STATUS OF THE LEP2 SPECTROMETER PROJECT

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Abstract

The LEP Spectrometer has been conceived to provide a determination of the beam energy with a relative accuracy of 10^{-4} in the LEP2 physics region where insufficient polarisation levels prevent the application of the resonant depolarisation method. The setup consists of a steel bending magnet flanked by a triplet of Beam Position Monitors (*BPM*) at each side providing a measurement of changes in the bending angle when the beams are accelerated to physics energies. The goal for a 100 ppm relative precision on the beam energy involves a ± 1 micron BPM resolution and the calibration of the dipole bending strength to a 30 ppm accuracy. This paper reports on the results of the commissioning of the Spectrometer during the 1999 LEP Run and on the experience acquired on the behaviour of the several sub-systems with circulating beams.

1 INTRODUCTION

The Large Electron-Positron (LEP) collider at CERN is presently used to study decays of W-bosons at energies in excess of 100 GeV per beam.

The knowledge of the beam energy E_b considerably improves the quality of the kinematic fit resolution to the W-boson mass M_W (Fig. 1) and sets the absolute energy scale for its measurement [1] to an uncertainty $\Delta M_W/M_W \approx \Delta E_\mathrm{b}/E_\mathrm{b}$.

To reduce the systematic contribution from the beam energy adding to the 25 MeV expected statistical uncertainty on M_W the target for the beam energy calibration at LEP2 is $\Delta E_\mathrm{b}/E_\mathrm{b} \approx \pm 1 \times 10^{-4}$, i.e. a $\approx \pm 15$ MeV uncertainty at a beam energy around 100 GeV.

Resonant spin depolarisation (*RD*) has been used at LEP1 to measure the Z mass to a total relative uncertainty of about $\pm 2 \times 10^{-5}$ [2]. As the beam energy is increased beyond 60 GeV a polarisation level sufficient for the *RD* method cannot be achieved and the beam energy is inferred from a NMR-based model of the integrated bending magnetic field at the LEP2 physics energies.

The accuracy of the model is limited by the fact that a limited number of NMR probes are installed in some of the LEP dipoles and by the *local* B-field information they provide. This led to the concept of the LEP Spectrometer.

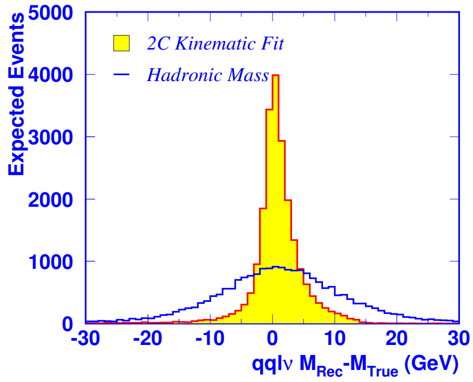

Figure 1: Improvement in the kinematic fit resolution when the knowledge of the beam energy is included.

2 THE LEP SPECTROMETER

The LEP Spectrometer was proposed in 1997 as an alternative method of beam energy determination [3]. After first functional tests in 1998 the final version was installed in the '98-'99 shutdown. The device consists of a laminated steel dipole powered synchronously with the magnetic structure of the accelerator. Two stations of three BPMs continuously monitor the incoming and outgoing beam trajectories for the reconstruction of the actual bending angle $\Theta(E)$ and the detection of deviations from the nominal value when the beam energy is ramped to the physics values (Fig. 2).

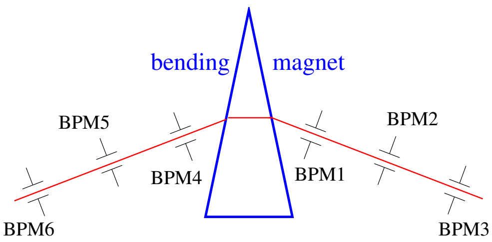

Figure 2: Conceptual principle of the LEP spectrometer. The calibrated dipole is powered synchronously with the accelerator magnetic structure and the two BPM stations detect the bending angle deviations during beam energy ramping.

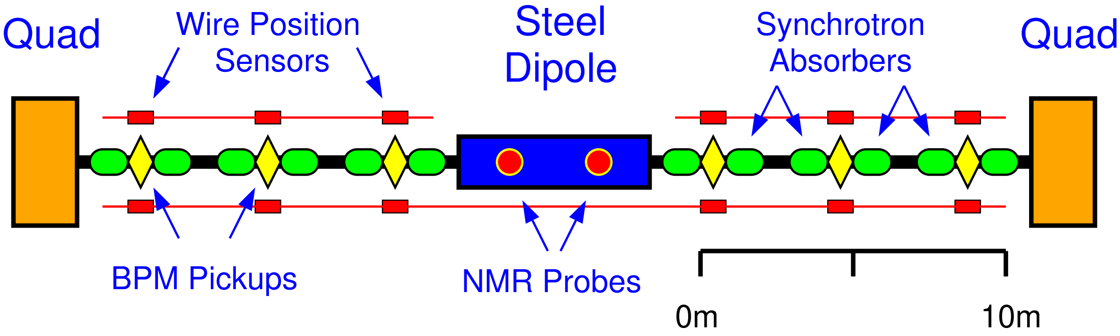

Figure 3: Layout of the LEP magnetic spectrometer. A laminated steel dipole magnet equipped with reference NMR probes is flanked by three-BPM stations at each side to provide reconstruction of the bending angle. Each BPM is protected against synchrotron radiation from nearby dipoles by water cooled copper absorbers. A triple wire positioning system provides a relative reference against ground-and thermal-driven motion of the BPM bodies.

2.1 Practical Realisation

The layout of the Spectrometer, integrated in the original magnetic structure of the accelerator, is illustrated in Fig. 3.

The calibrated dipole magnet is equipped with reference NMR probes for absolute measurement of the local B-field. The bending field strength has been determined as a function of the reference probe readings with a relative accuracy of $\pm 3 \times 10^{-5}$ [4][5]. As LEP is ramped from the injection to the physics energy, the radiated synchrotron power reaches $\sim$1 kW/m. In order to prevent motion due to thermal expansion, the magnet and the BPMs are water cooled with dedicated cooling stations. Any remaining thermally-induced motion can be detected using a stretched-wire positioning system (*WPS*) [6] and corrected for in the subsequent data analysis. The BPM buttons themselves are shielded from the synchrotron radiation by adjacent copper absorbers.

The pickup electronics were custom manufactured for the Spectrometer application, being based on a design for a synchrotron light source [7], with a specification of $\pm 1\,\mu$m relative accuracy [8][9].

It has been shown that the beam size affects the response of BPMs in a circular[10] and elliptical[11] beam pipes. Nonlinearities in the LEP BPMs response require the beams to be steered with stringent accuracy to the nominal trajectory before and after the energy ramp.

3 SPECTROMETER PERFORMANCE

For the performance of the Spectrometer to be independent of orbit drifts, the determination of the bending angle and of its deviations relies on the BPM gain calibration via the minimisation (Fig. 2) of the right and left Triplet Residuals defined as

$$TR_{R,L} = \frac{x_{1,4} + x_{3,6}}{2} - x_{2,5} \qquad (1)$$

where x_i are the x-position readings of the i_{th} BPM.
The Triplet Residuals response is practically independent of beam orbit drifts as shown in Fig. 4 where the radial beam position was deliberately modified with beam bumps.

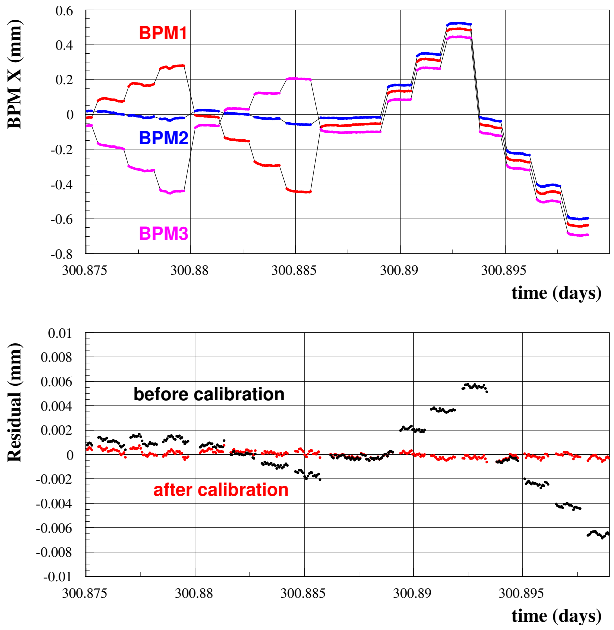

Figure 4: Triplet Residual response to deliberate beam position changes as compared to single BPM response before and after relative gain calibration from minimisation of Triplet Residuals.

3.1 Relative Energy Measurements

The procedure adopted to measure energy differences with respect to a *known* one goes through the following steps:

- The Spectrometer is *RD* calibrated at a polarisable energy E_{RD}, thus avoiding the need for an absolute angle measurement;
- The nominal beam energy is immediately ramped to the physics energy E_ϕ;

- The *ratio* between the two energies is directly obtained from the comparison of the bending angles Θ_{RD} and Θ_ϕ measured at the two BPM stations and the knowledge, from the dipole field mapping tables, of the bending strengths at the two energies

$$\frac{E_\phi}{E_{RD}} = \frac{\oint B_y \, dl \,|_{E_\phi}}{\oint B_y \, dl \,|_{E_{RD}}} \left(\frac{\Theta_{RD}}{\Theta_\phi}\right) . \tag{2}$$

The target accuracy

$$\frac{\Delta E_\phi}{E_\phi} \equiv -\frac{\Delta \Theta_\phi}{\Theta_\phi} \leq \pm 1 \times 10^{-4} \tag{3}$$

sets a limit on the acceptable beam position relative accuracy of ± 1 μm, imposed by the spacing between BPMs.

4 1999 EXPERIMENTAL RESULTS

During the 1999 LEP Run the Spectrometer was ramped up to beam energies E_ϕ=70, 90 and 92 GeV after *RD* calibrations at E_{RD}=41, 45, 50, 55 and 60 GeV.
The distribution of the *RD* calibrations data over the several dedicated LEP fills is shown in Fig. 5.

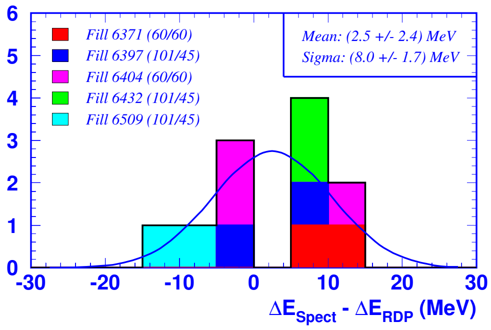

Figure 5: Distribution of Spectrometer *RD* calibration data.

The energy deduced from (2) by the Spectrometer is compared to that inferred from our NMR-based field strength model in Fig. 6.

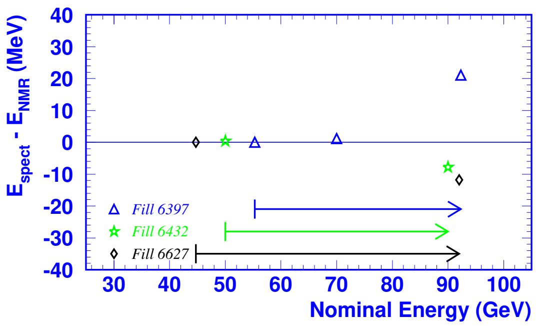

Figure 6: First measurement of the LEP2 Energy scale. The difference between the Spectrometer-detected beam energy and that inferred from NMR reading is plotted vs. the nominal LEP2 energy up to 92 GeV.

From the measurements shown in Fig. 6 the Spectrometer results in the 1999 LEP2 energy range are summarised as:

$$(E_{SP} - E_{NMR})_{RMS} = 14.7 \text{ MeV} \tag{4}$$

$$E_{SP} - E_{NMR} = (0.5 \pm 10.4) \text{ MeV} \tag{5}$$

The several contributions to the total error on the beam energy at 50 and 100 GeV are collected in Table 1.

Table 1: Errors (MeV) contributed from the different sources to the total energy error at two LEP nominal energies and with E_{RD}=41 GeV.

Source	50 GeV	100 GeV
Dipole mapping	1.5	3.0
RD error	2.0	3.0
RF model	3.0	5.5
$\Delta(\Theta_{RD}/\Theta_\phi)$	6.5	13.0
Total	**7.6**	**14.7**

5 OUTLOOK

The first Spectrometer measurements at the LEP2 energy scale confirmed the feasibility of the target imposed on the final beam energy error. Technical improvements suggested by the running experience in the accelerator environment where implemented during the '99-'00 shut-down and are expected to considerably improve the performance and the reliability of the Spectrometer in the year 2000.

6 REFERENCES

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