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J. Banaigs, J. Berger, M. Cottereau, F. L. Fabbri, L. Goldzahl, C. Le Brun, P. Picozza, T. Risser and L. Vu-Hai : OBSERVATION OF THE ABC EFFECT IN THE REACTION $d + d \rightarrow He^4 + (mm)^0$.

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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, T. Risser[(x,-)], L. Vu-Hai[(x)]:
OBSERVATION OF THE ABC EFFECT IN THE REACTION $d + d \rightarrow He^4 + (mm)^0$. (Submitted to Physics Letters).

ABSTRACT -

The reaction $d + d \rightarrow He^4 + (mm)^0$, where the missing mass system is in a pure state of isospin I = 0, is studied using 2.49 GeV/c incident deuterons and the missing mass technique. The ABC effect is observed, dominating the missing mass spectrum with a production cross section of 0.66 μb/sr at zero degrees in the center of mass system.

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With the deuteron beam extracted from the Saclay synchrotron Saturne we have begun the study of the reaction

(1) $$d + d \rightarrow He^4 + (mm)^0$$

and we present here the first results obtained with incident deuterons of 2.49 GeV/c.

Since the deuteron and the He^4 nucleus have isospin zero, the isospin of the missing mass system must also be zero. Reaction (1) is the simplest process accessible to laboratory study in which a pure

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isospin I = 0 meson system recoils against a single charged particle.

The experimental layout shown in Fig. 1 is that previously used in the study[1, 2] of the reactions

(2) $$d + p \rightarrow He^3 + (mm)^0$$

(3) $$d + p \rightarrow H^3 + (mm)^+$$

(4) $$d + p \rightarrow d + (mm)^+.$$

The incident beam (1.0 to 1.5 x 10^{11} deuterons per pulse) is focussed on a 6 cm liquid deuterium target. Nuclei emerging through the thin windows are momentum analyzed in a magnetic spectrometer. Two pairs of scintillation counters 14 meters apart (S_1 S_2 at the intermediate spectrometer image and S_3 S_4 at the final image) allow one to identify particles both by time of flight and by energy loss in plastic scintillator.

Two counter telescopes and a secondary emission chamber are used as a continuous relative monitor of the incident beam intensity; the three monitors always agree to within $\pm$ 1%. The absolute calibration of the monitors is obtained by irradiating thin targets of carbon and using the value σ = 43 mb for the activation cross section of the reaction $C^{12}(d, p2n)C^{11}$. This value is deduced from the measured value at 3.76 GeV/C[3], assuming that the activation cross section for the reaction $C^{12}(d, p2n)C^{11}$ has the same energy dependence as that for the well measured reaction $C^{12}(p, pn)C^{11}$. With this technique the uncertainty in the overall normalization of the cross sections is $\pm$ 10%. This large uncertainty has no effect whatsoever on the shape of the momentum spectrum, affecting only the overall magnitude.

The calibration of the spectrometer was done in the earlier experiments[1, 2]. The relative momentum scale of the spectrometer was determined from the position of the peaks due to the two body interactions $d + p \rightarrow He^3 + \pi^0$ and $d + p \rightarrow He^3 + \eta^0$ under various kinematic conditions. Then the absolute scale was determined by a measurement of the range of 1.05 GeV/c protons in copper. The uncertainty in momentum of the detected particles is $\pm$ 0.5%.

The momentum of the incident deuterons is determined to $\pm$ 0.5% by measuring the momentum spectrum of protons produced by stripping of the incident deuterons in the target.

Deuterons and He^4 nuclei (which, for the same momentum, have the same velocity) are separated from the other particles in the spectrometer by their time of flight. One then distinguishes without ambiguity the He^4 from the deuterons by the pulse heights in the four scintillation counters.

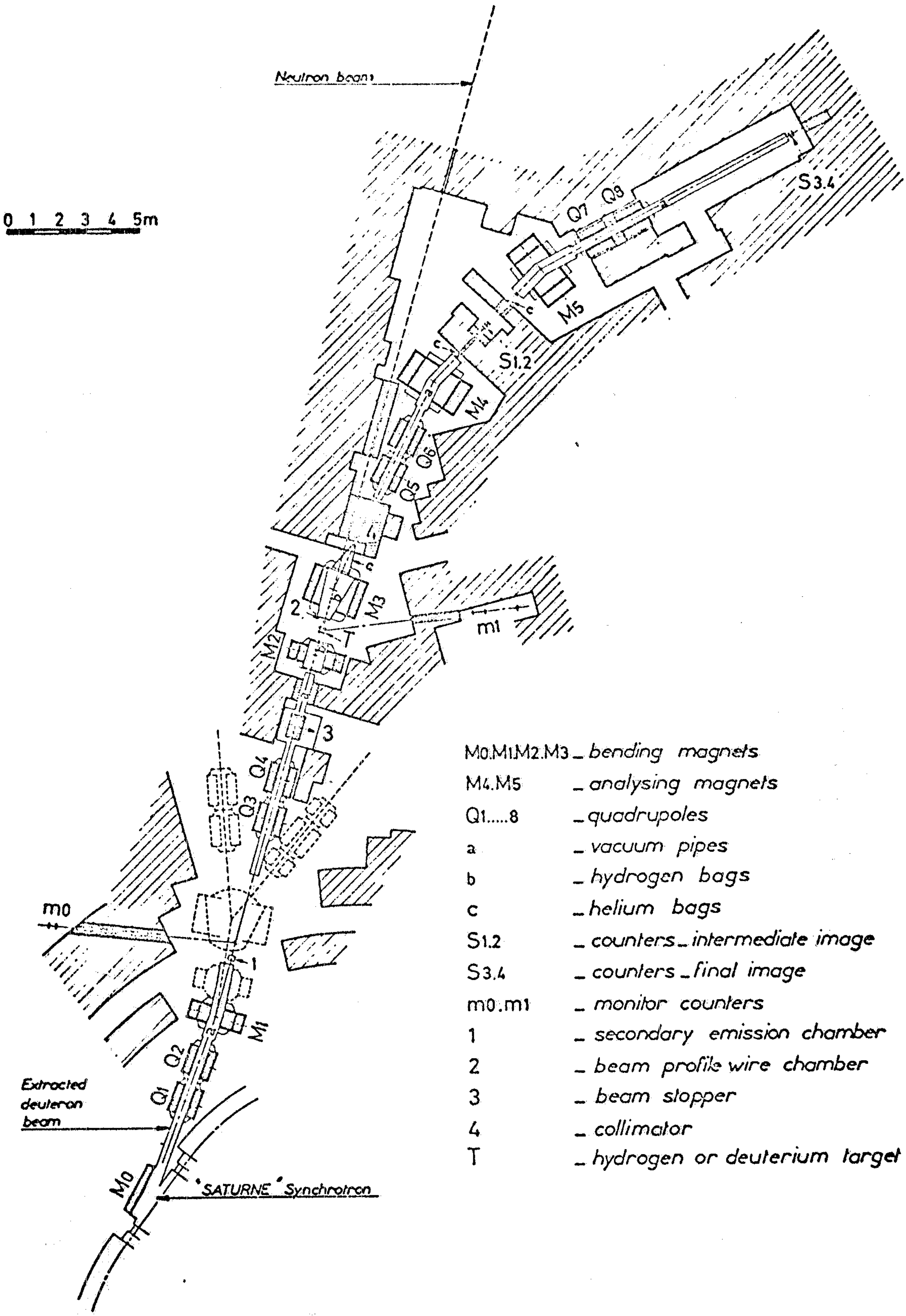

FIG. 1 - Experimental layout

The collimator 4 (Fig. 1) defines a solid angle of 2.2×10^{-4} steradians. The spectrometer acceptance for the He^4 nuclei is calculated using a Monte Carlo program which includes the multiple scattering and energy loss of the nuclei as they traverse the various materials between the point of production in the target and the final counter. Over the region of momenta analyzed, the spectrometer resolution $\Delta p/p$ is $\pm 1.2\%$ and its "reduced acceptance" $\Delta p \ \Delta\Omega/p$ is a monotonic function of the momentum which varies between 0.2 and 0.5×10^{-6} sr.

Figure 2 shows the momentum spectrum for He^4 nuclei emitted at zero degrees in the laboratory (180 deg. in the center of mass system) after the subtraction of the empty target data. The spectrum obtained with an empty target showed absolutely no structure and never exceeded in magnitude one third of the target full spectrum. The statistical error on the difference between the counting with full and empty target is less than 2.5%.

Figure 2 also shows the Lorentz invariant phase space predictions for the reactions $d + d \rightarrow He^4 + 2\pi$ and $d + d \rightarrow He^4 + 3\pi$; these curves include the experimental resolution. No combination of these phase spaces can account for the observed structure in the spectrum. The peak near 1.625 GeV/c is presumably the same as the ABC effect observed[1, 2, 4, 5] in the reaction $d + p \rightarrow He^3 + (mm)^0$ and also[1, 2, 5, 6] in the reaction $n + p \rightarrow d + (mm)^0$. The present experiment shows the first evidence for this effect in the reaction $d + d \rightarrow He^4 + (mm)^0$. The cross section for production of the ABC effect is more than twenty tymes larger than for any possible phase space contribution so that one can determine the position and width of the peak accurately independent of the exact form of the background subtraction. Figure 3 shows the differential cross section $d^2\sigma / d\Omega^* dM$ as a function of the missing mass M. Before transforming the momentum spectrum into the mass spectrum the phase space prediction for $d + d \rightarrow He^4 + 2\pi$ was subtracted (using the normalization of Figure 2). The ABC effect peak is centered at a mass of 332 ± 21 MeV and has a width of 61 ± 10 MeV. These values take into account the resolution of the spectrometer and the experimental uncertainties mentioned above. Integration of the peak yields an ABC production differential cross section of

$$\left.\frac{d\sigma}{d\Omega^*}\right|_{\theta_{cm} = 180^\circ} = 0.66 \pm 0.18 \quad b/sr$$

where the error includes the uncertainty on the incident beam intensity as well as the other experimental uncertainties.

It is interesting to note that this production cross section for the ABC effect is of the same order of magnitude as that in the reaction $d + p \rightarrow He^3 + (mm)^0$.[2]

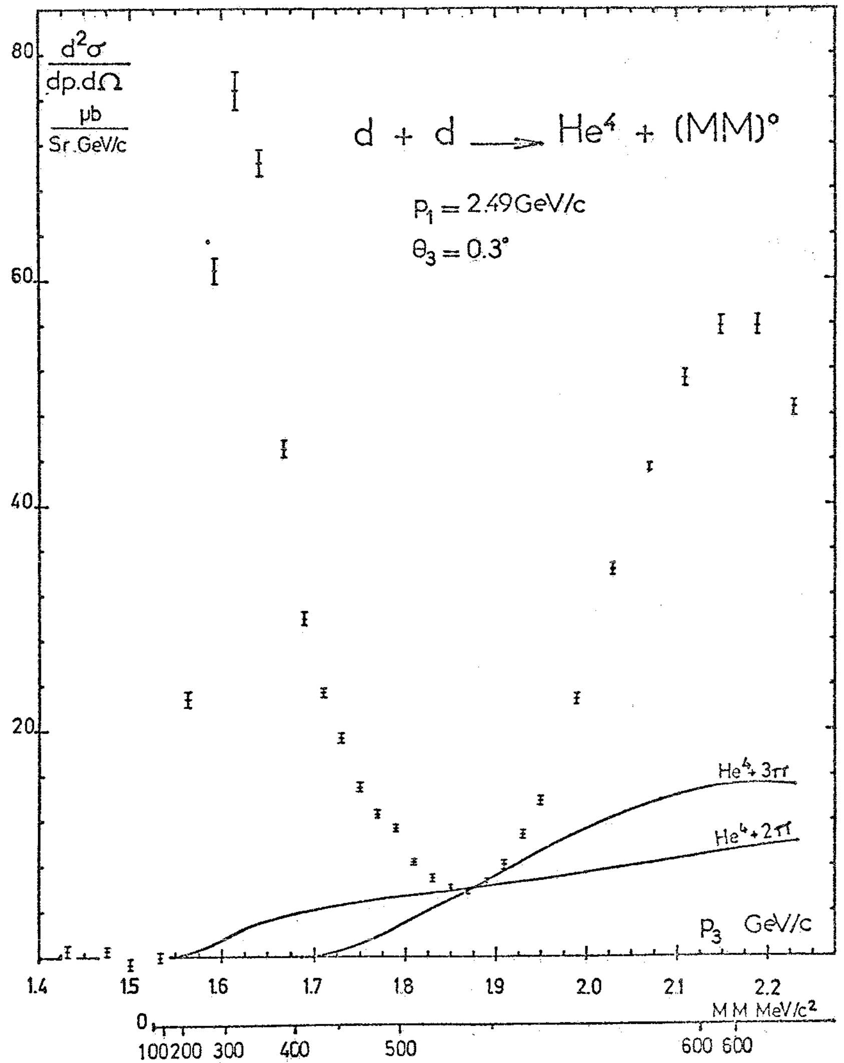

FIG. 2 - Laboratory momentum spectrum for He^4 produced at $\theta_{LAB} = 0$ deg in the reaction $d + d \rightarrow He^4 + (mm)^0$. The solid curves show the Lorents invariant phase space for two and three pion production.

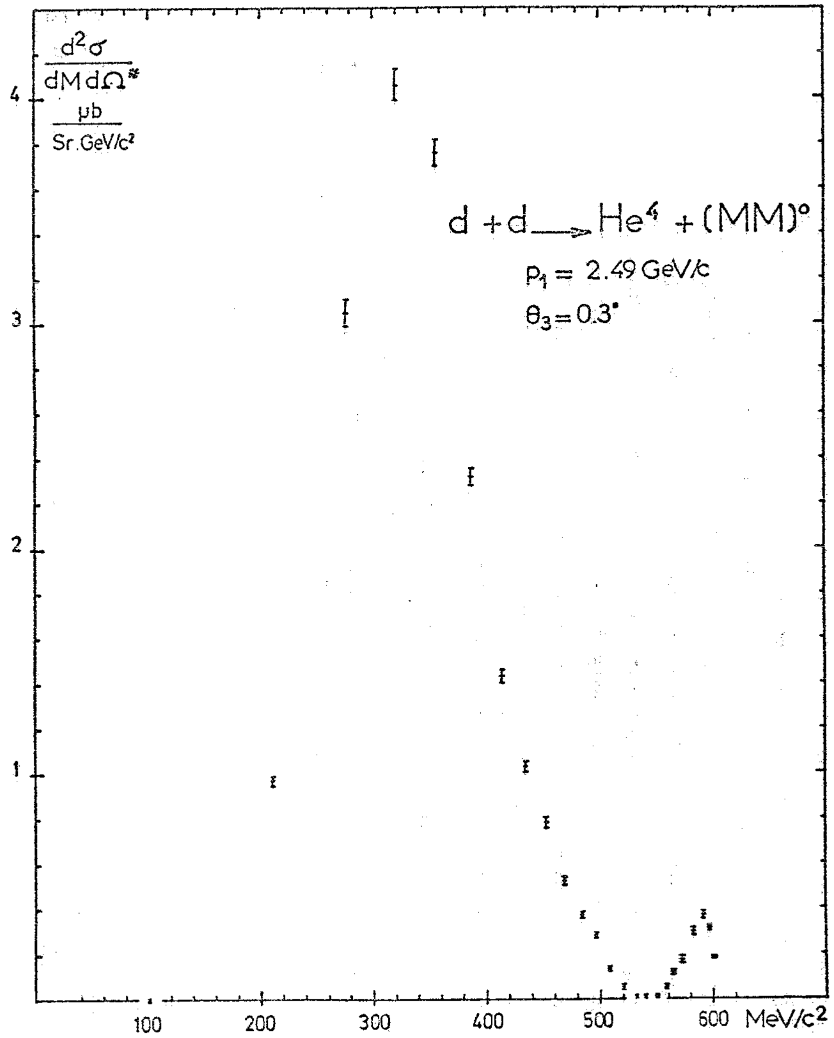

FIG. 3 - Differential cross section $d^2\sigma / d\Omega^* dm$ in the center of mass system for the reaction $d + d \rightarrow He^4 + (mm)^0$. Lorentz invariant phase space for two pion production has been subtracted.

The second obvious structure in the momentum spectrum (around 2.16 GeV/c) is much diminished when the spectrum is presented in the center of mass system. It corresponds to the maximum missing mass which can be produced in the reaction. An analagous structure was encountered in the reaction (2) under various kinematic conditions[1, 2]. This structure did not correspond to a fixed missing mass but changed its position so that it was always found at the maximum missing mass which could be observed. One model for the ABC effect produced in the reaction $n + p \rightarrow d + (mm)^0$ proposes that such a high missing mass enhancement should always be associated with the ABC effect.[7]

On the right flank of the ABC effect one notes a shoulder which could be due to the DEF effect[1, 2, 5] also of isospin zero, discovered in the reaction (2). Supplementary results, permitting a more complete analysis, are necessary before one may say if this effect is also seen in reaction (1).

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