# Novel Thin-Scintillator Beam Imager

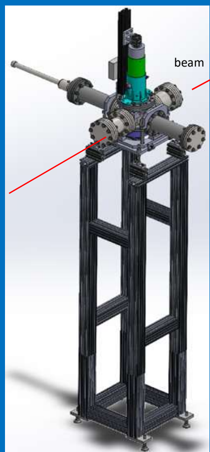
*P. S. Friedman* --- Integrated Sensors, LLC, Ottawa Hills, Ohio

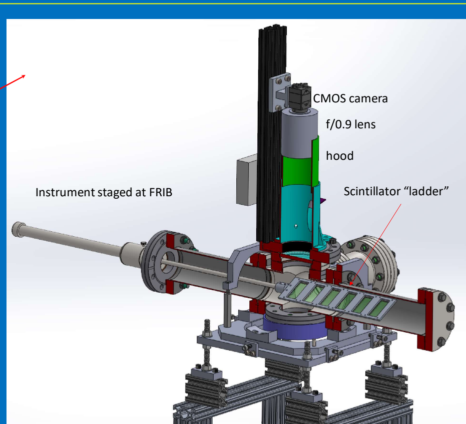
*D. S. Levin, N. Ristow, C. Ferretti* --- University of Michigan, Department of Physics, Ann Arbor, MI

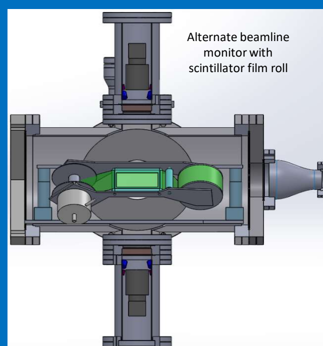
*T. N. Ginter, M. Cortesi* --- Michigan State University, Facility for Rare Isotope Beams (FRIB), E. Lansing, MI

*V. Bashkirov, R. Schulte* --- Loma Linda University, School of Medicine, Loma Linda, CA

PSD12: Birmingham UK, Sept 15, 2021




Particle beam imaging monitor uses 2 ***novel*** scintillators + machine vision CMOS camera + large aperture lens

Scintillators:

Type 1 - **PM** → An ultra-thin, semi-crystalline Polymer Material:
- demonstrated for nuclear physics & medical imaging
- hazy material, no total internal reflection (T.I.R), photons escape from surface
- reduced back surface reflection
- radiation damage resistance, superior to plastic scintillators such as BC-400
- available thickness from ~2 μm to 250 μm
- higher light-yield than PVT (polyvinyltoluene) and PS (polystyrene) based plastic scintillators

Type 2 - **HM** → Hybrid Multilayer scintillator:
- demonstrated for nuclear physics & medical imaging
- reduced back surface reflection, no T.I.R.
- variety of time constants
- thickness from 200-400 μm
- high light yield > 5 times light yield of BC-400
- Lambertian radiator --> angular independence of emitted light intensity

Cameras:

***Standard*** option: low cost CMOS machine vision camera from many tested:
- relatively large pixel size
- improved pixel Q.E.
- improved pixel-to-pixel noise uniformity
- improved photon angular acceptance at smallest f-number
- result → twice the ADC signal with better noise characteristics

***Alternative*** option: sCMOS camera with low noise (0.7 e) + high sensitivity 16 bits, but at much higher cost

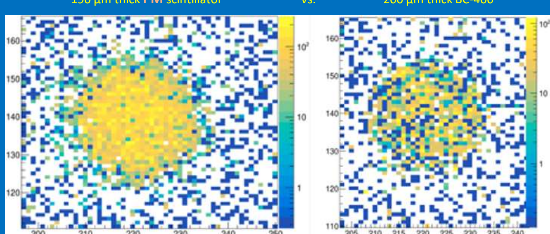
Lens: Ultrafast f/0.9 aperture

Capability: Single-particle imaging for protons & ions: alphas in lab, *heavy-ions* at FRIB

Real-time beamline tuning/monitoring for nuclear physics: analysis and display updated at 1 Hz
- includes corrections for: noisy pixels, depth-of-field distortion, background subtraction, perspective view transformations
- internal calibrations with UV-LEDs and UV-photodiode readout
- scintillators can quickly be shifted in/out of beam without breaking vacuum
- six scintillators includes **HM** type and several thickness of **PM** type, plus a reference CsI(Tl)
- display of beam centroids, widths vs. time, current 2D centroid, intensity, ADC spectrum, etc.

## PM vs. BC-400 Scintillator

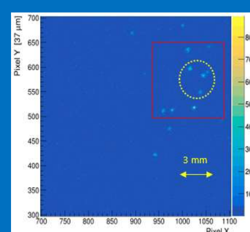
190 μm thick **PM** scintillator vs. 200 μm thick BC-400

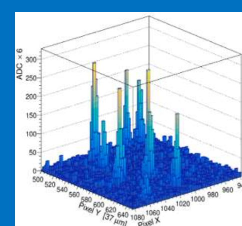


Test conditions:
- $^{90}$Sr ***beta*** source (2 MHz/cm$^2$)
- 3 mm diameter collimated beam
- energy loss = 0.05 MeV
- camera: 3 MP, 1.3 e RMS noise, gain 24 db
- 1 sec exposure and f/0.9 lens

Signals:
- ~250 ADC counts in **PM** vs <100 ADC counts in BC-400
- much higher hit density recorded in **PM** scintillator

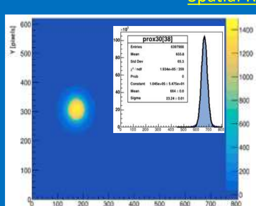
## Single Particle Sensitivity

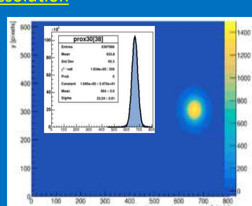


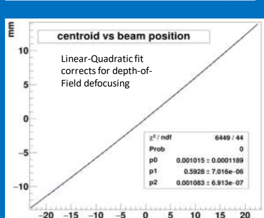



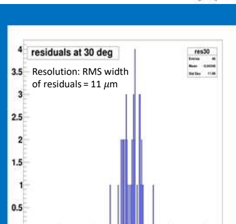

Single particle capture: Above images reveal isolated ***alpha*** particle hits from a weak $^{241}$Am source irradiating a 2x2 cm wafer of **HM** type scintillator and recorded with a sCMOS camera at 10 ms exposure. Lego plot on right of hits within red box on left is re-binned for clarity and shows strong signals.

## Spatial Resolution





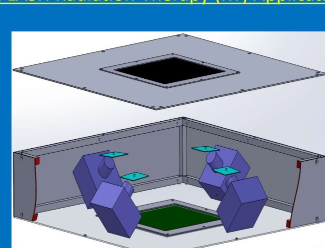



Method:
- Scan beam from laser (or beta source) across field-of-view with precision stepper
- Reconstruct centroids
- Obtain fit of centroid means vs. true beam position
- Non-linear fit corrects for depth-of-field defocusing
- Residual distribution from fit gives the resolution

This work is funded by the U.S. Dept. of Energy under FOA opportunity number: DE-FOA-0002155

## FLASH Radiation Therapy (RT) Application as an Ultra-Fast Beam Monitor



Exploded view of the detector with folded optics (left) to be positioned between beam snout and patient (right).

- FLASH effect: Radiation-induced healthy tissue toxicities can be *reduced without* affecting tumor control by *ultra-fast* delivery of radiation at dose rates *orders-of-magnitude* greater than conventionally fractionated external beam RT clinical practice (EBRT).
- FLASH RT implies that higher radiation dose treatments are possible, thereby, it increases the therapeutic index over conventional EBRT.
- FLASH delivers >40 Gy/s dose in ~0.1 s for 1-4 treatments. For protons: beam rates are ~$10^{12\text{-}13}$ particles/sec (pps). Conventional EBRT delivers $10^{9\text{-}10}$ pps, or 1-2 Gy/minute, 5-times per week, over several weeks of treatment and sometimes up to 1-2 months.
- The ultra-fast FLASH beam monitor adopts the design shown above using an array of fast imaging cameras operating at readout/analysis speeds of ~10 KHz.
- Standard dosimetry currently used for monitoring first clinical FLASH treatments (e.g., with the advanced Markus Chamber) *does not* fulfill the needs for FLASH dose rates & large-area coverage.
- This fast readout and low mass (< 0.5 mm water equivalent thickness) technology will enable clinical trials of FLASH.
- Monitor is positioned between beam nozzle exit point and patient, provides immediate (100 μs), spatially resolved dosimetric analysis and machine feedback signals for fast termination.
- Compact unit covers 26 cm x 30 cm with folded optics and multiple cameras.
- Spatial resolution expected to be 100 μm or better.
- Internal calibration system with UV-sources and UV-photodiode monitoring,