Strangeness Production and Nuclear Modification at LHC Energies

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for the ALICE collaboration

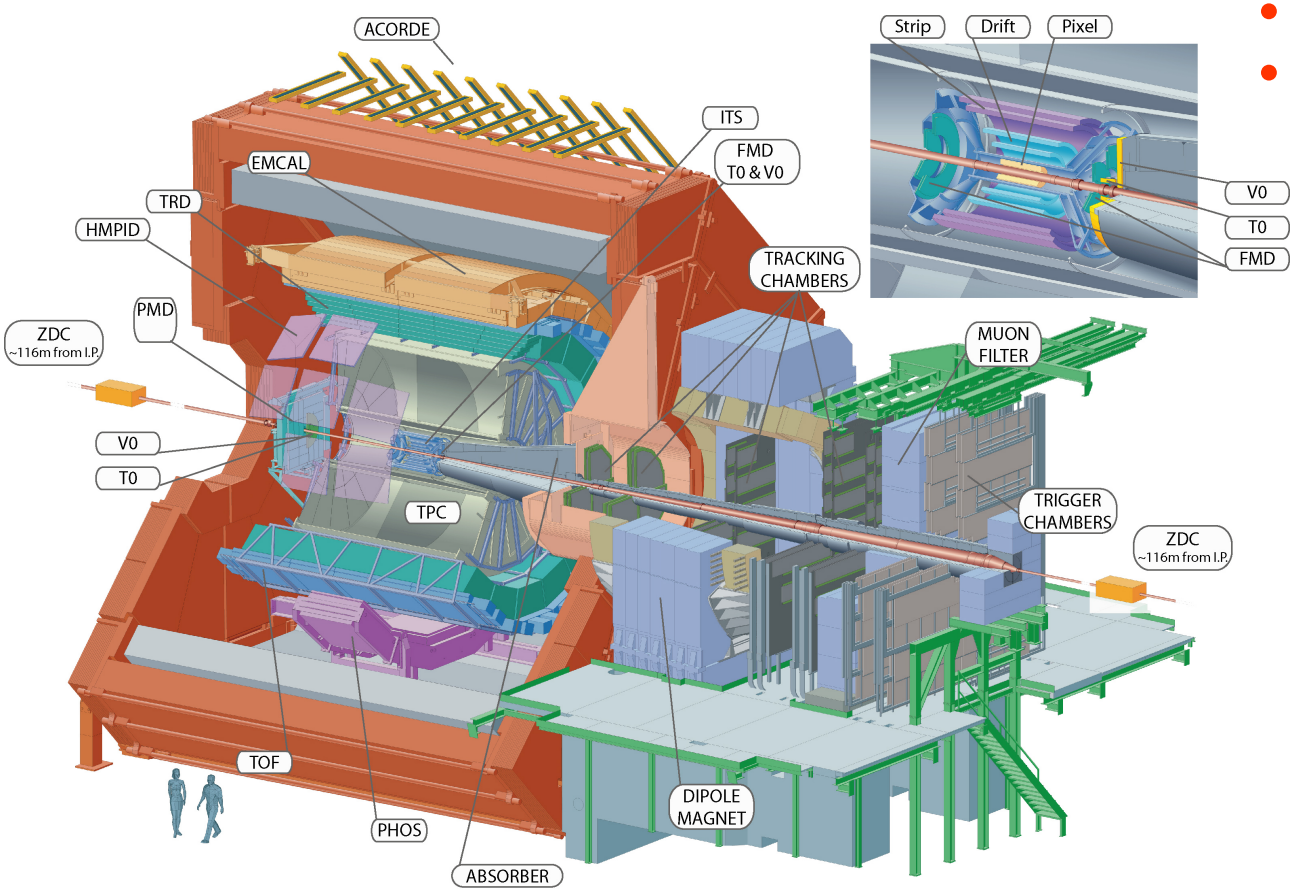
Outline

- Introduction
- Nuclear modification of identified hadrons in Pb-Pb collisions
- System size dependence of multi-strange particle production in pp, p-Pb and PbPb collisions

Strangeness with ALICE

forward detectors:

- trigger, timing,
- multiplicity, centrality



Inner Tracking System

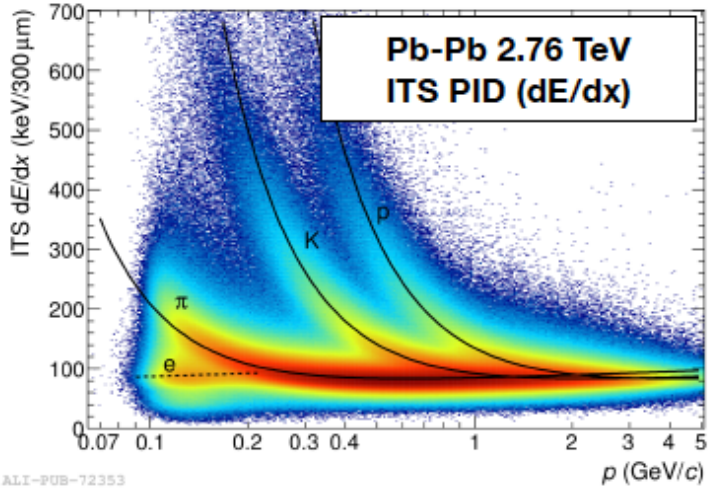
- vertex reconstruction
- low-p_T tracking

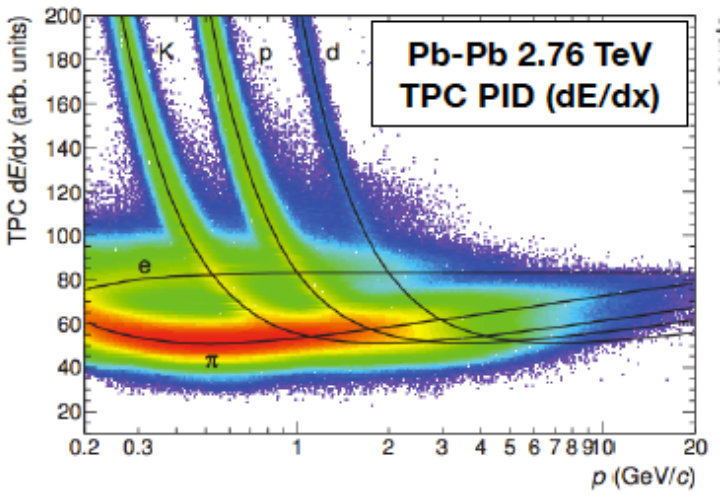
central barrel:

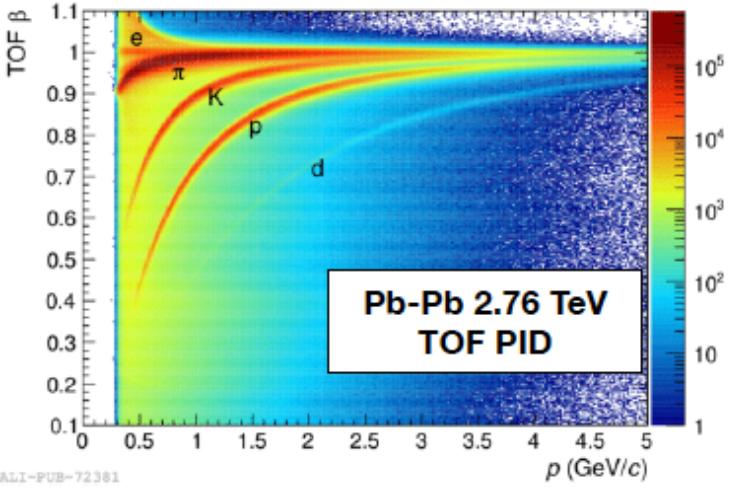
- tracking $|\eta| < 0.9$
- PID

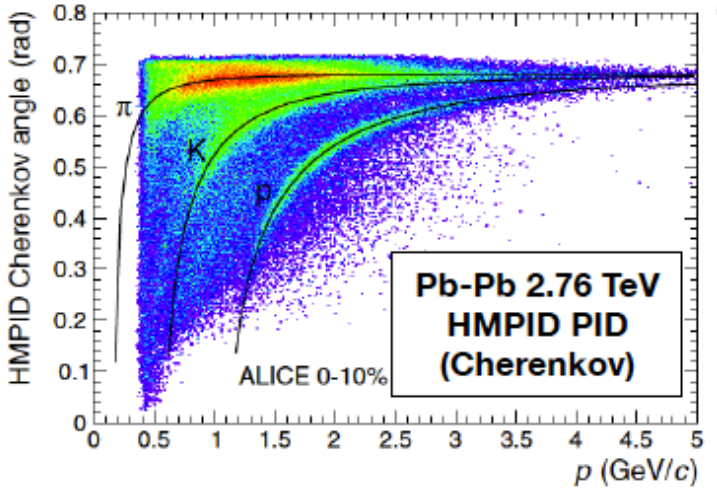
Charged particle identification

- practically all known particle identification techniques are used in ALICE
- identification of light flavour hadrons with p_T from 0.1 to 20 GeV/c

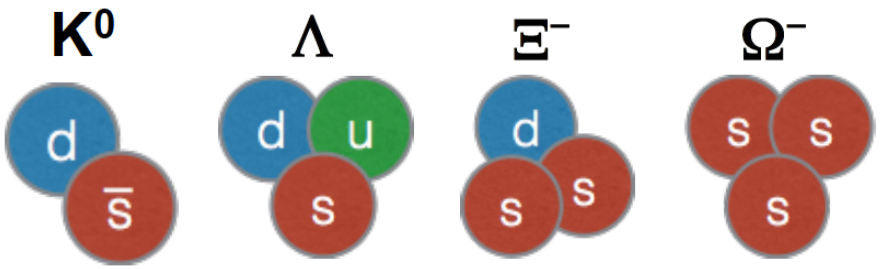






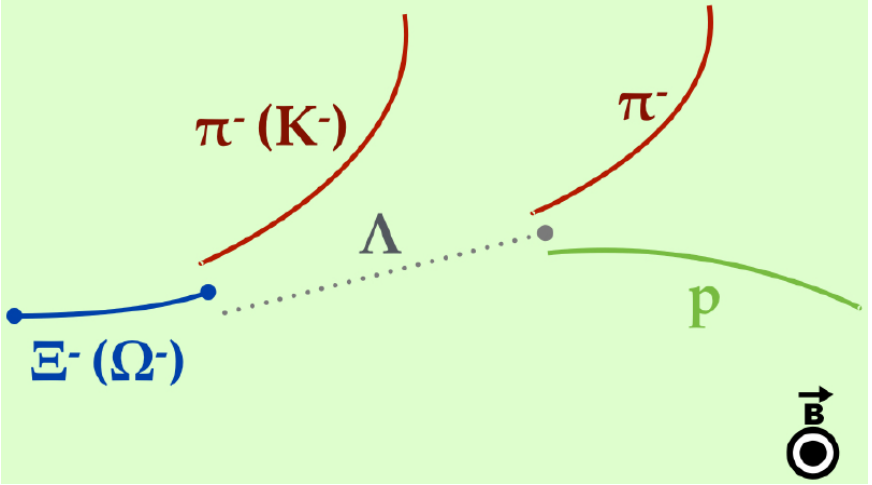


(Multi-)strange hadron reconstruction

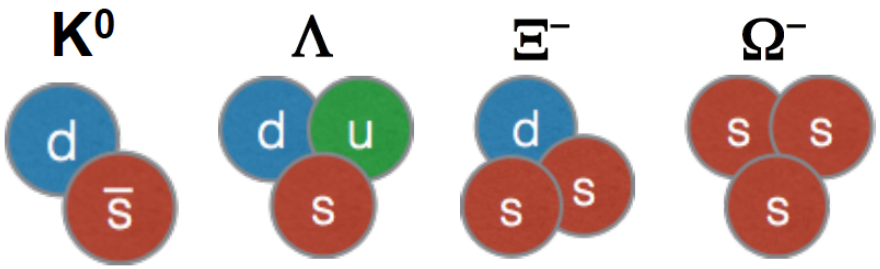


$$K^0_S \rightarrow \pi^-\pi^+ \ (B.R.\ 69.2\%)$$
$$\Lambda \rightarrow p\pi^- \ (B.R.\ 63.9\%)$$
$$\Xi^- \rightarrow \Lambda\pi^- \ (B.R.\ 99.9\%)$$
$$\Omega^- \rightarrow \Lambda K^- \ (B.R.\ 67.8\%)$$

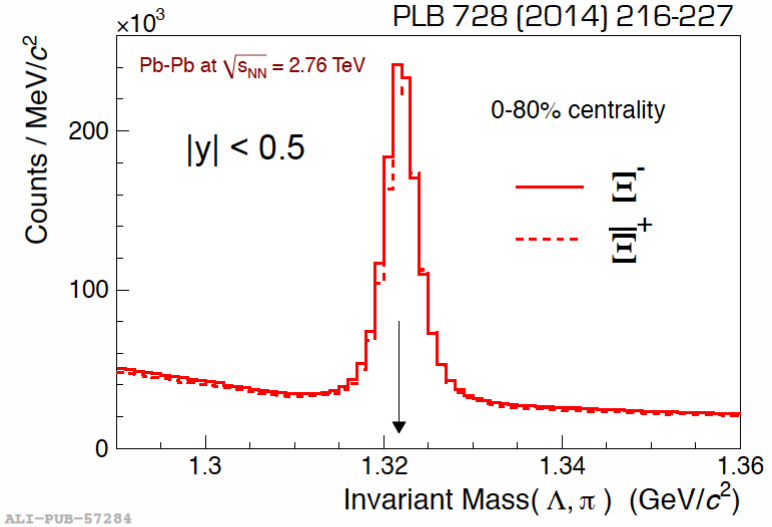
- charged tracks reconstructed in ITS and TPC
- TPC PID: identify decay daughters
- decay topology: combine reconstructed tracks to particle candidates

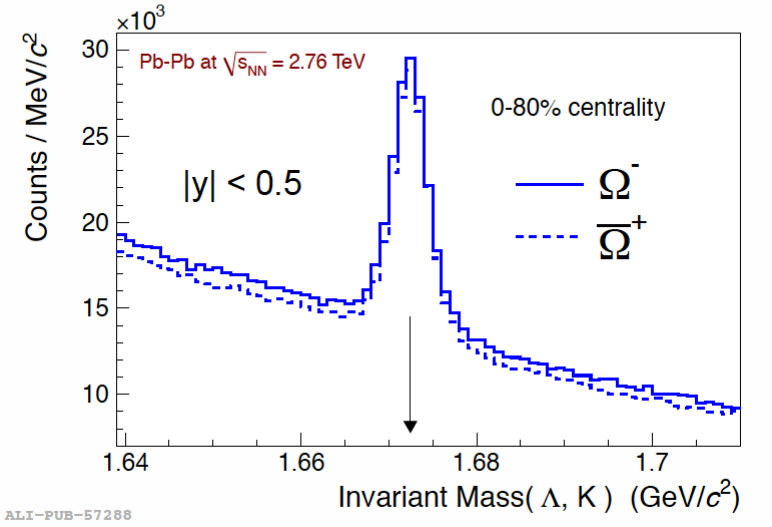


(Multi-)strange hadron reconstruction



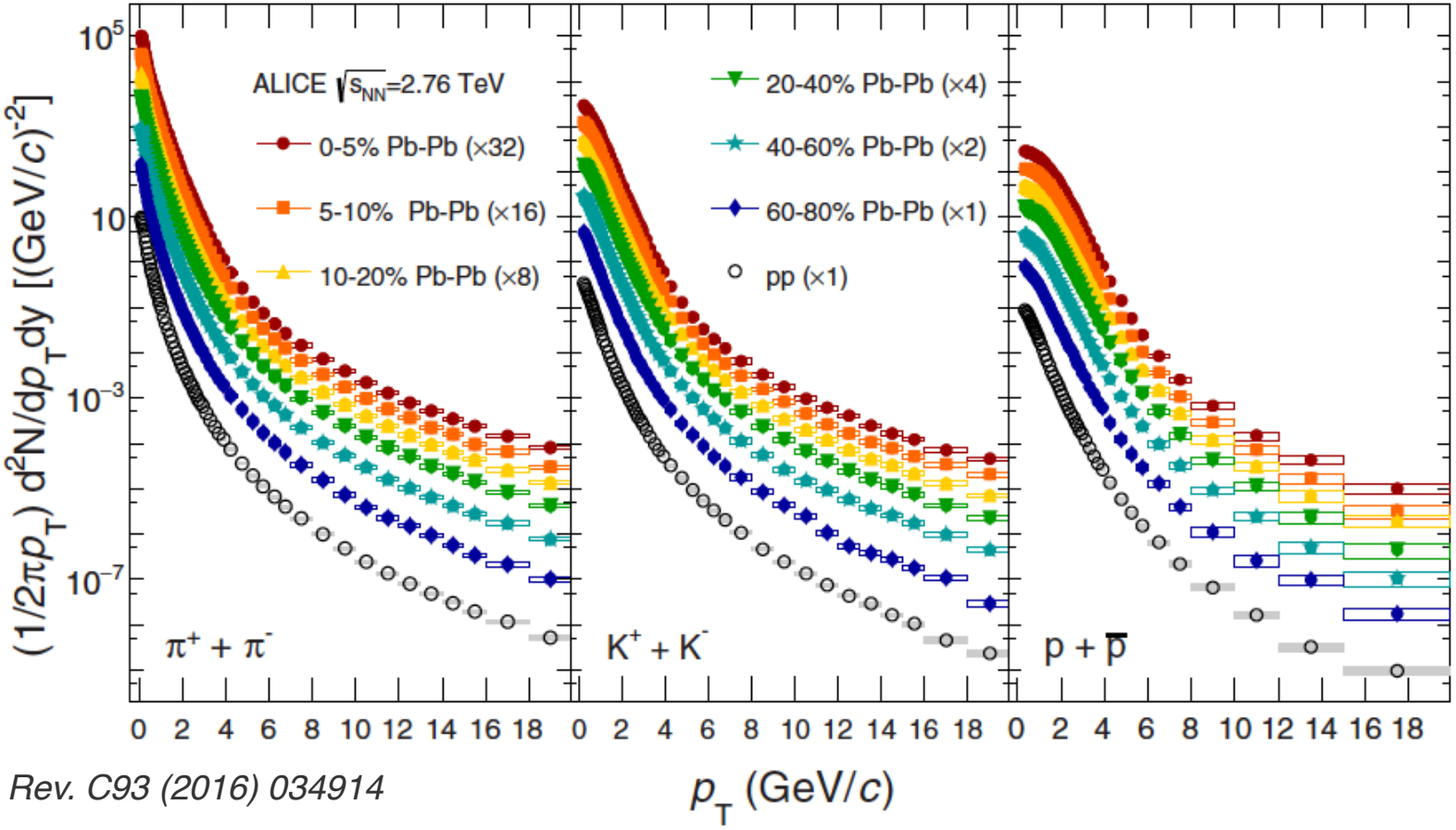
- charged tracks reconstructed in ITS and TPC
- TPC PID: identify decay daughters
- decay topology: combine reconstructed tracks to particle candidates
- yield extraction via invariant mass





π, K, p in pp and Pb-Pb at 2.76 TeV

- low p_T (< 3 GeV/c): bulk particle production, collectivity
- high p_T (> 10 GeV/c): fragmentation, parton energy loss
- intermediate p_T: interplay soft-hard, hadronization via recombination ?



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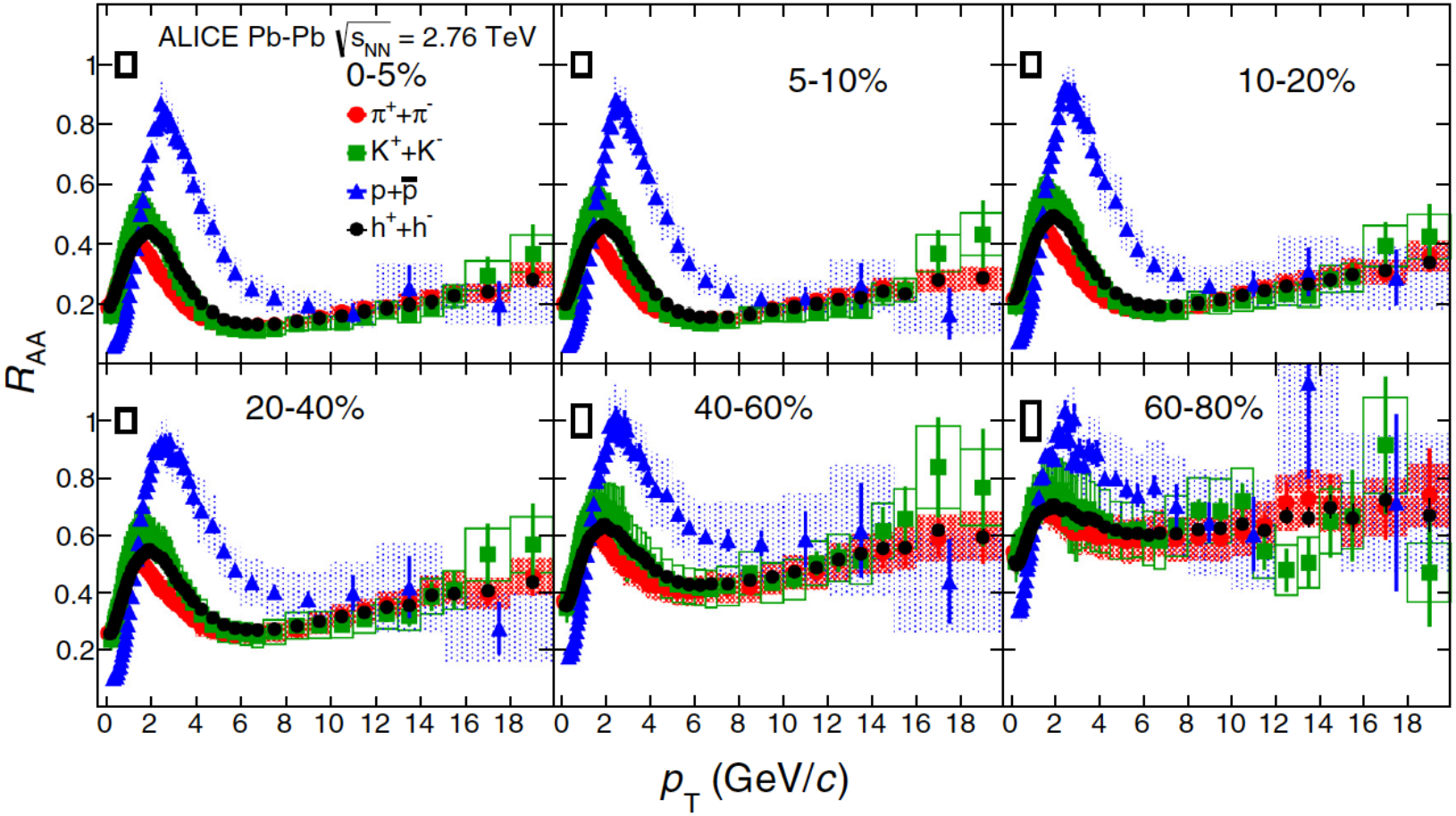
Nuclear modification factor

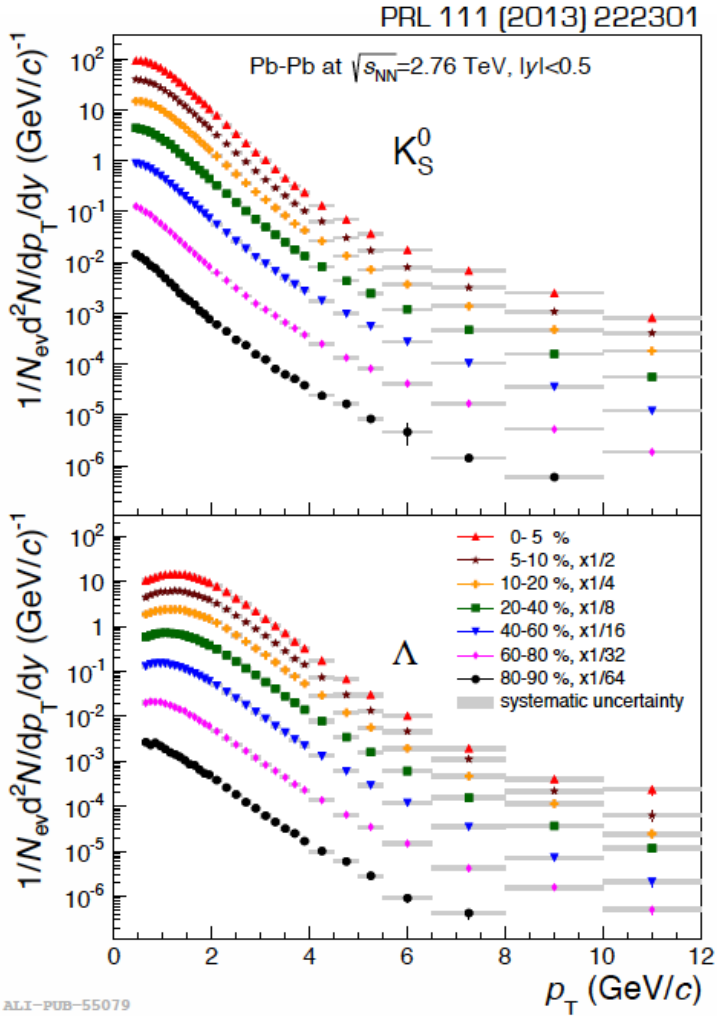
- R_{AA} < 1: at high p_T, strong, centrality dependent suppression
- no species dependence at high p_T

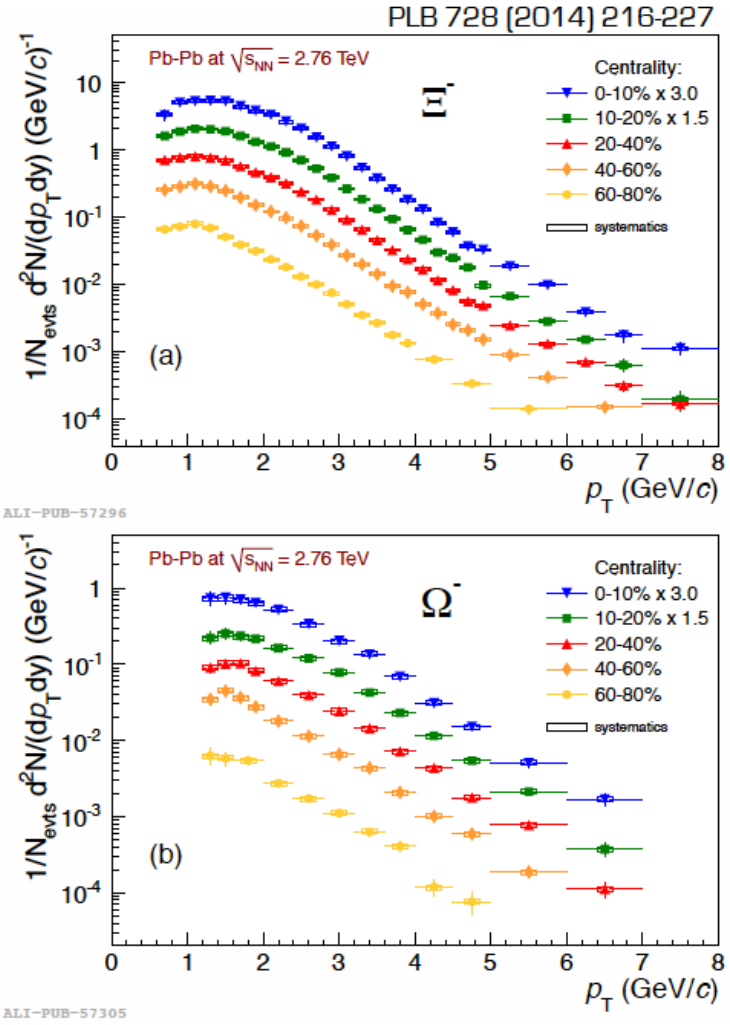
$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{d^2N_{ch}/d\eta\, dp_T}{d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$



(Multi-)strange hadron spectra

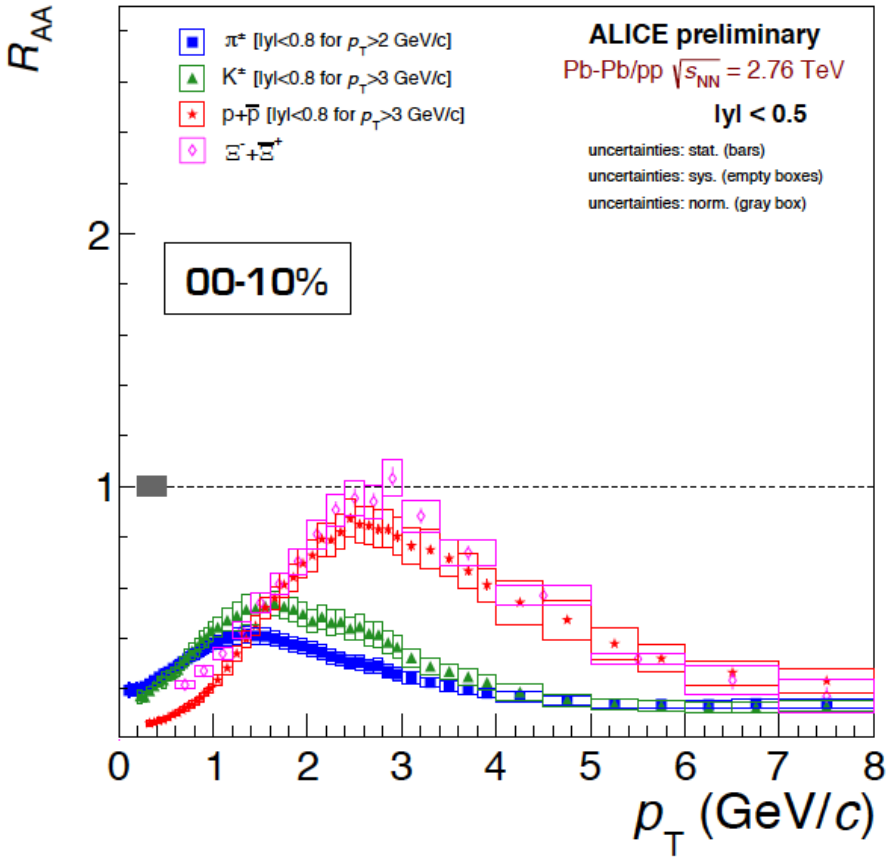
- particle and anti-particle spectra compatible
- spectra at low p_T harder for more central collisions and higher particle mass





Ξ nuclear modification factor

- R_{AA} < 1: at high p_T, strong suppression: jet quenching
- no species dependence at high p_T
- R_{AA} of Ξ consistent with p



- vacuum fragmentation in jet core ?
- fragmentation bias of hadronic observable ?

Strangeness production in jets:

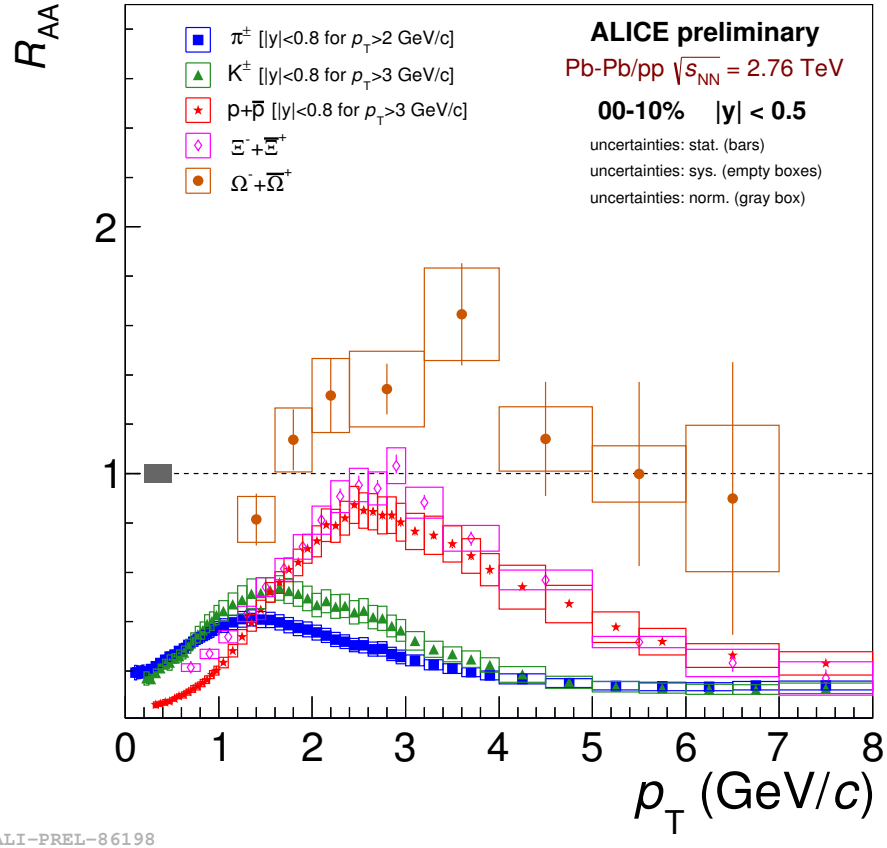
Y. Zhang, Session III

09/24 15:20

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{d^2N_{ch}/d\eta\, dp_T}{d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$

Ω nuclear modification factor

- R_{AA} < 1: at high p_T, strong suppression: jet quenching
- no species dependence at high p_T
- R_{AA} of Ξ consistent with p, **Ω R_{AA} > Ξ R_{AA}**



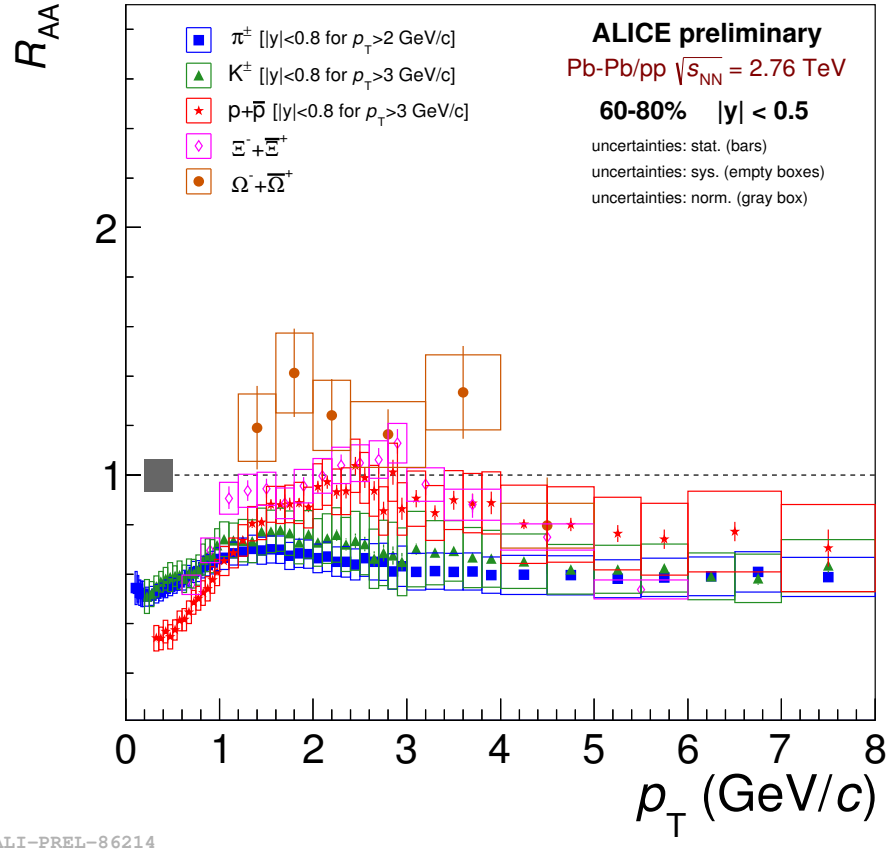
- mass ordering at mid-p_T
  - m_p = 0.94 GeV/c^2
  - m_Ξ = 1.32 GeV/c^2
  - m_Ω = 1.67 GeV/c^2

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{d^2N_{ch}/d\eta\, dp_T}{d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$

ALI-PREL-86198

Nuclear modification factor

- R_{AA} < 1: at high p_T, strong suppression, jet quenching
- no species dependence at high p_T
- R_{AA} of Ξ consistent with p, Ω R_{AA} > Ξ R_{AA}



- mass ordering at mid-p_T
  - m_p = 0.94 GeV/c^2
  - m_Ξ = 1.32 GeV/c^2
  - m_Ω = 1.67 GeV/c^2
- peripheral collisions: R_{AA} closer to unity for all species
- how about system size dependence (strangeness enhancement) ?

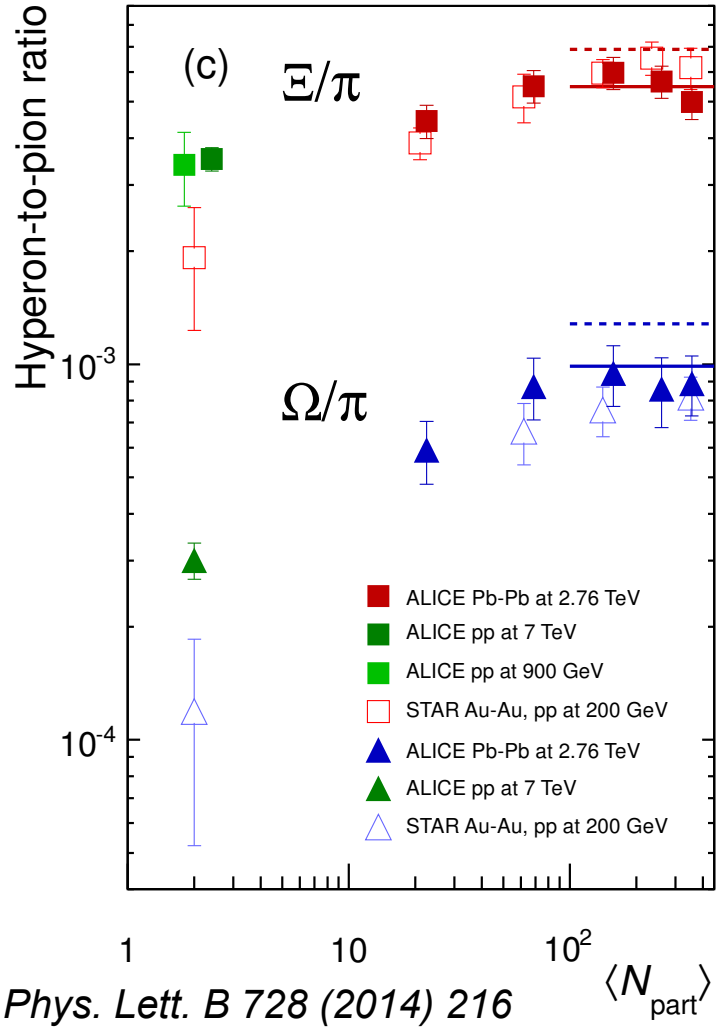
$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{d^2N_{ch}/d\eta\, dp_T}{d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$

ALI-PREL-86214

System Size Dependence

Strangeness enhancement: A-A

- one of the earliest proposed QGP signatures



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- pp: increase with $\sqrt{s}$
- A-A: enhancement over pp
- saturation for $N_{part} > 150$ at value expected from statistical grand-canonical models

—— GSI-Heidelberg T_{ch} = 164 MeV

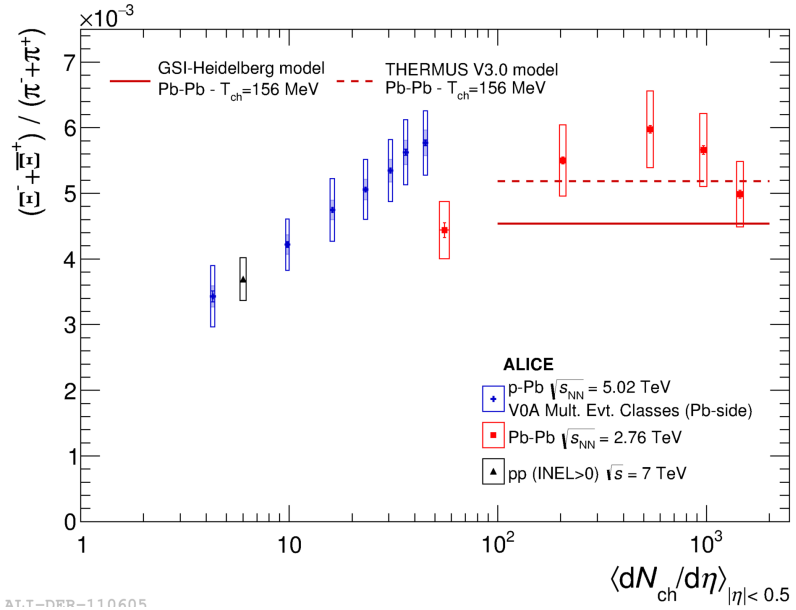
- - - Thermus T_{ch} = 170 MeV

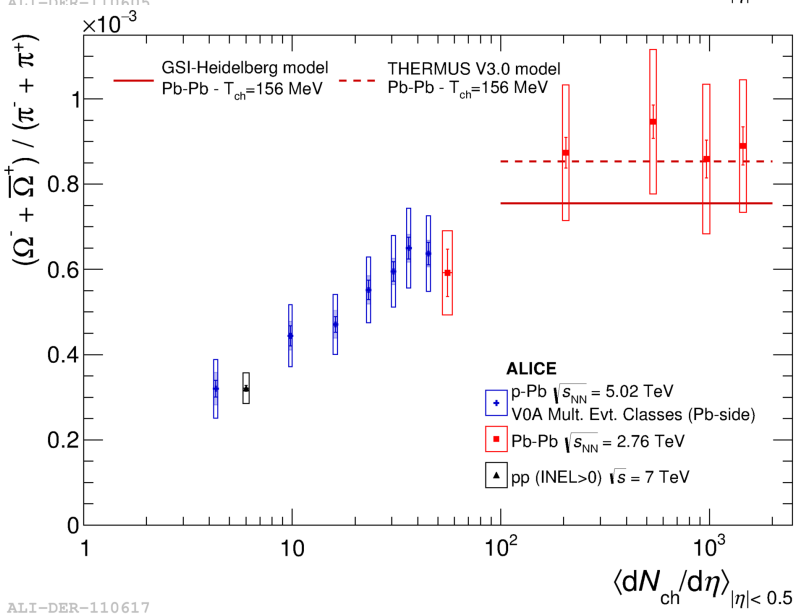
A. Andronic et al., PLB 673 (2009) 142

J. Cleymans et al., PRC 74 (2006) 034903

ALI-PUB-78357

Multiplicity dependence: p-Pb





- in p-Pb, both Ξ / π and Ω / π exhibit strong rise
  - Ξ / π reaches Pb-Pb saturation value
  - Ω / π up to 60-80%
- Ω stronger multiplicity dependence

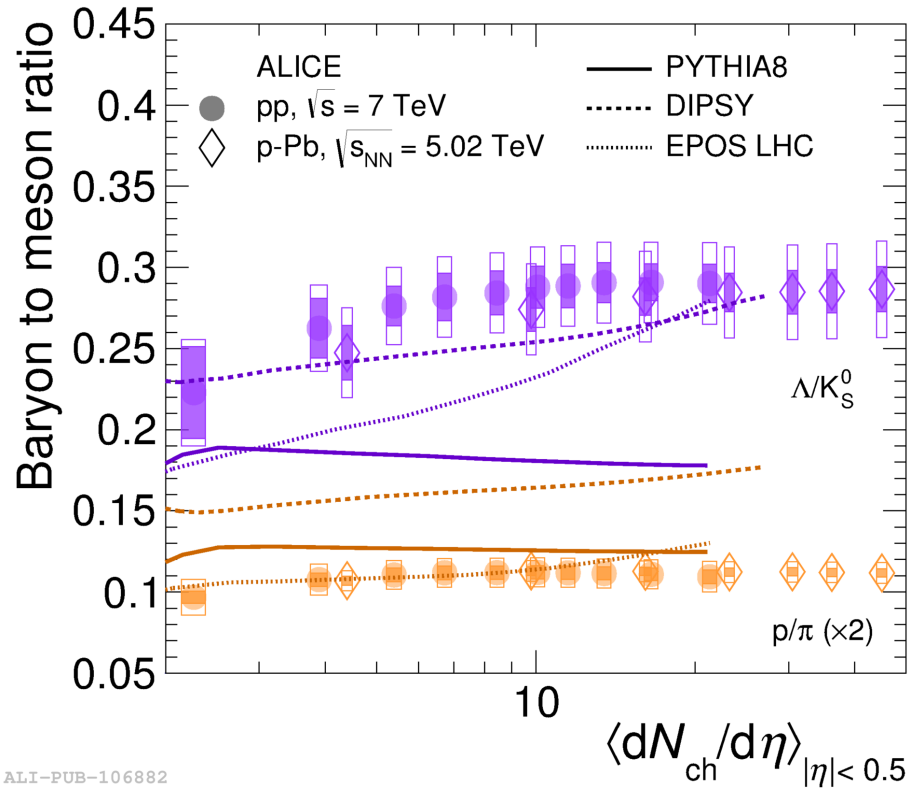
→ strangeness dependent effect

Phys. Lett. B 758 (2016) 389

Multiplicity dependence: pp

- multiplicity classes based on summed amplitude in V0 detectors ($2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)
- p / π and Λ / K^0_S: compatible between pp and p-Pb
- no significant multiplicity dependence
- enhancement in p-Pb governed by strangeness content

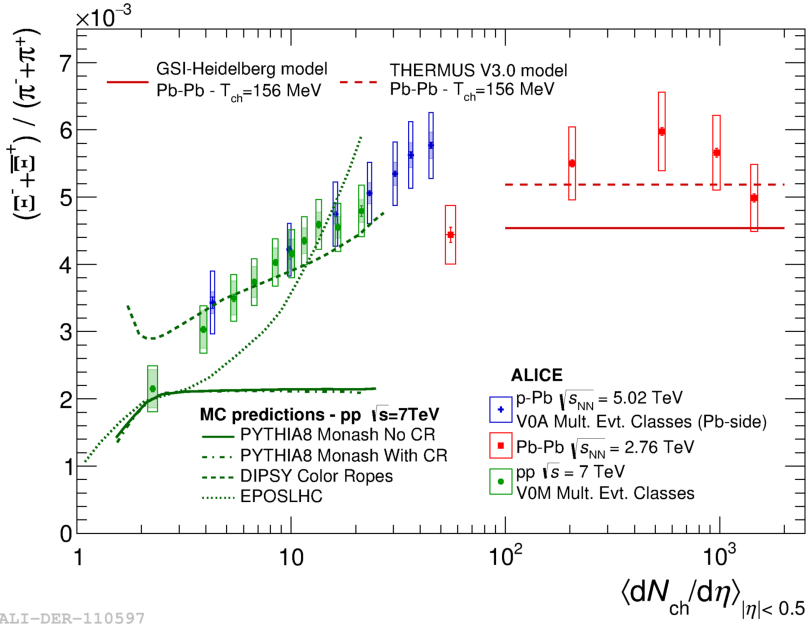
→ how about hyperons in pp ?

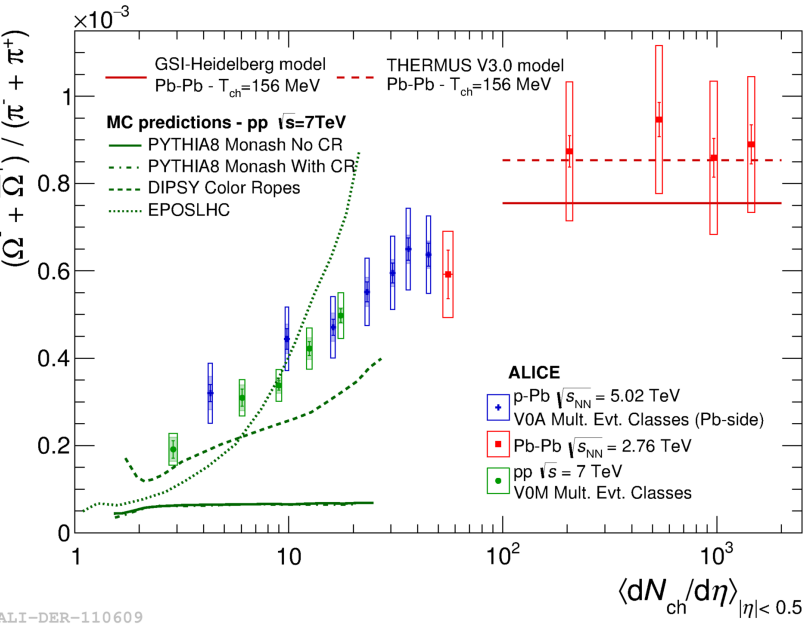


arXiv: 1606.07424 [nucl-ex]

ALI-PUB-106882

Multiplicity dependence: pp

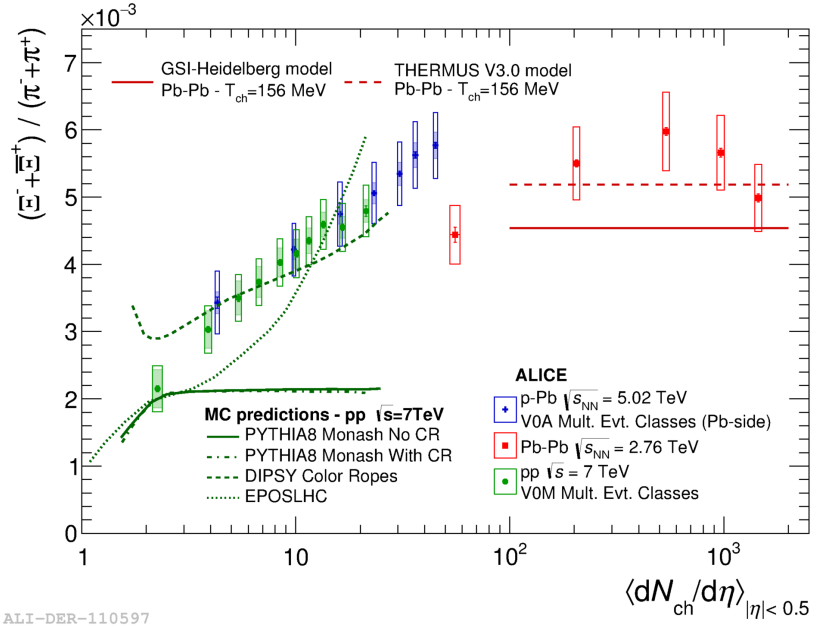




- Ξ and Ω in pp: strong multiplicity dependence !
- pp similar to p-Pb
- pp models: color ropes needed to produce multiplicity dependence
- no model describes both Ξ and Ω

arXiv: 1606.07424 [nucl-ex]

Multiplicity dependence: pp



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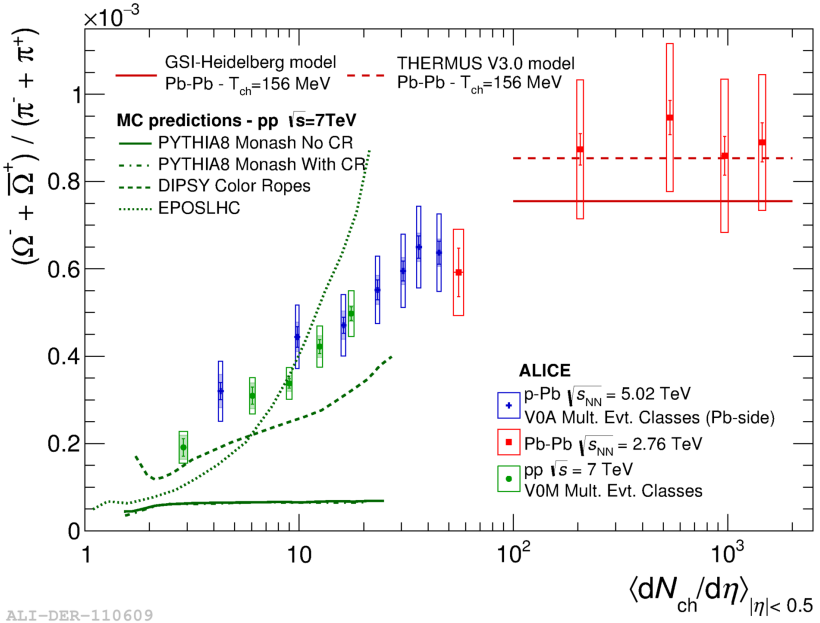
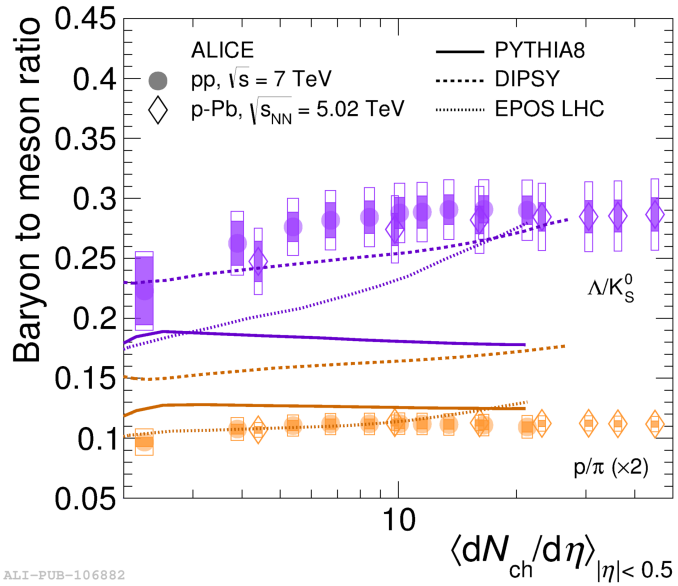
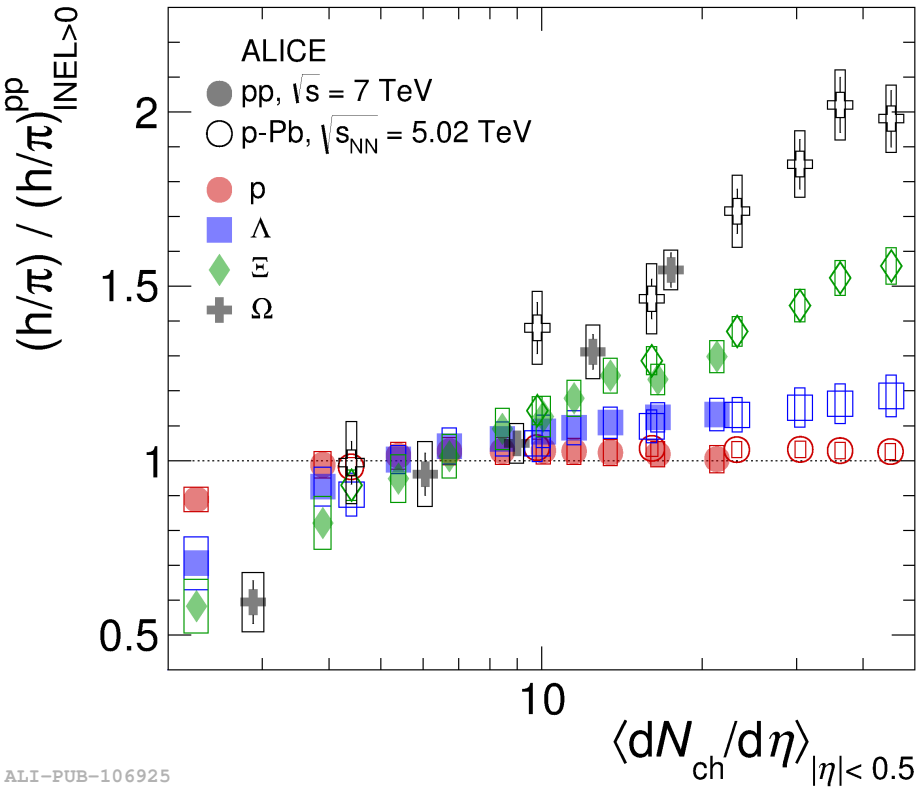
… and Λ and p !





Multiplicity dependence: pp

- yield ratios normalised to pp INEL > 0: reduced uncertainties
- p / π consistent with unity



arXiv: 1606.07424 [nucl-ex]

Multiplicity dependence: pp

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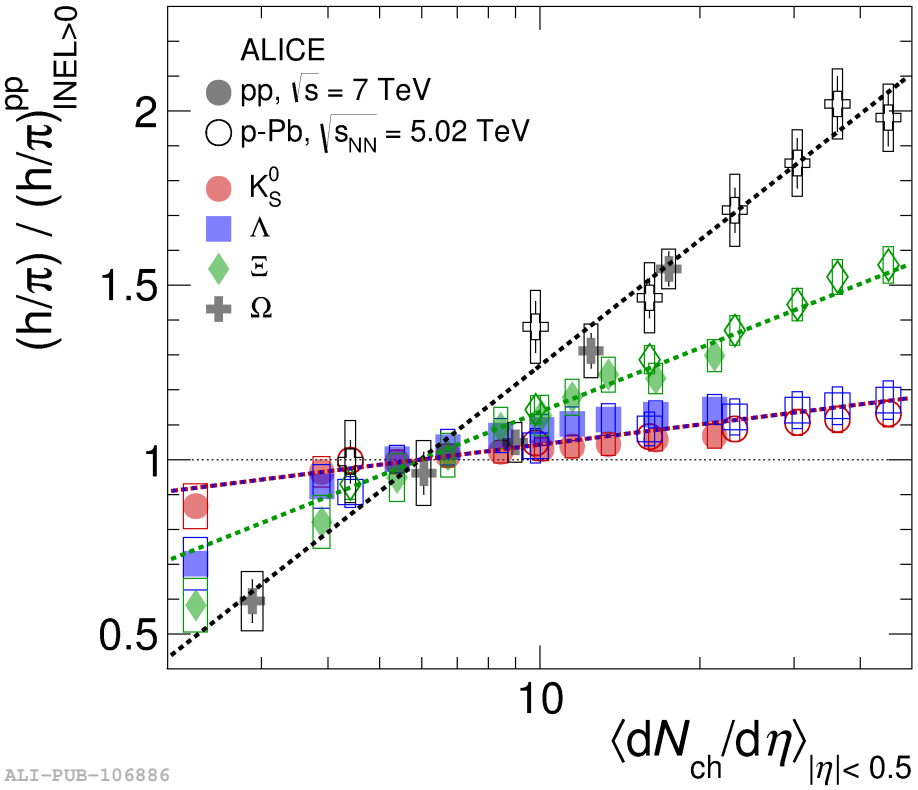


- dependence on strangeness content well described by

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

with b = 1.67

arXiv: 1606.07424 [nucl-ex]

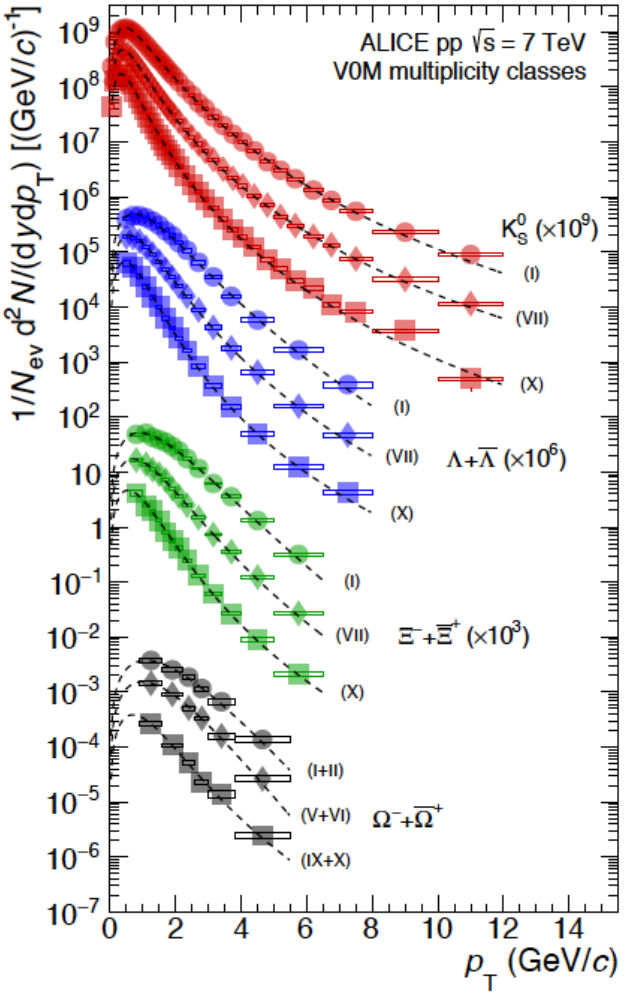
Summary

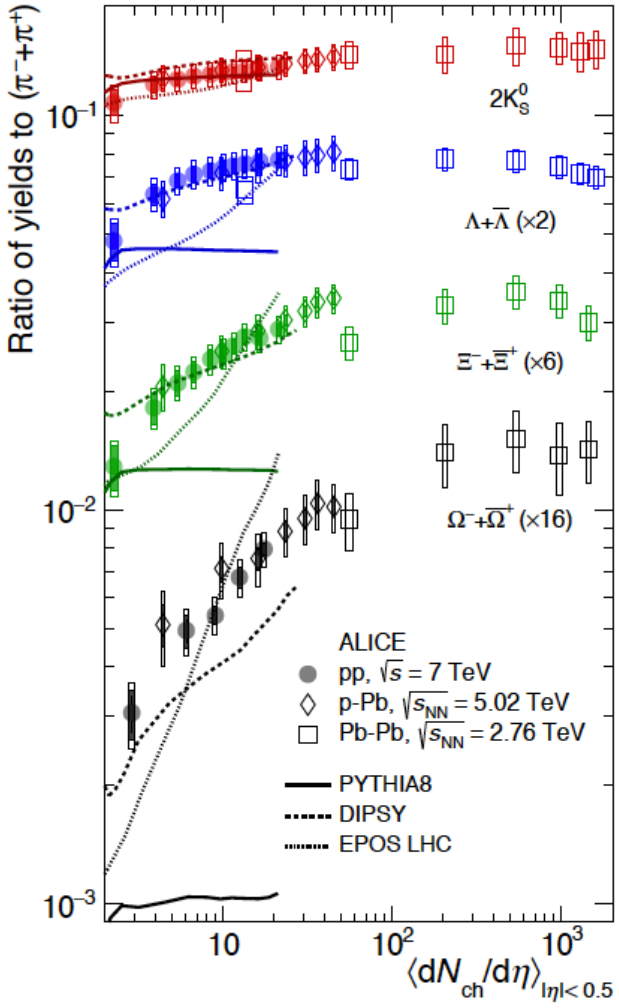
- identified charged π, K, p R_{AA} for $0.1 < p_T < 20$ GeV/c
- no significant species dependence observed
- Ω R_{AA} > Ξ R_{AA} in measured range ($p_T < 7$ GeV/c)
- first observation of a multiplicity dependence of strangeness production in pp collisions
- per-pion yields consistent between pp and p-Pb
- effect driven by strangeness content

backup

Multiplicity dependence in pp

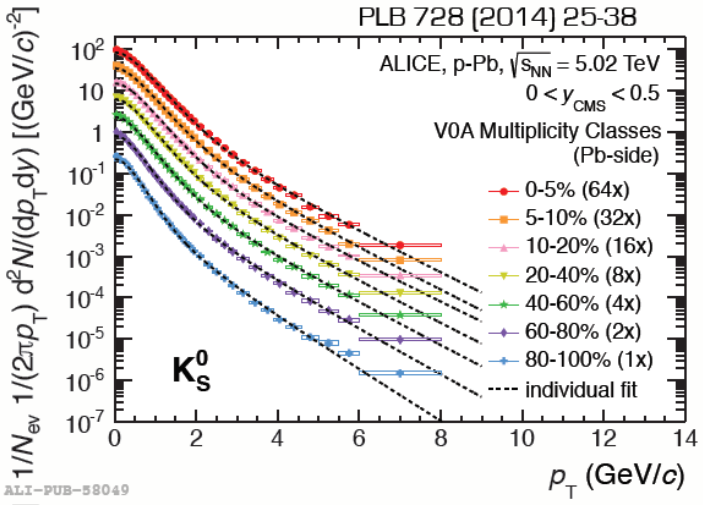
- INEL > 0 event class: 1 charged particle in $|\eta|< 1$
- lines: Levy-Tsallis fits
- blast wave OK within ~5%, T_{fo} = 163 +/- 10 MeV, β = 0.49

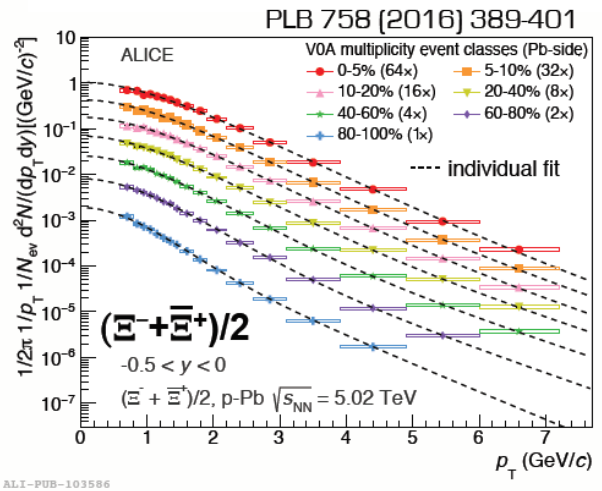


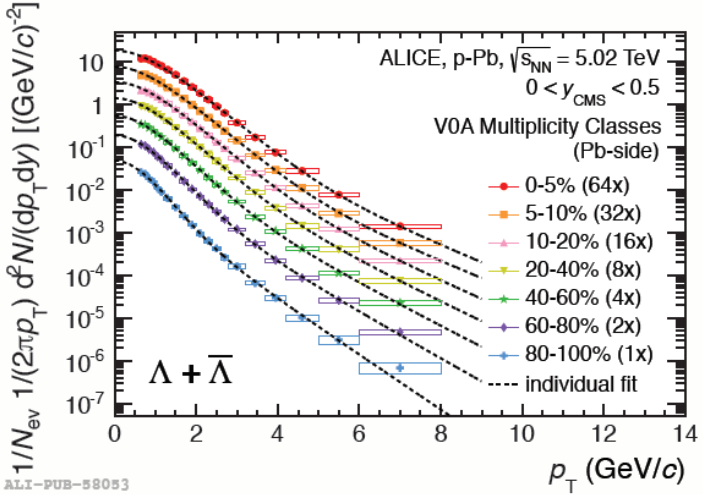


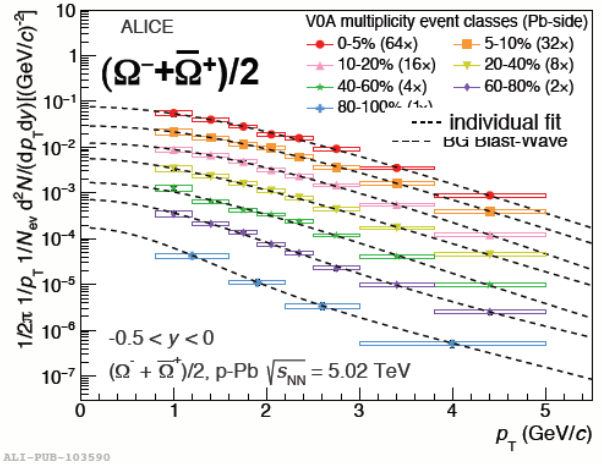
(Multi-)strange hadron spectra in p-Pb

- V0A multiplicity classes
- low-p_T spectral shape: similar trends as Pb-Pb





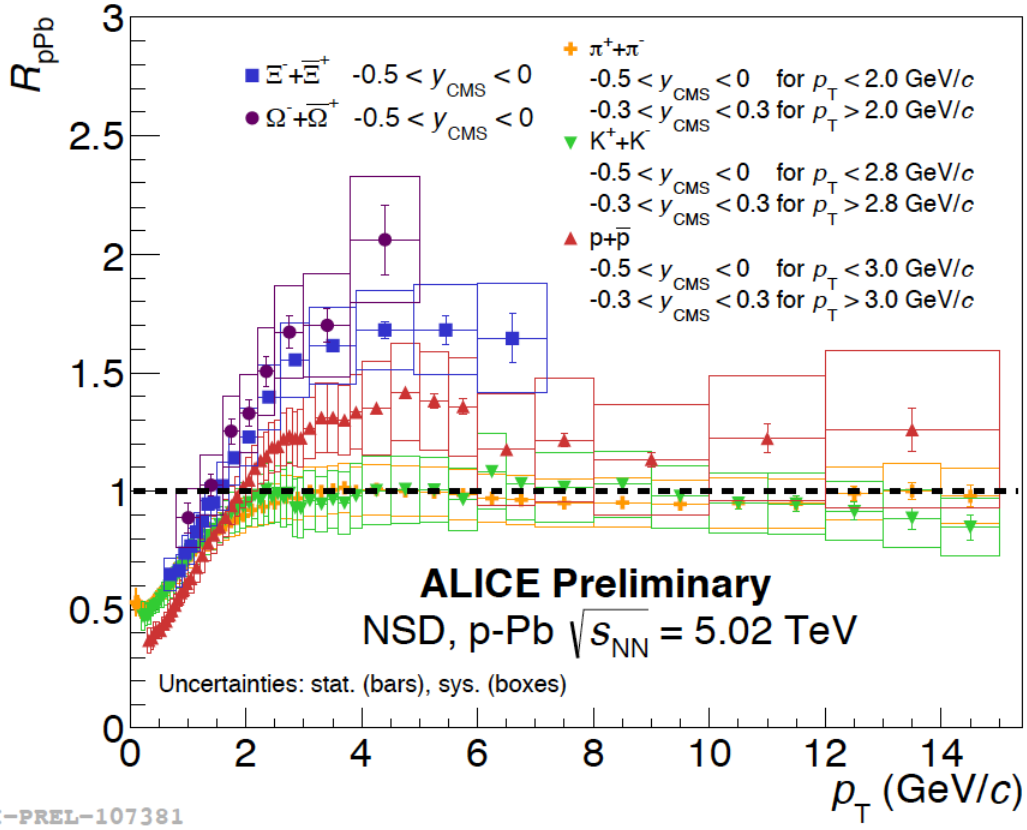




p-Pb nuclear modification factor

- π, K, p R_{pPb} at high-p_T consistent with unity

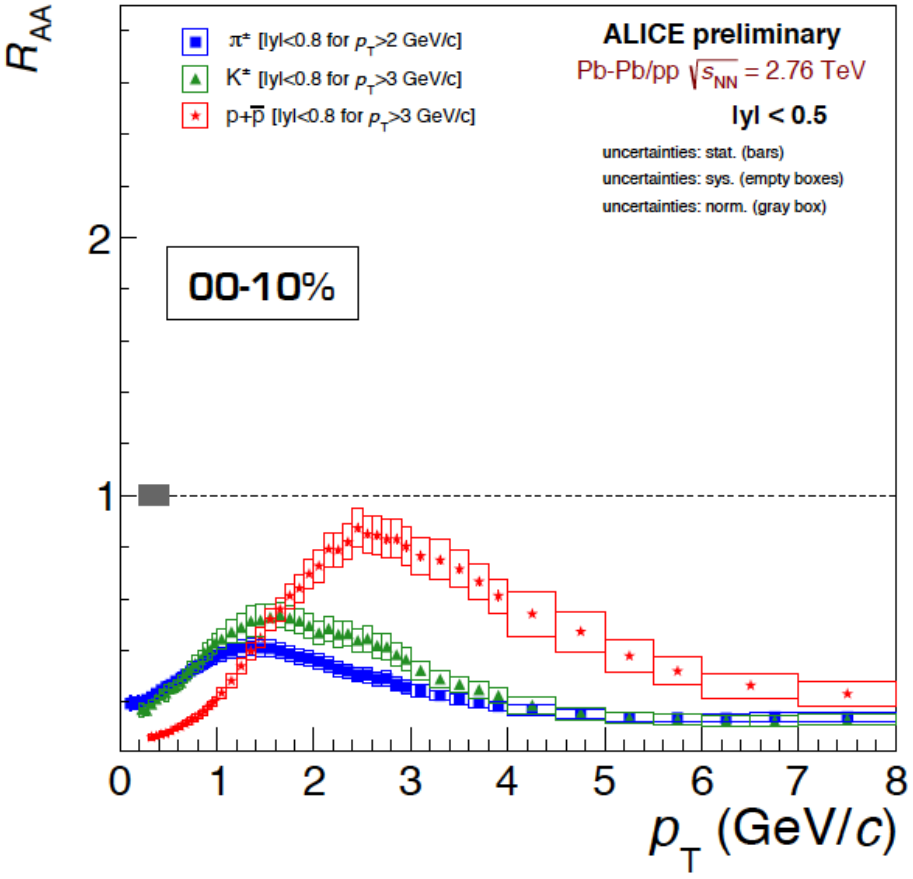
  → suppression in Pb-Pb a final state effect



- p, Ξ, Ω show enhancement at intermediate p_T
- mass ordering

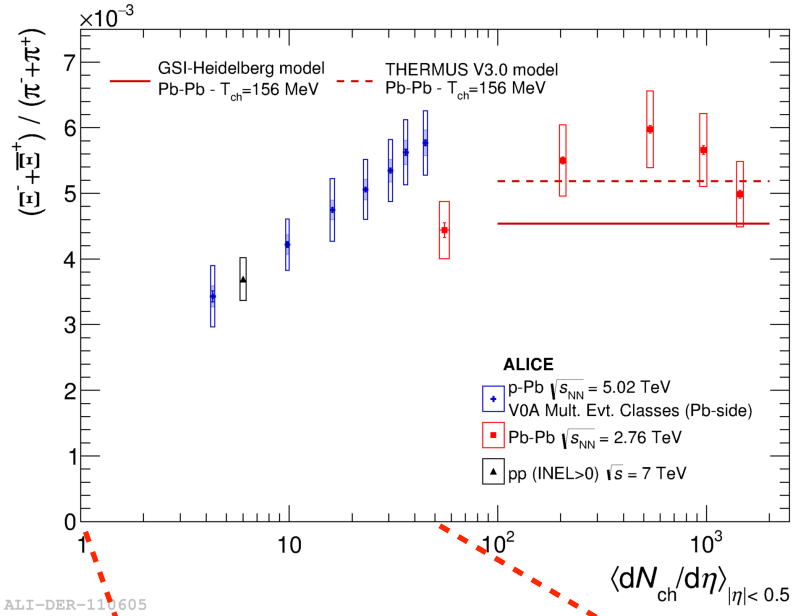
Nuclear modification factor

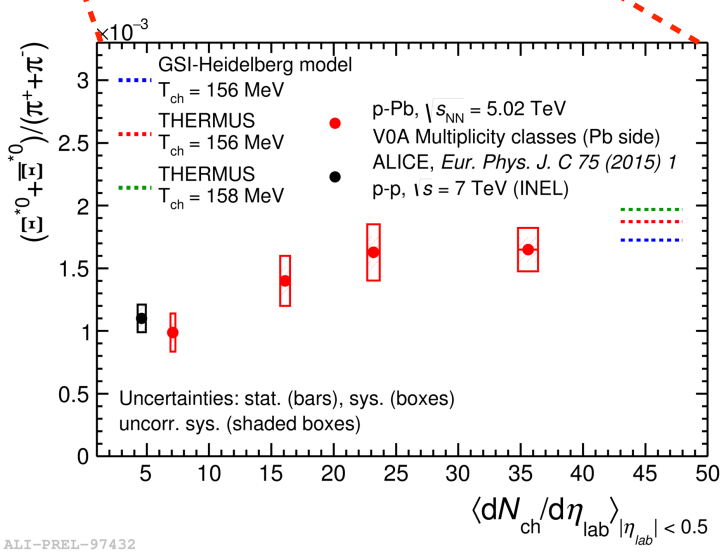
- R_{AA} < 1: at high p_T, strong suppression, jet quenching



$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{d^2N_{ch}/d\eta\, dp_T}{d^2\sigma^{pp}_{ch}/d\eta\, dp_T}$$

Multiplicity dependence: p-Pb





- in p-Pb, both Ξ / π and Ω / π exhibit strong rise
  - Ξ / π reaches PbPb saturation value
  - Ω / π up to 60-80%
- Ω stronger multiplicity dependence

- $\Xi(1530^0)$: strangeness content as Ξ
  - $m_{\Xi} < m_{\Xi^*} < m_{\Omega}$
  - increase of Ξ^* / π similar to Ξ / π

→ multiplicity dependence driven by strangeness, not mass

Outlook: hyperons in pp

- first measurement of hyperon production in pp minimum bias collisions at 13 TeV
- hint for an increase of hyperon-to-pion ratio with $\sqrt{s}$