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# SINGLE ELECTRON BEAMS FROM THE LEP PRE-INJECTOR

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## Abstract

At the request of the L3 collaboration (one of the LEP experiments) a new facility was built close to the Electron Positron Accumulator (EPA) to provide a single electron per beam pulse at an energy which can be selected between 180 MeV and 500 MeV. The intensity of the ejected electron beam is reduced by changing the gun parameters and by adjusting the aperture of the slits in the linac. The energy is defined by letting the beam do 1 $^{1}/^{4}$ turn in the EPA. The enery spread is limited to ± 0.5 $10^{-3}$ by reducing the slits aperture in the LIL/EPA transfer line. A new transfer line was built to transport the beam from the EPA ejection septum to the detector test stand. The facility was then used to test the response of the L3 electromagnetic calorimeter composed of Bismuth-Germanium-Oxide (BGO) crystals in the 100 MeV range.

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At the request of the L3 collaboration (one of the LEP experiments) a new facility was built close to the Electron Positron Accumulator (EPA) to provide a single electron per beam pulse at an energy which can be selected between 180 MeV and 500 MeV. The intensity of the ejected electron beam is reduced by changing the gun parameters and by adjusting the aperture of the slits in the linac. The energy is defined by letting the beam do $1\,^1/_4$ turn in the EPA. The enery spread is limited to $\pm$ 0.5 $10^{-3}$ by reducing the slits aperture in the LIL/EPA transfer line. A new transfer line was built to transport the beam from the EPA ejection septum to the detector test stand. The facility was then used to test the response of the L3 electromagnetic calorimeter composed of Bismuth-Germanium-Oxide (BGO) crystals in the 100 MeV range.

## Introduction

The request to produce single electrons at 100 MeV with LPI[1] was made in March 1988 and a feasibility study[2] done in April and May 1988 proved that both the energy and the number of particles could be reduced coming close to the specified values. During machine studies in June and July, single $e^-$ were produced[3] at 300 MeV. End of July, the decision was made to set up a project[4] in order to provide such a beam to the L3 calorimeter under the stringent constraint that single $e^-$ runs had to take place before the end of December 1988.

During the feasibility study, the method to obtain single $e^-$ was based on secondary electrons produced at the converter. Later on, to avoid the complexity of this scheme, a second method, using primary electrons only was tried out and used for the experiment.

The Fig. 1 shows a layout of LIL/EPA/HSE:

## Feasibility Study

The scheme was to use a single LIL pulse of the secondary $e^-$ obtained as a by-product at the $e^-/e^+$ converter, let it circulate in EPA and extract it to a dump line where a detector composed of six BGO crystals viewed by a single photomultiplier was installed at the end of the line. Due to space limitations, the detector was only six radiation lengths long. Nevertheless, the energy resolution was good enough to check that single electrons could be produced.

Figure 2 displays a quantized signal where the energy deposit corresponds to 1, 2 and 3 $e^-$ events at 500 MeV. This display comes from a Pulse Height Analyzer.

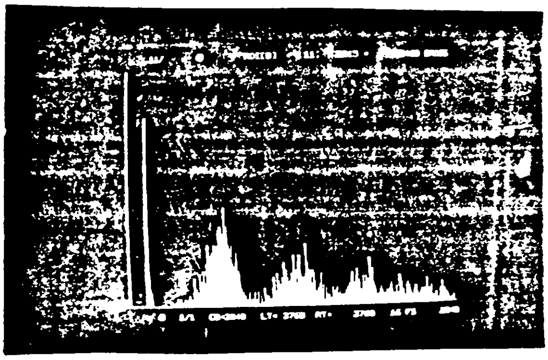

Fig. 2: Quantized Signal at 500 Mev

## Beam Optics

The large variety of needed manipulations and the difficulty to reproduce the non-standard working point of LIL-W led to a second scheme. In this scheme, only primary electrons from LIL-V were used. LIL-W acted as a transfer line, but its optics was not adapted for such a beam. It was designed for the acceleration and transverse confinement of positrons. Due to the lack of information concerning beam size and divergence in the single $e^-$ regime, at 180 MeV, the optimization of the transmission was made on an experimental basis. First the energy was reduced from 500 MeV down to 180 MeV, at the nominal beam current, to use the complete LIL instrumentation. Then the intensity was decreased by lowering the gun current and closing the slits.

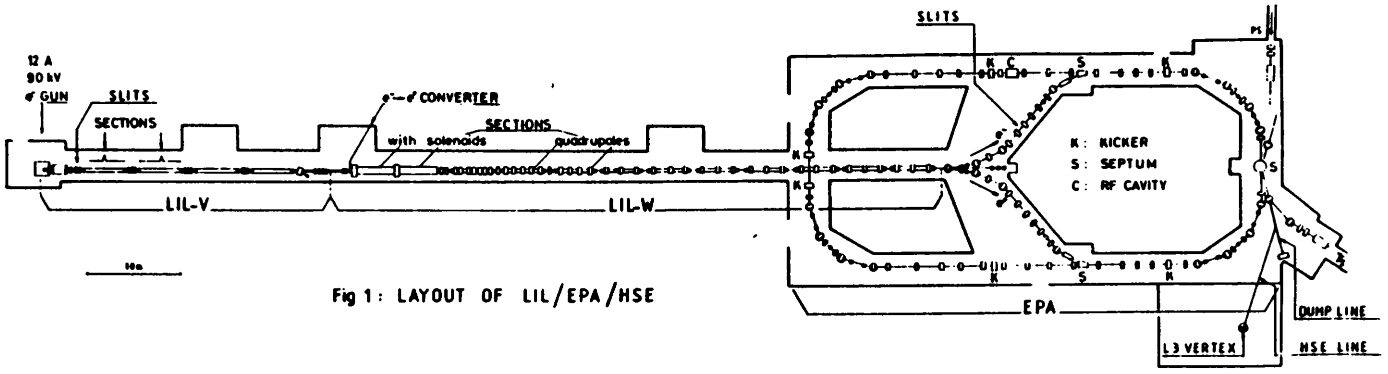

Fig 1: LAYOUT OF LIL/EPA/HSE

Fig. 1: Layout of HSE of LIL/EPA/HSE

EPA was used as a transfer line with the beam doing one turn and a quarter. In this scheme no fast injection/ejection was needed. A slow bump was used with a DC septum to inject particles and with a pulsed septum to eject them. Thanks to the small emittance of the electron beam and the large acceptance of EPA 1 1/4 turn oscillation is possible. The absolute energy (180 MeV) was defined by EPA better than ± 1 percent. For the calibration of BGO crystals, this accuracy was necessary.

## New Extraction Line

A new building was erected to house the half barrel of the L3 detector with its electronics and diagnostic systems, and a new beam transfer line (HSE) was designed using TRANSPORT code[5] (Fig. 3).

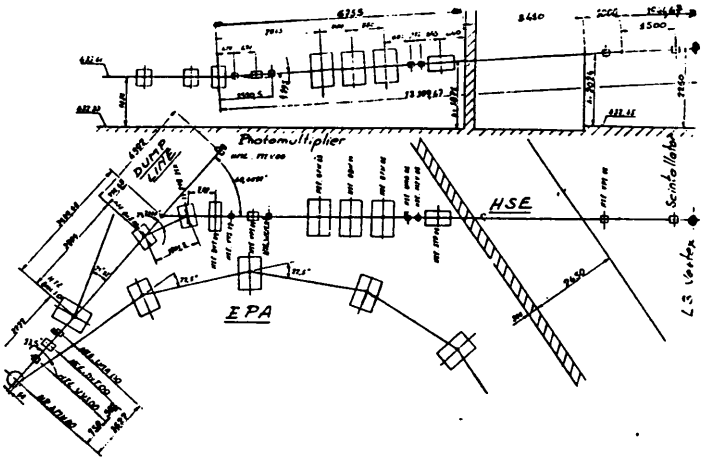

Fig. 3: Layout of HSE and HME Lines

The large variation range (100 MeV - 500 MeV) for a horizontal angle of 50 degrees implies for the bending magnets a working point which varies between fully saturated and non saturated regions. Magnetic measurements[6] were performed and an adequate shimming was realized to achieve, for this range, a field tolerance of ± 0.5 percent. The horizontal dispersion contribution to beam size is significant due to the large horizontal bending angle. However, it could be limited by reducing $\frac{\Delta p}{p}$.

As the vertex of L3 is at 2.2 m from the ground, it has been necessary to bend the HSE line in the vertical plane by 5 degrees, and to dispose a triplet to get the requested focusing at the vertex.

The input face of a BGO crystal is 4 cm². The requested spot area was 1 cm² in order to increase the chance that a single $e^-$ hits a given BGO crystal. However, as shown in table 1, the operational spot area was roughly 4 cm², the main reasons being the multiple Coulomb scattering caused by:

i) a 50 µm stainless steel window which closes the vacuum chamber at the end of the HSE line,

ii) a 3 mm plastic scintillator,

iii) a 2 m air gap.

Calculations made under these conditions show an increase by a factor 4 on the spot area. The single $e^-$ efficiency is defined as the following ratio: number of beam pulses with one single electron over all beam pulses for a given time.

Table 1 shows the beam characteristics requested compared to those obtained during the run.

Table 1

Beam characteristics at the Vertex of L3 Detector

| | Design | Operational | Best |
|---|---|---|---|
| Divergence (mrad) | 50 | 2 | 2 |
| Spot area at ± 2σ (cm²) | 1 | 4 | 1.3 |
| Energy (MeV) | 100-300 | 180 | 180 |
| Energy spread ($10^{-3}$) | ± 5 | ± 1 | ± 0.8 |
| Repetition rate (s) | 1.2 | 0.4 | 0.4 |
| Single $e^-$ Efficiency | 50% | 30% | 45% |

## Instrumentation Used

In addition to the existing instrumentation installed in LIL and EPA for high intensity beams, new devices have been used to monitor very low intensity beams. A high gain (200 instead of 50) has been implemented on the beam position monitors[7] after the ejection septum. One of them was also used in the interlock chain to protect BGO crystals of L3 half barrel against a high radiation dose. A sensitive TV screen associated with a CCD camera was able to measure $6.10^8$ particles/cm² at a repetition rate of 1 s.

During the experiment, a thin plastic scintillator was installed between the end of the vacuum pipe and the L3 calorimeter. This detector monitored the beam intensity during a run. The resolution was sufficient to discriminate between a few electrons per pulse and 'many' electrons. In addition, it was used as part of the trigger for the L3 calorimeter readout system. Two wire chambers were also installed (before and after the scintillator) to determine the trajectory of the single electrons.

The synchronisation[8] between the L3 detector and the complex LIL/EPA/HSE was made through 3 timing informations. The first slits used in LIL-V allowed a fine adjustment to maintain the single electron statistics, during small drifts of LIL parameters.

## Experimental Results

The facility described above was used to measure the low energy response of the L3 electromagnetic calorimeter. One half of the central calorimeter was placed in the beam. It was mounted on a specially designed table which could move in both θ and φ directions to allow any BGO crystal in the calorimeter to be exposed to beam. Every channel of the detector had been calibrated previously in electron beams at 2, 10 and 50 GeV. The purpose of this experiment was to test the low energy response of the detector, and to verify the procedure developed to extrapolate energy constants determined at high energy to lower energies. Thus, only a small number of crystals had to be exposed to the 180 MeV beam. The pulse height distribution in terms of energy, for a good run is shown in Figure 4. The peak at zero energy corresponds to events where no electron was present in the LIL pulse. For this particular run this occurred 27% of the time.

The peak at 160 MeV is from those pulses which contained exactly one electron (36% of all pulses). 19% of the pulses contained two electrons, and the rest had more than two. The machine parameters tended to drift, so that the typical run of one hour duration contained approximately 30% single electrons.

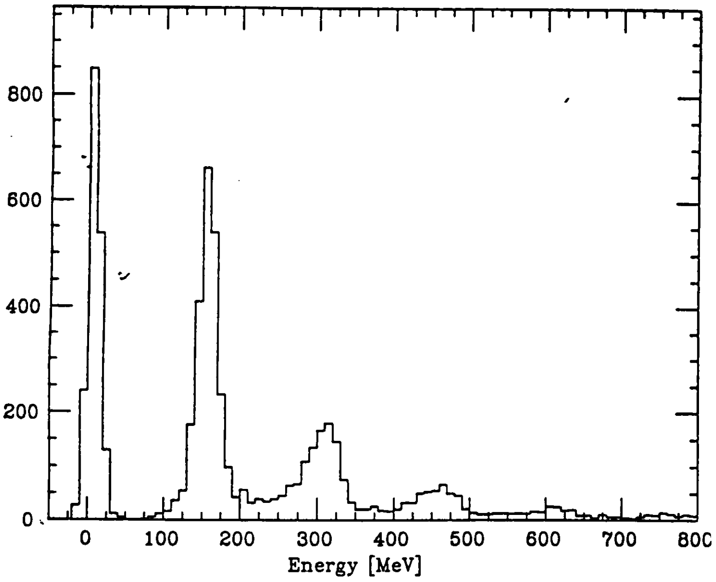

Fig. 4: Energy Distribution

The preliminary energy spectrum for an average crystal is shown in Figure 5. Only events with one electron present in the pulse have been included in the plot. The energy resolution is 3.6%, which meets the detector design specifications. The measured energy is 161 MeV, which agrees quite well with the Monte Carlo based on GEANT 3.11. The effects of energy loss in the material in front of the BGO, as well as the showering in the BGO were included. The energy loss was approximately 8.5 MeV, so that 171.5 MeV electrons impacted the detector. Losses from shower leakages account for another 7.5 MeV, yielding the expectation of 164 MeV.

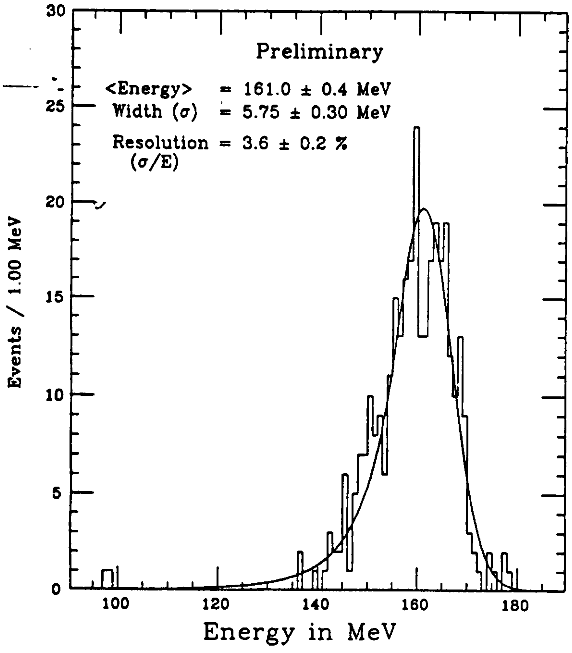

Fig. 5: Energy Spectrum

## Acknowledgements

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