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Energy-Dependent Sensitivity of MCP-Based Spectrometers on Sandia's Z Facility

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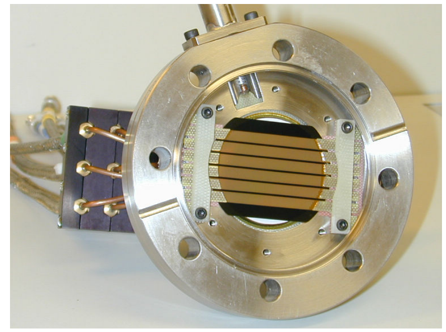
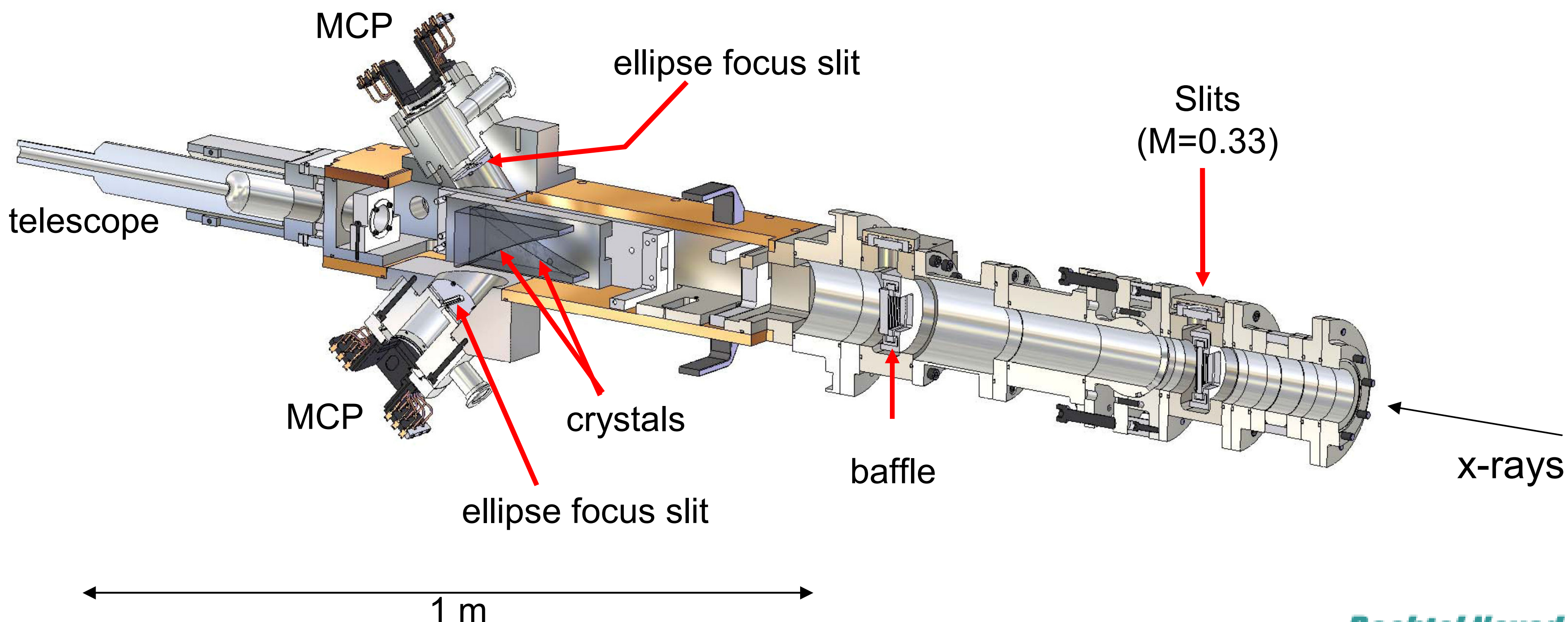
Abstract

In spectroscopy applications using microchannel plate (MCP) detectors, it is critical to understand the dependence of the MCP gain on time, position, angle of incidence, and photon energy. Measurements of each gain dependency have been done for MCP configurations commonly used for spectroscopy on Sandia's Z facility. In particular, the dependence of the MCP gain on photon energy was measured in the range 250 eV < $h\nu$ < 5000 eV on the National Synchrotron Light Source. These measurements are compared to a MCP relative efficiency model, and are shown to be in good agreement using an independent analysis of the MCP glass composition to determine the total material absorption cross-section. For time-gated elliptical spectrometers on the Z facility, the MCP efficiencies are found to dominate over filter transmission and crystal geometry/reflectivity in the relative energy-dependent efficiency of the system.

Time-Resolved Elliptical Crystal (TREX) Spectrometer



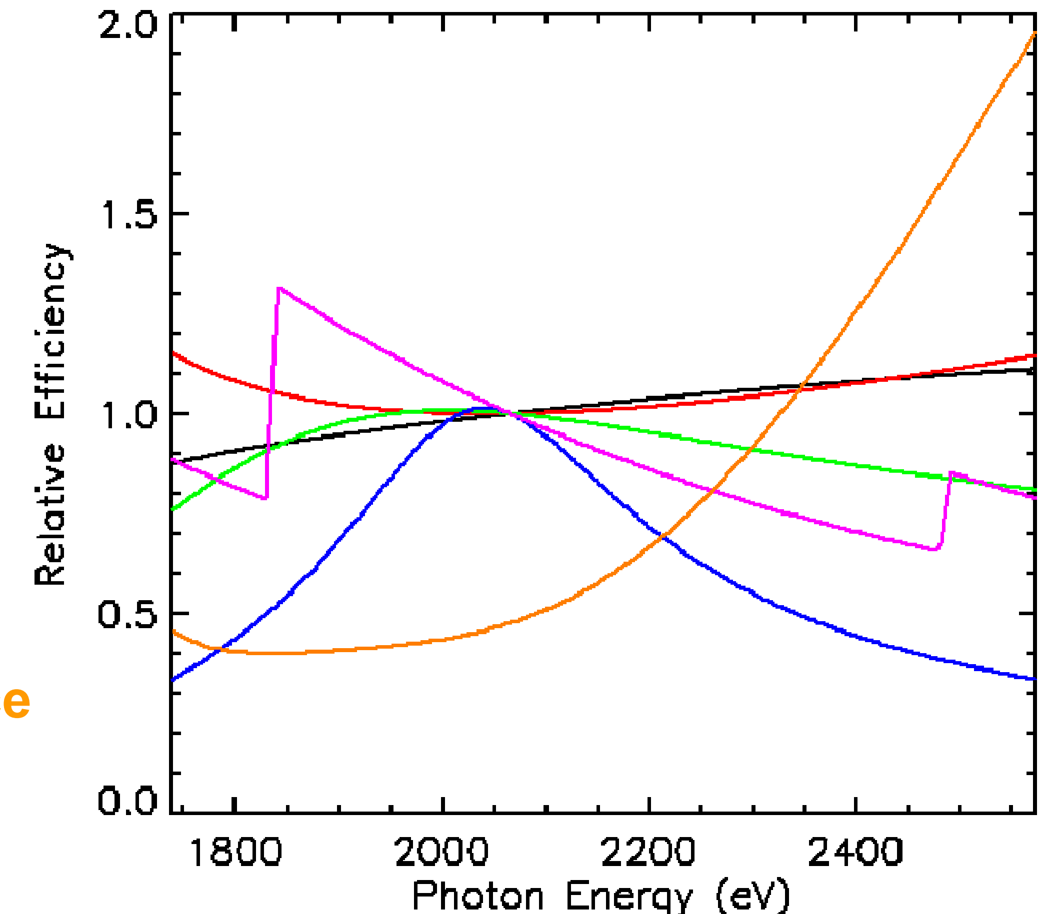
6-strip MCP
L/D = 46
L = 460 μm
D = 10 μm
Bias Angle = 8°



The photon-energy-dependent sensitivity of MCP-based spectrometers depends on many factors:

- **Filter Transmission**
- **Crystal Geometry**
- **Crystal Reflectivity**
- **MCP Angular-Dependence**
- **MCP Energy-Dependence**
- **MCP Pulse-Gain-Dependence**

Various Efficiencies for TREX Spectrometer in Si K-shell Emission Configuration



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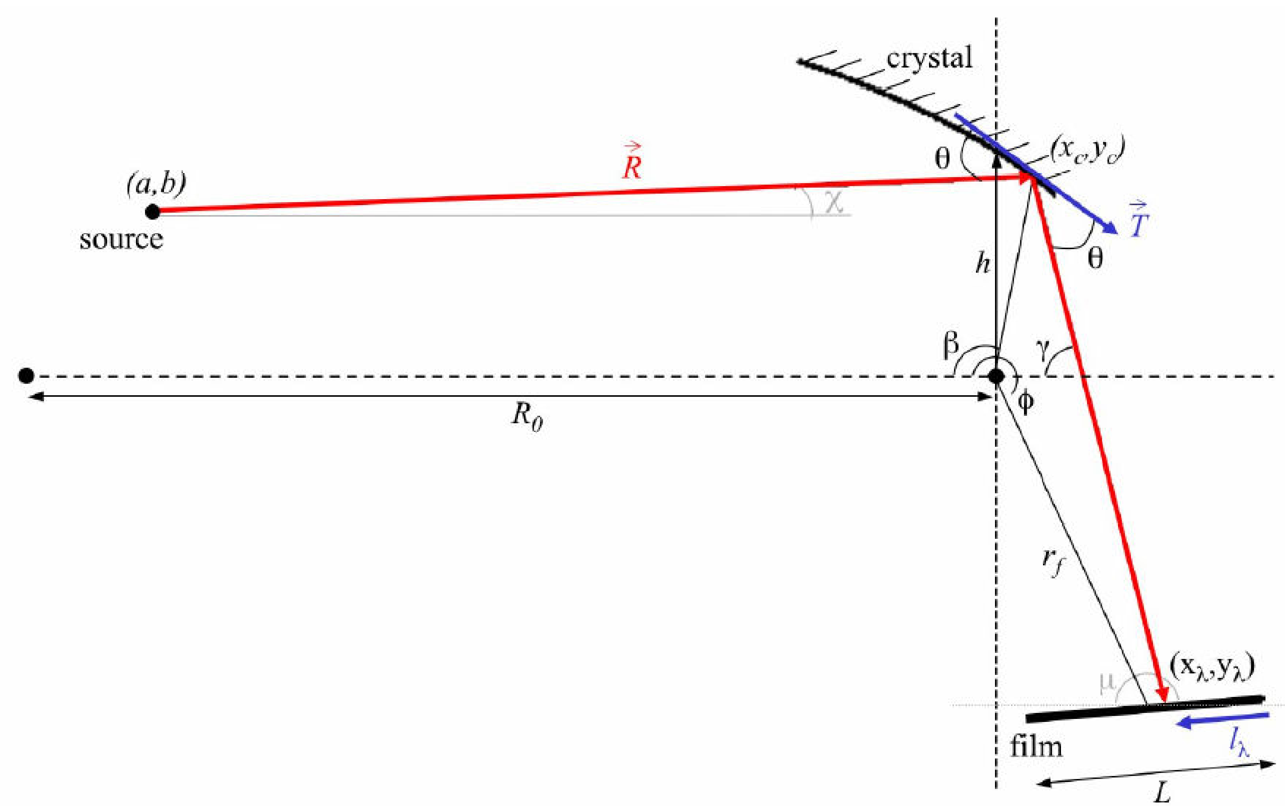
Crystal Reflectivity and Elliptical Geometry Correction*

$$\frac{dN}{dA} = \frac{S_0}{r_f L_r}\left(\frac{d\chi}{d\theta}\right)\left(\frac{d\theta}{d\beta}\right)\left(\frac{dE}{d\theta}\right) R \quad \longrightarrow \quad S_0 = \left[\frac{(1.602\times 10^{-19}) r_f L_r (hc)\tan\theta}{-\left(\frac{d\chi}{d\theta}\right)\left(\frac{d\theta}{d\beta}\right)\lambda^2 R}\right]\frac{dN}{dA}$$



dN/dA = film exposure (γ/µm²)

S_0 = source strength (J/sr/Å)

L_r = total ray path length

R = crystal reflectivity

*B.L. Henke et. al., Rev. Sci. Instr. **54**, 1311 (1983)

MCP Response Model

Relative response per unit energy[1]:

$$Q(E,\theta) = E^{-1} Y(E,\theta) \sum_n I_n(E,\theta) G_n(\theta)$$

- Photon intensity at channel *n*:

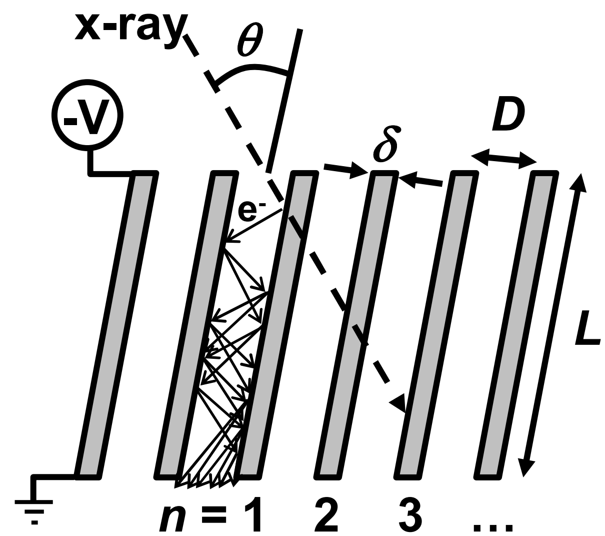
$$I_n(E,\theta) = I_0(E) \cos\theta \, e^{-\mu(E)\delta(n-1)/\sin\theta}$$

- Electron yield per photon[2]:

$$Y(E,\theta) \approx Y_s(E,\theta) = K_s E \mu(E) \left[1 + e^{-\mu(E)\delta/\sin\theta} \right] \csc\theta$$

- Discrete dynode gain[3]:

$$G_n(\theta) = \left(V/V_0 \right)^{L/4D \left(1 - x_n(\theta)/L\right)}$$



$\mu(E)$ = inverse attenuation length

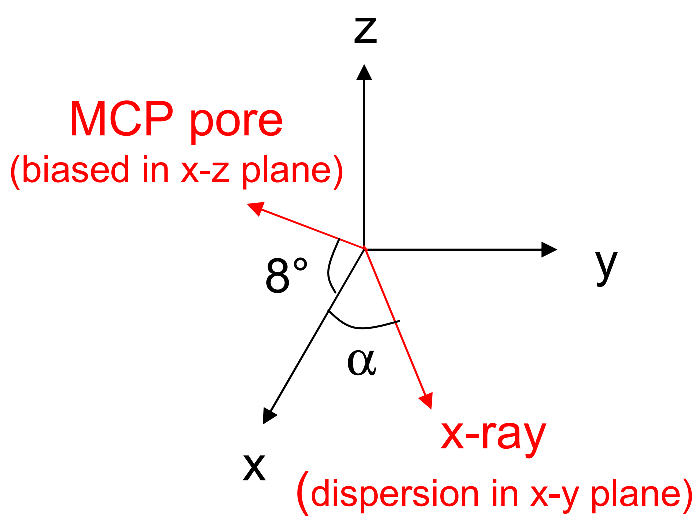
$$Q(E,\theta) = I_0(E)\mu(E) \left(1 + e^{-\mu(E)\delta/\sin\theta} \right) \cot\theta \sum_n e^{-\mu(E)\delta(n-1)/\sin\theta} \left(V/V_0 \right)^{L/4D \left(1 - x_n(\theta)/L\right)}$$

$$Q = I_0 \mu \cot\theta \left(V/V_0 \right)^{L/4D \left(1 - x(\theta)/L\right)}$$ for $$\mu\delta/\sin\theta \gg 1 \,, \; (\mathrm{E} < 3000\,\mathrm{eV})$$

[1]O.L. Landen et al., Rev. Sci. Instr. **72**, 709 (2001).
[2]B.L. Henke et al., J. Appl. Phys. **52**, 1509 (1981).
[3]P. Eberhardt, Appl.Opt. **18**, 1418 (1979).

Verification of Angular MCP Response*

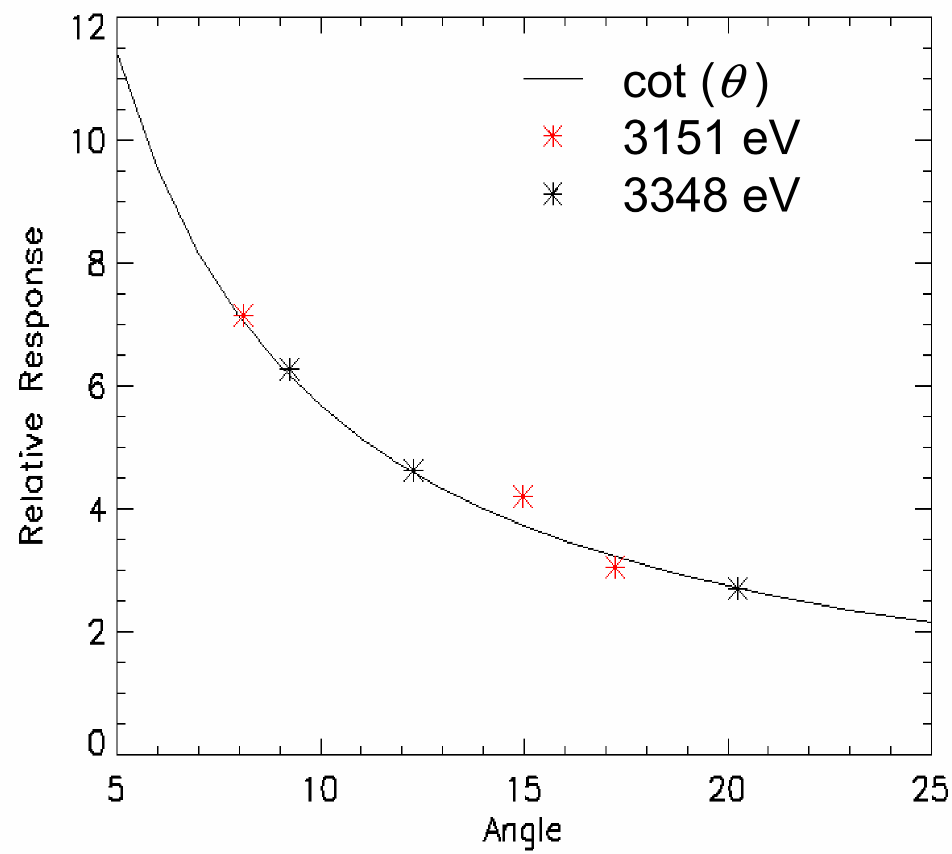
MCP channels oriented in dimension perpendicular to the dispersion direction



$$\vec{r}_{pore} \cdot \vec{r}_{ray} = |r_{pore}||r_{ray}| \cos\theta = x_p x_r$$

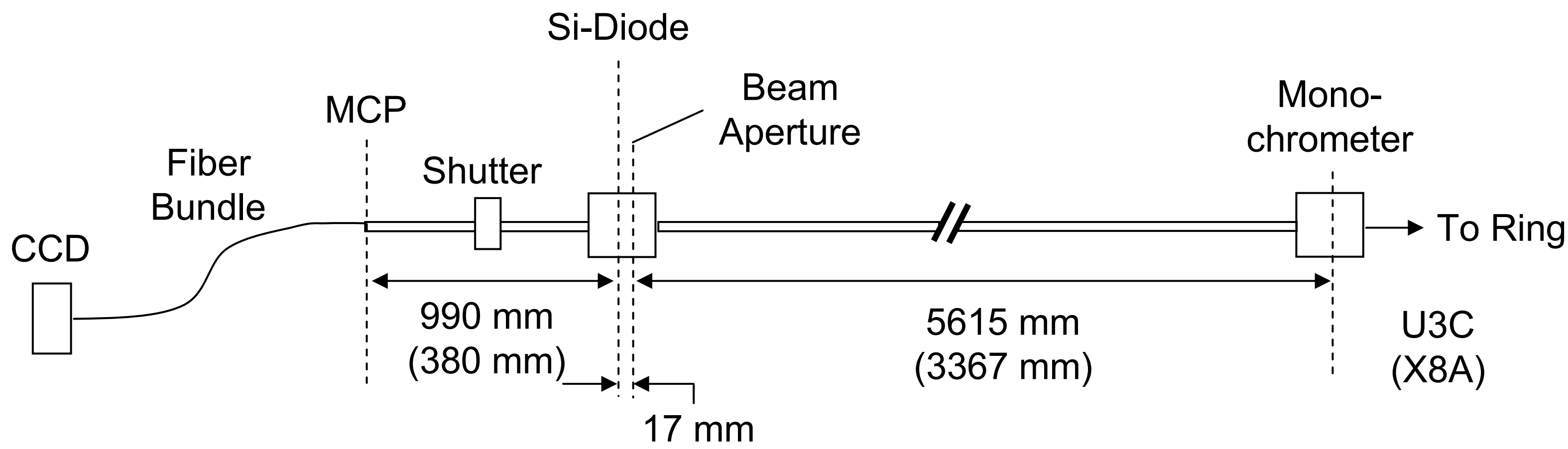
$$\theta = \cos^{-1}(\cos 8° \cos\alpha)$$

Manson Source Calibration
varying MCP angle along dispersion axis



*O.L. Landen et al., Rev. Sci. Instr. **72**, 709 (2001).

Photon-energy-dependent sensitivity of MCPs was measured at the National Synchrotron Light Source.

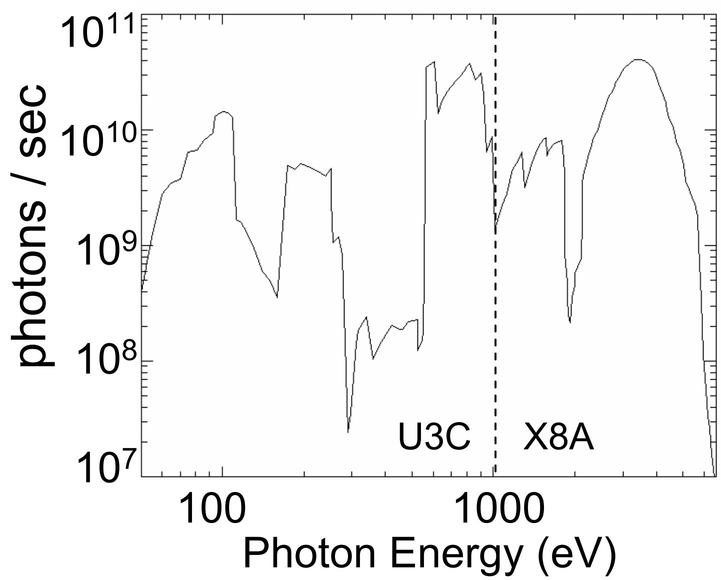


Beamline U3C

Grating Monochrometer

- 3.71 m, 1200 lines/mm
- E = 250 eV – 1200 eV
- $E/\Delta E$ > 300
- Spectral Purity > 95%

Max Beam Current



Beamline X8A

Dual Crystal Monochrometer

- W/Si Multilayer
  - E = 1000 eV – 2100 eV
  - $E/\Delta E$ ~ 50
- Si 111 crystals
  - E = 2100 eV – 6000 eV
  - $E/\Delta E$ ~ 2000

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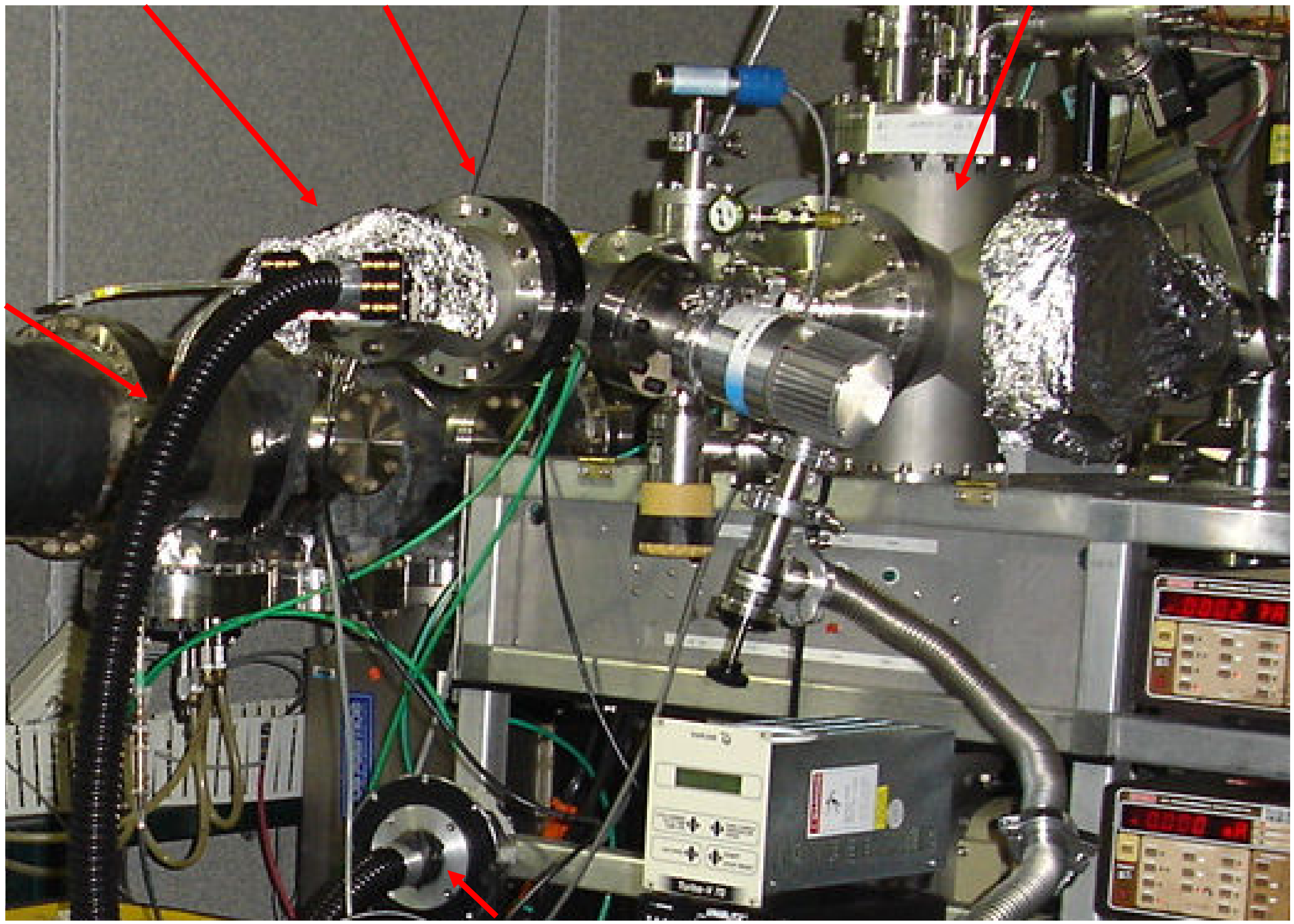
Experimental apparatus on the X8A beamline.



Measurement Procedure

• Set monochrometer to desired energy using Labview controlled motorized actuators on monochrometer, filter wheels, mirrors, and end-station.

• Record beam power with Si diode:
- Detune beam until diode current ~1 – 100 nA.
  - U3C: detuning done with alignment of M1 mirror
  - X8A: detuning done by misaligning aperture to wings of beam profile

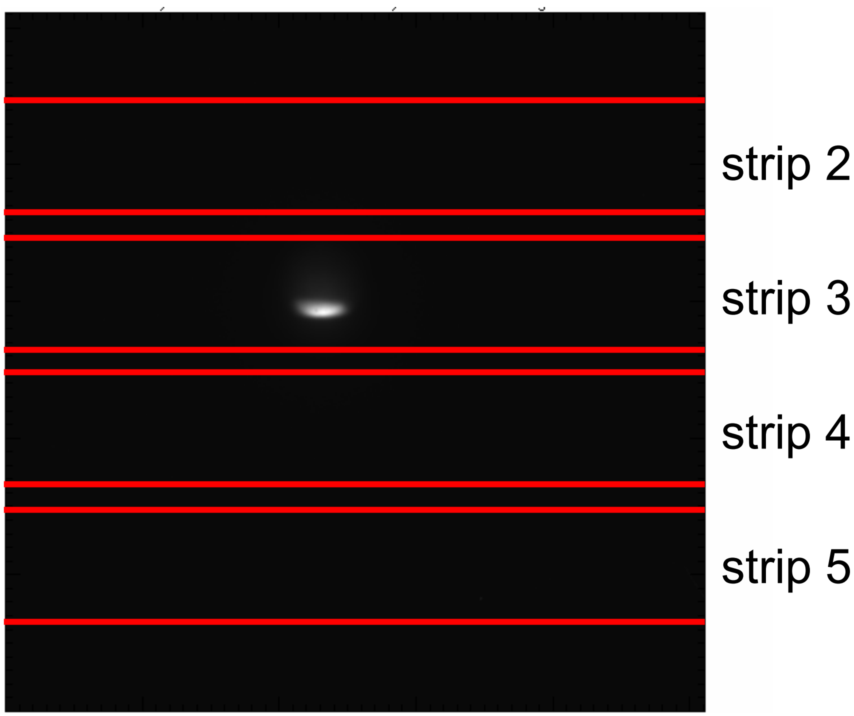
• Expose MCP at -400 V DC by opening shutter for 0.8 sec.
- DC bias and shutter time kept constant
- CCD image kept at peak counts < 40,000 to avoid saturation
- CCD linearity checked by varying shutter time
- MCP linearity checked by varying beam intensity

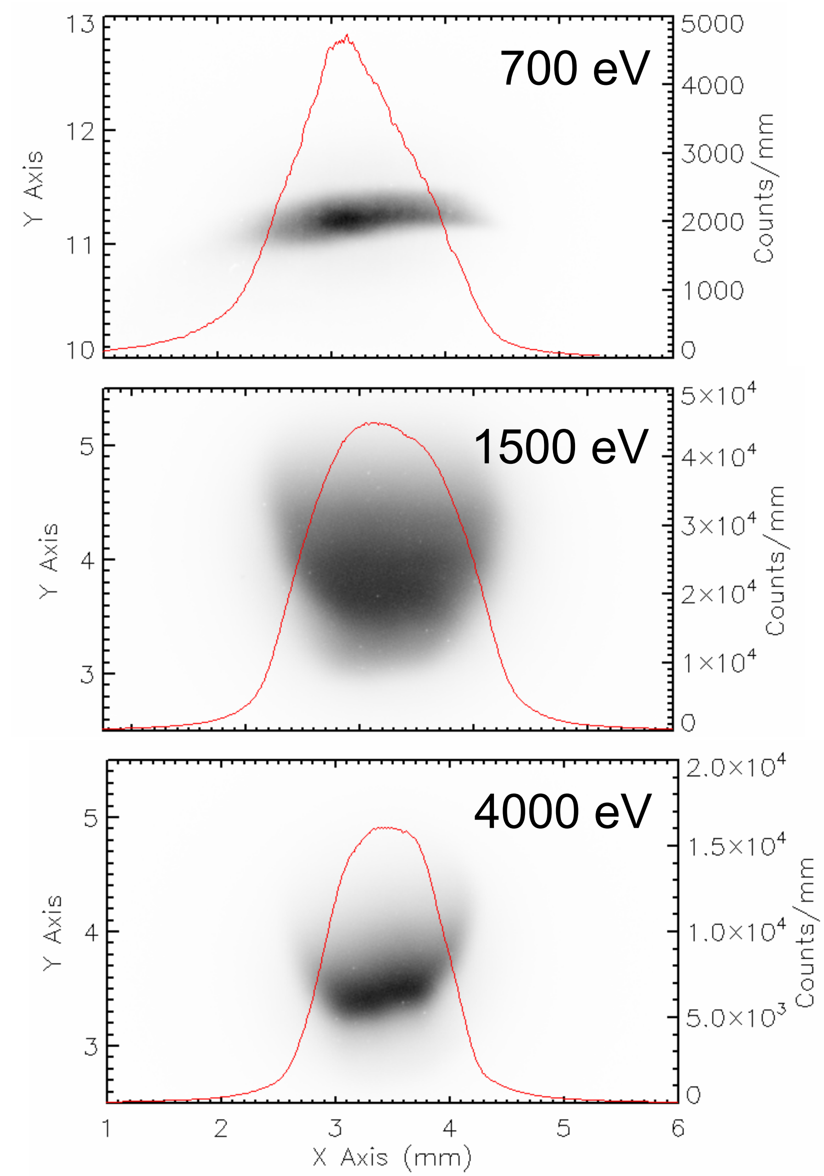
• Record beam power again with Si diode.

• Integrate background-subtracted CCD image and divide by beam power and shutter time to get system response (counts/J).

Monochromatic beam profiles under-fill the MCP strips, and show a changing shape with energy.

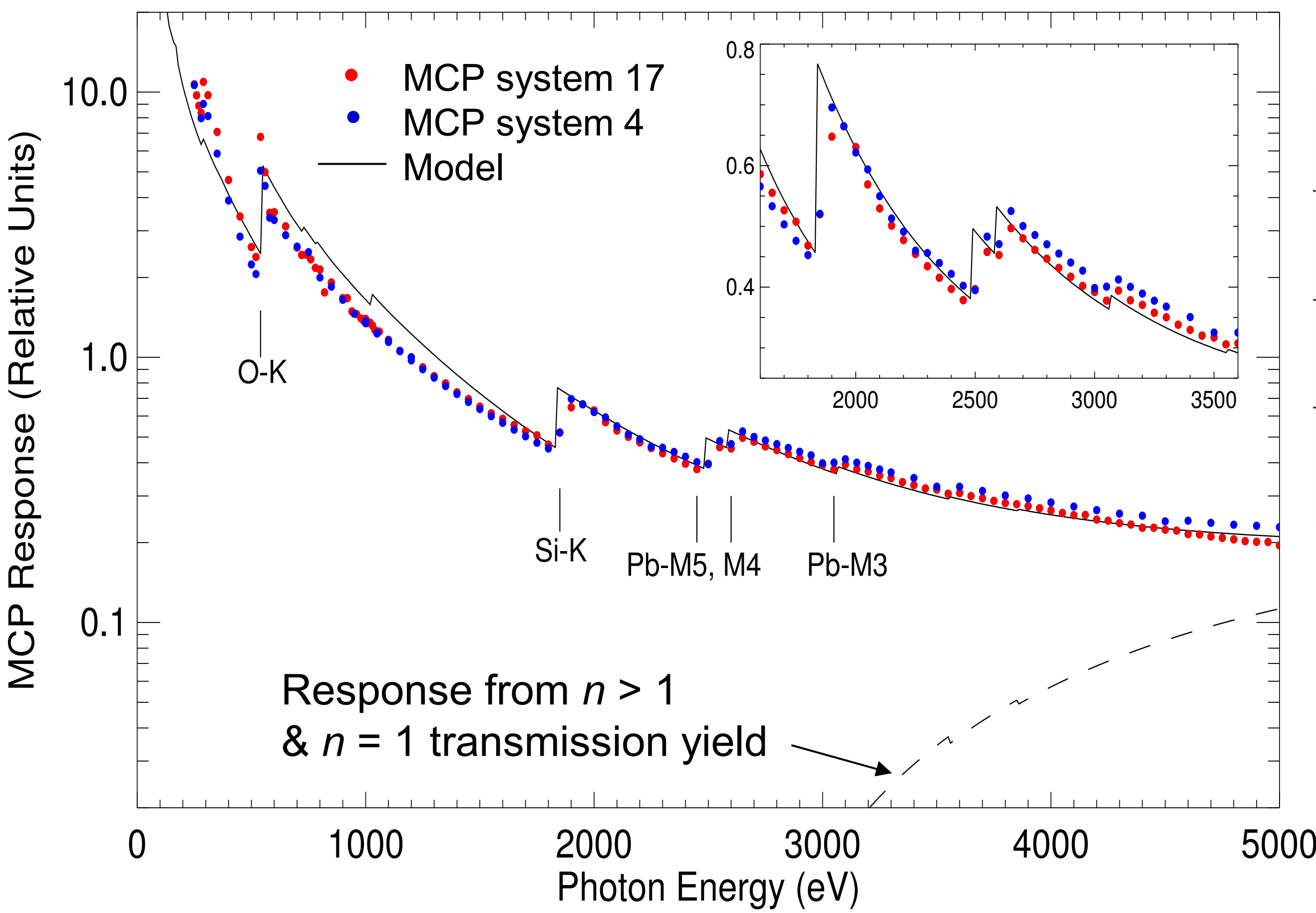
Full CCD image of mono-chromatic beam @ 2250eV



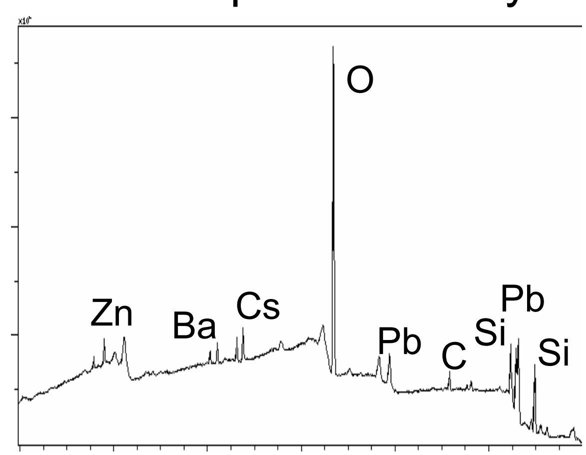


The measured MCP response agrees well with the model across the complete range of photon energies.

$$Q(E,\theta) = I_0(E)\mu(E)\left(1+e^{-\mu(E)\delta/\sin\theta}\right)\cot\theta\sum_n e^{-\mu(E)\delta(n-1)/\sin\theta}\left(V/V_0\right)^{L/4D\left(1-x_n(\theta)/L\right)}$$



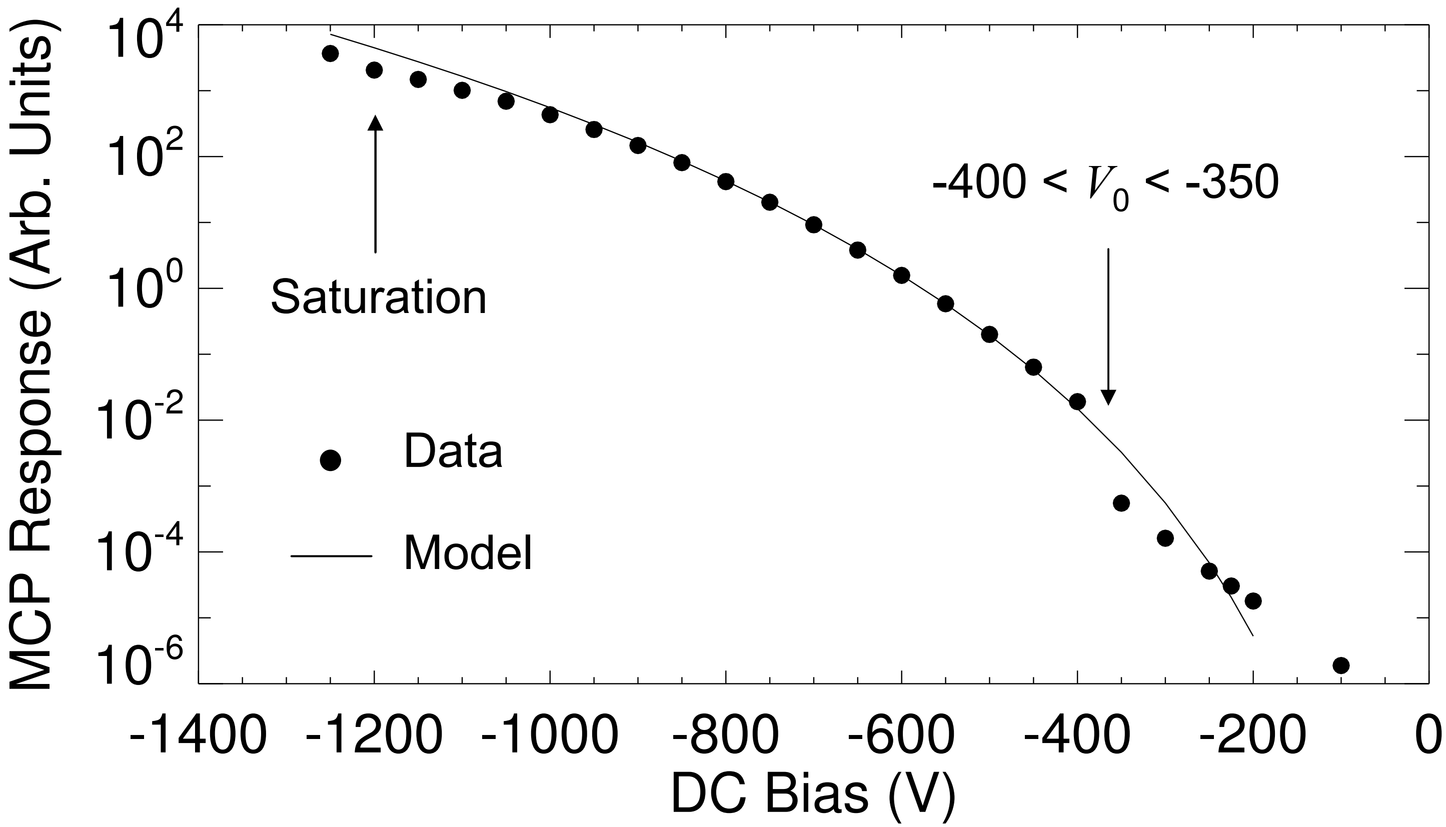
XPS Composition Analysis



~25% Pb by mass

The DC voltage dependent gain of the MCP was measured at 2300 eV, and found to agree well with the model.

$$G = \left(V / V_0 \right)^{L/4D} = \left(V / V_0 \right)^{11.5}$$



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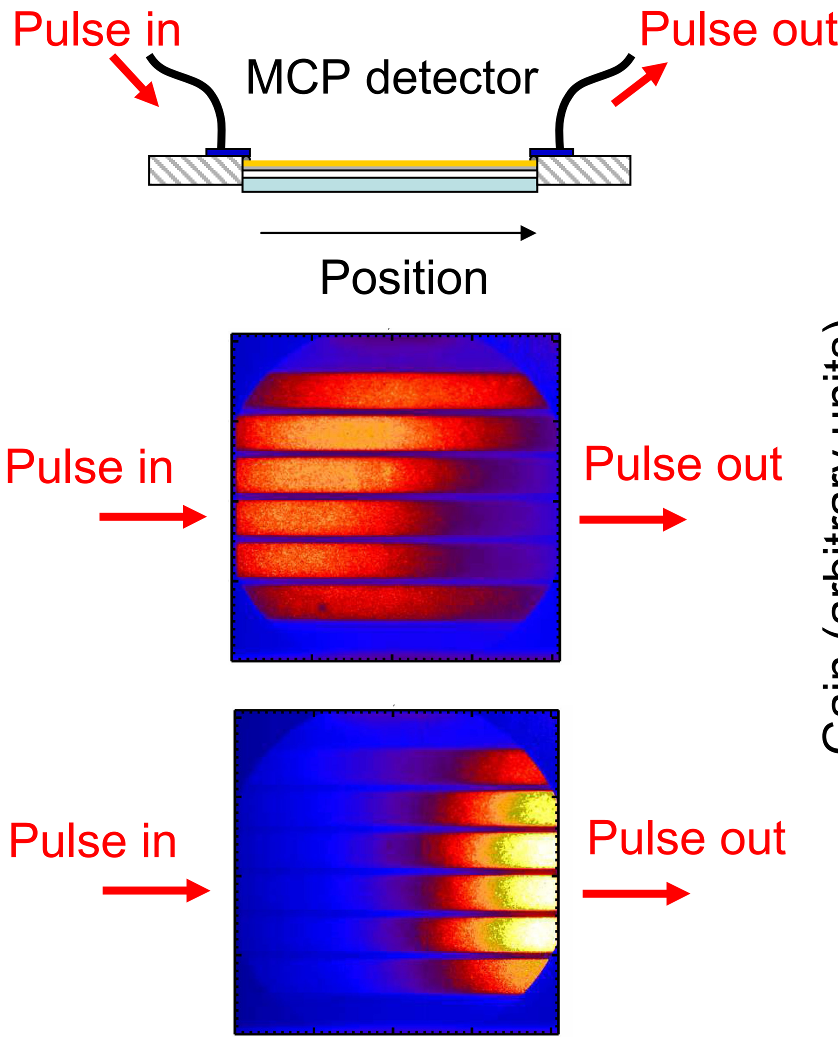
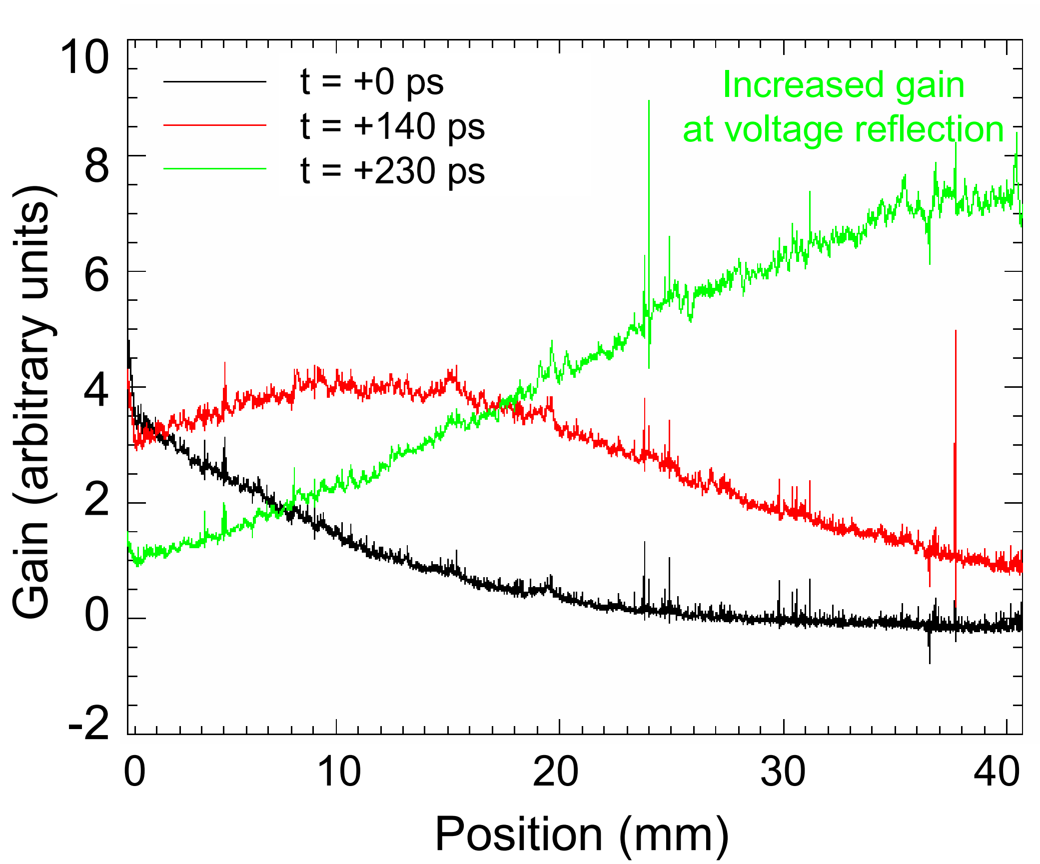
The voltage pulse propagation is measured to have a significant effect on the position-dependent MCP response.

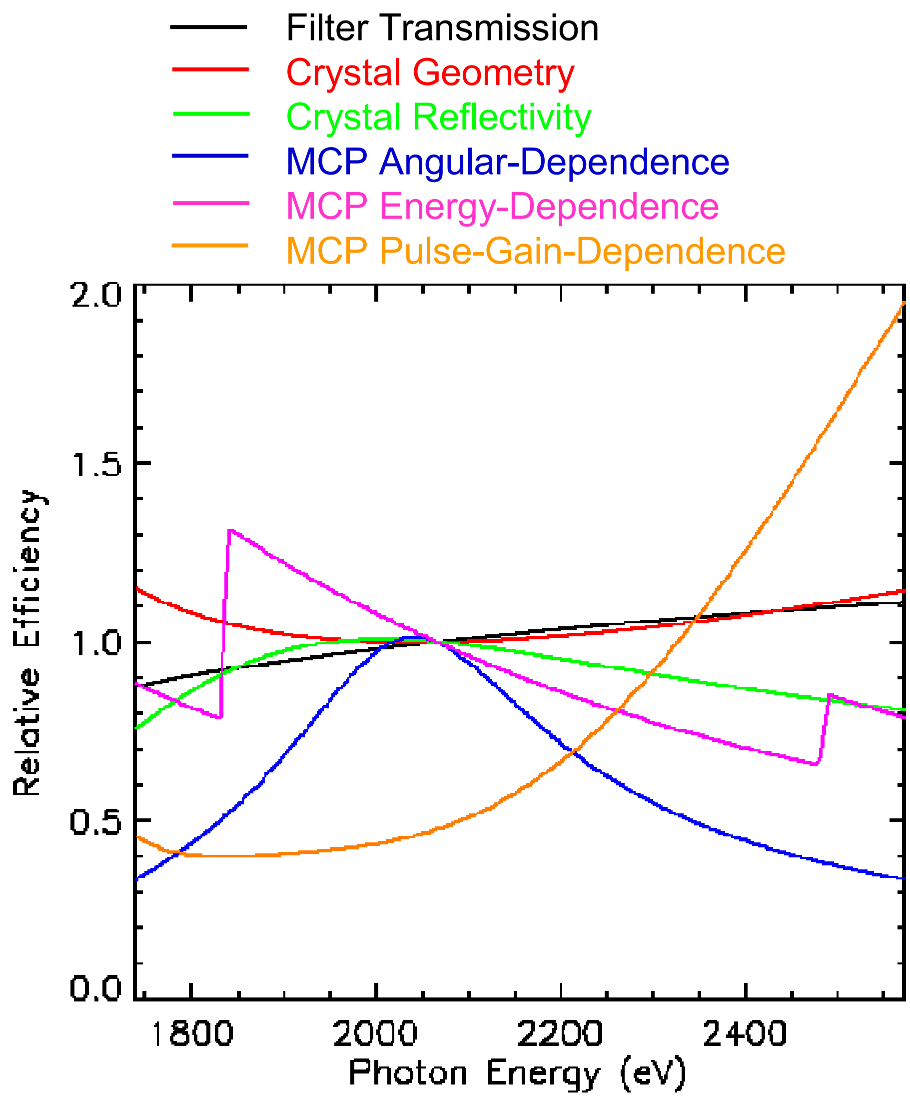


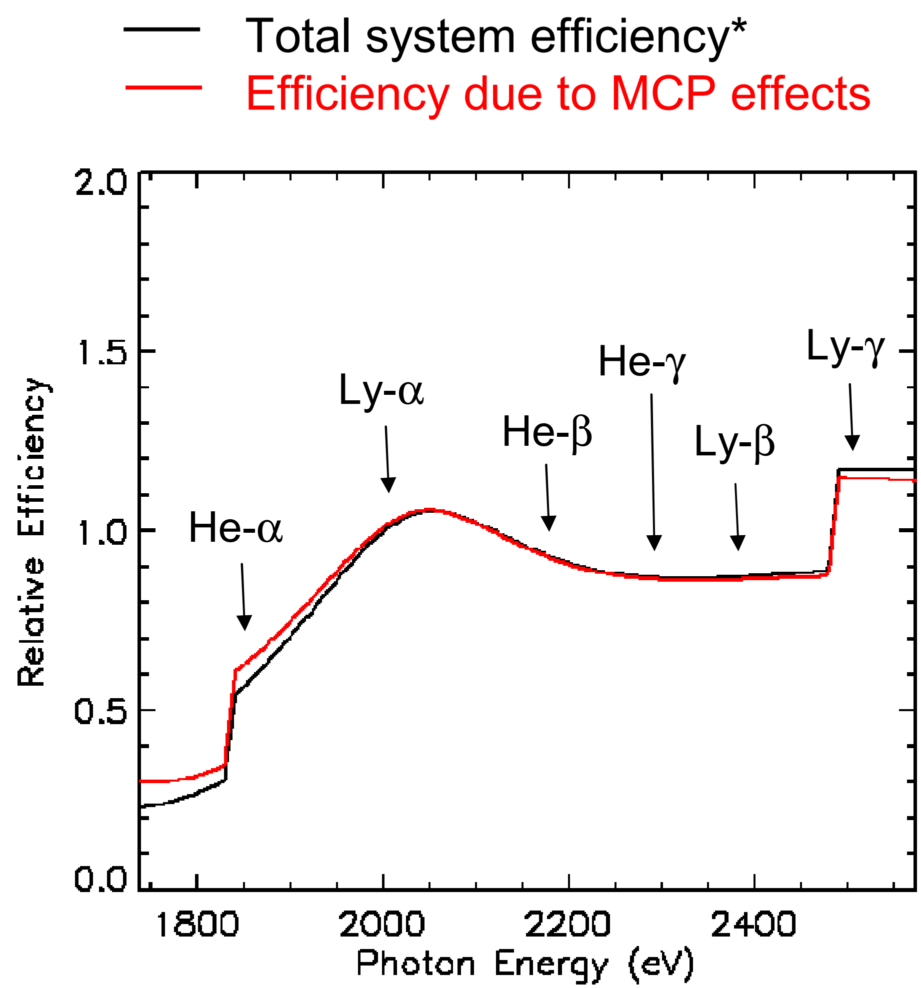
Measurement on BNLO short-pulse laser*



*See Poster: MP24

MCP effects can dominate the total relative system efficiency of time-gated spectrometers.





*TREX Spectrometer in Si K-shell Emission Configuration

Summary

- A number of factors contribute to the sensitivity of MCP-based spectrometers including:
  - -Filter transmission
  - -Crystal geometry and reflectivity
  - -MCP angular-dependence
  - -MCP energy-dependence
  - -MCP pulsed-gain-dependence

- The MCP angular response has been independently measured at E < 3500 eV, and shown to have the expected cot(θ) dependence.

- The MCP energy dependence has been measured in the range 250 eV – 5000 eV, and was found to agree with the model using a plate composition and turn-on voltage determined from independent measurements.

- At E < 3000 eV, the relative MCP response per unit energy is given by:

$$Q(E,\theta) = I_0(E)\mu(E)\cot\theta\left(V/V_0\right)^{L/4D}$$

- The MCP efficiencies dominate the total relative system efficiency of TREX spectrometers on Sandia's Z facility.

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