EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Paper submitted to the
XIVth International Conference
on High-Energy Physics
Vienna, 28 August - 5 September 1968.

CONFIRMATION OF THE TWO-PEAK STRUCTURE IN THE A_2 MESON IN $\pi^- p$ AT 2.6 GeV/c.

H. Benz*), G.E. Chikovani**), G. Damgaard***), M.N. Focacci†)
W. Kienzle, C. Lechanoine††), M. Martin†), C. Nef†), P. Schübelin†††)
R. Baud†), B. Bosnjaković*), J. Cotteron×), R. Klanner××) and A. Weitsch*)

ABSTRACT

A mass spectrum of the A_2 region has been obtained in $\pi^- p \rightarrow pX^-$ at 2.6 GeV/c, i.e. near threshold, with X^- produced at minimum momentum transfer. The results confirm, with a new method and instrument, the A_2 splitting found previously with the Jacobian-peak method.

* * *

(To be submitted to Physics Letters)

* * *

This work is dedicated to G.E. Chikovani (1928 - 1968).

Geneva - 23 July 1968

---

*) University of Munich, Germany.
**) Institute of Physics of the Georgian Academy of Science, Tbilisi, USSR.
***) Niels Bohr Institute, Copenhagen, Denmark.
†) University of Geneva, Switzerland.
††) On leave from the Faculty of Science, Paris, France.
†††) Physics Institute of the University of Bern, now at CERN.
×) Faculty of Science, Paris, France.
××) Max-Planck Institute for Physics and Astrophysics, Munich, Germany.

1. INTRODUCTION

We have explored the shape of the A_2 resonance with a new magnetic mass-spectrometer (CERN Boson Spectrometer, "CBS") which momentum-analyses the forward proton in reaction $\pi^- p \rightarrow pX^-$, X^- being produced at minimum momentum transfer.

This experiment was done in order to verify whether the two-peak structure of the A_2, first observed in 1965[1)] and 1967[2)] with the former Missing Mass Spectrometer ("MMS")[3)] at 6 and 7 GeV/c, is present also when the A_2 is produced close to threshold, and is thus independent of the c.m. energy.

The new A_2 spectra, obtained at p_1 near 2.6 GeV/c, show again a narrow dip at the A_2 centre near 1300 MeV and thus confirm the A_2 splitting.

Supporting evidence for a double A_2 has also come from a bubble chamber experiment in $\pi^- p$ at 6 GeV/c by Crennell et al.[4)].

2. EXPERIMENTAL METHOD

The kinematical conditions are illustrated in Fig. 1. The missing mass M_X is given by

$$M_X^2 = (E_1 + m - E_3)^2 - p_1^2 - p_3^2 + 2p_1p_3 \cos \Theta$$

(p_1 and E_1 refer to the incident pion, Θ, p_3, and E_3 to the recoil proton, m being the proton mass). At $\Theta = 0°$ where $dM_X/d\Theta$ vanishes, it is sufficient to measure p_3. Recoil protons near the forward direction (i.e. $\Theta^*_{c.m.} \cong 180°$) are selected in the range $300 < p_3 < 900$ MeV/c and are momentum-analysed; protons of lower momenta would not traverse the H_2 target. This gives an upper limit to p_1, since for fixed M_X, p_3 decreases with increasing p_1. If in the case of the A_2 full acceptance is required down to $M_X = 1.2$ GeV, this gives p_1^{max} near 2.6 GeV, a value very close to threshold.

For the mass range $2 < M_X < 5$ GeV for which the method was proposed, one is well above threshold. The present A_2 data were taken to test the new method and instrument.

The layout and trigger system are shown in Fig. 2. A pion beam, momentum analysed by three scintillation counter hodoscopes H_0, H_1, H_2, in the beam transport ($\Delta p_1/p_1 = \pm 0.3\%$), falls on a hydrogen target 26 cm long (H_0 is located up-stream at the momentum slit). H_1 and H_2 are two-dimensional hodoscopes giving the incident direction to ±1 mrad. They are covered by the trigger counters T_1 and T_2.

After passing through a spectrometer consisting of a collimator ($-1° < \Theta_{\mathrm{horiz}} < +13°$; $-3° < \Theta_{\mathrm{vert}} < +3°$), a large-gap magnet, and four wide-gap wire chambers SC_1 – SC_4 5,6), the proton is detected by the counter R. Its momentum is measured independently by magnetic deflection between $SC_{1,2}$ and $SC_{3,4}$, and by time-of-flight between T_2 and R.

The counters V_1 and V_2 require at least one charged decay product of X^- in SC_1 and SC_2. The interaction point is found by intersecting its track with the incident pion track. Four scintillation counters D around the target count additional charged secondaries of X^- which miss SC_1 and SC_2. Hence the full trigger condition is T_1 T_2 (V_1 or V_2) R. Due to the low value of p_1, the acceptance of the vertex system is not high enough to allow a decay analysis of $A_2 \rightarrow 3\pi^{\pm}$, as in earlier experiments with the MMS 7). In this experiment, only a few per cent of the events have all three decay pions emitted into SC_1 and SC_2.

The data acquisition and on-line control of the whole spectrometer system is done by an IBM 1800 computer. It writes on magnetic tape the information from the magnetostrictive wire chambers, the time-of-flight, the beam hodoscopes, and various other quantities which are all digitized through a fast scaler system. In addition, the computer analyses two events per PS burst, to provide a check on the technical performance of the system, such as efficiency of the chambers and counters, beam position in the hodoscopes, etc. The data-taking rate was three to five events per burst and limited by the relatively low beam intensity of $\approx 50{,}000$ π/burst. The detailed analysis was done off-line on a larger computer, in parallel with the run. About 500,000 triggers were processed per running week.

The proton momentum p_3 and hence M_X is obtained in two ways:

a) From magnetic deflection, by expressing p_3 as a function of the bending angle and the coordinates of the proton track in the magnet centre plane. Here the resolution is limited by multiple Coulomb scattering in the wire planes (±8 mrad at p_3 = 500 MeV/c).

b) From time-of-flight (TOF) between the counters T_2 and R, the latter being viewed by two independent TOF systems. After correcting for the impact point of the proton in the R counter, the TOF resolution is $\Delta t = \pm 0.5$ nsec.

Both momenta are corrected for the energy loss of the proton in the hydrogen target. These two measurements allow one to calculate the mass of the recoil particle and to identify it as a proton. The position and width of the proton mass were used to check the stability and resolution of the system.

The total mass resolution Γ_{total} at the A_2 centre for p_1 = 2.65 GeV/c, is composed of contributions from $\Delta p_1/p_1$, $\Delta p_3/p_3$ and the vertex precision, in the following way

	$\Gamma_{(\Delta p_1/p_1)}$ MeV	$\Gamma_{(\Delta p_3/p_3)}$ MeV	$\Gamma_{(\text{vertex precis.})}$ MeV	Γ_{total} MeV
Magnet	±2.2	±7.5	±2.8	±8.3
Time-of-flight	±2.2	±3.8	±2.8	±5.2

The mass spectra shown below are mainly $M_{X(TOF)}$, since $\Gamma_{(TOF)}$ is better than $\Gamma_{(magnet)}$.

3. RESULTS

In a first phase (Nov. 1967 - Jan. 1968) a few runs with different conditions have been taken:

Run	p_1 (GeV/c) π^-	Magnetic field B (kG)	Turn-table angle
1	2.60	3.0	27°
2	2.60	2.0	18°
3	2.55	2.0	18°
4	2.65	2.0	18°

Several variations of the experimental conditions were done in order to check against possible instrumental effects. In the A_2 region, a variation in p_1 from 2.55 to 2.65 GeV/c shifts M_X by 30 MeV for a fixed p_3, and would therefore wash out a false narrow structure, e.g. coming from a possible technical bias in the p_3 measurement.

In order to improve the signal-to-background ratio, all data shown in this paper contain the requirement that $X^- \to \geq 3$ charged decay products. (It has been checked that this selection does not influence the A_2 structure itself.) In addition, to eliminate the dependence of geometrical efficiency on M_X, events are accepted only if the c.m. proton angle is larger than 176°.

The sum of runs 1-4 (TOF data) is shown in Fig. 3a. A dip is present in the A_2 centre with the same mass and width as in the published MMS data$^{2)}$.

Having seen the structure in the A_2, the geometry of the spectrometer was changed for the <u>second phase</u>. The reasons were to increase the c.m. solid angle to operate at higher magnetic field, and to have another check against possible technical biases. Also, the box of D-counters (Fig. 2) surrounding the target was set up, and the H_0 hodoscope introduced to improve $\Delta p_1/p_1$. Using the spectrometer, we measured the absolute beam momentum $p_1 = 2.652 \pm 0.015$ GeV/c. This determines the absolute mass scale to ±4 MeV.

Two runs with different conditions were taken:

Run	p_1 (GeV/c)	Magnetic field B (kG)	Turn-table angle
5	2.65 π^+	5.5	30°
6	2.65 π^-	4.15	24°

In March, a positive beam was chosen for run 5 (Fig. 3b, TOF spectrum, same selection as Fig. 3a) to give a different background. In April-May, a large sample (700,000 triggers) was obtained in run 6 under very stable technical conditions. Figure 3c shows the TOF spectrum and Fig. 3d data from magnetic momentum analysis for this run. All these mass spectra show a dip close to 1300 MeV.

The signal-to-background ratio of the A_2 peak is now only about 1:5 due to the low p_1 (as compared to 1:2 in the MMS data) and is difficult to estimate since the A_2 signal sits on a broad maximum of the phase space.

The total CBS A_2 data in π^-p are shown in Fig. 4a together with the total MMS A_2 in Fig. 4b. The coincidence in mass and the similarity in width of the dips in the A_2 centre are apparent. The difference of the A_2 signals and the background slopes are due to the different p_1. With the same statistics in both sets of data, the dip is more significant (4.5 standard deviations measured from the peak) in Fig. 4b because of the stronger A_2 signal, than in Fig. 4a (~3.8 standard deviations).

The sum of CBS + MMS data (Fig. 4c) shows a dip of ~6 standard deviations, centred at $M_X = 1298\ (\pm 4)$ MeV, the two peaks having the same widths and same amplitudes within statistical errors. The positions and widths of the two A_2 peaks are:

$$\begin{array}{lll} A_2^{\text{high}} : & M = 1276\ (\pm 4)\ \text{MeV} & \\ & & \Gamma^{\text{low}} = \Gamma^{\text{high}} = 24(\pm 5)\ \text{MeV.} \\ A_2^{\text{low}} : & M = 1318\ (\pm 4)\ \text{MeV} & \end{array}$$

In conclusion, this experiment confirms the split A_2 which appears, even when produced near threshold, as a roughly symmetric double peak. However, a quantitative comparison between the shapes of A_2^{high} and A_2^{low} is not meaningful in the new data owing to uncertainty in background subtraction. To understand the splitting, a high-energy experiment with a stronger A_2 signal and a separate decay analysis of both halves is needed.

Acknowledgements

We are indebted to Drs. L. Dubal and B. Levrat and to Miss M.C. Jacob, who helped in the early stages of the experiment. The skilful technical support of Mr. G. Laverrière, V. Beck, Mrs. R. Lambert, Mr. A. Lacourt, R. Schillsott and W. Wolf is greatly appreciated.

One of us (W.K.) is grateful to Dr. K.W. Lai (BNL) for communication of data prior to publication.

We would like to thank Professors P. Preiswerk, G. Cocconi, and W. Paul for their continuous interest and support.

Part of this work was supported by the Swiss National Science Foundation.

REFERENCES

1) B. Levrat, C.A. Tolstrup, P. Schübelin, C. Nef, M. Martin, B.C. Maglić W. Kienzle, M.N. Focacci, L. Dubal and G. Chikovani, Physics Letters 22, 714 (1966).

2) G. Chikovani, M.N. Focacci, W. Kienzle, C. Lechanoine, B. Levrat, B. Maglić, M. Martin, P. Schübelin, L. Dubal, M. Fischer, P. Grieder and C. Nef, Physics Letters 25B, 44 (1967).

3) B. Maglić and G. Costa, Physics Letters 18, 185 (1965).

4) D.J. Crennell, U. Karshon, K.W. Lai, J.M. Scarr, I.O. Skillicorn, Phys.Rev.Letters 20, 1318 (1968).

5) G.E. Chikovani, G.C. Laverrière and P. Schübelin, Nucl.Instrum. Methods 47, 273 (1967).

6) G.E. Chikovani, M. Fischer, M.N. Focacci, W. Kienzle, G.C. Laverrière, C. Lechanoine, B. Levrat, M. Martin and P. Schübelin, CERN Report 67-13 (1967).

7) M. Martin, P. Schübelin, G.E. Chikovani, M.N. Focacci, W. Kienzle, U. Kruse, C. Lechanoine and B. Levrat. Presented at the Heidelberg Int.Conf. on Elementary Particles, Sept. 1967.

Figure captions

Fig. 1 : Kinematics of the reaction $\pi^- p \to pX^-$ at 2.6 GeV/c. The shaded area near $\Theta = 0°$ lab. angle indicates the region of full efficiency of the boson spectrometer during the A_2 runs ($0.3 < p_3 < 0.9$ GeV/c and $0° < \Theta < 10°$.

Fig. 2 : Boson spectrometer layout (schematic). H_1 and H_2: beam hodoscopes. Trigger condition T_1 T_2 (V_1 or V_2) R. $SC_1 - SC_4$ are wide-gap wire spark chambers operating in the track following mode (gap size 5 cm, sensitive area 1.5×1.5 m^2). The system operates on-line with the IBM 1800 computer.

Fig. 3 : Mass spectra of the A_2 region obtained in $\pi^\pm p \to pX^\pm$ near A_2 threshold with the CBS at different experimental conditions.

3a: Sum of TOF data obtained with first geometrical set-up (Nov. 1967 - Jan. 1968 runs 1 to 4).

3b: Incident π^+ beam, second geometrical set-up (run 5), TOF data.

3c: Same set-up as 3b, π^- beam (run 6 TOF data).

3d: Same as 3c, missing mass from magnetic analysis.

Only events with $X^\pm$ decaying into ≥ 3 charged particles and $\Theta^*_{c.m.} \geq 176°$ are shown.

Fig. 4 : Compilation of the total available mass spectrometer data relevant to an A_2 splitting in $\pi^- p \to pX^-$:

a) Total boson spectrometer ("0° method") data, A_2 produced close to threshold (p_1 near 2.6 GeV/c).

b) Total missing-mass spectrometer ("Jacobian-peak method") data, A_2 produced far above threshold ($p_1 = 6$ and 7 GeV/c). Dips coincide well in absolute mass.

c) TOTAL SUM = sample (a) + sample (b).

FIG.1 KINEMATICS OF THE REACTION **$\pi p \rightarrow pX$**
AT INCIDENT MOMENTUM P_1=2.6 GEV/C

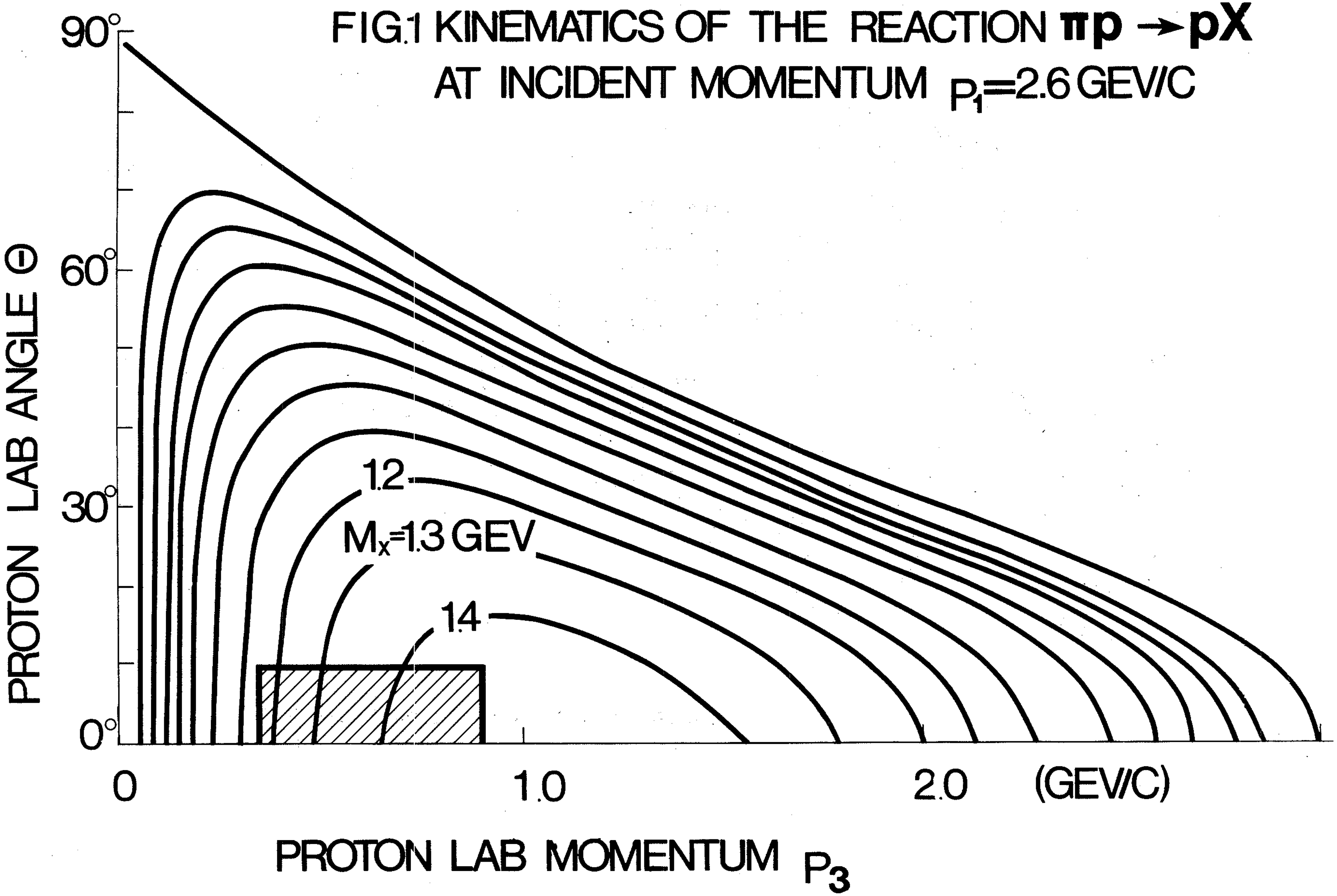
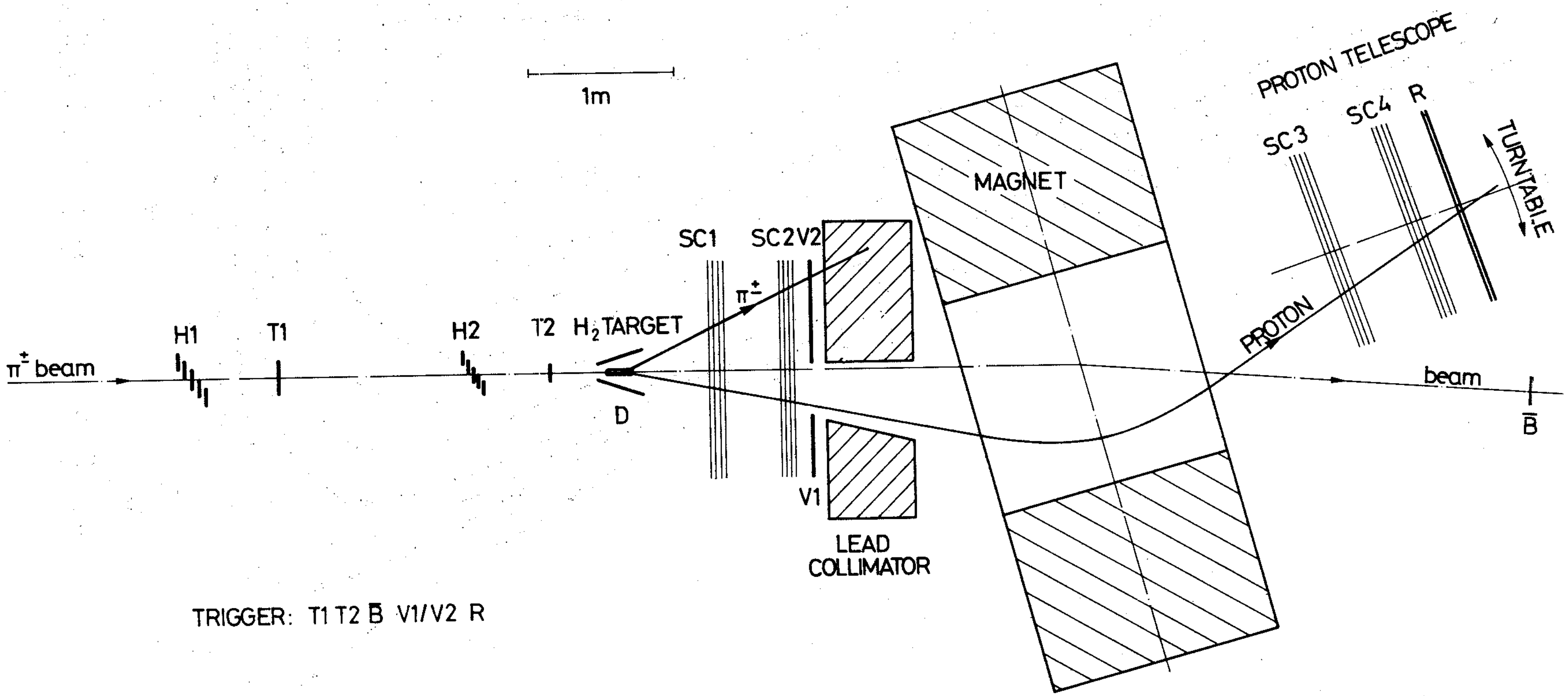


FIG.2
BOSONSPECTROMETER LAYOUT 1968 (SCHEMATIC)



TRIGGER: T1 T2 $\bar{B}$ V1/V2 R

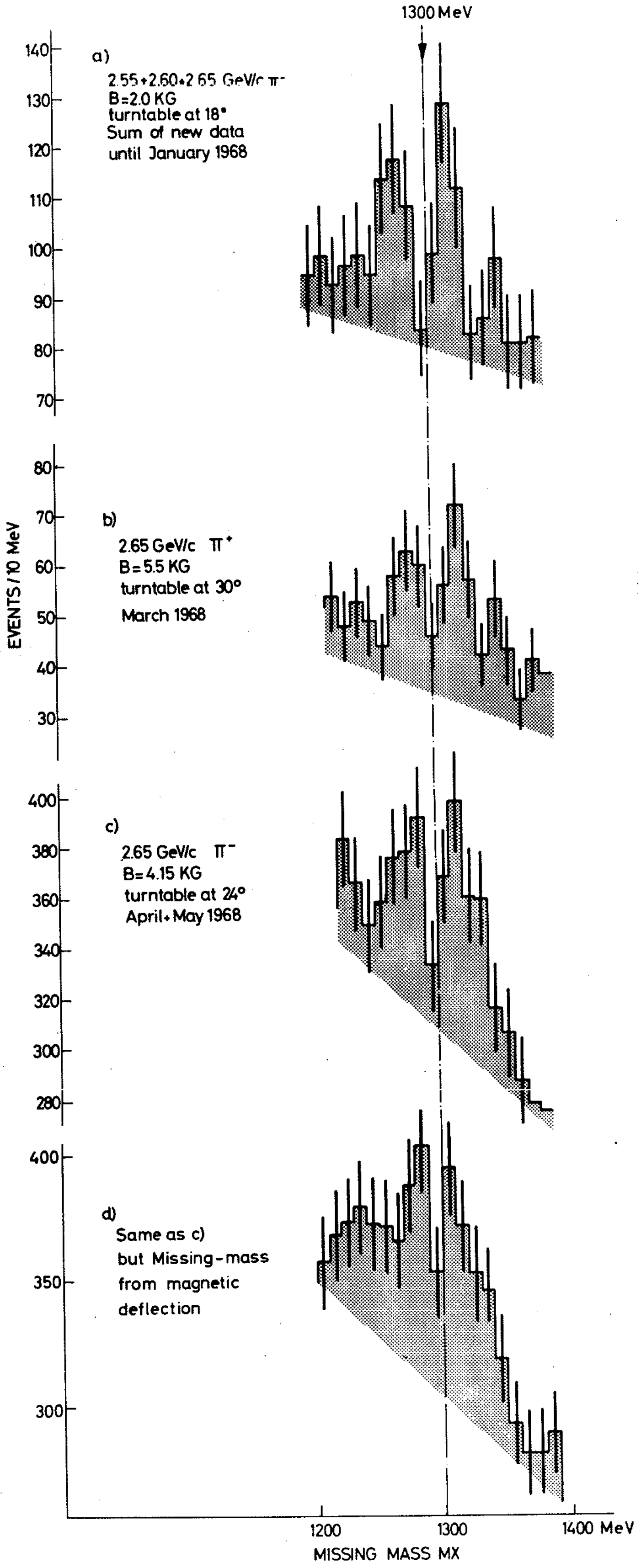


FIG.3 Mass spectra of the A2 region obtained in $\pi p \rightarrow pX$ with the CERN Bosonspectrometer (1968) under different experimental conditions

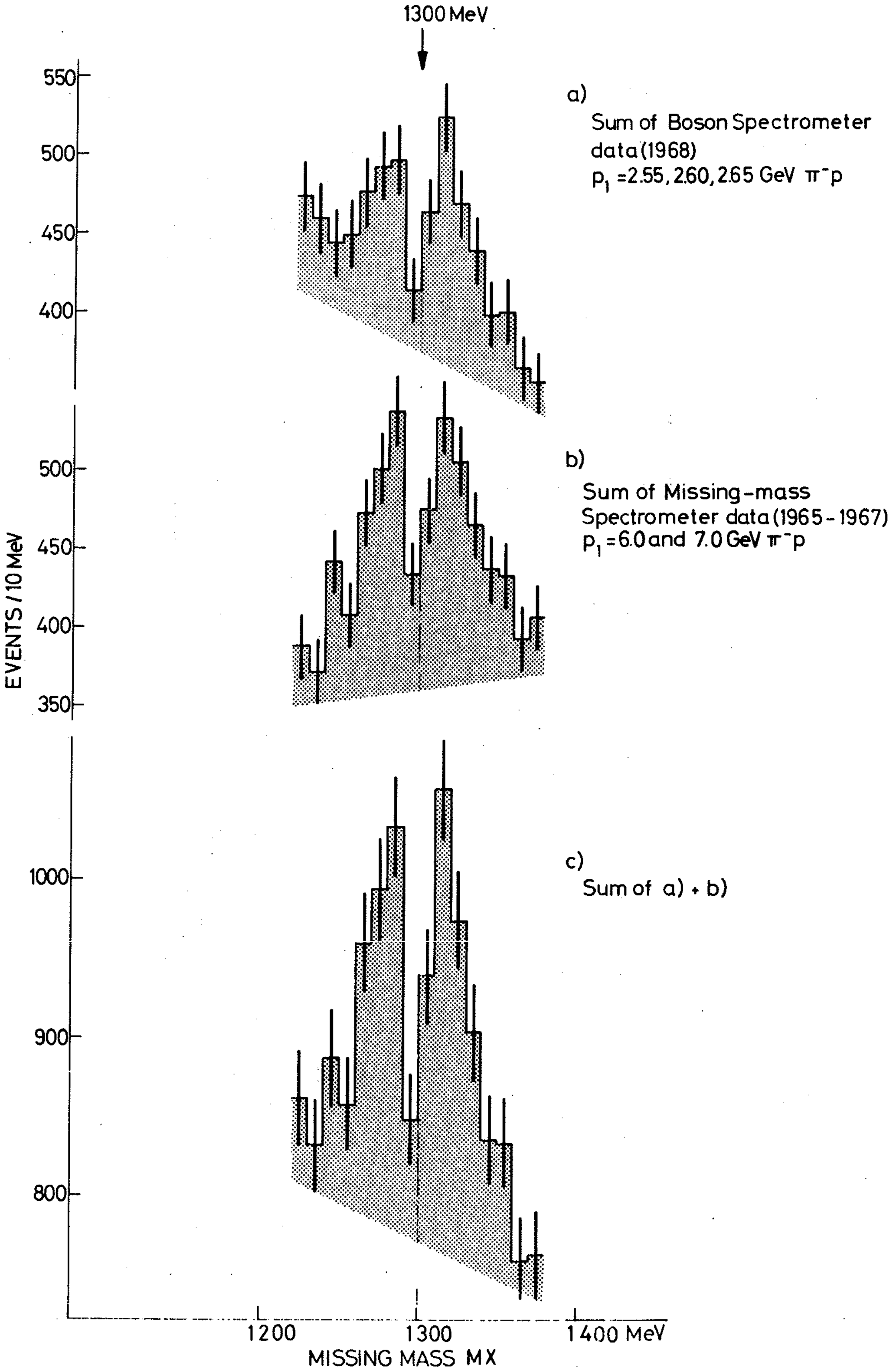


FIG.4 Compilation of the total A2 data from CERN Boson Spectrometer (0°method) 1968 and CERN Missing - mass Spectrometer (Jacobian peak method) 1965 - 67