Flexible X-Ray Imaging Detectors Using Scintillating Fibers

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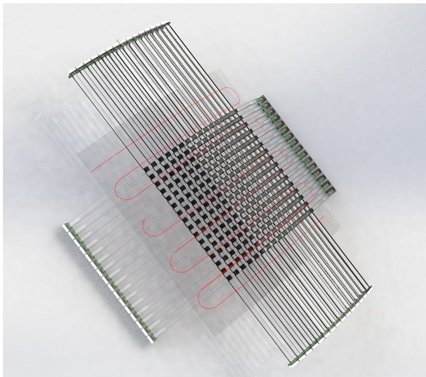
Introduction

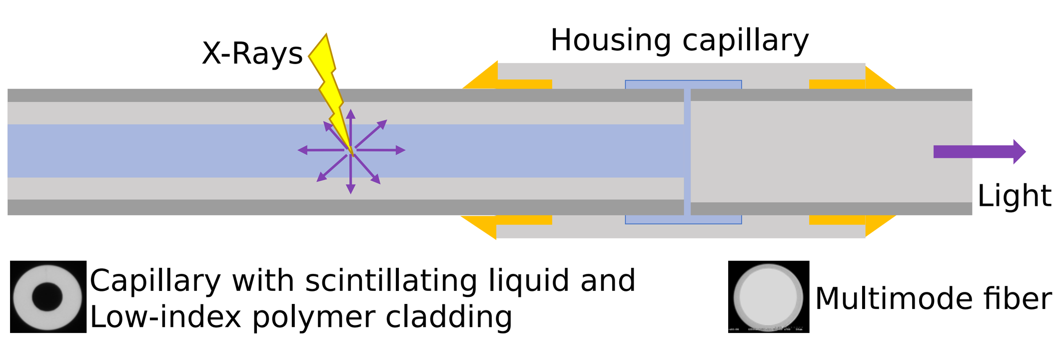


The FleX-RAY project aims to create a digital X-ray detector that is capable of producing high-resolution images, is flexible enough to produce an image on a curved surface, and is capable of self-reporting its final shape.

Many applications of non-destructive testing require X-ray imaging of complex shapes, and therefore still require (flexible) photographic film. The FleX-RAY design could modernize these applications. Additionally, the use of scintillating fibers allows the electronics to be moved out of the X-ray beam path, thus prolonging the lifetime of the detector.

Scintillating Fiber Technology

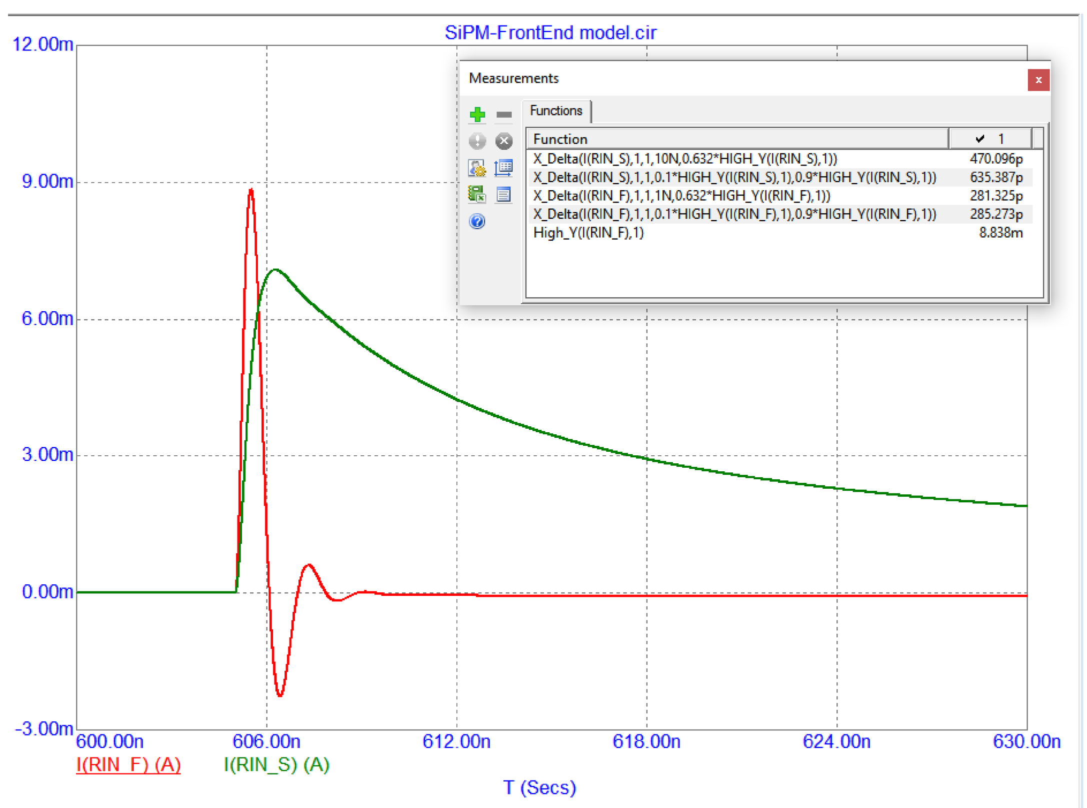
Scintillating liquids offer more flexibility in the choice of scintillating materials. This is important for optimizing photon yield and the timing characteristics of the scintillation. Several different design concepts based on capillaries filled with scintillating liquids have been proposed within the project, one of which is shown below.



The light collection for the current example is estimated to about 7%, which is achieved by coating the capillary with a low index polymer. The coating increases the collection angle but also acts as a cladding and allows light to be guided in the glass wall of the capillary with very low loss.

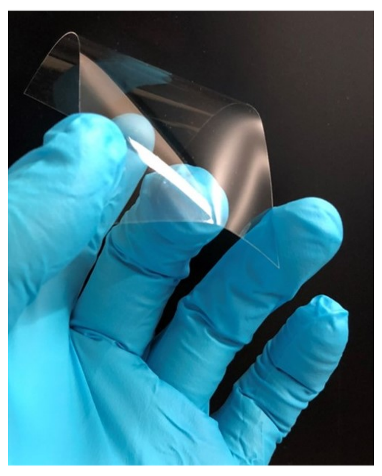
Electronics and TDCs

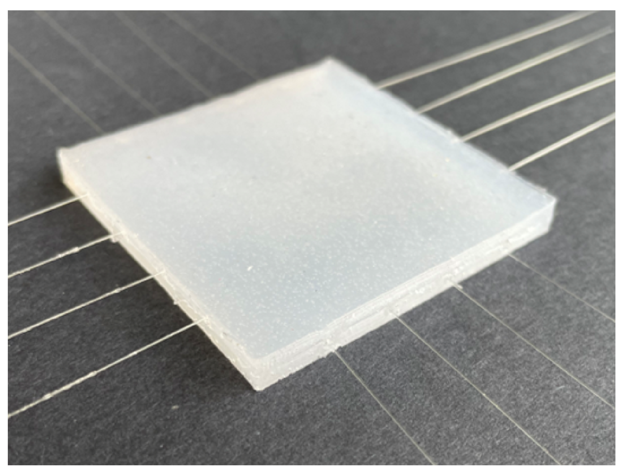
In Flex-RAY we will attempt to use the 'fast' output featured in some SiPMs, which extracts information from the junction of the diode that bypasses inactive microcells, allowing for significantly lower rise times. This approach can reduce the timing uncertainty at the expense of accurate energy information, as shown below.



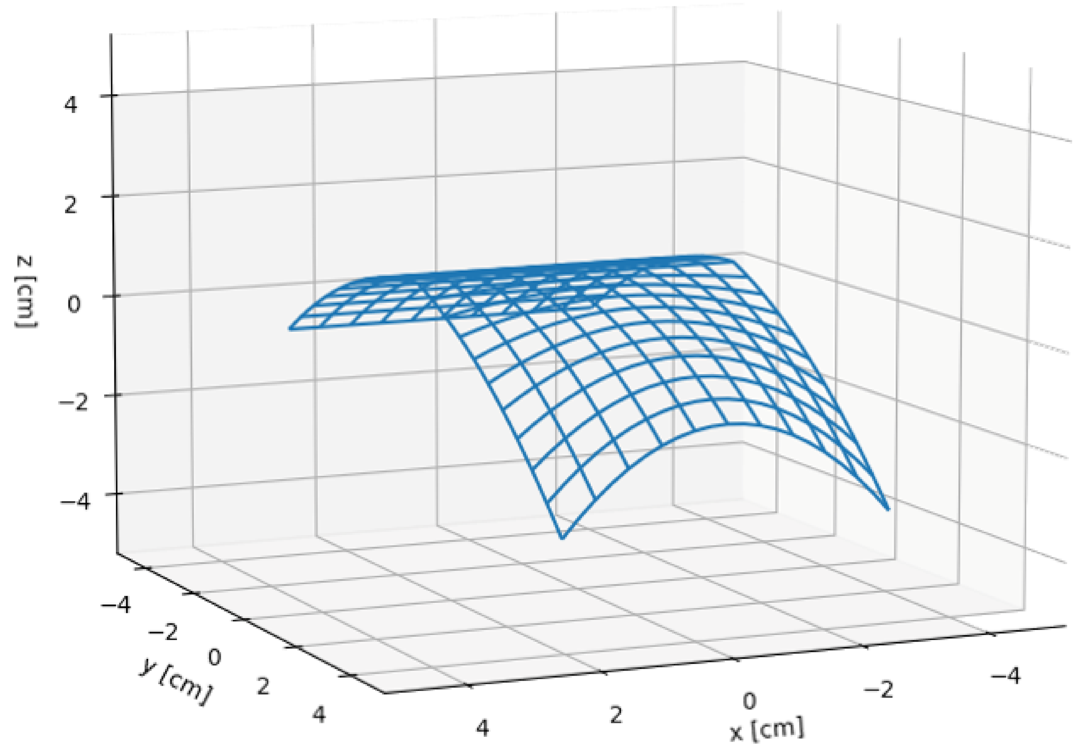
During the project we will also try to take advantage of FastIC, the latest SiPM frontend integrated chip from CERN, successor to NINO. Discriminated signals will be fed to parallel Time to Digital Converters (TDC) implemented in FPGAs for scalability.

Shape Self-Reporting



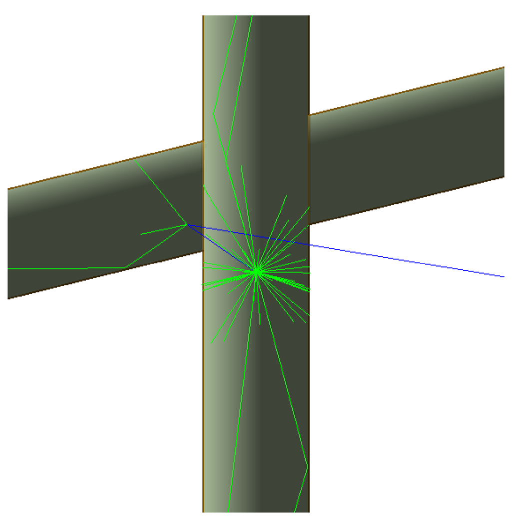


The 3D shape self-reporting is necessary for the X-ray image reconstruction. Bragg gratings are integrated as glass fibers into silicone as a substrate material or integrated directly into ultra-thin glass. Bragg gratings act as spectral mirrors reflecting the wavelength according to their grating point distance. When changing the shape of the surface onto which the 3D shape detector is mounted, the shape can be recalculated from the wavelength information and an algorithm relying on a geometrical interpolation or an artificial neural network.

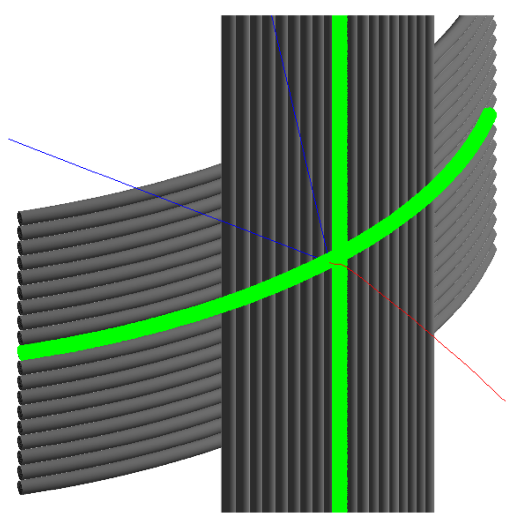


Detector Simulation

We have implemented a simulation of the detector in Geant4. This software simulates the X-ray scintillation and the transport of scintillation light to the SiPMs.



A 20-keV X-ray interacting twice in the detector.



A 1.332-MeV gamma ray interacting in the detector.

This simulation is being used to guide the FleX-RAY design process by evaluating the likely performance of the detector with various materials and X-ray sources. The novel scintillating fiber technologies that are being developed for the FleX-RAY project could significantly improve the detector performance.

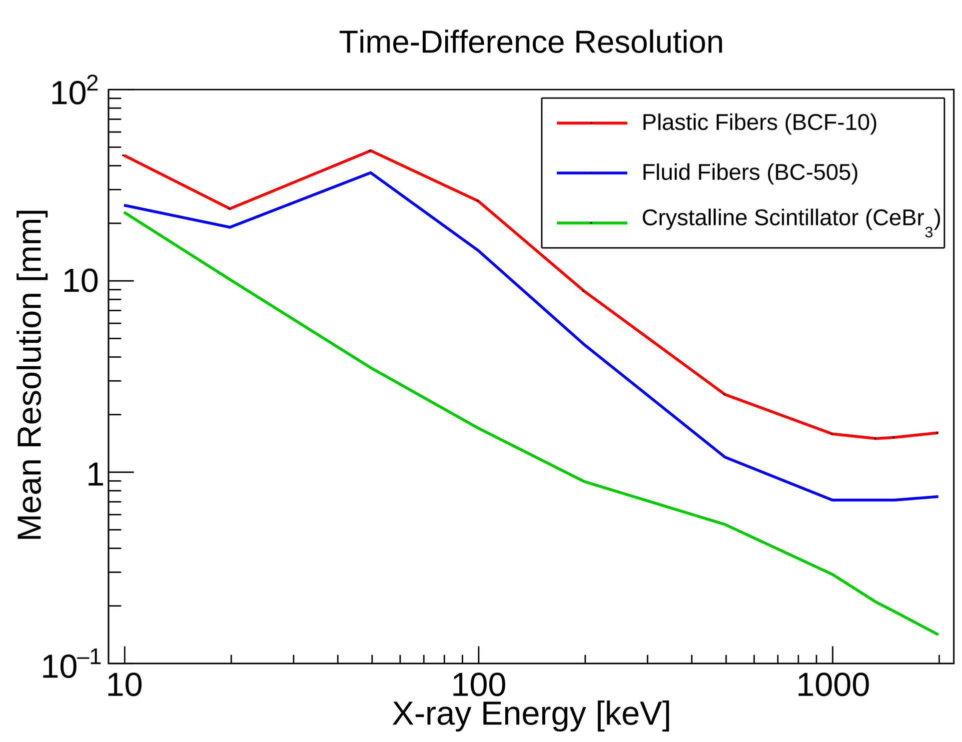
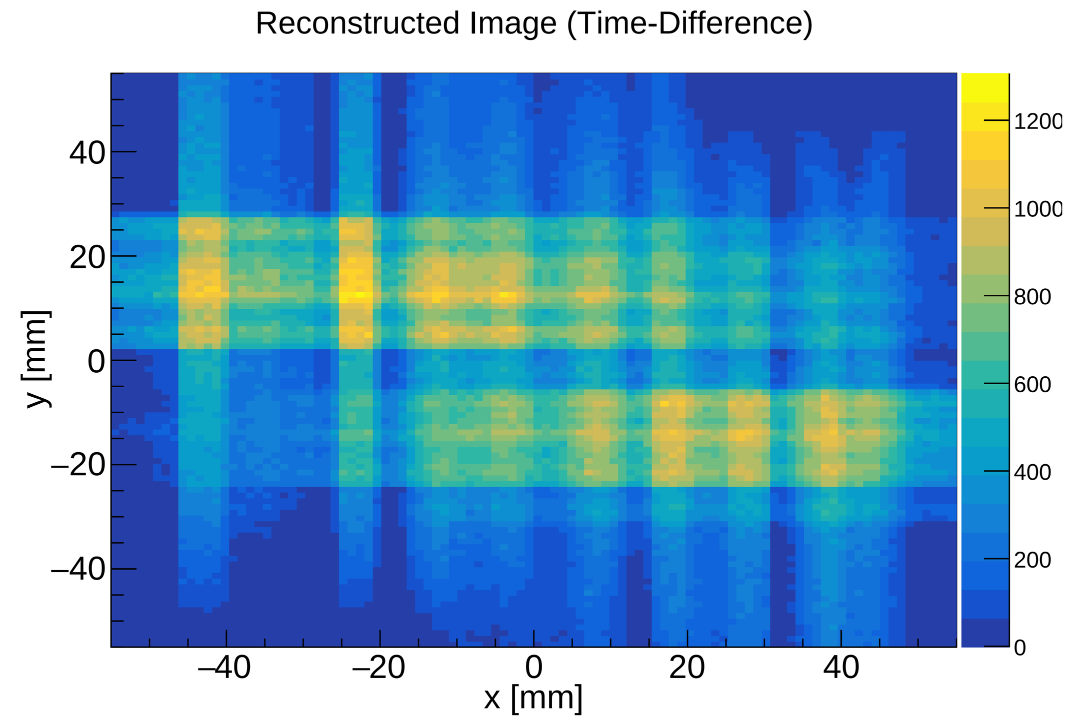
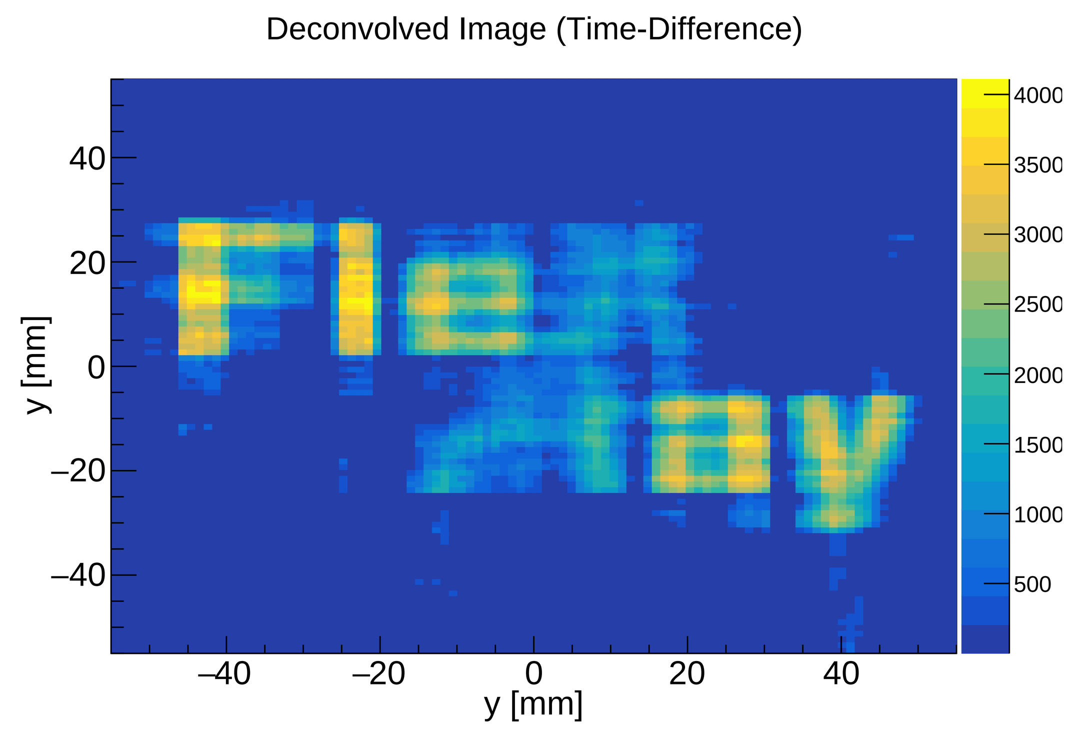


Image Reconstruction

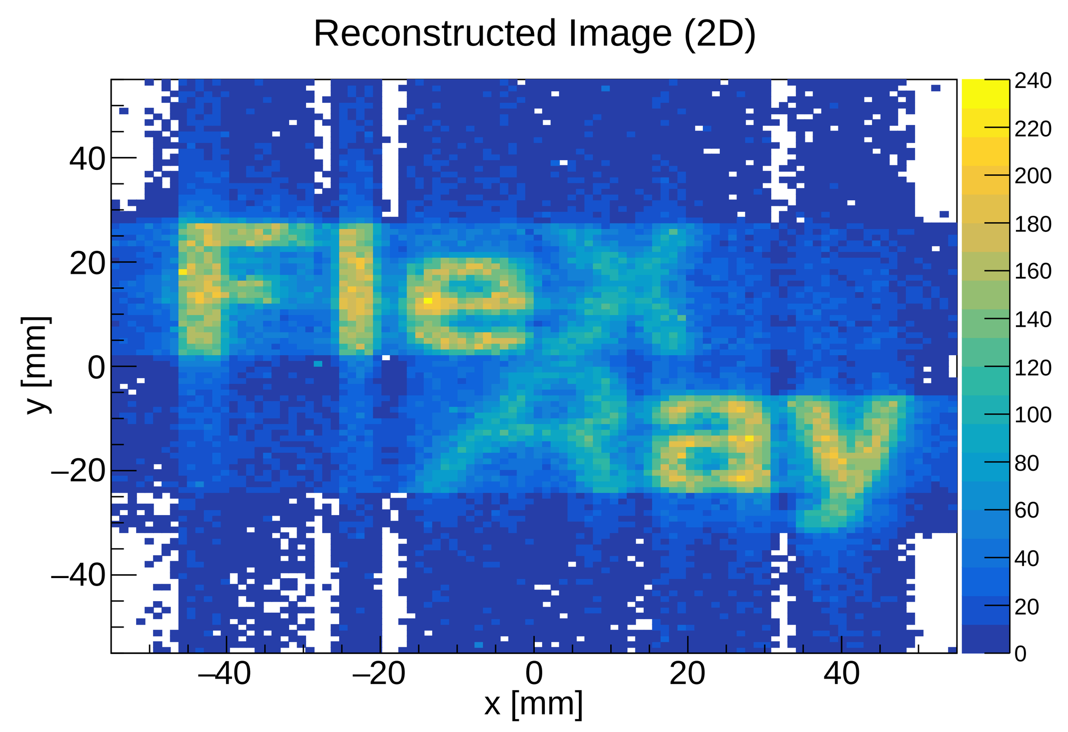
We can reconstruct a 2-D image from X-rays that interact in a single fiber by measuring the difference in light arrival time at each end of the fiber. This measurement has a large uncertainty (~ 10 cm) that's limited by the scintillation timescale and the number of photons detected.



If the properties of the scintillating fiber are well-understood, the uncertainty in the location measurement is well-known and the image can be deconvolved. Since each hit is blurred in only one dimension (and never diagonally), the deconvolution algorithm can be very fast due to the sparse convolution matrix.



A small number of X-rays will interact in both layers of fibers, but relying on these events requires a less-intense X-ray source to avoid swamping the signal with falsely-coincident single-fiber detections. If the application allows long exposure times (~ 10 minutes), the resolution can be significantly improved with these 2D detections.



Both detection methods are vastly improved at gamma-ray energies. Higher light yield improves the time-difference resolution and an increased number of 2D detections improves the 2D exposure time.

More Information

Project Website: `https://flex-ray.eu/`
LinkedIn: `linkedin.com/showcase/flex-ray/`

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