Production of Σ baryons as a function of multiplicity in pp collisions at the LHC with ALICE

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The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

Outline

- Motivation
- ALICE experiment in Run 2
- Σ^0 and $\bar{\Sigma}^0$ measurement
- Σ^+ and $\bar{\Sigma}^-$ measurement
- $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ measurement
- ALICE experiment in Run 3
- Prospects for Run 3
- Conclusion

Motivation

- The strangeness content of the final state in ultrarelativistic heavy-ion collisions has been studied through measurements of kaons ($K^{\pm}$, K^0_S), Λ, Ξ and Ω, but not yet Σ
- Σ-hyperons carry a significant fraction of the strangeness produced in the collision and are a useful probe of QGP formation [Phys. Rev. D 101, 034506]
- For the moment only Σ^0 was measured by ALICE at the LHC

$\Sigma^+ = \mathrm{uus}$

$m = 1189.37 \pm 0.07\ \mathrm{MeV}/c^2$

$\Sigma^+ \to p\pi^0 (51.57 \pm 0.30)\ \%$

$\Sigma^+ \to n\pi^+ (48.31 \pm 0.30)\ \%$

$\Sigma^- = \mathrm{dds}$

$m = 1197.449 \pm 0.030\ \mathrm{MeV}/c^2$

$\Sigma^- \to n\pi^- (98.848 \pm 0.005)\ \%$

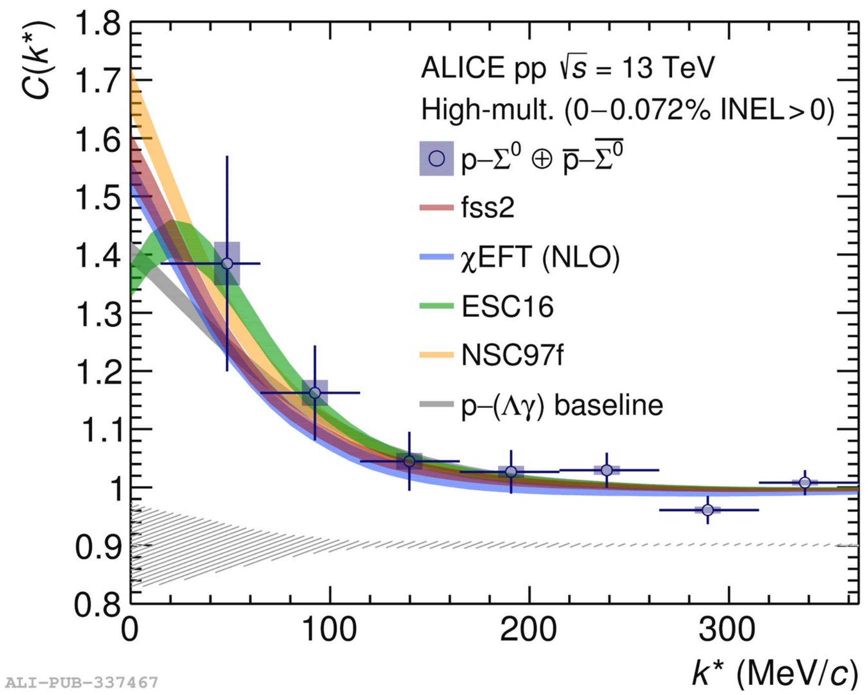
$\Sigma^0 = \mathrm{uds}$

$m = 1192.642 \pm 0.014\ \mathrm{MeV}/c^2$

$\Sigma^0 \to \Lambda\gamma (100)\ \%$

Motivation

- Measurement of N–Σ correlation should shed a light on the presence of Σ-hyperons in neutrons stars and constrain the Equation-of-State
- For the moment only $\mathrm{p}-\Sigma^0$ interaction via femtoscopy was measured
- $\mathrm{p}-\Sigma^0$ correlation function is consistent with the $\mathrm{p}-(\Lambda\gamma)$ baseline, and therefore the measurement indicates the presence of an overall shallow strong potential
- Presented femtoscopic data cannot discriminate between different models, which is also the case for the available scattering and hypernuclei data
- Measurement of interactions with charged Σ-hyperons will complement existing results



Phys.Lett.B 805, 135419

Motivation

- However, the measurement is a **challenging task**, because all decays of all Σ states **involves neutral decay products**, thus requiring high-resolution calorimeters or usage of Photon Conversion Method (PCM)

- Several approaches of charged Σ measurement were developed during LHC Run 2 and Run 3

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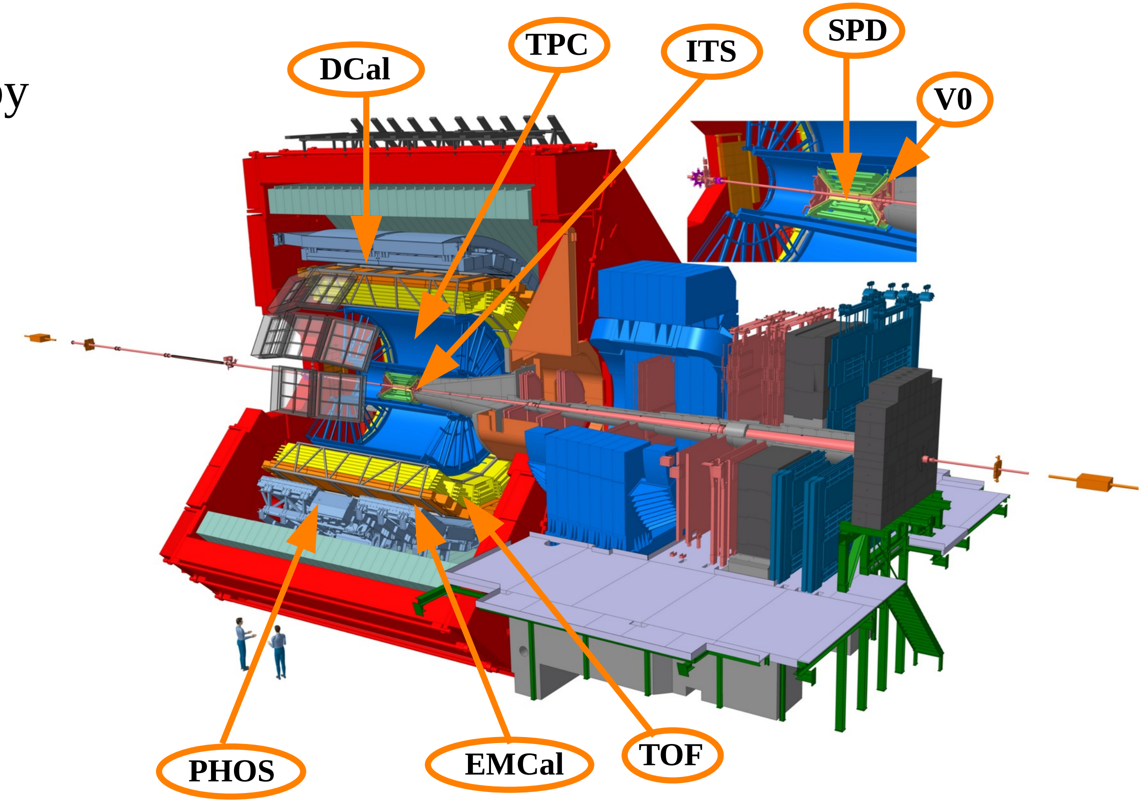
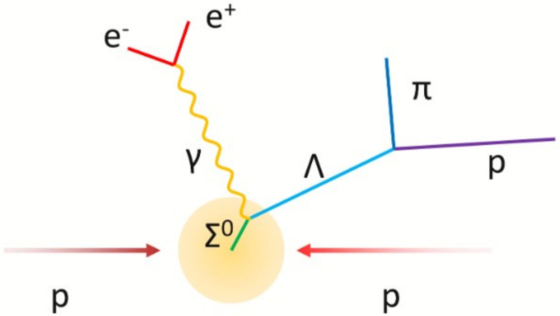
ALICE experiment in Run 2

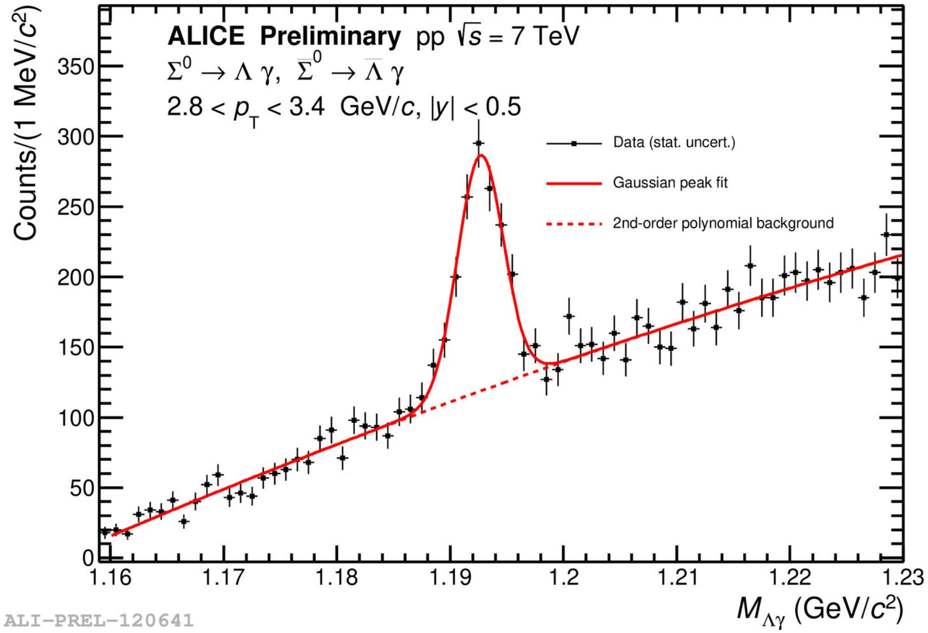
- Tracking down to low p_T is provided by the Inner Tracking System (ITS) and Time Projection Chamber (TPC)
- Charged particle identification is done with Time Projection Chamber (TPC) and Time-of-Flight (TOF)
- Electromagnetic calorimeters: PHOS, EMCal and DCal
- V0 and SPD are used for multiplicity estimation



Σ^0 and $\bar{\Sigma}^0$ reconstruction

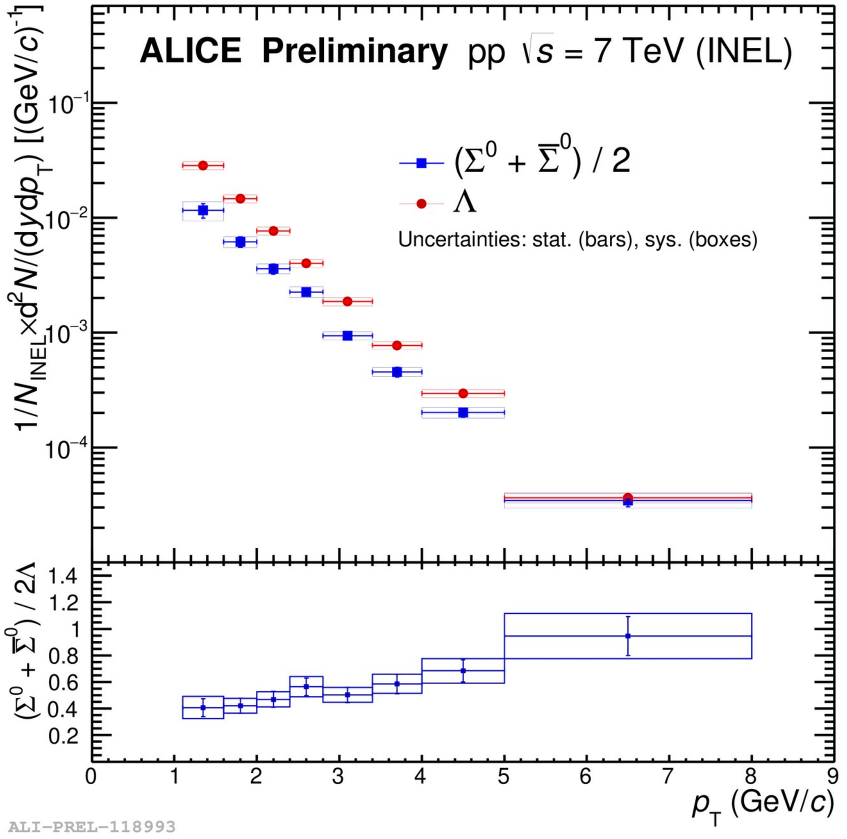
- Λ is reconstructed via the decay into proton and pion
- γ is reconstructed via Photon Conversion Method (PCM)
- Invariant mass distribution is constructed using selected candidates

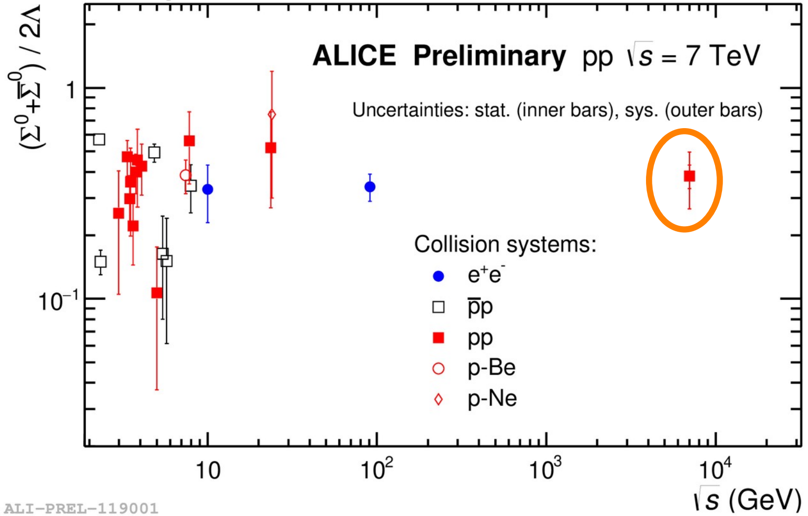




Σ^0 and $\bar{\Sigma}^0$ measurement

- Increasing trend of the $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio with p_{T} is an indication of different contributions of Σ^0 and Λ produced initially in the collision or coming from the decays
- $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio complements world data from lower energies





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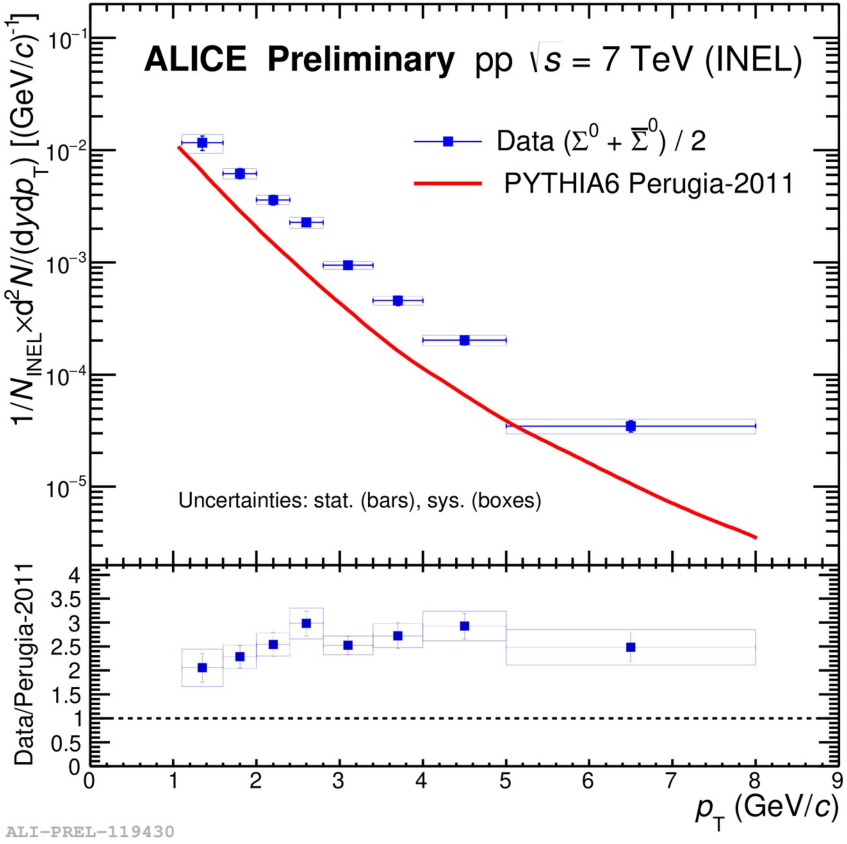
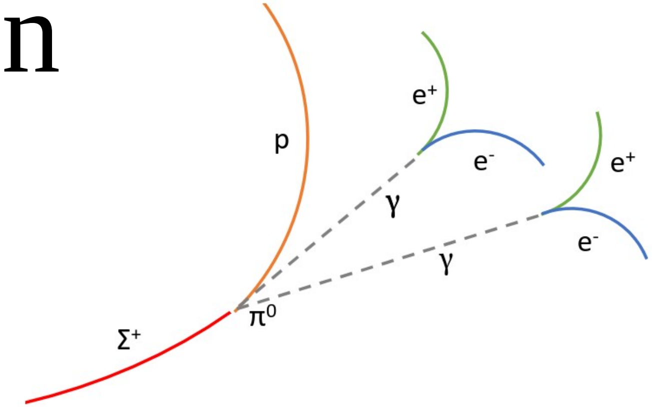
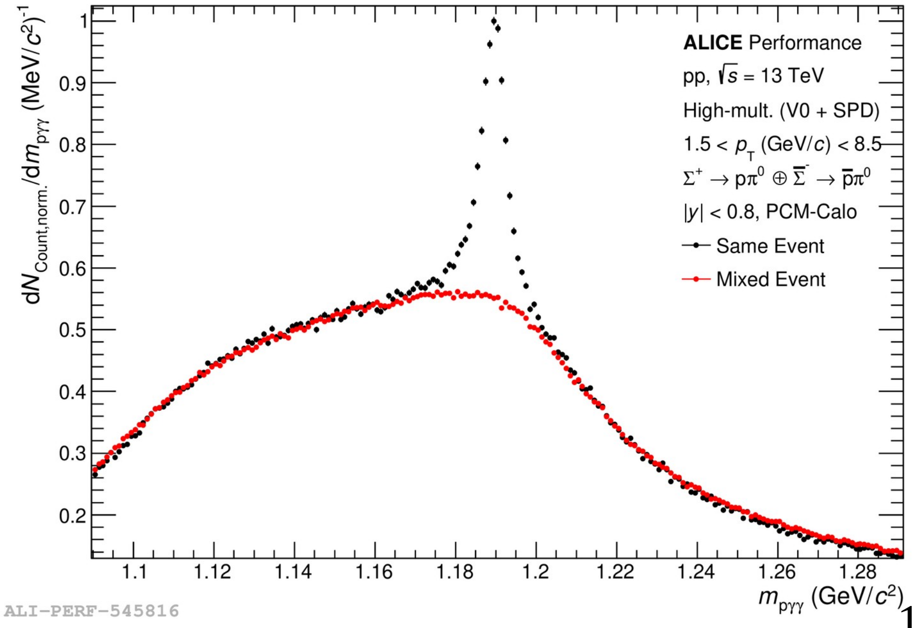
- $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio complements world data from lower energies
- PYTHIA6 [JHEP 0605:026,2006] underestimates the production of Σ^0



Σ^+ and $\bar{\Sigma}^-$ reconstruction

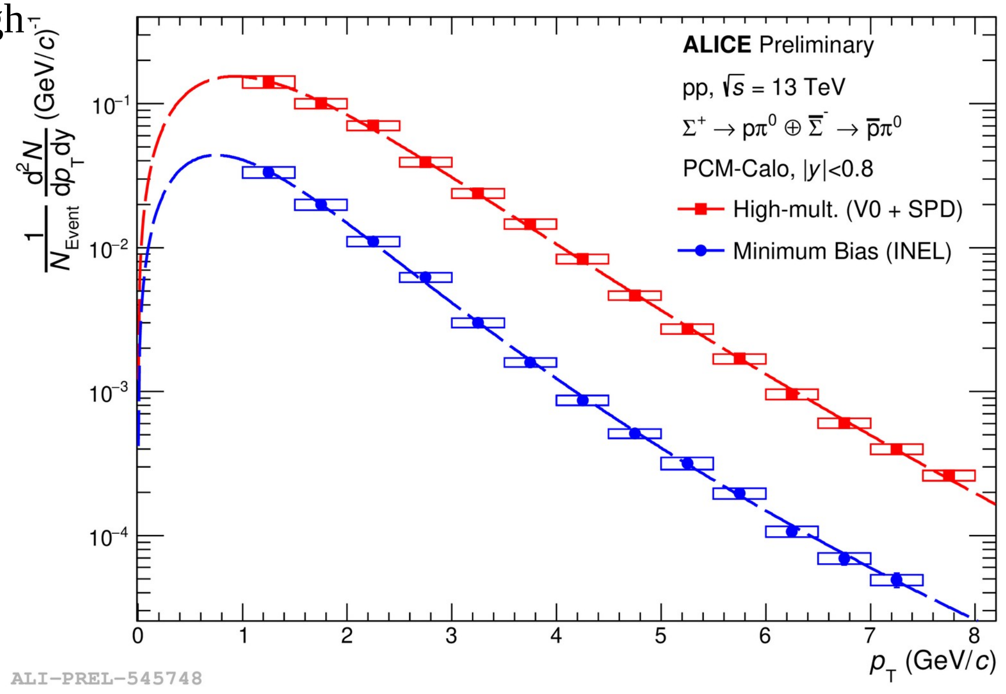


- Proton is detected in the tracking system
- Two γ can be detected either in calorimeters (PHOS, EMCal, DCal) or via PCM
- Both PCM-Calo and PCM-PCM techniques give results that are in agreement with each other
- Secondary vertex can be reconstructed using only γ measured with PCM



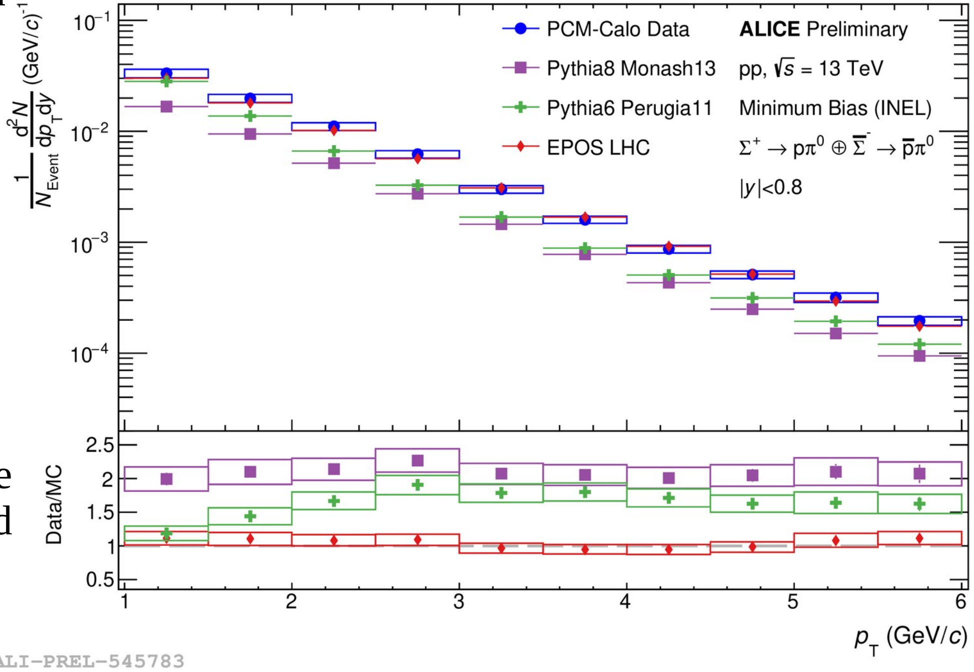
Σ^+ and $\bar{\Sigma}^-$ measurement

- Spectrum is measured both in Minimum Bias and High-Multiplicity collisions
- Mean multiplicity in MB is around 7.18 and in HM 30.46



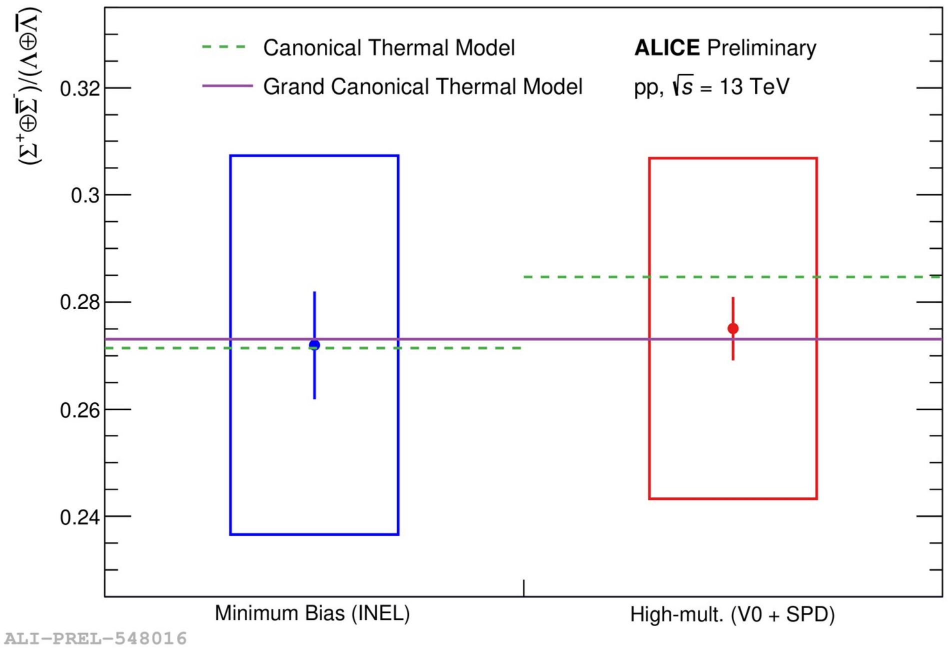
Σ^+ and $\bar{\Sigma}^-$ measurement

- Spectrum is measured both in Minimum Bias and High Multiplicity collisions
- Mean multiplicity in MB is around 7.18 and in HM 30.46
- Spectrum is well reproduced by EPOS LHC generator [Phys. Rev. C 92, 034906], while PYTHIA8 [arXiv:2203.11601] catches the shape, but underestimates the yield
- PYTHIA6 [JHEP 0605:026,2006] does not describe the shape of the spectrum at low transverse momentum and underestimates the yield



Σ^{+} and $\bar{\Sigma}^{-}$ measurement

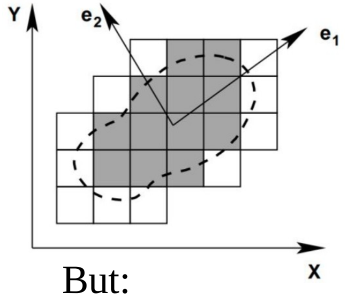
- Spectrum is measured both in Minimum Bias and High Multiplicity collisions
- Mean multiplicity in MB is around 7.18 and in HM 30.46
- Spectrum is well reproduced by EPOS LHC generator [Phys. Rev. C 92, 034906], while PYTHIA8 [arXiv:2203.11601] catches the shape, but underestimates the yield
- PYTHIA6 [JHEP 0605:026,2006] does not describe the shape of the spectrum at low transverse momentum and underestimates the yield
- Σ/Λ ratio is in good agreement with canonical and grand canonical thermal model calculations
- Within the uncertainties the yield ratio do not change in MB and HM events



Antineutron identification in PHOS

How can we identify antineutrons?

- Deposited energy of annihilation
- Neutrality (charged particle veto)
- Dispersion of cluster (M20, M02 – eigenvalues of S matrix)



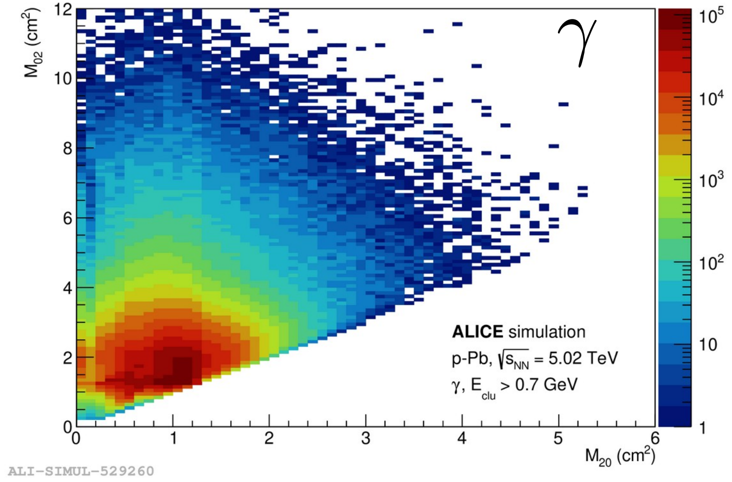
$$S = \begin{pmatrix} s_{xx} & s_{xz} \\ s_{zx} & s_{zz} \end{pmatrix}$$

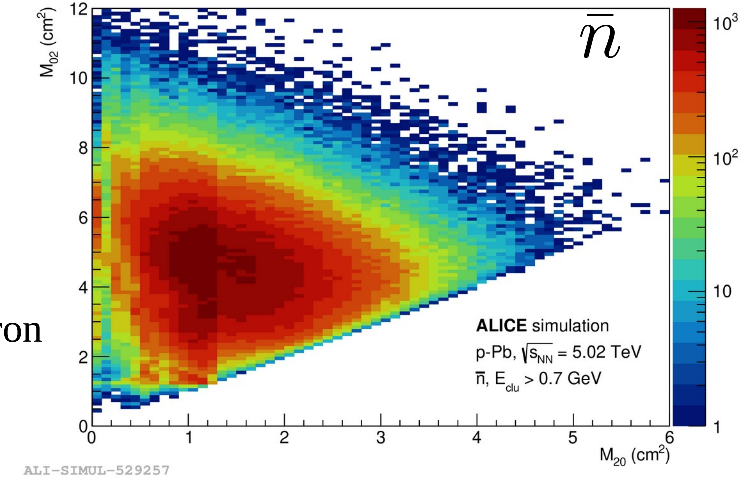
$$s_{xx} = \langle (x - \bar{x})^2 \rangle$$

$$s_{xz} = \langle (x - \bar{x})(z - \bar{z}) \rangle$$

But:

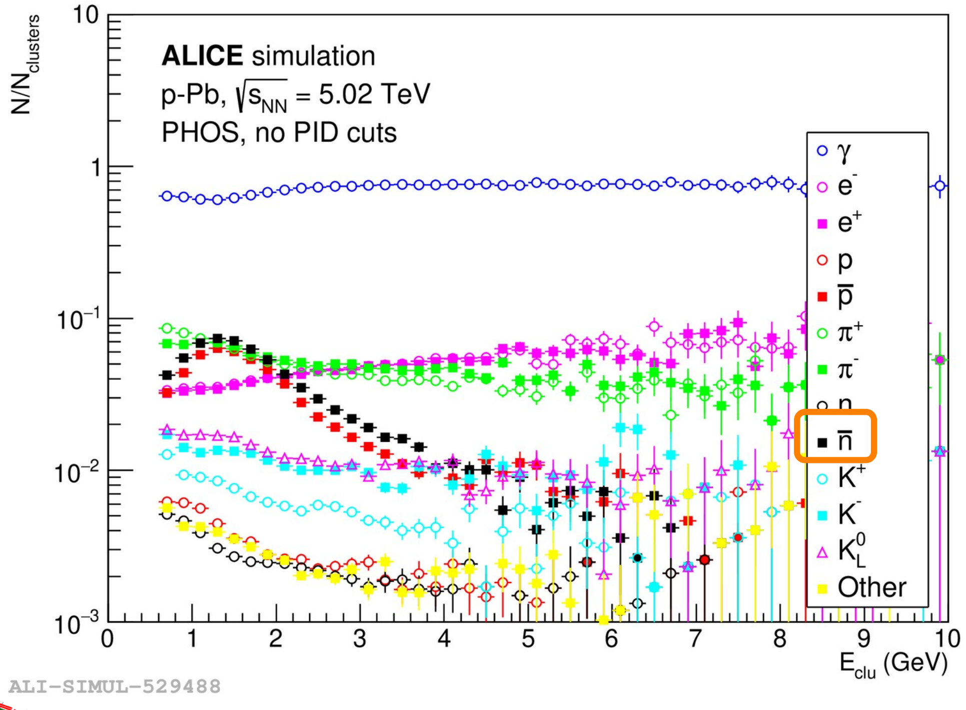
- Cannot measure momentum based on deposited energy
- Use time-of-flight information from PHOS to reconstruct antineutron momentum

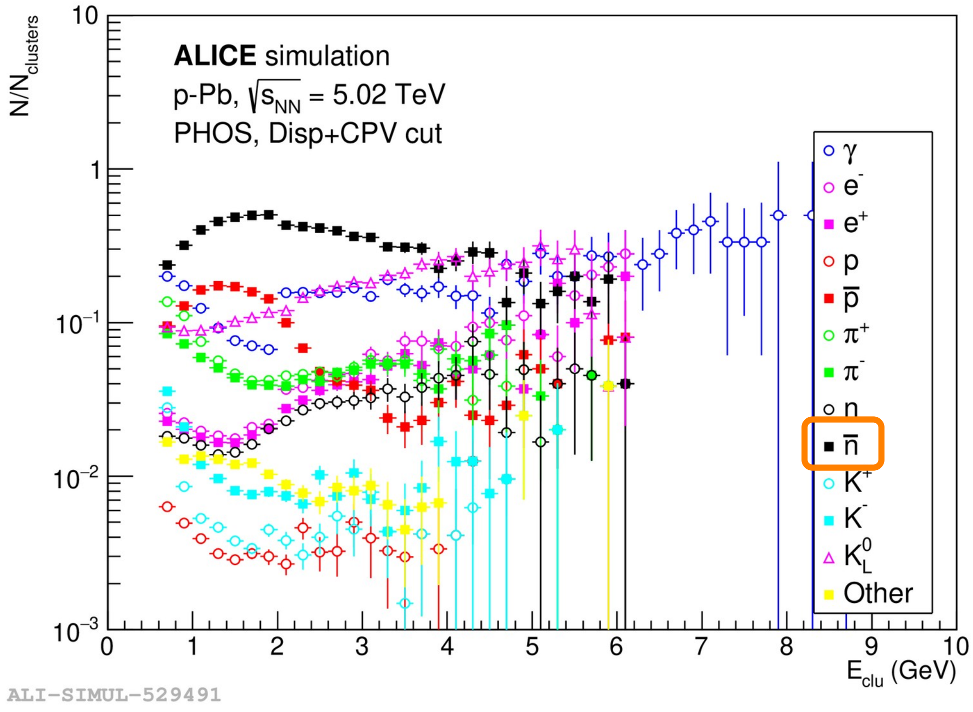




Fraction of different type of clusters

- After applying PID cuts the fraction of antineutron clusters reaches ~50-60%



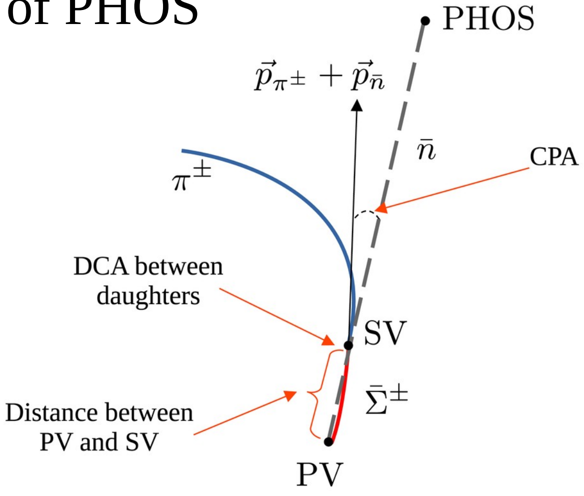


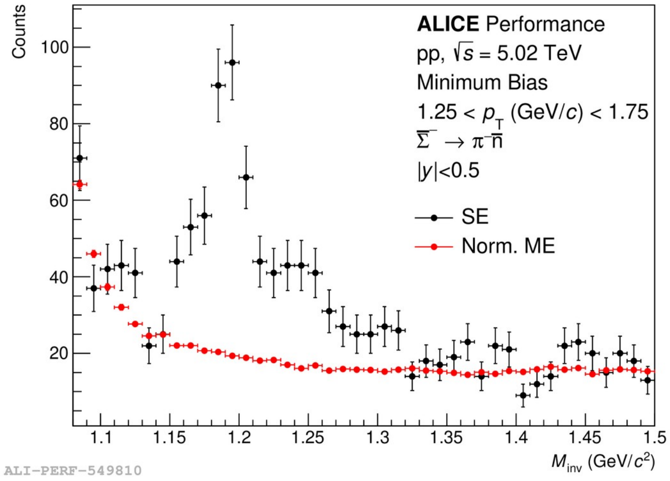
Without PID cuts

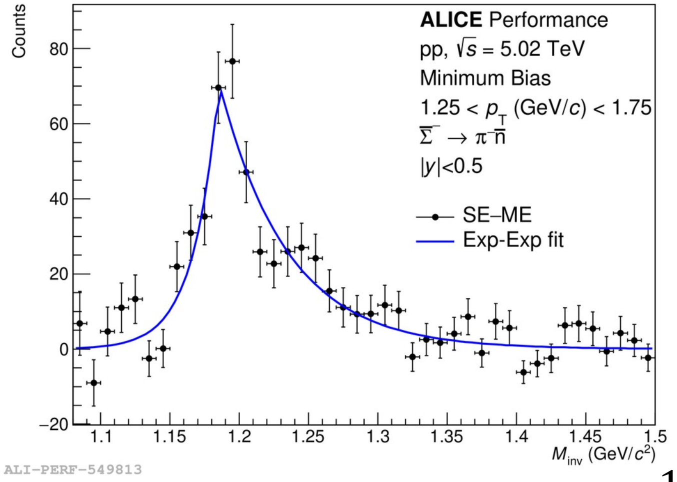
With PID cuts

$\bar{\Sigma}^{+}$ and $\bar{\Sigma}^{-}$ reconstruction

- Secondary vertex is reconstructed and topological selections are used to increase signal to background ratio
- Antineutron and pion candidates are combined to obtain invariant mass distribution
- Signal peak has non-gaussian shape due to finite time resolution of PHOS

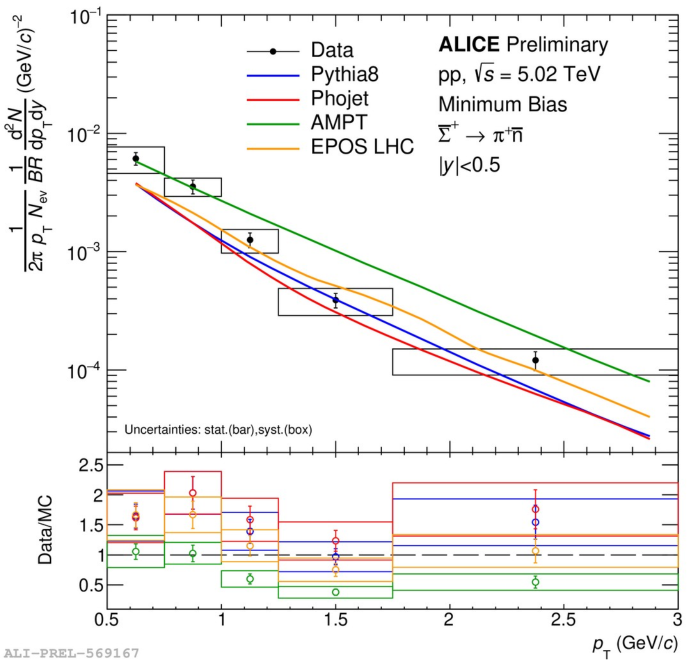


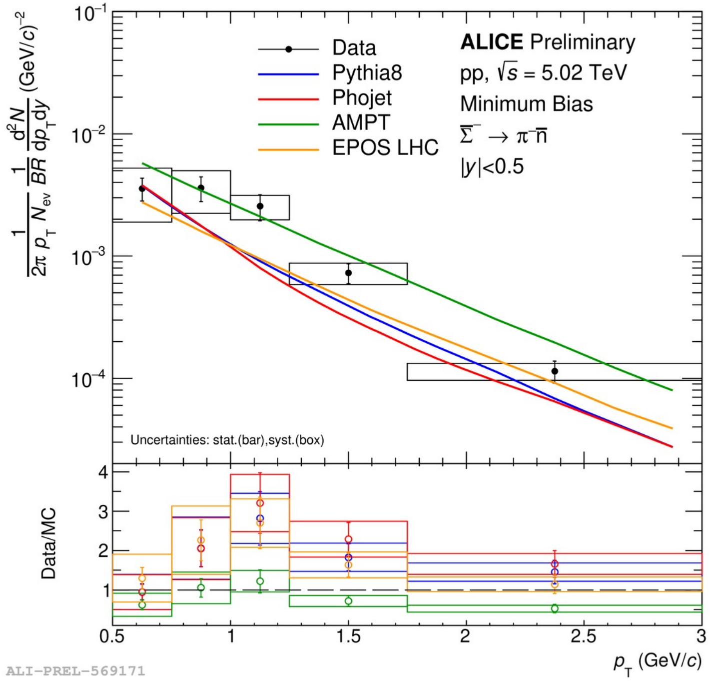




$\bar{\Sigma}^{+}$ and $\bar{\Sigma}^{-}$ measurement in pp

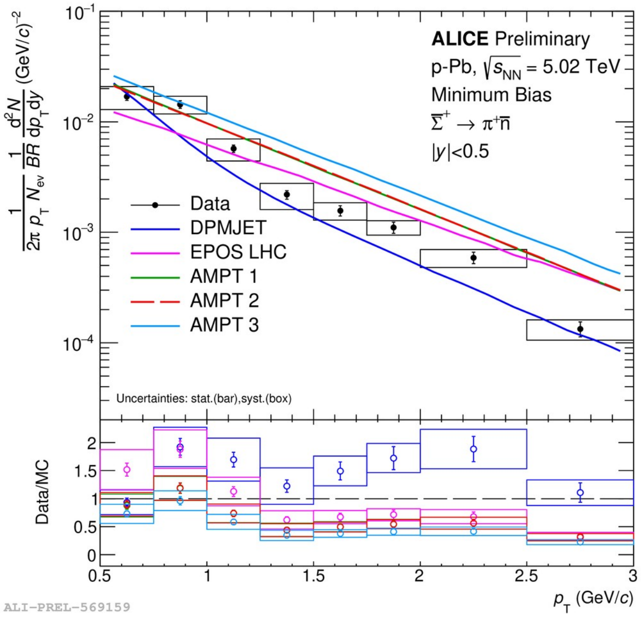
- EPOS LHC [Phys. Rev. C 92, 034906], PYTHIA8 Monash13 [arXiv:2203.11601] and Phojet [arXiv:hep-ph/9803437] show good agreement with data points within large uncertainties
- AMPT [Phys.Rev.C72:064901] have a good agreement at low p_{T} and overestimates the yield at high p_{T}

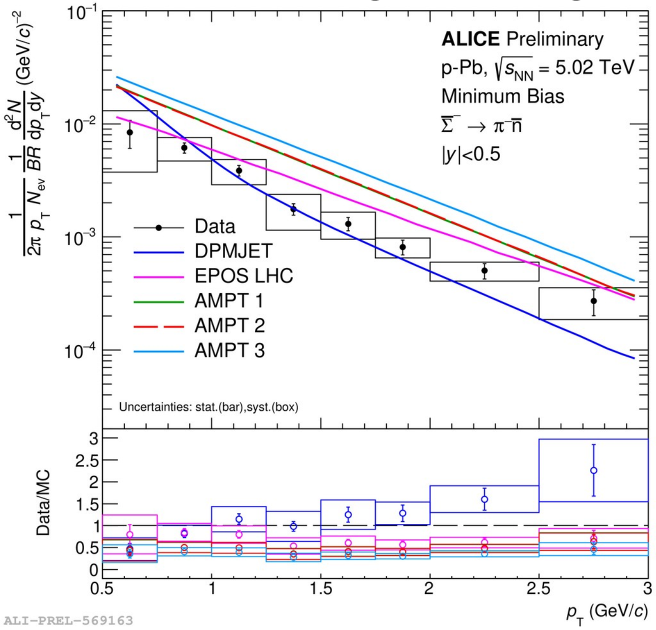




$\bar{\Sigma}^{+}$ and $\bar{\Sigma}^{-}$ measurement in p-Pb

- All AMPT [Phys.Rev.C72:064901] generator options tend to overestimate the yield (see back-up for options description)
- DPMJET [arXiv:hep-ph/0012252] shows good agreement at high p_{T} but have a rise at low p_{T}, which is not common to other models
- EPOS LHC [Phys. Rev. C 92, 034906] works slightly better for the whole p_{T} range within large uncertainties

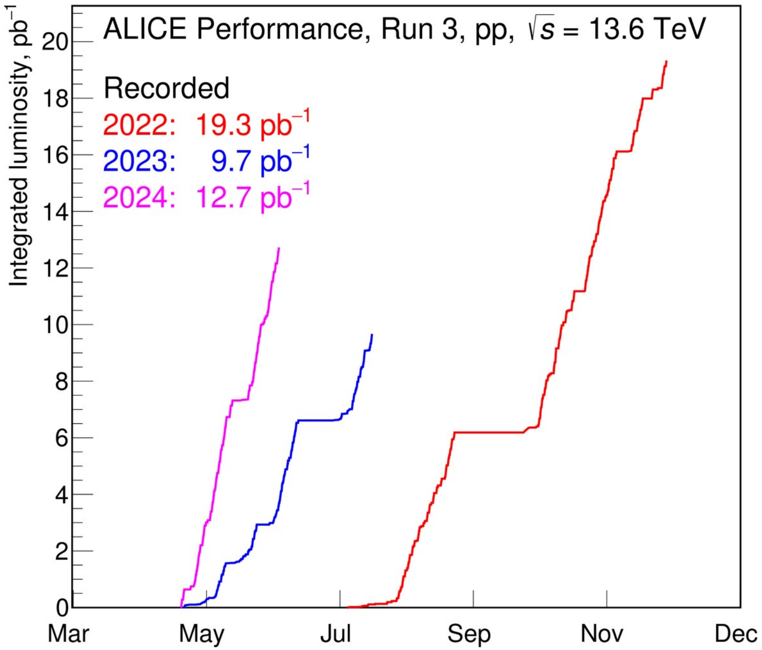




ALICE experiment in Run 3

What is new in Run 3:

- Upgraded detectors to handle continuous readout
- Improve vertexing capabilities in the central barrel allowing better reconstruction of primary and secondary vertices
- Increase of statistics, ALICE already collected more than **x1000** events compared to Run 2 in pp data taking at ~500 kHz in continuous readout



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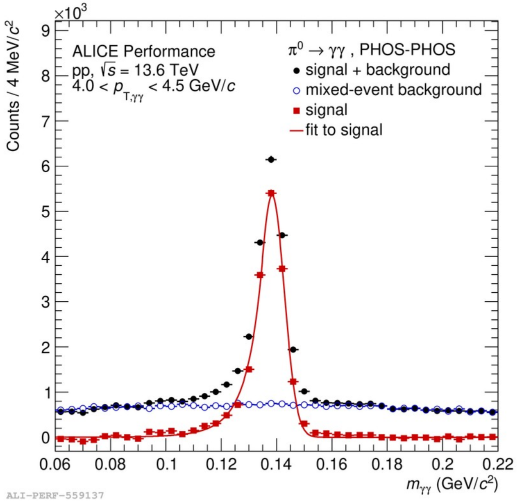
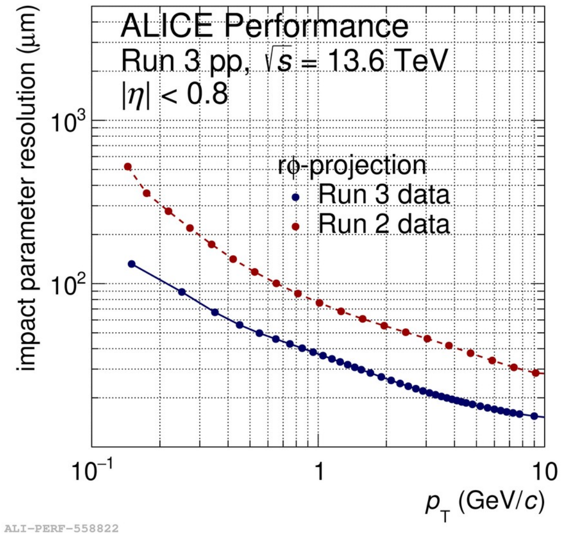
- Increase of statistics, ALICE already collected more than **x1000** events compared to Run 2 in pp data taking at ~500 kHz in continuous readout
- Σ analysis can be performed with higher precision in Run 3, compared to Run 2

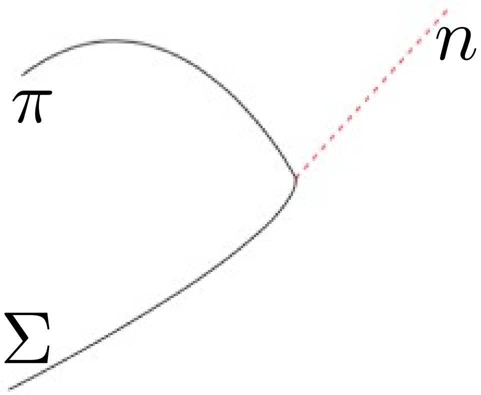


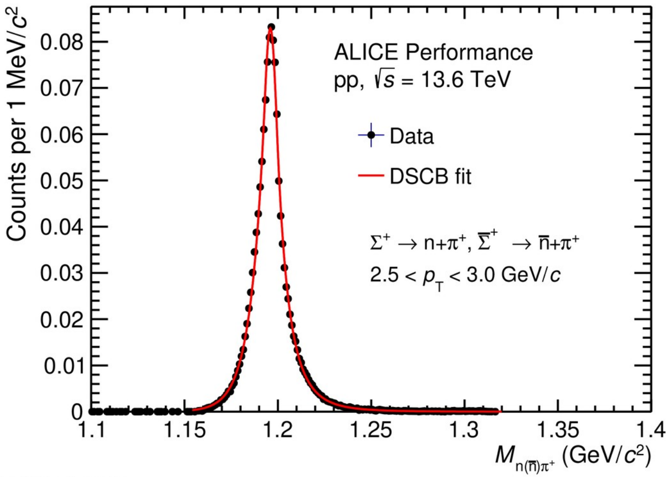


Prospects for Run 3

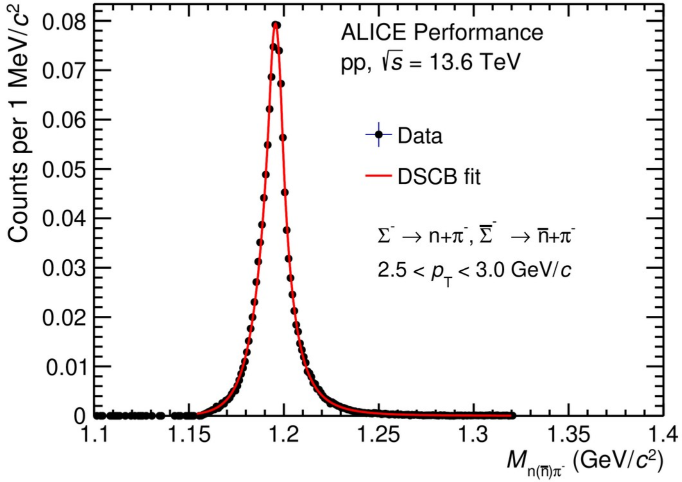
- Σ-hyperons can be reconstructed using kink-topology method in ITS2 by searching signals from particles in different detector layers
- Two differently charged Σ can not be distinguished from each other using this method
- ITS3 upgrade will reduce the invariant mass peak widths

More about ITS3 upgrade in Talk by Chunzheng Wang
June 4, 2:20 PM, Room Londres 1





ALI-PERF-549034



ALI-PERF-549030

Conclusion

- For the first time at the LHC, production of charged Σ-hyperons was measured
- Method for antineutron reconstruction was proposed, which opens up a variety of new observables
- Obtained results are more or less consistent with EPOS LHC [Phys. Rev. C 92, 034906] predictions, and can be used to constrain other MC generators
- Σ was studied both in High Multiplicity and Minimum Bias pp collisions and Σ/Λ ratio is consistent with Thermal model prediction
- More precise measurement of Σ-hyperons, Σ-hypernuclei search and hadron-Σ interactions measurement is foreseen at LHC with ALICE in Run 3 in 2022–2025

Thank you for your attention!

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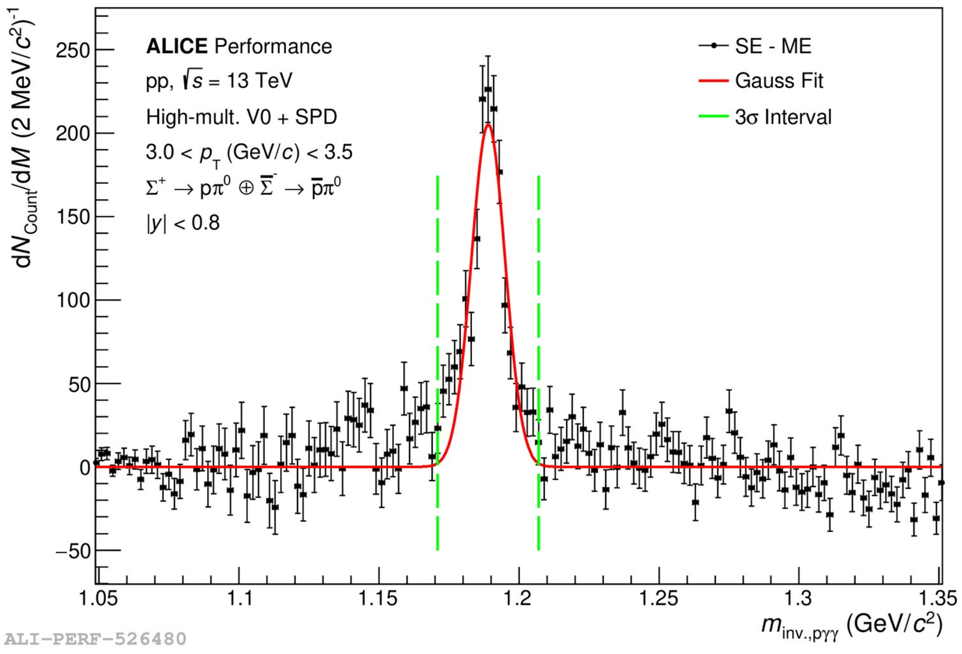
Back-up

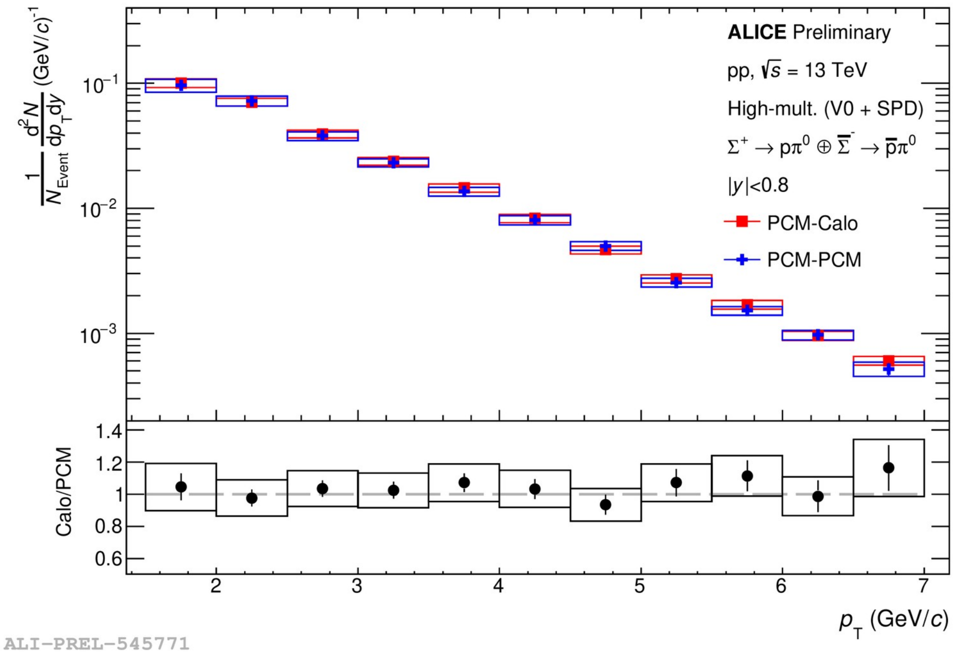
$\Sigma^{+}$and $\bar{\Sigma}^{-}$reconstruction

- Signal distribution after mixed event subtraction
- Fit performed with Gaussian function

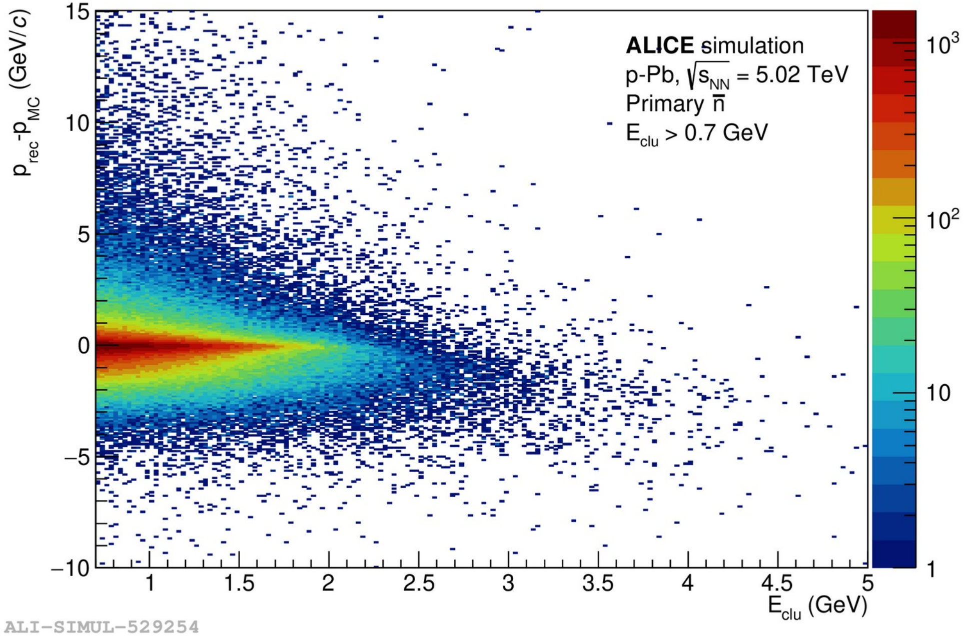


Σ^{+} and $\bar{\Sigma}^{-}$ reconstruction

- Both PCM-Calo and PCM-PCM techniques give results that are in agreement with each other



Reconstruction of antineutron momentum



$$p_{\text{rec}} = \frac{m_{\bar{n}}}{\sqrt{\left(\frac{t_{\text{TOF}} \cdot c}{L}\right)^2 - 1}}$$

L - distance between primary vertex and cluster coordinate in PHOS, m (about 4.6 m)

$m_{\bar{n}}$ - antineutron mass, $0.939485\ \text{GeV}/c^2$

t_{TOF} - time of flight, s

$\bar{\Sigma}^{+}$and $\bar{\Sigma}^{-}$measurement in p-Pb

- AMPT_1 - the hadron rescattering is switched off and the String melting is switched on. With shadowing
- AMPT_2 - the hadron rescattering is switched on and the String melting is switched on
- AMPT_3 - the hadron rescattering is switched off and the String melting is switched on. Without shadowing