NON-MAGNETIC DETECTOR FOR MEASURING σ_T AND CHARGED MULTIPLICITIES IN e^+e^- ANNIHILATION

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Abstract

Use is made of the large charged particle multiplicity expected at PEP and the assumption of one photon exchange dominance to achieve a simple design of apparatus for a high precision measurement of the total hadronic cross section, σ_T, and the average charged multiplicity. Especially important to the method is a single particle trigger whose intrinsic biases are small and well understood. The proposed apparatus consists of two rings of scintillation counters situated at angles of $\sim 55^\circ$ and 125° to the beam direction, and subtending a solid angle of $0.1 \times 4\pi$ each. The counters form a seven layer range telescope used for extrapolating loss of low energy particles. Within the counters is a set of proportional chambers, covering a very large fraction of 4π solid angle, used for measuring the charged multiplicity of events. The whole apparatus would fit within a cube of side 6 m. The total weight is less than 10 tons.

Experience with the large magnetic detector at SPEAR has shown that uncertainties in the measurement of the total cross section σ_T ($e^+e^- \rightarrow$ hadrons) are minimized if a single particle trigger is used for event identification. The reason is that the trigger bias inherent in any system is minimized, and further that these bias are easily understood; thus the model dependence of the estimates of the bias can be quite low. Unfortunately with the SPEAR magnetic detector it was not possible to use a single particle trigger because of large background rates, presumably due to numerous soft photons. Thus, it was necessary to rely upon elaborate efficiency calculations to simulate the two particle trigger which was used. Indications are that a single particle trigger might have been feasible if more than a two layer counter coincidence were available. Likewise a smaller solid angle for triggering would reduce the spurious trigger rate without equivalent losses to the real trigger rate because of the multiplicity of the event.

The assumption of one photon exchange makes a rather strict limitation on the complexity of the angular distribution:

$$\frac{d\sigma}{d\Omega} = A + B \cos^2\theta. \tag{1}$$

The integral of Eq. 1 over all solid angle is

$$\int \frac{d\sigma}{d\Omega} d\Omega = \langle N_{ch} \rangle \sigma_T = 4\pi \left(A + \frac{1}{3} B\right), \tag{2}$$

where $\langle N_{ch} \rangle$ is the average charged multiplicity. (This factor enters because each prong of the event contributes to the integral.) Through a happy trick of nature the integral of Eq. 2 can be obtained by measuring $d\sigma/d\Omega$ at $\cos^2\theta_m = 1/3$, $\theta_m \approx 55^\circ$ or 125°. Thus

$$\langle N_{ch} \rangle \sigma_T = \frac{1}{4\pi} \frac{d\sigma}{d\Omega} (\theta_m), \tag{3}$$

where no information on the relative magnitudes of A and B are required. If in addition to a trigger system situated at θ_m one employs a large solid angle tracking apparatus to measure $\langle N_{ch} \rangle$, then σ_T may be calculated.

Because of the charged multiplicity of events a trigger system having modest solid angle coverage can have relatively large detection efficiency. Qualitatively this can be seen in Fig. 1, where the trigger efficiency vs. the charged multiplicity is plotted for different values of solid angle coverage. For simplicity the angular distribution was assumed to be isotropic. Since the average charged multiplicity is expected to be ~6-8 at PEP energies, a solid angle coverage of 0.2 to 0.3 x 4π gives good trigger efficiency. In the interest of simplicity a solid angle of 0.2 x 4π will be chosen as a design parameter.

Any trigger system must face its bias against low energy particles. By employing a range telescope one can use the fraction of particles stopped within the system to estimate the fraction failing to give a trigger. These corrections are expected to be very low, as shown in Fig. 2. The most pessimistic assumption on the momentum spectrum of the hadrons is to assume that the shape of the invariant cross section, $E\, d\sigma/d^3p$ vs. E does not depend upon the beam energy E_o. This agrees well with SPEAR data over the limited range of E_o available. Even with this pessimistic hypothesis, where the average energy is ~500 MeV, the the losses are ~3% for a reasonable range of ~3 gm/cm^2. A telescope covering range between 8 and 25 gm/cm^2 can easily extrapolate such losses with high precision. A less pessimistic hypothesis on the momentum spectrum is to assume that at PEP energies Bjorken scaling holds for all x. The SPEAR data, which appear to scale at large x, were extrapolated for the estimates given here. These losses are so small as to be almost negligible, and the range extrapolation is very good indeed.

A possible solution to these design goals is shown in Figs. 3 and 4. The two rings (hexagons) of scintillation counters form seven-layer range telescopes plus an additional shower counter. The first 3-4 layers are used in the lowest level coincidence required to adequately reduce the spurious triggers. The remainder form the range telescope for extrapolating losses. The hexagonal symmetry has the advantage of maintaining nearly constant the angles at which the particle trajectories traverse the counter, and it also results in counter modules of modest proportions.

Modules for this geometry are shown in Fig. 5; Fig. 6 shows a detail of a module as well as the accumulated material. The hexagonal geometry suffers from having many adges and in practice the losses in azimuthal coverage may be prohibitive. An alternative is to use a square structure, where the packing is better, but larger modules are required. Several configurations are possible; one which was considered is shown in Fig. 7.

Within the ring of counters is a set of six gaps of proportional chambers used for tracking and counting the charged particles; see Fig. 3. This cylinder of chambers alone would cover $\sim 80\%$ of 4π solid angle. In addition three gaps of chambers at each end would cover much of the solid angle not covered by the first set. This combination should be sufficient to adequately reconstruct tracks even if the charged multiplicities are relatively high. The solid angle coverage should be so large that only small corrections will need be made for losses.

The data rates are favorable; see the Table. Estimates of the rate for $\sigma_T(e^+e^- \rightarrow \text{hadrons})$ range from 50/hr. to $\sim$1000/hr., depending upon how one extrapolates the known data. For the purpose of this part of the experiment it will be necessary to exclude all colinear two-body events in order to eliminate the QED processes. Measurements made at much lower energies of two-body hadronic events indicate that the fraction of such events is very small, and falling rapidly with energy. By their nature no totally neutral final states may be detected.

A convenient internal luminosity monitor is the number of Bhabha events. Since it may happen that the hadronic event rates exceed the Bhabha event rates, the statistical accuracy of this technique is not ideal, but the method minimizes systematic errors. An additional, small angle, high precision luminosity monitor would be desirable but not mandatory. Such a monitor would permit a check of QED by measuring the absolute rates of Bhabha scattering and μ-pair production. Even without the small angle monitor a test of μ-e universality is possible. The main problem in obtaining a clean μ signal is rejection of cosmic rays, which are $\sim$200 times as numerous. Vertex information alone will reject most of the cosmic rays, and time of flight information should effectively eliminate the remainder.

Crucial to the success of this experiment is the use of Eq. 1. Two photon annihilation processes will not satisfy this relation and represent a background which must be carefully considered. The large solid angle coverage by the proportional chambers allows consistency checks of the angular distribution of the prongs. It is essential, however, to incorporate at least a rudimentary small angle electron tagging system to identify at least a subset of such γ-γ events, so that meaningful background subtractions may be made. Crude estimates of the contamination due to two photon processes are possible.(1) There are large uncertainties in both the one-photon trigger cross sections and the two-photon trigger cross sections. However, the contamination does not appear to be alarming. Signal to background ratios range from 1:1 to 100:1 at $s = 900$ GeV^2. Clearly much more work and knowledge of cross sections are required. The pure QED two-photon processes are a significant part of the trigger rate, but are fairly easily identified by the angular distribution.

The apparatus described here represents an attempt to design an experiment with a very specific goal, rather than a general survey tool. This results in an attractive simplicity and a highly modular end product. The modular emphasis has obvious advantages in construction and testing; likewise it results in rather good access for maintenance, etc. The principal weakness of the design lies in its vulnerability to backgrounds. Survey experiments at SPEAR II could shed much light on such questions. With appropriate planning such an experiment could be carried out early in the life of PEP because of its modest proportions (by PEP standards anyway) and favorable data rate.

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(1) R. Gatto and G. Preparata, Nota Intera No. 479.
There are numerous obvious errors in this paper and deciphering the results of the authors is not unambiguous.

TABLE

ESTIMATED RATES OF DATA ACQUISITION

σ_T	50 2000	events/hr. $\left(\frac{E}{15\ \text{GeV}}\right)^2$	(R = 6) (σ_T = 20 nb)
Bhabha $e^+e^- \to e^\pm e^\mp$	50		
μ-Pairs $e^+e^- \to \mu^\pm \mu^\mp$	2		
Cosmic Rays	360		

Figure Captions

1. Estimates of trigger efficiency vs. charged multiplicity for various choices of solid angle.
2. Estimates of the fraction of particles penetrating a given range, assuming two extreme models.
3. Vertical section of apparatus.
4. End view of apparatus having hexagonal symmetry. (slightly exploded view)
5. Trigger, range telescope, and shower module for hexagonal symmetry.
6. Detail of counter module showing accumulated material in gm/cm^2, radiation lengths, and absorption lengths.
7. An interesting topology for square symmetry.

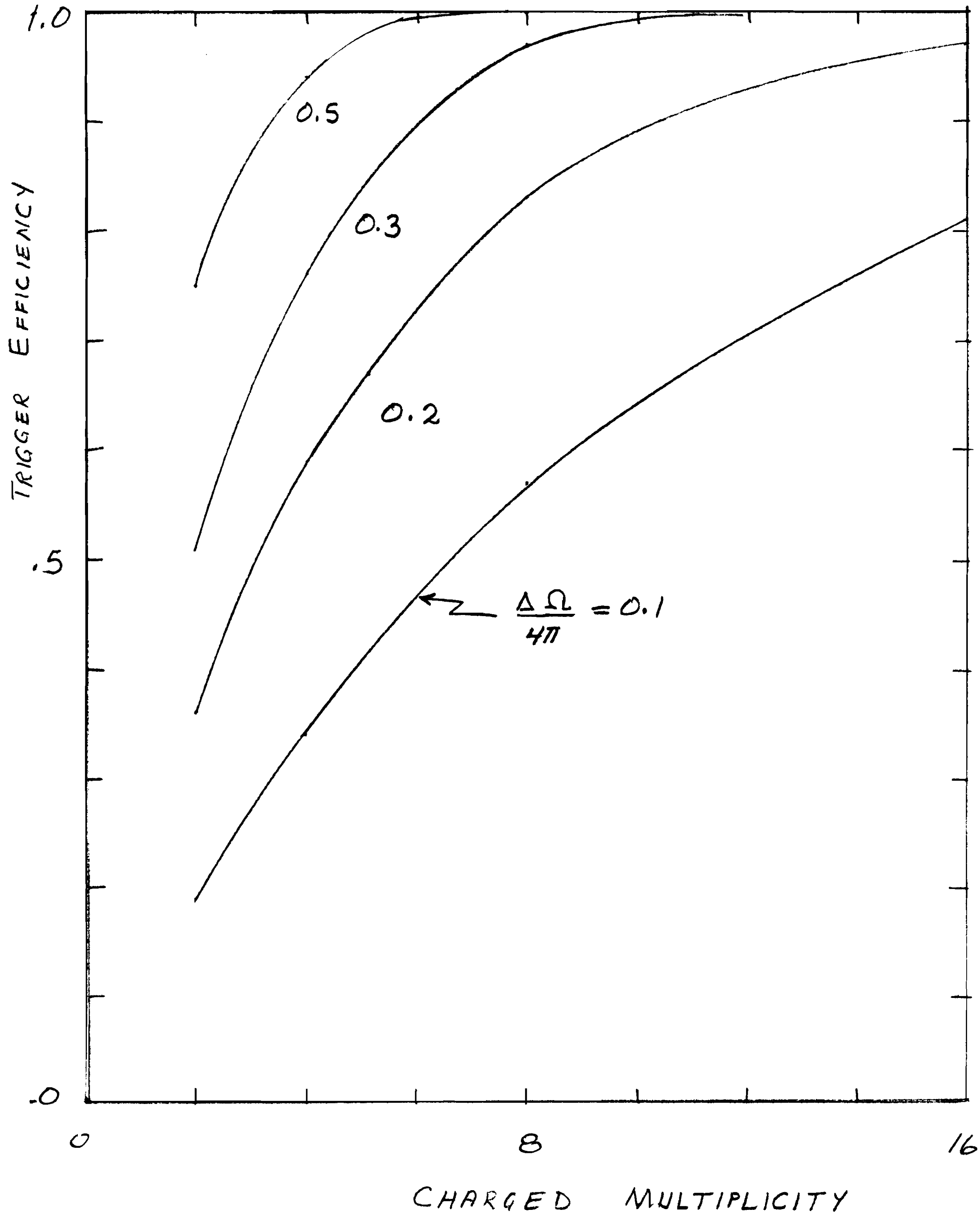

1.0
.5
.0
0
8
16
0.5
0.3
0.2
$\frac{\Delta\Omega}{4\pi} = 0.1$
TRIGGER EFFICIENCY
CHARGED MULTIPLICITY

FIG. 1

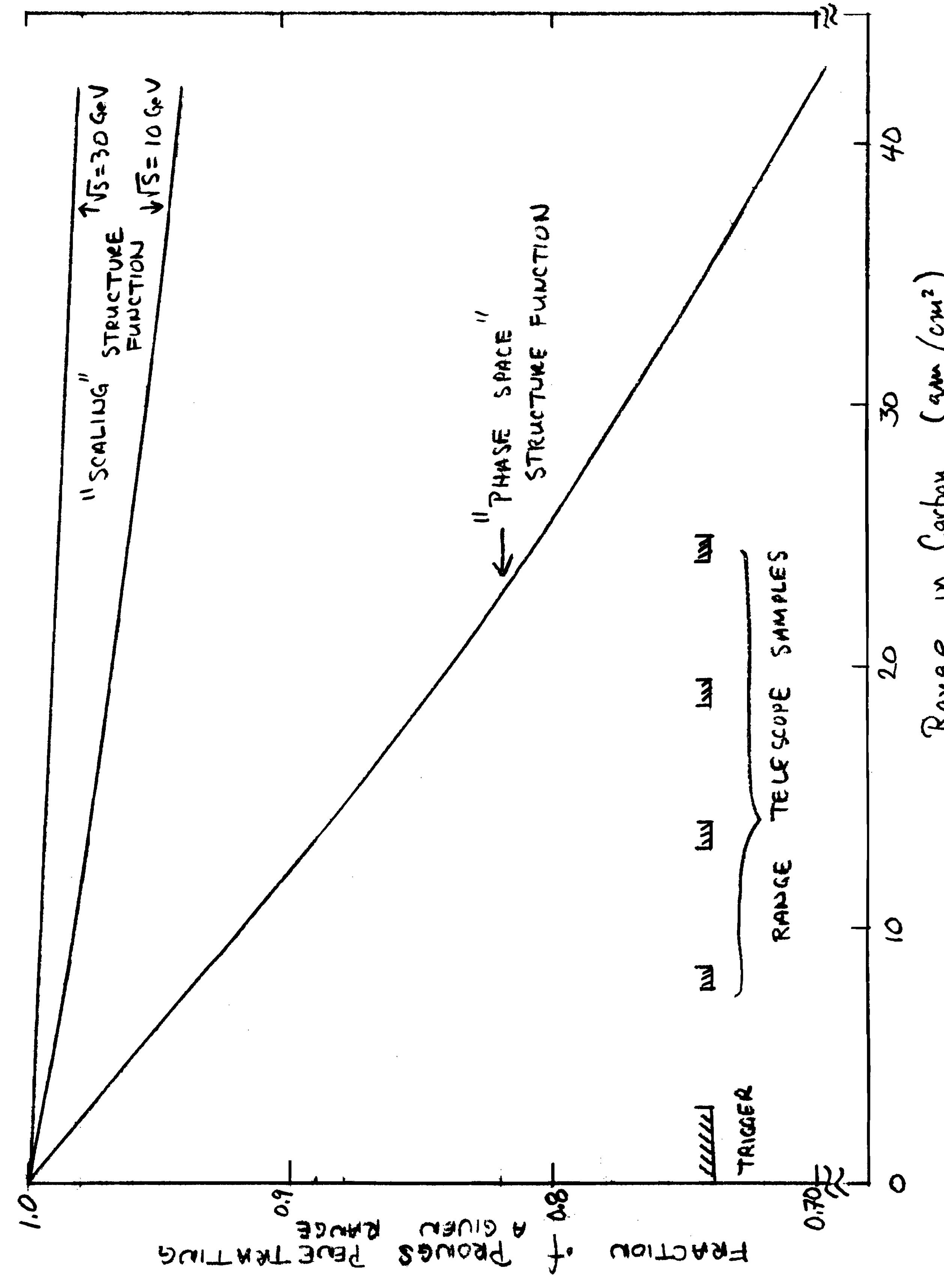
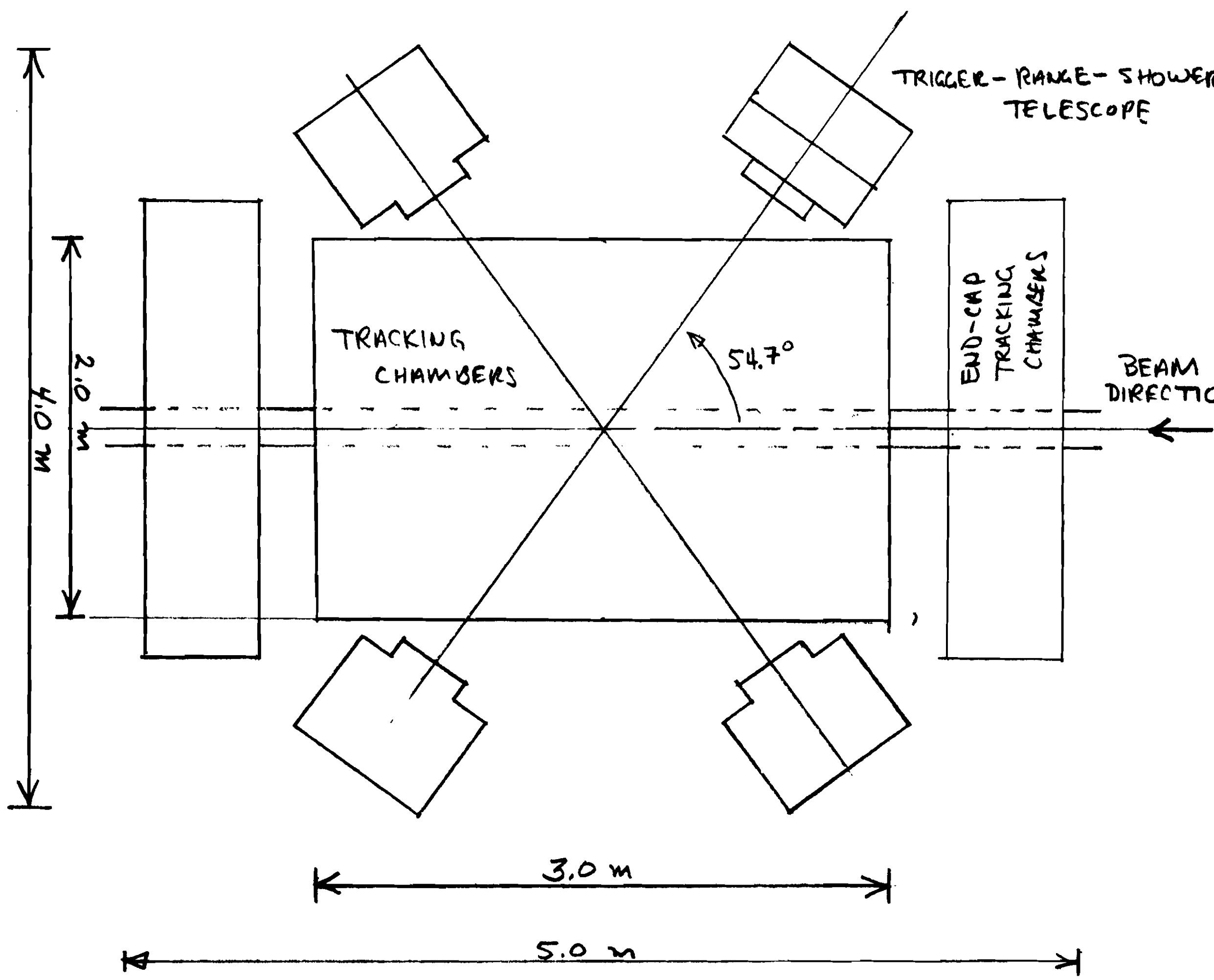
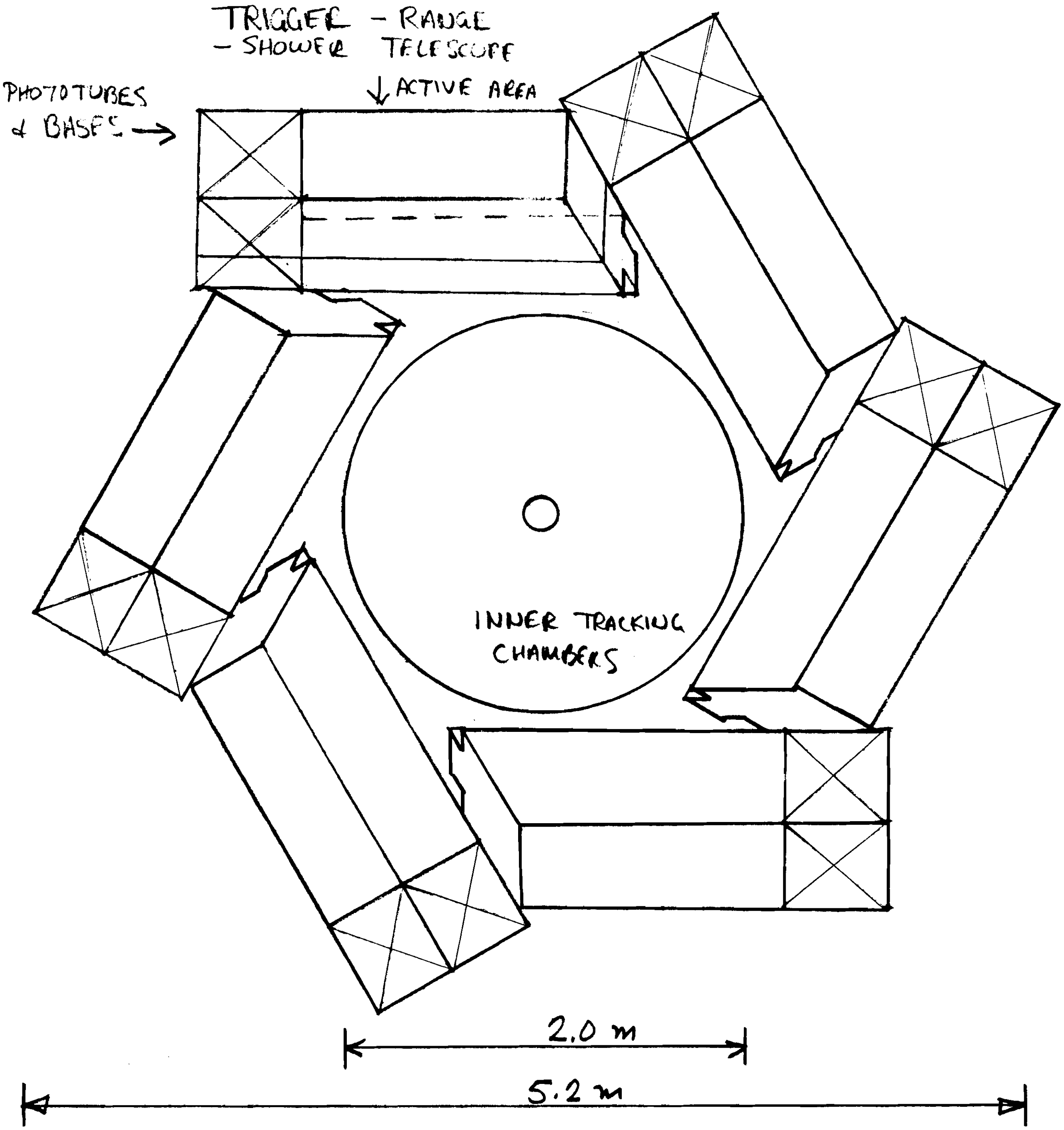

"SCALING" STRUCTURE FUNCTION
√S = 30 GeV
√S = 10 GeV
"PHASE SPACE" STRUCTURE FUNCTION
RANGE TELESCOPE SAMPLES
TRIGGER
0
10
20
30
40
Range in Carbon (gm/cm²)
1.0
0.9
0.80
0.70
FRACTION of PRONGS PENETRATING A GIVEN RANGE

FIG. 2.



SIDE VIEW

FIG 3



END VIEW

FIG 4

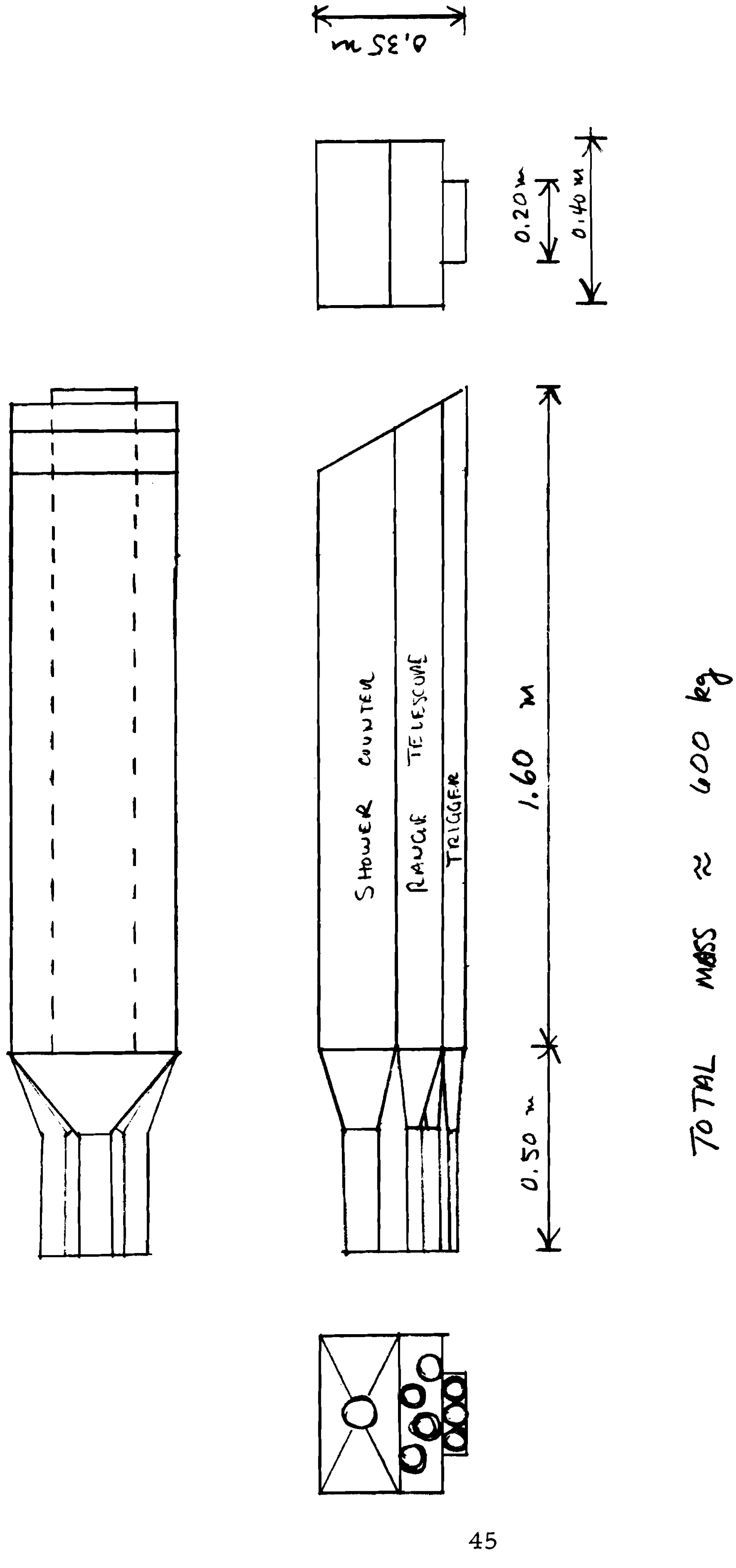
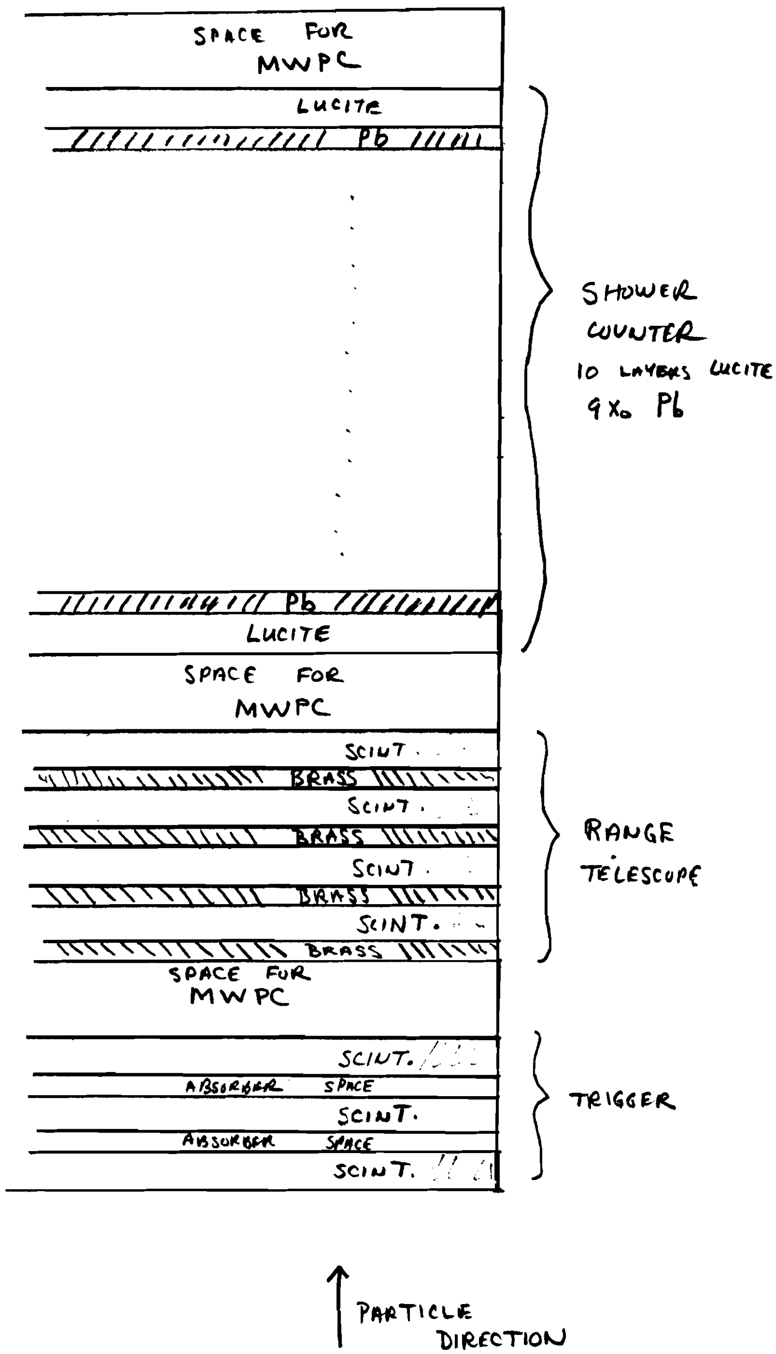

0.35 m
0.20 m
0.40 m
SHOWER COUNTER
RANGE TELESCOPE
TRIGGER
1.60 m
0.50 m
TOTAL MASS ≈ 600 kg

FIG. 5

DETAIL of TRIGGER – RANGE – SHOWER TELESCOPE



ACCUMULATED MATERIAL		
MASS (gm/cm²)	RAD. LENGTH (X_0)	ABSORP. LENGTH (λ_0)
94.0	10.78	1.05
26.2	1.522	.358
25.0	1.493	.338
19.5	1.137	.267
14.0	.781	.196
8.5	.425	.125
3.0	.069	.054
2.0	.046	.036
1.0	.023	.018

FIG 6

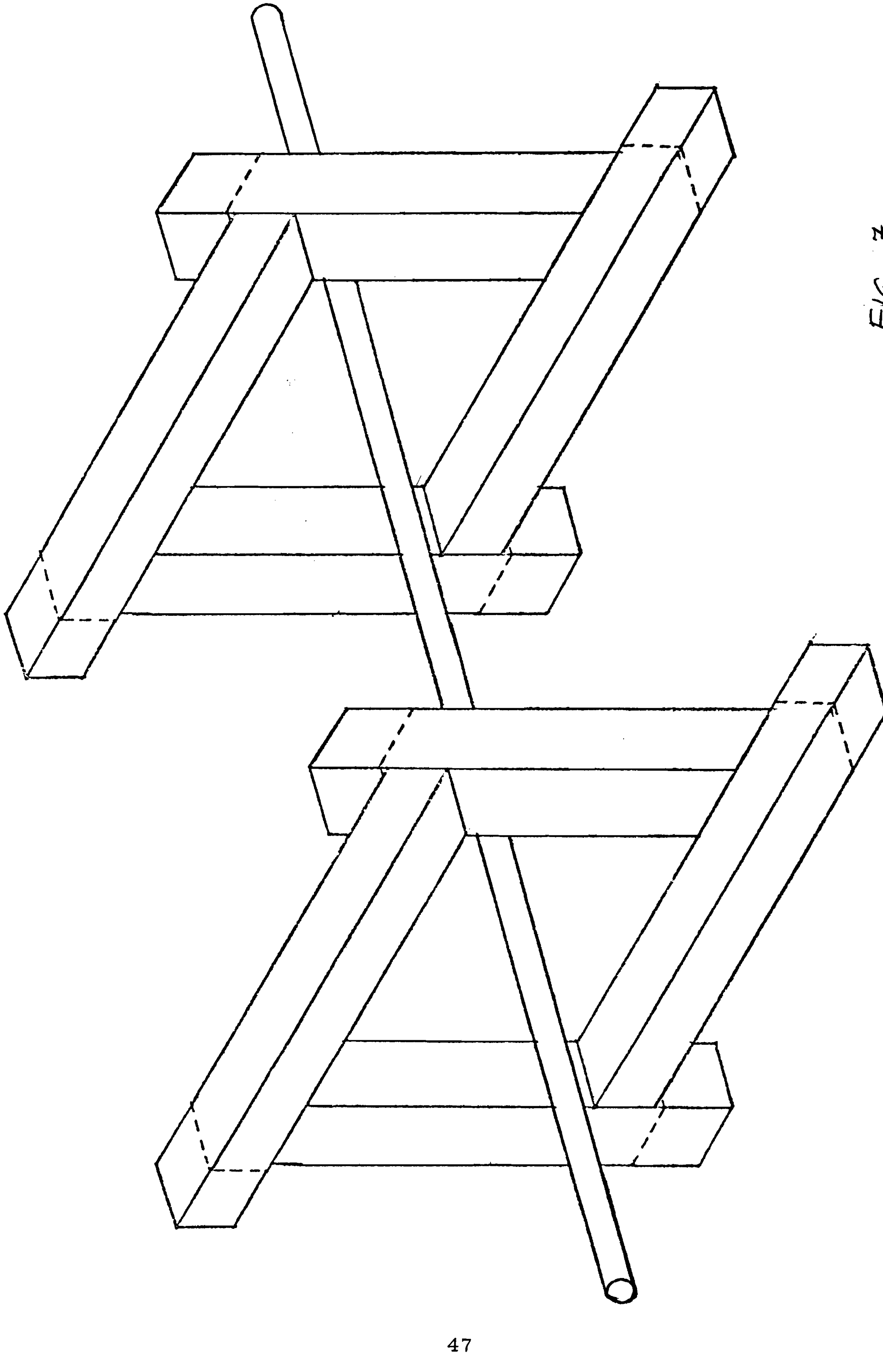


FIG. 7