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PROPOSAL TO SEARCH FOR LONG LIVED PARTICLES AT NAL

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by

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Abstract:

The purpose of this proposal is to use a large acceptance, high mass resolution pair spectrometer to search for two body and three body decays of long-lived particles up to the mass of 10 GeV, down to a cross section of 10^{-34} cm^2 with a mass resolution of σ = 5 MeV. The simplest way to accomplish this is to move our Brookhaven spectrometer to a slow extracted beam at FNAL without any modification of the detector.

MOTIVATION:

Since the discovery of the J particle there have been many explanations. The most attractive ones have been those proposed by Ben Lee [1], S.L. Glashow [2], and by C.N. Yang and T.T. Wu [3], C.G. Callan and S.B. Treiman [4]. Basically the theories can be classified into two groups, those using the symbol J and those using other symbols.

Independently of theory one can ask the following important experimental questions:

1. Are there long-lived particles which have the quantum numbers 0^+, 2^+, 3^- etc. and which decay into pp, K^+K^-, etc., but not to e^+e^-?

2. Are there long-lived baryon states π^-p, K^-p, etc.?

3. Are there long-lived strange mesons $K^+\pi^-$, $K^-\pi^+$, etc.?

4. Are there charged J particles, such as $J^+ \to e^+K^+e^-$ or $J^- \to e^-K^-e^+$, which would show up as a threshold cutoff in mass at m_{J^+} when we detect e^+K^+ in coincidence?

5. Are there really charmed particles which decay to Ke ν, which will also distinguish themselves with a cutoff behavior at the mass m_J when we detect Ke in coincidence?

By the end of July we will have results from our Brookhaven experiment to answer part of these questions down to a level of 10^{-34} cm^2 and kinematically up to a mass of 5.5 BeV. However, with a 30 BeV incident beam, phase space considerations will limit us to about 4 BeV mass.

By moving the detector to Fermi Lab, using a 300 BeV proton beam we will improve the sensitivity in the mass to 10 GeV, and experience indicates that at higher energy it is very likely that the J-like particles will have a much higher production cross section.

The parton model calculation of Gunion [5] shows that $J \to e^+e^-$, and charmed particles production at Fermi Lab can be three orders of magnitude higher than at BNL. The old thermodynamical model of Hagedorn also predicts a large increase of yields of these heavy particles at higher energies.

DESIGN CONSIDERATIONS:

In choosing the best kinematic region to detect the decay of new particles, one notes that at high energies, inclusive production of ρ,π and ω from p-p interactions can all be described in the c.m. system by a dependence of the form

$$\frac{d^3\sigma}{dp_{\parallel}^* \, dp_{\perp}^{*2}} = \frac{ae^{-bp^*}}{E^*}, \text{ independent of } p_{\parallel}^*$$

Thus the maximum yield will occur when the particle is produced at rest in the center of mass. If we look at the 90° decay of the x^+y^- pair, we note that they emerge at an angle $\tan\theta = \frac{1}{\gamma}$ in the lab. system. For an incident proton energy of 300 GeV, θ = 79 mr independent of the mass of m_J.

In moving the spectrometer from a 30 GeV accelerator to a 300 GeV accelerator we note the following compensating factors on acceptance and resolution:

a. For fixed bending power of the spectrometer, to keep the same mass resolution at high energies, we need better spatial resolution. This means we need to put our detector farther away from the magnet bending center and from the target.

b. To keep the same center of mass acceptance, the larger γ factor at higher energies means we can place the detector farther away from the target.

EXPERIMENTAL SET UP:

Since we propose to move all the equipment of the BNL experiment to Fermi Lab, we present here a simple description of the Brookhaven set up, shown in Fig. 1. This spectrometer has the following properties:

a. Bending is done vertically to decouple angle and momentum.

b. C_π and C_K are large threshold Cerenkov counters with thin mylar windows. The walls of the counters are black inside and light is collected with 1.5 m diameter elliptical mirrors, 3 mm thick.

These Cerenkov counters have been extensively calibrated to be 100% efficient over the whole phase space region (Fig. 2). Special high gain, high efficiency phototubes of the type RCA C31000M were used to enable us to see single photoelectron peaks.

c. To be able to handle a high intensity of 2×10^{12} protons/pulse, with consequent single arm rates of approximately 20 MHz, there are 11 planes of proportional chambers, totalling 4,000 wires on each arm, rotated 20° with respect to one another (shown in Fig. 3) to reduce multi-track ambiguities.

d. Behind A and C chambers, there are two planes (8x8) of hodoscopes, 1.6 mm thick, to improve time resolution. The point target and vertical hodoscope combinations A and C form straight lines, enabling us to reject scatterings from the edges of the magnets. The hodoscope and chamber combination enable us to sort out 8 tracks per arm.

e. At the end of the spectrometer here are two orthogonal banks of lead glass counters of three radiation lengths each. The first contains 12 elements, the second 13. These are followed by one horizontal bank of 7 lead-lucite shower counters, each 10 radiation lengths thick. These are used to identify electrons.

f. To improve the rejection against $\pi^{o}\to\gamma e^{+}e^{-}$, a very directional Cerenkov counter C_B was placed close to the target and below a specially constructed magnet M_o (Fig. 4). This counter is painted black inside and is sensitive to electrons of 10 MeV/c and pions above 2.7 GeV/c. The coincidence between C_B and C_o, C_e, the shower counters and the hodoscopes indicates the detection of an $e^{+}e^{-}$ pair from the process $\pi^{o}\to\gamma e^{+}e^{-}$, and such events are rejected. A typical plot of the relative timing of this coincidence is shown in Fig. 5. Conversely, one can trigger on C_B and provide a pure electron beam to calibrate C_o, C_π and the shower counters.

g. The resolution of the spectrometer is $\pm$ 5 MeV as shown in Fig. 6.

To move the spectrometer to a 300 GeV beam at NAL we preserve all the properties of the spectrometer discussed above and build no new detectors. The proposed new setup is shown in Figs. 7 and 8.

Comparison of Figs. 7 and 8 with Fig. 1 shows that to have the same solid angle as at BNL ($\Delta\theta^* = \pm\ 4^\circ, \Delta\phi^* = \pm\ 8^\circ$), we can move the detectors back by a factor of 3 - the relative ratio of the γ factor - with the opening angle now being 79 mr. Bending is accomplished by three standard NAL magnets BM109 shimmed down to a 7" gap to provide a field of 22 kiloGauss. We also enlarge the tank of the C_π Cerenkov counters by replacing the existing tube with a longer tube.

The acceptance of the spectrometer is shown in Fig. 9. It has a $\Delta M = 3.0$ BeV, $\Delta\theta^* = \pm\ 6^\circ, \Delta\phi^* = \pm\ 8^\circ$.

To cover the mass region from 2 to 10 GeV we need three magnet settings. This is because particle identification from the Cerenkov counters requires different pressures as shown in the following table:

Settings	high P (GeV)		medium P (GeV)		low P (GeV)	
	$25<<P_\pi<70$	$45<P_K<60$	$20<P_\pi<50$	$27<P_K<45$	$11<P_\pi<35$	$17<P_K<30$
operating conditions (atm,gas)	C_π $(0.7, H_e)$	C_K $(0.89, H_2)$	C_π $(1.38, H_e)$	C_K $(1.57, H_2)$	C_π $(0.72, H_2)$	C_K $(0.70, C_2H$
no. of photo-electrons	≥ 7	≥ 7	≥ 7	≥ 7	≥ 7	≥ 7

To reduce multiple scattering, we do not introduce new material in the spectrometer, and the following table lists the total amount of material along each arm.

Material in the spectrometer

		thickness in radiation lengths	distance from C counter
1.	target 70 mil Be	2.5×10^{-3}	1400"
2.	700" of H_e gas		
3.	8 mil H film		
4.	6 mil mylar for A_o chamber 6 mil for A chamber	2.4×10^{-3}	750"
5.	16 mil C_K front window		
6.	3.2 mm scintillator for A hodoscope	7.6×10^{-3}	700"
7.	150" of H_2 gas in C_K		
8.	16 mil mylar window for C_K back window		
9.	16 mil of mylar window for C_π front window	2.8×10^{-3}	500"
10.	500" of H_2		
11.	16 mil of mylar window for C_π back window		10"
12.	3.2 mm scintillator for C counter		0

RESOLUTION:

From the table above one can easily calculate the mass resolution of the detector as shown in the following table:

m_J (GeV)	$\frac{\delta p}{p}$	$\frac{\delta \theta}{\theta}$	$\frac{\delta m}{m}$	δm
2	1.9×10^{-3}	1.9×10^{-3}	1.9×10^{-3}	$\pm$ 4 MeV
4	1.2×10^{-3}	1.0×10^{-3}	1.1×10^{-3}	$\pm$ 4 MeV
8	10^{-3}	7.0×10^{-4}	9.0×10^{-4}	$\pm$ 7 MeV

SENSITIVITY:

The sensitivity of searching for a very narrow resonance is dominated by two kinds of background:

a. Random coincidences from single arm rates. To estimate this we used the published inclusive yields from the NAL and ISR [6].

b. Genuine non-resonant correlated pairs. We estimated this background from the correlation measurements from CERN. For a mass of 3 GeV or less we used our own measurement at BNL. We note that this background is much smaller than the single arm accidental coincidences.

In calculating the sensitivity we have used a point Be target in an external beam, which gives 10^9 to 10^{11} interacting protons per pulse. The following table gives some more details of the steps followed for the calculations and the resulting sensitivities.

Momentum Setting	High P	Medium P	Low P
P range (GeV/c):	$45<P<60$	$27<P<45$	$17\leq P<30$
M range (GeV)	$7<M<9.5$	$4<M<7$	$2.6<M<4.7$
Interacting Proton/pulse	0.5×10^{11}	10^{10}	0.3×10^{10}
Positive charged particle flux	0.25×10^6	6×10^5	0.7×10^6
Negative charged particle flux	10^5	2×10^5	0.3×10^6
Expected total pair rate/pulse (Random pairs in parenthesis)	2.5 (25)	19. (120)	110 (210)
Expected pair rate per 10 MeV Bin	at 6.4 GeV 0.05/pulse	at 4.8 GeV 0.7/pulse	at 3.4 GeV 0.8/pulse
Expected pair rate in 400 hours	13000	2×10^5	2×10^5
No. of events at 5σ	600	2000	2000
Sensitivity limit on σB for $\Gamma<10$ MeV			
$\pi^+\pi^-$	1.5×10^{-34}	2×10^{-33}	6×10^{-33}
$k^+\bar{p}$	$\sim 3 \times 10^{-35}$	$\sim 4 \times 10^{-34}$	$\sim 1.5 \times 10^{-33}$
$\bar{p}\,p$	$\sim 5 \times 10^{-35}$	$\sim 6 \times 10^{-34}$	$\sim 3 \times 10^{-33}$
$k\,\bar{k}$	$\sim 5 \times 10^{-35}$	$\sim 6 \times 10^{-34}$	$\sim 3 \times 10^{-33}$
$k^+\pi^-$	$\sim 1 \times 10^{-34}$	$\sim 2 \times 10^{-33}$	$\sim 3 \times 10^{-33}$
k^-p	$\sim 8 \times 10^{-35}$	$\sim 1 \times 10^{-33}$	$\sim 1 \times 10^{-33}$
e^-e^+	$\sim 5 \times 10^{-36}$	$\sim 2 \times 10^{-35}$	$\sim 6 \times 10^{-35}$
3 Body Decay			
$\Gamma = 1000$ MeV			
$J^+ \rightarrow (k^+e^+)e^-$			
$D \rightarrow (k^+e^-)\nu$	$\sim 3 \times 10^{-35}$	$\sim 2 \times 10^{-34}$	$\sim 3 \times 10^{-34}$

For e^+e^- the backgrounds from hadrons and $\pi^0\pi^0$ are negligible. We take 20 events peak in 10 MeV as a new particle.

LOGISTICS:

We are taking data on hadron pairs at a mass of 2 to 4 GeV at BNL. The data, though preliminary, shows highly suggestive structures. We will finish this experiment by April of this year.

At this point we will have two alternatives:

a. Move the detector to NAL, which we estimate will take two months. This will enable us to set up very quickly at NAL and be ready for data taking by summer.

b. Stay four more months at BNL to gather more data at low energy. Then our data taking at NAL would be delayed to late fall.

We request 1200 hours of running plus 200 hours of beam tuning.

We plan to bring all our detectors, including our two special M_0 magnets. We will need help from Fermi Lab. on the following items:

a. PDP 11/45 with a RK05 disk, a BD11 CAMAC interface, and a DR11B chamber readout system, and fast 9-track tape units - the last item being optional.

b. 100 channels of CAMAC scalers, and 80 channels of time of flight and 80 channels of ADC units.

c. Ordinary triggering logic - 100 channels of discriminators and 20 coincidence units. Part of these items may be provided by us.

d. Two 500 inch x 50 inch diameter tanks capable of standing vacuum, with the ends machined to a few microns for window mounting. We will provide the window flanges.

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3. T.T. Wu and C.N. Yang, Phys. Rev. Lett., Vol. 34, p. 49, 1975.
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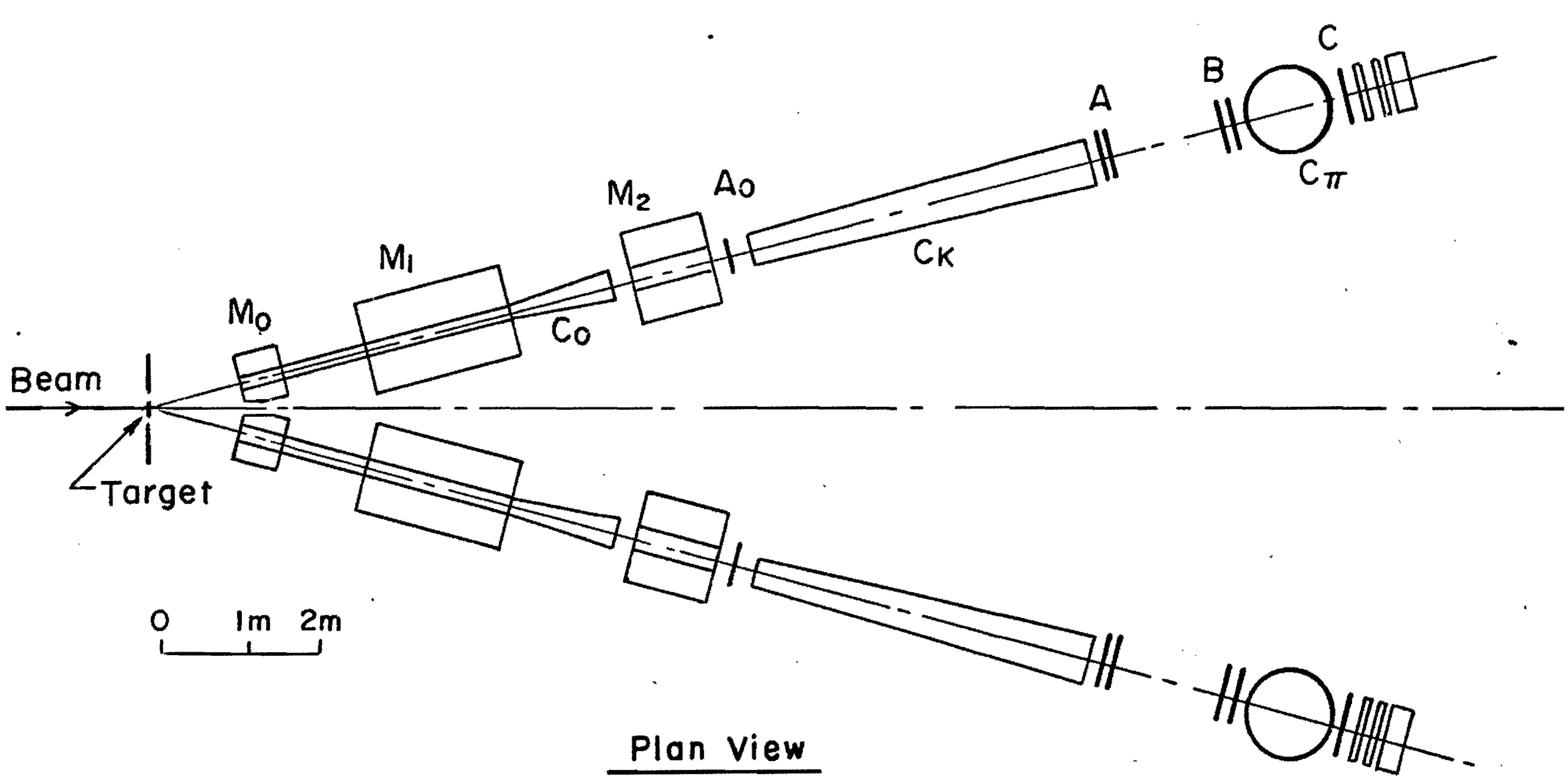
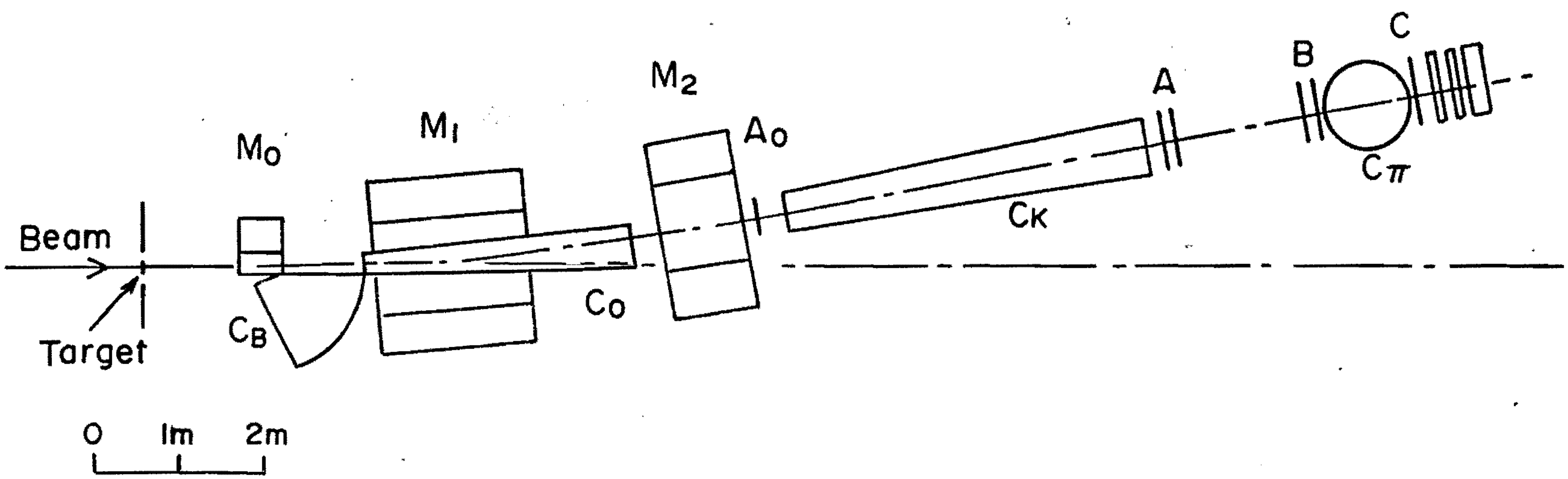
5. Gunion, private communication. R. Hagedorn, CERN report No. 71-12.
6. B. Alper et al., Phys. Lett. 44B, 521 (1973),
   F.W. Buesser et al., Int. Conf. on New Results from Experiments on High Energy Particle Collision, Vanderbilt University, 1973,
   J.W. Cronin et al., Phys. Rev. Lett., Vol. 31, P. 1426, 1973.

FIGURE CAPTIONS:

1. Schematic view of pair spectrometer at Brookhaven.
2. Typical efficiency map for Cerenkov counter.
3. Configuration of wire planes in proportional chambers of each arm.
4. Small pair spectrometer used to measure $\pi^{0} \rightarrow \gamma e^{+}e^{-}$.
5. Coincidence of C_B counter and the main spectrometer. The peak in the time of flight spectrum shows the detection of $\pi^{0} \rightarrow \gamma e^{+}e^{-}$.
6. The width of the J particle, measured by our spectrometer.
7. Plan view of the proposed spectrometer at NAL. All the detectors will be those of Fig. 1.
8. Side view of the NAL spectrometer.
9. Typical acceptance window.

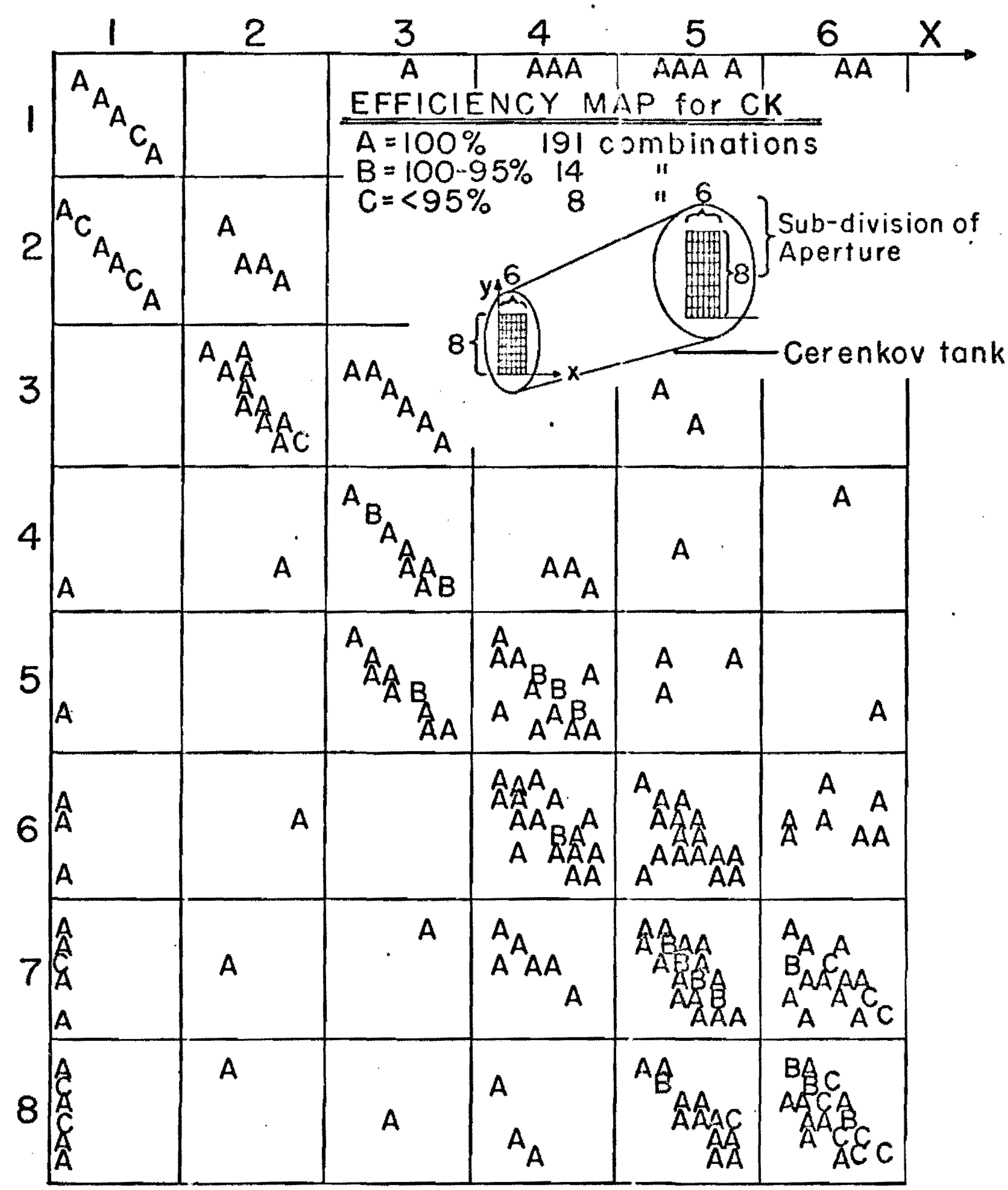


Plan View



Side View

Figure 1



1 2 3 4 5 6 X
EFFICIENCY MAP for CK
A=100% 191 combinations
B=100-95% 14 "
C=<95% 8 "
Sub-division of Aperture
Cerenkov tank

Figure 2

Configuration Of Wire Planes In Proportional Chambers

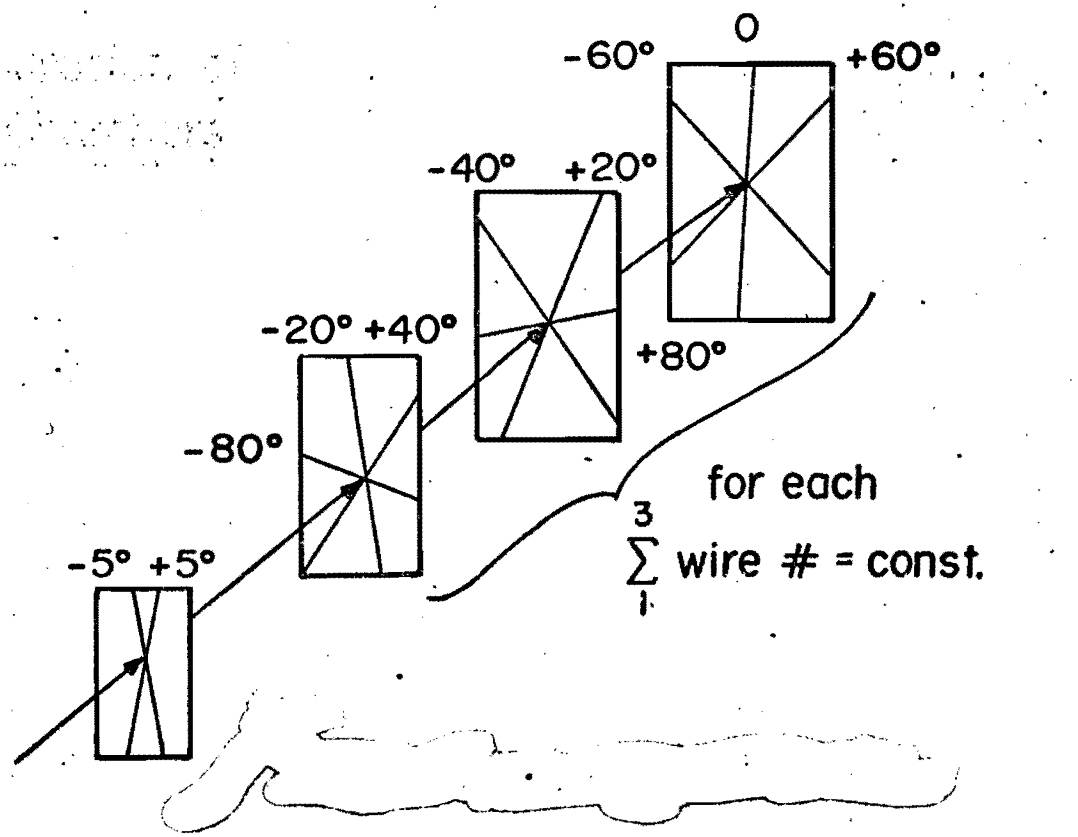
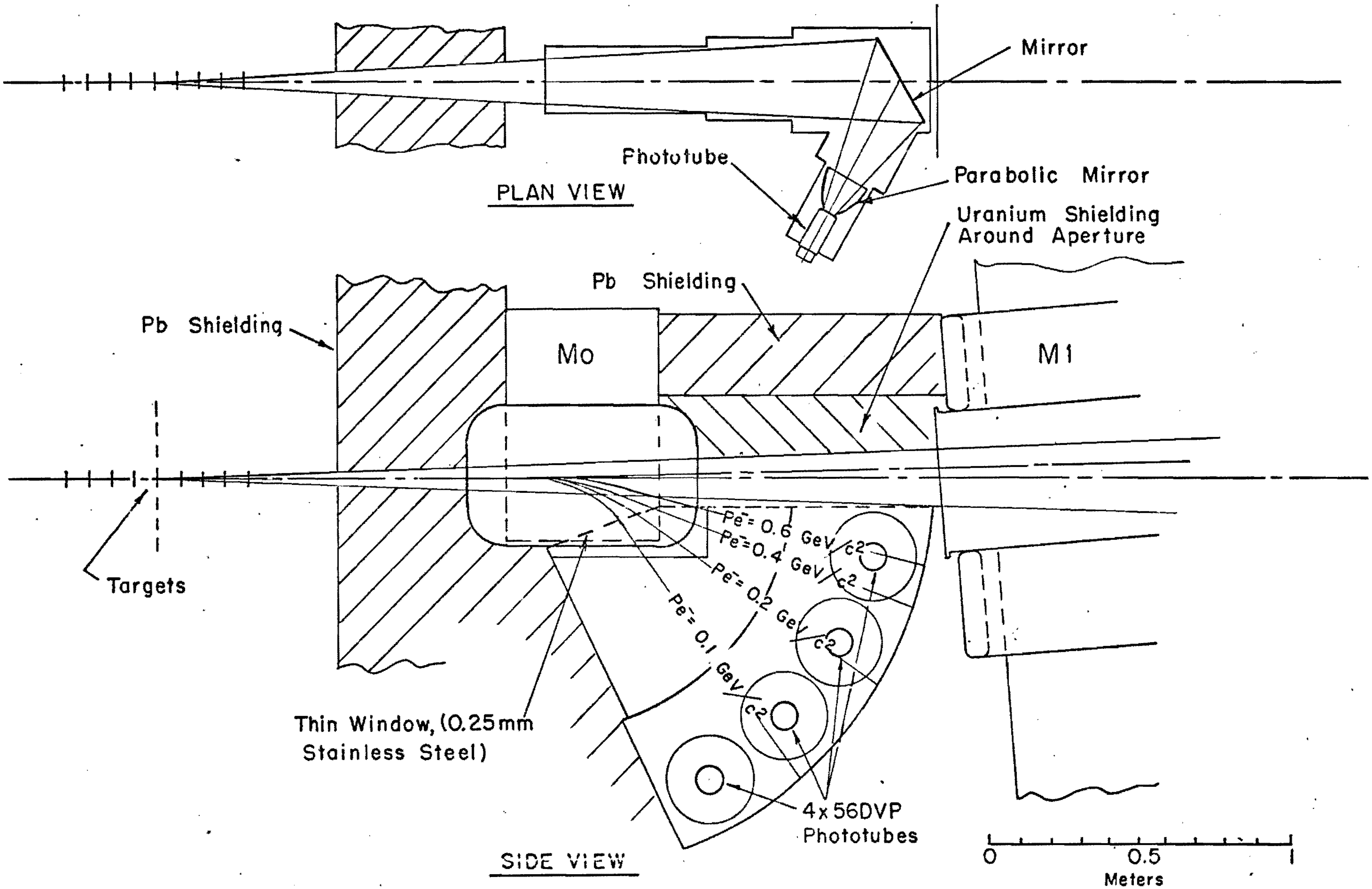


Figure 3



Mirror
Phototube
Parabolic Mirror
PLAN VIEW
Uranium Shielding Around Aperture
Pb Shielding
Pb Shielding
Mo
M1
Targets
Pe⁻= 0.6 GeV/c2
Pe⁻= 0.4 GeV/c2
Pe⁻= 0.2 GeV/c2
Pe⁻= 0.1 GeV/c2
Thin Window, (0.25mm Stainless Steel)
4x56DVP Phototubes
SIDE VIEW
0
0.5
1
Meters

Figure 4

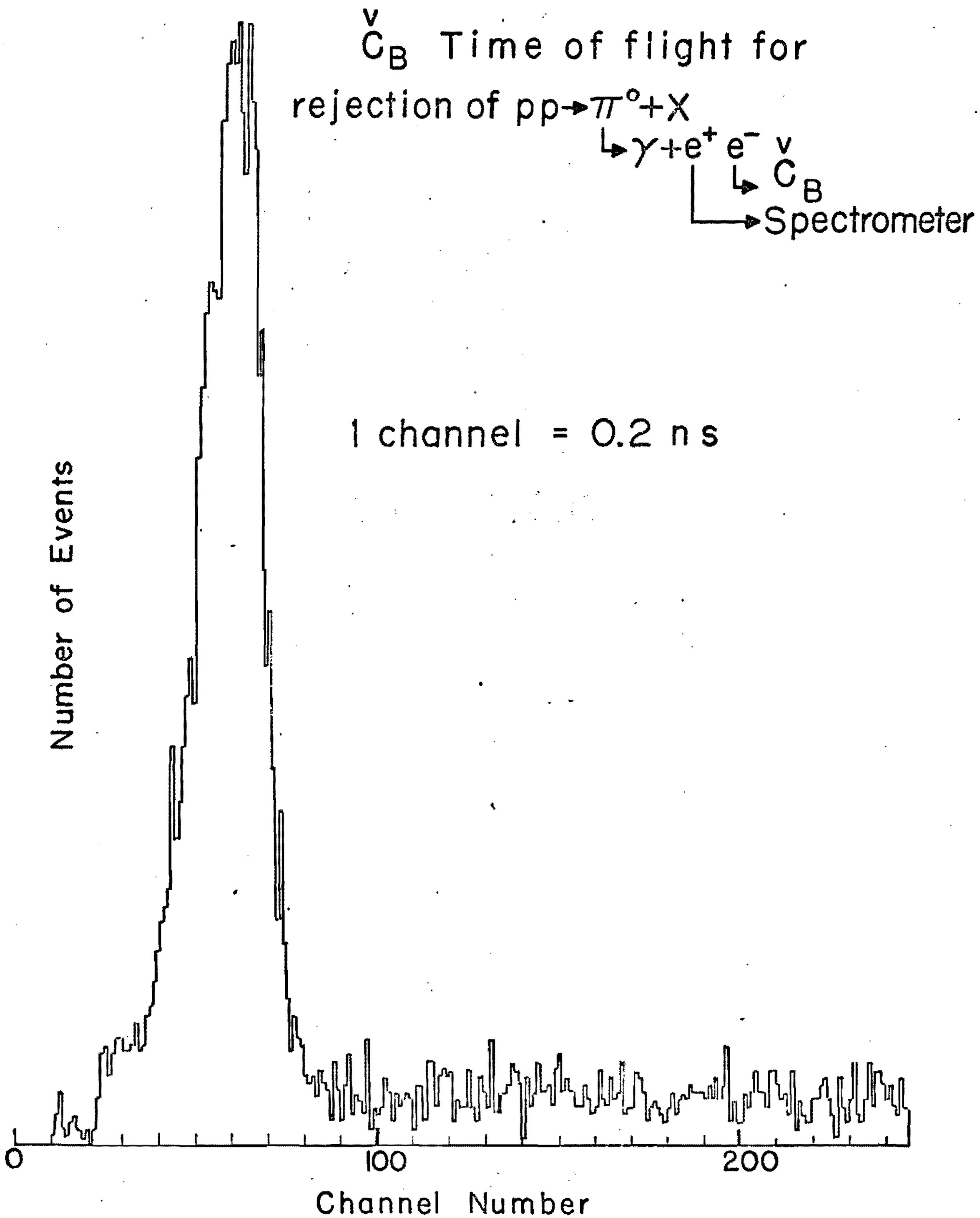
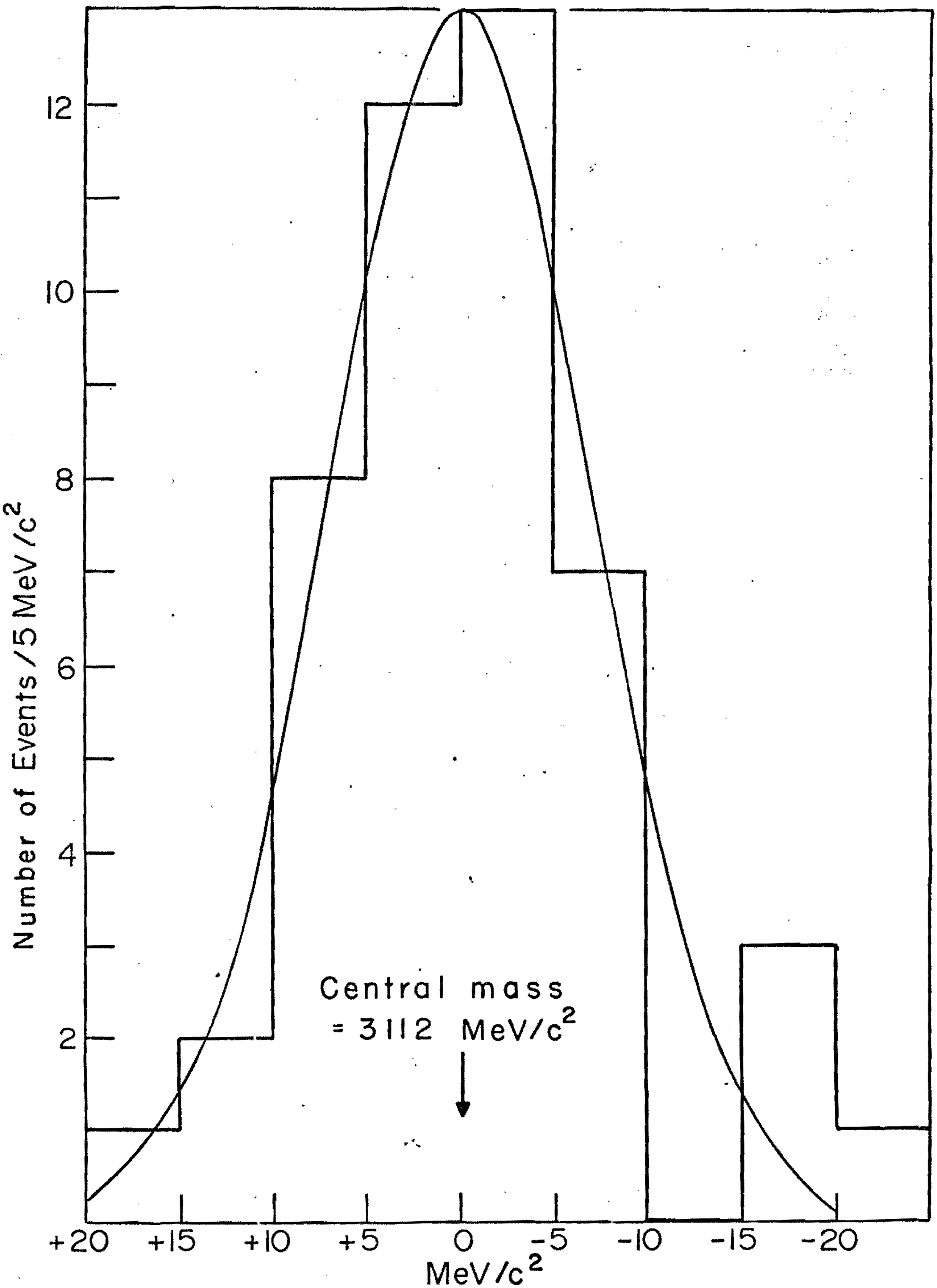

$\check{C}_B$ Time of flight for
rejection of $pp \to \pi^0 + X$
$\hookrightarrow \gamma + e^+ e^-$
$\hookrightarrow \check{C}_B$
$\to$ Spectrometer
1 channel = 0.2 ns
Number of Events
0
100
200
Channel Number

Figure 5



Number of Events / 5 MeV/c²
12
10
8
6
4
2
Central mass
= 3112 MeV/c²
+20
+15
+10
+5
0
-5
-10
-15
-20
MeV/c²

Figure 6

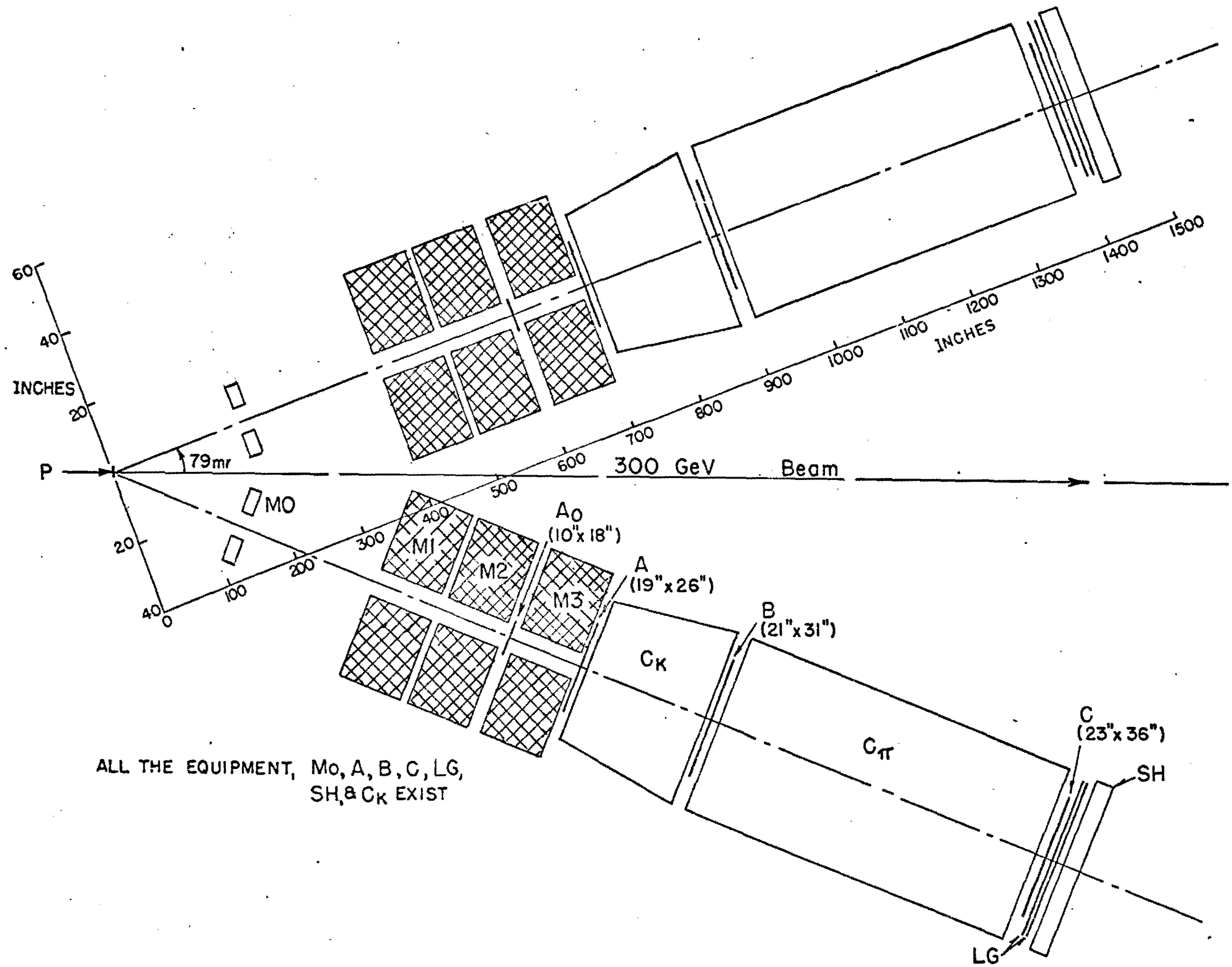
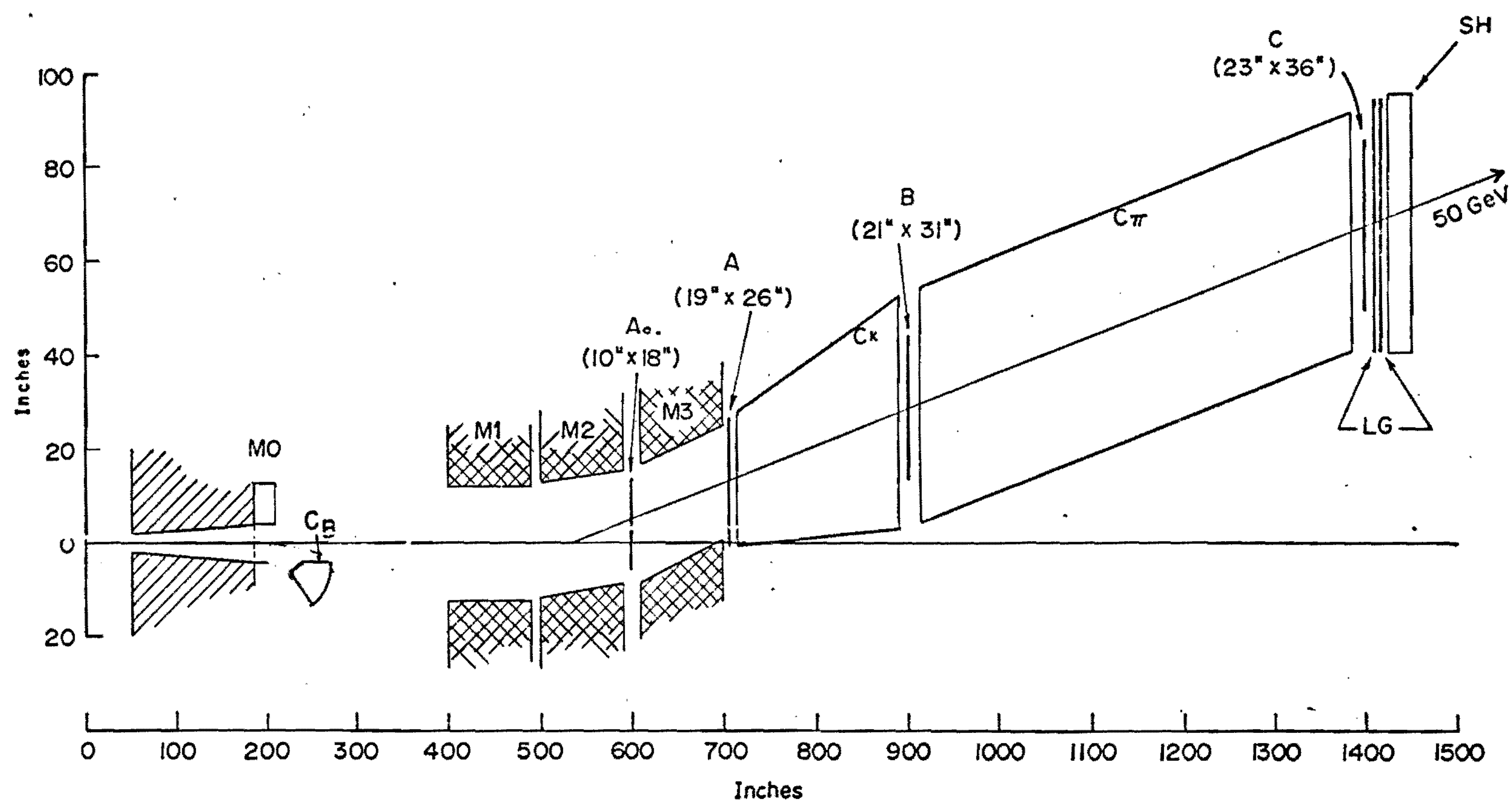
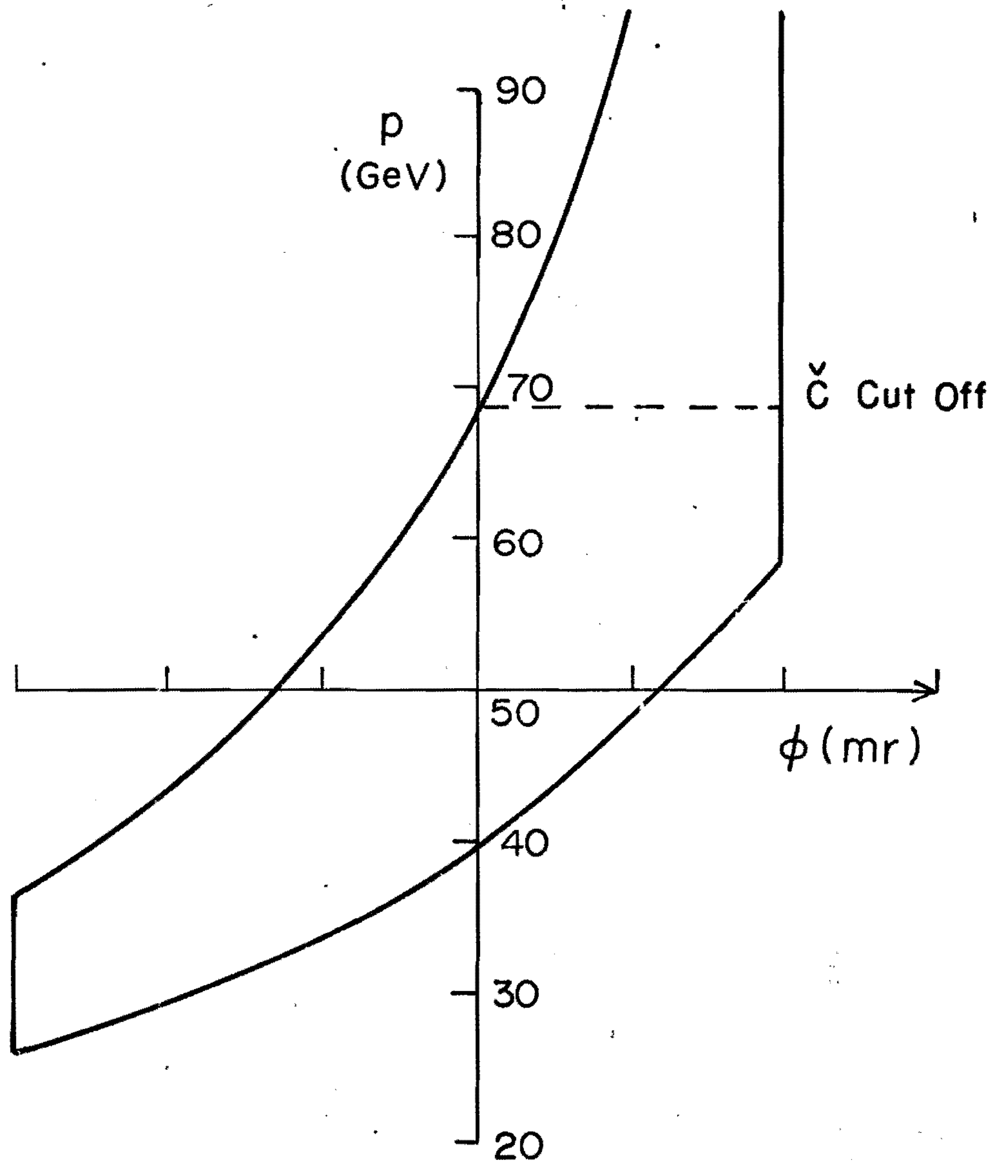

60
40
INCHES
20
20
40
P
79mr
MO
300 GeV
Beam
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
INCHES
M1
M2
M3
A_0
(10"x 18")
A
(19"x 26")
B
(21"x 31")
C_K
C_π
C
(23"x 36")
SH
LG
ALL THE EQUIPMENT, Mo, A, B, C, LG,
SH, & C_K EXIST

Figure 7



100
80
60
40
20
0
20
Inches
M0
C_B
M1
M2
M3
A_o
(10" x 18")
A
(19" x 26")
C_K
B
(21" x 31")
C_π
C
(23" x 36")
SH
50 GeV
LG
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Inches

Figure 8



p ~ φ Acceptance window for high mass run

Figure 9