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A MEDIUM ENERGY PION BEAM AT CPS (q_3 beam)

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S U M M A R Y

A medium energy pion beam was designed at CERN with the aim of allowing the study of pion resonances. Here we give its main characteristics and describe the tuning and momentum calibration procedure.

1. INTRODUCTION

A medium energy pion beam was designed at CERN with the main purpose of producing pion resonances around a mass of 750 MeV and in particular measuring the branching ratio for their radiative decay[1,2]. The maximum momentum was 3.5 GeV/c, but the tuning was made at a nominal momentum of 2.5 GeV/c, at which the first of the planned experiments was performed[1]. Up to a momentum acceptance of ± 1.3% the momentum definition at the experimental target was better than ± 0.3% as required for the kinematical reconstruction of the events. The beam has become, after some minor modifications, a general PS facility, and we thought it useful to describe its characteristics and the tuning procedure.

2. BEAM LAYOUT

The beam layout is shown in Fig. 1 and its optical diagram in Fig. 2. The source of particles is a Be wire, 1 mm Ø, 20 mm long, placed 100 mrad relative to the circulating proton beam. The q_3 beam starts at 23.5° and views the target at 18°; this one will then appear as an object of (6 + 1) mm in the horizontal plane, and 1 mm in the vertical one. The q_3 beam has an horizontal focus (F1) at the momentum slit, and two double focuses in front of the field lens (F2) and at the target position (F3)[x].

The acceptance of the beam is determined by the first collimator, and is $\pi \times 6.3 \times 18.2 \times 10^{-6} = 360\ \mu$sr.

3. TUNING PROCEDURE

The beam has been tuned by using two pairs of counters (1,2) and (3,4), each pair consisting of a "vertical" counter (2 or 4) and of a "horizontal" one (1 or 3): they had dimensions 3 mm × 10 mm × L, where L = 32 mm for "vertical" counters, and L = 50 mm for "horizontal" ones, the largest dimension being perpendicular to the beam direction.

Each pair of counters was allowed to move right and left, and up and down, with respect to the beam direction.

The pair (3,4), and (1,2) were placed at F2 and F3 respectively (see Fig. 2). A 10 × 10 × 1 cm^3 counter (5) about 50 cm ahead of F3 was also used. The magnets and quadrupoles, which are all standard CPS beam transport elements, were set at the values computed by TRAMP (a CERN Library programme), and indicated in Fig. 2.

x The layout allows the installation of a 3 metre electrostatic separator immediately after Q4; it would then be possible to separate positive pions from protons up to a momentum of about 1.8 GeV/c. A mass slit should be mounted at F2, as indicated in Fig. 1.

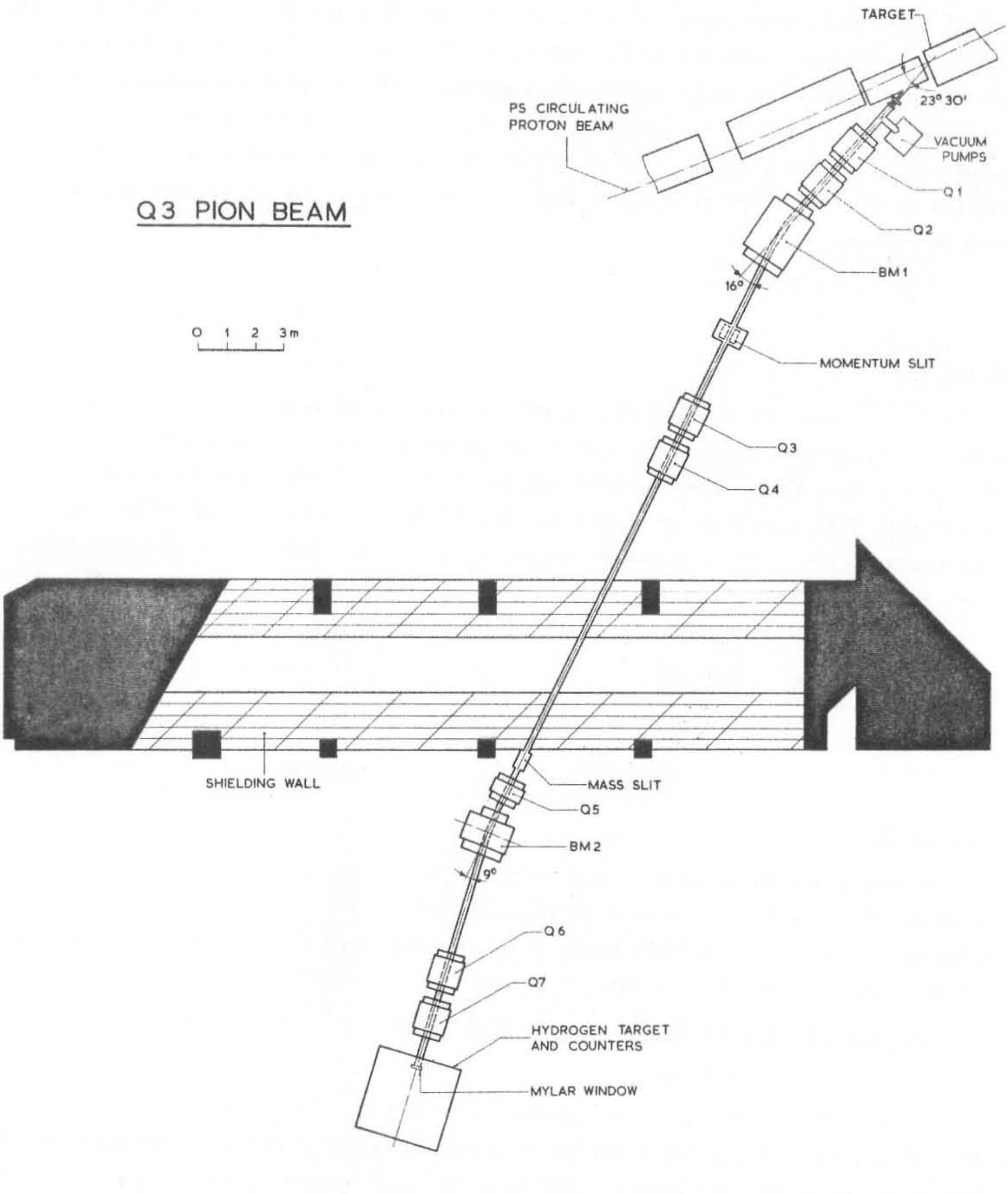

Fig. 1 - Beam layout. The mass slit (see footnote p. 3) was not installed, because eventually only negative pions were used.

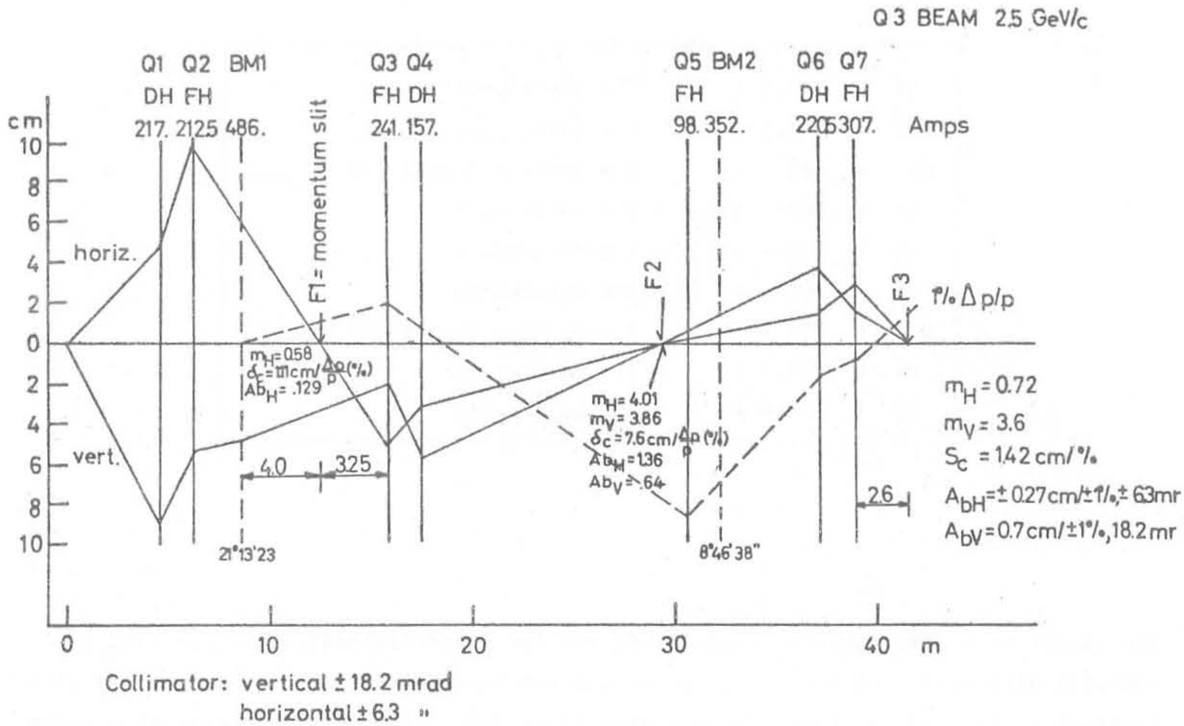

Fig. 2 - Optical diagram.

The last quadrupoles had been adjusted in the following way:

i) The momentum slit was closed at ± 0.5 cm.

ii) The maximum rate of coincidences (1,2) was looked for, as a function of the current in Q6 and Q7. To accelerate the convergence of the values, the currents have been changed in Q6 and Q7 so as to maintain the position of the focal point unchanged in one plane for each series of values.

iii) The pair of counters at F3 was then moved to scan the beam. The centre of the beam was found displaced 1.5 mm up and 0.5 mm right.

Then Q3, Q4 were adjusted with the following procedure:

i) The vertical focus was found by measuring the rate of coincidences (1,5) as a function of the current in Q4 for a fixed value of the current in Q3.

ii) The horizontal focus was found by measuring the rate of coincidences (2,5) as a function of the current in Q3 for a fixed value of the current in Q4.

Q1 and Q2 were adjusted in the same way.

The final values are listed in Table 1.

Table 1

Q1	=	212.5 A	1 m Quadrupole
Q2	=	200.5 A	1 m Quadrupole
BM1	=	486 A	2 m Bending Magnet (17 cm gap)
Q3	=	245 A	1 m Quadrupole
Q4	=	165.5 A	1 m Quadrupole
Q5	=	98 A	0.5 m Quadrupole
BM2	=	352 A	1 m Bending Magnet (14 cm gap)
Q6	=	229.5 A	1 m Quadrupole
Q7	=	315.0 A	1 m Quadrupole

The images were then explored again at F3 via the coincidences (1,2) always with the momentum slit opened at ± 0.5 cm. By moving the horizontal counter 1 up and down, the vertical profile of the beam was obtained, (Fig. 3a). The full width at half maximum (FWHM) is 6 mm. By moving the vertical counter 2 left and right, the horizontal image (Fig. 3b) was obtained, with a FWHM = 10 mm. It has been checked that the image widens according to the opening of the momentum slit, as is shown in Fig. 5. In the same figure the image corresponding to a momentum slit opening of ± 0.4 mm is also shown. The decrease of the intensity at the maximum is related to the fact that the image at F1 is much larger than the slit opening.

At F2 a FWHM = 5.4 mm was obtained for the vertical image, by counting the coincidences (3,4). This should be compared with a calculated one of 4 mm.

Possible misalignments in the beam elements were investigated by moving the vertical counters at F2 and F3 with a momentum slit opened at ± 0.3 mm. It was found that F2 was displaced by 8.5 mm to the right of the axis, and F3 1 mm to the left, as shown in Figs. 4a and 4b.

4. MOMENTUM CALIBRATION BY FLOATING WIRE MEASUREMENTS

The wire was stretched in the usual way[3)] along the beam line from the centre of the momentum slit, through F3 to a computed position F4. The position of the wire was defined by the survey with an accuracy of 0.1 mm. All the quadrupoles between the momentum slit and F3 were switched off, to get a more accurate calibration of the deflection power of BM2. BM2 was excited with currents ranging from 300 to 450 A and the corresponding current I in the wire determined. BM1, Q1, Q2 were then switched on

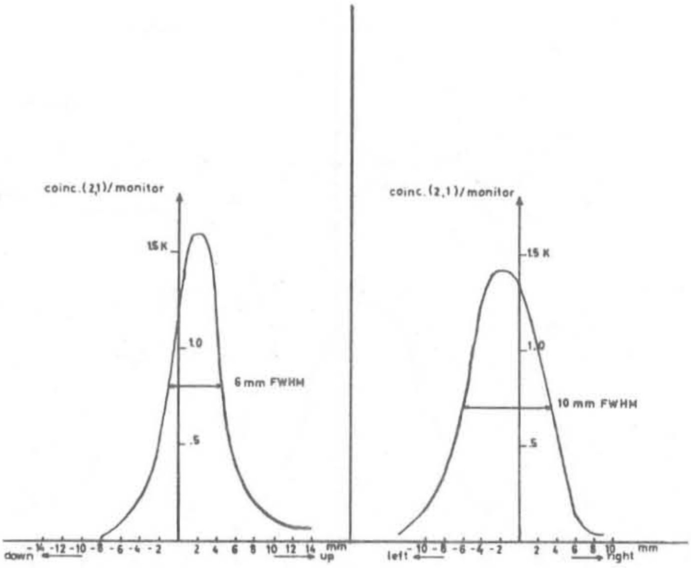

Fig. 3 - a) Vertical beam profile at F3, with the momentum slit at ± 5 mm. The zero position corresponds to the beam axis.

b) Horizontal beam profile at F3, with the momentum slit opened at ± 5 mm. The zero position corresponds to the beam axis.

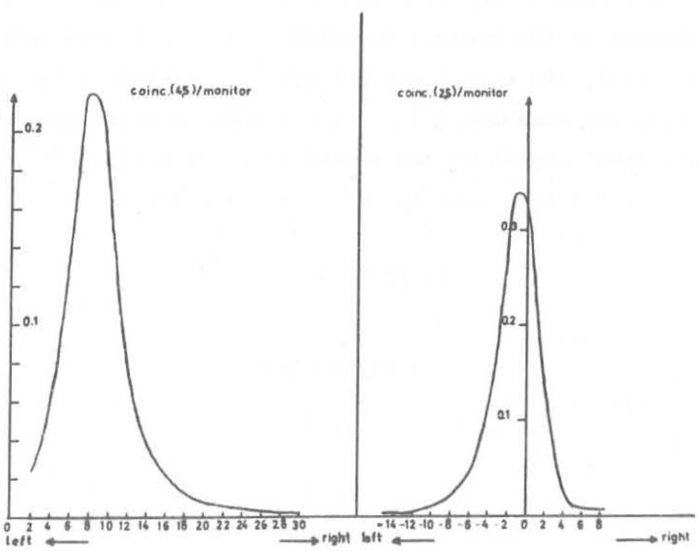

Fig. 4 - a) Horizontal beam profile at F2, with the momentum slit opened at ±0.3 mm. The centre of the image appears displaced by 8.5 mm. to the right of the beam axis (looking downstream).

b) Horizontal beam profile at F3, with the momentum slit opened at ±0.3 mm. The centre of the image appears displaced 1 mm to the left of the beam axis (looking downstream).

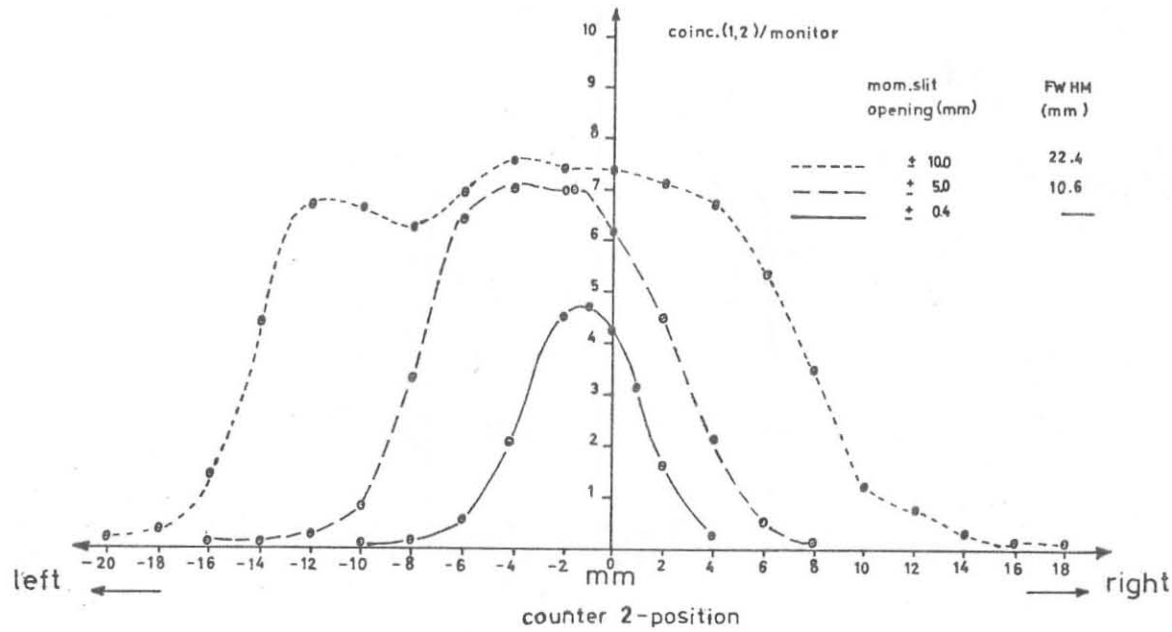

Fig. 5 - Horizontal beam profile at F3 for various momentum slit openings.

at the values of the tuning and the dependence of the coincidence rate (1,4) on BM2 current was looked at, all the other quadrupoles being off. The maximum was found for a current of 355 A corresponding to a momentum of 2.545 ± 0.003 GeV/c, which therefore should be considered as the central momentum of the beam when tuned. It has to be noted that, by this method, the energy calibration of the first stage of the beam was made (between PS target and momentum slit). The actual current value in BM2 is then affected by the small misalignment of the second stage elements. The values of the currents for three different beam momenta are given in Table 2.

Table 2

Element	Momentum (GeV/c)		
	2.545	2.450	0.600
Q1	212.5	204.6	50.1
Q2	200.5	193.0	47.3
BM1	486.0	464.8	110.2
Q3	245.0	235.9	57.8
Q4	165.5	159.3	39.0
Q5	98.0	94.3	23.1
BM2	352.0	335.7	80.7
Q7	315.0	302.7	73.3
Q6	229.5	220.9	54.1

Notice that Q1,2,3,4,5,6 are linear in the range observed. For Q7, BM1, BM2 the values of 2.450 and 0.600 GeV/c have been computed according to the curves found in PS Int EA 60-14, Oct. 1960 for BM1 (17 cm gap) and BM2 (14 cm gap), and in PS Int EA 60-5 Aug. 1960 for Q7.

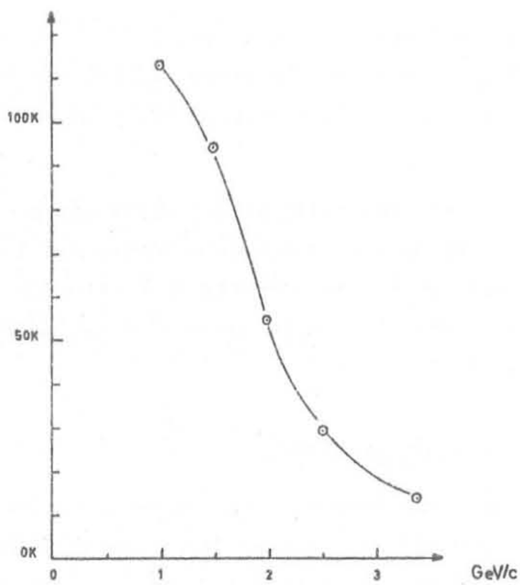

Fig. 6 - Beam intensity at F3 as a function of momentum, between 1.0 and 3.0 GeV/c (±1% momentum bite).

5. INTENSITY AS FUNCTION OF MOMENTUM

The intensity has been measured for negative particles by counting the singles in counter 5, and the results are shown in Fig. 6. The momentum slit was opened at ± 0.5 cm corresponding to a momentum bite of ± 0.45%. With this value of the slit opening there is no cut in the angular acceptance of the beam. With larger openings the beam intensity increases linearly up to ± 1.25 cm and then reaches rapidly a saturation value, as foreseen by the calculations. The muon and electron contamination has not been measured, but it should be less than 10% also at 1 GeV/c. The intensities were also computed by using the existing experimental data and the optical properties of the beam. Actually, for instance, for 2.5 GeV/c negative pions one gets at production[4]:

$$\left(\frac{d^2N}{d\Omega dp}\right) = 3.5 \times 10^{-2}\ \mathrm{sr}^{-1}\ (\mathrm{GeV/c})^{-1}\ (\text{inelastic interaction}^{-1})$$

350 mrad production angle

and extrapolating to a production angle of 410 mrad, for the angular acceptance of our beam and a momentum bite of ± 1%, one gets $2.7 \times 10^4 \pi^-/10^{11}$ interacting protons.

Assuming a 60% efficiency for the circulating beam (the losses being due both to the general target and target sharing efficiency and to the elastically scattered fraction of the protons), this number becomes $1.6 \times 10^4 \pi^-/10^{11}$ circulating protons.

The loss due to decay in flight is, as known, $1 - e^{-L/L_0}$, when L_0 is the decay length and is equal to $(55p_{GeV/c})$ m for the pion. At the position of counter 5 (40 m from the origin) one should then expect a loss of 50% at 1 GeV/c, 30% at 2 GeV/c, 13% at 2.5 GeV/c.

Finally the calculated beam intensity at 2.5 GeV/c ($\Delta p/p = \pm 1\%$) results in $1.75 \times 10^4 \pi^-/10^{11}$ circulating protons which is a factor 1.7 lower than the value we have measured. This may well be due to normalization error in Jordan evaluation[4], or to a wrong calibration of our monitor in terms of circulating protons (1 monitor = 4×10^8 circulating protons).

6. USE OF THE q_3 BEAM IN THE $\rho \to \pi\gamma$ EXPERIMENT

In the $\rho \to \pi\gamma$ experiment the beam was defined by the coincidence $1, 1_b, \bar{2}, \bar{3}$ where counter 1 ($60 \times 3.4 \times 7$ mm^3) was at the first double focus, and counters 1_b (Ø 40, 1.5 mm thick), 2 (Ø 18, 10 mm thick), 3 (Ø 20, 10 mm thick), were just before the hydrogen target.

For the $\rho \to \pi\gamma$ experiment, the q_3 beam had to be focused at about the hydrogen target. To obtain the right displacement of the focus from F3 to the H_2 target the corresponding change in the excitation of the last two lenses (Q6 and Q7) has been calculated to be:

$$\left(\frac{\Delta i}{i}\right)_{Q6} = -\,6.5 \times 10^{-2}\ \Delta S \qquad \Delta S \text{ in m}$$

$$\left(\frac{\Delta i}{i}\right)_{Q7} = -\,27.2 \times 10^{-2}\ \Delta S$$

However the optimum conditions which correspond to a minimum number of triggers with an empty target have been found with a focus at about 10 cm ahead of the target.

REFERENCES

1) G. Fidecaro, M. Fidecaro, J. Poirier and P. Schiavon, Physics Letters 23, 163, 1966.

2) G. Di Giugno, I. Peruzzi, G. Troise, F. Vanoli, M. Giorgi, P. Schiavon and V. Silvestrini, Nuovo Cimento 25, 1272, 1966.

3) A. Citron, F.J.M. Farley, E.G. Michaelis and H. Øverås, CERN 59-8 (1959).

4) B. Jordan, CERN 65-14 (1965).