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Scientific Spokesman:
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NUCLEAR-SIZE DEPENDENCE OF SINGLE-SPIN ASYMMETRIES IN HIGH-p_T HADRON PRODUCTION

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Summary

We are presenting a proposal to search for spin-dependent effects in high-p_T hadron production with nuclear targets. This experiment will use the Meson Lab polarized beam and will consist of two phases:

A. observation of single high-p_T hadrons with a magnetic spectrometer.

B. observation of high-p_T hadron jets with a scintillator calorimeter.

The left-right asymmetry A_N observed when the transverse beam polarization is reversed from up to down will be measured. Its variation as a function of nuclear size will provide new information on the short-time-scale behavior of hadronic constituents.

Physics Justification

The observation of anomalous A-dependence in high-p_T hadron production was unexpected, and the phenomenon still lacks a clear theoretical understanding. First observed in inclusive single-hadron production from nuclear targets[1], an A-dependence exponent $\alpha > 1$ has also been measured for inclusive pair production[2] and jet-like events.[3] Various models have been proposed to explain these results. Most of them can be divided into two categories:

1. Multiple-scattering models. After an initial hard pp collision, some unit of hadronic matter (jet, quark, etc.) undergoes further collisions on its way through the nucleus. The relatively small A-dependence of average multiplicity implies that this matter does

not behave like a free hadron.[4] This result is consistent with calculations of the minimum time needed for a hadronic constituent to develop into free particles.[5] One QCD-based model explains anomalous A-dependence as the high probability of gluons to scatter repeatedly inside the nucleus because of the triple-gluon coupling.[6]

2. Flux-tube models. In these models, the beam proton interacts simultaneously with some collection of particles within the nucleus, which is more massive than a single nucleon.[7,8] The enhancement of large-p_T production results from the change in kinematics.

The second class of models has no direct connection with QCD; however, there is an obvious relation between class (1) models and jet fragmentation functions. More experimental information is needed to indicate what kind of process is responsible for the anomalous A-dependence.[9]

Another unexpected effect has been the large size of polarization effects (that is, single-spin asymmetries) in high-energy hadron collisions - in particular, the polarization of inclusive Λ production[10,11] and the transverse spin dependence of high-p_T π° production.[12] According to QCD, single-spin asymmetries cannot arise from a first-order process. Again, the models which have been proposed to account for these large effects are semi-classical in nature.[13]

With the energies available in the Fermilab polarized beam (200-500 GeV), we are in the regime where QCD predicts that lowest-order and highertwist contributions are in competition, particularly for high-p_T single particles.[14] The rise in polarization with p_T seen at CERN may corroborate this idea. We will compare the kinematic dependence of asymmetries with different targets to see whether nuclear size can alter the proportion of these contributions.

A simple model can be developed to illustrate how single-spin asymmetries may be related to nuclear size. We assume that the processes involved in high-p_T collisions are single spin-one gluon exchange and higher-order processes. Single gluon exchange preserves quark helicity while the higher-order terms can flip helicity. A single-spin asymmetry can only arise from the interference between the flip and non-flip terms. Specifically, the imaginary part of the product of spin-flip and non-flip amplitudes, which is proportional to the asymmetry, must be nonzero.

Now consider the interaction of a single quark with the constituents of a nucleus, as shown in Fig. 1. The lowest-order process (I) above would produce a cross section proportional to the total number of constituents in the nucleus, which goes as A^1, so that the amplitude varies as $A^{1/2}$. For the higher-order process (II), the cross section would be proportional to A^2, since the possible ways to couple to the constituents of the nucleus with two gluons goes as A^2. Thus the spin-flip amplitude is proportional to A. Therefore, the intereference term varies as $A^{3/2}$; dividing by a cross section proportional to A yields a single-spin asymmetry which increases as $A^{1/2}$.

Experimental Technique

We propose to make two sets of polarization measurements: jet-like events and high-p_T charged hadrons. The detectors for each of the two phases have been described in separate proposals[11,12] in detail; we quickly review them here. The jet detector is a modular hadron calorimeter of iron-scintillator sandwiches, with large solid angle (see Fig. 2.). The single-particle detector is a pair of high-resolution magnetic spectrometers with drift chambers and Cherenkov counters for full hadron identification in the range $1.4 < p_T < 4.2$ GeV/c around $x_F = 0$ (see Fig. 3.).

The same array of nuclear targets will be used for both phases of the experiment. In order to minimize systematic errors, data will be taken simultaneously from three different target materials, using a segmented target with 10%-interaction-length blocks of Be, Fe, and Pb, separated by 15 cm along the beam line. The interaction point of each event is determined by the intersection point of the beam track with the scattered track(s). The beam track will be measured with a high-resolution hodoscope. The jet detector includes drift chambers for track reconstruction.

With this target arrangement, systematic errors due to beam intensity and detector efficiency drifts are completely canceled in comparing nuclei. Beam polarization will be reversed on a short cycle (< 1/2 hour) to cancel differences in the left and right detector arms. Two factors introduced by the multiple-target system, however, are beam attenuation in the upstream targets and change in detector acceptance due to target z-coordinate. To eliminate these effects (which should not affect an asymmetry measurement in any case), the target array will be reversed periodically.

Rates and Run Plan

Tables I and II show the accuracy which can be reached by the single-pion and jet measurements in relatively short running time. Note that the anomalous A-dependence effect makes a significant improvement in experimental error for the heavier nuclei, especially for the jet phase. It may, however, be necessary to run the jet measurement with a lower beam intensity to keep a manageable trigger rate.

We are planning to use equal interaction lengths for the three targets, in spite of the larger percentage errors for the smaller nuclei, because we assume that these measurements will be part of a broader research program with the polarized beam, including extensive measurements with liquid hydorgen and polarized proton targets. The data from these measurements will pin down the low-A end of the A-dependence plot.

It is assumed that tune-up time for each phase of the experiment will be taken care of by the single-nucleon spin-dependence experiments; therefore setup time is not included in our request:

Single-hadron spectrometer	300 hours
Hadron calorimeter	100 hours
Total	400 hours

REFERENCES

1. L. Kluberg _et al._, Phys. Rev. Lett. 38 670 (1977).
2. R. L. McCarthy _et al._, Phys. Rev. Lett. 40, 213 (1978).
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6. A. Krzywicki, Phys. Rev. D14 152 (1976).
7. S. Fredriksson, Nucl. Phys. B11, 167 (1976).
8. Meng Ta-Chung, Phys. Rev. D 15, 197 (1977).
9. A. Białas, Fermilab-Conf-79/35-THY (general review of theories).
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12. J. Antille _et al._, Phys. Lett. 94B, 523 (1980).
13. G. Gustafson, 1980 Symposium on HEP with Polarized Beams and Polarized Targets (Lausanne).
14. E. L. Berger _et al._, Phys. Rev. D23, 99 (1981).

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Acknowledgement

Our thanks to E. L. Berger for very helpful discussion on the theoretical principles of spin effects.

TABLE I

EXPERIMENTAL ACCURACY FOR SINGLE-PION ASYMMETRY

p_T	Target	# Events	% Error on Asymmmetry
2.9	Be	3.4 E4	1.1
	Fe	6.0 E4	0.9
	Pb	9.9 E4	0.7
3.2	Be	4.1 E3	3.3
	Fe	7.1 E3	2.6
	Pb	1.2 E4	1.9
4.0	Be	795	7.5
	Fe	1390	5.7
	Pb	2320	4.4

Assumptions:

α =	1.1 for all p_T (from Ref. 1)
50%	beam polarization
10%	interaction length for each target element
300	hours beam time (4.3×10^{11} protons)

TABLE II

EXPERIMENTAL ACCURACY FOR JET ASYMMETRY

p_T	Target	% Error on Asymmetry	α
3	Be	0.025	1.3
	Fe	0.016	
	Pb	0.011	
4	Be	0.08	1.5
	Fe	0.04	
	Pb	0.025	
5	Be	0.36	1.62
	Fe	0.17	
	Pb	0.09	
6	Be	1.6	1.75
	Fe	0.7	
	Pb	0.3	
7	Be	8.4	
	Fe	3.5	
	Pb	1.8	

Assumptions:

10% interaction length for each target element
50% beam polarization
100 hours beam time (1.8×10^{11} protons)
Values of α from Ref.3

Figure Captions

Figure 1 Processes used in the simple model.

Figure 2 The jet detector layout in the polarized proton beamline. PPT (polarized proton target) will be replaced by nuclear target tree for this experiment.

P1, 2, 3 - proportional chambers
D1-5 - drift chambers
SCM105 - spectrometer magnet (low-field)
C1 - threshold Cherenkov counter
EC - electromagnetic shower calorimeter
HC - hadron calorimeter modules

Figure 3 Layout of each arm of the two-arm charged-particle spectrometer. Each arm is at 70 mr to the beam line. Coincidence requirements between hodoscopes H1 and H2 impose a minimum momentum requirement, which can be varied from 25 to 50 GeV/c.

PWC1-5 - proportional chambers
DC1-4 - drift chambers
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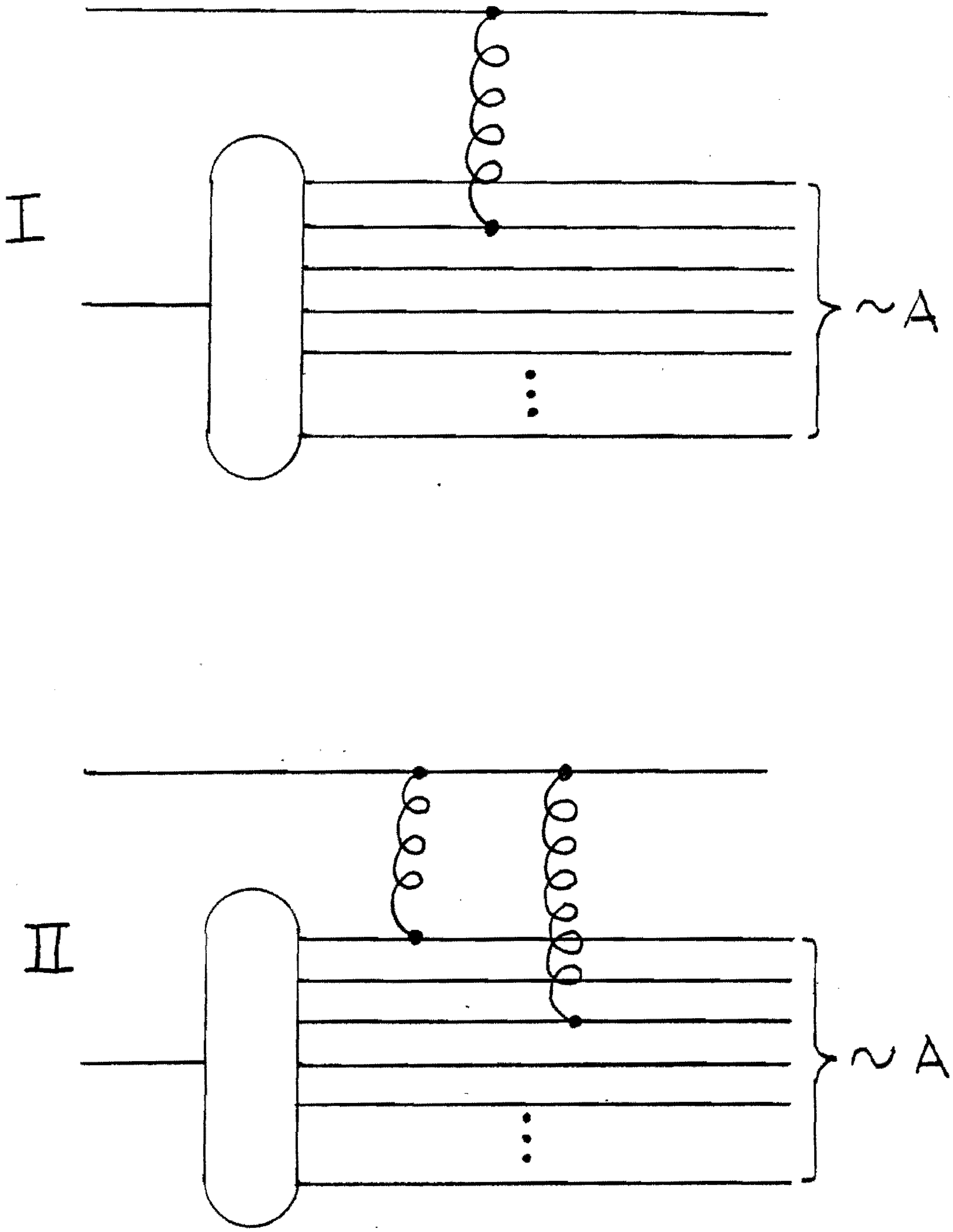
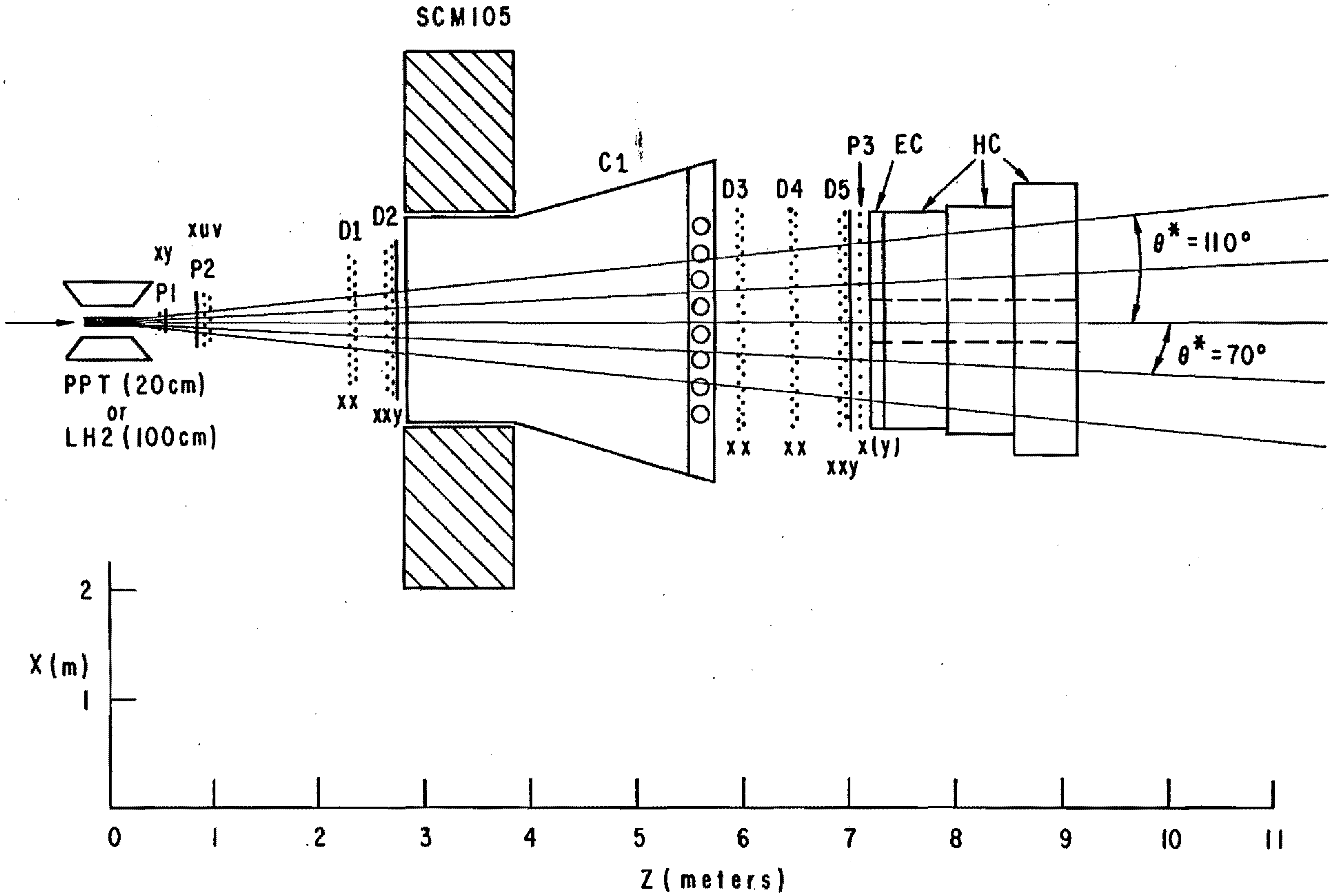


Figure 1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C1
P3
EC
HC
D3
D4
D5
D1
D2
xuv
xy
P2
P1
θ* = 110°
θ* = 70°
PPT (20cm)
or
LH2 (100cm)
xx
xxy
xx
xx
xxy
x(y)
2
X (m)
1
0
1
2
3
4
5
6
7
8
9
10
11
Z (meters)

Figure 2

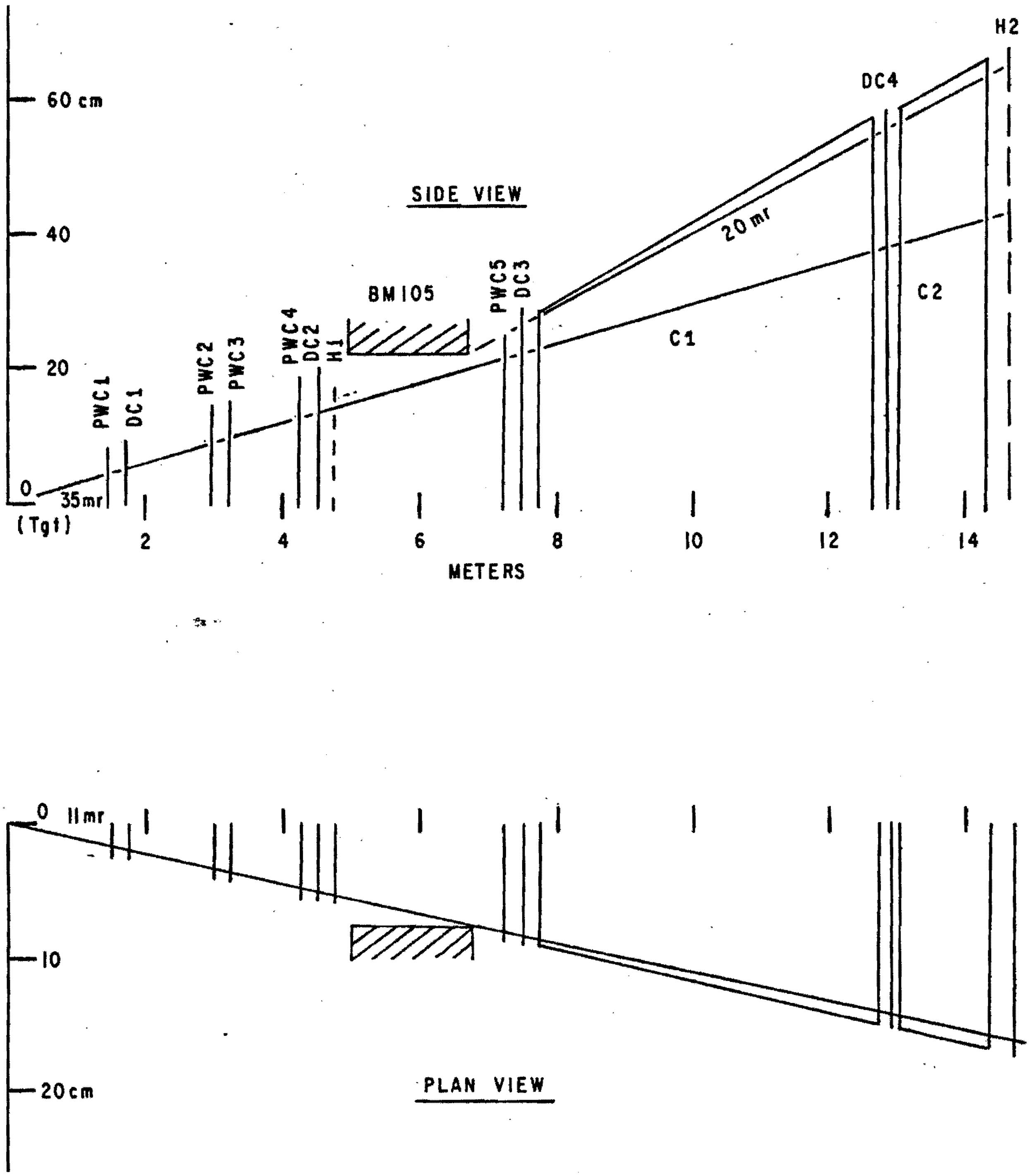
SIDE VIEW
60 cm
40
20
0
(Tgt)
35mr
PWC1
DC1
PWC2
PWC3
PWC4
DC2
H1
BM105
PWC5
DC3
20 mr
C1
DC4
C2
H2
2
4
6
8
10
12
14
METERS
PLAN VIEW
0
11mr
10
20cm

Figure 3

FNAL Proposal # 688
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We propose to make two sets of polarization measurements: jet-like high-p_T events and single high p_T charged hadrons. The jet detector will be a modular hadron calorimeter of iron-scintillator sandwiches, with large solid angle. The calorimeter will be described in a proposal to measure two-spin asymmetries with polarized beam and target; a possible layout is sketched in Fig. 2. The rates calculated in the next section assume the configuration and fiducial area of the E-609 calorimeter.

The single-particle detector is a pair of high-resolution magnetic spectrometers with drift chambers and Cherenkov counters for full hadron identification in the range $1.4 < p_T < 4.2$ GeV/c around $x_F = 0$ (see Fig 3). This system is described in detail in Proposal 682. To minimize systematic errors, A-dependence data will be taken simultaneously with three different target materials, using a segmented target with 10%-interaction-length blocks of Be, Fe, and Pb separated by 15 cm along the beam line. The interaction point of each event is determined by the intersection of the spectrometer track with the beam track, which is measured by a high-resolution beam hodoscope.

If the track detectors used with the calorimeter are capable of reconstructing the interaction point, a similar segmented target will be used for the jet measurement, although its total length will be only 0.10 interaction length.

With this target arrangement, systematic errors due to beam intensity and detector efficiency drifts are completely canceled in comparing nuclei. Beam polarization will be reversed on a short cycle (< 1/2 hour) to cancel differences in the left and right detector arms. Two factors introduced by the multiple-target system, however, are beam attenuation in the upstream targets and change in detector acceptance due to target z-coordinate. To eliminate these effects (which should not affect an asymmetry measurement in any case), the target array will be reversed periodically.

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	Pb	9.9 E4	0.7
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	Fe	7.1 E3	2.6
	Pb	1.2 E4	1.9
4.0	Be	795	7.5
	Fe	1390	5.7
	Pb	2320	4.4

Assumptions:

α =	1.1 for all p_T (from Ref. 1)
50%	beam polarization
10%	interaction length for each target element
300	hours beam time (4.3×10^{11} protons)

TABLE II

EXPERIMENTAL ACCURACY FOR JET ASYMMETRIES

p_t	alpha	target	events	error
3	1.3	Be	$2.4\ \mathrm{x}10^{9}$	$4.4\ \mathrm{x}10^{-5}$
		Fe	$4.2\ \mathrm{x}10^{9}$	$3.6\ \mathrm{x}10^{-5}$
		Pb	$6.2\ \mathrm{x}10^{9}$	$2.9\ \mathrm{x}10^{-5}$
4	1.5	Be	$2.6\ \mathrm{x}10^{7}$	$4.4\ \mathrm{x}10^{-4}$
		Fe	$6.5\ \mathrm{x}10^{7}$	$2.7\ \mathrm{x}10^{-4}$
		Pb	$1.2\ \mathrm{x}10^{8}$	$2.0\ \mathrm{x}10^{-4}$
5	1.62	Be	$2.1\ \mathrm{x}10^{6}$	$1.5\ \mathrm{x}10^{-3}$
		Fe	$6.5\ \mathrm{x}10^{6}$	$8.7\ \mathrm{x}10^{-4}$
		Pb	$1.5\ \mathrm{x}10^{7}$	$5.8\ \mathrm{x}10^{-4}$
6	1.75	Be	$1.7\ \mathrm{x}10^{5}$	$5.3\ \mathrm{x}10^{-3}$
		Fe	$6.7\ \mathrm{x}10^{5}$	$2.7\ \mathrm{x}10^{-3}$
		Pb	$1.8\ \mathrm{x}10^{6}$	$1.7\ \mathrm{x}10^{-3}$
7	1.75	Be	$9.7\ \mathrm{x}10^{3}$	$2.2\ \mathrm{x}10^{-2}$
		Fe	$3.8\ \mathrm{x}10^{4}$	$1.1\ \mathrm{x}10^{-2}$
		Pb	$1.0\ \mathrm{x}10^{5}$	$6.9\ \mathrm{x}10^{-3}$

Assumptions:

45% beam polarization
100 hours beam time
values of alpha from Ref. 3
4 grams/cm^2 for each target element (total 0.1 collision length)

Figure Captions

Figure 1 Processes used in the simple model.

Figure 2 The jet detector layout in the polarized proton beamline. PPT (polarized proton target) will be replaced by nuclear target tree for this experiment.

P1, 2, 3 - proportional chambers
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SCM105 - spectrometer magnet (low-field)
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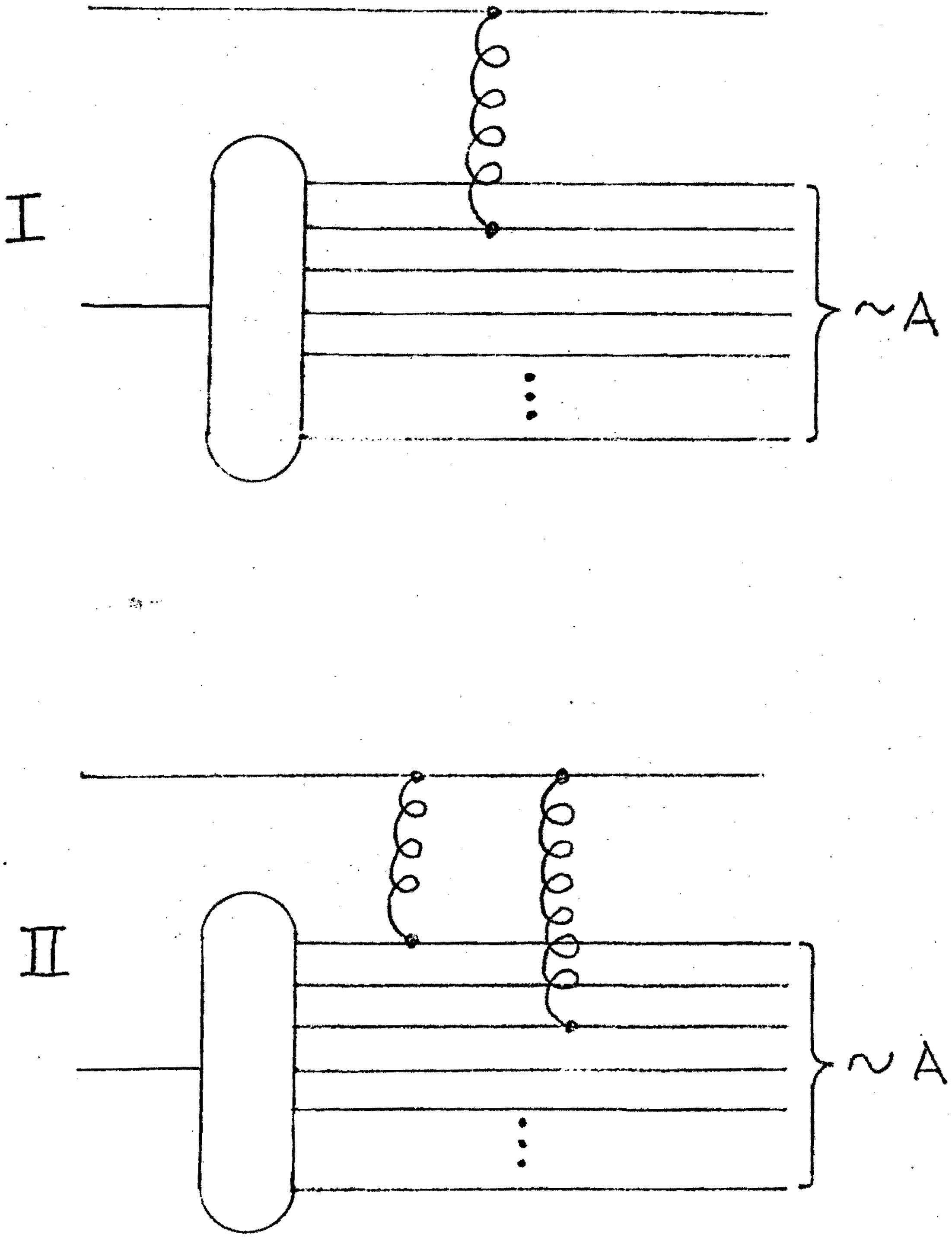
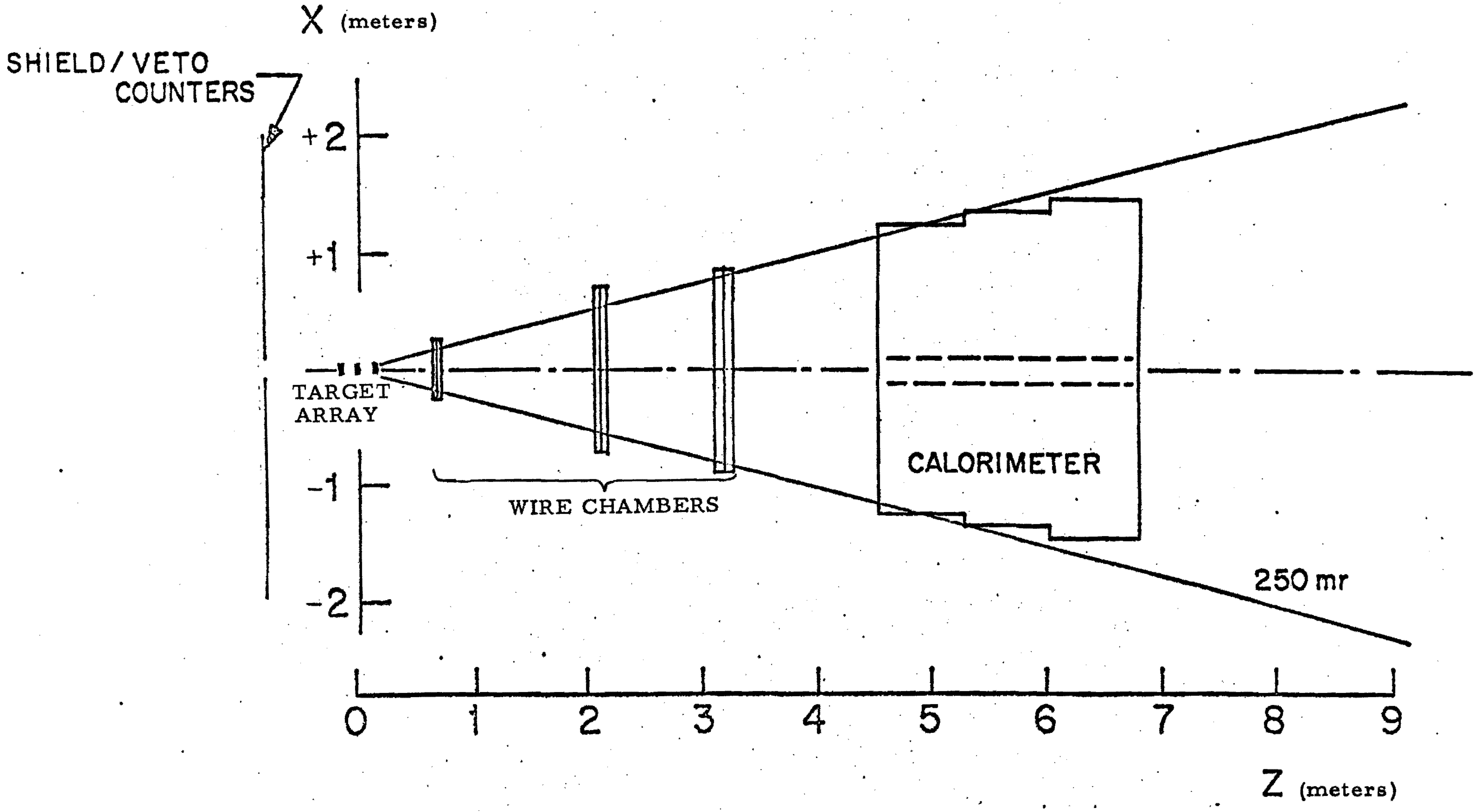


Figure 1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SHIELD / VETO COUNTERS
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+1
-1
-2
TARGET ARRAY
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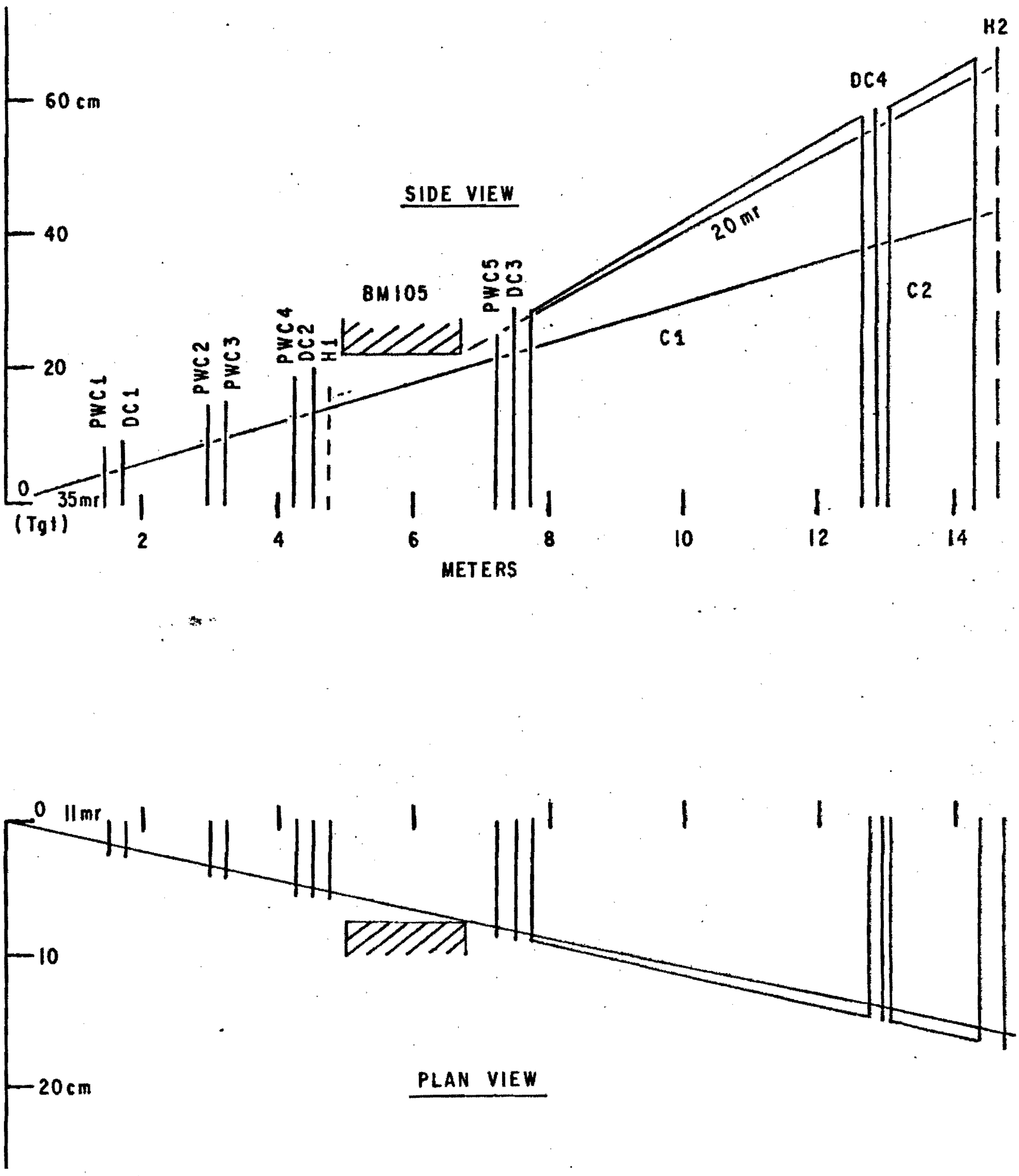
Z (meters)

Fig. 2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(Tgt)
35mr
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DC1
PWC2
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DC4
C2
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8
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14
METERS
PLAN VIEW
0
11mr
10
20cm

Figure 3