SICAL: Results of beam tests.

We have measured the deposited charge versus shower depth in tungsten for electrons in a silicon crystal detector similar to that foreseen for SICAL. In particular we have measured the maximum charge deposited in a single pad. Muon pulse heights were also measured for comparison.

We have studied the response of the crystal as a function of the energy of incident particles.

Results are compared with Monte-Carlo shower development based on GEANT.
1. Experimental layout

Following the beam axis, we had successively (Fig.1):
- $S_1$ and $S_2$: 2 small scintillators ($10 \times 5 \text{ mm}^2$) used as front trigger
- $A_3$: a large scintillator with a hole ($2 \times 5 \text{ mm}^2$) aligned on the beam axis used as front veto and beam definition
- variable number of tungsten plates
- silicon crystal in its support
- iron shield (1 m thick)
- $A_4$: a large scintillator used as back veto.

The coincidence $S_1 \cdot S_2 \cdot \overline{A_3} \cdot \overline{A_4}$ triggers on electrons, while $S_1 \cdot S_2 \cdot \overline{A_3} \cdot A_4$ selects muons.

In these conditions the beam size is defined by the hole in $A_3$, which projects on one pad along the beam axis (Fig.2). In fact, due to inefficiency in the read-out of $A_3$, the effective size of the beam was bigger than the hole dimensions (see later).

The crystal is equipped with a single electronic chain, consisting of pre-amplifier, amplifier with adjustable gain and ADC, allowing the read-out of one pad only.

2. Results.

2.a Muons.

First, we have recorded the signal given by muons of 70 GeV, i.e. signal defined as $\approx 1$ MIP (Fig.3).

The pedestal is due to particles which have fulfilled the trigger conditions but have gone through a non-connected pad. Despite the size of the hole in the counter $A_3$, this can happen because of inefficiency in the read-out of $A_3$ (ex. light collection efficiency behind the cut-out).

The estimator we have chosen to evaluate the deposited charge is the mean value of a gaussian fitted on the top of the response curve. After pedestal subtraction, and application of calibration constants, we found:

$$1 \text{ MIP} \rightarrow 3.6 \text{ fC}$$
2.b Electrons.

An important measurement, because of its implications on the pre-amplifier design, is the maximum deposited charge in one pad at LEP energies.

To obtain this number, we used electrons of 100 GeV and we measured the longitudinal profile of the shower by varying the tungsten thickness upstream the silicon crystal. To reproduce local sampling conditions of the final calorimeter, 4.6 $X_0$ were kept behind the crystal.

Fig.4 shows an example of the response obtained for a given thickness of tungsten and an appropriate gain of the electronic chain. Superimposed is the gaussian used to evaluate the deposited charge. The values of this charge as a function of the traversed tungsten thickness are plotted on Fig.5. The bars are not errors but the "widths" of distributions (i.e., the $\sigma$ of the gaussians). The points have been fitted by a curve of the form:

$$Q = Q_0 t^a e^{-bt}$$

t being the traversed thickness of tungsten.

The horizontal scale of Fig.5 take into account the fact that we have used a tungsten alloy (95% W + Cu and Ni) instead of pure tungsten.

From the fitted parameters, we deduce the peak charge on a single pad:

$$Q_{\text{Peak}} = 2254 \, \text{fC}$$

To determine the maximum charge expected into the pre-amplifier from this number, we have taken into account the following facts:

- the beam was not shooting at the largest pad
- there was an air gap of $\approx 2$ mm between tungsten and silicon
- the distribution is almost gaussian, and we want to measure up to 2-$\sigma$ above the peak.

Doing the corresponding corrections, we deduce:

$$Q_{\text{Max}} = 3500 \, \text{fC}$$
Similar measurements have been done with electrons of 35, 50 and 70 GeV. The corresponding longitudinal profiles are displayed on Fig.6. The positions of the maxima are summarized in Tab.1, and the values of the fitted parameters are listed in Tab.2. As expected, $Q_{peak}$ varies linearly with $E$ and $t_{peak}$ with $\log(E)$ (Figs.7).

An interesting curve is the one recorded with 1.8 mm (= 0.5 $X_0$) of tungsten (Fig.8), where we can see peaks corresponding to 1 Mip and 3Mips and, but less clearly, the peaks at 2 Mips and 5 Mips.

3. Comparison Data-MC.

The program used to simulate the shower development in tungsten is based on GEANT.

Fig.9 shows a comparison between data and MC for electrons of 50 GeV hitting silicon with no tungsten in front. The pedestal, due to particles missing the connected pad, have been used for the following purposes:
- the width is used to tune the smearing in the MC
- the relative height allows us to adjust the effective size of the beam.

On Fig.10 is shown a Data/MC comparison for electrons going through a tungsten thickness of 5.5 $X_0$. The shoulder on the left side of the peak is due to inefficiencies in the veto counter $A_3$ (incident particle hitting a neighbouring pad) causing a measurement of some fraction of the deposited energy.


We have measured the maximum charge visible by a single pad, in LEP conditions:

$$Q_{Max} = 3500 \text{ fC}$$

The Monte-Carlo correctly reproduces the data.
<table>
<thead>
<tr>
<th>E (GeV)</th>
<th>$Q_{\text{Peak}}$ (fC)</th>
<th>$t_{\text{Peak}}$ ($X_0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>824 ± 53</td>
<td>6.55 ± .02</td>
</tr>
<tr>
<td>50</td>
<td>1137 ± 36</td>
<td>6.86 ± .01</td>
</tr>
<tr>
<td>70</td>
<td>1625 ± 74</td>
<td>7.12 ± .02</td>
</tr>
<tr>
<td>100</td>
<td>2254 ± 64</td>
<td>7.59 ± .01</td>
</tr>
</tbody>
</table>

Table 1

<table>
<thead>
<tr>
<th>E (GeV)</th>
<th>$Q_0$</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>12.2 ± .5</td>
<td>4.78 ± .03</td>
<td>.720 ± .004</td>
</tr>
<tr>
<td>50</td>
<td>11.3 ± .3</td>
<td>4.97 ± .02</td>
<td>.725 ± .002</td>
</tr>
<tr>
<td>70</td>
<td>10.7 ± .3</td>
<td>5.22 ± .02</td>
<td>.732 ± .003</td>
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<tr>
<td>100</td>
<td>7.8 ± .2</td>
<td>5.52 ± .02</td>
<td>.727 ± .002</td>
</tr>
</tbody>
</table>

Table 2
**Muons 70 GeV**

- **ped** = 54.04
- **signal** = 81.54

**Electrons 100 GeV**

- $\chi^2 = 1.061$
- Constant: $33.97 \pm 0.4095$
- Mean: $581.4 \pm 2.385$
- Sigma: $134.2 \pm 1.682$

- Fig. 3 - Channel
- Fig. 4 - Run 159 Channel
Longitudinal shower profile
Electrons 100 GeV

Maximum
7.59 $X_0$
2254 fC

$\chi^2$ 4.4100E + 00
P1  7.827 ± 2.348
P2  5.517 ± 1.655
P3  0.7271 ± 0.2181

- Fig. 5 - Thickness ($X_0$)

Longitudinal shower profiles
Electrons 35, 50, 70 and 100 GeV

Charge (fC)

- Fig. 6 - Thickness ($X_0$)

1 Mip