Energy calibration at LEP using Nuclear Magnetic Resonance probes

E. Bravin, B. Dehning, G. Mugnai
CERN - 1211 Geneva Switzerland

Abstract

The accurate Standard Model investigations carried out at LEP require knowledge of the beam energies of the order of a few 10-5. The resonant depolarisation method, used for absolute calibration in dedicated experiments, cannot be used to monitor continuously the beam energy during the physics runs. Moreover appreciable polarisation of the beams has not been measured above energies of 55 GeV. A method for continuous energy monitoring based on Nuclear Magnetic Resonance (NMR) probes mounted in tunnel magnets has been in use at LEP since 1995. The average field of the dipole magnets is sampled via 24 NMR probes mounted in the gap of the C-shaped yokes on top of the vacuum chamber. The probes are distributed over the 27 kilometres of the accelerator. The probes are used for the continuous monitoring of the field during LEP operation and to determine the absolute field value. The reproducibility of the energy calculated from field measurements is below 1 MeV.

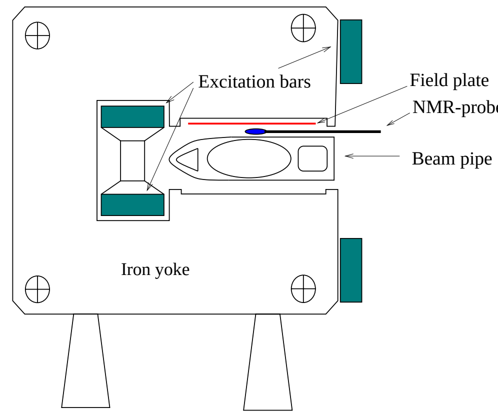

Figure 1: Cross section of the instrumented LEP dipole. The NMR probe is mounted in top of the chamber and below the field plate, which is glued on the pole surface.

1 INTRODUCTION

NMR probes were used in LEP first in a reference magnet placed in a surface building. The coil of this magnet is in series with the coils of the magnets in the tunnel. The reference magnet has iron laminations separated by 4 mm air gaps. This magnet was regarded as a appropriate representative of the LEP tunnel magnets. The tunnel dipole magnet is stacked together with a series of 1.5 mm thick steel laminations separated by 4 mm gaps [1, 2]. The mechanical stability of the construction is provided by the cement mortar which fills the space in between the laminations (see Fig. 1). It was quickly discovered (1991) that the field dependence on the temperature of the iron-concrete core is almost ten times larger than the dependence of all-iron core magnets. In 1993 long term (20 h) energy calibrations of the electron beam with the resonant depolarization method showed a discrepancy against the estimate of the energy from reference magnetic field measurements [3]. This was the motivation to install the Nuclear Magnetic Resonance (NMR) probes in the LEP tunnel magnets.

2 INSTALLATIONS

The NMR probes (METROLAB R1) are installed in a slit between the pole face and the vacuum chamber. An iron plate (170x200x1.5 mm^3) was glued on the magnetic pole surface (see Fig. 1), because at this off-centre position the magnetic field homogeneity is inadequate for the NMR probe operation. The probe head is shielded on the sides with lead, which also ensures an accurate repositioning of the probe. The bottom surface is in contact with the aluminium vacuum chamber. The preamplifier is outside the gap shielded by 10 cm of lead to avoid any synchrotron radiation damage.

Every octant of LEP is equipped with at least one probe (see Fig. 2). Near the interaction points 1, 3 and 5 strings are installed with up to five probes. In total 24 probes are used to determine the absolute magnetic field and to monitor the field evolution during LEP operation. At locations with more then one probe a multiplexer is used for the read out. Each NMR instrument is read every 7 seconds to record fast field variations. The switching time for the multiplexer is 2 seconds. To allow a fast and reliable locking of the instruments on the NMR resonance signal the scan range is limited ($\pm$ 1 G) and the start scan frequency of the instrument is deduced from a hall probe instrument which determines the field of the reference magnet. With this procedure it is possible to switch from one probe on a multiplexer to another in 7 seconds. For continuous monitoring of the resonance signal amplitude each instrument is connected to an ADC channel. In addition, to allow normalisation of the field measurement with an NMR probe to a reference temperature, a temperature probe is put inside the back leg of the C shaped magnet.

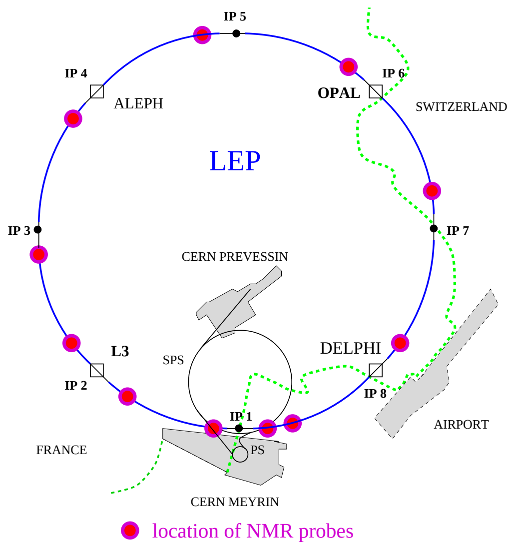

Figure 2: Location of the NMR probes around LEP. The probes left and right of point 1 are installed in the LEP injection magnets (iron core with twice the field of standard magnets). The location near point 3 is equipped with four probes for special test measurements.

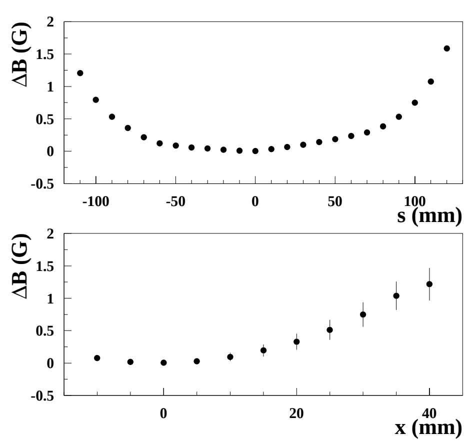

Figure 3: Variation of the magnetic field just below the field plate in the gap of the bending magnet as function of the longitudinal (s) and transverse (x) extension of the magnet.

3 FIELD PLATE AND IRRADIATION

The 1.5 mm thick horizontal field plate under the vertical lamination of the yoke reduces field inhomogeneities with a spacing of 4 mm (concrete thickness) to an inhomogeneity which is caused by the dimensions of the field plate (see Fig. 3). The probes are placed in the centre position (s=0, x=0) by maximising the resonance signal.

At LEP the NMR probes are operated at their lower field level limit of 430 G and they are directly exposed to the synchrotron light radiation on one surface side (9x25 mm^2). These two circumstances impose strong requirements on the radiation hardness of the probe heads. The strong dependence of the resonance signal amplitude on the magnetic field for two probes is shown in Fig. 4, top plot. The bottom plot shows the decrease of the resonance signal for several probes with time. During this time the probes received a dose of 3.5 10^5 Gray. The decrease of the signal permits the operation of the probes at the lower field level.

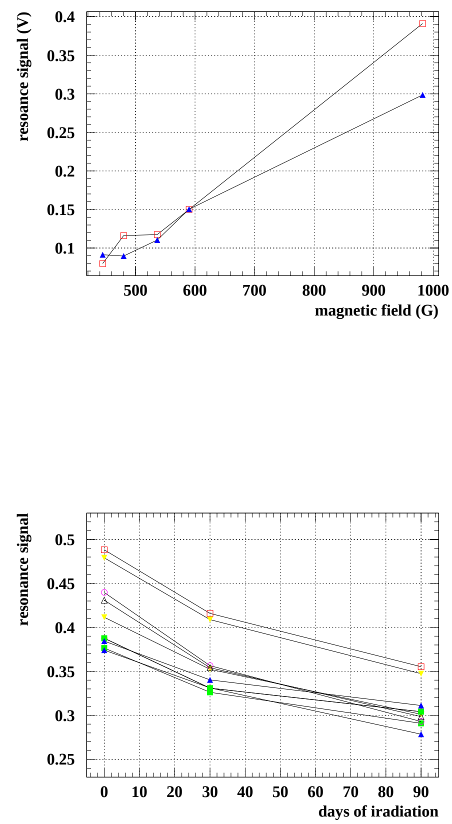

Figure 4: Variations of the NMR probe resonance signal. Top: Increase of the resonance signal of two probes with increasing field. Bottom: Decrease of the resonance signal with time of operation (irradiation time).

4 BENDING MAGNET FIELD

The plot (see Fig. 5) shows the magnetic field profile along the gap of a LEP dipole magnet for two different excitation currents. The curve for 2000 A has been scaled to the 4000 A excitation current curve. The three different regions (1900 to 2750, 2750 to 3850, 3850 to 5000 mm) are caused by different batches of iron. The mixing of different batches keeps the integral field for different magnet cores more equal, but the field level seen by the NMR is

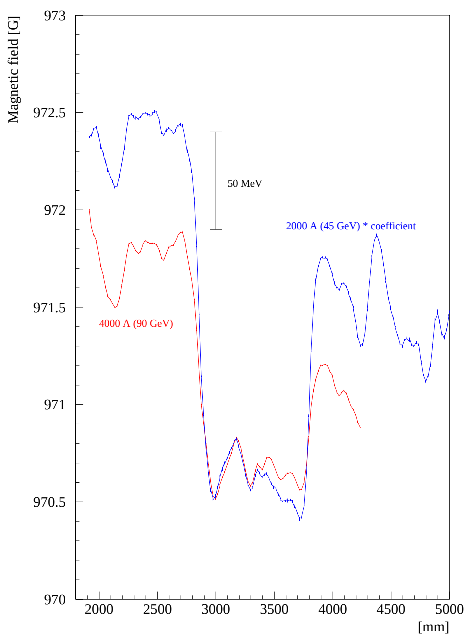

Figure 5: Variation of the field of the LEP iron concrete core magnet along the gap.

different for these regions and also the scaling with excitation current is different. Therefore to use NMR probes for the determination of the beam energy the field must be sampled at many different locations. In addition to the field variation due to the properties of the iron field variation occurred due to cooling circuit differences and different humidity levels in different parts of the LEP tunnel. These observations motivated the large number of distributed NMR probes used in LEP.

5 ACCURACY OF THE ENERGY DETERMINATION

The LEP probes are calibrated with the resonant depolarization method (RDM) using a polarized electron or positron beam. The Fig. 6 shows the difference between the beam energy determination with the RDM method and the averaged NMR probes (16) for four different energies and for two experiments (blue, red). The reproducibility of the measurements at the different energies is below 1 MeV. The characteristic energy dependence of the residuals is assumed to be caused by insufficient sampling of the magnetic field.

6 CONCLUSION

The installation of NMR probes in the LEP tunnel magnets was possible with minor modifications on the magnet core and the vacuum chamber. The operation of the probes is suffering from the increase of the lower field level limit due to synchrotron light irradiation. The number of the installed NMR probes is motivated by the field variations due iron property changes, magnet assembly differences and environmental effects. The reproducibility of the the beam energy using the measurements of magnet field level with NMR probes is below 1 MeV. The NMR probe field measurements led to the discovery of field variation due to a leakage current flow over the LEP vacuum chamber [4, 5]. For the calibration of the beam energy with the resonant depolarization method is the prestimate of the energy using the NMR probes indispensable [6].

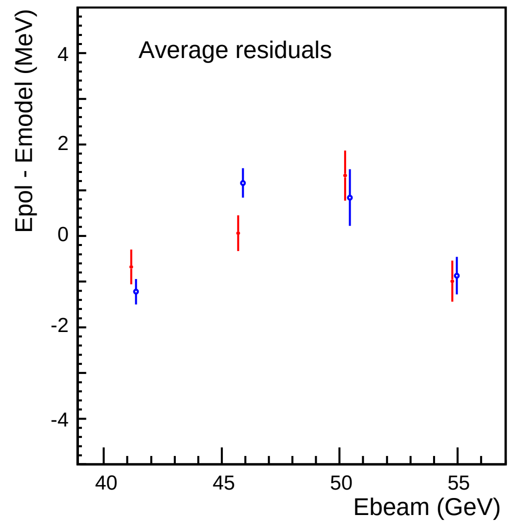

Figure 6: Residual beam energy variations for different beam energies comparing the resonant depolarization calibrations and the beam energy estimated using NMR probes.

7 REFERENCES

[1] "LEP design report", Vol. II, CERN-LEP/84-01 1984, 1984

[2] M. Giesch, J.P. Gourber, "The bending magnet system of LEP ", 11th International Conference on Magnet Technology : MT-11 Tsukuba, Japan, 28 Aug - 1 Sep 1989, CERN-LEP/89-68-MA

[3] "Accurate determination of the LEP beam energy by resonant depolarization", L. Arnaudon et al., Z. Phys., C : **66** (1995) 45-62.

[4] "A newly observed effect affects the LEP beam energy", G. Brun et al., 5th European Particle Accelerator Conference EPAC 96, Sitges, Spain, 1996.

[5] E. Bravin et al., "The Influence of Train Leakage Currents on the LEP Dipole Field", CERN-SL-97-047-BI

[6] B. Dehning, "Improvements in Polarization", PROCEEDINGS OF THE EIGHTH LEP PERFORMANCE WORKSHOP, CERN-SL-98-006 DI