THE L3 URANIUM HADRON CALORIMETER

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VIII International Conference on Calorimetry in High Energy Physics

Lisbon, June 13-19, 1999.

Outline

- **L3 Detector**
- **Hadron calorimeter components and structure**
- **Electronics**
- **Gain calibration**
- **Energy calibration**
- **HCAL status after 10 years in operation**
- **HCAL on LEP II**
- **Conclusions**

The L3 Detector

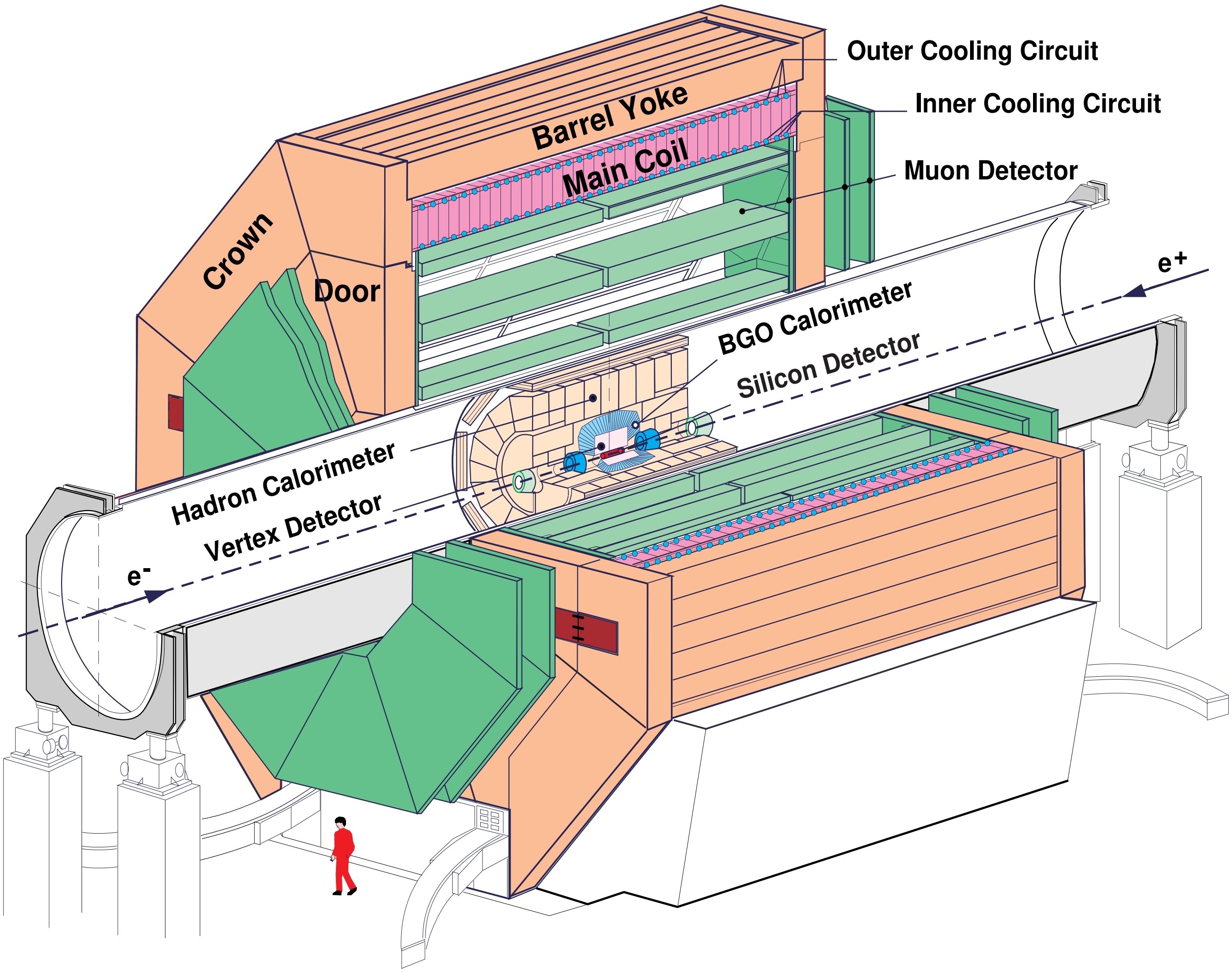


Figure 1: L3 detector

Electromagnetic Calorimeter (ECAL)

BGO crystall matrix calorimeter

Hadron Calorimeter (HCAL)

uranium absorber with proportional wire chambers

Gas : 80% Ar and 20% CO_2

The Uranium Hadron Calorimeter

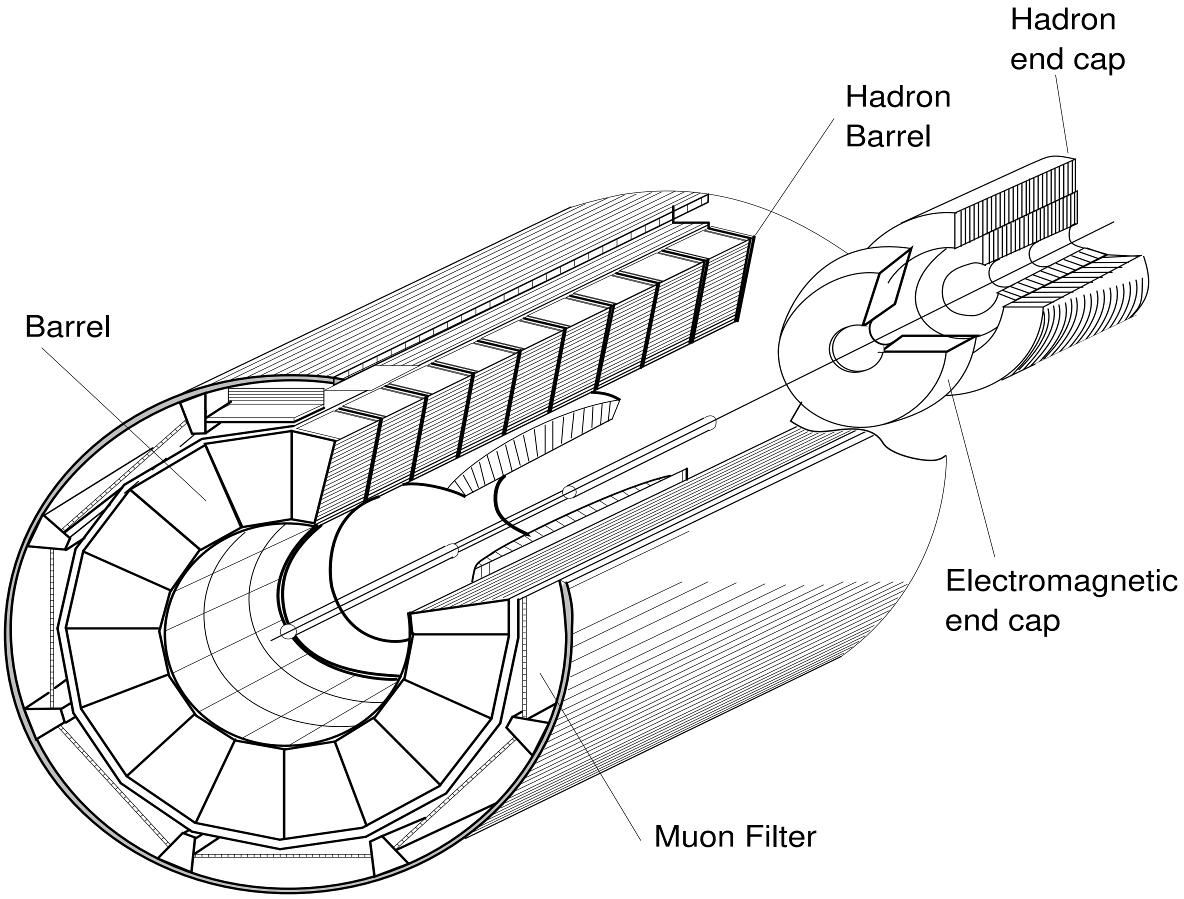


Figure 2: Side view of the L3 detector calorimeters.

L3 Hadron Calorimeter (A Short Biography)

Barrel - IHEP(Beijing), University Of Michigan
ITEP(Moscow), PSI (Wurenlingen), ETH (Zurich)

Endcaps - RWTH-I Aachen, TATA Institute (Bombay)

Muon filter - INFN (Florence) , University of Florence

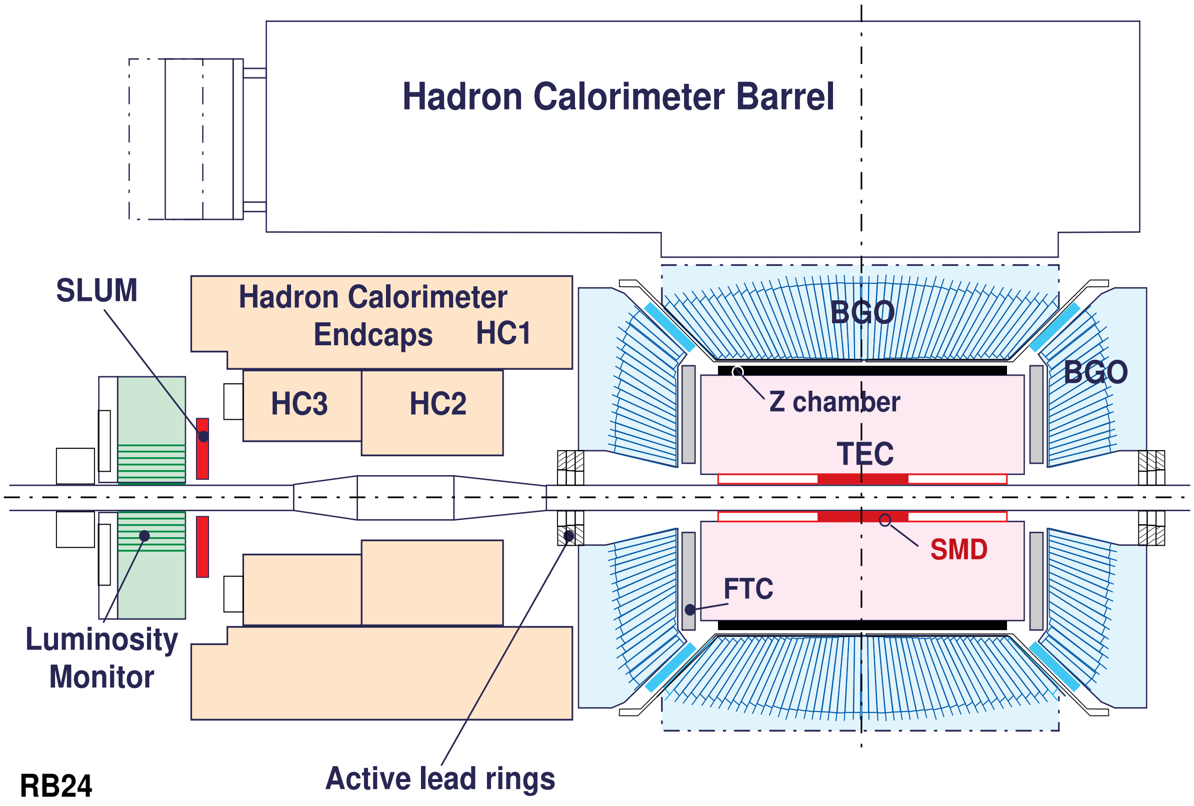


Figure 3: The central region of L3 detector.

The Uranium Hadron Calorimeter

HCAL to measure the energy and direction of hadrons produced in electron-positron interaction, to filter-out showering particles.

Design considerations [year 1984]:

- **limited radial distance available for the hadron calorimeter**
- **absorber with short nuclear interaction length (Uranium $\approx$ 11cm)**
- **the shower sampling detectors - proportional chambers**
  - **relatively easy in mass-production;**
  - **stable, reliable, well understood;**
  - **can operate in magnetic field;**
  - **offers a possibility of grouping the wires in a desired readout pattern, to get good granularity;**
  - **reasonable cost;**

The Uranium Hadron Calorimeter

- **BARREL**

  The barrel consists of 144 modules grouped into 9 rings of 16 modules each

  A module contains proportional wire chambers interleaved with 5 mm uranium plates.

  Modules of 3 central rings contain 60 chambers, modules of 6 outer rings contain 53 chambers.

  The anode wires in odd and even chambers are oriented at right angles, alternately in θ and ϕ directions. The signal wires are grouped into readout cells or towers.

  Subtends a polar angle θ between 25° and 155°

  - **9 rings**
  - **144 modules**
  - **7968 chambers**
  - **22464 towers (readout channels)**
  - **370K wires**

Grouping of wires into towers for ϕ and θ chambers

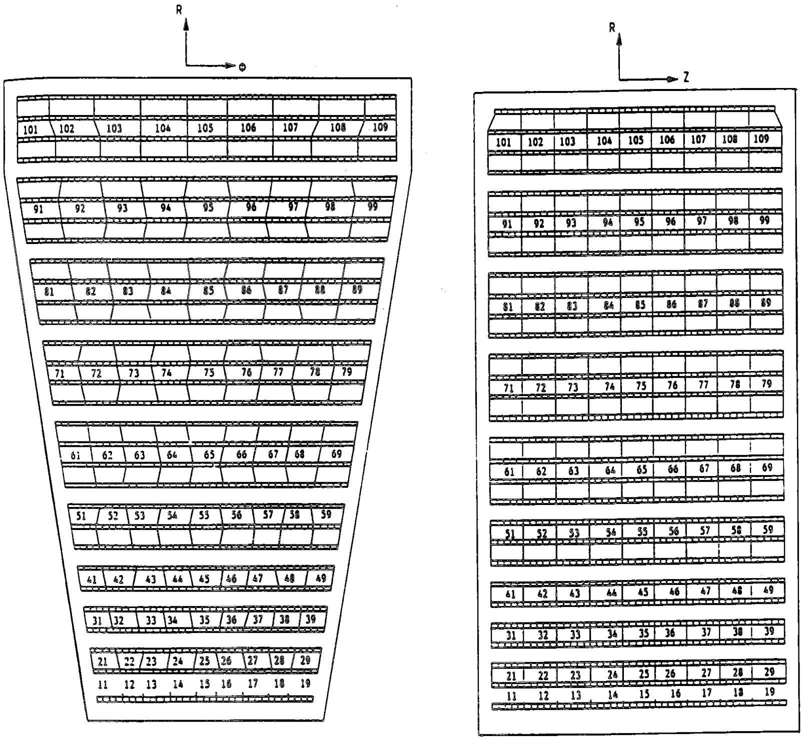


Figure 4: HCAL modules.

The Uranium Hadron Calorimeter

- **ENDCAPS**

Two HCAL Endcaps (upstream and downstream) are constructed of one outer and two inner rings; each ring is divided vertically into two half-rings. The forward part of the outer ring has the same sampling as the barrel (5 mm absorber). All other parts have a sampling that is twice as coarse (10 mm absorber).

The chamber wires are stretched azimuthally, thus the measuring the polar angle θ directly. Alternate chambers layers are oriented at 22.5° with respect to each other.

Cover polar angles θ
between 5.5° and 35°
and between 145° and 174.5°

readout channels - 3840

The Uranium Hadron Calorimeter

- **Muon Filter (MF)**

The Muon Filter is located outside the barrel and subtends about 85% of 4π in azimuth. ($25^\circ < \theta < 155^\circ$). For structurial reason the copper absorber is used for the muon filter.

The primary functions of the MF are to track muons between the barrel and the muon drift chambers and to absorb the tail of the hadron showers.

readout channels - 4600

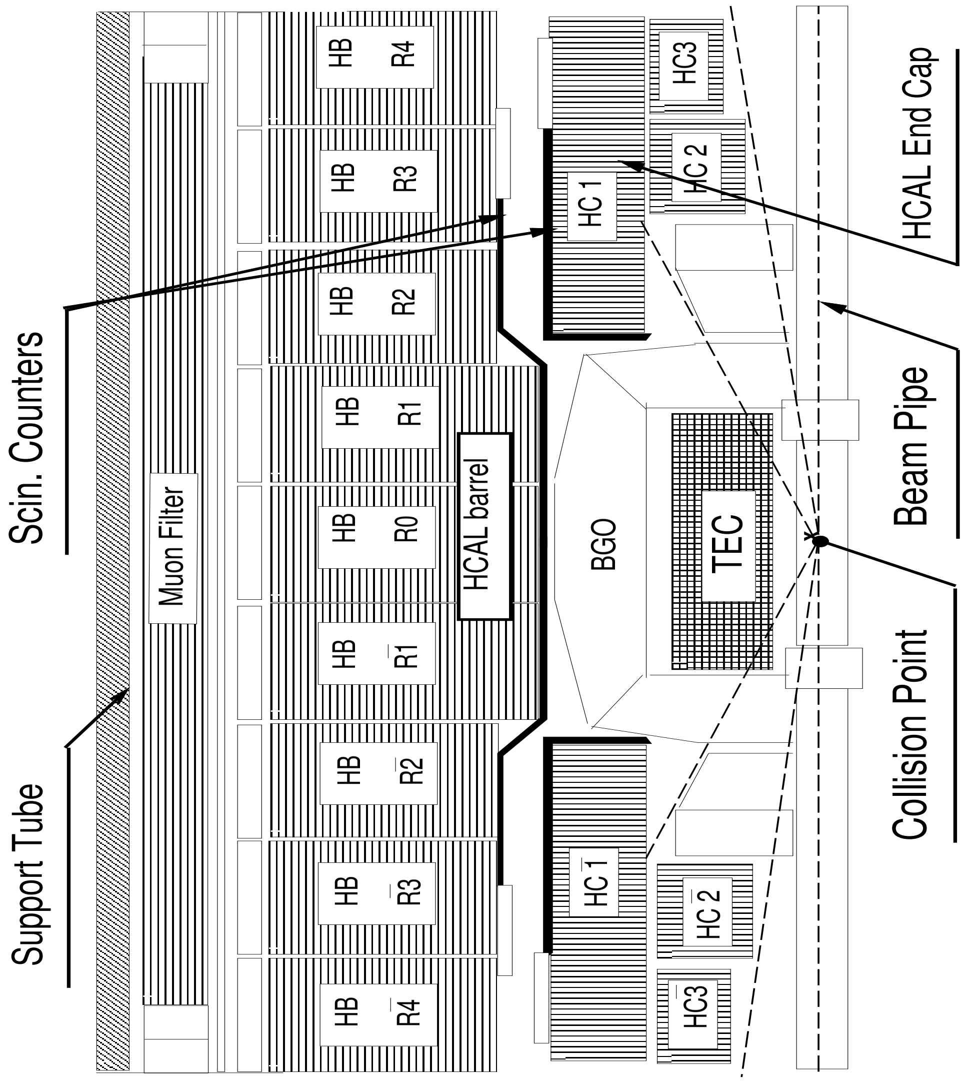


Figure 5: HCAL.

HCAL Readout Electronics

- **Handle signals from a few MeV up to 30 GeV**
- **Operates in 0.5T magnetic field**
- **Low electronic noise 0.5 MeV/channel**

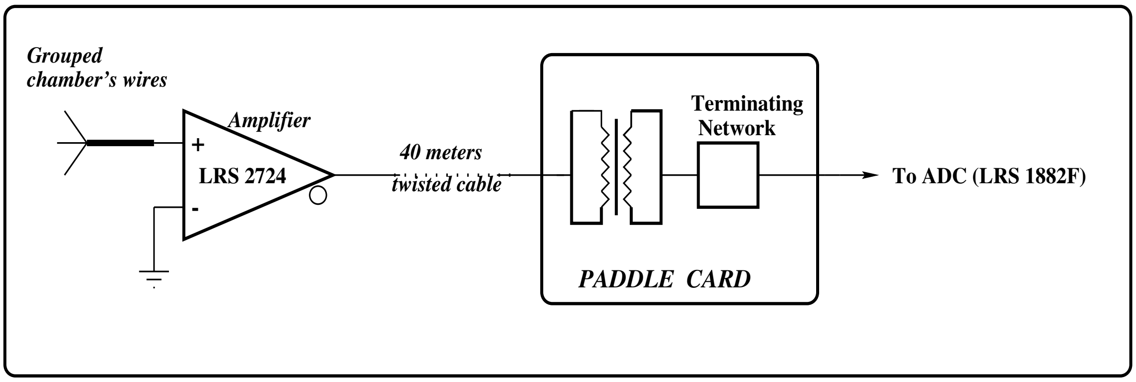


Figure 6: one tower readout channel

After paddle card the signal is splitted into 2 parts :

- **HCAL channel**
- **Analog sum for the energy trigger**

Gain calibration

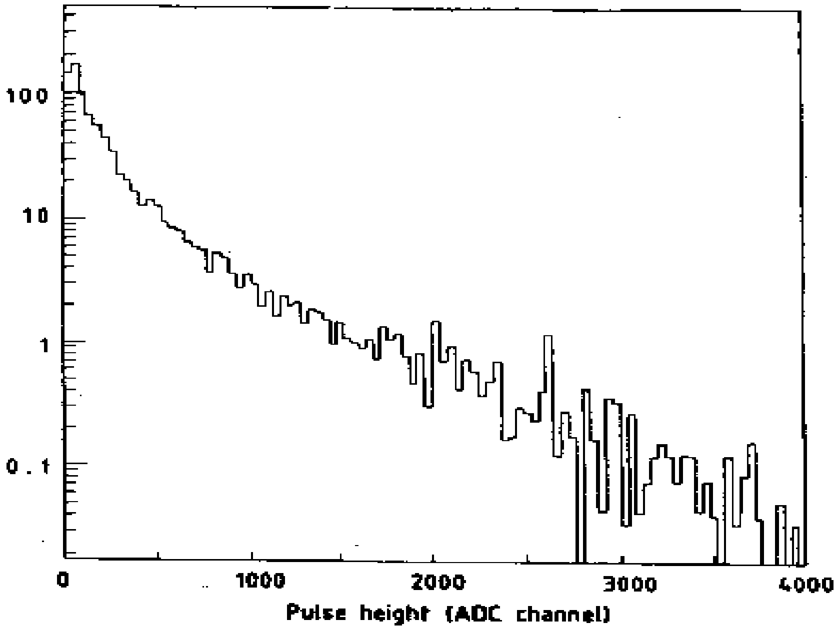
- **We periodically check the gain for each individual group**

The gain depends on the chamber high voltage, the gas density, the gas composition and the amplifier gain. The HV and chamber gas are continuosly monitored and held constant within 0.1% *and* 0.7%.
No drift of the amplifiers is observed.

- **Gain Calibration Method**

The intercalibration of HCAL channels is done using the γ signals from the uranium absorber. The U noise spectrum with random gating has a unique shape, the spectrum for each channel is fitted to a high-statistics reference spectrum. The parameters of the fit reflect the system gain (chamber and amplifier) with an occuracy of better than 2%.

Uranium calibration run is taken approximately 3 times per year



The energy spectrum of uranium noise measured in random trigger runs for a single channel in the module.

Figure 7: **The energy spectrum of uranium noise measured in random trigger runs with a single channel in the module**

Gain calibration

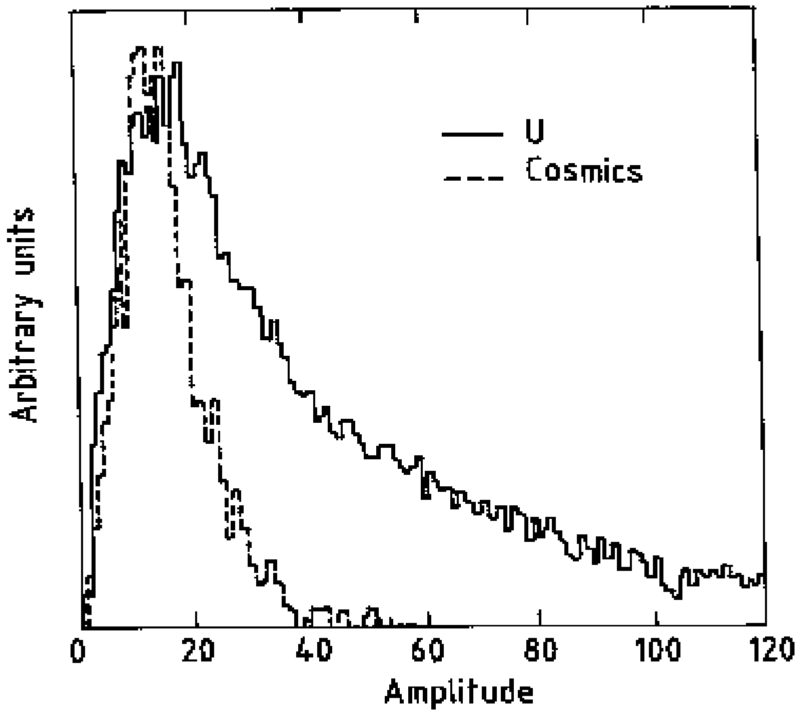


Figure 8: **Uranium induced pulse-height spectrum (full line) compared with cosmic-ray muons(dashed line)**

The Uniformity of Gain

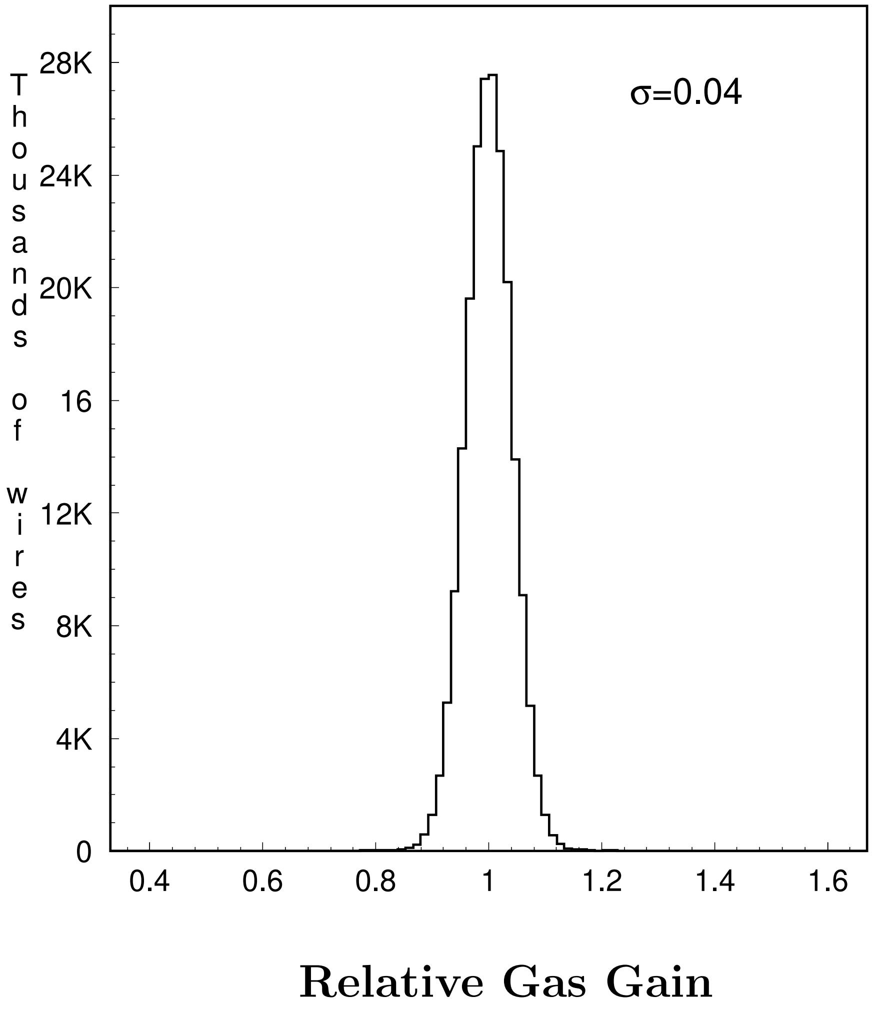


Figure 9: The distribution of the relative gas gain for the wires

Ageing tests

Method 1

With U-plates and increased HV for 6 months.
Lifetime > 10 years

Method 2

With strong radioactive source and nominal HV
Lifetime > 50 years Uranium equivalent

The gain stability for 10 years of running.

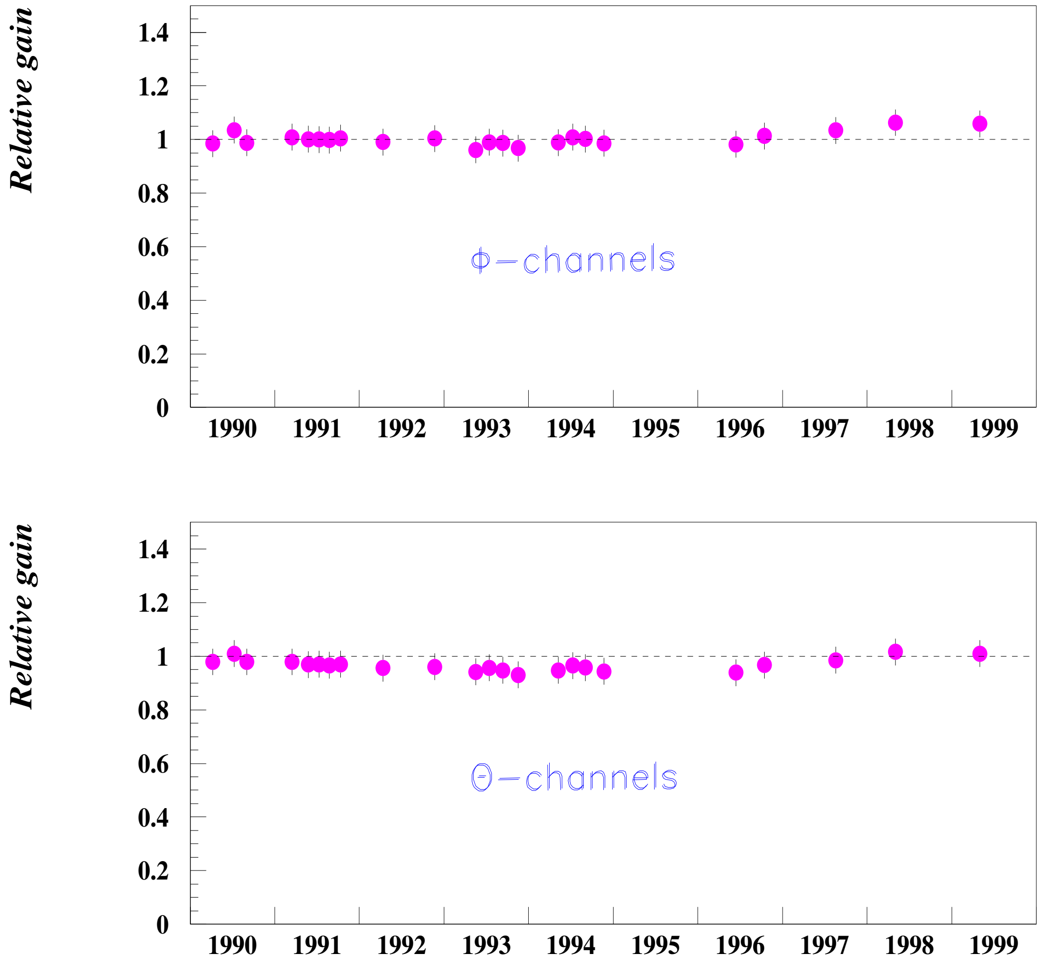


Figure 10: **Average relative gain**

No ageing is observed

Hadron Calorimeter Status

Dead Chambers Statistics

Chambers :	Total number - 7968
dead during assembling	74
1989	18
1990	7
1991	9
1992	10
1993	5
1994	9
1995	5
1996	-
1997	2
1998	2
1999	-

Total 141/7968 = 1.8%

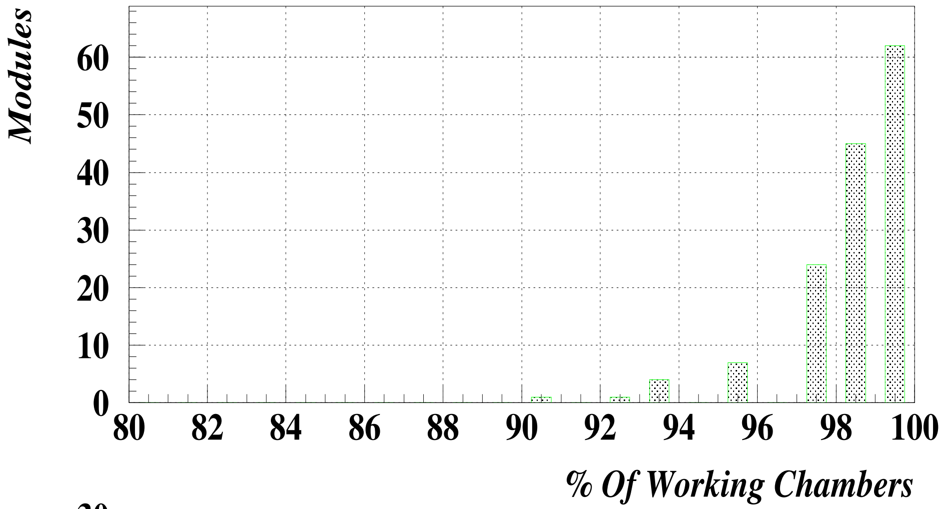
Channels: Total number - 22464

single channel dead	112
bad cable connection	97
because of dead chamber	81

Total 290/22464 = 1.3%

Number of dead chambers in HCAL Barrel :

Upper part	73	Lower part	68
Left part	69	Right part	72



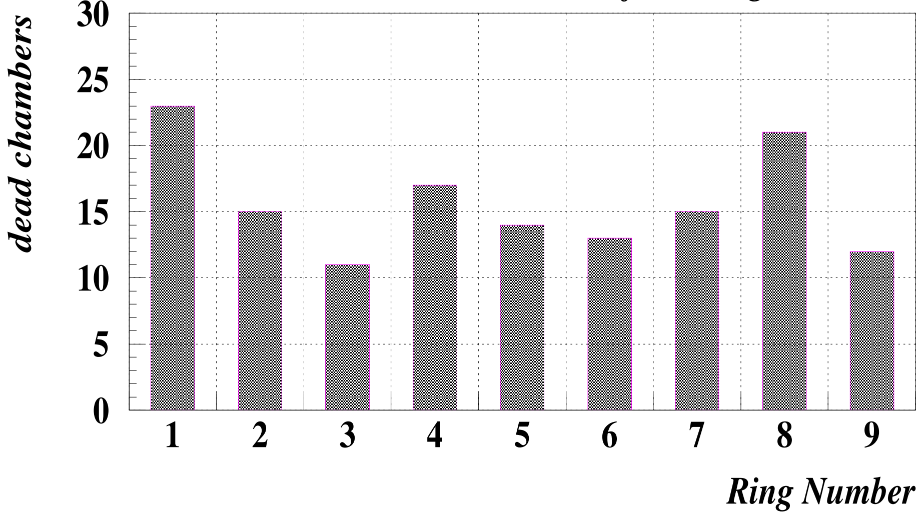
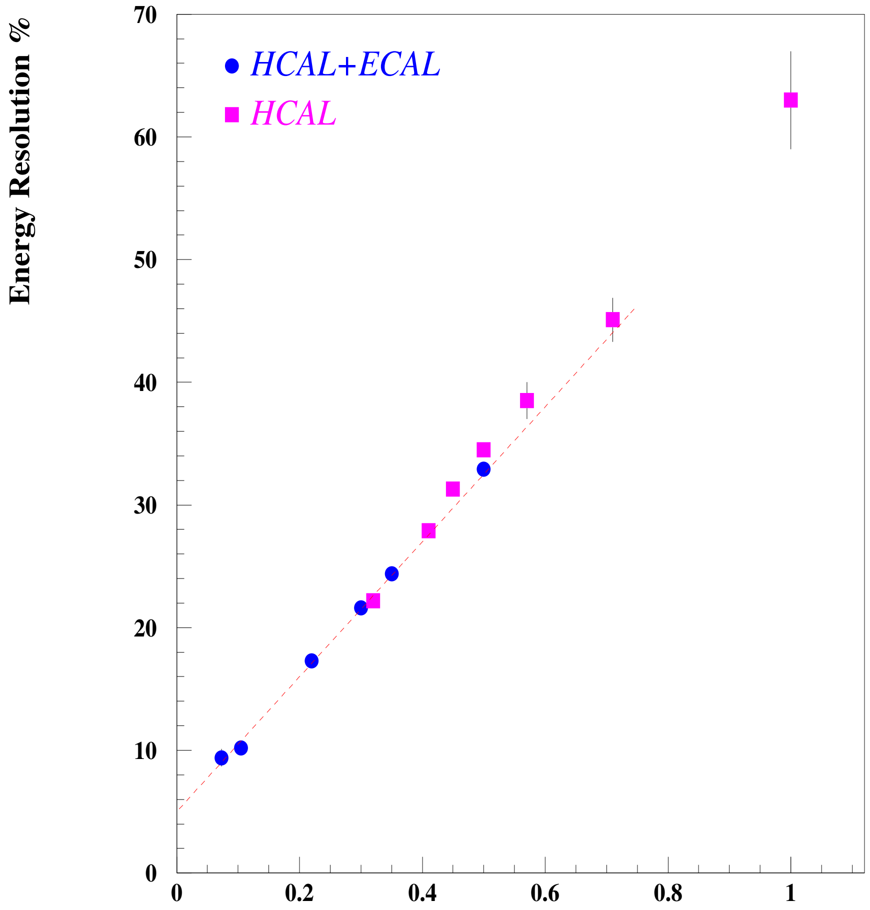


Figure 11: Fraction of dead/working chambers in rings/modules

Energy Resolution

HCAL modules were tested in beams of hadrons, electrons and muons. The measured energy resolution for HCAL and Electromagnetic calorimeter system for hadrons was found to fit $\sigma/\mathbf{E} = (\mathbf{55}/\sqrt{\mathbf{E}} + \mathbf{5})\%$, where E is in GeV.



$1/\sqrt{E}$ (GeV)

Figure 12:

Energy Resolution

Energy calibration of L3 calorimeter is done by scanning the detector by two back-to-back jets of known energy (91 GeV) and with the event thrust polar angle $5.5° < \theta < 174.5°$. The observed overall energy resolution for the central region is 10.2%.

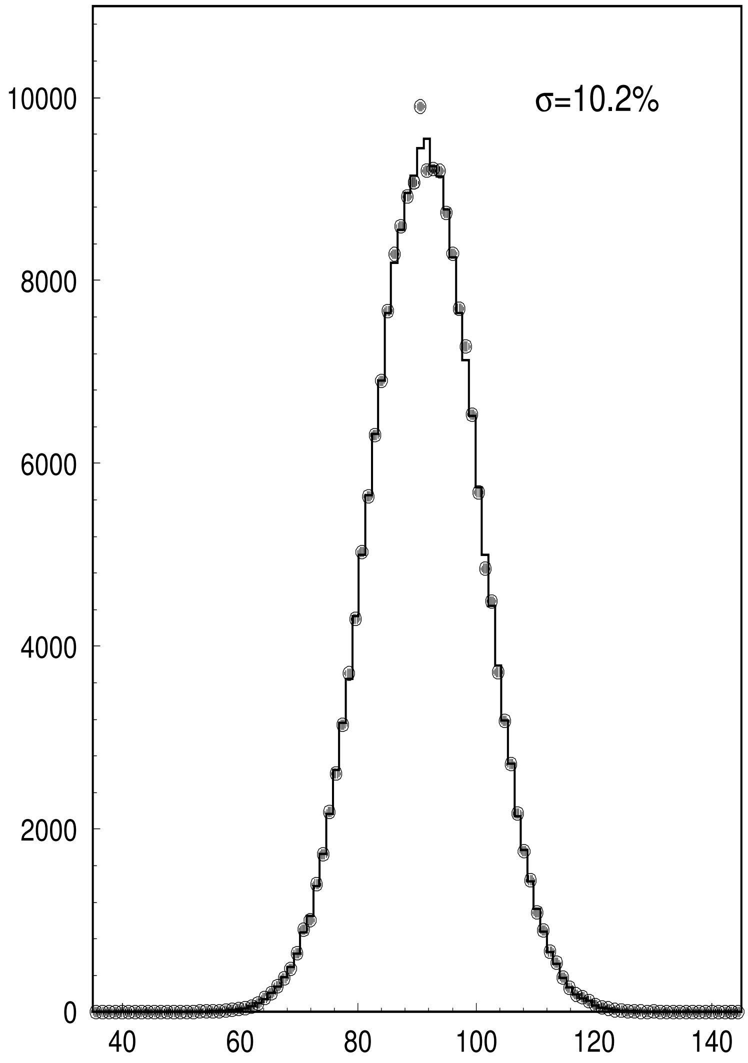


Figure 13: The distribution of the total energy for two-jet hadronic events.

Energy Resolution

The calorimeter energy resolution for hadronic events as a function of angle θ of the thrust axis.

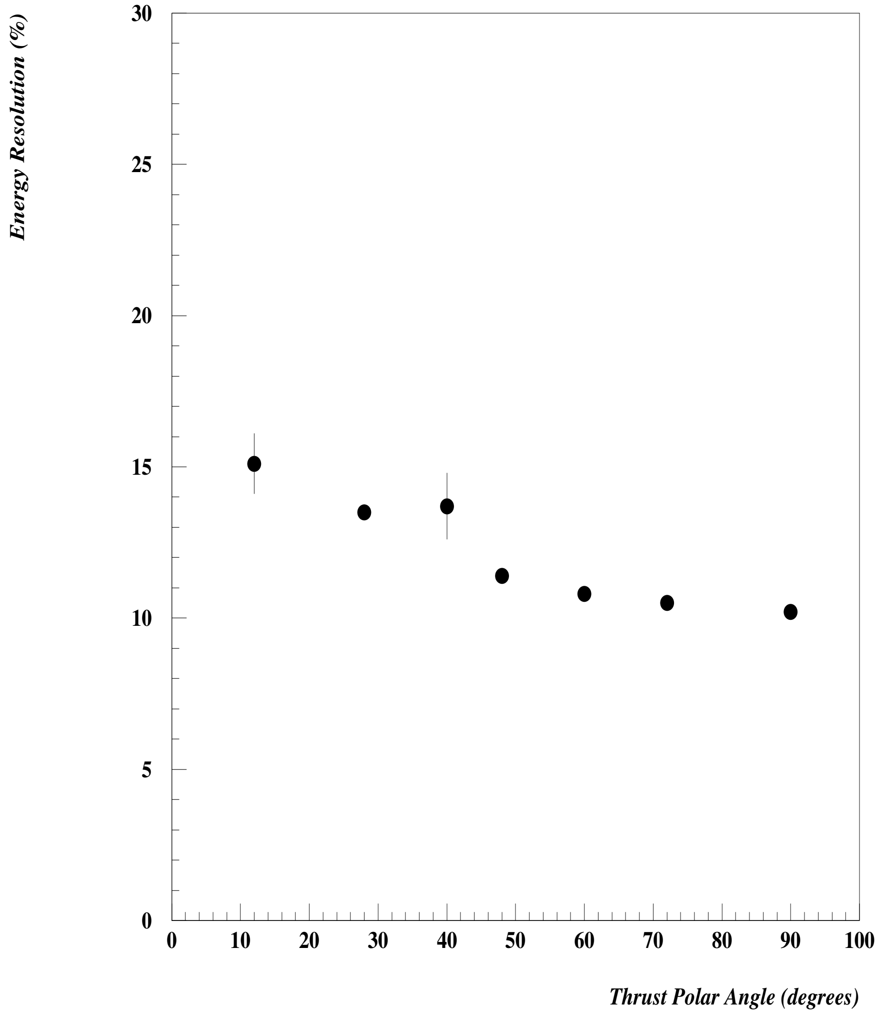


Figure 14:

$\mathbf{Z^0} \to \mu^+\mu^-$

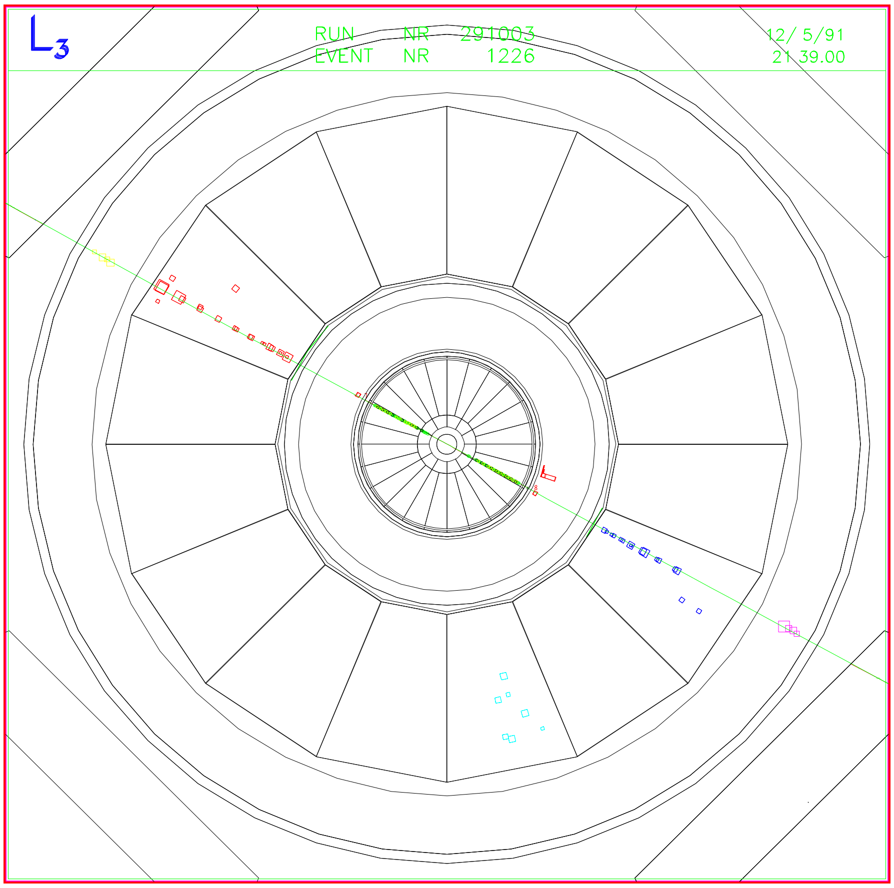


Figure 15: $Z^0 \to \mu^+\mu^-$.

$\mathbf{Z^0 \rightarrow q\bar{q}}$

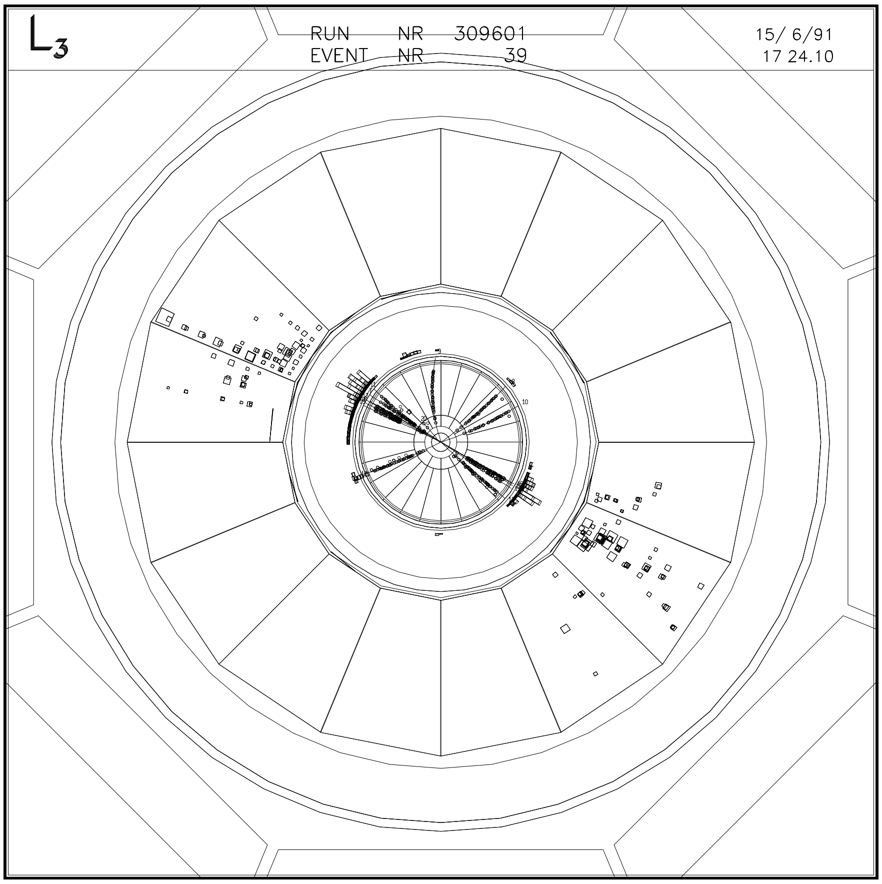


Figure 16: $Z^0 \rightarrow q\bar{q}$.

Cosmic

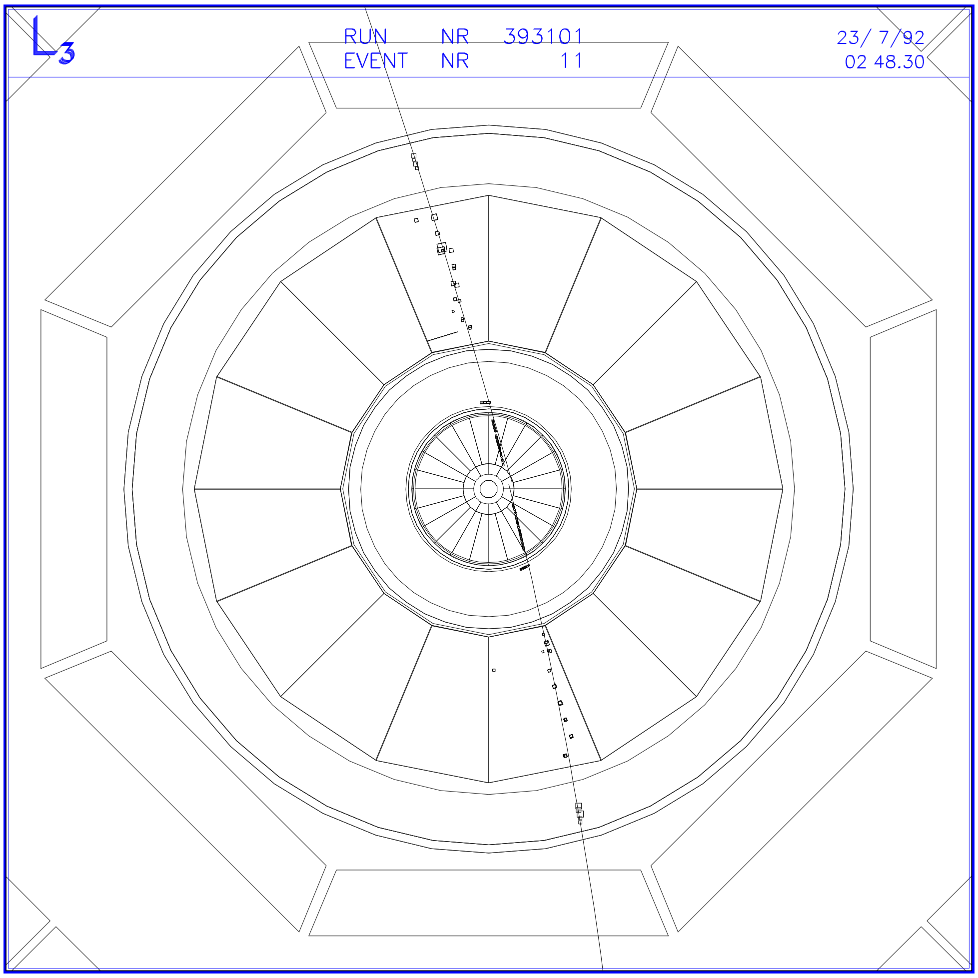


Figure 17: *Cosmic.*

HCAL on LEP II

In 1995 the centre-of-mass energy at LEP was increased to 140GeV, 1996 - 161-172GeV, 1997 - 183GeV, 1998 - 189 GeV, 1999-2000 - 192-200GeV and we expected 150 pb^{-1} per year
June 08, 1999, first 196 GeV fill.

The hadron calorimeter played the crucial role :

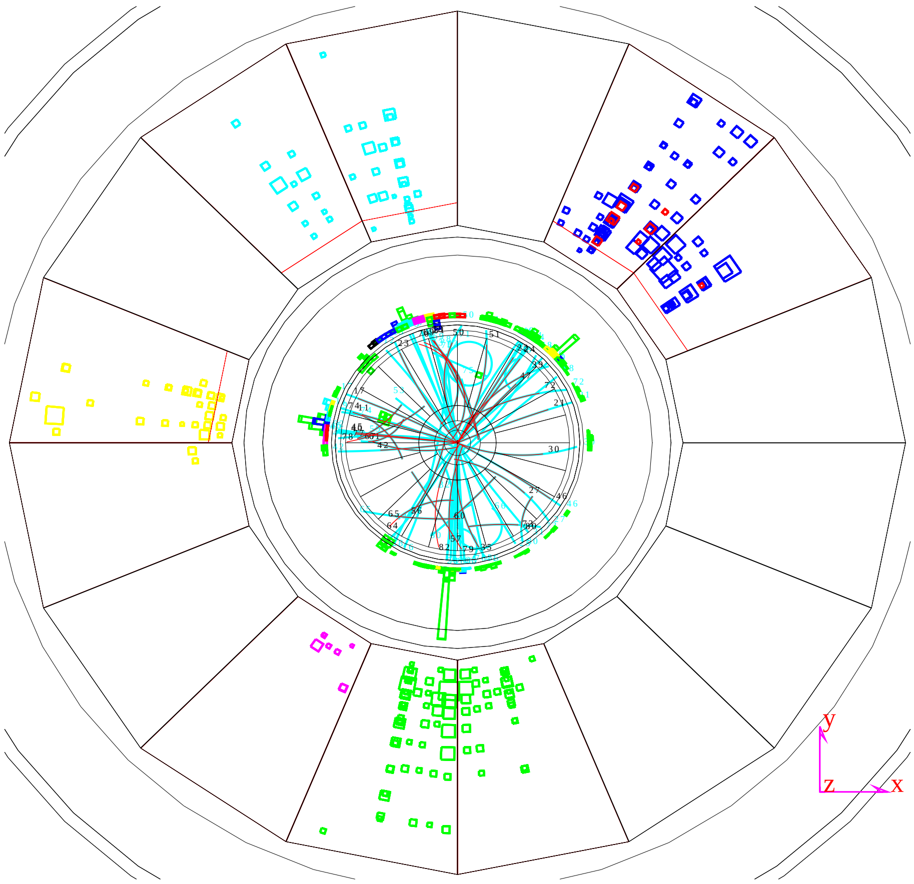
- **in measurement of the mass and width of W boson.**
- **limits on Higgs boson masses;**
- **in studying the main characteristics of hadronic events for testing QCD predictions and checking the validity of QCD models.**

Energy resolution for central part of L3 calorimeter for 189 GeV was measured to be

$$9.4 \pm 0.7\%$$

$e^+e^- \to W^+W^- \to qqqq$

Run # **714301** **Event #** **2096** Total Energy : 200.75 GeV

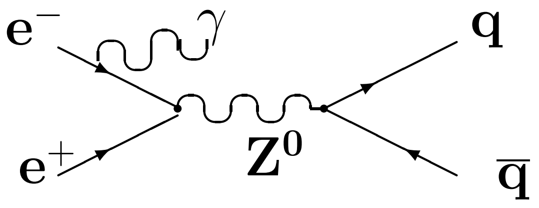


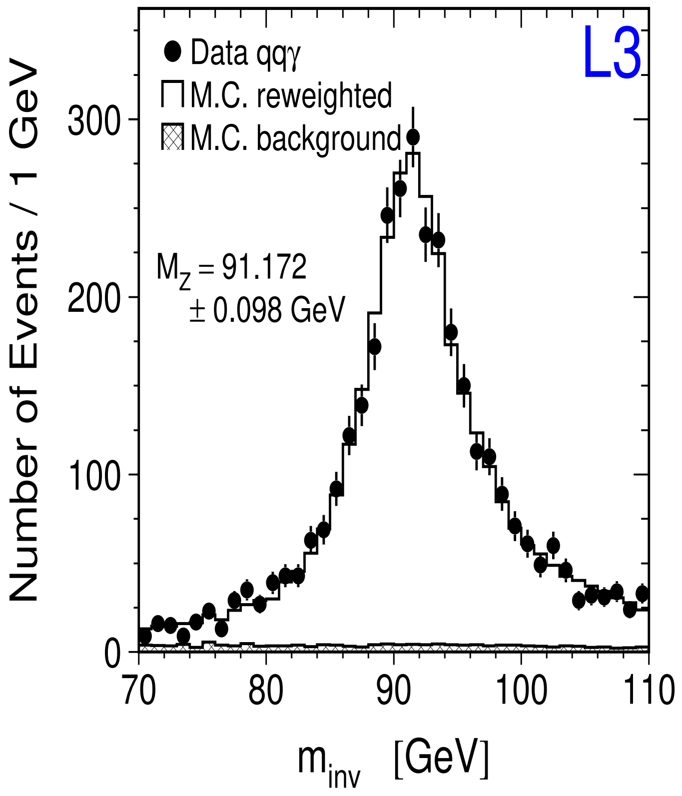
Transverse Imbalance :	.0352		**Longitudinal Imbalance :**	-.0157	
Thrust :	.6797	**Major :**	.5449	**Minor :**	.1580
Event DAQ Time :	*980811 112827*				

Figure 18: $e^+e^- \to W^+W^- \to qqqq$.

Direct Reconstruction of M_z with $q\bar{q}\gamma$

$e^+e^- \rightarrow q\bar{q}\gamma$ selected at $\sqrt{s} = 183\mathrm{GeV}$





(L3 at LEP I : $M_z = 91.195 \pm 0.009\mathrm{GeV}$)

Conclusions

- **The L3 Hadron Calorimeter is operating successfully since August 1989. It is robust and stable detector, producing a first class physics.**

- **The longterm overall stability of the chamber gain, readout and electronics is found to be better than 5%**

- **The observed energy resolution of central part of L3 calorimetry system is 10.2% for hadron jets from Z-decay**

Acknoledgements

Many thanks to A.Arefiev, V.Choutko, E.Choumilov, I.Vorobiev and C.Luci for their help in preparing this talk and useful contributions.