NAL PROPOSAL No. 84

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FTS/Commercial 216-368-4100

PROPOSAL FOR AN EXPERIMENT TO STUDY THE REACTION $\pi^- p \rightarrow \pi^\circ n$ at 30 to 150 GeV at N.A.L.

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July 22, 1970

Proposal for an Experiment to Study the Reaction $\pi^- p \to \pi^0 n$ at 30 to 150 GeV at N.A.L.

We propose to measure $\frac{d\sigma}{dt}$ for $\pi^- p \to \pi^0 n$ in the t range 0 to -1.0 with attention given to t=0. The quantity $\frac{d\sigma}{dt}$ at t=0 is directly related to the difference in the $\pi^+ p$ and $\pi^- p$ total cross sections and thus gives information on that difference with a single experiment.

The apparatus will consist of counters and wire chambers to detect the conversion points of the π^0 gamma rays and make rough measurements of their energy. Particular care will be given to the anti-counter surrounding the hydrogen target in order to suppress multi π^0 background.

The η^0 and any other higher mass neutrals decaying into 2 gamma will also be detected and analyzed.

We propose to run at 30, 60, 90, 120, and 150 BeV in a π^- beam of 10^6/pulse with $\Delta p/p$ about .2%. A running time of 650 hours will allow an accumulation of 3×10^4 events at each point and adequate test and checking time.

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Introduction

The reaction $\pi^- p \rightarrow \pi^o n$ in the forward direction is related to the difference in the total $\pi^- p$ and $\pi^+ p$ cross sections. The Serpukhov experiments of Allaby et al.,[1] (Fig. 1), indicate that the Pomeranchuk theorem may be violated and that in any event there is a difference of about one millibarn in $\pi^- p$ and $\pi^+ p$ total cross sections up to incident pion energies of 70 BeV. This means that forward charge exchange scattering can not vanish at high energies as had been previously supposed. By the optical theorem and charge independence the forward differential charge exchange cross section is given by

$$\frac{d\sigma}{dt} = \frac{\pi}{2k^2} \left(\text{Real}(\pi^+ p) - \text{Real}(\pi^- p)\right)^2 + \frac{1}{32} \left(\sigma(\pi^+ p) - \sigma(\pi^- p)\right)^2$$

The contribution from the difference in total cross sections of one millibarn is 30 μbarn/(BeV/c)^2.

The real amplitudes are related to the total cross sections and so in general the contribution from the real parts can not vanish either.

The proposed experiment would measure $\frac{d\sigma}{dt}$ in the forward direction in order to obtain the difference in the real amplitudes. Although we want to concentrate our efforts on the forward direction, we also propose to measure $\frac{d\sigma}{dt}$ out to $t = -1(\text{BeV/c})^2$ in order to observe the behavior of the dip at $-.6(\text{BeV/c})^2$.

In the forward direction we would be measuring the difference in the real amplitudes directly, a difference which may in some way be connected with the total cross section difference, rather than measuring each amplitude in separate scattering experiments and subtracting.

Another way to look at it is that this is a null experiment to test the equality of $\pi^- p$ and $\pi^+ p$ total cross sections at high energies.

If the $\pi^- p$ and $\pi^+ p$ total cross sections do maintain a constant difference out to infinity, a simple calculation of the real amplitudes by a subtracted dispersion relation yields:

$$\frac{1}{2}\,(Re_+ - Re_-)^2 = \frac{\Delta\sigma(\infty)^2}{32\pi^3}\left(\frac{1}{x}\left(2\tan^{-1}\left(\frac{1}{x}\right)+(1-x)\log(1-x)-(1+x)\log(1+x)\right)\right.$$
$$\left.-\log(1+x^2)+A\right)^2$$

where $\Delta\sigma(\infty)$ is the constant cross section difference, c is the momentum at which $\Delta\sigma = \Delta\sigma(\infty)$, x is $\sqrt{k/c}$ where k is lab momentum, and A is a subtraction constant (about 4).

In this notation the imaginary part of $d\sigma/dt$ is written:

$$\frac{1}{2}(Im_+ - Im_-)^2 = \frac{\Delta\sigma(\infty)^2}{32} \qquad \text{for } k > c$$
$$= \frac{\Delta\sigma(\infty)^2}{32\pi x^2} \qquad \text{for } k < c$$

so that the real and imaginary parts can be seen to approach each other as $x \ll 1$ as we expect. Figure 4 is a plot of $d\sigma/dt$ for c=30 BeV and for $c = \infty$ with $\Delta\sigma$ taken as 1 millibarn. Note the leveling off in $d\sigma/dt$ of c=30, that is if the difference in total $\pi^- p$ and $\pi^+ p$ cross sections remain constant from 30 BeV/c to infinity. Eventually, according to this model, around 200 BeV, $d\sigma/dt$ will begin to rise logarithmically. Since the behavior of $\Delta\sigma$ is not yet well known this discussion can be thought of only as a crude outline of the type of effect that one might expect to observe. The main point is that if $\Delta\sigma$ does not go to zero rapidly enough, this experiment (to the extent that it measures $d\sigma/dt$ at t=0) is sensitive to that asymptotic dependence.

We are proposing to carry out this experiment at energies ranging from 30 to 150 BeV at 30 BeV steps in the negative pion beam of about 10^6/pulse intensity. As higher energy beams become available the experiment could be extended to higher energies. The 30 BeV measurement is chosen to tie in with our proposed charge exchange experiment (similar to this one) at Brookhaven National Laboratory.

Past Experiments

The present experimental data at t=0 are summarized in Figure 2. The highest energy at which data have been obtained is 18 BeV where two groups[2,3] have performed experiments. The total cross section is about 24 μbarns at 18 BeV.

Proposed Experimental Technique

Figure 3a shows the target and anti counter arrangement and Figure 3b is a plan view of our experiment. The main experimental difficulty is the suppression of three-body background. Ballam et al.[4] measures the cross section for $\pi^- p \to \pi^- \pi^+ n$ at 16 BeV/c to be about 400 μb. A similar number for $\pi^- p \to \pi^0 \pi^0 n$ should be compared with the total cross section for $\pi^- p \to \pi^0 n$ of 24 μb at 18 Bev so that the 3-body background alone is about 50 times greater than the 2-body. The most dangerous background comes from low mass N* production which results in a forward π^0 near the two-body π^0 energy.

We propose to eliminate this background by construction of a highly efficient anti counter with which to surround the target. Previous experiments[2,3] have had lead scintillator sandwiches with about four radiation lengths in them. This method suffers from possible gamma absorption in the lead plates and insufficient radiation lengths. In order to get an anti efficiency of about one part in 10^3 for soft neutral pions and insure our ability to anti even 50 MeV gamma rays, and yet not build a thick detector that would anti neutrons from the two-body events, we plan to use a six or seven radiation length Cerenkov anti using lead-glass or some heavy liquid. Such a counter is shown in Figure 3a surrounding a charged anti and a six inch hydrogen target. In the forward and backward regions where no neutrons are expected we will place lead scintillator sandwiches with many plates (such as thirty-two one/quarter radiation length lead plates). This will insure that no soft π^0's will produce gammas with more than one escaping our anti geometry. This target geometry will remain the same at each energy because the neutron angles for a given t range remain constant.

We plan to make sure we can check for the presence or absence of 3-body background by obtaining resolution in opening angle of better than one per cent. This will enable us to make opening angle plots and opening angle cuts on the data to search for possible N* contamination.

In order to obtain good spatial resolution we plan to place our gamma detector forty-five feet downstream from the hydrogen target at 30 BeV, and move it proportionally thereafter out to a distance of 225 feet at 150 BeV. This corresponds to a gamma separation of 6 inches.

The gamma detector will consist of a three foot square lead plate converter (probably one half radiation length) followed by wire chambers to measure the gamma vertices as accurately as possible. This will be followed by a detector to measure the gammas' energies. An example of such a detector would be an array of alternate layers of lead plates and coarse mesh proportional chambers to sample the ionization in each gamma shower[5].

We would tie the wires of each of these chambers to those in all other layers at the same position because what is wanted is the sum of the ionization deposited by each gamma shower rather than its distribution in depth. We hope to attain 20-30% energy resolution by this method in order to resolve the 2-fold kinematic ambiguity in reconstruction.

A beam of $10^6\ \pi^-$/pulse with a momentum bite of $\pm$ .2% or better would be adequate. A larger momentum bite would be quite acceptable providing the beam could be tagged. Particle identification in the beam would be necessary to eliminate events that might otherwise look like $\pi^- p$ charge exchange.

Reconstruction

The errors in locating the gamma conversion vertices are the chief source of measurement error in the momentum transfer variable t. We estimate that an error of ± .5 mm will result in a one half per cent opening angle measurement.

The biggest error in t can result from failure to resolve the two fold kinematic ambiguity. The measurement errors introduce an error in t of about .005 at t = - .5. Figure 5 is a plot of the Δt that results from taking the bisector of the gamma directions as the π^0 direction as a function of the percent difference in gamma energies for various values of t. Clearly, the better the energy resolution on the gammas, the better the t resolution. The t resolution actually is a function of the orientation of the plane of the gammas with respect to the plane of the reaction and figure 5 shows the largest values of Δt. By selecting events whose gamma plane is nearly perpendicular to a line drawn to the x axis, Δt can be made to approach arbitrarily close to zero (except for measurement error). Thus we plan to cut the data so that the ambiguity error is comparable to the measurement error.

An alternate method of data reduction would not make use of the energy measurements at all but would depend on an assumed functional form for $d\sigma/dt$. Parameters in the functional form would be adjusted in a maximum liklihood distribution of gamma vertices. A somewhat similar scheme has been used at lower energies.[7]

Available Equipment

We possess all of the electronic logic and phototubes required. We will be able to provide the anti-counters, wire spark chambers, and associated logic. We would require the construction by the laboratory of a 6 inch hydrogen target and the use of a small computer on-line for which we would provide the interface.

For a six inch target, a π^- beam of 1×10^6/pulse, and a conversion efficiency of .2 we have an event rate of .1 /pulse/μbarn total cross section. We would like to have about 3×10^4 events at each energy in order to have enough statistics to make possible opening angle cuts to check for N* contamination, to sharpen t resolution through cuts and to obtain good statistics near t=0. If we assume that the total cross section for charge exchange falls off as the inverse of the lab momentum from 24 μb at 18 BeV, we need 500 hours in order to obtain 3×10^4 events at 30, 60, 90, 120, and 150 BeV. Adding on 150 hours for tune up and checks, we request a total of 650 hours. The checks will consist of empty target runs and runs with various anti counters turned off to study the many body background.

Other Reactions

The process $\pi^- p \to \eta n$ with $\eta \to 2\gamma$ will be present in our data. We expect about 15% as many such events as $\pi^- p \to \pi^0 n$ events on the basis of previous experiments[6]. We may also be able to search for higher mass states decaying into two gammas. Events such as $\pi^- p \to \pi^0 \pi^0 n$ in which both π^0's convert in our detector can also be analyzed to find their effective mass.

References

1. Allaby et al., Phys. Letters 30B (1969), 500.
2. A.V. Sterling et al., Phys. Rev. Letters 14 (1965), 763.
3. I. Manelli et al., Phys. Rev. Letters 14 (1965), 408.
4. Ballam et al., SLAC preprint #716, March 1970.
5. C.A. Heusch, NAL Summer Study 3 (1969), 51.
6. Guisan et al., Phys. Letters 18B (1965), 200.
7. F. Bulos et al., Phys. Rev. 187, 1826 (1969).

Figure Captions

1. π^-p and π^+p total cross sections from Allaby et al. The π^+p curve is actually taken from π^-n data.

2. Summary of present forward charge exchange data. "Our" results refer to reference 2 and Mannelli et al., refers to reference 3.

3A. Liquid hydrogen target and anti-counter assembly.

3B. Plan view of whole experiment. Shower detector consists of layers of lead and proportional chambers.

4. Theoretical curves for $\frac{d\sigma}{dt}$ at t=0 for high energy charge exchange. Solid curve is for $\sigma_{\pi+p}-\sigma_{\pi-p} \sim$ const/E. Dotted curve is for

$$\sigma_{\pi+p}-\sigma_{\pi-p} \sim \text{const/E for E} < 30 \text{ BeV}$$

$$\sim 1 \text{ mb. for E} > 30 \text{ BeV}$$

5. Error in t from failure to resolve the kinematic ambiguity when one gamma is more energetic than the other. Δt is the error in t for each of three values of t which results from taking the bisector of the two gamma angles as the π^0 direction. D is the percentage difference in gamma energy and also the percentage of events with that energy separation or less. Plot is independent of energy.

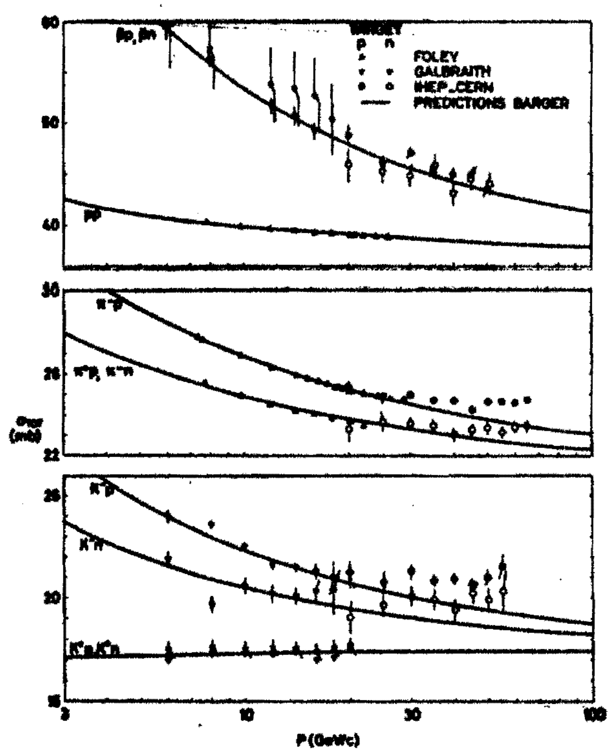

Figure 1

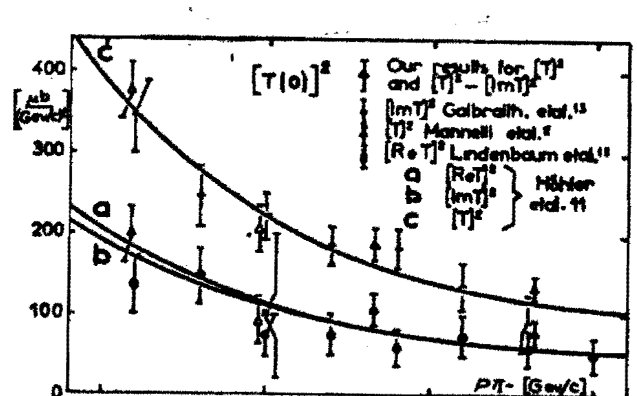

Figure 8

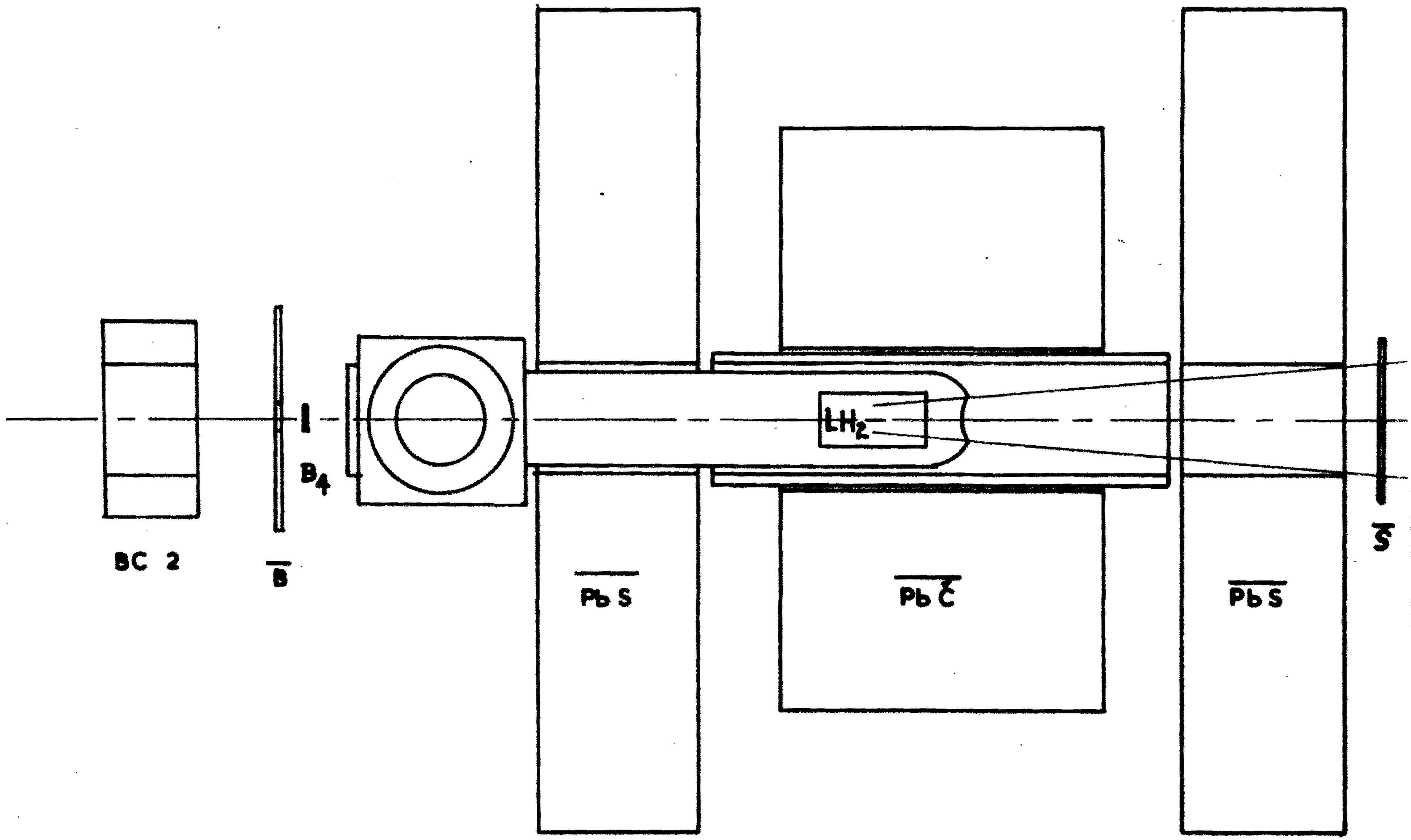

Figure 3A

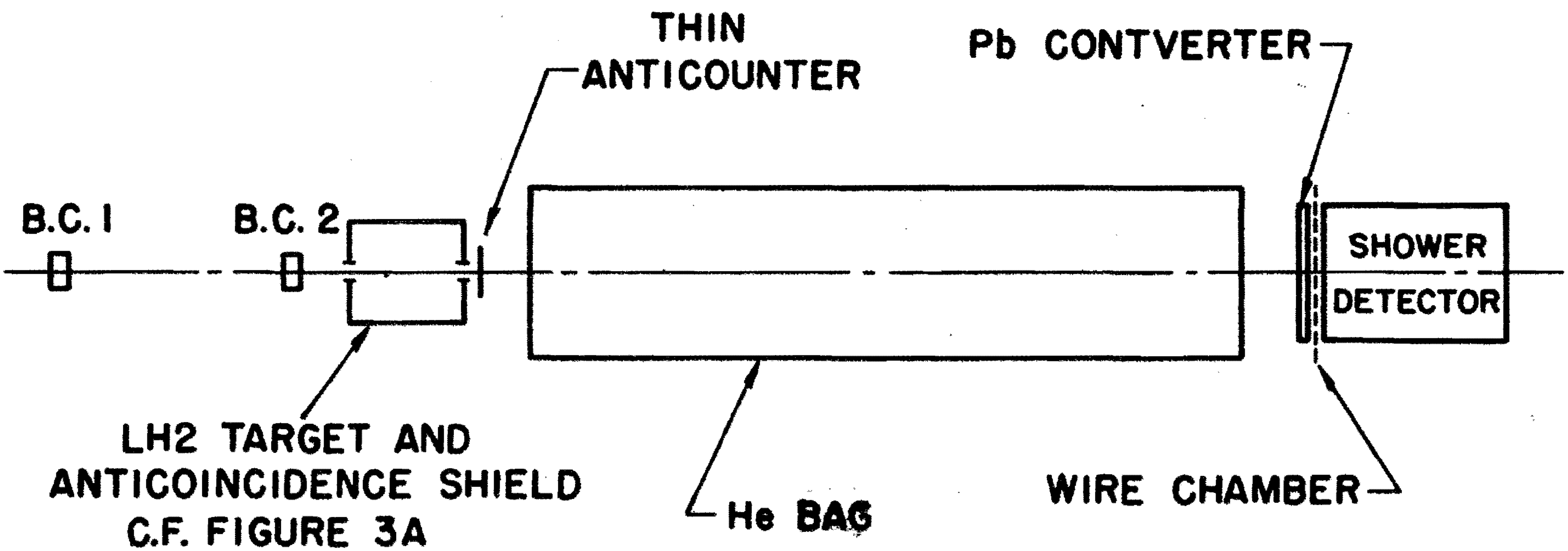
THIN
ANTICOUNTER
Pb CONTVERTER
B.C. 1
B.C. 2
SHOWER
DETECTOR
LH2 TARGET AND
ANTICOINCIDENCE SHIELD
C.F. FIGURE 3A
He BAG
WIRE CHAMBER

Figure 3B

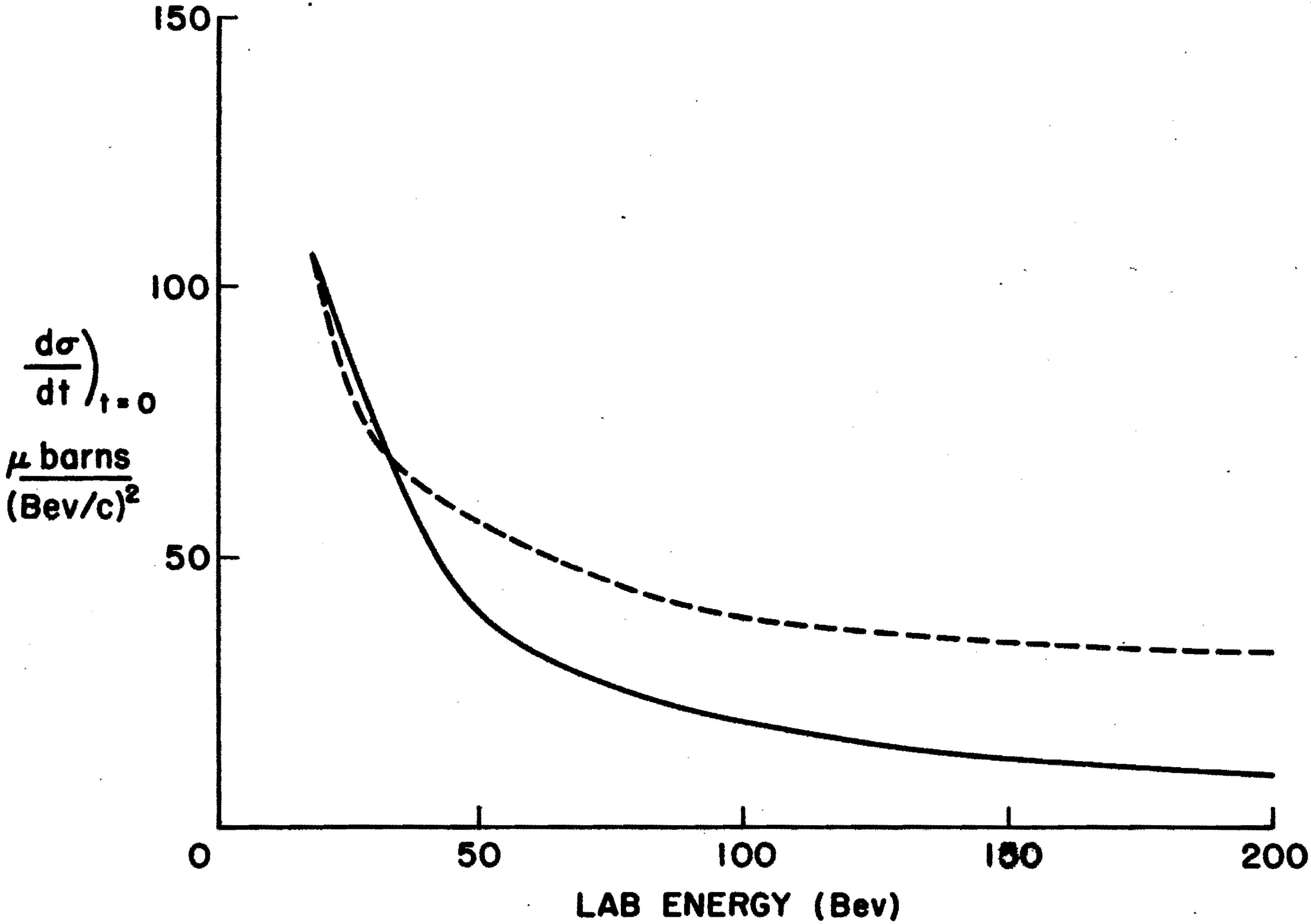
150
100
50
$\left.\frac{d\sigma}{dt}\right)_{t=0}$
$\frac{\mu \text{ barns}}{(\text{Bev/c})^2}$
0
50
100
150
200
LAB ENERGY (Bev)

Figure 4

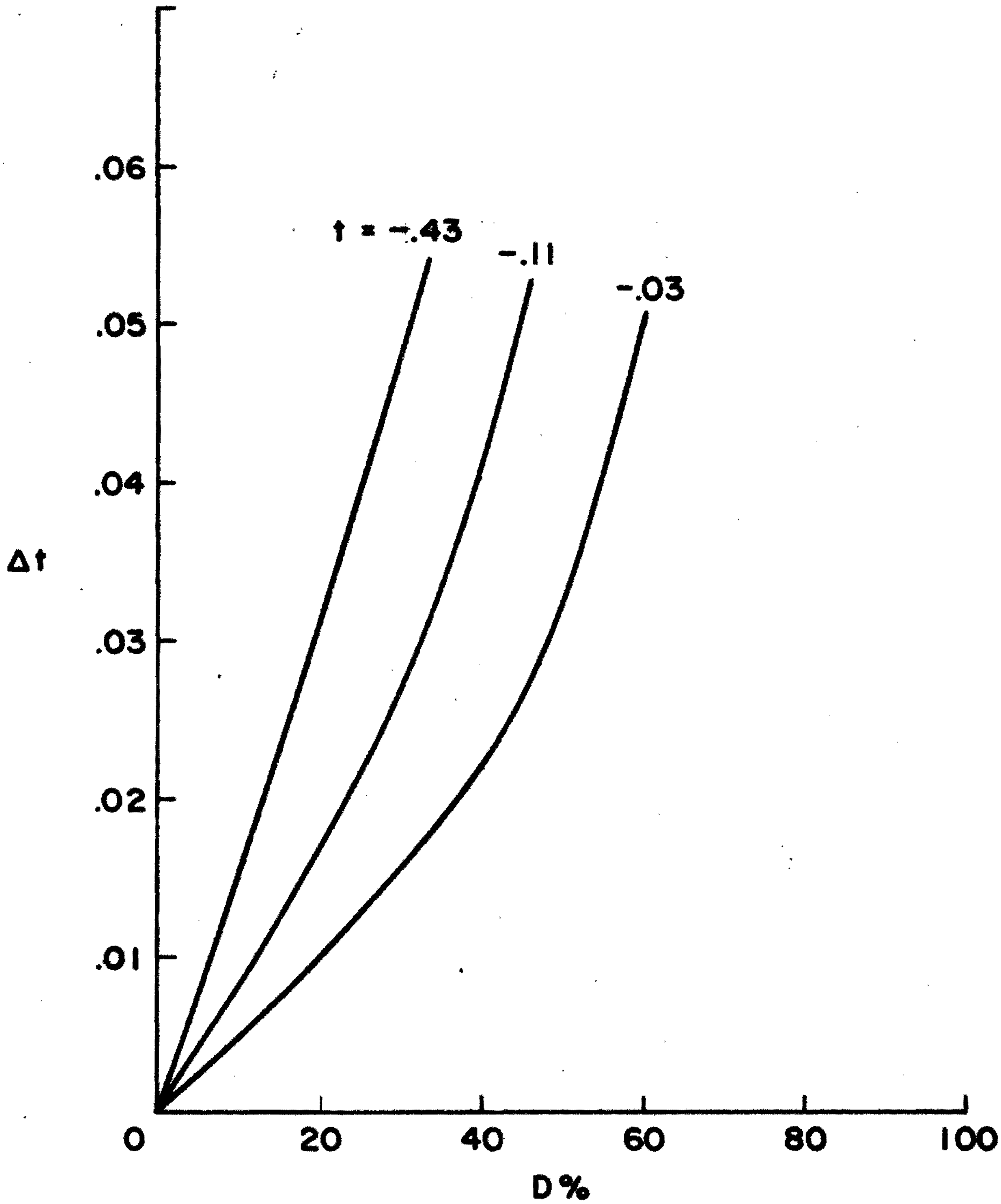

Figure 5