Measurement of multiple (multi-)strange hadron production in small collision systems with ALICE

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

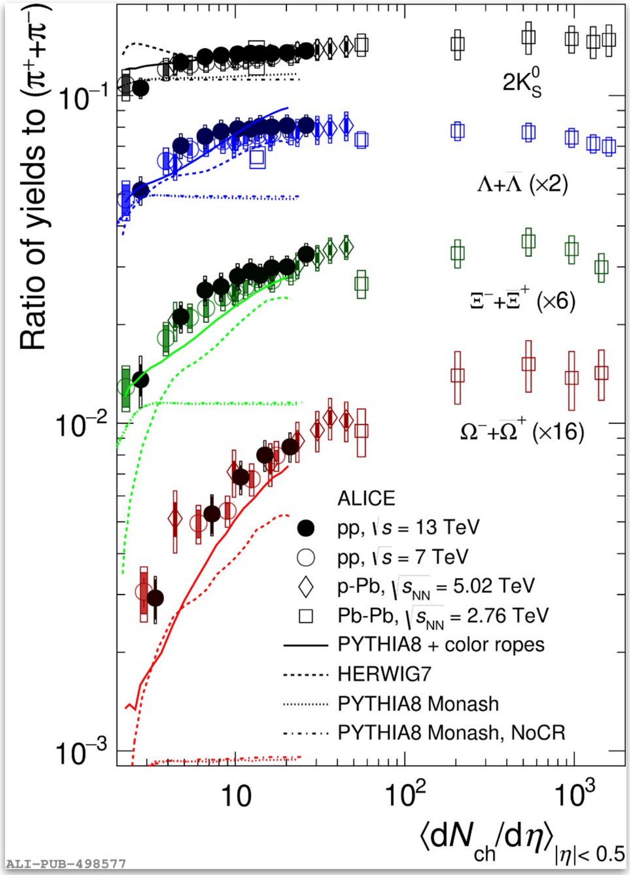
6° incontro nazionale di Fisica Nucleare
26-28 Feb.

1. Università degli Studi di Torino

2. INFN Torino

Strangeness Enhancement (SE):

- at the LHC S/π increases as a function of multiplicity independently on the collision energy and system
- hierarchy: enhancement proportional to the strangeness content in the hadron
$\rightarrow \Omega > \Xi > \Lambda$



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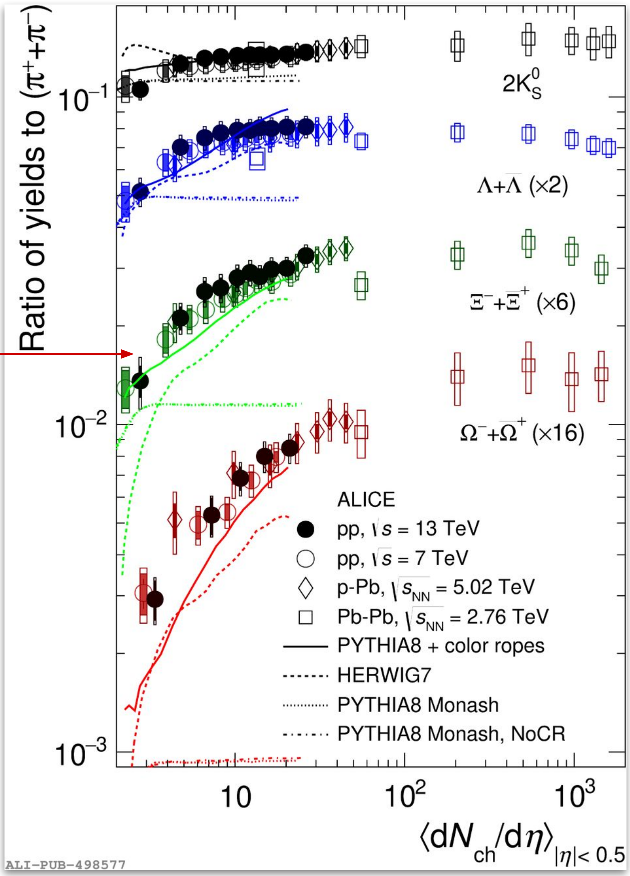

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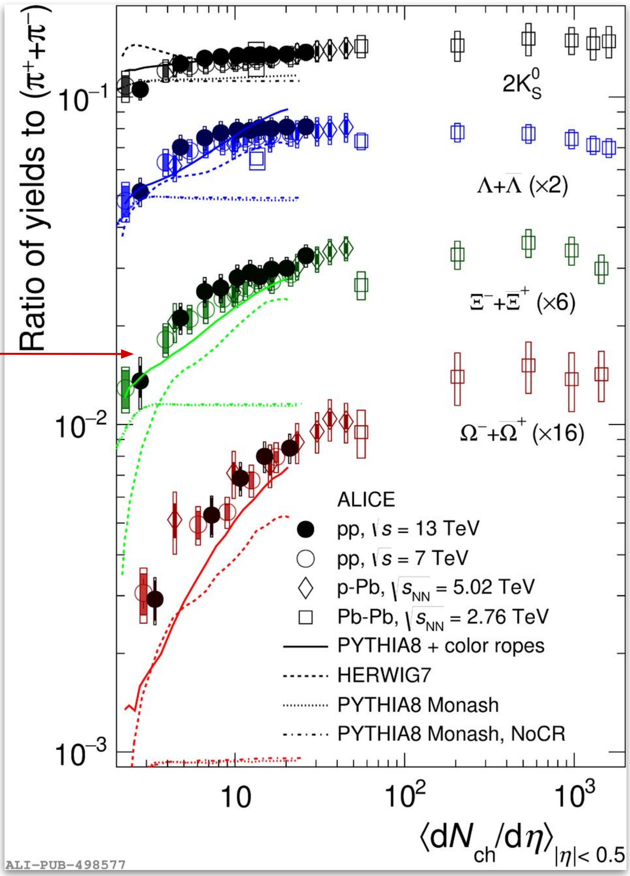

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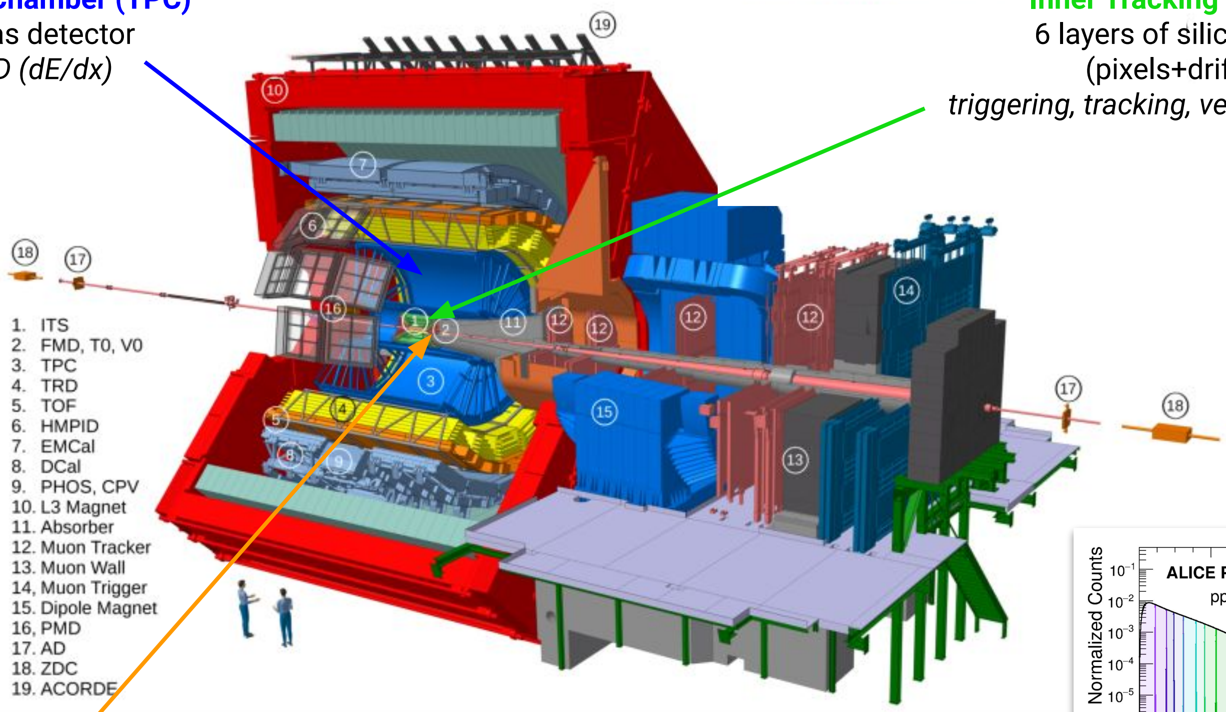
New in this talk:
Strange particle multiplicity distribution ($P(n_S)$) for K^0_S, Λ, Ξ, Ω

- extend beyond the average of the distribution
- unique opportunity to test the connection between charged and strange particle multiplicity production
- stronger constraints to models

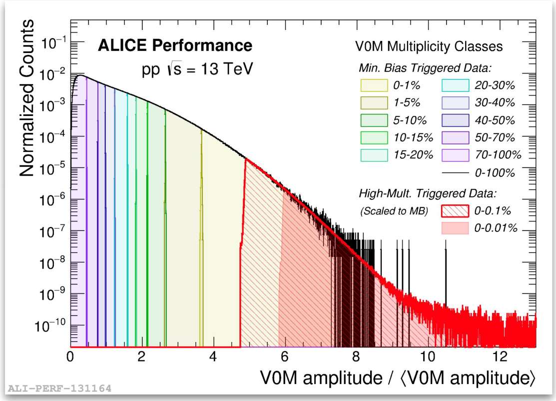
Time Projection Chamber (TPC)
Large area gas detector
tracking, PID (dE/dx)

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



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

- V0M amplitude distribution is divided into percentiles to define multiplicity classes
- The corresponding charged particle multiplicity at mid-rapidity was constructed



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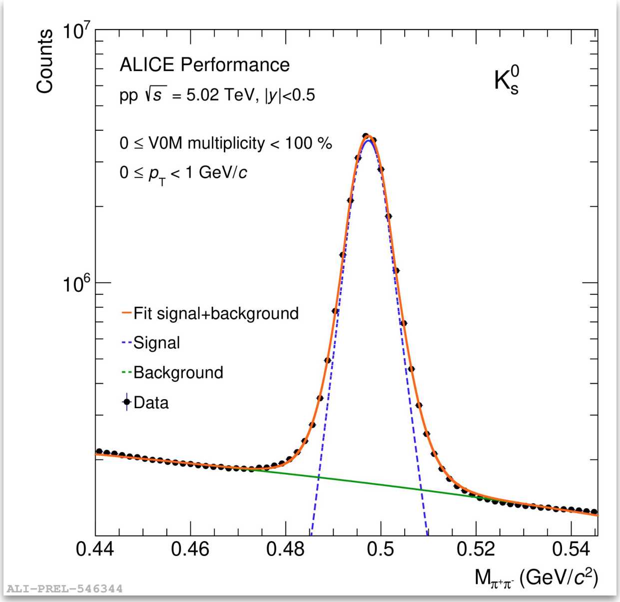
Analysis based on counting the number of strange particles event-by-event in pp collisions at $\sqrt{s}$ = 5.02 TeV



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

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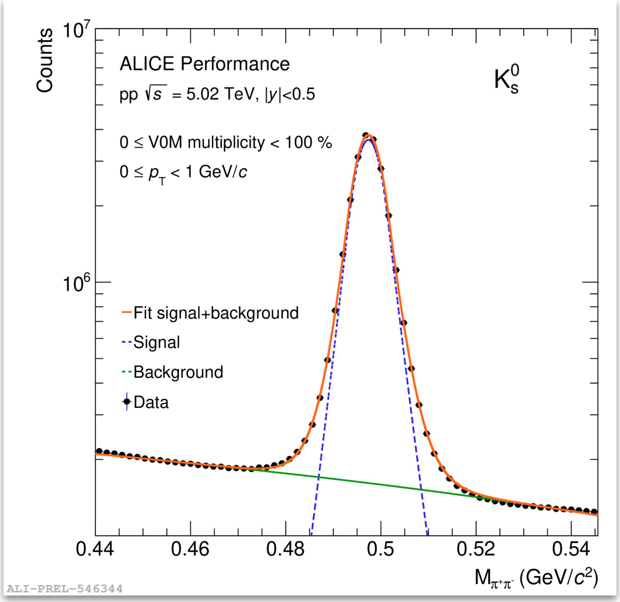

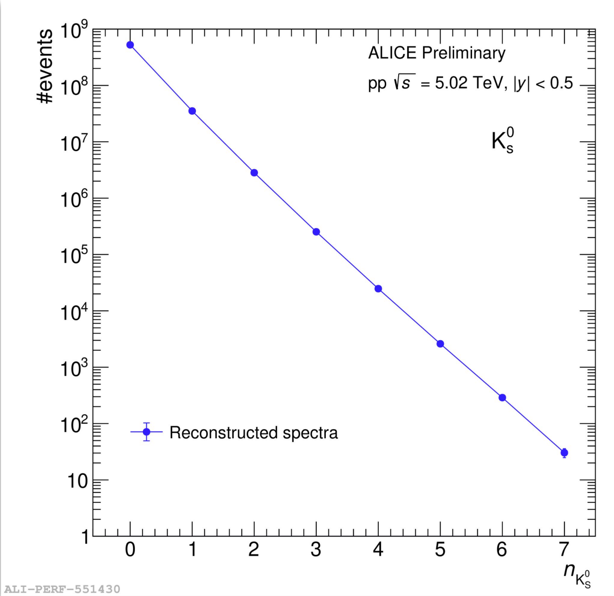

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Weights associated to each of the N candidates combined to obtain: P(all-sig), … , P(all-bkg)

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

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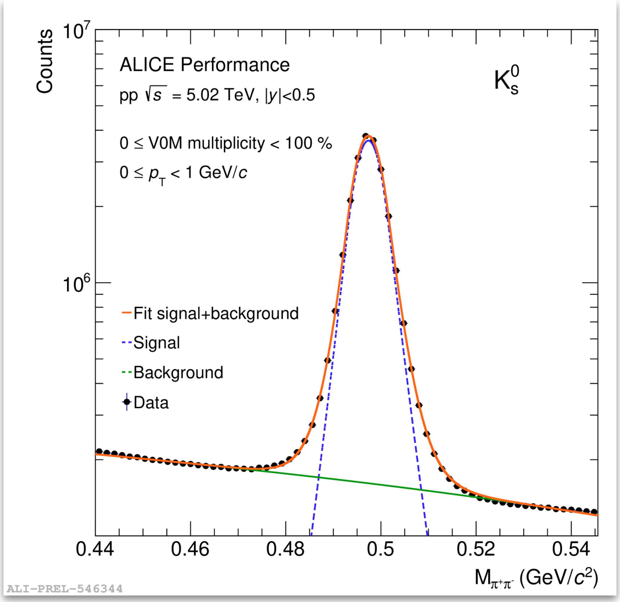

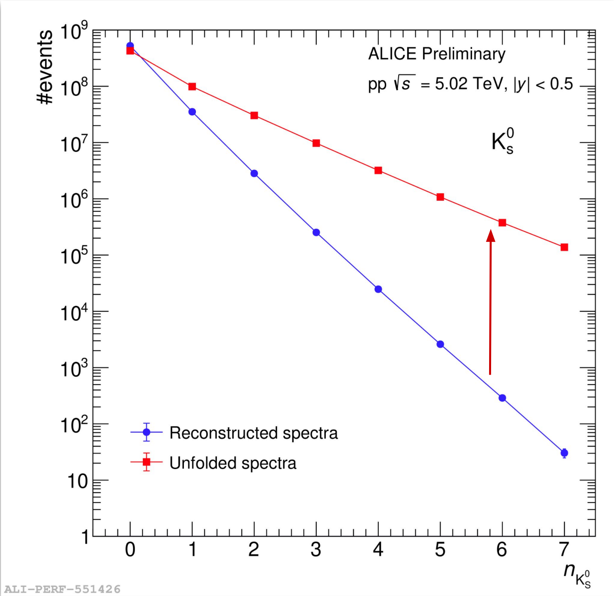

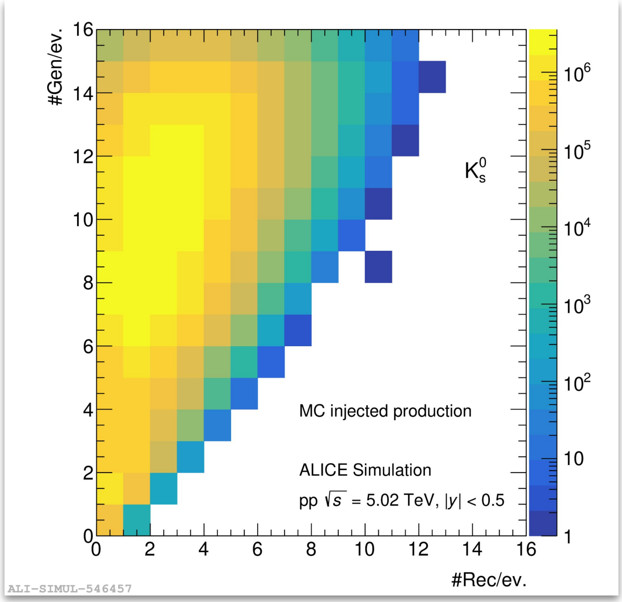

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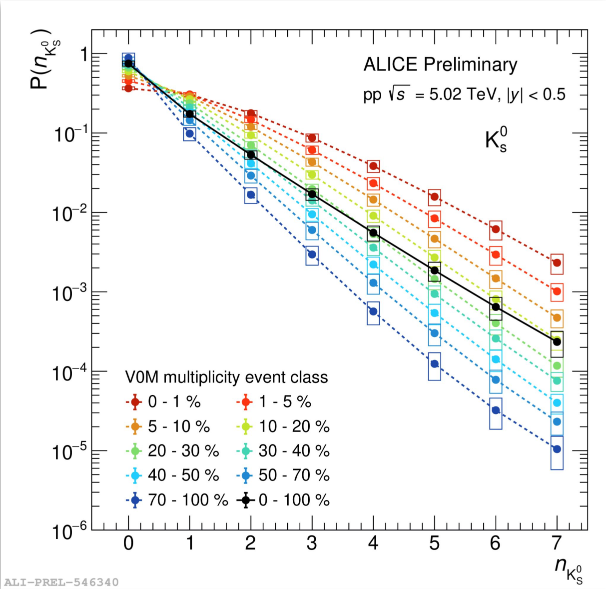
Correction for detector response (MC simulation: measured p_T distribution)

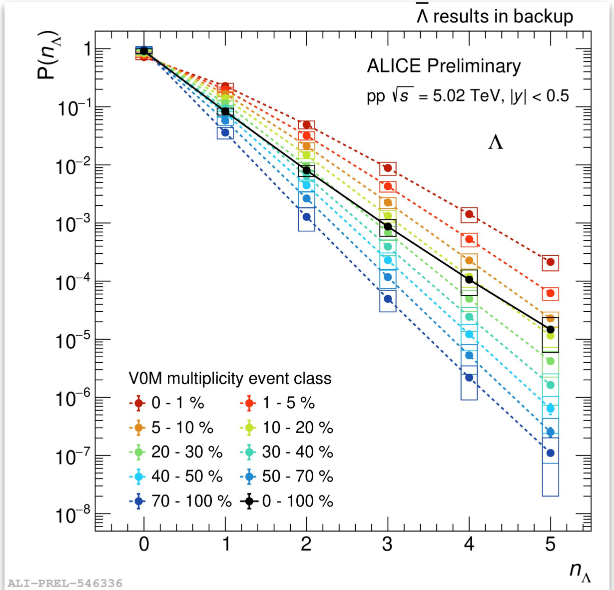
Bayesian unfolding procedure applied

Probability to measure V0s

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

- $P(n_{S>1})$ increases with the event charged-particle multiplicity
- Spanning across large ranges of strange/multiplicity variations, all the way to very "extreme" situations (e.g. 7 K^0_S at low average charged-particle multiplicity, 0 K^0_S at high average charged-particle multiplicity)



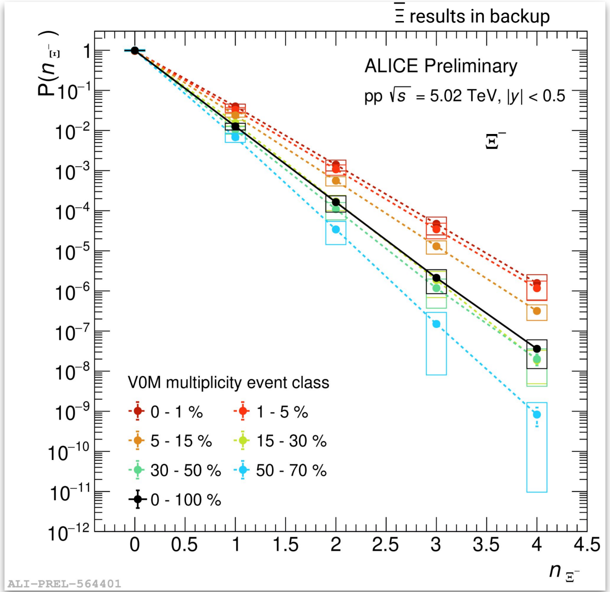


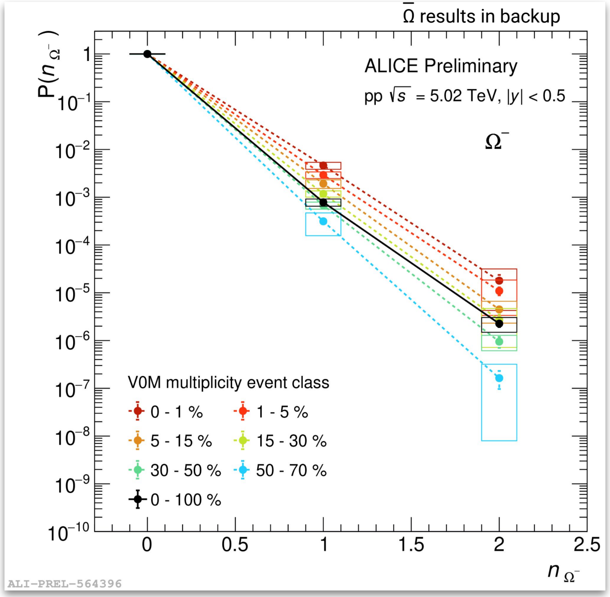
Unique opportunity to test the connection between charged and strange particle multiplicity production

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

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

- $P(n_{S>1})$ increases with the event charged-particle multiplicity
- Spanning across large ranges of strange/multiplicity variations, all the way to very "extreme" situations (e.g. 4 Ξ at low average charged-particle multiplicity, 0 Ξ at high average charged-particle multiplicity)





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Multiple strange K^0_S and Λ production yields

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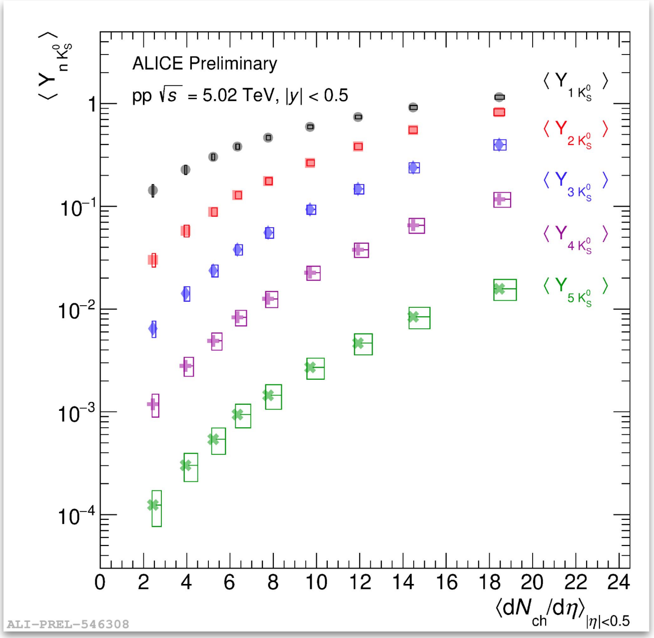
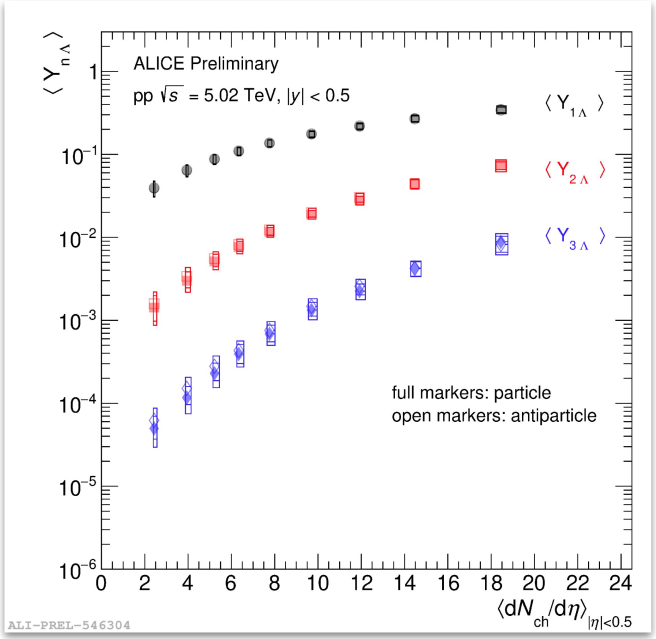
The distribution allows to calculate the average probability for the production yield of 1, 2, 3 , … particles/event:

$$< Y_{k-part} >= \sum_{n=k}^{\infty} \frac{n!}{k!(n-k)!} P(n)$$





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* (2017)
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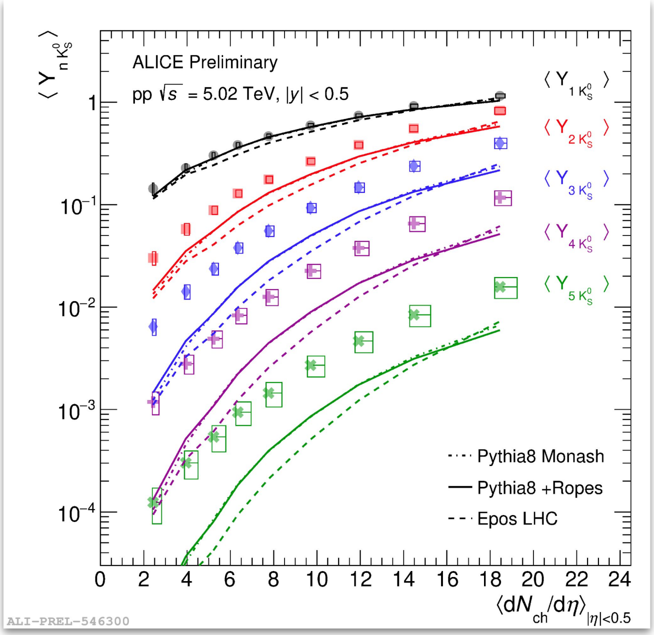

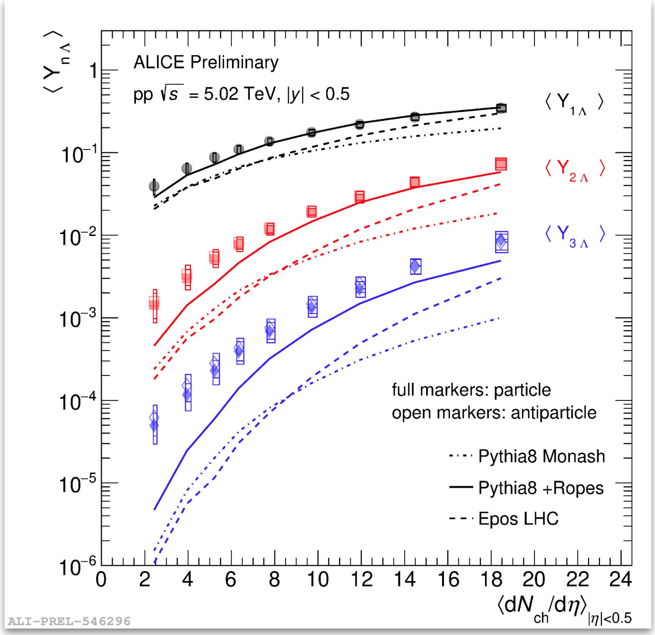

No difference between Pythia8 Monash and Ropes for K^0_S: Pythia8 + Ropes (with QCD-CR) tends to increase baryons

Ropes approaches the data at high multiplicity for Λ

Epos LHC has a better agreement with the data at high multiplicity, but departs from the trend at low multiplicity

For both particles the agreement gets worse as *n* increases

Multiple strange Ξ and Ω production yields

The distribution allows to calculate the average probability for the production yield of 1, 2, 3 , … particles/event:

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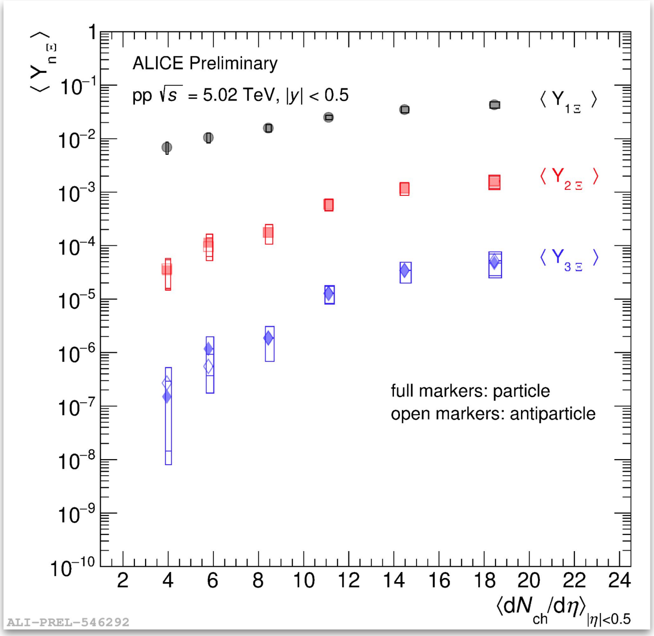

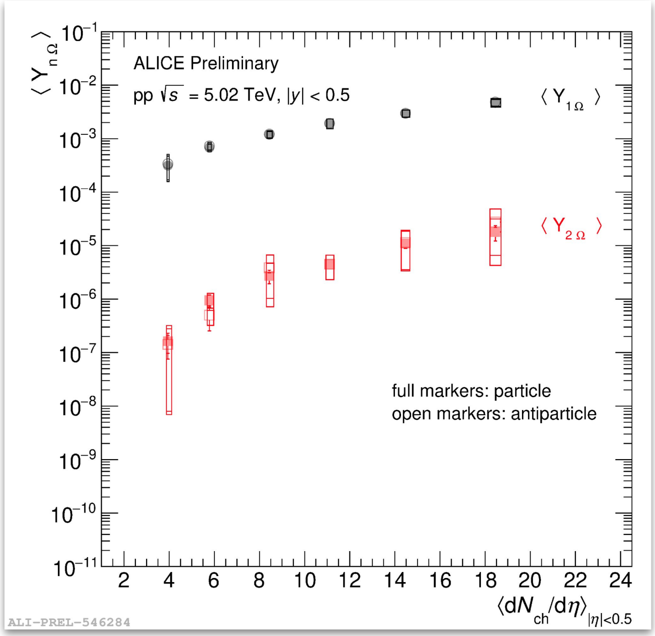

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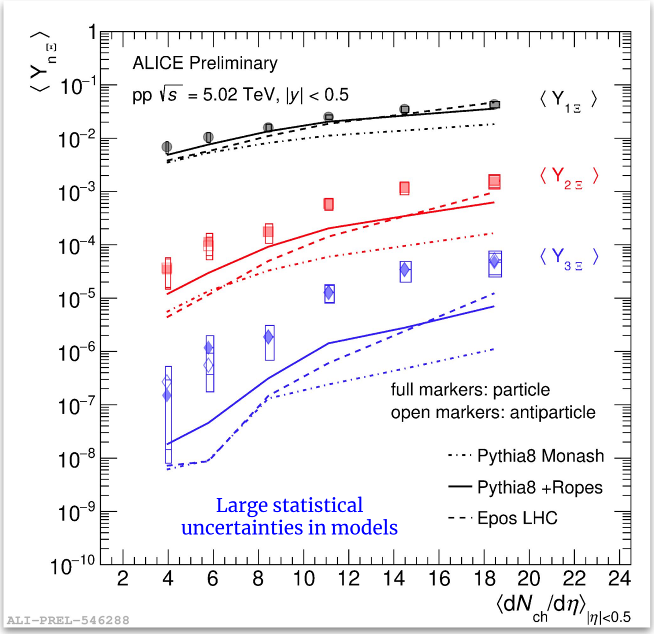
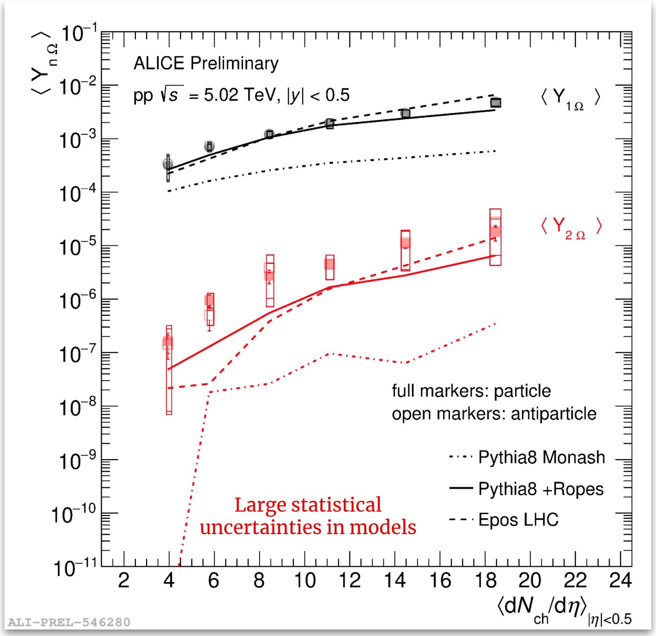


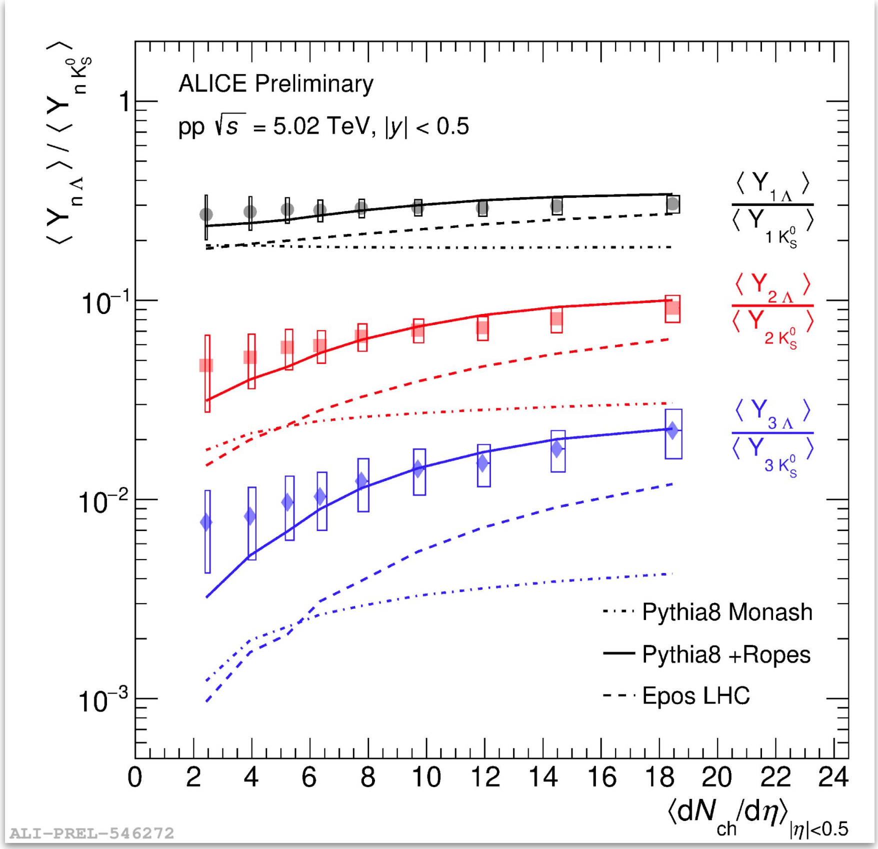


Pythia8 + Ropes approaches the data at high multiplicity

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

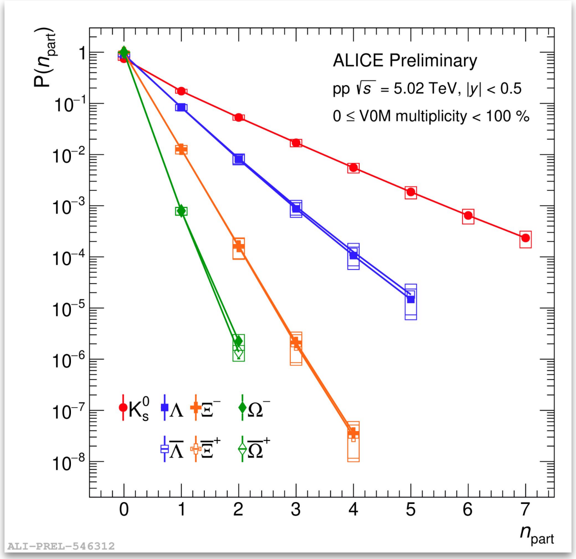
Very important to decouple strangeness-related from baryon-related effects!

- 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



First measurements of (multi-)strange particle multiplicity distribution ($P(n_S)$)

- perfect benchmark to MC models to test the interplay between charged particle and strange particle multiplicity
- it is a relevant extension of <d*N*/d*y*> studies, as it tests at a higher order the connection between global and local characteristics of the analyzed event
- 2- and 3- Λ/K^0_S yield ratios increase with multiplicity (baryon-related effect)
- Comparison to model comparison:
  - for K^0_S Pythia8 Monash and Ropes are equal across multiplicity
  - for baryons all trends are rather well reproduced by Pythia8 + Ropes: very good improvement in this model except for purely-strangeness effect, all other models fail



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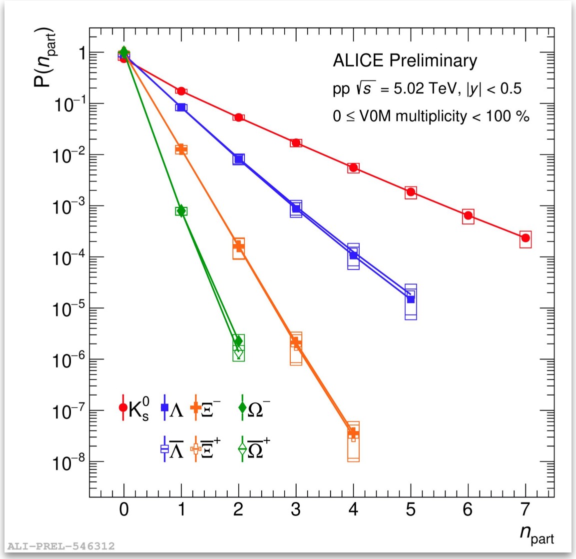

Outlook:

- different yield ratios under investigation to show the relative importance of baryon and strangeness effects
- obtained results can be used to study strangeness enhancement at its extremes (yield ratios with $\Delta S>3$)
- Run3 will allow to have larger statistics (3/4 orders of magnitude higher) useful for cascade analyses

Backup slides

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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"

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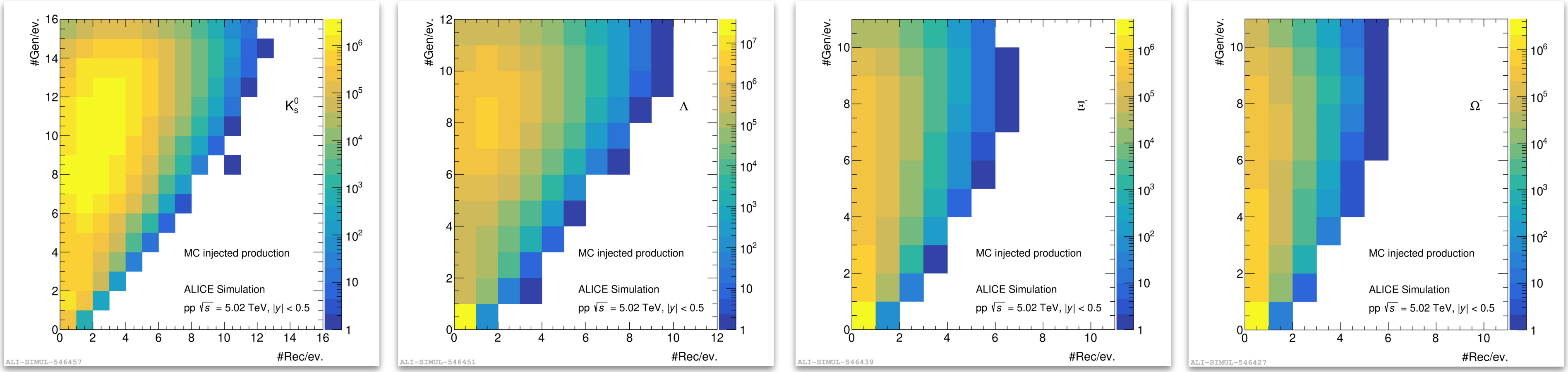
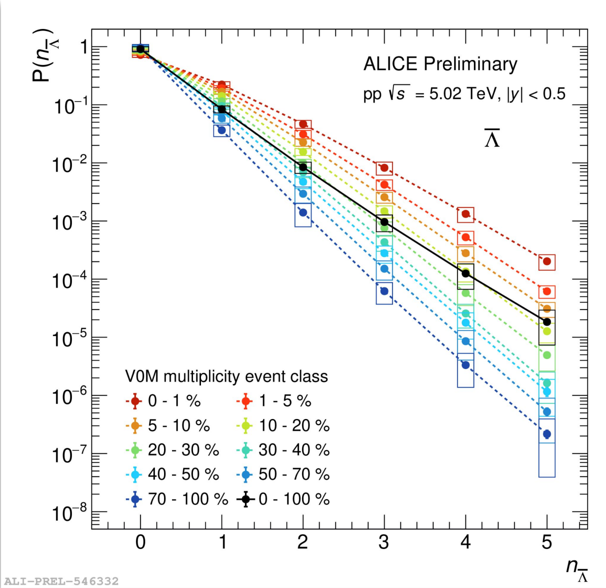
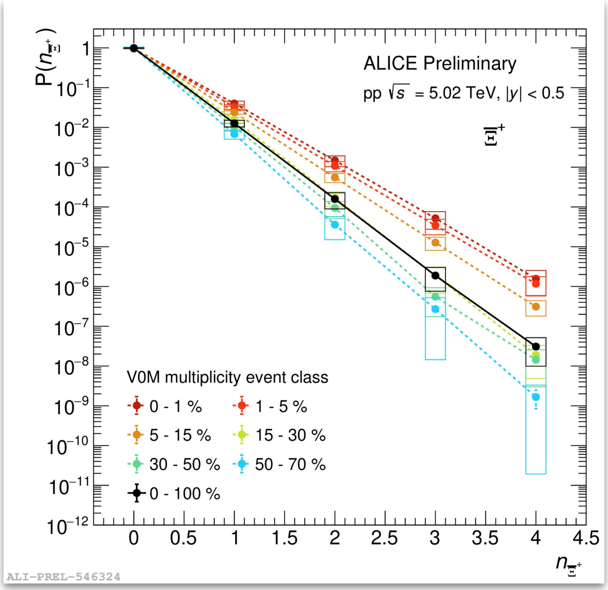
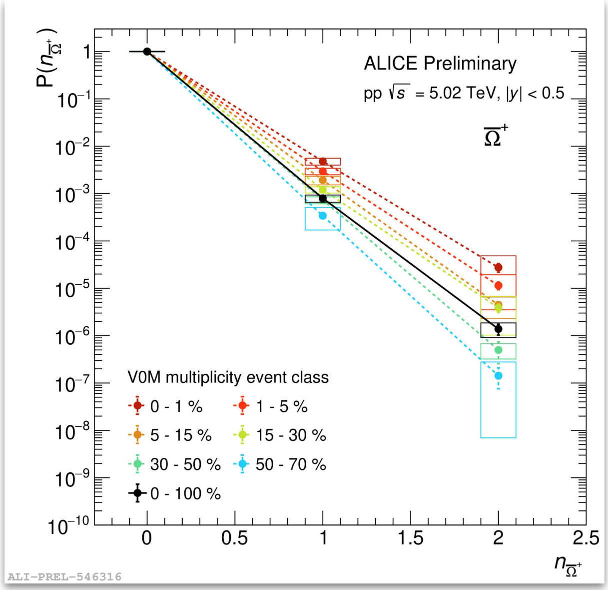


Moving from K^0_S to Ω particle the response matrices are increasingly "squeezed" toward a low number of reconstructed particles/event







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

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