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THE USE OF BEAM INSTRUMENTATION WITH BUNCH TRAINS

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Abstract

Filling LEP with trains of bunches separated of only 247ns instead of the present eight equidistant bunches (at 11μs intervals) has important implications for the use of beam instrumentation. The BPM system will be limited in its measuring capabilities. Most other instruments will not be able to identify bunches unless further developments are made in their timing and acquisition electronics. A review of the situation is presented together with the planned actions to cope with the observation of individual bunches in trains.

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The Use of LEP Beam Instrumentation with Bunch Trains

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Filling LEP with trains of bunches separated of only 247 ns instead of the present eight equidistant bunches (at 11 µs intervals) has important implications for the use of beam instrumentation. The BPM system will be limited in its measuring capabilities. Most other instruments will not be able to identify bunches unless further developments are made in their timing and acquisition electronics. A review of the situation is presented together with the planned actions to cope with the observation of individual bunches in trains.

INTRODUCTION

In order to reach the higher luminosity needed for $W^{\pm}$ physics, LEP is likely to run, in the future, with a newly proposed filling scheme of "Bunch Trains with Head-On Collisions" [1] to replace the present pretzel scheme (8 equidistant bunches).

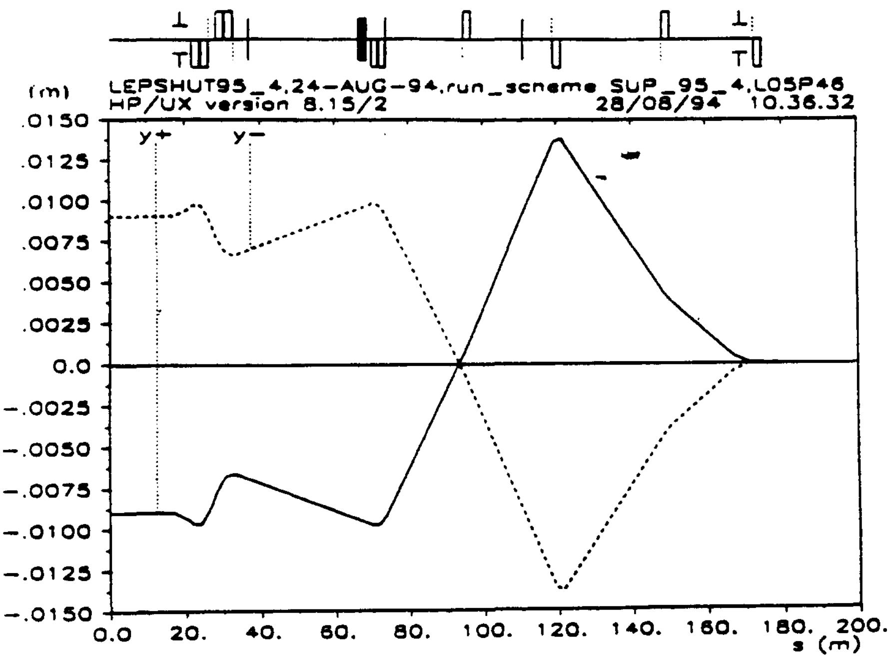

Figure 1. Vertical separation bumps for positrons (y^+ full) and electrons (y^- dashed) on the right side of the crossing point IP1 at 45 GeV.

The trains will have a maximum length of 220 m and if four trains are circulating in each beam, an adequate separation has to be provided over a length of ±110 m around the 8 IP's. The vertical separation foreseen around IP1 is shown in Fig. 1 and poses specific problems for some instruments layed down in this section of the machine: the tune-meters, the synchrotron light sources (mini-wigglers) and the polarimeters.

The short distances between bunches in the trains will influence in different ways the measurements that can be done with the various instruments. For someones the measurements will remain valid and be representative of all bunches in the train, for some others the measurements will concern only the first bunch or be completely corrupted. All instruments are reviewed here to see how best they can be used with bunch trains and what modifications should be foreseen for them to be more performing.

Front-end Electronics

Bunch trains impose severe constraints to the use of the existing electronic systems which have been conceived for bunches separated by 22 μs. Table 1 reviews the situation of the front-end electronics of the various instruments. The aim and the proposed action are explicitated in more details under the specific names of the instruments, in the following paragraphs.

Table 1: Front-end Electronics with Bunch Trains

Instrument	Possibility of 100ns-gating	Aim	Action
BCT	no	parallel acquisition	new front-end needed
BOM WB	yes	orbits for individual bunches	special gating of 2 BPMs
BOM NB	no	no hope !	
Tune-meter	yes	bunch selection	additional gating
BEUV	yes	bunch selection	faster intensifiers
BEXE	no	16 bunches in a row	new pulsed bias needed
Streak camera	yes	32 bunches in the picture	more picosecond gating
Luminosity det.	yes	parallel acquisition	additional electronics
Polarimeters	yes	bunch selection	none

Bunch Selection

None of the acquisition systems used in LEP beam instrumentation is capable of reading data at the rate of the bunches in a train (4 MHz) but they all can read at the frequency of the trains (44 kHz). Therefore, provided that the front end can cope with a gate of 100 ns, a triggering sequence like 1,2,3,4 in Fig. 2 can provide a full acquisition of the 16 bunches in 4 revolutions. Alternatively, in order to reveal the systematic behaviour of the different bunches in a train, a sequence of acquisition as illustrated in line 5 could be specially helpful.

Such sequences can be produced and computer controlled by means of a VME module which can any timing sequence over 16 LEP turns, with a resolution of 50 ns and a jitter of 1 ns. Any programmed sequence is synchronsed to the beams by means of a dedicated timing system[2].

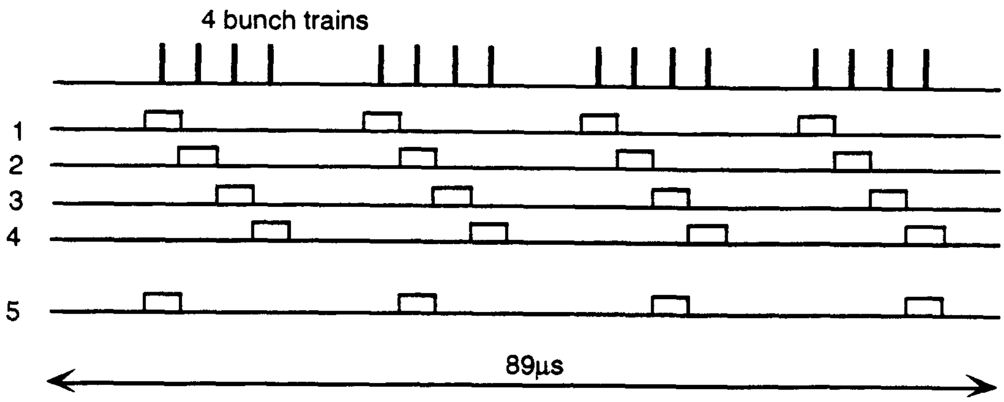

Fig. 2. Different gatings of individual bunches.

BUNCH CURRENT TRANSFORMERS[3]

BCTs in LEP are set up to measure the 16 bunches of the present pretzel scheme. For future bunch trains their integration window has been enlarged from 730 ns to 1100 ns, to accommodate trains of up to 750 ns, but the measurement cannot distinguish between bunches in a train. To do this, a new signal processing is needed. Software development is presently under way to get on line digital information from the bunch shape observation made with the help of a Lecroy 9350M oscilloscope. The scope sampling will be triggered by an external clock at a frequency of 1 GHz during the passages of the trains, i.e., for 1 μs every 22 μs. In its first version this should provide for bunch equalisation during filling. For more accurate measurements leading to lifetime determination for all individual bunches, more work is needed before next LEP start-up (March 1995).

BEAM ORBIT MEASURING SYSTEM[4]

BOM will measure only the first bunch in a train, and, for a fraction of the BPMs, this will only be possible for trains arriving at a collision point and not for those leaving.

BOM Wide-Band Electronics

This system, used for the 56 BPMs located close to the 8 crossing points, is auto-triggered by the first bunch of the selected polarity, and remains busy for 2 μs during the data acquisition sequence. For the measurement to be valid the signal should not be perturbed by another bunch signal arriving in the interval -20 ns/ +40 ns. This may occur for some BPMs close to the IP's when trains of bunches are crossing.

For incoming trains the first bunch will be measured correctly since the double time of flight from a BPM to the IP is always larger than 40 ns (see the distance to IP in Table 2). For outgoing trains the situation is more involved, because of the interferences between the two trains and Table 2 shows that two thirds of the pickups near the odd IP's, located at QL2B's and at QL4B's, will not work because of this odd coincidences.

Table 2. Wide band pickup excitation by trains with bunch separation of 87 λ_{RF}

Position	Distance to IP	Dt	dt(e–)	dt(e±)
	[m]	[ns]	[ns]	[ns]
Odd IP's				
QL1B R	+26.485	176.7	–176.7	70.3
QL2B R	+32.984	220.0	–220.0	**27.0**
QL4B R	+74.087	494.0	**–0.3**	246.7

Observation of Individual Bunches in Trains

Computer simulation has shown that all bunches will have different vertical closed orbits because of the different beam-beam kicks they experience at the various crossing points where the separation bumps have unequal amplitudes. This effect would be interesting to check at a point in the machine, with a suitable phase advance.

Contrary to NB electronics, the analogue part of the WB electronics can follow the sequence of bunches separated by 247 ns. But the digital encoding puts a dead time of 2 μs after each reading, which precludes the measurement of successive bunches in a train. In order to remove this constraint the following strategy can be employed. With some hardware modification an external trigger produced by the BST can be introduced to provide a gating of the wanted bunch in a train. This gating can be done of any bunch in a given train and be different on four successive revolutions so that all 16 bunches are eventually recorded. Such special gating could be introduced for a few WB pickups near one given pit.

BOM Narrow-Band Electronics

For BPMs with NB electronics a measurement can be validated only if the interval –600 ns to +90 ns is clear from any other signal. A detailed analysis (see Ref. [ ]) shows that a total of 80 NB pickups will not be able to measure outgoing trains with 4 bunches separated by 87 λ_{RF}. With trains of only 2 bunches this number reduces to 28 but, if the bunch spacing is increased to 150 λ_{RF}, then the number of deficient pickups rises again to 48. All of those pickups would work well with WB electronics but the conversion is a major operation which costs time and money. Due to the modularity of the components it would make sense to extend the WB system modulo 8 BPMs per pit. Converting 32 BPMs (for instance 8 per even IP) would cost 800 kSF and take a year to implement.

TUNE MEASUREMENT[5]

Individual bunch excitation for tune measurement is provided by four shakers located at 122 m and 152 m from IP1. They are fed with two types of pulses: the short ones are too long for exciting individual bunches in a train but the long ones can be used for exciting equally all bunches in a given train.

Bunch observation is presently done with a front end electronics similar to the wide band of BOM and therefore is auto-triggered on the first bunch of a train. A more sophisticated gating will have to be provided for the observation of signals obtained from two directional couplers located at ±957 m from IP1. The advantages are numerous : no displacement of the beams due to the vertical separation bump, no time interference due to crossing trains, higher sensitivity.

SYNCHROTRON RADIATION TELESCOPES[6]

The four BEUV telescopes are located in the machine tunnel around IP8. In their TV mode they integrate the light emitted by lepton bunches during 20 ms. The beam cross-section is therefore averaged over all bunches of a beam and this will not change with bunches grouped in trains. For single shot measurements the gated image intensifiers used so far could not separate bunches in a train, but this has become possible with the faster light intensifier (MCP), now under test, timed directly from the RF clock signal available at IP8.

HARD X-RAYS MONITORS (BEXE)[7]

The acquisition electronics integrates the signal during 2 μs and cannot separate bunches in a train. But the integrating front end shows a linear response for bunches separated by some 247 ns and the system, as it stands, will give profile measurements averaged over a whole train. For the selection of a particular bunch in a train a new development is required : of either a pulse generator for the polarisation voltage of the detector, or of a new front-end to the measuring system which would allow for a much shorter integration time.

In any case a sophisticated gating will have to be used in order to acquire all 16 bunches in a minimum of 4 revolutions (see Fig. 2).

STREAK CAMERA[8]

With the vertical bumps needed to separate the trains near IP1 the light of the mini-wigglers will have to compete with the radiation produced in the quadrupoles QL4. MD work and computer simulation are underway to see if these two sources can be disentangled, which would be desirable because the source in the QL4 is too long (3.70 m) to be focused properly and its characteristics are not stable since they depend on the bump amplitude.

Streaks can be fired at a maximum frequency of 45 kHz and can be triggered on any circulating bunch. The selection of different bunches in a train requires a fine tuning of the timing, modulo 247 ns, which can now be done remotely from the LEP control center. For the time being one given bunch can be seen at successive revolutions, or if the repetition time is set to a quarter revolution, the same bunch number can be seen from each train in succession, for a few revolutions.

In the future the timing module which divides the RF frequency to generate the streak camera triggers will have to be modified to allow for more sophisticated selections of different bunches (a to d) from each train (1 to 4), see Fig. 3.

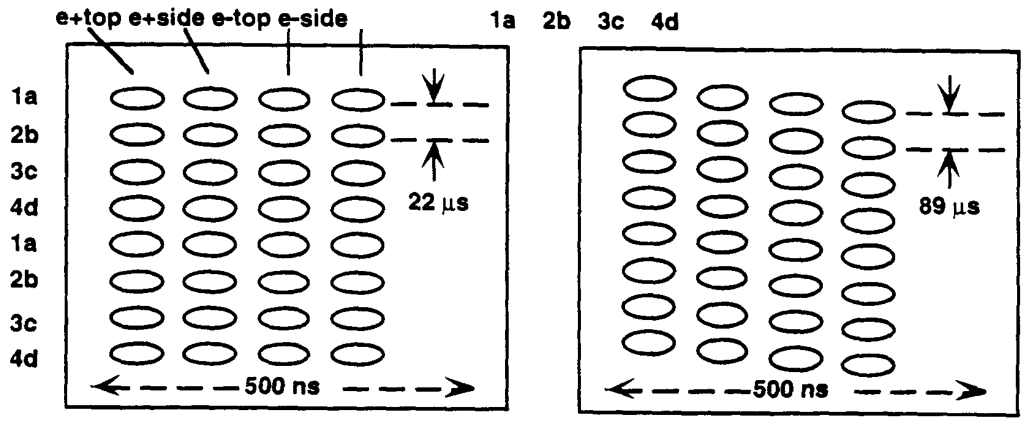

Fig. 3. Data taking sequences with the streak camera : 1,..4 trains, a,..d bunches

LUMINOSITY DETECTORS[9]

As it stands the system composed of 8 pairs of detectors is counting events in a time window of 120 ns centred on the crossing at the IP, every 11 µs. The digital recording takes several microseconds, therefore it is able to monitor the luminosity of only one bunch crossing per train, which is not adequate to represent the total luminosity and means a considerable loss in statistics. In order to count Bhabha events from all bunch crossings, additional electronic channels will have to be implemented with delayed gating corresponding to the different bunches in the trains. The software for the analysis of Bhabha events and the subtraction of background coincidences will have to be supplemented to take care of the added complexity.

POLARIMETERS[10]

Back scattered photons are obtained from the interaction of laser pulses with a given circulating bunch at a frequency of 100 Hz. Any bunch can be selected for this measurement and the grouping of bunches in trains is of no particular consequence.

The new machine optics foreseen for bunch trains and the vertical slope introduced by the separation bump near IP1 will prevent the use of the laser-beam interaction region (LIR) at its present position, at 73 m from IP1 (see Fig. 1). Plans are being made for moving the LIR to IP1, which will be more favourable from the optical point of view, acceptable for the bump (zero slope and a maximum displacement of 10 mm) and will give a perfect symmetry for e^+ and e^- measurements.

The multi-layered dielectric mirrors which are at the limit of standing the present level of radiation inside the LEP vacuum chamber will have to be replaced by all-metallic mirrors, in order to stand the additional radiation created by the vertical bump in the middle of LSS1.

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