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A proposal for the study of $\bar{p}$ D annihilation in the 2m BC, in the momentum range 760 - 200 MeV/c.

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Summary : We propose to take 2.5×10^6 pictures of $\bar{p}$ D annihilations at antiproton momenta in the region 760-200MeV/c. Of particular interest is the study of the reaction

$$\bar{p}D \rightarrow (\bar{p}n) + p_s$$

where the p_s stops in the chamber. The objective is to search systematically for narrow states in the $(\bar{p}n)$ system above and below threshold, utilizing the momentum measurent of p_s.

A study will also be made on the $\bar{p}n$ annihilation, complementary to the proposed high statistics study of $\bar{p}p$ annihilation in hydrogen, in the same momentum region.

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[*] The proposed experiment would require the collaboration of several laboratories.

I. Questions of interest in $\bar{p}D$ low energy annihilations.

The case for a high statistics study of $\bar{p}N$ low energy annihilations has been presented (1) extensively and a request has been made$^{(2)}$ for a high statistics $\bar{p}p$ experiment in the momentum range $760 > p > 0$ MeV/c. The specific interest in studying $\bar{p}N$ annihilations in a $\bar{p}D$ experiment has been also mentioned and includes the following:

A. Study of the region above and below the $(N\bar{N})$ threshold.

If we study the reaction

$$\bar{p} + D \rightarrow p_s + X^- \qquad (1)$$

where the p_s is visible, we are in fact looking at a formation $(\bar{p}n)$ reaction off the mass shell. If X^- is a specific resonance a corresponding enhancement will appear in the momentum distribution of p_s in the CMS (quasi two body state). In fact such an enhancement has been observed in $\bar{p}D$ at rest (3) and has been attributed to a resonance X^- (1795) decaying to an even number of pions (Fig.1). The reaction $\bar{p}d \rightarrow \pi^- p_s$ has also been observed in $\bar{p}d$ annihilations at rest (4).

Furthermore, for in flight annihilation it is useful to treat reaction (1) as the deuterium stripping by the antiproton, completely analogous to the stripping of deuterium by nuclear targets$^{(5)}$, The differential crossection is

$$\frac{d^2\sigma_{\bar{p}d}}{dq\,d\omega} = q^2 \frac{|Fd(q)|^2}{(2\pi)^3} \frac{|\vec{K}+\vec{q}|}{K} \sigma_{\bar{p}n}(Q) .$$

where $\sigma_{\bar{p}d}$ is the measured crossection of reaction (1) and $\vec{K}, \vec{q}$ are the $\bar{p}$ and spectator momenta in the laboratory system respectively.

The solid angle Ω is defined with the Z axis along $\vec{q}$, $F_d(q)$ is the Fourier transform of the deuteron wavefunction and $\sigma_{\bar{p}N}(Q)$ is the $\bar{p}$ annihilation crossection on bound neutrons. Q is defined as invariant mass $(\bar{p}N)$ $-2m_p$.

From figure (2) where we plot Q versus the momentum of p_s we observe that the study of reaction (1) for investigating the $(\bar{p}n)$ reaction has two advantages: (a) : Since Im$(\bar{p}n)$ is a function of (k,q, cos θ) the same value of Q can be reached from a range of relative momenta k, q. This fact has important implications if one is studying high spin $(\bar{N}N)$ resonances above threshold. Their production will be suppressed in $(\bar{p}p)$ in hydrogen by the factor $(KR)^{2J}$, but in deuterium by properly selecting the beam and spectator momenta this centrifugal barier suppression can be bypassed.

(b) : The low energy, $Q < 25$ MeV region which corresponds to beam momenta < 300 MeV/c, is inaccessible in $\bar{p}p$ in the HBC, since the uncertainty in the beam momentum is large. Using reaction (1) the higher (and therefore more accurate) beam momentum regions can be utilized. In Fig. 3 we reproduce$^{(6)}$ some results from a 300K exposure of $\bar{p}D$ annihilations in the 30" BNL bubble chamber in the momentum region 630 - 250 MeV/c, where there is evidence of structure. Thus both the above and below threshold regions can be investigated for the existence of narrow $(\bar{N}N)$ states that cannot be detected in $\bar{p}$ annihilations on free nucleons.

The usefulness of this method in searching for narrow $(N\bar{N})$ states depends on the measurement resolution of the beam and spectator momenta . If the available beam$^{(1)}$ has a resolution of 0.5%, and the spectator proton is measured by range then the energy resolution is of the order of 2 MeV (Table 1). Less than 1/5 of the $\bar{p}D$ interactions will have a visible proton spectator. Thus a high statistics experiment is needed.

B. Complementary study to $\bar{p}p$ in hydrogen.

A knowledge of $\bar{p}n$ annihilation means that the I=1 component of $N\bar{N}$ annihilations is known. Thus the $\bar{p}D$ experiment can be used to extract the I=0 component from $\bar{p}p$. Although there are $\bar{p}p$ annihilations in deuterium their study has the difficulty of the neutron spectator. A coordinated study of $\bar{p}p$ in hydrogen and $\bar{p}n$ in deuterium will enable a systematic analysis of all the points of interest in $\bar{p}N$ annihilations presented in ref. 1. Statistics similar in magnitude to the $\bar{p}p$ in hydrogen would be desirable.

C. Isotopic spin constraints in $\bar{p}D$ annihilations.

The system $\bar{p}D$ is unusual in the sense that it has a unique isotopic spin, I=1/2. A general relation (7) derived by the use of a maximum complexity theorem and charge independence gives several relations for inclusive and exclusive channels.

One of these relations predicts

$$\begin{aligned} & N(\pi^+) + N(\pi^-) = 2N(\pi^0) \\ \text{i.e.}\quad & \langle N^{\pm} \rangle = 2\langle N^0 \rangle = \langle N_\gamma \rangle \end{aligned} \qquad (2)$$

While in a recent experimental test$^{(8)}$ using $\bar{p}D$ at rest, we found

$$3.05 \pm 0.02 \neq 3.77 \pm .07$$

for the two sides of equation (2).

An excess of neutral energy of the order 100 MeV per interaction has also been found.

The above excess of neutrals is consistent with what has been observed(9) in $\bar{p}p$ annihilations. The strong constraints in the derivation of relation (2) require a depletion in the number of neutrals for $\bar{p}n$ which experimentally is not observed.

The above result indicates electromagnetic effects an order of magnitude higher than expected from η production. (A 20% η rate would explain the data). A repetition of the experiment is desirable as well as a study of the energy dependence of the phenomenon.

II. Selection of incident momenta and the expected number of events.

A final selection of incident momenta will depend on the experience gained by the $\bar{p}p$ experiment. The present proposal must be considered as complementary to the one of Ref.2.

Assuming the antiprotons enter at 0° in the chamber, that they are spread over y on 10 cm and a fiducial volume for the interactions extending on $\Delta Y = \pm 8$cm, $\Delta X = {}^{-80}_{+20}$ cm, the following beam and picture-taking conditions could be met:

Run 1	H = 17kG	$760 > p > 720$ MeV/c	Useful length		= 58 cm
" 2	H = 17kG	$720 > p > 680$ MeV/c	"	"	= 53 cm
" 3	H = 17kG	$680 > p > 630$ MeV/c	"	"	= 50 cm
" 4	H = 17kG	$630 > p > 570$ MeV/c	"	"	= 50 cm
" 5	H = 17kG	$570 > p > 500$ MeV/c	"	"	= 47 cm
" 6	H = 14kG	$500 > p > 390$ MeV/c	"	"	= 49 cm
" 7	H = 10kG	$450 > p > 0$ MeV/c	"	"	= 51 cm

Run-1	Number of $\bar{p}$/picture		= 10	Number of pictures	= 350k
" 2	"	"	= 10	" "	= 350k
" 3	"	"	= 10	" "	= 350k
" 4	"	"	= 10	" "	= 350k
" 5	"	"	= 8	" "	= 400k
" 6	"	"	= 4	" "	= 600k
" 7	"	"	= 4	" "	= 100k

With these tentative numbers we expect the number of interactions shown in the table below.

Number of Interactions

Run	Total	Non Annihilation	Annihilations	With visible spectator
1	1.6×10^6	5.4×10^5	1.1×10^6	2.2×10^5
2	1.5×10^6	5.4×10^5	9.6×10^5	1.9×10^5
3	1.4×10^6	5.3×10^5	8.7×10^5	1.7×10^5
4	1.5×10^6	$6. \times 10^5$	9×10^5	1.8×10^5
5	1.4×10^6	5.6×10^5	8.4×10^5	1.7×10^5
6	1.2×10^6	4.8×10^5	7.2×10^5	1.4×10^5
Beam 350<	1.6×10^5	5.8×10^4	1×10^5	2×10^4
7 350>	2.4×10^5		2.4×10^5	5×10^4
Total			4.8×10^6	1.2×10^6

These numbers have been estimated using the $\bar{p}D$ total crossection and a parametrization of the non annihilation channel(6)

$\sigma_{\text{nonann.}} = 183 - 138 P_L$ in mb. The visible spectators have been estimated at 20% (see also Table 2).

Since the total CMS energy varies only from o → 100 MeV we expect that the topological frequencies for annihilation channels will be not much different from those at rest. Table 2 gives these frequencies from $\bar{p}D$ at rest (8).

In this film there will also be about

a) 10000 $\bar{p}D \rightarrow \pi^+\pi^-\pi^-(p_s)$ events per 10^6 annihilations

b) 2300 $\bar{p}D \rightarrow \pi^+\pi^-(n_s)$(10) " " " "

1600 $\bar{p}D \rightarrow \pi^-\pi^0(p_s)$ " " " "

c) 70000 strange events(11), i.e. $K\bar{K}$ pairs, " " " " .

The statistics requested above will allow a good study of these channels.

III. Measuring capacity

The Demokritos measuring capacity includes 4 scanning tables and 4 IPD On Line to a CDC 1700 computer.

Table 1

P_s MeV/c Δp	100 ± 5		200 ± 3		300 ± 1		400 $\pm .5$	
P_{beam} MeV/c Δp	$\cos\theta=1$	-1	+1	-1	+1	-1	+1	-1
300 ± 1.5	0.30	1.6	0.6	1.5	0.6	0.7	0.6	0.4
400 $\pm$ 2.	0.5	1.9	0.7	1.6	0.7	0.7	0.8	0.5
500 $\pm$ 2.5	0.8	2.2	0.8	1.8	1.0	0.8	1.1	0.5
600 $\pm$ 3.	1.2	2.5	1.1	2.0	1.2	0.9	1.3	0.5
700 $\pm$3.5	1.5	2.8	1.3	2.2	1.5	1.0	1.6	0.6

Error ΔQ. The beam momentum has been assumed with an error .5%. An error of .05 cm in the length has been used to determine the error in p_s. The error in the relative angle θ enters proportional to $\sin\theta$ and affects ΔQ not more than 20% for $\Delta\theta$ = 5mr and $\theta = \pi/2$.

Table 2

Topology	number of interaction for 10^6 annihilations
$\bar{p}p$ 0 prongs	$(2.6 \pm 0.3) \times 10^4$
$\bar{p}n$ 1 prong p_s unseen	$(4.1 \pm 0.3) \times 10^4$
$\bar{p}n$ 2 prongs, p_s seen	$(4.3 \pm 0.3) \times 10^4$
$\bar{p}p$ 2 prongs	$(25.4 \pm 0.9) \times 10^4$
$\bar{p}n$ 3 prongs, p_s unseen	$(14.6 \pm 0.7) \times 10^4$
$\bar{p}n$ 4 prongs, p_s seen	$(11.3 \pm 0.6) \times 10^4$
$\bar{p}p$ 4 prongs	$(26.2 \pm 0.9) \times 10^4$
$\bar{p}n$ 5 prong, p_s unseen	$(5.7 \pm 0.4) \times 10^4$
$\bar{p}n$ 6 prongs, p_s seen	$(3.7 \pm 0.3) \times 10^4$
$\bar{p}p$ 6 prongs	$(1.9 \pm 0.2) \times 10^4$
$\bar{p}n$ 7 prongs, p_s unseen	$.2 \times 10^4$
$\bar{p}n$ 8 prongs, p_s seen	$.06 \times 10^4$
$\bar{p}p$ 8 prongs	$.03 \times 10^4$

Number of events per topology expected from 10^6 $\bar{p}D$ annihilations.

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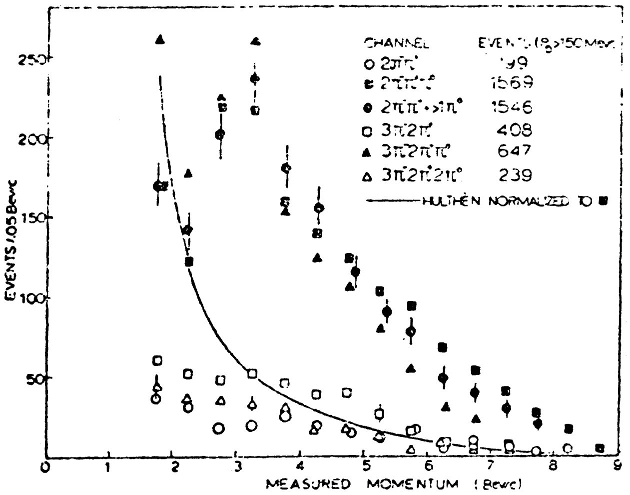

FIG. 1. The $3\pi^- + 2\pi^+ + \pi^0$ spectrum is normalized to the $2\pi^- + \pi^+ + \pi^0$. The Hulthén curve is normalized to *all* (including three-prong) $2\pi^- + \pi^+ + \pi^0$ events.

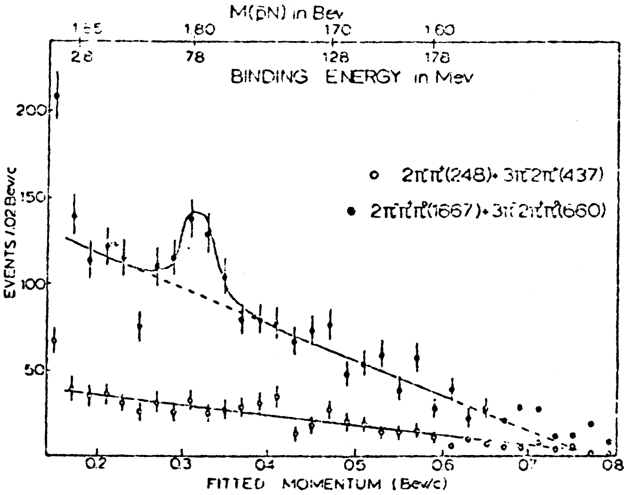

FIG. 2. Fitted momentum spectra for the 4C and 1C events. The curves are least-squares fits by second-order polynomials and a Breit-Wigner form of variable mass and width.

Fig 1.

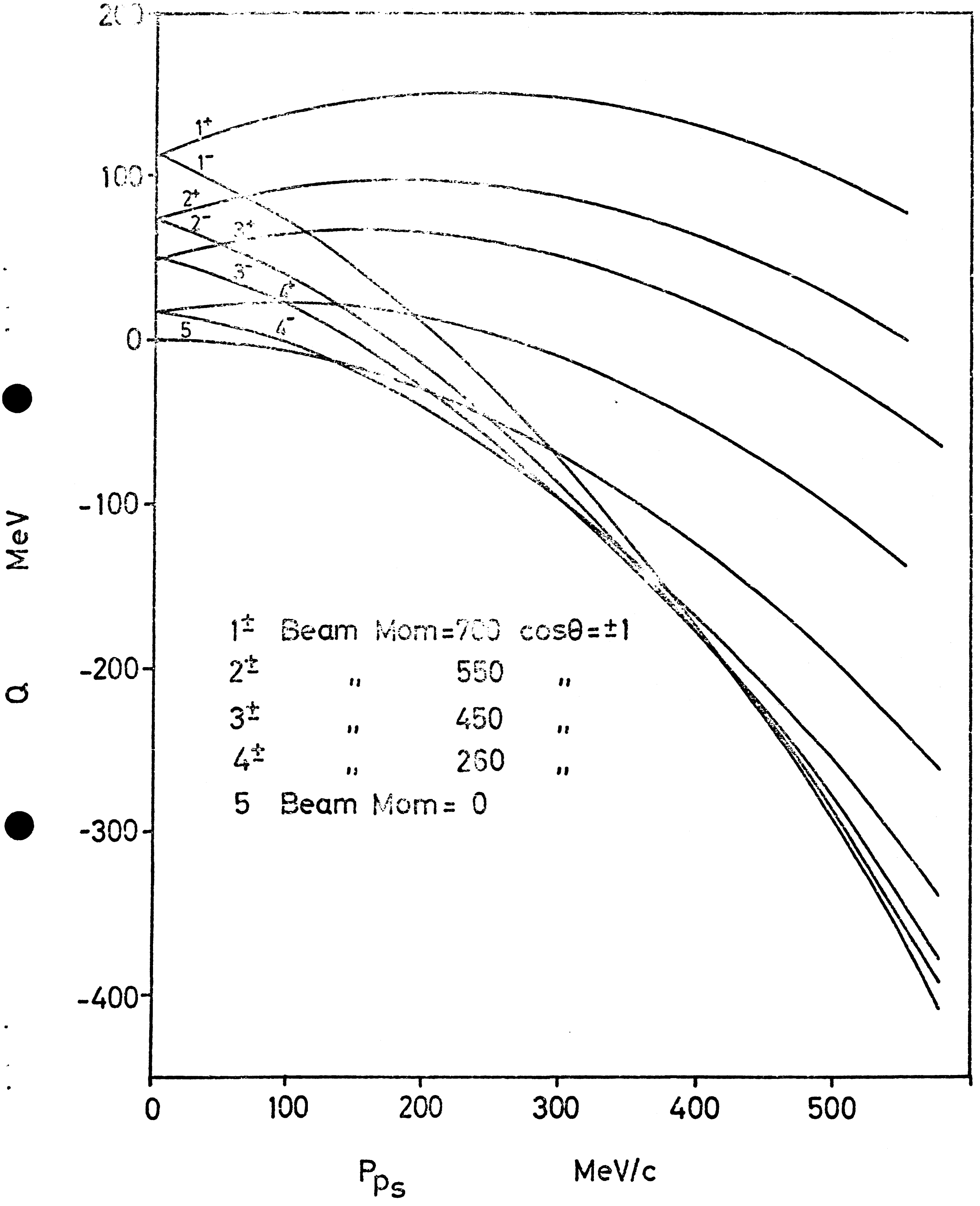
200
100
0
-100
-200
-300
-400
Q MeV
0
100
200
300
400
500
P_ps MeV/c
1+
1−
2+
2−
3±
3−
4+
4−
5
1± Beam Mom=700 cosθ=±1
2± " 550 "
3± " 450 "
4± " 260 "
5 Beam Mom= 0

Fig 2

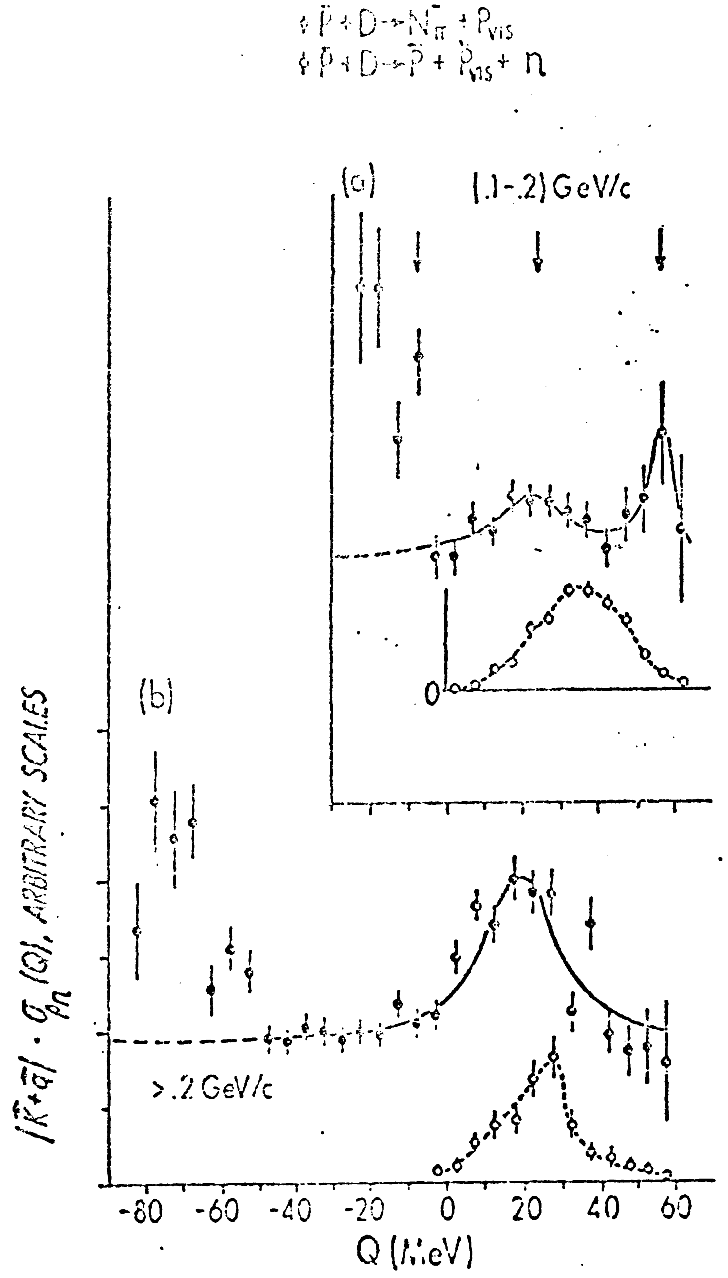

Fig 3

Distributions for "elastics" are the measured Q distributions. (a) Fit to two Breit-Wigners and uniform background. Results (Q, Γ) = (22.7 ± 2.4, 19.4 $^{+2.4}_{-1.4}$), (56.8 $^{+2.5}_{-1.5}$, 7.6 $^{+2.5}_{-1.3}$) MeV. (b) Fit to Breit-Wigner plus univorm background. (Q, Γ) = (19.4 ± 1.0, 23.5 ± 1.2) MeV.