A prototype of fine granularity lead-scintillating fiber calorimeter with imaging read-out

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The starting point: the KLOE Calorimeter

Light readout in 4.4x4.4 cm² cells on both sides via light-guides + fine mesh PMs

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<tr>
<td>⟨ Density ⟩</td>
<td>ρ ~ 5 g cm⁻³</td>
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<tr>
<td>Rad. Length</td>
<td>X⁰ ~ 1.2 cm</td>
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<tr>
<td>Light att. Length</td>
<td>λ ~ 400 cm</td>
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<td>Sampling fraction</td>
<td>12 %</td>
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Excellent performances:

\[ \sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})} \]
\[ \sigma_T = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps} \]

PID mostly from TOF
Motivation

Exploit the KLOE calorimeter homogeneity to build a dense imaging device. Accurate cluster shape reconstruction would allow:

- efficient PID
- near energy depositions separation
- study details of the energy release process for different particles types and tune clustering algorithms accordingly.

Note: this idea has started in the KLOE-2 project, but its implementation into an upgrade of the KLOE calorimeter turned out to be very difficult. Then it has to be considered an independent development.
The concept: thin light guides + multi-anode PMs

A KLOE calorimeter prototype was available
Standard light readout already present on
one side: 15 cells 4.2 x 4.2 cm\(^2\) over 5 planes,
each instrumented with a standard 1” PM.

Our project:

• Collect the light with segmented guides
• Detect the light with multi-anode PMs
  1 KLOE cell \(\rightarrow\) 16 pixels

3 x 5 4.2x4.2 cm\(^2\) cells \(\rightarrow\) 240 small cells 1.05x1.05 cm\(^2\)
Hamamatsu R8900-M16

Window material: Borosilicate glass  
Arrangement and Type: 4 x 4 grid  
Number of channels: 16 (each 5.7x5.7mm²)  
Effective Window Area: 23.5x23.5mm²  
Photocathode material: Bialkali  
Spectral response range: 300 to 650 nm

Compact design

Operation HV: 800-900 V  
A signal with sum of all the 16 last dynodes is also provided  
Up to 30% gain variation between the 16 pixels

We purchased 12 standard R8900 + 3 with higher quantum efficiency
A dedicated 16+1 channel pre-amplification stage has been developed using simple inverting x10 amplifiers. Positive signals are needed to be able to use the KLOE electronic chain.

16 ch HV distribution board also produced

Test version

Preamp stage
A ps laser pulse used to illuminate single pixels and study the multi-anode response.
**Gain (non) uniformity**

For each channel the response has been measured relatively to the one @ 500 V

- Slopes with HV are essentially the same
- Offset is quite different from channel to channel
Two sample cases:

Gain non-uniformity measured for all our multianodes. Similar behaviour always found.
Cross talk

Laser pulse injected in individual pixels, Charge response measured in all the others.

For each PM we obtain a 16x16 cross talk matrix:

Electronic cross talk between nearby channels can be as much as few %

Non adjacent channels have almost negligible cross talk
Want to map 16 contiguous cells 1.05x1.05 cm$^2$
into 16 cells 0.53x0.53 cm$^2$ each separated by a 0.11 cm dead zone
(multinode cell area is indeed 0.57x0.57 cm$^2$).
**UV transparent plexiglass BC800 has been used**, to fully match the R8900 spectral response

**Not trivial mechanics:**
- all surfaces at different angles
- guides are 6 cm long and touch each other only on the calorimeter surface.
- a small aluminum grid keeps the 16 guides in place at the PM side
Light guides: final product

No black painting or envelopes on individual guides.
Air/plexiglass surface considered the best compromise.
Optical cross talk will have to be checked out.
Final assembly in a 3 x 5 matrix

Ready to be glued on the calorimeter surface
Full mechanical design

- Multianode
- Segmented light guides
- PM case
- Calorimeter
- Electronics
- Socket
PM case holds also HV distribution and preamp board

The full case is light tight
Prototype mounted on a support that allows $180^\circ$ rotation
Finally the optical contact!
Cross talk : electronic vs optical

We dismantled the opposite side light readout system (later on we reinstalled it).

We injected the light pulse on individual fibers on this now free calo side and study the response of the pixels on the other side:

Single multi anode cross talk confirms what previously observed: few % on nearby channels.

The response of the two nearest row of the adjacent PM show really Negligible optical cross talk !!!
Readout and Data acquisition

It is fully made with KLOE electronics:

• signals are first splitted, discriminated and summed (SDS boards)

• KLOE ADCs and TDCs are then used to digitize them

• DAQ goes via asynchronous readout Using 2 custom buses and a chain of ROCKs (read out controller for KLOE)

• online CPU is the only new element: a Motorola MVME6100

• Trigger exploits the signal sums provided By SDS, but it is simply done by NIM
First cosmic rays!

Calorimeter in auto-trigger on the coincidence of first and last plane of m-anodes:

Simple event display shows the imaging power of the detector

Interesting topology can be searched for (muon range, muon decay, protons...)

P. Branchini
Looking for MIPs …

Total energy has nice Landau shape as also the number of channels...
Pixel counting at this level is a good energy estimate!
Equalization:

Due to gain non-uniformity HV can be used only to equalize the full multianode response.

We used the summ of all pixels in same PM, and fixed it around 3000 counts.
Fitted track and residual distribution

The MIP energy distribution is clearly visible also on single anode.
MIP energy deposition in 1 Ma PMT

Mip energy deposition on a single anode of the Ma PMT
A couple of displays from BTF

400 MeV electron in the calorimeter

100 MeV electron in the calorimeter

400 MeV electron energy distribution after a raw equalization.

ADC A.U.
Electron energy reconstruction and resolution

Single and double 100 MeV electron impinging the calorimeter

$\text{ADC} = 68 \times \text{energy(MeV)} + 569$

Resolution vs beam energy:

$\text{res} = 0.06/\sqrt{\text{energy(GeV)}} + 0.03$
Conclusions

A fine granularity calorimeter prototype has been realized using a KLOE calorimeter piece with segmented light guides and Hamamatsu multianode PMs.

The response of individual channels has been studied with a laser pulse and the cross talk measured. Optical cross talk is negligible.

A full system is now operating. Many cosmics rays have been acquired and are being analyzed.

A test beam with electron at BTF is now over and data are being analysed.