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QUASI ELASTIC SCATTERING OF 600 MeV PROTONS BY ALPHA CLUSTERS IN LIGHT AND MEDIUM NUCLEI

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ABSTRACT

Knockout of α - clusters from light and medium weight nuclei by 600 MeV protons has been investigated. The outgoing protons and α - particles were detected in coincidence ; their momenta were measured with two large magnetic spectrometers with proportional wire chambers. Experimental methods used to work with a high beam rate and an efficient proton rejection in the α-arm are described. Separation energy spectra are given for ^{6}Li, ^{7}Li, ^{12}C, ^{24}Mg, ^{27}Al and ^{40}Ca nuclei. A peak is observed at an excited energy equal to zero, except for the ^{27}Al target.

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I - INTRODUCTION

Recently, alpha clusters knocked out of light nuclei by protons, with energies of about 150 MeV, have been investigated[1-4]. Our (p,pα) experiment was performed with a 600 MeV proton beam from the synchrotron Saturne (Saclay). This energy is necessary to detect fast alpha particles (50-120 MeV range) with a reasonable cross section[5], the strong α-particle absorption by the nucleus and secondary reactions (sequential decay, spallation) are minimized.

When the α- particle momentum in the nucleus before knock-out is about or less than $1 f_m^{-1}$ the kinematical conditions of the reaction are close to those of free p-α scattering. Two magnetic spectrometers, with a 25 msr acceptance, were used to detect (p,pα) reactions. The low (p,pα) cross section required a 10^9 protons/burst beam and the flux of particles in each spectrometer compels the use of proportional wire chambers with low memory time. To avoid the large background due to (p,2p) or (p,pd) reactions, a drastic selection on the alpha arm (Ionization and range counters) is achieved[6-7].

High energy (which means precise localization), large solid angles, high beam rate, efficient proton rejection were difficult constraints ; we will thus describe the experimental methods with some details in paragraph II. Data analysis and separation energy spectra are discussed in paragraph III.

II - DESIGN OF THE EXPERIMENT

A/ KINEMATICS

The quantities of interest in a (p,pα) experiment are the separation energy E_s of the knock-out α-particle and the momentum p_R of the recoil nucleus. The separation energy can be calculated from the equation :

$$E_s = E_0 - E_1 - E_2 - E_R \qquad (1)$$

where E_0, E_1, E_2 are the kinetic energies of the incoming proton, the knock-out α-particle and the scattered proton respectively.

The recoil nucleus energy E_R can be neglected ($E_R = p_R^2/2M_R$). E_s is related to the excitation E_X of residual nucleus by $E_s = E_X - Q$, where Q is the Q value of the reaction. The recoil momentum p_R can be computed from the relation :

$$p_R = p_0 - p_1 - p_2 \qquad (2)$$

If the impulse approximation is valid, the α - particle momentum q in the nucleus before the reaction is related to p_R by $q = - p_R$.

To obtain the quantities E_s and p_R, it is sufficient to determine the momentum vector of the outgoing particles. The schematic diagram of our experiment is shown in Fig. 1.

B/ EXPERIMENTAL ARRANGEMENT AND BACKGROUND LIMITATION

The 600 MeV proton beam, extracted by a resonance method was focused to a spot of about 1 x 1,5 cm at the target position. The duty cycle was about 10% and the energy resolution was estimated as better than 1 MeV. Two double scintillation counter telescopes were checking the beam position and intensity, one directed towards the target and the second towards a thin aluminium foil on the beam line far away from the target.

The scattered protons were detected after the bending magnet by four telescopes. To limit the γ - ray background, each of these was defined by a double scintillation counter. In these conditions, the ratio of single counting rates with and without a 20 mg/cm^2 target was about 2. All the wires of the PC2 chamber were used as a fast counter and included in the trigger.
This geometrical configuration selected mainly particles coming from the target. On the α - particle arm, the same background limitation was obtained with the wire chamber PC5. Besides, the large difference between the ionization of single and double charge particles gave reliable high voltage working conditions where the α - particles were detected with a total efficiency and about 80% of the protons rejected.

The α- particles were detected after the bending magnet by three telescopes. On each one, a threshold on the thin scintillation counter ΔE_α (0.25 m/m thickness rejected protons. The ratio between the pulse height of the fastest α - particle and the slowest proton was better than 3. The thick counter E_α (8 m/m thickness) stopped α - particles up to 120 MeV. The third counter SC3 rejected particles of range greater than that of a 120 MeV α - particle.

The trigger of a $(p,p\alpha)$ reaction was defined by the coincidence between the proton and alpha arms. The target faced the alpha spectrometer and was limited to a 20 mg/cm^2 thickness. With an incident beam of 10^9 protons/burst on a Lithium target, 2 coincidences were typically obtained with 10% random coincidence rate and the efficiency of the whole apparatus was equal to 0.7 ± 0.1.

C/ MAGNETIC SPECTROMETERS AND WIRE CHAMBERS

The direction of each outgoing particle was defined by two wire proportional chambers. Its momentum was analysed using a bending magnet followed by a third chamber. Three wire planes per chamber gave a horizontal accuracy σx = 0.5 m/m. Two of these planes with wires inclined at ±15° gave the vertical coordinate with an accuracy $\sigma y \simeq$ 2m/m. In order to minimize multiple scattering of protons and α - particle absorption, the two spectrometers were equipped with helium bags.

The multiwire proportional chambers and their electronics were derived mainly from prototypes proposed by Charpak[8]. However, to avoid energy spread on the α - particle arm, the chambers were studied and equipped with thin aluminized Mylar foil (6 μm thickness) as HV planes.

To reduce the electronics required by the large number of wires (∿4500), the largest chambers were encoded by a matrix procedure.
8 groups of 8 adjacents wires were connected in two different ways. A set of 8 bits defined the wires with the same position within the groups and a second set defined the groups themselves. Thus 16 bits represented a matrix of 64 wires and the number of electronic components was divided by 4.

Fired wires, Time of Flight between proton and alpha (TOF) and pulse heights (ΔE_α, E_α) in SC1 and SC2 counters were recorded on magnetic tape. The data handling was checked on line with a display of the ΔE_α, E_α, TOF correlated informations.

To obtain sufficient accuracy in the proton momentum calculation, a map of the magnetic field to 5 Gauss precision had been made. Using the three components of the field[9], a set of theoretical trajectories was precisely calculated. For data analysis, each experimental momentum was estimated by linear interpolations between the theoretical set values. The accuracy of the method was Δp = 1.2 MeV/c (FWHM) and calculation time on CDC 6600 was about 1.5 ms. On the α - particle arm, a rough precision $\Delta p/p$ = 1% was sufficient and had given spread $\Delta E_\alpha \simeq 1.5$ MeV.

III - DATA ANALYSIS AND EXPERIMENTAL SPECTRA

We choose the following selection rules for data analysis.

a) The intersection coordinates of the proton and alpha trajectories must lie within the target. This reduces random coincidences and (p,pα) reactions where one of the outgoing particles has been scattered by the wires.

b) On the alpha arm, the correlation of E_α and ΔE_α pulse heights is connected to the charge of the particle (figure 2). Single-charged particles are well rejected. Furthermore, if some of such unwanted particles are considered as double charge, the error on their calculated momenta will be larger than 400 MeV/c.

c) To separate ^{3}He and ^{4}He, the calculated momentum p_α is compared to the alpha energy estimated from pulse height measurements in E_α counters, (figure 3). A complementary selection is obtained with the Time of Flight (TOF) and the momentum.

Using equations (1) and (2), the separation energy E_s and the recoil momentum p_R is calculated. To estimate the systematic error due mainly to uncertainty in the incident energy (about 5 MeV), the ^{6}Li (p,pα) ^{2}H reaction is used to calibrate the separation energy scale absolutly. The peak must correspond to the value E_s = 1.5 MeV (figure 4). The experimental width of the peak is 10 MeV (FWHM) and represents an upper limit of the energy resolution.

The figures 4 to 9 show the separation energy spectra for ^{6}Li, ^{7}Li, ^{12}C, ^{24}Mg, ^{27}Al and ^{40}Ca. Till ^{24}Mg the peak corresponding to quasi free reactions letting the residual nucleus in its ground state is well observed and it is enhanced by the selection of small recoil momenta (fig.4-7 (a)). For ^{27}Al this peak disappears and only inelastical events corresponding to high excitation energies are detected. In the case of ^{40}Ca the peak for $E_x = 0$ is again observable. The recoil momenta selection has not been possible for this two nuclei because of the deficiency of statistics.

The preliminary values of the differential cross section $d^3\sigma/d\Omega_1 d\Omega_2 dE$ for the ^6Li and the ^{12}C are shown on figure 10. For the ^{12}C the energy resolution is not sufficient to show evidence of the 2.9 MeV excited state of ^8Be. However, a difference in form between the ground and first excited state momentum distribution may be supposed[3] and the differential cross section (figure 10) show a maximum at $p_R = 0$. That seems to indicate a low population of the first excited state.

IV - CONCLUSION

We conclude that (p, pα) reactions with high energy protons are efficient probes for the study of α - clusters structures.

Results on ^6Li, ^7Li, ^{12}C and ^{24}Mg are significant, but for ^{27}Al and ^{40}Ca more statistics are needed.

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FIGURE CAPTIONS

Figure 1 : Experimental layout

Figure 2 : Charge dependance of the correlation between total and partial losses in energy in plastic scintillators.

Figure 3 : ^{3}He and ^{4}He separation by the correlation between the energy lost in a thick scintillator and the impulse mesured in the α - arm spectrometer.

Figure 4 : Separation energy spectra for ^{6}Li, and $60 < E < 80$ MeV.

Figure 5 : Separation energy spectra for ^{7}Li, and $60 < E < 80$ MeV

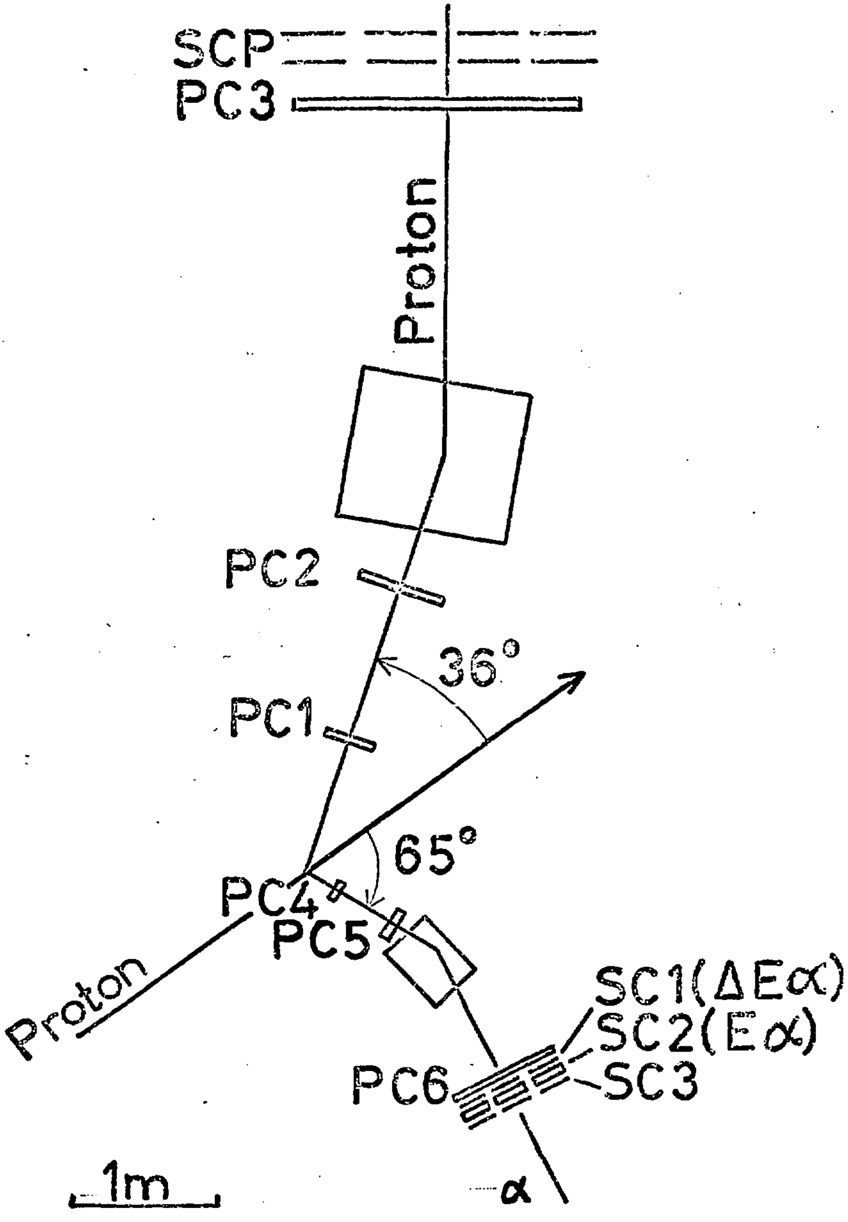
Figure 6 : Separation energy spectra for ^{12}C, and $60 < E < 80$ MeV

Figure 7 : Separation energy spectra for ^{24}Mg, and $50 < E < 90$ MeV

Figure 8 : Separation energy spectrum for ^{27}Al, and $50 < E < 90$ MeV

Figure 9 : Separation energy spectrum for ^{40}Ca, and $50 < E < 90$ MeV

Figure 10 : Differential cross sections vs recoil momentum for ^{6}Li ($\bar{\underline{\triangle}}$) and ^{12}C ($\bar{\underline{\circ}}$) .



SCP
PC3
Proton
PC2
36°
PC1
65°
PC4
PC5
Proton
SC1(ΔEα)
SC2(Eα)
PC6
SC3
1m
α

Fig. 1

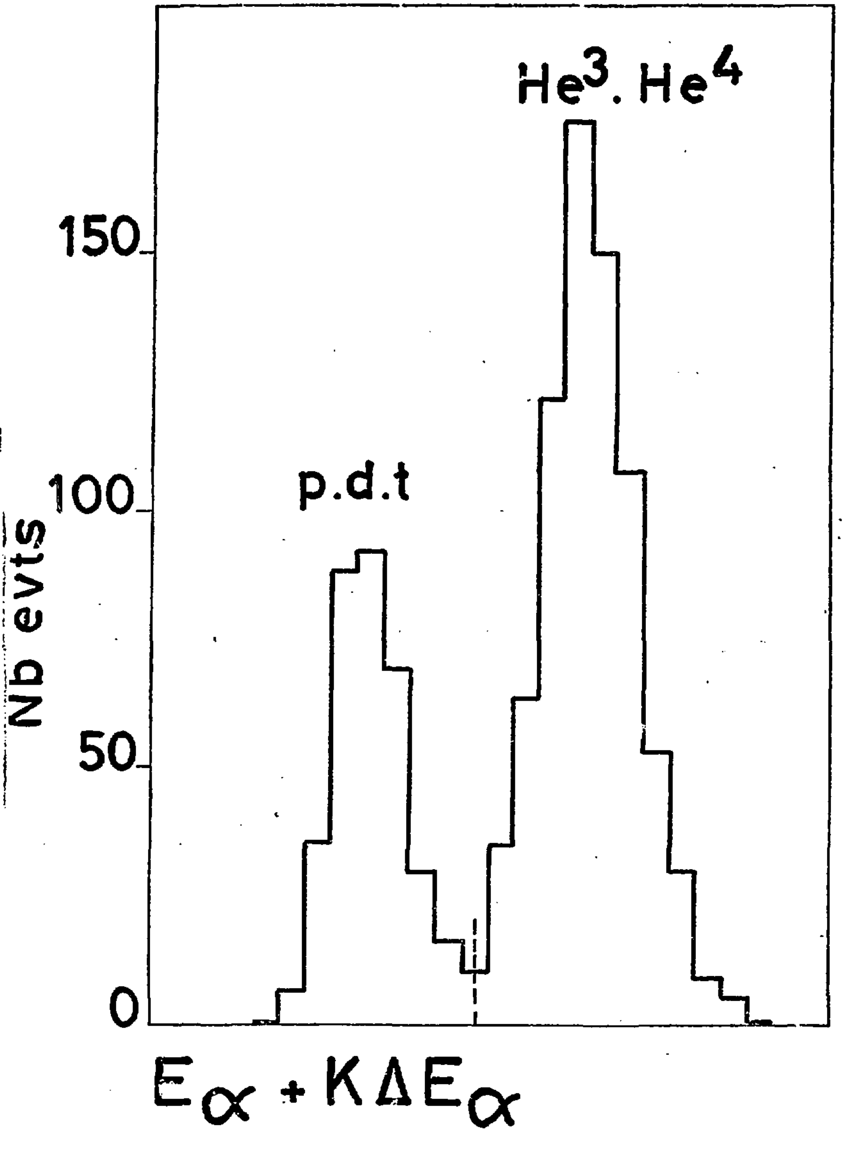
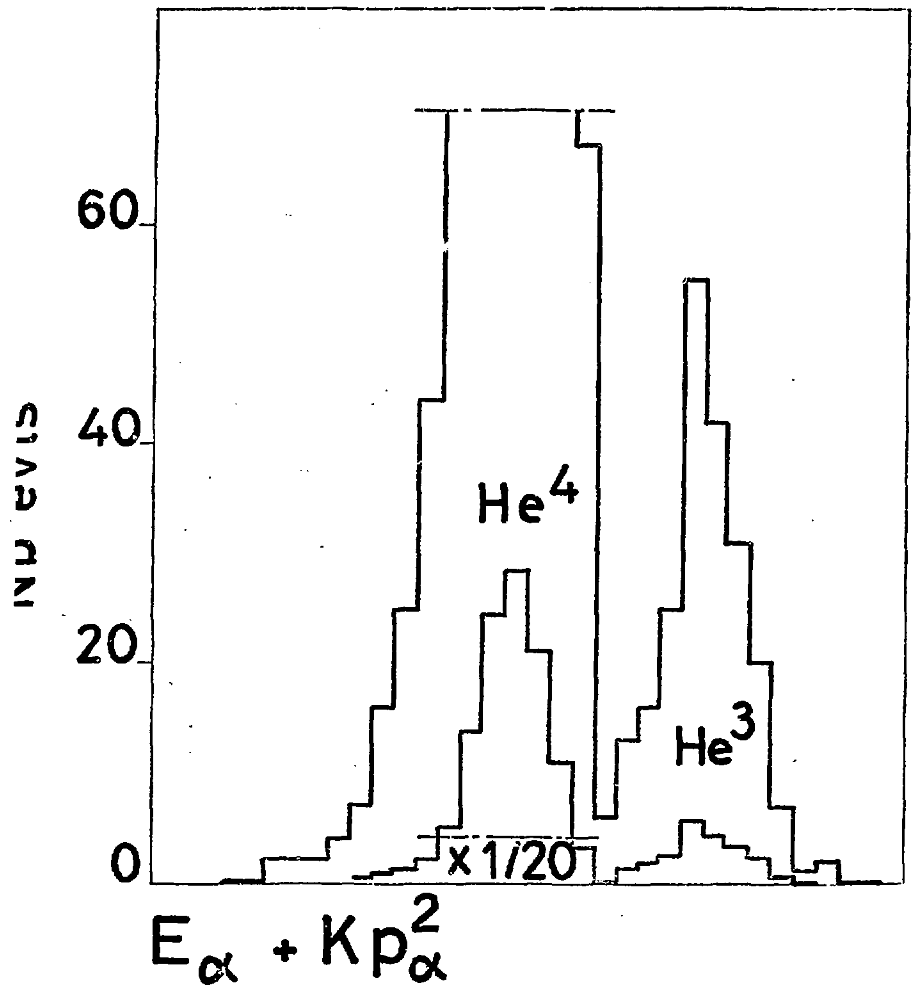


Fig. 2



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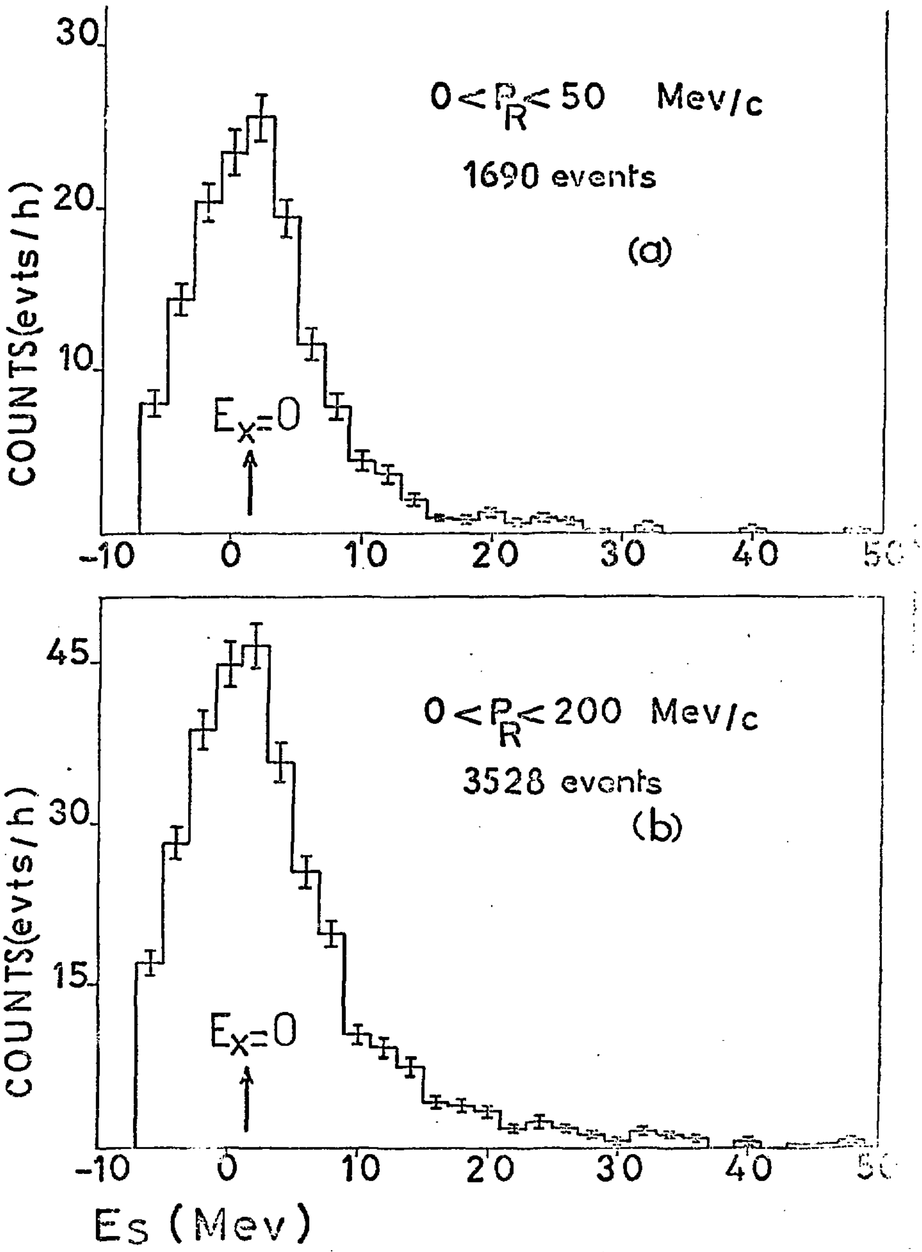
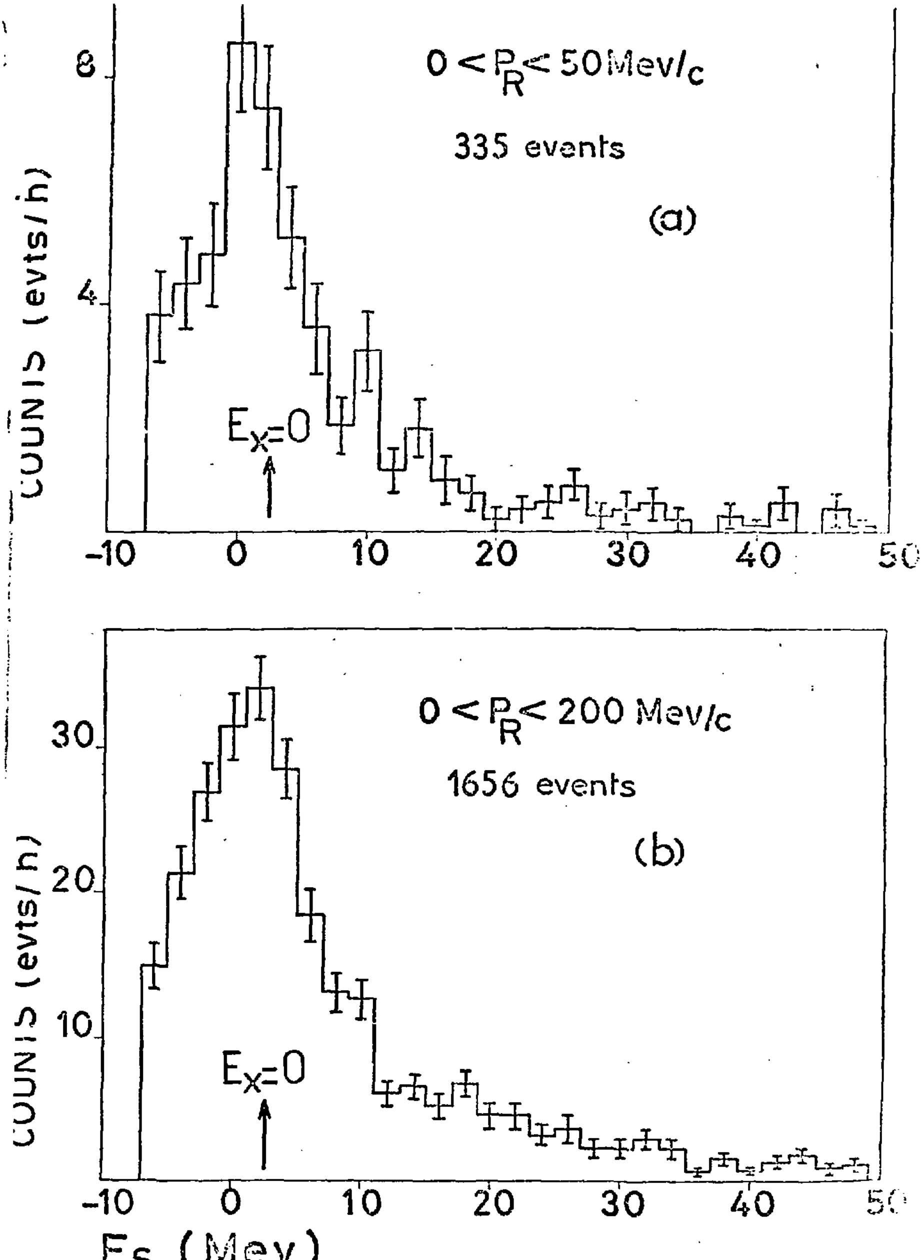


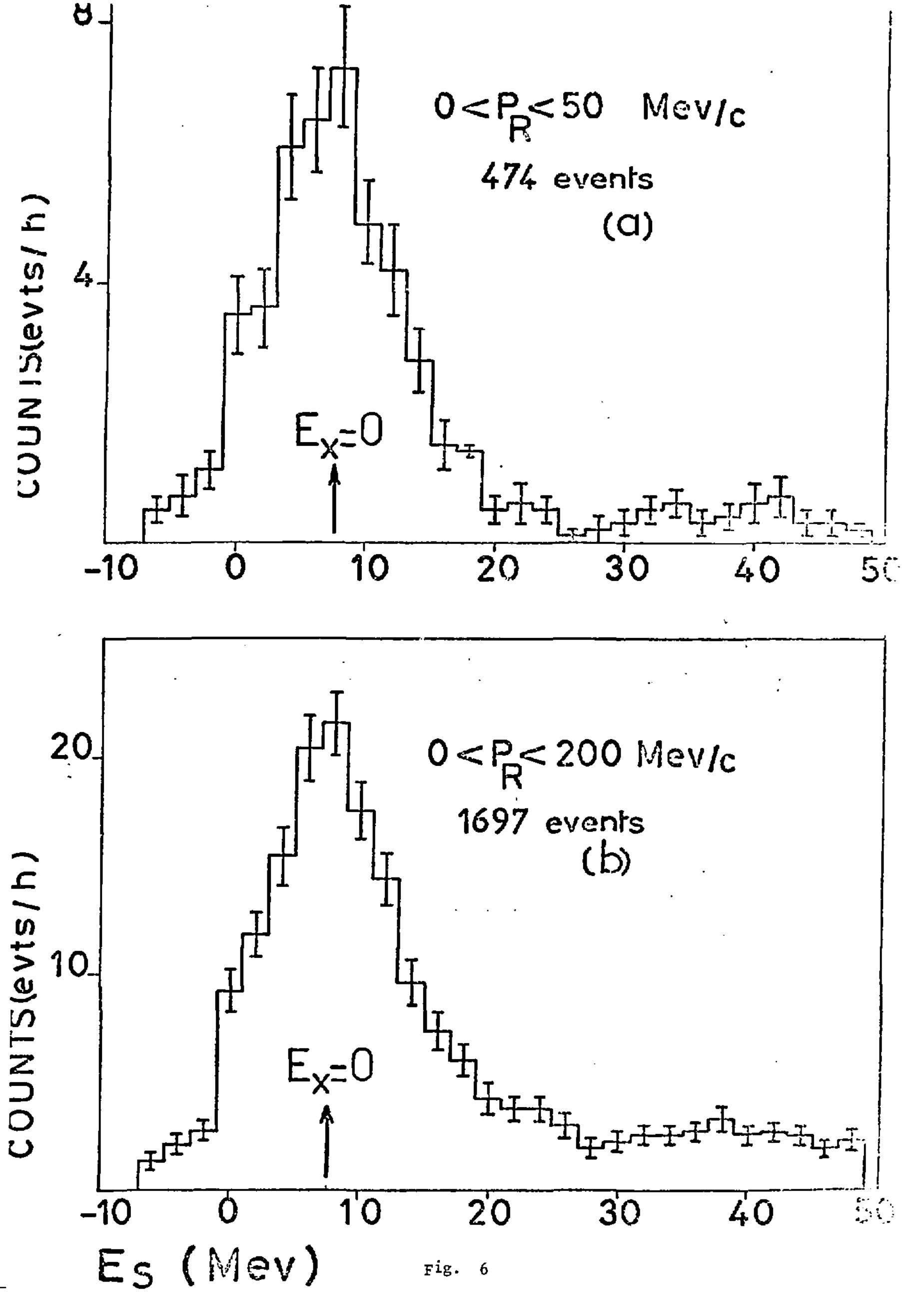
30
20
10
COUNTS(evts/h)
0<P_R<50 Mev/c
1690 events
(a)
E_x=0
-10
0
10
20
30
40
45
30
15
COUNTS(evts/h)
0<P_R<200 Mev/c
3528 events
(b)
E_x=0
-10
0
10
20
30
40
Es (Mev)

Fig. 4



0 < P_R < 50 Mev/c
335 events
(a)
COUNTS (evts/h)
E_x=0
8
4
-10
0
10
20
30
40
50
0 < P_R < 200 Mev/c
1656 events
(b)
COUNTS (evts/h)
E_x=0
30
20
10
Es (Mev)

Fig. 5



0<P_R<50 Mev/c
474 events
(a)
E_x=0
COUNTS(evts/h)
4
-10
0
10
20
30
40
50
0<P_R<200 Mev/c
1697 events
(b)
E_x=0
COUNTS(evts/h)
20
10
Es (Mev)

Fig. 6

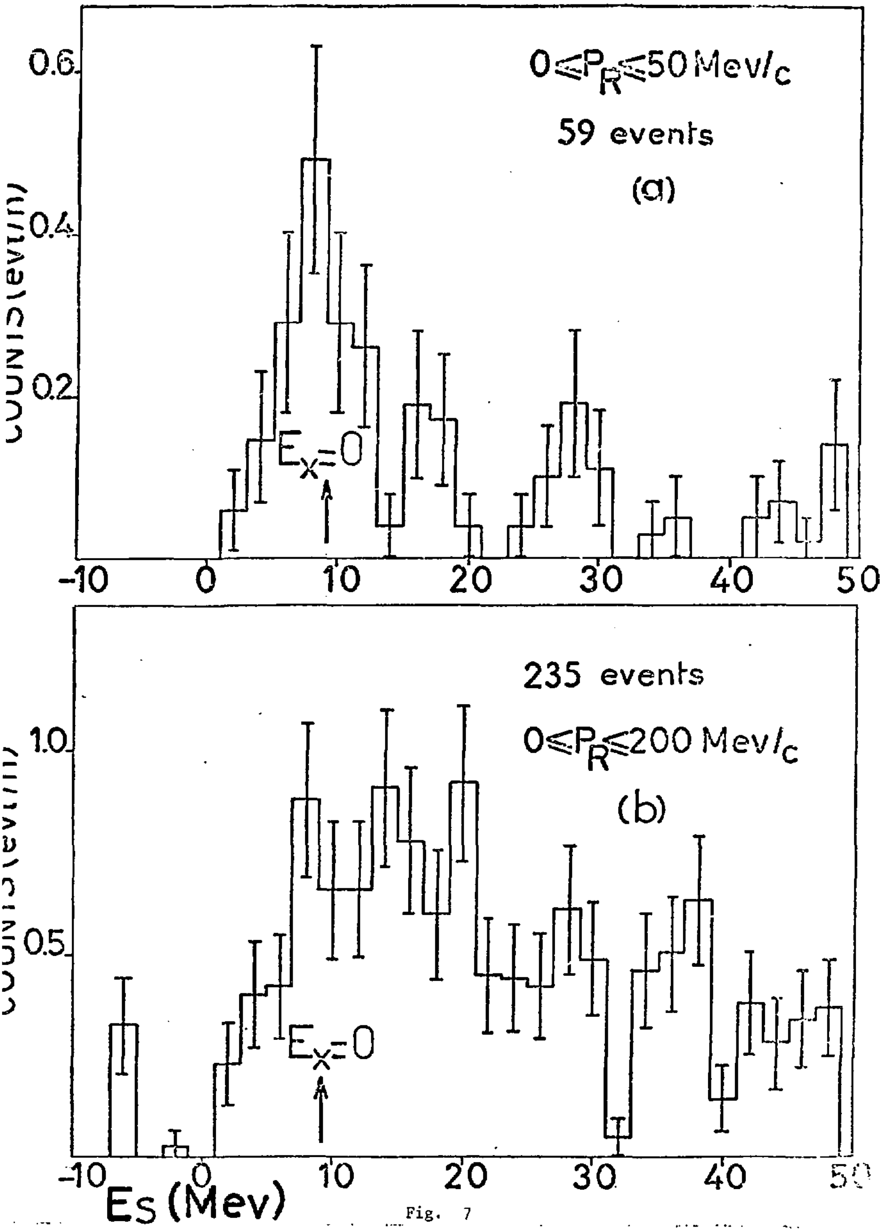

0≤P_R≤50 Mev/c
59 events
(a)
COUNTS(eV/10)
0.6
0.4
0.2
E_x=0
-10
0
10
20
30
40
50
235 events
0≤P_R≤200 Mev/c
(b)
1.0
0.5
E_x=0
Es (Mev)

Fig. 7

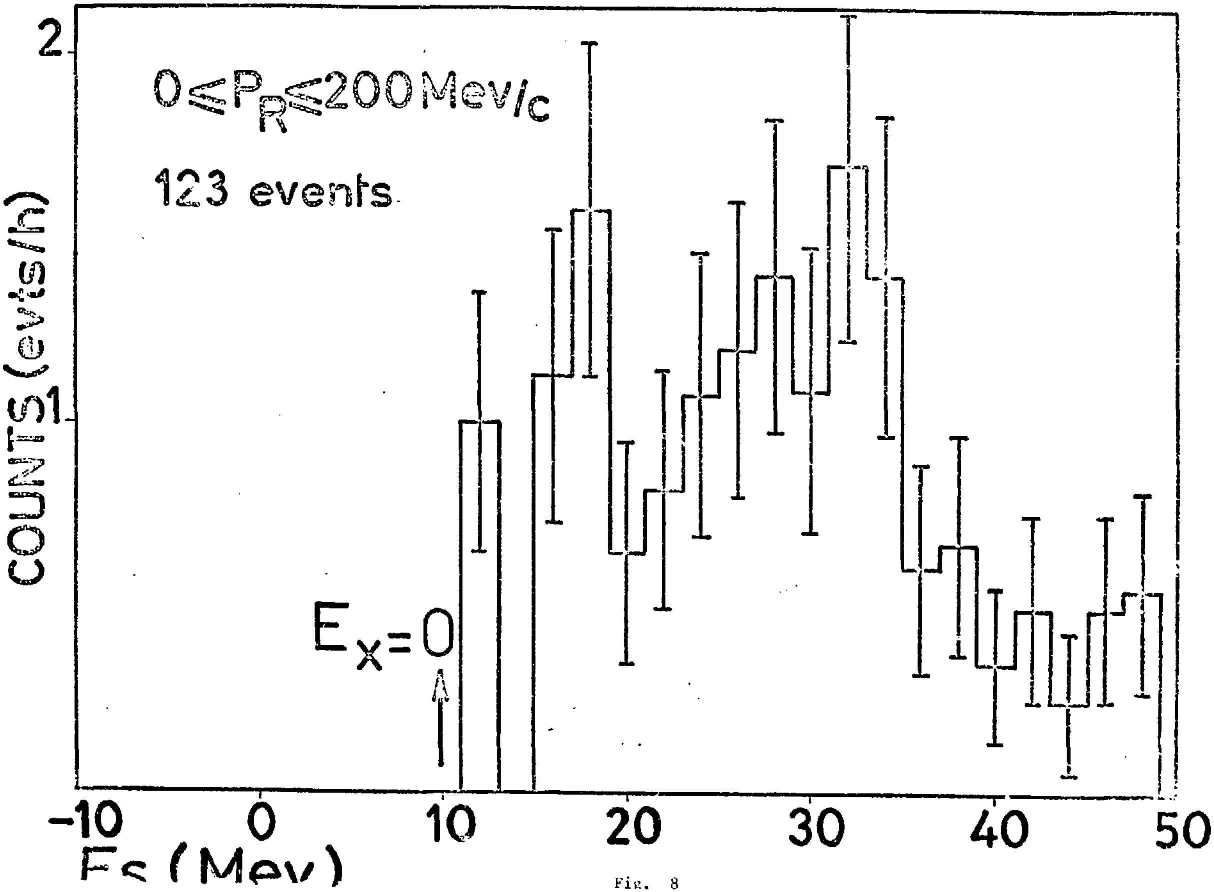
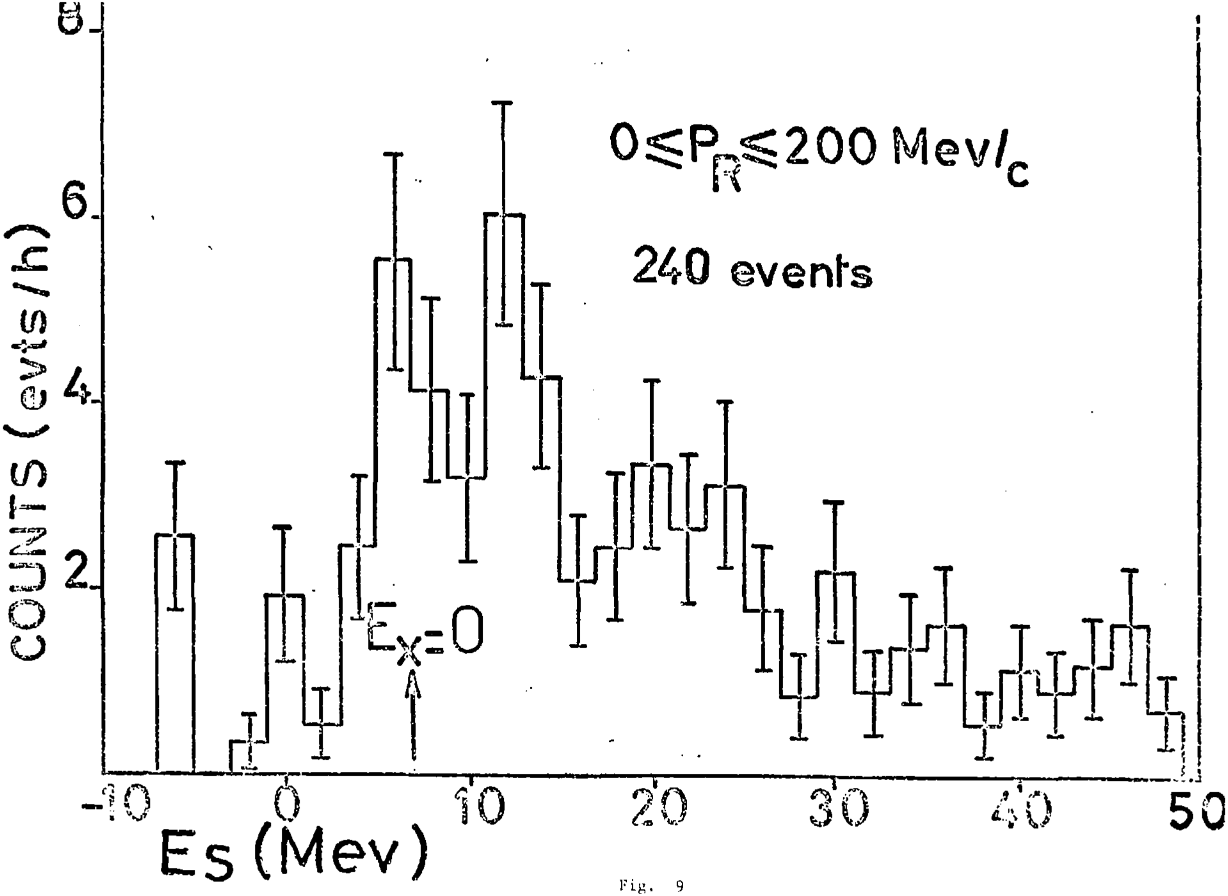
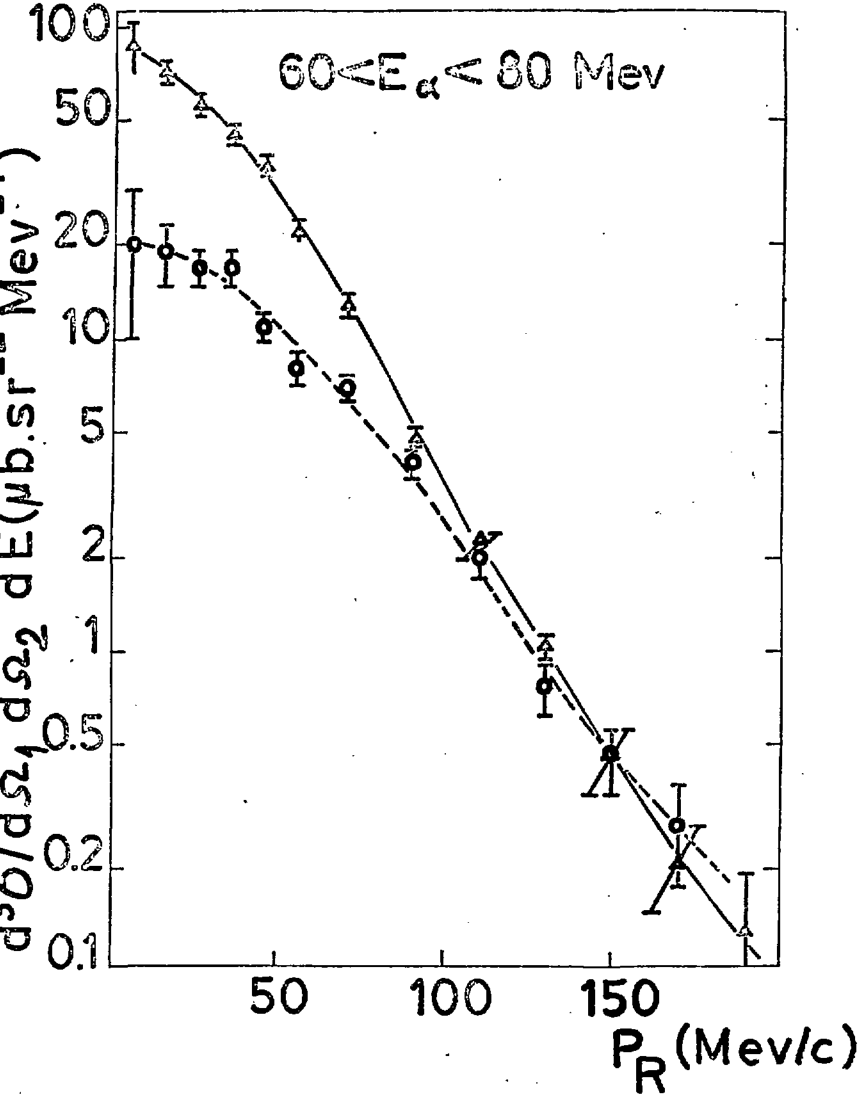

COUNTS (evts/h)
2
1
0≤P_R≤200 Mev/c
123 events
Ex=0
-10
0
10
20
30
40
50
Es (Mev)

Fig. 8



0≤P_R≤200 Mev/c
240 events
E_x=0
COUNTS (evts/h)
8
6
4
2
-10
0
10
20
30
40
50
Es (Mev)

Fig. 9



60<E_α<80 Mev
d³σ/dΩ₁dΩ₂ dE(μb.sr⁻² Mev⁻¹)
100
50
20
10
5
2
1
0.5
0.2
0.1
50
100
150
P_R (Mev/c)

Fig. 10