The L3 Electromagnetic calorimeter

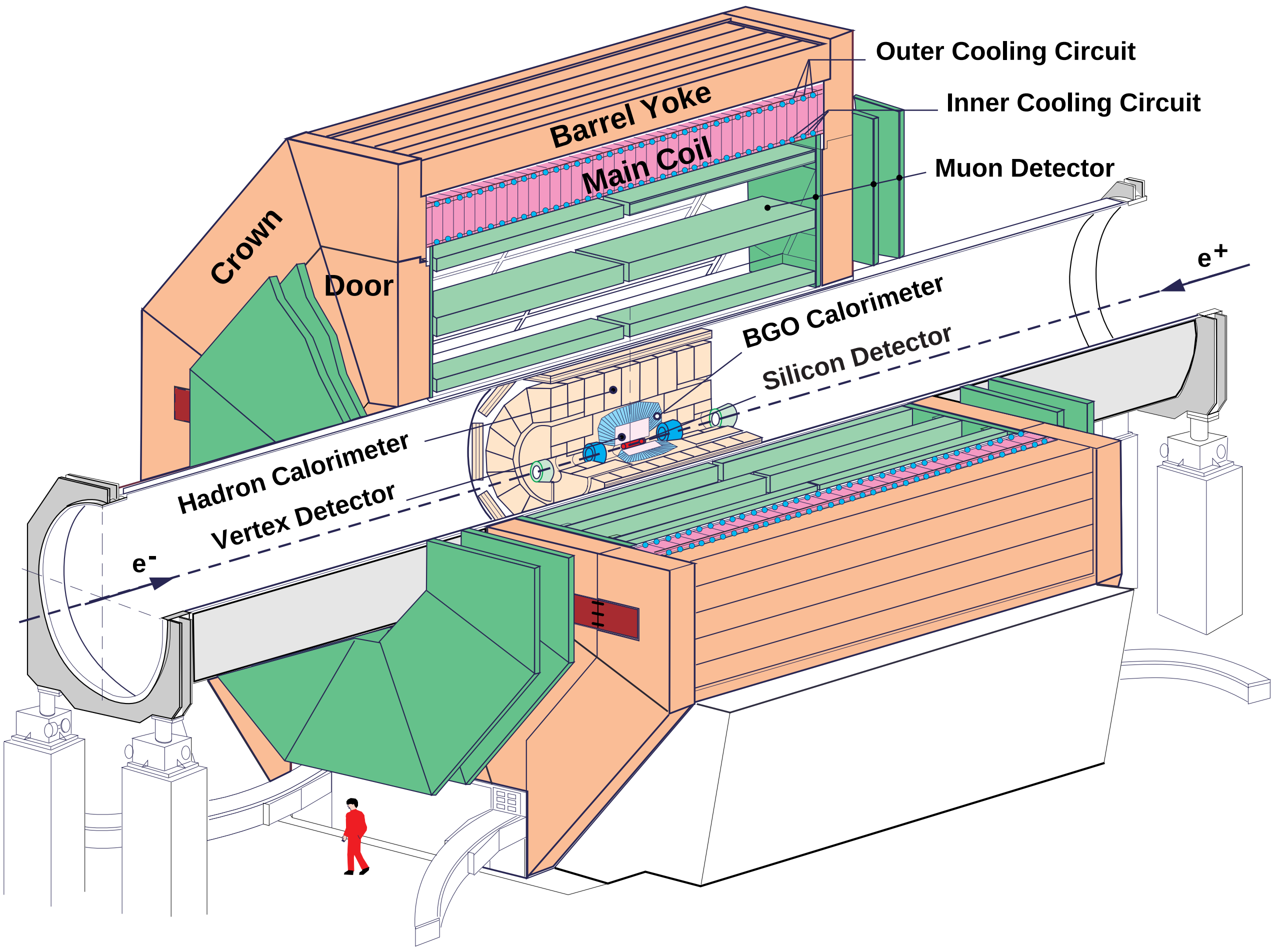
Jean Fay

Institut de Physique Nucléaire de Lyon
IN2P3/CNRS and Université Claude Bernard

The L3 electromagnetic Calorimeter

- Introduction.
- Mechatronics.
- Xenon monitor
- Thermal regulation.
- Calibration.
  - Precalibration with an electron beam
  - The RFQ system
- (few) Physics results.
- Conclusion

The L3 detector



The L3 detector is optimized for measuring with high precision electrons, photons and muons

- Large magnetic volume housing the whole detector
- <u>Electromagnetic calorimeter: BGO Crystals</u>

The BGO ($Bi_4Ge_3O_{12}$) crystals

Characteristics	BGO	NaI	CeF_3	$PbWO_4$
Density (g/cm^3)	7.13	3.67	6.16	8.28
Radiation length (cm)	1.12	2.59	1.68	0.89
Moliere radius (cm)	2.3	4.8	2.6	2.2
Wave Length (nm)	480	410	320	440
T. dependence ($\%/°C$)	-1.55	0.22	0.14	-2
Relative light output	0.18	1.	0.08	0.013

All crystals were grown, cut to size, and polished on all six faces at the Shangai Institute of Ceramics in China.

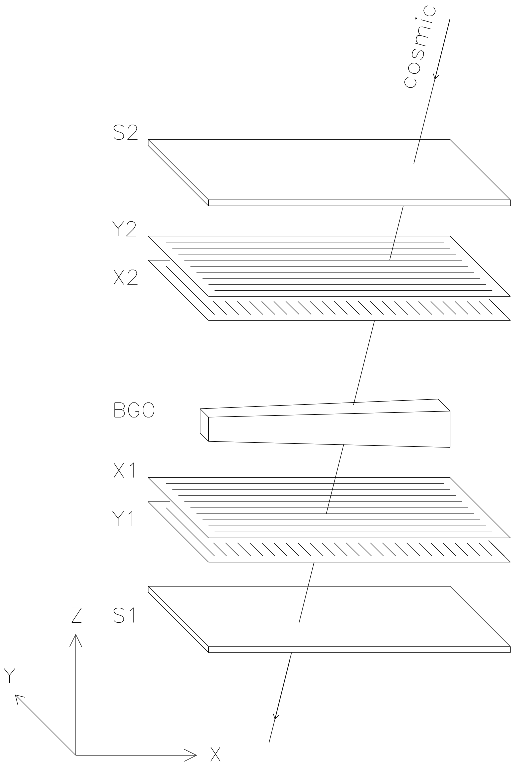
At CERN, systematic tests were performed on all crystals: they had to satisfy the following tolerances before to be accepted:

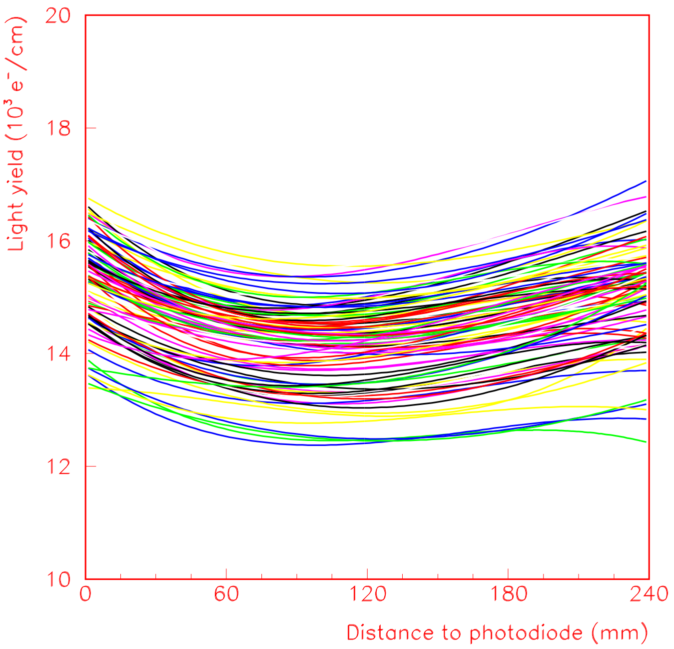
- Optical transmission: 55% at 400nm, 65% at 630nm
- Dimensions: 300μm in transverse, 400μm in length, 50μm in planarity of all faces

They were coated with a 30 to 80 μm thick layer of NE560 paint to obtain a nearly flat light collection together with a good light yield

The BGO

All the crystals were measured on a cosmic ray bench

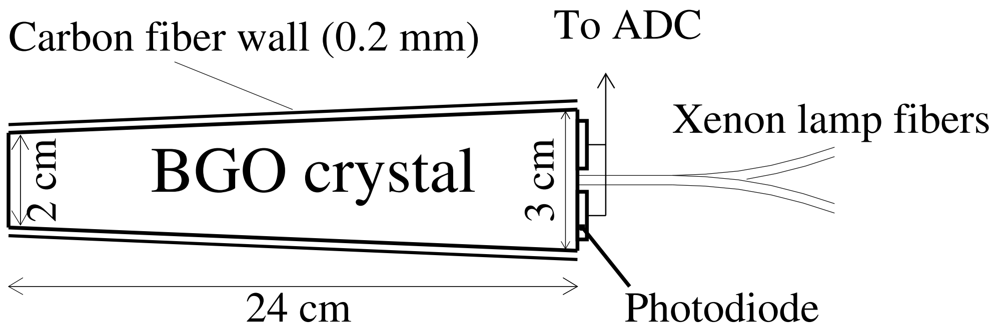




Light output variations along the length must be less than 10%.

The calibration constants obtained in the cosmic bench (E≈25 MeV) were used as entry point in the beam calibration procedure.

The BGO



The crystals are

24 cm long,

2×2 cm (front),

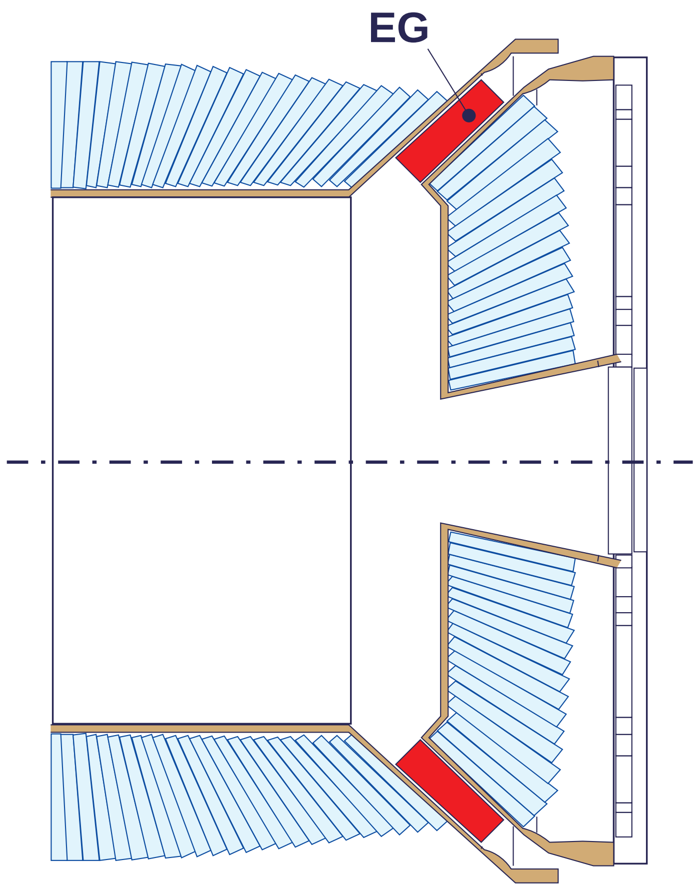
3×3 cm (rear).

Each crystal is equipped with:

- Two silicon Hamamatsu S-2662 photodiodes (s=1.5cm^2 each) and Q=60%.
  Epoxy glue is used to fix them on the crystal
- One low noise pre-amplifier
- Two optical fibers used for Xenon calibration

Mechanical structure

The calorimeter is made of two half barrels and two end caps



Half barrel: 3840 crystals, 24 crystals in θ and 160 in ϕ, .

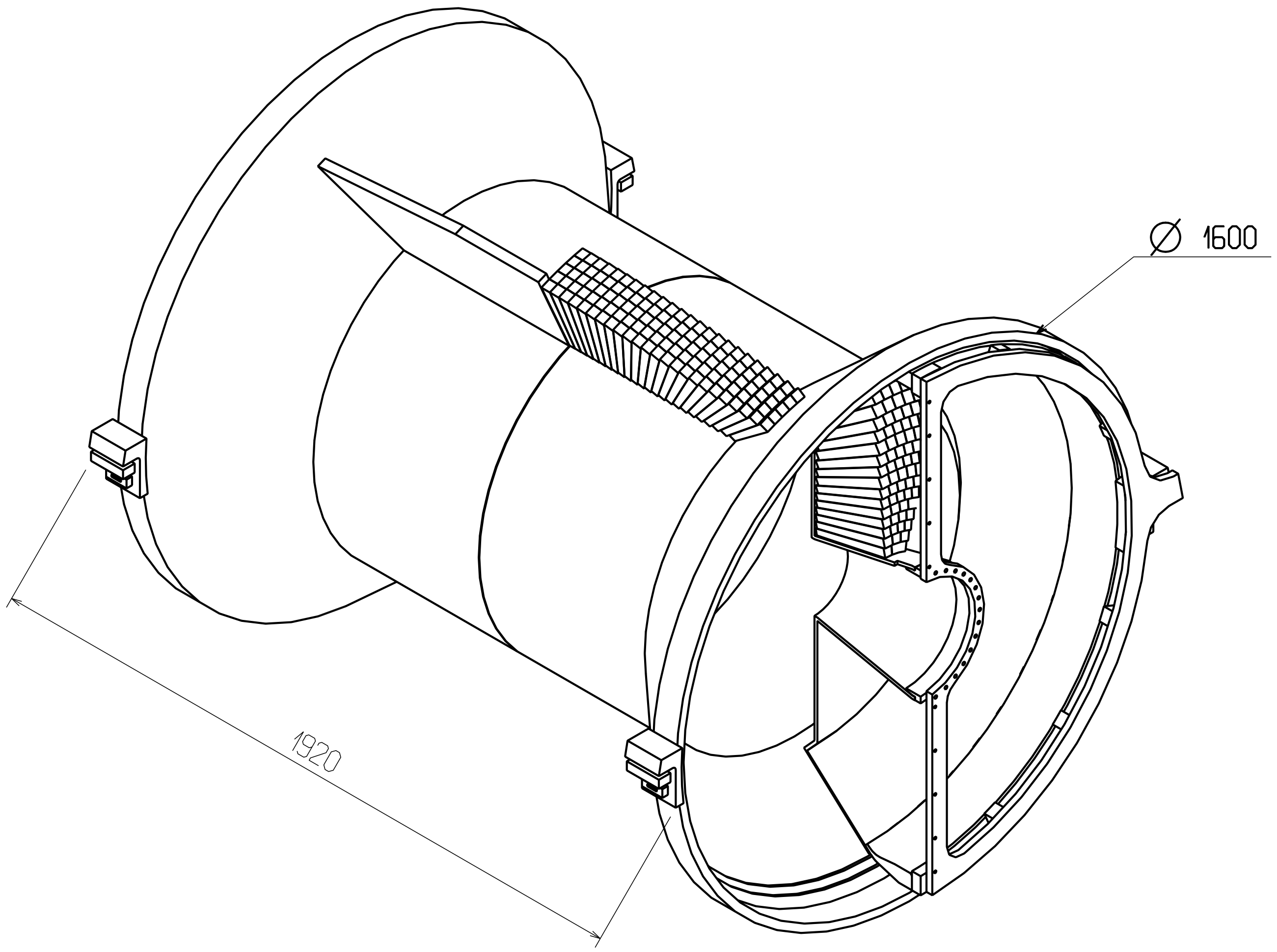
End Cap: 1527 crystals, 17 θ rings.

Acceptance :	Barrel	$42^\circ < \theta < 138^\circ$
	End Cap	$10^\circ < \theta < 36.8^\circ$

Projective geometry in θ but crystals are tilted by 10 mrad in ϕ to avoid cracks.

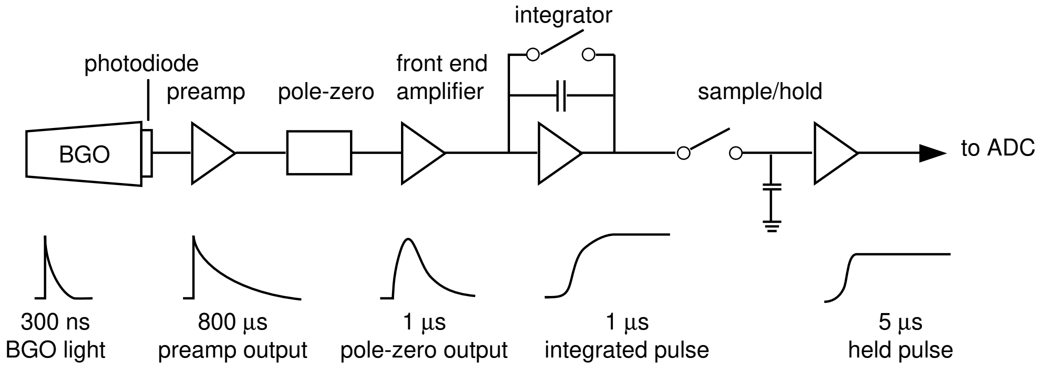
The crystals are mounted in the cells of a honeycomb structure:

- Epoxy resin carbon fiber composite material.
- No stress to other crystals, the weight is transmitted only to the structure.
- 1cm of carbon fiber in front of crystals (0.04 X_0), 250μm between.



Electronics

- Aim to measure signals from a few MeV to 100 GeV
- Operate in a 0.5 T magnetic field



* Low noise charge sensitive preamplifier directly behind the crystal

* Wide dynamic range ADC, 3m away

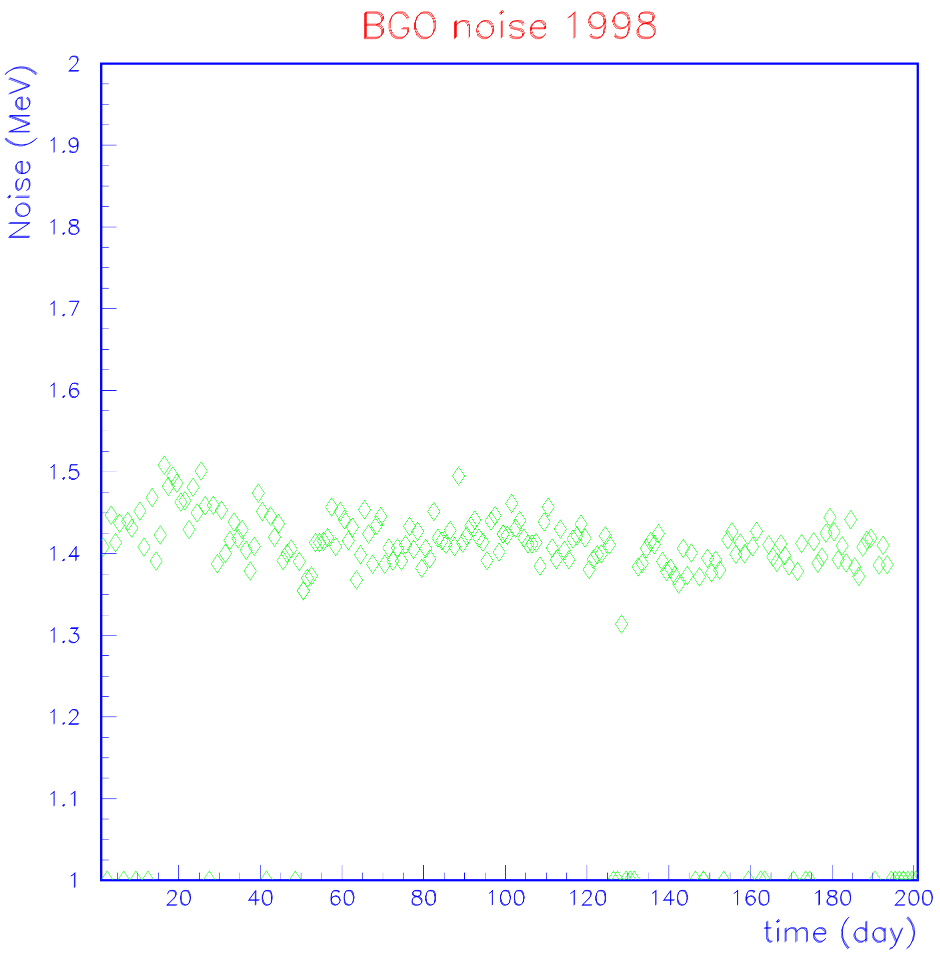
* One microcomputer (Motorola 68010) for each channel

After pole zero the signal is splitted into 3 parts :

- Low energy channel, for signals up to 4 GeV
- High energy channel
- Analog sum for the trigger

A challenge: keep noise level below 2 MeV, day after day, for 10 years

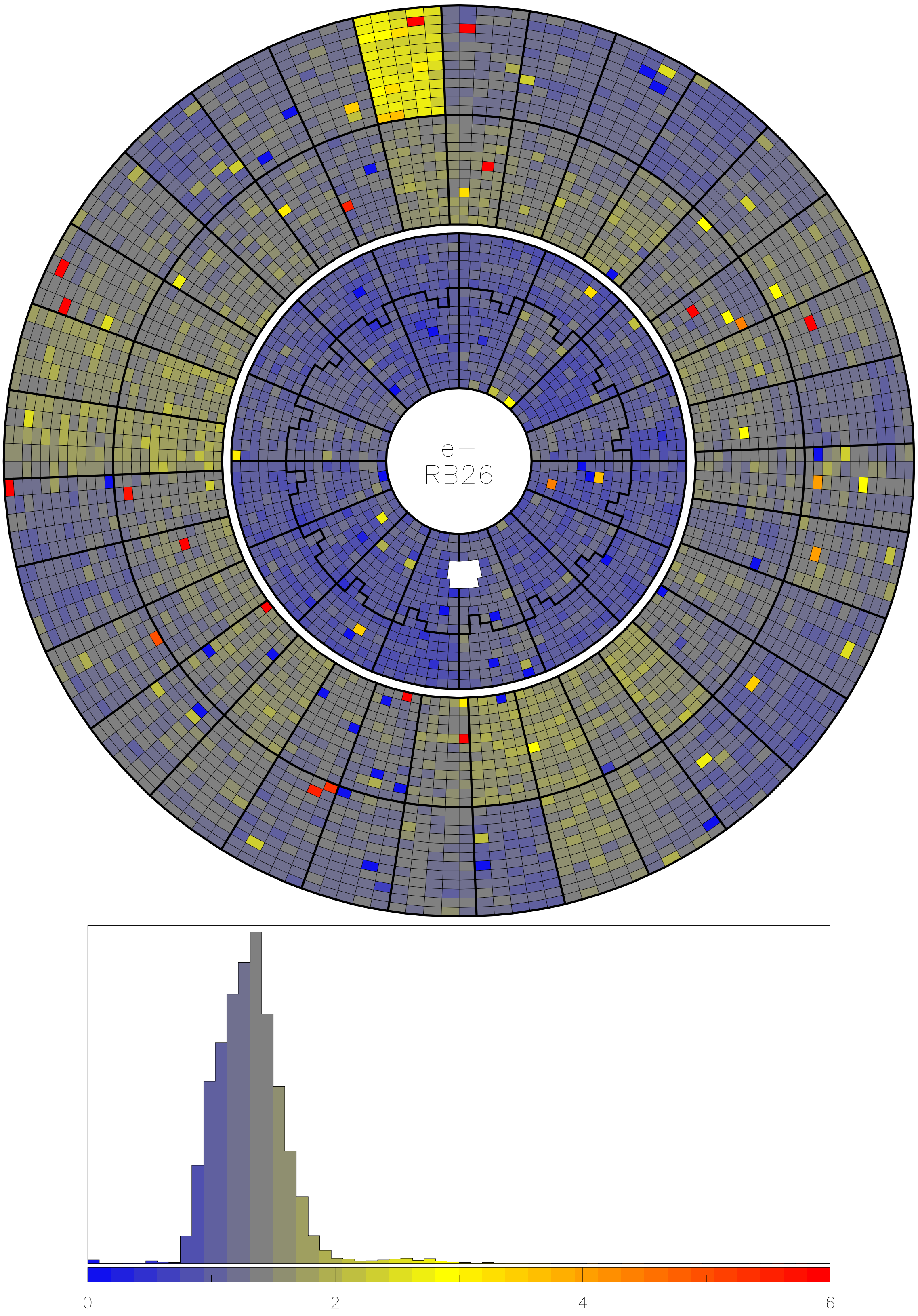
fully achieved after lot of work.



Improved grounding of the analog electronics

Off-line correlated noise suppression

electronic noise on '98 Nov. 6^{th}



Dead channels

Photodiodes and preamplifiers are unreachable

dead channels are for ever.

Present status:		
	barrel	81 / 7680
	End Caps	58 / 3054

Less than 1.4%, sparse dead channels, no dead region

Stable situation from one year to the other

Power supply problems lead to dead ring

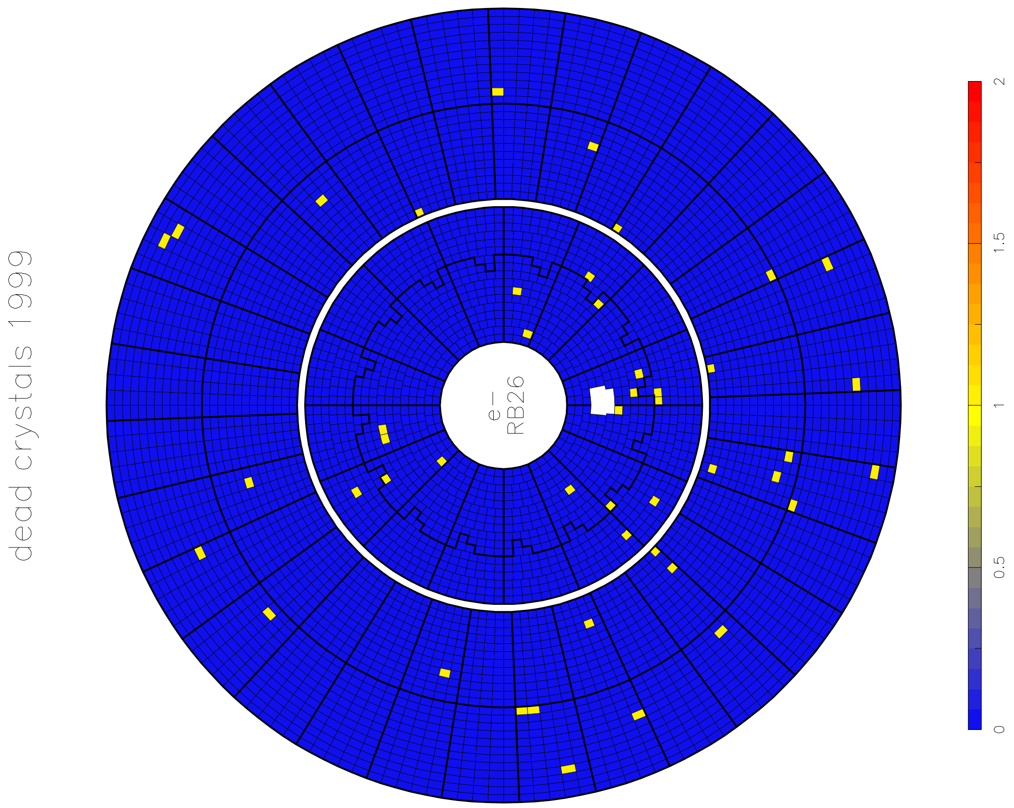
60 to 240 dead channels at once.

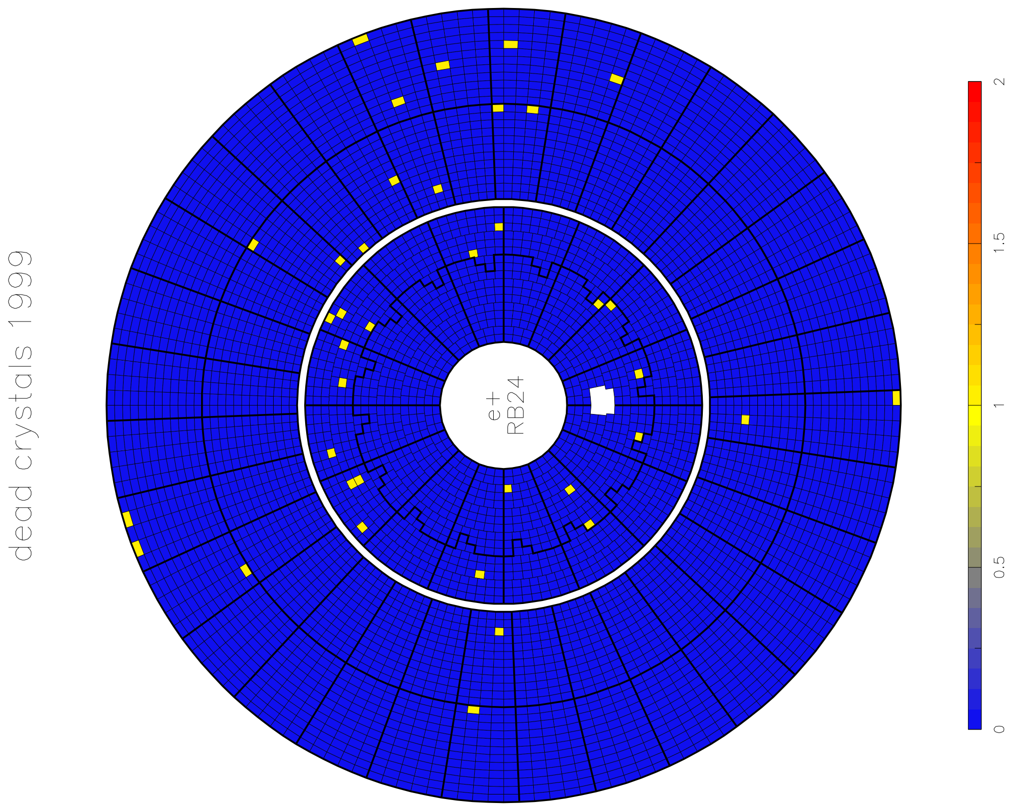
Need a controlled access to repair them

In 1998, more than 99% of the time, more than 99% of the rings were up

In 1999,up to now, 100% of the rings are up

Electronics





Thermal regulation

Light decreases by 1.55 % per °C

The crystal temperature must be maintained constant within a few tenth of a degree

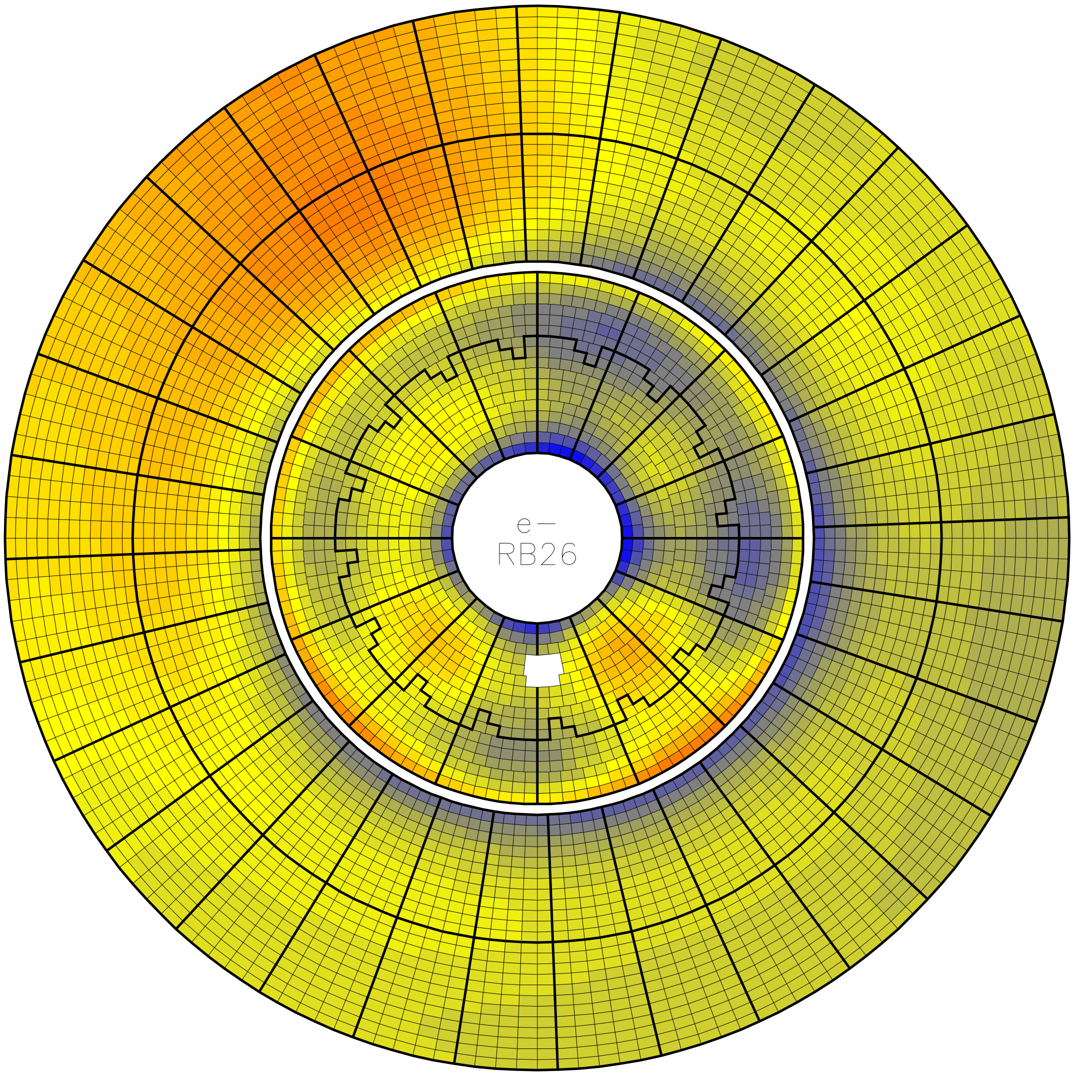
Each preamplificator dissipates 0.2 W, in contact of cooling fluid (Dow Corning 200/5 CS) circuits

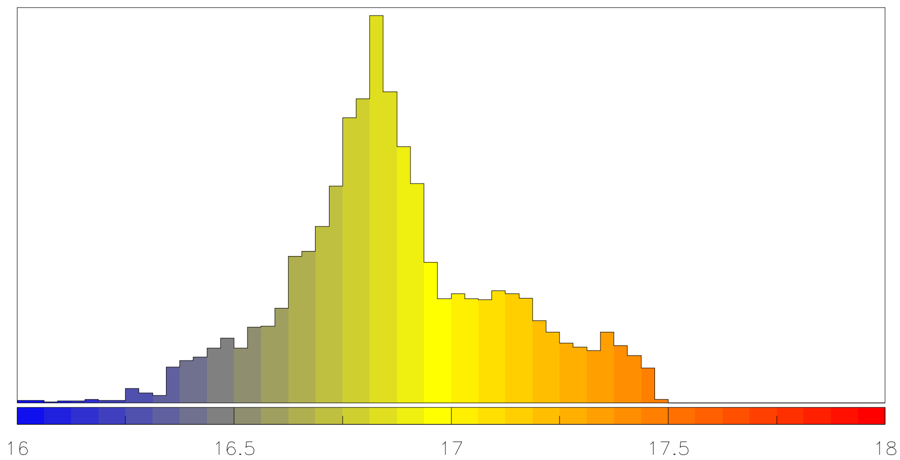
Thermal screens surround the BGO

The temperature is measured by two AD590 sensors glued on the front face and on the rear face of every 12^{th} crystal (2×320 for the barrel and 2×128 for the end caps) .

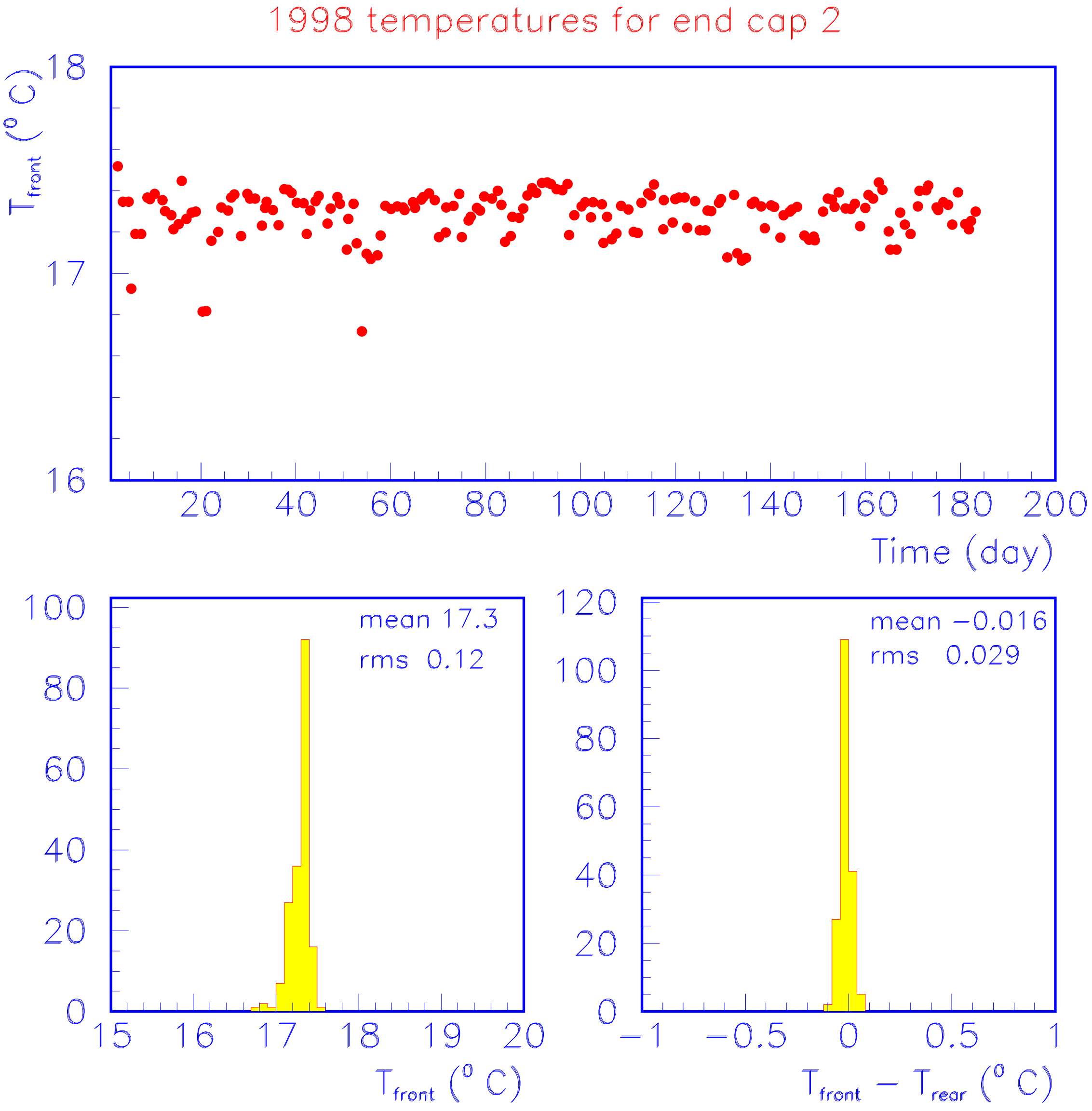
Temperature control

front temperature on ’99 Jun. 7^{th}





Thermal regulation



Temperature correction per crystal

$$\epsilon = 1 + 0.0155(T_c - 18^\circ)$$

with

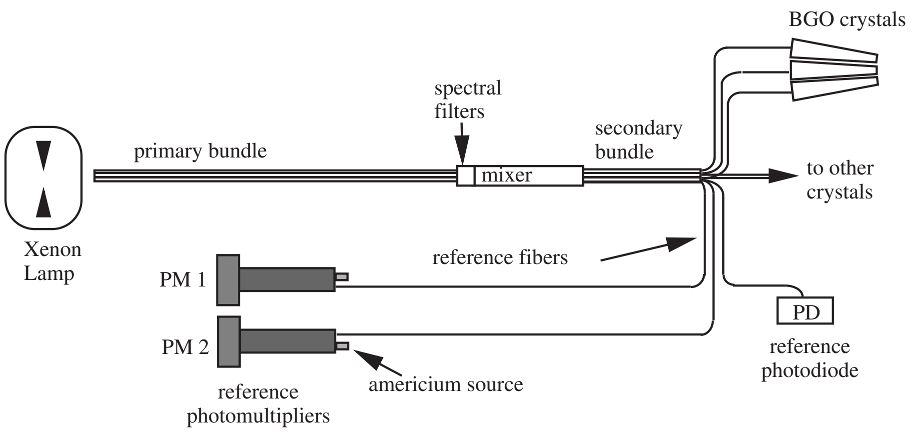
$$T_c = T_f + \eta(E)(T_r - T_f)$$

Temperature is measured with a precision of 0.2°C .

The Xenon monitor

System based on light pulses emitted by Xenon lamps.

Light collection efficiency and electronic's gain are controlled.



- Hamamatsu L2453 Xenon lamp.
- 2 PM's and a reference photodiode.

Two fibers per crystal on barrel:

- Low intensity ($\approx$ 1GeV)
- High intensity ($\approx$ 30GeV)

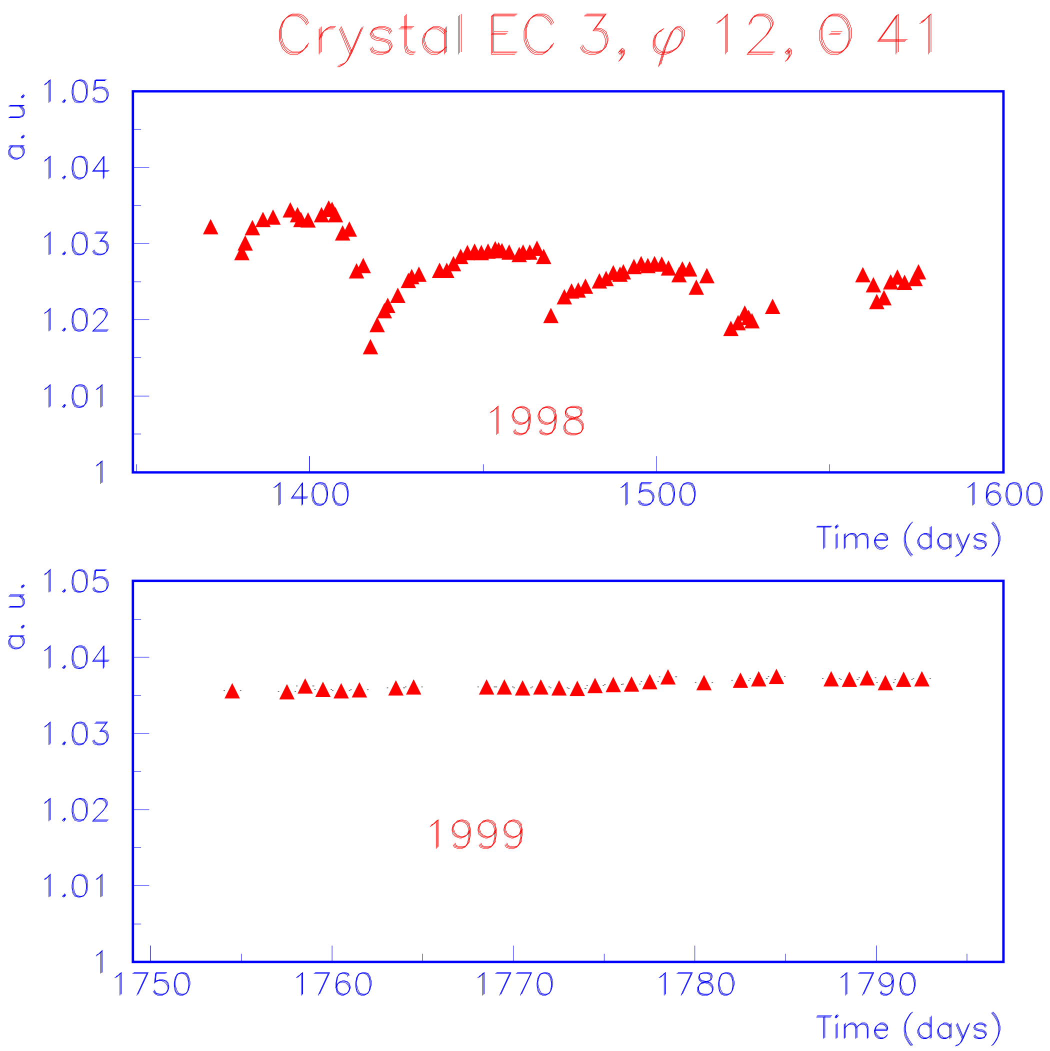
One fiber per crystal on end caps

Xenon monitor

Light output varies in time. The Xenon system is necessary to follow variations and correct for losses.

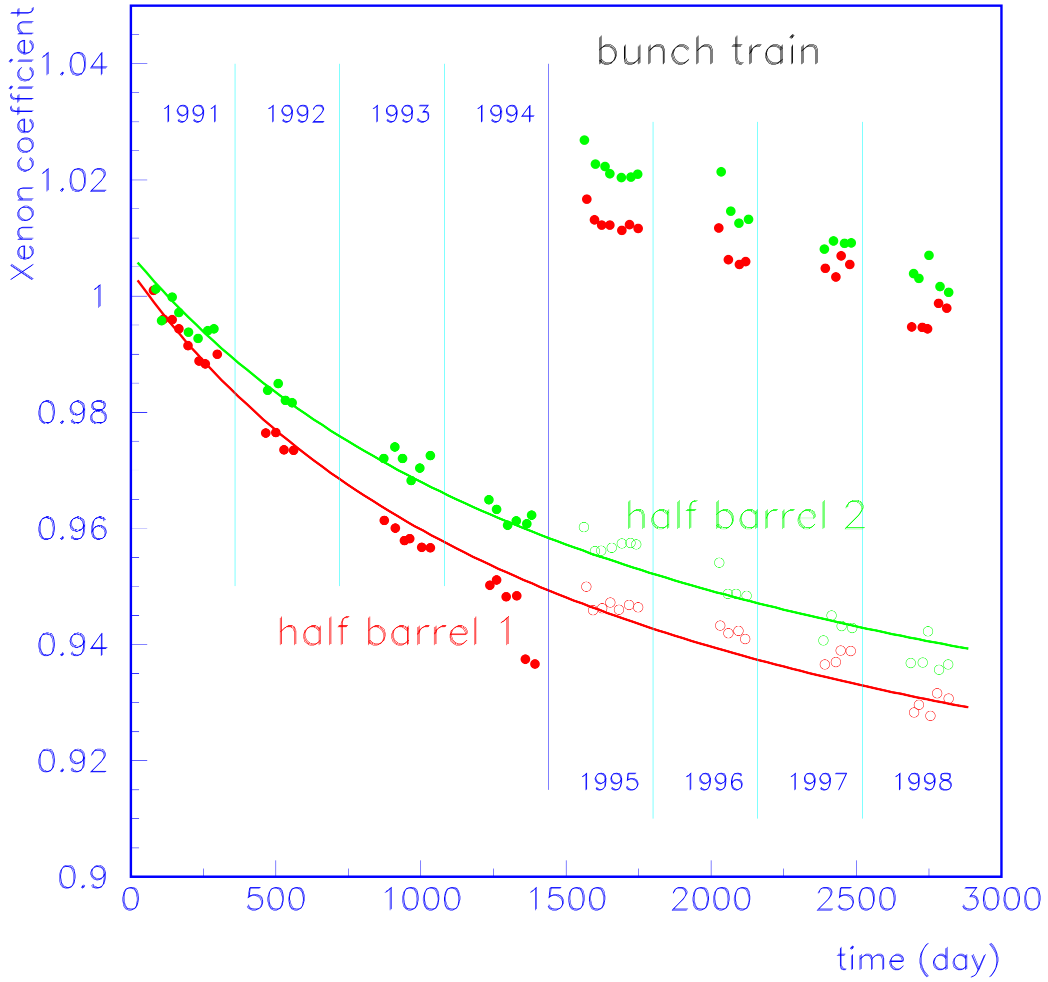
An example of radiation damage accidents.

Crystal recovers almost initial light after about 20 days.



Xenon monitor

Pulse height as a function of time



$$\boxed{\mathrm{F(t)} = \frac{a}{t+t_0} + c_\infty}$$

with

region	c_∞	region	c_∞
HB1	0.886 ± 0.010	HB2	0.896 ± 0.011
EC1	0.907 ± 0.011	EC2	0.879 ± 0.013

The Xenon system is robust and reliable. It allows to record, on a daily basis, the variations of each crystal

Energy calibration with electron beams

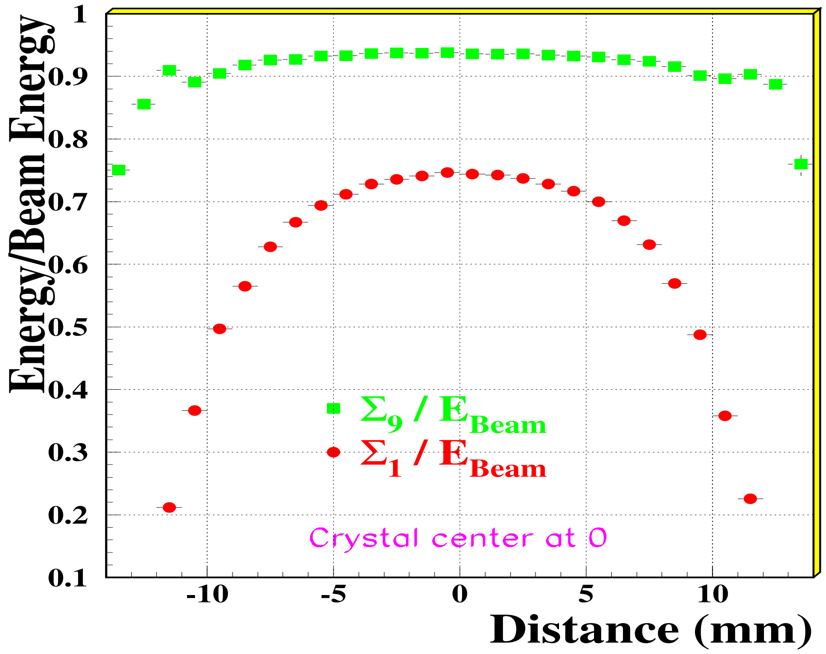
Determination of the individual calibration constants for all crystals:

$$\mathrm{k} = \frac{Energy\ deposited\ in\ a\ crystal}{Signal\ read}$$

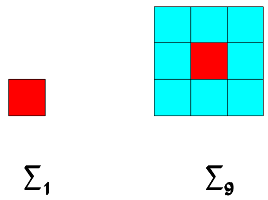
- All barrel crystals and a fraction of the end caps, were calibrated with an electron beam from the SPS.
- About 1500 events were recorded per crystal at 2, 10 and 50 GeV.
- One half barrel was moved to LIL and 200 crystals were calibrated at 180 MeV.

Method

Deposited energy depends on impact point:



Use of the peak value of the sum of 9 crystals Σ_9, for measuring k.

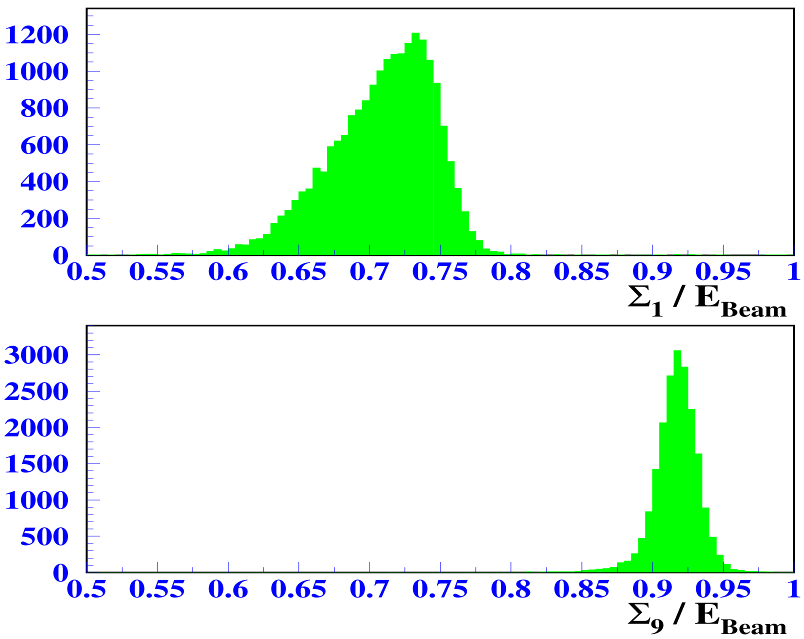


Iterative method

Initial constants came from the cosmic bench.

Precalibration

- use of events only in the central region (-7mm < x,y < 7mm)
- Rear and lateral losses taken into account by Monte Carlo
- Precise beam momentum measurement
- During calibration strict temperature control and regular Xenon runs were required.

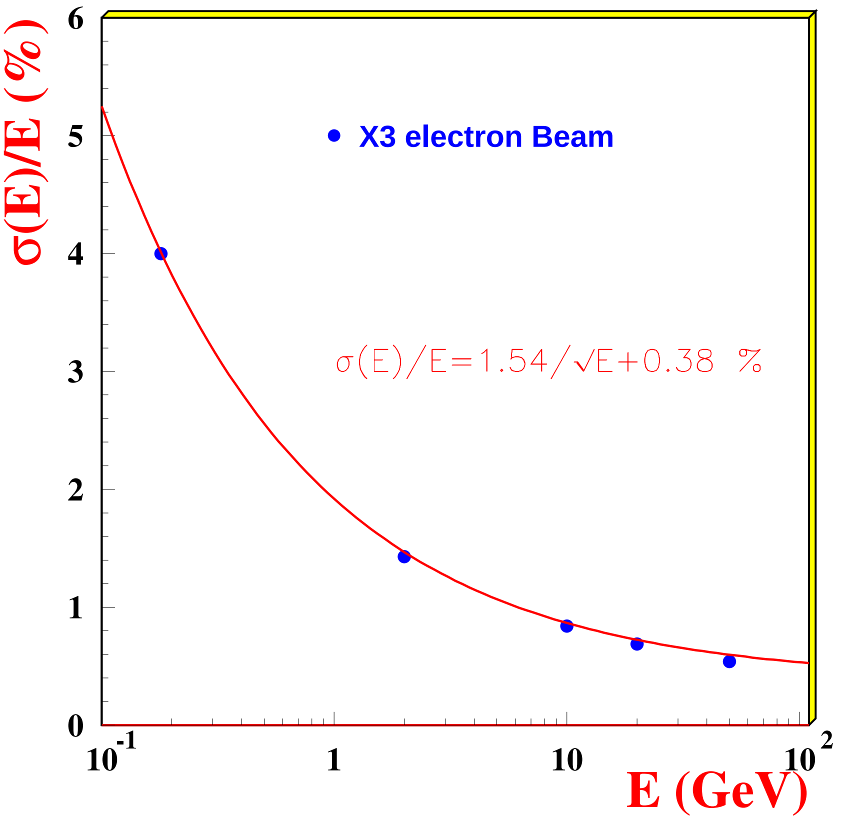


Resolution

Energy distribution is fitted with a gaussian plus an exponential function.

- Local resolution: Width of the energy distribution for a crystal.
  - Energy leakage and electronic noise.
- Global resolution: Variation of the mean energy from crystal to crystal.
  - Accuracy of the calibration method.

Final resolution is the quadratic sum of local and global ones



RFQ calibration

The calorimeter is recalibrated twice a year with a Radio Frequency Quadrupole accelerator:

1.85 MeV H beam sent on a lithium target inside the BGO calorimeter

$$\boxed{\mathrm{p} + {}^{7}_{3}\mathrm{Li} \rightarrow {}^{8}_{4}\mathrm{Be} + \gamma}$$

17.6 MeV photons

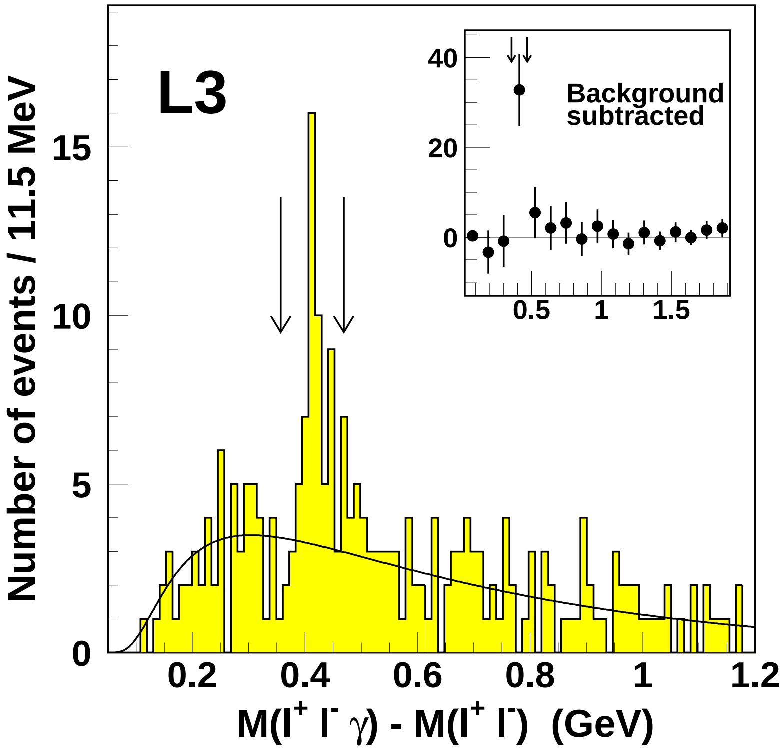
All crystals calibrated at once in a few day run

To achieve the best resolution, electrons from Bhabha events are used

Resolution:		
	Barrel	1.06%
	End Cap	0.86%

cf Marat Gataullin presentation

χ_{c1} production



$e^+e^- \to Z \to \chi_{c1} + X$

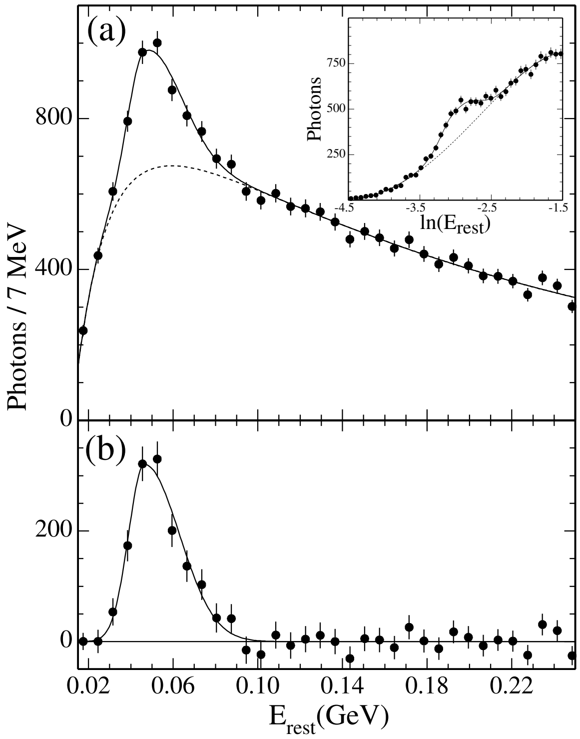
$\chi_{c1} \to J/\psi + \gamma$

$J/\psi \to \ell^+\ell^-$

$\boxed{N(\chi_{c1}) = 32.8 \pm 8.0}$

$\epsilon_{\chi_{c1}} = (8.1 \pm 0.4)\%$

B^* production



$e^+e^- \to Z \to BB^*$

$B^* \to B\gamma$

$\boxed{N(B^*) = 1378 \pm 145}$

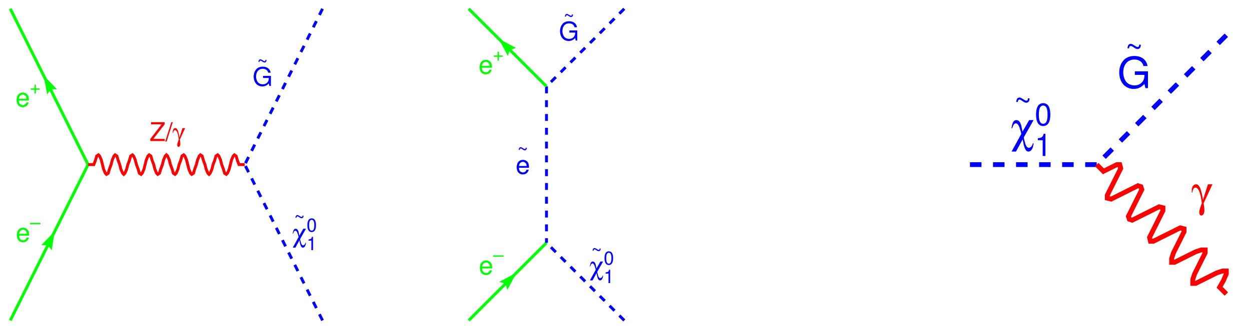
SUSY

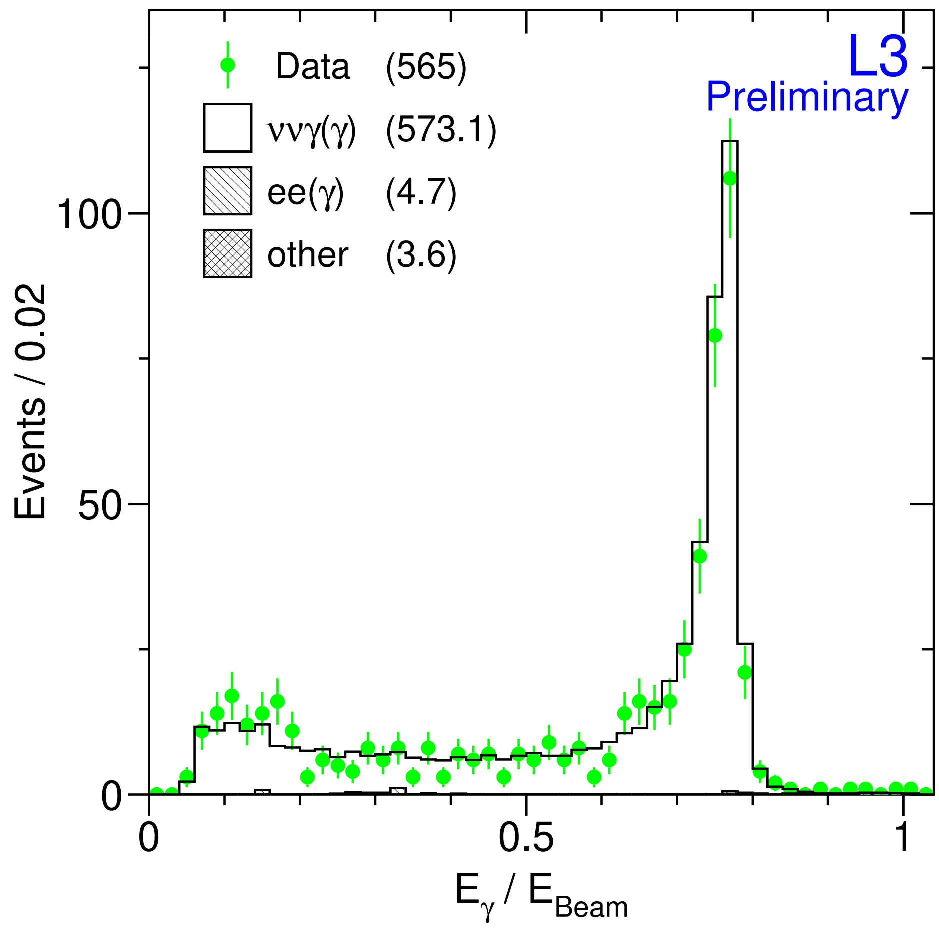
In Gauge Mediated Susy Breaking (GMSB) models:

gravitino $\tilde{G}$ Lightest Susy Particle (LSP)

neutralino $\tilde{\chi}_1^0$ Next to Lightest Susy Particle (NLSP)

one photon final state





Conclusions

- The BGO electromagnetic calorimeter has an excellent energy resolution ($\sim 1\%$ above 10 GeV).
- It is stable over a long period of time
(few dead channels: $\sim 1\%$)
Some improvements have been obtained, due to a deep understanding of the apparatus
(low noise: < 1.5 MeV).
- It is ready for unexpected physics in any electron or photon channel.
- Unique experience for coming experiments with crystal calorimeter such as CMS at LHC.