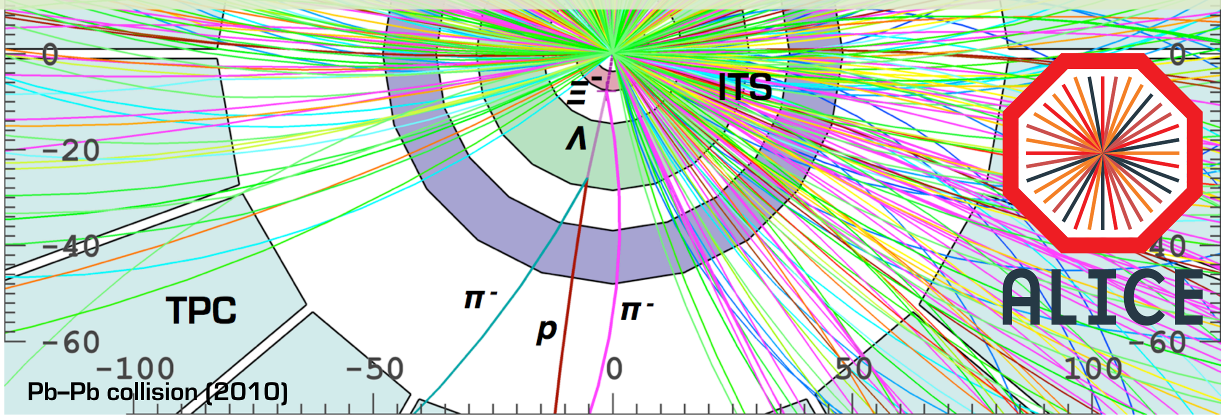
HOT QUARKS '14

Las Negras – Cabo de Gata Natural Park,
Andalucia, Spain
September 21-28 2014

Multi-strange baryon production in pp, p–Pb and Pb–Pb collisions measured with ALICE



Domenico Colella
University and INFN, Bari (Italy)
on behalf of the ALICE Collaboration

INFN Istituto Nazionale di Fisica Nucleare

SIGILLUM UNIVERSITATIS BARENSIS MCMXXV

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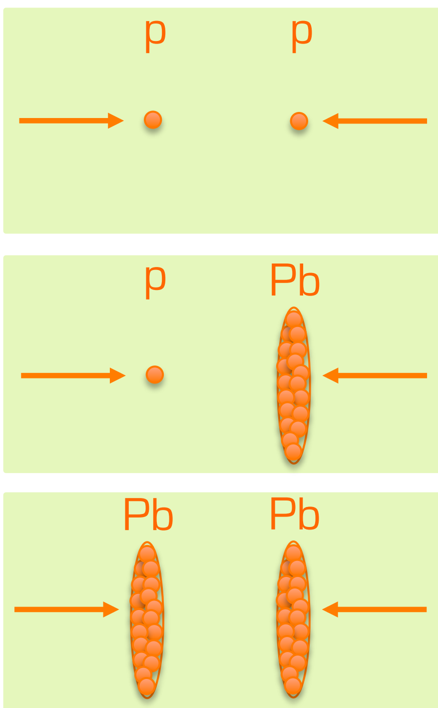
Measuring multi-strange baryons

Physics motivation

- Why measure (multi-)strange hyperons
  - ✓ no net strangeness content in the colliding system
  - ✓ abundantly produced wrt heavier particles
  - ✓ small hadronic cross-section → information on the early stages of the system evolution in Pb–Pb collisions



pp: *(benchmark for heavy-ion physics)*
- ✓ Particle production mechanisms at low (soft QCD) and high (pQCD) transverse momentum.
- ✓ Tuning of MC.

p–Pb: *(reference as intermediate between pp and Pb–Pb)*
- ✓ Initial state effects (shadowing/gluon saturation)
- ✓ Indications of final state effects and collectivity

Pb–Pb: Thermal production, flow, strangeness enhancement, recombination, jet quenching and fragmentation in the Quark Gluon Plasma

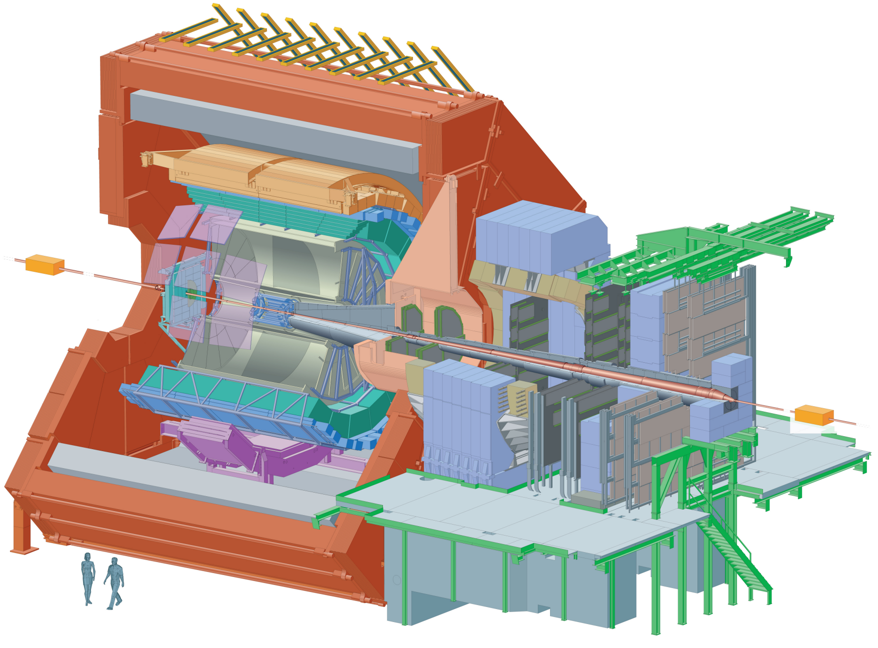
Measuring multi-strange baryons

Multi-strange baryon detection

Detectors used in this study:

i. **TPC:** Tracking, Vertexing, PID (dE/dx)
ii. **ITS:** Tracking, Vertexing
iii. **VZERO:** Trigger, Multiplicity/Centrality classes

A Large **I**on **C**ollider **E**xperiment at the LHC



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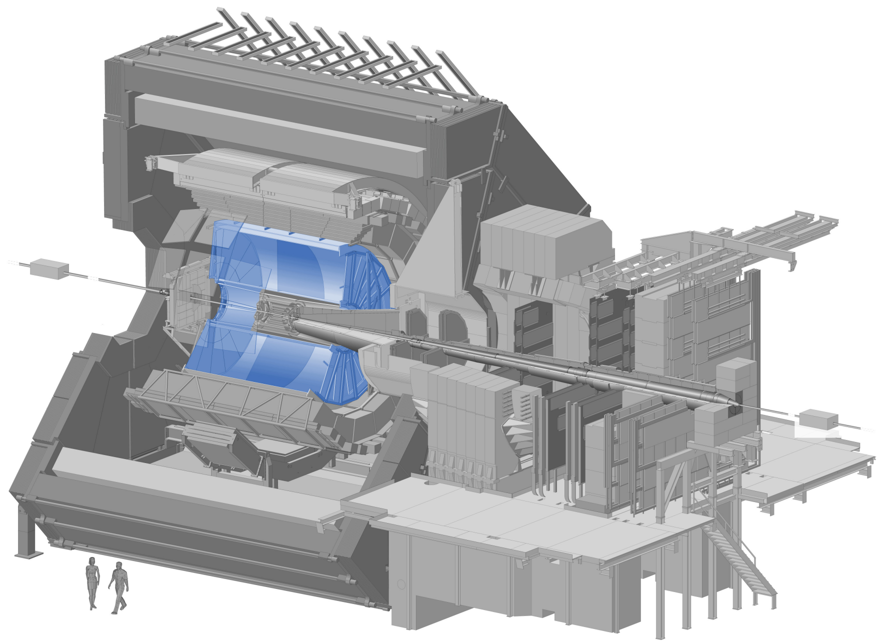

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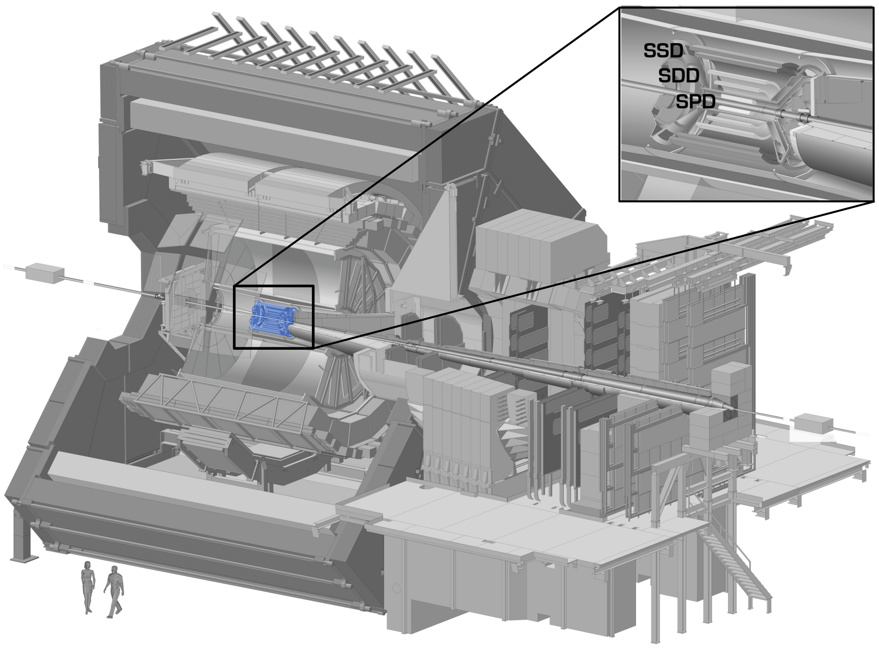

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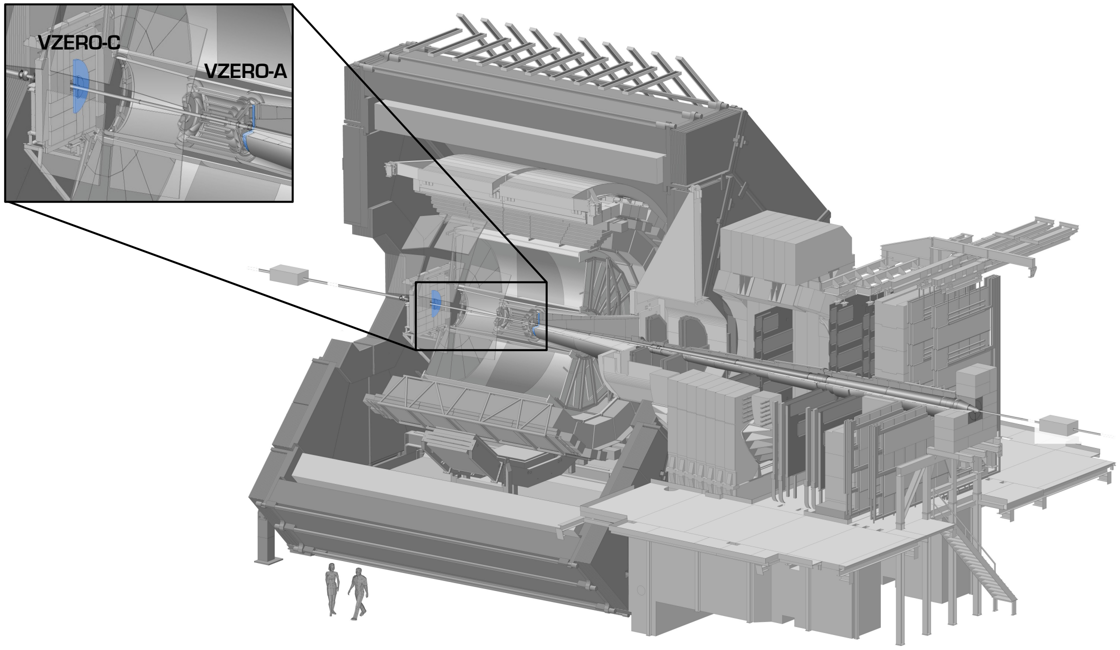

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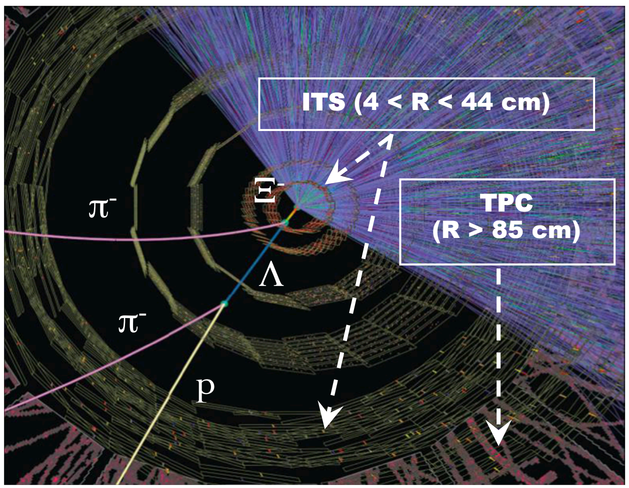


Pb-Pb 5.5 TeV Hijing MC event, not all tracks shown; ALICE Physics Performance Report, Vol II, J Phys. G 32, 1295, (2006).

$$\Xi^-(dss) \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^- \quad (B.R.\ 63.9\%)$$
$$\overline{\Xi}^+(\overline{dss}) \rightarrow \overline{\Lambda}\pi^+ \rightarrow \overline{p}\pi^+\pi^+ \quad (B.R.\ 63.9\%)$$
$$\Omega^-(sss) \rightarrow \Lambda K^- \rightarrow p\pi^- K^- \quad (B.R.\ 43.3\%)$$
$$\overline{\Omega}^+(\overline{sss}) \rightarrow \overline{\Lambda} K^+ \rightarrow \overline{p}\pi^+ K^+ \quad (B.R.\ 43.3\%)$$

Multi-strange baryons in ALICE are reconstructed via their weak (cascade) decay topology:

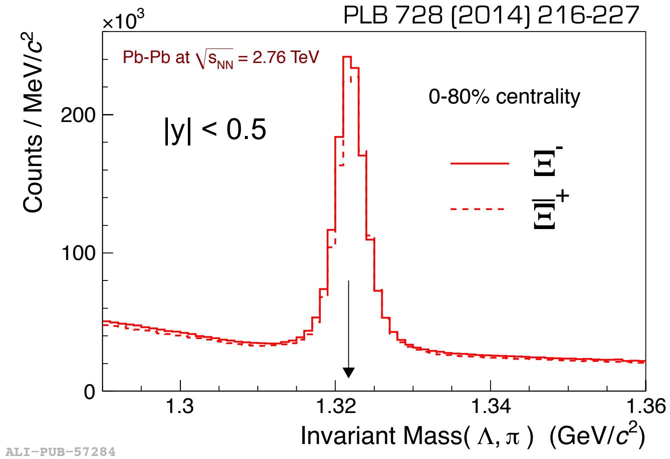
① charged tracks reconstructed in the tracking system (ITS + TPC)

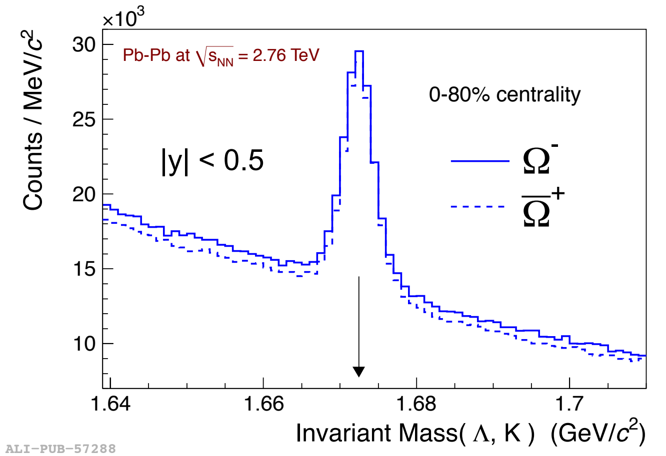
② specific ionization (in the TPC) used to identify daughters

③ cascade candidates obtained by combining reconstructed tracks and applying cuts on geometry and kinematics

Measuring multi-strange baryons

Multi-strange baryon detection





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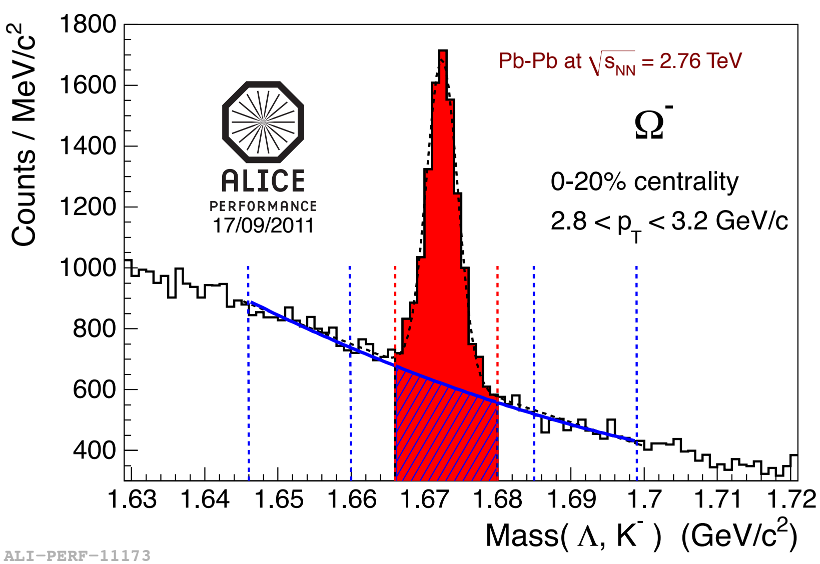
Measuring multi-strange baryons

Multi-strange baryon detection

Yields extraction in different transverse momentum bins via invariant mass analysis:



Signal = Summed bin count – Integral of background fit function

$$\Xi^-(dss) \to \Lambda\pi^- \to p\pi^-\pi^- \ (B.R.\ 63.9\%)$$
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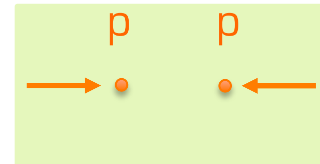
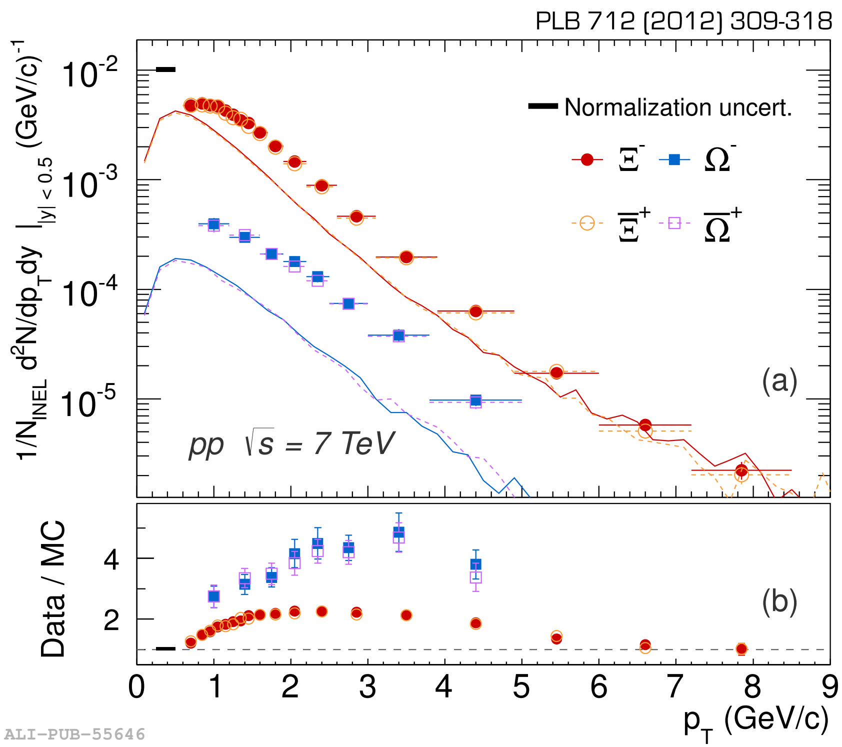
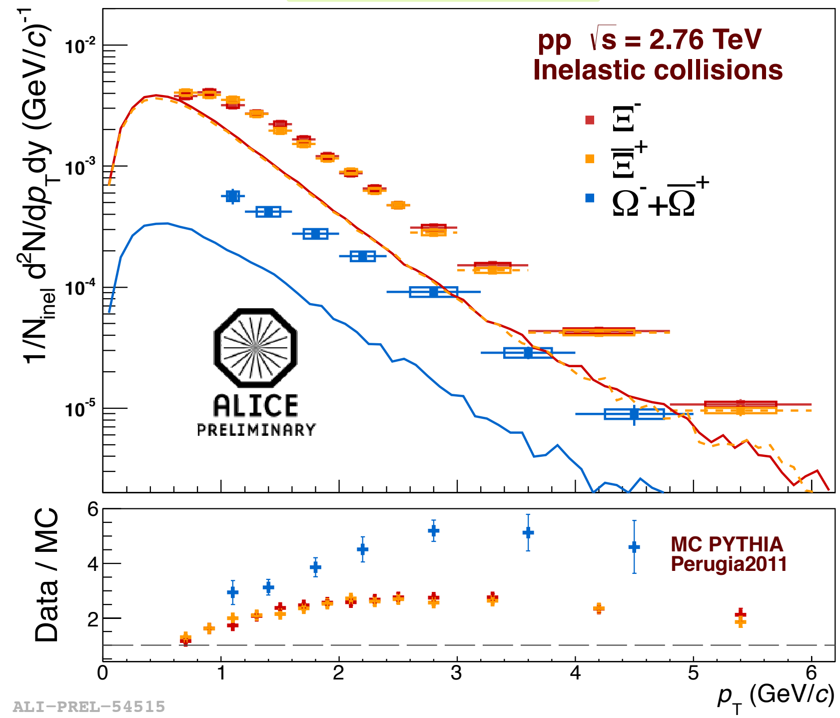
Results

Transverse momentum spectra





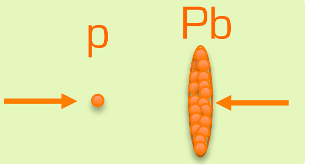


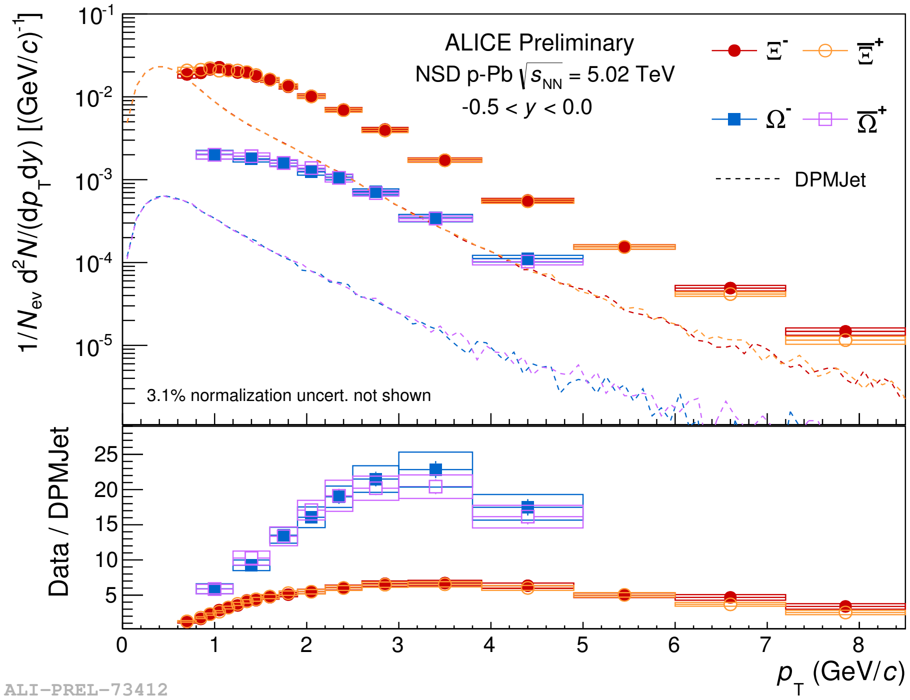
- @7 TeV: precise cascade measurements with p_T reach of 8.5 (5) GeV/c for Ξ (Ω)
- @2.76TeV: crucial results as baseline for Pb–Pb (eg. for measuring R_{AA})
- Antiparticle/Particle ≈ 1 within uncertainties
- Comparison with PYTHIA Perugia-2011[1]: deviations in soft region (increasing with strangeness) and hints of a possible agreement beyond 6 GeV/c

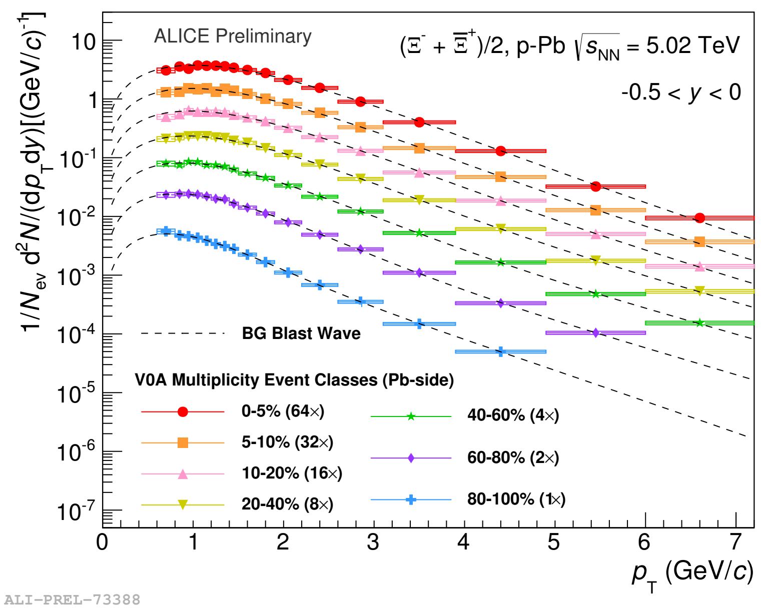
[1] Phys. Rev. D 82, 074018 (2010)

Results

Transverse momentum spectra





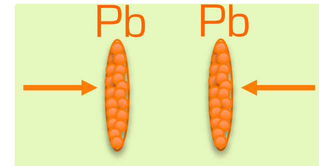


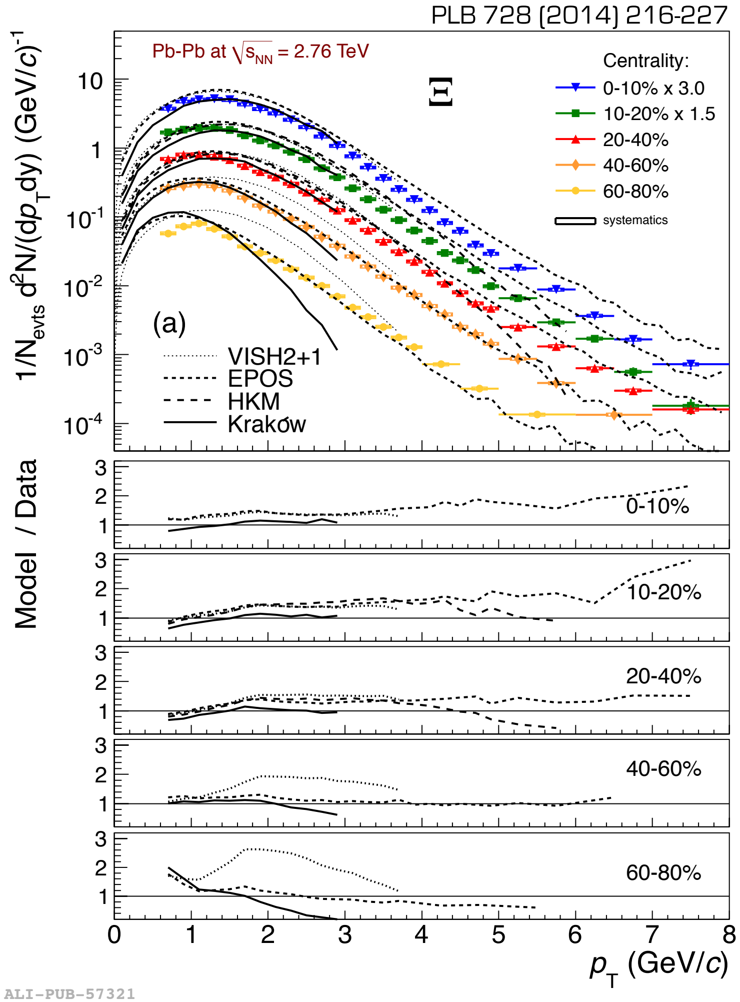
- p_T reach of 8.5 (5) GeV/c
- Antiparticle/Particle ≈ 1 within uncertainties
- Comparison with DPMJet[1]: reproduces $dN_{ch}/d\eta$ satisfactorily, but fails to do so for Ξ and Ω by a factor up to 7 and 25, respectively
- Multi-strange particles also measured in 7 multiplicity classes

[1]: arXiV:hep-ph/0012252

Results

Transverse momentum spectra



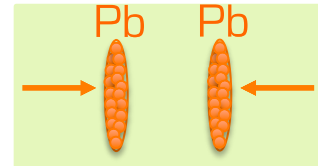


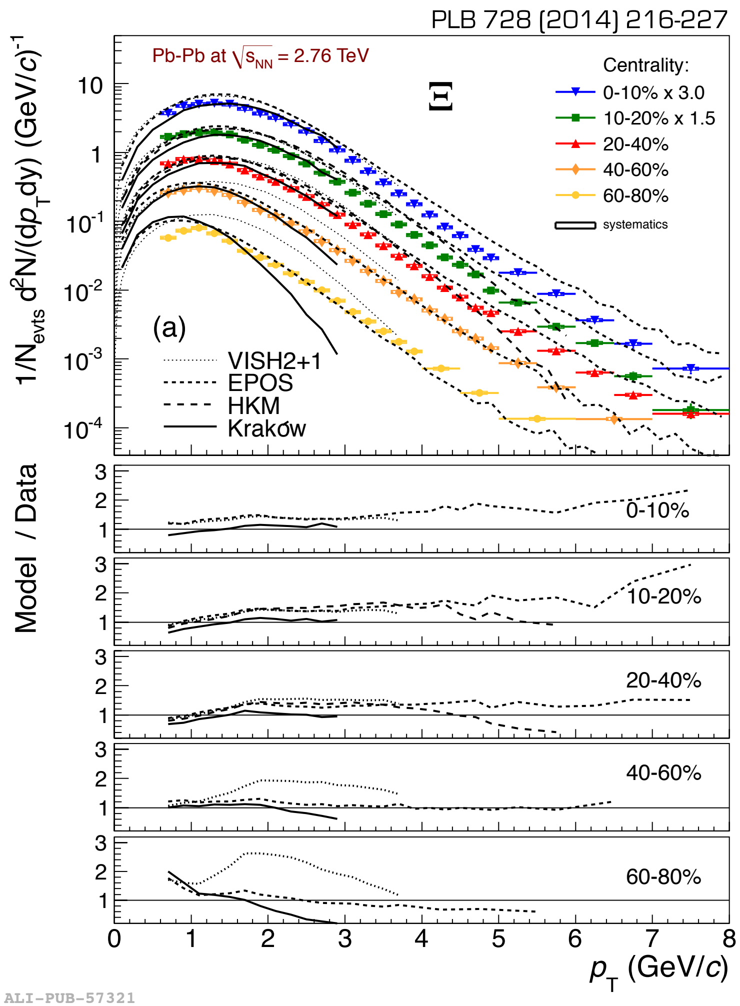
- p_T reach: 8 (Ξ) and 7 GeV/c (Ω) in 10% most central Pb–Pb collisions
- Antiparticle/Particle ≈ 1 within uncertainties
- Comparison with models
  - VISH2+1[1]: viscous hydrodynamic model
  - HKM[2]: ideal hydro model, with hadron cascade (UrQMD)
  - Kraków[3]: hydro + bulk viscous corrections
  - EPOS[4]: hydro + UrQMD, bulk + jets
- Results
  - Kraków model provides a good description for both yields and shapes ($p_T < 3$ GeV/c)
  - EPOS gives the most successful description of spectra shape in a wider p_T range

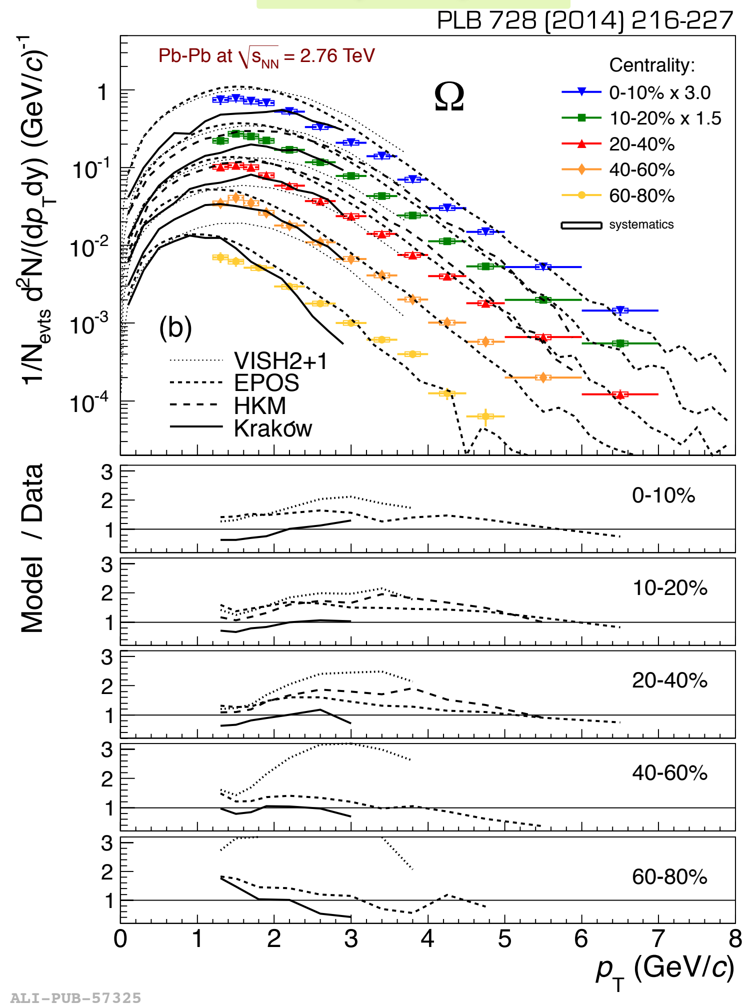
[1] Phys. Rev. C 84, 044903 (2011)
[2] J. Phys. G 38, 124059 (2011), 1204.5351 [nucl-th] (2012)
[3] Phys. Rev. C 85, 034901 (2012), Acta Phys. Pol. B 43, 4, 689 (2012)
[4] Phys. Rev. C 85, 064907 (2012), 1204.1394 [nucl-th], (2012) 1205.3379 [nucl-th] (2012)

Results

Transverse momentum spectra







Results

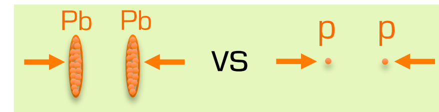
Strangeness enhancement

$$E = \frac{Yield_{PbPb} / < N_{part} >}{Yield_{pp} / 2}$$

- Among the first probes of Quark Gluon Plasma [Phys. Rev. Lett. **48**, 1066 (1982)]
- Found to qualitatively match predictions at SPS and RHIC
  - Increasing with strangeness content of the particle
  - Increasing with collision centrality
  - Decreasing with increasing centre-of-mass energy

Results

Strangeness enhancement



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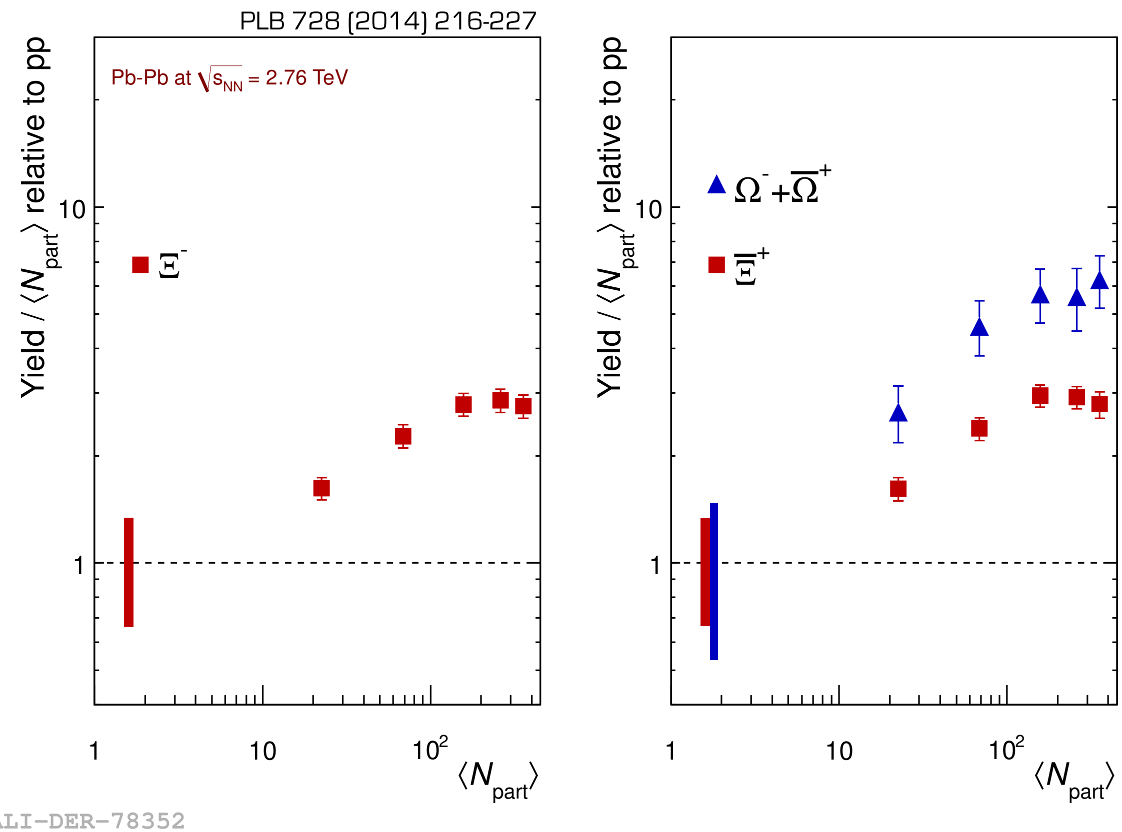

- Hierarchy based on strangeness content

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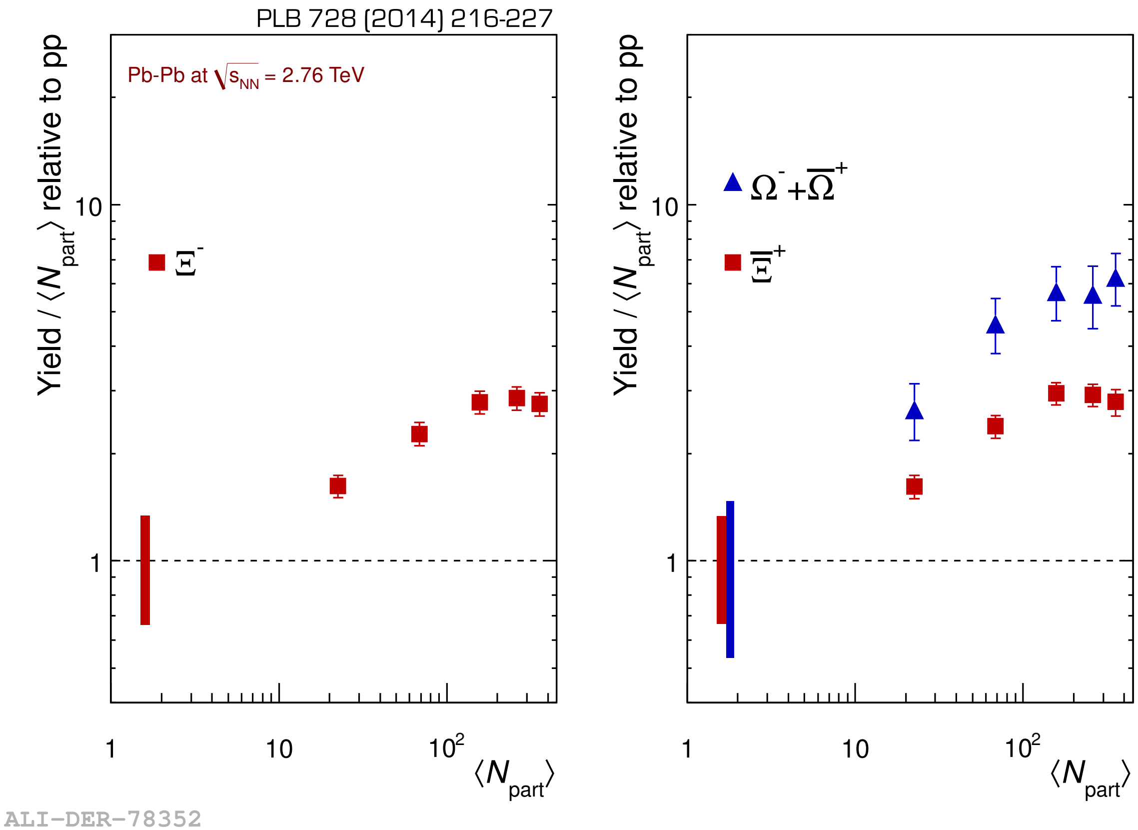
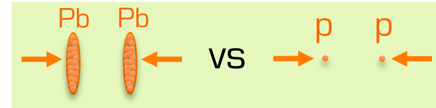


- Hierarchy based on strangeness content
- Magnitude increases when going from peripheral to most central collisions

Results

Strangeness enhancement



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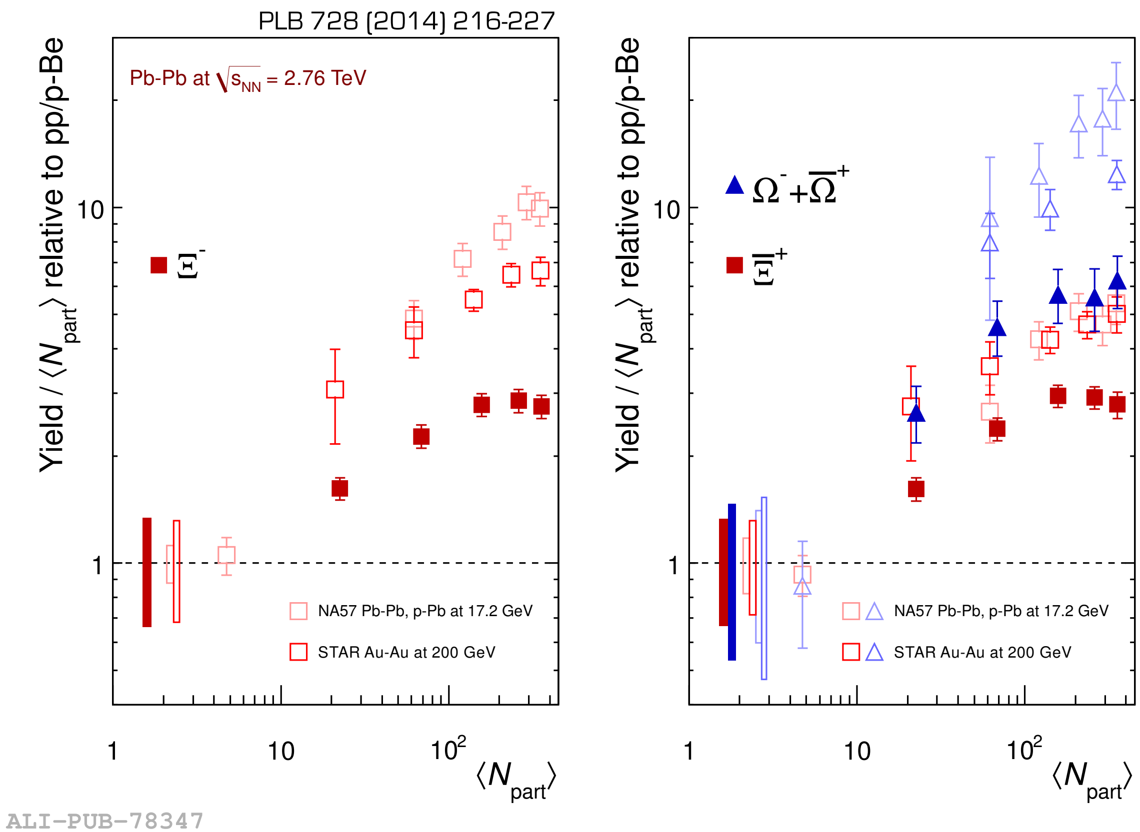

- Hierarchy based on strangeness content
- Magnitude increases when going from peripheral to most central collisions
- Decreasing trend with energy as observed at SPS energies and from SPS to RHIC

NA57: J. Phys. G 32, 427 (2006),
J. Phys. G 37, 045105 (2010)
STAR: Phys. Rev. C 77, 044908 (2008)

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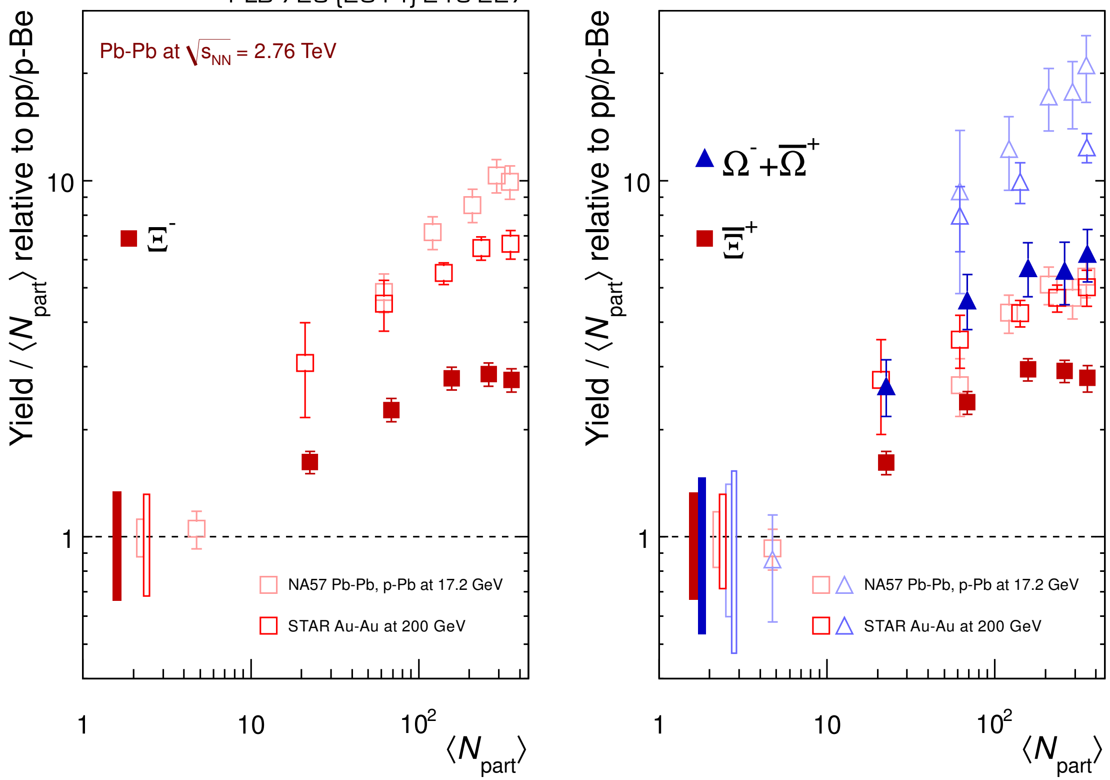
Strangeness enhancement

$$E = \frac{Yield_{PbPb} / < N_{part} >}{Yield_{pp} / 2}$$

PLB 728 (2014) 216-227



ALI-PUB-78347

- Hierarchy based on strangeness content
- Magnitude increases when going from peripheral to most central collisions
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<u>Question</u>

Is the N_{part} scaling the right assumption?

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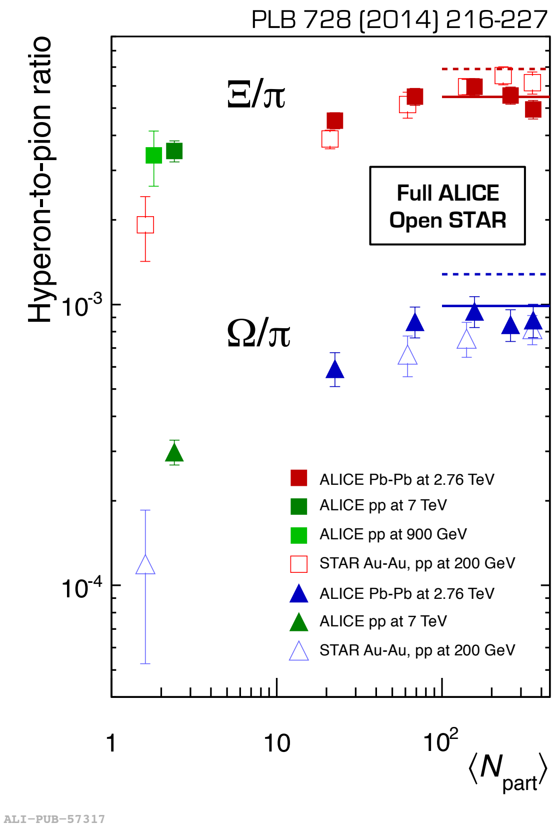

- Hyperon to pion ratios in Pb–Pb:

ALICE: Phys. Lett. B 712, 309 (2012)
1303.0737v1 [hep-ex]
Eur. Phys. J. C 71, 1594 (2011)
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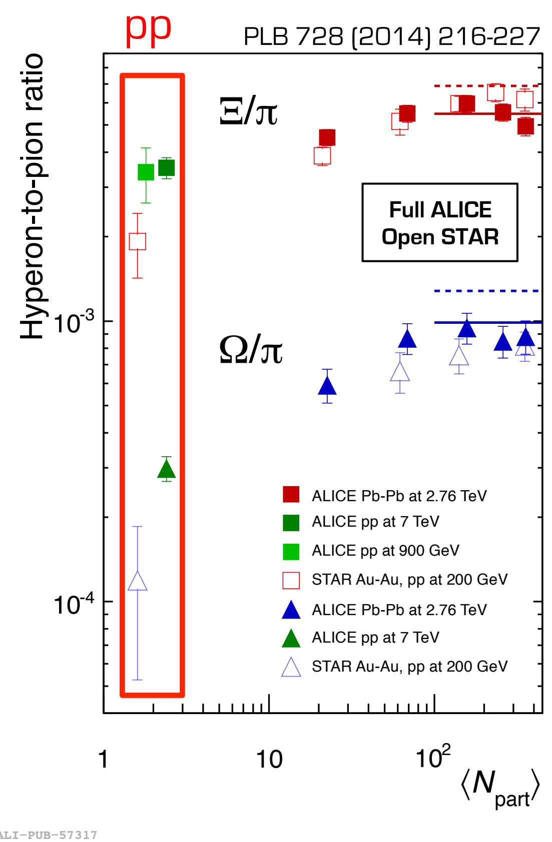

- Hyperon to pion ratios in Pb–Pb:
  - Relative production of strangeness in pp increases faster with energy than in A–A going from RHIC to LHC
    (removal of canonical suppression)

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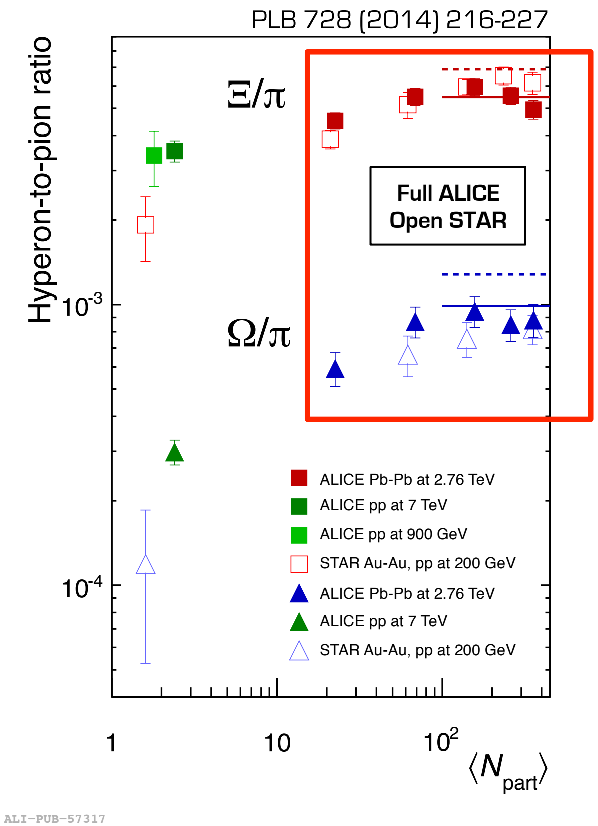

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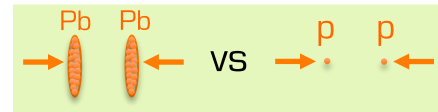

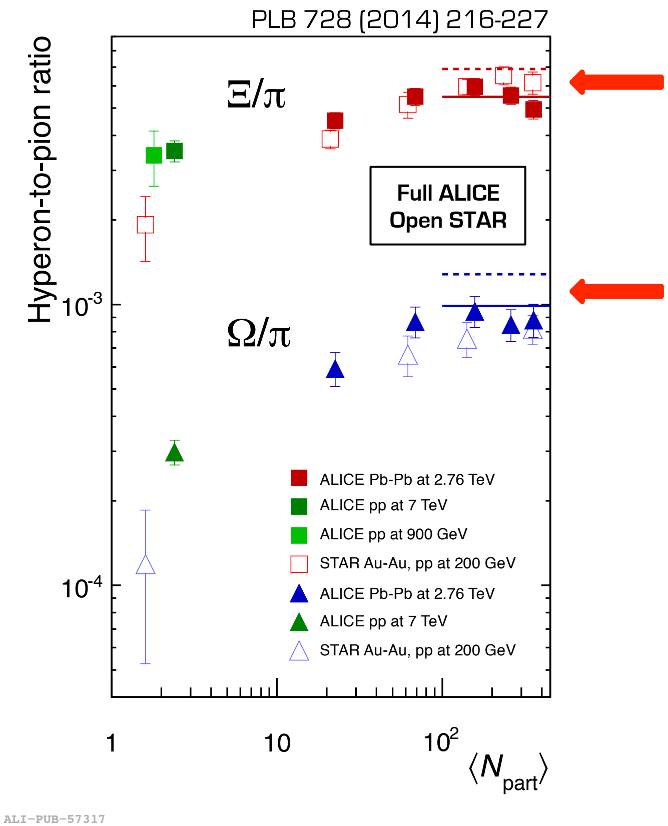

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  - Ratios in Pb–Pb at LHC for $N_{part} > 150$ match predictions from thermal models based on a grand canonical approach
    - — GSI model [1]: T_{ch} = 164 MeV
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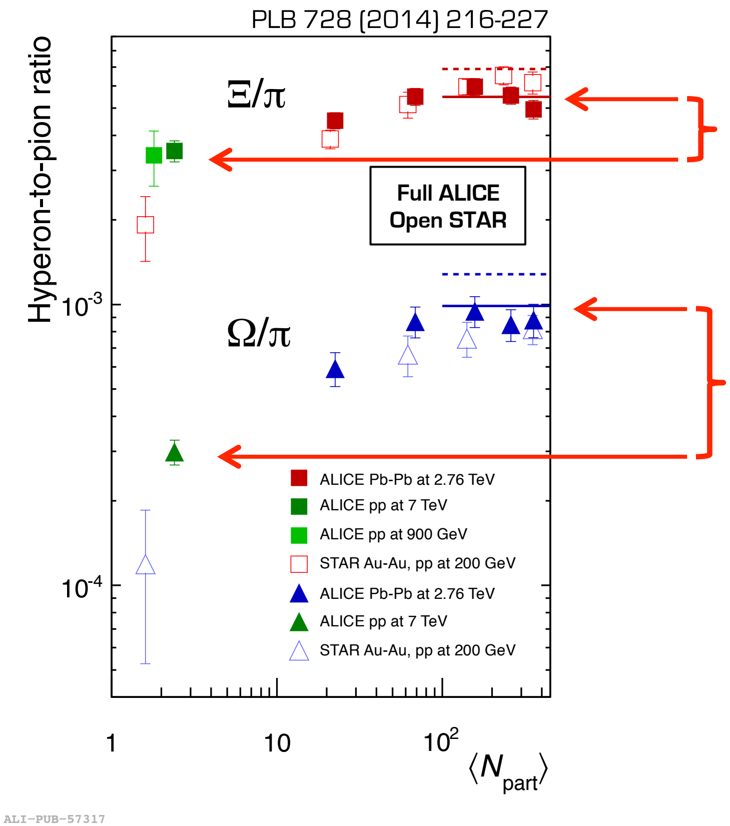
[1]: Andronic, A. et al. Phys.Lett. B673 (2009) 142-145, Erratum-ibid. B678 (2009) 516
[2]: Wheaton, S. et al. Comput.Phys.Commun. 180 (2009) 84-106

Results

Strangeness enhancement

ALICE



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    - — GSI model [1]: T_{ch} = 164 MeV
    - … THERMUS model [2]: T_{ch} = 170 MeV
  - Increase of Ξ/π and Ω/π from pp to Pb–Pb: almost half of the Ξ and Ω enhancements as defined by the participant-scaled yields (E, see previous slides)

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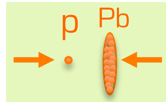
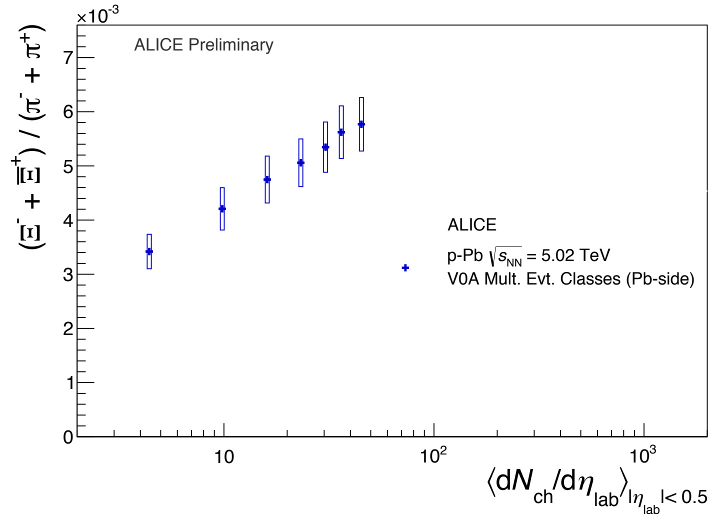
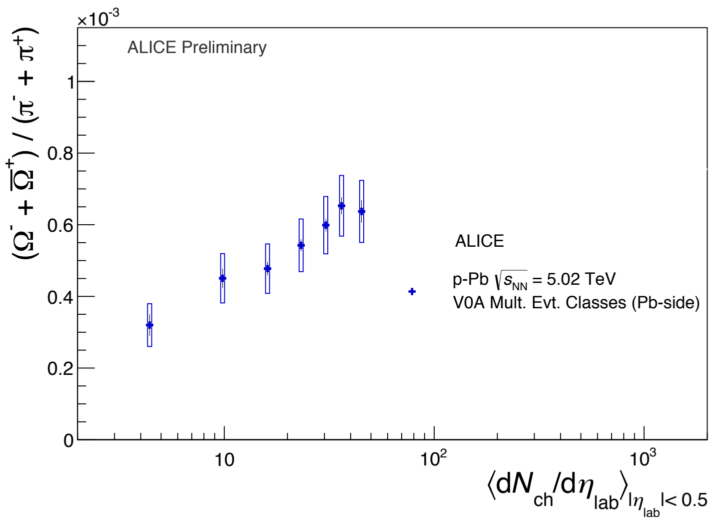




- Hyperon to pion ratios in p–Pb:
  - Multi-strange baryon production with respect to pions increases for larger $dN_{ch}/d\eta$



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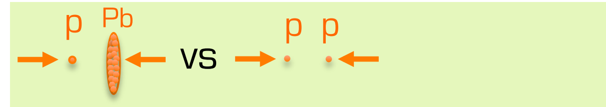
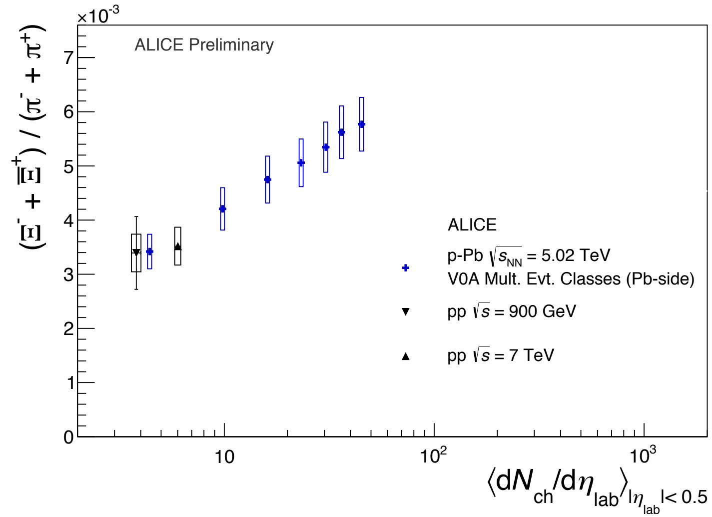
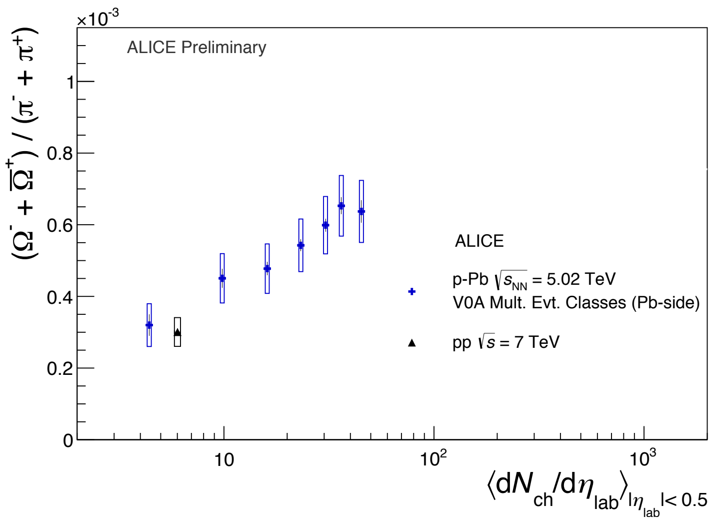


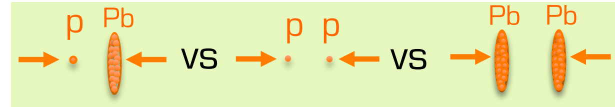


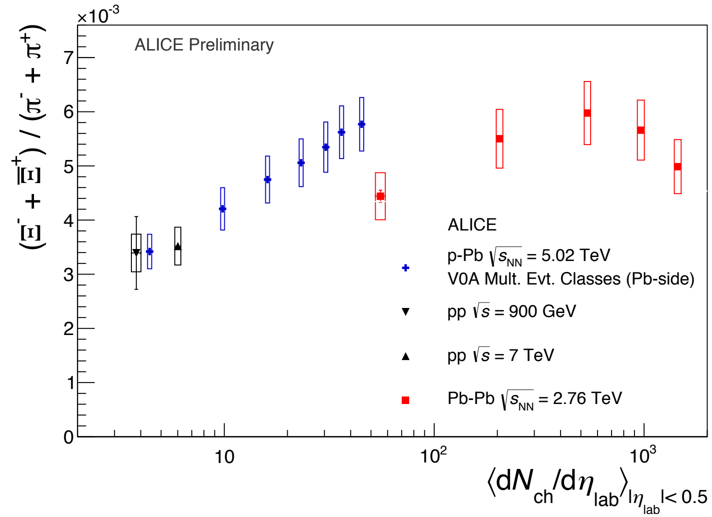


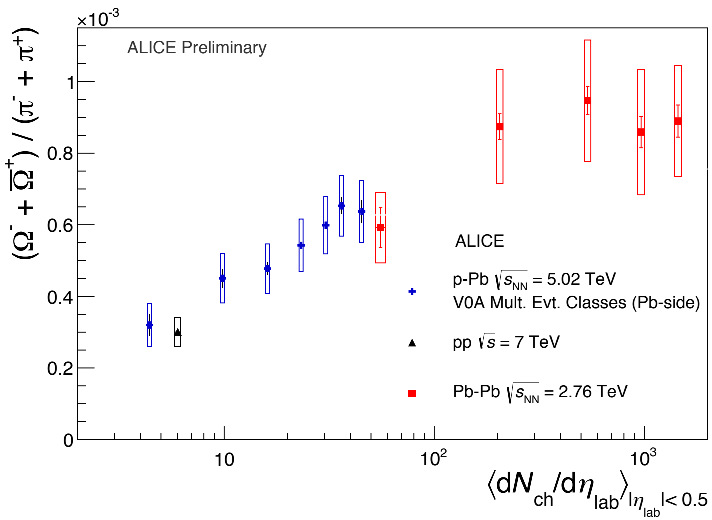
- Hyperon to pion ratios in p–Pb:
  - Multi-strange baryon production with respect to pions increases for larger $dN_{ch}/d\eta$
  - Lowest multiplicity ratios are compatible with pp values

Results

Strangeness enhancement



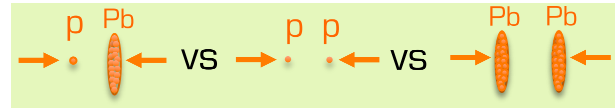


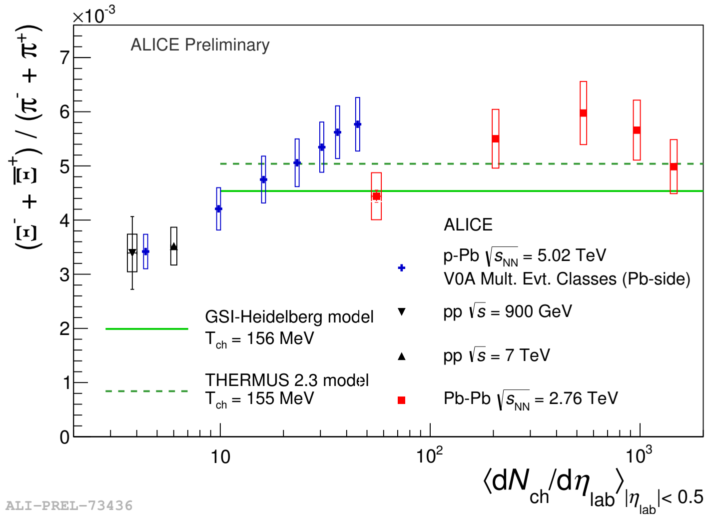


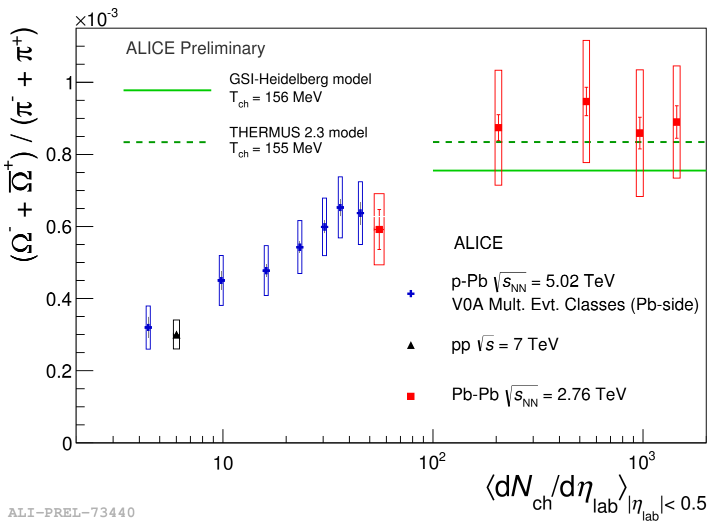
- Hyperon to pion ratios in p–Pb:
  - Multi-strange baryon production with respect to pions increases for larger $dN_{ch}/d\eta$
  - Lowest multiplicity ratios are compatible with pp values
  - Compared to Pb–Pb:
    - ✓ $(\Xi^-+\Xi^+)/(\pi^++\pi^-)$ reaches values comparable to central Pb–Pb
    - ✓ $(\Omega^-+\Omega^+)/(\pi^++\pi^-)$ reaches values close to results from peripheral Pb–Pb

Results

Strangeness enhancement







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  - Comparison with thermal models:
    - — GSI model [1]: T_{ch} = 156 MeV
    - ... THERMUS model [2]: T_{ch} = 155 MeV
    - ✓ $(\Xi^- + \Xi^+)/(\pi^+ + \pi^-)$ values are comparable to thermal model predictions
    - ✓ $(\Omega^- + \Omega^+)/(\pi^+ + \pi^-)$ values do not reach the equilibrium limits

[1]: Andronic, A. et al. Phys.Lett. B673 (2009) 142-145, Erratum-ibid. B678 (2009) 516
[2]: Wheaton, S. et al. Comput.Phys.Commun. 180 (2009) 84-106

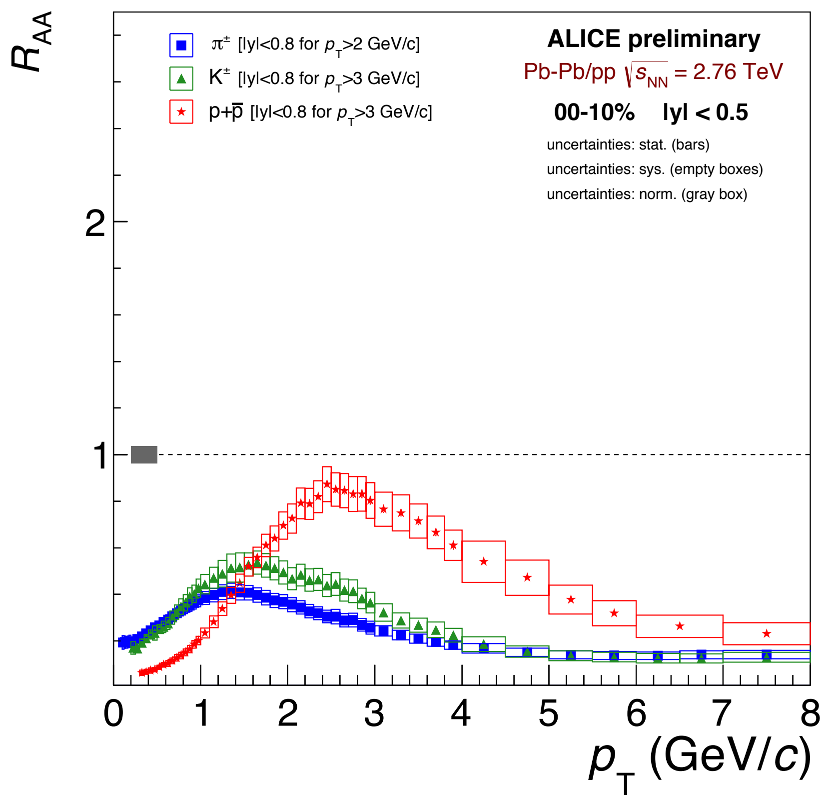
Results

Nuclear modification factor

- π
- K
- p

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{(d^2N/dydp_T)_{A-A}}{(d^2\sigma_{INEL}/dydp_T)_{pp}}$$

no nuclear modification → R_{AA} **= 1**



- Large suppression for π, K and p that at high p_T does not depend on the mass of the particle

ALICE: arXiv:1401.1250v2

Results

Nuclear modification factor

- π
- Ξ
- K
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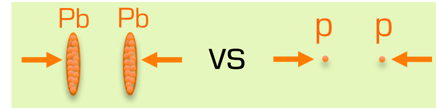

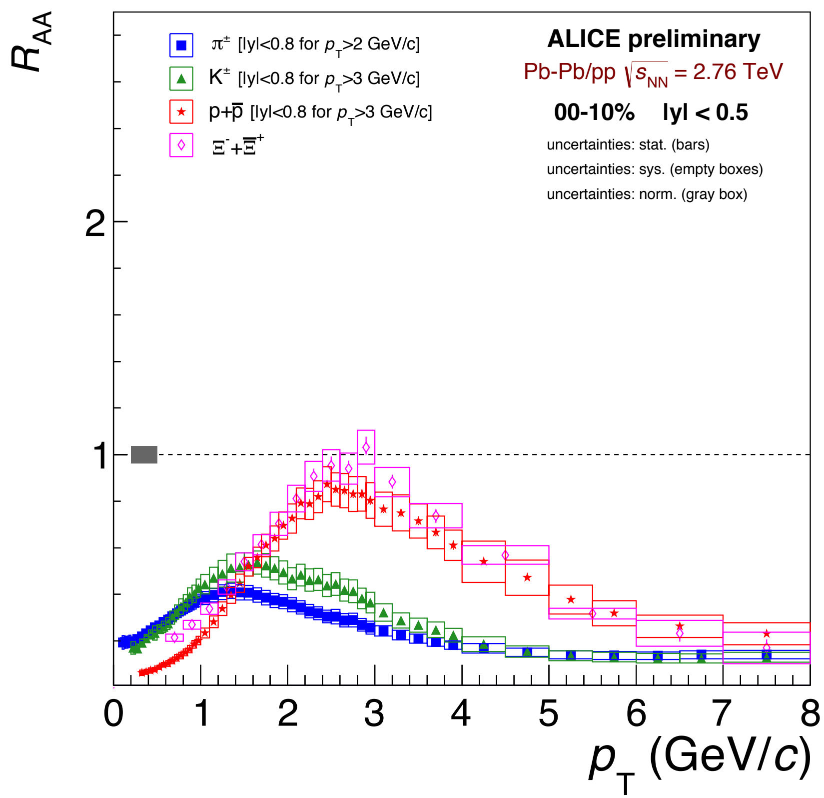

- Large suppression for π, K and p that at high p_T does not depend on the mass of the particle
- Behavior of Ξ similar to that of p
- Mass ordering at mid-p_T

ALICE: arXiv:1401.1250v2

Results

Nuclear modification factor

■ π ■ K ■ p ■ Ξ ■ Ω

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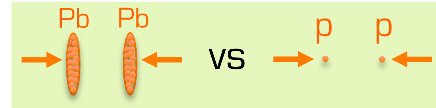

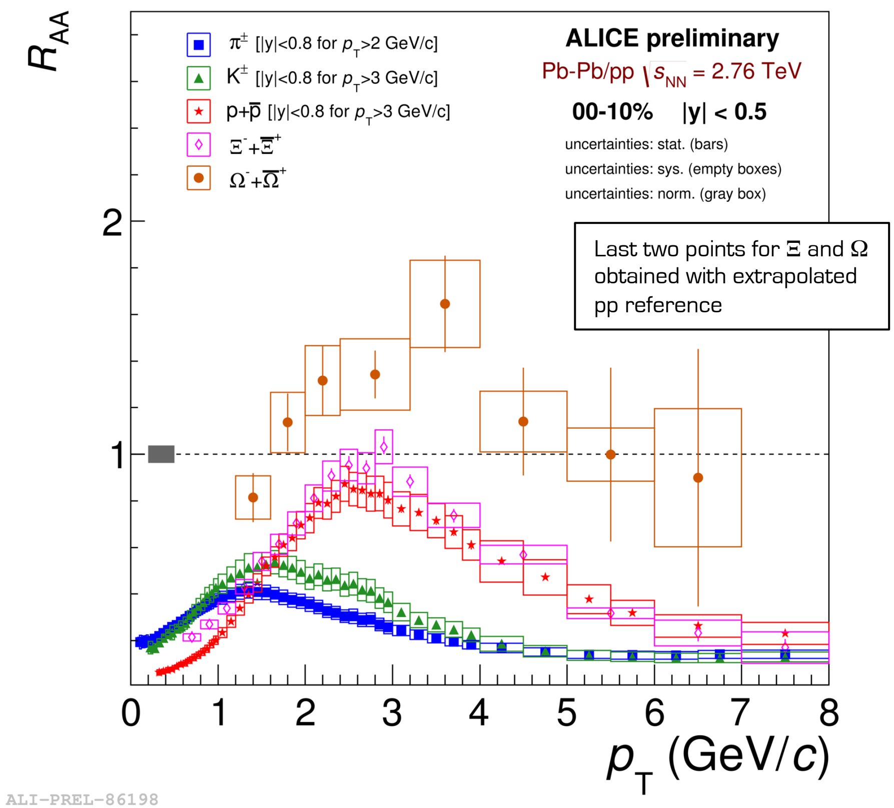

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Results

Nuclear modification factor

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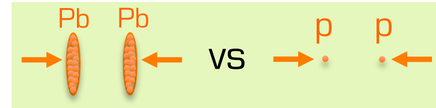

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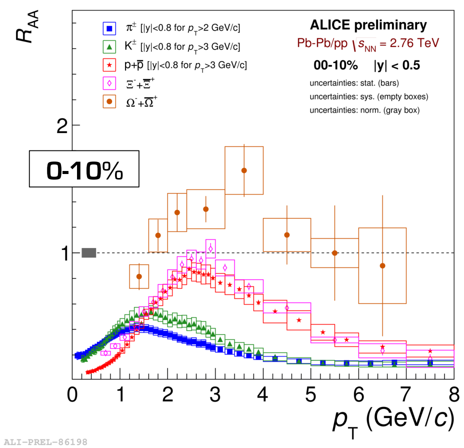
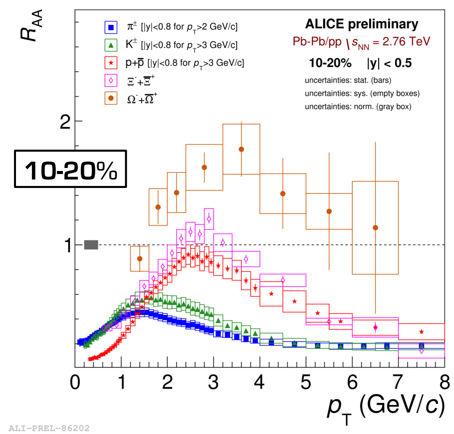
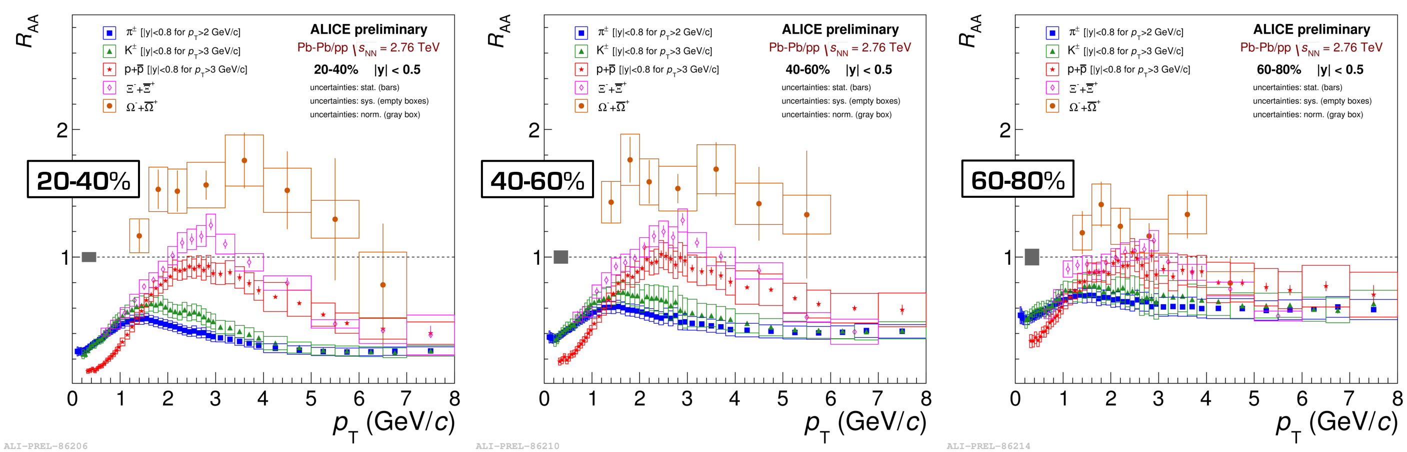
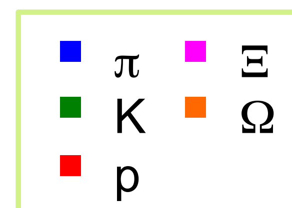
- R_{AA} vs centrality: similar trend than for other particles





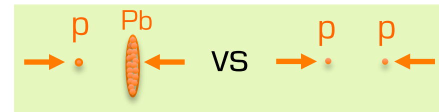




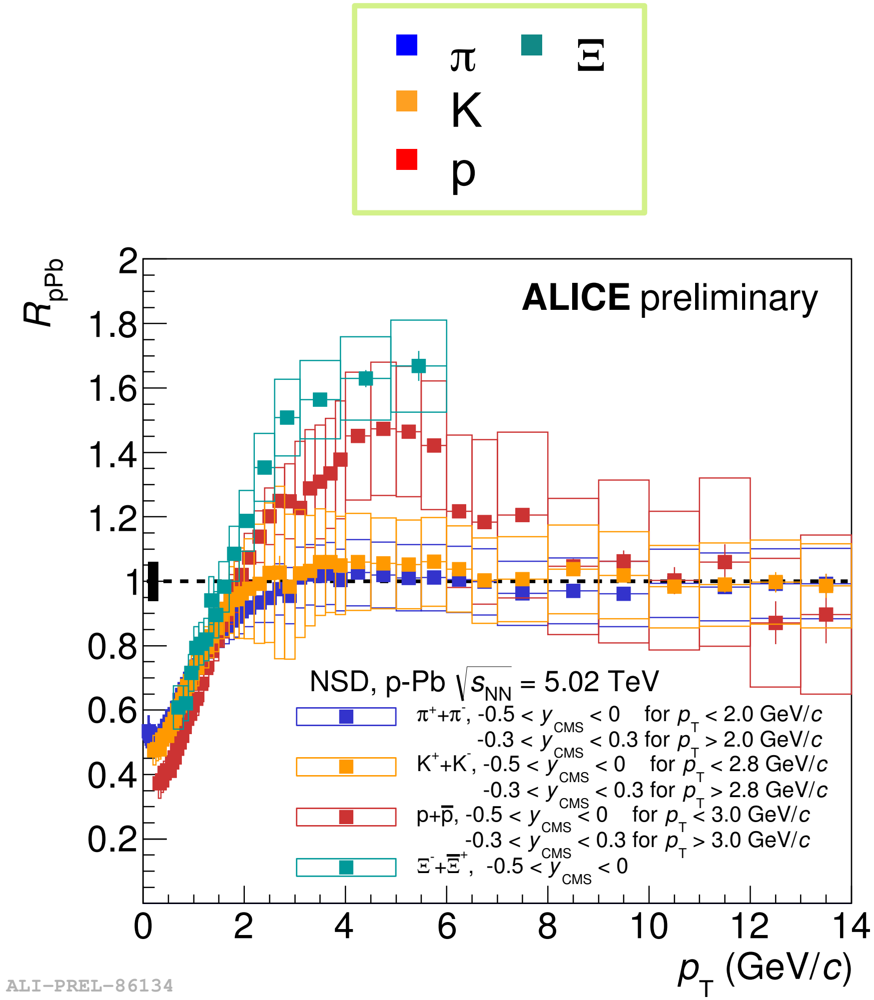
ALICE: arXiv:1401.1250v2

Results

Nuclear modification factor



$$R_{pA} = \frac{1}{\langle T_{pA} \rangle} \frac{(d^2N/dydp_T)_{p-A}}{(d^2\sigma_{INEL}/dydp_T)_{pp}}$$



- Comparing π, K, p and Ξ:
  - π and K flat
  - π, K, p and Ξ mass ordering in Cronin-region (2-8 GeV/c)
  - Strong enhancement for p and Ξ
- R_{pPb} for all particles consistent with unity at large p_T

See talk by A. Knospe for the ϕ

ALICE: arXiv:1401.1250v2

Summary

- Compare spectra with models
  - pp: PYTHIA Perugia2011 tune underestimates the multi-strange spectra, both at $\sqrt{s}$ = 7 and 2.76 TeV
  - p–Pb: DPMjet unable to predict cascade yields by large factors
  - Pb–Pb: Best agreement with the Krakow and EPOS hydrodynamical models

- Strangeness enhancement
  - Basic features as at lower energies
  - Weaker at LHC than at RHIC, controlled by the behavior of strangeness production in pp
  - Hyperon-to-pion ratios in p–Pb bridge pp and Pb–Pb and grow with charged particle multiplicity
  - Strangeness enhancement visible also in p–Pb

- Nuclear modification factors
  - Ξ R_{AA} behaves similarly to the other particles at high p_T
  - Ω R_{AA} strongly affected by strangeness enhancement
  - mass ordering at mid-p_T (flow), no mass dependence at high p_T
  - reduced suppression going from central to peripheral collisions
  - R_{pPb} shows no deviation from N_{coll} at high p_T ($R_{pPb} \approx 1$)

THANK YOU!

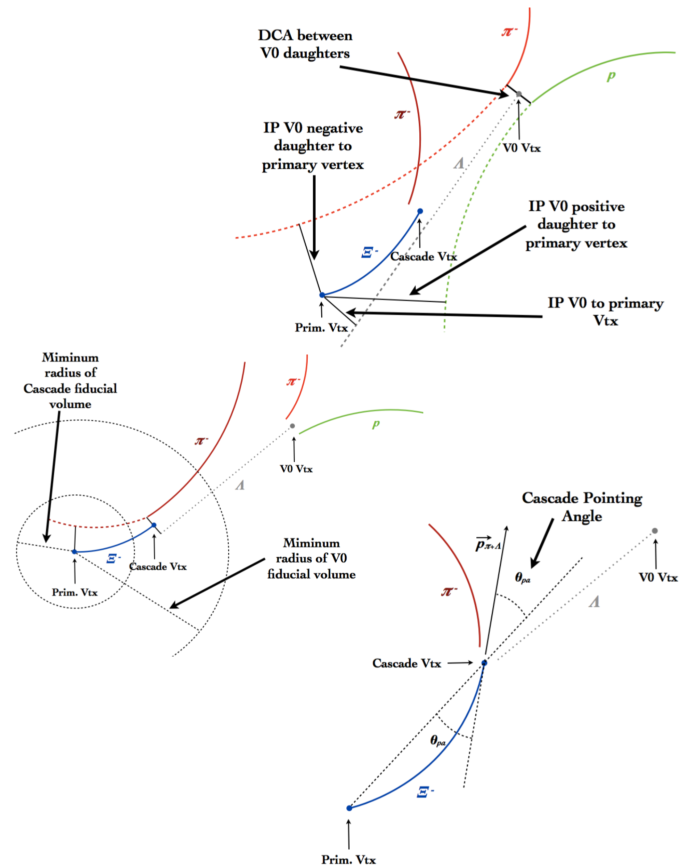
Backup

Backup

Topological cuts in Pb–Pb and pp analysis

Cuts for cascades	Pb–Pb Ξ (Ω)	pp@2.76TeV Ξ (Ω)	pp@7TeV Ξ(Ω)
Min Allowed V0 ip (cm)	0.1	0.05(0.01)	0.07
Window around the Λ mass (MeV/c^2)	0.005	0.006(0.008)	1.110 – 1.122
Min allowed bachelor ip (cm)	0.03	0.03(0.01)	0.05
Max allowed DCA cascde daugh (cm)	0.3	1.5(0.5)	1.6 (1.0)
Min allowed cos of cascade PA	0.9992	0.985(0.990)	0.97 (re-set)
Min radius of the fid. vol. (cm)	1.5(1.0)	0.4(0.4)	0.8 (0.6)
Proper length cascade (cm)	15(8)	-	–

Cuts for V0	Pb–Pb Ξ (Ω)	pp@2.76TeV Ξ (Ω)	pp@7TeV Ξ(Ω)
Min allowed ip for 1° daught (cm)	0.1	0.05(0.05)	0.04 (0.03)
Min allowed ip for 2° daught (cm)	0.1	0.05(0.05)	0.04 (0.03)
Max allowed DCA between daught. tracks (cm)	0.8	1.5(1.5)	1.6 stan. dev.
Min allowed cosine of V0's PA	0.998	pt dependent	0.97
Min radius of fiducial volume (cm)	3.0	0.2(0.2)	1.4



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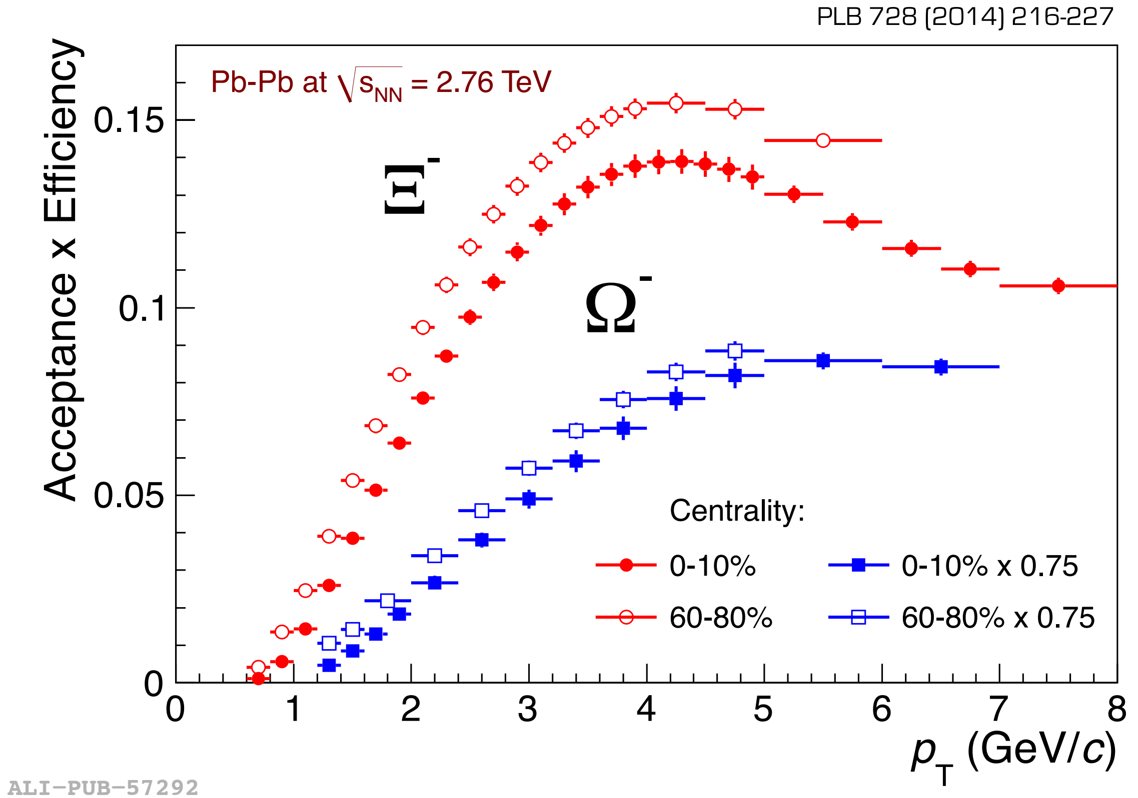
Acceptance-efficiency correction vs p_T



Backup

Blast-wave and Lèvy-Tsallis parametrizations

- To measure the yields in the full p_T range the following parametrization have been used in Pb–Pb and pp analysis:
  - *Blast-wave* [1]: hydrodynamically inspired model which assumes a thermalized, transverse expanding source.
    - Three fit parameters: kinetic freeze-out temperature, transverse velocity and exponential power (T, β_T and n)
    - Gives the best fit to individual particles
    - From PHOBOS evidence that this parametrization gives a good description to very low p_T
  - *Lévy-Tsallis* [2]: the function is grounded in Tsallis statistics and approximates an exponential component (represented by T parameter) as well as a power-law dependence for high-p_T tail.

$$\frac{d^2N}{dy dp_T} = \frac{(n-1)(n-2)}{nT[nT + m_0(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1 + \frac{m_T - m_0}{nT}\right)^{-n}$$

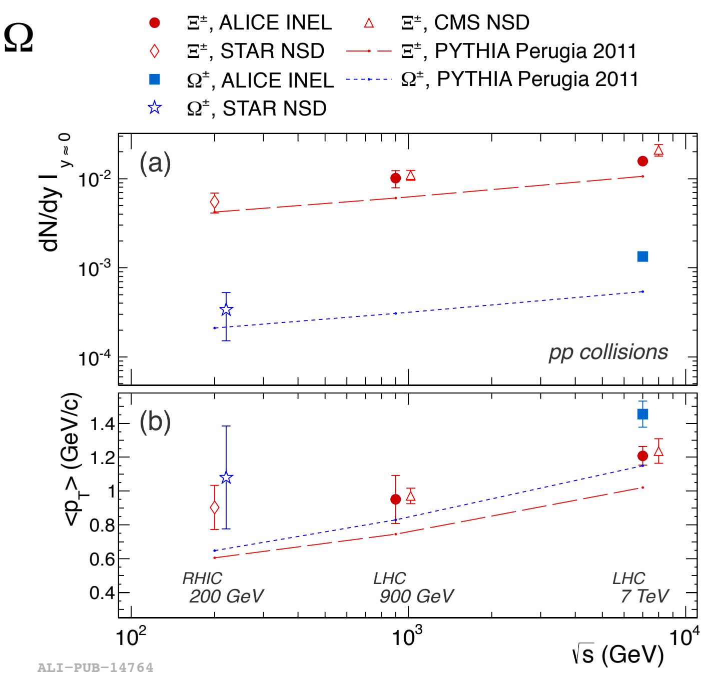
    - where T, n and dN/dy (this representing the particle yield per unit rapidity) are fit parameters, $m_T = \sqrt{(m_0^2+p_T^2)}$ and m_0 denotes the particle mass.

[1] E. Schnedermann, J. Sollfrank and U. Heinz, Phys. Rev. C 48, 2462 (1993)
[2] C. Tsallis, J. Stat. Phys. 52 (1988) 479

Backup

Yields for reference pp strangeness enhancement measure

- Reference for enhancements at LHC
  - Interpolate 0.9[1] and 7[2] TeV pp data for Ξ
  - Interpolate 200[3] GeV (STAR) and 7[2] TeV pp data for Ω
  - Use excitation function from PYTHIA Perugia-2011[4]: $s^{0.25}$ ($s^{0.22}$ for charged multiplicity)
  - Checked to match the preliminary measurement in pp collision at $\sqrt{s}$ = 2.76 TeV



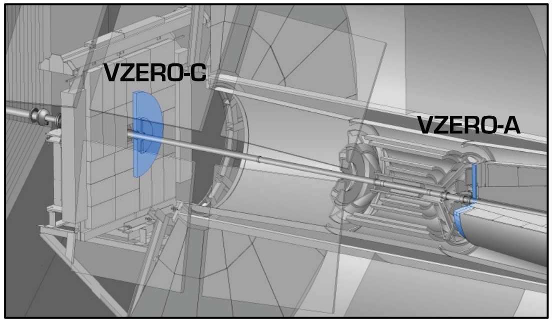
pp@2.76 TeV	Yield Ξ	Yield Ω
Interpolated	(Ξ^-) 0.0068±0.0023 (Ξ^+) 0.0066±0.0022	($\Omega^-+\Omega^+$) 0.00107±0.00050
Measured	(Ξ^-) **0.0059±0.0001** $^{+0.0007}_{-0.0007}$ (Ξ^+) **0.0060±0.0001** $^{+0.0007}_{-0.0007}$	($\Omega^-+\Omega^+$) **0.00092±0.00007** $^{+0.00017}_{-0.00017}$

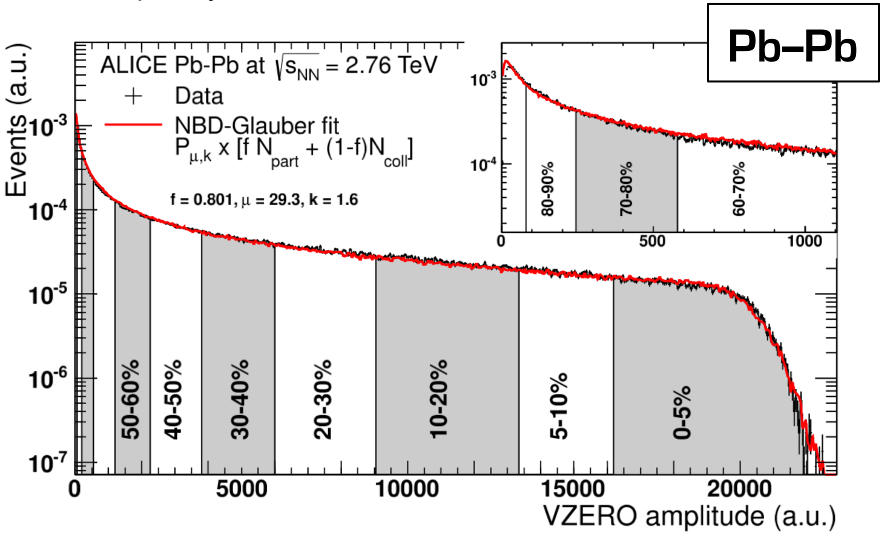
[1] Phys. Lett. B 712, 309 (2012)
[2] Eur. Phys. J. C 71, 1594 (2011)
[3] Phys. Rev. C 75, 064901 (2007)
[4] Phys. Rev. D 82, 074018 (2010)

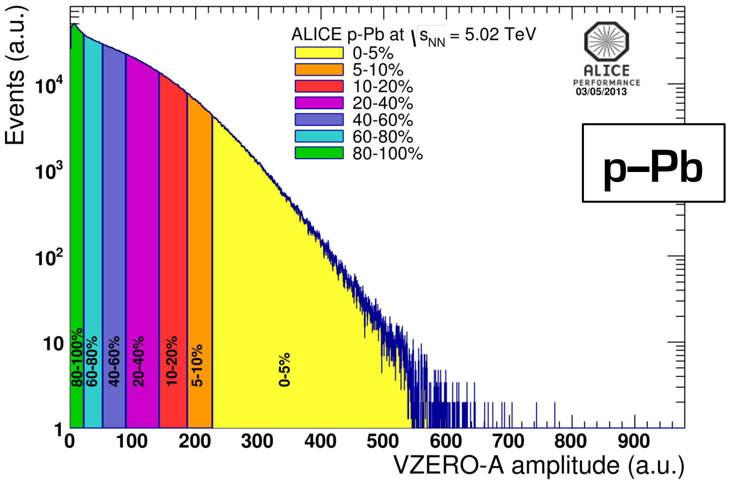
Backup

Centrality/Multiplicity determination in Pb—Pb/p—Pb collisions

- The VZERO detector is composed of a pair (VZERO-A and VZERO-C) of forward scintillator hodoscopes ($2.8 < \eta < 5,1$ and $-3.7 < \eta < -1.7$).
- **Pb–Pb:** the centrality of the events has been determined using the VZERO amplitude distribution.
  1. The distribution was fitted with Glauber MC model to compute the fraction of hadronic cross section corresponding to any given range of VZERO amplitude.
  2. Than, the data were divided into several centrality percentiles selecting on signal amplitudes measured in the VZERO.
- **P–Pb:** 7 multiplicity classes based on the amplitude measured by forward detector VZERO-A (placed on the outgoing Pb side) that is proportional to the particle multiplicity in the event.





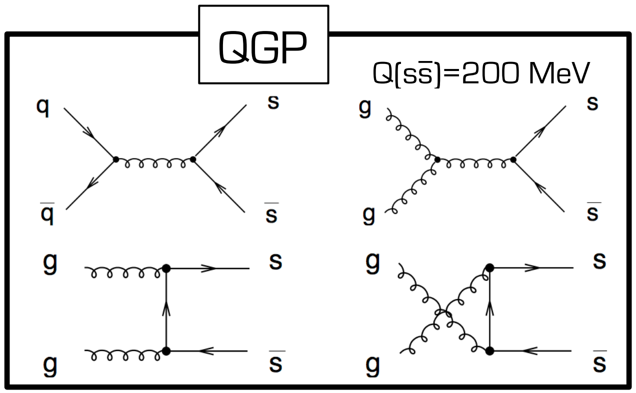


Backup

Compare strangeness production in hadron gas and QGP

- In the Rafelski-Muller argumentations there are two considerations:
  1. Production mechanisms:
     - ✓ In hadron gas (HG) scenario strange hadron are prouced trough direct (N+N→N+ Λ +K) or indirect reactions.
     - ✓ In QGP scenario basic strange (anti-)quarks production process is the fusion of two gluons.

     ➜ **Should be much easier to generate strangeness once a plasma state has been formed.**



HG

Direct production:
π + π → π + π + strange hadron + antiparticle
Q(Ξ) = 2642 MeV and Q(Ω) = 3344 MeV
Indirect production:
1) π + N → K + Λ
2) π+ Λ → K+ Ξ and π+ Ξ → K+ Ω
Q(Ξ) = 1100 MeV and Q(Ω) = 1810MeV

  2. The equilibration time of partonic reactions, expecially due to the gluon fusion process, is much shorter than the one for the hadronic reactions. The difference is especially large, if rare multi-strange (anti-)baryons are considered ($^{eq}\tau_{QGP}$≃10 fm; $^{eq}\tau_{HG}$=30 fm).

     ➜ **Would be very difficult to produce multi-stange particle in large abundances in a hadron resonance gas, while the presence of a QGP would be reflected in much higher production rates of these particles.**