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Electro-Optical Detection

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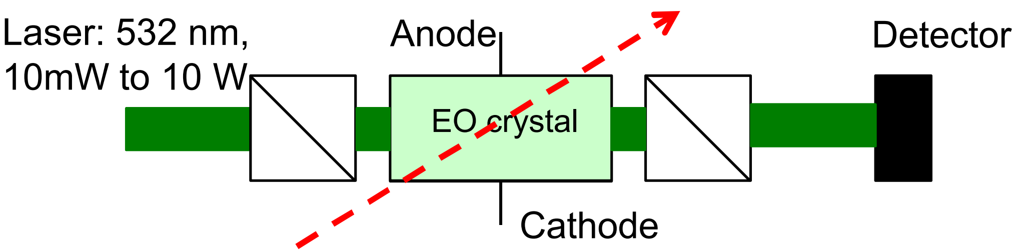

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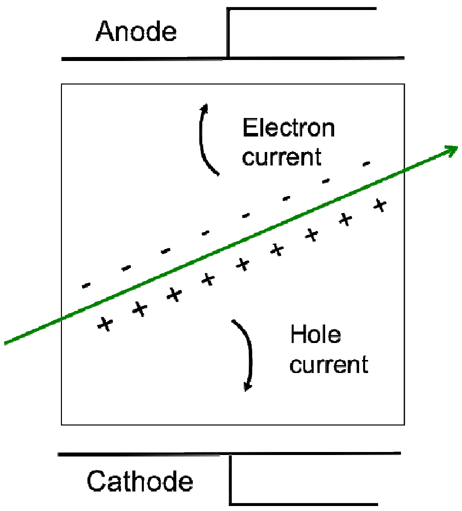
We are investigating a new type of radiation detector that supplies tracking information and identification.



An ionizing event generates free electron/hole pairs in the medium with which it interacts. This leads to a change of the index of refraction

Advantages:
The measured signal is independent of the scintillation light.
The intensity of the detected signal is proportional to the intensity of the incident signal and the effect (index change) in space and time, and can be time gated

We choose to develop a step by step understanding of the effects and detection limits

Given the magnitude of the change expected, we looked first at bulk effects. These have been seen and the community agrees.

<u>Gammas</u>:
A. I. Gusarov and D. B. Doyle, Vol. 37, No. 4, Applied Optics, Feb 1, 1998, bulk effect of gamma radiation on commercial optical glass.
M. Fernandez-Rodrıguez et al., Thin Solid Films 455 –456 (2004) - gamma rays on coatings
<u>Electrons</u>:
D. Gardner, Journal of applied polymer science vol. 11, pp. 1065-1078 (1967) - 13 MeV electrons in plastic

<u>X-rays</u>:
Berzins and Graser, Appl. Phys. Lett., 34, 500 (1979)
Robert E. Green, <u>Metallurgical and Materials Transactions A</u>, <u>Volume 20, Number 4</u>, 595-604, 1989
Z. Marka et l., ieee transactions on nuclear science, vol. 47, no. 6, December 2000, effect of x-rays measured through second harmonic generation.
Previous internal reports for this project in LiTaO3, not in KDP

<u>Neutrons</u>:
K. Nelson et al., "Investigation of CdZnTe and $LiNbO_3$ as electro-optic neutron detectors", Vol 620, Issue 2-3, 11–21 August 2010, Pages 363–367 (2010)
Nelson, K.A., et al., Nuclear reactor pulse calibration using a CdZnTe electro-optic radiation detector. Appl. Radiat. Isotopes (2012), doi:10.1016/j.apradiso.2011.12.038
K. Nelson et al., NIM A 680 (2012) 97-102 – Electro-optic detector response to nuclear power pulses
Y. Eisen and A. Shor, IEEE transactions on nuclear science, vol. 56, no. 4, august 2009 - 1cm thick pixelated CZT detector, neutrons create bulk defects affecting spectral quality

Single track detection is more difficult

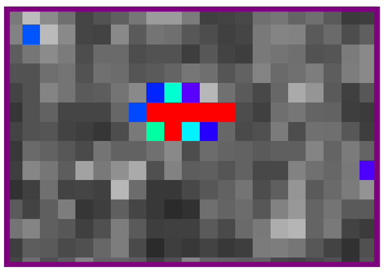
To understand single ionizing event we need to understand the detection limit experimentally in space and time.

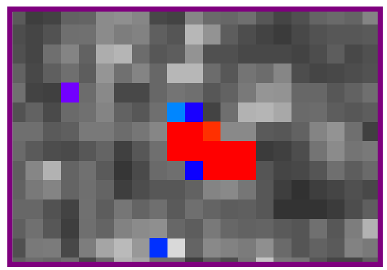
Typical statistically significant features

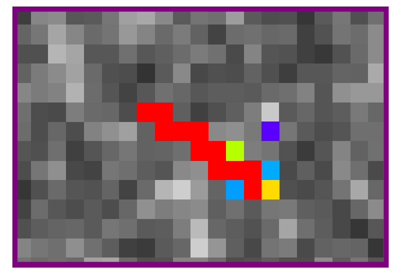
Greater maximum intensity: >50× background

Larger sizes: up to 13 pixels

Wider features: 5 – 8 pixels





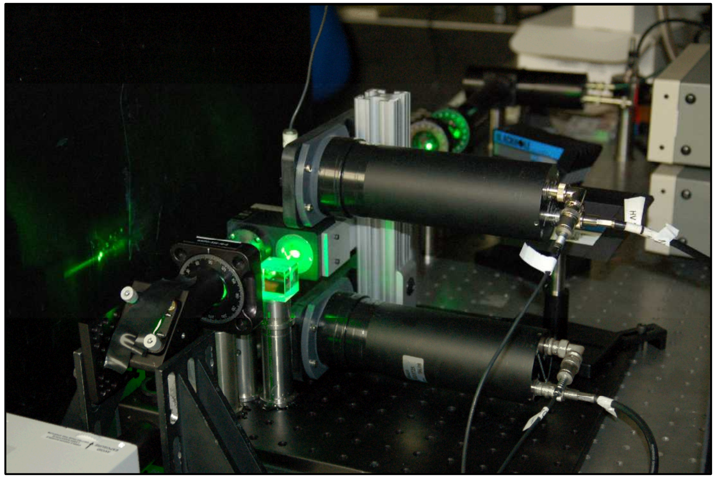


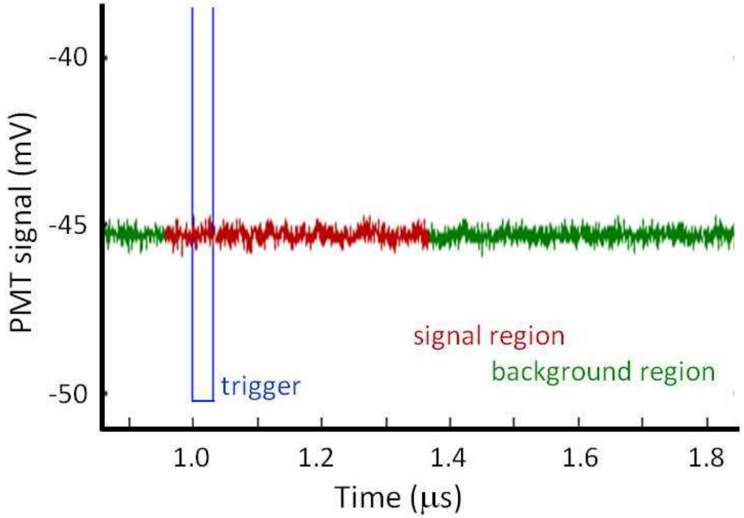
Direct imaging has limitation:

- Viewing region is ~1.7mm by 0.425mm with a 30 μm depth of focus, 25μm resolution
- Background cosmic ray interaction with CCD
- Direct radiation interaction with CCD
- Acquisition time 15μs

Background interactions in the CCD camera imitate charge particle interactions within the crystal

Timescale of the effect of a single ionizing event is expected to be ns to 10ns in crystals





Average of Raw Signal

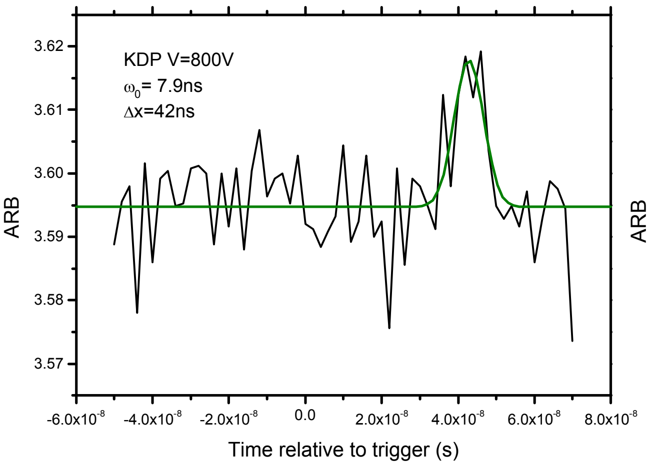
Method: Compare an average of PMT traces from 47 triggers

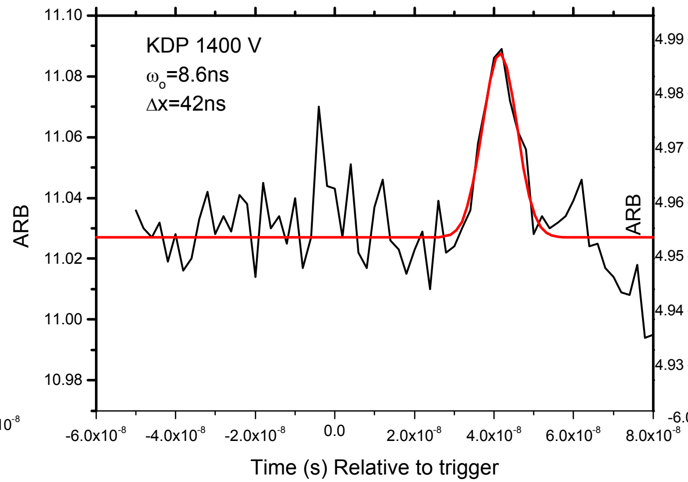
- Identify signal and background regions of the recorded data
- Signal region: + 0.4 ms from the trigger
- Background region: Time prior to and > 0.4 ms from the trigger
- Perform an FFT on both signal and background regions, and background-subtract

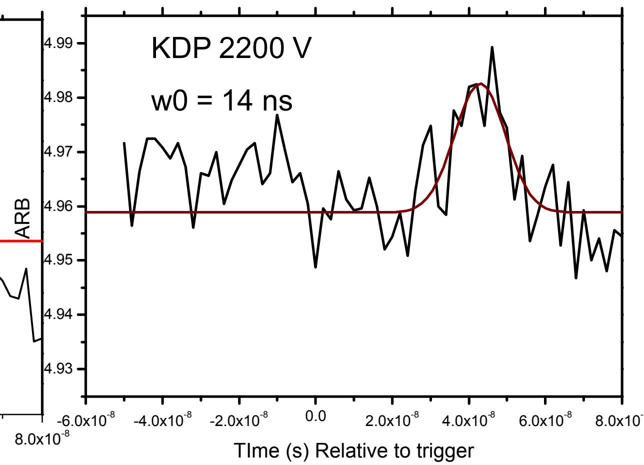
Result: region of interest identified at 39-45 MHz. Its amplitude varies with applied voltage.

Suspected signal is a few count above background. Further statistical analysis in progress

The effect varies with Crystal Voltages



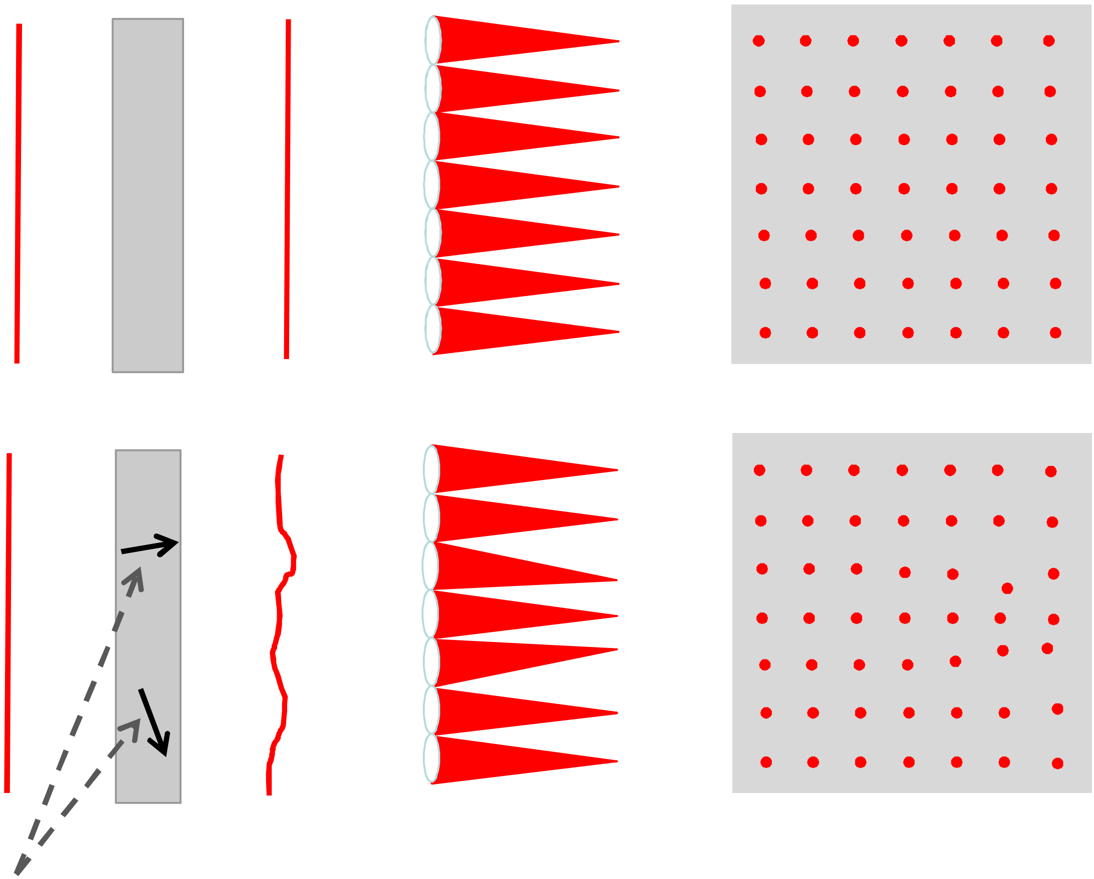




- Average of 130 triggers
- 0.5 % of the light on the tracks is rotated to pass through the cross polarizer
- 0.75 ns / 100 V change in the track duration
- Significant reduction in noise due to polarization impurity
  - Replaced mirrors with metal coatings
  - True 45^o light reflections
  - Limited by electronic noise

Improved understanding leads to multi-parameter method to supply track information and identification.

A planar wavefront incident on the array of micro lenses is focused into a regular pattern



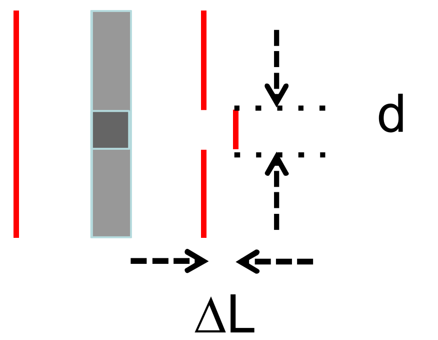
A deformed wavefront incident on the array of micro lenses is focused into a different pattern of dots

Recoils paths in material from ionizing radiation

Wavefront sensing is a well-known technique in astrophysics and high intensity lasers

An appropriate material and thickness as well as array of micro lenses will optimize potential for detection

Phase shift



$$\Delta L/\lambda \sim \frac{2}{\lambda}\left(\frac{n^3 r\sim}{\varepsilon}\right)\frac{eE\gamma/Epair}{4\pi\,\varepsilon_0 d} \sim 2.3\ 10^{-3}$$

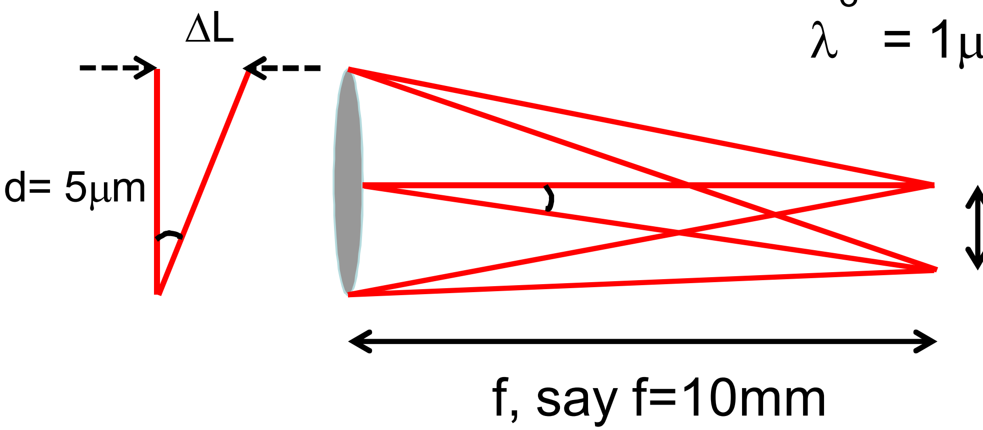
Material: CdTe

$n_o = 2.6$

$r\sim = 6.8\ 10^{12}$ m/V

$n_o^3 r\sim = 149$pm/V

$\lambda\ = 1\mu m$

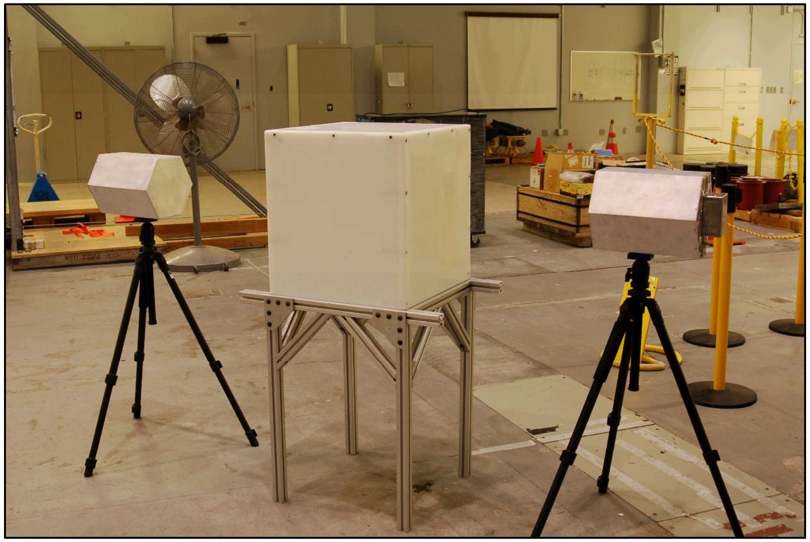


Corresponding displacement
$\delta min = \Theta min{*}f \sim 4.7\mu m$

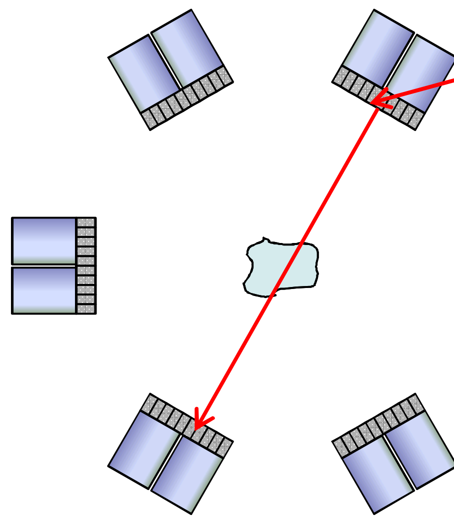
The pattern observed is different than background interactions in the CCD and sensitive to x, y, z, time, wavelength, intensity.

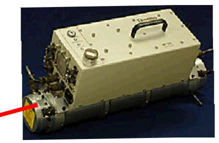
Because the method can potentially tell the direction of incoming radiation, just a few events can pinpoint to a location, while background is isotropic

Material Identification by Resonance Attenuation (MIRA) can identify elements and show their 3D shape



The detector is symmetric, allows for multiple sources (neutron or gamma) interrogating from opposite directions simultaneously.





$$E_{scat.} = \sqrt{\frac{E_{inc}}{1+\tan^2(\theta)}}$$

Fast neutrons have best potential for good penetration

Of all the threats considered (biological, chemical, nuclear, explosive materials), the detection of explosives has always been one of the main priorities, because explosives:

- are most frequently used by terrorists
- can be relatively easily bought or produced from available components
- can be relatively easily transported
- are relatively difficult to detect

Measurements are made over a large range of energies simultaneously. This helps constrain algorithms for material identification

- Feasibility has been proven
- Simulations are used for system design and data validation
- Commercial parts are used
- Blocks are segmented for spatial resolution
- Portable, modular, user friendly system
- Tests of the first block have started