Insights on strange quark hadronization in small collision systems with ALICE: multiple strange hadrons and $\Sigma^{\pm}$ baryons

Sara Pucillo[1,2]
on behalf of the ALICE Collaboration

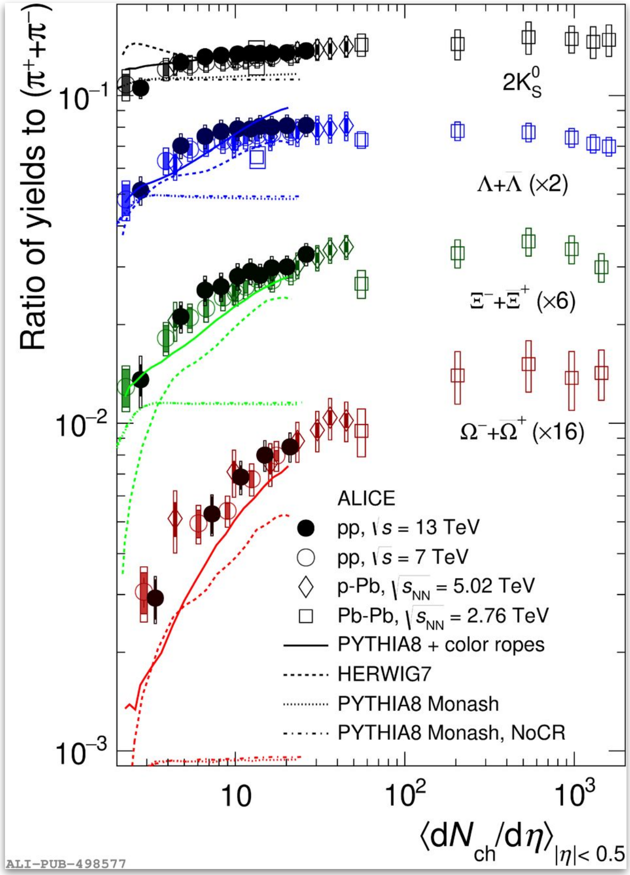
QM 2023 - Houston
03-09 Sept.

1. Università degli Studi di Torino
2. INFN Torino

Physics motivation

Strangeness Enhancement (SE):

- S/π increases as a function of multiplicity identically across different energies and collision systems.
- Enhancement proportional to the strangeness content in the hadron



ALICE Coll., Eur. Phys. J. C 80 (1616) 693

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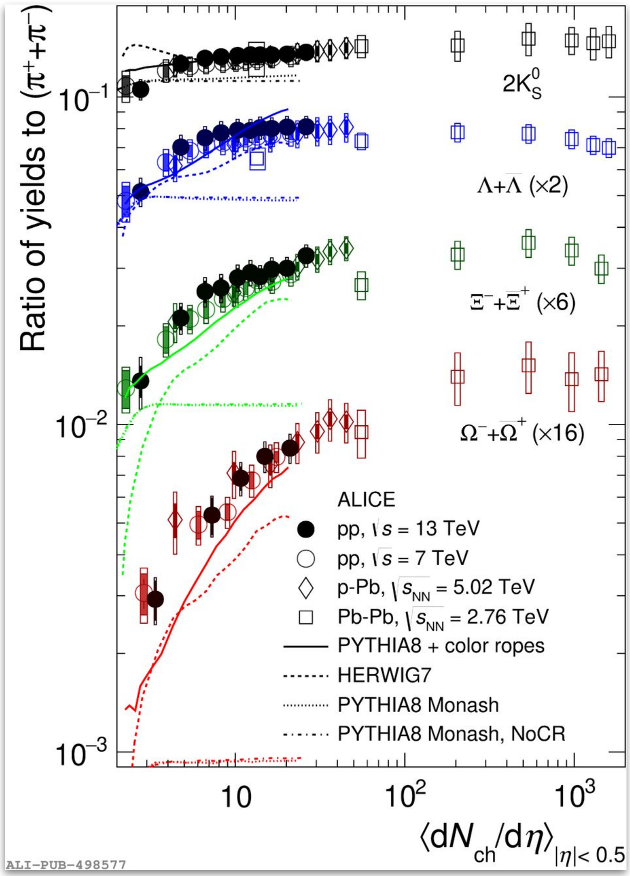
<u>New in this talk</u>:

- (anti)$\Sigma^{\pm}$ baryons → same strangeness content as Λ
- Probability Density Function (PDF) for K^0_S, Λ, Ξ, Ω
  - extend beyond the average of the distribution
  - unique opportunity to test the connection between charged and strange particle multiplicity production



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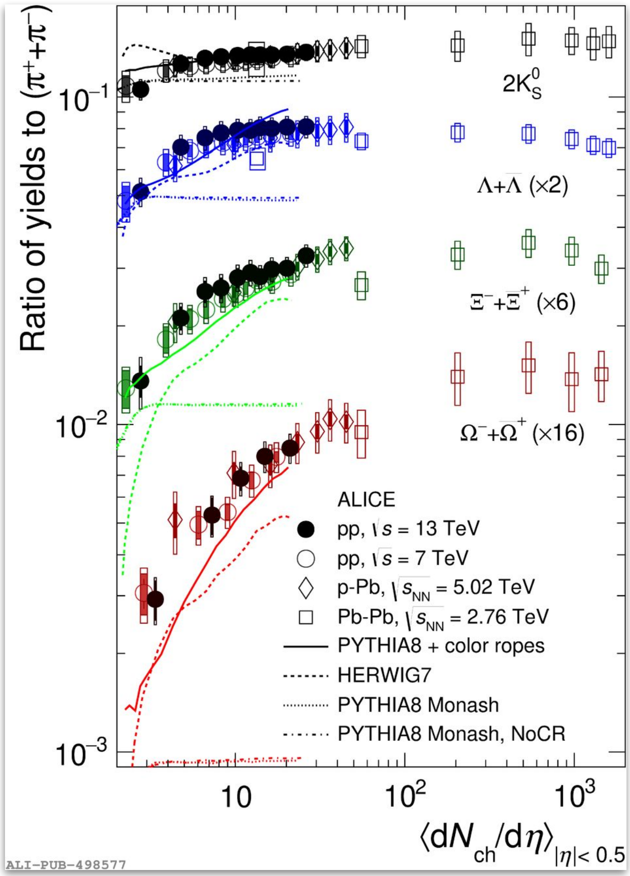
Comparison to models:

- in-vacuum hadronization (e.g. Pythia, AMPT, ...)
- thermal production: Statistical Hadronization Model (e.g. GSI-Heidelberg, FIST, ...)
- two-component models (e.g. EPOS, DCCI, ...)



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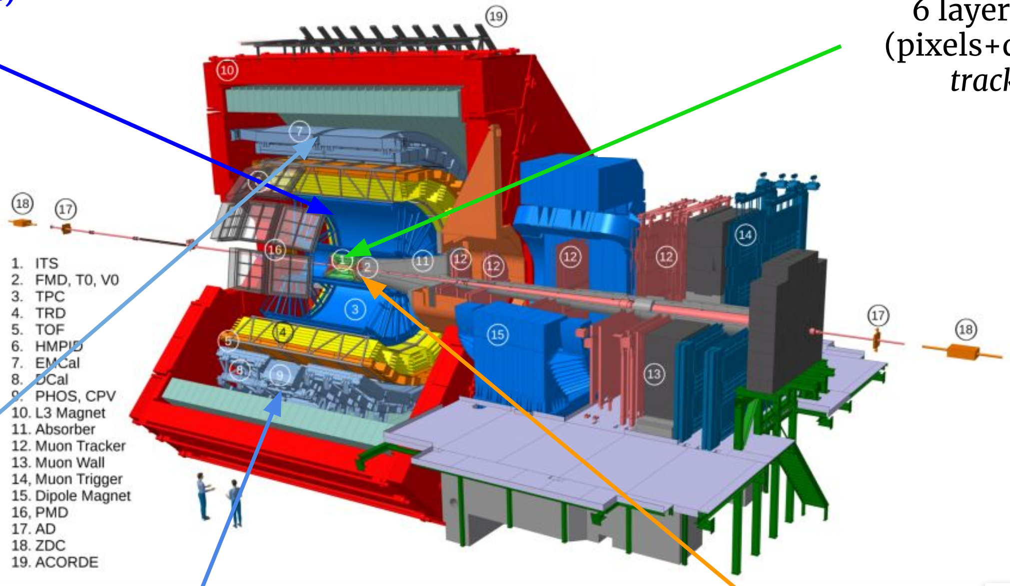
Time Projection Chamber (TPC)
Gas filled detector
tracking, PID (dE/dx)

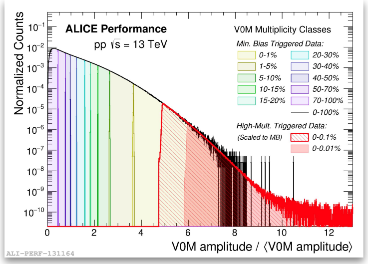
Inner Tracking System (ITS)
6 layers of silicon detectors (pixels+drift+strips) *triggering, tracking, vertexing, PID*



ElectroMagnetic CALorimeter (EMCal)
Pb-scintillator sampling calorimeter

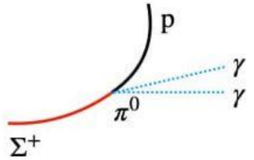
PHOton Spectrometer (PHOS)
High-granularity electromagnetic calorimeter ($PbWO_4$)

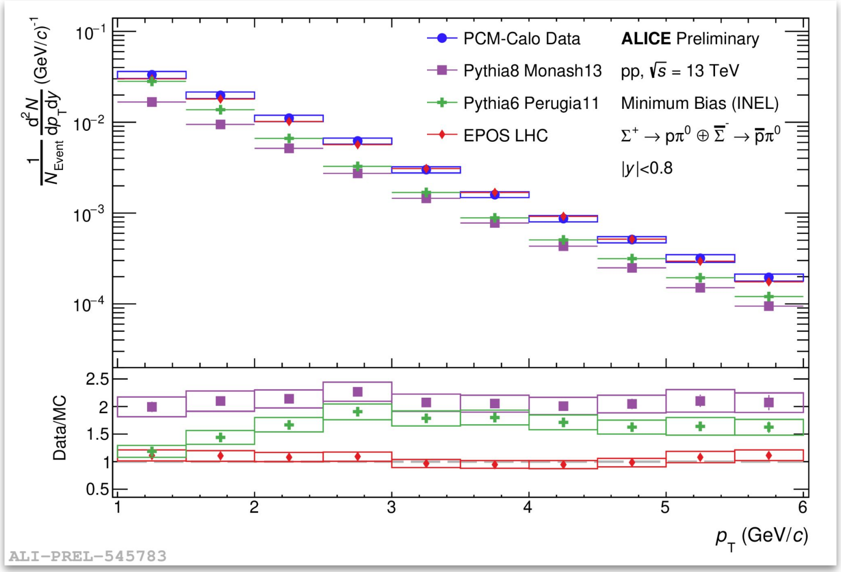
V0 detectors (V0A, V0C)
Forward-rapidity arrays of scintillators
triggering, particle multiplicity estimation



New

Photons reconstructed in the calorimeters
or via the photon conversion method (PCM).





p_T-shape well reproduced by EPOS LHC and Pythia8,
but the latter underestimates the yield

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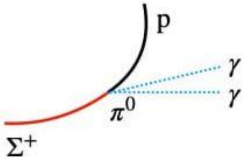

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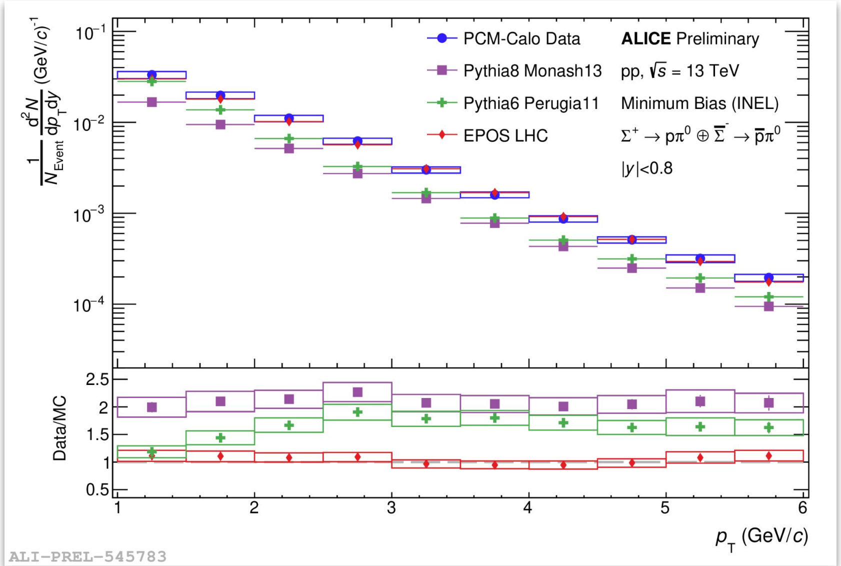

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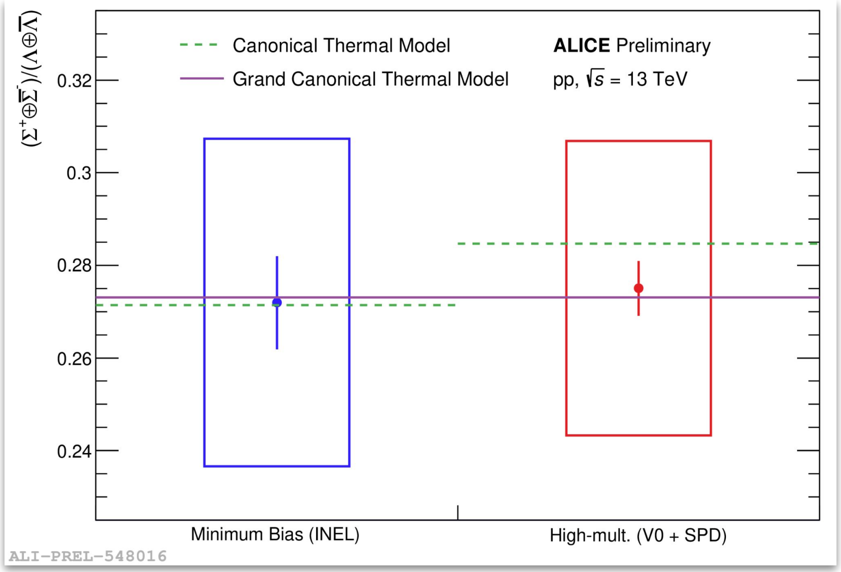
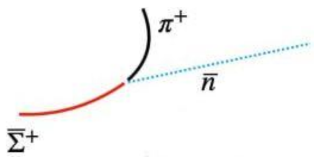
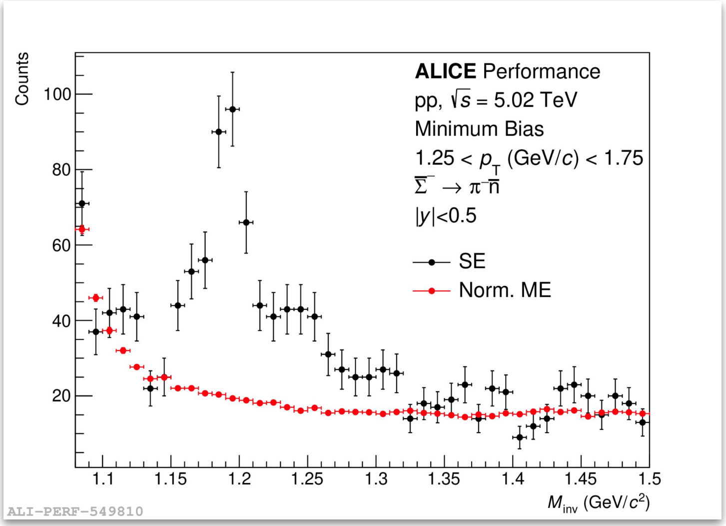


Σ/Λ does not depend on multiplicity (large uncertainties) and is reproduced by the thermal model

New

$\overline{\mathrm{n}}$ detection from signal in the PHOS calorimeter + momentum reconstructed using time-of-flight





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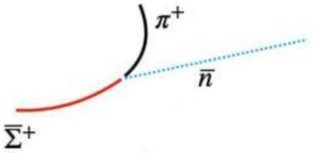
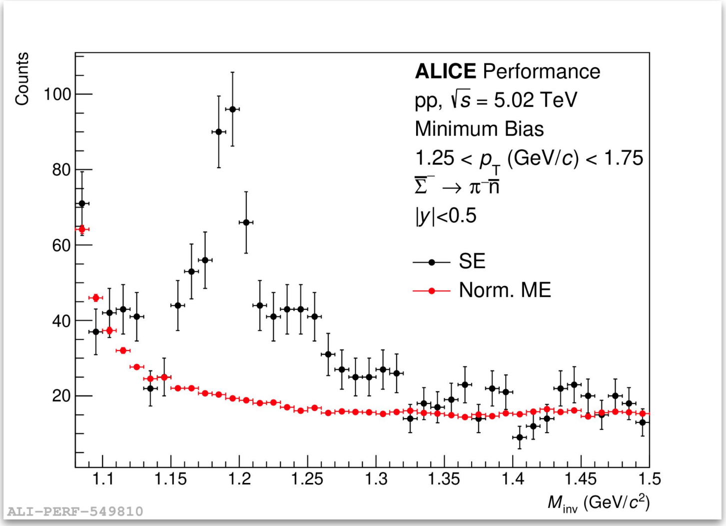
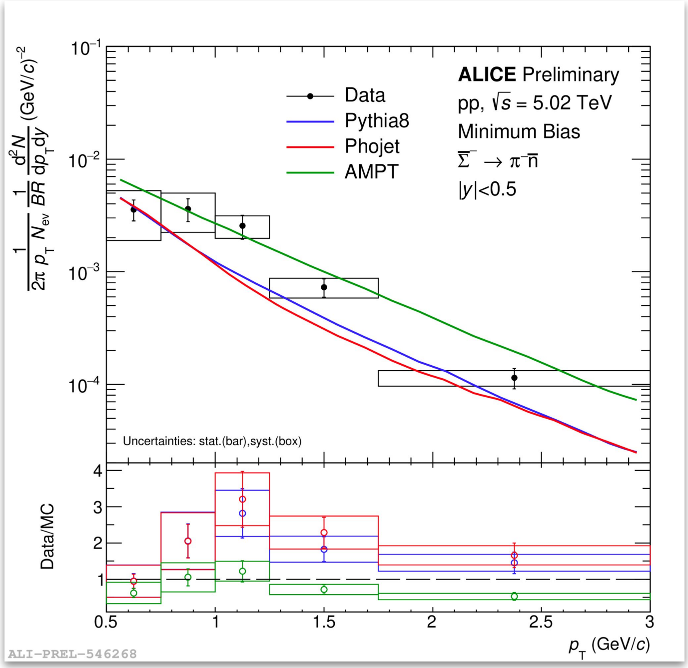


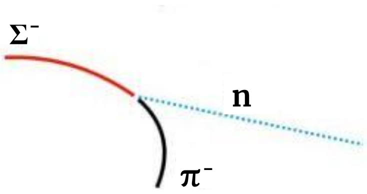


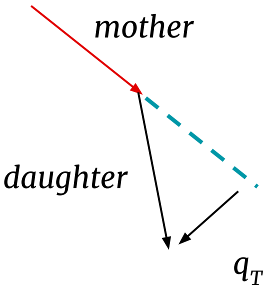
Production yield extracted in several p_T bins and compared to phenomenological models



Very promising technique.
Uncertainties will shrink with Run 3

→ B. Heybeck's poster (409)

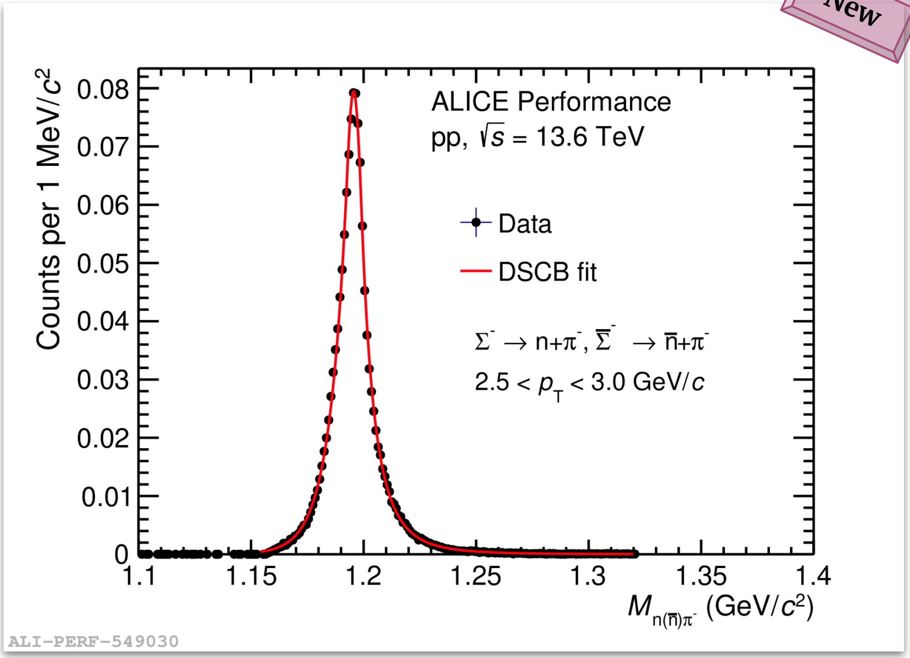




Kink-topology using the upgraded ITS2 detector

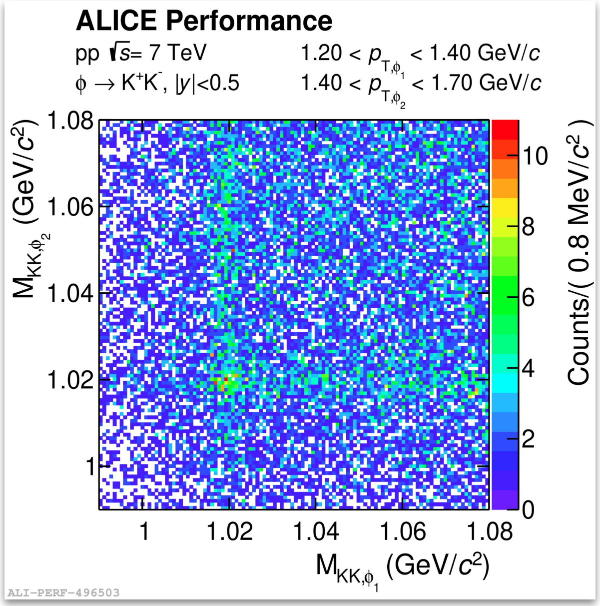
- combine same charge tracks
- minimize the distance between mother and daughter + apply several topological cuts
- q_T = momentum of the neutral daughter = difference between mother and charged daughter momentum → invariant mass of the mother can be evaluated

New



Double ϕ production

Measurement of the ϕ meson pair yield at mid-rapidity in MB pp collisions at $\sqrt{s}$ = 7 TeV



- 2D invariant mass technique in order to extract the signal
- Yield and p_T distribution extraction

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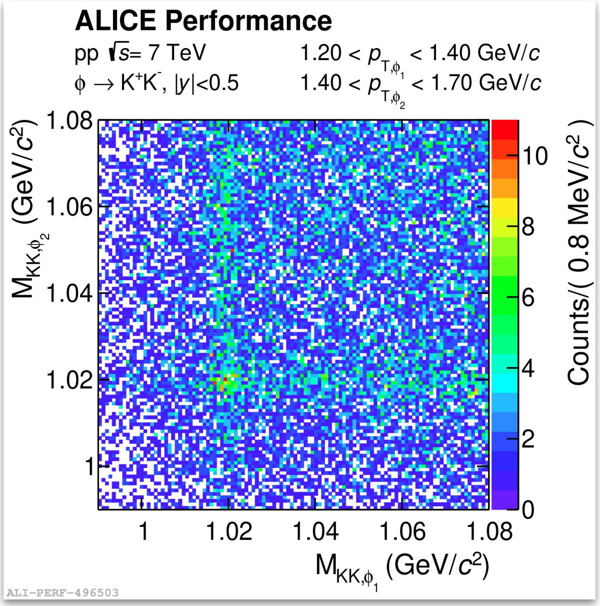
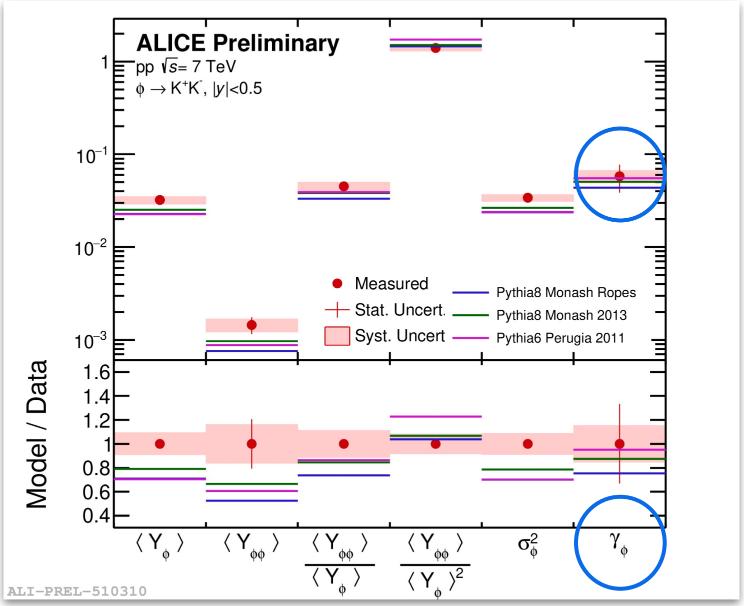




$$\gamma_\phi = \frac{\sigma_\phi^2}{\mu_\phi} - 1 = 2\frac{<Y_{\phi\phi}>}{<Y_\phi>} - < Y_\phi >$$

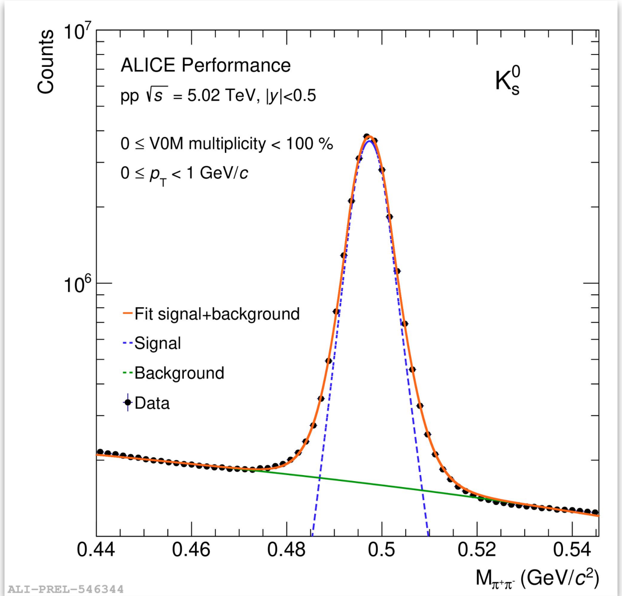
- 2D invariant mass technique in order to extract the signal
- Yield and p_T distribution extraction

- $\gamma_\phi = 0$ for poisson distribution
- observed $\gamma_\phi > 0$ → not poissonian

Multiple strange hadrons production: technique

New

Analysis based on counting the number of strange particles event-by-event in pp collisions at $\sqrt{s}$ = 5.02 TeV



Each candidate weighted by P(S) or P(B) estimated by 1D invariant mass fit in p_T/multiplicity bins

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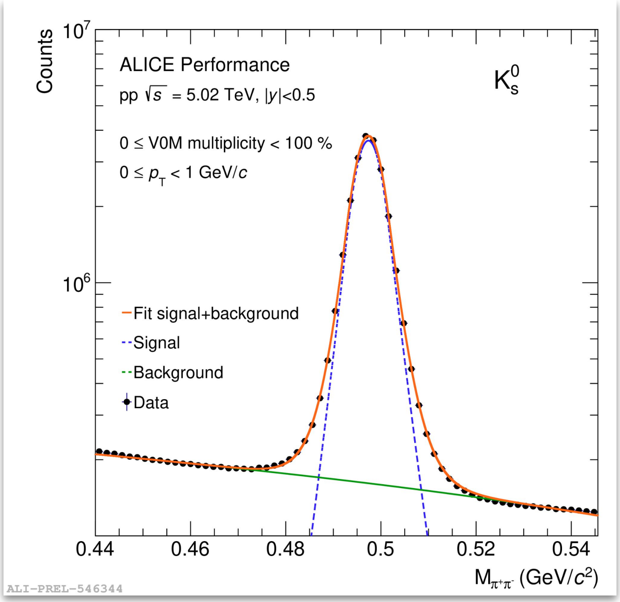

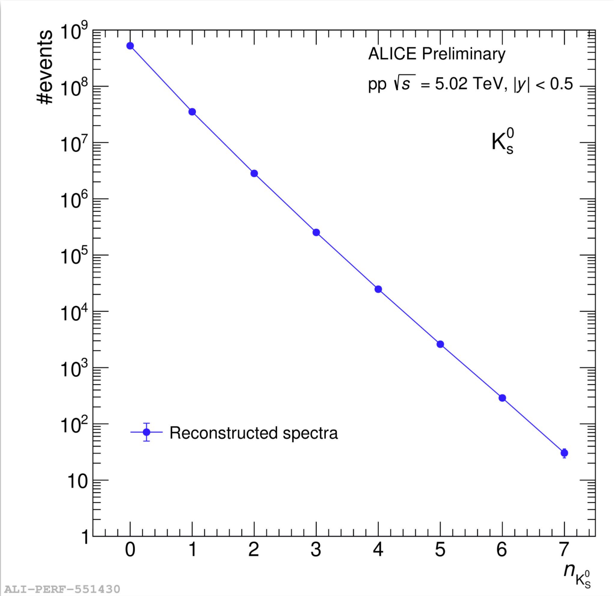

Each candidate weighted by P(S) or P(B) estimated by 1D invariant mass fit in p_T/multiplicity bins

Weights associated to each of the N candidates combined to obtain: P(all-sig), ... , P(all-bkg)

For each event: full probability spectrum spanning from 0 to N

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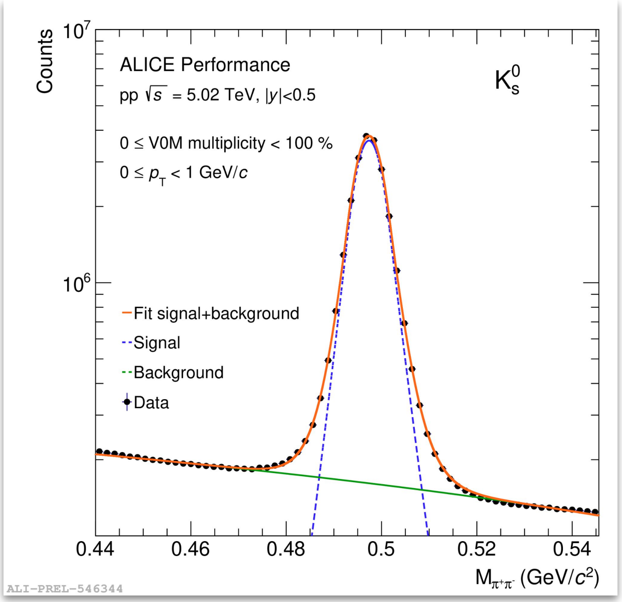

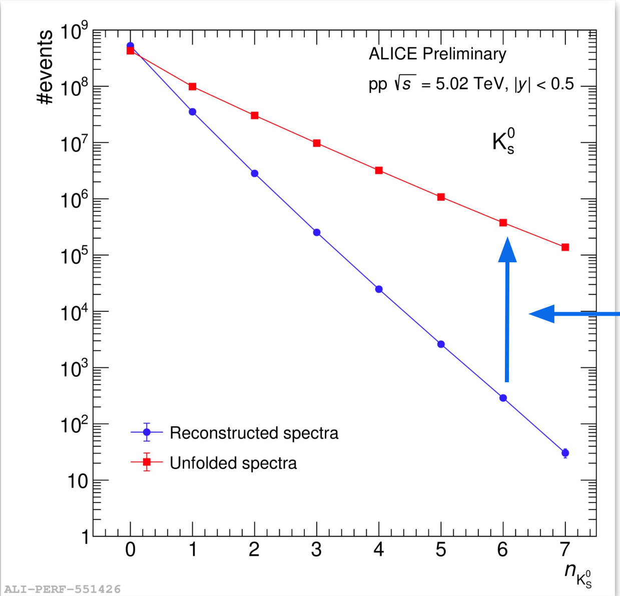

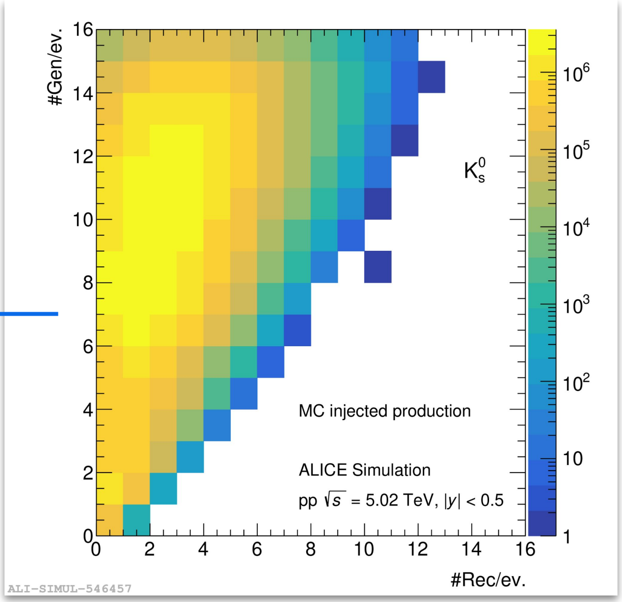

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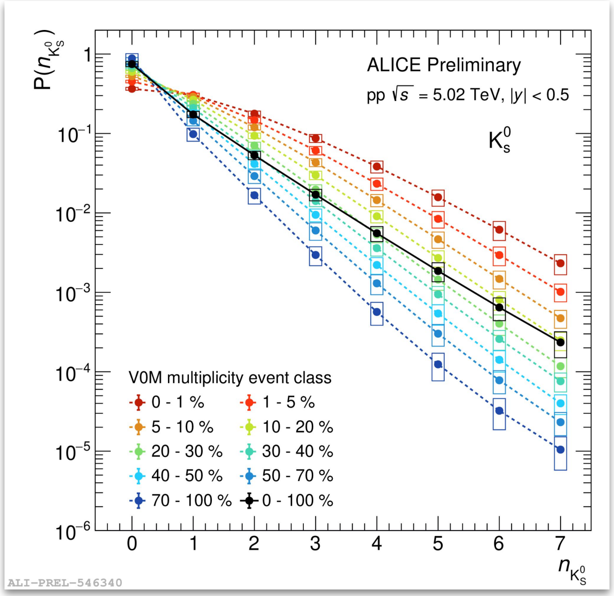
For each event: full probability spectrum spanning from 0 to N

Correction for detector response (MC production: measured p_T distribution)

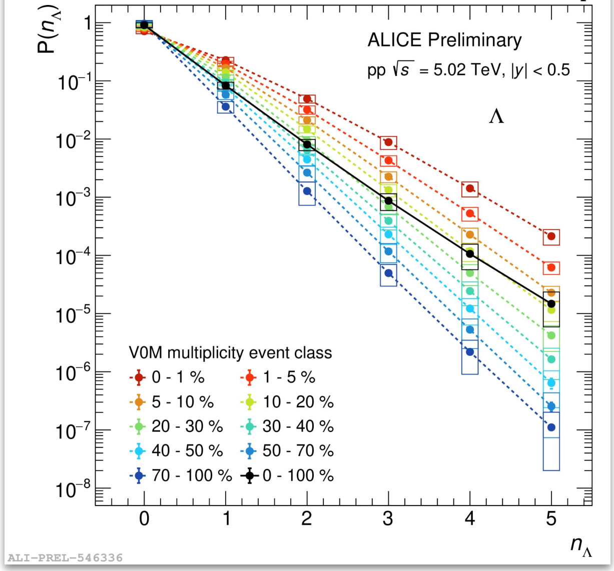
Bayesian unfolding procedure applied

Probability density function - V0s

New



$\bar{\Lambda}$ results in backup



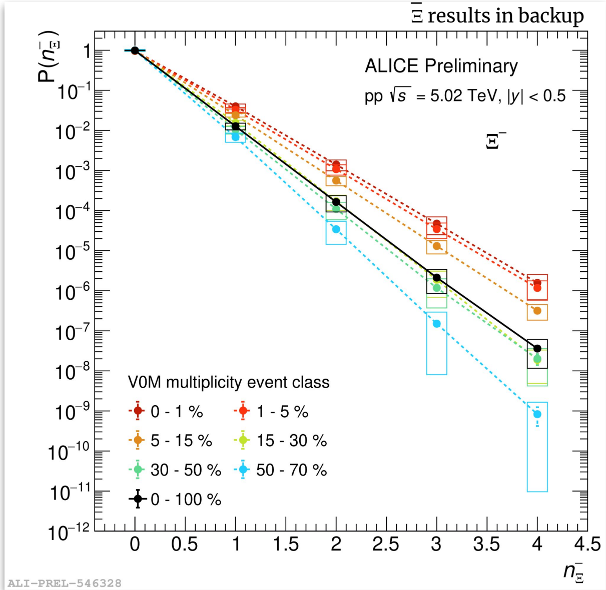
Probability to produce *n* particle (*n* up to 7 for K^0_S, 5 for Λ) of a given species per event

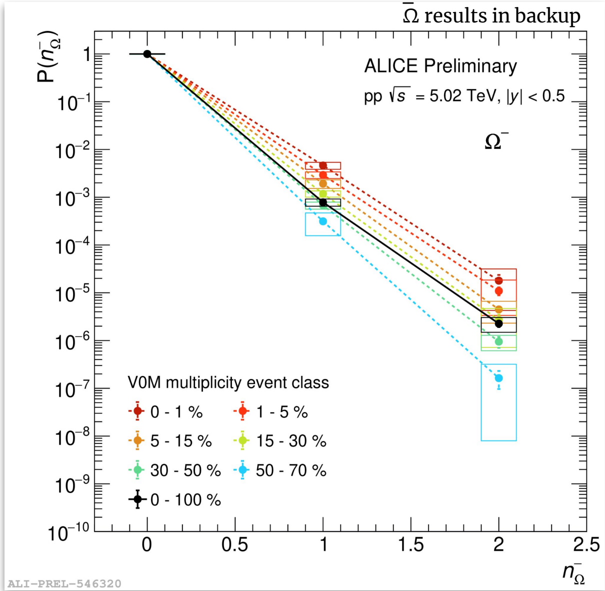
Spanning across large ranges of strange/multiplicity variations, all the way to very "extreme" situations (e.g. 7 K^0_S at low average multiplicity, 0 K^0_S at high multiplicity)

Unique opportunity to test the connection between charged and strange particle multiplicity production

NOTE: in each V0M bin multiplicity can fluctuate and $<dN_{ch}/d\eta>$ can significantly change for events with small/large n_S

New





Probability to produce *n* particle (*n* up to 4 for Ξ, 2 for Ω) of a given species per event

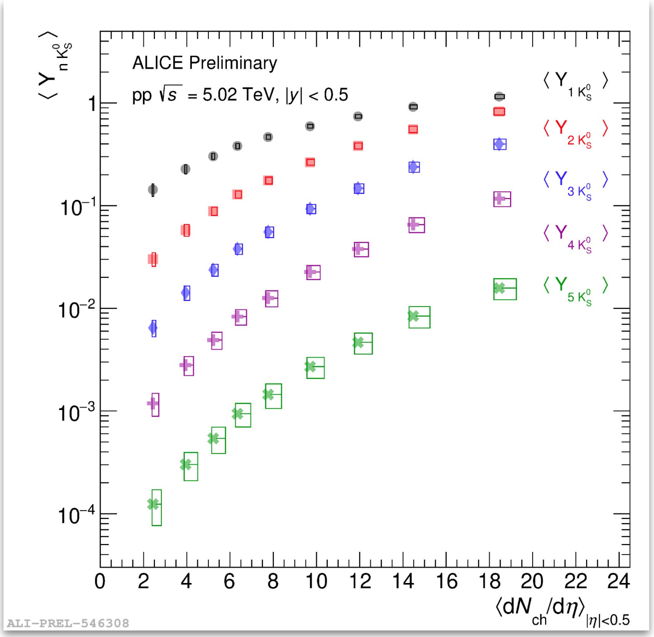
Spanning across large ranges of strange/multiplicity variations, all the way to very “extreme” situations (e.g. 4 Ξ at low average multiplicity, 0 Ξ at high multiplicity)

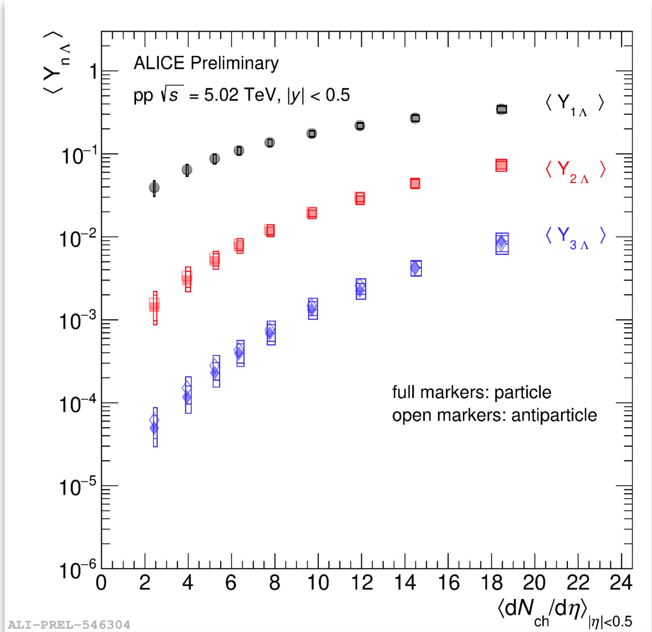
Unique opportunity to test the connection between charged and strange particle multiplicity production

NOTE: in each V0M bin multiplicity can fluctuate and <$dN_{ch}/d\eta$> can significantly change for events with small/large n_S

New

The PDF allows to calculate the production yield of 1, 2, 3, ... particles/event: $< Y_{k-part} >= \sum_{n=k}^{\infty} \frac{n!}{k!(n-k)!} P(n)$





The increase with multiplicity of the probability for multiple strange hadrons is more than linear

NOTE: very good agreement between $<Y_{1\text{-}part}>$ and previous results ([1],[2])

[1] ALICE, Nature Physics v13, pages 535–539 (1617)
[2] ALICE, Eur. Phys. J. C 80, 167 (1616)

Multiple strange hadron production yields

sara.pucillo@cern.ch

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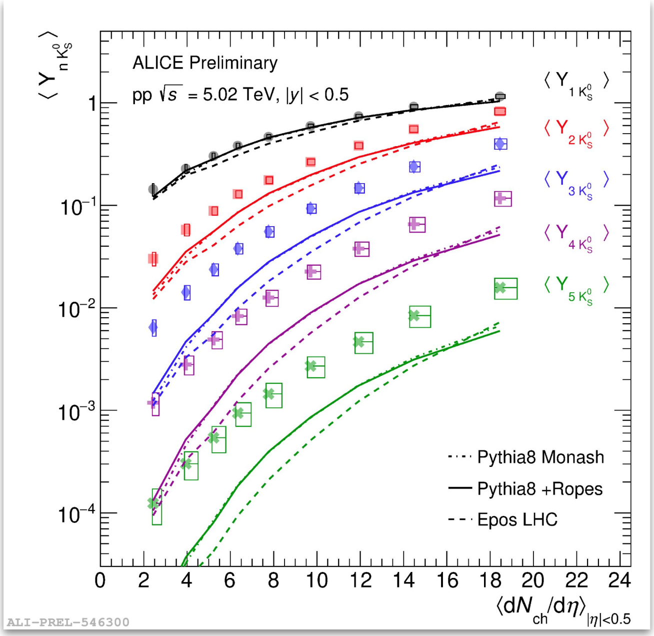

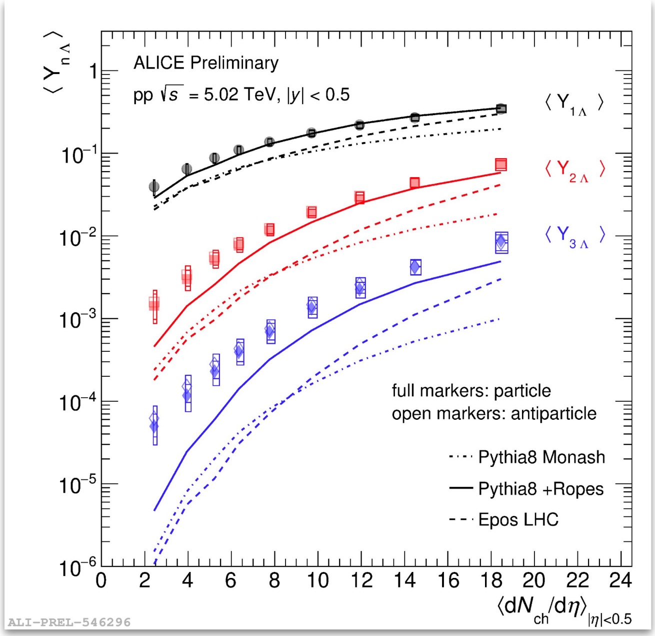

No difference between Pythia8 Monash and Ropes for K^0_S: Pythia8 + Ropes (with QCD-CR) tends to increase baryons

Ropes approaches the data at high multiplicity for Λ

Epos LHC does a rather good job at high multiplicity, but shows larger discrepancy at low multiplicity

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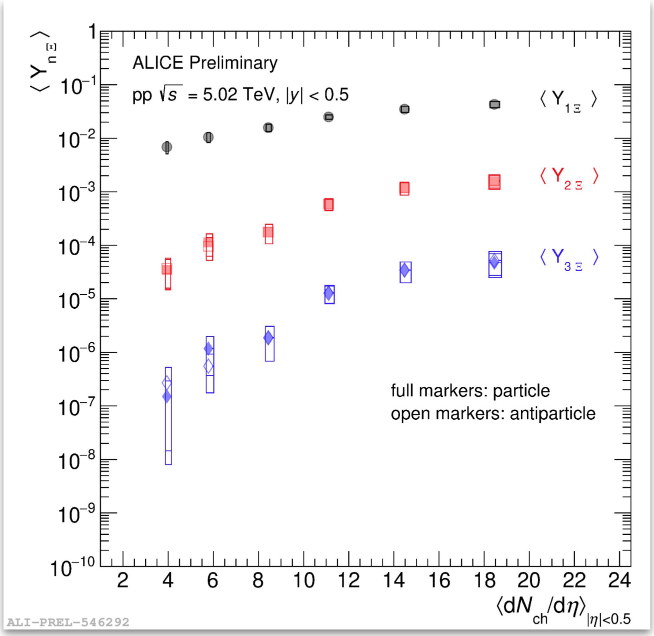

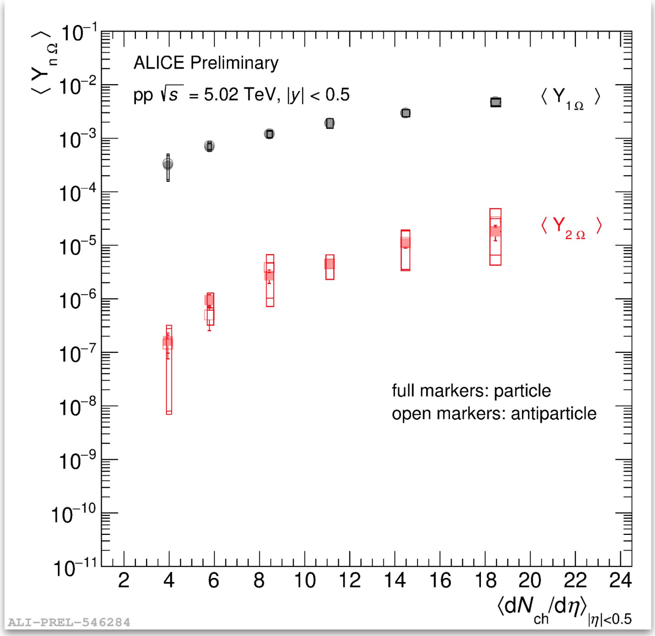

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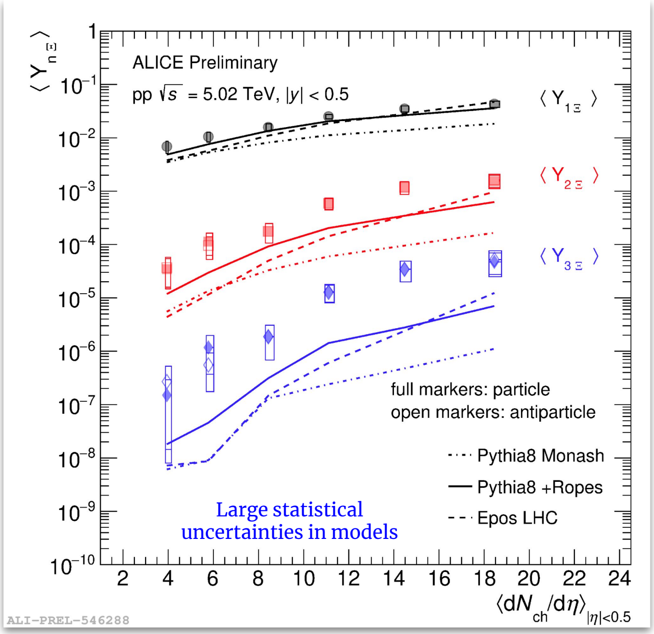

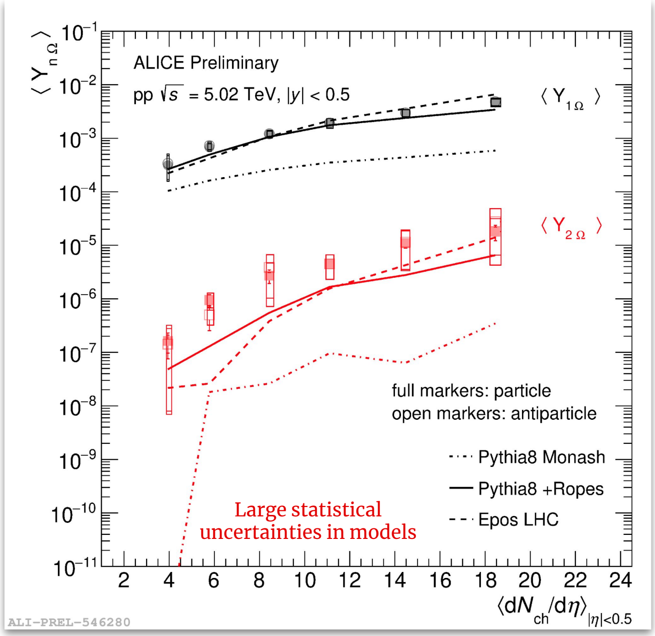

Ropes approaches the data at high multiplicity

Epos LHC does a rather good job at high multiplicity, but shows larger discrepancy at low multiplicity

Larger MC statistics will be produced to compare models in $<Y_{k\text{-}part>1}>$

$n\Lambda/nK^0_S$: strangeness/baryon enhancement

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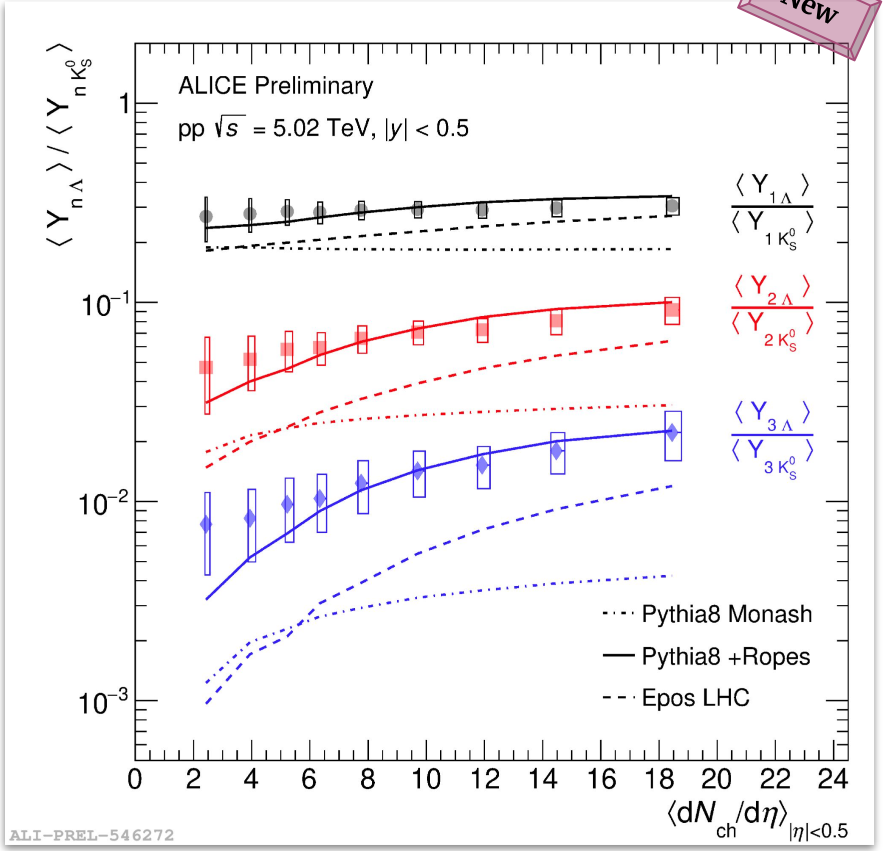
Very important to disentangle baryon-related from strangeness-related effects!

- Increase of Λ/K^0_S VS multiplicity when looking at multiple production!
- Possibly in all strange-hadron/π VS multiplicity plots we have a strangeness-related AND a baryon-related contribution to the enhancement
- Baryon-related effect well reproduced by Ropes (with QCD-CR) at high multiplicity

New



- **First measurement of (anti)$\Sigma^{\pm}$ baryons at LHC energies**:

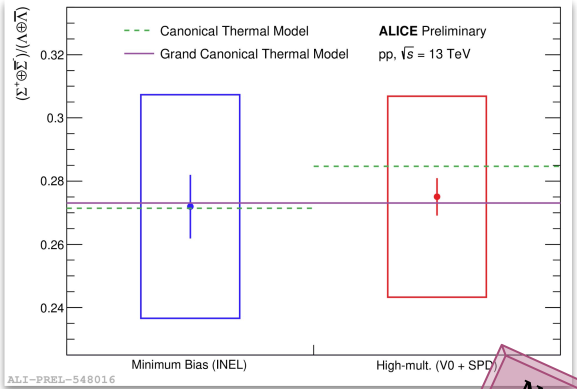
  → 2 different techniques tested with Run 2 data

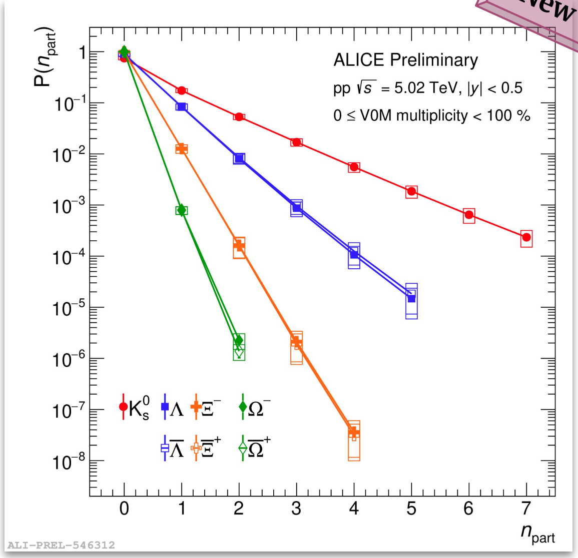
  - p_{T} distribution and Σ/Λ compared with phenomenological models
  - Σ/Λ does not depend on multiplicity

- **Multiple strange hadron production:**

  → first measurements of the PDF for (multi-)strange particles

  - perfect benchmark to test production models in events spanning from extreme unbalances between charged and strange particle multiplicity
  - 2- and 3- Λ/K^0_S yield ratios increase with multiplicity (baryon-related effect)





Summary

- **<u>First measurement of (anti)Σ± baryons at LHC energies</u>**:

  → 2 different techniques tested with Run 2 data

  - p_T distribution and Σ/Λ compared with phenomenological models
  - Σ/Λ does not depend on multiplicity

- **<u>Multiple strange hadron production:</u>**

  → first measurements of the PDF for (multi-)strange particles

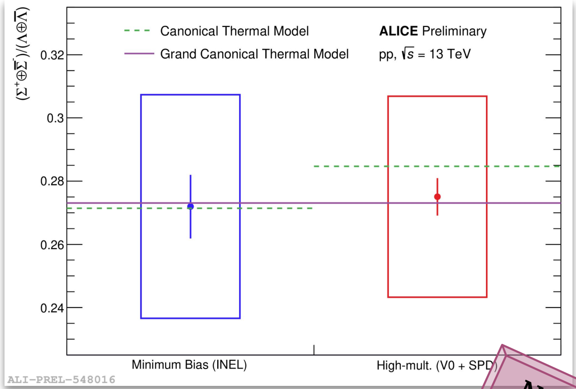
  - perfect benchmark to test production models in events spanning from extreme unbalances between charged and strange particle multiplicity
  - 2- and 3- Λ/K^0_S yield ratios increase with multiplicity (baryon-related effect)

Run 3:

- will allow to apply kink topology to the measurement of (anti)Σ± baryons
- larger statistics (3/4 orders of magnitude higher) useful for cascade analyses
- for the future: extended PDF study to higher number of particles/event

→ B. Heybeck's poster (409)

→ F. Ercolessi's talk (Tuesday, h 12.40)
C. De Martin's poster (150)



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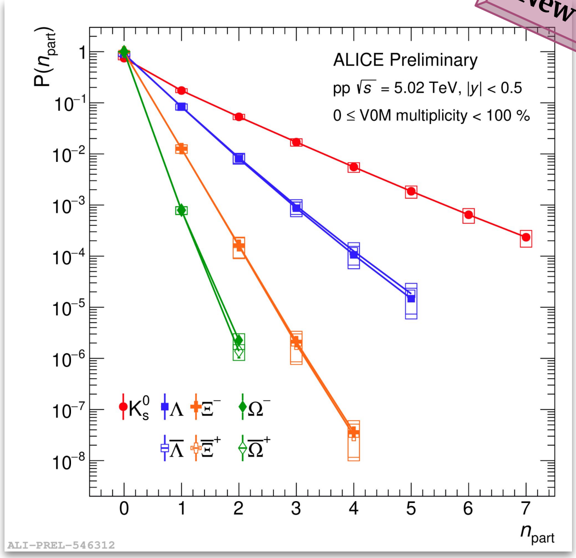


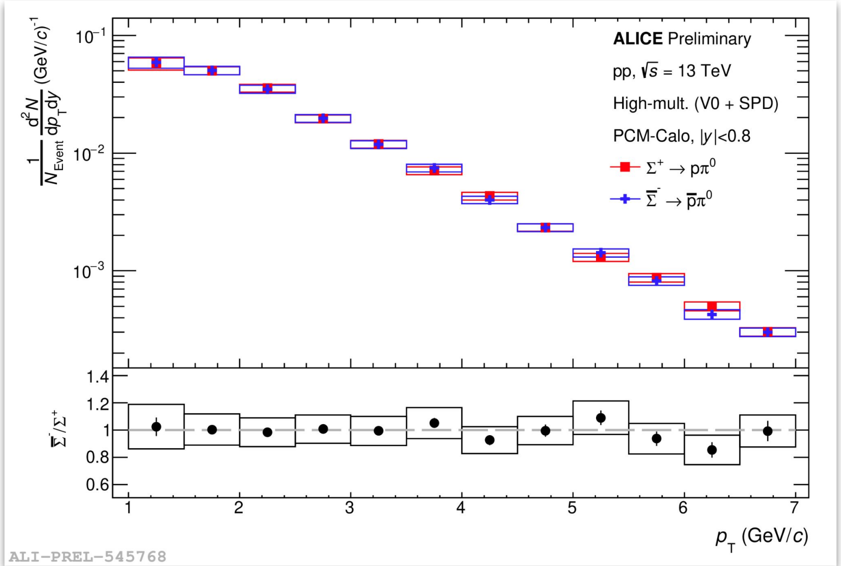
Backup slides

1. Università degli Studi di Torino

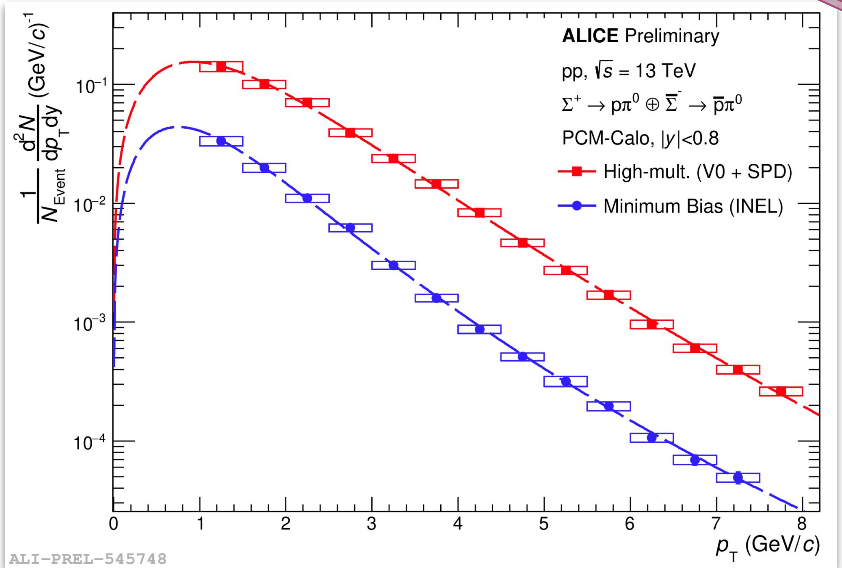
2. INFN Torino

Σ baryon production in pp at √s = 13 TeV

New



Comparison between particle and antiparticle p_T spectra → good agreement

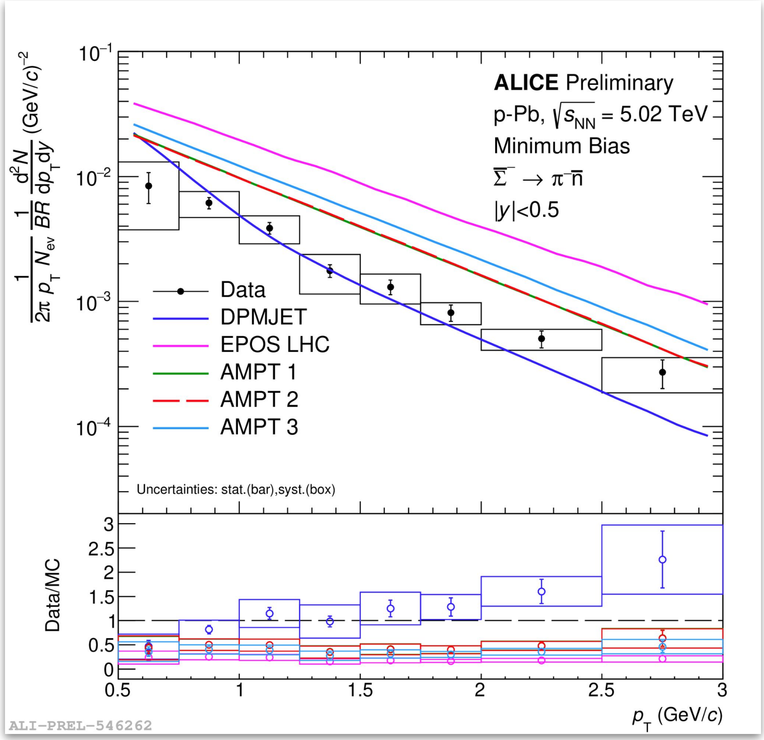


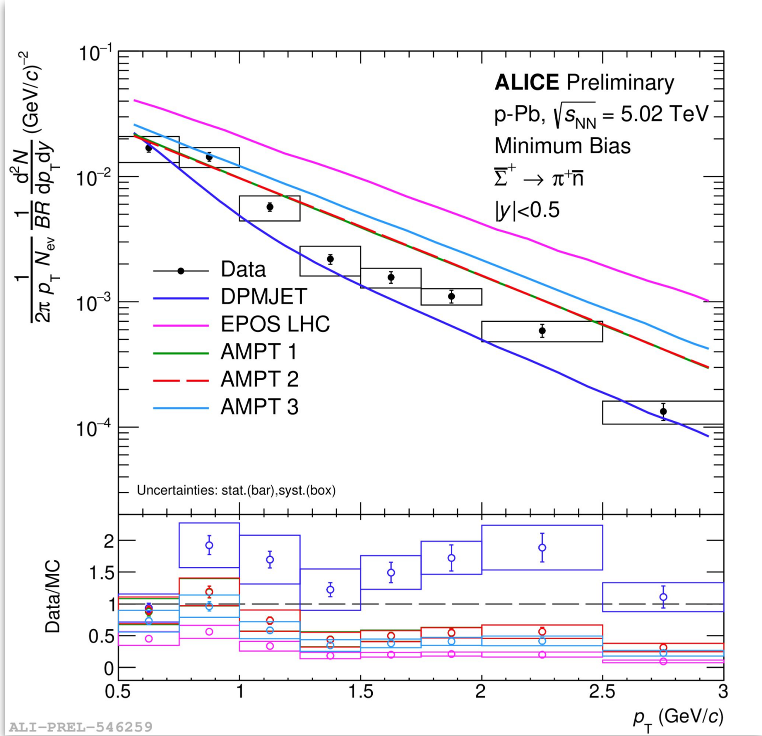
→ Comparison between particle and antiparticle p_T-spectra in high multiplicity and minimum bias triggered pp collisions

→ Results have been fitted with a Levy-Tsallis function

New

Production yield extracted in several p_T bins and compared to phenomenological models





iterative procedure based on the Bayes' theorem using a picture of causes C ("true values") and effects E ("observed values")

$$P(C_i|E_j) = \frac{P(E_j|C_i)\cdot\pi(C_i)}{\sum_{i=1}^{n_C} P(E_j|C_i)\cdot\pi(C_i)}$$

$P(E_j|C_i)$ estimated by using Monte Carlo (response matrix)

$P(C_i|E_j)$ → probability that different C_i were responsible for the observed effect E_j → GOAL

$\pi(C_i)$ → prior probabilities (initially arbitrary, but updated on subsequent iterations)

- Choosing a prior distribution in order to apply Bayes' theorem → posterior probability matrix obtained
- Applied to "observed spectra" → 1st estimation of the corrected spectra
- The corrected spectra obtained in the previous step becomes the prior probability and the correction proceeds as before
- Procedure is re-iterated until stability is achieved (**regularization parameter: n_{iter}**)

$$\hat{n}(C_i) = \frac{1}{\epsilon_i}\sum_{j=1}^{n_E} n(E_j)\cdot P(C_i|E_j) = \sum_{j=1}^{n_E} M_{ij}\cdot n(E_j)$$

expected number of events in the cause bin *i*

→ M_{ij} is the unfolding matrix: $M_{ij} = \frac{P(E_j|C_i)\cdot\pi(C_i)}{\epsilon_i\cdot\sum_{l=1}^{n_C} P(E_j|C_l)\cdot\pi(C_l)}$

→ $n(E_j)$ measurements (effects)

→ ε_i efficiencies

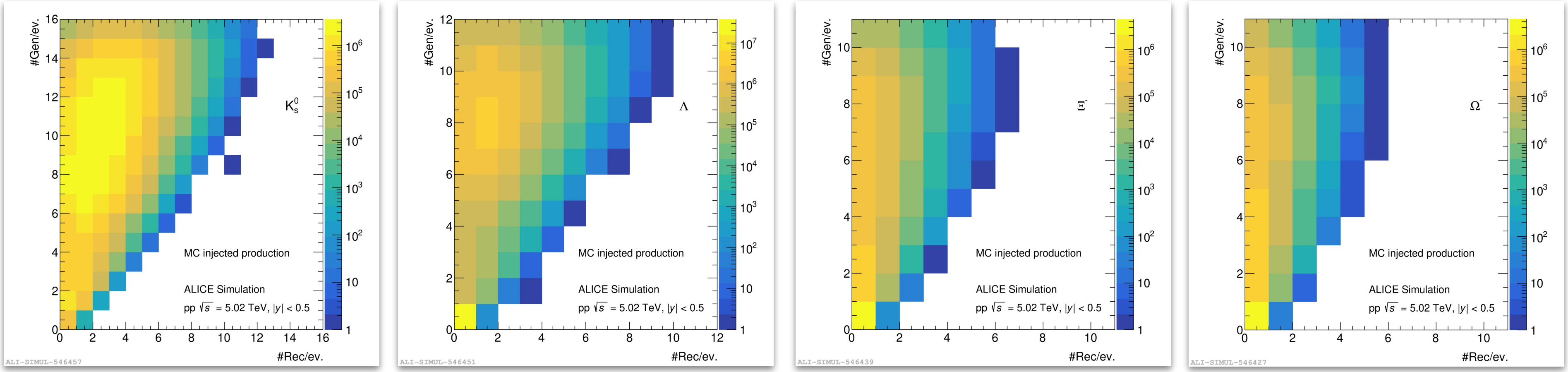
unfolding errors: covariance matrix

$$V(\hat{n}(C_k),\hat{n}(C_l)) = \sum_{i,j=1}^{n_E} \frac{\partial\hat{n}(C_k)}{\partial n(E_i)} V(n(E_i),n(E_j)) \frac{\partial\hat{n}(C_l)}{\partial n(E_j)}$$

G. D'Agostini, "A multidimensional unfolding method based on Bayes' theorem"

Response matrices for all particles

New



Moving from K^0_S to Ω particle the response matrices are increasingly "squeezed" toward a low number of reconstructed particles/event

Probability density function - antiparticles

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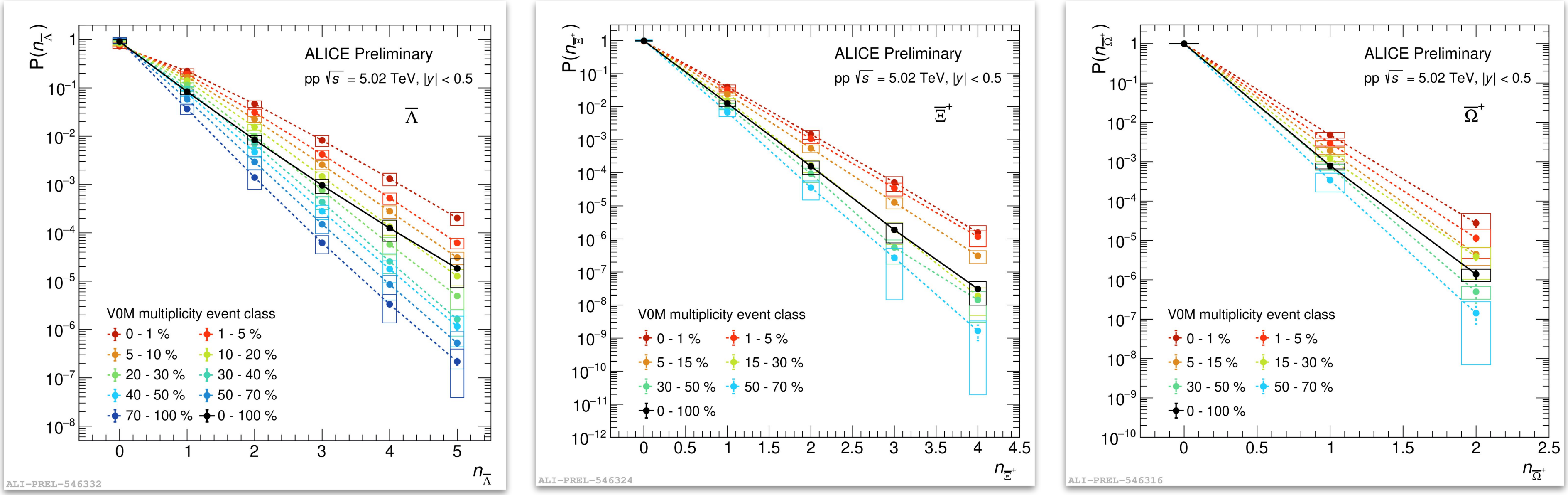

New

Probability to produce *n* particle (*n* up to 5 for $\overline{\Lambda}$, 4 for $\overline{\Xi}$, 2 for $\overline{\Omega}$) of a given species per event

Spanning across large ranges of strange/multiplicity variations, all the way to very "extreme" situations

Unique opportunity to test the connection between charged and strange particle multiplicity production

NOTE: in each V0M bin multiplicity can fluctuate and <$dN_{ch}/d\eta$> can significantly change for events with small/large n_S