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An Open Geometry Magnetic Spectrometer for the Tevatron Muon Beam

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I. Introduction

The point-like leptons with their well-defined interactions provide ideal probes for studying the murky hadronic world of quarks and gluons. The muon is especially suited for this purpose because of the ease with which it is detected and the supression of radiative losses resulting from its large mass relative to the electron. The building of an intense, high energy muon beam at the Tevatron will open a new era of muon scattering experiments which probe nuclear matter at the highest possible values of Q^2.

We feel that, in addition to structure function measurements with inclusive muons, such a program should include experiments which study the final state hadrons along with the scattered muon. Since the initial state of the parent quarks is in principle well prepared by the probing muon, much can be learned about the nature of quark confinement. To perform such experiments it will be necessary to have an open geometry muon spectrometer.

We propose to build a new muon spectrometer utilizing the Chicago Cyclotron Magnet. This magnet has already demonstrated its versatility in the old Muon Laboratory. It will be important to have a spectrometer with the same flexibility in the Tevatron muon beam. Because of the non-parasitic nature of the proposed beam and the superconducting coils on the magnet, it will be possible to carry out an ongoing muon physics program with such a detector.

In particular, we would initially investigate the scattering of muons at the largest possible values of Q^2 using a high luminosity Be target. We would simultaneously study the high momentum hadrons produced by muons scattered in thin nuclear targets. At a later stage we would supplement the cyclotron magnet spectrometer with a magnetic vertex detector for more extensive investigations of the muon-produced hadrons. Finally, we would make an accurate determination of the nucleon structure functions in the intermediate Q^2 range using high luminosity hydrogen and deuterium targets.

II. Physics Objectives

In this section we outline the physics objectives of a program of muon scattering with an open geometry spectrometer at the Tevatron. We first discuss what can be learned from high luminosity studies of inclusive muon scattering. Then we outline a program for the study of the final state hadrons produced from both nuclear and hydrogen targets.

A. Inclusive Muon Scattering at Large Q^2 and Nucleon Structure Functions

Tevatron energy muon beams may be the best means by which the nucleon structure functions can be determined and as a result may be one of the few reliable testing grounds for the

PHYSICS JUSTIFICATION

The asymmetry in the charged decay of polarized lambda hyperons has been used to study the polarization in the process $P + A \rightarrow \Lambda + X$ where it is found that there is negligible dependence of the polarization on s, but it is linear in P_T. The observation of lambda polarization has stimulated some theoretical work which is in agreement with the observed data and makes new predictions for the processes described in this proposal.

DeGrand and Miettinen[3] note that the lambda produced in $P + P \rightarrow \Lambda + X$ is formed by a spinless (u,d) pair picking up an s-quark from the sea. They argue that the acceleration of the s-quark during the lambda formation results in a Thomas precession and hence an effective interaction $\vec{\omega}_T \cdot \vec{S}$. This is used to predict polarization which is along the $\vec{P}_\Lambda \times \vec{P}_P$ axis and proportional to P_T. The argument depends only on kinematics and can be applied to other processes with the following results relevant to our proposal.

1.) The polarization in $\vec{P} \rightarrow \vec{\Lambda}$ is the same as in $P \rightarrow \Lambda$.

2.) The polarization in $K^- \rightarrow \Lambda$ is zero, since there is no Thomas interaction for the spinless (u,d) pair.

3.) Meson produced lambdas where the s-quark comes from the sea are expected to all have the same polarization. Examples are $K^+ \rightarrow \Lambda$, $\pi^\pm \rightarrow \Lambda$.

The Thomas term used here is an analogue to the Thomas part of the spin orbit interaction found in atomic physics, where it is known that electromagnetic interactions of the electron spin are larger and of opposite sign to the Thomas term. Similarly, departures from the above predictions could be evidence for the spin dependence of the dynamical interaction of strange quarks. One should also note that a more detailed model by Andersson et al.,[1] where the correlation between transverse momentum and quark spin arises from considerations of angular momentum of pairs produced in a string, gives many of the same predictions.

RUNNING CONDITIONS

We select as our running conditions those which offer us "the best combination" of statistical power and freedom from systematic biases. In making this decision we consider the following parameters:

Number of detected lambdas (antilambdas) per proton incident on the meson target.

Number of triggers per detected lambda (antilambda).

"transverse" detection efficiency.

In addition, we use for the statistical error in the measured decay asymmetry (in the proposed running conditions).

$$< \delta\alpha > = [24/N\Delta^3]^{1/2}$$

where N is the number of reconstructed lambda (antilambda) decays,

Δ is the "useful" range in the cosine of the C.M. decay angle. We define as "useful", the kinematic region over which the acceptance of the experiment is independent of the decay geometry. We note that it is very important to keep Δ as close as possible to $\Delta = 2$ (its maximum).

a Measured decay asymmetry.

From the data collected with the 1978 configuration of the M-4 spectrometer (E-383), we conclude that the number of detected lambdas (kaon trigger) or antilambdas (antiproton trigger) per proton incident on the meson targer is approximately independent of the beam momentum. We have no data for lambda production by pions.

From the same data we conclude that the trigger becomes considerably cleaner as the beam momentum increases, as the table below shows:

P(Beam)	Trigger/($\overline{P},\overline{\Lambda}$)	Trigger/(K^-,Λ)
70 GeV	63	402
115 GeV	--	185
175 GeV	33	113

The acceptance of the spectrometer for decays of long lived neutral particles is given by two classes of effects:

A.) Decay geometry independent.

Here we merely ask whether the decay vertex is within the vacuum decay volume ("longitudinal acceptance").

B.) Potentially decay geometry dependent.

Here we ask whether a decay which occurs within the vacuum decay volume is reconstructable, ("transverse acceptance").

Using our studies for the acceptance of the E-383 spectrometer for ($K \rightarrow \pi^+ + \pi^-$) decays, we conclude (Fig. 1) that for an incident beam momentum of 115 GeV and for $0.6 < x < 1.0$, the transverse acceptance is independent of t for the interval $0.0 < |t| < 0.45$. For the beam momentum of 175 GeV, the acceptance under the same conditions is flat out to $|t| = 1.5$. From this we conclude that we should run in the high momentum (175 GeV) configuration.

EXPERIMENTAL EQUIPMENT

We propose to collect the data for this experiment with the M-4 multiparticle spectrometer currently taking data (when the accelerator is running) for E-585.

The spectrometer consists of two parts:

A.) Beam Spectrometer (Fig. 2)

The differential Cerenkov counter has been used to identify kaons or antiprotons between 65 GeV and 175 GeV. By locating a mask over the secondary mirror, we expect to tag antiprotons and kaons simultaneously. Particle momentum and directions are measured with a set of eight proportional wire planes, read into a 20 MHZ rotating solid state memory (to minimize dead time). The two magnets, excited in series, have equal and opposite field integrals. While traversing this spectrometer, the particles are displaced to the west by approximately 150 mm.

B.) Target and Forward Spectrometer (Fig. 3)

The beam spectrometer is followed by a 0.71 m long liquid hydrogen target, 5 cm in diameter. Currently, this target is followed by a set of lead/scintillator shower detectors used in E-585. We propose to remove these detectors and in its place locate the sweeping magnet previously used in E-383. This magnet currently is located on the floor, about 3 m from its intended position.

The magnet is followed by a 14 m long vacuum decay region. This in turn is followed by a wire chamber spectrometer which consists of four detector stations and an analysis magnet. Each detector station consists of an (X,Y) proportional wire chamber module and an (X,X',Y,Y',U,U',V,V') drift chamber module. This equipment is currently collecting data for E-585. The analysis magnet is currently used at a transverse momentum of 0.20 GeV/c.

The aperture of the upstream detector is 1.20 m x 0.75 m, that of the downstream detector, 1.75 m x 1.20 m. The separation between modules in each detector is 5 m. The spacing of the detectors across the analysis magnet is 2 m.

In addition to these detectors, there are scintillation counters used in the trigger and to identify (π,μ) decays.

RATE ESTIMATES

To estimate the yield of the proposed experiment, we make the following assumptions:

Beam Momentum	175 GeV/c	
Accelerator Operation		
Energy	400 GeV	
Spill	12 Sec	
Efficiency	3.10^4 Spills/week	
Triggers/5.10^{12} Protons	$\bar{P}$: 33 K^-: 81	(1)
$\Lambda(\bar{\Lambda})/5.10^{12}$ Protons	$\bar{P}$: 1.0 K^-: 0.7	(1)
Dead Time/Trigger	0.004 Sec	
Run Length	5 Weeks	

Under these conditions we expect the following results, assuming both 5.10^{12} and 2.10^{12} protons per spill on the meson target.

		5.10^{12}	2.10^{12}	
$\bar{P},\bar{\Lambda}$	Total	150K	74K	
K^-,Λ	Total	106K	52K	
$\bar{P},\bar{\Lambda}$	(X,P_T)	84K	42K	(2)
K^-,Λ	(X,P_T)	85K	42K	(2)
δa		.019	.027	(3)

Notes:

1.) Yields determined experimentally with the E-383 setup. We expect that the current configuration of the spectrometer will give us substantially larger yields.

2.) Subset of events for Feynman x between 0.4 and 1.0 and P_T between 0.5 GeV/c and 1.0 GeV/c. Under these conditions we expect an average decay asymmetry of 0.1 for lambdas produced by protons. The fractional yields in this kinematic region were determined experimentally with the E-383 setup.

3.) If we divide the events collected in the kinematic region defined in 2.) into ten t-bins of equal population, δa is the statistical error on the asymmetry for each bin.

<u>TRIGGER (Fig. 4)</u>

We propose to use an improved version of the trigger developed in E-383, where we collected data for the study of inclusively produced $K^- \to K^0$.

The trigger consists of two stages:

A.) The fast pretrigger detects the fact that a beam particle with the appropriate Cerenkov signature interacts in the target and that at least one charged particle traverses the downstream aperture and hits the I-counter scintillator wall.

B.) The fast pretrigger initiates the local processing of the wire chamber and ADC data. 75 microseconds after the fast pretrigger the data are located in local storage, ready for Camac transfer. As the proportional wire chamber data is scanned into local storage (one scanner per plane), it passes through a "slow" preprocessor in a time short compared to the scan time. The preprocessor will decide whether the hit pattern on the eight PWC planes warrants transferring the data through Camac to tape.

In case of a rejected event, the system is reset in one microsecond. When running at 5 x 10^{12} protons/spill, the pretrigger introduces a 4% dead time, the Camac data acquisition a 30% dead time. This digital preprocessor replaces faster analog preprocessor used in E-383, which suffered from rate effects.

In addition to the lambda (antilambda) sample described above, this trigger collects a large sample of $K_s \rightarrow \pi^+ + \pi^-$ decays. They are needed to demonstrate our knowledge of the biases which might introduce systematic errors in the asymmetry measurements.

MODIFICATIONS TO EXISTING EQUIPMENT AND COST TO FERMILAB

As mentioned elsewhere, the modifications to the E-585 setup, needed to conform to this proposal, are:

A.) Locate mask on secondary mirror of differential Cerenkov counter.

B.) Implement the digital preprocessing logic.

C.) Remove lead/scintillator shower detectors.

D.) Reinstall the 4B7 sweeping magnet.

Items A.) and C.) will be done by the experimenters and are estimated to require 1-2 days. Item B.) requires some commercially produced equipment. The design and construction will take two to four weeks, the debugging, one week. All components are on hand, and funding has been approved, contingent on approval of this proposal. Item D.) is the only installation cost to Fermilab. We estimate one day of rigging and less than one day for power and water connections and testing.

RUN PLAN

We expect to complete the data taking for E-385, assuming "reasonable" running in fall/winter of 1980/81, by the start of the January 1981 shutdown. During that shutdown we propose to implement the changes discussed. Following the shutdown, we propose to run for ten weeks as follows:

	Trigger	Intensity
3 Weeks	$\overline{P}$, K^-	5.20^{12}
1 Week	π^-	Low
2 Weeks	P	Low
2 Weeks	$\overline{P}$, K^-	5.10^{12}

One week will be spent on trigger studies and one week on miscellaneous monitoring runs, most of this at low intensity.

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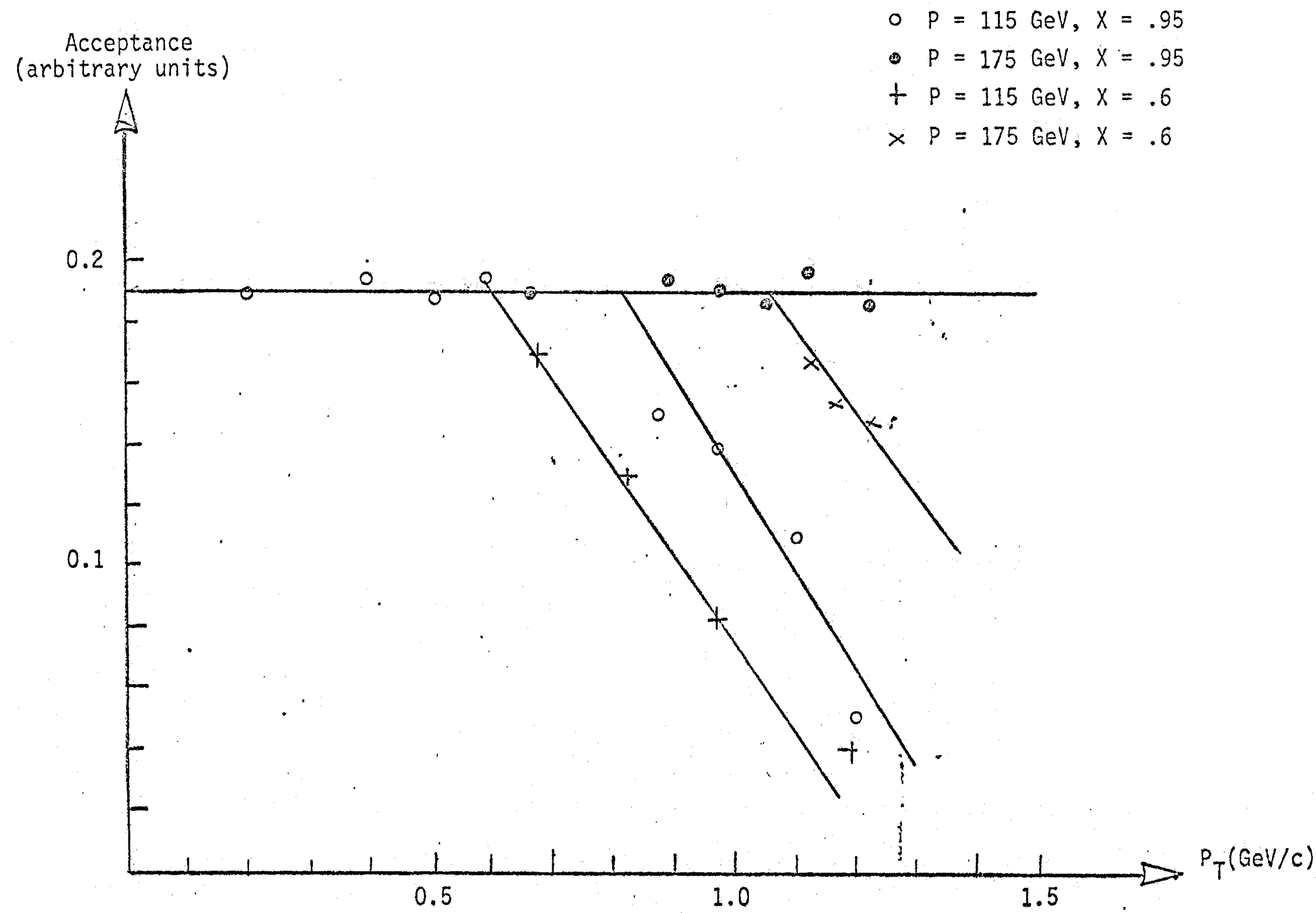
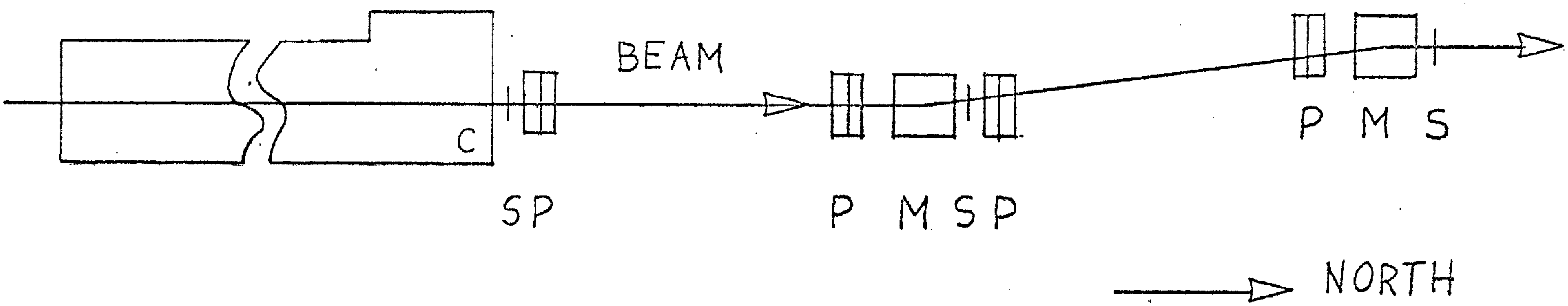


ESTIMATED ACCEPTANCE FOR $\Lambda \rightarrow \pi^- + p$

FIG 1

p. 1980

C CERENKOV COUNTER
S SCINTILLATION COUNTER
P (x,y) PWC
M 1.5-5-120 EPB MAGNET



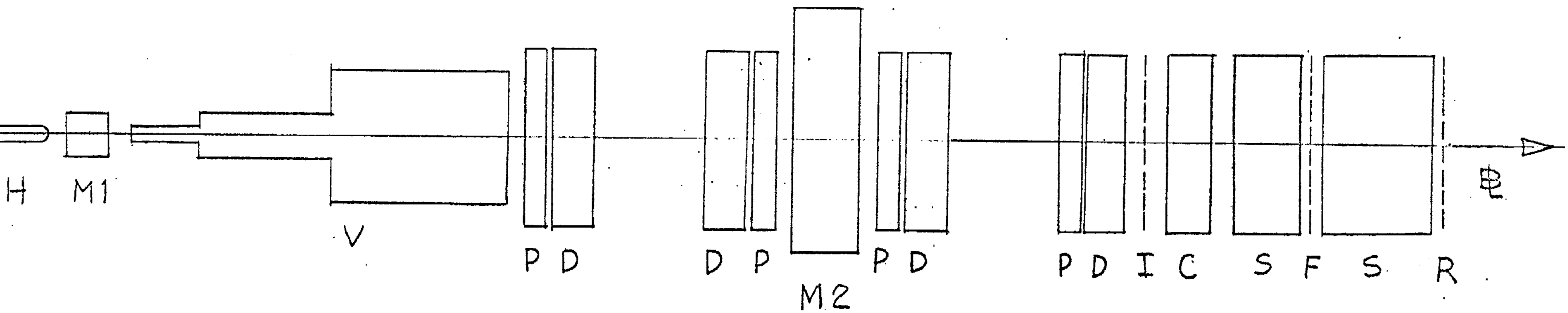
E-585 BEAM SPECTROMETER

FIG. 2

SEP 1980

DOWNSTREAM SPECTROMETER

(PROPOSED CONFIGURATION)



H	HYDROGEN TARGET
M1	SWEEPING MAGNET
V	VACUUM DECAY PIPE
P	PROPORTIONAL WIRE CHAMBER (X,Y)
D	DRIFT CHAMBER (X,X',Y,Y',U,U',V,V')
M2	ANALYSIS MAGNET
I	INTERACTION COUNTERS
C	SHOWER CALORIMETER (NOT USED)
S	STEEL
F	FRONT MUON COUNTERS
R	REAR MUON COUNTERS

SEP 1980

FIG. 3

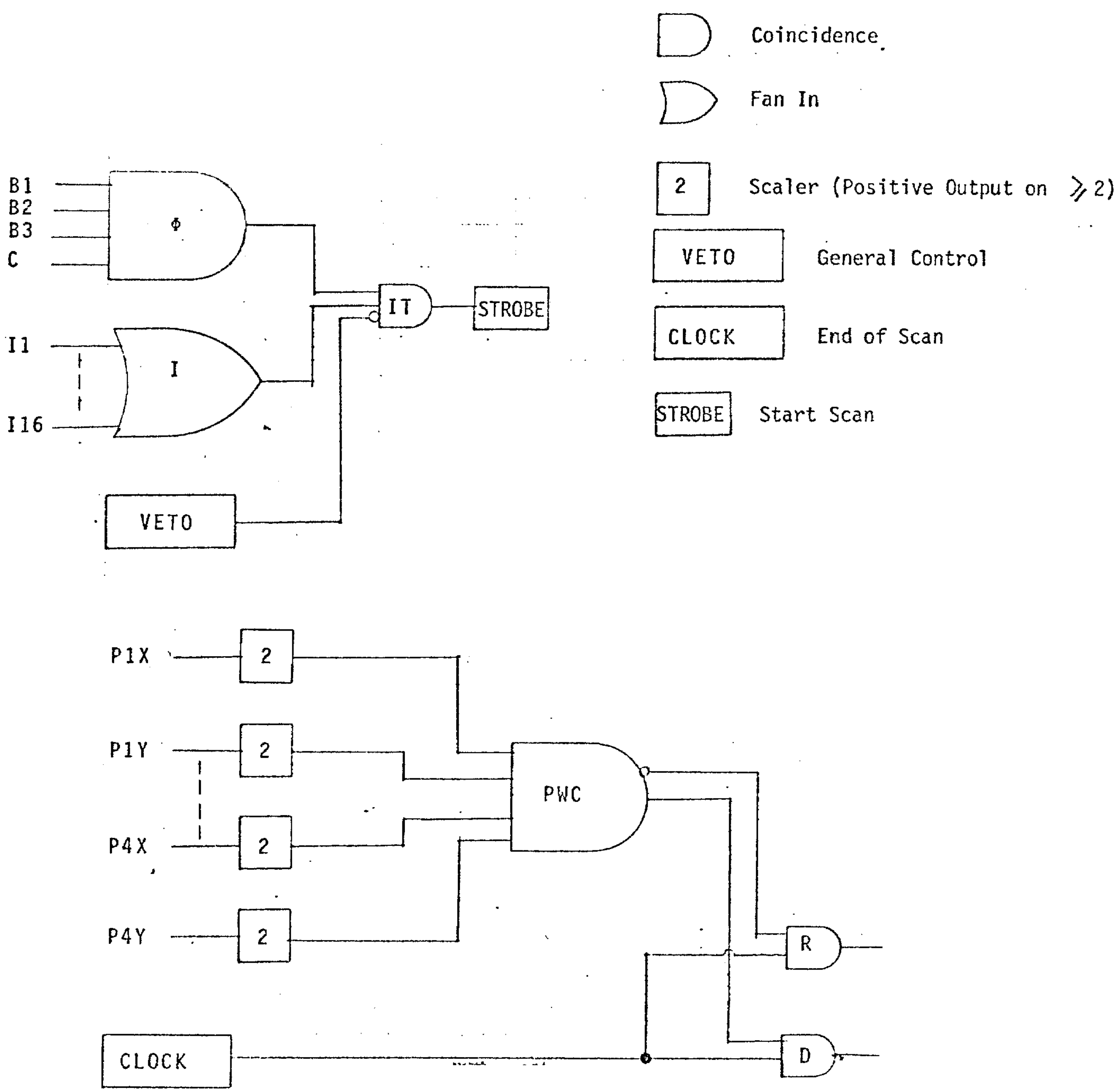


FIG. 4

EXAMPLE OF TRIGGER LOGIC

(Here we require at least two hits in each of the eight PWC planes)

B1,B2,B3	Beam Counters	Φ	A beam particle is present
C	Cerenkov Counter	IT	An "interaction" occurred
I1,...I16	Interaction Counters	R	No data, reset
P1X...P4Y	PWC Wire Scan	D	Data, write on tape