EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH
CERN

AC/DI/FA/Note 92-07
PS/BD Note 92-04
SL Note 92-67 (BI)

LHC Note 212

PRELIMINARY STUDIES ON BEAM-LOSS DETECTORS FORESEEN FOR LHC

J. Bosser, L. Burnod, G. Ferioli, J.B. Jeanneret

Abstract

Beam loss detectors will have to play an important role in the quench protection of the superconducting LHC magnets. At the nominal energy of 7.7 TeV, the quench level is expected to be as low as 10^7 protons lost per second per magnet.

This paper describes a proportional ionisation chamber, mounted outside the cryostat, as a promising candidate for beam loss detection.

November, 1992

1. INTRODUCTION

The future LHC accelerator [1] will have superconducting magnets and even fairly small beam losses will induce quenches which significantly perturb the operation. The beam loss detector (BL) system will then have to play an important role.

The number protons lost per second is estimated to be of the order of 5.10^9 [2], at full intensity and under normal conditions. When operating at full energy, if about 10^7p/s are lost over one meter of a bending magnet, the latter will quench. In consequence, a beam cleaning system is foreseen [2] to reduce the number of particles hitting the superconducting magnets.

A surveillance of the beam loss behaviour is an indispensable diagnostic. Moreover, if for any reason the losses exceed a given threshold, the BL system must be able to trigger the beam dump in less than 2 or 3 revolution periods.

According to computer estimations, the present BL detector, used at SPS (and named SPSBL) will not have the required sensitivity. Therefore a new type of detector, based on the principle of ionization proportional chambers, has been launched and tested (called LHCBL in the following)..

In the next section some estimates and results of measurements are given. From these numbers we can come to some preliminary conclusions on the beam loss system project itself and on the future work and improvements.

Emphasis has been put on BL detectors using gas ionization. They are simple and their good reliability is an important criteria of their choice. The detectors are foreseen to be installed close to, but outside the magnet cryostat, such that :

- their location can easily be changed,
- their maintenance is easy,
- thermal and technical difficulties which occur when the detector is inside the cryostat (due to cable feed throughs) are avoided.

The total number of BL detectors is 1300, including those requested for the transfer lines.

2. LOSS ESTIMATES AND PRELIMINARY MEASUREMENTS.

First of all, we will try to estimate the sensitivity one may expect from ionization chambers. Following this section the results of measurements made in the SPS and in the laboratory will be given and commented. Taking into account the numbers given by computer simulations, it will be possible to check if the proposed detectors are able to cope with the various modes of operation.

2.1. Estimate of the charge collected from ionization beam loss detectors.

2.1.1. Losses induced by one traversing particle

Let us express the losses in gray (Gy), recalling that 1 gray = 1 joule/kg = 100 rad. The energy deposited in a volume $V=\pi.r^2.l$ (see Fig 1) of specific weight ρ(kg/m^3 or gram/litre) by "g" gray is therefore given by:

$$dE=g\,.\,\pi\,.\,r^2\,.\,l\,.\,\rho$$

If the ionization of one electron-ion pair requires an energy W (eV) then, the number N, of ionized pairs will be:

$$N=\frac{dE}{W}=\frac{g(\pi.r^2.l)\rho}{W}$$

this will result in a collected charge Q [C] = N.e.

Example 1: Let us consider a beam loss detector foreseen for LHC (LHCBL). Argon: W=27eV, ρ= 1.78 gramme.dm^{-3}, r=4 cm, l=0.5 m.

$$\frac{Q}{g}\ [C/Gy]=q_g= 1.657\,.\,10^{-4}$$

Example 2 : The FNAL detector, filled with argon, has the following dimensions: r= 2 cm, l= 0.1 m. Then :

$$q_g\ [C/Gy]= 8.285\,.\,10^{-6}$$

in their report they mentioned : 7.10^{-6} C/Gy .

Example 3 : The SPS beam-loss (SPSBL) has a volume of 1 dm^3 filled with air. W= 35 eV, ρ = 1.29 gram.dm^{-3}. Then :

$$q_g\ [C/Gy]= 3.7\,.10^{-5}.$$

Experiences and measurements have shown that $q_{greal} = 10^{-5}$ [C/Gy]. This gives some confidence in our estimates.

2.1.2. Expected continuous losses

Let us now consider that each lost particle will result in a dose of "g" Gy and that Np particles are lost each second. We then come to an intensity :

$$I\ [A] = Np \cdot g \cdot q_g$$

Example : In LHC, we would like to set the threshold of the detector corresponding to a loss of $Np=10^5$ particles/s on a dipole. Let us assume that a loss of one proton on a dipole corresponds to a dose of $g = 10^{-12}$ Gy at the detector location.

When using the Example 1 we come to a current:

$$I = 16.57\ \text{pA}.$$

This must be compared to the offset current of a good operational amplifier which is of the order of 0.1 pA.

The computed current will give at the output of an integrator of capacity C=50 pF (see Figure 2) a voltage rise ΔV such as :

$$\Delta V = I/C = 331\ \text{mV/s} \text{ which is comfortable.}$$

Taking now Example 2 (with $q_g = 7.10^{-6}$) gives

$$I = 700\ \text{fA}$$

which is not compatible with the present amplifier offset currents. This is due to the small "FNAL loss monitor" volume.

2.1.3. Number of Electron-Ion pairs created by one particle

Let us define by dE/dx the energy loss [eV] per unit length of a particle traversing the beam loss detector. The number of ionized ion-electron pairs will be :

$$n_t = \frac{dE/dx}{W} \cdot d$$

where d is the ionization length. As a consequence, a charge q [C] = n_t . e, per traversing particle, will come out of the ionization chamber.

Example : For Ar: W=27 eV and dE/dx = 2.5 keV/cm , if d=8 cm (see Fig.1 and Ref. [3]) then: $n_t \doteq 740$ electron-ion pairs.

In the case of a proportional chamber having a gain G, one has to multiply this number by G .

Example : G = 1000; then q [C] = $G . n_t . e = 1.2\ 10^{-13}$. In order to obtain 10^{-11}A, one must expect 100 particles traversing the detector per second.

2.2. Measurements made with the SPS and the short LHC detectors

Measurements have been made at the SPS machine and in the laboratory with a radioactive source, to compare the SPS beam-loss detector to a beam-loss detector foreseen for LHC.

The SPSBL consists of a 1 dm^3 chamber, filled with air, acting as a ionization chamber. Its gain is therefore equal to unity. The applied voltage is of the order of 800 Volt.

The LHCBL consists of a coaxial tube. The inner wire diameter is $d_o = 50\mu m$ while the outer diameter is D = 8 cm and its length 0.5 m. It is filled with argon (90%) and CO_2 (10%). The gas flow can be controlled. For voltages larger than 400 V, it starts to work like a proportional chamber with gains which may be in excess of 1000, as required if one wants to detect the LHC losses before the magnet quenches (see 2.3).

The electronic circuit connected to each beam-loss detector is shown in Figure 2. Depending on the necessary electronic gain, different integrating capacity have been used.

2.2.1. Type of measurement made on the beam-loss detectors

Several type of measurements have been made with the LHCBL and the SPSBL detectors tested under the same conditions. They are :

- In the laboratory, without any ionization source, in order to measure the base current, improperly named "noise". This "noise", which occurs at relatively high voltages, is subtracted from all measurements made with any of the ionization sources at the time when we have to compute the gains.
- In the laboratory with a 3.7 10^8 Bq (10 mCi) source put in contact with the detector outer surface.
- In the SPS, when no beam is circulating in the machine and the detectors are therefore submitted to the remanent radioactivity.
- In the SPS, during p-pbar storage, looking at the systematic particle losses due to the halo.

The two latter measurements include of course the remanent radioactivity. Depending on the magnitude of the signal to be integrated, the capacity has been changed in order to get a high or low gain. This will not always explicitely appear in the measured data.

2.2.1.1. *Data*

ADC output	:	1 bit corresponds to V_{bit}= 5 mVolt.
Electronic high gain	:	Integrating capacity C_h of 5 nF.
Electronic low gain	:	Integrating capacity C_l of 1 μF.

Integration time : $\Delta t = 5$ seconds.
Induced radioactivity : 1 mRad; at beam loss-detectors location.
Gas pressure, flow : 1000 mbar, 4 litre/hour.

2.2.2. Analysis of the measurements

For the LHCBL, on Figure 3, four curves are plotted, each one corresponding to the different type of measurements explained in 2.2.1. The abscissa represents the HT voltage, whilst on the ordinate the integrated charges are given over 5 seconds. The equivalent number of bits, also given on the ordinate, are referred to the high gain mode.

On Figure 4 the measured gains, deduced from Fig.3 after subtracting the "noise", are plotted as a function of the high voltage. As previously explained, the gains are referred to the measurements made with the SPSBL, which is considered to have a unity gain. The number of bits related to this unity gain are written on Fig. 3.

From these two figures one can see that for an HT of about 1600 Volts :

- The "noise" level is negligible.
- The gain is about 1000, for any type of measurement. The gains slightly diverge for higher voltages. This can be explained by the effects of the space charge inside the detector due to the slow migrating ions.

2.2.2.1.*Measurements with the artificial radioactive source*

The radioactive source has an activity of 3.7 10^8 Bq. It is reproducible and stable and it is worthwhile putting some emphasis on this type of measurement. Looking at the corresponding measurement of Fig. 3, one can observe a plateau of 40 bits when the HT ranges from 40 to 400 V. This means that $n_{bit} = 40$ is measured when the LHCBL operates without amplification. The integrated charge is then :

$$Q\,[C] = C_h . n_{bit} . V_{bit} = 10^{-9} \text{ coulomb in } \Delta t = 5 \text{ seconds.}$$

The number of primary electron-ion pairs is thus :

$$\frac{dn_t}{dt} = \left(\frac{Q}{e.\Delta t}\right) = 1.25\;10^9 \text{ pairs/s.}$$

We therefore can state that 3.37 electron-ion pairs are generated for one γ emitted by the source. When using the SPSBL (filled with air) we have measured that one γ gives 1.35 electron-ion pairs. The ratio 3.37/1.35 = 2.5 is the relative yield of the LHCBL with respect to the SPSBL one. This will be used later on.

Remarks:

a) These numbers must of course be treated as calibration factors. If one considers that one γ will generate about 100 electrons/cm for a mean traversing length of 4 cm, one comes to 400 pairs ionized by one γ traversing the chamber. The ratio $3.37/400 \cong 8.4.10^{-3}$ represents the fractional part of the solid angle, and the effect of the absorption by the wall, which participates in the process.

b) One has to recall that the unity gain is given by the SPSBL. Therefore, for the HT between 40 and 400V (40 bits on Fig. 3) we have, for the LHCBL, a relative yield of 40/16 = 2.5. For example, from Fig.3, the number of bits, measured when the HT is 2000V, is 7.10^4. The gas amplification is therefore $7.10^4/40 = 1750$, whereas the gain relative to the SPSBL is :
$G = (7.10^4/40) \cdot 2.5 = 4375$.

2.2.2.2. *Some estimations resulting from the p-pbar run*

During a p-pbar run the number of stored particles was 3.10^{11} particles. For an (1/e) lifetime of 48 hours one could expect that $1.89.10^{11}$ would be lost within 2 days or 1.10^6 particles lost per second. We suppose that all these lost particles do hit the collimator in front of the beam loss detector. From Figure 3, when V=2000V, the measurements give a total of 17000 bits integrated over 5 seconds or 3400 bits/s.

At the requested threshold of 10^5 p/s, about 340 bits will be measured. That would be quite comfortable when extrapolated to LHC as far as the induced radioactivity would be the same (or less) than that measured in the SPS.

2.2.3. Additional measurements made with the SPSBL

2.2.3.1. *Calibration with protons*

In view of an absolute calibration, L = 10^{12} protons were made to traverse the ionization chamber [4]. During this experiment 10^{-5} C were measured at the detector output such that :

$$\varepsilon_1 = \frac{Q}{e} \cdot \frac{1}{L} = 62.5$$

is the number of ionized electrons per proton traversing the SPSBL chamber.

2.2.3.2. *Measurements made with stored protons*

During a machine development session, deliberate losses were induced from the stored proton beam. The results are given in Table 1 when the electronics operates in a high gain mode. The last line represents the sum of all measurements and therefore $206.\ 10^{-10}$ is the average value of B/L.

The ratio : $\varepsilon_2 = C_h \cdot (B/L) \cdot (V_{bit}/e) = 3.2$ = ionized electrons/lost protons.

A cross check of ε_2 has been made in the following way. During another run we recorded a continuous loss of 3.10^{11} p over 5.5 hours (or $N_p = 1.5\ 10^7$ protons lost/second), whilst at the ADC output we measured 1.56 bits every $\Delta t = 5$ s. Therefore we came to:

$$\varepsilon_3 = \frac{(1.56 \cdot C_h \cdot V_{bit})}{(e \cdot \Delta t \cdot N_p)} = 3.22 \text{ ionized electrons/lost proton}$$

which is about equal to ε_2 thus showing the coherence between our measurements.

These measurements show that the classical SPSBL is able, in the SPS environment, to measure losses in excess of 10^{10} protons on a collimator placed nearby the detector itself.

L:losses in 10^{10} p	Measured bits:B	B/L (10^{-10})
1.55	300	193
1.43	294	206
1.8	369	205
1.05	227	216
0.8	172	215
6.62	1362	206

Table 1

2.2.4. Influence of the gas flow

Figure 5 gives the influence of the gas flow on the gain, whilst the LHCBL is exposed to the point-like source of $3.7\ 10^8$ Bq.

The nominal flow of 4 litre/hour is stepwise reduced and the gain is recorded as a function of time. One observes that, at a flow of 1 l/h, the reduction in gain is quite acceptable since one comes to a reduction of 5% after about 2 hours.

The LHCBL volume is 2.5 dm^3 so that, at a first approximation, for a gas flow of 1 l/h, we need about 2.5 hours to renew the gas volume .

Also, with a flow of 1 l/h, the number of gas molecules traversing the chamber is:

$$n_{ar} = \frac{\text{Na(Avogadro)}}{\text{22.4 litre}} = 2.69 \cdot 10^{22}/\text{hour} = 7.465\ .10^{18}\ \text{molecules/s.}$$

With the source, according to our previous computations (see Fig. 3 and 2.2.2.1), we showed that 1 emitted γ by the source gives 3.37 primary electron-ion pairs such that, for a gain of 5000, the total number of ionized pairs will be:

$$\frac{dn_t}{dt_i} = 3.37\ .\ n_s\ .\ G = 6.23.10^{12}\,\text{pairs/second}\ .$$

Therefore, the ratio $\frac{dn_t}{dt}$ / n_{ar} is rather small and in fact, the nominal gas flow of 4 l/h looks to be quite large. An improvement could consist in a better choice and cleaning of all the constitutive parts of the beam-loss detector.

2.2.5. Influence of the gas pressure

In addition to the nominal measurements made at 1000 mbar and represented by Figures 4 and 5, additional tests have been made at different gas pressures.

Figure 6 gives the gain and noise when using a pressure of 100 mbar. It shows that the "noise" is relatively high. Only small relative gains can be obtained and that for these gains, the HT margin is quite small . This can be explained by the fact that, since the LHCBL is not hermetic, the external air may leak inside the tube and pollute the gas.

Figure 7 gives the gains measured with a gas pressure of 2000 mbar. This situation is comfortable, but there is no significant improvement with respect to the use of a 1000 mbar pressure.

Consequently, the pressure of 1000 mbar looks to be adequate for our purpose.

2.3. Requested Beam-loss sensitivity for LHC

When at full energy, 10^7 p/s are lost over 1 metre of a dipole, a quench will occur [2]. This means that the alarm threshold may be set for a loss of 10^6 p/s and therefore the expected BLM resolution must be 10^5 p/s, or about 10 protons lost at each LHC turn .

2.3.1. Expected dose induced by one lost proton

Simulations on radiation doses induced by a proton lost on the LHC dipole are reported in reference [5]. From this paper the distribution of the dose absorbed in CH_4 as a function of the longitudinal depth, and represented by Fig. 8, is of interest to us. The impact point of the 8 TeV lost proton is at 5 metres from the origin in the scale of Fig. 8. The maximum dose, of about 5.10^{-12} Gy/p lost, occurs around 2 metres downstream of the impact point. This number is reduced by a factor of 100 after about 10 metres. Assuming the BL detector is located within 10 metres of the impact point, we can take $5.10^{-14} < g < 5.10^{12}$ Gy/p lost.

Another parameter is the volume average fluence Φ. Fig. 9 gives the plot of $d\phi/d(\ln E) = E(d\phi/dE)$ for different types of secondary particles at the position of a beam loss detector. From these curves one sees that the production of photons is relatively important and may influence the choice of the type of detector.

2.3.2. Beam-loss detector sensitivity

As previously seen (see 2.1.1), the SPSBL has a sensitivity : $q_g = 10^{-5}$ C/Gy. The LHCBL with a gain of 1000, with respect to the SPSBL, will therefore have a sensitivity : $q_g = 10^{-2}$ C/Gy. Considering a loss of 10^5 p/s, one obtains a current I at the BL output

$$I = g.q_g.10^5 = \begin{array}{ll} 5.10^{-14} < I[A] < 5.10^{-12} & \text{for the SPSBL} \\ 5.10^{-11} < I[A] < 5.10^{-9} & \text{for the LHCBL} \end{array}$$

In order to be sensitive to a beam displacement of $\cong 1\sigma$ at top energy, following a main or a COD power supply trip, the integration time must be 20 ms. Therefore the measured charges will be

$$10^{-15}\,[C] < Q(SPSBL) < 10^{-13}\,[C]$$

$$10^{-13}\,[C] < Q(LHCBL) < 10^{-10}\,[C]$$

This must be compared with the offset current of a good amplifier which is of the order of $0.1\,.10^{-12}$ A (or 2.10^{-15} C for an integration time of 20 ms).

These results show :

- that the present SPSBL will not have the required sensitivity or resolution and that amplification is needed,
- that the LHCBL may cope with the LHC required sensitivity.

3. ELECTRONIC SYSTEM, FUTURE IMPROVEMENTS

3.1. Electronic system

Basically the electronic system, shown in Figure 10, is the one which is already used in the SPS. The beam loss detector is a current generator and the voltage at the integrator output is :

$$V_S = (1/C) \int I(t)\,dt = (1/C) \int (dQ/dt)\,dt$$

If the cable capacitance is negligible any fast loss will appear in less than 1µs at the integrator output. The output voltage V_S is classically processed by an ADC and memorised. Digital differentiating will permit the retrieval of loss evolution versus time.

Capacity resetting is foreseen to be linked with the general timing system which must therefore be operational during storage.

When V_S exceeds a given threshold, a comparator will generate a signal which may trigger the beam dumping and warn the operators.

Coaxial cables must be used in order to transmit these alarms towards the beam-dumping system in less than 3 beam revolution periods. Post mortem data will be available on a time scale defined by the timing system and the amount of memory.

A test signal can be applied at the integrator summing point. It aims at checking that the electronic and dumping system is working correctly.

Due to the large dynamic range which has to be covered by the beam loss system, studies of charge to frequency converters or log amplifiers are under consideration.

3.2. Other improvements

Tests are underway with a LHCBL type detector of 3 to 6 metres long. This will reduce the geographic incertitude of the loss detection.

Detailed studies of the remanent radioactivity remain to be done, since the consequent effects may partially saturate the detector and therefore hide the loss measurements.

We are also looking at Cerenkov scintillator, solid-state, micro-calorimeter detectors. Their efficiency will depend on the type and energy of the secondary particles, which come out of the shower generated by the lost protons. As a consequence all the simulation programs must give reliable data.

4. CONCLUSIONS.

The use of proportional detectors (LHCBL), with a gain of 1000 , located outside the cryostat should allow us to detect the loss of of 10^5 protons over one metre of a magnet. This means, of course, that an alarm corresponding to a local loss of 10^7 p/s may be issued. The LHCBL can be installed on the exterior of any magnet. Except for the cleaning region, it could be placed upstream and downstream of a quadrupole where the losses are likely to occur (local maximum of $\beta_{H,V}$ and of dispersion D). It is fast enough to trigger the beam-dump system in less than 3 revolution periods. It needs a gas flow at atmospheric pressure.

In the cleaning region, normal losses are of the order of 5.10^9 p/s, the use of the SPSBL detectors, with eventually larger HT voltages in order to reduce the ion collection time, can be foreseen. They will be installed near the scrapers and collimators.

Other methods are under consideration. Nevertheless, in the present state of our knowledge, we may conclude that a solution does exist for the LHC beam loss diagnostic and alarm system.

References

[1] Design study of the large hadron collider (LHC). The LHC Study Group. CERN 91-03. 2 May 1991.

[2] Beam losses and collimation in the LHC : A quantitative approach. L. Burnod, J.B. Jeanneret. CERN SL/91-39 (EA), LHC Note 167.

[3] Radiation detection and measurements. G.F. Knoll, J. Wiley, 1979.

[4] SPS Beam loss monitor system. Description of the system and tests of components. B. Moy, G. Rau, N. Aguilar. LABII-RA/Note/73-9.

[5] The estimation of radiation doses, fluences and spectra from FLUKA code simultions of particles cascades induced by beam losses on LHC dipoles. J.M. Zazula and G. Stevenson. CERN/TIS-RP/IP/92-30.

FIGURE CAPTIONS

FIGURE 1. Definition of the symbols used for the beam loss detectors.

FIGURE 2. Ionization detector and the integrator circuit.

FIGURE 3. SPSBL. Integrated charges (and corresponding number of bits) as a function of the high voltage. Notice the change of scale of V_{HT} at 1000 V. High electronic gain, Gas flow 4 l/h (Pressure 1000 mbar), Integration time : 5 s.

The numbers of equivalent bits measured with the SPSBL are :
a) 16 with the source of 10mCi;
b) 1,56 with p-p bar losses and induced radioactivity;
c) 0.05 with induced radioactivity.

FIGURE 4. LHCBL. High voltage (HT) versus gain. The gain is referred to the SPSBL. Integration time : 5 s, Gas flow 1 l/h, pressure 1000 mbar.

FIGURE 5. LHCBL. Gain as a function of time for different gas flow. Source 10mCi, High Voltage : 2000 V, Integration time : 5 s, Low gain electronic, Gas pressure 1000 mbar.

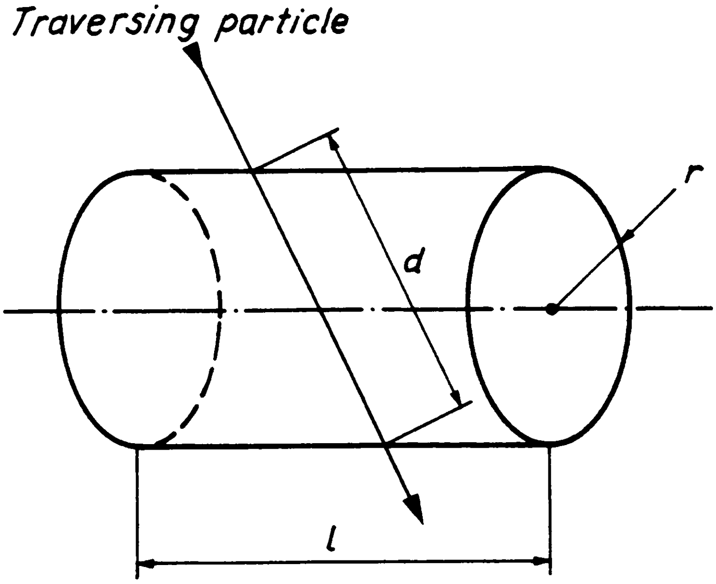
FIGURE 6. LHCBL. Gain (or equivalent numbers of bits) and noise versus high voltages. Source 10 mCi, Gas pressure 100 mbar, High gain electronic, Integration time 5 s. The SPSBL gave 15 bits.

FIGURE 7. Same conditions as for FIGURE 8, but with a gas pressure of 2000 mbar.

FIGURE 8. Longitudinal distribution of the absorbed energy densities at different locations of the LHC dipole (taken from Ref. [5]).

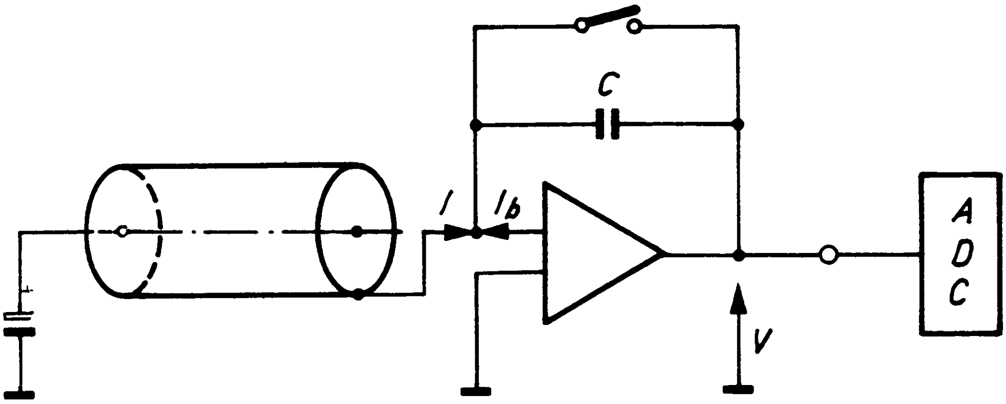
FIGURE 9. Volume averaged fluence per unit logarithmic energy interval, taken at the beam loss detector level, for different types of secondary particles (taken from Ref. [5]).

FIGURE 10. Alarm electronic principle.



Definition of symbols

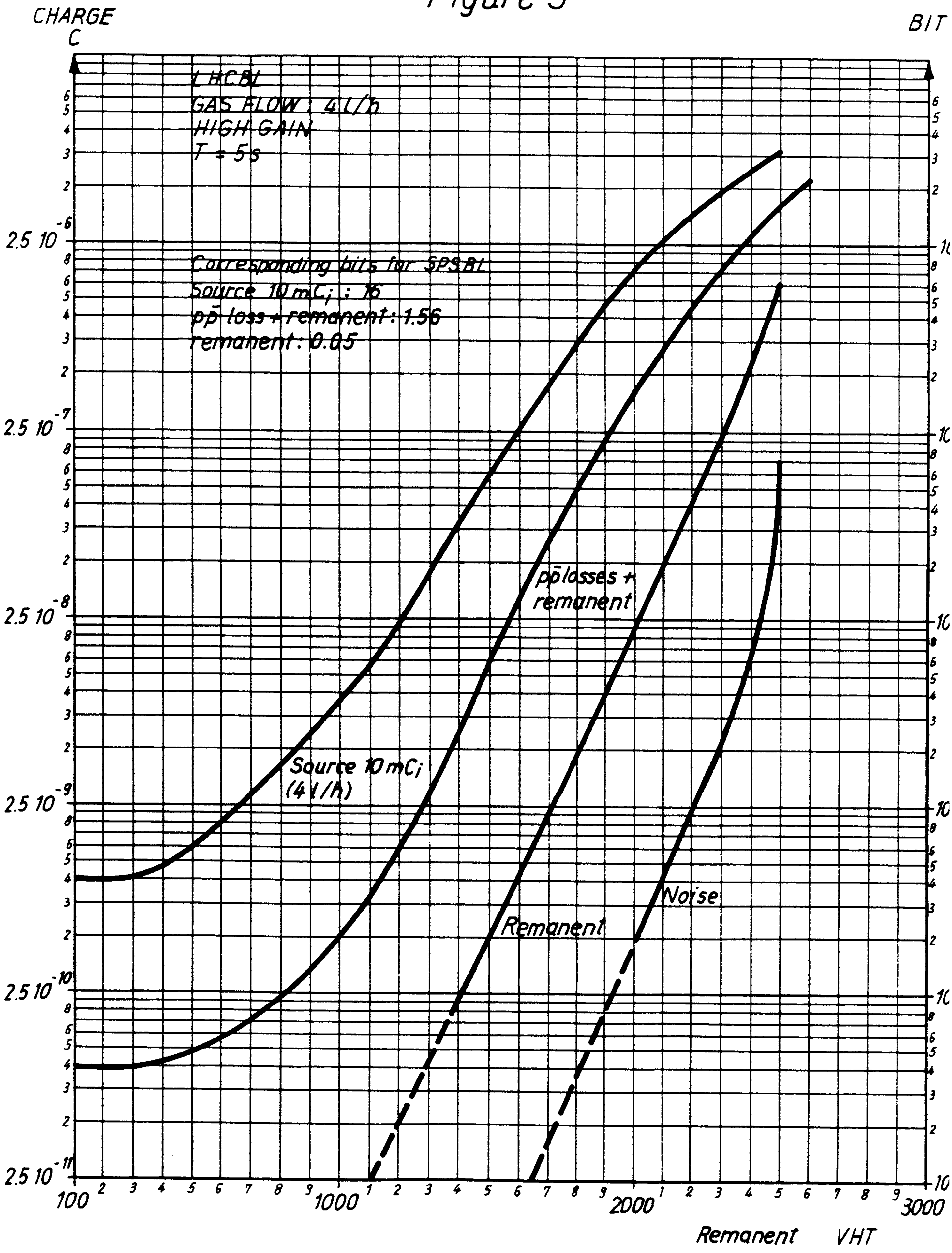
Figure 1



Ionisation chamber and integrator

Figure 2

Figure 3


CHARGE
C
BIT
LHCBL
GAS FLOW : 4 l/h
HIGH GAIN
T = 5s
Corresponding bits for SPSBL
Source 10 mCi : 16
$p\bar{p}$ loss + remanent : 1.56
remanent : 0.05
Source 10 mCi
(4 l/h)
$p\bar{p}$ losses +
remanent
Remanent
Noise
2.5 10^{-6}
2.5 10^{-7}
2.5 10^{-8}
2.5 10^{-9}
2.5 10^{-10}
2.5 10^{-11}
100
1000
2000
3000
Remanent
VHT

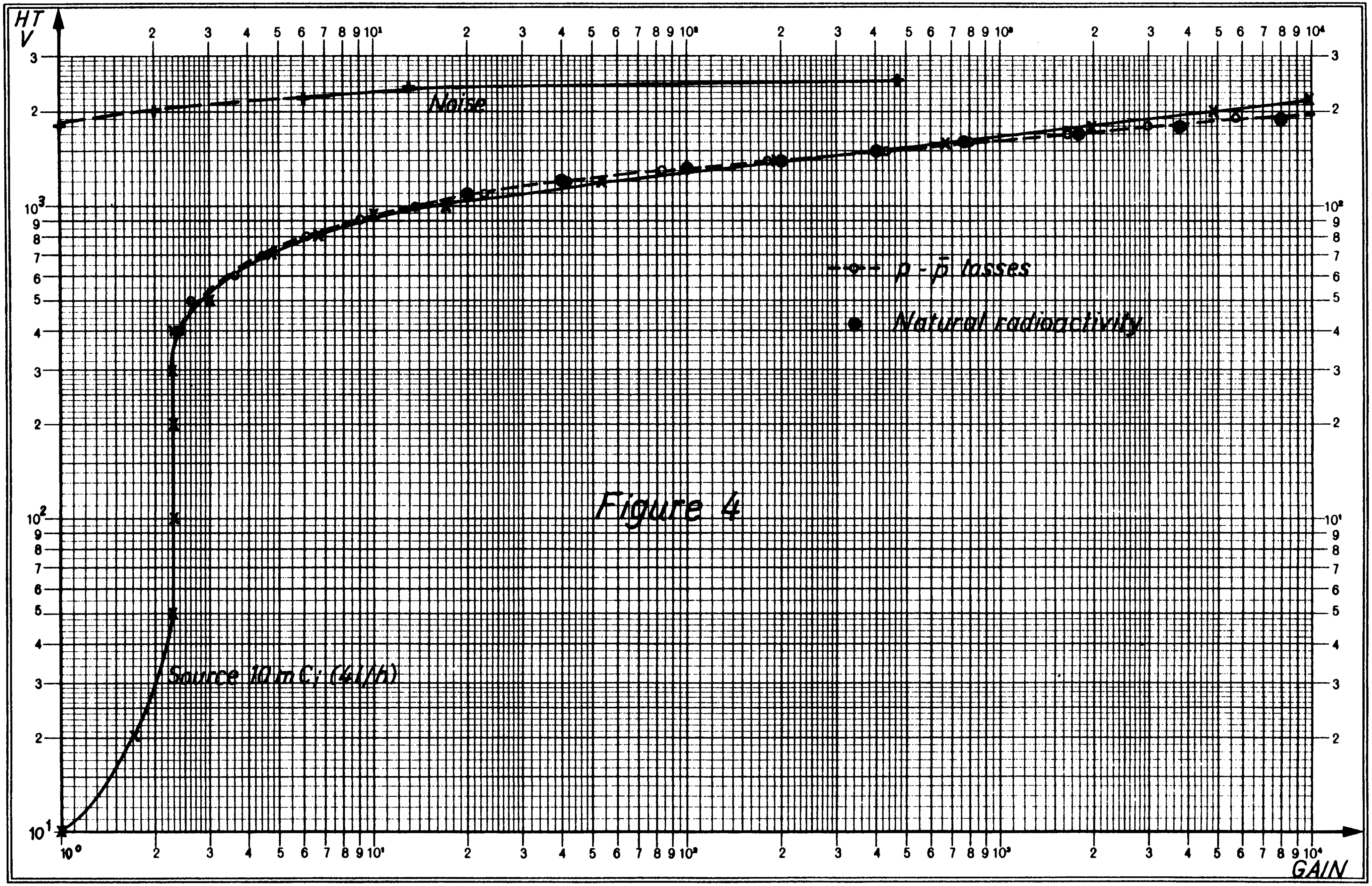

HT
V
GAIN
10^0
2
3
4
5
6
7
8
9
10^1
10^2
10^3
10^4
10^1
10^2
10^3
3
Noise
$- \phi -$ p - $\bar{p}$ losses
● Natural radioactivity
Source 10 mCi (4l/h)

Figure 4

Logar. Teilung / Division } 1-300 u. 1-10000 Einheit / Unité } 62,5 mm
Ed. Aerni-Leuch, Bern, Nr. 551

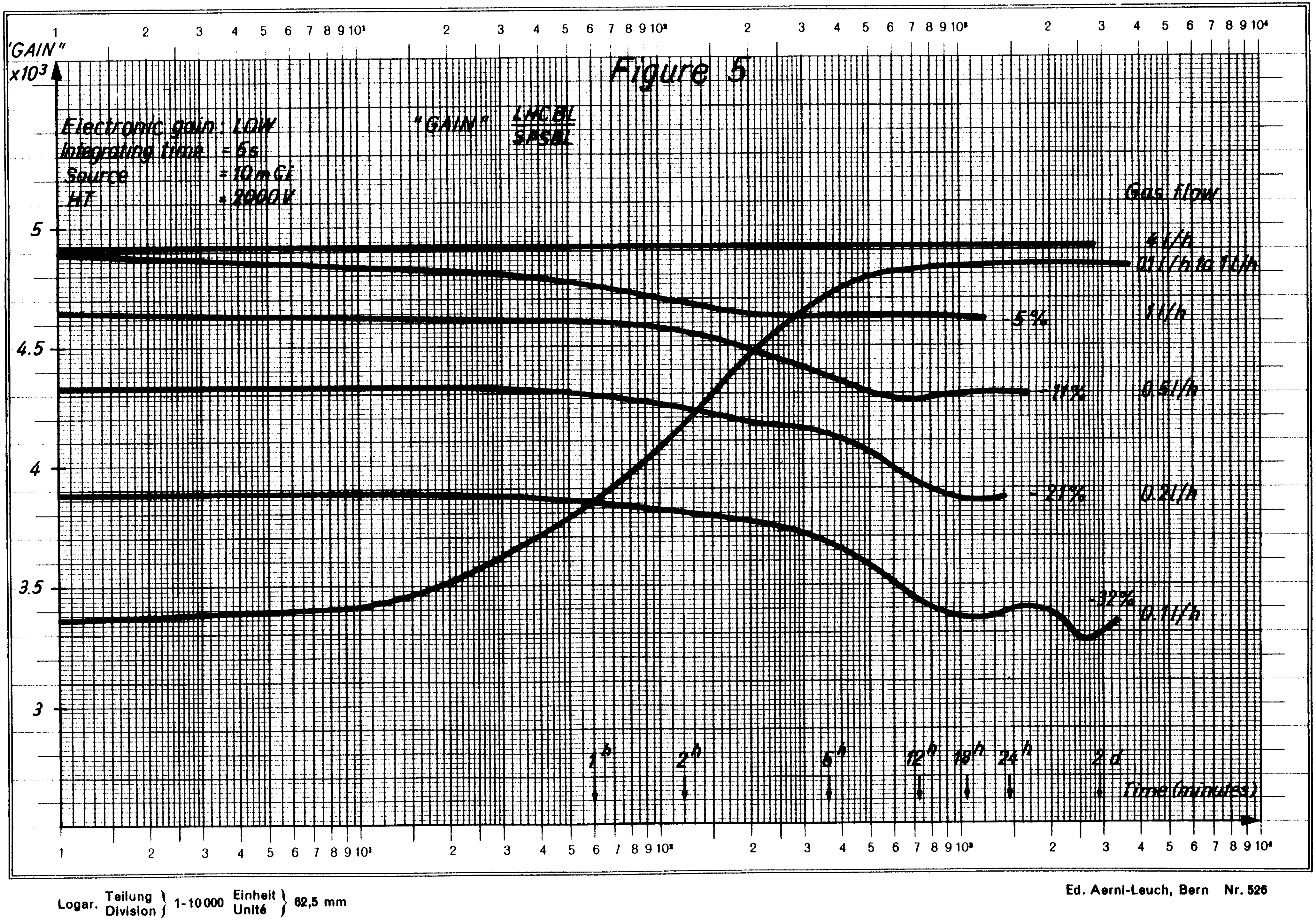


Figure 5

"GAIN" x10³
Electronic gain : LOW
Integrating time = 6s
Source = 10 mCi
HT = 2000 V
"GAIN" LHCBI / SPSBI
Gas flow
4 l/h
0.1 l/h to 1 l/h
-5%
1 l/h
-11%
0.5 l/h
-21%
0.2 l/h
-32%
0.1 l/h
5
4.5
4
3.5
3
1^h
2^h
6^h
12^h
18^h
24^h
2 d
Time (minutes)
1
2
3
4
5
6
7
8
9
10¹
10²
10³
10⁴
Logar. Teilung / Division } 1-10000 Einheit / Unité } 62,5 mm
Ed. Aerni-Leuch, Bern Nr. 526

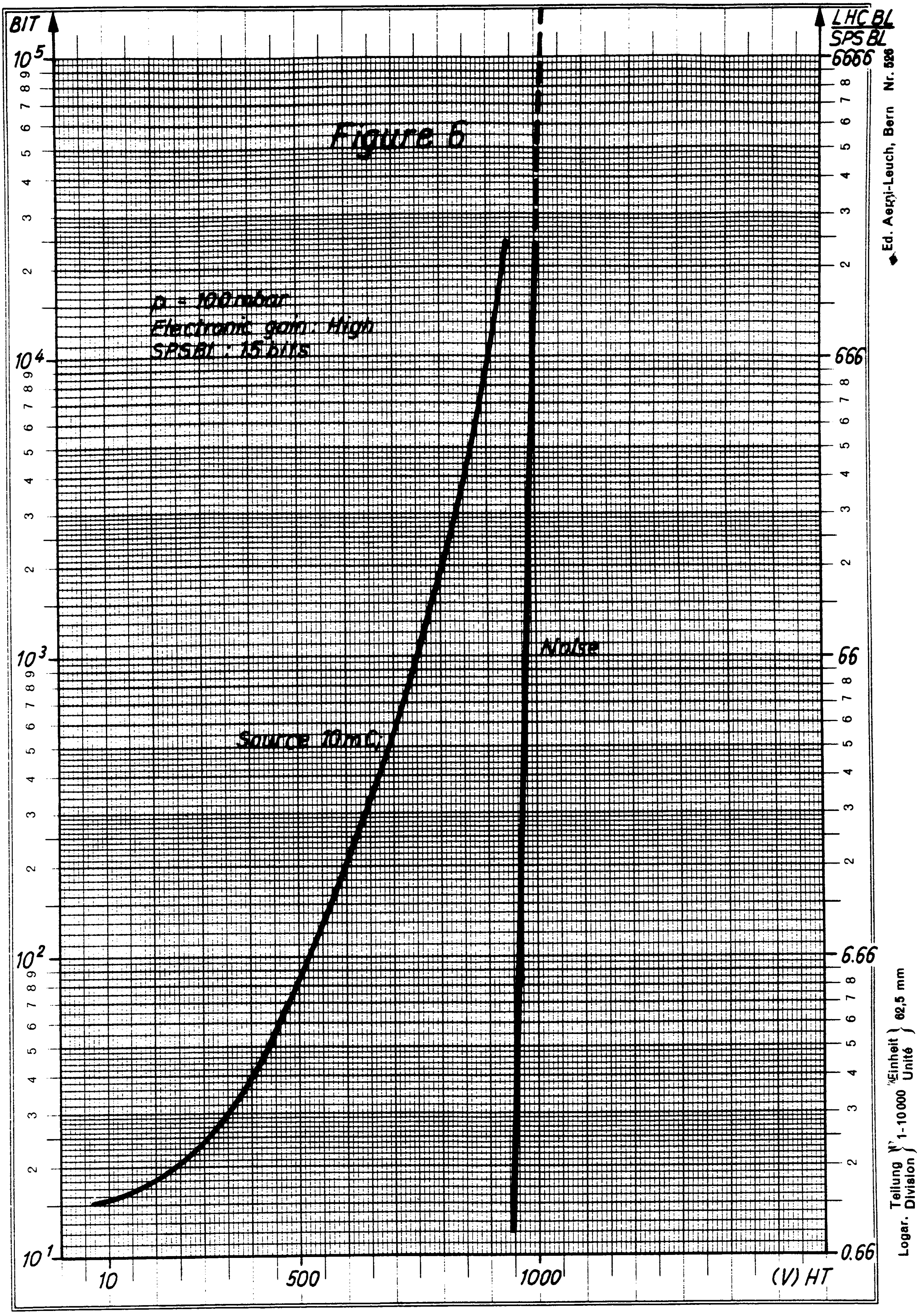


Figure 6

BIT
10^5
10^4
10^3
10^2
10^1
LHC BL / SPS BL
6666
666
66
6.66
0.66
p = 100 mbar
Electronic gain: High
SPSBL : 15 bits
Source 10 mCi
Noise
10
500
1000
(V) HT
Ed. Aerni-Leuch, Bern Nr. 526
Logar. Teilung / Division 1-10000 Einheit / Unité 62,5 mm

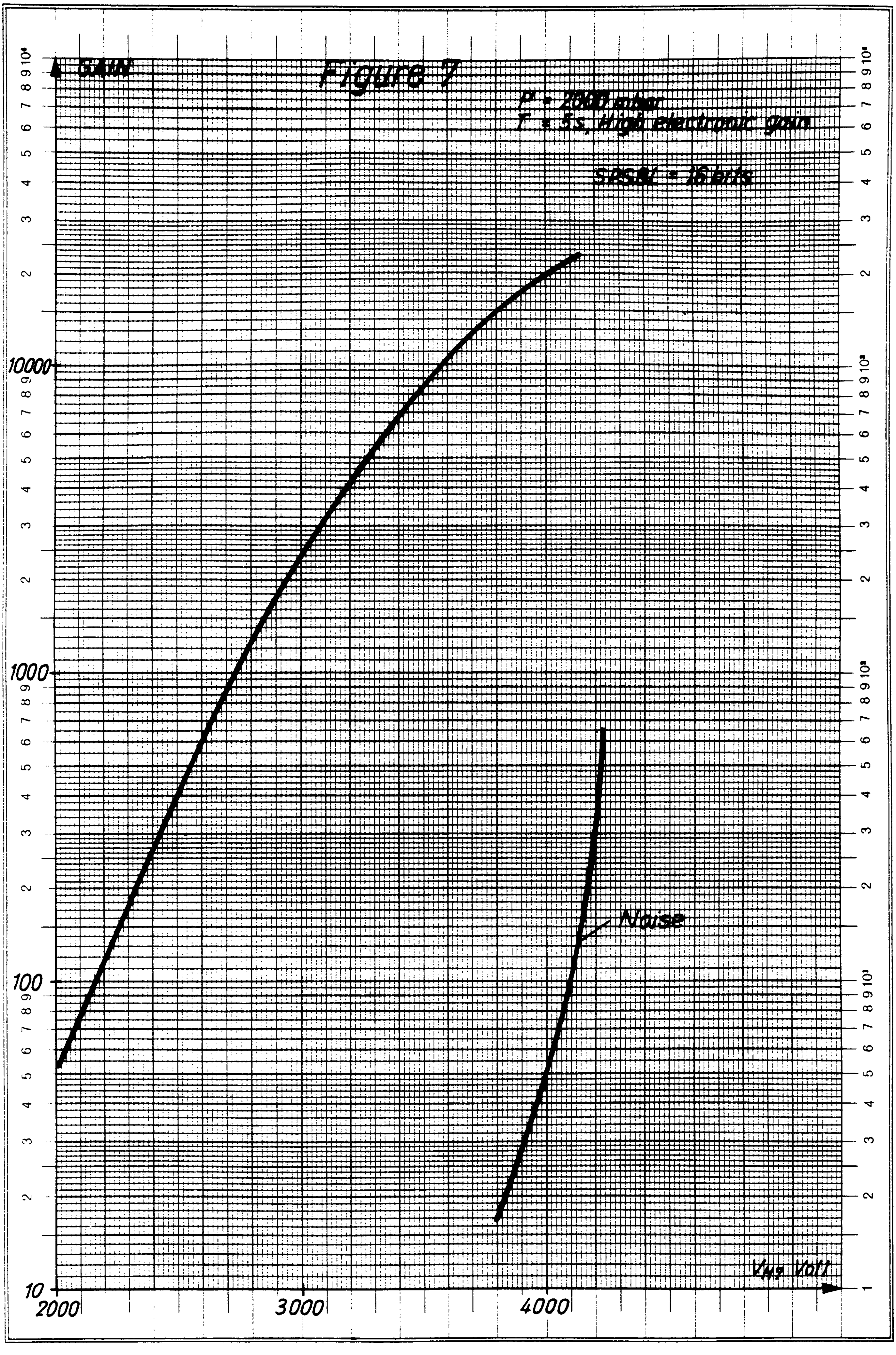


Figure 7
GAIN
P = 2000 mbar
T = 5 s, High electronic gain
SPS.U = 16 bits
Noise
V_HV Volt
10
100
1000
10000
2000
3000
4000
1 2 3 4 5 6 7 8 9 10¹
2 3 4 5 6 7 8 9 10²
2 3 4 5 6 7 8 9 10³
2 3 4 5 6 7 8 9 10⁴

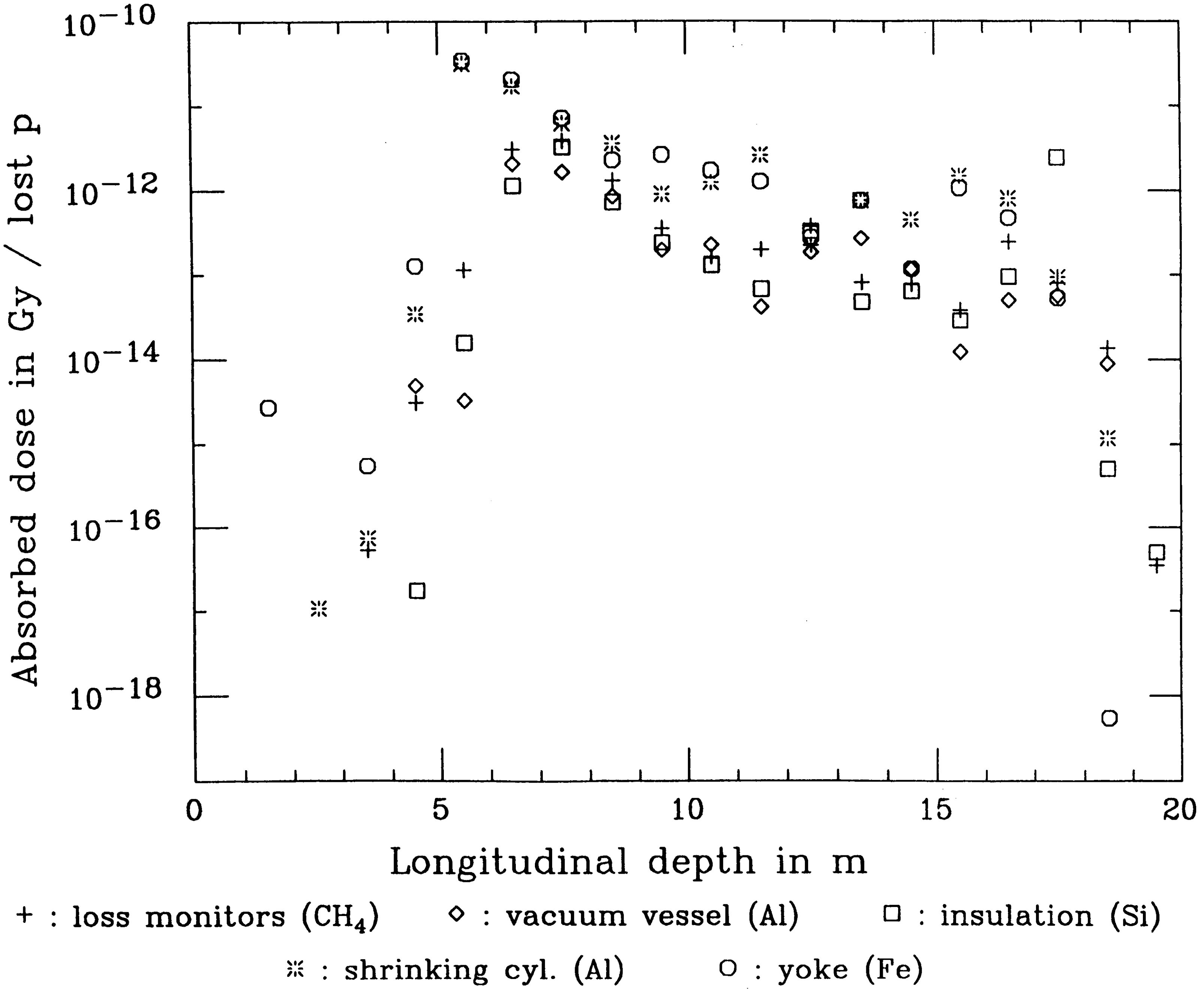

Absorbed dose in Gy / lost p
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
0
5
10
15
20
Longitudinal depth in m
+ : loss monitors (CH_4)
◇ : vacuum vessel (Al)
□ : insulation (Si)
⁎ : shrinking cyl. (Al)
○ : yoke (Fe)

Figure 8

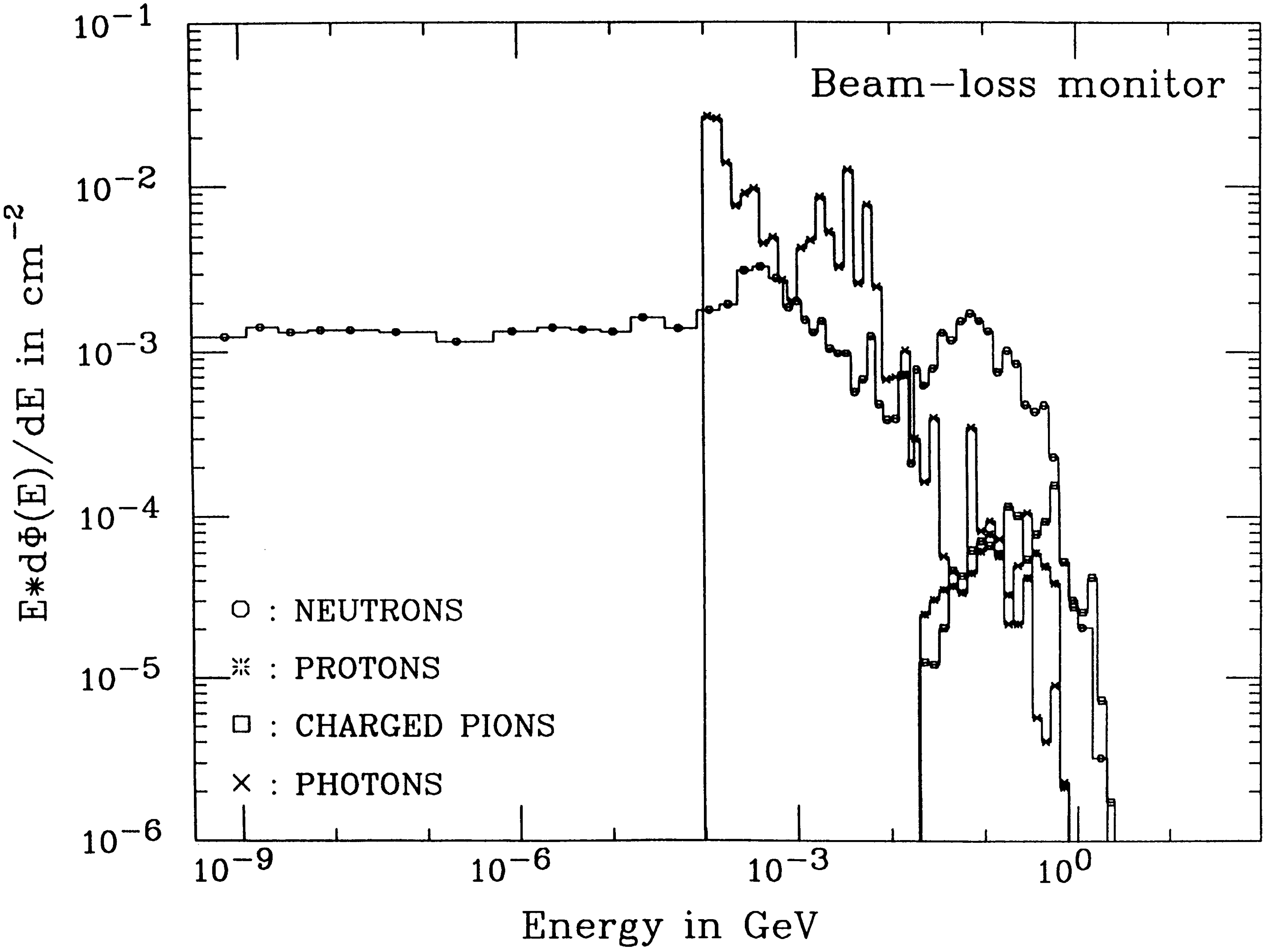

Beam−loss monitor
E∗dΦ(E)/dE in cm^{-2}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
○ : NEUTRONS
⋇ : PROTONS
□ : CHARGED PIONS
× : PHOTONS
10^{-9}
10^{-6}
10^{-3}
10^{0}
Energy in GeV

Figure 9

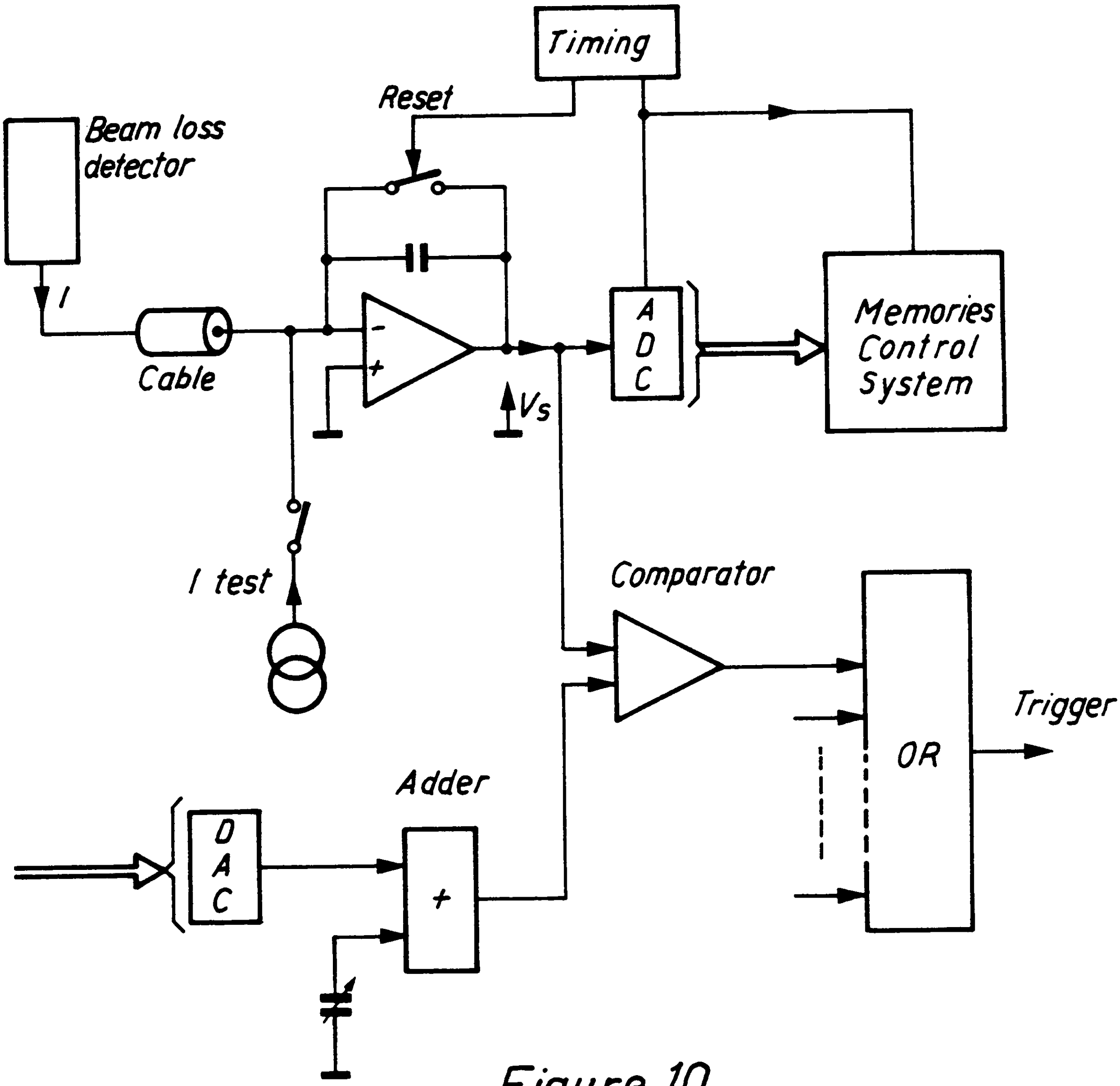


Figure 10

Alarm Electronic principle