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PROPOSED STUDY OF A_1^- AND A_2^- MESONS USING THE CERN/ETH MAGNETIC SPARK CHAMBER

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1. Motivation

Since the first indications in the middle of 1963, considerable evidence has now accumulated in favour of resonant states of three pions at 1090 MeV (A_1 meson) and 1310 MeV (A_2 meson). A summary of the experiments is given in Table 1.

Table 1

Interaction	Incident energy GeV/c	Technique	Authors ref.
π^+ + nucleus	17	Heavy liquid bubble chamber	Bellini et al.[1]
"	17	" "	Fretter et al.[2]
"	14-17	Photographic plate	Caforio et al.[3]
π^+ + p	3.65	H_2 bubble chamber	Goldhaber et al.[4]
"	4.0	"	Aderholz et al.[5]
"	3.5	"	Lander et al.[6]
π^- + p	3.22	"	Chung et al.[7]

9205/p/cm

It has been apparent from the start that the process could be easily studied with a spark chamber technique, which should give the following advantages :

i) better resolution in mass of the resonances because the virtual absence of multiple scattering allows a more accurate momentum measurement, e.g. at 10 GeV/c

heavy liquid	$\Delta p/p \sim 9\%$
H_2 chamber	$\Delta p/p \sim 3\%$
CERN magnetic spark chamber	$\Delta p/p \sim 1\%$

ii) the production target is known, and can easily be varied;

iii) simple trigger signature can be used to collect a large number of events.

At present further information is needed on:

i) resonant energy and widths;

ii) Dalitz plots for spin parity assignments;

iii) the production mechanism: diffraction dissociation, peripheral ρ exchange, and electromagnetic have all been suggested. By obtaining better data on the transverse momentum distribution of the compound states, and by varying the target material, we expect to obtain significant information on this problem.

Note, finally, that the new mass formula of Brown[8]) predicts mesonic states at 1089 MeV (I = 1) and 1306 MeV (I = ½): this is a remarkable coincidence, seeing that the author is apparently unaware of the experimental work on the A_1 and A_2 resonances mentioned above.

2. Experimental design

To produce a resonance of mass M the minimum four-momentum transfer needed is

$$q_{min} = M^2/2E_0$$

where E_0 is the incident pion energy. Therefore for all targets it should pay to use high energy: experimentally when the target is a nucleus, this is apparently essential because the resonant states do not appear if the nucleus is broken up. Therefore the experiment is planned for 15 GeV/c incident π^-, the highest available in the d_{17} beam.

Study of events observed in previous experiments[1,3] indicates that the following requirements would project out the desired events:

i) three fast charged secondaries inside the 16° forward cone, and none outside.

ii) no heavy prongs due to evaporation from the target nucleus.

The background would consist of events with additional neutral secondaries, or events in which all the nuclear excitation energy is released by emission of neutral particles.

We propose to exploit this by using the experimental layout shown diagrammatically in Fig. 1 to collect events occurring in the target scintillation counter C_1. The spark chambers will be triggered if there are simultaneously:

1) pulses from C_4 and C_5 indicating the arrival of an acceptable beam particle;
2) a pulse from C_2 corresponding in height to the passage of three relativistic singly-charged particles through it;
3) no pulse from the anticoincidence shield C_3;
4) a sufficiently small pulse from the target counter C_1.

Spark chambers S_1 to S_4 then measure the momentum and direction of the incident particle. The set of spark chambers S_5 in a magnetic field (actually the magnetic spark chamber of the CERN/ETH group) measure the momenta of the charged secondary particles. Note that the desired tracks will pass nicely through the useful region of this chamber.

A small hole made in C_2 so that beam particles traversing C_4, C_5 and C_1 pass through it, prevents triggering on beam particles that do not interact. It also greatly reduces the rate of triggering on diffraction scatters, delta rays, and directly produced electron pairs occurring in C_1; and eliminates triggering on interactions occurring in C_2.

Events with neutral secondaries may be identified by the consequent lack of energy balance among the charged particles. The number of such events photographed will be reduced by using a lead-scintillator sandwich for the anticoincidence shield C_3.

3. Choice of target

In order to vary the target, and so obtain information on the production process we propose to run with three different targets:

i) liquid H_2
ii) plastic scintillator
iii) CsI scintillator ($Z = 53,55$).

We will thus have information for targets of H, C and $\bar{Z} = 54$.

In cases ii) and iii) the scintillation signal from the target is used to discriminate against events in which heavy fragments are emitted by the nucleus. The pulse height in this scintillator will be recorded, and also used in the trigger logic. In case i) this is, of course, unnecessary.

4. Precision of measurements

We are interested in the invariant mass of the three-pion final state, given by:

$$M^2 = 4\left[p_1 p_2 \sin^2\frac{\gamma}{2} + p_2 p_3 \sin^2\frac{\alpha}{2} + p_3 p_1 \sin^2\frac{\beta}{2}\right]$$

$$+ m^2\left[3 + \frac{p_1}{p_2} + \frac{p_2}{p_1} + \frac{p_2}{p_3} + \frac{p_3}{p_2} + \frac{p_3}{p_1} + \frac{p_1}{p_3}\right]$$

where p_1, p_2 and p_3 are the momenta of the three particles and α, β, γ the angles between them, m being the pion mass. To estimate the accuracy obtainable in M we may approximate, neglecting m^2 and assuming small angles,

$$M^2 \sim p_1 p_2 \gamma^2 + p_2 p_3 \alpha^2 + p_3 p_1 \beta^2 .$$

This yields

$$\frac{\Delta M}{M} \sim \frac{\Delta p}{p} + \frac{\Delta \Theta}{\Theta}$$

where p is a typical momentum, Θ is a typical angle.

With secondary momenta of order 5 GeV/c we expect $\Delta p/p \leq 1\%$, while angles will be of order 100 mrad measurable to 1 mrad, again 1%. Hence the resolution in mass will be ~ 1%, or 10 MeV, compared with the present width estimates of 150 MeV and 80 MeV for A_1 and A_2 resonances.

Errors due to multiple scattering in the target and spark chambers have been included in the above estimates.

The incoming pion momentum is needed only to eliminate events with neutral pions by using energy balance. The π^0 must carry at least 140 MeV and will typically take ~ 500 MeV. Hence the incoming momentum will be measured to ~ 1%, by the auxiliary spark chamber system shown in Fig. 1.

5. Counting rate, background, machine time

A precise estimate of the triggering efficiency and background processes has been obtained by looking in detail at the photographic plate data[3]. The results are set out in Table 2.

Table 2

Total interactions	2258
Interactions with no detectable nuclear fragments	693
Ditto, + pulse height in counter C_2 = (2.75-4) × minimum	212
Ditto, + no count in anticoincidence shield	75
∴ Triggers due to interactions	75
+ triggers due to delta rays, diffraction scattering and electron pairs	25
Total triggers	100
including	
measurable events (n_s = 3)	60
good events	20

In carbon, therefore, the partial cross-section for triggering is ~ 20 mb, and ~ 20% (4 mb) will be good events.

With a beam intensity $5 \cdot 10^3 - 10^4$ π^- per pulse (easily available) we will take one photograph per pulse, which gives

12,000 photos/shift
including 2,400 good events/shift.

Therefore four shifts for taking data will give us ~ 2,000 - 3,000 events with each of the three targets. Including setting-up and normal difficulties our total request is 12 shifts. Probably we shall only need a fraction of the PS beam on our target (target 1).

6. Apparatus availability

Nearly all the equipment needed for this experiment already exists and will be set-up in the d_{17} beam for other work. This statement includes (see Fig. 1)

- magnetic spark chamber + optics, S_5
- anticoincidence shield counter, C_3
- beam spark chambers S_1 ... S_4
- bending magnet
- electronics and triggering logic.

This leaves special equipment to be provided:

- target counter C_1
- hydrogen target
- counter C_2
- small amount of extra electronics.

There will be no difficulty in having this ready and tested by (say) November 1964.

7. Scanning and measuring

It is proposed that the main task of scanning and measuring the film will be undertaken by the Bristol and Stockholm sides of our collaboration. We already have commitments to allocate the following measuring machines to this experiment:

at Bristol : 1 Dobbie-McInnes co-ordinatometer
at Stockholm : 1 S.O.M. machine (similar to I.E.P.)
at CERN : 1 x-y co-ordinatometer*).

The rate of measurement is 20 events/machine/day - i.e. ~ 6 months to complete the measurements with 3 machines, single shift working.

If, however, the present effort to measure magnetic spark chamber events with HPD is successful, and HPD is available, the whole data could be measured in ~ 15 days. There is a good hope that this technique will be available, but we are not dependent on it.

8. Collaboration with CERN/ETH magnetic spark chamber group

This is an essential element in this proposal, as we have found that the magnetic spark chamber is ideally suited to this experiment. One gains tremendously from the detailed development of apparatus, optics and programming which has already been made by the magnetic spark chamber group.

While the group do not wish to put forward this experiment as part of their own programme they are happy to make their apparatus available, and collaborate in the taking of the pictures. It has been decided not to go into the finer details of the collaboration until the experiment has been approved, and machine-time allocated in principle. We hope, however, that some members of the Michelini group will be interested in participating fully in the experiment.

9. Summary of our request

Twelve shifts in the d_{17} beam towards the end of 1964, with partial PS beam on target 1.

Sw. Frs. 20,000 for apparatus, film, scanning and measuring expenses.

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*) We have arranged this provisionally with Professor Fidecaro.

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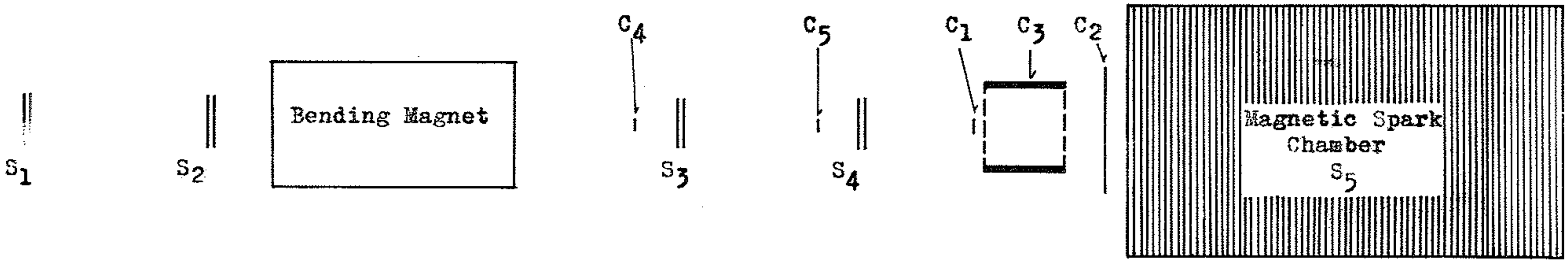

FIG. 1: Diagram of apparatus: Trigger on $C_4C_5C_1C_2C_3$ with constraints on acceptable pulse heights in C_1 and C_2.

C_1: The target counter, 5x5x2 mm
C_2: 1 cm thick plastic scintillator with 1 cm diameter hole at centre
C_3: lead-plastic scintillator sandwich
C_4,C_5: plastic scintillator, 5x5x3 mm

All spark chambers made from 25 Al foil