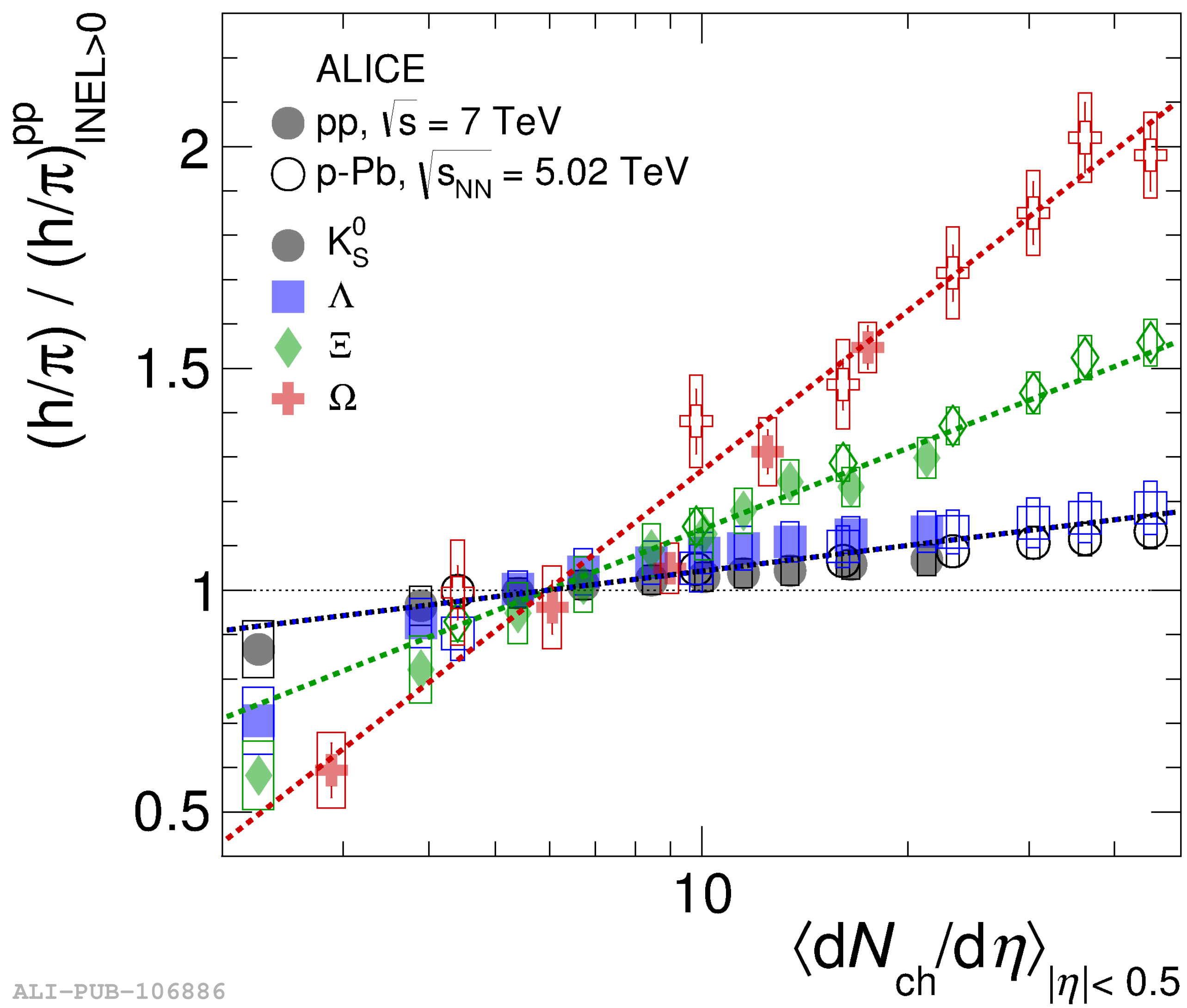
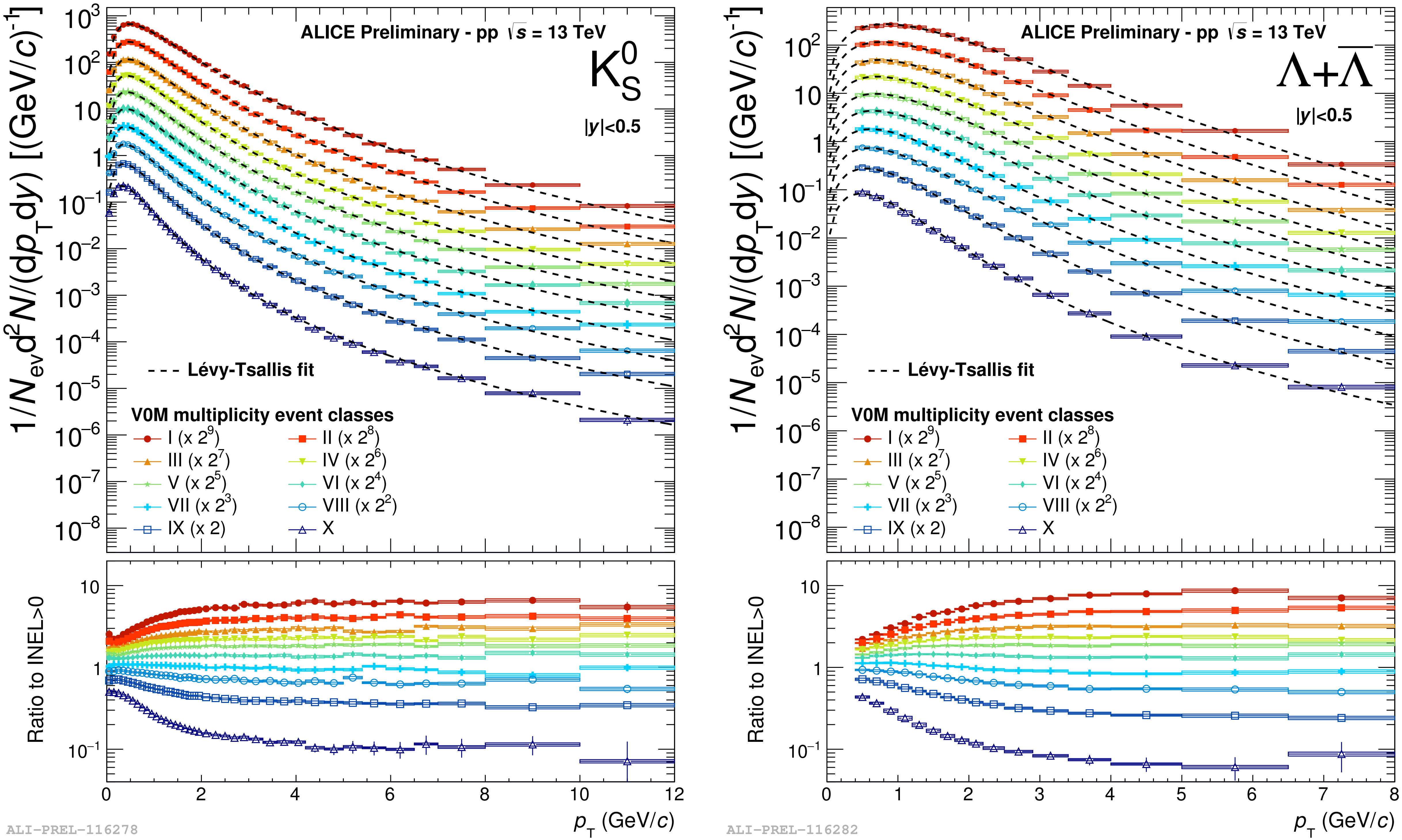
- can be fitted by empirical function with the number of valence quarks as a fixed parameter (S=1,2,3):

$$\frac{(h/\pi)}{(h/\pi)^{\rm pp}_{\rm INEL>0}} = 1 + a\mathrm{S}^b \log\left[\frac{\langle \mathrm{d}N_{\rm ch}/\mathrm{d}\eta\rangle}{\langle \mathrm{d}N_{\rm ch}/\mathrm{d}\eta\rangle^{\rm pp}_{\rm INEL>0}}\right]$$

Hierarchy of the enhancement determined by the hadron strangeness!

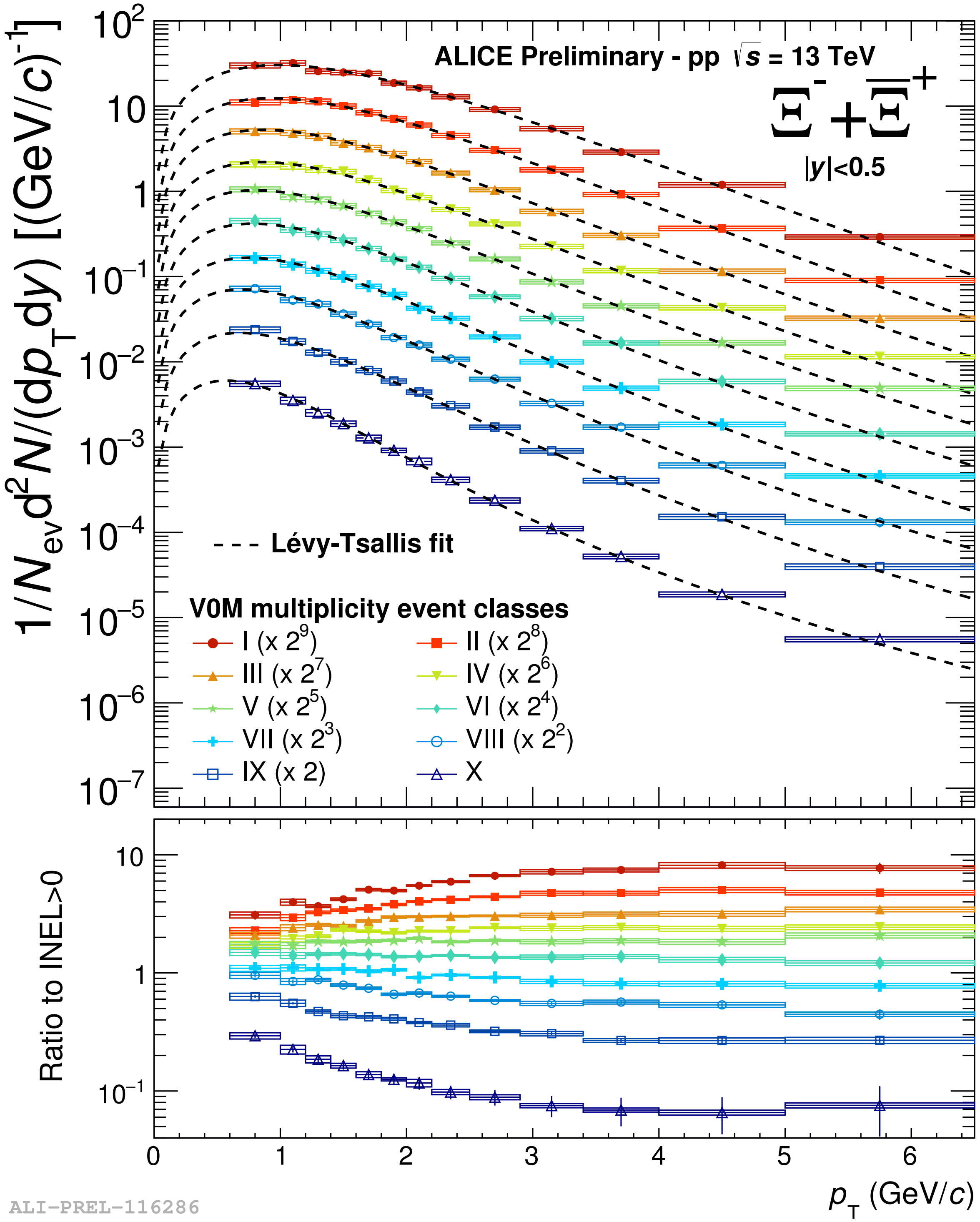


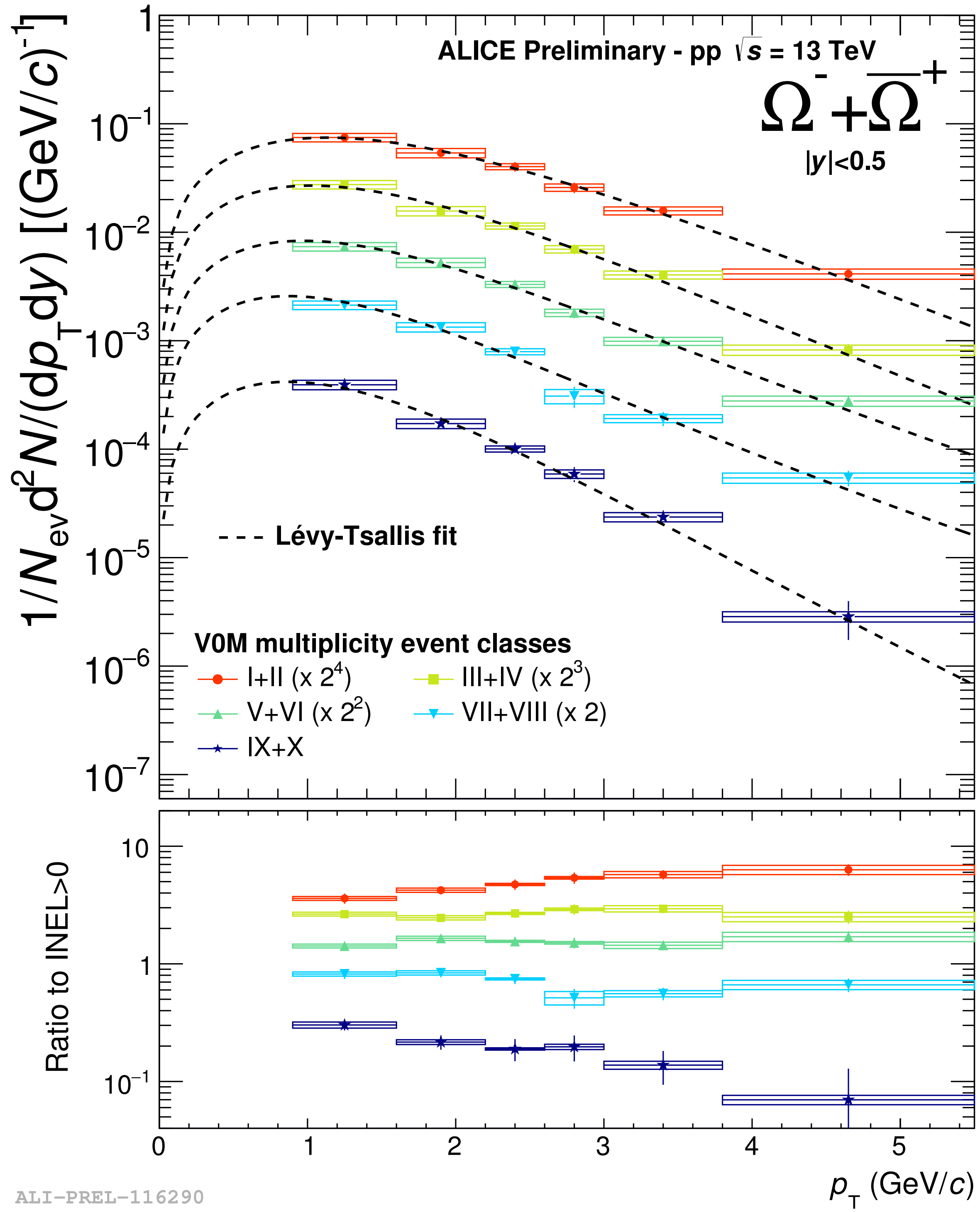
Strange particle p_T spectra at 13 TeV



- hardening of the spectra with increasing multiplicity observed in the p_T-region:| p_T |<4 GeV/c

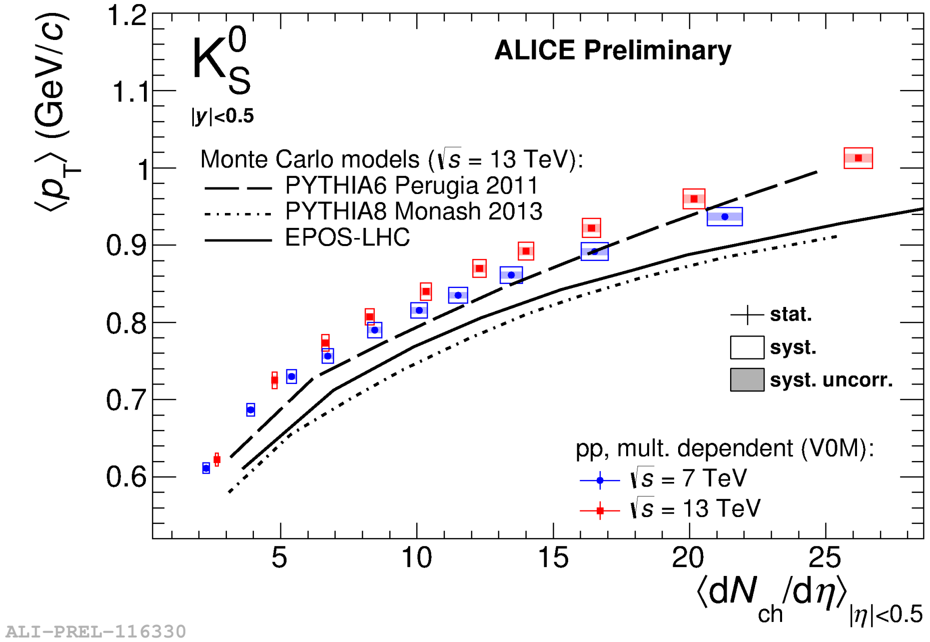
Multi-strange particle p_T spectra at 13 TeV

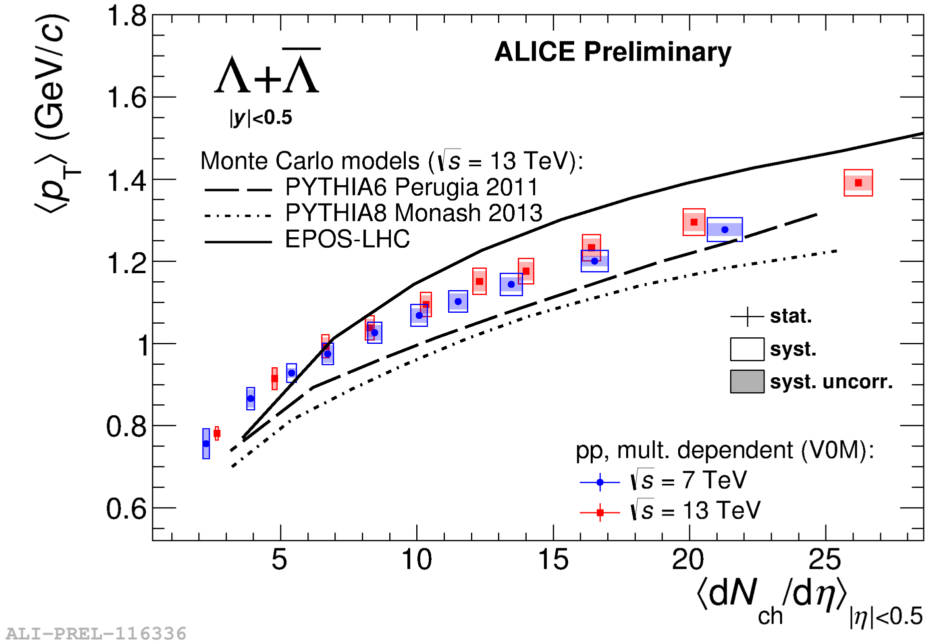


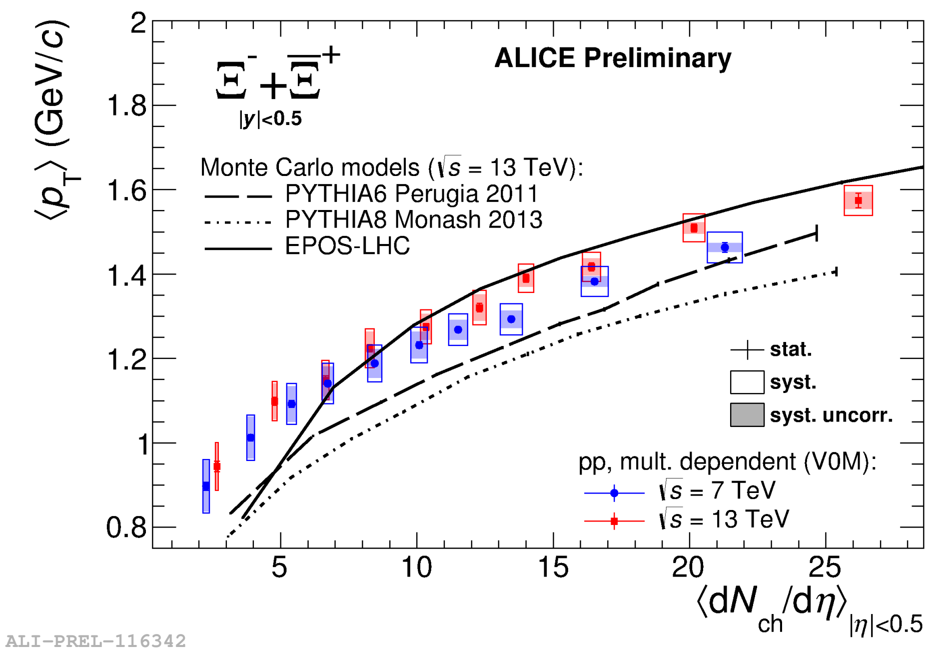


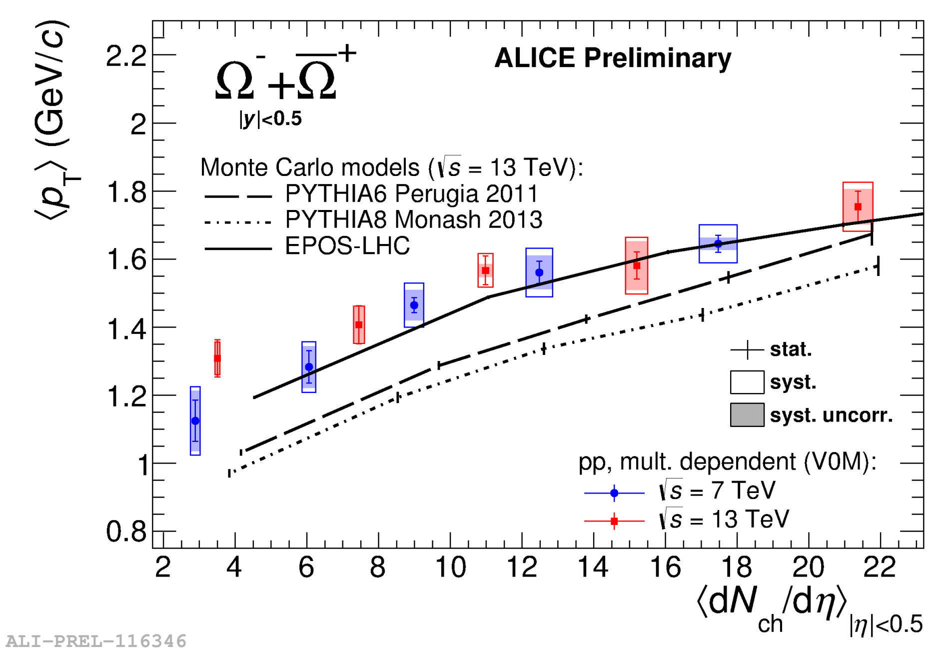
- hardening of the spectra seems to be species dependent

⟨p_T⟩ as a function of multiplicity



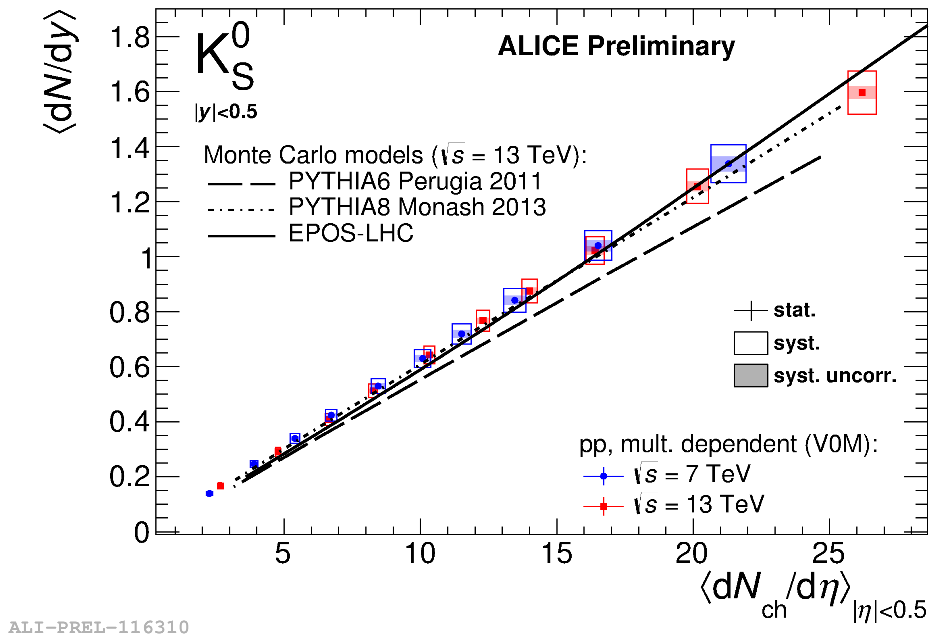


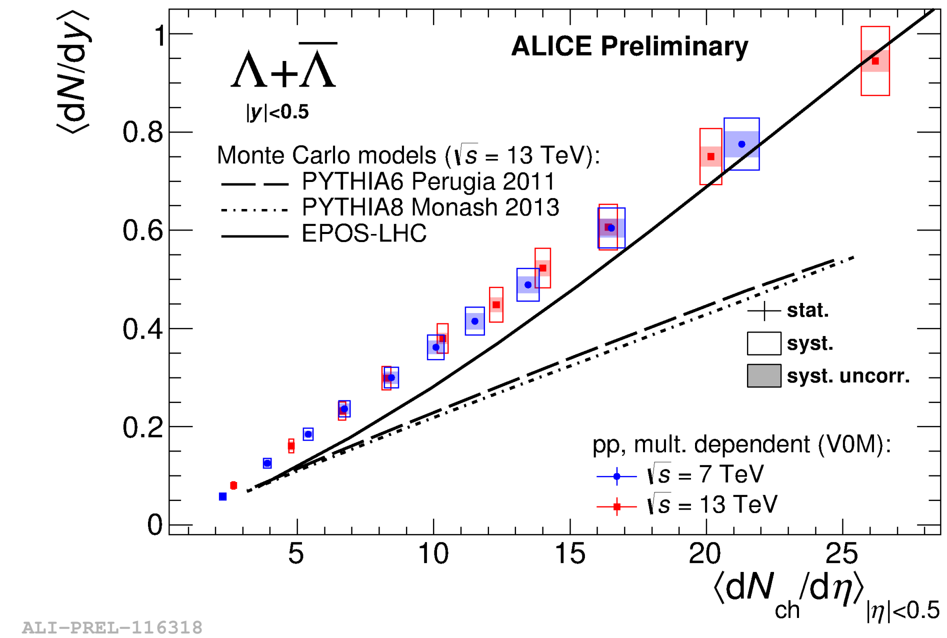


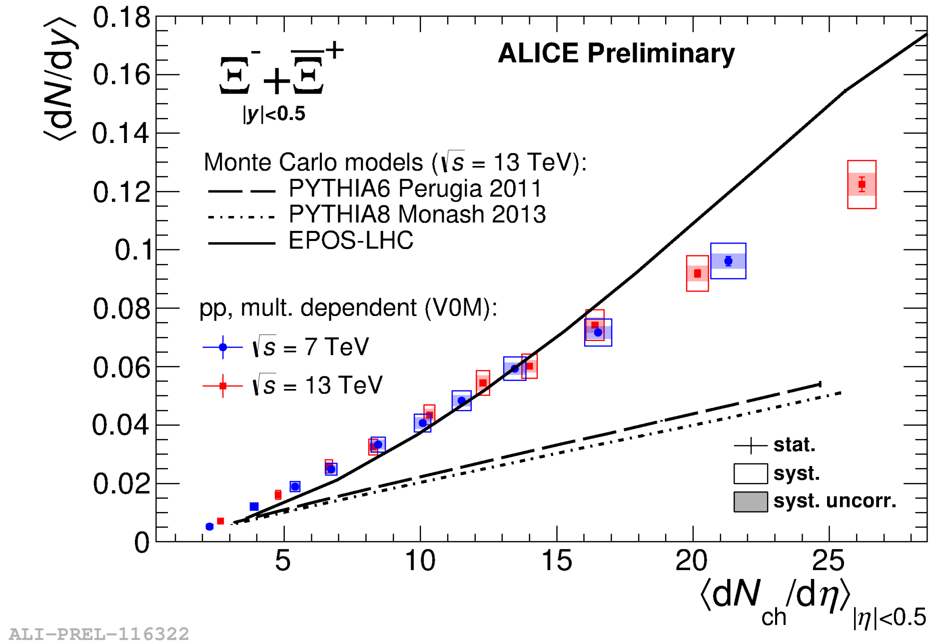


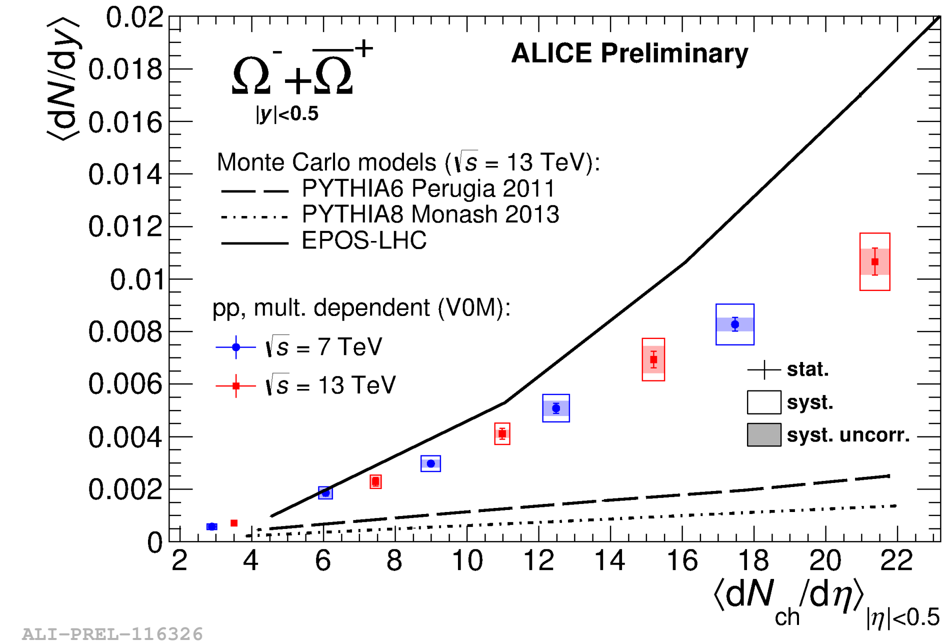
- spectra harder in 13 TeV than in 7 TeV for the same multiplicity

Yield as a function of multiplicity





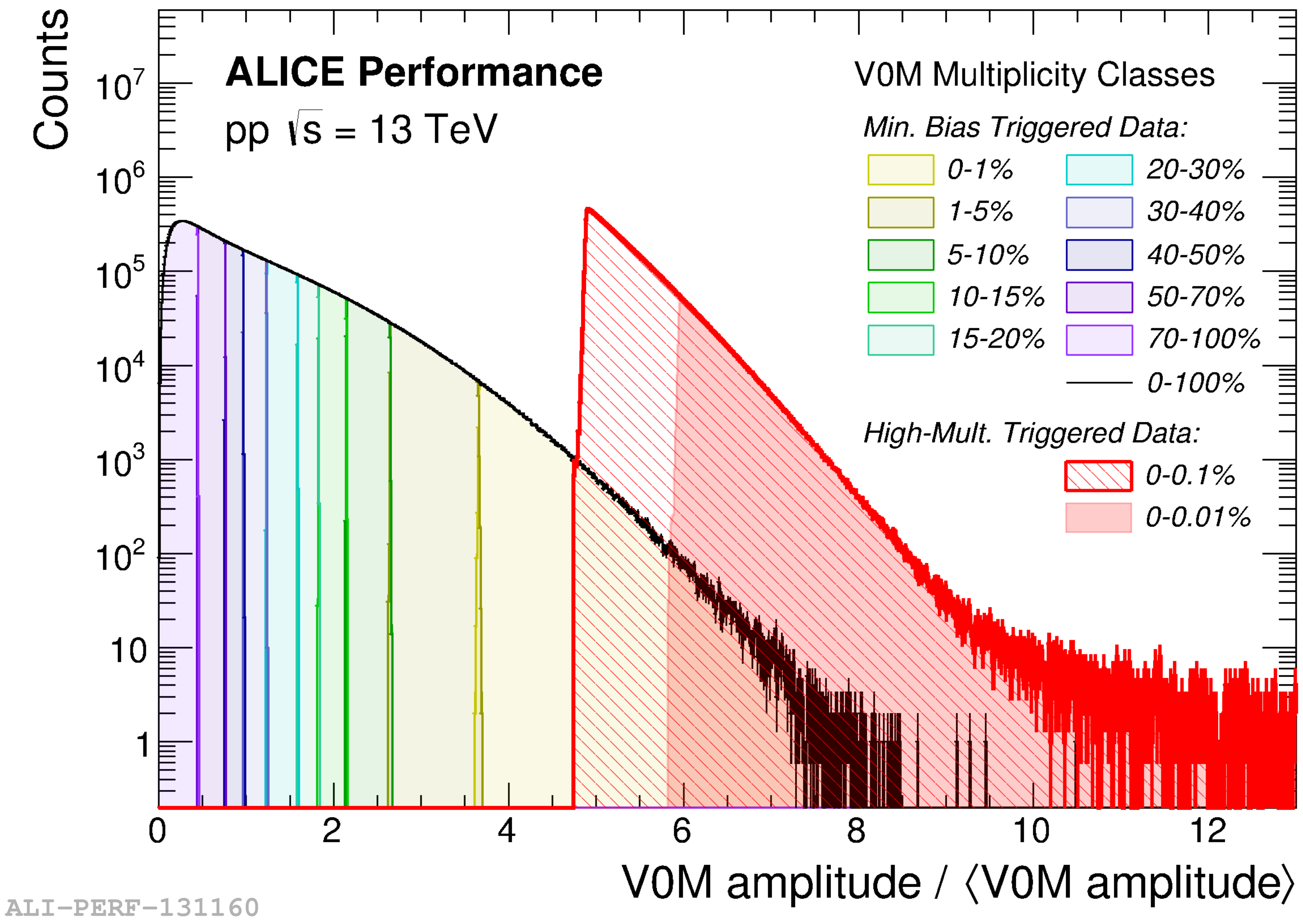




- linear increase of the yields with multiplicity, yields are invariant with respect to collision energy for a given event multiplicity!

Outlook

- a special high-multiplicity trigger in pp at 13TeV was used during the data taking in 2016
- enough statistics to study 0–0.1% and 0–0.01% multiplicity samples



Summary

- intriguing trends observed in strangeness production in high multiplicity pp collisions resembling the trends from Pb−Pb, like e.g. hardening of p_T spectra or similarities in B/M ratios

- enhancement of strange particle production w.r.t. pion production as a function of multiplicity seen in pp collisions

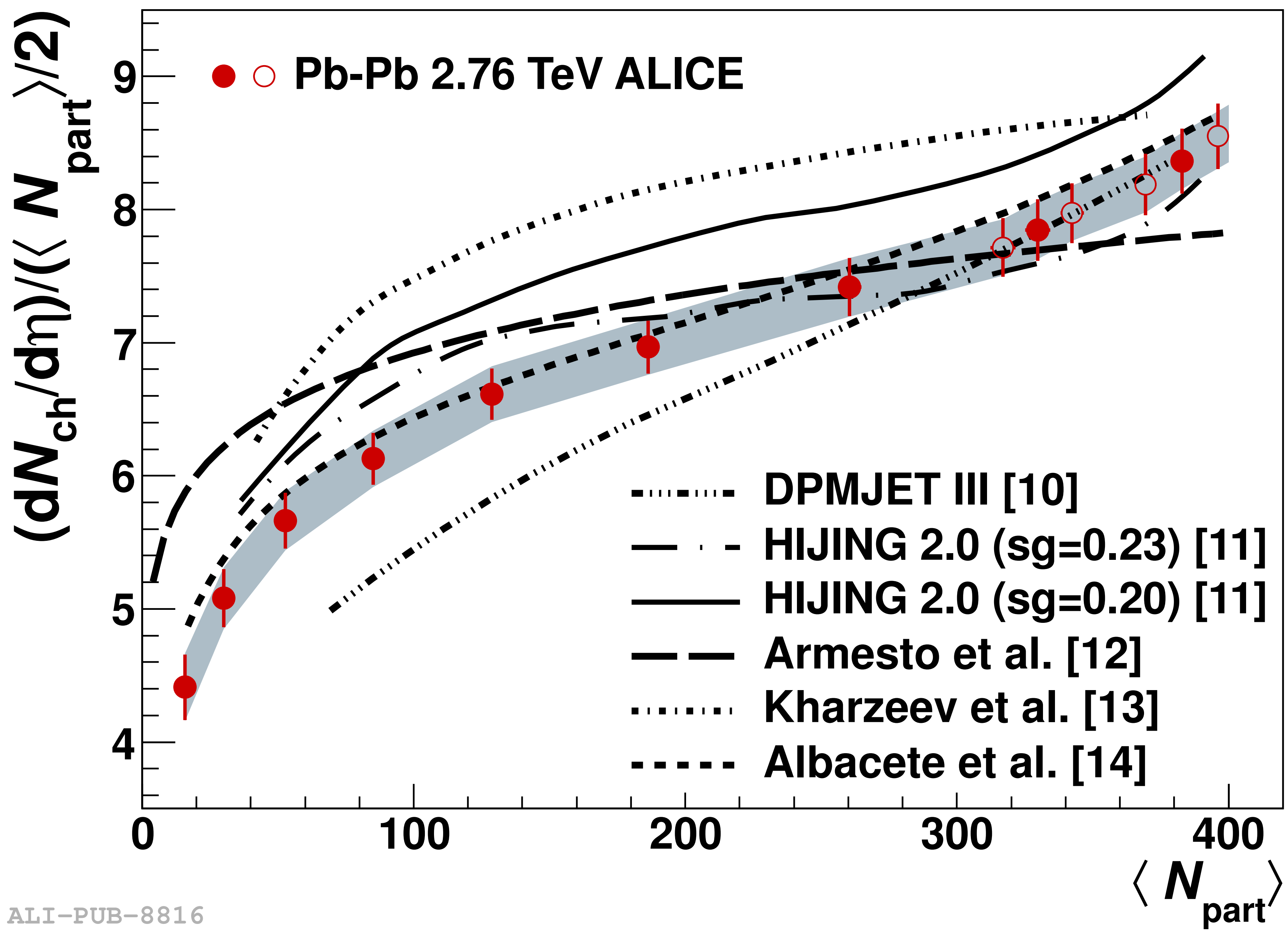
- for the same multiplicity: the strangeness production does not depend on collision system and (at least for LHC) also on collision energy

- production of particles with higher strangeness content is more enhanced in comparison with inclusive production

- stay tuned for the results obtained using data collected with a high-multiplicity trigger in pp collisions at 13 TeV

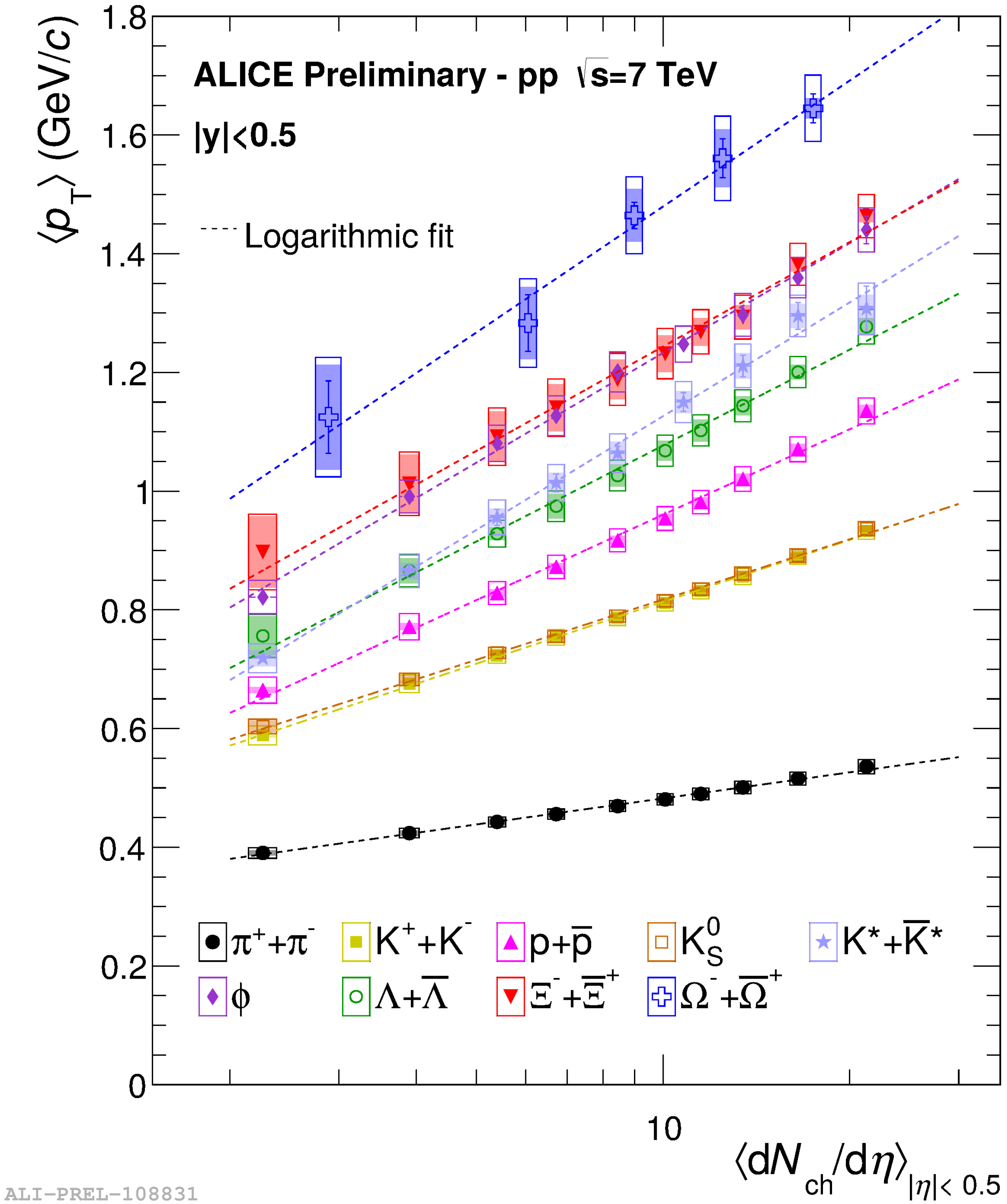
Backup slides

$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$ as a function of the number of participants



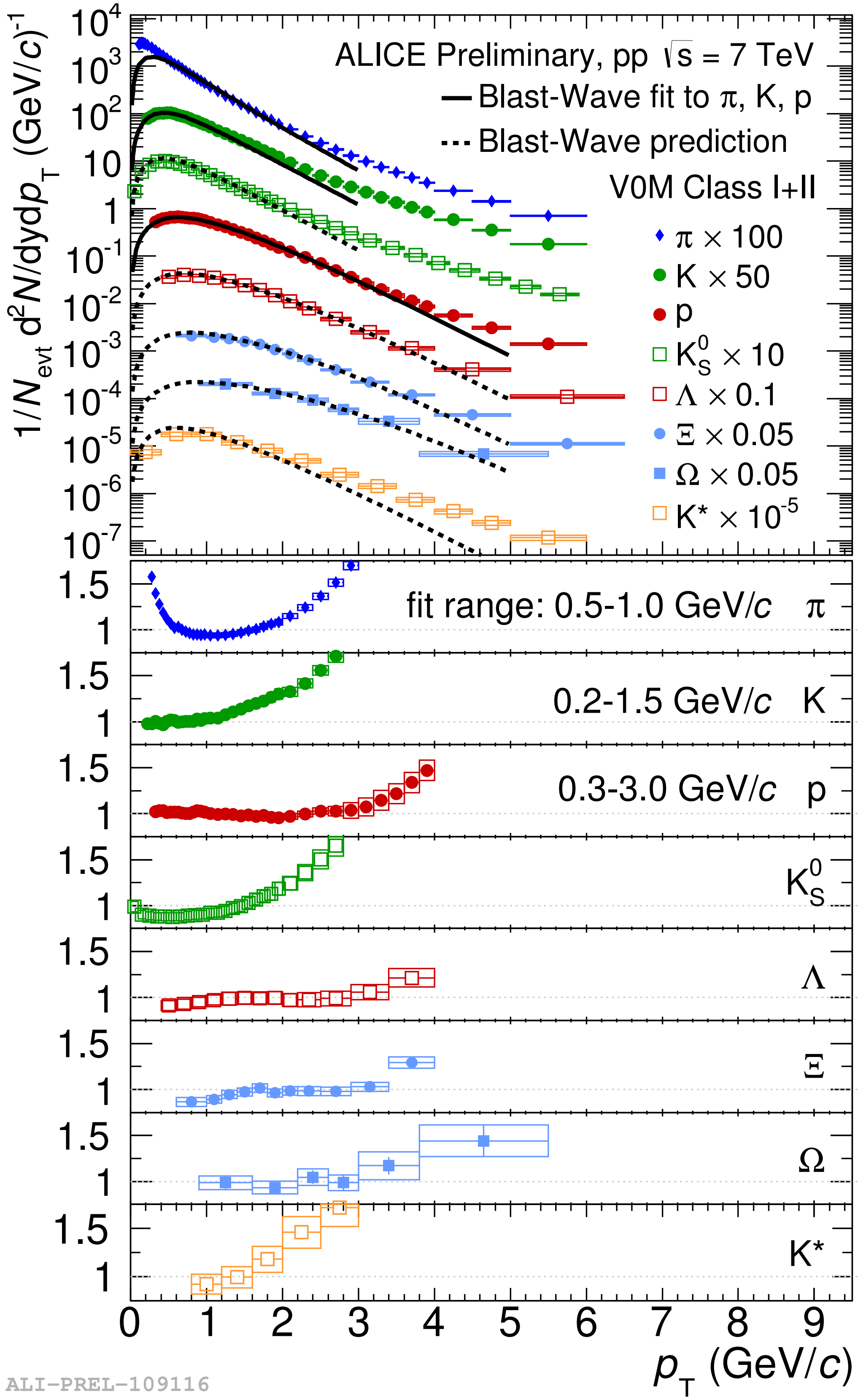
ALICE, Phys. Rev. Lett. 106 (2011) 032301

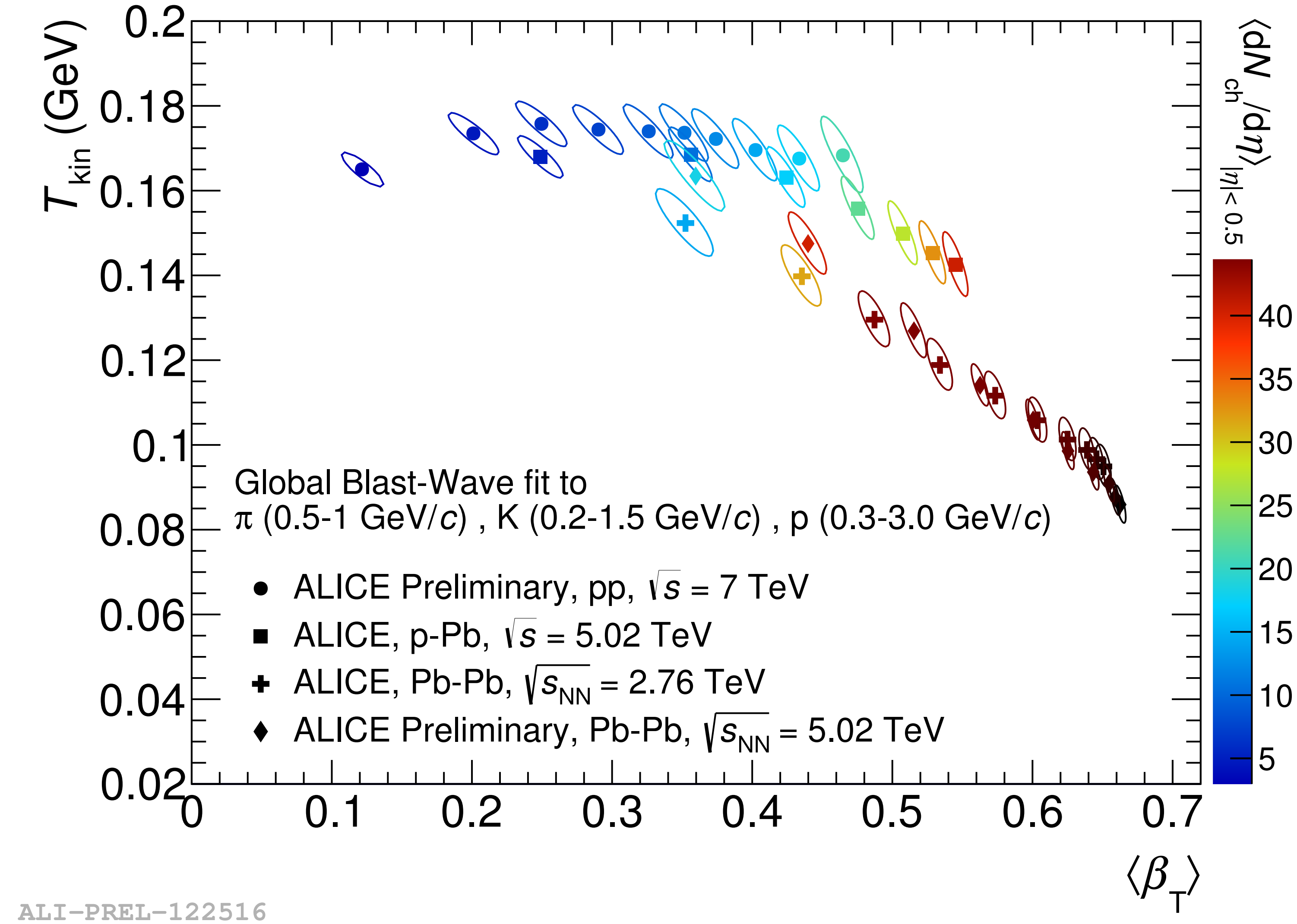
p_T spectra at 7 TeV



- the hardening is more pronounced for heavier particles
- similar behaviour observed also in p−Pb and Pb−Pb collisions where it can be interpreted as a particle emission from a collectively expanding thermal source (radial flow)
- do we see a radial flow in pp as well?

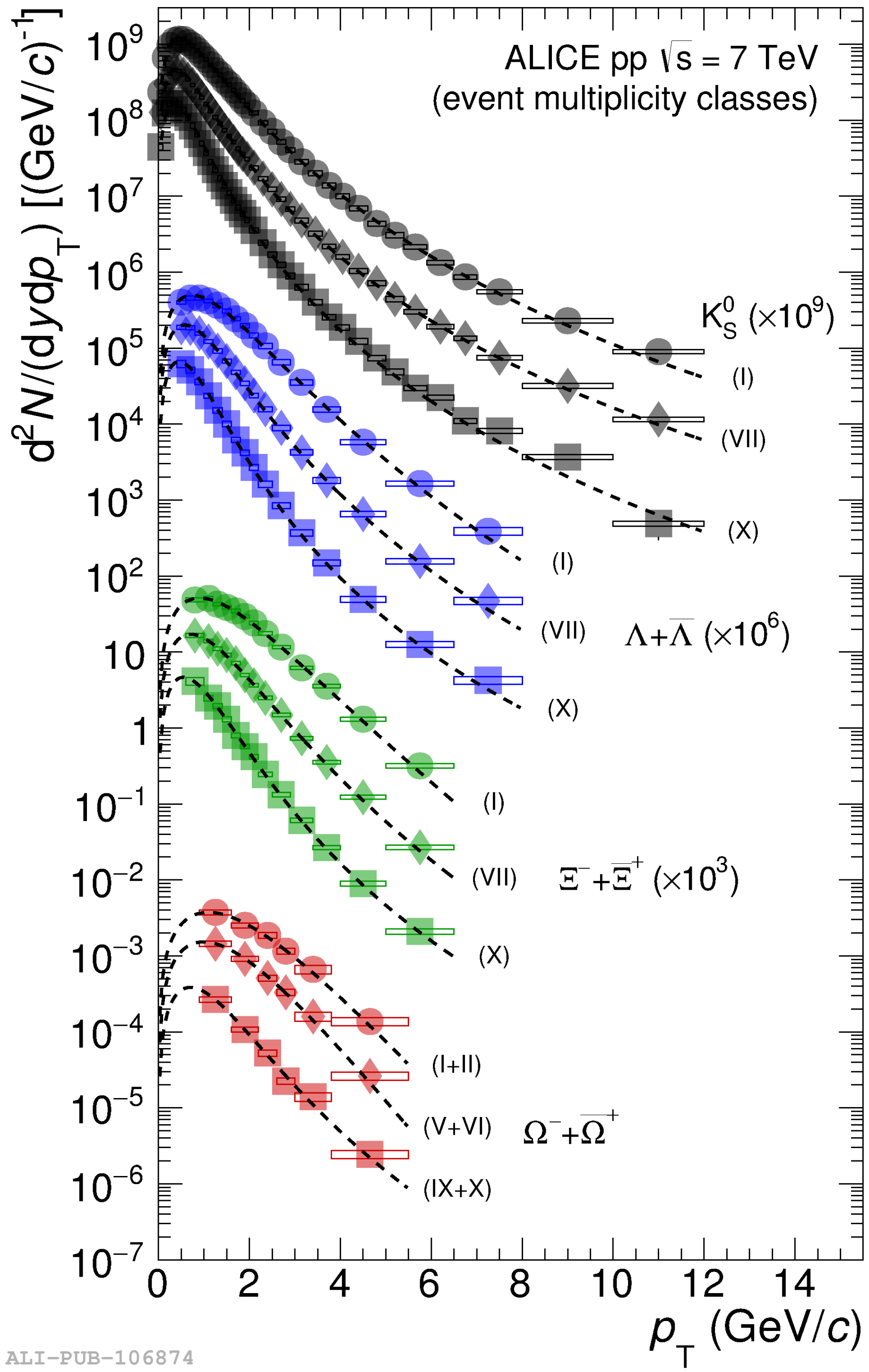
Blast-Wave fit





- for the similar multiplicity: the kinetic freeze-out temperature and the average transverse velocity are higher for pp than for Pb–Pb

p_T spectra at 7 TeV



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- Spectra are harder for higher multiplicity event classes. Similar effect seen in p–Pb can be explained by collectivity.
- in HI such behaviour could be explained by models based on relativistic hydrodynamics
- blast-wave fit to all species for class I points to thermal source at kinetic freeze-out temperature 163 MeV and common transverse velocity 0.49