KRUGER 2012:

Workshop on Discovery Physics at the LHC

Kruger National Park, South Africa, December 3-7, 2012

Strangeness in ALICE

Domenico Elia

INFN, Bari (Italy)

on behalf of the ALICE Collaboration

Contents

- Measuring strangeness with ALICE:
  - Physics motivation
  - Experimental apparatus
  - Strange particle detection

- Results:
  - Spectra, Model comparisons in pp
  - Spectra, Ratios, Thermal model comparisons in Pb-Pb
  - Strangeness enhancement
  - Collectivity: elliptic flow (v_2)
  - High p_T: nuclear modification factor (R_{AA})

- Summary and prospects

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More on Strangeness at KRUGER 2012:

- Charged kaons (R. Preghenella)
- Strange resonances (H. Oeschler)
- Hypertritons (N. A. Martin)
- Strange hadron flow (M. Krzewicki)

- Results:
  - Spectra, Model comparisons in pp
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Physics motivation

- Why measuring Strangeness:
  - no net strangeness content in the colliding system
  - strange quark relatively light and abundantly produced
    - → handle on the particle production mechanisms
    - → understanding hadrochemistry of the system

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- Strangeness in pp collisions:
  - benchmark for heavy-ion physics
  - handle on particle production mechanisms
    - → low and medium p_T (< 6 GeV/c): soft interactions
    - → high p_T (> 6 GeV/c): high transferred momenta (pQCD)

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  - benchmark for heavy-ion physics
  - handle on particle production mechanisms
    - → low and medium p_T (< 6 GeV/c): soft interactions
    - → high p_T (> 6 GeV/c): high transferred momenta (pQCD)
  - constrain QCD-inspired models (eg PYTHIA)
  - strangeness production vs. charged multiplicity

Physics motivation

- Strangeness in Pb-Pb collisions:
  - strange quarks light enough to be produced thermally in QGP:
    - → compare production rates with the thermal model predictions
    - → check if strangeness production enhanced in Pb-Pb wrt pp

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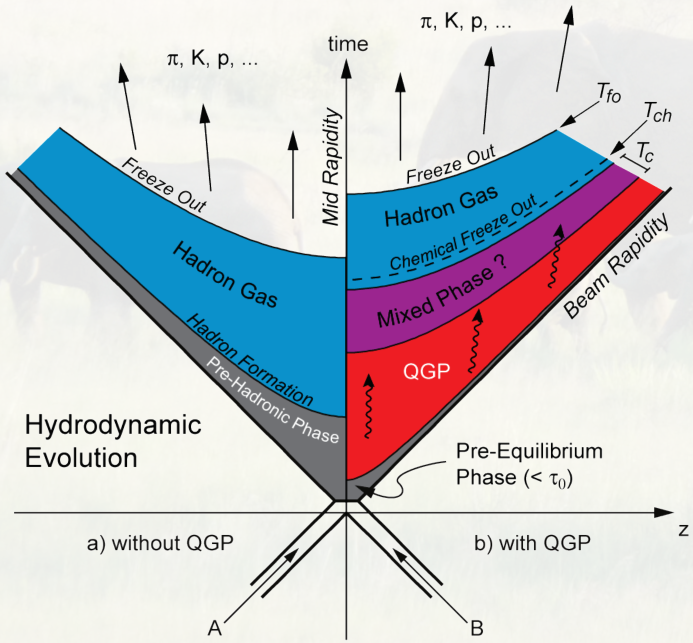
  - strange quarks light enough to be produced thermally in QGP:
    - → compare production rates with the thermal model predictions
    - → check if strangeness production enhanced in Pb-Pb wrt pp
  - insights in the whole evolution of the system, eg:

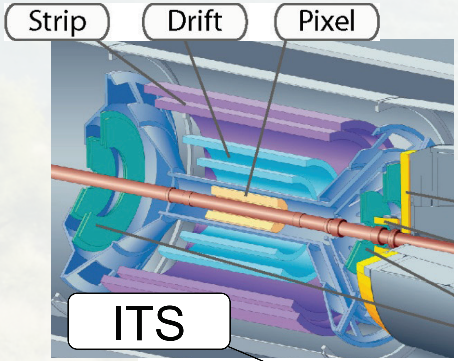


Multi-strange baryons spectra:
small hadronic cross section, early decoupling
→ probe early (pre-equilibrium) stages

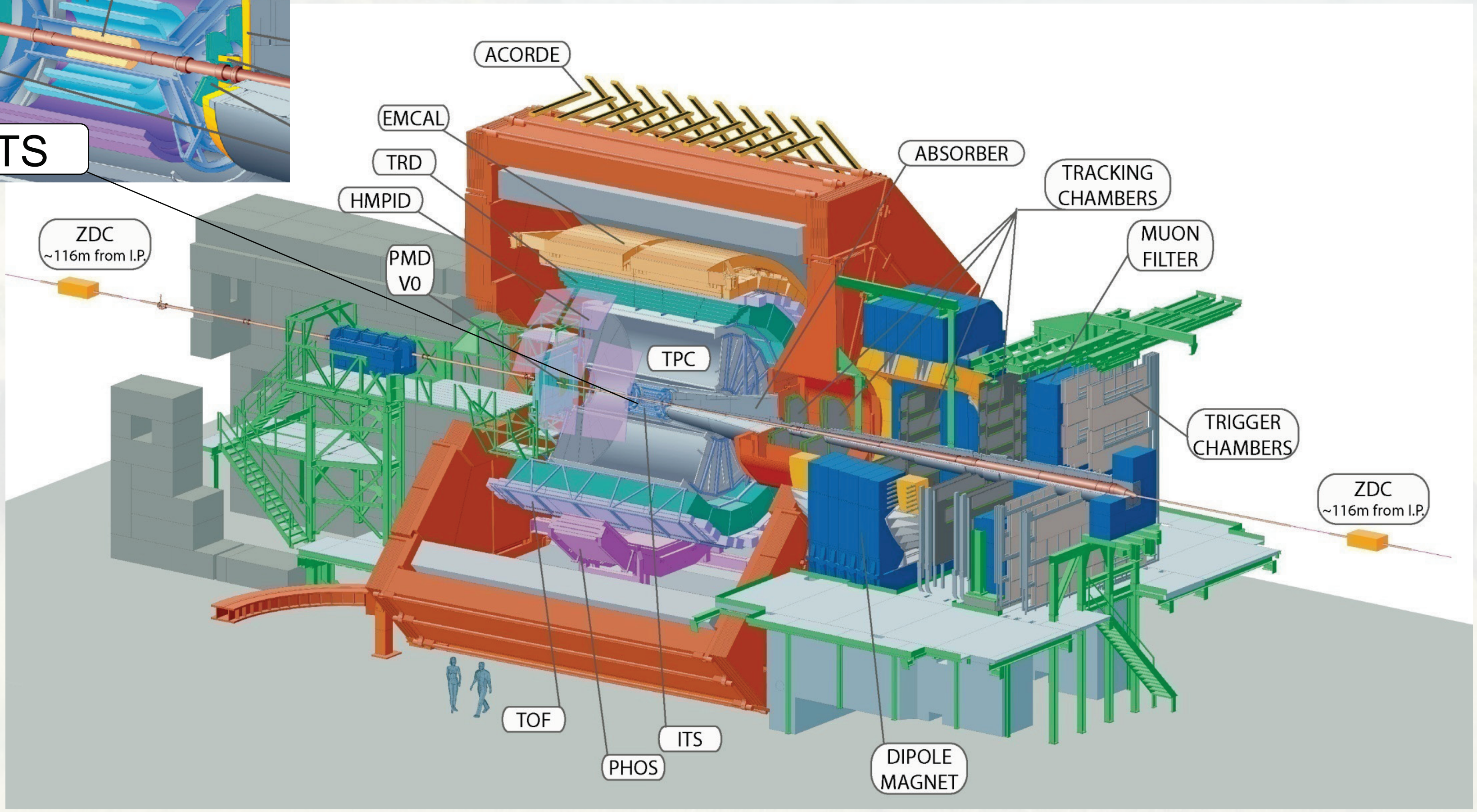
Strange particle flow:
→ probe hydrodynamics (thermalization)

Also:
High p_T spectra (R_{AA}), Resonances,
Jet flavour content …

Experimental apparatus

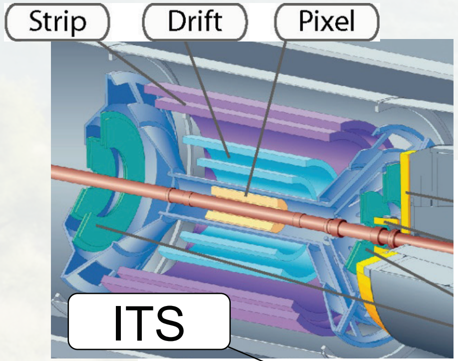


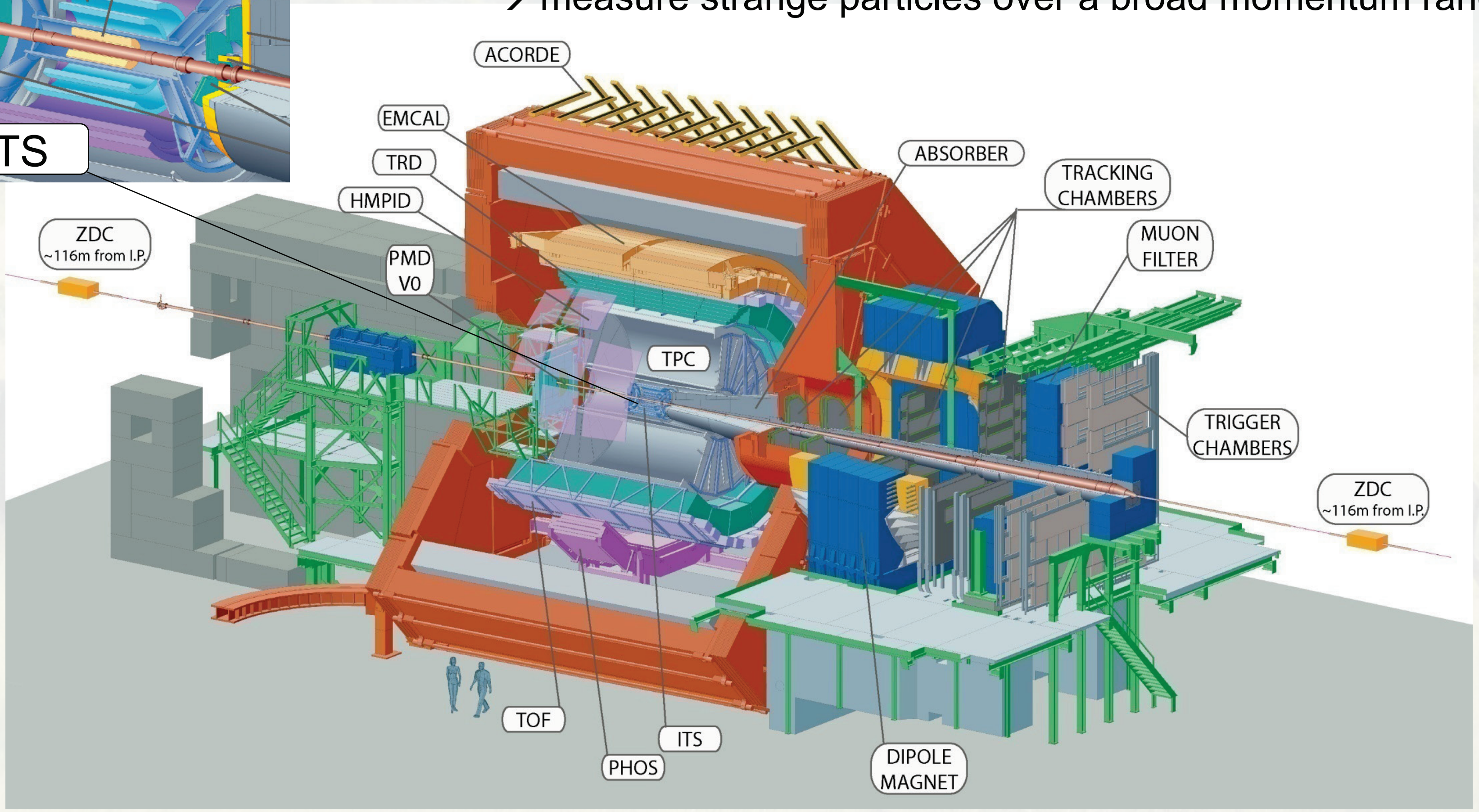
A Large Ion Collider Experiment at the LHC



Experimental apparatus

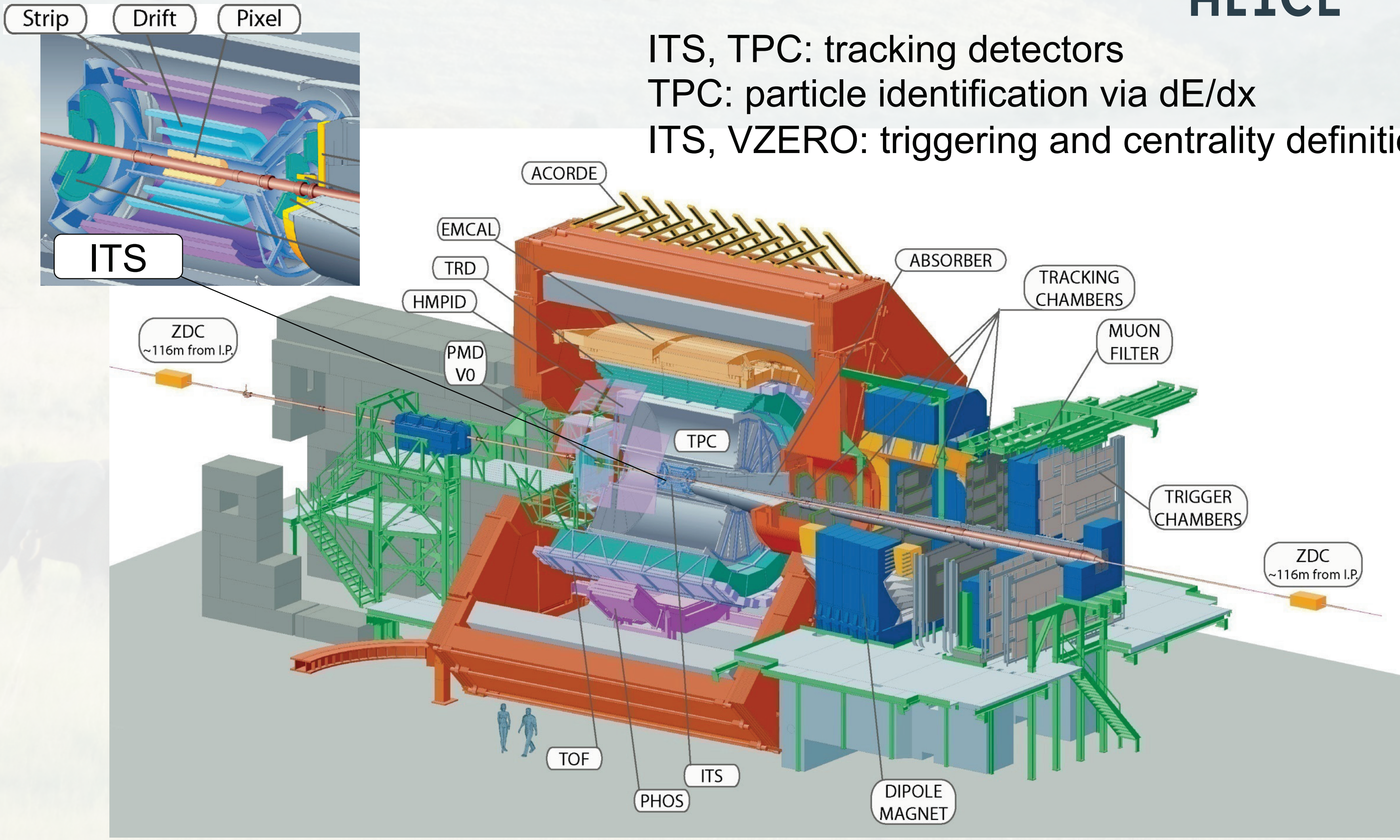
Low material budget in the central region
Complementary particle identification techniques
→ measure strange particles over a broad momentum range





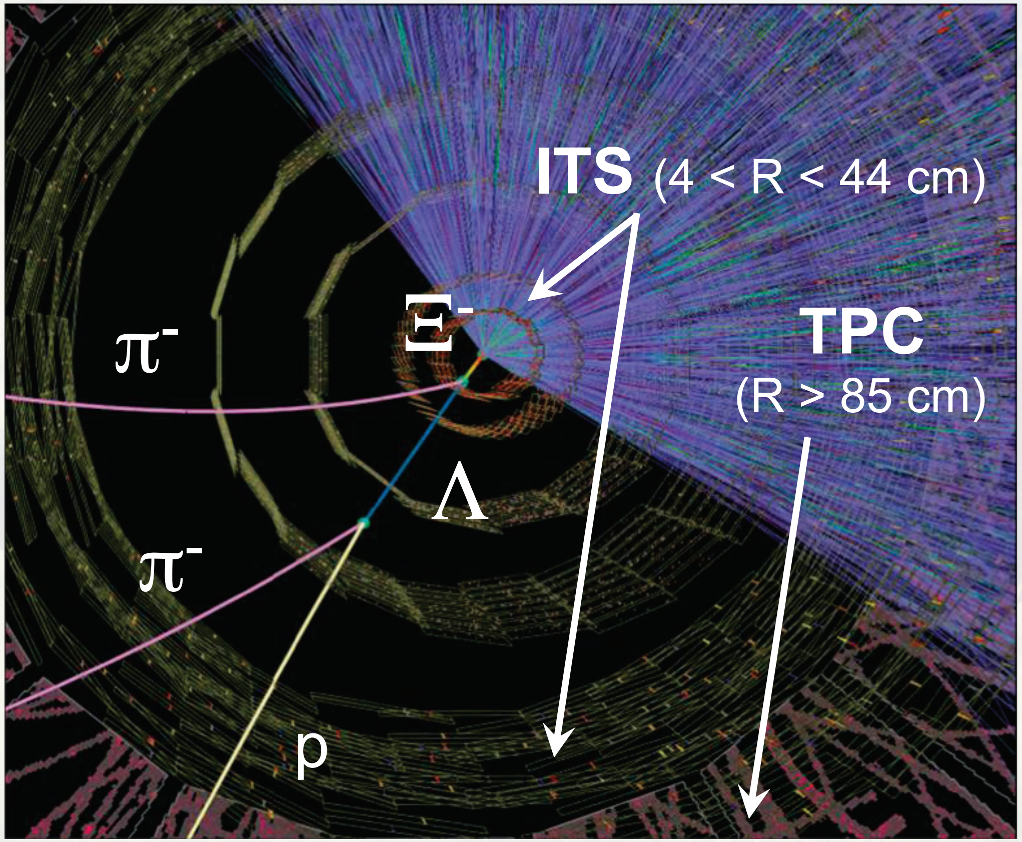
Experimental apparatus

ITS, TPC: tracking detectors
TPC: particle identification via dE/dx
ITS, VZERO: triggering and centrality definition



Strange particle detection

Reconstruction of weak decays into charged particles:



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

Single-strange

$K_S^0 \rightarrow \pi^+ + \pi^-$ (B.R. 69.2%)

$\Lambda \rightarrow p + \pi^-$ (B.R. 63.9%)

$\overline{\Lambda} \rightarrow \overline{p} + \pi^+$ (B.R. 63.9%)

Multi-strange

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

$\overline{\Xi}^+ \rightarrow \overline{\Lambda} + \pi^+ \rightarrow \overline{p} + \pi^+ + \pi^+$ (B.R. 63.9%)

$\Omega^- \rightarrow \Lambda + K^- \rightarrow p + \pi^- + K^-$ (B.R. 43.3%)

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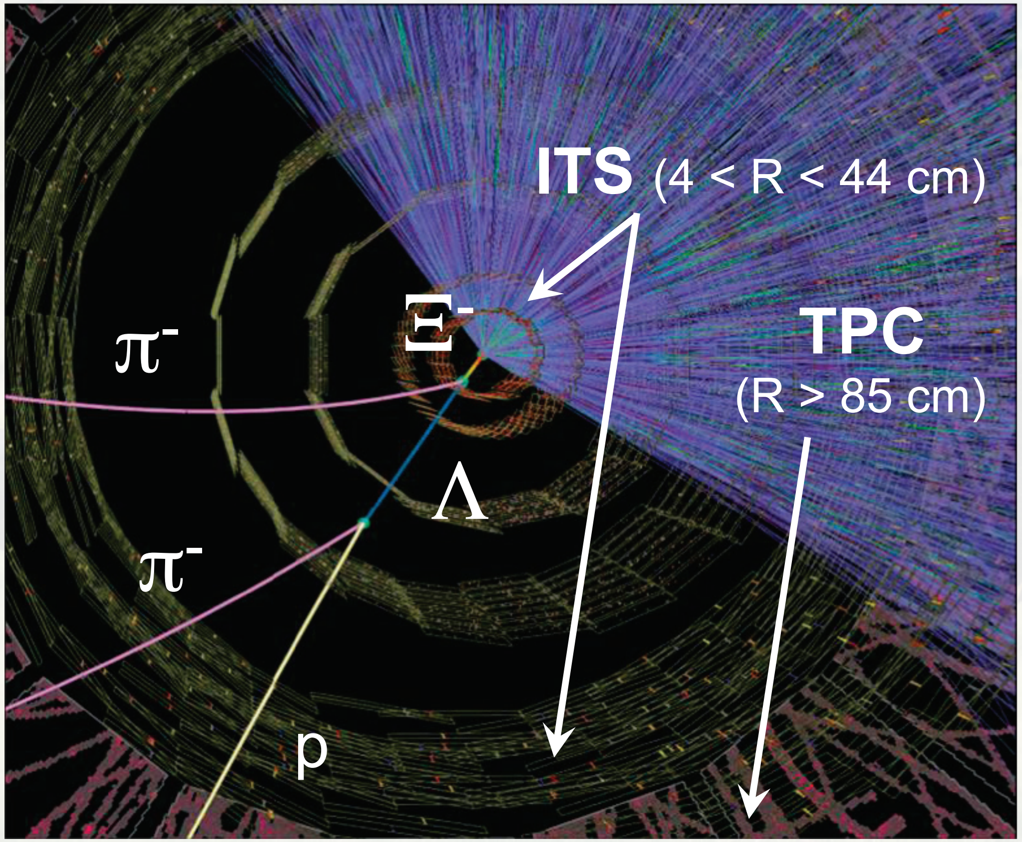

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Track based selections:
- → topological selections
- → TPC dE/dx selection
- → competing decay rejection

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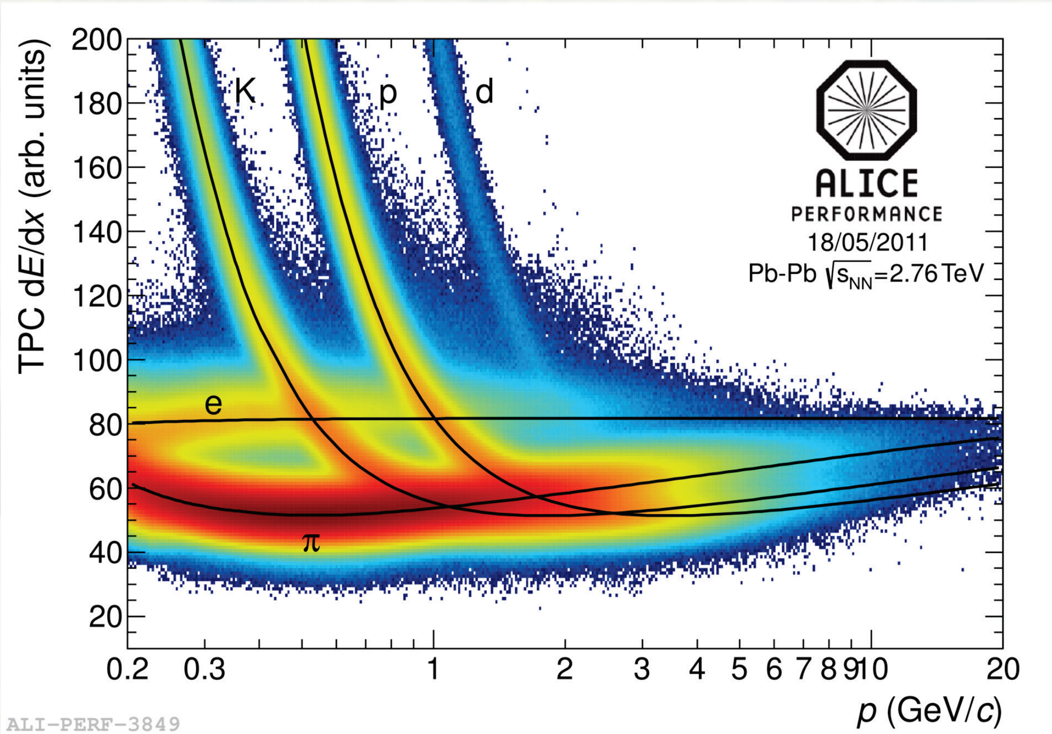

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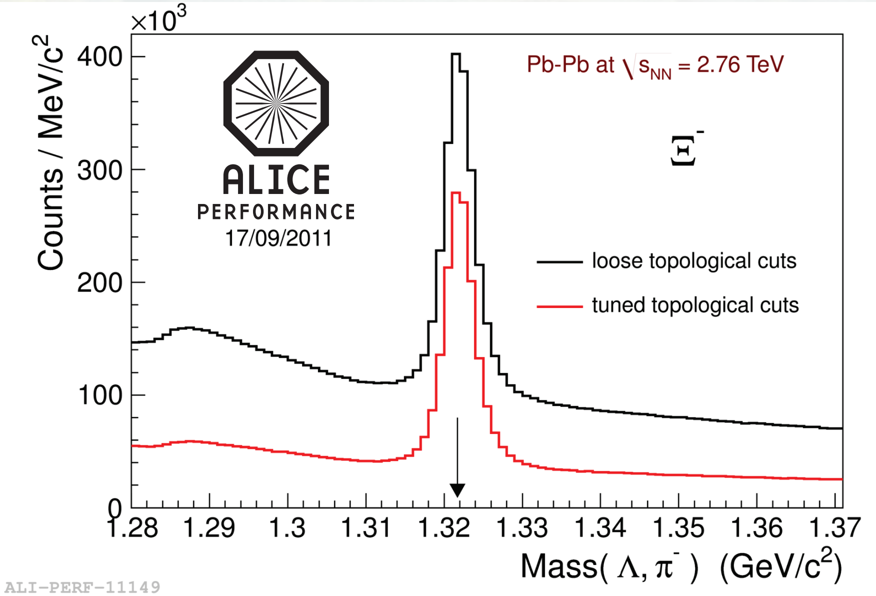
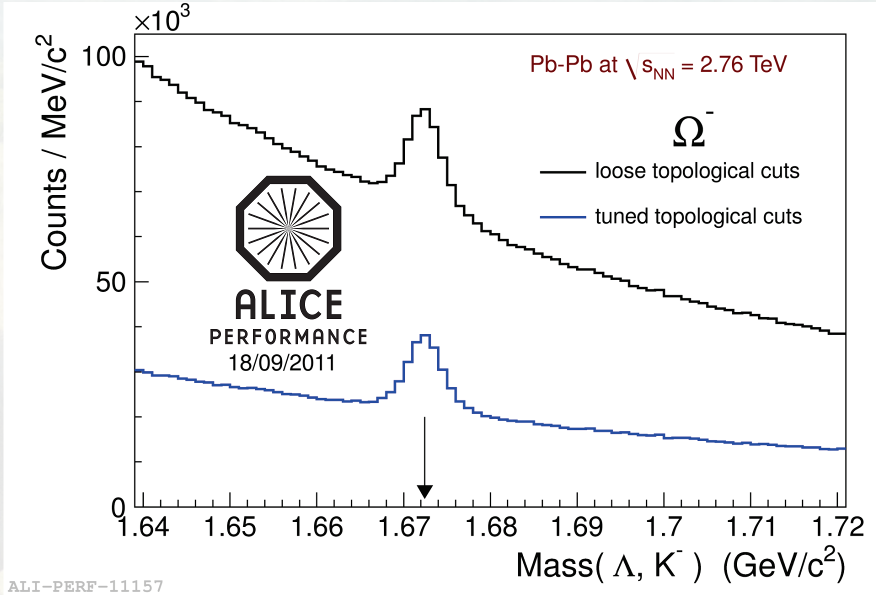
Strange particle detection

Examples of invariant mass peaks:





Strange particle detection

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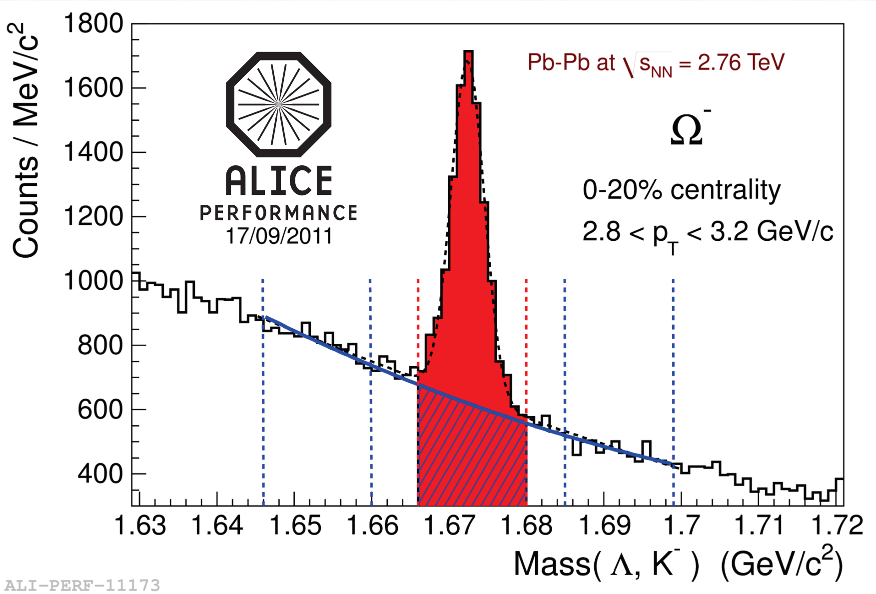
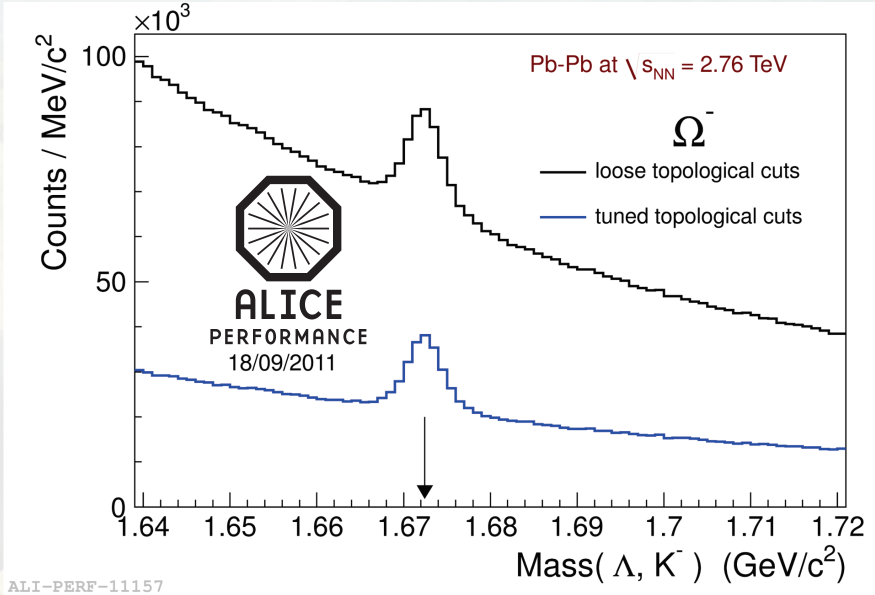


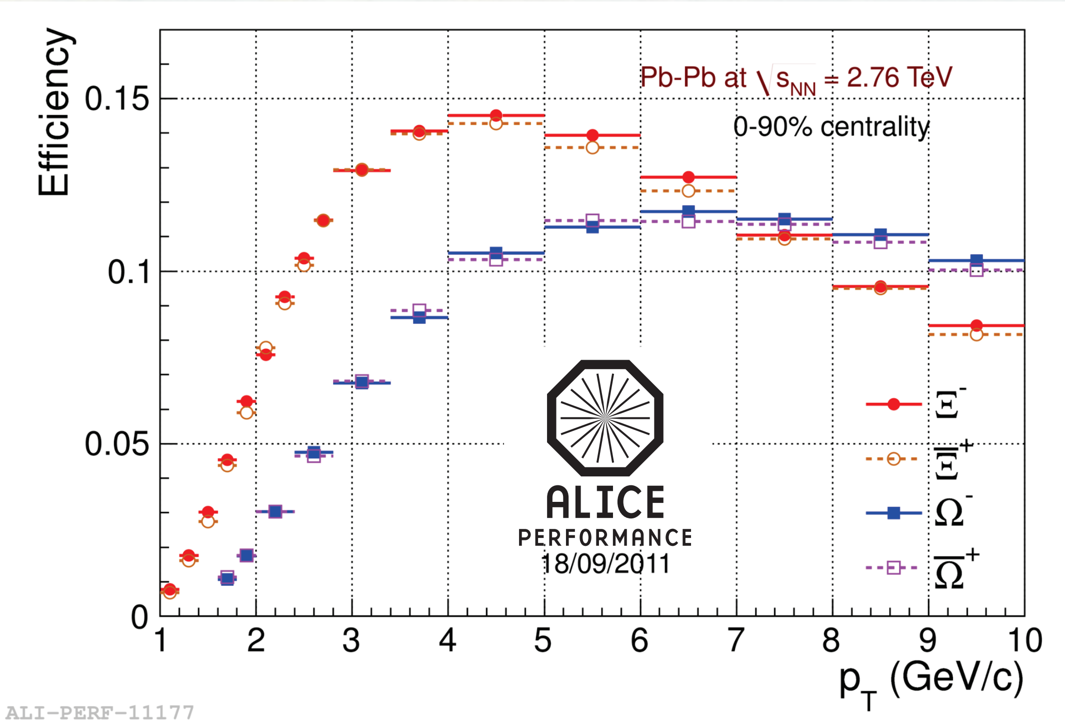


Signal extraction in p_T bins:

→ fit gaussian peak and background shape to define peak region
→ fit background (side regions) with a smooth function
→ subtract background from the integral of the peak region

Strange particle detection

Examples of efficiency p_T dependence:



For multi-strange baryons:

→ use Hijing enriched with multistrange particles

→ checked: no bias on the final efficiency

Strange particle detection

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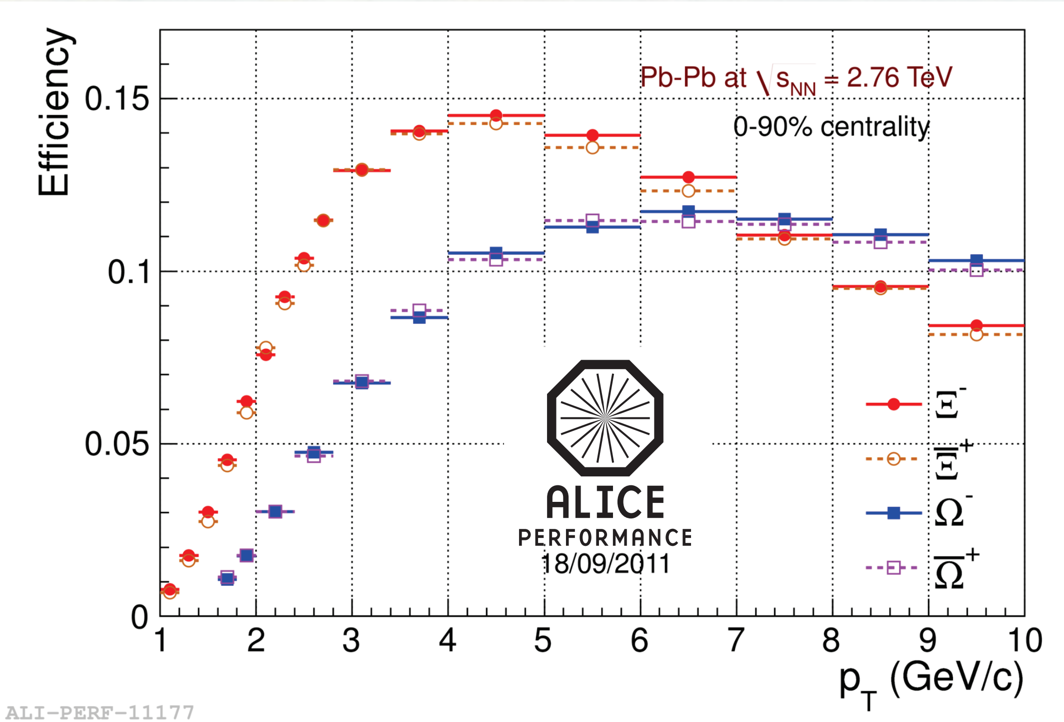
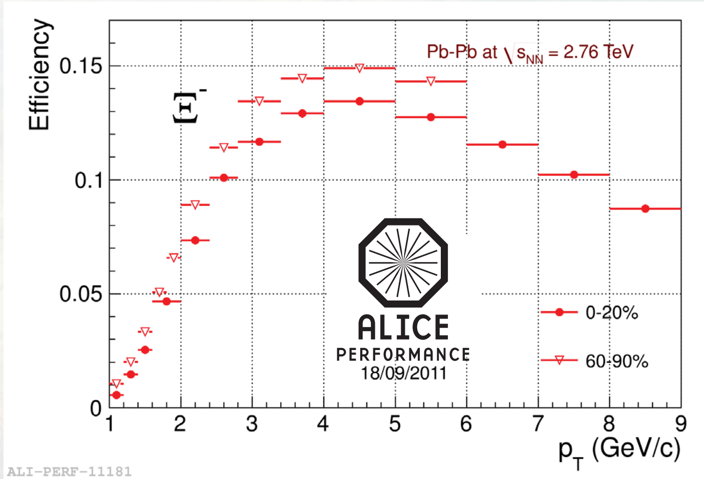
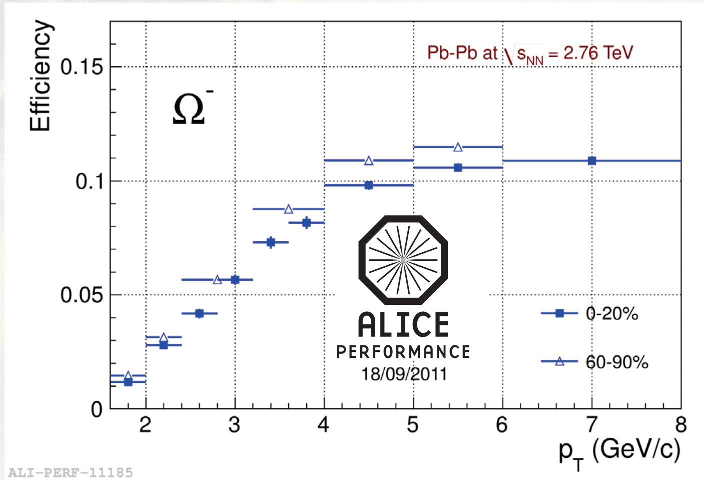


Centrality dependence





For multi-strange baryons:

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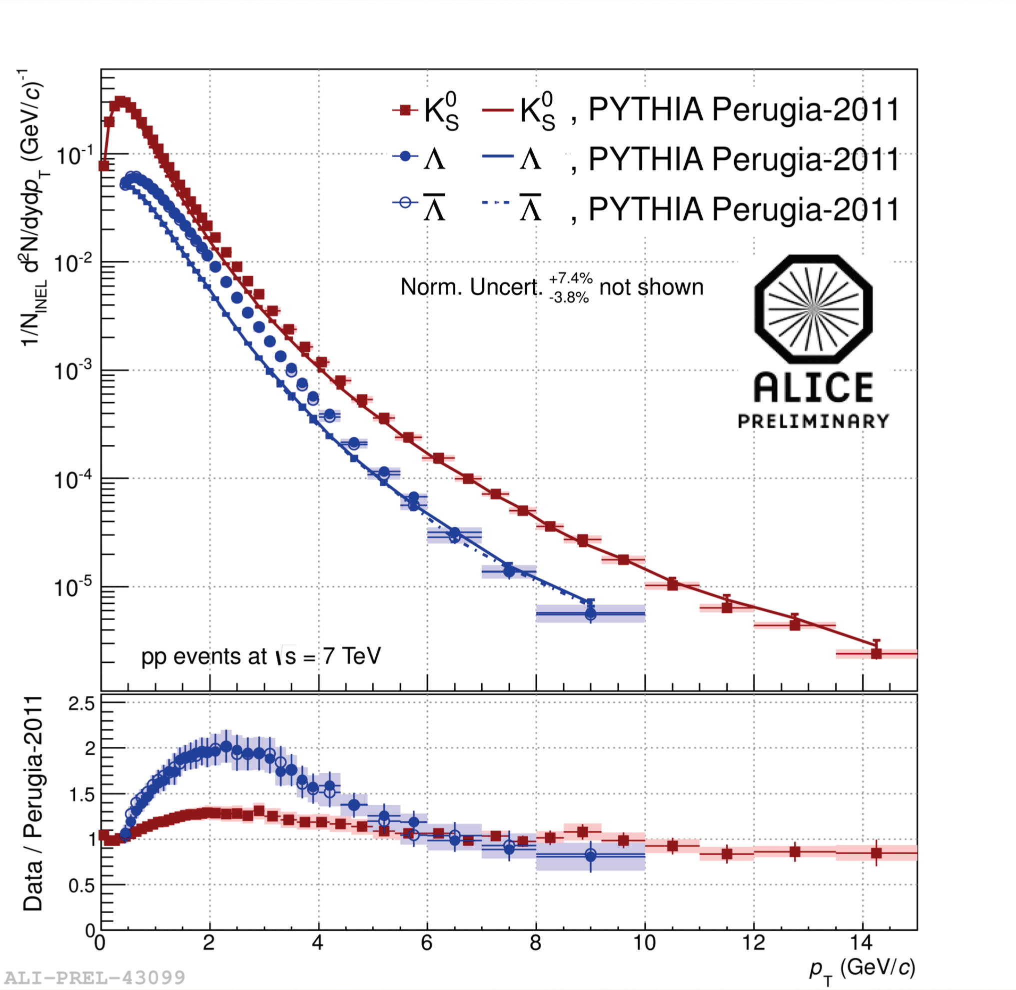
  - High p_T: nuclear modification factor (R_{AA})
- Conclusions and prospects

Single-strange spectra



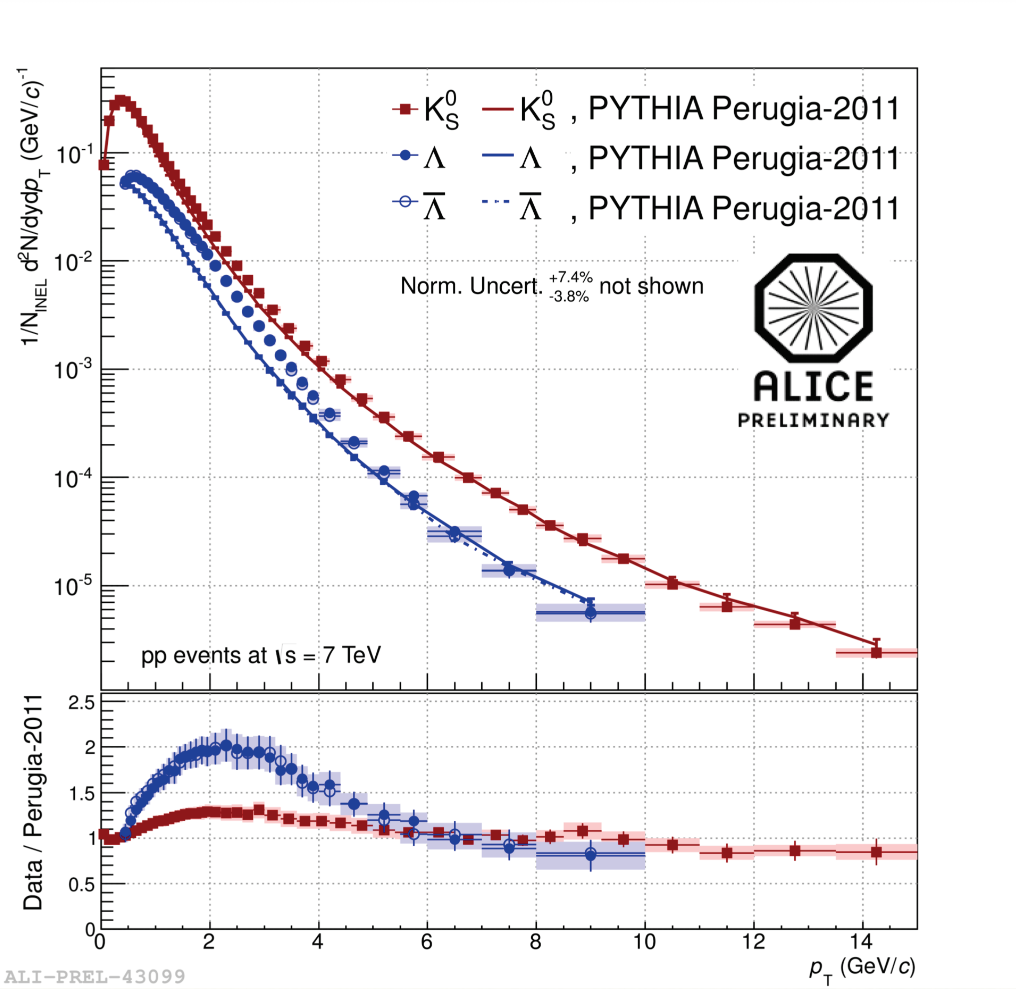
Range of p_T measurements:

→ $0.0 < p_T < 15.0$ GeV/c for K^0_s

→ $0.4 < p_T < 10.0$ GeV/c for Λ

Antiparticle/particle ≈ 1

Single-strange spectra



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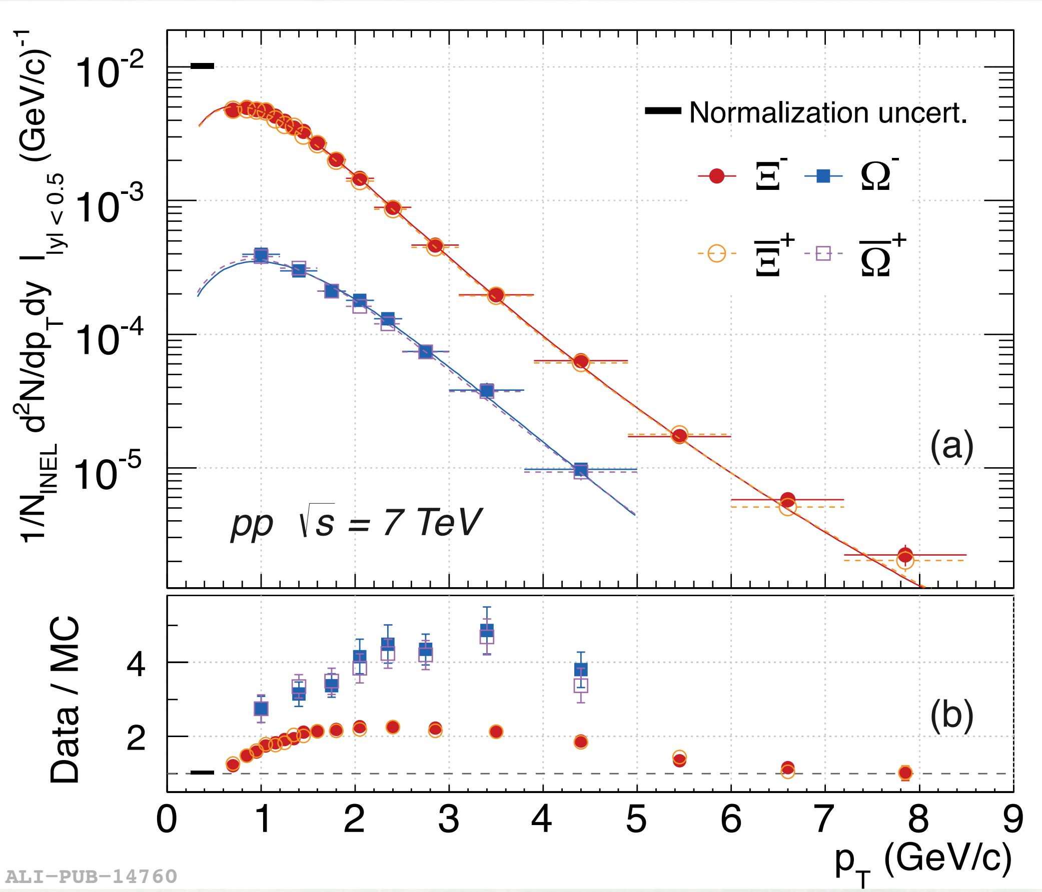
Comparison with PYTHIA Perugia-2011:
→ problems in the soft region (more for Λ)
→ better agreement $p_T > 6$ GeV/c
→ consistent with other observations (ϕ, K^{*0}):
http://arxiv.org/abs/1208.5717

→ See talk on resonances by Helmut Oeschler

Multi-strange spectra



PLB 712, 309-318, (2012)

Range of p_T measurements:

→ $0.6 < p_T < 8.5$ GeV/c for Ξ

→ $0.8 < p_T < 5.0$ GeV/c for Ω

precise cascade measurements!

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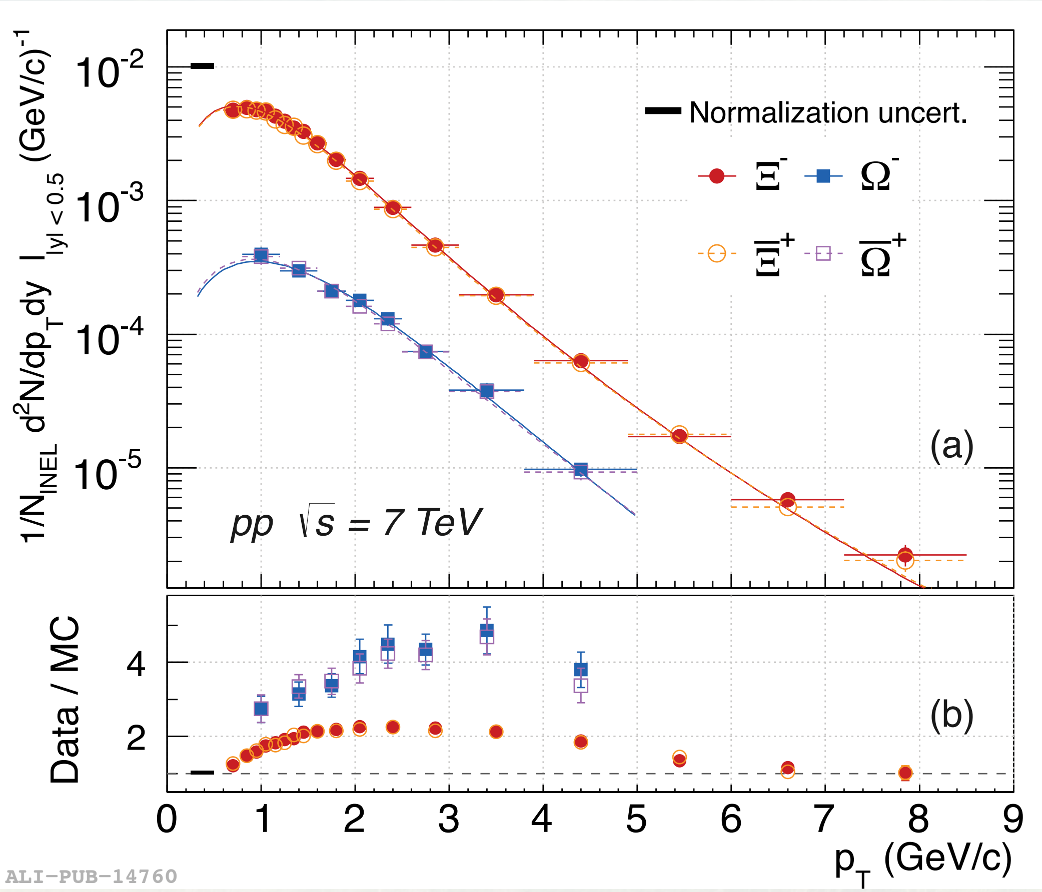

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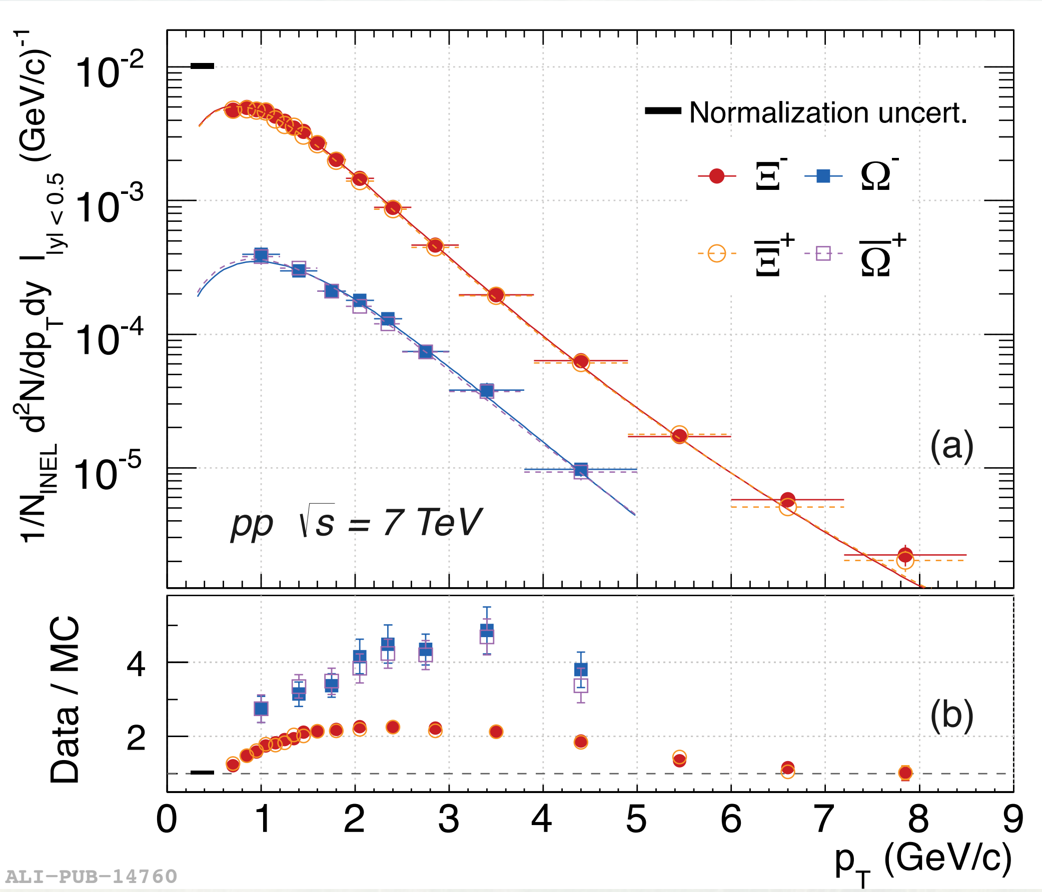
Comparison with PYTHIA Perugia-2011:
tuned with measured multiplicity
pop-corn OFF
adjust strange di-quark probability
→ deviations in the soft region (increasing with strangeness)
→ hint of agreement for $p_T > 7$ GeV/c

Multi-strange spectra



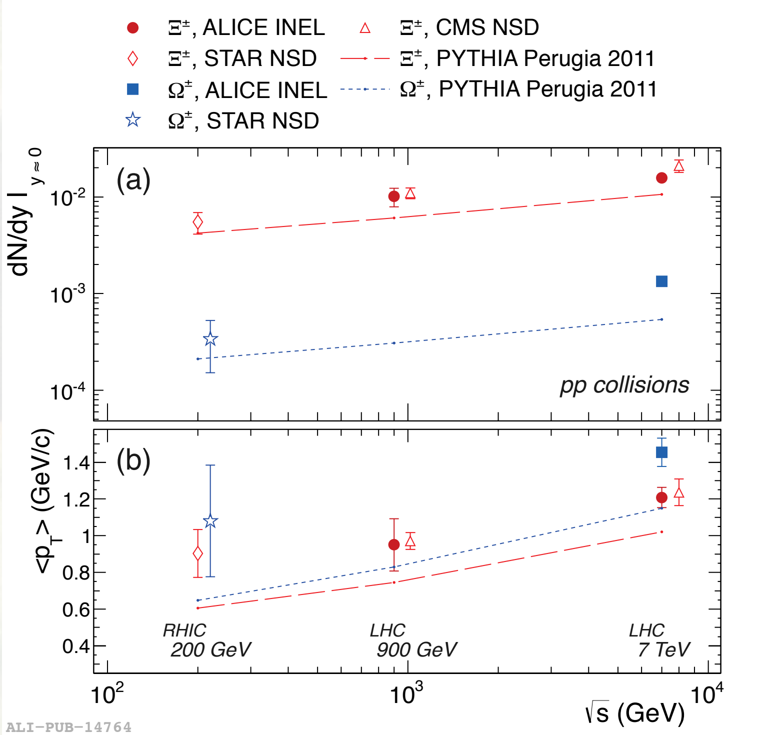
PLB 712, 309-318, (2012)

Excitation function:

→ PYTHIA OK, ~ $s^{0.25}$

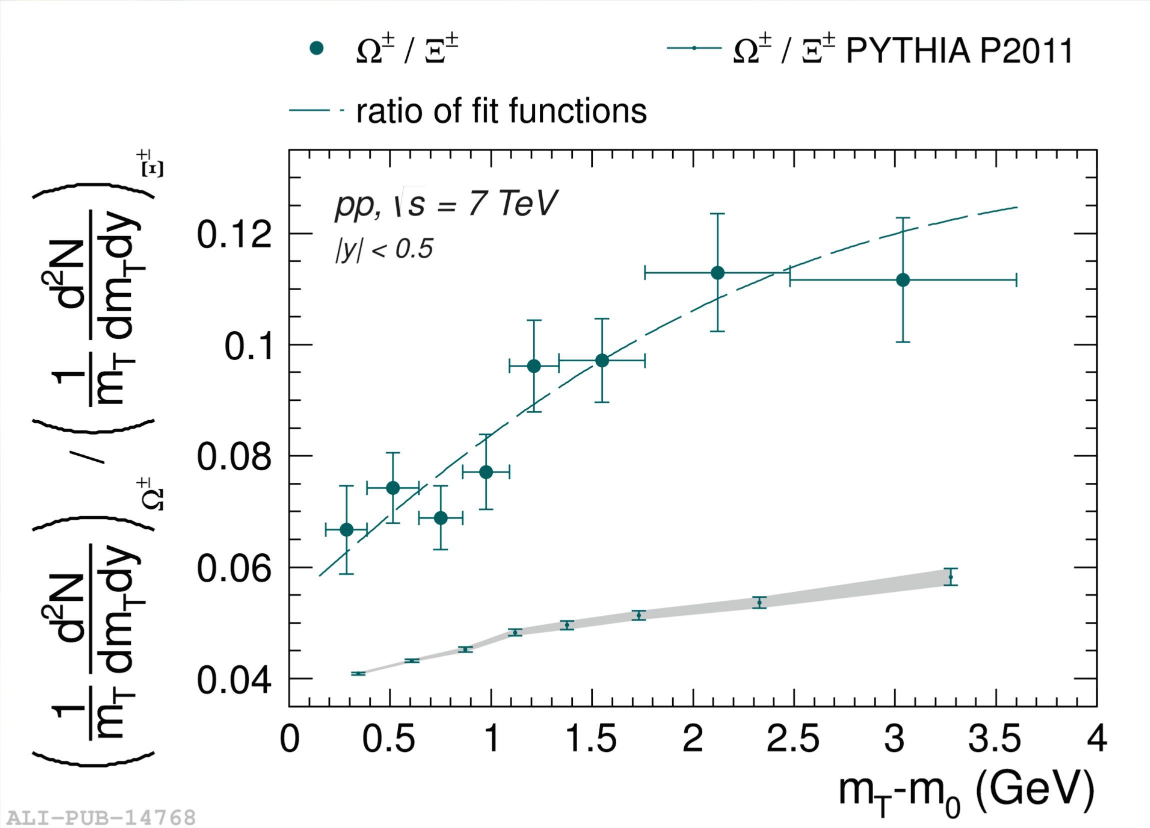
($s^{0.22}$ for charged multiplicity)

Yields, $<p_T>$ underestimated



Multi-strange spectra

Ratio of combined $\Omega^{\pm}$(sss) and $\Xi^{\pm}$(dss) spectra:



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$m_T - m_0$:
→ to remove mass effect
→ look at d- vs s-quark

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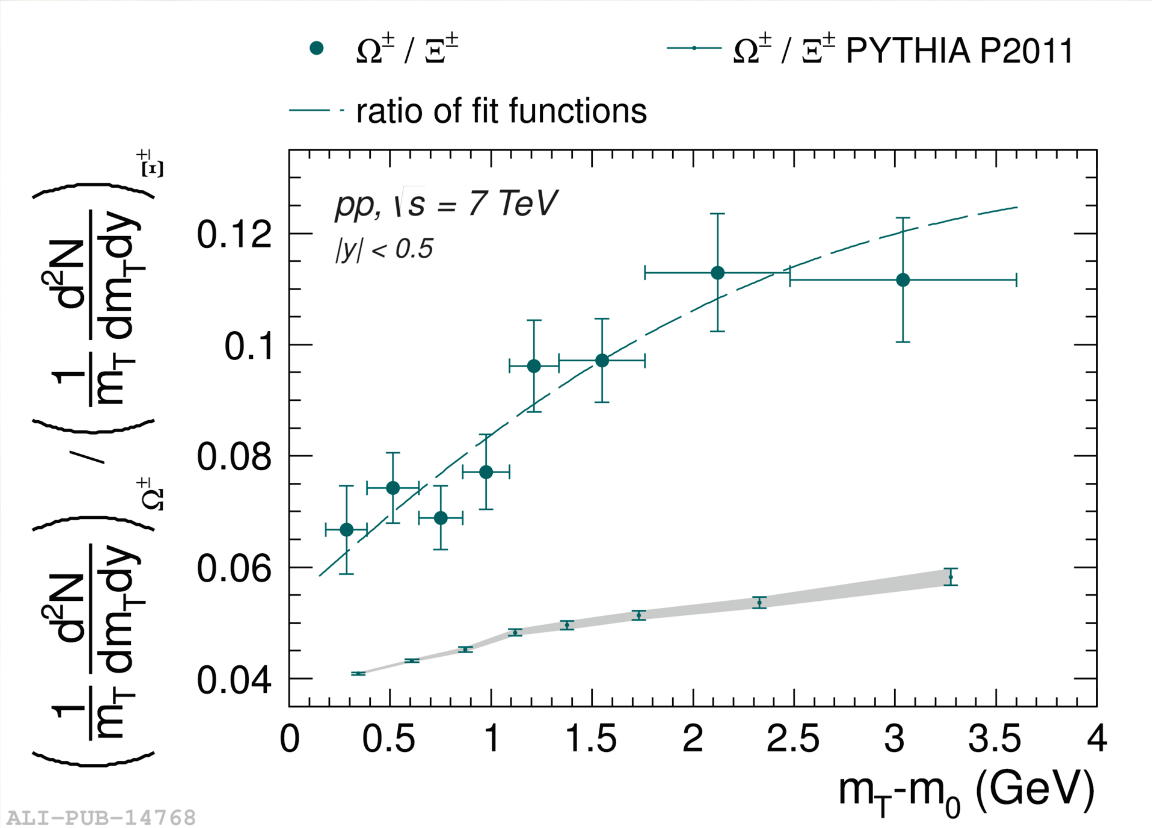

PLB 712, 309-318, (2012)

m_T - m_0:
→ to remove mass effect
→ look at d- vs s-quark

Easier to produce an s-quark at high p_T ?

PYTHIA Perugia-2011:
→ reproduces shape
→ magnitude off

No evidence for s-quark saturation

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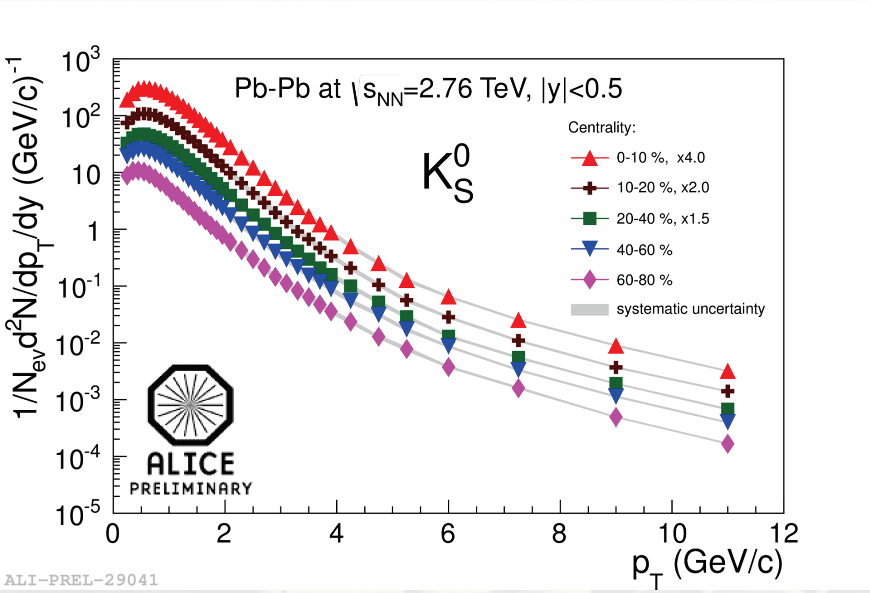
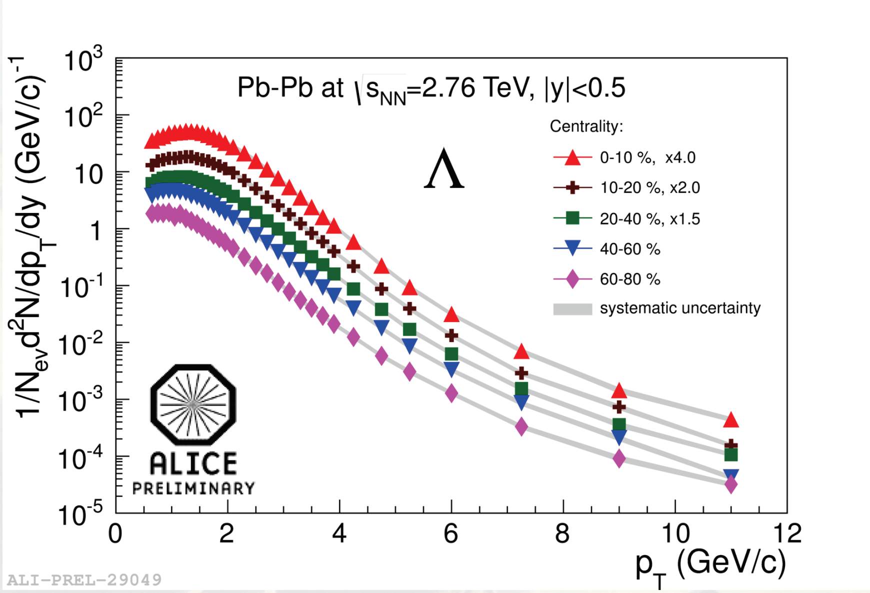




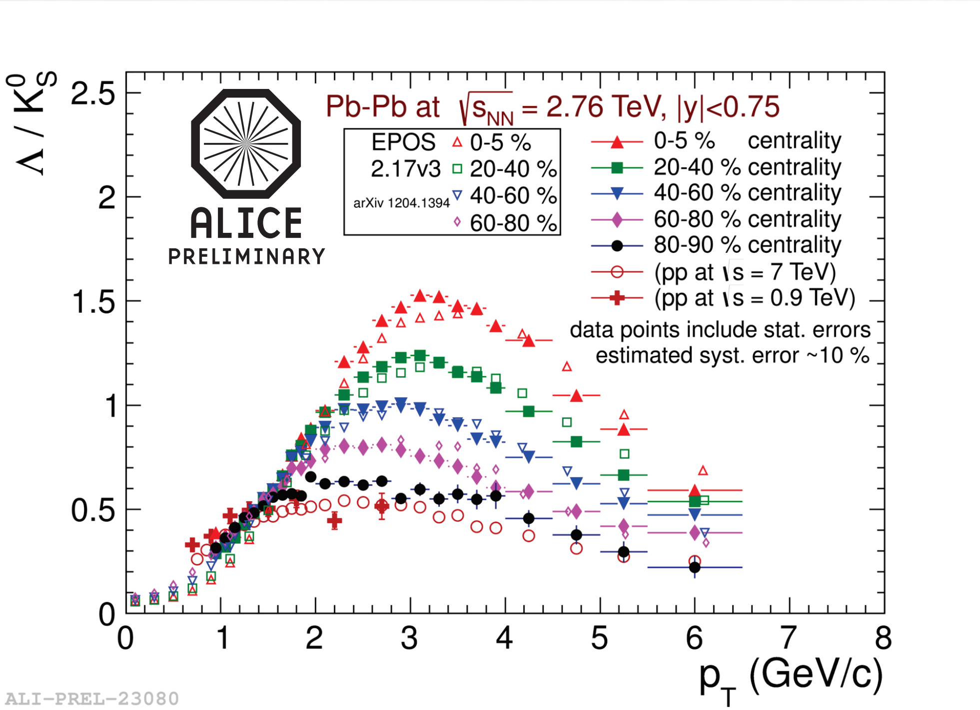
Data sample:

Analysis on ~ 20 M minimum bias events Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV taken in 2010

5 centrality bins, p_T reach of 12 GeV/c

Particle and anti-particle spectra compatible

Baryon to meson ratio



Baryon/meson ratio strongly enhanced:

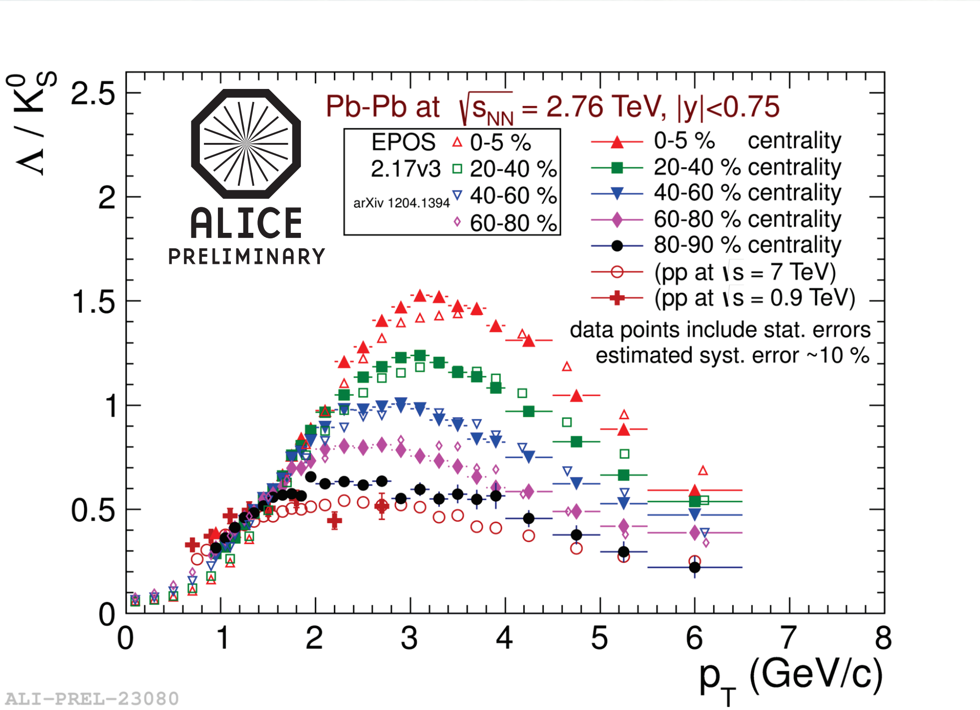
→ increasing with centrality

→ up to x 3 wrt the pp value

→ enhancement still present at 6 GeV/c

→ reproduced by EPOS (also centrality)

Baryon to meson ratio



Slightly larger at the LHC than at RHIC

Maximum shift very small in p_T, despite significant differences in spectra

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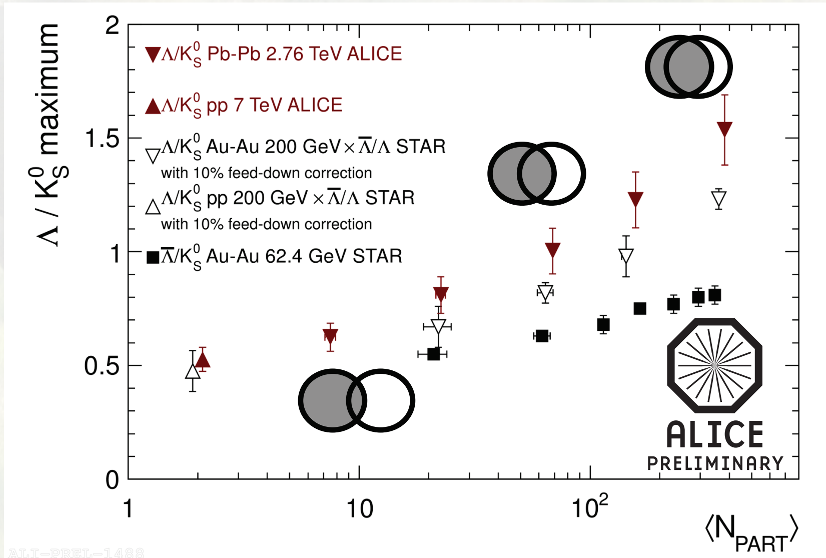
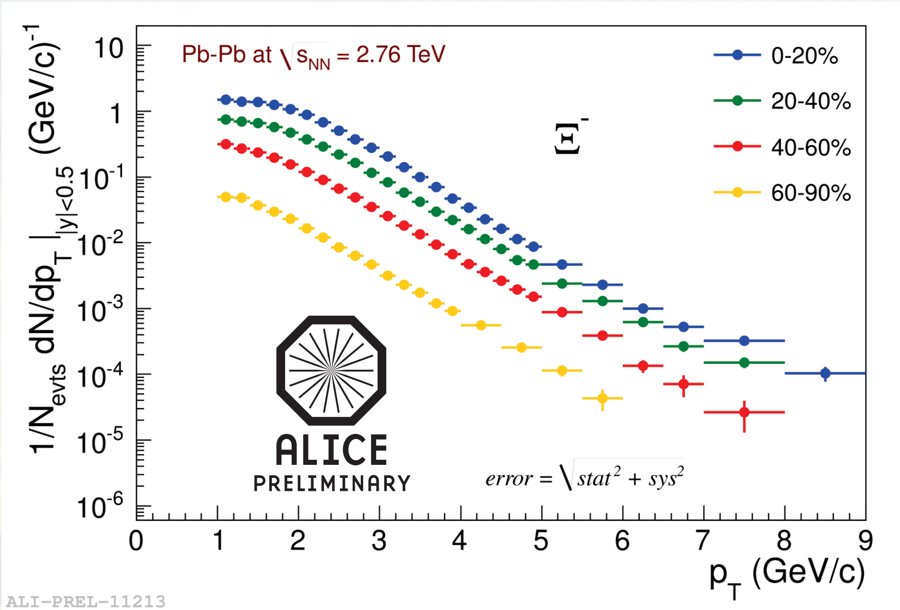
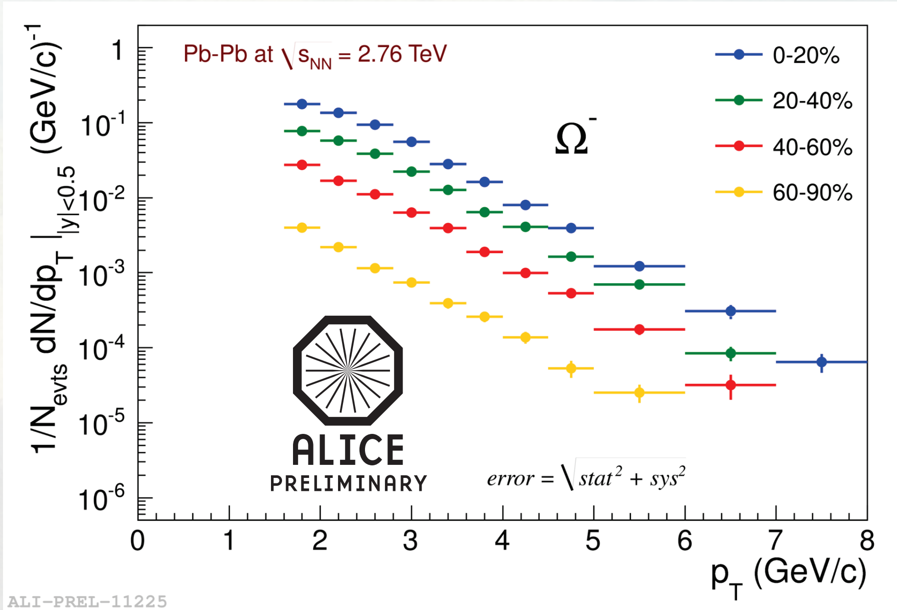


Multi-strange spectra





Data sample:

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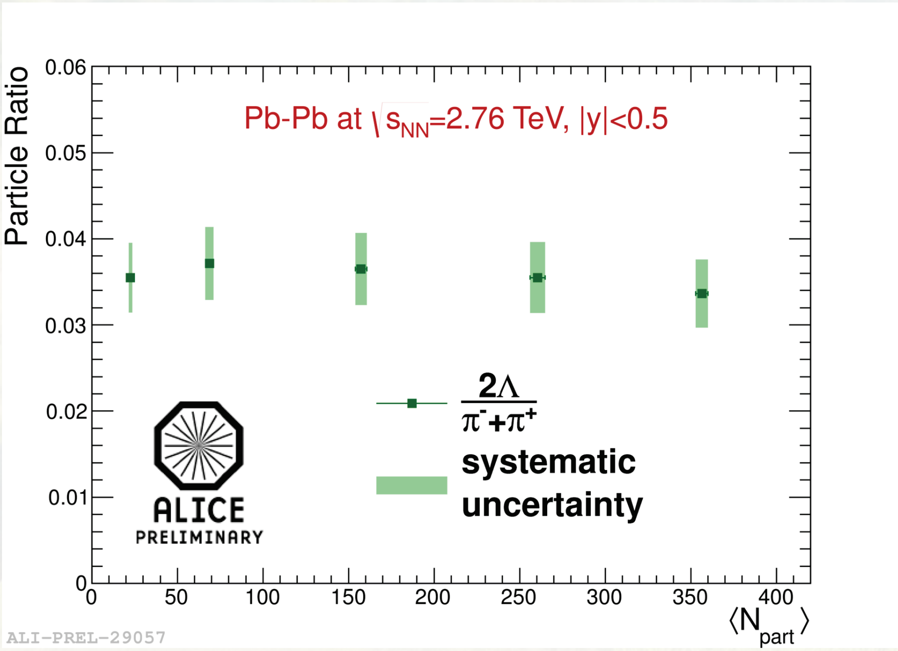
4 centrality bins, p_T reach of 9 (Ξ) and 8 GeV/c (Ω) in 0-20%

Particle and anti-particle spectra compatible

Strange to non-strange ratios

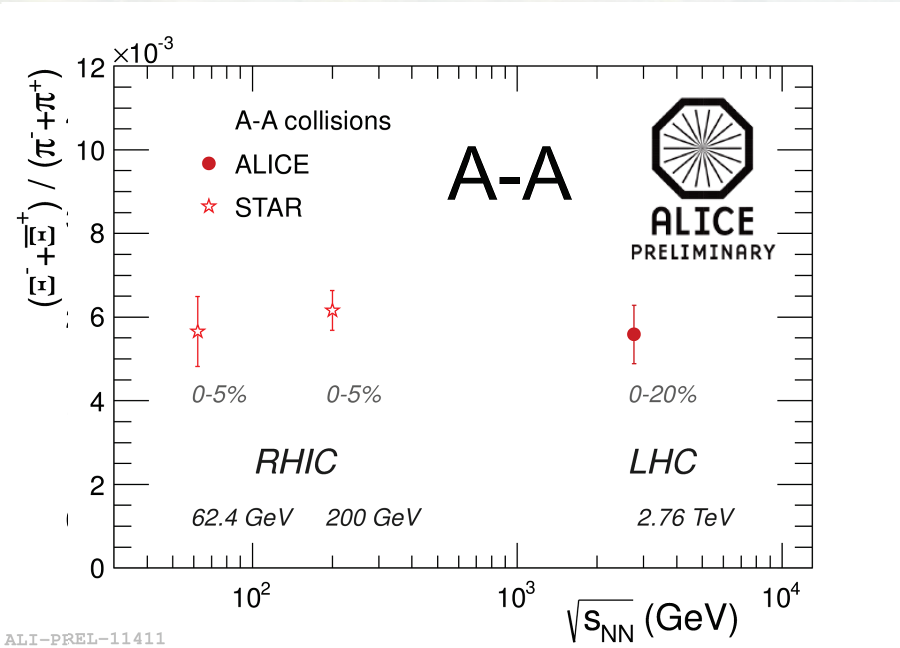
Ratios to pions as a function of centrality:



Λ/π, no significant dependence on centrality

Strange to non-strange ratios

Ratios to pions as a function of centre-of-mass energy:

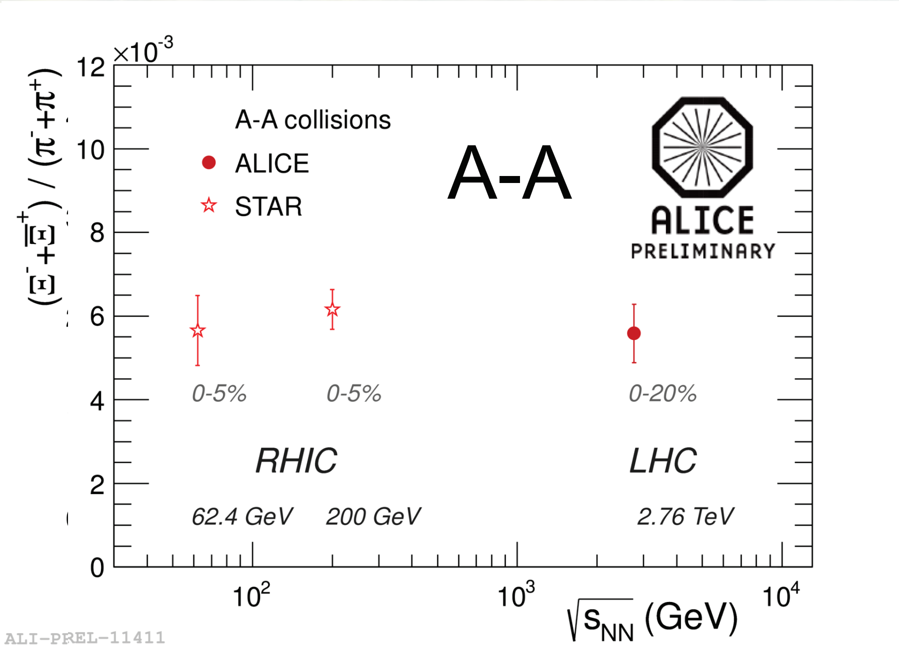


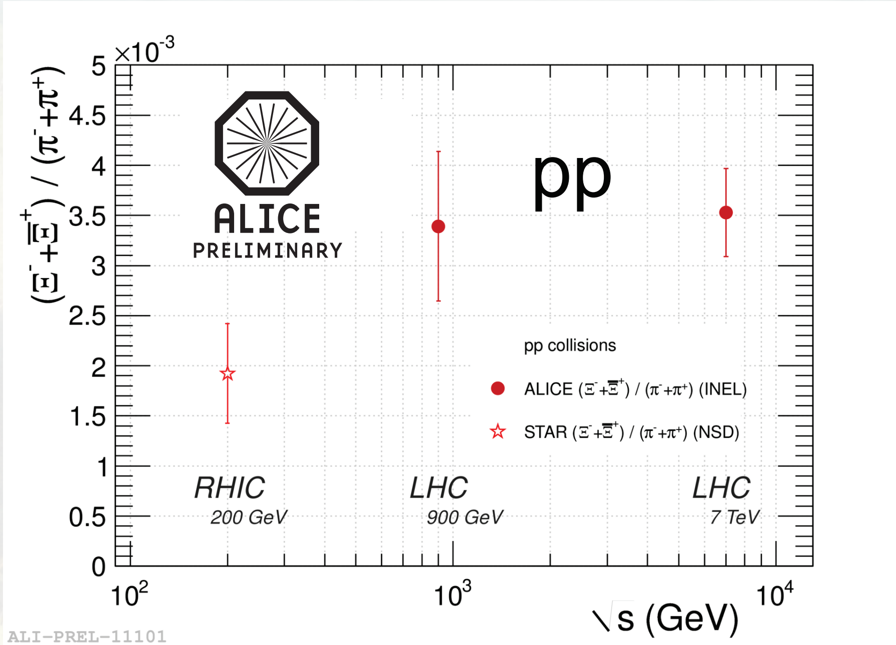
Ξ/π independent of collision energy

Strange to non-strange ratios

ALICE

Ratios to pions as a function of centre-of-mass energy:





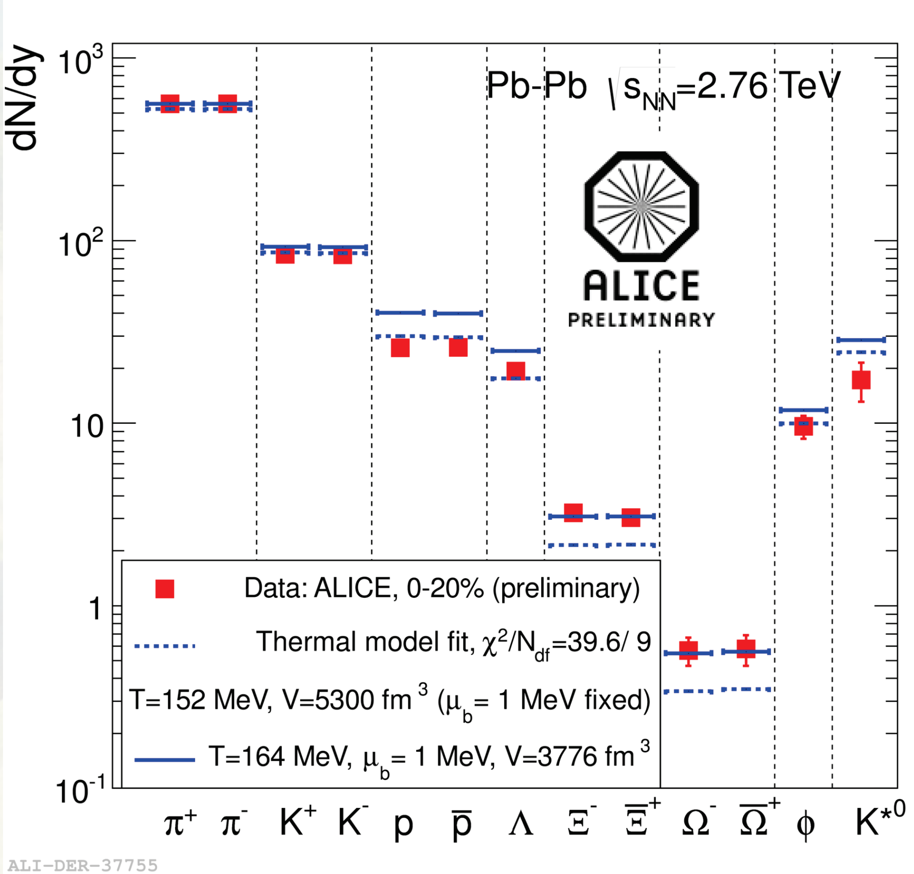
Ξ/π independent of collision energy

Ratio in pp: slightly faster increasing wrt A-A from RHIC to LHC

→ decreasing relative enhancement of A-A wrt pp at LHC

INFN Istituto Nazionale di Fisica Nucleare Sezione di Bari

Thermal model predictions

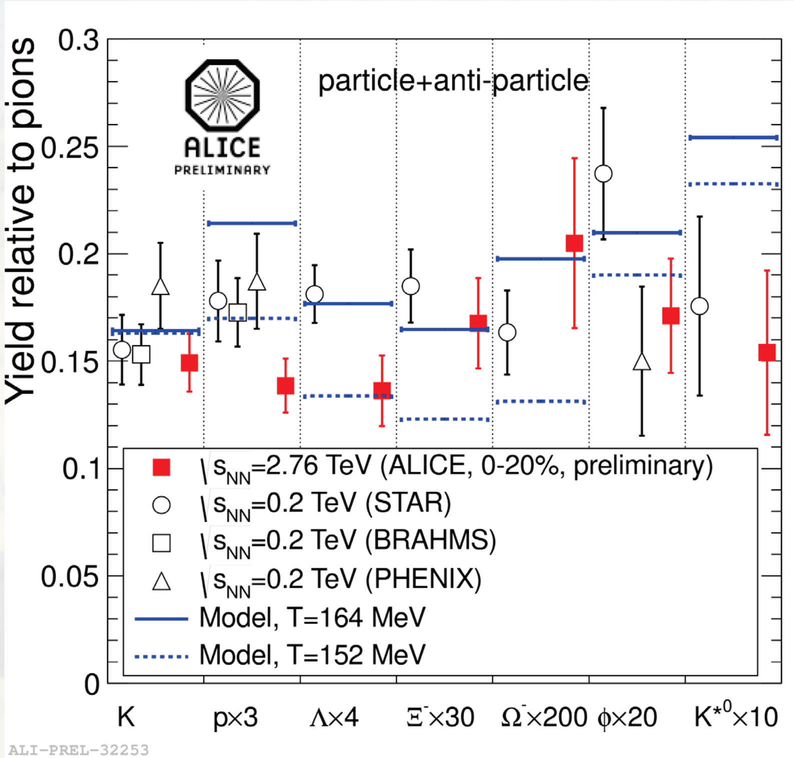


Predicted chemical freeze-out temperature at the LHC: 164 MeV
→ problems with p and Λ yields, ratios

Lower T_{fo} from fit: 152 MeV
(ϕ and K^{*0} not included)
→ correctly predicts Λ
→ misses multi-strange

A. Andronic *et al.*, PLB 673, 142 (2009)
Thermal hadronization model, assuming γ_s = 1

Thermal model predictions



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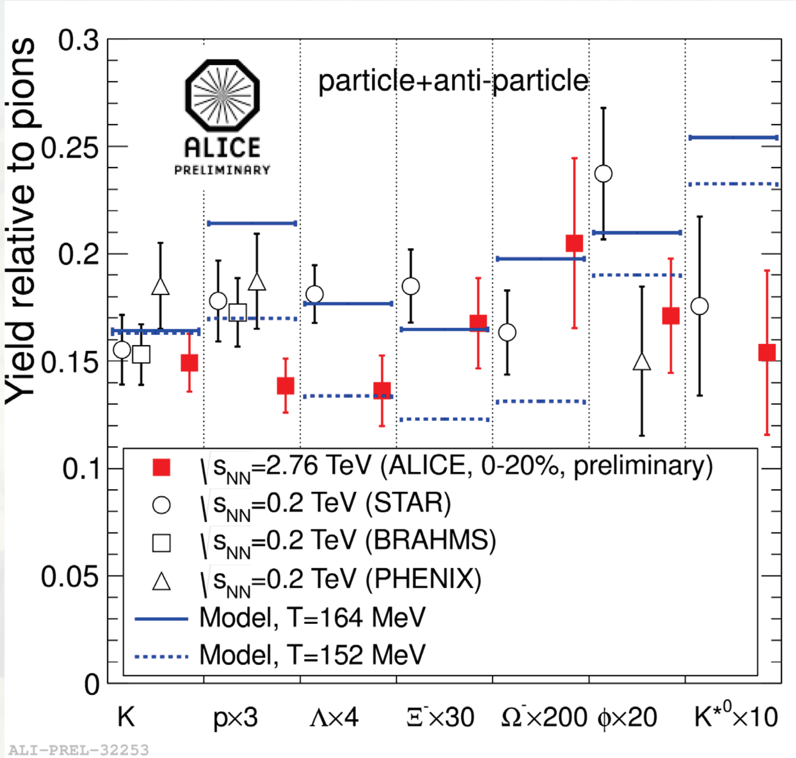
Difficult to fit p and hyperons with a single set of thermal parameters!

Thermal model predictions



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Possible solutions to "proton anomaly":

→ detailed calculations of proton annihilations in the final hadronic phase

→ non-equilibrium models with $\gamma_{q,s} > 1$?

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Strangeness enhancement

How it is defined:

$$E_i = (Yield_i^{A\text{-}A} / \langle Npart \rangle) / (Yield_i^{pp} / 2)$$

Connected to one of the earliest predictions for QGP formation*

Found to match basic predictions at SPS and RHIC:
→ increasing with strangeness content
→ decreasing with centre-of-mass energy

* J. Rafelski and B. Müller, PRL 48, 1066 (1982)
P. Koch, J. Rafelski and W. Greiner, PLB 123, 151 (1983)

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Found to match basic predictions at SPS and RHIC:
→ increasing with strangeness content
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Reference for preliminary enhancements at LHC:
→ interpolate 0.9 and 7 TeV pp data for Ξ
→ interpolate 200 GeV (STAR) and 7 TeV pp data for Ω
→ use excitation function from PYTHIA Perugia-2011

* J. Rafelski and B. Müller, PRL 48, 1066 (1982)
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Strangeness enhancement

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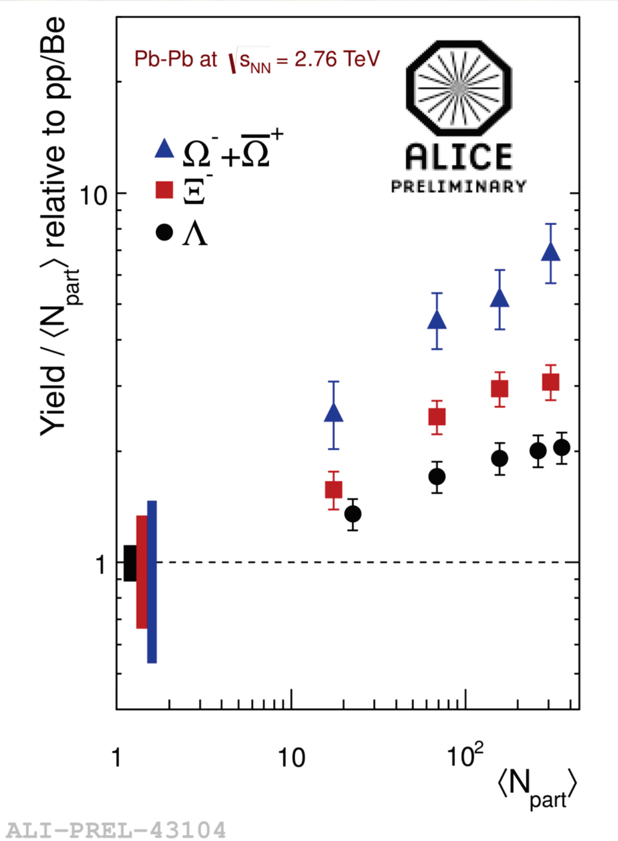


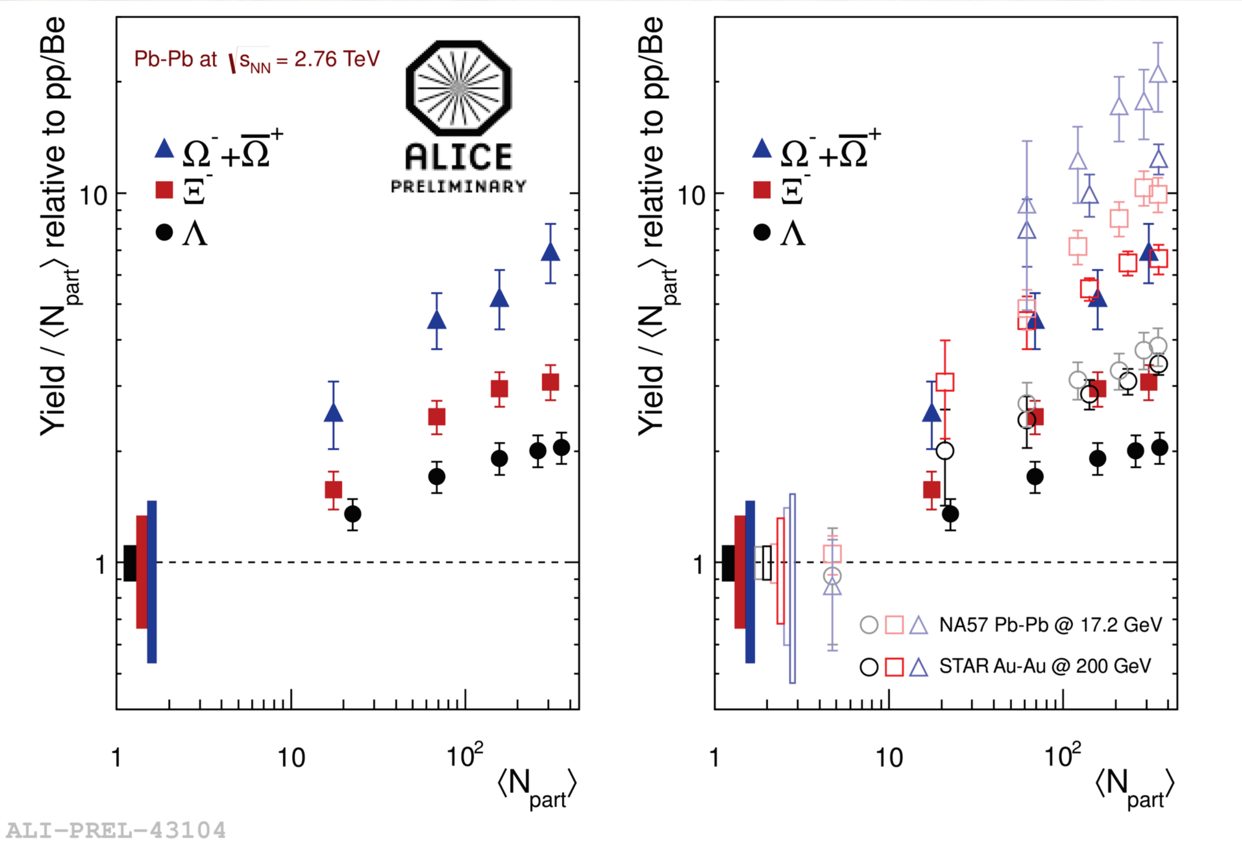
Hierarchy based on strangeness content

Results in Pb-Pb @ 2.76 TeV

Strangeness enhancement

How it is defined:

$$E_i = (\mathrm{Yield}_i^{A\text{-}A} / <\mathrm{Npart}>) / (\mathrm{Yield}_i^{pp} / 2)$$



Hierarchy based on strangeness content

Decreasing trend with energy as observed at SPS energies and from SPS to RHIC

Strangeness enhancement

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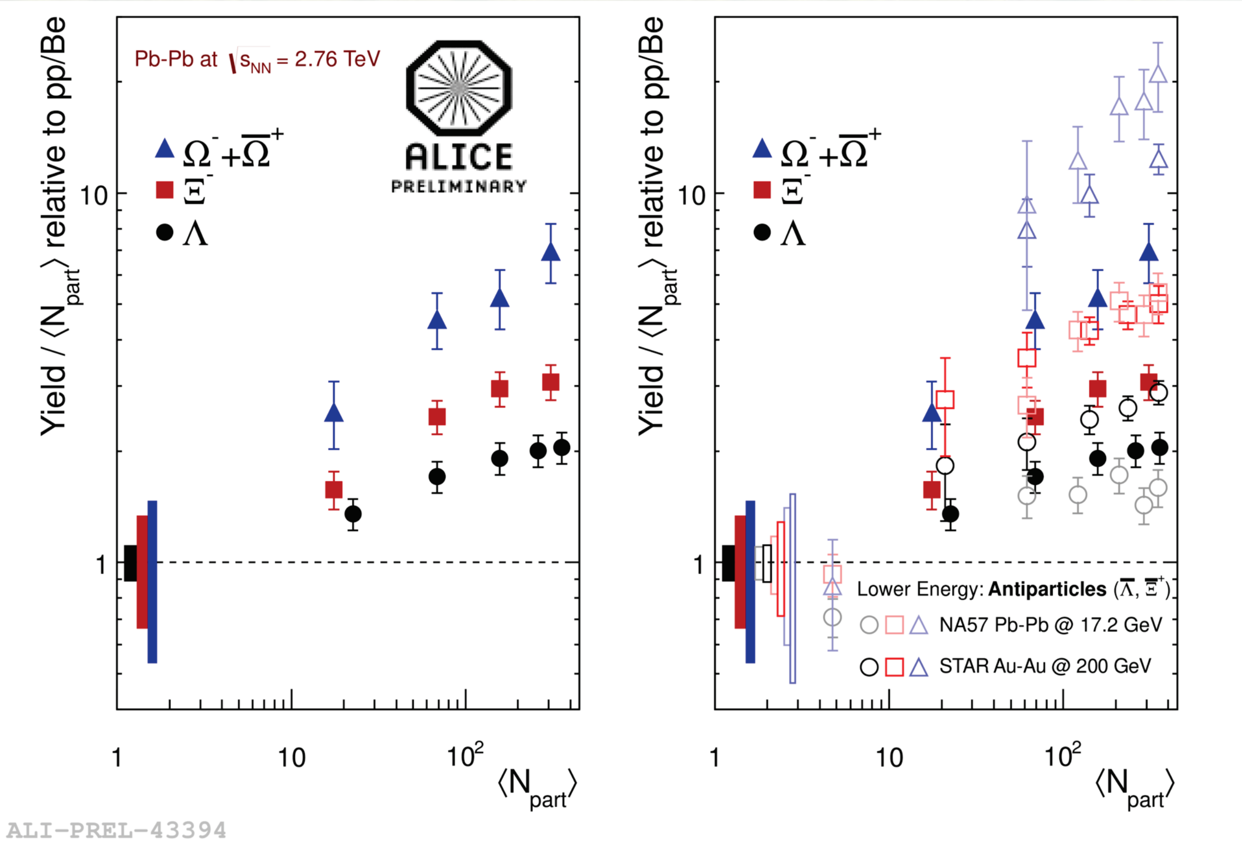

Hierarchy based on strangeness content

Decreasing trend with energy as observed at SPS energies and from SPS to RHIC

NB
Antiparticle/particle < 1 at lower energy

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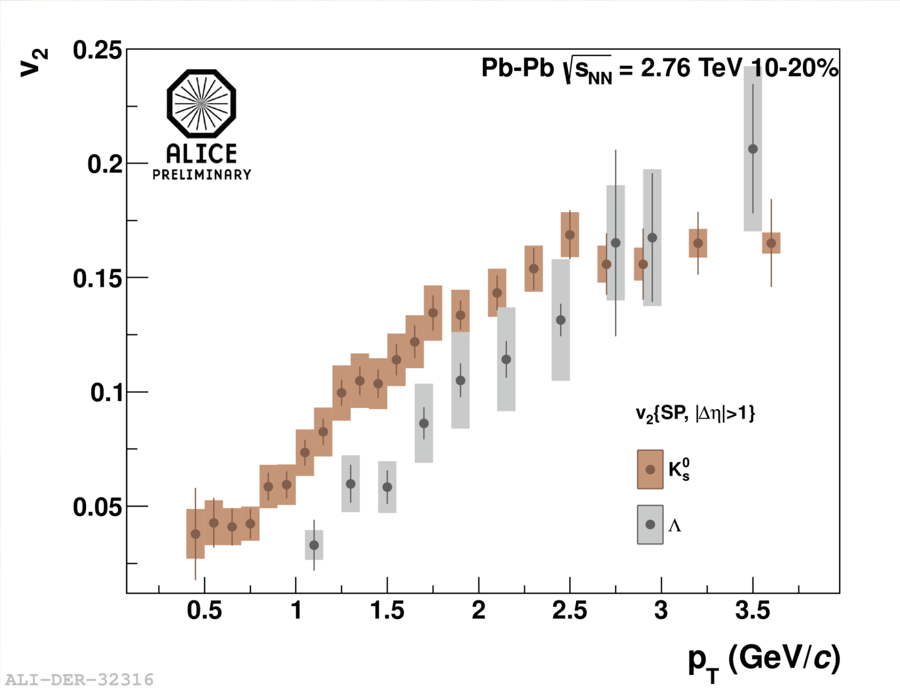
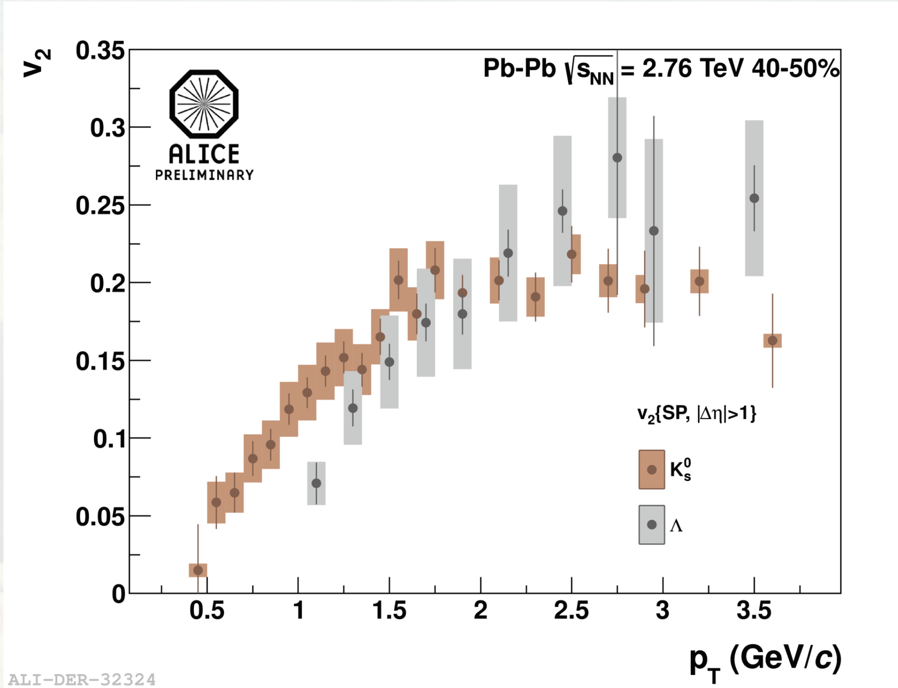
Elliptic flow (v_2)

Comparison of v_2 for K^0_S and Λ:



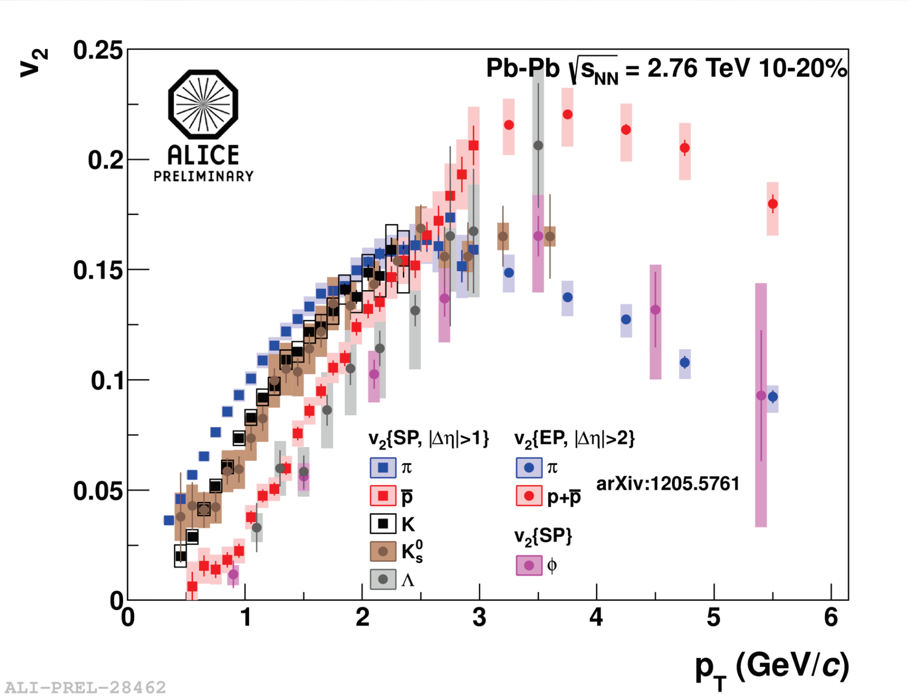


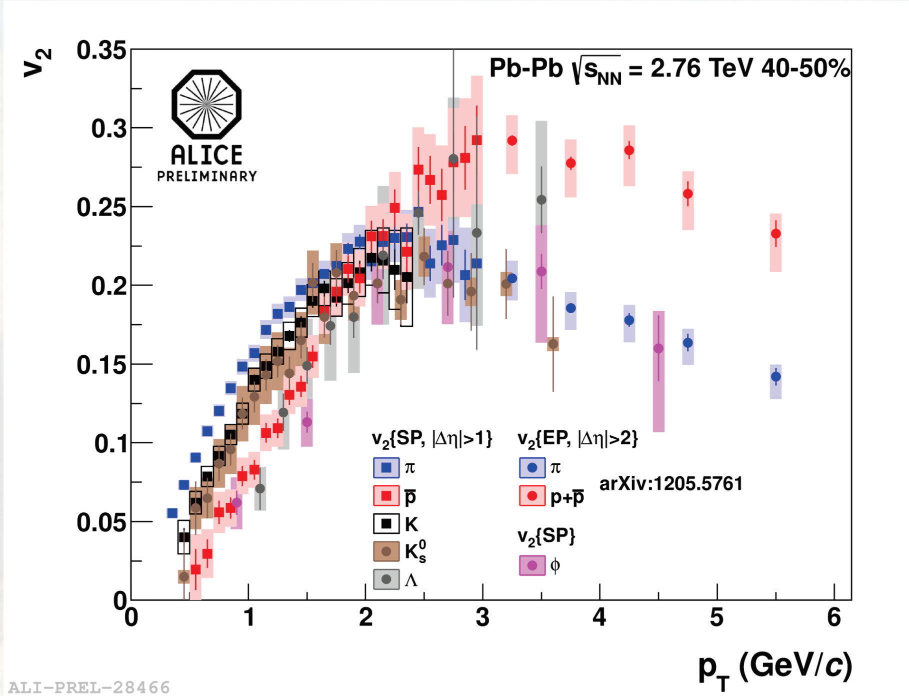
Evident mass ordering, changing with centrality:

→ the larger the mass the more v_2 is pushed at higher p_T

Elliptic flow (v_2)

Comparison of v_2 for K^0_S and Λ:



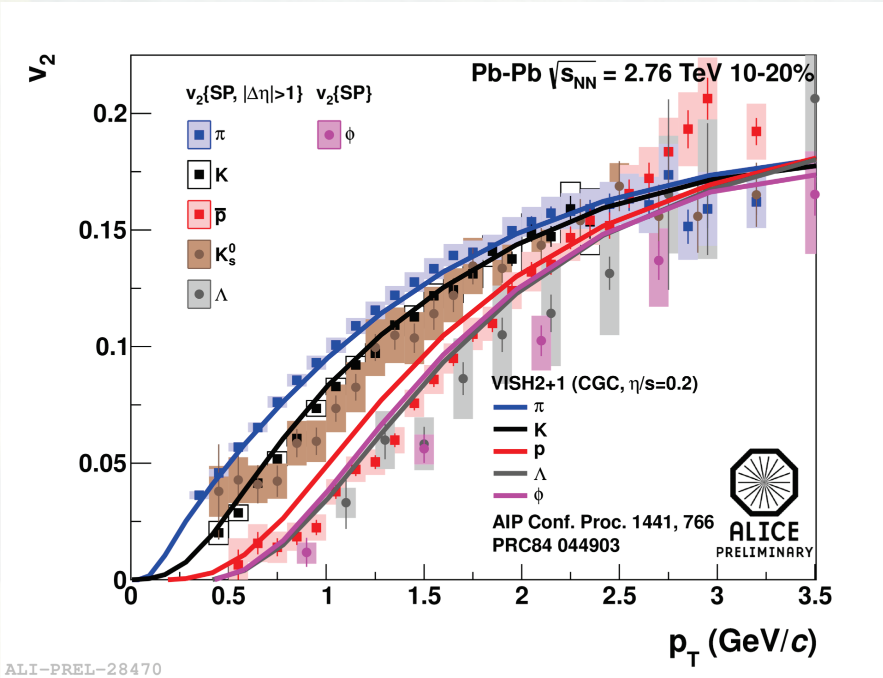


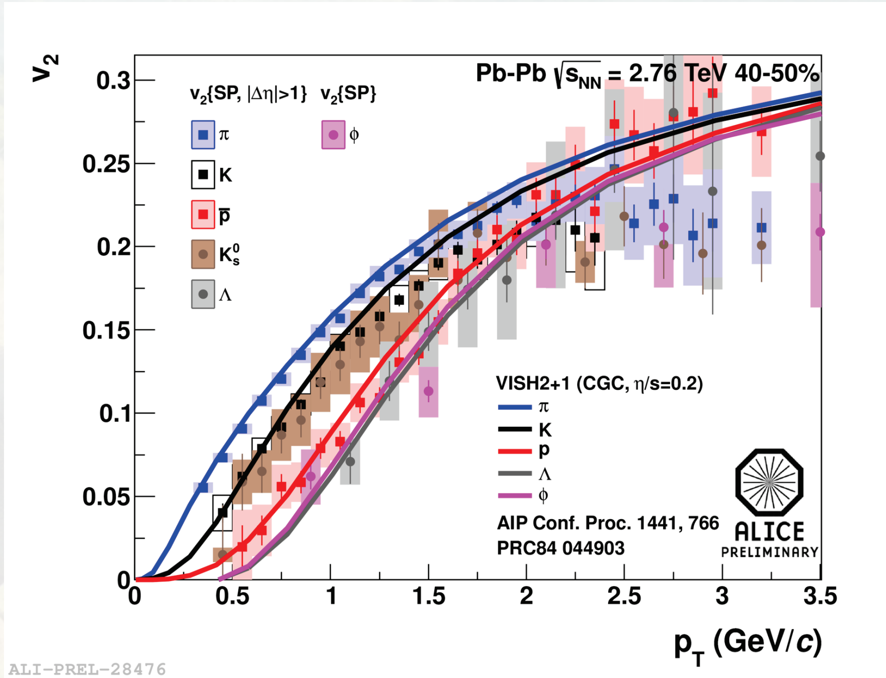
Evident mass ordering, changing with centrality

Similar ordering observed for charged kaons and protons

Elliptic flow (v_2)

Comparison with viscous-hydro predictions:



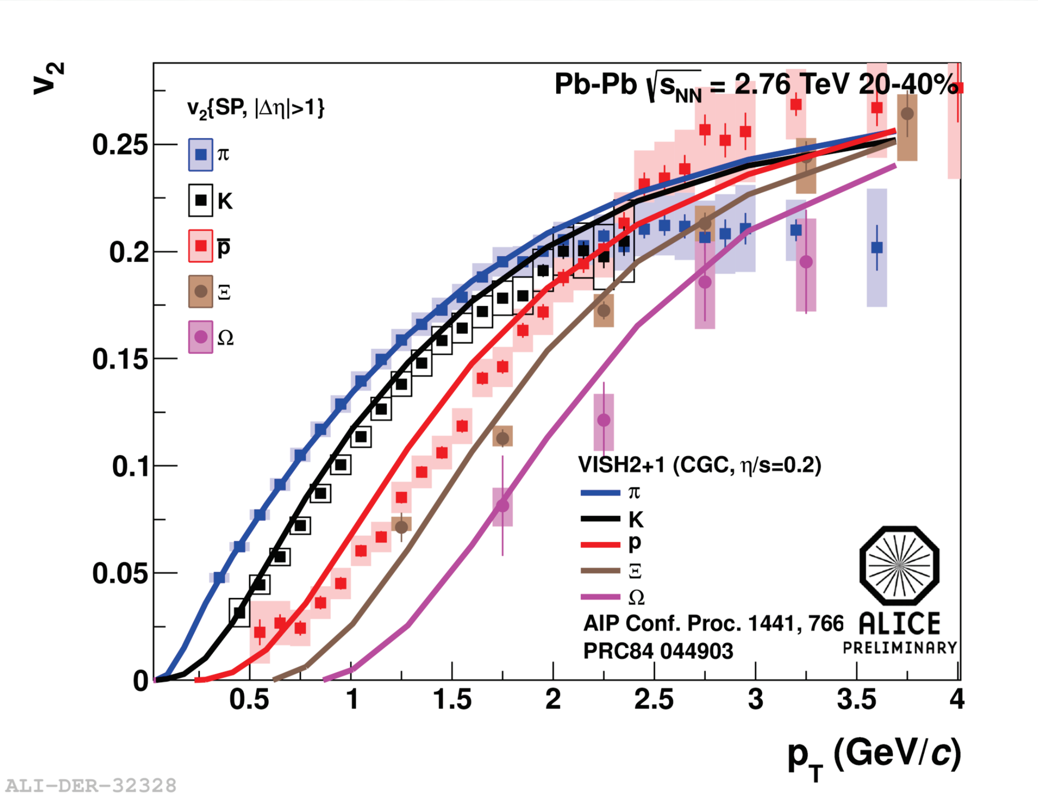


Good agreement with VISH2+1* ($\eta/s=0.2$) at low p_T
Mass dependence better modelled for peripheral collisions

* Shen *et al.*, PRC 84, 044903 (2011)

Elliptic flow (v_2)

Elliptic flow for multi-strange compared with hydro:



Hydro calculations reproduce larger boost towards higher p_T

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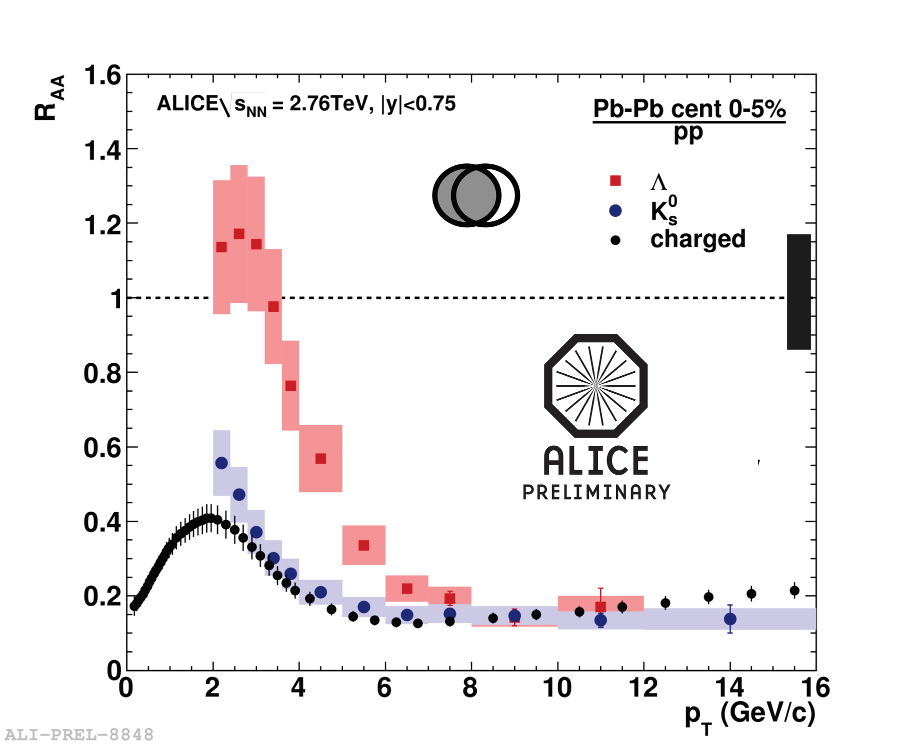
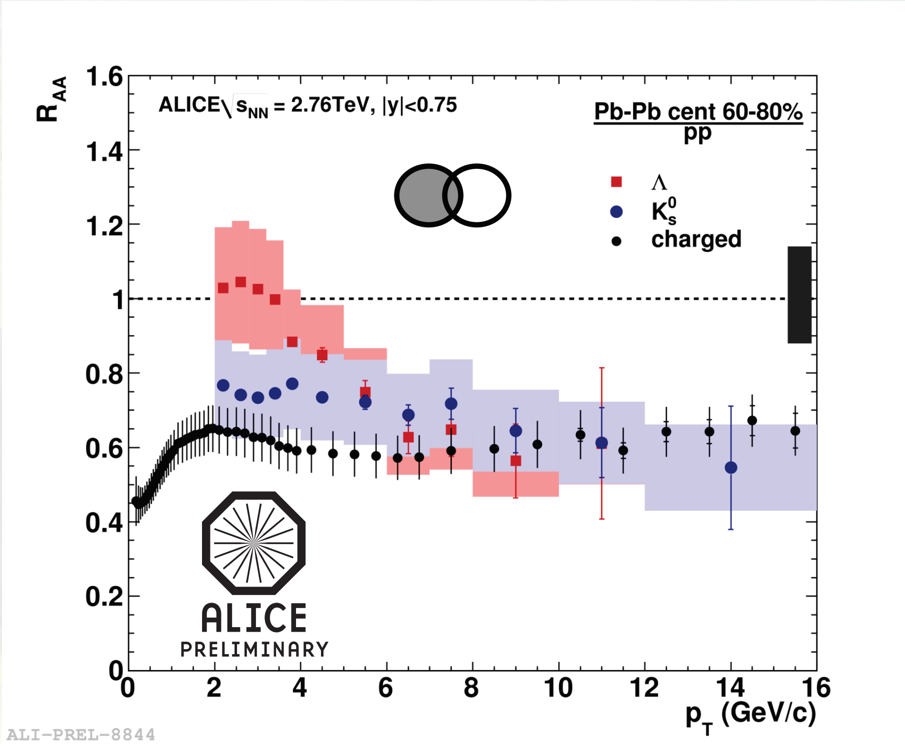
Nuclear modification (R_{AA})

Suppression of K^0_S and Λ in central and peripheral events:

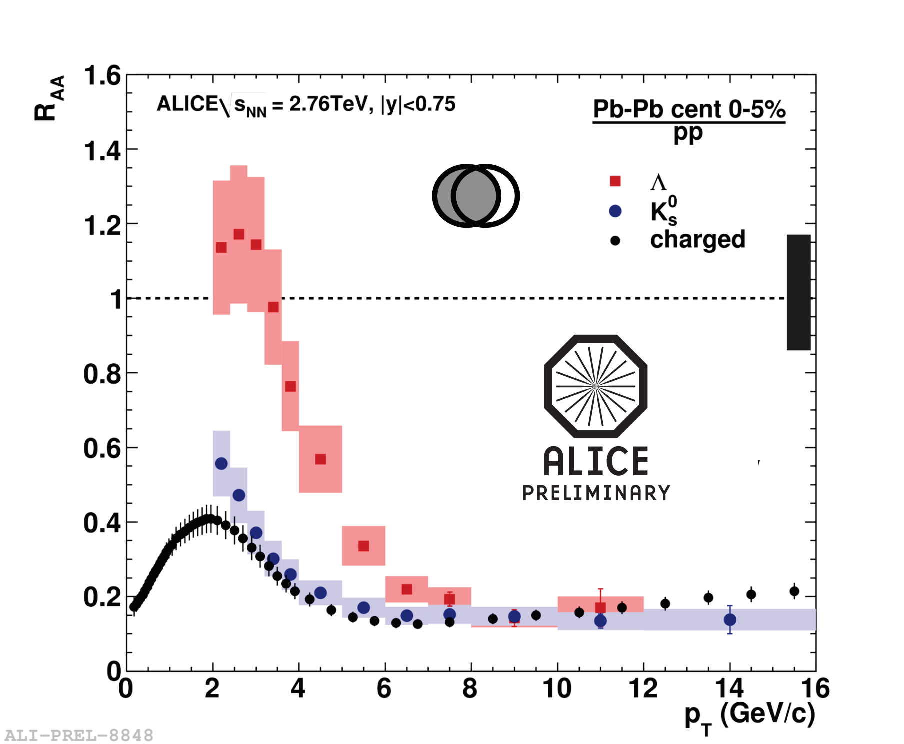


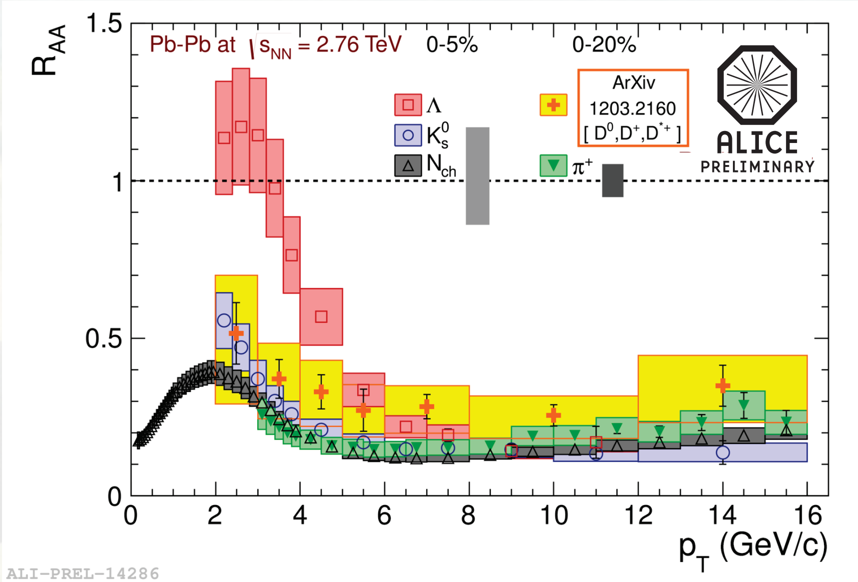


Central collisions: K^0_S and Λ similar to charged at high p_T
→ no strong flavour or meson/baryon dependence

Nuclear modification (R_{AA})

Suppression of K^0_S and Λ in central and peripheral events:



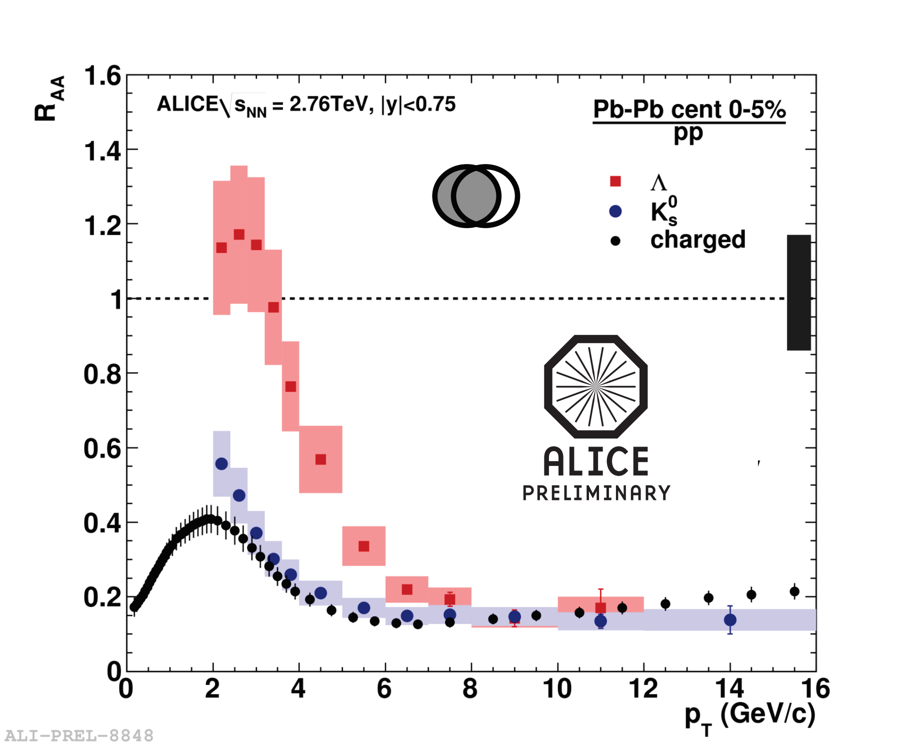


Same also for heavy flavours!
[D^0,D^+,D^{*+}]: JHEP 09, 112, (2012)

Central collisions: K^0_S and Λ similar to charged at high p_T
→ no strong flavour or meson/baryon dependence

Nuclear modification (R_{AA})

Suppression of K^0_S and Λ in central and peripheral events:



Low p_T (< 6 GeV/c):

→ K^0_S R_{AA} still similar to charged

→ Λ R_{AA} significantly higher

(baryon enhancement at intermediate p_T)

Central collisions: K^0_S and Λ similar to charged at high p_T

→ no strong flavour or meson/baryon dependence

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Summary and prospects

- Summary:
  - wide range of strangeness measurements both in pp and Pb-Pb
  - latest PYTHIA tune (Perugia-2011) closer to data in pp:
    - good agreement at high p_T
    - worse predictions at low p_T and for multi-strange

Summary and prospects

- Summary:
  - wide range of strangeness measurements both in pp and Pb-Pb
  - latest PYTHIA tune (Perugia-2011) closer to data in pp:
    - good agreement at high p_T
    - worse predictions at low p_T and for multi-strange
  - lot of physics from Pb-Pb data:
    - baryon/meson vs p_T shows same trend as at RHIC and increases from pp above unity in central Pb-Pb at LHC
    - Λ/π independent of centrality, Ξ/π independent of $\sqrt{s_{NN}}$
    - p and hyperons do not fit to a single set of thermal params and γ_s=1
    - strangeness enhancements weaker at LHC than at RHIC
    - strange hadron v_2 consistent with viscous hydro and small η/s
    - Λ and K^0_S high p_T suppression similar to non-strange

Summary and prospects

- Summary:
  - wide range of strangeness measurements both in pp and Pb-Pb
  - latest PYTHIA tune (Perugia-2011) closer to data in pp
  - lot of physics from Pb-Pb data

- Prospects:
  - multiplicity-binned analysis in pp
  - finer centrality bins, more particles/resonances in Pb-Pb
  - exploit centrality range of p-Pb

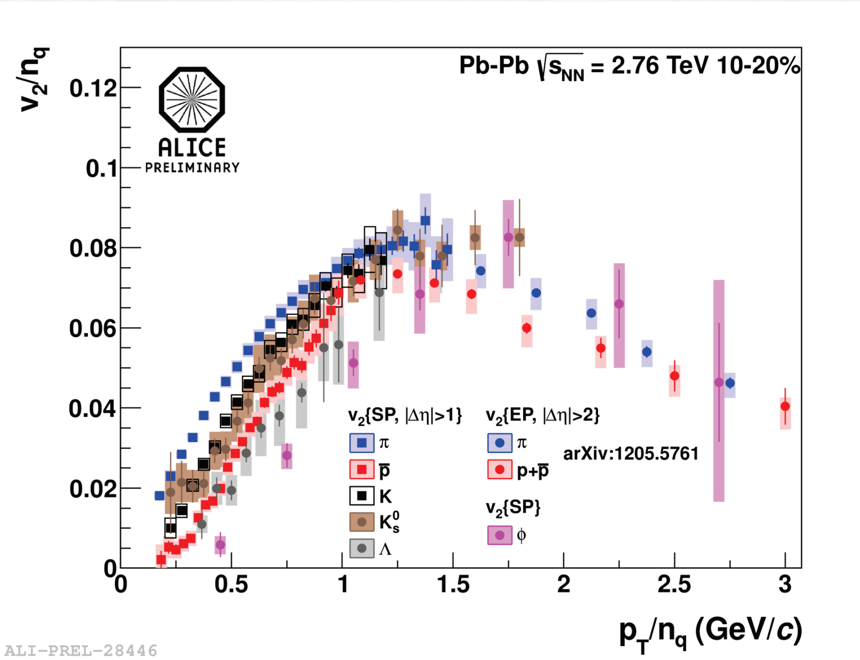
Thanks!

Backup slides

Elliptic flow (v_2)

Quark scaling:

NCQ = number of constituent quarks

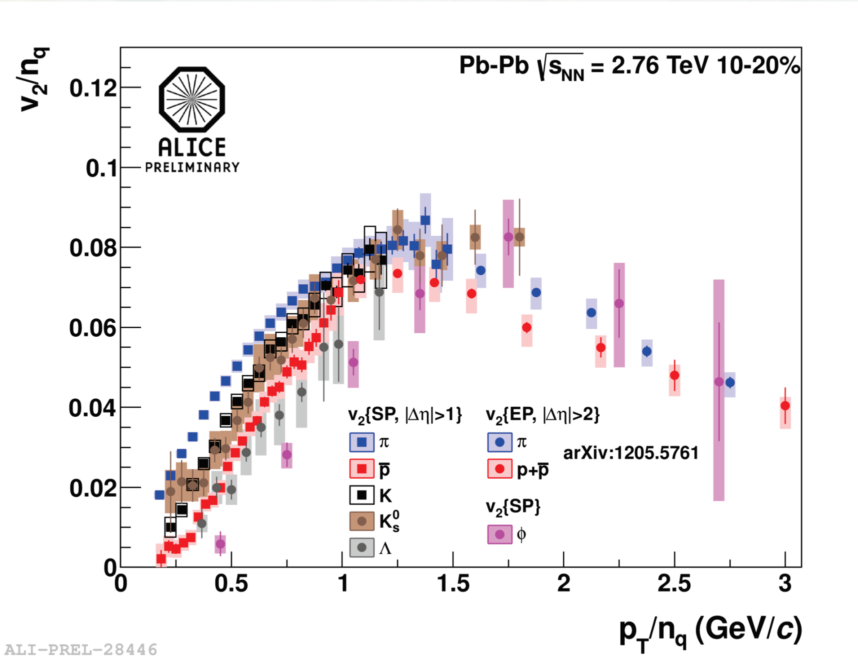


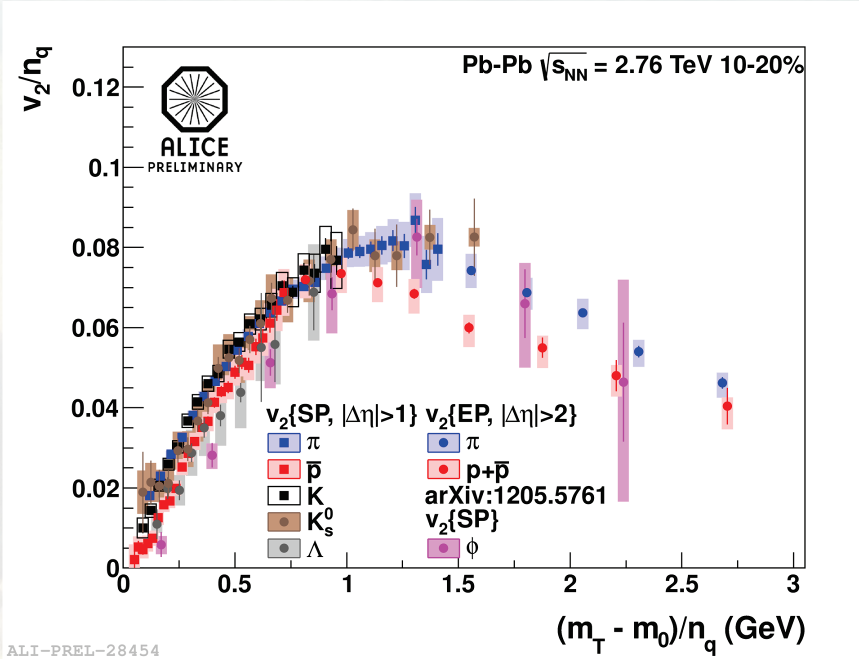
Mesons and baryons seem to scale differently with NCQ

Elliptic flow (v_2)

Quark scaling:

$KE_T = m_T - m_0$
NCQ = number of constituent quarks

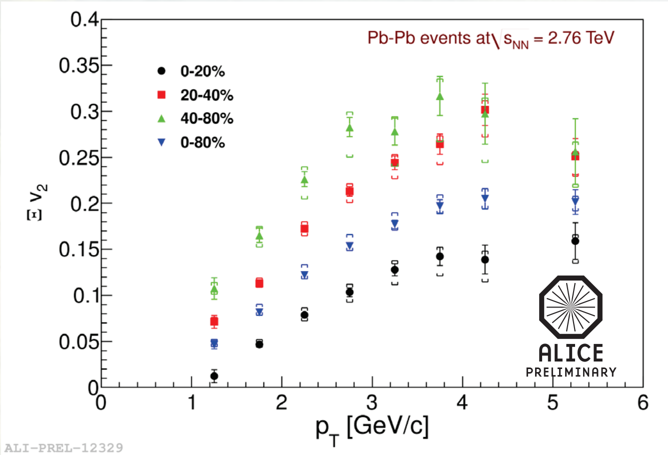


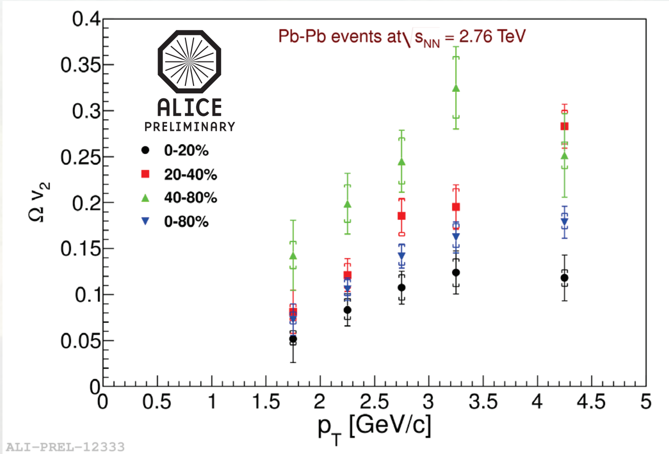


Mesons and baryons seem to scale differently with NCQ
Slightly better as a function of transverse energy (for KE_T<1)

Elliptic flow (v_2)

Elliptic flow for multi-strange:



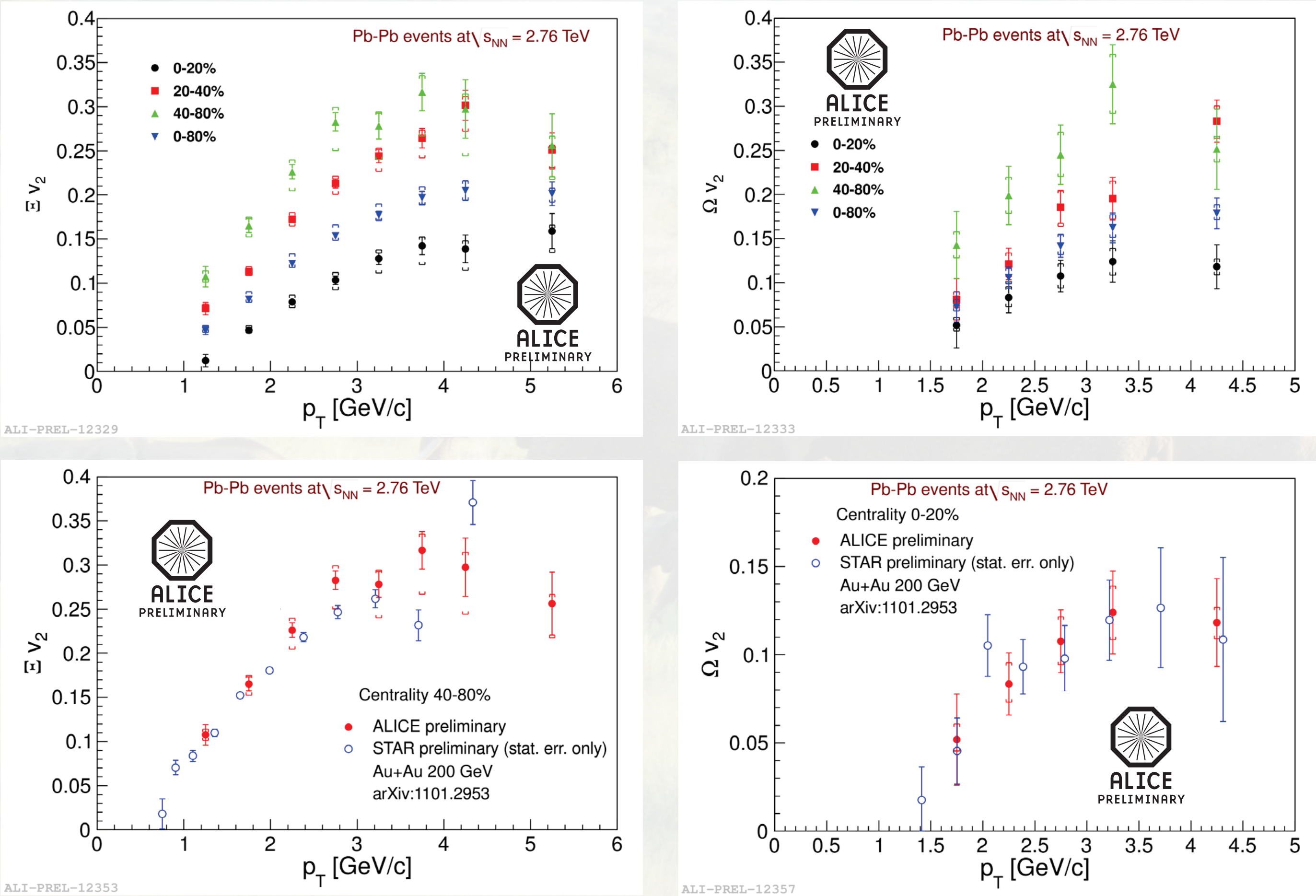


Shifted to higher p_T wrt single-strange

Increasing with centrality

Elliptic flow (v_2)

Elliptic flow for multi-strange:



Shifted to higher p_T wrt single-strange

Increasing with centrality

Similar to RHIC for central and mid-central