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J. Banaigs, J. Berger, M. Cottereau, F. L. Fabbri, L. Goldzahl, C. Le Brun, P. Picozza and L. Vu-Hai: EXPERIMENTAL TEST OF CHARGE SYMMETRY IN STRONG INTERACTIONS THROUGH THE REACTION $d + d \longrightarrow He^4 + \pi^o$.

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J. Banaigs[(x)], J. Berger[(x)], M. Cottereau[(o)], F. L. Fabbri, L. Goldzahl[(x)], C. Le Brun[(o)(+)], P. Picozza and L. Vu-Hai[(x)]: EXPERIMENTAL TEST OF CHARGE SYMMETRY IN STRONG INTERACTIONS THROUGH THE REACTION $d+d \rightarrow He^4 + \pi^o$.

ABSTRACT. -

The reaction $d+d \rightarrow He^4+\pi^o$, forbidden by isotopic spin conservation, has been studied using 1.89 GeV/c incident deuterons. The upper limit of the differential cross section ($d\sigma/d\Omega$) obtained for this reaction at $\theta_{c.m.} = 79^o$ is: 1.9×10^{-35} cm^2/sr.

Charge independence and charge symmetry belong to the elementary symmetries assumed to be valid for hadronic interactions. However, a violation of charge-independence amounting to (2.13 ± 0.52)%, after data correction for long-range electromagnetic effects, has been shown experimentally[(1)], and some evidence - though indirect and some what unclear - seems to exist also for a charge-symmetry breaking[(2)]. These violations may be consistent with effects of electromagnetic origin; however, no complete theoretical explanation has been provided for them. The breaking of charge independence in strong interactions should be primarily due to the mass splitting of mesons. For charge-symmetry breaking, a possible mechanism[(3)] may be the isospin mixing, occurring whenever states with the same quantum numbers, except

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isospin, are nearly degenerate: in particular the electromagnetic mixing of isovector and isoscalar mesons (ρ-ω-ϕ and π-η). Such effects lead to a true charge dependence of the nuclear forces.

We have studied the process:

$$d + d \longrightarrow He^4 + \pi^o , \qquad (1)$$

where π^o production through strong interaction is forbidden by isotopic spin conservation. Actually, the absence of π^o production in this reaction would simply confirm the validity of charge symmetry[1]. Process (1) then provides a good test for charge symmetry since the long-range electromagnetic forces don't affect this process, and the short-range ones can only give small contributions (e.g. electromagnetic π^o production with a γ reabsorbed, which is a second-order effect in the fine-structure constant). The most relevant mechanism expected in process (1) is based on virtual η^o production and π^o-η^o mixing[4]. Thus the study of this reaction may be a way of measuring experimentally the π-η mixing, the theoretical value of which varies between 1% and 4%[1,5].

This experiment was performed with the extracted deuteron beam of the synchrotron Saturne at Saclay. The incident momentum was 1.89 GeV/c, and α particles were detected at $\theta = 11^o$ in the laboratory frame. The experimental layout was basically the same as that already used previously in another study of dd interactions[6].

The incident extracted beam of $1\text{-}2 \times 10^{11}$ deuterons per pulse was focused on a liquid deuterium (or hydrogen) target of 6 cm length. The position and the vertical and horizontal profiles of the beam were permanently controlled by two wire chambers located at the beginning of the transport channel and in front of the target. The incident beam intensity was monitored by two telescopes of counters: both informations were constantly checked to be in agreement with each other within $\pm$ 1%. The method used for determination of the incident intensity has been presented in a previous paper[7]. The uncertainty in the absolute monitoring was about 10%. The incident deuterons' momentum was determined within $\pm$ 0.5% by measuring the momentum spectrum of protons produced through stripping of the deuterons on the target. Particles emitted from the target at 11^o in the lab frame were analysed by a double-focusing magnetic spectrometer, which had been calibrated in our previous experiments[8]. The uncertainty in the momenta of detected particles was $\pm$ 0.5%. Two contiguous scintillation counters, placed at the intermediate spectrometer image, selected two momentum bins; each one of them was in coincidence with three super-imposed counters located at the final image, 14 meters down-stream from the intermediate image. The particles were identified without ambiguity through the time of flight and the energy loss in the four plastic scintillators. A collimator defined a solid angle of 2.2×10^{-4} sr. For each spectrometer channel, the momentum resolution, constant in the range analyzed, was $\Delta p/p = \pm 0.86\%$; the reduced acceptance $\Delta p \Delta\Omega/p$, which was a monotonic function of the momentum, varied between 2.1 and 2.9×10^{-6} sr. The lab. angle of the scattered particles was checked by using dd elastic scattering.

The kinematics for the reaction

$$d + d \rightarrow He^4 + X \qquad (2)$$

with $X = \gamma, \pi^o, 2\pi^o$ is shown in Fig. 1. We have measured the α particles' yield from the target filled with deuterium or hydrogen, for six

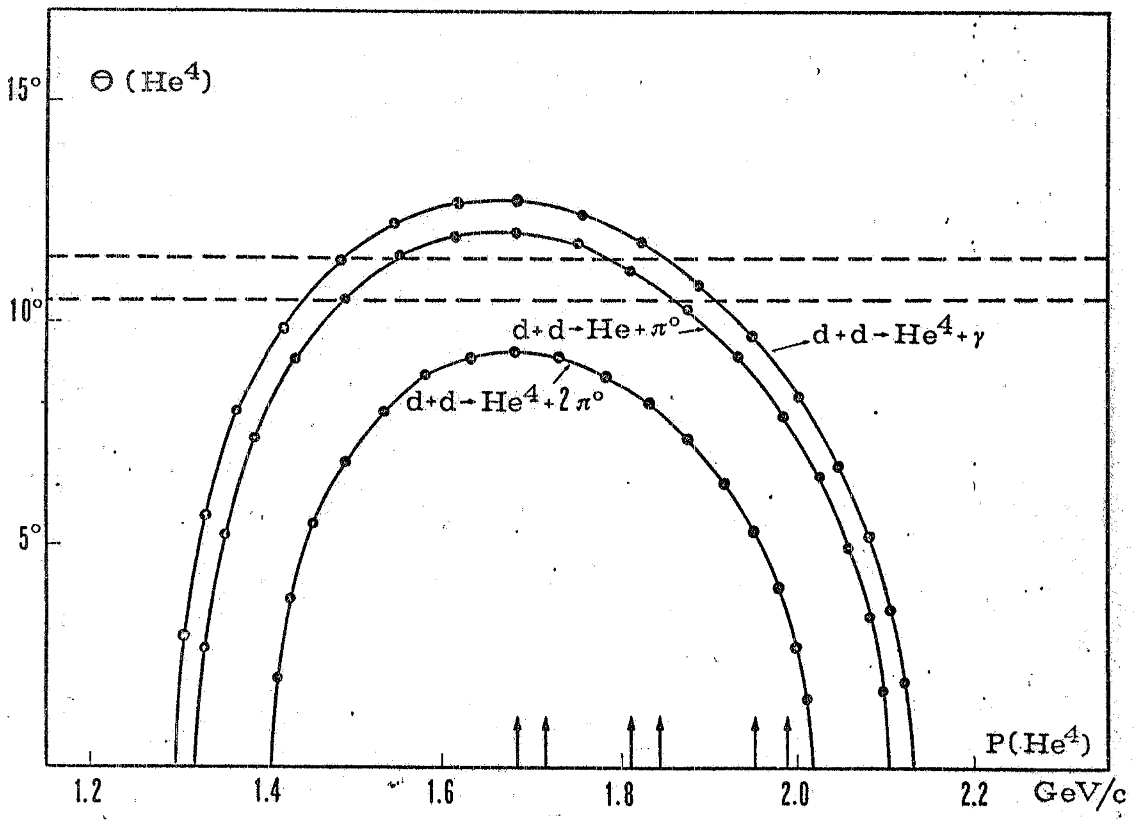

FIG. 1 - Kinematics of the reactions $d+d \rightarrow He^4+\gamma$, $d+d \rightarrow He^4 + \pi^o$, and $d+d \rightarrow He^4 + 2\pi^o$ at $P_1 = 1.89$ GeV/c. Lab. angle θ_{He^4} vs momentum P_{He^4}. The full circles correspond to center-of-mass angles which are multiple of 10^o. The dotted lines show the angular aperture of the spectrometer. The arrows indicate the momenta of the points measured.

different values of analysed momenta. For each measurement, the stability of the experimental apparatus was verified with a very good accuracy by checking the constancy of the high rate of scattered deuterons ; this stability appeared to lie within 1%. The particle fluxes for 10^{14} incident deuterons are given in Table I. The counting rates

TABLE I - Counts per 10^{14} incident deuterons.

$P(He^4)$ (MeV/c)	α counts D_2 target	α counts H_2 target	Total deuterons counts D_2	Total deuterons counts H_2
1682	21.7 ± 1.3	21.9 ± 1.4	23×10^3	16×10^3
1714	28.2 ± 1.5	25.4 ± 1.5		
1810	35.1 ± 1.8	32.5 ± 1.5	100×10^3	48×10^3
1842	42.7 ± 1.9	37.5 ± 1.7		
1952	48.9 ± 2.3	42.8 ± 2.0	242×10^3	178×10^3
1988	42.1 ± 2.1	38.7 ± 1.9		

of α particles are also shown in Fig. 2. Only the data at 1810 and 1842 MeV/c are in the kinematical range expected for π^0 production

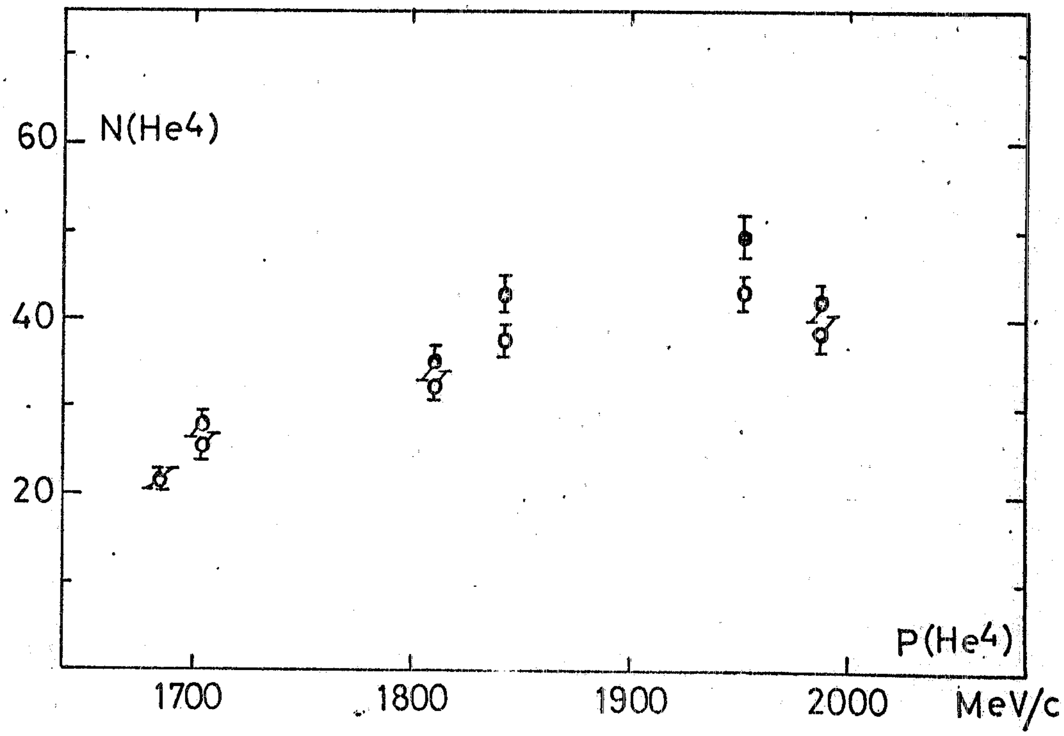

FIG. 2 - α yields from reaction $d+d \rightarrow He^4 + \pi^0$ for 10^{14} incident deuterons, vs α momentum. • measurements with a deuterium target; o measurement with a hydrogen target.

(see Fig. 1), taking into account the spectrometer's momentum resolution and angular acceptance. At the four momentum values which are "off-kinematics", tha data obtained are to be considered as background, essentially due to the production of α particles from deuteron interaction with the target windows. On the other hand, the hydrogen data also give the background of our measurements, since α particles cannot be produced in deuteron-proton collisions.

In order to evaluate the cross section of reaction (1), we have added together the data from both contiguous spectrometer channels, so that we could define the momentum of the α particles by its average value, i.e. 1698, 1826, 1970 MeV/c for the three sets of data respectively. The difference $\alpha_D - \alpha_H$ obtained by subtracting the hydrogen data (α counts) at 1826 MeV/c from the deuterium results at the same momentum yields the net α signal from d d collisions at this momentum value. If we assume this signal to be entirely due to reaction (1), we obtain at $\theta_{c.m.} = 79^o$:

$$(d\sigma/d\Omega)_{c.m.} = (3.6 \pm 1.6) \times 10^{-35} \ cm^2/sr \ . \qquad (3)$$

There is however some strong evidence that not all α particles were produced through reaction (1). Actually, since the data for both deuterium and hydrogen at 1698 MeV/c and 1970 MeV/c should have measured the same background, we expected a zero signal $\alpha_D - \alpha_H$ for these momentum values; however we obtained here again a net positive yield of α particles (see Fig. 2). This positive signal should be due to secondary effects, such as the inelastic scattering, from the liquid target, of α particles produced by the deuteron beam at (and before) the target windows; that scattering should be larger from the deuterium than from the hydrogen target. We have taken into account all these experimental informations in order to determine an upper limit of the cross section for reaction (1). We made the assumption - which looks reasonable - that the yields from $\alpha_D - \alpha_H$, due to the secondary processes just described, varied linearly with the momentum. By linear interpolation of the data $\alpha_D - \alpha_H$ within the interval between the points 1698 and 1970 MeV/c, for which the kinematics excludes π^o production, we obtain the number of α particles produced through the same secondary effects at 1826 MeV/c, where the π^o is located. This value, i.e. (5.8 ± 2.3) α counts, was to be considered as a further background adding itself to the hydrogen data for the same point. On the other hand, the counting rate experimentally obtained from $\alpha_D - \alpha_H$ at 1826 MeV/c was: $(7.8 \pm 3.5)\alpha$ particles. The difference between these two values gives the number of α particles possibly produced by reaction (1). The thus obtained c.m. cross section, i.e. $(0.9 \pm 2.0) \times 10^{-35}$ cm^2/sr, allows us to define an upper limit $\theta_{c.m.} = 79^o$ for 1.89 GeV/c incident deuterons:

$$(d\sigma/d\Omega)_{c.m.} \leq 1.9 \times 10^{-35}\ cm^2/sr\ , \tag{4}$$

with 68% confidence level. This value is five times smaller than the smallest of the previously obtained values. The results of these former experiments, performed at Berkeley and at Dubna, are shown in Table II.

TABLE II

P inc GeV/c	θ c.m. (deg)	Results cm^2/sr	Ref.
1.39	All	$\sigma_{tot} = 70 \times 10^{-33}\ cm^2$	9
1.29	55°	$< 9 \times 10^{-34}$ with 90% C.L.	11
1.39	90°	$< (0.097 \pm 0.027) \times 10^{-33}$	10
1.89	79°	$< 2 \times 10^{-35}$ with 68% C.L.	our exp.

There exists no rigorous method in order to derive a limit of validity of a law such as charge symmetry from the experimental study of a reaction which is forbidden by this law. In the case of reaction (1), the previous limits were obtained through a comparison either with the allowed reaction $d + d \to He^4 + \gamma$, or with an estimation following the method developed by Greider[12] on the basis of the impulse approximation. This method provides a value for the differential cross section of the reaction $d + d \to He^4 + \pi^o$, which is derived - ignoring isospin - from the differential cross sections[13] of the reactions $p + d \to He^3 + \pi^o$ and $n + d \to H^3 + \pi^o$. In order to relate our experiment to the former results, we have performed that computation for our experimental conditions, thus obtaining:

$$(d\sigma/d\Omega)^{calculated} = 7.1 \times 10^{-33}\ cm^2/sr\ . \tag{5}$$

From the comparison of this value with our experimental result (4), it would result that isospin conservation amounts to at least 99.73%. This value is of the same order as those obtained at lower energy.

Finally, the study of reaction (1) shows no evidence for the existence of an isoscalar particle in the pion-mass region, such as predicted in a recent gauge theory model of strong interactions[14].

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REFERENCES. -

(1) - E. M. Henley, Isospin in Nuclear Physics (ed. D. H. Wilkinson) (North-Holland, Amsterdam, 1969), p. 16; and references here quoted.

(2) - J. W. Nagele, Nuclear Phys. A165, 305 (1971); S. Schlomo, Phys. Letters 42B, 146 (1972).

(3) - E. M. Henley and T. E. Keliher, Nuclear Phys. A189, 632 (1972).

(4) - E. M. Henley, in High Energy Physics and Nuclear Structure (ed. G. Tibell) (North-Holland, Amsterdam, 1974), p. 22.

(5) - N. A. Törnqvist, Phys. Letters 40B, 109 (1972), and references here quoted.

(6) - J. Banaigs et al., Phys. Letters B43, 535 (1973).

(7) - J. Banaigs et al., Nuclear Instr. and Meth. 95, 307 (1971).

(8) - J. Banaigs et al., Nuclear Phys. B67, 1 (1973).

(9) - N. E. Booth, O. Chamberlain and E. H. Rogers, Lawrence Radiation Laboratory Report UCRL-8944 (1960).

(10) - J. A. Poirier and M. Pripstein, Phys. Rev. 122, 1917 (1961); 130, 1171 (1963).

(11) - Yu. K. Akimov, O. V. Savchenko and L. M. Soroko, Soviet Phys. - JEPT 14, 512 (1969).

(12) - K. R. Greider, Phys. Rev. 122, 1919 (1961).

(13) - J. Banaigs et al., Phys. Letters 45B, 394 (1973); C. A. Heusch et al., UC SC 73/008 (1973).

(14) - M. B. Halpern, Nuclear Phys. B66, 78 (1973), and private communication.