Role of the Pisa particle physics lab in ALEPH

I thank the organisers for proposing me this talk.

But I cannot start this presentation, before mentioning Lorenzo Foa, who was the key physicist for the Pisa and actually for INFN contribution to ALEPH.

Of course you will see his name in many of my slides , but it is clear that, if he was still with us, he would be the speaker today rather than me, explaining with his usual passion accompanied by a critical mind his views on the ALEPH adventure.

Memories of Lorenzo

This was at the change of mandate party, just before Lorenzo took the charge of ALEPH spokesman.
For those of you who do not remember how we looked in 1993 the other 2 persons listening are Jack Steinberger spokesman from 1980-1990 and J.L. spokesman 1990-1993

The first meeting (I)

The start of ALEPH can certainly be dated back to this meeting in Jack Steinberger's office in July 1980

Dear Sir,

this is to confirm the place and the time of our first discussion meeting on LEP physics:

Wednesday 9 July 1980, 10.30 h a.m.
CERN, J. Steinbergers office (building 2, 1-029).

Representatives from the following institutions agreed to take part in this meeting: CERN (May, Steinberger, Wahl), Dortmund (Eisele, Kleinknecht), Heidelberg (Dydak, Geweniger, Kluge, Tittel), MPI München (Blum, Lorenz), Orsay (Davier, Lefrançois) Pisa (Bellettini, Foa), and Saclay (Rander, Turlay).

Yours sincerely,

F. Dydak

The first meeting (II)

I have never discussed in depth with Jack's on the selection which was made.

However it is clear that the idea was to form a nucleus of a collaboration with laboratories and physicists who had shown they could take responsibility for big and complicated projects.

From this first meeting and for the next two years we attracted other labs and designed the apparatus as presented in our letter of intent

The early labs

The list on the left is on the first slide (real slide before powerpoint!) of my presentation of the letter of intent to the LEPC in March 1982, on the right is a list of labs in the technical report sent to the LEPC by May 1983

One can see, in the second list, the arrival of Frascati which was to play a major role with Pisa in the HCAL construction, and Beijing which would collaborate for the muon chambers. One sees also an allusion to minivertex but its construction was delayed and restarted in around 1988 (more later)

19 labs in 82, 25 in 83, 32 in 1998

ALEPH

List of participing institutes

Bari, Pisa, Torino, Trieste	Italy
Demokritos	Greece
Dortmund, Heidelberg, MPI München	GERMANY
Edimburgh, Glasgow, Lancaster, Rutherford, Sheffield, Westfield College	U.K.
E.P. Palaiseau, Orsay, Saclay	France
Wiscomsin	U.S.A.
CERN	

Share of the work

Magnet: CERN for the iron and refrigerator, and Saclay for the coil

TPC: MPI, CERN, Wisconsin, Dortmund, Glasgow, Pisa, Trieste, Edinburgh + a financial participation of Heidelberg and Siegen

Electromagnetic Calorimeter: End caps: all UK participants (except IC London), Barrel: All French institutes

Hadron Calorimeter, inner muon chambers: Barrel: Frascati, End caps: Pisa and Bari

Other muon chambers: Beijing

Inner Chamber: Imperial College London

Luminosity monitors: Siegen and Copenhagen

Minivertex detector: Pisa

Trigger: Heidelberg and RAL

DAQ: CERN

Physics and apparatus "knowledge" in early 80's (I)

These knowledge guided the apparatus choices

Most important was the existence of the W and Z: they had not been discovered yet (1983 UA1 UA2 at CERN) but from E-W theory and neutral current measurements (starting in 1973) their masses were predicted with reasonable accuracy (this was the "motivation" for LEP construction as a 200 GeV e+e- collider)

Top had not been found but after the φ at 1 GeV the J/ψ at 3 GeV and the Υ at 9 GeV a primary school child would predict the top-topbar state at 27 GeV! => PEP Petra construction => 1978 no top at < 30 GeV but it could not be excluded that top would be part of the LEP program (brief rumor in 1984 that "tantalizing events" were seen in UA1 but actually in 1985 UA1 published $m_{top} > 40$ GeV)

QCD was rather well established and actually gluon jets had been observed at Petra in e+e- =>qqbarg in 1979

Physics and apparatus knowledge in early 80's (II)

Since the event structure had been validated at PETRA-PEP and gluon jets observed one could have confidence in our simulation of how typical events would look like.

We therefore convinced ourselves that a key property of the detector was a fine granularity to observe the detail of an event. This was essential to identify e and μ in jets from heavy flavor decays but also, as it was learned gradually, to do better jet energy and angle measurements using "particle flow".

The technique of MWPC including pad readout were known since the early 70's and gradually "children" were born like the streamer (Iarocci) tube technique (1980) and a first TPC was invented at SLAC in late 70's and started to take data in 1984

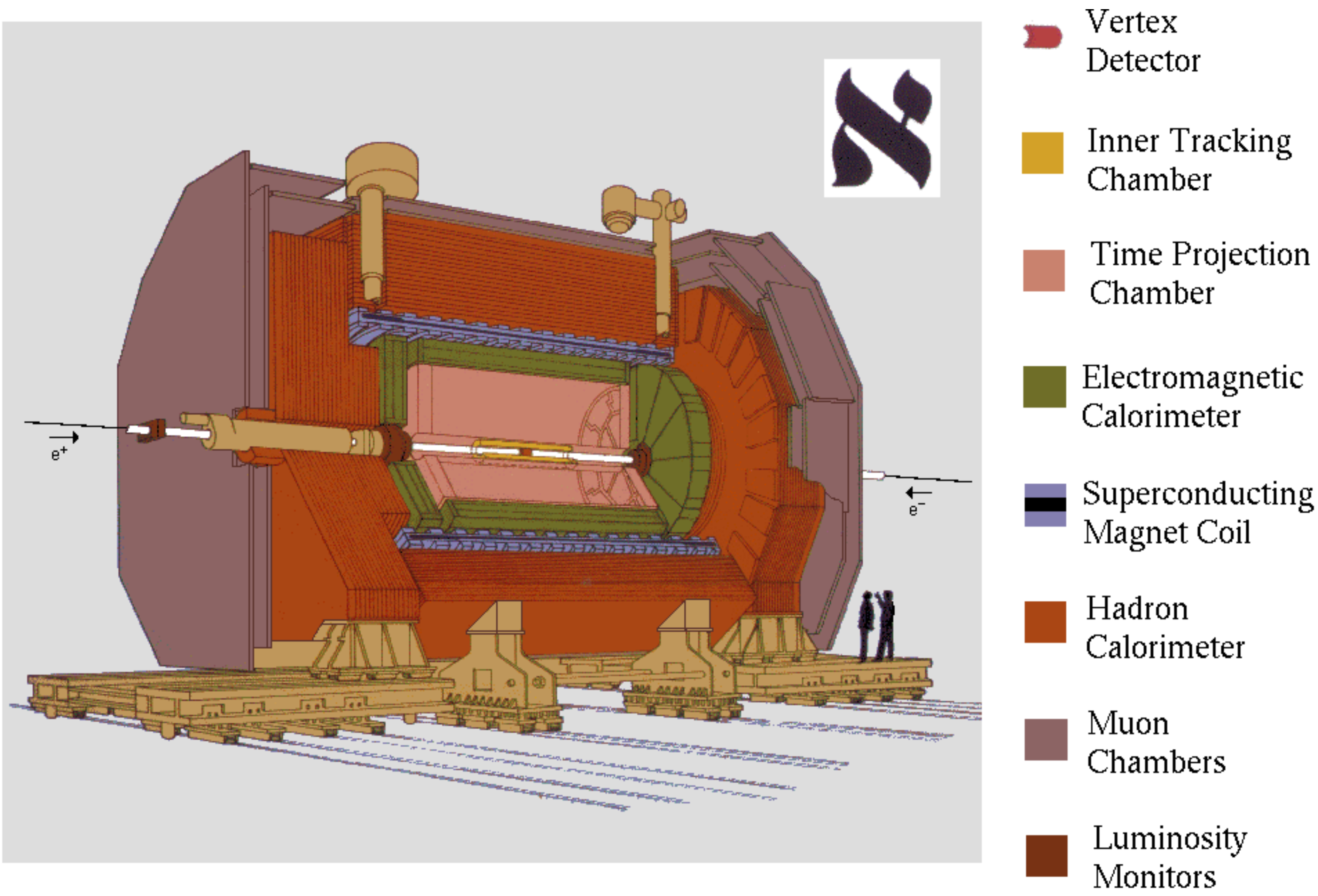
The most important thing was the gradual electronic chip improvement allowing larger number of channels to be reads ($X*10^5$ channels not millions) 4-5 years before, high granularity ALEPH would have been impossible (see UA1 UA2…)

Early brainstorming

- During the first years, before the technical report in 1983, responsibilities were not frozen and senior physicist from Pisa like Lorenzo Foa, Italo Manelli, Giorgio Bellettini took part in discussions on the general concept (TPC or Drift chamber, Solenoid or Sphere, scintillators or wire chambers for calorimeters… or liquid Argon for ECAL)
- But of course gradually some “brain children” evolved and responsibilities were assigned as I have shown before…(and some seniors left to other projects) however something remained of this period in the fact that even if a lab like Pisa would have a main responsibility the HCAL with Lorenzo Foa being the project leader (and I will talk later of VDET), it was possible for some physicist to continue working on some other subject like the TPC

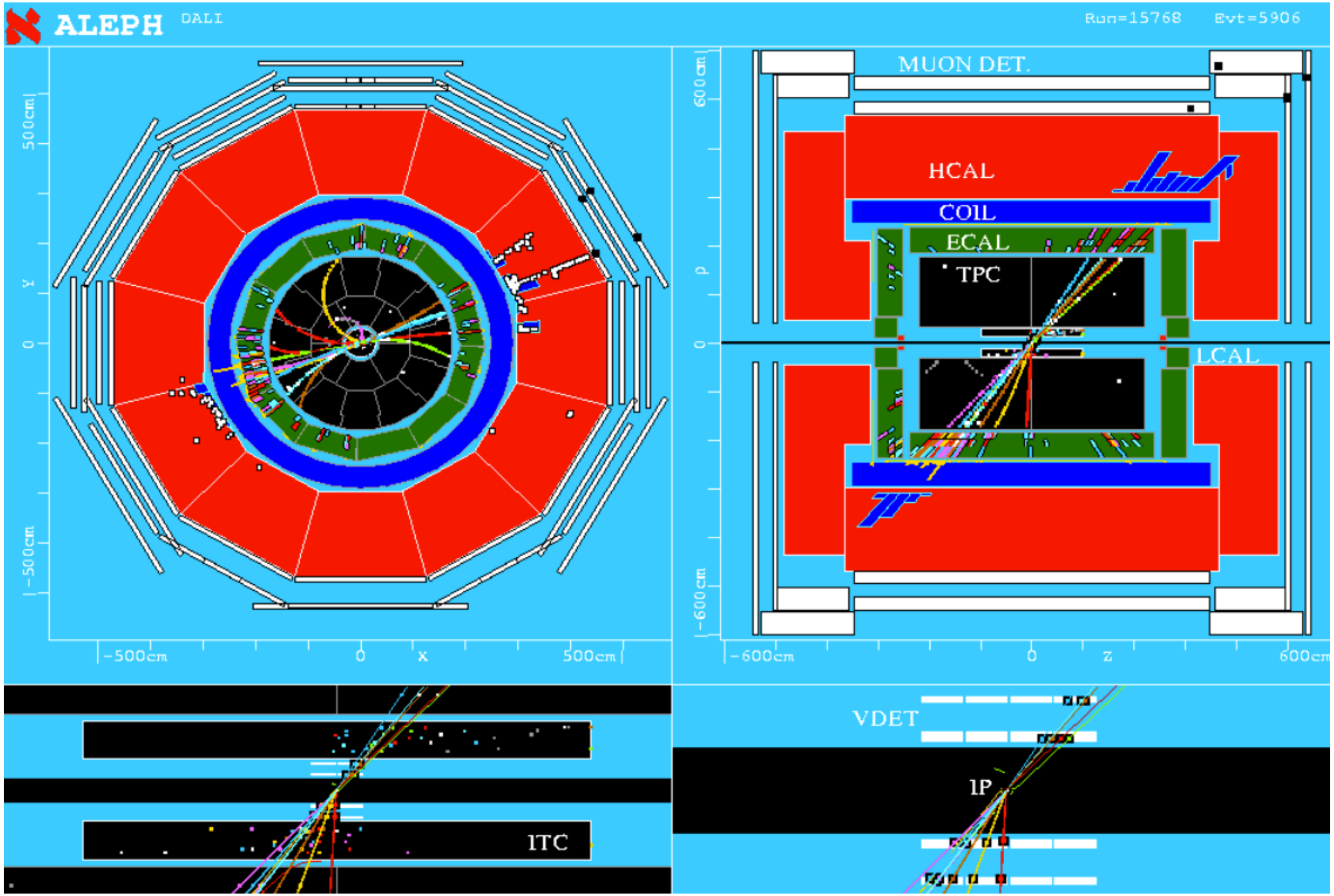
The ALEPH apparatus structure

Pisa had responsibilities, in the innermost detector (VDET) and the outermost the HCAL and muon chambers



The ALEPH Detector

Example of a 2-Jets event (with muons)



The Hadron Calorimeter (HCAL)

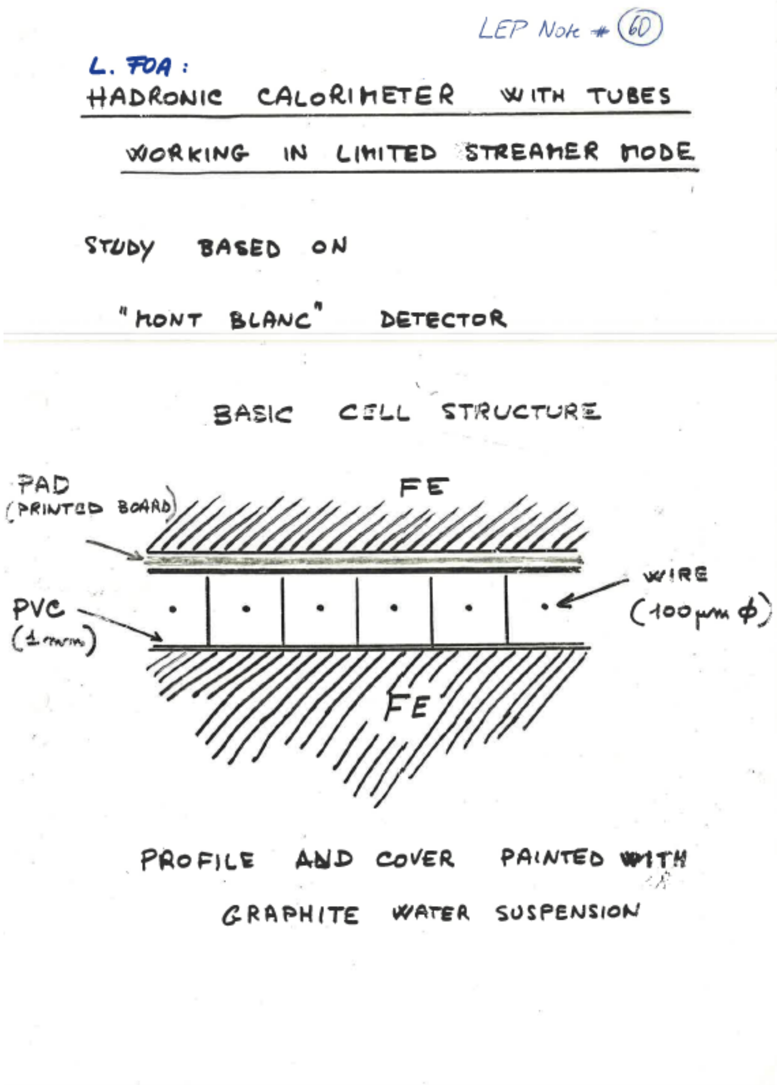
The initial idea to have an HCAL made with Iron and scintillator read by PMT, as was done for the UA1 and UA2 experiments at the CERN p-pbar collider or CDF at Fermilab. But to obtain better granularity, the choice was to use sandwiches of iron plates and long streamer tubes (up to 700 cm) of 1cm x 1cm size with cathode readout similar to a detector for proton lifetime being built at the time. The advantage of the streamer mode is that pulses are higher than for MWPC => easier=> cheaper electronics. The pulses made on the wires being large one can read easily the induced pulses on the cathode pads or strips. Because of the saturation of the streamer mode the system does not measure "energy deposited by ionisation" but rather the number of particles each creating a streamer.

Upon the insistence of Jack Steinberger that we should minimize the number of different techniques used in ALEPH detector the muon chambers were build with the same streamer tube technique with X and Y readout by cathode strip.

Because of the extra work a collaboration was started between Chinese collaborators of IHEP (who took charge of the second muon layer) and the INFN Italian labs of Frascati Bari and Pisa, the project leader being Lorenzo Foa. In Pisa apart from Lorenzo, Carlo Bradaschia had a key role and also Roberto Tenchini, Alberto Messineo and Giovani Betignani.

ALEPH note 60

Early documents of ALEPH are of course not easily accessible on the WEB as now. However in the basement of CERN building 4 there are treasures! Many archived paper of ALEPH. Among these one can find ALEPH notes (1-171 from 29/10/1980 to 10/12/86) Sometime these are printed detailed notes but sometime they are photocopies of slides shown at our group meetings. Shown here is the first page of note 60 (26/11/1981) the first mention by Lorenzo Foa of the streamer tube idea for the ALEPH HCAL



HCAL Design (I)

Since a shower produced by a hadron in iron is quite bigger than the one of electrons or photons in ECAL made of lead, it is natural that the towers of HCAL be bigger than the ones of ECAL (about 3x3° instead of 1x1°) and therefore the number of towers smaller (4800 instead of 70000). However the BRILLANT idea was to decide to read each tube using a strip

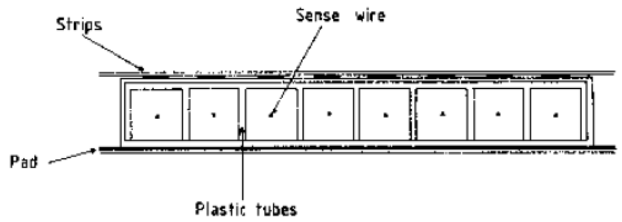
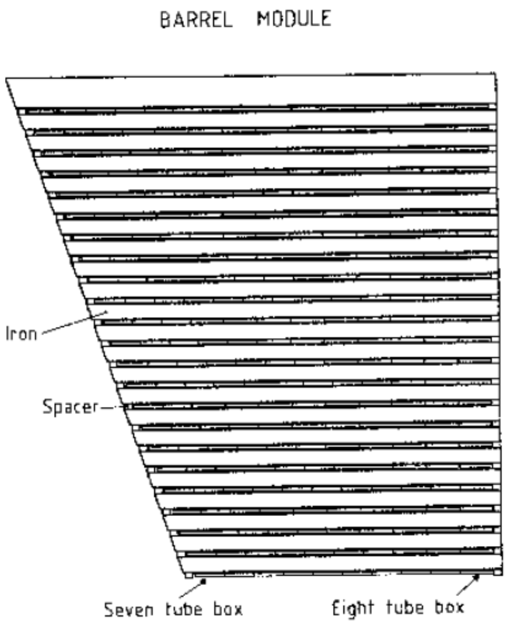
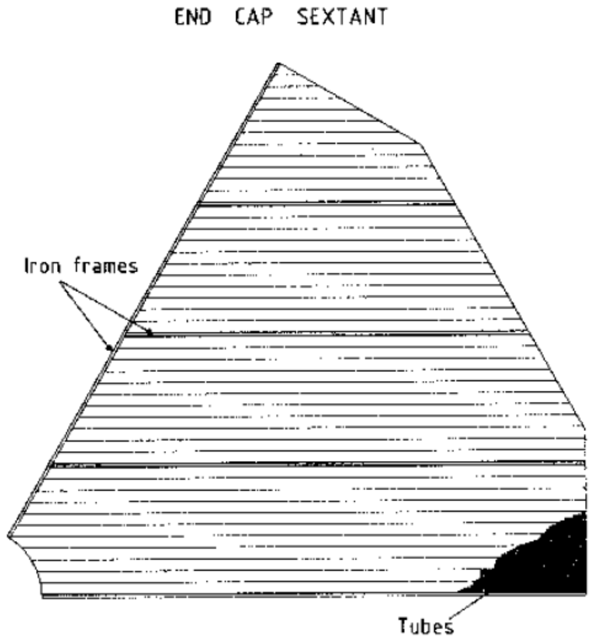


Fig. 6.1

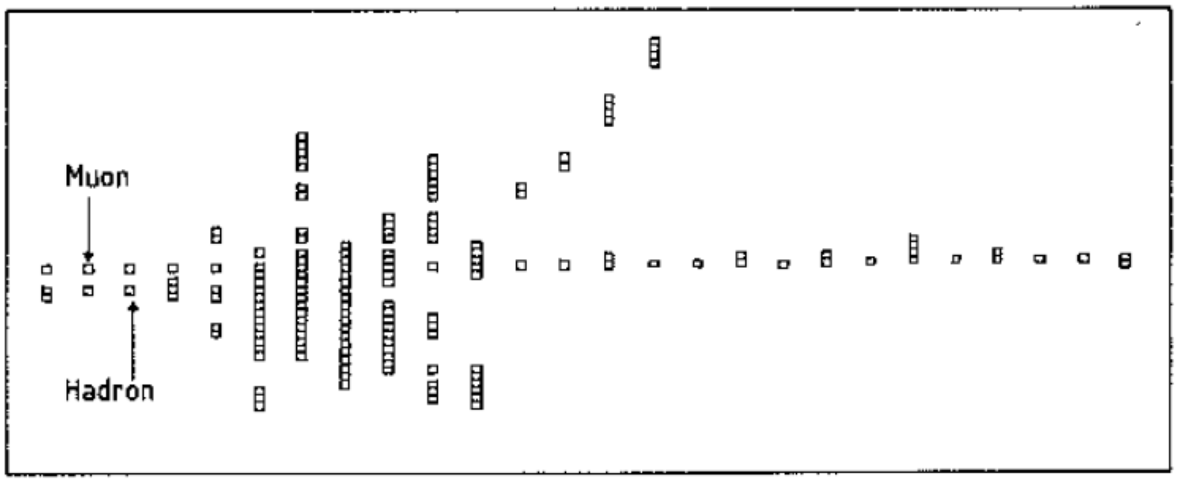




HCAL Design (II)

The great advantage of reading strips was the granularity . This is useful for muon ID as seen below and also for measuring jet energy and angle using particle flow technique. In this case. Charged hadrons are measured by the TPC, photons by the ECAL and neutral hadrons by the HCAL, this is only possible when the granularity is good enough to exclude energy release in HCAL related to charged particles. The price to pay was the large number of channels 120000 for HCAL+ 40000 for muon chambers.. Similarly the granularity of ECAL meant 210000 channels and about 50000 channels for the TPC

DIGITAL PATTERN OF AN EVENT



HCAL Performance

Because of the sampling with a gaseous detector one could have been afraid of obtaining worse resolution compared to scintillator-Iron HCAL… but the energy resolution was $\sigma = .84*\sqrt{E}$ GeVquite similar.

More important because of the excellent granularity one could use the particle flow method and obtain for jet energy measurement $\sigma = 0.54*\sqrt{E} + .6$ GeV . This was better than other LEP experiments and played an important role in Higgs searches for example.

Again using the granularity one could have an algorithm identifying muons in jets with an efficiency of 86% while rejecting hadrons with an efficiency of 99.2%

The ALEPH Vertex Detector (VDET), Initial history

Already in the LOI, under the main influence of Marcello Giorgi from Pisa, there was a proposal for a Silicon vertex detector (two elements of the 2 proposed layers are shown in the fig) Since one layer was measuring the φ coordinate and the other z, this VDET would have given only a precise point on the trajectory.
Because of overall funding problem anyhow after LOI approval the VDET construction was staged

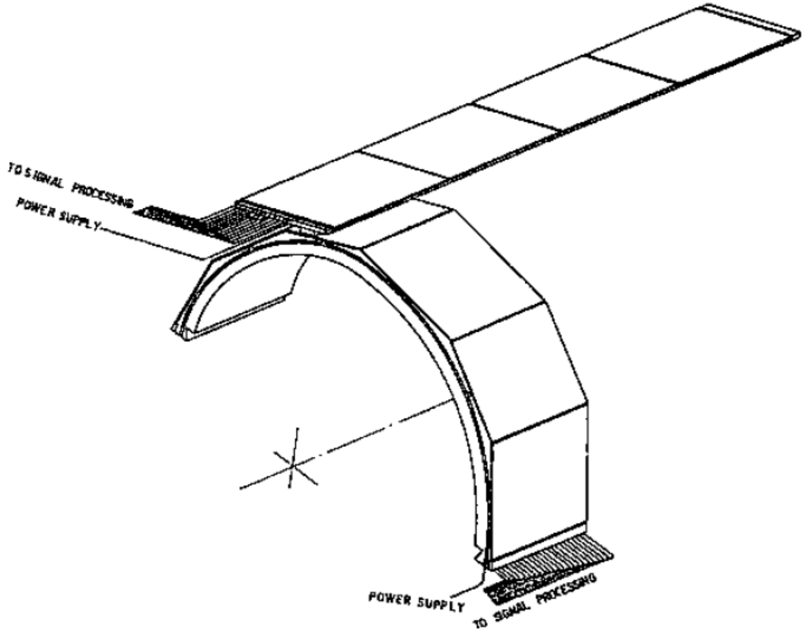
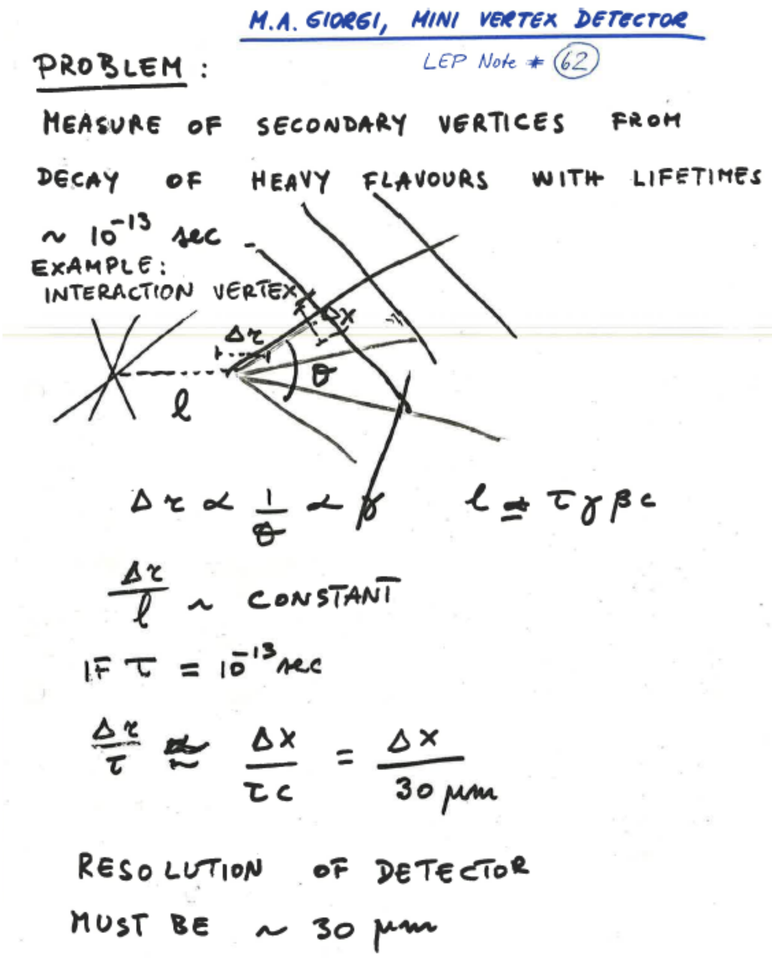


Fig. 9.5

ALEPH note 62

Shown here is the first page of ALEPH note 62 (26/11/1981) explaining that the required accuracy was about 30 mu and on following slides how this could be obtained from silicon detectors



VDET(1992) (I)

Then, in 1984,85, there was the brilliant suggestion to build two side readout of each silicon detector, one side reading the r-φ coordinate, the other side reading the z coordinate, this allowed to measure accurately position and angle just outside the beam pipe. Of course it was nevertheless more expensive than single face readout and this project was a collaboration between Munich and Pisa, (enlarged later to CERN, Marseille, Santa Cruz, Wisconsin) Marcello Giorgi was the first project leader , other Pisa contributors were L. Bosisio, F. Forti, E.Focardi, and G. Tonelli

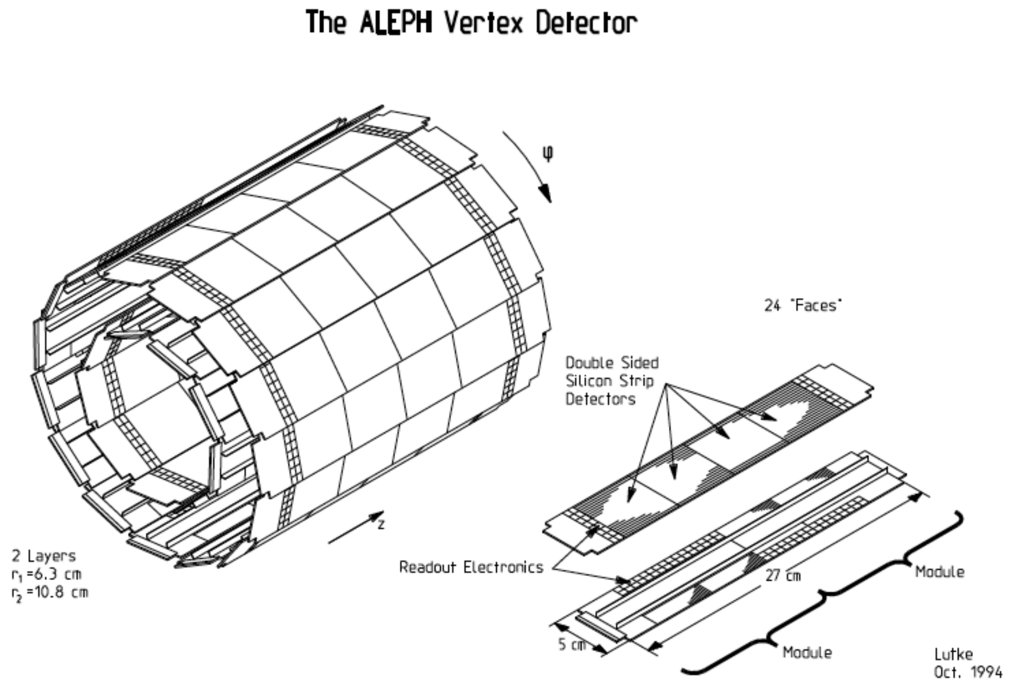


Figure 1: Configuration of the ALEPH silicon vertex detector.

VDET(1992) (II)

The amplifiers were chips with 64 channels (electronics progress)!

The double sided idea was brilliant but took some effort to make it work!

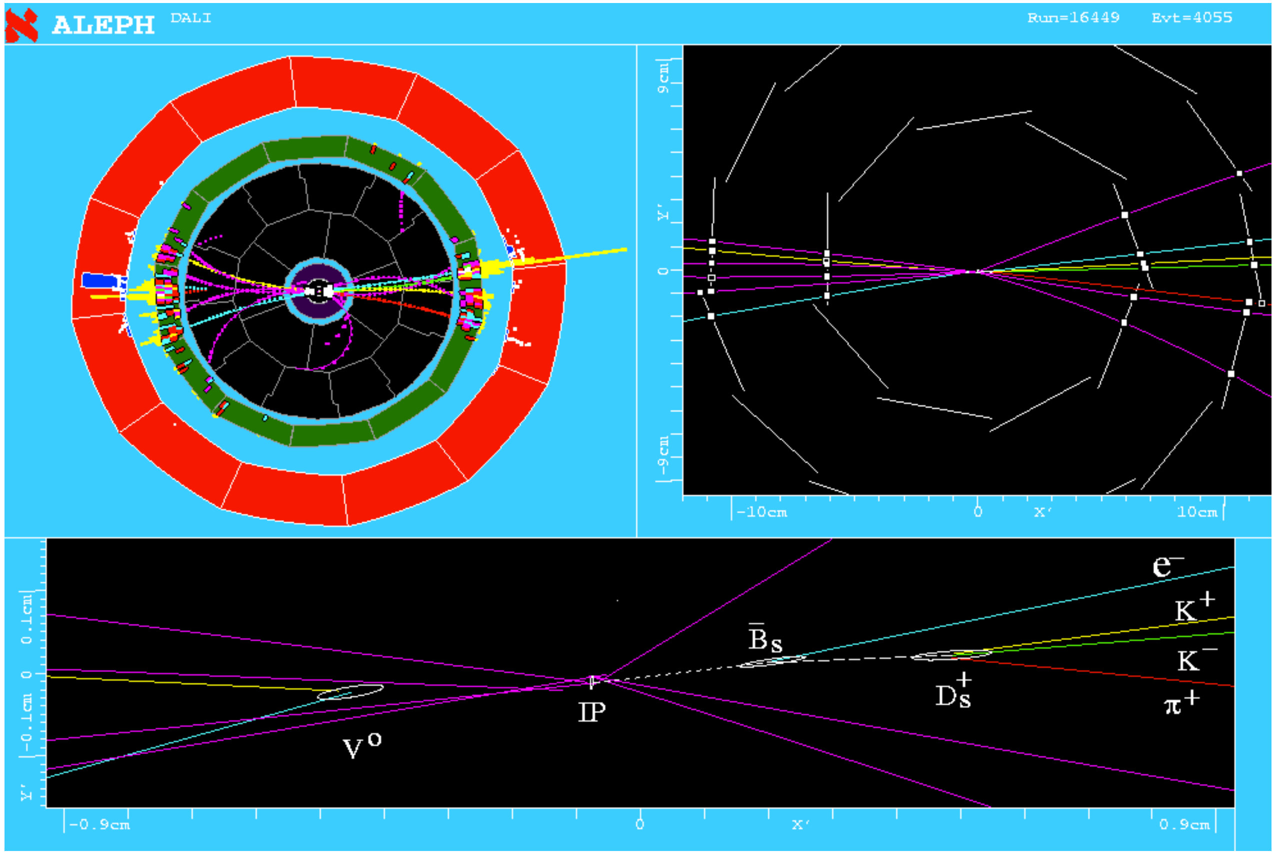
So in 89 only a few modules were installed and in 1990 a bit more than one layer but there were also unforeseen difficulties, the worse one in my opinion was a puncture of the thin capacitor used in series between detectors and amplifiers in case of very large pulses (few hundred volts) when there was a huge radiation from LEP beam loss. It turned out that the only way to protect ourselves (VDET but also TPC) was to detect in a sensitive way "early signs of beam instability" and voluntarily dump the beams rapidly in a safe place… This is of course now a trivial idea at the LHC, but it was new at LEP.

Finally, for the 1992 run, the full detector was installed and ran beautifully

VDET(1992) (III)

The accuracy of the device was about 12 μ in both views in each layer. The impact on the physics was extraordinary. It allowed to measure lifetime of τ or B mesons or baryons. But it also allowed to recognised events with the production of a pair of b quarks.

This had a great impact in measurements of the fraction of events with b quarks (Rb) or b quark asymmetries but also ,since the Higgs boson decay mostly to b quark pair the VDET played also a major role in Higgs searches



Second VDET(1996)

The first VDET had been of limited size because the realisation was already challenging! But, rather rapidly after its successful operation, there was the idea of having an improved version for LEP2 physics with its more complicated event structure (like WW=>4jets or ZHiggs searches) So a new VDET was built which was twice as long and with thinner detectors. Pisa had an important role in the conception and construction but it within a much larger collaboration with addition of groups from Italy France, UK and US. It still used the great idea of double sided readout.

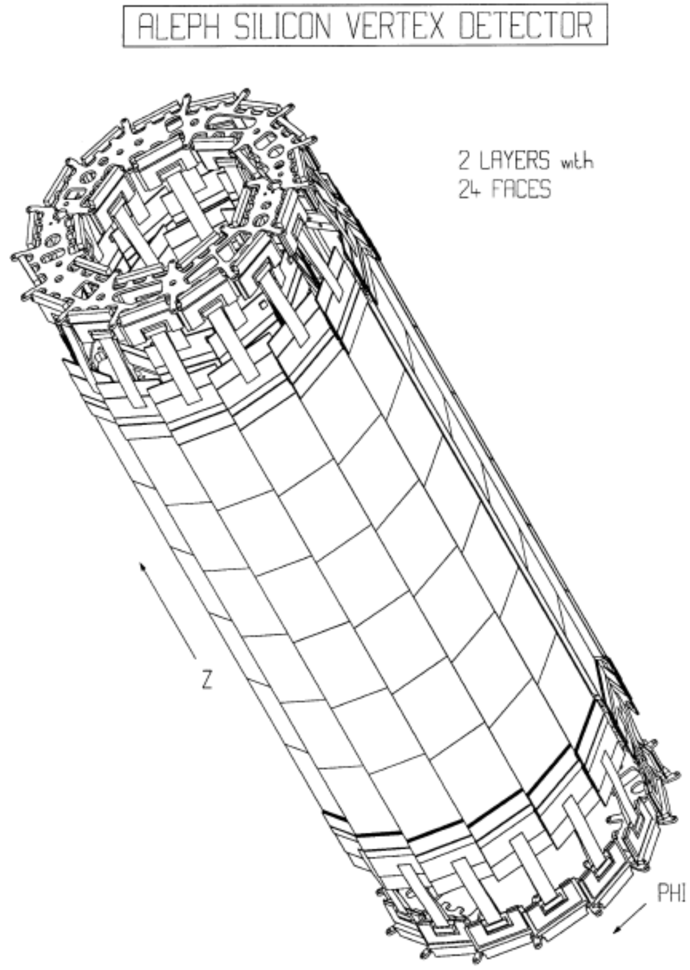


Fig. 2. VDET overall view.

Other apparatus contributions

As I mentioned earlier other physicist showed their interest and then contributed to other detectors than the HCAL and VDET for example in ALEPH note 83 (Oct 82) on the test result of a prototype TPC, 4 signatories were from Pisa (and L. Rolandi and F Ragusa from Trieste were “closely associated”)

ALEPH Note # 83

0042w/FR/gs
12 October 1982

PRELIMINARY RESULTS ON H4-TPC TEST

S.R. Amendolia, G. Batignani, M. Dris, F. Fidecaro, F. Liello,
J. May, T. Meyer, F. Ragusa, J. Richstein, L. Rolandi.

ABSTRACT

This report summarizes the preliminary results of the analysis of the data taken with a test TPC during July with H4 beam. Results are given for pad response function, resolution at 0°, resolution at 0° with magnetic field and width of pad response function as a function of angle.

Some physics analyses, and Pisa's role

It would be unreasonable to try to review the few hundred's of analyses, so I have made an arbitrary choice (using a personal prejudice): I will focus on 2 general results that in my view where the most important for ALEPH (and LEP) talking also of Pisa's physicists involved

- The measurement of the number of ν families
- The prediction from accurate EW results of M_{top} (before it was discovered at Fermilab) and then the prediction of M_{higgs} (before its discovery at LHC)

And then, increasing the prejudice, I will present a nice special case with Pisa physicists involved where I happened to be internal referee before publication:

- The first ALEPH τ lifetime measurement with the VDET in 92

Number of ν families

In principle the only thing to do is to measure the Z width and then subtract the partial width to leptons and hadrons, but it is more accurate to use the peak x-section which is prop to $1/\Gamma^2$

$$\sigma_f^0 = \frac{12\pi(\hbar c)^2}{M_Z^2}\frac{\Gamma_e\Gamma_f}{\Gamma_Z^2}$$

This can be transformed to

$$N_\nu = \frac{\Gamma_\ell}{\Gamma_\nu}\cdot\left(\sqrt{\frac{12\pi R_\ell}{M_Z^2\sigma_{had}^{peak,0}}} - R_\ell - 3\right)$$

R_l = the ratio Γ_h/Γ_l was taken initially from E-W theory and corrected by the QCD correction

The first data gave $N_\nu = 3.27 \pm 0.24_{stat} \pm 0.16_{sys} \pm .05_{th}$ but later the R_l value was measured with our own data with the result (with more stat) as N_ν = 2.993 ±0.015

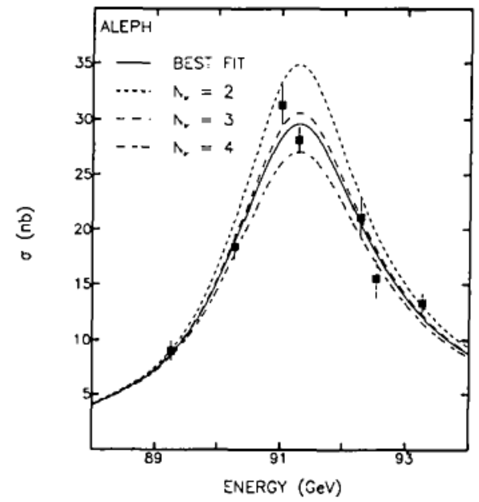


Fig. 5. The cross-section for $e^+e^- \to$ hadrons as a function of centre-of-mass energy and result of the three parameter fit.

Number of ν families (Pisa Physicists)

The result was extremely important because it could not be excluded that a 4th family existed with quarks and charged leptons too heavy to have been observed, the result $N_\nu = 3$ (for Z => ννbar) made this extremely unlikely.

The initial analysis of course requested understanding the apparatus, there were two groups doing the analysis, one relying on purely calorimeter signature for the hadronic events led by J Steinberger and another group relying on pure TPC signature and led by A. Blondel. Both results were averaged. Fabrizio Palla from Pisa was part of Jack's group. The later analysis used our own measurement of Rl and this involved work from the lepton groups among them the tau group (L.Rolandi (originaly from Pisa) was one of the convenors)

Precision EW measurements predict M_{top} M_{Higgs}

I remember this prediction of Mtop as one of the most exciting moment of ALEPH. EW measurements receive correction which are like$(1+a*(M_{top}/M_w)^2)$ or like $(1+b*\ln(M_{Higgs}/M_Z))$ These EW measurements include the width Γ_Z but most important $\sin^2(teta_w)$ obtained from asymmetries. Even with only the 1989, 1990 data ALEPH could publish (Zeit.Phys. C53 (1992)1. or CERN PPE 91-105 July 91) an EW precision measurement paper, giving the prediction from ALEPH data alone

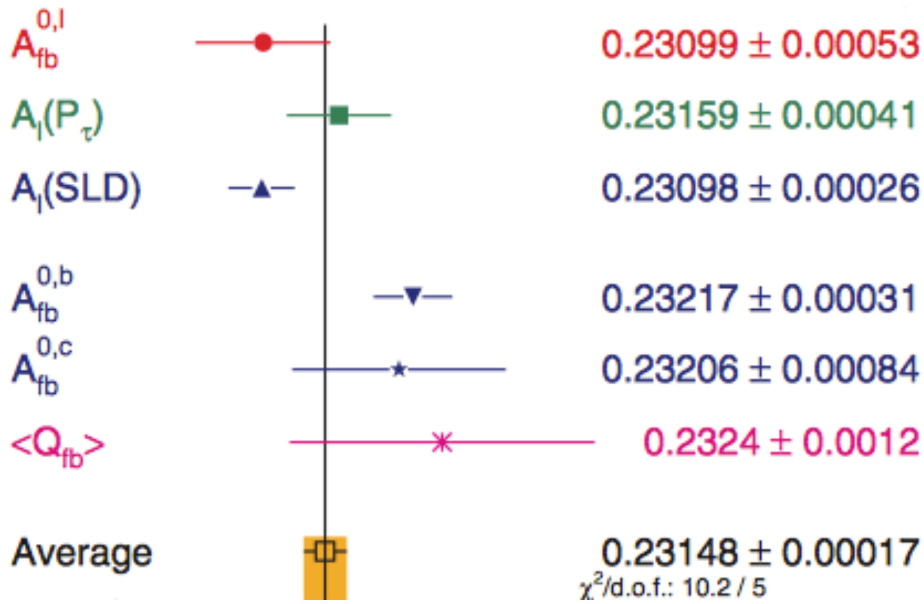
M_{top} =170 GeV±45(expt)±20(Higgs 30GeV-1000GeV)

By 1994 the accuracy was (173+-12+-19) for the 4 expts and then the top was seen at Fermilab and its mass measured Mtop=176±16GeV.

As is well known after mtop was measured the data could be used to predict Mhiggs (at ICHEP 2002 M_H= 81 +52 -33 GeV). We certainly owe a lot to theorist for this but experimentalist are also allowed to be proud!

Asymmetries

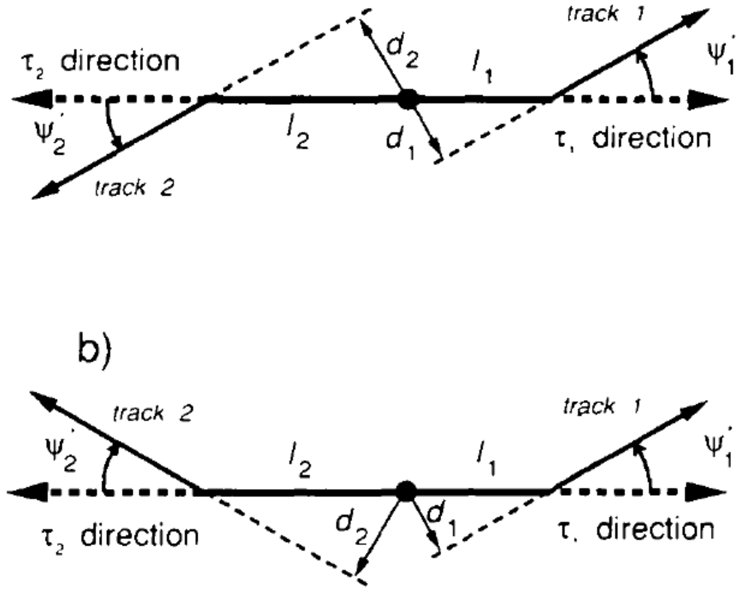
As can be seen in the enclosed plot A^{0b}_{fb} the asymmetry in Z=>bbar events was the most sensitive tool at LEP to determine $sin2\theta W$. Different methods were used using the lepton charge in b semileptonic decays or signing events with decay pattern using the VDET and then using the jet charge to distinguish b from bbar.



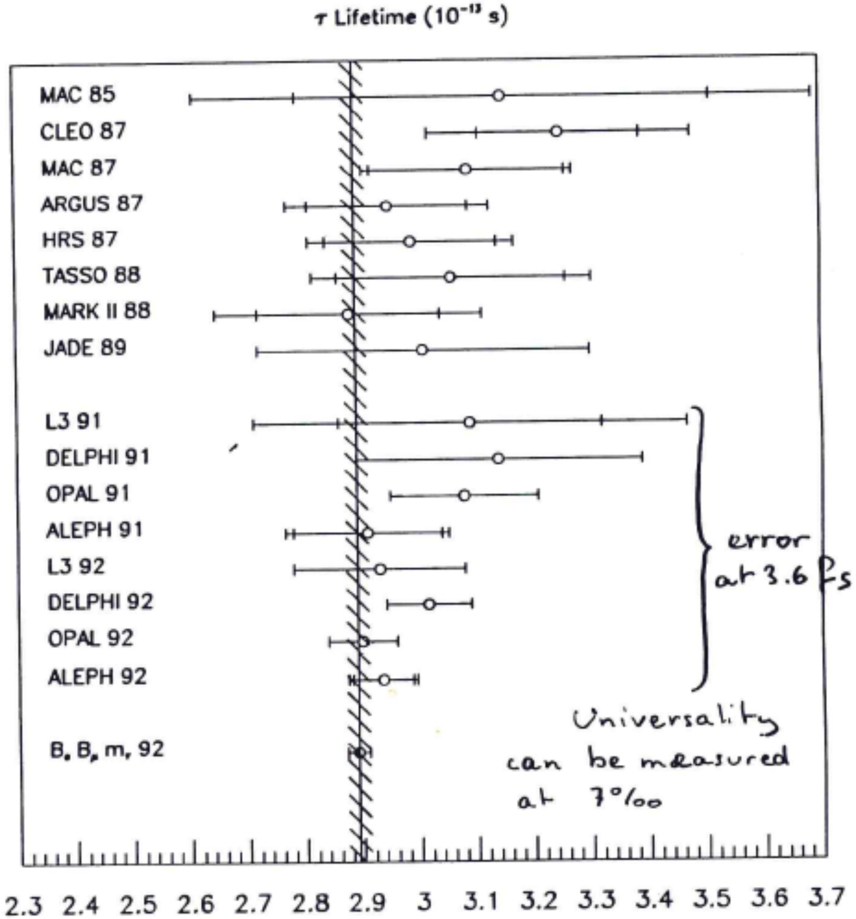
ALEPH result was more accurate (by about 20% to 50%) than other LEP expts. We owe this to the apparatus but also to our Pisa B team of D.Abbaneo, F.Ligabue, F.Palla and R. Tenchini.
Roberto by 1994 was convenor of the EW Heavy Flavour group.

τ lifetime (I)

The first measurement done using the operational VDET was the τ lifetime.
It was a very nice analysis done by 4 physicist from Pisa, F.Fidecaro and A.Lusiani ,A. Messineo, I.Ferrante
Being at the Z peak had advantages:
higher xsection, => large evts number
Almost 0 background from qqbar events
45 GeV τ energy=> 2.5mm <decay length> for tau=>3 pi
For 1-1 topology one uses impact parameter sum or differences (typically 150μ)



τ lifetime (II)



I remember that I was ALEPH referee for the analysis and paper and the discussions were a pleasure! There were subtle points, for example the radial position of the VDET detectors were not know well enough, however the size of the detectors and their overlap (using tracks) were know to a few μ => 2πR =>R accurately (Oval problem…no!)

The last 3 results shown used Silicon vertex detectors and one can see the impact on accuracy. Using the ALEPH result alone one can deduce the equality of μ and τ coupling to W with a 1.2% error

Pisa physicist responsibilities and conclusion

Apart from the responsibilities in apparatus construction and some analysis (or convenor of analysis groups) which I have mentioned. There were other general contributions

Lorenzo Foa was spokesperson 1993-1994

Gigi Rolandi (Pisa=>Trieste=>CERN=>+Pisa) was Physics coordinator (1989-1994) and spokesperson 1994-1997

Roberto Tenchini was spokesperson (2001-2005)

I thank the organisers for giving me a chance of remembering these days close to my heart! And I thank F.Fidecaro, L.Rolandi and R.Tenchini for exchanges of emails to help me to prepare this talk

If some of you wish to send some corrections before the written version=> lefranco@lal.in2p3.fr

Spare slides

N_ν October 1989

Experiment	hadronic Zs	Z mass (GeV)	N_ν
MARKII	450	91.14 ± 0.12	2.8 ± 0.60
L3	2538	91.13 ± 0.06	3.42 ± 0.48
ALEPH	3112	91.17 ± 0.05	3.27 ± 0.30
OPAL	4350	91.01 ± 0.05	3.10 ± 0.40
DELPHI	1066	91.06 ± 0.05	2.4 ± 0.64
Average		91.10 ± 0.05	3.12 ± 0.19

Table 1: *First results from LEP and SLC on the Z mass and the number of light neutrino species, as published around 12 October 1989 (in order of submission to the journal).*

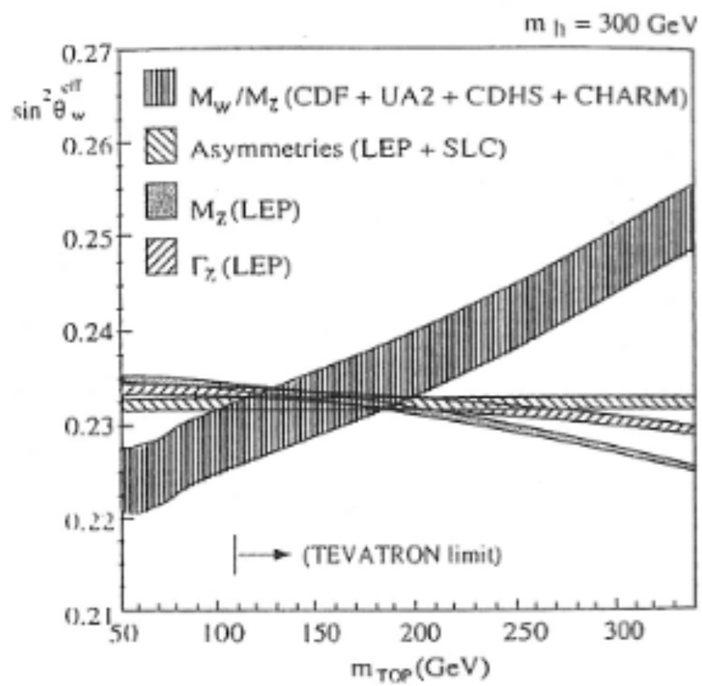
E-W precision measurements

Even with only the 1989, 1990 data ALEPH could publish (Zeit.Phys. C53 (1992)1. or CERN PPE 91-105 July 91) an EW precision measurement paper, giving the prediction from ALEPH data alone

M_{top} =170 GeV±45(expt)±20(Higgs 30GeV-1000GeV)

It was an intense pleasure, which I remember very well, to be able to predict a new particle mass. We are now all waiting either for new particles found directly or at least, as at that time, for a sign of new physics (but life is now more difficult.)

Different measurements contribute to the top mass prediction as shown on the plot right =>
By 1994 at the winter conference the prediction was M_{top} =173±12±19(M_H) By the summer 1994 the top was found at the Fermilab collider with Mtop=176±16GeV
I think the prediction was a fantastic achievement of LEP and generally of the S.M.
As is well known, similarly, using all E-W data the Higgs mass was predicted for example in ICHEP 2002 as M_H= 81 +52 -33 GeV



ALEPH apparatus structure (event)

The nice granularity and clarity the "obvious muon"