$\Lambda\Lambda$ and Λp Correlations
Status of Paper Draft

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NA49 Collaboration Meeting

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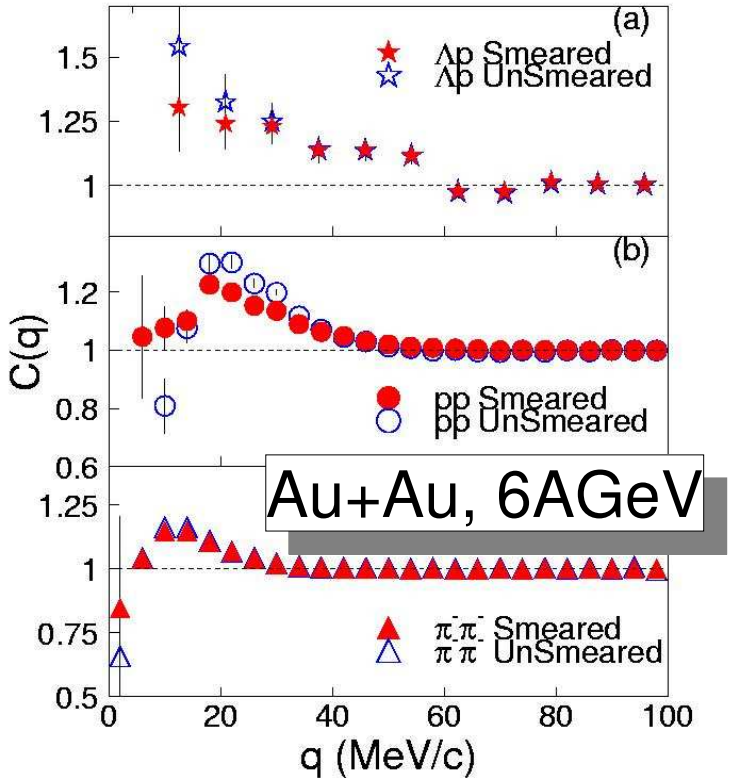
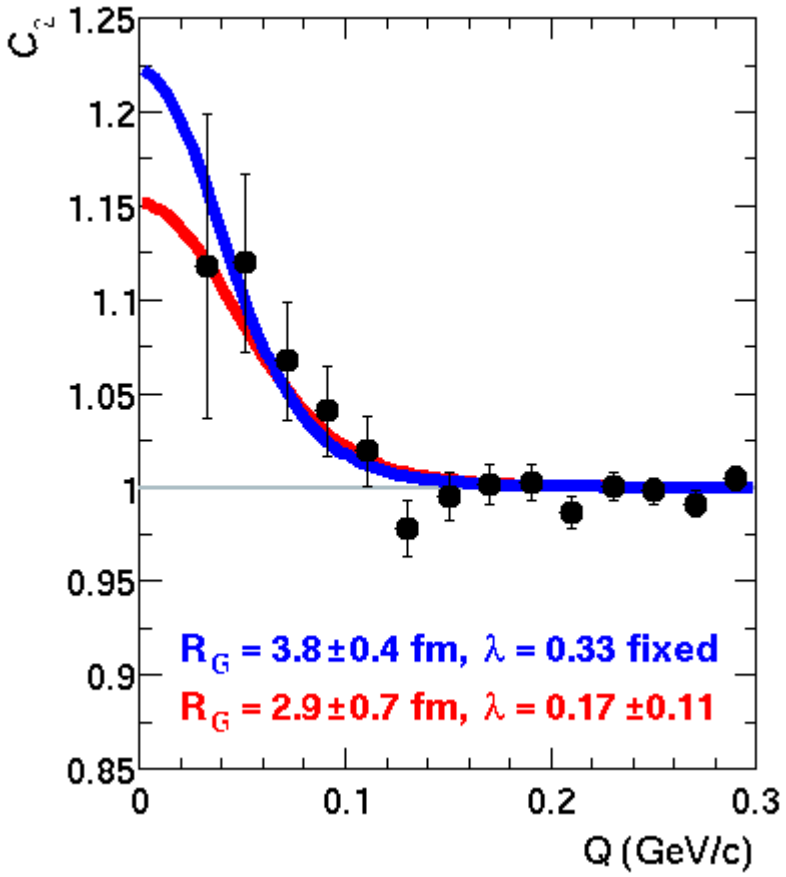
Status

- Paper draft existing
- Open questions in analysis:
  - $\Lambda\Lambda$ c.f. flat $\rightarrow$ significant conclusions possible?
  - Can one open cuts (e.q. in q_{inv} of daughter Λ tracks) to increase pair statistics?
  - Study of ''uncorrelated" background (fake) Λ pairs
  - Effects not fully understood yet
- Improved p identification for pΛ (propability cut)
- Final corrections needed
  - Uncorrelated background
  - Feed down (Σ^0!)
- Momentum resolution?
  - Preliminary study with CRAB shows no big effect

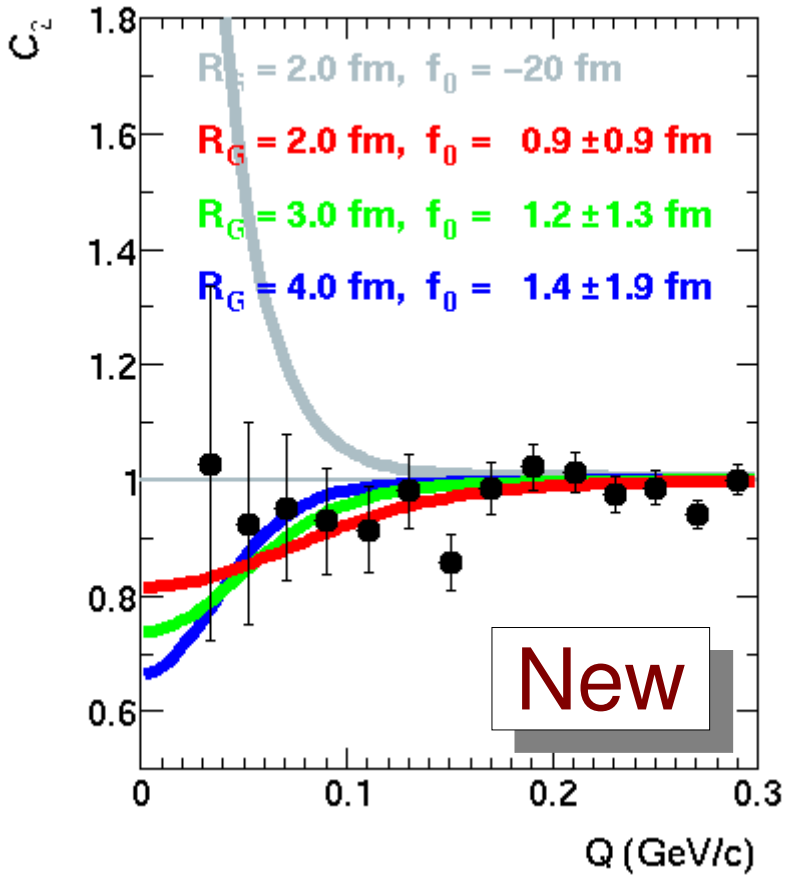
Λp Correlation Function (QM02 Result)

- Central Pb+Pb, 158 AGeV
- Paper with pΛ recently submitted by E895 (nucl–ex/0212028)

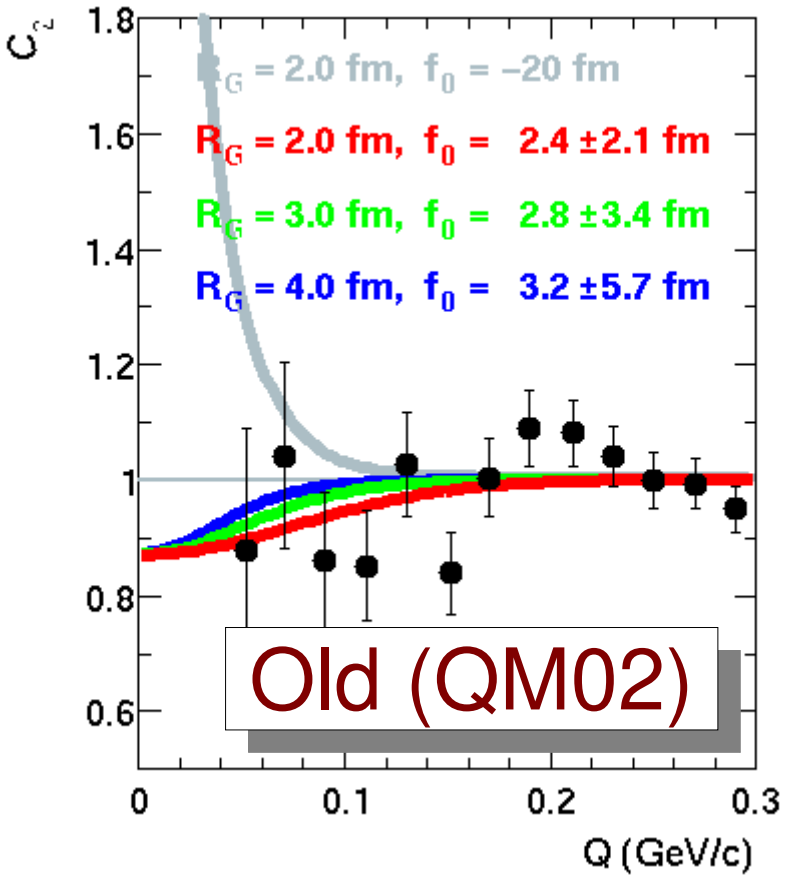




ΛΛ Correlation Function



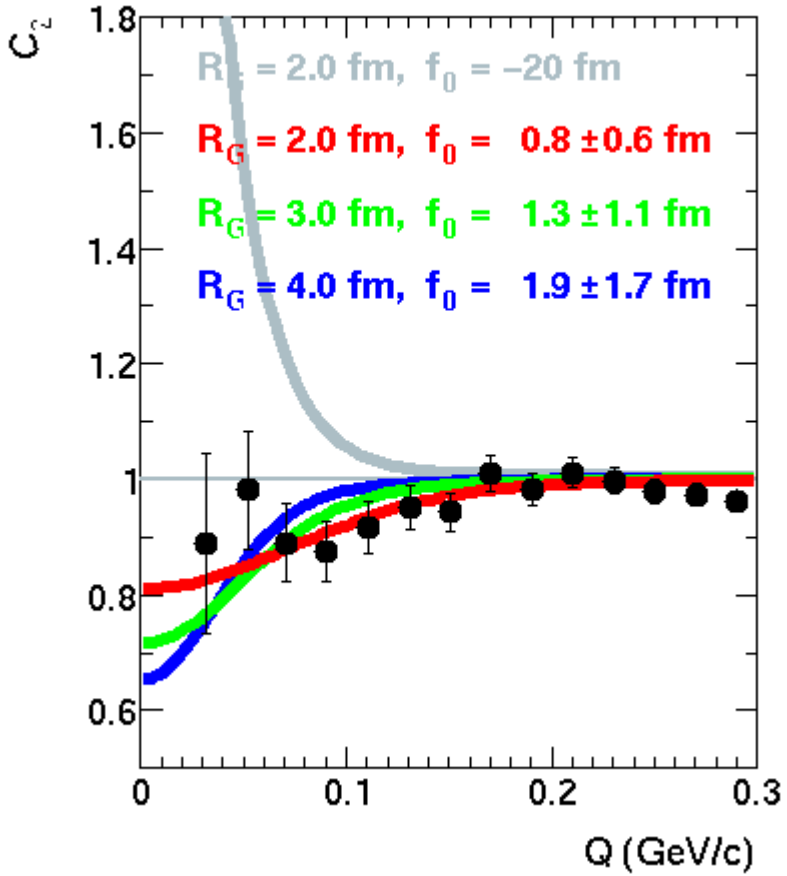
- Includes 40, 80,158 AGeV

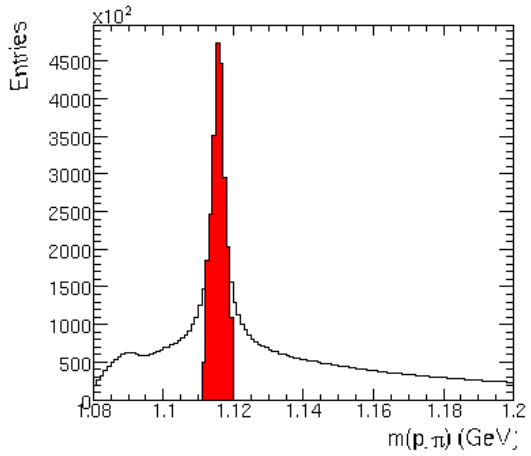


- Includes only 158 AGeV
- Both with q_{inv} cut

ΛΛ Correlation Function without q_{inv} Cut

- Includes 40, 80, 158 AGeV
- Cut on daughter q_{inv} taken out
- Significant anti–correlation
- Real ΛΛ correlation?




Entries
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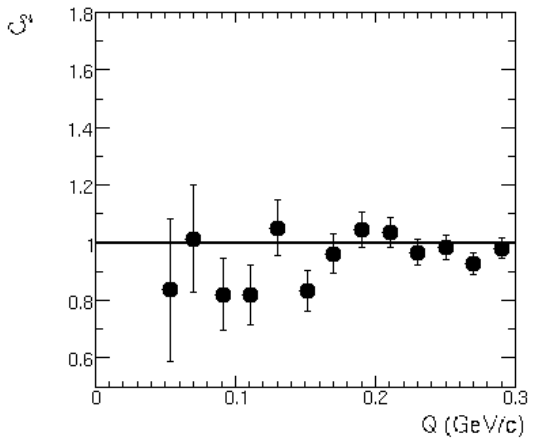
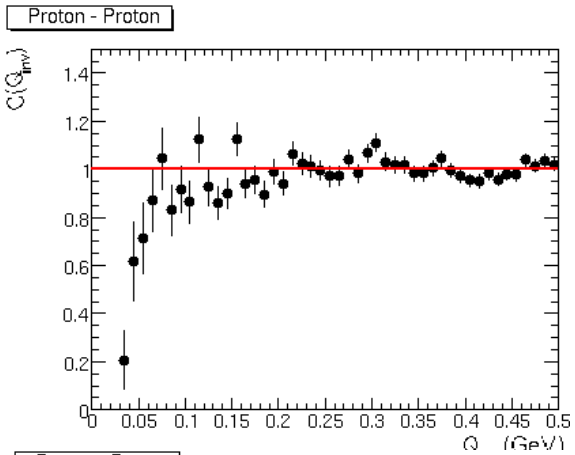
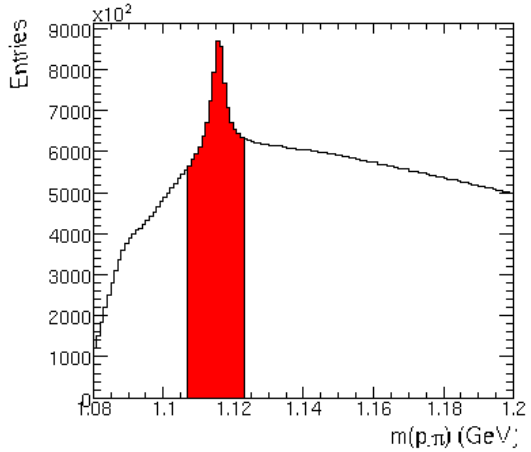
m(p,π) (GeV/c²)


C₂
Q (GeV/c)


Proton - Proton
C(Q_inv)


Entries
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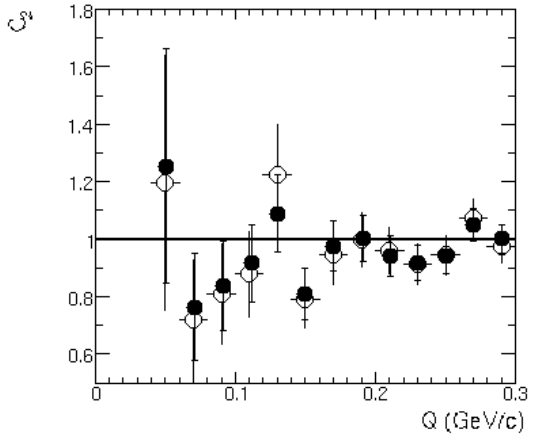
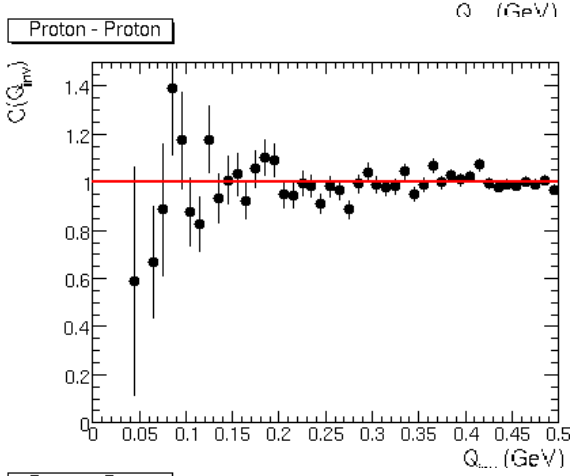
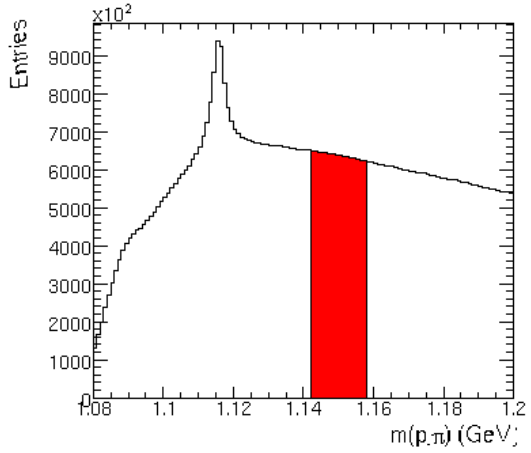
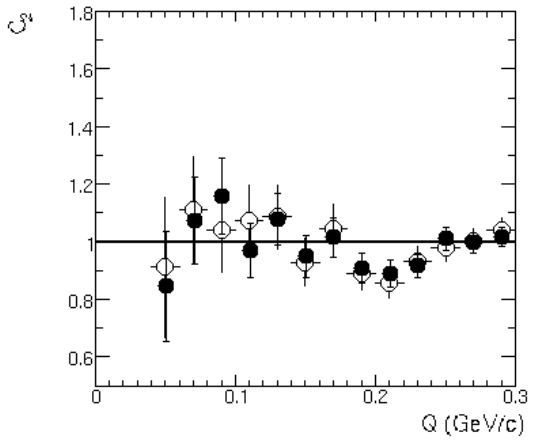
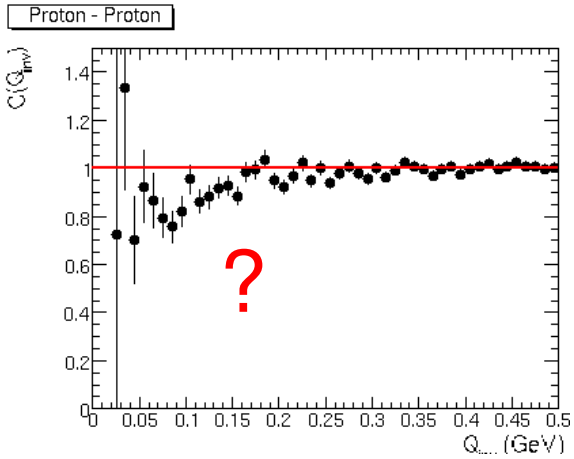
m(p,π) (GeV/c²)


C₂
Q (GeV/c)


Proton - Proton
C(Q_inv)
Q_inv (GeV)


Entries
x10²
m(p,π) (GeV/c²)


C₂
Q (GeV/c)


Proton - Proton
C(Q_inv)
?
Q_inv (GeV)

How to Proceed?

- Revealed lots of subtle effects
  - E.g. selection of unique Λ
- Not fully understood
- Things to check:
  - Conversion pairs (dEdx)
  - $N_{point}/N_{maxpoint}$ cut (0.5), should be studied systematically
- But propably not a big chance to increase pair statistics for $\Lambda\Lambda$
- Systematic error

- Update of pΛ
  - New proton selection
  - Input from $\Lambda\Lambda$

ΛΛ and Λp correlations in central Pb+Pb collisions at 158 AGeV

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(DRAFT 0.1)

The Λp and the ΛΛ correlation functions for central Pb+Pb collisions at 158 AGeV have been measured by the NA49 experiment. The observed Λp correlation function shows a clear enhancement for low relative momenta. By comparison to theoretical calculations a value for the effective source size is deduced. The measured ΛΛ correlation function shows no significant structure. An attempt is made to derive a value for the ΛΛ scattering length. The result indicates that the two Λ interaction is rather weak.

Keywords:

Heavy ion collisions at ultra-relativistic energies produce strongly interacting matter under extreme conditions. The main goal of studying heavy ion reactions is to create a state in which the confinement of quarks and gluons inside hadrons is no longer valid, the so-called quark-gluon plasma [1]. The large abundance of strange particles produced in heavy collisions at the CERN SPS allows to study the two particle correlation between pairs of strange particles or pairs of strange and non-strange particles. For example the Bose-Einstein correlations of charged kaons can provide insight into the space-time extent of the reaction system [2]. In this paper we report on the measurement of Λp and ΛΛ correlation functions.

It has been suggested that the correlation between Λ and protons can be employed to measure the size of the emitting source [3]. The correlation function of Λp pairs is only affected by the strong interaction between the particles. This distinguishes Λp correlations from the two-proton case, whose correlations are widely used in heavy ion reactions to determine source sizes [4–6]. The two-proton correlation function is dominated by the repulsive Coulomb interaction and the Fermi-Dirac statistic

for very low relative momenta. Both effects are absent in the Λp correlation function, which makes it better suited for the study of large sources [3]. A sufficient knowledge on the strong interaction between pairs of protons and Λ is, however, necessary to relate the strength of the correlation function to the size of the emitting source. Since there is a substantial set of data on $K^- d - \Lambda p \pi^-$ scattering [7–9], this is easy to deduce.

The situation is quite different in the case of $\Lambda\Lambda$ correlations. The only information on the strong interaction between Λ pairs available so far, is derived from the analysis of double hyper-nuclei. Unfortunately, only a few events have been observed in the past, and their interpretation is rather inconclusive [10–13]. Recently, a new event has been reported, which, in contrast to the older measurements, would suggest a $\Lambda\Lambda$ interaction that is only weakly attractive [14]. In the light of the poor experimental situation it is evident that any other way of learning about the interaction between Λ pairs is of great importance. The study of the $\Lambda\Lambda$ correlation function offers such an alternative tool, since it is directly determined by the two particle interaction [15]. It has also been suggested that the hypothetical H^0-dibaryon, which has been suggested based on bag model studies [16], might be visible in the correlation function. This, however, would require that its mass is above the two Λ threshold, so that the H^0 appears as a strongly decaying resonance.

The data presented here have been measured by the NA49 experiment at the CERN SPS. A detailed description of the experimental setup can be found in [17]. This analysis was done on $2.9 \cdot 10^6$ Pb+Pb events at 158 AGeV recorded in the year 2000, which cover the 20% most central part of the total inelastic cross section. In order to increase the available statistics, $0.8 \cdot 10^6$ Pb+Pb events from the 1996 run period with a different centrality selection (10 % most central) have been added, resulting in $3.7 \cdot 10^6$ analysed central events in total.

The Λ are measured via their charged decay $\Lambda \rightarrow p\pi^-$. The reconstruction is done by forming pairs of positively and negatively charged tracks and testing whether they could originate from a common secondary vertex. Under the assumption of proton and pion mass for the positively and negatively charged decay particle, the invariant mass of the Λ candidates can be calculated. By requiring that the found secondary vertex is well seperated from the main interaction vertex and that the extrapolation of the Λ candidate points back to the main vertex, a significant reduction of the combinatoric background is achieved. The signal to background ratio is further improved by enriching the protons in the sample of positively charged tracks by applying a cut on the measured energy loss. Additionally, a lower cut in the Λ transverse momentum of $p_t > 0.2$ GeV/c is applied. An important point with respect to correlation studies is the requirement that each Λ candidate must be unique. Since a daughter track of a given Λ candidate can in principle also be assigned to another candidate, which would result in a strong artificial correlation between both candidates. It is therefore assured in this analysis that a given track only appears as a daughter track of one unique Λ candidate. Similarly, decay particles that were not reconstructed as a single track, but as separate track pieces ("split tracks"), will cause a distortion of the measured correlation function. This is here avoided by requiring that the number of measured points of each accepted track is higher than 50% of the number of points that this track should have according to its trajectory in the TPCs. Fig. 1 shows the Λ invariant mass distribution that is obtained this way. The applied cuts were tuned to accept as many real Λ as possible while trying to keep the background contribution on a reasonable level. In the accepted mass window $[m_0 - \Delta m, m_0 + \Delta m]$, where $m_0 = 1.115683\,\mathrm{GeV}/c^2$ is the PDG value for the Λ mass [18] and $\Delta m = 0.004\ \mathrm{GeV}/c^2$ is the chosen width, the signal to background ratio is found to be 4.16. A substantial fraction of these Λ candidates originate from the weak and electro-magnetic decay of heavier particles ("feed down") and will therefore not show any correlation. Since the important contribution from Σ decays is experimentally unknown, one has to rely on simulations. We used the VENUS model (version 4.12) [19] to estimate the fraction of feed down Λ, which is found to be (77±7)%.

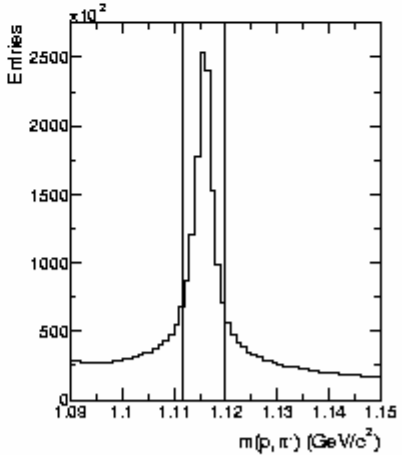

FIG. 1: The invariant mass distribution of proton pion pairs for central Pb+Pb reactions at 158 AGeV. The two vertical lines indicate the mass window used to define valid Λ candidates.

Protons are identified via their energy loss in the relativistic rise region measured in the two large main-TPCs. Here a typical resolution of 3-4% can be achieved [17].

The proton selection used in this analysis requires at least a 75% probability of the track candidate to be a proton. The acceptance window covers momenta above $p = 3\,\mathrm{GeV}/c$ and the rapidity region above $y = 2.3$. As in the case of the Λ decay particles it is ensured that split tracks are removed from the track sample. The fraction of protons originating from feed down was estimated to be (77±77)%.

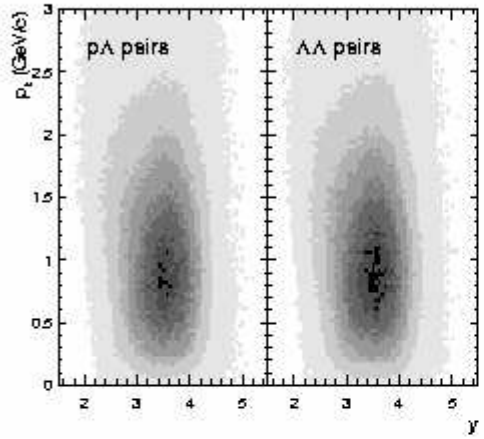

FIG. 2: The phase space population of Λp pairs (left hand side) and $\Lambda\Lambda$ pairs (right hand side) as a function of pair rapidity y and p_t.

The selected Λ and proton candidates are then combined to Λp and $\Lambda\Lambda$ pairs. The pair distributions are measured as a function of their relative momentum in the center of mass of the pair [21]: $Q = \vec{p}_1 - \vec{p}_2$. For the construction of the uncorrelated background an event mixing method is employed. Since the reconstruction of real pairs is affected by the limited two track resolution of the detector [17], a track distance cut of 2 cm is applied for real pairs as well as for the event mixed pairs. Figure 2 shows the phase space population of the accepted Λp and $\Lambda\Lambda$ pairs. The averaged k_t of the pairs [22] is $\langle k_t \rangle = 77\,\mathrm{GeV}/c$ for Λp pairs and $\langle k_t \rangle = 77\,\mathrm{GeV}/c$ for $\Lambda\Lambda$ pairs.

Effect of momentum resolution!!!

In total, 60,000 Λp pairs with $Q < 0.3\,\mathrm{GeV}/c$ were measured. Dividing the signal distribution by the event mixing background yields the final Λp correlation function, as shown in Fig. 3. The correlation function exhibits a significant enhancement for small Q. Such a correlation would be expected as the effect of the strong interaction between the proton and the Λ. Since the width of this correlation should be inversely proportional to the size of the emitting source volume, the data can be used to

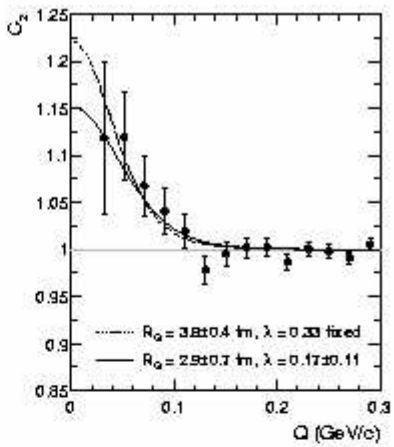

FIG. 3: The Λp correlation function for central Pb+Pb reactions at 158 AGeV, shown as a function of the relative momentum in the pair center of mass. The lines display the result of the fit with the calculated correlation function (solid line: free λ parameter, dashed line: fixed λ parameter). Only statistical errors are shown.

extract information on the radius parameter. This requires a theoretical calculation of the correlation function, which can be fitted to the data points. We use here an effective range approximation of the S-wave interaction, following the description given in [20]. In this approximation the strength of the interaction is defined by two parameters, the effective range d_0^S and the scattering length f_0^S. Based on the available information on the Λp two particle interaction, values of $d_0^S = 2.0$ fm and $f_0^S = -2.3$ fm (singlet), -1.8 fm (triplet) are used. The source is assumed to be spherically symmetric and its spatial distribution is described by a Gaussian. The calculation was fitted to the data by varying two parameter: The radius parameter R_G, defined as the σ of the spatial distribution, and the λ parameter that takes possible reductions of the height of the correlation into account. If both parameters are left to vary freely, the best fit is obtained for $R_G = 2.9 \pm 0.7$ fm and $\lambda = 0.17 \pm 0.11$ (solid line in Fig. 3). Additionally, an attempt was made to estimate the λ parameter. The height of the original correlation is reduced due to impurities in the particle identification and due to feed down. Using the numbers given above, the λ parameter was estimated to be 0.33±??, in agreement to the fitresult *really???*. Fixing λ to this value result in a best fit to the data for $R_G = 3.8 \pm 0.4$ fm (dashed line in Fig. 3).

Naturally, the statistics for the $\Lambda\Lambda$ correlation function is lower than in the Λp case. In total, 3,500 $\Lambda\Lambda$ pairs were measured with $Q < 0.3\,\mathrm{GeV}/c$. The resulting correlation

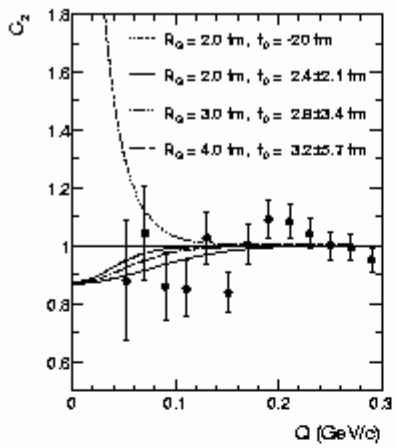

FIG. 4: The ΛΛ correlation function for central Pb+Pb reactions at 158 AGeV, shown as a function of the relative momentum in the pair center of mass. The lines display the result of fits with calculated correlation functions with the scattering length f_0^S as free parameter, assuming different source sizes R_G. Also included is the expectation for a scattering length as in the nucleon nucleon case ($f_0^S = -20$ fm, dot-dashed line). The errors given are statistical only.

function is displayed in Fig. 4. There is no indication for a significant structure visible, the data points all center around 1. *Include points with all available data !?* However, the measurement still provides some information on the strength of the interaction between Λ pairs. This is illustrated by the fits to the data points included in Fig. 4. In these fits the source size parameter R_G and the λ parameter are fixed ($R_G = 2.0/3.0/4.0$ fm and $\lambda = 0.16$ as estimated from PID background and feed down). The free parameter, instead, is here the scattering length f_0^S. Independent from the assumed source size, the best fit is achieved for relatively small scattering lengths (solid and dashed lines in Fig. 4). This is in striking contrast to the nucleon nucleon case with a scattering length of $f_0^S = -20$ fm. *reference !!!* As a comparison, the expectation for the ΛΛ correlation function assuming the nn scattering length is also included in Fig. 4 (dot-dashed line). Even though it is not totally ruled out by the data, it appears to be rather unfavoured by the measurement.

In summary, the NA49 experiment has measured the first Λp and ΛΛ correlation functions from central Pb+Pb collisions at 158 AGeV. The Λp pairs exhibit a clear positive correlation for small relative momenta. By comparison to a calculated correlation function a one-dimensional Gaussian source size parameter of $R_G = 7 \pm 7$(stat.)± 7(syst.) fm can be extracted. This value is close to a previous measurement of the source size via pp correlations: $R_G(\mathrm{pp}) = 4.0 \pm 0.15(\mathrm{stat.})^{+0.08}_{-0.18}(\mathrm{syst.})$ fm [4]. The ΛΛ correlation function, however, appears to be flat in the measured region of relative momentum ($Q > 40$ MeV/c). Although the error bars are large the data points still can be used to derive some limitations on the possible strength of the Λ pair interaction. Our measurement indicates a small S-wave scattering length, which would suggest that the interaction is rather weak compared to the nucleon nucleon case. This is supported by the interpretation of the recently measured double hyper-nuclei, resulting in a small ΛΛ interaction energy of $\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}$ MeV [14].

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