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

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Physics Motivation

- Strange hadrons are useful probes to investigate the properties and evolution of the system created in heavy-ion collisions at the LHC, since there is no net strangeness content in the colliding system and the high energy and luminosity available allow for an abundant production of such particles.
- Strangeness enhancement (higher yields per participant nucleon for strange and multi-strange particles relative to those in pp collisions) has been predicted as a signature for the Quark Gluon Plasma (QGP) formation[1], and already observed both at SPS[2] and RHIC[3] energies.
- Nuclear modification factors for strange particles at the LHC provide additional constraints to parton energy loss models.

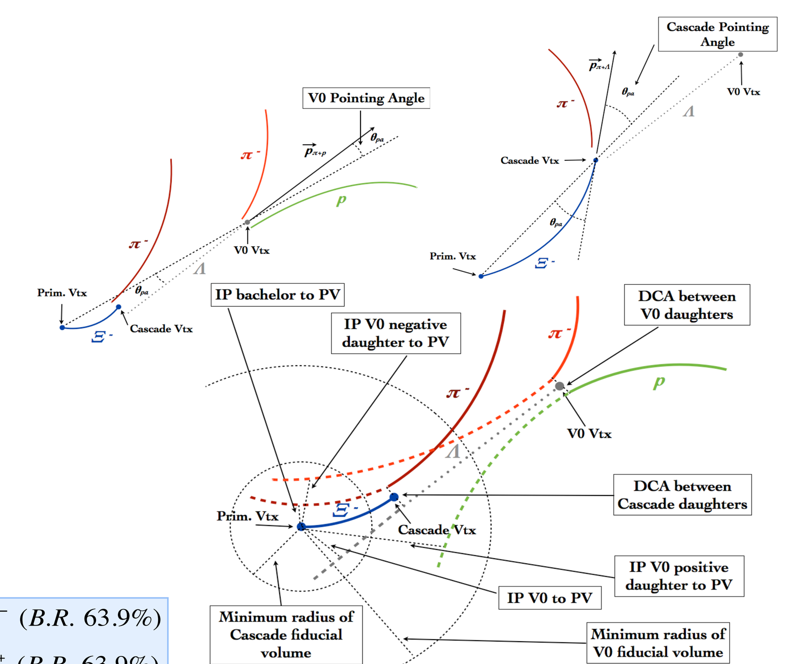
[1] J. Rafelski and B. Müller, PRL 48, 1066 (1982); P. Koch, J. Rafelski and W. Greiner, PLB 123, 151 (1983)
[2] E. Andersen *et al.* (WA97 Collab.), Phys. Lett. B **449**, 401 (1999); F. Antinori *et al.* (NA57 Collab.), J. Phys. G **32**, 427 (2006);
[3] B. I. Abelev *et al.* (STAR Collaboration), Phys. Rev. C **77**, 044908 (2008)
[4] K. Aamodt *et al.* (ALICE Collaboration), Phys. Rev. Lett. **106**, 032301 (2011)
[5] E. Schnedermann, J. Sollfrank and U. Heinz, Phys. Rev. C **48**, 2462 (1993)
[6] Andronic, A. et al. Phys.Lett. B673 (2009) 142-145, Erratum-ibid. B678 (2009) 516
[7] Wheaton, S. et al. Comput.Phys.Commun. 180 (2009) 84-106

References

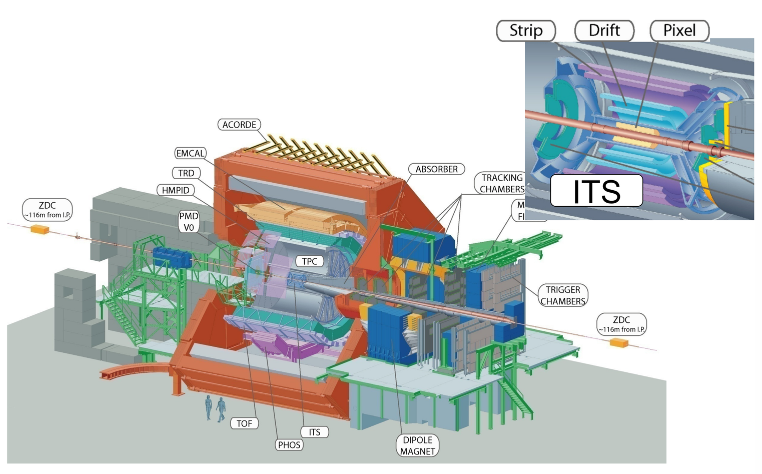
Measuring cascade decays in ALICE

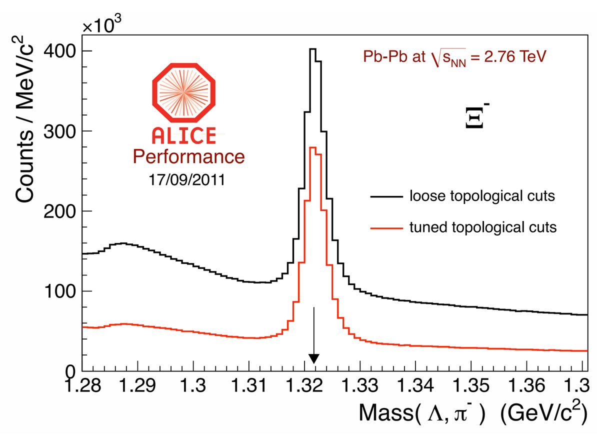
Multi-strange baryons in ALICE are reconstructed via their (cascade) decay topology, through the following steps:

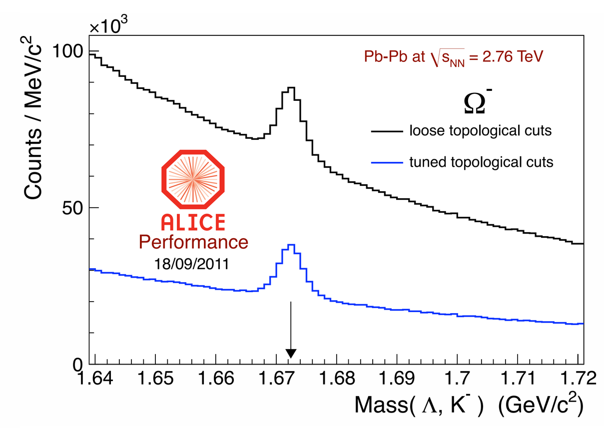
① charged tracks are reconstructed in the **I**nner **T**racking **S**ystem (ITS) and **T**ime **P**rojection **C**hamber (TPC);
② specific ionization (in the TPC) is used to identify daughter particles;
③ cascade candidates are selected combining reconstructed tracks and applying loose cuts on geometry and kinematics;
④ selection cuts are finally tightened to reduce background at the analysis level.



$\Xi^-(dss) \to \Lambda\pi^- \to p\pi^-\pi^-$ (B.R. 63.9%)
$\bar{\Xi}^+(\bar{d}\bar{s}\bar{s}) \to \bar{\Lambda}\pi^+ \to \bar{p}\pi^+\pi^+$ (B.R. 63.9%)
$\Omega^-(sss) \to \Lambda K^- \to p\pi^- K^-$ (B.R. 43.3%)
$\bar{\Omega}^+(\bar{s}\bar{s}\bar{s}) \to \bar{\Lambda}K^+ \to \bar{p}\pi^+ K^+$ (B.R. 43.3%)



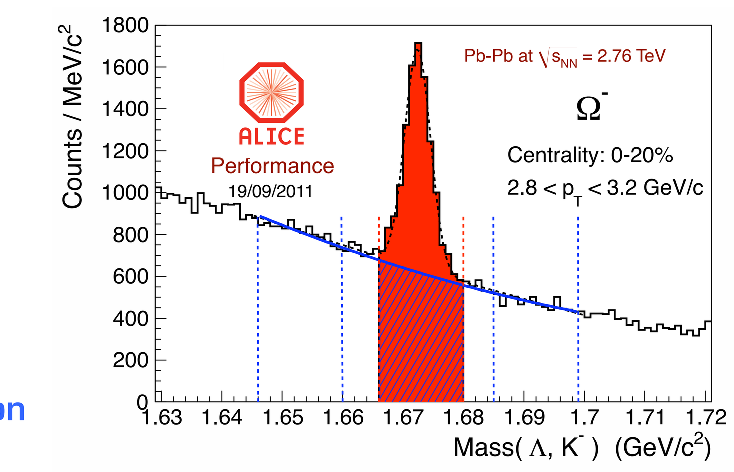




Signal extraction

- Fit polynomial+gaussian to get mean and σ;
- bin counting in the signal region ($\pm 3\sigma$);
- fit background sampled on both sides of signal region;
- integral of background fit function in the signal region.

→ **Signal** = Summed histogram – Integral of background function

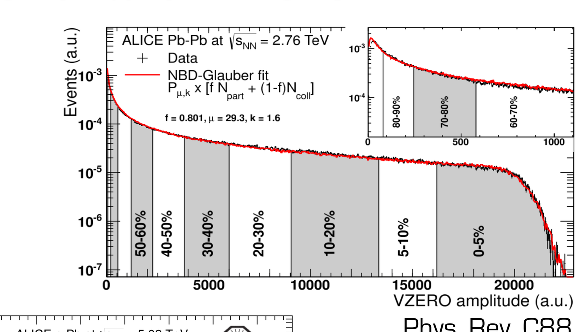


Samples

- **pp**: about 80x10^6 minimum bias collisions at $\sqrt{s}$ = 2.76 TeV taken in 2011.
- **p—Pb**: about 100x10^6 minimum bias collisions at $\sqrt{s}$ = 5.02 TeV taken in 2013.
- **Pb—Pb**: about 30x10^6 minimum bias collisions at $\sqrt{s_{NN}}$ = 2.76 TeV taken in 2010 .

Centrality/multiplicity selection

- **Pb—Pb**: centrality classes defined on the sum of the amplitudes measured in the VZERO detectors[4] (scintillation hodoscopes placed on either side of the interaction region: VZERO-A $2.8<\eta<5.1$ and VZERO-C $-3.7<\eta<-1.7$).
- **p—Pb**: multiplicity classes based on the amplitude measured by forward detector VZERO-A (placed on the outgoing Pb side).



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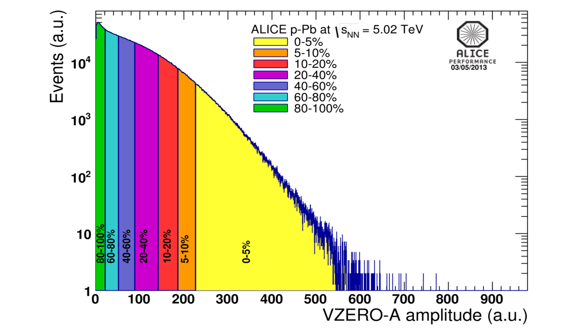


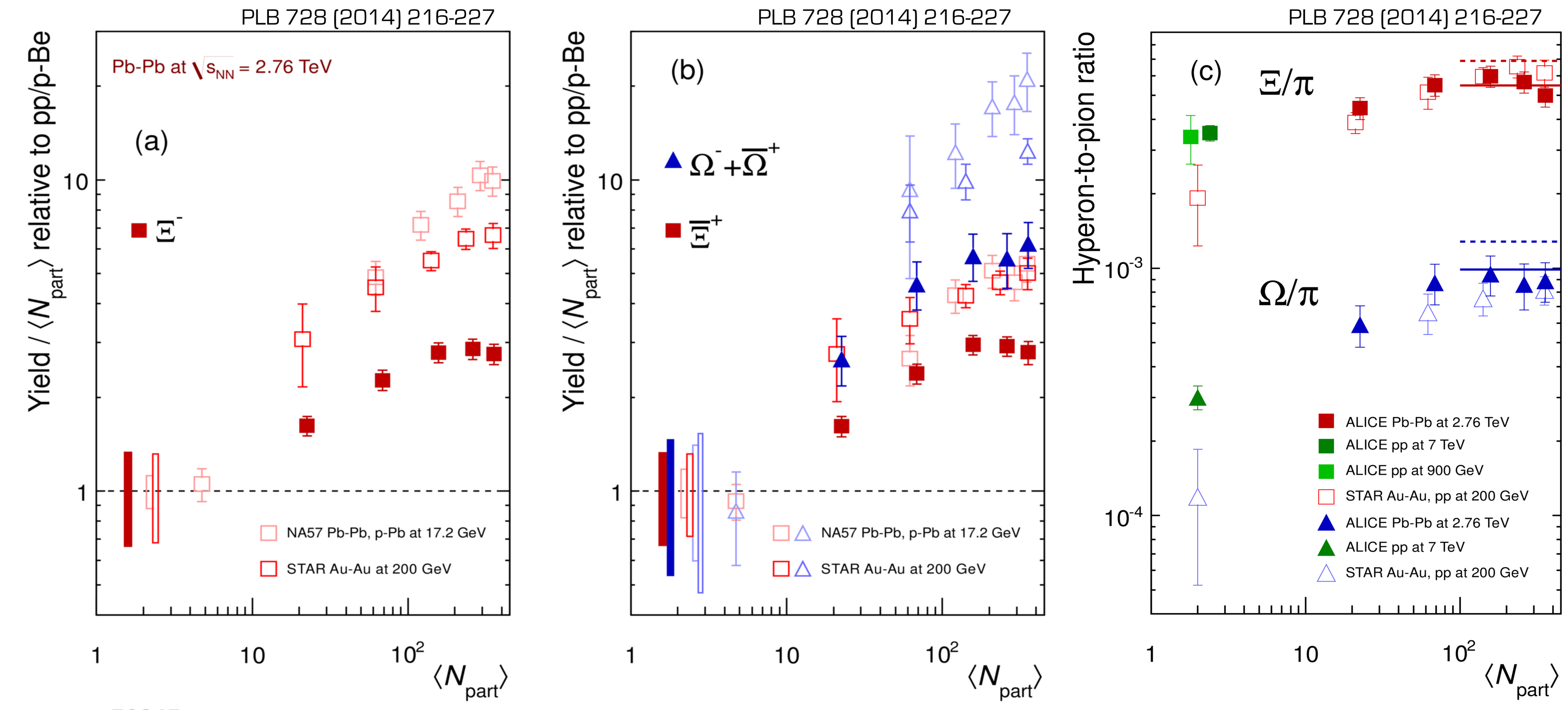
Results - Strangeness Enhancement

The strangeness enhancements are defined as the ratios between the yields measured in Pb—Pb collisions, normalized to the average number of participant nucleons ⟨N$_{part}$⟩, and the corresponding quantities in pp interactions at the same energy(*).

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

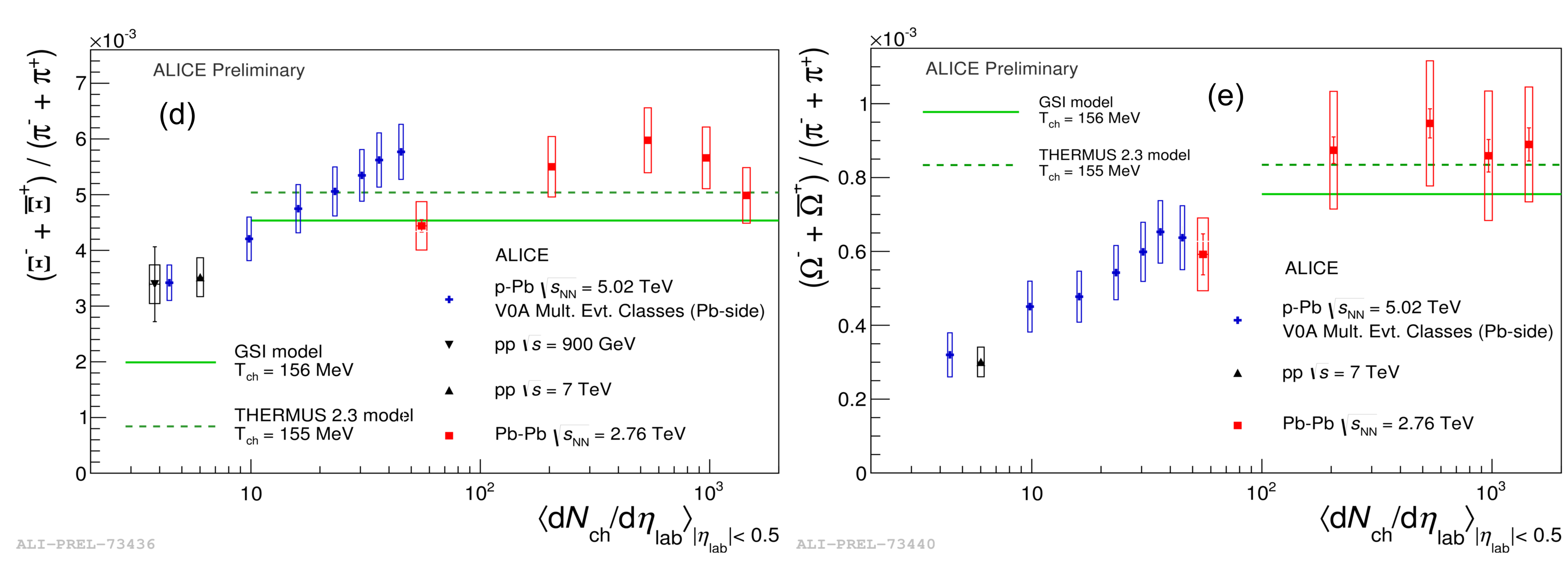
Main findings:

- enhancements for all the cascades (particles and anti-particles) are observed also at the LHC energy and their magnitude increases when going from peripheral to most central collisions;
- as already seen at lower energies, they follow the hierarchy based on the strangeness content of the particle: Ω are more enhanced than Ξ;
- confirmed their decreasing trend with increasing centre-of-mass energy, first established when going from SPS to RHIC energies.



Hyperon-to-pion ratio

- Relative production of strangeness in pp increases faster with energy than in A—A going from RHIC to LHC (removal of canonical suppression) [Panel c].
- Increase of Ξ/π and Ω/π from pp to Pb—Pb represents almost half of the Ξ and Ω enhancements as defined by the participant-scaled yields [Panel c].
- Observation of an increase as a function of multiplicity in p-Pb collisions [Panels d and e]:
  - Lowest multiplicity ratio comparable to pp ratios at $\sqrt{s}$ = 0.9[6] and 7[7] TeV
  - Ξ/π reaches values comparable to results from 0-60% most central Pb—Pb collisions
  - Ω/π reaches values close to the results from peripheral Pb—Pb collisions (60-80% class)
  - Enhancement hierarchy dependent on number of strange quarks observed
- Comparison with thermal model predictions (lines show saturation limits based on Grand Canonical approach at two different chemical freeze-out temperatures):
  - Pb—Pb [Panel c]: Andronic et al. (164 MeV, full line), Cleymans et al. (170 MeV, dashed line)
    - ✓ Ratios for N$_{part}$ > 150 match predictions from thermal models with T = 164 MeV
  - p—Pb [Panels d and e]: GSI[6] (156 MeV, full line), THERMUS[7] (155 MeV, dashed line)
    - ✓ High multiplicity Ξ/π values comparable to thermal model limits
    - ✓ Ω/π ratios do not reach equilibrium limit



(*) Note: pp reference values obtained from interpolation: ALICE data at $\sqrt{s}$ = 0.9 and 7 TeV for Ξs, and STAR data at $\sqrt{s}$ = 200 GeV and ALICE at 7 TeV for Ωs, assuming PYTHIA $\sqrt{s}$ dependence.

Results – Nuclear modification factors

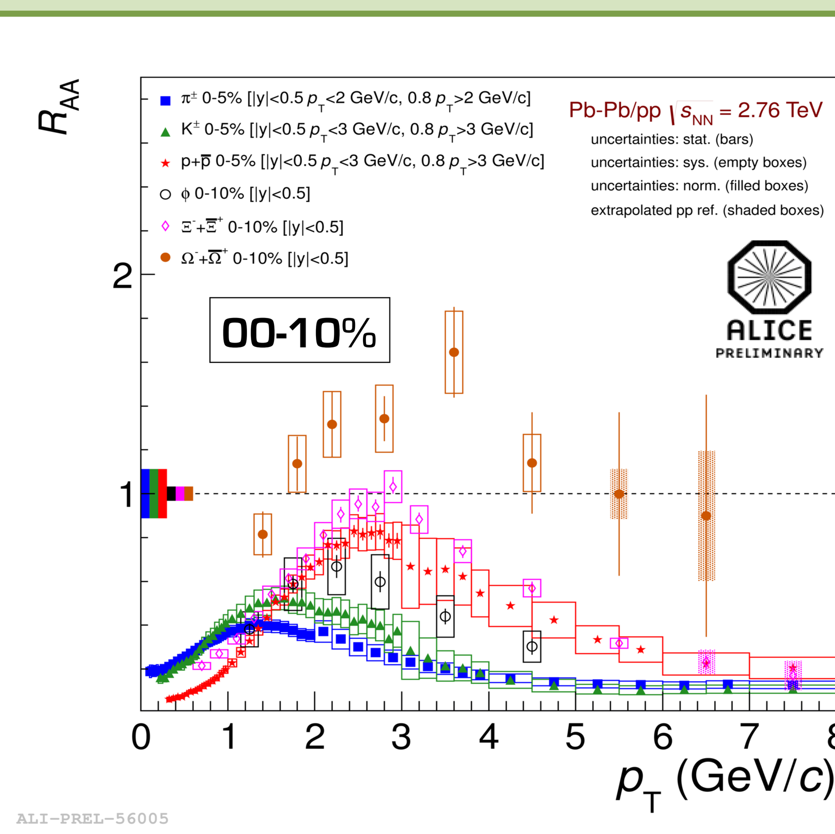
Nuclear modification factor is defined as the ratio between the transverse momentum spectrum in A–A collisions and the cross-section of particle production in pp collisions, normalized to the number of binary collisions.

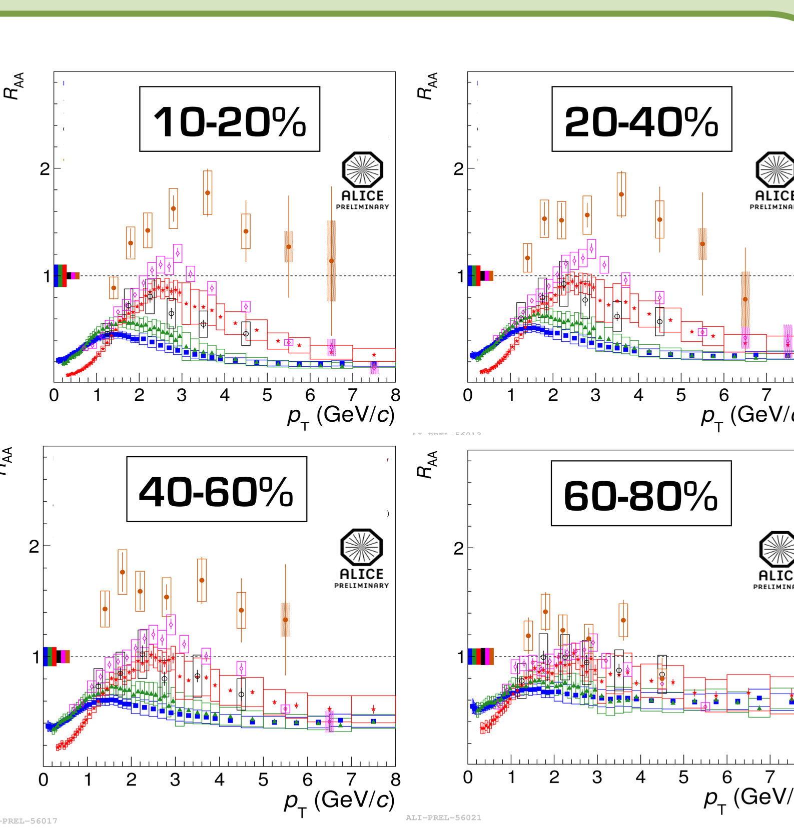
$$R_{AA} = \frac{1}{N_{coll}} \frac{(d^2N / dydp_T)_{A-A}}{(d^2\sigma_{INEL} / dydp_T)_{pp}}$$

R$_{AA}$ = 1 → No medium interaction.

Main findings:

- At high p$_T$, Ξ R$_{AA}$ behaves similarly to the other particles → No mass particle dependency.
- Mass ordering at mid-p$_T$ → R$_{AA}$(p) < R$_{AA}$(Ξ) < R$_{AA}$(Ω) and R$_{AA}$(π) < R$_{AA}$(K).
- Effect of strangeness enhancement on the Ω (and Ξ).
- R$_{AA}$ as a function of centrality follows a trend similar to other particles.





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