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Production of Σ^0 hyperon and search of Σ^0-hypernuclei at LHC with ALICE

- Introduction
- Detection of Σ^0
- Σ^0 world data and Σ^0/Λ cross section ratio
- Search of Σ^0-hypernuclei
- Summary

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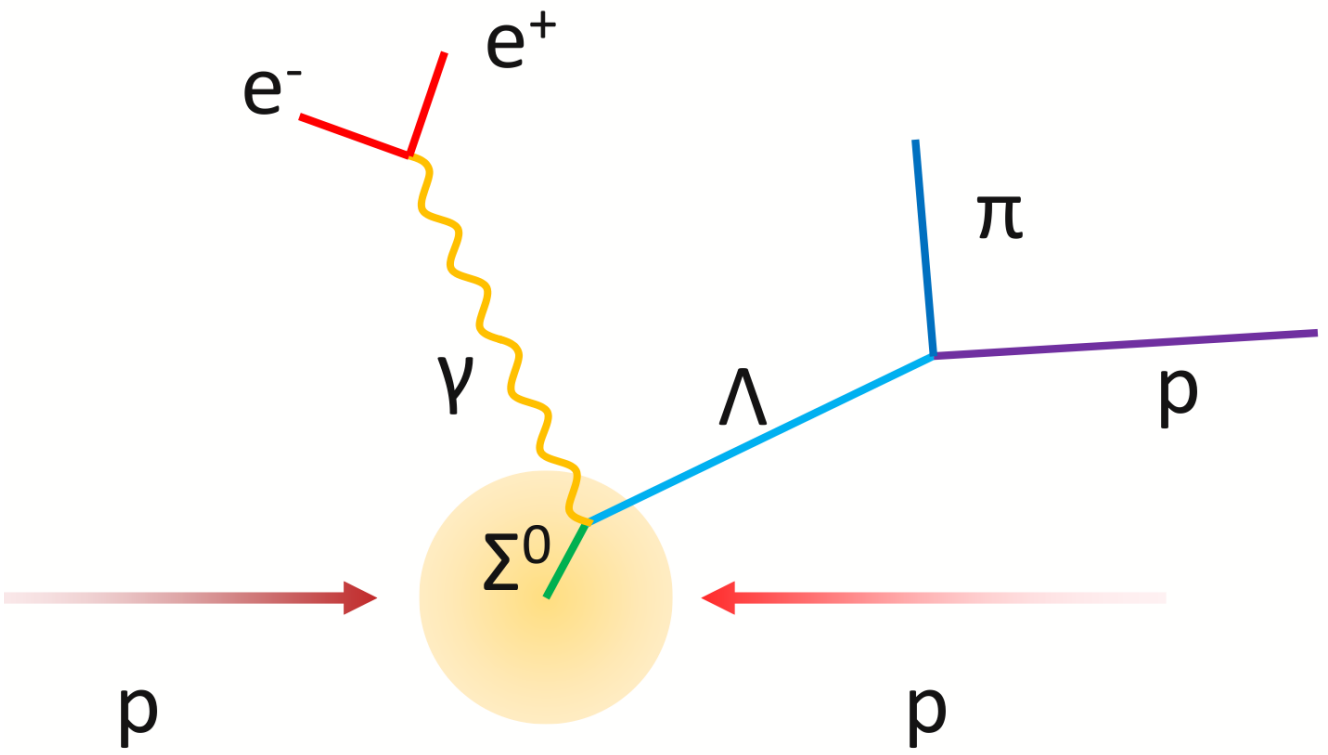
Σ^0 cross section in pp collisions

Complementary to S. Kiselev overview *"Hadronic resonance production with ALICE at the LHC"*

Particle	Quarks	Mass (MeV/c^2)	Width (MeV/c^2)	Lifetime (fm/c)	Decay*	Branching ratio (%)
Σ^0	uds	1192	~ 0	22 200	$\Lambda + \gamma$ (2)	100

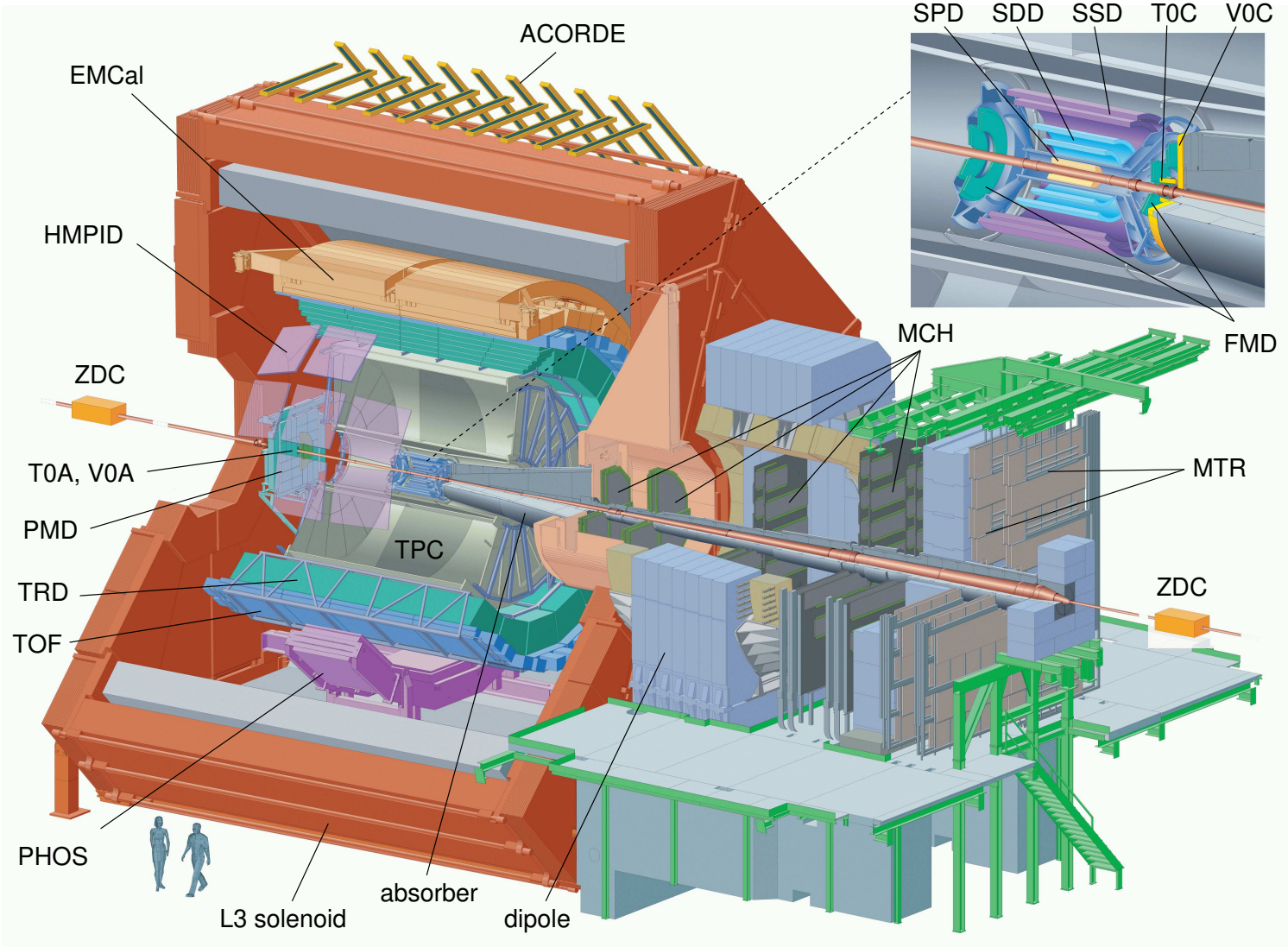
- **No production cross section measurements at energies larger than 91 GeV**
- Comparison with the Λ baryon, which has the same quark content but different isospin.
- Discrimination of prompt and decay hyperons: prompt Λs vs ones from Σ^0 decay.
- Constrain feed-down corrections for protons, pions and direct photons at low transverse momenta.
- 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 PbPb data.

Topology of the detection of $\Sigma^0 \to \Lambda + \gamma$ and $\overline{\Sigma}^0 \to \bar{\Lambda} + \gamma$



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

The ALICE detector



ITS, TPC and TOF are mainly used for reconstruction and identification of tracks

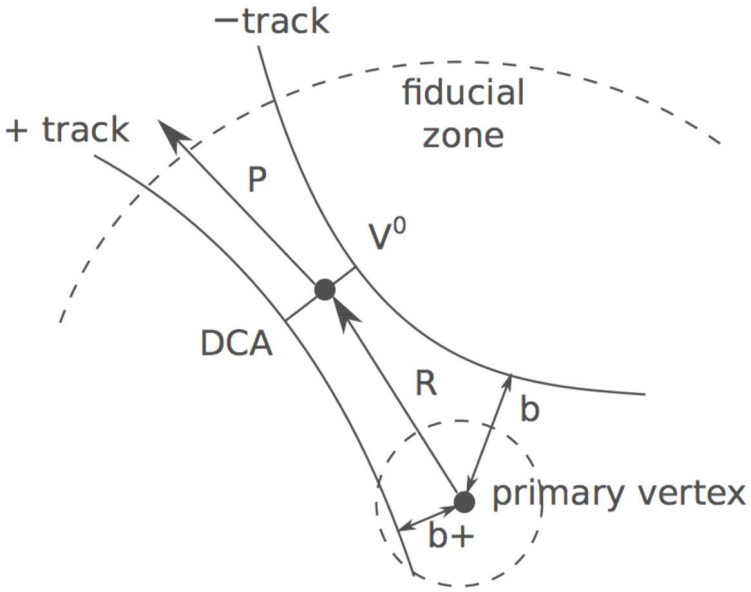
V0A+V0C and ZDC for multiplicity, centrality, trigger and timing.

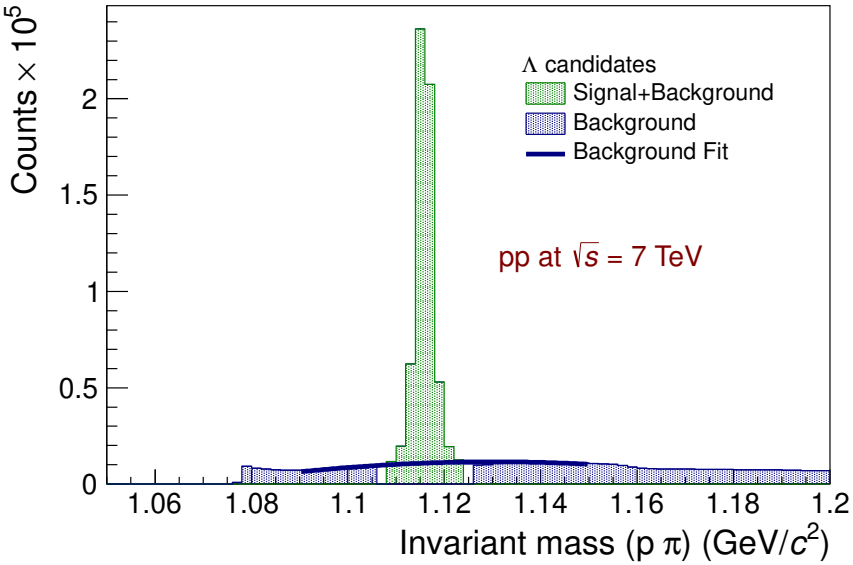
Unique particle identification, high granularity, tracking down to $p_{\mathrm{T}} = 0.1$ GeV/c.

Size 16$\times$ 26 meters, weight $\sim$ 10000 tons.

$\Lambda\ (\bar{\Lambda}\ ) \rightarrow p\pi^{-}(\bar{p}\pi^{+})$ detection

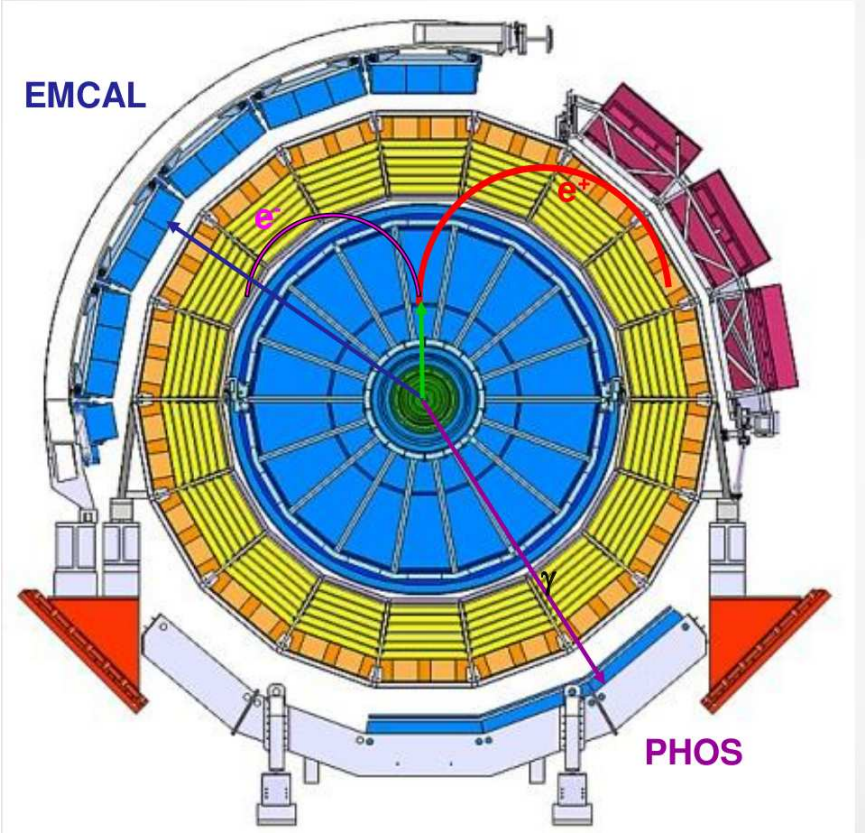
(ALICE collab., Eur. Phys. J. C 73 (2013) 2496)

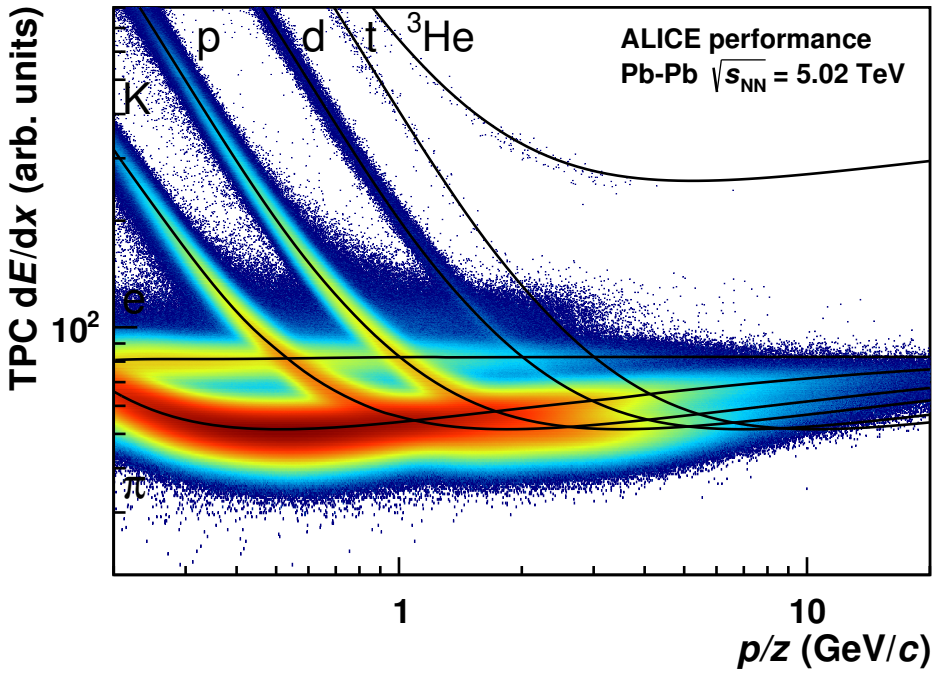




- secondary vertex (V^0) with oppositely charged tracks
- V^0 radius $R = \sqrt{x_{V^0}^2 + y_{V^0}^2}$ $(0.5 < R < 180$ cm)
- distance of closest approach (b) between positive (neg.) track and primary vertex > 0.06 cm
- pointing angle θ_Λ between P and a vector connecting the primary vertex and the V0 position $\cos\theta_\Lambda > 0.993$
- for Σ^0 analysis Λ selected in narrow region of $1.110 < M_{\Lambda\ (\bar{\Lambda}\ )} < 1.120$ GeV/c^2

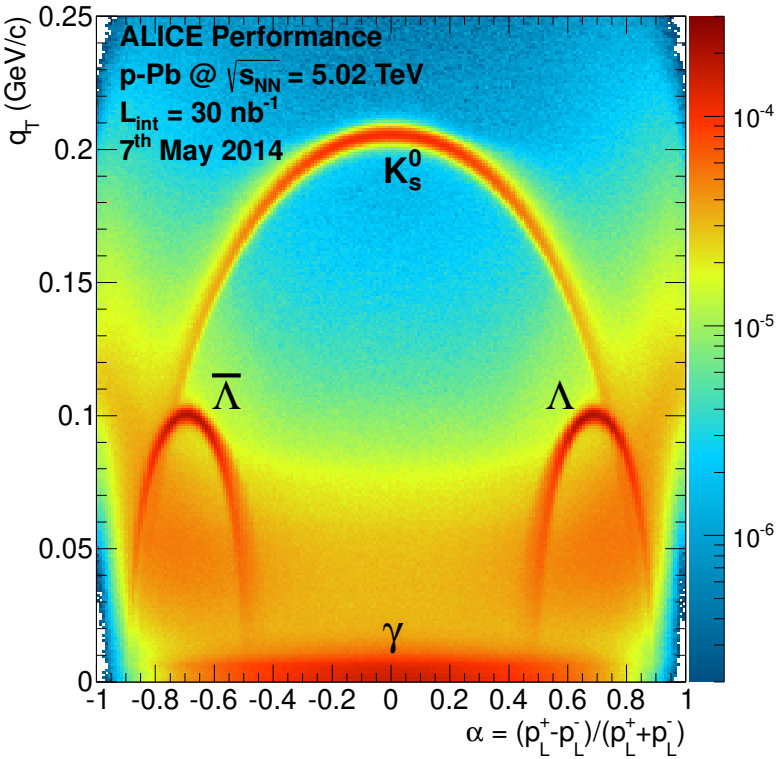
Photon detection in ALICE

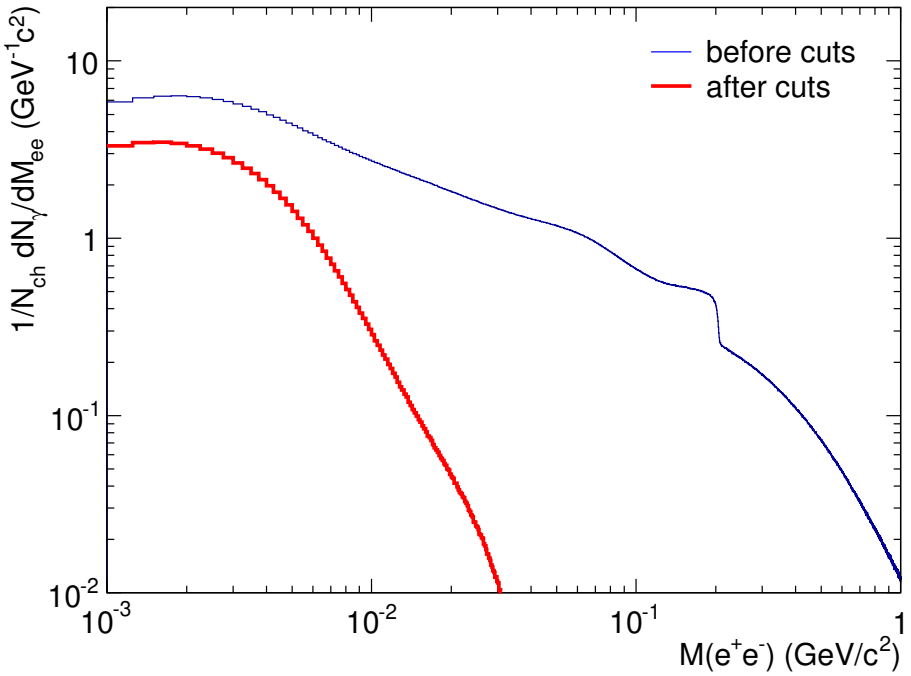




- EMCAL: large acceptance (100^o, $|\eta| < 0.9$) but limited energy resolution
- PHOS: good energy resolution but limited acceptance (60^o, $|\eta| < 0.135$)
- Photon Conversion Method (PCM)
  - good momentum resolution at low $p_{\mathrm{T}} \sim 1 - 5$ %
  - excellent particle identification capabilities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

γ reconstruction with PCM

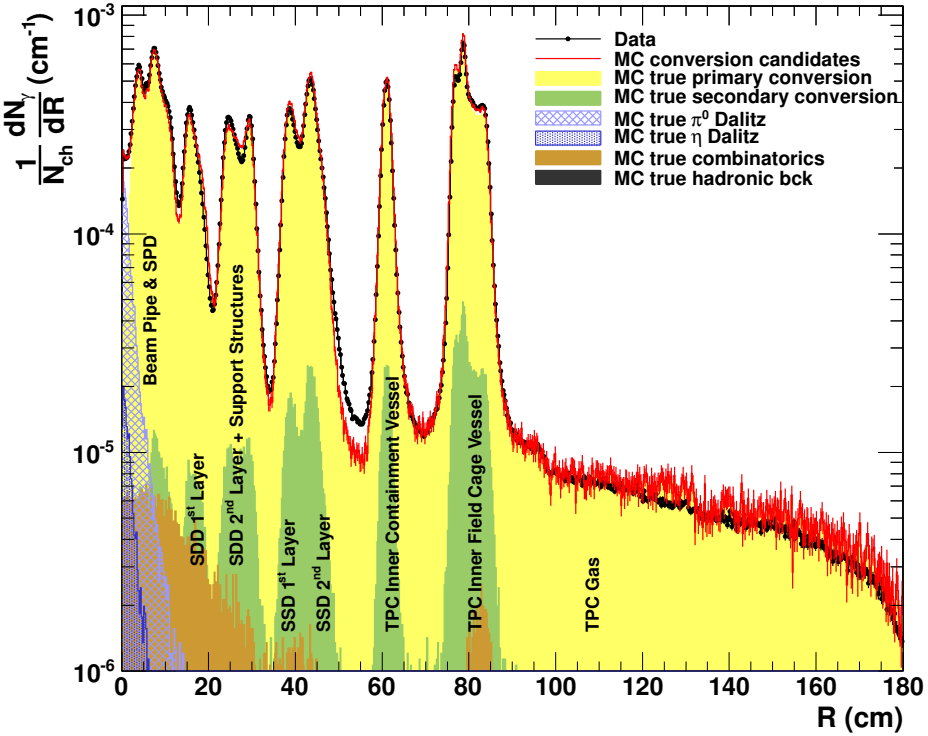


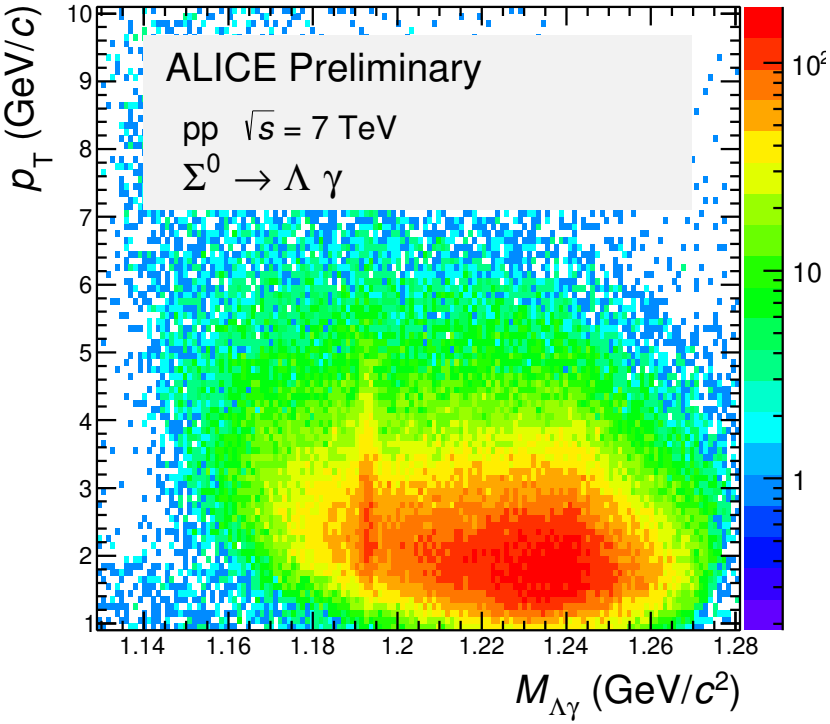


- $e^+(e^-)$ track selection with track $p_{\mathrm{T}} > 50$ MeV/c
- γ conversion vertex at distance to primary vertex $5 < R < 180$ cm
- cut on the angle between e^+e^- pair plane and the plane perpendicular to the magnetic field of the ALICE magnet
- remaining V0 (Λ , K^0_S) removed with further selections: $q_{\mathrm{T}} < 0.05$, corresponding to transverse momentum of e^+ with respect to the γ momentum.

  $\Longrightarrow$ small contamination of the photon sample

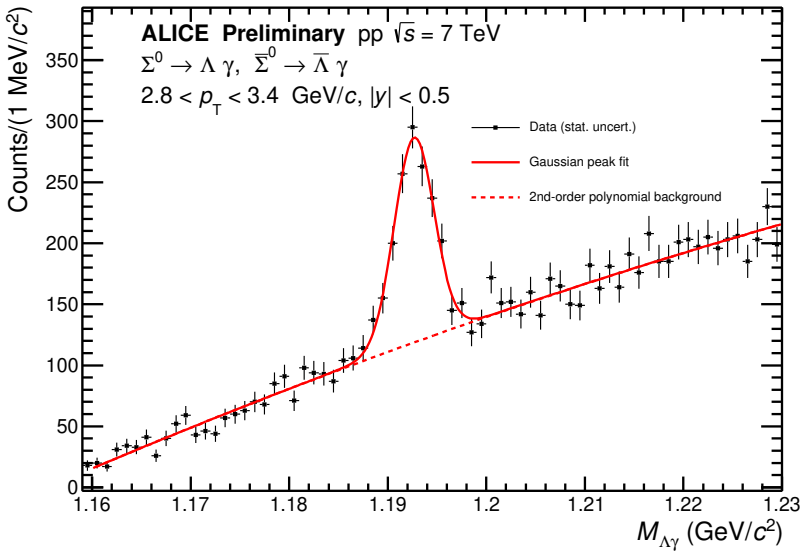
$\Sigma^0 \to \Lambda + \gamma$ and $\bar{\Sigma}^0 \to \bar{\Lambda} + \gamma$

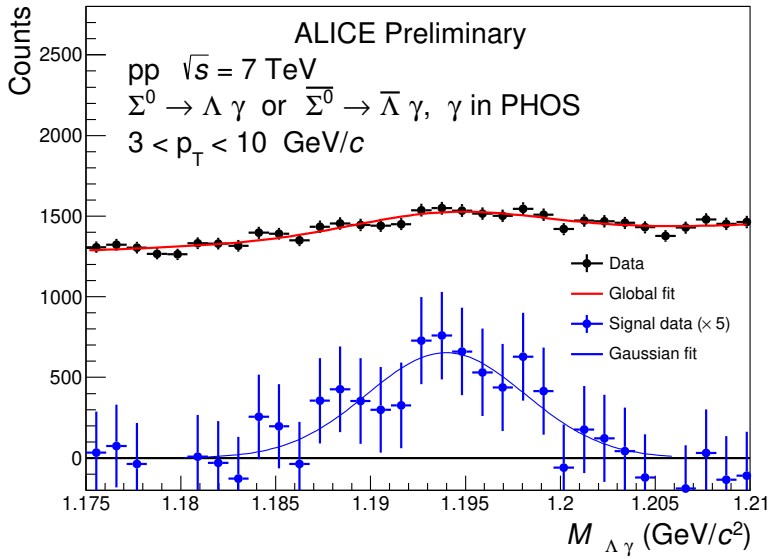




- $\gamma \to e^+ + e^-$ is detected through the secondary V^0 vertex with Photon Conversion Method (PCM) in the central barrel detectors
- The distribution of the conversion points is well reproduced by MC.
  The radiation thickness of the detector material integrated for $R < 180$ cm and $|\eta| <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

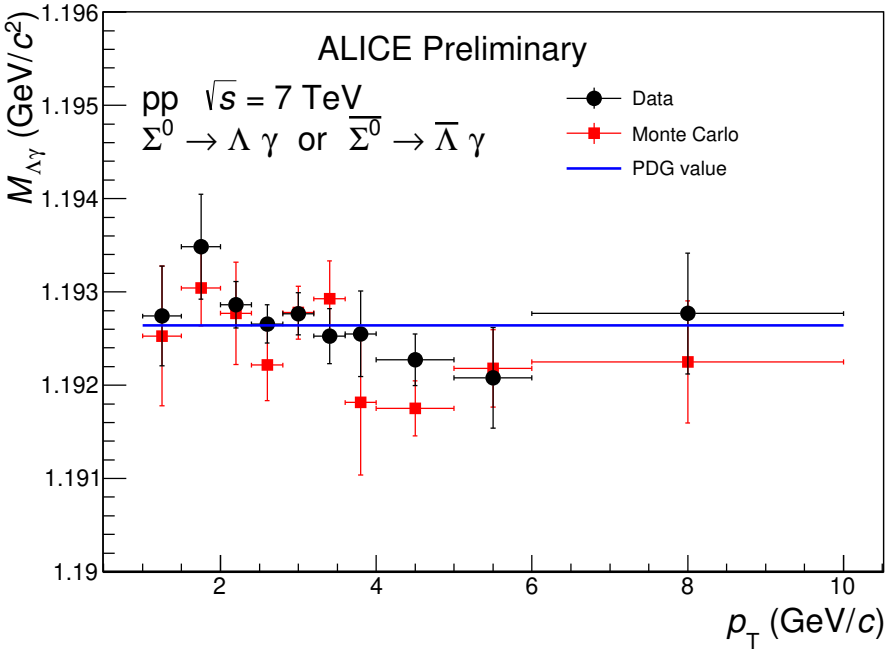
Mass of $\Sigma^0 \to \Lambda + \gamma$ + $\bar{\Sigma}^0 \to \bar{\Lambda} + \gamma$

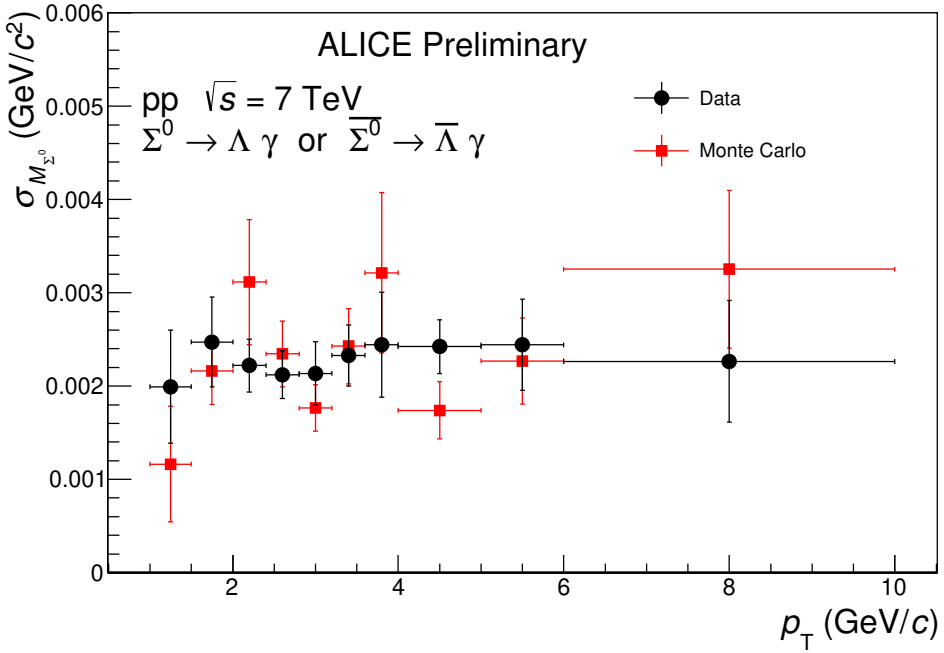




- Σ^0 invariant mass is calculated from the four-momenta of the selected Λ and γ candidates. **Note low $E_\gamma \approx$ 100 MeV.**
- Σ^0 mass resolution $\sigma_M^{PCM} = 2$ MeV/c^2 at $2.8 < p_{\mathrm{T}} < 3.4$ GeV/c
- Proof-of-principle: Σ^0 peak is also observed with photon detected in PHOS calorimeter, but with worse mass resolution.

Σ^0 mass and width from PCM



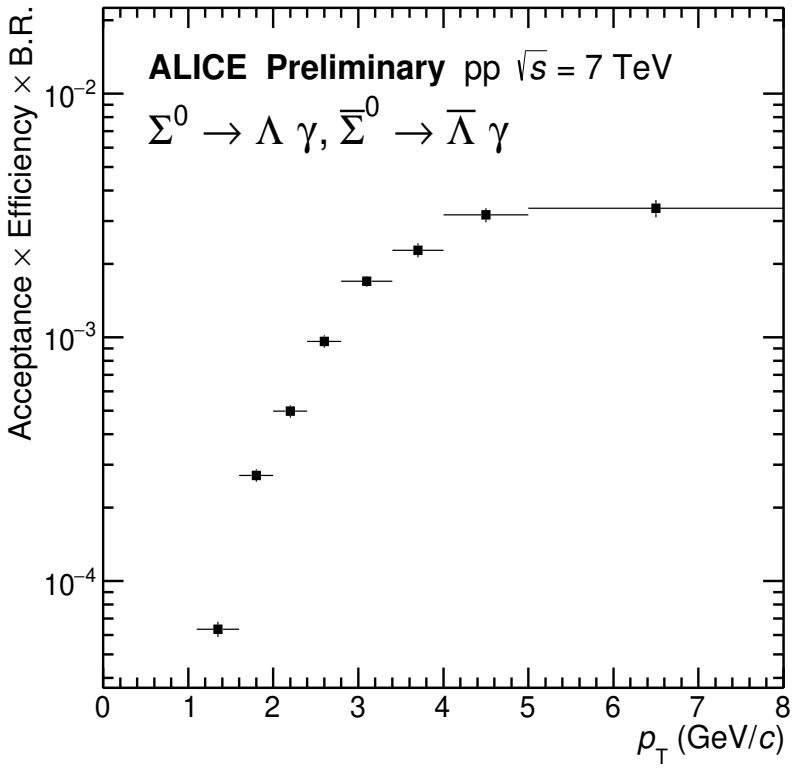


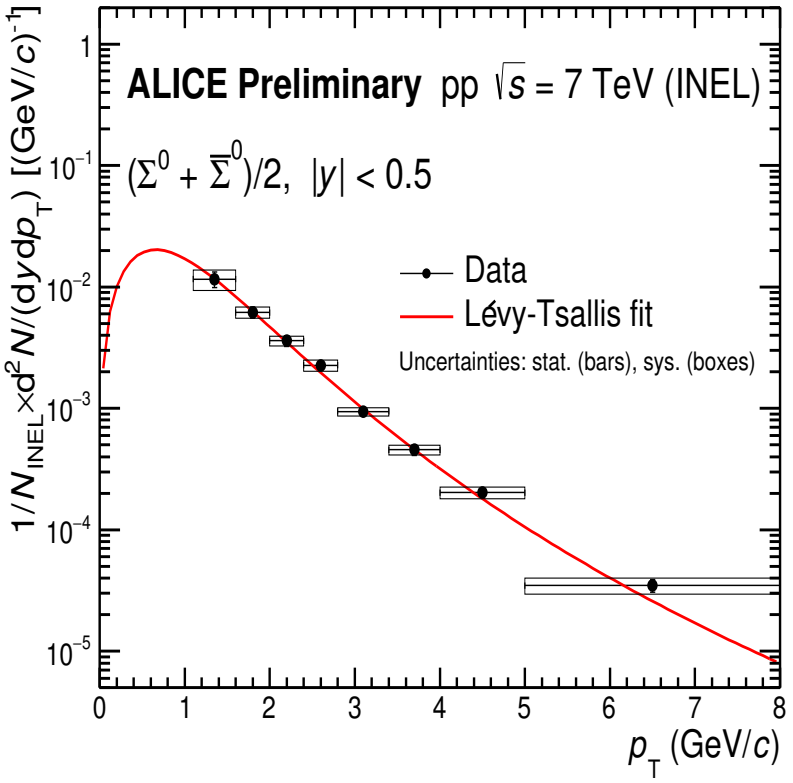
$\Longrightarrow$ Reconstructed peak position is in good agreement with the PDG value:

$$M_{PDG}(\Sigma^0) = 1192.642 \pm 0.024 \text{ MeV}/c^2$$

$\Longrightarrow$ The Σ^0 mass resolution is determined only by the detector resolution due to the short lifetime of the Σ^0 and is in agreement with the simulations

Σ^0 corrections, spectrum and Lévy-Tsallis fit



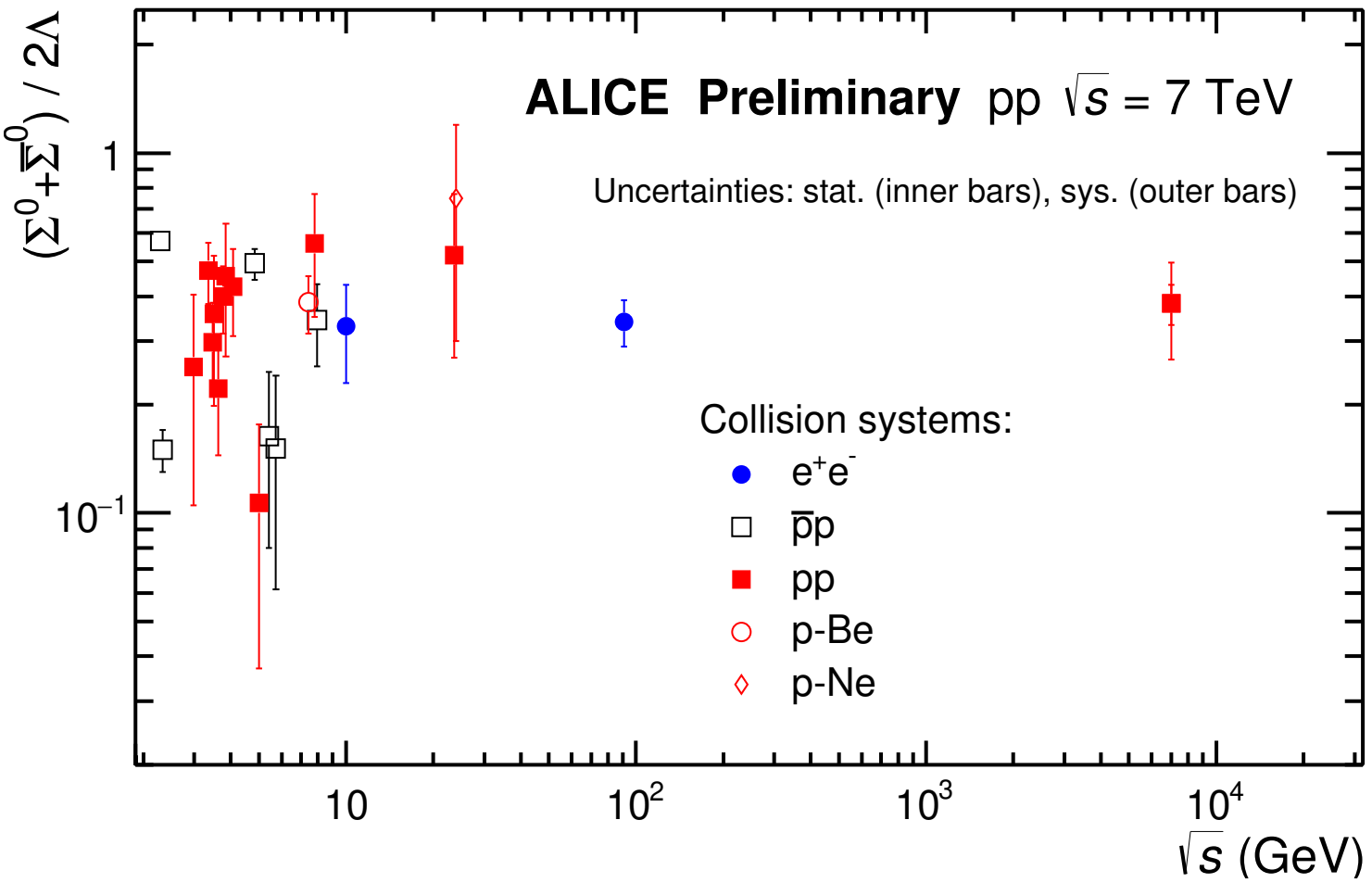


γ conversion probability < 0.085

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.

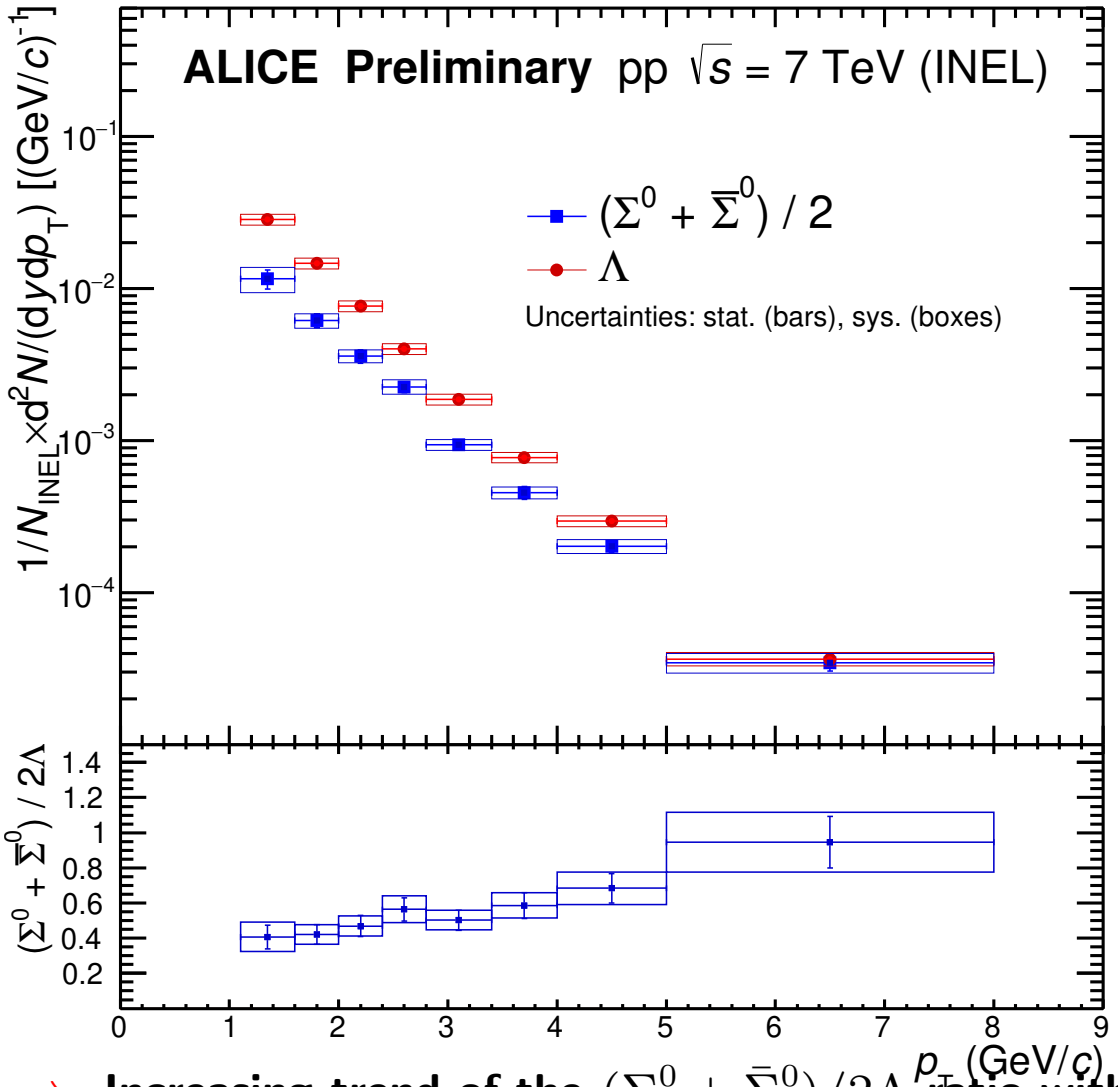
$\sim$ 60% of the yield is in the extrapolated region between 0 and 1.1 GeV/c. Relative uncertainty of the yield due to the extrapolation is $\sim$ 18%.

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

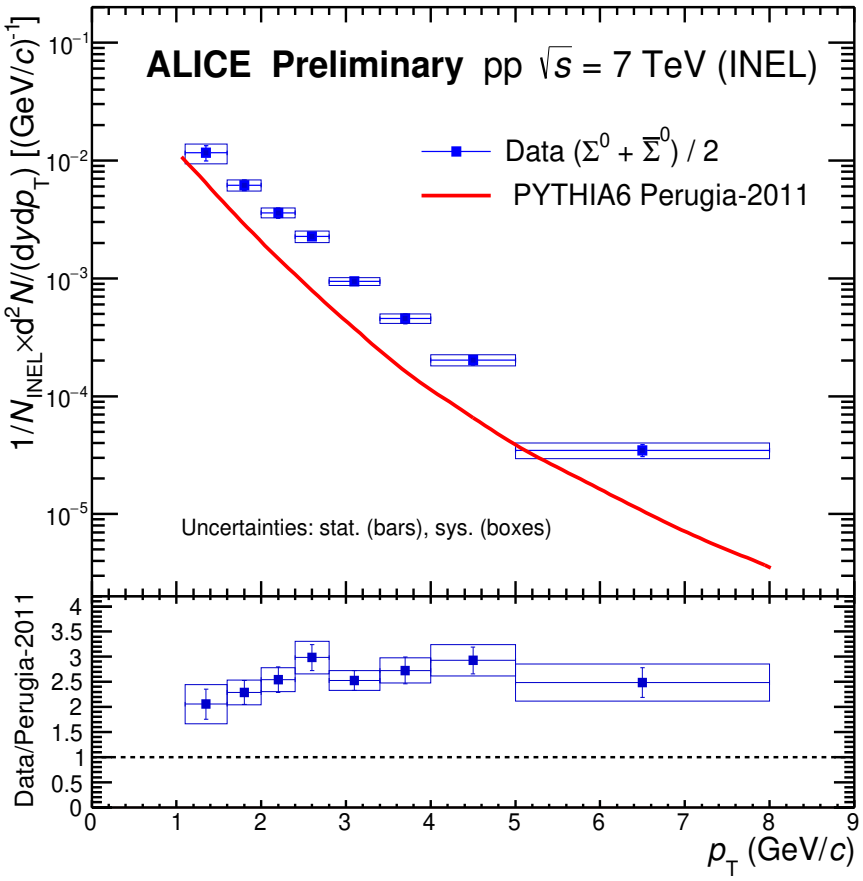


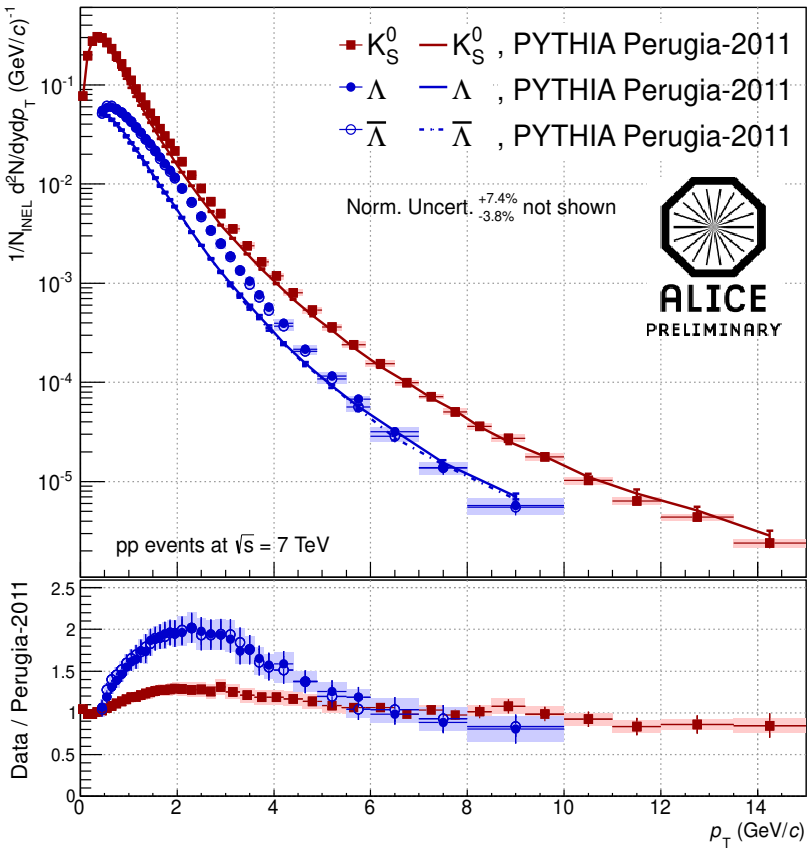
$\Longrightarrow$ **Increasing trend of the $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ ratio with p_{T} is an indication of different contributions of primordial and final Σ^0 and Λ production.**

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

Σ^0 and Λ vs PYTHIA6

(ALICE, Phys. Rev. Lett. 111 (2013) 222301; D.D.Chinellato arXiv:1211.7298 [hep-ex])

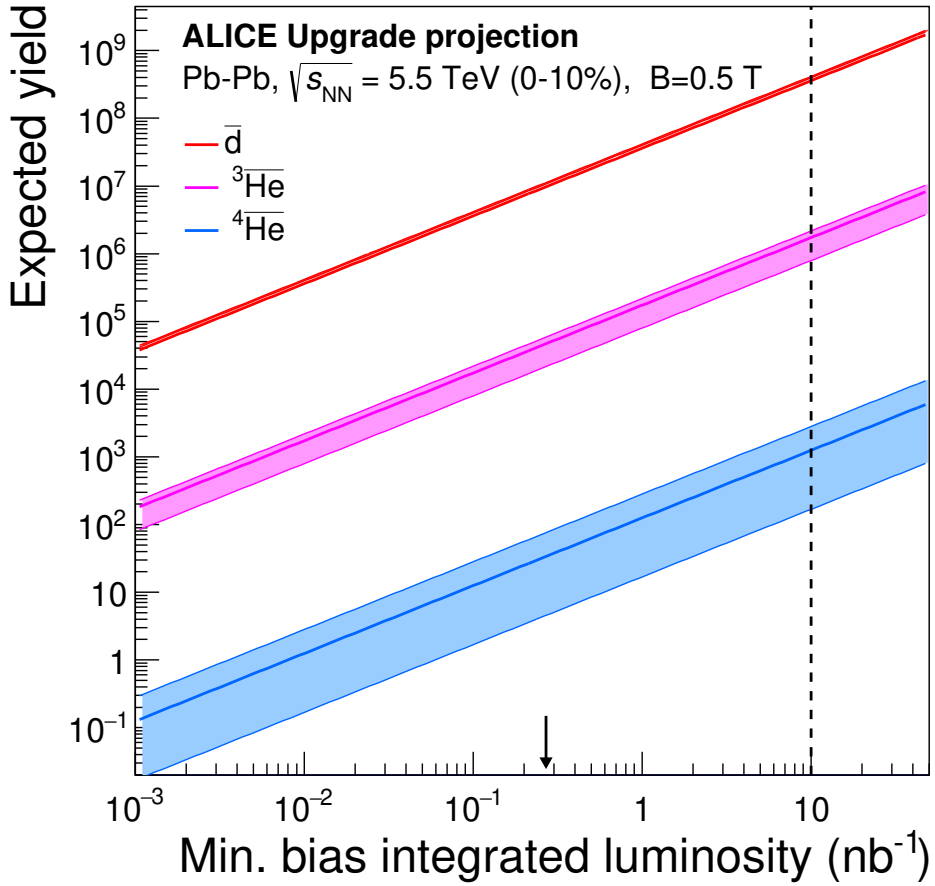


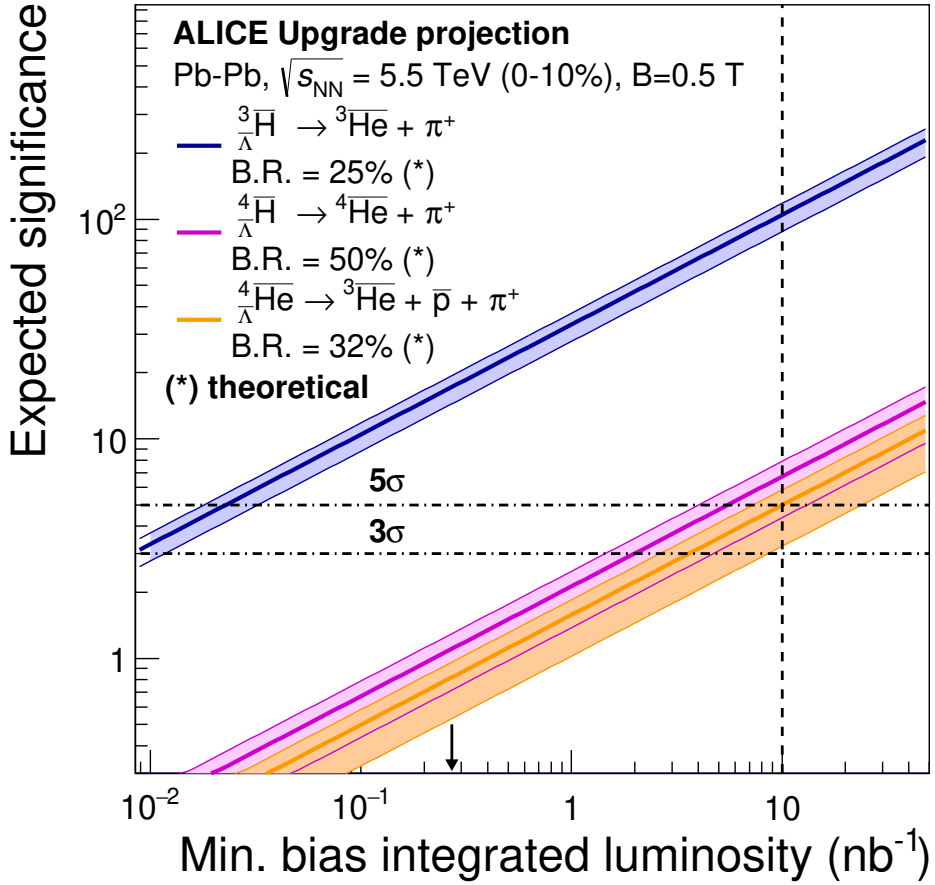


⟹ **PYTHIA6 Perugia-2011 clearly underestimates the production of both ground-state hyperons in the intermediate p_{T} -range**

Projections for the next 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

${}^{4}_{\Sigma^0}\mathrm{He}$ Hint of detection of ${}^{4}_{\Sigma^0}\mathrm{He}$ bound state, E ∼

Production mechanism considered for Λ hy strangeness exchange (K

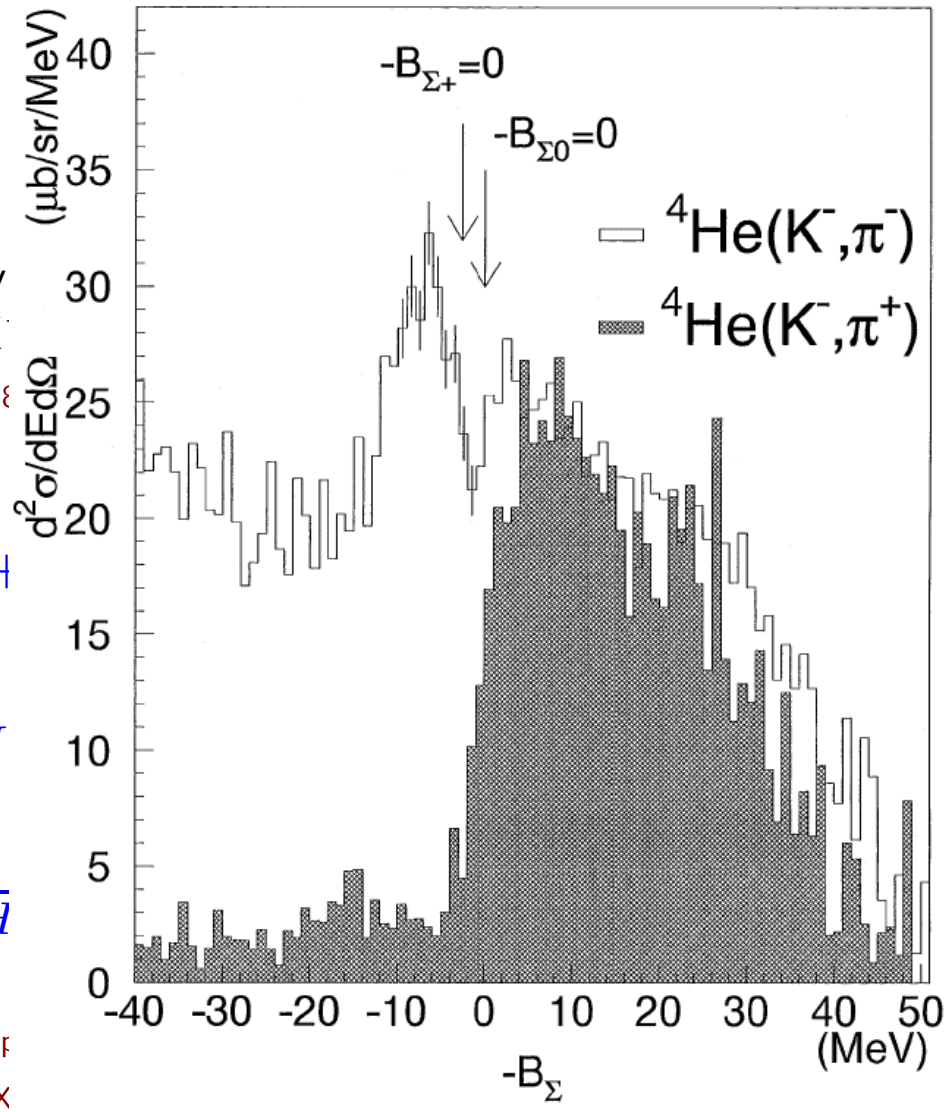
(T.Nagae et al., Phys. Rev. Lett. 8

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

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

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

(Z.Citron et al. "Future physics opp at the LHC with heavy-ion...", arX LPCC-2018-07)

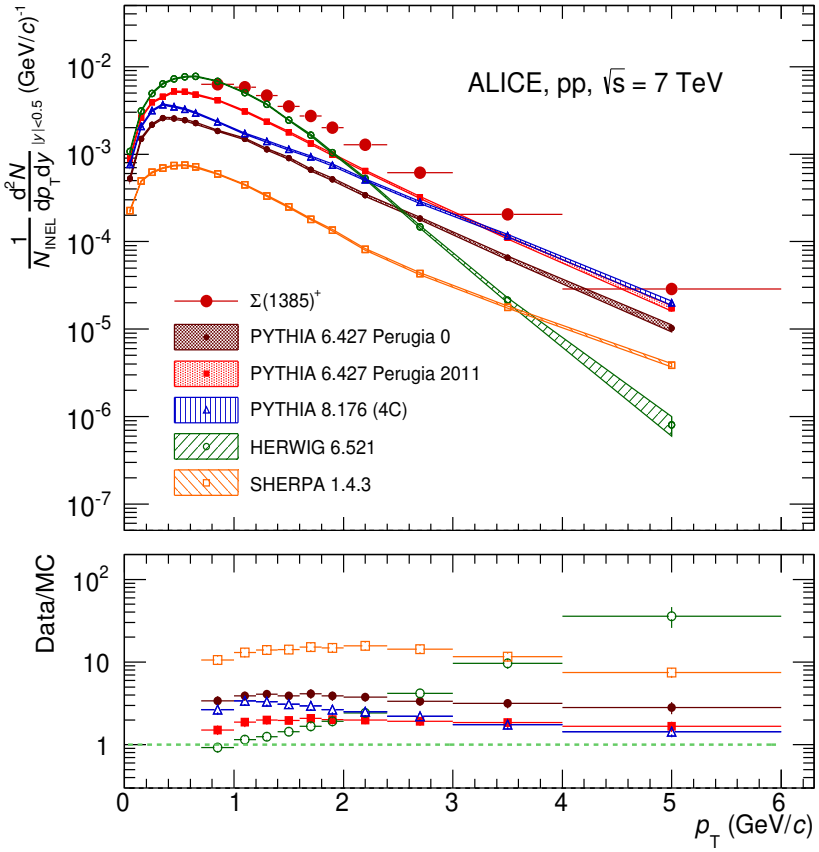


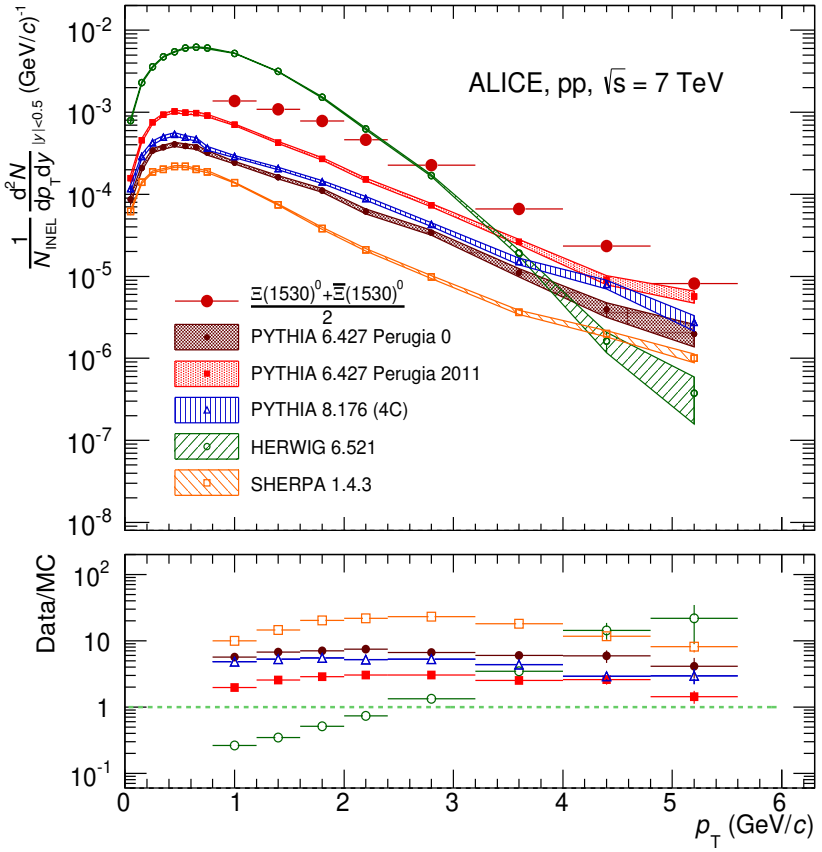
Summary and outlook

- Σ^0 and $\bar{\Sigma}^0$ are detected by means of PCM and PHOS
- First measurement of Σ^0 ($\overline{\Sigma}^0$) production cross section in pp collisions at 7 TeV.
  But disagreement with the PYTHIA-based generators is observed for Λ , Σ^0 (also $\Sigma(1385)^{\pm}$, $\Xi(1530)^0$) p_{T} -spectra
  $\Longrightarrow$ **Hyperons call for finer tunes of MC models and generators!**
- First measurement of cross section ratio $(\Sigma^0 + \bar{\Sigma}^0)/2\Lambda$ in pp at $\sqrt{s} = 7$ TeV at the LHC.
- The results can help to constrain production models and contribute to the previously very limited set of world data.
  $\Longrightarrow$ Dedicated paper is under development, analysis of pp data at 13 TeV has started.
- Σ^0-hypernuclei search is foreseen at LHC with ALICE in Run 3 in 2022–2025 years.

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

Backup. $\Sigma(1385)^{\pm}$ and $\Xi(1530)^{0}$ vs models





(ALICE, Eur. Phys. J. C 75 (2015) 1)

- **PYTHIA underpredicts the data**
- PYTHIA 4C with color reconnection gives qualitative agreement in spectral shape
- HERWIG predicts a much softer production than other models and data.
- SHERPA describes the spectral shape, but largely underestimates the yields


Σ^0