

To be published in
Physical Review D

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-82/39(P)
9 Giugno 1982

D. Besset, D. M. Chew, R. P. Ely, S. J. Freedman, R. Fries,
B. Gobbi, W. Guryn, F. A. Harris, I. Karliner, A. M. Litke,
A. Marini, D. H. Miller, J. Napolitano, S. Parker, I. Peruzzi,
M. Piccolo, T. P. Pun, F. Ronga, M. C. Ross, V. Vuillemin,
T. C. Wang and D. E. Yount: EXPERIMENTAL LIMITS ON
QUARKS, TACHYONS AND MASSIVE PARTICLES IN
COSMIC RAYS

INFN - Laboratori Nazionali di Frascati
Servizio Documentazione

LNF-82/39(P)
9 Giugno 1982

EXPERIMENTAL LIMITS ON QUARKS, TACHYONS, AND MASSIVE PARTICLES
IN COSMIC RAYS

A. Marini, I. Peruzzi, M. Piccolo, F. Ronga
INFN - Laboratori Nazionali di Frascati

D. M. Chew¹, R. P. Ely, T. P. Pun, V. Vuillemin²
Lawrence Berkeley Laboratory

R. Fries³, B. Gobbi, W. Gury, D. H. Miller, M. C. Ross
Physics Department, Northwestern University

D. Besset, S. J. Freedman⁴, A. M. Litke⁴, J. Napolitano, T. C. Wang⁵
Department of Physics, Stanford University

F. A. Harris, I. Karliner⁶, S. Parker, D. E. Yount
Department of Physics and Astronomy, University of Hawaii

ABSTRACT

A large detector designed for e^+e^- physics is used to search for various types of anomalous particles in cosmic rays at sea level. Previously obtained limits on the fluxes of charge $1/3$ and $2/3$ particles are reduced to $2.9 \times 10^{-10} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$ and $2.6 \times 10^{-10} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$ respectively. The flux of ionizing tachyons is determined to be less than $2.4 \times 10^{-9} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$. The massive particle flux limit we obtain is inconsistent with previous claims of such particles assuming that these particles are isotropic in zenith angle.

1 On leave from University of Paris VI, France.

2 Present address: EP Division, CERN, Geneva, Switzerland.

3 Present address: Physics Department, Indiana University, Indiana.

4 Alfred P. Sloan Foundation Fellow.

5 Present address: High Energy Physics Institute, Beijing, Peoples Republic of China.

6 Present address: Department of Physics, University of Illinois, Champaign-Urbana.

1. - INTRODUCTION

This paper presents results of a search for anomalous particles in cosmic rays obtained with a detector designed to search for fractionally charged particles produced in high energy e^+e^- annihilation⁽¹⁾ at the Positron Electron Project (PEP) at the Stanford Linear Accelerator Center. The detector as used for cosmic ray studies is described in detail in a previous publication⁽²⁾.

Briefly, the detector consists of 24 segmented layers of plastic scintillator interleaved with large area multiwire proportional chambers (MWPC's). Ten scintillation counter layers are equipped with time-of-flight (TOF) readout. The acceptance for cosmic rays depends on the trigger requirements and analysis cuts for the specific application but the geometric admittance for cosmic rays is $4.0 \times 10^3 \text{ cm}^2 \text{sr}$. Fig. 1 is a diagram of the detector which consists of two identical arms each covering one face of a cube. The range of cosmic ray zenith

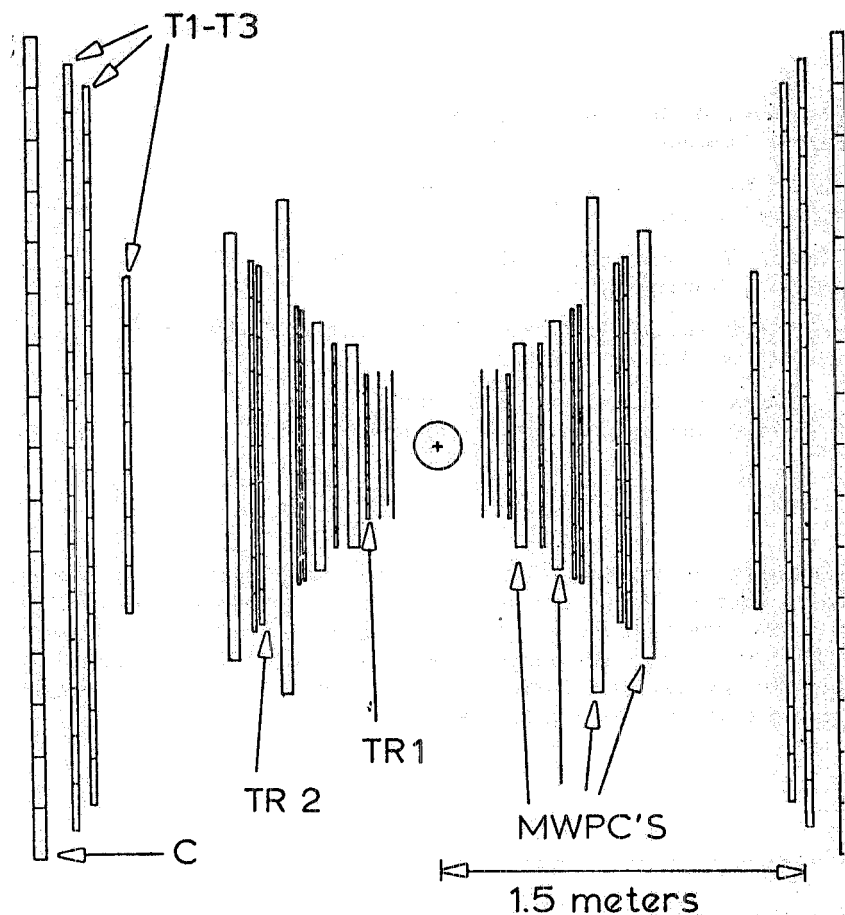


FIG. 1 - Elevation view of the detector showing the two symmetric arms. T1-T3, and TR1 and TR2 are equipped with time-of-flight. The trigger is a hit in layer TR1, either arm, and layers TR2, both arms. Layers C are lucite Cerenkov counters.

angles is from 45° to 90° . Cosmic ray particle properties are inferred from measurements of energy loss in plastic scintillators and velocity measurements by TOF. Good tracking reduces backgrounds from showers and interactions in the detector. The results reported here are from single particle cosmic ray experiments at sea level.

2. - SEARCH FOR QUARKS IN COSMIC RAYS

The charge of particles passing through the detector is inferred from the Bethe-Bloch formula,

$$\frac{1}{\rho} \frac{dE}{dX} = \frac{Q^2}{\beta^2} f(\beta)$$

where $(-1/\rho)dE/dX$ is the energy loss and $f(\beta)$ is a material dependent function slowly varying in the velocity ($\beta = v/c$). The detector is triggered by a particle passing through scintillation layers TR1 and TR2 shown in Fig. 1. All scintillation counters have a photomultiplier tube at each end. For a trigger hit both tubes must have pulse heights above $1/30$ the pulse height of a minimum ionizing $Q=1$ particle. The single counter time resolution is 150 psec. An overall charge resolution of $\pm 3.5\%$ was determined with a sample of clean cosmic ray events. Our cosmic ray quark search analysis procedure is described in detail in Ref. (2).

In a run of 1.5×10^6 sec live-time we find no evidence for particles with either $Q=1/3$ or $Q=2/3$. For this run the detector was located outside but adjacent to the PEP shielding tunnel. That is, only one direction of incidence was shielded. In Fig. 2 the flux limits from this experiment are combined with the limits from a previous run made while the detector was inside the PEP tunnel. The total live-time for all the data reported is 2.3×10^6 sec.

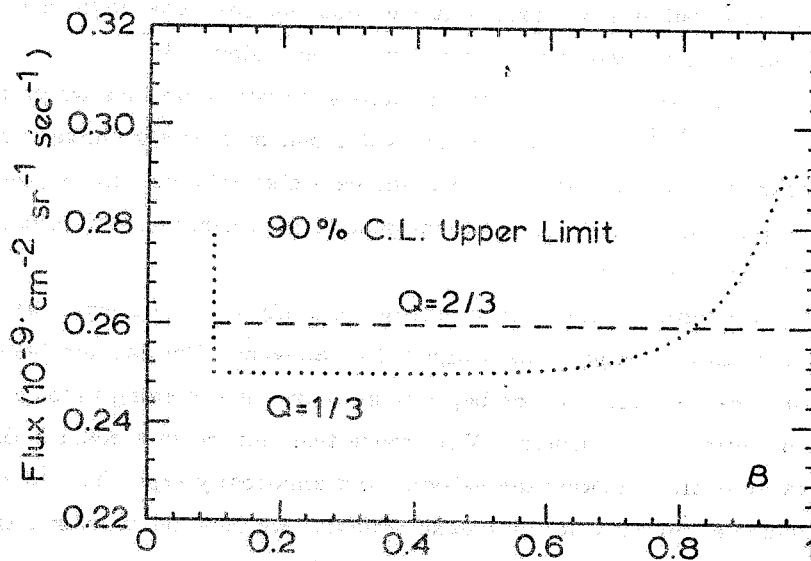


FIG. 2 - Flux limits for particles with charge $|Q| = 1/3$ and $2/3$ as a function of velocity.

Table I compares our results to other searches for quarks in cosmic rays at large zenith angles. We emphasize that the present search is unique because it combines sensitivity over a wide range of zenith angles with sensitivity over a significant range of particle velocities.

TABLE I - Searches for Fractional Charge at Large Zenith Angles.

Expt.	Range of Zenith Angles	Flux*		Flux*	
		Q = 1/3	β	Q = 2/3	β
Ref. (3)	$45^\circ \leq \theta \leq 90^\circ$	$\leq 2.3 \times 10^{-10}$	$\beta \approx 1$	----	----
Ref. (4)	$75^\circ \leq \theta \leq 90^\circ$	$\leq 1.7 \times 10^{-8}$	----	$\leq 1.7 \times 10^{-8}$	----
Ref. (5) ⁺	$\theta \approx 84^\circ$	----	----	$\leq 5.1 \times 10^{-8}$	$0.5 \leq \beta \leq 0.9$
This expt.	$45^\circ \leq \theta \leq 90^\circ$	$\leq 2.9 \times 10^{-10}$ $\leq 2.5 \times 10^{-10}$	$0.6 \leq \beta \leq 1.0$ $0.1 \leq \beta \leq 0.6$	$\leq 2.6 \times 10^{-10}$	$0.1 \leq \beta \leq 1.0$

* $\text{cm}^{-2} \text{sr}^{-1} \text{sec}^{-1}$ 90% c.l.

+ This experiment was designed to detect slow massive particles. Though pulse height information was retained, efficiencies and results for fractional charge were not discussed.

3. - SEARCH FOR TACHYONS IN COSMIC RAYS

Several cosmic ray experiments have searched for particles traveling faster than light (tachyons) since it was first pointed out that their existence is not ruled out by the equations of relativity. Nearly all the searches sought to discover charged particles preceeding the relativistic front of air showers originating high in the atmosphere⁽⁶⁾. Positive evidence has been reported by some authors but none of these observations were confirmed by subsequent experiments and sources of systematic errors have been identified⁽⁷⁾.

To our knowledge, there are only two previous tachyon searches which attempted to directly measure velocity^(8,9). Both used a time-of-flight method and large area plastic scintillators. The results of Ref. (8) apply to charged particles with velocities greater than 1.6 c which are able to deposit 24 MeV/cm in three plastic scintillators. The flux limit obtained was $\Phi_t \leq 2.2 \times 10^{-5} \text{ cm}^{-2} \text{sr}^{-1} \text{sec}^{-1}$.

Since charged particle velocity is measured directly in our detector we simply search for tracks with anomalously high β as a signal for tachyons. The largest background is due to ordinary cosmic ray particles which begin to shower while passing through the detector producing multiple hits in the counters. With more than one hit in a counter the inferred counter hit will be early in time making the velocity systematically high. To reduce this background and to insure accurate velocity measurements, we require at least 8 time measurements along the track and not more than 2 hits in TOF counters not associated with the

track. Fig. 3 shows the velocity distribution from a hour long run before and after the above

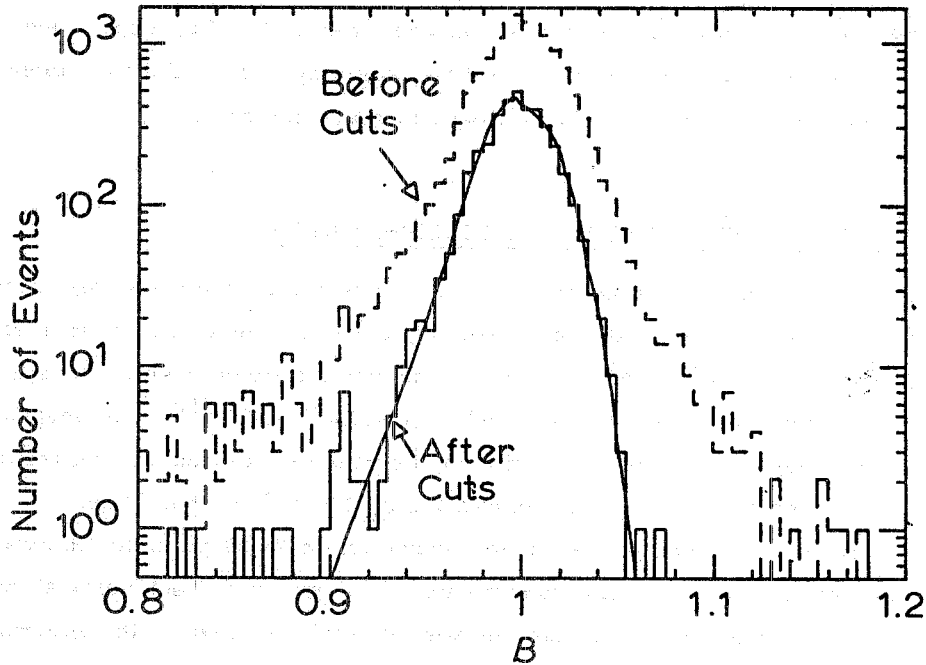


FIG. 3 - Velocity distribution from a one hour run. The smooth curve is a fit to a gaussian plus an exponential. The data after cuts is consistent with a gaussian tail at high velocities.

cuts are applied. The final distribution has a tail toward low velocities expected from slowly moving cosmic ray particles. After the cuts the high velocity region of the distribution is consistent with a gaussian shape. The full-width-half-maximum of the gaussian is 0.042 giving a velocity resolution of $\pm 1.8\%$.

For a run of 8×10^5 sec we observe 6 events with velocity greater than 1.1 c and none above 1.2 c. If the resolution is gaussian we expect only ≈ 0.04 events above 1.1 c. Examination of the events above 1.1 c shows that in each case, a shower developed but it stayed close enough to the particle path to pass the imposed cuts. The shower is clearly indicated by the dE/dX distribution along the track. Although we believe that these events are due to ordinary particles, we exclude the region of β from 1.1 to 1.2 for determining the flux limit. The cuts for the tachyon search reduce our acceptance to 1.2×10^3 cm^2 sr. Thus we obtain a tachyon flux limit of

$$\Phi_t \leq 2.4 \times 10^{-9} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1} \quad \beta \geq 1.2 \quad 90\% \text{ C.L.}$$

To be seen in our detector the tachyon must deposit at least as much energy as a relativistic $Q = 1/3$ particle. This corresponds to an energy loss of about 0.23 MeV/cm in scintillator plastic. Whether or not the hypothetical tachyon ionizes in plastic scintillator is not

certain. For example, Lemke⁽¹⁰⁾ suggests that the ionization energy loss may be considerably less than that for ordinary minimum ionizing particles. Efficiencies for the trigger and for the analysis of lightly ionizing particles are discussed in Ref. (2). This experiment was carried out while our detector was enclosed by the PEP shielding tunnel. Thus the tachyon must penetrate $\approx 250 \text{ gm/cm}^2$ concrete shielding blocks to reach our detector.

4. - SEARCH FOR MASSIVE PARTICLES IN COSMIC RAYS

A previous cosmic ray experiment⁽¹¹⁾ provides evidence for a singly charged particle with mass $\approx 4.2 \text{ GeV}$ at sea level. Interestingly, there may be evidence for a similar particle produced at accelerators⁽¹²⁾. However, a mountain altitude cosmic ray spectrometer experiment with comparable sensitivity failed to confirm Ref. (11)⁽¹³⁾. The measurements of Ref. (11) were made at sea level for zenith angles near the vertical and velocities in the range $0.48 < \beta < 0.60$. The observed flux is approximately $2 \times 10^{-9} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$.

In an effort to confirm this result we search for massive particles in data obtained while the detector was outside of the shielding tunnel. A 30 gm/cm^2 thick vertical steel absorber $60 \times 60 \text{ cm}^2$ in the center of the detector makes the total thickness of the apparatus comparable to the absorber thickness in Ref. (11).

To search for slowly moving particles we apply the following cuts:

- a) The track must intersect at least 5 TOF counters with hits in both phototubes.
- b) The trigger condition must be satisfied by the intersected TOF counters (layers TR1 and TR2).
- c) The track must pass through the steel absorber.
- d) Average β (determined from a linear fit through the TOF data) must be less than 0.80.

From a total of $\approx 7 \times 10^6$ triggers, these cuts select about 1300 events.

Although we measure dE/dX and TOF as in Ref. (11) we do not follow the previous procedure for determining the mass directly. After studying this method we found a strong correlation between measurement errors in the velocity and the value of the inferred mass because particle ranges vary extremely rapidly with velocity^(14, 15). Indeed this systematic error may be the origin of the apparent positive evidence presented in Ref. (11)⁽¹⁵⁾. In our analysis we fit the TOF data to a function of position along the track with the incident particle velocity as a free parameter. Whenever the track crosses a scintillator, MWPC, or the steel absorber, the change in velocity is calculated from the relation

$$\Delta\beta = \Delta t \left[\frac{1}{e} \frac{dE}{dx} \right]_{\text{avg}} \frac{Q^2}{M} \frac{(1 - \beta^2)^{3/2}}{\beta},$$

where Q and M are the particle charge and mass. Δt is the material thickness, and $(-1/e)(dE/dx)_{\text{avg}}$ is the calculated average loss of a unit charged particle with velocity β ⁽¹⁶⁾.

For a given track we use this procedure to determine if the TOF data is consistent with the particle being a proton. The 230 tracks remaining from our 1300 selected tracks which are not consistent with the proton hypothesis are examined further. Approximately 90% of these are associated with showers or interactions in the detector and not genuine slowly moving particles. All the other events are consistent with being produced by deuterons. (For more details of the procedure see Ref. (15)). Thus we have no evidence for particles with mass any greater than that of a deuteron. We emphasize, however, that if β is too large ($\beta > 0.65$) we are insensitive to the difference between a deuteron and a heavier particle.

We calculate our sensitivity using a Monte Carlo technique. The sensitivity goes to zero at low velocities where the particle does not penetrate the detector far enough to generate a trigger. It goes to zero at high velocities where higher mass particles are indistinguishable from deuterons. The optimum velocity is $\beta \approx 0.51$ where the sensitivity for particles of mass 4.2 GeV is about 90%. The running time with the steel absorber in place was 1.5×10^6 sec. The steel does not cover the entire fiducial volume at the center of our detector reducing our admittance by 20%. Half the particles must pass through the concrete shielding tunnel on one side of the detector, and we include only particles incident from the opposite direction. The resulting flux limit is shown in Fig. 4 compared to the result presented in Ref. (11). Our limit is inconsistent with the flux presented in Ref. (11) if we compare directly.

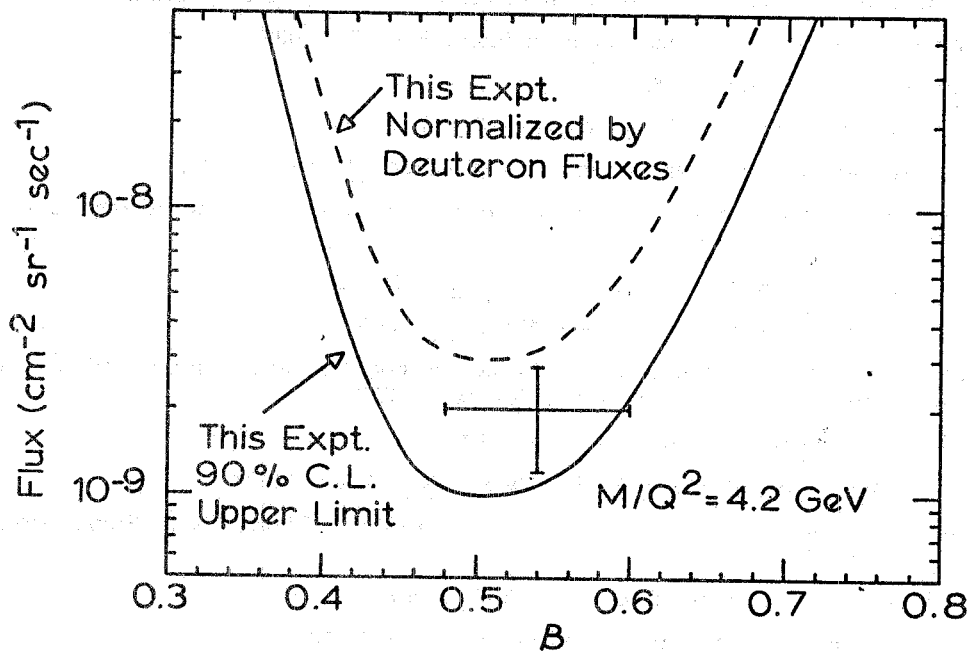


FIG. 4 - Flux limits for unit charged particles with mass 4.2 GeV as a function of velocity. The data point is from Ref. (11).

With our acceptance, running time, and sensitivity, the result presented in Ref. (11) implies that we should have observed four events. The probability of seeing none is less than 2%.

However, the zenith angle dependence of the massive particle flux is uncertain and it may be incorrect to compare the two results directly. For example, if we assume the massive particles have the same zenith angle distribution as deuterons, we can normalize the two experiments based on the observed number of deuterons in each. From Fig. 2 in Ref. (11) we obtain a vertical deuteron flux of $\approx 3 \times 10^{-8} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$. The present experiment obtains a deuteron flux, for $0.50 \leq \beta \leq 0.60$, of $\approx 10^{-8} \text{ cm}^{-2} \text{ sr}^{-1} \text{ sec}^{-1}$. With this relative normalization we expect to see only about one massive particle and the inconsistency between the two experiments is no longer significant. The above comparison is also displayed in Fig. 4.

This research was supported in part by the U. S. Department of Energy.

REFERENCES

- (1) - "A search for exclusive free quark production at PEP", to be published.
- (2) - J. Napolitano et al., to be published in Phys. Rev. D (1982).
- (3) - T. Kifune et al., JPSJ 36, 629 (1974).
- (4) - R. B. Hicks et al., Nuovo Cimento 14A, 65 (1973).
- (5) - P. Franzini and S. Schulman, Phys. Rev. Letters 21, 1013 (1968).
- (6) - For a brief review of searches for tachyons preceding air showers see: L. W. Jones, Rev. Mod. Phys. 49, 717 (1977).
- (7) - J. R. Prescott, J. Phys. G: Nuclear Phys. 2, 261 (1976).
- (8) - F. Ashton et al., Nuclear Instr. and Meth. 93, 349 (1971).
- (9) - H. Hanni and E. Hugentobler, in "Tachyons, Monopoles, and Related Topics", ed. by E. Recami (North Holland Publishing Company, 1978).
- (10) - H. Lemke, Lett. Nuovo Cimento 17, 6 (1976).
- (11) - P. C. M. Yock, Phys. Rev. D22, 61 (1980); D23, 1207 (1981).
- (12) - A. Bussiere et al., Nuclear Phys. B174, 1 (1980); D. Cutts et al., Phys. Rev. Letters 41, 363 (1978).
- (13) - H. B. Barber et al., Phys. Rev. D22, 2667 (1980).
- (14) - F. Ashton et al., Nuclear Instr. and Meth. 95, 109 (1971).
- (15) - J. Napolitano, Ph. D. Thesis, Stanford University (1982; unpublished).
- (16) - A. M. Bakich and L. S. Peak, Nuclear Instr. and Meth. 148, 167 (1978).