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Corrigendum

Corrigendum to "Search for a common baryon source in high-multiplicity pp collisions at the LHC" [Phys. Lett. B 811 (2020) 135849]

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1. Corrected core radius of the proton source

In the original paper [1], the relative distance $\vec{r}^*$ for p–p pairs composed of one primary and one secondary (i.e. coming from resonance decay) proton was not calculated correctly. Specifically, Eq. (5) in the original paper for the scenario in which one proton (proton 1) is primary and the other (proton 2) originates from a resonance decay should read $\vec{r}^* = \vec{r}^*_{\text{core}} + \vec{s}^*_{\text{res},2}$, but it was implemented in the code used to extract the source core radius with a minus sign, namely $\vec{r}^* = \vec{r}^*_{\text{core}} - \vec{s}^*_{\text{res},2}$. The mistake was not present in the code used for the p–Λ results. The error leads to a reduction of the final total source size which hence required eventually a larger source core size to describe the measured p–p correlations in the different m_{T} ranges. In Fig. 1 we present the original (left panel) and the updated (right panel) values of the r_{core} extracted from p–p correlations, compared with the published p–Λ results. The plot in the right panel of Fig. 1 replaces Fig. 5 in the original manuscript. The corrected numerical values are also available via HEPData [2]. The fitting procedure and the modelling of the resonances used for the updated results are the same as in the original paper, described respectively in Sec. 3 and Sec. 4 [1]. The net effect of the correction is a systematic shift, across all m_{T} bins, of the r_{core} value for the p–p system of ~ 0.09 fm. Considering the statistical and systematic uncertainties, the number of standard deviations (n_σ) between the p–Λ (NLO13) and the corrected p–p results in the entire m_{T} range is $n_\sigma = 1.9$. This value was obtained using the NLO13 p–Λ interaction from Ref. [3] for direct comparison with the results in the original manuscript. However, more recent studies on the source and the p–Λ interaction [4,5] have shown that the NLO parameterization [1,3] overestimates the spin-averaged scattering length by 10–15%. This implies that the extracted r_{core} for p–Λ (red points in Fig. 1) are biased towards larger radii. To address this, the p–Λ correlation functions in each m_{T} bin have been re-fitted with an Usmani potential [6], fine-tuned to the eight best solutions listed in Table 1 of [5]. The best compatibility ($n_\sigma = 0.90$) between the p–p and p–Λ source sizes is achieved using point iv) from Table 1 in [5], which has scattering length (f) in the singlet (s) and triplet (t) channel of $f_s = 2.50$ fm and $f_t = 1.32$ fm. The corresponding m_{T} scaling (red points) is plotted in the right panel of Fig. 2 and compared to the p–p results (blue band). These findings confirm the original message of the paper about the observation of a common m_T scaling of the r_{core} for particle pairs in high-multiplicity pp collisions at center-of-mass energy $\sqrt{s} = 13$ TeV.

2. Implications for other femtoscopic analyses

In the original paper, the r_{core} values, extracted from the p–p correlation functions, were parameterized using the function

$$r_{\text{core}} = a\ \langle m_{\text{T}} \rangle^b + c \tag{1}$$

and used in several subsequent femtoscopic analyses [9–17]. For these analyses, the source distribution was determined by calculating the average m_{T} of the analysed pairs, evaluating the corresponding r_{core} (Eq. (1)), and then incorporating the pair-specific source broadening caused by resonance decays. This approach, outlined in Eqs. 4 and 5 of [1], typically results in a source distribution that resembles a Gaussian with an additional tail attributed to resonances. In most cases, the source function can be approximated by an effective Gaussian described by its width r_{eff}. This parameter is then used to extract the properties of the mutual strong interaction between the species under study from the measured two-particle correlation function. In particular, the published results [9–17] used the r_{core} extracted from p–p correlations [1] to fix the core of the emission source, from which the corresponding r_{eff} has been estimated. The procedure to include the resonances has been properly implemented in all analyses [9–17], apart from the p–p correlation [1]. Since the effective Gaussian source size r_{eff} depends on the underlying r_{core}, its modification affects all subsequent analyses [9–17]. In this work, this modification is investigated and quantified.

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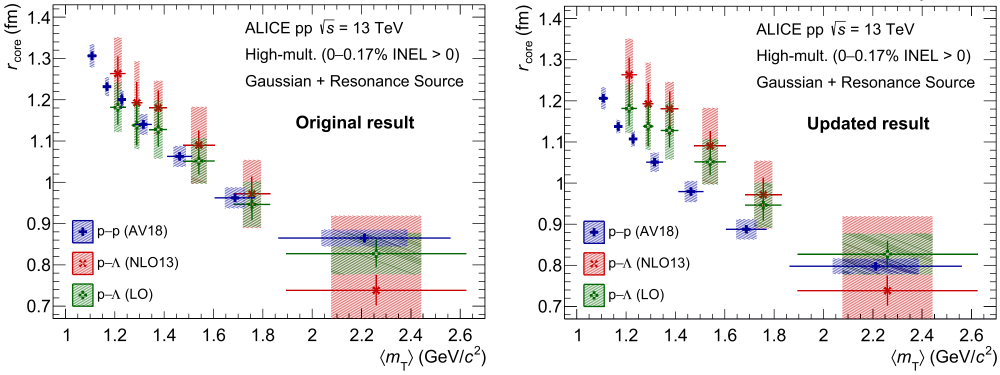

Fig. 1. Source radius r_{core} as a function of $\langle m_{\mathrm{T}} \rangle$ for the assumption of a Gaussian source with added resonances. The blue crosses result from fitting the p–p correlation function with the strong Argonne v_{18} [7] potential. The green squared crosses (red diagonal crosses) result from fitting the p–Λ correlation functions with the strong χEFT LO [8] (NLO13 [3]) potential. Statistical (lines) and systematic (boxes) uncertainties are shown separately. The left panel shows the original figure whereas in the right panel the p–p data have been corrected.

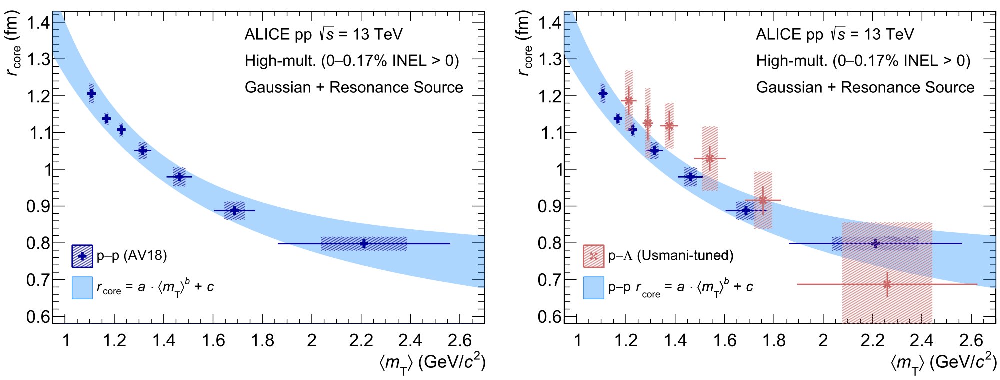

Fig. 2. *Left panel:* Extracted source core radii for p–p pairs (right panel of Fig. 1) and their parameterization using Eq. (1). *Right panel:* The results from the left panel, overlaid with p–Λ results obtained using the Usmani potential tuned to point iv) from Table 1 in [5].

Table 1
Values for the parameterization (Eq. (1)) of $r_{\mathrm{core}}(m_{\mathrm{T}})$ for p–p pairs (blue band in Fig. 2). The different columns represent the parameters to describe the lower/mean/upper part of the error band. The values in brackets are the previous outdated results.

Parameter	Lower limit	Mean values	Upper limit
a $\left(\mathrm{fm} \cdot [\mathrm{GeV}/c^2]^{-b}\right)$	0.773 (0.86)	0.675 (0.74)	0.632 (0.69)
b	−1.39 (−1.31)	−1.93 (−1.85)	−2.57 (−2.55)
c (fm)	0.481 (0.50)	0.649 (0.69)	0.770 (0.83)

The values of the r_{core} for p–p pairs reported in the right panel of Fig. 1 are shown in Fig. 2, without the p–Λ results. The blue band shows the parameterization by Eq. (1) with the parameter values given in Table 1. The input argument m_{T} has units of GeV/c^2, while the output r_{core} is in fm. The old and updated values of the a, b and c parameters are in agreement within the reported limits.

In Table 2 we report the updated values for the r_{core} and the effective single-Gaussian source sizes used in the different femtoscopic analyses to evaluate the theoretical correlation function employed to model the data. In brackets we list the values obtained using the r_{core} extracted in the original paper [1]. For most systems both the r_{core} and r_{eff} have been affected, nevertheless for the N–N source within the p–d system [15] the $r_{\mathrm{eff}}^{\mathrm{NN}}$ remains unchanged. This is because the wrong code has been used both to evaluate r_{core} as well as $r_{\mathrm{eff}}^{\mathrm{NN}}$, leading to a cancellation of the error.

Table 2
Updated r_{core} values and corresponding r_{eff} for the femtoscopic analyses that use the source core radius scaling as a function of m_{T} from the original paper [1]. The average transverse mass m_{T} for each pair type, as quoted in the corresponding publications, is reported as well. In brackets: published values of the source parametrization based on the original paper.

Pair	$\langle m_{\mathrm{T}} \rangle$ (GeV/c^2)	r_{core} (fm)	r_{eff} (fm)
p–Ξ⁻ [9]	1.9	0.86 ± 0.05 (0.93 ± 0.04)	0.95 ± 0.05 (1.02 ± 0.05)
p–Ω⁻ [9]	2.2	0.80 ± 0.06 (0.86 ± 0.06)	0.89 ± 0.05 (0.95 ± 0.06)
p–Λ [10]	1.55	0.94 ± 0.04 (1.02 ± 0.04)	1.15 ± 0.04 (1.23 ± 0.04)
p–ϕ [11]	1.66	0.90 ± 0.04 (0.98 ± 0.04)	1.00 ± 0.05 (1.08 ± 0.05)
p–$\bar{\mathrm{p}}$ [12]	1.45	0.98 ± 0.04 (1.06 ± 0.04)	1.14 ± 0.04 (1.22 ± 0.04)
p–$\bar{\Lambda}$ [12]	1.75	0.88 ± 0.04 (0.95 ± 0.04)	1.09 ± 0.04 (1.15 ± 0.04)
Λ–$\bar{\Lambda}$ [12]	2.12	0.81 ± 0.04 (0.87 ± 0.04)	1.07 ± 0.04 (1.11 ± 0.04)
p–D⁻ [13]	2.7	0.75 ± 0.07 (0.80 ± 0.08)	$0.84^{+0.07}_{-0.20}$ $(0.89^{+0.08}_{-0.22})$
Λ–Ξ⁻ [14]	2.01	0.825 ± 0.051 $(0.894^{+0.054}_{-0.052})$	0.963 ± 0.051 $(1.032^{+0.054}_{-0.052})$
p–d [15]	1.64	0.91 ± 0.06 (0.99 ± 0.05)	1.00 ± 0.06 (1.08 ± 0.06)
N–N within p–d [15]	n/a	1.26 ± 0.12 (1.35 ± 0.14)	1.43 ± 0.16 (1.43 ± 0.16)

Table 3
Same as in Table 2 but for an effective double-Gaussian source parametrization. For the $\mathrm{D}^{(*)}$–π and $\mathrm{D}^{(*)}$–K results, we report the values of average m_T for both same charge (SC) and opposite charge (OC) pairs.

Pair	$\langle m_\mathrm{T}\rangle$ (GeV/c^2)	r_core (fm)	$r_\mathrm{eff,1}$ (fm)	$r_\mathrm{eff,2}$ (fm)	ω_s	λ_s
Λ–$\mathrm{K}^\pm$ [16]	1.35	1.03 ± 0.04 (1.11 ± 0.04)	1.12 ± 0.04 $(1.202^{+0.043}_{-0.042})$	2.24 ± 0.04 $(2.330^{+0.050}_{-0.045})$	$0.7942^{+0.004}_{-0.0022}$ $(0.7993^{+0.0037}_{-0.0027})$	$0.9794^{+0.0003}_{-0.0005}$ $(0.9806^{+0.0006}_{-0.0008})$
$\mathrm{D}^{(*)}$–π [17]	SC:2.54 OC:2.55	0.76 ± 0.07 (0.82 ± 0.07)	$0.93^{+0.09}_{-0.08}$ $(0.97^{+0.09}_{-0.08})$	$2.42^{+0.36}_{-0.20}$ $(2.52^{+0.36}_{-0.20})$	$0.66^{+0.03}_{-0.02}$ $(0.66^{+0.03}_{-0.02})$	fixed to 1
$\mathrm{D}^{(*)}$–K [17]	SC:2.68 OC:2.63	0.75 ± 0.07 $(0.81^{+0.08}_{-0.07})$	$0.81^{+0.09}_{-0.07}$ $(0.86^{+0.09}_{-0.07})$	$1.92^{+0.19}_{-0.12}$ $(2.03^{+0.19}_{-0.12})$	$0.78^{+0.02}_{-0.01}$ $(0.78^{+0.02}_{-0.01})$	fixed to 1
K^+–d [15]	1.50	0.96 ± 0.04 (1.04 ± 0.04)	1.04 ± 0.04 (1.10 ± 0.04)	$2.01^{+0.03}_{-0.07}$ $(2.14^{+0.03}_{-0.07})$	0.76 (0.76)	fixed to 1

Table 4
The deviation between the data published in [10] and several different χEFT calculations. These results are an update of Table 2 in [10], where the core source size r_core is correctly set to 0.94 ± 0.04 fm.

	Standard deviation (n_σ)			
	$k^* \in [0, 110]$ MeV/c		$k^* \in [0, 300]$ MeV/c	
$\mathrm{p}\Sigma^0$ ($\rightarrow$) $\mathrm{p}\Lambda$ ($\downarrow$)	χEFT	Negligible $\mathrm{p}\Sigma^0$ FSI	χEFT	Negligible $\mathrm{p}\Sigma^0$ FSI
LO-600	6.1 (6.8)	8.5 (9.8)	9.9 (>10)	>10 (>10)
NLO13-500	6.0 (7.9)	4.5 (4.7)	7.2 (>10)	5.7 (6.6)
NLO13-550	4.3 (5.5)	2.9 (2.9)	4.0 (6.4)	2.9 (3.1)
NLO13-600	4.9 (5.0)	3.6 (3.9)	4.1 (4.5)	3.4 (4.2)
NLO13-650	4.7 (4.4)	3.9 (4.7)	4.1 (3.8)	4.0 (5.5)
NLO19-500	4.4 (4.8)	3.0 (3.0)	5.3 (6.8)	4.4 (4.2)
NLO19-550	3.7 (3.7)	2.5 (2.6)	3.1 (3.5)	2.5 (3.2)
NLO19-600	3.0 (2.9)	2.2 (2.7)	3.1 (3.4)	2.9 (4.2)
NLO19-650	3.3 (3.3)	2.4 (3.4)	2.9 (3.0)	3.4 (5.3)

For the results in [16,17] and for the K^+–d analysis in [15], the total source was modelled with a linear combination of two Gaussians $S_\mathrm{eff}(r^*) = \lambda_s[\omega_s S_1(r^*) + (1-\omega_s)S_2(r^*)]$. In Table 3 we report the updated values for these analyses.

The revised values of r_core and r_eff listed in Tables 2 and 3 are overall in agreement with the old ones within the experimental uncertainties. The new effective radii in Table 2 are compatible with the old values within 1.4 standard deviations. For the parameters of the double-Gaussian sources in Table 3, the maximal deviation is observed for $r_\mathrm{eff,2}$ of the K^+–d pairs and amounts to $n_\sigma = 1.7$. Notice that the contribution of the second Gaussian is sub-dominant in the modelling of the source, as the corresponding weight is given by $(1-\omega_s)$.
The impact of the revised source radii on the analyzed systems has been investigated, paying particular attention to high-precision cases like p–Λ and Λ–K^- pairs. In these analyses the bias on the source dominates over the statistical uncertainties. The aim is to check that the effect of the updated source on the extracted interaction parameters and/or on the compatibility with tested models is negligible and hence the physics conclusions drawn from these studies remain valid.

The p–Λ analysis in [10] compares the measured correlation function to chiral effective field theory (χEFT) calculations [3,18,19]. In particular, multiple calculations (leading-order LO [18] and next-to-leading-order NLO [3]), different parameterizations (NLO13 [3] and NLO19 [19]) and several cutoff values of the theory have been compared to the data. The results demonstrated incompatibility of the LO potentials, while the comparison between NLO13 and NLO19 showed a preference towards the latter, pointing out the necessity of lower scattering parameters. The best compatibility to the data for $k^* < 110$ MeV/c was for the NLO19-600 potential-cutoff, leading to an $n\sigma \in [2.2,\ 3.2]$ depending on the choice of $\mathrm{N}\Sigma$ interaction and baseline. The final conclusion of the paper was that even the best solution shows a hint of deviation, pointing to the necessity of further fine-tuning of the theory.

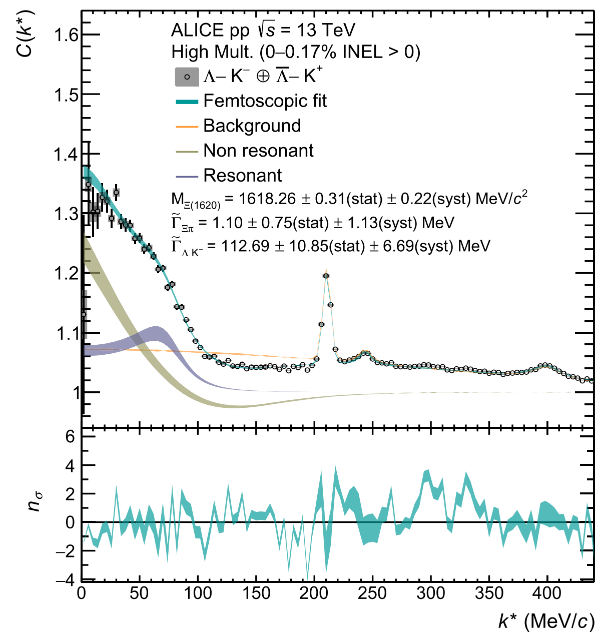

Fig. 3. Measured correlation function of Λ–K^- pairs [16]. Statistical (bars) and systematic (boxes) uncertainties are shown separately. The light cyan band represents the total fit performed assuming the new values of source radii in Table 3. The violet band represents the $C^\mathrm{res}_\mathrm{LL}(k^*)$ correlation stemming from the resonant interaction, while the olive green band is for the non-resonant one. The orange band represents the $C_\mathrm{background}(k^*)$ modelled using the Monte Carlo simulations. Lower panel: n_σ deviation between data and model in terms of numbers of standard deviations.

This has been recently achieved in [4,5]. In this work we repeated the original p–Λ analysis by ALICE [10] using the exact same potentials, but changing the source to the updated value of $r_\mathrm{core} = 0.94 \pm 0.04$ fm. The outcome of the re-analysis is summarized in Table 4, which replaces Table 2 in [10]. Indeed, all physics conclusions discussed above remain valid, with a slight change of the best $n\sigma \in [2.2,\ 3.0]$, for the case of NLO19-600. These updated results are not only consistent with the original manuscript [10], but also with the two subsequent independent re-analyses [4,5], both using a different treatment of the source.

The analysis of the Λ–K^- correlation in [16] delivered the first evidence of the $\Xi(1620)$ in the Λ–K^- channel, and even if within a pure effective modelling approach, it showed that the Λ–K^- interaction can proceed via a resonant and a non-resonant part. In Fig. 3 we show the results of the fit to the measured Λ–K^- correlation, in which the updated source parametrization was used. In Table 5 we show the new values for the real and imaginary part of the scattering length ($\Re f_0$, $\Im f_0$) for the non-resonant contribution, along with the extracted effective range d_0. We report as well in the third column the values presented

Table 5
Extracted scattering parameters for the non-resonant part of Λ–K⁻ interaction in pp collisions. Statistical and systematic uncertainties are reported.

	Λ–K⁻ in this work	Λ–K⁻ in [16]	Agreement ($n\sigma$)
$\Re f_0$ (fm)	$0.30 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})$	$0.33 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})$	0.6
$\Im f_0$ (fm)	$0.46 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})$	$0.46 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})$	0
d_0 (fm)	$-6.01 \pm 0.39(\text{stat}) \pm 0.28(\text{syst})$	$-5.47 \pm 0.36(\text{stat}) \pm 0.26(\text{syst})$	0.8

in [16] assuming the old source parametrization. As can be seen in the last column, the updated and old values are well in agreement. A similar scenario holds also for the extracted properties of the Ξ(1620) state shown in Fig. 3, with the new ones in agreement within a maximum of 0.4σ with the previous ones.

To conclude, the mistake of the minus sign in the code used to extract the p–p core radius has been corrected. The updated core and effective radii are found to be in agreement with the old ones within the experimental uncertainties. The impact of this correction was investigated in two exemplary cases, p–Λ and Λ–K⁻, in which the highest precision in the measured correlation was achieved. The analysis shows that the reevaluation of the source radii has a negligible effect on the conclusions drawn from these measurements.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data are available in a HEPData repository at: https://www.hepdata.net/record/ins1791631.

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