Fast Time-gated Intensified Camera Electronics for Proton and FLASH Dosimetry

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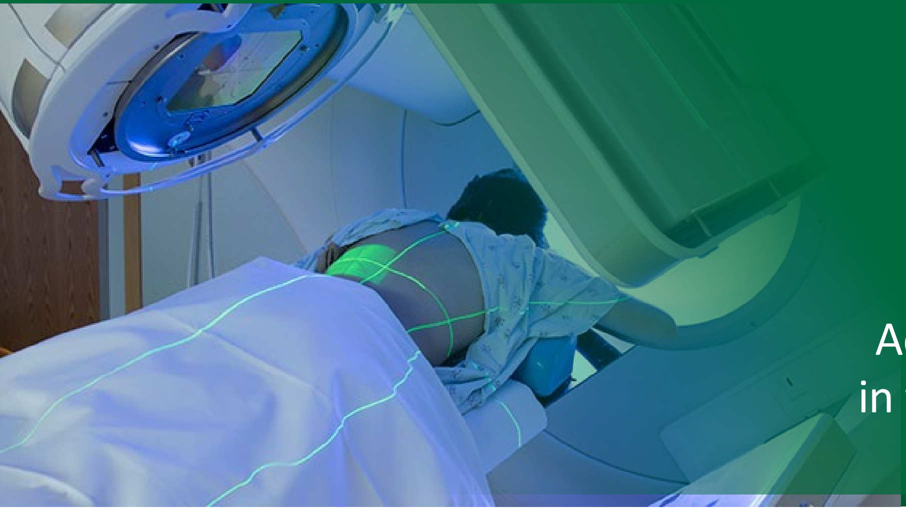

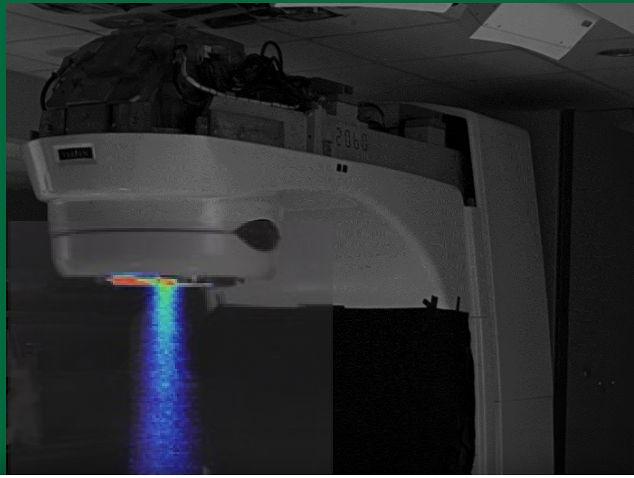

DOE / NIH workshop
Advancing Medical Care through Discovery in the Physical Sciences: Radiation Detection
March 16-17, 2023

DARTMOUTH

THAYER SCHOOL OF ENGINEERING AT DARTMOUTH

Dartmouth GEISEL SCHOOL OF MEDICINE

Dartmouth Health

DOSEOPTICS
Visualize radiation therapy

Disclosures

Funding Support and Conflict of Interest:

I am a principal investigator of SBIR award R44CA268466, and a co-owner of DoseOptics LLC.

This work used equipment provided at no cost by DoseOptics to Dartmouth College and Dartmouth Health.

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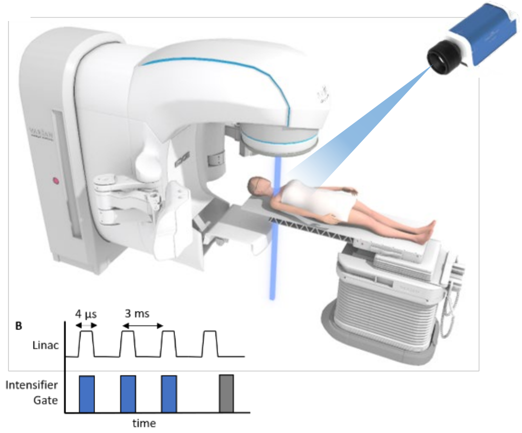
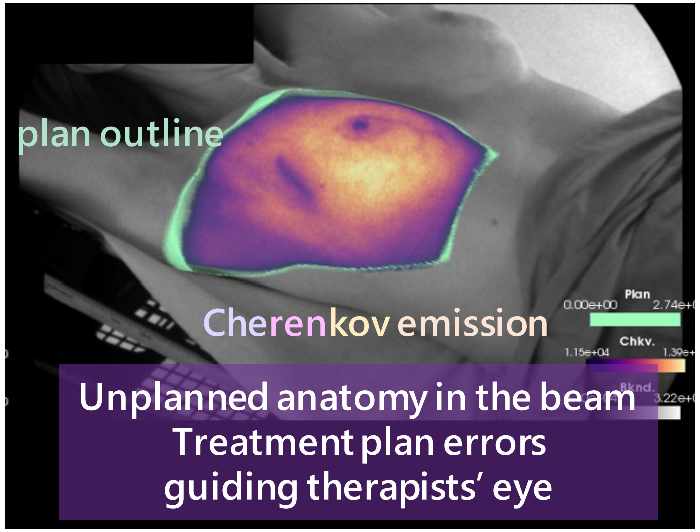
Gated optical imaging at Dartmouth – translating to clinics

L. A. Jarvis, et al. *IJROBP* 1; 109(5), 2020
X Cao, et al. *IJROBP* 111(1), 2022

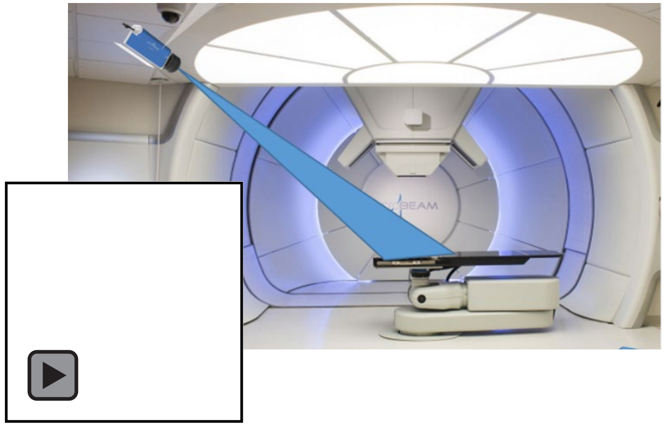
Cherenkov imaging visualizes dose in patients "for free"



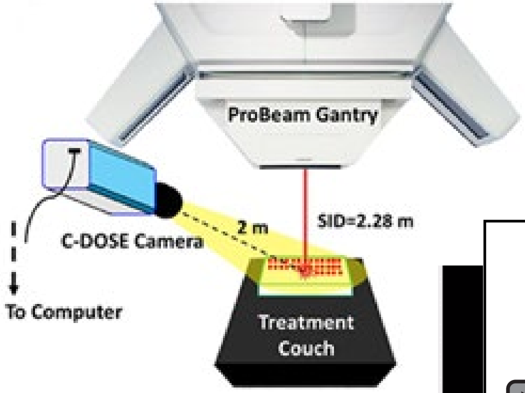


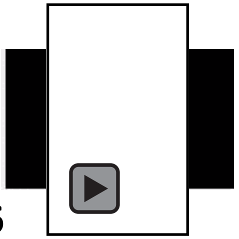
R01 EB023909 R44 CA265654
P30 CA023108-41

Fast cameras image ultra-high dose rate beams (FLASH) *in vivo*



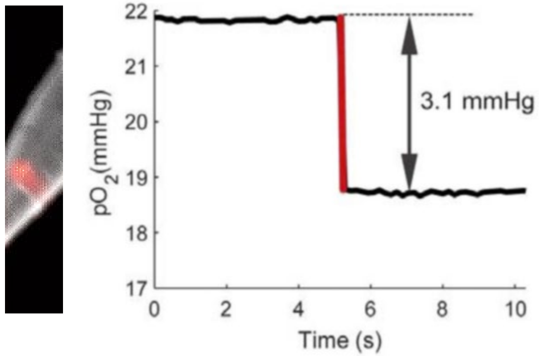
Capture kHz time-resolved dose dynamics of PBS proton beams





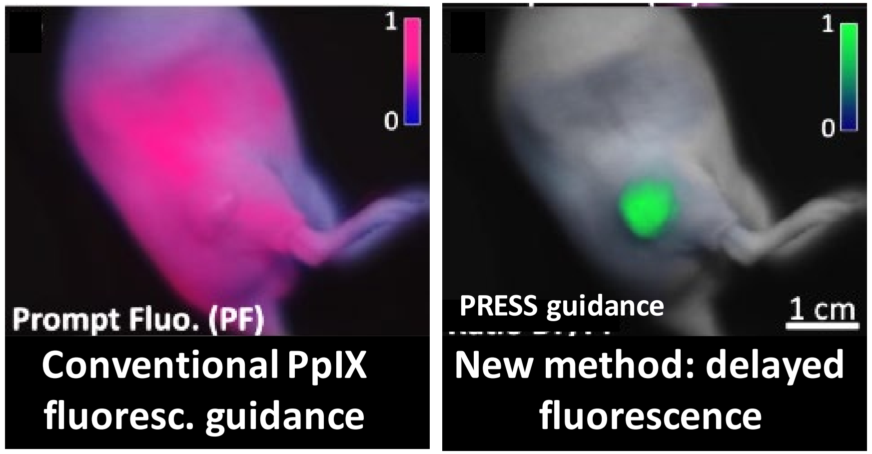
R44 CA268466

Fast gated cameras measure i.c. oxygen *in vivo* during FLASH RT…



U01 CA260446

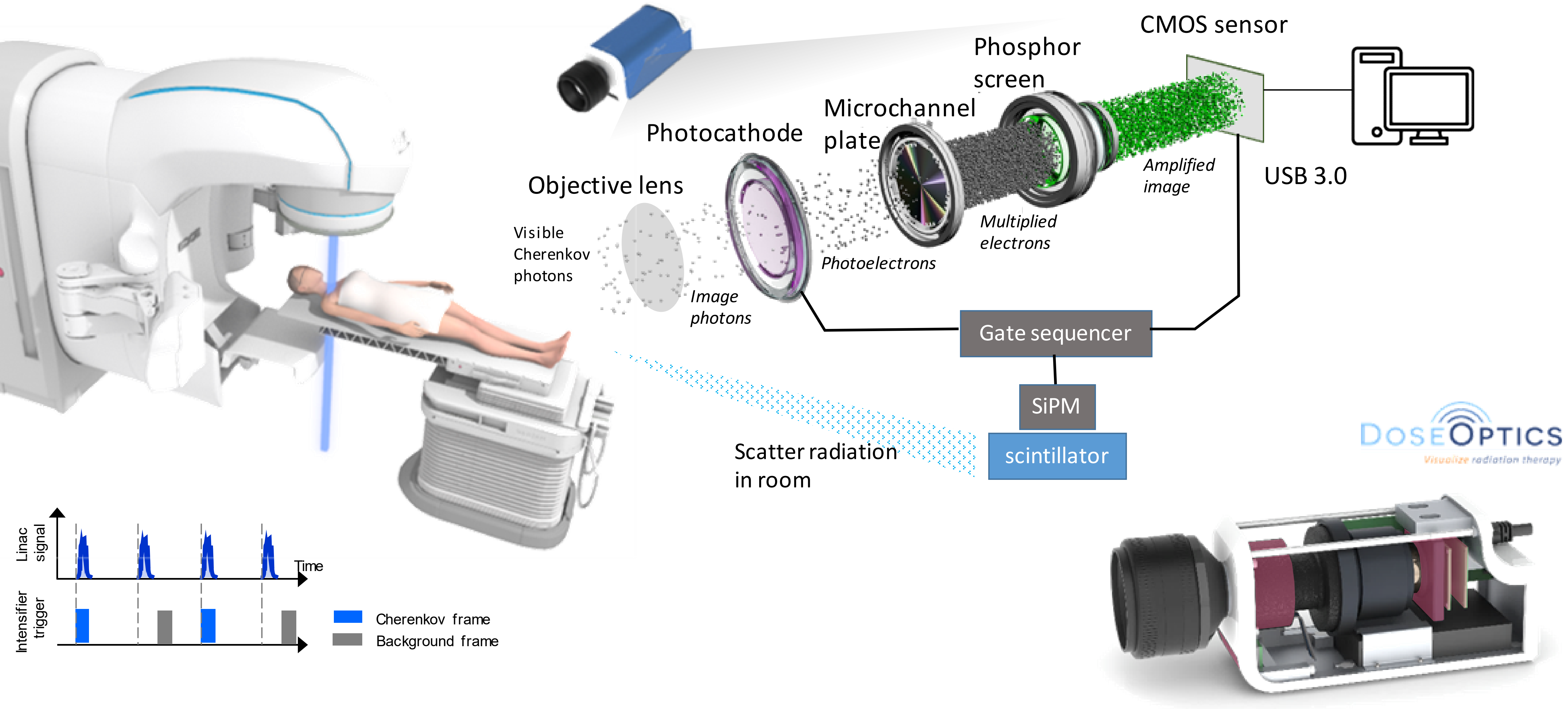
….and navigate surgeons (tumor resection, trauma..)



DHC Pilot award, Not NIH funded (yet!)

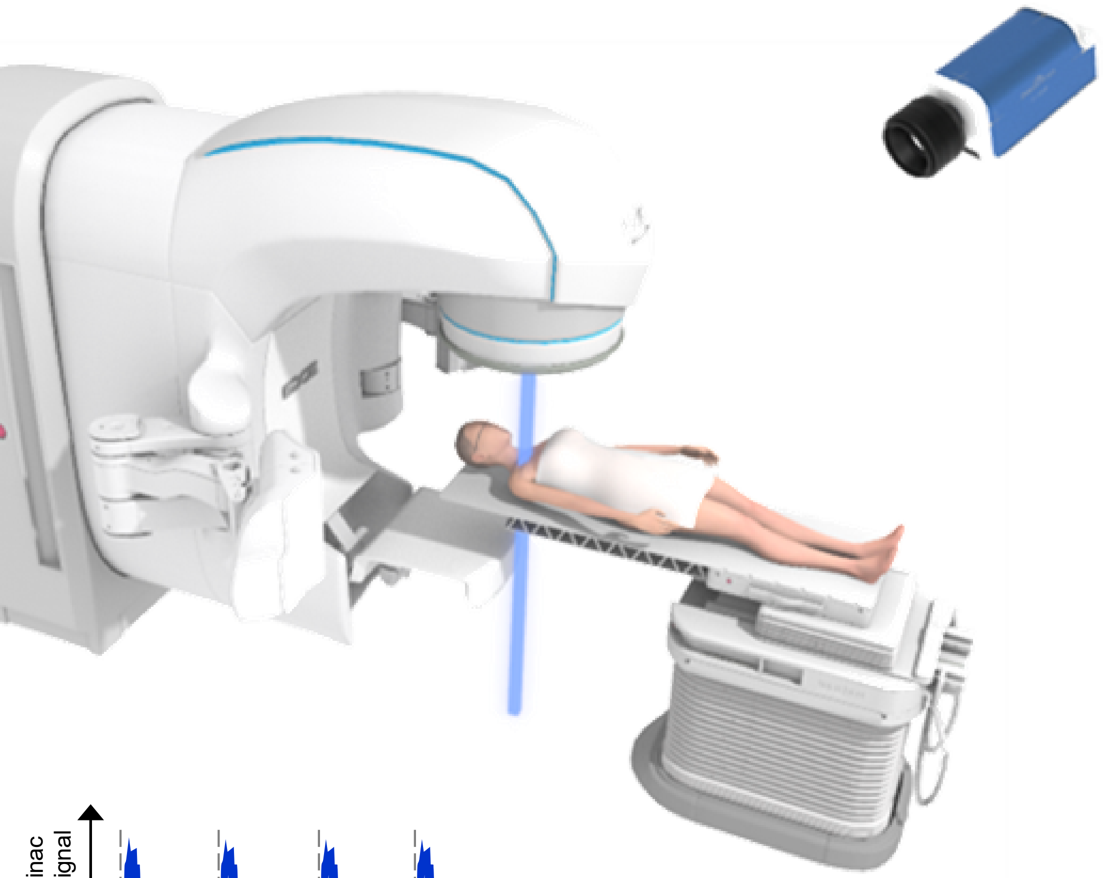
Gated camera to capture weak visible Cherenkov light during radiotherapy

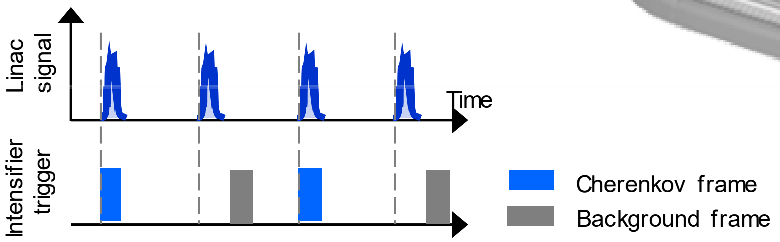
Cherenkov light directly indicates dose deposition in patients treated with external radiotherapy beams

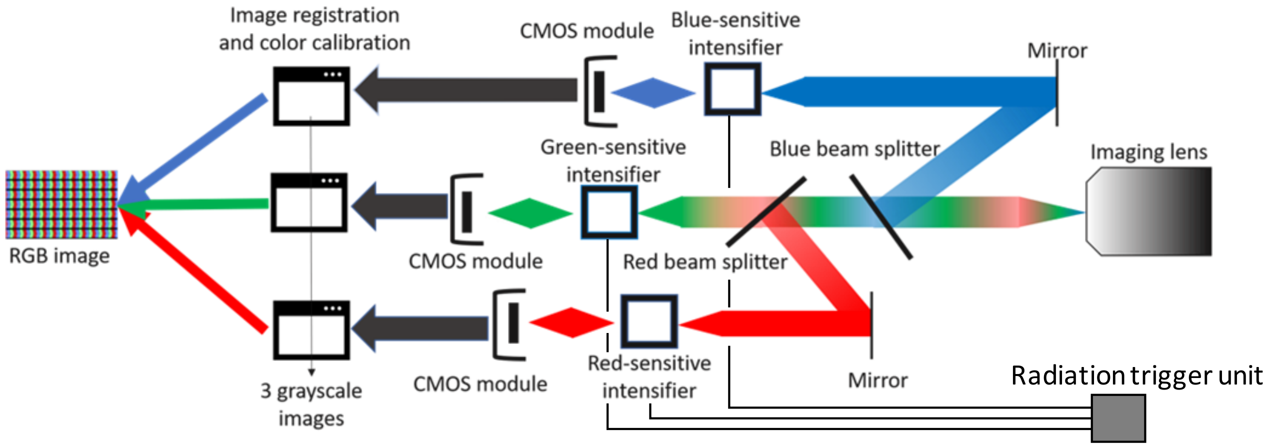


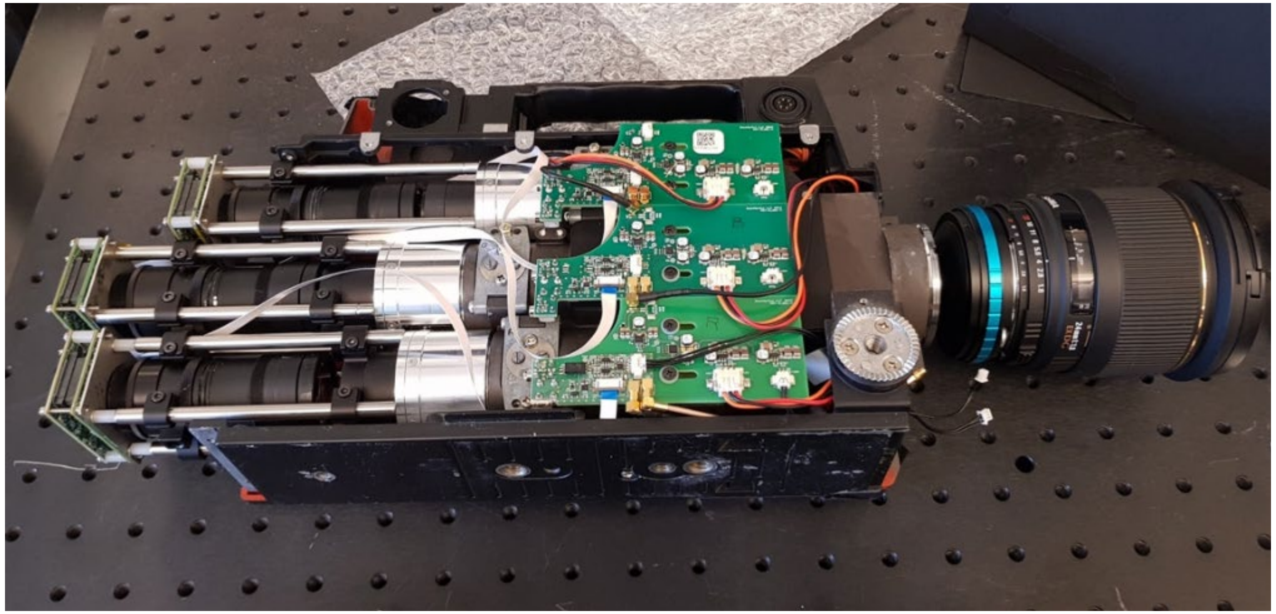
L. A. Jarvis, et al. *IJROBP* 1; 109(5), 2020

Imaging Cherenkov light in color



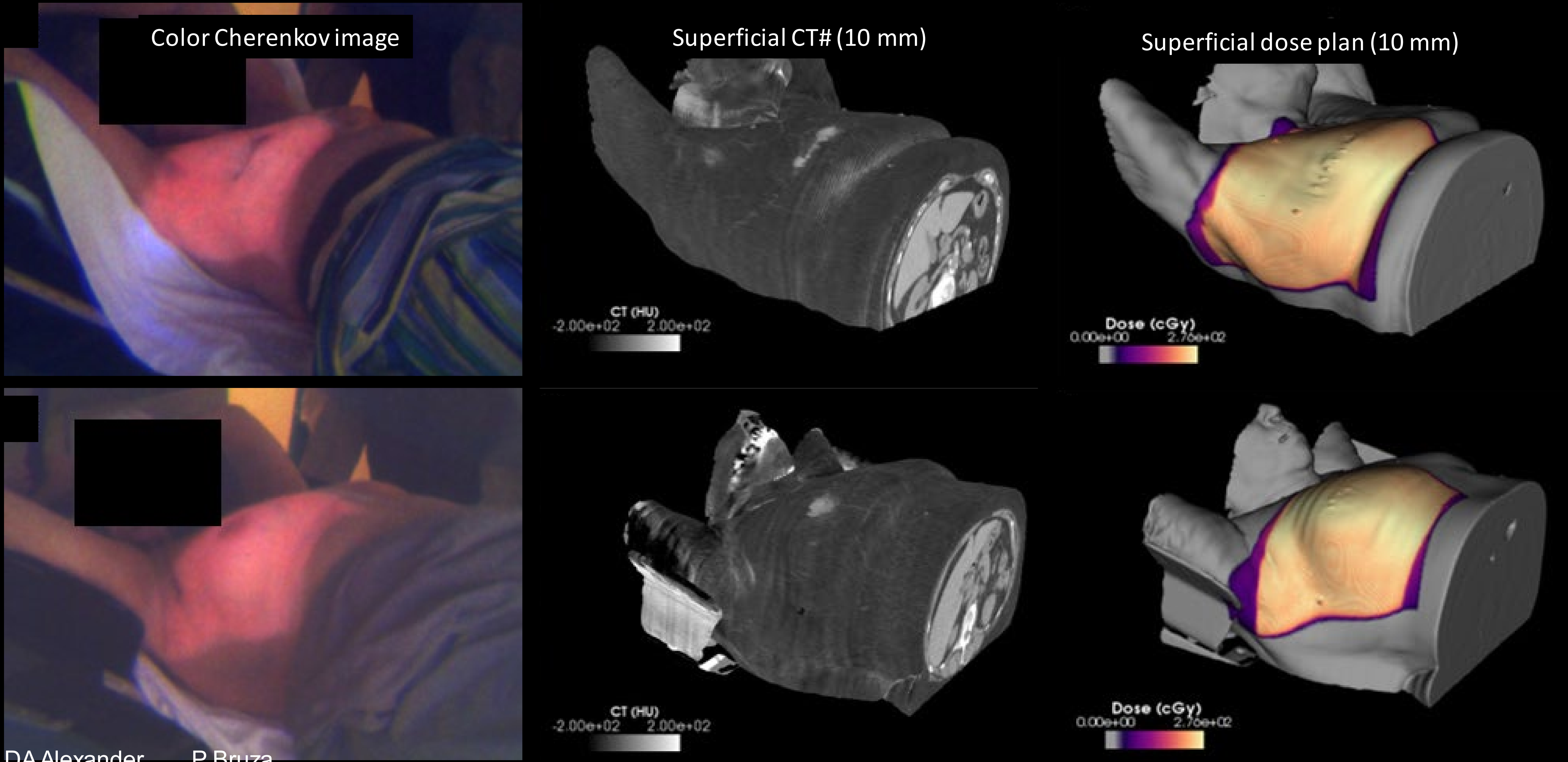






DA Alexander, …, P Bruza.
Color Cherenkov imaging of clinical radiation therapy. Light: Science & Applications 10 (1), 1-7

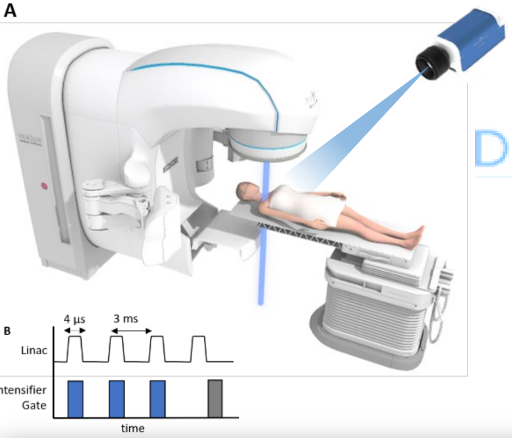
Cherenkov light: How does it really look like?



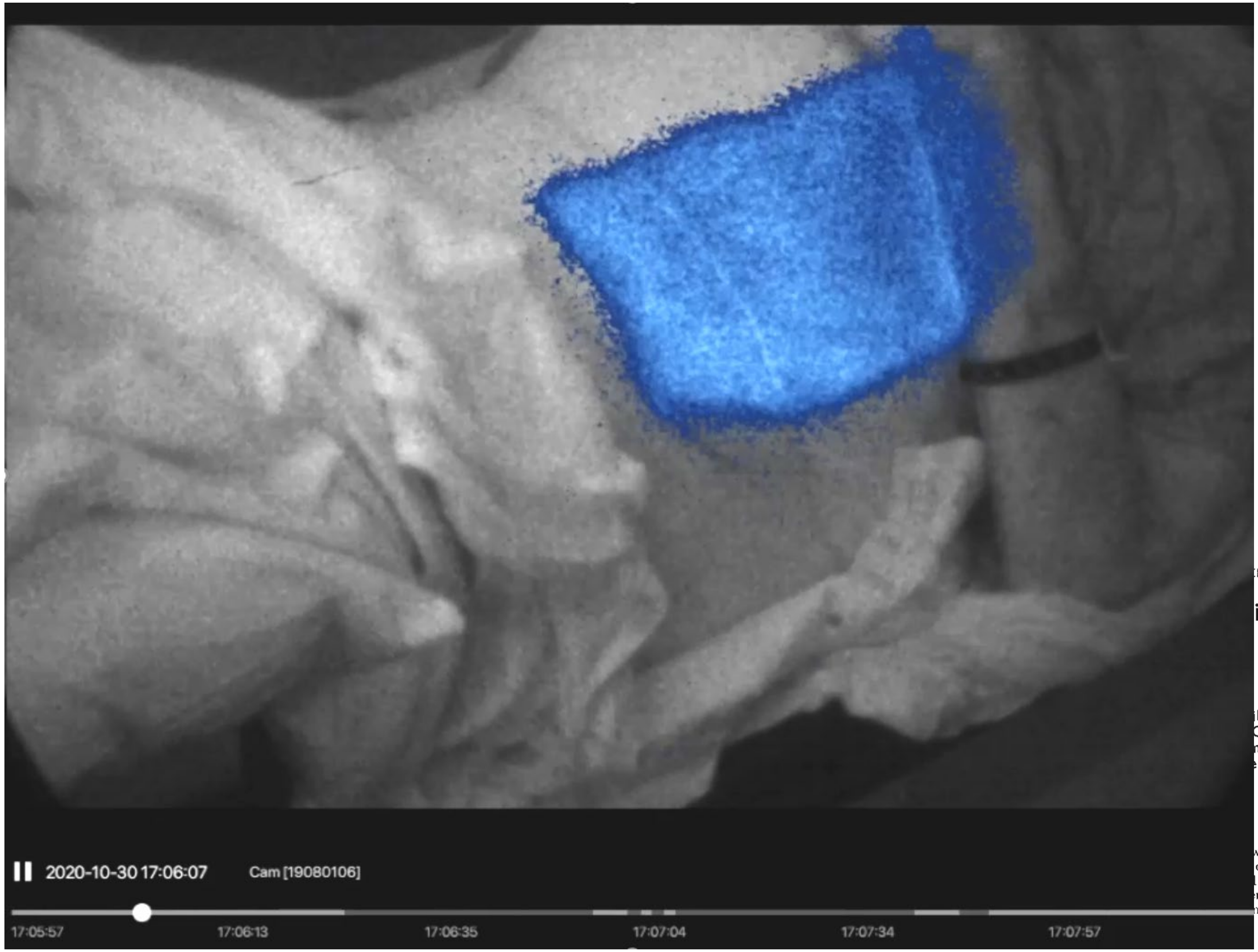
DA Alexander, …, P Bruza.
Color Cherenkov imaging of clinical radiation therapy. Light: Science & Applications 10 (1), 1-7

Successful research & business story: Cherenkov imaging

To prevent mis-treatments and secondary cancer as a result of external beam radiotherapy
Simple, low cost, visual feedback - easy deployment in less advanced RT sites



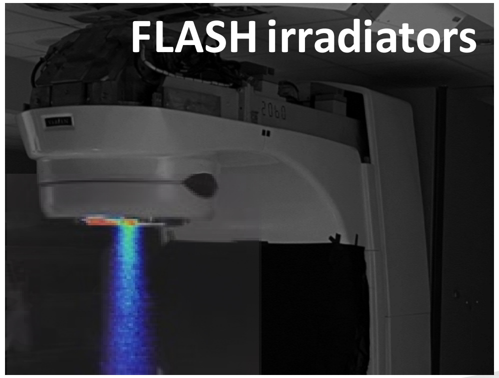
DoseOptics
Visualize radiation therapy

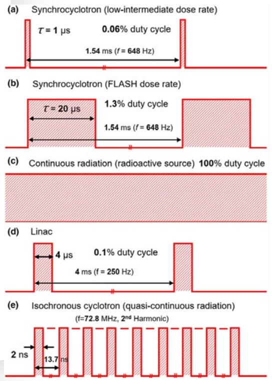


L. A. Jarvis, et al. *IJROBP* 1; 109(5), 2020, Tendler et al. IJROBP 106 (2), 2020

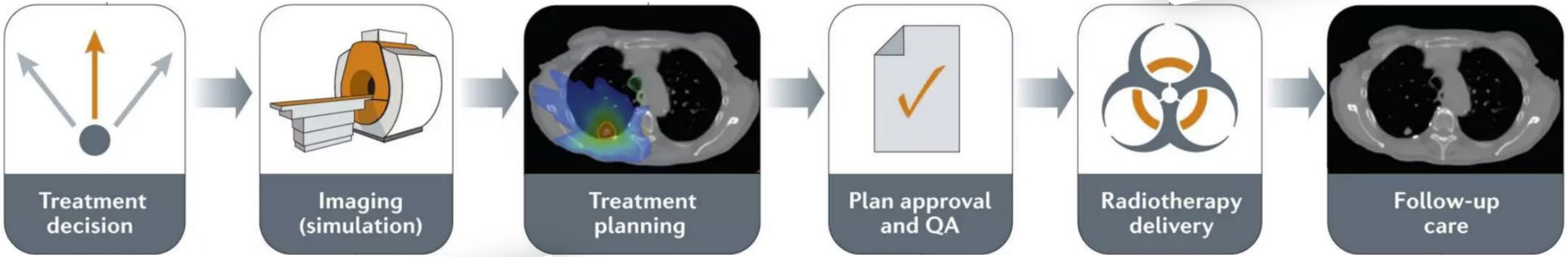
Same technology helps improving accuracy and safety of FLASH radiotherapy

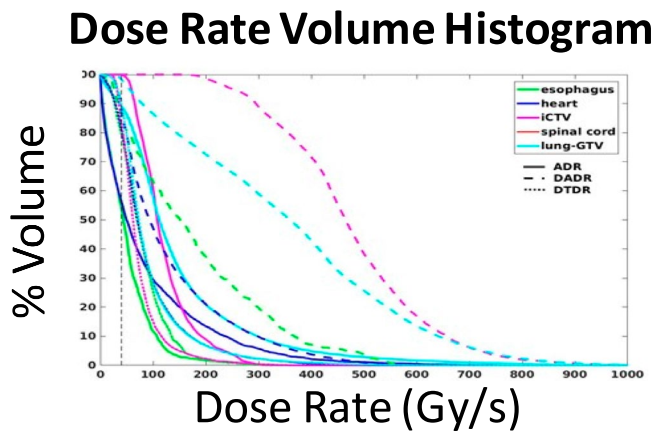
Dose rate paradigm shift:
Conventional: 0.01 Gy/s
FLASH: >40 Gy/s



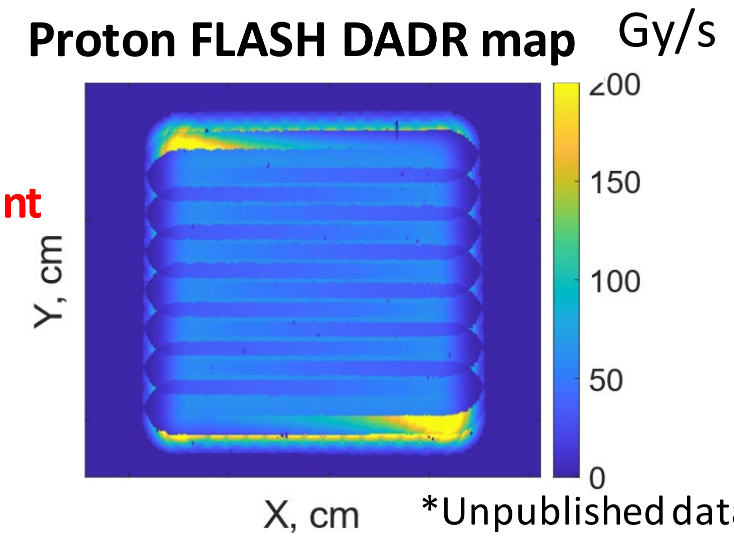


Radiotherapy course:





Example of new treatment quantities to validate: Dose-averaged dose rate

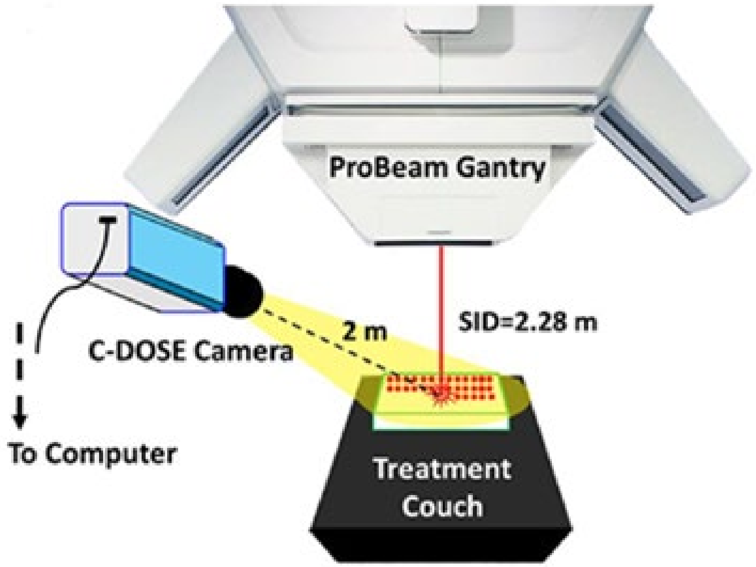


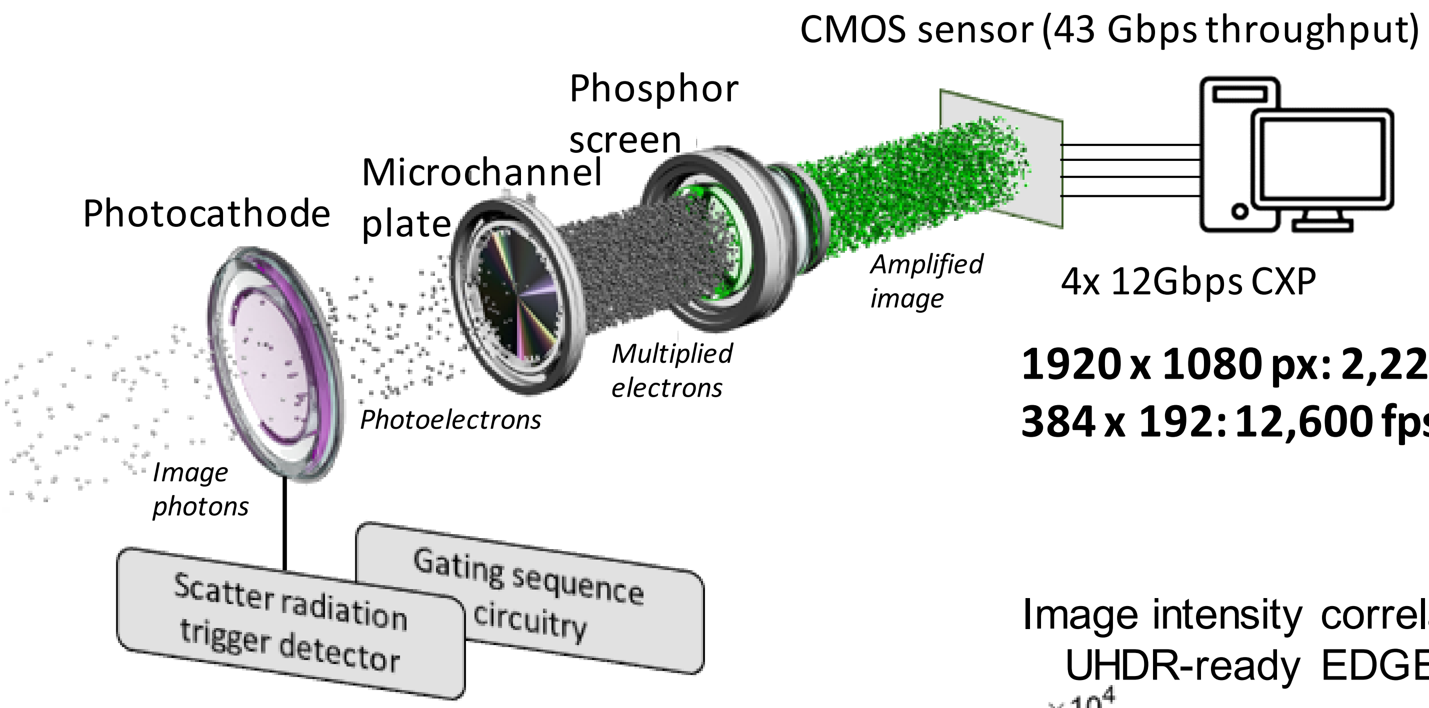
Wei et al. 2021

*Unpublished data

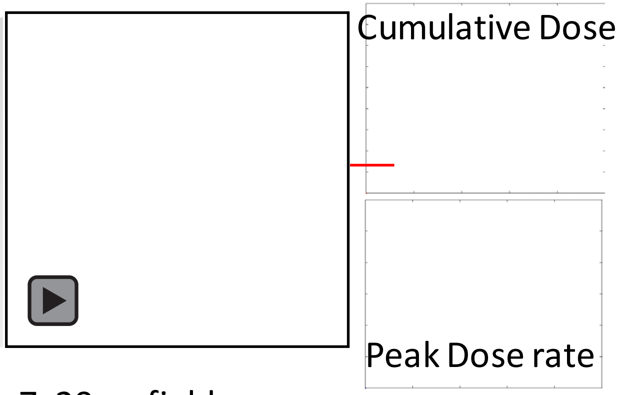
New multi-kHz camera developed for UHDR imaging

SBIR R44CA268466



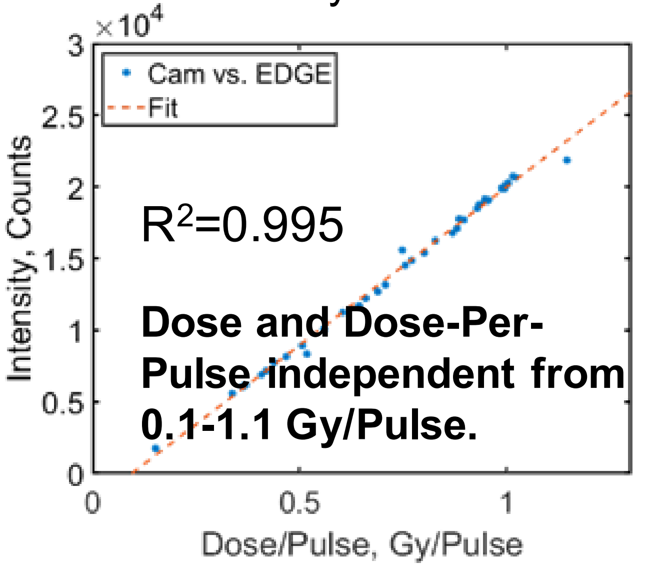


1920 x 1080 px: 2,220 fps
384 x 192: 12,600 fps

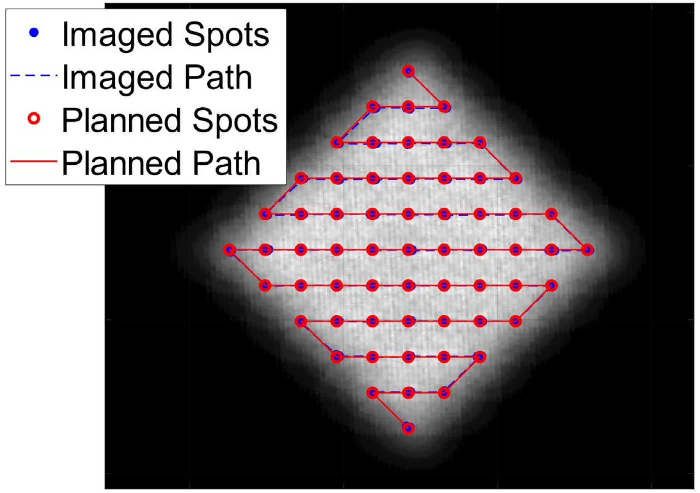


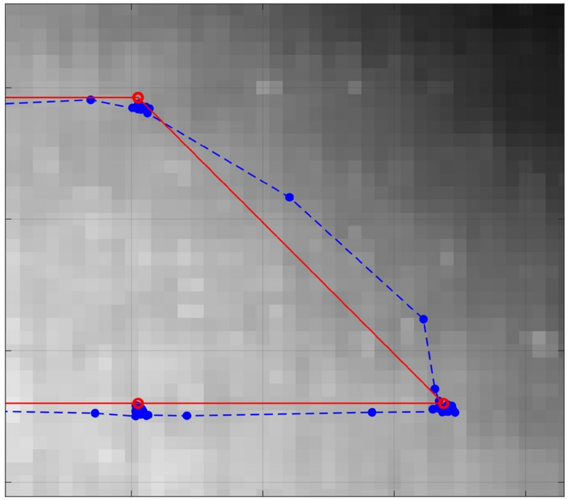
7x20cm field,
250 MeV PBS, 459ms total duration, 4500 fps

Image intensity correlates with UHDR-ready EDGE diode



Capturing beam trajectory and true scanning speeds



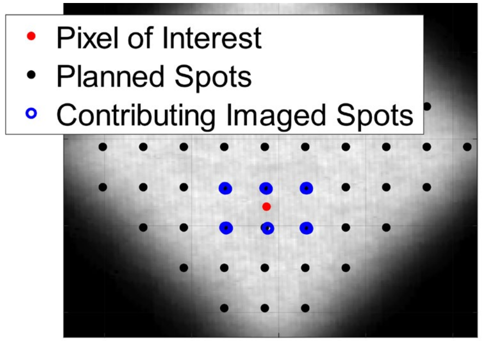


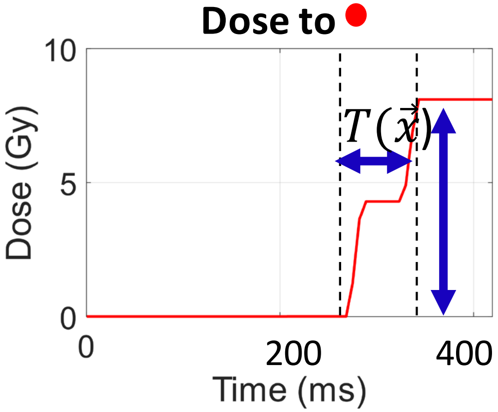
M. Clark, P. Bruza et al. Phys Med Biol 68(4), 2023.

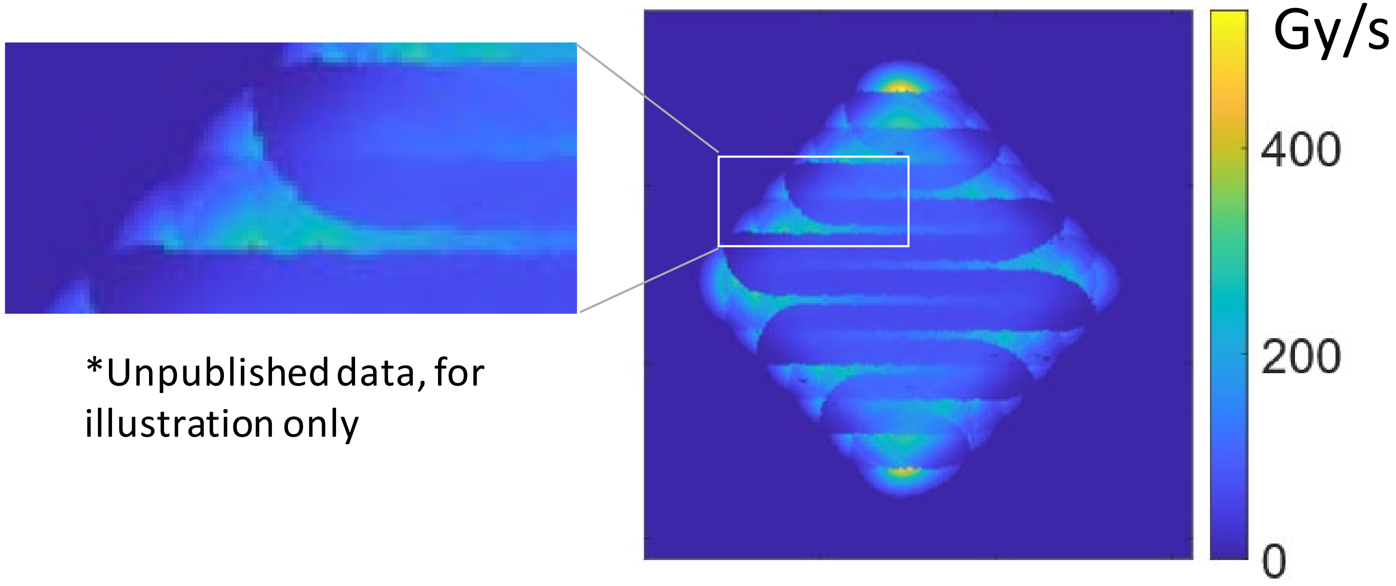
UAB MEDICINE

Proton International

Imaging dose-averaged dose rate maps (4.5-12 kHz, 0.2 mm, ~10 x 20 cm FOV)





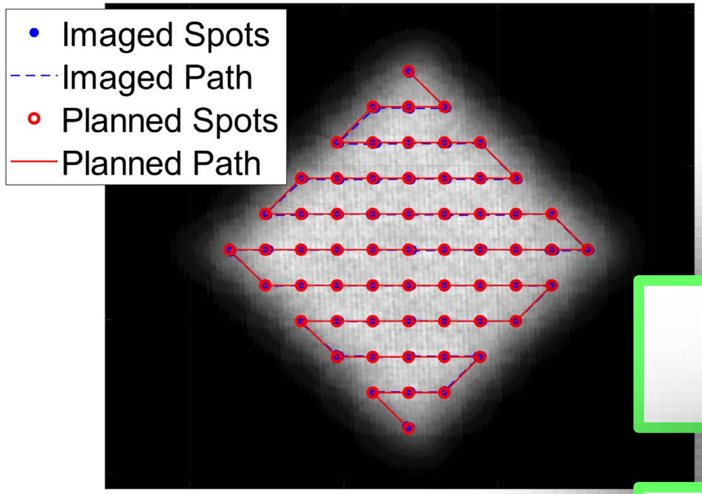


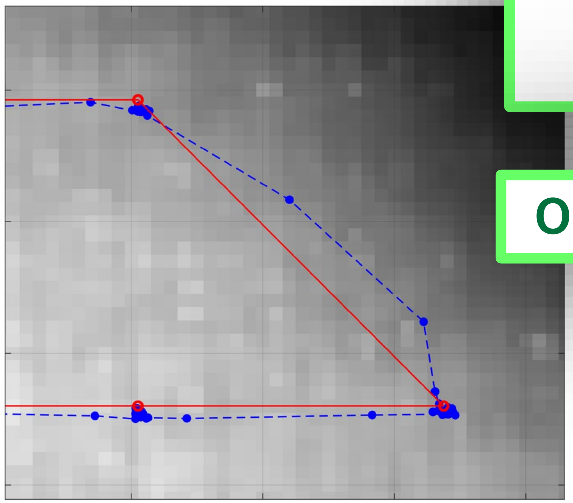
*Unpublished data, for illustration only

Validated 215 nA UHDR beams used in recent FLASH clinical trial, stay tuned for results

Cincinnati Children's changing the outcome together | UC Health | Beaumont

Capturing beam trajectory and true scanning speeds





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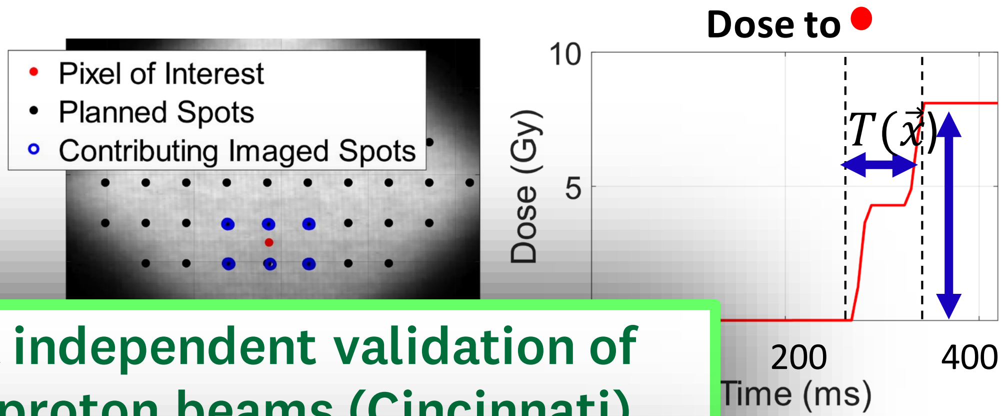
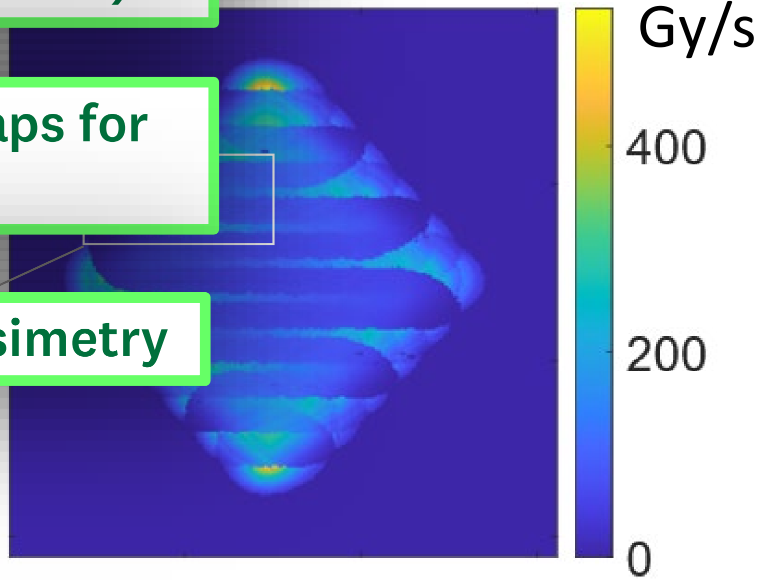


Just performed first independent validation of FLASH clinical trial proton beams (Cincinnati)

Measuring scanning speeds and DADR maps for dose rate optimization in TPS

Open geometry allows seamless *in vivo* dosimetry

illustration only



Validated 215 nA UHDR beams used in recent FLASH clinical trial, stay tuned for results

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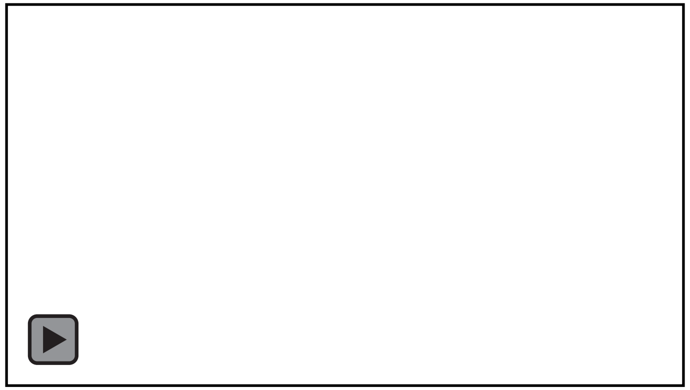
Cincinnati Children's
changing the outcome together

UC Health

Beaumont

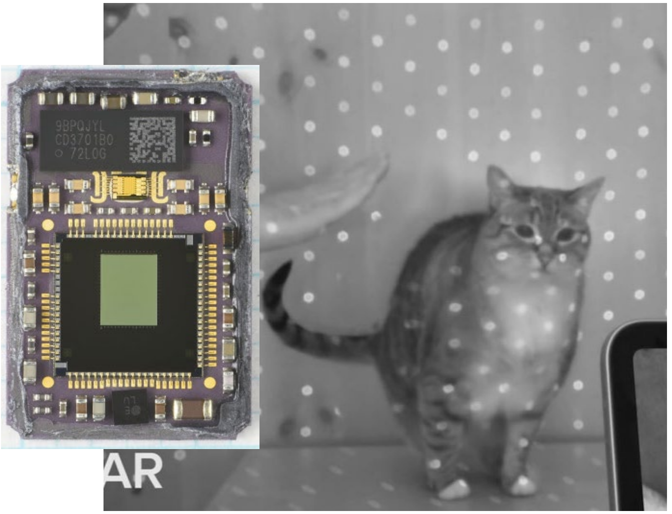
- **We use intensifers: High-speed imaging needs single- or few photon detection capability**
- **Intensified cameras are proven but have disadvantages (damage threshold, mfg scalability..)**

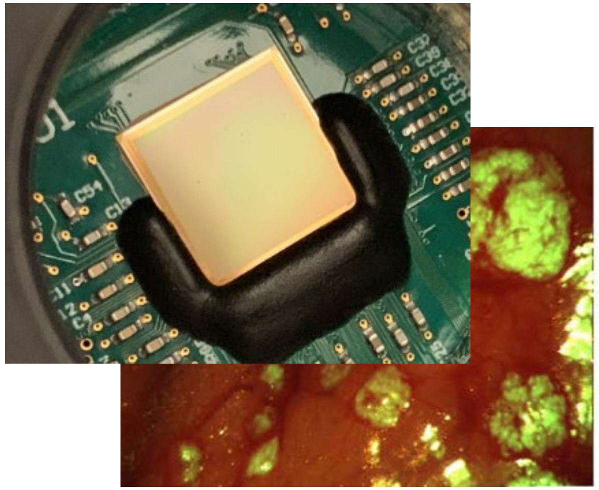
Alan Bean looking at sun with an intensified camera during Apollo 12 mission (1969)

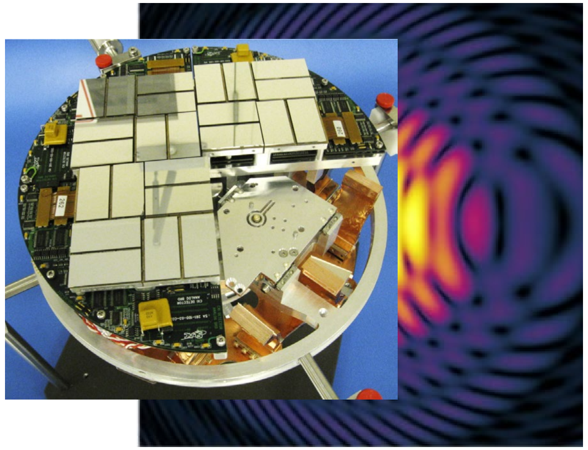


- **Semiconductor high-performance sensors (SPADs, QIS) to replace ~century-old intensifier concepts**

$	**unobtainium**	$$$
qty > 1000	100 > qty > 1	qty < 10





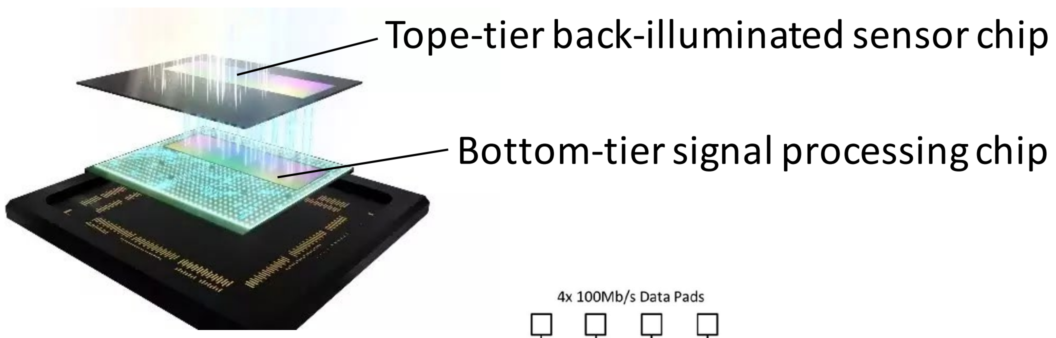


P. Hart *et al.*, *2012 IEEE NSS/MIC*, 2012.

- **Message #1: Accelerate technology transfer of an 1-ph sensitive, ps-ns gated, 10^{3-5} kfps sensor for optical medical imaging…**

Heinz Graafsma: "*You cannot develop the ultimate detector for every application*"

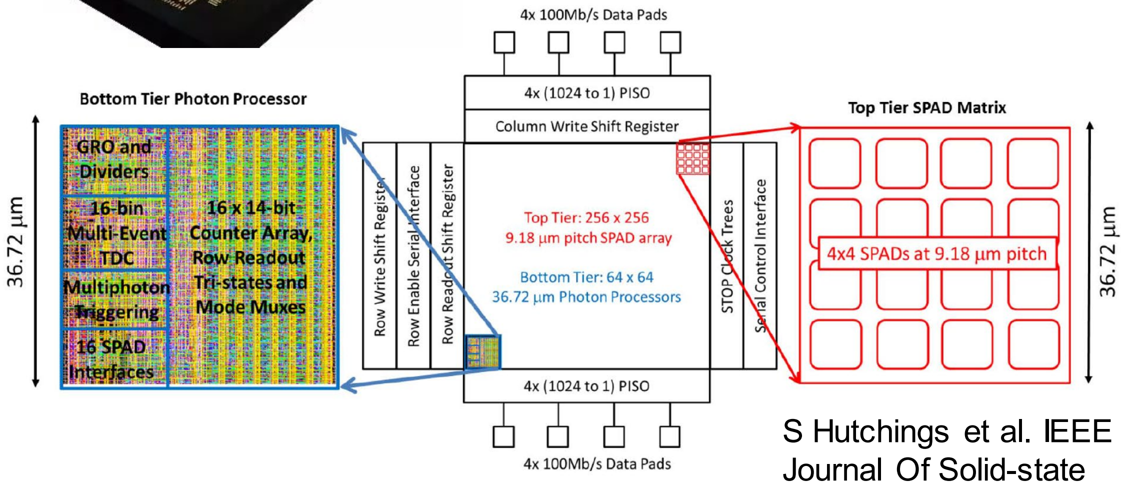
… we'd be fine with a good enough one that will replace intensifiers



- **3D stacked optical SPADs/QIS are the future ---->**

- **Similar approach as CERN -> Medipix?**

- **Optical detectors and applications as one of the focus areas of the NIH/DOE dialogue**



S Hutchings et al. IEEE Journal Of Solid-state Circuits 54(11), 2019

- **Flexibility of in-pixel signal processing**
- **Good competitor to iCMOS in terms of photon detection efficiency**
- **~10-100 kfps readouts**

.. for safer radiotherapy, better diagnostics & surgeries.

- **Message #2: Combining cutting edge technology with immediate clinical translation is a big plus for NIH science**

*Certainly with existing, proven technology backup

- **This can incredibly broaden the impact**

2014

2023

Exploring basic concepts Of Cherenkov imaging

R01 EB023909

Scintillation dosimetry

R43 CA268466

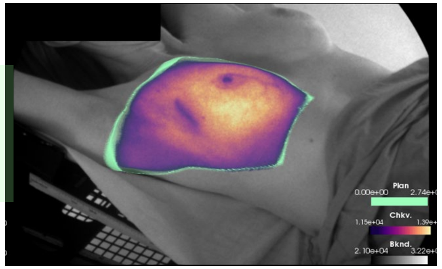
Commercialization, validating clinical beams

R44 CA268466

Real-Time Cherenkov camera

R44 CA265654

Commercialization, clinical studies



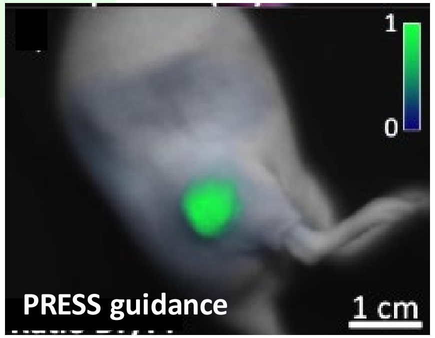
Imaging FLASH beams

R43 CA268466

validating beams in **clinical trials**

Tumor visualization to minimize residual tumor **during surgery**

R01 submitted



Dosimetry & Oxygen sensing in pre-clinical studies of FLASH

U01 CA260446

Electron **FLASH clinical trial**

R01 submitted

Acknowledgement

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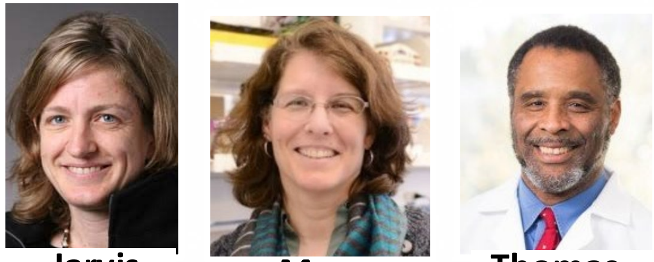
Clinical Oncology & IRB support



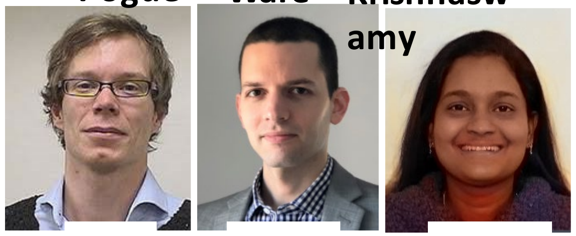
Jarvis   Mansur   Thomas

Clinical Physicists

Gladstone   Zhang   Williams

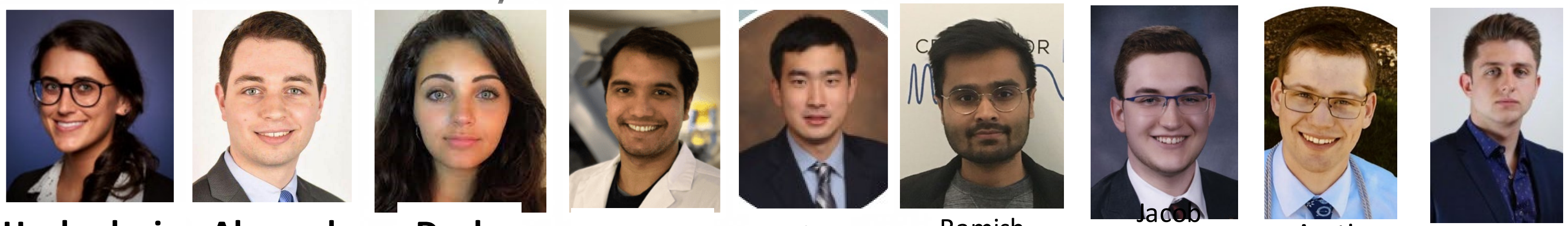
DoseOptics

Brian Pogue   Bill Ware   Venkat Krishnaswamy



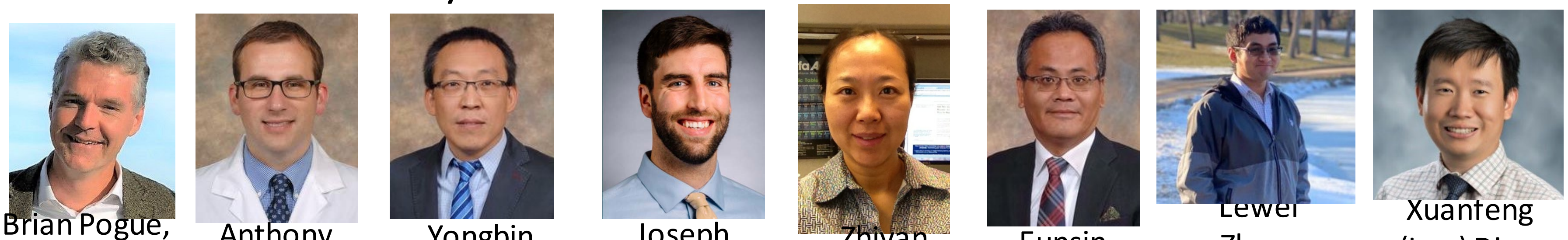
Petr Bruza   Mike Jermyn   Farzeen Christie   Srikanth Majji

Medical Physics PhD Students incl. alumni



Hachadorian   Alexander   Decker   Rahman   Miao   Ramish Ashraf, PhD   Jacob Sunnerberg   Austin Sloop   Roman Vasyltsiv

Faculty + External Collaborators



Brian Pogue, PhD   Anthony Mascia, PhD   Yongbin Zhang, MS   Joseph Harms, PhD   Zhiyan Xiao, PhD   Eunsin Lee, PhD   Lewei Zhao, PhD   Xuanfeng (Leo) Ding, PhD

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U01 CA260446
R44 CA268466
R44 CA265654

Dartmouth Engineering Thayer School 1867   Dartmouth Health   UAB Medicine Proton International   Cincinnati Children's changing the outcome together   UC Health   Beaumont

Thank you for your attention!