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ELECTRONICS EXPERIMENTS COMMITTEE

Proposal

A search for exotic mesons using Omega

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Abstract

It is proposed to search for doubly charged exotic mesons coupled to baryon-antibaryon states. The production mechanism is baryon exchange, the sensitivity is such that several hundred events per typical 0.1 μb cross sections are expected. The reaction is $\pi^- d \to (p_s) + p_{fast} + E^{--}$ $(\to p\bar{p}\,\pi^-\pi^-)$. 12 days of production are requested, preceded by some testing time; the yoke configuration is probably non standard.

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1. Introduction

All hadrons well established so far fit well into the $q\bar{q}$ and qqq wuark schemes for mesons and baryons respectively. Duality arguments require nevertheless the existence of exotic mesons ($qq\bar{q}\bar{q}$) coupled to baryon-antibaryon states. The argument goes as follows: As is well known, finite energy sum rules establish a successful connection between direct channel resonances and the behaviour of cross sections at high energy. More specifically one associates direct channel resonances to usual Regge trajectories, while to the Pomeron corresponds the non resonant background. But this connection breaks down for $B\bar{B}$ channel in a definite pattern$^{1)}$. A striking example is the following gedariken reaction. Consider the $\Delta\bar{\Delta}$ channel and let us isolate the odd signature charge exchange reaction, proceeding by ρ exchange. For the two different charge states of the channel considered one gets the following FESR

$$\text{(a)} \int_0^N \nu^n \{\mathrm{Im}A(\overline{\Delta^{++}}\Delta^{++} \to \overline{\Delta^{+}}\Delta^{+}) - \mathrm{Im}A(\Delta^{+}\Delta^{++} \to \Delta^{++}\Delta^{+})\}\, d\nu = X_\rho(N)$$

$$\text{(b)} \int_0^N \nu^n \{\mathrm{Im}A(\overline{\Delta^{0}}\Delta^{++} \to \overline{\Delta^{-}}\Delta^{+}) - \mathrm{Im}A(\Delta^{-}\Delta^{++} \to \Delta^{o}\Delta^{+})\}\, d\nu = X_\rho(N)$$

with the same right hand term in both cases. Now in (a) the $B\bar{B}$ channel involved is a $Y = 0$, $Q = 0$ non-exotic one while in (b) it is exotic ($Y = 0$, $Q = +2$). Possible ways out of this contradition are:

(1) to forget about 2 component duality
(2) to assume that the ρ contribution vanishes ($X_\rho(N) = 0$)
(3) to postulate the existence of such exotic states

We consider here the third possibility and try to prove or disprove the existence of $B = 0$ $qq\bar{q}\bar{q}$ exotic resonances in the 10, 10^* and 27 plots coupled to $B\bar{B}$. In order to keep the nice features of exchange degeneracy one should admit that they are only coupled to $B\bar{B}$ and therefore relatively narrow. One could expect for them a relatively high spin, maybe $J \simeq \alpha' M^2 - 1$.

The production of such mesons via meson exchange is forbidden; rather, they are expected to be produced mainly via baryon exchange (usually Δ exchange; see Fig. 1), with the "normal" baryon exchange cross sections found for analogous reactions with non-exotic produced particles2). These cross sections are low anyway, the optimum energy for given masses is reached when $|u_{min}|$ is already small and where the high energy cross section dependence, $\sigma \sim p^{-2.5}$ typically, is going to set in.

Omega is well sized and equipped for searches of this kind. So far two exploratory searches of strange and non-strange exotic mesons respectively have been carried out:

(1) in 1973 and 1974, in experiment S114, via the reaction

$$\pi^+ p \to \underset{\to\, p\pi^-}{\Lambda^o}\ \tilde{E}^{++} \qquad \text{at 12 GeV/c, and}$$

(2) in 1974, in experiment S117, via the reaction

$$\pi^+ p \to \underset{\to\, p\pi^-}{N^{*o}}\ E^{++} \qquad \text{at 9 GeV/c.}$$

Results from (1) are negative; those from (2) should be available in the very near future. We think that a third search, to be carried out in 1975, is unavoidable because none of these runs had enough sensitivity to reach the cross section level anticipated for exotic mesons of high mass, nor was there the possibility to unambiguously identify baryon-antibaryon decay channels.

In a preceding Letter of Intent (CERN/EEC-74/36) the reactions

$$\pi^+ p \to \Lambda\tilde{E}^{++} \text{ and } \pi^+ p \to N^{*o}\, E^{++} \quad \text{leading to}$$

$$\pi^+ p \to p_{fast}\ \pi^-\ \bar{p}\ \bar{n}\ \pi^+$$

were advocated. We now prefer the following reaction

$$\pi^- n \to p_{fast}\ \underset{\to\, p\bar{p}\pi^-\pi^-}{E^{--}}$$

where E^{--} could be a bound state or resonance, $\overline{\Delta^{++}}\,\Delta^{o}$. A deuterium target is used. The beam momentum is 12 GeV/c, the accessible E^{--} mass range is 2.2 - 2.9 GeV/c^2.

There are 2-3 advantages of the $\pi^- n$ over the $\pi^+ p$ reaction:

a) the useful flux of π^- at this momentum is 5-10 times higher than that of π^+, mainly because of the high p/π^+ ratio,

b) the fast proton trigger works very well with a π^- beam, while with a π^+ beam some fast π^+ leak through,

c) all final particles are charged, therefore ambiguities are less likely to occur.

The main drawback is that no strange exotic mesons can be studied.

Table 1 gives the values of $|u_{min}|$ and the predicted cross sections for various beam energies and masses of the exotic system. The cross section was assumed to be given by ordinary Δ exchange i.e. taken from $\pi^- p \to p\pi^-$ and $\pi^- p \to p\rho^-$ 3). The energy dependence was taken to be $\left(\frac{p}{12}\right)^{-2.5}$. and the shape of the backward peak e^{5u}, so that the quoted value is simply the area under the peak beyond $|u_{min}|$

$$\sigma = 700 \text{ nb } e^{-5|u_{min}|} \left(\frac{p}{12}\right)^{-2.5}$$

The optimum beam energy for masses of 2.3 - 2.7 GeV is around 12 GeV, which we choose.

2. Experimental Layout and Trigger

The layout is shown in Fig. 2. The trigger requires a fast proton, together with a suitable multiplicity and topology of the secondaries. The fast proton trigger has been studied and used by experiment S117, both for negative and positive beam. The momentum selection was obtained by a matrix correlating two sets of proportional wire chambers; the identification by two Cerenkov counters, the usual atmospheric pressure one and a special high pressure counter. With a negative beam, we could check on a sample of 4C 4-prongs events that the trigger particle was indeed a proton. But in that experiment, for physical reasons, the threshold for protons in the high pressure Cerenkov was set at ∿ 1.05 p_{inc} and the matrix accepted momenta down to .55 p_{inc}: therefore kaons were accepted in a narrow band of momenta just above this lower limit and this represented ∿ 25% of the trigger. Here, the momentum of the fast proton is between 7 and 10 GeV/c, for incident π of 12 GeV/c, when $m_{E^{--}}$ is varied from 3 to 2.3 GeV/c^2. So one can now choose the threshold for protons in such a way that all kaons belonging to the right momentum band are rejected. We therefore expect a very clean proton trigger. This is welcome since the reaction we are studying, because of Fermi momentum, is not really a four constraints channel.

In the experiment S117 the goal was to trigger Omega in a totally unbiased way and, apart from the fast proton, the only requirement was an interaction in the target, i.e. a positive answer from a counter surrounding the target. In the present exploratory experiment slight biases are not so serious and we intend to minimize the triggering cross section and therefore to exploit as far as possible the peculiar features of the considered channel, i.e. apart form the fast proton:

- its multiplicity
- the presence of a $\bar{p}$ in the final state
- its topology, i.e. three negative particles which all leave the Omega detector on the same side.

Since the E system is also strongly boosted forward, all products of the reaction are first emitted forward and the multiplicity can be measured in the proportional chamber (M2(y, z; 1 x 1.5 m^2). All wanted reactions have a multiplicity of $\geqslant 3$ in M2; a resulting reduction of the trigger rate by a factor of 4 has been experimentally measured.

The map of the impact of the antiprotons on the side of Omega is such that the existing slow proton counter slightly modified can accept a large fraction of them. This is at least true as long as the E^{--} mass and therefore the Q value in its rest system is not too high, so that its heavier decay products are emitted at small angles and stay in the neighbourhood of the horizontal plane. For E masses between 2.3 and 2.7 GeV, the $\bar{p}$ momentum ranges from 1.5 to 3.2 GeV/c. No unambiguous on-line identification of the $\bar{p}$ is possible. However its time of flight is measured to ± 0.3 nsec and allows an off-line identification at least up to 2 GeV/c. For 85% of all detected $\bar{p}$ the difference in time of flight with an identical π trajectory is > 1 nsec. The acceptance of the modified antiproton counter is .72 for an E^{--} mass of 2.5 GeV and .30 for 2.9 GeV. Next, the π^-'s have momenta mostly below 1 GeV/c and angles which may be large. A good fraction of them is detected either by the antiproton counter or by the counter π added along the side of geometry II. Then the requirements on topology could be at least two hits in one or both counters: the p^- and one of the π^-. Finally, either two scintillators above and below the target, or the corresponding zones of a cylindrical proportional chamber which should soon be available, can be used to veto configurations which cannot be satisfactorily analysed.

A Monte Carlo study has led to optimal counter positions and to mass-dependent acceptance figures, shown in Table 2 for a typical mass of $M_E = 2.6$ GeV/c^2. The main mass-dependent factor is the $\bar{p}$ acceptance and has been already mentioned. The same Table gives an estimate of the trigger rate, based partly on experimental measurements, and partly on a scanning of 700 events of experiment S117 (12 GeV/c $\pi^- p \rightarrow$ forward proton).

3. Event Identification and Analysis

The spectator proton does not leave the d_2 target. We wish to isolate the reaction

$$\pi^- n \rightarrow p_{fast}\ p\pi^-\ \bar{p}\pi^-$$

The fast proton is unambiguously defined by the trigger conditions. 5-prong overall negative final states are selected. An event is retained if among the negative particles there is one which reaches the $\bar{p}$ counter and has the time of flight characterising it as an antiproton. An overall fit checks then whether the target neutron is at rest within the small Fermi momentum in the deuteron. This check is quite efficient to reject final states with a missing neutral - which have been found experimentally to be rare anyway in this configuration. The effective mass of the 4 slow particles is then computed, with no ambiguity for the individual mass assignments (hence the choice of identifying the $\bar{p}$ rather than the p). The E^{--} mass resolution is of the order of $\Delta M_E = \pm 25$ MeV.

In principle, the events thus isolated could be produced by the diffractive process

$$\pi^- n \rightarrow (\bar{p} p_{fast} \pi^-) \; \pi^- p$$

rather than by the baryon exchange process

$$\pi^- n \rightarrow p_{fast} \; E^{--} \; (\rightarrow \bar{p} \pi^- \pi^- p).$$

In fact, this kind of diffractive dissociation is also rare; furthermore, the $\overline{\Delta}^{++}$ momentum band is higher and has no overlap with $\overline{\Delta}^{++}$ momenta from decaying E^{--}'s, as long as both compound masses are within .5 GeV of the respective thresholds. One hopes therefore that the background from such reactions will be small and will not mask the wanted exotic mesons.

4. Event Rates and Beam Requirements

Table 2 gives the values of the predicted cross sections. With a detected Branching Ratio for $\Delta\bar{\Delta} \rightarrow p\bar{p}\pi^-\pi^-$ of 1/6, one finds an average useful cross section of 25 nbarn. The average detection efficiency is 14%.

The trigger cross section, already estimated in Table 2, is 10 μb on protons, i.e. 20 μb on deuterons. We use a 60 cm. target. The trigger rate is then

$$TR = 2.5 \; 10^{24} d/cm^2 \times 20 \; 10^{-30} \; cm^2 \simeq 5 \; 10^{-5}$$

With 250,000 π^-/burst and a dead-time of 15 msec, we will have 170,000 useful π^-/burst and 8.5 triggers/burst. The number of good events for a hypothetical E^{--} of $N_E = 2.6$ GeV will be, with a safety factor of 1/2,

$$N = 170{,}000 \; (\pi^-/b) \times 20{,}000 \; (b/day \times 1/2) \times 2.5 \; 10^{24} \; (p/cm\;) \times 25 \; 10^{-33} (\sigma \times B.R.)$$

$$\times \; .14 \; (\text{efficiency}) \qquad = 30/\text{day}.$$

We request a running time of 10 days preceded by some time to set up (parasitically if possible) the $\bar{p}$ counter. We expect from such a production run 2 ± 1 million triggers, and a few hundred good events per channel.

The conditions are rather standard except for the slow (anti) Proton counter which will mask part of the LP $\check{C}$ and may require a special yoke configuration (Fig. 2).

References

1. J. Rosner, Phys. Rev. Letters 21, 950 (1968).

2. M. Jacob, J. Weyers, N.C. 69A, 521 (1970) and N.C. 70A, 285 (E)

3a. E.W. Anderson et al., Phys. Rev. Letters 22, 102 (1969). $(p\bar{p})$

b. " " 20, 1529 (1968) $(p\pi^-)$

Table 1

Cross section estimates, based on the formula

$$"\sigma" = 700 \text{ nb} \times e^{5\,u_{min}} \times \left(\frac{p}{12}\right)^{-2.5}$$

u_{min} in $(\text{GeV}/c)^2$, σ in nb.

p	M_E =	2.3	2.5	2.7
9	u_{min}	-.34	-.46	-.64
	σ	260	145	60
12	u_{min}	-.23	-.29	-.38
	σ	225	160	105
15	u_{min}	-.17	-.21	-.27
	σ	170	140	105

Table 2

Condition	Trigger Cross Section	Acceptance for good events N = 2.6
Fast p, 7-10 GeV/c	120 μb (measured)	100%
Detection of fast p (1 at Freon!)	x 70%	70%
> 3 in M2	x 25%	100%
$\bar{p}$ in $\bar{p}$ counter	x 60%	58%
> 1 π^- in π or $\bar{p}$ counter	($\bar{p}$ not identified)	67%
Top, bottom veto	70%	-
Enough sparks for each track (Pattern Recognition)		52%
Final Result	10 μb	14%

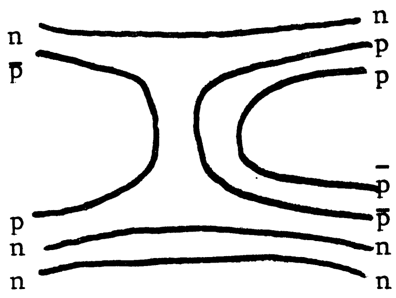


Fig. 1a. Quark diagram for $\pi^- n \to p\, E^{--}$

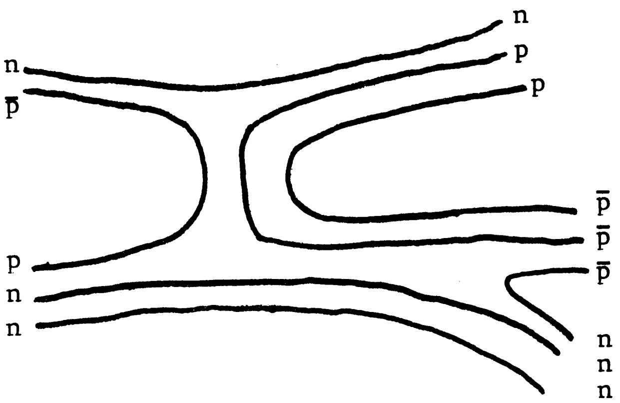
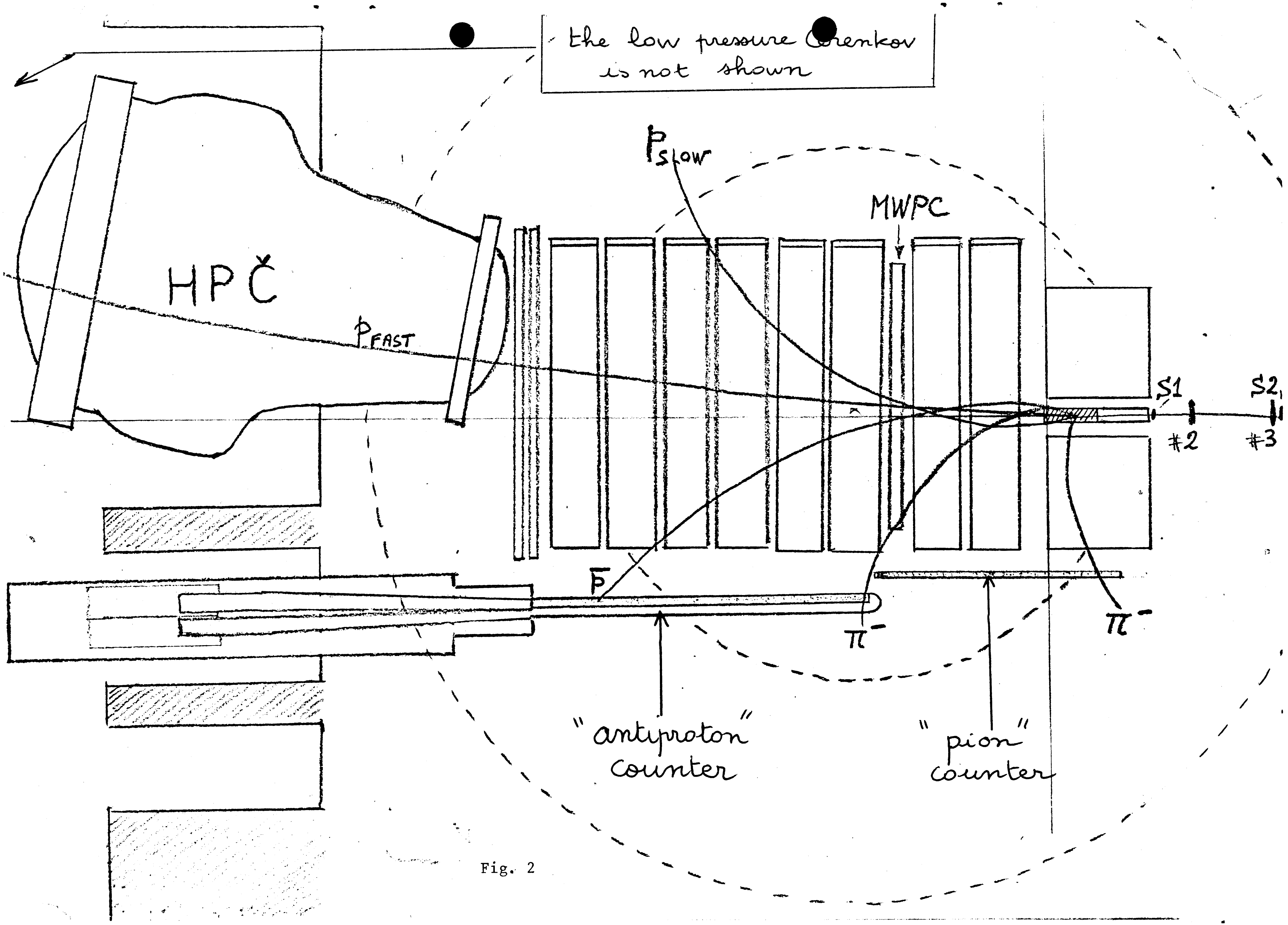


Fig. 1b. An additional quark line leads to $\pi^- n \to p\overline{\Delta^{++}}\Delta^0$



the low pressure Cerenkov is not shown

Fig. 2