SYSTEM CONSISTING OF SONIC SPARK CHAMBERS, TIME-OF-FLIGHT AND PULSE-HEIGHT COUNTERS ("MISSING-MASS SPECTROMETER") WITH ON-LINE COMPUTER

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(presented by B. Maglić)

1. INTRODUCTION

We have built a system consisting of sonic spark chambers, time-of-flight, pulse-height and hodoscope counters (see Fig. 2). Such an instrument was proposed recently under the name of "missing-mass spectrometer"[1], for the search of new unstable particles, X. (X can be boson, nucleon isobar or excited hyperon, depending on the type of the bombarding particle.)

We have in mind an investigation of the reaction

$$\pi^- + P \rightarrow P + X^- \qquad (1)$$

particle index: 1 2 3 4

with X = unstable boson.

In Fig. 2 we have listed the measurements which are supposed to be done by the MM-spectrometer. According to its function, the instrument can be divided into two parts:

Part i) : "Pion line". It contains:
- hodoscopes H_1 -H_2 -H_3 -H_4
- "vertex" counter, V.

Part ii) : "Proton line". It contains:
- sonic chambers S_1 -S_2 -S_3 -S_4
- hodoscopes for recoil proton R_1 -R_2 -R_3
- aluminium degraders D_1 -D_2 -D_3, of variable thickness.

Part ii), the "Proton line", has been tested in a proton beam (with a 20% pion admixture) from the CERN Synchro-cyclotron. In Fig. 1, we show the diagram of this tested part of the system.

2. QUANTITIES INVOLVED IN THE MEASUREMENT OF MISSING-MASS

Mass of particle 4, M_4, in Reaction (1) is equal to the missing-mass of particle 3, m_3. In general, (miss. mass)^2 = (miss. energy)^2 - (miss. momentum)^2, which, for the case of Reaction (1), ($M_2 = M_3$) becomes:

$$m_3^2 = M_4^2 = M_1^2 - 2\left[\left(P_1^2 + M_1^2\right)^{\frac{1}{2}} + M_1\right]\left[\left(P_3^2 + M_3^2\right)^{\frac{1}{2}} - M_3\right] + 2P_1P_3\cos\Theta_3. \quad (2)$$

All quantities in Eq. (2) are in the laboratory system. Knowledge of m_3 requires simultaneous measurement of six quantities; they are listed in Table 1, together with the description of the measuring technique used.

All measured quantities listed in Table 1 are first digitized and then registered in scalers. The existing CERN scaler readout logic is used to transfer the information from the scalers, either onto magnetic tape or to the Mercury computer.

In the following text we describe only the essential facts about the operation of our system. Overall description of the interconnections and parts of the instrument will not be given. Apart from the descriptive figures 1 and 2, the reader is referred to talks presented by F. Iselin in Session IV and by H. Slettenhaar in Session V.

3. DATA STORAGE

All raw data without any pre-selection or pre-computation, are stored from the scalers onto the magnetic tape. We use the IBM unit, placed in an air-conditioned trailer. The tape speed is 36"/sec with a density of 200 characters per inch. A 2,400 ft reel can store 3×10^4 events (from 30 scalers).

Assuming a 100% running efficiency and 100 msec for the recording of an event, one expects, on the average, 2 events per 300 msec/burst of the Proton-Synchrotron, or 3,600 events/hour. Our estimate is a 30% efficiency; thus, the expected data getting rate is 1,000 events/hour or 2.4×10^4 events/day.

4. ROLE OF THE ON-LINE COMPUTER

Due to the slowness of the Ferranti "Mercury" computer used, only one out of three to four events can be processed to the point of computing M_3, Eq. (1). This makes the computer a sampling facility. The importance of sampling is two-fold:

i) It makes it possible to test the goodness of the physics result (missing-mass distributions) by applying certain prescribed checks on the Θ_3 vs P_3 dot density distributions. The proposed method of "particle hunting" depends on these tests (described in paragraph 5). The Θ vs P display is done by the mechanical x-y plotter.

ii) It constantly checks the functioning of the whole instrument: whenever an event cannot be "fitted", the reason for the failure (type of error) is displayed (see paragraph 6) on the typewriter on-line.

5. ON-LINE CHECKS AGAINST FALSE PEAKS

We know, today, only of two X^- resonances (I = 1): ρ and B, whose masses are 750 and 1,220 MeV, respectively, and width Γ = 100 MeV. If there are no new resonances, the Number vs m_3 distribution would show a continuum (phase space), with only these two peaks superimposed on it. A new heavy boson would show as another peak on the continuum.

However, in the past bubble-chamber work, peaks in N vs MM distribution frequently turned out to be false ones. (All unstable bosons were found in the effective mass, rather than MM distributions.)

The proposed method prescribes definite tests, to be made in the course of the experiment, which should be capable of revealing if the peak is false or not.

Θ_3 vs P_3 scatter diagram

In this technique, the result is not displayed in the usual N vs MM histogram. Since, at fixed P_1, MM is a function of only two variables, $MM = f(\Theta_3, P_3)$, each event can be represented by a dot in a Θ_3-P_3 plane. This gives more information than N vs MM histogram. First, it shows, simultaneously, cross-section as a function of the momentum transfer Δ^2 ($\simeq P_3^2$). Secondly, the scatter diagram provides two independent tests:

Test 1: If there is a discreet mass in X, the dots should lie along one mass-line whose shape is well known at any incident P_1 = fixed. (See, for example, Θ_3-P_3 mass lines for P_1 = 6 GeV in Fig. 3.) An increase of dot-density, if the effect is real, is expected along a given line. If this condition appears to be satisfied in the course of the run, the physicist proceeds to

Test 2: The mass-lines shift in a known manner with the change of the incident momentum P_1; the increase (decrease) of P_1 by 1 GeV/c, typically increases (decreases) the maximum angle by about 3°. At any beam setting, the variation of the beam momentum of ± 1 GeV/c is possible without changes in the beam design.

Therefore, the second test consists of repeating the run at P_1 + 1 GeV/c and P_1 - 1 GeV/c, and seeing if the density distribution follows the scale prescribed by kinematics. For example, the dotted line in Fig. 3 shows the shift of the 1.5 GeV mass line for P_1 = 8 GeV/c, in respect to the one at P_1 = 6 GeV/c (solid line), i.e. it shows the effect of ΔP = + 2 GeV/c.

6. OPERATION OF THE "PROTON LINE"

Here, we shall describe the procedure of identifying the proton and computing its Θ_3 and P_3 in its time sequence:

From the sonic information obtained from 24 transducers in chambers S_1, S_2, S_3 and S_4, the spark co-ordinates (x,y) in each of the six gaps are fitted; then a straight line (proton direction) is fitted through the points;

- The straight line is extrapolated into the R_1 hodoscope; the programme computes which of the three counters should have been hit by the particle; on the other hand, the programme checks the information stored in the pattern unit and sees if the observed counter number, R_{1i}^{obs} is equal to $R_{1i}^{expected}$. If yes, the position of the particle in the plane of the R_{1i} counter is computed; then, the time of propagation of the light signal from this point to the photo-multiplier is subtracted from the observed time-of-flight, $(TOF)^{obs}$. This gives "first-corrected TOF".

- The straight line is then extrapolated forward to the target to find the intersection with the incident pion direction. [This is the vertex of Reaction (1)]; then the time-of-flight taken for the pion to travel from H_4 to the vertex is subtracted from the first corrected TOF. This gives the real time-of-flight, $(TOF)^{real}$.

- Check is made on the counter number R_{2i} which is hit by the proton.

- Using the $(TOF)^{real}$ and the information on the thickness of degrader D_2, the expected pulse height, $(PH)_2^{exp}$, in hodoscope R_2 is computed, on the assumption that the particle is proton; then, the information on the $(PH)_2^{observed}$ is compared, and if they agree to 20%, proton is identified.

- Similar procedure is repeated for the hodoscope R_3; then,

- P_3 is computed.

- Θ_3 is computed.

7. USE OF TYPEWRITER ON-LINE

The typewriter is in the experimental area, on-line with the computer output; it gives the evidence on the functioning of every instrument of the system at any time:

i) whenever an event cannot be "fitted" by the missing-mass programme, the reason for the failure is typed. This can be illustrated by the following examples:

- If the pion line operates properly only one counter in each of the hodoscopes H_1 -H_4 should go off. If, in one hodoscope, (say H_3), two counters, (say 2 and 4), give signals, the event will not be fitted.

  Error H324 will be typed.

- There were two sparks in S_2. This will give too short sonic times.

  Error type: 6S2

- One transducer, say No. 1 in S_3, has become insensitive or disconnected. This gives too long sonic time.

  Error type: 5S31

- One spark chamber gap became inefficient. This would result in the absence of the stop signals in any of the four microphones in that gap.

  Error type: 5.

- An event does not satisfy the PH criterion for proton of given TOF.

  Error type: 9.

ii) The repetition of any of these errors draws the experimentalist's attention to the specific part of the apparatus. He requests the computer operator to output the quantities related to the part of the system which is malfunctioning. He can plot the distribution of each of the quantities.

  An example of this is given in Figs. 4 and 5. Distribution has revealed that the spark chamber S_1 was inclined by 1° to the vertical.

ACKNOWLEDGEMENTS

Thanks are due to G.R. Macleod for suggesting and helping to organize the use of the Mercury computer; to D. Harting for his help in the planning of the system; to B. Levrat*) for his help in the later stages; J. Tischhauser for his constructions; J.W. Beck, L. Dubal*), F. Marciano and G. Genova for their invaluable assistance.

Reference 1) : CERN Memorandum MM-1 (1963).

*) University of Geneva.

Table 1

Physical quantities involved in measuring "missing-mass spectrum"

Observable	Method of measuring	Accuracy
1. Mass of incident pion, M_1	Not measured. Beam is presumed to contain 99.3% pions.	
2. Momentum of incident pion, P_1	Magnet 120 mrad, with 4 counter hodoscopes H_1, H_2, H_3, H_4	± 1%
3. Direction of incident pion, $\hat{P}_1$	2 counter hodoscopes H_3 - H_4	± 1 mrad
4. Mass of recoil proton, M_3	Differential pulse-height (3 hodoscopes R_1 -R_2 -R_3) and time-of-flight	± 20%
5. Momentum of recoil proton, P_3	Time-of-flight	± 0.5 nsec
6. Direction of recoil proton, $\hat{P}_3$ (measurements 3 and 6 give angle Θ_3)	2 three-gap sonic spark chambers	± 1 mrad
7. Number of charged particles, N, into which X-boson decays (not directly related to the measurement of m_3) but essential to our method of eliminating background.	Pulse-height counter	In 5% cases one more particle will be counted due to Landau tail.

Figure captions

Fig. 1 Simplified version of missing-mass spectrometer, tested 19-20 December, 1963. Results of the test are given in Figs. 4-11. See also Fig. 2.

Fig. 2 Complete diagram of the data reduction system for MM-spectrometer. The "proton line" was tested (see Fig. 1).

Fig. 3 Kinematic "mass-lines" in the Θ_3 vs p_3 plane at incident pion momentum of $p_1 = 6$ GeV/c. An example for the shift of the mass-line is shown for $p_1 = 8$ GeV/c (dotted line). See paragraph 4 of the text.

Fig. 4
Fig. 5 } Distribution of the differences of the spark positions in two gaps in the sonic chamber of active area of 40×80 cm^2, for the x and y coordinates, respectively. The systematic shift of 1 mm in the y coordinate helped us in finding out that the chamber was inclined 1° to the vertical.

Fig. 6 Distribution of the differences of the shock-wave parameter Δt in two gaps. Δt is proportional to the square root of the spark energy (see Lillethun et al., Operation of a sonic spark-chamber system, CERN report 1963).

Fig. 7 Angular distribution of the collimated proton beam, as measured by two sonic spark-chamber gaps, 150 cm apart. This measurement gives our angular resolution to be $\pm 0.05^\circ$.

Fig. 8 Pulse-height distribution in a scintillator 50×30 cm^2, 1 cm thick, obtained with protons of 0.9 GeV/c. This gives our pulse-height distribution, which is $\pm$ 23%.

Fig. 9 Momentum resolution, obtained by time-of-flight measurements.

Fig. 10 Flow diagram of the MM-programme used in the test of "proton line". The set-up is shown in Fig. 1.

Fig. 11 Missing-mass resolution, obtained with the proton line set-up, described in Fig. 1.

Fig. 12 Layout of the cable connecting four experimental areas on the CERN site to Mercury computer (M). Details of the link are described by Slettenhaar, Session V.

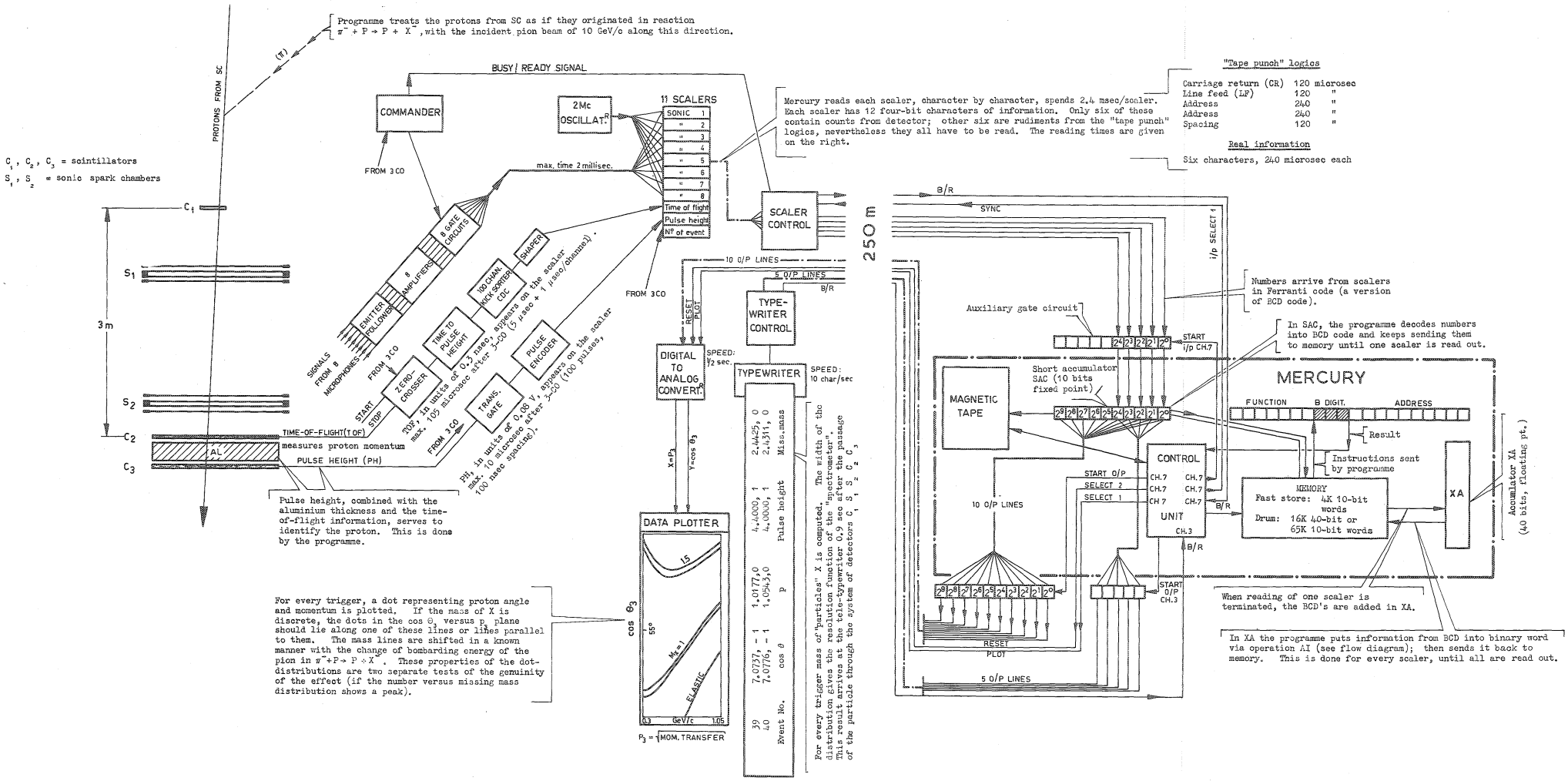


FIG. 1. SIMPLIFIED VERSION OF MM - SPECTROMETER, TESTED 19 - 20th DECEMBER, 1963. RESULTS ARE GIVEN IN THE FOLLOWING FIGURES.

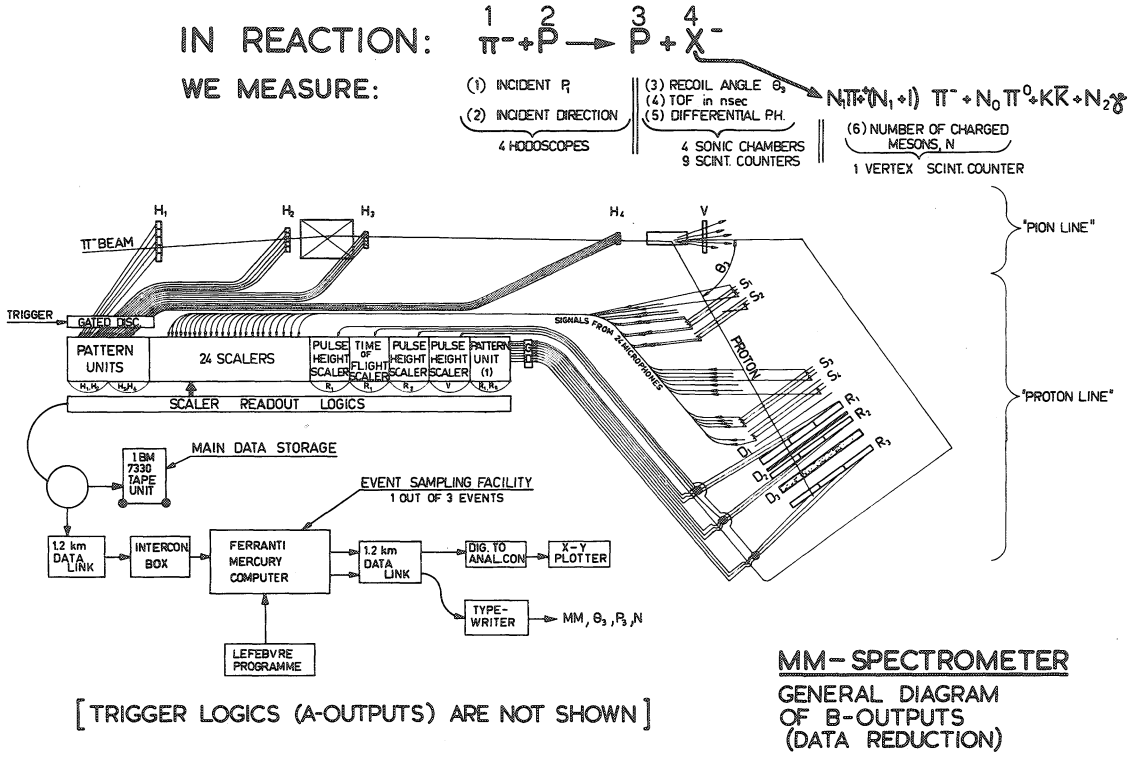
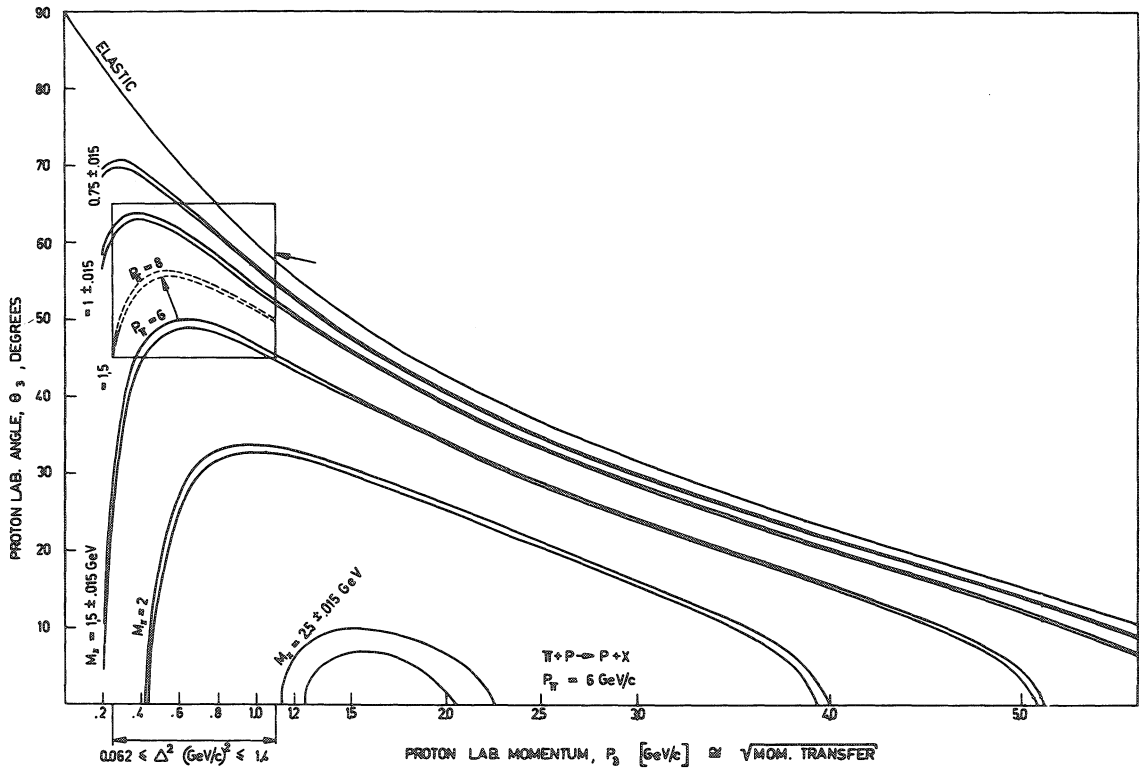


Fig. 2



Experiment uses "kinetic splitting" of the mass lines: angular resolution needed for ΔM = ± 15 MeV is ± 0.5°; momentum resolution needed for the same mass resolution is typically 20% to 45%.

Dotted line is the line corresponding to mass of 1.5 GeV at incident momentum of 8 GeV/c. All solid lines correspond to incident momentum of 6 GeV/c. The mass line shifts ~ 3° per 1 GeV/c. This property provides a check of the effect in MM-distribution, if some observed.

Fig. 3

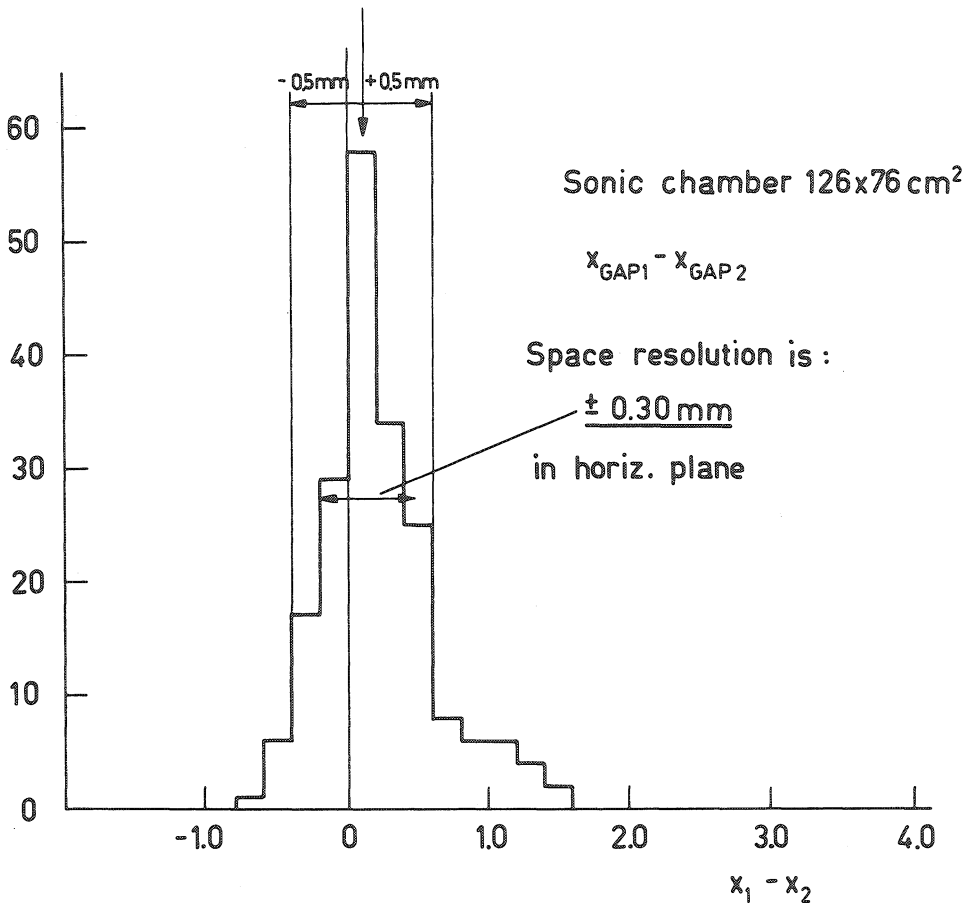

-0.5mm
+0.5mm
Sonic chamber 126x76 cm²
$x_{GAP1} - x_{GAP2}$
Space resolution is :
± 0.30 mm
in horiz. plane
60
50
40
30
20
10
0
-1.0
0
1.0
2.0
3.0
4.0
$x_1 - x_2$

Fig. 4

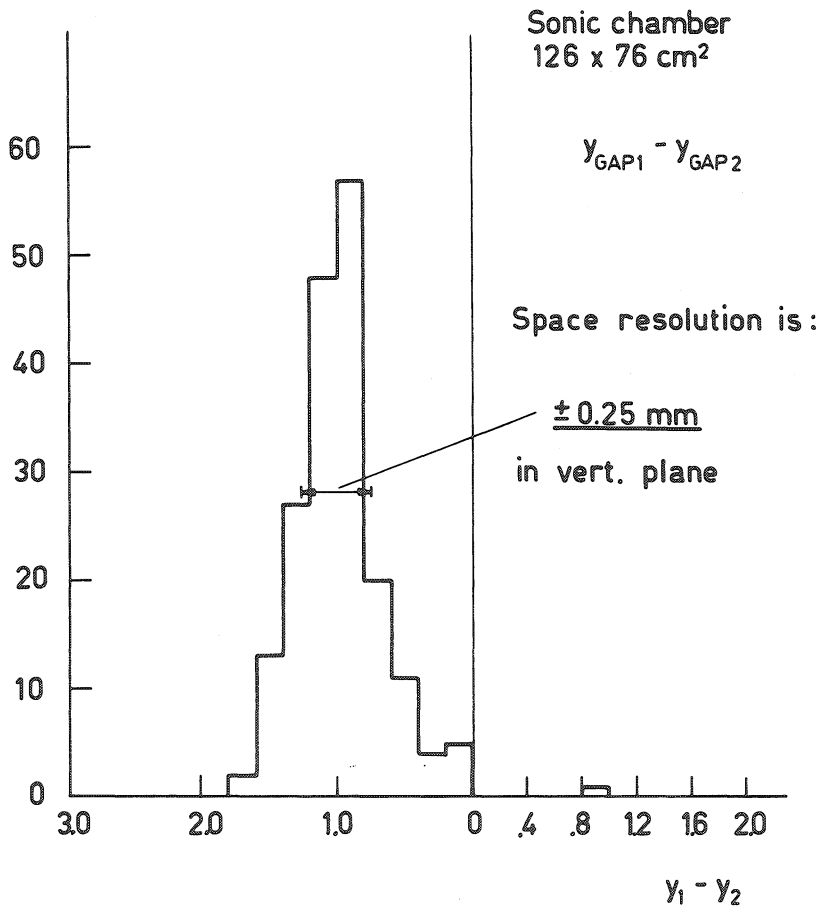

Sonic chamber
126 x 76 cm²
$y_{GAP1} - y_{GAP2}$
Space resolution is :
± 0.25 mm
in vert. plane
60
50
40
30
20
10
0
3.0
2.0
1.0
0
.4
.8
1.2
1.6
2.0
$y_1 - y_2$

Fig. 5

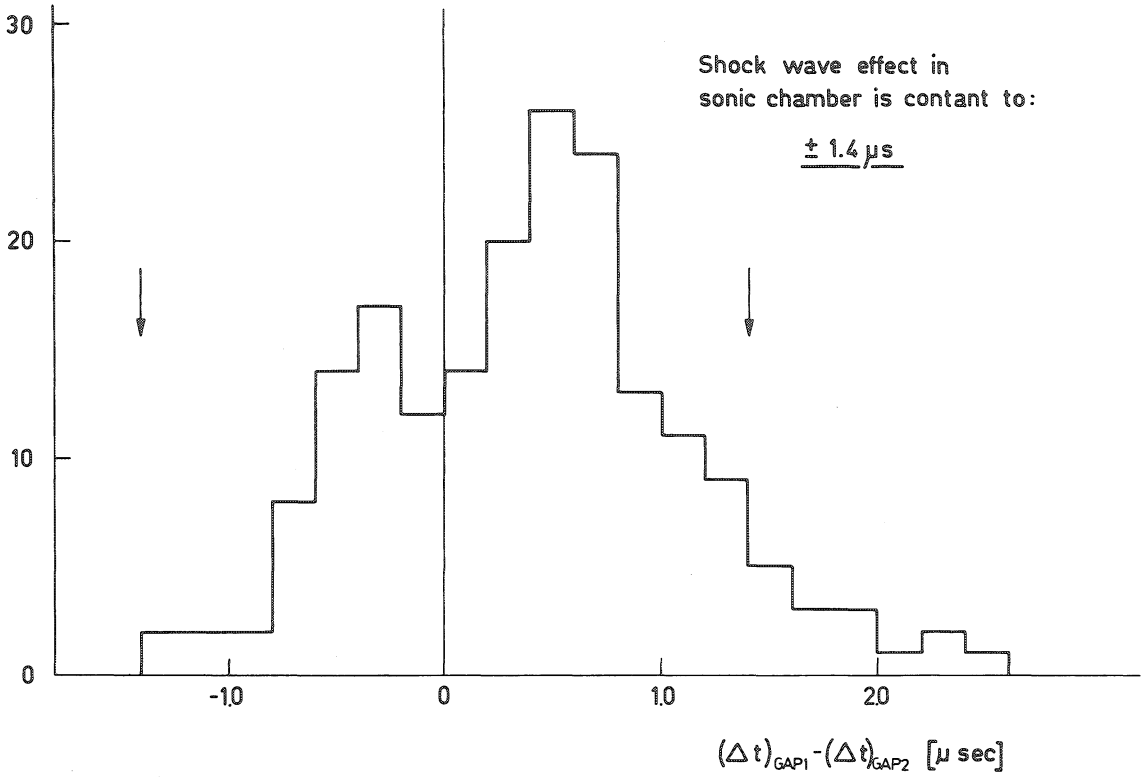

Shock wave effect in
sonic chamber is contant to:
± 1.4 μs
30
20
10
0
-1.0
0
1.0
2.0
$(\Delta t)_{GAP1} - (\Delta t)_{GAP2}$ [μ sec]

Fig. 6

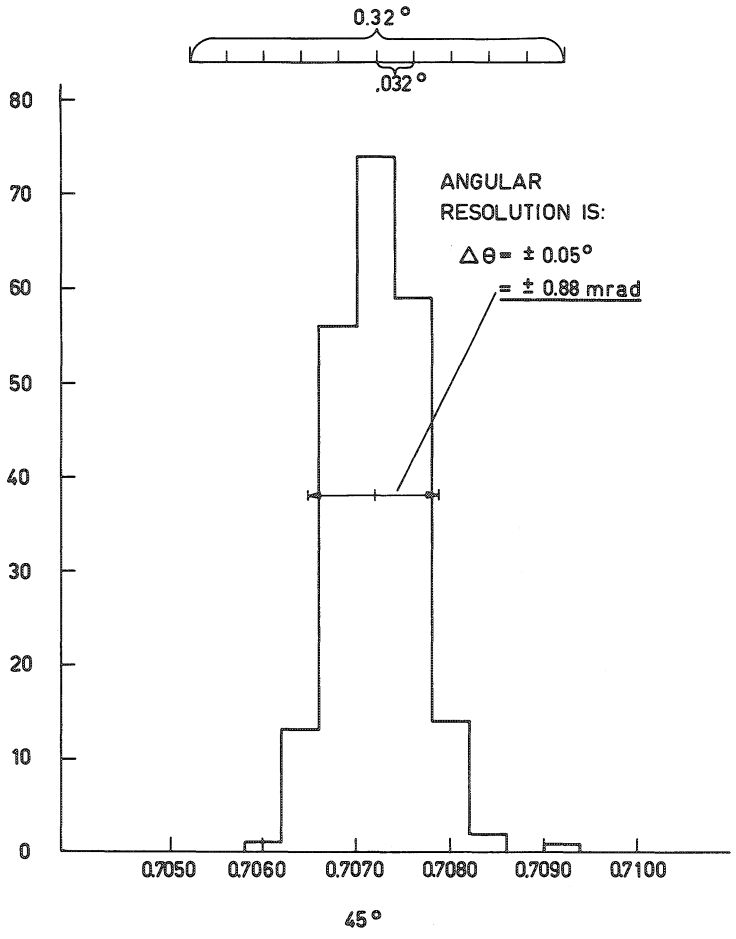

0.32°
.032°
ANGULAR
RESOLUTION IS:
Δθ = ± 0.05°
= ± 0.88 mrad
80
70
60
50
40
30
20
10
0
0.7050
0.7060
0.7070
0.7080
0.7090
0.7100
45°

Fig. 7

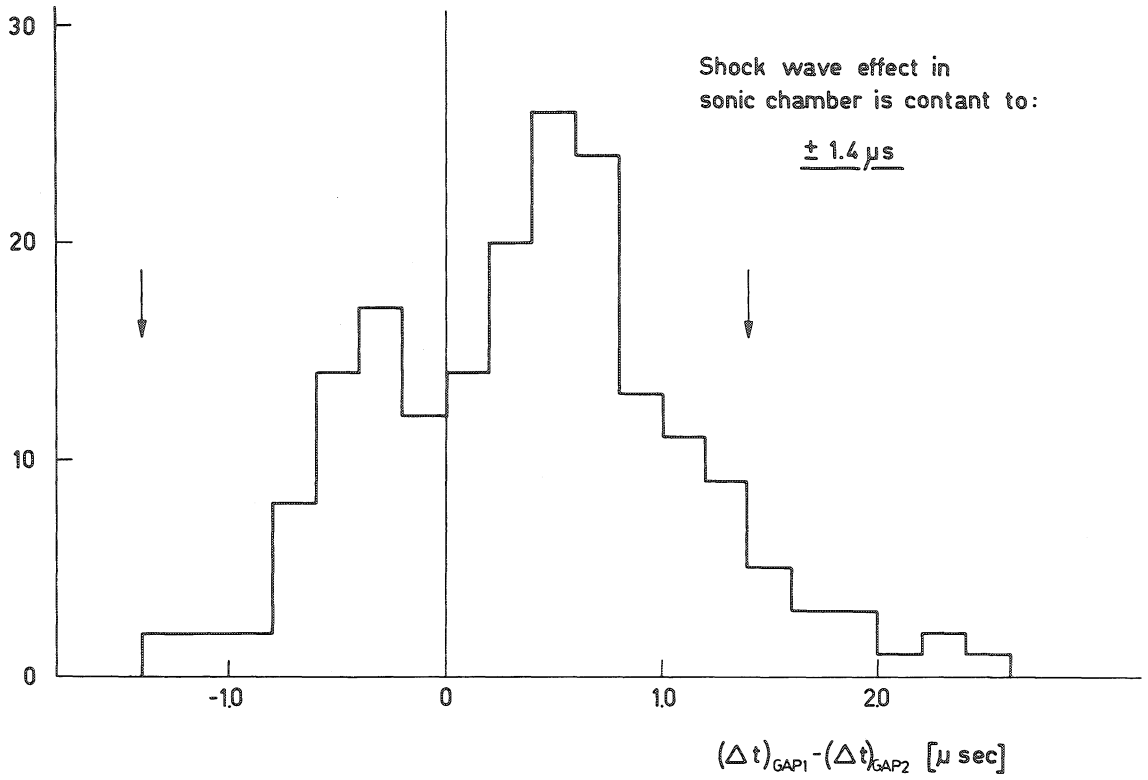

30
20
10
0
-1.0
0
1.0
2.0
Shock wave effect in
sonic chamber is contant to:
± 1.4 μs
$(\Delta t)_{GAP1} - (\Delta t)_{GAP2}$ [μ sec]

Fig. 6

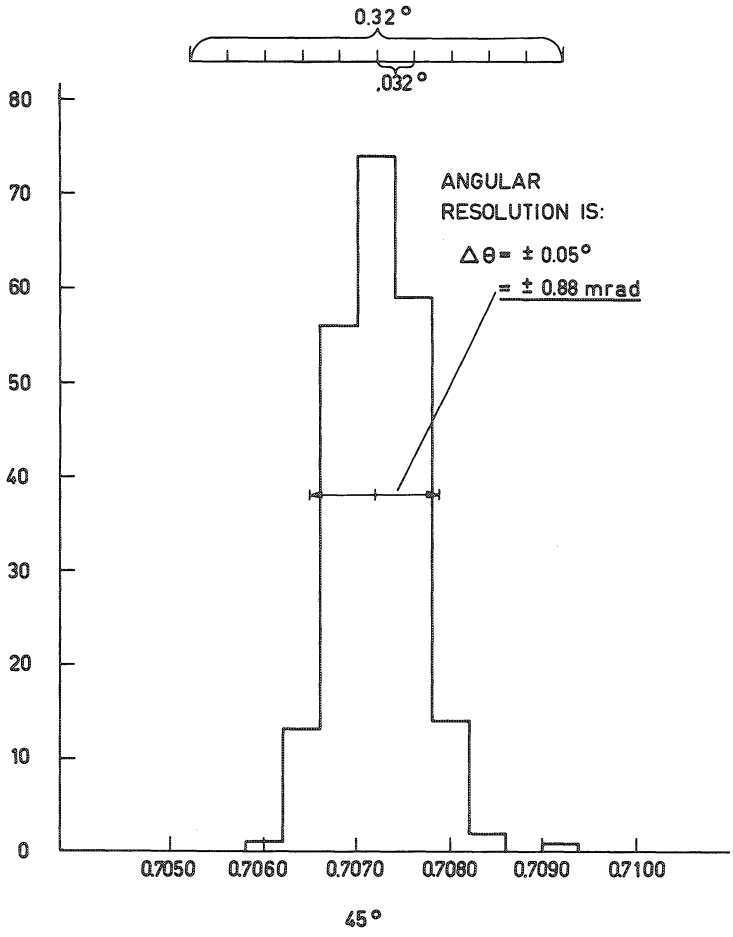

0.32°
.032°
80
70
60
50
40
30
20
10
0
ANGULAR
RESOLUTION IS:
Δθ = ± 0.05°
= ± 0.88 mrad
0.7050
0.7060
0.7070
0.7080
0.7090
0.7100
45°

Fig. 7

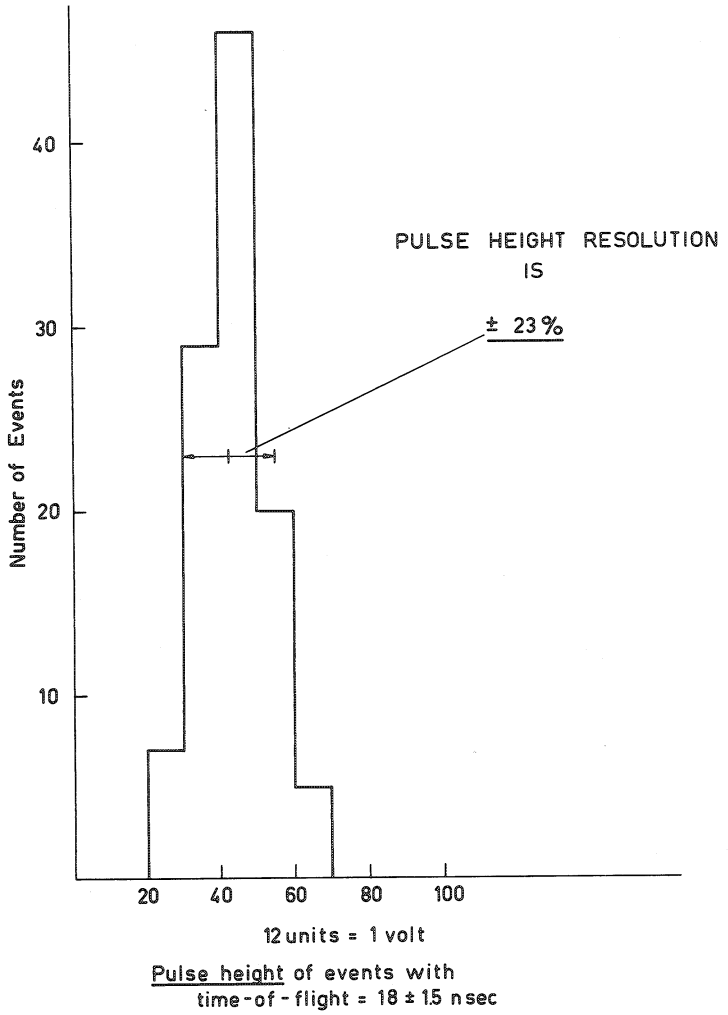

PULSE HEIGHT RESOLUTION
IS
± 23 %
Number of Events
40
30
20
10
20
40
60
80
100
12 units = 1 volt
Pulse height of events with
time-of-flight = 18 ± 1.5 nsec

Fig. 8

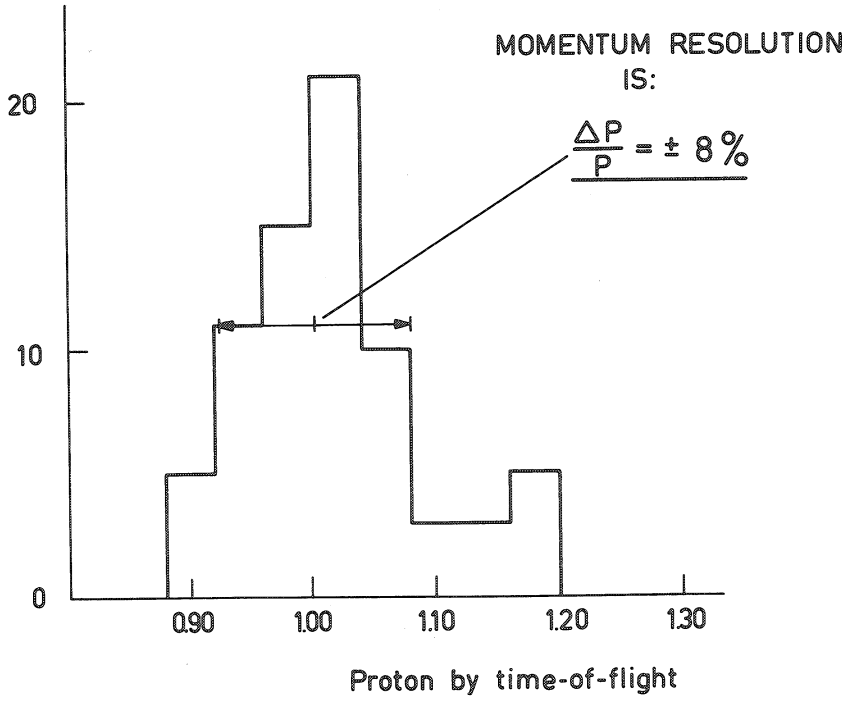

MOMENTUM RESOLUTION
IS:
ΔP/P = ± 8 %
20
10
0
0.90
1.00
1.10
1.20
1.30
Proton by time-of-flight

Fig. 9

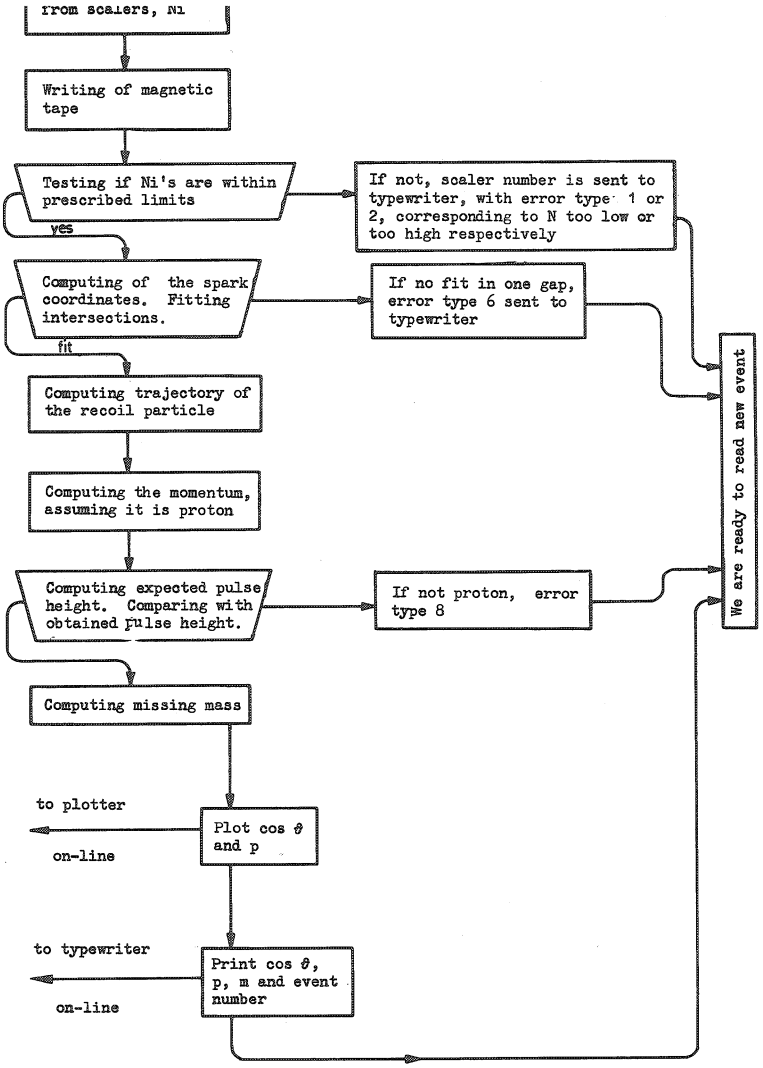

from scalers, Ni
Writing of magnetic tape
Testing if Ni's are within prescribed limits
If not, scaler number is sent to typewriter, with error type 1 or 2, corresponding to N too low or too high respectively
yes
Computing of the spark coordinates. Fitting intersections.
If no fit in one gap, error type 6 sent to typewriter
fit
Computing trajectory of the recoil particle
Computing the momentum, assuming it is proton
Computing expected pulse height. Comparing with obtained pulse height.
If not proton, error type 8
We are ready to read new event
Computing missing mass
to plotter
Plot cos ϑ and p
on-line
to typewriter
Print cos ϑ, p, m and event number
on-line

Fig. 10

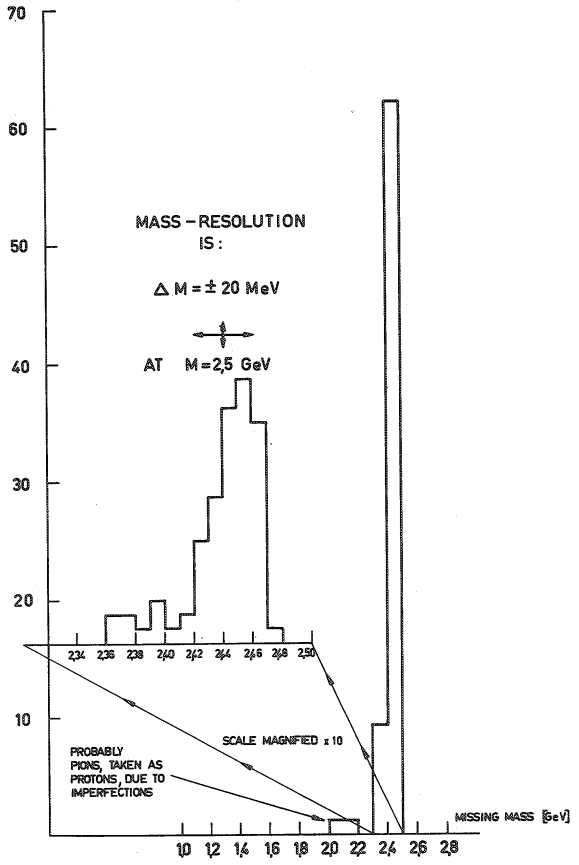

70
60
50
40
30
20
10
MASS - RESOLUTION IS:
Δ M = ± 20 MeV
AT M = 2,5 GeV
2,34 2,36 2,38 2,40 2,42 2,44 2,46 2,48 2,50
SCALE MAGNIFIED x 10
PROBABLY PIONS, TAKEN AS PROTONS, DUE TO IMPERFECTIONS
MISSING MASS [GeV]
1,0 1,2 1,4 1,6 1,8 2,0 2,2 2,4 2,6 2,8

Fig. 11

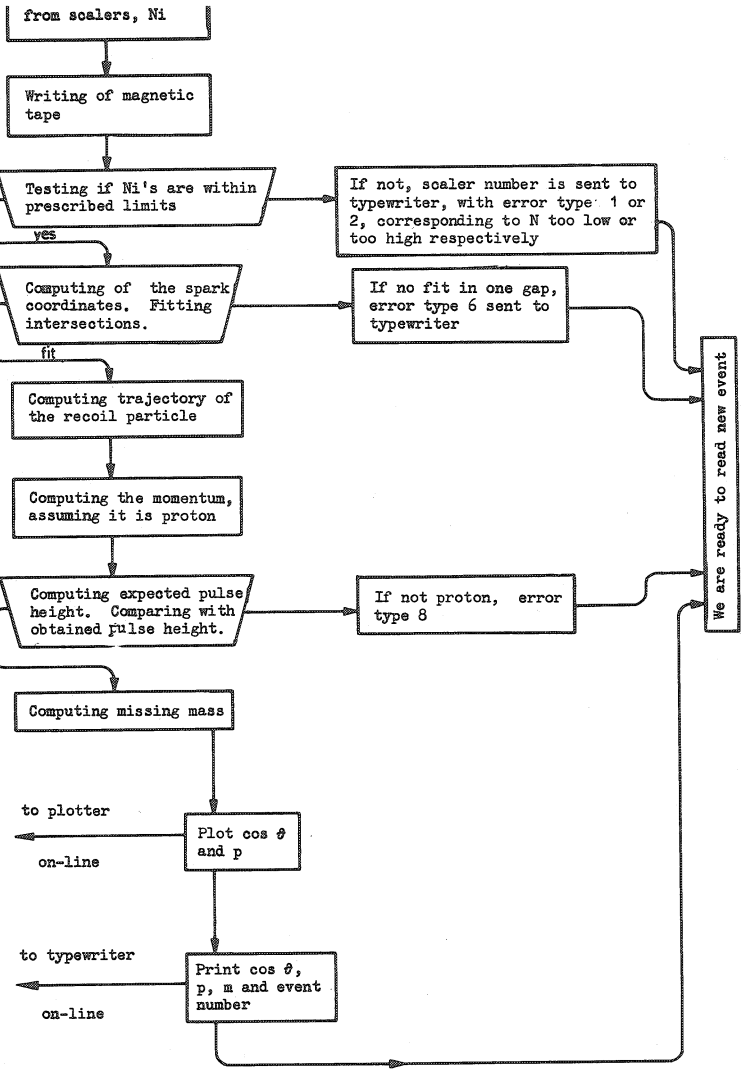

from scalers, Ni
Writing of magnetic tape
Testing if Ni's are within prescribed limits
yes
If not, scaler number is sent to typewriter, with error type 1 or 2, corresponding to N too low or too high respectively
Computing of the spark coordinates. Fitting intersections.
fit
If no fit in one gap, error type 6 sent to typewriter
Computing trajectory of the recoil particle
Computing the momentum, assuming it is proton
Computing expected pulse height. Comparing with obtained pulse height.
If not proton, error type 8
We are ready to read new event
Computing missing mass
to plotter
on-line
Plot cos θ and p
to typewriter
on-line
Print cos θ, p, m and event number

Fig. 10

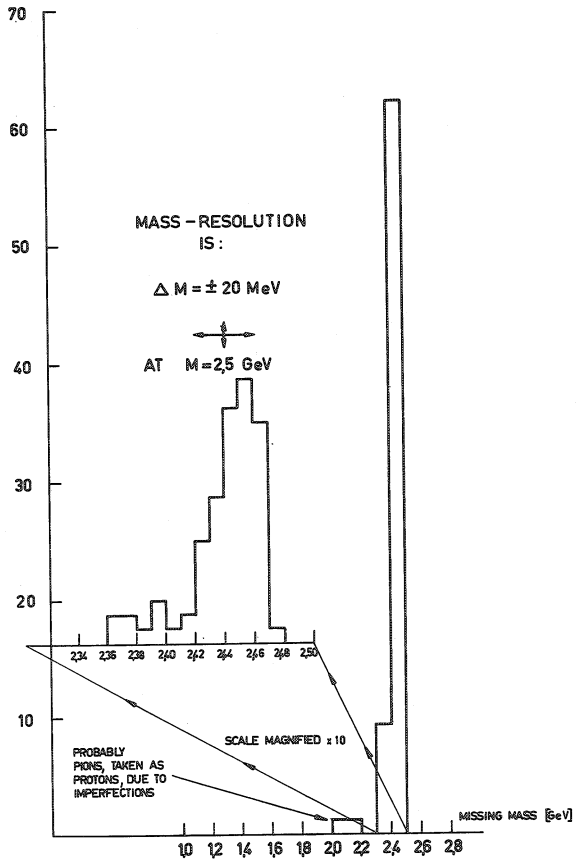

70
60
50
40
30
20
10
MASS - RESOLUTION IS:
Δ M = ± 20 MeV
AT M = 2,5 GeV
2,34 2,36 2,38 2,40 2,42 2,44 2,46 2,48 2,50
SCALE MAGNIFIED x 10
PROBABLY PIONS, TAKEN AS PROTONS, DUE TO IMPERFECTIONS
MISSING MASS [GeV]
1,0 1,2 1,4 1,6 1,8 2,0 2,2 2,4 2,6 2,8

Fig. 11

SIS/R/8048

FIG. 12