March 1997
FERMILAB-PROPOSAL-0886

E-886 (Melissinos) Compton Scattering X-Ray Experiments at the Fermilab Electron Source Facility

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Status: *No Data Yet*

We propose to use the intense electron source that is being built at Fermilab to generate x-ray pulses with picosecond time resolution and with tunable wavelength in the range 2A < λ < 50A. The x-rays are produced by backscattering an infrared (IR) laser pulse, λ = 1054 nm, from the pulsed electron beam. The same laser pulse, but after quadrupling to the UV (λ = 263 nm), is used to excite the photocathode and thus generate the electron beam. Consequently the laser and the electron beam have the same time-structure and can be kept synchronized. Initially we plan to use pulses with 10 ps FWHM.

The x-ray energy in the forward direction is given by

$$E_X = 4\gamma^2\hbar\,\omega_0$$

where $\gamma = E_0/mc^2$ is the γ-factor of the electron beam and ω_0 the laser frequency. The x-ray energy can be selected by adjusting the electron beam energy, or by moving to larger scattering angles. Using the parameters shown in Table I, the x-ray rate is found to be 5.4×10^{-5} x-rays/e^-; the x-ray spectrum is shown in Figure 1(a) whereas Figure 1(b) gives the dependence of the x-ray energy on the scattering angle. The electron beam will contain 5×10^{10} e^-/pulse (8nC) and there will be 1000 pulses in a 1 ms macropulse. Initially the macropulse repetition rate will be 1 Hz but could be increased later. For a 10% acceptance in x-ray energy ($\Delta E_X/E_X = 0.1$) the usable flux is 2.7×10^8 x-rays/s.

Table I. Parameters Used to Calculate the Backscattered X-Ray Flux

Electron Beam	
Energy	18 MeV
Bunch length (FWHM)	10 ps
Beam radius ($\sigma_x = \sigma_y$)	6.0 μm
Laser Beam	
Wavelength	1.054 μm
Energy	500 μJ
Pulse width (FWHM)	10 ps
f/D of lens	12.0
Total Rate	5.4×10^{-5} photons/e^-

A layout of the electron source, laser-electron interaction region and of the x-ray target chamber is presented in the schematic diagram of the electron source facility. A portion of the laser beam is transported to the target chamber so that pump-probe experiments can be carried out. The IR beam has a 1-micron diameter at the 1σ intensity point and collides with the electrons at an angle of 3°. Finally we note that the x-ray energy spans the "water window" ($20 < \lambda < 50A$) and is therefore suitable for the study of biological samples.

One interesting application involves the investigation of the dynamics of heme proteins. Deterministic protein motion has been observed in the heme proteins hemoglobin and myoglobin[1]. In myoglobin, a polypeptide helix is folded around a heme group, (an iron atom in a porphyrin ring) and several ligands cross-link the helix. Hemoglobin is a tetramer composed of four units structurally similar to myoglobin. After ligand photodissociation (with a green laser pulse), deoxy-myoglobin undergoes a ball-and-socket motion in <10 ps with a displacement of about 6A, inferred from phase-grating studies. This vibrational energy is quickly dissipated to the surrounding aqueous environment. A pump-probe experiment using the unconverted green laser light and the picosecond x-ray source would contribute to the understanding of the dynamics of vibrational energy relaxation of macromoleculcules. A distinct advantage of the laser backscattered x-ray source is the easy availability of circular polarization; this can be used to explore condensed matter structures with specific helicity.

The backscattered x-rays are incoherent and are spread over a continuous spectrum. If, however, the electrons are scattered not from a single laser focus but from a longitudinal standing wave of sufficient field strength, they can radiate coherently at $E_X = 2\gamma^2\hbar\,\omega_0$. This is the same principle as for the free electron laser except that the undulator is now optical rather than a macroscopic magnetic field. One deals with a single pass FEL so that spontaneous start up from noise must be considered. It should be noted that the required emittance for this technique may be prohibitively small. However, improvements in beam transport and generation may make this an attractive approach.

The required field strength is of order B = 1 T or $E = 3\times10^6$ V/cm at λ = 1054 nm. For a 1 m long undulator of cross sectional area 5 mm^2 the energy stored in the cavity is 4 J. This can be supplied by the "slab" amplifier used in the laser drive system. To keep the fluence on the cavity mirrors below 10 J/cm^2 it is neceseary to enlarge the beam area by a factor of ten at the mirrors. The length of the two counter-propagating laser pulses will be 6 ns, that is, twice the cavity length.

Initially we will use a single laser pulse (at 1 Hz) in order to observe this coherent radiation process. Eventually the laser pulse rate, or the storage time in the cavity can be increased to accommodate the entire pulse train. If the optical undulator results in coherent radiation, it could be used in conjunction with much higher energy electrons to produce coherent high energy sources.

It is worthwhile to note that coherent x-ray sources can be used for future investigations of plasma beatwave or laser wakefield excitation of plasma waves in a solid-state accelerator, although high peak powers and sub-picosecond pulses would be then needed.

References

1. R. J. Dwayne Miller, Accounts of Chemical Research 27, 145 (1994); R. J. Dwayne Miller, Ann. Rev. Phys. Chemistry, 42, 581 (1991).

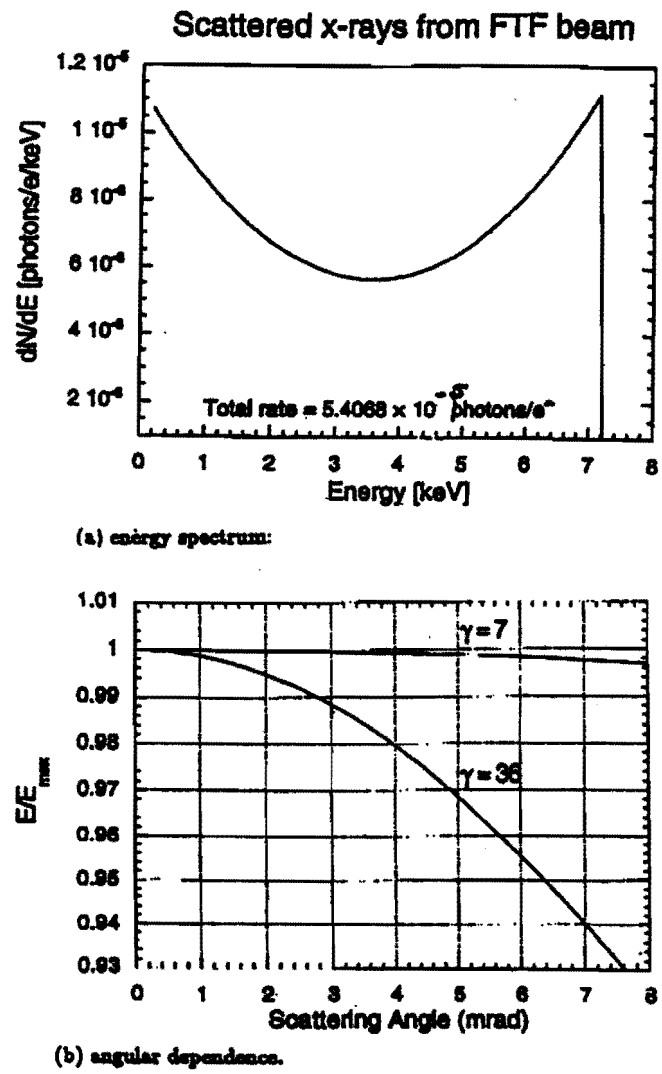

Figure 1. Yield of backscattered x-rays from the Fermilab Bright Electron Source (BES).

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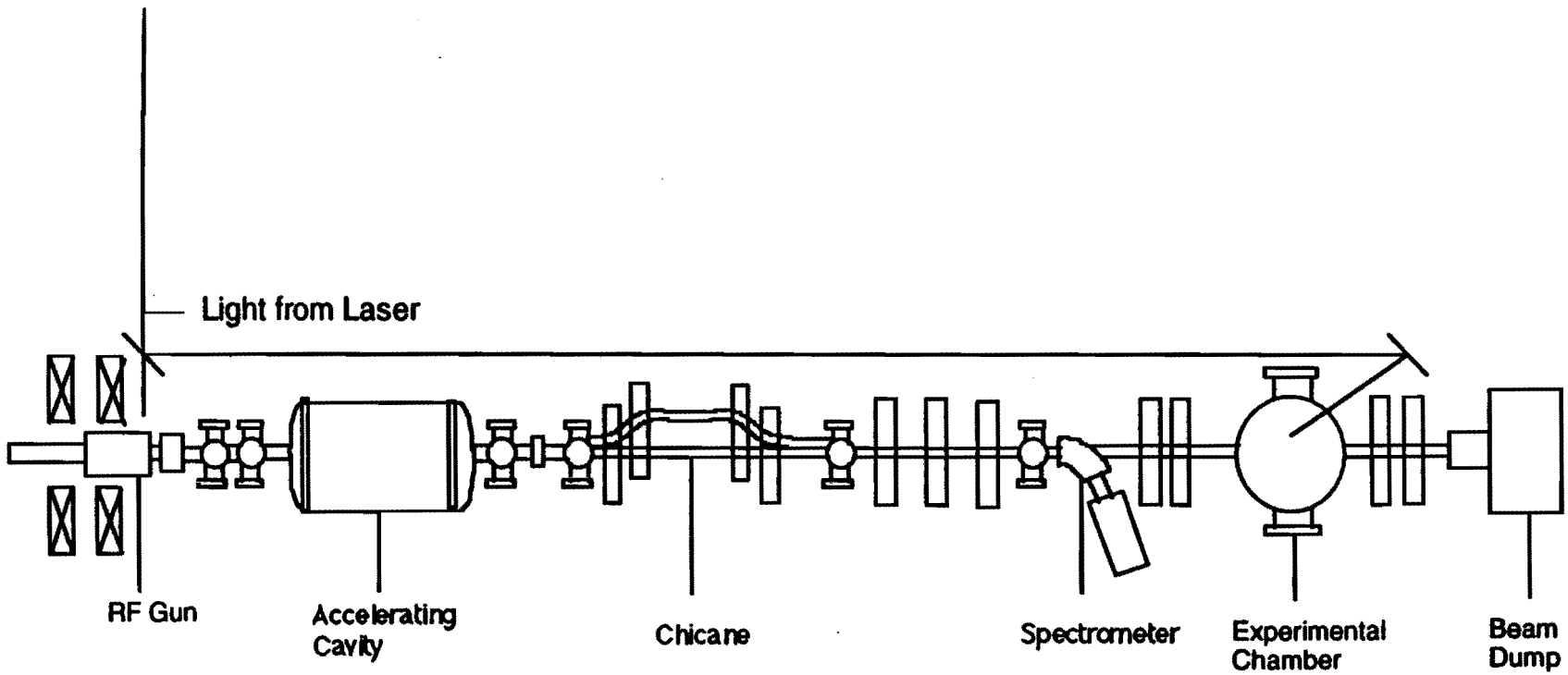

Schematic diagram of the electron source facility. A laser-driven photocathode produces short electron bunches which are accelerated by a superconducting cavity. A magnetic chicane is used to compress the bunches longitudinally, which are then focussed into the experimental chamber.

#	886
Title	Compton Scattering X-Ray Experiments at the Fermilab Electron Source Facility
Short Title	Picosecond X-Ray Source
Spokesperson(s)	Melissinos, A.
Status	Approved
Beamline	A0 Facility
Date Submitted	May 14, 1996
Date Approved	October 8, 1996

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