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ANTIPROTON LIFETIME MEASUREMENT IN THE ICE STORAGE RING USING COUNTER TECHNIQUE

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ABSTRACT

Results are presented of the search for an antiproton decay into an electron and a neutral pion. Using a stacking scheme based on stochastic cooling an average of 7000 antiprotons was accumulated and stored in the ICE ring for 10 days. No experimental evidence for such an antiproton decay was found. The following lower limit for the antiproton lifetime has been established in the antiproton rest frame:

$$\tau > \mathrm{BR} \times 1700 \text{ h at } 90\% \text{ confidence level (CL)},$$

where BR is the branching ratio for this decay channel.

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According to the CPT theorem the lifetime of particles and antiparticles should be equal. The proton lifetime has been found experimentally to be $> 2 \times 10^{30}$ years [1]. Recently a possible violation of baryon number conservation has however been discussed on the grounds of cosmological models. The relatively small amount of antimatter observed in the universe was used as an argument for a finite stability of the antiproton [2,3].

Some of these cosmological models predict an antiproton lifetime of only a few hours [4]. These predictions can be tested with stored antiprotons. In a previous experiment in the ICE (Initial Cooling Experiment) ring at CERN an antiproton lifetime limit of 32 h was measured [5,6]. In that experiment the antiproton lifetime was measured by following the time behaviour of about 240 antiprotons stored at 2.1 GeV/c in the ICE ring. This method is limited by beam-gas interactions, giving a finite beam lifetime. A direct comparison of proton and antiproton beam lifetime in ICE would have been unreliable, since the change of the magnetic field polarity and the variation of the rest gas composition could have influenced the beam lifetime significantly. Also the long term stability of the stochastic cooling system and of the beam intensity signal was not guaranteed. A way to increase the lifetime limit significantly is the direct search for an antiproton decay [2]. The sensitivity of this method strongly depends on the number of stored antiprotons and the observation time. It is not limited by beam-gas interactions because the ring can be refilled in order to compensate for the losses. The results depend on assumptions for the decay channels and the corresponding branching ratios.

Assuming energy conservation, the antiproton is constrained to decay into lower mass particles, and the only known particles of lower mass are leptons and pions. A possible decay mechanism for the antiproton is quark fusion, i.e. a process in which two (anti)quarks transform into one quark and a negative lepton. The surviving antiquark and quark then lead naturally to a π^0, giving the observable decay into a π^0 and an electron. A similar mechanism is postulated for an hypothetical proton instability, where a branching ratio of about 60% is expected for the two-body decays:

$$p \to e^+ + (\pi^0, \rho, \omega, \eta, \ldots) .$$

The particular decay

$$p \to e^+ + \pi^0$$

should have a branching ratio of the order of 20% [7]. We looked for the two-body decay

$$\bar{p} \to e^- + \pi^0$$

by measuring the total energy of the final state. The antiproton lifetime is then given by:

$$\tau = BR \frac{\varepsilon N t}{n \gamma} \quad (1)$$

where

BR: branching ratio,

ε : total detection efficiency,

N : number of stored antiprotons,

t : measuring time,

γ : Lorentz factor,

n : number of observed events.

In order to obtain a high number of stored antiprotons, it was necessary to cool and stack a large number of antiproton bunches. It was the first time that particles were accumulated in a storage ring using stochastic cooling.

EXPERIMENTAL SET-UP

Antiprotons were produced by 18 GeV protons from the CERN Proton Synchrotron (CPS) impinging on a tungsten target and transported to the ICE ring. For each pulse of protons from the CPS, about 100 antiprotons at 2.1 GeV/c were injected into the ICE ring, where they were stochastically cooled down to a momentum spread of $\pm 3 \times 10^{-5}$, and bunched into one third of the ring by an RF system working at the revolution frequency of the particles. Subsequent pulses of antiprotons could then be injected into the empty space outside the bunch and progressively transferred to the RF bucket by means of the stochastic cooling process. The injection and the storage procedure were repeated at intervals of about 5 min., until a maximum of 1.5×10^4 antiprotons were accumulated in the ring. The average number over a period of 10 days was 7.2×10^3 antiprotons. Transverse stochastic cooling counteracted the blow-up by multiple scattering on the rest gas. The resulting beam lifetime was of the order of 60 h. The intensity and momentum spread of the beam were measured by observing the signal induced in a resonant cavity by the Schottky noise of the circulating particles [6].

The experimental set-up schematically shown in Fig. 1 was composed of four scintillation counters ($20 \times 1 \times 180$ cm^3) positioned around the vacuum pipe, and two linear arrays each of eleven lead-glass total absorption Čerenkov (Č) counters ($15 \times 15 \times 35$ cm^3). The detectors were surrounded by fourteen scintillation counters ($60 \times 50 \times 0.5$ cm^3), which externally covered the total 4π solid angle in order to veto spurious cosmic-ray events in the final analysis.

The lead-glass detectors and external counters were separated by 8 radiation lengths (R.L.) of lead to prevent leakage of electromagnetic showers. Location and total energy determinations were made only from the lead-glass shower counters.

Twelve of these lead-glass counters had a built-in radioactive source (NaI + Am impurities) and were calibrated separately in a test beam at the CERN PS. The lead-glass counter linearity was checked up to 2 GeV, and the FWHM fractional resolution was $\sim$ 15% at E = 1 GeV. The equivalent energy of the sources was of the order of 1 GeV. These counters were used in the final mechanical assembly to measure the cosmic ray energy losses and to calibrate the other counters. Taking into account the counter resolution and the 10% accuracy of the calibration, the total energy was measured with a precision of ±14% at 2.3 GeV.

During the measurement the 12 radioactive sources were removed to avoid accidentals in the energy region characteristic of the antiproton decay. The variation of the response of the Č shower detector throughout the experiment was checked by recording the energy losses of cosmic rays crossing the counter. The rate of each scintillation counter was checked during the entire experiment.

TRIGGER

The trigger logic required that:

a) at least one internal scintillation counter fired,

b) at least ∿ 50 MeV was deposited in each one of the two linear arrays of Č counters.

The pattern of all counters that had fired was recorded on magnetic tape for each event together with pulse-height information for the Č counters and time of flight between the two sides for the four internal counters. The trigger rate was ∿ 1 event/sec, giving a total of ∿ 10^6 events recorded on magnetic tape.

A Monte Carlo calculation, which took into account the experimental set-up and the parameters of the ICE ring allowed us to establish the selection criteria to distinguish possible antiproton decays. The calculation has shown that most of these decays share the energy between the two rows of counters (Fig. 2a). For this reason the criteria used to select candidates were:

i) No external counter had fired. Only 1% of the events survive owing to the inefficiency of the veto system or to the interaction of neutral cosmic rays in the lead-glass.

ii) One of the internal scintillation counters in the horizontal plane had fired.

iii) More than 250 MeV was deposited in each row of counters.

iv) The total energy was between 1700 MeV and 2900 MeV.

Because the total energy was measured, decays in which one γ of the π^0 decay escapes could also be detected and are included in the detection efficiency calculation. Figure 2b shows the bidimensional energy distribution for the two opposite rows of Č counters for the events satisfying the conditions (i) and (ii). In fig. 3 the two events are shown that satisfy the conditions (i) to (iv) and must be considered as two possible decays. The over-all detection efficiency, determined by the Monte Carlo calculation taking into account the energy resolution of the lead-glass detector and the criteria used to select candidates, was 0.45%.

BACKGROUND

Three types of background might simulate events satisfying the imposed conditions.

a) Cosmic-ray background

This background has been measured in a separate run without the beam circulating. After 15 days of running, 4 events were measured, corresponding to 2.7 ± 1.3 events expected in 10 days.

b) Annihilation of antiprotons in flight

During the measurement the vacuum in the experimental straight section was about 3×10^{-10} Torr with 90% H_2 + 10% N_2. A total number of $\sim$ 15 annihilations in flight were expected. However, taking into account the possible final states of the $\bar{p}p$ annihilation, the solid angle, and the energy requirements used to select candidates, less than one background event is expected.

c) Annihilation of antiprotons lost by the circulating beam

This kind of background is difficult to evaluate, because the beam losses are not uniform around the ring and the cross-section dimensions of the ICE vacuum chamber vary. For example, in the experimental straight section of the ring the vacuum chamber is circular, about 15 cm in diameter, while in the following straight section it is of square cross-section with 5 cm sides.

At the end of the measurement the circulating beam of about 1.2×10^4 antiprotons was destroyed by gradually inserting one scraper into the beam. During the beam-killing 4 events were recorded with total energy between 1 GeV and 1.6 GeV. The number of events of this kind expected during normal data taking in the same time interval ($\sim$ 30 sec) is $\sim$ 1. However, not one of these four events satisfied the criteria used to select the candidates for an antiproton decay.

CONCLUSIONS

Two events corresponding to possible decays have been observed. However ∿ 2.7 similar events were expected from cosmic rays. To give a lower limit for the antiproton lifetime we neglect the other possible sources of background and consider the possible statistical fluctuation in the number of observed events and expected cosmic-ray background events. Assuming a Poisson distribution for the decays and the cosmic-ray events we require that the probability of observing 2 or less than 2 decays and 4 or more than 4 cosmic-ray events should be 10% [8]:

$$p(n < 2,\ n_{CR} > 4) = 10\%\ ,$$

where n = number of observed events in 10 d of measurement and n_{CR} = number of observed cosmic-ray events in 15 d of measurement. This condition corresponds to a curve in the μ_D, μ_{CR} plane, where μ_D and μ_{CR} are the average number of decays and cosmic-ray events. The maximum μ_D corresponding to this 90% CL line is 1.8. Using this number in the expression (1) we get a lower limit:

$$\tau > \mathrm{BR} \times 1700\ \mathrm{h\ at\ 90\%\ CL}\ .$$

We point out that the main limitation of the experiment was the relatively low number of antiprotons stored in the ICE ring. In the near future beams with more than 10^{11} antiprotons will be produced at CERN, and it will be possible to repeat this search far beyond the present limit.

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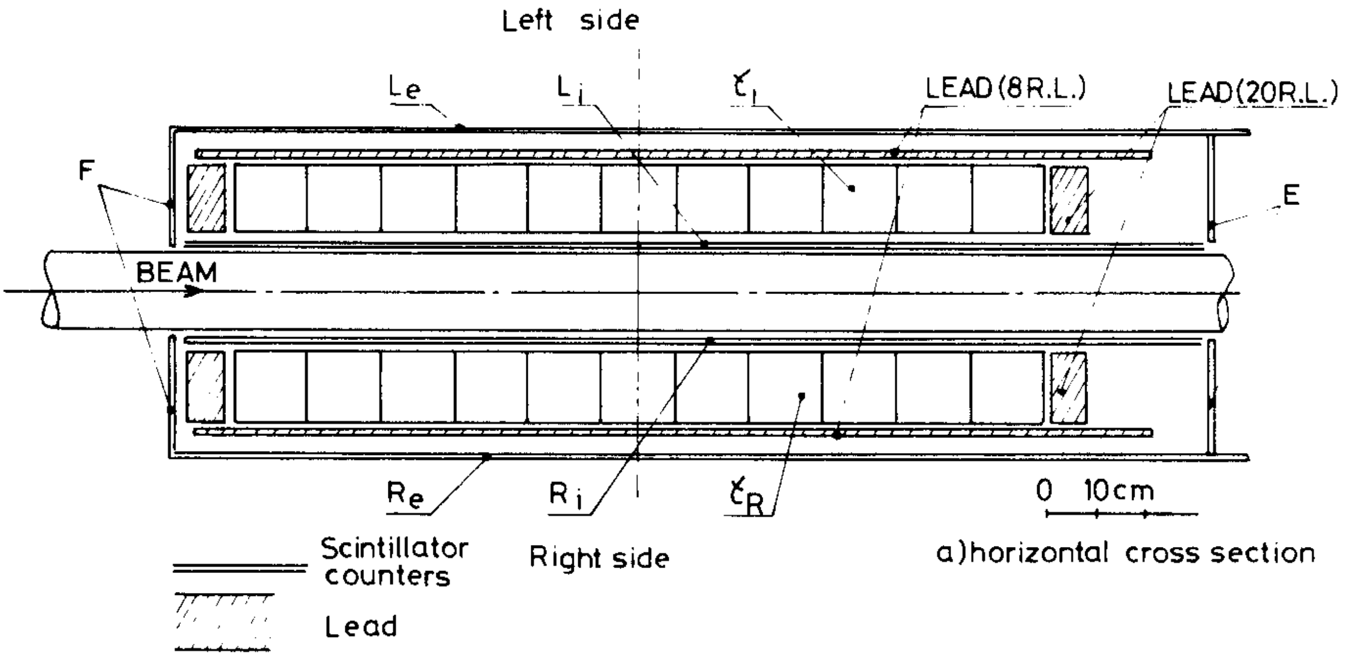
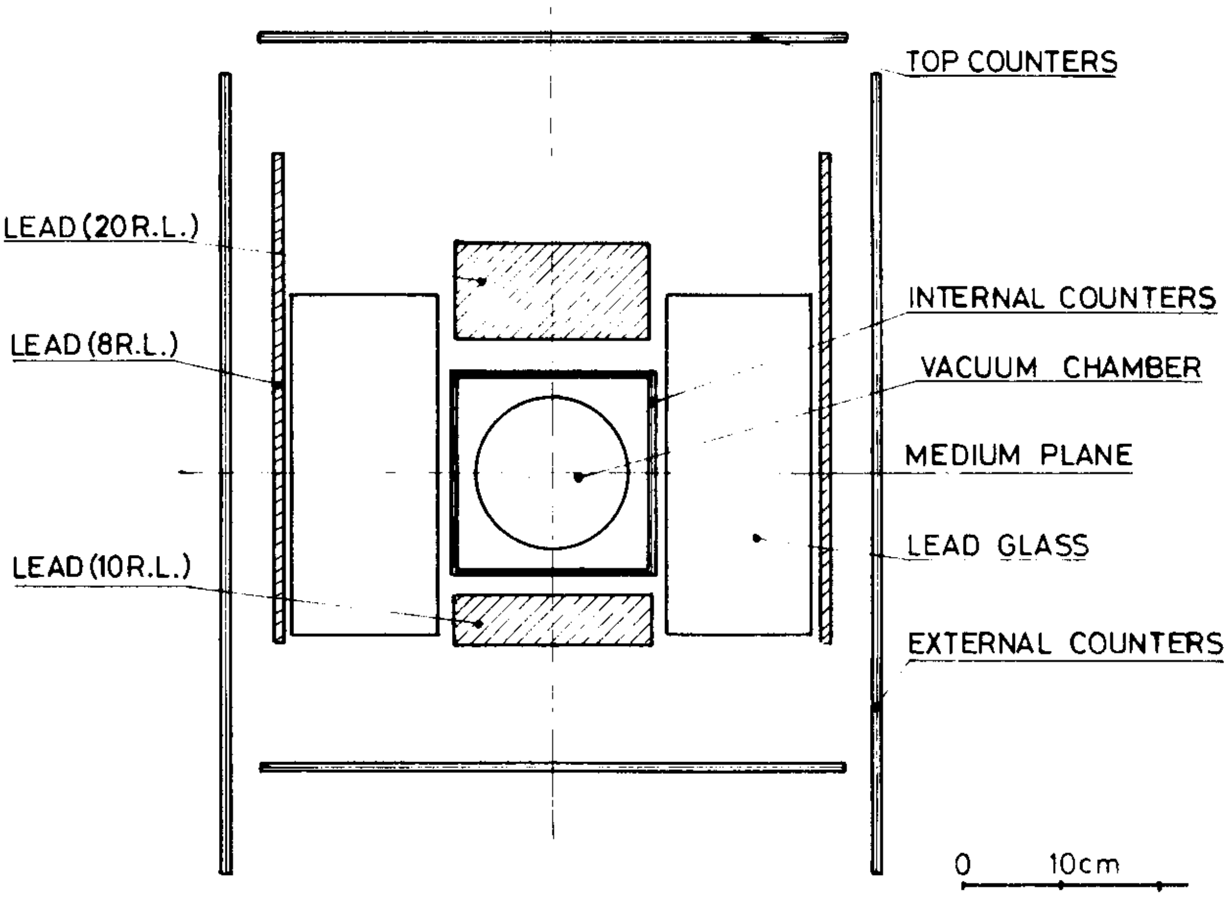
Figure captions

Fig. 1 :	Experimental set-up for antiproton lifetime measurement.
Fig. 2a :	Scatter plot of energy losses in the two rows of $\check{C}$ counters obtained with a Monte Carlo calculation for the assumed decay $\bar{p} \to e^- + \pi^0$.
Fig. 2b :	Scatter plot of energy losses in the two rows of $\check{C}$ counters for all the recorded events satisfying conditions (i) and (ii). The enclosure corresponds to conditions (iii) and (iv).
Fig. 3 :	Pattern of the two events satisfying conditions (i) to (iv).



a) horizontal cross section



b) Vertical cross section perpendicular to circulating beam

FIG. 1

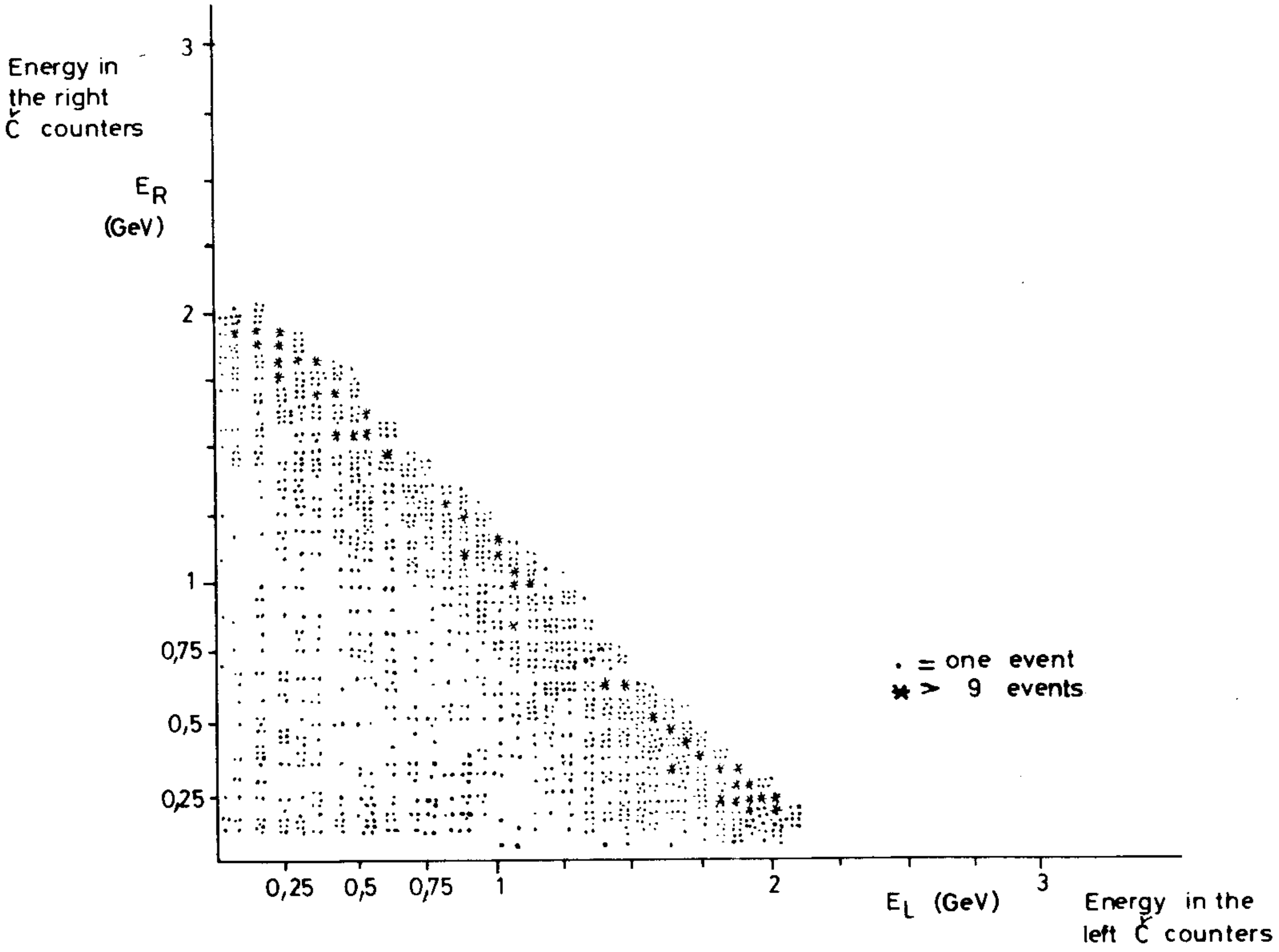

Energy in the right Č counters
E_R (GeV)
3
2
1
0,75
0,5
0,25
0,25
0,5
0,75
1
2
3
E_L (GeV)
Energy in the left Č counters
· = one event
✱ > 9 events

FIG. 2a

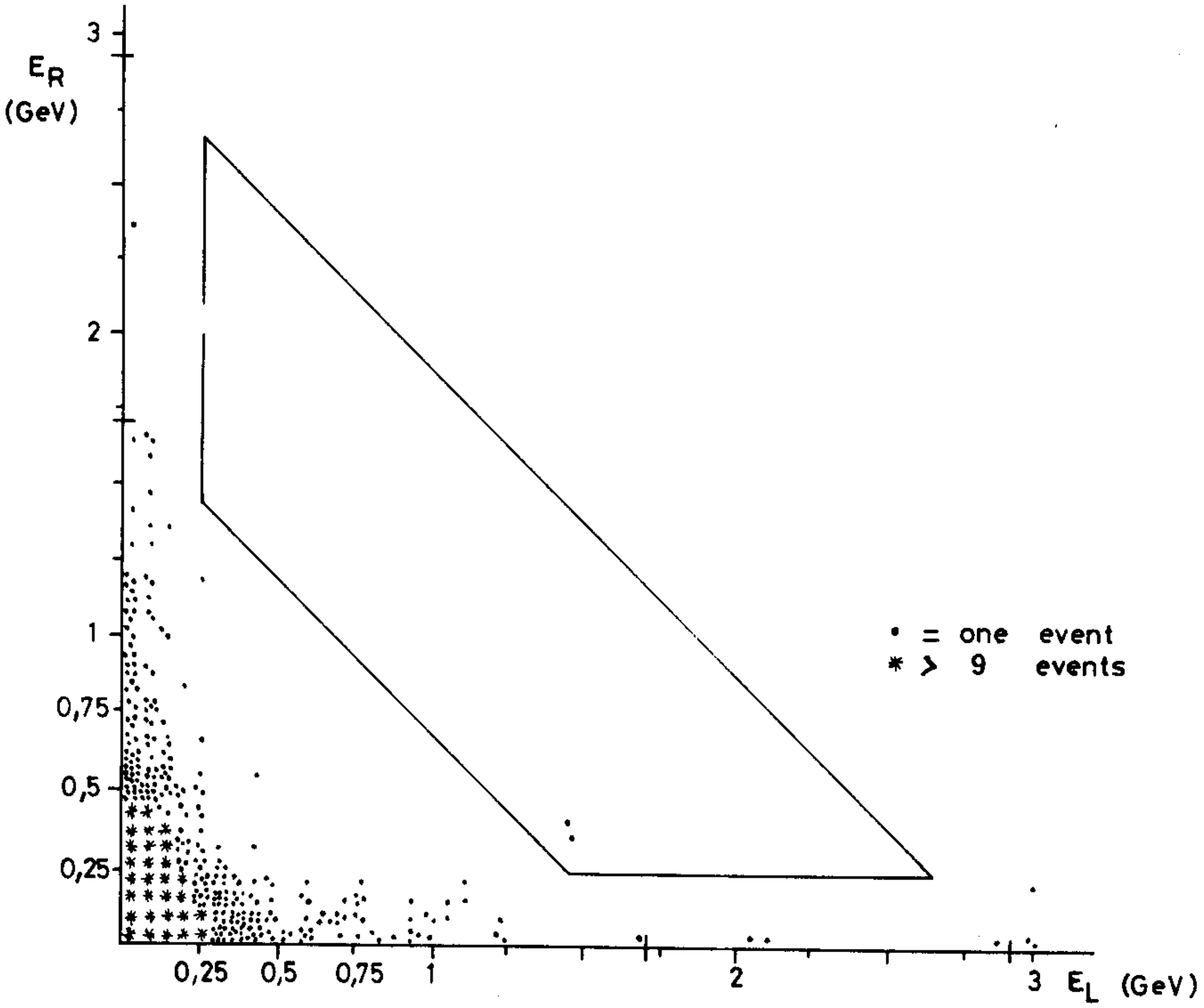
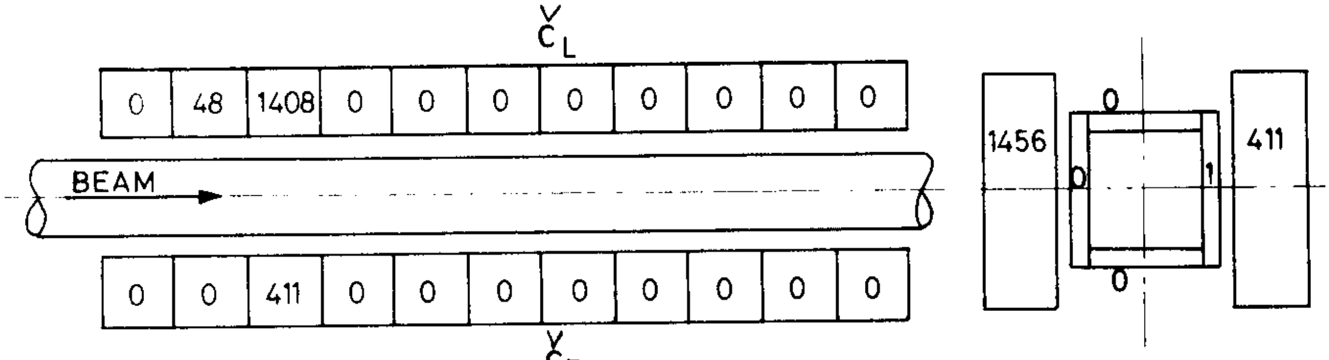
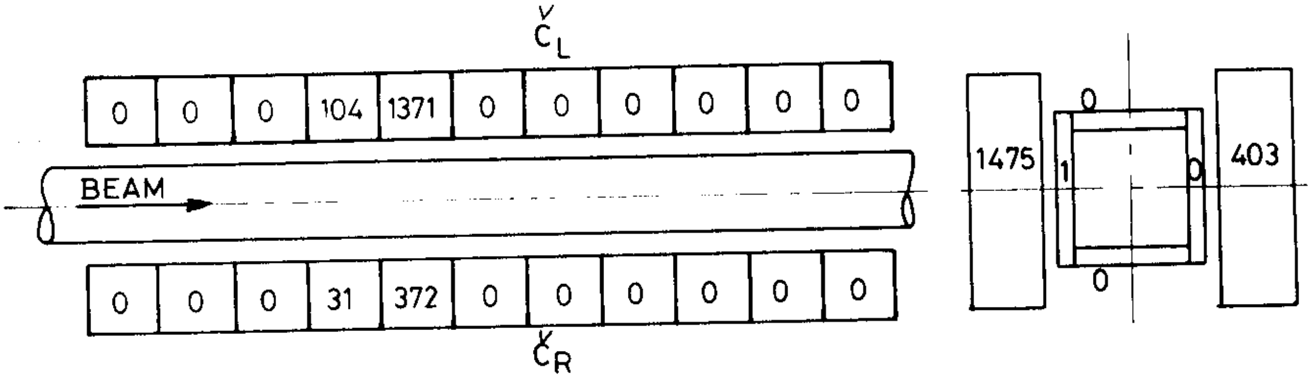


FIG. 2b



Energy deposited in the left Č: 1456 MeV
Energy deposited in the right Č: 411 MeV



Energy deposited in the left Č: 1475 MeV
Energy deposited in the right Č: 403 MeV

FIG. 3