Real Time Measurement of Bunch Instabilities in LEP in three Dimensions using a Streak Camera

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Abstract

The performance of a streak camera used for real time measurements of LEP bunches will be described. The streak camera jitter has been determined with the help of a laser diode. An optimum use of both slow and fast sweeps has been achieved in order to stack many bunch images on the same picture. The slow sweep serves to stagger up to 32 streaks corresponding to different bunch passages. The fast sweep can register several bunch images simultaneously : two different bunches (e+ and e-) or two different views of the same bunch (top view and side view) or images of a sliced bunch. This setup has demonstrated evidence for head-tail effects in both horizontal and vertical planes in LEP.

1. INTRODUCTION

Synchrotron light is produced by both LEP beams when traversing small wiggler magnets placed at ±67 m from intersection point #1; it is extracted from the machine by means of thin beryllium mirrors and brought to an underground optical laboratory, located at 15 m from the tunnel, where it can be focussed onto different instruments. With this optics the photon bunch size is $\sigma_x \approx 500$ µm, $\sigma_y \approx 250$ µm and the length being precisely preserved for monochromatic photons is $\sigma_s \approx 12$ mm. The shape of the particle bunch can be deduced from the measured shape of the photon bunch and the respective density distributions can be scaled from each other.

2. STREAK CAMERA

A double sweep streak camera [1] built by A.R.P. [2] has been used at LEP for three years with increasing sophistication. Here a brief description of its setup is given.

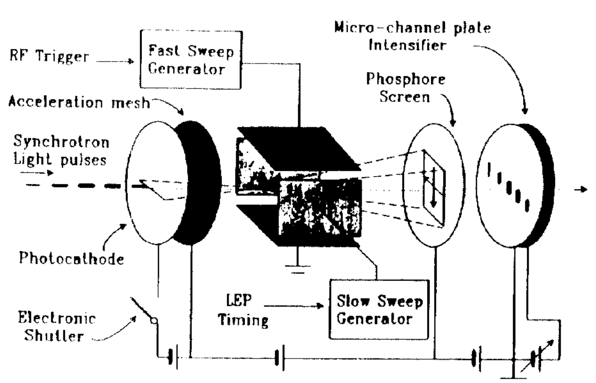

Figure 1. Setup diagram of the streak camera.

Photons from synchrotron light hit the photocathode of a vacuum tube where electrons are emitted, accelerated and quickly deflected by an electric field as they pass between two horizontal plates. This causes the bunch of electrons to rotate in space and strike the phosphor screen leaving an image of its length, as if we were observing it from above. A second pair of plates, perpendicular to the first one, allows to stagger successive streaks. The composite image on the phosphor screen is recorded by a CCD camera and digitized before being processed by a computer. The computer displays show the bunch projected density with colours and the frame is rotated by 90^0 so that the streaks (time scale direction) always appear horizontal.

With the readout system provided by A.R.P. the streak camera can be left running at a rate of 10 to 25 Hz. The data analysis is done locally with a IBM PC which primarily creates and refreshes a colour display in RGB standard. These images have been transmitted to the LEP control room by means of a commercial TV set, in PAL standard which degrades the resolution significantly. All pictures can be recorded in digital form and kept on file for off-line subsequent analysis.

3. TEST OF STREAK CAMERA JITTER

A very fast laser diode is triggerered at the machine revolution frequency (intervals of 89 µs). It yields simultaneously a light pulse of 35 ps FWHM and an electric pulse used to trigger the streak camera. The light pulses registered by the streak camera should therefore appear at the same moment on the successive streaks. This test, shown in figure 2, demonstrates a stability better than 5 ps, including the jitter of the diode and of the streak camera.

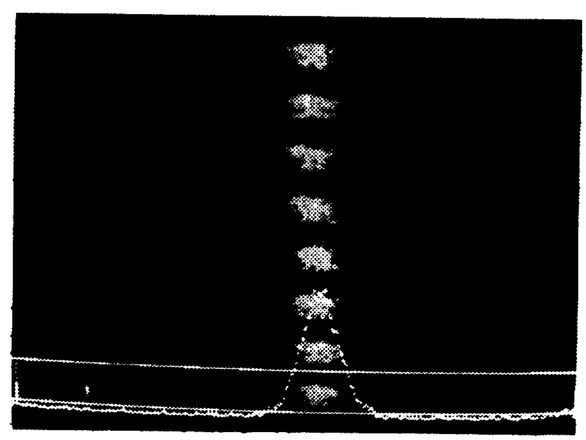

Figure 2. Test of streak camera triggering jitter.

For the observation of LEP bunches the triggering of the streak camera is done with a very stable signal derived from the radio-frequency master clock and transmitted over 4 km through an optical fibre.

4. DIGITIZED PICTURES

The following figures show typical examples of pictures taken under different machine conditions.

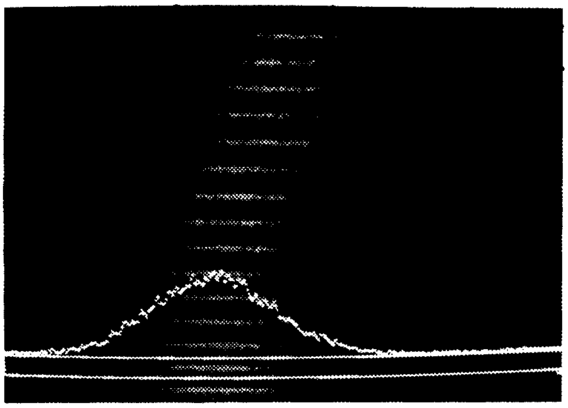

Figure 3. Stable beam at 45 GeV, σ_S=12 mm.

At 20 GeV with 61 MV rf voltage, bunches are very short but the beam appears pretty noisy (figure 4).

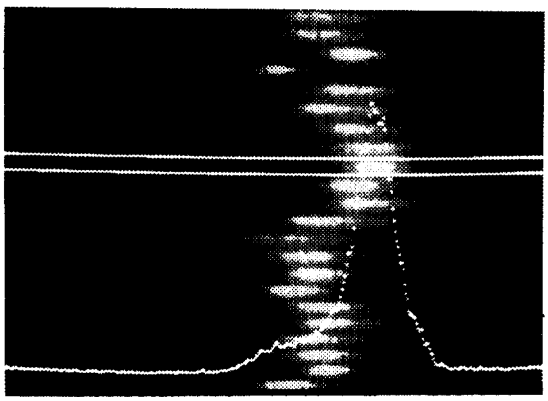

Figure 4. Noisy beam at 20 GeV, σ_S=8 mm.

An interesting phenomenon is the appearance of quadrupolar longitudinal oscillations at a frequency double of the synchrotron oscillations (Qs=0.08) : the bunch lengthens and shortens every sixth revolution [3] (figure 5).

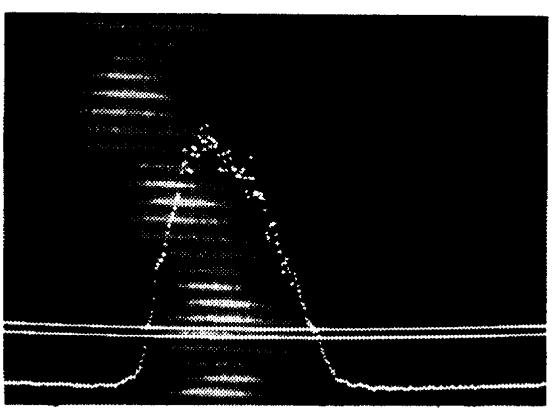

Figure 5. Quadrupolar oscillations with a period of 6 turns.

Figure 6 has been obtained with synchrotron light from both beams being simultaneously focussed onto the streak camera. The optimum distance in time between e+ bunches (on the left) and the e- bunches (right) is adjusted with an optical delay of a few centimeters.

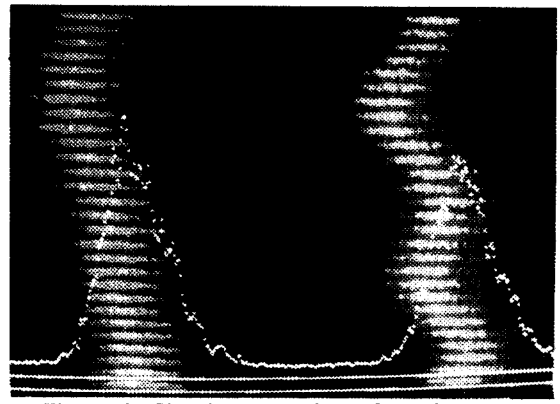

Figure 6. Simultaneous view of two beams :
on the left are positrons with longitudinal feedback,
on the right are electrons without longitudinal feedback.

5. REAL TIME TOP AND SIDE VIEWS

One additional facility has been provided during 1991 : the ability to see the bunch with a top view and a side view simultaneously. The scheme to achieve this peculiar feature is shown in figure 7.

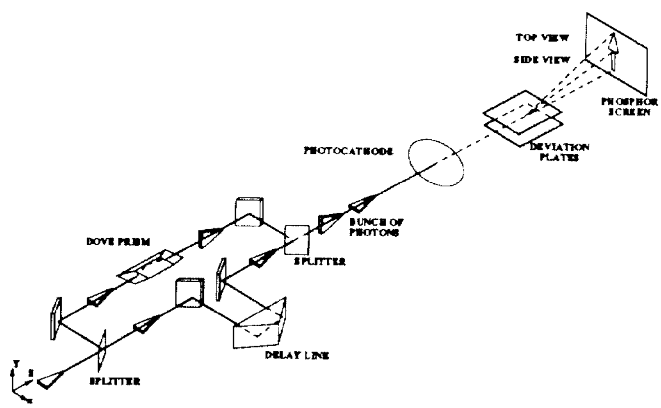

Figure 7. Optical setup to provide top view
and side view of the same bunch.

The bunch of photons represented here as a triangle is divided by a splitter into two parts. On one way the bunch goes through a Dove prism and is rotated by 90° about the longitudinal axis. On the other way an optical delay is used to carefully stagger both photon bunches in time and avoid their superposition when they are spread out together on the same streak. Thus both vertical and horizontal motions of a bunch can be observed simultaneously. The first time we were able to do this measurement we had observed an interesting effect. At an intensity of some 300μA the particles began to swing about the centre of the bunch in the vertical plane. This head-tail effect had been predicted theoretically but it had never been demonstrated so evidently [4].

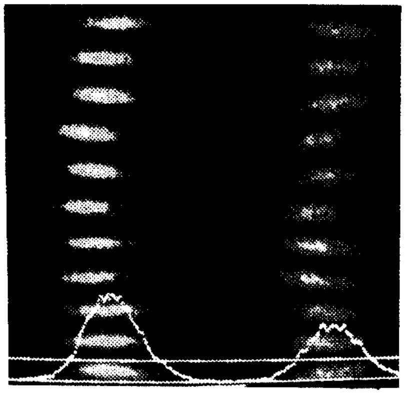

Figure 8. Simultaneous observation of the side view (left) and top view (right) of the same bunch.

6. REAL TIME SLICE TOMOGRAPHY

The method explained in section 5 is elegant and convincing but all images obtained in this way show the full bunch density projected on a plane (horizontal for the top view, vertical for the side view). On special occasions it might be interesting to investigate the bunch density in different slices of its three dimensional volume. An optical stratagem has been designed to provide a real time tomography and is shown in figure 9.

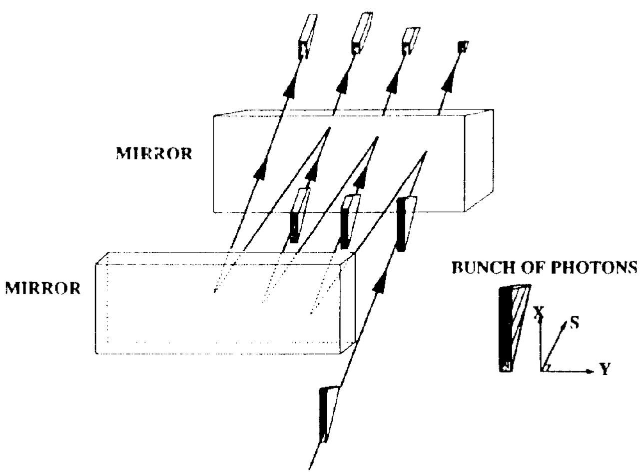

Figure 9. Schematic of the optical slicer.

The light pulse arrives at an angle between two mirrors and undergoes successive reflections. At each impact of the bunch the edge of the first mirror acts as a slit cutting progressive slices, because of the skew incidence. The distance between both mirrors is adjusted in relation to the bunch length and the incidence angle is choosen to suit: i) the bunch width (horizontal direction) and ii) the slice height (vertical direction). The number of slices produced is limited by the desired time resolution since all slices are to be staggered on the same streak.

This setup has been tested with beam on the last day of 1991 LEP run. Since the beam intensity was low, only three vertical slices could be recorded, as it can be seen in figure 10. These preliminary results are very promising and show that a tomography with ten slices is feasible.

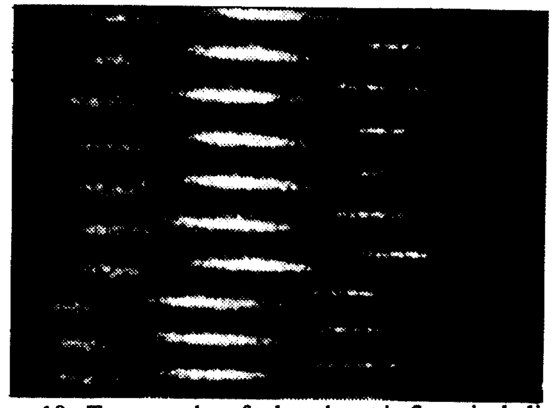

Figure 10. Tomography of a bunch cut in 3 vertical slices.

7. CONCLUSIONS

Various levels of sophistication have been recently introduced in the use of the streak camera to observe LEP bunch behaviour [5]. During machine development periods the instrument was under constant maintenance and an operator was always present in the underground optical laboratory.
In order to make the information from the streak camera available in the LEP control room, a crash programme has been launched in order to install vital interlocks, a feedback loop on the light intensity regulation and a remote control of several parameters.

8. ACKNOWLEDGEMENTS

We would like to thank particularly Y. Solberg for a software contribution which permitted to condense the data of digitized images so that hours of observation could be kept on file. Also, we would like to express our thanks to the firm A.R.P. for their advice of using the streak camera, as well as N. Adams and D. Merel who have built and commissioned the fast electronic for the timing control of this equipment.

9. REFERENCES

[1] E. Rossa et al., Double sweep streak camera for LEP, Proc. EPAC 1990, p. 783.

[2] A.R.P., route de Hausbergen, F-67088 Strasbourg Cedex, France.

[3] D. Brandt et al.,Experimental observations of instabi lities in the frequency domain in LEP, at this Conference.

[4] D. Brandt et al., First experience with a low emittance lattice for the LEP Energy Upgrade Programme, at this Conference.

[5] A video film demonstrating the use of the streak camera with real beam in LEP can be obtained from E. Rossa, CERN, CH-1211 Geneva 23, Switzerland.