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Influence of Surface Preparation of Bar-shaped Crystals on Detector's Performance

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G. S. Camarda[a], A. E. Bolotnikov[a], T. Chan[b], Y. Cui[a], M. Dudley[c], A. Hossain[a], K. H. Kim[a,d], K. Lee[a,d], B. Raghothamachar[c], U. Roy[a], G. Yang, and R. B. James[a]

[a]Brookhaven National Laboratory, Upton, NY
[b]University of Alabama in Huntsville, Huntsville, AL
[c]Stony Brook University, Stony Brook, NY
[d]Korea University, Seoul, Korea

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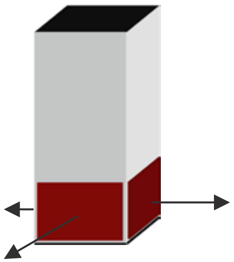
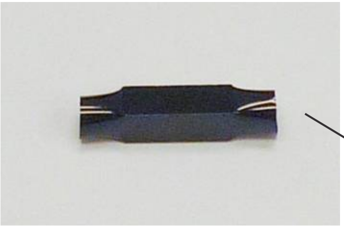
Motivation

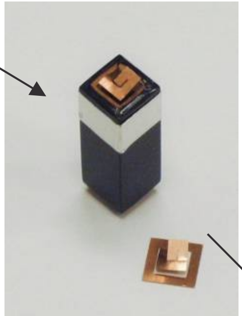
Schematic of a position sensitive virtual Frisch-grid detector



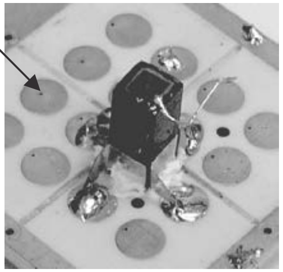
$6x6x15\ mm^3$



Detector encapsulated inside a thin polyester shell

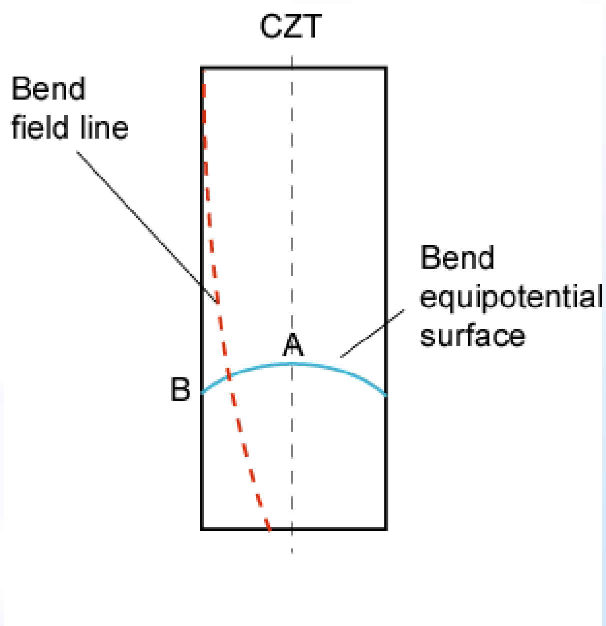


Assembled detector with two spring-loaded contacts



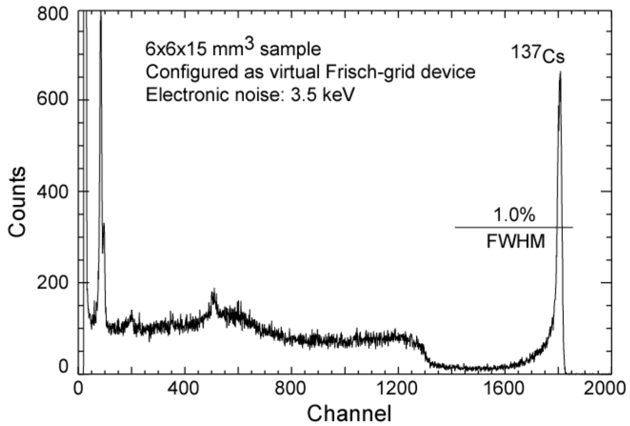
We have demonstrated that position-sensitive detectors can overcome the response nonuniformity in large-volume CdZnTe crystals

One important issue left to be solved is to optimize the fabrication process to minimize edge effects to guarantee the correct distribution of potential on the sidewalls of the bar detectors and to ultimately produce a device with focusing E-field



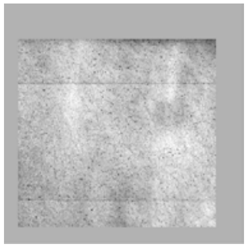
An Excellent Bar Detector

2D and 3D X-ray response maps

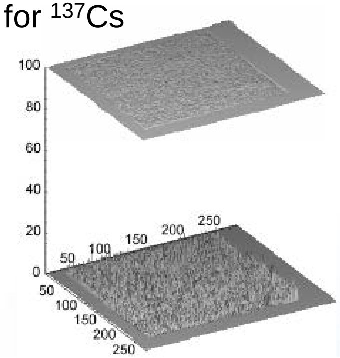


For each bar detector tested we measured

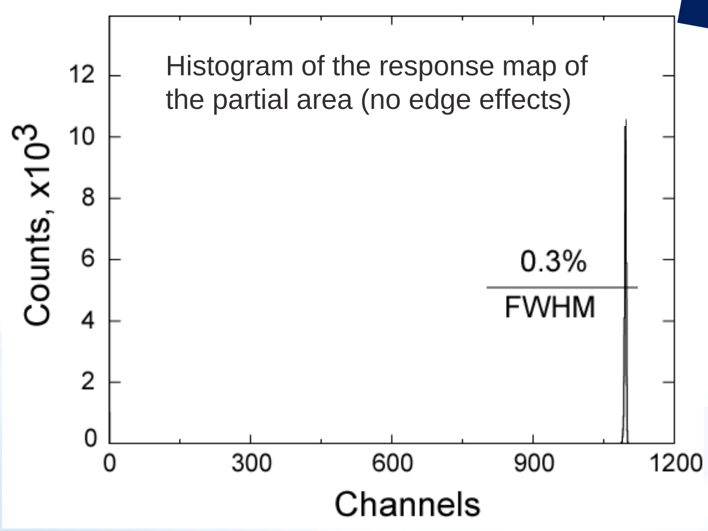
- Histogram of pulse height spectra
- Energy spectra for ^{137}Cs



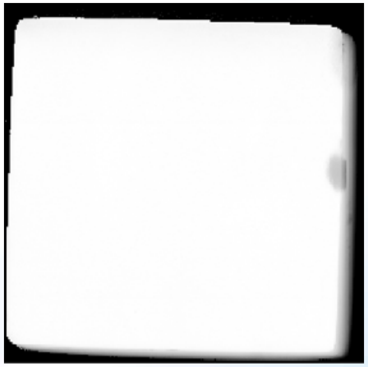
Partial area X-ray response map (no edge effects)



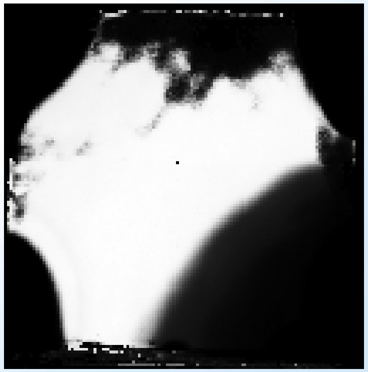
3D plot of partial area X-ray Response map



2D and X-ray response maps



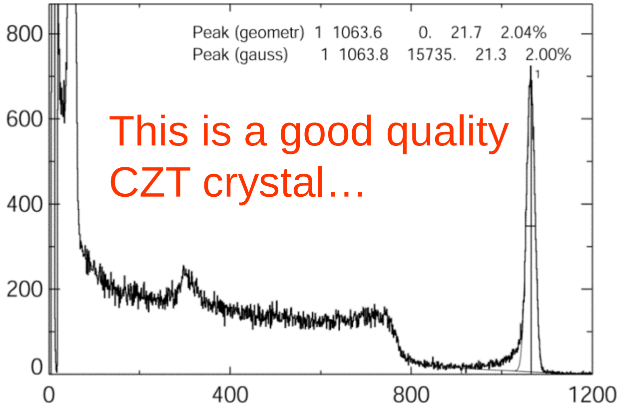
Detector as received from eV Products



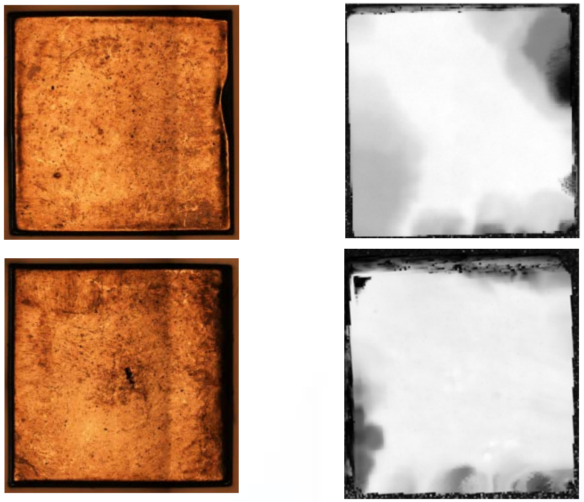
…after two years of… measuring it

An Average Bar Detector

^{137}Cs energy spectrum



Micrographs X-ray response maps



For this detector geometry the surface resistivity plays a very important role in the performance and efficiency of the detector

What is responsible for the incomplete charge collection near certain detector's edges?

A simple answer is that there is weak or defocusing E-field in those regions due to …

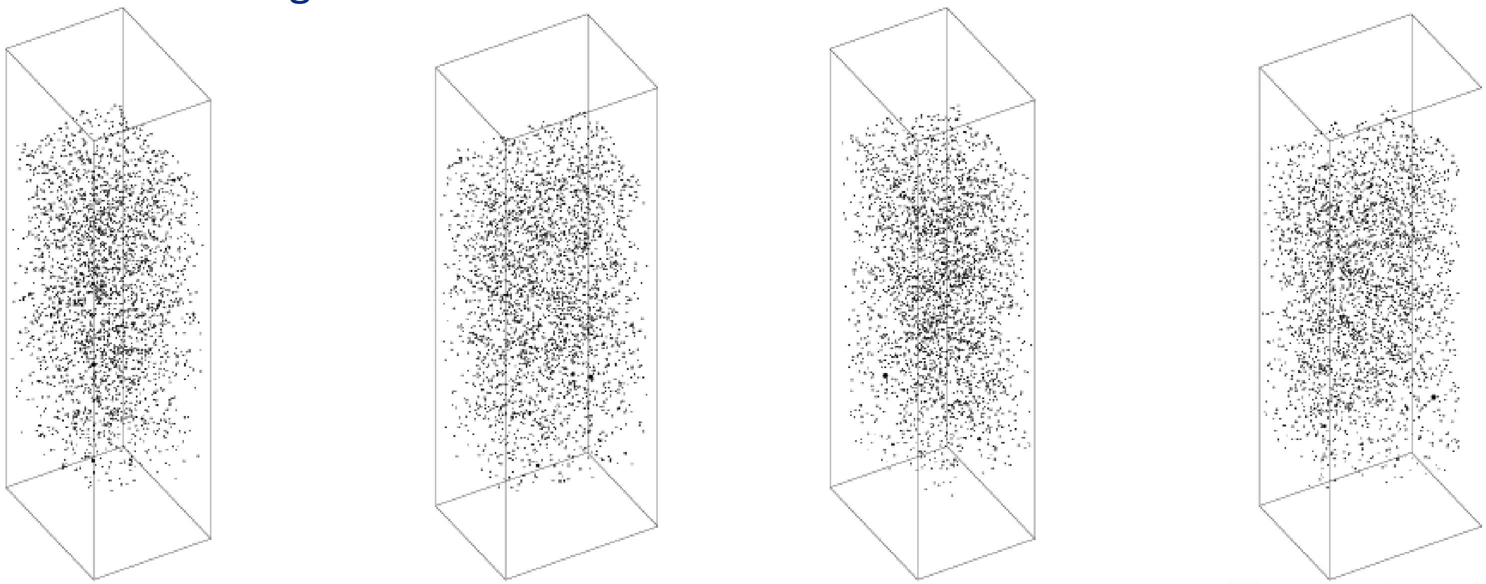
Surface preparation?, Fabrication process?, Crystal orientation? Surface treatment?

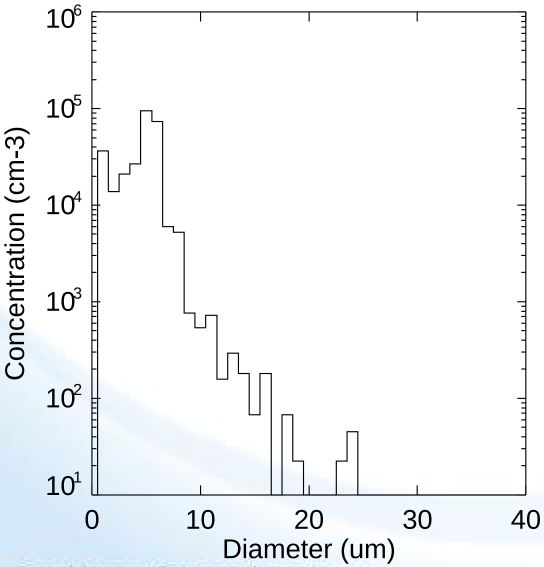
Many detectors received did not perform as expected. We refabricated them, tried different surface treatments and tested them with the micro-beam at Beamline X27B

6 x 6 x 15 mm^3 CZT

IR Transmission: Extended Defects Distribution

Volumetric regions size: 1.1 x 1.5 x 5 mm^3

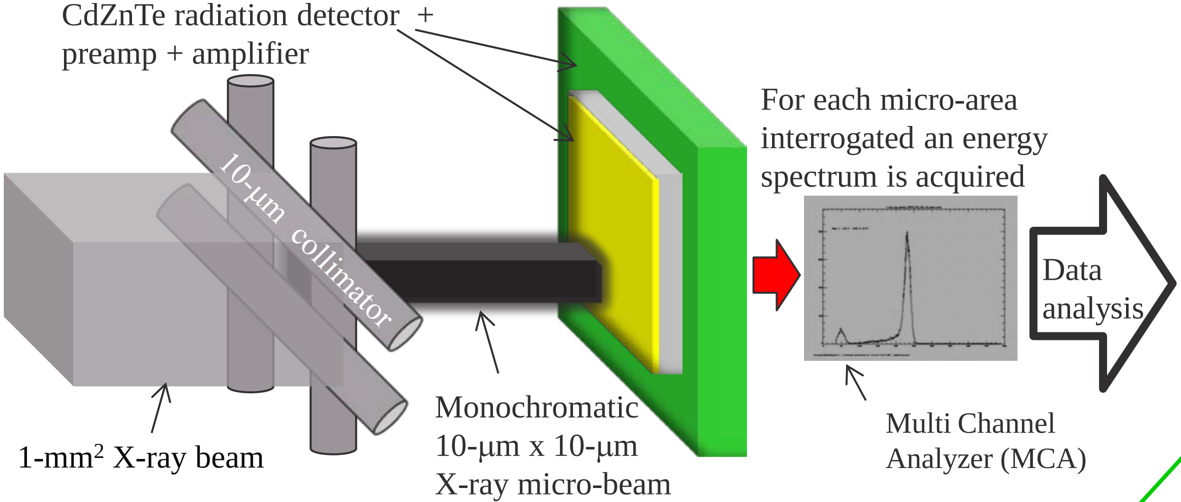


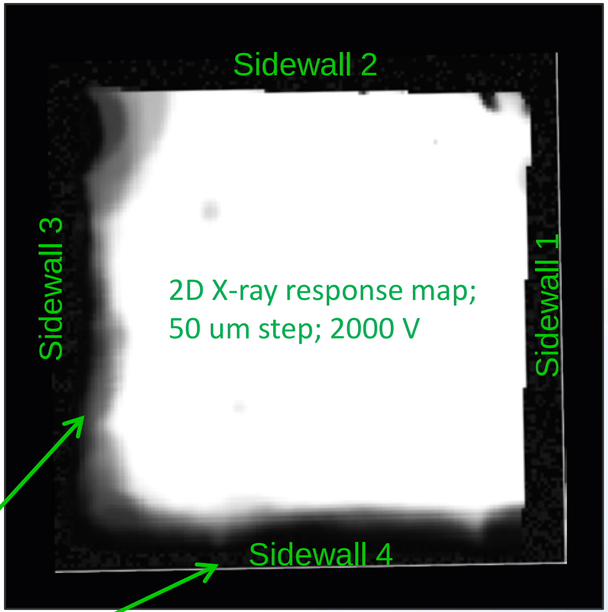


These images and distribution of extended defects are representative of all the bar detectors that were measured

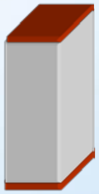
Characterization Technique: X-ray Response Maps

Micro-scale X-ray Detector Response Mapping is a unique and powerful measurement technique to evaluate detector performance





2D X-ray response map of a 6 x 6 x 15 mm^3 CZT detector



X-ray response maps can give information on:

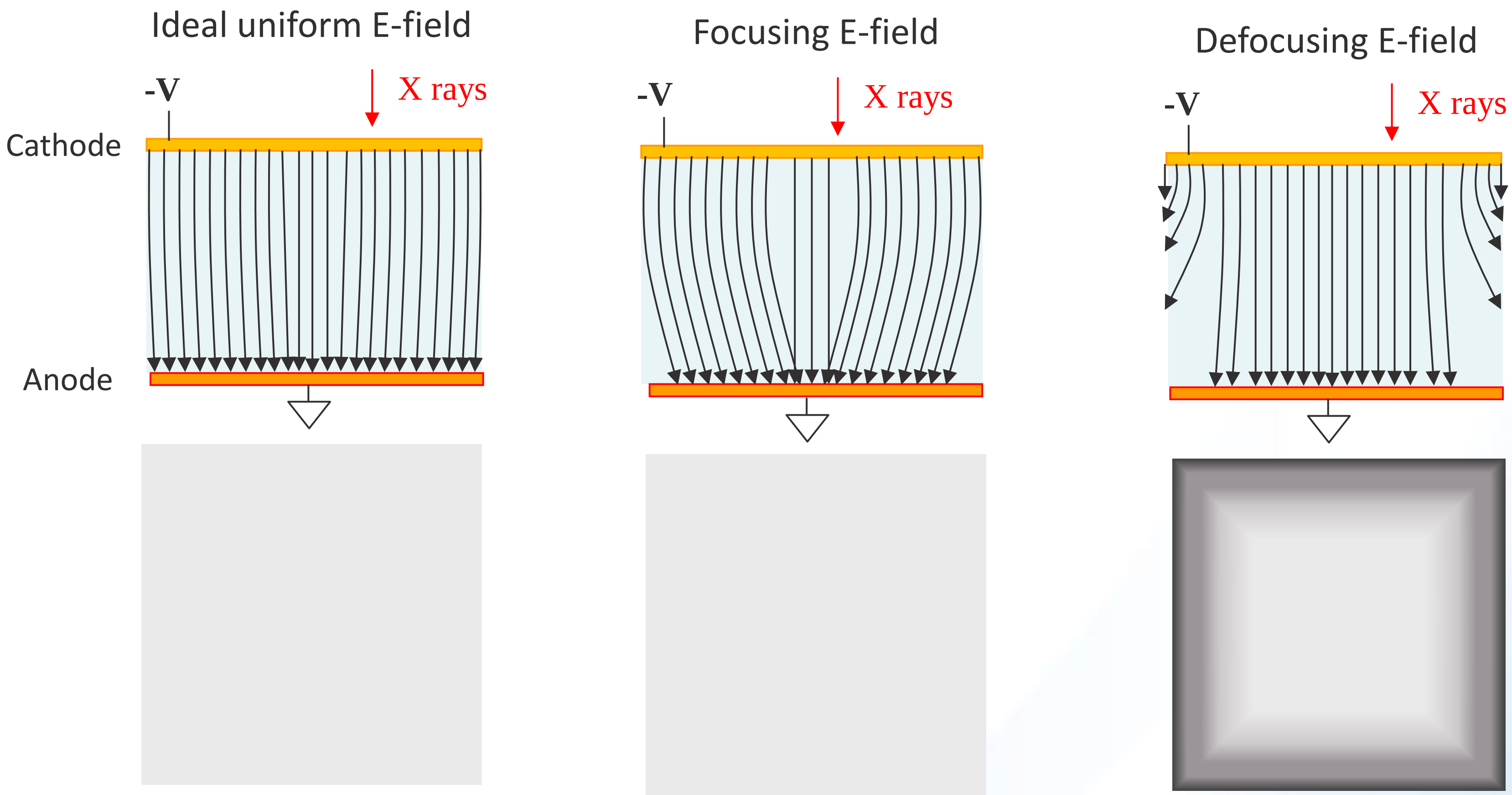
1. Detector polarization
2. **Local and global E-field non-uniformity**
3. **Extended defects**
4. **Electrode- and side-surfaces fabrication damage**
5. Electrodes design
6. Nonuniformity of material

?

Why is there incomplete charge collection near the anode’s edges 3 and 4?

Responsible for deteriorating energy resolution in spectrometers and for introducing aberrations in imaging devices

Understanding X-ray Response Maps versus E-field

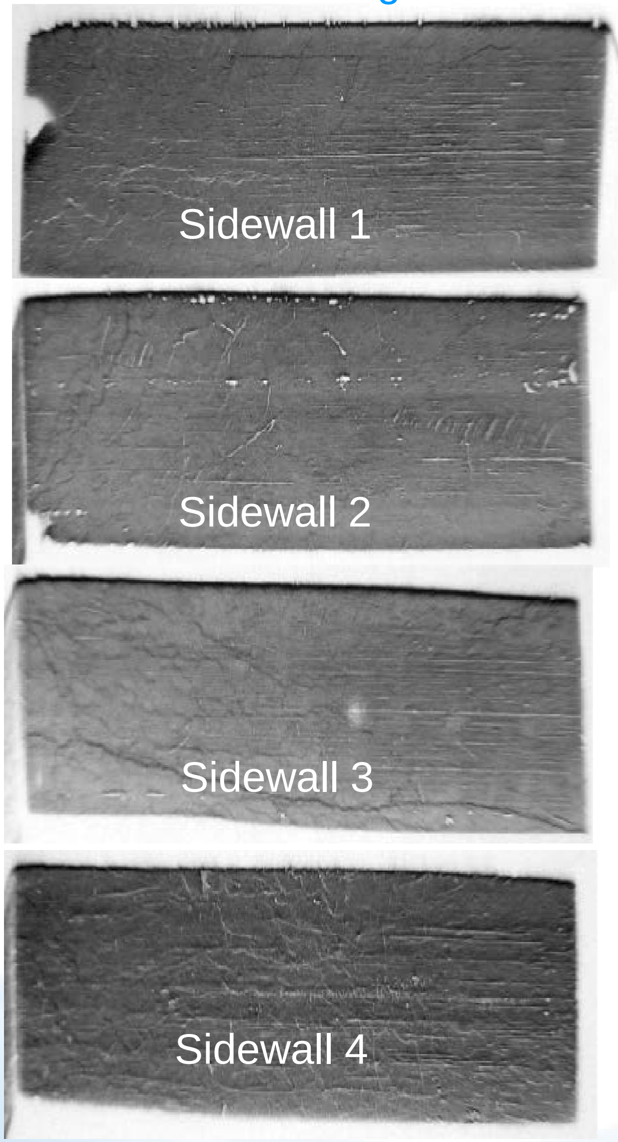


X-ray response maps

If an X-ray-response-map dimension corresponds to the anode area, this implies that the E-field of the device is focusing

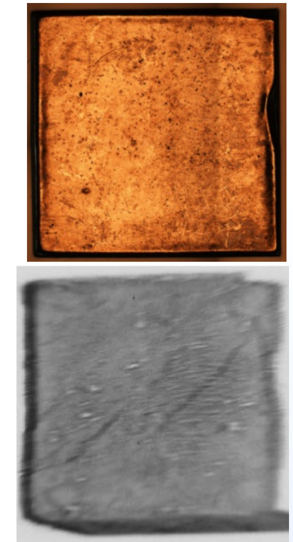
WBXDT Images and Bright-Field Micrographs

WBXDT images

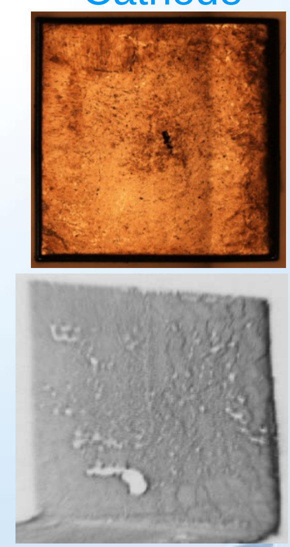


Micrographs

Anode

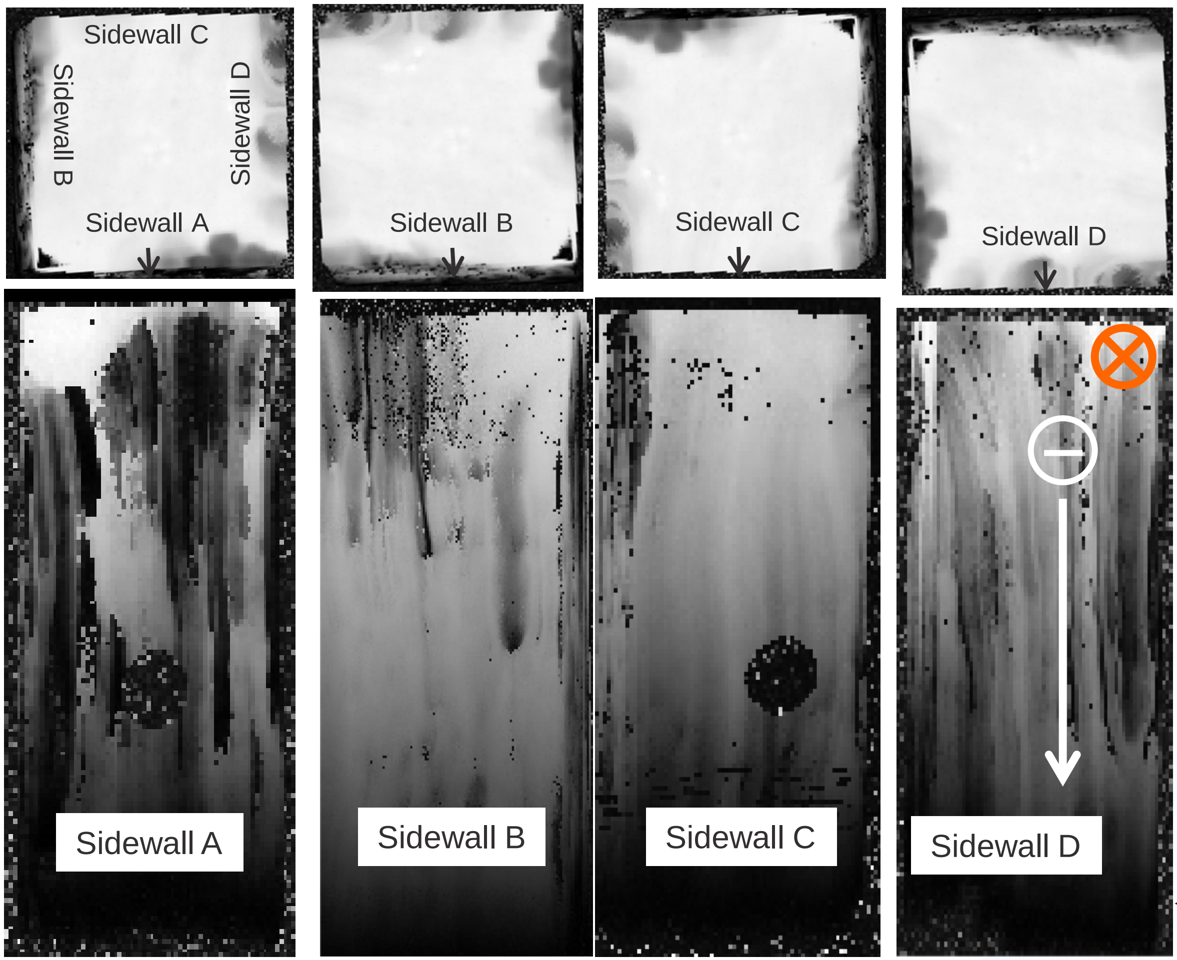


Cathode



Extended defects and surface preparation are revealed

X-ray Response Maps with Anode as Collecting Electrode



X-ray-maps' step-size of the sidewalls is 100 um

X-rays

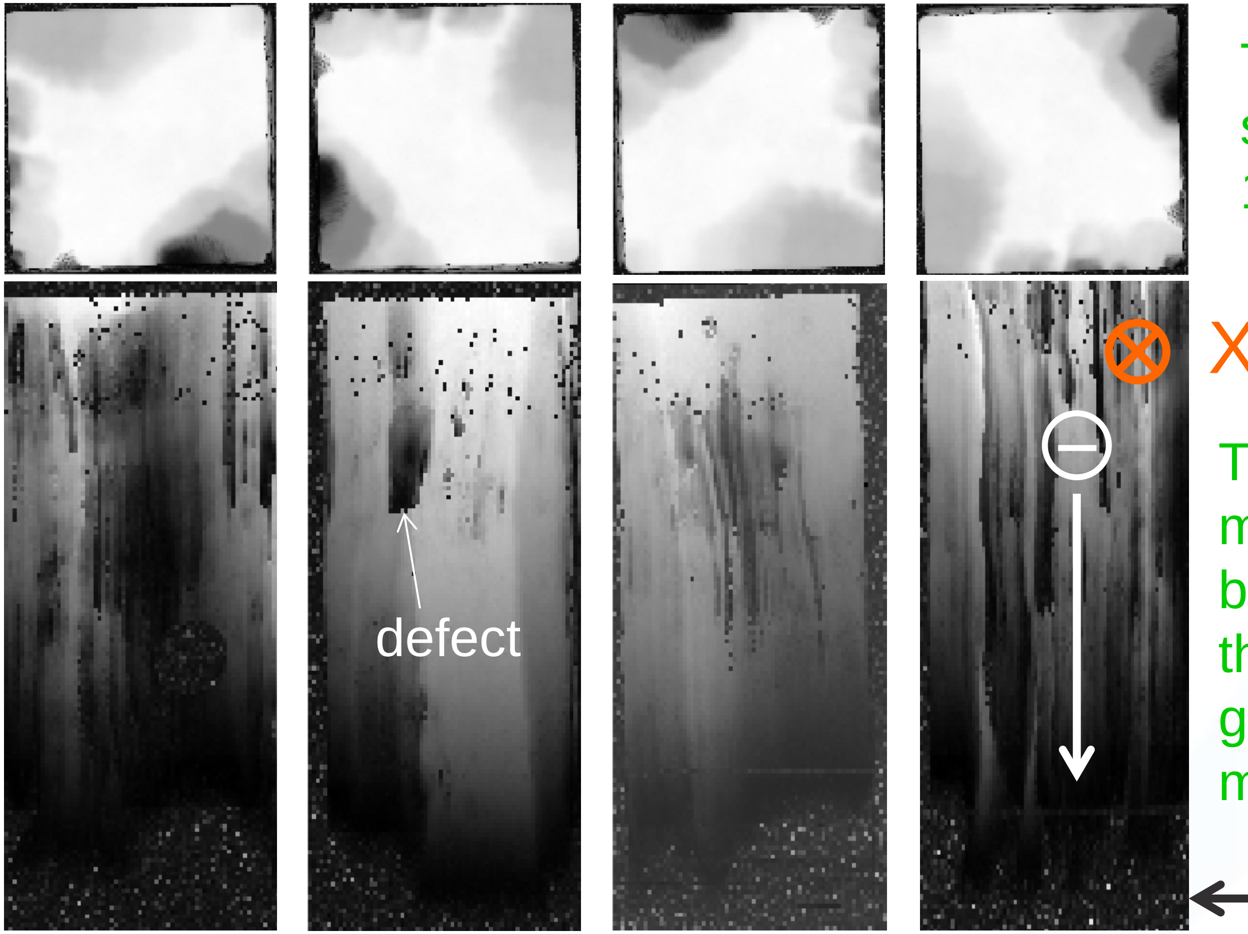
These non-uniformities in the X-ray response maps are indicative of defocusing local E-field due to both extended defects and surface preparation

← Collecting-electrode side

Overall there is focusing global E-field in this detector

Defects affect the local E-field

X-ray Response Maps with Cathode as Collecting Electrode



The step size of the raster scan of the sidewalls is 100 um

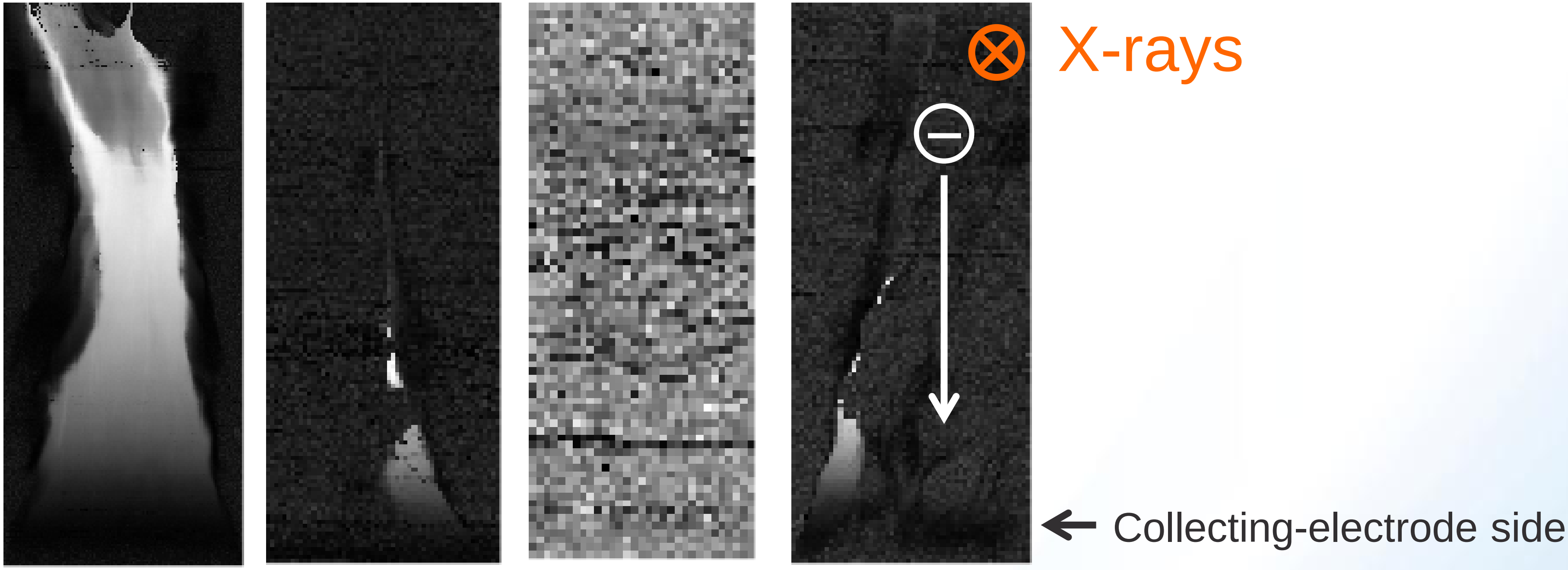
These X-ray response maps are the result of both drift and diffusion of the electron's cloud generated by the X-ray micro-beam

Defocusing E-field is responsible for the dark regions

These regions are often not visible with an optical microscope (internal crystal damage?); therefore, optical microscopy is not suitable to evaluate the optimal surface preparation for high charge collection along the edges

Detector Mechanically Polished with 1200-grit SiC Paper

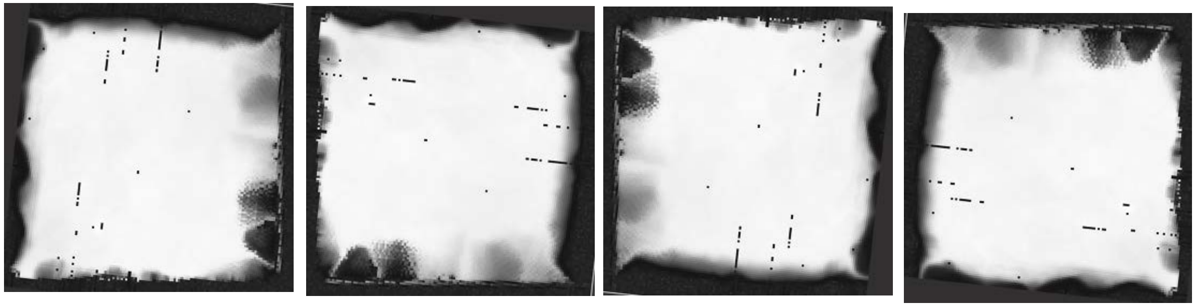
X-ray-maps' step-size of the sidewalls is 100 um



These non-uniformities in the X-ray response maps are indicative of defocusing local E-field due to both extended defects and surface preparation

Also polarization is observed in the dark-grey regions

Detector Mechanically Polished with 3 µm AlO_2 Powder on Velvet Cloth



X-ray-maps' step-size of the sidewalls is 100 um

X-rays

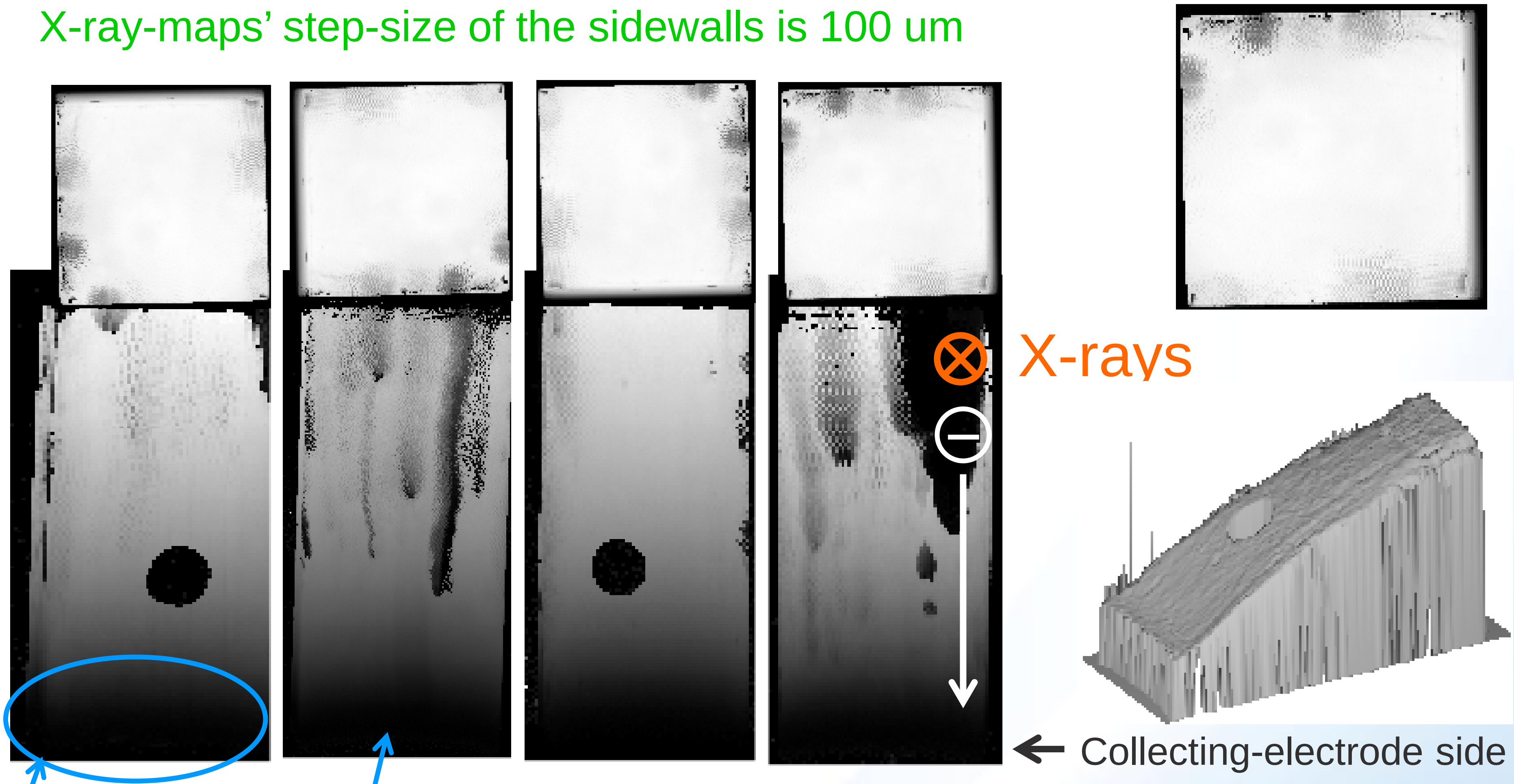
Preparation and orientation (surface conductivity) of the side-surfaces seems to affect the performance of the detector

Collecting-electrode side

Sidewalls 1 and 2: these non-uniformities in the X-ray response maps are indicative of defocusing local E-field due to both extended defects and surface preparation. Maybe the resistivity of sidewalls 3 and 4 is too high. R_s = 300 GΩ/□

Detector Chemically Etched

X-ray-maps' step-size of the sidewalls is 100 um



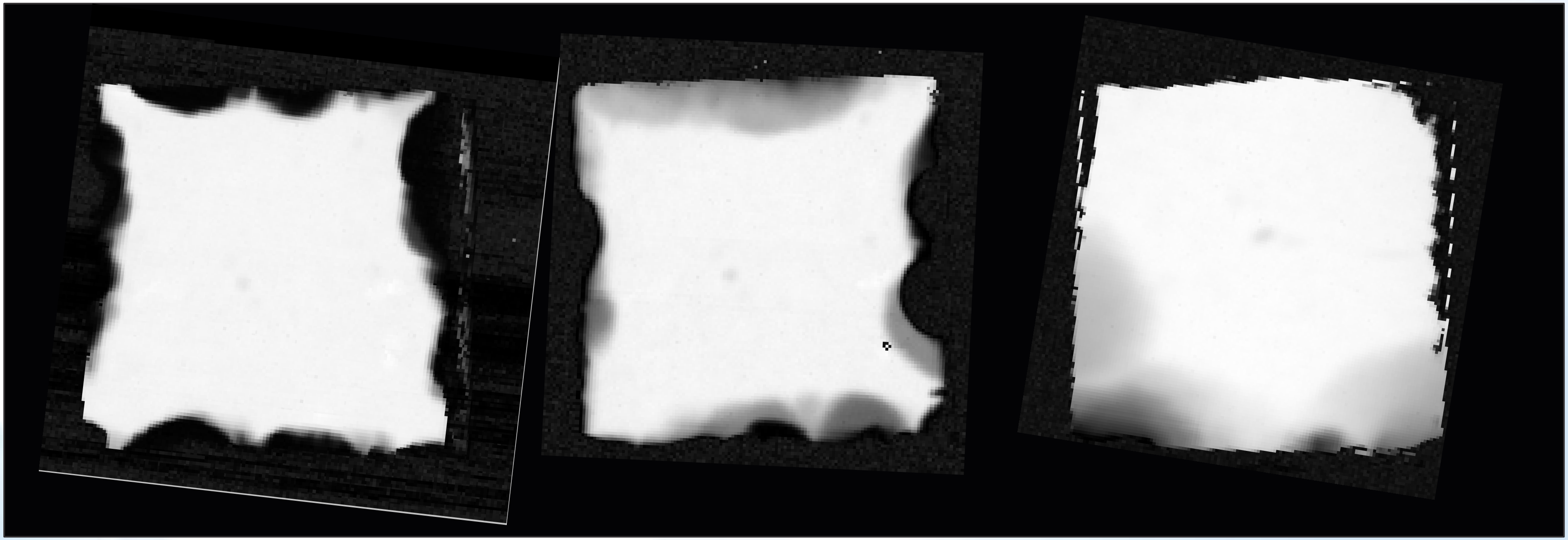
Remember, no signal generated when the pencil beam irradiates the sidewall near the anode

Preparation and orientation (surface conductivity) of the side-surfaces seems to be important to control the surface leakage current (resistivity, charge recombination, and local E-field). $R_s = 80\ G\Omega/\square$

A CZT Detector from As-received to Refabricated

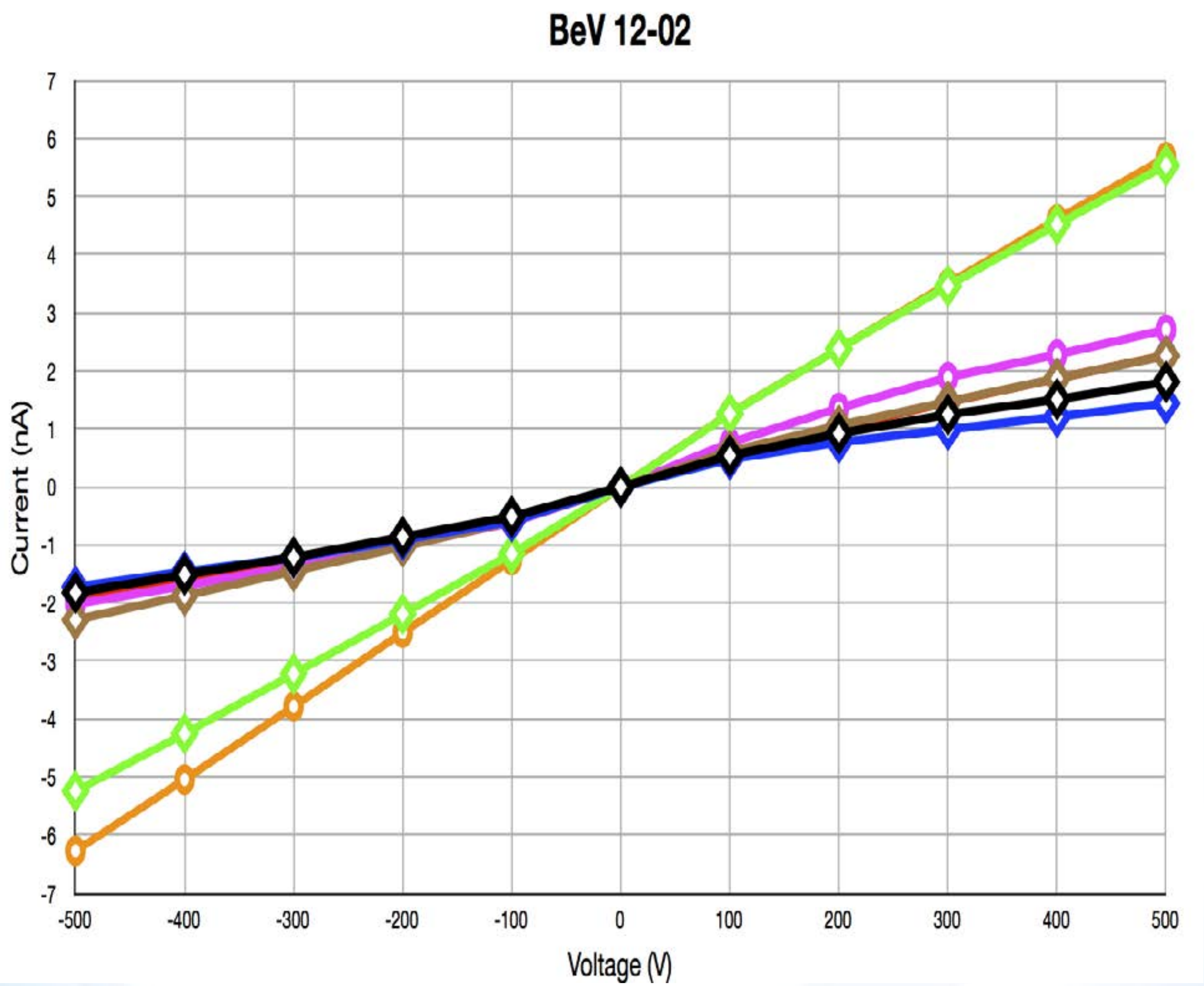
Detectors that did not meet the requirements were mechanically polished, chemically etched in Bromine-methanol solutions at different concentrations, passivated with different chemical solutions, such as CS_2 and $NH_4F + H_2O_2$. The best results were obtained when using <0.5% Bromine etching, which increased the surface leakage current to a certein extent to ultimately assure the correct distribution of potential on the edges for a focusing E-field. The surface resistivity was measured to be: R_s = 111 GΩ/□

X-ray response maps



As received   Mechanically polished   Chemically etched

I-V Curves of One of the Bar Detectors



IV Curve

- As received
- After CS_2
- After Polishing
- After NH_4F+H2O2
- After Br-etching
- After Br-etching (new contact)
- After Br-etching 2nd time
- After Br-etching 2nd time (new contact)

Conclusions

- Extended defects and surface treatment affect the local E-field

- Optical microscopy seems inadequate to reveal relevant crystal damage and therefore to evaluate the optimal surface preparation

- WBXDT gives information on crystal defects

- MXDM gives information on the effects of (1) orientation, (2) surface preparation, (3) global- , and (4) local E-field non-uniformity

- MXDM can be employed to improve the surface preparation of a device

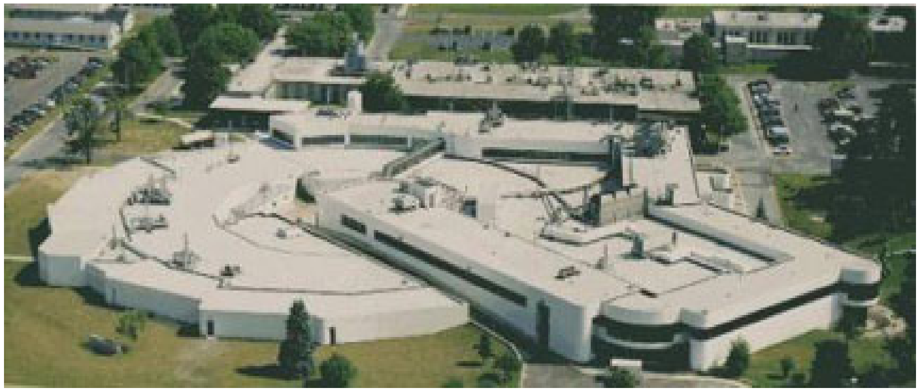
- Bromine-methanol etched samples showed a focusing E-field

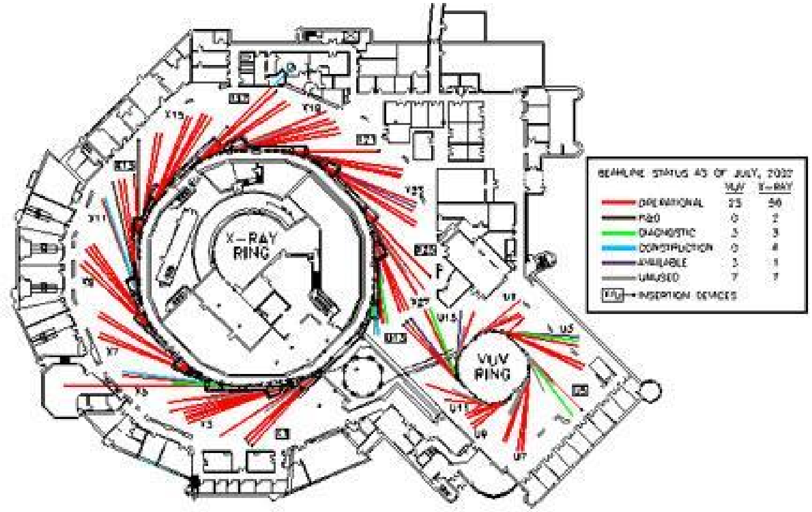
Future Work

- More detectors need to be measured
- Continue to measure detectors with different surface preparation
- Install and measure detectors with a multi-channel readout system
- Receive and measure YOUR samples and detectors

Acknowledgments

BNL's National Synchrotron Light Source (NSLS) is a user facility





- NSLS at Brookhaven National Laboratory in New York is a national user research facility founded by the U.S. Department of Energy's Office of Basic Energy Sciences

For more information: http://www.bnl.gov/ps/ GiuseppeC@bnl.gov

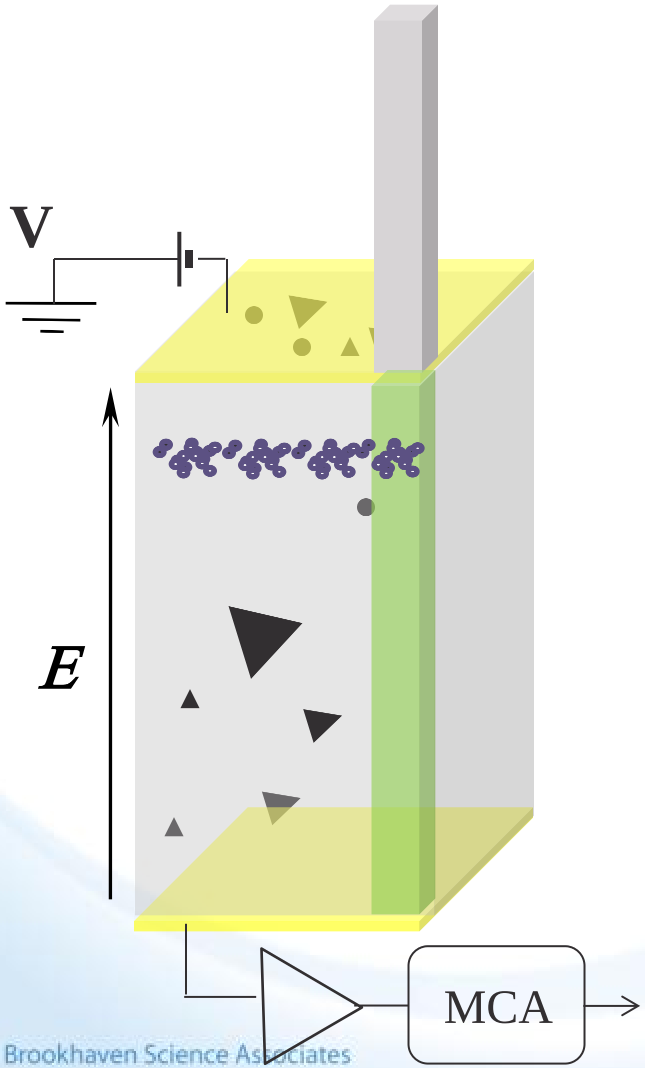
- Please come to visit or send samples if you are interested
- Thanks for the support to the U.S. Department of Energy, Defense Nuclear Nonproliferation R&D, DNN R&D

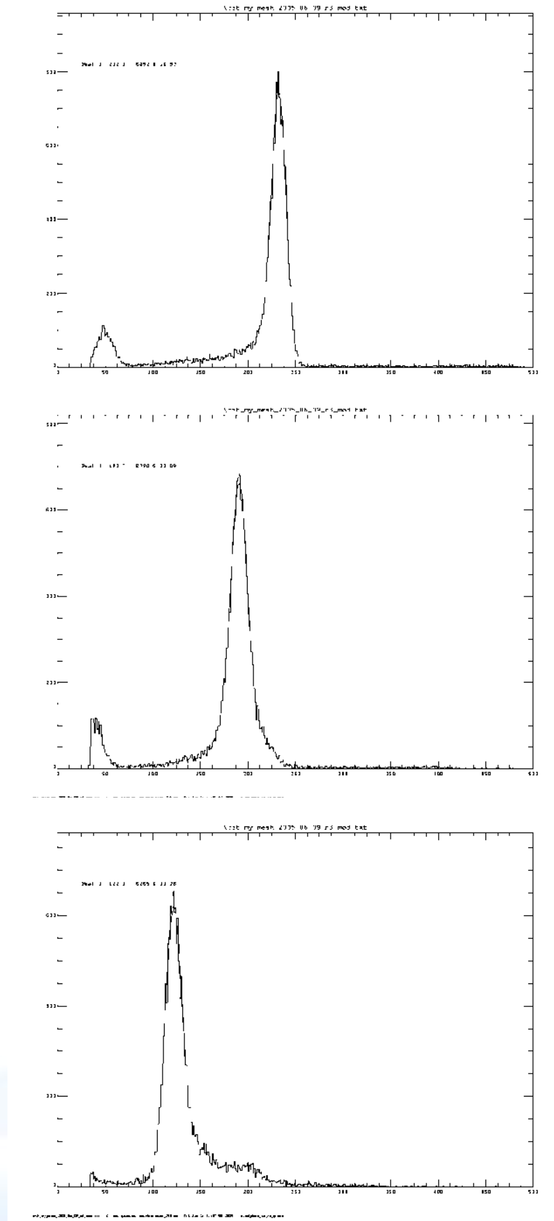
Thank you for your attention!

Extra Slides

MXDM - Charge Loss with X27B X-ray Beam

A monochromatic X-ray micro-beam is used to map the whole area of the detector





Full charge collection:

Photopeak at ch 480:

No defect is in the path

Some charge is trapped:

Photopeak at ch 350:

A small defect is in the path

More charge is trapped:

Photopeak at ch 150:

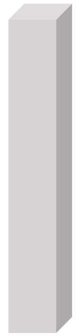
A large defect is in the path

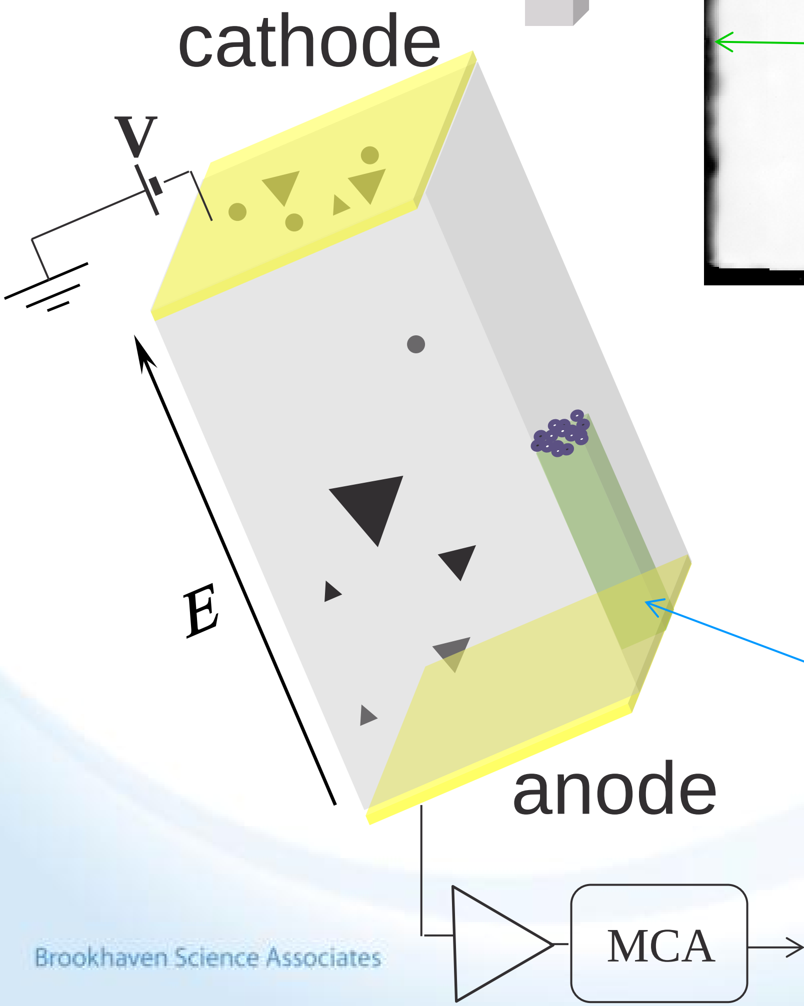
MXDM – Irradiating the Sidewalls

Useful to study:

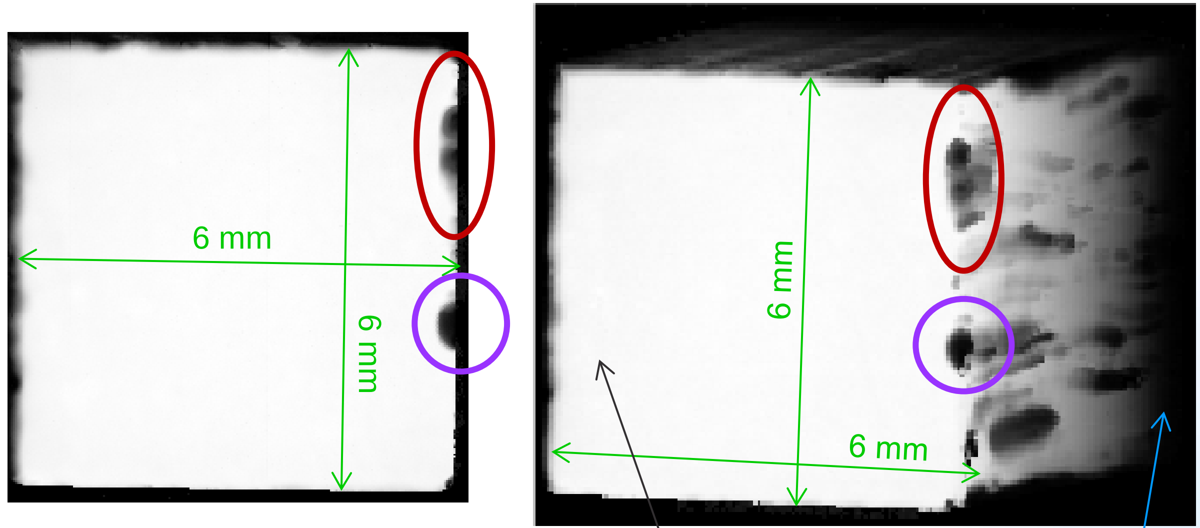
1- Global and local E-field non-uniformity

2- Surface damage





2D X-ray response maps of a 6 x 6 x 15 mm^3 CZT detector



The global E-field is focusing because the X-ray response map extends to the edges of the anode electrode

No signal generated when the pencil beam irradiates the sidewall near the anode