Refining the inner core of the Paris $N\bar{N}$ potential

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The parameters of the short range part of the Paris $N\bar{N}$ potential are readjusted by fitting to a new set of data which includes the recent measurements on the charge exchange $p\bar{p}\to n\bar{n}$ reaction. Significant improvements in the fit are obtained. [S0556-2813(99)04504-5]

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The Paris $N\bar{N}$ optical potential was constructed in 1982 [1] and upgraded in 1994 [2]. Both times, the long and medium range (LR+MR) parts, i.e., for interdistances $r > 1$ fm, were taken from the Paris NN potential by G-parity transformation, while for the short range (SR) part, both real and imaginary potentials were parametrized to fit to the set of existing data (915 data points in 1982 and 3800 in 1994). Since then, many new data for the charge exchange (CEX) $p\bar{p}\to n\bar{n}$ reaction have come out from LEAR. Although most of them agree well with our predictions [3], some others [4,5] are not well reproduced.

We present here a reanalysis of the phenomenological SR part by fitting to a set of about 4000 data which consists of the new data as well as a selected set of the pre-1994 data.

In Ref. [2] we already have noticed that some data in the $p\bar{p}$ differential cross sections are inconsistent with others, giving rise to very large χ^2 (see Table I of [2]). In Ref. [6], precisely the same data (505 points) were excluded from their $N\bar{N}$ database (the so-called Nijmegen 1993 $N\bar{N}$ database). After some controversy, there seems to be a consensus about the inconsistency of these data. We also omit 50 other spurious elastic and 76 CEX pre-1994 data, in the same way as in Ref. [6]. We thus retain a final set of 3814 data consisting of 3111 elastic data [8], 585 CEX data [3–5,7,9], 70 total cross sections [10], and 48 annihilation cross sections [11].

The 15 parameters of the SR part for each isospin state as defined in the Appendix of Ref. [2] are adjusted to fit to the above set of data. The fitting procedure is also described in that appendix. We start the search by setting, for $r<r_c \sim 1$ fm, all potentials except the central to zero, and then introduce progressively the tensor and spin-orbit components. In this process, it is found that the important parameters are (i) for the real part, the six parameters giving the heights of the central triplet and singlet, of the tensor, and of the LS components at $r=r_2=0.6$ fm; (ii) for the imaginary part, the four couplings of the triplet and singlet central components. The remaining five parameters allow just a fine-tuning of the fit.

A best fit to the above new data set yields a χ^2/data $=2.95$.[1] In more detail, the values of χ^2/data are 2.16 for

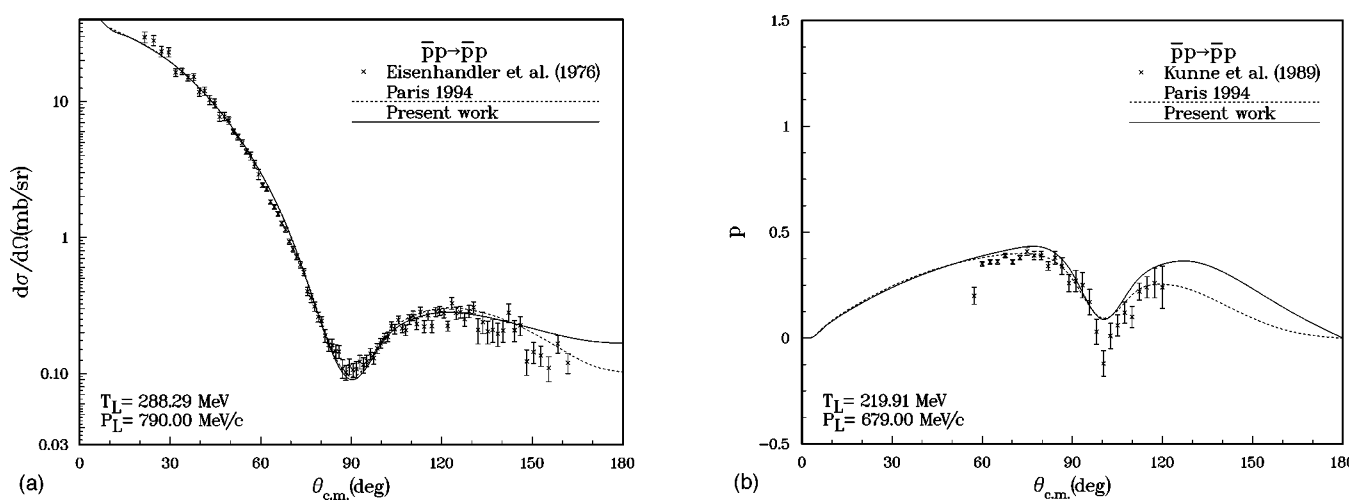

FIG. 1. Elastic differential cross sections and polarizations. Curves labeled 1994 are from Ref. [2]. Data are from Eisenhandler *et al.* and from Kunne *et al.* [8].

[1]In contrast to Ref. [2], to compute χ^2/data, Ref. [6] added 103 normalizations to the number of data points. Here, we proceed in the same way, introducing 86 normalizations for elastic and 36 for CEX data.

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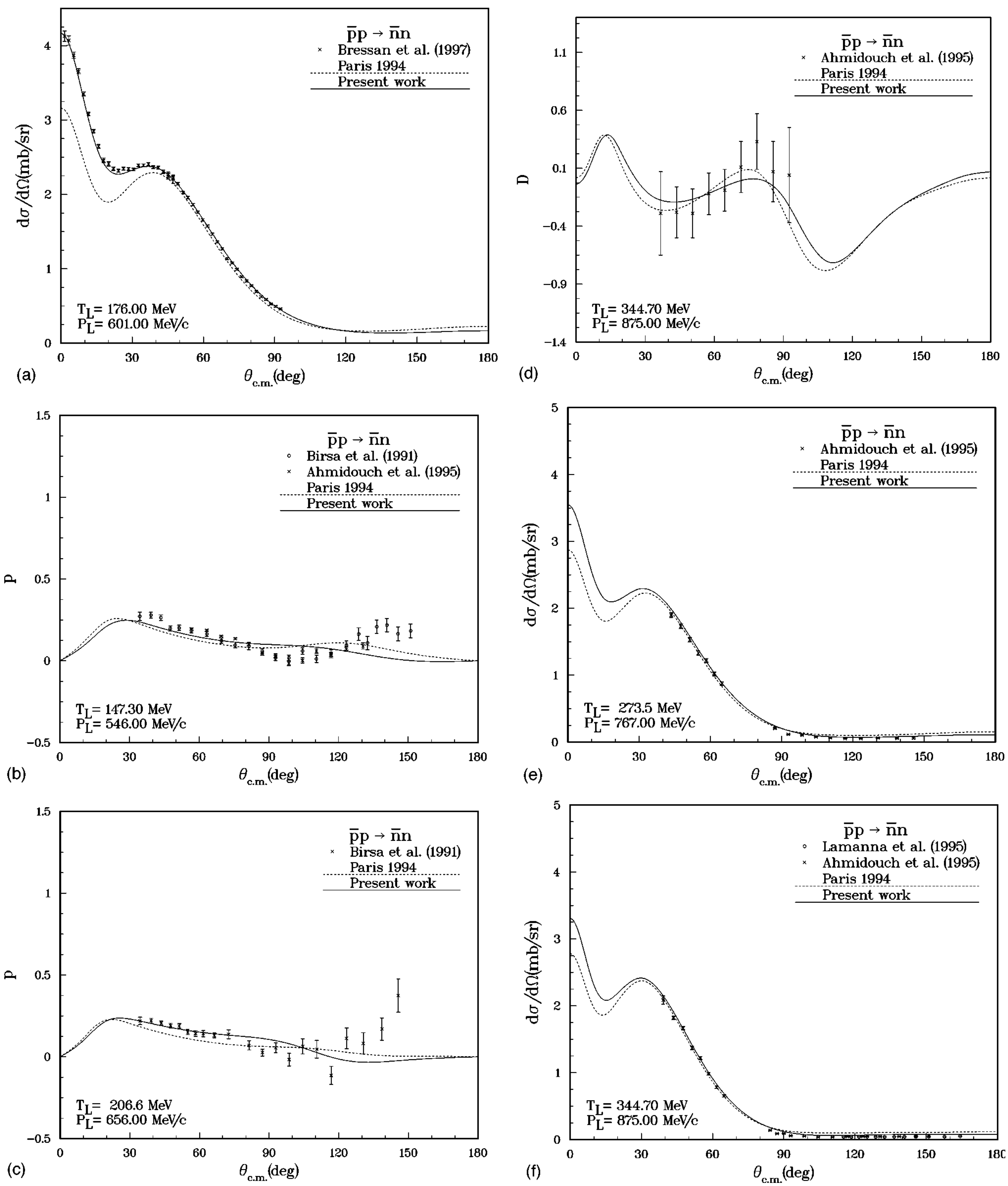

FIG. 2. CEX differential cross sections and polarizations. Curves labeled 1994 are from Ref. [2]. Data are from Ahmidouch *et al.* [4], Birsa *et al.* [9], Bressan *et al.* [5], and Lamanna *et al.* [7]. Curves are multiplied by a factor 0.8 in (a), by a factor 0.76 in (e) and by a factor 0.66 in (f).

elastic data, 6.50 for CEX data, 6.41 for total cross sections, and 4.47 for annihilation cross sections. For elastic $p\bar{p}$ differential cross sections, the quality of the fit remains equivalent to that of the 1994 version, while the elastic polarizations are slightly improved. The main improvements occur in the charge exchange observables. For the same complete data set, the 1994 version gives 6.37. Some examples of the significant results are shown in Figs. 1 and 2. The values for the 15 parameters of the model obtained in this fit are given in Table I.

It is worth noting that in some new measurements [4,7] the quoted experimental uncertainties are so tiny that in spite of an apparent good fit [see Figs. 2(e) and 2(f)] the corresponding χ^2/data contribute very significantly to the total

TABLE I. Parameters of the real and imaginary parts, as defined in [2], of the Paris $N\bar{N}$ potential obtained with the fit to our 1998 data set.

Potentials		$T=0$	$T=1$
$U_0^a(r_3)$		8594.41	−1917.54
$U_0^a(r_2)$		−489.08	−1716.76
$U_0^b(r_2)$		1.307	−0.131
$U_1^a(r_3)$		−5286.67	3121.01
$U_1^a(r_2)$		−810.89	−1135.07
$U_1^b(r_2)$		−1.741	−1.931
$U_{LS}(r_2)$		788.30	−423.71
$U_T(r_2)$		397.14	128.14
$U_{SO2}(r_2)$		75.03	172.48
	i	g_i	f_i (MeV^{-1})
$T=0$	C	124.86	0.0190
	SS	−3.83	−0.0373
	LS	35.369	
	T	2.057	
$T=1$	C	78.40	0.0335
	SS	19.94	0.0412
	LS	12.027	
	T	5.073	

value. Moreover, the differential cross sections need rather large renormalization factors.

In 1994, Timmermans *et al.* [6] performed a partial wave analysis (PWA) of the 1993 Nijmegen database along the same lines as in their PWA of the NN data, and their best fit gives the very good value of χ^2/data=1.043 for a total set of 3543 data points (see footnote 1 concerning the number of data points). For comparison, we apply our fitting procedure to our model but using the 1993 Nijmegen database. We obtain a χ^2/data=1.92 for their total database. In more detail, the values of χ^2/data are 1.64 for 3024 elastic data, 4.22 for 341 CEX data, 2.39 for 70 total cross sections, and 1.25 for 48 annihilation cross sections. Since we have no free parameters in our LR+MR forces, we consider the value 1.92 as satisfactory. To see how well this solution can fit to our data set that includes the new CEX data, we *calculate* χ^2/data for this set and find the value of 3.39. This probably means that these new CEX data are not well reproduced with the present version of Ref. [6].

We have redetermined the parameters of the SR part of the Paris $N\bar{N}$ potential by fitting to a new set of data which includes, in particular, the recent measurements on the charge exchange $p\bar{p}\to n\bar{n}$ reaction at LEAR. Significant improvements in the fit are obtained even though the new values for the parameters do not exhibit strong deviations from those determined in 1994. This shows a strong stability of the model, in spite of the number of adjustable parameters. We would like to stress again that, in our judgment, this number is minimal if one wishes to get an accurate account of the simultaneous presence of scattering and annihilation processes as well as the complex spin and isospin structure in the $N\bar{N}$ system. Our analysis shows also the usefulness and the need of new and accurate low energy data to make progress in the description of the nucleon-antinucleon forces. Finally, we wish to mention that for applications of the Paris $N\bar{N}$ potential, like the initial state of final state interactions in various processes, besides the SR part described here, the values for the LR+MR potentials can be provided upon request.

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