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Observation of Thomson Backscattered X-rays at 450 eV in the NRL Laser Synchrotron Source Experiment *

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Objectives

- **To demonstrate Thomson backscattering of laser photons from a relativistic electron beam.**

  -- Laser photons derived from a Nd:glass laser.

  -- Electron beam derived from an RF electron gun.

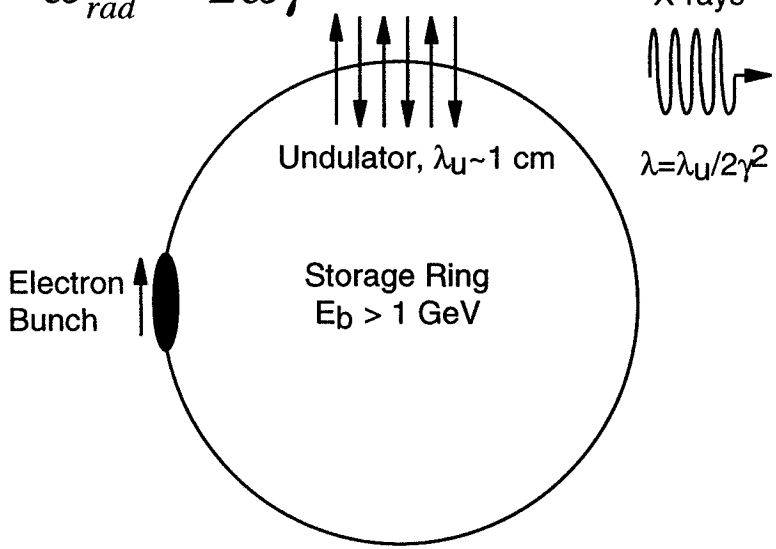
  -- LSS x-ray photon energy ~ 450 - 900eV (~ 13 - 27 Å).

  -- Total X-ray flux ~10^8 ($\Delta\lambda/\lambda$) photons/pulse.

Synchrotron Radiation

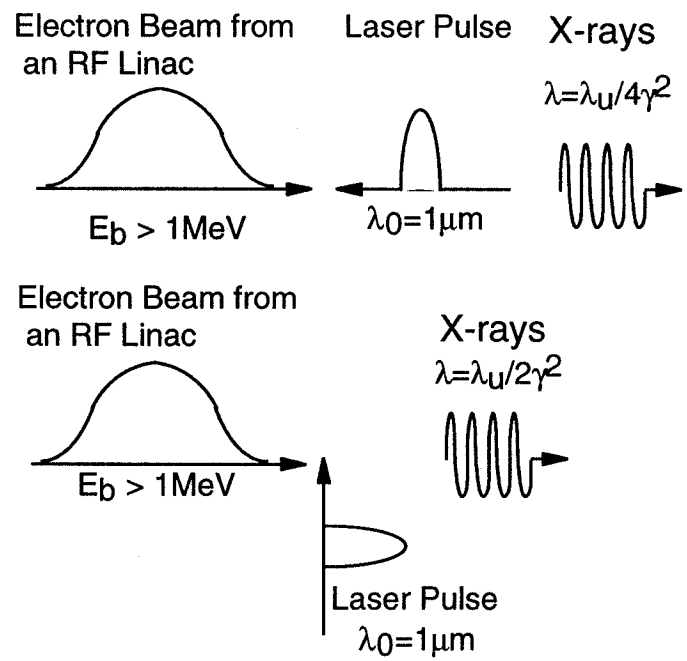
Conventional Synchrotron

$$\omega_{rad} = 2\omega\gamma^2$$



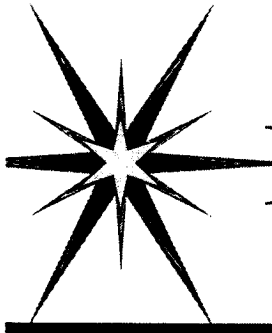
LSS

$$\omega_{rad} = \omega\gamma^2(1-\beta\cos\theta)(1+\beta)$$



Example to produce 30 keV x-rays

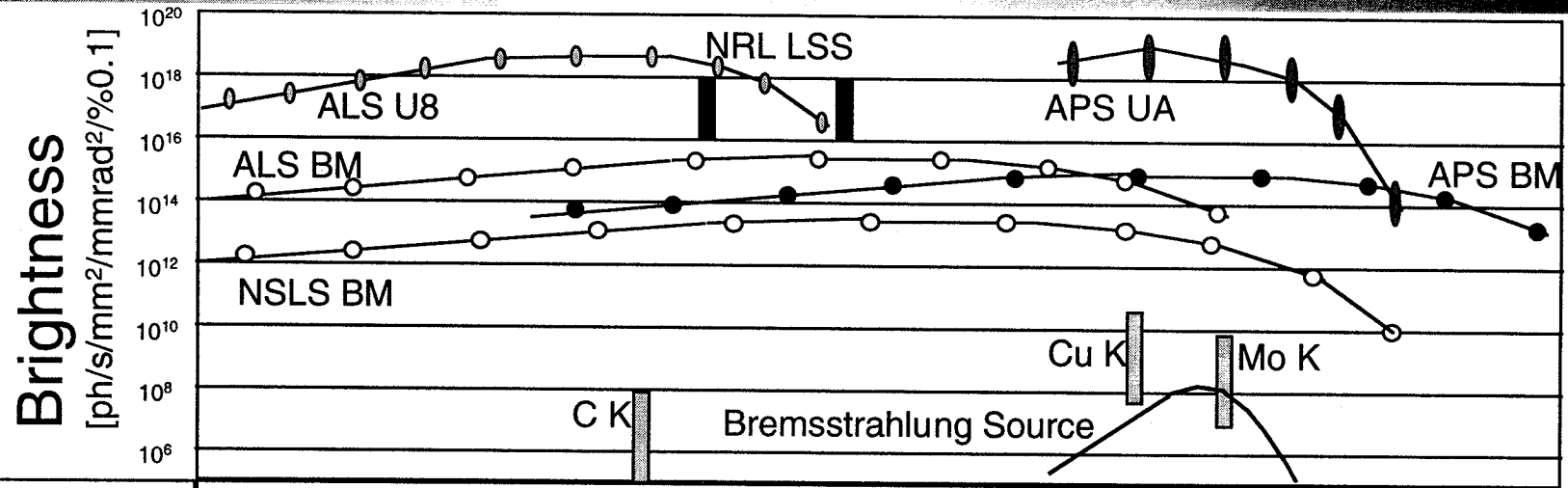
Energy	
λ = 4 cm E_b = 12GeV	λ = 1 μm E_b = 40 MeV
Pulse Duration (micropulses)	
τ > 1ps	τ =1ps-100 fs
Intrinsic Bandwidth	
Δω/ω=1/N=1/100=1%	Δω/ω=1/N=1/100 to 1/10000 =1% to 0.01%



LSS Characteristics

- High Brightness (Spectral Brightness $>10^{18}$ [$s^{-1}\,mm^{-2}\,mrad^{-2}$, $\delta\omega/\omega=0.1\%$])
- Near Monochromatic (less than 1% Bandwidth)
  - Bandwidth is a function of number of undulation periods, beam focusing, beam emittance, and energy dispersion.
- Tunable
  - By selection of beam energy, interaction angle and laser wave length.
- Short Pulse (Through Beam Interaction time <1ps)
- Arbitrary Polarization (by laser polarization)
- Well Collimated ($\theta < 10$ mrad)
- Compact (Laboratory or Hospital Sized and Costs < $ 500 K)

Playing Field



Applications	H_2O Window; Mammography; Angiography
K edge Absorption	Li; Be B; C N; O; Na; P; Cu; Mo; I
Energy [eV]	10; 100; 1000; 10K; 100K
Wavelength [m]	10^{-7}; 10^{-8}; 10^{-9}; 10^{-10}; 10^{-11}
Wavelength [Å]	10^{3}; 10^{2}; 10^{1}; 10^{0}; 10^{-1}

Approach

- Construction of a 4.5 MeV RF gun.
- Construction of a Nd:glass laser.
- Thomson backscattering of laser photons from the electron beam.
- Characterization of the Thomson backscattered x-rays.

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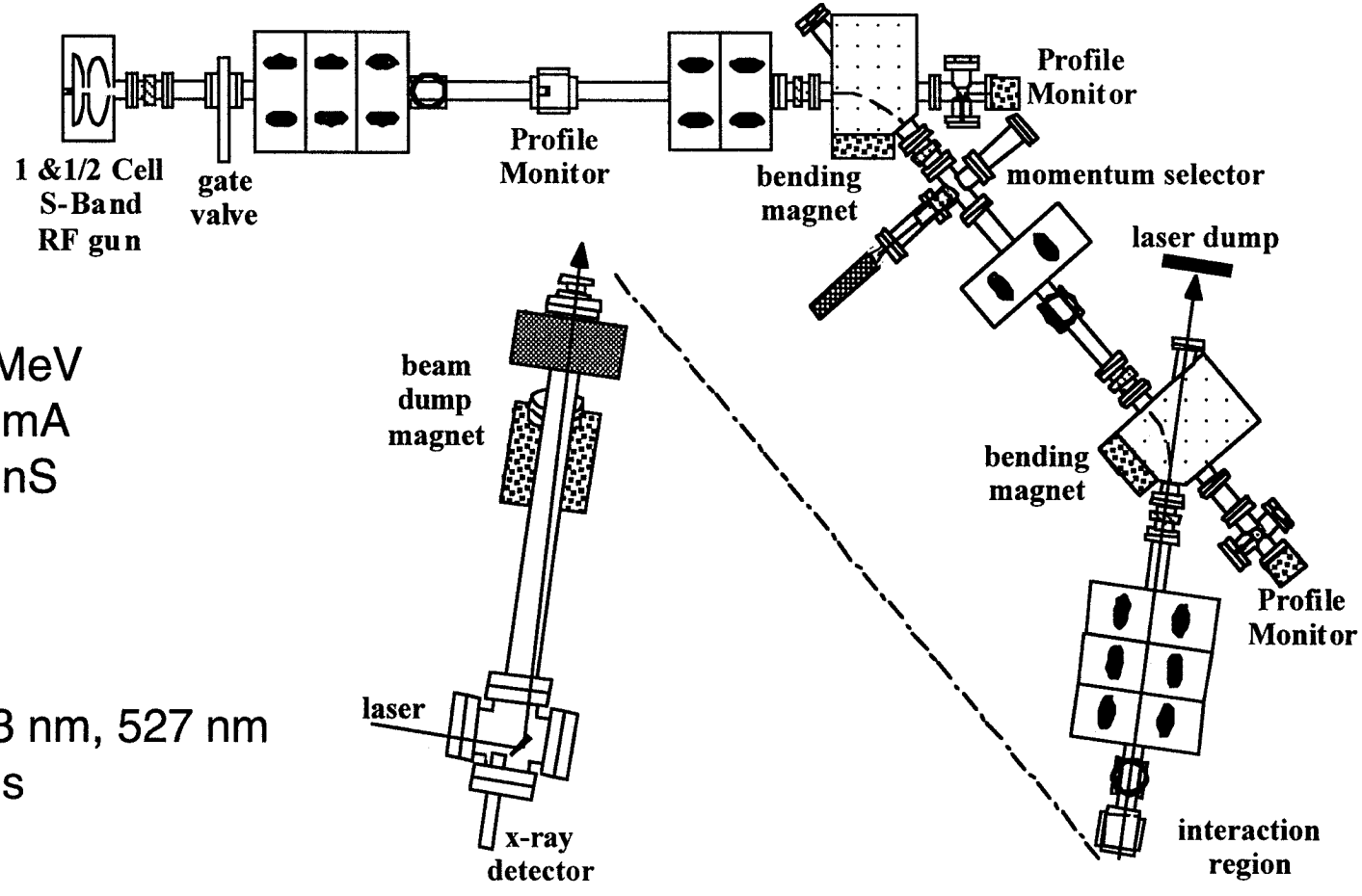
Thomson Backscattered X-Ray Experiment



Electron Beam

Energy	4.5 MeV
Current	300 mA
Macro Pulse	500 nS

Laser Beam

Energy	10 J
Wavelength	1053 nm, 527 nm
Pulse Length	10 ns

X-Rays

Energy	450 eV, 900 eV

NRL RF Gun Electron Beam Parameters

RF frequency	2.856	GHz
Beam Energy, E_b	4.5	MeV
Macropulse length	0.5	μsec
Macropulse beam current, I_b	300	mA
Beam radius at focus, r_b	500	μm
Beam energy spread, $\Delta E_b/E_b$	2	%
Normalized emittance, ε_n	~7	π mm mrad

NRL Nd:glass Laser Parameters

Wavelength, λ_0	1.054 (0.527) μm
Energy/pulse	20 (10) J
Pulse length	10 nsec
Focal spot radius	250 μm

X-ray Pulse Design Parameters

Photon energy	450 (900) eV
Photon wavelength, λ	2.7 (1.35) nm
Photon macropulse length	10 nsec
Linewidth from emittance, $(\Delta\lambda/\lambda)_\varepsilon$	2.7 %
Linewidth from beam focus, $(\Delta\lambda/\lambda)_\varepsilon$	~10 %
Half-angle divergence at $(\Delta\lambda/\lambda)_\varepsilon$	16 mrad
Total photons/macropulse	10^8 photons
Total photons/macropulse at $(\Delta\lambda/\lambda)_0$	10^7 photons

Progress

- Electron Beam

---Full cuurent electron beam (1.3 A) extracted at full RF power (7 MW) at RF gun output.
---Full current electron beam (300 mA) propagated past momentum selector to final focus and beam dump.
--- Maximum electron beam energy measured to be 4.3-4.5 MeV.

- Laser

---Nd:glass laser delivered 10 nsec pulse at 20 J/pulse (1.053 mm) and 10J/pulse (527 nm).
---Laser aligned to final focus and laser dump.
--- Nd:glass laser aligned and synchronized to the RF gun electron beam in the interaction chamber.

X-ray diagnostics

---Scintillator/Photomultiplier tube used as detector for x-rays was overwhelmed by background noise from both the laser and the electron beam.

---Electron multiplier tube was used as detector. First dynode acts as photocathode for x-rays. Low efficiencies but no noise from visible light or high energy x-rays of electron beam.

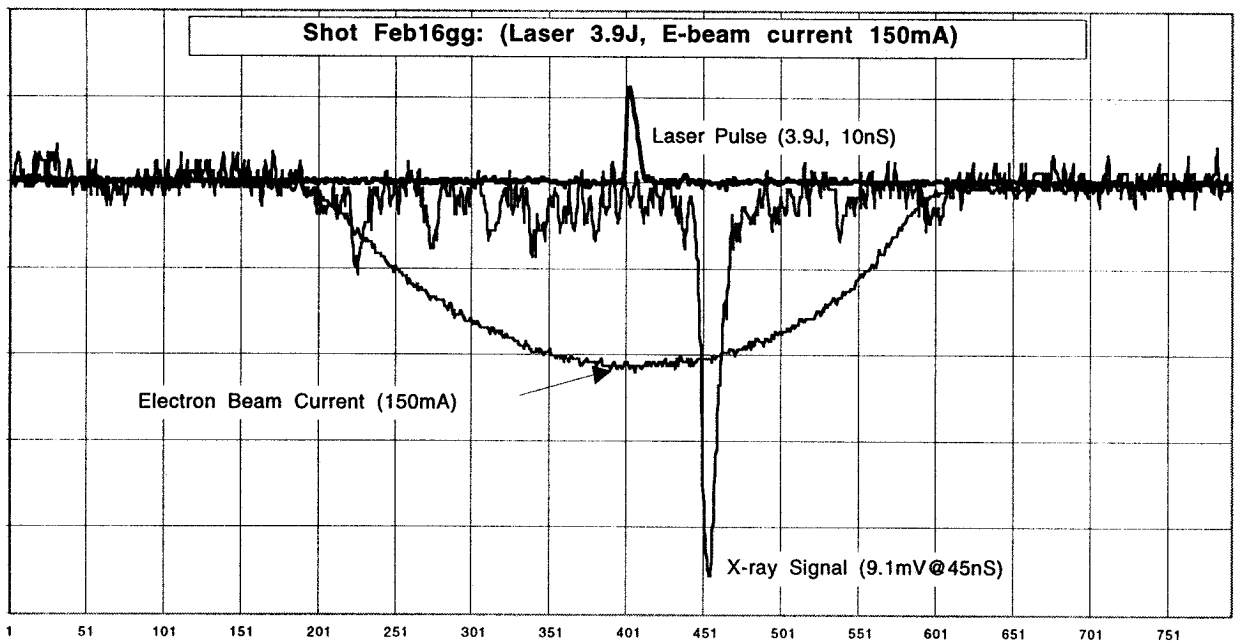
--- Generate and characterize x-rays produced in the demonstration LSS experiment.

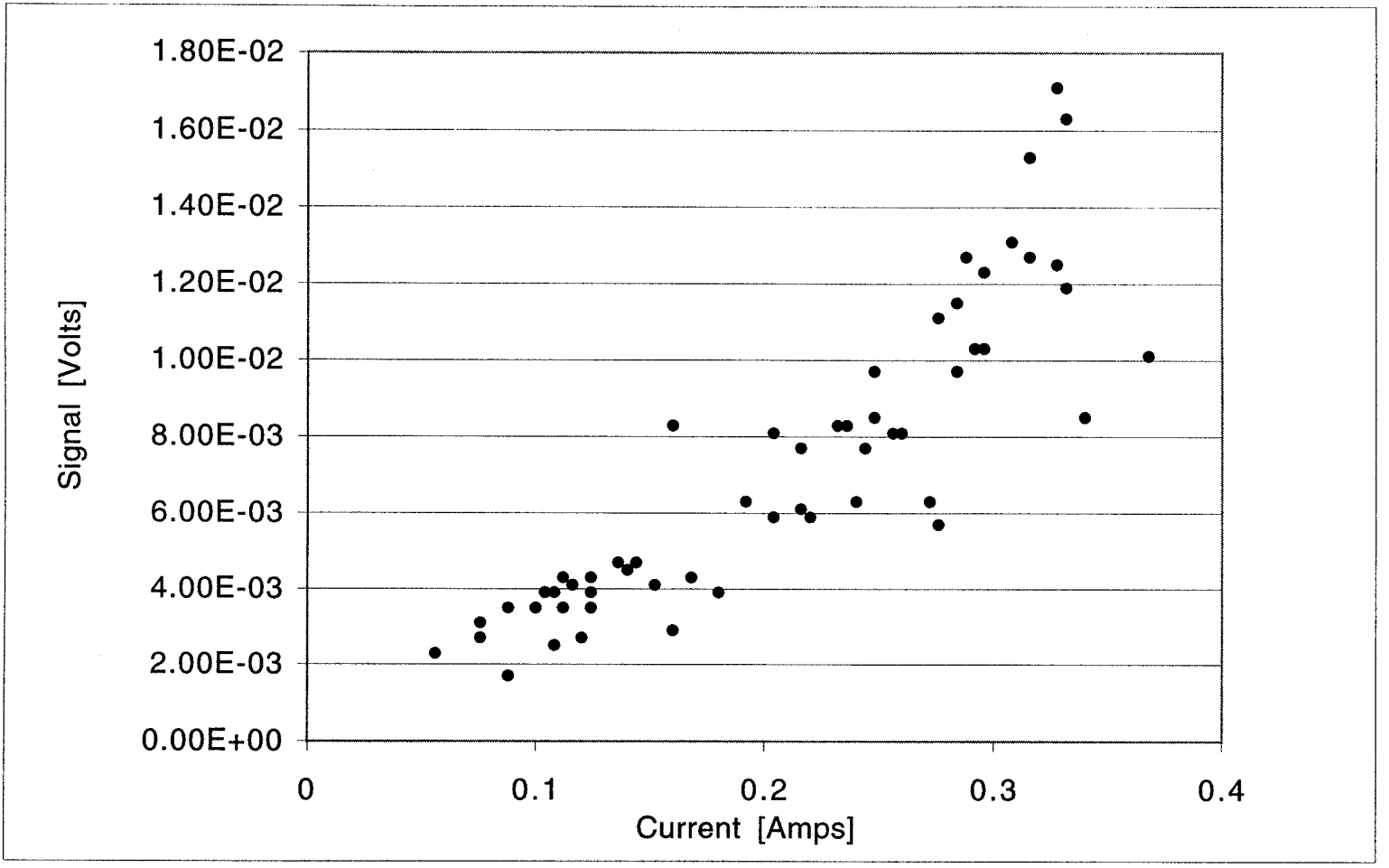
--- Minimize background x-ray production by the electron beam.

--- Measure the photon flux of the x-rays.

--- Measure the energy spectrum of the x-rays.

First Light: LSS X-ray demonstrated




1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
Signal [Volts]
0
0.1
0.2
0.3
0.4
Current [Amps]

Flux Estimate

How many synchrotron x-rays produce a 1 mV signal?

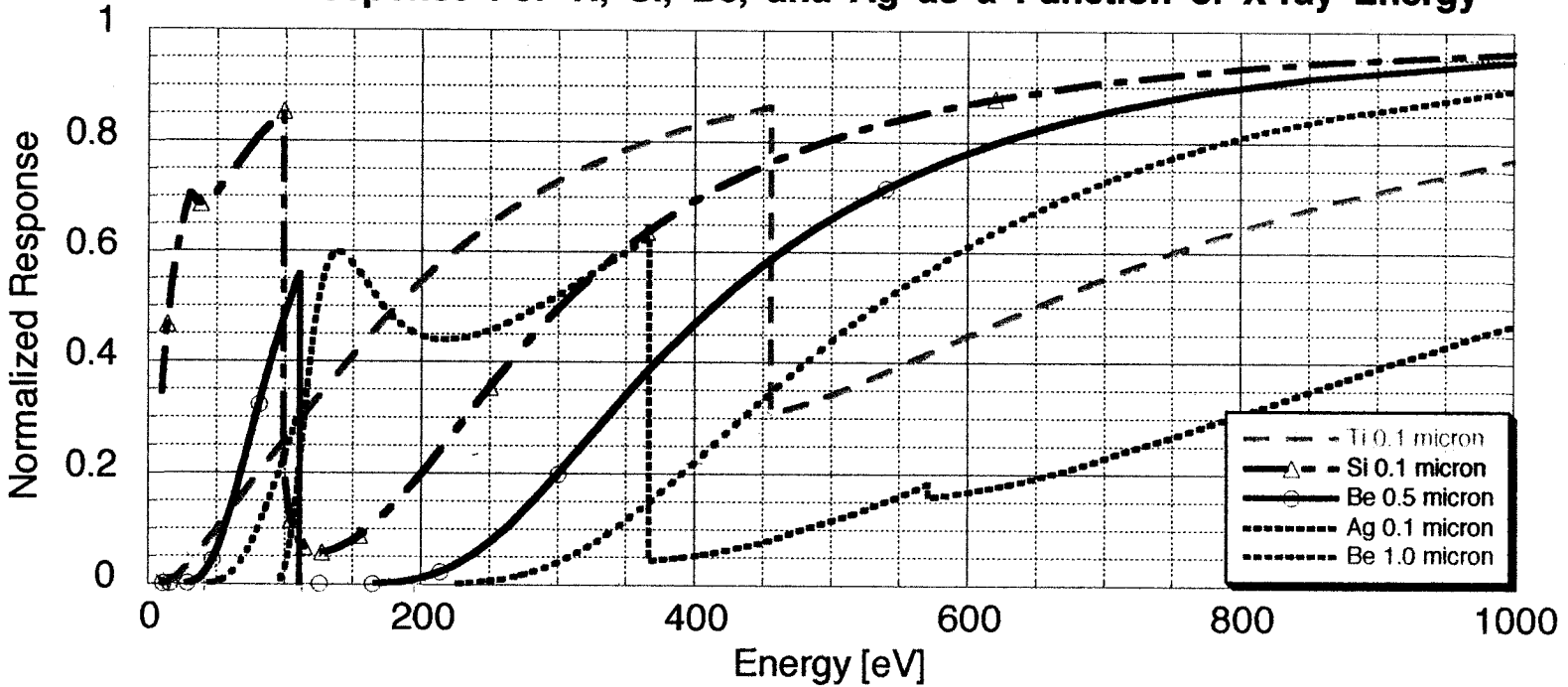
$$\frac{1mV}{50\Omega}\cdot\frac{10nS}{1.6\times10^{-19}C/electron}=1.25\times10^{6}electrons$$

The gain of the EMT can not be greater than $1.25\text{x}10^6$ so we surmise that a single electron was emitted from the photocathode.

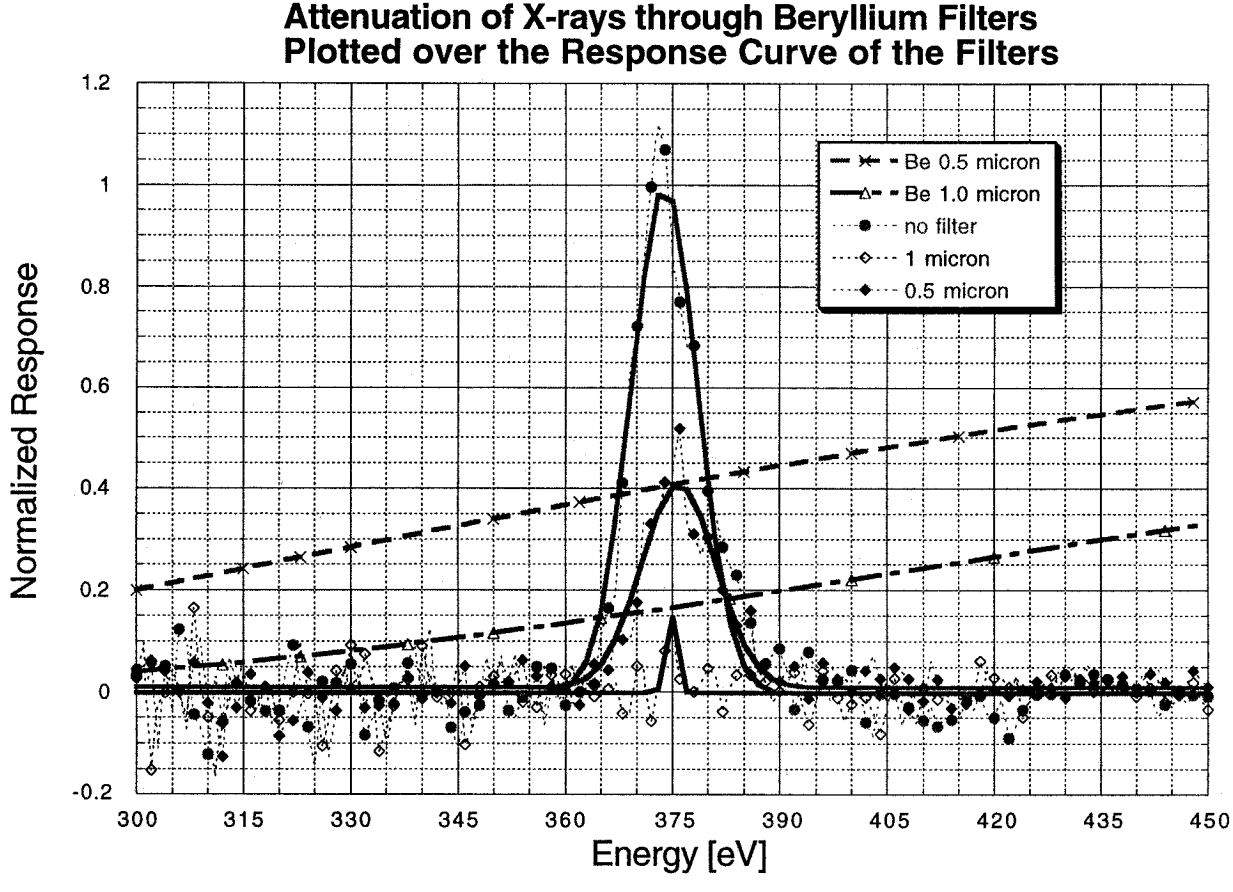
The photocathode has an efficiency of 1% so on the order of100 x-ray photons were incident on it. The area of the cathode is 1 sq cm and is 170cm from the source. The area of the x-rays at that distance is $\pi(17\text{cm})^2$ based on a cone of half angle $1/\gamma$, so that the fraction of x-rays encountering the detector is 1sq cm/ 904 sq cm = 10^{-3}

Therefore, the total number of x-rays produced in the forward direction is 90489.

The typical signal is 10 times this so the estimate of flux is between 10^5-10^6 photons.


Filter Response For Ti, Si, Be, and Ag as a Function of X-ray Energy
Normalized Response
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Energy [eV]
Ti 0.1 micron
Si 0.1 micron
Be 0.5 micron
Ag 0.1 micron
Be 1.0 micron

Energy Measurement



Conclusions

- X-ray production from Thomson backscattering of Nd:glass laser photons (1.18 eV) from a relativistic electron beam (4.3 MeV) observed.
- Preliminary data indicate x-ray energy ~400 eV.
- Flux, spectral, and angular properties of x-ray to be measured.