ALEPH 87 – 93
NOTE 87 – 16
20-October-1987
E. Fernandez *et al.*

A Small Angle Luminosity Monitor for Aleph

E. FERNANDEZ, L. GARRIDO, J. GOMEZ, M. MARTINEZ, P. OLMOS* AND J. A. PERLAS

Laboratori de Física d'Altes Energies
Universitat Autònoma de Barcelona
08193 Bellaterra, Barcelona

ABSTRACT

The design and simulated performance of a very small angle luminosity monitor (SALM) for Aleph, as well as a time-table for its construction, are described.

⋆ Permanent Address C.I.E.M.A.T., Av. Complutense 22, 28040 Madrid.

1. Introduction

The Aleph main Luminosity Monitor will detect Bhabha scattering with a rate of approximately 0.25 Hz at a LEP luminosity of $10^{31} cm^{-2} s^{-1}$. This rate is clearly insufficient to detect rapid changes in the LEP luminosity which are likely to occur especially during the initial LEP operation. As has been discussed previously in the collaboration,[1] it is both possible and highly desirable to build a system made of four small calorimeters to detect Bhabha events at very small angles, with a counting rate about 20 times higher than that of the main luminosity monitor. This counting rate can be made available on-line, so that the relative LEP luminosity can be constantly monitored. At a luminosity of $10^{31} cm^{-2} s^{-1}$ the statistical precision of the measurement would be 5% in about 1 minute of monitoring time. In this note we describe the design of such a system and the schedule of its construction. In the following we will refer to this system as the SALM (Small Angle Luminosity Monitor).

The SALM could also be used in the monitoring of the synchrotron and off-momentum electron backgrounds in the ALEPH detector. As explained in section 4 below, it is not well known what those backgrounds will be. We will monitor single rates in each counter as well as simultaneus showers in counters located back to back (the signature for Bhabha events). In addition we will count back to back showers whith one of the showers comes from a given bunch crossing and the oposite side shower comes from the next crossing of the same bunches. With these three measurements one can obtain the true backgroud rates. Presumably the background in the central part of the ALEPH detector will be proportional to the measured background in the SALM. The latter can be one of the signals given to the LEP operators as a measurement of the background in ALEPH.

As described in reference 2, the exploitation of the physics with polarized beams in LEP requires a measurement of the relative luminosity of different bunch polarization configurations with an error smaller than 10^{-3}. The SALM is presently the only detector in ALEPH that could accumulate enough statistics to perform such a measurement (the rate on the SALM is about 20 times that of the Z_0 rate in ALEPH). We describe, with the current design, what possible systematic differences between the different bunch luminosities are tolerable so as to maintain the above precision in the measurement of the relative luminosity.

2. SALM location and acceptance

The SALM detector will consist of four identical calorimeters located symmetrically on each side of the beam pipe with respect to the horizontal (bending) plane, and on each side of the interaction point along the beam (Fig. 1). (In the following we use a coordinate system in which the z axis is along the beam and the x axis is in the horizontal plane and perpendicular to the beam). The beam pipe has been made elliptical in the region from 7.66m to 7.91m in z, in order to locate the monitors as close as possible to the beam line. The ellipse's smaller inner radius (in the x direction) is 6cm and the counters will be located just outside the beam pipe, with the active area of the counter starting at 6.5 cm from the beam. (It may be possible to come slightly closer to the beam. All the acceptance calculation in this paper assume that the minimun distance is 6.5 cm).

The superconducting (mini-beta) quadrupole located in the region $3.7m < z < 5.7m$ will defocus Bhabha electrons and positrons going towards the monitors from the interaction point so that the effective minimun angle seen by the monitors is $\theta_{production} = 5.1\ mrad.$ Fig. 2 shows the constant $\theta_{production}$ lines seen on the x-y plane at $z = 7.7m$, the beginning of the monitor. The beam pipe elements before the region of the monitor define a vindow such that the maximun acceptance angle in the x-z plane is $\theta_{production} \approx 6.7\ mrad.$ as seen in Fig. 3 . There is no additional gain in making the monitor wider than 2cm.

An estimation of the acceptance can simply be obtained by integrating the lowest order *q.e.d.* Bhabha cross section

$$\frac{d\sigma}{d\Omega} = \frac{(\hbar c\alpha)^2}{16E^2}\frac{(9 + 6cos^2\theta + cos^4\theta)}{(1 - cos\theta)^2}$$

over the acceptance region after taking into account the effect of the quadrupole magnet. With the design strengh of the quadrupole magnet, k=-0.1646 m^2, the calculated acceptance with this method is .67 $\mu barns.$ A more sofisticated calculation, taking into account complete *q.e.d.* radiative corrections to third order and Z_0 self-energy diagrams[3] , gives a total acceptance of .57 $\mu barns.$. The efficiency for detecting Bhabhas will be about 75 % as explained in the next section. Taking this into account the expected counting rate at a luminosity of $5 \times 10^{30} cm^{-2}s^{-1}$ is about 2Hz, which provides a measurement with an statistical precision of 5% in about 3.5 minutes.

3. Calorimeter design

Each of the four counters consists of a sampling calorimeter made with tungsten converter sheets interspersed with sampling layers made of plastic scintillator and a plane of vertical silicon strips as described below. The overall shape of the calorimeter is that of a rectangular box of $2cm \times 5cm \times 12cm$ as shown on the drawing of Fig. 4 . Tungsten was chosen for its small radiation length (0.35 cm) needed to locate the calorimeter in the limited space available. The first tungsten layer has four radiation lengths, which are needed to protect the sampling layers from the high flux of synchrotron radiation photons. The next 4 tungsten layers are each 2 radiation lengths thick. The first sampling plane has both a plane of silicon strips and a scintillator layer, while the next four sampling planes have only one layer of scintillator. Finally a thick plate of tungsten 2.1 cm (6 radiation lengths) protects the sampling planes from synchrotron radiation photons entering the back of the calorimeter.

The five plastic scintillators planes will be read-out individually with silicon photodiodes and their signals will be added to get one measurement of the total energy. Hamamatsu photodiodes with a rise-time of 15ns are available and we are investigating their use with a full-size calorimeter prototype made of copper instead of tungsten. We hope to obtain a time-resolution on the signal of about 20 ns. This should be sufficient to distinguish between signals associated with beams coming from the interaction point after collision and beams going towards the interaction point before collision (the time separation between those two classes is 48 ns). This time information provides a large enhacement in background rejection. Our present plan is to use scintillators 1 cm thick and match the $2cm \times 1cm$ cross sectional area of the scintillator to the Hamamatsu S1723-05 $1cm \times 1cm$ pin photodiode with an a small photoguide. In the mechanical design we make allowance for reading the scintillator with phototubes should them be more suitable than photodiodes.

The energy resolution with the scintillator read out is dominated by the lateral leakage, since most of the electrons enter the counters very near the edge. Shown in Fig. 5 is the average energy deposited in the scintillator by a 50 GeV shower versus the point of entry from the edge of the calorimeter. The error bars are the fluctuations on the average energy deposited. The showers were simulated, as in the rest of this paper, by the GEANT program.[4] A Bhabha event will be defined as a back to back shower with an energy above a certain threshold and therefore the effect of the leakage is to reduce the Bhabha detection efficiency. Shown in Fig. 6 is the simulated efficiency as a function of the threshold energy cut, expressed as a percentage of the total maximun energy. The rather poor efficiency reflects the fact that most of the electrons or positrons enter the calorimeters near the edge where both the average energy deposited and the energy resolution are poor, but an efficiency of 75 % is easily achievable. The efficiency would be considerably improved if we had information on the distance of the point of entry from the edge of the calorimeter. This is one of the purposes of the silicon strips in the first sampling layer.

As just mentioned the fisrt sampling layer will also contain a plane of vertical silicon strips. The main reason for this plane was to obtain information on the point of entry of the showering particle. We have simulated how to obtain this point by clustering the charge deposited in the strips. In principle the determination of this point should improve as the width of the strips decreases. The simulation shows that with $1mm$ strips one can obtain a resolution on the entry point of about $0.5mm$. More narrow strips do not improve significantly this resolution since we are already 4 radiation lengths into the converter and most showers will be already developped. With this information we can make the threshold energy cut for Bhabha triggers dependent on the distance from the edge and increase the efficiency. The exact cut will have to be determined after the first data are taken and background studies are performed. Another use of the strips will be the definition of two acceptance regions to minimize beam divergence and beam displacement effects. This is discussed in the next paragraph.

Our plans for the silicon planes is to use one of the strip geometries, read-out chips, and associated electronics being developed for tracking or calorimeter devices in the LEP experiments. Even if they generally involve more segmentation (and consequently more channels) that we need, the cost may be smaller than if we have to order special strips and special discrete electronics for our particular application. The work on this has started recently and will be done in collaboration with some members of the Microelectronics Division of CIEMAT (Madrid) interested in this technology.

By adding four more planes of silicon (without strips) we could also have another independent measurement of the shower energy. Silicon planes for this purpose have been used succesfully at CERN[5] and will be used at LEP by the LEP instrumentation group in the calorimetric devices located in the collimators inmediately behind our counters.[c] We are also considering this possibility.

4. Background rates

Two kinds of background will hit the monitors. One is the synchrotron radiation photons emitted from the quadrupole fields in the straight section around the interaction points. The other is the off-momentum electrons produced by beam gas bremsstrhalung in in the straigh sections and in the arcs.

The synchrotron radiation backgrounds depends critically on the position of the collimators just behind our calorimeters.[7] The energy spectrum of the photons ranges from 10 KeV up to about 5 MeV. Most of them will be absorbed by the thick tungsten layers on each side of the active layers of the calorimeters but a tail remains that can reach these active layers. There are in addition the photons entering the sides of the monitor. The effect of this background will be a small signal present with every beam crossing which will be almost completely suppressed by the threshold cut on the Bhabha triggers. We have started a detailed calculation of the amount of photons reaching the monitors as well as a simulation of the signal induced in the active volume of the calorimeters.

Off-momentum electrons and positrons reaching the area of the interaction region are produced by beam gas bremsstrahlung in the straight section of the beam pipe around the interaction point as well as in the arcs. The amount depends, for a given lattice of the machine, on the beam gas concentration in different regions of the machine. Based on the estimations by A. Smith[8] we estimated that the rates of off-momentum electrons in one calorimeter would be at most 10^{-3} per bunch which implies a back to back counting rate of 0.01 Hz, or 0.4% of the Bhabha rate. New calculations have been done by G. von Holtey in a very recent note[9] , with the result that the rate of off-momentum electrons reaching the collimators near the SALM will be considerably higher than expected. In this note two additional one-jaw scrapers are proposed on each side of the experimental region producing a complete blocking of off-momentum electrons in the straight sections from anywhere else in the machine. The detailed investigation of this problem for the region of our monitors is in progress.

It should be noted that the background rate can be inferred from rates of showers in a single counter, the rate of simultaneous showers in back to back counters (the signature of Bhabha events) and the rate of back to back showers where one of the showers comes from a given beam crossing and the oposite shower comes from from the next crossing of the same bunches. We will monitor these three rates in order to measure the background.

5. Precision measurement of the relative luminosity of different bunch polarization configurations in LEP.

One of the goals of the polarization program discussed for LEP is the measurement of the Left-Right Asimmetry with an error smaller than 0.001[2]. This requires a measurement of the relative luminosity between the various bunch polarization configurations of 10^{-3} or better. Statistically this precision can be obtained with the SALM, but it is less clear if systematic differences between bunches with different polarizations can be kept at this level. Two effects are particularly important. One would be the possible change in the transverse (x direction) position of the crossing point between two different polarization configurations (two successive bunches). The other would be the possible difference of the beam divergence between such configurations.

To investigate both effects we have written a Monte Carlo program. The beam divergence is simulated by generating e^+e^- beams with directions gaussianly distributed with respect to the +z and -z axis. The resulting Bhabha scattering between the acollinear e^+e^- produces an also accollinear e^+e^- pair in the final state. Since Bhabha events are only counted by the simultaneus observation of e^+ and e^- showers in a pair of counters located back-to-back, an increase on the beam divergence produces a decrease on the counting rate. Shown in Fig. 7 curve (a) is the accepted Bhabha cross section in the SALM system as a function of the beam divergence. To calculate this curve we assume a beam width (full-width at half maximun of the gaussian distribution) of 250 μm in the horizonthal plane, of 50 μ in the vertical plane and of $1cm$ in z. The average beam position was kept at the x=0, y=0, z=0 point. As it can be seen from this curve, at a beam divergence of $.16mrad.$ (the nominal value) a change of $0.01mrad$ in the beam divergence decreases the acceptance by 0.4 %.

The effect of a possible systematic change on the average position of the collision point of the two beams in the horizontal plane is also a decrease on the counting rate as we move from the x=0 point. This is shown in Fig. 8 curve (a) which shows the dependence of the acceptance on the beam displacement in the x direction. To calculate this curve the beam widths were kept as described above and the beam divergence was fixed at $.16mrad.$ A displacement of the beam by 10 μm from $x = 0$ produces a decrease in the acceptance of .2%.

The dependence of the acceptance on beam divergence and beam displacements would be reduced if we were able to define a restricted acceptance region characterized by a smaller area in the front face of the calorimeters (Fig. 7). A Bhabha event could be defined by a coincidence of a shower on the inner acceptance region of one counter with a shower anywhere on the oposite counter. For a hit in a given inner region of one counter we can guarantee that the other particle hits the oposite side counter provided the acollinearity angle and the displacement of the beam from the nominal interaction points are smaller than certain values.[10] The smaller the inner region the larger those values but of course the acceptance would also be smaller. This is ilustrated by the curves (b) and (c) in Figures 7 and 8, which show tha acceptances for two possible definitions of restricted inner regions.

6. Mechanical support

The calorimeter will be built inside an aluminum box which also will house the front-end electronics. The box will rest in a fixed position on a table supported by the mobile cantilever garder of the superconducting quad. This table has adjustable devices so that the calorimeter box can be precisely located with respect to the nominal beam line. The table has been designed at CERN by Mr. J. Bouad of the EF/LI Division and will be built at Barcelona. The table will slide on rails so that the calorimeter can be moved away from the beam pipe when the pipe has to be "baked-out" after a vacuum leak. The final position of the table can be surveyed.

7. Data acquisition

Our idea at the beginning was to keep all the SALM information on scalers to be displayed visually and to be read periodically by the ALEPH data acquisition system. The need for position information requires to read and process several ADC channels from the silicon. The minimun number of channels is 30 for each of the calorimeters. What we propose is to treat the information online and to accumulate the processed output in a buffer of the online system. This buffer, containing the accumulated luminosity for the different bunch configurations, can be appended to the event buffer of each real Aleph trigger for further off-line analysis. Clearly more discussions are needed with the polarization, trigger and online groups of Aleph before deciding on a final scheme.

8. Timetable for construction

Finalize the scintillator read-out design:	Jan 1, 1987
Acquire scintillator and all components for read-out:	March 1, 1988
Acquire machined tungsten:	March 1, 1988
Decide silicon strip sizes and system to use:	Jan 1, 1987
Acquire silicon and all components for read-out:	May 1, 1988
Construction of support table:	March 1, 1988
Finish construction of prototype box for one calorimeter:	May 1, 1988
Asemble full size prototype:	July 1, 1988
Test beam at CERN:	Summer, 1988
Build and assemble the 4 calorimeters:	Jan 1, 1989

9. Budget estimates

Mechanical supports:	500,000 Ptas.
Tungsten:	1,000,000 Ptas.
Silicon microstrips:	2,200,000 Ptas.
Photodiodes:	400,000 Ptas.
Electronics for photodiodes:	1,000,000 Ptas.
Electronics for microstrips:	1,000,000 Ptas.
Data acquisition electronics:	2,000,000 Ptas.

REFERENCES

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7. G. Von Holtey and K. M. Potter, "Estimates of the synchrotron radiation background in LEP experiments", CERN/LEP-BI/87-05, 1987
8. A.M. Smith, " Estimated Rates of Electron Backgrounds at LEP", LEP Notes 469 (1983) and 559 (1986)
9. G. von Holtey, " Electron Background due to Gas Bremsstrahlung", LEP/BI/Note 87-13, August 1987
10. We thank H. Hansen and R. Mollerud for bringing this idea to our attention and W. Blum for enlightning discussions.

FIGURE CAPTIONS

1. View of the ALEPH detector showing the approximate location of the SALM
2. Detailed scheme of the beam-pipe in the region close to the SALM calorimeters. Note the difference in scale in the direction transverse to the beam and along the beam
3. Lines of constant $\theta_{production}$ seen after the quadrupole magnets in the x-plane at $z = 7.76m$. The cross-hatched area is the region occupaid by the monitor
4. Schematic drawing of the calorimeter
5. Average energy deposited in the scintillator by a 50 GeV particle versus distance of point of entry from the edge of the calorimeter
6. Efficiency of detecting a 50 GeV Bhabha electron versus energy threshold
7. Accepted cross-section in SALM as a function of the beam divergence for three different values of EPSX. EPSX is the distance from the edge of the calorimeter in the front face to the edge of the restricted region.
8. Accepted cross-section in SALM as a function of the beam displacement from x=0 for three different values of EPSX.

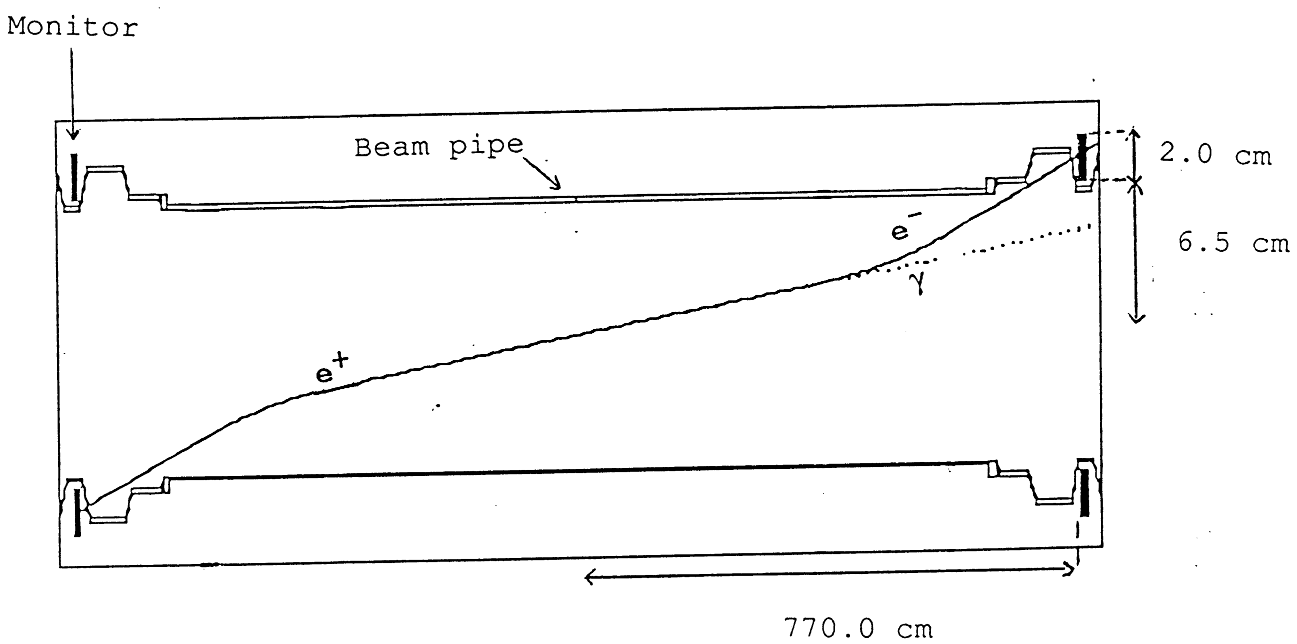


Fig 1

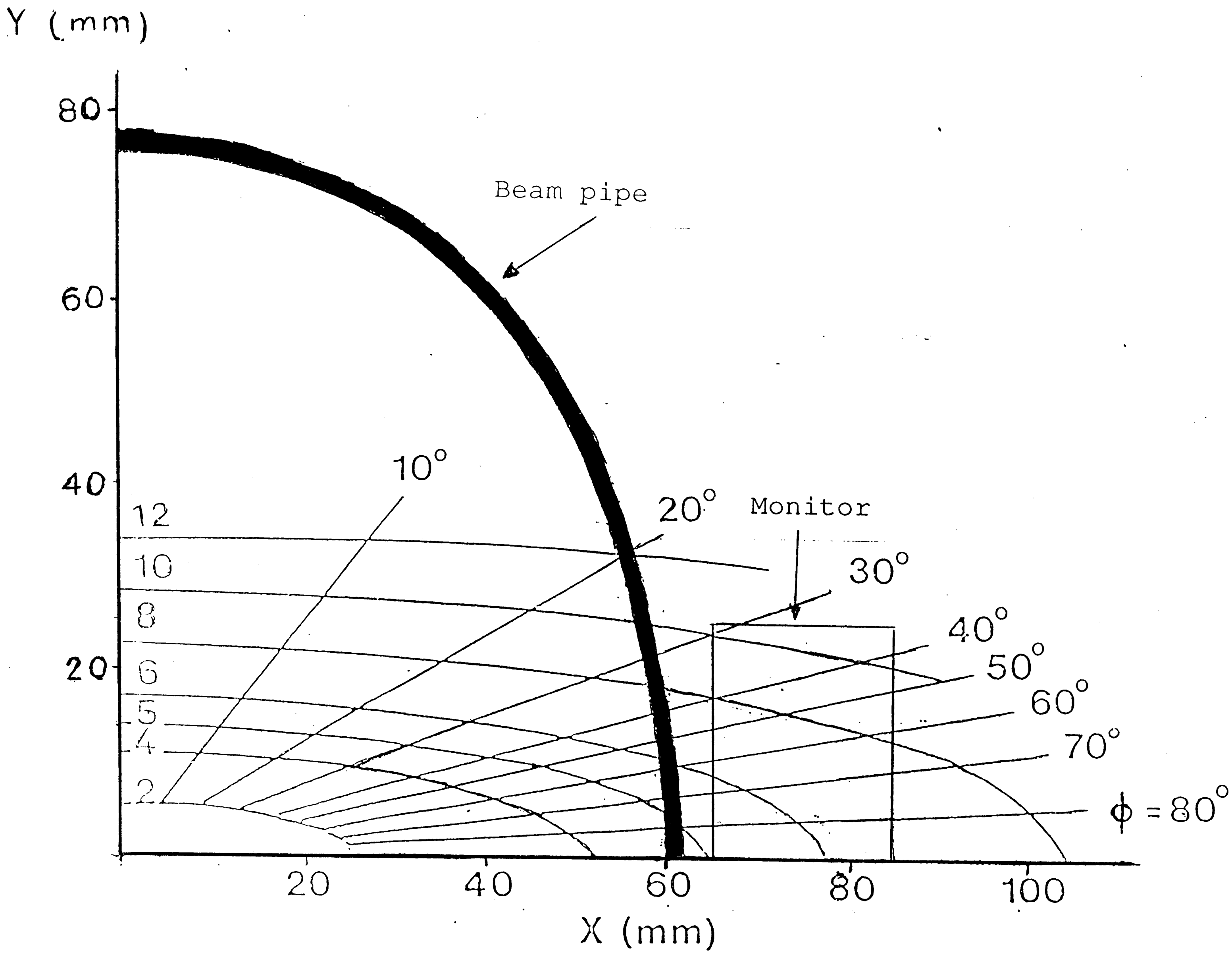
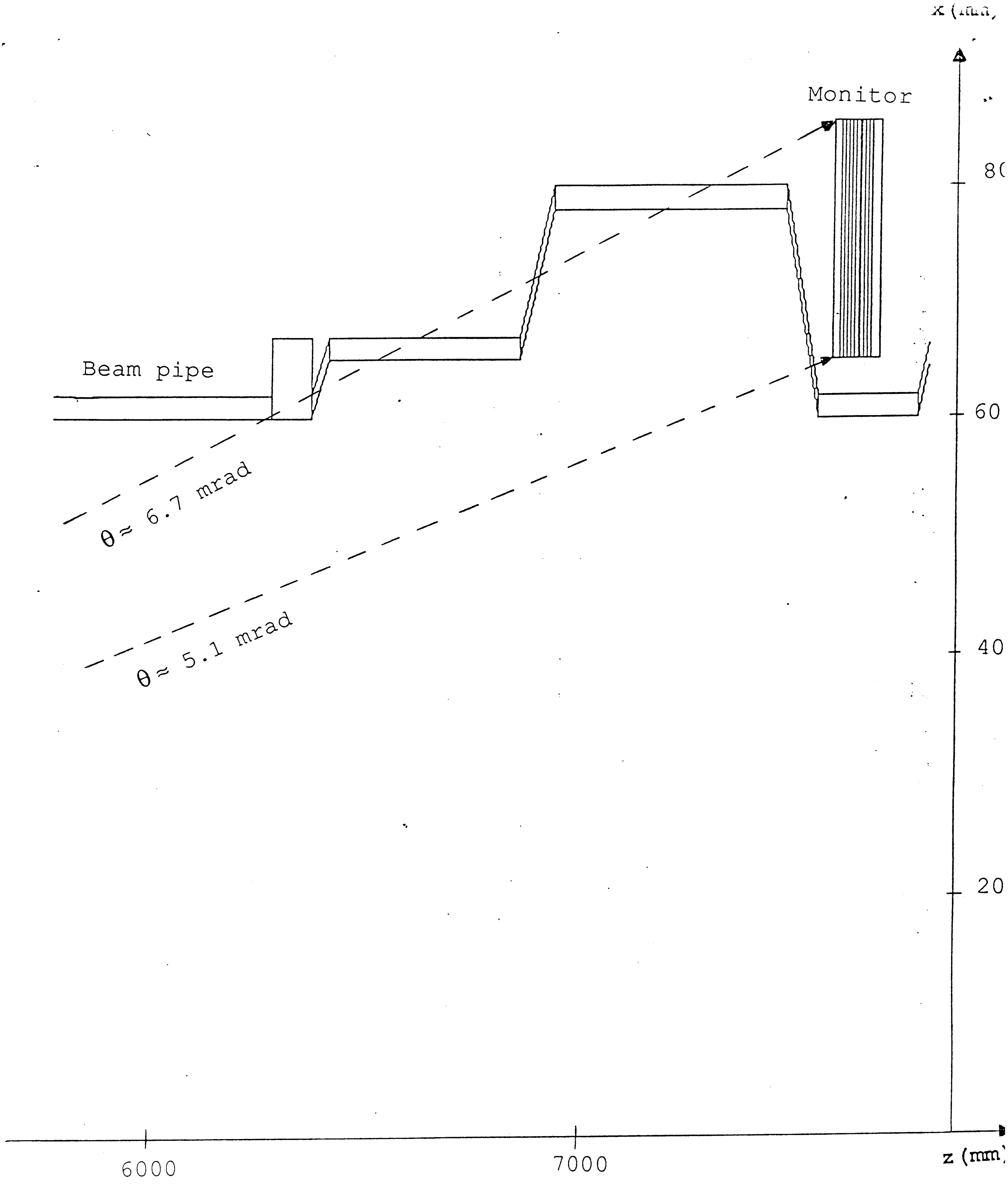

Y (mm)
80
60
40
20
Beam pipe
10°
20°
30°
40°
50°
60°
70°
ϕ = 80°
Monitor
12
10
8
6
5
4
2
20
40
60
80
100
X (mm)

Fig 2


x (mm)
Monitor
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Beam pipe
60
θ ≈ 6.7 mrad
θ ≈ 5.1 mrad
40
20
6000
7000
z (mm)

Fig 3

MONITOR

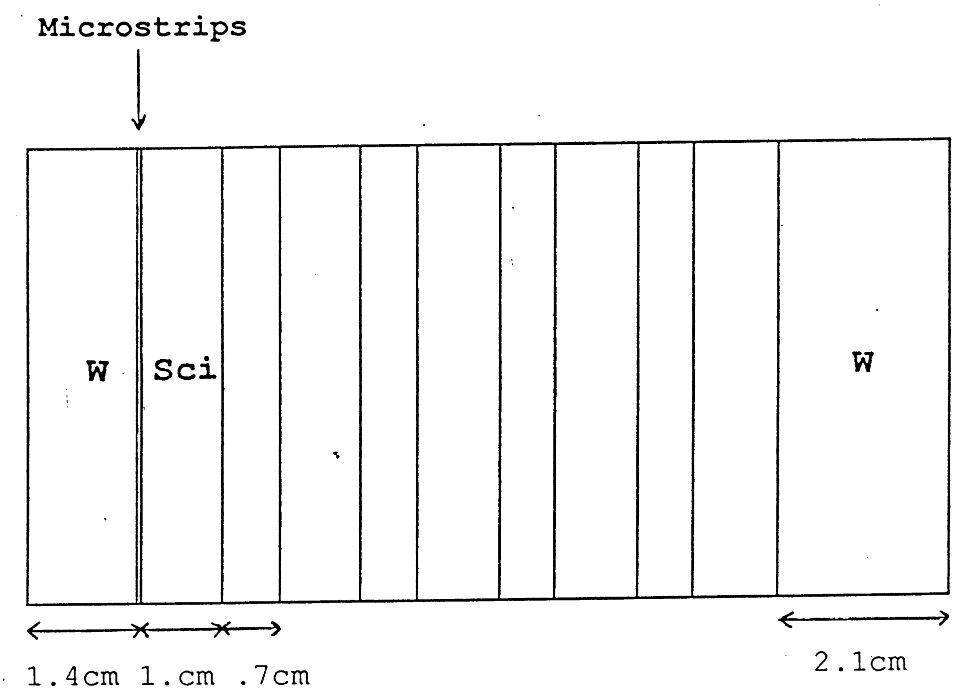


Fig 4

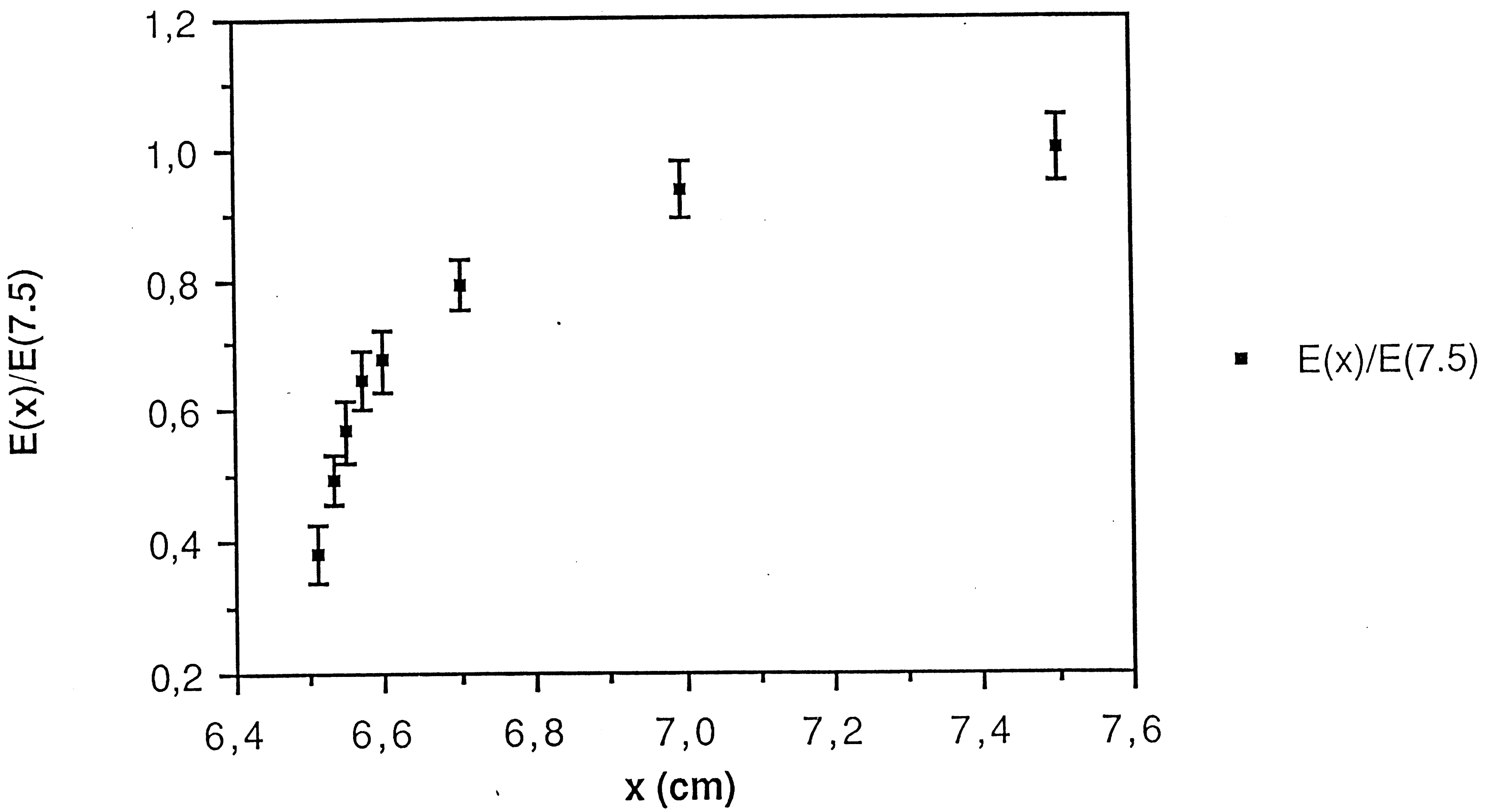
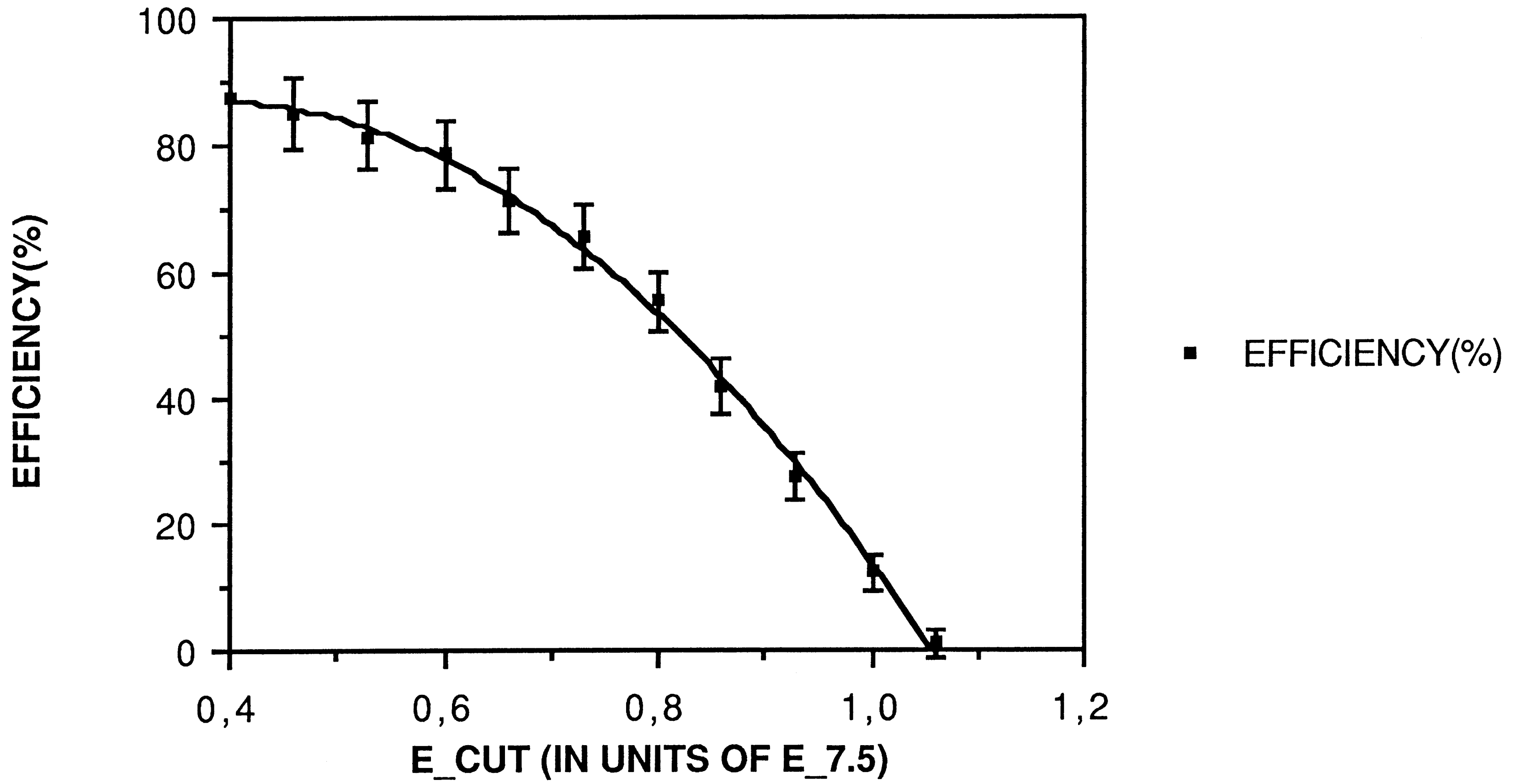


Fig 5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60
40
20
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0,8
1,0
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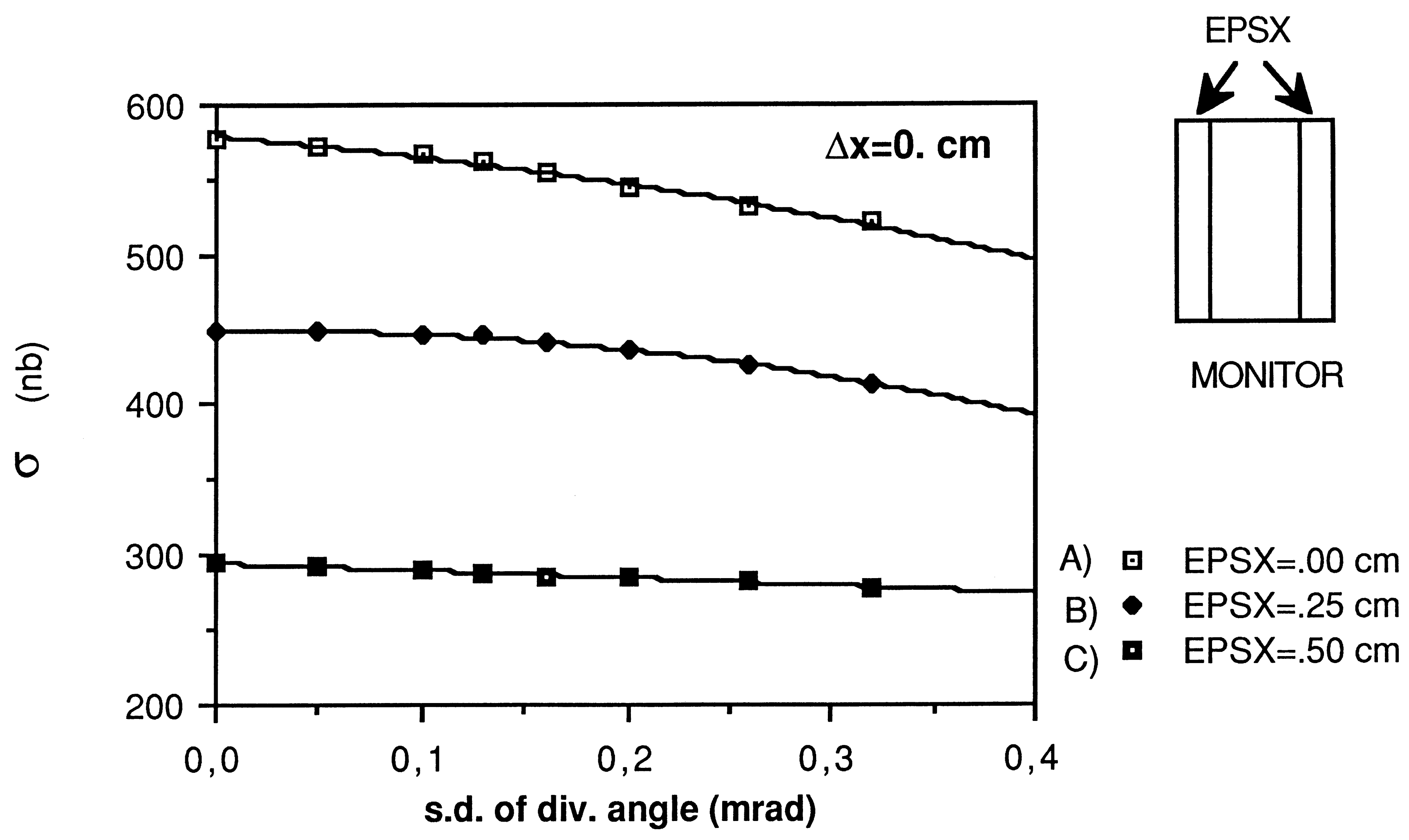
E_CUT (IN UNITS OF E_7.5)
EFFICIENCY(%)

Fig. 6


EPSX
MONITOR
Δx=0. cm
σ (nb)
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500
400
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200
0,0
0,1
0,2
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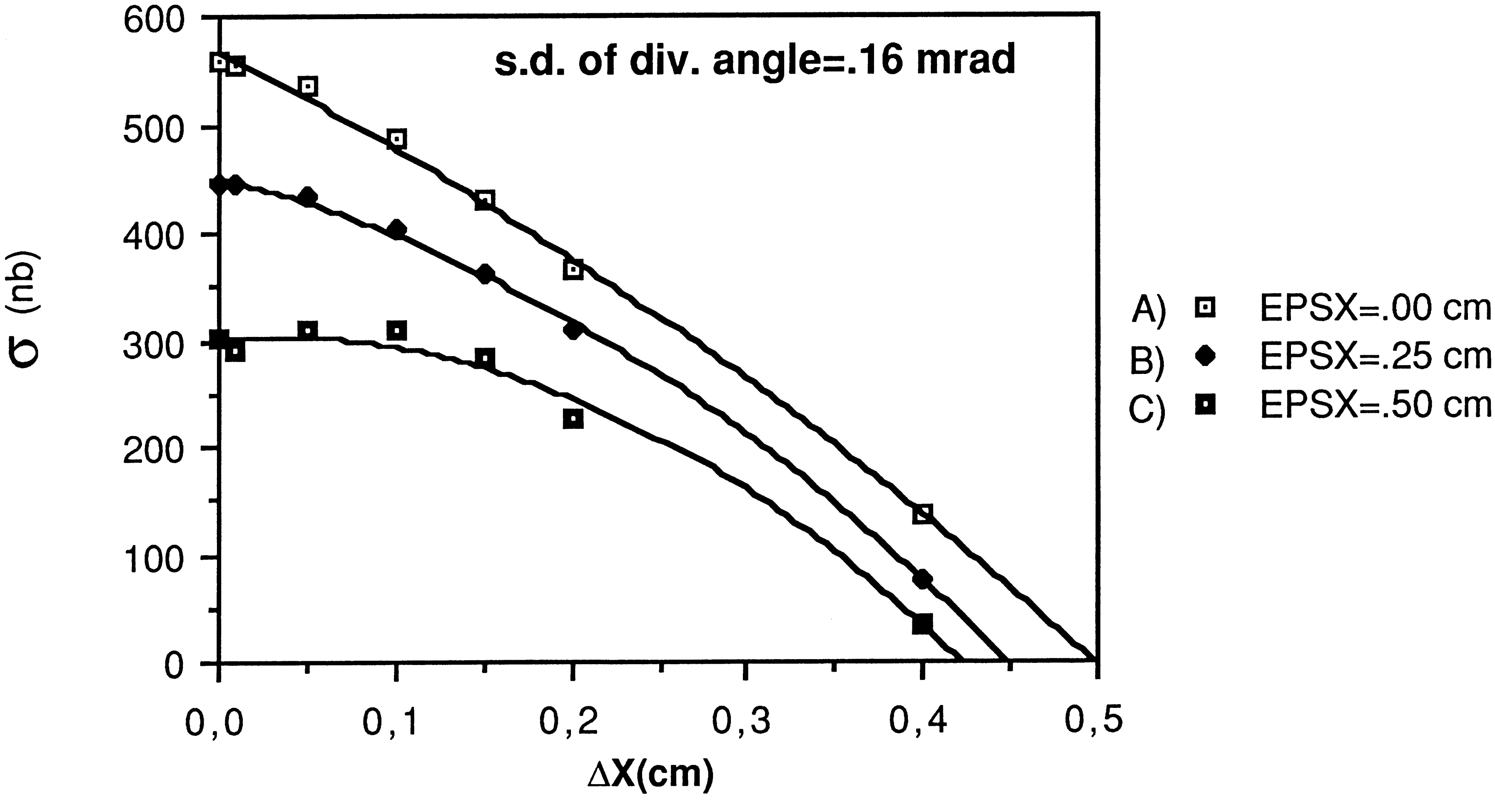
s.d. of div. angle (mrad)
A) EPSX=.00 cm
B) EPSX=.25 cm
C) EPSX=.50 cm

Fig. 7



s.d. of div. angle=.16 mrad
σ (nb)
600
500
400
300
200
100
0
0,0
0,1
0,2
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0,4
0,5
ΔX(cm)
A) EPSX=.00 cm
B) EPSX=.25 cm
C) EPSX=.50 cm

Fig. 8