Rome, 17 Jan. 90


University of Rome 'La Sapienza' and INFN Section of Rome.

(*)- in partial fulfilment of doctoral thesis.

1- Present status of L-5 experiment

The experimental apparatus to detect single bremsstrahlung (SB) photons from the interaction point of LEP consists essentially of a low-Z absorber and an EM calorimeter made of lead and scintillating fibres. This apparatus measures both the total energy and the space distribution of the single bremsstrahlung photons.

The main features of the calorimeter are summarized in Table 1.

The EM calorimeter consists of 42 modules. Each module is made of lead and scintillating fibres, contained in stainless steel tubes held parallel to the module axis, which will be oriented almost parallel to the incident photons. Each lead module contains 144 fibres which are bounded in a bundle,
connected through a light pipe of polystyrene to a PMT. In order to improve the space resolution in the central region the fibres of the six central modules are bunched in 4 bundles of 36 fibres each, connected to 4 PMTs by light pipes. The total number of read-out channels is therefore 60.

A calorimeter prototype with the first 9 modules was used during the 10 days test on July 89 at the SPS X7 electron beam. The complete set of 42 modules has been used during the run periods from September to December 89 at the SPS X5 electron beam.

The results concerning the energy and the space resolution show that the calorimeter performances are consistent with its utilization as a monitor for both the measurements of the luminosity at LEP, according to the program of the LEP-5 experiment.

We tested the experimental apparatus in its final configuration, which includes:

a) The 60 channel e.m. calorimeter aforementioned (Table I).

b) An absorber of 2 R.L. (Carbon+LiH) placed upstream of the calorimeter

c) A 420 m long cable (NE48P) made of 24 twisted pairs of wire was used to read-out the PMT signals. Therefore the calorimeter was tested and calibrated with the same read-out cables to be used in the LEP tunnel.

Concerning the read-out system, a prototype of the fast processor of the ADC data has been tested successfully in Rome (see Sect.3).

At present the cables are being installed in the IP-1 LEP tunnel, while the movable (remote controlled) platform supporting our apparatus has been designed at CERN and has been committed for construction.

2- Experimental results of the SPS tests performed.

Tests were performed on the electron beams X5 and X7 at the energies of 50,35,25,10 and 5 GeV. The main experimental results are shown and explained in the following.

A cross shaped scintillator in front of the calorimeter allows to select incident electron beam cross
sections of 2x2, 6x6 or 10x10 mm². A remotely controlled platform was able to displace the calorimeter so that the beam could be centered with an accuracy better than 1 mm at the center of each calorimeter channel (12.6 x 12.6 mm² or 25.2 x 25.2 mm²).

The final aim of the measurements was the determination of the calibration constants for all of the calorimeter channels. These values are needed in order to measure the total energy transported by the SB photons coming from IP-1 of LEP, and their space distribution.

As an example of the calorimeter performance concerning the last kind of measurements, we also show in this paper the space distribution of a 10 GeV electron beam determined by the energy distribution in the calorimeter channels. It is important to realize that the width of the electron beam space distribution is quite similar to the width of the SB photons to be measured in LEP IP-1. As will be shown in the following, the width has been measured at 1-2 % level. Furthermore we obtained a measurement of a 20 GeV bremsstrahlung spectrum.

The results on energy measurement and bremsstrahlung have been performed with the final detector configuration according the a), b) and c) of Sect.1.

i) Energy measurements.

In Fig.1a the energy measured by our calorimeter is plotted against the energy of the electron beam X-5, for five beam energies: 5, 10, 25, 35 and 50 GeV. The calorimeter response turns out to be linear on the whole energy range from 5 to 50 GeV.

In Fig.1b the quantity \( (E_{\text{meas}} - E_{\text{beam}}) / E_{\text{beam}} \) is plotted versus \( E_{\text{beam}} \). The linearity in the energy measurement turns out to be better than \(+/- 1\% \) R.M.S.

It has been studied the energy resolution \( \sigma_E / E \) as a function of \( E \) at five energies 5, 10, 25, 35 and 50 GeV, at different beam sizes and at several tilt angles between the beam axis and the fibres direction.

In Fig.1c the energy resolution \( \sigma_E / E \) obtained at 0° tilt, is shown versus \( 1 / \sqrt{E} \) (GeV) for the
values 5, 10, 25, 50 GeV. The solid straight line corresponds to a resolution value of $\sigma_E/E = 21%/\sqrt{E} + 6%$. The energy dependent term is consistent with the Montecarlo simulation result 18% quoted in our Add. 2 (pag.11).

Since during the luminosity measurement an absorber of 2 R.L. of LiH will be used, we have recalibrated the calorimeter with this absorber in front of it. Results concerning both linearity and energy resolution are given in Fig. 1d and Fig. 1e respectively.

Fig. 1d shows that the linearity is still very good despite the effect of energy loss in the absorber, in the range 10 to 50 GeV. It turns out to be better than 0.4 % R.M.S..

In Fig. 1e the energy resolution $\sigma_E/E$ is shown at beam energies of 20, 35, 50 GeV, in case of 0° and 10° tilt angles. The resolution values are 40% / $\sqrt{E} + 1.5%$ and 35% / $\sqrt{E} + 1%$ respectively. Therefore the effect of the absorber is to decrease the constant term by a factor 4 or 6 and to increase by a factor about 2 the energy dependent term. Since at LEP IP-1 the energy impinging on the apparatus (absorber + calorimeter) is of the order of 40 GeV / crossing, the absorber slightly improves the energy resolution.

Fig. 2 shows two plots obtained with a 50 GeV electron beam making a tilt angle of 0°. In Fig. 2b a LiH absorber 2 R.L. thick is placed in front of the calorimeter. It can be seen that the distribution is almost equal to that without absorber (Fig. 2a).

\section*{ii) Space resolution}

Fig. 3a and Fig. 3b show a comparison between reconstructed $<X>$ and actual X horizontal coordinate of the 2 x 2 mm² cross section beam. The beam coordinate has been reconstructed by taking for each incident electron a weighted mean of the energy contents of the surrounding channels. The spatial resolution r.m.s. turns out to be 1.1 mm.
An horizontal scanning through two adjacent calorimeter channels is shown in Fig.4. The average pulse height of each channel is given as a function of the horizontal coordinate at step of 2 mm.

The FWHM turns out 13.0 and 12.7 mm for the two channels respectively and the distance between the two distribution centers is 13.5 mm.

The size of a channel is 12.6 mm, however the two adjacent channels of Fig.4 belong to two different calorimeter modules, so that a gap of 0.5 mm between the two modules should be taken into account.

iii)- Space distribution of the 10 GeV electron beam.

Fig. 5 shows a three-dimensional plot of the energy released in the calorimeter channels by $6 \times 10^4$ electrons of the incident 10 GeV X5 beam (tilt angle =0°).

In order to obtain the width of the beam electron distribution, two independent methods have been used: an event by event approach and a global fitting of the data plotted in Fig.5.

In the first approach, the coordinates of each impinging electron are evaluated by determining the centre of mass of the charge distribution in the calorimeter modules (This method can be used at LEP only in the single-photon i.e. low luminosity regime). RMS values of 12.4 ± 0.1 mm and of 23.2 ± 0.2 mm were obtained for the horizontal and the vertical distributions respectively.

The second procedure can be used at LEP in the multi-photon regime. A fitting procedure is performed on the distribution shown in Fig.5 assuming a gaussian form for the beam profile and a combination of two gaussian functions for the transverse shower distribution. The following eight parameters are kept free in the fit: two widths and two amplitudes for the two gaussian functions needed to represent the Molière distribution of the electron showers in the calorimeter; the two centres coordinates and the two widths ($\sigma_H$ and $\sigma_V$) for the horizontal and vertical gaussian distributions; the last two parameters are relevant to the luminosity measurement. As a result of the fit we obtain the
values $\sigma_H = 11.4 \pm 0.7$ mm, $\sigma_V = 22.8 \pm 0.3$ mm.

The quoted errors are statistical only. Since the two methods are independent, it can be seen that the systematic errors are of the same order as the statistical ones.

The $\sigma_V$ value is of the same order of the width expected to be measured in LEP IP-1; therefore it is interesting to compare such value with the projected vertical distribution of the X5 beam at 10 GeV. This has been measured by wire chambers and the results extrapolated by a Montecarlo simulation to the position of our calorimeter (L. Gatignon, private communication).

In Fig. 6 the results of the first method (dashed line histogram) and of the second method (bell shaped line) for the vertical coordinate are compared to the aforementioned vertical distribution of the X5 beam at 10 GeV (solid line histogram). The R.M.S. value for this distribution is 21.0 *).

**iv**)- Bremsstrahlung spectrum measurement

For luminosity measurement at LEP the total energy released in the calorimeter by the bremsstrahlung photons produced in the beam crossing has to be measured.

Just before the SPS test end, i.e. after calorimeter calibration was completed, a bremsstrahlung beam was produced along the X-5 SPS test line. For this aim a thin lead target (0.2 R.L.) was placed on the electron beam, which was swept out afterward by a bending magnet. The bremsstrahlung energy spectrum of the resulting outcoming photon beam was measured by our apparatus.

In Fig. 7 the spectrum $(dN/dK)K$ versus $K$ is plotted (solid line histogram), where $dN/dK$ is the

*) Due to the Montecarlo statistics one estimates a 0.3 mm error on this number. However this distribution was obtained with a wire chamber located 100 meters upstream the calorimeter. Extrapolation over this distance can increase this error if the multiple scattering has been underestimated.
number of photons per energy bin, and K is the photon energy. The results of a Montecarlo simulation (crosses) are also shown; a 20 GeV bremsstrahlung beam goes through the absorber (2 R.L. carbon), and hits a calorimeter with an energy resolution of $\sigma_E/E = 21\% / \sqrt{E} + 6\%$. (No effect due to target thickness was taken into account). Notwithstanding the poor statistics due to lack of time and low efficiency in photon production, a reasonable agreement is found.

We are confident that after the installation in LEP, we will be able to setting up our apparatus by using the beam-gas bremsstrahlung, before to ask for bunch crossing.

3- Status of the FERA PROCESSOR

We recall that the FERA PROCESSOR (see our Add. 2, page 6) is a specially designed module (one per each FERA), whose purpose is to process the ADC data via the fast ECL front port and to provide the sum over a great number of bunch crossings (up to $10^{11}$) of the content of each channel.

A prototype of this module has been realized in Rome using the wire-wrap technique. A series of lab tests have been carried out on this prototype to check its full CAMAC compatibility. More specific tests have been successfully performed to check the communication to and from the DSP56001. At present a pair of a FERA and the relative FERA PROCESSOR has been assembled and connected to a Macintosh computer and the full acquisition chain is under test.

In the meantime the design of the printed-board master for the final version of the FERA PROCESSOR is in progress in Rome with the help of a CAD. We expect 4 FERA PROCESSORS to be ready by March 19, the date of LEP starting up.
4- Conclusions

The E-2 time schedule enclosed to LEPC/I 8, Add. 2 has been fulfilled.

The results on the calorimeter performances have shown that its features are matching the expected requests for a fast and accurate measurement of luminosity at LEP.

We are confident that our apparatus is ready to be installed at LEP IP-1 before the end of the shut-down, on March 19, 1990.

Acknowledgements

We want to recognize the unvaluable support of our group technician M. Bertino and of the technical staff of the INFN Sezione di Roma: in particular L. Andreanelli, F. Bronzini and R. Simonetti.
Table 1

Main features of the LEP-5 modular electromagnetic calorimeter

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillator</td>
<td>Polystyrene</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>1 mm</td>
</tr>
<tr>
<td>Absorber</td>
<td>Lead</td>
</tr>
<tr>
<td>Filling factor (scintillator/total volume)</td>
<td>18%</td>
</tr>
<tr>
<td>Average density</td>
<td>9.6 g cm⁻³</td>
</tr>
<tr>
<td>Average radiation length</td>
<td>0.68 cm</td>
</tr>
<tr>
<td>Average Moliere radius</td>
<td>1.84 cm</td>
</tr>
<tr>
<td>Total length in R.L.</td>
<td>~ 50</td>
</tr>
<tr>
<td>Fibre number/channel</td>
<td>144 or 36</td>
</tr>
<tr>
<td>Channel sensitive volume (length x section)</td>
<td>35 cm x (2.52 x 2.52) or (1.26 x 1.26) cm²</td>
</tr>
<tr>
<td>Read-out PMT/channel</td>
<td>1 XP1911</td>
</tr>
<tr>
<td>PMT useful photocathode diameter</td>
<td>14 mm</td>
</tr>
<tr>
<td>Calorimeter front area (width x height: cm²)</td>
<td>17.6 x 15.1</td>
</tr>
<tr>
<td>Number of modules</td>
<td>42</td>
</tr>
<tr>
<td>Fibres bundles, PMTs and ADC channels</td>
<td>60</td>
</tr>
</tbody>
</table>
Fig. 1d
With Absorber (2 r.l. LiH)

$\sigma/E (\%)$

$1/\sqrt{E}$

Fig. 1c
Fig. 3b

\[ \langle X \rangle - X \text{ [mm]} \]

\( X \) - horizontal coordinate [mm]