#125: An UltraFast Large-Area Multi-Camera Scintillator-based Beam Monitor and Dosimeter for Proton FLASH-RT Operating at 20,000 Frames/Second

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FLASH Scintillator Beam Monitor Features

- One (1) high-speed machine-vision camera in 1st Gen prototype vs two (2) high-speed cameras in 2nd Gen system.
- Folded optics reduced profile ~12 cm.
- 1st Gen scintillator area 15x15-cm^2, vs 2nd Gen scintillator area 15x23-cm^2.
- Positioned between nozzle & patient
- Novel low-mass thickness (<0.5 mm water equivalent), transmissive *hybrid* inorganic crystal + polymer scintillator

Fast, Real-Time DAQ

- FPGA-based image processing & analysis
- Continuous real-time analysis during treatment
- Images acquired at 20 kHz frame rate with analysis performed in ~1 µs
- Fast analysis includes beam position, measured profile and dose
- Dose measurement is referenced to clinical radiation program
- Out-of-tolerance beam interrupt signal generated 50 µs after dose is delivered.

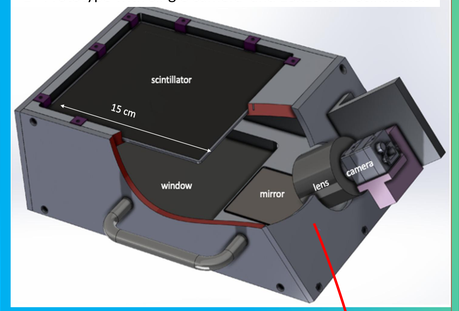
Calibration Program

- Design/fabrication of robotic calibrator that uses ^{90}Sr source as standard candle
- Images generated of uniform beam over the relevant field-of-view (FoV)
- Position specific intensity data set of intensity corrections generated for FoV
- Measured intensities compared with calibrated radiochromic films

1st Generation Design & Test Facilities

- 8 MeV electrons, FLASH compatible beam (used at Notre Dame Radiation Lab)
- 6-16 MeV electrons using Varian LINAC at UM Hospital Radiation Oncology (**UMH**)
- 10 MV photons at UMH
- FLASH-level 16 MeV electrons on UMH modified Varian Trilogy linac.

1st Prototype with single camera and 15x15-cm^2 scintillator

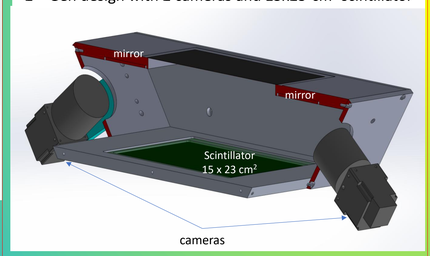


1st Generation prototype tested with Varian ***6-16 MeV electron*** linac at UMH.

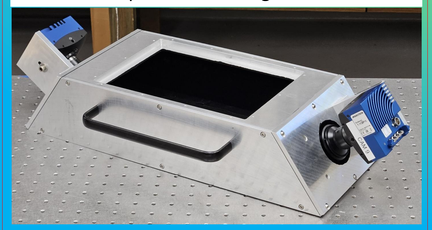
2nd Generation Design & Fabrication

- 2nd Gen design has 15x23-cm^2 active area scintillator as compared to the 15x15-cm^2 area in the 1st Gen design.
- Each camera views the scintillator indirectly via a mirror thus constituting a folded optical system configuration.
- Each camera has a field-of-view (FoV) of 15x15-cm^2, resulting in an overlap area of 7 mm in the scintillator center, thus yielding enhanced resolution by a factor of ~ 1.4X.

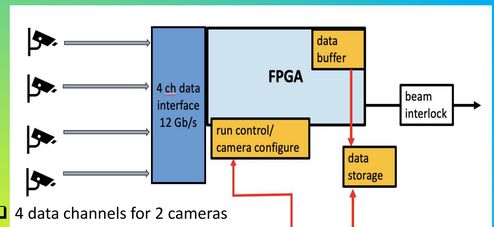
2nd Gen design with 2 cameras and 15x23-cm^2 scintillator



Fabricated 2nd Gen beam monitor with two (2) cameras attached. System in photo is rotated 180° with respect to the design shown above.



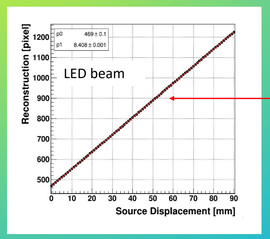
FPGA Readout



- ❑ 4 data channels for 2 cameras
- ❑ Data rate 12.5 Gb/channel
- ❑ Data processing:
  - ➢ Background subtraction
  - ➢ Image correction for non-uniformity and distortion
  - ➢ Beam centroid, shape and dose measurement

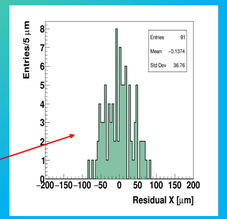
Performance Test Results

1. Spatial resolution using test bench LED "beam"



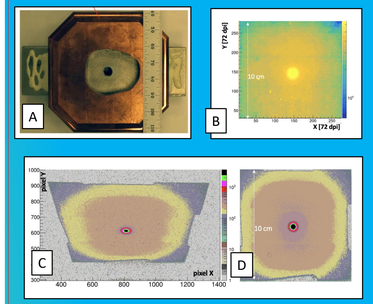
Reconstructed beam centroids vs true LED beam position of stepper motor

Residuals of above linear fit shows spatial resolution of ~ 36 µm



Spatial position resolution

2. Varian LINAC at UMH: 6-16 MeV electrons at conventional therapeutic dose rates.



[A]: Varian 16 MeV e$^-$ beam collimator

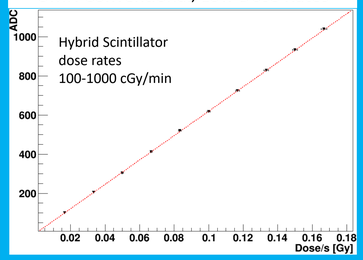
[B]: Beam image on Gafchromic film

[C]: Beam monitor "raw" image

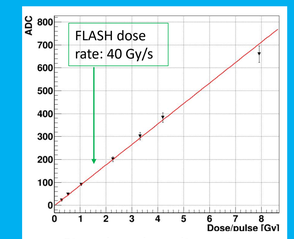
[D]: Beam monitor image in clinic coordinates

[E]: Beam profiles from monitor and Gafchromic film

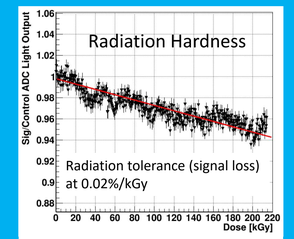
Measured signal vs dose linearity at UMH Conventional, Low Dose Rates



3. Notre Dame Radiation Lab: 8 MeV e$^-$ FLASH compatible beam



Signal vs dose linearity exceeding FLASH dose rate



Signal vs dose exposure

Conclusions

- 1st, 2nd Gen FLASH beam monitors built & functionally tested.
- Images downloaded & analysis of beam parameters performed in <50 µs at 20 kHz with no pileup.
- Beam intensity measurement is linear with dose for FLASH rates.
- High spatial resolution that matches Gafchromic film, but is provided "instantly" <50 µs.
- Position precision is ≤50 µm.
- Exceptional radiation hardness.

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