P-609

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Spokesman: W. Selove
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A STUDY OF THE STRUCTURE OF HIGH p_T HADRONIC INTERACTIONS

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1. Introduction

We have prepared this brief document, in connection with proposal P246, for use by the laboratory administration[1]. We include responses to questions that have been raised following the consideration of P246 thus far. Our intent is that this material would help expedite the approval and implementation of the program described in P246.

We must emphasize this last point. At present the results on jets obtained at Fermilab, in particular by our previous experiment E395, have placed the laboratory at the forefront of research in high p_T jet physics. This lead cannot be held by Fermilab for very long unless it takes steps to continue a significant program in jet physics. Note that two very powerful high p_T experiments are presently being mounted at CERN[2].

2. Objectives

a) Study of $d\sigma/dt'$

The prime objective of this experiment is to study $d\sigma/dt'$ for parton collisions using high p_T jets. Experimentally we will define the jet axis and the p_T of the jet by sorting events according to the total p_T within a given solid angle $(\Delta\Omega)_a$ around a trial jet axis. Several values of $(\Delta\Omega)_a$ will be used, roughly between 1 and 2 sr. Experience from E395 has shown us that only about 10% of the jet p_T will remain outside such a solid angle trigger region. If the p_T within the solid angle is corrected statistically for missing p_T, the jet momentum may be determined to a few percent, and the jet angle to a few degrees[3]. The two-jet cross section $d\sigma/d\Omega_1 d\Omega_2$, measured for fixed parton momentum fractions x_1 and x_2 and for varying jet angles, will be directly proportional to $d\sigma/dt'$ (multiplied by simple kinematic factors). The results for the t' dependence of $d\sigma/dt'$ can be tested for consistency by seeing whether they are independent of the size of $(\Delta\Omega)_a$.

This procedure will give the shape (i.e., the t' dependence) of $d\sigma/dt'$ at fixed s' (s' is the parton-parton Mandelstam mass-squared variable). To obtain

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[1] For further details see the P246 proposal (May 1978) and the material referenced therein.

[2] See the proposals of the BNL-CERN-Scandinavian collaboration and the CERN-Munich collaboration.

[3] Reports UPR-46E (Tokyo Conference) and UPR-47E (M. Dris, to be published in Nucl. Instr. and Methods.)

the absolute normalization, extrapolation to the cross section for nominal full containment of the jets can be carried out by using successively larger values of $(\Delta\Omega)_a$. This will give a normalization in a straightforward but model-dependent way.

These studies of $d\sigma/dt'$ require large angular coverage, good calorimeter resolution, accurate angular determination, and bias-free events. Our experimental design provides all these capabilities. In particular we note that the modular calorimeter alone provides a jet axis angular measurement better than $\pm 5^{\circ}$ CM, even before incorporating the drift chamber information. Fractional energy resolution will be about $0.8/\sqrt{E_{lab}}$, or about 10% for a typical jet.

The drift chamber information is primarily needed for 2 reasons: 1) to check that the events observed come in fact from interactions in the LH_2 target (typically with a resolution along the beam of 1 cm), and 2) to provide a sharper definition of the solid angle and p_T of the jet within $(\Delta\Omega)_a$ than is achieved by the calorimeter modules alone.

Drift chamber spatial resolution in E395 was about 400 microns. With more accurate surveying we estimate that accuracy would be about 250 microns. An automatic track reconstruction program is operating; development is still in an early stage, but the program currently has about 85% efficiency for the typical event, giving typically 5 tracks clearly identified for 6 tracks total into the calorimeter. With manual intervention the program can achieve close to 100% efficiency.

b) Quark-gluon separation

This is a second highly important objective. This separation is likely to be possible because of predicted differences in $d\sigma/dt'$, in structure functions, and in jet "softness" (fragmentation) for gluons as compared to quarks.

c) Additional objectives, Phase I

Additional objectives, which can be pursued with data taken for the study of $d\sigma/dt'$, are

- Structure function information
- Multi-jet events
- P_T dependence of jets.

It is also important to study jet production in heavy nuclei.

d) The internal structure of jets

A final objective listed here is the study of the internal structure of jets. This study is important for the purposes of

- Identifying parent quark flavors (thus for example for the study of $d\sigma/dt'$

for like and unlike quarks)

- separating quark and gluon jets.

This study is dependent on the existence of the CID and the magnetic spectrometer which we are proposing to include in the second phase of the experiment. More details on the suggested phases are included in section 5.

3. Angular coverage

We discuss here the angular coverage of this proposed experiment. We give our main discussion for the case of a beam of 200 GeV, where it is much more difficult to obtain large CM coverage than at higher beam energies. It is of course important to make measurements over a wide range of energies, for many reasons--for example, for consistency checks and for determination of non-scaling effects.

Figures 1 and 2 show the apparatus for Phase 1 (see below). At 200 GeV the extreme edges of the calorimeter, in the configuration shown, are at 23° and 136° CM. Allowing a 25° edge region (see below), this allows measurements of jets from 48° to 111° CM. By moving some modules to alternate locations one can readily go out for example another 10° -- jets to 121°, and calorimeter edge at 146°. We note that 146° CM at 200 GeV corresponds to a lab angle just past 300 mrad. It is to be emphasized that bias-free coverage of jet fragments out to such relatively large angles is indispensable if one is to study $d\sigma/dt'$ for a significant range of scattering angle θ'.

We note also that at 300 mrad lab angle the jet fragments of interest have laboratory energies down to 1 GeV.

Fiducial solid angle for jets

We compare here the fiducial solid angle coverage, for the jet axis, of the detector proposed here with that of E395. Figure 3 indicates roughly the fiducial coverage for the two experiments. Useful jet detection requires that the jet axis not be too close to the calorimeter edge. The fiducial regions shown go roughly to 25° from the calorimeter edge. It is possible to work approximately that close to the edge when, as in E395 and in Phase I here, there is no magnetic smearing of jet fragment directions. With such a 25° edge region allowed, Figure 3 shows that the fiducial solid angle of E395 at 200 GeV was, for the 2 sr right arm for example, about 1/4 sr, a quite restricted region. The left arm had an even smaller fiducial solid angle.

Figure 3 indicates also the fiducial coverage at 200 GeV for the new array. Near the horizontal plane this fiducial region covers θ^{*} values from 48° to 111°.

From 48° to 78° there is complete 360° azimuthal fiducial coverage; at $\theta^{*} = 100^{\circ}$ the azimuthal coverage is 225°. The total fiducial solid angle is about 4 sr at 200 GeV, or about 15 times that of E395.

The array shown in this proposal gives the ability to see, in a bias-free way, not only a wide angular range for the jet axis, but gives also the ability to see a large angular region outward from the jet axis. The ability to see this wide range of angles is necessary for the meaningful study of $d\sigma/dt'$; and at the same time it provides the capability for observing possible multiple-jet type events.

We note that this 4 sr figure gives the fiducial solid angle at 200 GeV. At higher beam energies it is much easier to get fiducial coverage this large or larger and which extends to larger θ^{*}. We remark that we can also extend our coverage, even at 200 GeV, by moving or adding modules.

4. Shield

To eliminate background from neutral particles coming along the beam direction, a shield is necessary just ahead of the LH_2 target. E395 had such a shield, which did eliminate such background; other calorimeter jet experiments at Fermilab were run without such a shield, and showed background effects which ultimately limited the p_T range which could be cleanly studied.

The shield must effectively remove all neutrals which come from interactions in our upstream beam counters, or from other upstream interactions or halo particles. The shield thickness must reduce spurious events, in which low p_T could simulate high p_T, to a level of the order of a few events a day. With a beam flux up to 10^8 per second of spill, this requires a shield with attenuation about 10^9. We plan to use about 5 feet of steel, preceded by about 24 feet of concrete.

5. Phases of the experiment

a) Phase I

The apparatus for Phase I is shown in Figs. 1 and 2. It consists of a large calorimeter array, the presently existing and operating six drift chamber planes, the presently existing 18 inch LH_2 target, and various scintillation counters for beam definition, muon identification, and vetoes (essentially identical to those used in E395). The cost estimates for Phase I are given briefly on page 6 and in considerable detail in an Appendix which we are providing to the laboratory.

The only major equipment change and expense to the experimenters over the existing equipment of E395 would be the construction of additional calorimeter modules of existing design.

The beam requirements would be 1) 400 GeV energy capability, 2) at least 10^8 protons/sec on the experiment target, with as many pions in the beam as possible, and 3) two (existing) beam Cherenkov counters capable of π-p separation at 200 GeV or more. We believe either the M1 or M2 beams in the Meson Area would be appropriate.

We request 1500 hours running time for Phase I. This time would be divided roughly 1:2 for (calibration and tuneup):data. After an initial tuneup period, in which we would use some parasitic time (stray muons) and some prime time, the total time used would be divided into 3 or 4 blocks.

b) Phase II

The apparatus is shown in Fig. 4. The additions in this phase consist of:

- large aperture magnet (SCM-105, currently at Argonne; the aperture would be enlarged from 0.35 m x 2.1 m to 1.0 m x 2.1 m.)
- Cerenkov imaging device (CID), which is intended to identify particles over a wide kinematic range
- PWC's replacing the drift chambers, to permit $\sim$ 100 times higher flux
- A beam hodoscope system, to permit operation with two or more beam particles per r.f. bucket.

c) Phase III

We anticipate the existence of beams at momenta of 500 to 1000 GeV/c and would like to continue our studies at higher s. This will require the addition of an additional 2 absorption lengths (1 module) for each segment of the array.

Summary of Lab costs in new cash $, for Phase I

Meson Department	$ 120 K
Research Services	90 K
Total	$ 210 K

These are the best current estimates by the Laboratory staff. Details are provided in an Appendix.

$ from Experimenters, Phase I

1) Calorimeters	(150 K)	Existing equipment, from E395
	350 K	new (U.W. and U. Pa.)
2) Cables, delay boxes, and special electronics	(40 K)	Existing equipment, from E395
	80 K	new (U. Pa.)
3) Drift chambers, electronics, cables	(60 K)	Existing equipment, from E395 (U.W.)

Total existing: ($250 K)
Total new 430 K*

(*approximately $80 K has been spent toward this sum, as of September 1978)

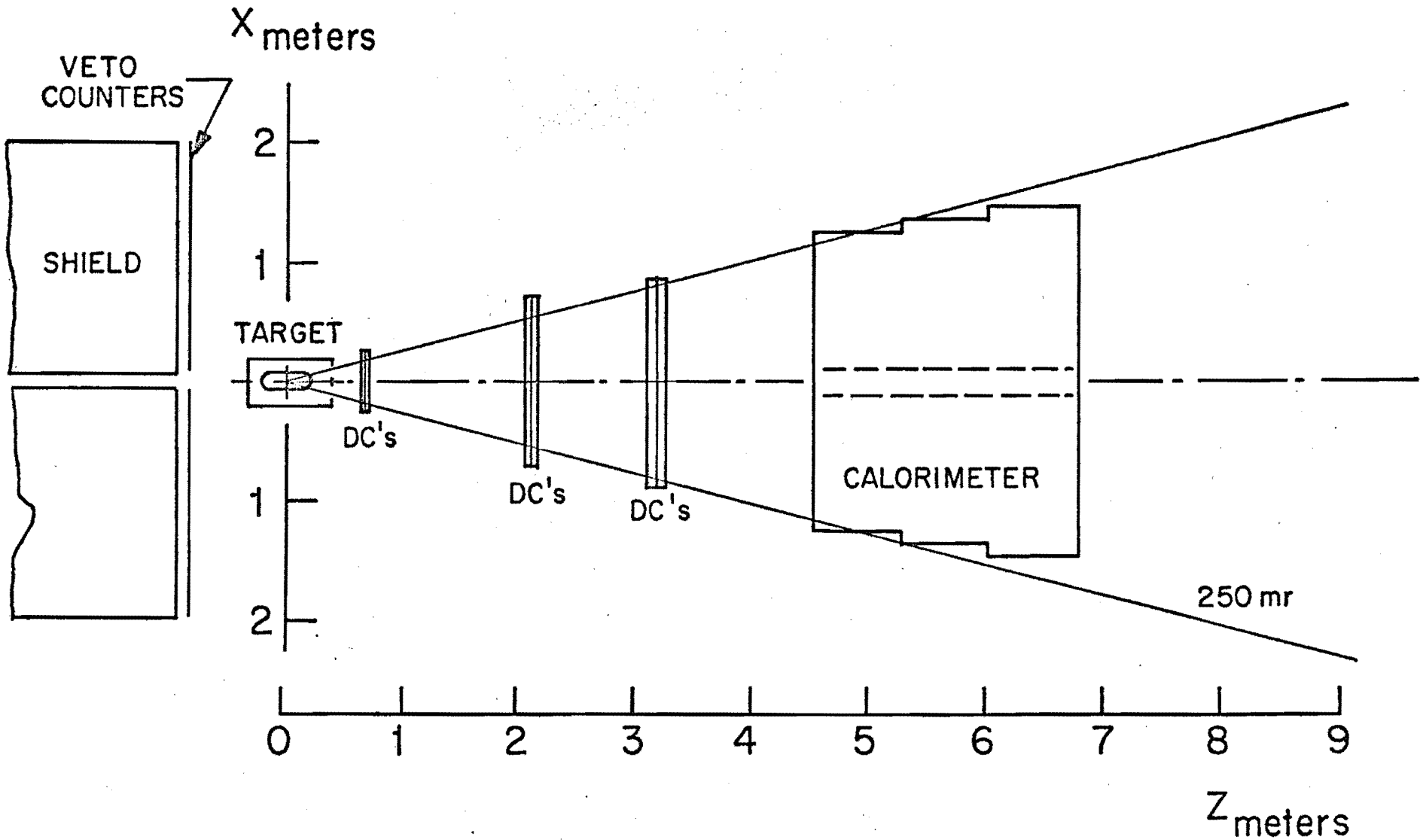

Fig. 1 Plan view of experimental layout (Phase I)

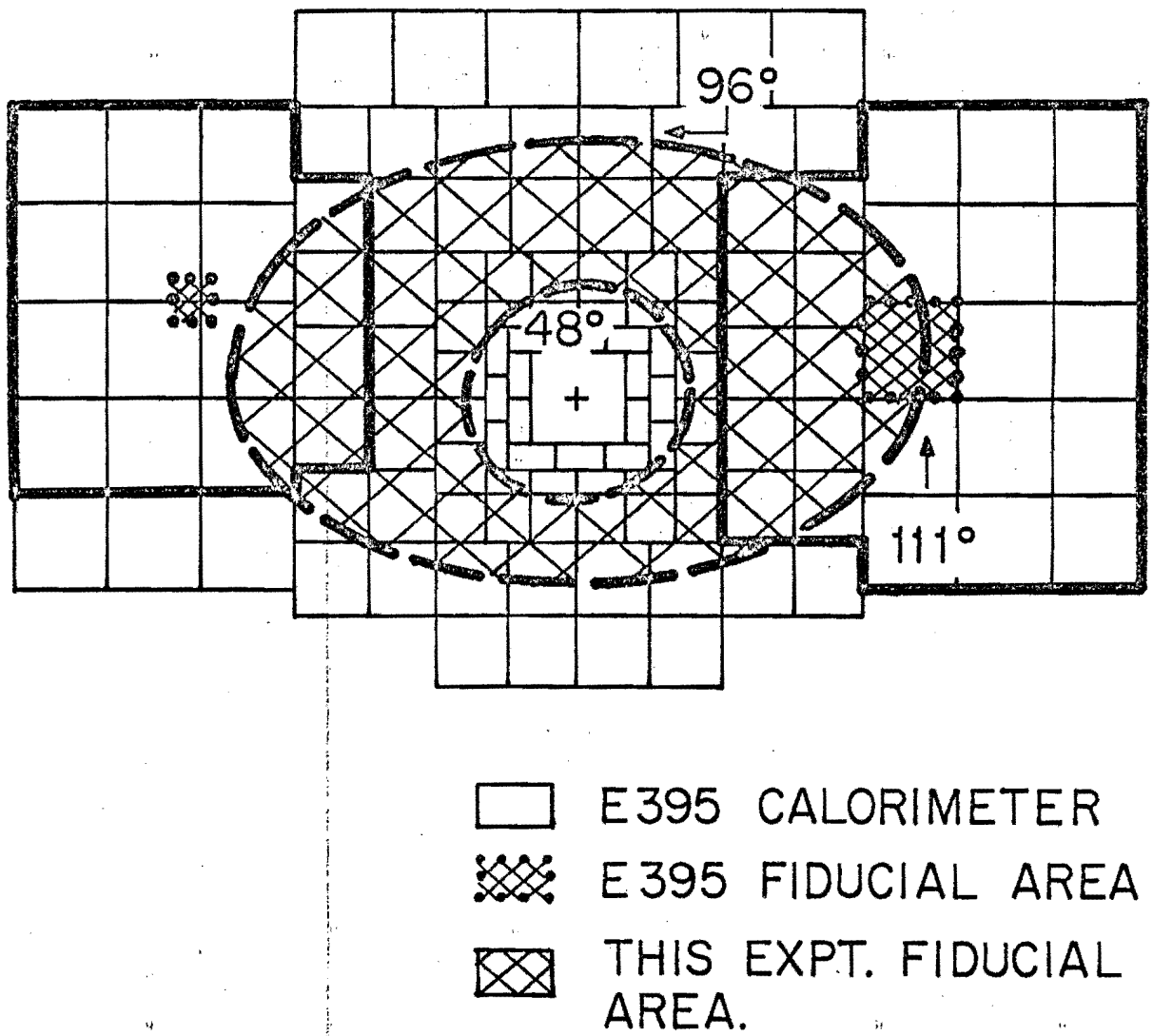

Fig. 3 Front view of calorimeter array, showing fiducial solid angles at 200 GeV.

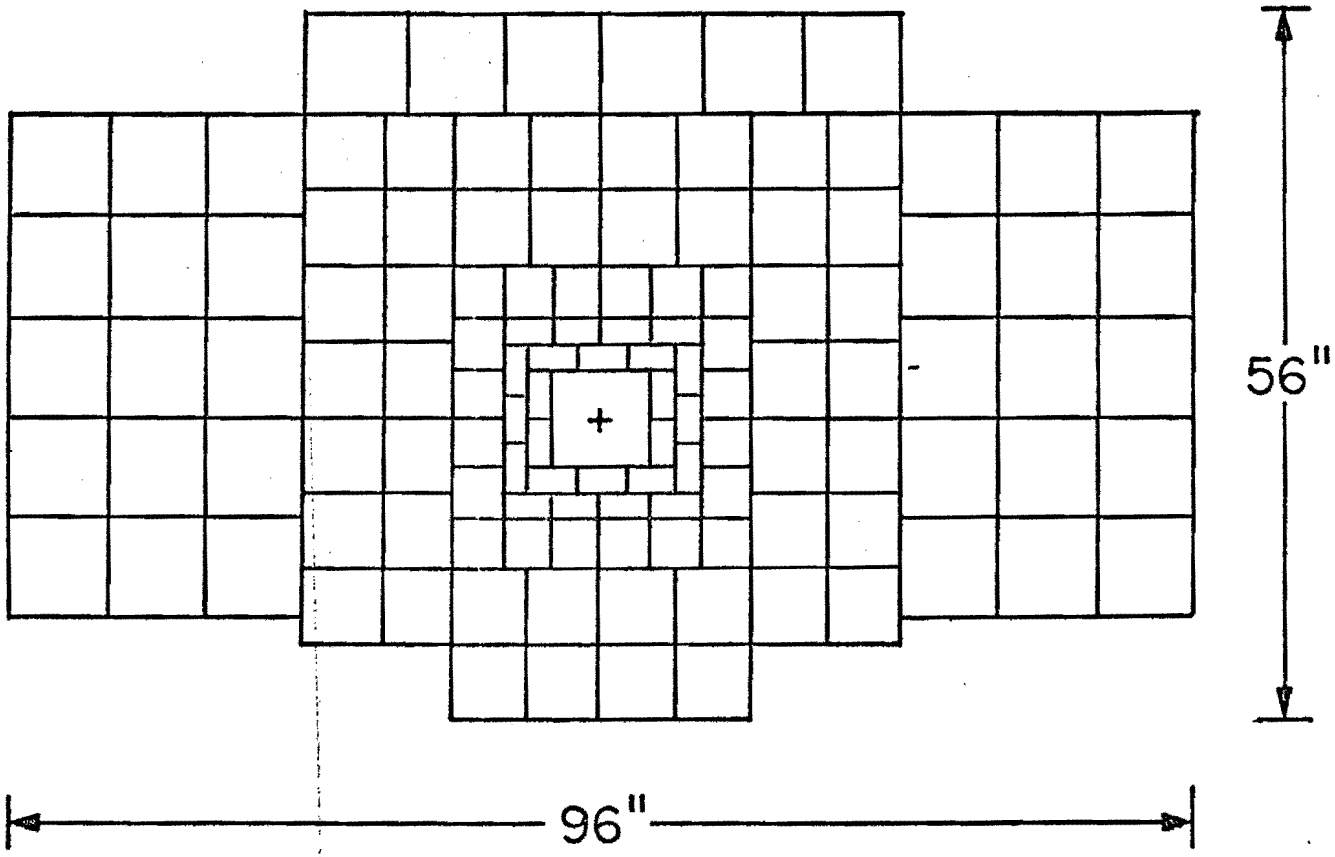

Fig. 2 Front view of the calorimeter array. The modules are 2"x4", 4"x4", 6"x6", and 8"x8" in cross section. The beam hole extends ± 4" from the beam.

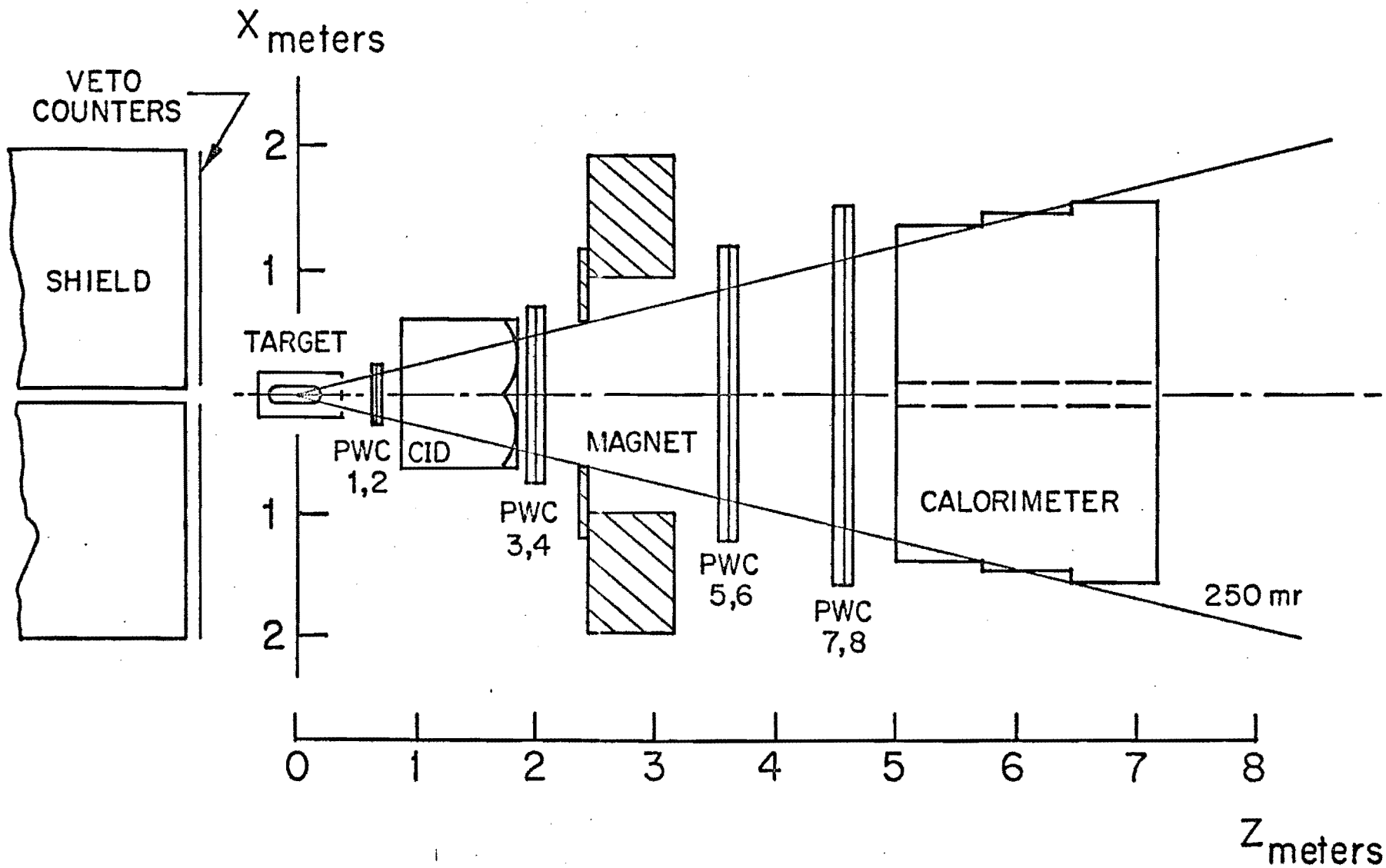

Fig. 4 Plan view of experimental layout (Phase II)