Possible Upgrades to HPS Ecal

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On behalf of INFN -Italy

Introduction

INFN proposes to have an active role in the Ecal upgrades mentioned in the HPS 2014 proposal, for production run.

Two main tasks:

- Design, construct, and test the new ``Motherboards'' for signal, LV, and HV distribution.
- Design the light monitoring system.

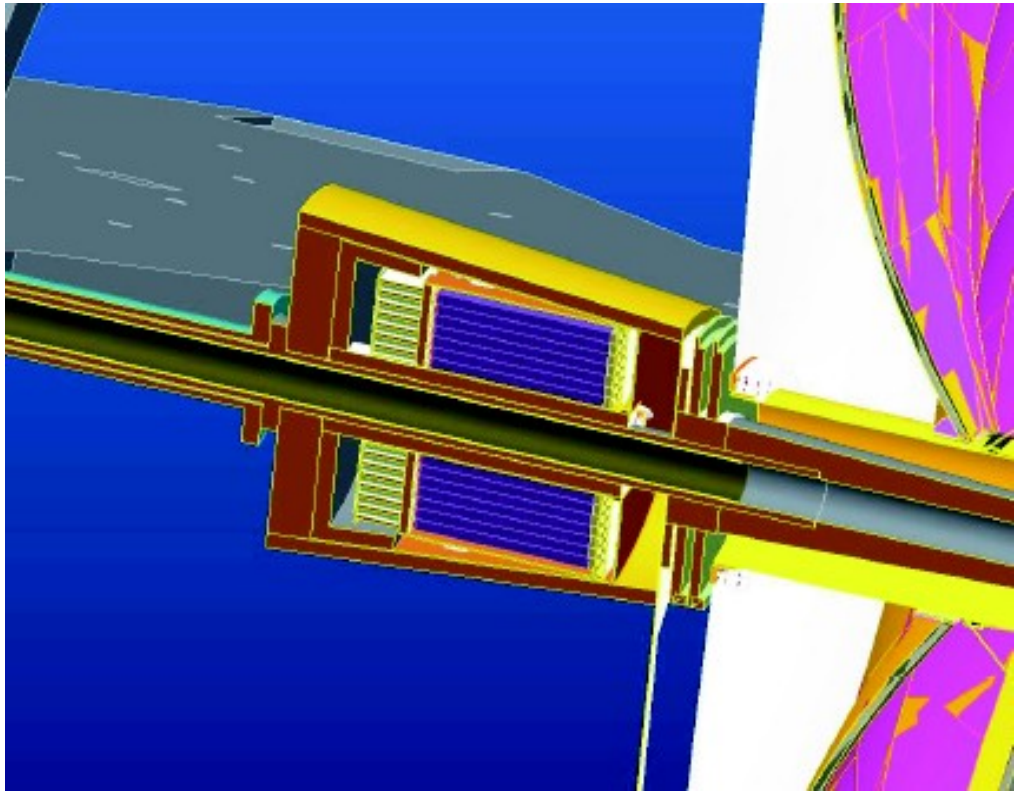
We developed the experience for these tasks from the construction of the “Forward Tagger Calorimeter” for the CLAS12-MesonEx experiment.

A third possible upgrade, subject to the availability of the required founds, is the replacement of current APDs with larger ones (see M. Battaglieri and M. Carpinelli talk).

The FT-Cal for CLAS12 in Hall B

The Forward Tagger Calorimeter (FT-Cal) for the CLAS12-MesonEx experiment in Hall B has a similar structure as the HPS Ecal.

- PbWO4 crystals.
- S8664-1010 APDs for light readout.
- Current-sensitive preamplifier coupled to each photo-sensor.
- Temperature control with stability better than 0.1 C.
- Mounted around the beam-line.

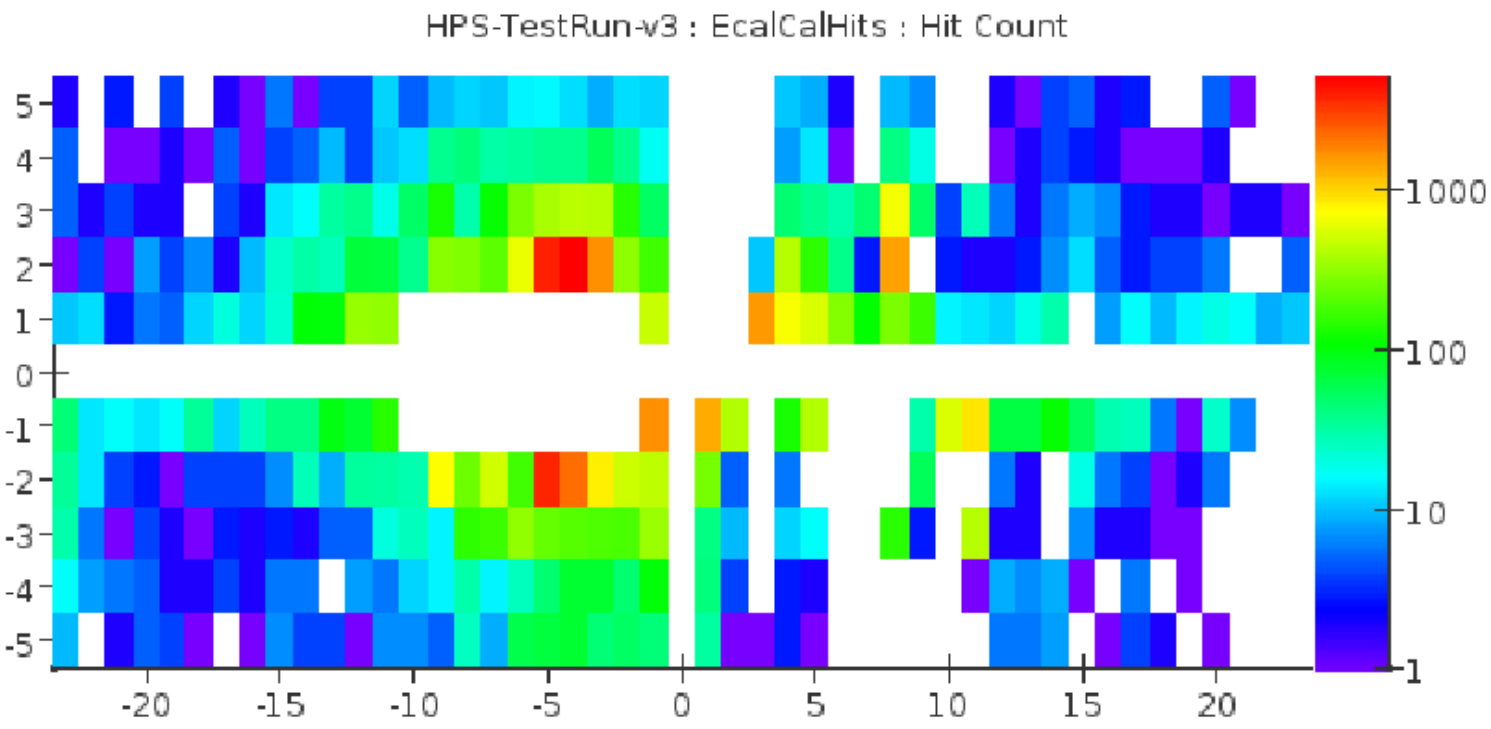


Motherboard

The HPS Ecal is equipped with four PCBs, two per sector, that distribute HV and LV to APDs and amplifiers and collects output signals: **the ``Motherboards''.**

During the 2012 test run, motherboards had issues.
26 channels over 442 (6%) were disabled because of absence of electrical connection.

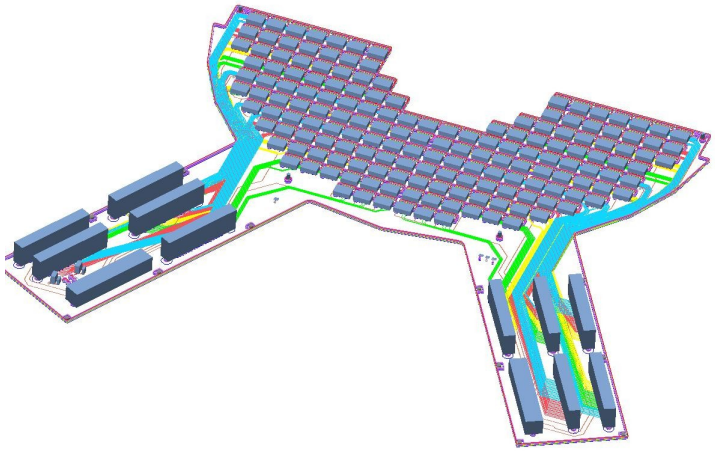
This calls for a new, updated version of the motherboards for the production run.



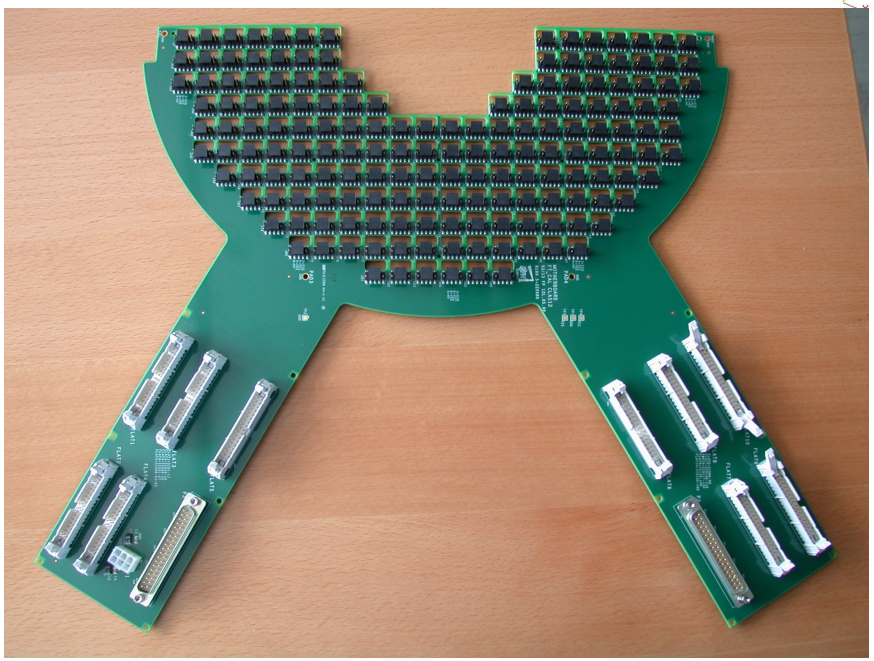
Motherboard

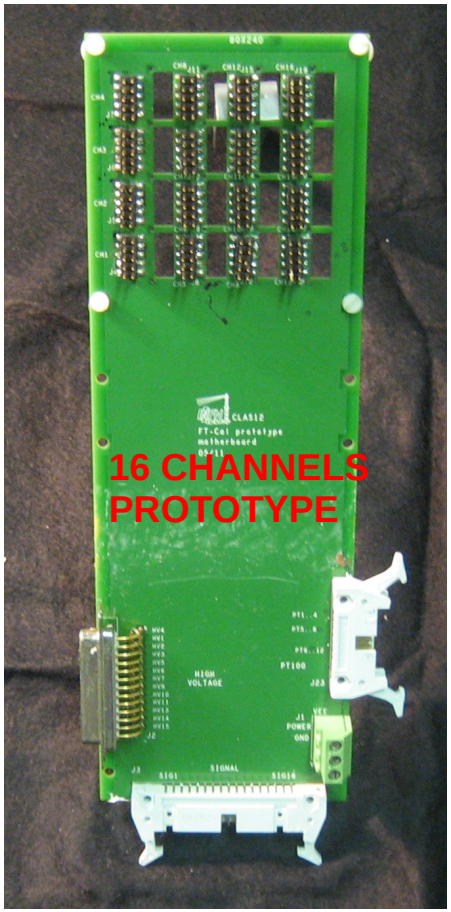
We successfully designed, constructed, and operated a similar motherboard for the Forward Tagger Calorimeter

Designed by INFN Genova electronic group, in collaboration with E. Raully (IPN Orsay).



- Different layers for LV, HV, signals.
- Signal layers in between 2 ground planes to provide noise isolation.
- Signal paths at controlled 50 Ω impedance.
- Ground paths in between signal paths, on the same plane, to reduce cross-talk.



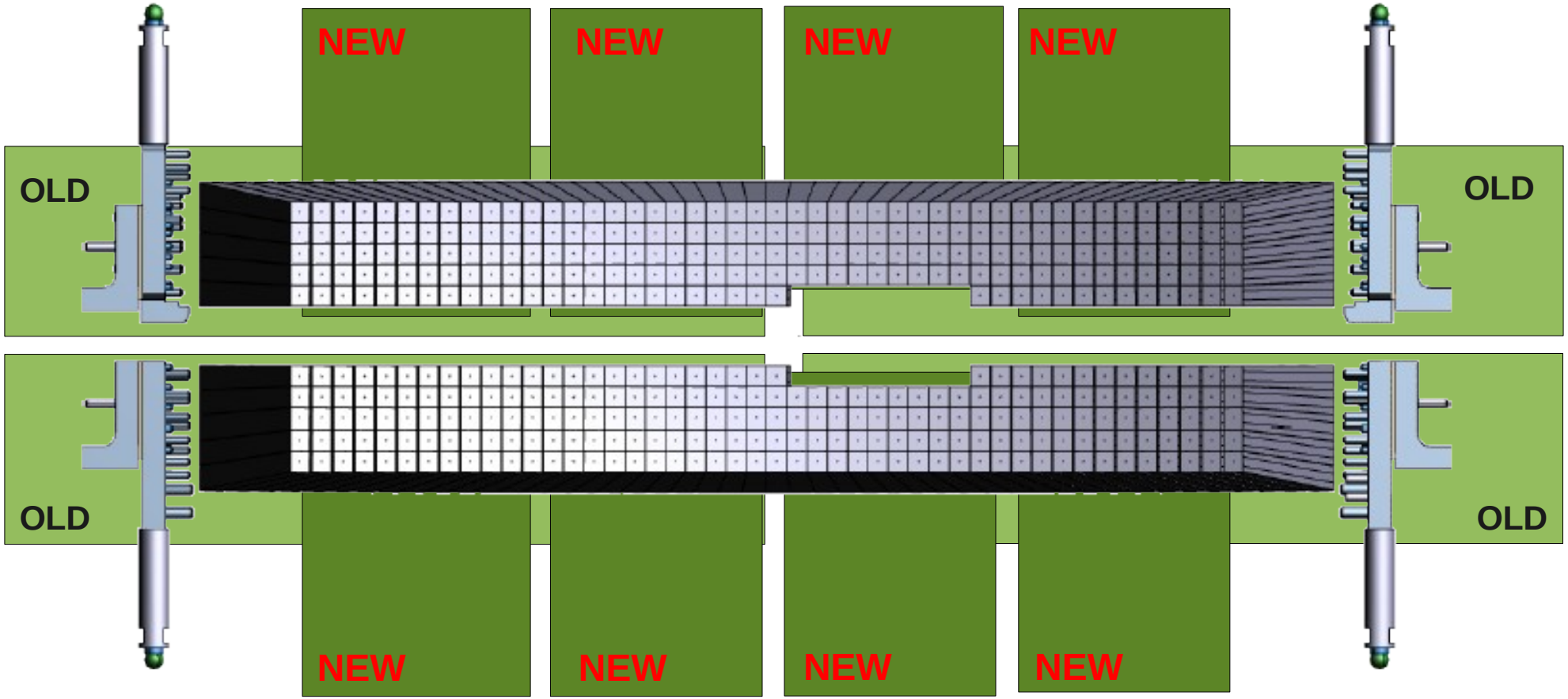


Motherboard

We propose to design, construct and test the new HPS Ecal motherboards.

• The four original motherboards had connectors were on the side of the Ecal, to keep place for further Ecal modules.

• No new Ecal modules are foreseen: we propose to switch to shorter motherboards, with connectors on Ecal top and on bottom.

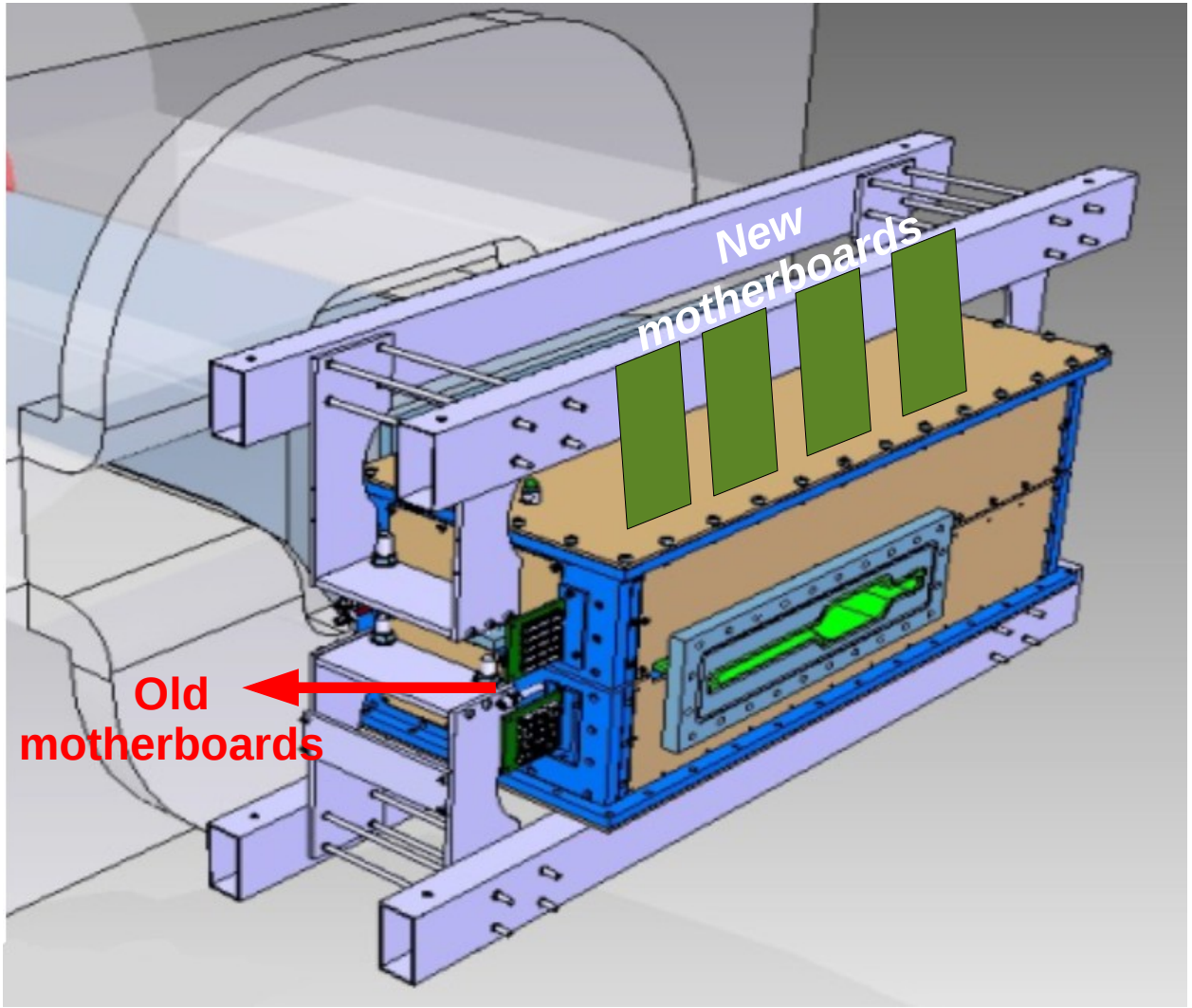


Motherboard

The Ecal mechanical design must be reviewed to accommodate the new motherboards.

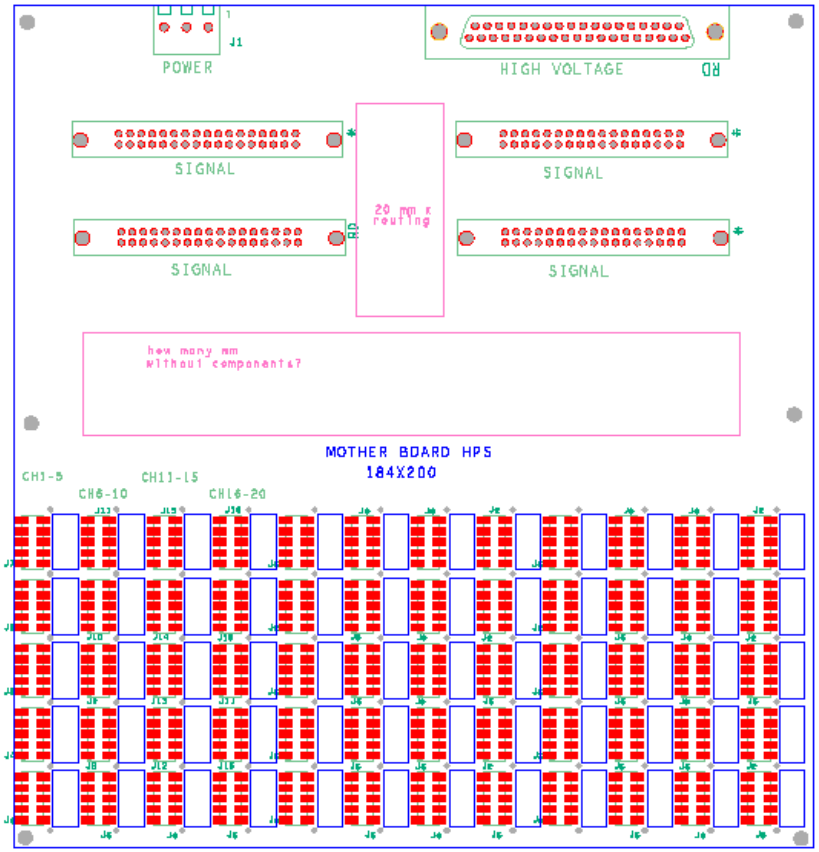
- The new design interferes with the Ecal cooling system.
- The new motherboards exits are located on Ecal top and bottom, thus the enclosure has to be modified.

We are in contact with P. Rosier (IPN Orsay) to coordinate the mechanical design of the motherboards in the Ecal framework.



Motherboard

New HPS motherboard proposal



- 60 channels.
- Channels arranged in groups of 10 for HV bias.
- 4 signal connectors.
- 1 HV connector.
- 1 LV connector.

- 10 layers.

- 8 PCBs in total, in groups of 6 and 2.

Motherboard

Proposed work plan

- Manpower
  - F. Pratolongo (main design), E. Rauly (supervision), P. Rosier (mechanical support), Genova group (tests).
- May - August 2013: new motherboard design
  - Precise Ecal geometry definition (Orsay).
  - Mechanical enclosure modification (Orsay).
  - Final motherboards layout (Genova).
- September 2013: new motherboards production
  - Same company used for the FT-Cal (Phoenix).
- Oct - Dec 2013: new motherboards tests
  - Electrical connections fine checks for all channels.
  - Cross-talk measurement with FT-Proto 16.

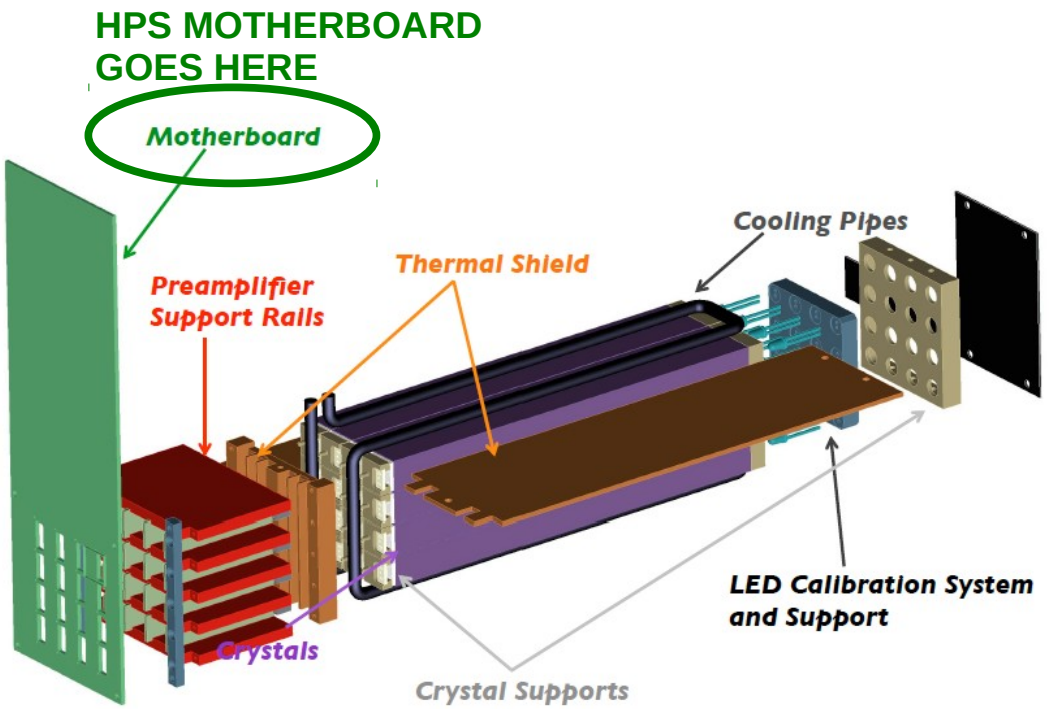
Motherboard

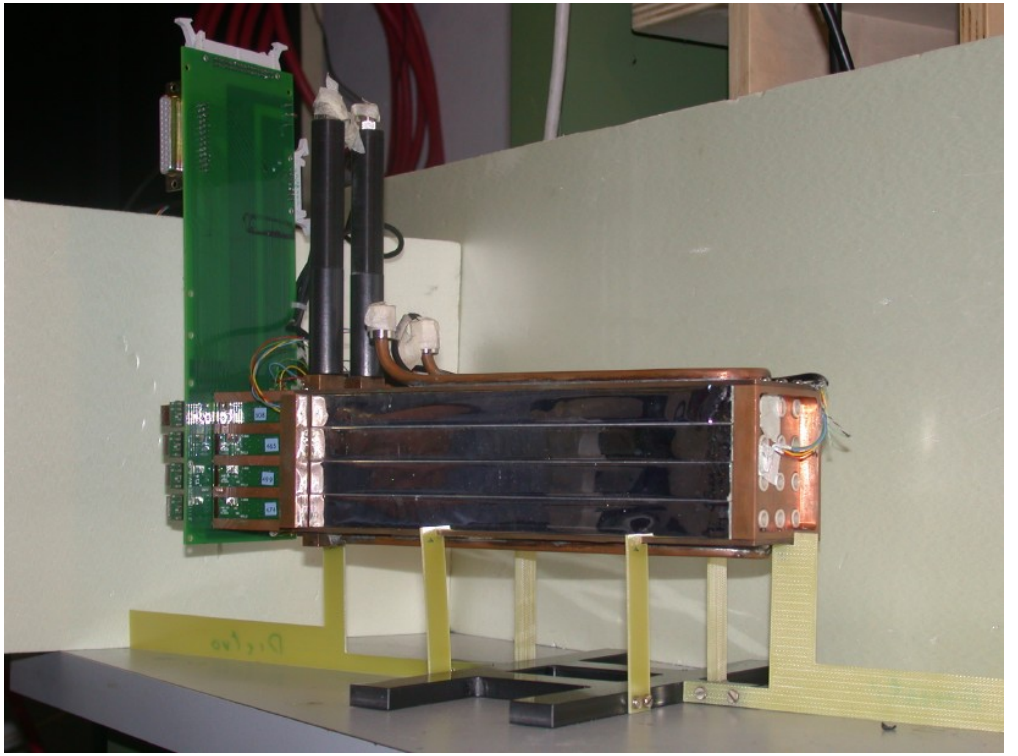
Test plan

1) Verify that all the electrical connections are fine and there are no short circuits. Can be done with a standard electrical tester ~ 1 day.

2) Measure cross-talk, coupling the motherboard to the FT-Cal 16 channels prototype, with LED monitoring system. Requires ~ 1 day/16 channels.

- Connect the 16 amplifiers to 16 motherboard channels.
- Turn on one LED at time and measure response of neighborhood channels.





Light monitoring system

Motivations for a light monitoring system in the HPS Ecal:

- $PbWO_4$ crystals are radiation-sensitive, light transmission lowers resulting in effective LY loss.
- Such a process is non-uniform in the Ecal, due to the different irradiation in each crystal (geometrical effect).
- Crystals response needs to be monitored continuously and, if necessary, re-calibrated
- Possible APDs gain variation during time needs to be under control.

From the CLAS12 FT-Cal experience, we learned that, during commissioning, it is critical to switch on/off channels independently for fast debugging.

- Test the correct functionality of all APDs / amplifiers.
- Check all the electronic channels.
- Verify correct cabling.

Light monitoring system

Different possibilities available:

1) Use a small radioactive source, like a YAP pulser with α-emitter deposited on it.

- Excellent time stability.
- Fixed emission amplitude, can't do timing measurement, can't provide independent trigger signal.

2) Use a laser as light source, and distribute light to crystals with optical fibers.

- Relatively simple design, lasers available “on the shelf”.
- From CLAS-IC laser monitoring system, we know such a system is very sensitive to environmental conditions.

3) Use individual LEDs for each Ecal channel.

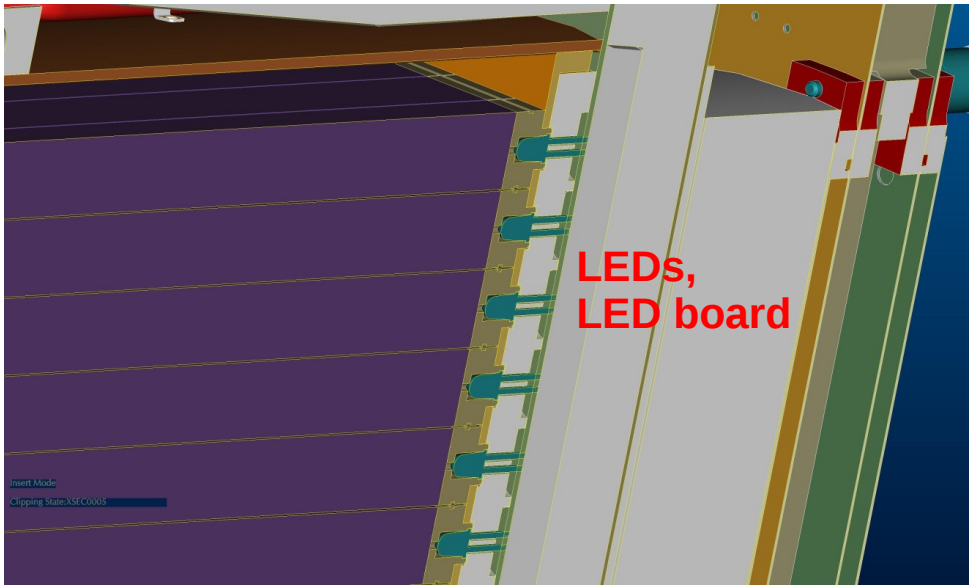
- Versatile system, LEDs can be coupled directly in front of each crystal or trough optical fibers.
- LEDs with different colors permit to check different Ecal parameters:
  - Blue LED: optical transmission.
  - Red LED: APD gain.
- Such a solution has been already adopted efficiently in other EM calorimeters:
  - PANDA-EC (optical fibers coupling)
  - ALICE-PHOS (direct coupling)
- Requires a custom-designed driver for each LED, compliant with the required dynamic range.

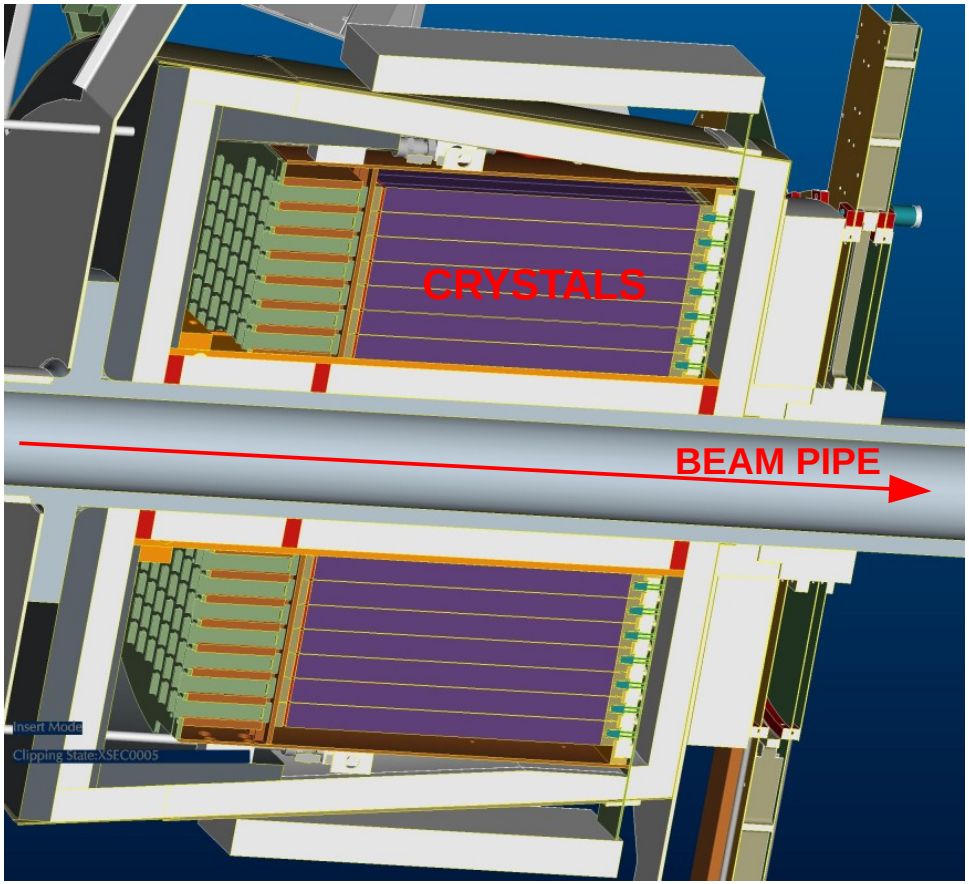
Light monitoring system

We propose to design the HPS Ecal monitoring system starting from the existing FT-Cal LED monitoring system.

FT-Cal monitoring system:

- **Blue** LEDs coupled directly to crystals trough a proper PEEK support.
- Each LED is pulsed by a dedicated, fast driver.
- The whole system is managed trough a dedicated controller, EPICS compliant.





Light monitoring system

Design of the system for HPS ECal

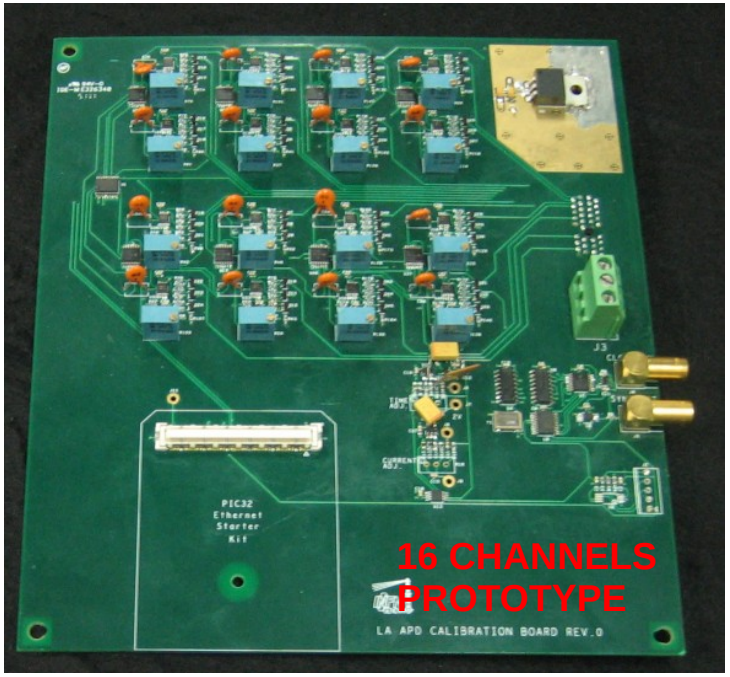
The FT-Cal light monitoring system is currently made of 3 separate sub-components:

The main controller

- Provides communication with the system trough Ethernet/USB interfaces.
- EPICS compliant.
- Mounted in a crate, ~10 m from the calorimeter.
- No further modifications are needed.

The driver board

- Hosts the independent LED pulser circuits.
- Communicates via I^2C with the main controller.
- Mounted out of the calorimeter enclosure, it is connected to the LED board (see next slide).



Light monitoring system

Design of the system for HPS Ecal

The LED board

- It is mounted in front of the calorimeter, inside the thermal enclosure.
- It is connected to the driver board trough a board-to-board connector.
- It needs to be re-designed according to HPS mechanics.

All LEDs must be tested independently before mounting on the LED board, to check if they are compliant with the required dynamic range and timing response.

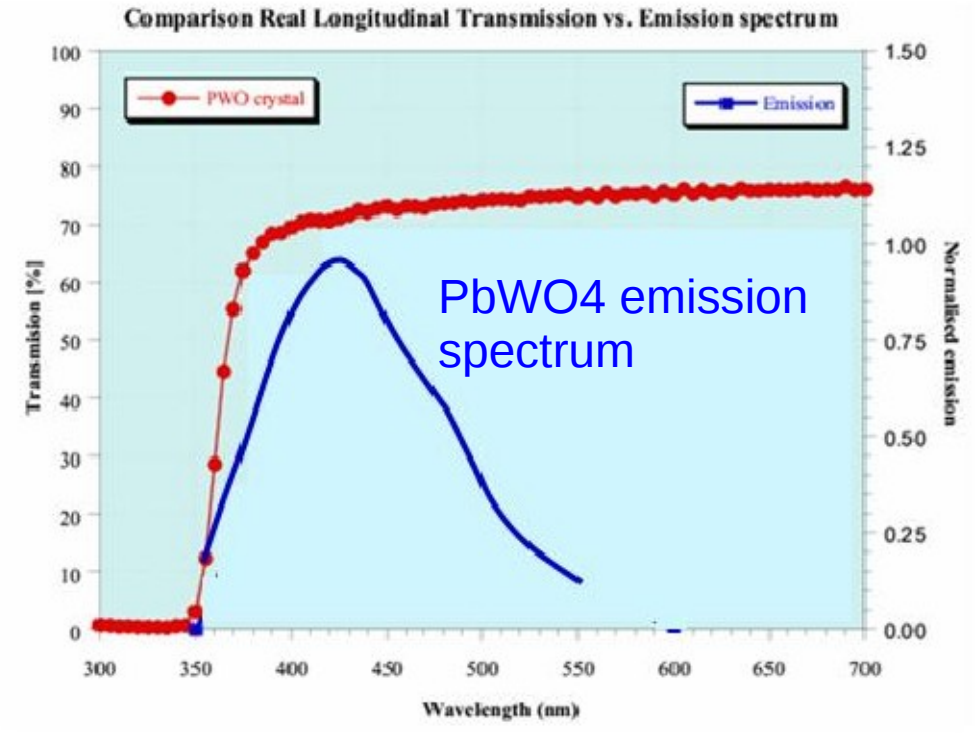
- We use a single-channel LED driver coupled to a $PbWO_4$ crystal + APD.
- The whole test procedure requires ~ 5 minutes / LED.

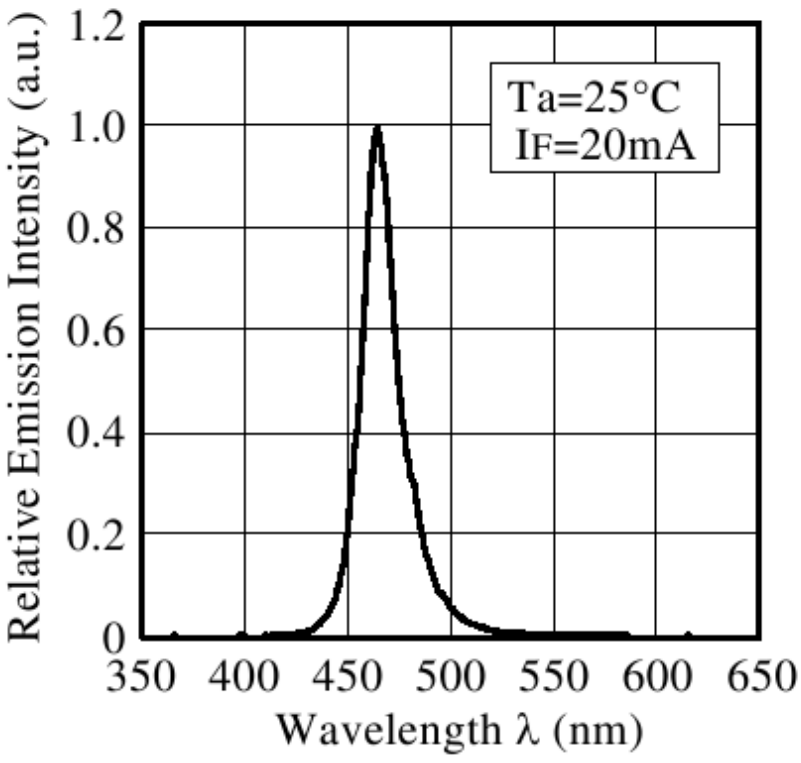
Light monitoring system

LED choice was a critical task.

It was difficult to find a device emitting short-enough light pulses: data-sheets do not report LED performances at ns scale.

Final choice: **NICHIA NSPB500AS blue led**, well matched to the $PbWO_4$ spectrum and capable to emit fast (~10 ns) pulses.

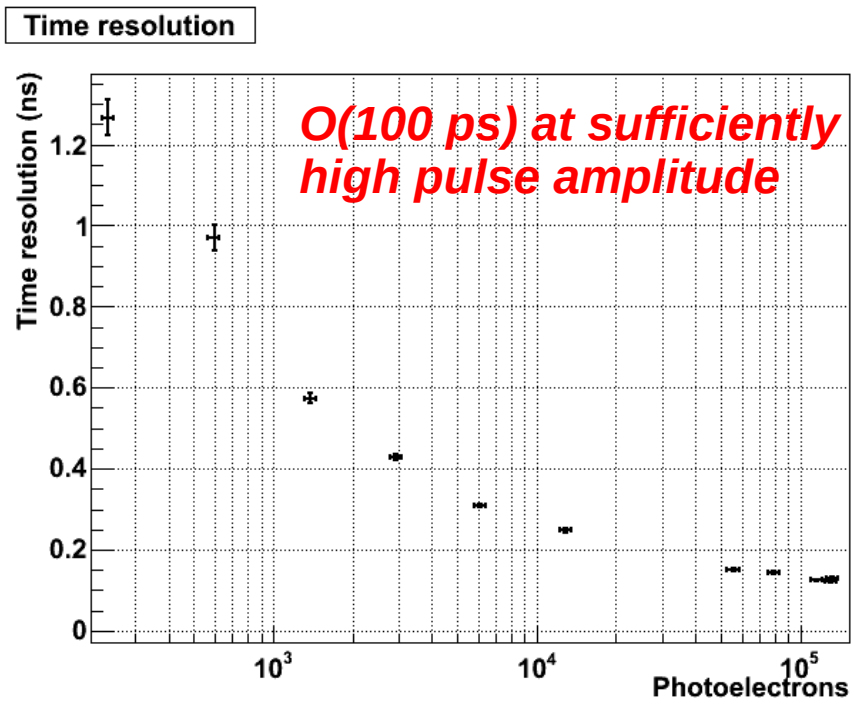


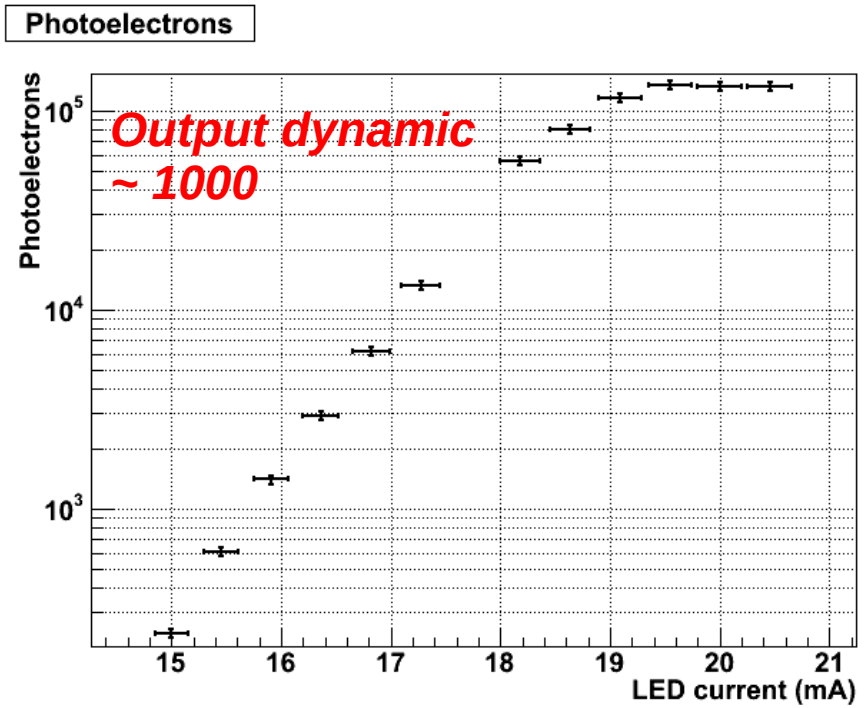


Light monitoring system

Driver Performances

Both the dynamic range and the timing of a prototype of the LED driver were measured using a fast PMT (XP2262B).





Current resolution:
0 – 50 mA, 12 bits ⟶ 0.012 mA

Light monitoring system

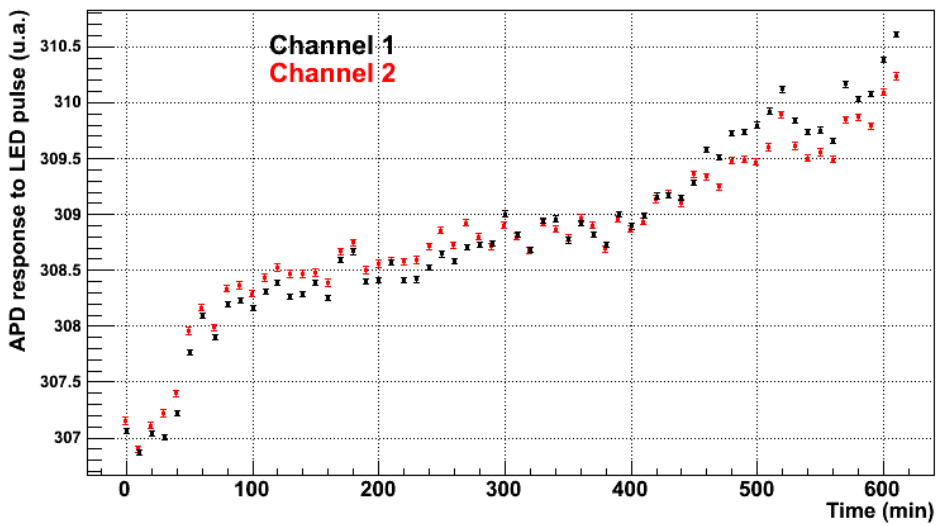
System stability

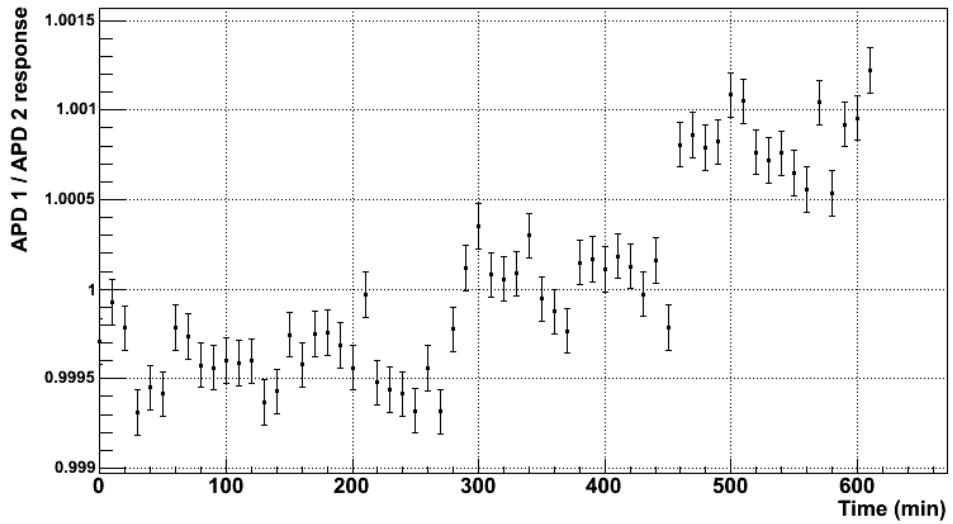
Time stability of the light monitoring system is a mandatory requirement.

We measured the stability of a 16-channel prototype of the FT-Cal light monitoring system, during a **100h** time period.

- Single channel response variation ~ 2.2 %
- Variation in the ratio between two different channels response ~ 0.1 %

10 hours strip-charts

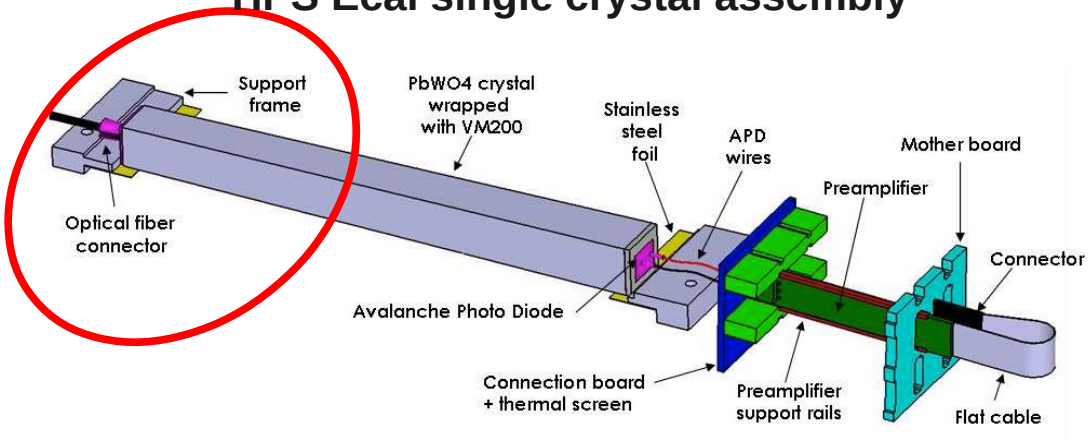




Light monitoring system

Option 1: couple LEDs to crystals with optical fibers (CLAS-IC solution)

HPS Ecal single crystal assembly

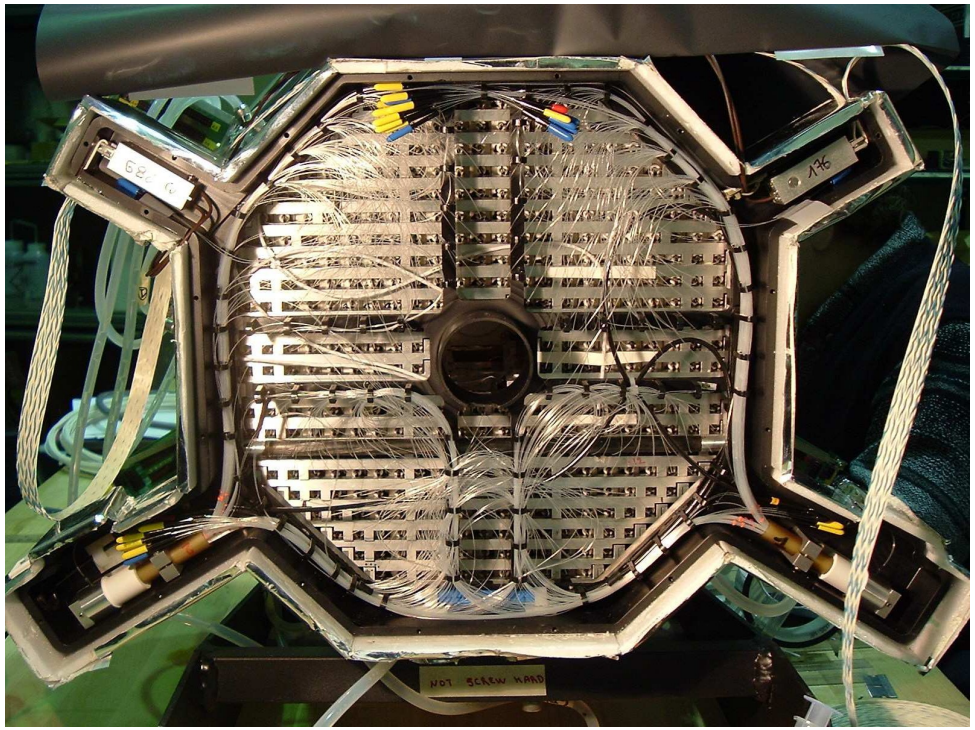


PRO:

- Crystals already have optical fiber connector.
- No necessity to separate LEDs from the drivers on different PCBs.

CON:

- Need to select optical fibers and study their response.
- Need to route the 442 optical fibers out of the Ecal enclosure.
- Need to study the coupling between LEDs and optical fibers.



Light monitoring system

Option 2: couple LEDs directly to crystals (FT-Cal solution).

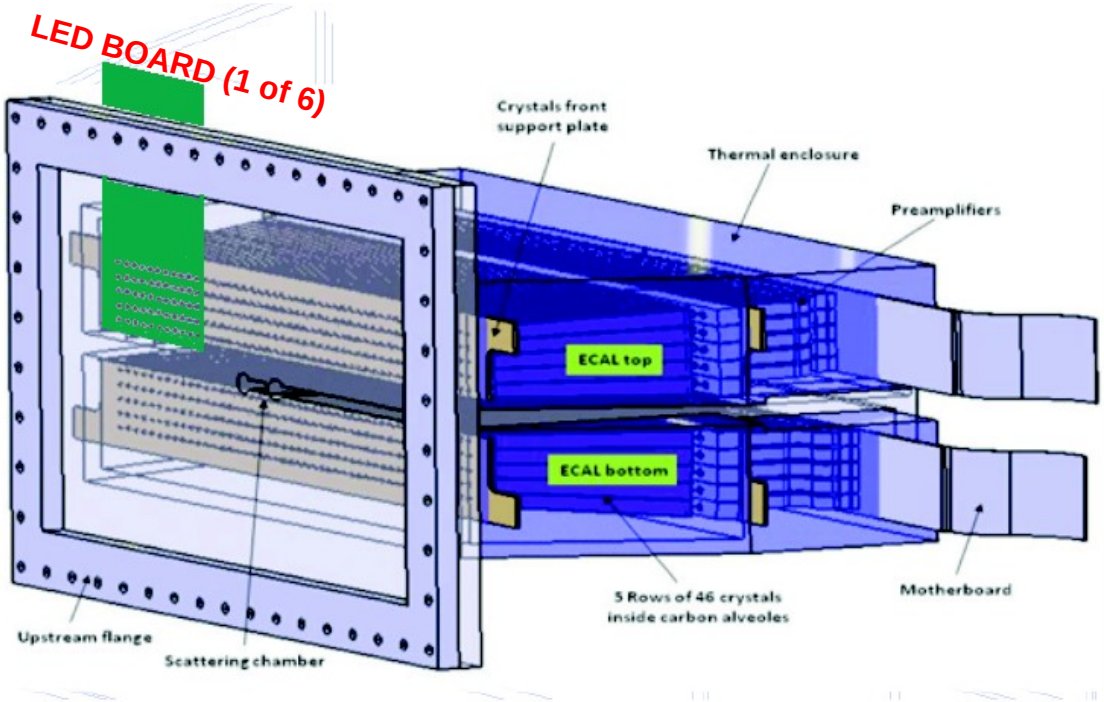
New PCB boards hosting LEDs needed in front of the Ecal, with connectors out of the vacuum-tight box.
3+3 boards, hosting ~ 70 LEDs each, can furnish the full Ecal.

PRO:

- Tested solution, already validated with a 16-channels prototype.
- Only a re-arrangement of the PCB components is required for design.

CON:

- Need to re-design single-crystal assembly, changing the upstream PEEK support.
- Need to modify Ecal enclosure to accommodate new PCBs
  (The enclosure has to be modified anyhow for the new motherboards).



Optical sensors upgrade

- 5X5 mm^2 APDs are currently used in the HPS Ecal.

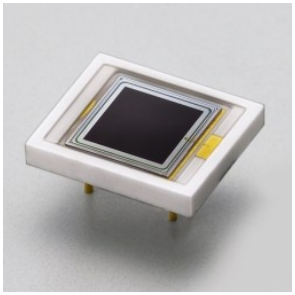
- Current APDs could be substituted with “large-area” APDs, 10x10 mm^2: sensitive area is 4 times bigger. This corresponds to four times collected light, for the same deposited energy, thus to 4 times better S/N ratio.

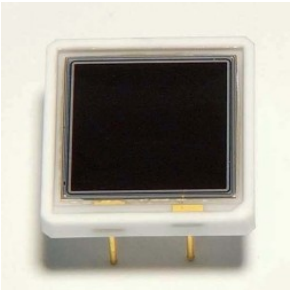
- New APDs can be ordered with more uniform gain. This corresponds to a better uniformity in the Ecal response, and in trigger thresholds.

- Active area and intrinsic capacitance are the two main differences between two sensors. Other properties (Q.E., sensitivity, ..) are the same.

	S8664-55	S8664-1010
Active area	25 mm^2	100 mm^2
Intrinsic capacitance	80pF	270pF

Different detector capacitance:
need to modify the amplifiers adapting their input impedance (IPN Orsay).



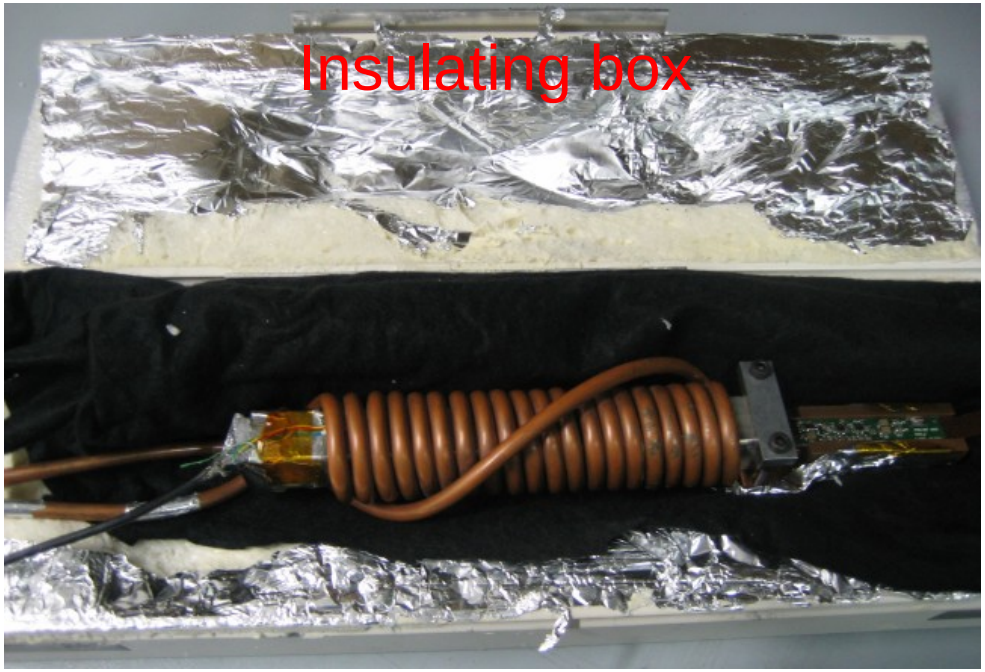


Optical sensors upgrade

Comparison between small APD / large area APD

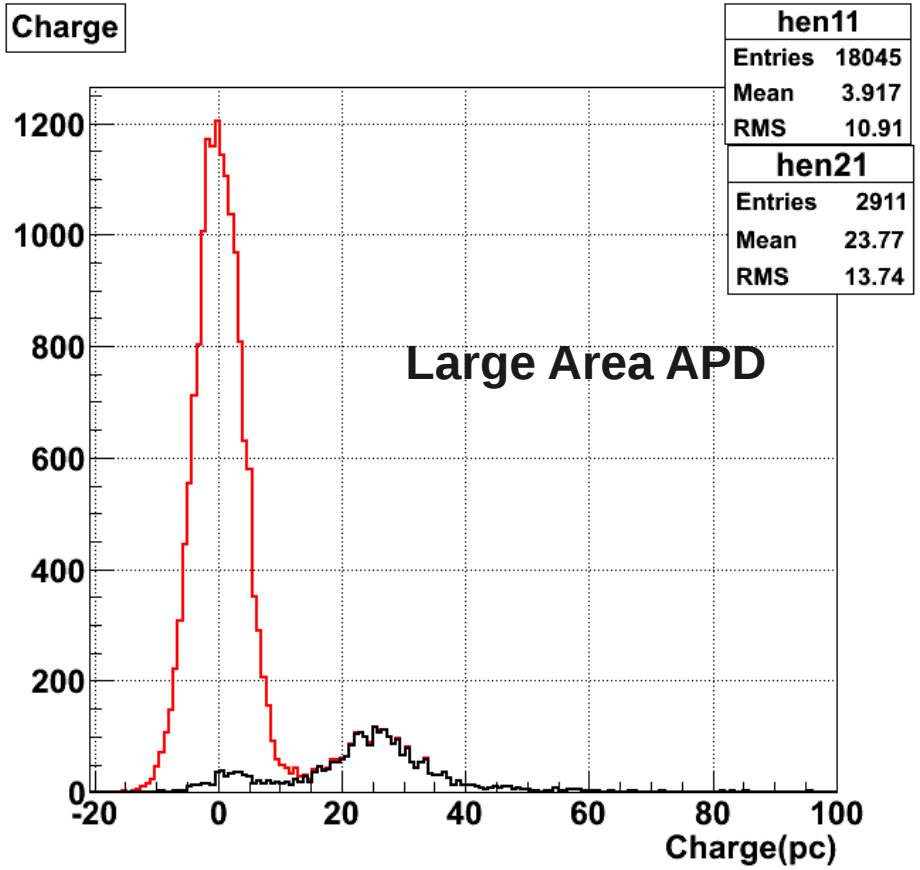
We performed a test with cosmic rays to compare the response of small area (5x5 mm^2) and large area APD (10x10 mm^2)

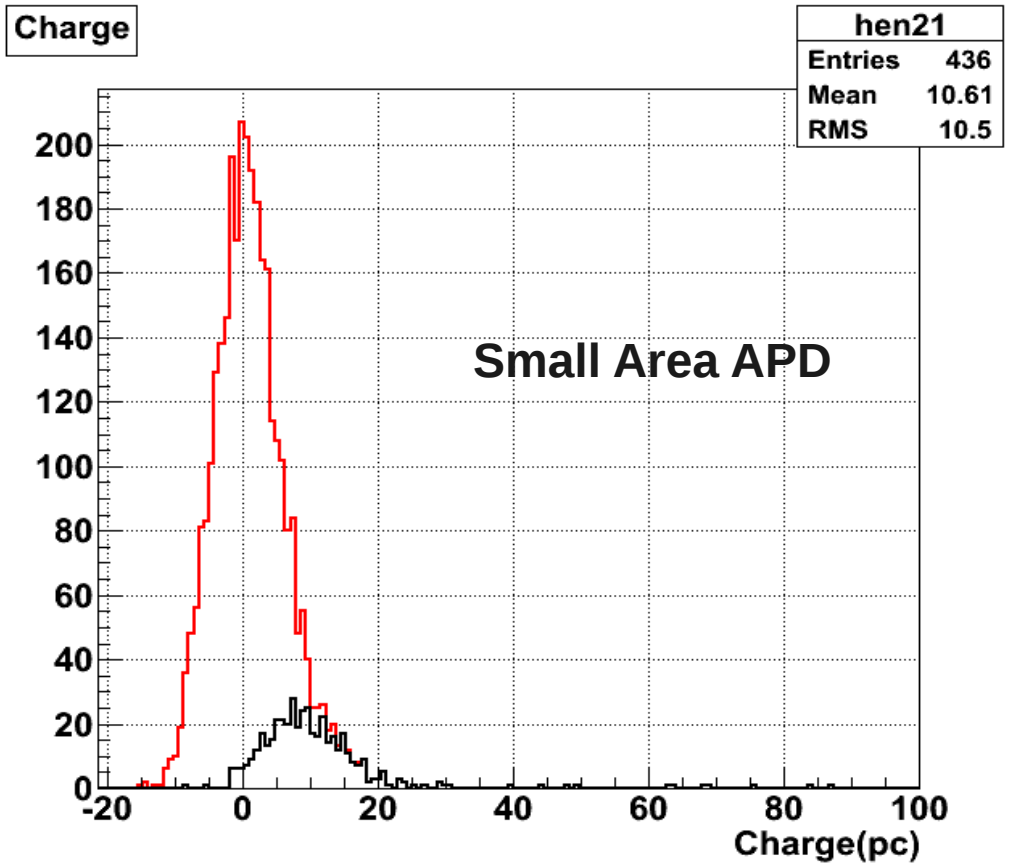
- APD has been attached to a $PbWO_4$ crystal wrapped with a VM2000 reflecting foil.
- The assembly was put in a insulated box, with thermal stability within 0.1 C.
- The box was put in the middle of a scintillator telescope, horizontally.
- Cosmic rays passed trough the crystal perpendicular to its axis.



Optical sensors upgrade

- Red: charge distribution for all triggers.
- Black: charge distribution requiring a 100 ns coincidence window with the telescope signal.





- With large area APD, **cosmic ray signal can is separated from the noise**: online Ecal calibration.
- The amplifier gain can be reduced, with better noise performances.

Optical sensors upgrade

APD intrinsic gain depends on the bias voltage and working temperature. Sensors must be characterized before use to fix the working point.

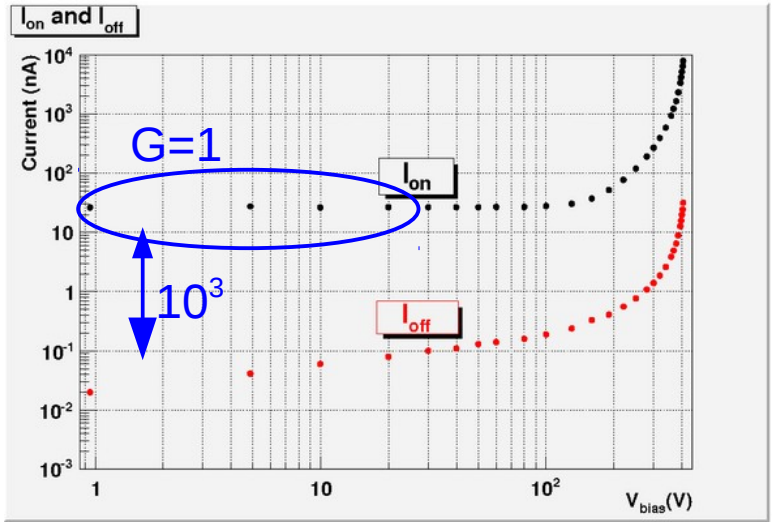
The measure is realized in DC mode, using a LED.
APD works as a constant current source.

1) Measure the current that flows trough APD with LED on, varying the bias voltage in the range 0<V<400 V

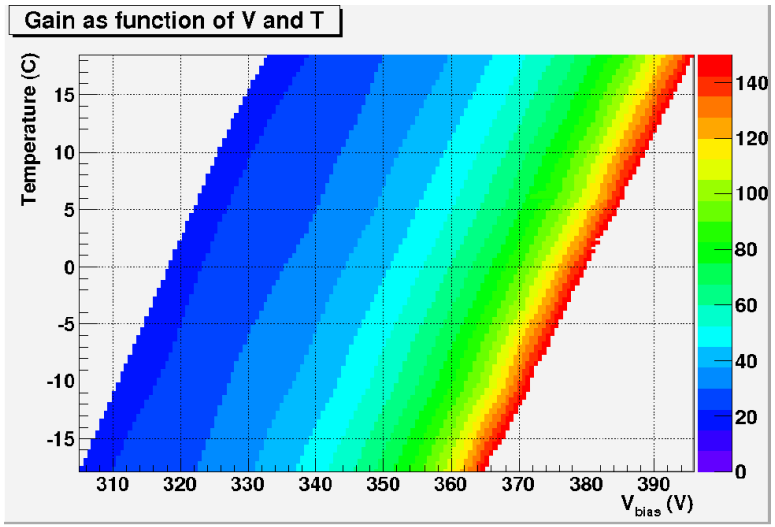
2) The same measure is repeated with LED off

3) Gain is calculated as

$$G(V)=\frac{I_{ON}(V)-I_{OFF}(V)}{I_{ON}(G=1)-I_{OFF}(G=1)}$$



We developed an automatic system to characterize up to 24 APDs at once, in one day.
The ~ 460 Ecal APDs can be characterized with this system in ~ 30 working days (33% contingency)

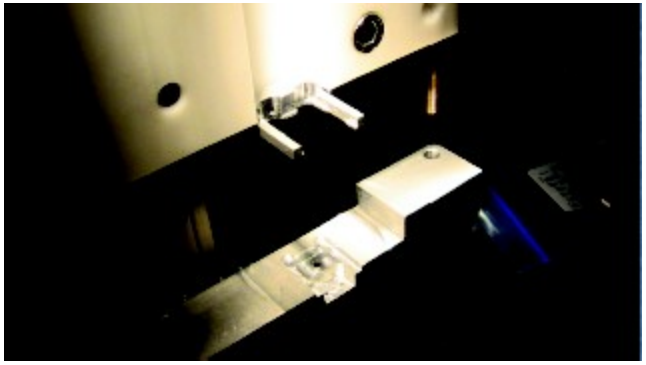


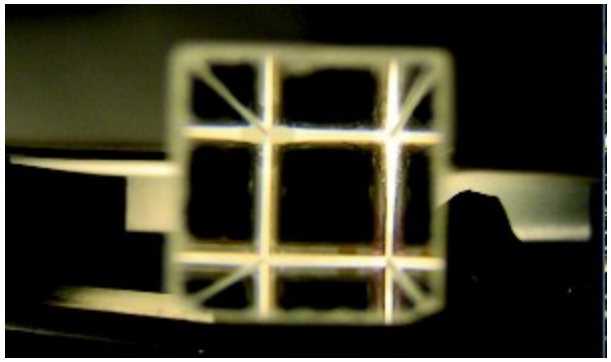
Optical sensors upgrade

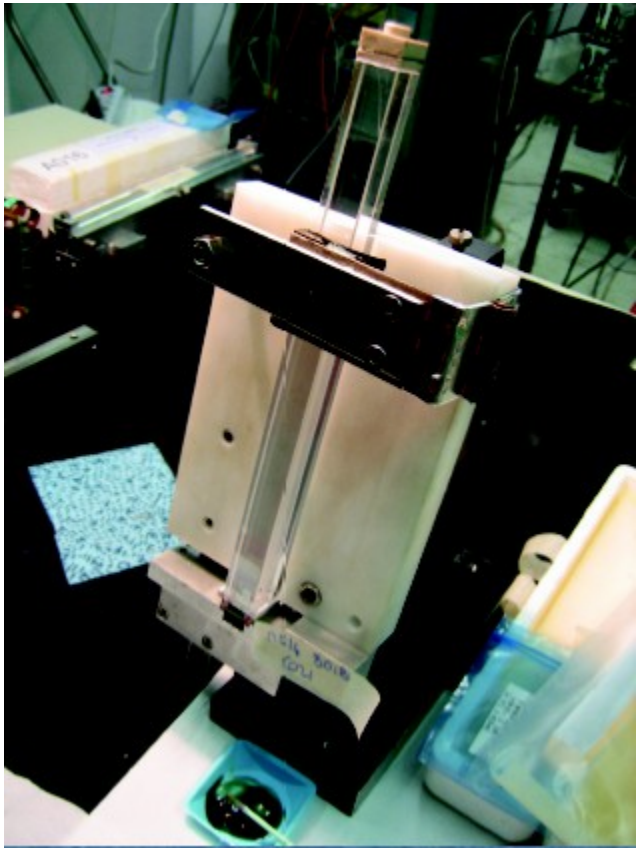
If adequate founding are available, we propose to replace Ecal APDs with large area models.

- Move crystals to Italy.
- De-wrap VM2000 foil and detach old APDs.
- Glue new APDs (previously characterized in gain).
- Re-wrap VM2000 foil.
- Re-send crystals to JLab.

All the necessary tools have already been developed, after the FT-Cal experience.







Conclusions

INFN proposes to take an active role in the design and construction of the HPS detector for the production run.

We can share the experience we maturated with the realization of the FT-Cal detector for CLAS12.

Two main tasks:

- Design and construct the new ``Motherboards'' for signal, LV, and HV distribution.
- Design the light monitoring system.

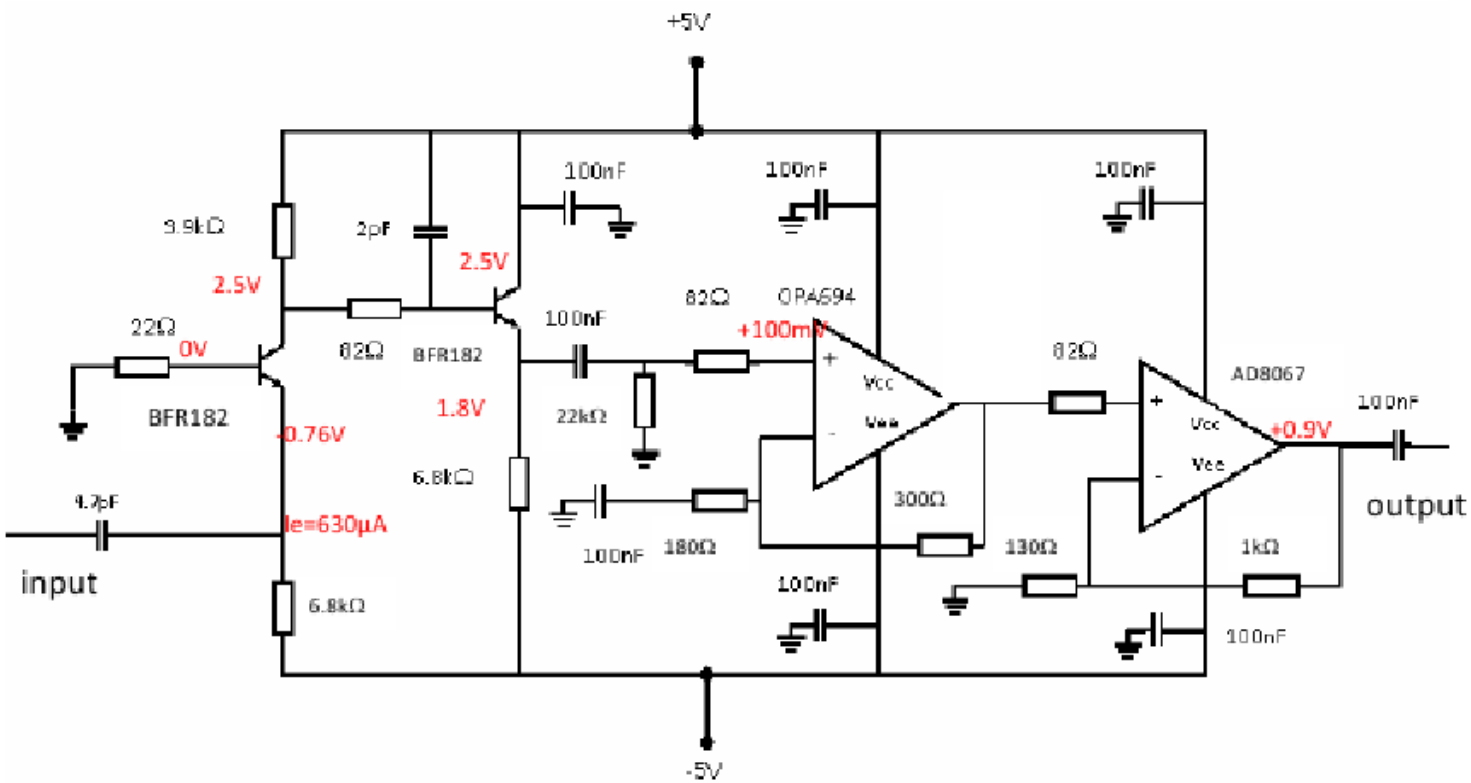
A third possible upgrade, the APD replacement, is subject to the availability of the required founds.

Amplifier

- Designed in collaboration with IN2P3 Orsay, starting from the existing CLAS-IC amplifier board.
- Matched to APD Hamamatsu S8664-1010 large area (different input capacitance wrt CLAS-IC APDs)
- Nominal charge gain: ~ 1800. Output noise ~ 6 mV RMS.
- Output range: 0 – 5 V (linearity guaranteed up to 4.5 V) on 50 Ohm load.

Layout: 3-stages amplifier.

- First stage: NPN transistor common base configuration + voltage follower
- Second stage: OPA694 current feedback op-amp, non-inverting configuration
- Third stage: AD8067 rail-to-rail true voltage feedback op-amp, non inverting configuration



$$G = G_1 \cdot G_2 \cdot G_3$$

$$G_1 = \frac{3.9k\Omega}{50\Omega} \simeq 80$$

$$G_2 \simeq 2.67$$

$$G_3 \simeq 8.7$$