Strangeness in Quark Matter
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ALICE

Multi-strange baryon production in Pb-Pb and pp collisions with ALICE

Domenico Colella
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on behalf of the ALICE Collaboration

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

INFN Istituto Nazionale di Fisica Nucleare

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Measuring multi-strange baryons

Physics motivation

- Why measure (multi-)strange hyperons
  - no net strangeness content in the colliding system
  - small hadronic cross-section → information on the early stages of the system evolution in Pb-Pb collisions
  - measurements in pp:
    - baseline to understand Pb-Pb
    - insight into different production mechanisms at play

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ALICE

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  - ✓ measurements in pp:
    - baseline to understand Pb-Pb
    - insight into different production mechanisms at play

- What can be inferred
  - ✓ constraints on QCD-inspired models in pp collisions (e.g. PYTHIA)
  - ✓ constraints on hydro-dynamical models in Pb-Pb collisions (e.g. EPOS, Kraków, VISH2+1 and HKM)
  - ✓ origin of observed "strangeness enhancement" in Pb-Pb wrt pp collisions
  - ✓ behavior of nuclear modification factor (R_{AA})

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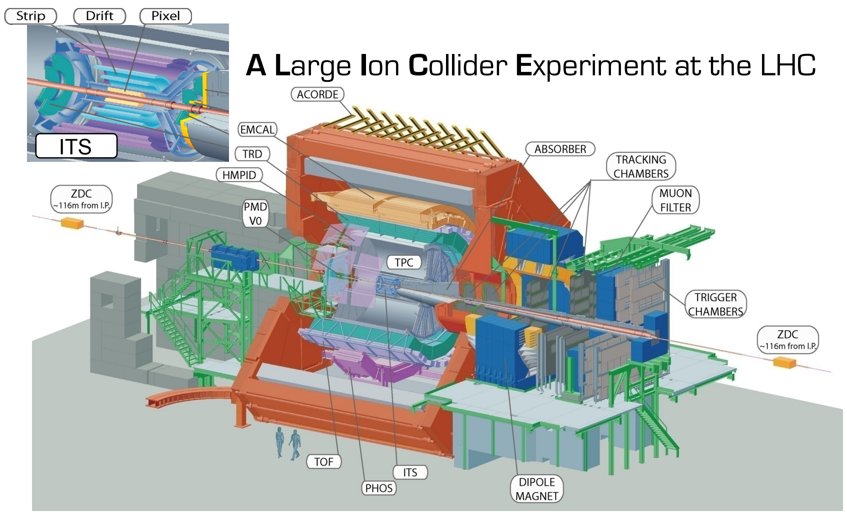
Measuring multi-strange baryons

Multi-strange baryon detection



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

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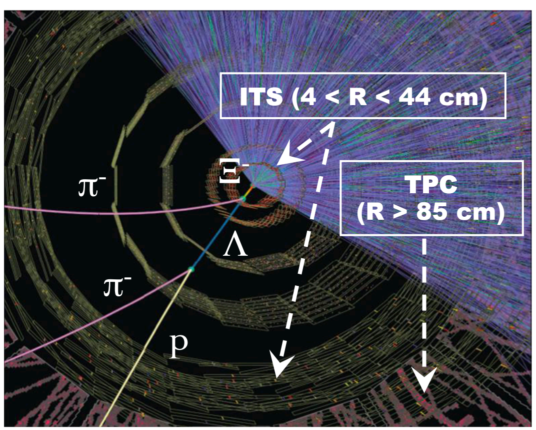
Multi-strange baryons in ALICE are reconstructed via their weak (cascade) decay topology:

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

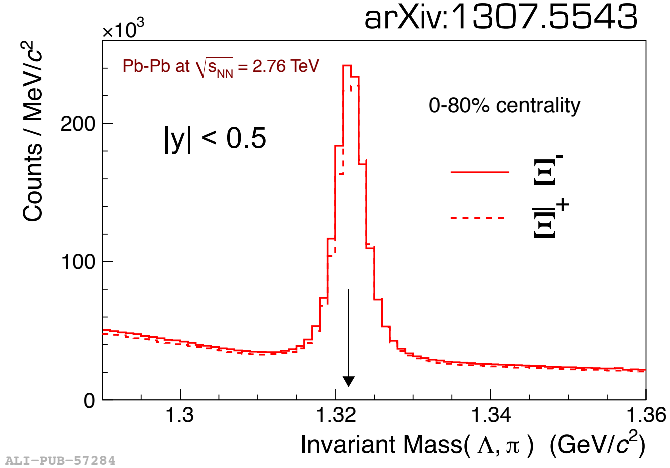


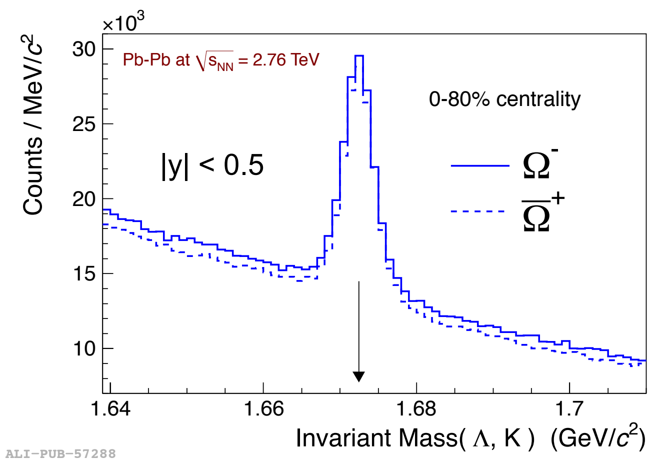
Pb-Pb 5.5 TeV Hijing MC event, not all tracks shown; ALICE Physics Performance Report, Vol II, J Phys. G 32, 1295, (2006).

Measuring multi-strange baryons

Multi-strange baryon detection

arXiv:1307.5543





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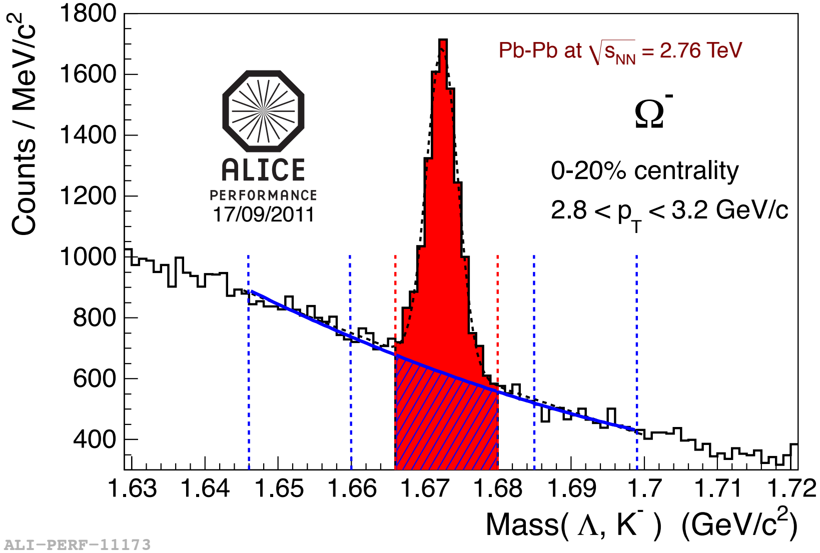
Measuring multi-strange baryons

Multi-strange baryon detection



Signal = Summed bin count – Integral of background fit function

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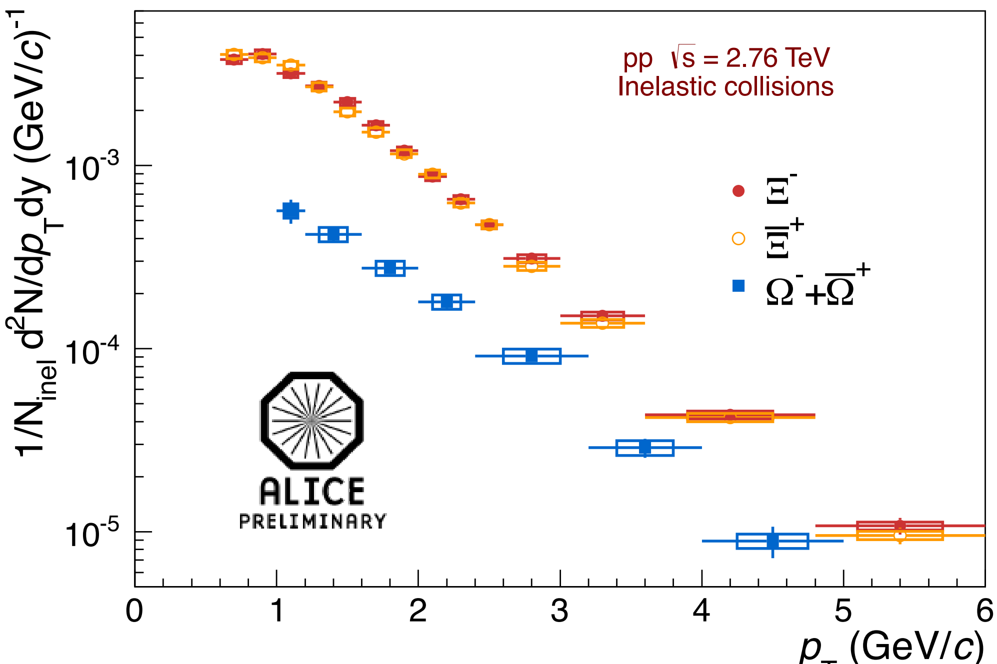
Results

Spectra in pp collisions

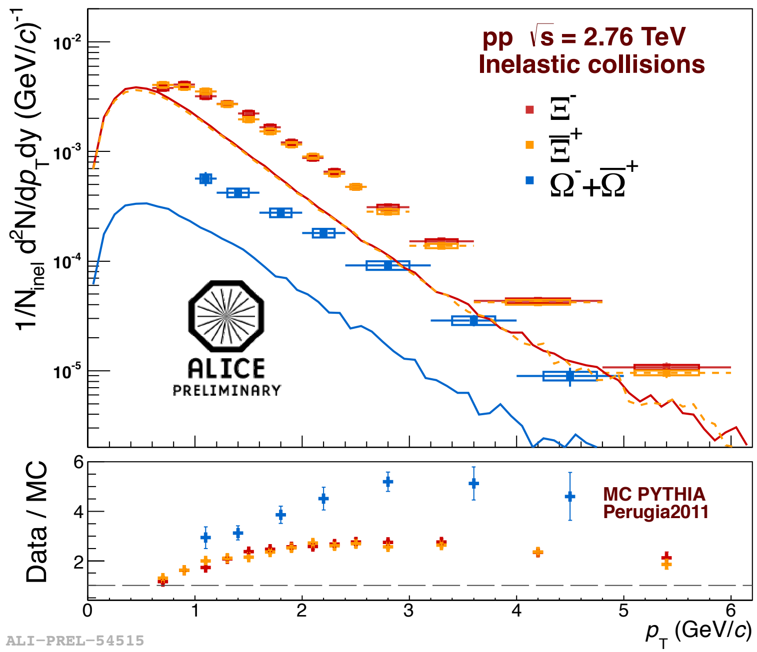


ALI-PREL-49282

- Analysis on a data sample of about 80M minimum bias events pp at $\sqrt{s}$ = 2.76 TeV taken in 2011
- p_T reach of 6 (Ξ) and 5 GeV/c (Ω)
- Particle and anti-particle spectra identical within uncertainties

Results

Spectra in pp collisions

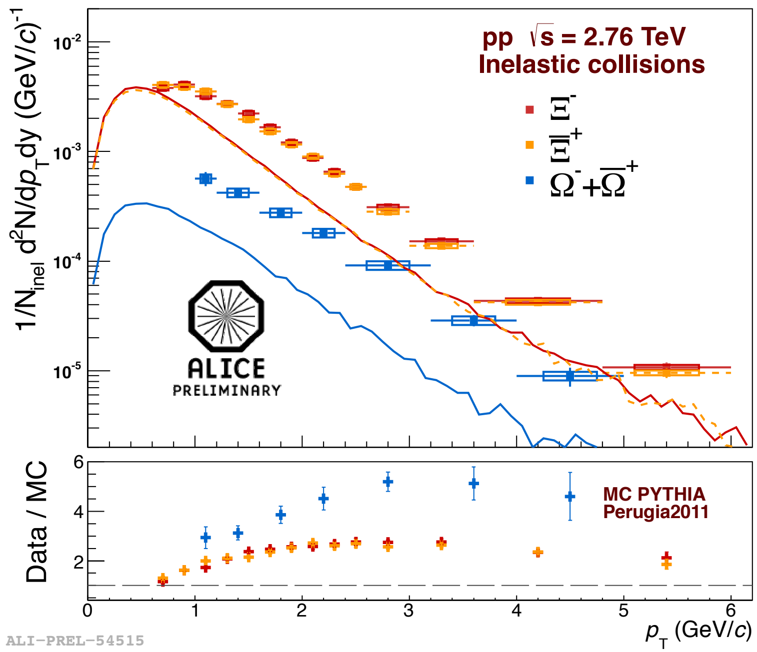


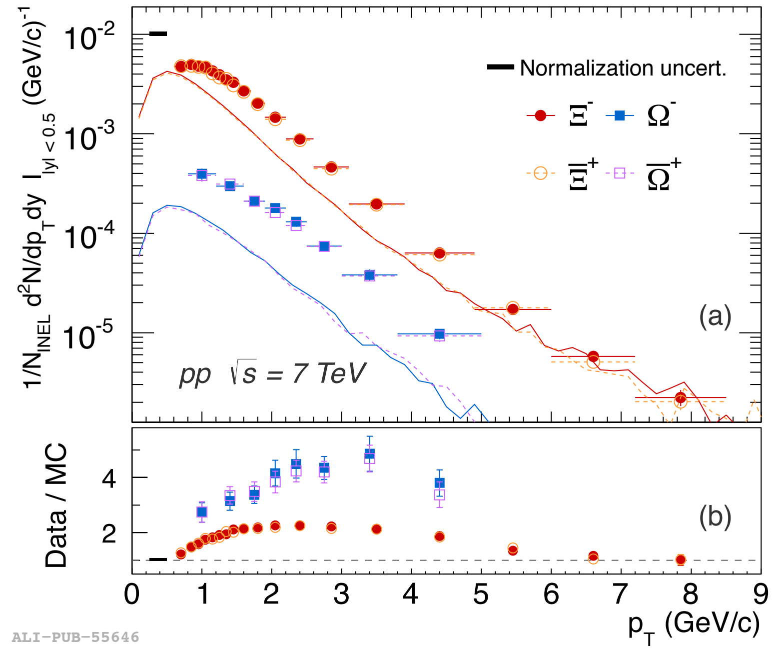
- Comparison with PYTHIA Perugia-2011[1]:
  - ✓ tuned with measured multiplicity at 7 TeV,
- Deviations in the low p_T region (increasing with strangeness)

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

Results

Spectra in pp collisions





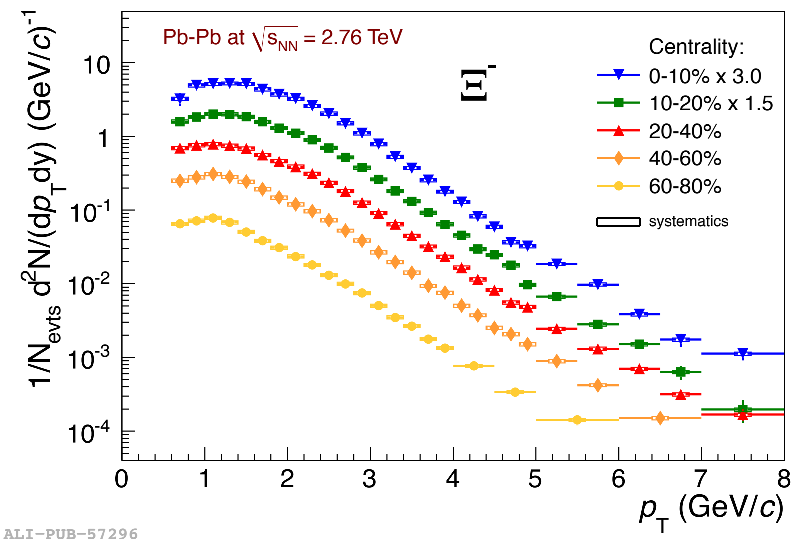
- Comparison with PYTHIA Perugia-2011[1]:
  - ✓ tuned with measured multiplicity at 7 TeV,
- Deviations in the low p_T region (increasing with strangeness)
- Same results at the two energies $\sqrt{s}$ = 7 TeV[2] and 2.76 TeV
- Hint of agreement above 7 GeV/c for Ξ

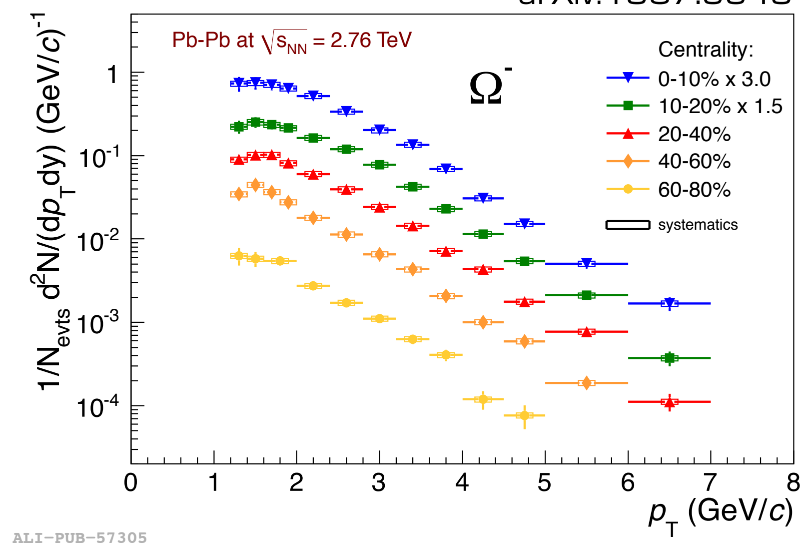
[1] Phys. Rev. D 82, 074018 (2010)
[2] Phys. Lett. B 712, 309-318 (2012)

Results

Spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

arXiv:1307.5543



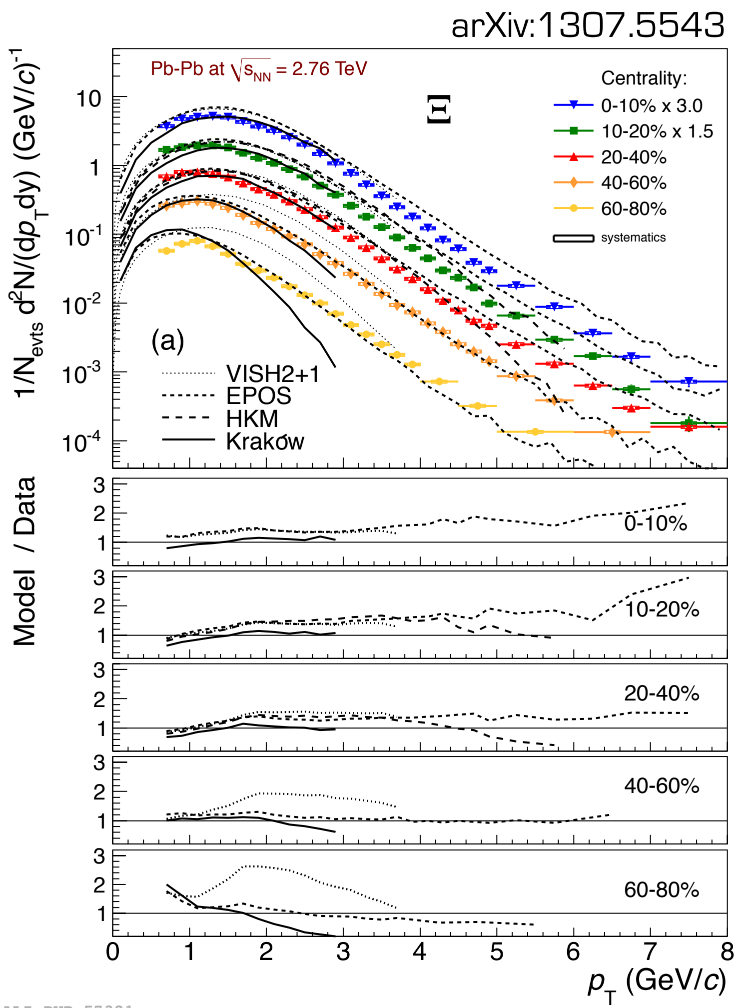


- Analysis on a data sample of about 20M minimum bias events Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV taken in 2010
- 5 centrality bins
- p_T reach: 8 (Ξ) and 7 GeV/c (Ω) in 10% most central Pb-Pb collisions
- Particle and anti-particle spectra identical within uncertainties

Results

Spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

ALICE



- Models
  - VISH2+1[1]: viscous hydrodynamic model
  - HKM[2]: ideal hydro model, with hadron cascade (UrQMD)
  - Kraków[3]: non-equilibrium corrections due to bulk viscosity in transition from hydrodynamics to particles
  - EPOS[4]: incorporates hydrodynamics and models the interaction between high p_T hadrons and expanding fluid, also use UrQMD as hadronic cascade model

[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)

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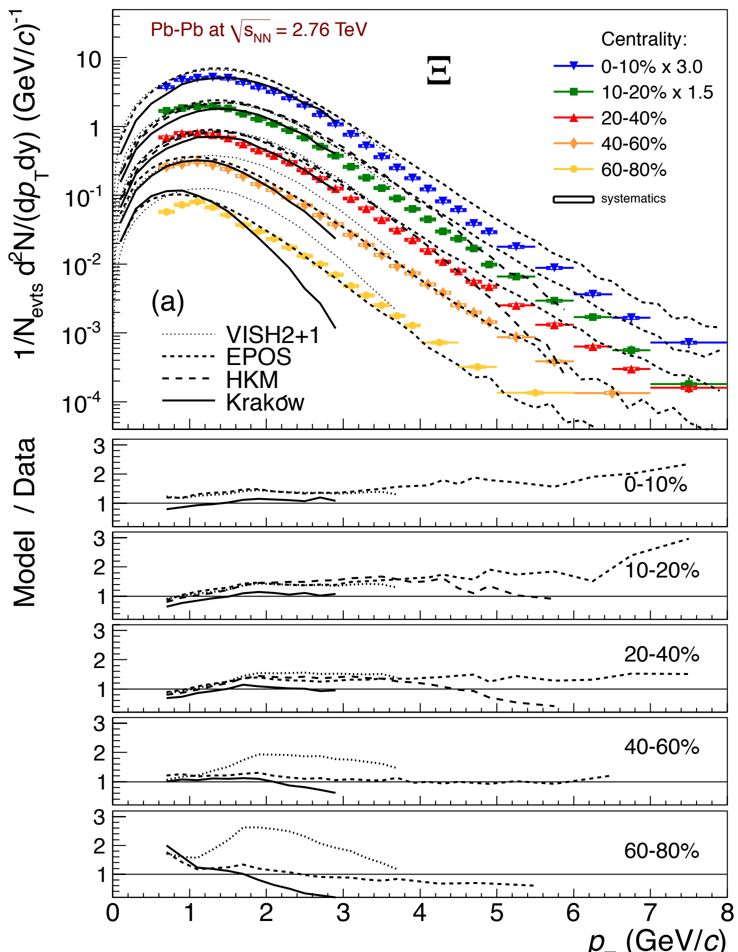

ALI-PUB-57321

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  - Kraków[3]: non-equilibrium corrections due to bulk viscosity in transition from hydrodynamics to particles
  - EPOS[4]: incorporates hydrodynamics and models the interaction between high p_T hadrons and expanding fluid, also use UrQMD as hadronic cascade model
- 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)
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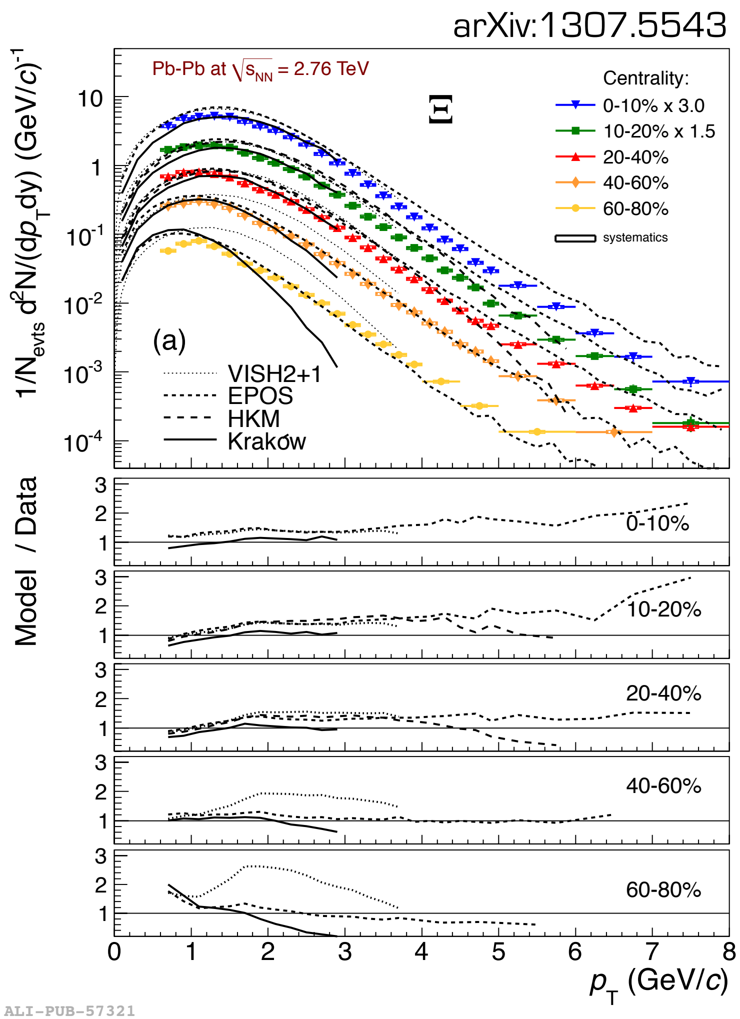
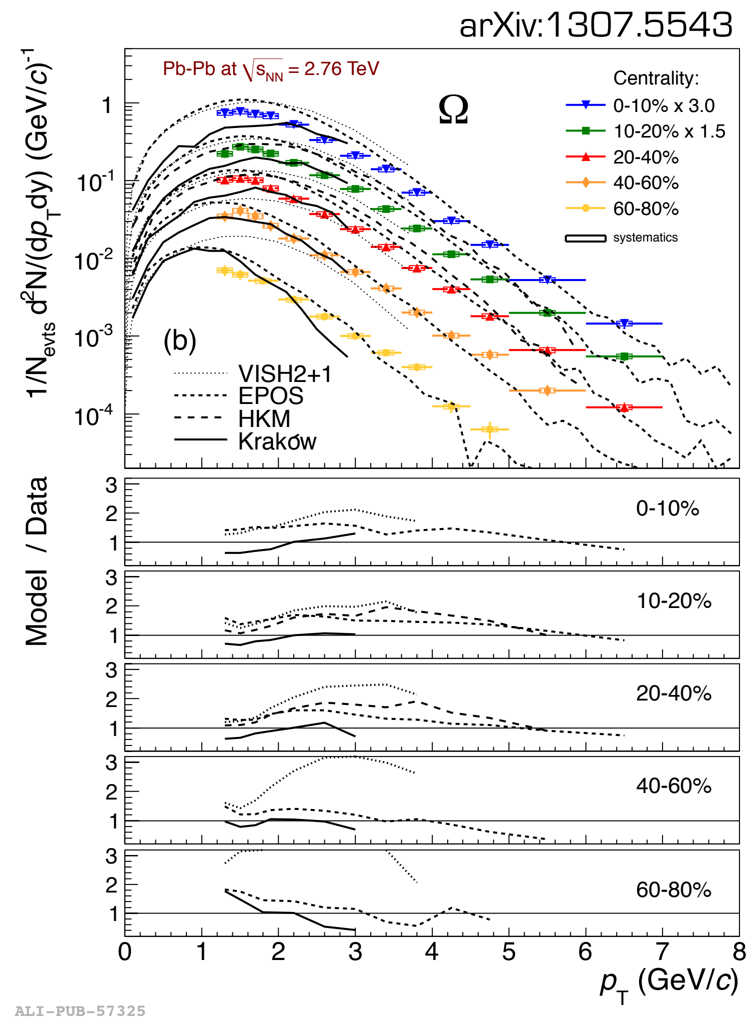
Results

Spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV





Results

Strangeness enhancement

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

- Historical probe of Quark Gluon Plasma [Phys. Rev. Lett. **48**, 1066 (1982)]
- Found to qualitatively match predictions at SPS and RHIC
  - Increasing with strangeness content
  - Decreasing with centre-of-mass energy

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- Reference for enhancements at LHC
  - Interpolate 7 TeV and lower energies pp yields using excitation function from PYTHIA Perugia-2011[1]
  - Checked with preliminary measurement in pp collision at $\sqrt{s}$ = 2.76 TeV

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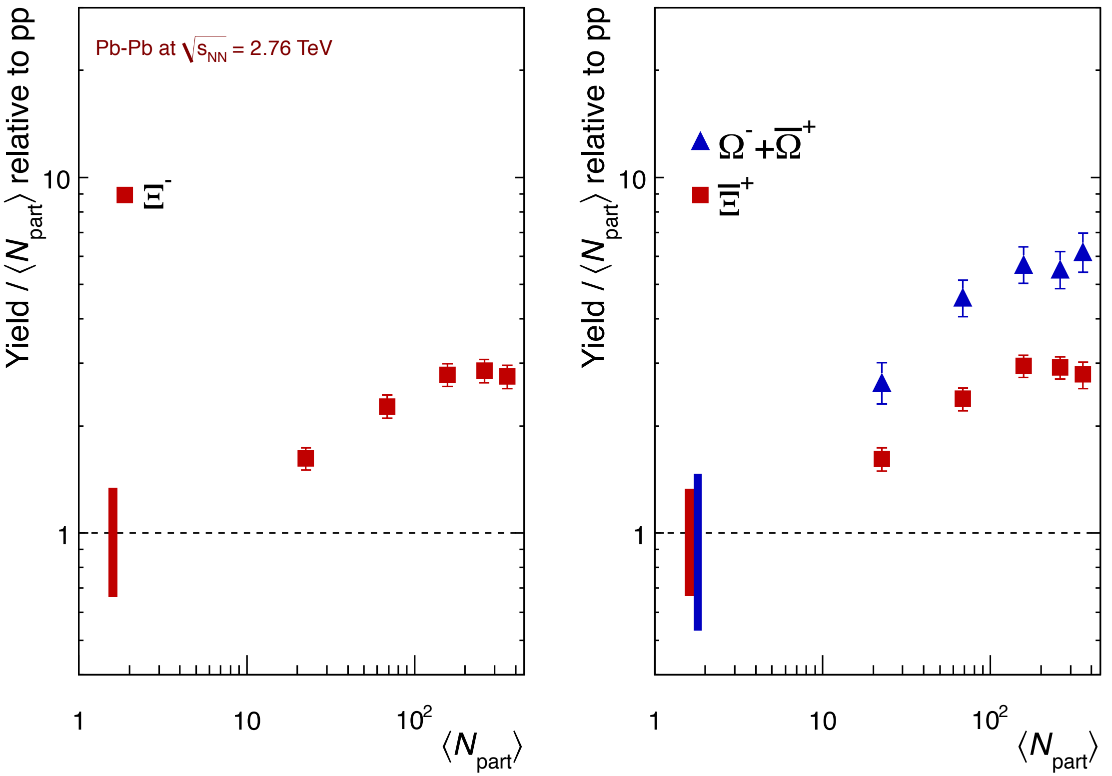

- Hierarchy based on strangeness content

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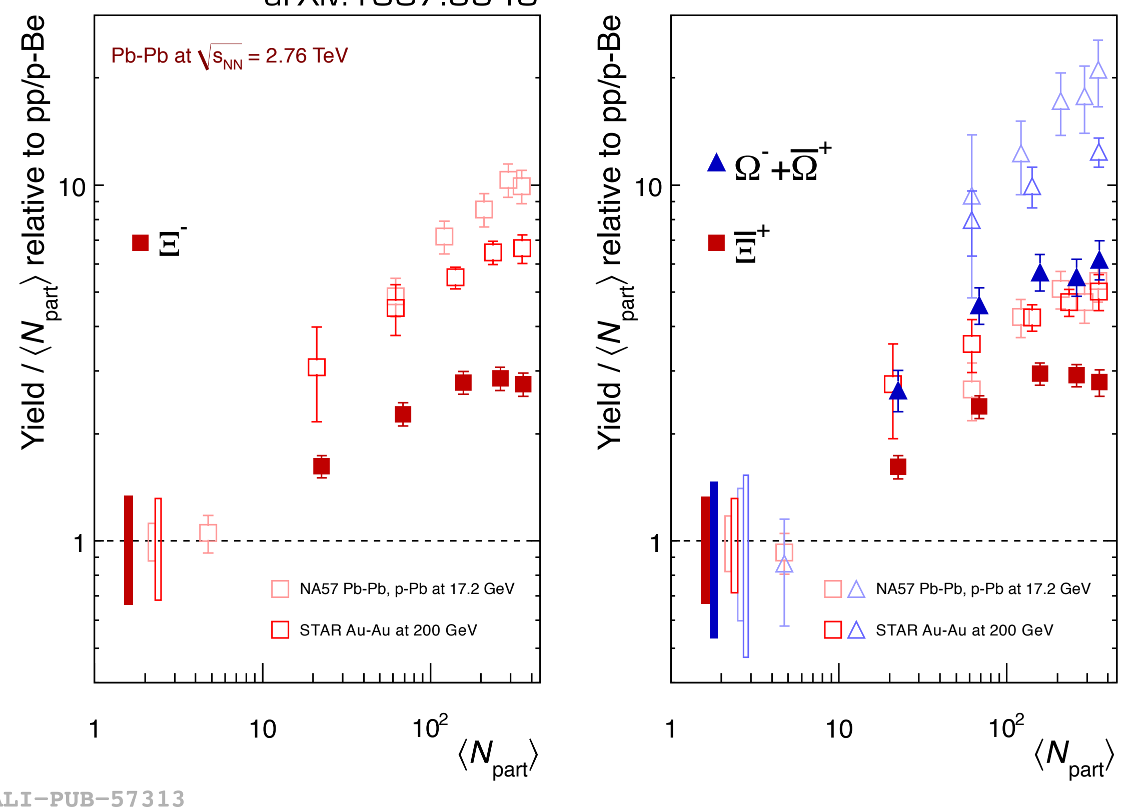

- Hierarchy based on strangeness content
- Decreasing trend with energy as observed at SPS energies and from SPS to RHIC

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

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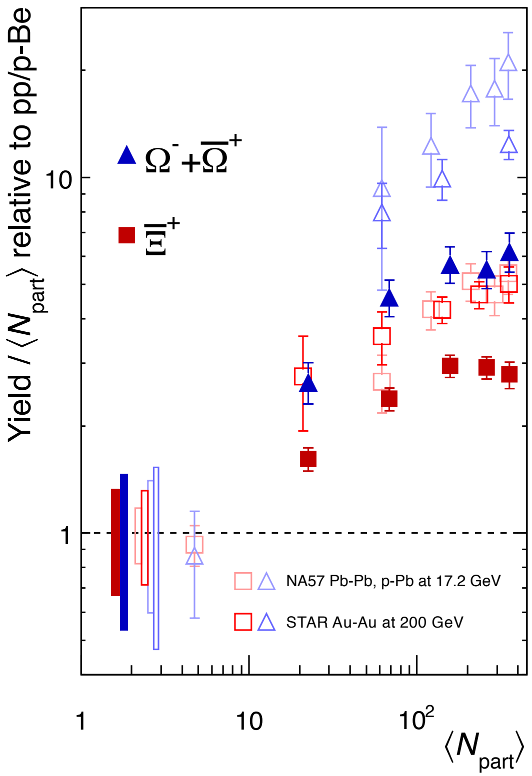
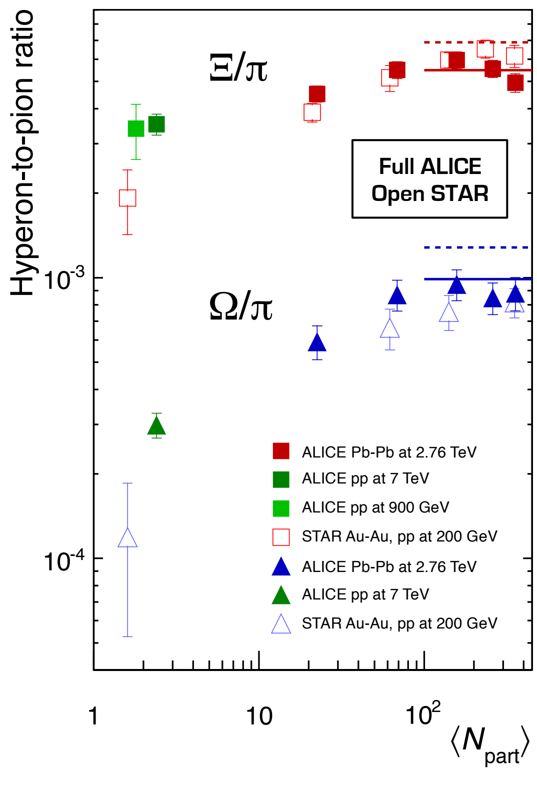




- Hierarchy based on strangeness content
- Decreasing trend with energy as observed at SPS energies and from SPS to RHIC
- Hyperon to pion ratios:
  - enhancement almost half of that in the left hand plot
  - found to match predictions from thermal models (grand canonical approach) with T = 164 MeV[1] (full lines)

STAR: Phys. Rev. C 75, 064901 (2007)
Phys. Rev. Lett. 98, 62301 (2007)
Phys. Rev. C 79, 034909 (2009)

ALICE: Phys. Lett. B 712, 309 (2012)
1303.0737v1 [hep-ex]
Eur. Phys. J. C 71, 1594 (2011)
Eur. Phys. J. C 71, 1655 (2011)

[1] Phys. Lett. B 673, 142 (2009)
Erratum Phys. Lett. B 678, 561 (2009)
Phys. Rev. C 74, 034903 (2006)

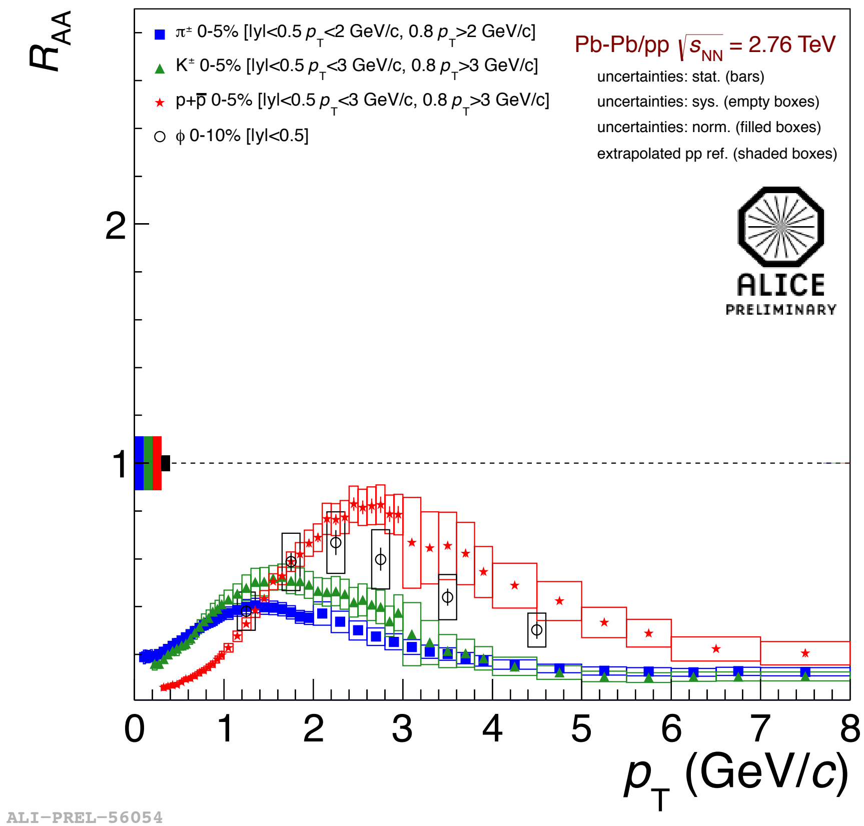
Results

Nuclear modification factor

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

- Compared with π, k, p and ϕ

■ π ■ ϕ
■ k
■ p



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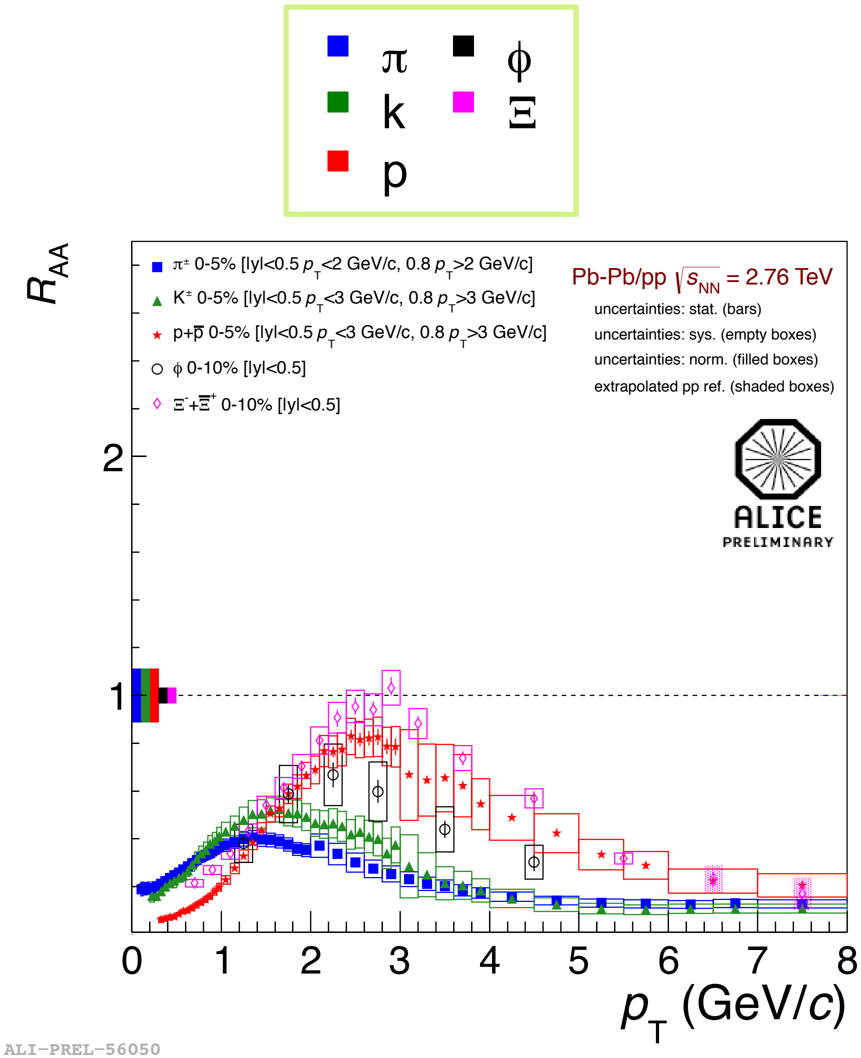

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- At high p_T R_{AA} does not depend on the mass of the particle
- Mass ordering at mid-p_T

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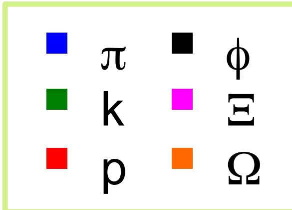

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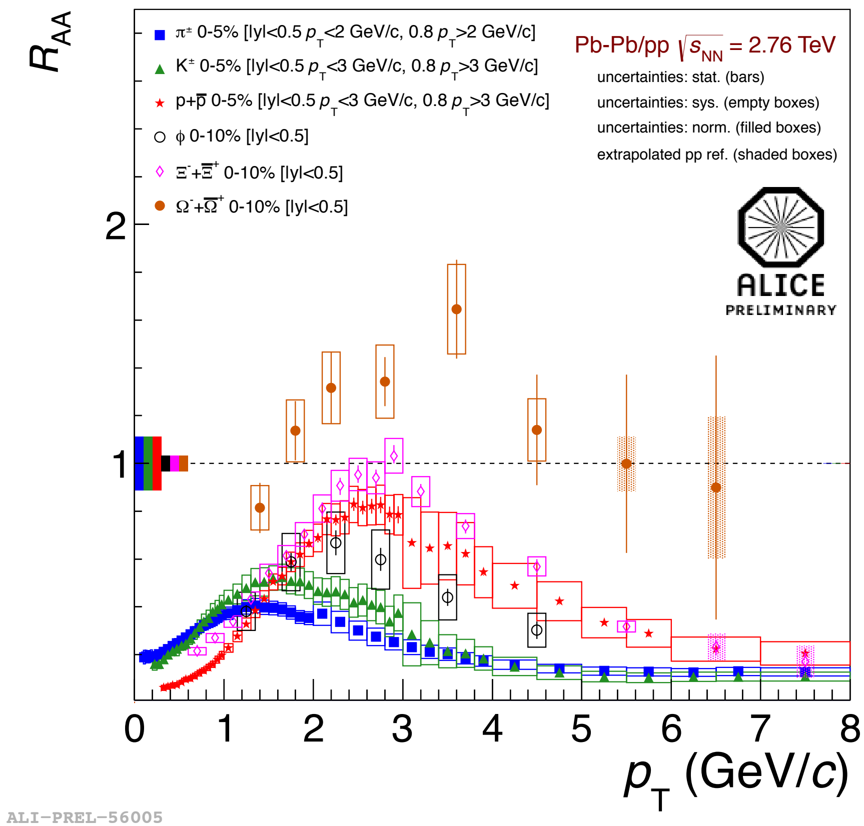

- Compared with π, k, p and ϕ
- At high p_T R_{AA} does not depend on the mass of the particle
- Mass ordering at mid-p_T
- Effect of strangeness enhancement on the Ω (and Ξ)
- Shaded points for Xi and Omega obtained with extrapolated pp ref.

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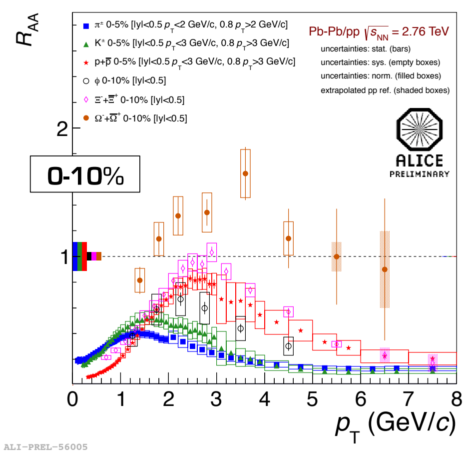
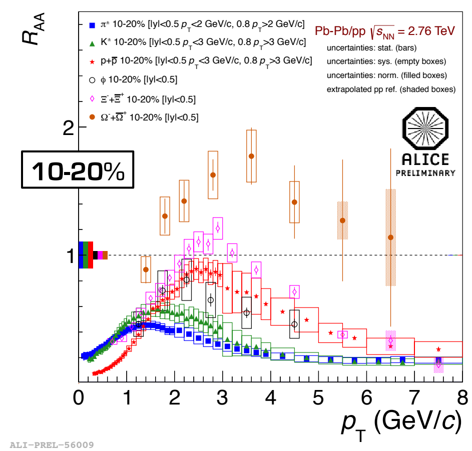
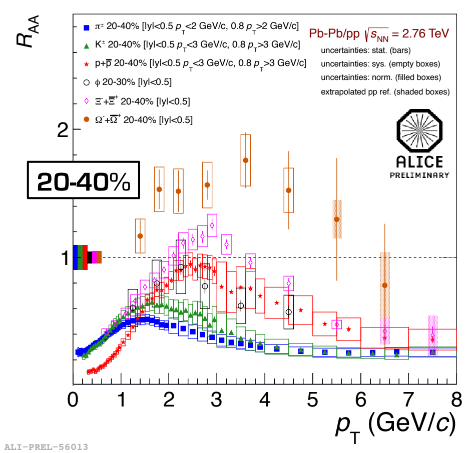
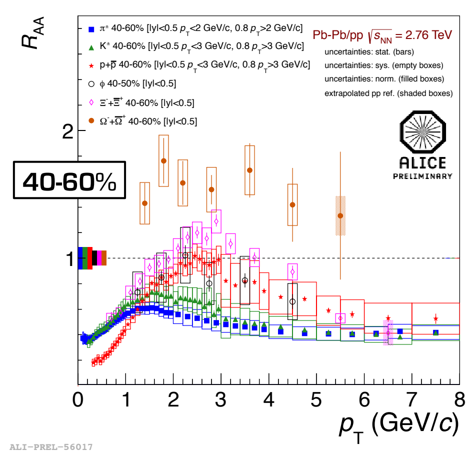
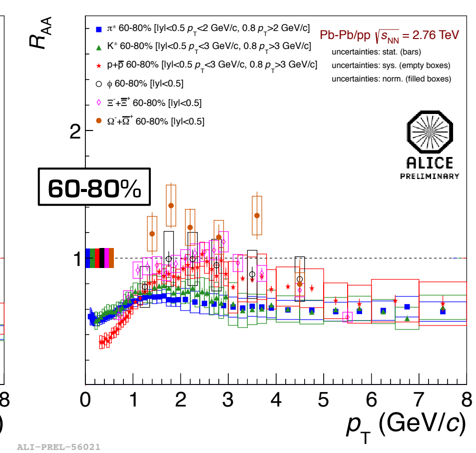
- Compared with π, k, p and ϕ
- At high p_T R_{AA} does not depend on the mass of the particle
- Mass ordering at mid-p_T
- Effect of strangeness enhancement on the Ω (and Ξ)
- R_{AA} vs centrality: follows trend similar to other particles











π	ϕ
k	Ξ
p	Ω

Summary

- pp collisions
  - Preliminary multi-strange p_T spectra: p_T ranges [0.6,6.0] GeV/c for Ξ and [1.0,5.0] GeV/c for Ω.
  - PYTHIA Perugia2011 tune underestimates the multi-strange spectra, both at $\sqrt{s}$ = 7 and 2.76 TeV.
- Pb-Pb collisions
  - Multi-strange p_T spectra in 5 centrality classes: p_T ranges [0.6-8.0] GeV/c for Ξ and [1.2,7.0] GeV/c for Ω in the most central class (0-10%).
  - Reasonably good agreement with the Krakow and EPOS hydrodynamical models.
- Strangeness enhancement weaker at LHC than at RHIC, manly due to the behavior of strangeness production in pp.
- Ξ nuclear modification factor: behavior at high p_T similar to the other particles.
  - Ω R_{AA} strongly affected by strangeness enhancement.

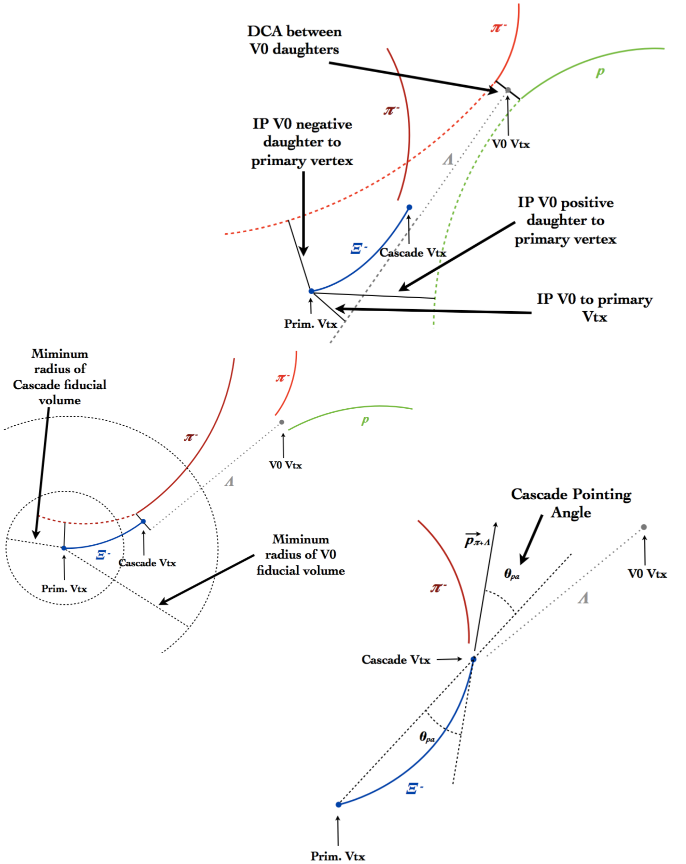
Backup

Backup

Topological cuts in Pb-Pb and pp analysis

Cuts for cascades	PbPb 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/c²)	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)	-	–

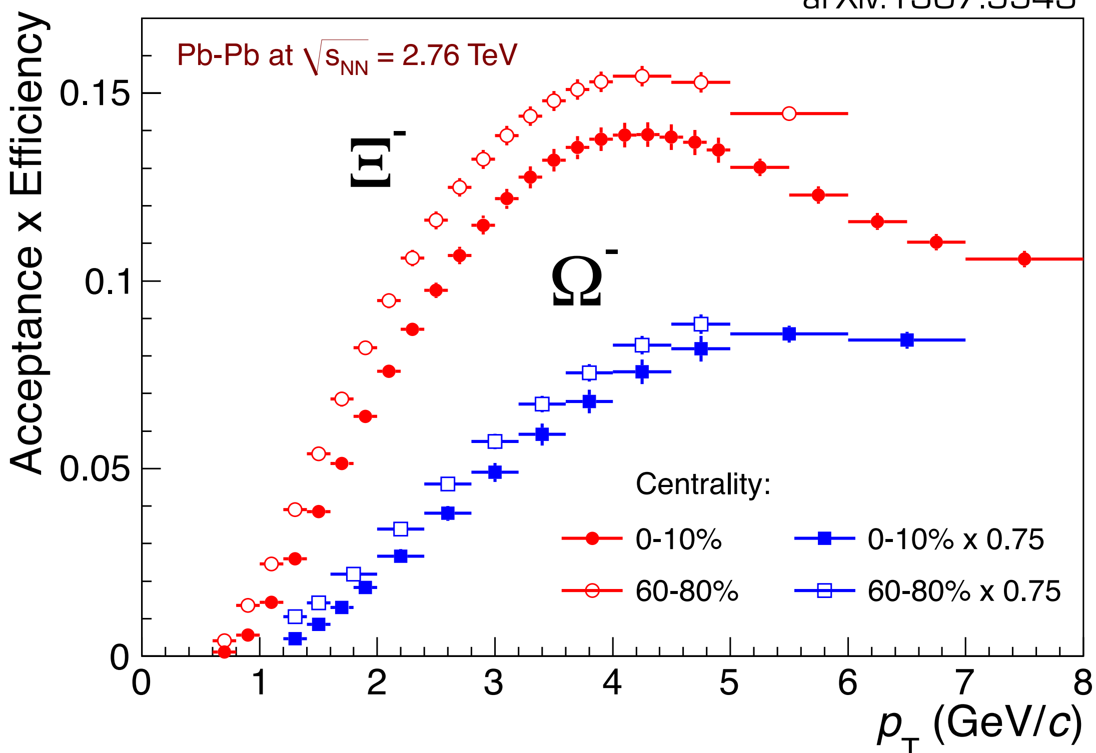
Cuts for V0	PbPb Ξ (Ω)	pp@2.76TeV Ξ (Ω)	pp@7TeV Ξ(Ω)
Min allowed ip for 1° daught (cm)	0.1	0.05(0.05)	0.04 (0.03)
Min allowed ip for 2° daught (cm)	0.1	0.05(0.05)	0.04 (0.03)
Max allowed DCA between daught. tracks (cm)	0.8	1.5(1.5)	1.6 stan. dev.
Min allowed cosine of V0's PA	0.998	pt dependent	0.97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



Backup

Acceptance-efficiency correction vs p_T

arXiv:1307.5543



ALI-PUB-57292

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.

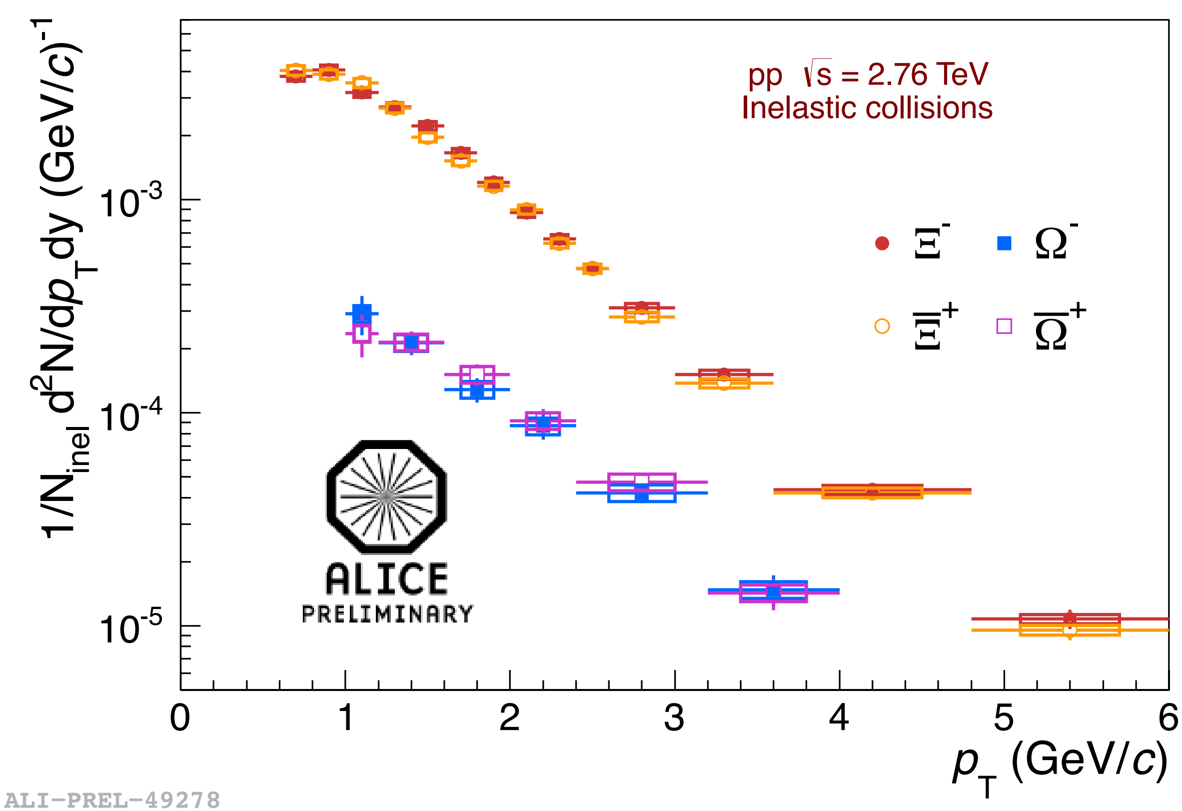
$$\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT+m_0(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1 + \frac{m_T - m_0}{nT}\right)^{-n}$$

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

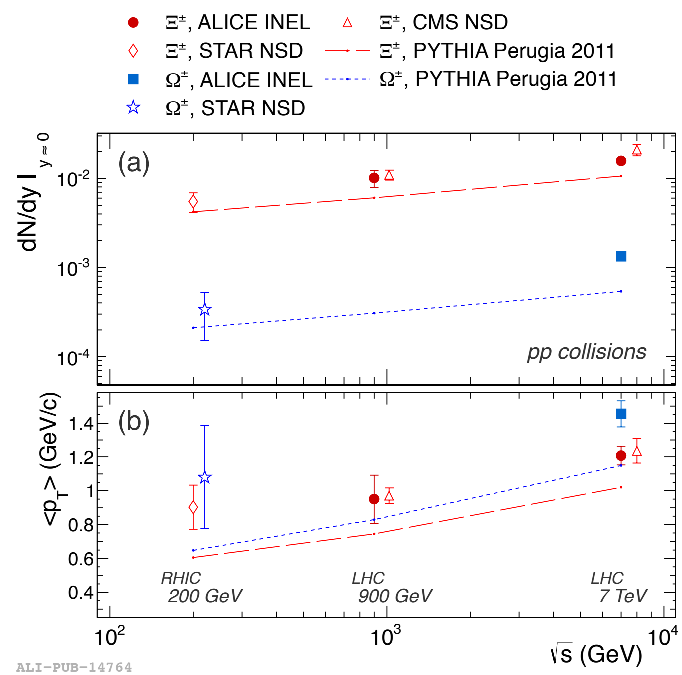
p_T spectra in pp collision at $\sqrt{s}$ = 2.76 TeV with omega particle and anti-particle separated



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)