SUMMARY: OPERATIONAL SCENARIOS FOR HIGH ENERGY

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1 INTRODUCTION

In 1999 LEP's mandate was to run at the highest possible beam energy compatible with high luminosity running. In the event, record values in both beam energy (101 GeV) and integrated luminosity (254 pb^{-1}) were achieved, thanks to relentless optimisation of the RF system and general machine performance. With one year of LEP running left, the challenge for 2000 will be to operate the machine in such a way as to maximise the energy reach of the various physics searches, on the assumption that the major increases in available RF voltage have already been made.

2 REVIEW OF 1999

The high integrated luminosity produced in 1999 was in part due to higher instantaneous luminosities, with roughly 30% more luminosity per physics hour than in 1998.

The RF cavity antenna cables, which in 1999 imposed a limitation on total beam current, had been replaced during the shutdown, enabling slightly higher bunch currents to be used.

Optimisation of vertical beam size was greatly helped by the use of "dispersion free steering", which enables deterministic correction of the vertical dispersion at the same time as the vertical orbit, while minimising the average corrector strengths. Fast luminosity diagnostics based on the beam lifetime measurement also aided optimisation, and after only three weeks of running, the vertical emittance was already below the best 1998 value.

A new high energy working point was found with the horizontal tune at about 0.36, which gave a luminosity increase of around 15-20%. This entailed performing a jump in Q_x over the third integer resonance at the start of coast.

The highest start-of-fill luminosity achieved was 1.10^{32} cm^{-2}s^{-1} with a beam-beam parameter of 0.083, the highest ever seen at LEP.

The integrated luminosity was also improved by maximising the time available for physics, with faster turnarounds (an average of 92.5 minutes compared with 110 minutes in 1998). The time needed to fill LEP was reduced by around 30%, due to the improved lepton intensities from CPS and SPS (50% higher than in 1998), and a new 20cm β_y* injection optics improved the injection efficiency by a factor of two compared with the old 10cm optics.

Without the bunch length constraints imposed by the RF antenna cables in 1998, energy ramps were more stable, and automatic control of J_x in physics reduced the number of fills lost due to RF trips.

3 PHYSICS MOTIVATION

The relative importance of energy and luminosity is different for the various types of physics measurements.

For extending the reach of the standard model Higgs search, an increase in beam energy of 1 GeV is equivalent to about a factor of 4 in integrated luminosity. For supersymmetric Higgs the dependence on energy is much smaller, and very high integrated luminosities (>500 pb^{-1}) would be required to make a marginal improvement in 2000. For gaugino searches, around 5 pb^{-1}at the highest possible energy would be desirable.

The uncertainty on the W mass measurement will be limited by systematic errors at $\delta m_w \sim (40 \pm 1)$ MeV, including the additional statistics from the 2000 run. However, reducing the LEP energy calibration uncertainty from 20 MeV to 10 MeV would do more to reduce δm_w than increasing the integrated luminosity by a factor of two. In the event of high energy running being unavailable due to RF problems or cryogenics de-icing, a fallback energy of 80.5 GeV/beam could be used for W pair cross-section measurements, if at least 30pb^{-1} per experiment could be delivered at this energy during the year.

It is proposed to use the standard model Higgs search as a benchmark for optimisation of the energy/luminosity trade-off, as the other searches will also benefit from more luminosity and higher energy.

4 OPERATIONAL SCENARIOS

Since it seems likely that the available RF voltage is already close to its ultimate limit, we will be obliged to look elsewhere for a substantial increase in beam energy.

Up to now a positive RF frequency offset has always been used to reduce the horizontal beam size, increasing luminosity and reducing backrounds. At 101 GeV, about 0.7 GeV could be recuperated by dispensing with the typical offset of +100 Hz (J_x~1.6), at the cost of a luminosity decrease of about 20% and increased backgrounds. With careful optimisation of the collimators, it has been found to be just possible to run at central frequency (J_x=1). With some modification to the optics in IR4 and 8 it may even be possible to run with negative J_x.

Reliable running has always required an RF voltage margin of 2 half-units (200 MV). Running with reduced margin would allow higher energies but increase the risk of beam loss due to RF trips. There is also a trade-off between RF margin and frequency of trips: pushing up the cavity fields gives a bigger margin, but also increases the number of trips. Increasing the beam energy towards the end of a coast could provide a compromise solution to these tradeoffs, as the increased risk of losing the remainder of the coast is offset by the gain in beam energy. A mini-ramp procedure to do this has been successfully tested with colliding beams between 101 and 102 GeV.

The mini-ramp procedure could also be used to avoid unnecessary exposure to RF trips while performing beam adjustments before going into coast. Loading of orbits, collision and tune shifts, etc. would be done safely below physics energy followed by a mini-ramp to the final energy.

There is still some scope for increasing the integrated luminosity through improved operational efficiency. Higher ramp speed, a shorter degauss cycle and streamlining of the turn-around sequence should reduce the turn-around time. Careful optimisation of fill lengths will be required, especially when mini-ramps are used, as the weighting factors relating energy versus luminosity will have to be taken into account.

5 OPTICS CHANGES IN IR4 AND IR8

Due to the constraints imposed by the bunch train scheme, the horizontal beta function at the collimator COLH.QS3 in IR4 and IR8 is rather large (55m). This prevents the collimator from being closed sufficiently tightly to protect the experiments from grazing incidence photons generated in the straight section quadrupoles at large horizontal beam sizes, leading to high backgrounds in ALEPH and DELPHI when J_x is reduced close to 1. Removing the bunch train constraints for the high energy optics has permitted rematching of the optics in IR4 and IR8 to give a reduction of β_x to 35m at the collimator, limited by the increase of β_y at the QS6 and QS8 quadrupoles. This should allow running with good background conditions at central RF frequency or even below.

6 BENDING FIELD SPREADING WITH HORIZONTAL CORRECTORS

The energy loss per turn varies as the square of the bending field integrated around the ring. A Bending Field Spreading (BFS) scheme has been proposed using the horizontal orbit correctors as additional bending dipoles, allowing the field of the main bends to be reduced. A constant kick of about 70 μrad would be applied to each corrector, leaving about 20 μrad for steering. With one corrector per arc cell, this would result in about 0.12 GeV of energy gain at 100 GeVfor the same RF voltage.

The main problem with this scheme is that in LEP only 2 out of 3 arc correctors are powered, leading to large uncorrectable orbit distortions and large energy losses in the quadrupoles. Thus in order to make the scheme feasible, the remaining 1/3 of the correctors will be powered, including those in the dispersion corrector sections, except for a few cases where collimators occupy the position of the corrector.

As the beam is off-momentum with respect to the main bend dipoles, it will pass off-centre in the quadrupoles, amplifying the energy gain by about 50%, giving a total energy gain of about 0.19 GeV and a small horizontal emittance reduction of about 2%.

BFS will be implemented as a knob comprising all the the corrector trims for BFS and orbit, the energy scaling of quadrupole and sextupole strengths along with the necessary correction for β_y*.

7 ENERGY CALIBRATION

The uncertainty on the LEP beam energy is now a major contribution to the error on the W mass measurement, so energy calibration will be very important in 2000.

The magnetic extrapolation using the NMR probes has shown good long-term stability, with energy variations between different years of about 2.10^{-5}. The uncertainty obtained by comparison with flux loop measurements is now about 20 MeV, which is probably about the best achievable with this method.

The spectrometer dipole has been mapped with a precision of 3.10^{-5}, and the μm sensitive beam position monitors commissioned. An automatic calibration procedure using a sequence of orbit bumps has been devised. Preliminary cross-check measurements against multi-point depolarisation runs show no significant bias, with a scatter of about 8 MeV. The three test ramps performed in 1999 indicate that the spectrometer could yield a precision at high energy of less than 15 MeV. The spectrometer program will continue in 2000 with multipoint calibrations against depolarisation, each fill being taken to high energy for a "gold-plated" measurement. Shorter calibration runs against the NMRs without depolarisation will also be performed to add to the statistics.

The third method of energy calibration, Q_s versus RF voltage, has been shown to give an energy precision of about 25 MeV, in good agreement with the NMR method, and still has scope for improvement, possibly to below the 20 MeV level.

8 CONCLUSIONS

The overall performance of LEP will be, as it was in 1999, highly dependent on the performance of the RF system. However, we must assume that the available RF voltage is now very close to its ultimate limit, and look for energy increases elsewhere. Operations will be equipped with an array of tools such as mini-ramps, Bending Field Spreading and running at reduced J_x which will enable them to run LEP at the highest possible energy. The trade-off between energy and luminosity is steeply biased in favour of energy, which means that finding the right compromise will require continuous optimisation of fill length and choice of beam energy. Further optimisation of turn-around time and mini-ramping before physics to minimise the number of lost fills will help to maximise integrated luminosity.