LEP BEAM ENERGY CALIBRATION IN 1995

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A three point energy scan was performed in 1995 to improve the errors on the Z width and to confirm the results of the 1993 scan. For the first time since LEP was commissioned the bending field has been monitored with probes installed inside tunnel dipole magnets. Short term fluctuations, sudden jumps and typical rises in the magnetic field corresponding to several MeV per beam during a fill have been observed. Operating LEP in 1995 with bunch trains implied a shift of the center of mass energies in the case of beams colliding with an collision offset. This contribution reports the present status of the knowledge of these new effects.

1 Introduction

The 1995 LEP run was devoted to a three point[1] energy scan around the Z resonance to improve the accuracy on the Z width and to confirm the results achieved in the 1993 scan [1]. The contributions of the LEP beam energy uncertainties to the mass and the width of the Z for the 1993 scan are ([1]) $\delta\Gamma_Z$ = 1.5 MeV and δM_Z = 1.4 MeV respectively with a statistical error of 2 MeV and 3 MeV and a negligible systematic error contribution from the experiments. Since LEP delivered in the 1995 scan about $10\ pb^{-1}$ integrated luminosity at each off-peak point, the expected statistical errors have the same size as in 1993. To reduce the systematic errors, the beam energy was calibrated as often as possible with the resonant depolarization technique, a method used at LEP since 1991 [2]. Newly installed **N**uclear **M**agnetic **R**esonance (NMR) probes monitored the variation of the magnetic field in tunnel dipole magnets throughout a fill. Energy calibrations at the beginning and at the end of a fill have been performed to verify the observed drifts in the magnetic field.
The operation mode of LEP in 1995 was different to that used in 1993. The "bunch train" operation scheme [3] implied a beam separation around the **I**nteraction **P**oints (IP), which is leading to opposite sign vertical dispersion at the IPs. To control center-of-mass energy shifts due to this vertical dispersion a dedicated technique to adjust the collision offset at the IPs has been improved and successfully operated.

2 The LEP Dipole Field

Any variation of the dipole field B results in a shift of the beam energy since:

$$E \sim \int_0^L B_{dipole}\, dl \qquad \text{L = length of closed orbit} \tag{1}$$

In 1995 more emphasis is put on the monitoring and understanding of variations of the mag-

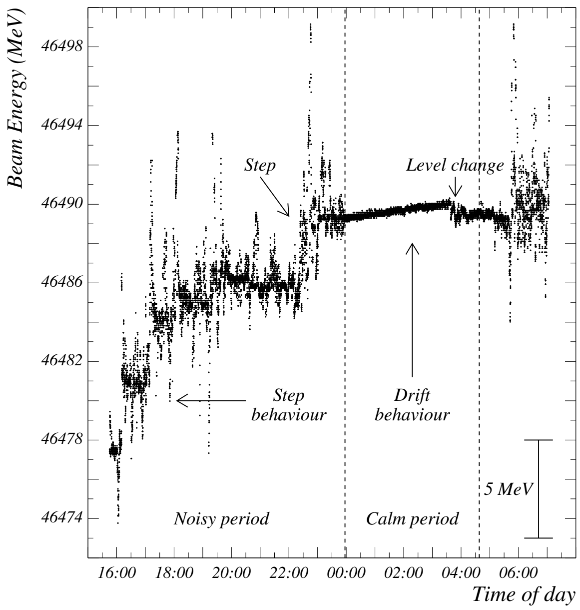

Figure 1: Magnetic field as measured in NMROCT8 as a function of the time in the fill. The duration of the short term field variations is of the order of a few minutes. The field increase in this fill is not continuous in time but with variations of the slope and steps of various sizes. The jumps occur after a strong fluctuation of the B field. Furthermore around 4:00 a negative level change happens.

[1] at "Peak-2", "Peak" and "Peak+2" energy settings

netic dipole field of LEP. The magnetic field is measured simultaneously with 4 NMR probes. Two NMRs are installed in a reference magnet residing in a surface building. The other probes (NMROCT4 and NMROCT8) are mounted in two tunnel dipole magnets and are available since 1995. The reference magnet is connected in series with the tunnel dipoles. The measure-

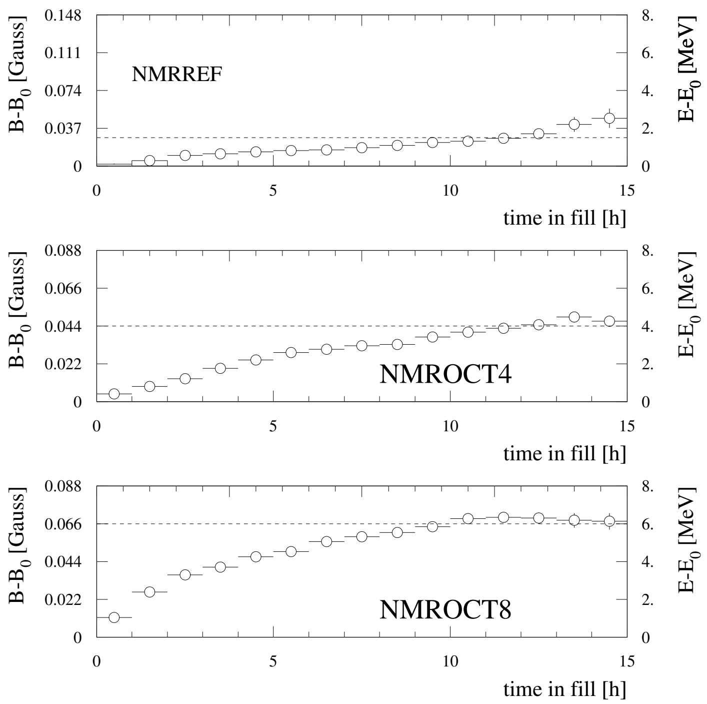

Figure 2: Increase of the B field with respect to the first measurement in a fill as a function of the time after the declaration of physics conditions. The scale on the left side is given in units of the magnetic field (Gauss), the scale on the right side in units of equivalent (see eqn. 1) beam energy (MeV). NMROCT4 saturates at a level of about 4 MeV, NMROCT8 at a level of 6 MeV. A more detailed discussion is given in [4].

ments of the NMR probes show characteristic time dependences. While the two NMRs in the reference magnet show only weak and slow variations of the B field with time, the B field in the tunnel varies with sudden fluctuations of up to 10 MeV equivalent beam energy between 05:00 and 24:00 (fig. 1). In the period from midnight to around 4:00 the tunnel NMR probes

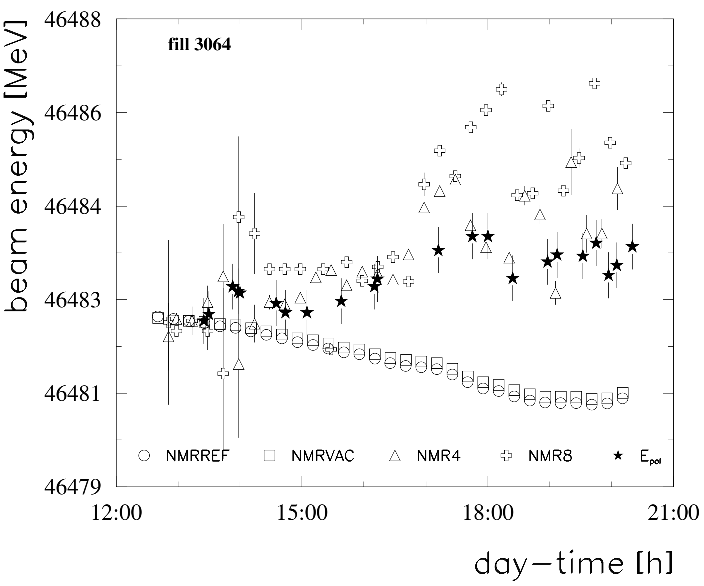

Figure 3: Evolution of the energy measured by resonant depolarization and the measurements of all NMR probes as a function of time in fill 3064, on Oct. 8th 1995. During this fill a dedicated energy calibration experiment was performed at an energy setting of “Peak+2”. The NMR readings are normalized to the first calibration measurement. The total rise is relatively small due to the fact that on this day, a Sunday, fewer trains pass on the rails.

behave almost as the reference magnet probes. This pattern is observed in all fills which cover this particular time period. An anti-correlation of the short term field fluctuations measured by NMROCT4 and NMROCT8 is observed. The average increase of the magnetic field for the different probes as a function of the fill duration (shown in fig. 2) is derived for the whole scan period. While NMRREF shows only small average drifts (< 2 MeV) with a tendency to rise more towards the end of a fill, both tunnel probes rise most during the first hours of a fill with a tendency to saturate after about 12 hours. The B-field measurements with the tunnel probes are verified with beam energy calibrations. Figure 3 shows one of 6 dedicated experiments with frequent calibrations. While the two reference magnet probes do not track the beam energy evolution, the two probes in the tunnel reproduce reasonably well the energy calibration data.

Investigations to understand this behaviour show that currents of up to a few amperes circulate on the vacuum chamber and on the ground cable of LEP. Correlation measurements (fig. 4, bottom) between different parts of the ring demonstrate that these currents enter LEP through the injection lines and leave the ring over a relatively wide zone around IP6 (fig. 4, top) causing most probably the observed anti-correlation between NMROCT4 and NMROCT8. The origin of these "vagabond" currents is a known problem of DC railroads: a certain fraction of the current supplied to the locomotive is leaking into the ground. The currents affecting LEP are mostly due to the railway line between Geneva main station and destinations in France via Bellegarde, which is powered with DC voltage (1500 V) while the swiss lines

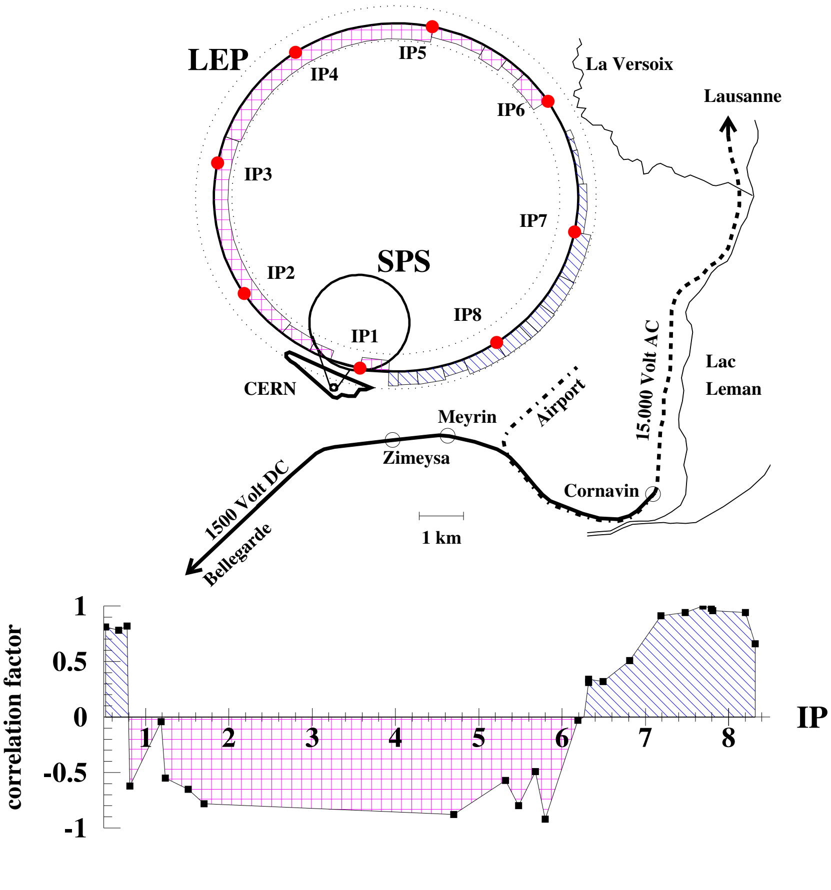

Figure 4: Schematic View of LEP with the 8 IPs and the railroads in the Geneva Area. Below the correlation factor of the "vagabond" current with respect to the position of NMROCT8 as a function of the position along the ring. The correlation factor changes sign around the injection lines (i.e. around IP1) and the interaction point IP6. In principle, the current supplied by the power stations to the locomotive returns to the power stations over the railroad tracks, but in practice a certain fraction of this current ($\simeq$ 25 %) leaks into the ground and flows back to the generator along other "roads". In our case, some of the return current flows back to the generator via the good conductors that are installed in LEP: the ground cable and the vacuum chamber.

use 15000 Volt AC (fig. 4, top). A controlled experiment is performed during the LEP high energy run in 1995 to confirm this explanation. The result is shown in figure 5. The current

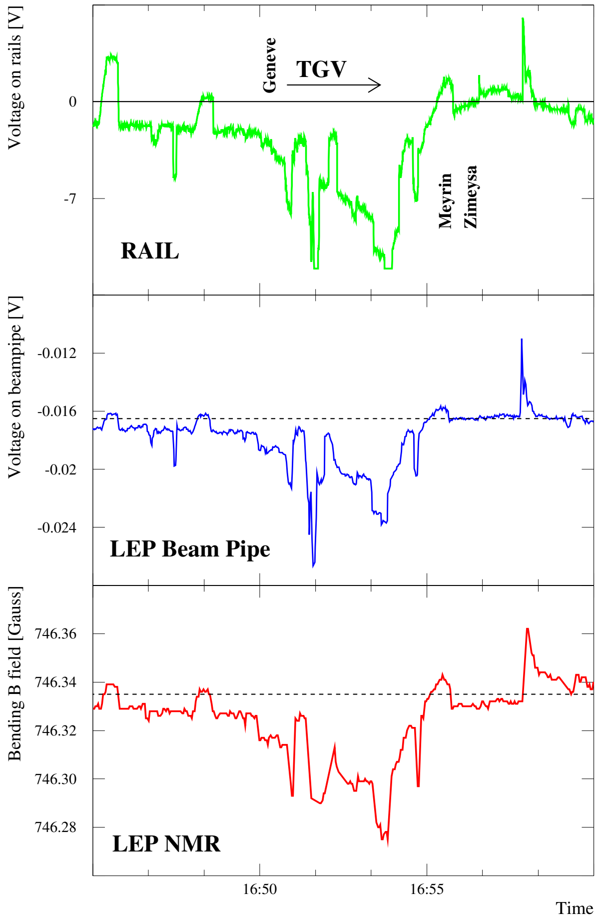

Figure 5: In a controlled experiment, the voltage on the rails is measured simultaneously with the magnetic field in the tunnel and the voltage on the vacuum chamber. Voltage of the railway tracks against earth (top), voltage of beam pipe against earth (center) and the resulting change in the magnetic field measured by NMROCT8 (bottom) for 15 minutes during a "busy" afternoon around the time a "TGV" is passing. The quiet periods between 00:00 and 04:00 correspond to a time window where no trains circulate.

carried by the beam pipe changes the magnetic field of the tunnel dipoles surrounding the vacuum chamber and causes the increase in the integral bending field. The total rise in the field depends most likely on the frequency and amplitude of the current spikes.

3 Collision Offsets in Presence of Vertical Dispersion

The presence of opposite sign vertical dispersion of electrons and positrons (ΔD_y^*) at the IPs in bunch train operation of LEP leads to shifts in the center-of-mass energy E_{cm} if the particle beams are colliding with a vertical collision offset Δy [5]:

$$\Delta E_{cm} = -2\,\Delta y\,\frac{\Delta D_y^*\,\sigma_E^2}{E_0\,\sigma_B^2} \tag{2}$$

where σ_E is the energy spread, σ_B the vertical beam size and E_0 the nominal energy. This effect can be explained with the simple picture shown in figure 6. A shift of 1 to 3 MeV due to a collision offset of 1 micron was expected [6]. A strategy to control these shifts is based on the fact that the energy shifts are minimized when the luminosity is maximized which corresponds to optimized collision offsets. This condition is ensured by regular beam separation scans, where the e^+ and e^- beams are scanned stepwise one against another. At each scan

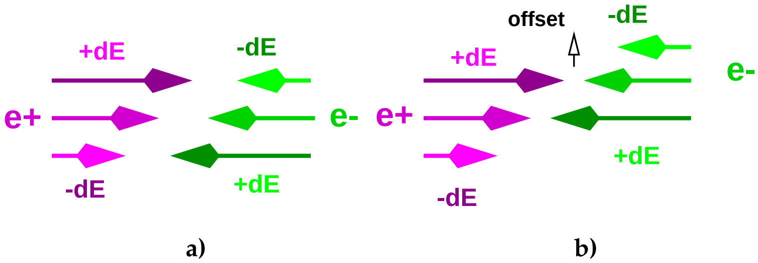

Figure 6: Schematic view of the collision of two beams with opposite sign vertical dispersion. (a): The nominal energy is maintained. (b): The low energy particles are not colliding ⇒ the center-of-mass energy is in this example shifted by +dE.

point the luminosity is measured. Finally a Gaussian fit is applied to obtain the optimal adjustment. A procedure to perform these scans automatically is improved. Furthermore the difference between opposite sign vertical dispersion of electrons and positrons is measured to be $\Delta D_y^* \leq 2$ mm at all IPs. A good performance of these beam separation scans is observed with a reproducibility of about 1 μm and residual mean collision offsets of 0.3 ± 0.3 μm at all IPs. Hence the effect on ΔE_{cm} is very small with an uncertainty of less than 1.0 MeV, leading to additional errors of about 0.4 MeV on the Z width and of about 0.5 MeV on the Z mass.

4 Conclusions

The "highlight" of the 1995 LEP energy scan was the discovery of the energy variations induced by leakage currents from railroads. This new effect, unknown in 1993, implies to revise the 1993 results and will lead most likely to a shift in the Z mass. Since the analysis of the 1995 data is still going on, no preliminary estimate could be given for the Rencontres de Moriond. Further studies will be made in 1996. The effect of vertical dispersion at the IPs has been successfully anticipated, leading to a preliminary contribution to the uncertainty on ΔE_{cm} of less than 1.0 MeV.

References

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