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Neutron Diffraction Dissociation and Coulomb Dissociation from Various Nuclei

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ABSTRACT

We propose to use the 1.75 mr neutral beam in the Meson Lab to study the reaction

$$n + A \rightarrow N^* + A$$
$$\quad\quad\quad\quad \hookrightarrow (p + \pi^-)$$

for targets with as large a range in atomic weight as possible (e.g., hydrogen through lead) and incident neutron energies from approximately 80 to 200 GeV. The aim is to study

(1) the cross section vs. energy and mass for ($p\pi^-$) masses from 1.08 to approximately 4.7 GeV,

(2) The A dependence of the cross section from which information on N* total cross sections in nuclear matter can be extracted,

(3) the t-dependence which, for the lighter elements, gives information on nuclear structure parameters,

(4) angular distributions of the decay products from which information on quantum numbers of the N* and the exchanged particle can be extracted.

This experiment would be a natural extension of a similar experiment carried out by our group at the AGS last summer. The experience gained in the AGS experiment will be very valuable in designing an experiment for NAL.

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I. Introduction

In the past few years coherent production processes off nuclei have become the subject of intense experimental and theoretical study. Such processes are typically only possible with very high energy beams and the extension of these studies to NAL energies is of great interest. The requirement that the target nucleus remain intact and in its ground state for coherence considerably restricts the quantum numbers of the particle exchanged between the beam particle and the target nucleus, thus making such processes amenable to theoretical analysis. Nevertheless there is at present relatively little data to confront the various theories,[1] and our understanding of these processes is still limited. Recent reviews of the current situation have been given by Bingham[2] and Morrison.[3]

Beams of neutral particles (γ, K^o, n) are rather convenient for studies of coherent production because they can dissociate into two charged particles. We propose to use a neutron beam with a broad energy spread ($\cong$ 80 to 200 GeV) to study the process

$$n + A \rightarrow N^* + A$$

where the N^* is any excited state decaying into $p+\pi^-$. The angular distribution of coherently produced N^*'s is strongly peaked forward. If t is the four-momentum transfer to the nucleus squared, then the t-distribution is roughly exponential, i.e.,

$$\frac{d\sigma}{dt} \propto e^{bt}$$

where $b \cong 10\ A^{2/3} (\mathrm{GeV/c})^{-2}$.

For reasonably small N* masses the opening angle of the $(\pi^- p)$ pair is rather small. [Typically $\theta_{op} \leqslant 2\sqrt{m^{*2}-1}\ /p$ where m* is the mass of the N* in GeV and p the incident neutron momentum in GeV/c.] It is therefore possible to use a spectrometer with rather small aperture to detect both the p and π^-. If the vector momenta of the p and π^- are measured all the relevant kinematical quantities can be determined; these include the momentum of the incident neutron, the N* mass, $t' = t - t_{min}$ $(\cong p_\perp^2)$, the decay angle, and the angle of the decay plane relative to the production plane. The fit is with zero constraints. However the requirement that the t'-distribution must show a sharp peak whose width is characterized by the nuclear radius provides a means of estimating noncoherent background. Our experience at the AGS shows that it is indeed possible to obtain a clean signal. This will be discussed in the next section.

II. The AGS Experiment

The AGS experiment was completed last August. The data analysis is well underway, but no results have yet been published.

No other group has studied this reaction. We therefore present here a brief discussion of some very preliminary results to serve as a framework for our proposal to extend these measurements to NAL energies. Most aspects of the experiment scale readily to higher energies. Cross sections are expected to remain roughly constant between 30 and 200 GeV/c. The range of N* masses available is of course larger at higher energies.[4] In many respects the experiment is easier at higher energies.

The circumstances of the AGS experiment were somewhat unusual and deserve explanation. The experiment was undertaken without official approval upon completion of an approved experiment to study n-p charge exchange. The setup, tuning, and data taking of the diffraction dissociation experiment were carried out in a total <u>calendar</u> time of about three weeks. The experiment made use of equipment from the charge-exchange experiment which had to be rearranged.

Despite the severely limited running time and simple triggering arrangement we were able to record ~10^6 triggers with targets of C, CH_2, Cu, and Pb. About 10% of the triggers reconstructed to give ($\pi^- p$) events with t and m* in the desired range. The experimental arrangement used is shown in Fig. 1. The target was surrounded by an anti-counter except for a small hole in the forward direction. The trigger was $P_1\overline{A}_1\overline{A}_2$ in coincidence with either L_1R_1 or L_2R_2. Event rates were limited only by the spark chamber recovery time. Trigger rates greater than 30 per burst could easily have been obtained.

Figure 2 shows the uncorrected incident neutron spectrum reconstructed from the carbon data. Figure 3 shows the distribution in t' for the carbon and lead data. The background under the coherent peak is $\cong$ 20% for carbon and somewhat less for lead. This may be reduced somewhat as the analysis proceeds. The exponential slope of the background is $\cong 10\ (\text{GeV/c})^{-2}$, indicating that it is probably due to incoherent production from individual nucleons. The exponential slope at small t' for carbon is $\cong 49\ (\text{GeV/c})^{-2}$, about that expected. For lead it is $\cong 233\ (\text{GeV/c})^{-2}$, which is considerably smaller than the expected value of approximately $350(\text{GeV/c})^{-2}$. This is due at least in part to the smearing out of the peak by both the experimental angular resolution and coulomb scattering in the lead target. This emphasizes the need for good resolution and thin targets to reduce this smearing and thereby minimize the background under the coherent peak.

Figure 4 shows preliminary $(\pi^- p)$ mass distributions for a sample of our data with carbon and lead targets for events in the coherent peak. No well defined peaks appear. As has been observed in p-p experiments[5] the mass distribution is dominated by a broad peak at low masses. The requirement that the recoil nucleus remain intact puts a limit on the maximum momentum that can be transferred to the mucleus and sets an effective upper limit on m*. If we take $p_{max} \cong m_{\pi}/A^{1/3}$, for 25 GeV/c incident neutrons this is ≅ 1.95 GeV for carbon and ≅ 1.4 GeV for lead. This partially explains the paucity of events with masses of this order in the data samples presented, although for carbon the mass distribution falls off faster than would be expected from this kinematical effect and the geometrical efficiency of the apparatus.

No evidence for a peak corresponding to the Δ(1236) can be seen in the lead data. It should be possible to produce isospin 3/2 states by photon exchange. The cross section for Δ(1236) production should therefore vary as Z^2 and is expected to be sizeable for lead. The cross section for Δ(1236) production by incident neutrons has been calculated explicitly by Nagashima and Rosen.[6] It may be that when the data analysis is further along, some evidence for Δ(1236) production will be seen but at present there is no sign of it.

We are presently studying the angular distribution of the N* decay products in both the Jackson and helicity frames. This should provide information on the quantum numbers of the states involved. Preliminary results indicate that neither s-channel nor t-channel helicity is conserved, in contrast to results obtained in several other reactions.[7]. Further results from the AGS experiment will be forwarded as soon as they are available.

III. The Proposed Experiment

A. Purpose

On the basis of our experience at the AGS we have a pretty good idea of what to expect at NAL energies. It will be possible to study a much larger range of m* in the NAL experiment (up to approximately 4.7 GeV with carbon targets and 3 GeV with lead). It is possible that well-defined peaks will show up in the mass spectrum at higher energies. However even without such peaks the mass spectrum and angular distributions and their variation with energy and atomic weight are of great interest.

The chances of seeing a clean $\Delta(1236)$ peak from Coulomb dissociation at higher energies seem relatively good. The total cross section for producing the $\Delta(1236)$ is expected to increase by about a factor of five between 25 and 170 GeV/c (Ref. 6). Diffraction dissociation by "Pomeron" exchange is expected to remain fairly constant at high energies (depending somewhat on the model chosen), so it may be easier to see coulomb production of the $\Delta(1236)$ at NAL energies.

Perhaps one of the most important lessons of the AGS experiment is that one would like to obtain a really large number of events ($\geqslant$ 10 times the number obtained in the AGS experiment). This is basically because we are binning in a multidimensional space (incident neutron energy, N* mass, atomic weight,...). To determine the quantum numbers of the states involved it is necessary to study the angular distribution of the decay products for small ranges in m* and t'. This requires a large number of events and sensitivity over as large a range of angles as possible.

Basically then the purpose of the NAL experiment would be to obtain good statistics over as large a range of the relevant variables as possible. From this we hope to determine the following:

1) The energy dependence of the cross sections
2) The A dependence
3) The dependence on N* mass
4) The dependence on t'
5) The angular distributions of the decay products vs. mass and t'.

So little is known about these processes at present that it is hard to predict exactly where the most important physics lies. It seems reasonable to expect that such information will go a long way in furthering our understanding of coherent production processes.

B. Experimental Arrangement

We propose an experiment generally similar to the AGS experiment, but with considerable refinement in the experimental technique and at least an order of magnitude more data. The details of the experimental arrangement depend to a large extent on the availability of magnets for the spectrometer. If larger magnets are not available we envision an arrangement that would use two 24" x 72" magnets[8] with two slightly different configurations. For relatively small N* masses ($m^* \leqslant 2.0$ GeV), we would probably use a setup similar to that used at the AGS shown in Fig. 1 with distances along the beam direction scaled by a factor of approximately 6 and with two 24" x 72" magnets. For larger masses a setup like that shown in Figure 5 would be more appropriate. To cover the desired range of M* and decay angles the magnet currents and target-magnet spacing L would be varied in steps. Rates are expected to be quite high so the small solid angle subtended by the 24" x 72" magnets is tolerable, but larger magnets would obviously be preferable to reduce biases and allow a more complete coverage of masses and decay angles. The setup shown does have the advantage of flexibility. If a particular mass region turns out to be interesting it can be studied in more detail.

The proposed arrangements are not optimized and should only be considered as representative. Details would be worked out in consultation with NAL staff. A fairly modest setup is envisioned, since the experiment is basically exploratory in nature. Our requirements are summarized below:

Beam - 1.75 mr neutral beam. Neutron flux ~10^6/burst

Magnets - Two 24" x 72" (or larger) magnets for spectrometer.

Targets - Most of the running would be done with solid targets.

A hydrogen-deuterium-helium target ≈ 12" long may be used if available.

Machine time - ~300 hours tuneup, 400 hours running.

Other Requirements - A long spill is important since rates will be limited by chamber recovery time. A modest amount of fast electronics from the electronics pool will be sought. The spark chambers, on-line data acquisition electronics, and scintillation counters will be provided by the University of Michigan out of funds from an existing contract. Some use of an NAL computer for preliminary offline data analysis would be desirable.

Scheduling - We would hope to follow the Ohio State-Michigan State np charge-exchange experiment (#12) in Beam 24. Our proposed spectrometer is very similar to theirs. We could use the same magnets and possibly other apparatus.

Footnotes and References

1. See for example:

J. S. Trefil, Phys. Rev. 180, 1366 (1969).

K. S. Kölbig and B. Margolis, Nucl. Phys. B6, 85 (1968).

Fournier, Orsay Report LAL 1237, July 1970.

B. Margolis, Phys. Letters 26B, 524 (1968).

2. H. H. Bingham, CERN Report D. Ph. II/PHYS 70-60, October, 1970.

3. D. R. O. Morrison, Rapporteur's Talk at Kiev Conference, Sept. 1970; CERN Report D.Ph. II/ PHYS 70-64.

4. The condition for coherence is that

$$q\, a \leqslant 1$$

where q is the momentum transferred to the nucleus and a is the nuclear diameter, $a \cong 2A^{1/3}/m_\pi$. The minimum four-momentum transfer squared t_{min} is

$$|t_{min}|^{\frac{1}{2}} \cong (m^{*2} - m_n^2)/2p$$

where p is the beam momentum. The two relations lead to an effective "threshold" momentum for producing a given m*,

$$p_{th} \approx (m^{*2} - m_n^2)\, A^{1/3}/2m_\pi .$$

5. W. E. Ellis *et al.*, Phys. Rev. Letters 21, 697 (1968).

E. L. Berger, Phys. Rev. Letters 21, 701 (1968).

6. Y. Nagashima and J. L. Rosen, Univ. of Rochester Report UR-875-295, Nov. 1969 (unpublished).

7. H. H. Bingham *et al.*, Phys. Rev. Letters *24*, 955 (1970).

J. Ballam *et al.*, Phys. Rev. Letters *24*, 960 (1970).

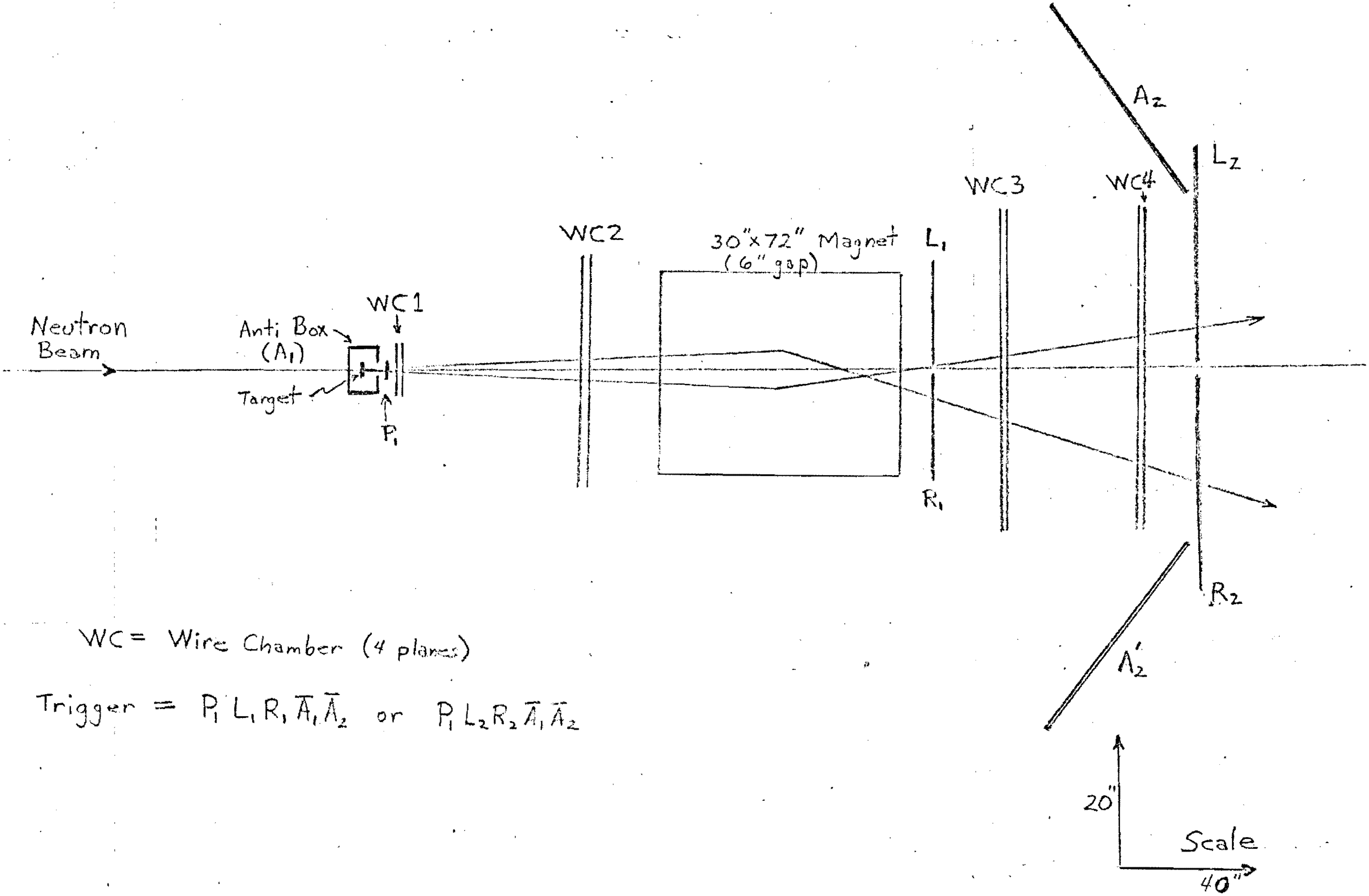
J. V. Beaupre *et al.*, Preprint, CERN/D. Ph. II/PHYS 70-65

G. ~~Sdv~~Ascoli *et al.*, Preprint, Univ. of Illinois, COO-1195-204.

8. Two 24" x 72" magnets will also be used in the Ohio State-Michigan State np charge-exchange experiment which we hope to follow in the neutral beam.

Figure 1

Layout of AGS Experiment



WC = Wire Chamber (4 planes)

Trigger = $P_1 L_1 R_1 \bar{A}_1 \bar{A}_2$ or $P_1 L_2 R_2 \bar{A}_1 \bar{A}_2$

Figure 2

Uncorrected
neutron spectrum
from carbon target

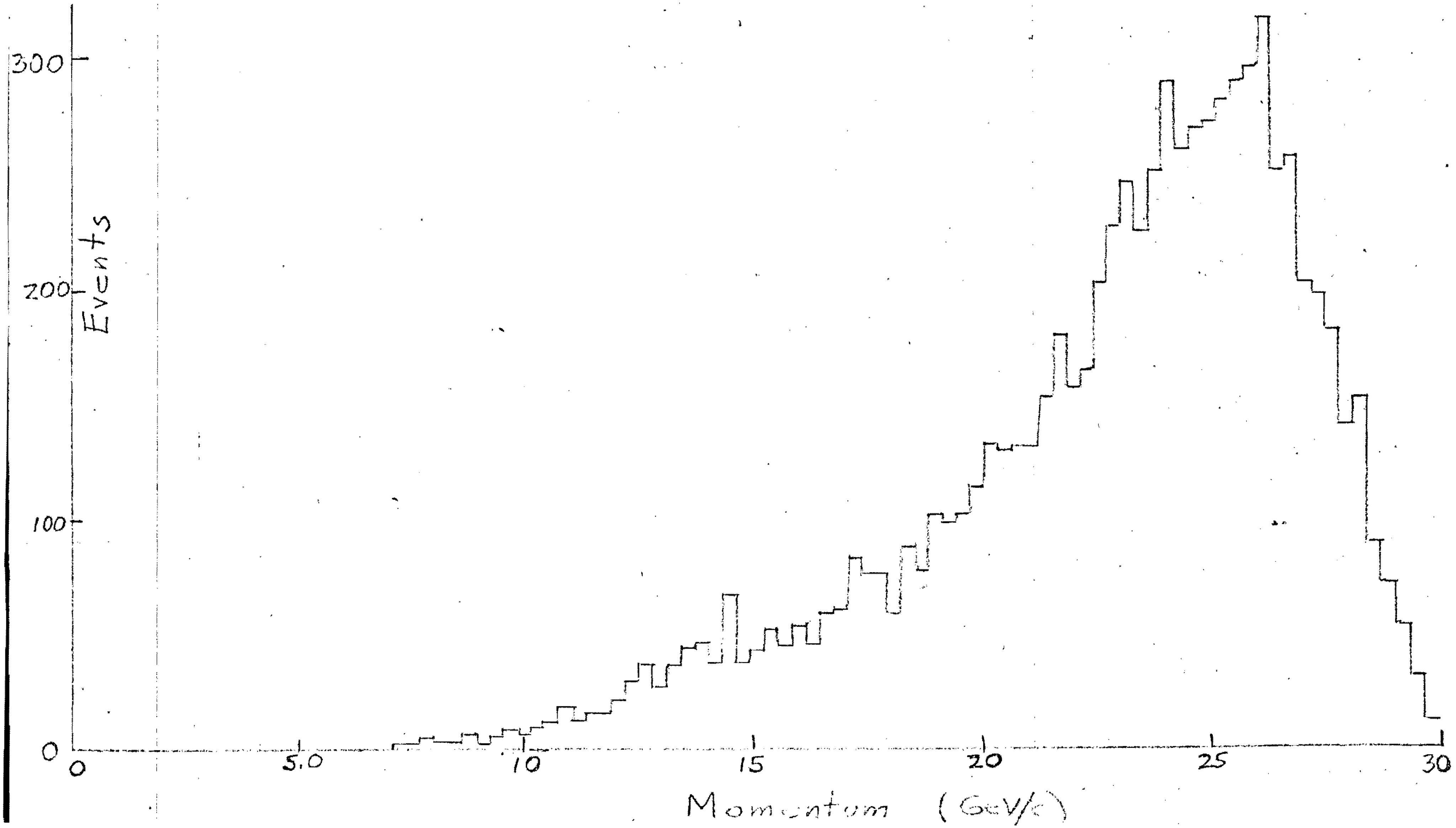
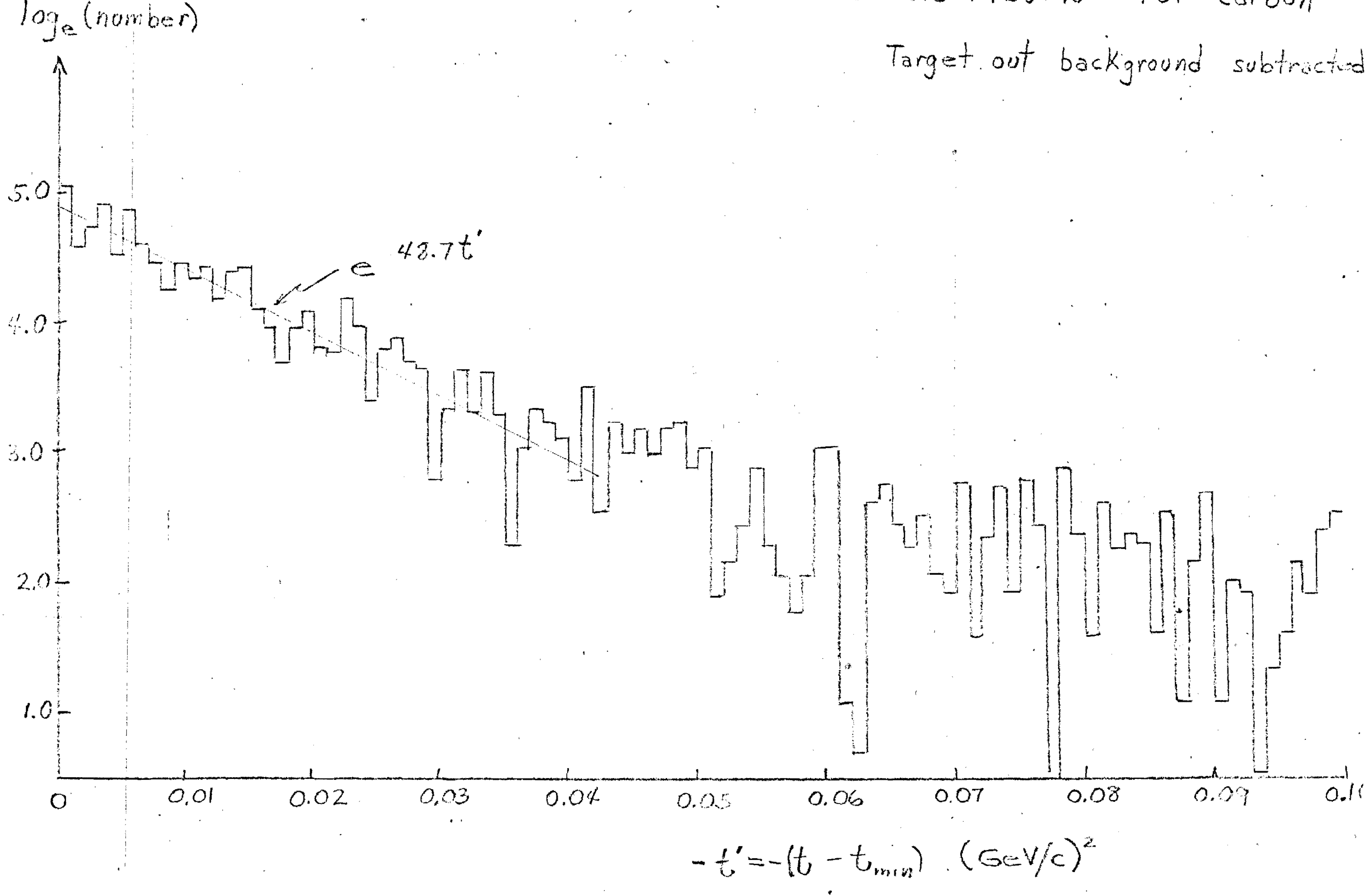


Figure 3a

t' distribution for Carbon

Target out background subtracted



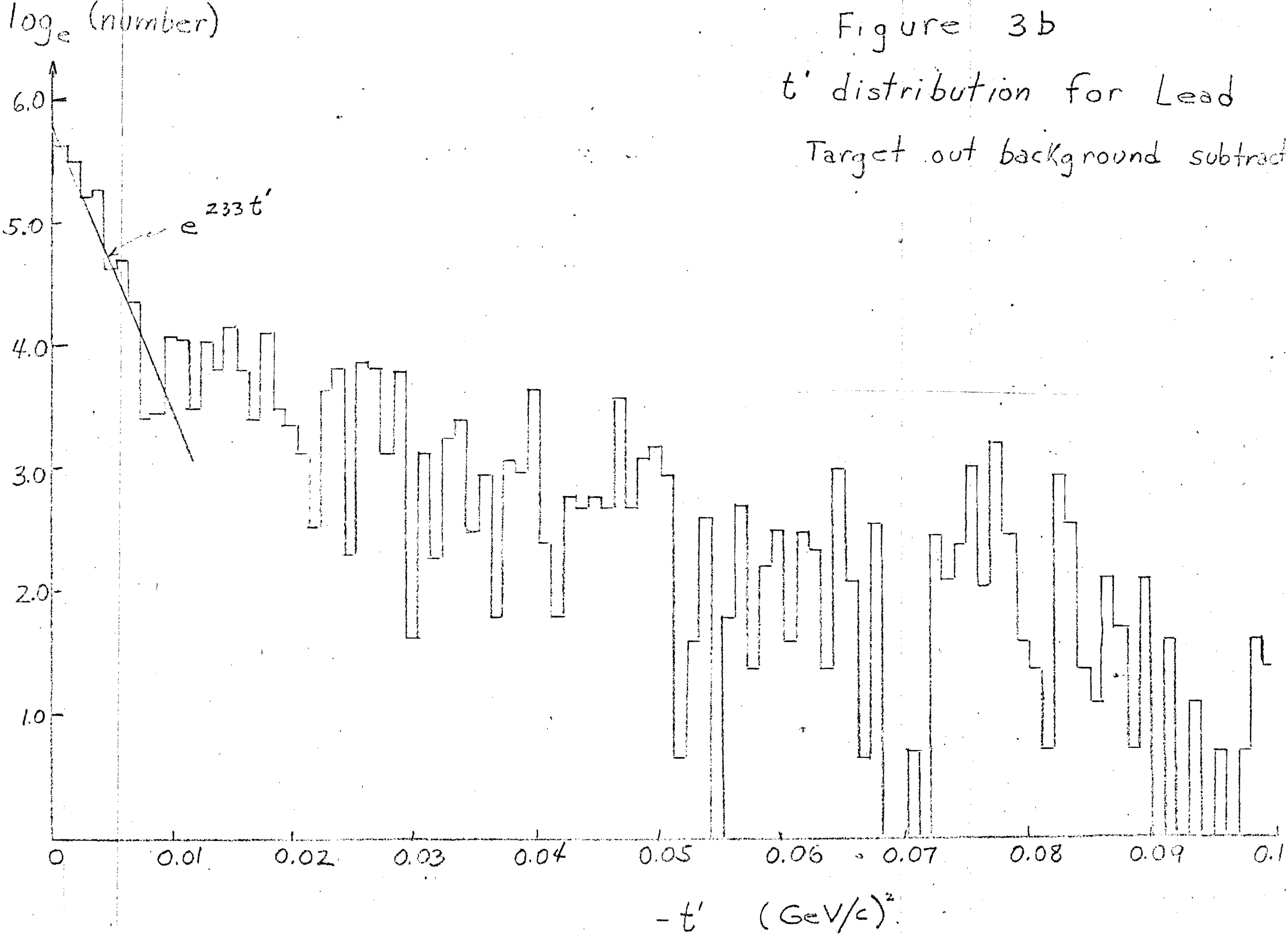


Figure 3b

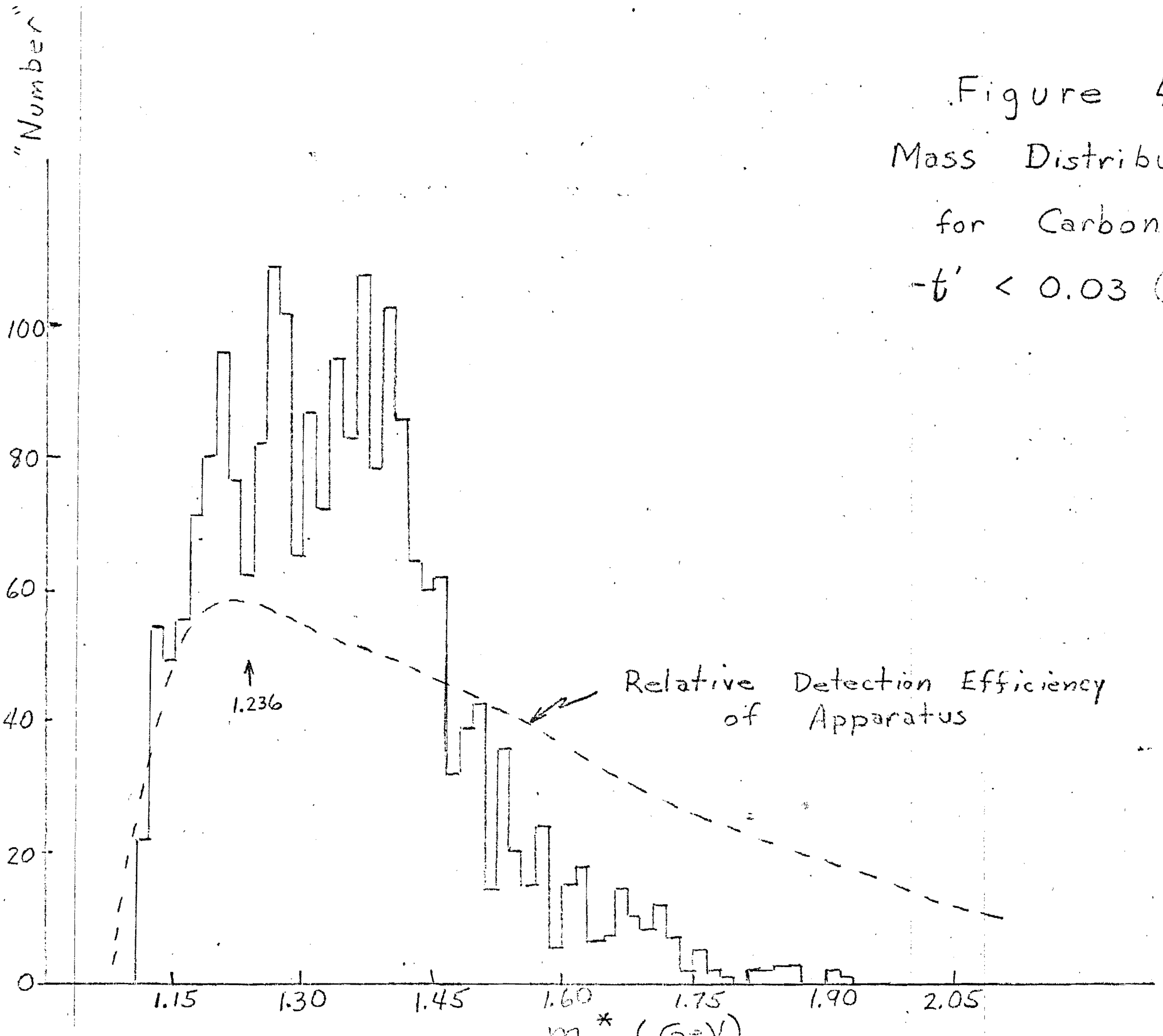
t' distribution for Lead

Target out background subtracte

Figure 4a

Mass Distribution for Carbon

$-t' < 0.03\ (\text{GeV}/c)^2$



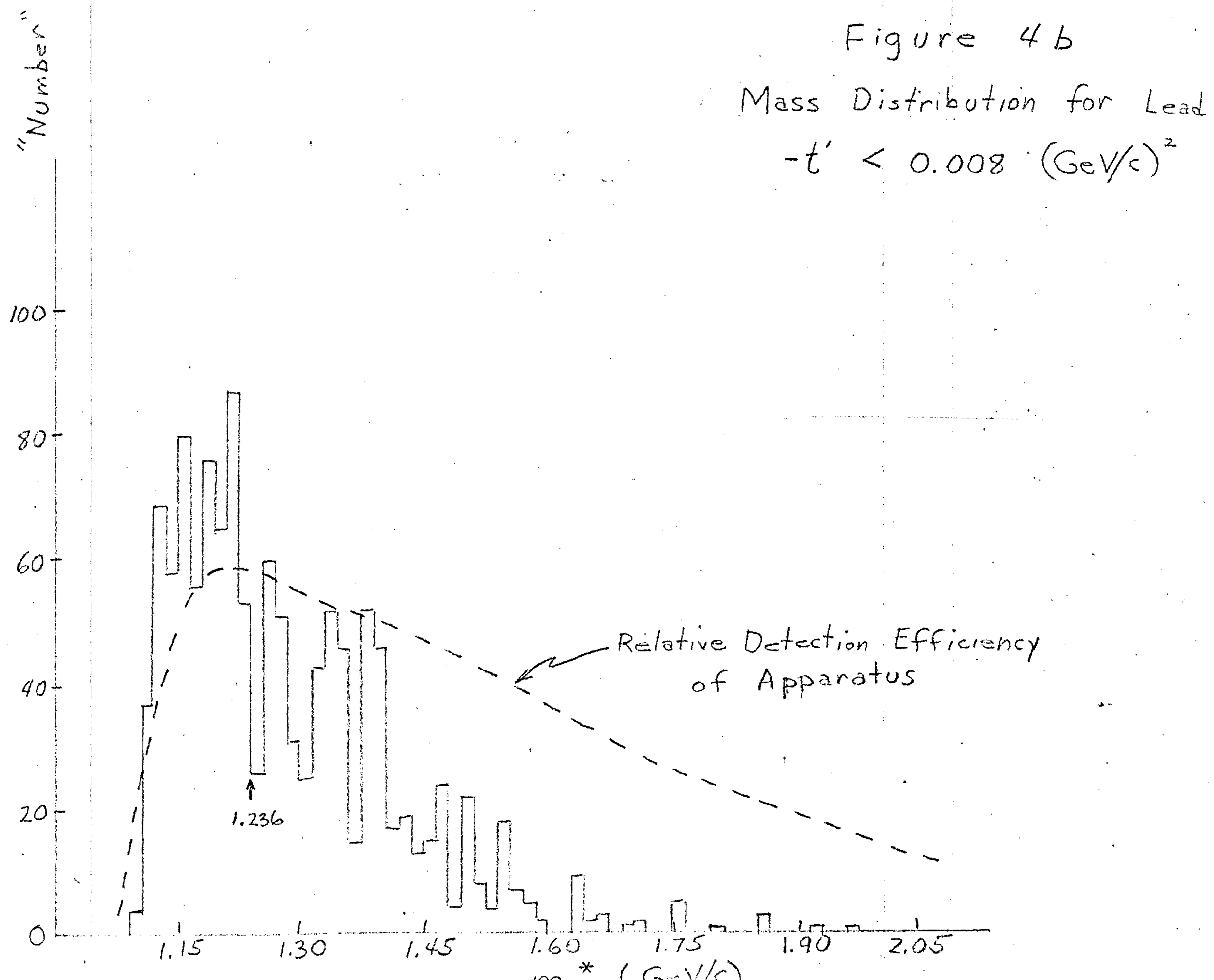
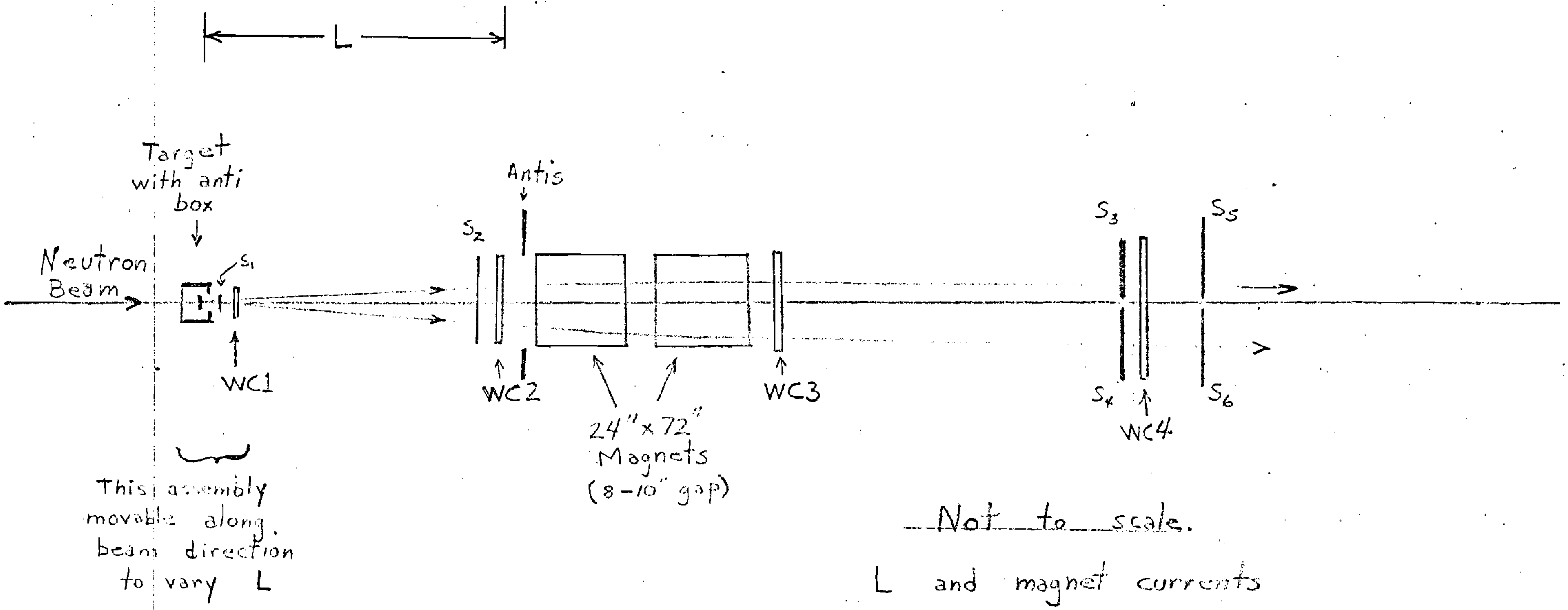


Figure 4b
Mass Distribution for Lead
$-t' < 0.008 \ (\mathrm{GeV}/c)^2$

Figure 5

Possible arrangement for large m^*

S= Scintillation Counter
WC= Wire Chamber



Not to scale.

L and magnet currents are varied to optimize geometry for a particular range of m^*