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Simulation of Parametric X-Ray Radiation

Todd Seiss
Mentor: Tanaji Sen
Lee Teng Summer Internship Program

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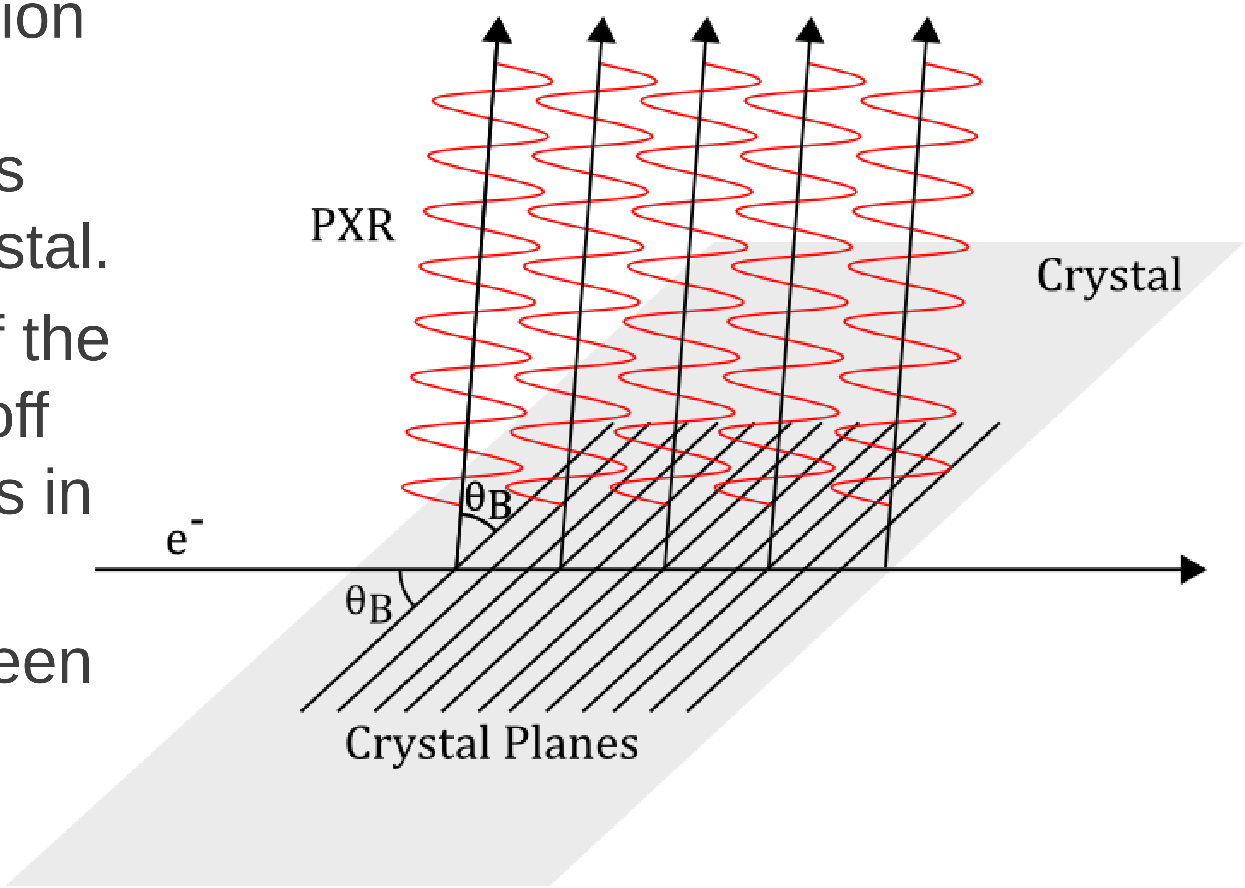
Outline

- What is Parametric X-Ray Radiation?
- Why PXR?
- Properties in the Idealized case
- Anomalous Effects
- Future of the experiment at Fermilab
- Conclusion

What is PXR?

- PXR is x-ray radiation emitted when relativistic electrons pass through a crystal.
- The electric field of the electron “reflects” off the planes of atoms in the crystal.
- The distance between the planes and the angle of reflection determine the properties of the PXR.



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Why PXR?

- PXR can be emitted at large angles with respect to the beam, avoiding other background radiation (Bremsstrahlung, channeling)
- Quasi-monochromatic
- Energy can be tuned simply by rotating the crystal.
- Relatively narrow emission cone.
- Potential use for clean medical imaging

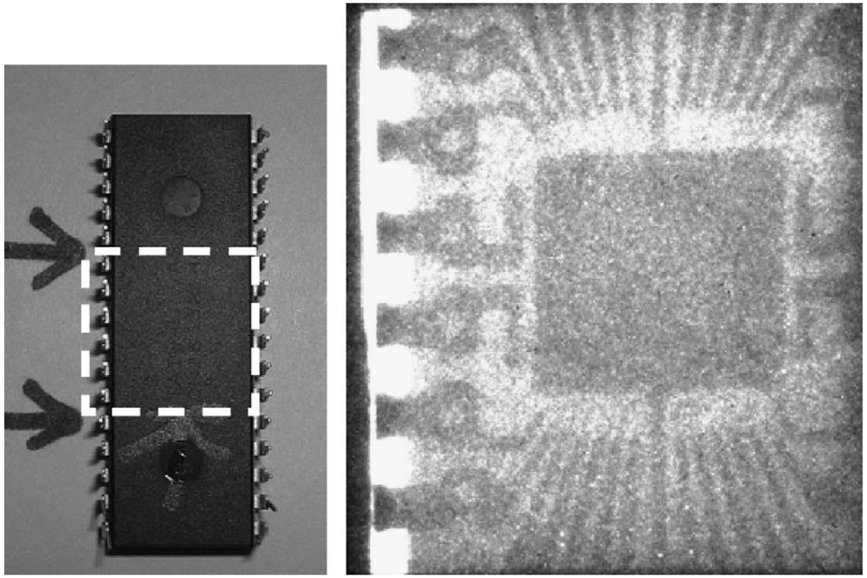
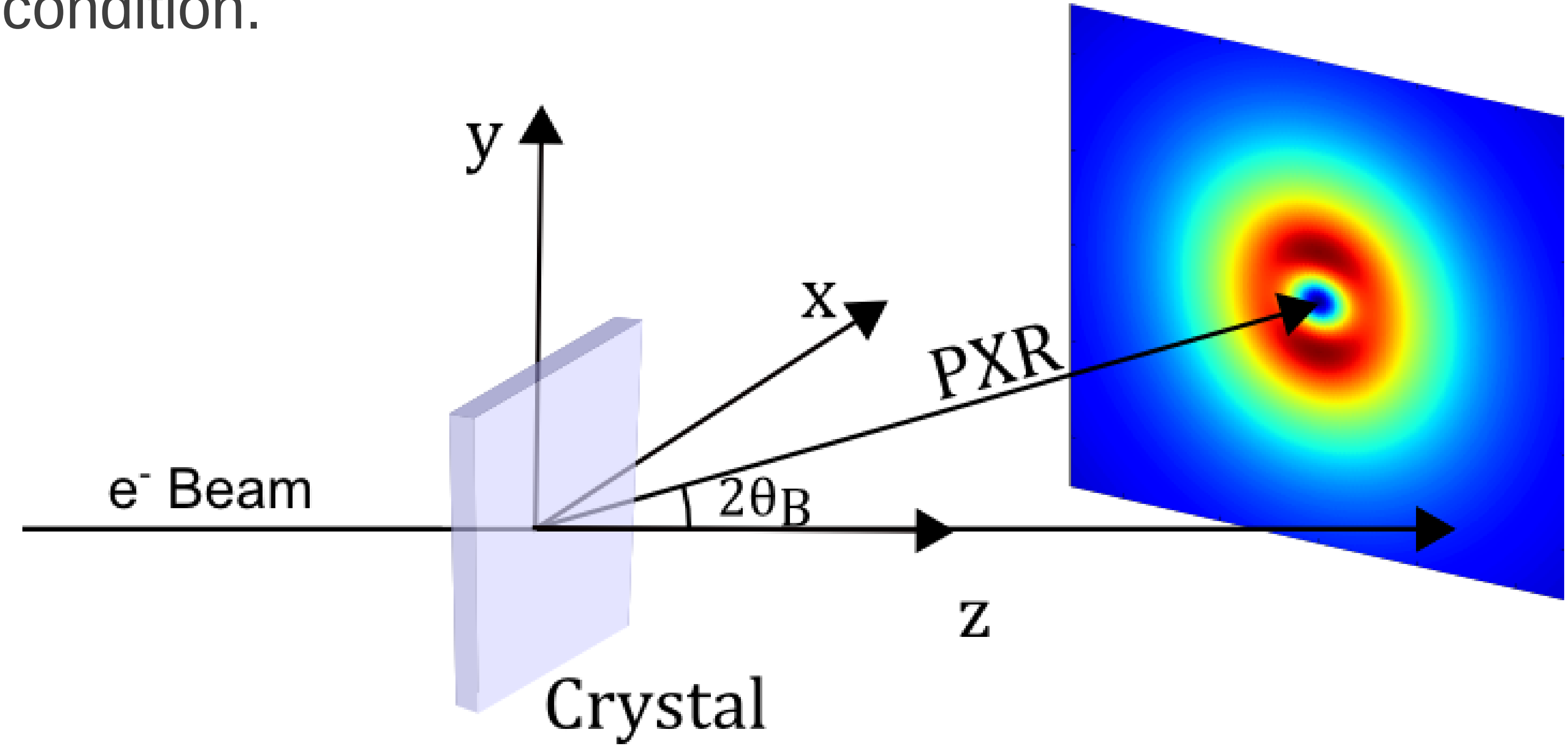


Image Source: Sones, Danon, Block. X-Ray Imaging with parametric X-rays. RPI. 2006

Idealized Properties – Angular Distribution

- The theory developed for PXR states that it should have two intensity peaks, above and below the diffraction (yz) plane. There would be zero radiation at exactly the Bragg condition.



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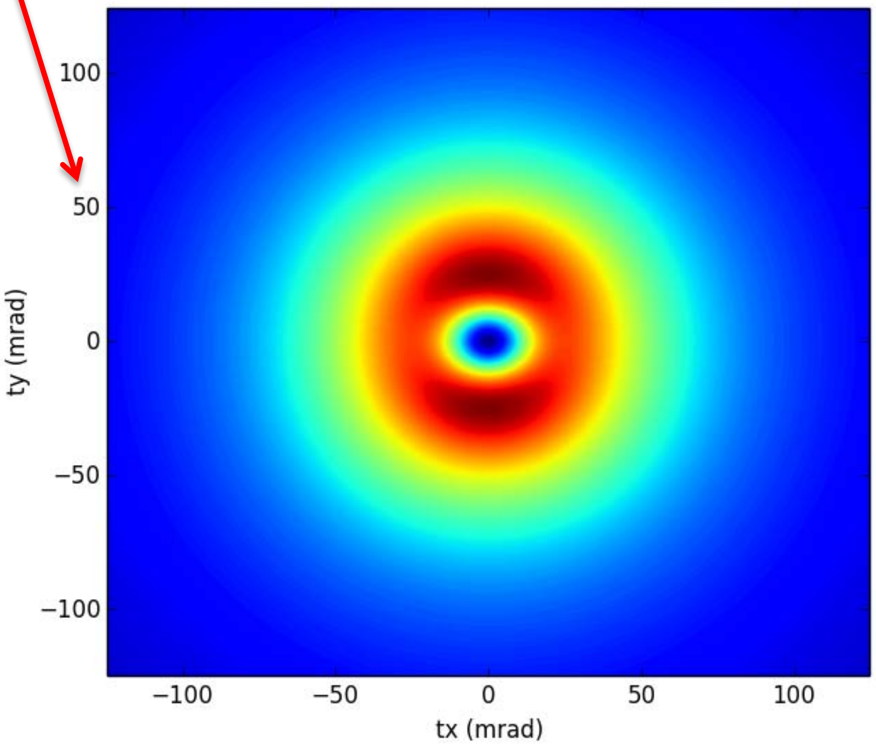
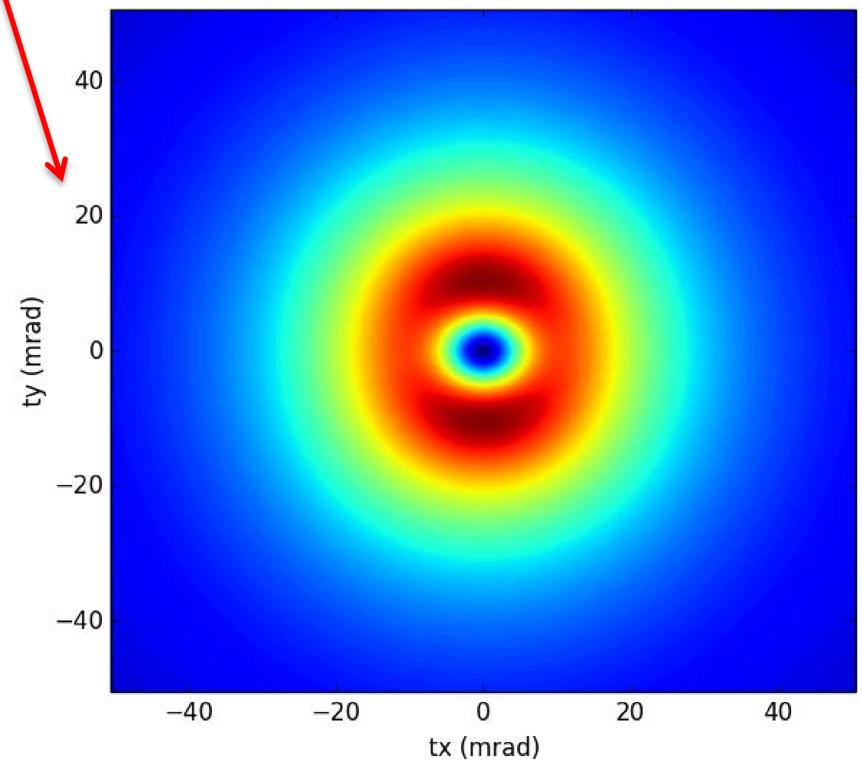
Idealized Properties – Angular Distribution

- Angular distance of peaks from center is $1/\gamma$ ($1^{o} \approx 18$ mrad)



20 MeV



50 MeV

Idealized Properties – Energy

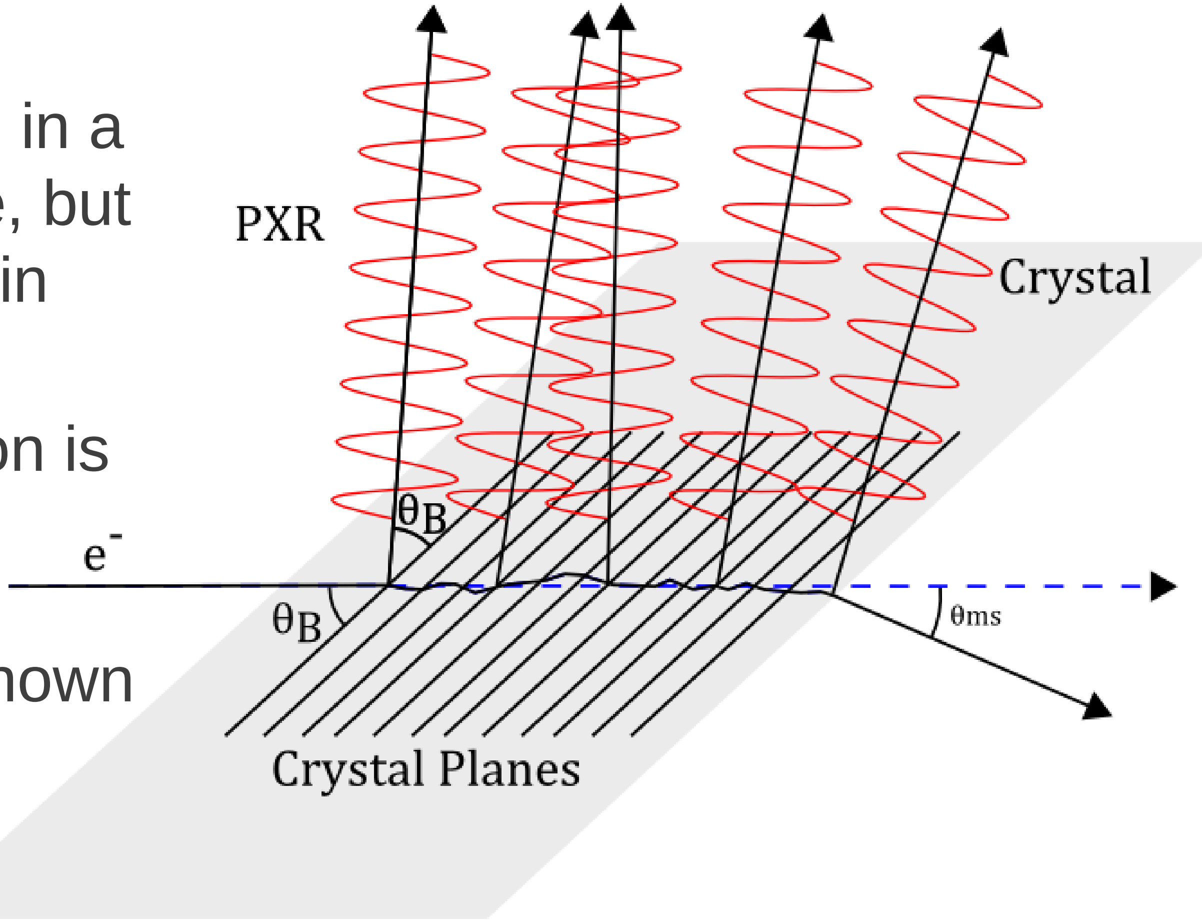
- In principle, the natural energy linewidth of PXR is extremely narrow (on the order of millielectronvolts), determined by the Bragg angle.

$$E = \frac{\hbar c \tau}{2 \sin \theta_B}$$

- Tau is a property of the crystal related to the spacing between the crystal planes.
- Rotating the crystal changes θ_B, which changes the energy. This means crystal rotations can be used to tune the x-ray energy.
- PXR energy **NOT** affected by beam energy.

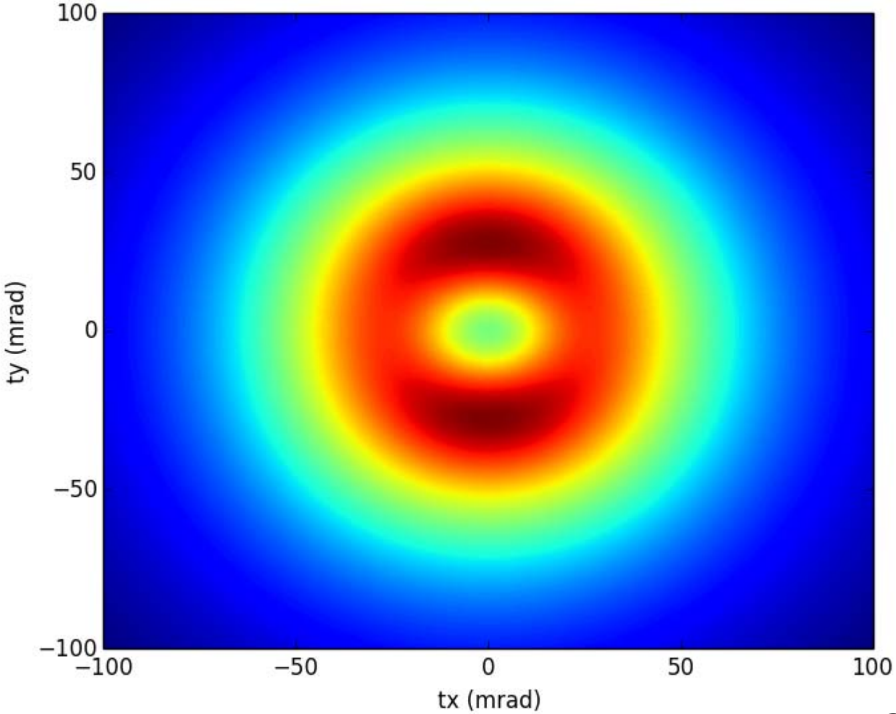
Anomalous Effects: Multiple Scattering

- When the electron passes through the crystal, it does travel in a perfectly straight line, but scatters from atoms in the crystal.
- This scattering motion is effectively random through the crystal, though with a well-known spread.



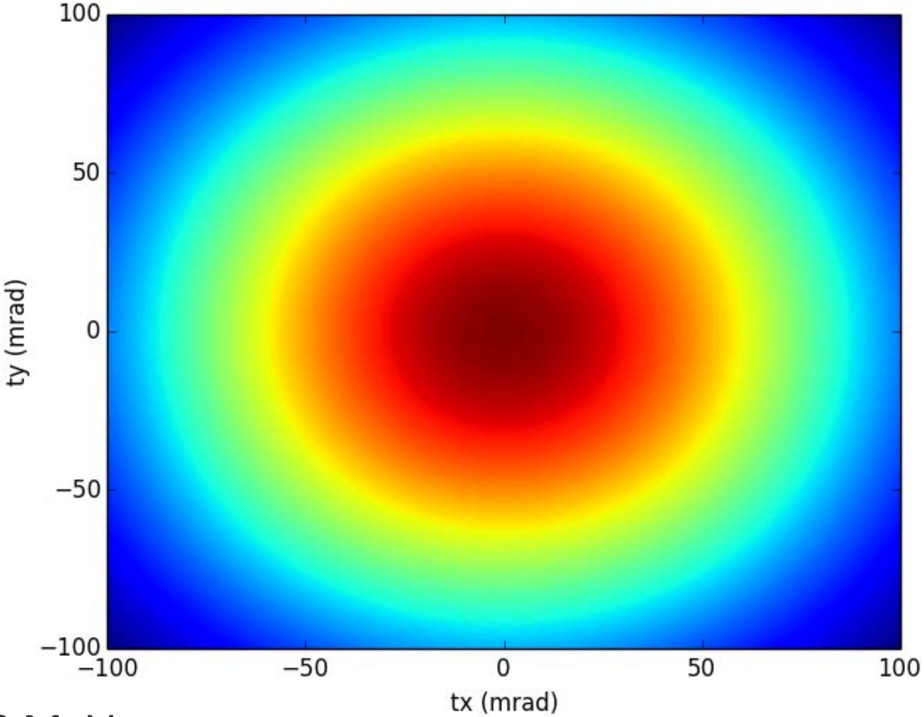
Anomalous Effects: Multiple Scattering – Angular Spread

- The thicker the crystal or the lower the beam energy, the more the electron tends to be deflected off-axis and the more significant the effect.



50µm Thickness

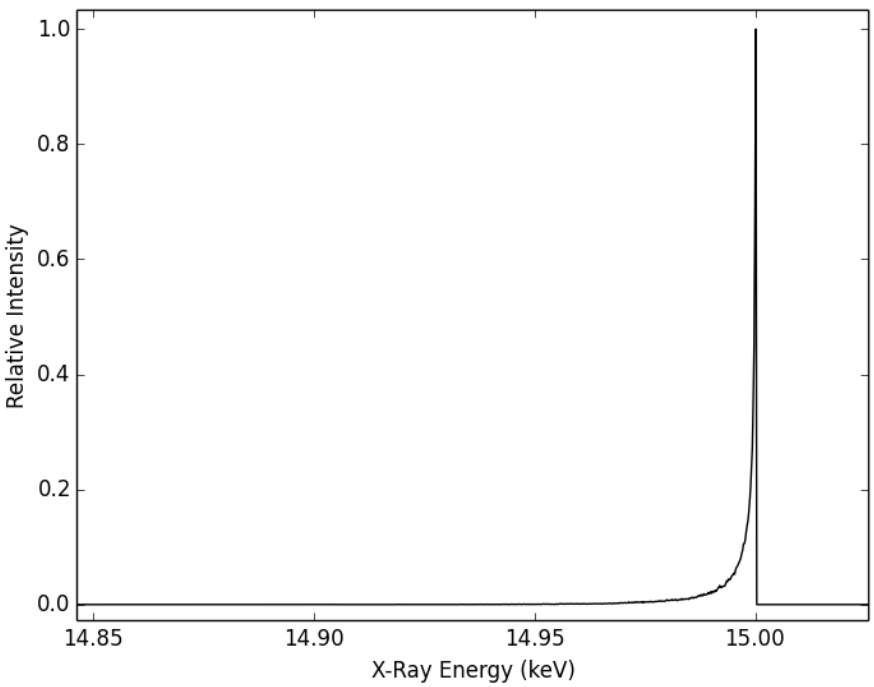
20 MeV Electrons



1mm Thickness

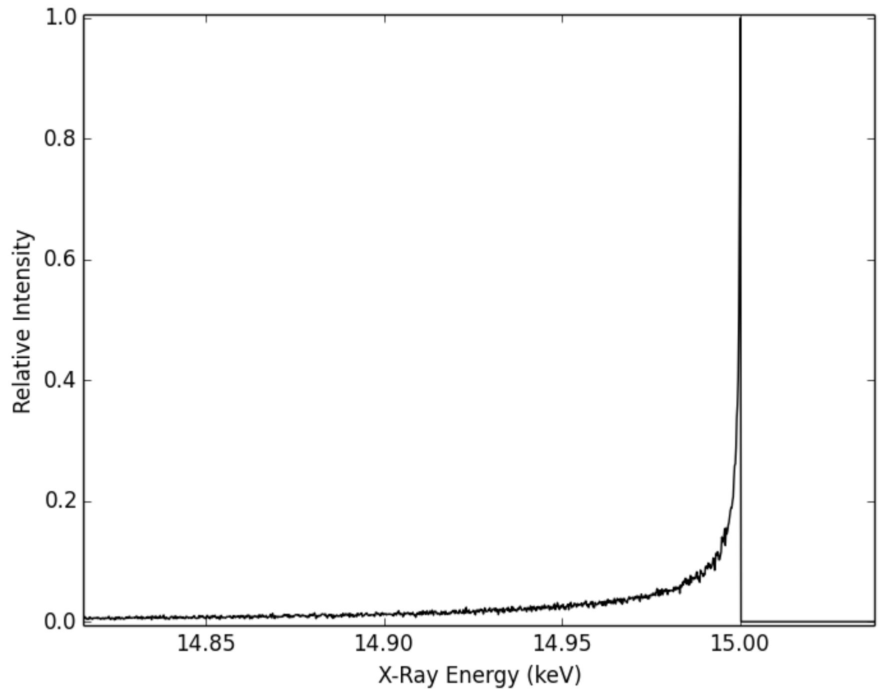
Anomalous Effects: Multiple Scattering – Energy

- Since the Bragg angle is changing at each crystal plane, the energy will have a larger spread at a given observation angle.



50µm Thickness
σ_E = 8.7 eV

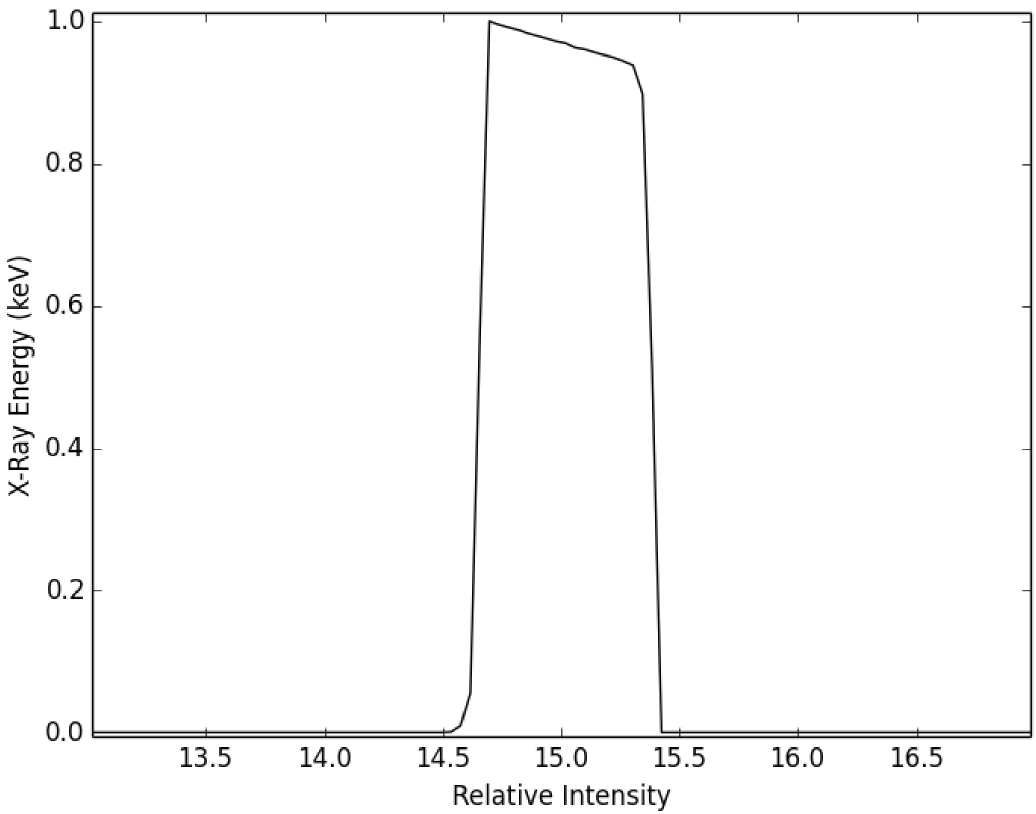
20 MeV Electrons



1mm Thickness
σ_E = 193 eV

Anamolous Effects: Detector Size

- Any detector spans a finite range of angles; therefore it also spans a range of energies. For a square detector 1cm on each side, 1 meter away from the crystal, the simulated energy distribution is shown.



σ_E = 213 eV

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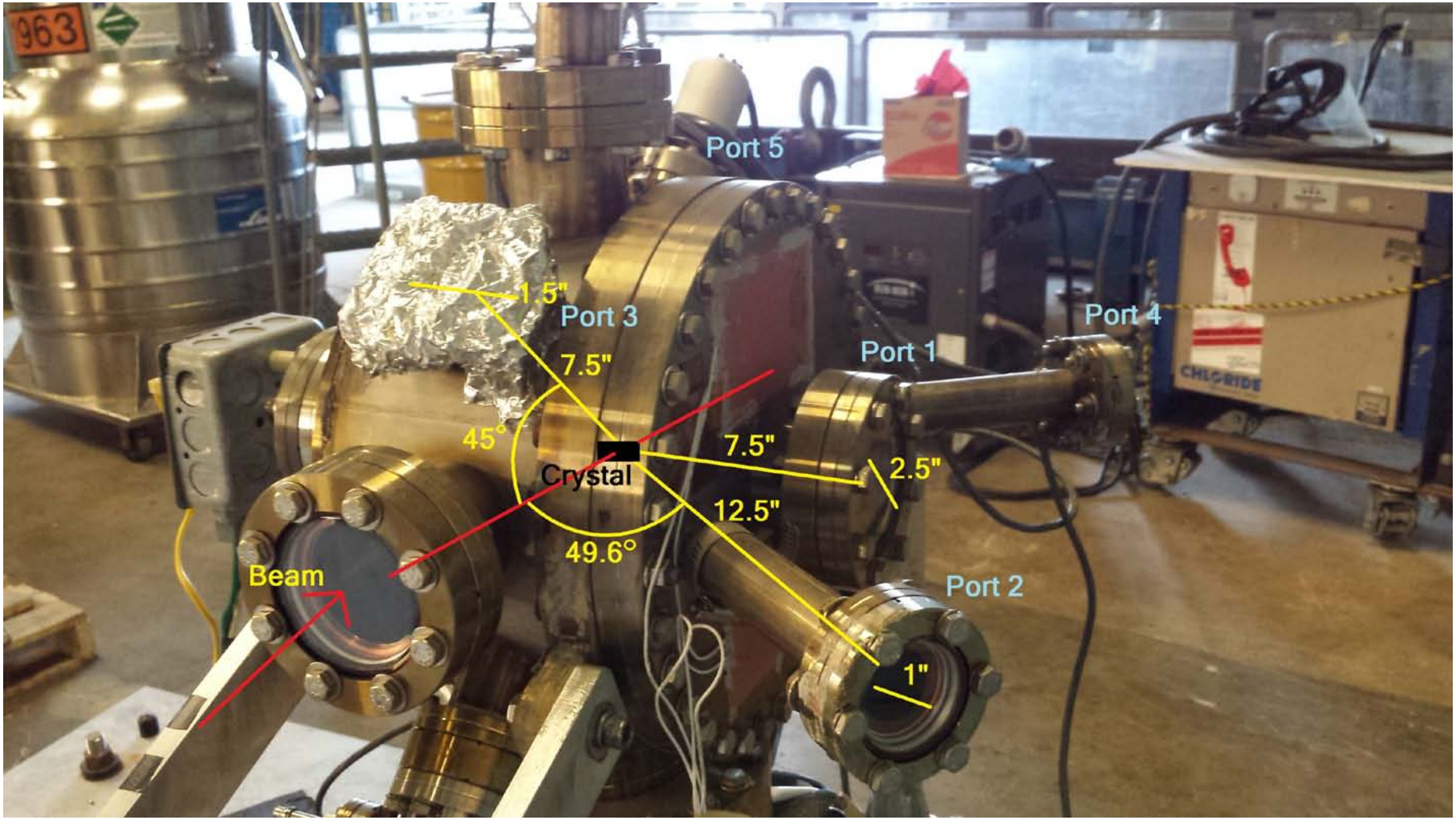
Other Anamolous Effects

- Beam divergence
  - Included, negligible
- Crystal Mosaicity
  - Negligible for diamond/silicon
- Finite bream radius
  - Negligible
- Finite PXR spot size due to crystal thickness.
  - Negligible
- Electron Energy Loss through Crystal
  - Negligible

Future

- PXR will eventually be tested at the low energy beamline at ASTA.
- Another type of radiation produced from crystals is channeling radiation, produced in the direction of the beam.
- This is going to be the experimental focus at first, though it may be possible to study PXR at the same time with judicious crystal rotations to properly orient appropriate crystal planes.

Future: New Goniometer



Summary

- I've characterized what will hopefully be seen at ASTA.

- PXR is an interesting new source of x-rays with many nice properties.

- Problems to overcome for it to be more useful:
  - Higher brightness
  - Higher energies
  - Tabletop setup

References

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