Performance limits of a Streak Camera in Real Time three-dimensional measurement of Bunch Oscillation in LEP

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Abstract

A new method using a streak camera to observe the synchrotron radiation of LEP was developed for the bunch measurement. This allowed monitoring of the particle density distribution in three dimensions in space at successive bunch passages. The optical set-up allows to see the top view and side view of the bunch simultaneously. The software analyzes the density distribution in these two perpendicular planes and extracts online the σ and the center of gravity for the bunch length and also for transverse dimensions. We will give the experimental results of the resolution limits due to the streak camera in this application. The resulting influence of the transverse photon bunch dimension on the measured bunch length will be presented and compared with the calculation.

I. INTRODUCTION

Small wiggler magnets produce synchrotron radiation to monitor the shape of both LEP beams [2]. The density distribution in space of the emitted photon bunches is proportional to the density of the particles in the e^+ and e^- bunches. Two beryllium mirrors collect the light in the vacuum tube. Two achromatic lenses create the image of the source onto the double sweep streak camera (S.C.) in an underground optical laboratory [3, 4]. The optical set up allows observation of the side view and the top view of both bunches simultaneously. Up to 50 single successive bunch passages can be recorded on one image. The system visualizes instabilities in all three dimensions [5] and extracts the bunch length. Alternatively the front view of the bunches can be displayed.

The precise knowledge of the bunch length is essential to obtain the best performance of LEP.

II. OPTICAL SETUP

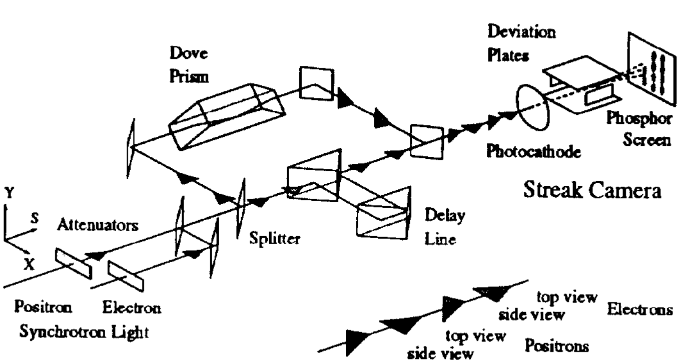

Figure 1: Optical setup to provide side and top view at the same time

The setup is shown schematically in Figure 1. The synchrotron radiation of the e^+ and e^- bunches arrives slightly separated in time ($\sim$ 500 ps). An automatic attenuation system of motorized continuously varying neutral density filters and a photomultiplier keeps the intensity of the light constant. A semi-transparent mirror divides the light and a dove prism rotates one bunch by 90° about the longitudinal axis with respect to the other. So the streak camera displays both top and side view which are the density projection of the beam in the horizontal and vertical plane, respectively [5]. The side- and top-view of both beams can be shown simultaneously in one streak of the camera. So a single sweep gives the following display on the computer screen (Fig 2):

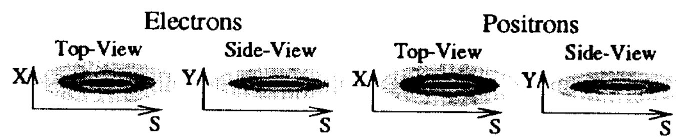

Figure 2: Views obtained in one single streak

Figure 3 shows an example of six successive bunch passages. The displayed profile shows the projection of the streak selected in the window.

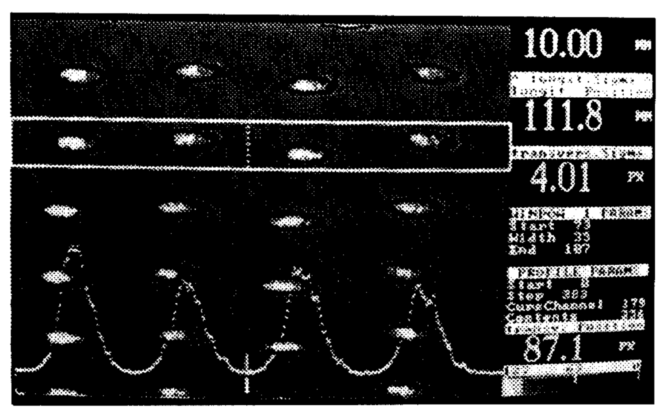

Figure 3: Stable beam at 45 GeV, $\sigma_S = 10\,\mathrm{mm}$

The software is tracking the bunches in real time at a frequency of 12.5 Hz and extracts the photon bunch length and transverse dimensions to a precision of better than 2%. Head-Tail-Effects in the horizontal or vertical plane appear very clearly on the image.

III. RESOLUTION LIMITS OF THE ENTIRE SYSTEM

The limit of resolution for the streak camera and the digitizing system is shown in Table 1.

X,Y $_{transverse}$	$< 15\,\mu m$
S (length)	< 0.8 mm
jitter $_{fast\ sweep}$	< 2 ps
$\widehat{=}$ center of gravity	< 0.6 mm
sensitivity$_{max}$	1 photon/count/pixel

Table 1: Resolution limits at the input photocathode plane

The spatial resolution limit of 15 μm in direction of the fast sweep and perpendicular to the direction has been obtained by measuring the smallest spot size possible.

A picosecond laser pulse measured with the S.C. has shown a F.W.H.M. of 6 ps which corresponds to σ=0.8 mm [3]. That means that the resolution of the S.C. itself is better than this.

The software calculates the center of gravity of the bunches in real time. We measure the trigger jitter, with a laser diode pulse of σ=12 ps, by taking the standard deviation of the center of gravity on the screen. Thus, the measured value of 2 ps includes the jitter of the laser diode. So this corresponds to the precision on the center of gravity of the bunches in the RF-phase.

The sensitivity is high enough to analyze profiles of some thousands photons per pulse.

IV. INFLUENCE OF SPOT SIZE

The streak camera in this application is used — in contrary to most other — without a slit in front of the photocathode to visualize the bunch size and instabilities in all dimensions. So there is a finite spot size in the direction of the fast sweep which broadens the measured bunch length. For a Gaussian distribution, with a dimension σ_X of the light spot on the phosphor screen of the streak camera, the broadening of the measured bunch length σ_{meas} is expected to be

$$\sigma_{meas} = \sqrt{\sigma_L^2 + \sigma_x^2}. \quad (1)$$

σ_{meas} is the length measured on the phosphor and σ_X the finite spot size there.

Hence the correction to achieve from the measured σ_{meas} the real σ_L is

$$\sigma_L = \sqrt{\sigma_{meas}^2 - \sigma_x^2}. \quad (2)$$

To verify this effect, the light pulse of a laser diode is projected by a lens onto the S.C.. The light is strongly attenuated in order to have no intensity effects as described later. The position of the lens is varied to achieve different spot sizes on the photocathode. The gain on the micro-channel-plate of the S.C. is adjusted to have a good signal/noise ratio. The spot size is measured in focus mode of the S.C. . Then the fast sweep is set to the maximum streak speed and the length of the pulse is measured. Fig. 4 shows the obtained result.

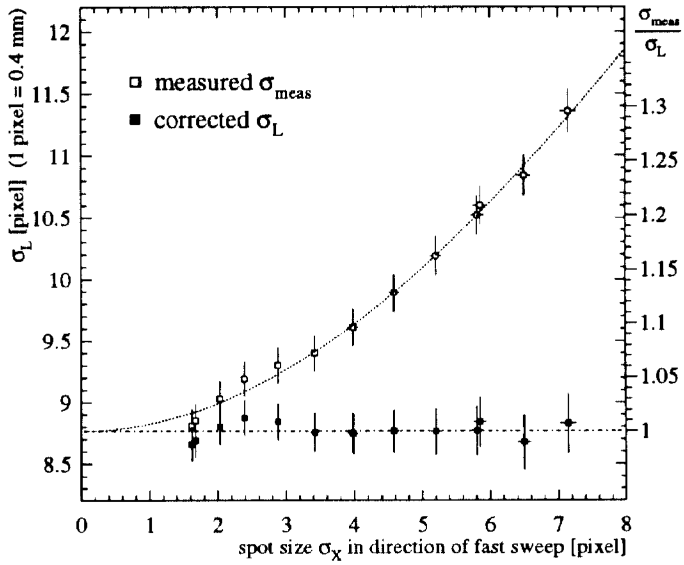

Figure 4: Influence of spot size on measured length

It proves that the correction according to (2) is valid for a wide range of spot sizes σ_X. Even when the spot dimension on the phosphor becomes comparable to the dimension of the bunch length profile the correction still yields the correct result.

It is preferable to choose a spot size not to small to maintain a good resolution of the transverse measurement.

V. INFLUENCE OF INTENSITY

It is known that the measured pulse length increases with higher intensity of the incident light pulse, especially for short pulses [6]. But this effect was only measured for constant slit which induces that there is always a proportionality between total intensity and intensity per unit area.

In our application it is necessary to know the influence of both. The precision we like to achieve is 5%. So we define the dynamic range to be the range where the deviation for the measured bunch length after spot size correction (2) is less than 5% (common for S.C.: 20%).

A. *Influence of light intensity*

The bunch length at a fix spot size is measured with different optical attenuators in front of the streak camera to vary the total intensity.

As in Ref. [6] we expect an increase of the measured bunch length due to space charge effects inside the camera tube. The result is plotted in Fig. 5. The lowest intensity is 10^{-15} J/pulse.

The measured length stays constant in a dynamic range of 30. According to common definition the dynamic range is 100. With longer pulses as coming from LEP ($\sigma \sim 30$ ps) the dynamic range should be even better than this [6].

Anyway, we can select the appropriate attenuation of the incoming light and it is kept constant with the automatic attenuation system. So the dynamic range in this application does not impose any limits.

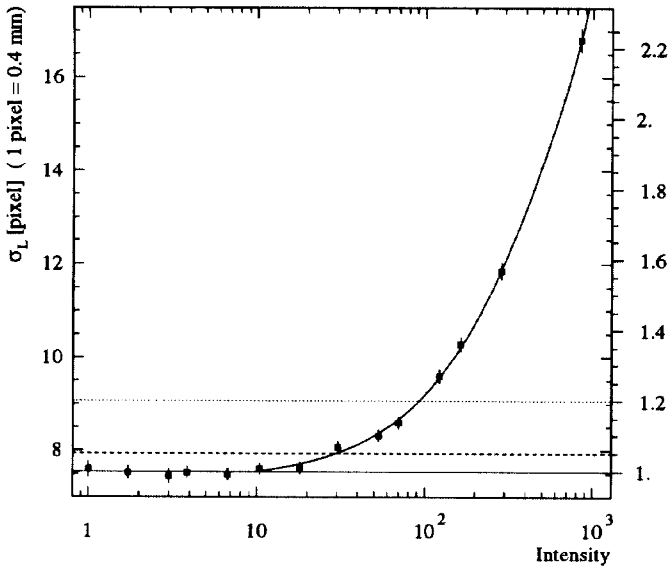

Figure 5: Influence of total intensity on measured length

B. *Influence of photon flux*

The measurement described in section IV. is repeated for a higher total intensity. The total intensity of the pulse is kept constant while the spot size on the photocathode is varied by moving the lens. Thus, the average photon flux is inversely proportional to the square of the spot size. The measured bunch length is corrected for spot size according to (2). Fig. 6 shows the results obtained at a total energy of $3.5 \cdot 10^{-14}$ J per pulse.

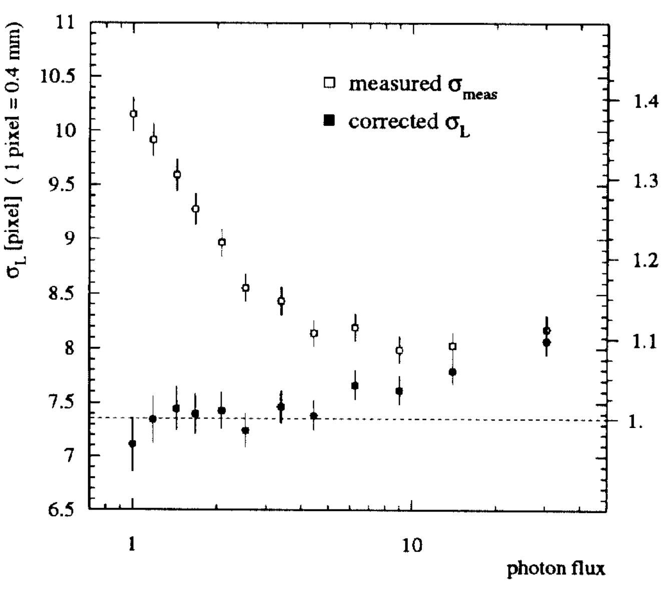

Figure 6: Influence of photon flux on measured length

The corrected bunch length varies less than 5% in a dynamic range of 13 for the photon flux. For higher fluxes the measured length increases.

As in the case of the total light intensity, we can choose an appropriate level of light not to be affected by this effect.

VI. OUTLOOK FOR REAL APPLICATION

Since two perpendicular views of one bunch can be displayed at the same time, length and both transverse spot dimensions (X, Y) are known.

The spot size perpendicular to the direction of the fast sweep measured with the fast sweep 'ON' corresponds with the spot size in focus mode better than 1.5%.

So the bunch length measured on the top view can be corrected in real time for spot size with the transverse dimension of the side view and vice versa.

The transverse emittance of the beam could be deduced after calibrating the transverse dimensions σ_x and σ_y precisely with the beam.

VII. CONCLUSION

We measure the density projection of single bunches in three views:

- front view (focus mode) $\Rightarrow$ X, Y

  or
- side view $\Rightarrow$ Y, S
- top view $\Rightarrow$ X, S.

Thus the three dimensions and the center of gravity of the photon-bunches can be extracted in real time.

The presented way of correcting the measured bunch length for the spot size allows to determine in real time the bunch length very precisely without loosing the possibility to observe all kinds of instabilities in the bunches of LEP.

VIII. ACKNOWLEDGMENTS

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