XXV International Baldin Seminar
on High Energy Physics Problems
Relativistic Nuclear Physics & Quantum Chromodynamics
September 18 - 23, 2023, Dubna, Russia

Production of Σ hyperons in pp and p–Pb collisions at LHC with ALICE

- Introduction
- Photon Detection
- Σ^0 detection, comparison with world data and models
- $\Sigma^+ + \Sigma^-$ detection, comparison with models
- $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ detection in pp and p-Pb collisions
- Outlook on incoming data
- Summary

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This work is supported by the RSF grant 22-42-04405

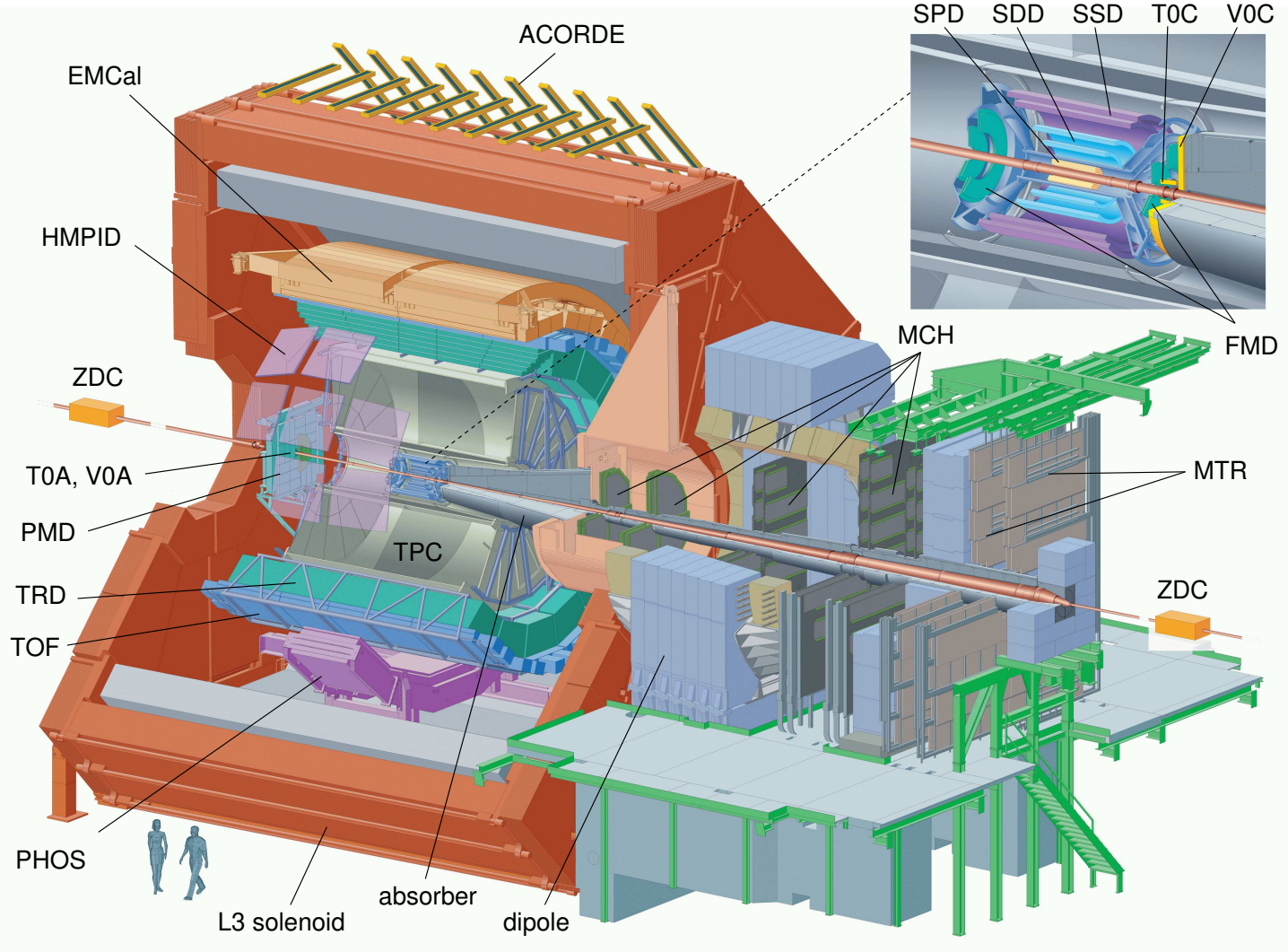
Σ hyperons production in pp collisions

...Complementary to G. Feofilov overview

Particle	Quarks	Mass	$c\tau$	Decay	Branching
Σ^0	uds	1192.642	22 200 fm	$\Lambda + \gamma$	100
Σ^+	uus	1189.37	2,404 cm	$p + \pi^0$ $n + \pi^+$	51.57 48.31
Σ^-	dds	1197.449	4.434 cm	$n\ \pi^-$	99.848

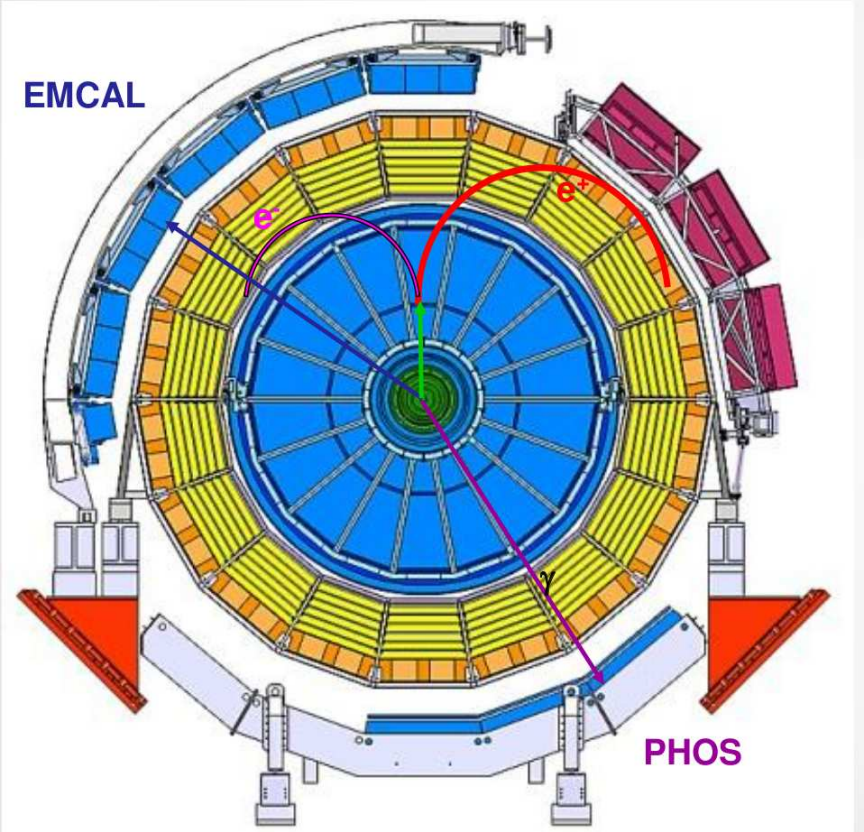
- **No production cross section measurements at energies larger than 91 GeV**
- Contribution to the understanding of hadron production mechanisms
- Reference for tuning Monte Carlo event generators such as PYTHIA, EPOS and DIPSY
- Baseline for comparison with Pb–Pb data
- Comparison with the Λ baryon, which has the same quark content but different isospin
- Discrimination of prompt and decay hyperons
- Constrain feed-down corrections for baryons, mesons and photons at low transverse momenta

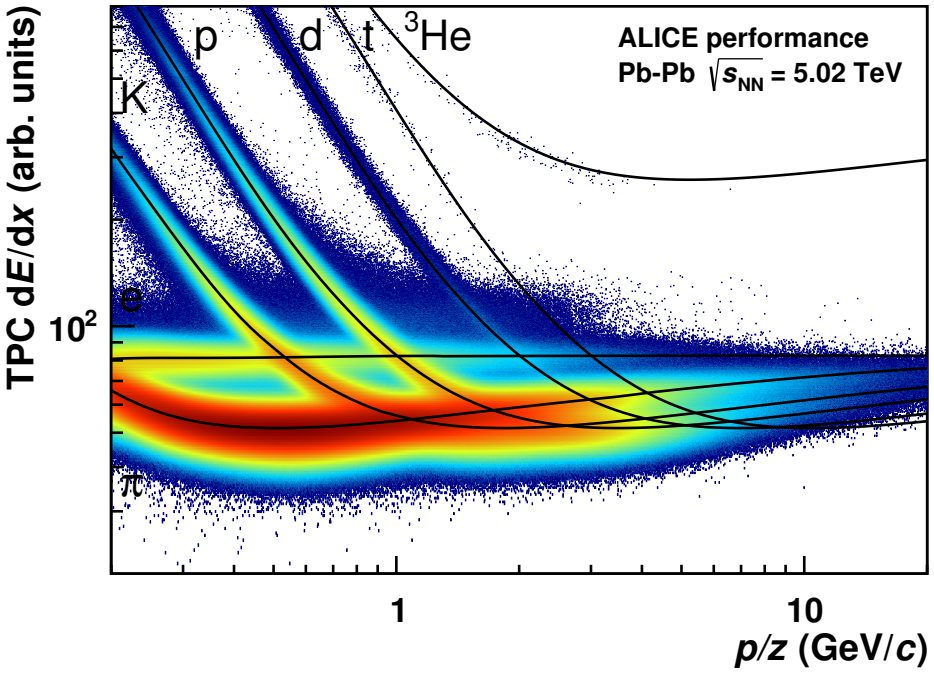
The "old" ALICE detector in 2010–2018



ITS, TPC and TOF are mainly used for reconstruction and identification of tracks
V0A+V0C and ZDC for multiplicity, centrality, trigger and timing.
Unique particle identification, high granularity, tracking down to $p_{\mathrm{T}} = 0.1$ GeV/c.
Size 16× 26 meters, weight $\sim$ 10000 tons.

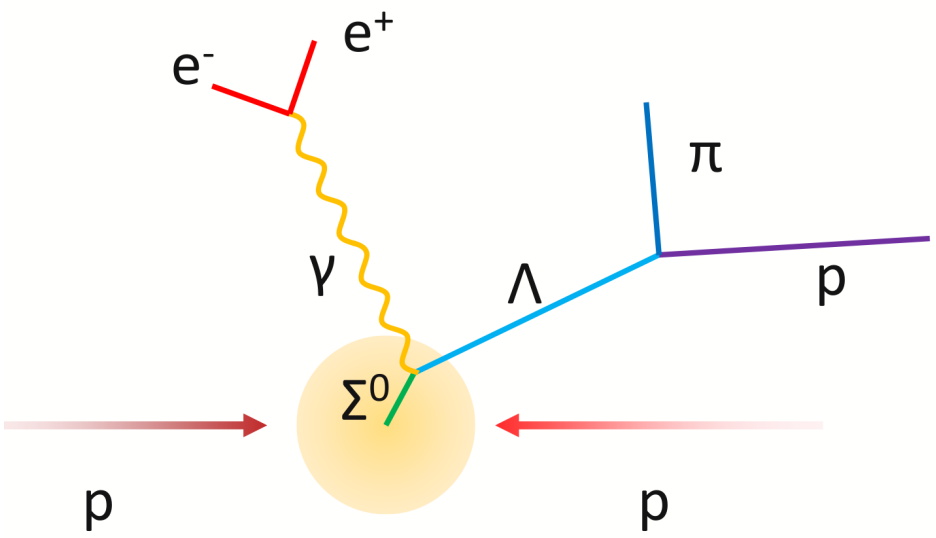
Photon detection in ALICE



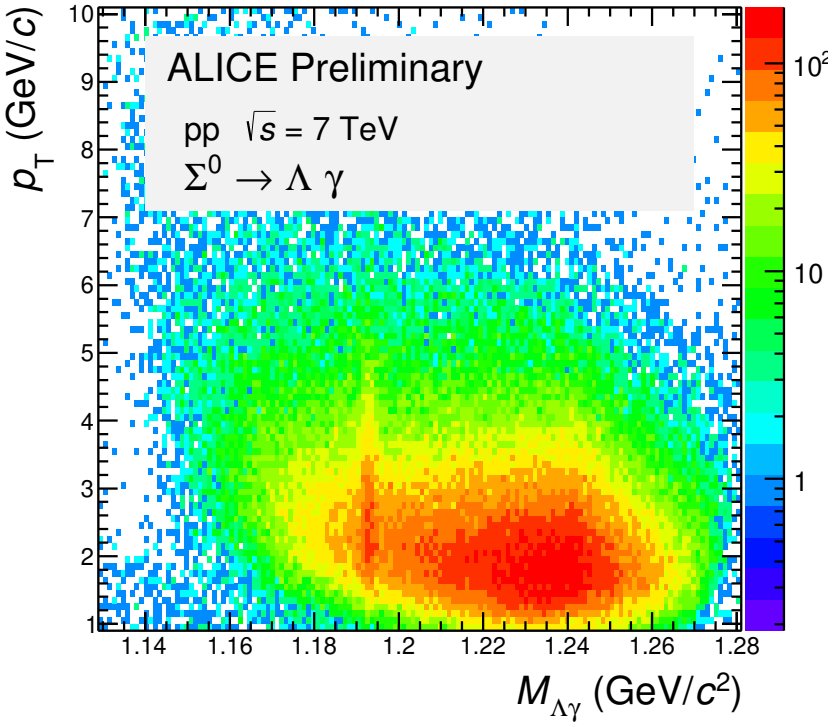


- EMCAL: large acceptance ($\delta\phi = 100^o$, $|\eta| < 0.9$) but limited energy resolution
- PHOS: good energy resolution but limited acceptance ($\delta\phi = 60^o$, $|\eta| < 0.135$)
- Photon Conversion Method (PCM)
  - good momentum resolution at low $p_{\mathrm{T}} \sim 1 - 5$ %
  - excellent particle identification capabilities in a wide p_{T} range 0.1 - 20 GeV/c
  - full azimuthal angle coverage and $|\eta| < 0.9$
  - conversion probability < 0.085

Topology of $\Sigma^0(\bar{\Sigma}^0)$ detection

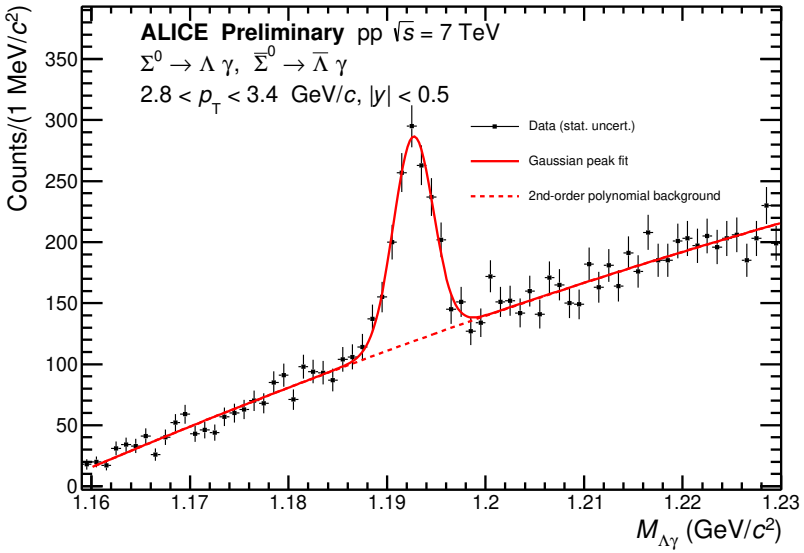


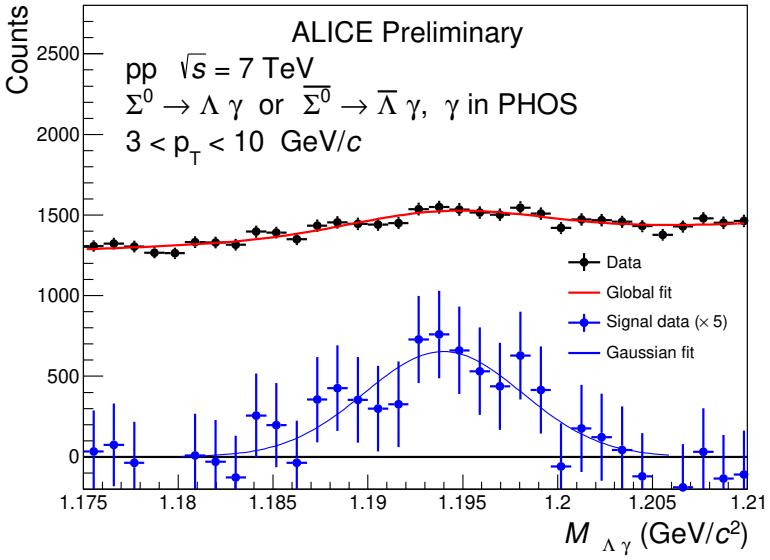
(without the lifetime scale, yellow circle only for Σ^0 vizualisation)



- $\gamma \rightarrow e^+ + e^-$ is detected through the secondary V^0 vertex with Photon Conversion Method (PCM) in the central barrel detectors or in PHOS calorimeter
- The distribution of the conversion points is well reproduced by MC.
- The radiation thickness of the detector material integrated for $R < 180$ cm and $|\eta| < 0.9$ is determined to be $(11.4 \pm 0.5)\%$ X_0 (ALICE, Int. J. Mod. Phys. A 29 (2014) 1430044).

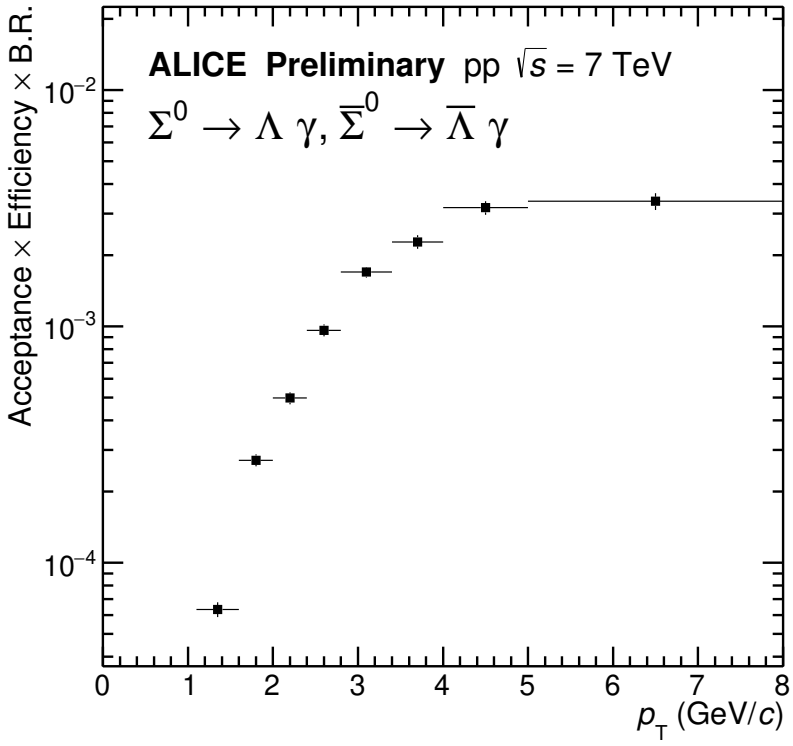
Mass of $\Sigma^0 \to \Lambda + \gamma$ + $\bar{\Sigma}^0 \to \bar{\Lambda} + \gamma$

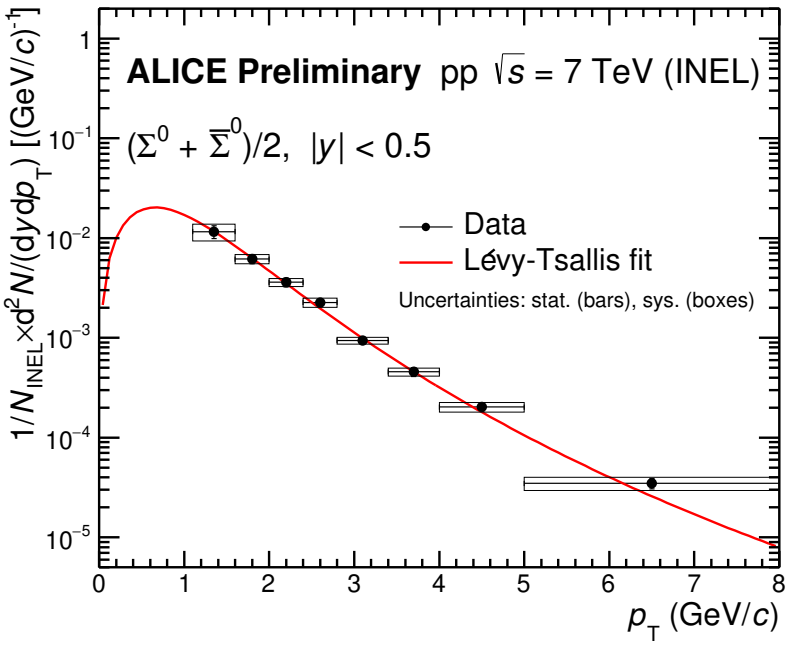




- Σ^0 invariant mass is calculated from the four-momenta of the selected Λ and γ candidates. **Note low $E_\gamma \approx$ 200 MeV.**
- Σ^0 mass resolution $\sigma_{\mathrm{M}}^{\mathrm{PCM}} = 2$ MeV$/c^2$ at $2.8 < p_{\mathrm{T}} < 3.4$ GeV$/c$
- Proof-of-principle: Σ^0 peak is also observed with photon detected in PHOS calorimeter, but with worse mass resolution.

Σ^0 corrections, spectrum and Lévy-Tsallis fit



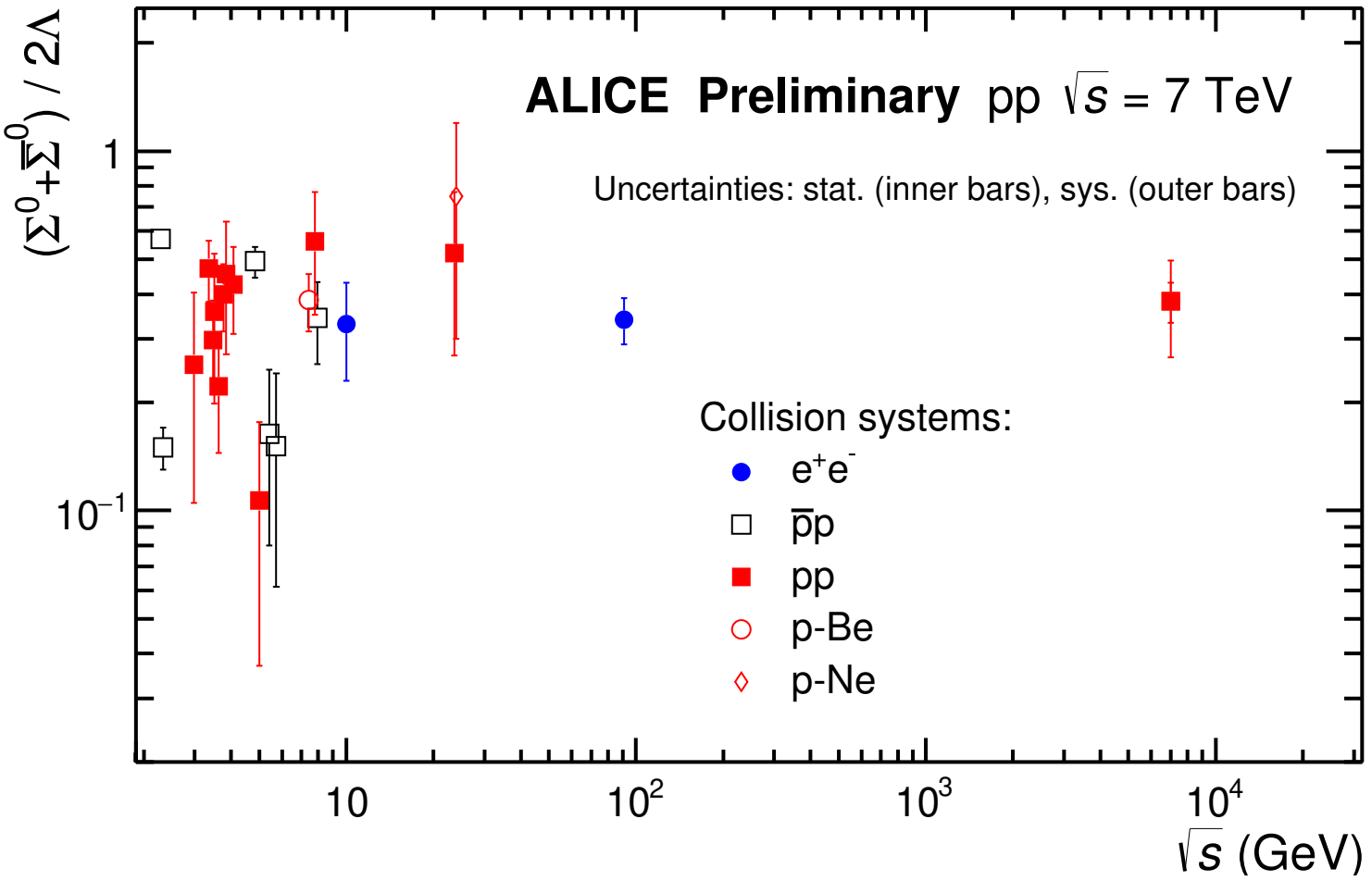


γ conversion probability < 0.085

The p_{T} -integrated yield is determined by summing up the spectrum in the measured range and the extrapolation to $p_{\mathrm{T}} = 0$ based on the Lévy-Tsallis fit.

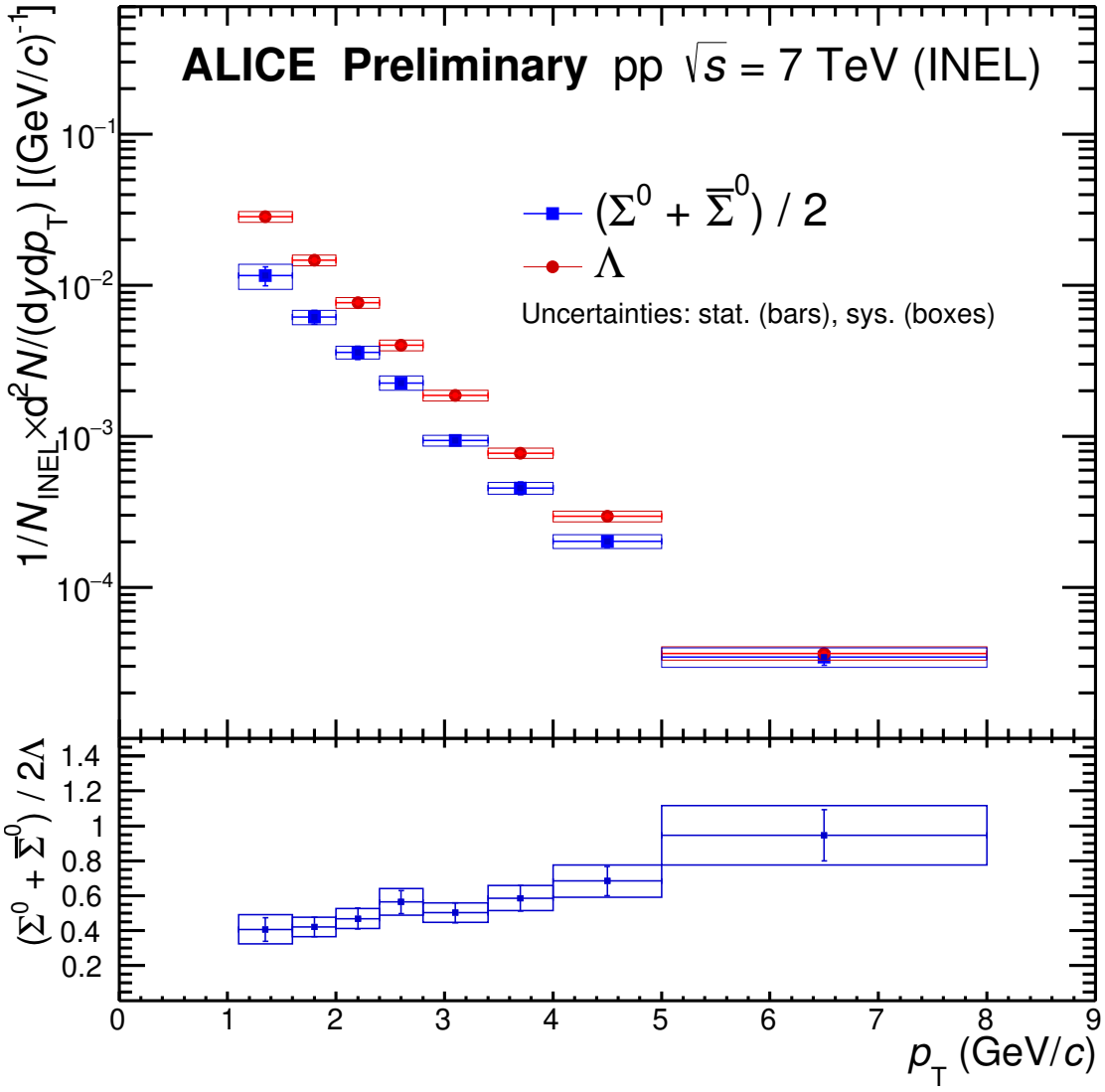
$\sim$ 60% of the yield is in the extrapolated region between 0 and 1.1 GeV/c. Relative uncertainty of the yield due to the extrapolation is $\sim$ 18%.

ALICE measurement and world data



- First measurement at LHC of $\frac{\Sigma^0}{\Lambda}$ cross section ratio complements world data from lower energies
- e^+e^- data at $\sqrt{s} = 91$ GeV from L3 experiment at LEP reported $\frac{\Sigma^0}{\Lambda} = 0.33 \pm 0.03$, where both Σ^0 and Λ detected in hadronic Z decays (M. Acciarri et al, L3 collab., Phys. Lett. B 479 (2000) 79-88.)

p_{T} -differential $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio

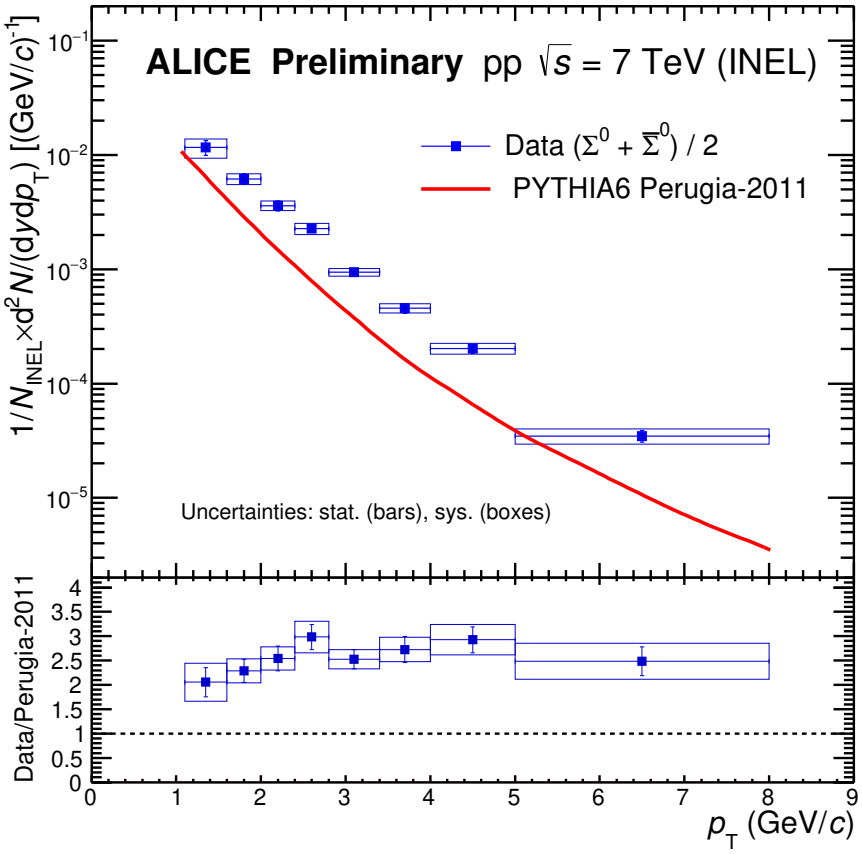


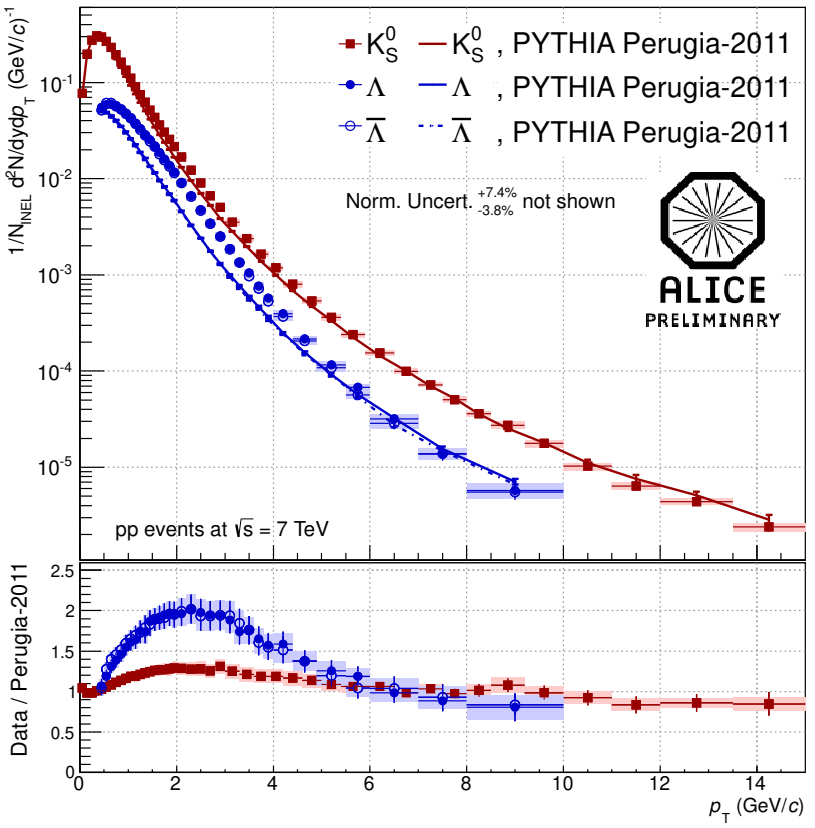
$\Longrightarrow$ **Increasing trend of the $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio with p_{T} is an indication of different contributions of primordial and final Σ^0 and Λ production.**

$\Longrightarrow$ **More data is needed! LHC run II data is under analysis.**

Σ^0 and Λ vs PYTHIA6

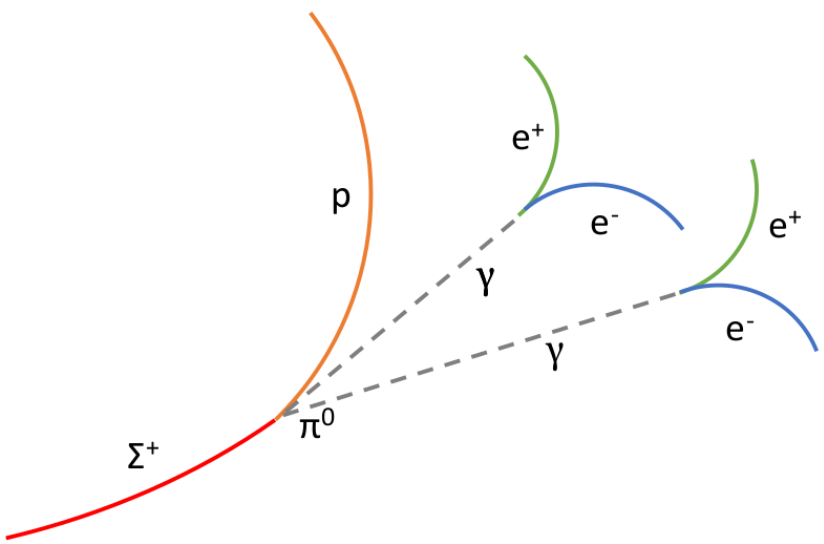
(ALICE collab., Eur. Phys. J. C, 81, 256, 2021)

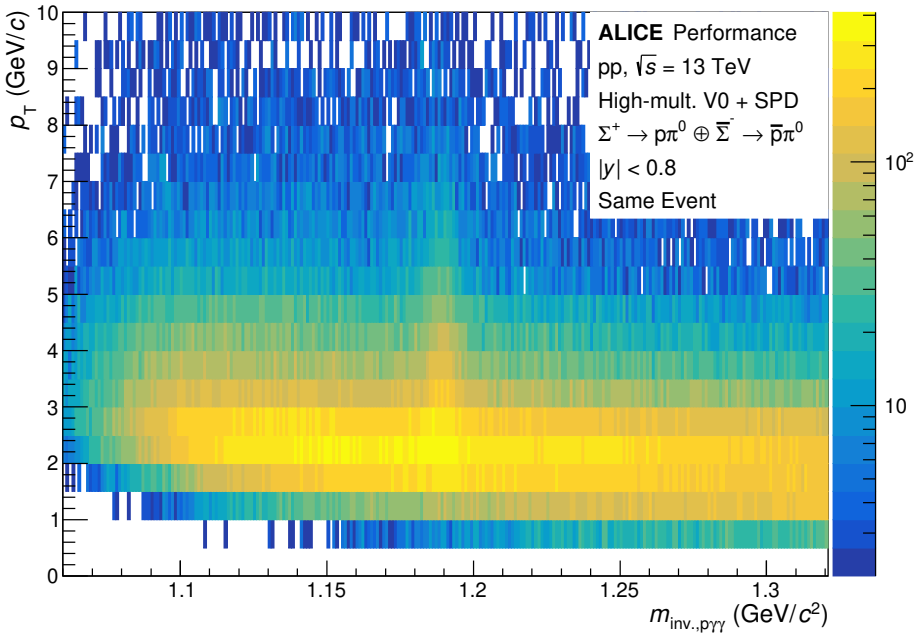


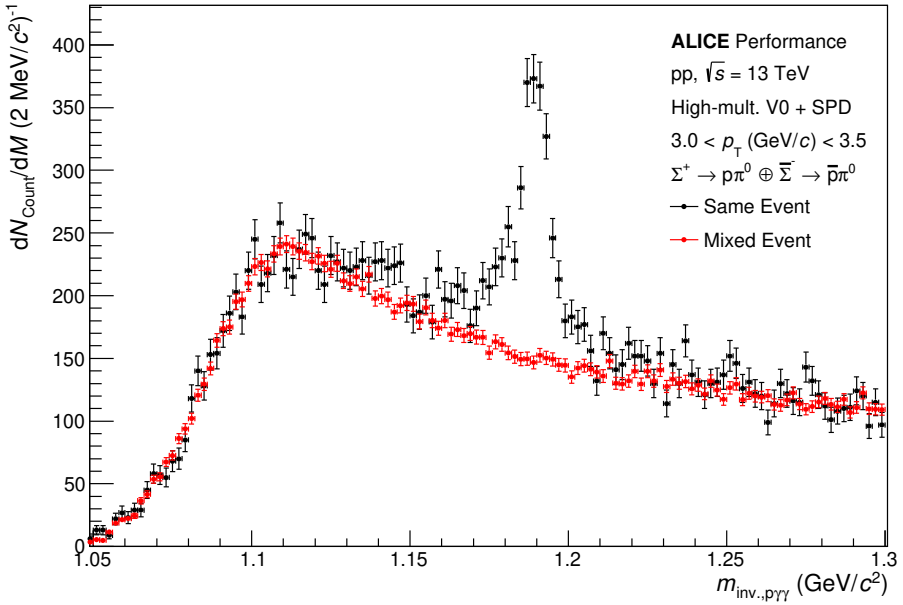


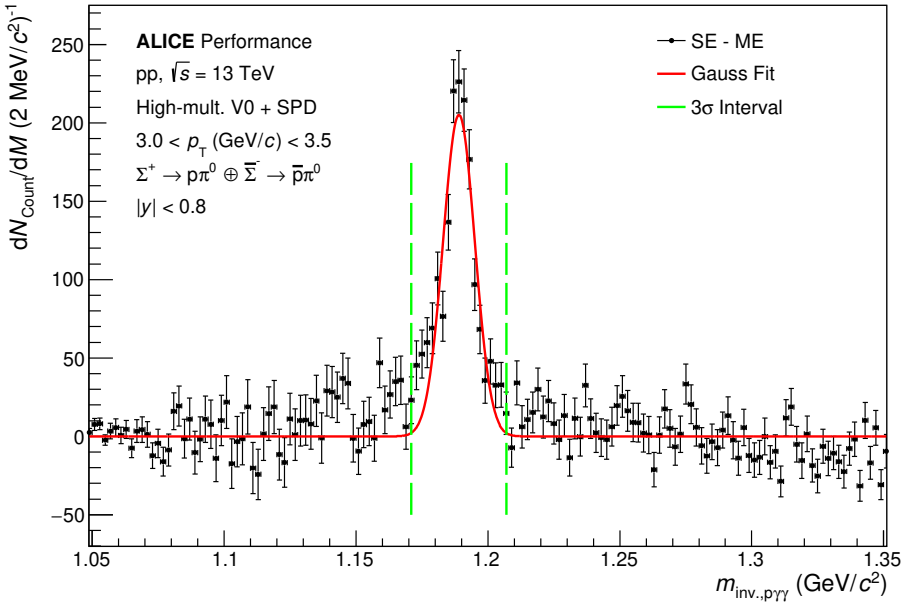
$\Longrightarrow$ **PYTHIA6 Perugia-2011 clearly underestimates the production of both ground-state hyperons in the intermediate p_{T} -range**

First observation of $\Sigma^+(\Sigma^-) \rightarrow p(\bar{p}) + \pi^0$ at LHC



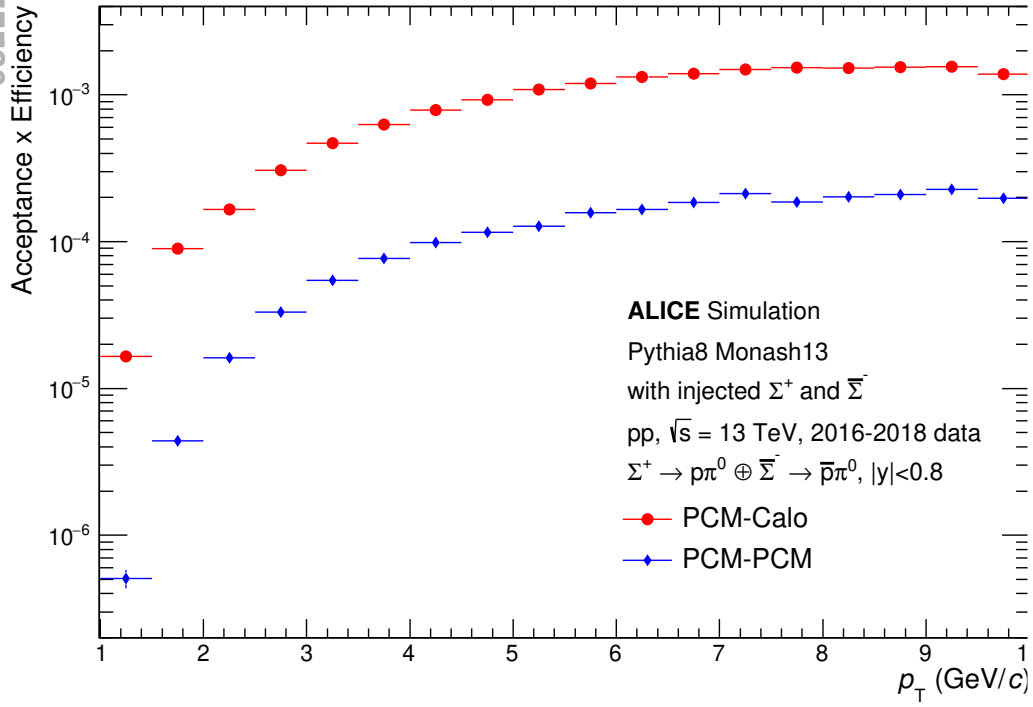


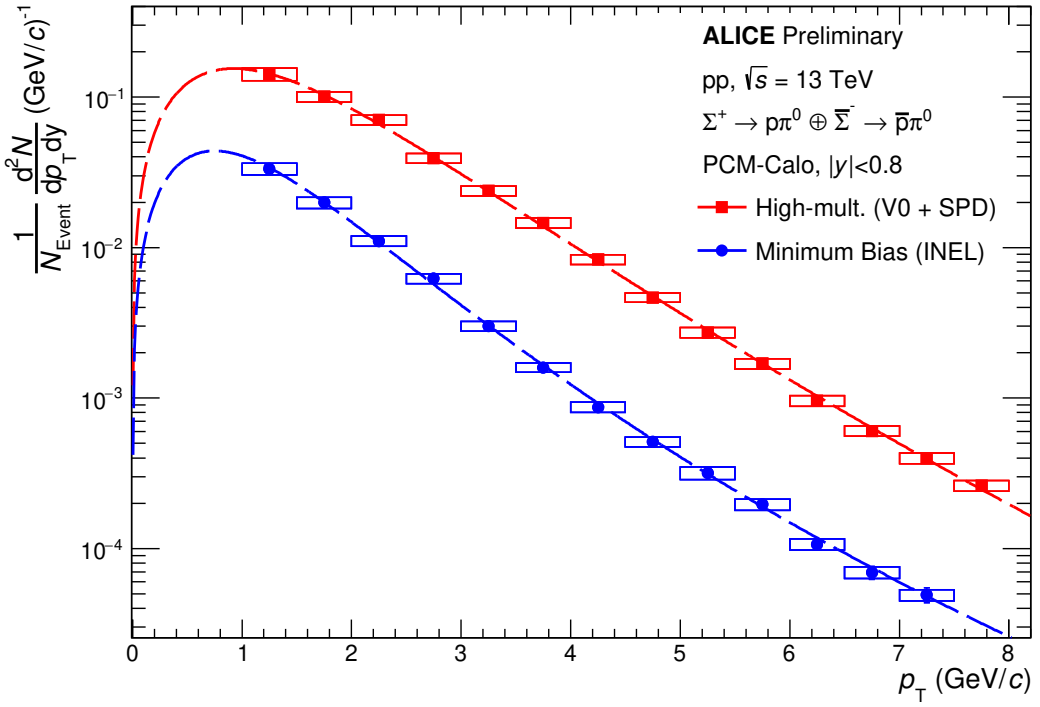




Low p_{T} π^0 are measured by reconstructing their decay photons using the PCM method or the calorimeters

Efficiency and Integrated Yields of $\Sigma^+ + \bar{\Sigma}^-$

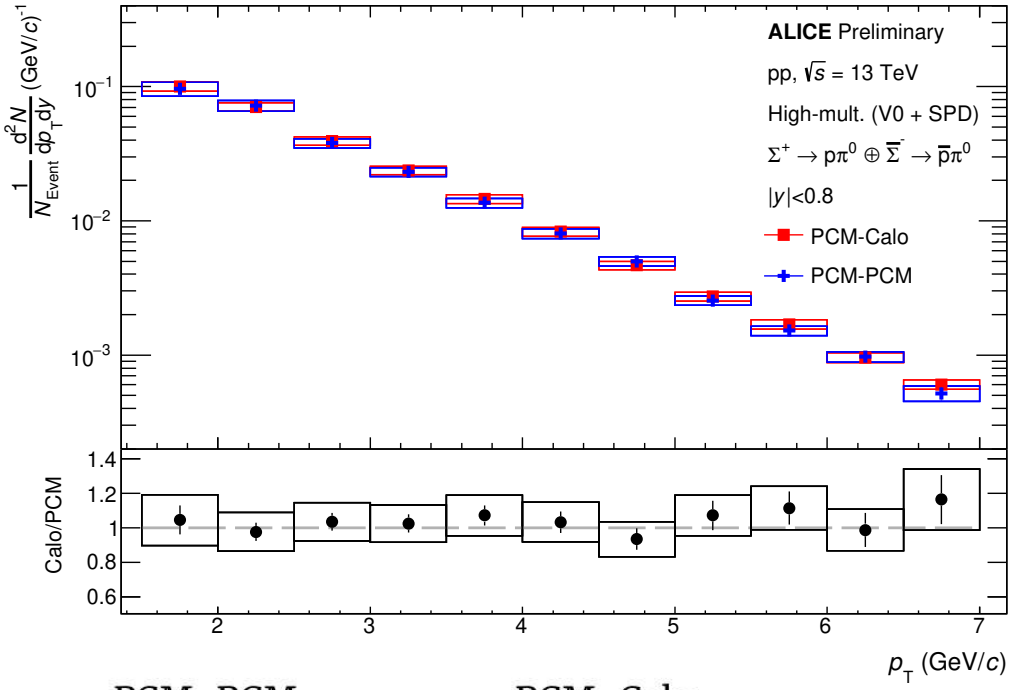


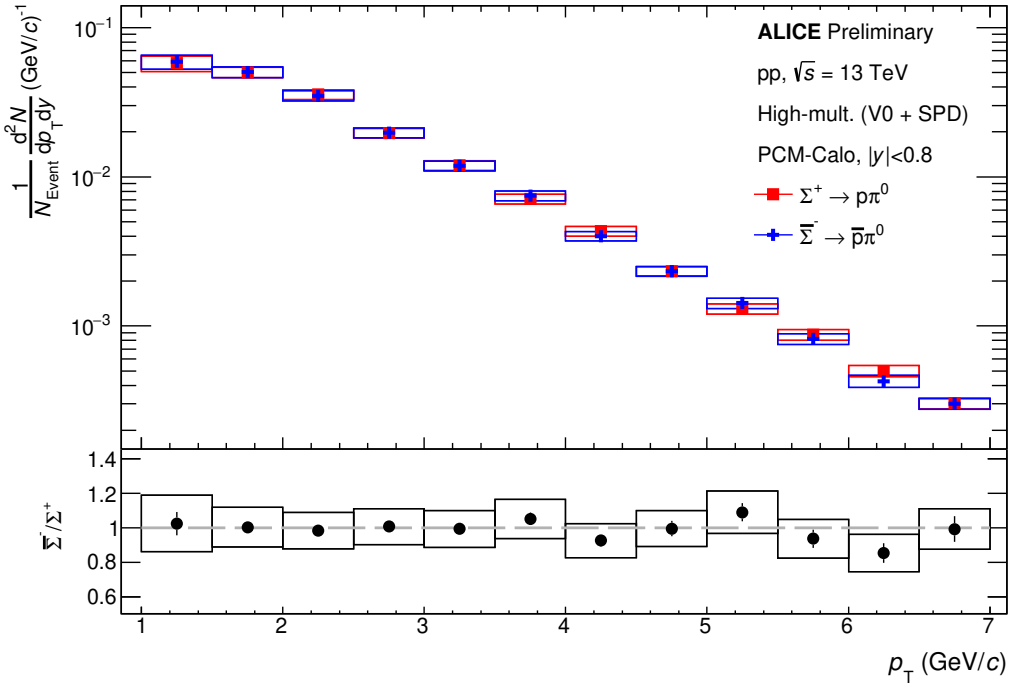


Data from the high multiplicity and the minimum bias triggers

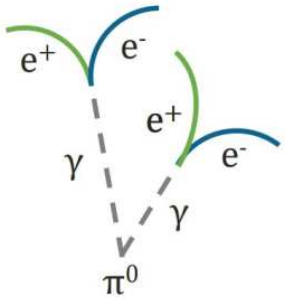
$\Longrightarrow$ **p_{T} -spectra are fitted with a Levy-Tsallis function to extrapolate down to $p_{\mathrm{T}} = 0$**

Method comparison and $\Sigma^+/\bar{\Sigma}^-$ Ratio

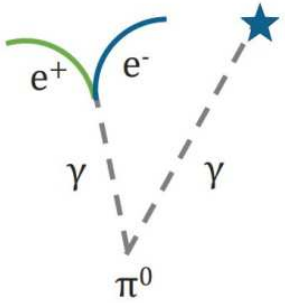




PCM-PCM

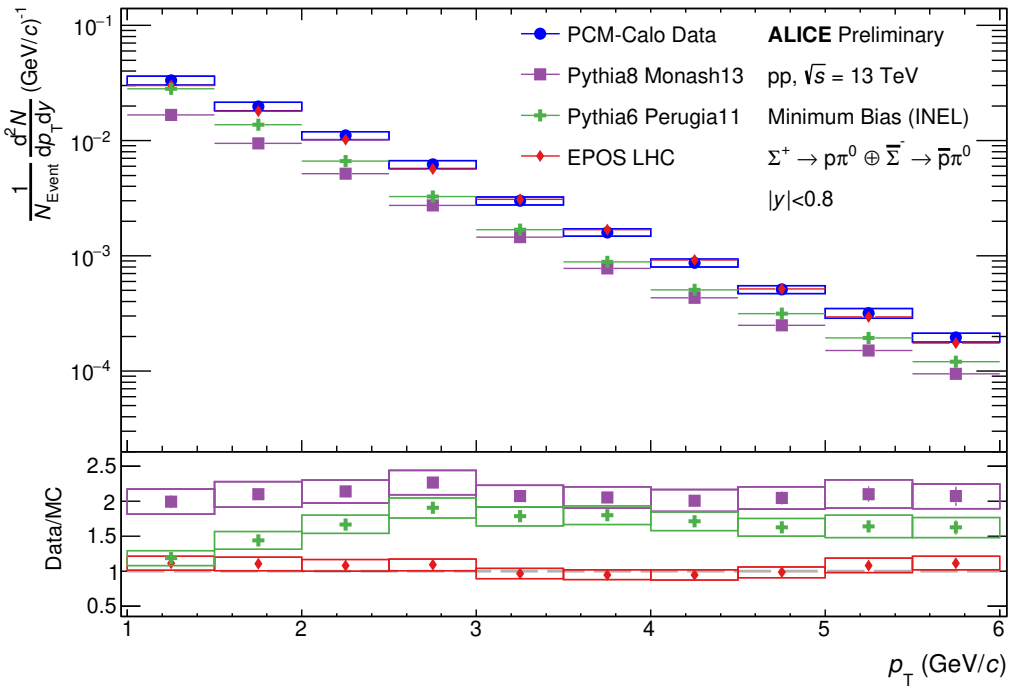


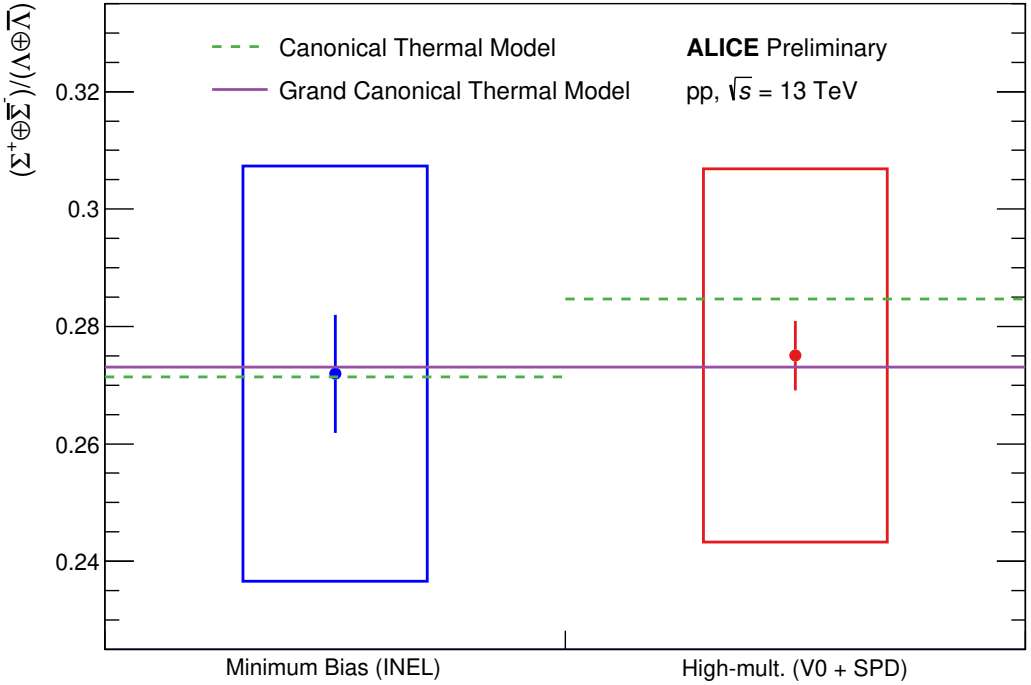
PCM-Calo



$\Longrightarrow$ Cross checks show full agreement

Model comparisons of $\Sigma^+ + \bar{\Sigma}^-$ production

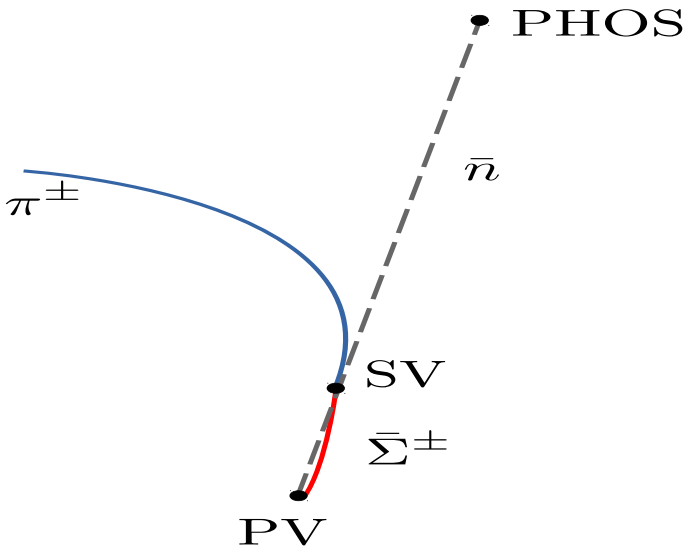


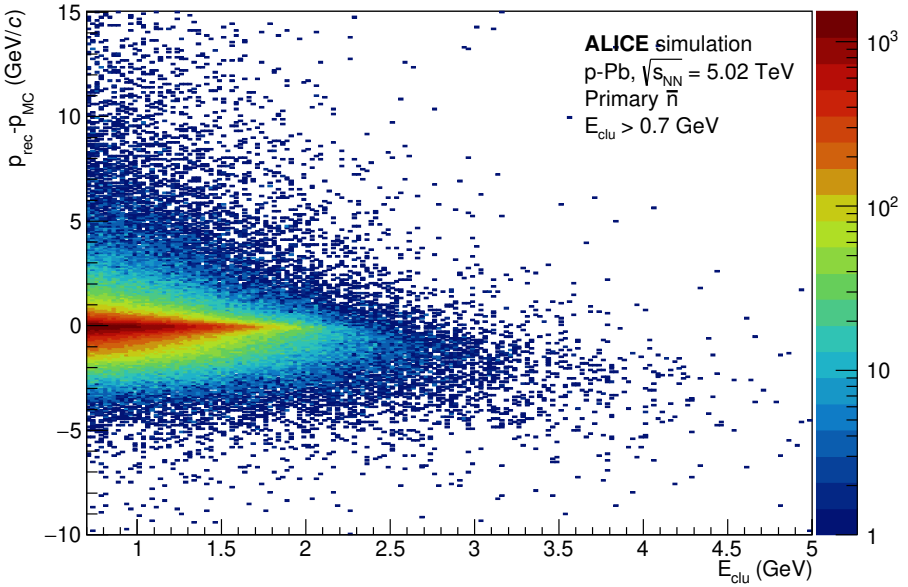


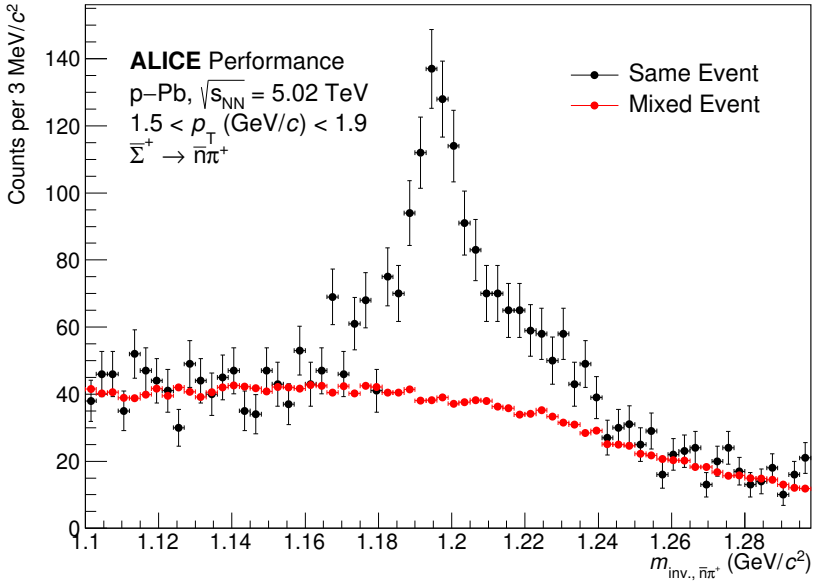
Σ/Λ ratio is in good agreement with canonical and grand canonical thermal model calculations

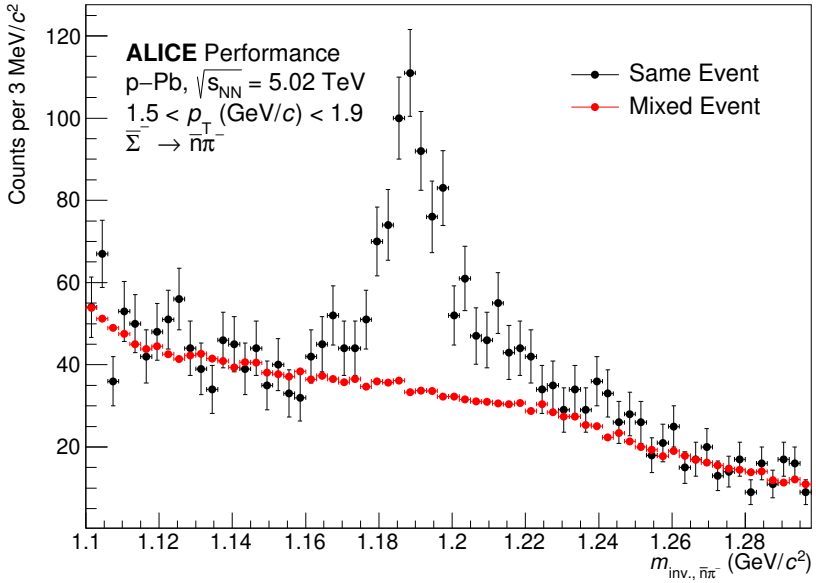
⟹ **Spectral shape well reproduced by EPOS and Pythia8. Yields well described by EPOS, but underestimated by Pythia**

First observation of $\bar{\Sigma}^{+}(\bar{\Sigma}^{-}) \rightarrow \bar{n} + \pi^{+}(\pi^{+})$ at LHC



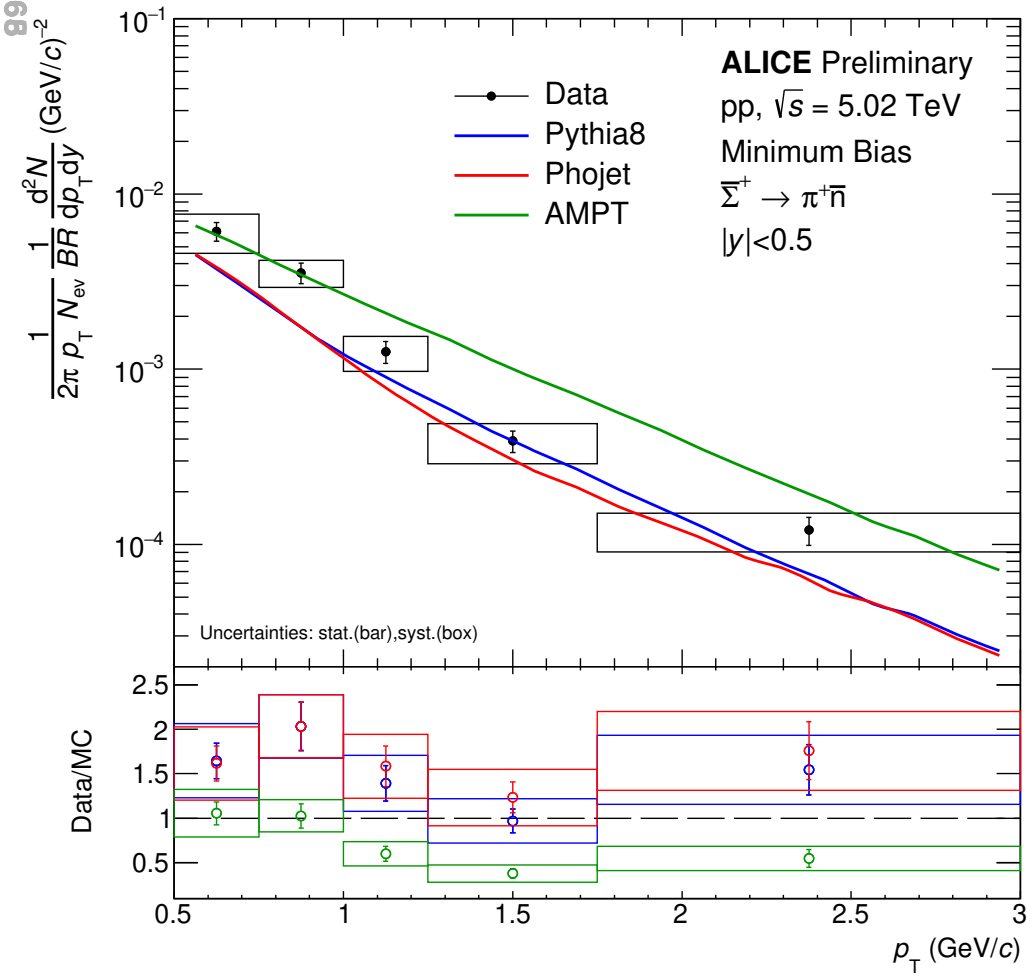


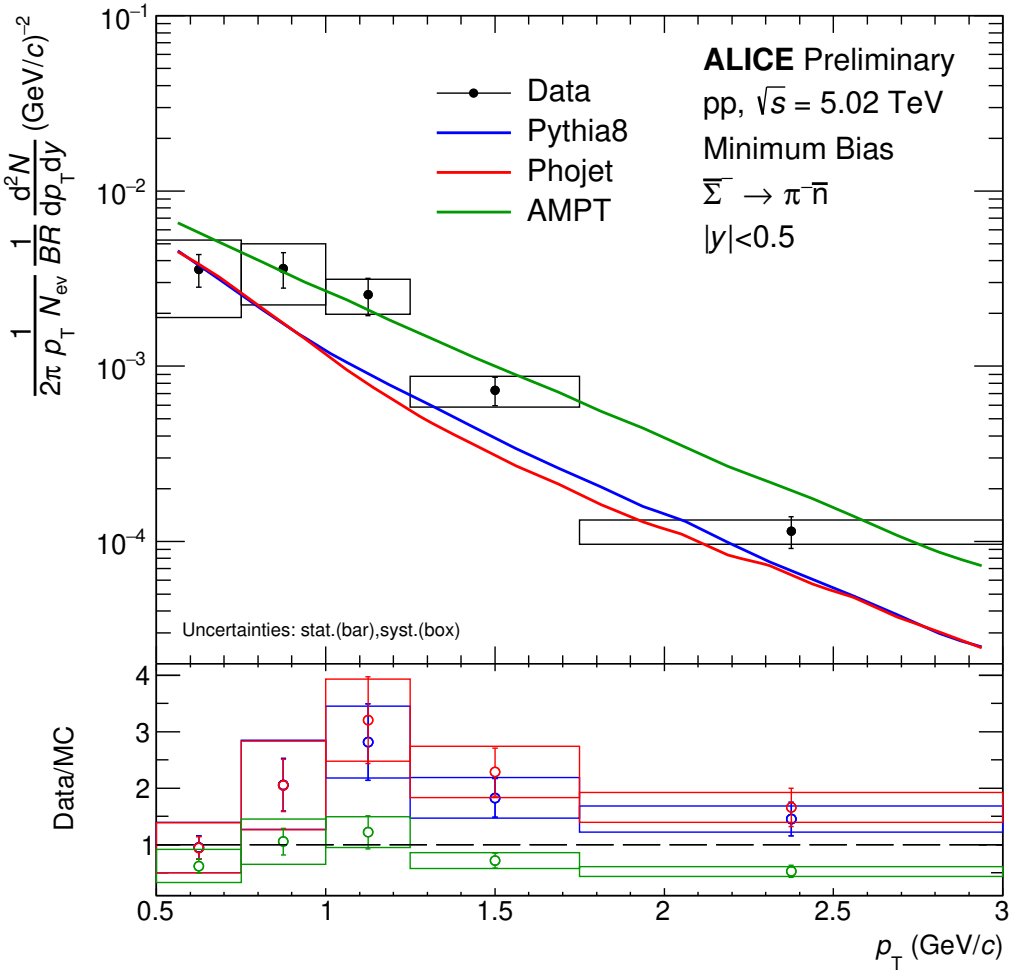




$\bar{n}$ is identified by using the cluster shape in PHOS. The momentum is measured using time-of-flight

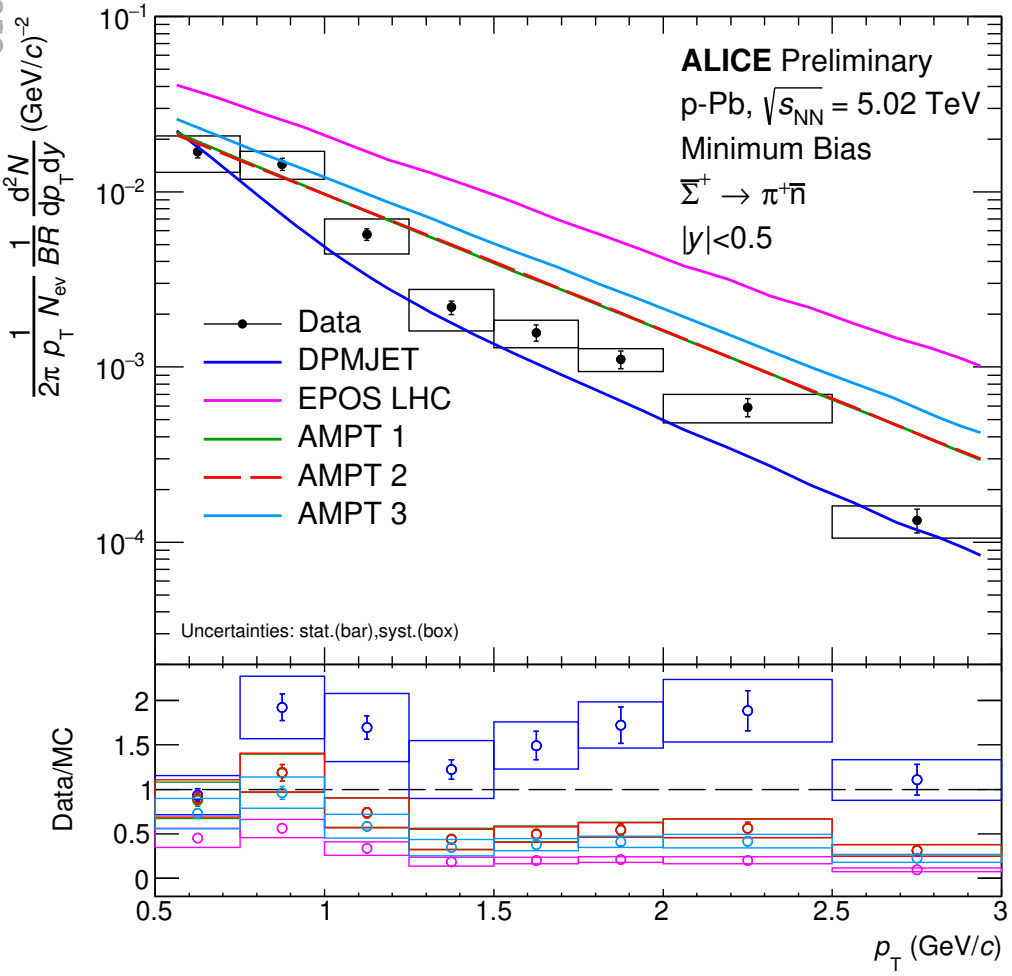
Spectrum of $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ in pp at $\sqrt{s}$= 5.02 TeV

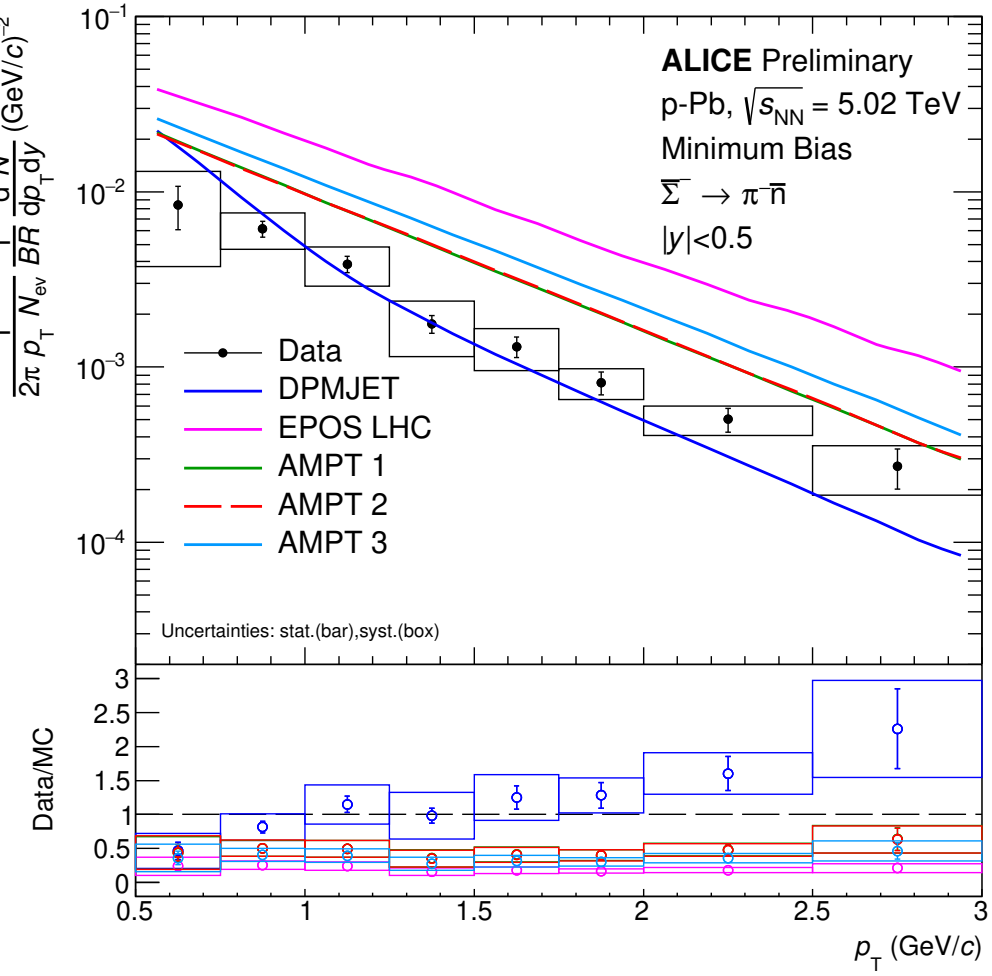




For comparison with other Σ hyperons and p-Pb data

Spectrum of $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ in p-Pb, $\sqrt{s}$= 5.02 TeV



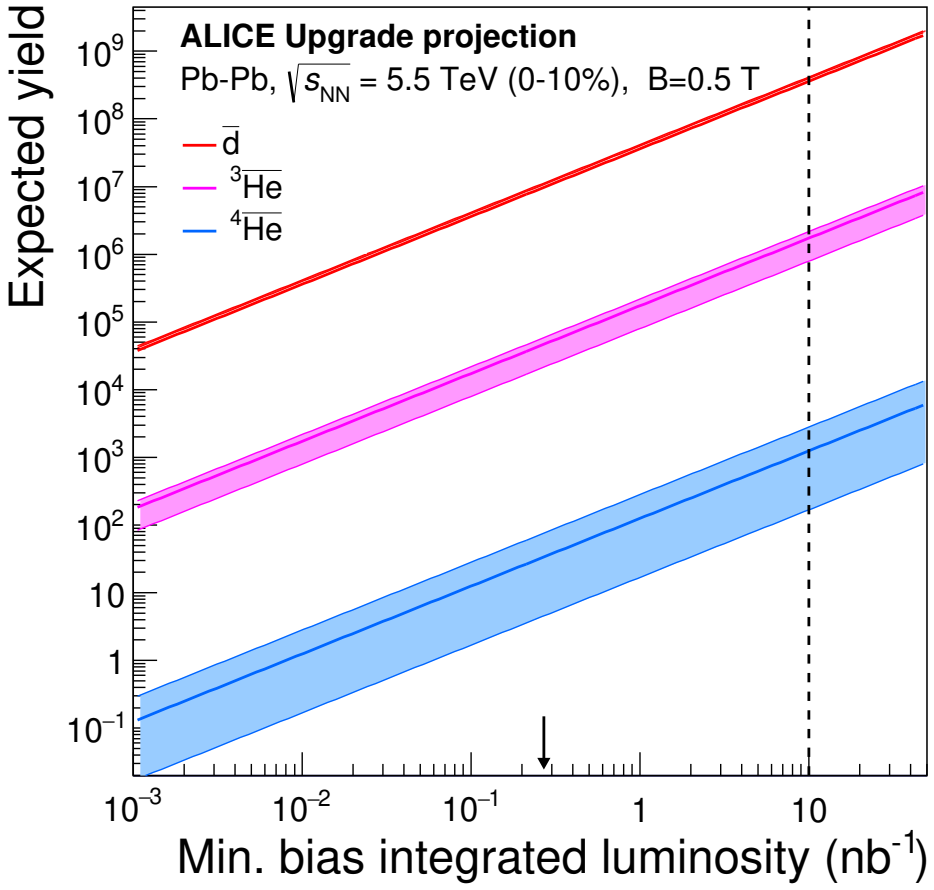


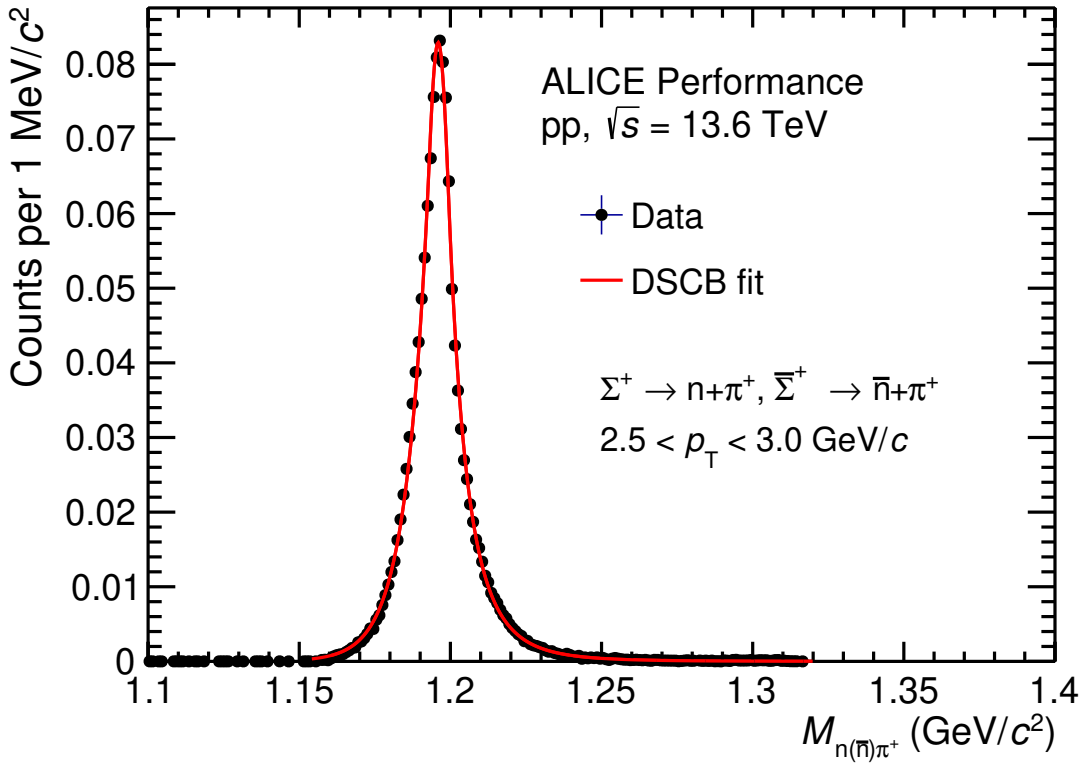
Data on $\bar{\Sigma}^+$ and $\bar{\Sigma}^-$ in pp and p-Pb will be compared with the results on Σ^{1385}

(ALICE collab. Eur. Phys. J. C 77 (2017) 389; ALICE collab. Eur. Phys. J. C 75 (2015) 1)

Projections for Run 3 LHC data taking period

- Expected higher integrated luminosity: ~ 10 nb^{-1} ($\sim$8x10^9 collisions at 0-10 % centrality)
- New ITS: less material budget and more precise tracking for the identification of hyper-nuclei





Search for ${}^{3}_{\Sigma^0}\mathrm{H}$ and ${}^{4}_{\Sigma^0}\mathrm{He}$ in LHC runs 3 & 4

Hint of detection of
${}^{4}_{\Sigma^0}\mathrm{He}$ bound state, E $\sim$ 4 MeV, $\Gamma \sim$ 7 MeV

Production mechanism similar to those considered for Λ hypernuclei like, e.g., strangeness exchange (K^-, $\pi^{\pm}$)

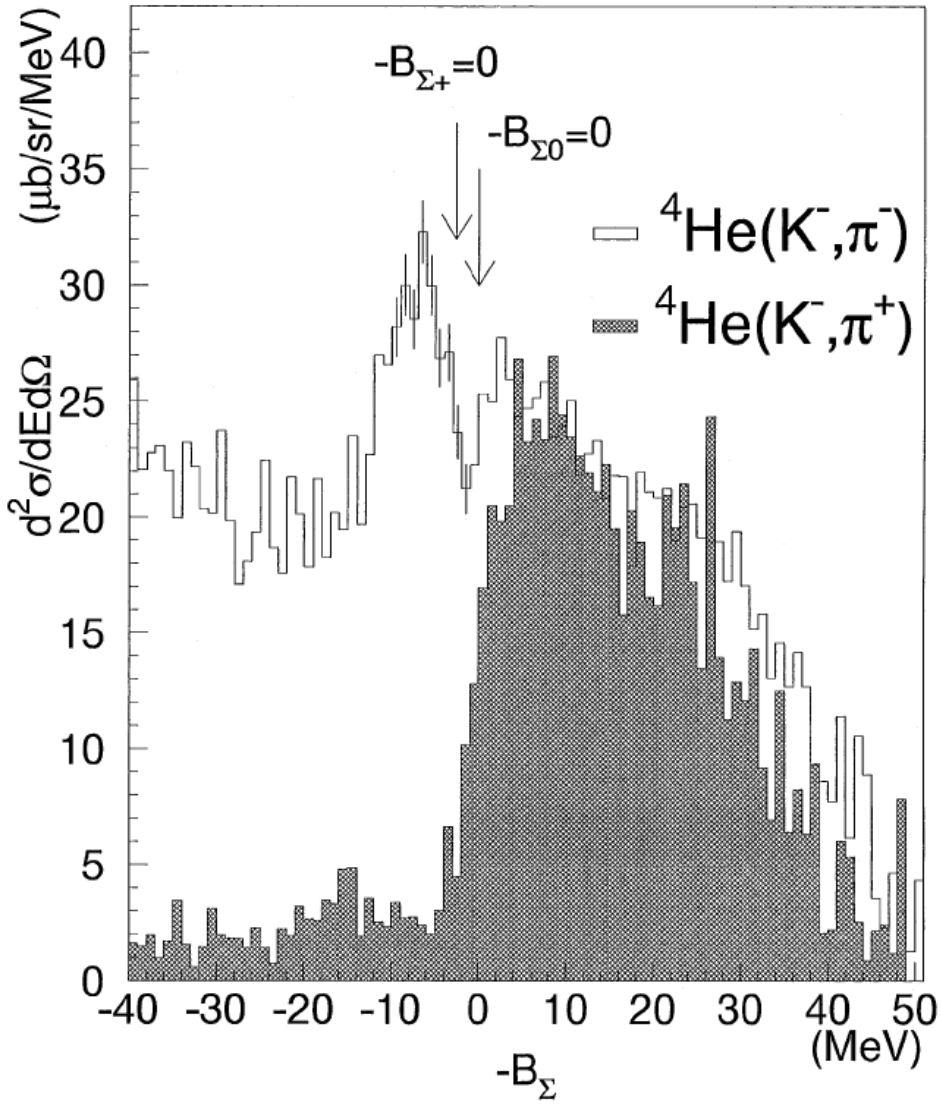
(T.Nagae et al., Phys. Rev. Lett. 80 (1998) 1605)

Search for
${}^{3}_{\Sigma^0}H^3({}^{3}_{\overline{\Sigma}^0}H) \rightarrow \Lambda(\overline{\Lambda}) + d$

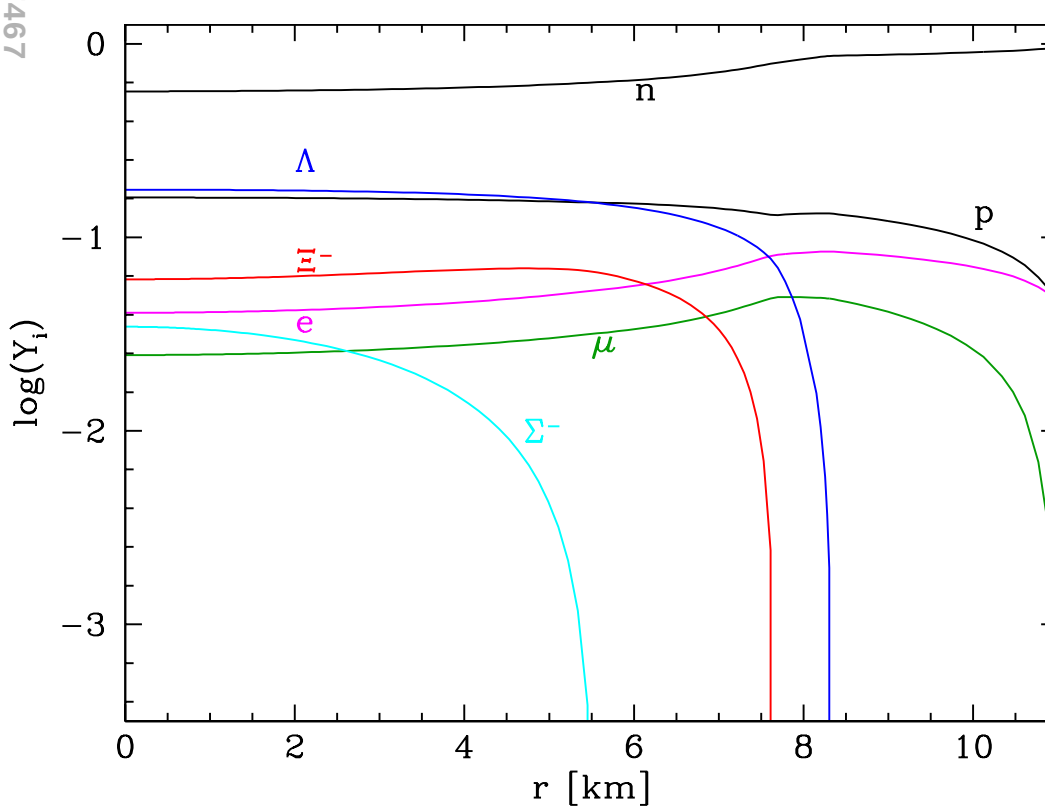
and
${}^{3}_{\Sigma^0}H({}^{3}_{\overline{\Sigma}^0}H) \rightarrow {}^{3}_{\Lambda}H({}^{3}_{\overline{\Lambda}}H) + \gamma$

on the basis of observed
${}^{3}_{\Lambda}H^3({}^{3}_{\overline{\Lambda}^0}H) \rightarrow {}^{3}He(\overline{{}^{3}He}) + \pi^{-(+)}$

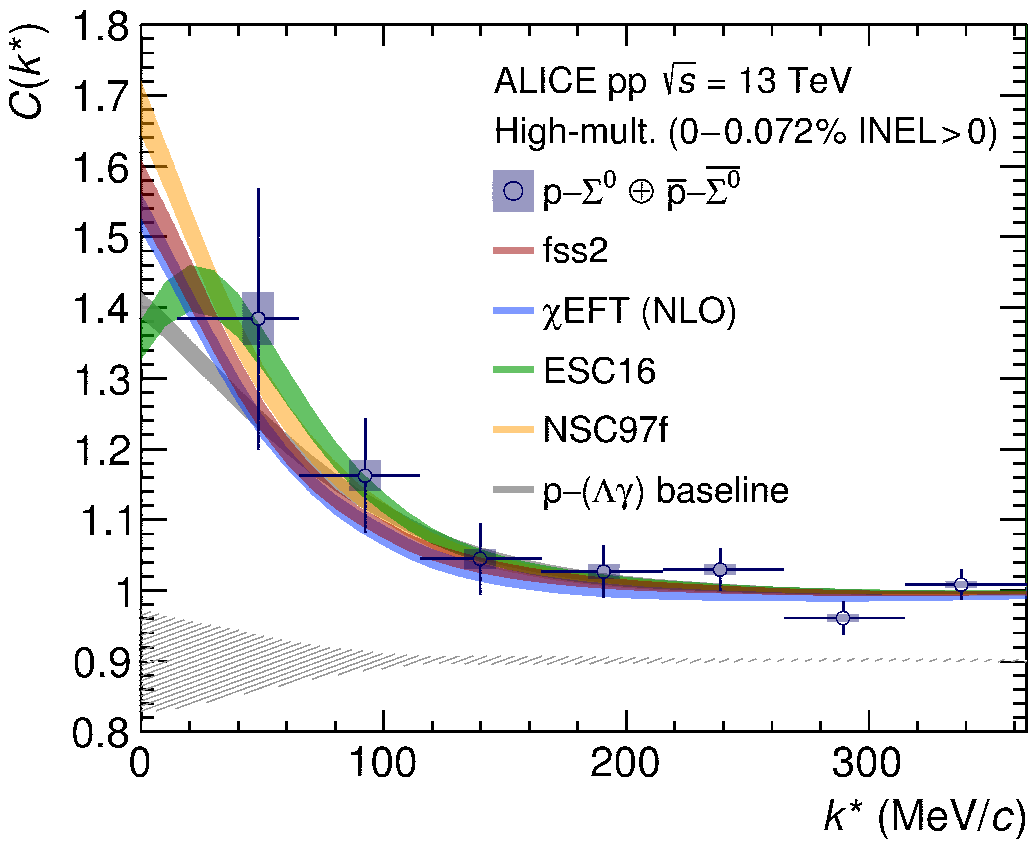
(Z.Citron et al. "Future physics opportunities for high-density QCD at the LHC with heavy-ion...", arXiv:1812.06772 [hep-ph], CERN-LPCC-2018-07)



Hyperons in neutron stars



I.Bednarek et. al., A&A, 543 (2012) A157



ALICE collab. PLB 805 (2020) 135419

$\Longrightarrow$ Direct measurements of the p-Σ hyperon interaction via femtoscopy are continued

(Overviews are in 14th International Conference on Hypernuclear and Strange Particle Physics - HYP2022)

Summary

- All ground state Σ hyperons are detected at LHC with ALICE

- No full agreement with Monte Carlo generators so far

  $\Longrightarrow$ Hyperons call for finer tunes of MC models and generators!

- The results can help to constrain production models and contribute to the previously very limited set of world data.

- Σ-hypernuclei search is foreseen at LHC with ALICE in Run 3 in 2022–2025.

- Analysis of p-Σ interactions via femtoscopy is continued

$\Longrightarrow$ **Further investigations are very interesting and needed**


Σ