Chapter 1

Introduction

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Femtosecond beam science consists of the generation, measurement and application of a variety of ultrashort beams. Synchronized femtosecond beams are used to visualize ultrafast microscopic phenomena. The science is also applied to advanced compact radio frequency (RF) accelerators.

Chapter 2 covers femtosecond beam generation. Femtosecond laser pulses are produced by chirped pulse compression. Analogous magnetic bunch compression of electrons generates a femtosecond electron beam in high quality linear accelerators (linacs). In synchrotrons, femtosecond electron/synchrotron radiation (SR) pulses are produced by slicing with a wiggler and femtosecond laser. Momentum compaction control and strong longitudinal focusing can realize femtosecond electron and SR pulses. Femtosecond and picosecond hard X-ray pulses can be produced by compact systems based on terawatt (TW) laser–plasma interaction and inverse Compton scattering between short electron and laser beams. The configuration of a femtosecond beam generation system and the relevant physics is depicted in Fig. 1.1. Large intense X-ray free electron lasers and energy recovery light sources are in development. Tabletop TW lasers have recently enabled the generation of several kinds of ultrashort beams from laser–plasma, as schematically shown in Fig. 1.2. Laser plasma cathodes can produce femtosecond electron beams. Picosecond ion, THz radiation and positron pulses can also be generated via the TW laser–gas/cluster/solid

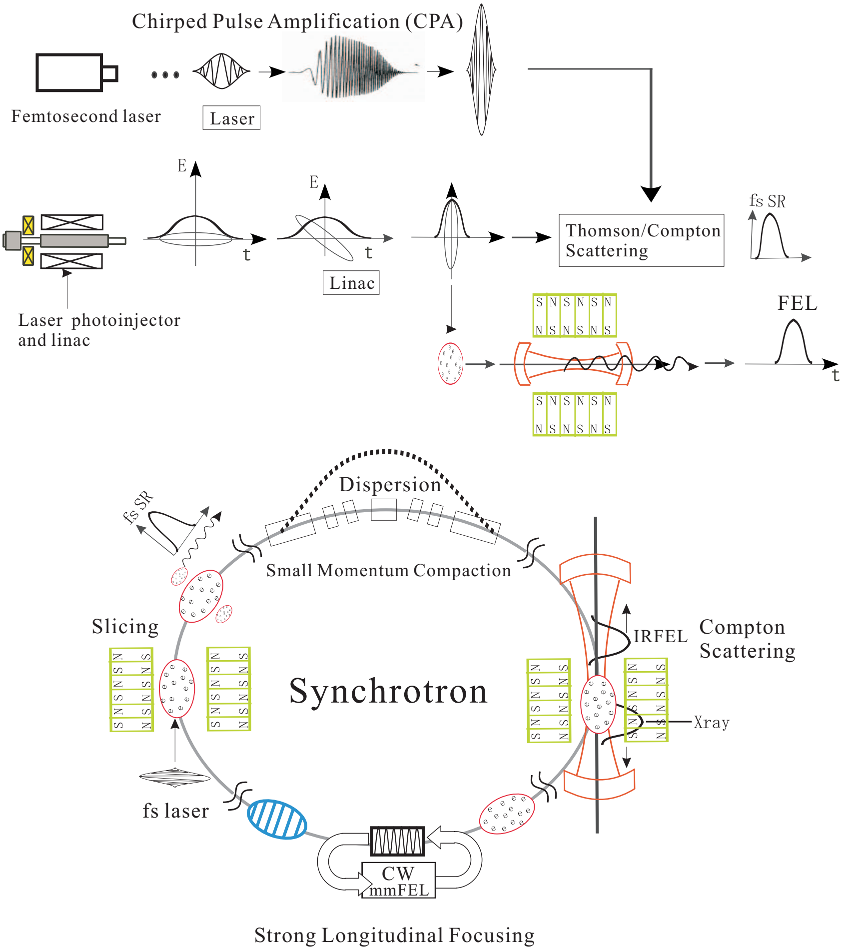

Fig. 1.1 Femtosecond particle beam generated by femtosecond laser in a particle accelerator.

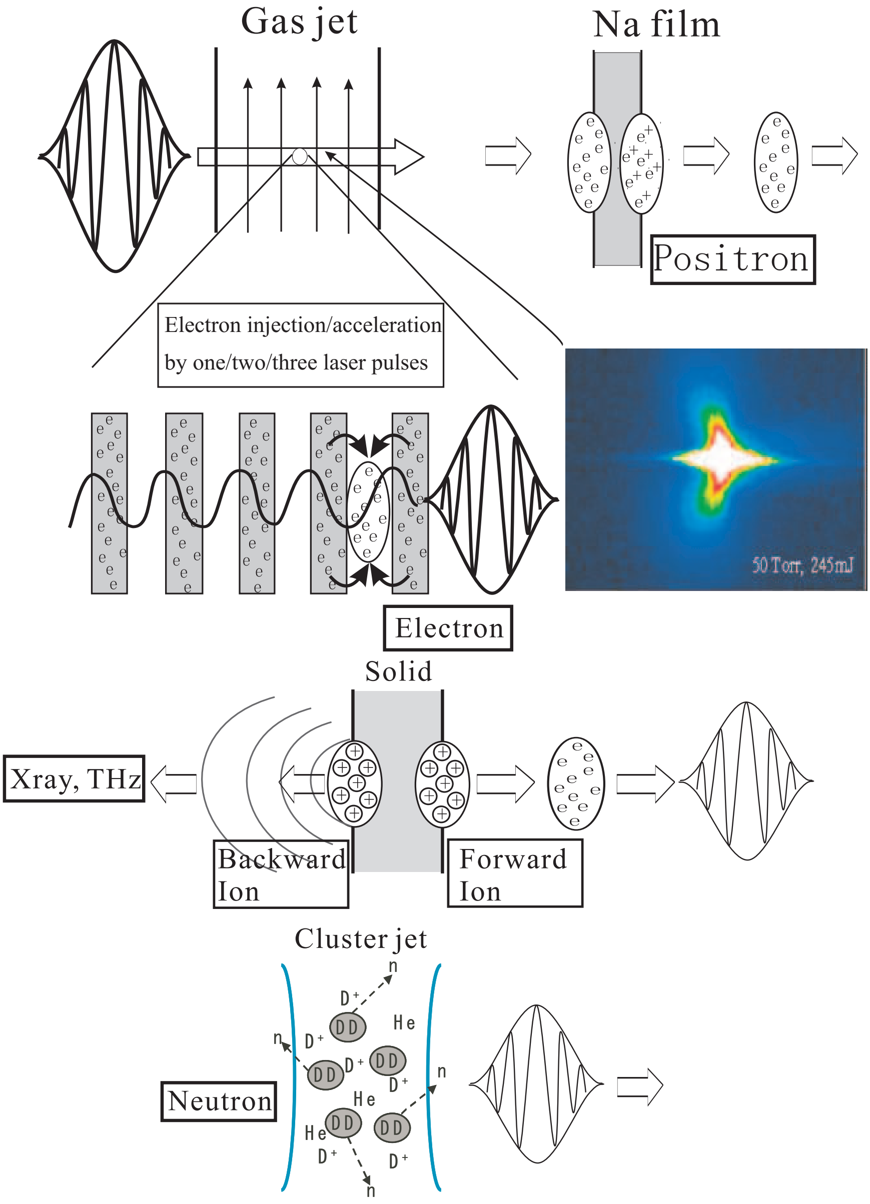

Fig. 1.2 Laser–plasma beam generation schemes for electron, ion, X-ray, THz radiation, neutron and positron pulses.

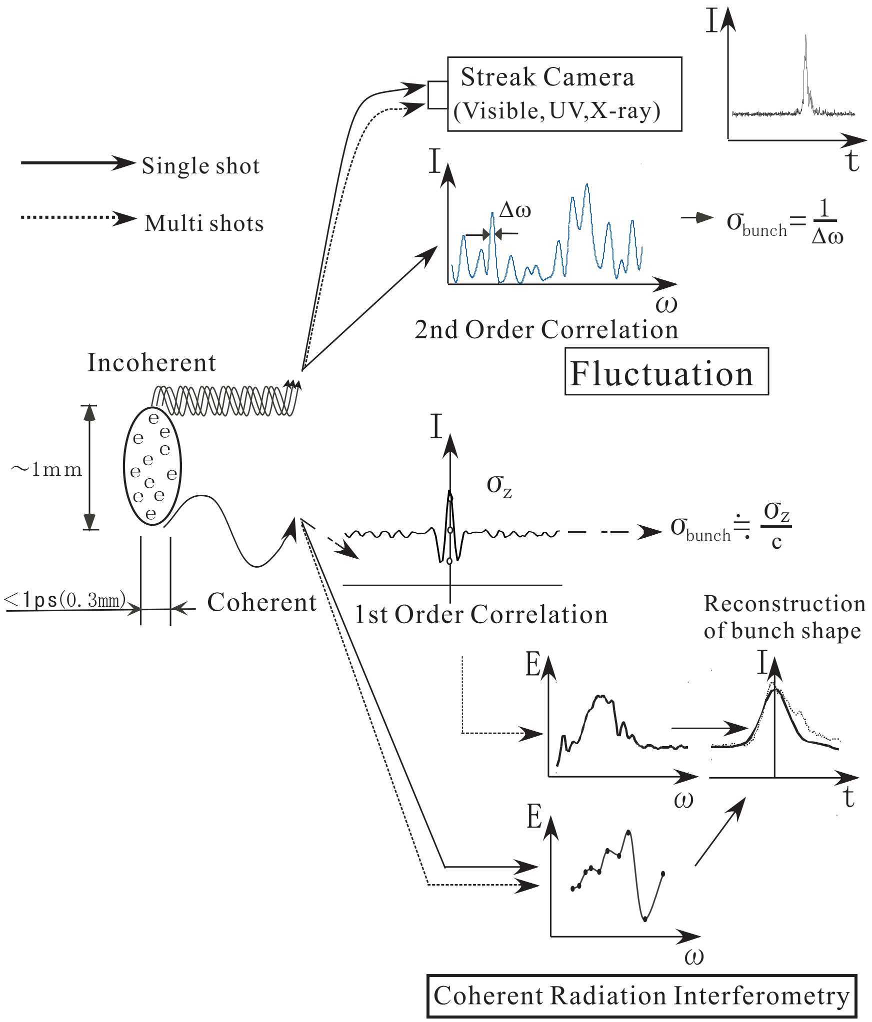

Fig. 1.3 Diagnostic methodologies of femtosecond electron beams.

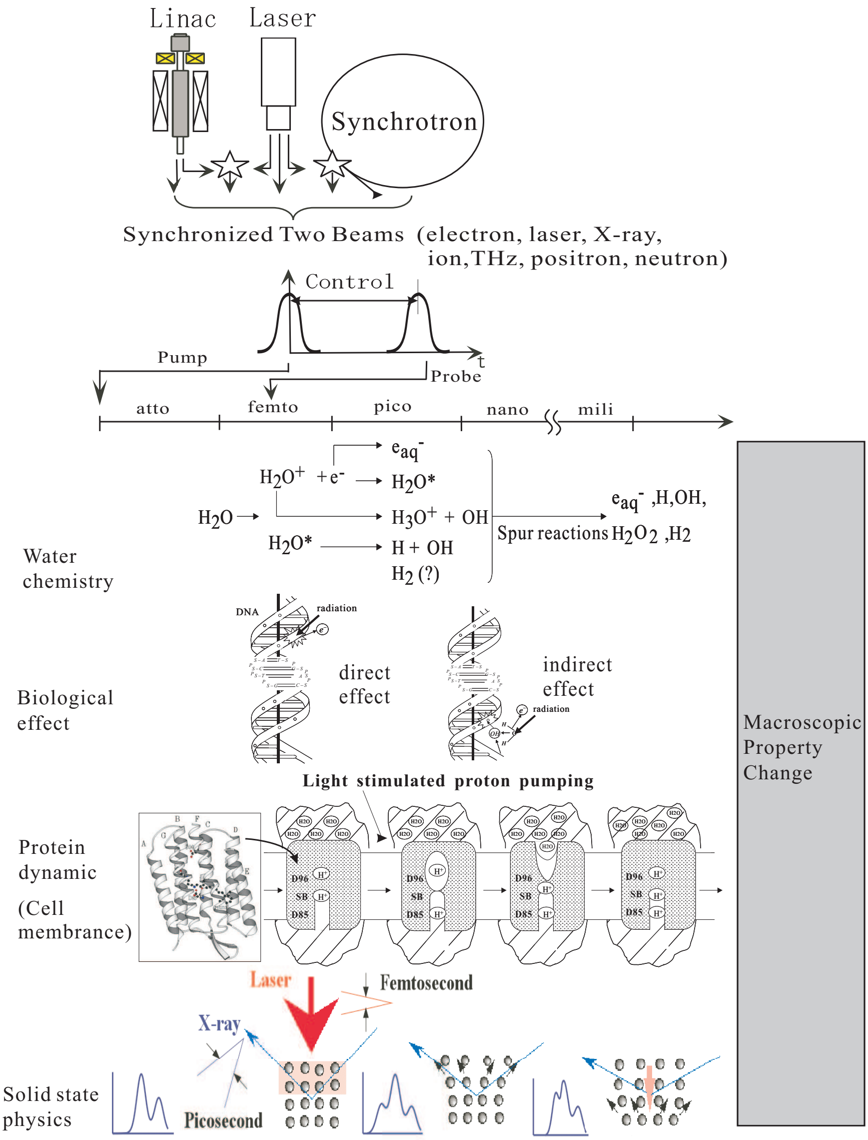

Fig. 1.4 Applications of femtosecond beam pump-and-probe analysis.

interaction. The TW laser–D_2 cluster interaction initiates nuclear fusion and yields picosecond neutron pulses.

The major diagnostic methodologies for femtosecond radiation and electron beams are explained in detail in Chapter 3. The physics of these methodologies is depicted in Fig. 1.3. An overall comparison among the methodologies for electron beam diagnosis is given. A newly developed jitter free X-ray streak camera using a GaAs optical switch is described. Several new promising ideas are also referenced. Details of a synchronization system between femtosecond lasers, linacs and synchrotrons are given. This system consists of an RF control system, timing stabilizer, passive mode-locked laser, RF amplifier and linac. Timing jitter between laser and electron pulses, the sources used in the system and the method of suppression are described. The influence of the environment, such as temperature, humidity, laser transport line, dust, etc., is discussed. New synchronization schemes and advances are also described.

The applications of femtosecond beams are summarized in Chapter 4. In pump-and-probe analysis with two synchronized beams, the pump pulse induces a reaction and the delayed probe pulse extracts a signal of the state at specified time steps. This is summarized in Fig. 1.4. State-of-the-art pulse radiolysis systems for radiation chemistry using synchronized femtosecond lasers and linacs (including the use of laser photocathode RF guns) and recent results are described. Recently, X-ray pulses have been used as probe pulses in time-resolved X-ray diffraction. Laser plasma X-ray sources and SR have also been used. Phonons, thermal expansion and shock wave propagation in semiconductors have been visualized by pump-and-probe analysis using laser plasma X-ray sources and third generation synchrotron light sources. Furthermore, time-resolved Laue diffraction analysis of phase transitions and fast motion of photoactive proteins is under way at third generation synchrotron light source facilities, which will lead on to future experiments with fourth-generation synchrotron light sources. Femtosecond intense lasers are being used to develop a new chemistry in intense laser fields. Finally, computer simulations of ultrafast microscopic phenomena are described.