Flexible X-Ray Imaging Detectors Using Scintillating Fibers

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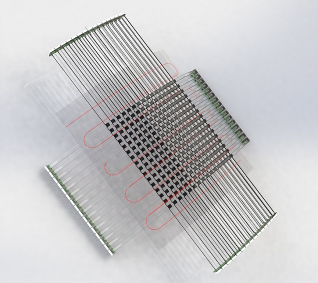
The FleX-RAY Project

- Many X-ray imaging applications use photographic film for flexibility (pipes, airplane wings, etc.)
- Flat-panel electronic detectors lead to image distortion
- Project aims to create an electronic detector with the flexibility of film
- Using flexible scintillating fibers and detecting scintillation at edges
- Work funded by EU Horizon 2020 grant No. 899634

Benefits of FleX-RAY

- Can achieve benefits of electronic and film detectors
- Allows fragile electronics to be out of the beam path (can be more radiation-hard)
- Capable of self-reporting its flexed shape
- Can be cheaper than large-area flat panel detector

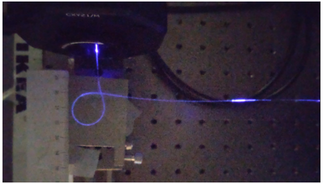


Scintillating Fibers

- Need bright and fast (few ns) scintillation for detection
- Size of fibers is principal factor in detector resolution
- Commercially-available plastic fibers at 250 μm - 1 mm (e.g. Saint-Gobain, 8000 photons/MeV, 2.7 ns scintillation time)
- Have developed smaller liquid-filled fibers at 50 μm
  - Comparable to resolution of film and flat-panel electronic detectors
  - Developed by colleagues at Research Institutes of Sweden
  - Easily filled in parallel by pressure or capillary action
  - Spliced to standard optical fiber at end

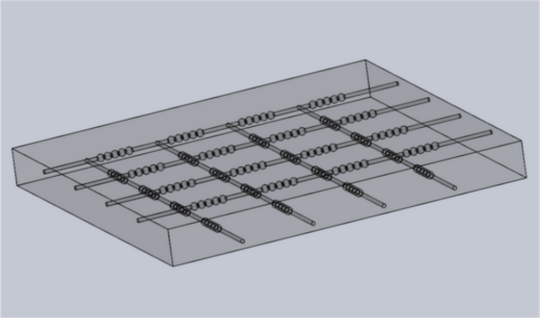
Custom Liquid-Filled Fibers

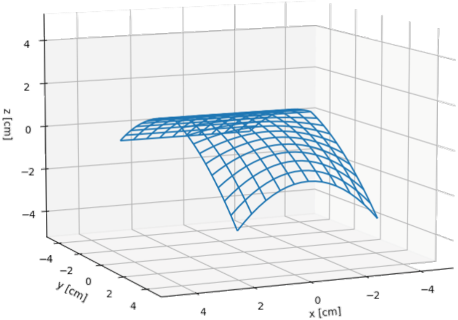
- Develeoped by colleagues at RiSE
- Flexible glass fiber with 50 μm capillary (120 μm OD)
- Many commercially-available scintillating liquids
  - Saint-Gobain BC505, brighter/faster than plastic
  - High-Z loaded liquids
  - Choose to optimize efficiency / yield / scintillation time
- Can potentially be refilled in-place (more radiation-resistant than plastic)



Shape Sensing

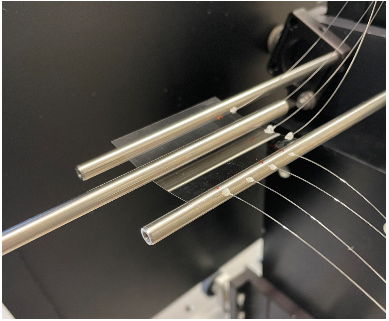
- Waveguides with Bragg gratings reflect light at specific wavelength
- Reflects longer wavelength when stretched, shorter when compressed
- Can calculate 3D shape from reflected light





Shape Sensing Technology

- Developed by colleagues at Fraunhofer HHI
- Femtosecond pulse laser engraves waveguides and gratings onto thin glass
- Sensor's reponse is highly linear and repeatable



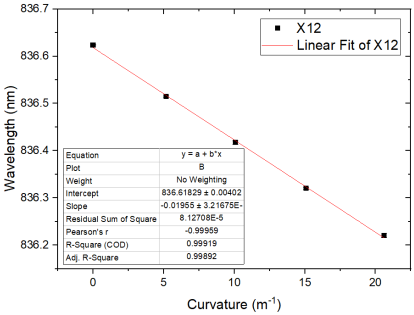


Image Reconstruction (Time-Difference)

- Detect scintillation light on both ends of one fiber
- Time-of-flight difference to measure position along fiber
- Significantly blurred along fiber
- Custom deconvolution algorithm can take advantage of cross-shaped blur

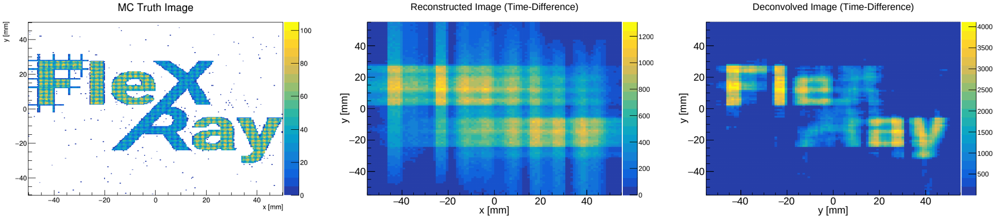
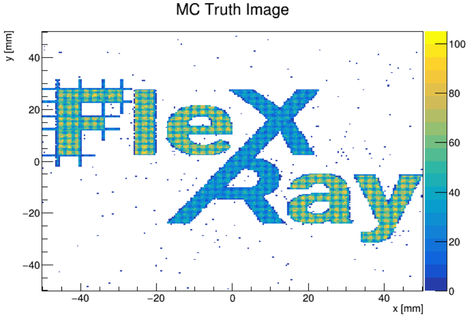
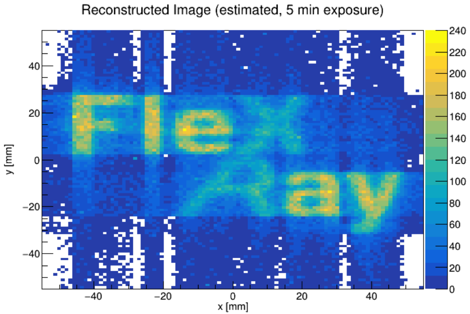


Image Reconstruction (Two-Dimensional)

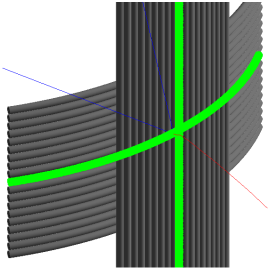
- Detect scintillation light on two fibers at once
- 2D detections rare at X-ray energies, but much more common above $\sim$ 511 keV
- Can give better image quality if the application uses (for example) a Co-60 source

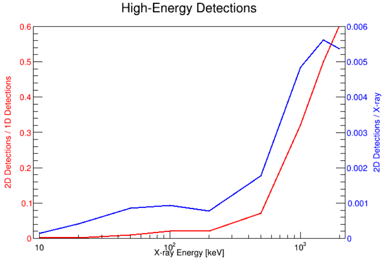




2D detections with Gamma-Ray Energies

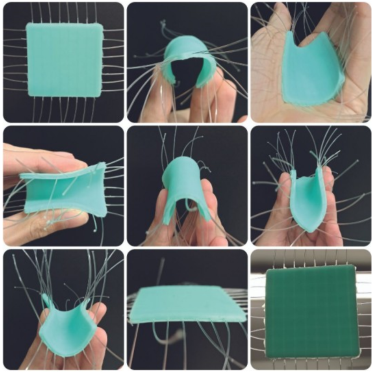
- Higher-energy gammas transfer more energy to electron
- Higher-energy electron travels farther, hits both fiber layers
- Most detections are two-dimensional
- Exposure time proportional to $1/\sigma^2$ – down from many minutes to seconds

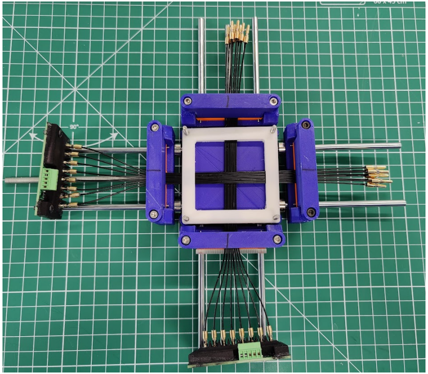




Prototype Preparation

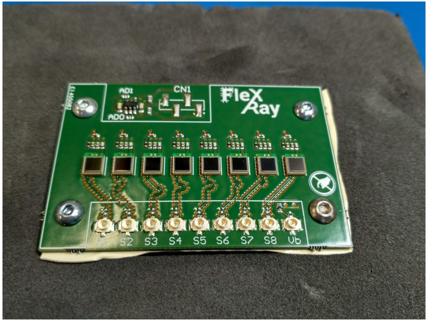
- Building a proof-of-concept prototype
- Fibers enclosed in silicone matrix





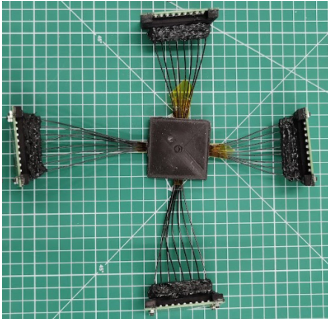
Prototype Electronics

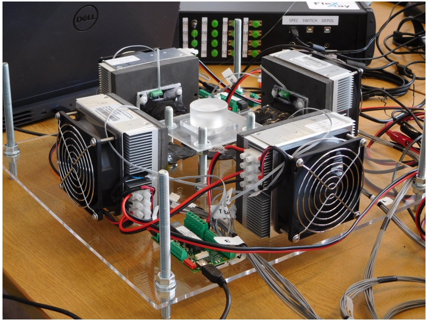
- Using Hamamatsu S13360-3075CS 3mm SiPMs
- Fibers coupled to arrays of 8 SiPMs
- Signals read out by weeroc Petiroc2A board
- Developing a custom front end with better price and performance



Proof-of-Concept Prototype

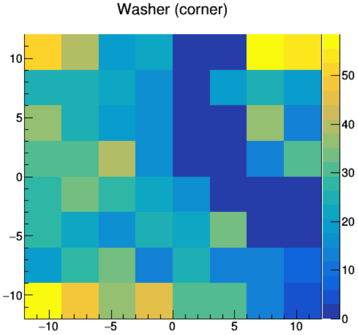
- We have an early 8 $\times$ 8-fiber prototype
- All parts are working together and producing images
- Timing resolution at 200 ps: works for 2d image reconstruction, sufficient for 1d only with long exposure and deconvolution

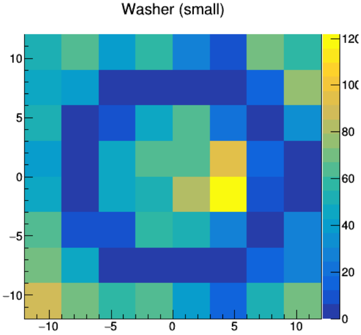




Initial Tests - Images

- First tests with prototype last month
- First tests using weak radioactive sources and simple test shapes
- Iterating and improving prototype, next tests soon with high-intensity X-rays

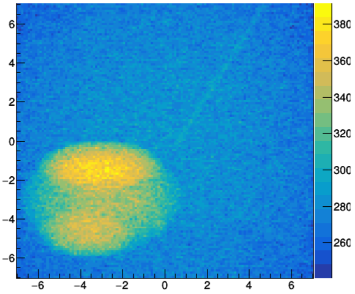




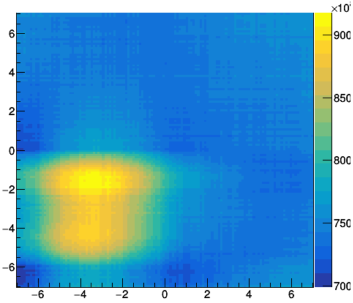
Simulations of Realistic Situation

- Spoke to representatives from industry about typical defects
- Simulated expected performance of FleX-RAY detector
- 5-cm radius pipe with corroded region and 0.1-mm crack

Reconstructed Image (2D)



Deconvolved Image (Timing)



Conclusions

- FleX-RAY project proving that technology is feasible
- We have a (tiny) working prototype
- Now looking into a follow-up project to continue development

Thank You!

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No. 899634.