STUDY ON CALIBRATION AND MONITOR SYSTEM OF LEAD GLASS CALORIMETER FOR e^+e^- EXPERIMENT

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Abstract

We are constructing and calibrating an electromagnetic calorimeter for the $e^+ e^-$ colliding experiment at TRISTAN. It is consists of 5160 lead glass total absorption counters and is designed to detect photons and electrons of energy over 1 GeV. Energy measurement of electrons and photons produced by e^+e^- collision is important for the physics objectives. We must calibrate each counter's gain with enough precision for precise energy measurement, and monitor the gain variations of the counters during the long term experiment for stable energy measurement, and finish the calibration of all lead glass counters by the start of the experiment. So we developed automatic calibration system, and we are doing the calibration of the lead glass counters by e^- beam. Energy resolutions of the lead glass counters are σ/E = 5.9±0.2 % at 1 GeV. The gains of the counters are adjusted within ±2 % relatively. Also we have been operating the Xe flash lamp monitor system since the start of the calibration experiment. We have been monitoring the fluctuation of Xe flash lamp within ±1 %.

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Chapter 1 Introduction

At National Laboratory for High Energy Physics (KEK), an e^+e^- colliding beam machine TRISTAN (TRansposable Intersecting STorage Accelerators in Nippon) is being constructed. For e^+e^- colliding experiment, VENUS collaboration/1.1/ are constructing detectors. TRISTAN will have maximum total energy of 70 GeV with use of superconducting cavity, a maximum design luminosity of 8 x 10^{31} $cm^{-2}s^{-1}$ at 54 GeV. The first collision of electron and positron will be seen at the end of November in 1986. A schematic diagram of TRISTAN and VENUS detector is shown in Fig.1-1 and Fig.1-2. Main features of VENUS detecter are as followes.

- General purpose,
- Nearly 4π solid angle coverage,
- Use of well established technology for each detecter component,
- Large space reserved for a future detecter with particle identification,
- Principle of separated function for each device,
- Charged particle tracking optimized for pattern recognition,
- Electromagnetic calorimetry with good energy

resolution, optimized granularity and orientation,

- Several independent ways of triggering with flexibilities,

The physics objectives are search for the sixth quark 'top', and the neutral Higgs boson, and bottom physics such as $e^+e^- \rightarrow b\bar{b}$ forward backward asymmetry, and so on. Energy measurement of electrons and photons produced by e^+e^- collision is important for processes like monochromatic photons from $(t\bar{t}) \rightarrow H^0\gamma$ for Higgs search, $e^+e^- \rightarrow \gamma\tilde{\gamma}\tilde{\gamma}$ for supersymmetric particles search. The electromagnetic calorimeter for this purpose must have good energy resolution in a wide energy range, and good electron/Hadron separation. We have selected lead glass counter as electromagnetic calorimeter of barrel part. The barrel is the cylindrical part around the beam pipe. The barrel calorimeter covers polar angles from 37° to 143° and azimuthal angles from 0° to 360°. The calorimeter is segmented into 5160 lead glass counters. And each counter is pointing to the e^+e^- interaction region to minimize the multi-hit probability of particles. Study on lead glass counter performance and characteristics are made by VENUS barrel calorimeter group/1.2/ and some important study is reported as master thesis of Mr. K.Doi./1.3/.

As mentioned above, we must measure the energy of electron and photon with high resolution. But we use a great number of counters (5160 elements) placed in inaccesible region and operate them for a long period. So we must calibrate each counter's gain with enough precision, and monitor the gain variation during the long term experiment. Because the gain fluctuation deteriorates the energy resolution and may make the pseudo peak.

In this thesis, we describe the calibration of lead glass counter and its monitor system, and some results of calibration, and expected performance of our calorimeter at e^+e^- colliding experiment by TRISTAN.

Chapter 2 Calibration and Monitoring

2.1 Purpose of Calibration and Monitoring

In order to measure the energy of photon and electron produced by e^+e^- collision precisely, the lead glass counters are required to be calibrated precisely. The target precision value of absolute energy calibration is ±0.5 % for each counter. The statistic requirement is indicated by following argument. Uncertainty σ_μ associated with the determination of the mean μ obtained by gaussian fitting of data is expressed by following equation.

$$\sigma_\mu = \sigma/\sqrt{N}$$

In our case, typical σ value is 6 % at 1 GeV. The σ_μ needs to be much less than the target precision 0.5 % . Since we take 10000 events at each calibration point, σ_μ is typically 0.06 %.

The gain of each counter should be adjusted to certain fixed value because of following reasons. If a counter has high gain, it causes ADC overflow, and disables the energy measurement. If a counter has low gain, the energy resolution is limited by the resolution of the ADC. Other reason is the requirement of the online event trigger. In the e^+e^- experiment, we trigger the event by several conditions. The lead glass energy sum is one of them. When sum of the energy deposit of a group of lead glass counters is greater than a threshold level, one of the trigger conditions is satisfied and trigger is enabled. If each counter has gain difference, we need to adjust the trigger threshold level over wide ranges. If the gain of counters is adjusted at the same value, we obtain a fine event trigger with almost the same threshold level. If we do not adjust the gains of the output of the counter itself but use of attenuator and amplifier, it increases the number of parts and decreases reliability. The high voltage supplied to the lead glass counter is determined so that each counter has almost the same gain. We will adjust the gains of counters within ±2 % relatively.

The experiment is expected to go on for several years. Over the experiment time, the gain of counter fluctuates according to several factors, PMT (Photo Multiplier Tube) gain fluctuation, temperature variation, High voltage supply fluctuation etc. We must correct this variation. For this purpose, we intend to monitor the counters by Xe flash lamp system.

The gain of lead glass counters are calibrated by measuring the pulse heights with 4 GeV electrons from Accumulation Ring. Lead glass counters are also flashed by the light from a Xenon flash tube and output pulse heights are recorded for the gain monitoring.

Each lead glass counter is monitored by two Xe flash lamps. Each Xe flash lamp light intensity is monitored also by some reference phototubes and photodiodes. Each reference phototube is monitored by NaI-Am light pulser attached on the reference phototube to correct the gain fluctuation of reference phototube. We expect to suppress the fluctuation of the counter gain within ±1 % by this monitoring system. This monitor system will be described at section 2.2.5

2.2 The apparatus and the beam line

2.2.1 Lead glass counter

The structure of our lead glass counter is illustrated in Fig.2-1. A lead glass (DF6 of Nikon, 1 Xo = 1.7 cm, Xo:radiation length, 1 Xo corresponds to the distance where the initial electron energy becomes 1/e of initial state by bremsstrahlung) and a photomultiplier (PMT, Hamamatsu R1911, the characteristics of R1911 is shown in table 2-1) and an acrylic light guide (6 cm length, 7.2 cm in diameter) are optically glued together. The lead glass is 18 Xo (= 30 cm) in depth and has a cross section of about 12 cm x 12 cm square. PMT is shielded by a mu-metal for stable operation under the weak leakage field from solenoid magnet. The lead glass itself is wrapped by thin aluminized myler sheets (50 μm x 2). And a black heat shrink sheet (50 μm) covers surrounds the myler sheets for light shielding. An acrylic light guide of 6 cm length is necessary for effective magnetic shielding of PMT. A metal flange for mechanical support is glued to the glass surface. Two holes are drilled at the flange for light injection from Xenon flash tubes. They are used for gain monitoring of the lead glass counters. We perform the sight check and light leak test before mounting the counter.

2.2.2 beam line

We use TRISTAN accumulation ring (AR) IT4 internal photon beam line for the calibration of our lead glass counters. Fig.2-2 indicates AR IT4 beam line. The internal target of IT4 is 4 mm thick Molibden. Photons from the internal target is extracted to the converter. The converter is 30 mm width and 70 mm height. The converter thickness and its material is indicated in table 2-2. The momentum of electron emitted from the converter is selected by the bending magnet. The electron is transported through a collimator (6mm width) to defining scintillation counter S1 (10 mm x 10 mm scintillater) and S2 (30 mm x 30 mm scintillater). The lead glass counters mounted on a movable table are set just behind the defining counters. Momentum resolution of the electron beam is about 1.5 %. This value is calculated from evaluation of the beam phase space. Typical trigger rate (electron yield) is summarized in table 2-3. Fig.2-3 shows the relation of the converter thickness to the electron yield. Fig.2-4 shows the relation of the converter thickness to the counter resolution. The beam resolution is constant below the converter thickness of 0.2 radiation length, and it increases over the converter thickness of 0.7 radiation length. So we have selected the converter of 0.2 radiation length.

2.2.3 Movable calibration table

The structure of the calibration table is illustrated in Fig.2-5. 36 or 48 lead glass counters are mounted on it. The table can move along x-axis (horizontal, normal to the beam axis) and y-axis (vertical) independently. Computer controlled pulse motors (Nippon pulse motor, CD504U for x-axis, CD512U for y-axis) and the combination of gears and screws perform the function. Moving speed is 6.7 mm/sec along x-axis and 4.0 mm/sec along y-axis. The table position is read with optical position scales (Nikon V-5) attached along x- and y-axis. The digital read out unit (Nikon MC202) reads the position. An online computer gets the position data from the units through the CAMAC interface. The pulse motor is controlled by online computer through CAMAC interface module. It enables us to perform automatic calibration.

2.2.4 High voltage power supply system for Photo multiplier tubes

The high voltage power supply system for Photo multiplier tubes consists of a main power supply (SATO-denshi, HV-3-0.25N), a 256 channel high voltage distributer (SATO-denshi, MDST256N), and a 256 channel distributer controller CAMAC module (SATO-denshi). The system is shown in Fig.2-6. Following functions are available in this system.

1. Main power supply voltage read out --- read the voltage of main power supply which supplys power to 256 channels distributer. Read out is digitized into 32767 divisions (15 bits) for the range of 0 to 2500 Volts.

2. Setting of PMT high voltage --- set each PMT's high voltage. Setting of the high voltage is done in 255 divisions (8 bits) from the minimum (main voltage - 1100) volts to the maximum (main voltage - 100) volts. It means 1 division equals to about 4 volts (1000 volts/ 255).

3. Setting voltage read out --- read the voltage supplied to each PMT. Actually, it reads the value of dropping voltage from main power supply. This value is in 100 to 1100 volts. Reading is digitized into 32767 divisions (15 bits) from 0 to 1000 volts. It means 1 division equals to about 0.03 volts.

2.2.5 Xe monitor system

An optical monitor system is used to check the gains of lead glass counters where a Xe flash tube illuminates through optical fibers a group of lead glass counters, several reference phototubes, and photodiodes (Hamamatsu S1337-33BR). A Xe tube emits light with a spectrum similar to that of Cherenkov light in the lead glass, when the light attenuation in the lead glass and quantum efficiency of the phototube is considered. The output variation of the light source (Xe flash tube) is monitored by photodiodes and reference phototubes. The gain variation of the reference phototubes are monitored by NaI-Am (3μCi) light pulser attached on each phototube.

A schematic diagram of the system is shown in Fig.2-7. Light from a Xe flash tube is distributed to 7 bundles of optical fibers. Each bundle consists of 35 quartz fibers with core diameter of 100 μm. Each fiber of 100 μm diameter in the bundles is connected to a light distributer. 14 (or 16) quartz fibers with core diameter of 80 μm are glued on the distributer (distributer 1-30). Each fiber of 80 μm diameter is connected to a lead glass counter (counter 1 to 12, or 1 to 14). Two fibers of 80 μm are spares. 3 quartz fibers with core diameter of 80 μm are glued on a distributer for reference. Each fiber is connected to a reference phototube (REF1,REF2,REF3). Rest of the bundles (Spare 1,2,3,4) are spares. The reproducibility of light transmission at the connectors is better than 99.5 %.

Furthermore, we use another similar Xe monitor system for monitoring. So each lead glass counter is monitored by two independent systems (Xe1 and Xe2).

At each calibration procedure (about 9 hours for 42 counters), only 36 or 42 lead glass counters and reference phototubes are flashed by the light from Xe tube. The rest of fibers are not connected to lead glass counters.

2.2.6 Miscellaneous electronics and the online computer

The fast electronics (trigger and data taking) diagram is shown in Fig.2-9. The computer controlled automatic calibration system diagram is shown in Fig.2-10. DEC PDP-11/73 minicomputer is used for the data taking and equipment controlling. All pulse outputs of the lead glass counters, reference phototubes, and photodiodes are gated and integrated and digitized by ADC's (LeCroy, 2249W). We use different width gate for the beam, Xe light, and NaI-Am light pulser. So we use 4 individual gate generators (beam, Xe1, Xe2, NaI-Am) and select the gate by AND operation of the gate output and the level output of CAMAC output register.

2.3 Calibration system and procedure

The calibration of one lead glass counter is performed with following procedures.

1. High voltage determination by e^- beam (4 GeV)

2. Calibration data acquisition with the confirmed High voltage by e^- beam (1, 2, 4 GeV).

3. Monitoring data acquisition by Xe flash lamp monitor system (Xe1 system and Xe2 system).

4. Replacement of the counter to be calibrated with the next in line by automatic movable table.

All the above sequences is performed automatically by our automatic calibration system. In addition to the above procedures, we perform monitoring of ADC pedestal and NaI-Am light pulser.

Furthermore, we print some histograms and data in order to monitor calibration procedures and prepare for unexpected situations. All histograms of pulse heights are recorded on magnetic tapes.

In the following, we describe each procedure.

2.3.1 High Voltage determination with e^- beam

The relation of High voltage and PMT's gain is described by following equation./2.1/

$$G = C \times V^{\alpha}$$

In this equation, G is the gain of the PMT, C and α are PMT dependent constants. V is the high voltage. Using this relation, we can find the value of high voltage that gives us desired gain

G_X. This sequence is mentioned in following.

1. At first, we take 3000 event at a certain high voltage value V_1 (volt) by 4 GeV e^- beam. The mean G_1 is obtained by gaussian fitting. We get the next high voltage value V_2 by the next calculation.

   $$V_2 = V_1 \times (G_X / G_1)^{1/4.8}$$

   The smaller value of 4.8 is chosen from the known α value range. (Fig. 2-10 shows the α distribution of some calibrated lead glass counters). This equation is obtained by

   $$G_X = C \times V_2^{1/4.8}$$
   $$G_1 = C \times V_1^{1/4.8}$$

2. As the next step, we take another 3000 events at the high voltage value V_2. Again the mean G_2 is obtained by gaussian fitting. At this time, we can calculate both of C and α, since we have two data points (V_1, G_1) and (V_2, G_2).

   $$\alpha = \log(G_1/G_2)/\log(V_1/V_2)$$
   $$C = G_2/V_2^{\alpha}$$

   We determine the next high voltage V_3 by the next formula.

   $$V_3 = (G_X/G_2)^{1/\alpha} \times V_2$$

3. As the 3rd step for High voltage determination, we take 3000 events at V_3. If the mean G_3 is in the range of desired gain, from $G_X-\Delta G$ to $G_X+\Delta G$, the high voltage value of this counter is fixed at this value. ΔG is the maximum error of gain determination, in our case it is 1 % of G_X. If G_3 is out of the range, we try 4th step of this sequence. The 4th step high voltage is given as follows.

   $$V_4 = V_3 + 4 \text{ volt (case of } G_X > G_3 \text{)}$$
   $$V_4 = V_3 - 4 \text{ volt (case of } G_X < G_3 \text{)}$$

   The value of 4 volt is the minimum adjustable value of our high voltage supply system.

4. Similarly we take 3000 events at V_4. If the mean G_4 is in the range of target gain, this value V_4 is accepted as the counter high voltage. Unfortunately G_4 is out of the range, we stop the calibration sequence and check the system, lead glass counter, high voltage supply, electronics etc.

This procedure takes about a minute. An online print out of this procedure is shown in Fig.2-11. In this figure, we adjust the gain of the counter with 3 iterations, and determined high voltage is 1358.7 volts.

2.3.2 Calibration data acquisition

The counter's high voltage has been determined, according to the previous procedure. In the present stage, we take the calibration data with the electron beam at various energies. At first, we take 10000 events at 4 GeV. After that, the dipole magnet current is changed by the online computer with CAMAC magnet controller. This current is set at 2 GeV. We also take 10000 events at this energy. After 2 GeV beam data taking, we take the data at 1 GeV beam similarly. Fig.2-12 shows the pulse height distribution at 4 GeV. This procedure takes about a few minutes.

2.3.3 Xe monitor data acquisition

After the beam calibration data acquisition, we take the monitoring data, 3000 events for both of Xe1 and Xe2 systems. Xenon flashes at the rate of 30 Hz. The light intensity of Xe tube is equivalent to that of Cherenkov light by electron with energy of 4 to 7 GeV. We record pulse height distributions of a lead glass counter and three reference PMTs and six photodiodes. Fig.2-13 shows pulse height shape of a lead glass counter.

To monitor the pulse to pulse fluctuation of Xe tubes, we calculate the ratios of a lead glass counter pulse height and reference phototubes' pulse height event by event, and record the their distributions. An online print output of this procedure is shown in Fig.2-14.

2.3.4 Calibration counter change

After all the data acquisition with a counter is finished, we move the calibration table so that the next counter can be calibrated. The table that holds a group of lead glass counters, is automaticaly moved by pulse motors controlled by the online computer (about 0.001 mm per pulse). The table position is read by optical linear scale (0.005 mm digit). The computer reads the position data via CAMAC system, and check the position. The error of table position is within ± 0.1 mm.

2.3.5 Other data acquisition

Periodically, we take ADC's pedestals also.

To monitor the gain of reference photo-multipliers, we also take the data of NaI-Am light pulser attached on reference PMTs. Fig.2-15 shows typical pulse height distribution of NaI-Am light pulser.

Chapter 3 Result of calibration experiment

We have been performing test of this automatic calibration system since July in 1984. We started the calibration of lead glass counters in October in 1984. One counter is calibrated in 11 minutes on the average. Although AR machine time dependent, We expect to finish the whole calibration by the end of 1985 and be ready for the start of experiment.

3.1 Result of calibration of lead glass counters

We have done calibration of lead glass counters only partially. Fig.3-1 shows a distribution of lead glass counters' resolution. Fig.3-2 shows the gain distribution of lead glass counters. The gain is distributed in the range of 420 ± 4 counts. It indicates that the gain variation between the counters is in ±1 %.

3.2 Stability of Xe monitor system

Fig.3-3 and Fig.3-4 show the pulse height variations of the reference phototubes and photodiodes that are shone with Xe flash tube. From Fig.3-3 to Fig.3-9, the abscissa is time (in hour unit) and the ordinate is a ratio of a value and a initial value (in percent unit). In the period, we calibrated about 300 lead glass counters. REF1 to REF3 are reference phototubes for Xe1 system. PD1 to PD6 are photodiodes for Xe1 system.

Fig.3-3(a) shows pulse height of REF1 increases about 8 % during this term. It means that the gain of REF1 increases while Xe1 intensity is stable, or that the gain of REF1 is stable while Xe1 intensity increases, or that both of REF1 gain and Xe1 intensity have changed.

To consider the relation between the gain variations of photodiodes, the ratio of each pulse height of photodiode (PD2 to PD6) and that of PD1 is plotted. In Fig.3-5 the variations of 6 photodiodes are same within 0.5 %. Similarly the ratio of each pulse height of reference phototube (REF1 to REF3) and that of PD1 is plotted. In Fig.3-6, the variation of a reference phototube and photodiode does not show same.

Fig.3-7 shows the pulse height variations of reference phototubes that are shone with the

NaI-Am light pulser. In this figure, REFNaI1, REFNaI2, and REFNaI3 mean these pulse heights of the reference phototubes. If the light intensity of NaI-Am light pulser is stable, the variations of these pulse heights indicate the gain variations of the reference phototubes. To correct gain variation of reference phototubes, we normalize the pulse height of reference counters by NaIAm monitor data at each data taking time. Fig.3-8 shows these normalization results. To compare this result and photodiode variation, the ratio of normalized reference phototubes and photodiodes is plotted.

In Fig.3-9 the variation of photodiodes and normalized reference phototubes show the same tendency within 1 %. By these results, we conclude :

1. photodiodes are stable within 0.5 % during this term.

2. some reference phototubes are not stable.

3. reference phototubes normalize by NaI-Am monitor are stable within 1.0 %

4. light intensity of Xe flash tube decreases about 2 % during this term.

5. light intensity of Xe flash tube can be monitored within 1 % by this system.

Chapter 4 Conclusion

We are performing the calibration of the lead glass electromagnetic calorimeter for the e^+e^- colliding experiment at TRISTAN. We have done the calibration of the lead glass counters partially. The energy resolutions of these counters are 5.9±0.2 % at 1 GeV. The gains of the counters are adjusted within ±2 % relatively. It satisfies the requirements of online trigger, online monitor, and offline analysis.

The gain fluctuation of lead glass counter are expected to be monitored by the Xe flash lamp gain monitoring system within 1 % due to the result of Xe monitoring data during the calibration experiment.

These performances satisfy the requirements of barrel calorimeter of VENUS detector for e^+e^- experiment.

Acknowleagement

I wish to thank Prof. Y.Nagashima and Prof. S.Sugimoto (Osaka Univ.) for discussion, and encouragement throughout this work. I also wish to thank Prof. F.Takasaki, Dr. K.Ogawa, and Dr. T.Sumiyoshi (KEK) of VENUS barrel calorimeter group for collaboration, and discussion. I acknowledge the help of Mr. S.Uehara (Hiroshima Univ.) in the programing the automatic calibration data taking online programs. I also acknowledge the help of Prof. H.Yoshida (Fukui Univ.) for the discussion of Xe monitor system.

References

/1.1/ VENUS collaboration

/1.2/ VENUS Barrel calorimeter group; Y.Nagashima, S.Sugimoto, H.Kusumoto, H.Osabe, T.Kamitani, T.Yamashita (Osaka Univ.), F.Takasaki, K.Ogawa, T.Sumiyoshi (KEK), H.Yoshida, J.Iwahori (Fukui Univ.)

/1.3/ K.Doi, 'STUDY ON ELECTROMAGNETIC SHOWER CALORIMETER FOR e^+ e^- EXPERIMENT', Master thesis submitted to Osaka University, 21-Mar-1984

/1.4/ VENUS collaboration, 'PROPOSAL FOR A LARGE SPECTROMETER AT TRISTAN', Jan-31-1983

/2.1/ Dr. Ralph W Engstrom, 'RCA Photo multiplier handbook', RCA, 1980

Figure captions

Table captions

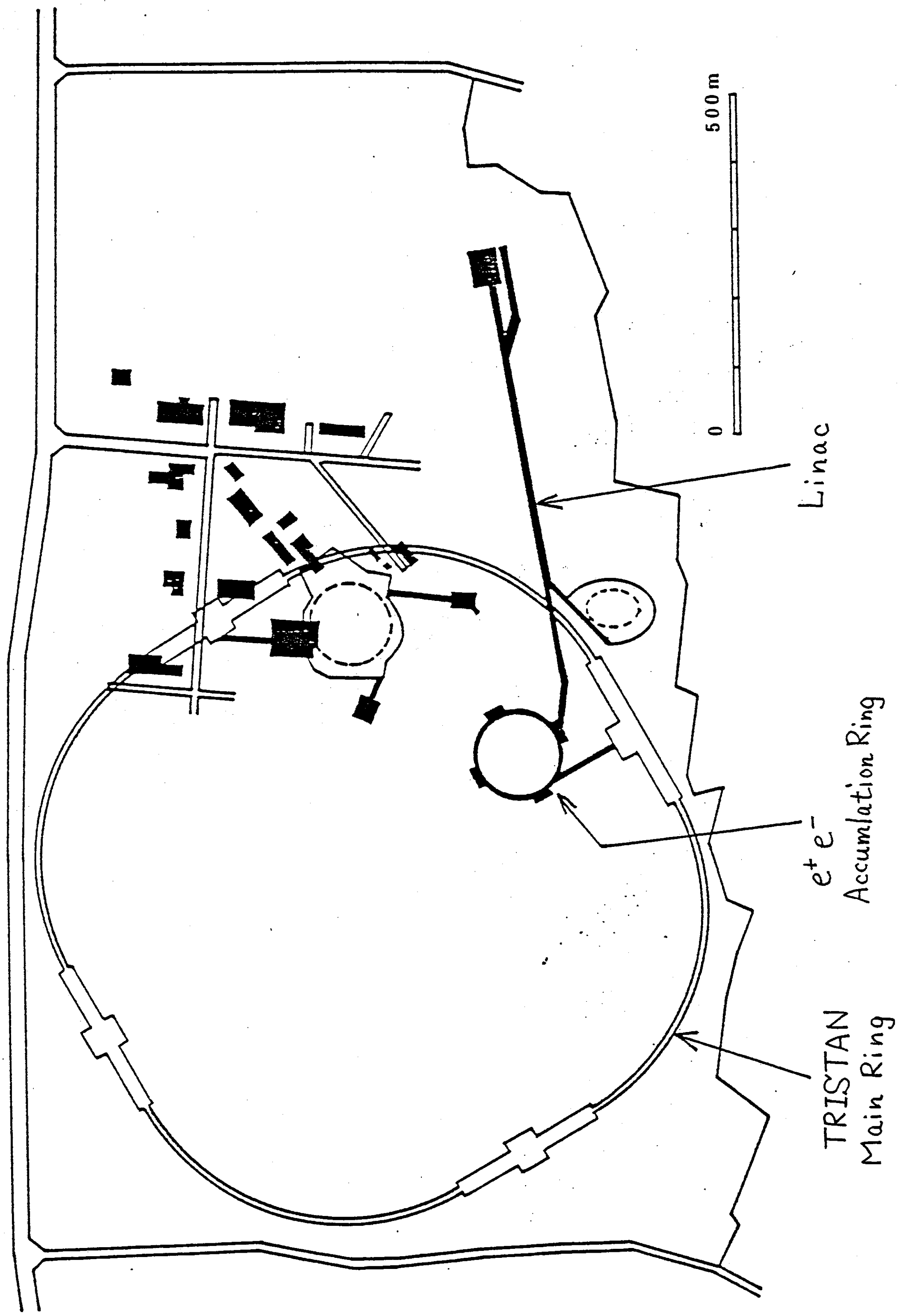
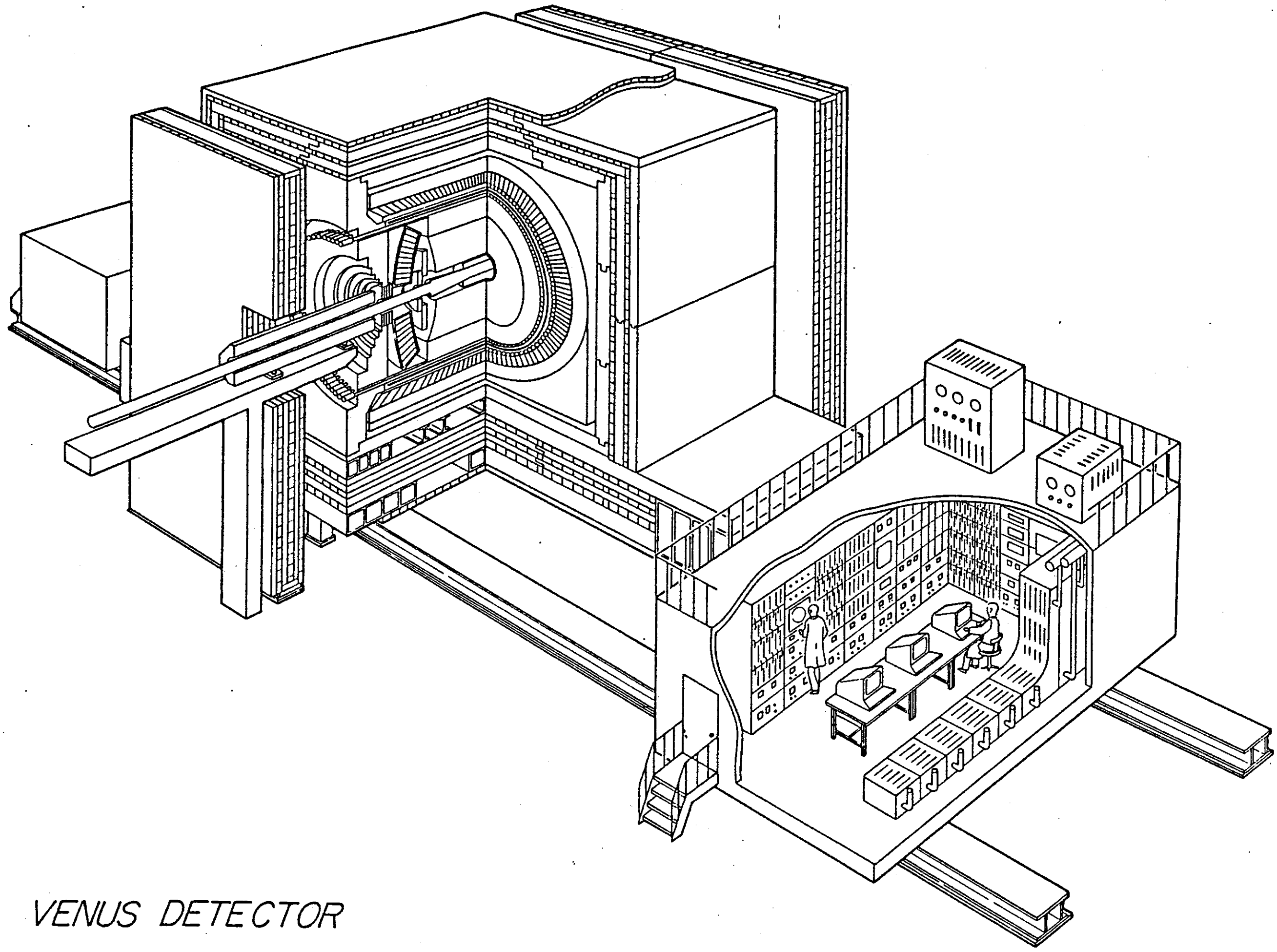


Fig. 1-1 TRISTAN accelerators



VENUS DETECTOR

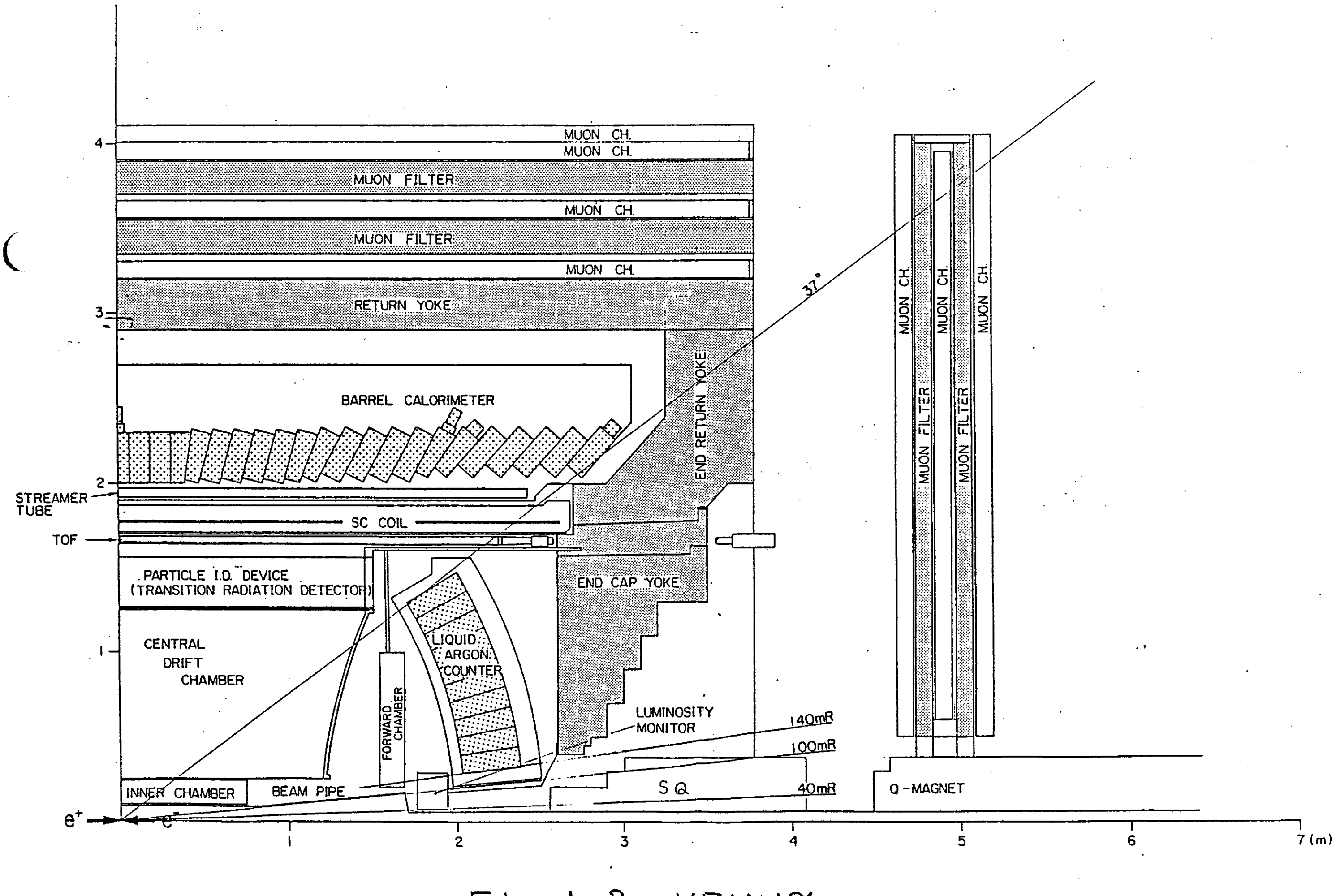
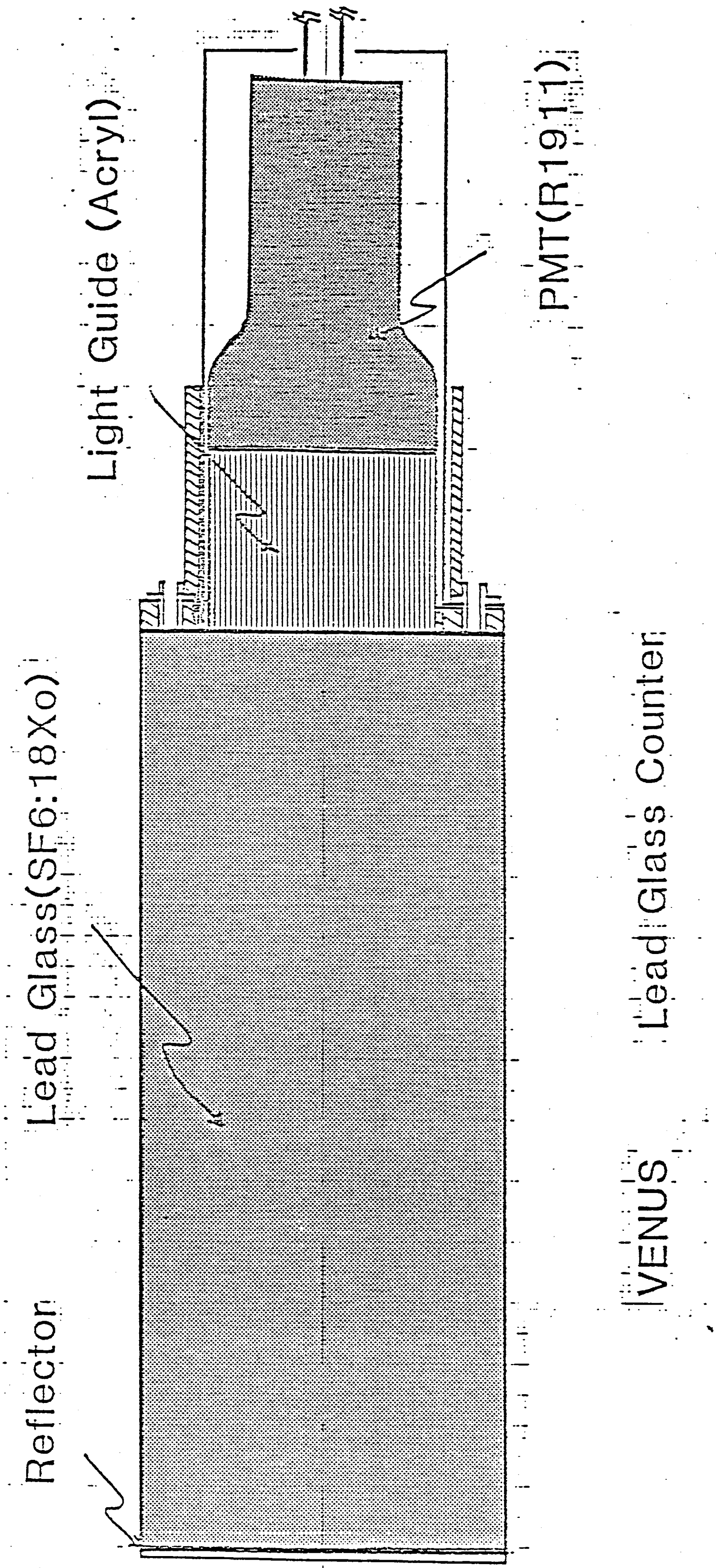


Fig. 1-2 VENUS DETECTOR



Light Guide (Acryl)
PMT(R1911)
Lead Glass(SF6:18Xo)
Lead Glass Counter
VENUS
Reflector

Fig. 2-1

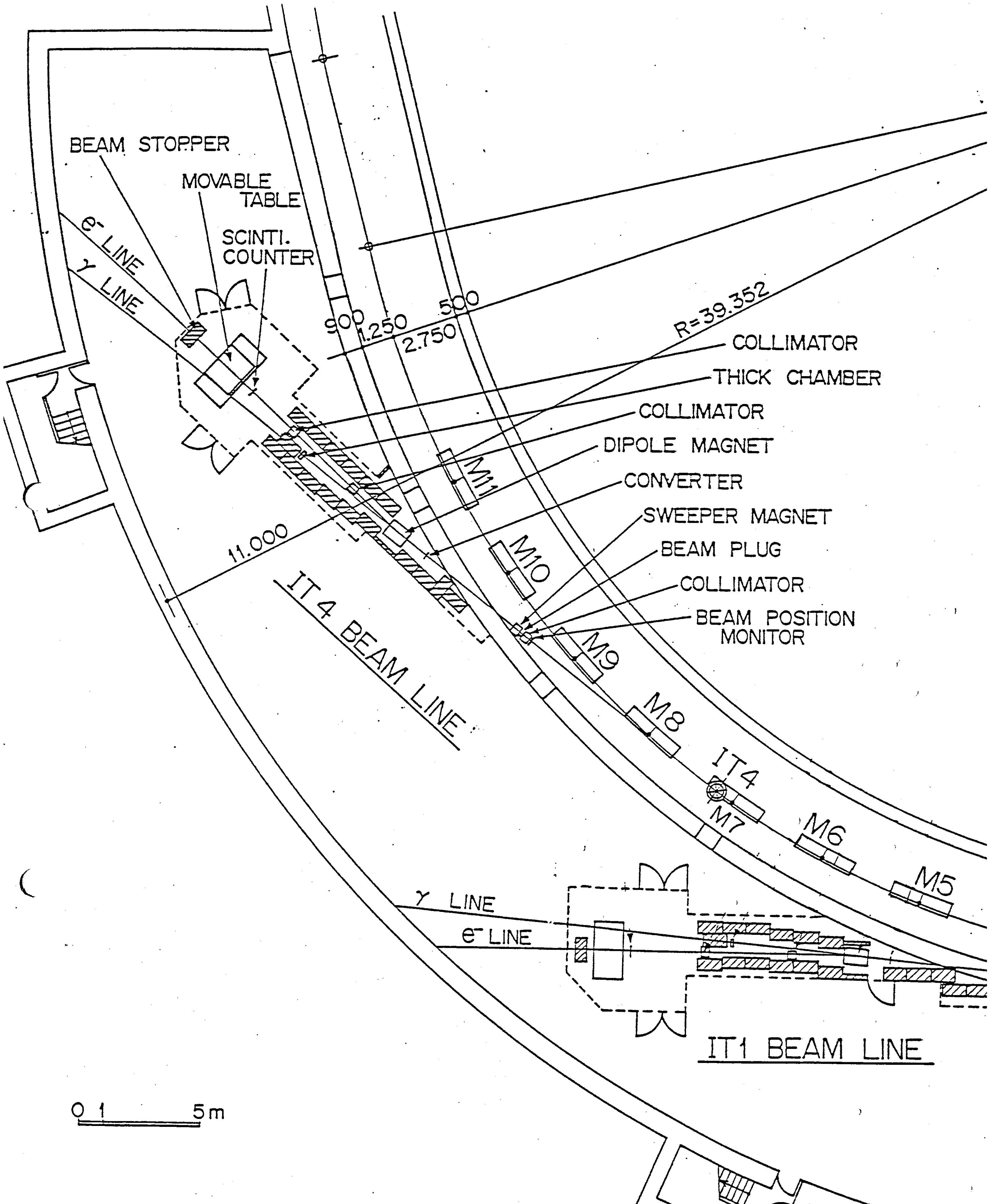
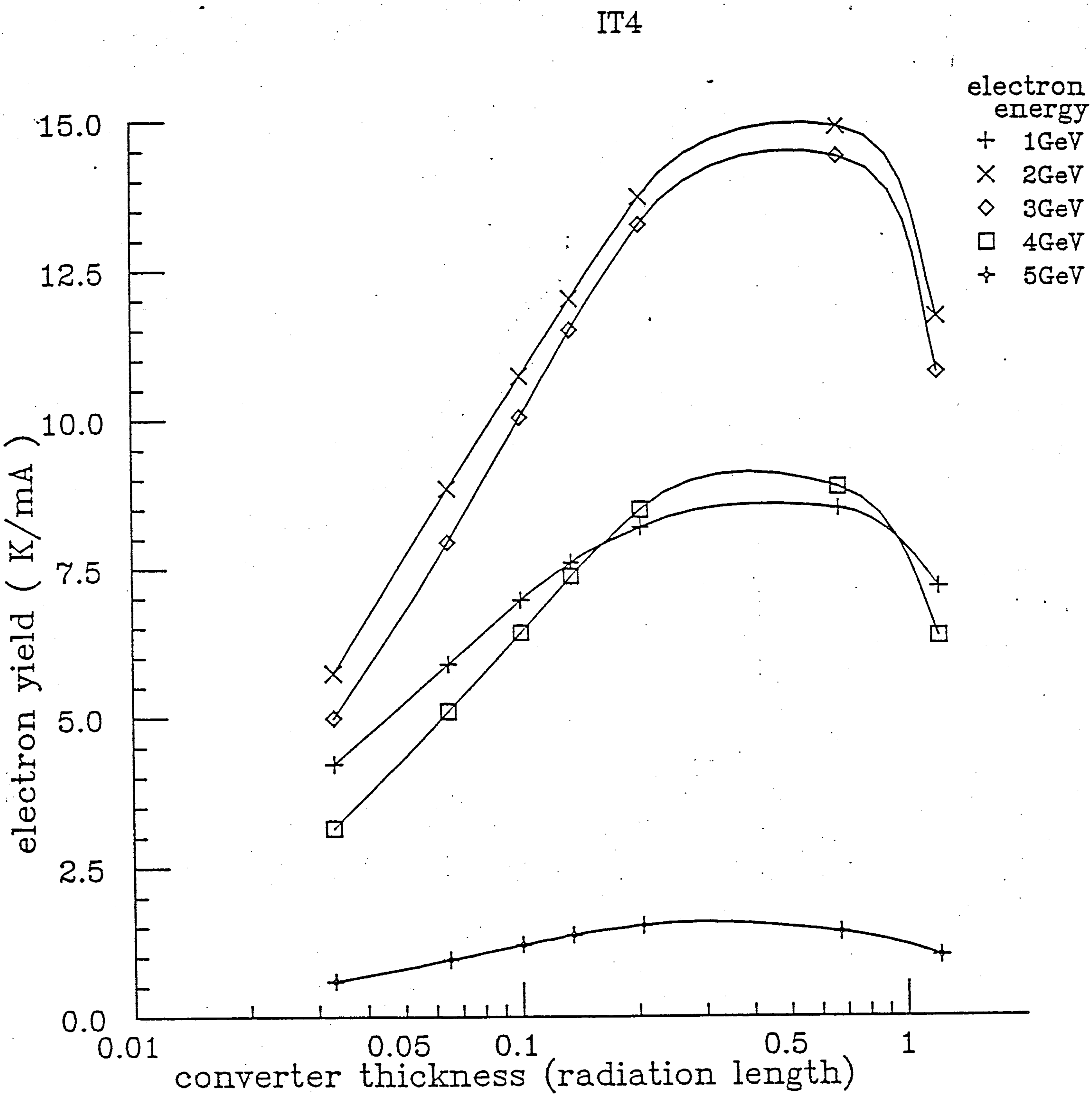


Fig. 2-2 Accumlation ring IT4 beamline



IT4
electron energy
1GeV
2GeV
3GeV
4GeV
5GeV
15.0
12.5
10.0
7.5
5.0
2.5
0.0
electron yield (K/mA)
0.01
0.05
0.1
0.5
1
converter thickness (radiation length)

Fig. 2-3

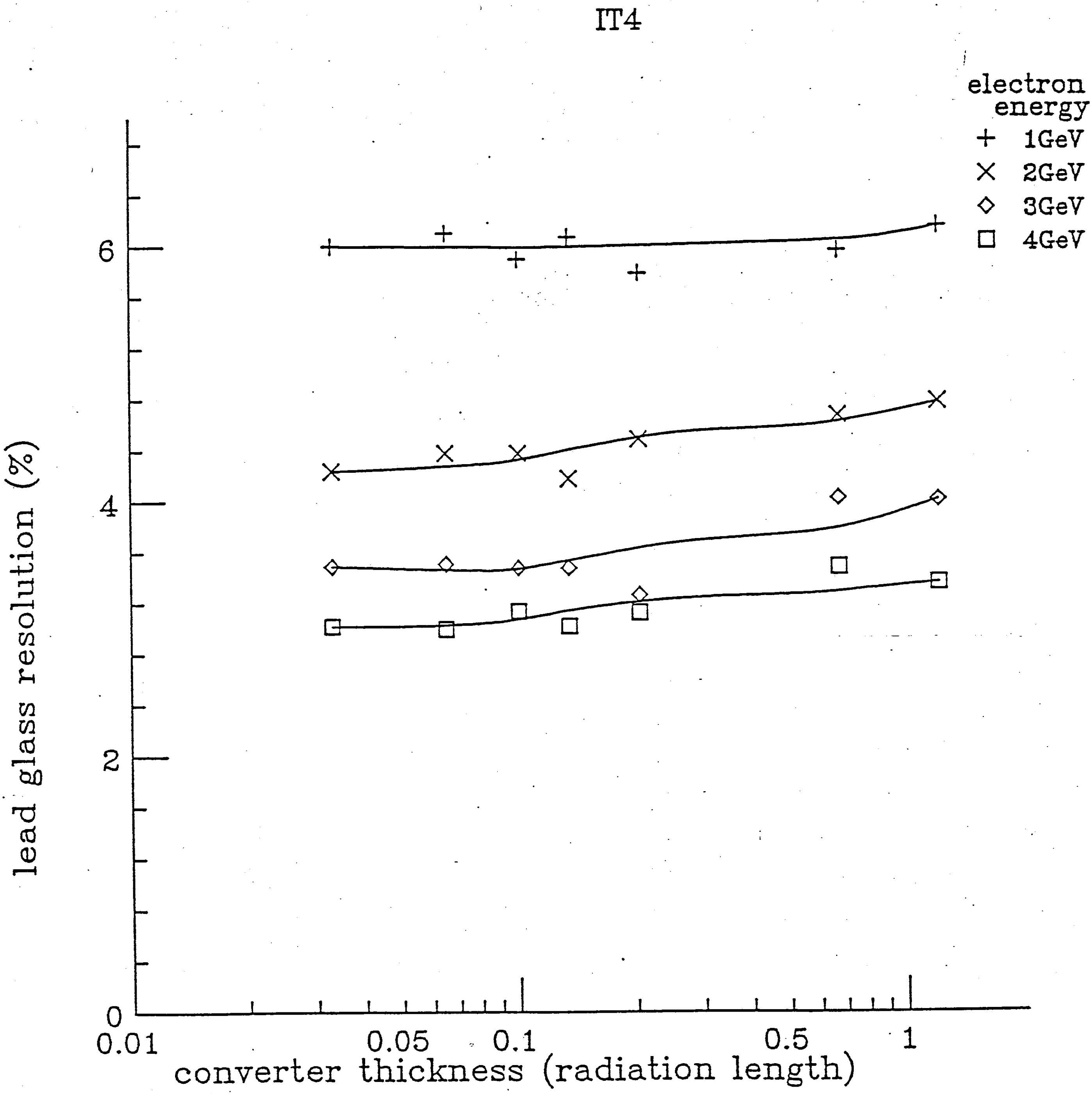
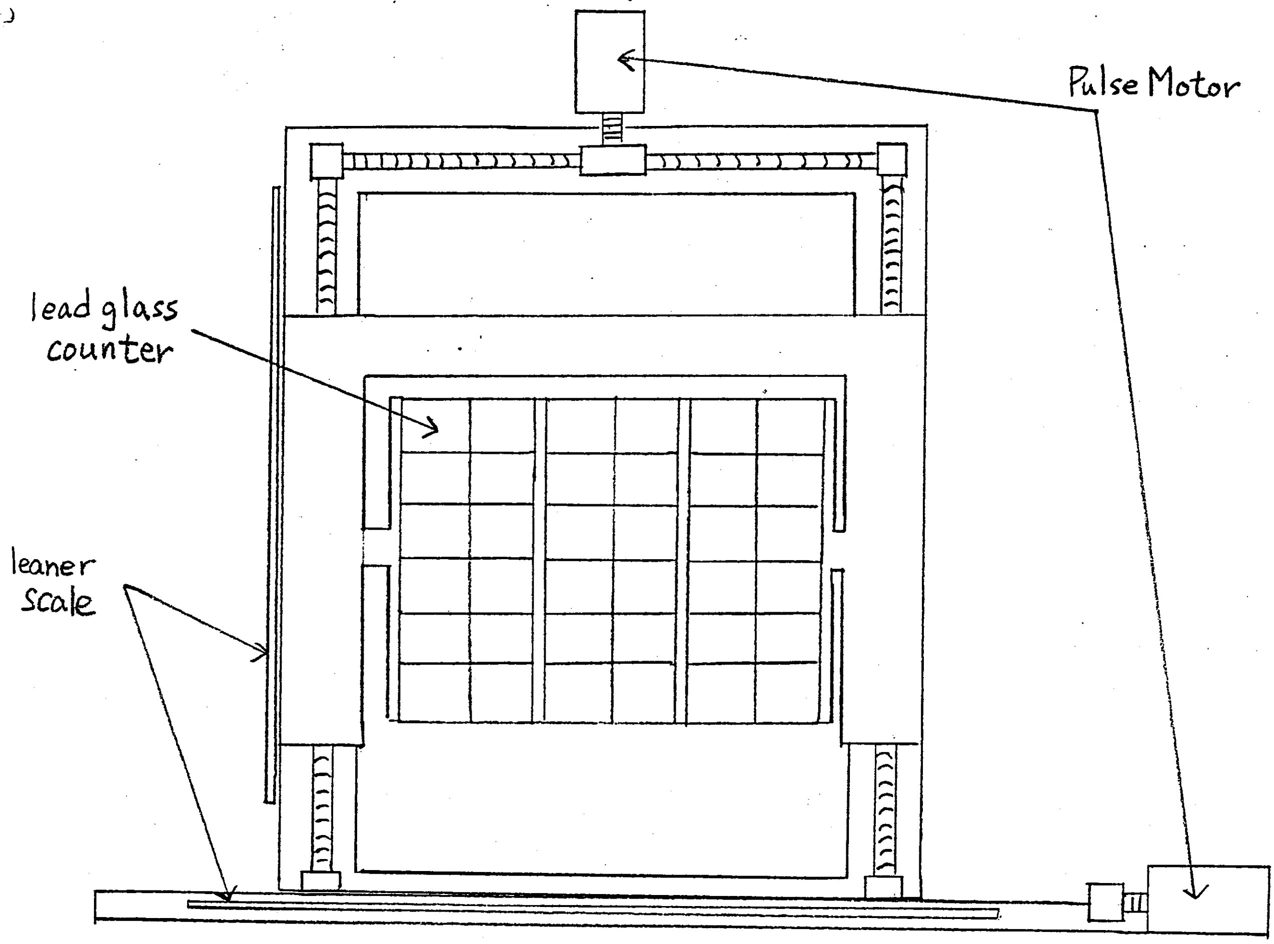

IT4
electron energy
1GeV
2GeV
3GeV
4GeV
lead glass resolution (%)
6
4
2
0
0.01
0.05
0.1
0.5
1
converter thickness (radiation length)

Fig. 2-4

(a) view from upstream of beam line



(b) side view

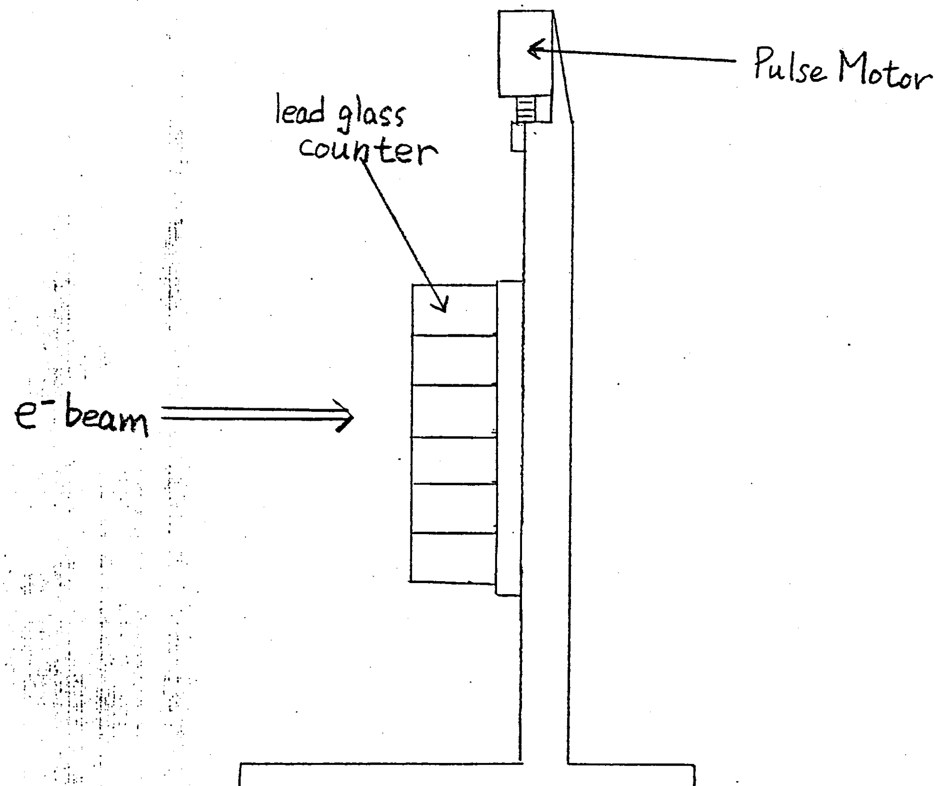
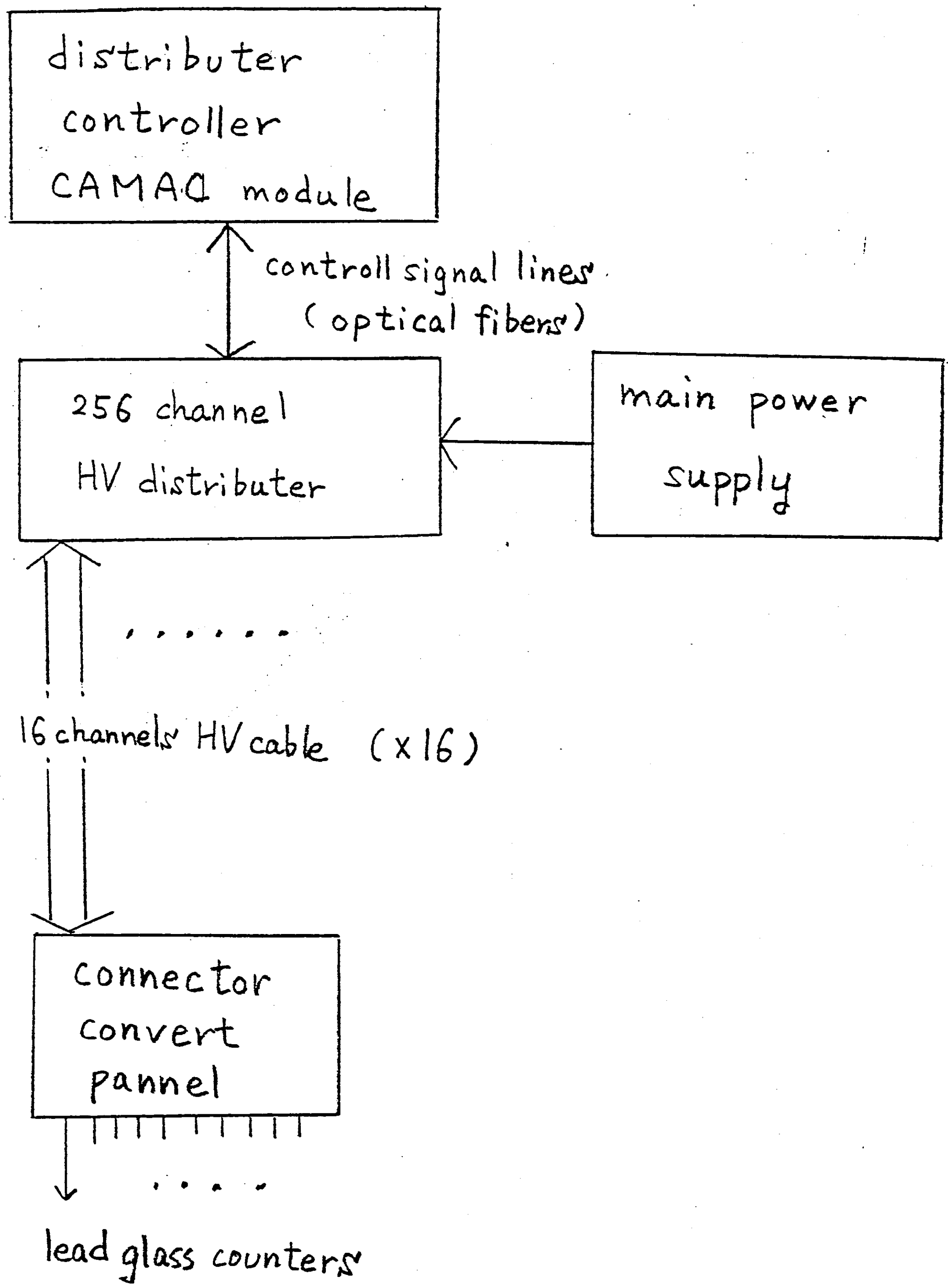


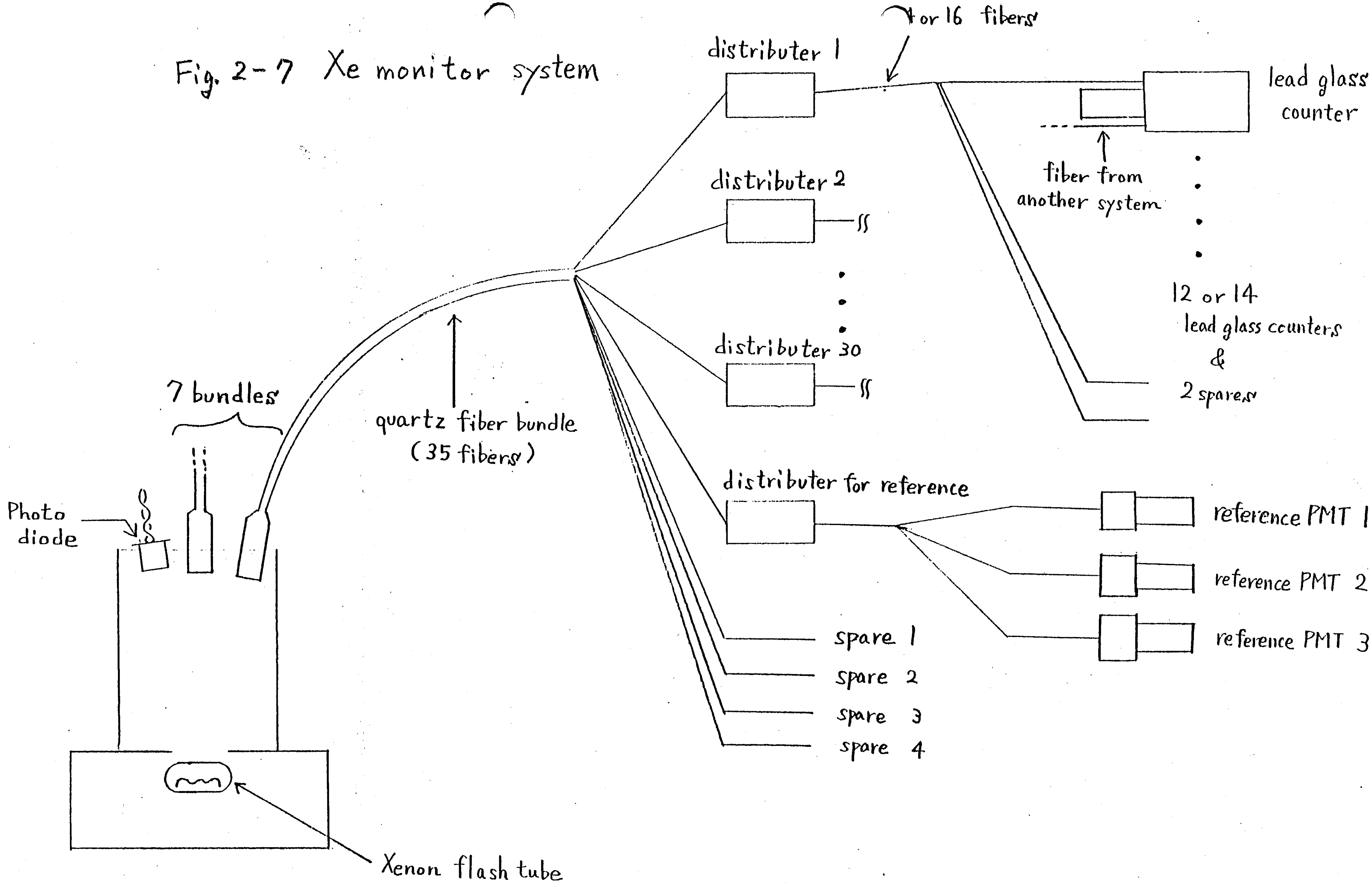
Fig. 2-5



distributer
controller
CAMAC module
controll signal lines
(optical fibers)
256 channel
HV distributer
main power
supply
16 channels HV cable (x16)
connector
convert
pannel
lead glass counters

Fig. 2-6

Fig. 2-7 Xe monitor system



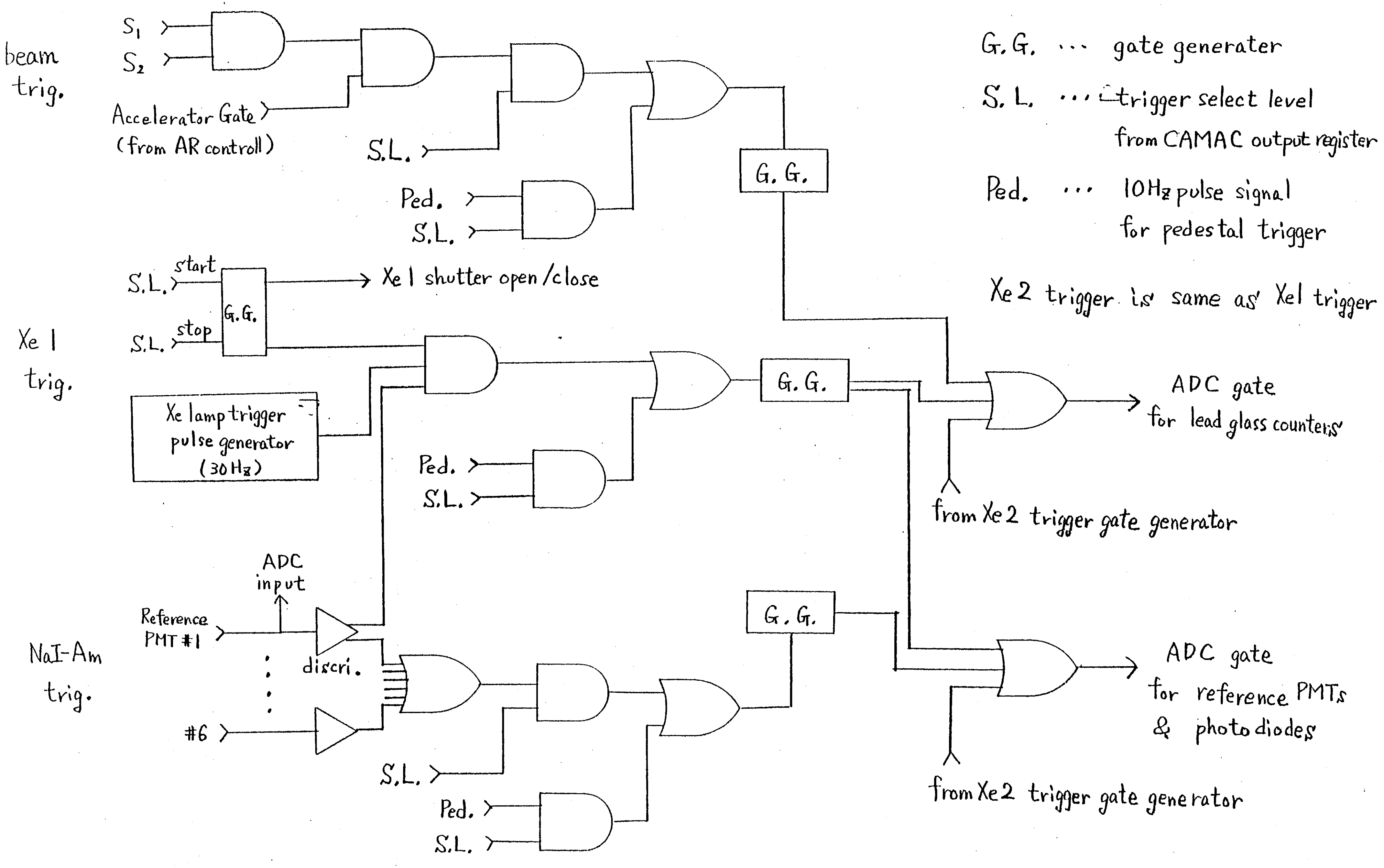


Fig. 2-8 Fast electronics

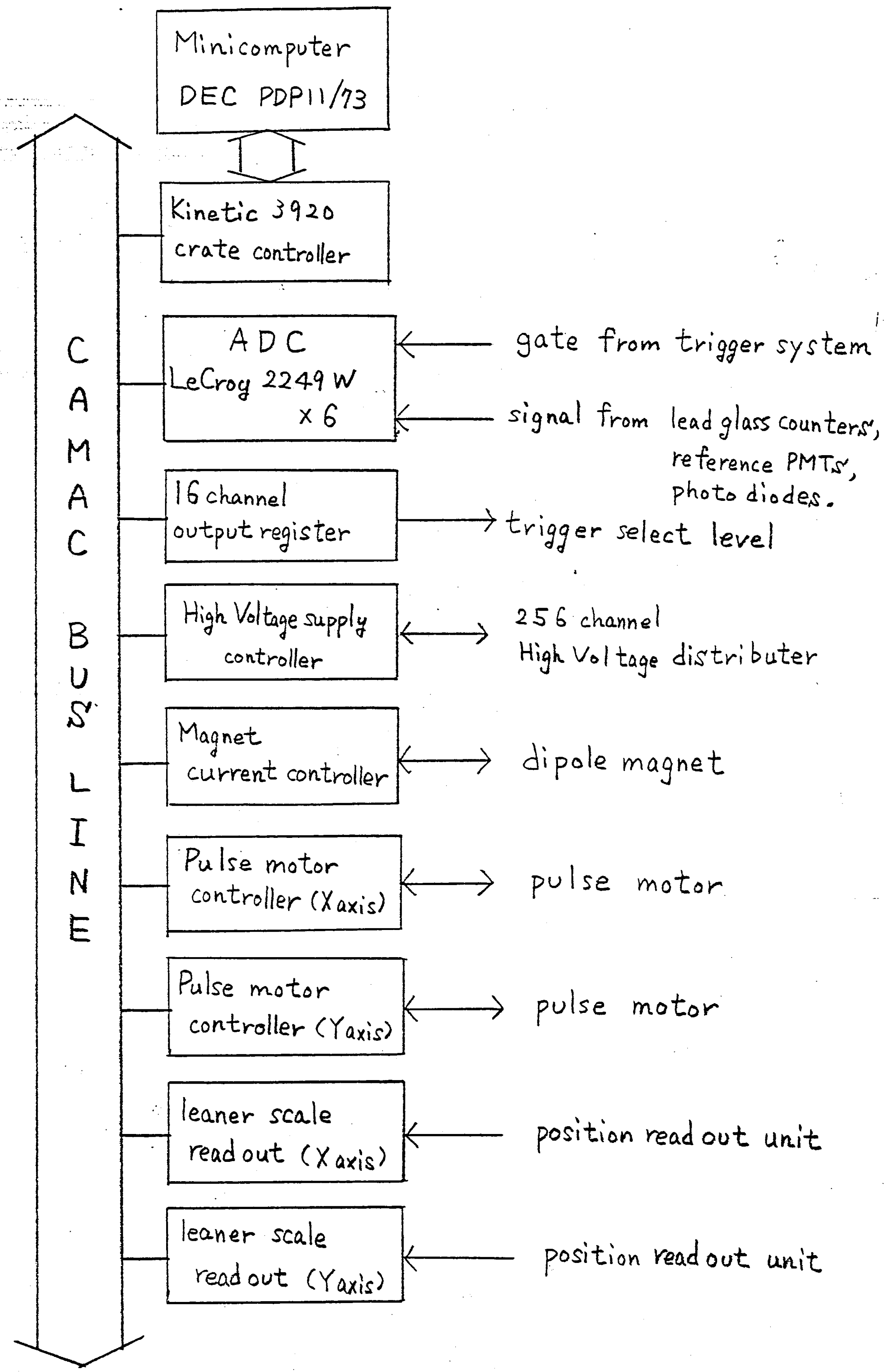

Minicomputer DEC PDP11/73
Kinetic 3920 crate controller
ADC LeCroy 2249 W x 6
gate from trigger system
signal from lead glass counters, reference PMTs, photo diodes.
16 channel output register
trigger select level
High Voltage supply controller
256 channel High Voltage distributer
Magnet current controller
dipole magnet
Pulse motor controller (X axis)
pulse motor
Pulse motor controller (Y axis)
pulse motor
leaner scale read out (X axis)
position read out unit
leaner scale read out (Y axis)
position read out unit
CAMAC BUS LINE

Fig. 2-9

****** D-07-1a calibration 19-OCT-84 03:51:30 ******

Iteration #1:	HV:1202.09	Mean: 217.1	Sigma: 14.93
Iteration #2:	HV:1378.29	Mean: 452.0	Sigma: 25.38
Iteration #3:	HV:1358.72	Mean: 418.9	Sigma: 22.76

Fig. 2-10

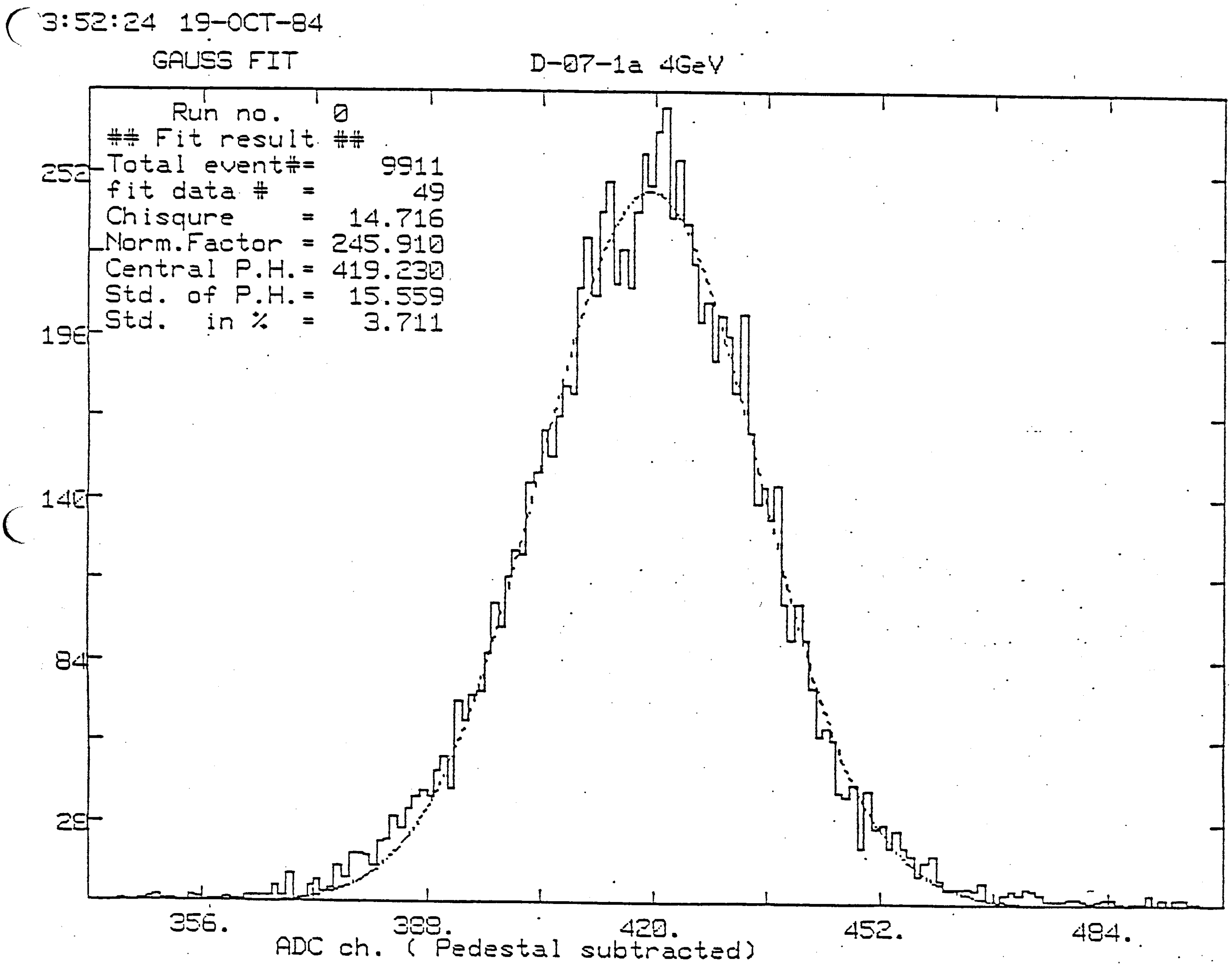


Fig. 2-11

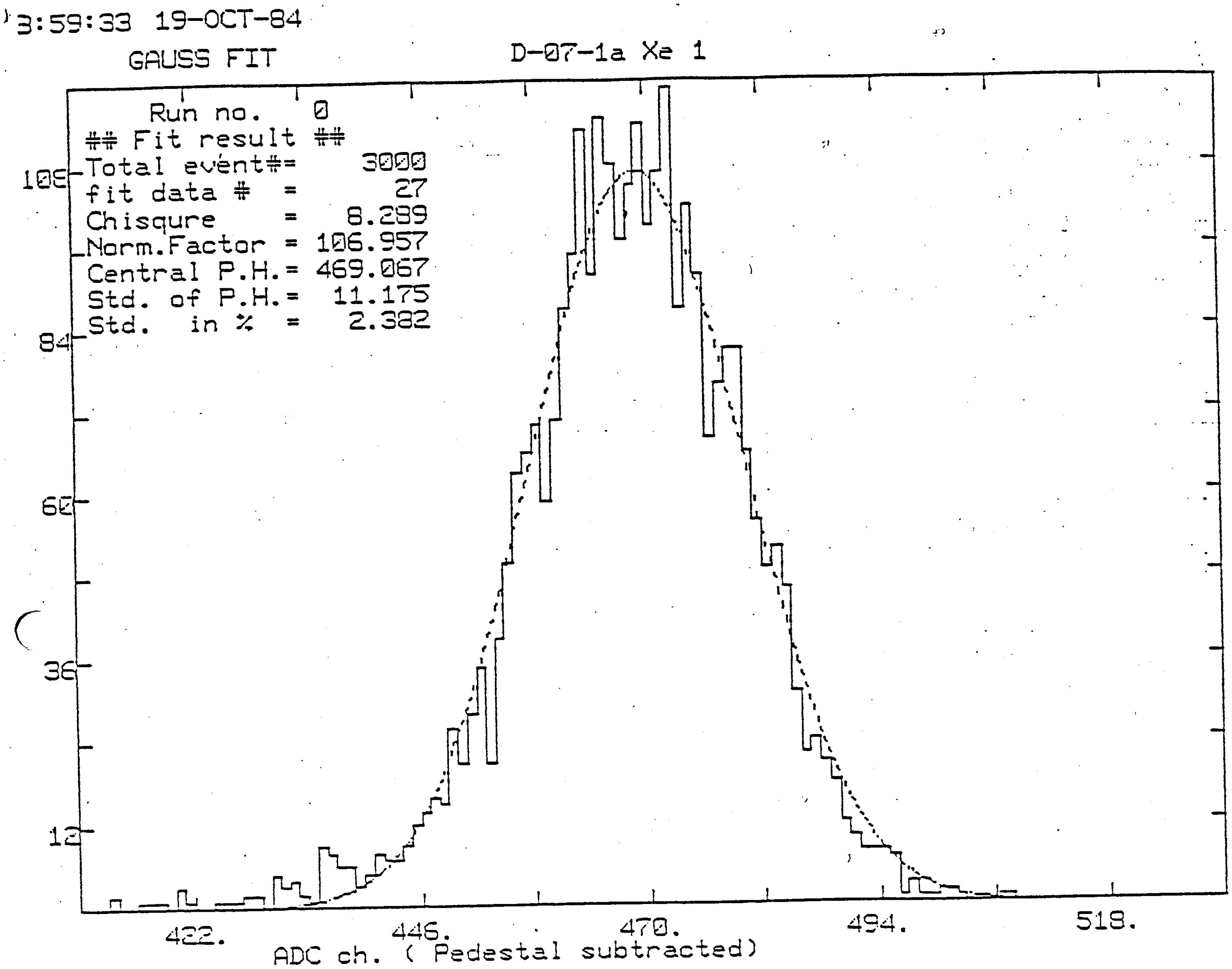


Fig. 2-12

XE1 RUN	19-OCT-84		03:59:00	
PD6	Mean:	371.2	Sigma:	4.22
PD5	Mean:	414.7	Sigma:	5.17
PD4	Mean:	451.9	Sigma:	5.00
PD3	Mean:	392.1	Sigma:	5.18
PD2	Mean:	403.1	Sigma:	4.57
PD1	Mean:	464.6	Sigma:	6.19
Pb/REF3	Mean:	836.2	Sigma:	19.51
Pb/REF2	Mean:	789.8	Sigma:	17.21
Pb/REF1	Mean:	1059.4	Sigma:	23.16
REF3	Mean:	560.9	Sigma:	7.79
REF2	Mean:	593.4	Sigma:	8.53
REF1	Mean:	442.6	Sigma:	8.09
D-07-1a	Mean:	469.1	Sigma:	11.17

Fig. 2-13

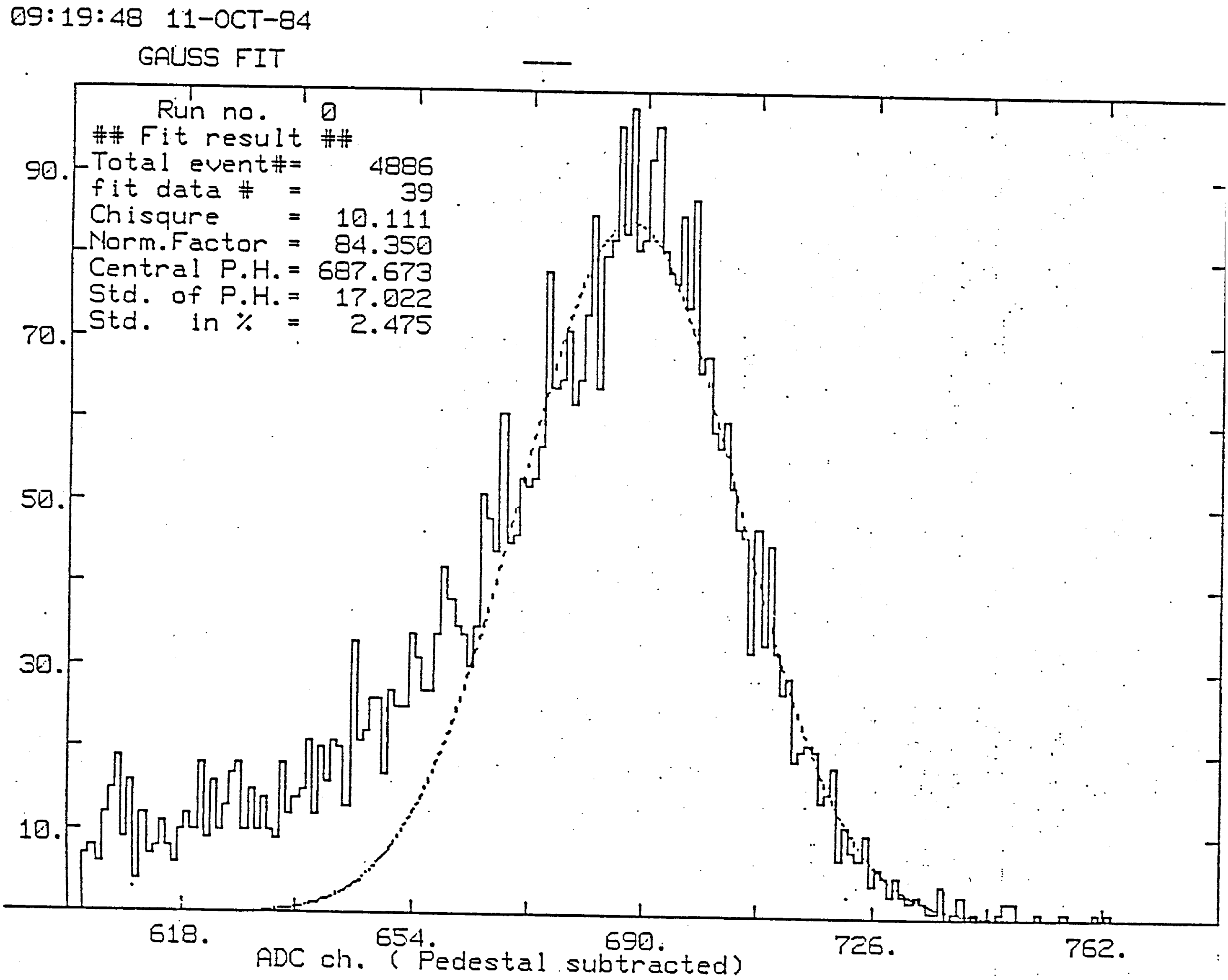

09:19:48 11-OCT-84
GAUSS FIT
Run no. 0
Fit result
Total event#= 4886
fit data # = 39
Chisqure = 10.111
Norm.Factor = 84.350
Central P.H.= 687.673
Std. of P.H.= 17.022
Std. in % = 2.475
90.
70.
50.
30.
10.
618.
654.
690.
726.
762.
ADC ch. (Pedestal subtracted)

Fig. 2-14

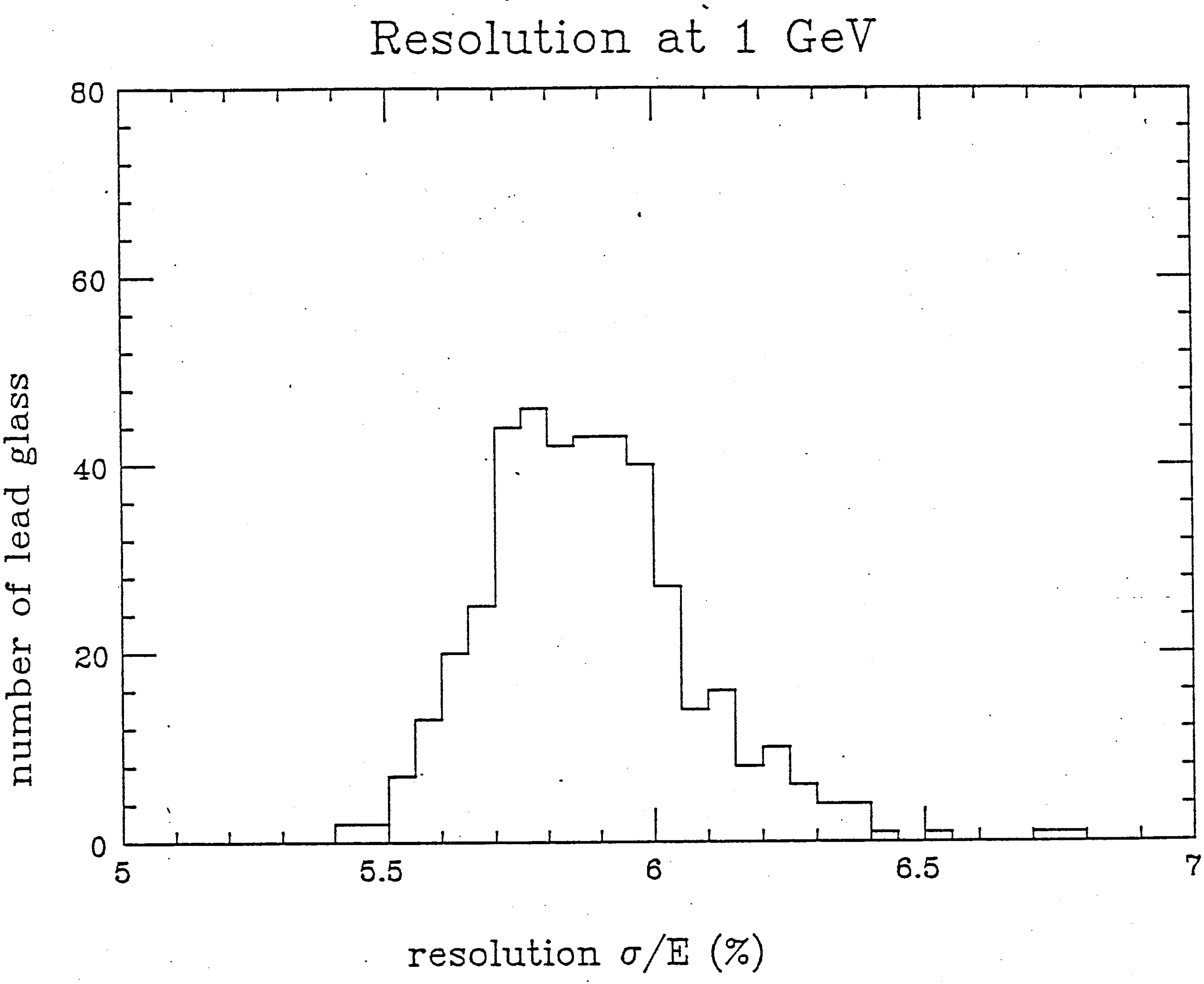
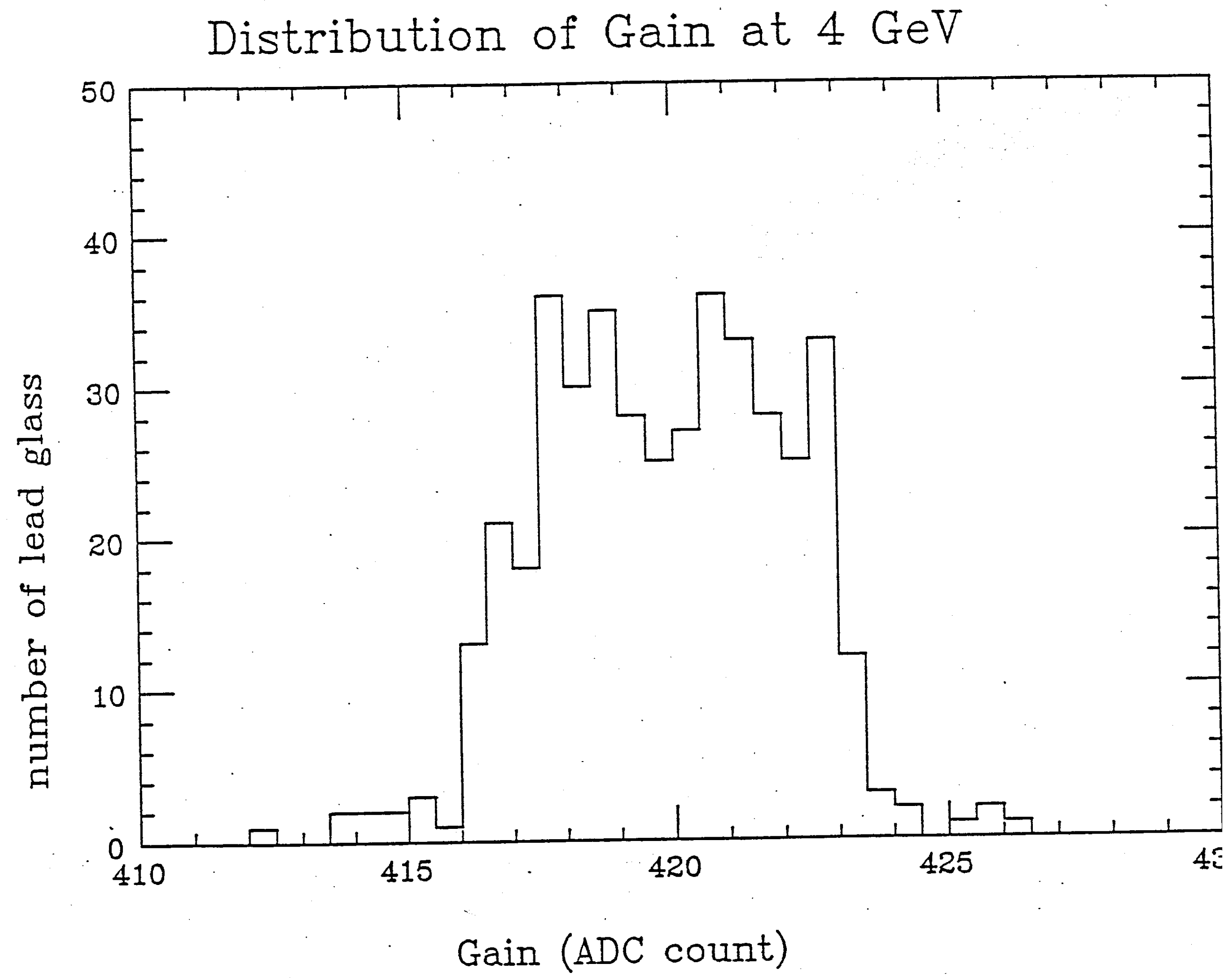
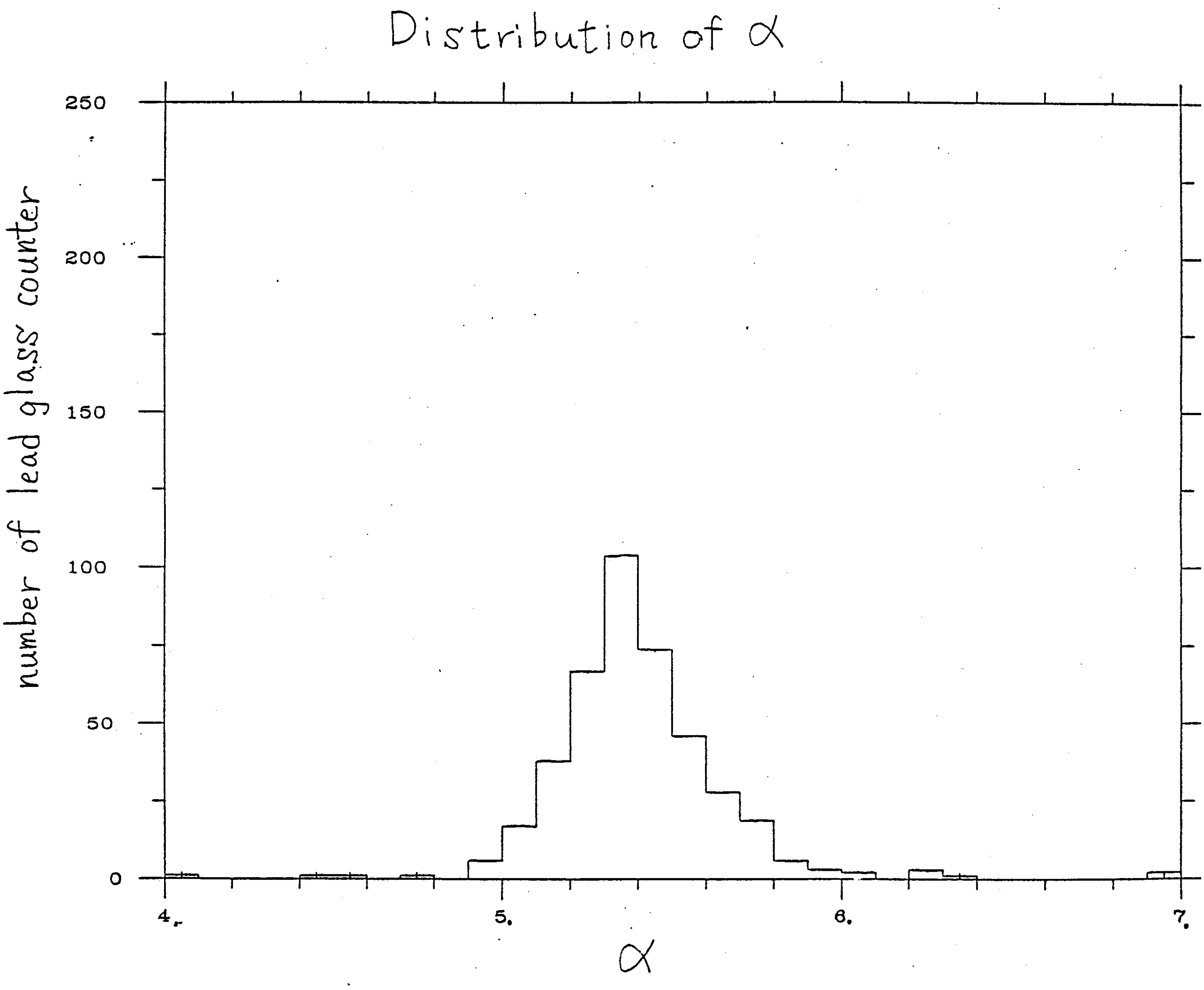

Resolution at 1 GeV
number of lead glass
resolution σ/E (%)
0
20
40
60
80
5
5.5
6
6.5
7

Fig. 3-1



Distribution of Gain at 4 GeV
number of lead glass
Gain (ADC count)
0
10
20
30
40
50
410
415
420
425

Fig. 3-2



Distribution of α
number of lead glass counter
250
200
150
100
50
0
4.
5.
6.
7.
α

Fig. 3-3

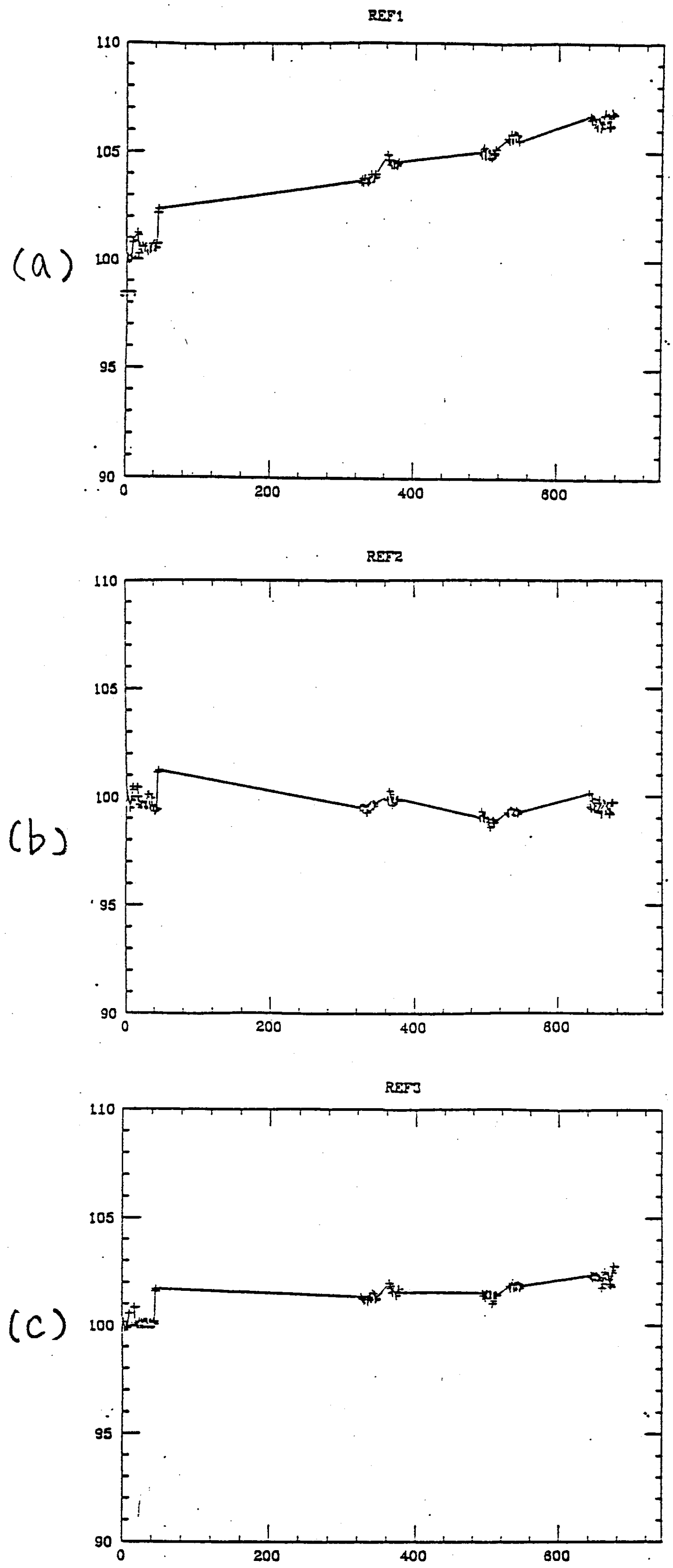

REF1
110
105
100
95
90
0
200
400
600
(a)
REF2
110
105
100
95
90
0
200
400
600
(b)
REF3
110
105
100
95
90
0
200
400
600
(c)

Fig. 3-4

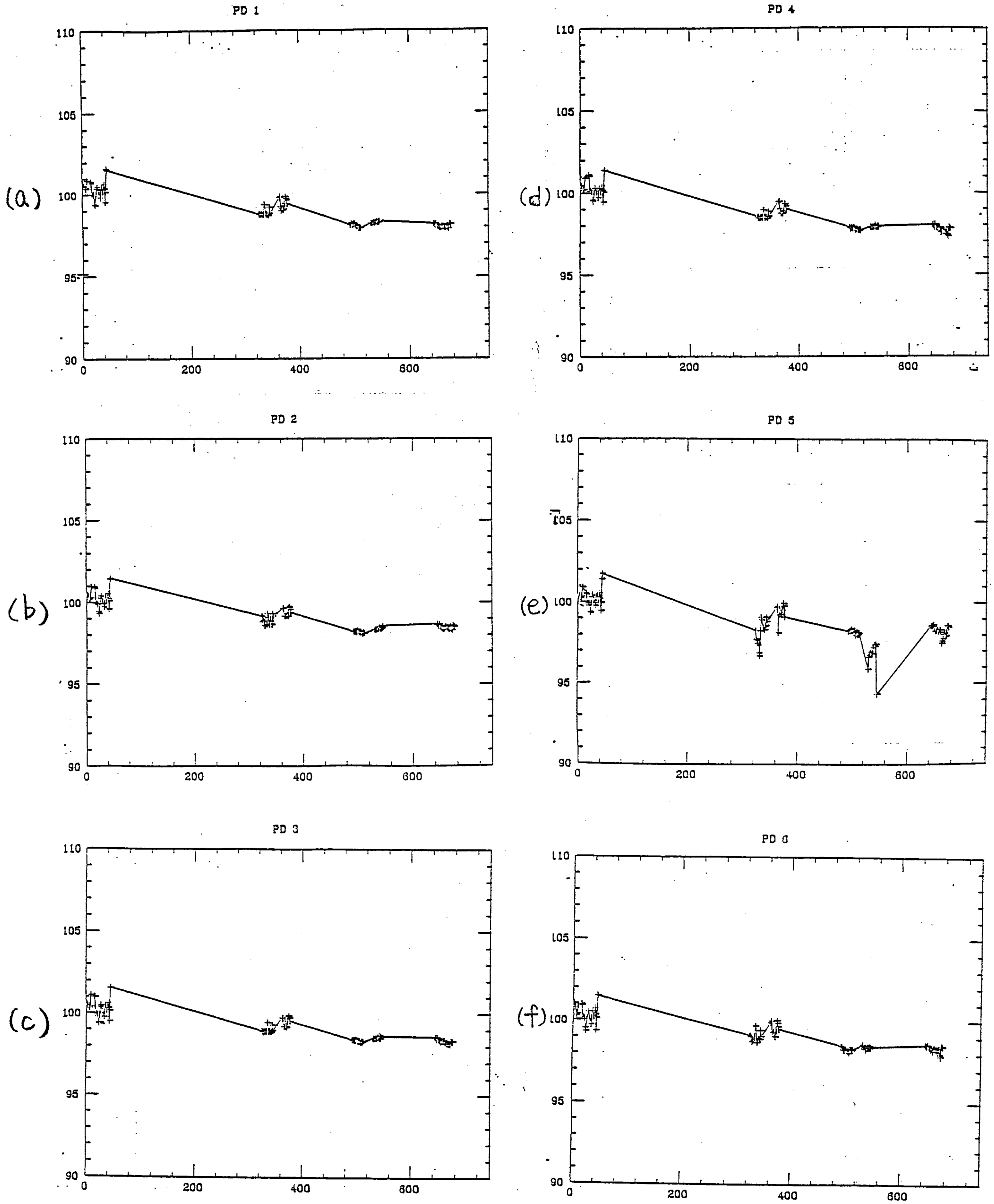

PD 1
PD 2
PD 3
PD 4
PD 5
PD 6
(a)
(b)
(c)
(d)
(e)
(f)
110
105
100
95
90
0
200
400
600
800

Fig. 3-5

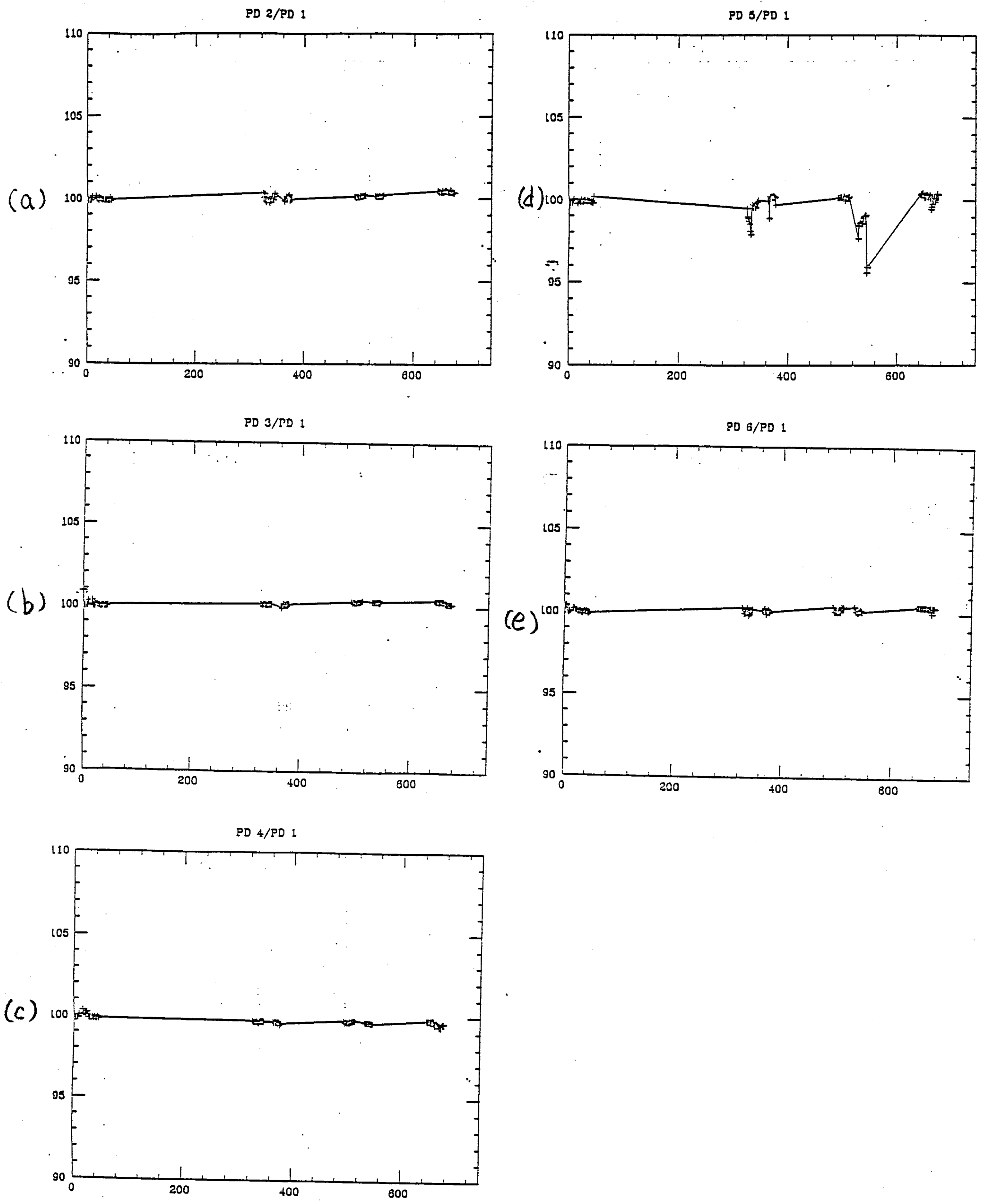

PD 2/PD 1
PD 5/PD 1
PD 3/PD 1
PD 6/PD 1
PD 4/PD 1
(a)
(b)
(c)
(d)
(e)
110
105
100
95
90
0
200
400
600

Fig. 3-6

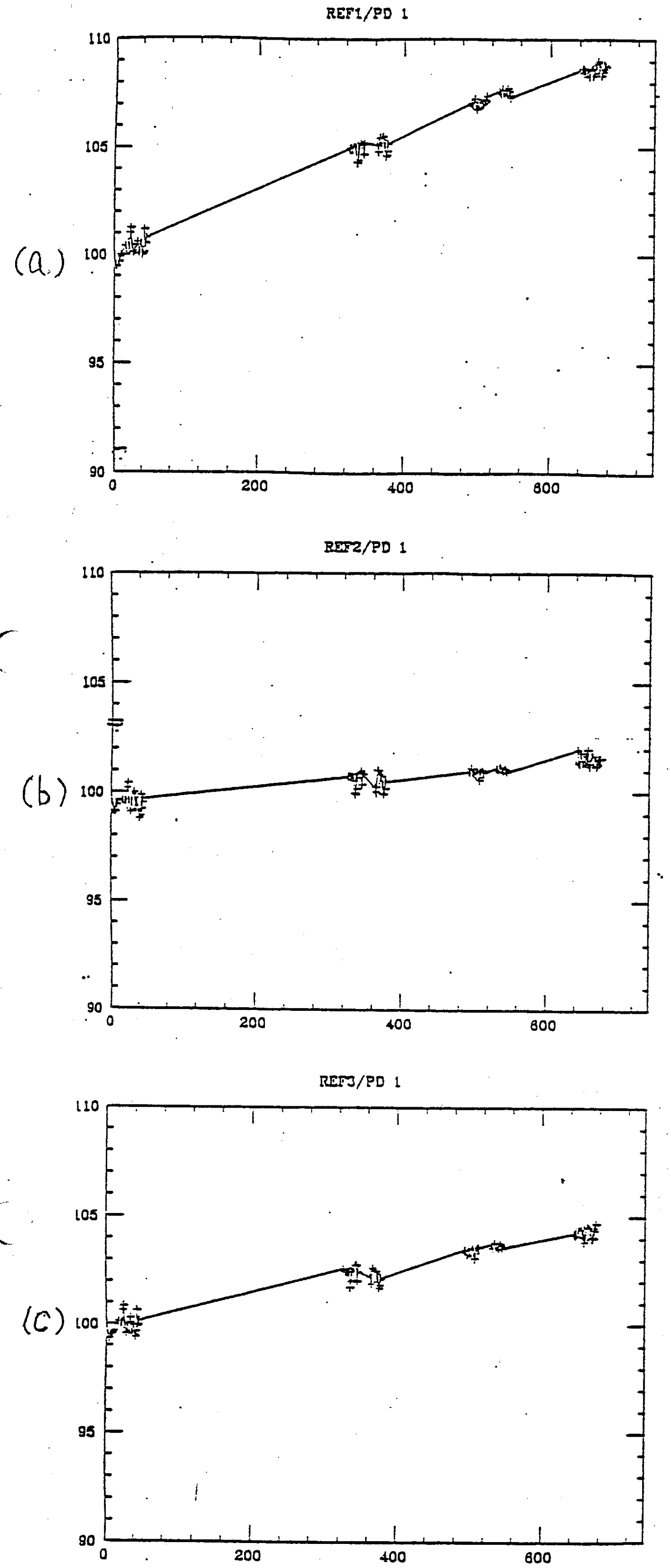
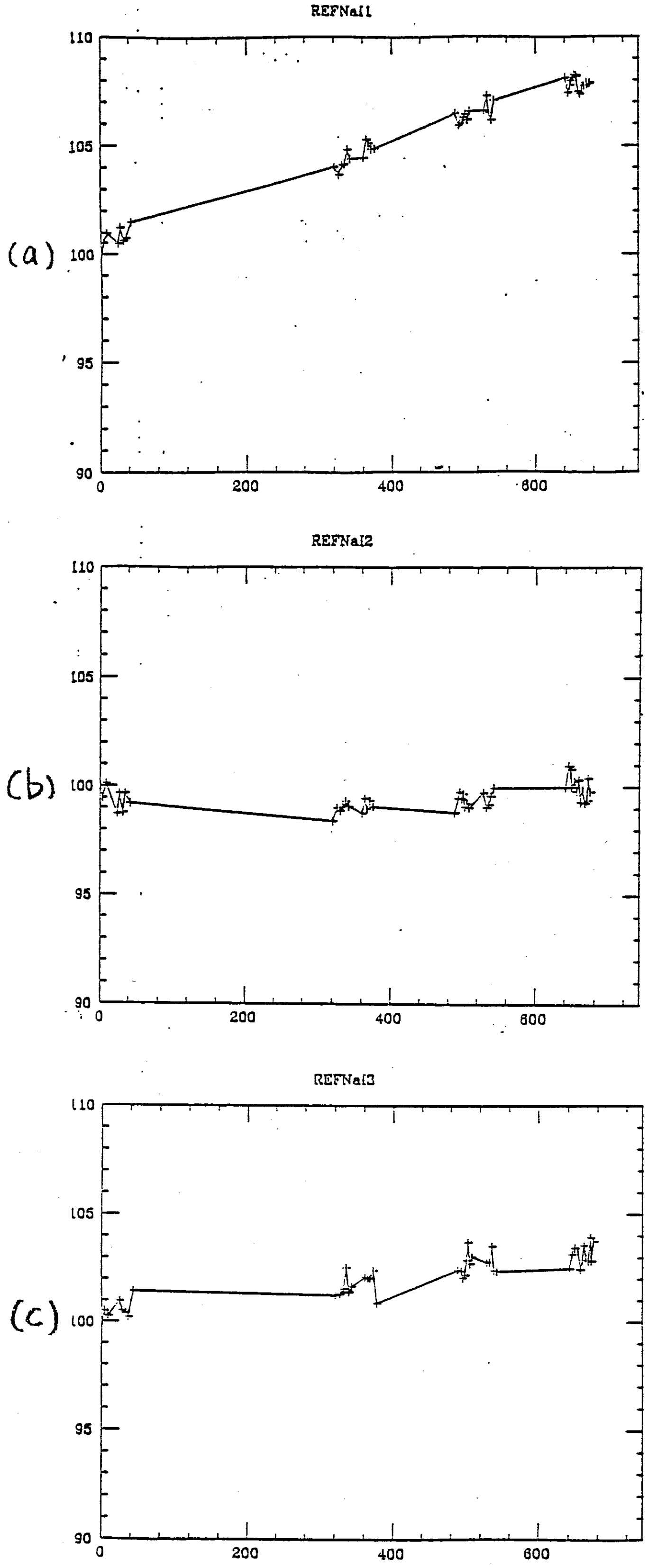
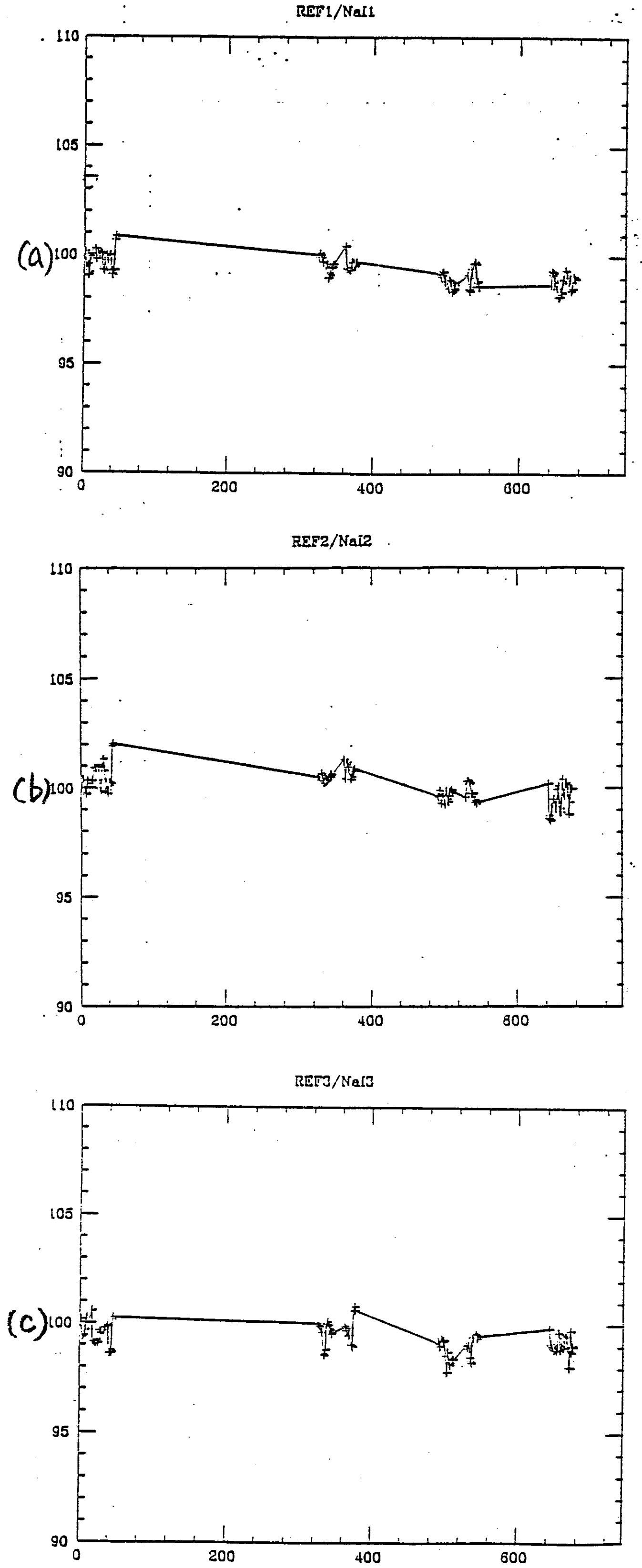

(a)
REF1/PD 1
110
105
100
95
90
0
200
400
600
(b)
REF2/PD 1
110
105
100
95
90
0
200
400
600
(c)
REF3/PD 1
110
105
100
95
90
0
200
400
600

Fig. 3-7


REFNaI1
REFNaI2
REFNaI3
(a)
(b)
(c)
110
105
100
95
90
0
200
400
600
Fig. 3-8


REF1/NaI1
REF2/NaI2
REF3/NaI3
(a)
(b)
(c)
110
105
100
95
90
0
200
400
600
Fig. 3-9

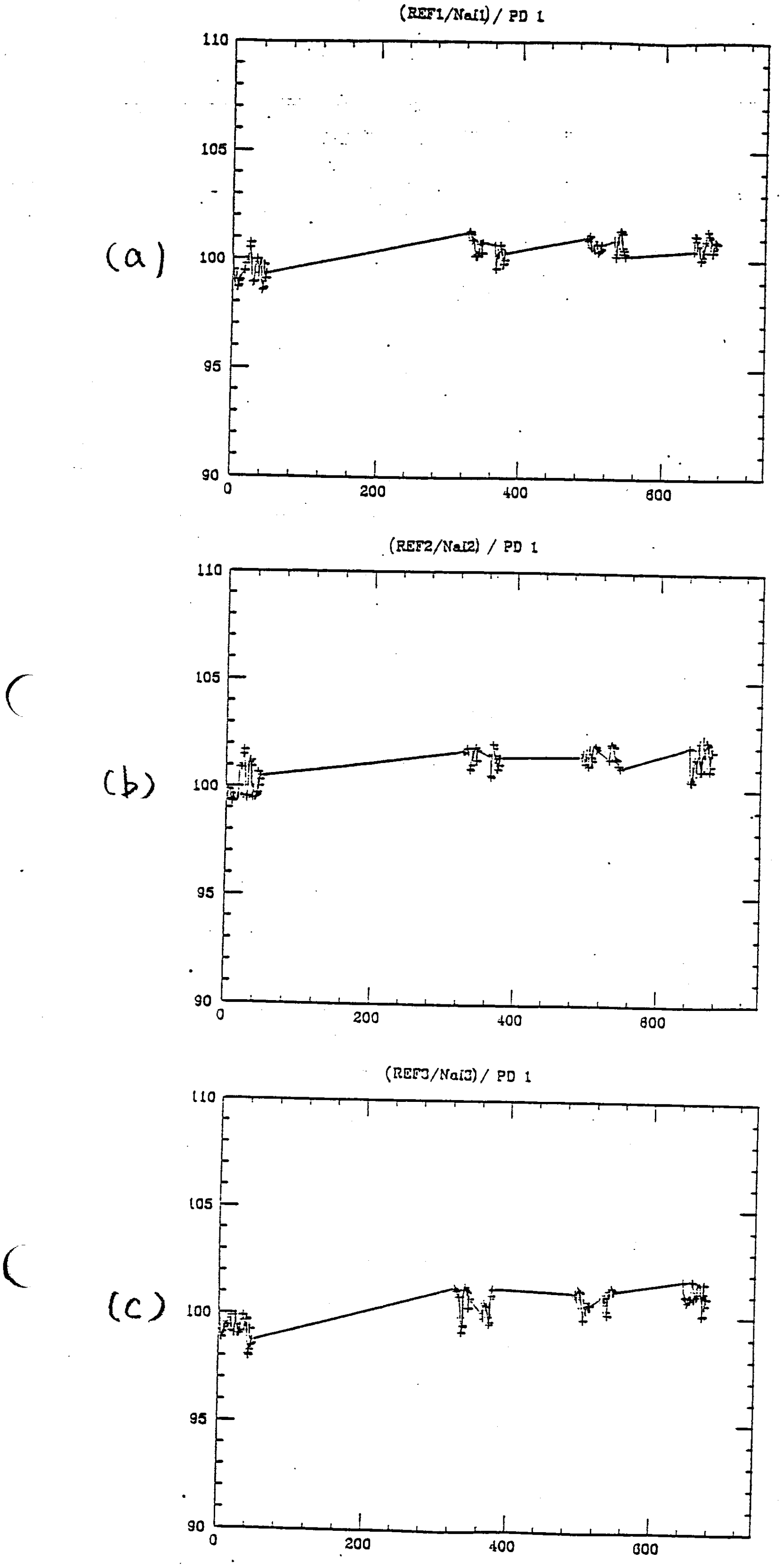

(REF1/NaI1) / PD 1
(a)
(REF2/NaI2) / PD 1
(b)
(REF3/NaI3) / PD 1
(c)
110
105
100
95
90
0
200
400
600

Fig. 3-10

Characteristics of R1911

Gain	$\sim 10^5$
Peak current	30 mA
resolution (σ/E)	$\sim 4.3\% / \sqrt{E}$
number of stages	6 stages
dynode type	Box and Grid (+ Mesh)
diameter	3 inch.
length (+bleader)	12 cm

table 2-1

converter thickness (in X_0 unit)	materials
0.033	Pt 0.1 mm
0.065	Pt 0.2 mm
0.100	Pt 0.2 mm + Cu 0.5 mm
0.135	Pt 0.2 mm + Cu 1.0 mm
0.205	Pt 0.2 mm + Cu 2.0 mm
0.670	Pt 0.2 mm + Cu 1.0 mm + Pb 3.0 mm
1.210	Pt 0.2 mm + Cu 1.0 mm + Pb 6.0 mm

table 2-2

electron yield summary

Energy	S1 rate (/sec) (10mm x 10mm)	S2 rate (/sec) (30mm x 30mm)	S1 S2 rate (/sec) (10mm x 10mm)
4 GeV	320	1000	280
2 GeV	630	2800	600
1 GeV	500	2400	400

table 2-3