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RD30 - Status report : Study of an Optical Trigger to be used for beauty search in fixed target mode at the LHC

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1 Introduction

The next generation of high-luminosity hadron colliders will require novel detectors able to operate in a very high-rate environment. The selection of rare events out of a background rate of $\sim$ 100 MHz will present a substantial challenge. Particularly in the case of beauty studies, an efficient yet highly selective trigger could be invaluable. For example, in the fixed-target mode at LHC the cross section for B-meson production is $\sim 1\,\mu$b, thus minimum-bias events need to be rejected by 4-5 orders of magnitude.

Following the suggestion of [1], we have studied the feasibility of an Optical Impact-Parameter Discriminator for beauty selection in an LHC-fixed-target experiment. We submitted an R&D proposal to the CERN-DRDC committee [2], and in October 1992 the proposal was recommended for approval with the following milestones:

- Investigate and understand the background at zero impact parameter.
- Demonstrate the feasibility of a 0.5 mm impact-parameter threshold.

Additional future improvements including multi-layer radiators and solid-state photomultipliers (VLPCs) were also mentioned.

Since the beginning of our project we have built and tested three prototypes.

1) A LiF crystal with ellipsoidal focussing mirror and photomultiplier readout was extensively tested in 1992. Details of the apparatus and experimental results have been published in [3] (Reference [4] describes a parallel but less ambitious effort carried out at Fermilab). Additional tests to understand the magnitude and origin of the background were performed in early 1993.

2) The same crystal was equipped by the end of 1993 with optical-fiber readout.

3) To improve the sensitivity at small impact parameter, a two-layer sapphire-plus-liquid device was built and tested.

In addition our collaboration has recently been reinforced by a significant number of physicists (including experts on VLPC photodetectors), some of who have carried an optical discriminator test at FNAL [4], in order to facilitate the preparation for and carry out the upcoming measurements. The VLPC readout [5] under preparation is meant to improve light collection and its high segmentation opens the possibility to improve the background rejection by providing information on the direction of the emitted light.

The optical discriminator device is part of the proposed apparatus for the GAJET experiment at the LHC [6] and proposals under study at the Tevatron [7]. Although the required point-like target limits the use of the optical impact-parameter discriminator (as a secondary-vertex trigger) to fixed-target experiments, other ideas are under study to use an impact-parameter discriminator following a toroidal magnet as a p_t trigger in a symmetric-collider experiment [8] or in an asymmetric hadron collider with a small crossing angle [9].

In the following section we present results obtained with the various prototypes. Future improvements are also discussed, and a detailed testing and development program and schedule are given.

2 Experimental test results

2.1 First LiF prototype - Background investigations

We have tested a LiF spherical shell, 3 mm thick, with a diameter of 60 mm and radius of curvature of 100 mm, in the CERN PS T9 test beam, which provides 8 GeV/c pions. The experimental setup is shown in Figure 1: the trapped light emerging from the crystal's edge is focussed onto a photomultiplier (PMT) by an ellipsoidal mirror. A typical pulse-height distribution from the PMT (2-in.-diameter quartz-window R2059 Hamamatsu) is shown in Figure 2, it exhibits clear photoelectron peaks. The particle impact parameter is measured by reconstructing the track with two drift chambers, each equipped with x-y planes and mounted upstream and downstream of the crystal system. Taking into account such factors as the chamber spatial resolution and some misalignments, the resolution in impact parameter is 250 μm.

The results are illustrated by Figure 3, which shows the x-y coordinates of the impact point on the crystal for tracks giving more than two photoelectrons. The center is depopulated, the signal being minimum for low impact-parameter tracks. The signal amplitude is shown in Figure 4 versus the impact parameter b for various diaphragms and filters mounted in front of the PMT.

The fall at large b is a diaphragm acceptance effect: Cherenkov light from high impact parameters is emitted with large angles and is cut by the diaphragm. This property can be used to reduce the background – from delta-rays, created mainly with high impact parameter – and from nuclear interactions occurring in the crystal. Without filter, short-wavelength light is trapped inside the crystal even at zero impact parameter due to the value of $n_{LiF}(\lambda)$. Thus, in order to discriminate tracks with non-zero b, a filter has to be used to select the appropriate wavelength region; this has been achieved with a filter cutting off at wavelengths below 305 nm. With a diaphragm of 40 mm and the 305 nm filter, the amplitude of the signal is shown in Figure 5 versus the signed b value in the vertical (down-up) direction and in the horizontal (left-right) one.

Comparison with the Monte-Carlo simulation indicates that the behaviour of the device is well understood. The simulation takes into account such physical effects as the polarization of the Cherenkov photons, the Fresnel reflection and refraction conditions, the LiF index chromaticity, the mirror reflectivity, the measured filter transmission, the PMT quantum efficiency, and the drift-chamber resolution.

An obvious background is due to the scintillation and Cherenkov light emitted in the air during the passage of the particles; it was measured by hiding the crystal from the PMT and found to be (0.03 ± 0.01) photoelectrons at zero impact parameter, and it is independent of b (Figure 6). This level has been substracted in the distributions given in Figure 5 and the final remaining background is (0.04 ± 0.02) p.e. at $b = 0$. Our Monte Carlo simulates some sources of the crystal-inherent background but still some sources have to be added: delta rays, nuclear interactions, multiple scattering in the various components, tracking errors. At our present level of precision, the good compatibility between data and Monte Carlo indicates that these parasitic backgrounds are small, but they still need to be measured more precisely. A more systematic study of the background is difficult and requires full tracking reconstruction, especially downstream from the crystal, in order to identify nuclear interactions or delta-ray production in the crystal. We hope to investigate this by improving our tracking system by adding other drift chambers and MWPCs (see section 3.5).

The efficiency of the device for B's depends on the threshold imposed on the signal (see section 4). Figure 7 gives the efficiency at impact parameters of 1 mm (a) and 10 mm (b) as a function of the threshold in photoelectrons. With a LiF crystal, the sensitivity at low b values is too small for application to B-event selection. Other crystals are needed to increase the light collection and sharpen the signal rise slope to discriminate lower impact-parameter particles (see section 2.3).

2.2 Second prototype, fiber readout

In the second prototype, the light collection is done with Kuraray poly styrene optical fibers of 835 μm diameter. The setup was designed to be compatible both with phototube readout and with the VLPC readout to be installed in a coming test. The fibers are set projective to collect the outgoing light: the collecting ends are arranged on a cone whose apex coincides with the average virtual source of the outgoing photons, and are brought very close to the exit face of the crystal. To ensure the correct orientation, a conical aluminium ring is employed, with holes 850($\pm$2) μm in diameter drilled to accomodate the fibers (Figure 8). To keep the light loss $\lesssim$25%, special care was taken to ensure the thinnest possible gaps, no more than 50 μm between adjacent holes. Outgoing photons are collected by three bundles of fibers. The first covers one-half of the azimuth of the crystal (550 fibers), and conducts the light to a first photomultiplier. The second (356 fibers) and the third (192 fibers) bundles are connected to two other PM's. Moreover, these last 192 fibers are grouped by 32 and equipped with special 32-channel fiber connectors, which can be coupled to fibers leading to the VLPCs inside the cryostat. In the present test they were only guided to the PMT's. The full setup is shown in Figure 9.

The sum of the signals collected by the three PMT's is shown in Figure 10. The behaviour is similar to that previously observed using an ellipsoidal mirror to focus the light, and the shape is compatible with Monte-Carlo simulations. The reduction of light is mainly due to the UV cut of polysterene fibers below 400 nm. The higher background at low impact parameters comes from the larger angular acceptance of the Kuraray fibers compared to the first protype where the acceptance was reduced by using a diaphragm in front of the PMT.

2.3 Sapphire-liquid prototype

In this configuration the sapphire crystal is the Cherenkov radiator having a refractive refractive index n_1 and is surrounded by a liquid medium of refractive index n_2. To avoid the detection of relativistic particles coming from the target, i.e. with $b = 0$, it is shown in [1] that the refractive indices should satisfy the condition

$$n_1^2 - n_2^2 = 1 - \varepsilon \tag{1}$$

with ε small and positive. When a single crystal is used in air or vacuum, $n_2 = 1$, and n_1 has to be close to, but lower than, $\sqrt{2}$. The choice of ε determines the minimum impact parameter b_{min}, which is the threshold of the device. In order to obtain good sensitivity to very small impact parameters, but avoid background from minimum-bias tracks coming from the optical centre, the minimum impact parameter must be small but greater than some lower limit.

Chromatic dispersion has also to be taken into account: n, ε, and b_{min} are λ-dependent. Unfortunately, a quasi-achromatic behaviour cannot be obtained with a single medium ($n_1 \simeq \sqrt{2}$ and $n_2 = 1$): b_{min} varies with the wavelength. However, if the crystal is constructed with a core of a high-index material (n_1) and a cladding of an appropriate lower-index material (n_2), the wavelength dispersion of the core material may be balanced by the dispersion of the cladding material, giving an achromatic pair.

The sapphire-liquid setup is shown in Figure 11. It has the following main components: a sapphire crystal, a vessel enclosing the liquid cladding, an ellipsoidal mirror, two flat mirrors, and a photomultiplier. The crystal shell was shaped and delivered by the Swiss firm Kyburtz. It is a portion of a spherical shell with 50 mm radius of curvature, 1.5 mm thickness, and a diameter of 30 mm. The ellipsoidal mirror was produced by a process which begins with the electrolytic deposition of a nickel substrate and ends with the electrolytic coating of the mirror with a rhodium layer. Rhodium reflects in the visible and UV band of interest, 300–700 nm, with a mean reflectivity of about 80%. Rhodium adheres well to nickel and is resistant to tarnishing and oxidation.

Outgoing light from the crystal is focussed by the ellipsoidal mirror onto the photomultiplier via the two flat mirrors. The flat mirrors were made by vacuum deposition of aluminium and a protective MgF_2 layer on a 3 mm glass substrate. Their reflectivity was measured to be 90% in the 300–700 nm band. The photomultiplier is a photon-counting photodetector having a 2-in.-diameter quartz window. The refractive index matching on the convex face of the sapphire crystal was realised by using the crystal as the window of a 12 mm thick aluminium container with a back window of 0.5mm and a diameter of 26mm. The tightness of the assembly was assured by a 1mm thick O-ring, 27 mm in diameter.The crystal was pressed by four thin clips at 90 degrees minimising light losses at the edge of the crystal. Some light losses are nevertheless expected at the O-ring contact and this point needs further sudy.The container was held and filled through an isolating PVC cylinder and the fluid temperature at the entrance measured with a PT100 sensor. The siloxane liquid was circulated in closed-loop and its temperature regulated.

Figure 12 shows the refractive index as a function of wavelength for the siloxane ("liquid-1") that we have used for our test. The grey area is the desired region for the refractive index in order to keep the quantity ε smaller than 1%. It is seen that the index is higher than desired, and that the quantity ε, which (as desired) is quite independent of wavelength, is however too large to obtain an optimal result. By mixing liquid-1 with various quantities of acetone, one can decrease the refractive index while retaining a good dispersion match to sapphire. (In upcoming tests another appropriate liquid ("liquid-2") will be used in order to improve the sensitivity to small impact parameters.)

Since liquid-1 is soluble in acetone we have mixed those two liquids in order to decrease the high refractive index of liquid-1 and vary ε within the range of interest. Figure 13 illustrates this effect, showing the signal vs. impact parameter obtained for various mixtures of liquid-1 and acetone. For pure liquid-1 ε is positive but too large, giving small sensitivity for small impact parameters. With the addition of increasing quantities of acetone, ε becomes smaller and smaller, increasing the sensitivity to small impact parameters, until it changes sign, giving signal even at zero impact parameter. When ε becomes sufficiently negative, all the light produced in the crystal is collected. This is well illustrated in Figure 13: the signal at zero impact parameter is maximum with pure acetone, and the same amplitude of signal was observed with air in the vessel.

These results demonstrate that the use of liquid claddings gives great flexibility to our detector. The sensitivity to small impact parameter can be tuned by adding small quantities of a second liquid. In the case of liquid-2, which has a refractive index very close to the optimal value, small temperature variations of of the liquid (a few degrees) will be sufficient to vary the index within the region of interest. Moreover the recirculation of the liquid can be used to alleviate possible degradation effects due to radiation damage.

The following figures show some further preliminary results obtained with this prototype. Figure 14 shows the amplitude of the collected signal as a function of the impact parameter. The sign is attributed either in the vertical direction y (curve a) or in the horizontal direction x (curve b). In this run the liquid mixture was 73% siloxane and 27% acetone. The amplitude of the signal versus impact parameter is shown in Figure 15 for the same run. The signal is quite small for zero impact parameter and rises rapidly, reaching its maximum value for $b = 2.5$ mm, then falling to a minimum value at $b = 5$ mm. It is a great improvement compared to the result obtained with the first LiF prototype and is very close to the performance required for an efficient B-meson Optical Trigger. The sensitivity at smaller impact parameters will be further improved with the multilayer device.

A second test was performed using CCl_4 liquid, which also has refractive index close to the optimal value. With CCL_4 however, ε becomes negative in the UV region, and this produces some signal contribution at $b = 0$. This is confirmed in Figure 16 (a), which gives the amplitude of the signal as a function of the impact parameter signed along x. A result similar to that of Figure 15 is obtained, but with some additional signal at $b = 0$. However, by adding about 15% of liquid-1 the signal at $b = 0$ decreases giving a more favorable signal to noise ratio (Figure 16 b). Note that the number of photoelectrons obtained is 1.2 at the maximum. We expect to improve this by a factor of two in the next runs by improving the UV quality of our optical devices, selecting a higher quantum-efficiency photomultiplier, and using the optimal liquid. In the case of VLPC readout, a significant increase of the signal is expected, due to the higher quantum efficiency. Notice that the agreement with the Monte Carlo simmulation is quite good (continuous line on Figure 16).

3 Future developments and time schedule

3.1 VLPC's

A potential improvement of the Optical Impact-Parameter Trigger can be made using VLPCs (Visible Light Photon Counters) due to their high quantum efficiency, as high as 85% for wavelengths around 500 nanometers (see Figure

18). VLPCs can operate at high avalanche gain (4×10^4) and high speed with very low noise. When the Cherenkov photons are collected by optical fibers around the periphery of the crystal shell, their pattern in azimuth may provide information about the multiplicity of the decay particles, and heavy-quark decay is expected to give a different pattern than those of background events. For that we plan to test the efficiency of the background rejection in a second trigger level trying various pattern recognition algorithms and possibly neural network software technology. This information can also be used to enhance the trigger efficiency. We are in the process of putting together a VLPC system of 192 channels. The system will be tested at Fermilab in early March 1994 and will be shipped to CERN for beam tests.

One sixth of the present prototype (192 fibers) will transmit Cherenkov light to individual VLPCs sitting in a liquid-He cryostat, with built-in temperature regulation in order to keep the VLPCs at 6.8 K (the temperature required for optimal signal-to-noise ratio). Figure 17 is a view of an assembly of 32 VLPC channels connected to polystyrene fibers. The VLPC output signals will be amplified and shaped by the Fermilab QPA02 chip, and the collected charge will be digitized by charge-sensitive ADCs (CAEN-C205). The data-acquisition program for that readout is now in preparation.

This prototype system will provide some initial data about photoelectron yield. We hope in the future to complete a larger system so that the efficacy of pixel pattern-recognition can be evaluated.

3.2 Sapphire-liquid

A second sapphire-liquid prototype featuring readout over the full azimuth with fibers and VLPCs should be prepared and tested by the end of the year. A second milestone for the coming year should be the optimization of the sapphire-crystal prototype with liquid cladding. The aim is to improve the crystal response to get the maximum signal and obtain the best chromaticity compensation by selecting the optimal liquid or mixture of liquids. A laboratory setup is in preparation to measure the refractive index of the liquid. The evaluation of the contribution of various background sources will be studied, and an improved precision telescope (see section 3.5) will allow better charged particle-tracking and measure double tracks.

3.3 Solid cladding

At the same time, developments will continue intensively on the solid-cladding version. Contacts and collaborations have been established with research laboratories (CEA/LETI, Ecole de Physique de Marseille, ...) and companies (Evap/Service, Merk, ...) working in the field of thin-film optics. A Ph.D. thesis is beginning on this subject, granted by the CEA-Saclay.

Discussions with specialists from the above laboratories have allowed us to identify more precisely the problems to solve and the studies to be carried out. For a given Cherenkov radiator, the problem is to deposit one or several optical films so that the angular reflection conditions will be satisfied. Two main directions are proposed:

- The possibility of deposition of several layers of alternating high and low indices, to build an angular interference filter or a similar device will be simulated and the feasibility of this approach will be studied.

- Deposition of a relatively thick ($\geq 2\mu$m) film of a material whose refractive index fulfils the characteristic equation (1) in a sufficient wavelength interval. This material can be a simple compound, whose optical properties are close to the required ones, or a mixture of compounds, whose indices surround the desired index. Many parameters contribute to the final optical properties of a given deposited film. A major part of the planned work will be to delimit their influence properly.

Among the single materials, silica (SiO_2) and potassium chloride (KCl) are well adapted to sapphire to satisfy equation (1). Silica is a material frequently used in thin-film optics. Many technologies are employed, and their influence on the index is well known, at least at one wavelength. Nevertheless its index dispersion should be adjusted. The deposition technologies and "a-priori" or "a posteriori" doping will be tested for that purpose. KCl has an index slightly too high for sapphire (2%) but an almost perfect dispersion. It is however not employed in thin-film optics. We will check in the near future the mechanical, structural and optical properties of KCl films deposited by classical or assisted vacuum evaporation.

The most promising way to get a solid film with the right dispersion curve is to coevaporate two or more materials. The control of the index of refraction and especially its dispersion is thus achieved via the control of the deposition rates of the materials (which determine the film composition). The resulting refractive index of the film can then be estimated by the Lorenz-Lorentz relation as a function of the indices of the various constituents and their concentration in the mixture. Among the large number of possible mixtures, ZnS/NaF seems promising and will be investigated. Theoretically, a mixture of ZnS and NaF with 24 % of ZnS in weight might fit the dispersion relation (1) from 400 nm to 800nm with a mean ε of 0.007. The deposition of such a film will also be studied this year. It is also planned to investigate other Cherenkov radiators than sapphire, for example magnesium oxide (MgO).

3.4 Multilayer

The construction of thin sapphire crystals (400 μm) to be used for the projective multilayer prototype will start in 1994, and we will investigate the minimum crystal thickness which is possible with present technology. We then plan to design a full LHC-optimized prototype and test it in a particle beam in 1995.

3.5 Tracking upgrade

A new telescope with redundant track measurement is in preparation. A precision telescope of 8 drift tubes [10] will be installed. A 80-wire MWPC with 2-mm pitch is also availlable. It will allow double-track identification. New drift chambers, for a flexible, general use facility, are being designed.

4 Efficiency of the Optical Discriminator in the GAJET experiment

The optical trigger was simulated as a level-1 trigger in the GAJET experiment proposed at the LHC [6]. The result of its response for $B_d \rightarrow \pi^+ \pi^-$

Table 1: Estimated budget for the development of the Optical Trigger on 1994-1995

Year	Item	Cost [kSF]
1994	Sapphire crystals	20
	Fiber read-out development	20
	VLPCs + electronics	25
	Photomultipliers	10
	Electronics and DAQ	50
	Mechanics	10
	Tracking upgrade	25
	Laboratory tests	10
	Solid cladding tests	20
	Liquid circulation and temperature regulation	10
TOTAL		170
1995	Multilayer prototype	100

and for minimum bias events is shown in figure 19. As expected, the minimum bias events give a much steeper spectrum of photo-electrons (mean of 2.8 p.e.) than do the $B_d \rightarrow \pi^+\pi^-$ vevents (mean of 14.6 p.e.). A cut at $N_{p.e.} \geq 6$ gives an efficiency of 60% for $B_d \rightarrow \pi^+\pi^-$ events and 10% for minimum bias events. The results are similar for $B_d \rightarrow J/\psi K_s$events. Improved configurations under study of the device could yield tighter rejections.

In the actual understanding of the Gajet trigger it is foreseen to construct a level-1 trigger by requiring a signal in the optical discriminator $N_{p.e.} \geq 5$, at least a secondary (displaced vertex) track in the silicon triggger "striplets" and a high p_t muon, electron or hadron. The efficiencies expected from simulation are 0.24 for $B_d \rightarrow J/\psi K_s$events, 0.20 for $B_d \rightarrow \pi^+\pi^-$ events with a reduction by 1.5×10^{-3} of minimum bias events. The expected latency should be of the order of 1μs, so > 40 events deep pipelines will be required. The interest of the fast trigger provided by the optical discriminator is to reduce the complexity of the system.

5 Budget requests

The RD-30 collaboration wishes to continue the R&D work on the Optical Discriminator in order to accomplish the original goals. The budget request is summarized in table 1. The request excludes personnel and travel expenses, assuming that they are included in the Internal home Institution support, as well as computing time needed for simulation and analysis work. Although the main part of the budget is supported from home Institutes the request to CERN are the following :

- Test beam : for 94 we ask for 8 weeks running time in the T9 PS test-beam.
- Continuation of the electronic pool facility
- Continuation of the CERN contribution in this development.

6 Internal RD30 notes and seminars

Y. Giomataris, "Trigger for Beauty", Jet Gas meeting, CERN, 13th March 1991.

J. Derré, "About the Optical Trigger", Jet Gas meeting, CERN, 17th April 1991.

C. Morel, "Simulation Monte-Carlo d'une logique de déclenchement à Cherenkov", IPN/UNIL Note, June 1991.

J.P. Perroud, "Optical Trigger", Jet Gas meeting, CERN, 12th June 1991.

Y. Giomataris, "Techniques Cherenkov pour la physique auprès des collisionneurs hadroniques", Séminaire au Département de Physique des Particules Elémentaires du C.E. Saclay, 5th July 1991.

G. Charpak et al., "Study of an optical trigger to be used for beauty search in fixed target mode at the LHC", CERN/DRDC/P30, 20th August 1991.

R. Chipaux, "Les différents matériaux possibles pour le Cristal", Saclay Note, 3rd October 1991.

J. Derré, "Study of an optical trigger to be used for beauty search in fixed target mode at the LHC", 3rd B-ECFA meeting, CERN, 30th October 1991.

R. Chipaux and J.P. Perroud, "Optical triggering for beauty physics", Image Processing for Future High Energy Physics, Erice, 13-18th November 1991.

S. Loucatos, "Trigger optique pour cible fixe", Journée de Physique $B\overline{B}$, Saclay 20th November 1991.

S. Loucatos, "B Physics at LHC", Ioanina H.E.P. Workshop, 9th January 1992.

R. Chipaux et al., "Etude d'un discriminateur optique pour la recherche en Physique des Particules", 12ème Journées Nationales d'Optique Guidée", Paris, 22-23 January 1992.

S. Loucatos, "Fiber read-out and Roman pots", Jet Gas meeting, CERN, 3rd March 1992.

S. Loucatos, "Une expérience de Violation de CP dans le système $B\overline{B}$ avec un Jet de Gaz au LHC", Séminaire à l'Université de Strasbourg, 30th April 1992.

Y. Giomataris, "About the Optical Trigger", Jet Gas meeting, CERN, 13th May 1992.

S. Loucatos, "Beam test setup on T9", Jet Gas meeting, CERN, 13th May 1992.

M. Tran, "Analysis of the runs done in the week of June 22 to 26", Jet Gas meeting, CERN, 2nd July 1992.

C. Kochowski, "Optical Trigger Status", Jet Gas meeting, CERN, 2nd July 1992.

R. Chipaux, J. Derré, C. Kochowski, Y. Lemoigne, S. Loucatos, Ph. Rebourgeard, "Trigger Optique pour la physique du B sur cible fixe : résultats et perspectives", Internal Report DAPNIA-CE Saclay, 22th July 1992.

J. Derré, "La collection de lumière par des fibres optiques", Saclay Note, 31st July 1992.

Y. Giomataris, "Comments on the future of B-Physics in hadron machines", Université de Lausanne, Note IPNL 92-4, August 1992.

26th International Conference on High Energy Physics, Dallas, 6-12th August 1992.

S. Loucatos, "B physics with Hadrons Beams", 4th Hellenic School on E.P. Physics, Corfu, 3rd September 1992.

C. Kochowski, "Optical trigger test on the PS T9 beam", Jet Gas meeting, CERN, 2nd October 1992.

S. Loucatos, "Fiber read-out design", Jet Gas meeting, CERN, 2nd October 1992.

G. Charpak et al., "Addendum to the proposal DRDC/P30. Optical discriminator to be used for beauty search in fixed target mode at the LHC : experimental results and perspectives", CERN/DRDC/92-53, 5th November 1992.

Y. Giomataris, "Study of an optical trigger to be used for beauty search in fixed target mode at the LHC", talk at Geneva University, December 1992.

P. Mottier, "Etude du dépôt de Silice sur Substrats Saphir", LETI report, December 1992.

R. Chipaux, "R et D Trigger Optique", Comité Scientifique et Technique du Service d'Etudes des Detecteurs", Saclay, 8th December 1992.

R. Chipaux, "Conséquences de l'augmentation de l'indice du radiateur dans le trigger optique", Saclay Note, 21st December 1992.

C. Kochowski, "Le Trigger Optique : contraintes de réalisation, status au 1/1/93", Saclay Note discussed at the LETI meeting, 1rst January 1993.

R. Chipaux, "Compte-Rendu de la réunion Lausanne-LETI-Saclay au LETI, pré-étude depôt SiO_2 sur Saphir", Saclay Note, 21st January 1993.

Y. Lemoigne, "A CP violation Gas Jet experimental at the CERN LHC", presented at the UNK B-Factory Workshop, Liblice Castle, République Tchèque, 18-22th January 1993.

G. Charpak et al., "Experimental study of an Impact-Parameter Optical Discriminator", CERN-PPE/93-14, DAPNIA 93-2, IPNL 93-2, 26th January 1993, NIM A332(1993)91.

C. Kochowski, "Status des dépôts solides sur Saphir", Saclay Note, 20th February 1993.

V. Buzuloiu and O. Vlad, " A second-hand study of the impact-parameter optical discriminator" June 1993.

J. Derré, "Achromaticité par prisme dans la collection de lumière du trigger optique", Saclay Note, 17th March 1993.

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C. Kochowski, "Optical Trigger Status Report", Jet Gas meeting, CERN, 5th April 1993.

"Physique du B aux accélérateurs hadroniques", Note destinée au CSTS du SPP du 17/4/1993, DAPNIA, CE Saclay.

"Les perspectives de la Physique du B au LHC et le Trigger Optique", presenté" au CSTS du SPP le 17/4/1993, DAPNIA, CE Saclay.

S. Loucatos, "B physics in dedicated experiments at LHC", Talk given at University of Chicago and at FNAL, 19-22th April 1993.

R. Chipaux et al., "Un discriminateur optique pour l'étude de la physique des mésons B en cible fixe", Treizièmes Journées Nationales d'Optique Guidée,

26-27th May 1993, Marseille.

J.P. Perroud, "Correlation between Pt-trigger and Optical Discriminator", Jet Gas meeting, CERN, 26th April 1993.

J.P. Perroud, "Optical discriminator and Pt trigger", Jet Gas meeting, CERN, 4th May 1993.

J. Derré, "New ideas on the Optical Trigger", Jet Gas meeting, CERN, 4th May 1993.

Y. Giomataris and S. Loucatos, "An Impact-Parameter Optical Discriminator for B decays", Beauty Physics at Proton Accelerators, Snowmass, 21st June 1993.

Y. Giomataris and J. Derré, "The Pt selection of B events with the Optical Trigger Disriminator" Beauty Physics at Proton Accelerators, Snowmass, 21st June 1993.

S. Loucatos, "Review of trigger systems in proposed European B experiments at hadron accelerators", Beauty Physics at Proton Accelerators, Snowmass, 21st June 1993.

S. Loucatos, "Measurement of the β angle from $B_d^0 \rightarrow J/\Psi K_s^0$ decays in the GaJet experiment at the LHC" Beauty Physics at Proton Accelerators, Snowmass, 21st June 1993.

G. Charpak et al., "RD30 Addendum No 2", CERN/DRDC 93-33, 29th August 1993.

Y. Giomataris, "New detector developments for high rate environments", invited talk given in the "Third London Conference on Position-Sensitive Detectors", London, 8th September 1993.

Y. Giomataris, "Développement d'un trigger optique pour la physiaue du B au LHC" Marseille, 20th September 1993.

R. Chipaux, "The Optical Discriminator, a Guided Cherenkov Light Device for a Very Fast Trigger on Impact Parameter in Fixed-Target Experiment" IEEE '93 Nuclear Science Symposium, San-Francisco, 3d November 1993.

Y. Giomataris, "B-physics and cheap experiments", seminar at Ecole Normale Supérieure, Paris, 16th December 1993.

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[3] G. Charpak et al., "Experimental study of an impact-parameter optical discriminator", Nucl. Instr. and Meth. **A332** (1993) 91.

[4] D.M. Kaplan et al., "Test of principle of an optical trigger for beauty", Nucl. Instr. and Meth. **A330** (1993) 33.

[5] M. Atac et al., Nucl. Instr. and Meth. A314 (1992) 56-62.

[6] Letter of Intent "Study of CP violation in B-meson decays using an internal gas jet target at LHC", GaJet Collaboration, CERN/LHCC 93-

54, 15th October 1993 and presentation by T. Nakada at the CERN LHCC open session, November 16th, 1993.
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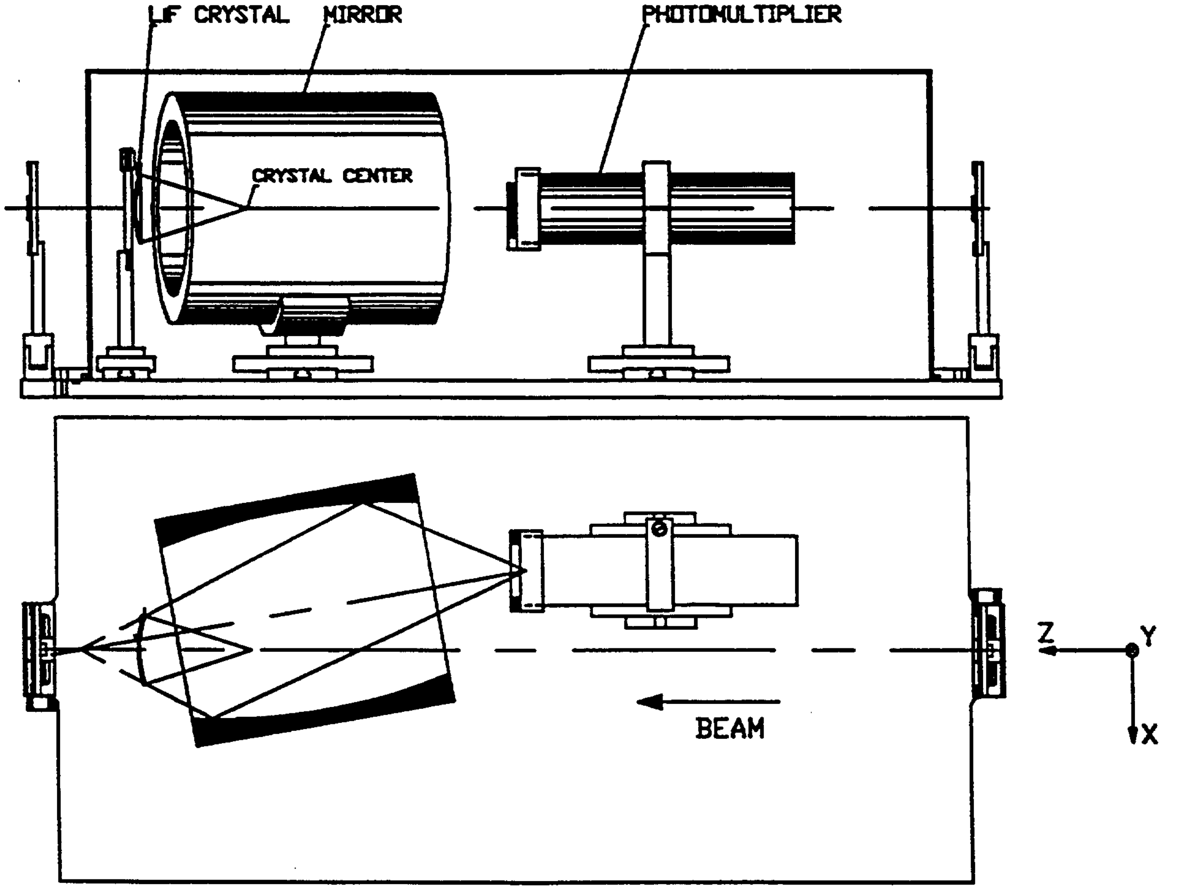
[8] J. Derre and Y. Giomataris, "The Pt selection of B events with the optical trigger discriminator", submitted to Snowmass workshop on B physics at hadron accelerators, June 21-July 2,1993.
[9] Y. Giomataris et al., Proc. 26th Int. Conf. on High Energy Physics, Dallas, 1992, Vol. 2, p. 1738.
[10] D.M. Kaplan et al., "A simple drift-tube telescope for detector tests", Nucl. Instr. and Meth. **A336** (1993) 116.

Figure captions

- Figure 1: The experimental setup: the LiF crystal, the ellipsoidal mirror and the photomultiplier.
- Figure 2: The photomultiplier pulse-height distribution. The peak at zero photoelectron is divide by 10.
- Figure 3: x-y impact in the crystal of tracks giving a signal of more than two photoelectrons.
- Figure 4: Amplitude of the signal as a function of the impact parameter with two different diaphragms (20 and 40 mm diameter), with and without filter. The lines are Monte Carlo simulations.
- Figure 5: Amplitude of the signal as a function of the signed impact parameter with a 40 mm diaphragm and a 305 nm filter. The lines are Monte Carlo predictions.
- Figure 6: Signal versus impact parameter when the crystal is hidden from the photomultiplier. Units on the vertical axis are arbitrary ADC units. The pedestal is at 41.8 units.
- Figure 7: Efficiencies at impact parameters of 1 mm (a) and 10 mm (b) as a function of the threshold in photoelectrons.
- Figure 8: conical ring used to accomodate fibers on the LiF crystal.
- Figure 9: The fiber read-out set-up.
- Figure 10: LiF read-out with fibers: amplitude of the signal as a function of the impact parameter (a), and the signed one (b,c). The signal is the sum of the three photomultipliers collected charge.
- Figure 11: The set-up used for the sapphire crystal test using a liquid cladding : Al_2O_3 crystal, ellipsoidal mirror, two flat mirrors and the photomultiplier.
- Figure 12: Refractive index versus wavelength for liquid-1 and various mixtures with acetone : 0%, 10%, 20%, 25%, 30%. The index of liquid-2 (dotted line) and CCl_4 (dashed line) is also shown. The grey zone indicates the optimal inex region.
- Figure 13: Collected signal versus signed impact parameter for various mixtures of liquid-1 with acetone.
- Figure 14: Amplitude of the signal as a function of the signed impact parameter : a) vertical plane, b)horizontal plane.
- Figure 15: Amplitude of the signal as function of the impact parameter obtained with a mixture of liquid-1 and 27% acetone. The temperature was 25 degrees.

- Figure 16: Amplitude of the signal as function of the impact parameter obtained with pure CCl_4 liquid (a) or with 15% of liquid-1 (b).
- Figure 17: Measured quantum efficiency versus wavelength for the VLPC.
- Figure 18: Photography of a typical module of 32-channel of VLPC detectors and the interface to optical fibers.
- Figure 19: Distribution of the number of p.e. per event for $B_d \to \pi^+\pi^-$ events (full circles) and for minimum bias events (open circles).



LIF CRYSTAL
MIRROR
PHOTOMULTIPLIER
CRYSTAL CENTER
Z
Y
X
BEAM

Fig. 1

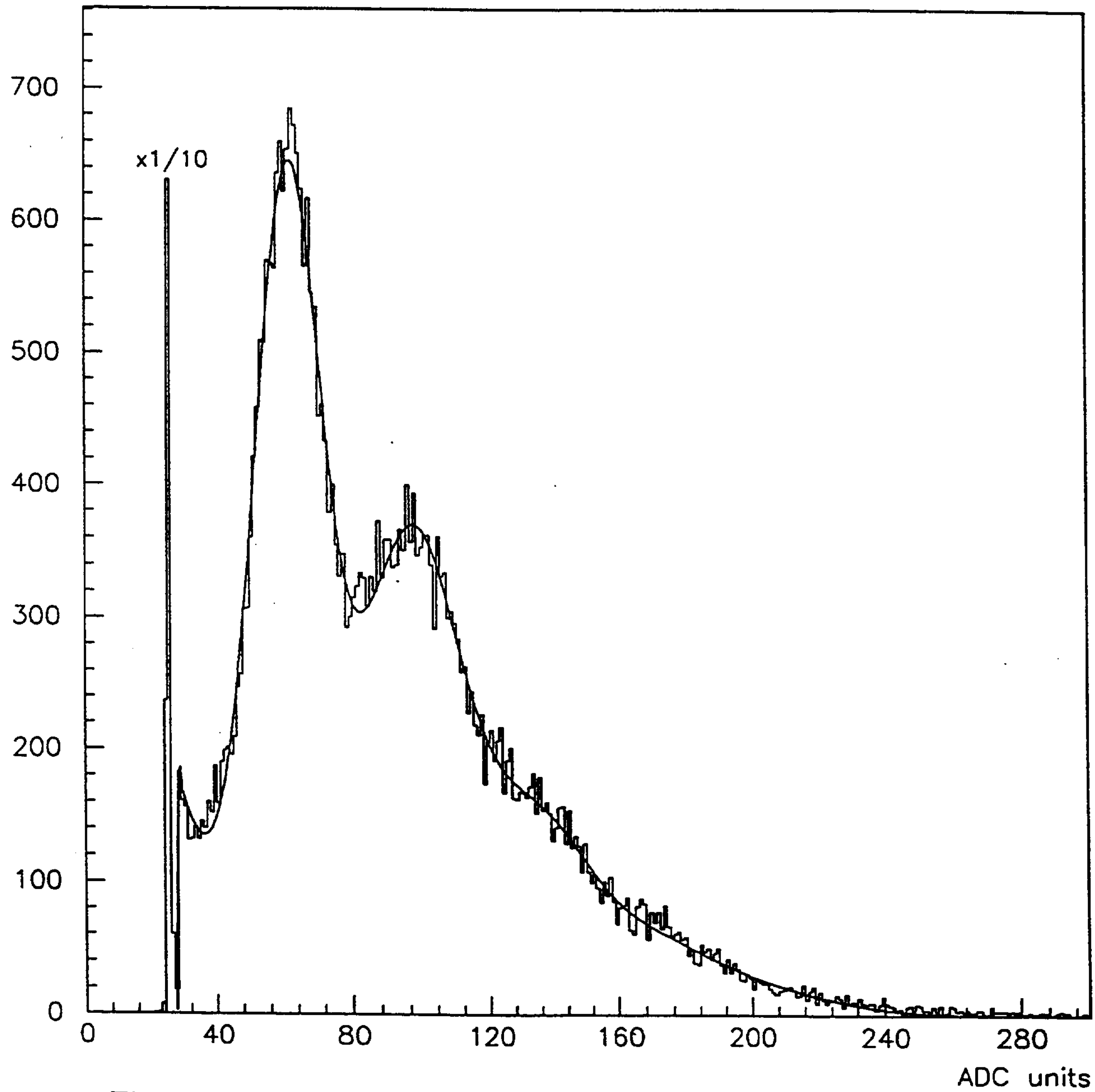

700
600
500
400
300
200
100
0
x1/10
0
40
80
120
160
200
240
280
ADC units

Fig. 2

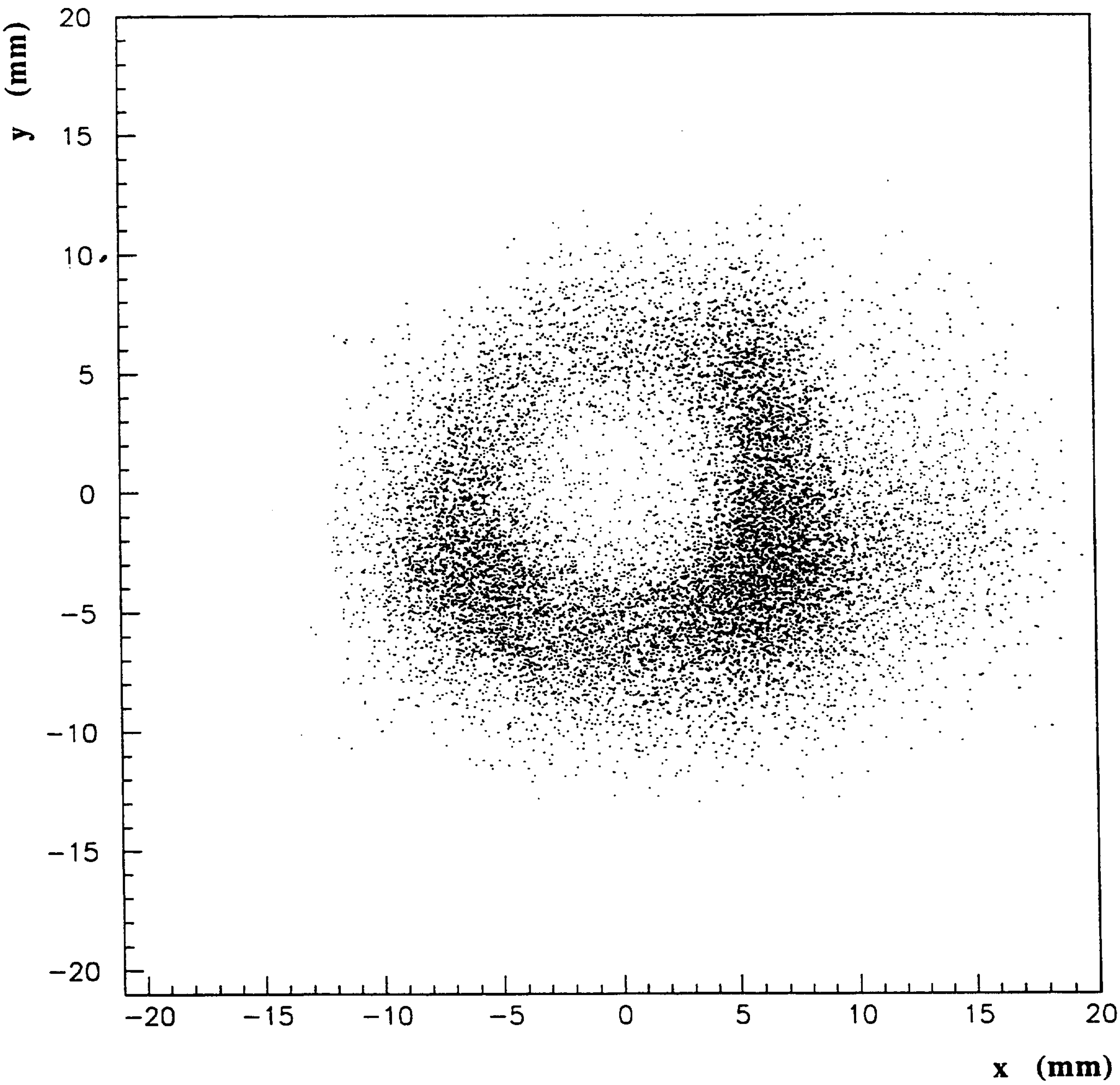
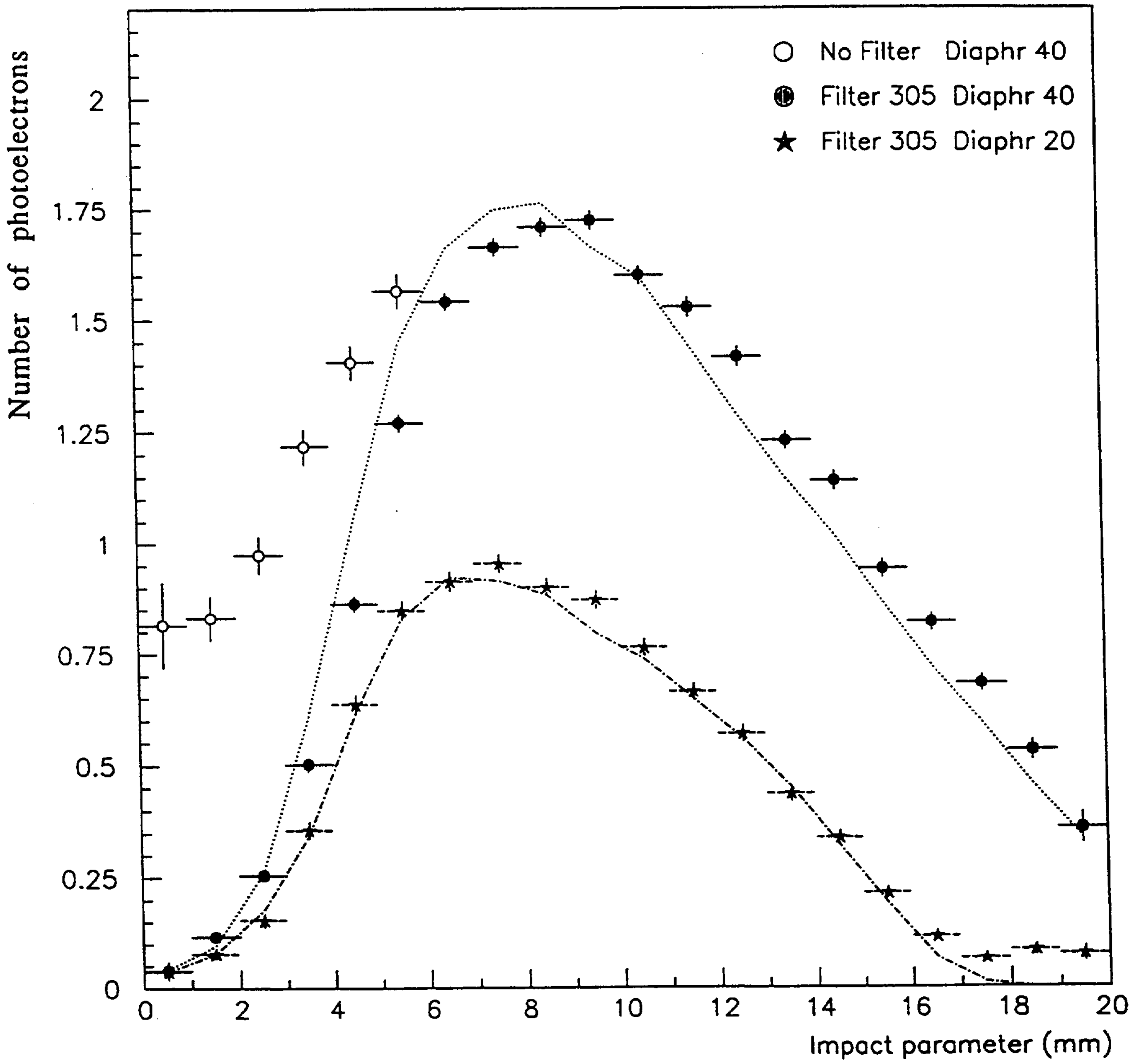


Fig. 3



No Filter Diaphr 40
Filter 305 Diaphr 40
Filter 305 Diaphr 20
Number of photoelectrons
Impact parameter (mm)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0
2
4
6
8
10
12
14
16
18
20

Fig. 4

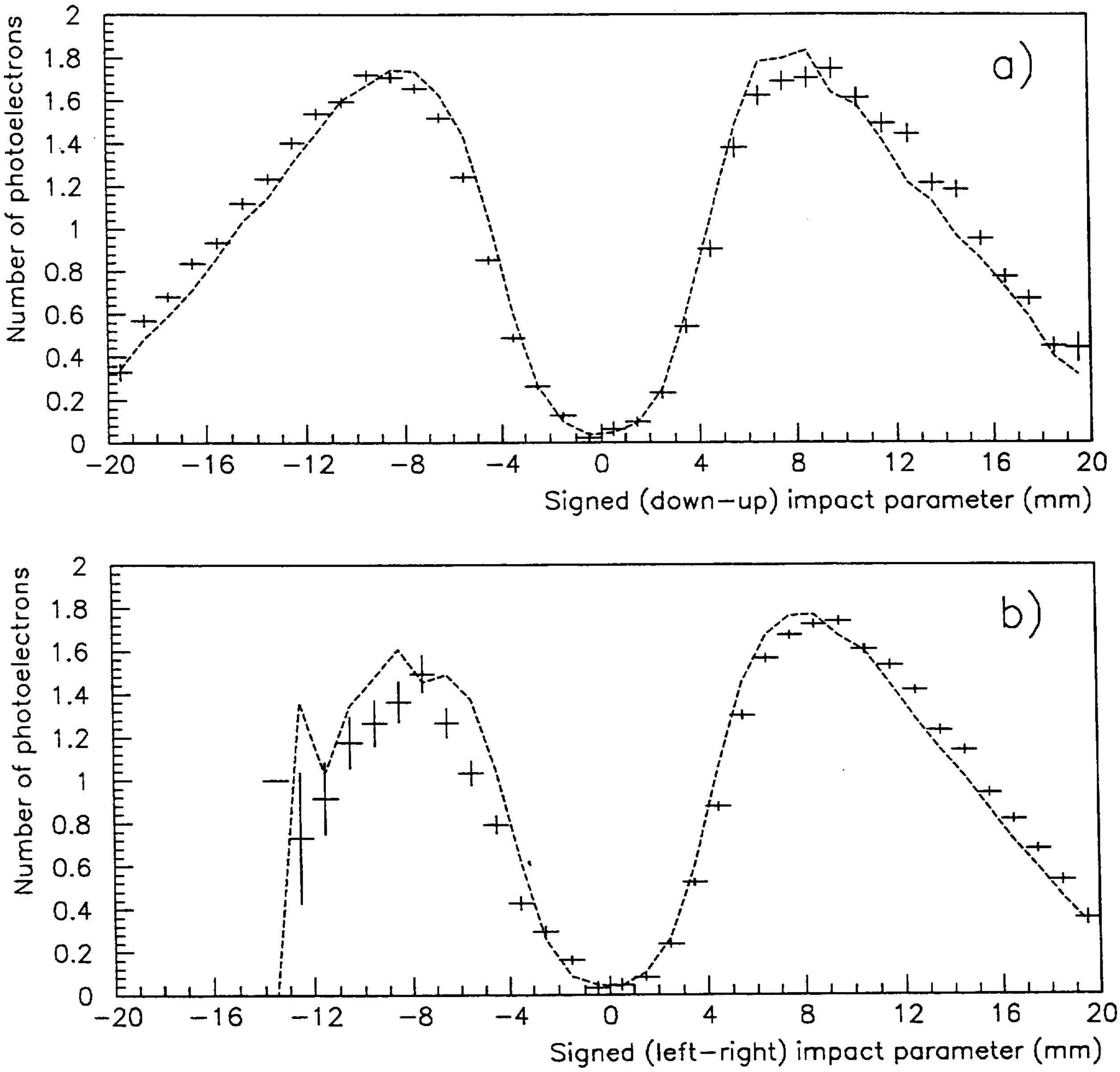

a)
Number of photoelectrons
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−20 −16 −12 −8 −4 0 4 8 12 16 20
Signed (down−up) impact parameter (mm)
b)
Number of photoelectrons
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−20 −16 −12 −8 −4 0 4 8 12 16 20
Signed (left−right) impact parameter (mm)

Fig. 5

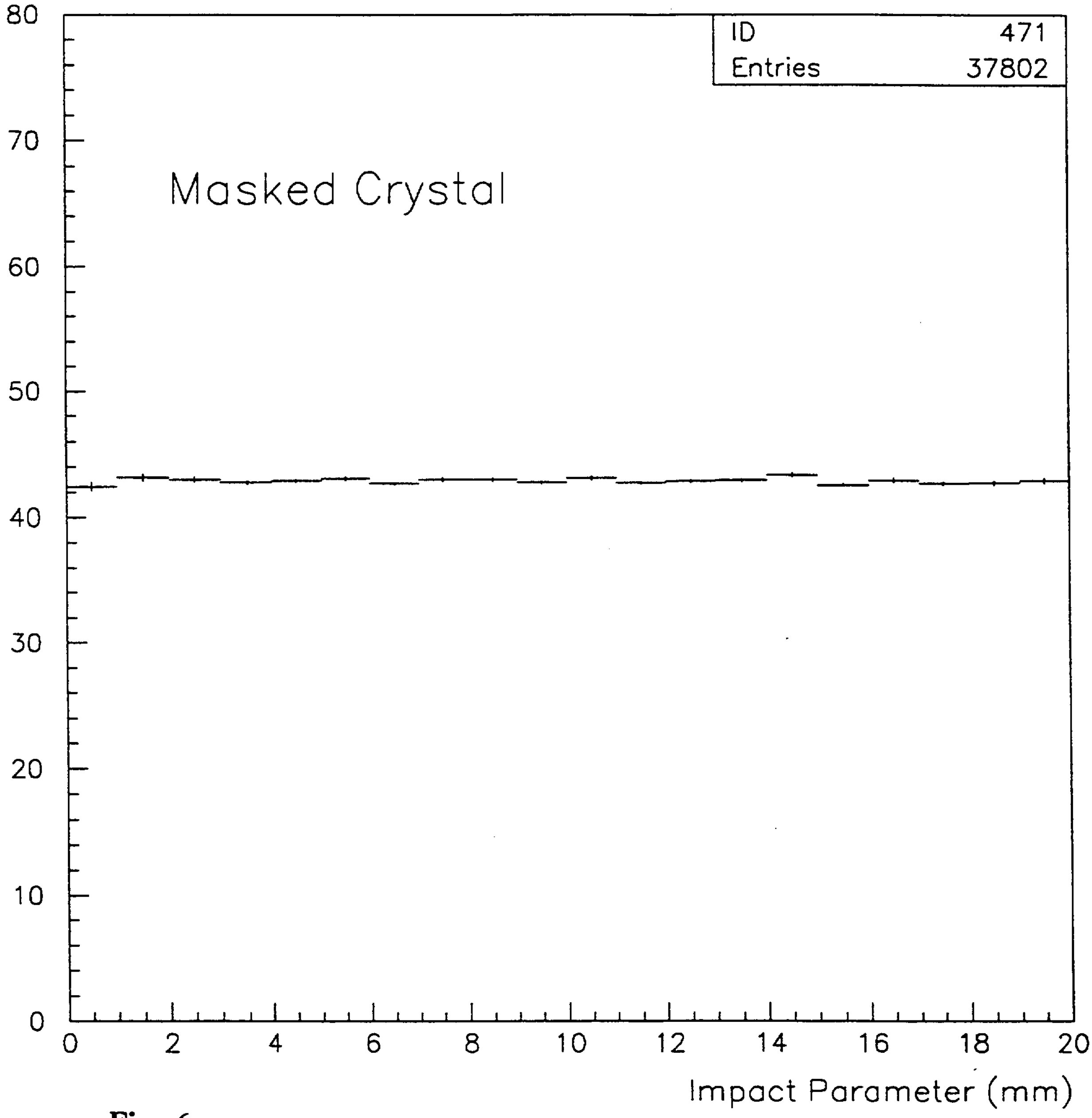
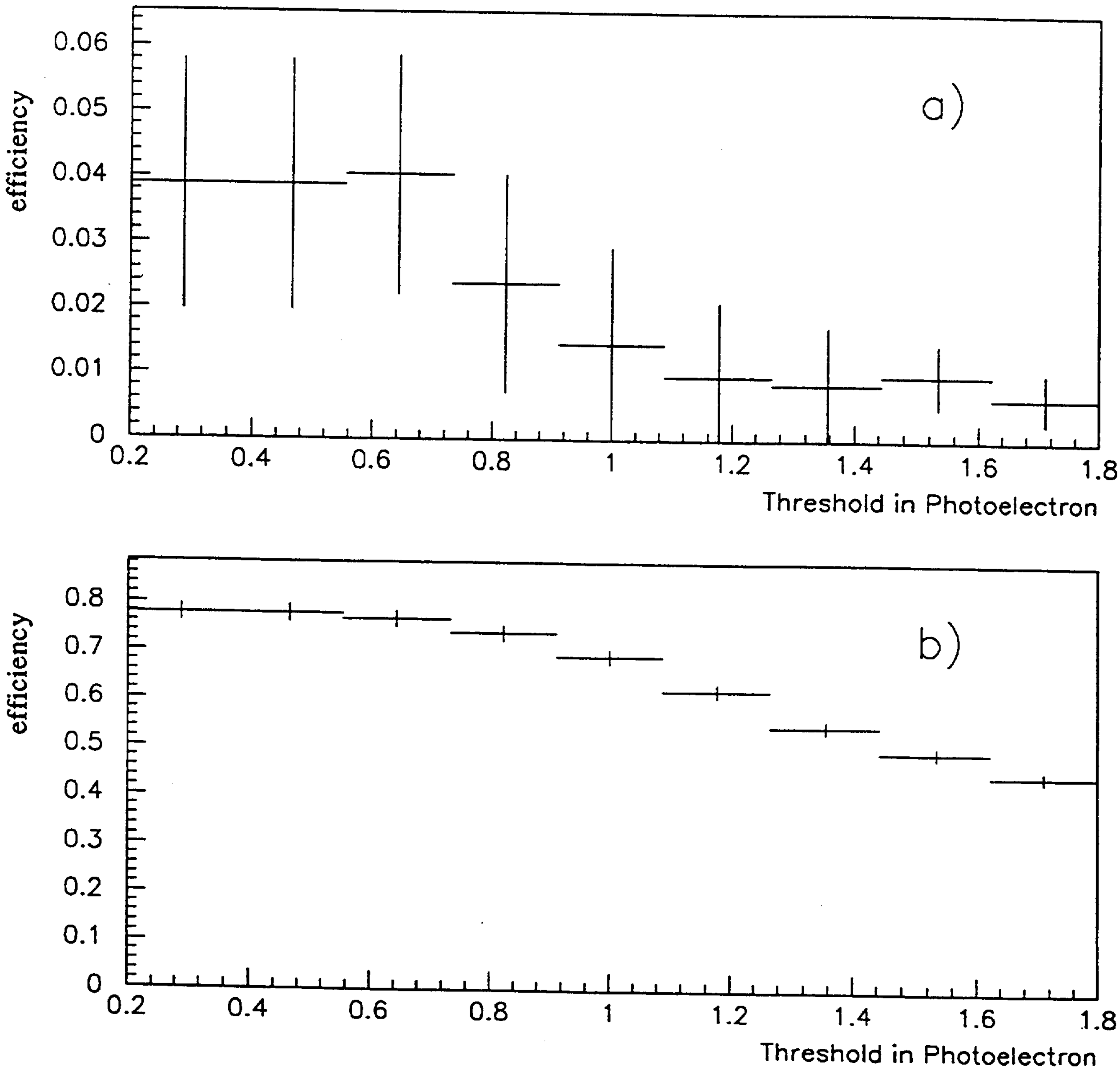

ID 471
Entries 37802
Masked Crystal
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20
Impact Parameter (mm)

Fig. 6



a)
efficiency
0.06
0.05
0.04
0.03
0.02
0.01
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Threshold in Photoelectron
b)
efficiency
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Threshold in Photoelectron

Fig.7

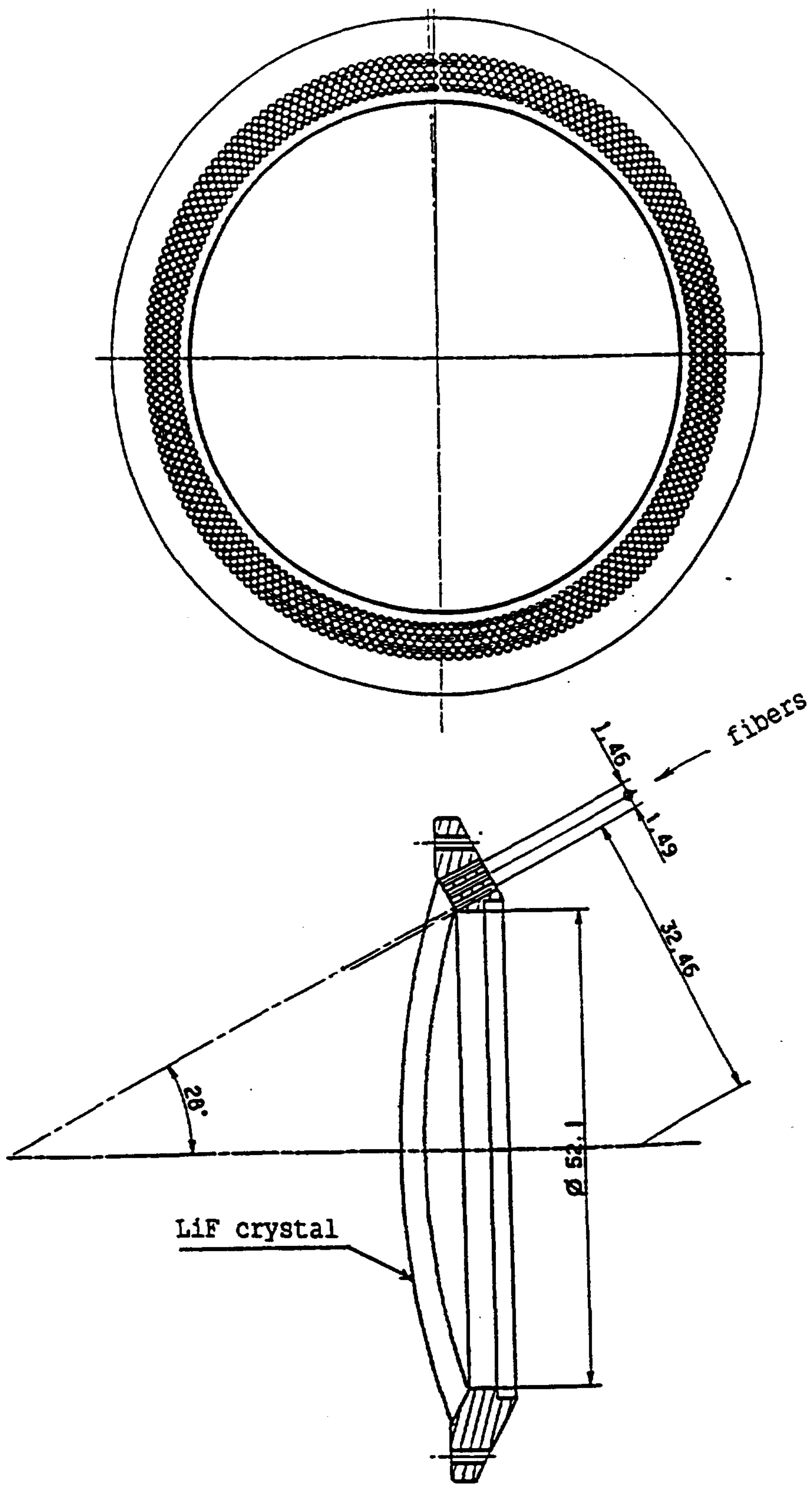


Fig. 8

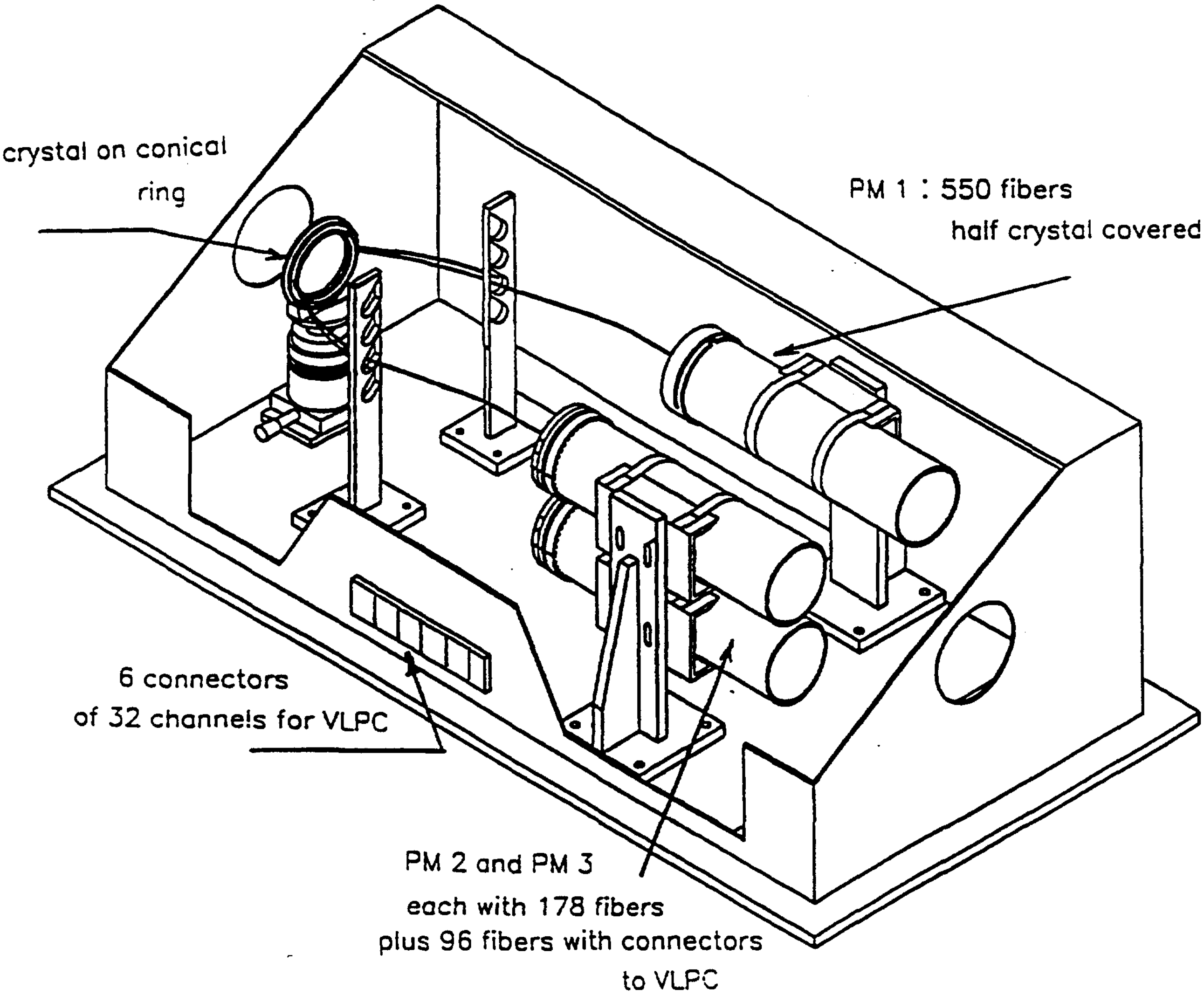

crystal on conical
ring
PM 1 : 550 fibers
half crystal covered
6 connectors
of 32 channels for VLPC
PM 2 and PM 3
each with 178 fibers
plus 96 fibers with connectors
to VLPC

Fig. 9

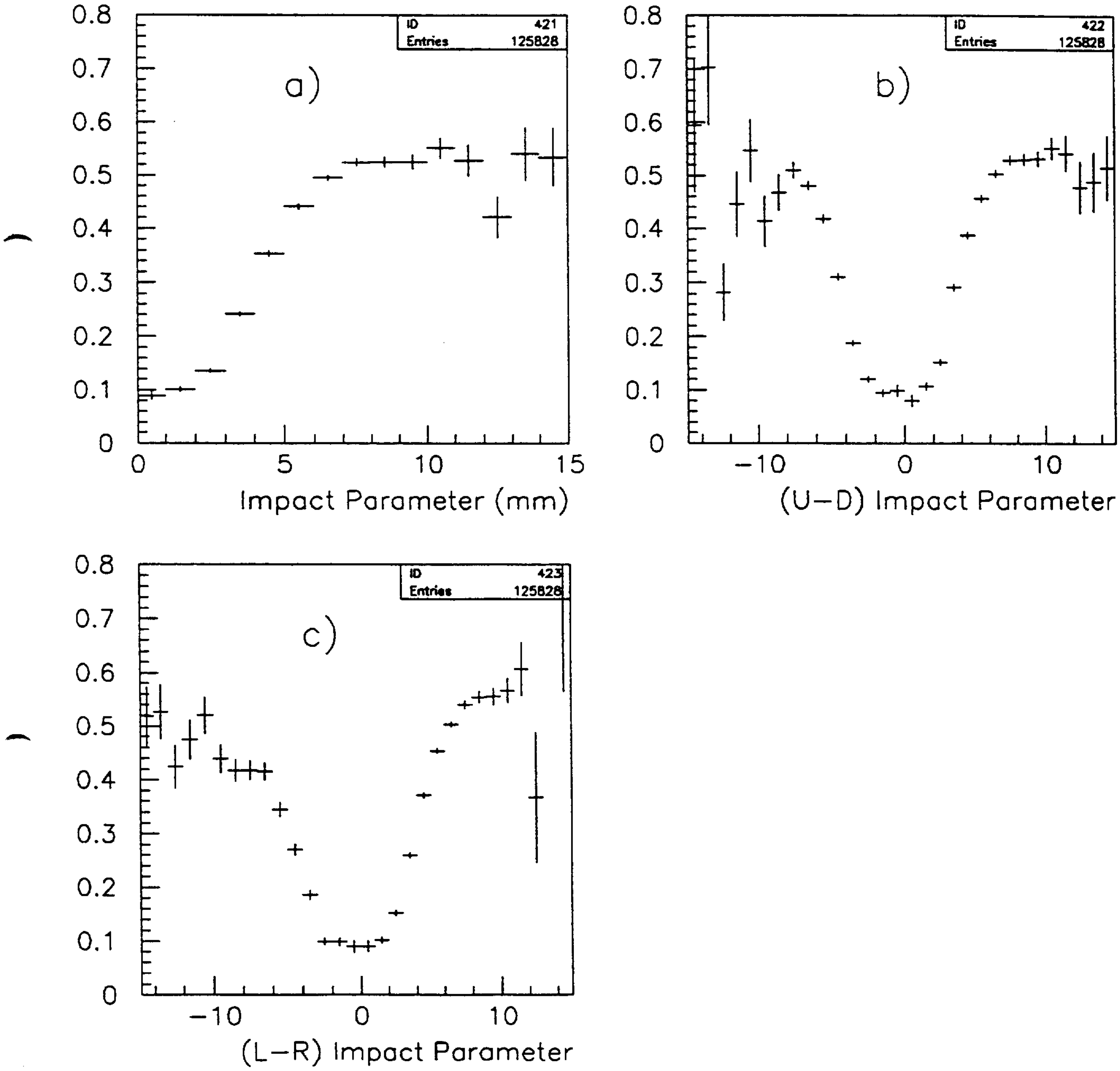

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ID 421
Entries 125828
a)
0
5
10
15
Impact Parameter (mm)
ID 422
Entries 125828
b)
−10
0
10
(U−D) Impact Parameter
ID 423
Entries 125828
c)
(L−R) Impact Parameter

Fig. 10

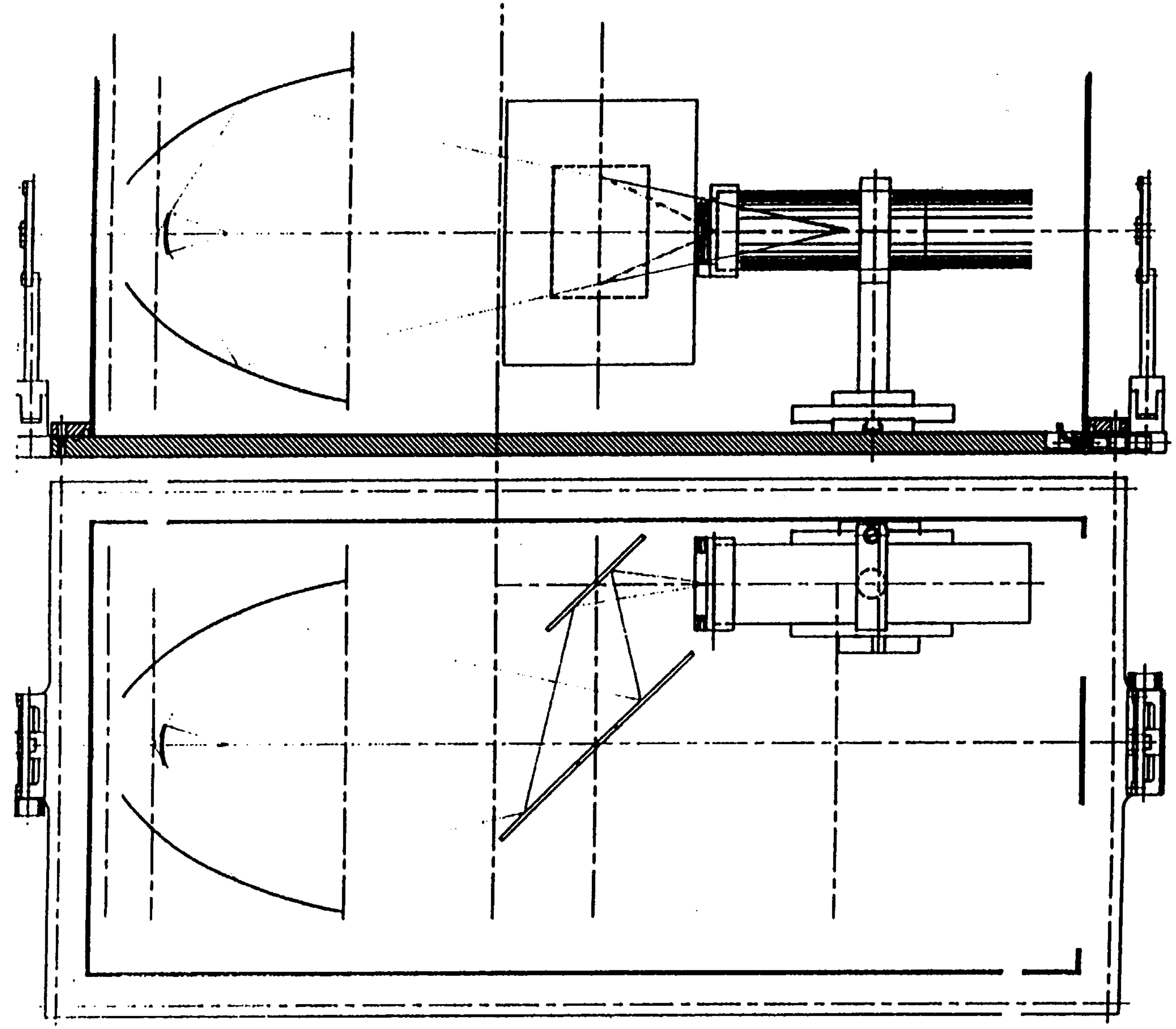


Fig. 11

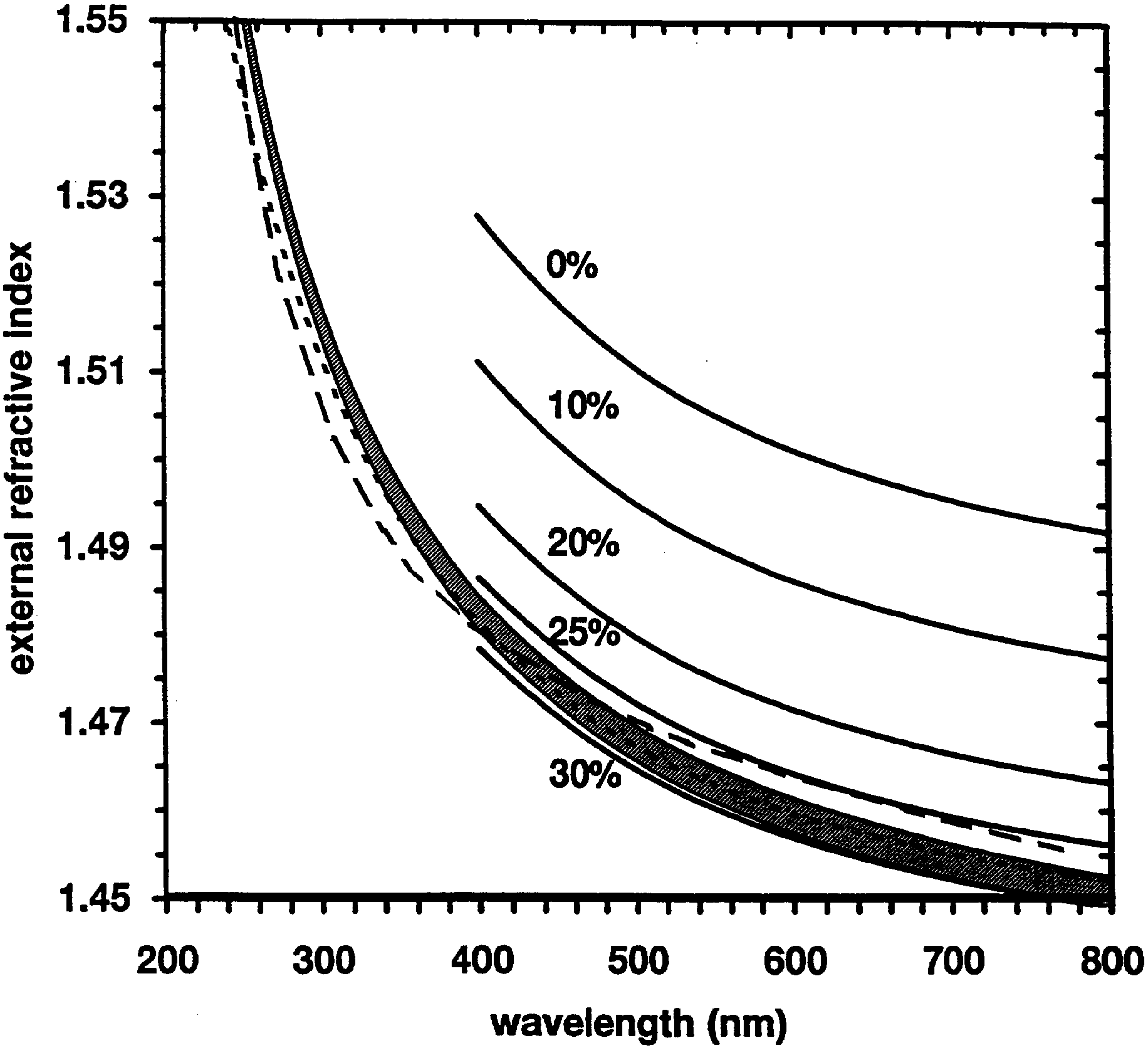

1.55
1.53
1.51
1.49
1.47
1.45
external refractive index
0%
10%
20%
25%
30%
200
300
400
500
600
700
800
wavelength (nm)

Fig. 12

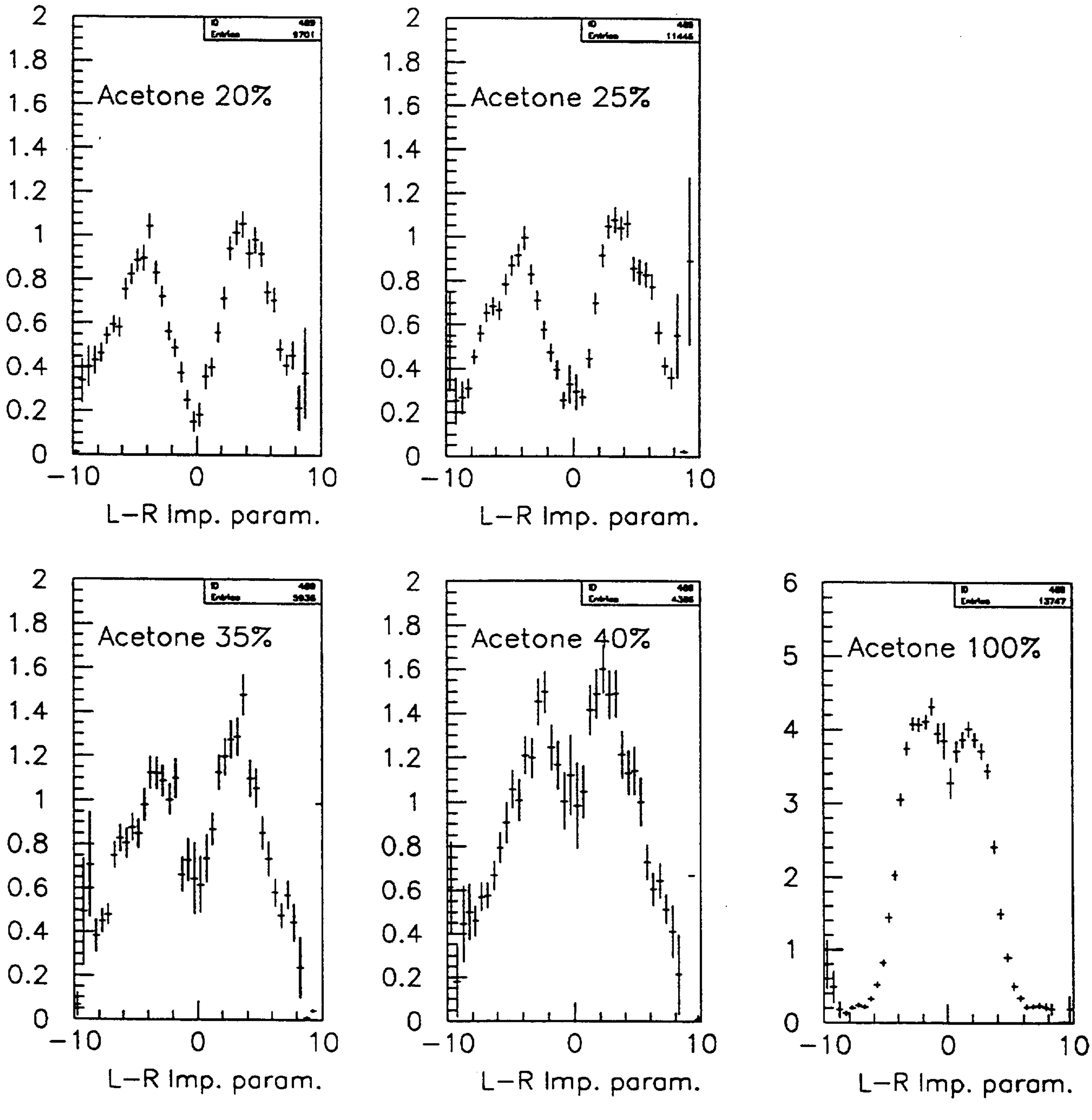
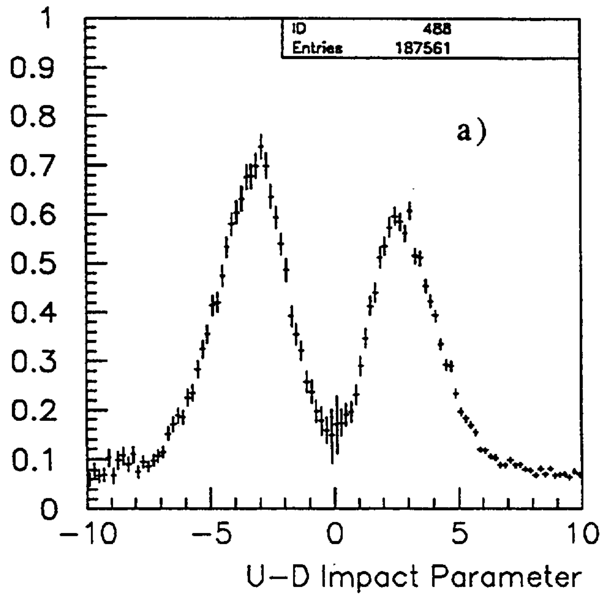
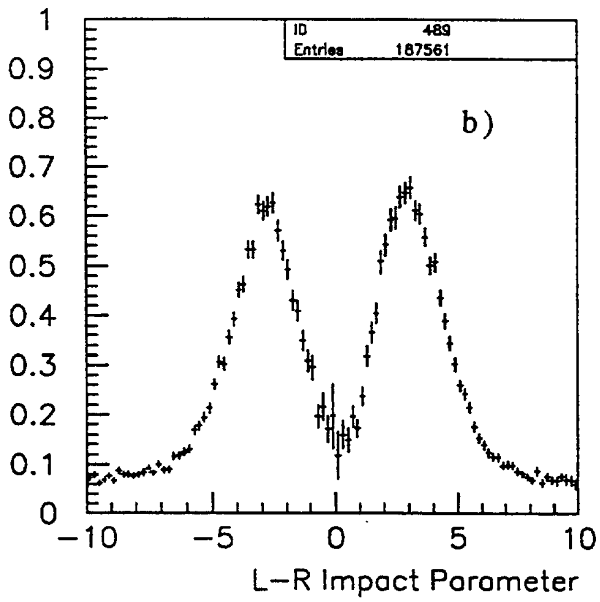

Acetone 20%
Acetone 25%
Acetone 35%
Acetone 40%
Acetone 100%
L−R Imp. param.

Fig. 13

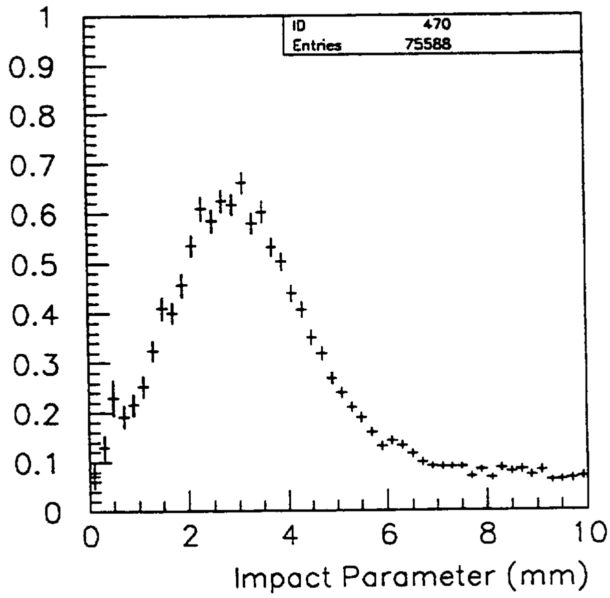


ID 488
Entries 187561
a)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−10
−5
0
5
10
U−D Impact Parameter



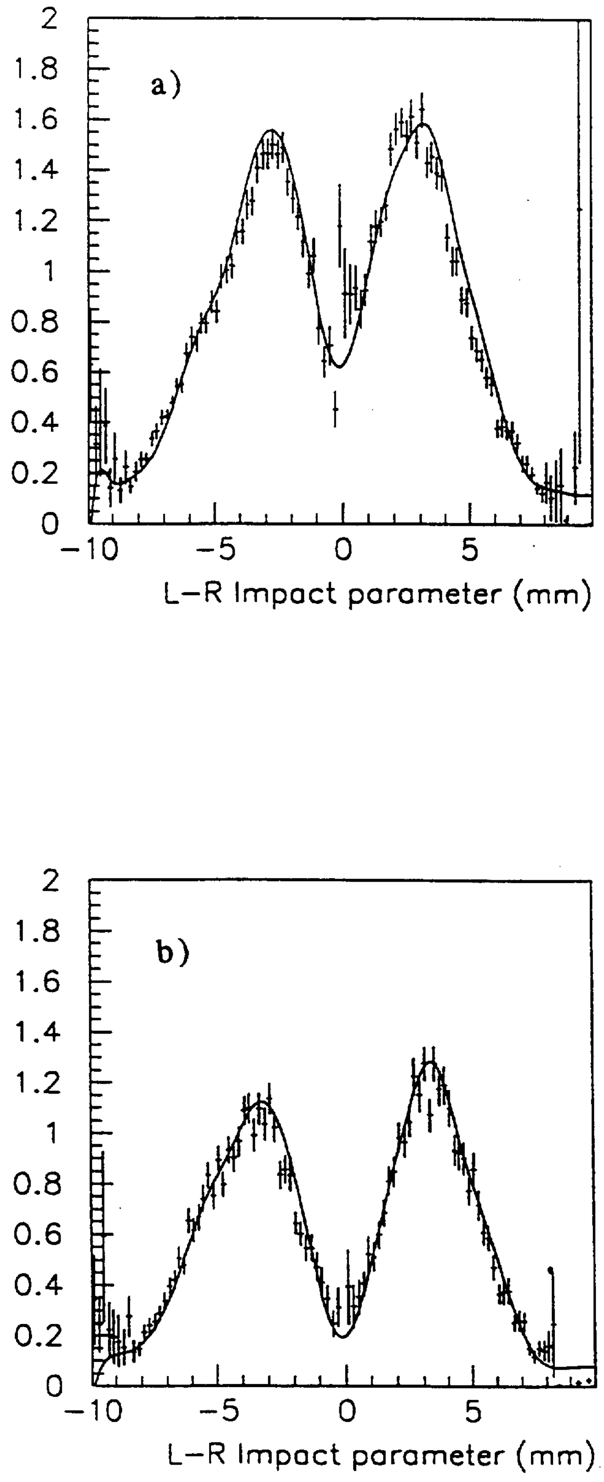
ID 489
Entries 187561
b)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−10
−5
0
5
10
L−R Impact Parameter

Fig. 14



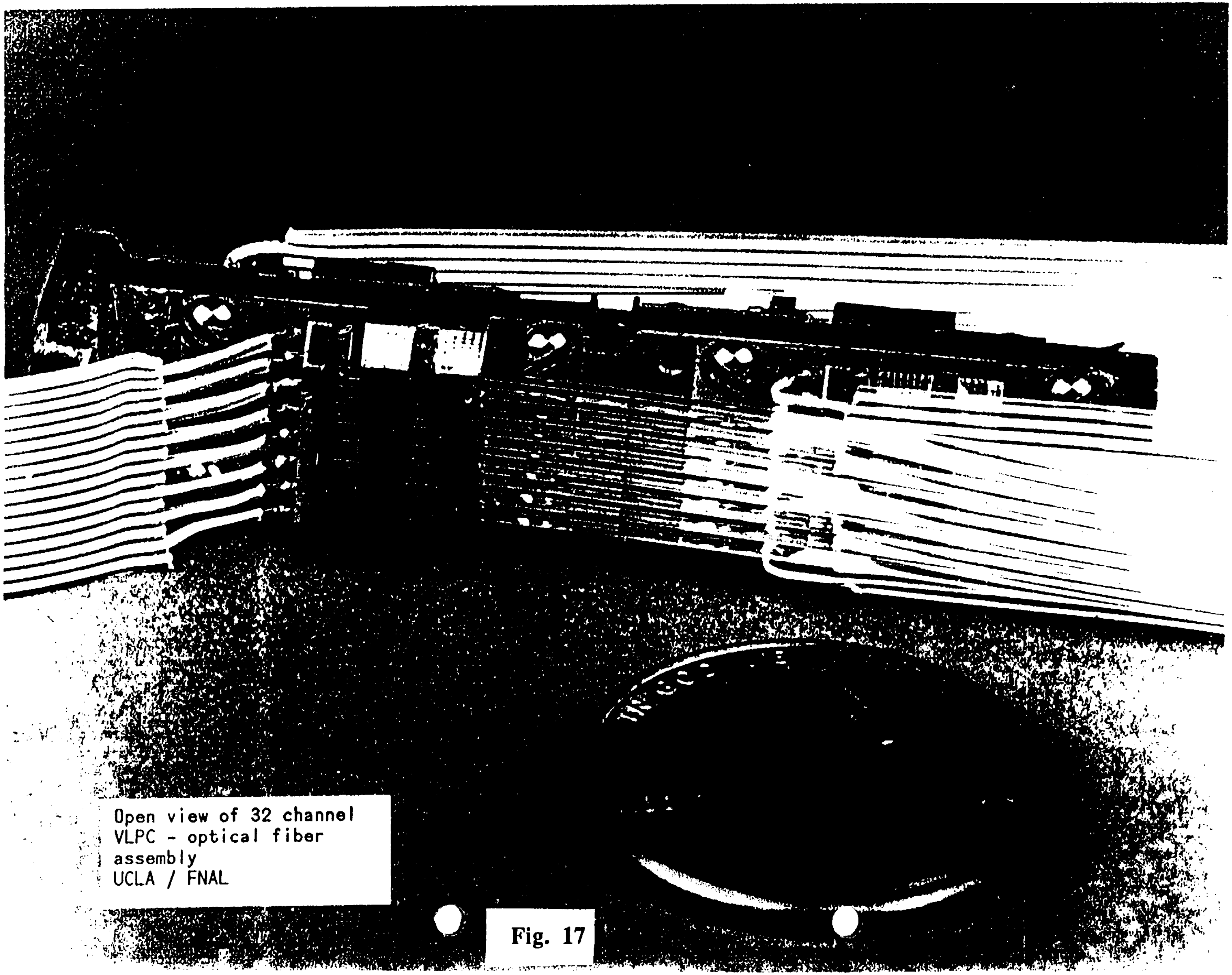
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ID 470
Entries 75588
0
2
4
6
8
10
Impact Parameter (mm)

Fig. 15



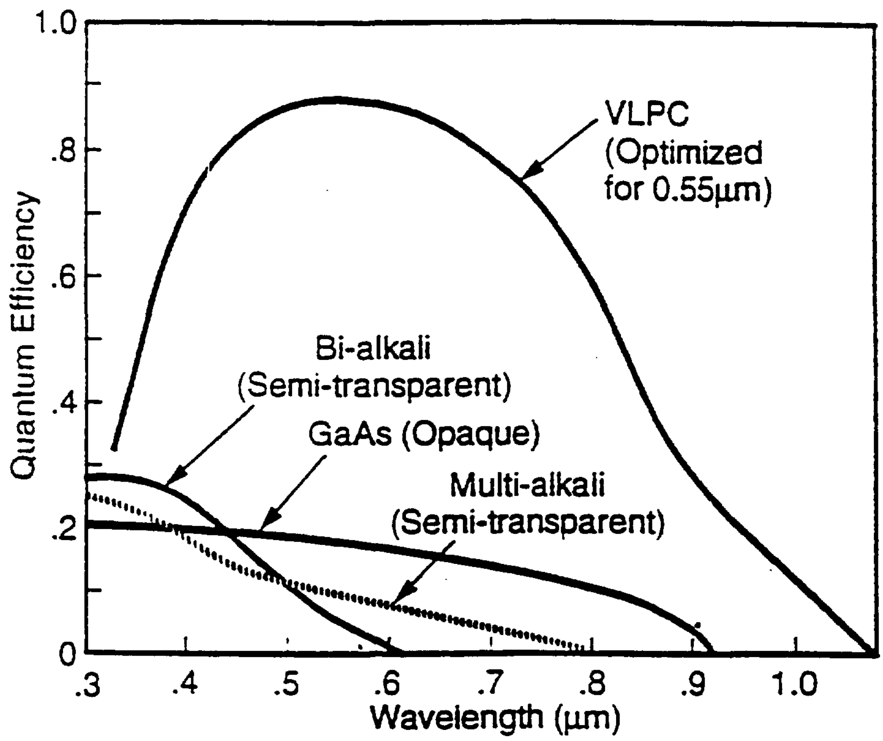
a)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−10
−5
0
5
L−R Impact parameter (mm)
b)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−10
−5
0
5
L−R Impact parameter (mm)

Fig. 16



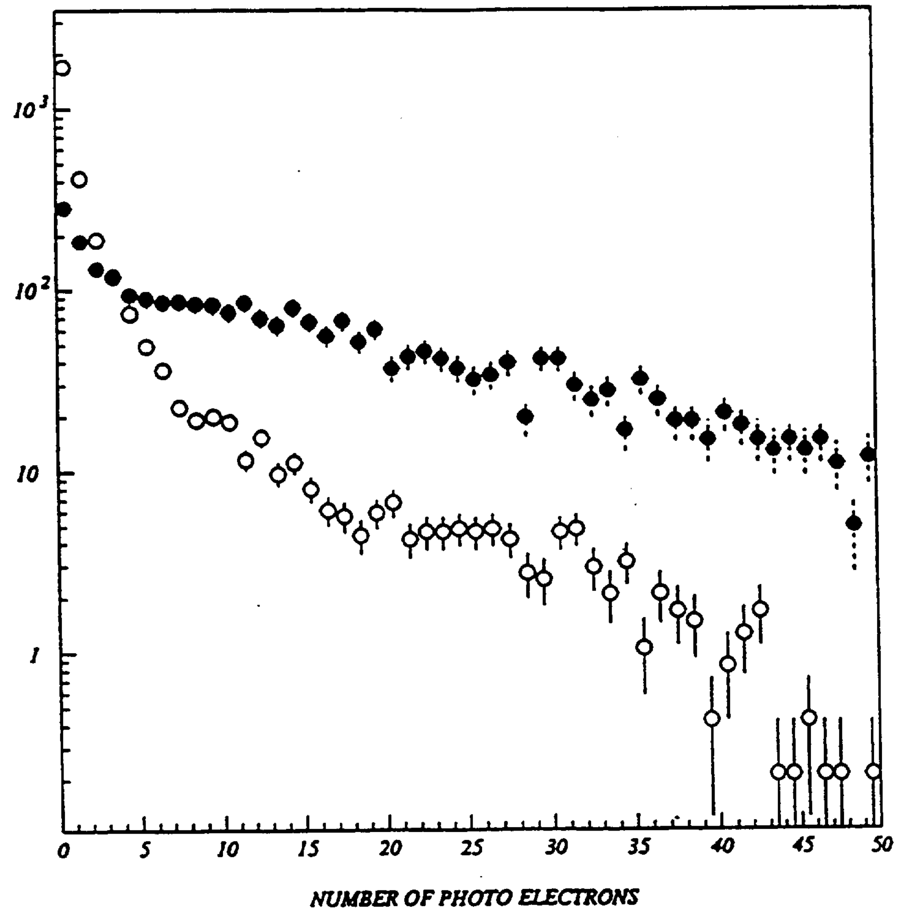
Open view of 32 channel
VLPC - optical fiber
assembly
UCLA / FNAL

Fig. 17



1.0
.8
.6
.4
.2
0
Quantum Efficiency
VLPC
(Optimized
for 0.55μm)
Bi-alkali
(Semi-transparent)
GaAs (Opaque)
Multi-alkali
(Semi-transparent)
.3
.4
.5
.6
.7
.8
.9
1.0
Wavelength (μm)

Fig. 18



10³
10²
10
1
0
5
10
15
20
25
30
35
40
45
50
NUMBER OF PHOTO ELECTRONS

Fig. 19