The L3 Electromagnetic calorimeter

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L3 Collaboration

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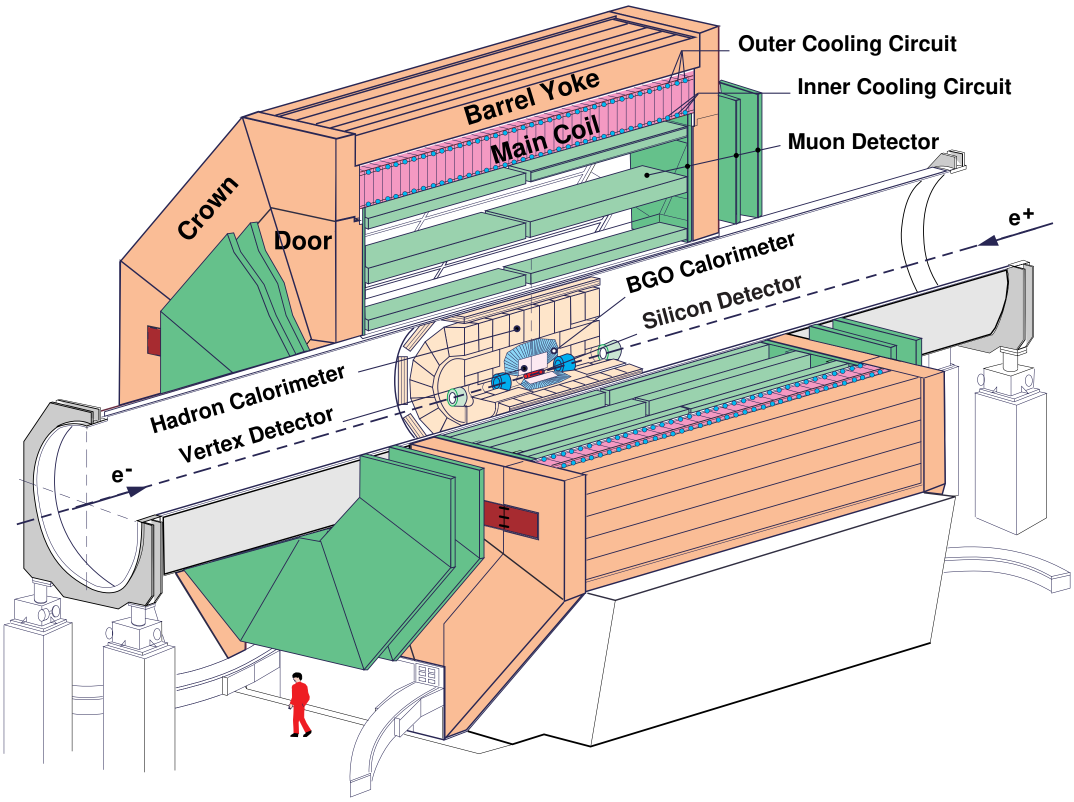
Outline of the Presentation

The L3 electromagnetic Calorimeter

- Introduction.
- The crystals, the mechanical structure, the electronics.
- The calibration.
  - Electron Beam before LEP.
  - Xenon calibration during data taking.
  - The RFQ system.
  - Cosmics.
- Temperature control.
- Electron and Photon identification.
- Energy resolutionn at LEP.

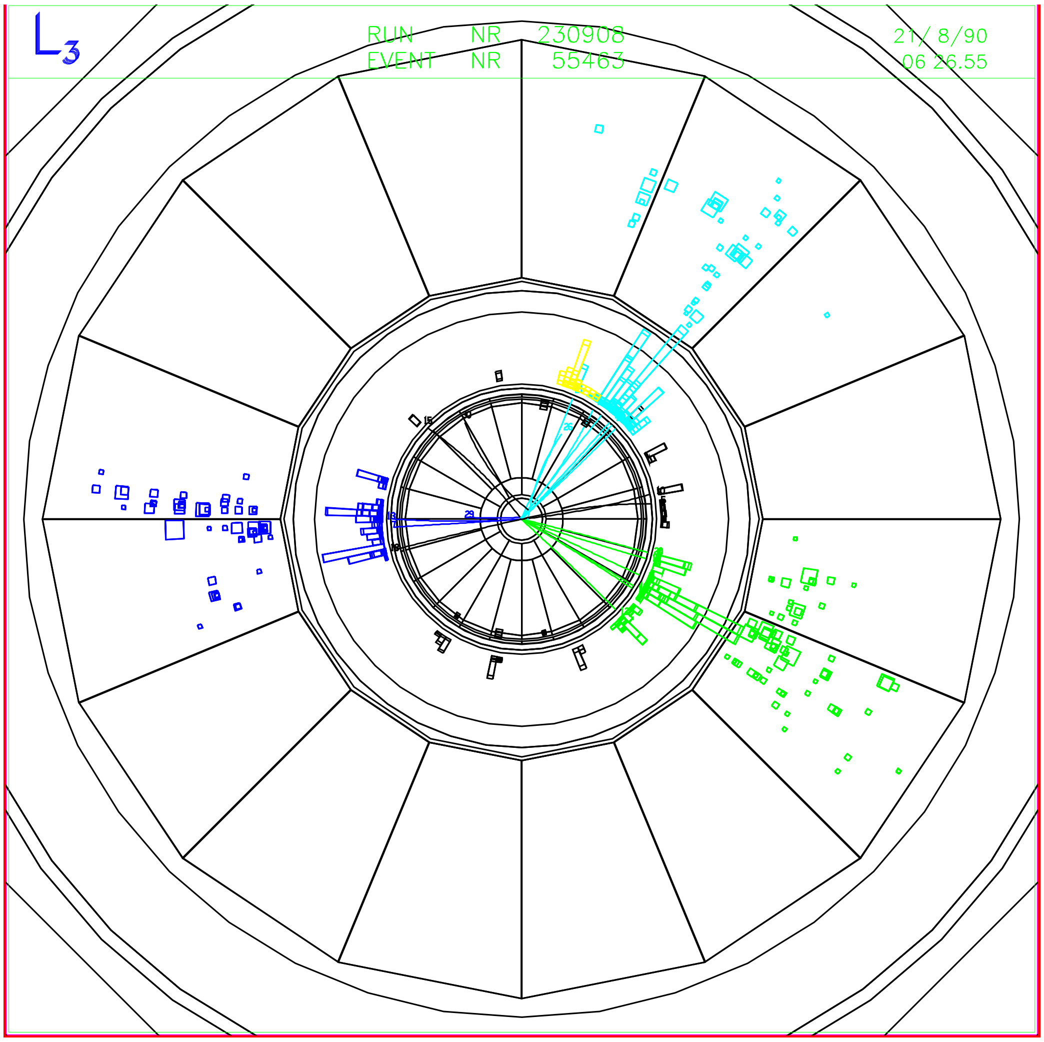
The L3 detector



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

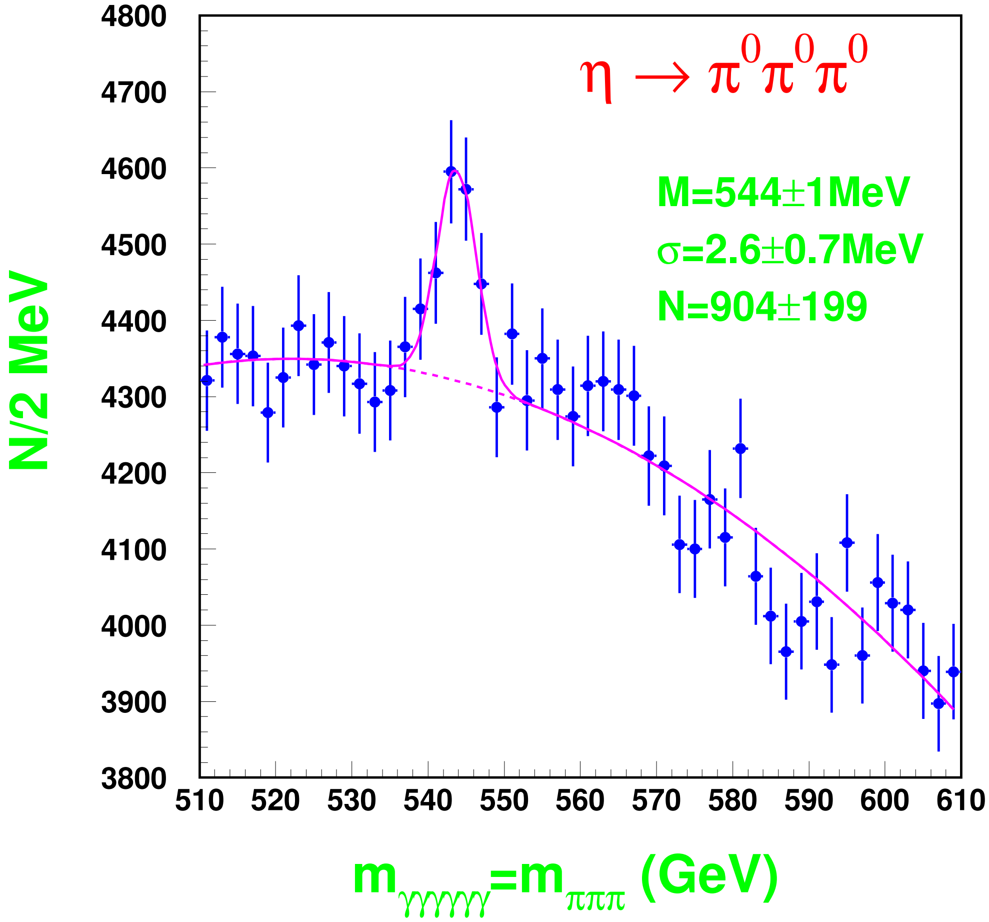
- Electromagnetic calorimeter: BGO Crystals
- Muon spectrometer.

What the BGO calorimeter can do in such an environment ??

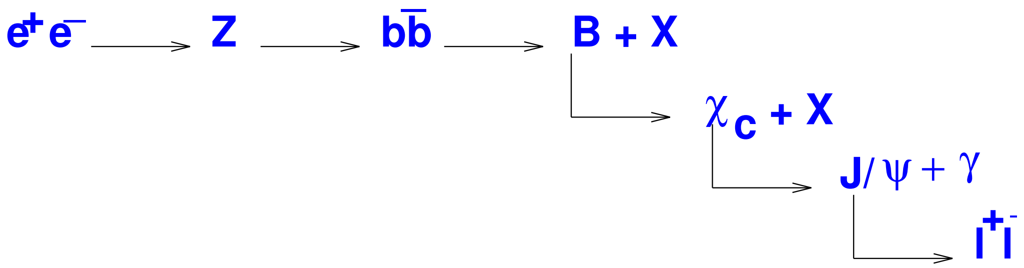


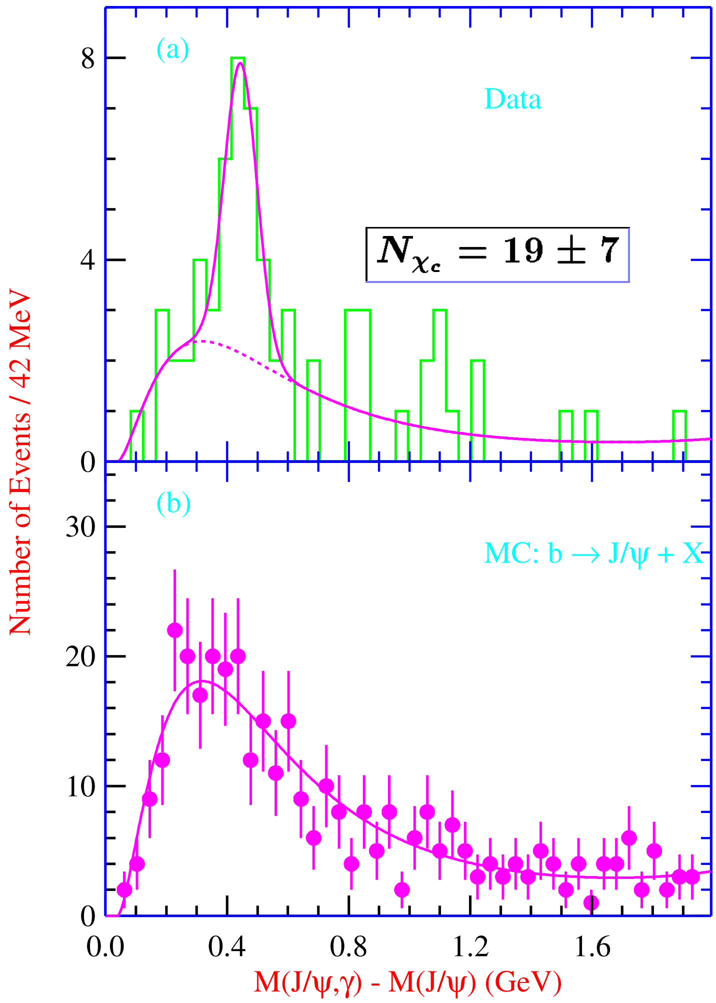
A 3 jet event

Looking for multi-photon resonances in a hadronic environment



High energy resolution for low energy photons is required. Unexpected physics may show up and L3 is a unique place to study.





One gets

$$\mathbf{Br}(Z \rightarrow \chi_{c1} + X) = (0.75 \pm 0.29 \pm 0.06) \times 10^{-2}$$

If χ_{c1} are produced only from B

$$\mathbf{Br}(B \rightarrow \chi_{c1} + X) = (2.4 \pm 0.9 \pm 0.2) \times 10^{-2}$$

The BGO ($Bi_4Ge_3O_{12}$) crystals

Characteristics	BGO	NaI
Density (g/cm^3)	7.13	3.67
Radiation length (cm)	1.12	2.59
Interaction length (cm)	22.0	41.1
Moliere radius (cm)	2.3	4.4
Wave Length (nm)	480	410
Temperature dependance ($\%/^\circ C$)	-1.55	0.22

All crystals were grown (Bridgeman method), cut to size, and polished on all six faces at the Shangai Institute of Ceramics in China. Crystals of 24 cm long and 2 $\times$ $2cm$,3 $\times$ $3cm$, front and rear faces.

- Received at CERN and tested before being equipped and installed.

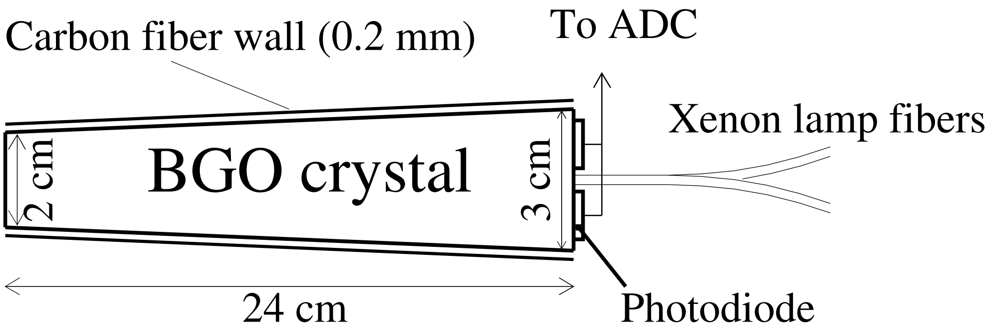
Crystals were accepted after satisfying the following tolerances:

- Optical transmission, 55$\%$ at 400nm, 65$\%$ at 630nm
- Dimensions, $300\mu m$ in transverse, $400\mu m$ longitudinally $50\mu m$ in planarity of the faces
- Light output variations along the length, measured on a cosmic ray bench, of less than 10$\%$

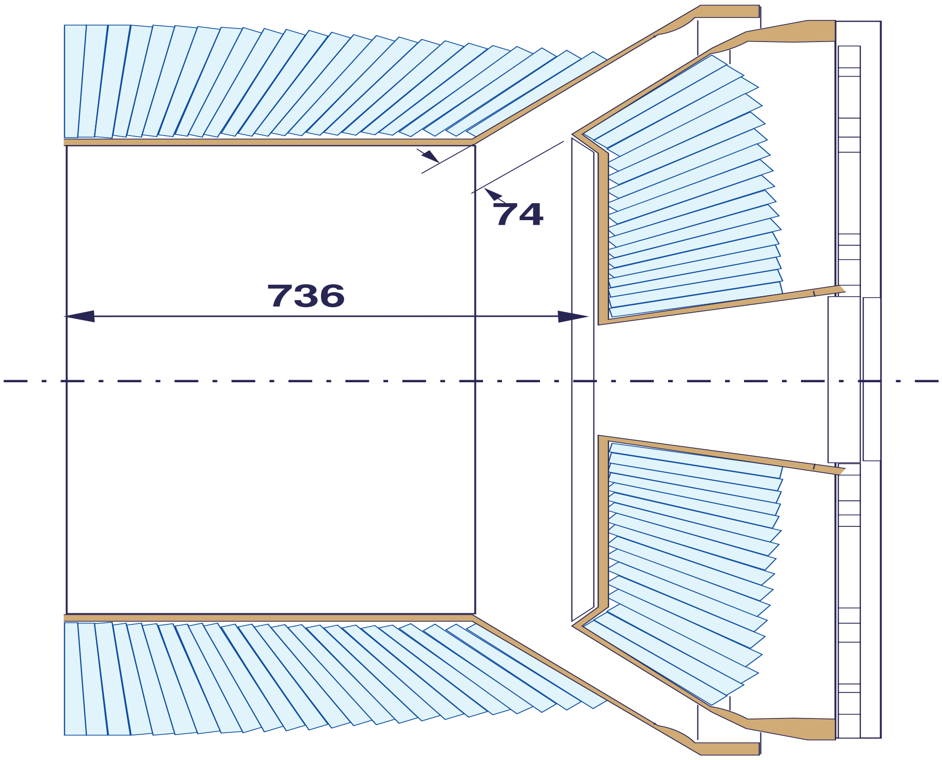
All faces are painted with a 30 to 80 μm thick coat of NE560 paint for maximum light collection

All crystals were equipped with :

- **Two silicon photodiodes, Hamamatsu S-2262, total surface of $s = 3.cm^2$, and Q=60%. Epoxy glue is used to fix them on the crystal.**
- **Two optical fibers used for light calibration**
- **Two thermal sensors (front and rear faces) for temperature control (Only 1/12 crystals)**
- **One low noise pre-amplifier**



Two Half Barrels and two End caps



- **24 crystals in θ and 160 in ϕ for each half barrel. 7680 crystals.**
- **More complicated structure for the End Caps. 3054 crystals**

Acceptance :

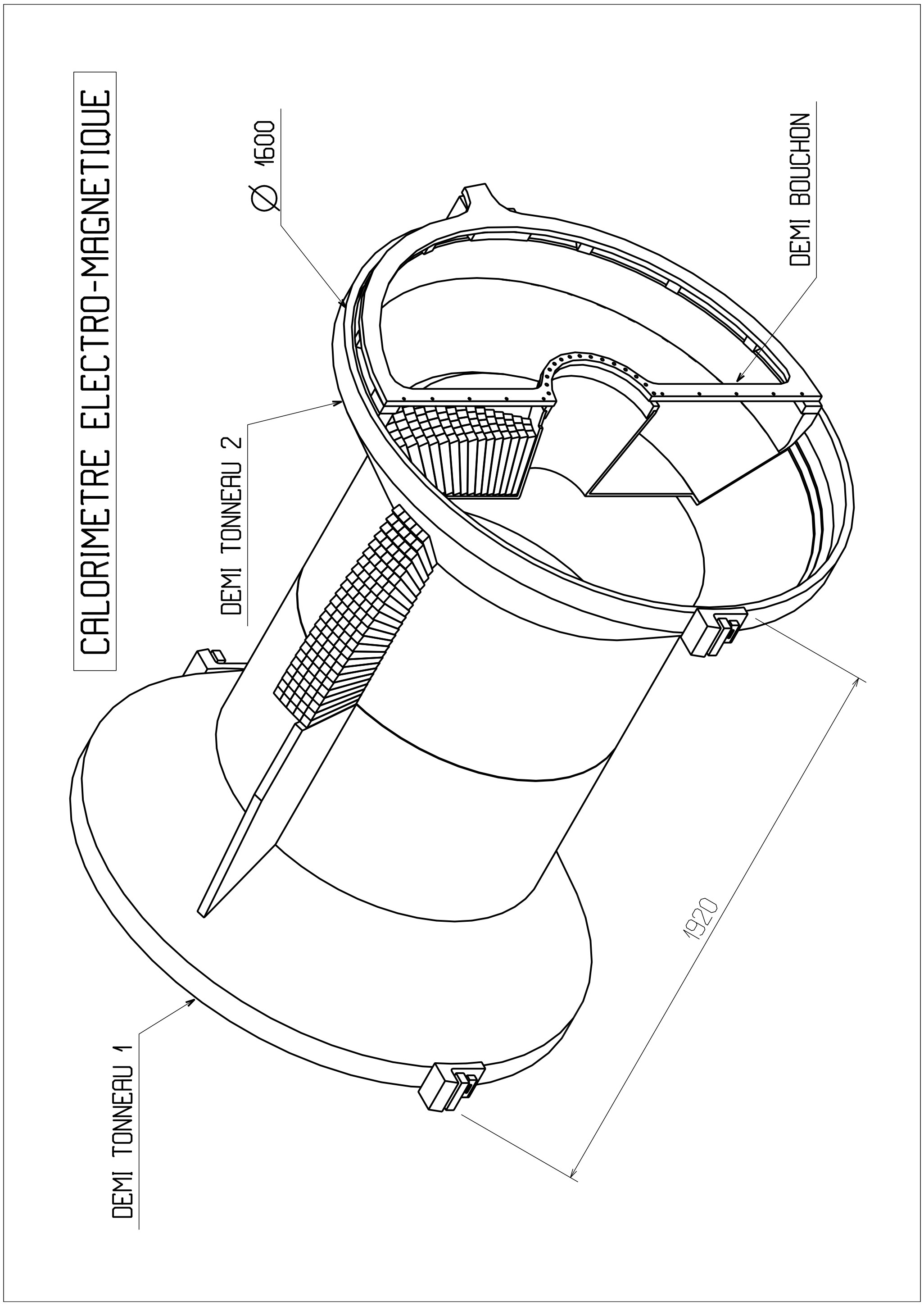
- **Barrel $42^\circ < \theta < 138^\circ$**
- **End Cap $10^\circ < \theta < 36.8^\circ$**

How to support 10734 crystals without material in front and no cracks between ??

- **A supporting structure, plus individual cells,alveoli, containing the crystals.**
- **Epoxy resin carbon fiber composite material.**
- **No effort to surrounding crystals, the weight is transmitted only to the structure.**

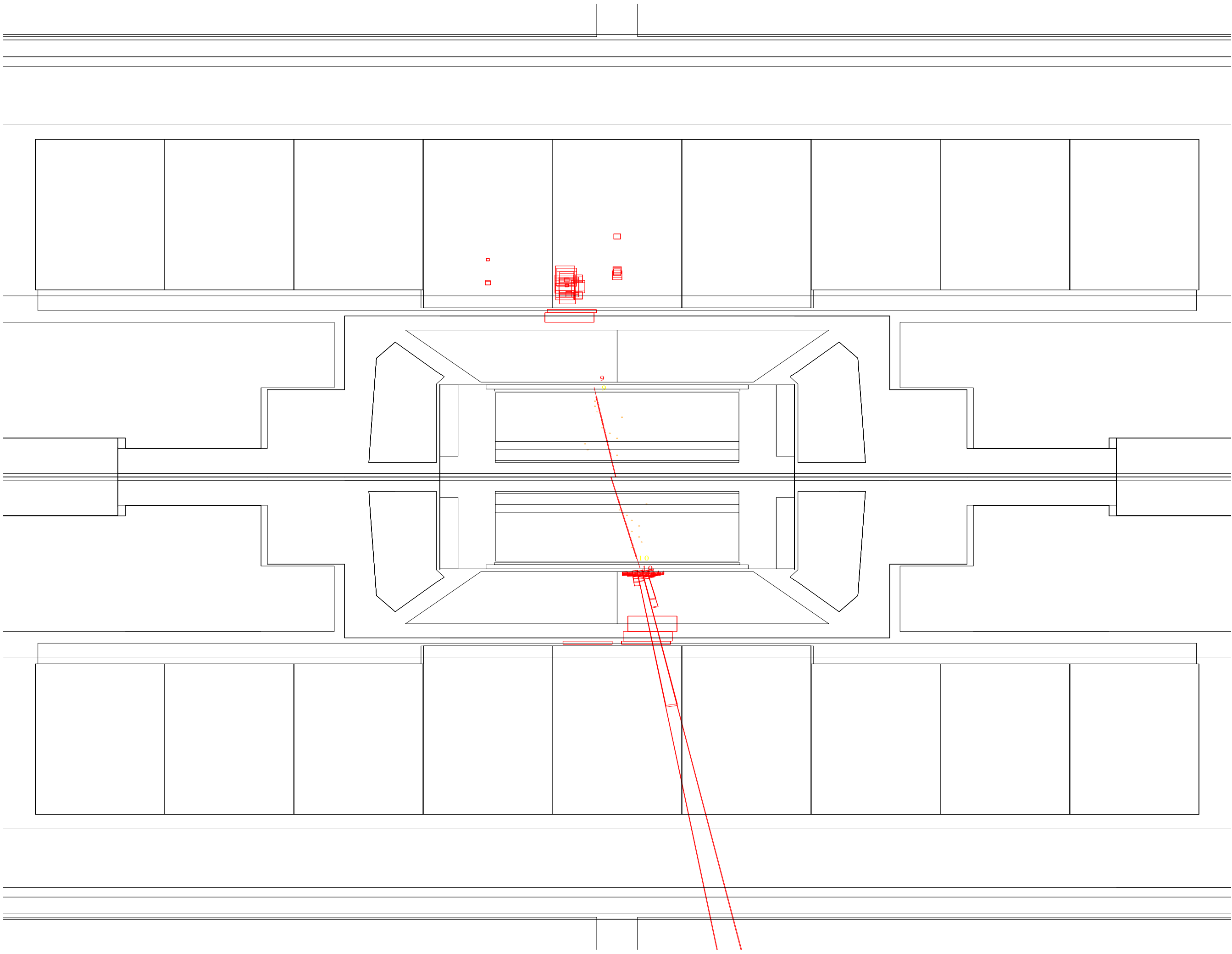
This results to :

- **1cm of carbon fiber in front of crystals, 250μm between.**
- **projective geometry in θ but crystals are tilted by 10mrad in ϕ to avoid cracks.**


CALORIMETRE ELECTRO-MAGNETIQUE
Ø 1600
DEMI BOUCHON
DEMI TONNEAU 2
DEMI TONNEAU 1
1920

Bhabha event. One of the electrons escapes detection !!

Run # 388901 Event # 3192 Total Energy : 81.44 GeV

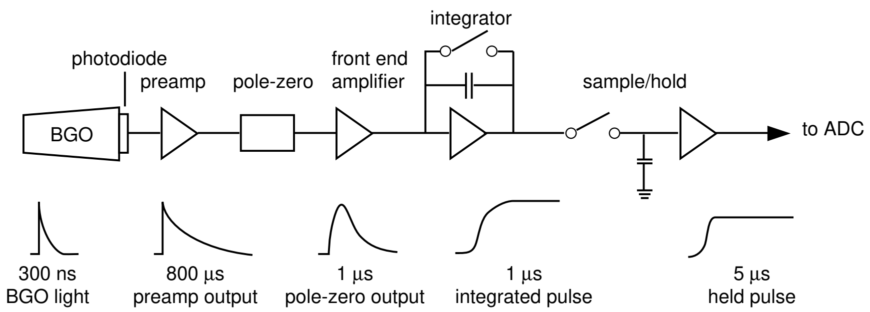


Transverse Imbalance :	.1261		**Longitudinal Imbalance :**	-.0170	
Thrust : 1.0000		**Major :** .0077		**Minor :** .0014	
Printed Date :					

0.6% losses due to cracks inside the barrel.

- **Handle signals from a few MeV to 100 GeV**
- **operate in a 0.5 T magnetic field**
- **Low electronic noise 1.5 MeV/channel**

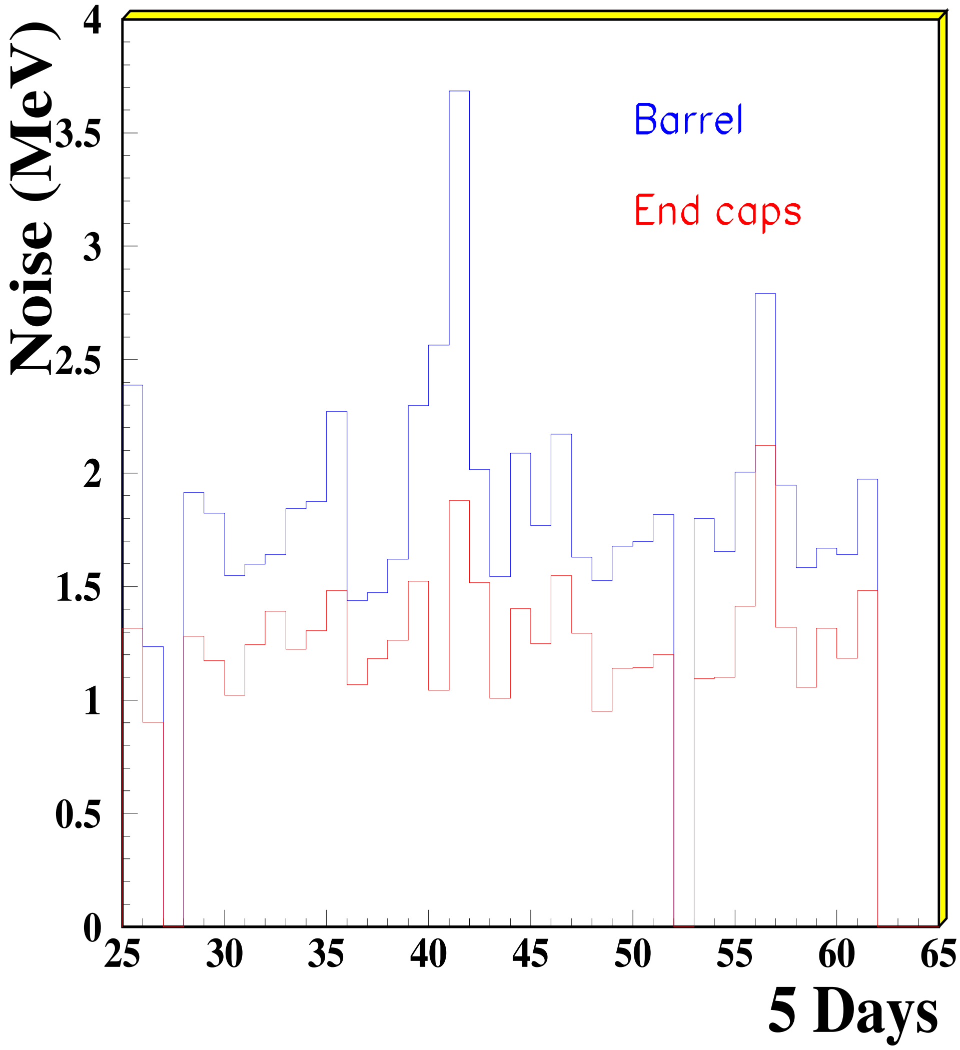
Low noise charge sensitive preamplifier
Wide dynamic range ADC



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**

Hunting noise is a continuous sport
2 MeV is an acceptable situation



We need to measure the individual calibration constants for all crystals

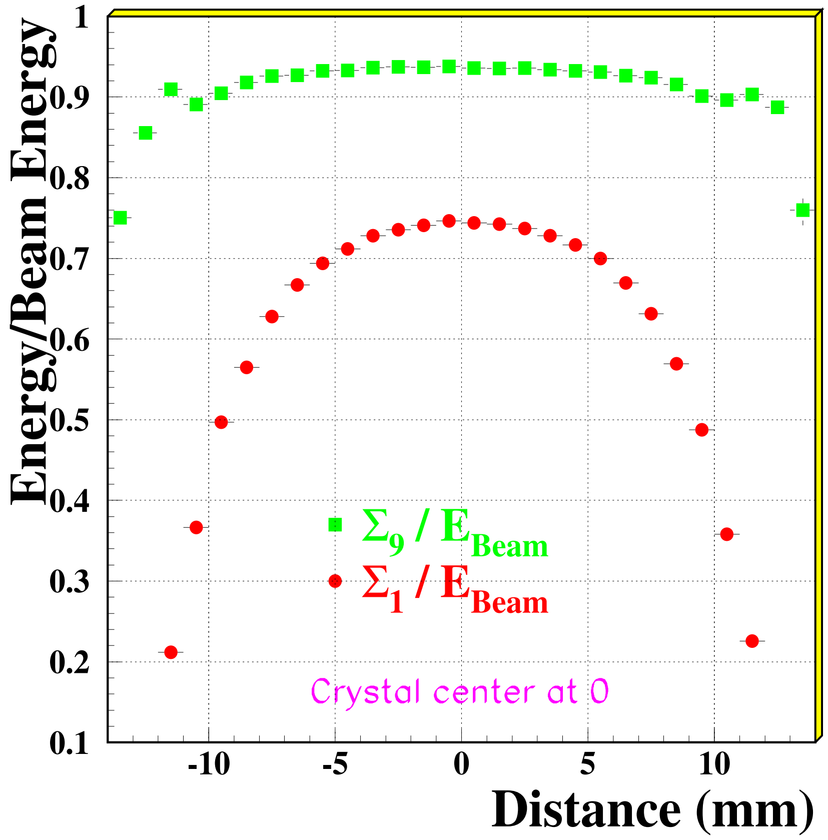
$$\mathrm{k} = \frac{Energy\ deposited\ in\ a\ crystal}{Signal\ read}$$

- **All barrel crystals and a fraction of the end caps, were calibrated at CERN, SPS X3 beam.**
- **Each half barrel fully equipped was installed on a rotating table to enable each crystal to be moved in front of the electron beam.**
- **About 1500 events were recorded per crystal at 3 energies 2,10,50 GeV.**
- **One half barrel was moved to LIL and 200 crystals were calibrated at 180 MeV.**

A real experiment that took 2 years, not a test.

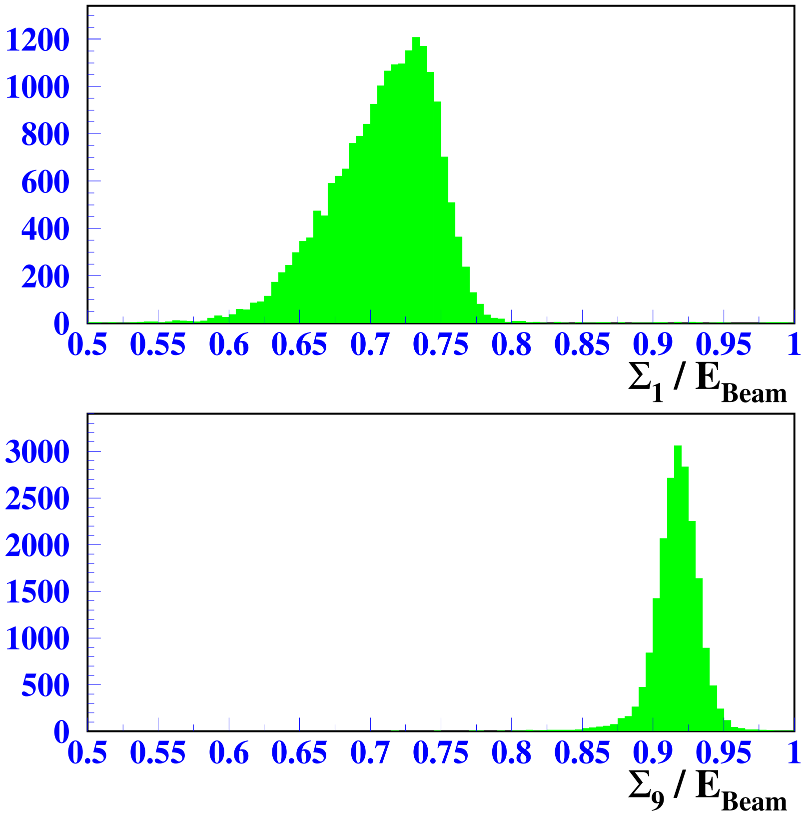
Calibration Method

Deposited energy depends on impact point



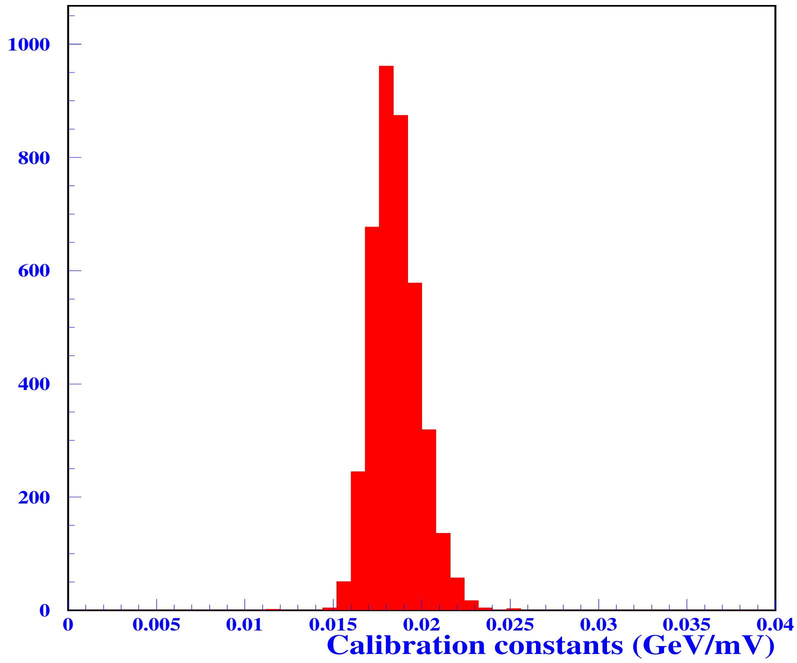
We sum all crystals of a 3×3 matrix around the central one. We use the peak value of the sum of 9 crystals Σ_9, for measuring k. Iterative method, initial constants are measured by the cosmic bench.

Energy calibration with electron beams



- **We used events in the central region (-7mm <x,y < 7 mm)**
- **Rear and lateral losses taken into account by Monte Carlo**
- **Precise beam momentum measurement**

During calibration strict temperature control and regular Xenon runs are required.



Resolution

Energy distribution is fitted with a gaussian and 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.**

Overall resolution is the quadratic sum of local and global resolutions

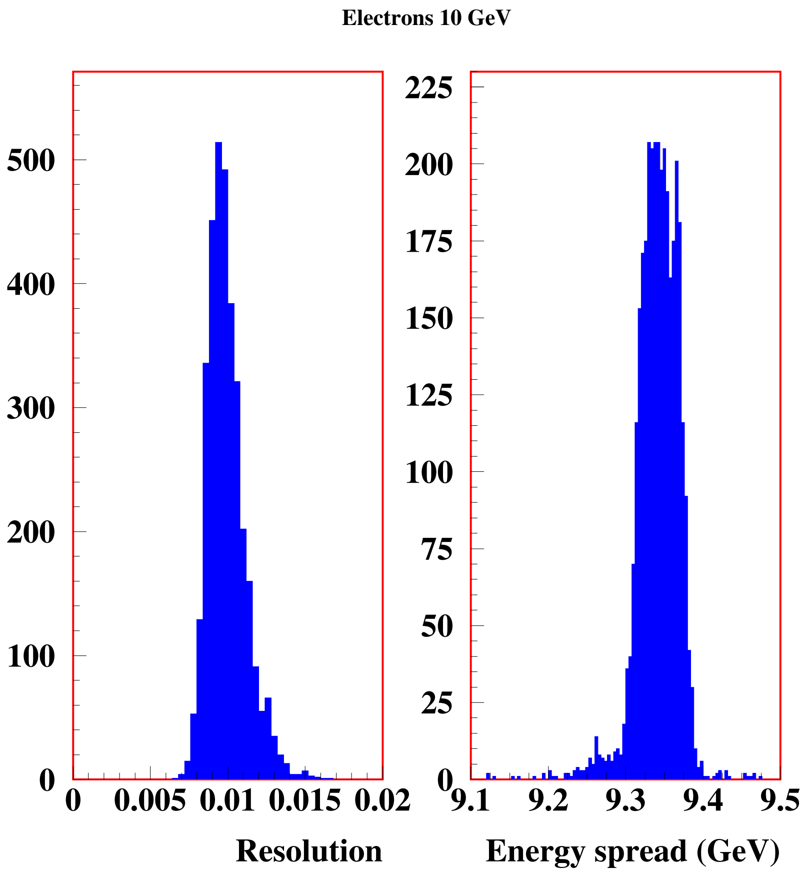
Energy (GeV)	2	10	20	50
Local measured resolution (%)	2.2	0.99	0.73	0.51
σ_p/p (%)	0.88	0.39	0.28	0.17
Electronic noise(%)	1.70	0.34	0.17	0.07
Intrinsic resolution (%)	1.33	0.79	0.64	0.42
Local resolution (%)	2.30	0.93	0.72	0.48

Local resolution at different energies measured

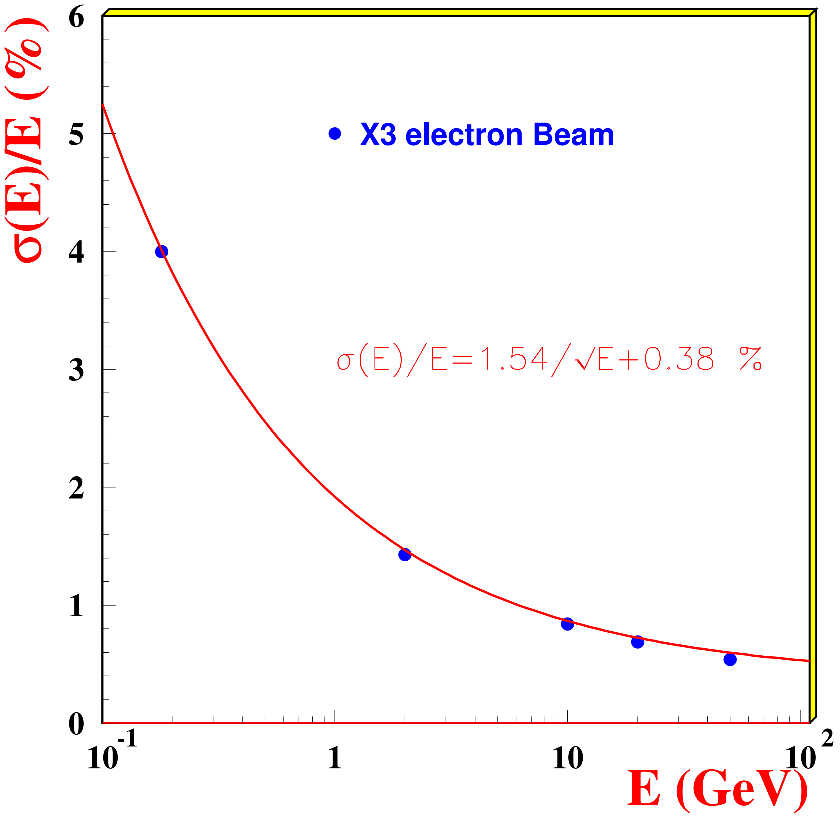
Energy (GeV)	2	10	20	50
Intrinsic resolution (%)	1.33	0.79	0.64	0.48
Global resolution (%)	0.57	0.29	0.27	0.26
Overall Resolution (%)	1.45	0.84	0.69	0.54

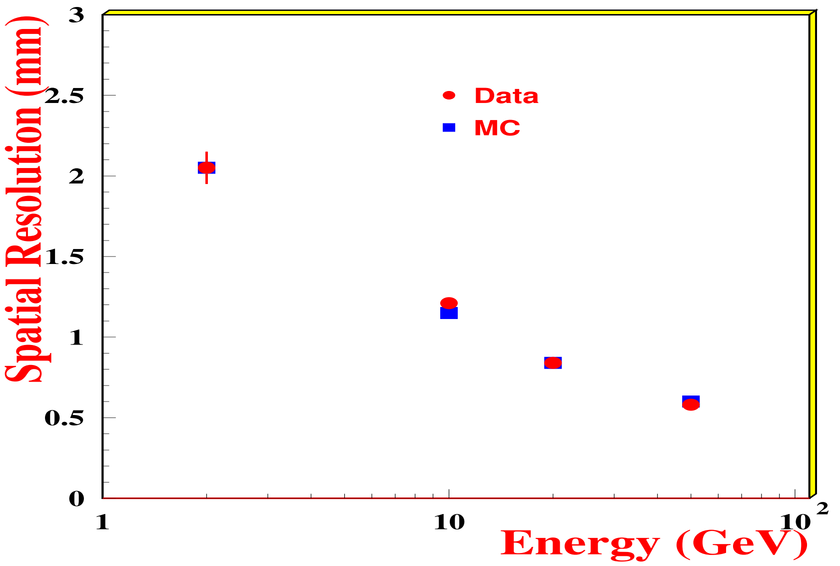
Global BGO resolution at different energies

Local and global resolutions.



Energy calibration with electron beams



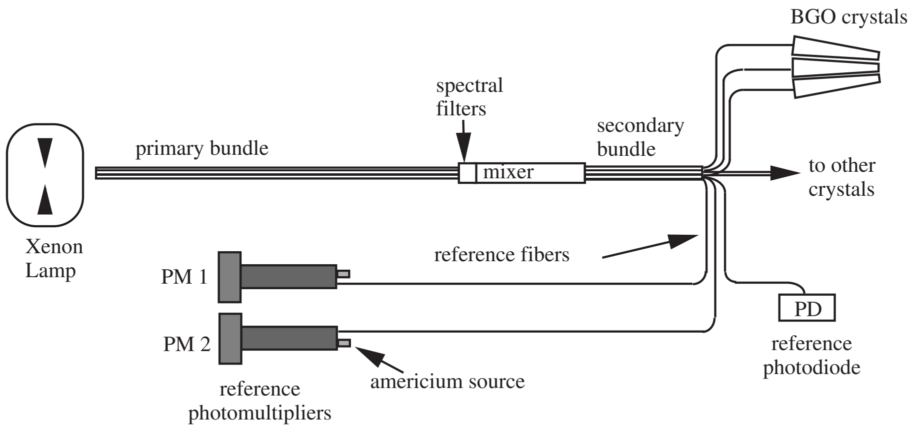


Light output and electronics gain must be carefully followed during data taking in order to obtain the best energy resolution.

We have three ways of monitoring :

- **The Xenon Monitor, light pulses**
- **The RFQ accelerator, photons of 17.6 MeV**
- **Cosmic muons**

System based on light pulses emitted by Xenon lamps. Light collection efficiency and electronic's gain is controlled.



- **Hamamatsu L2453 Xenon lamp.**
- **14 primary quartz optical fibers 600μ, 35m.**
- **Plexiglas mixer.**
- **240(barrel),192 (End caps) secondary optical fibers 200μ, 2 to 3m.**
- **2 PM's and a reference photodiode.**

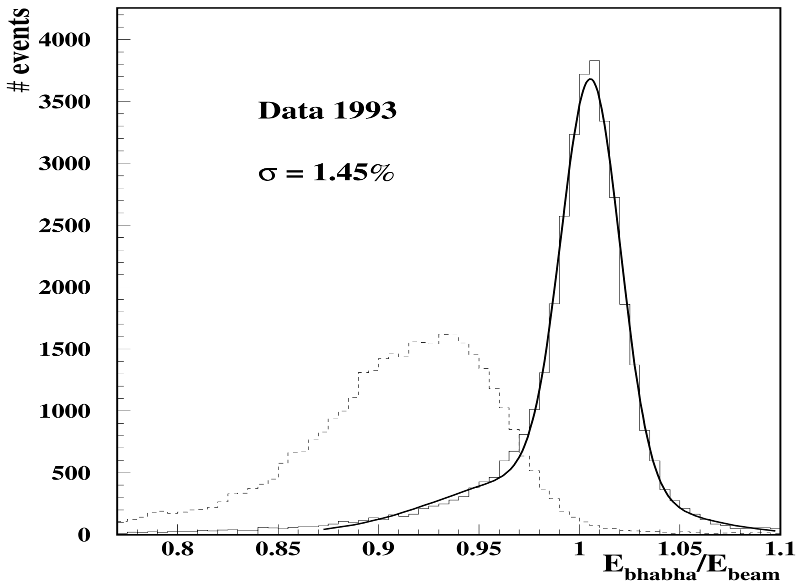
Two fibers per crystal. (Only barrel)

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

Crystals are grouped in geographical regions. Calibration method in two steps for each region :

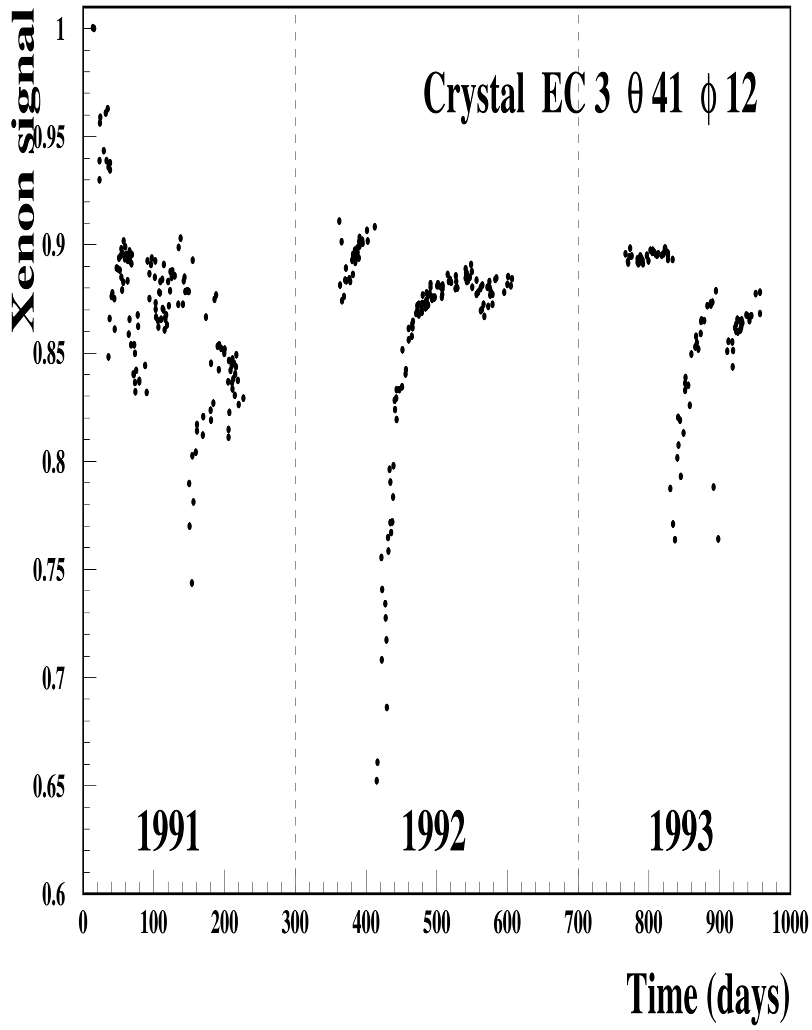
- **Inter-calibration. Using both fibers we adjust the calibration constants in order to get the same answer for all crystals in the same region. Value very stable versus time, 0.2% over 20 days**
- **The absolute scale for a region is fixed using electrons from non radiative Bhabha events**

Absolute calibration with a precision of 0.9% is achieved using the Xenon system and electrons from Bhabha process.

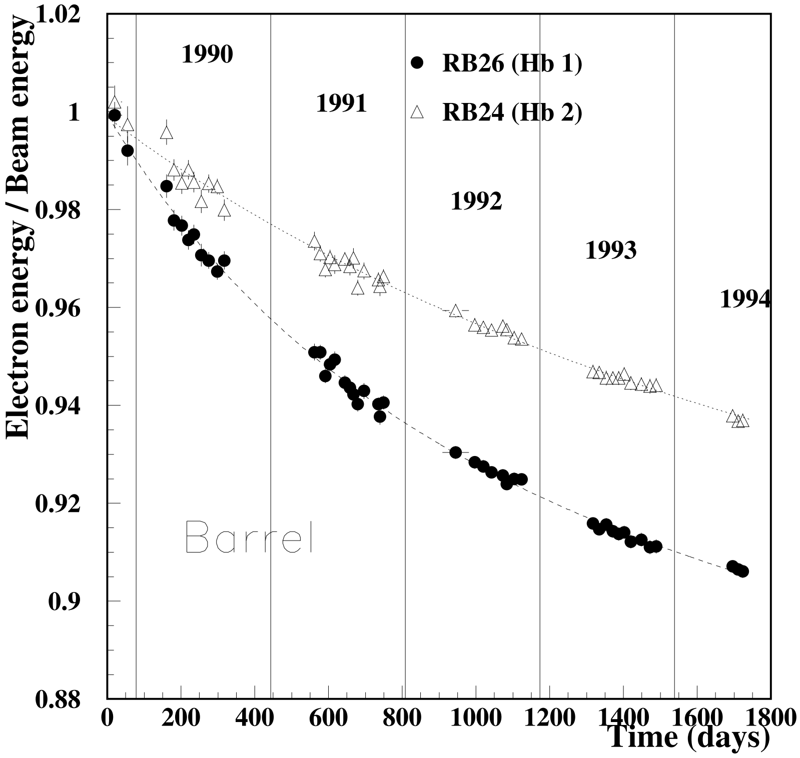


Light output varies in time. The Xenon system is necessary to follow variations and correct for losses.

An example of radiation damage accident. Crystal recovers almost initial light after about 20 days



Pulse hight from electrons of 45 GeV (Bhabha events) as a function of time



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

with

parameter	HB1	HB2
a(days)	233.4 ± 7.9	385.9 ± 13.0
t_0(days)	1381.6 ± 35.4	2545.0 ± 59.8
c_∞	0.830 ± 0.002	0.848 ± 0.002

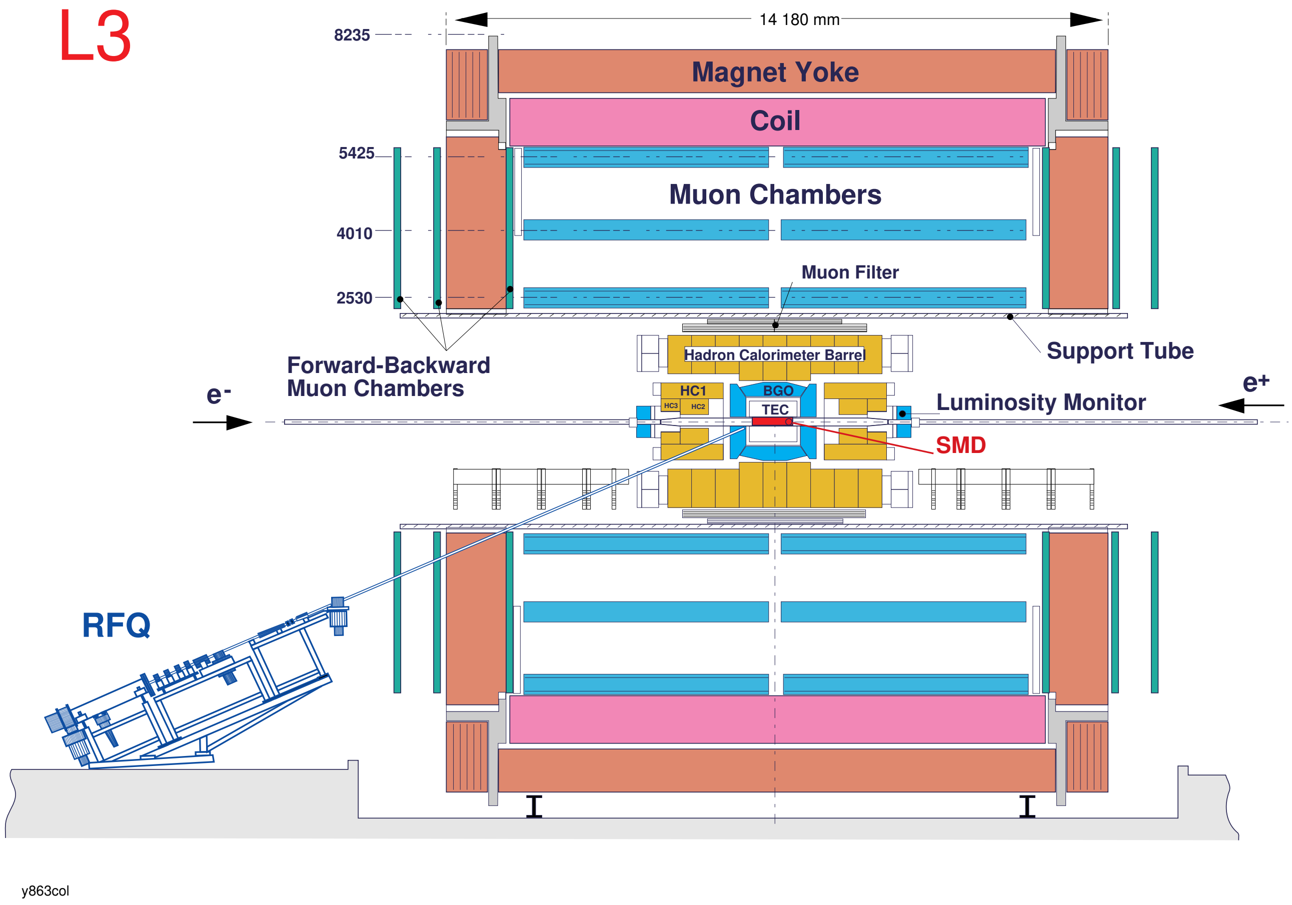
5% of light lost between electron calibration and Lep first run for unknown reasons !!!!

The Xenon system is robust and reliable, necessary for the intercalibration, but could not give the absolute calibration, which has to rely on a physics process

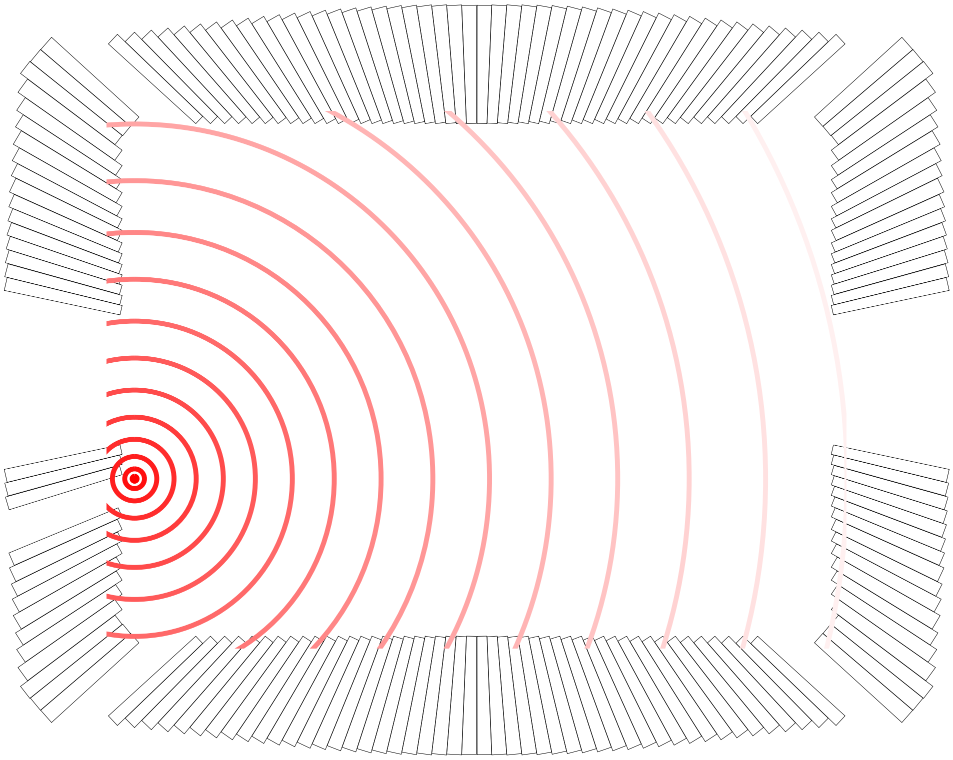
RFQ Calibration Method

1.85 MeV H beam from RFQ accelerator incident on Li target provides source of 17.6 MeV γ's via

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

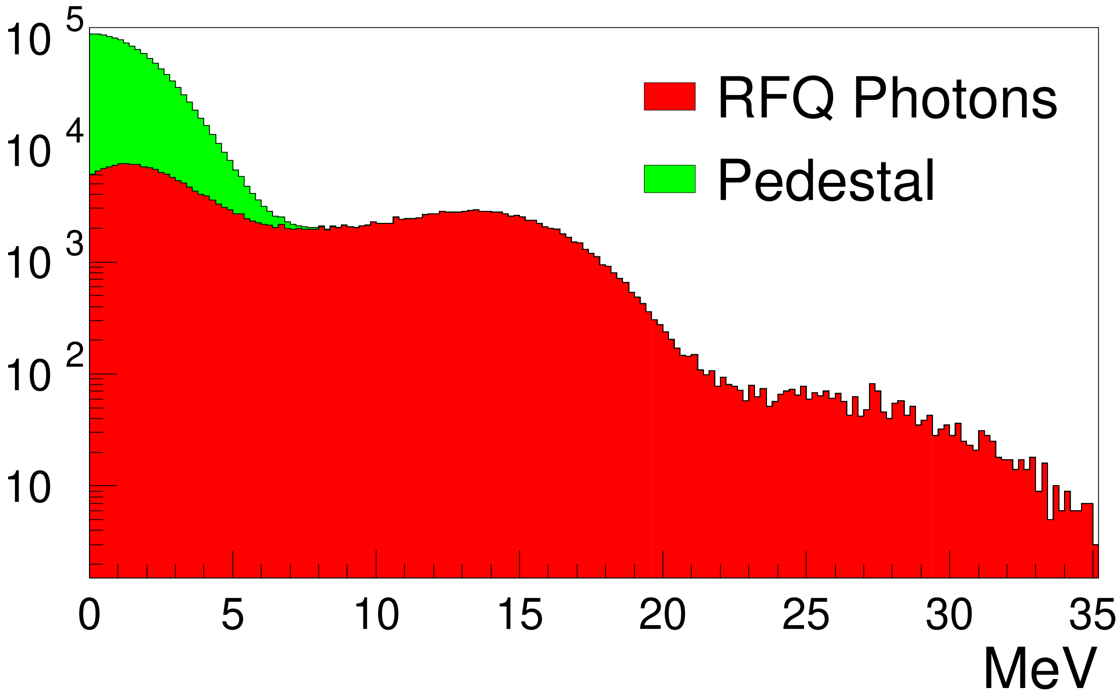


Exposure of each crystal depends on distance from target, orientation, material in front, etc.

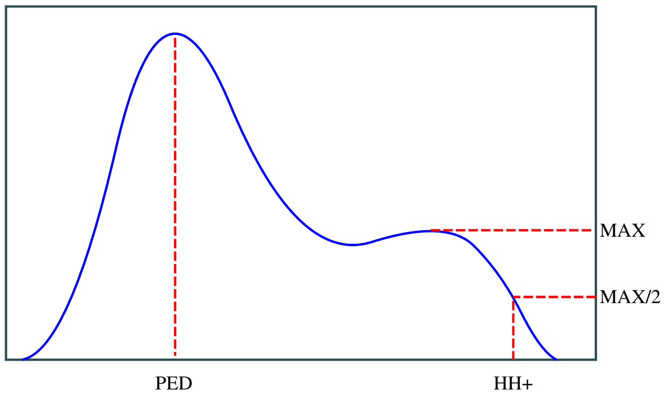


Select hits centered in a crystal
$\Rightarrow$ energy in neighbors < noise RMS ($\sim$ 2 MeV).

near crystal ($\theta = 38$, $\phi = 53$):



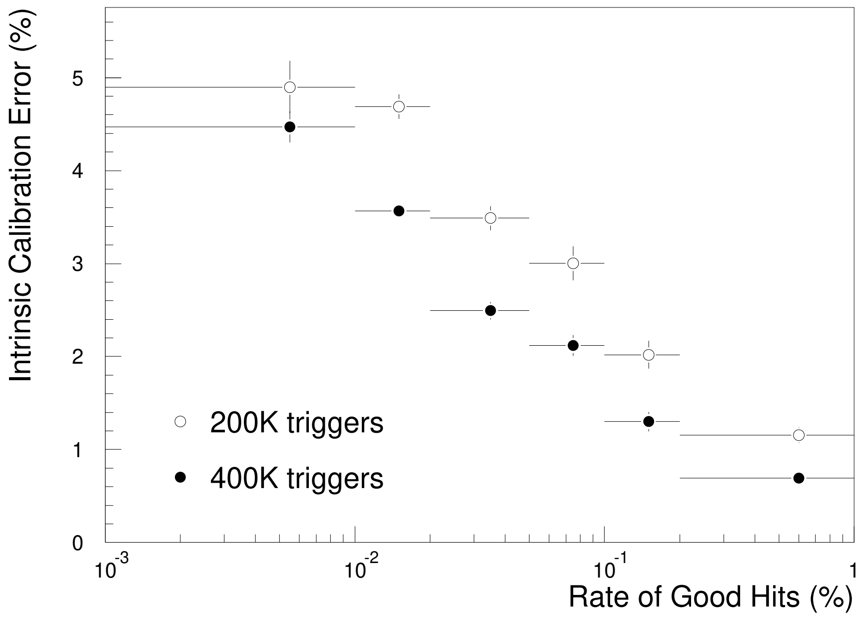
Identify HH$^+$ edge for each crystal



Define edge energy $E_{\mathrm{HH}^+} \sim 17$ MeV. Small variations due to geometry, material in front, etc, taken into account with MC simulation.

Stability of HH^+ edge determination sets lower bound on calibration error. Stability is affected by

- **rate of RFQ photons in a crystal $\Rightarrow$ spectrum shape**
- **differential nonlinearity of readout $\Rightarrow$ systematic fluctuations**
- **number of RFQ photons in a crystal $\Rightarrow$ statistical fluctuations**



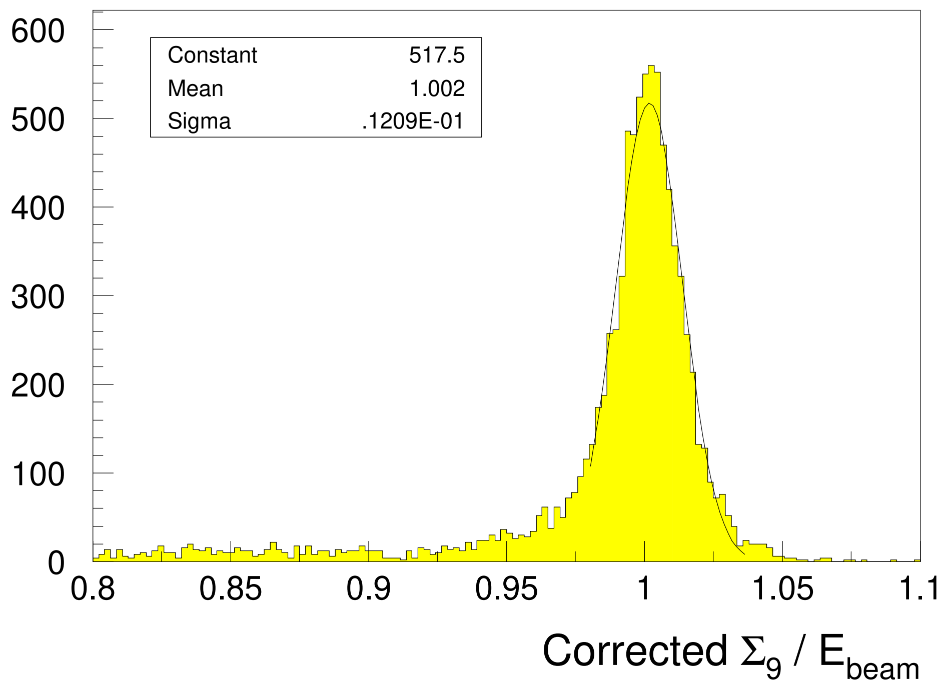
Calibration run of 29/9/93 (900K triggers):
$\Rightarrow$ $<$ 1% for $\sim$ 10% of RB24 barrel, $\sim$ 30% of RB24 endcap.

Two methods:

- **“RFQ only”**
  extrapolate absolute RFQ calibration 17 MeV → 45 GeV
  (nonlinearity 2–3% between 1–50 GeV !)
- **“RFQ + Bhabha”**
  use RFQ for intercalibration in 3×3 matrix
  + Bhabha events for overall energy scale

“RFQ + Bhabha” Calibration

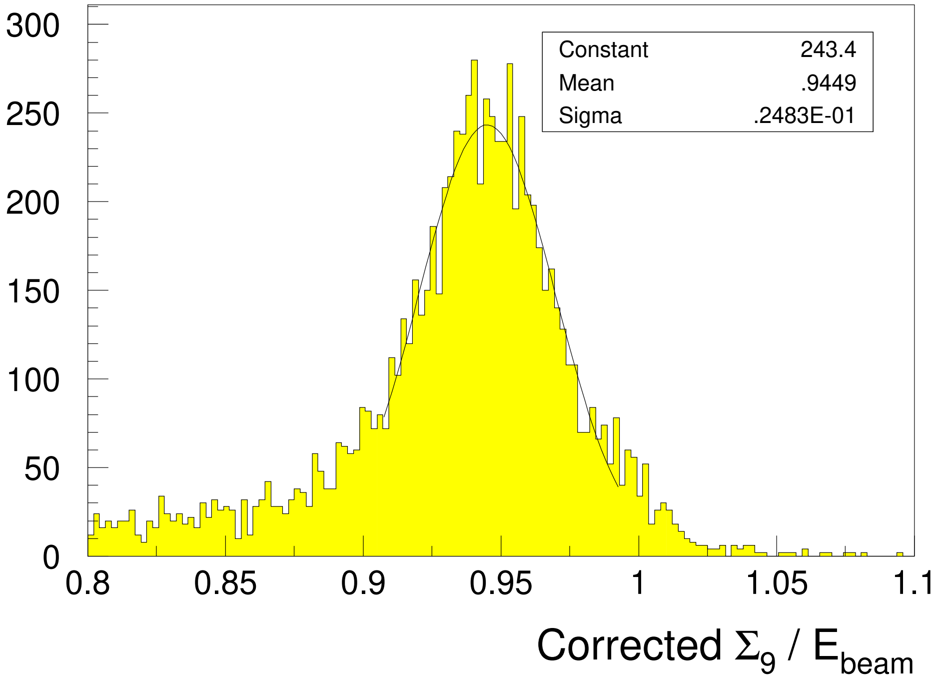
RB24 barrel: $\sigma = 1.2\%$ (Xenon+Bhabha $\Rightarrow$ 1.34%)



RB24 endcap: $\sigma = 1.6\%$ (Xenon+Bhabha $\Rightarrow$ 1.5%)

“RFQ Only” Calibration

RB24 barrel: $\sigma = 2.5\%$



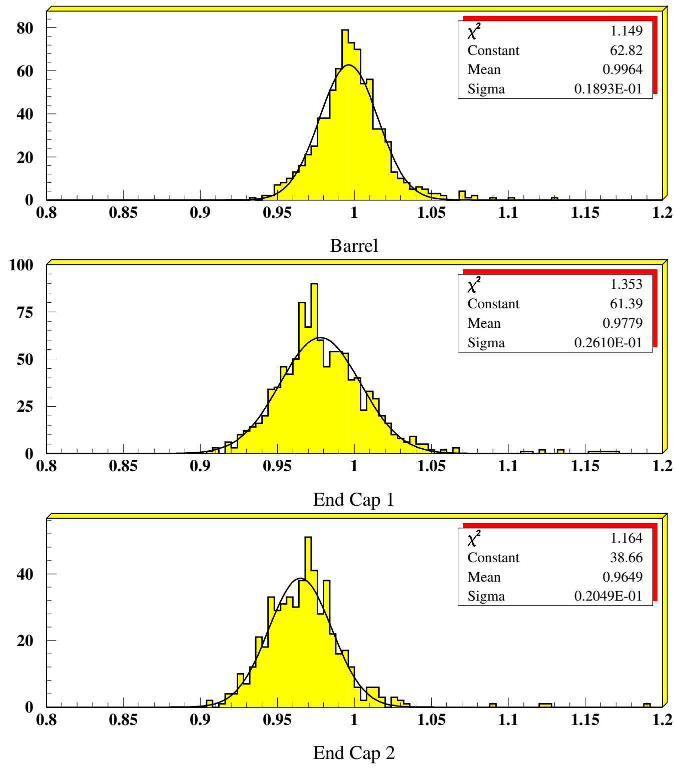
Using RFQ Calibration we find for the π^0 Resonance

- **RFQ:** $m_{\pi^0} = 133.3$ **MeV** , $\sigma = 8.8$ **MeV**
- **Xenon:** $m_{\pi^0} = 132.0$ **MeV** , $\sigma = 8.8$ **MeV**

Energy lost by a muon that passes through a BGO crystal can be used for calibration.

Only two dedicated runs during 91. 5×10^6 triggers collected.

Crystals traversing opposite faces only are used. 200 events per crystal



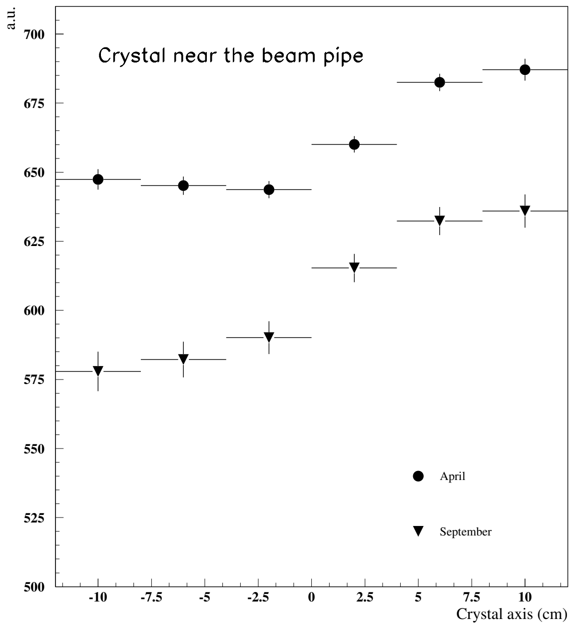
Ratio of Measured Energy and Beam Energy for electrons from Bhabha events

Cosmic ray calibration

Measurement is limited by errors on the track length,pedestal fluctuations,and Landau fluctuations.

We achieved a precision of 1.3% on the calibration constants.

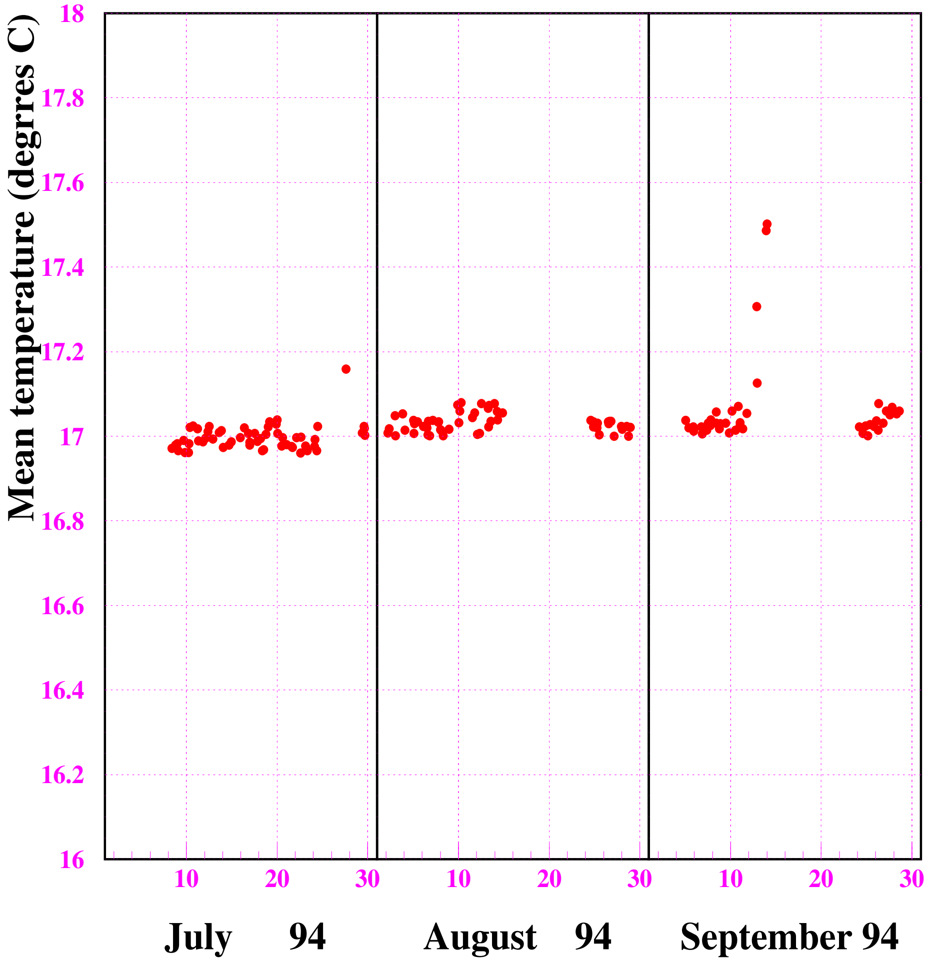
Light collection efficiency along the crystal is also measured.



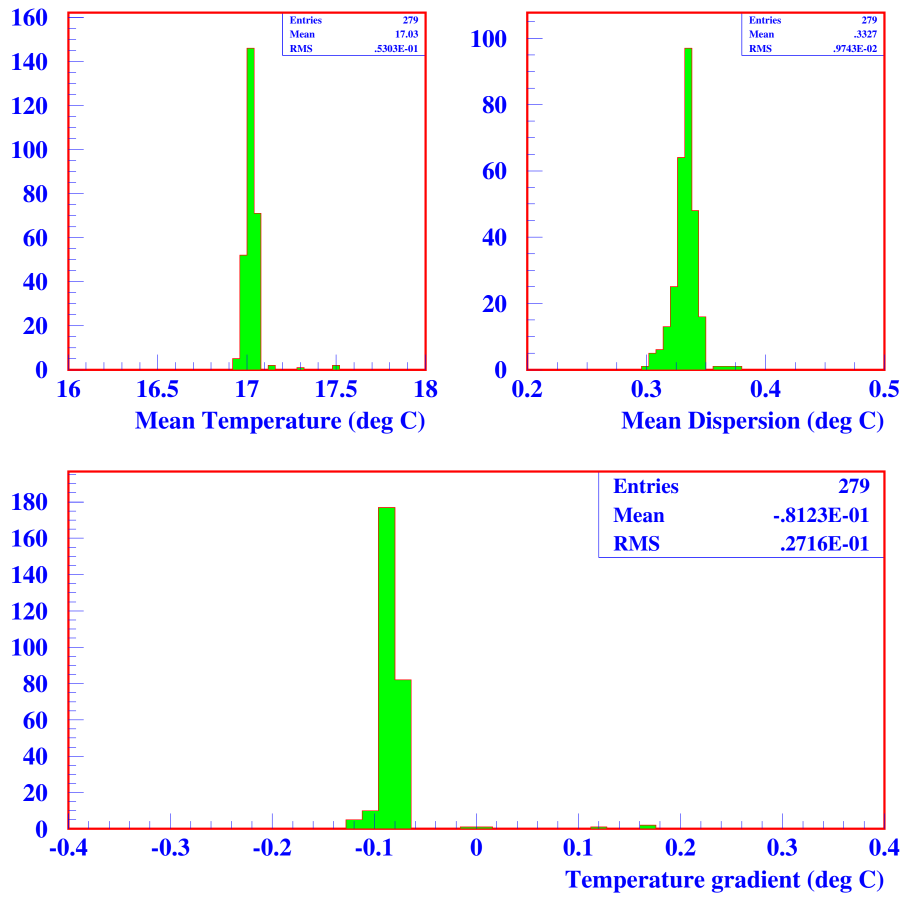
Light output varies with temperature :

Light decreases by 1.55 % per °C

The crystal temperature is measured by two AD590 sensors glued on the front face and on the rear face of a subset of the crystals(320 for the barrel and 2×128 for the end caps) .



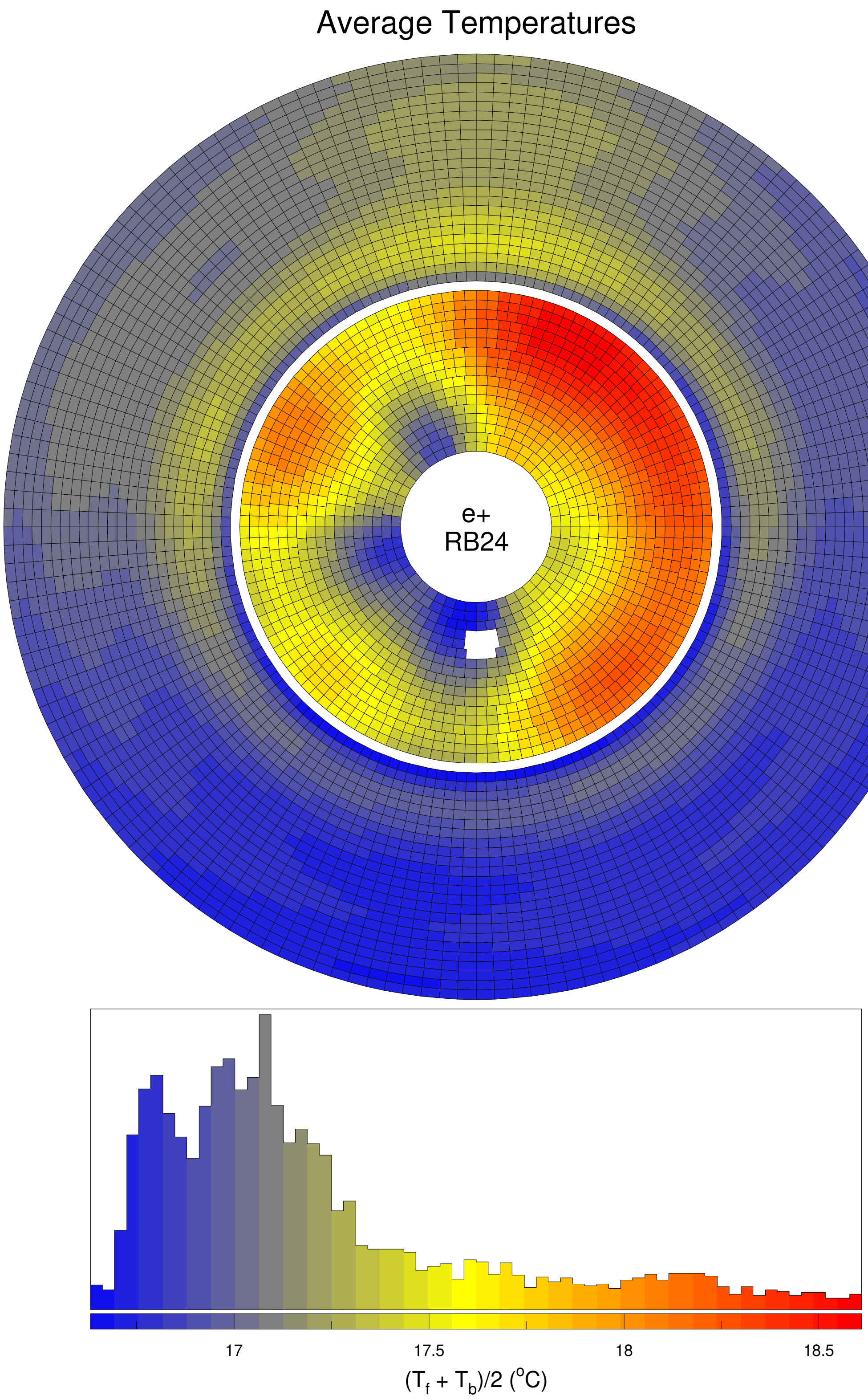
Thermal screens surrounding the BGO keep temperature value constant and temperature gradient small.



Temperature correction per crystal

$$\epsilon = 1 + (T_c - 18^\circ) \quad T_c = T_f + \eta(E)(T_b - T_f)$$

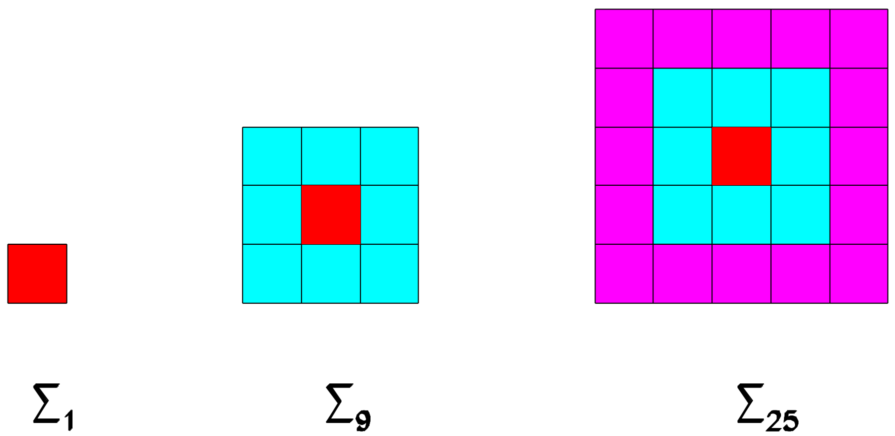
Temperature is measured with a precision of 0.2°C .


Average Temperatures
e+
RB24
17
17.5
18
18.5
(T_f + T_b)/2 (°C)

Transverse shape of the shower is used.
Identification depends on the environment, isolated photons, hadronic event, etc..

The most commonly used estimators :

$$\rho_{BGO} = \Sigma_9/\Sigma_{25}$$

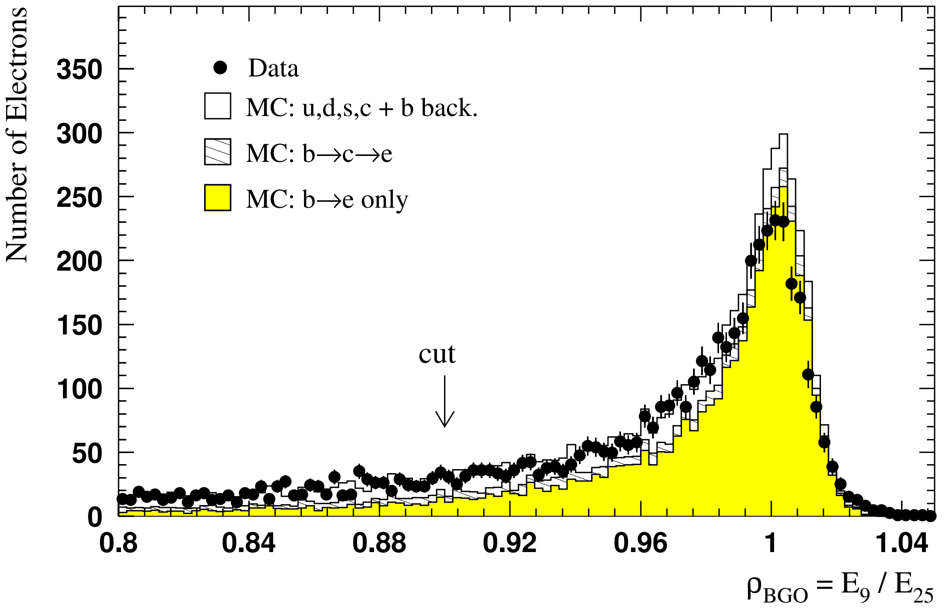


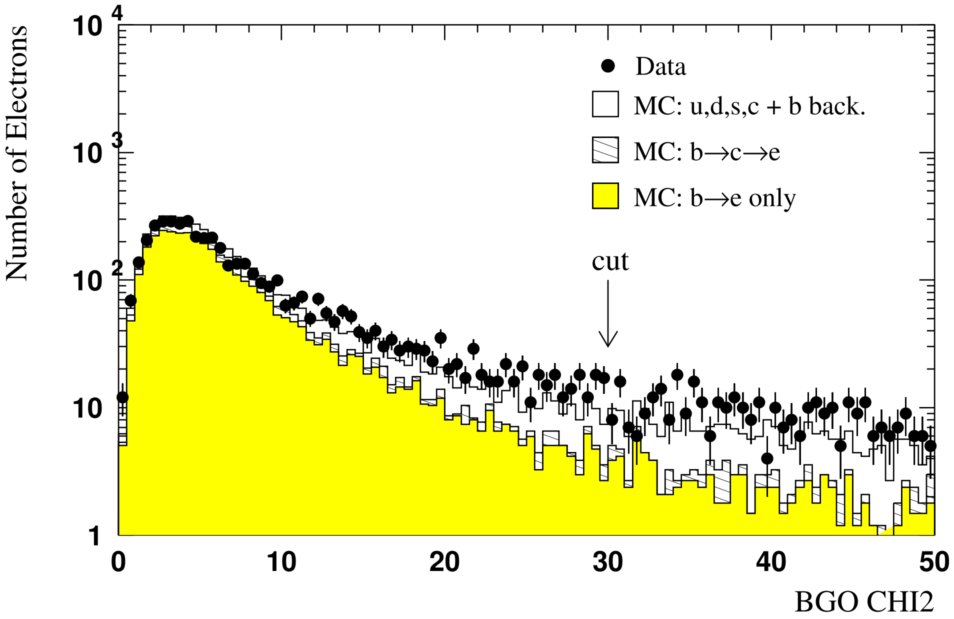
ρ_{BGO} should be about 1 for electromagnetic showers

$$\chi^2_{BGO} = \sum_{i=1}^{9} \left(\frac{F_i - F_i^{TB}}{\sigma_i^{TB}} \right)^2 \quad (1)$$

where F_i is the fraction of energy deposited in the crystal i (i = 1, 9), F_i^{TB} and $\sigma_i{}^{TB}$ are the fraction and the width of the fraction of energy deposited, as determined from the test beam.

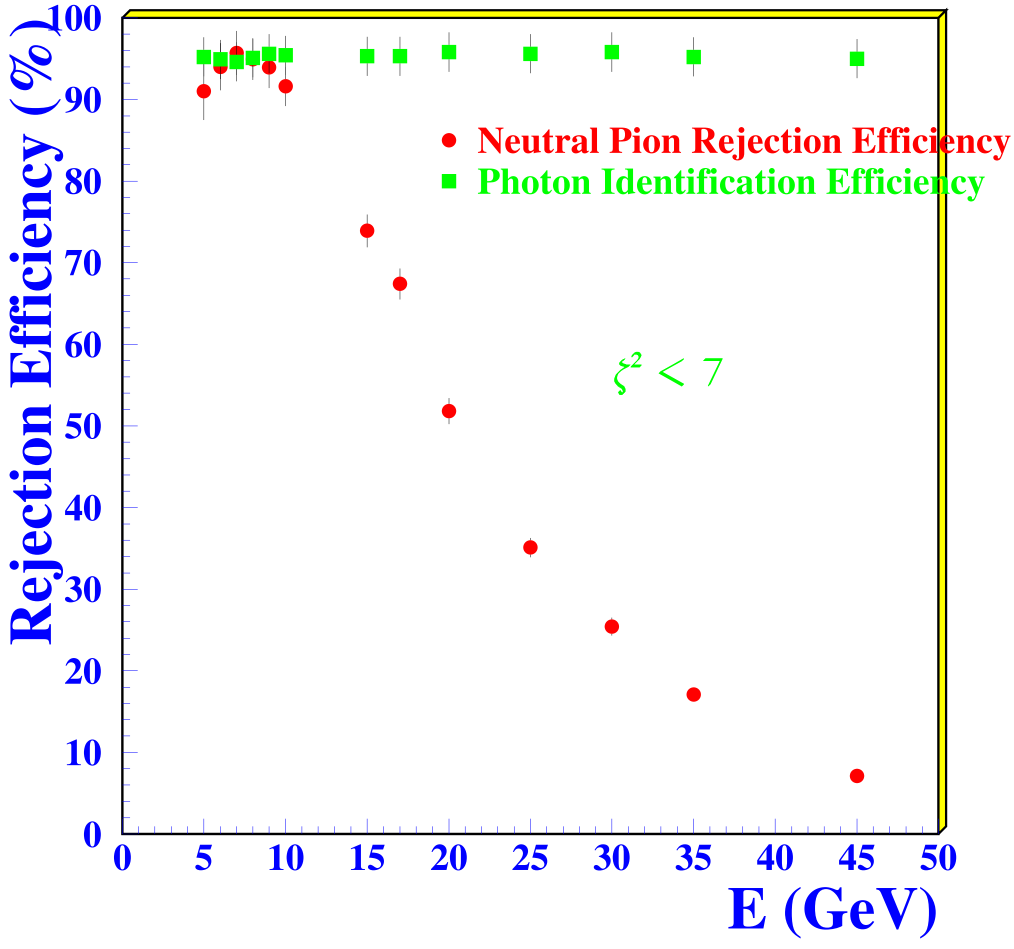
Distributions of ρ and χ^2 taken from semi-leptonic B decays



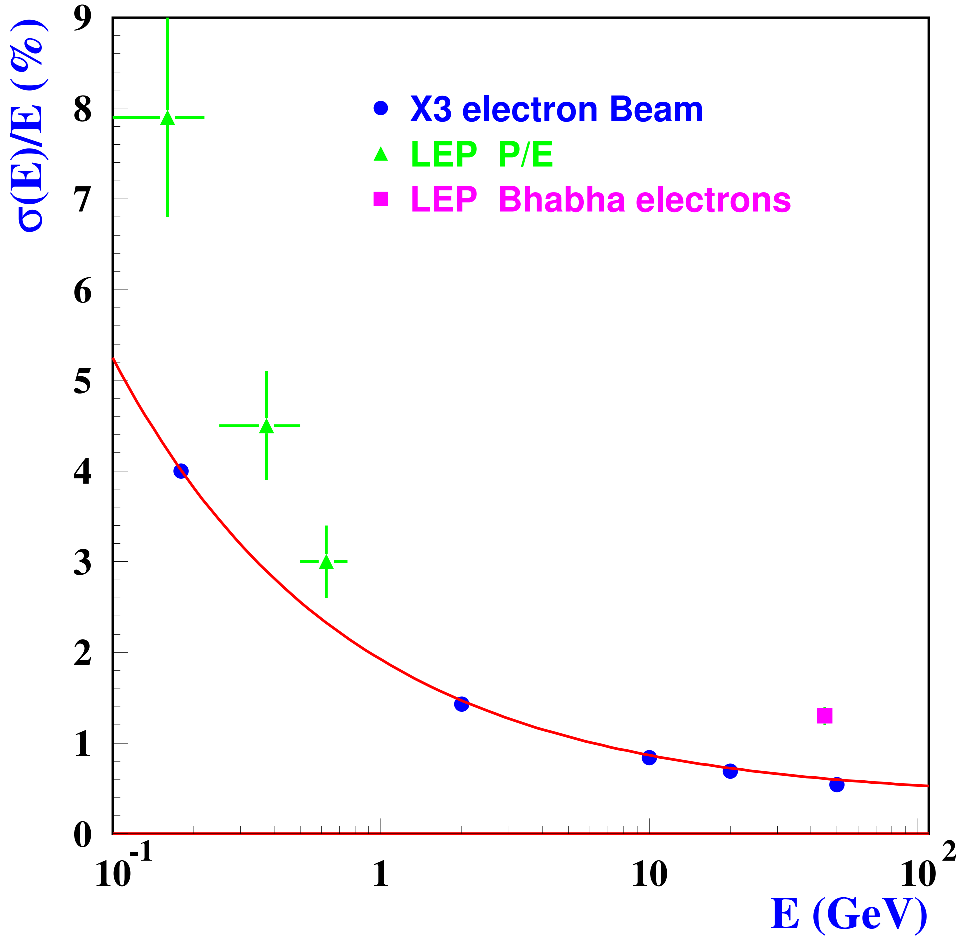


Single photon,π^0 rejection.
More sophisticated methods needed to reject energetic π^0

χ^2, or neural network technic.



Which energy resolution at LEP ?



- **The BGO electromagnetic calorimeter is robust and stable detector, producing a lot of unique and first class physics.**

- **Excellent energy resolution was achieved, giving a clear advantage to the L3 detector, for all channels concerned by electrons and photons.**

- **If unexpected physics shows up with high statistics at Lep 100 or later at Lep 200, the L3 detector measuring with high precision all leptons will be on the first line to catch it.**