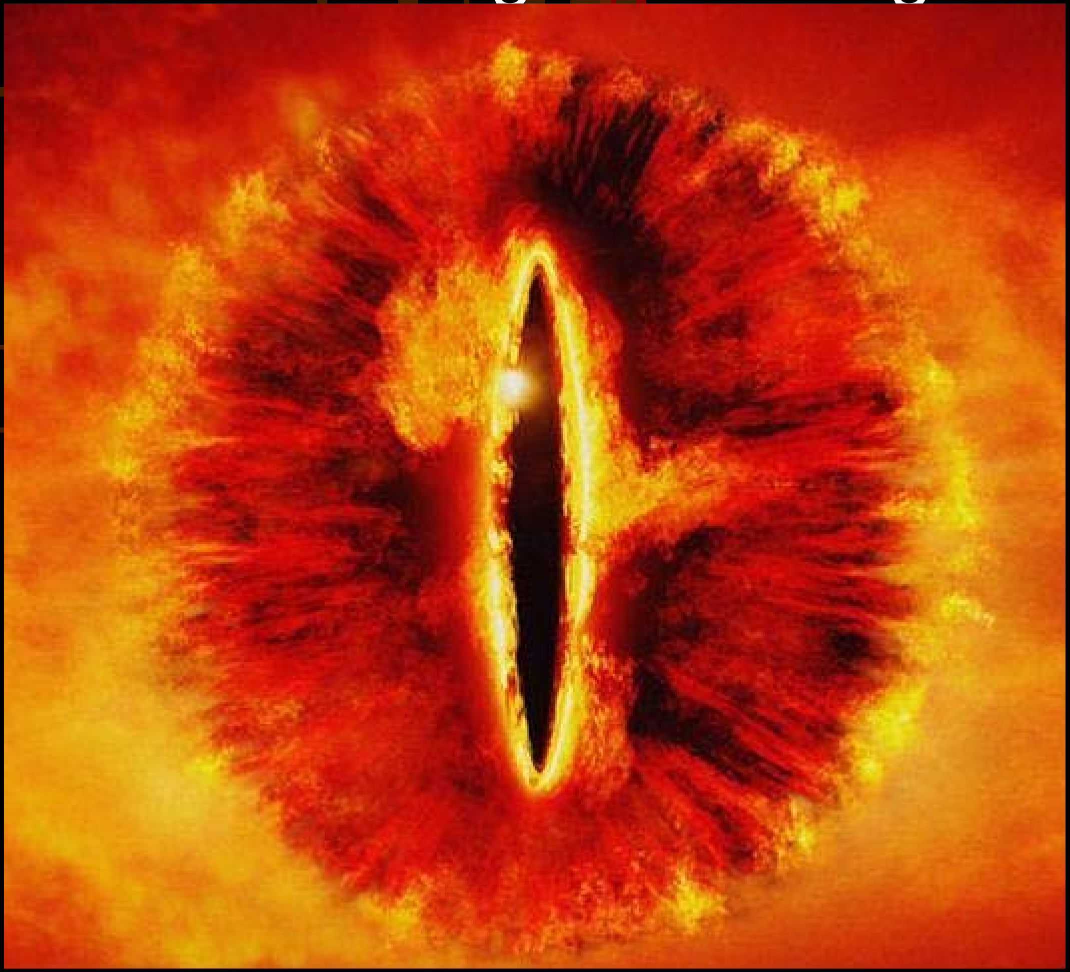
Characterization of the BNL ATF Compton X-ray Source via K-edge Absorbing Foils



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Motivation for Experiments at the ATF

- Attempting to do initial characterization of source to verify:

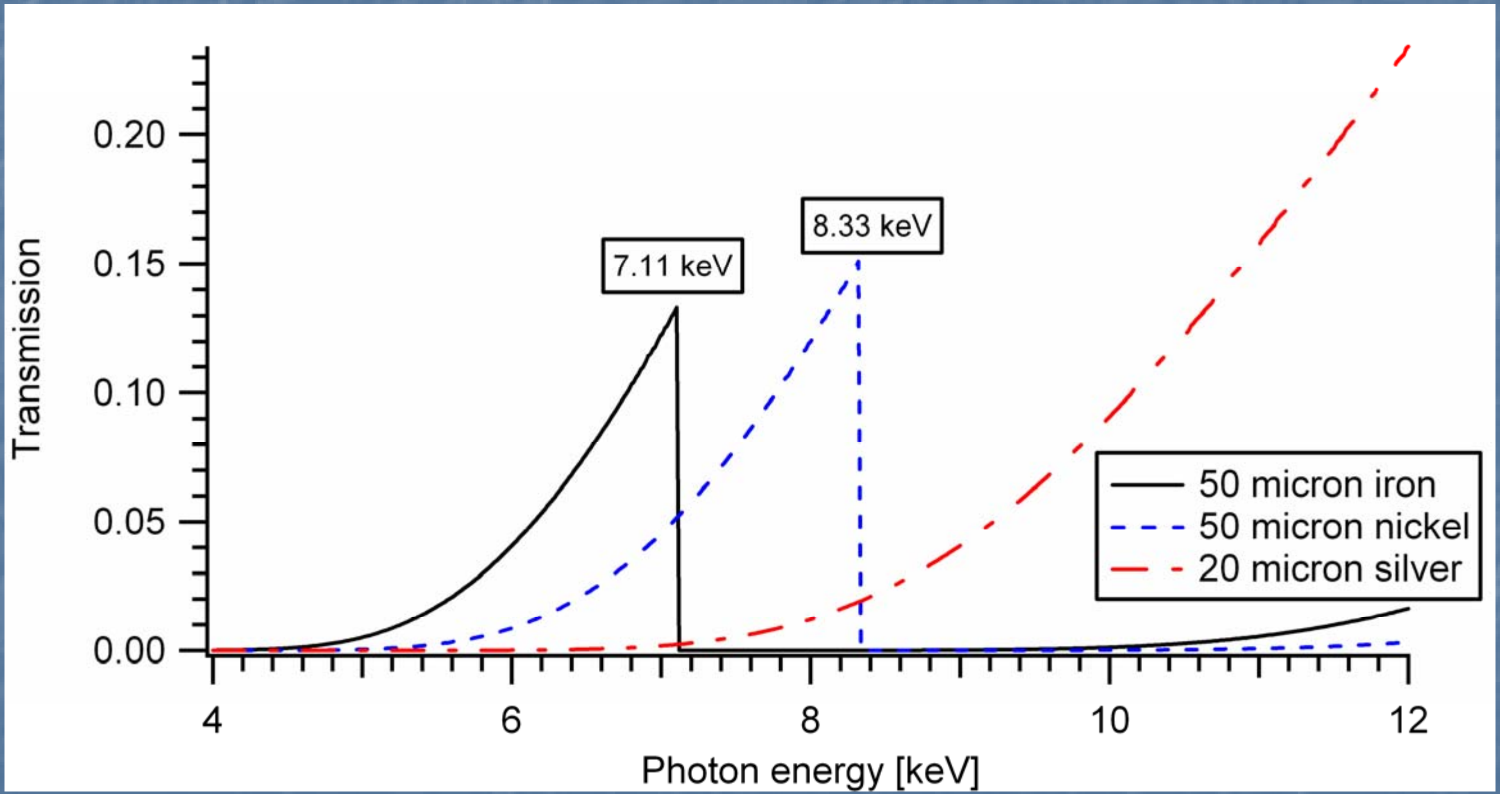
  1) Photon energy
  2) Angular distribution
  3) Flux
  4) Bandwidth (without spectrometer, if possible!)
  5) Change in conditions for sub-ps pulses
  6) Shot-to-shot source stability

Initial applications: K-edge and phase contrast imaging, polarization dependent material studies, and dynamic diffraction/pump-probe experiments

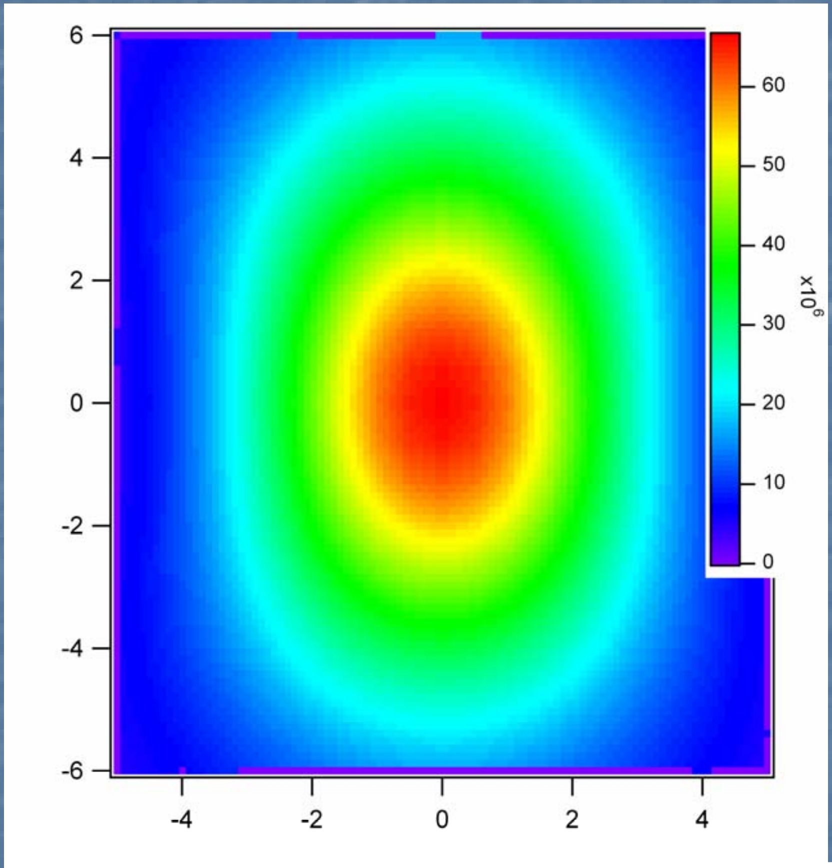
Energy/Angular distribution without a spectrometer?

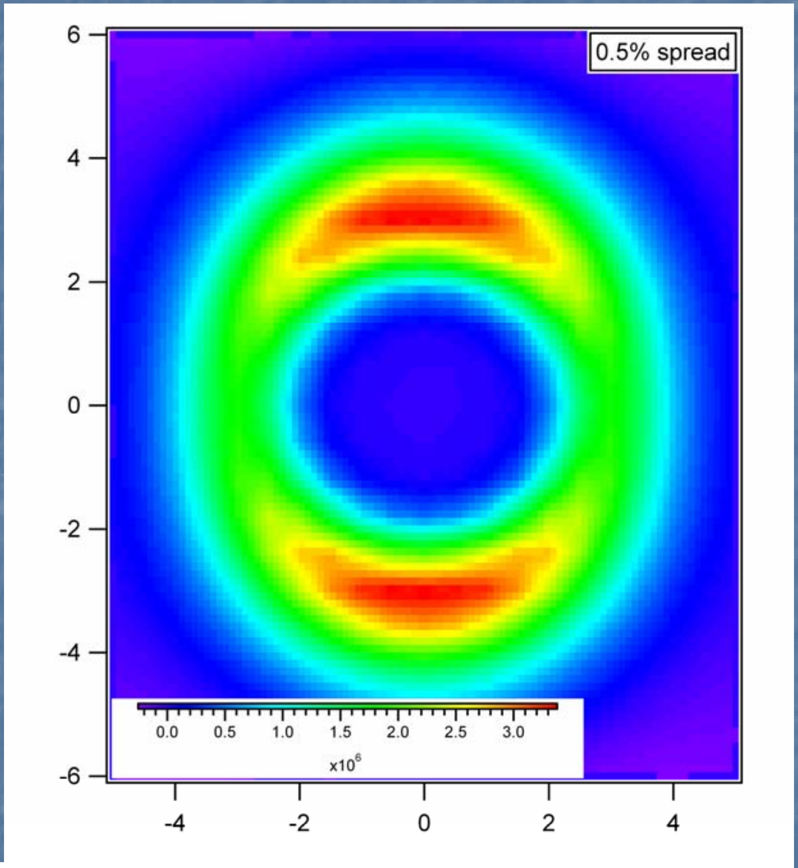
- Strong photon absorption near element K-edge
- Foil thickness + K-edge = low-pass filter
- Above K-edge, photons absorbed, others pass

Photon transmission through foils



Simulated intensity distribution before and after foil





$$E_x = \frac{4\gamma^2}{\left(1 + \frac{a_L^2}{2} + \gamma^2\theta^2\right)} E_L$$

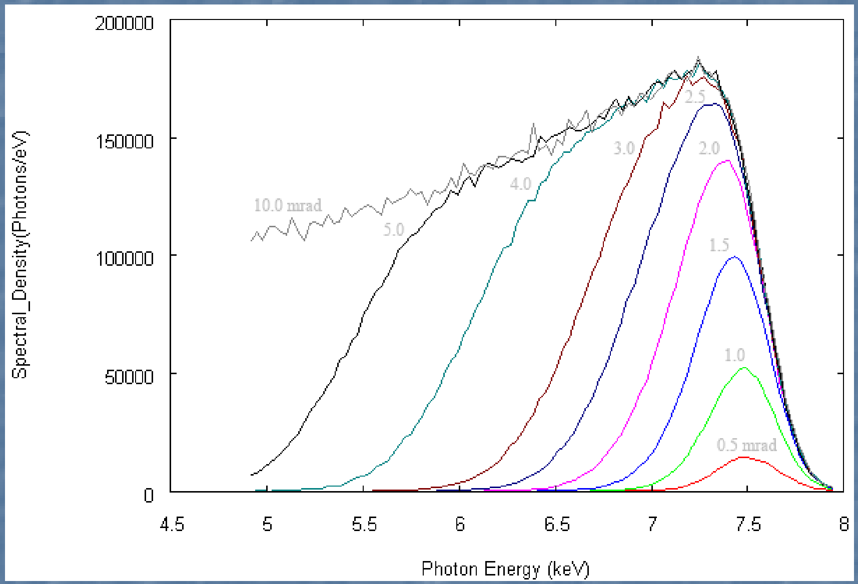
Simulated parameters

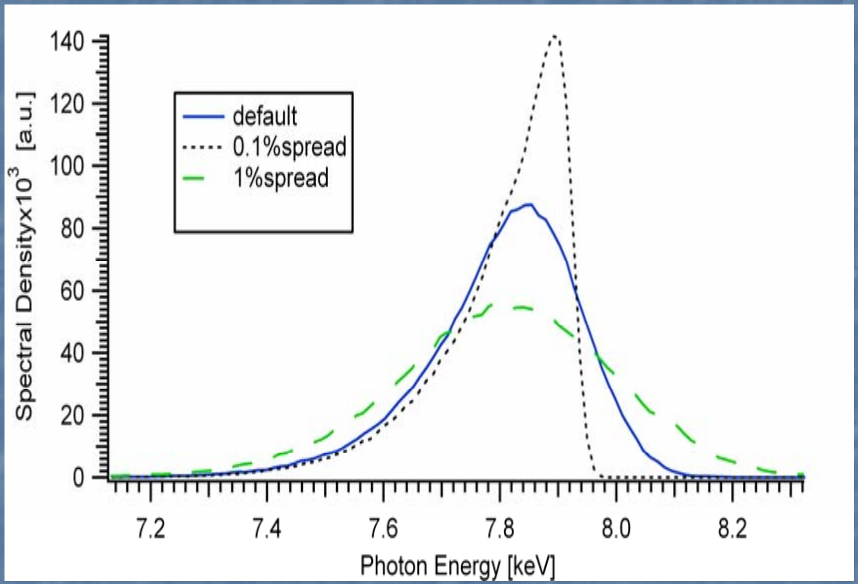
Electron Beam	
Parameter	**Value**
Energy	64-72 MeV
Beam size (RMS)	30 μm
Bunch length (FWHM)	0.3-4 ps
Emittance	2 mm-mrad
Energy spread	0.5-1.0%
Charge	300 pC

Laser Beam	
Parameter	**Value**
Laser energy	2 J
Waist size (RMS)	60 μm
Pulse length (FWHM)	6 ps
Bandwidth	~0.6%
Wavelength	10.6 μm
Laser potential (a_L)	0.38

X-rays	
Parameter	**Value**
Total Photons (N_T)	1×10^9 (on-axis: 2×10^7)
Energy (on-axis)	7-8.9 keV
Bandwidth	2-3%
Pulse length	0.3-4 ps
Full opening angle	~8 mrad
Peak Brightness (B_{peak})	10^{19}-10^{20} ph/s/mm^2/mrad^2 (0.1% BW)

Simulated x-ray spectra





ICS spectra for various acceptance angles (0.5 to 10 mrad) at 65 MeV and $\Delta\gamma/\gamma$=1.0%.

ICS spectra on-axis and the effects of e-beam energy spread. Reducing to 0.1% spread results in the dominance of beam angles on the bandwidth.

Making the photons

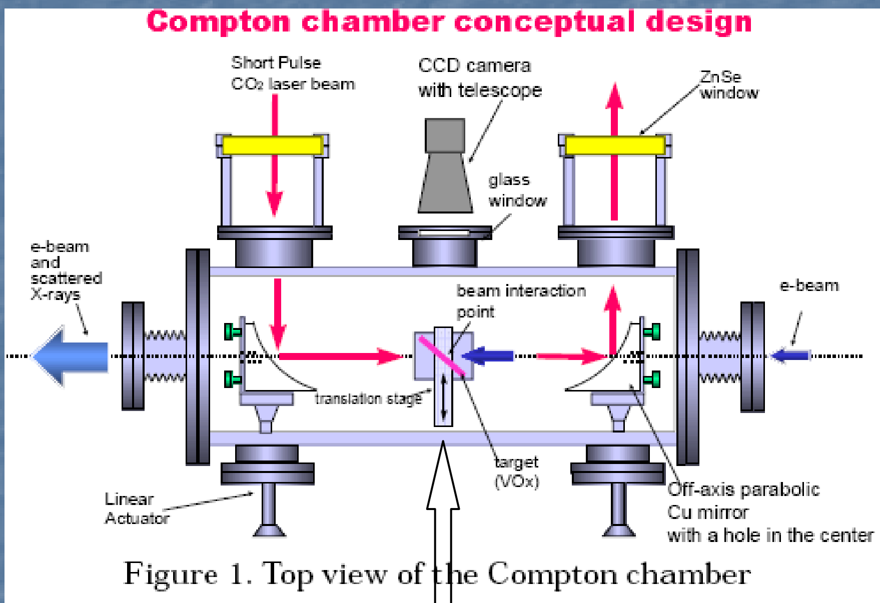


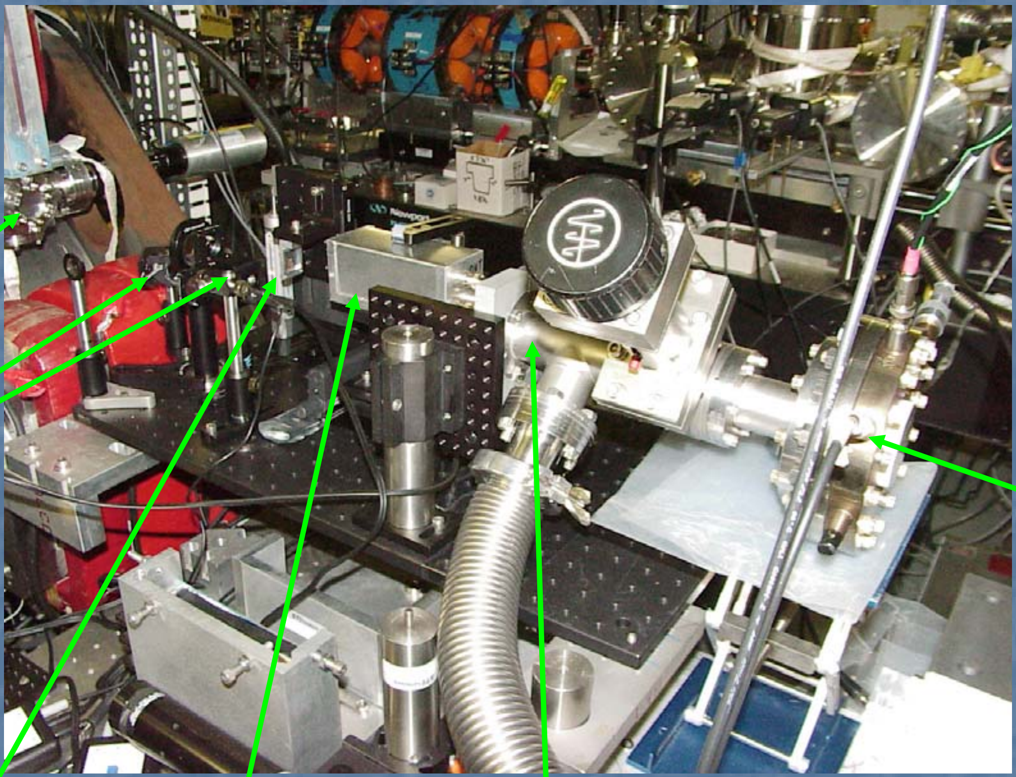
Figure 1. Top view of the Compton chamber

Alignment probe now replaced with retractable 120 μm pinhole and Ge-wafer on micro-positioner

Analyzing the photons

250 µm Be-window

Insertable Ni and Fe foils



MCP image intensifier

1 mrad pinhole on remote 2-axis control

Remotely insertable Si-diode detector

250 µm Be-window

Microchannel Plate (MCP) Image Intensifier

- 12 μm channel spacing
  (~12 μm limiting resolution)
- 40 mm detection area
- Fiber-optically coupled phosphor
- few % detection efficiency
- High gain "chevron": 10^7

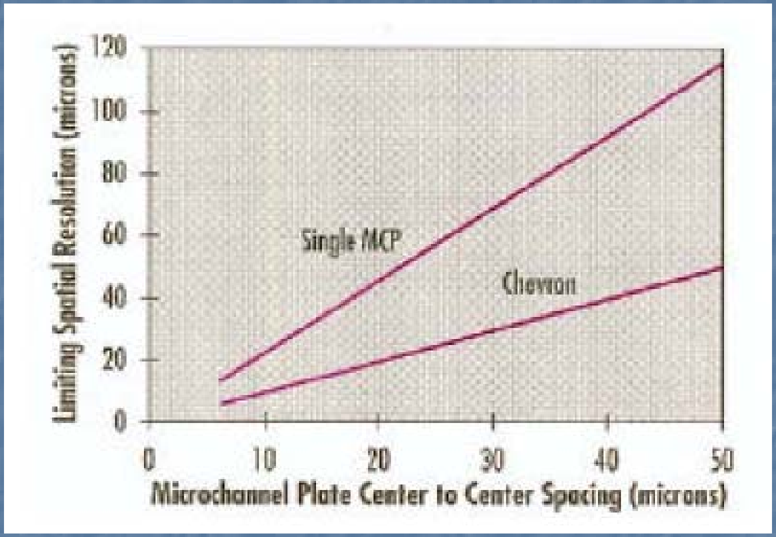
Voltage required after foil:

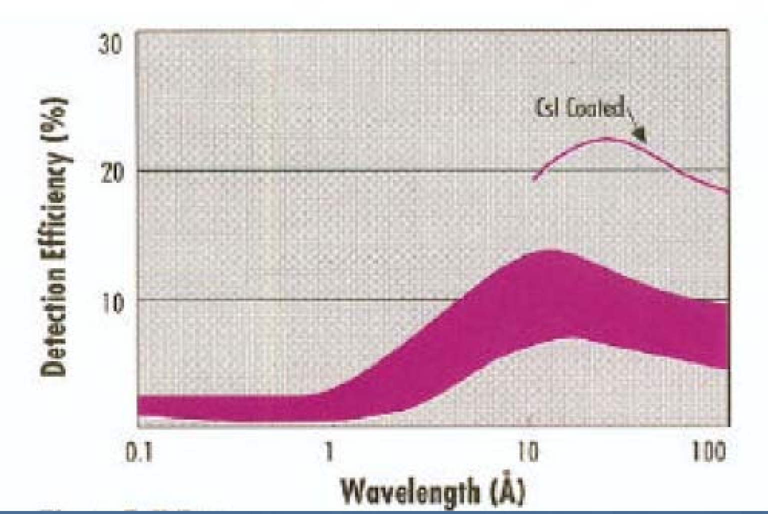
Phosphor screen = 6 kV
MCP stack = 1.5 kV

Our intensifier accepts:

Phosphor screen = 6.5 kV
MCP stack = 2.4 kV

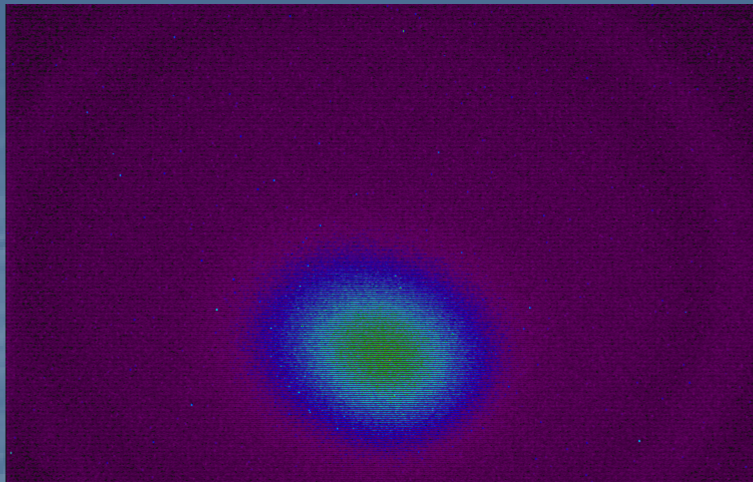
*Higher gain available for smaller (e.g. diffracted) signals



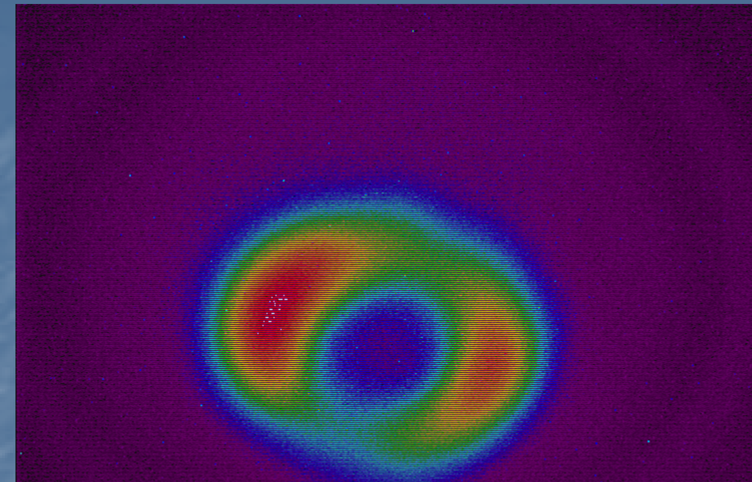


Confirming K-edge effect

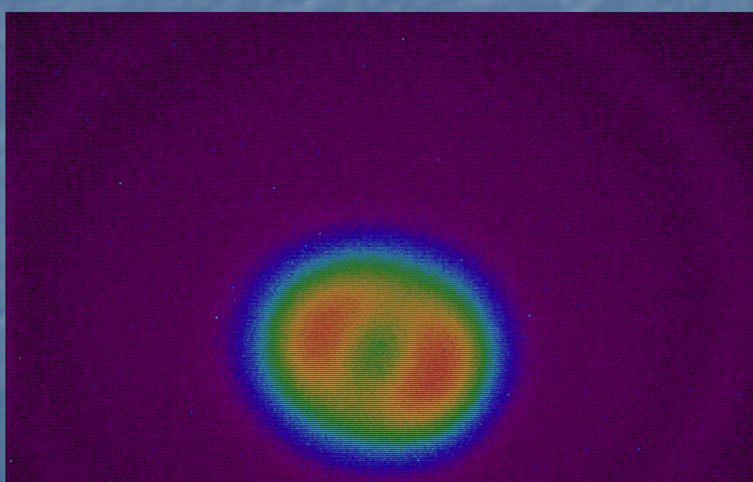
- Start with an e-beam energy of 72 MeV (~8.9 keV ICS photons)
- Guarantees being above K-edge of both iron (7.11 keV) and nickel (8.33 keV) for red-shifted off-axis photons
- Laser is linearly polarized



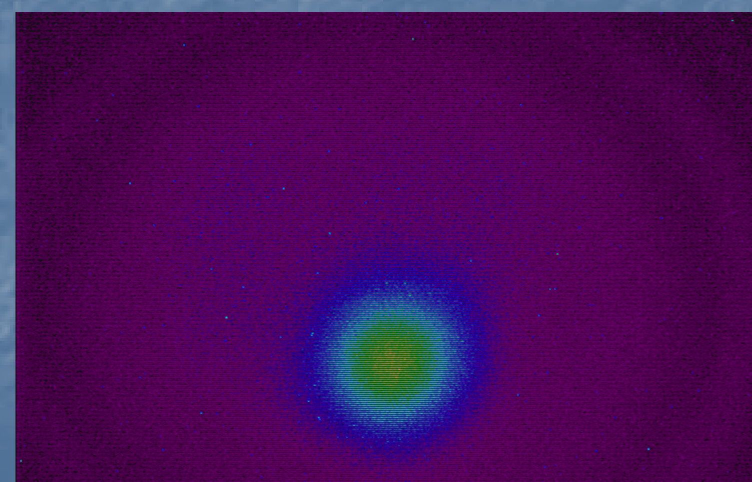
No foil



Iron foil



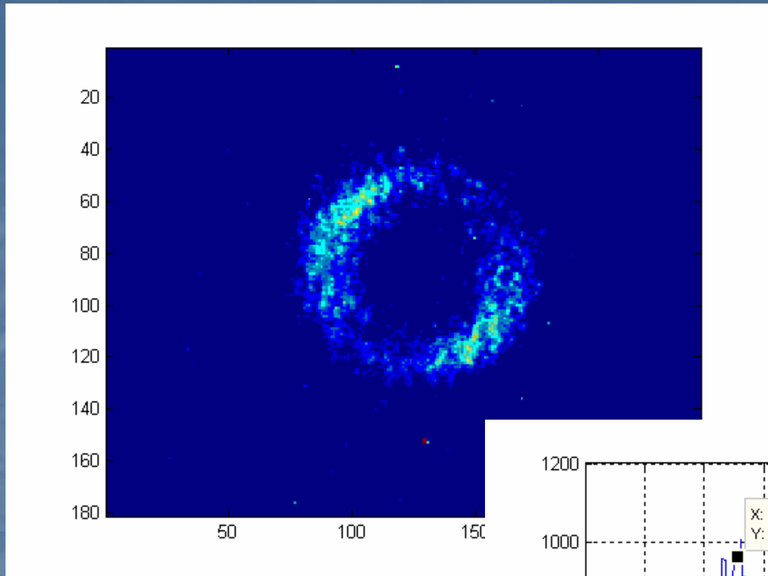
Nickel foil



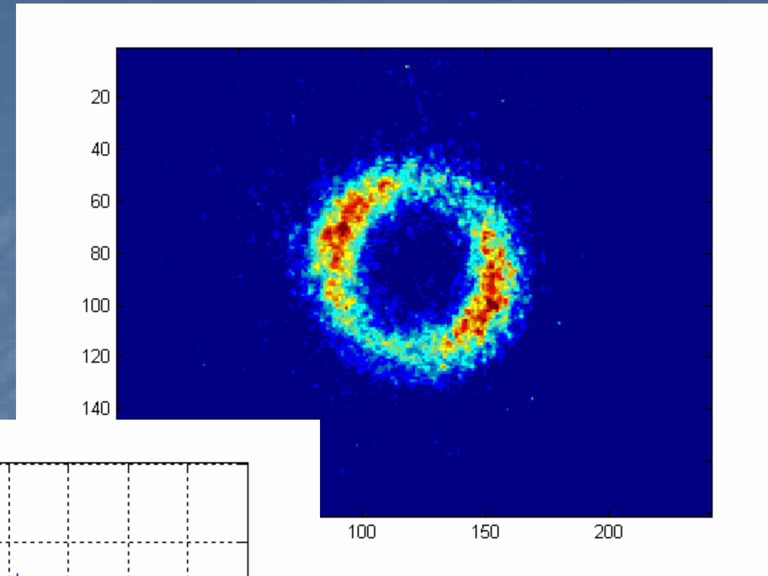
Silver foil

Double Differential Spectrum

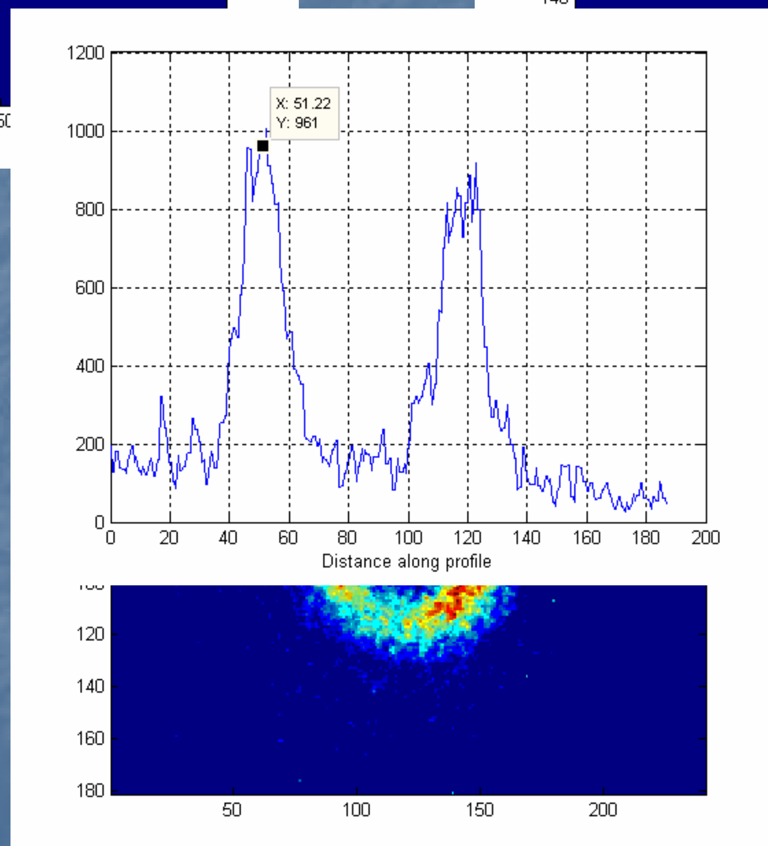
- e-beam energy scan from 72 MeV to null closure
- Does data match simulation? Undulator equation?
- Can we quantify bandwidth?



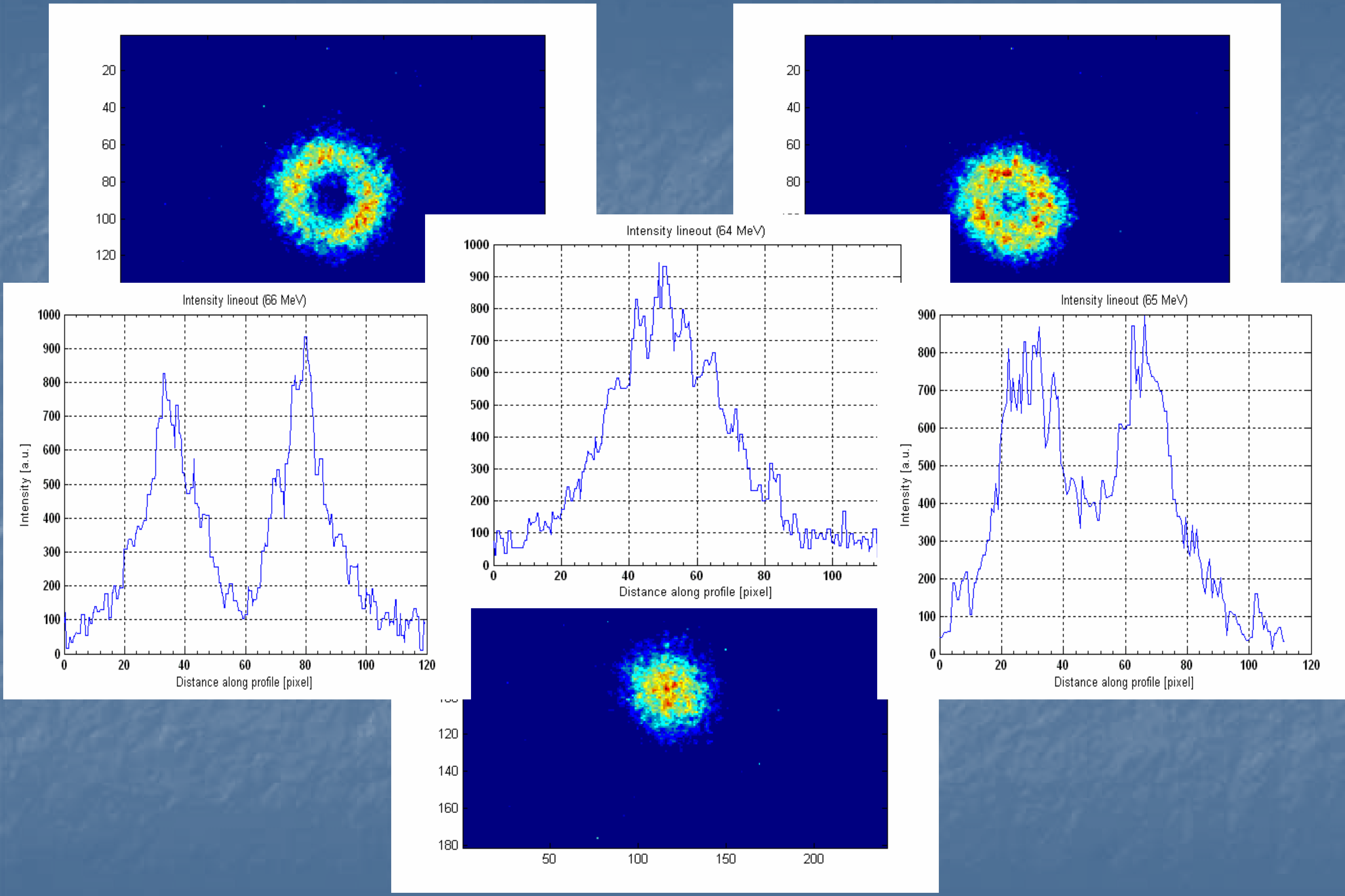
72 MeV



70 MeV

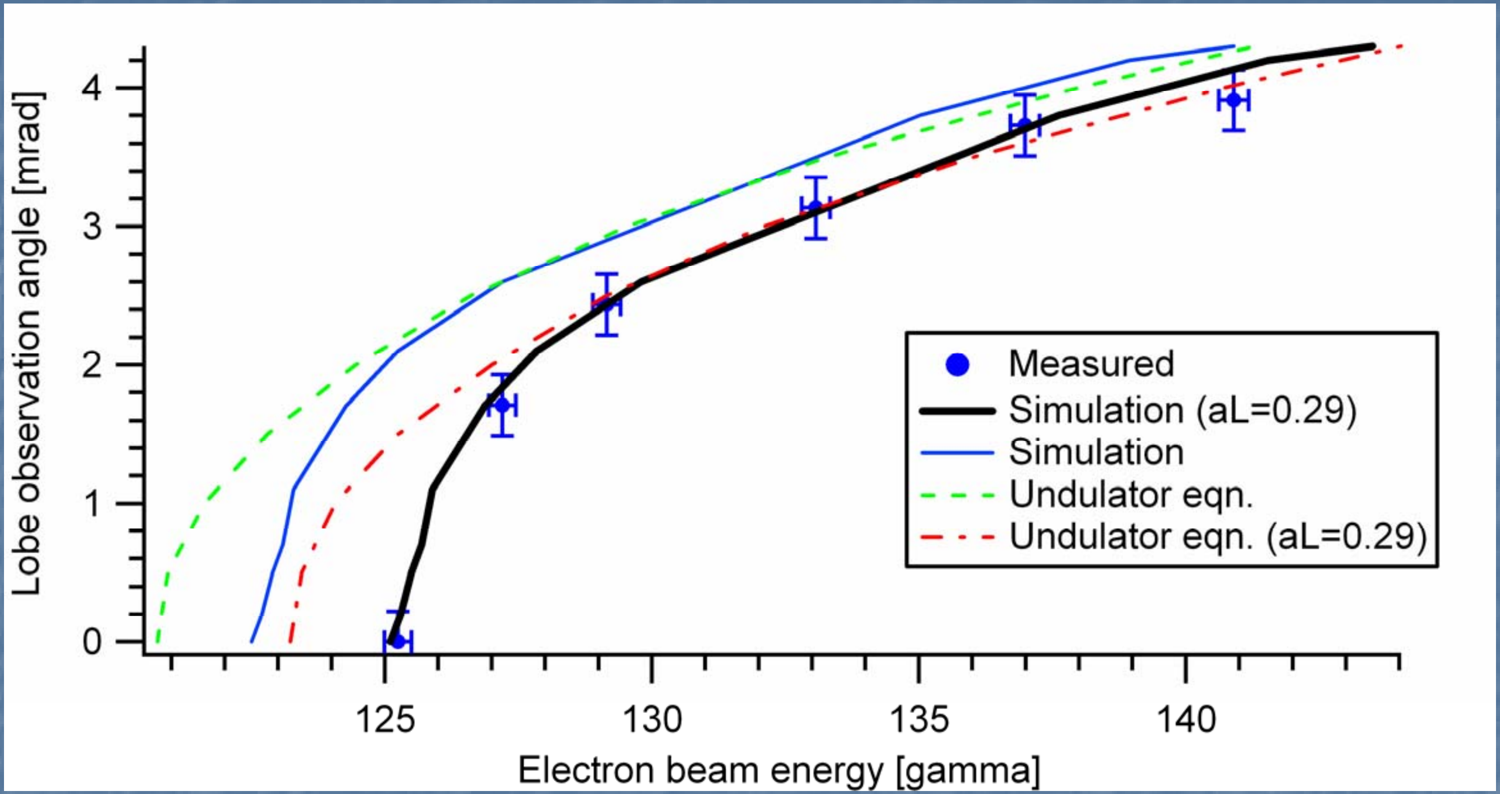


68 MeV


Intensity lineout (66 MeV)
Intensity lineout (64 MeV)
Intensity lineout (65 MeV)
Intensity [a.u.]
Distance along profile [pixel]
Distance along profile [pixel]
Intensity [a.u.]
Distance along profile [pixel]

64 MeV

Lobe observation angle

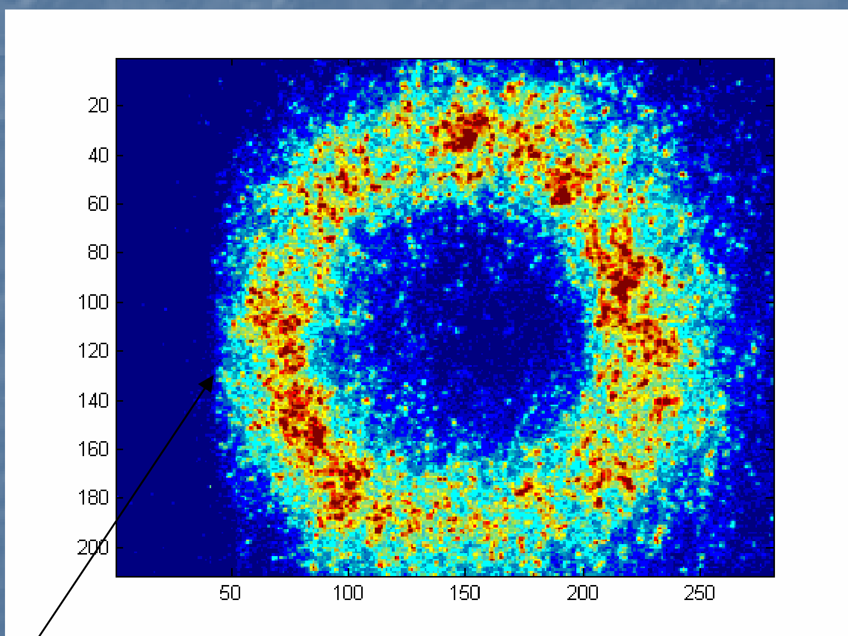


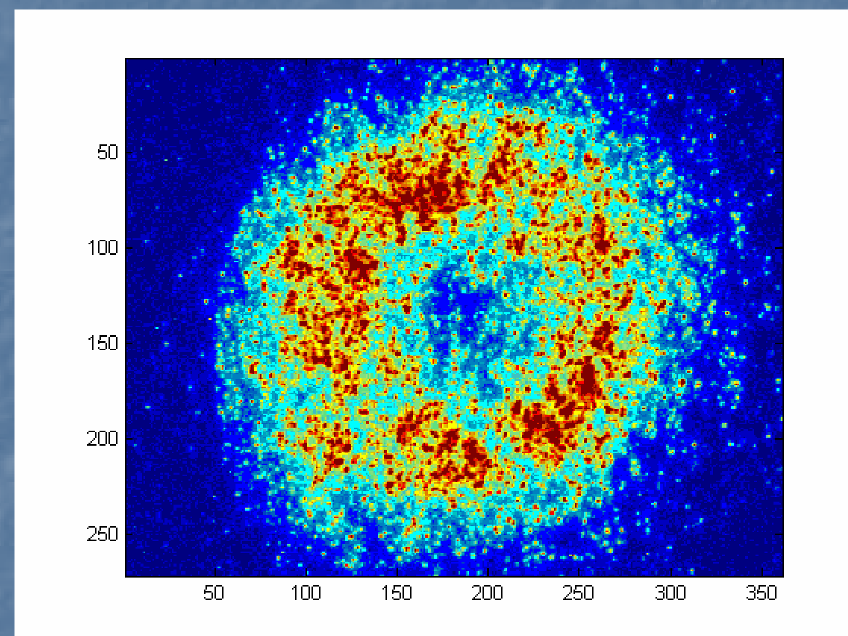
-Max simulated lobe intensity shows peak at 6.9 keV

-Fit simulation curve to data by adding energy offset (~290 eV)

-Energy offset could be due to absolute e-beam energy calibration or nonlinear induced red-shifting (a_L>0)

Circular polarization/compression





X-rays clipped passing through hole in laser mirror

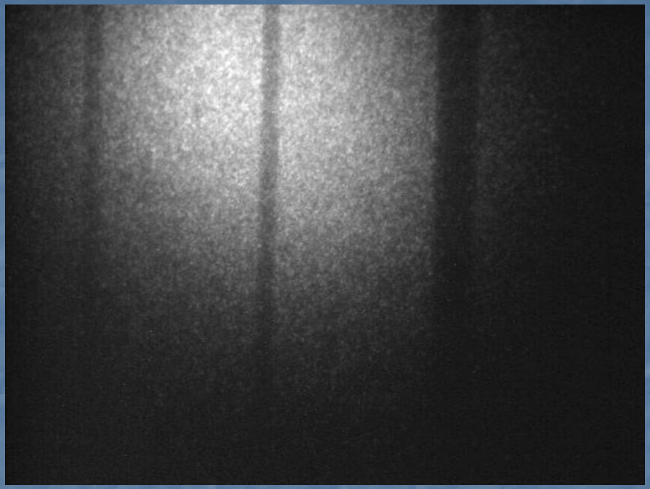
68 MeV, 4 ps FWHM e-beam
($2\Delta\gamma/\gamma=\Delta E/E=1\%$)

68 MeV, 300 fs FWHM e-beam
($2\Delta\gamma/\gamma=\Delta E/E=2\%$)

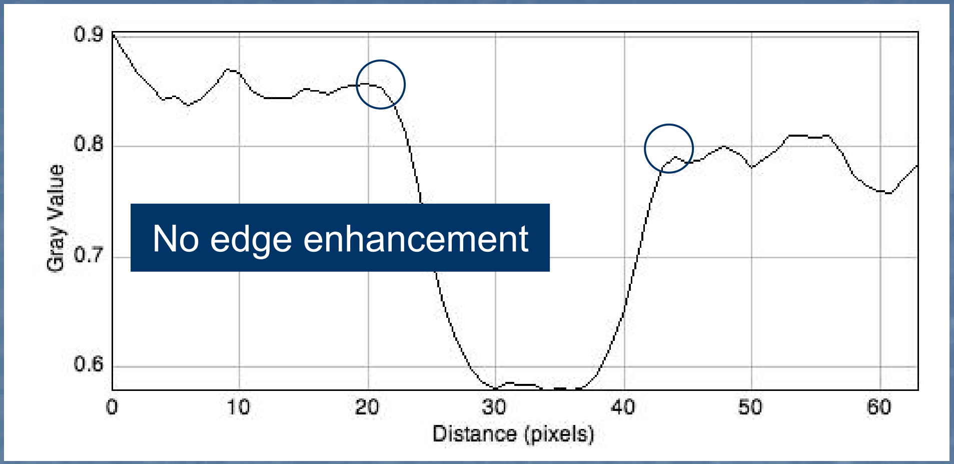
Measured on-axis flux and BW

- Need ~65 MeV e-beam to create ≤1 mrad null (with <50% photons transmitting on-axis)
- ΔE= 1.3 MeV = 290 eV => **BW = 4.0%**
- Measured **~2x10^{6} photons** through **1 mrad** pinhole placed on-axis
- B_{peak}= 10^{18}-10^{19} in pulses from 4 ps to 300 fs

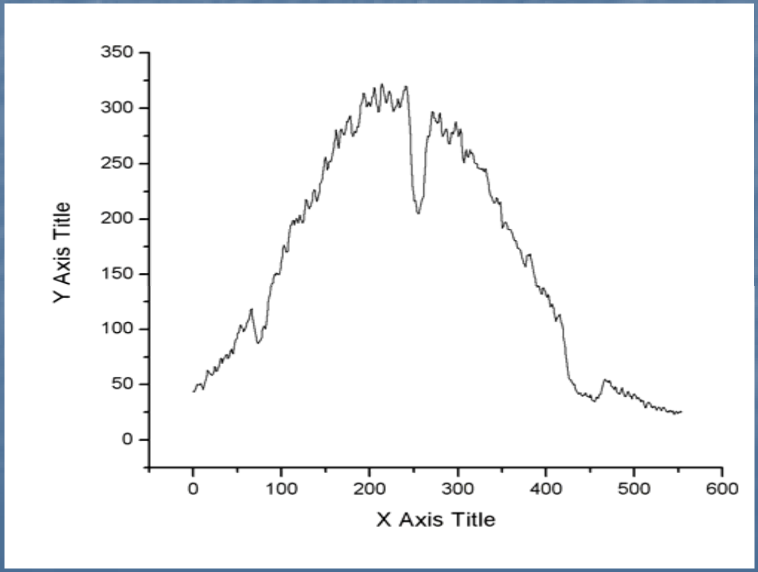
Phase Contrast Imaging

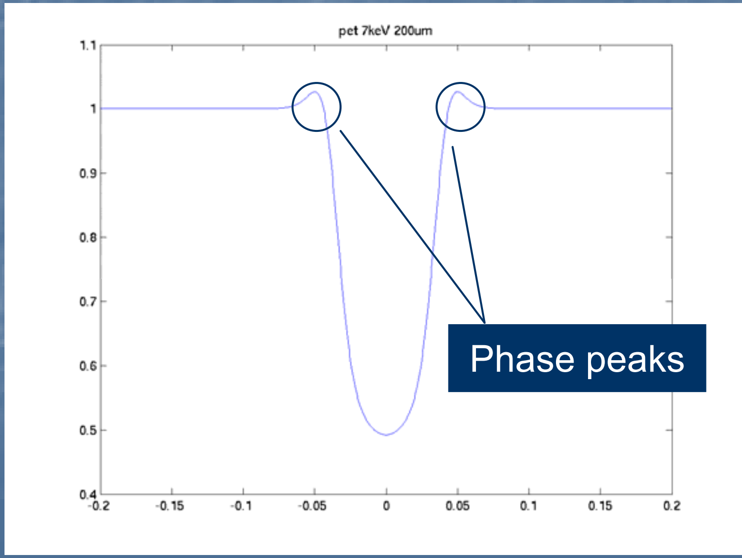


500 μm PET



Zoomed intensity lineout

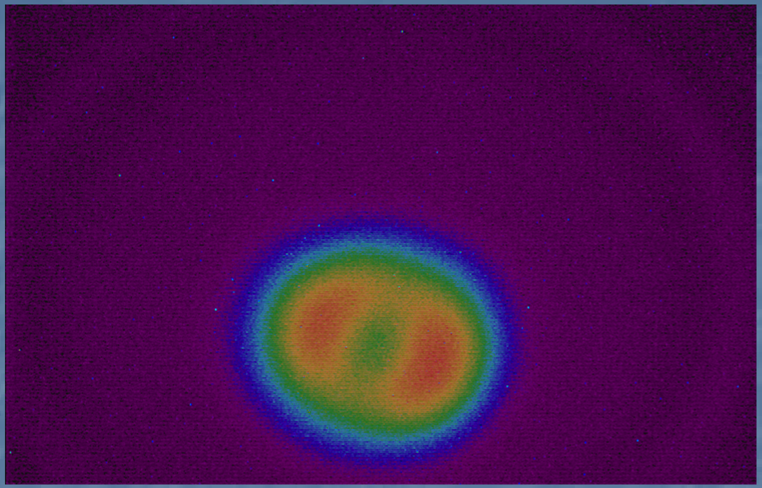




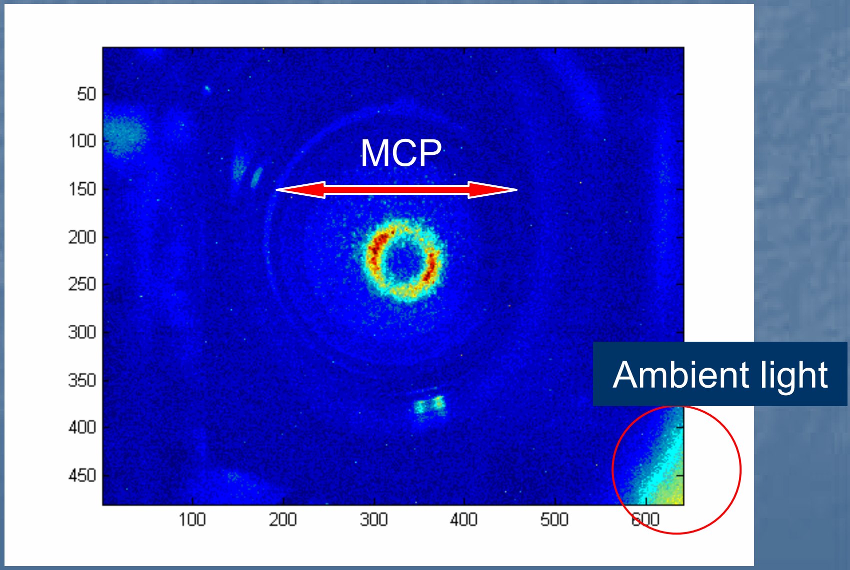
Simulated lineout

Limiting resolution

- Resolution limit due to: gain, channel size/spacing, MCP-phosphor distance, imaging optics and CCD
- Do not expect worse than 50 μm resolution from MCP
- "Grains" exist in CCD image; not due to MCP



Standard CCD



TE-cooled CCD (req'd different lens)

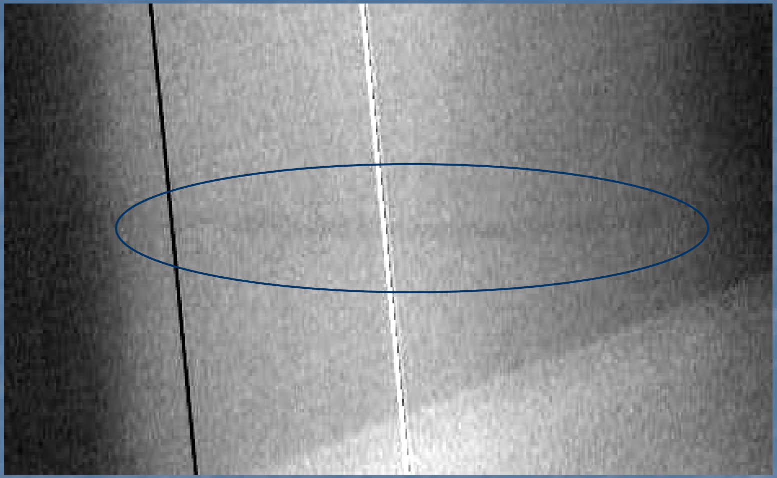
Possible imaging improvements

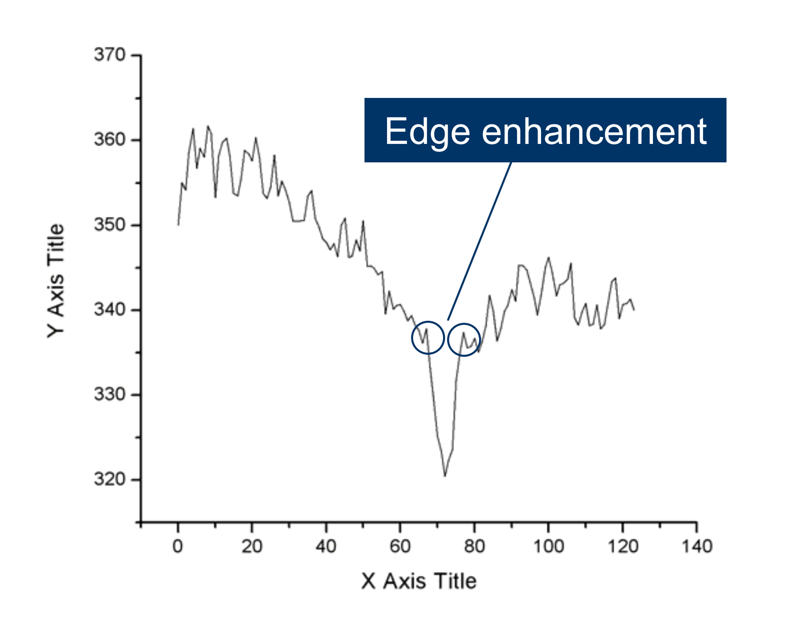
- High resolution CCD and imaging optics:
  - -Optimized transport optics
  - -Fiber-coupled CCD
- Direct detection using in-house x-ray camera:

  -50 µm/pixel

  -req. ≥ 10 keV x-rays

  -Higher resolution imaging necessary for future applications and better source characterization





Summary

- ATF Compton source characterized:
  - ~2×10^6 photons over 1 mrad with 4-5% bandwidth in 0.3-4 ps
  - Linear or circularly polarized x-rays
  - Easily tunable source energy
  - $B_{peak}=10^{18}$-10^{19} photons/s/mm^2/mrad^2 (0.1% BW)
- Source qualities show promising imaging capabilities
- Need to work on optimizing imaging
- Higher energy x-rays (>10 keV) allow for fewer imaging elements in form of direct detection via x-ray camera