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Measurement of Bose-Einstein Correlations between Charged Pions using the LEP1 data

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Abstract

Bose-Einstein correlations between like-sign charged track pairs have been studied in e^+e^- collisions in the hadronic events at centre-of-mass energies around the Z peak as a function of the four-momentum difference of the pair. Assuming all charged tracks are pions, the strength of the effect λ and the radius of pion emitting source σ were found to be $\lambda = 0.252 \pm 0.006$ (stat.) $\pm\ 0.044$ (sys.) and $\sigma = 0.764 \pm 0.024$ (stat.) $\pm\ 0.153$ (sys.) fm.

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1 Introduction

The first observation of interference between like-sign pions was made in the late 1950's by Goldhaber, Goldhaber, Lee and Pais [1] in $p\bar{p}$ annihilations. The effect was attributed to Bose-Einstein (BE) statistics obeyed by identical pion pairs. The effect resulted in an enhancement of like-sign charged tracks compared to unlike-sign charged tracks when the two particles had similar momenta. Since then, the BE correlations have been studied using pairs of charged pions by number of different experiments [2] including the ones at LEP [3].

The BE correlations can be described in terms of a correlation function C defined by

$$C(k_1, k_2) \;=\; \frac{\rho(k_1, k_2)}{\rho_0(k_1, k_2)} \tag{1}$$

where k_1 and k_2 are the four-momenta of the two tracks, $\rho(k_1, k_2)$ is the measured density for two identical bosons, and $\rho_0(k_1, k_2)$ is the two-particle density in the absence of BE correlations. It has been observed experimentally [4] that the effect can be described in terms of the variable Q, defined by

$$\begin{aligned} Q^2 \;&\equiv\; (k_1 - k_2)^2 \\ &=\; M^2(\pi\pi) - 4m_\pi^2 \end{aligned} \tag{2}$$

where M is the invariant mass of the two pions. The correlation function can then be written as

$$C(Q) \;=\; \frac{\rho^{'}(Q)}{\rho_0^{'}(Q)} \tag{3}$$

If the pion source is assumed to have a Gaussian shape in the rest frame of the pion pair, $C(Q)$ can be parametrised as

$$C(Q) \;=\; 1 + \lambda e^{-Q^2R^2} \tag{4}$$

The parameter λ in the above equation represents the strength of correlations and it assumes values between 0 and 1. The parameter R is related to the size of σ of the pion emitting source through the relation $\sigma \;=\; R\hbar c$.

$C(Q)$ is usually determined by dividing the differential cross section for pairs of like-charged pions by that for the pairs in a 'reference sample', which should be free of BE correlations, but would otherwise have a differential cross section identical to that of the like-charged pairs. One such reference sample consists of pairs of unlike-sign tracks. An approximation to $C(Q)$ is then given by

$$C_{+-}(Q) \;=\; \frac{N_{like}}{N_{unlike}} \tag{5}$$

where N_{like} and N_{unlike} are the number of like and unlike-charged pairs as a function of Q. Another method of obtaining a reference sample uses the technique of combining tracks from one event hemisphere with the tracks from the other hemisphere. In this method, one divides the event into two hemispheres using the thrust axis, then one reflects the momentum vector of a charged track through the origin. This technique clearly requires a two-jet event topology. In this case $C(Q)$ is given by

$$C_{mix}(Q) \quad = \quad \frac{N_{like}}{N_{mix}} \tag{6}$$

The two ratios $C_{+-}(Q)$ and $C_{mix}(Q)$ are obtained both for the data and Monte Carlo and the double ratios are formed:

$$C(Q) \quad = \quad \frac{C_{+-}^{data}(Q)}{C_{+-}^{mc}(Q)} \tag{7}$$

$$C(Q) \quad = \quad \frac{C_{mix}^{data}(Q)}{C_{mix}^{mc}(Q)} \tag{8}$$

The advantage of the double ratio is that it is not sensitive to the efficiency, purity and acceptance effects.

2 Event Selection

A detailed description of L3 detector may be found in [5]. The hadronic events were selected at Z peak using 1994 data corresponding to a total integrated luminosity of 50 pb^{-1}. For the selection of hadronic events $e^+e^- \rightarrow Z \rightarrow \mathrm{q\bar{q}}$, the cuts applied are:

- $\mathrm{N_{ASRC}} \geq 10$
- $0.5 \leq E_{vis}/\sqrt{s} \leq 1.5$
- $0.05 \leq E_{had}\sqrt{s} \leq 0.95$
- $E_{\perp}/E_{vis},\ E_{||}/E_{vis} \leq 0.6$

where N_{ASRC} are the number of ASRC's found using calorimeters, E_{vis} and E_{had} is the total visible and the total energy measured by the hadron calorimeter respectively. $E_{\perp}$ and $E_{||}$ is the energy imbalance in the direction perpendicular and parallel to the beam axis respectively. With these cuts a total of 1507k hadronic events are selected.

In addition to above cuts, further cuts were applied to select events with good charged tracks and to assure that the tracker did not suffer from any problems. The cuts applied are as follows;

- $N_{TRK} \geq 5$
- $p_{TOT}^{TRK}/\sqrt{s} \geq 0.15$
- $p_{||}/p_{TOT},\ p_{\perp}/p_{TOT} \leq 0.75$

As mentioned before, for the mixed-pairs sample we need to have clear two-jet event topology, we consider events with thrust greater than or equal to 0.97.

3 Analysis

In Fig. 1, we show the numbers of like and unlike-sign pairs found in the L3 data as a function of Q. In figures 2 and 3, we show the ratios of like-sign pairs to unlike-sign pairs and mixed-pairs, respectively. In both figures, one can see a clear enhancement in the region $Q < 0.3$ GeV. In figure 2, one can see that the ratio slowly falls with decreasing Q. This can be explained by the following arguement: pairs at small Q are formed predominantly by pairing particles from the same jet, and assuming that the total charge of a jet is always zero, it is easy to see that there are fewer like-sign combinations available within a jet than unlike-sign ones. In the same figure, one also sees small dips near $Q = 0.4$ GeV and $Q = 0.7$ GeV. These dips can be explained by $\pi^+\pi^-$ pairs resulting from the decays $K^0 \rightarrow \pi^+\pi^-$ and $\rho^0 \rightarrow \pi^+\pi^-$, respectively.

In our distributions we also correct for the Coulomb interaction which acts differently for the like and unlike-sign pairs. This correction is applied by using the Gamow factors [6];

$$W_l = \frac{exp(2\pi\eta) - 1}{2\pi\eta} \tag{9}$$

$$W_u = \frac{1 - exp(-2\pi\eta)}{2\pi\eta} \tag{10}$$

$$\eta = \alpha m_\pi / Q \tag{11}$$

where α being the electromagnetic coupling constant and m_π the pion mass.

Finally, for fitting the correlation function instead of using the form given in equation 4 we use the following form;

$$C(Q) = a(1 + bQ)[1 + \lambda\ exp(-Q^2R^2)] \tag{12}$$

in the fit λ, R, a, and b are the first, second, third and fourth parameters respectively. In all our fits we exclude the region between $0.388 < Q < 0.924$ GeV. The double ratios with the fit both for the reference sample of unlike-sign and mixed pairs are shown in figures 4 and 5 respectively.

4 Results

From the fit of figure 4 one gets a value of $\lambda = 0.303 \pm 0.006$ and R = 4.795 ± 0.124 GeV^{-1} for the reference sample of unlike-sign pairs. Similarly from the fit of figure 5, one obtains a value of $\lambda = 0.200 \pm 0.016$ and R = 2.967 ± 0.259 GeV^{-1} for the reference sample of mixed pairs. The two values are not compatible with each other within the limits of statistical errors. This difference between the values of λ and R due to the reference samples gives the largest contribution to the systematic error i.e. 17% and 19% for λ and R respectively. The selection procedure contributes 3.7% in case of λ and 4% in case of R to the total systematic error. Finally we get the following numbers;

$$\lambda = 0.252 \pm 0.006(\text{stat}) \pm 0.044(\text{syst})$$

$$R = 3.881 \pm 0.124(\mathrm{stat}) \pm 0.776(\mathrm{syst})\ \mathrm{GeV}^{-1}$$
$$\sigma = 0.764 \pm 0.024(\mathrm{stat}) \pm 0.153(\mathrm{syst})\ \mathrm{fm}$$

References

[1] G. Goldhaber, S.S. Goldhaber, W. Lee and A. Pais, Phys. Rev. Lett **3** (1959) 181.

[2] CLEO Collab., P. Avery et al., Phys. Rev. **D 32** (1985) 2294;
TPC Collab., H. Aihara et al., Phys. Rev. **D 31** (1985) 996;
TASSO Collab., M. Althoff et al., Z. Phys. **C 30** (1986) 355;
MARKII Collab., I. Juricic et al., Phys. Rev. **D 39** (1989) 1.

[3] OPAL Collab., P.D. Acton et al., Phys. Lett. **B 267** (1991) 143;
ALEPH Collab., D. Decamp et al., Z. Phys. **C 54** (1992) 75;
DELPHI Collab., P. Abreu et al., Phys. Lett. **B 286** (1992) 201.

[4] E. A. De Wolf, I. Dremin and W. Kittel, Phys. Rep. **270** (1996) 1.

[5] L3 Collab., B. Adeva *et al.*, Nucl. Inst. Meth. **A 289** (1990) 35;

[6] R. Lednicky, V.L. Lyuboshits, Sov. J. Nucl. Phys. **35** (1982) 770.

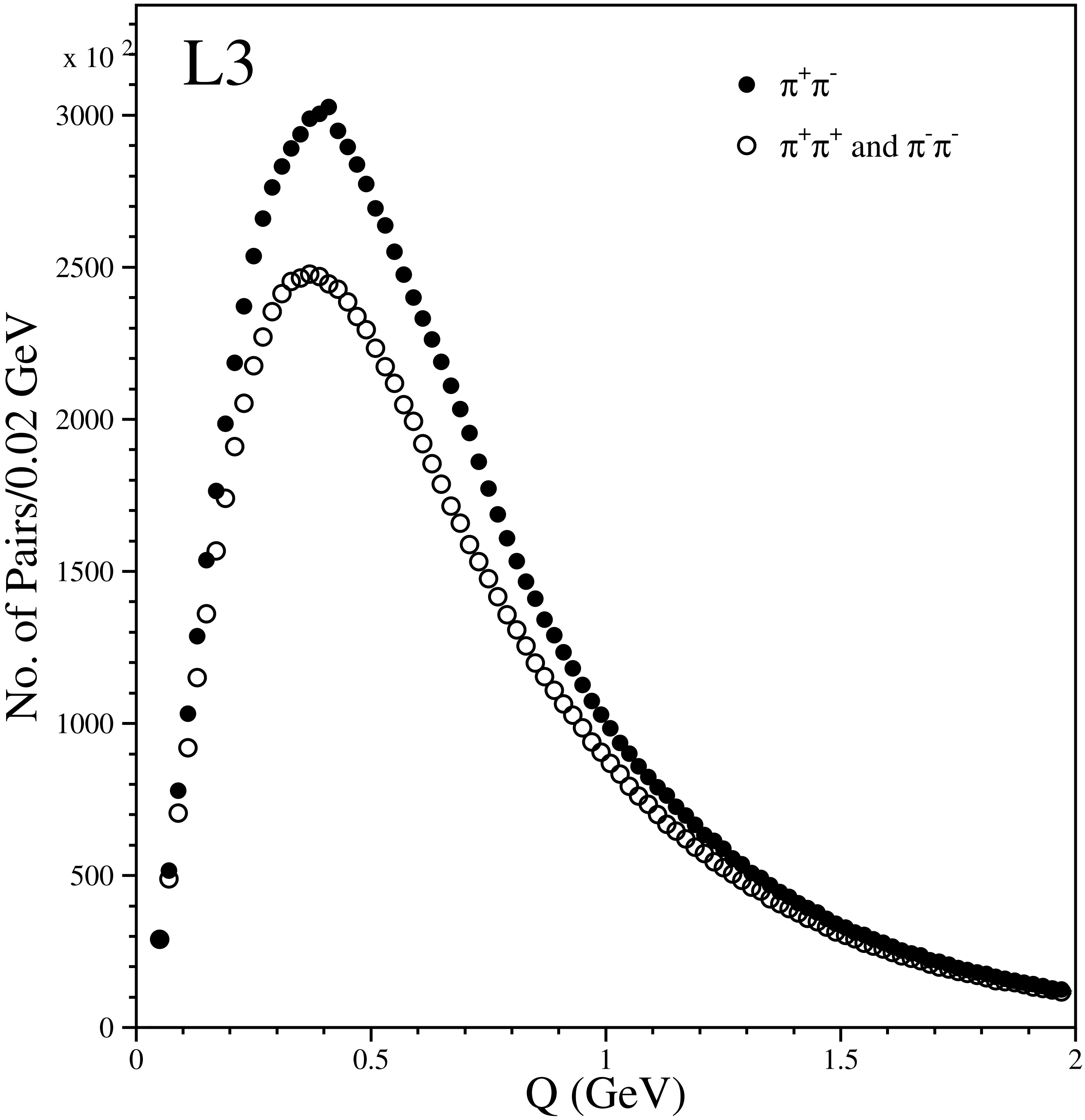

Figure 1: The distributions of unlike-sign and like-sign pairs is shown with respect to the variable Q. The solid pionts represent unlike-sign pairs whereas open points represent like-sign pairs.

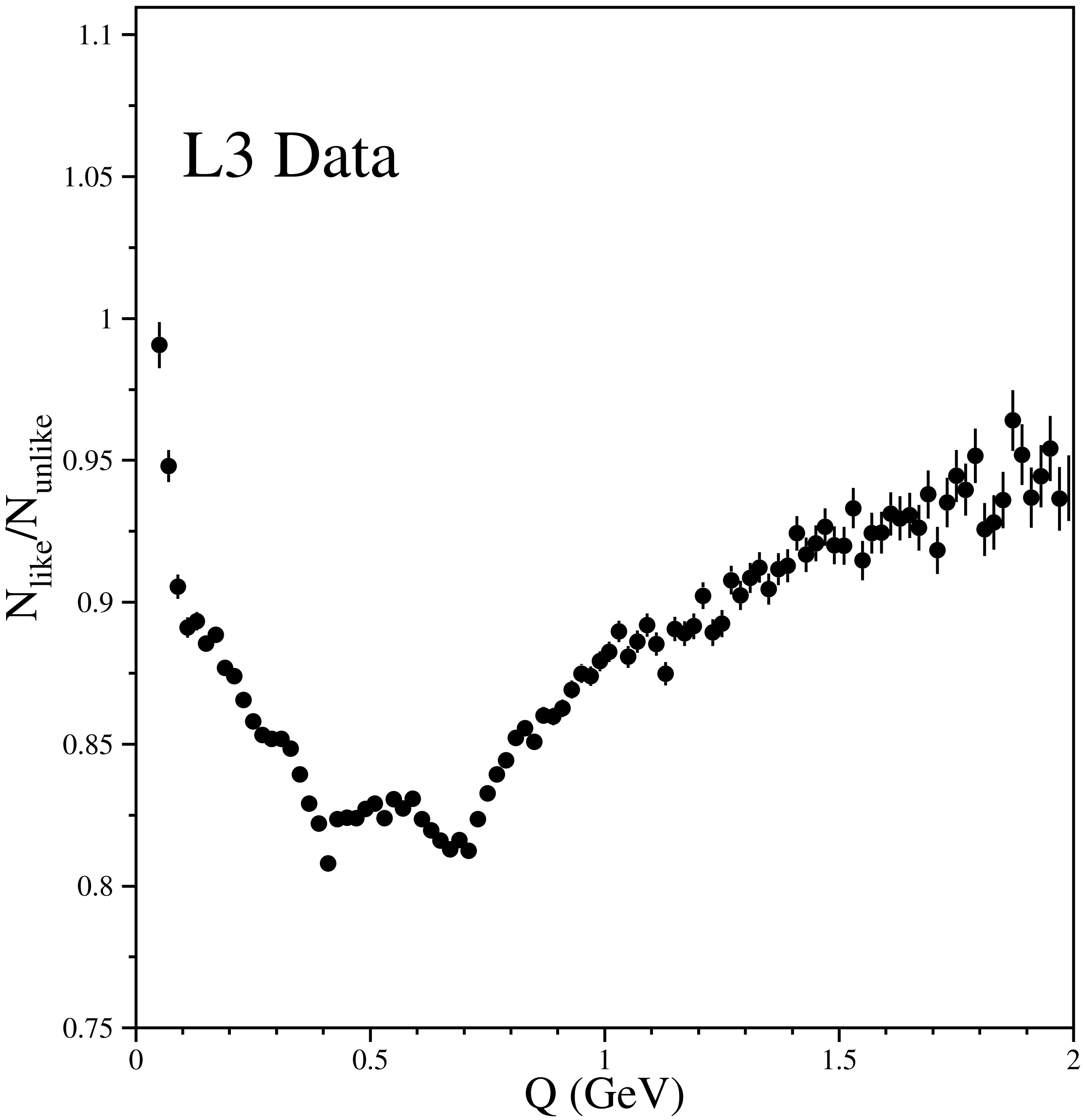

Figure 2: The ratio of like-sign pairs to unlike-sign pairs is shown with respect to the variable Q.

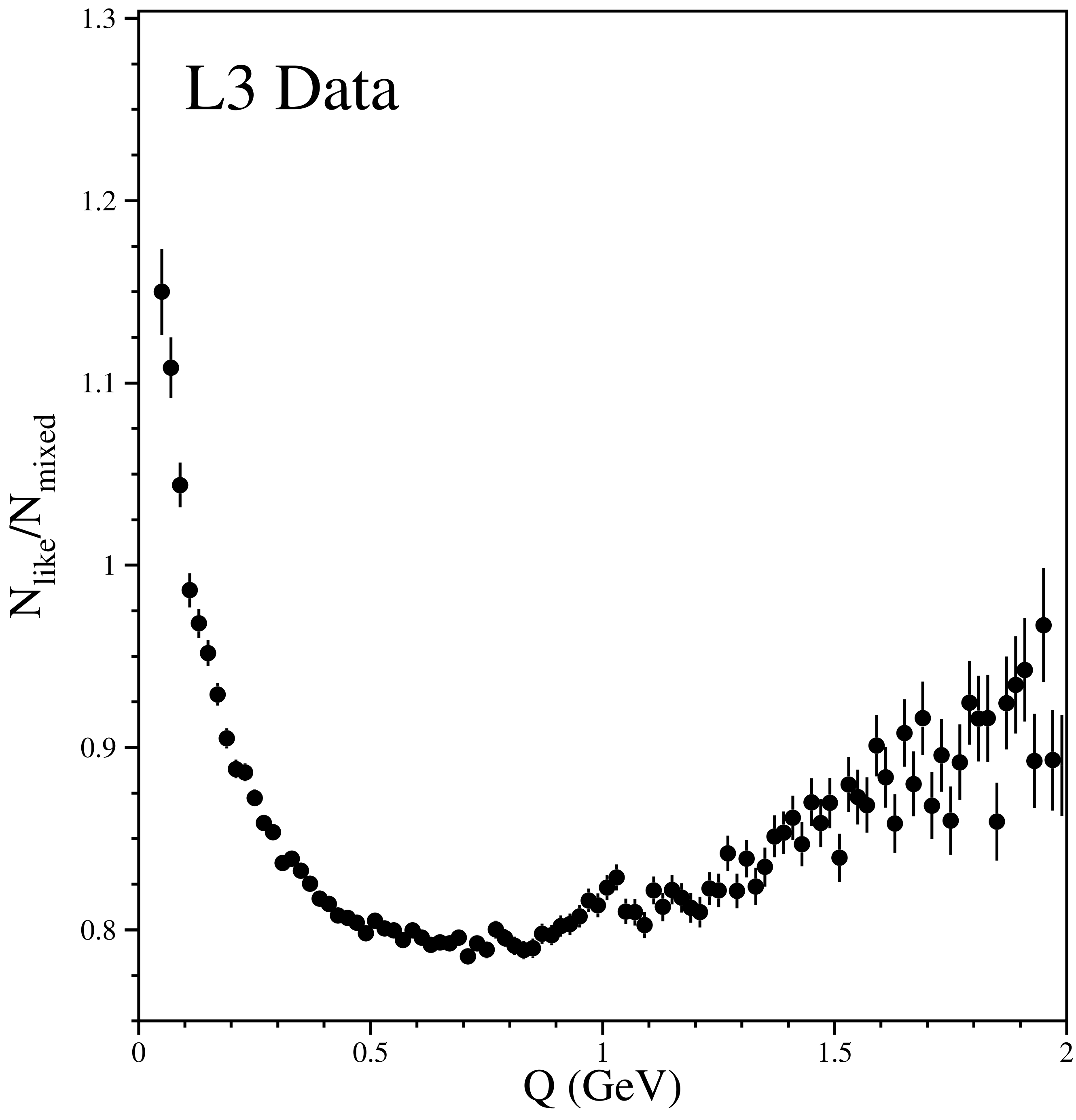

Figure 3: The ratio of like-sign pairs to mixed-pairs is shown with respect to the variable Q.

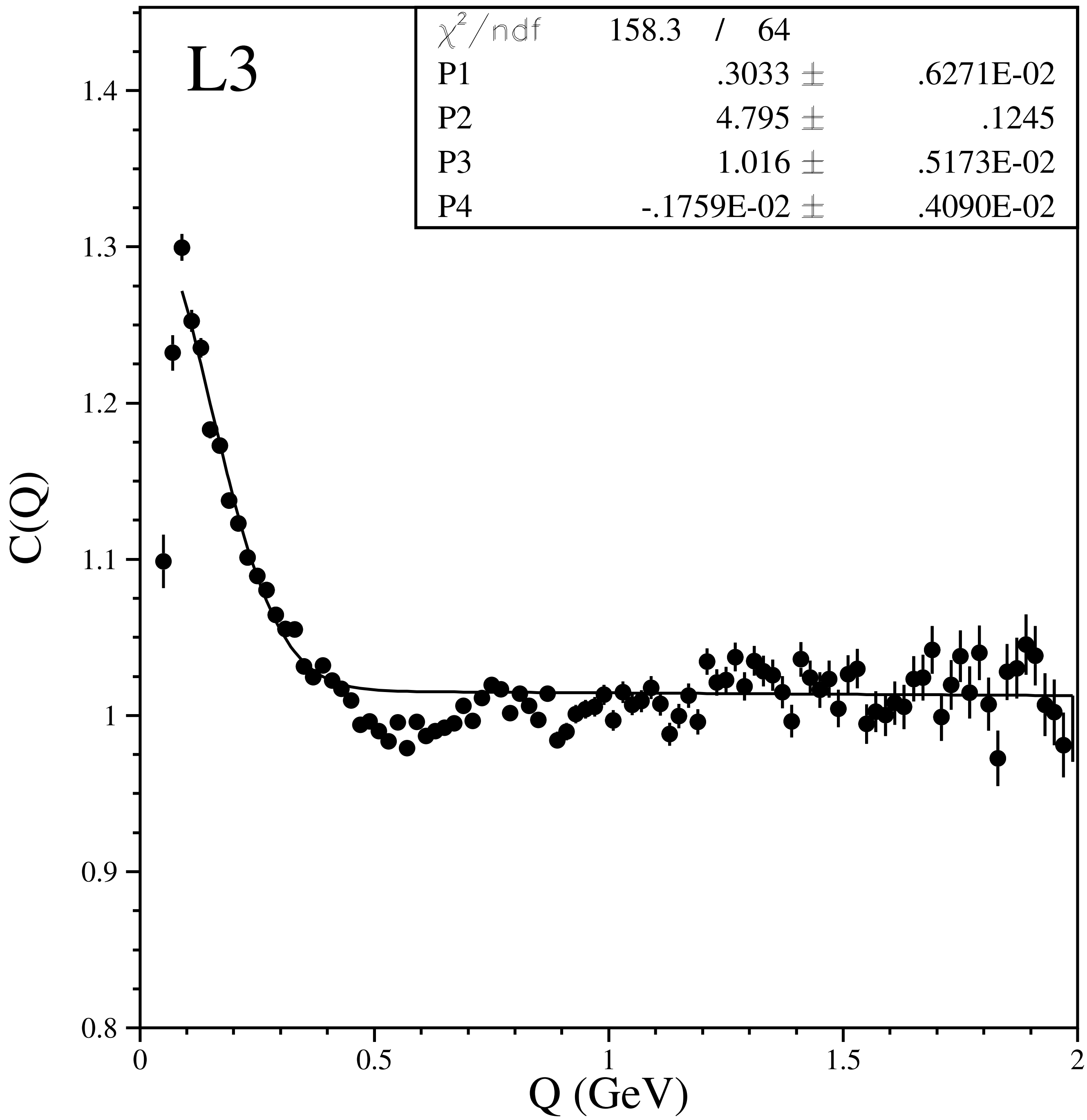

Figure 4: The double ratio in the case where reference sample used is the unlike-sign pairs is shown with respect to the variable Q.

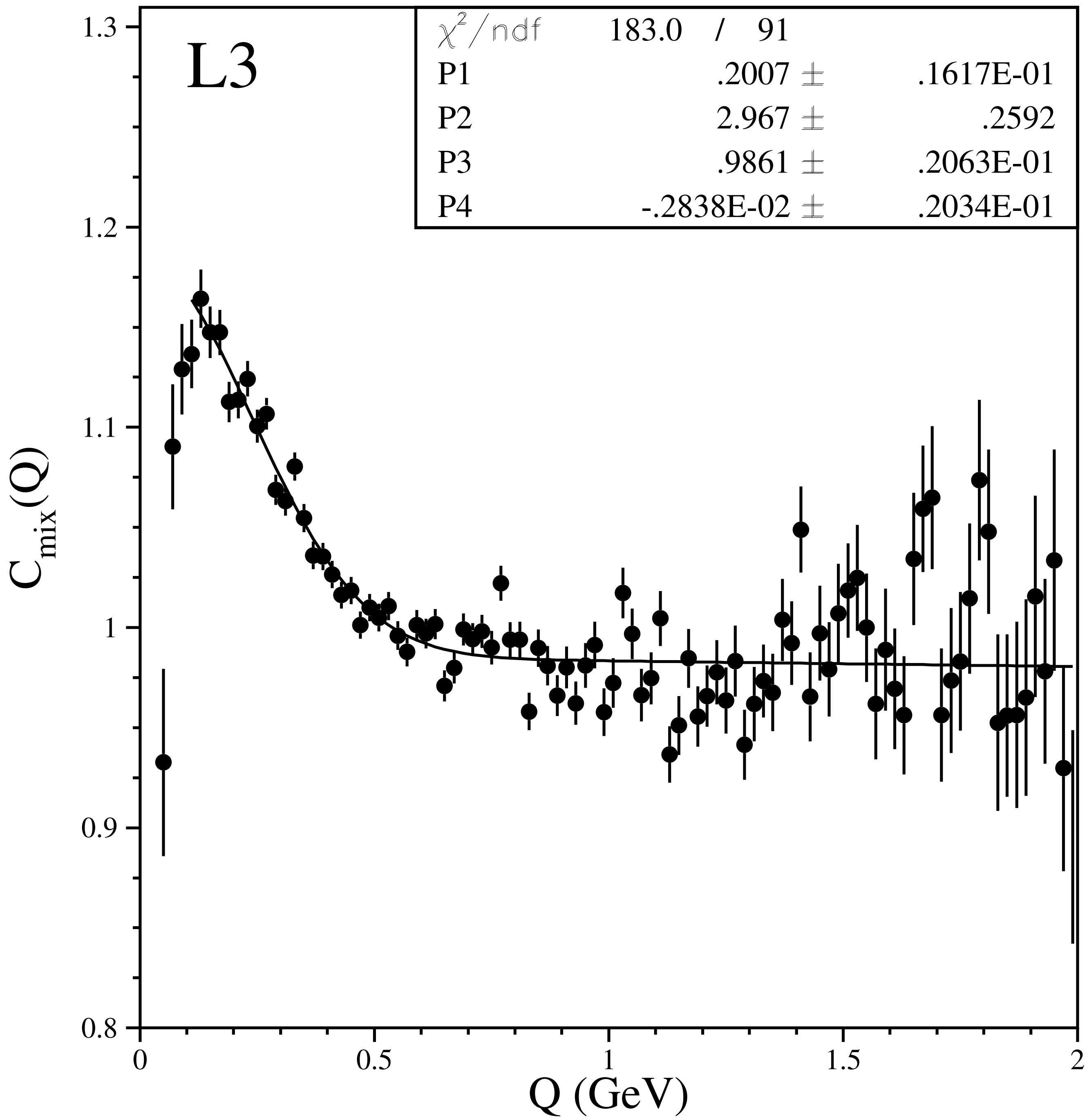

Figure 5: The double ratio in the case where reference sample used is the mixed-pairs is shown with respect to the variable Q.