DARTMOUTH

UHDR DOSIMETRY FOR FLASH-RT

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04/17/2023

Council on Ionizing Radiation Measurements & Standards

WMC Health | Westchester Medical Center

Westchester Medical Center Health Network

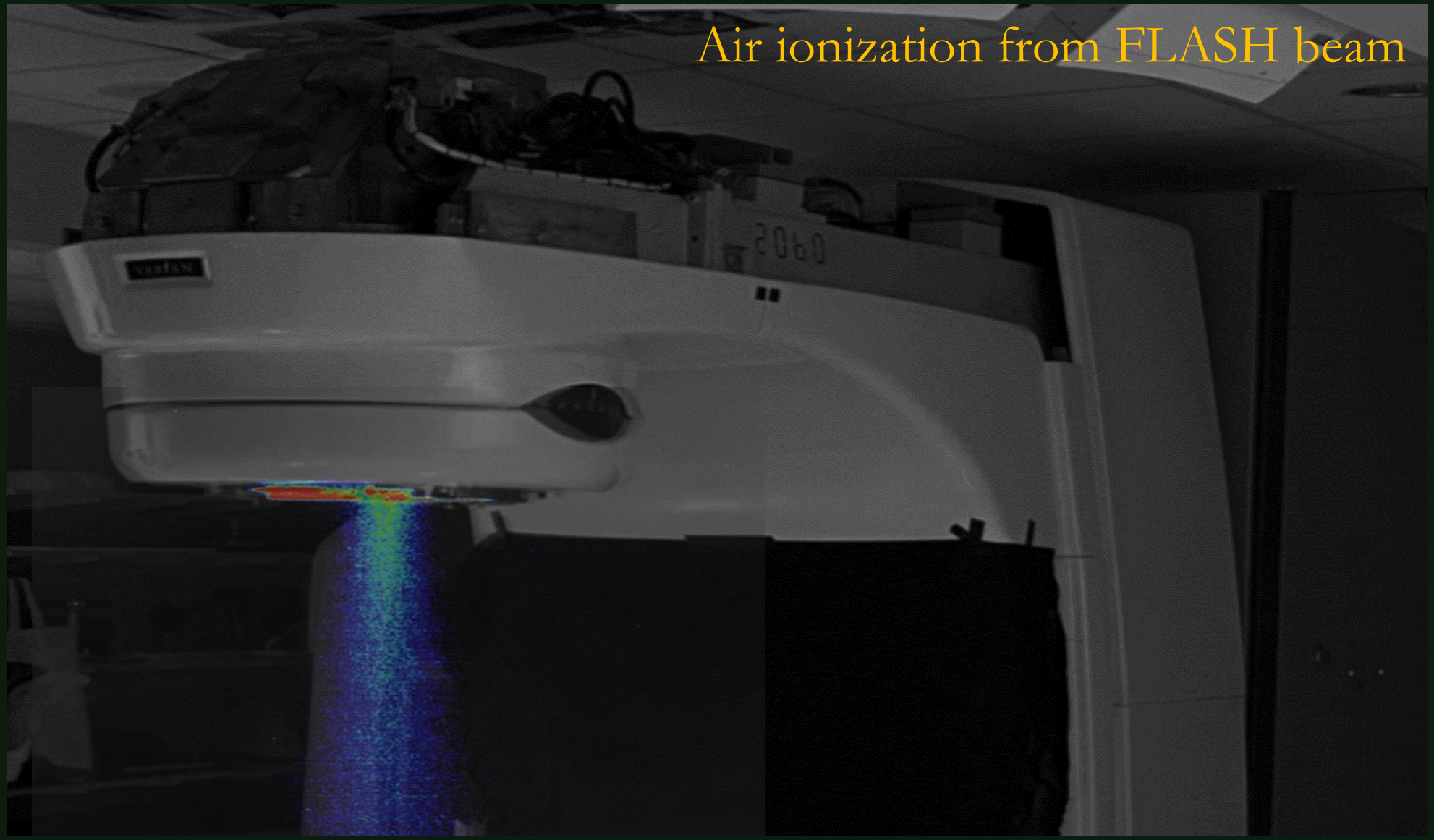
NEW YORK MEDICAL COLLEGE

A MEMBER OF THE TOURO COLLEGE AND UNIVERSITY SYSTEM

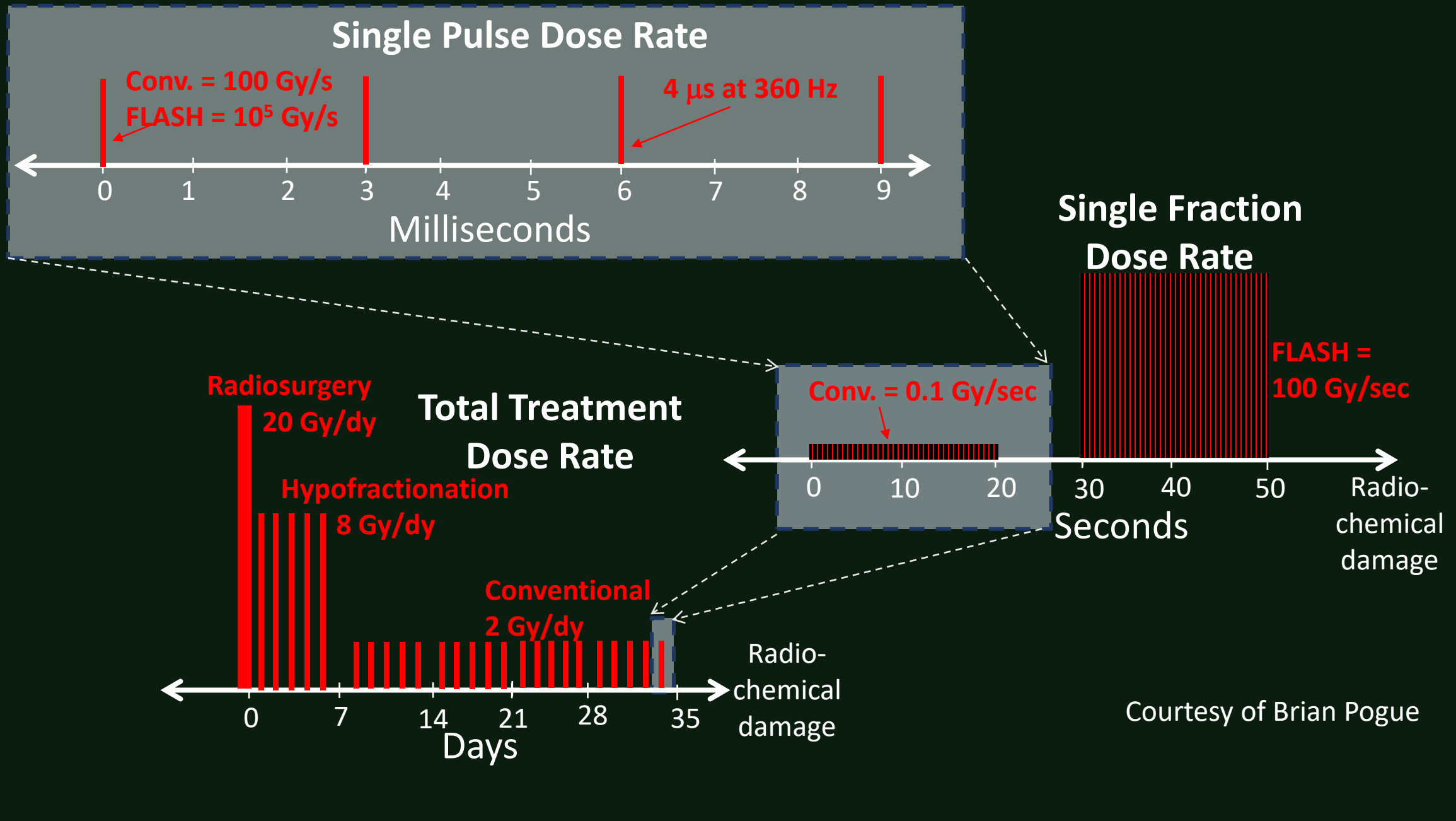
Disclosure

DoseOptics: IP, consultation
MathWorks: consultation

UHDR

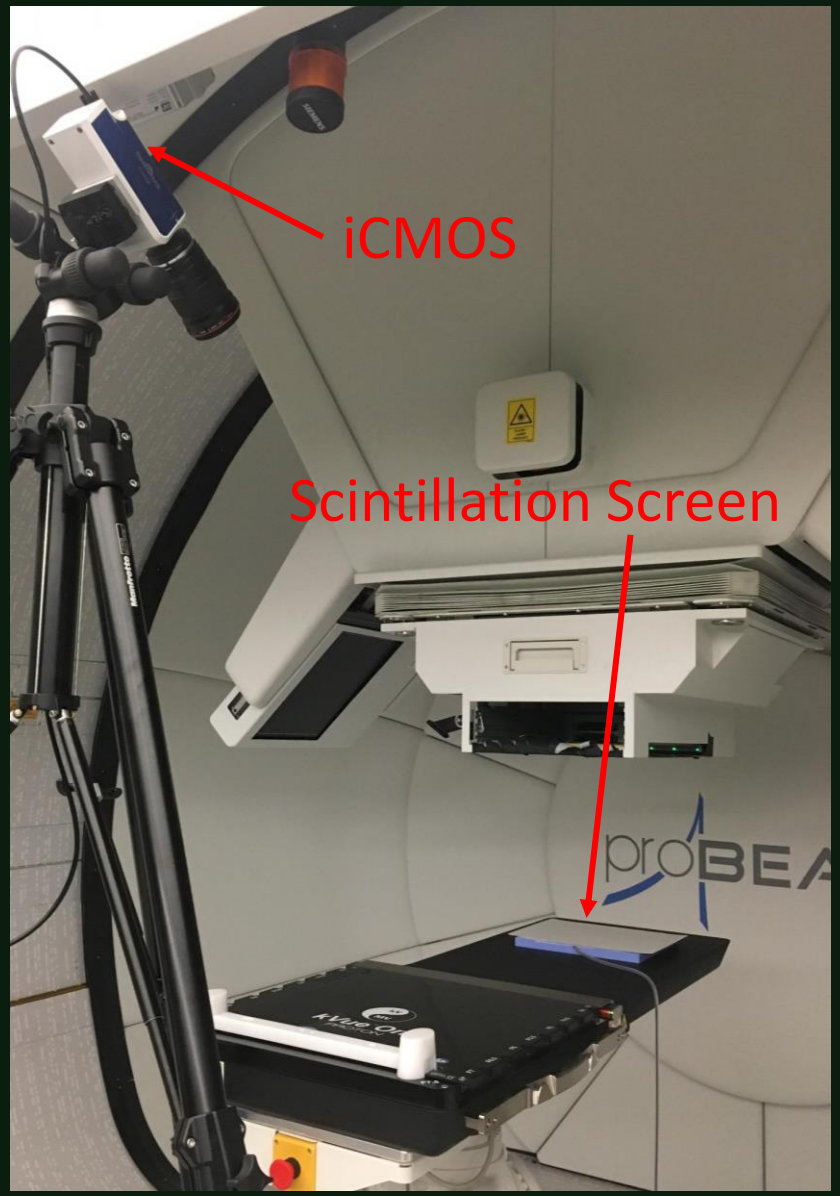


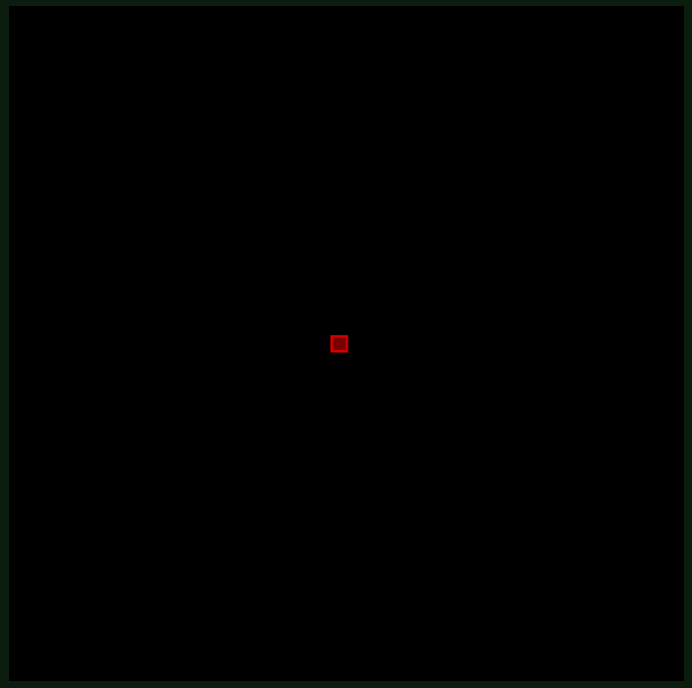
FLASH RT – dose rate

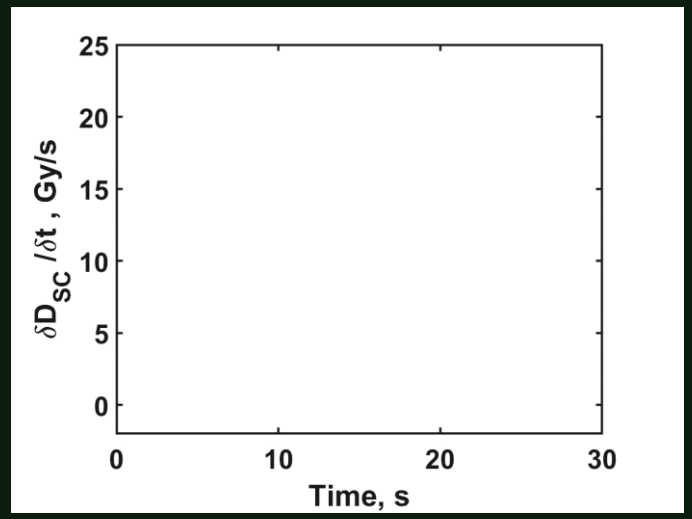


Courtesy of Brian Pogue

Proton PBS

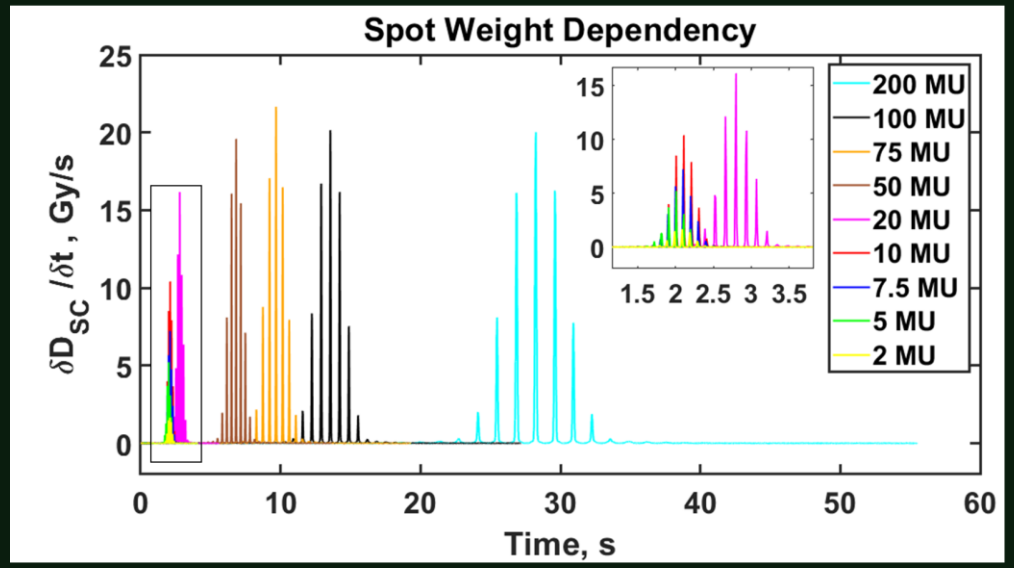


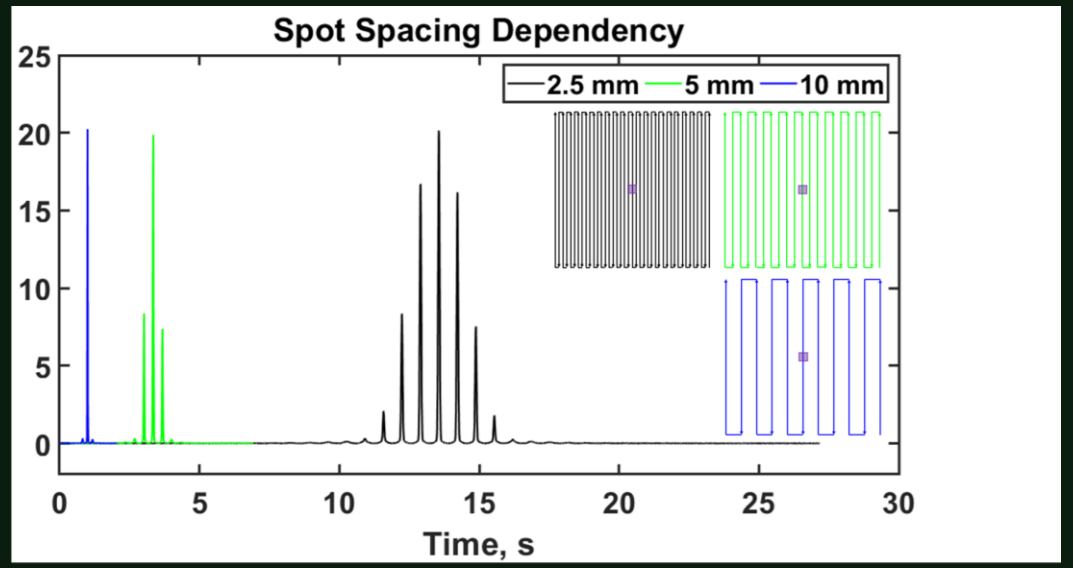


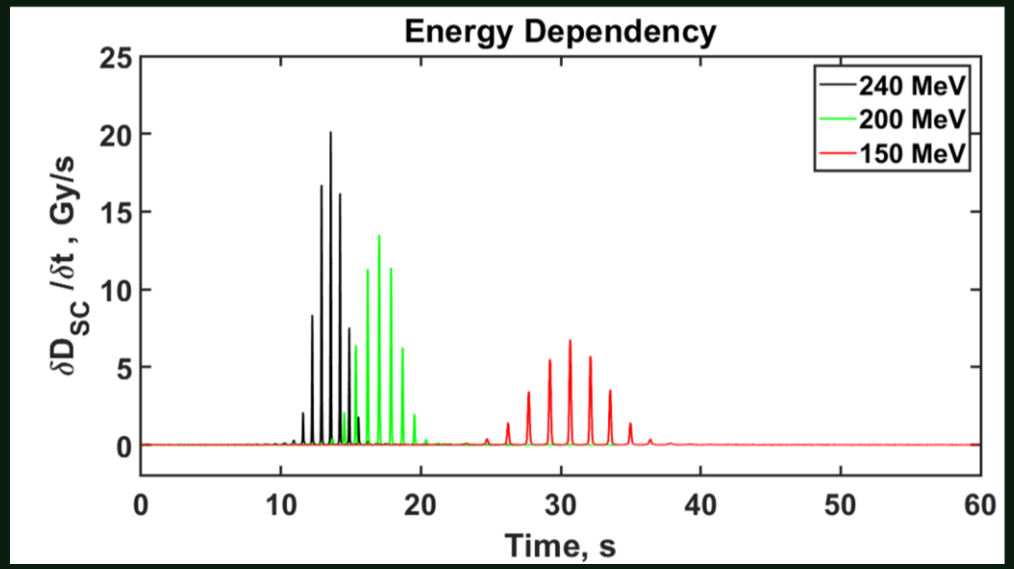


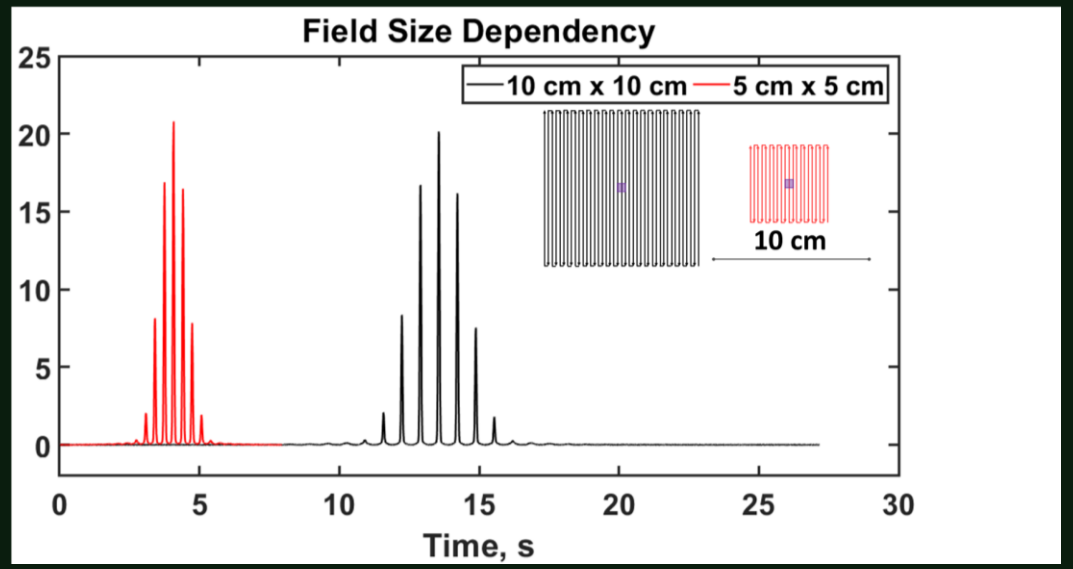
Rahman et al., Physics in Medicine and Biology, 2020

FLASH RT – proton



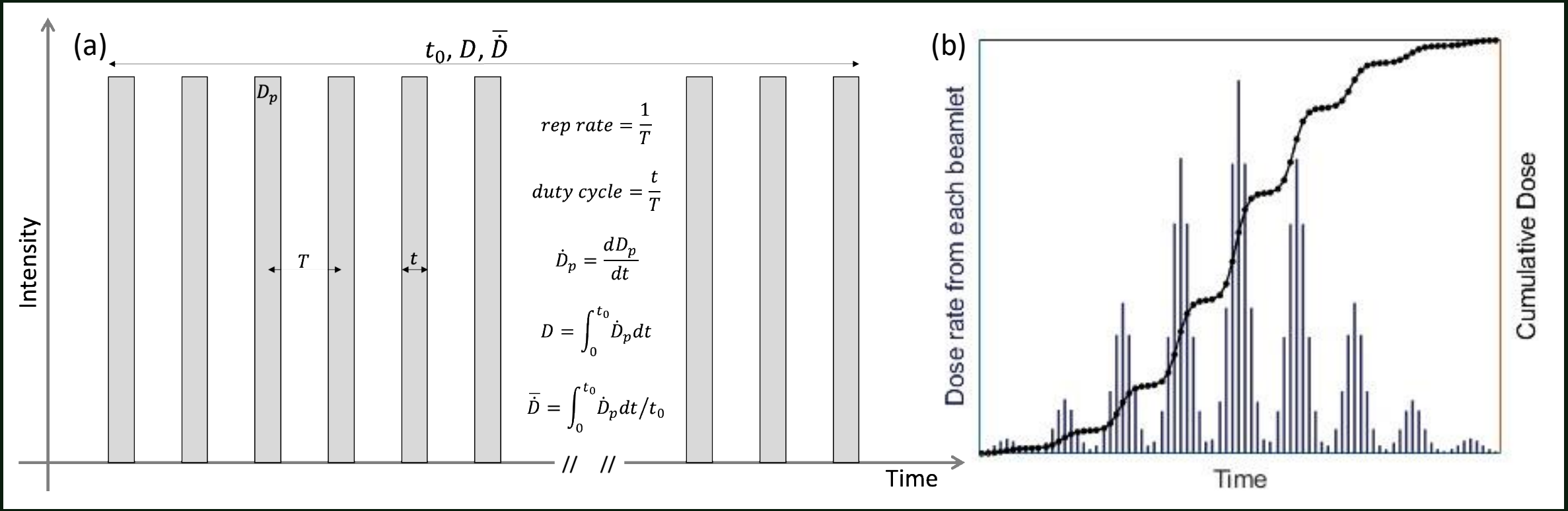






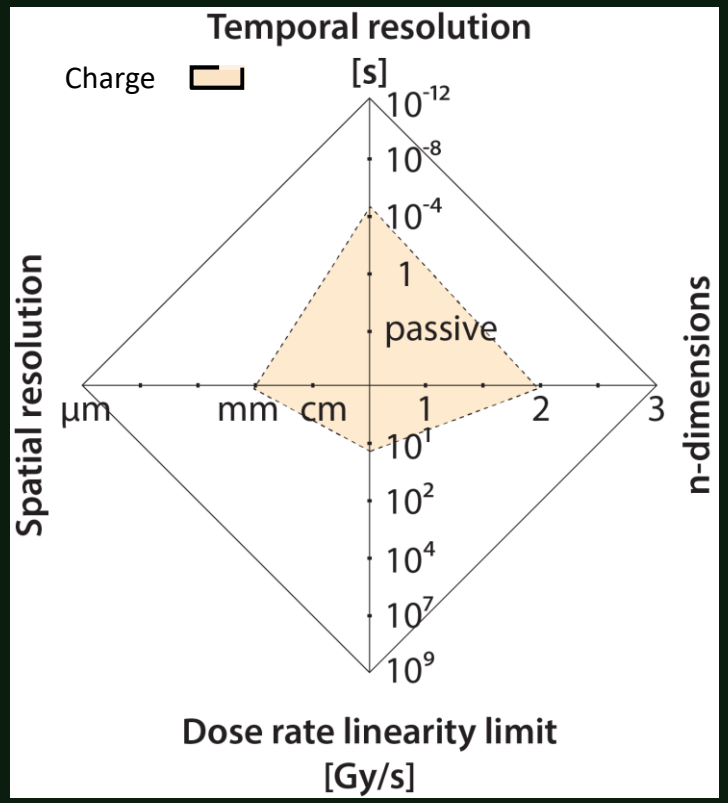
Rahman et al., Physics in Medicine and Biology, 2020

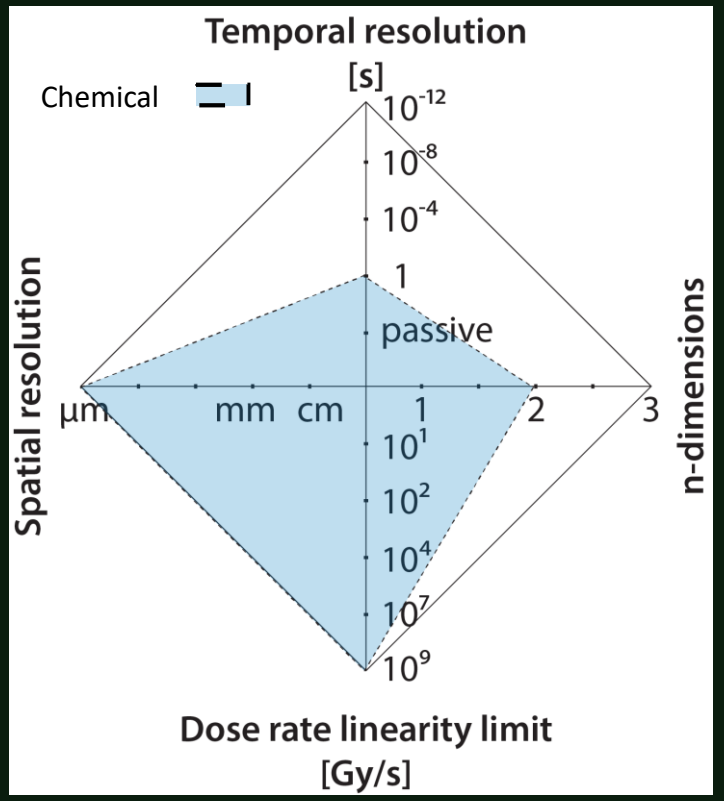
Dose rate and delivery dynamics

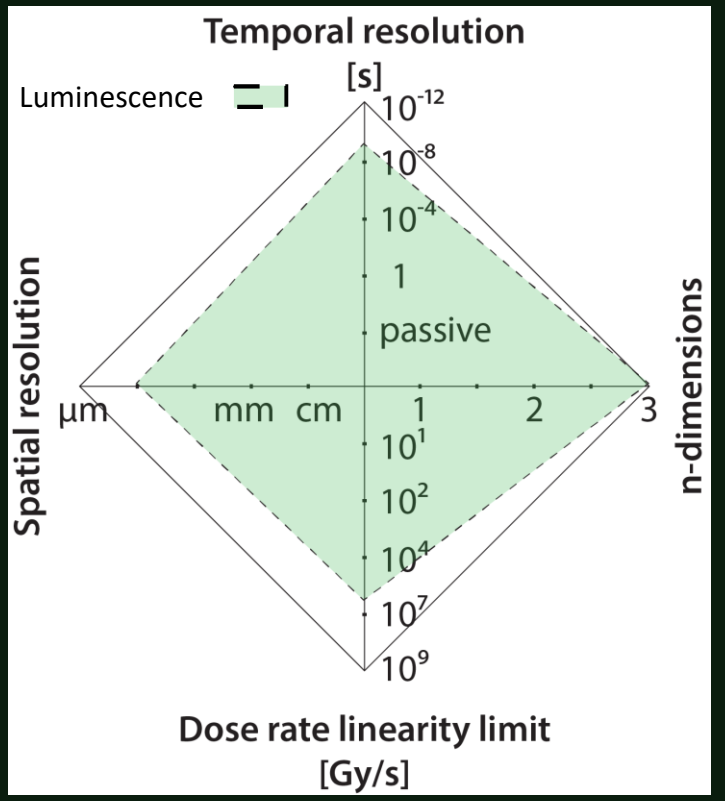


Zou et al., IJROBP, under review

FLASH RT – dosimetry

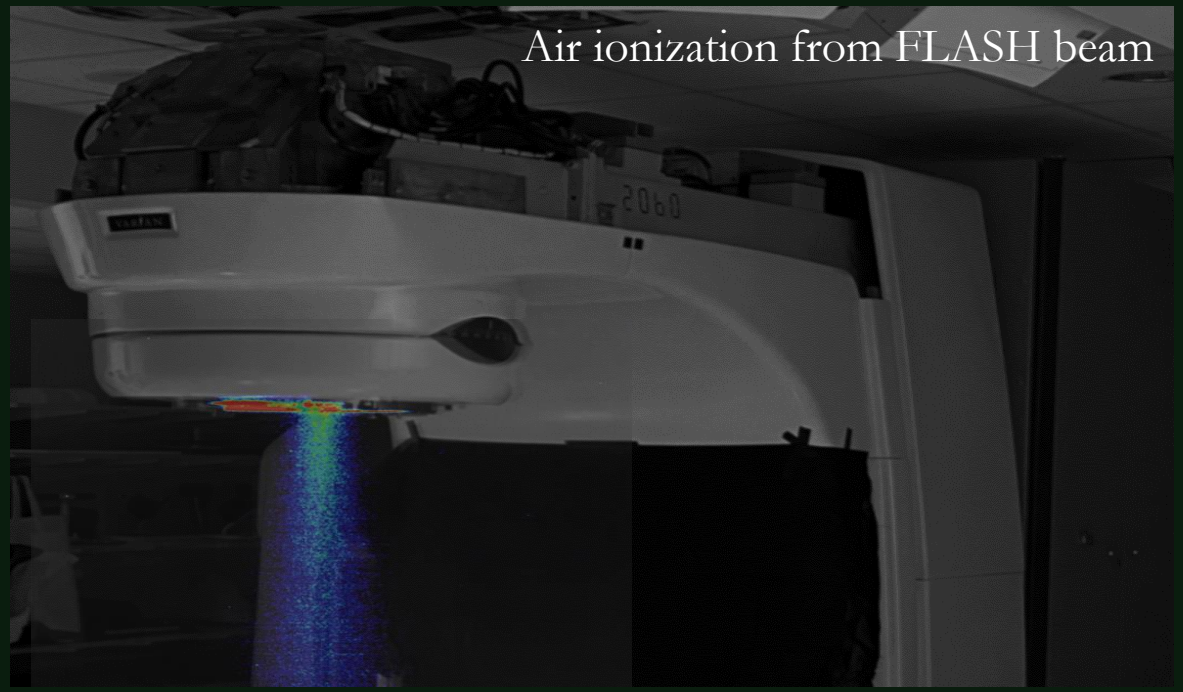






Ashraf et al., Frontiers in Physics, 2020

FLASH RT – dual purpose linac in clinical settings

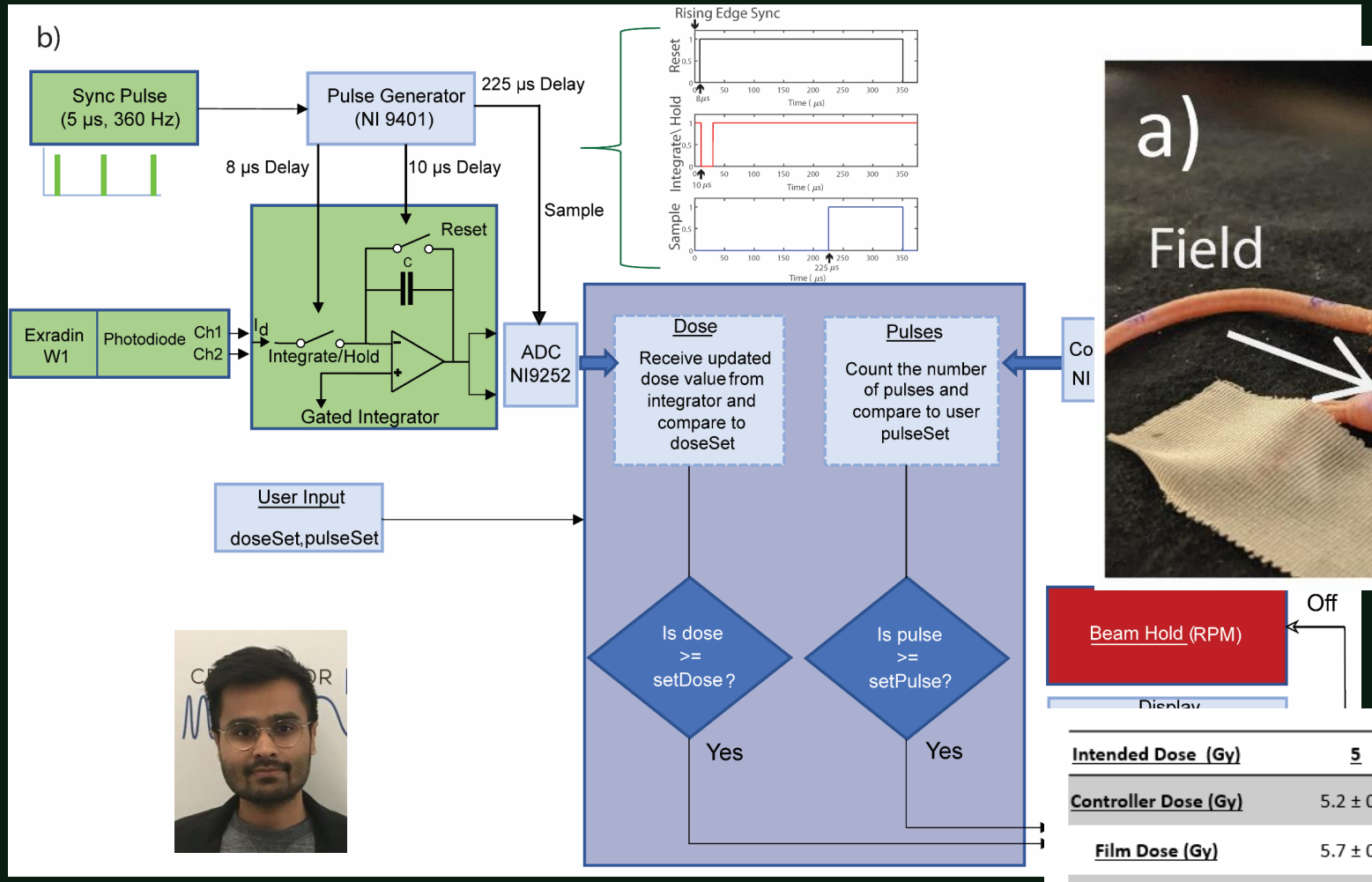


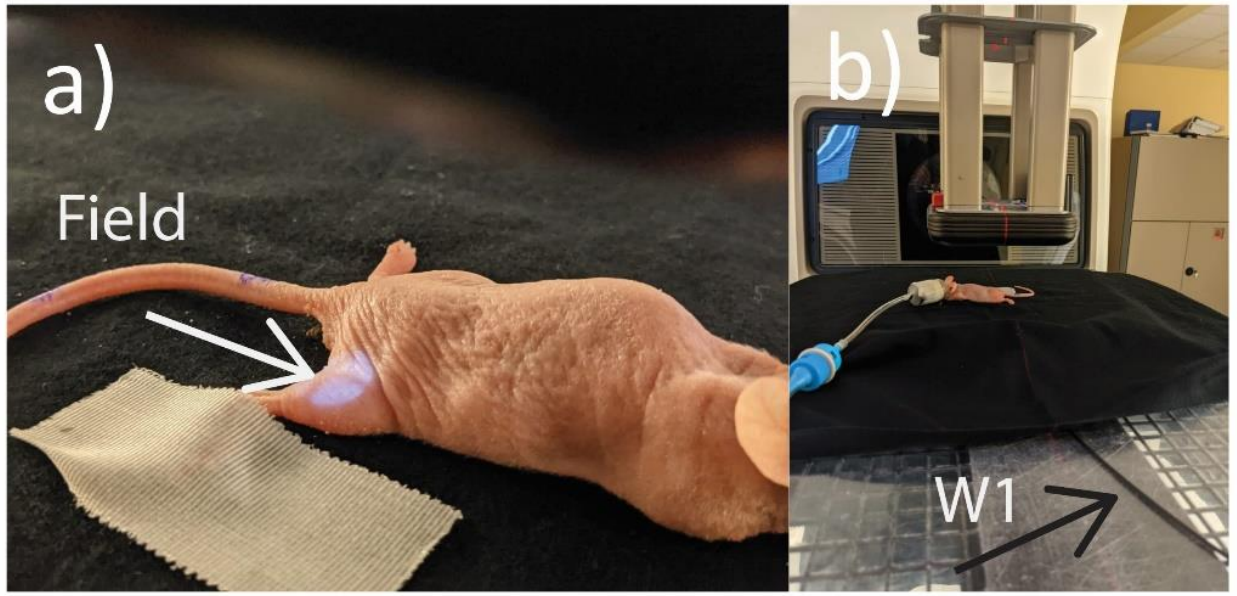
- Converted over 150 times for > 2 years
- 300 Gy/sec at isocenter and 2000Gy/sec at face plate
- Minimally-modified clinical settings
- Each conversion takes 2 minutes, essentially turnkey

Rahman, M., et al. (2021). "Electron FLASH Delivery at Treatment Room Isocenter for Efficient Reversible Conversion of a Clinical LINAC." International Journal of Radiation Oncology*Biology*Physics **110**(3): 872-882.

Rahman, Mahbubur, et al. "Comparing fast imaging techniques for individual pulse imaging by Cherenkov in vivo from electron FLASH irradiation." arXiv preprint arXiv:2207.05847 (2022).

FLASH RT – control

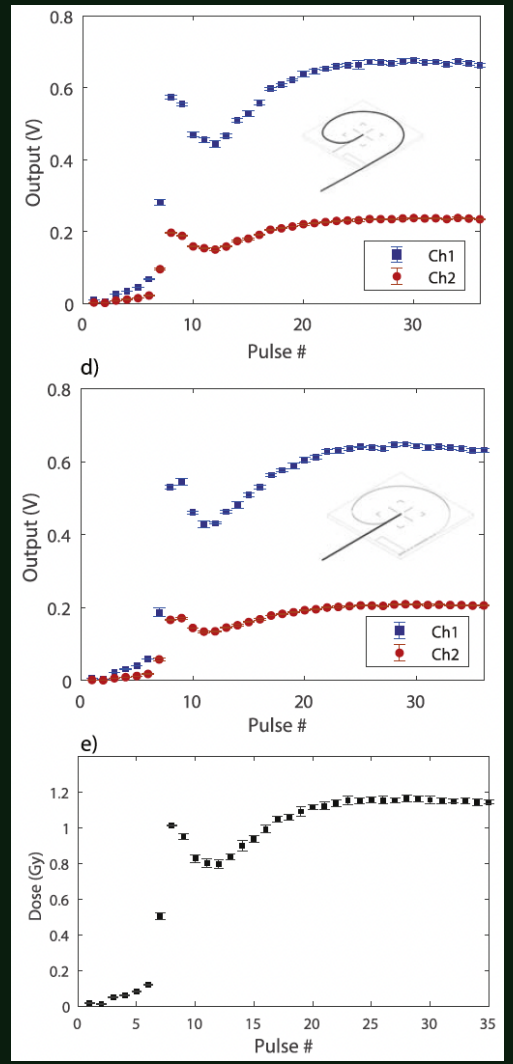


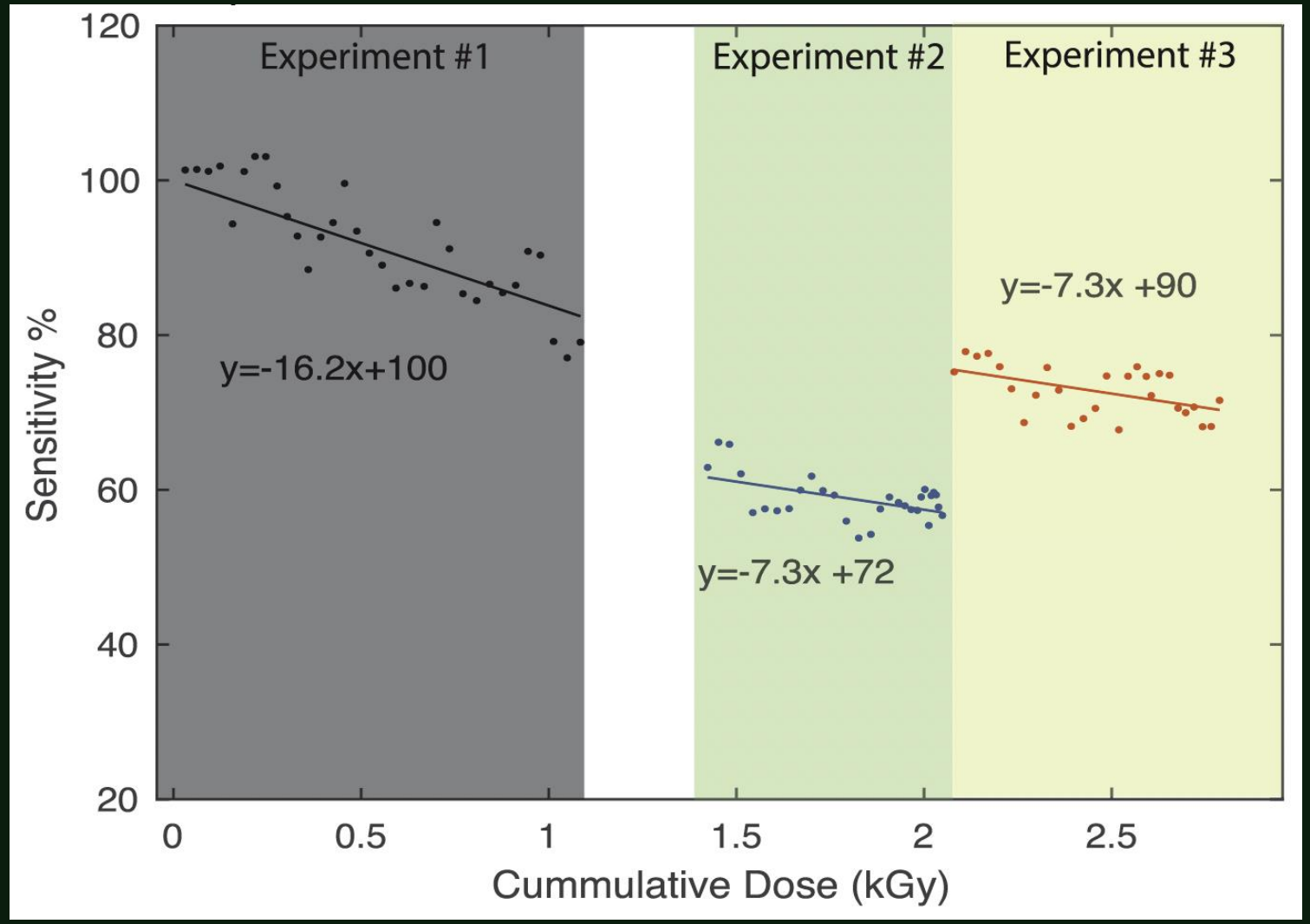


Intended Dose (Gy)	5	10	20	30
Controller Dose (Gy)	5.2 ± 0.1	10.4 ± 0.2	20.5 ± 0.5	30.45 ± 0.2
Film Dose (Gy)	5.7 ± 0.1	11.1 ± 0.1	21.8 ± 0.7	31.7 ± 0.3
Difference (Gy)	0.48 ± 0.1	0.63 ± 0.2	1.25 ± 0.9	1.35 ± 0.4
Num.Pulses	{15,14,14,16,15}	{28,24,28,29,25}	{42,38,38,43,42}	{56,53,53,54,58,58}

Ashraf, M. R., et al. PMB 2021. "Individual Pulse Monitoring and Dose Feedback System for Pre-Clinical Implementation of FLASH-RT."

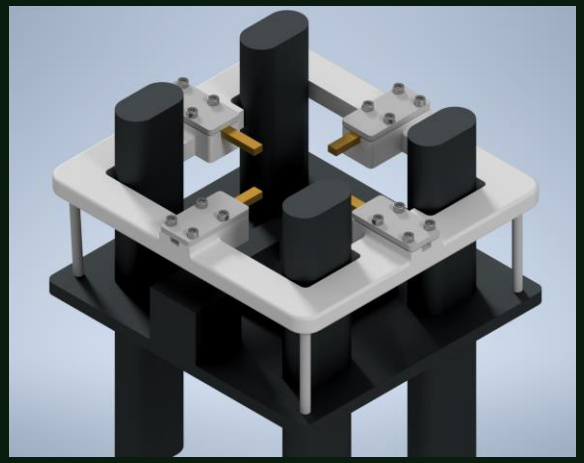
FLASH RT – control

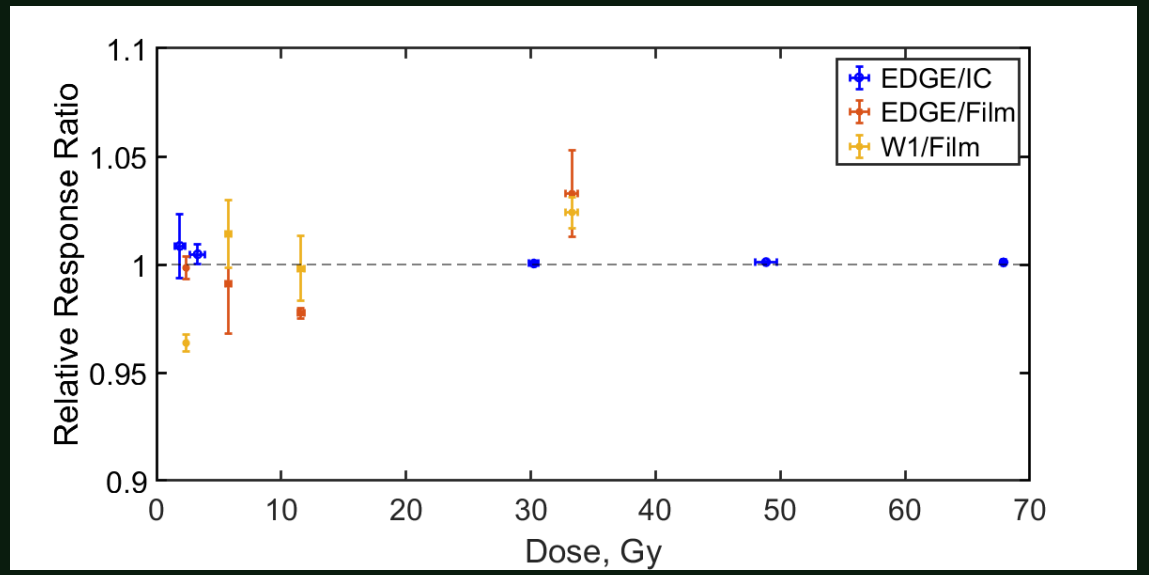


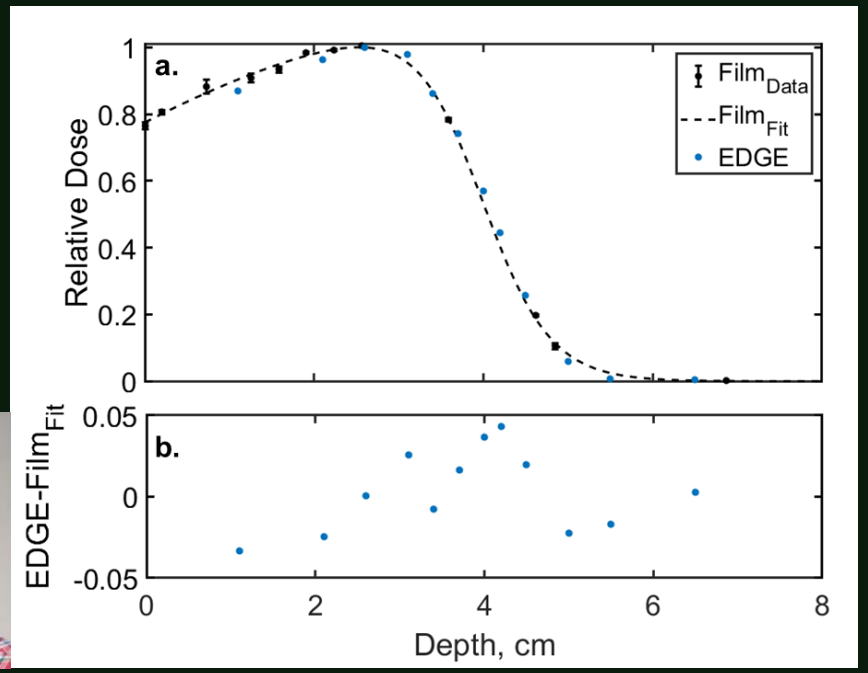


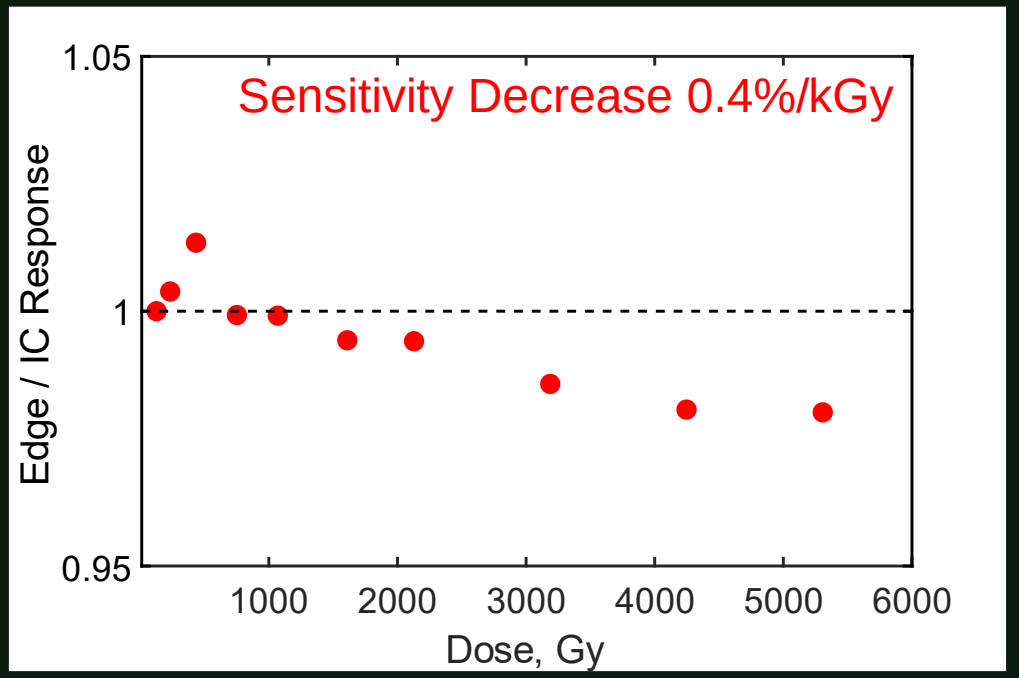
Ashraf, M. R., et al. PMB 2021. "Individual Pulse Monitoring and Dose Feedback System for Pre-Clinical Implementation of FLASH-RT."

UHDR Diode characterization



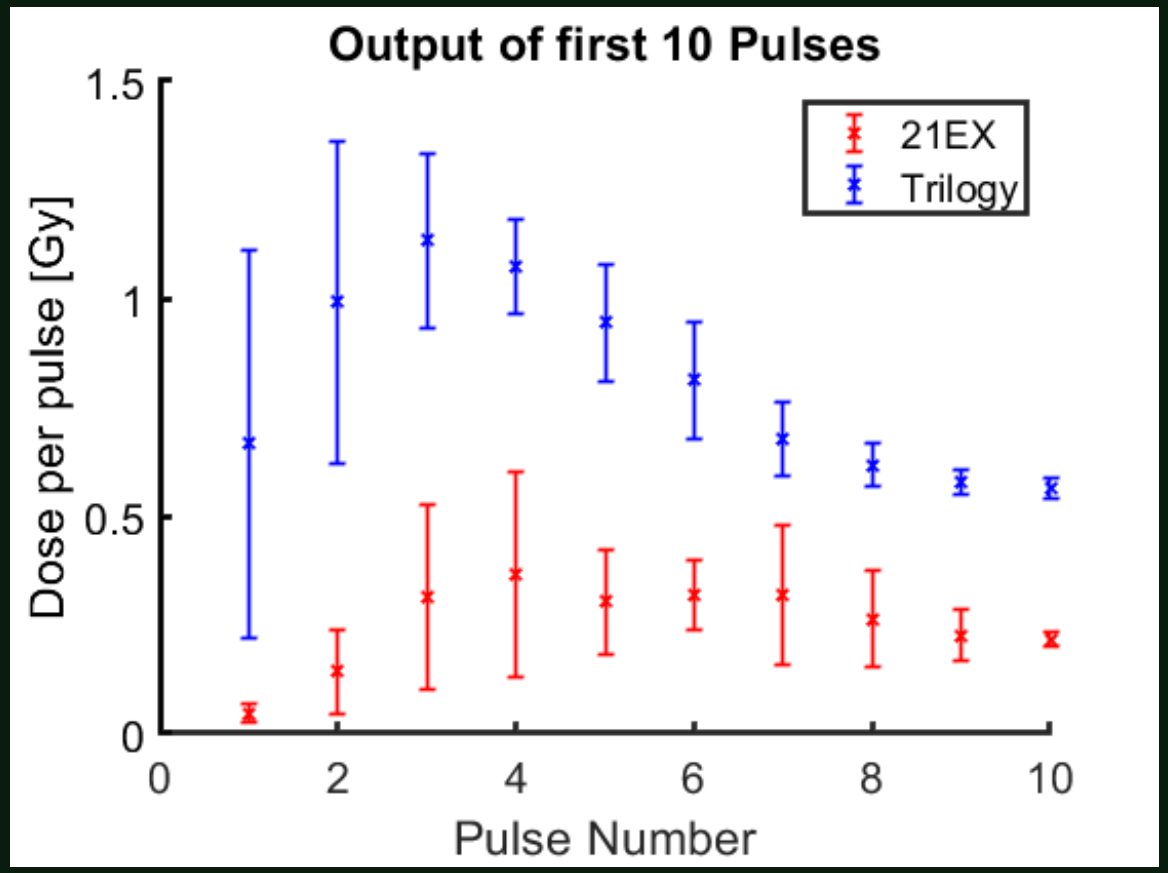


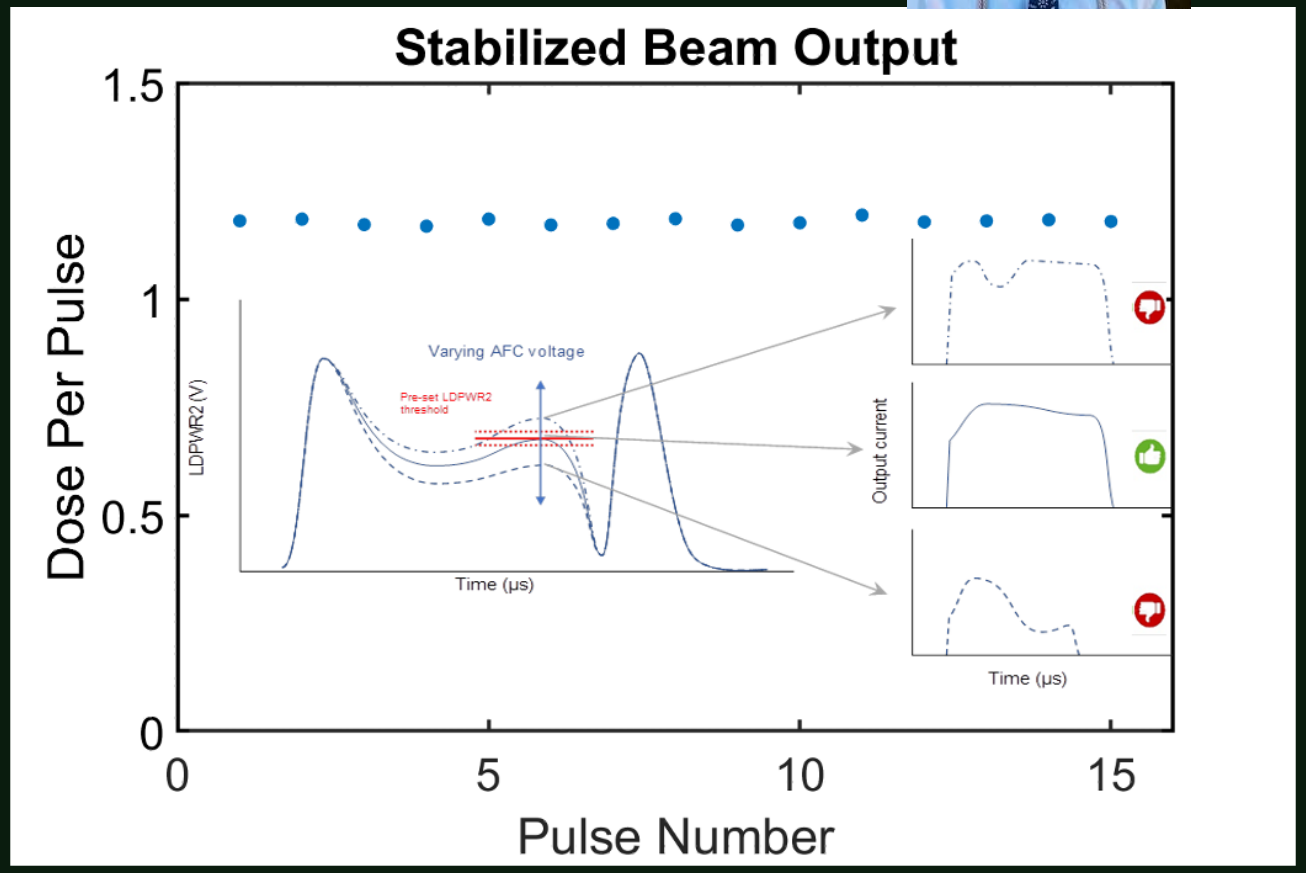




Rahman et al., MedPhys, under review

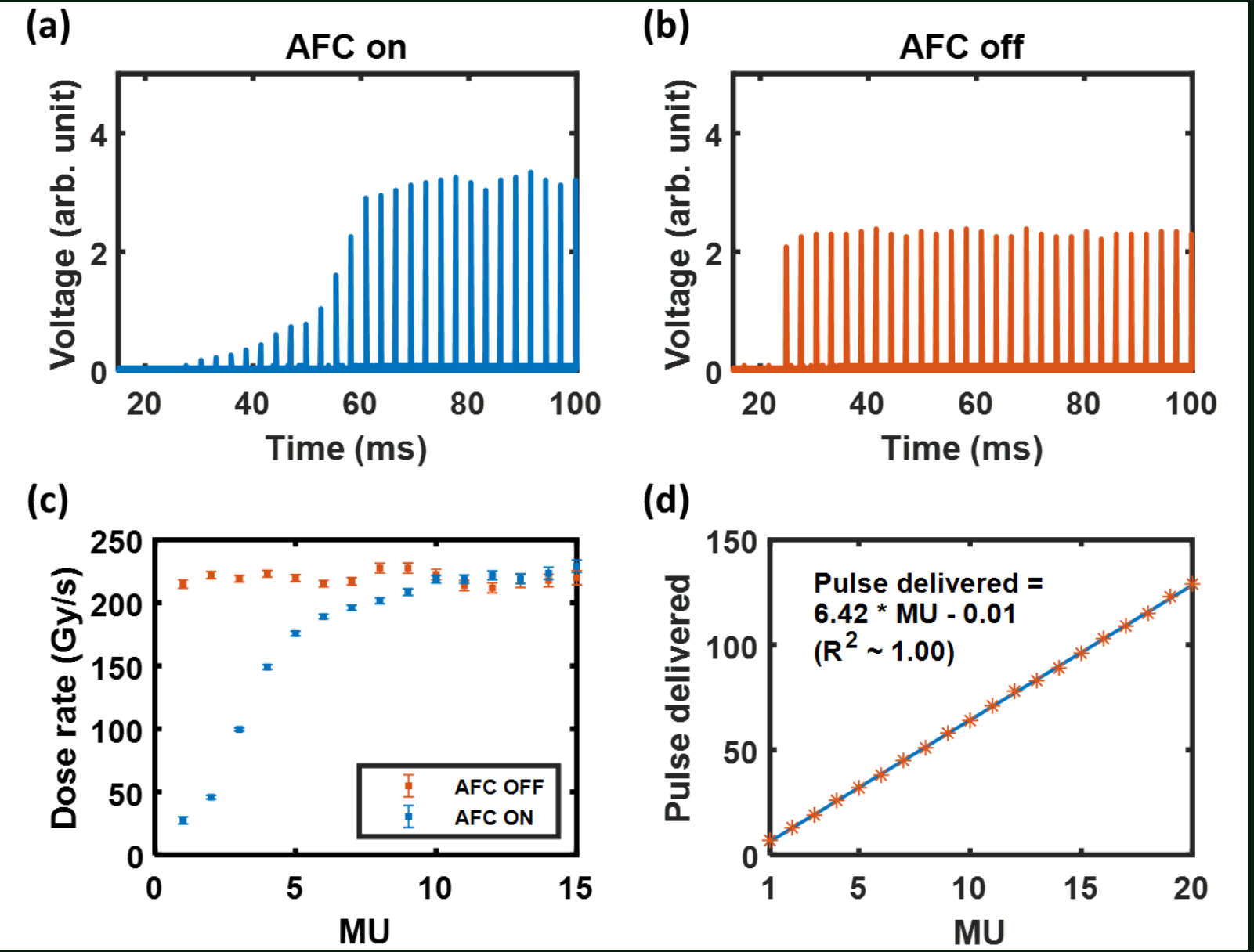
Beyond pulse counting





Sloop et al., under review

Beyond pulse counting

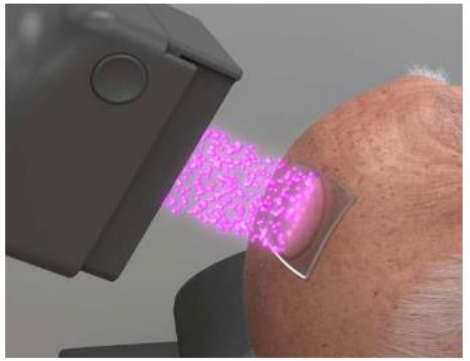


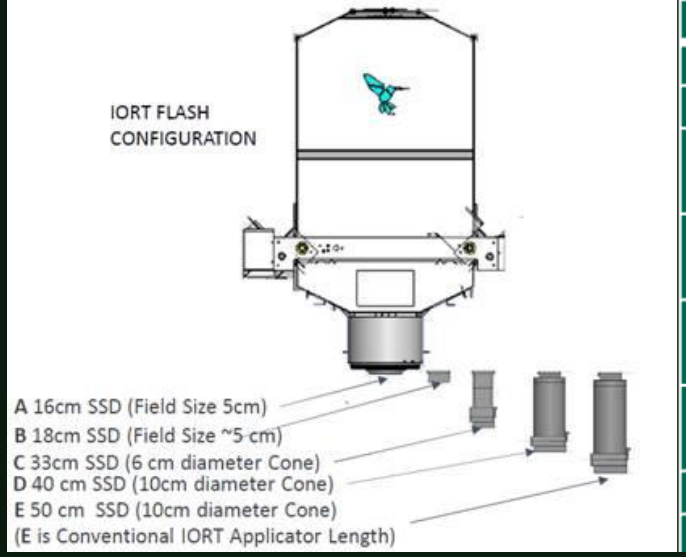
Banghao Zhou et al, under review

UHDR Mobetron

Dedicated FLASH Irradiator: 2 FLASH Channels – 6 & 9 MeV
Conventional Channels – 6 & 9 MeV

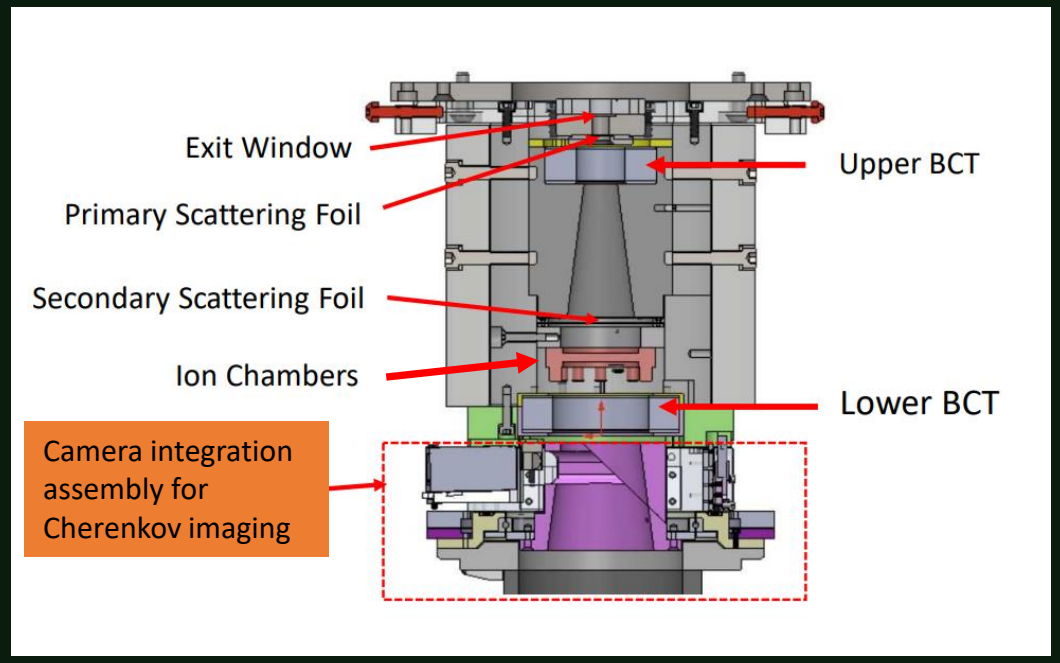
Superficial Electron Therapy
Variety of adapters, geometrically uncomplicated
Curative dose, low complications

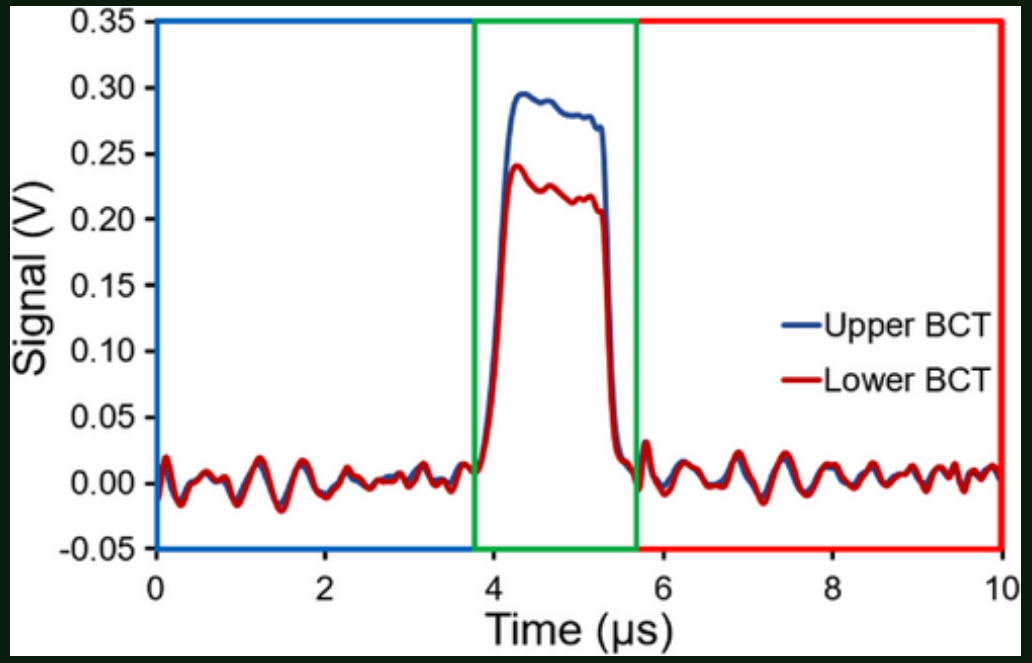


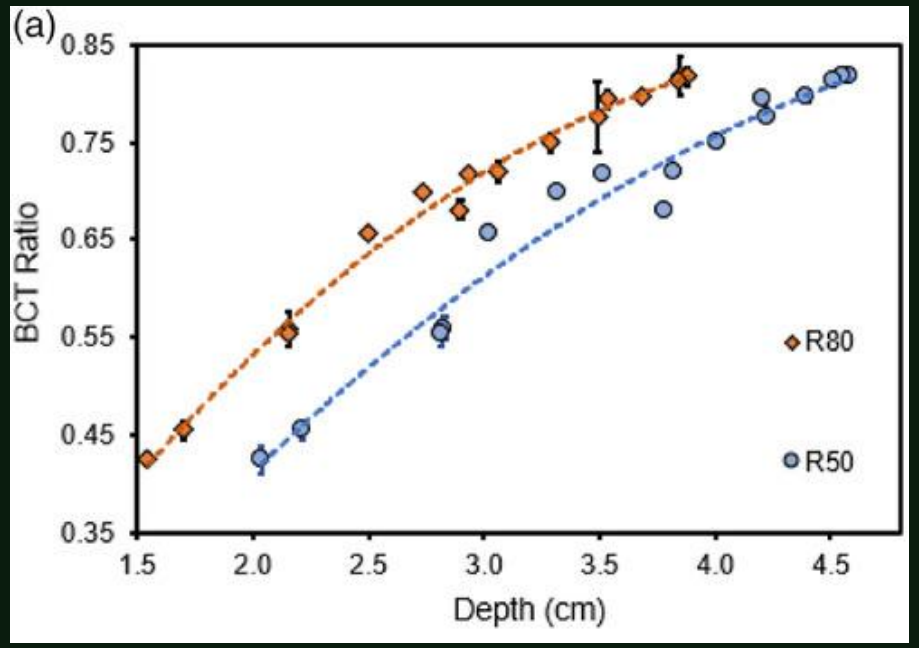


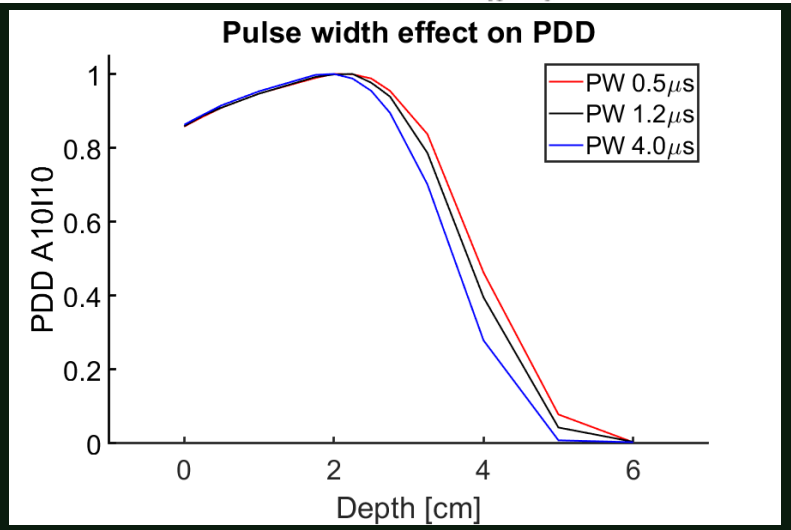
	Dual Purpose linac		Mobetron FLASH-IQ				
	Animals	Humans	A	B	C	D	E
Energy (MeV)	10	10	6 & 9	6 & 9	6 & 9	6 & 9	6 & 9
Pulse width (us)	3.25	3.25	0.5-4	0.5-4	0.5-4	0.5-4	0.5-4
Dose Rate (Gy/S)	40-3000	40-300	1251-1387	1066-1065	444-600	236-238	153-155
Dose per pulse (Gy)	0.5 - 4	0.5 - 1	10-11.1	8.5-8.6	3.6-4.8	1.9	1.2
Dose rate within pulse	10^5 to 10^6	10^5 to 5x10^5	2.5-2.8 x10^6	8.5-8.6 x10^6	8.9x10^5 to 1.2x10^6	4.7-4.8 x10^5	3.1 x10^5
Field size (cm)	0.5 to 40	0.5 to 25	~5	~5	6	10	10
SSD (cm)	60 - 120	95 - 120	16	18	33	40	50

Beam current transformer (BCT)



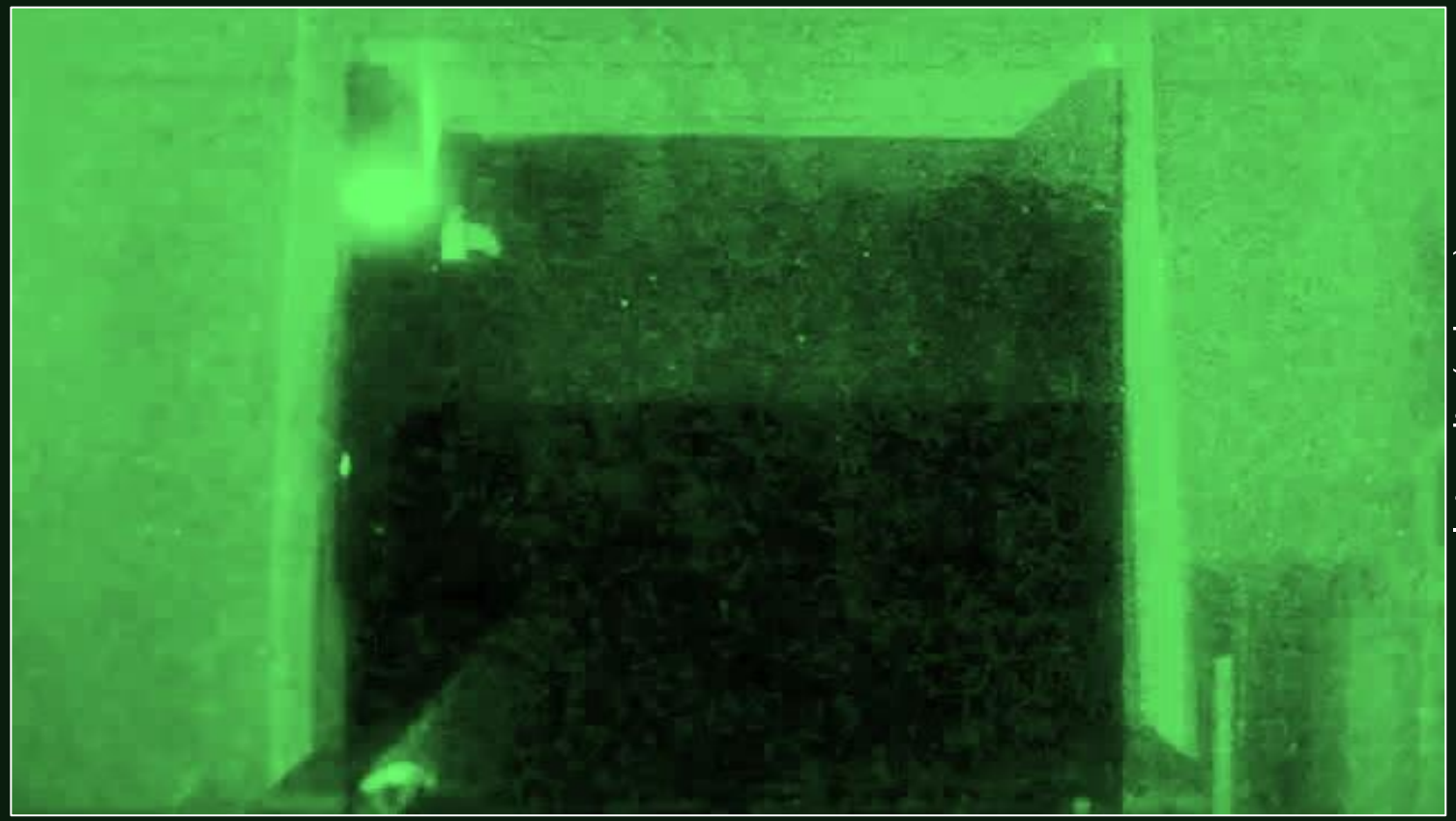


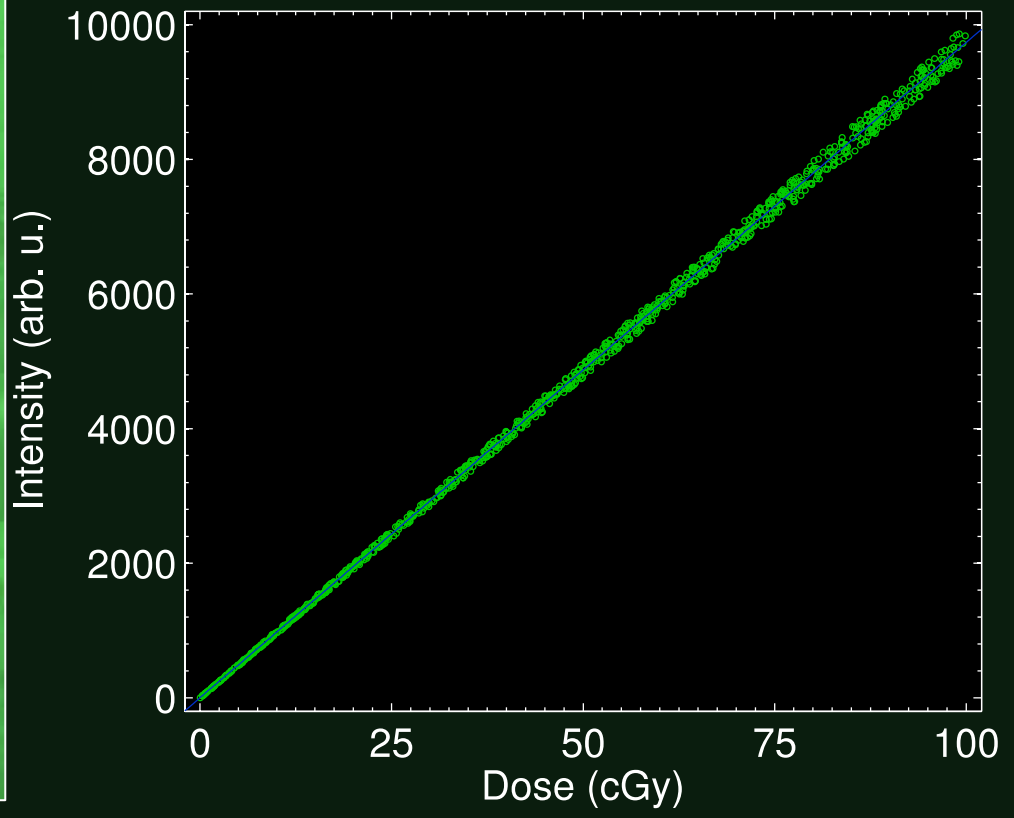




Liu, Kevin, et al. "Dual beam-current transformer design for monitoring and reporting of electron ultra-high dose rate (FLASH) beam parameters." *Journal of Applied Clinical Medical Physics* (2023): e13891.

Imaging Cherenkov and radioluminescence





Glaser, Adam K., et al. "Optical dosimetry of radiotherapy beams using Cherenkov radiation: the relationship between light emission and dose." *Physics in Medicine & Biology* 59.14 (2014): 3789.

Zhang, Rongxiao, et al. "Beam and tissue factors affecting Cherenkov image intensity for quantitative entrance and exit dosimetry on human tissue." *Journal of biophotonics* 10.5 (2017): 645-656.

Video rate QA

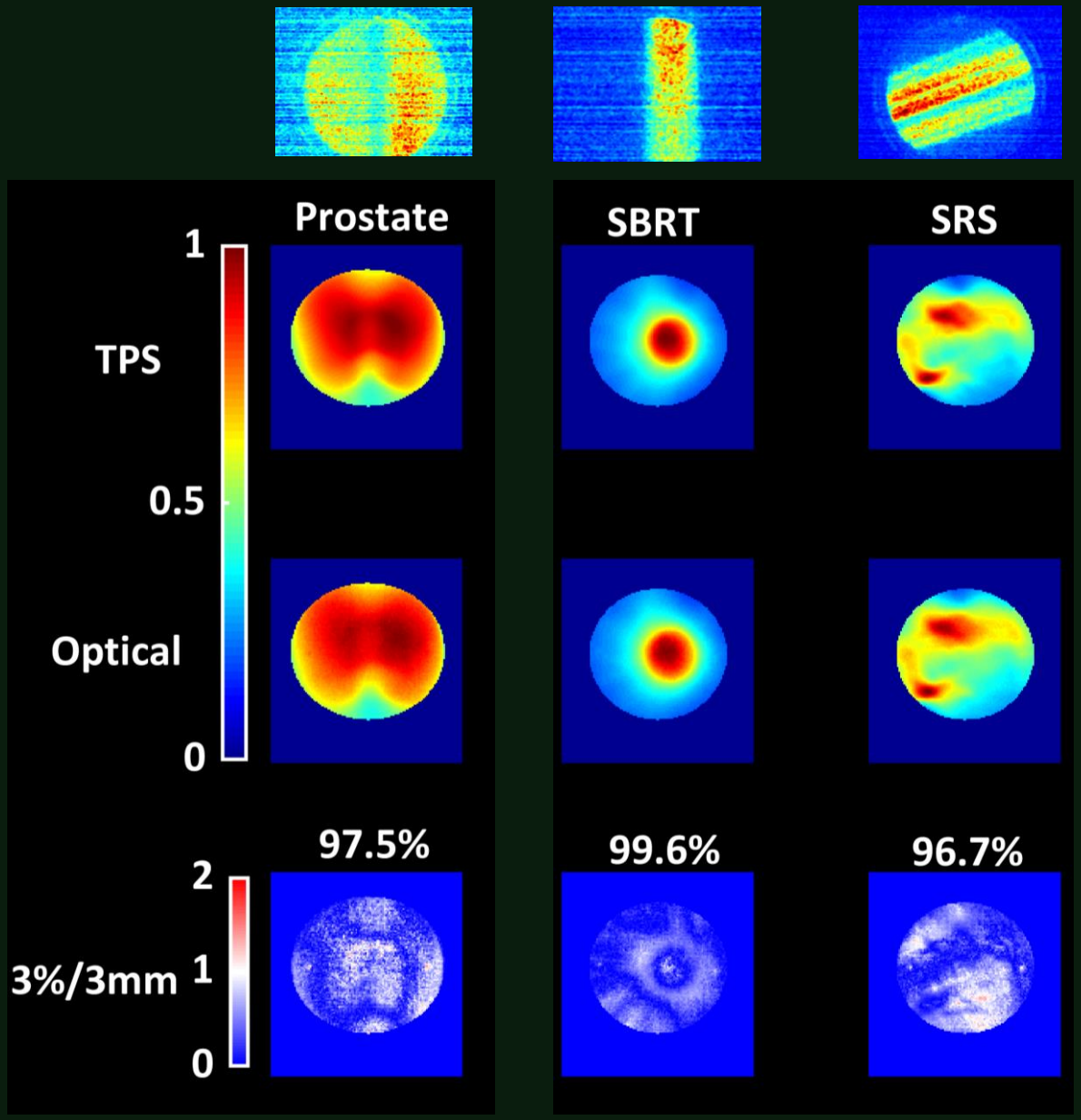
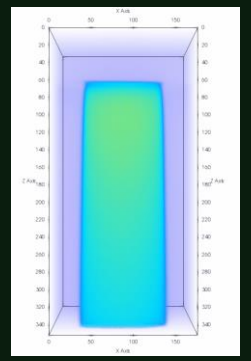
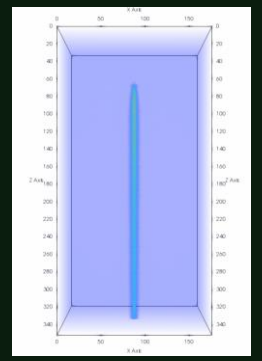


Table: 3%/3mm Gamma Index Passing Rates		
Plan	ArcCheck	Optical Imaging
Prostate	96.9%	97.5%
SBRT	96.5%	99.6%
SRS	94.5%	96.7%

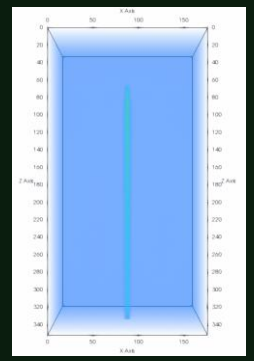
10 cm



5 mm

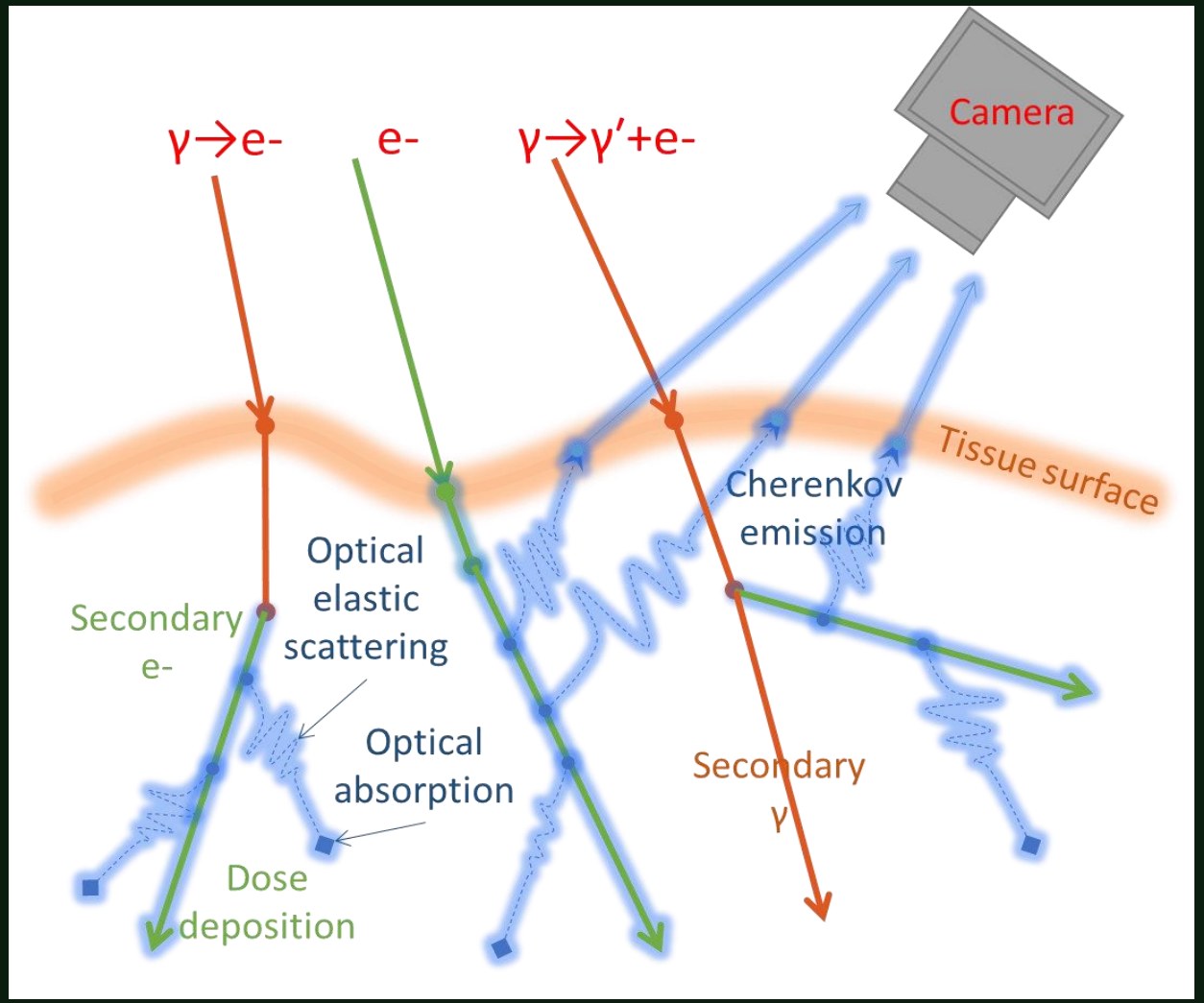


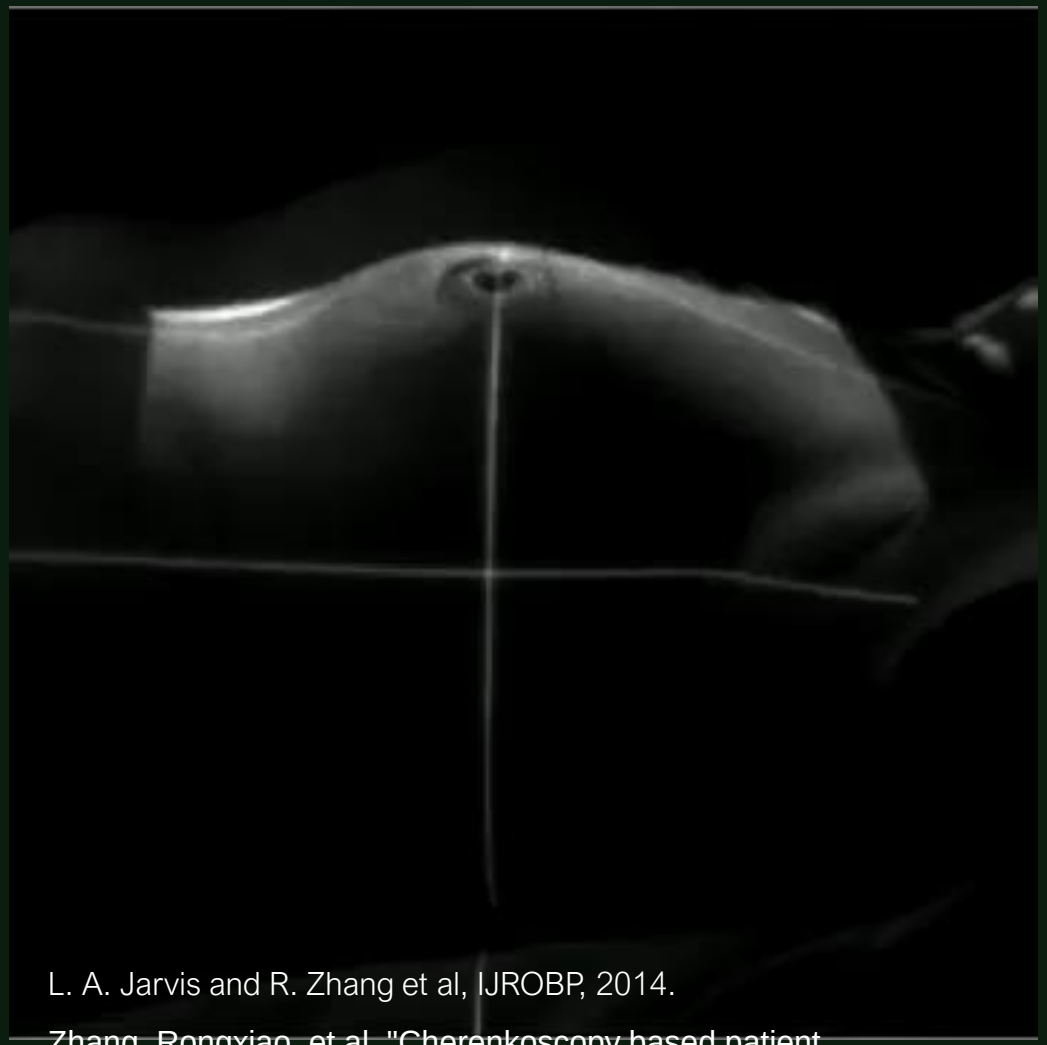
4 mm



Ashraf, M. R., Bruza, P., Pogue, B. W., Nelson, N., Williams, B. B., Jarvis, L. A., & Gladstone, D. J. (2019). Optical imaging provides rapid verification of static small beams, radiosurgery, and VMAT plans with millimeter resolution. *Medical Physics*, *46*(11), 5227–5237. https://doi.org/10.1002/mp.13797

Imaging Cherenkov and radioluminescence

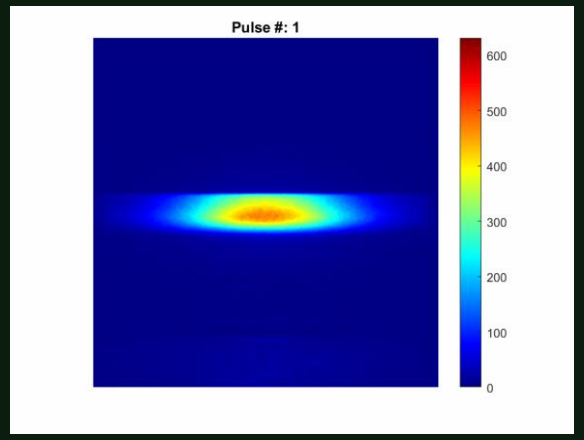


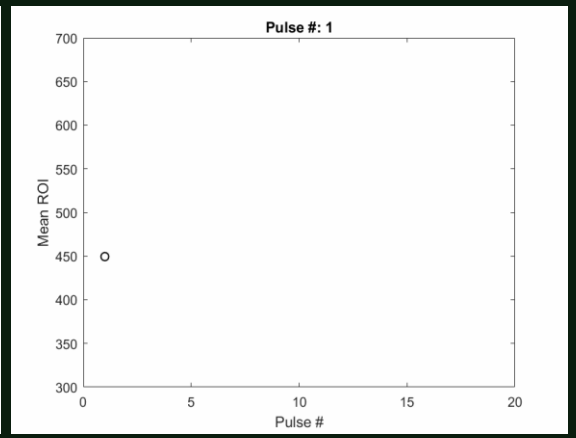


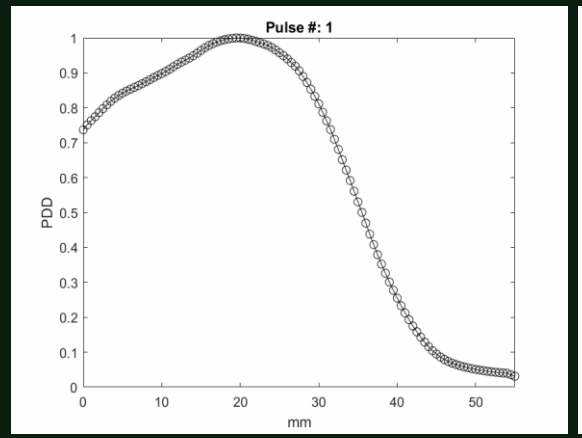
L. A. Jarvis and R. Zhang et al, IJROBP, 2014.

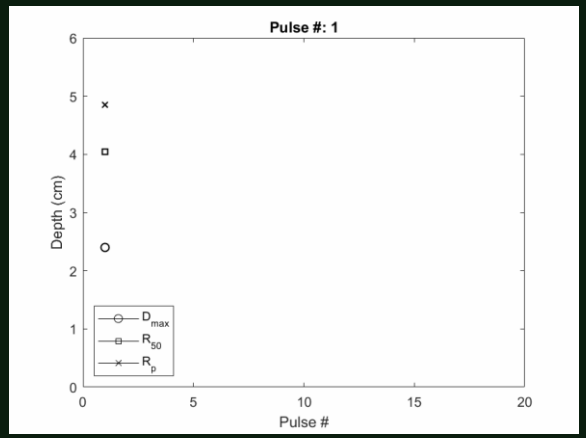
Zhang, Rongxiao, et al. "Cherenkoscopy based patient positioning validation and movement tracking during post-lumpectomy whole breast radiation therapy." *Physics in Medicine & Biology* 60.1 (2014): L1.

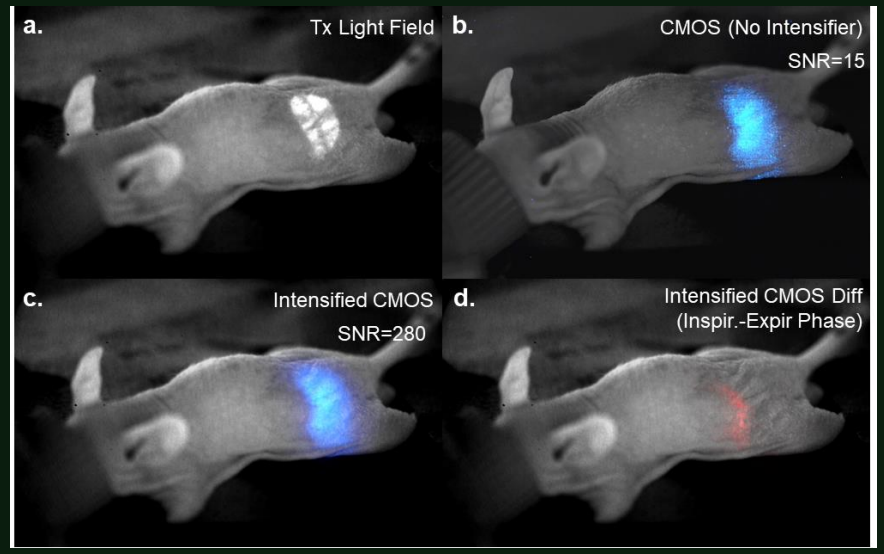
FLASH RT – dosimetry via imaging











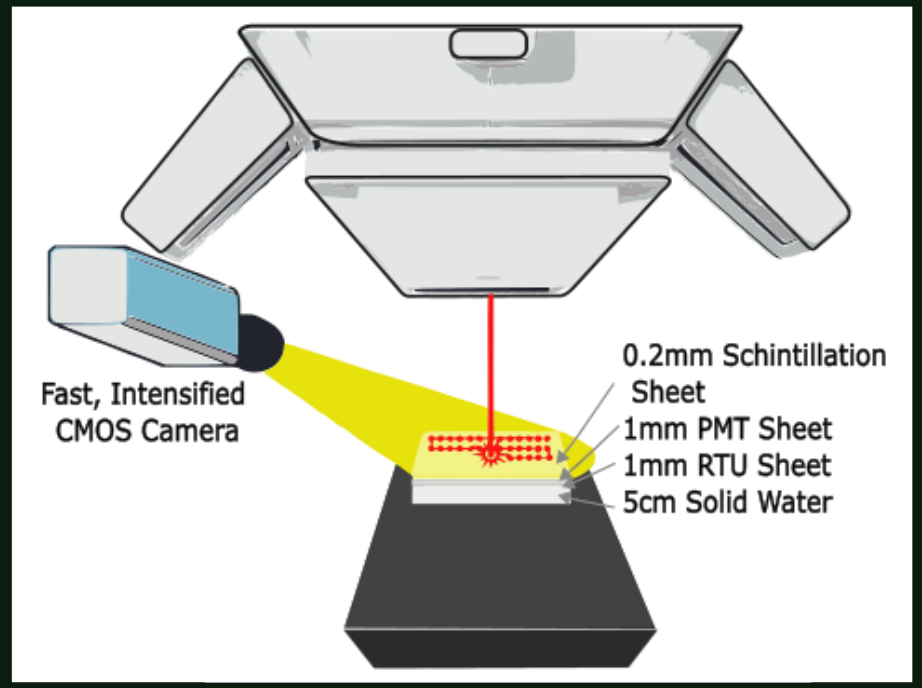
DOSEOPTICS

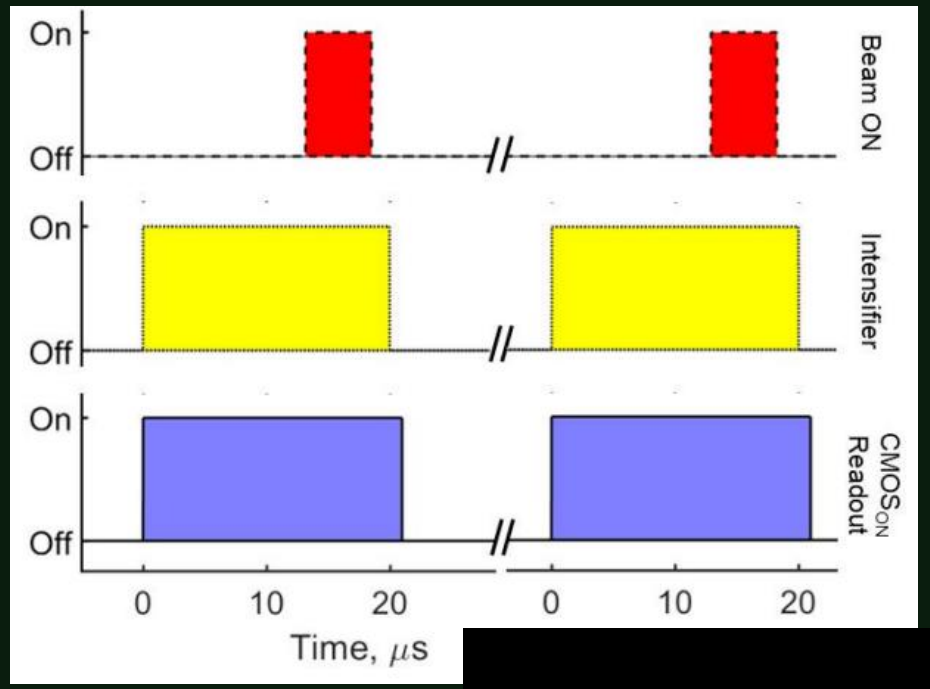
Mahbubur Rahman *et al* 2021 *Phys. Med. Biol.* **66** 135009

Ashraf, M. R., et al. (2021). "Technical Note: Single-pulse beam characterization for FLASH-RT using optical imaging in a water tank." Medical Physics **48**(5): 2673-2681.

Rahman, Mahbubur, et al. "Comparing fast imaging techniques for individual pulse imaging by Cherenkov in vivo from electron FLASH irradiation." arXiv preprint arXiv:2207.05847 (2022).

Proton PBS QA

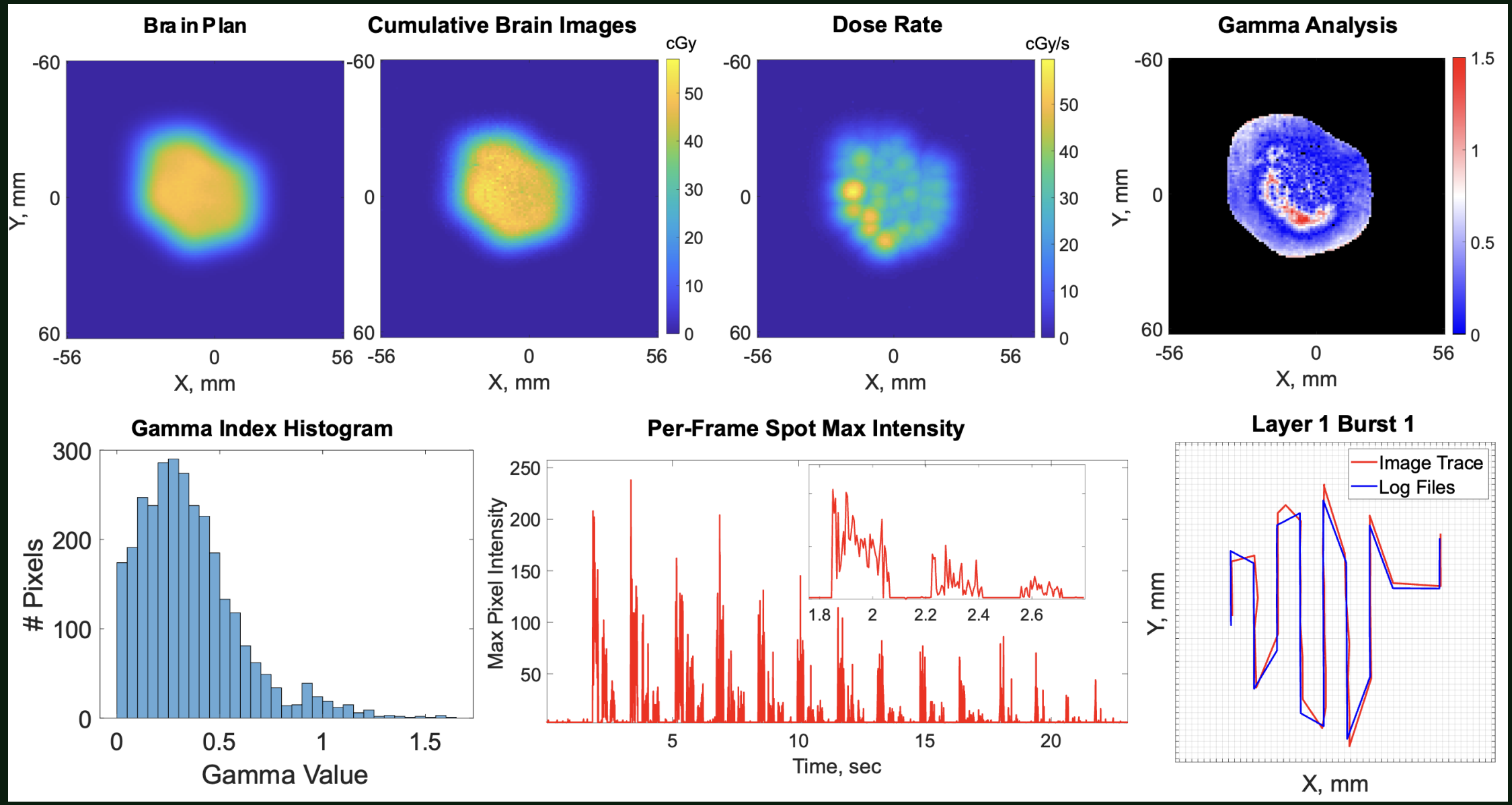




- 1000 frames per second, 1×1 mm^2 spatial resolution
- Modified BeamSite Ultra, DoseOptics LLC
- Remote trigger unit (RTU) coupled to scintillating sheet
- Photomultiplier (PMT) signal for beam-on verification
- Calibrated to film

Clark, Megan, et al. "Ultra-fast, high spatial resolution single-pulse scintillation imaging of synchrocyclotron pencil beam scanning proton delivery." *Physics in Medicine & Biology* 68.4 (2023): 045016.

Proton PBS QA



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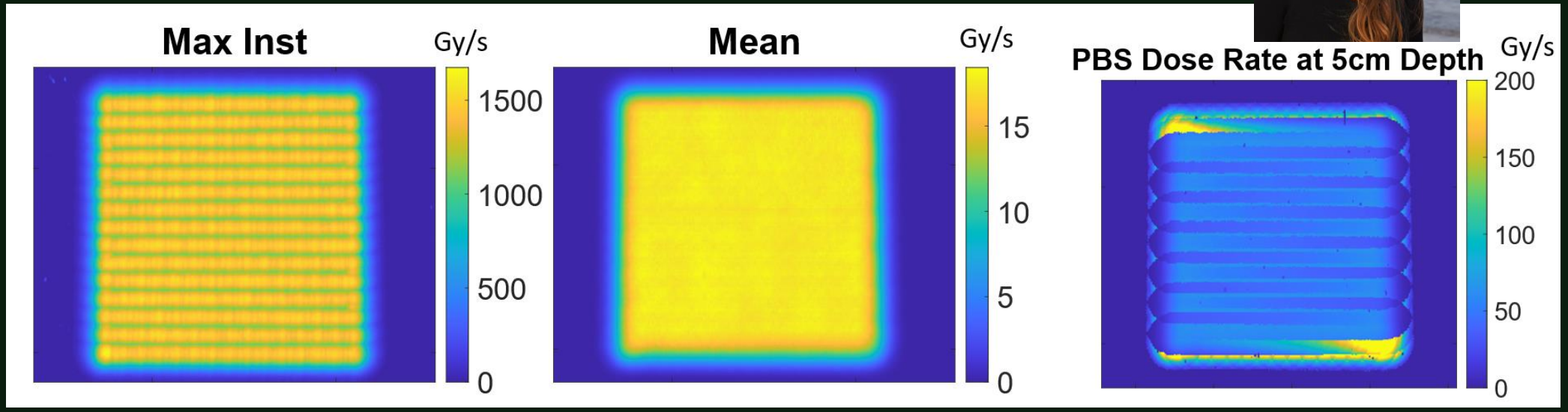
UHDR Proton PBS QA



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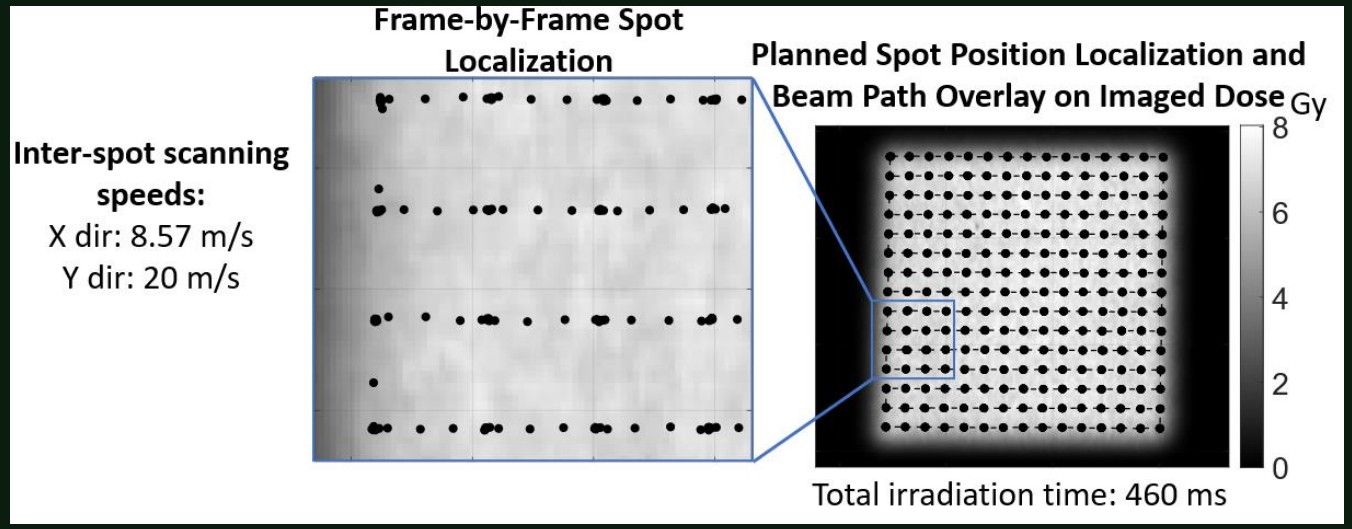
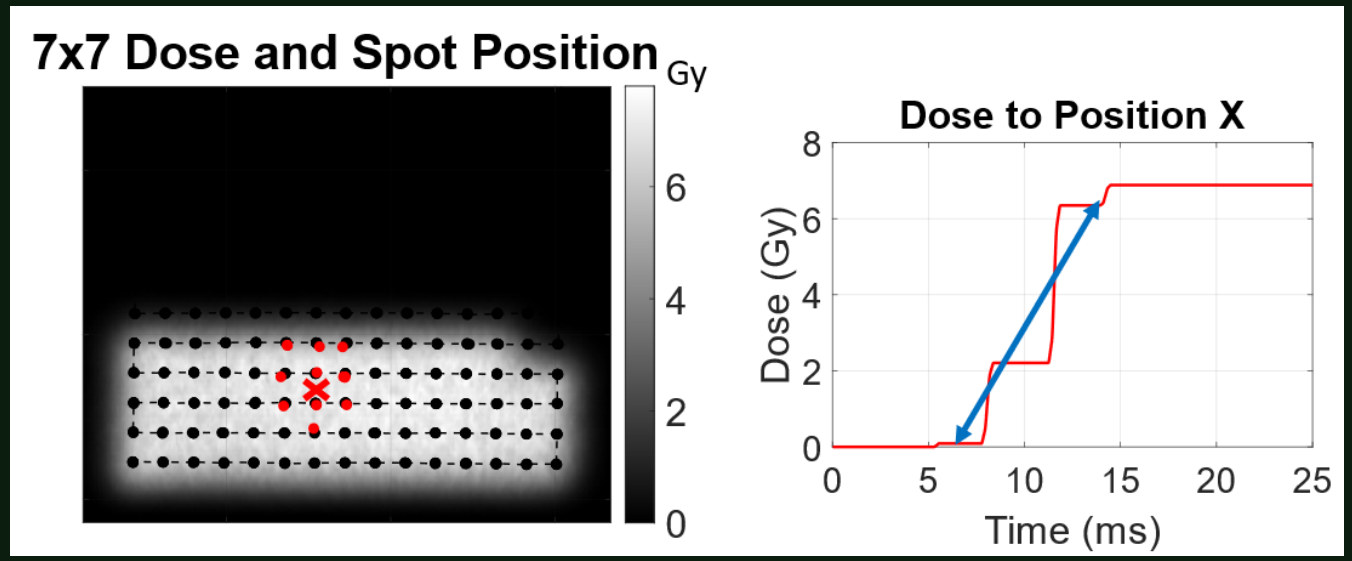
Feasibility Study of FLASH Radiotherapy for the Treatment of Symptomatic Bone Metastases (FAST-01)

Clark, Megan, et al, under review

UHDR Proton PBS QA





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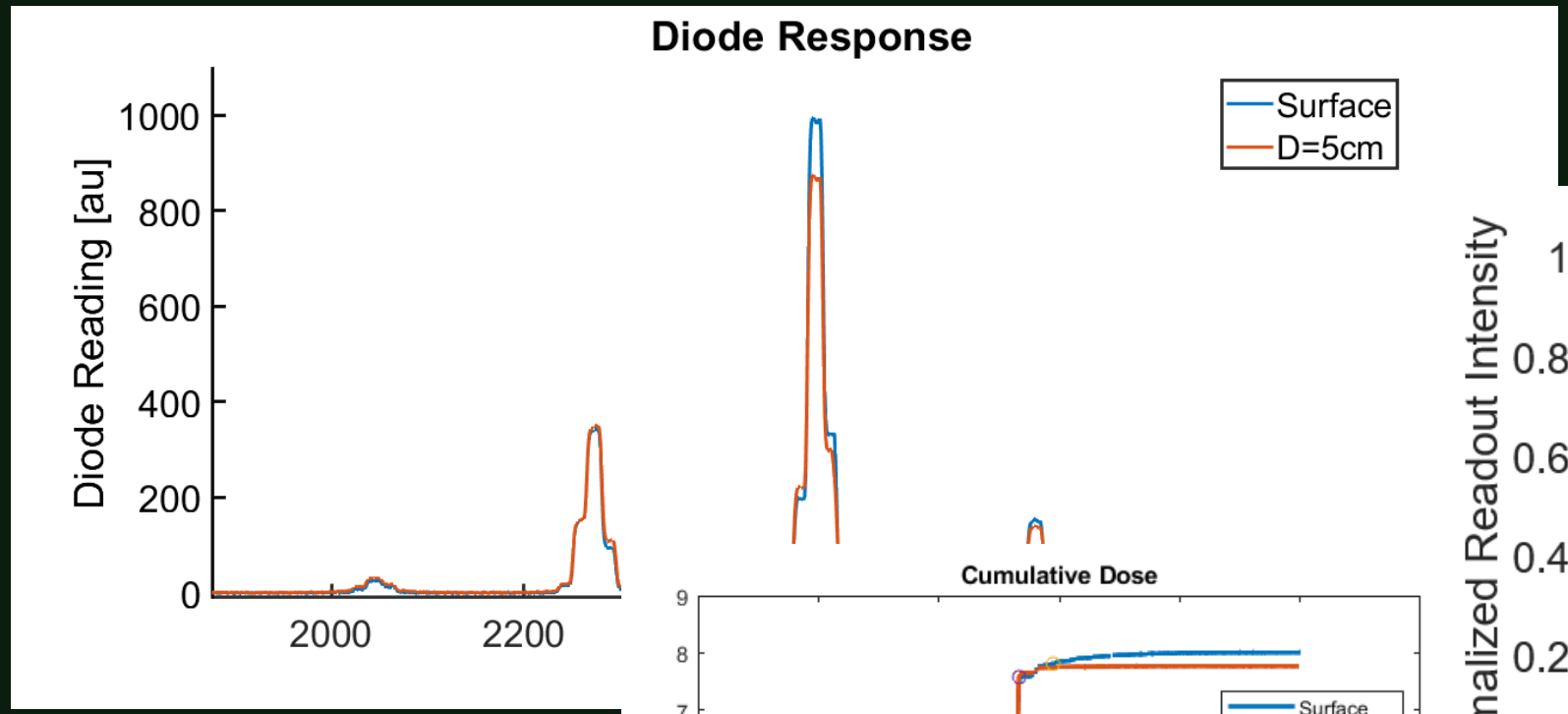
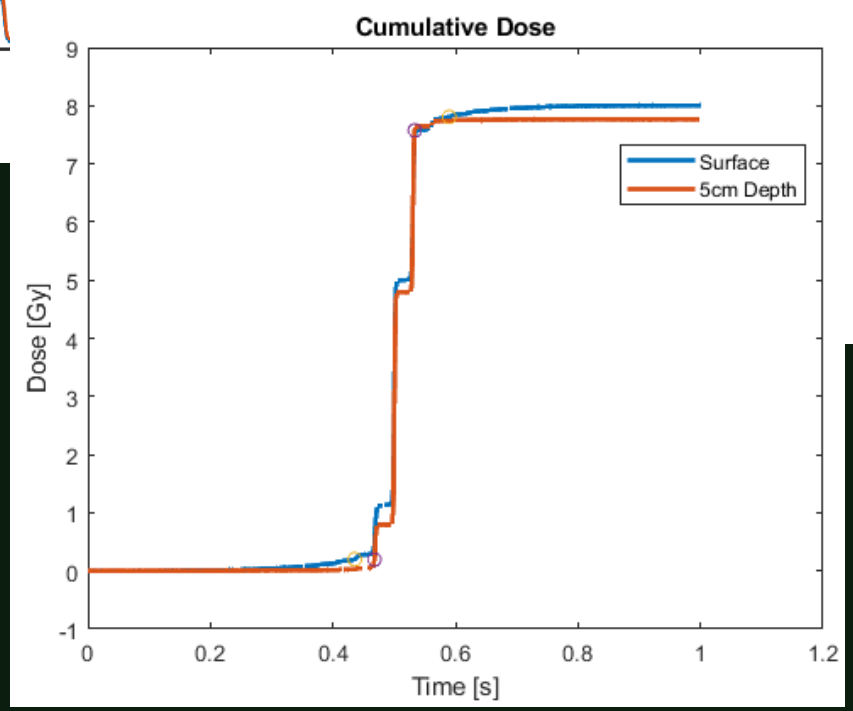
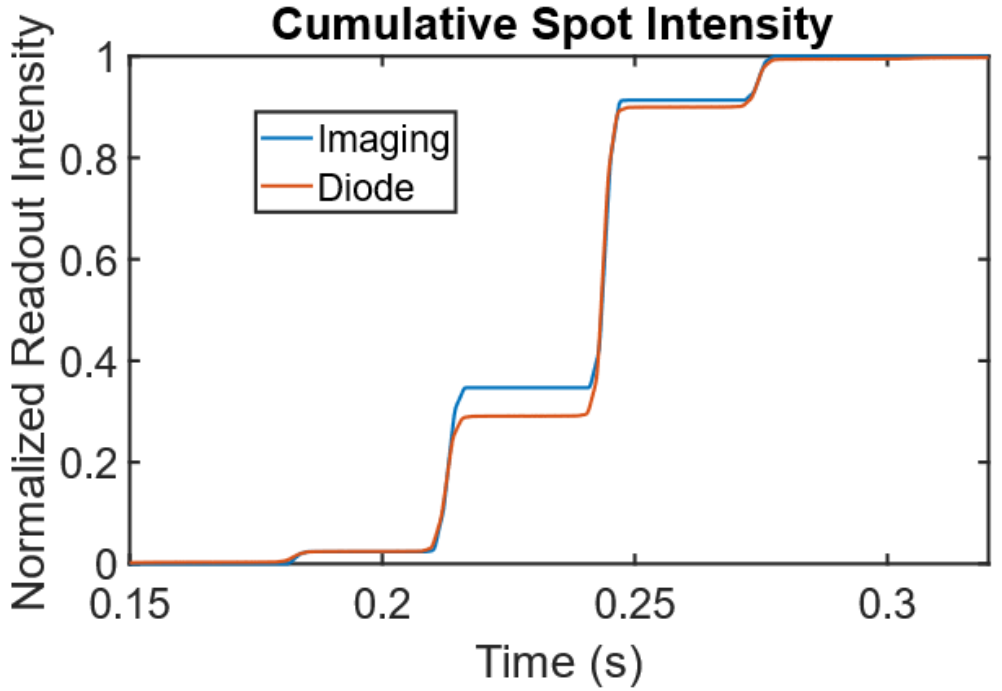
UHDR Proton PBS QA







Conclusion

Response	Detectors	Measurement type	FLASH study	Instantaneous dose-rate/dose per pulse (D_p) dependence	Spatial resolution	Time-resolution	Energy dependence
Luminescence	TLD/OSLD	**1D,** 2D	e [15, 37, 71]	Independent (~10^9 Gy/s) [80, 137]	~ 1 mm	Passive	Tissue-equivalent
	Scintillators	1D, **2D**, 3D	p [13, 18]	Independent (~10^6 Gy/s) [29]	~ 1 mm	~ns	Tissue-equivalent
	Cherenkov	**1D**, 2D, 3D	e [29]	Independent (~10^6 Gy/s) [29]	~ 1 mm	~ps	Energy dependent
	FNTD	2D	NA	Independent (~10^8 Gy/s) [85]	~ 1 μm	Passive	Energy dependent
Charge	Ionization chambers	**1D**, **2D**	p [13, 18, 19] e [15, 37, 71] ph [16, 17]	Dependent on D_p [48, 52] (>1 Gy/pulse),	~3–5 mm	~ms	Energy dependence shows up > 2 MeV
	Diamonds	**1D**	p [18]	Dependent on D_p (>1 mGy/pulse) [49]	~ 1 mm	~μs	Tissue-equivalent
	Si diode	**1D**, 2D	NA	Dependent on D_p [54] (Independent ~0.2 Gy/s) [138]	~ 1 mm	~ms	Energy dependent
Chemical	Alanine pellets	**1D**	e [12, 15, 37, 139]	Independent (10^8 Gy/s) [69]	~ 5 mm	Passive	Tissue-equivalent
	Methyl viologen/fricke	**1D**	e [29, 48]	Depends on the decay rate and diffusion of radiation induced species	~ 2 mm	~ns	Tissue-equivalent
	Radiochromic film	**2D**	p [18, 19] e [10–12, 15, 30, 37, 71, 140] ph [16]	Independent (10^9 Gy/s) [70, 71]	~1 μm	Passive	Tissue-equivalent
	Gel dosimeters	3D	NA	Strong dependence below 0.001 Gy/s [141] and above 0.10 Gy/s [142]	~1 mm	Passive	Tissue-equivalent

The color scheme of the "Response" and "Detectors" panel matches the spider plots in ***Figure 14****. Performance of each dosimeter for a specific parameter is color coded: green (good), yellow (moderate), and red (poor).*

Ashraf et al., Frontiers in Physics, 2020

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