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Measurement of the Bunch Structure in the DESY Synchrotron

by

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2 HAMBURG 52 · NOTKESTIEG 1

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Introduction

In high-energy electron accelerators the particles are compressed into discrete bunches.The distance of two bunches is determined by the wave-length of the accelerating frequency. In the DESY 7-GeV-Synchrotron the bunches have a distance of about 2 nsec, due to an accelerating frequency of about 500 MHz. The length of one bunch is assumed to be in the order of magnitude of 100 psec. In the last years several attemps have been made to get an idea of the real bunch-structure by measuring the electric signal induced by an electron bunch passing an electromagnetic detector. But up to that time no pick-up system was found which was able to detect the bunch-structure within a time-resolution of about ten picoseconds, and the real bunch-structure was unknown. The DESY-double storage ring DORIS which is under construction, will also operate at a frequency of 500 MHz. For storage rings the bunch-length is an important parameter for calculating the luminosity[1)]. Therefore it is necessary to have an idea of the bunch-length.

The equipment for measuring the bunch-length described herein is not the final one; it was only a laboratory set-up which was tested at the DESY synchrotron. An equipment to be used on the storage ring DORIS will allow the measurement of the bunch structure of a single bunch. In this paper a sampling technique is described, which allows the investigation of the bunch structure sampled over several bunches by means of the synchrotron light.

Measuring system

In the bending magnets of the synchrotron the electron bunches emit synchrotron radiation. The number of the emitted photons is proportional to the number of electrons in the bunch. Since the velocity of electrons is very close to the velocity of light, the time structure of the bunches is very close to the time-structure of the emitted synchrotron-light: by detecting the time-structure of the synchrotron-light the time-structure of the bunches can be measured.

The time structure of synchrotron radiation pulses can be measured by the combination of a mode-locked laser pulse-train and a Kerr-cell driven by the laser pulse train. Mode-locked Nd-glass-lasers e.g.,[2)] emit pulse trains of about 50 to 100 pulses with a pulse-length of 5 to 10 psec and a pulse repetition time of several nsec due to the optical path-length of the laser resonator. The pulses transport a power of several 100 MW up to a few GW. When these pulses enter a Kerr-cell filled with CS_2 they produce a birefringent zone[3]. Since the relaxation time of CS_2 is about 2 psec the birefringent zone travels with the laser pulse at the speed of light. With this set-up a time resolution of 10 psec could be measured[3].

With a system described in an earlier report[3] two kinds of measurements can be done:

a) With a single laser-pulse selected from the pulse train the time structure of a single synchrotron light pulse can be detected. The light-pulse to be measured is widened along the path of the laser pulse in the Kerr-cell. So the light arriving at the Kerr-cell at a certain time can only pass it at the point where the laser pulse is. The time-structure is converted into a local structure which can be photographed.

b) The light to be measured consists of a pulse train of identical pulses. The repetition frequency of the laser pulse is slightly different from the repetition frequency of the pulse-train to be measured. So the unbroadened light-pulses can be detected by a sampling technique.

The second operation mode was chosen, because the technical equipment installed thus far is not capable of selecting one laser-pulse from the pulse train.

In Fig.1 the measuring system is sketched. The visible portion of the synchrotron radiation is separated from the high energy photons by two mirrors. The beam of visible light is compressed by a telescope system and enters the Kerr-cell via first polarizer. A part of the synchrotron light is splitted and detected by photomultiplier 3.

A pulse-train of about 100 laser-pulses is generated in the triangular-type laser-resonator. The distance between two laser-pulses is 94.535 ± 0.02 cm. The laser beam is focused into the interaction region of the two light-beams. Photomultiplier 1 gives a signal when a laser pulse has passed the Kerr-cell and triggers both oscilloscopes and a ramp-generator. Both the signals from PM2 and the ramp-generator are added and can be seen on the oscilloscope. The addition of the ramp-signal to the signal has the following advantage: when the laser emits more than one pulse-train the signals detected by PM2 can be seen at different vertical positions on the scope.

Results

Two typical photographs are shown in Figs. 2 and 3. The time scale is 20 nsec/ division in Fig.2 and 50 nsec/division in Fig.3. The distortion of the picture of Fig.3 is caused by an image converter tube which amplifies the picture of the oscilloscope screen. Without any knowledge of the light to be measured one can say by looking at the photographs that the measured light is not emitted continuously. With a continuously radiating light source no peaks can be measured, for the rise-time of photomultiplier and scope is nearly equal to the pulse-repetition time of the laser-pulse: a continuous envelope of the beam transmitted through the Kerr-cell must be seen. The peaks in the pictures say that the light to be measured has a very pronounced time-structure: after a laser-pulse has coincided with a synchrotron-pulse the following pulses see no light.The coincidence of laser pulse and synchrotron light occurs at defined distances: the light to be measured has a repetitive time-structure.

The beam current at both shots was 8 mA.The energy of the beam was not observed and is therefore unknown.

The bunch-to-bunch distance is expected to be 59.99879 cm, due to the frequency of 449,666 MHz. The distance of the laser-pulses was 94.535 ± 0.02 cm. With these two pulse-distances the real bunch-length can be calculated. In Fig. 4 the peaks of Fig.2 are interpreted. In Fig.5 the bunch is drawn in real-time. The halfwidth of the bunch is 6.7 ± 0.6 cm.

In Fig. 3 the peaks can be explained in a similar way. The translation in real-time can be seen in Fig. 6 . Bunch No. 74 in Fig.6 has a computed distance of 3.52 cm from the assumed bunch-centre, but the peak produced by this bunch is higher than the other peaks. That may be due to bunch 74 transporting more electrons than the bunches before it, but it is also possible that all bunches oscillate in a complicated oscillation mode.

Especially in the last example the disadvantage of the sampling system can be seen. The sampling method works well only when all bunches are equally filled, when they have equal length and when they do not oscillate. Therefore a single-bunch measuring device working similar to a stop-motion-camera will be installed in a few months.

Acknowledgement

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Literature:

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2) R.Fischer and R.Rossmanith: A proposed method of measuring synchrotron-radiation pulses in the picosecond range, DESY-H5/4; Dez. 1969.

3) R.Fischer and R.Rossmanith: A Kerr camera with ten picoseconds Time resolution; Optics Communications No. L.5(1972) 53, and DESY 72/14.

Figure Captures

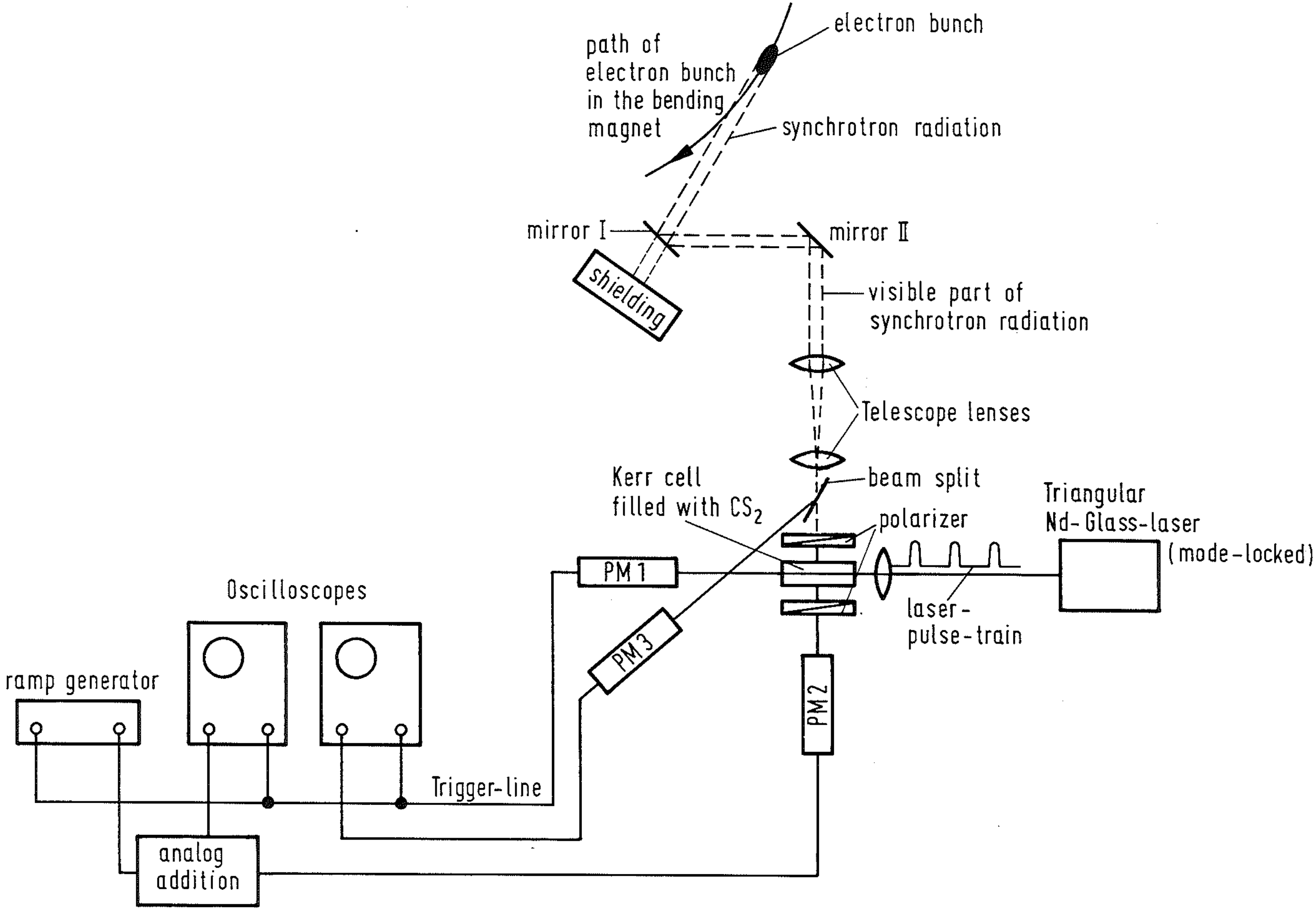

electron bunch
path of
electron bunch
in the bending
magnet
synchrotron radiation
mirror I
mirror II
shielding
visible part of
synchrotron radiation
Telescope lenses
beam split
Kerr cell
filled with CS_2
polarizer
Triangular
Nd-Glass-laser
(mode-locked)
PM1
Oscilloscopes
PM3
laser-
pulse-train
ramp generator
PM2
Trigger-line
analog
addition

fig. 1

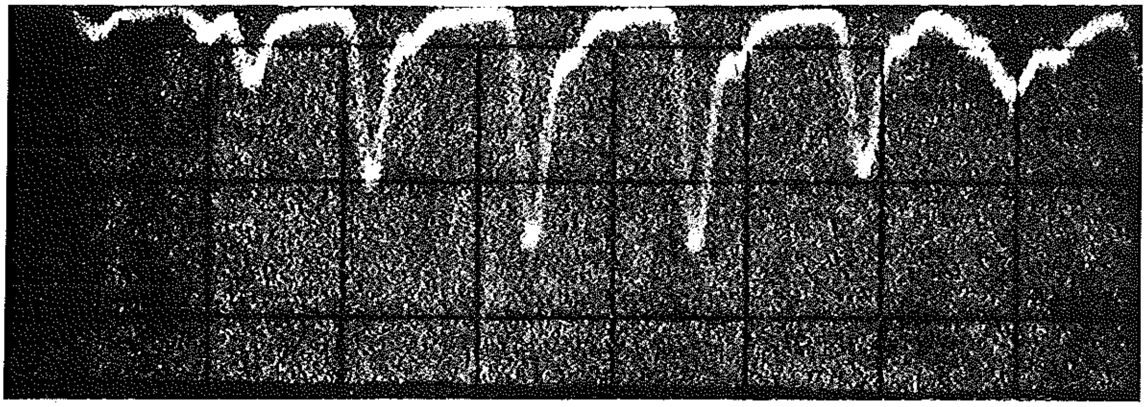


fig. 2

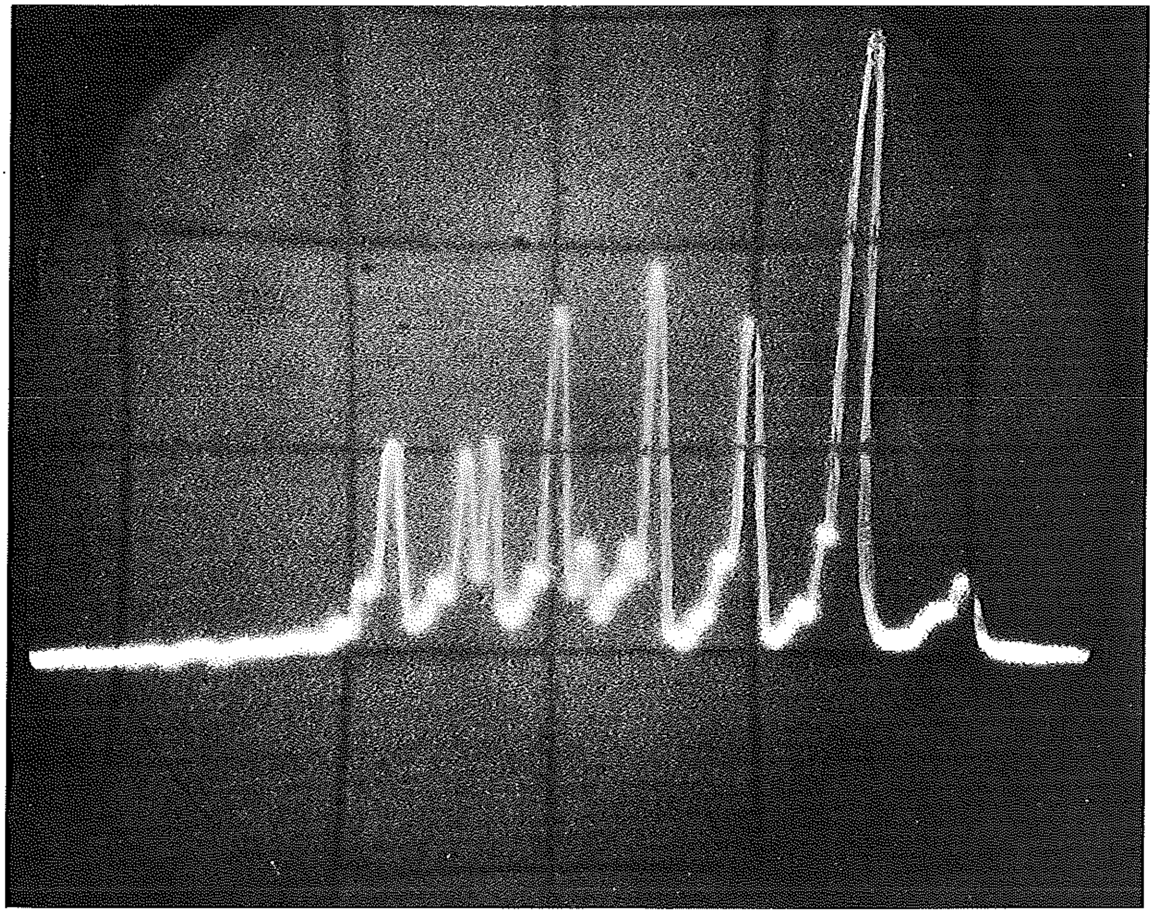


fig. 3

distance between two laser pulses in cm	calculated distance from assumed bunch centre in cm							
94.555	-4.75	4.36	-2.85	-0.95	0.95	2.85	-4.36	4.75
94.535	-4.4	4.67	-2.64	-0.88	0.88	2.64	-4.68	4.4
94.515	-4.05	4.99	-2.43	-0.81	0.81	2.43	-4.99	4.05

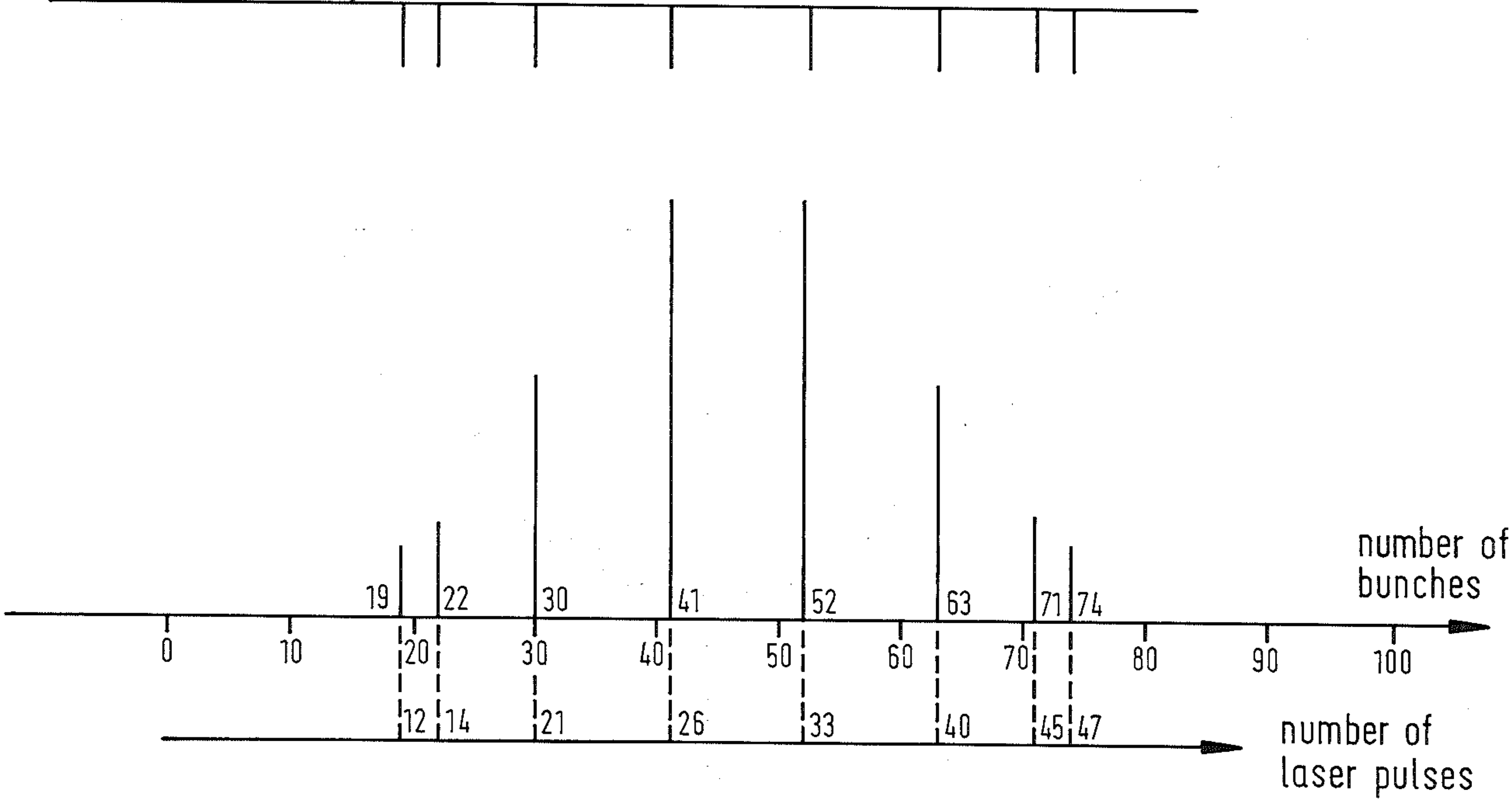


fig. 4

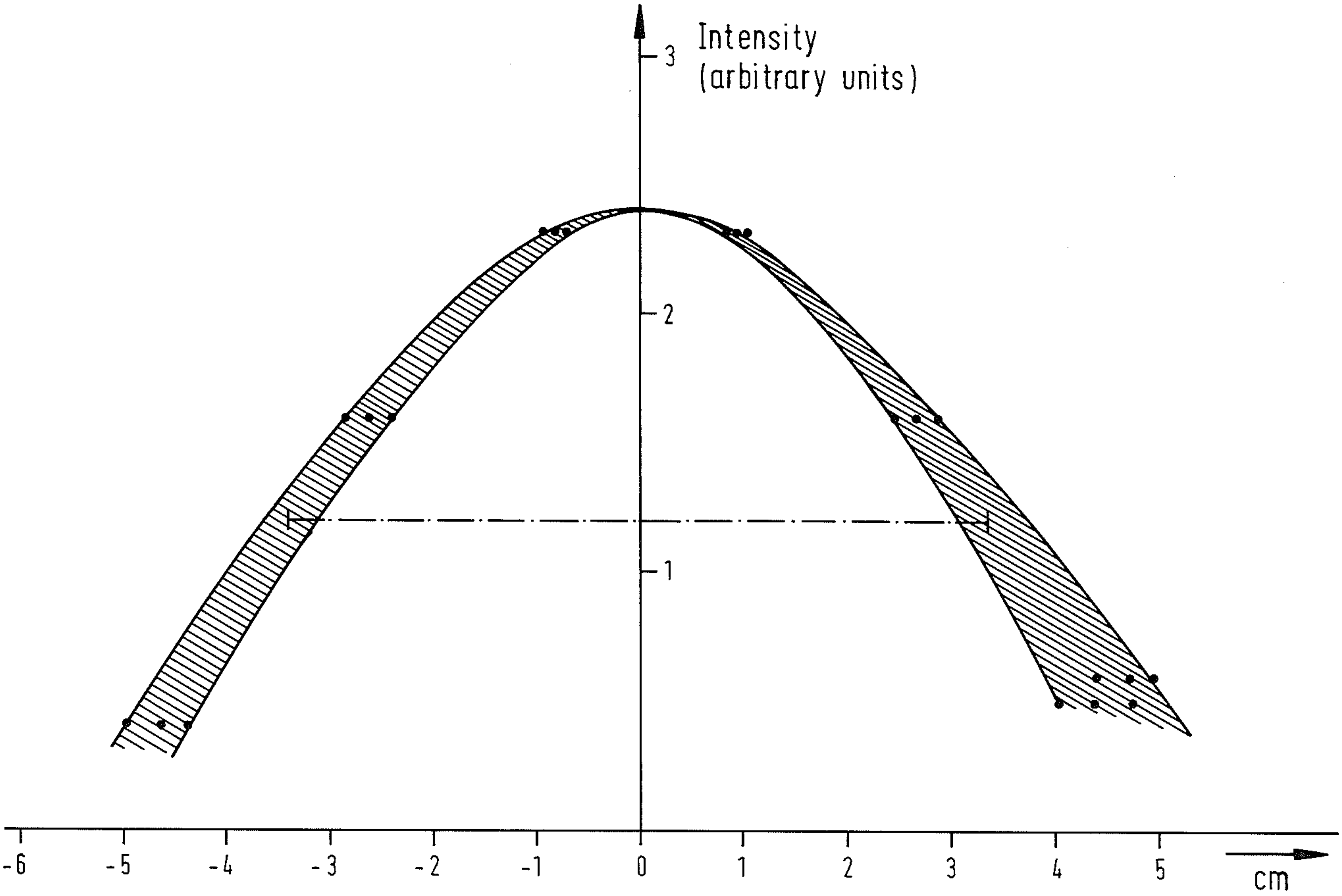
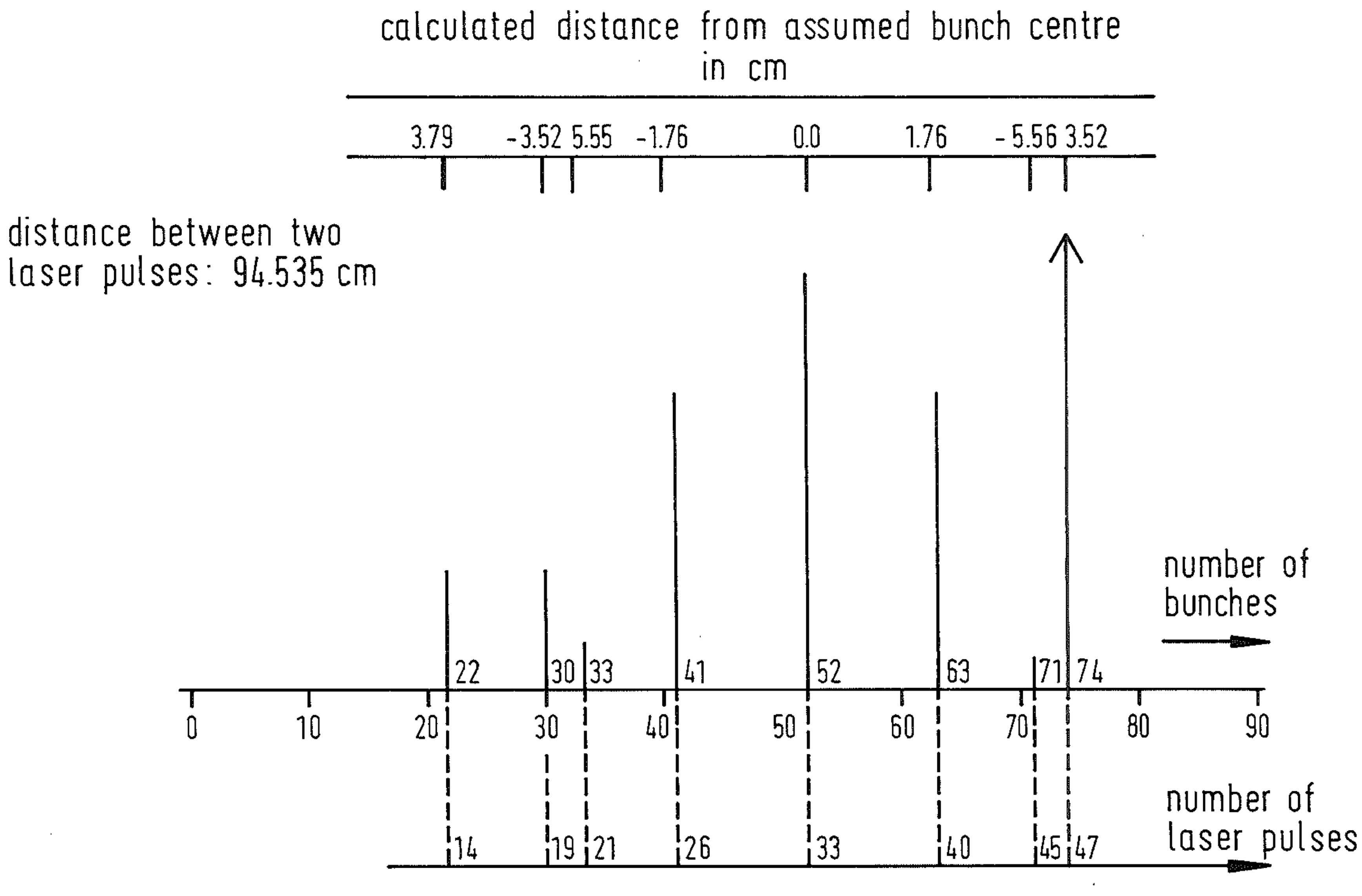


fig. 5



calculated distance from assumed bunch centre
in cm
3.79
-3.52
5.55
-1.76
0.0
1.76
- 5.56
3.52
distance between two
laser pulses: 94.535 cm
number of
bunches
22
30
33
41
52
63
71
74
0
10
20
30
40
50
60
70
80
90
number of
laser pulses
14
19
21
26
33
40
45
47

fig. 6