31st Annual CIRMS Meeting

Efficient image-guided rodent irradiations on high-throughput eFLASH platforms

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MON, APR 29TH

Disclosures

I have no financial disclosures or conflicts of interest related to the content covered in this presentation.

About me

Position: Research Medical Physicist, Department of Radiation Oncology, UMSOM

Location: Medical School Teaching Facility (Office: 7-00E)

Role: Provide preclinical radiation physics and dosimetry support to the MCMP

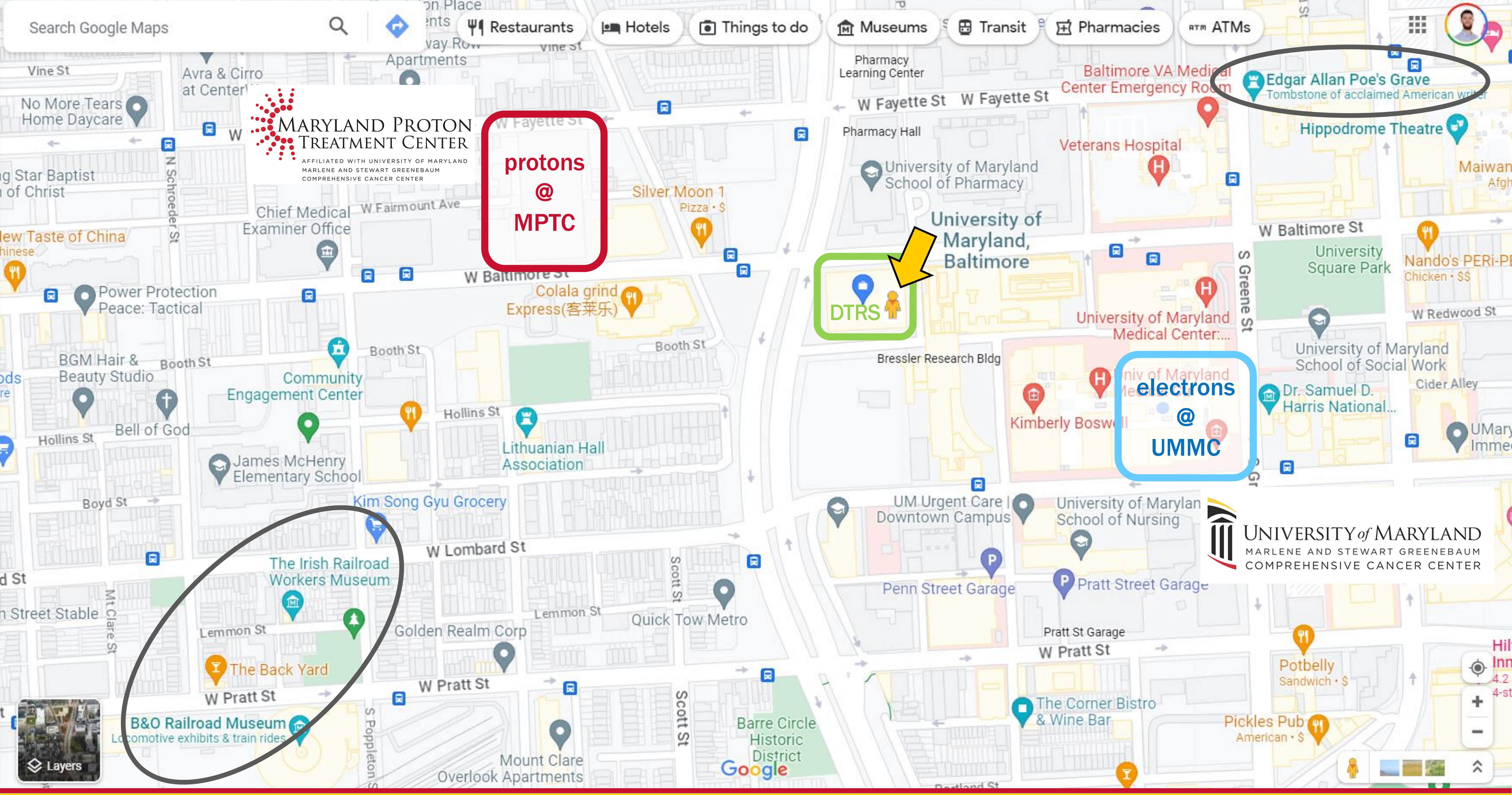
Primary Responsibilities: Perform animal irradiations for MCMP studies and as a service to other investigators

Maintain QA program for irradiators and dosimeters

MCMP @ RadOnc @ UMSOM

The Medical Countermeasure Program (MCMP) advances the development of potential mitigators of acute radiation sickness (ARS) and delayed effects of acute radiation exposure (DEARE).

Internationally recognized for our expertise in MCM development studies in mouse, rabbit, pig, and NHP models.


Maryland Proton Treatment Center
Affiliated with University of Maryland Marlene and Stewart Greenebaum Comprehensive Cancer Center
protons @ MPTC
DTRS
electrons @ UMMC
University of Maryland Marlene and Stewart Greenebaum Comprehensive Cancer Center
University of Maryland, Baltimore
Edgar Allan Poe's Grave
The Irish Railroad Workers Museum
B&O Railroad Museum
W Fayette St
W Baltimore St
W Lombard St
W Pratt St
Booth St
Hollins St
Bressler Research Bldg
University of Maryland Medical Center
University of Maryland School of Pharmacy
University of Maryland School of Nursing
University of Maryland School of Social Work
Veterans Hospital
Hippodrome Theatre
Lithuanian Hall Association
Community Engagement Center
Barre Circle Historic District

UMSOM FLASH systems

UHDR electrons

Varian Clinac 21-EX

Energy	16 MeV
PRF	up to 180 Hz
Nominal PW	5 µs
$DR_{average}$	up to ~130 $Gy.s^{-1}$
$DR_{instant}$	up to 10^5 $Gy.s^{-1}$
Duty Cycle	<0.1%

UHDR protons

Varian ProBeam

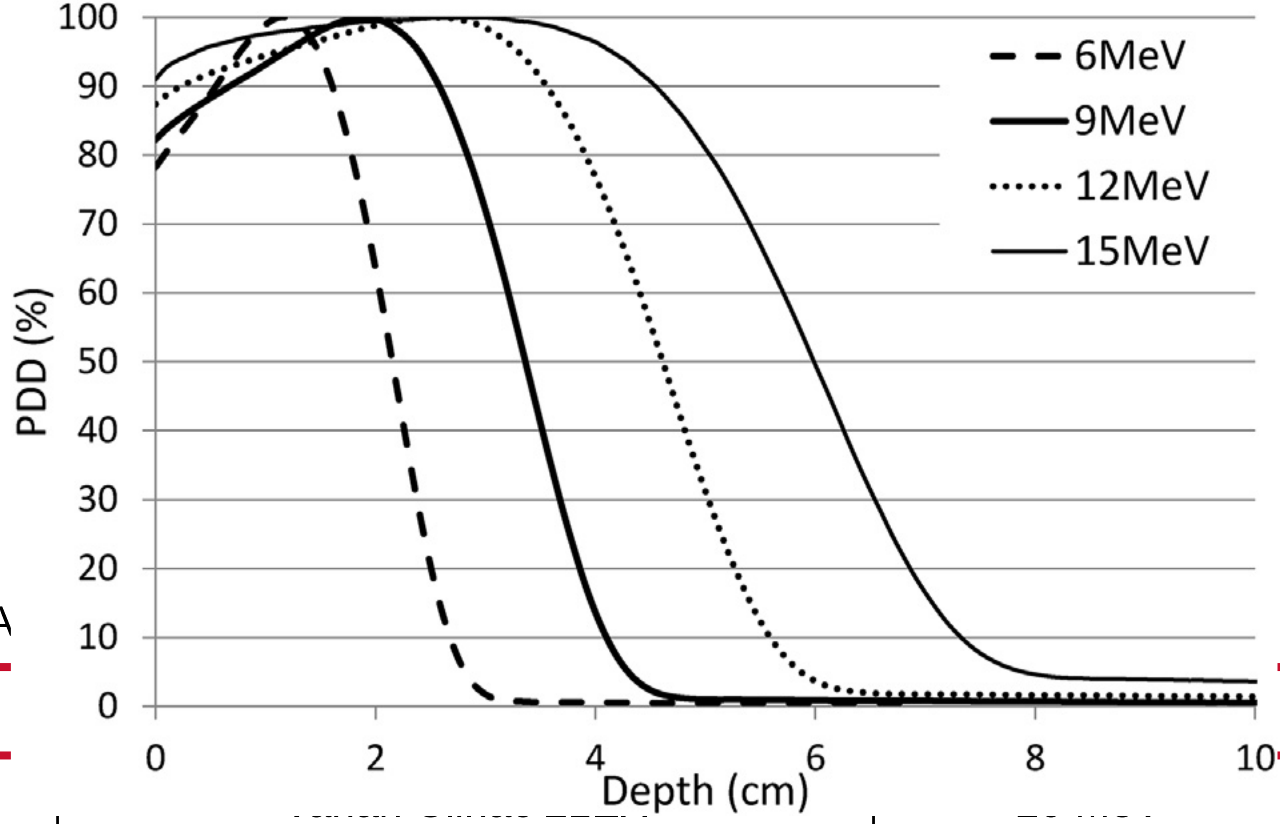
Energy	250 MeV
$DR_{average}$	up to ~120 $Gy.s^{-1}$

Varied parameters:

PRF, Duty Cycle, PW, $DR_{instant}$ (10^3 $Gy.s^{-1}$)

Linac-based eFLASH systems

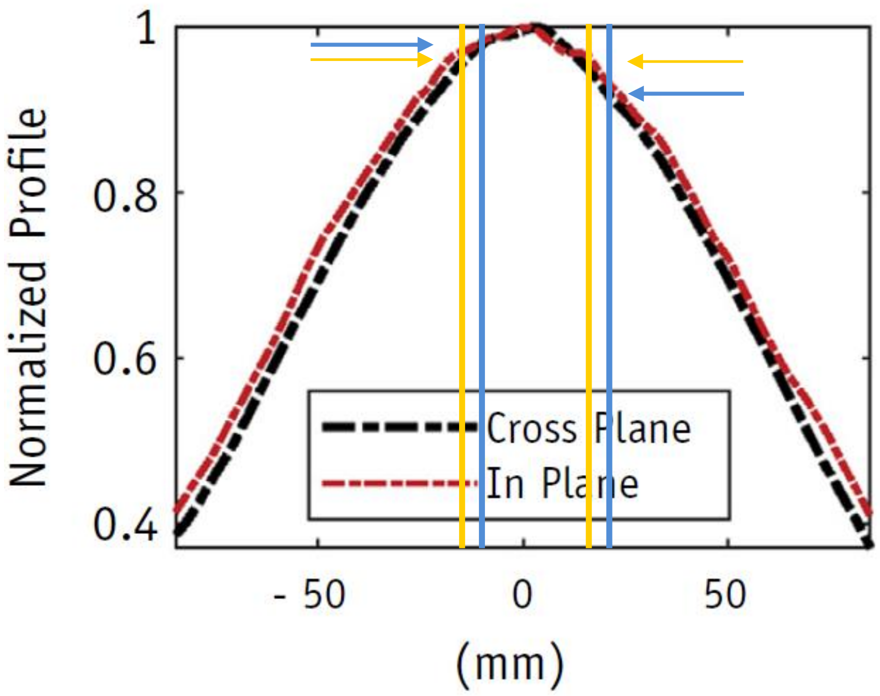
Institution	Scattering Foils
Oxford, UK	none
Sun Yat-sen, China	none
Columbia, USA	none
Lund, Sweden	none
Dartmouth, USA	none
BC Cancer (Surrey), CA	9 MeV
UMSOM, USA	16 MeV
Stanford, USA	20 MeV



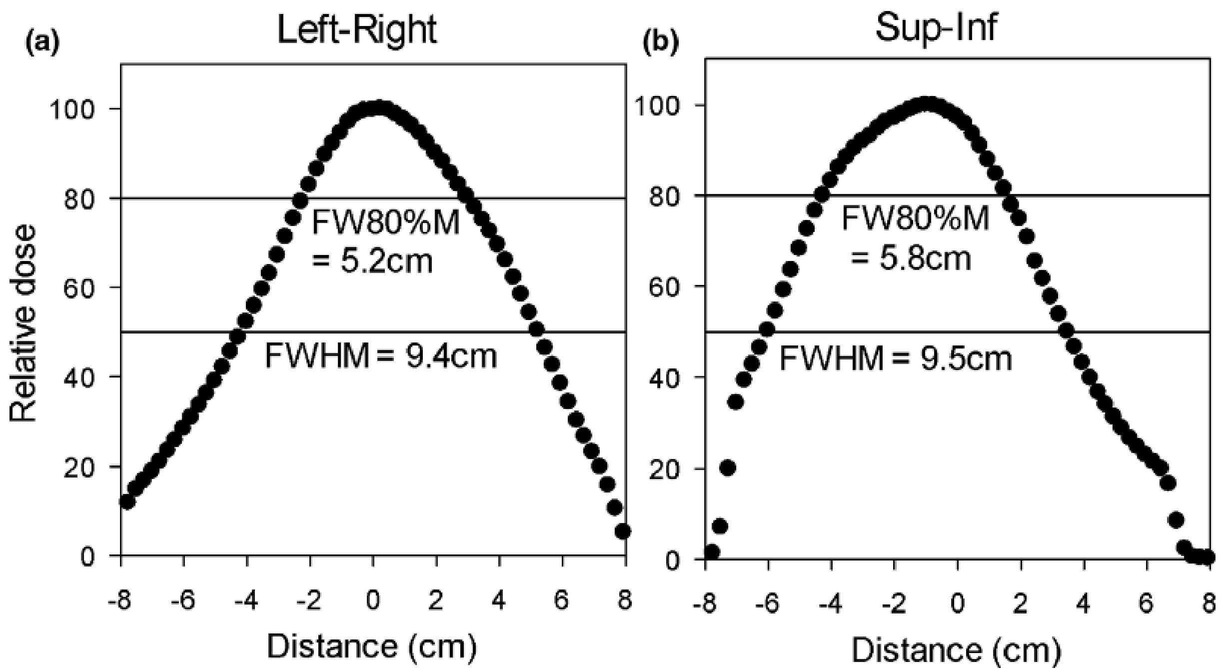
Mott et al (2021) doi.org/10.1016/j.clon.2020.06.021

Courtesy of Dr. Kai Jiang

Institution	Linac	Beam Energy	Scattering Foils
Dartmouth, USA	Varian Clinac 2100	10 MeV	none
BC Cancer (Surrey), CA	Varian iX	18 MeV	9 MeV



Dartmouth, USA



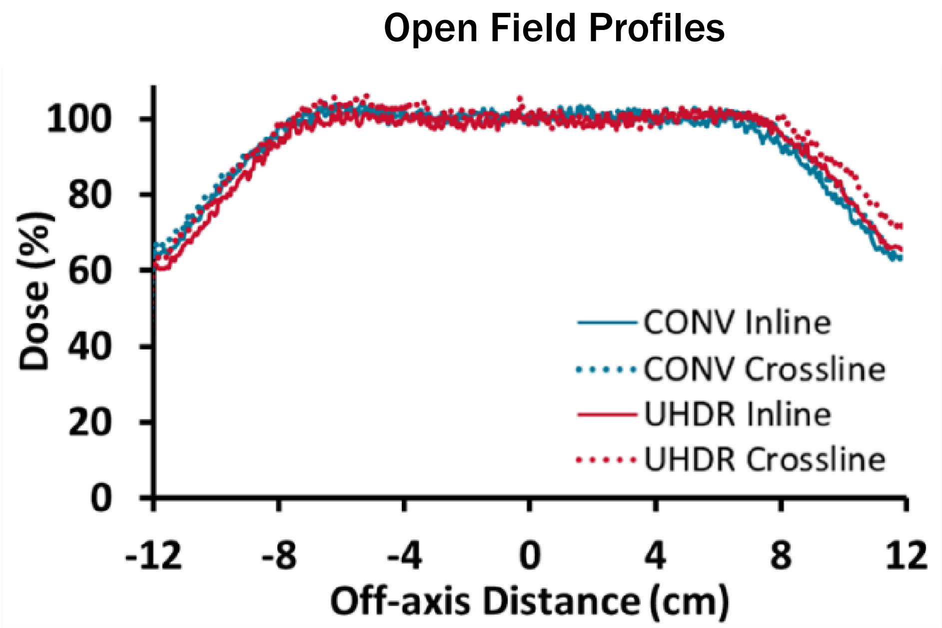
BC Cancer, Surrey, Canada

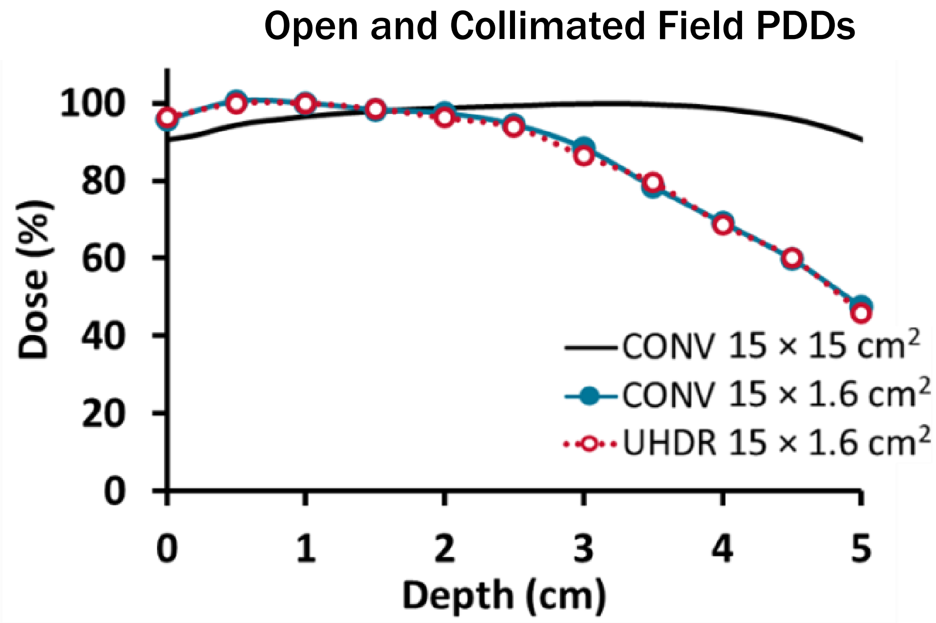
>300 Gy.s^{-1}

Rahman et al (2021) 10.1016/j.ijrobp.2021.01.011

Splaza et al (2021) doi.org/10.1002/mp.16909

Matched UHDR and CONV beam at UMSOM



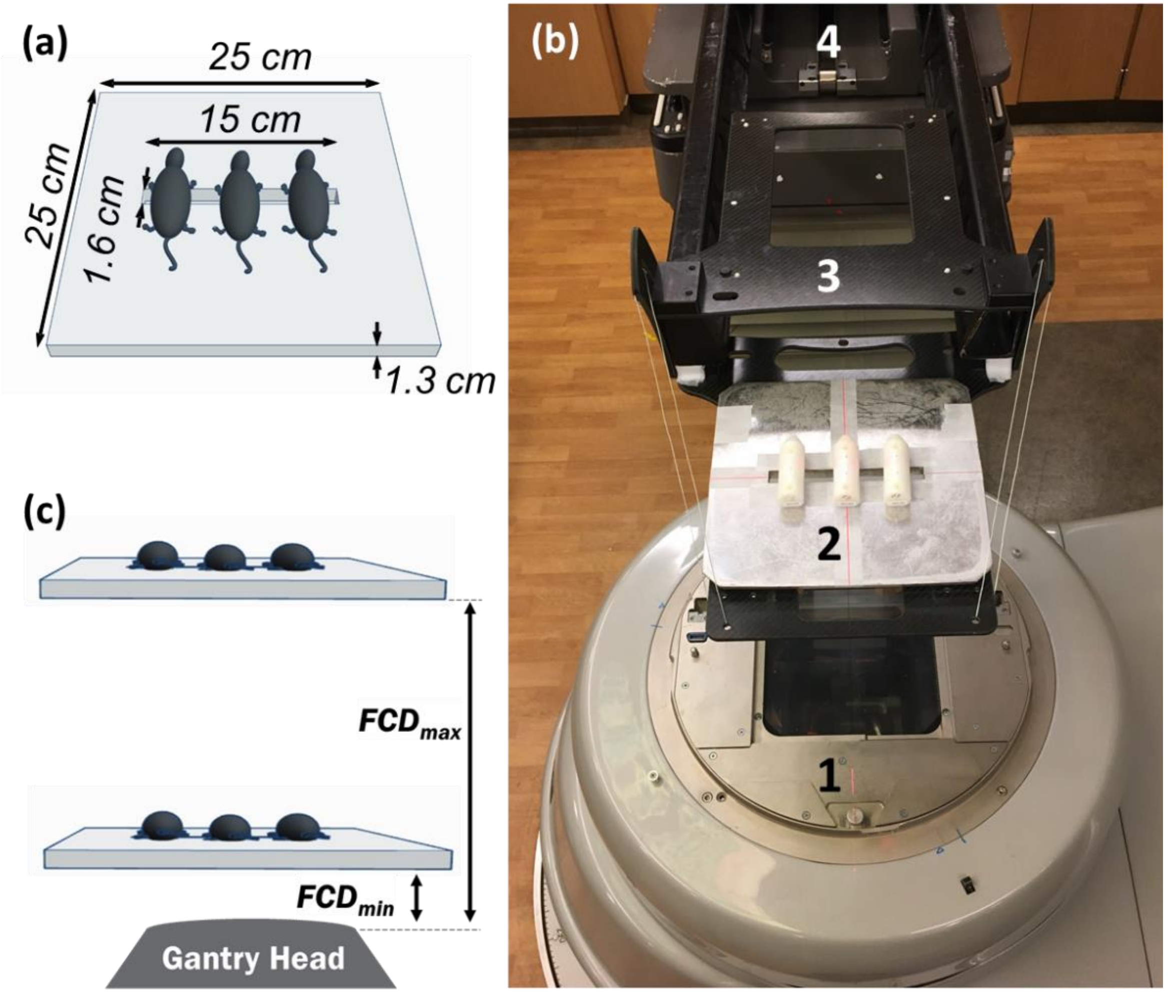


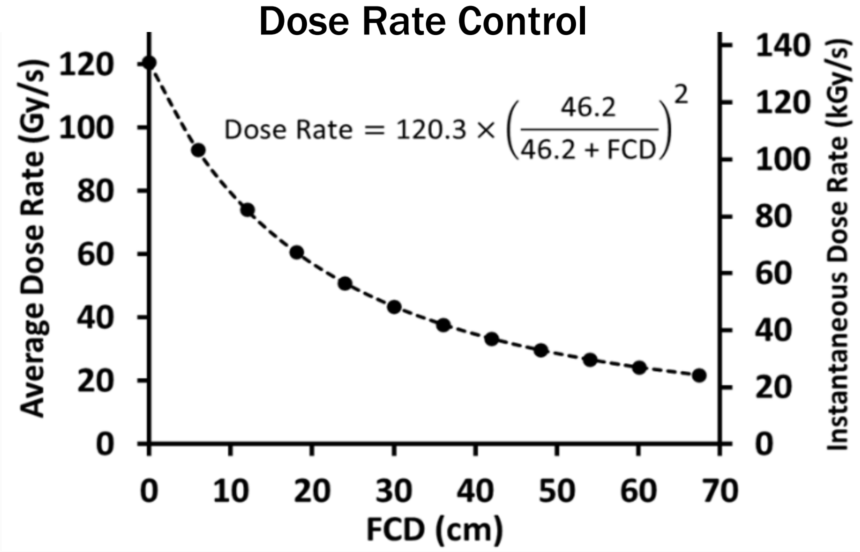
d_{max} reduced from 3.4 to 0.5 cm

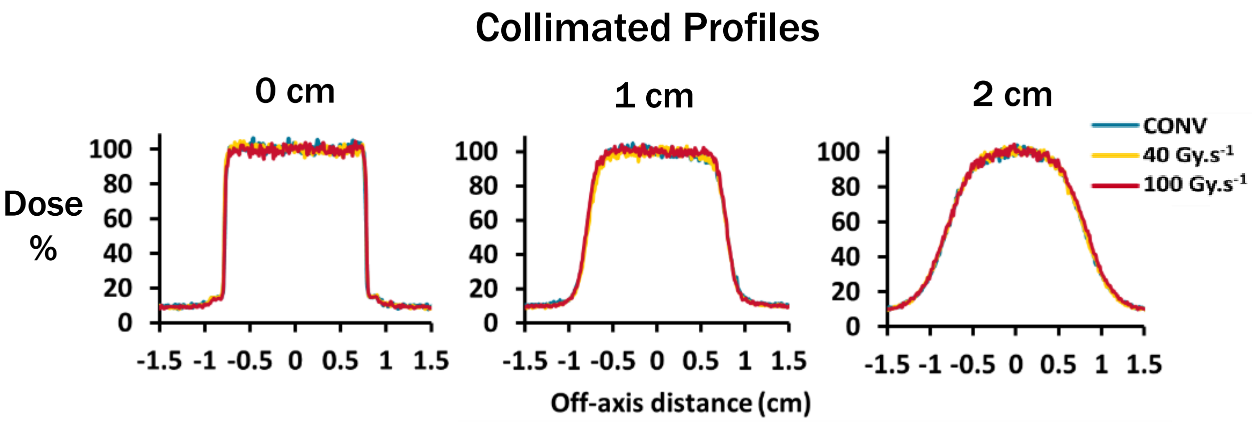
96% until 2 cm

Byrne et al (2024) doi.org/10.1002/mp.16909

eFLASH Platform

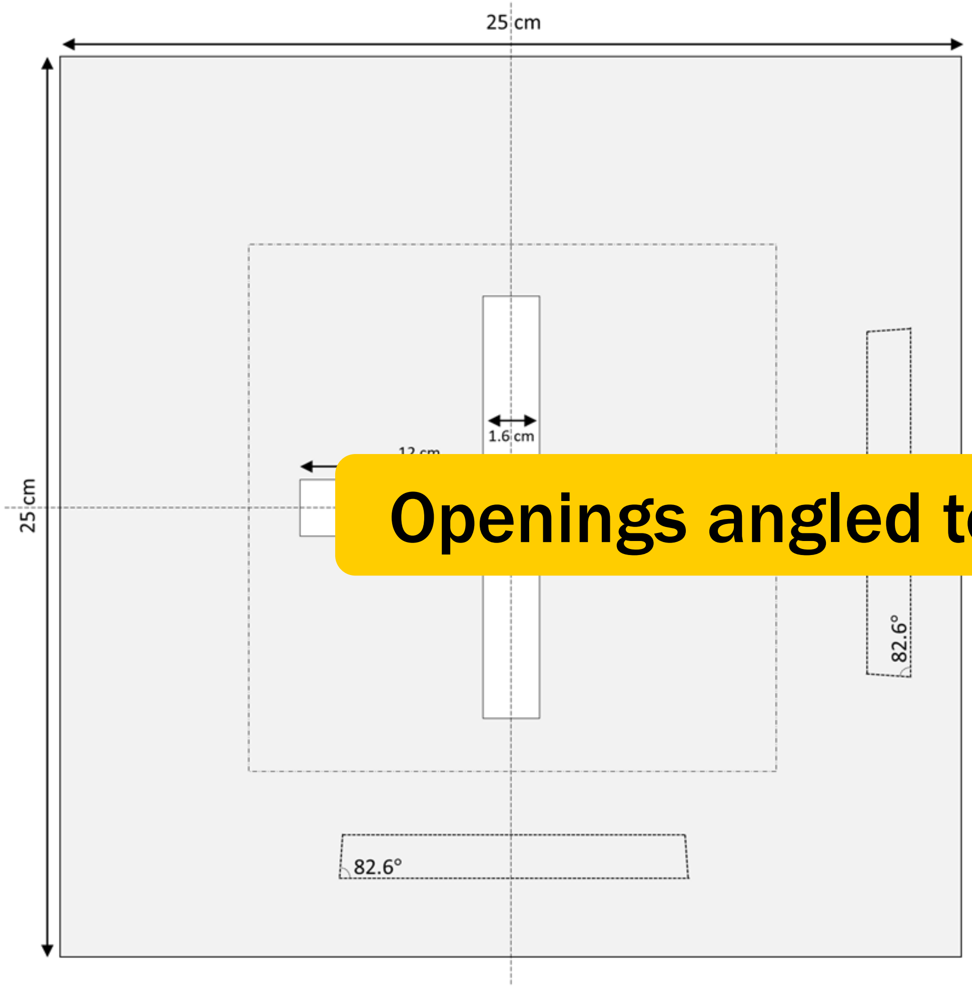






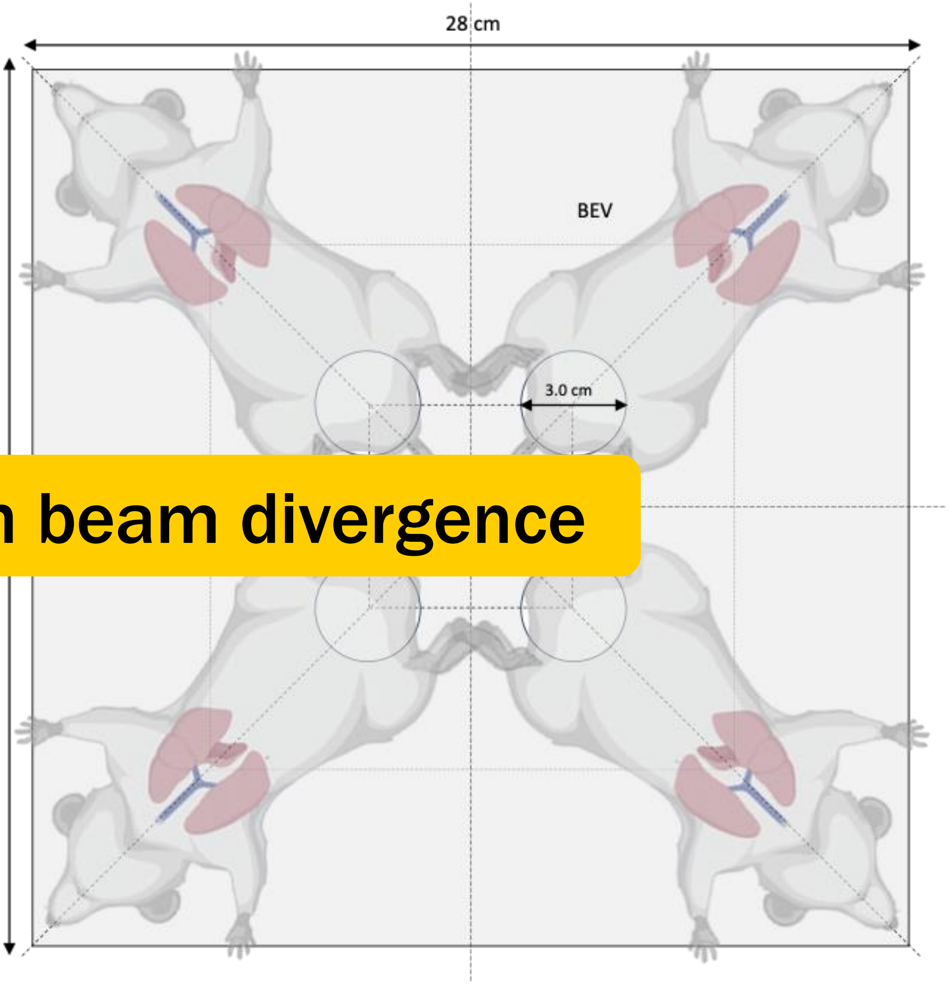
up to ~130 $Gy.s^{-1}$

Sample Collimator Designs



4 x HTLI (or 3 x WTLI) – 3 cm diameter

Openings angled to match beam divergence



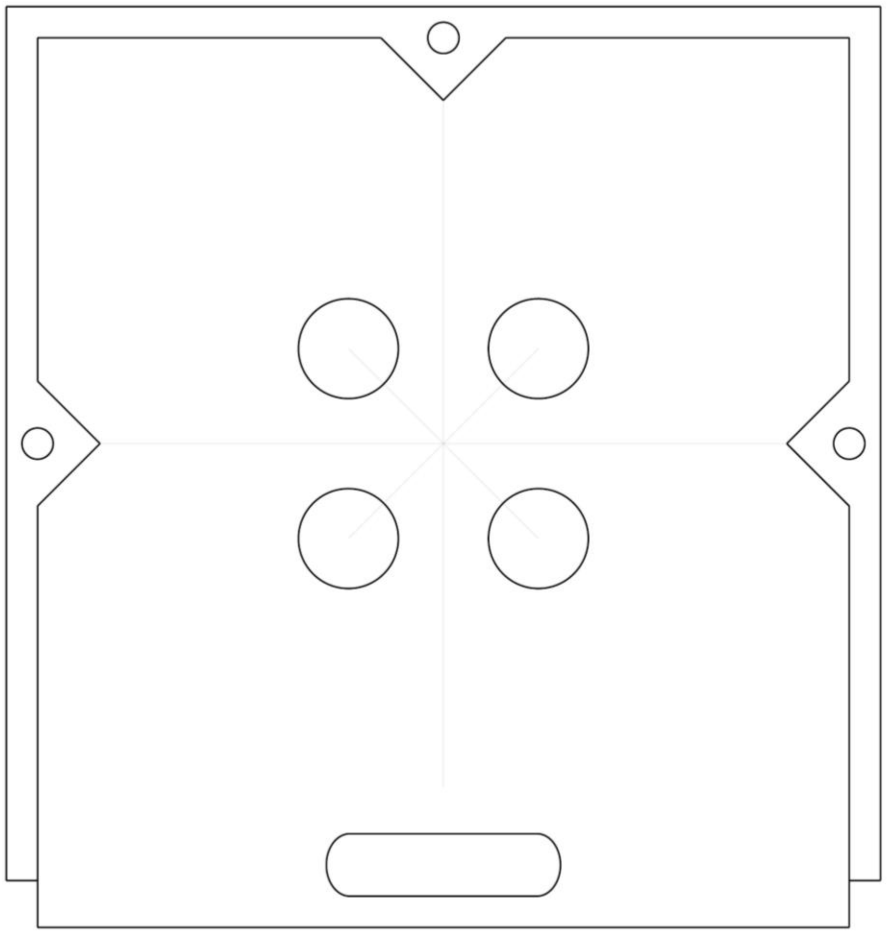
4 x Rat Prostate – 3 cm diameter

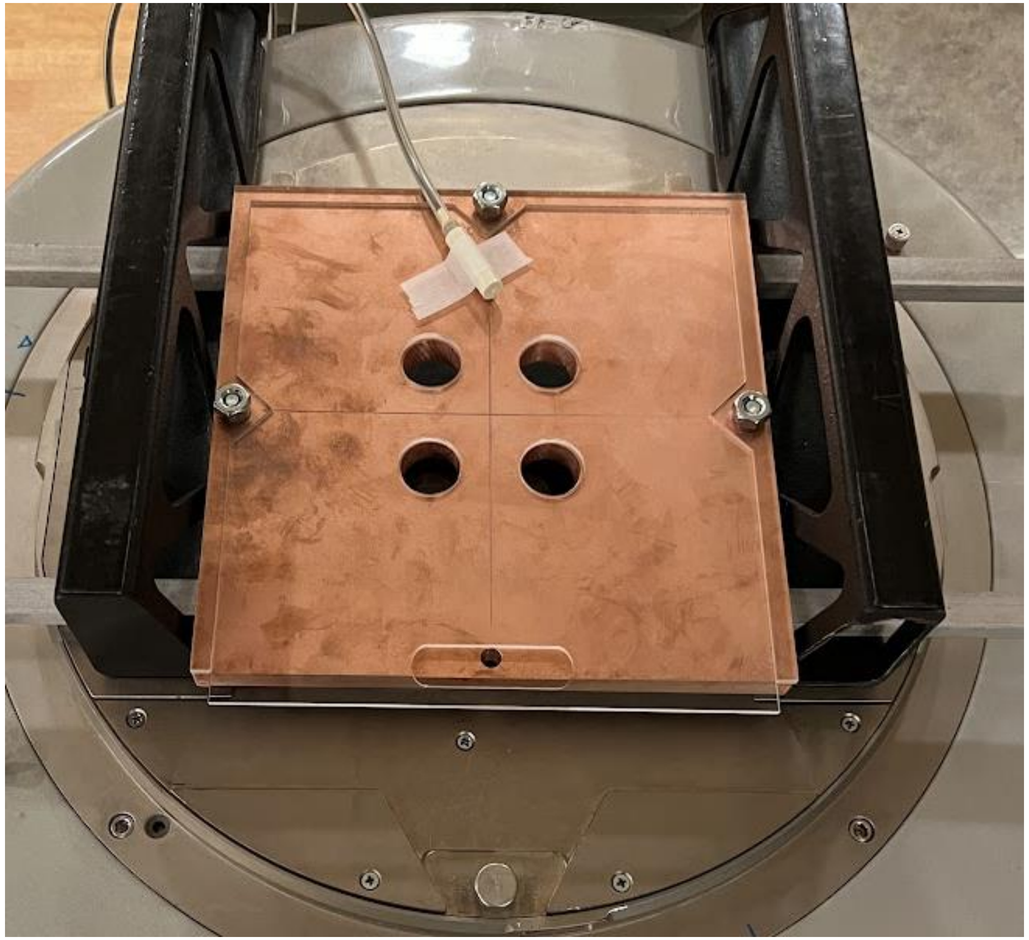
Collimator-Template Matching

4 x HTLI (or 3 x WTLI) – 3 cm diameter

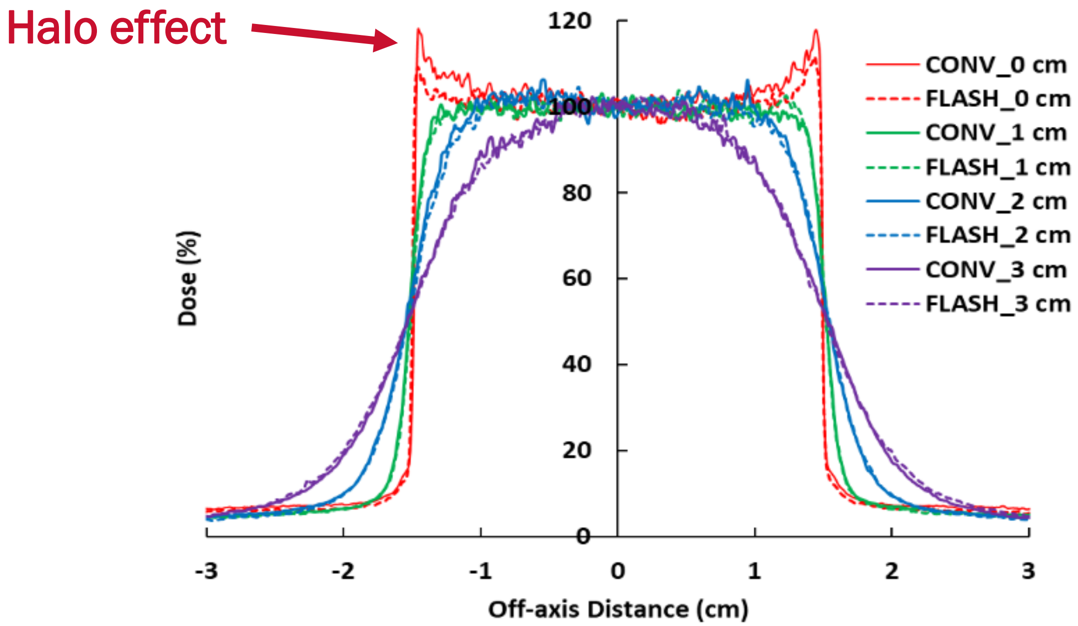
5 x flank – 1 cm diameter

Positioning Templates

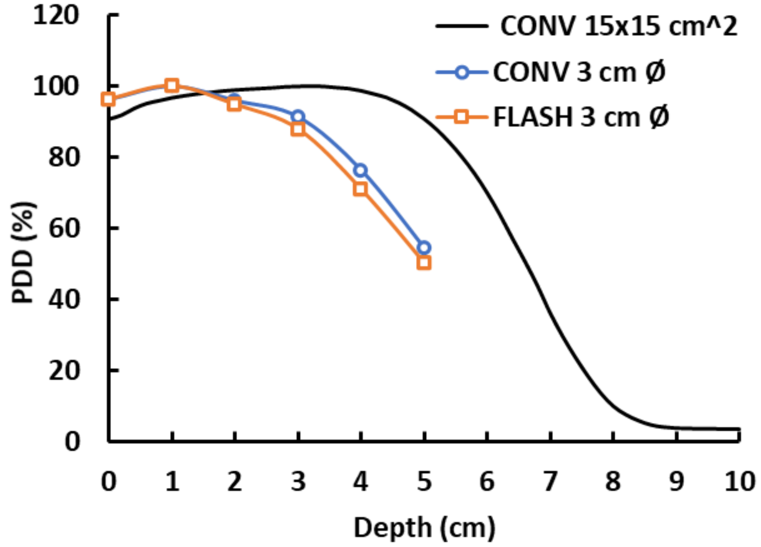




UHDRe – Rat Prostate



Collimated beam profiles obtained at conventional (CONV) and ultra-high (FLASH) dose rates. The 80%-20% penumbra increases from 0.035 cm at the entrance (0 cm depth) to 0.87 cm at 3 cm depth.



The PDD of the collimated UHDR beam remains above 88% up to 3 cm, the approximate anterior-posterior thickness of an adult rat.

“Anatomy […] of Rat Prostate”

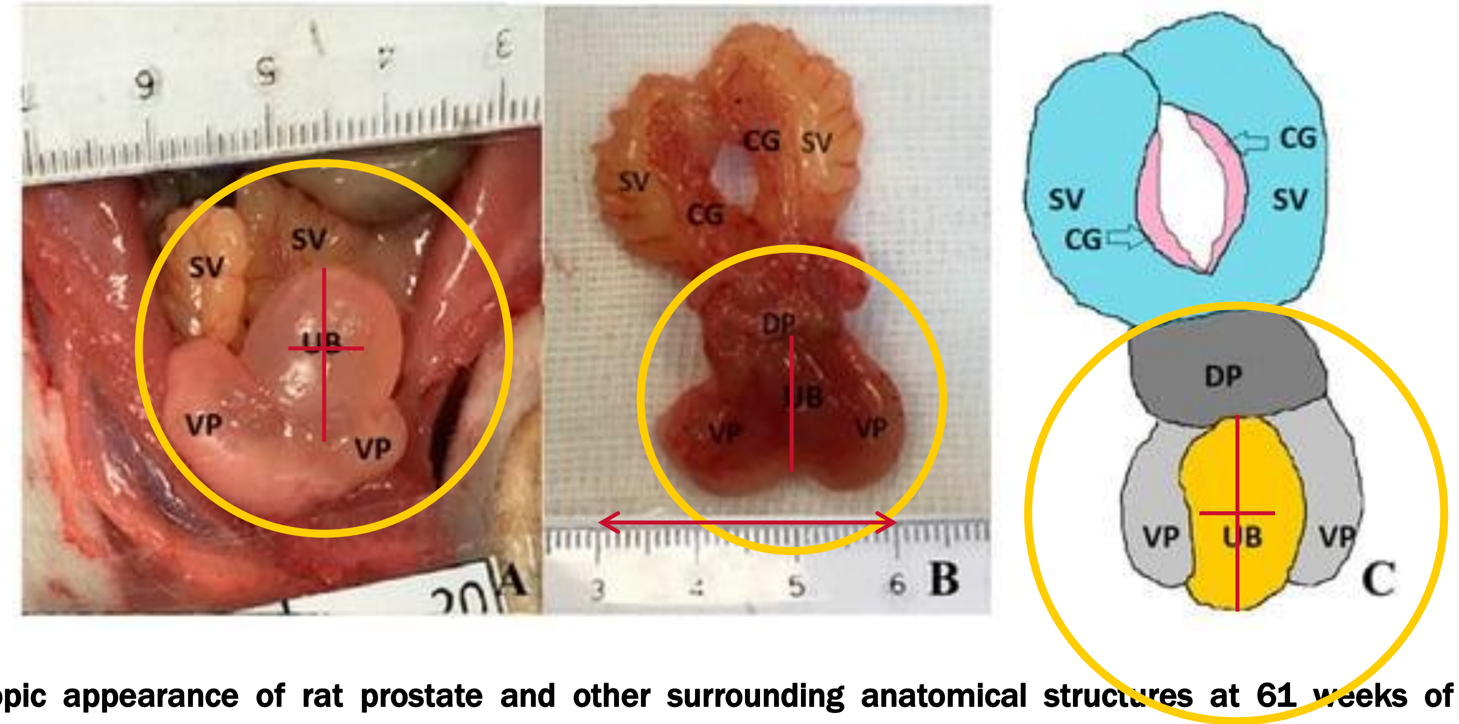
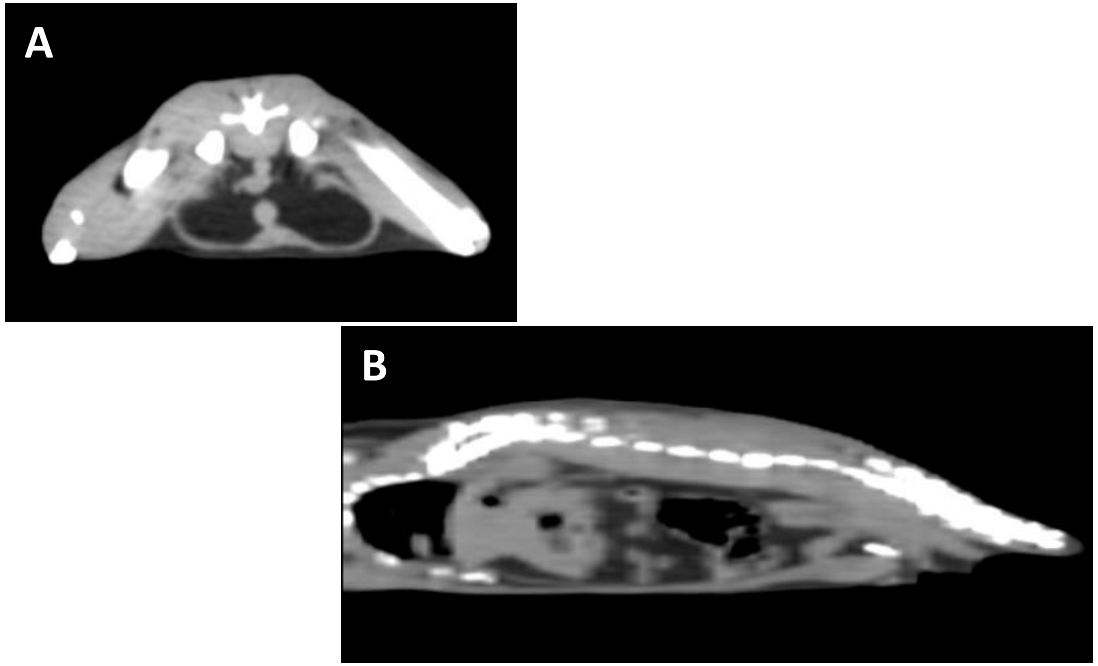
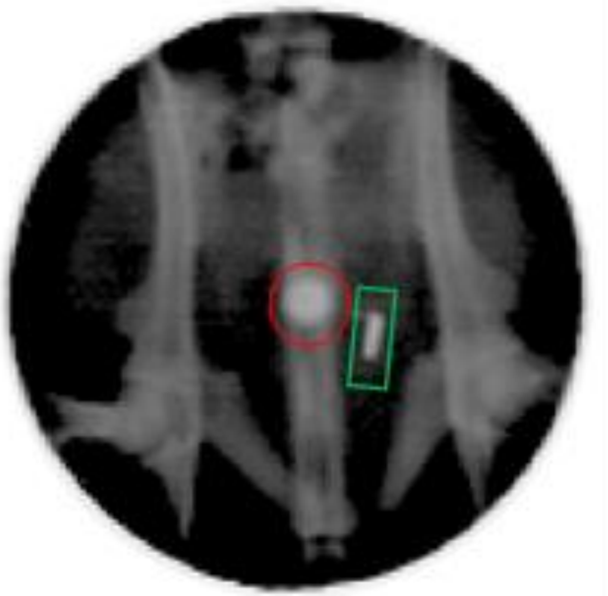


Figure 1. Macroscopic appearance of rat prostate and other surrounding anatomical structures at 61 weeks of age. (A) In situ photography of an animal from control group, ventral view; (B) Photography of prostate from an induced animal (dorsal view). Seminal vesicles and coagulative glands extended caudally. (C) Line diagram of prostate, urinary bladder and closed sex glands. Coagulating glands (CG), dorsal (DP) and ventral prostate lobes (VP), seminal vesicles (SV) and urinary bladder (UB).

Electron FLASH: Rat Prostate

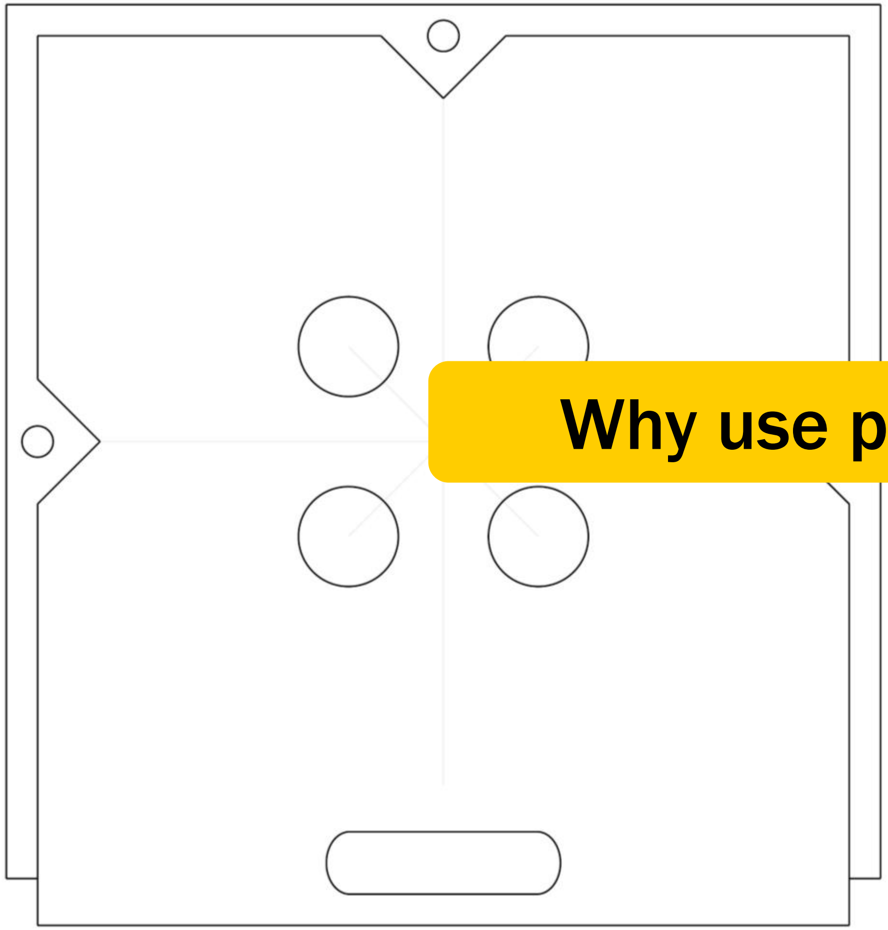


CBCT images showing adequate contrast for lower abdominal soft tissue visualization in the axial (A) and sagittal (B) views of a Copenhagen rat.



2D kV planar image highlighting the location of a CT dot (red circle) and the scintillator tip (green rectangle).

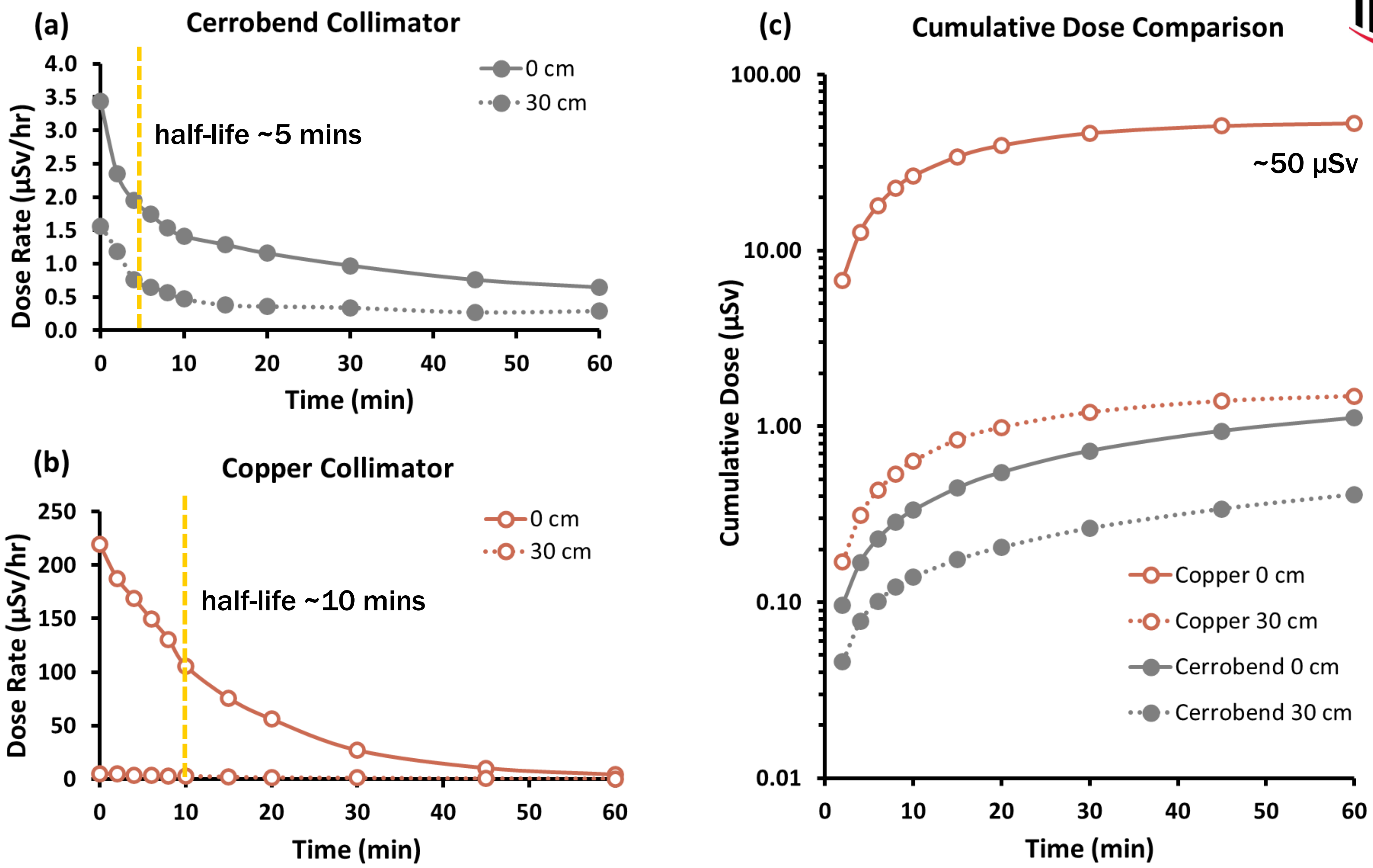
Positioning Templates



Why use positioning templates?

Reason #1
Collimator Activation

Inovision 451P
ion chamber survey meter
(Fluke Biomedical LLC)



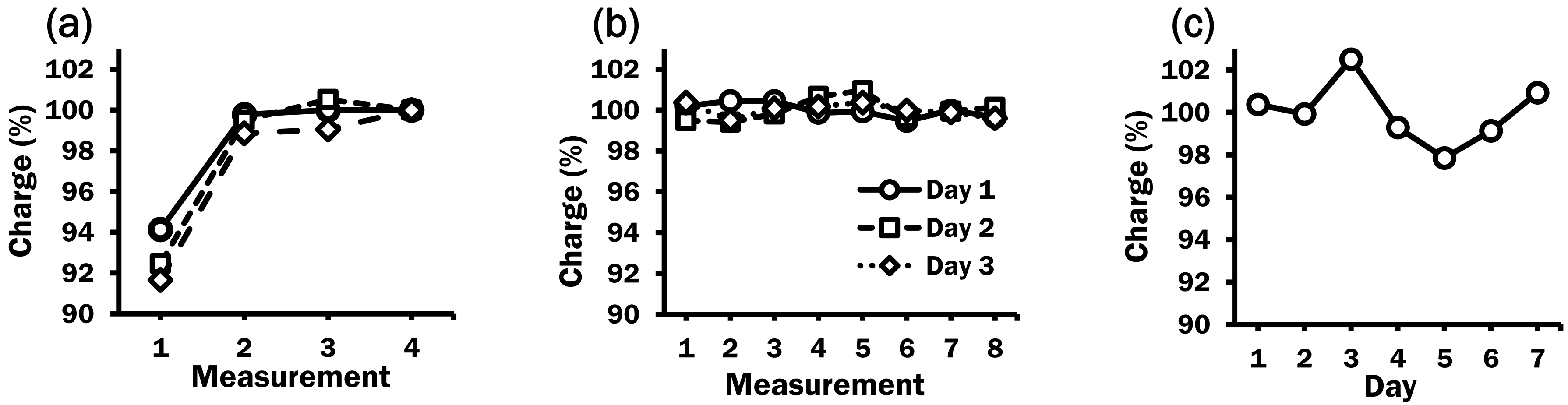
Byrne et al (2024) doi.org/10.1002/mp.16909

Reason #2 – UHDR Setup

It takes time to leave service mode, image, re-position, re-enter service mode

<u>AND</u>

The beam needs to be warmed up



Beam stability measurements. (a) FLASH beam ramp-up on 3 separate days. **(b)** FLASH beam repeatability on 3 separate days. **(c)** FLASH beam reproducibility over 7 days.

X-RAD 320 (PXi)

Up to 320 kVp (relatively high)

Static x-ray tube (robust, few moving parts)

Broad beam (fits more animals, high throughput)

Classic muscle car: “fast and simple”

Small Animal Radiation Research Platform (SARRP, Xstrahl)

Rotating X-Ray tube, couch motion (x, y, z, yaw)

Up to 225 kVp (intermediate)

CBCT (gantry at 90, couch rotates)

MuriPlan TPS

Crossover SUV: “versatile and practical”

https://xstrahl.com/sarrp/

$$Total\ (\$) = 200\ mice\ \times 10\ \frac{fractions}{mouse} \times 0.25\ \frac{hours}{fraction} \times 240\ \frac{\$}{hour} \times 75\% =$$

2024 BMW M4 Competition xDrive Coupe

Coupe

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MSRP

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Apply For Financing

AVAILABLE AT:

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6700 Baltimore National Pike, Baltimore, MD 21228
(410) 744-2000

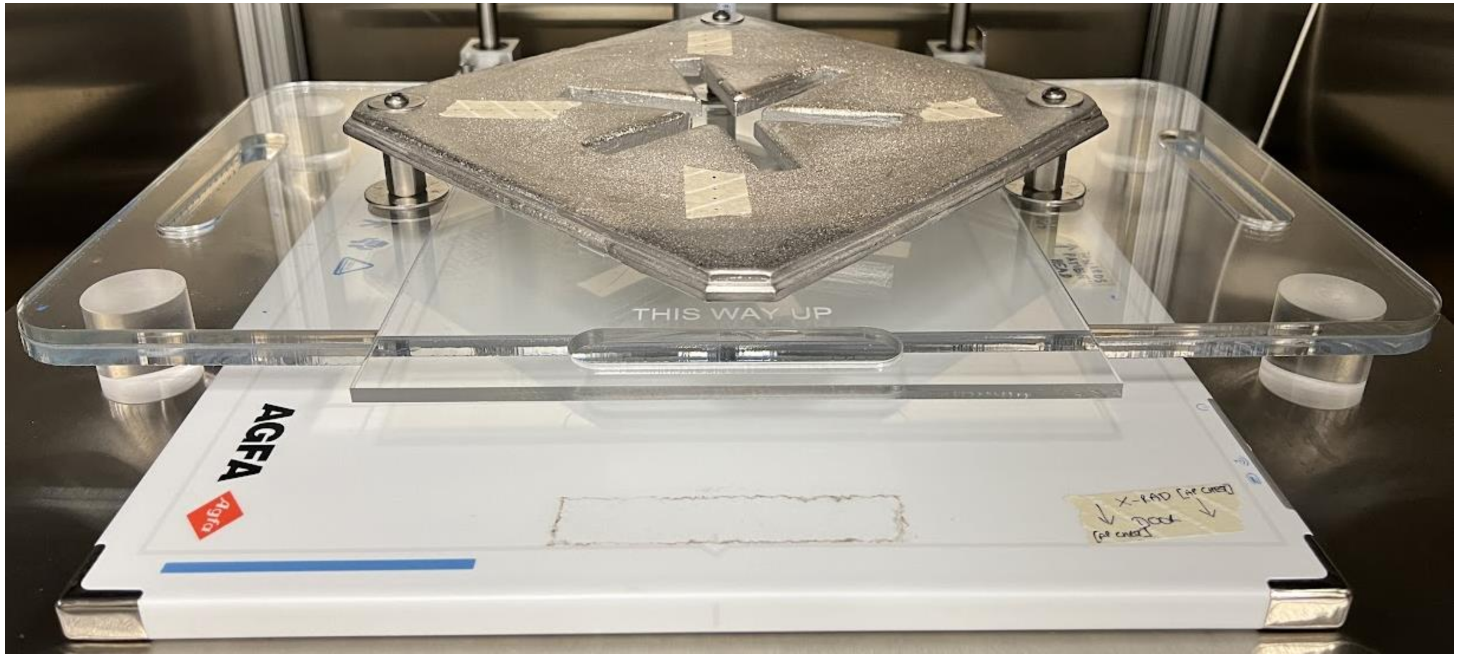
Contact Dealer **Test Drive**

View Vehicle On Dealer's Website

Incentives

Calculate Payment

High-throughput platform for the X-RADs

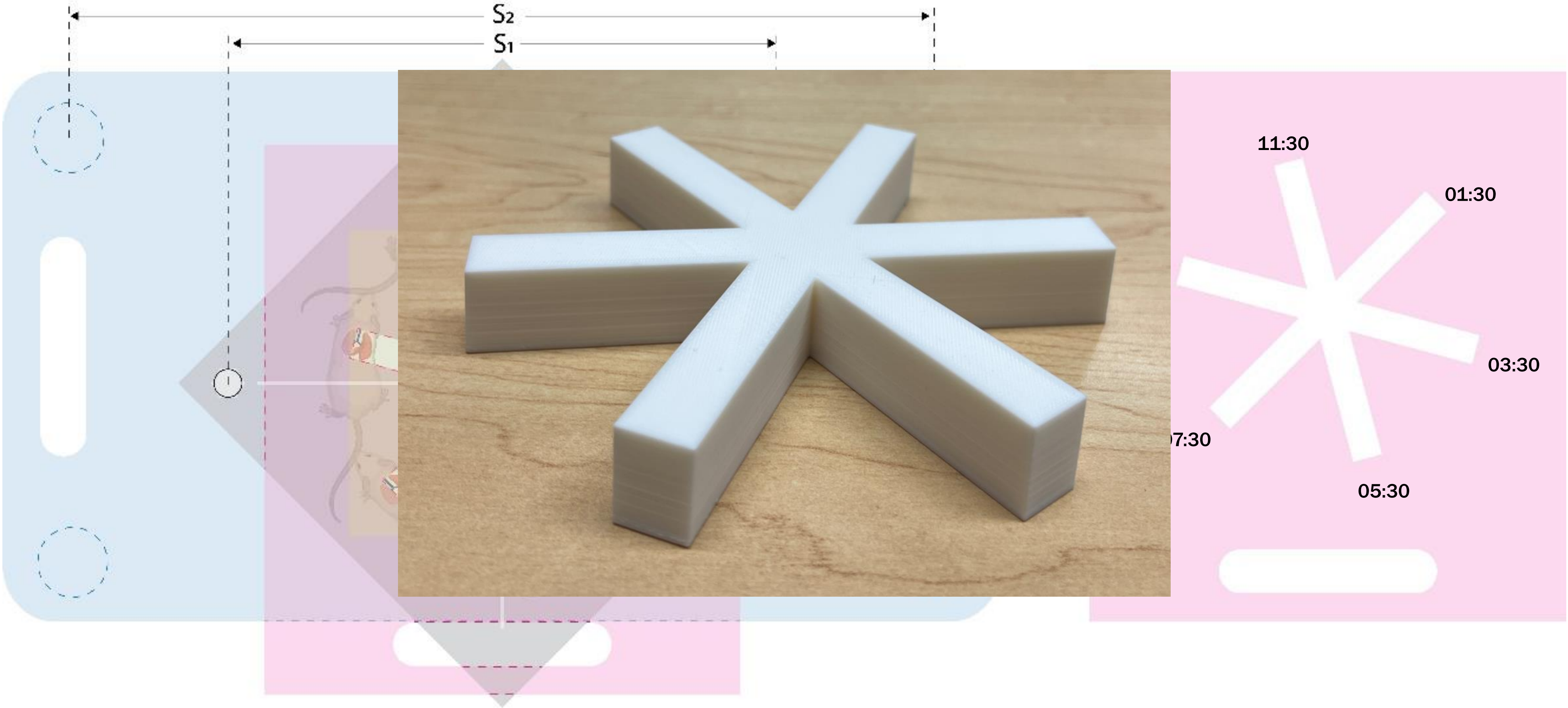


AGFA DR14s
Wireless Digital
Radiography Panel

Beam	SARRP	X-RAD 320 F1	X-RAD 320 F2
Peak Energy (kVp)	225	320	320
Filtration	0.15 mm Cu	2 mm Al	0.75 mm Sn + 1.5 Al + 0.25 Cu
Mean Energy* (keV)	~80	~90	~160
HVL	0.6 mm Cu	1.0 mm Cu	3.8 mm Cu

*SpekCalc

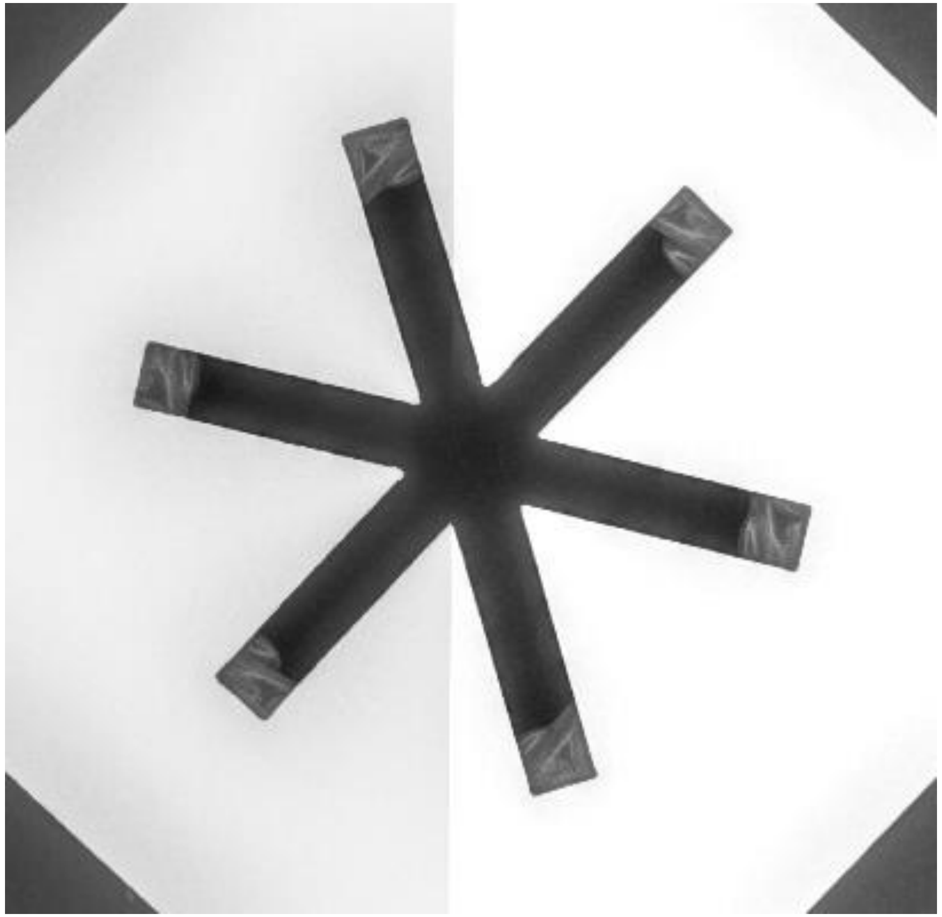
Solution: High-throughput collimator for the X-RAD



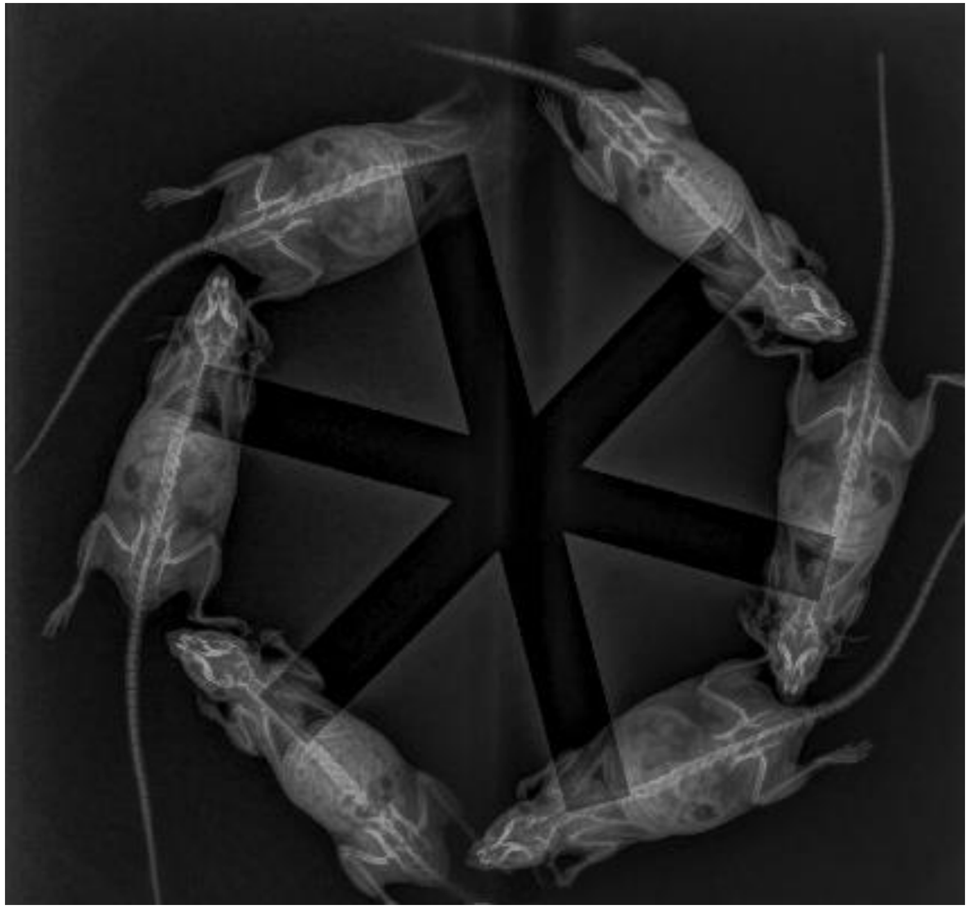
Reason #3 – Workflow Parallelization (CONV kV example)

https://www.accela.eu/precision-x-ray/x-rad-320

“Banking” into place conserves positioning

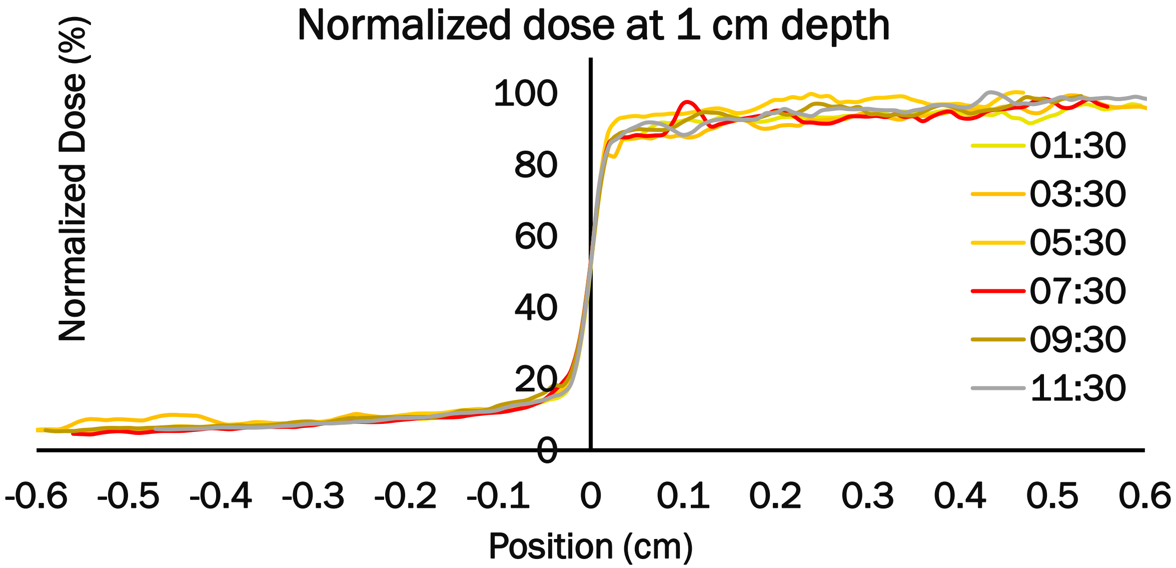


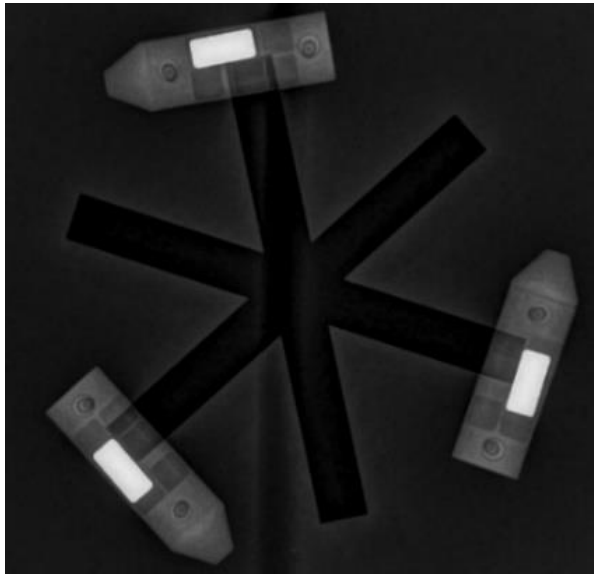
Through collimator

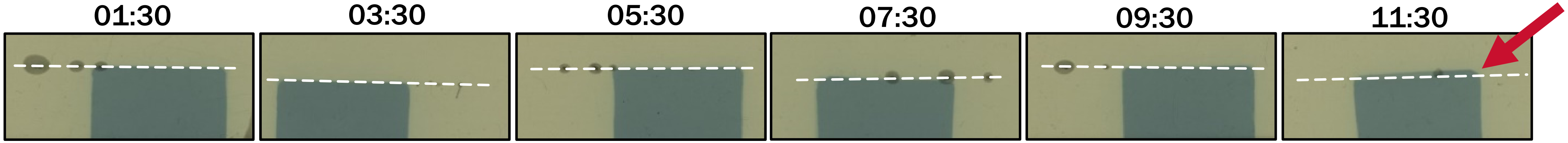


Through Positioning Plate only

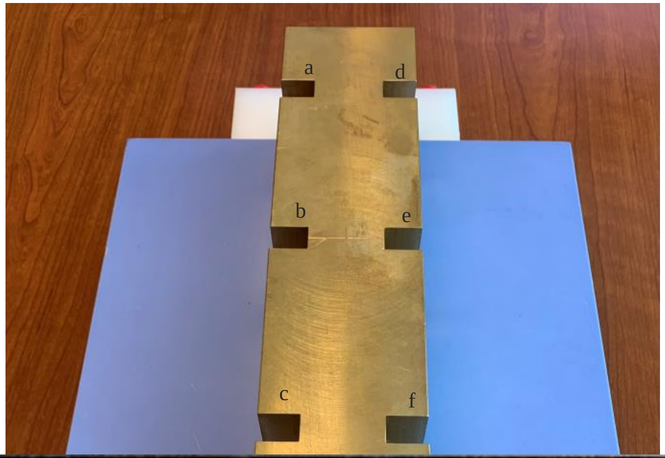
Characterization: Profiles and E2E

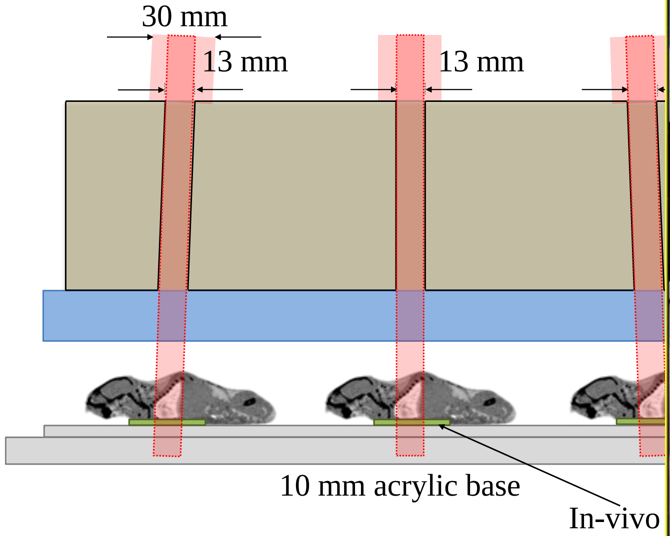


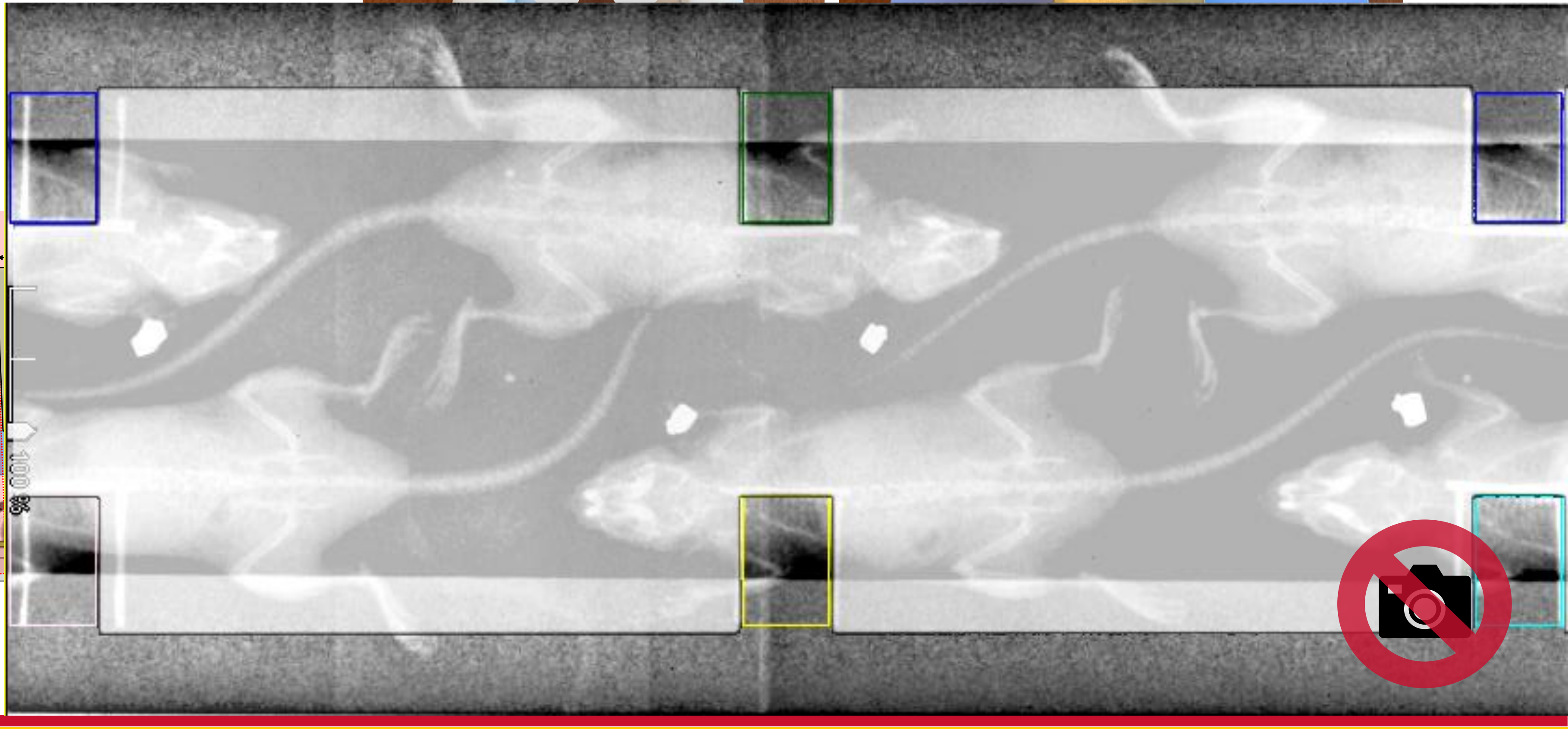




Proton FLASH example: Hemi-thorax







Mossahebi et al (in review)

Take home points

1. SAI throughput can be improved, without adversely affecting accuracy, by using customized collimator templates and image guidance

2. Parallelization of the workflow improves efficiency and is especially useful in FLASH experiments involving collimators, where wait times are required between runs due to activation.

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