LS–3
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6 GeV Synchrotron – Survey and Alignment

Introduction

This report will outline briefly alignment problems to be encountered in construction and operation of the six GeV Synchrotron Radiation Facility and proposed solutions to these problems.

The primary problem of alignment in the 6 GeV Synchrotron light source is to insure that synchrotron light from undulators, wigglers and bending magnets is aimed at the detectors mounted around the periphery of the machine. All users must be able to optimize each of the many wiggler and undulator systems operating simultaneously without disturbing any of the others. The facility must be easy to turn on and use, as beam time would be densely scheduled.

At present it seems that these requirements can be met with existing technology. Surveying systems already developed for accelerators should be adequate, when combined with beam position control systems. These surveying systems generally have measurement errors around 0.1 mm, however measurements can be made to an accuracy greater than this if desired.[1,2,3] Specific techniques proposed for alignment of the European Synchrotron Radiation Facility could be used in the present design.[4]

Position control systems useful for controlling the position of the equilibrium orbit have likewise been studied in detail for many accelerators.[5] These techniques are directly applicable to problems of alignment of beams in wigglers and undulators.

Problems of Alignment

After the machine is initially assembled (using systems described below), the primary difficulty associated with alignment of the 6 GeV Synchrotron light source will be to insure that each user has independent control of the beam position and direction over that part of the circumference which affects a particular experiment. Since experiments will be performed using a wide variety of apparatus of widely varying sensitivities, it is important that experimenters should not be able to disturb each other, less critical users, for example, changing conditions on more critical users.

Alignment tolerances are set, to first order, by the emittance of the electron beam, machine properties and the dimensions of the experimental apparatus. Typical experiments might be 50 meters away from an undulator which was utilizing a beam with an emittance of $\sim 1 \times 10^{-8}$ m. Assuming beta functions of 0.4–30m, the beam dimensions will be in the range 0.06 mm to 0.55 mm. Collimator systems could thus be expected to define photon emittances on the order of 0.1 –0.01 ε_e.

These constraints, while severe, are further complicated by the mutual interactions of users and interactions with the outside environment, which includes ground motion due to natural and artificial causes.

The effects of ground motion have been reviewed by Fischer, as part of the recent Fermilab Accelerator School.[6] Ground motion causes quads to be displaced, which in turn bend the beam by an amount

$$\Delta x' = g\ \ell\ \delta x/\beta\varrho$$

where gl is the quadrupole gradient and length, δx is the quad displacement, and $\beta\varrho$ is the rigidity of the beam. In general a random displacement of N quadrupoles in a machine will cause a displacement of the beam at location 1 by an amount

$$\delta y_1 = \frac{\langle\delta x_{rms}\rangle\ \sqrt{\beta_{av}\beta_1}\ \sqrt{N}\ g\ell/B\varrho}{2\sqrt{2}\ \mathrm{Sin}\ \pi\ Q}$$

where $\langle\delta x_{rms}\rangle$ is the average displacement, $\beta_{av}\beta$ are the beta functions at quadrupoles and location 1, and Q is the betatron tune. Assuming 1 μm vibrations due to ground motion, vacuum pumps, air conditioning etc, with N = 288, β_{av} = 15 m, β_1, = 30 m, $|g\ell/B\varrho| \cong 0.5$, and Q = 34.3, beam deflection will be of the order

$$\delta y \cong 1.10^{-6}\frac{\sqrt{15 \times 30}\ \sqrt{288}\ 0.5}{2\sqrt{2}\ |\mathrm{Sin}\ \pi\ 34.3|} \cong 80\ \mu\mathrm{m},$$

which is a small fraction of the expected width of the beam at this point, $\sqrt{\beta\varepsilon} = \sqrt{30 \times 10}^{-8}$ = 550 μm. One can, however, expect users to demand greater stability than this.

Although ground motion can be as large as 1μm at some frequencies, natural vibration tends to occur at low enough frequencies (~0.14 Hz) that a machine the size of the 6 GeV light source would move as a whole. Higher frequency (cultural) noise can be damped out locally at the source or machine components can be isolated. The remaining vibrations and beam deflections can be damped with the orbit control system described below.

Possible Surveying Methods

Since the primary purpose of alignment systems is to insure the relative orientation of beams with respect to experimental apparatus, it seems natural to survey both the beamlines and storage ring from the same monuments, using techniques which can be used during all stages of machine operations. One possible system would be that shown in Fig. 1a. Monuments external to the ring would be used to define beamline directions using extrapolation, and locations of insertion devices using interpolation. Monuments would be ~ 24 m apart and could be placed in position using laser interferometers and Fresnel optics, as shown in Fig. 1b. The secondary

survey monuments for beam lines could be surveyed and maintained using a system shown in Fig. 1c. In principle, monument position could be measured with errors of <10μm, if necessary, much less than the 0.1 mm tolerances obtained, for example, at CERN[1], however thermal fluctuations, mechanical settling and other effects will require correction to insure component accuracy at this level. Mechanical corrections and resurveys might be done at regular intervals, however position accuracy better than 0.1 mm should not be required since most of the corrections could be done using the beam–steering system.

Orbit Correction System

Since the 6 GeV light source will require a very good orbit correction system, it is desirable to examine the system in some detail, as it interacts with, and may in some cases replace, many other systems commonly included in accelerator facilities. For example, beam perturbations at user request may be larger than those due to low frequency mechanical vibration, settling, thermal motion of components, magnet power supply drifts, etc. Thus, there may be cost savings possible by designing the orbit correction system required by users first, and removing redundant precision from associated components, if this is possible.

In order that x, x', y, and y' are independently adjustable at each insertion region, trim magnets must be placed upstream and downstream of the insertion regions. These trim magnets will steer the beam in the desired direction (upstream) and return the beam to its original orbit (downstream). Ideally one would like two magnets in each plane at each end of the insertion region with phase shifts of $\sim 90°$ between magnets bending in the same plane. In order to minimize orbit distortions around the ring these trim magnets should be as close as possible to the insertion region, however the horizontal and vertical phase advance of the lattice sets a limit to how compact these systems can be. This phase advance is shown in Fig. 2 for an example lattice. Sample orbit correction systems based on the lattice and trim magnets in Fig. 2 are shown in Fig. 3. These systems assume one correction magnet would be located at each end of the insertion regions and another bending magnet would be located roughly $\psi = \pi/2$ up or downstream. In principle the large bending magnets could be utilized, although in practice this may be difficult, as low inductance magnets would be desirable.

The system described in Fig. 3 should be capable of satisfying the requirements for user control of the x–ray beam with a minimum of interactions with other users. Specific design details can be worked out as needed. The present report has not covered frequency response, magnet or power supply design or diagnostic systems, although we have assumed that user diagnostics and beam monitors would probably be of sufficient accuracy to control the beam position. The engineering details should be straightforward, however, and will be covered as other details of the design converge.

Multiple Beam Lines from Undulators and Wigglers

As control over the local position and direction of the electron beam in the light source could lie with experimenters, it is desirable to look at other possible benefits of this system. One

potentially useful option is to enable users to make major changes in the direction of the electron beam to move photon beams from one piece of apparatus to another as shown in Fig. 4. The perturbation in the closed orbit required to do this depends on the conscruction of the users apparatus and the distance of this apparatus from the machine. Displacements of ΔX of 15–30 cm at 50 m would seem to be useful, and may be possible. Large angular displacements of the electron beam would complicate the chromaticity correction in the straight sections, however it should be possible to make the required adjustments with quadrupoles. Reasonable limits to the amount of motion that could be tolerated are being studied.

Conclusions

It should be possible to solve alignment problems with existing technology. The limits on user control of the equilibrium orbit should be studied in more detail.

References

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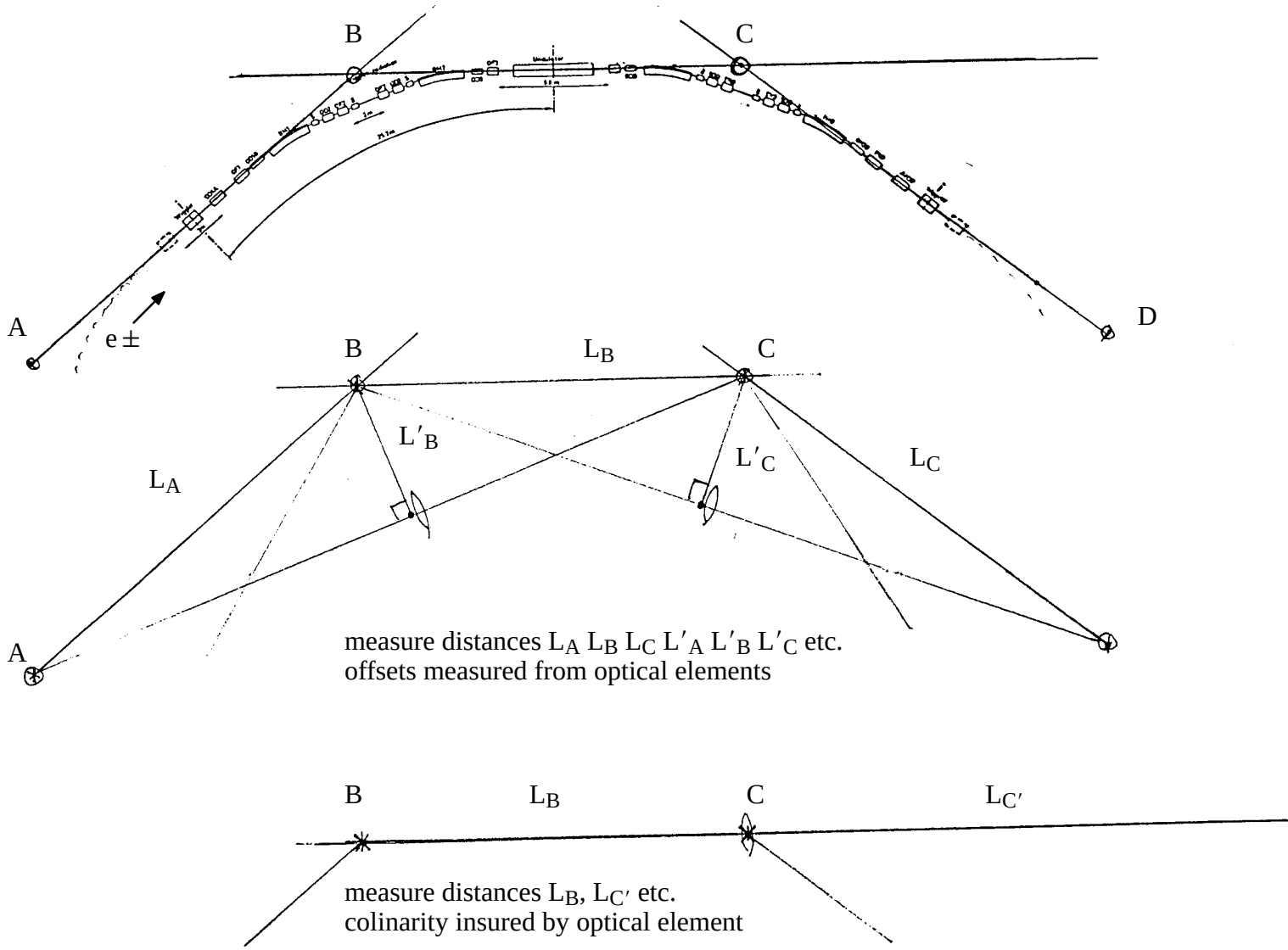
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Fig. 1

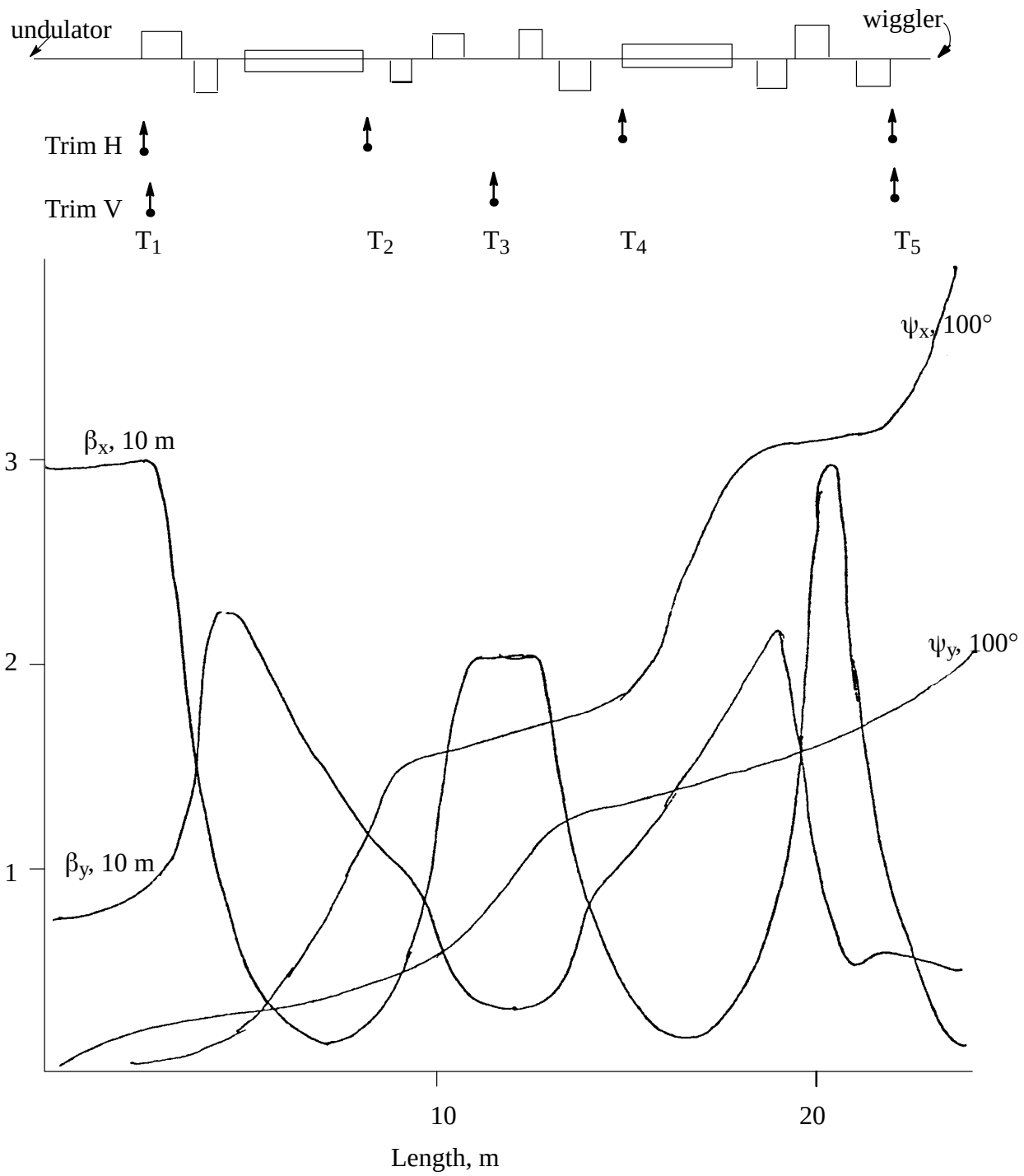
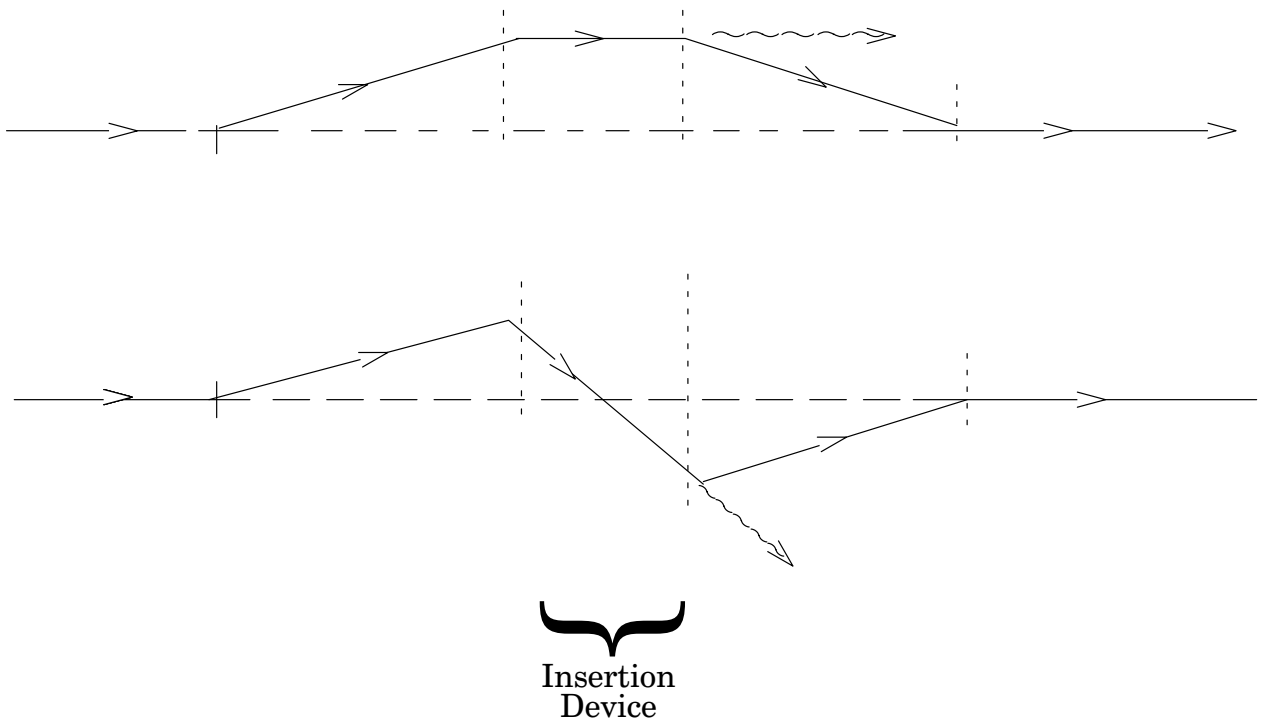


Fig. 2 Example lattice with phase advance and trim magnet locations.



Trim Magnet Settings (kG – m)

Deflection	T_1	T_2	T_3	T_4	T_5
x_u = 10 mm	0.053	0.29	0.0	0.0	0.0
x_u'	−0.57	0.24	0.0	0.0	0.0
x_w = 10 mm	0.0	0.0	0.0	0.66	1.51
x_w'	0.0	0.0	0.0	0.33	0.0
y_u = 10 mm	−0.019	0.0	0.46	0.0	0.0
y_u'	−0.62	0.0	0.40	0.0	0.0
y_w = 10 mm	0.0	0.0	0.5	0.0	0.11
y_w'	0.0	0.0	0.21	0.0	0.48

Fig. 3 Orbit Correction System

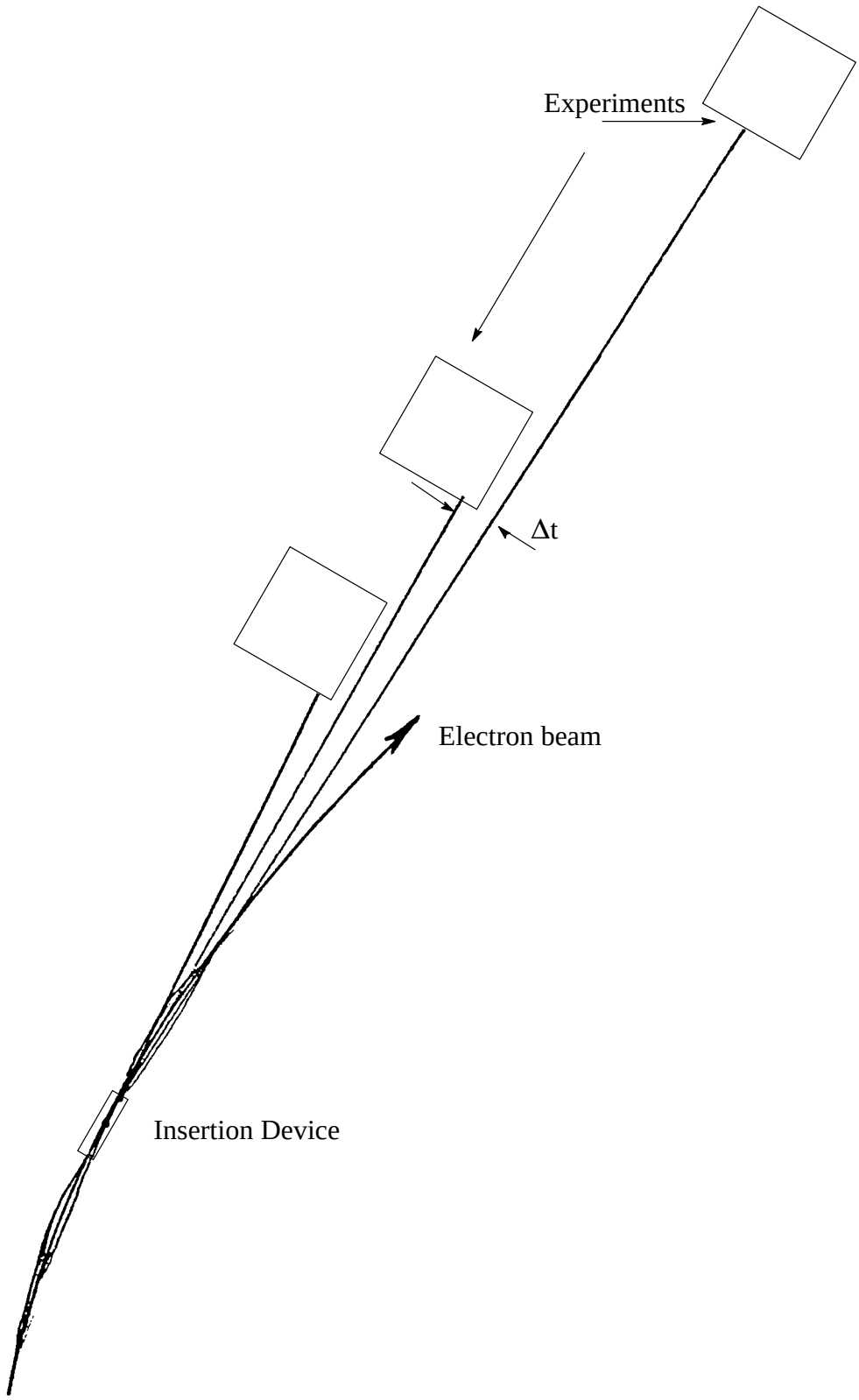


Fig. 4 Multiple Beam Line