Exploring the N-N coupled system with high precision correlation techniques at the LHC

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Exploring the NΛ–NΣ coupled system with high precision correlation techniques at the LHC

ALICE Collaboration*

Abstract

The interaction of Λ and Σ hyperons (Y) with nucleons (N) is strongly influenced by the coupled-channel dynamics. Due to the small mass difference of the NΛ and NΣ systems, the coupling strength of the N$\Sigma \leftrightarrow$ NΛ processes is non-negligible and constitutes a crucial element in the determination of the NΛ interaction. In this letter we present the most precise measurements on the interaction of pΛ pairs, from zero relative momentum up to the opening of the NΣ channel. The correlation function in the relative momentum space for p$\Lambda \oplus \overline{\mathrm{p}\Lambda}$ pairs measured in high-multiplicity triggered pp collisions at $\sqrt{s}$ = 13 TeV at the LHC is reported. The opening of the inelastic NΣ channels is visible in the extracted correlation function as a cusp-like structure occurring at relative momentum $k^* = 289$ MeV/c. This represents the first direct experimental observation of the N$\Sigma \rightarrow$ NΛ coupled channel in the pΛ system. The correlation function is compared with recent chiral effective field theory calculations, based on different strengths of the N$\Sigma \leftrightarrow$ NΛ transition potential. A weaker coupling, as possibly supported by the present measurement, would require a more repulsive three-body NNΛ interaction for a proper description of the Λ in-medium properties, which has implications on the nuclear equation of state and for the presence of hyperons inside neutron stars.

*See Appendix A for the list of collaboration members

The proton–Lambda (pΛ) system is one of the best-known examples in hadron physics where the role of coupled-channel dynamics is crucial for the understanding of the two-body and three-body interaction, both in vacuum and at finite nuclear densities [1–4]. The coupling between the nucleon–Sigma (NΣ) and NΛ systems arises from these baryon pairs having the same strangeness content and a small mass difference ($\approx$70 MeV/c^2), and it is responsible for the dominant attractive pΛ interaction in the spin-triplet state of coupled-channel potentials [3, 5, 6].

The attractive nature of the interaction between a proton and a Λ was established from measurements of binding energies of light Λ-hypernuclei [7, 8] and scattering experiments at low energies [9–11]. The measured scattering cross sections are characterised by large uncertainties and limited to hyperon momenta above p_{lab} $\sim$100 MeV/c. In the region where the Σ^+n and Σ^0p channels open, which occurs around $p_{\mathrm{lab}} \approx 638$ MeV/c, the momentum resolution of the existing data is very poor [12, 13]. Thus it remains unclear whether there is any threshold structure in the pΛ cross section due to the coupling to the NΣ system. Experimental observations of a cusp-like structure at the NΣ threshold stem only from studies of the pΛ invariant mass spectrum in strangeness exchange processes such as $\mathrm{K^-d} \rightarrow \pi^-\mathrm{p}\Lambda$ [14, 15] and more recently from measurements of the reaction $\mathrm{pp} \rightarrow \mathrm{K^+p}\Lambda$ [16, 17].

It has been known for a long time that the strength of the NΣ $\leftrightarrow$ NΛ conversion is of particular relevance for the behaviour of Λ hyperons in infinite nuclear matter [18–20]. This has been emphasised again in a recent study of the YN interaction based on chiral effective field theory (χEFT) [3]. Specifically, this work discussed the interplay between the NΣ $\leftrightarrow$ NΛ conversion, the in-medium properties of the Λ and the role played by three-body forces. The abundant data on hypernuclei allowed the determination of the average attraction (-30 MeV) experienced by a Λ hyperon within symmetric nuclear matter at the nuclear saturation density ($\rho_0 = 0.16\ \mathrm{fm}^{-3}$) [21]. However, the interaction of hyperons, and in particular of the Λ, with the surrounding nucleons at larger baryonic densities ($\rho > \rho_0$) is not known empirically. Pertinent calculations are afflicted by a certain degree of model dependence and the outcome strongly depends on the employed NΛ and NNΛ interactions in vacuum. These contributions are also directly correlated to the NΣ $\leftrightarrow$ NΛ conversion, as the parameters driving the coupling strength in the theory can be tuned differently while still reproducing, at the same accuracy level, the existing experiments [3]. For example, compared to the original version of the NLO χEFT (NLO13) [2], the revisited version (NLO19) [3] involves a weaker NΣ $\leftrightarrow$ NΛ transition potential. However, it still leads to practically identical results for NΛ two-body scattering, but to an enhanced attractive behaviour in the medium. This points to a stronger (and repulsive) three-body force needed within the latter realisation. The interplay between the NΛ and NNΛ interaction is relevant to the widely debated presence of Λ hyperons inside the core of neutron stars (NS), i.e. to the so-called hyperon puzzle [21–23]. The puzzle originates from the contraposition between the energetically favored production of hyperons in the interior of NS [24] and the subsequent softening of the corresponding equation of state (EoS). The latter does not support the existence of the heaviest observed NS of up to 2.2 solar masses [25–27]. Applications of the NLO19 χEFT potentials in calculations of the EoS [4] demonstrated that a repulsive genuine NNΛ interaction causes a large increase in the chemical potential of Λ hyperons inside NS. Thus their appearance is suppressed, giving a more quantitative reference for the solution of the hyperon puzzle. In this context new experimental data of high precision with the aim to provide additional constraints on the NΣ $\leftrightarrow$ NΛ dynamics are needed. This will result in a more reliable estimation of contributions from a genuine NNΛ interaction and to establish a tighter connection between the YN two- and three-body forces, and the EoS.

Recent studies of two-particle correlations in pp, p–Pb and Pb–Pb collisions have been successful in studying the final-state interaction (FSI) and in delivering high precision data on particle pairs which have a very limited accessibility using traditional experimental techniques [28–36]. Most prominently, the multi-strange sector was studied via p–Ξ^- and p–Ω^- correlations [37, 38]. Performing such measurements in small collision systems results in a stronger sensitivity of the experimental correlation to the coupled-channel dynamics, as recently proven by means of p–K$^-$ correlations measured by ALICE in pp collisions [32, 39, 40].

In this letter we present the combined measurement of pΛ and $\overline{\mathrm{p}}\overline{\Lambda}$ pairs in pp collisions with a high-multiplicity (HM) trigger at $\sqrt{s}$ =13 TeV [41, 42]. The obtained results represent the most precise measurement of the pΛ interaction, leading to relevant implications for astrophysical studies. Further, they provide the first experimental evidence for a threshold effect at the opening of the NΣ (pΣ^0, nΣ^+) channel in the pΛ two-body final state. Comparisons with recent χEFT calculations are presented, along with a different modelling of the interaction for the residual pΣ^0 contributions.

The relevant observable in this analysis is the measured two-particle correlation function $C(k^*)$. This is related to an effective particle emission source $S(r^*)$ and to the wave function $\Psi(\vec{k}^*,\vec{r}^*)$ of the relative motion of the particle pair, by means of the Koonin-Pratt equation $C(k^*) = \int S(r^*)|\Psi(\vec{k}^*,\vec{r}^*)|^2 d^3r^*$ [43], where the relative distance r^* and relative momentum $q^* = 2k^*$ between the two particles are evaluated in the pair rest frame. The experimental correlation is defined as $C(k^*) = \mathcal{N} N_{\mathrm{SE}}(k^*)/N_{\mathrm{ME}}(k^*)$, where $N_{\mathrm{SE}}(k^*)$ is the distribution of pairs where both tracks are measured in the same event and $N_{\mathrm{ME}}(k^*)$ is the reference distribution of uncorrelated pairs sampled from different (mixed) events. The uncorrelated sample in the denominator, $N_{\mathrm{ME}}(k^*)$, is obtained by combining particles from one event with particles from a set of other events. The two events are required to have comparable number of charged particles at midrapidity and a similar primary vertex coordinate V_z along the beam axis (z). The normalisation factor $\mathcal{N}$ is dimensionless and arbitrary, since it will be absorbed by the non-FSI background present in Eq. 2.

The ALICE experiment excels in correlation studies thanks to its good tracking and particle identification (PID) [41, 42]. These capabilities are related to the three subdetectors, the inner tracking system (ITS) [44], the time projection chamber (TPC) [45] and the time-of-flight detector (TOF) [46] that are located in a solenoidal magnet that provides a uniform field of 0.5 T parallel to the beam line. The event trigger is based on the measured amplitude in the V0 detector system, consisting of two arrays of plastic scintillators located at forward ($2.8 < \eta < 5.1$) and backward ($-3.7 < \eta < -1.7$) pseudorapidities [47]. The selected HM events correspond to 0.17% of all events with at least one measured charged particle within $|\eta| < 1$ (INEL$>$ 0). This condition results in an average of 30 charged particles in the range $|\eta| < 0.5$ [38]. The reconstructed primary vertex (PV) of the event is required to have a maximal displacement with respect to the nominal interaction point of 10 cm along the beam axis, in order to ensure a uniform acceptance. The innermost silicon detector (SPD, part of ITS) [44] is used to remove pile-up events with multiple primary vertices following the procedure described in [28, 29, 37, 38]. The final number of selected HM events reaches approximately 10^9. Charged particles, such as protons and pions, are directly measured, while the Λ candidates are reconstructed based on the invariant mass of the decay products (protons and pions). The correlation functions obtained for particles (pΛ) and anti-particles ($\overline{\mathrm{p}}\overline{\Lambda}$) are identical within uncertainties, thus the final result is presented as their weighted sum pΛ $\oplus$ $\overline{\mathrm{p}}\overline{\Lambda}$.

Both the protons and the Λ candidates are reconstructed using the procedure described in [29], while the related systematic uncertainties are evaluated by varying several of the kinematic and topological observables used in the reconstruction process. In the following text, the systematic variations are enclosed in parentheses. The primary protons are selected in the momentum inverval 0.5 (0.4, 0.6) $<$ $p_{\mathrm{T}} < 4.05$ GeV/c and $|\eta| < 0.8$ (0.77, 0.85). To improve the quality of the tracks a minimum of 80 (70, 90) out of the 159 possible spatial points (hits) inside the TPC are required. The candidates are selected by comparing the measurements in the TPC and TOF detectors to the expected distributions for a proton candidate. The agreement is expressed in terms of the detector resolution σ (n_σ^{PID}). For protons with $p_{\mathrm{T}} < 0.75$ GeV/c the n_σ^{PID} is evaluated only based on the energy loss and track measurements in the TPC, while for $p_{\mathrm{T}} > 0.75$ GeV/c a combined TPC and TOF PID selection is applied ($n_\sigma^{\mathrm{PID}} = \sqrt{n^2_{\sigma,\mathrm{TPC}} + n^2_{\sigma,\mathrm{TOF}}}$). The n_σ^{PID} of the accepted candidates is required to be within 3 (2.5, 3.5). To reject non-primary particles the distance of closest approach (DCA) to the PV of the tracks is required to be less than 0.1 cm in the transverse plane and less than 0.2 cm along the beam axis. The contribution of secondary protons stemming from weak decays, of misidentified candidates, and of protons interacting with the detector material are extracted using Monte Carlo (MC) template fits to the measured distributions of the DCA to the PV [28]. The resulting proton purity is 99.4% with a 82.3% fraction of primaries. The associated uncertainties are negligible.

The Λ candidates are reconstructed via the weak decay $\Lambda \rightarrow \mathrm{p}\pi^-$. The secondary daughter tracks are subject to similar selection criteria as for the primary protons regarding the $|\eta|$ and number of hits in the TPC. However, the particle identification criterion is loosened to $\left|n_\sigma^{\mathrm{PID}}\right| < 5$ (4). In addition, the daughter tracks are required to have a DCA to the PV of at least 0.05 (0.06) cm. The DCA of the corresponding Λ candidates to the PV has to be below 1.5 (1.2) cm. The cosine of the pointing angle (CPA) between the vector connecting the PV to the decay vertex and the 3-momentum of the Λ candidate is required to be larger than 0.99 (0.995). To reject unphysical secondary vertices, reconstructed with tracks stemming from collisions corresponding to different (bunch) crossings of the beam, the decay tracks are required to possess a hit in one of the SPD or SSD detectors or a matched TOF signal [30]. The final Λ candidates are selected in a 4 MeV/c^2 mass window around the nominal mass [48]. The number of primary and secondary contributions for Λ are extracted similarly as for protons, using the CPA as an observable for the template fits. The average fractions of Λ hyperons produced from primary interactions are 57.6 (52.1, 60.6)% and 19.2 (15.4, 21.9)% originate from the electromagnetic decays of Σ^0. The systematic variations are enclosed in parentheses, where the number of Σ^0 particles is related to their ratio to the Λ hyperons, which is fixed to 0.33 (0.27, 0.40). These values are based on predictions from the isospin symmetry, thermal model calculations using the Thermal-FIST package [49] and measurements of production ratios between these two hadrons [50–52]. This ratio is also related to the size of the cusp at the NΣ threshold present in the pΛ correlation, as discussed below. Further, each of the weak decays of Ξ^- and Ξ^0 contributes with 11.6 (13.5)% to the yield of Λ hyperons. The number of secondaries stemming from a Ξ depends on the k^* of the pΛ pair and is, by default, averaged over all pairs, while the systematic variation considers the pairs with k^* below 480 MeV/c only. The purity of Λ and $\overline{\Lambda}$ was extracted by fitting, as a function of k^*, the invariant mass (IM) spectra of candidates selected in the mixed-event sample. The fits were performed in the IM range of 1088 to 1144 MeV/c^2 using a double Gaussian for the signal and a third-order spline for the background. The resulting k^* dependence is negligible, thus the result was averaged for $k^* < 480$ MeV/c, leading to a purity $P_\Lambda = 95.3\%$. Due to an imperfect fit quality, the systematic variations include a modelling of the signal using the sum of three Gaussians, which leads to an improved χ^2 of the fit and a purity of 96.3%. The effect of misidentified Λ candidates ($\tilde{\Lambda}$) can be accounted for by the relations

$$C_{\mathrm{exp}}(k^*) = P_\Lambda C_{\mathrm{corrected}}(k^*) + (1 - P_\Lambda) C_{\mathrm{p}\tilde{\Lambda}}, \tag{1}$$

$$C_{\mathrm{corrected}}(k^*) = B(k^*) \left[\lambda_{\mathrm{p}\Lambda} C_{\mathrm{p}\Lambda}(k^*) + \lambda_{\mathrm{p}(\Sigma^0)} C_{\mathrm{p}(\Sigma^0)}(k^*) + \lambda_{\mathrm{p}(\Xi)} C_{\mathrm{p}(\Xi)}(k^*) + \lambda_{\mathrm{ff}} + \lambda_{\tilde{\mathrm{p}}\Lambda}\right], \tag{2}$$

where the signal is decomposed into its ingredients, weighted by the corresponding λ parameters and corrected for the non-FSI baseline $B(k^*)$. The correlation function, shown in Fig. 1, is corrected by subtracting the contribution $C_{\mathrm{p}\tilde{\Lambda}}$ from the measured $C_{\mathrm{exp}}(k^*)$. The former is obtained experimentally by using the sideband technique [31], that pairs the reconstructed protons with misidentified $\tilde{\Lambda}$ candidates, characterised by a pπ invariant mass 3–8σ away from the nominal Λ mass. The resulting corrected correlation function $C_{\mathrm{corrected}}(k^*)$ consists of an admixture of the genuine pΛ signal $C_{\mathrm{p}\Lambda}(k^*)$, the residual (feed-down) contributions for which at least one of the particles of the pair stems from weak or electromagnetic decays, and a small fraction of pairs related to misidentified protons $\tilde{\mathrm{p}}$. The latter is assumed to have a negligible (flat) contribution, thus accounted for by the constant factor $\lambda_{\tilde{\mathrm{p}}\Lambda}$. In this study only the feed-down from Σ^0 and Ξ ($\Xi^- \oplus \Xi^0$) into Λ is explicitly modelled, as all other contributions are expected to produce an approximately flat correlation signal. The corresponding contributions are denoted by the subindices p(Σ^0), p(Ξ) and flat feed-down (ff). The residual contributions $C_{\mathrm{p}(\Sigma^0)}(k^*)$ and $C_{\mathrm{p}(\Xi)}(k^*)$ are

Table 1: Weight parameters of the individual components of the pΛ correlation function. The two last rows correspond to the minimum and maximum value of the λ parameters within the systematic variations.

Pair	pΛ	p(Σ^0)	p(Ξ)	Flat feed-down	$\tilde{\mathrm{p}}\Lambda$
λ_{Pair} (%)	47.1	15.7	19.0	17.6	0.6
min$\{\lambda_{\mathrm{Pair}}\}$ (%)	42.7	12.6	–	–	–
max$\{\lambda_{\mathrm{Pair}}\}$ (%)	49.6	18.0	22.1	–	–

obtained by transforming the corresponding genuine correlation functions to the basis of the pΛ interaction, using the formalism described in [53] and [28]. The λ weight factors are the product of single particle purities and fractions, both determined as described above. The resulting values are summarised in Table 1.

Recent correlation studies of the p–Σ^0 system showed that the interaction between these two baryons is rather weak [31]. This channel contributes with $C_{\mathrm{p}(\Sigma^0)}(k^*)$ and a weight $\lambda_{\mathrm{p}(\Sigma^0)} = 15.7\%$ to the total pΛ correlation function and is modelled assuming either a flat function or employing results from the same χEFT calculations used for the genuine pΛ interaction [3]. The contribution from the p–Ξ (p–$\Xi^- \oplus$ p–Ξ^0) channel $C_{\mathrm{p}(\Xi)}(k^*)$ ($\lambda_{\mathrm{p}(\Xi)} = 19.0\%$) is modelled employing the lattice potentials from the HAL QCD collaboration [54]. They were experimentally validated by comparison with high precision ALICE measurements of pΞ^- pairs in pp and p–Pb collisions [37,38].

The non-FSI background (baseline) is parameterised by a third-order polynomial $B(k^*)$ constrained to be flat at $k^* \to 0$ and fitted to the data (Eq. 2). A similar fit, excluding the FSI, was performed on MC simulations based on Pythia 8.2 [55] showing an agreement between the two approaches in the k^* range up to 200 MeV/c, with $B(k^*) \approx$ const. By default, the fit is performed for $k^* \in [0,456]$ MeV/c, with systematic variations of the upper limit to 432 and 480 MeV/c. Further, due to the observation of a flat baseline at low k^*, a systematic cross-check has been performed by assuming the hypothesis of a constant $B(k^*)$ and fitting the correlation function for k^* below 336 MeV/c. The measured correlation function for pΛ $\oplus$ $\overline{\mathrm{p}}$–$\overline{\Lambda}$ is shown in Fig. 1. The presented data are unfolded for the detector momentum resolution, which affects the correlation function up to 3% only in the momentum region of $k^* < 60$ MeV/c. The theoretical correlation functions in Eq. (2) (pΛ, p–Ξ^-, p–Ξ^0, p–Σ^0) were evaluated using the CATS framework [56]. The size of the emitting source employed in the calculation was fixed from independent studies of proton pairs [29], which demonstrate a common primordial (core) Gaussian source for pp and pΛ pairs when the contribution of strongly decaying resonances is explicitly accounted for [29]. This source exhibits a pronounced m_{T} dependence and considering the average transverse mass $\langle m_{\mathrm{T}} \rangle =$ 1.55 GeV of the measured pΛ pairs a corresponding core source radius of $r_{\mathrm{core}}(\langle m_{\mathrm{T}} \rangle) = 1.02 \pm 0.04$ fm is obtained. The total source function can be approximated by an effective Gaussian emission source of size 1.23 fm. The upper panels in Fig.1 present the correlation function in the whole k^* range, while the middle panels show the region where the NΣ channels (Σ^+n, Σ^0p) open, clearly visible as a cusp structure occurring at $k^* = 289$ MeV/c. This result represents the first direct experimental evidence of the NΣ $\to$ NΛ coupling in a two-body final state. The genuine pΛ correlation function was modelled by two different versions of χEFT hyperon-nucleon potentials (with the default cut-off parameter of 600 MeV). In panels a) and b) of Fig. 1 the comparison with the latest NLO calculation (NLO19) [2,3] is shown and in panels c) and d) both LO and NLO results of the previous χEFT computation (LO13, NLO13) [1,2] are presented. The residual p–Σ^0 contribution was modelled according to the χEFT calculations and assuming a flat correlation, corresponding to a weaker pΣ^0 interaction than predicted. The deviation between data and prediction, expressed in terms of numbers of standard deviations n_σ, is shown in the bottom panels of Fig.1 and the deviations, evaluated up to $k^* = 300$ MeV/c, for the different interaction hypotheses are summarised in Table 2.

The amplitude of the cusp is determined by the properties of the interaction, and further modified by

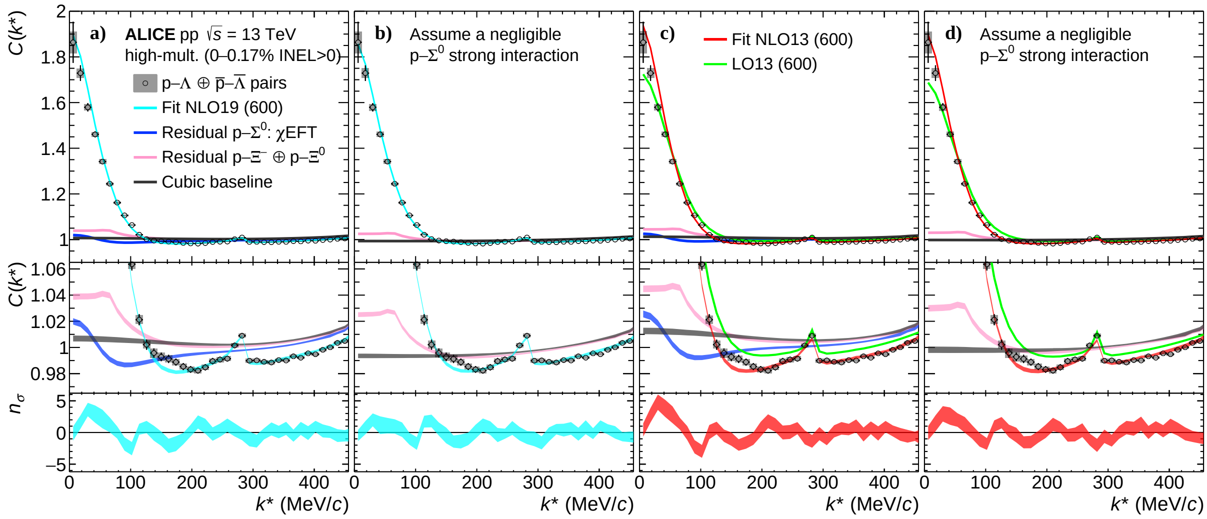

Figure 1: Upper panels: pΛ correlation function (circles) with statistical (vertical bars) and systematic (grey boxes) uncertainties. Middle panels: zoom on the region with the cusp-like signal at $k^* = 289$ MeV/c due to the NΣ ↔ NΛ coupling. Lower panels: The deviation between data and predictions, expressed in terms of n_σ. The fit is performed using NLO13 (red) and NLO19 (cyan) χEFT potentials with a cut-off parameter of 600 MeV [2, 3] and using a cubic baseline (dark grey). The residual p–Ξ^- ⊕ p–Ξ^0 (pink) and p–Σ^0 (royal blue) correlations are modelled using, respectively, a lattice potential from the HAL QCD collaboration [37,54] and a χEFT potential [2]. Both contributions are plotted relative to the baseline, while in panels b) and d) the strong interaction of p–Σ^0 is neglected.

the relative amount of NΣ and pΛ initial state pairs leading to the final state (measured) pΛ pairs. The amount of initial state pairs was fixed by the above-mentioned Σ:Λ ratio, enabling the direct test of the strong interaction. The LO chiral calculation [1], predicting a smaller NΣ cusp with respect to the NLO, was already ruled out from scattering data, and the results shown in Fig. 1 confirm this. The updated NLO19 calculation with a cut-off parameter of 600 MeV gives the best description of the pΛ correlation function, in particular of the cusp, independently of the assumed pΣ^0 interaction and of the baseline. The assumption of a constant baseline leads to the same conclusions and similar n_σ values. For both NLO13 and NLO19 the best agreement with the data is achieved at the same cut-off value (550–650 MeV) which also provide the best description of the available scattering and hypertriton data [2, 3]. However, unlike the previously existing experimental data, the present results have the sensitivity to discriminate between the NLO13 and NLO19 version of χEFT, showing a slight preference towards the latter. The best $n_\sigma = 3.7$ achieved by χEFT suggests that further improvements in the theory are needed. The main discrepancy stems from the slight difference in the slope of the experimental and theoretical correlations at low k^*. The χEFT NLO19 potential seems to still predict a too large two-body pΛ attraction with respect to the present experimental data. Possibly, an even weaker coupling to NΣ could be needed in order to reduce the disagreement, but it would lead to an overestimation of the Λ single-particle potential in nuclear matter, necessitating an increased three-body repulsion that can be modelled approximately by the theory. In turn, this would disfavour the production of these strange hadrons in neutron stars and result in a stiffer EoS [4]. Nevertheless, the same kinematic region at low k^* is influenced by the p–Σ^0 residual correlation and the compatibility to the data can be improved by assuming a weaker (flat) pΣ^0 interaction ($n_\sigma = 1.6$). At present the pΛ and p–Σ^0 signals cannot be disentangled in a model independent way due to the insufficient precision of the direct p–Σ^0 measurement [31]. The situation will improve in the upcoming LHC Run 3 due to the expected increase in statistics [57].

In conclusion, two-particle correlation techniques were used to study the final state interaction in the NΣ ↔ NΛ coupled system. This was achieved by studying the pΛ correlation function at low relative

Table 2: The deviation, expressed in terms of n_σ, between data and prediction for the different interaction hypotheses of p–Λ and p–Σ^0, evaluated for $k^* \in [0,300]$ MeV/c. The default values correspond to the fit with a cubic baseline and the values in parentheses represent the results using a constant baseline. The default interaction (in bold) is the χEFT NLO19 calculation [3], at a cut-off parameter of 600 MeV. Each row corresponds to a different variation of the χEFT used for the pΛ correlation, while the columns discriminate between the two assumptions on the p–Σ^0 correlation.

	Standard deviation (n_σ)	
p–Σ^0 ($\rightarrow$) p–Λ ($\downarrow$)	**χEFT**	Negligible FSI
LO13-600	5.6 (7.5)	10.2 (10.3)
NLO13-500	7.3 (10.3)	4.5 (5.3)
NLO13-550	4.4 (6.5)	2.1 (2.2)
NLO13-600	5.8 (5.8)	3.3 (3.6)
NLO13-650	5.5 (5.5)	4.2 (5.0)
NLO19-500	5.6 (7.2)	3.0 (3.0)
NLO19-550	4.5 (4.3)	1.8 (2.2)
NLO19-600	3.7 (3.9)	1.6 (3.0)
NLO19-650	3.7 (3.7)	2.3 (4.1)

momenta with an unprecedented precision. The significance of the coupling of pΛ to NΣ is manifested as a cusp-like enhancement present at the corresponding threshold energy, which is the first direct experimental observation of this structure. Further, using different modellings for the p–Σ^0 feed-down leads to a statistically significant modification of the measured pΛ correlation, implying an indirect sensitivity to the genuine p–Σ^0 correlation in convolution with the direct pΛ signal. The final results, presented in Table 2, exhibit a slightly better compatibility with the updated version of χEFT (NLO19), compared to the NLO13 prediction. The former involves a weaker NΣ $\leftrightarrow$ NΛ transition potential and a more attractive two-body interaction of the Λ hyperon in the medium. The latter requires a stronger repulsive NNΛ three-body force, in order to achieve a stiffening of the EoS at large densities [4]. The large value of the best $n_\sigma = 3.7$ indicates that the presented ALICE data increase the constraining power on the pΛ interaction and provide an opportunity to improve the existing theoretical calculations for the NΣ $\leftrightarrow$ NΛ coupled system. The existing constraints from hypernuclei data relate the problem to the Λ properties in the dense medium.

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