NAL PROPOSAL No. 175

Scientific Spokesman:

Samuel C. C. Ting
Department of Physics
Mass. Institute of Technology
Cambridge, Mass. 92139

FTS: 8-617-864-6900 Ext. 5822

Stage I to Proposal # 144

A SIMPLE SPECTROMETER TO MEASURE PHOTOPRODUCTION OF VECTOR MESONS AND PIONS AT HIGH ENERGY

B. Margolis, P. M. Patel, W. Ross, D. G. Stairs
Department of Physics, McGill University, Montreal

L. Bird, C. Halliwell, R. Morrison, John Walters
Department of Physics, Carleton University, Ottawa

E. Coleman, T. Fesesse, Y. Makdisi
Department of Physics, University of Minnesota

U. J. Becker, P. Biggs, W. Busza, M. Chen, T. Nash,
H.F.W. Sadrozinski, Samuel C. C. Ting, Sau Lan Wu, Tai Tsun Wu
Department of Physics, Massachusetts Institute of Technology

May 1972

May 1972

Stage I to Proposal # 144:

A SIMPLE SPECTROMETER TO MEASURE PHOTOPRODUCTION

OF VECTOR MESONS AND PIONS AT HIGH ENERGY

by the Canadian - Minnesota - MIT collaboration

In NAL Proposal # 144, we described a three magnet system, consisting of a forward focussing spectrometer made up of two large aperture magnets, M1 and M2, and a solenoid magnet from the PPA to detect the recoil proton. This spectrometer will enable us to study seven experimental reactions at the same time with high precision.

We propose here a much scaled down set up which has the following features:

1) We will do only photoproduction of vector mesons and pions.

2) We can use either a 500 BeV proton beam at 10^{13} protons/pulse to study photoproduction of vector mesons at 200-300 BeV

or

3) This spectrometer will enable us to use a 200 BeV proton beam with 10^{12} protons/pulse to study vector meson production at $\approx$100 BeV.

4) The beam momentum resolution needed is ± 2 % instead of ±0,5 %. No hodoscopes are needed in the electron beam.

5) The cost of this system will be about a factor of two lower than NAL # 144.

6) Instead of building another large magnet (M2) for the forward spectrometer, we will use two existing CEA magnets: Henry Higgins (120 x 86 x 56 cm^3 and 10 KG maximum field strength) as M1 and Jolly Green Giant (120 x 150 x 50 cm^3 and 15 KG maximum field strength) as M2 (see Figure 1). The focussing property of this spectrometer is demonstrated in Figure 2. The arrangement of

the trigger counter is shown in Figure 3.

7). In order to distinguish inelastic processes like

$$\gamma + p \rightarrow V + N^*$$
$$\hookrightarrow \pi^+ n$$
$$\rightarrow \pi^\circ p$$

from diffractively produced vector mesons, we propose to put 3 wire spark chambers on each side of the LH_2 target (Fig. 4) to measure the direction of the recoil protons. This measurement results in two additional kinematic constraints which will supress events from the above reactions by a factor of more than a thousand for $|t| \geq 0.2$ $(GeV/c)^2$. The constraint using the measurement of the energy of the recoil proton is useful only for $|t| < 0.2$ GeV^2/c^2 therefore is not crucial for the first generation experiment and some range system as described in Appendix III of proposal No. 144 can be added at a later stage.

8) The flux of $e^\pm$ background from conversion of the primary photons in the hydrogen target at different positions in the forward spectrometer is shown in Figure 5. The maximum yield of $e^\pm$ coming off in the forward direction is $\approx 10^6$/pulse. We also see that the total flux of $e^\pm$ is $< 10^5$/sec for the chambers on the two sides and in the back, i. e. at positions 6 and 7. Therefore proportional wire chambers will only be used for positions 1→ 5. The total number of wires is ~5k. For positions 6 and 7 and for recoil proton detector magnetostrictive spark chambers will be used.

The sizes and locations of all the trigger counters are listed in Figures 3, 6 and 7. The functions of all counters except hodoscope E, which is used to select events of a certain opening angle, are described in proposal # 144.

9) We will take data in two separate runs with different trigger systems.

a) In the first period, the same trigger system as that described in proposal # 144 will be used to detect all photoproduction of vector mesons and pions. The logic diagram for the trigger is presented in Figure 8.

b) Afterwards we will use a much more stringent trigger system, to select certain types of reactions which have total cross sections much lower than σ_γ .

$$\gamma + p \to p + \rho \text{ with } |t| \geq .6 \ (\text{GeV/c})^2$$

$$\gamma + p \to p + \rho^* \quad (m^* \gtrsim 1 \text{ GeV}) \quad \rho^* \to \pi^+\pi^-$$

$$\to p + \omega, \phi \quad (\to 3\pi)$$

$$\to p + \phi \quad (\phi \to K^+K^-)$$

$$\to (n\pi) + p \text{ where } n = 3, 4, 5...$$

The logic diagram of this very selective triggering system is shown in Figure 9.

The physics we can learn with this apparatus is described as follows:

1. π inclusive reactions

The detector is sensitive to the pions in the forward going hemisphere in the (γ, p) c. m. system, i. e., with the Feynman parameter $x = \frac{P_z}{\sqrt{s}} > 0$.

The resolution of the transverse momentum and the longitudinal momentum for various pion production angles and $P_\perp = 0.2$ GeV are listed in the following table.

θ_π (mr)	80	50	10	4
P_π (GeV)	2.5	4	20	50
$\pm\Delta P_\perp$ (MeV)	.7	1	4	10
$\pm\Delta P_\parallel$ (MeV)	5	12	60	350
$\pm\frac{\delta\sigma_\pi}{\sigma_\pi}$	$\lesssim$1 %	$\lesssim$1 %	$\lesssim$1 %	$\lesssim$3 %

Assuming the differential cross-section of $\gamma p \rightarrow \pi$ + anything (at 100 GeV) to be the same analytical form as $P + P \rightarrow \pi^\pm$ + anything (at 30 GeV/c):

$$\sigma_\pi = \frac{d^3\sigma}{d^2P_\perp \, dP_\parallel} = \frac{1}{E_\pi} e^{-2.44 (P_\perp + P_\perp^2/M_p)} . G(const)$$

we find the uncertainty in σ_π due to measurement error in E_π and $P_\perp$ is

$$-\frac{d\sigma_\pi}{\sigma_\pi} = 2.44 \left(1 + \frac{2P_\perp}{m_p}\right) \delta P_\perp + \frac{\delta E_\pi}{E_\pi}$$

The percentage errors for various production angles are also listed in the above table. We observe that the resolution is more than sufficient for this experiment.

The rate of $\pi^\pm$ events per 10^{12} incident protons at 200 GeV/c is $\sim$ 3×10^2/hour for the tagged photon energy range from 50 - 100 GeV. for $x > 0$

2. $\rho \to \pi^+\pi^-$, $\phi \to K^+K^-$, high mass vector meson $\to \pi^+\pi^-$

The mass resolution and counting rates for vector mesons of various masses are listed in tables I and II. The rates per hour are calculated using 4×10^5 γ/pulse and 115 cm of liquid hydrogen.

3. ω, ϕ, high mass vector meson $\to 3\pi$

The resolution and counting rates for various vector mesons decaying into 3π are presented in table II. The mass resolution at the ω mass is 50 % worse ($\pm$24 MeV compared with $\pm$15 MeV before) because the magnetic field strength has been reduced and the energy resolution of the beam is worse. We see that the apparatus is sensitive to vector mesons up to about 6 GeV.

4. ρ, ω, ϕ off complex nuclei

The resolutions are the same as for those in 2) and 3).

OPERATIONS SCHEDULE

We have planned the following sequence of operations:

1.	Beam construction	9 months
2.	Beam studies aimed at understanding and improving the beam.	3 months
3.	Constructions and Testing of the spectrometer while the UCSB group takes data on the total hadronic cross section.	6 months
4.	Set up of the experimental apparatus	3 months
5.	Debugging of apparatus. (Mainly parasitic operation, distributed suitably in time)	200 hours
6.	Main run with 4×10^5 photons/pulse, $\delta k/k = \pm 2$ %, a 1 % radiation length tagging radiator and 10^{13} protons/pulse incident on the production target.	500 hours on Hydrogen 200 hours on Complex Nuclei

TABLE I

a) Mass Resolution for $\rho \rightarrow 2\pi$ as a function of E_γ.

E_γ (GeV)	Δm (MeV/c^2)
50	±10
100	±13
150	±16
200	±20
250	±24

The resolution for $\phi \rightarrow 2k$ is about 1/4 of these values.

b) Mass resolution for $V° \rightarrow 2\pi$ or 2k (wide angle system)

E_γ / Mass (GeV/c^2)	2	4	6	8	10
50	±42 MeV/c^2	±83	±123	±164	±205
100	±83	±162	±242	±323	±403
200	±165	±324	±485	±646	±807

TABLE II

part A

Number of events/ hour for 10^{13}p at 500 GeV

i) $\rho \to 2\pi$, $\phi \to 2K$, $V^\circ \to 2\pi$, $2K$

E_γ range (GeV)	Mass of vector meson						
	ρ	ϕ	2	4	6	8	10
90 - 190	34.9k	788	278	203	107	56	17.

ii) ω, ϕ, $V^\circ \to 3\pi$ for E_γ = 90 to 190 GeV

	Mass of vector meson				
	ω	ϕ	2	4	6
Rate	3750	264	254	126	40
Mass resolution (MeV/c^2)	±24	±26	±55	±145	±250

Rates are in events/hour assuming

4×10^5 tagged photons/pulse and a 115 cm H_2 target

and $\frac{d\sigma}{dt}(\rho) = 120\ e^{8t}\ \mu b/(GeV/c)^2$

$\frac{d\sigma}{dt}(\phi) = 3.4\ e^{4.7t}\ \mu b/(GeV/c)^2$ BR $\to$ 2K 49 %, $\to 3\pi$ 20 %

$\frac{d\sigma}{dt}(\omega) \doteq 13\ e^{8t}\ \mu b/(GeV/c)^2$

$\frac{d\sigma}{dt}(V^\circ) = e^{8t}\ \mu b/(GeV/c)^2$ all branching ratios = 1.0

TABLE II

part B

Number of events/500 hours for 10^{12}p at 200 GeV

i) $\rho \rightarrow 2\pi$, $\phi \rightarrow 2K$, $V^\circ \rightarrow 2\pi$, 2K

Range in E_γ (GeV)	Mass of vector mass (GeV/c^2)				
	ρ	ϕ	2	4	6
32 - 72	174K	3.9K	1.4K	1K	540
100 ±10	4.3K	100	-	-	-

ii) ω, ϕ, $V^\circ \rightarrow 3\pi$

Range in E_γ (GeV)	Mass of vector mass (GeV/c^2)				
	ω	ϕ	2	4	6
32 - 72	19K	1.3K	1.3K	630	200
100 ± 10	470				

Figure Captions:

Fig. 1. The simplified focusing spectrometer for various photoproduction reactions. M1 and M2 are two existing magnets. Some recoil proton detector can be added at later stages. 1), 2), 3), 4) and 5) are proportional wire chambers. 6) and 7) are wire spark chambers or FET chambers.

Fig. 2. Focusing properties of the spectrometer. Particles with the same production angle end up at the same point at the focal plane.

Fig. 3. Positions and sizes of various trigger counters, magnets, tagging target and LH_2 target.

Fig. 4. Simple recoil proton detector . A range system can be added in order to measure the energy of proton, as well as the directions at the later stages.

Fig. 5. The number of $e^{\pm}$ incident on various chambers.

Fig. 6. Dimensions of shower counters at positions 5), 6) and 7). Shower 4 is used to detect the high mass vector mesons and therefore is not needed if one restricts oneself just to detect the known vector mesons at high energy.

Fig. 7. Dimensions of the trigger hodoscope B, C, D, E. The hodoscope E is used to select pairs with wide opening angle or high momentum transfer.

Fig. 8. Trigger logic for $\gamma\, p \to Vp,\ \pi + x,$ etc.

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \llcorner\!\!\to n\pi$

Fig. 9. Trigger logic for selecting events with low cross section,

e. g. $\gamma p \to p + \omega,\ \phi$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad \llcorner\!\!\longrightarrow 3\pi$

$\to p + V^* \quad (m^* > 1\ \mathrm{GeV})$

$\quad\quad\quad \llcorner\!\!\longrightarrow 2\pi$

$\to (n\pi) + p$ with $n = 3$ or 4

$\to \quad \phi + p$

$\quad\quad\quad \llcorner\!\!\to K^+K^-$

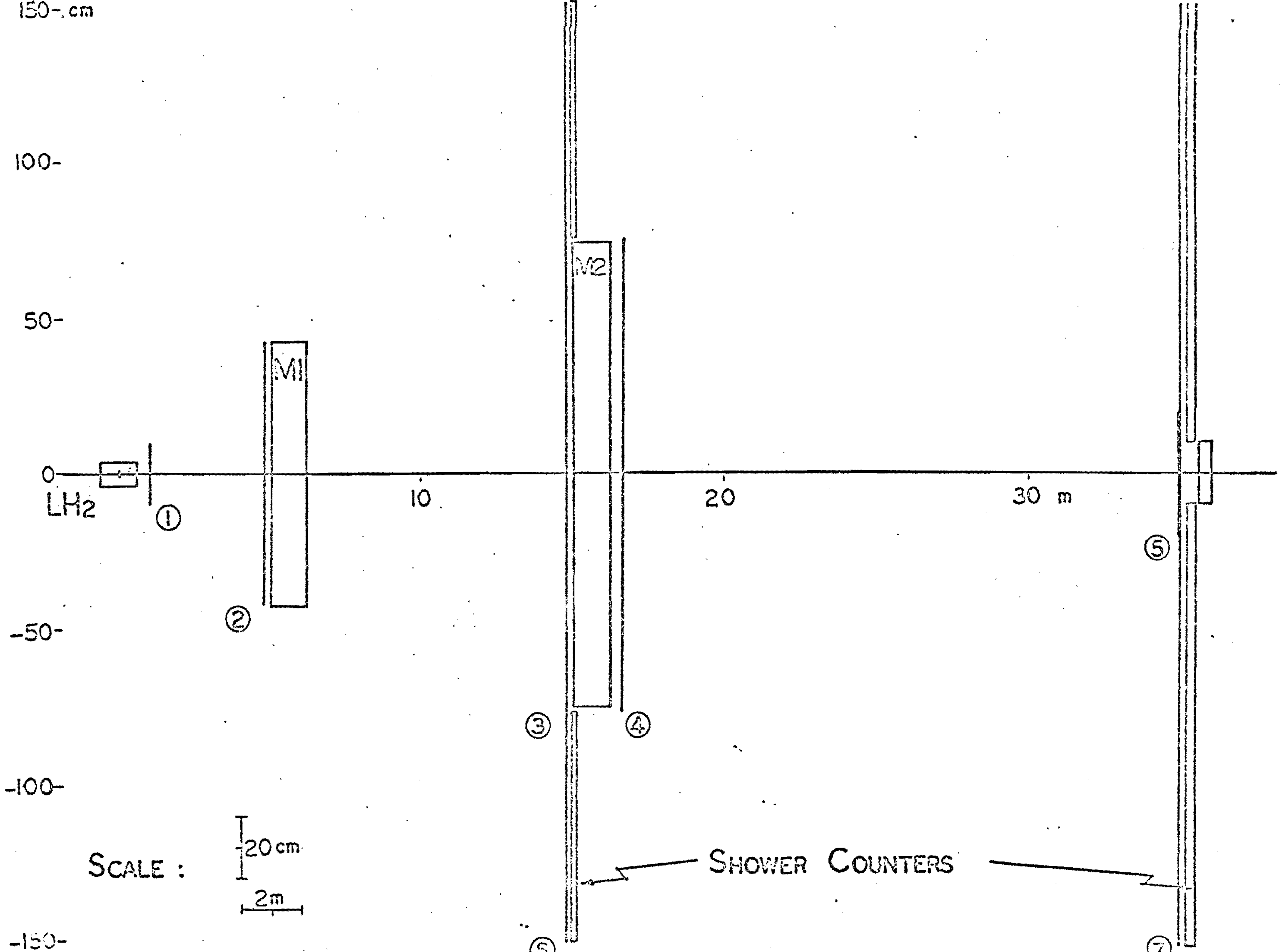

Fig. 1 The Spectrometer

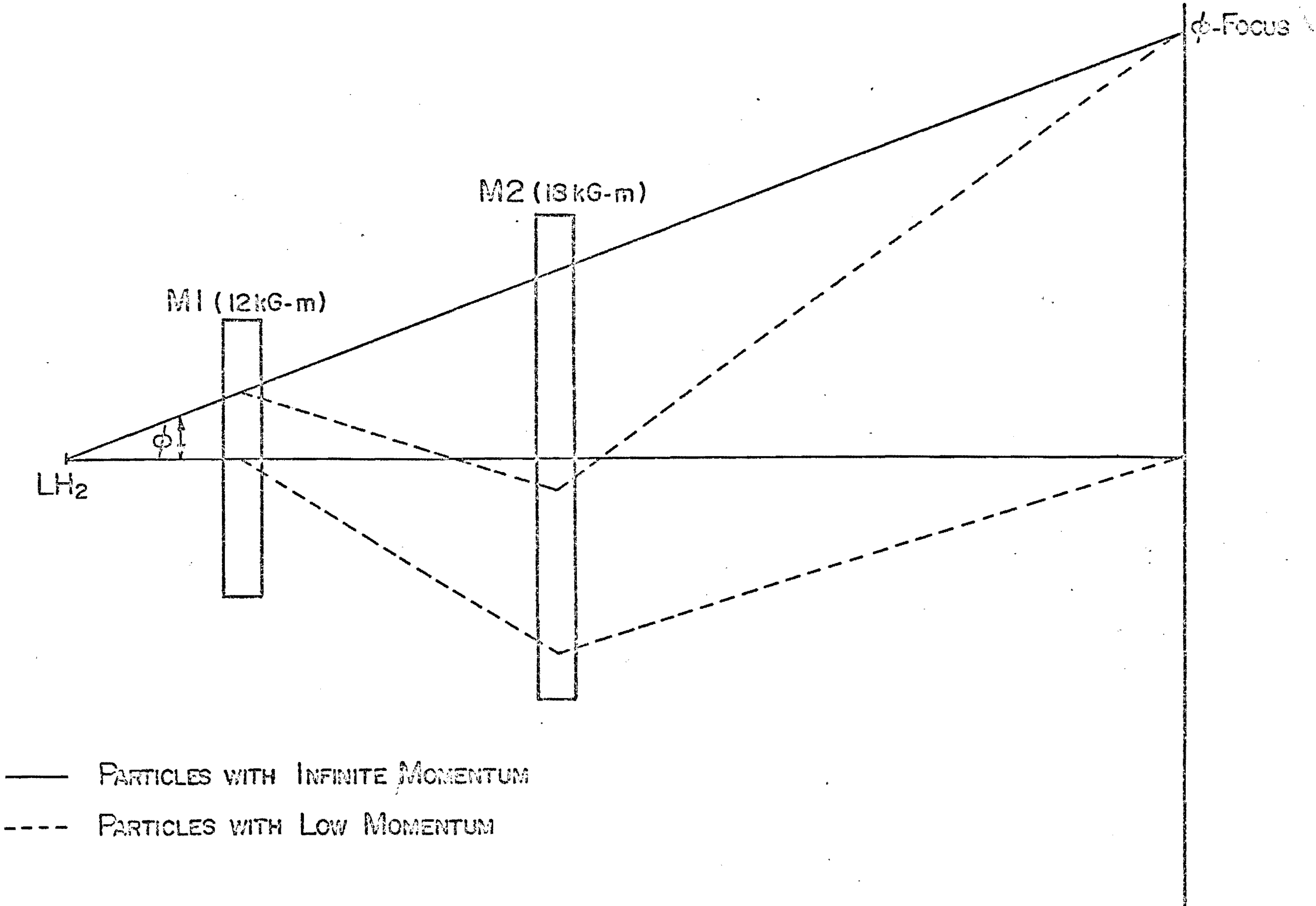

Fig. 2 Focussing Property of the Forward Spectrometer

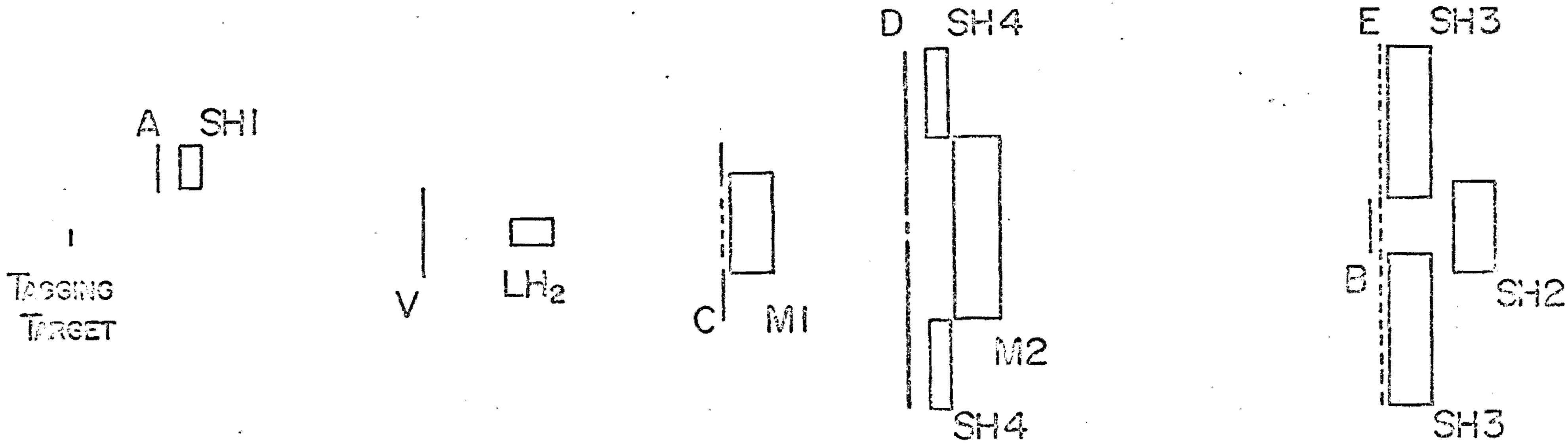

FIG. 3 SKETCH OF ALL TRIGGER COUNTERS

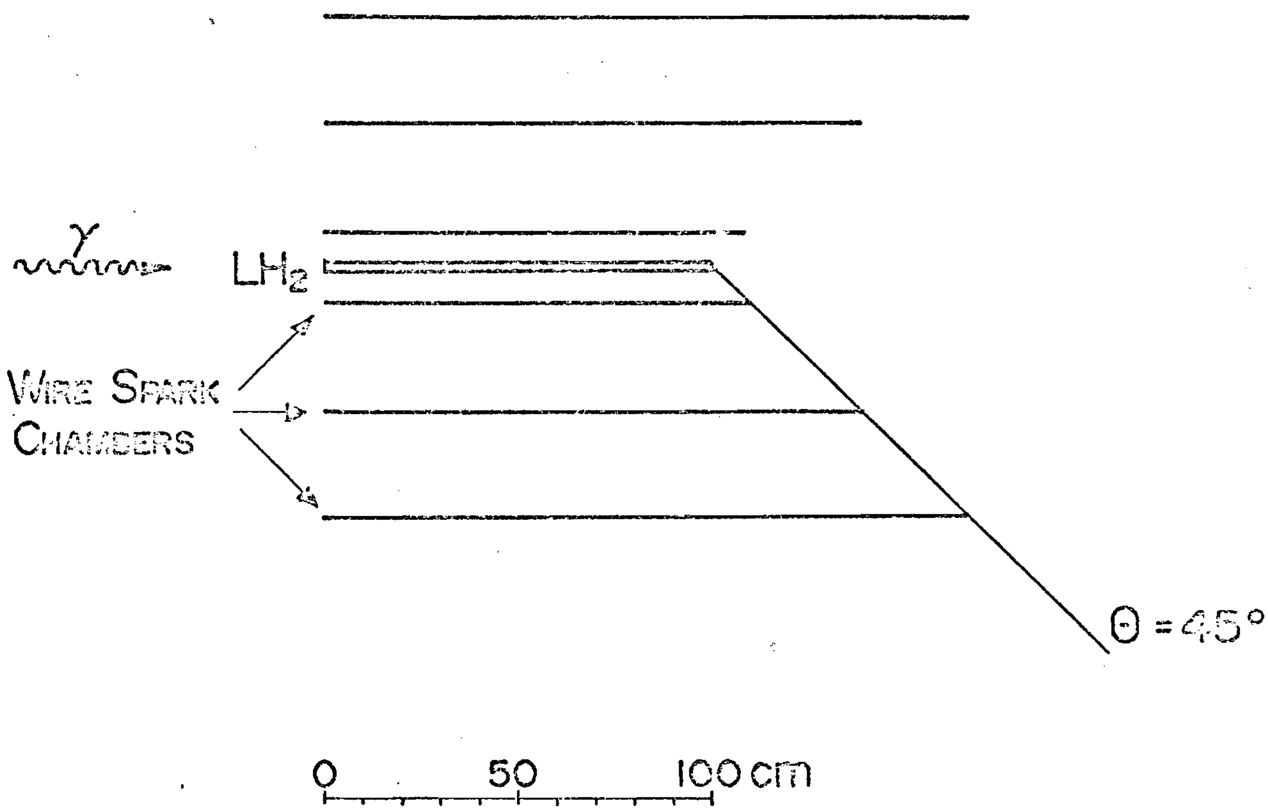

Fig. 4 Recoil Detector

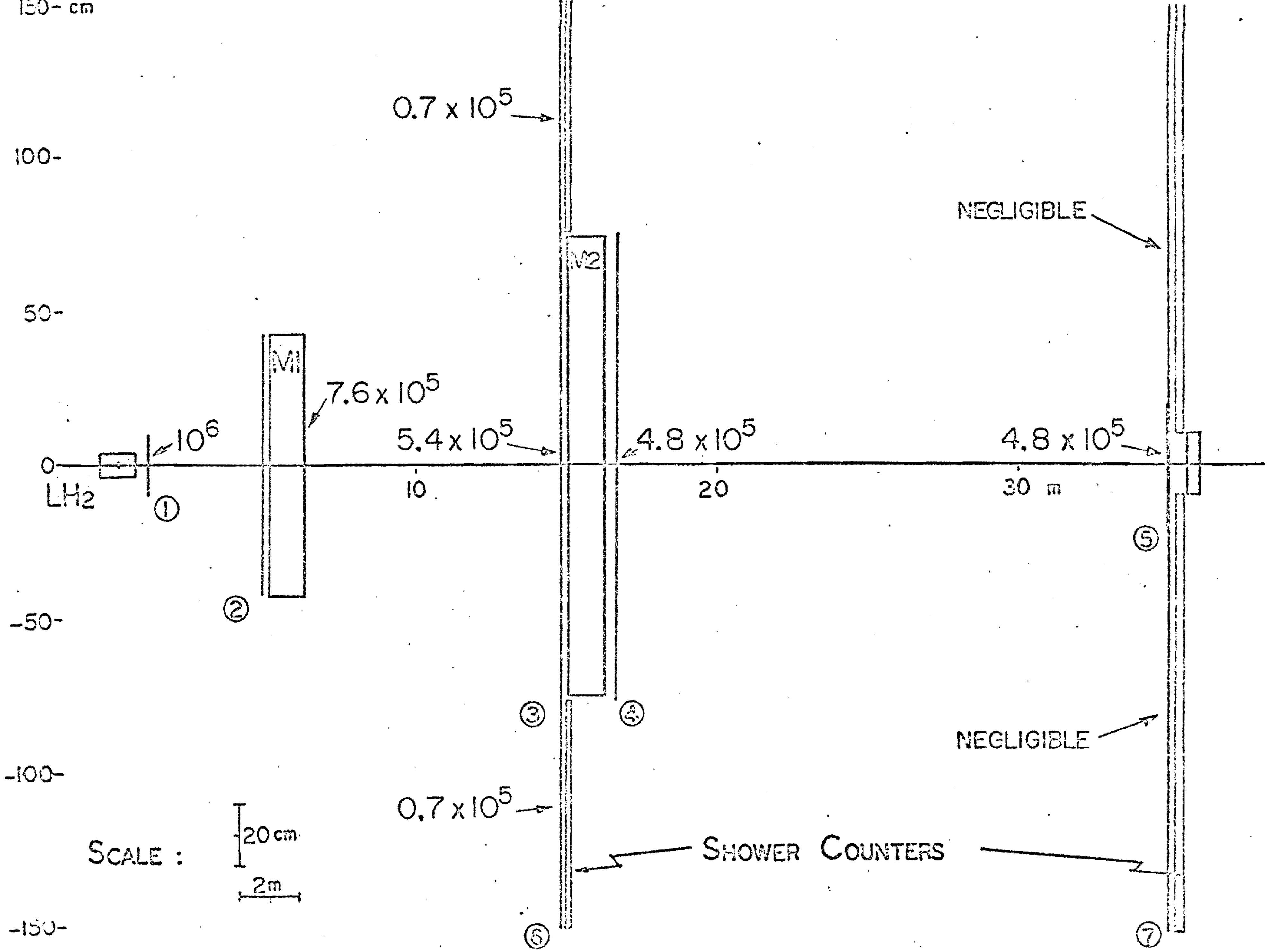

FIG. 5 THE $e^{\pm}$ FLUX AT VARIOUS POSITIONS IN THE FORWARD SPECTROMETER

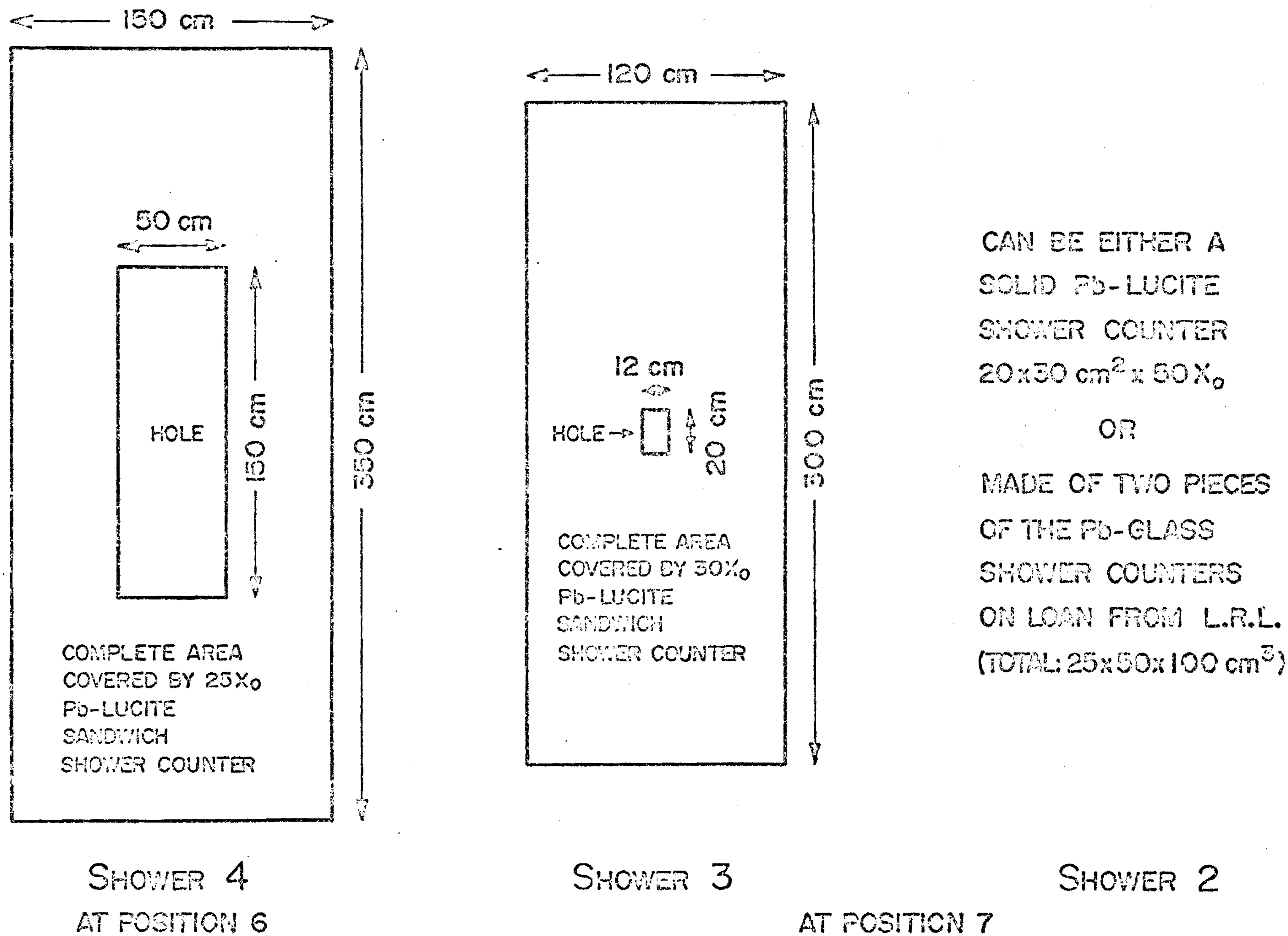

FIG. 6 SHOWER COUNTERS

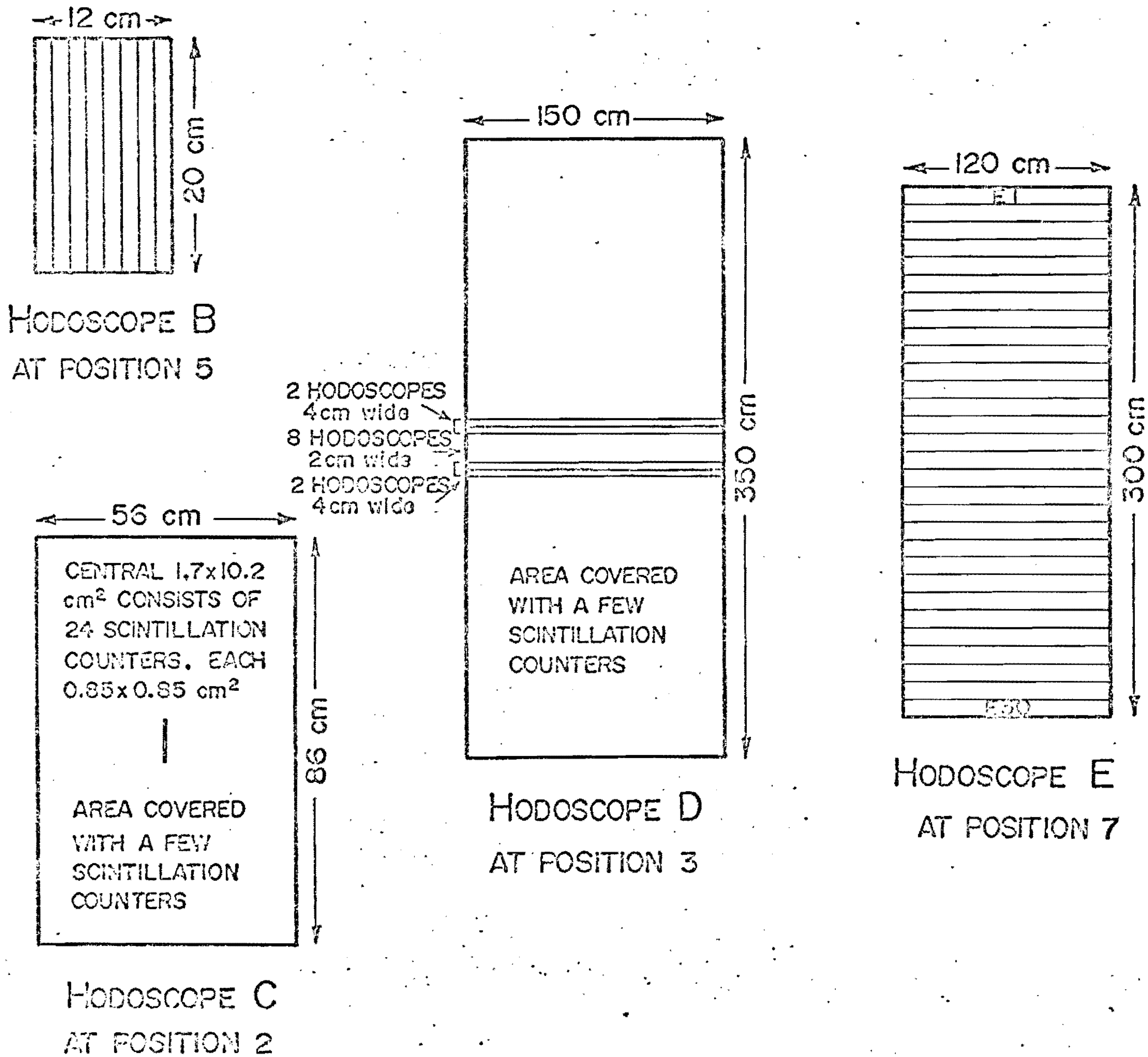

FIG. 7 HODOSCOPES B, C, D AND E

FIG. 8 LOGIC DIAGRAM FOR TRIGGER SYSTEM FOR

$\gamma p \to \underline{V}p \to n\pi^{\pm}$

$\gamma p \to \pi + X$

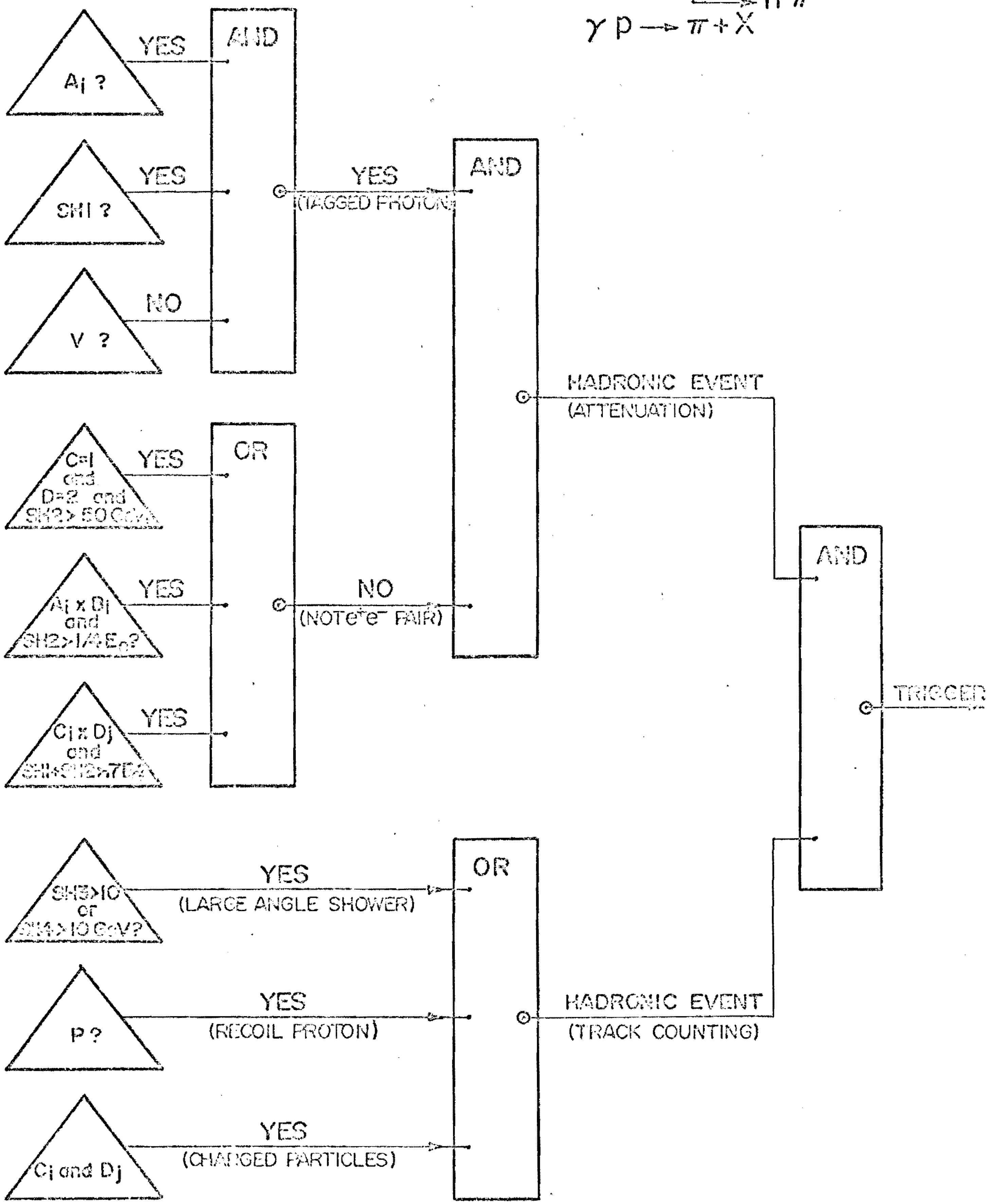

FIG. 9 LOGIC DIAGRAM FOR TRIGGER SYSTEM FOR