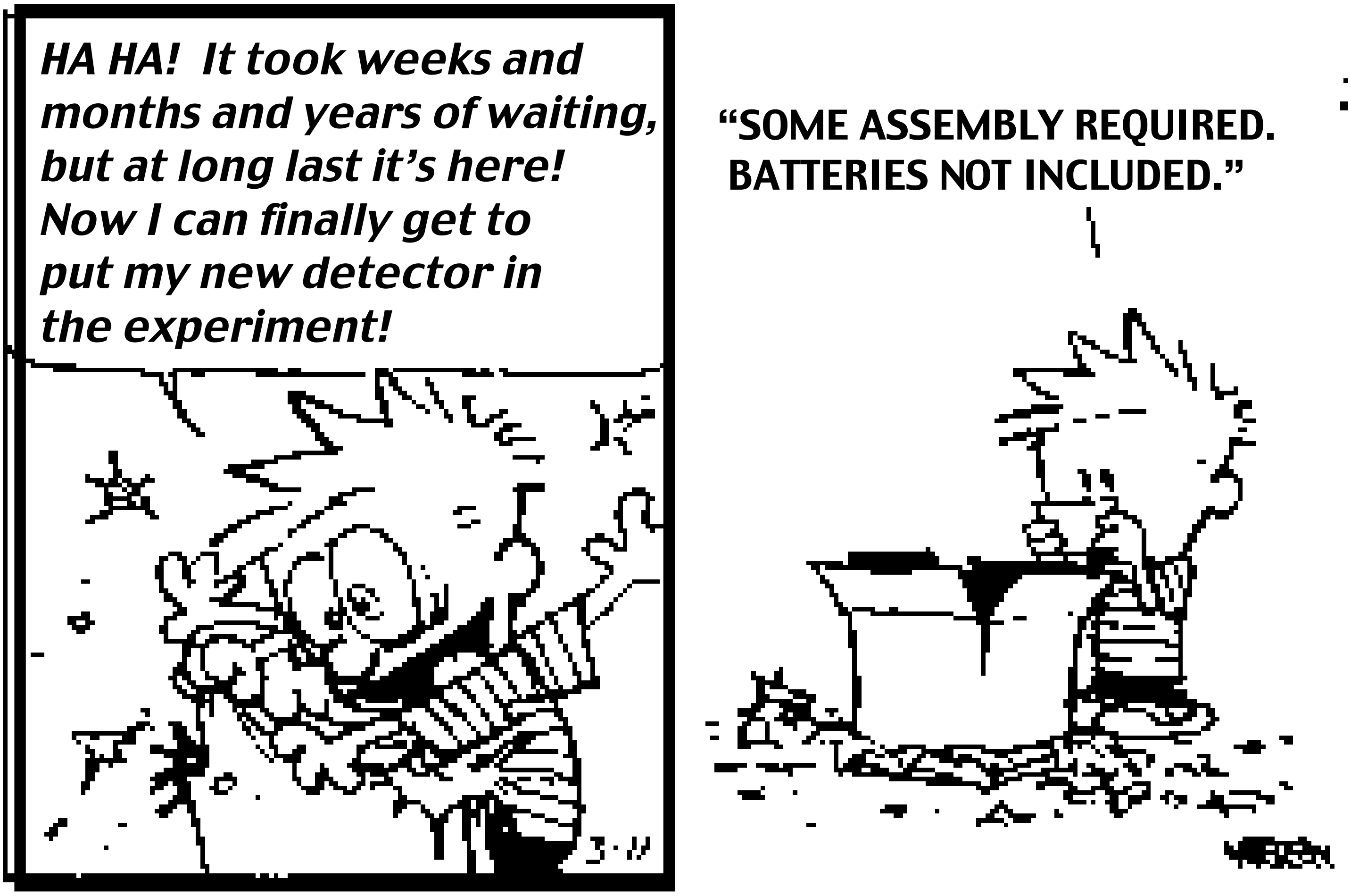
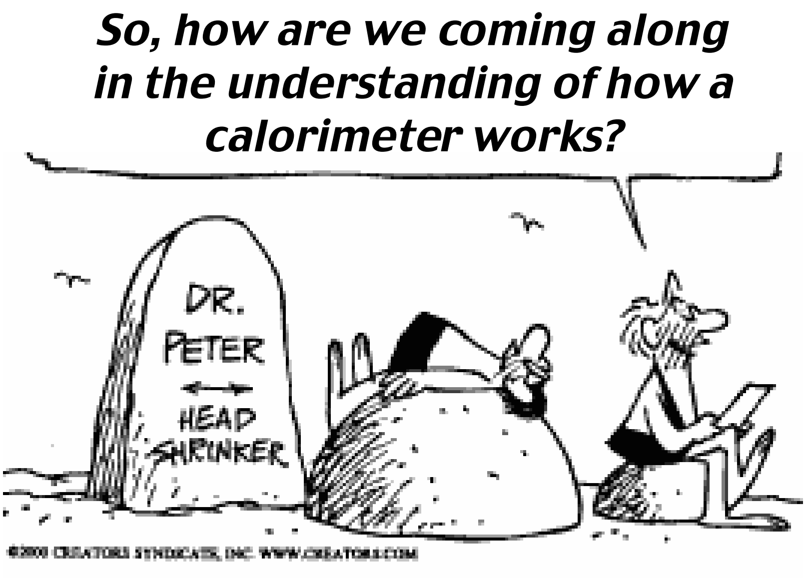
Particle Identification and Calorimeters at LEP

RICH Counters
BGO Crystals
dE/dX Measurements
Si/W Luminosity monitors

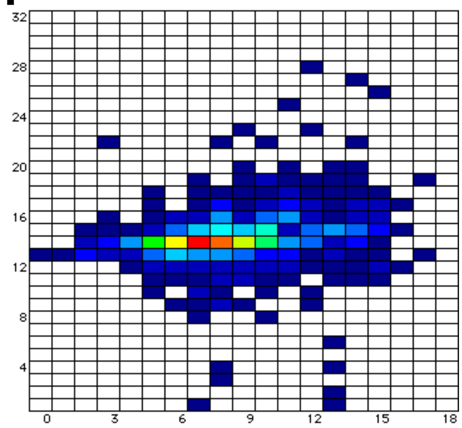


Olav Ullaland EP CERN 11 October 2000



A calorimeter is a class of detectors that measures the energy and the position of the particles through total absorption in these devices.

It is a rather destructive method.
For the particle.



The energy resolution of a calorimeter is usually parameterized as

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

a **is the stochastic term**
b **is the constant term**
c **is the electronic noise contribution**

For the class

Homogeneous calorimeters

the scintillating crystals are virtually free from intrinsic fluctuations.

We then get

$$\frac{\sigma}{E} = \frac{1}{\sqrt{N_{pe}}} = \frac{1}{\sqrt{E(GeV)} \times \sqrt{N_{pe}/GeV}}$$

N_{pe}/GeV is observed number of photons per energy unit.

To get this number the absolute light yield, the number of emitted photons for each energy unit, has to be multiplied with

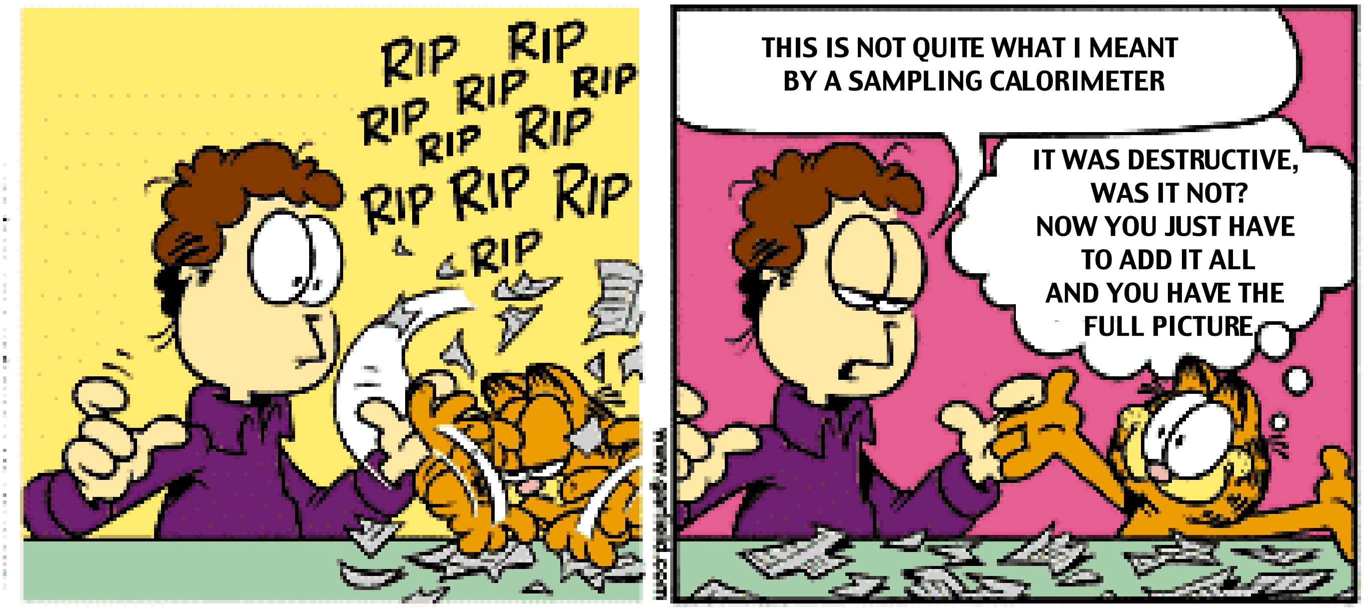
- light collection efficiency
- geometrical efficiency of the photon detector
- quantum efficiency integrated over the emission spectrum
- ....

And then we have the

- Lateral leakage
- The punch through
- The material in front of the detector

which does not help.

For the moment, we will not discuss the sampling calorimeters at LEP.



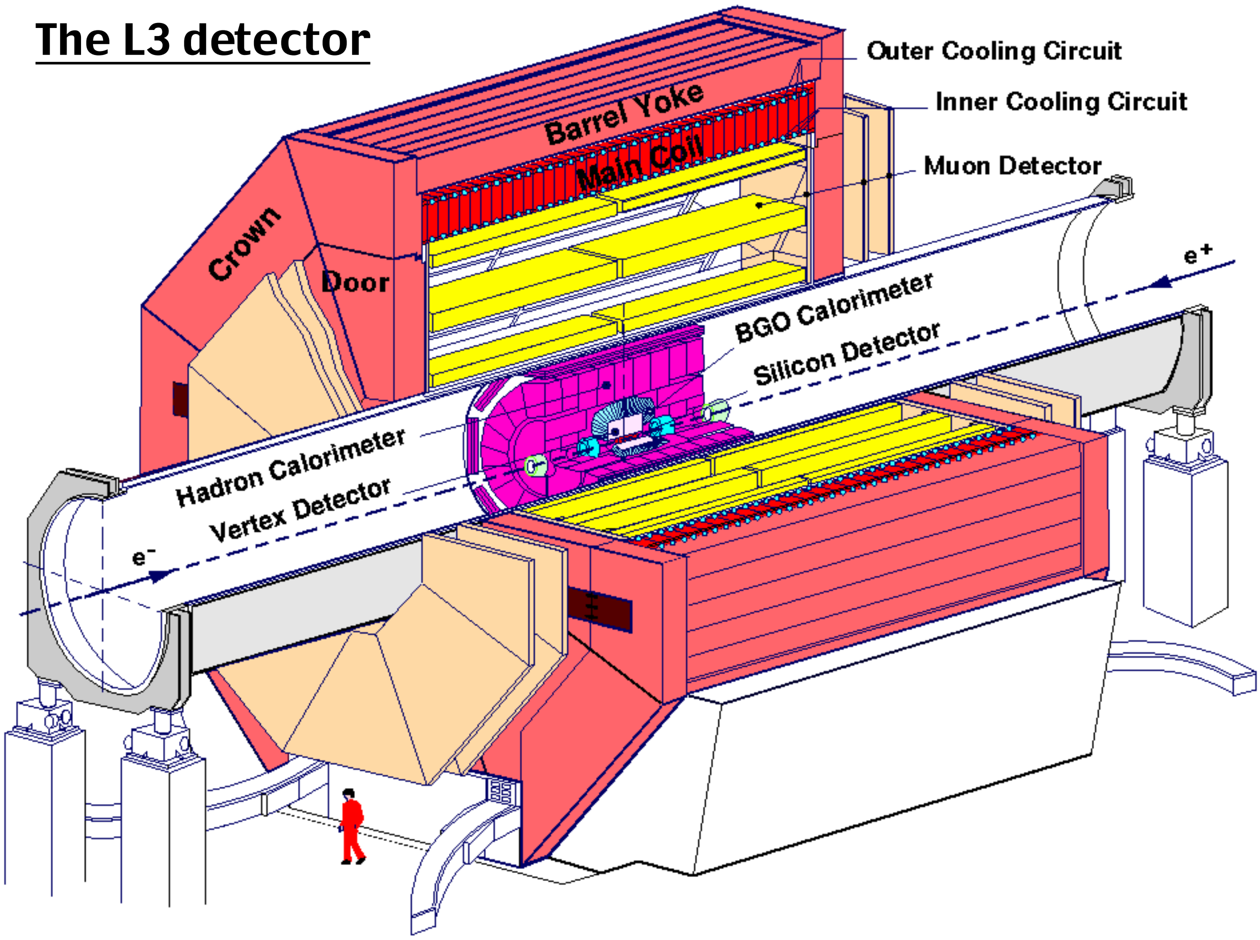
They have their own features.

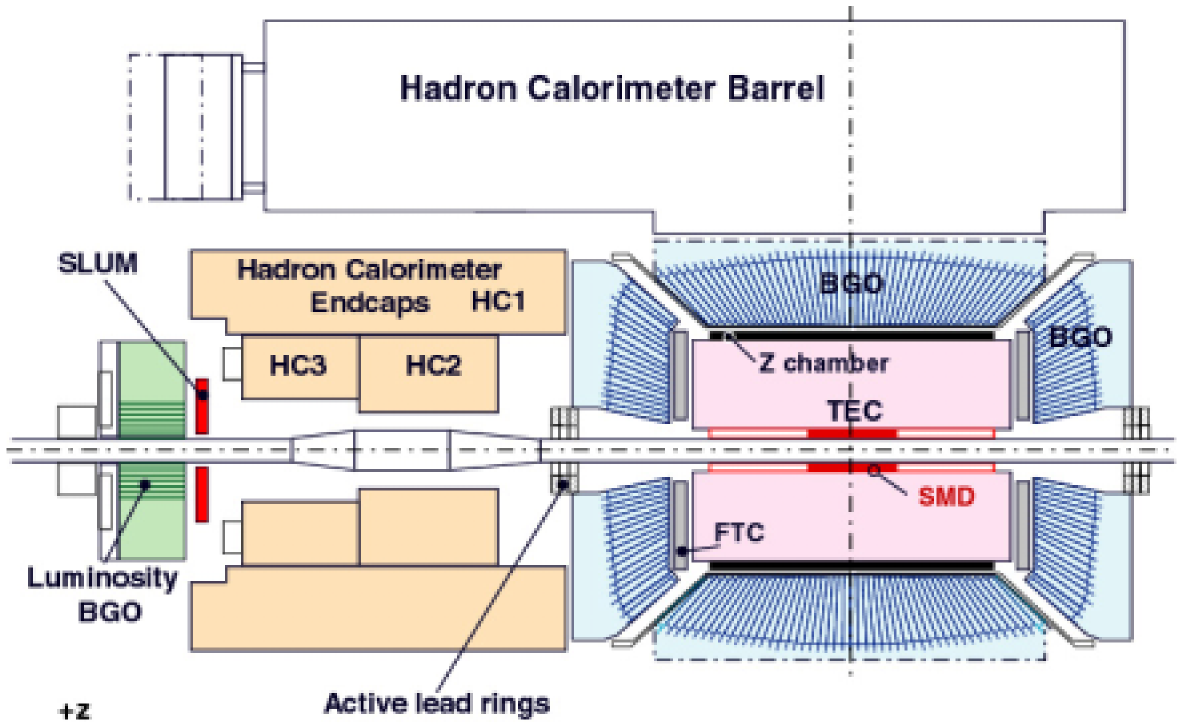
The L3 collaboration set out to make an electromagnetic calorimeter with

- **Best obtainable E resolution for *e*, γ from 50 MeV to 50 Gev**
- **Good angular resolution for γ down to 50 MeV**
- **Hadron rejection around 10^3 for *e* >1 GeV**
- **Good separation between *e*, γ showers in narrow jets**

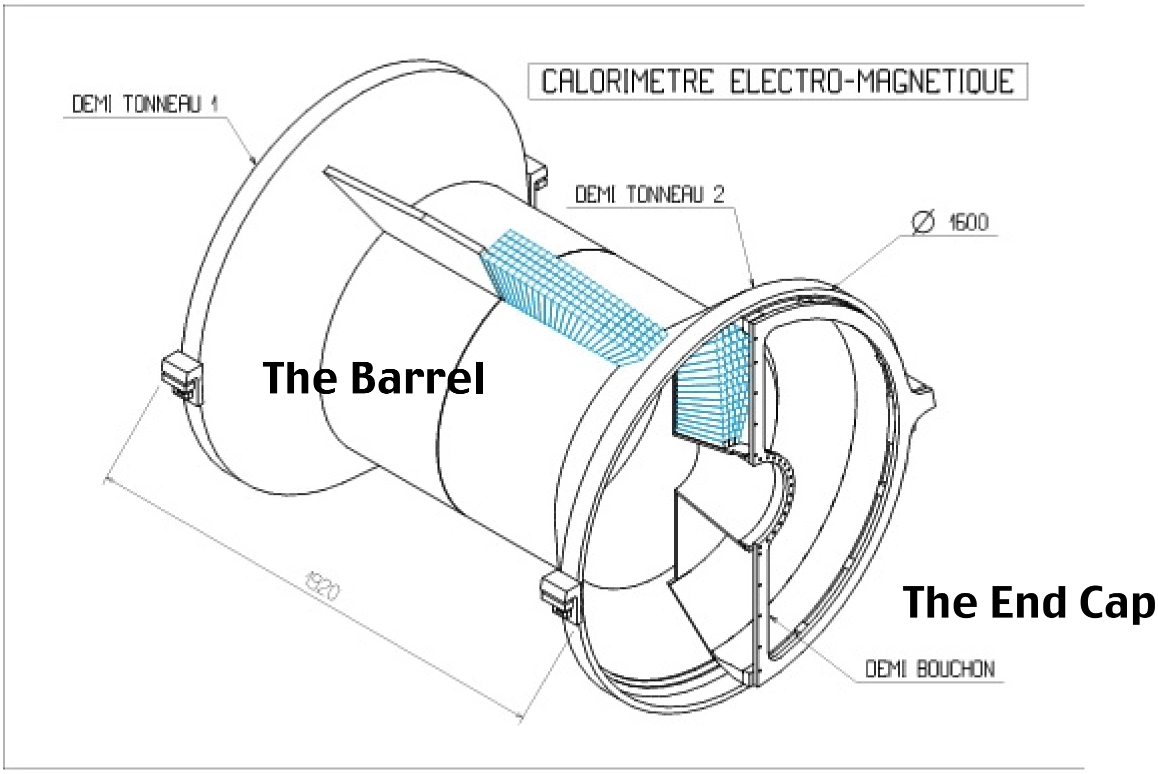
Crystal		BGO	CsI:Tl	CsI	PWO	NaI:Tl
Density	g/cm^3	7.13	4.53	4.53	8.26	3.67
Radiation length	cm	1.12	1.85	1.85	0.89	2.59
Wave length	nm	480	565	310	420	410
Light yield	% of NaI	10	85	7	0.2	100
Decay time	ns	300	1000	6+35	5+15+100	250
Temp. dependence	%/°C @18°	-1.6	0.3	-0.6	-1.9	0
Refr. index		2.15	1.8	1.8	2.29	1.85

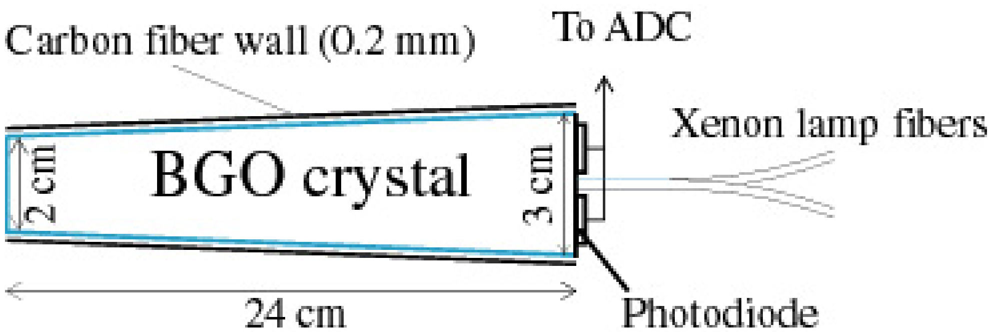
The L3 detector





The L3 Electromagnetic calorimeter BGO
Bismuth Germanium Oxide $Bi_4Ge_3O_{12}$





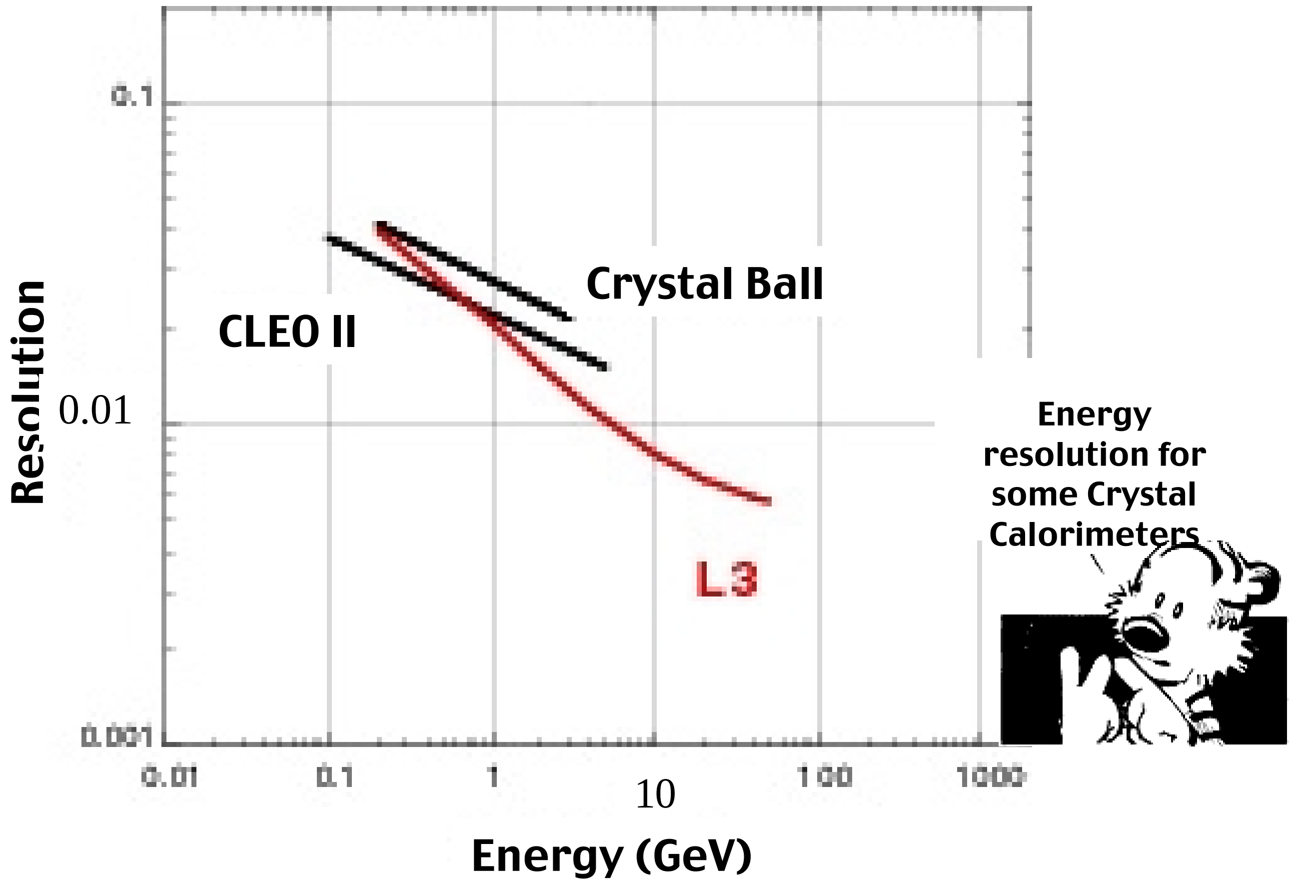
24 crystals in θ and 160 in ϕ in each half barrel.

- **7680 Crystals**

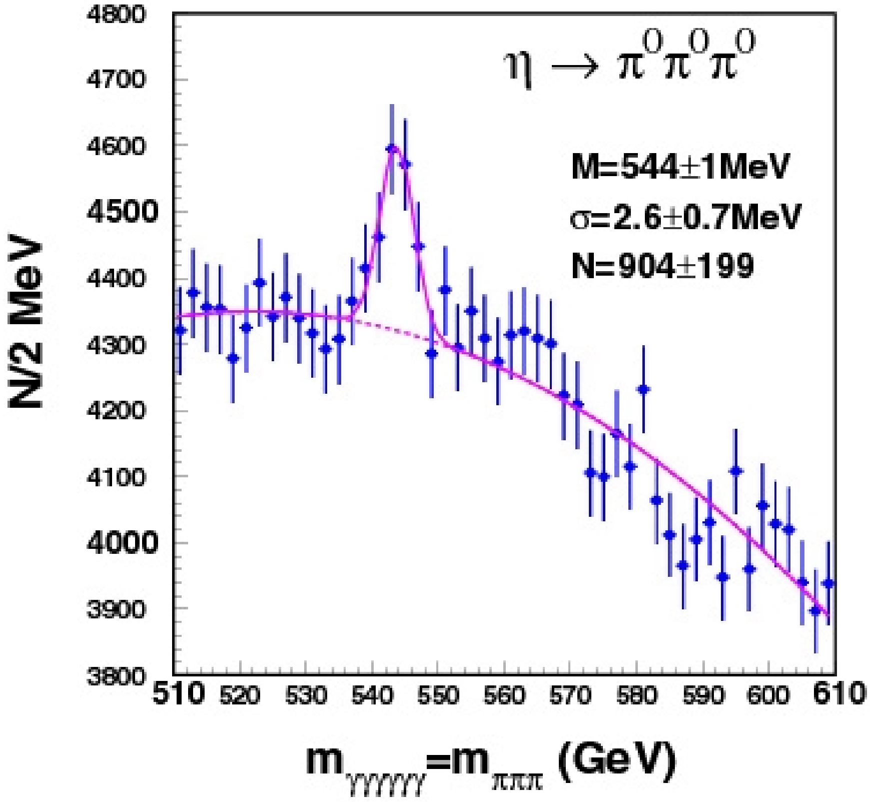
ϕ slices ranging from 48 to 128 across 17 radial segments in the End Caps

- **3054 Crystals**

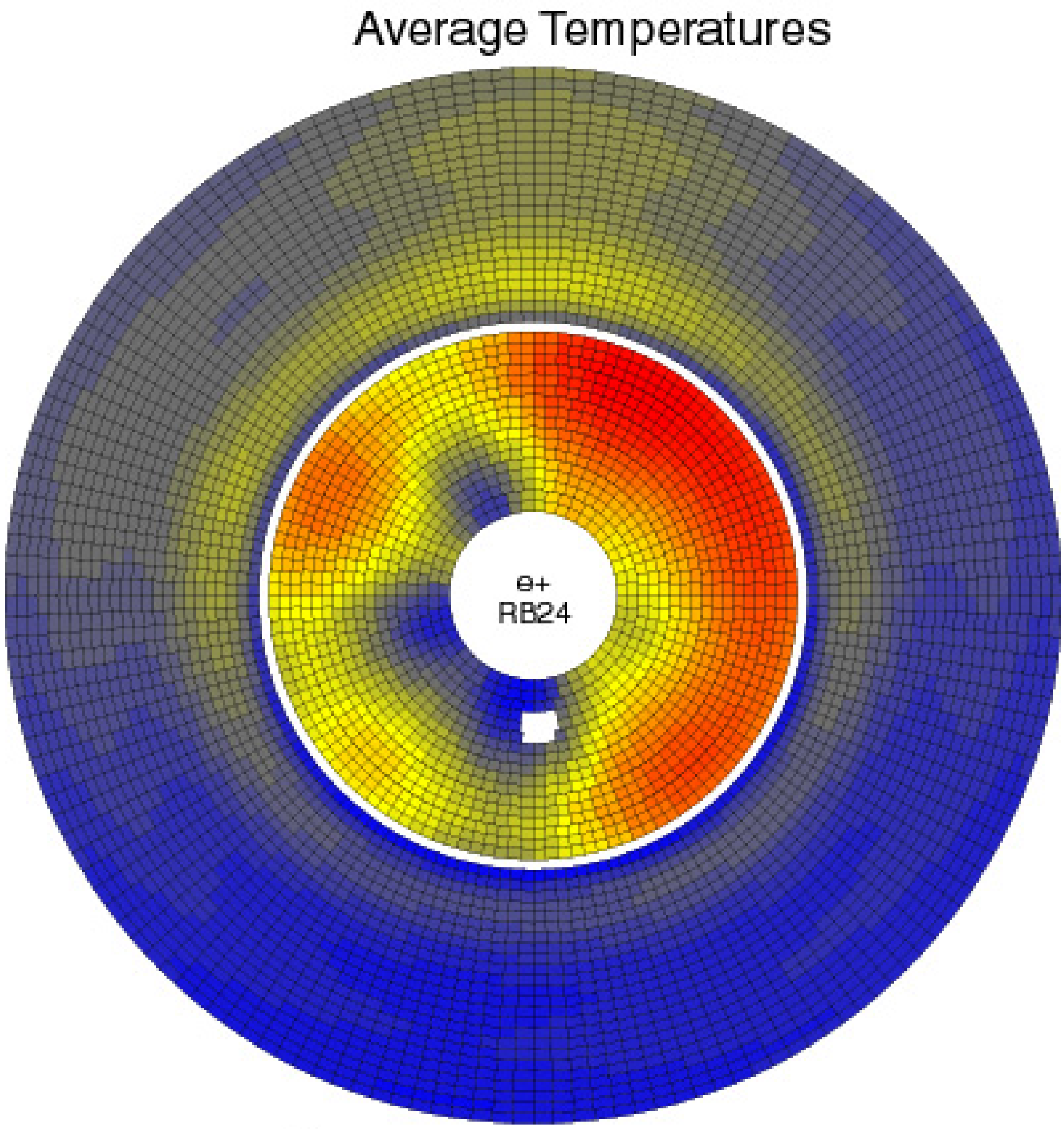
L3, Beijing Calorimetry Symposium,1994

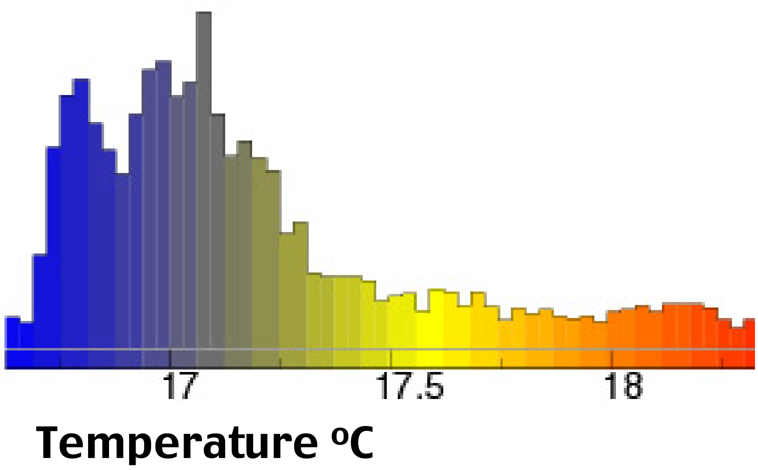


E. Longo, Calorimetry with Crystals, submitted to World Scientific, 1999



L3, Beijing Calorimetry Symposium,1994





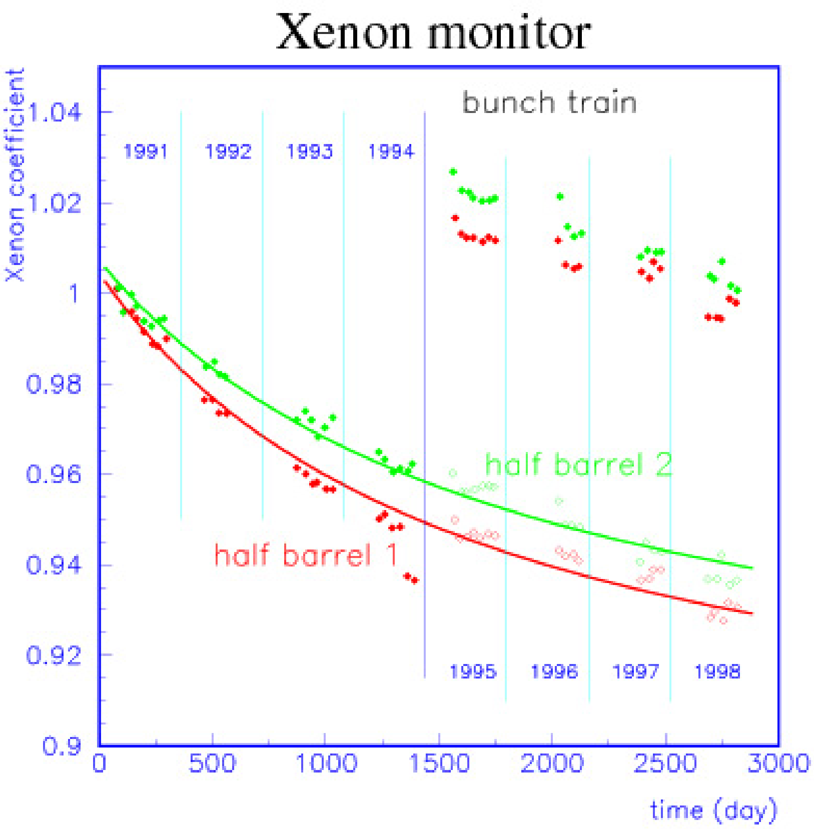
L3, Beijing Calorimetry Symposium,1994

To keep all parameters under control, a massive amount of calibration has been done

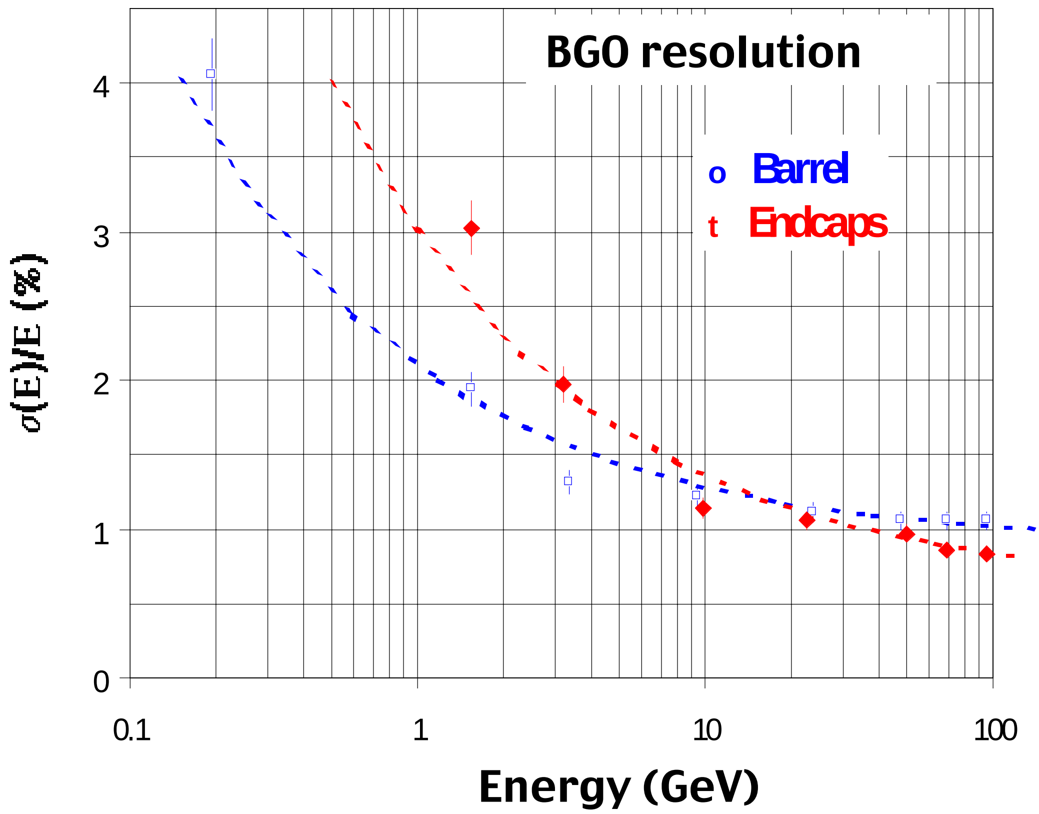
- **All crystals were measured in a cosmic ray bench**
- **most crystals were measured in an electron beam at 2, 10, 50 GeV**
- **Half the Barrel was measured in an electron beam at 180 MeV**
- **Each crystal was calibrated in their final support**

During LEP running:

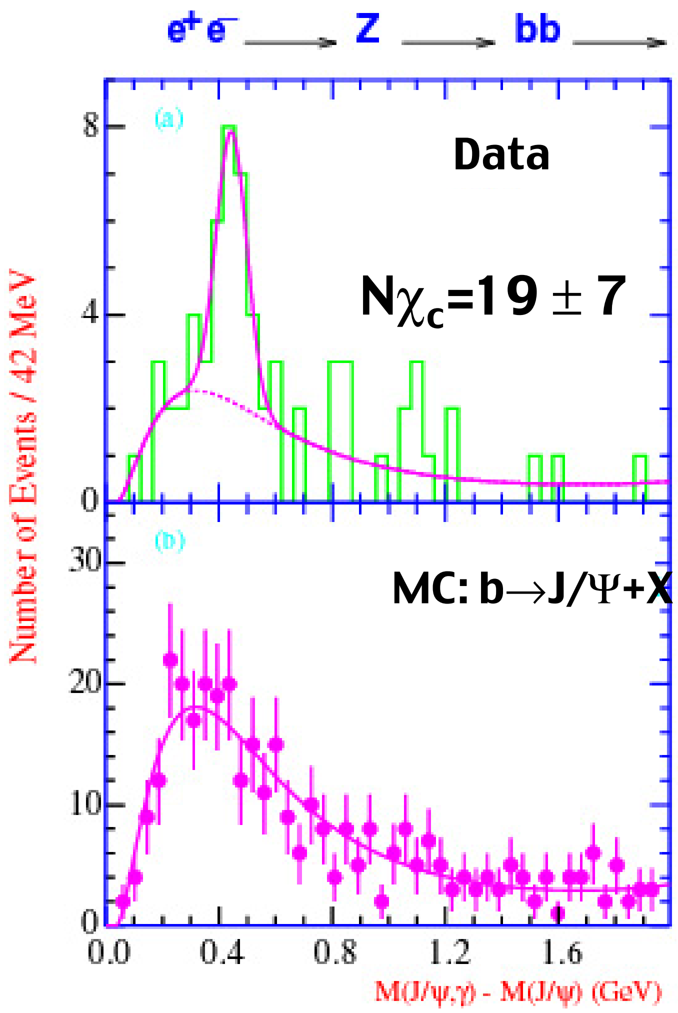
- **The Xenon monitoring system**
- **The Radio Frequency Quadruple (RFQ) system**
- **Cosmic muons**
- **LEP data with Bhabha, MIPs and π^0**



L3, CALOR99



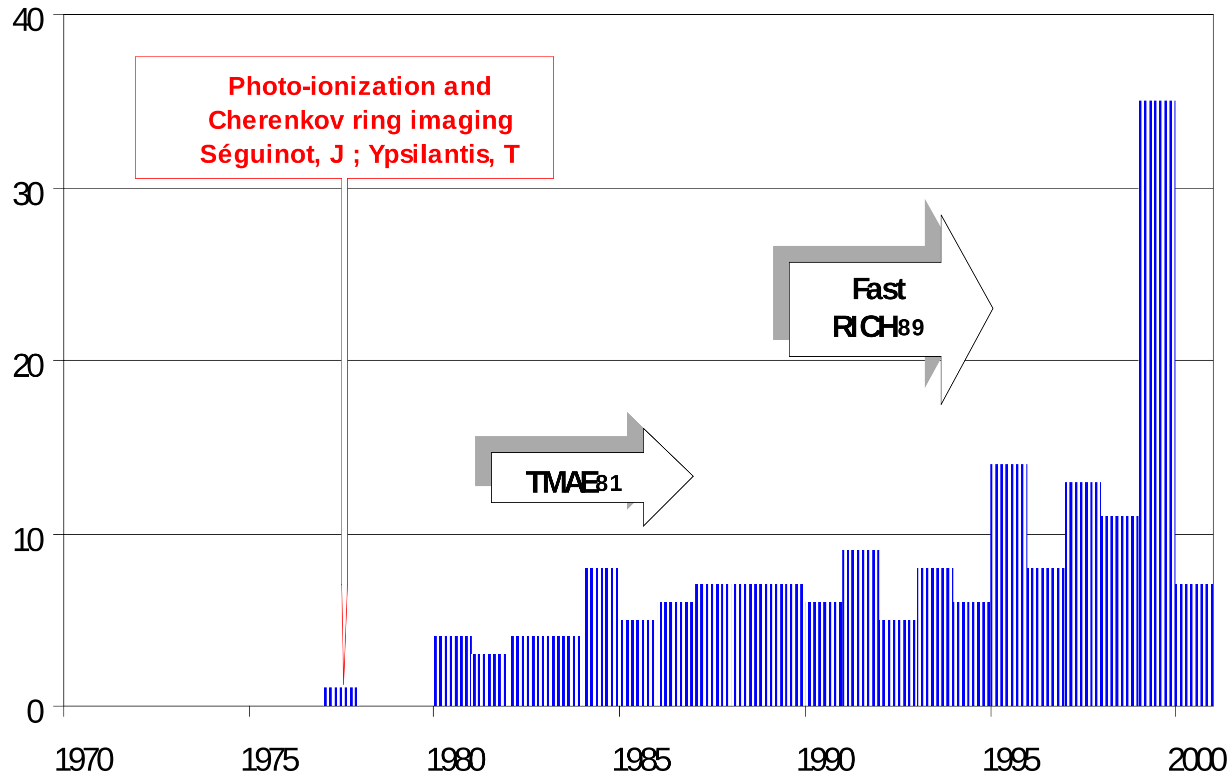
L3, NIM 78(1999)465



L3, Beijing Calorimetry Symposium,1994

That's cool, man.
yessssir!!!

Published articles with "Cherenkov Ring Imaging"



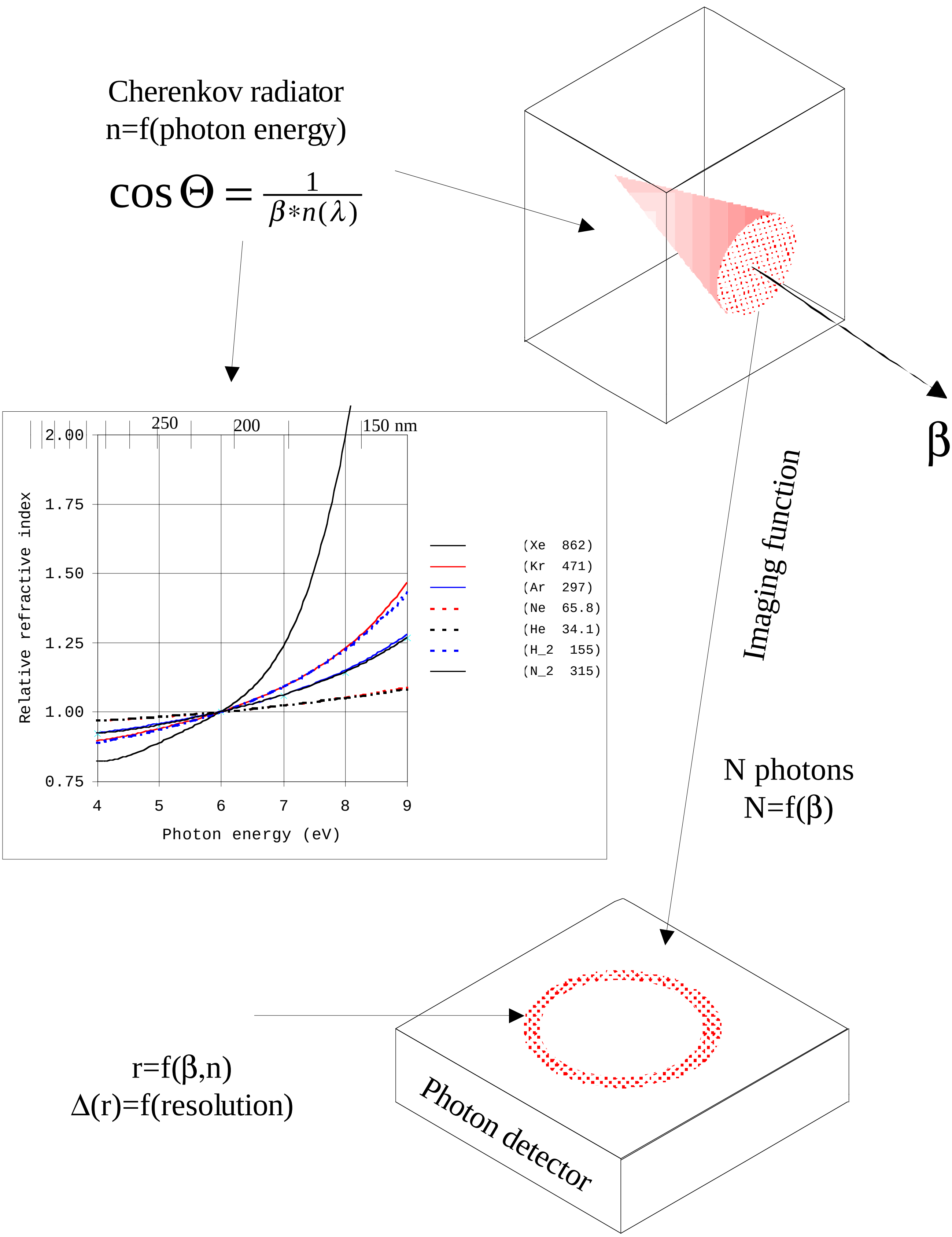
....

The development of ring-imaging Cherenkov detectors is a difficult area, due to the mismatch between the Cherenkov light in the gas media and its conversion into ionization in a spatial detector. However, as we have heard at this conference [18], the problem has been solved......

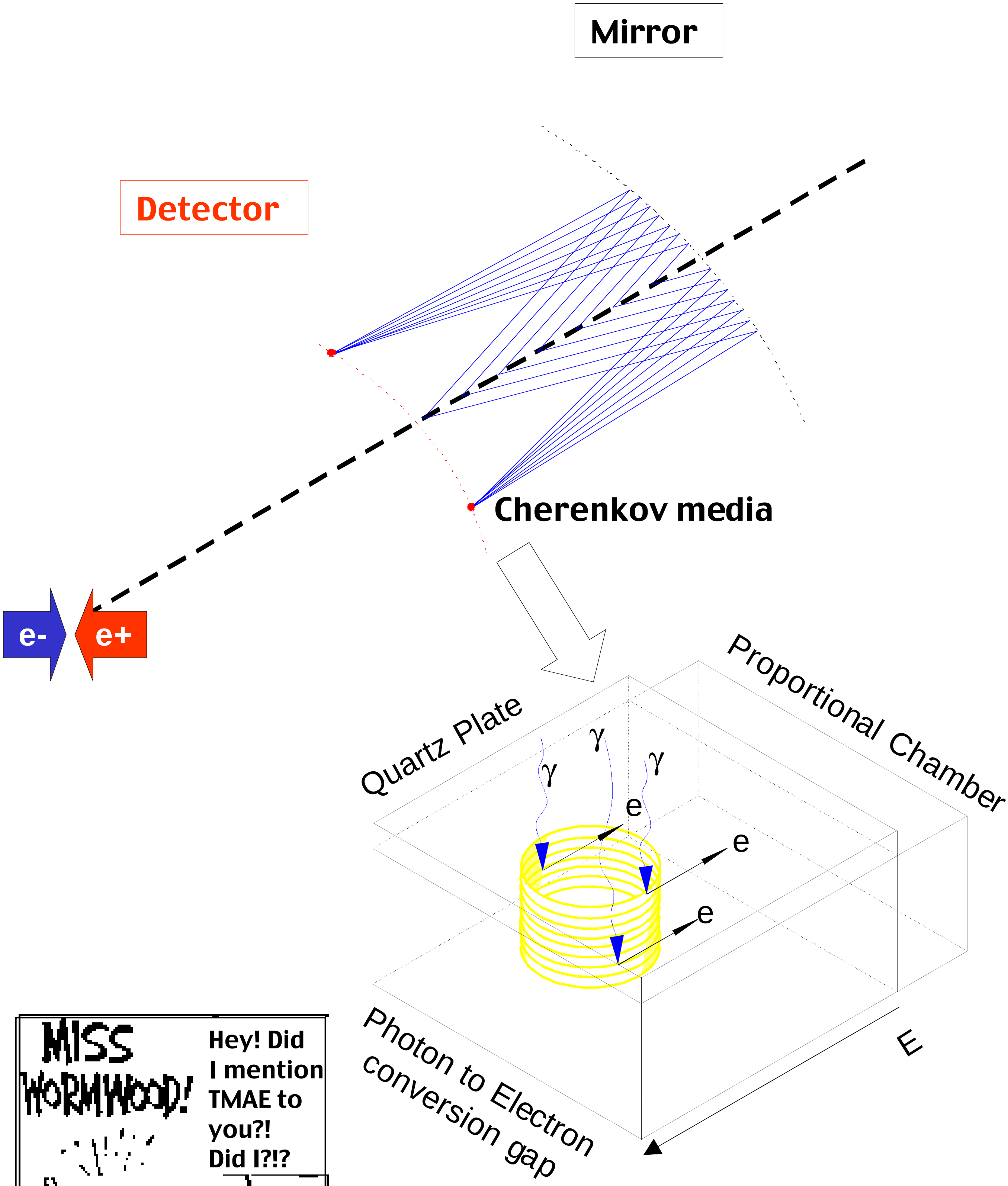
....

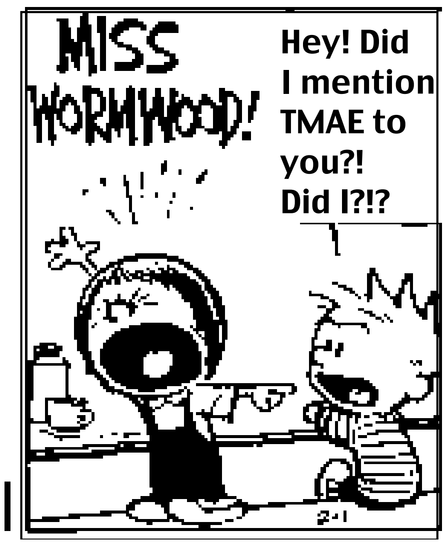
However, the techniques required going from a small development to a modest size detector are very challenging, and a successful outcome will have tremendous impact in all areas of physics.....

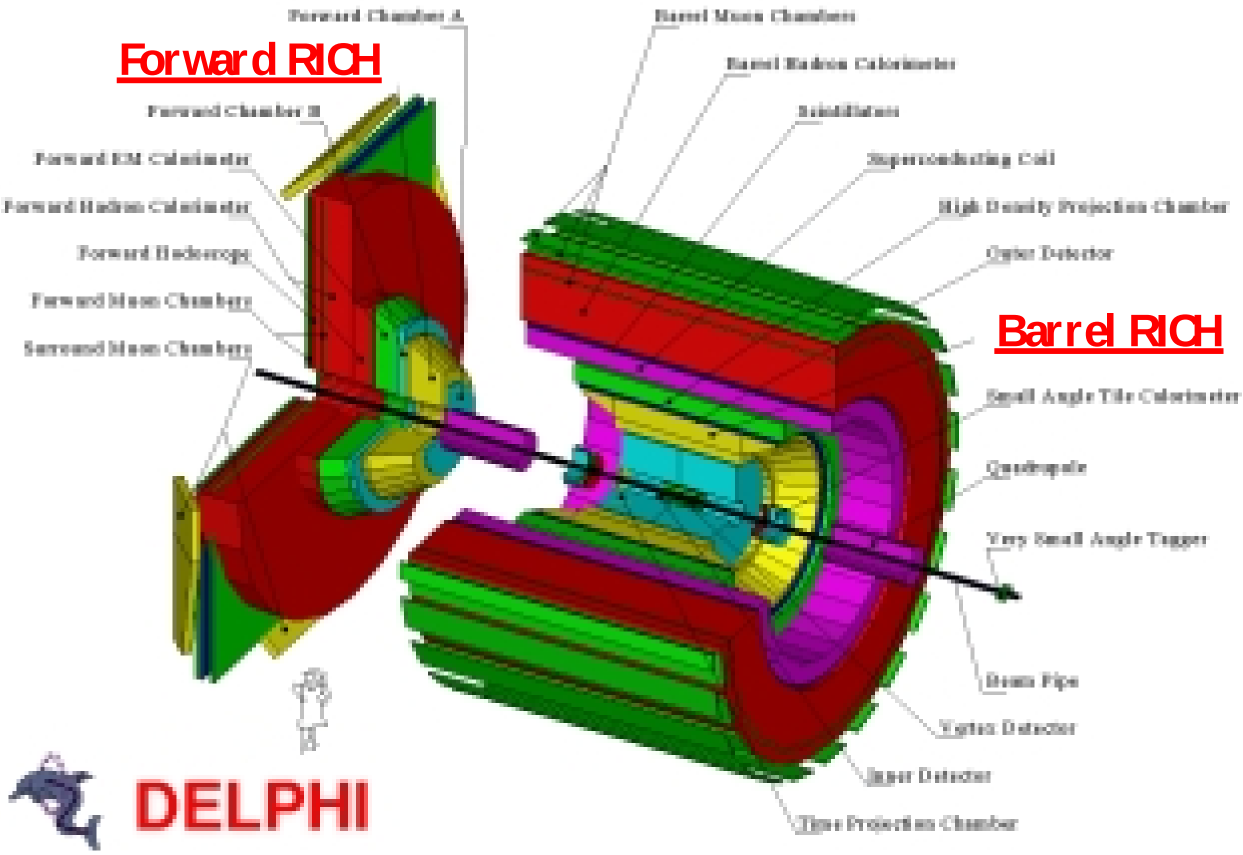
Erwin Gabathuler,
Conclusions from the Uppsala Conference on Experimentation at LEP, June 1980



Cherenkov radiator
n=f(photon energy)
$$\cos\Theta = \frac{1}{\beta * n(\lambda)}$$
β
Imaging function
N photons
N=f(β)
250
200
150 nm
2.00
1.75
1.50
1.25
1.00
0.75
Relative refractive index
4
5
6
7
8
9
Photon energy (eV)
(Xe 862)
(Kr 471)
(Ar 297)
(Ne 65.8)
(He 34.1)
(H_2 155)
(N_2 315)
r=f(β,n)
Δ(r)=f(resolution)
Photon detector


Mirror
Detector
Cherenkov media
e-
e+
Quartz Plate
Proportional Chamber
γ
γ
γ
e
e
e
Photon to Electron conversion gap
E

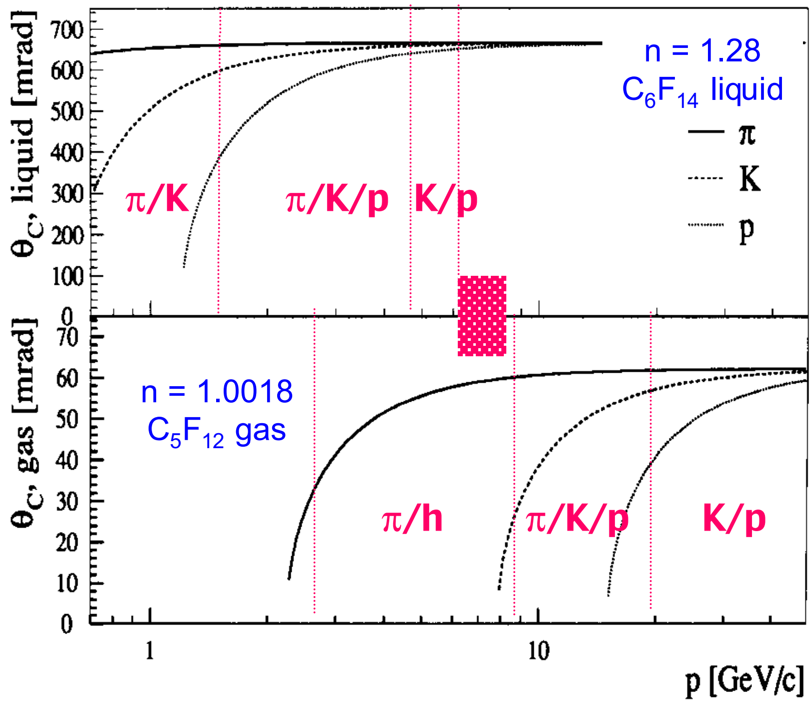

MISS WORMWOOD!
Hey! Did I mention TMAE to you?! Did I?!?



Particle Identification in DELPHI at LEP I and LEP II

→ $0.7 \leq p \leq 45$ GeV/c

→ $15° \leq \theta \leq 165°$



2 radiators + 1 photodetector

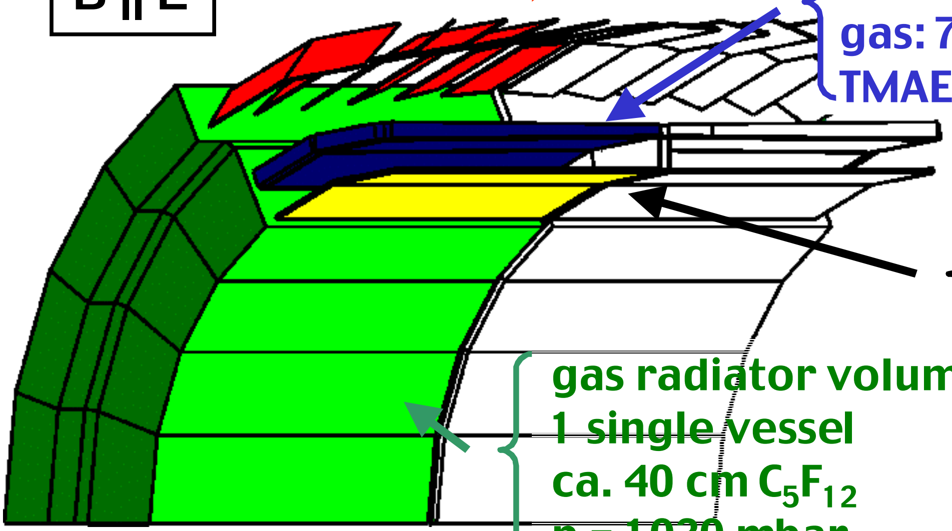
Barrel RICH

1 of 2×12 sectors

B || E

2 × 6 parabolic mirrors

2 drift tubes + 2 MWPC (= 1 bitube)
gas: 75% CH_4 + 25% C_2H_6
TMAE @ 28°C



2 liquid radiator
1 cm C_6F_{14}, quartz windows
p = 985 mbar

gas radiator volume
1 single vessel
ca. 40 cm C_5F_{12}
p = 1030 mbar

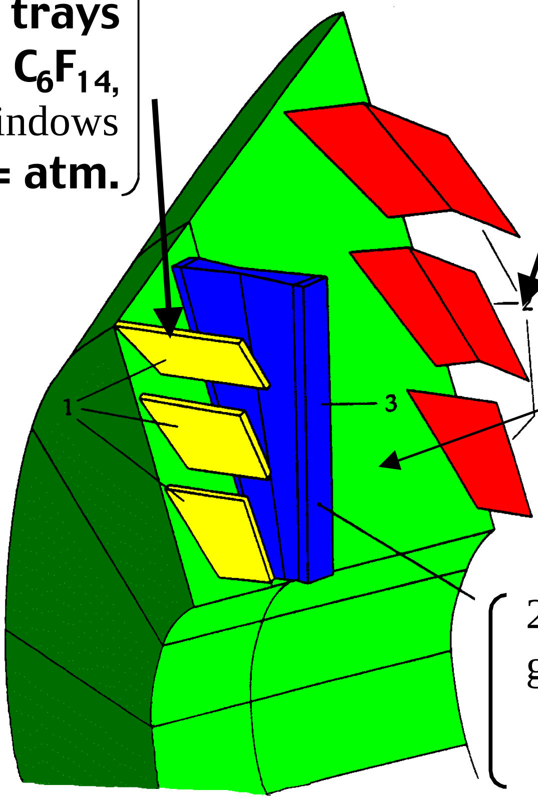
Complete detector heated at 40 ± 0.3 °C. Pressure to ±0.5 m

Forward RICH

1 of 2×12 sectors

B ⊥ E

3 liquid radiator trays
1 cm C_6F_{14},
quartz windows
p = atm.

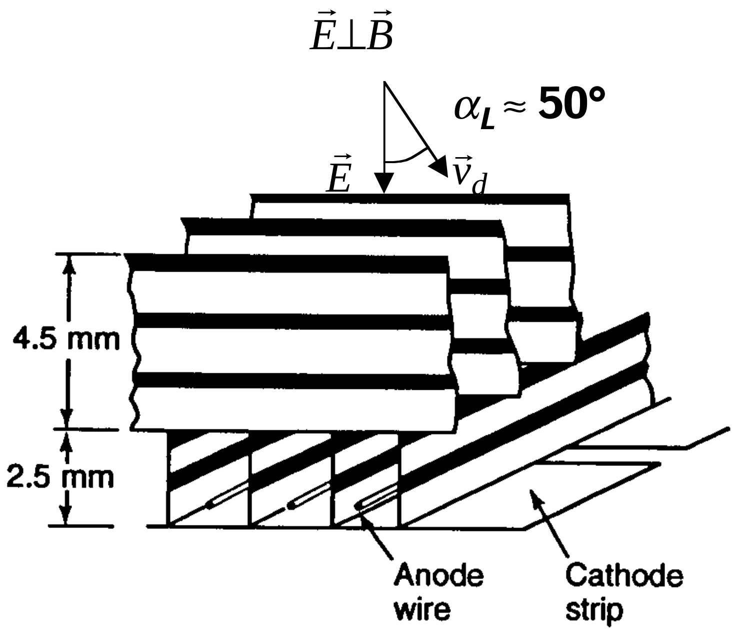


5 spherical mirrors

gas radiator volume
2 half vessels / side
ca. 50 cm C_4F_{10}
p = atm.

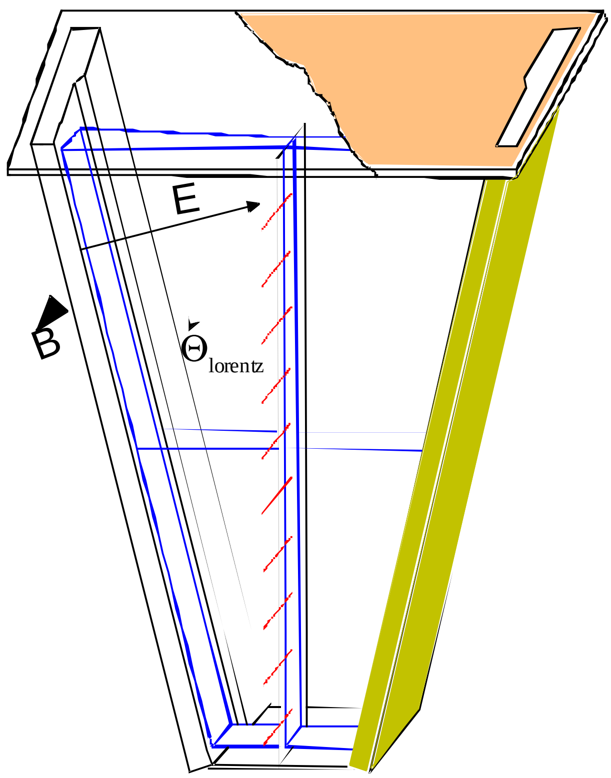
T_{vessel} ≈ 30°C, unregulated.

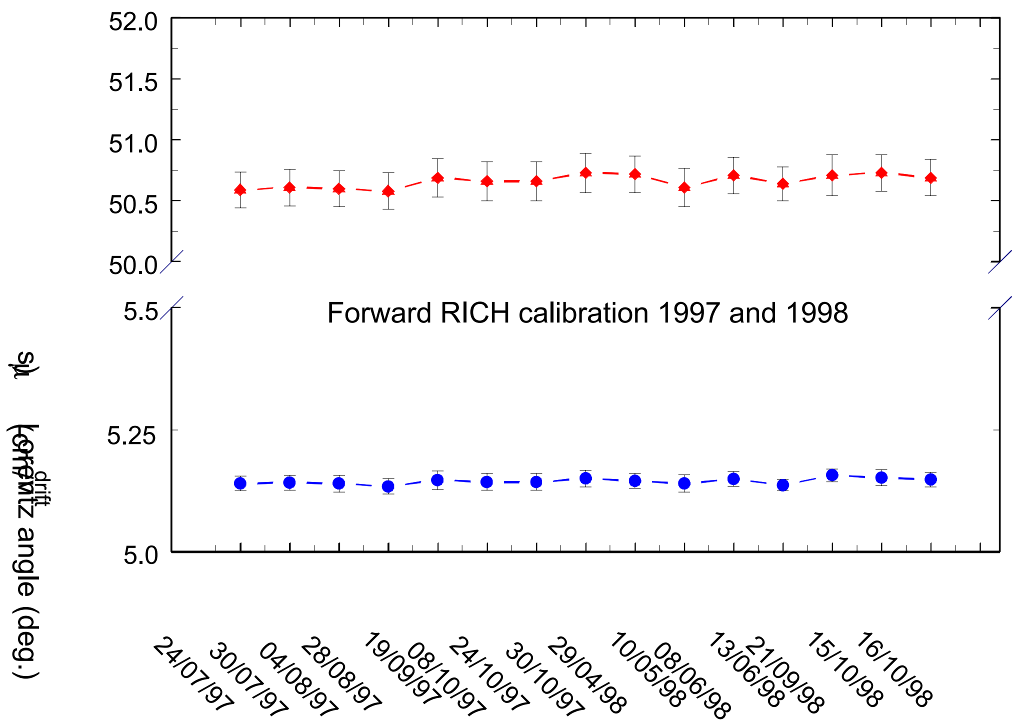
2 drift boxes + 2 MWPC's
gas: C_2H_6 + TMAE (24°C)



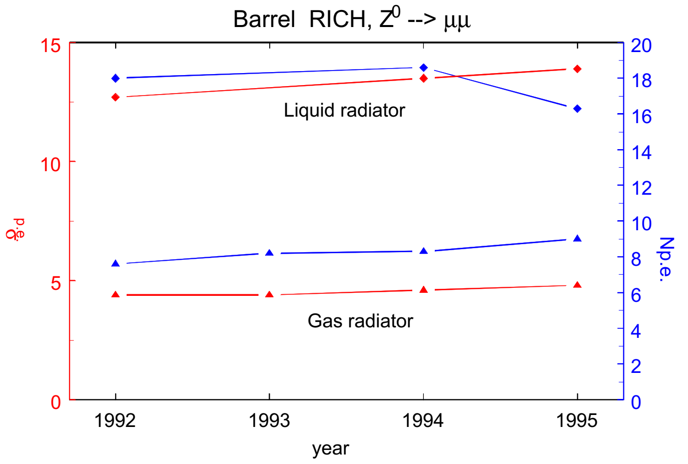
Proportional Chamber with UV blinds

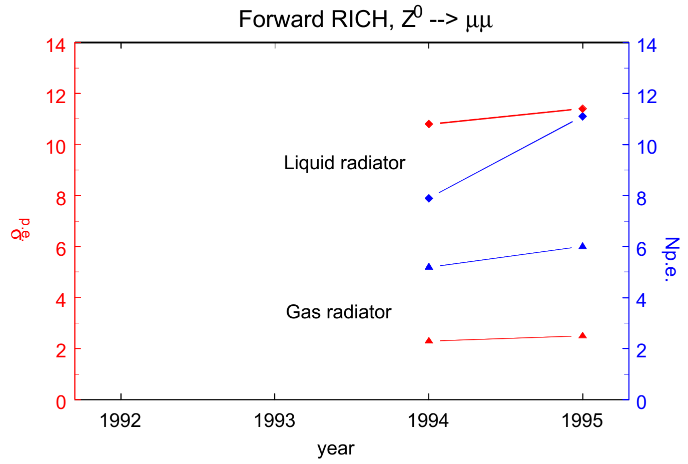
Forward RICH photon Detector

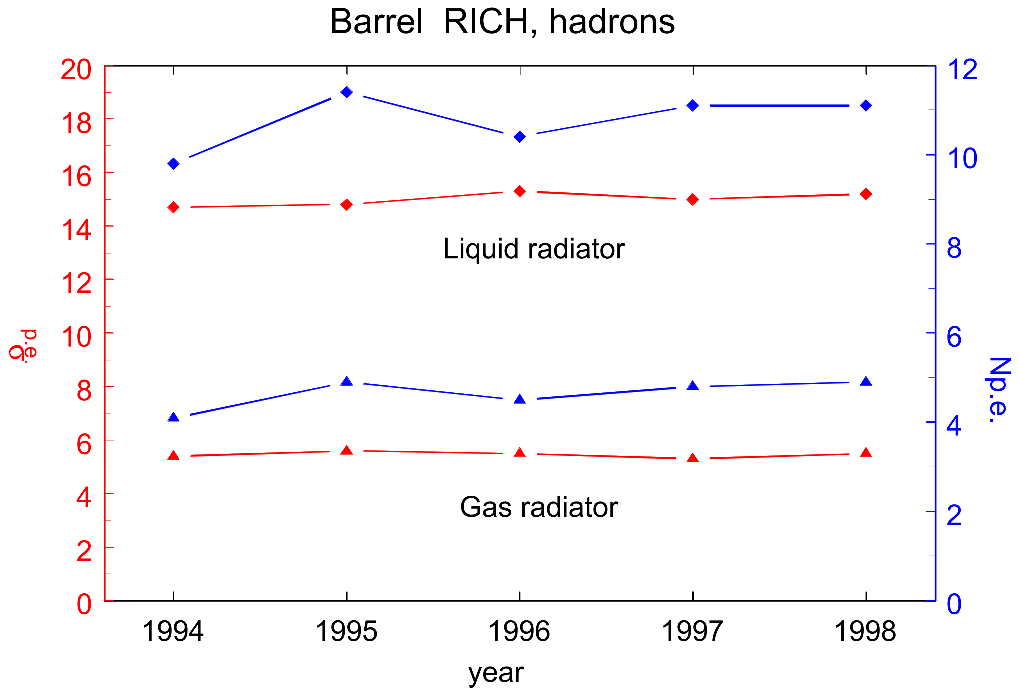


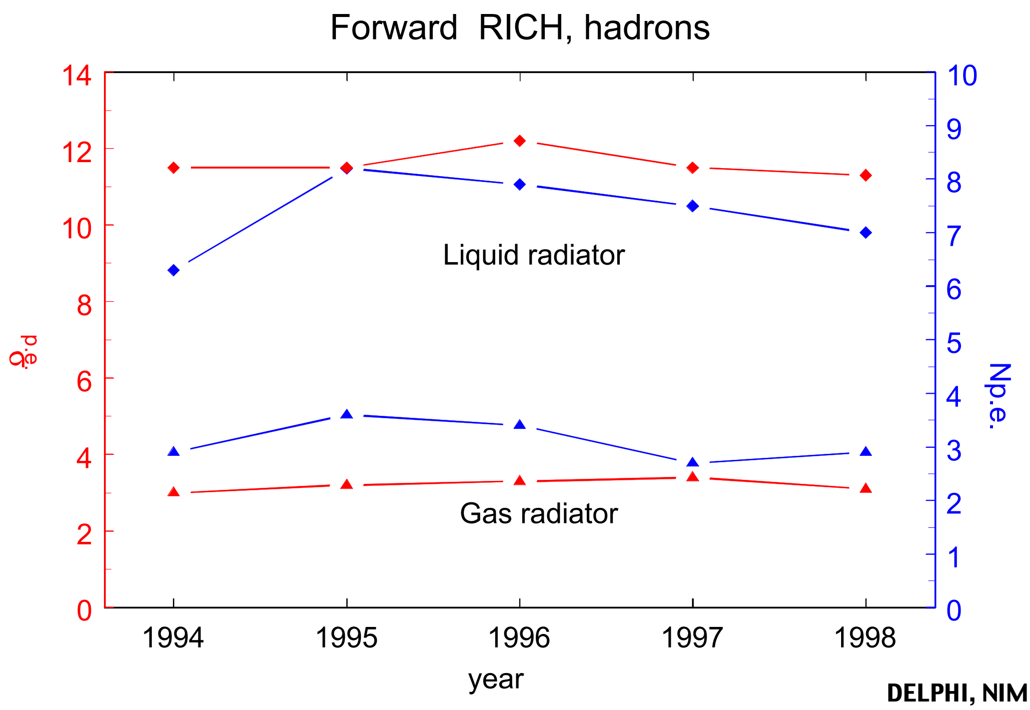


DELPHI, NIM A 433(1999)47



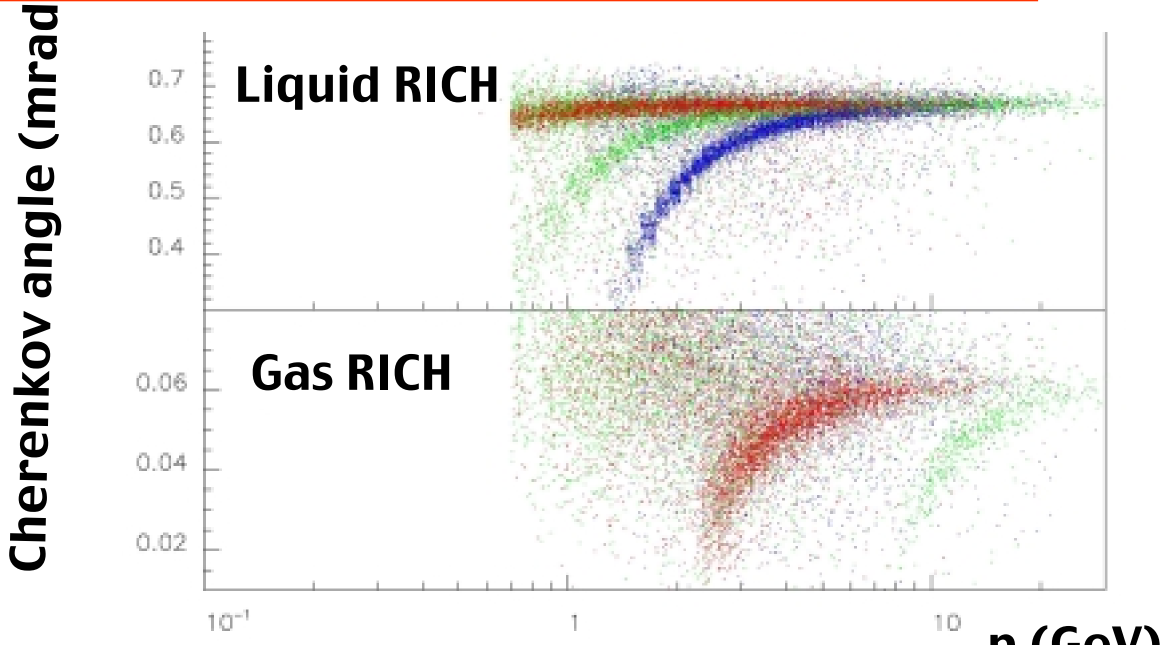






DELPHI, NIM A 433(1999)47

Particle Identification with the DELPHI RICHes



http://delphiwww.cern.ch/delfigs/export/pubdet4.html

DELPHI, NIM A: 378(1996)57

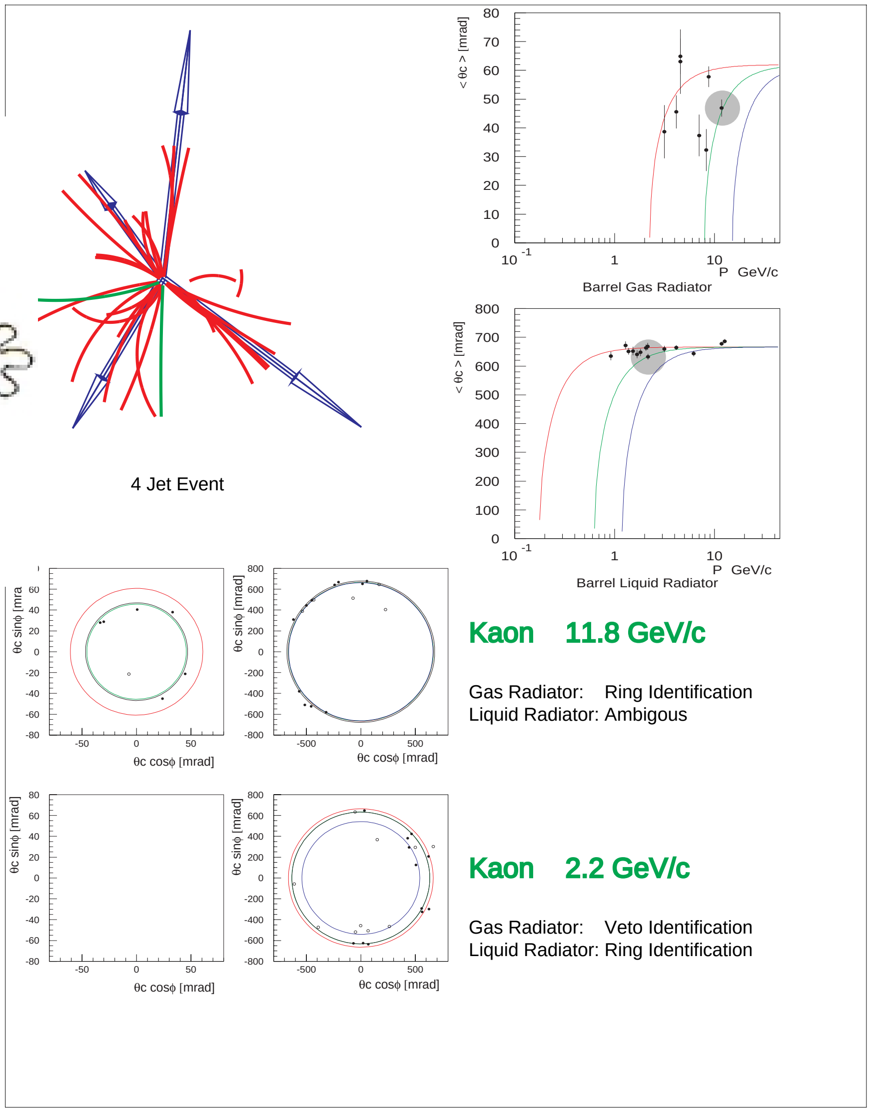
From data

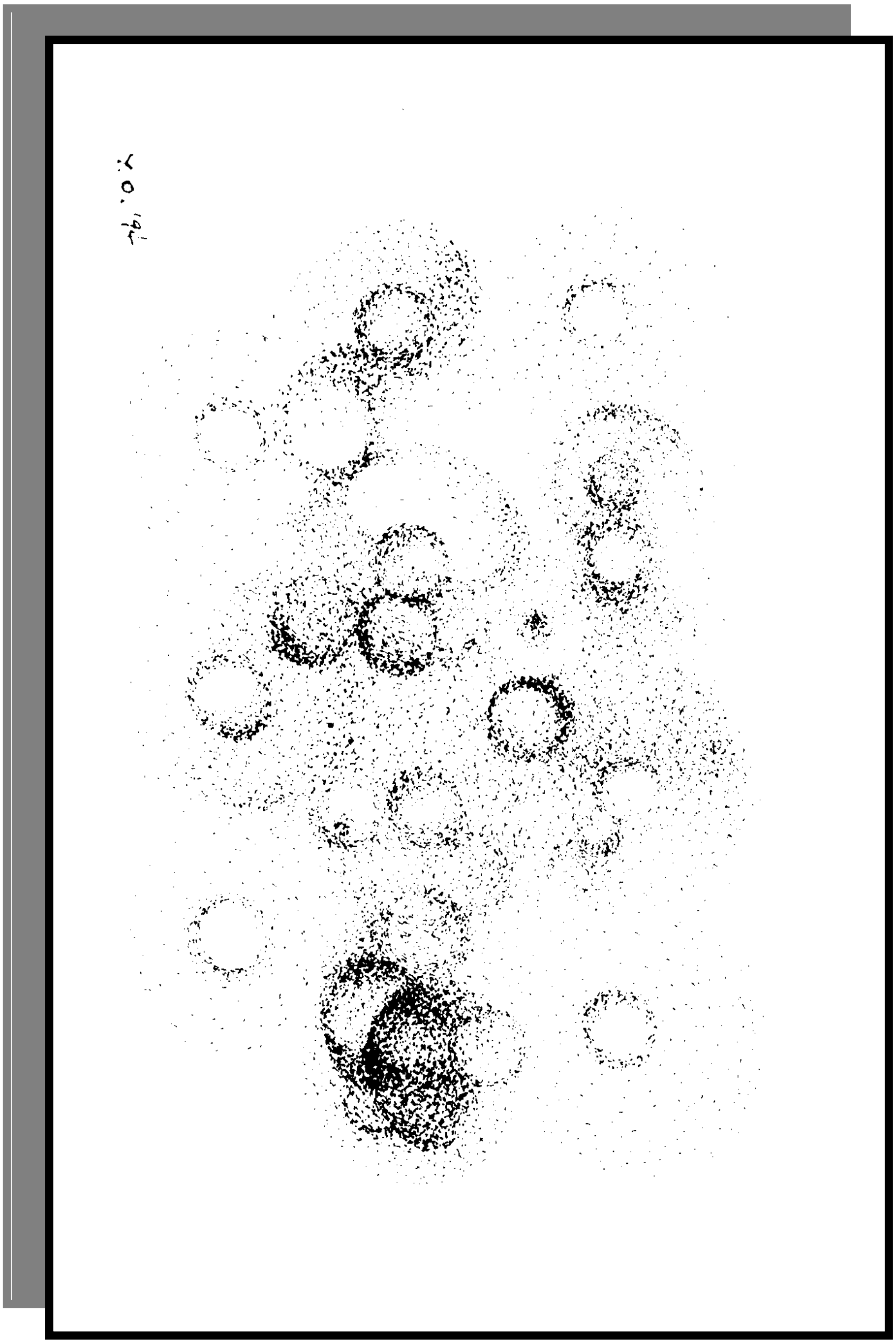
p from Λ

K from Φ

D*

π from K°





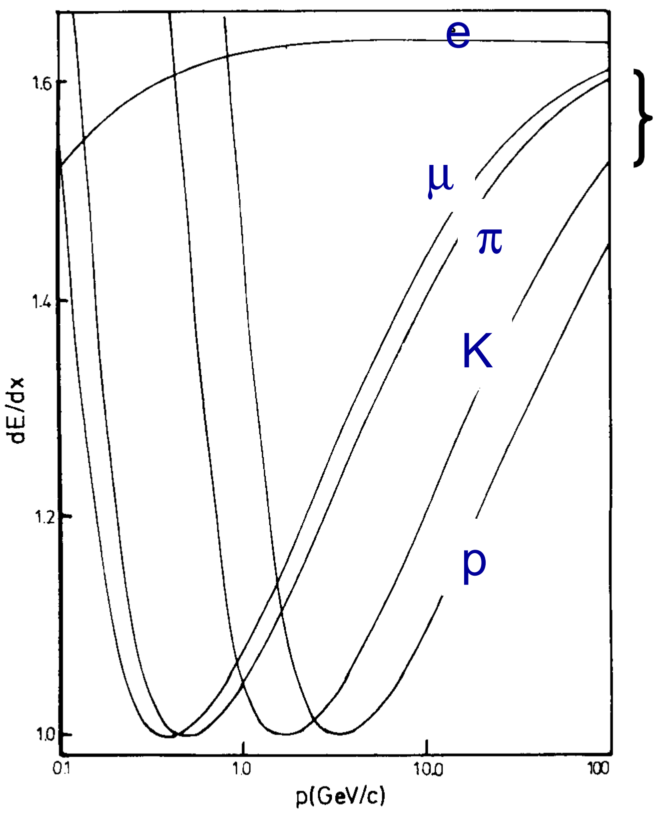
Yoko Ono Æ1994
FRANKLIN SUMMER SERIES, ID#27
I forbindelse med utstillingen i BERGEN KUNSTMUSEUM, 1999

Particle identification through
<u>ionization losses.</u>

Energy loss detection with MWPC started more or less at the same time as the first MWPC was operational. It was already a proven technique in the early days of the ISR.

$$
\left.\begin{aligned} &p = m\beta\gamma \\ &\frac{dE}{dx} \propto \frac{1}{\beta^2}\ln\left(\beta^2\gamma^2\right) \end{aligned}\right\}
$$

Simultaneous measurement of *p* and *dE/dx* defines *m*.



Average energy loss in 80/20 Ar/CH_4 (NTP)
(J.N. Marx, Physics today, Oct.78)

π/K separation at a 2σ level requires a *dE/dx* resolution in the range of 2 to 3% - depending on the momentum range

But:
Large fluctuations and Landau tails !

The Use of *dE/dX* **really took off with the coming of the** JET chambers **and the** TPC **like detectors. The workhorses for tracking.**

The underlying physics and techniques of particle identification using the relativistic rise of the total ionization loss (dE/dX) in proportional counters seems to be understood in its basic limits.

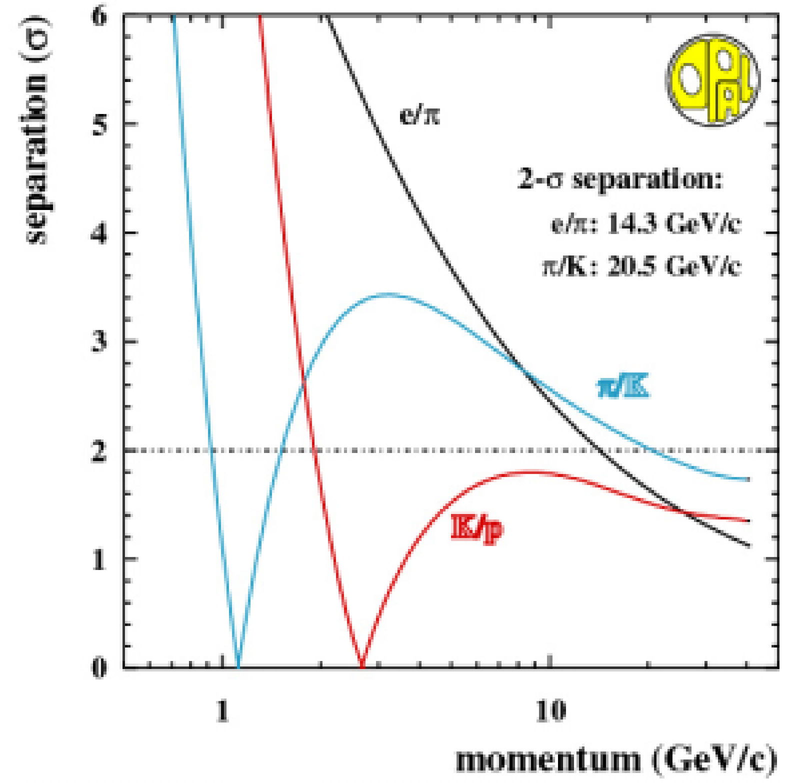
....

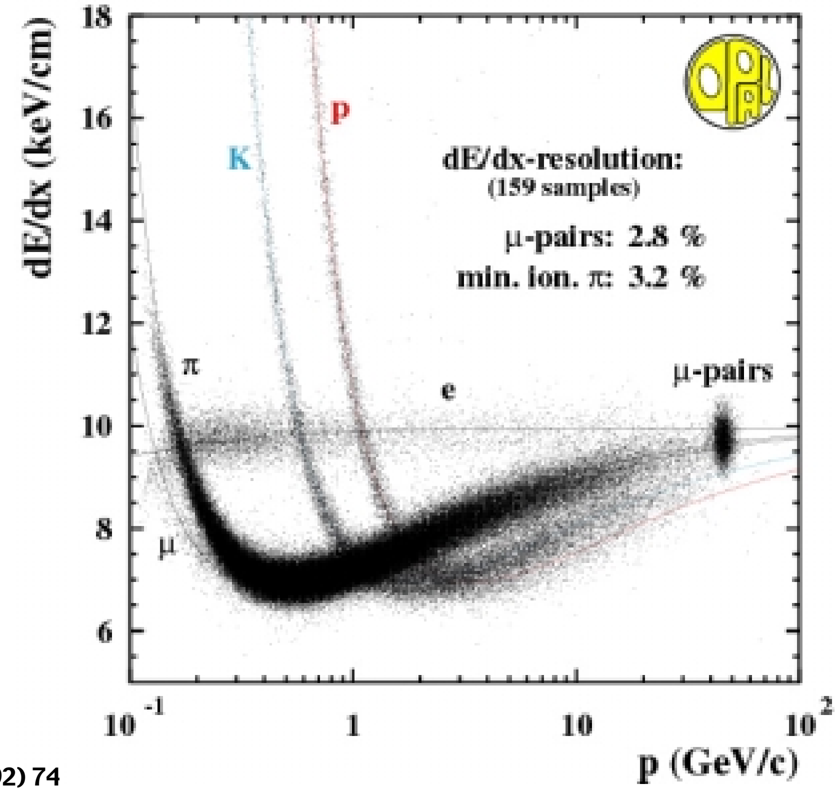
Each one of them has its problems, but improved particle identification may result from a more complete understanding of the energy loss and detection mechanism.

A. H. Walenta,
Performance and Development of dE/dX Counters, Uppsala 1980

The OPAL JET Chamber

The chamber is 4 m long with an inner diameter of 0.5 m and an outer diameter of 3.7 m. The sensitive volume is divided into 24 identical sectors, each containing a plane with 159 sense wires.

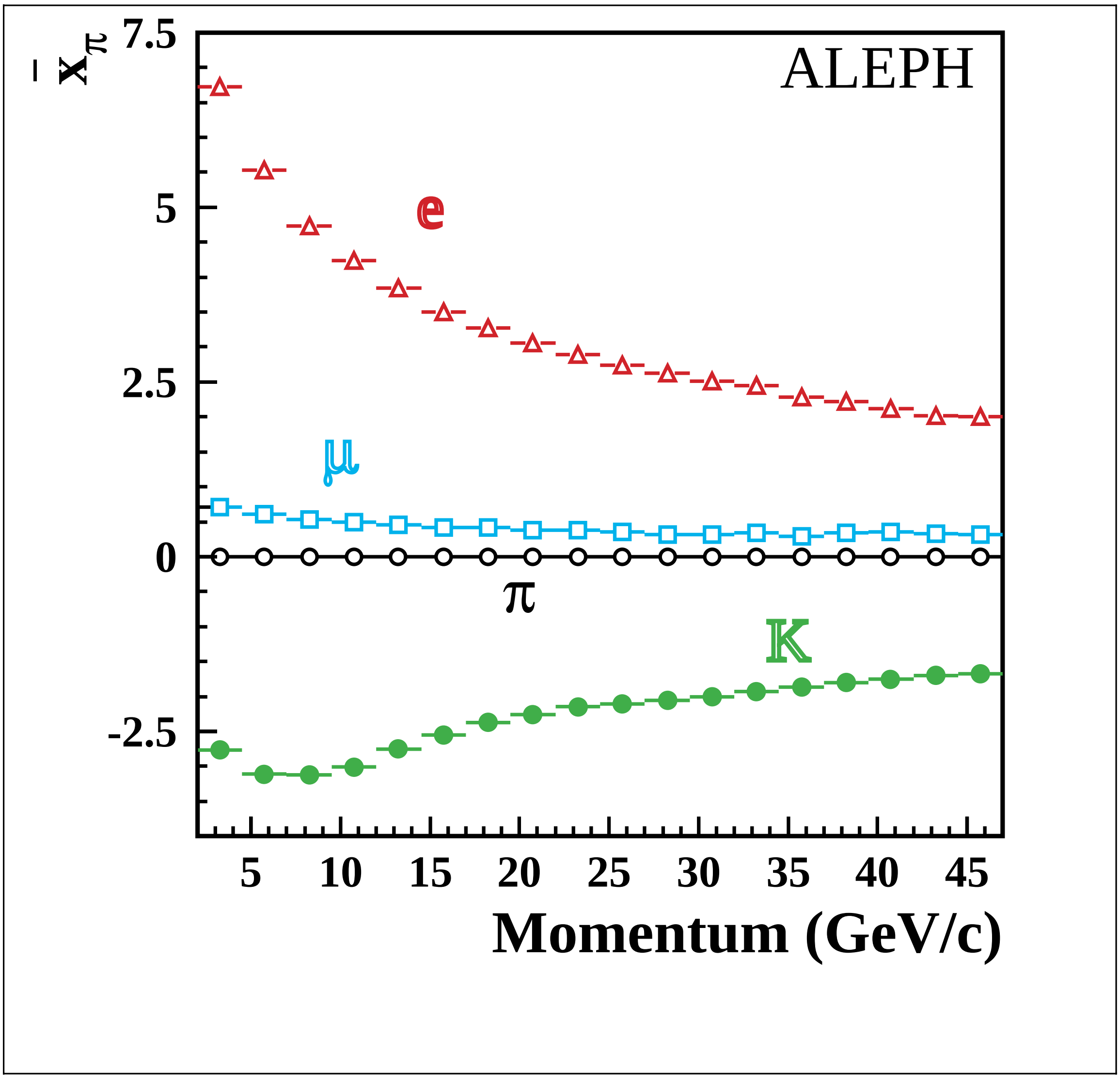




OPAL, NIM A314 (1992) 74

The ALEPH Time Projection Chamber

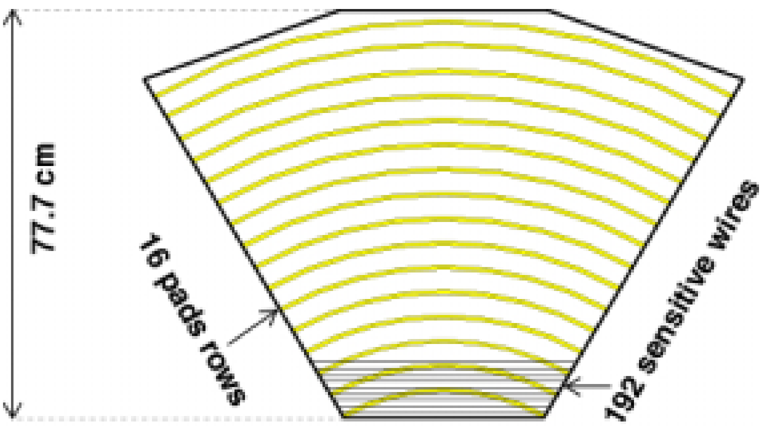
Sectors	R_{min}	R_{max}	# Pad Rows	# trig. Pad Rows	# Wires
Type K	38 cm	91 cm	9	8	148
Type W, M	100 cm	170 cm	12	11	196

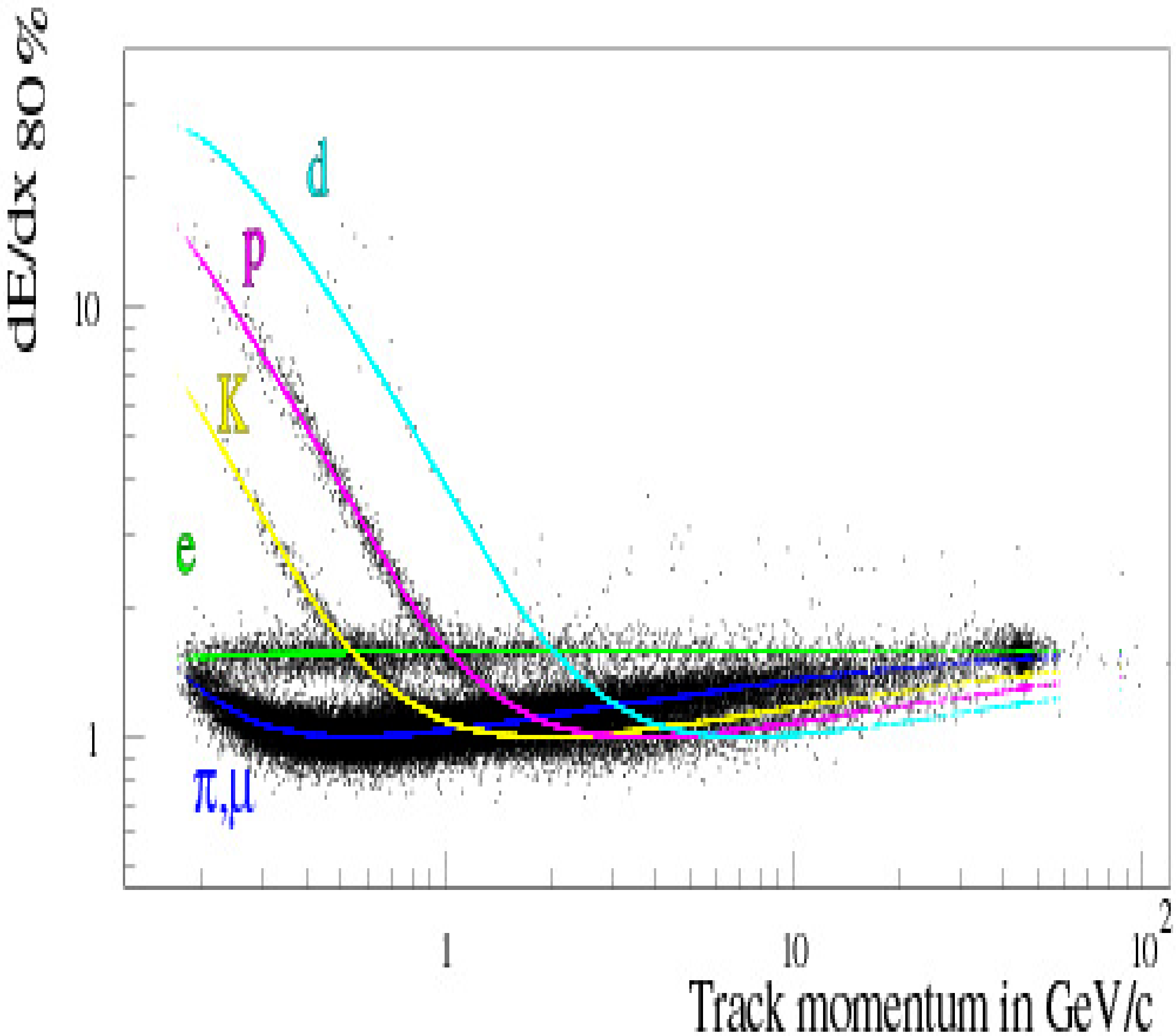


Separation from pions in standard deviations for different particle types as a function of momentum

ALEPH, Eur. Phys. J., C : 10 (1999) no.1

The DELPHI Time Projection Chamber



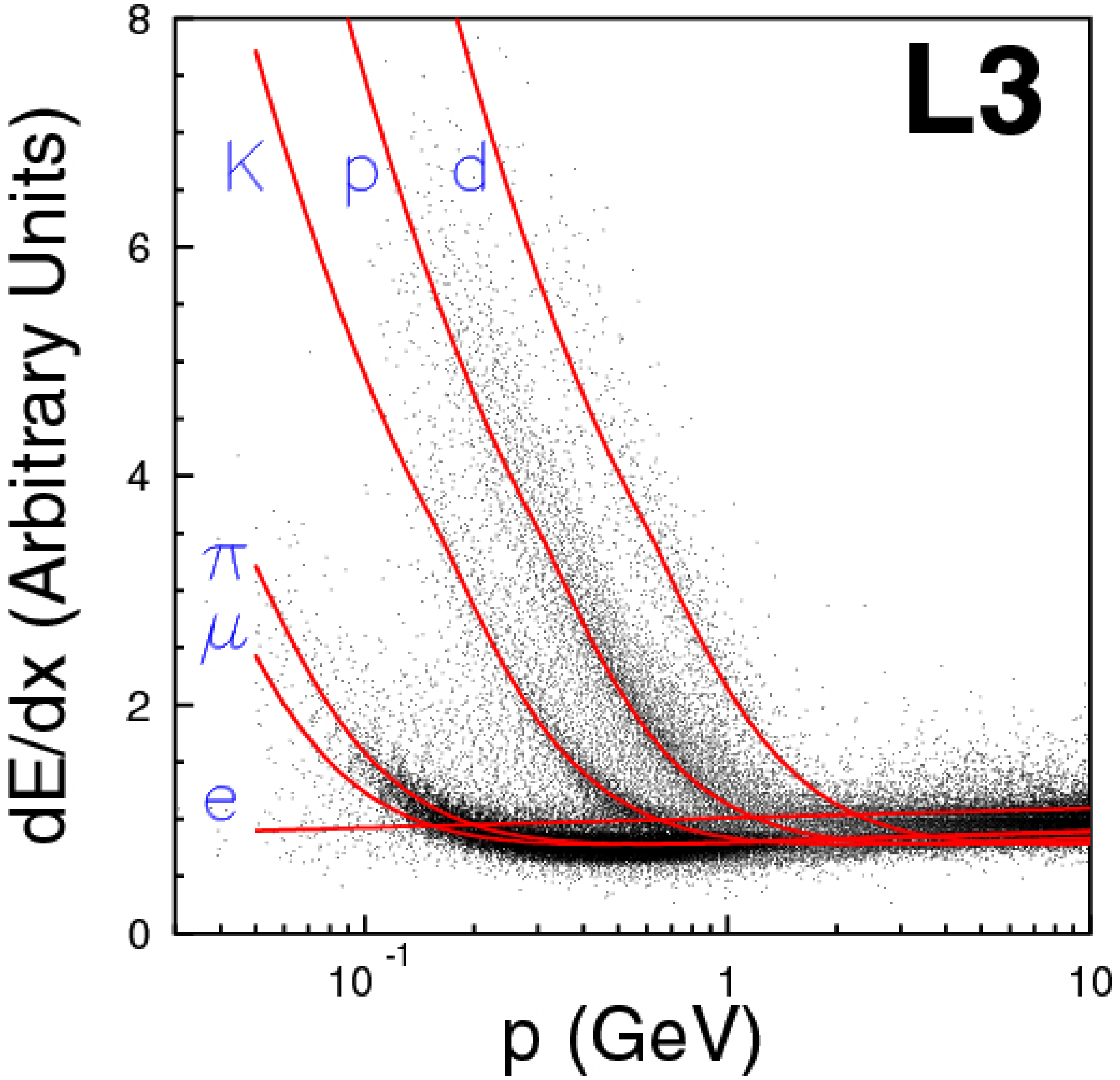


http://pubxx.home.cern.ch/pubxx/tasks/hadident/www/dedx/#A1.5.1

L3 Time Expansion Chamber

inner radius 90 mm
outer radius 457 mm
with 62 sense wires.

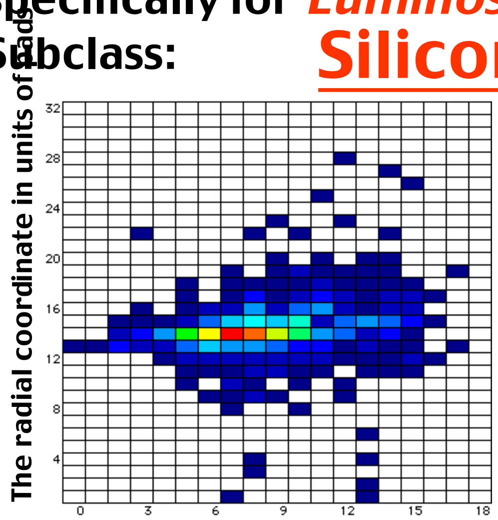
Truncated mean at 80% and > 50 wires.



L3 Collaboration, S. Braccini, Ph.D. Thesis, University of Geneva, 2000

We will now go back to Electromagnetic Sampling Calorimeters and look at the Very High Precision detectors built specifically for *Luminosity* measurement.

Subclass: **Silicon–Tungsten calorimeters**



The depth within the calorimeter, numbered by detector layer

OPAL CERN-EP-99-13

In sampling calorimeters the

- **Particle absorption**
- **Shower sampling**

is separated.

This can give an optimal choice for converter material and position determination.

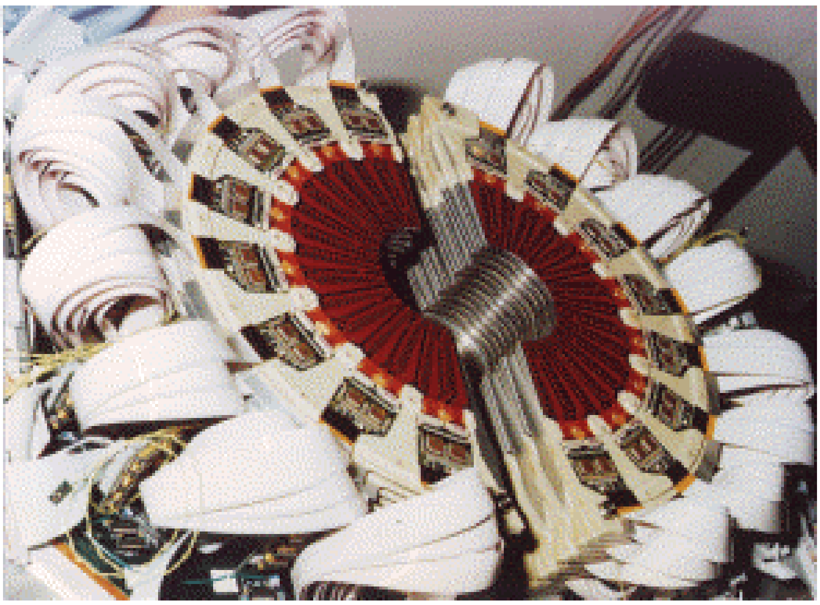
$$\frac{\delta\sigma^{acc}}{\sigma^{acc}} = \frac{2\delta R}{R_{\min}}\left(1 + \frac{R_{\min}^2}{R_{\max}^2 - R_{\min}^2}\right)$$

$$\leq 1\,‰ \quad \rightarrow \quad \leq 30\mu m$$

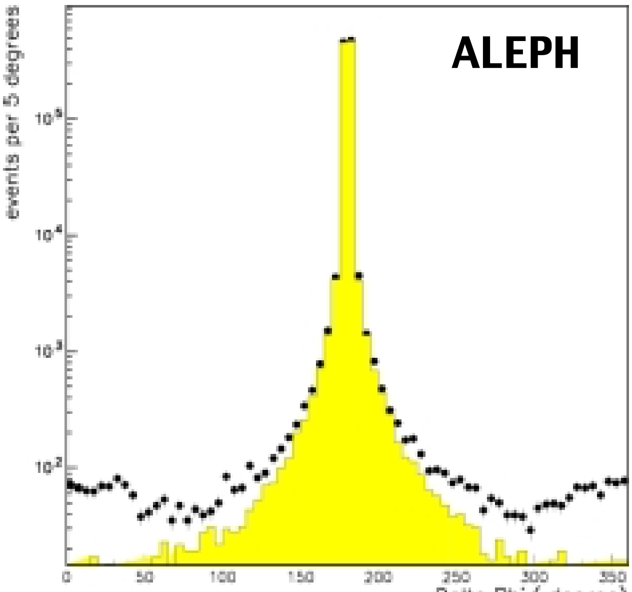
The calorimeters were built to have good position and energy resolution.

- **The position resolution is needed for the precise determination of the acceptance of the calorimeter**
- **the energy resolution is needed to distinguish true Bhabha events from the off-momentum beam particles which contribute to the background.**

ALEPH 1992

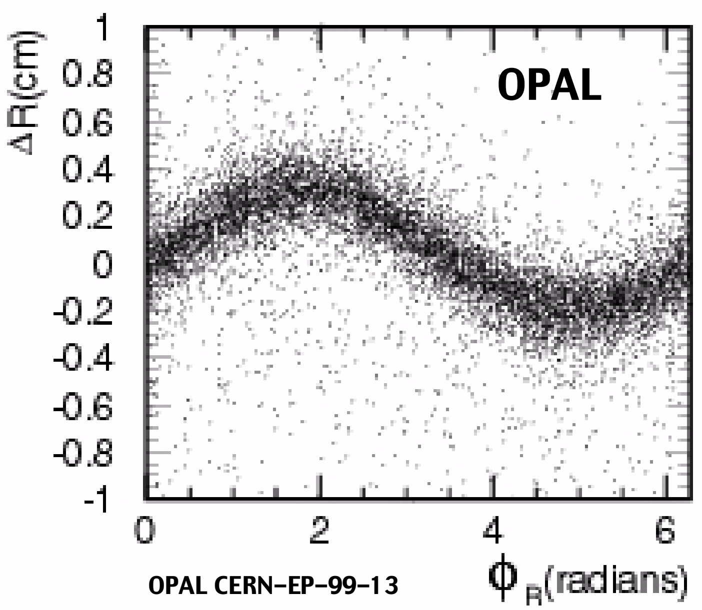


The ultimate limit of the absolute luminosity measurement is defined by the knowledge of the absolute radial position of the silicon pads and the absolute distance between the calorimeters



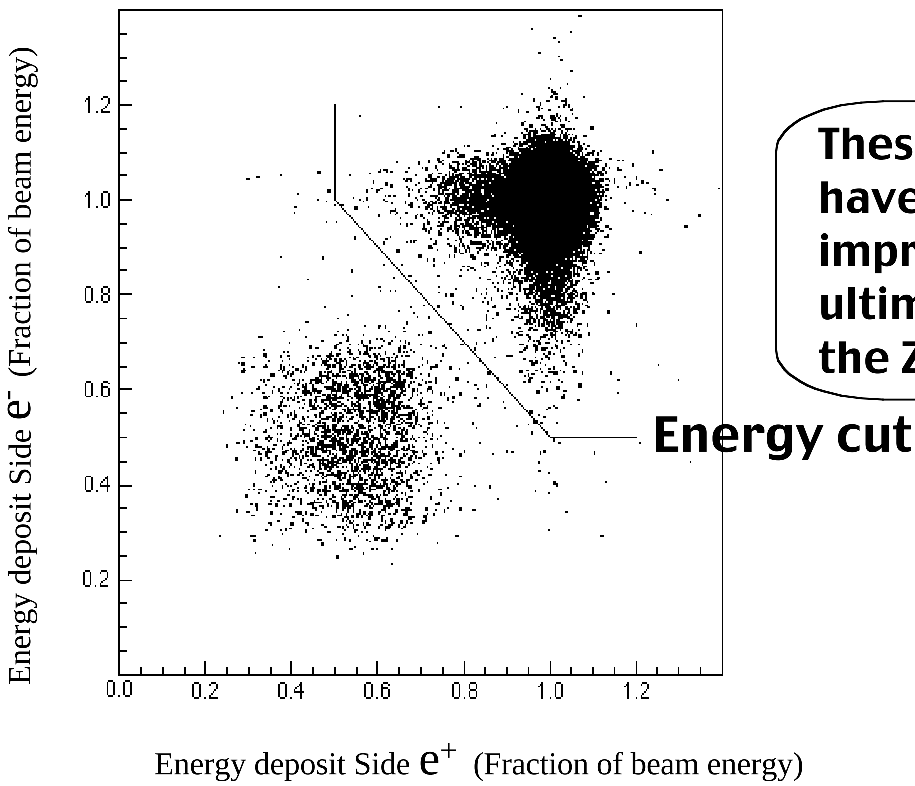
ALEPH NIM A 360 (1995) 481

$\Delta\phi$ distribution for real and MC.
Background : Off momentum and (mainly) t-channel 2/3 hard γ

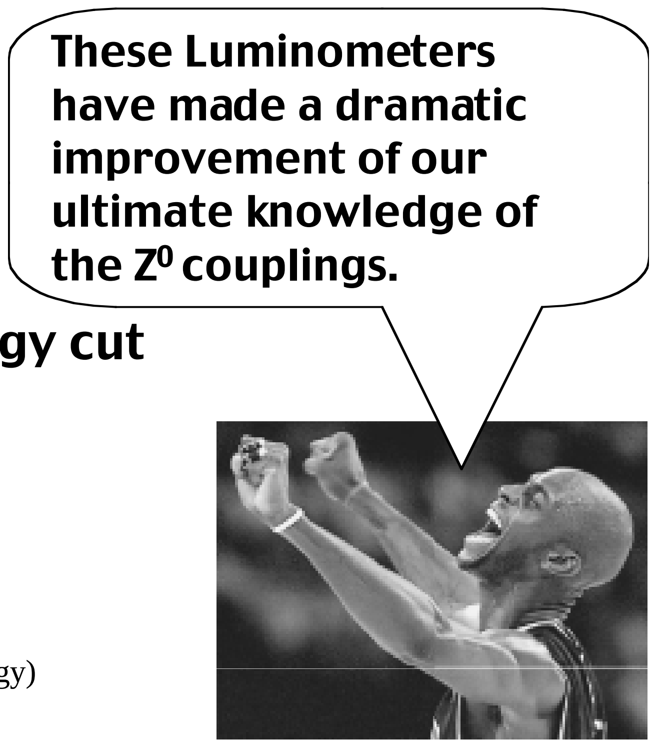


OPAL CERN-EP-99-13

Beam spot position.
The acollinearity of non-radiative Bhabhas in the detector frame



OPAL CERN-EP-99-13



Have we learnt something which should be passed over to the next generation experiments?

Conclusion

The years of LEP have taught us a lot about Detectors
and more than what we have deserved about detector systems.

- **Accessibility**
- **Ease of operation**
- **Ease of calibration**
- **Ease of trouble shooting**

and above all
In order to have excellent and consistent data

Stability

Stability

and more Stability

If these functions are not built into the systems from the very start, it is hard to get them in afterwards.

Thanks to all who have helped me in putting together this talk.
Excuses to everybody who should have been mentioned and have not.
Special thanks to the cartoonists of this world and in particular to Edvard Munch who did, without knowing, so perfectly painted the coming of the LHC.