Conclusions of the Third LEP Performance Workshop

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Abstract

The Third LEP Performance Workshop was held from January 10 till January 16, 1993 in Chamonix, France. The workshop was sub-divided into ten major sessions, each with a duration if between 3.5 and 4 hours. A summary of the conclusions and important issues raised during these sessions is given in this report.

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The luminosity may be further increased by reduction of the transverse emittance since even with 1 mA per bunch the beam-beam limit is not reached. The emittance may easily be reduced by variation of the damping times. However, this results in an increase in the bunch energy spread and requires additional RF voltage to maintain the required quantum lifetime. In effect this would result in a loss of centre of mass energy of around 4 GeV unless the dynamic aperture is severely limited. Another very interesting possibility to reduce the emittance is to operate with a very high tune lattice, with a phase advance significantly greater than 90° in the horizontal plane. Such an optics would not only improve the luminosity but also allow the maximum centre of mass energy to be increased by around 2 GeV. A first attempt at an optics with 135°/45° (H/V) has highlighted possible problems with beam stability and dynamic aperture. These studies will be intensified in 1993.

10 LEP2 Equipment Status

The following presentations were made:

- LEP2 status report
- Superconducting cavities series production
- Acceptance tests of cavity modules
- Report from the workshop on main couplers
- Measurements of HOM power and temperature of bellows and cones
- Diagnostics around superconducting cavities
- Operational aspects with 120 copper and 192 superconducting cavities

In the LEP2 status report it was pointed out that although the superconducting cavities are the most discussed system they nevertheless only represent about one quarter of the total cost and effort of the project. The other major sub-systems are the huge cryogenic plant, the civil engineering needed for the additional klystron galleries, the high power klystrons and all control electronics for the cavities, power distribution, power supplies, separators, cooling and ventilation, magnets, and vacuum. All of these activities are progressing on schedule and in particular the cryogenics project which is of the same magnitude as the cavities is progressing very well. The cold boxes for the cryoplants at points 6 and 8 were delivered in October 1992 according to planning and will be commissioned early in 1993.

Replacement of the magnet power supplies will be done during the 1992/1993 shutdown; this will increase the energy range of the magnets to 100 GeV. As mentioned in the Optics session, all odd interaction points will be converted, during the 1992/1993 shutdown, to the configuration optimized for LEP 2. This major intervention will require careful recommissioning at the 1993 start-up.

On the superconducting cavities front, significant progress has been made on the production of the high gradient cavities. The transfer of "know-how" (technology transfer) to industry is now complete and each manufacturer has produced several cavities with the specified high accelerating gradient. However since the rejection rate is still too high great emphasis has now been placed on quality control.
circumference) of the product of the $\beta$ function and the transverse coupling impedance. Consequently the limitation is most severe at injection energy and could be increased by raising the extraction energy of the SPS. For 1993 it will be possible to increase the SPS energy by at least 10% for machine studies, however long term operation at these levels would require additional RF and a careful study of the influence of the increased synchrotron radiation. Another possibility to increase the threshold is to increase the synchrotron frequency by simply increasing the RF voltage at injection. Initial tests in 1990 showed that the current per bunch could be increased to 800 $\mu$A with a $Q_s$ of .12. The problem is that the $Q_s$ needs subsequently to be reduced during the ramp with the problems of crossing synchro-betatron resonances. This situation has been simulated and shown to be feasible and provisions have been made in the quadrupole power supplies to allow a fast tune jump. This work will be actively pursued in 1993.

In general the "effective" transverse impedance seen by the bunches can be reduced by increasing the bunch length. Present operational procedures use every installed wiggler magnet to maximize the bunch length and in this way the maximum current per bunch is attained. The bunches may be lengthened even further by reducing the energy damping rate: this can be done by moving the beam off central energy by simply changing the RF frequency. This technique causes an increase in the energy spread and may result in problems with the required accuracy of chromaticity correction but nevertheless has been used operationally in previous colliders.

The bunch length may also be increased by the use of a higher harmonic RF system. However this technique also causes an enormous reduction in the synchrotron frequency and it is not intuitively clear whether or not it will increase the threshold for TMCI. For this reason several independent techniques are currently being used to clarify the situation. Very preliminary results, obtained just days before the workshop indicated that the threshold is actually reduced by the use of a 3rd harmonic system. These studies will continue in 1993 and experimentation will continue with the cavities used for longitudinal feedback modified so as to produce a very limited higher harmonic system.

A feedback system can in principle be used to compensate the transverse impedance seen by the beam. Such a system was successfully tested in the PEP collider and more than doubled the threshold. The results of many studies and simulations are somewhat contradictory and highly dependent on the model of the impedance. In addition the influence of feedback when the synchrotron tune is so high has also been questioned. High priority will be given to studies and experimentation on beam feedback in 1993.

The surest way to increase the threshold would be, of course, to remove the objects causing the impedance. In the case of LEP the major source of impedance is in the room temperature cavities. The 120 copper cavities could be replaced in the future by 32 superconducting cavities operating at 6MV/m. The superconducting cavities present greatly reduced transverse impedance due to their large beam port diameter. An upper limit to the bunch current for this scenario is $\sim$ 1 mA which would produce a luminosity of $\sim 3 \times 10^{31}$ with 4 bunches per beam. However a word of caution, although the TMCI is the fundamental uppermost limit to the bunch current for a single beam it must be emphasized that the limit has been shown to be somewhat less when accumulating 2 beams. The cause of this lower limitation must be carefully studied and understood and will be given high priority for machine studies in 1993 and 1994.
For pretzel with LEP2 energies it was shown that no additional horizontal separators would be needed for the base line performance due to the relatively low beam-beam strength parameter value of .015. However for the ultimate intensity goals for LEP2 it is not yet known whether or not additional horizontal separators will be required. Machine studies will be performed in 1993 to experimentally investigate this point. It was shown that horizontal adjustments of the crossing points are indeed needed for LEP2 and are foreseen.

The results from recent tracking indicate that the dynamic aperture is indeed marginal and is reduced when an RF unit trips and breaks the symmetry of the voltage distribution. Although these more recent results are less worrying than the tracking done in 1990, there was some concern about the fact that the measured and computed dynamic aperture values have not yet been shown to coincide. This work will be actively pursued in 1993.

Finally it was shown that with the installation of one klystron per 8 cavities the beam power considerations would allow 16 bunch operation up to 1 mA per bunch. This limit is somewhat lower for the power handling capabilities of the Higher Order Mode couplers ( .75 mA/bunch if the HOM couplers can handle 400 W).

In the final talk of this session was shown the very interesting results of a preliminary study to convert LEP1 into a “Z² factory” by operating with bunch trains and a crossing angle at the interaction points. Although there remain many unsolved problems the possibility of a luminosity of $\sim 2 \times 10^{32}$ is very exciting and of course will be studied further.

9 LEP2 Performance

In this session the following presentations were made:

- Baseline performance
- Single bunch current limitations and cures
- Higher harmonic RF
- Emittance control
- High phase advance optics
- Asymmetries and saw-tooth
- Background and collimation
- Vacuum

For the baseline performance of LEP2, the present performance of 500 $\mu$A per bunch, 4 bunches was extrapolated to 90 GeV where the natural emittance (without emittance control) is $\sim 50$ nm. These parameters result in a peak luminosity of $1.1 \times 10^{31}$ cm$^{-2}$ s$^{-1}$, and beam-beam tune shifts ($\xi$) of .014. It was shown that even with these rather pessimistic parameters an integrated luminosity of $\sim 80$ pb$^{-1}$ per year could be attained by running for 200 days physics with an overall efficiency of 60%. The low values of $\xi$ clearly indicates the need for higher current densities; i.e. higher bunch currents and lower emittances.

The fundamental limitation to the LEP bunch current is due to the Transverse Mode Coupling Instability (TMCI) which results from the electro-magnetic interaction of the charged particles with their environment. The threshold for the TMCI depends directly on the beam energy and the synchrotron frequency and inversely on the summation (around the LEP
7 Optics for 1993

The reserve session on Thursday morning was taken up to discuss the important subject of the choice of optics for 1993 physics running. The session on energy calibration and polarization had already made a strong recommendation that the same optics be used for physics and measurement of the beam energy. Since the energy calibration could only be guaranteed on an optics with 60° phase advance in the vertical plane this implied the use of the 90/60 optics in 1993. This lead to the very clear conclusion that, if energy calibrations were to be performed in future operation of LEP at Z° energies, then the optics to be used in 1993 was the 90/60 optics which had been extensively tested in the latter part of 1992. In view of the urgency of this decision it was agreed by the Chairman of the LEPC that he would convene a special meeting in early February to discuss the question of energy scanning.

8 Pretzel Operation at 45 and 90 GeV

The following talks were presented in this session:

- Operational experience in 1992
- Beam physics aspects
- Separators
- Operation in 1993
- Use of trim separators
- LEP2 optics for pretzel
- Beam dynamics with LEP2 pretzel
- RF limits
- Z° factory

The operation of the 8 bunch pretzel scheme in 1992 had been highly successful and the goal of the Second LEP Performance Workshop, to reach break-even luminosity, was rapidly achieved. It was pointed out that a large part of this success was due to the unified optics as well as a high level of preparation and sophistication. However, subsequently it proved difficult to increase the luminosity substantially with the available tools. The missing factor of two was evenly divided between horizontal miss-crossings and the reduction of the bunch current. In 1993 the former effect should be greatly reduced by improved diagnostics and new horizontal trim separators which will allow better control over the horizontal vernier scans. The reduction in the bunch current with 8 × 8 bunches is not yet understood and will receive top priority for machine time in 1993.

The behaviour of the horizontal separators was reported to be excellent even at 1.2 MV/m with very few sparks.

The operation in 1993 should be facilitated by the proper implementation of a bunch current equalizer which should be also available for the new 8 bunches per cycle in the SPS. In addition new sextupoles will be installed which allow variation of the tunes of the electrons and positrons differentially. This should prove highly beneficial in the optimization of the luminosity.
enhanced radiation already at 45 GeV and therefore did not produce a reliable measure of beam position. For this reason a special test section will be used to monitor the performance of the BOM system in the presence of radiation similar to that anticipated in LEP2.

6 Energy Calibration with Polarization

The following presentations were made:

- Measuring $M_z$, $\Gamma_z$, and $M_w$: Physics motivations and requirements
- Summary of 1991/92 experiments and tidal effects
- Effect of correctors and pretzel on energy calibration and energy differences
- Transporting calibration from one optics/energy to another
- Determination of energy differences: a scenario
- Temperature coefficient and regulation of LEP magnets
- Flux loop, field display and dipole current
- RF differences between IPs: dependence on optics and energy
- Results of polarization and optimization simulations
- Towards a polarized LEP

The accurate measurement of $M_z$, requires an absolute calibration of the beam energies to a high precision (± 2 MeV), whereas the measurement of the line width $\Gamma_z$ requires accurate knowledge of the difference between two or more energy points as well as a high statistics energy scan. In order to meet the energy accuracy requirements many proposals were listed for logging and control of parameters which have a possible effect on the beam energy (temperature, humidity, atmospheric pressure in the tunnel and of the dipole magnets etc.) It was once again emphasized that special runs for energy calibration would cost significantly in integrated luminosity and for this reason high priority should be given to calibrations at the end of physics runs. The vertical realignment of the machine which will be carried out during the 1992/93 shutdown is expected to increase the level of polarization. However there was no compelling evidence to assume that the realignment would produce polarization on the 90/90 optics because of the insufficient sampling of the vertical closed orbit.

The influence of the pretzel scheme, different optics, and orbit correctors was analyzed in detail with the strong recommendation that physics runs and energy calibration should be performed on the same optics. The transfer of energy calibration from one optics to another was considered delicate due to the possible introduction of systematic errors. Consequently there was a strong recommendation to switch to the 90/60 optics for both physics and energy calibration in 1993. In addition there was strong support in this session for the beam alignment scheme using modulation of the quadrupole gradients since the alignment improvements would increase the level of polarization.
satisfied during 1992 and the streak camera provided top and side views of the bunches in real time in both physics and machine studies. This was made possible by the development of the automatic light controller. The future development of the device is aimed at full remote control of all parameters and calibration of the transverse beam dimensions. The intrinsic limitation on the resolution is .6 mm longitudinally and .03 mm transversely with an expected precision of around 5% after calibration. Concerning the BEXE, it was shown that the intense x-ray radiation emitted by the dipole magnets did not allow the device to remain continuously in its measuring position. The newly developed detector will have a thin protective layer deposited upon it at the end of processing in order to protect it. Improved electronics in 1992 now allow a .1 mm resolution in 64 channels for each vertical profile of 8 bunches. In machine studies the BEXE was used successfully to compare the emittance measured by the BEUV, wire scanner and streak camera. Future development includes improvements in the mechanics, reproducibility of installation and connections to the detector itself.

Two new applications were then proposed for the Q-metre. Firstly, the revolution frequency on central orbit (at the sextupoles) could be automatically measured by modulating the RF frequency and recording the resulting tune modulation for several different values of the chromaticity. Auto-correlation of the tune data with the frequency data gives the central frequency. In the following discussion it was suggested that the measurement should be synchronized with the SPS super cycle in order to avoid tune modulation due to magnetic coupling. The second application involves the use of the new Q-metre in continuous sweep mode with multi-bunch excitation in order to excite and measure the 0 and π modes driven by the beam beam forces. This will give a measure of the beam beam strength parameter (ξ) which is essential in the optimization of the luminosity. In the discussion it was feared that the relatively large excitation would render the technique unsuitable for physics for reasons of beam beam induced lifetime and background. This will be experimentally investigated in 1993.

The next presentation was on the use of the LEP luminosity monitors. Since these monitors have typically 25 times the rate of the experimenters monitors they are very useful for optimizing the luminosity and have been used throughout 1992 for the vernier scans. However the background rate in 1992 was between 4 and 20 greater than in 1991 due to the fact that the “off momentum” collimators which protect the luminosity monitors were left (due to time constraints) at their 60° locations even though the optics was changed to 90° settings. Although the increased background increased the measurement error on the luminosity, the monitors were used throughout 1992 for logging the luminosity. For operation with pretzel these monitors are essential for ensuring head on collisions in both planes. In addition, for LEP2 with the greatly reduced cross section, these monitors will be invaluable for optimizing the luminosity. It was proposed that the vernier scans be automated in 1993 to reduce the time from its present value of around 1 hour per IP to around 5 minutes. This will require significant software effort.

The last presentation in the Beam Instrumentation session was on the subject of upgrades needed for LEP2. Here it was shown that with minor modifications the existing beam instrumentation is capable of operating in the environment of energies around 90 GeV and with the maximum bunch currents foreseen. A large number of new collimators are foreseen to cope with the background situation of higher energies. One area of concern were the contested observations that beam pick-ups downstream of wiggler magnets suffered from the
In the following talk two new applications of the 1000 turn system were proposed. The first required orbit acquisition triggered by the general machine timing (GMT) during the ramp and squeeze. A total of around 35 orbits would be acquired and later processed for the application of corrections in the next ramp and squeeze. The accuracy of orbits averaged over 19 and 48 turns during ramp and squeeze respectively was stated to be sufficiently good for correction. The second application would allow measurement of the momentum dispersion during physics and involves the excitation of synchrotron oscillations by modulation of the RF phase accompanied by measurement of the 1000 turn system. Harmonic analysis at the synchrotron frequency would later be performed on the data and should give a dispersion resolution of around 5 cm. It was hoped that this procedure, which should only take around 5 seconds, could be performed during normal physics data taking.

Laboratory tests and measurements with prototype electronics have shown that the 1993 hardware modifications to the BOM narrow and wide band system will result in better performance and reliability of the system. The new narrow band electronics practically eliminate the present offset of .9 mm and brings the scaling factor extremely close to that of the wide band system which is known to be accurate. It was emphasized that the mechanical and electrical alignment of the pick-ups with respect to the quadrupoles can only be measured by an independent technique such as modulation of the gradient of the quadrupoles (see later).

In the talk on beam current measurement, it was stated that each of the two installed current transformers would be dedicated to one type of particle, half cell 148 for positrons and 158 for electrons. For the 1993 start-up a new software control panel would be ready as would a turn by turn measurement which would allow injection and beam loss post mortem studies. The lifetime measurement software will be modified so as to vary the integration time as a function of the measured lifetime. This will allow faster response times for lower lifetimes. In the discussion the need for bunch equalization for pretzel was emphasized and a request was formulated for distribution of the bunch currents on the network or at least to the klystron galleries.

Several improvements will be made to the LEP polarimeter during the present shutdown. The laser power will be increased by a factor of five and the laser beam cross section at the LIR will be reduced by nearly a factor of two. These measures will reduce the error on the measurement of polarization by a factor of three and reduce the setting up time from 1 to 0.5 hours and allow the measurement of the spin tune in 1.5 to 2 hours. It was suggested in the discussion that the polarimeter could be used to measure the vertical beam size. A determination of the possible resolution should be evaluated.

The next presentation concerned the measurement of the beam size by wire scanners and the synchrotron light monitors (BEUV). The wire scanners can be used to cross calibrate the other devices, however their use should possibly be restricted to specialists since the measurements are sensitive to beam intensities (there is a software intensity interlock at 1.8 mA) and the closed orbit. For the BEUV, many hardware and software improvements were made during 1992. For the 1993 start up all four devices will be brought up to the same hardware standard. A new "corona" mode which allows the measurement of the tails of the bunch distribution will be made available during 1993.

The status of the streak camera and the x-ray synchrotron radiation monitor (BEXE) were reported. The recommendations of the Second LEP Performance Workshop were fully
extension of the super-optics idea was to take all the advantages (low horizontal emittance and ease of operation with pretzel) offered by the high horizontal tune of the 90° horizontal phase advance and combine this with the vertical advantages (better orbit measurement and correction and hence increased possibility of polarization) offered by 60° vertical phase advance. This optics was extensively tested during the latter part of 1992 and exhibited all the expected advantages. Accumulation and ramping of high currents was achieved as was operation with pretzel. Polarization was successfully performed on two occasions and on one of these occasions the influence of the tidal forces on the LEP beam energy was confirmed.

The definitive 90/60 optics should have the $\beta_y$ in the RF straights minimized so as to ensure a high threshold for the TMCI. In addition the higher $\beta_z$ at the collision points should be included to allow minimization of the background with emittances greater than 45 nm.

The discussion on the strategy for 1993 was postponed until after the session on the energy calibration by resonant depolarization and for the same reasons will be presented after this session.

5 Beam Instrumentation (BI) 45 and 90 GeV

The following presentations were made:

- Integration of BI equipment into SLOPPYSOFT
- Beam Observation Monitoring (BOM) System
  - BOM system and orbit correction
  - Exploitation of the 1000 turn system
  - Hardware plans for BOM system
- Beam current measurements
- Polarimeter
- Beam size measurements
- Tune measurements etc.
- Luminosity monitoring
- LEP2 preparation

The high level software needed to integrate the BI equipment into the operational software packages is presently being developed and the prototype, using an on-line data base, should be ready for testing in May 1993.

In the presentation on use of the BOM system a “wish list” of software upgrades was generated which included improvements to both the trajectory and orbit measurement software. “Bad” pick-ups cause errors in the evaluation of the “bare” orbit due to the conditioning of the transfer matrices and poor absolute precision poses problems with the positioning of collimators for background minimization. During the discussion it was pointed out that “bad” pick-ups could possibly be better identified by using the calculated spread in the measured positions (for each pick-up) over many turns. This information is actually calculated by the BOM system but is currently not displayed.
reduction in the rms misalignment to .12 mm. The LEP model was used to simulate the alignment situation as measured. The results indicated that by realigning the 350 quads a vertical rms orbit distortion of only .56 mm would be achieved using only 60 correctors. This would certainly be adequate for standard operation. However for polarization it was stressed that the closed orbit is of paramount importance and that at least 450 quads should be realigned. Following discussions it was agreed that the survey teams should use all the available shutdown time to minimize the misalignment. A similar engagement had been agreed before the shutdown in the SL Technical Committee.

An analysis of the effect of the demagnetization of the Nickel layer (performed in the '91/92 shutdown) showed that the skew quadrupole component has been reduced by a factor of 5.3 and does not remagnetize with time. This result will allow more flexibility in future choices of the integer tune differences between the horizontal and vertical planes.

On the subject of optical imperfections it was shown by simulation that the 90° optics is less sensitive to vertical dispersion than the 60° optics. It was also reported that the β beating is less when the empirical "trim" of the QS0 is included. It was suggested that this trim be included in the 1993 optics files. It was also shown that the beam beam tune shift (.03) produces a ±20% β beating. Although this effect is probably not important for lifetime considerations since it only applies at low betatron amplitudes, the beating at beam observation points must be taken into account in the analysis of the beam sizes.

A careful analysis was made of all the aperture measurements made since 1989. This analysis strongly suggests that a physical horizontal aperture limitation has existed in the LEP vacuum pipe since the initial installation. Since the beginning of the present shutdown, a search has been ongoing to discover the exact location of this limitation. The search has involved visual inspection of all vacuum sectors which must be opened, search for unwanted magnetic material near the vicinity of the beam, careful check of the "out" position of all collimators, and a radiation survey around the 27 km. A photograph was shown of the RF shields in half cell 341 (installed in June 1989!) which indicated that some of the RF "fingers" were not in their intended position and were encroaching into the beam aperture. Unfortunately the limitation was too small to explain the measured results with beam. Nevertheless it should be remembered that there are about 3000 such bellows around the LEP circumference.

A top priority test during the start-up is to try to measure the azimuthal location of the aperture limit using the multi-turn trajectory measurement system. It is imperative that this system be made fully operational as quickly as possible. For the longer term, dynamic aperture measurements should be made to compare the tracking results with reality.

There were then presentations on the proposed optics to be used in 1993. It was shown that the changes to be carried out during the present shutdown are numerous and that a complete recommissioning of the machine will be needed independent of the choice of optics. In particular all the high β regions in the odd interaction points will be completely changed (for LEP2) and will need to be carefully commissioned at the start-up. All power converters will also be upgraded for LEP2 and these will need careful testing before and during the 1993 commissioning.

The "super optics" proposed for 1992 had, as predicted, produced high luminosity, high luminosity lifetime, and relative ease of operation of the 8 × 8 bunch pretzel scheme. However polarization had not been possible on this optic. Based on this experience a natural
4 Optics

During this session the following presentations were made:

- Misalignment from closed orbit measurements
- Measurement of offsets in quadrupoles by gradient modulation
- Survey data and strategy for realignment
- The 1992 super optics
  - Design choices
  - Limitations to the closed orbit correction
  - Effects of demagnetization
  - Optics imperfections
  - Geometric, dynamic and momentum apertures
  - Dynamic optics: ramp and squeeze
- A Hyper optics for 1993
  - Analysis and lessons from the start-up in 1992
  - Changes to the LEP lattice and consequences
  - Motivation, design and results of the 90°/60° optics

In the opening presentation of the optics sessions a fitting technique was described which uses the "bare orbit" data to predict quadrupole misalignments. The predictions using this technique were only partially successful with the 90° optics and allowed detection of the greatest depression (between points 7 and 8) but failed to detect the second one (between 2 and 3) due to the poor configuration of the pick-ups with this optic. It was concluded that a special low phase advance optics would greatly improve the predicting power of this technique.

In the following presentation it was demonstrated that beam displacements with respect to the centre of quadrupoles could be detected to an accuracy of better than .1 mm by modulating the gradient of the quadrupole at low frequency and measuring the response on nearby pick-ups. This technique was tested experimentally towards the end of 1992 and produced very exciting results. This technique would allow an absolute calibration of the electrical centre of each pick-up with respect to the corresponding quadrupoles. Since many of the LEP quadrupoles are connected in series, additional hardware would need to be designed and installed before this objective could be attained. A full design study is now under way for this exciting new possibility.

The results of the vertical and tilt measurements of the alignment of all LEP quadrupoles showed, as suspected from the more limited statistics, that the rms of the alignment had degraded from .1 mm to .5 mm since 1989. In addition two large depressions over large lengths were found between points 7 and 8 (-11 mm) and between points 2 and 3 (-4 mm). The strategy for realignment involves displacing all quadrupoles which are beyond a pre-set limit to a polynomial fitted to the measured data. If this pre-set limit is fixed to .4 mm then 350 quadrupoles need to be realigned, resulting in a reduction of the rms from .5 mm to .17 mm. Reduction of the limit to .3 mm increases the number of quads to 450 with a concomitant
chosen and lies in a region of high luminosity and high lifetime. However other regions showed the promise of even higher luminosity. These regions will be further investigated in 1993. In addition it is planned to extend the tune range of the system, improve the synchronization, and add new parameters such as the measured luminosity and loss detector signals. During ensuing discussions it was suggested that future tune scans could be done with maximum intensity, with single beams and at injection energy.

In the next presentation it was shown that calculations of the beam-beam strength parameter ($\xi$) from the measured luminosity of the experiments showed maximum values of .04 during operation with the 90° optics and 4 × 4 bunches. The average values with 4 bunch operation was around .032 as compared with the 1991 average of .022. It was also reported that the run to run spread was significantly less in 1992. During operation with $8 \times 8$ bunches the average value of $\xi$ dropped to .02. It was also shown that the luminosity as calculated from the measured beam sizes according to the synchrotron light monitors (BEUV) gave values which were a factor of 2.0 lower for $4 \times 4$ bunch operation and 1.7 lower for $8 \times 8$ bunch operation. These discrepancies will be pursued in 1993. In the discussion which followed it was suggested that if LEP is not at the horizontal beam beam limit then it may be better to use a combination of coupling and wiggler excitation instead of just wigglers to maximize the luminosity and minimize the background. This idea will be tried early in 1993.

In the presentation on “Aperture and Background”, it was shown that the limitation in lifetime and background results from the beam size and aperture in the horizontal plane. It was demonstrated by simulation results that the major contribution to background comes from back scattered photons which are created in the quadrupole QS1 where the horizontal $\beta$ function and the gradient are both high. A great reduction in this background can be achieved by reducing the beam size at QS1 by reducing the horizontal focusing at the Interaction Point. Towards the end of 1992 an experiment was performed with the $\beta_x$ increased by a factor of 2 which confirmed the simulation results. For 1993 a “knob” will be made available to vary the horizontal $\beta_x$ during the run.

In the discussion it was stated that the tight settings of the collimators were predominantly to protect the central detectors from radiation coming from accidental beam loss. The situation could be relaxed when all 4 experiments are equipped with radiation interlocks which can trigger the beam dump.

The following presentation on “Beam -beam and Lifetime” showed a clear correlation between the beam-beam lifetime and the normalized luminosity ($L/I_b$) over a wide range of bunch currents. From these results it was clear that the lifetime in LEP was totally dominated by beam-beam bremsstrahlung and that the correlation indicated a cross section for this process of .21 barn. The best calculation of this cross section gives a value of .3 barn. This discrepancy is vitally important for future high luminosity electron positron storage rings and deserves further investigation.

It was then shown that a rather simplified model of the behaviour of particles in the presence of beam-beam forces could explain the reduction in lifetime which occurs with strong beam-beam forces. Once again this study showed that higher bunch currents in collision would need more aperture.
ramp and squeeze would be needed. It was also assumed that the pretzel would be used for the major part of 1993 and that energy scanning, with about 1/3 of the time off peak would be a requirement. Concerning software requirements for the pretzel the following requests were made:

- All separator software should now be included in the operational software package (SLOPPYSOFT).
- New software for differential control of the tunes of the electrons and positrons by use of the pretzel sextupoles is essential for luminosity optimization.
- Improved diagnostics are needed for the control of the “head-on” collisions in the experimental regions.
- An automatic measurement of the central frequency would be a great asset for the energy calibration of the beams.

Finally it was recommended that the beam energy calibration by resonant depolarization should become an operational procedure.

3  Performance Limitations at 45 GeV

During this session the following presentations were made:

- Coherent effects
- Beam-beam; tune scans and simulations
- Beam-beam; tune shifts in physics
- Aperture and background
- Beam-beam and lifetime
- “Tails” of the transverse density distribution of the beams
- Separations and aperture

In the first presentation it was demonstrated that longitudinal effects are not presently limiting the performance and studies are now concentrating on transverse effects. The accuracy of the transverse impedance has been substantiated with measurements of the growth rate of head-tail instabilities and the dependence of the Transverse Mode Coupling Instability (TMCI) threshold current on the bunch length. The uppermost fundamental intensity limitation results from the TMCI at injection energy and the present limitation is around 650 \( \mu A \) per bunch for a single beam and a bunch length of 20 mm. However this limiting value is reduced to about 550 \( \mu A \) per bunch when accumulating 4 \( \times \) 4 bunches, and reduced to 320 \( \mu A \) per bunch with 8 \( \times \) 8 bunches. The reason for these substantial reductions is not yet fully understood. It was strongly recommended that these effects be studied experimentally in 1993.

An automatic scheme (tune scan) was presented which allows controlled variation of the horizontal and vertical tunes with simultaneous measurement of beam sizes and beam current. Such tune scans were made at the end of several physics runs with typical currents of about 150 \( \mu A \) per bunch. These results confirmed that the present working point is well
an integrated luminosity of 500 pb$^{-1}$ is still the physics minimum target. For the same reason it was conjectured that data taking at W pair energies may sometimes be interrupted to go back to the Z$^0$ peak in order to check out the detectors with a much higher data taking rate.

The summary of the presentation on “Operations in 1992” was that ’92 was a good year and that the 90$^\circ$ optics had paid off. The integrated luminosity reached 28.6 pb$^{-1}$ as compared with 17.3 pb$^{-1}$ in 1991. This increase could be attributed to the increase in the luminosity lifetime, the reduction in the filling time and the improvement in the overall efficiency. Commissioning of the 8 bunch pretzel scheme also proved, as expected, to be much easier with the new 90$^\circ$ optics, and indeed LEP was operated for physics during the last 5 weeks of the year with 8 bunches per beam. The integrated luminosity with pretzel was slightly higher than without, thus indicating that the “break even” point had quickly been reached.

Although the LEP peak performance is not limited by the intensity of the injectors, reliability of the injectors is a key factor in the efficiency of LEP. It was shown that the reliability of the SPS had improved in 1992 with respect to 1991. In addition great progress has been made in 1992 to decouple the machine development in CPS and SPS from the filling of LEP by means of a new super cycle for machine studies. In effect this opens up the possibility that LEP could be filled independently of the mode of operation of the injectors.

During 1992 the injectors have been tested with 8 bunches per beam right up to the beam stoppers in the LEP transfer lines T112 and T118. Operation with 8 bunches in the injectors will greatly simplify the filling of LEP in pretzel mode. In this context it was noted that the system for equalizing the bunch intensity must be operational with this mode of filling.

It should be possible in 1993 to increase the ejection energy of the SPS to 22 GeV in order to investigate the energy dependence of the maximum bunch current in LEP. It was stressed however that the energy could only be increased for a test period and that continuous operation at 22 GeV should not be considered for 1993. Machine studies will be foreseen during 1993 to measure the dependence of the threshold current in the beam energy.

The optimization of the luminosity is still somewhat an art rather than a science since the parameters which are measured are not necessarily those which uniquely control the luminosity. It is still not clear which are the critical parameters for luminosity optimization since different results are obtained on different days and fills. It was pointed out that correlation plots would be a very useful tool in this respect. It was reported that the luminosity can be affected by changes in the beam angle and position through the interaction point and by small changes of the momentum dispersion. The effect of these “dispersion bumps” on the dispersion at the interaction points and the RF straight should be measured. It was once again stressed that the task of optimizing the luminosity and the background would be somewhat easier if the experimenters would be willing to accept higher rates during this optimization. Once again the importance of the vertical angle of the beam through the interaction region was indicated in the process for background minimization. Automatic feedback on this parameter should be explored in 1993.

This session was concluded by a presentation on “Operational Requirements for 1993”. It was stated that for operational simplicity the separate ramp and squeeze was preferred, however it was pointed out that in this case the residual beam-beam tune shift increases linearly with energy. If this turns out to be a limit to the LEP performance then a combined
1 Introduction

The third LEP Performance Workshop took place from January 10 till January 16 and was held, for the third time in Chamonix, France. The workshop was sub-divided into 10 major sessions, each with a duration of between 3.5 and 4 hours. The titles of the sessions are given below with the names of the session chairmen and the scientific secretaries given in parentheses

1. Operational Experience; 2 sessions (L. Rolandi, G. de Rijk)
2. Performance Limitations (A. Hofmann, K. Cornelis)
3. Optics (J.P. Koutchouk, J. Miles)
4. Beam Instrumentation 45 and 90 GeV (E. Keil, H. Schmickler)
5. Energy Calibration with Polarization (A. Blondel, H. Burkhardt)
6. Pretzel Operation 45 and 90 GeV (J. Gareyte, R. Bailey)
7. LEP2 Performance (L. Evans, P. Collier)
8. LEP2 Equipment Status (D. Boussard, P. Collier)
9. Conclusions (S. Myers, J. Poole)

A summary of the conclusions and important issues raised at each of the sessions is given below.

2 Operational Experience (Two Sessions)

During these sessions the following presentations were made:

- Follow-up of Second LEP Performance Workshop
- Report from the LEPC
- Operations in 1992
- LEP Injectors; a critical review
- Turn-around procedure and its optimization
- “Haute-cuisine” done in operation to increase the luminosity
- Collimation and background to the experiments
- Limitations to luminosity
- Operational requirements for 1993

In the first presentation it was clearly shown that nearly all of the proposals from the Second LEP Performance Workshop were in fact implemented during the running of 1992. The exceptions to this were either shown to produce no advantage to the machine or impossible for technical reasons.

In the report from the LEPC working groups on physics at LEP2, in November 1992, it was emphasized that the cross-section reduces dramatically as the energy is increased above the peak of the $Z^0$. This reduction highlights the need for high luminosity at LEP2 energies;
Some technical problems have been encountered on the design and production of the cavity couplers. It has been painfully discovered that small design modifications may generate large differences in behaviour. Although some progress has been made with better simulation programmes it is still difficult and risky to predict behaviour, especially with insulating materials such as ceramics. Nevertheless a very likely source of difficulties with the main power coupler has been identified and should soon be confirmed.

The few people involved have put an enormous effort into the design of the HOM couplers, resulting in many design changes, however a fully satisfactory design has not yet been proven. There are new ideas for improving the situation and this work is recognized as being of crucial importance for the LEP2 project (as in 1992) and will be given the maximum support from all divisions concerned.

A major milestone is due in spring 1993 when a complete Niobium film, 4 cavity module, delivered from industry, will be installed in LEP.