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September 30, 1976

Dr. T. H. Groves, Secretary
Fermilab Program Advisory Committee
Director's Office

Dear Tom:

We are enclosing a proposal to measure proton-proton deep elastic scattering in the cms angular range of 40° to 90° at high energies in the proton west area. At the present time the proposal has only four collaborators which we feel is an insufficient number to perform the experiment. We are therefore receptive to discussion about extending our collaboration to include other experimenters with similar interests.

Yours sincerely,

James K. Walker / F. E. Taylor

James K. Walker

JKW:jkd
enc.

13 pgs.

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Proton-Proton Deep Elastic Scattering

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Summary

We propose measuring the differential cross section for p-p elastic scattering in the CMS angular range $40^{\circ} \lesssim \theta^* \lesssim 90^{\circ}$ at high energies.

We will use the halo free P-West proton beam. The apparatus consists of two identical spectrometers, each of which contains two 10' EPB dipoles and scintillation counters. The momentum resolution of 1% and angular resolution of ±0.5 mrad is adequate to eliminate inelastic background. A cross section of $d\sigma/dt \sim 10^{-39} cm^2/(GeV/c)^2$ corresponds to 1 event/day with a 200 GeV beam.

Physics

If any aspect of hadron physics could be simple - reflecting the properties of underlying basic interactions at short distances - then it must be collision processes involving particles at very large transverse momentum. The resulting cross sections are invariably small. Proton beams have the unique property in their intensity and small phase space, compared to any other type of particle beam. For this reason, it is clear that the largest range in energy and momentum transfer can be explored with proton scattering.

A striking pattern of scaling laws has been observed in both exclusive and inclusive data at large $p_{\perp}$. It is of great interest to know whether this pattern survives after extending the measurements by several decades in sensitivity. Figure 1 shows the p-p elastic cross section at 90^{0} in the CMS. Two possible extrapolations to higher energy are shown.

The angular distribution of the normalized pp differential cross section is shown in Figure 2. There is a marked lack of energy dependence. An excellent fit to that data is given by the expression $\sin^{-12.4}\theta^*$. To give a feeling for possible event rates we have used two expressions for the extrapolation of the pp cross section: -

$$\frac{d6}{dt} = \frac{1}{s^2}\sin^{-12.4}\theta^* \qquad \text{I}$$

and

$$\frac{d6}{dt} = \frac{1}{s^{10}}\sin^{-12.4}\theta^* \qquad \text{II}$$

Both expressions are normalized to the existing data point at 90^0 cms and $S = 41\ GeV^2$.

At some point interference between strong and weak or strong and electromagnetic scattering amplitudes should manifest themselves.

Alternatively, elementary gluon exchange or other such effects could force a slow down of the steeply falling s-dependence of the cross section at 90^0. We would like to trace the angle and energy dependence out as far as possible.

Apparatus

The proposed apparatus is shown in Figure 3. The two spectrometers are identical and have a common axis of rotation at the front of the existing P-West pit. The size of the pit is such that the maximum angles of the spectrometers are 18^0 and 29^0. The minimum angle reached by each spectrometer is 4.0^0 and is determined by the first magnet location. The corresponding angular range in the cms is shown in Figure 4. The design is chosen to maximize the angular coverage at 50 GeV. If the observed energy dependence is relatively mild leaving an observable cross section at 100 - 200 GeV then relocation of the first dipole on one of the spectrometers will allow an increased angular coverage at the higher energies.

The first dipole D1 is used to sweep out low energy particles and minimize the rates in scintillation counter hodoscopes H1 and H2. The particle trajectory is determined using H1, H2 and dipole D2 is used for momentum analysis. Two further counter hodoscopes H3 and H4 are used to determine the particle trajectory after D2. All bending is done in the vertical plane. The hodoscopes are Gray coded scintillation counters with 1mm logical bin width in both vertical and horizontal dimensions. Their overall sizes are given below: -

Hodoscope	Size V. x H.	No. of Photomultipliers V.	H.
H1	5.9 x 1.8 cm	6	5
H2	8.4 x 2.6 cm	7	5
H3	12.8 x 4 cm	7	6
H4	15 x 4.7 cm	8	6
		28	22

The total number of hodoscope photomultipliers in each spectrometer is therefore 50. We have built a prototype counter element using the 0.5" Japanese tube #R647 (cost $35) and 0.02" thick scintillator. A clean 0.4 volt minimum ionizing signal was obtained indicating that the total thickness of the thickest counter would be no more than 0.28". The contribution of multiple scattering in the hodoscopes to the momentum and angular resolution of the spectrometer is small for momenta > 5 GeV/c. The resulting resolutions of the spectrometer are then: -

Momentum: $\Delta p/p \simeq 1.1\%$

Angle: $\Delta\theta_{H,V} \simeq 0.5$ mrad

The fast time resolution of the scintillation counter hodoscopes is essential for the success of this experiment.

A calorimeter is used at the back of the spectrometer to measure the particle energy with the usual resolution, $\sigma \sim 8\%$ at 50 GeV.

There are two kinematic requirements for elastic events - coplanarity of the two scattered protons with the beam axis and their angles satisfying the elastic kinematics. Calculations of inelastic backgrounds show that they are adequately rejected by these criteria.

Backgrounds

The P-West proton beam is extremely clean. Recently, 100 GeV beam has been transported at intensities up to 5 x 10" protons per 2 second spill without significant increase in halo being observed in the P-West pit. The large number of adjustable collimators in the upstream quadrupole enclosures permit effective elimination of halo. We have made a series of measurements of scintillation counter singles rates behind 8' of magnet as a function of angle in the range 5^0-28^0. These measurements were made with a 12 cm hydrogen target. We conclude that at a beam intensity of 2×10^{12} protons/pulse the singles rate in the entire hodoscope H1 will not exceed 10^6/second at the minimum angle.

Trigger

Trigger counters S1, S2, S3, and S4 are located immediately adjacent to the corresponding hodoscopes. The trigger for the experiment is an event

$(S_1S_2S_3S_4)$ in each spectrometer

plus the appropriate pulse heights in each of the calorimeters. Pulse height information from the S_i and calorimeters is then recorded, together with the bit information from the hodoscopes $H_{1,2,3,4}$ from both spectrometers.

Rates

The proposed liquid hydrogen target is 20 cm long and has an effective length defined by the spectrometer at the larger angle. The solid angle of acceptance is likewise defined by the same spectrometer to be $12.8 \times 4\ cm^2$ at 35', corresponding to $\sim 4.0 \times 10^{-5}$ster. The rate is computed using the expression

$$\text{Rate} = \text{Flux} \times \text{Effective Target Length} \times \frac{d6}{dt} \times \frac{p^{*2}}{\pi} \times \Delta\Omega_{lab} \times J$$

where J is the Jacobian defined by $\frac{d\Omega^*}{d\Omega_{lab}}$.

Two assumptions have been made regarding the cross section d6/dt as described earlier; they are denoted by I and II. The rates for some energies and angles are given below:

E_{inc} = 30 GeV

θ*	t	d6/dt I	d6/dt II	Rate/Day I	Rate/Day II
50	9.7	36 10^{-35}	29 10^{-36}	1340	108
60	13.6	8 10^{-35}	6.3 10^{-36}	650	51
70	17.9	2.9 10^{-35}	2.3 10^{-36}	420	33
80	22.5	1.6 10^{-35}	1.3 10^{-36}	420	33
90	27.3	1.3 10^{-35}	1.0 10^{-36}	570	45

E_{inc} = 40 GeV

θ*	t	d6/dt I	d6/dt II	Rate/Day I	Rate/Day II
50	13.1	203 10^{-36}	160 10^{-38}	1520	12
60	18.3	44 10^{-36}	35 10^{-38}	760	6
70	24.1	16 10^{-36}	13 10^{-38}	510	4
80	30.3	9 10^{-36}	7.2 10^{-38}	510	4
90	36.7	7.5 10^{-36}	6 10^{-38}	640	5

E = 50 GeV

θ*	t	d6/dt I	d6/dt II	Rate/Day I	Rate/Day II
40	10.7	1100 10^{-36}	1500 10^{-39}	5040	6.7
50	16.4	130 10^{-36}	170 10^{-39}	1470	2
60	23	28 10^{-36}	38 10^{-39}	660	1
70	30.3	10 10^{-36}	14 10^{-39}	480	.7
80	38	5.8 10^{-36}	7.7 10^{-39}	510	.7
90	46	4.8 10^{-36}	6.4 10^{-39}	750	1

θ^*	t	dσ/dt I	dσ/dt II	Rate/Day I	Rate/Day II
E = 100 GeV					
60		$7.1\ 10^{-36}$	$37\ 10^{-42}$	909	.005
70		$2.6\ 10^{-36}$	$13\ 10^{-42}$	663	.003
80		$1.4\ 10^{-36}$	$7.5\ 10^{-42}$	651	.004
90		$1.2\ 10^{-36}$	$6.2\ 10^{-42}$	976	.005

θ^*	t	dσ/dt I	dσ/dt II	Rate/Day I	Rate/Day II
E = 200 GeV					
90	187	$3\ 10^{-37}$	0	339	0

Requirements from Fermilab

We require four 10-ft. EPB dipoles. The liquid target, calorimeters, computer, electronics cabling etc. presently set up at the P-West pit for E-284 are adequate for this experiment. We need only construct new scintillation counter hodoscopes. Rapid approval would permit the installation of the apparatus by Spring, 1977. We have never transported a 50 GeV beam into P-West although we do not expect a problem. We request approval of this proposal, contingent upon a successful test with a low energy beam.

As the projected rates are so uncertain no precise request of beam energies and running times can be made. We therefore request about 600 hours of beam at energies between 30 and 200 GeV.

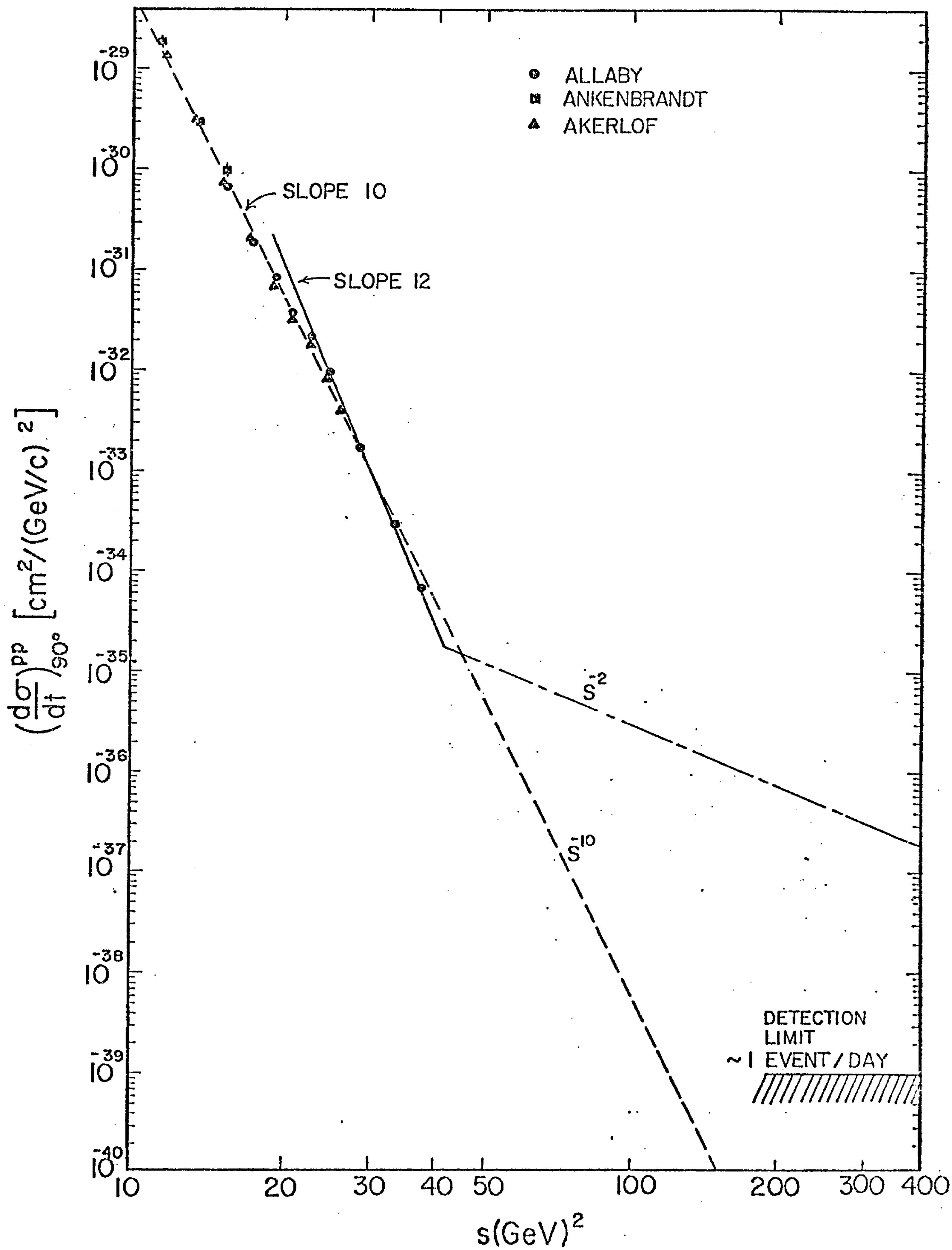
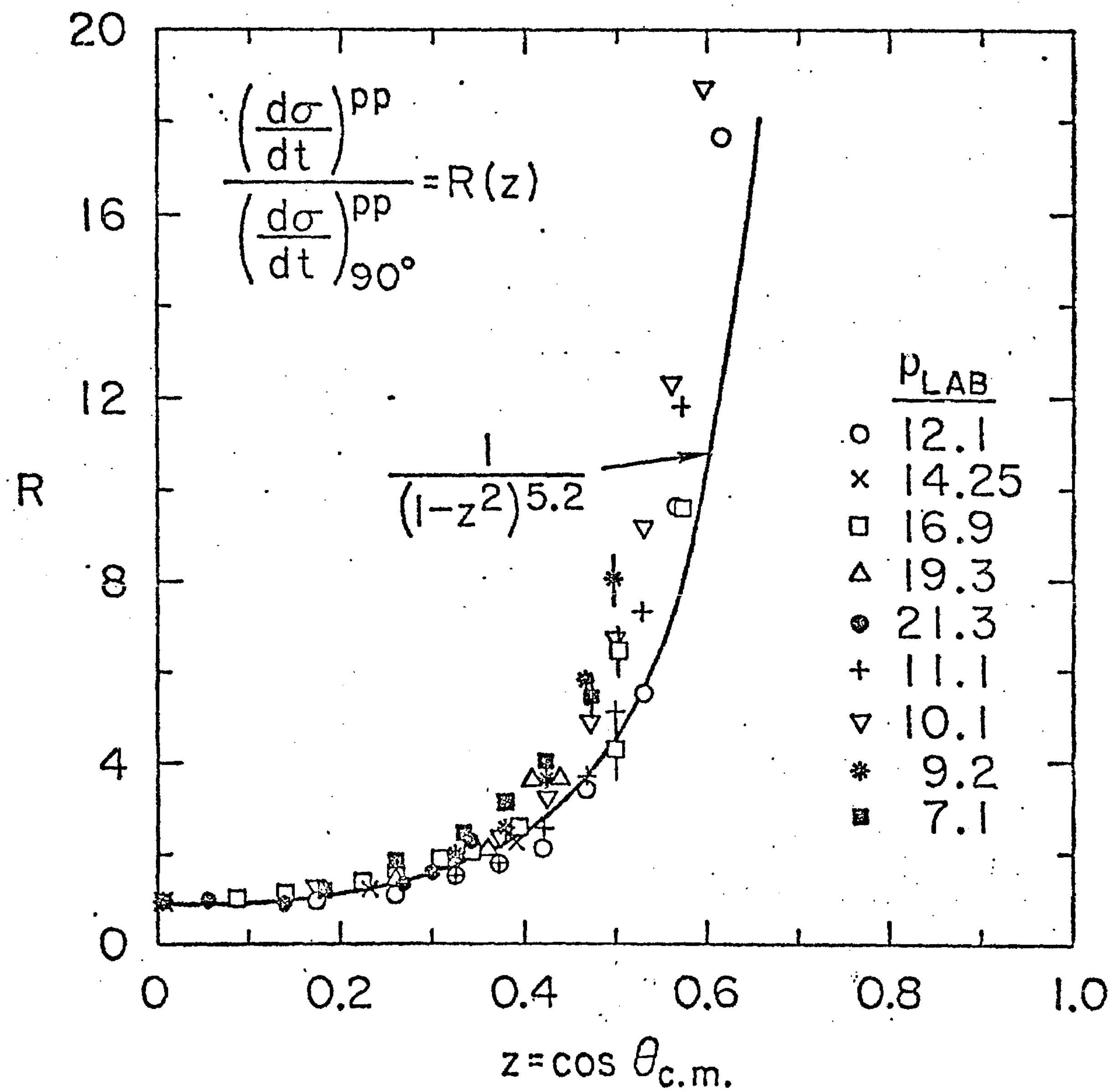
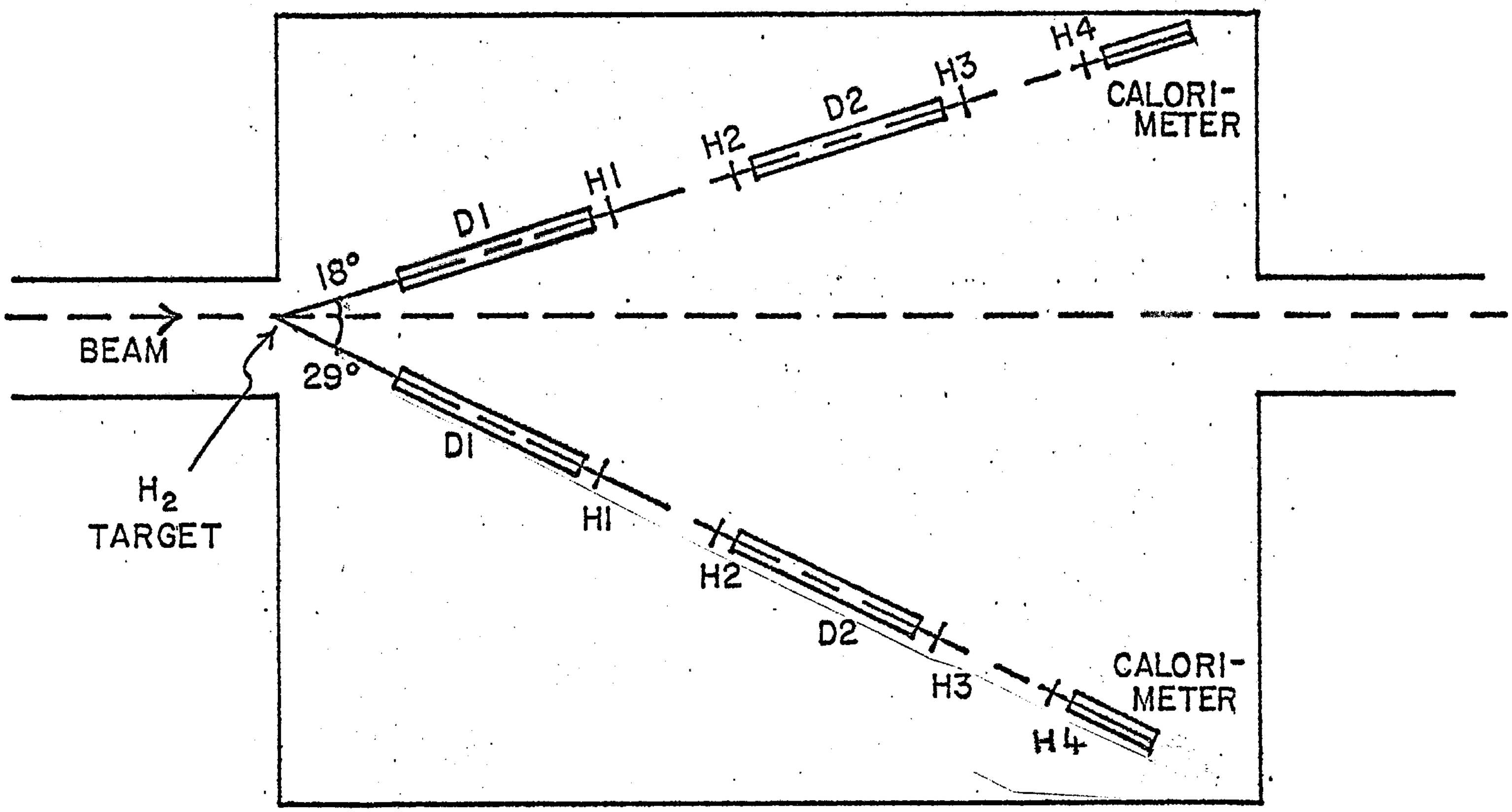

ALLABY
ANKENBRANDT
AKERLOF
SLOPE 10
SLOPE 12
S^{-2}
S^{-10}
DETECTION
LIMIT
~1 EVENT / DAY
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
$\left(\frac{d\sigma}{dt}\right)^{pp}_{90°} \left[cm^2/(GeV/c)^2\right]$
10
20
30
40
50
100
200
300
400
$s(GeV)^2$

Figure 1



20
16
12
8
4
0
R
$\frac{\left(\frac{d\sigma}{dt}\right)^{pp}}{\left(\frac{d\sigma}{dt}\right)^{pp}_{90°}} = R(z)$
$\frac{1}{(1-z^2)^{5.2}}$
p_{LAB}
o 12.1
× 14.25
□ 16.9
△ 19.3
● 21.3
+ 11.1
▽ 10.1
✱ 9.2
■ 7.1
0
0.2
0.4
0.6
0.8
1.0
$z = \cos \theta_{c.m.}$

Figure 2



P- WEST PIT

Figure 3

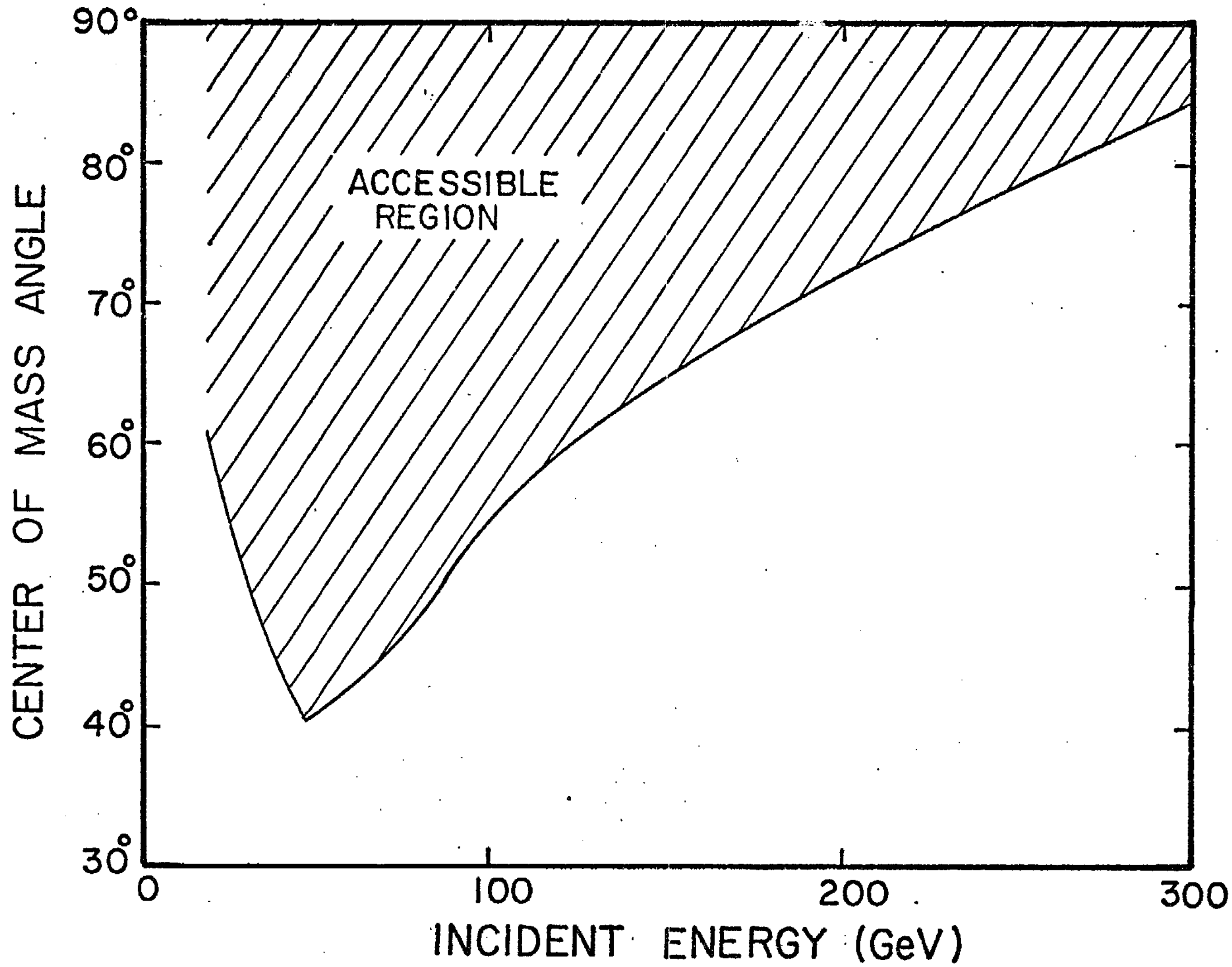

90°
80°
70°
60°
50°
40°
30°
CENTER OF MASS ANGLE
ACCESSIBLE
REGION
0
100
200
300
INCIDENT ENERGY (GeV)

Figure 4