Remembering Giordano Diambrini Palazzi: the LEP-5 experiment at CERN

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1 Introduction

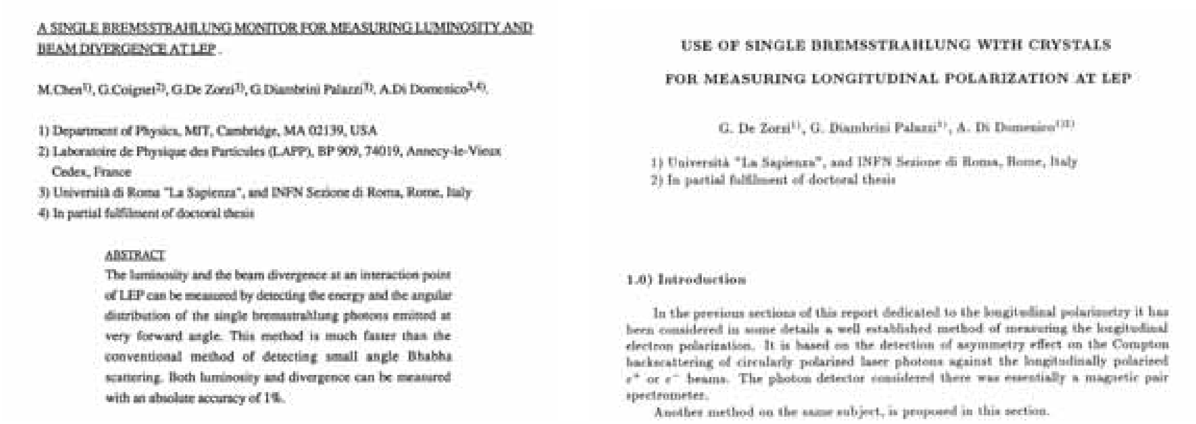
LEP-5 was the last experiment led by Giordano Diambrini Palazzi at CERN. It was in fact the fifth LEP experiment, and it was performed by a small group of Italian physicists from Rome University and INFN. I had the opportunity and the privilege to join the Giordano's group in 1989, soon after my degree, when the project was already started from a couple of years.
The original name of the experiment before the approval by the LEP Committee, was PLP (in Italian: Progetto Luminosità e Polarizzazione), which indicated the goal of the project: to realize a monitor of the luminosity and beam polarization of the LEP e^+e^- collider.
At the project stage of the machine, the possibility to exploit longitudinally polarized electrons was extensively studied: the idea was to measure the Left-Right asymmetries

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \simeq 2P_e \frac{V_e A_e}{V_e^2 + A_e^2}$$

where $\sigma_{L,R}$ is the cross-section of processes like

$$e^-_{L,R} + e^+ \to X$$

with left or right polarized electrons, V_e and A_e are the vector and axial couplings of the elactrons to the Z, and P_e is the electron polarization. From such asymmetries one would have obtained a precise measurement of one of the fundamental parameter of the Standerd Model, $\sin^2 \vartheta_W$.
From November 9 to 11, 1987, the Workshop "Polarization at LEP" was held at CERN. Two contributions [1] [2] (fig.1) were presented by Giordano, together with Guido De Zorzi and Antonio Di Domenico (Giordano's student at that time). The first one is the proposal to use the Single Bremsstrahlung photons to measure the



A SINGLE BREMSSTRAHLUNG MONITOR FOR MEASURING LUMINOSITY AND BEAM DIVERGENCE AT LEP .

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ABSTRACT
The luminosity and the beam divergence at an interaction point of LEP can be measured by detecting the energy and the angular distribution of the single bremsstrahlung photons emitted at very forward angle. This method is much faster than the conventional method of detecting small angle Bhabha scattering. Both luminosity and divergence can be measured with an absolute accuracy of 1%.

USE OF SINGLE BREMSSTRAHLUNG WITH CRYSTALS FOR MEASURING LONGITUDINAL POLARIZATION AT LEP

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1.0) Introduction

In the previous sections of this report dedicated to the longitudinal polarimetry it has been considered in some details a well established method of measuring the longitudinal electron polarization. It is based on the detection of asymmetry effect on the Compton backscattering of circularly polarized laser photons against the longitudinally polarized e^+ or e^- beams. The photon detector considered there was essentially a magnetic pair spectrometer.
Another method on the same subject, is proposed in this section.

Figure 1: Front pages of the two contributions to the CERN yellow report on Polarization at LEP [1] [2].

luminosity and the beam divergence of LEP, written in collaboration with two members of the L3 Collaboration. The second one, the real focus of the PLP project, was the proposal to use crystals to measure the longitudinal polarization of the beam electrons, in line with the historical research line of Giordano.

Actually the interest of Giordano for this subject started even before, in 1986, when he participated, together with some collaborators of the Genoa University, in the drafting of the proposal for the polarization measurement at the SLC collider at SLAC [3].

In September 1988 the PLP Letter of Intent was presented to the LEP Committee. In the following I will briefly describe the proposal, and then what was the follow-up of the project, the detector construction and installation at LEP, and the results of the experiment.

2 The luminosity proposal

The idea to measure the luminosity with the Single Bremsstrahlung, $e^+e^- \to e^+e^-\gamma$ (also called radiative Bhabha Scattering), was first exploited at ADONE in Frascati in the '70 [4], and then at VEPP in Novosibirsk [5].

The main feature of this process is that its cross-section slightly increases with energy, $\sigma_{SB} \sim \ln s$, unlike for the Bhabha Scattering, $e^+e^- \to e^+e^-$ the process generally used to measure luminosity, whose cross-section decreases like $1/s$. This made the Single Bremsstrahlung convenient especially at high energy machines, like LEP (fig.2). With a luminosity $L \simeq 10^{31}$ cm^{-2} s^{-1} one expected a photon rate of the order of 3 MHz, which means about 100 Single Bremsstrahlung photons per bunch-crossing, about three orders of magnitude greater than the Bhabha Scattering rate(fig.3).

Another important feature of this process is the extremely collimated angular

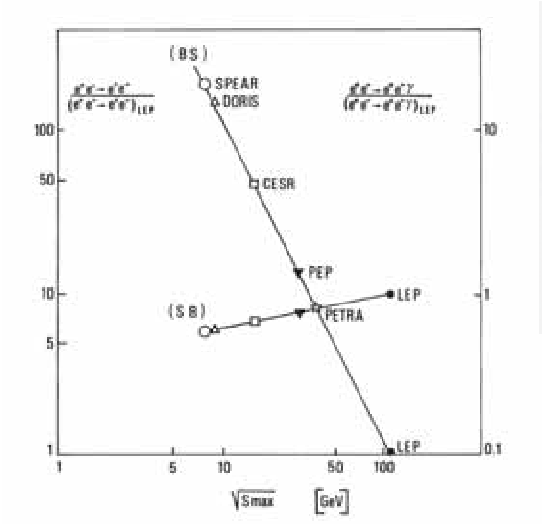


Figure 2: Comparison of the Bhabha scattering and Single Bremsstrahlung cross-sections versus the center of mass energy. [1]

	SPEAR	PETRA	LEP
Luminosità ($cm^{-2}\ sec^{-1}$)	10^{31}	[illegible]	10^{31}
Energia del fascio (GeV)	2.6	8.5	55
Frequenza eventi Bhabha $10 < \theta < 20\ mrad$ (Hz)	$3.5 \cdot 10^{3}$	30	6.5
Frequenza eventi brems. sing.- soglia $0.5 GeV$ - (Hz)	$6.7 \cdot 10^{5}$	$1.5 \cdot 10^{5}$	$3.3 \cdot 10^{6}$

Figure 3: Comparison of Bhabha scattering and Single Bremsstrahlung rates at different e^+e^- colliders (from the thesis of A. Di Domenico).

distribution, the typical emission angle being $\vartheta_\gamma \simeq \frac{m_e}{E} \simeq 10\ \mu$rad at LEP with $\sqrt{s} = 91$ GeV.

In fig.4 it is shown a scketch of a LEP straight section: the photons traveling with the beams escaped the beam-pipe at the beginning of the curved section, reaching a detector placed at the end of the straight section, about 350 m far from the interaction point (IP).

The high photon rate implied that we would have worked in multiphoton regime, in which the luminosity is obtained from a measurement of integrated energy on the detector, rather than from photon counting.

$$E_{meas} - E_{bckg} = AL \int_0^{E_{beam}} \epsilon(k) k \frac{d\sigma_{SB}}{dk} dk$$

where k is the photon energy and L the luminosity. In fig.5 it is shown the expected spatial distribution of the deposited energy on the detector, compared with the angular distribution of the SB. From a two dimensional fit of this distribution, the acceptance A would have been evaluated, obtaining in this way also a measurement of the beam position in the transverse plane, and of the beam divergence at the IP.

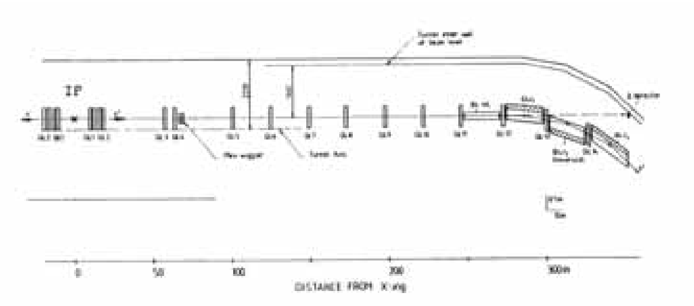


Figure 4: Sketch of the LEP straight section from the IP to the photon detector. [1]

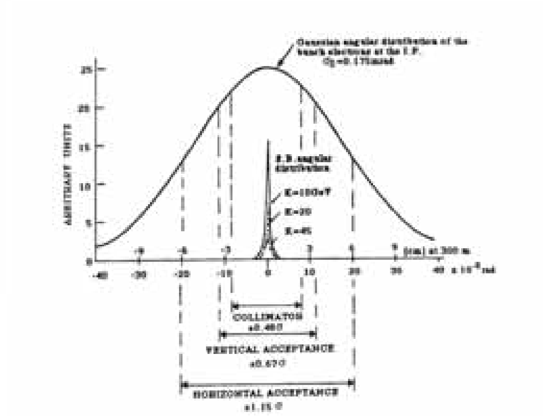


Figure 5: Angular distribution of the Single Bremsstrahlung photons due to the beam divergence. [1]

3 The polarization proposal

The method proposed by Giordano to measure the polarization was innovative with respect to the conventional method, based on the detection of the asymmetry in Compton back-scattering of right and left circularly polarized laser photons against the longitudinally polarized electrons.

The proposed method took advantadge from the fact that if the electrons are longitudinally polarized, the Single Bremsstrahlung photons will have a certain degree of circular polarization given by:

$$P_\gamma^c(X) = P_{e^-} P_\gamma^1(X) = P_{e^-} \frac{X(1-\frac{X}{4})}{1 - X + \frac{3}{4}X^2} \tag{1}$$

where X is the fractional energy of the photon ($X = k/E_{e^-}$). P_γ^1 is the photon polarization for fully polarized electrons, and according to eq.(1) goes to unity when $X \to 1$, as shown in fig.6.

The experimental setup is sketched in fig.7: the circularly polarized photon impinged on a first, thin, crystal that acted as a $\lambda/4$ plate, converting the γ polarization from circular to linear. The second, thick crystal is the polarization analyzer because the transmission coefficient for linearly polarized photons depends on the orientation of the polarization vector $\vec{\varepsilon}$ and the symmetry axes of the crystal. By rotating the second crystal, and measuring the transmission coefficient at different ϕ angles, P_γ^1 could be measured, then obtaining P_{e^-}.

One of the advantages of this method is that the electron polarization is measured exactly at the IP where the Single Bremsstrahlung process takes place.

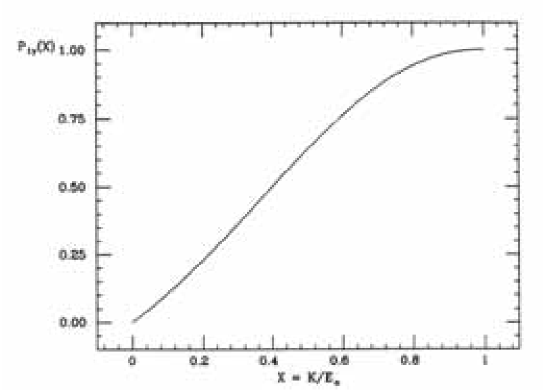


Figure 6: Circular polarization of Bremsstrahlung photons for longitudinal polarized electrons. [2]

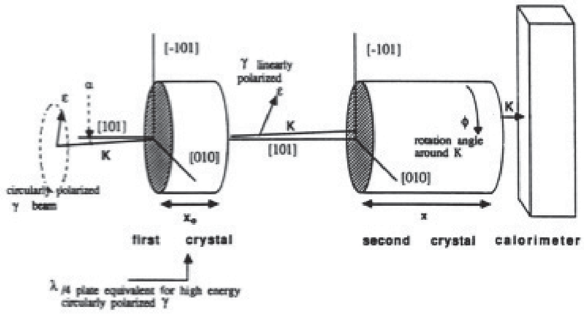


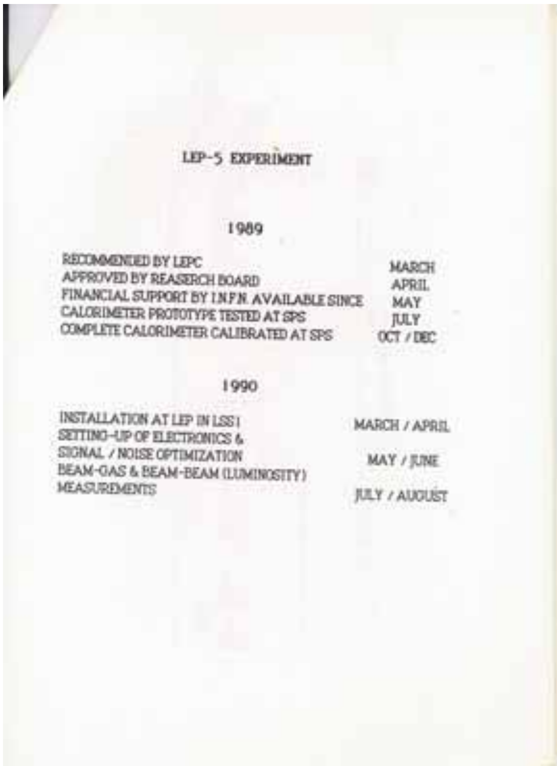
Figure 7: Experimental setup for the measurement of the polarization. [2]

4 The experiment

It is well known that the beam polarization at LEP was not exploited (while it was at the SLC later on). But the first part of the project, the luminometer, was developed.
The group that performed the experiment consisted in three senior physicists, Giordano, Guido De Zorzi, and Dino Zanello, and four young pepole, two degree students, Gianluigi Di Cosimo and Antonio Di Domenico and two graduate students, Cesare Bini and me. To complete the group composition, our technician Mario Bertino has to be mentioned, whose help was essential for the realization and the installation of the detector. At a second stage also Daniele De Pedis joined our group.
The schedule of the LEP-5 experiment is shown in fig.8. The experiment was approved by CERN in 1989 as a test experiment to be performed in IP-1[1], an interaction region without detectors since the four LEP experiments were installed in the even IPs.

In normal conditions the beams were separated in order not to affect the beam lifetime. They were put into collisions in IP-1 (and in IP-5 by symmetry) only in the final 2 - 3 hours of a LEP fill, which used to last 10 - 12 hours. Moreover, also with colliding beams, the experimental conditions were different from even IPs. Since the beams were not optimized for collisions, the luminosity was lower by about one order of magnitude and the beam divergence smaller.
The apparatus is scketched in fig.4: at the end of the straight section there was a thin aluminum window on the beam-pipe to allow photons to escape and to reach

[1]This is the site where now is installed the ATLAS detector at the LHC.



LEP-5 EXPERIMENT

1989

RECOMMENDED BY LEPC	MARCH
APPROVED BY REASERCH BOARD	APRIL
FINANCIAL SUPPORT BY I.N.F.N. AVAILABLE SINCE	MAY
CALORIMETER PROTOTYPE TESTED AT SPS	JULY
COMPLETE CALORIMETER CALIBRATED AT SPS	OCT / DEC

1990

INSTALLATION AT LEP IN LSS1	MARCH / APRIL
SETTING-UP OF ELECTRONICS & SIGNAL / NOISE OPTIMIZATION	MAY / JUNE
BEAM-GAS & BEAM-BEAM (LUMINOSITY) MEASUREMENTS	JULY / AUGUST

Figure 8: Schedule of the LEP-5 experiment from the Giordano's talk at the Conference in honour of Giorgio Salvini's 70^{th} birthday.

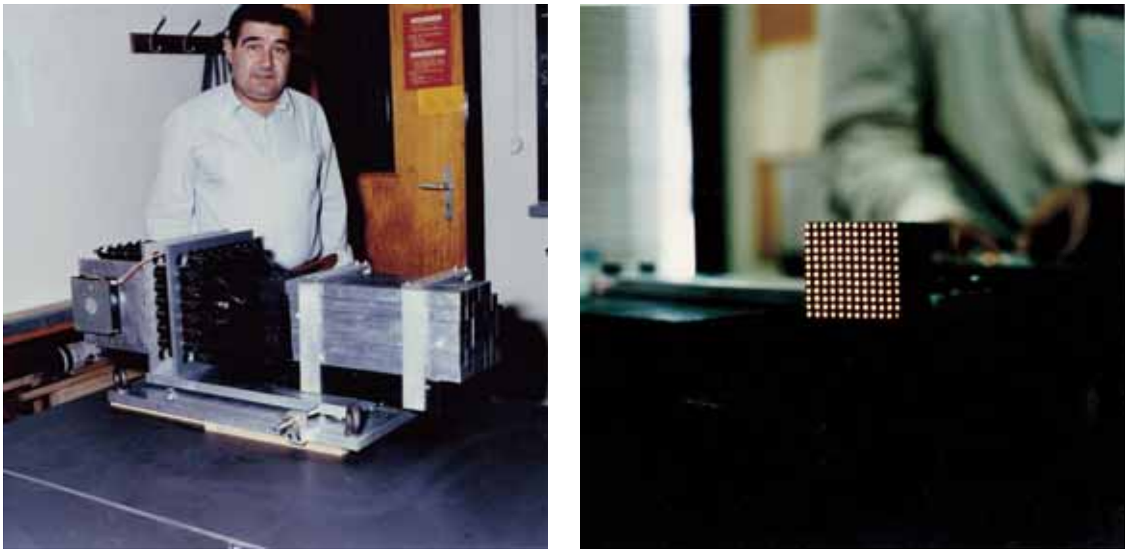


Figure 9: Left: Mario Bertino with the LEP-5 calorimeter. Right: a calorimeter module illuminated from back.

the photon detector placed about 350 m far from the IP.
The detector was an electromagnatic calorimeter made of a lead with scintillating fibers as active medium. In front of the calorimeter there was a 2 X_0 long absorber of LiH, a low Z material to stop sinchrotron radiation. The calorimeter (fig.9), has been one of the first detectors of this type operated in an experiment. It consisted of a matrix of 7×6 modules each of $2.5 \times 2.5 \times 35$ cm^3 volume. The modules were built with a melting technique: molten lead was poured into a mould with spacers holding 144 steel tubes to accommodate the scintillating fibers of 1 mm diameter. The fibers were almost parallel to the flight direction of the incoming photons. From the read-out point of view each of the 6 central modules was divided into 4 separate channels to increase the spatial resolution in the central region of the calorimeter. Each readout channel was connected through a light guide to a photomultiplier.

In fig.10 some pictures of the test beam are reported, where the calorimeter has been tested and calibrated.

The calorimeter was installed in IP-1 during spring 1990, and data were taken during the following summer, in June - August 1990. In fig.11 some pictures of Giordano in the LEP-5 counting room are shown.

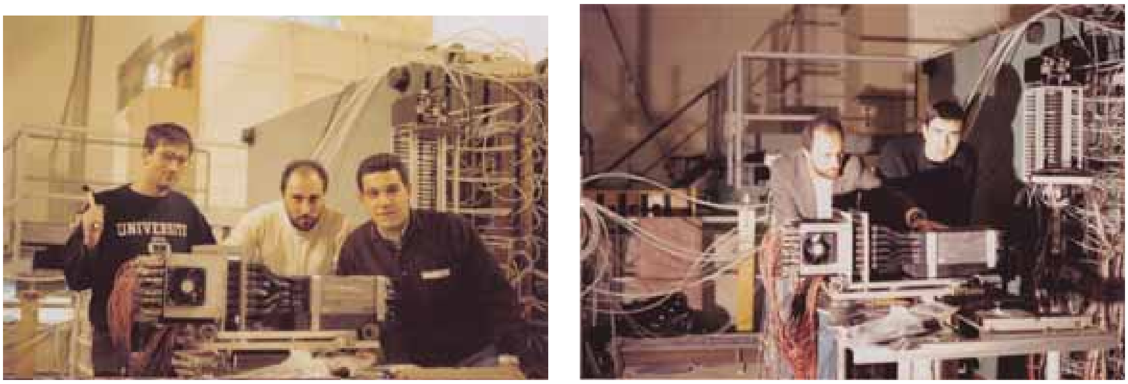


Figure 10: C. Bini, A. Di Domenico and G. Di Cosimo during the test at the SPS beams, before the installation in IP-1 of LEP.

5 Experimental results

In the following the best results, obtained during Fill 409 of LEP, are shown [6]. With separate beams in IP-1 the background from single beam radiation, due to the beam-gas Bremsstrahlung and to the Compton scattered thermal photons, was measured. The beam-gas contribution was expected to be proportional to the beam current (of the positrons in our case), and to the density of residual gas in the beam-pipe, which is again proportional to the circulating currents. Also the Compton scattering of thermal photons was expected to be proportional to the beam current. Those two effects combined to produce the parabolic behaviour shown in fig.12.

When the beams were put into collisions a sudden signal increase was observed (fig.13), clearly showing the additional contribution of the beam-beam Bremsstrahlung photons. At the end of the collision regime, the last three points of fig.13, the integrated energy went back to the background level extrapolated as a function of the beam current.

In order to determine the absolute luminosity, the acceptance had to be evaluated from the spatial distribution of the energy on the calorimeter (fig.14). Finally, in fig.15 the result of the measurement is reported: each point corresponded to 10 minutes of data-taking, the statistical uncertainty was of the order of 1%.

The method appeared to work properly, however at that time Giordano and all of us were concerned about that "oscillating" behaviour of the luminosity shown in fig.15, while a smooth curve was expected.

The explanation was simple, and was provided by George von Holtey of the LEP machine group. During Fill 409 a β-waist scan was performed in the OPAL interaction point, and that was the reason of the luminosity variations observed, not

Figure 11: Giordano in the LEP-5 counting room (June 1990).

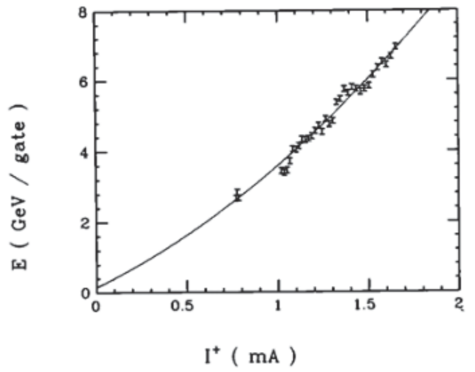


Figure 12: Deposited energy in the calorimeter with separate beams in IP-1. [6]

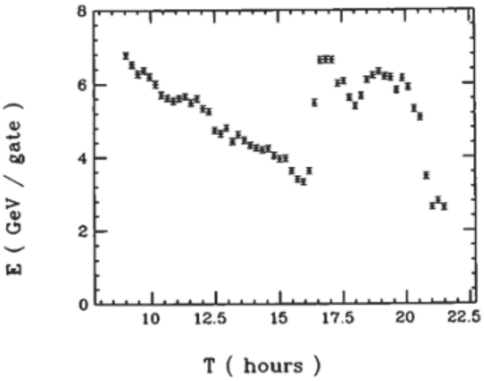


Figure 13: Signal of the Bramsstrahlung photons, collisions starts at about 16:00 hrs. [6]

only by us but also by all the other 4 experiments as shown in fig.16.

6 Compton scattering of thermal photons

A very interesting by-product of our experiment was the possibility to measure for the first time the Compton scattering of the thermal photons present in the LEP beam-pipe against the high energy electrons [7].
The LEP vacuum pipe could be considered as a black body at about 300 K temperature, hence filled with electromagnetic radiation with an energy distribution following the Planck law with a peak at $k_{max} \simeq 0.07$ eV. In the rest frame of the LEP electrons, a photon with energy k_{max} incident at a 180^o appear to have an energy $K^\star \simeq 2\gamma K_{max} \simeq 13.7$ keV due to the Lorentz boost. After a Compton back-scattering the photon gains another factor 2γ, then in the laboratory frame its energy will be $k \simeq 4\gamma^2 k_{max} \simeq 2.8$ GeV, well inside the energy range of the Single Bremsstrahlung photons.
Hence the Compton back-scattered photons constituted a relevant source of background for the measurement of the luminosity, of the same order of magnitude of the beam gas Bremsstrahlung, due to the extremely low vacuum pressure of LEP (of the order of 10^{-10} torr). We measured the total background, with separate beams in IP-1, and in fig.17 it is shown the experimental spectrum of the integrated energy on the calorimeter, compared with the Monte Carlo expectations for beam gas Bremsstrahlung and beam gas plus Compton back-scattering. The best agreement was found for an average number of beam gas photons per ADC gate of $\mu_{BG} = 0.44$ and of thermal photons $\mu_{TP} = 1.47$. From these values we

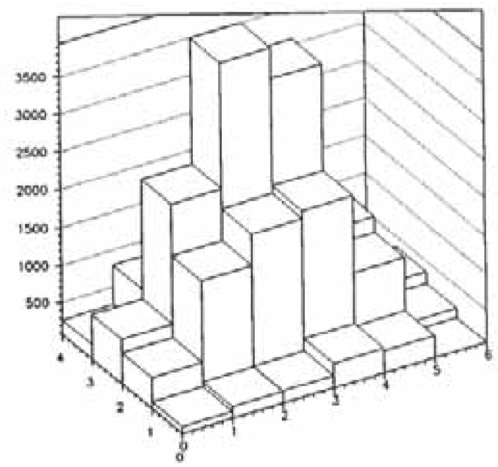


Figure 14: Spatial distribution of the deposited energy in the central modules of the calorimeter. [6]

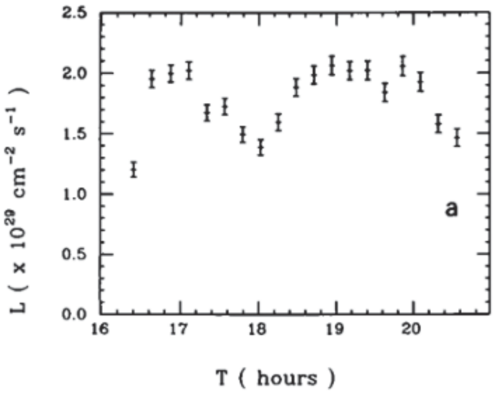


Figure 15: Luminosity as a function of time. [6]

could obtain an estimate of the temperature of the beam-pipe and the pressure of the residual gas in it: they turned out to be $T \simeq 291$ K and $P \simeq 2.2 \times 10^{-10}$ torr, respectively. This Compton scattering of thermal photon could in principle decrease the beam lifetime; however our conclusion was that it could not degrade significantly the LEP performance. To be complete it must be mentioned that a similar measurement was performed at the same time by the group of Adrian Melissinos [8].

7 The LEP-5 upgrade and the second data-taking

During 1991 an upgrade of the experiment was performed in order to fully exploit the high rate capability of the luminosity measurement method [9]. In doing that, the possibility to measure the luminosity of the four bunches separately was also tested. This last feature would have been very important in case of polarization of LEP beams, since schemes with different polarization bunch per bunch were proposed [10].
A faster readout electronics was employed, able to process and store the signals from the calorimeter acquiring all the bunch crossings.
With this new readout we took data on October-November 1991, but unfortunately, the LEP beam optics was different and the new one caused severe instabilities when the beams collided in IP-1. Then we had only few minutes of collisions, sufficient however to prove the feasibility of the measurement (see fig.18). More-

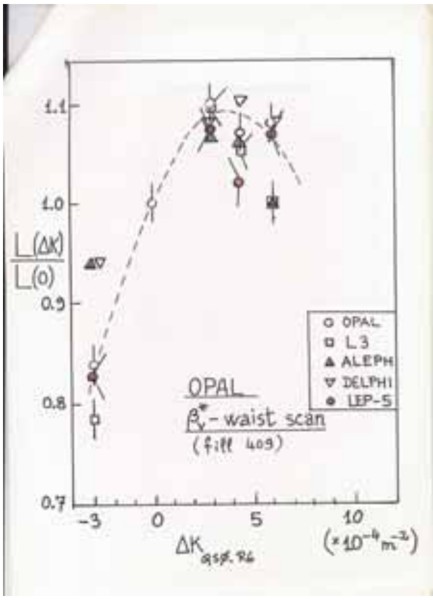


Figure 16: Comparison of the luminosity measured in the various IPs during the β-waist scan of Fill 409. [6]

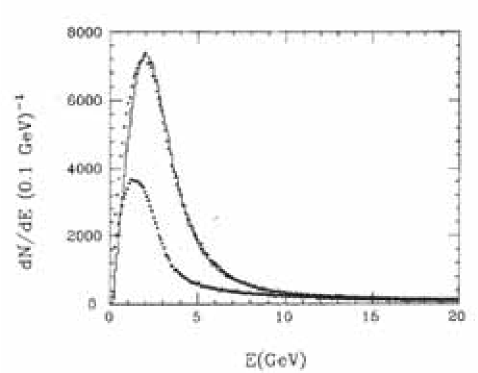


Figure 17: Spectrum of the deposited energy(histogram) compared with Monte Carlo simulation of beam gas (black points) and with beam gas plus Compton scattering (crosses) [7].

over the new optics was such as the photons distribution was centered out of the window, then we had a larger systematic uncertainty due to the evaluation of the geometrical acceptance from a tail of the distribution. But the collected data showed that we could measure the bunch per bunch luminosity with a statistical uncertainty of 0.2% with a 20 s long measurement.
Nevertheless the LEP-5 experiment did not proceed further, since the interest of the LEP experiments, in particular of the L3 Collaboration that at the beginning supported the project, dropped in the meantime.

8 Conclusions

After the end of the LEP-5 experiment, we continued an R&D activity on lead-scintillating fiber calorimeters. In those years they still were considered an option for the calorimetry at the LHC. We studied low melting point alloys, and also we studied different readout segmentations to optimize the space resolution, and tested the radiation damage of the scintillating fibers. In this phase however Giordano was directing his scientific interest to other topics, mainly concerning possible experimental tests of quantum gravity.

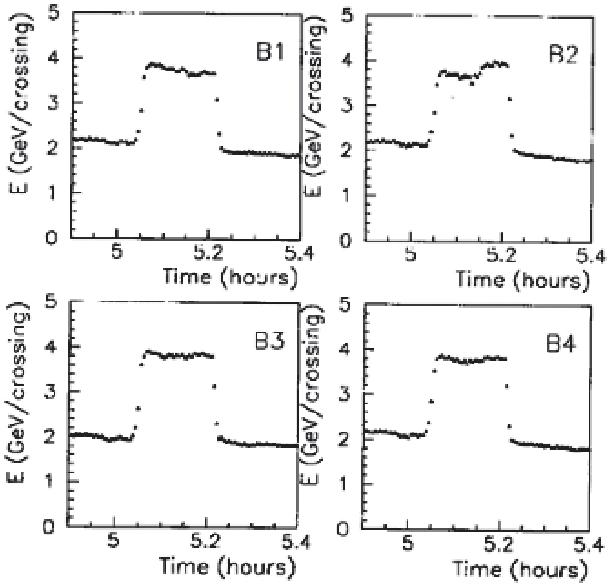


Figure 18: Deposited energy in the calorimeter for the four bunches separately [9].

The LEP-5 experiment, although downscaled with respect to the original project, succeeded in demonstrating the possibility to measure the LEP luminosity with high precision using the Single Bremsstrahlung.
Concerning my personal experience, and I am sure this is also true for the other young (at that time) members of Giordano's group, this experiment has been an extraordinary school. It made us excited about the experimental physics, that for many of us has become a profession, and for that we must be very grateful to Giordano and also to the other senior members of the group.

Acknowledgements

I wish to thank C. Bini, A. Di Domenico, and M. Bertino for the material and the help in the preparation of the presentation.

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