Strangeness Production at LHC energies as measured with ALICE

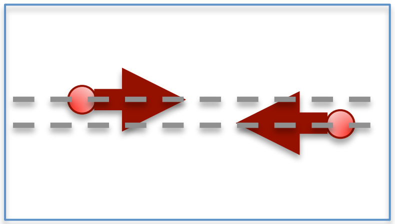
D.D. Chinellato
For the ALICE Collaboration

UNICAMP ALICE

Outline

- **Introduction**
  - Physics Motivation
  - The ALICE Experiment
- **Results**
  - Proton-proton (pp) collisions
  - Lead-lead (Pb-Pb) collisions
  - Proton-lead (p-Pb) collisions
- **Conclusions and Prospects**

Strangeness: Physics Motivations



1) Proton-proton Collisions

Strangeness as benchmark for heavy-ion physics

Study of production mechanisms

- ***pQCD*** *(high transverse momentum,* > 6 GeV/*c*)
- ***Soft*** *interactions (low and mid transverse momentum,* < 6 GeV/*c*)

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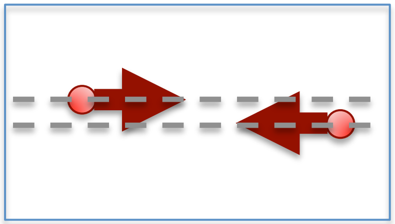

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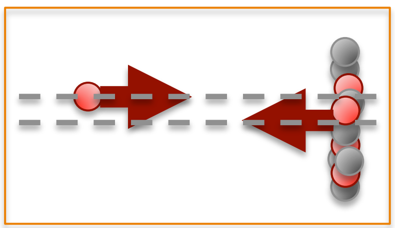

2) Proton-Lead Collisions

Intermediate system in terms of size and multiplicity: is there any collectivity?

Potentially very interesting to disentangle role of initial (Pb beam) and final state (hot QCD matter) effects

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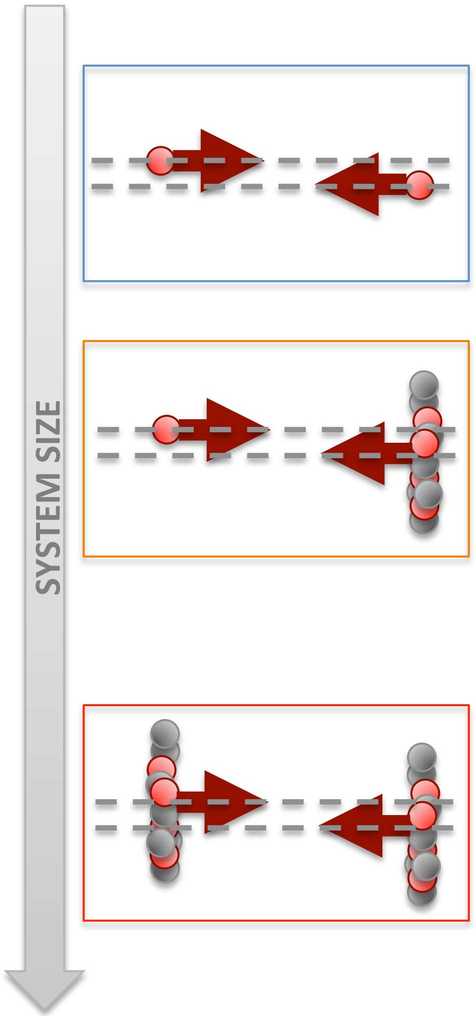

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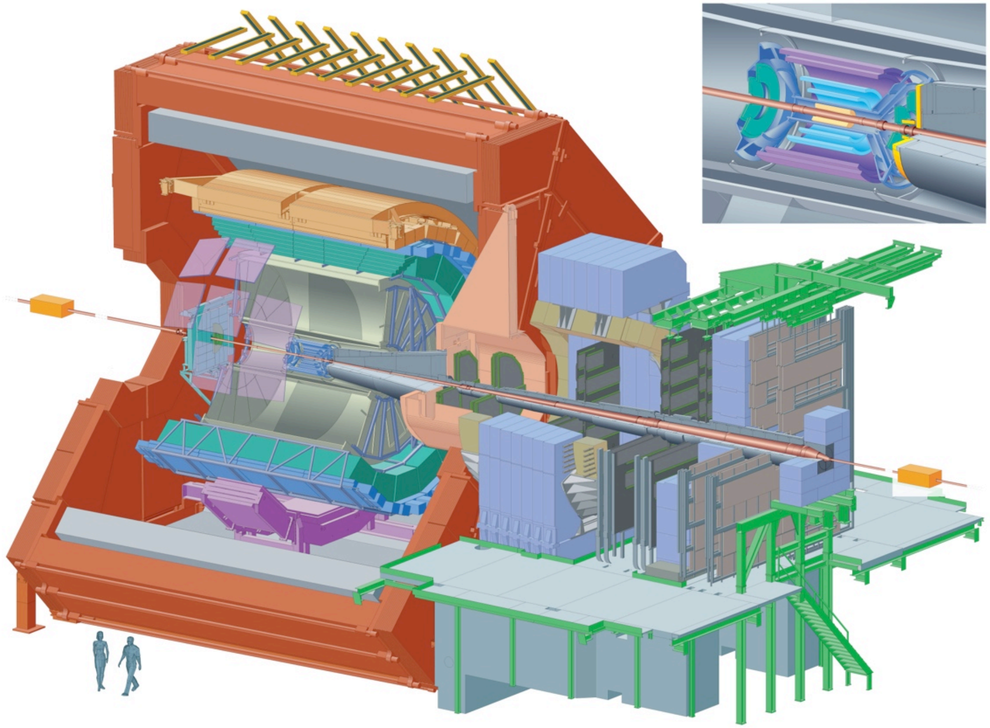
3) Lead-Lead Collisions

Multi-Strange Baryons: small hadronic cross-sections and early de-coupling enable probing of earlier stages of system evolution

Strange quark: light enough to be produced thermally in QGP:

- *Are the production rates consistent with **thermal production**?*
- *Is strangeness **enhanced** if scaled and compared to pp?*
- *How are the transverse momentum spectra **modified**?*

The ALICE Experiment at the LHC



Collaboration:
1275 members
135 institutes
37 countries

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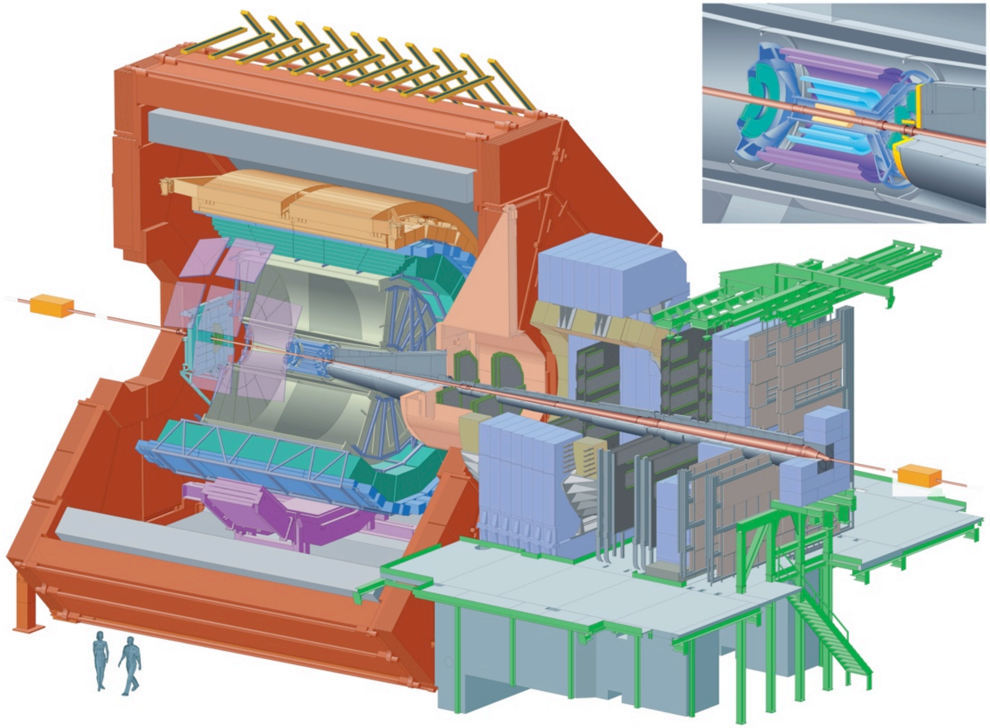

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PID over a wide p_T range using:
- Energy loss (dE/dx)
- Time of flight
- Topological decays

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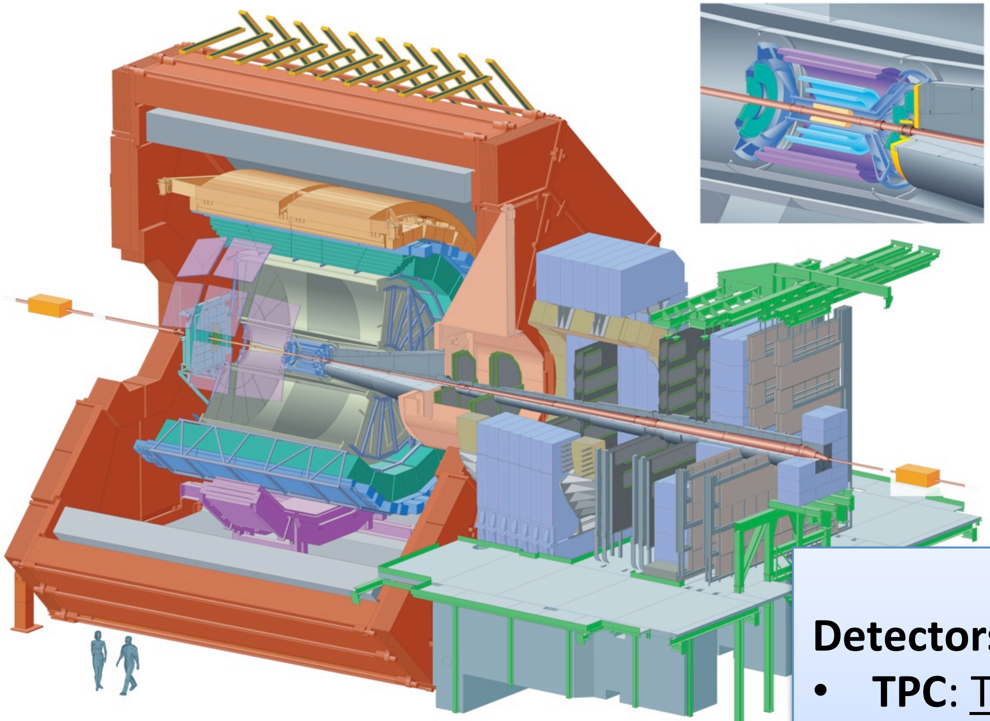

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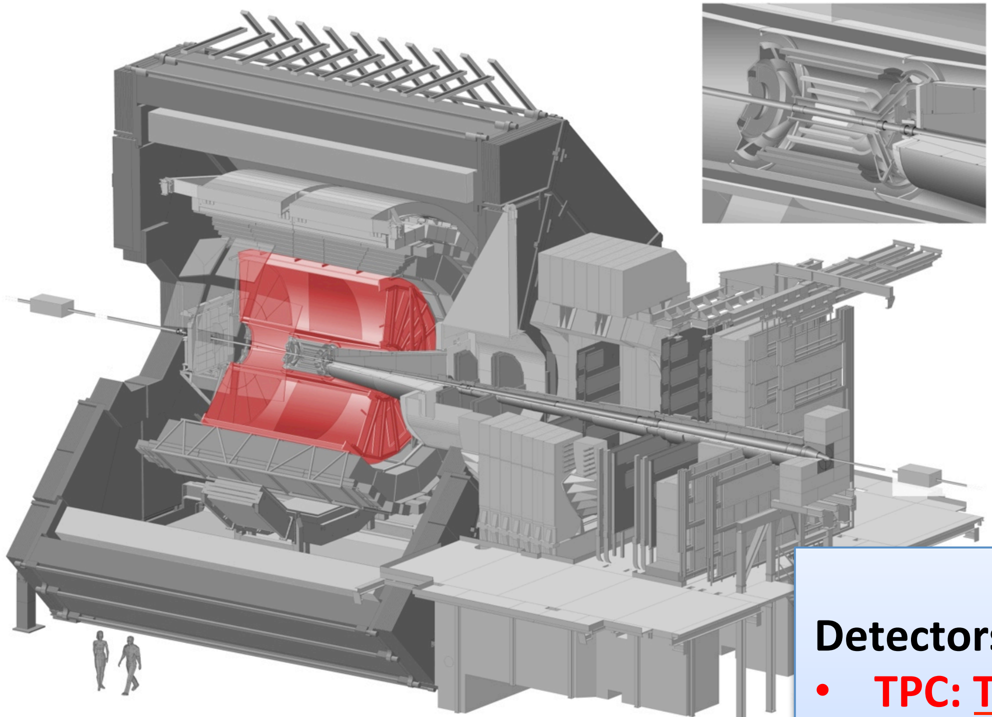

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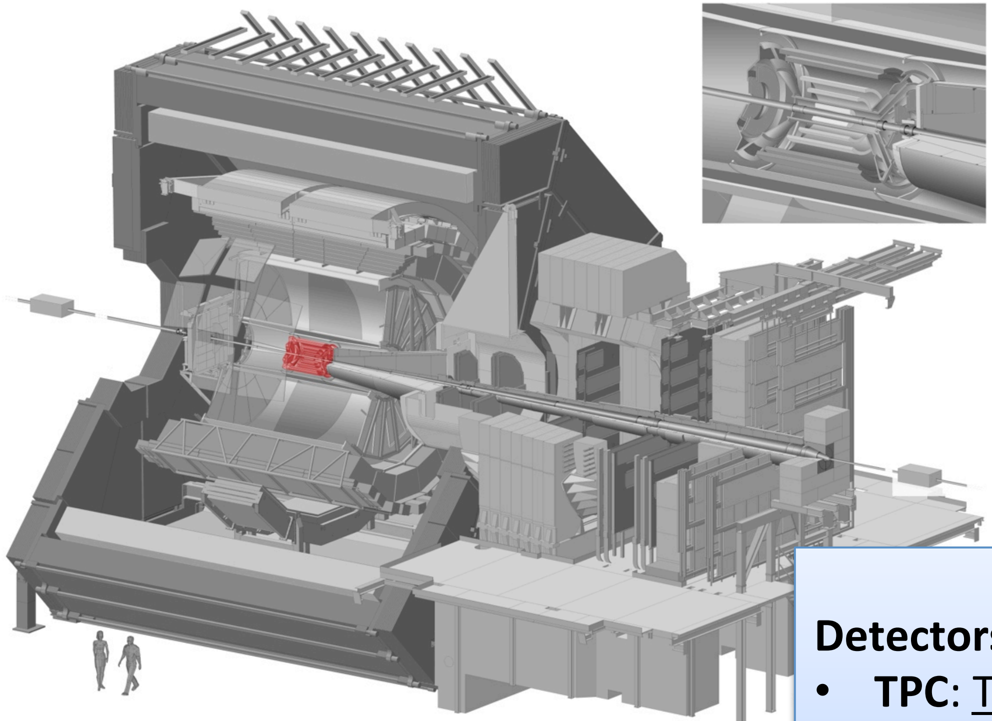

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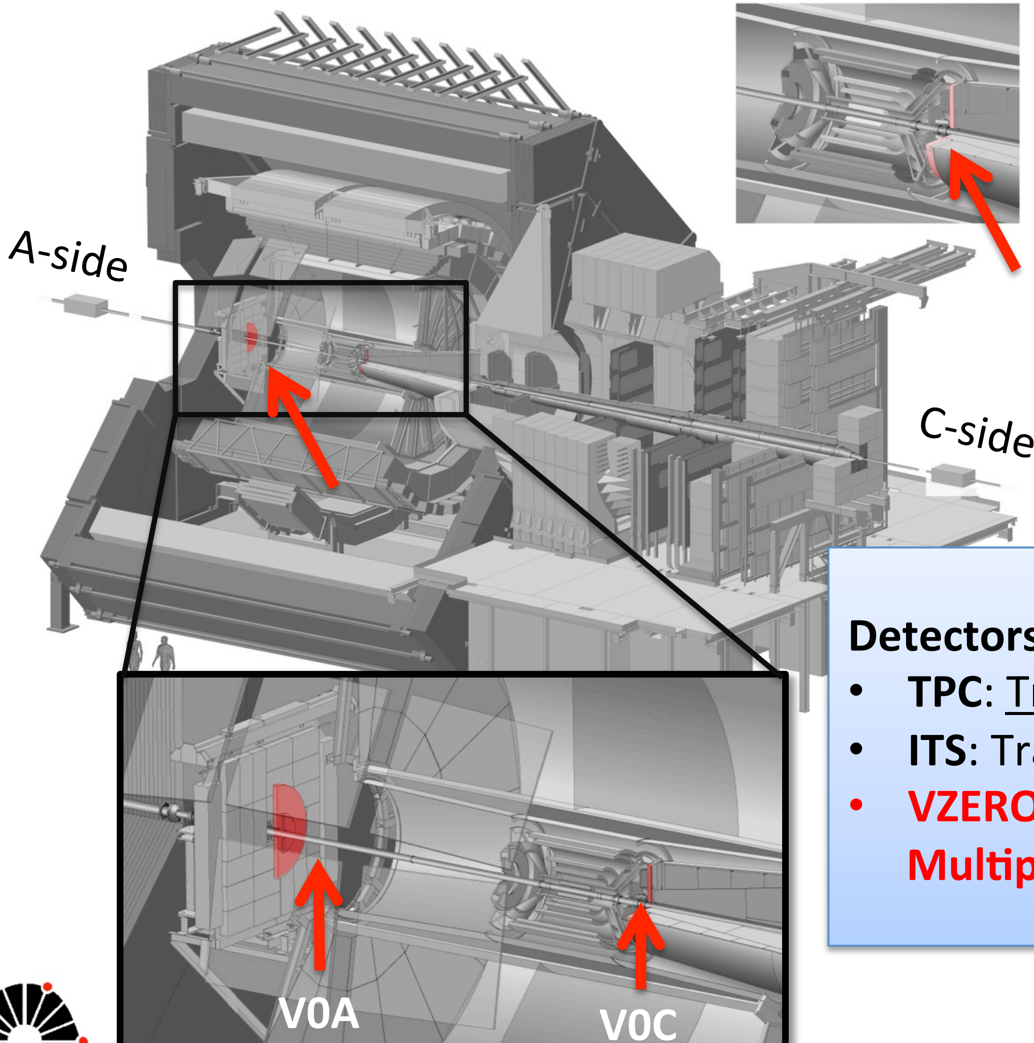

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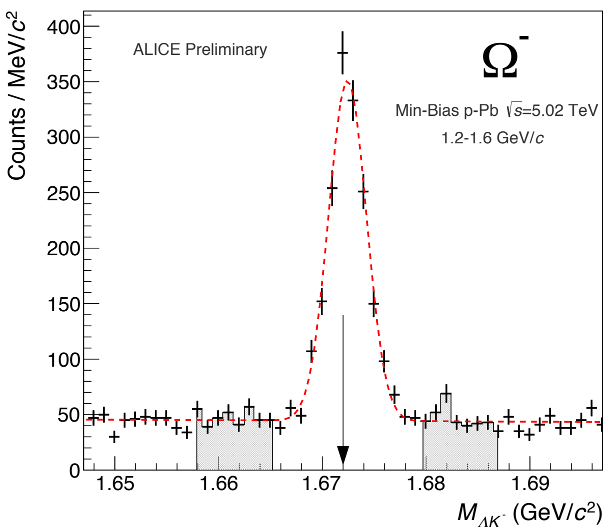
Reconstructing Strange and Multi-Strange Hadrons with ALICE

General procedure employed for K^0_s, Λ, Ξ^- and Ω^- and their antiparticles

Decay Candidate Selections:
- *Topological*
- *Particle Identification: TPC dE/dx*
- *Competing Decay Rejection*



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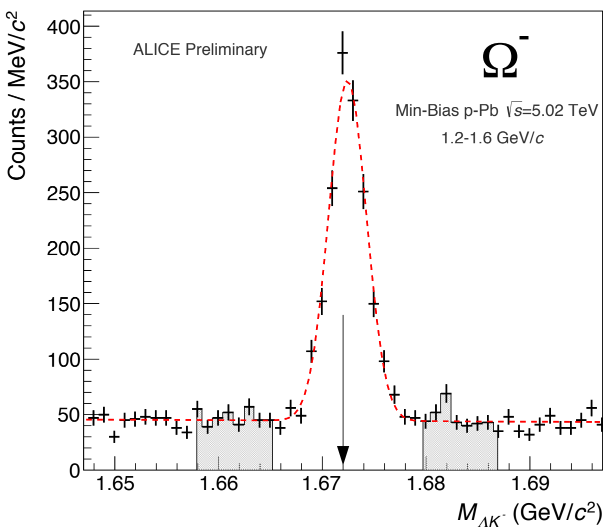
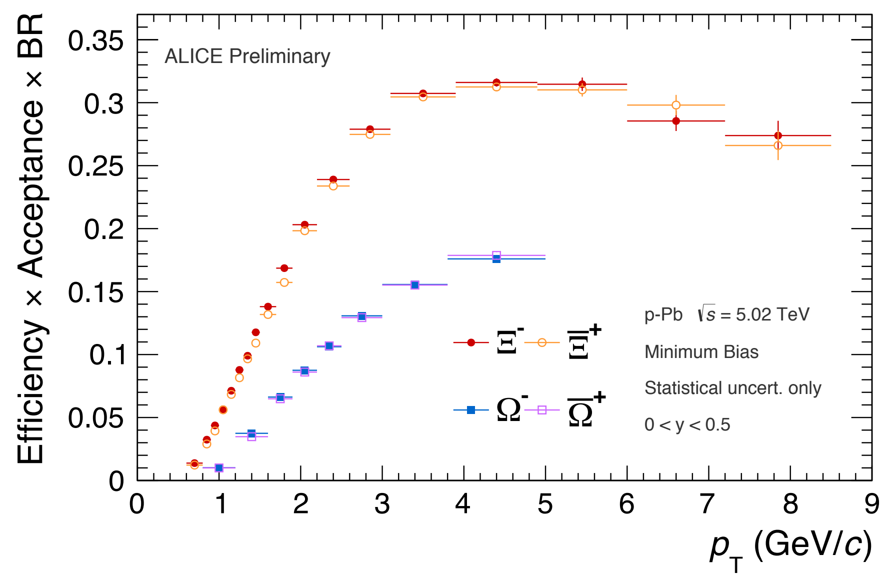
Corrections Applied:
- *Feedown correction (Λ)*
- *Acceptance x Efficiency x B.R.*





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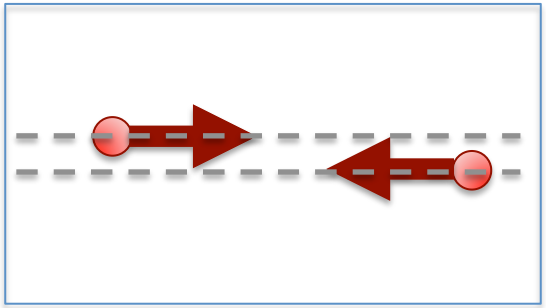
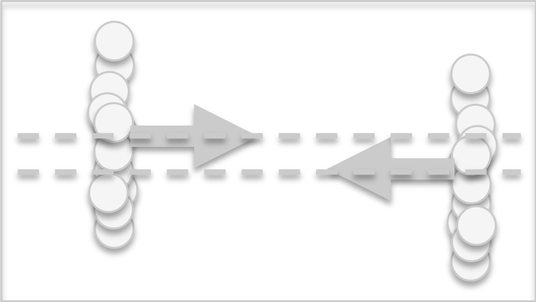


Proton-proton collisions (pp)



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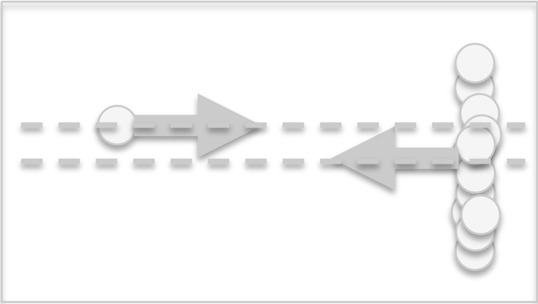
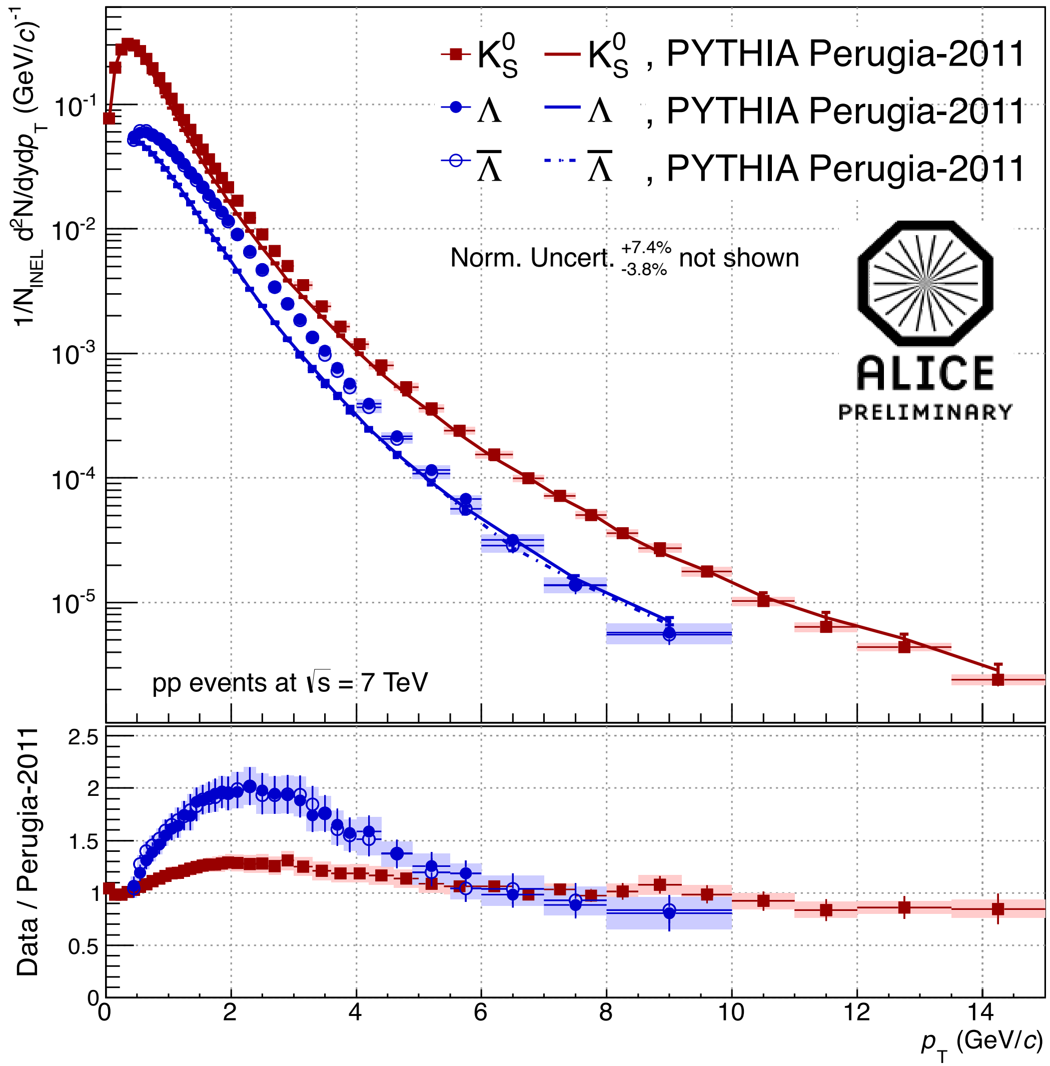


Proton-lead collisions (p-Pb)

Proton-Proton at 7 TeV

Results: Single-Strange

p_T Ranges:
K^0_s: 0.0-15.0 GeV/c
Λ: 0.4-10.0 GeV/c



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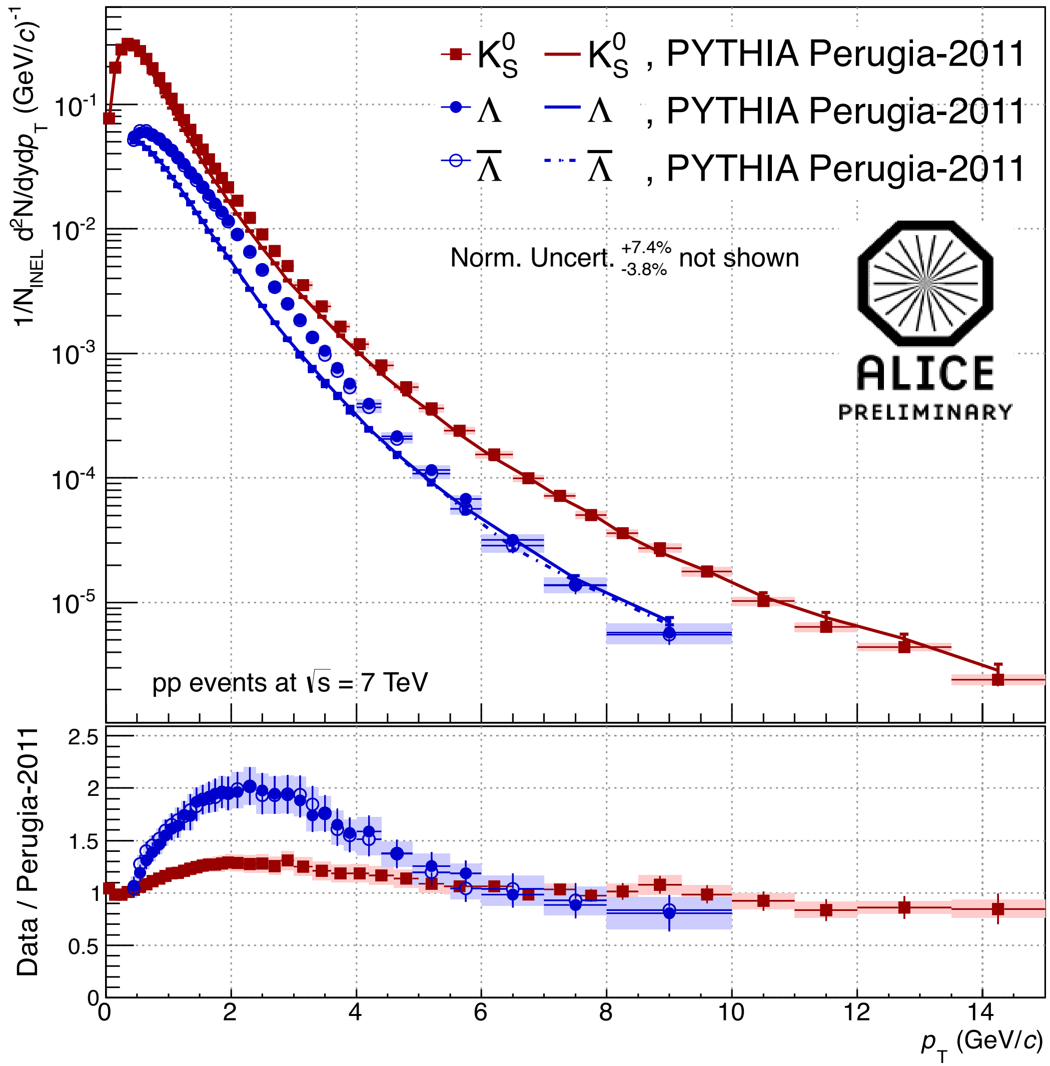

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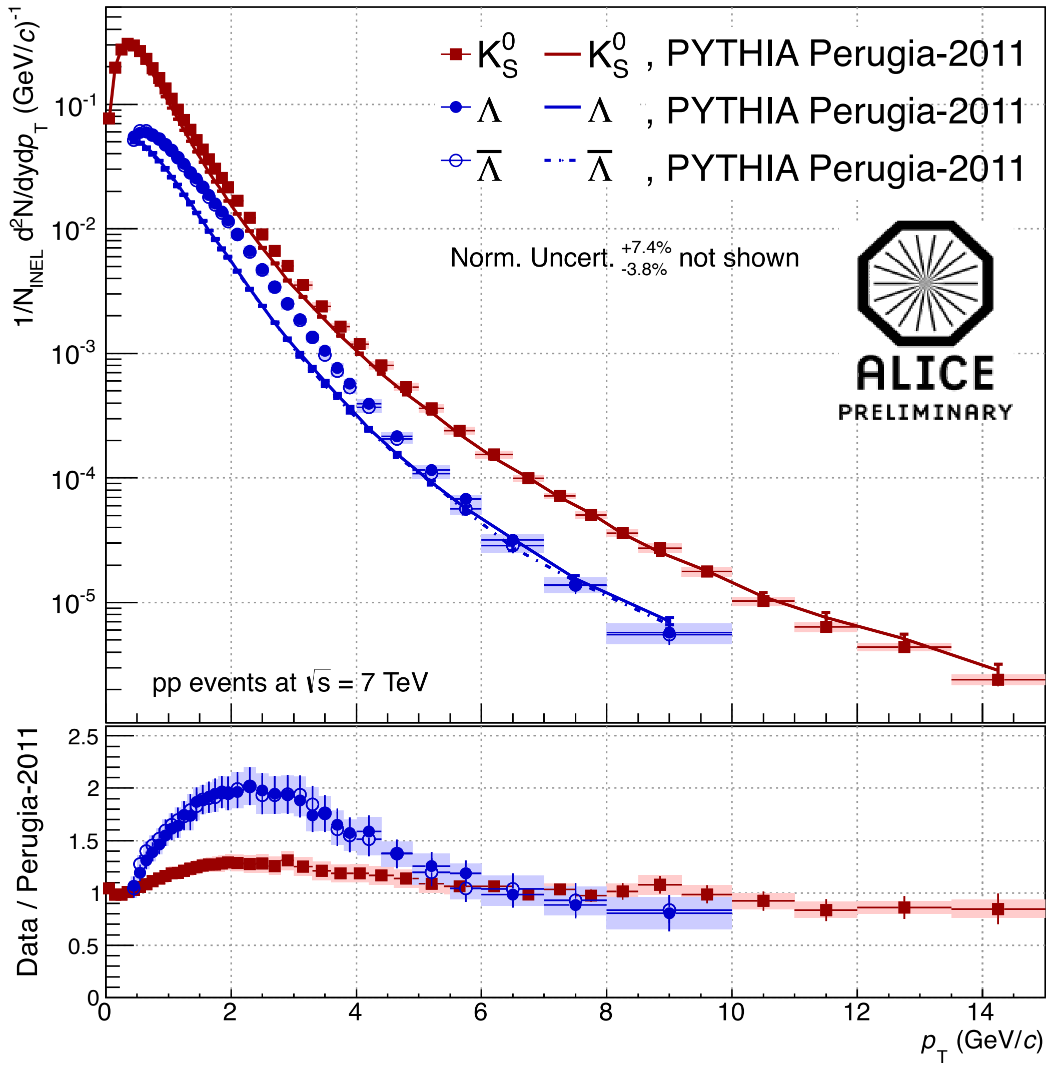

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Comparison to PYTHIA Perugia-2011:

- **Inadequate for soft region (worse for Λ)**
- **Good description for p_T > 7 GeV/c**

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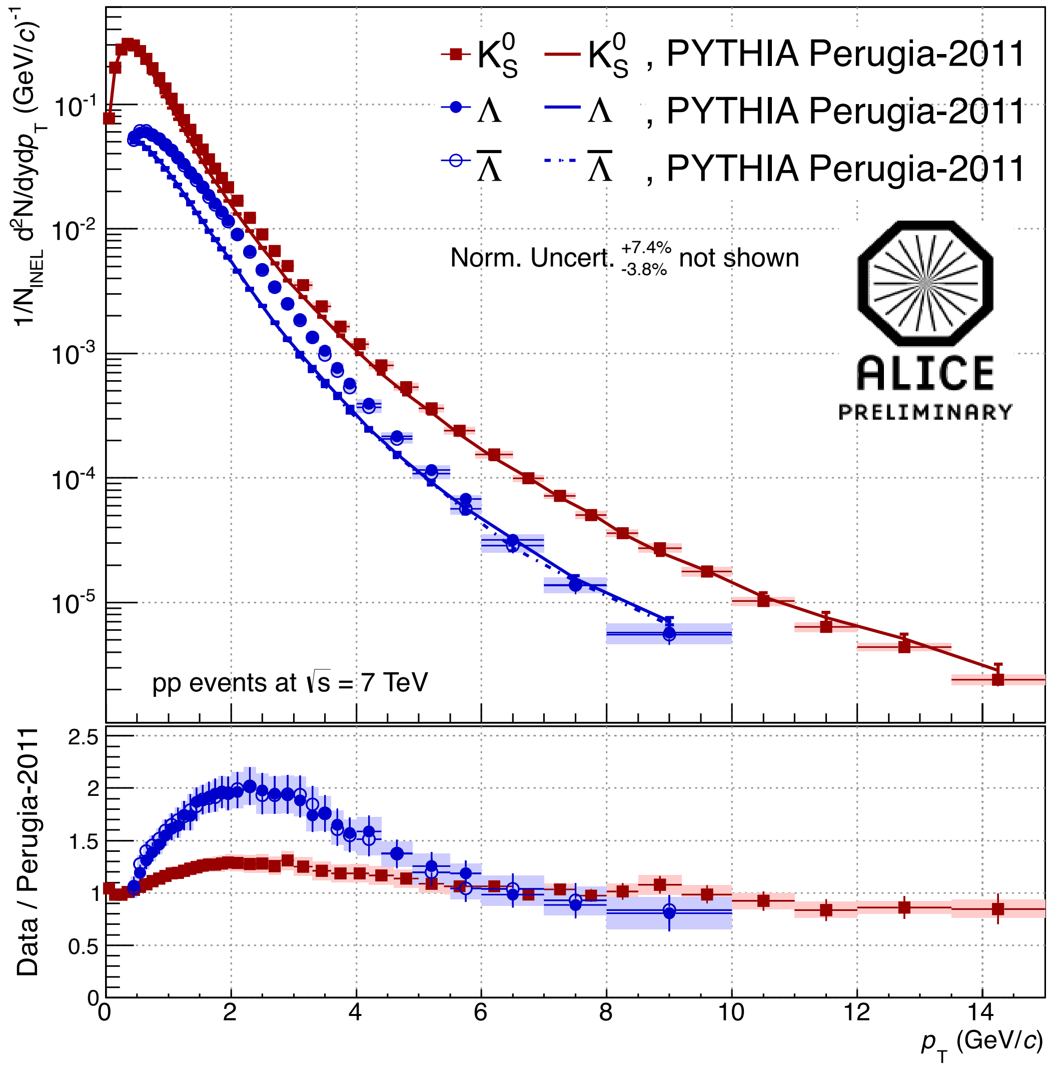

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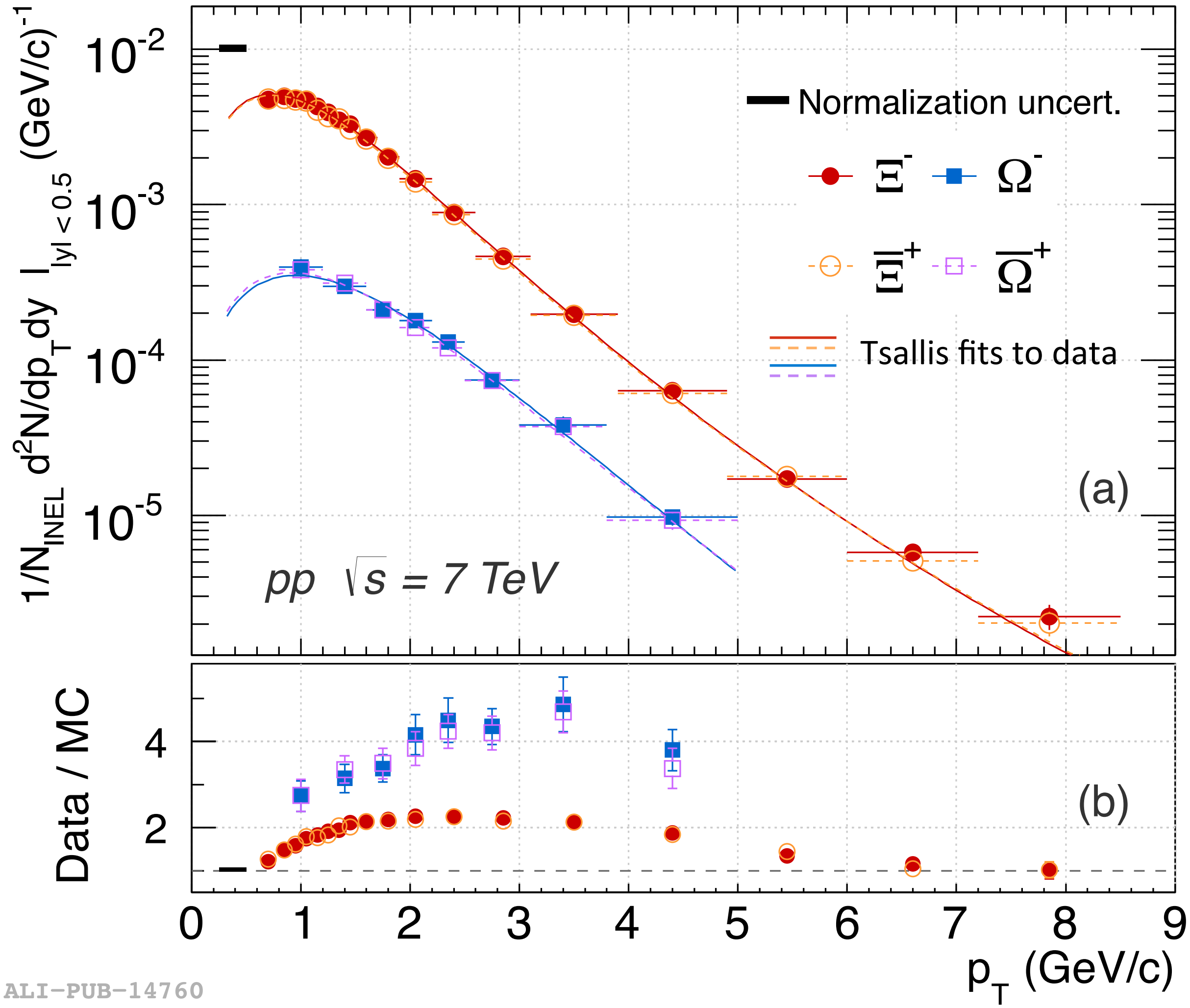
Better MC description at high p_T consistent with other observations: ϕ, K^{*0}: http://arxiv.org/abs/1208.5717

Proton-Proton at 7 TeV

Results: Multi-Strange



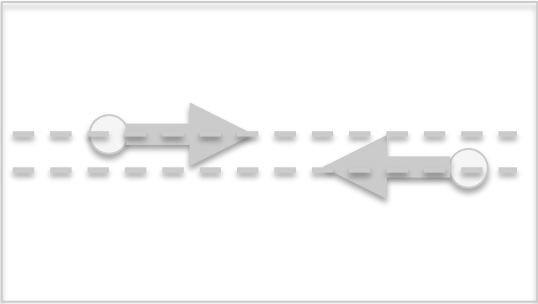
Antiparticle to particle ratio: compatible with unity

Comparison to PYTHIA Perugia-2011:

- **Deviation in the soft region increases for higher strangeness content**
- ***p_T* > 7 GeV/*c* : hint of agreement**

PLB Volume 712, 12 June 2012, Page 309

Results



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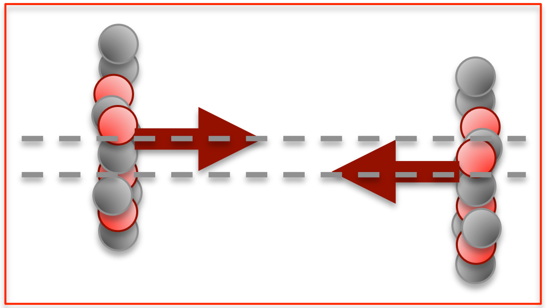

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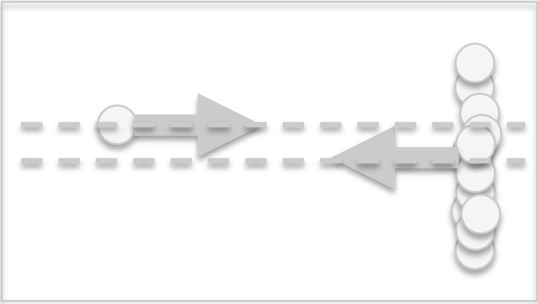


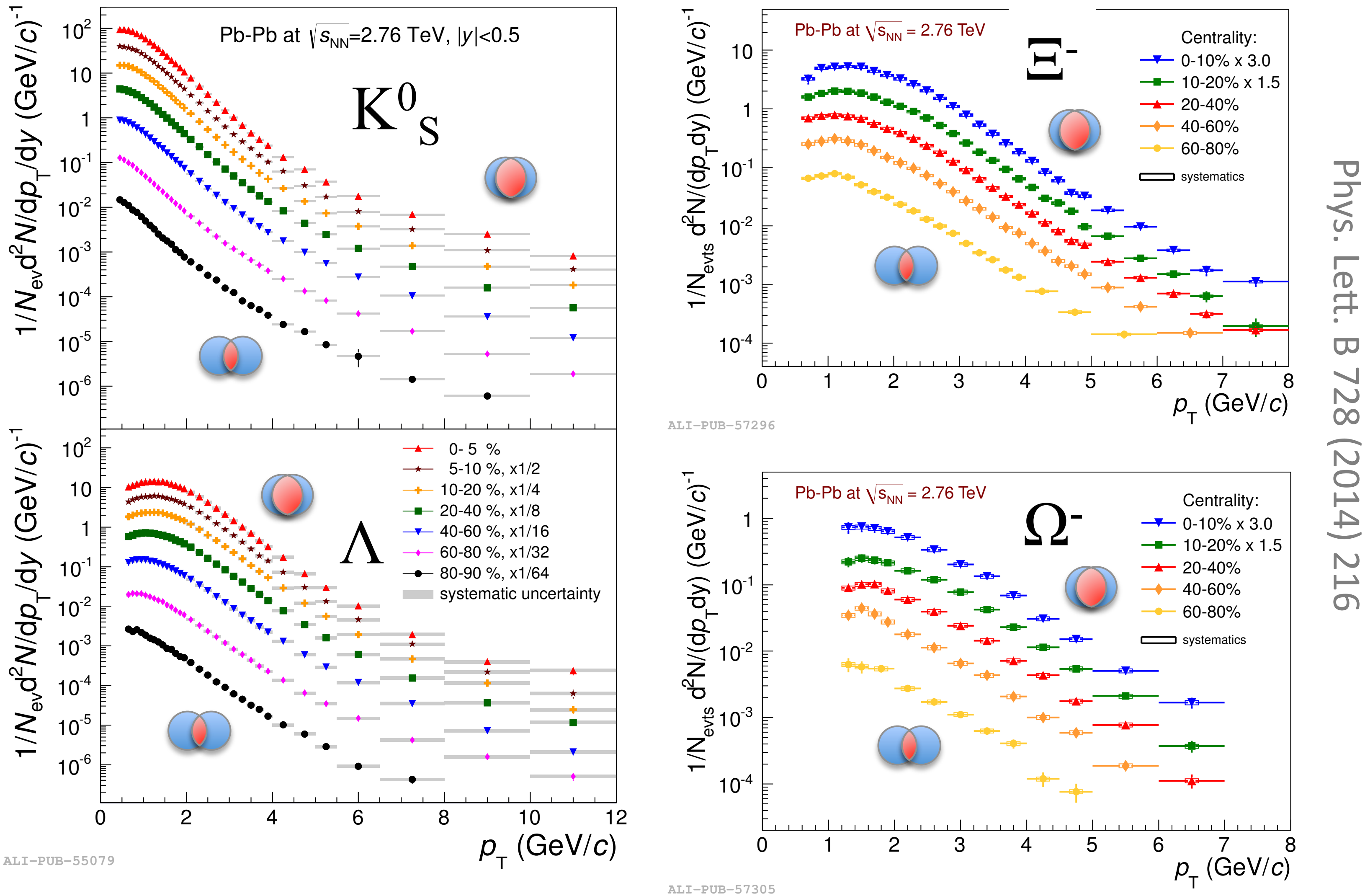
Proton-lead collisions (p-Pb)

Pb-Pb at 2.76 TeV

Transverse momentum spectra

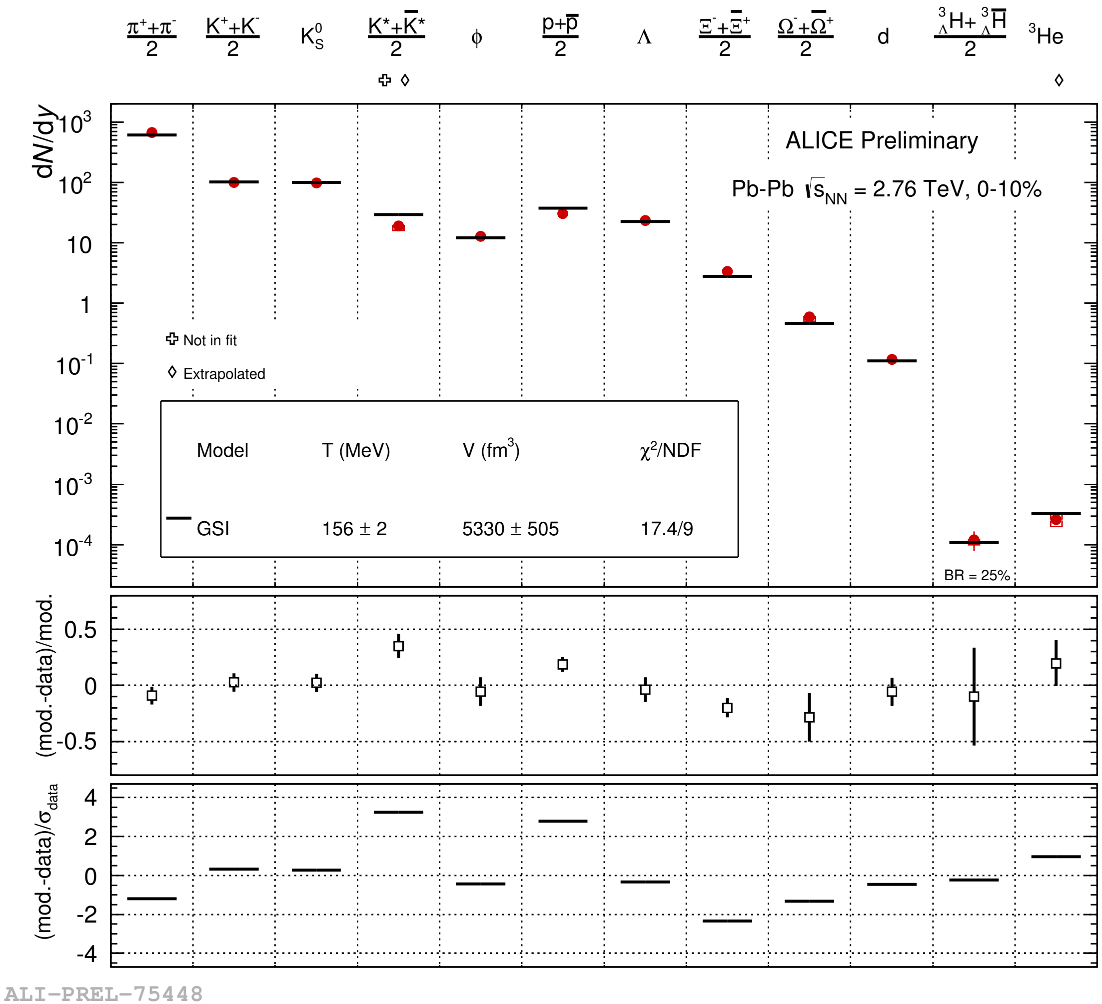
Shown: Particles, antiparticles compatible

Phys. Rev. Lett. 111, 222301 (2013)



Phys. Lett. B 728 (2014) 216

Question 1:
Are production rates consistent with thermal statistical models?



Thermal hadronization model (Grand Canonical)

Fit at 156 MeV:

- Correctly predicts Λ/π
- Still a bit off for p/π
- Misses Multi-strange

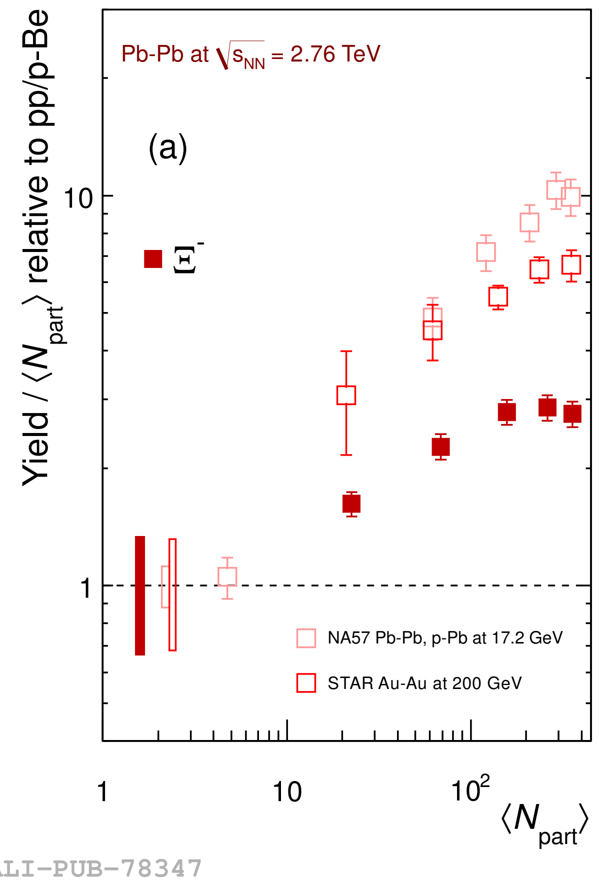
[1] A.Andronic, P.Braun-Munzinger, J.Stachel NP A772 167

Model configuration:

- μ_B fixed at zero
- γ_S fixed at 1
- γ_C fixed at 20

Question 2:
Is strangeness production enhanced?

With respect to the prod. rates observed in more elementary collisions?



$$E_i = \frac{\frac{Yield_i^{AA}}{\langle N_{part} \rangle}}{\frac{Yield_i^{pp}}{2}}$$

Enhancement larger for hadrons with higher strangeness content

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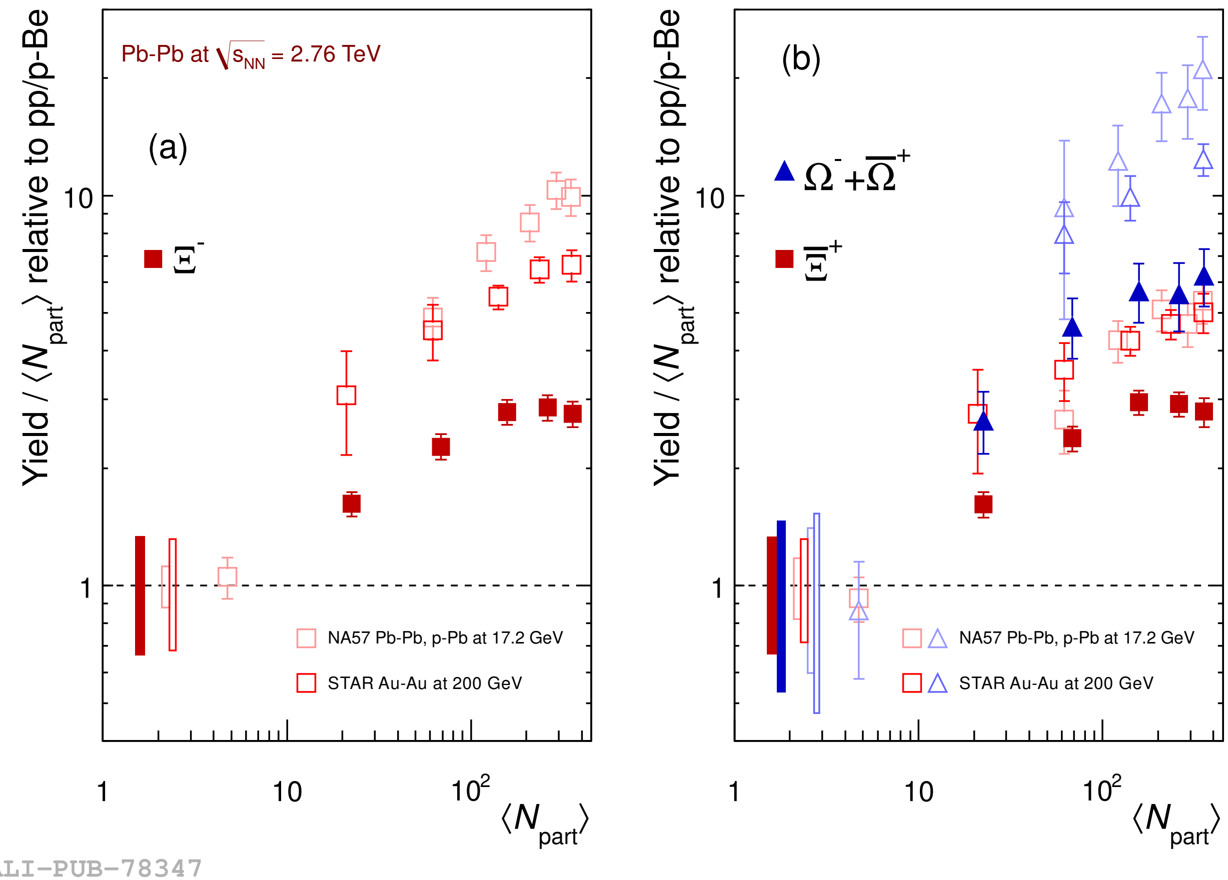

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Enhancement larger for hadrons with higher strangeness content

Enhancement weaker at ALICE than RHIC, NA57

But is the N_{part} scaling the right assumption?

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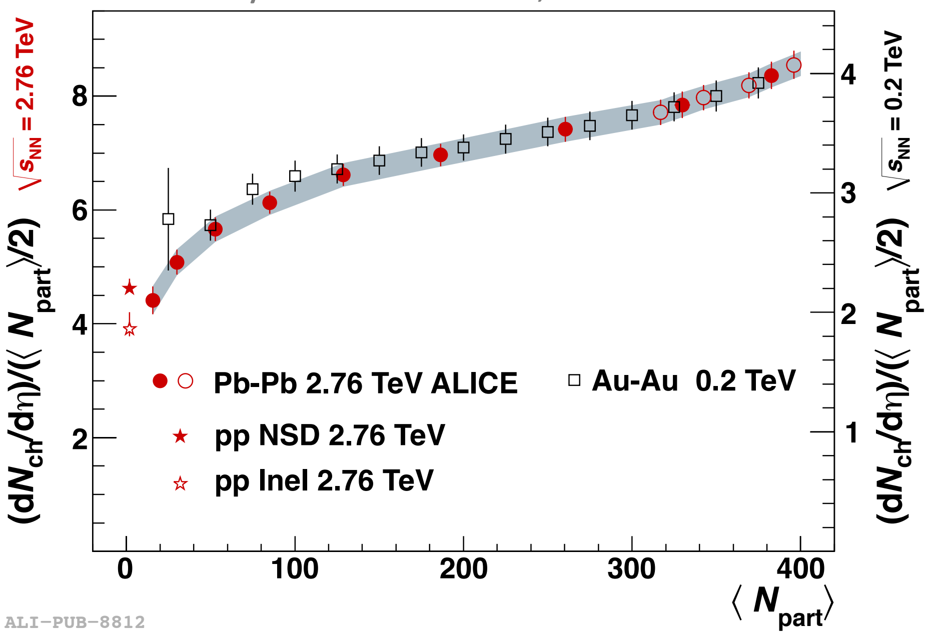
Question 2: Is strangeness production enhanced?

Strangeness Enhancement: Ratio to Pions

Phys. Rev. Lett. 106, 032301



Charged particles do not scale with Npart
Normalize with pion production?

Question 2: Is strangeness production enhanced?

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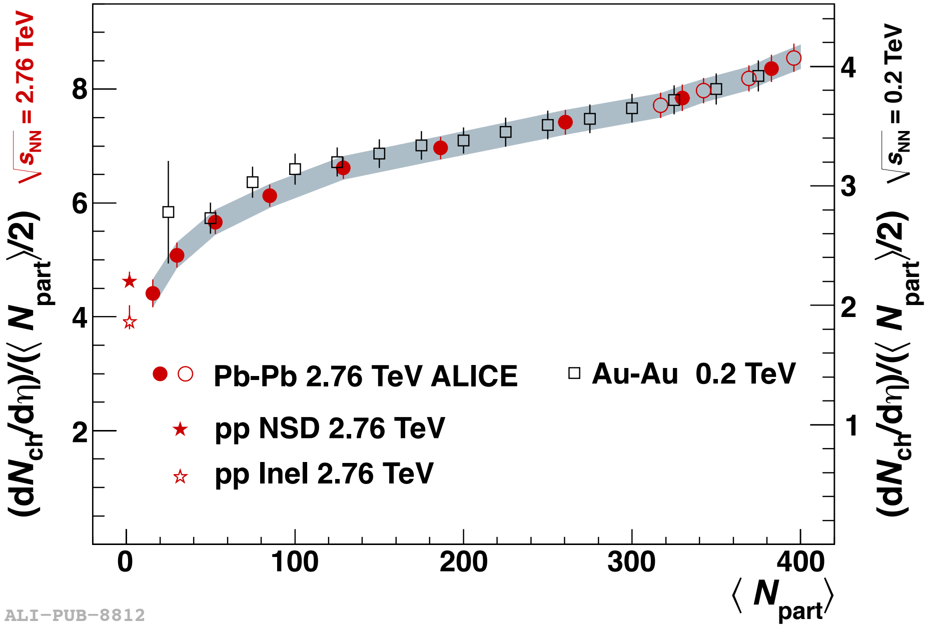

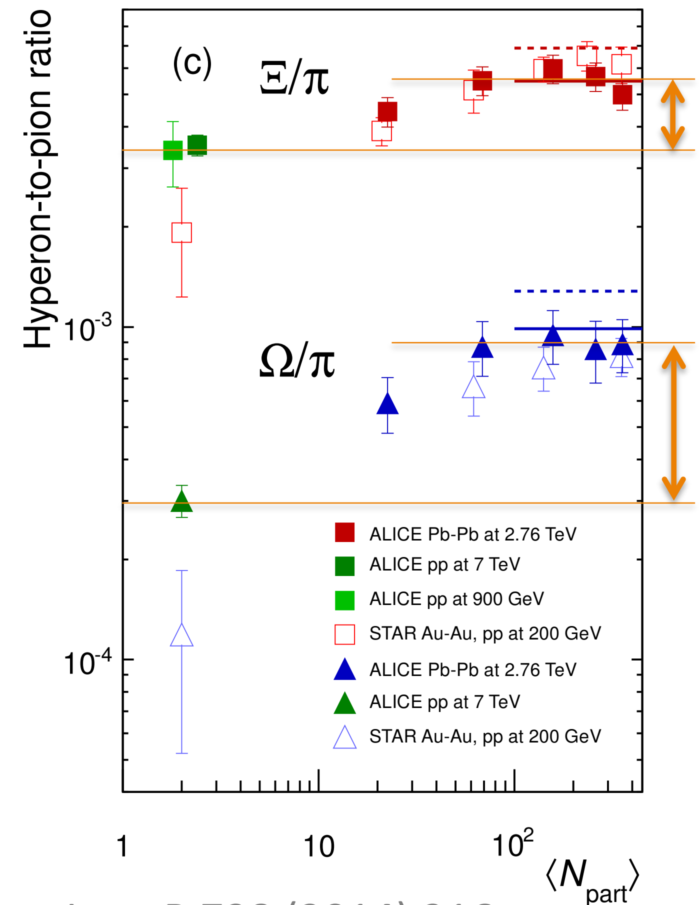

Charged particles do not scale with Npart
Normalize with pion production?

Increase more modest if compared to pions

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Solid Lines: GC thermal fit, T = 164 MeV
Dashed Lines: GC thermal fit, T = 170 MeV

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Question 3:
How are the transverse momentum spectra modified?

-> Binary collision scaled spectrum compared to proton-proton collisions:

$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \frac{\frac{d^2 N^{AA}}{dy dp_T}}{\frac{d^2 \sigma_{INEL}}{dy dp_T}}$$

T_{AA}: Nuclear overlap function
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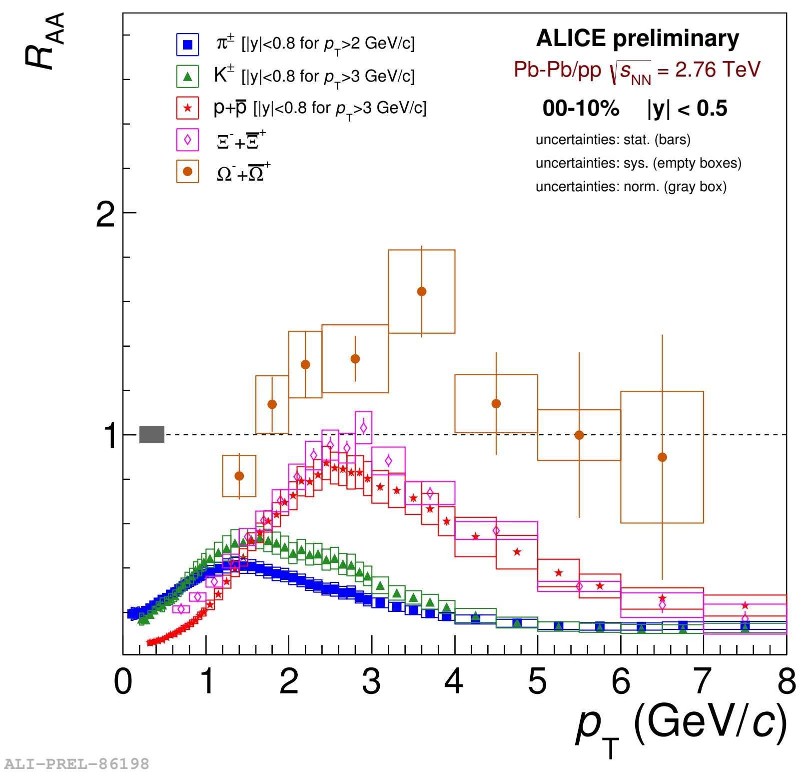

π/K/p compared to Ξ:
- all particles suppressed at larger p_T
- Intermediate p_T: mass ordering
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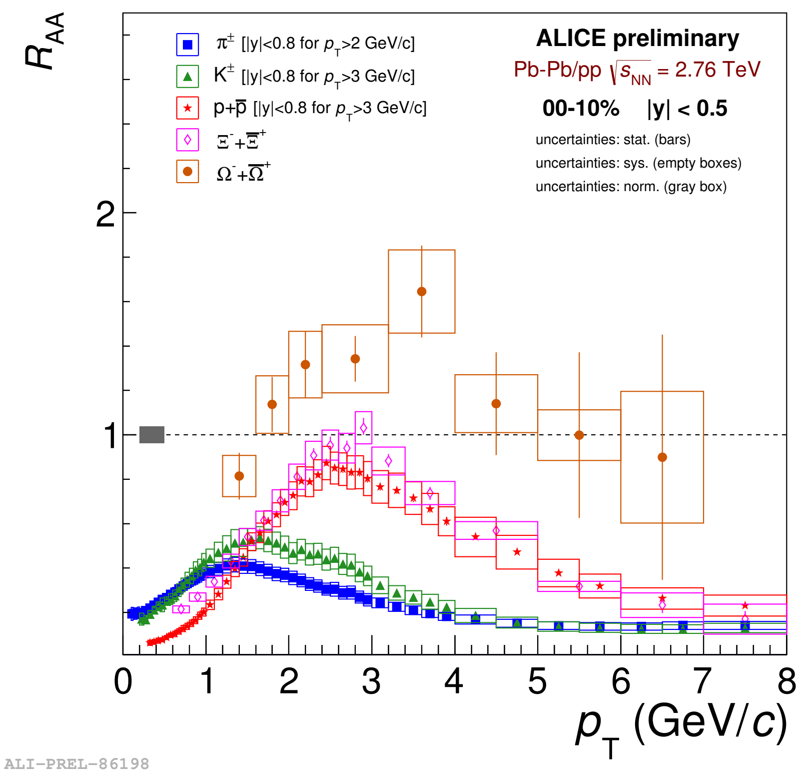

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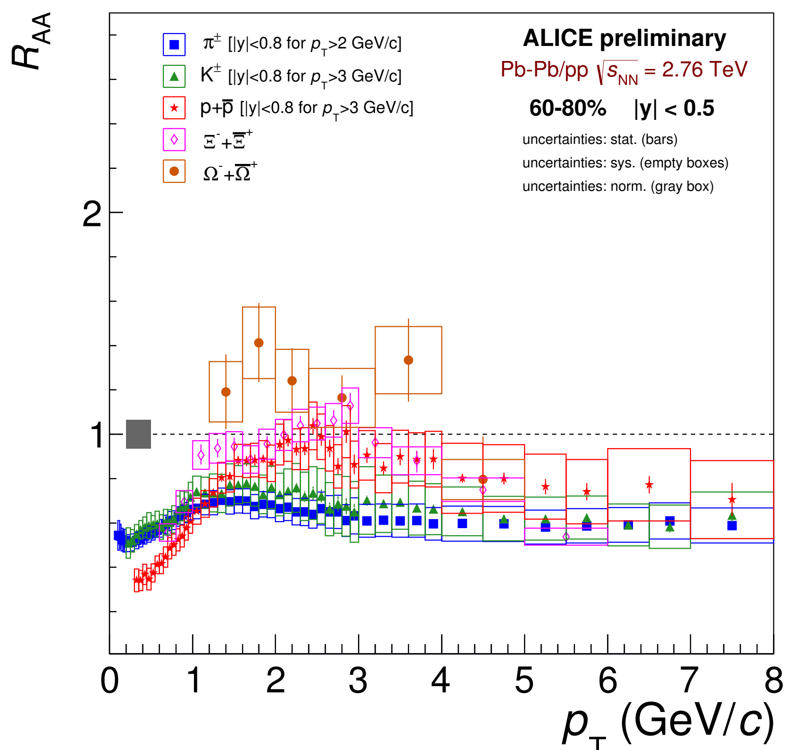

ALI-PREL-86214

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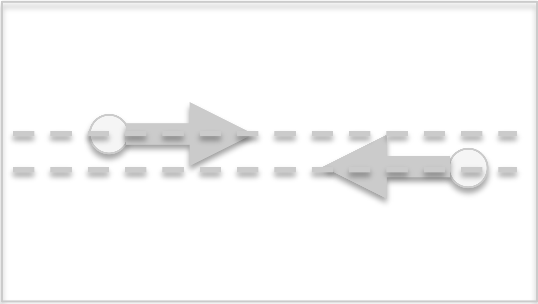
Peripheral collisions: less suppression

Results



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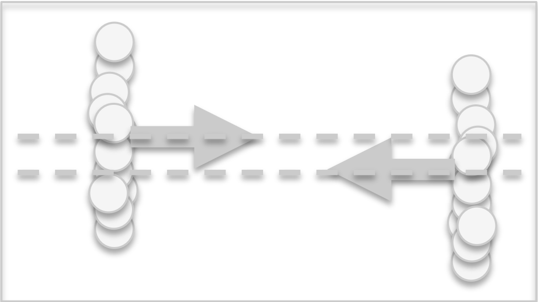

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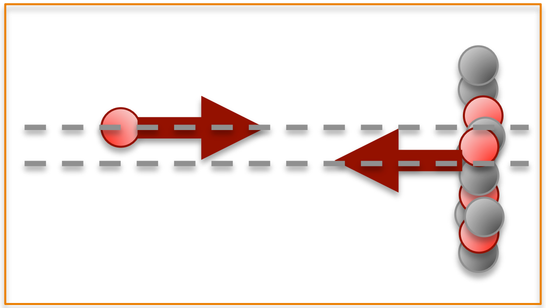

Proton-lead collisions (p-Pb)

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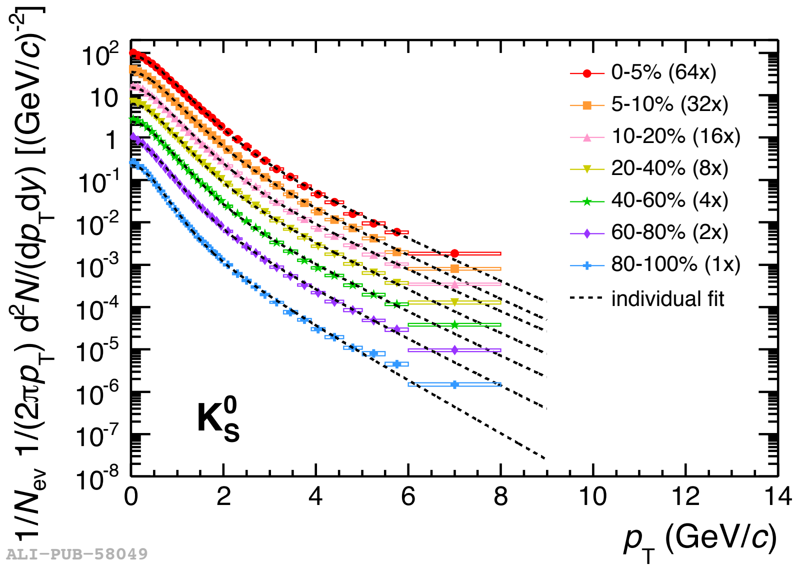
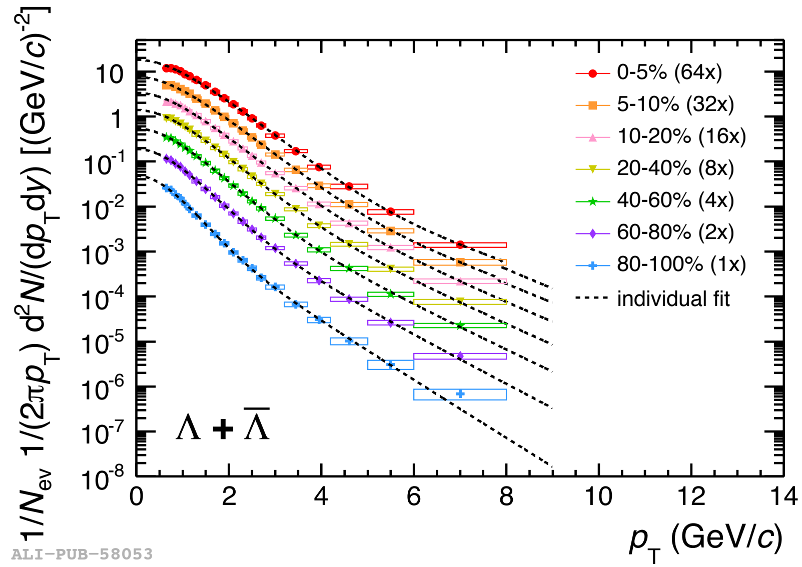
p-Pb at 5.02 TeV

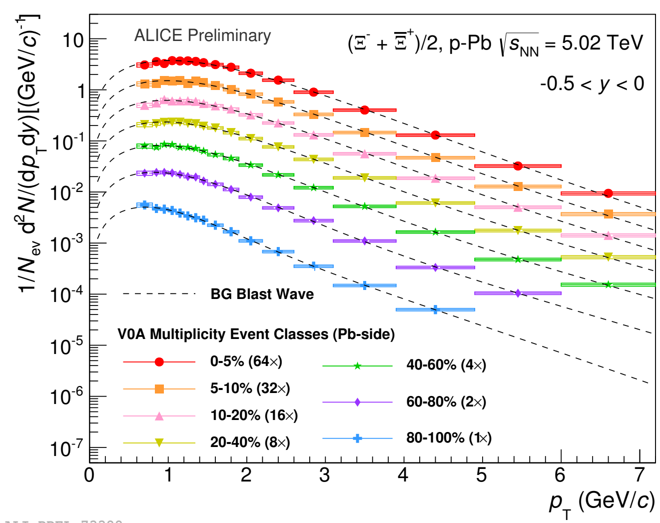
Transverse momentum spectra

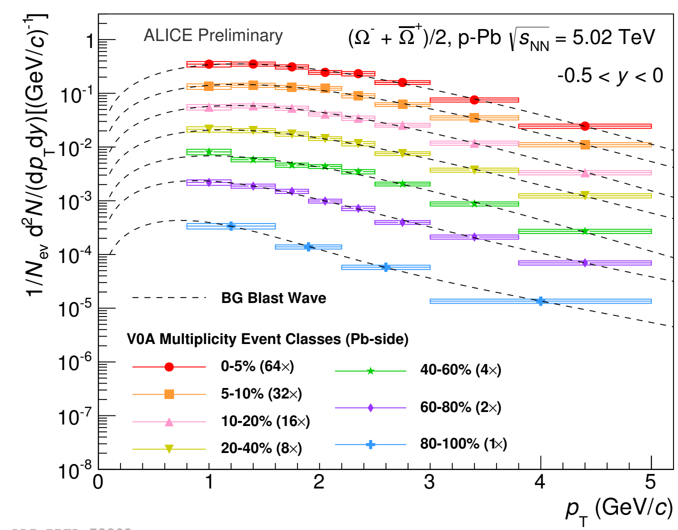
in V0A multiplicity classes





ALICE, arXiv:1307.6796 [nucl-ex]





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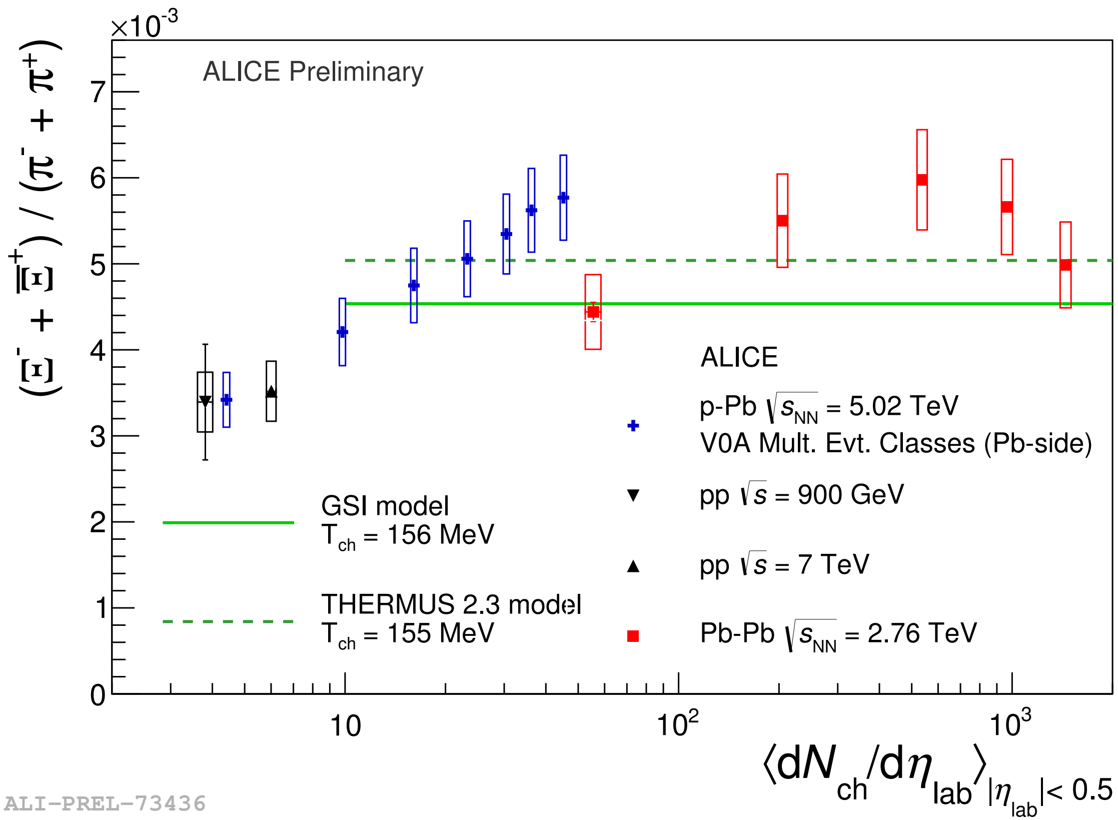
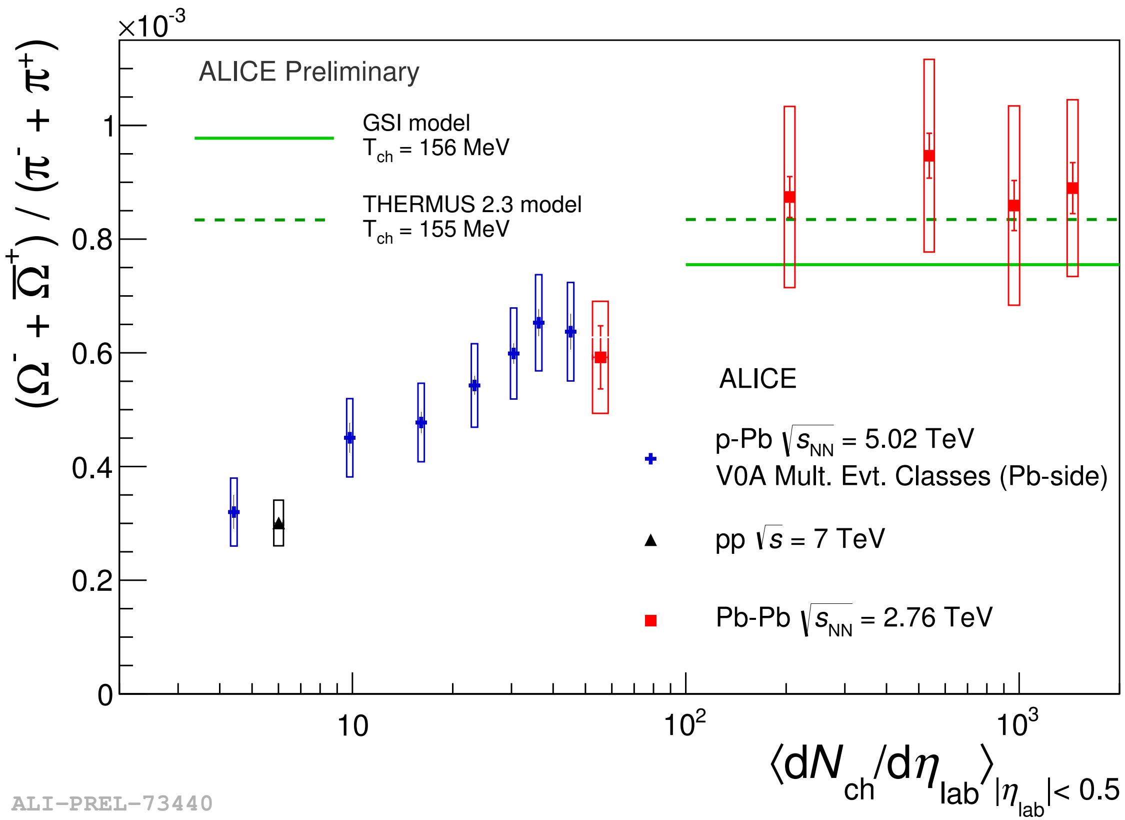
Strangeness Enhancement: Ξ/π



p-Pb results:
Bridge the gap between pp and Pb-Pb

Statistical Hadro. Models:
Fits for Pb-Pb are slightly below p-Pb high-multiplicity value

Strangeness Enhancement: Ω/π



p-Pb results:
Bridge the gap between pp and Pb-Pb

Statistical Hadro. Models:
Consistent within errors with Pb-Pb results, ratio above p-Pb

Conclusions

- **Strangeness in pp collisions**
  - Measured K^0_s, Λ, Ξ, Ω
  - Antiparticle to particle ratios compatible with unity
  - Comparison to latest PYTHIA tune (Perugia 2011):
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- **Strangeness in Pb-Pb Collisions**
  - Strange and Multi-Strange in thermal fit
    - Unique chemical freezeout temperature does not describe relative p, Λ, Ξ, Ω
  - Strangeness enhancement: weaker at the LHC than at RHIC
    - New description: ratio of strange particles to pions, factors out N_{ch} increase
  - Nuclear modification factor: large suppression at high p_T, all species

Conclusions

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  - Antiparticle to particle ratios compatible with unity
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Thank you!

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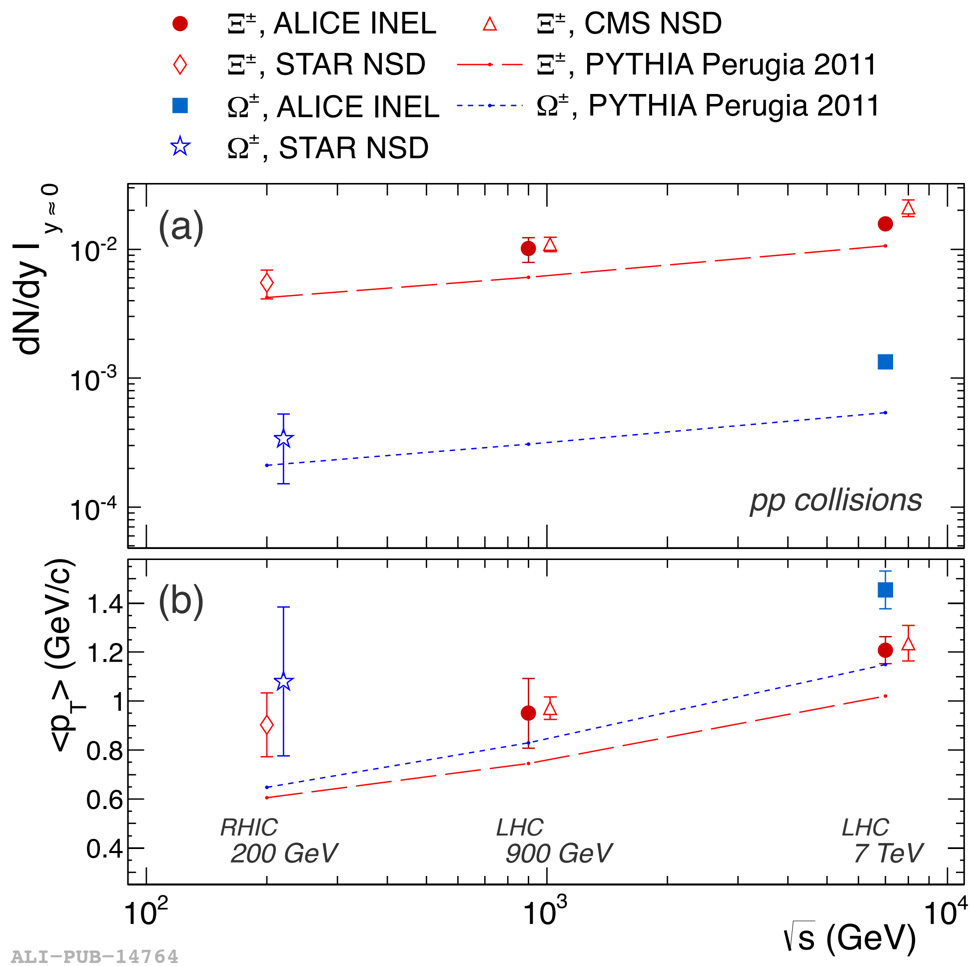
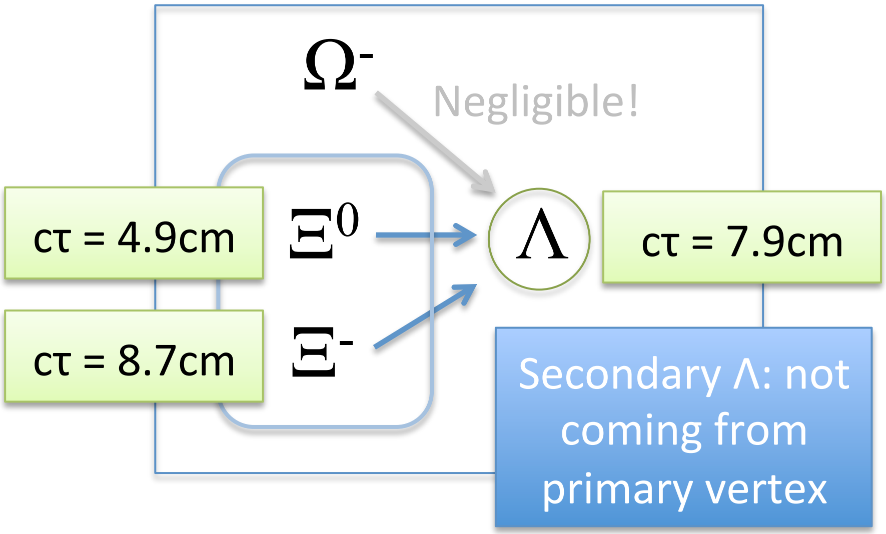
BACKUP

Multi-Strange Yields in pp

Beam energy dependence



Feeddown Subtraction for Λ



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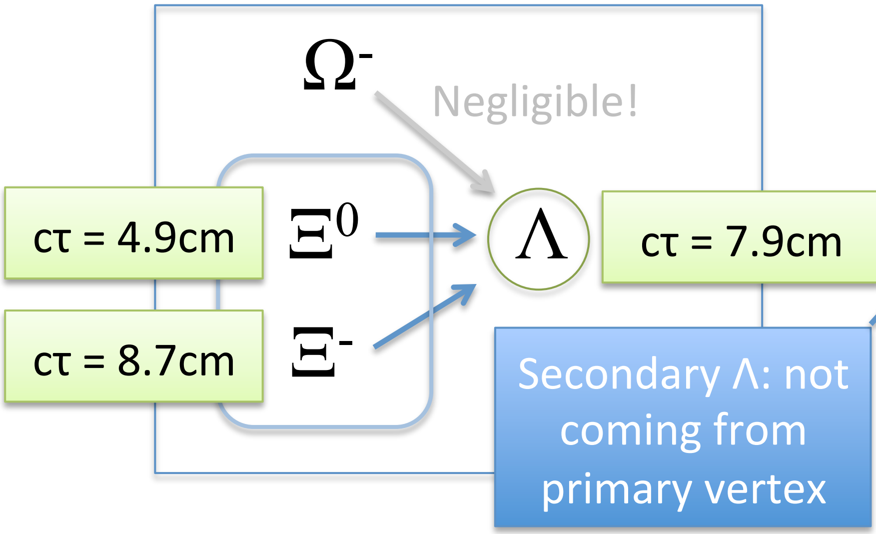

Desired Measurement requires subtracting an estimated Λ raw yield coming from Ξ

How does the Λ from Ξ enter the analysis?

- *Compute Feeddown Matrix*

In what magnitude does it contribute?

- *Use a Ξ measurement as weight*

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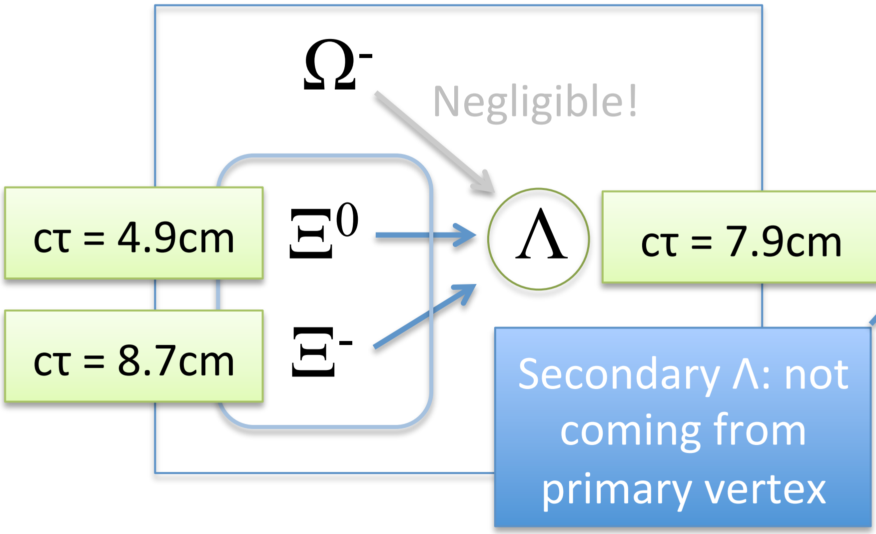

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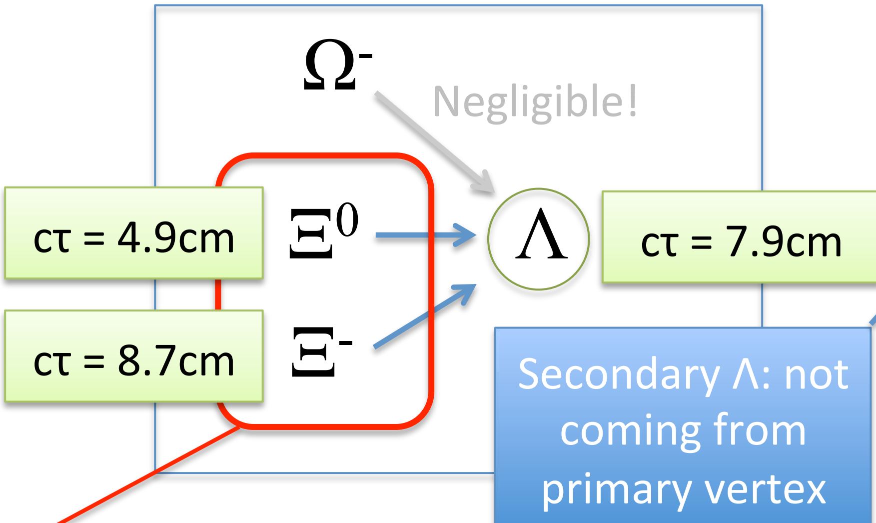

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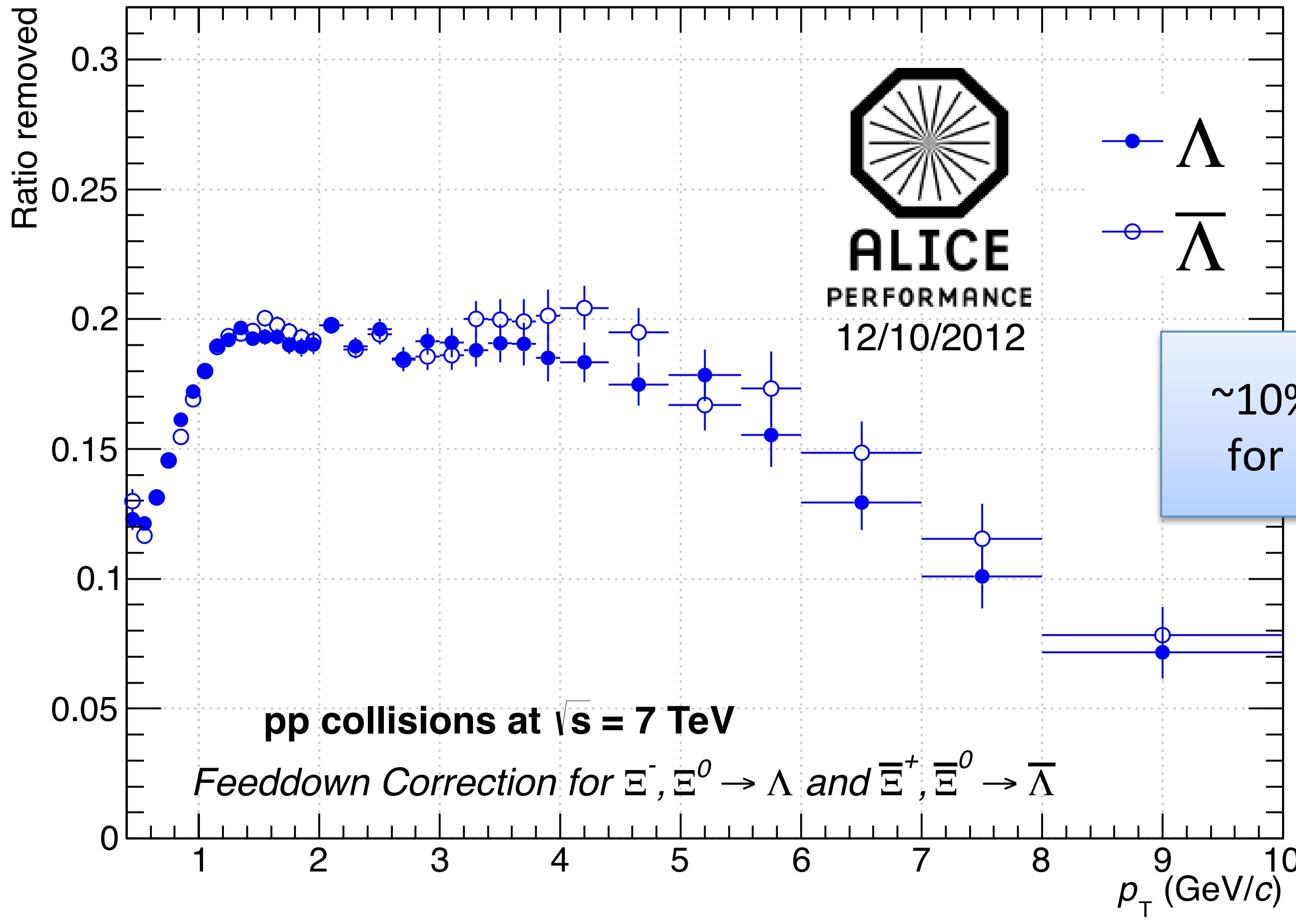
Two methods for considering Ξ^0 tested:
- Fill F_{ij} with Λ coming from both charged and neutral Ξ
- Multiply charged Ξ feeddown by 2

Consistent Results

Total Feeddown Subtraction Fraction Example

(proton-proton @ 7 TeV)



~10% total removal for each Ξ species

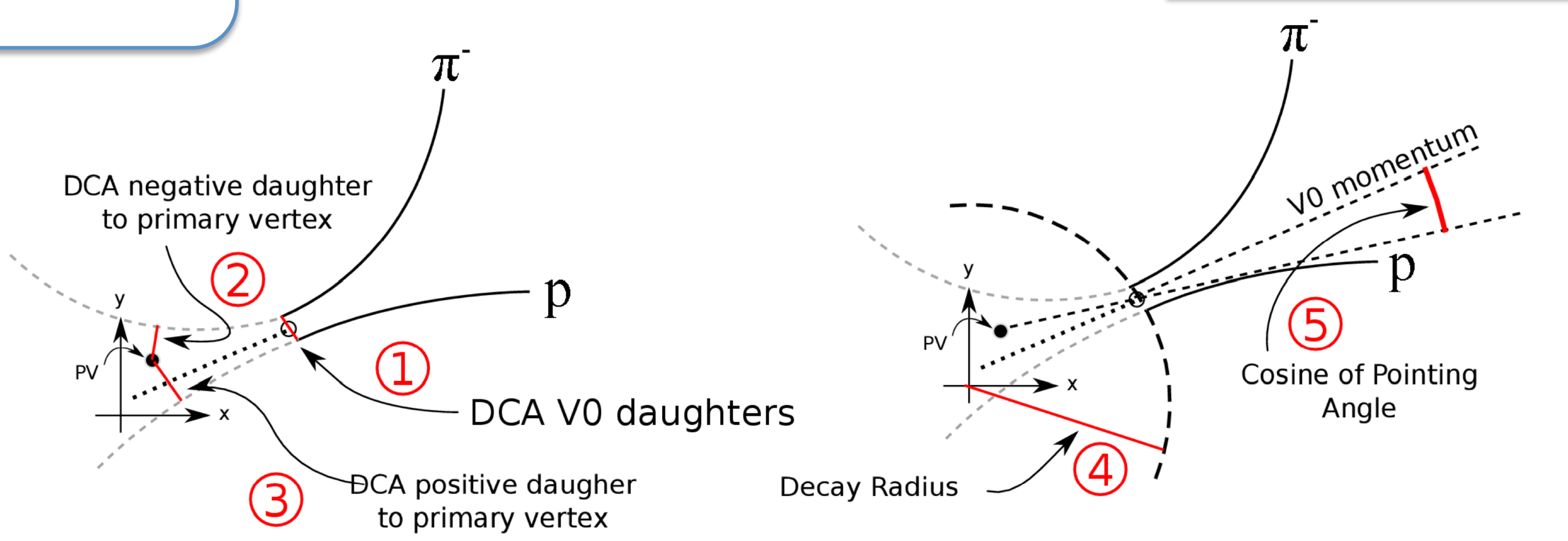
Candidate Selections

Λ, K^0_S

V0 Decays:
5 Variables

Topological Sel.

Use Track Geometry!

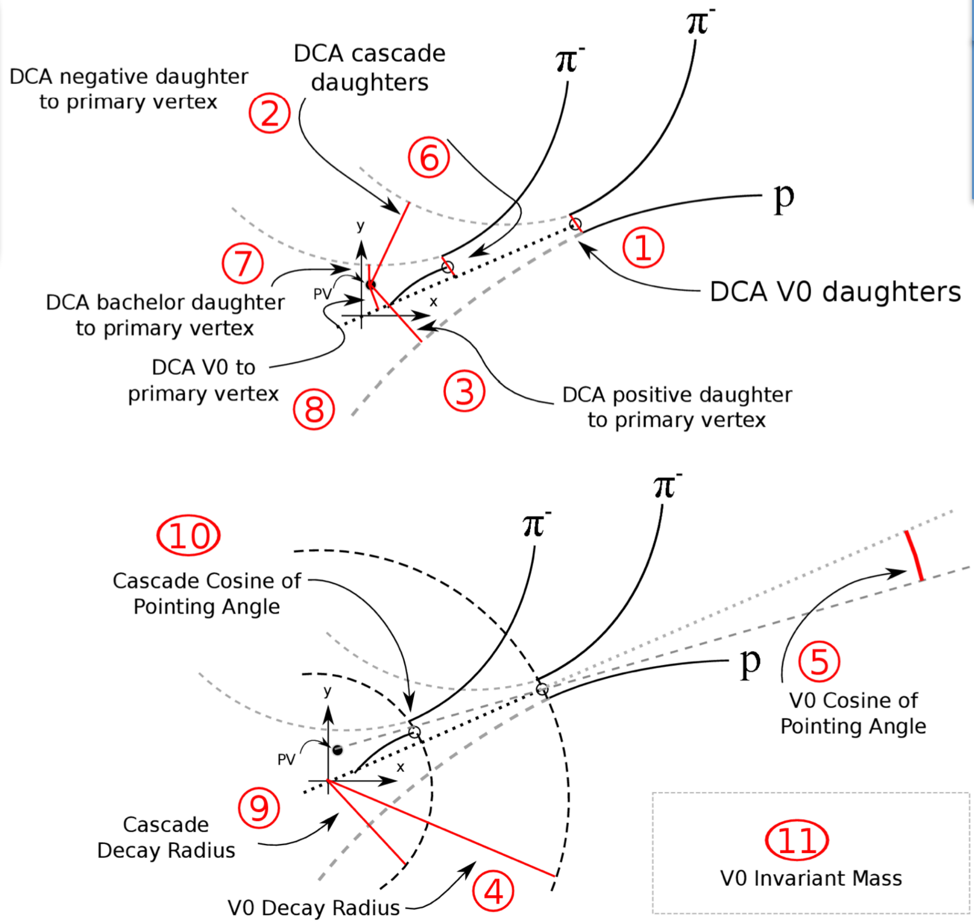


Candidate Selections

Ξ^-, Ω^-

Cascade Decays:

11 Variables



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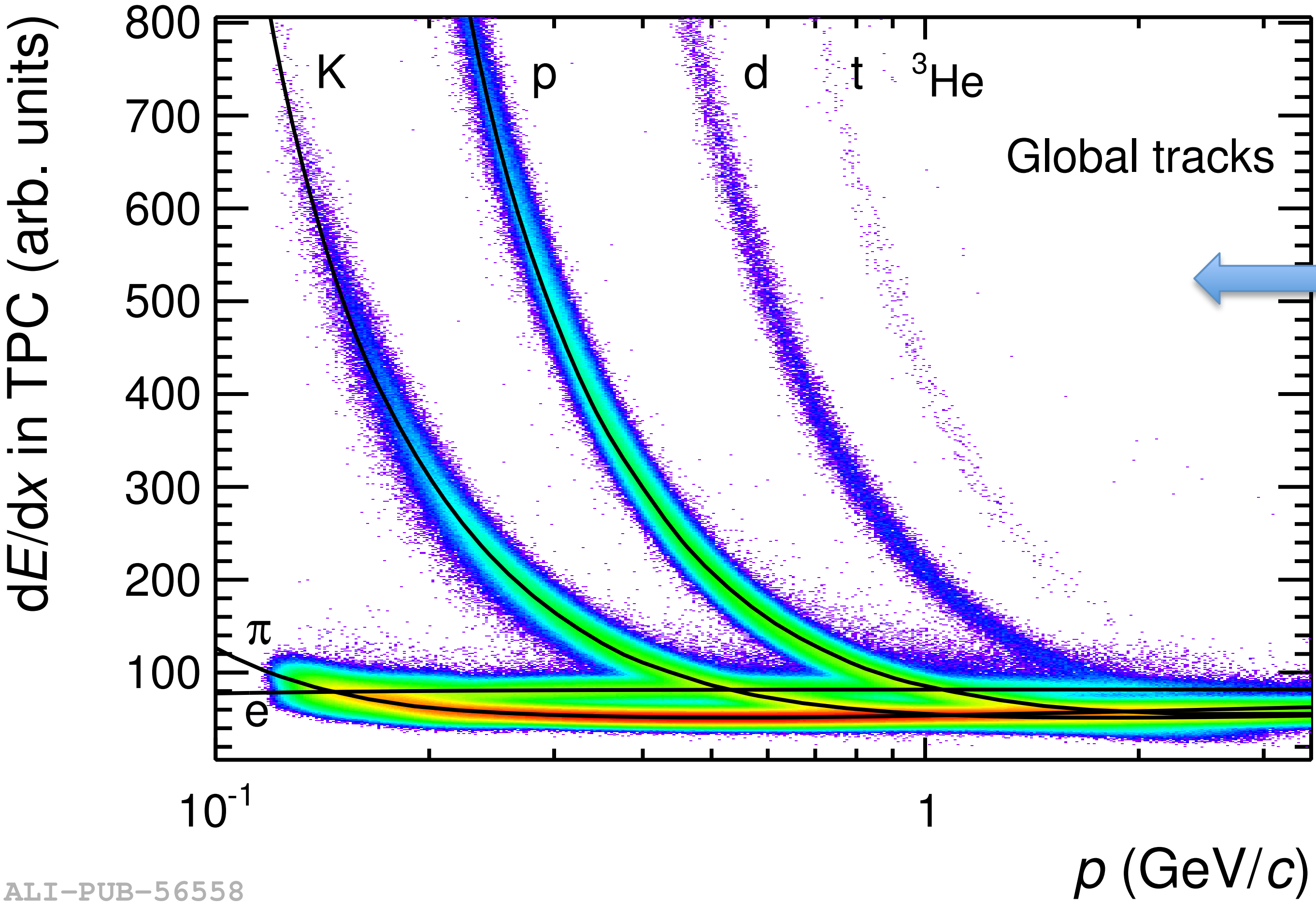

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Daughter PID

Energy deposition in the TPC gas (dE/dx)

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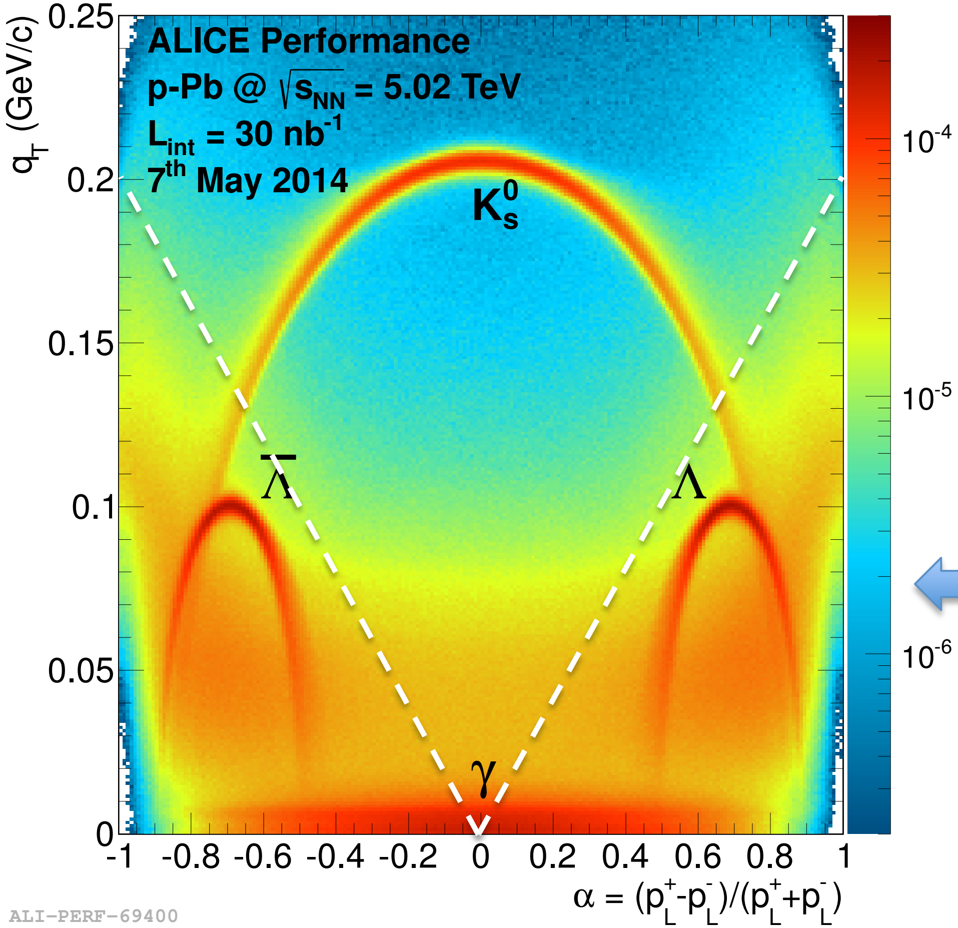

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Daughter PID

Energy deposition in the TPC gas (dE/dx)

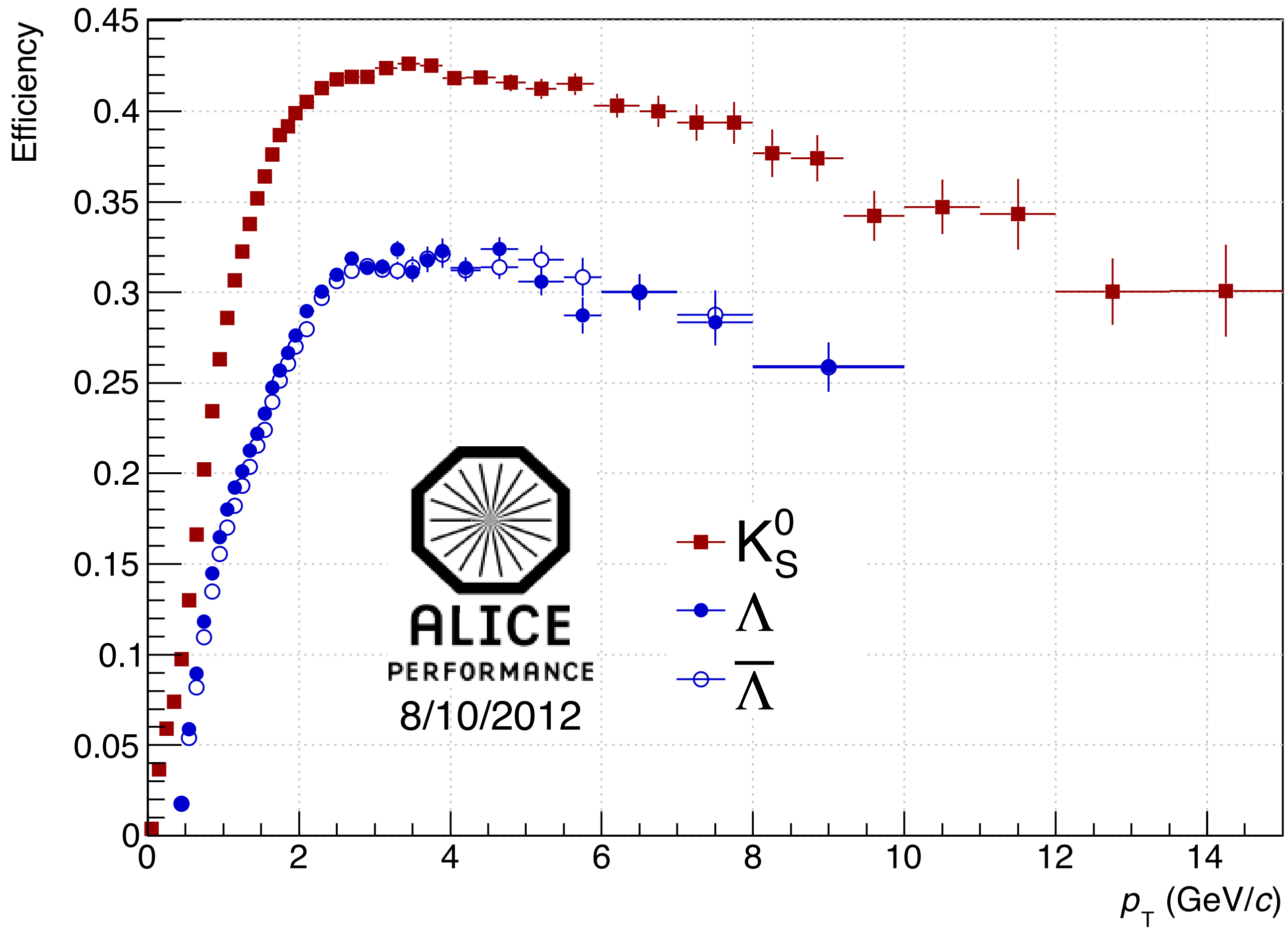
Competing Species Decays

In pp: *Invariant mass rejection of competing V0 species*
In Pb-Pb: *Armenteros-Podolanski selection for K^0_s*

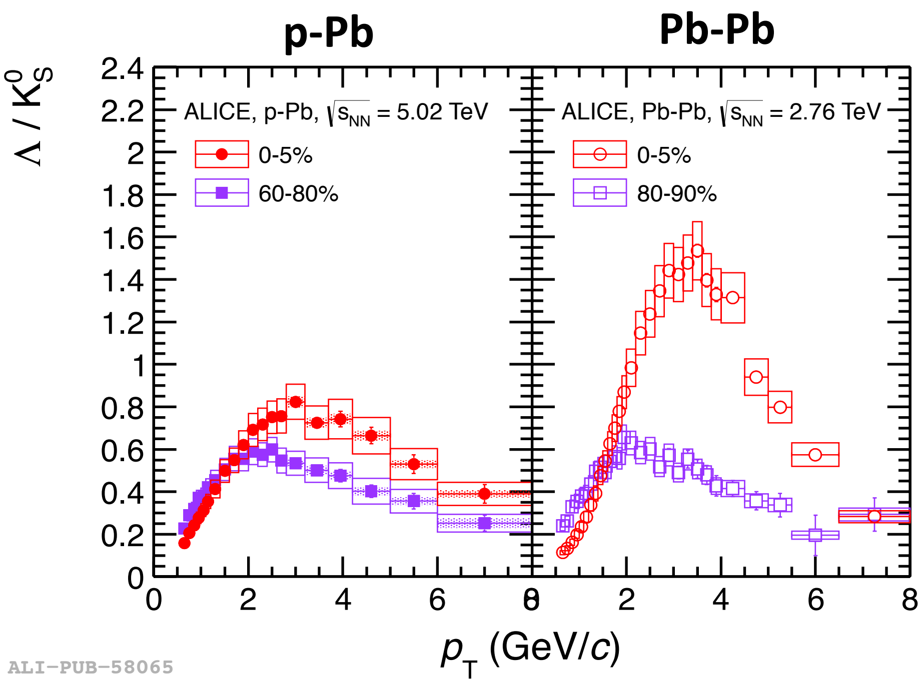
α_{arm}: asymmetry in longitudinal momentum distribution
p_T^{arm}: total transverse momentum of daughters
(longitudinal and transverse directions with respect to V0)

Efficiency Corrections

Example: proton-proton collisions, √s = 7 TeV



Baryon-to-meson Ratio:
Evolution with Multiplicity



Λ/K^0_s ratio vs multiplicity:

For a higher $dN_{ch}/d\eta$, we see:

- Increase at mid- to high p_T
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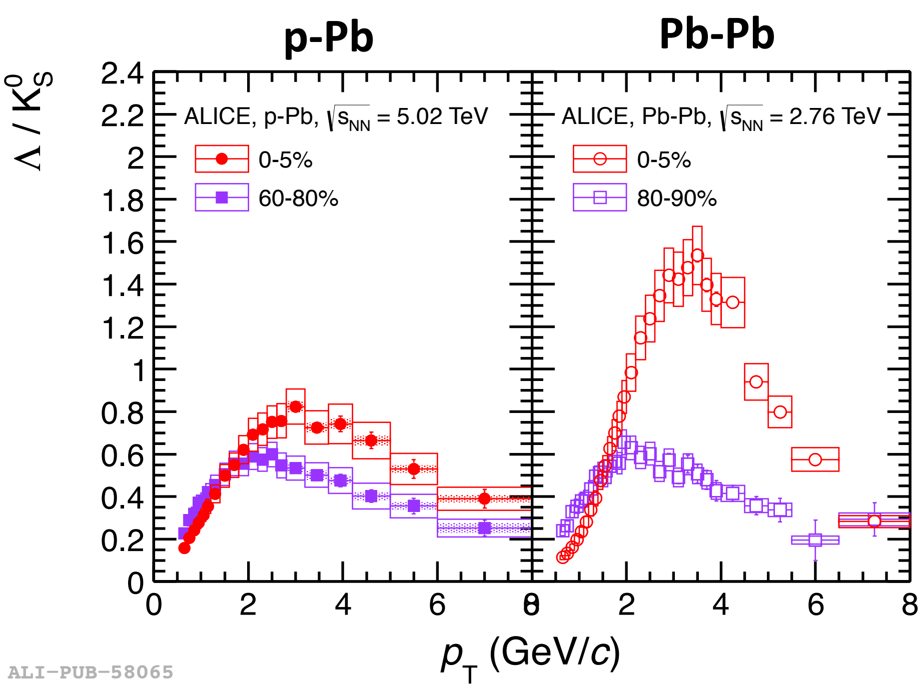

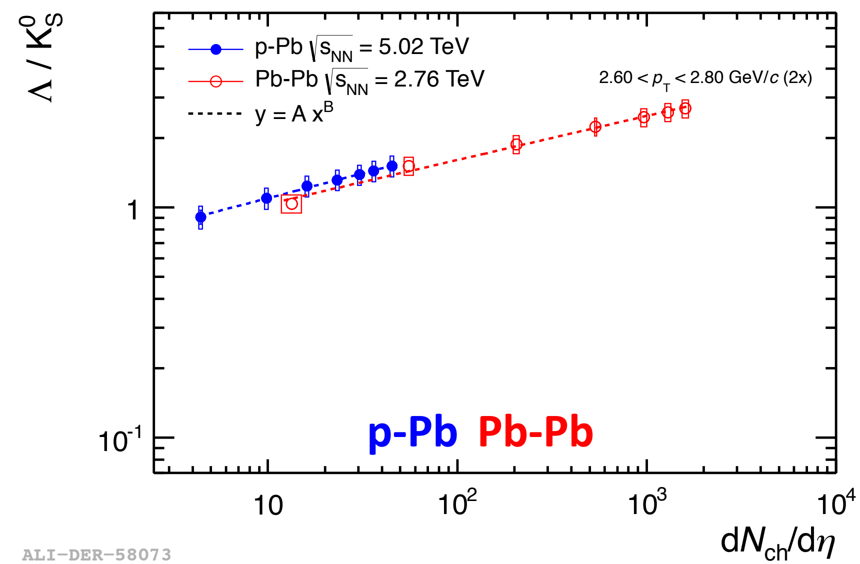

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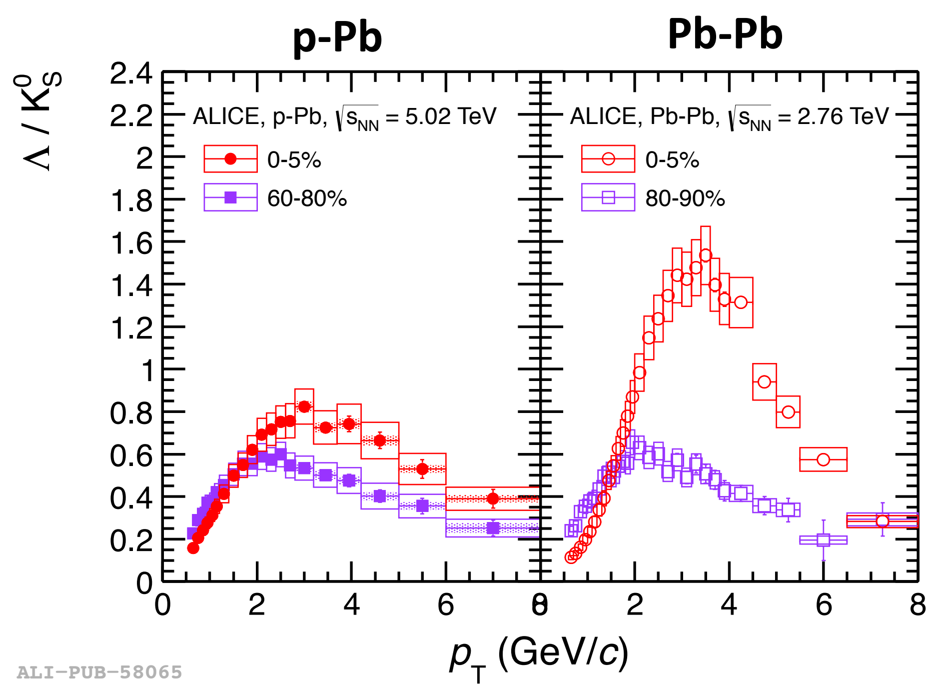

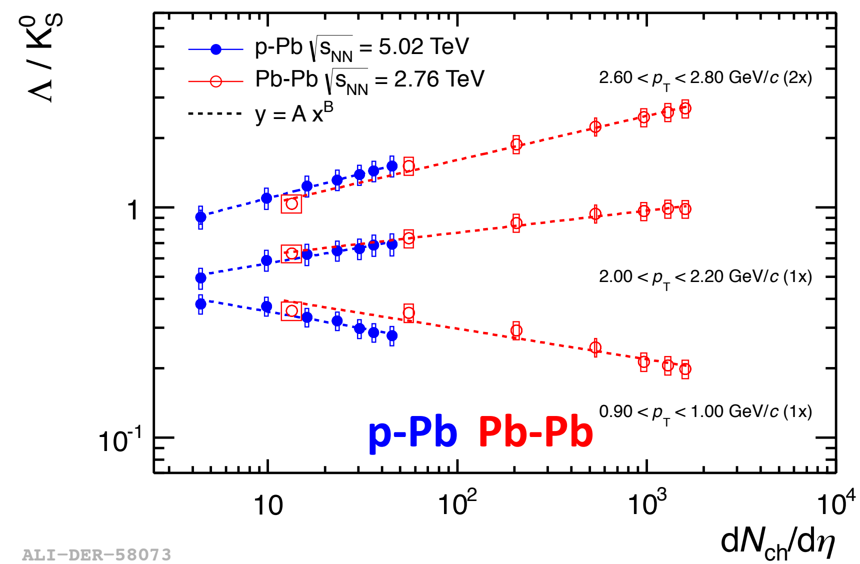

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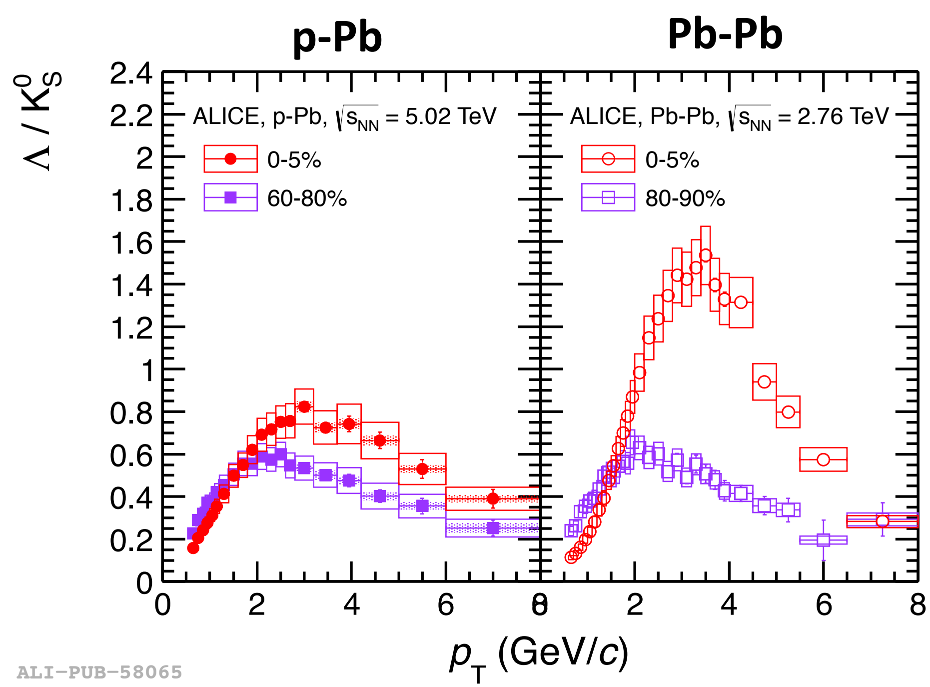

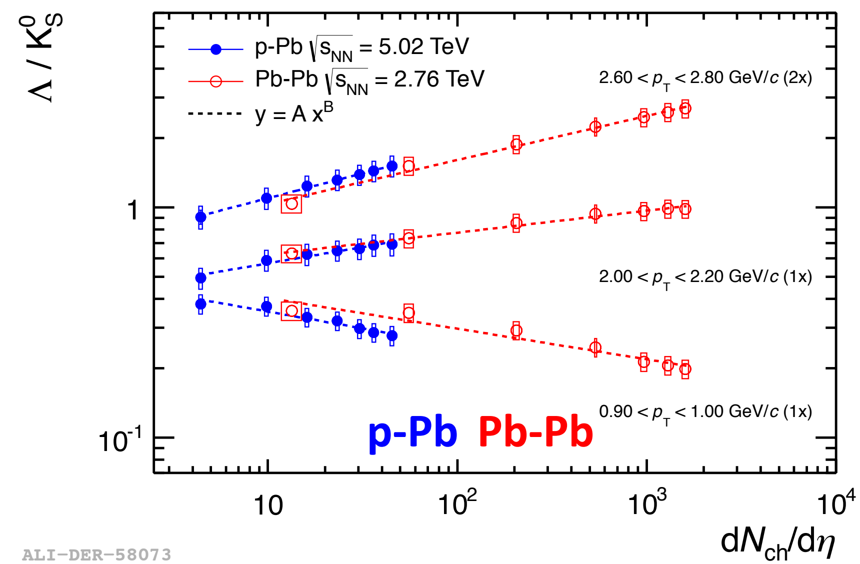

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Quantitative comparison:
Fitting the ratio with a power law,

$$\Lambda/K^0_s = A\,(dN_{ch}/d\eta)^{B}$$

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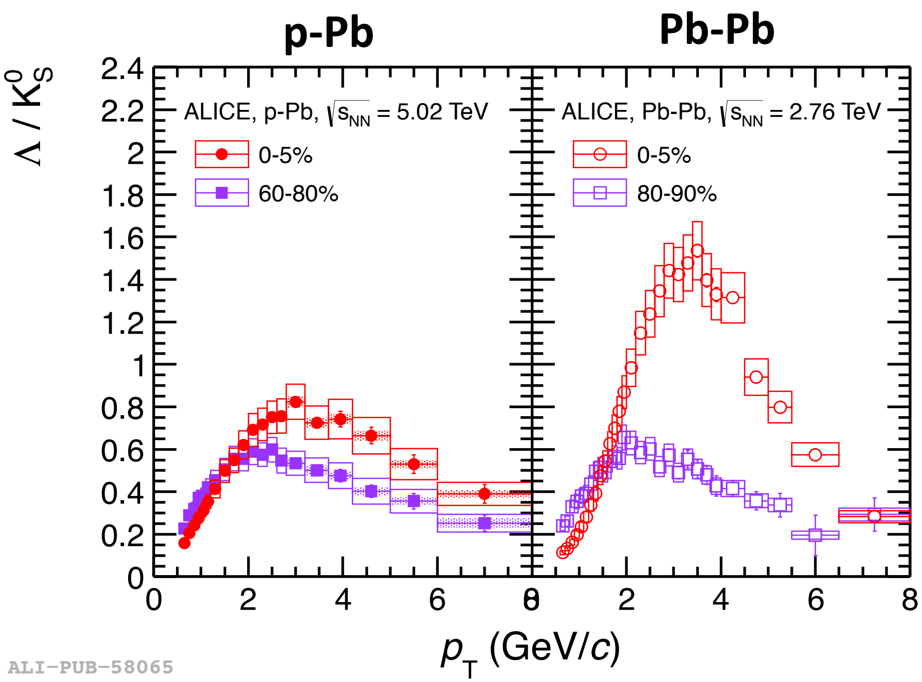

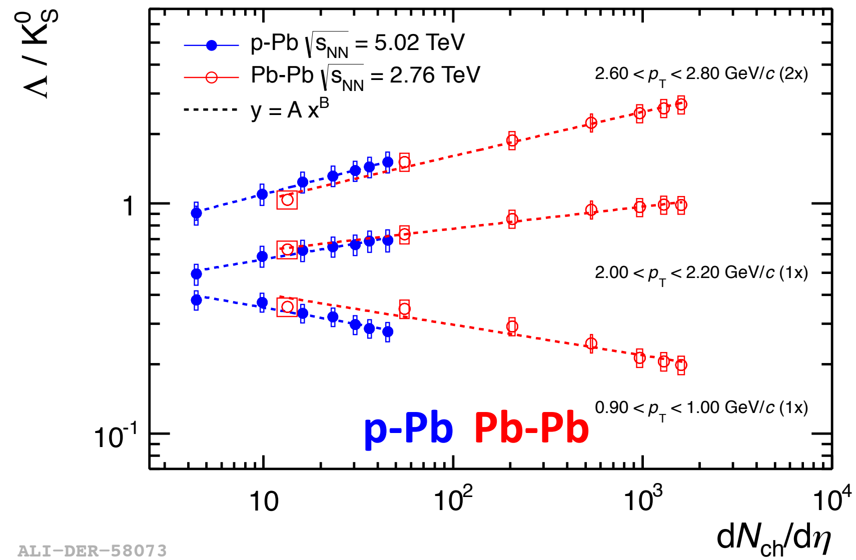

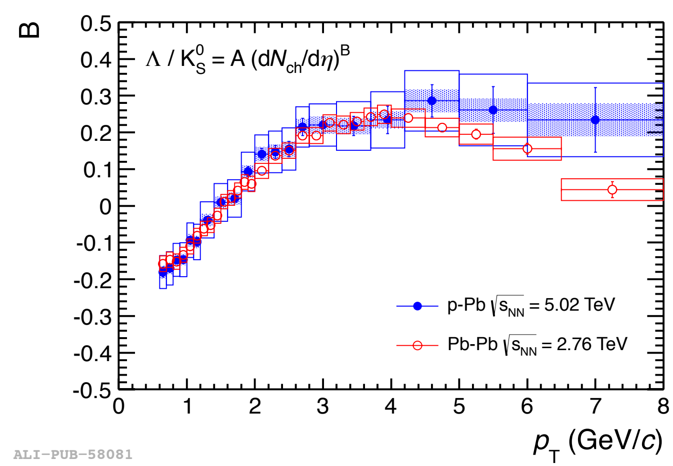

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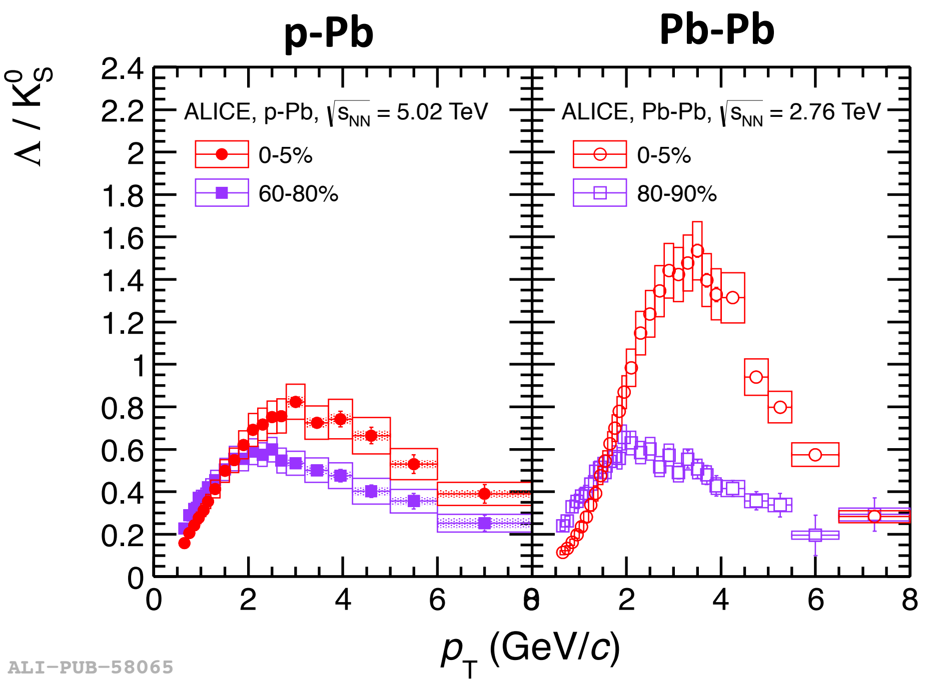

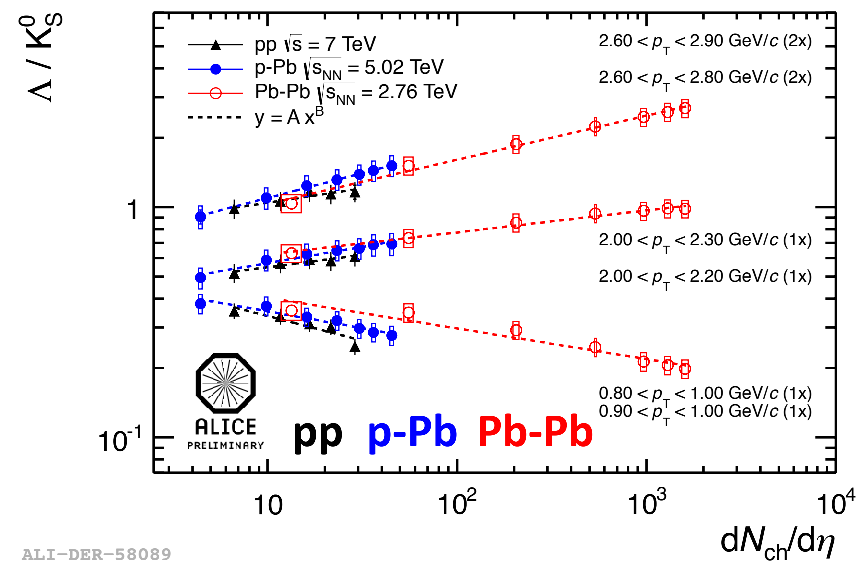

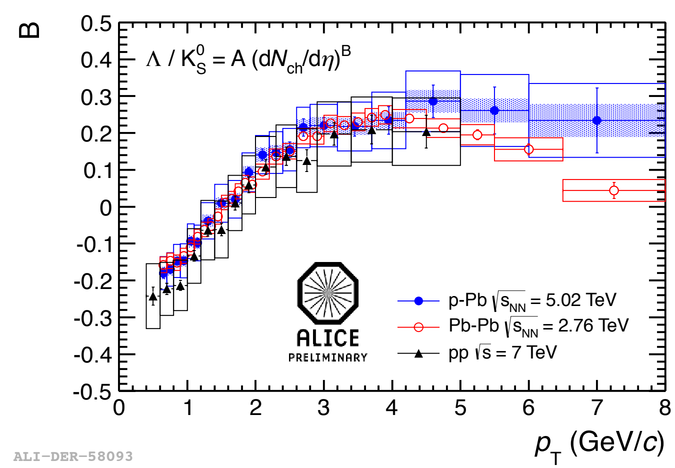

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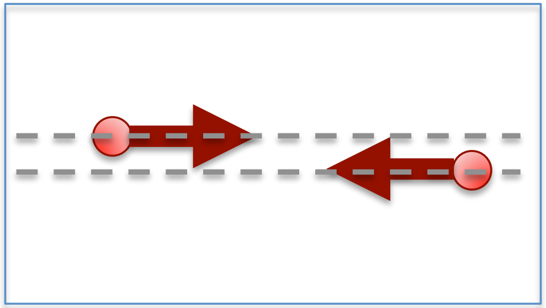
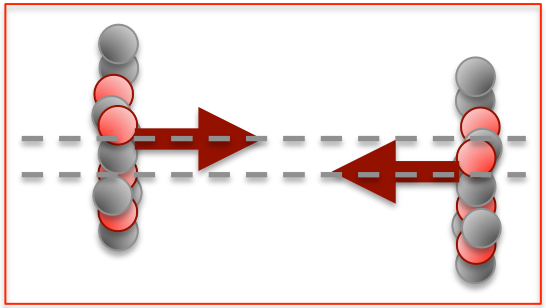
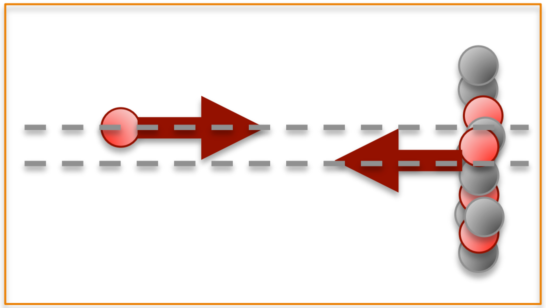
Results



Proton-proton collisions (pp)



Lead-lead collisions (Pb-Pb)



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