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Pulse Resolved Beam Characterization and Feedback for FLASH-RT Using Radioluminescent Dosimeters

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AAPM, Annual Meeting, 2021

FLASH Beamline @ Dartmouth

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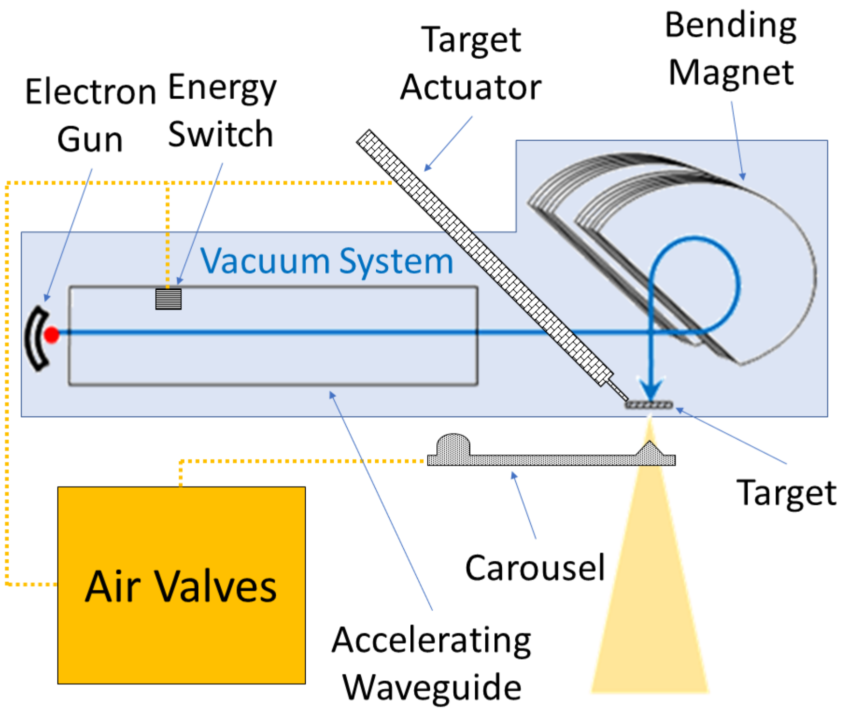


Rahman M*, Ashraf MR*, Zhang R, Bruza P, Dexter CA, Thompson L, Cao X, Williams BB, Hoopes PJ, Pogue BW, **Gladstone DJ. Electron FLASH Delivery at Treatment Room Isocenter for Efficient Reversible Conversion of a Clinical LINAC. Int J Radiat Oncol Biol Phys. 2021 Jan 11:S0360-3016(21)00024-9. doi: 10.1016/j.ijrobp.2021.01.011. Epub ahead of print. PMID: 33444695**. (* Equal Contribution)

At iso-center (100 cm SSD)

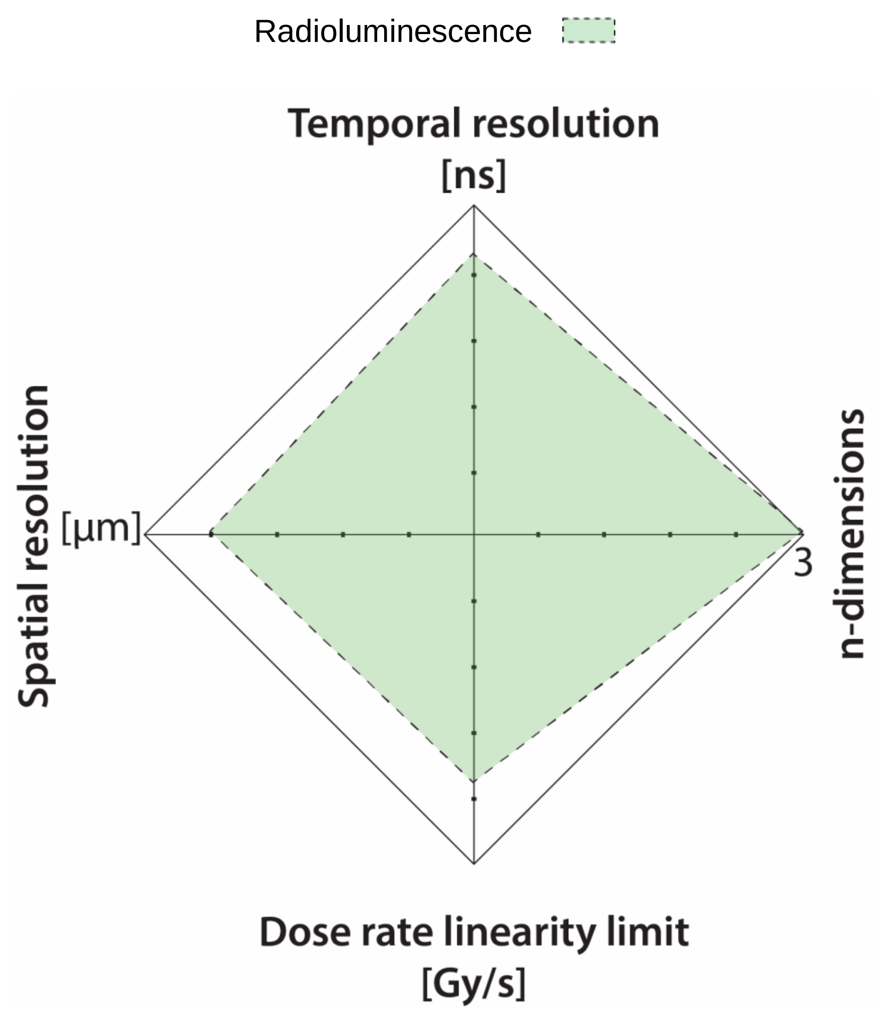
Beam characteristics relevant to FLASH (Total Pulses: 35)

	Total Dose (Gy)	Mean Dose Rate (Gy/s)	Dose Per Pulse (Gy)
Jaws Open	28.2± 0.5	290 ± 5	0.87± 0.01
1.5 cm Circular	25.5± 0.5	262 ±5	0.72± 0.01
1 cm Circular	23.2± 0.5	238 ± 5	0.66± 0.01

1) 10 MV at treatment console
2) Target Retracted (~ 10 MeV FLASH Beam)
3) Feedback Mechanisms turned off!

- Dose Monitoring for FLASH-RT is Non-Trivial

- Radioluminescent Detection Techniques for FLASH-RT



Ashraf, M. R.*, Rahman, M*., Zhang, R., Williams, B. B., Gladstone, D. J., Pogue, B. W., & Bruza, P. (2020). **Dosimetry for FLASH Radiotherapy: A Review of Tools and the Role of Radioluminescence and Cherenkov Emission. Front. Phys. doi:10.3389/fphy.2020.00328. (* Equal Contribution)**

Two Distinct Approaches Presented here:

1) Camera Based Single Pulse Central Axis Beam Profiling

2) Fiber Optic Based Detectors and Fast Electronics for Pulse Resolved Dosimetry and Feedback

Camera Based Approach: Imaging in a Water Tank

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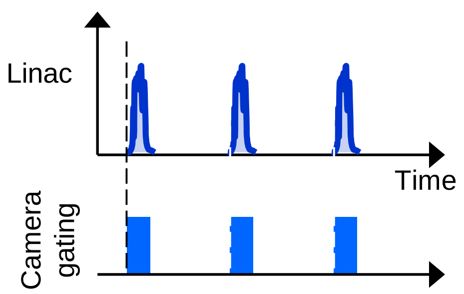
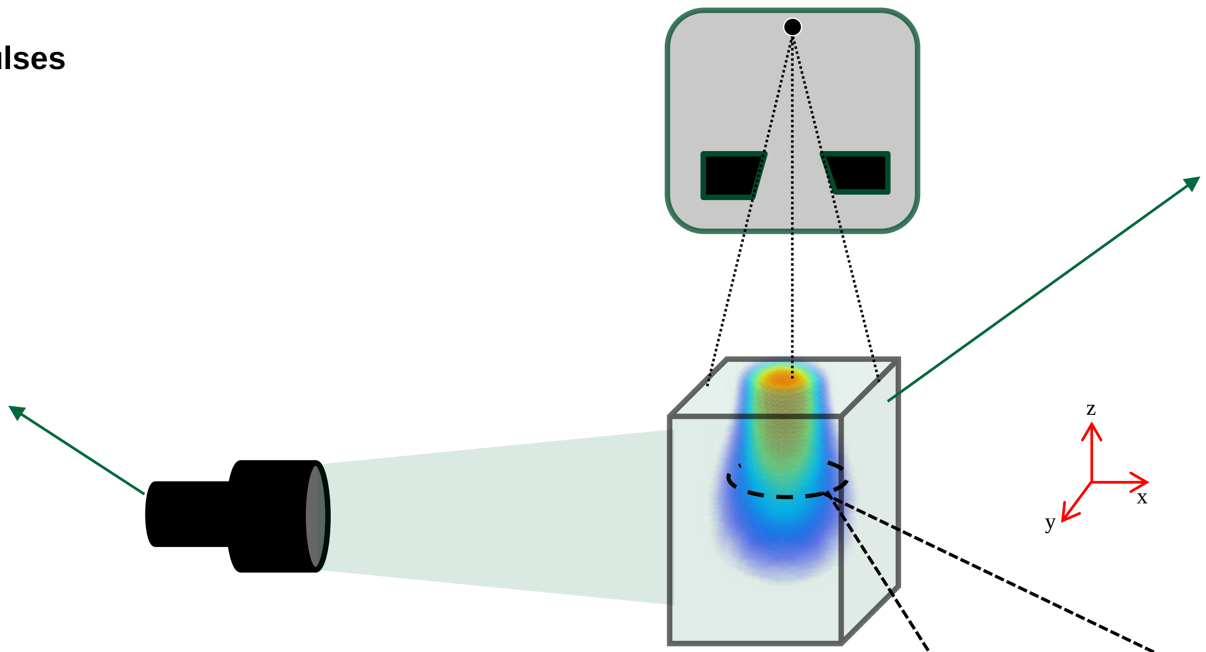
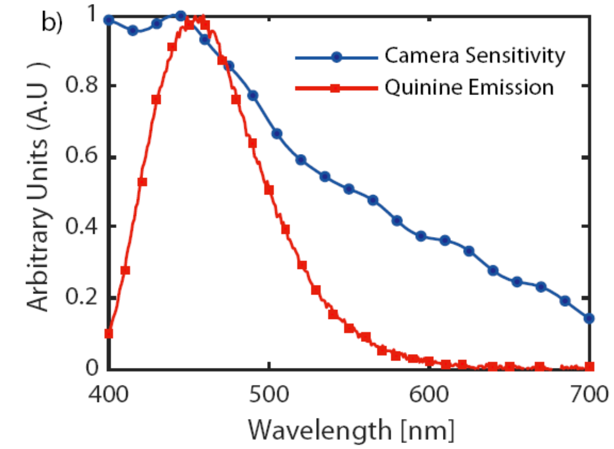
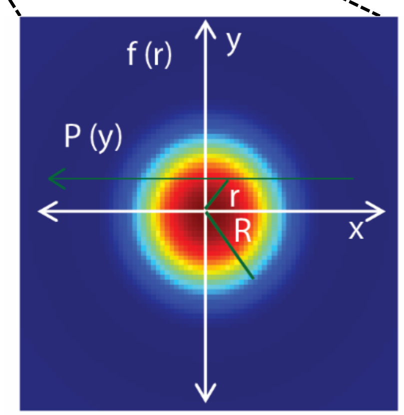
CMOS camera gated to Linac pulses









Projected Measurement

$$P(y) = 2\int_{y}^{R} f(r)\frac{r}{\sqrt{r^2 - y^2}}dr \qquad (1)$$

Inverse Abel Transform

$$f(r) = -\frac{1}{\pi}\int_{r}^{R}\frac{dP(y)}{dy}\frac{1}{\sqrt{y^2 - r^2}}\mathrm{d}y \quad (2)$$

Ashraf, M.R., Rahman, M., Zhang, R., Cao, X., Williams, B.B., Hoopes, P.J., Gladstone, D.J., Pogue, B.W. and Bruza, P. (2021), **Technical Note: Single-pulse beam characterization for FLASH-RT using optical imaging in a water tank**. Med. Phys., 48: 2673-2681. https://doi.org/10.1002/mp.14843

Radially Symmetric Beam allows recovery of central axis data from single projection image using Abel Inversion

Central Axis Comparison vs GafChromic Film-XD

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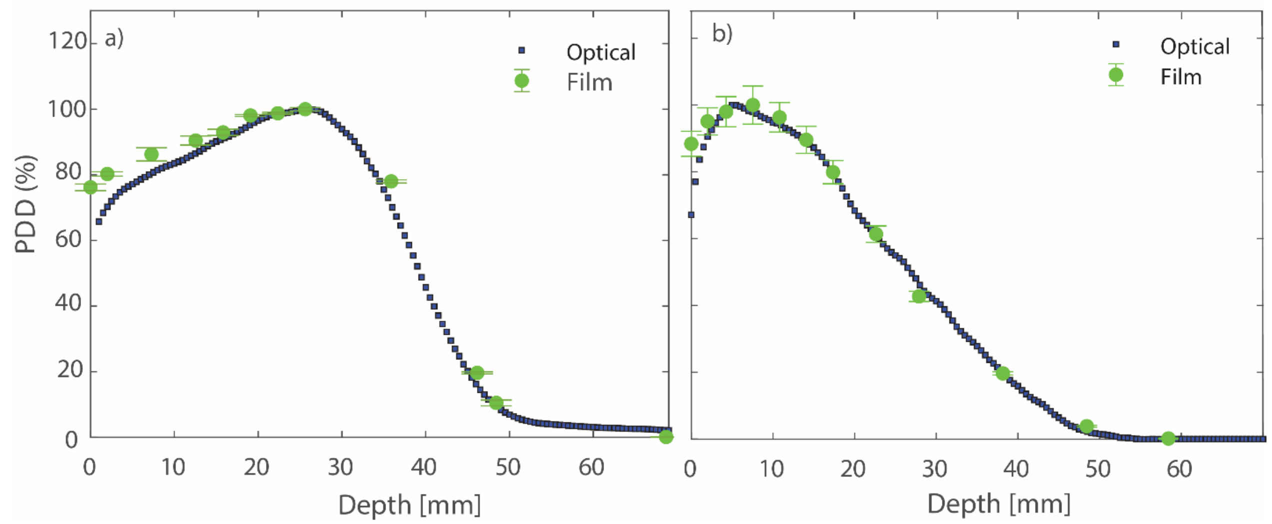
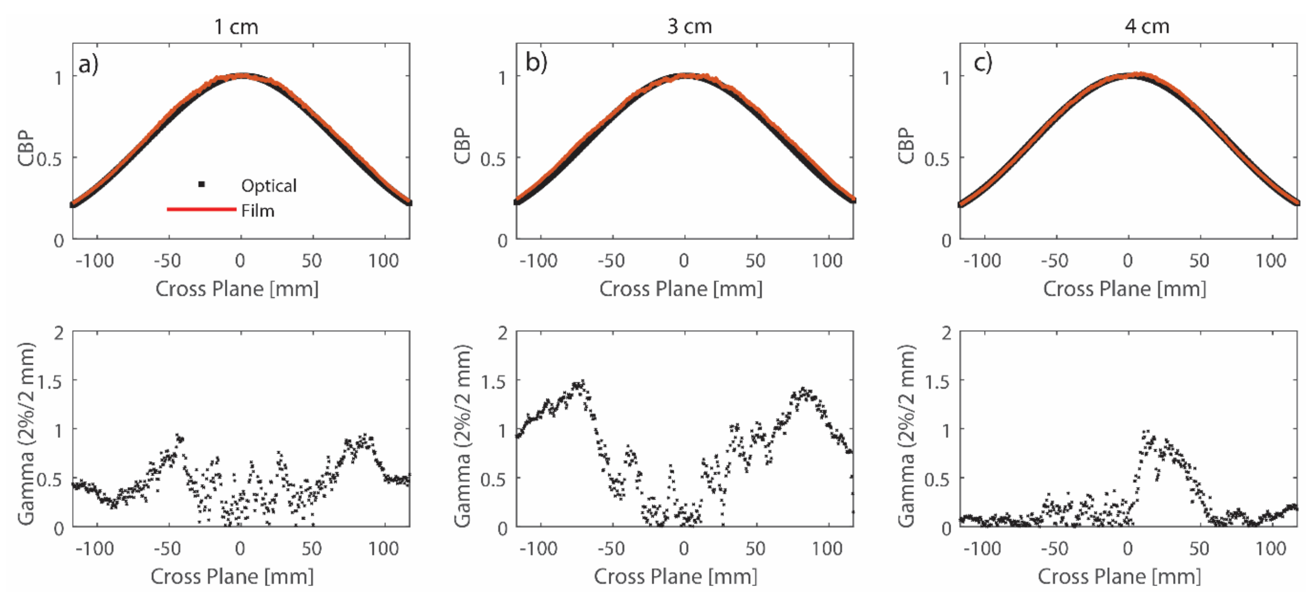
Jaws Open

1.5 cm

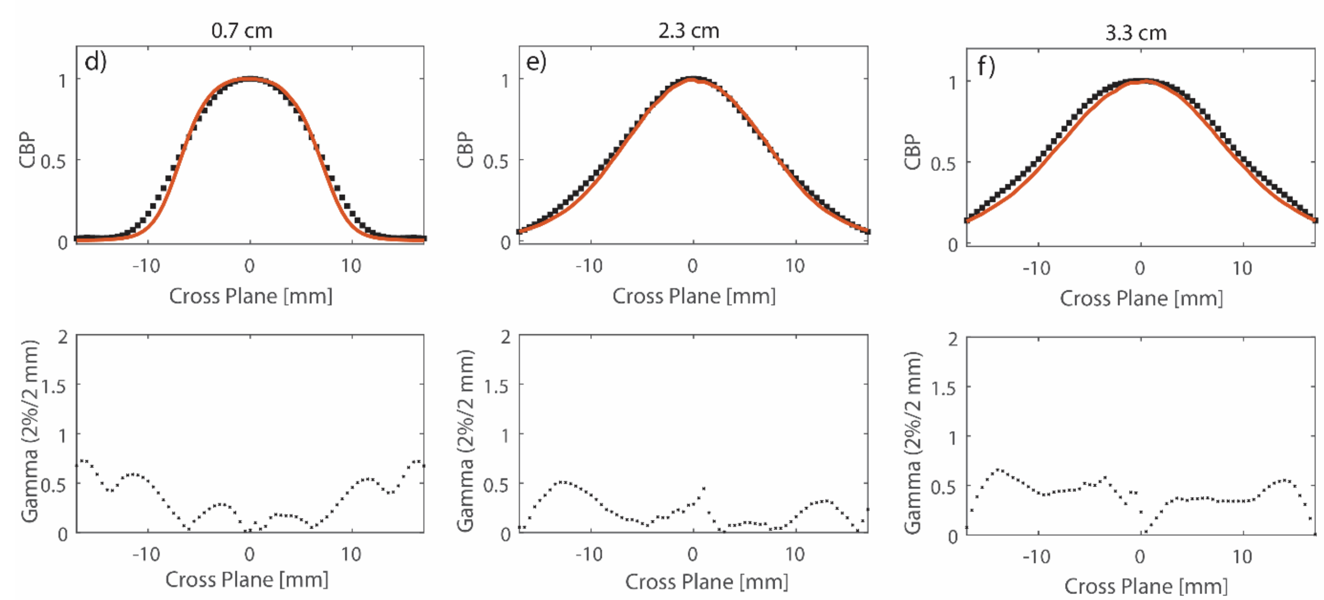


- Discrete data points using Film!
- However, optical imaging provides complete picture!

Jaws Open



1.5 cm



Single Pulse Central Axis Characterization for FLASH

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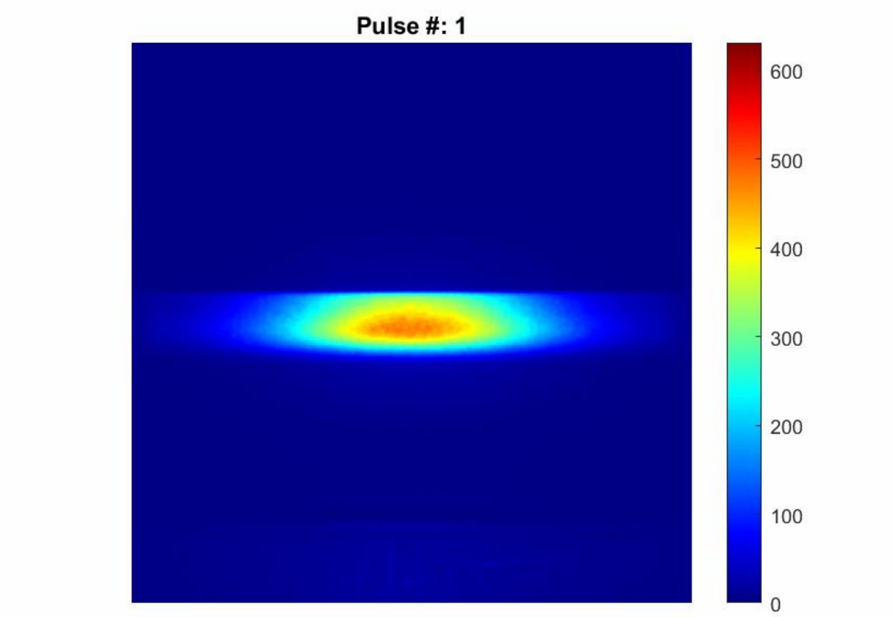

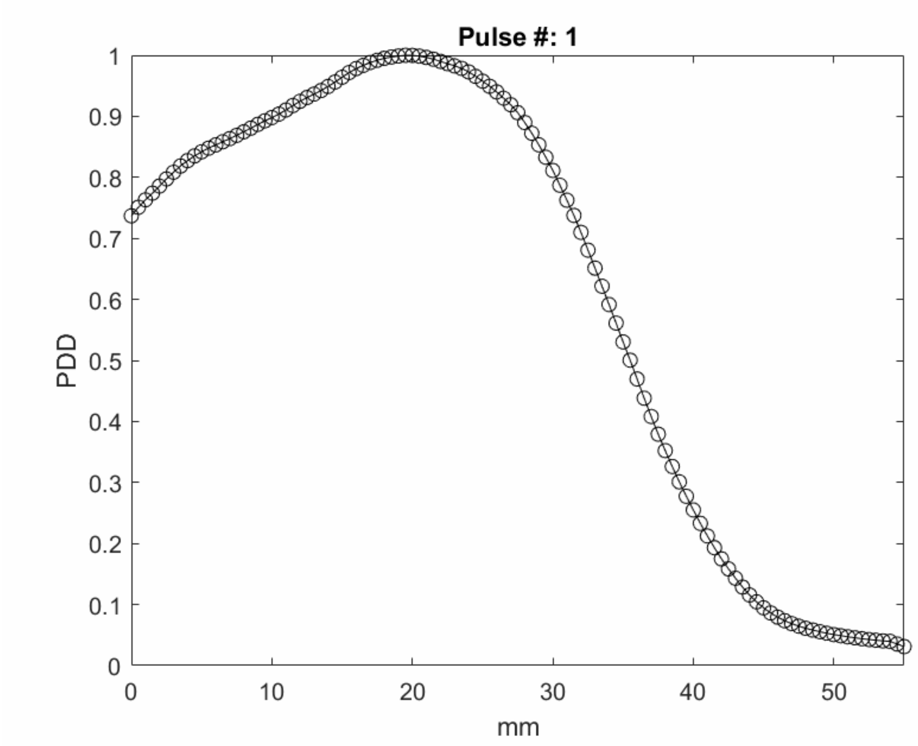

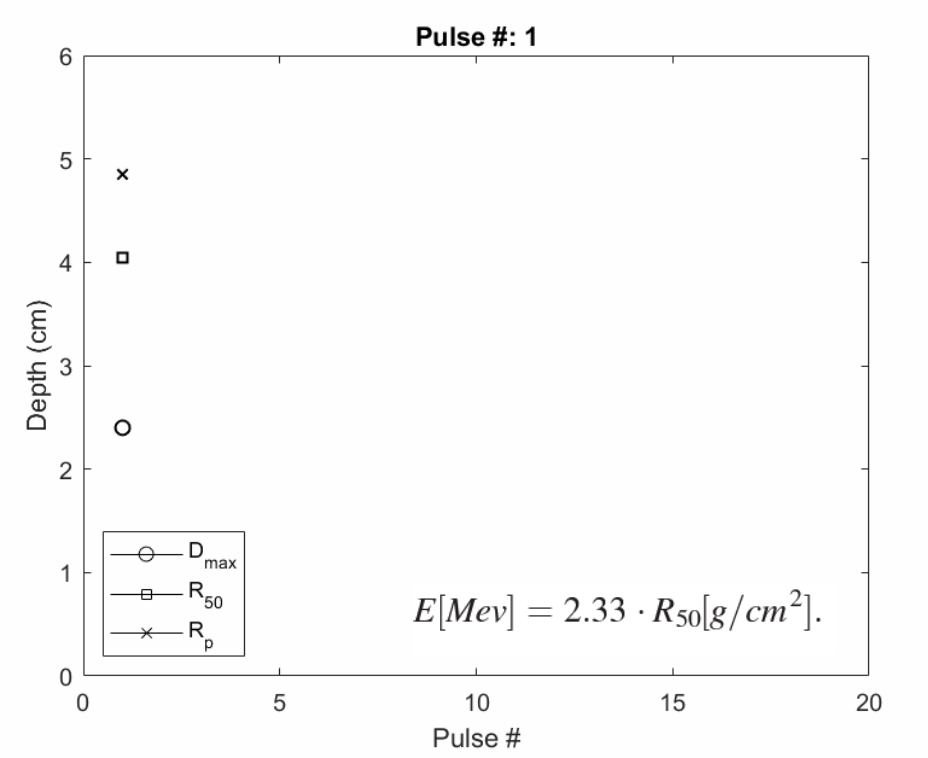

Beam energy was stable from one pulse to the next. However, a ramp-up in intensity was observed for the first few pulses!

Pulse Counting and Cherenkov Based PMT Detector For Temporal Analysis

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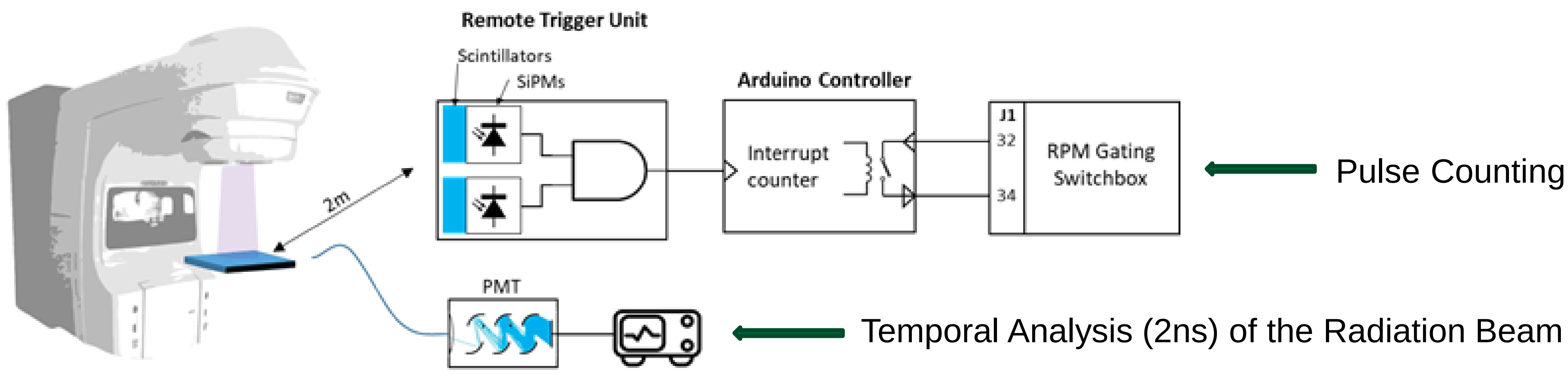
Ashraf, M.R., Bruza, P., Krishnaswamy, V., Gladstone, D.J. and Pogue, B.W. (2019), Technical Note: Time-gating to medical linear accelerator pulses: Stray radiation detector. Med. Phys., 46: 1044-1048. https://doi.org/10.1002/mp.13311



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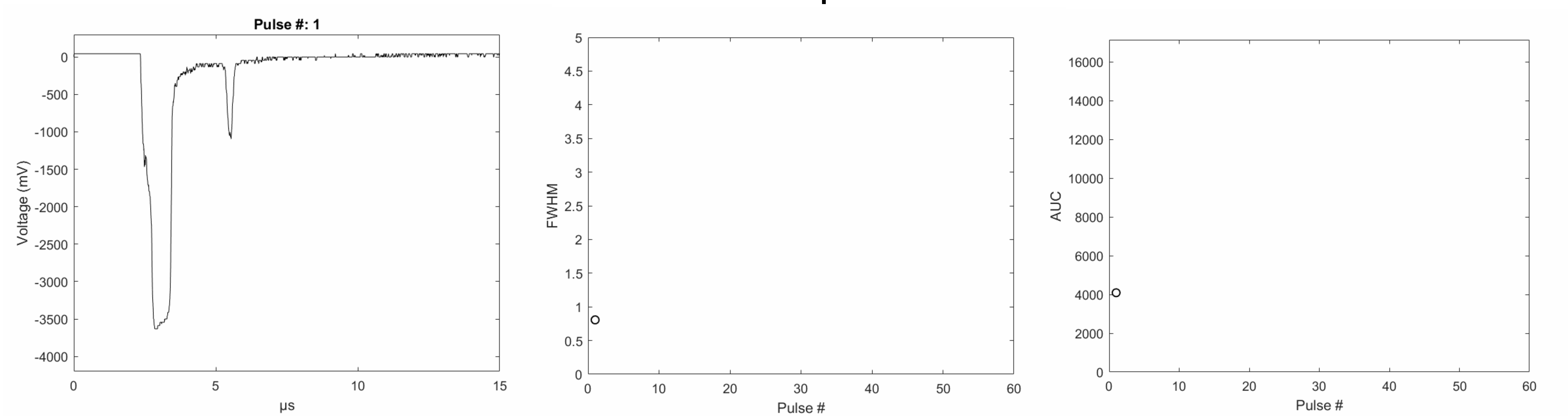
PMT Output:



Although data is collected at 2 ns resolution, it is processed after dose delivery.. we need dose accumulation in real-time.

Field Programmable Gate Array (FPGA) Based Hardware: Use Dose as a Feedback

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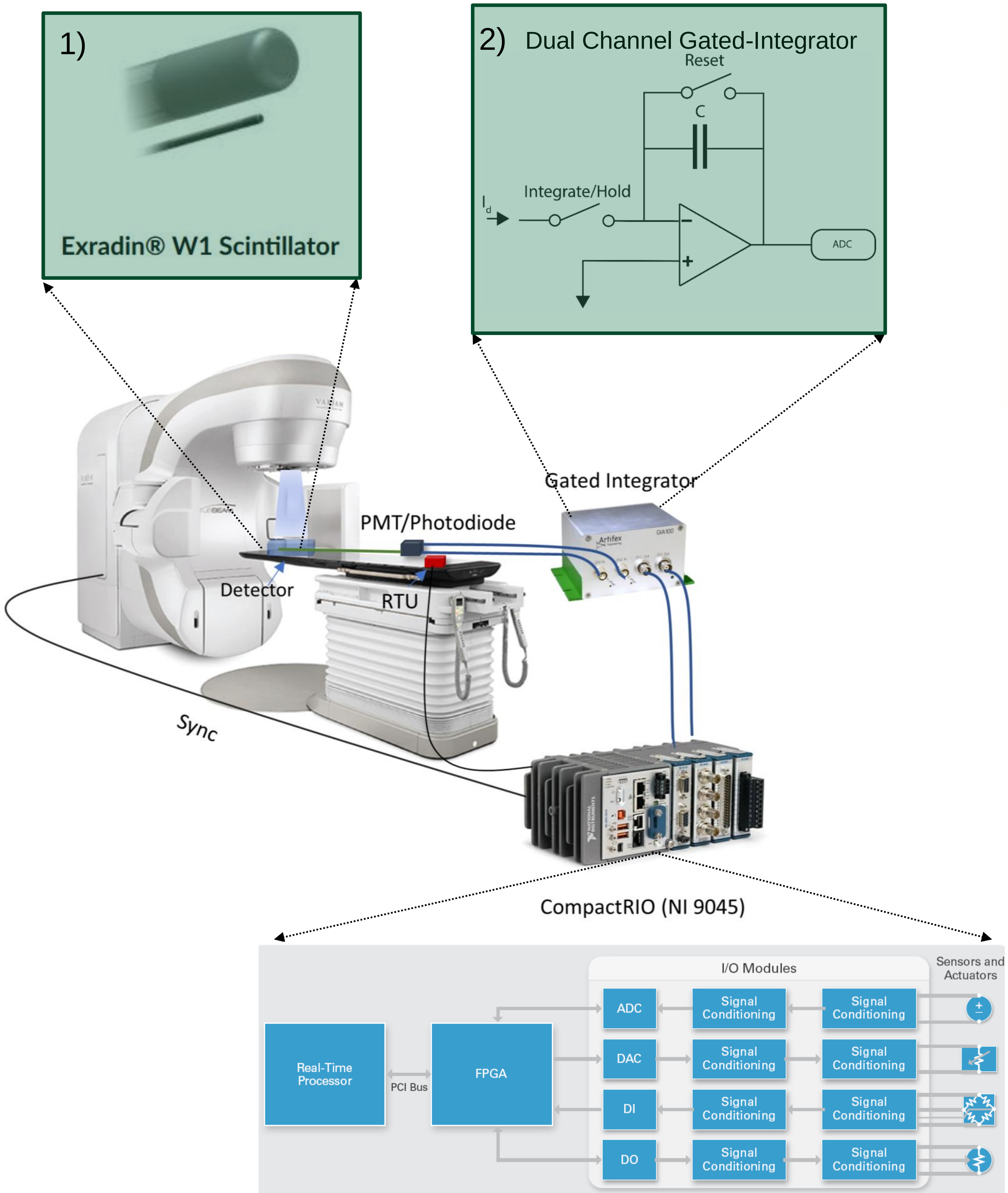
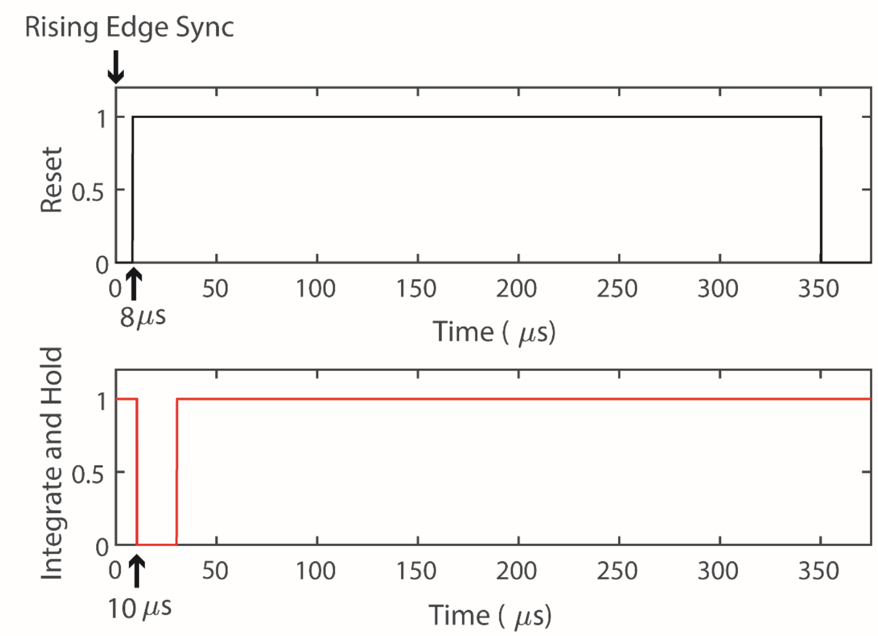
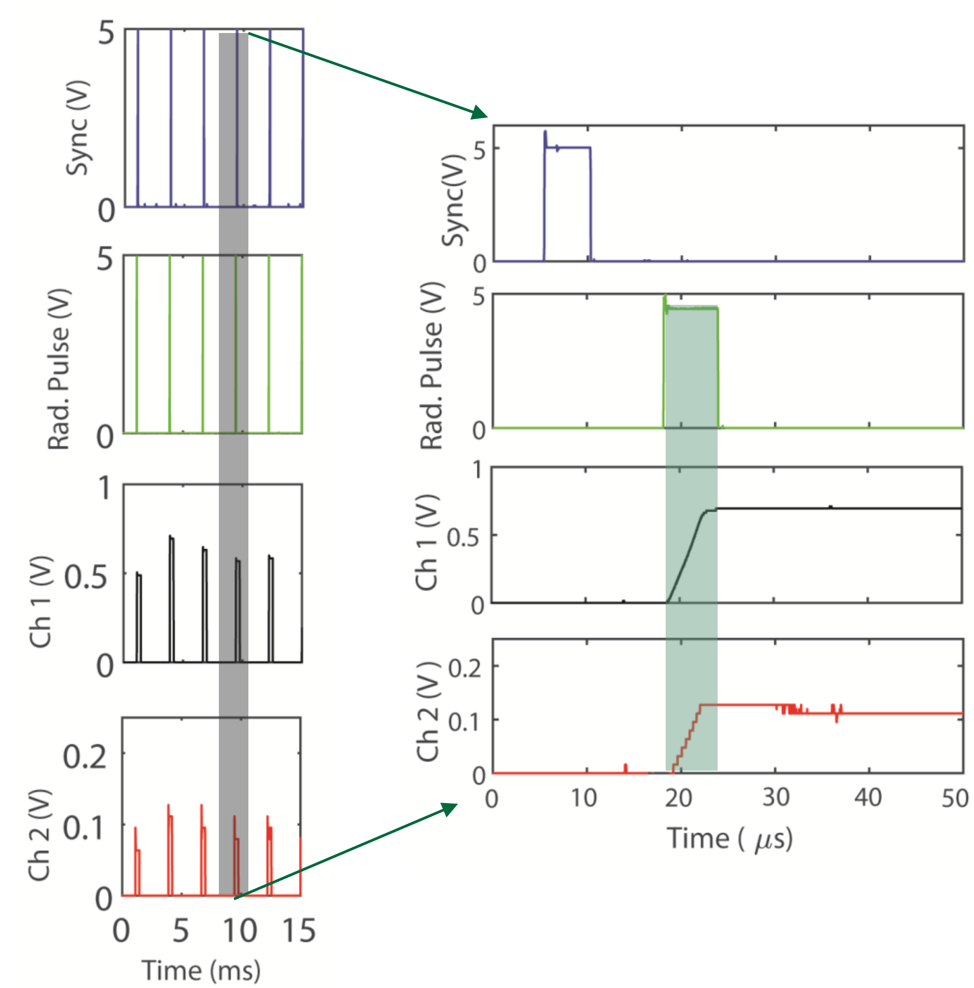
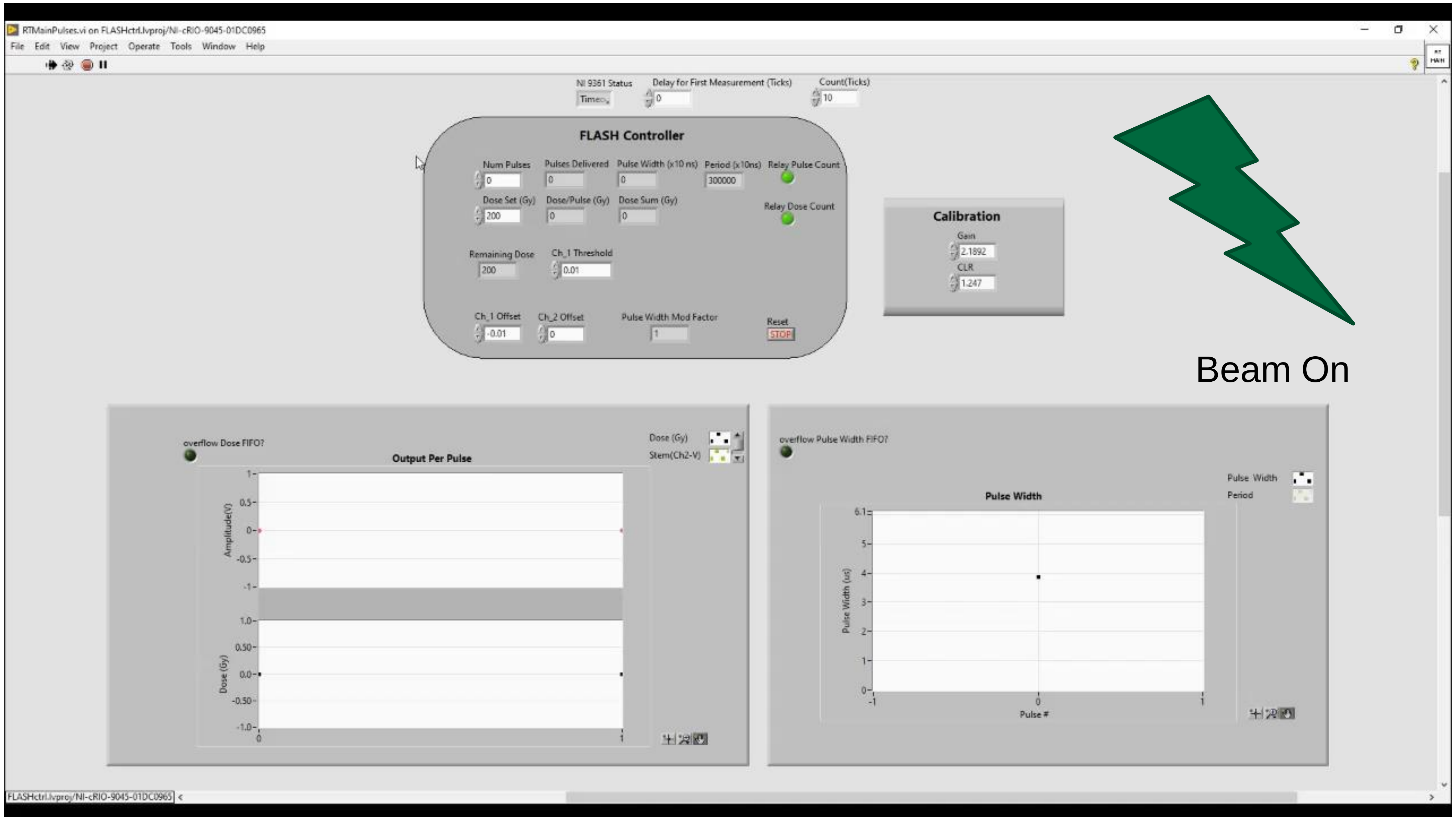






User Interface Displaying Quantities Pertinent to the FLASH Effect



Beam On

1) Dose per pulse information
2) Number of pulses
3) Pulse Repetition Rate
4) Pulse Width

Exradin W1 Characterization and In-Vivo Dosimetry

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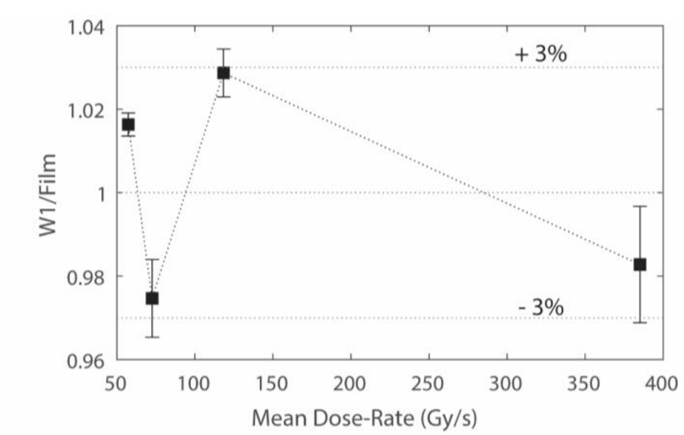
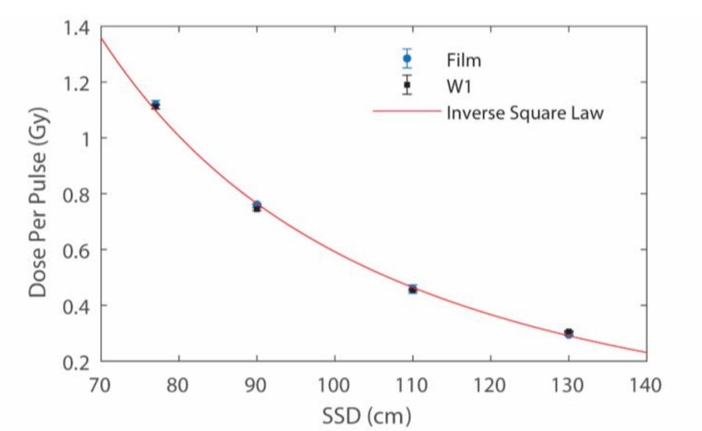
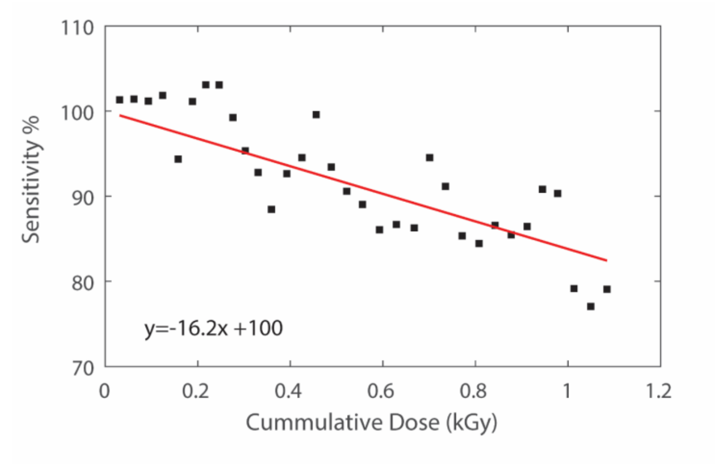
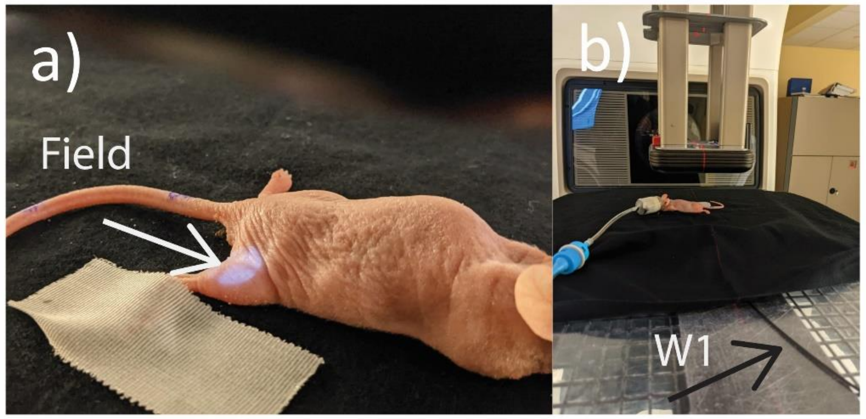
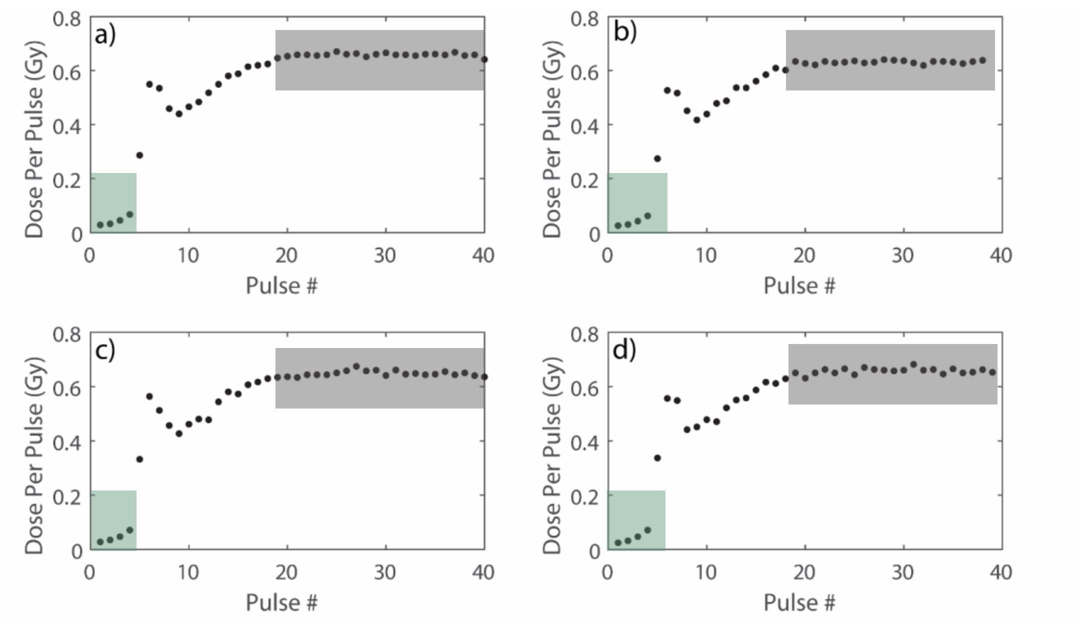










Initial 4 Pulses: 0.045 Gy/Pulse

Last 20 Pulses: 0.65 Gy/Pulse

Conclusions

- Single Pulse Central Axis Beam Profiling Using a time-gated Camera.

- Temporal Analysis of the beam using a PMT-Based Cherenkov detector revealed a ramp-up period.

- Ramp-up necessitates that feedback be in terms of dose accumulation for each pulse. A FPGA based monitoring system was developed.
  - The monitoring system can be coupled to other potentially attractive dosimeters for FLASH (i.e., microdiamond detector)
  - The code for the FPGA can be requested and easily implemented at other institutions performing FLASH experiments.

- Arduino controller has been replaced with new hardware (for pulse counting feedback) and dose-based feedback is currently being worked on.

Acknowledgements


Dr.Brian Pogue


Dr.Petr Brůža


Sally Hull


Jason Gunn


Kathy Burnham

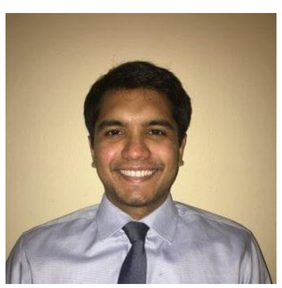

Dr. Rongxiao Zhang


Dr.David Gladstone

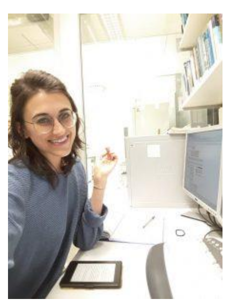

Dr.Benjamin Williams

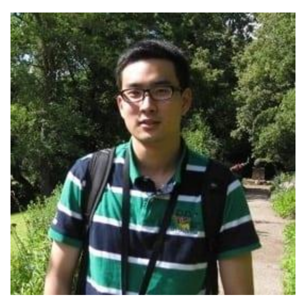

Dr. Lesley Jarvis


Dr. Colleen Fox


Mahbubur Rehman

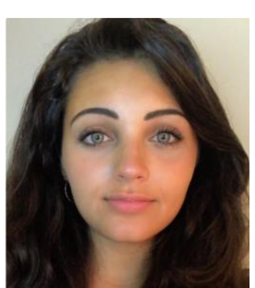

Daniel Alexander


Rachael Hachadorian


Tianshun Miao


Arthur Petusseau


Phuong Vincent


Savannah Decker


Ben Malone


Alberto Ruiz


Sam Streeter

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Dartmouth-Hitchcock

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Thank you!

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