TRIUMF

Detectors for Life Science Applications

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Research Scientists | Life Sciences

Science Week, 17 - 21 Aug 2020

Discovery, accelerated

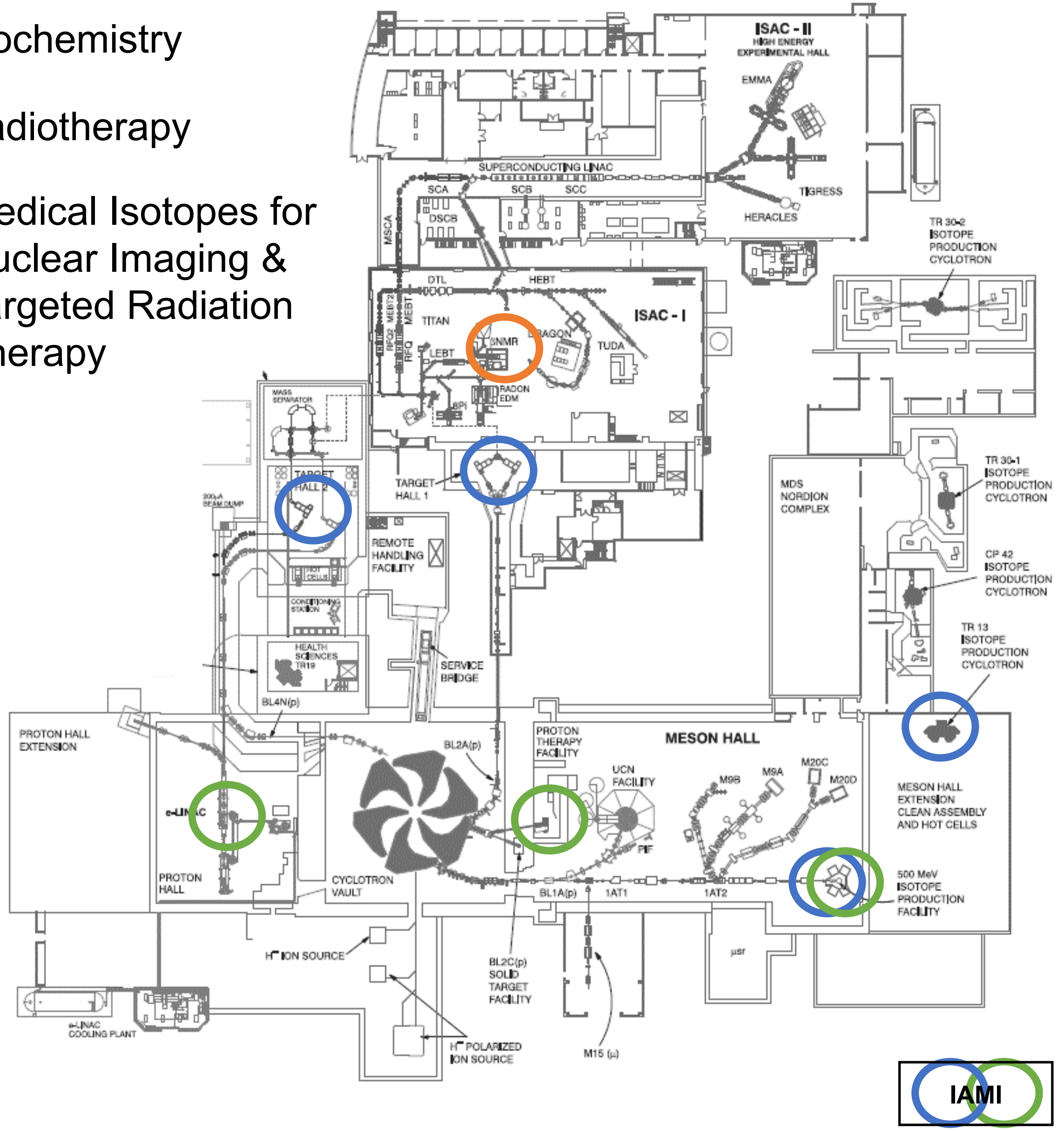
Life Science applications @ TRIUMF

- 50% of all Canadians will suffer from cancer in their lifetime and 25% will succumb to the disease
- **Goal: improve cancer care**
- TRIUMF long history of radiotherapy (pions and protons) and medical isotopes
- All TRIUMF accelerators utilized for medical applications
- Atomic and nuclear techniques used – need for appropriate detector solutions

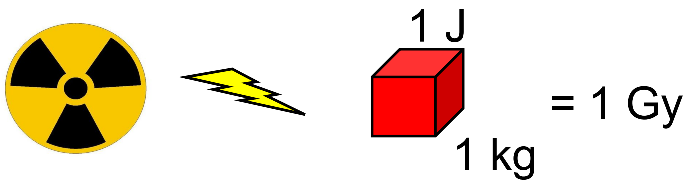
— Biochemistry

— Radiotherapy

— Medical Isotopes for Nuclear Imaging & Targeted Radiation Therapy



Radiotherapy



Dosimetry - The measurement, calculation and assessment of the ionizing radiation dose absorbed by the human body. At TRIUMF, from photon, proton and neutron beams.

Ideal dosimeter should be:

- Linear with dose
- Linear with dose rate
- Good spatial resolution
- Non-toxic for in vivo measurements
- Independent from external influences (magnetic field, light, temperature, pressure, water-tight)
- Tissue equivalent
- Energy independent
- Real time
- Measure physical and biological dose – distinguish between different particles

Typical dosimeters:

- Ionization chambers

- TLDs (Thermoluminescent detectors)

- OSLDs (Optically-stimulated luminiscent detectors)

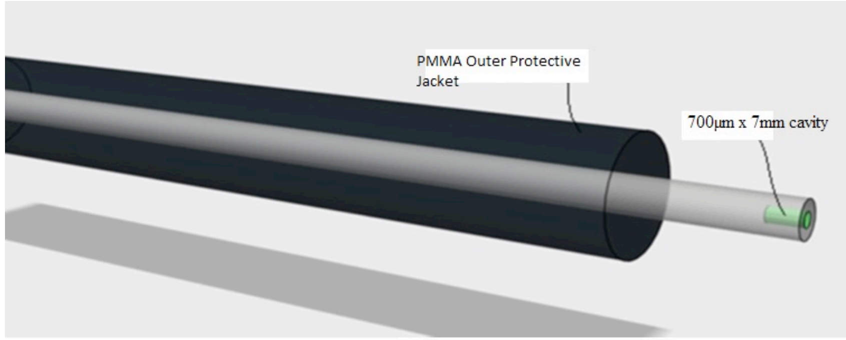
- Films

- MOSFETs (metal-oxide-semiconductor field-effect transistor)

- Diodes

→ **None fulfills all criteria**

Different Sensors – organic fiber with scintillator & doped inorganic fibers



Organic fiber with different scintillators (with University of Limerick – **Prof. S. O'Keeffe, Ireland**)

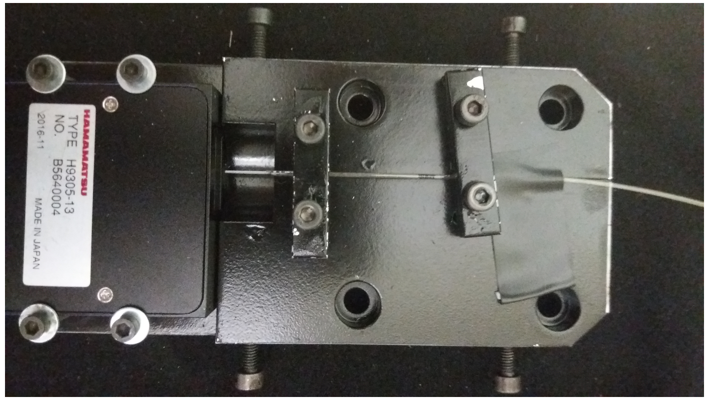
- Around 0.5 mm diameter and 1 mm length
- $C_5H_8O_3$ (PMMA) fiber
- Water equivalent

Scintillator examples:

- Gd_2O_2S:Tb
- Gd_2O_2S:Eu
- Y_2O_2S:Eu
- Y_2O_3:Eu
- YVO_4:Eu

Inorganic, sol-gel silica fibers doped with different materials (with University of St Etienne – **Prof. S. Girard** and collaborators, France)

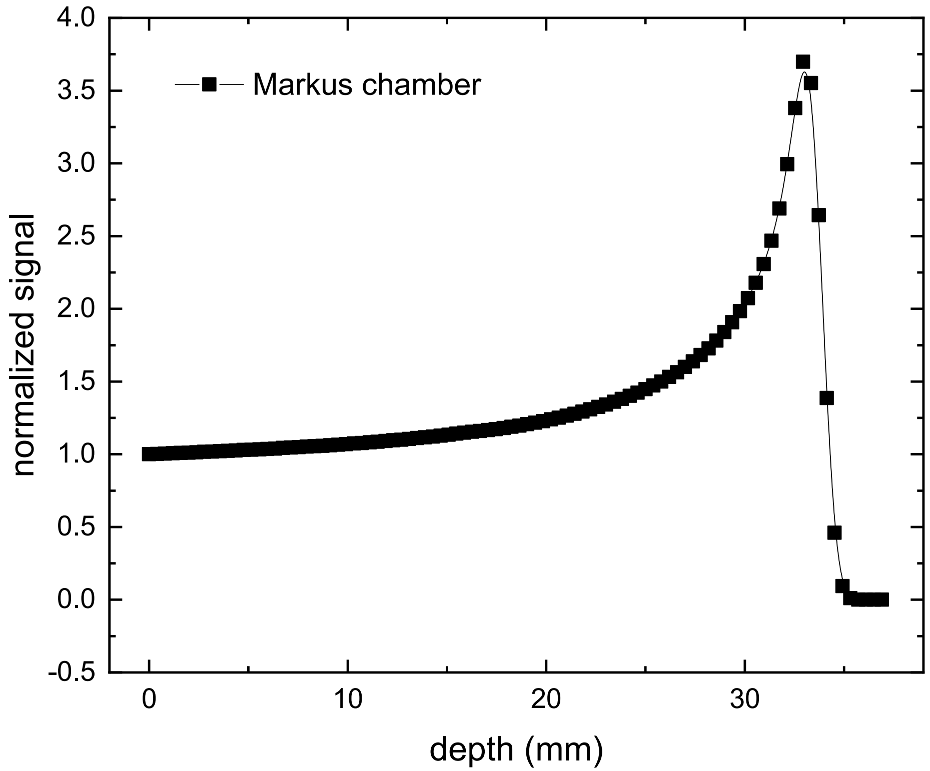
- Different diameters: 5 – 700 µm
- Doped silica (Cu, Ce, Gd, N)
- Radiation hard

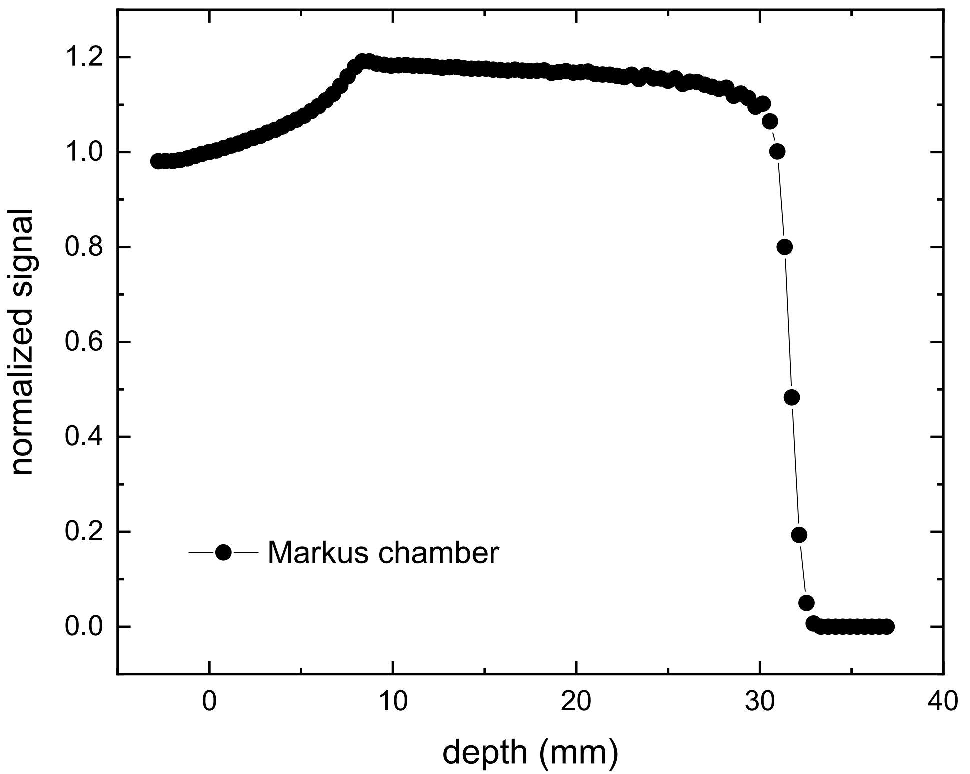


All fibers tested with X rays (BC Cancer), protons (PIF) and neutrons (TNF):

- Linear in dose and dose rate
- Measure beam signal in real time
- Spatial resolution only limited by size
- Need to be shielded from ambient light

Energy Dependence – proton beam

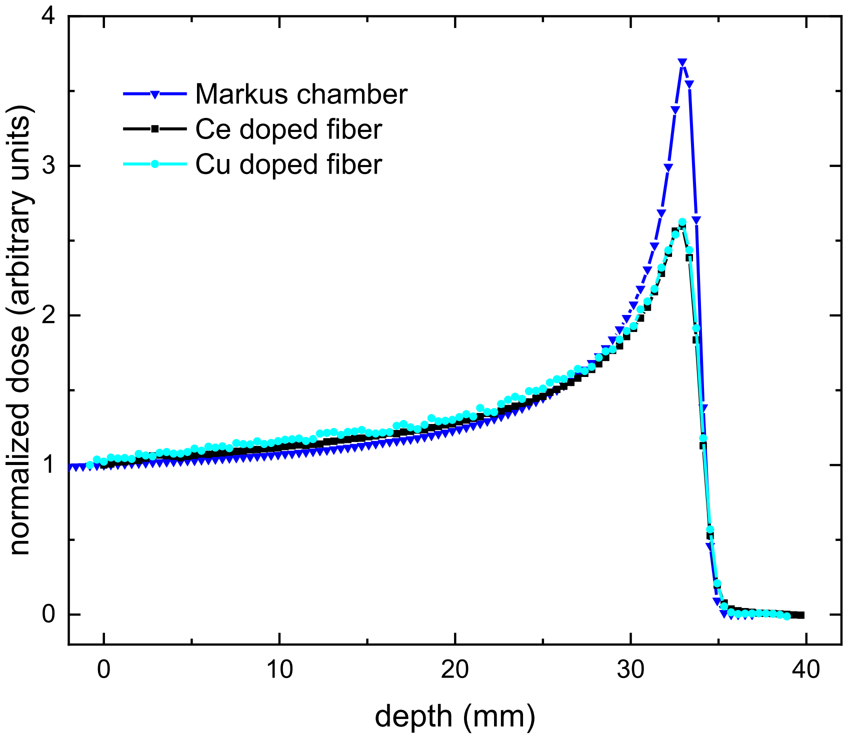


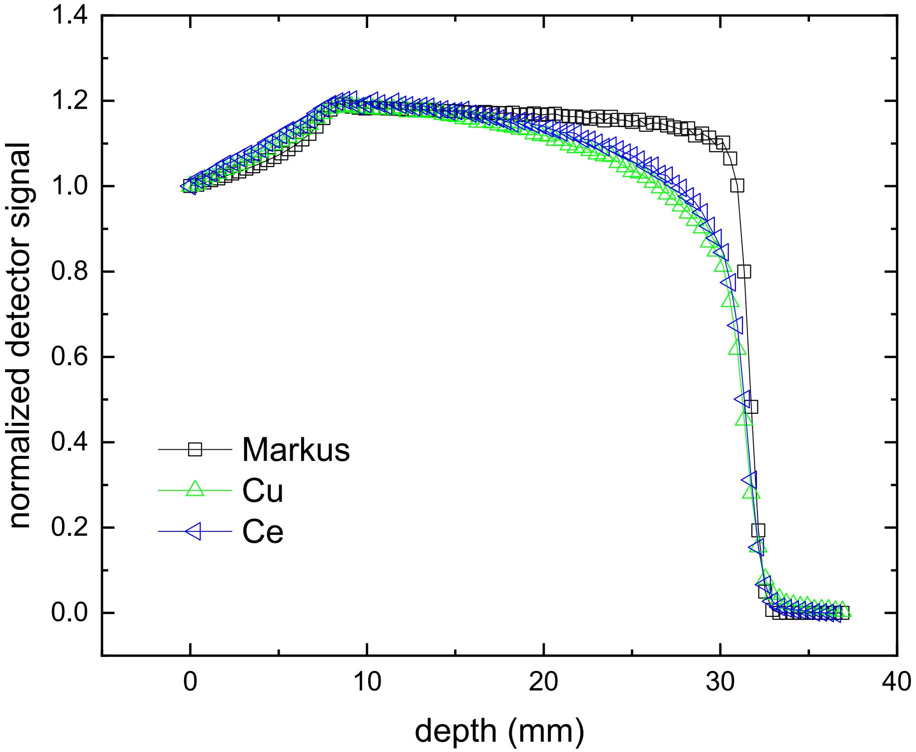


- Raw Bragg peak and Spread-out Bragg Peak (SOBP) at PIF (Proton Irradiation Facility) on 2C1.
- Markus chamber is gold standard for proton therapy dosimetry.
- Peak to entrance ratio: 3.7

Nature: Scientific Reports, 9 17599 (2019)

Energy Dependence





- Markus: 3.7
- Cu-doped silica fiber: 2.6
- Ce-doped silica fiber: 2.6

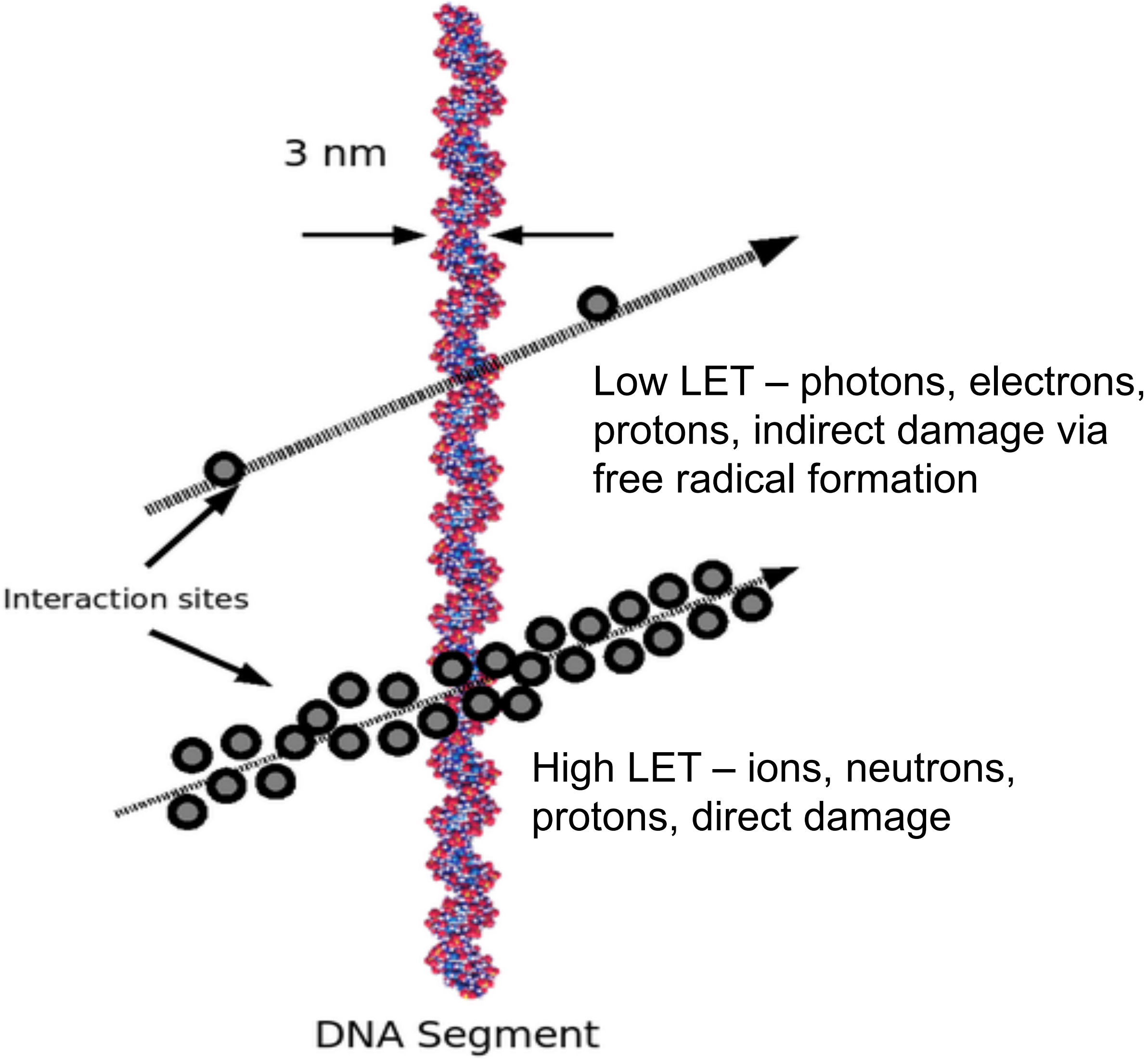
All organic fibers behaved similarly.

IEEE Transactions on Nuclear Science, 64 567 (2017)

Quenching

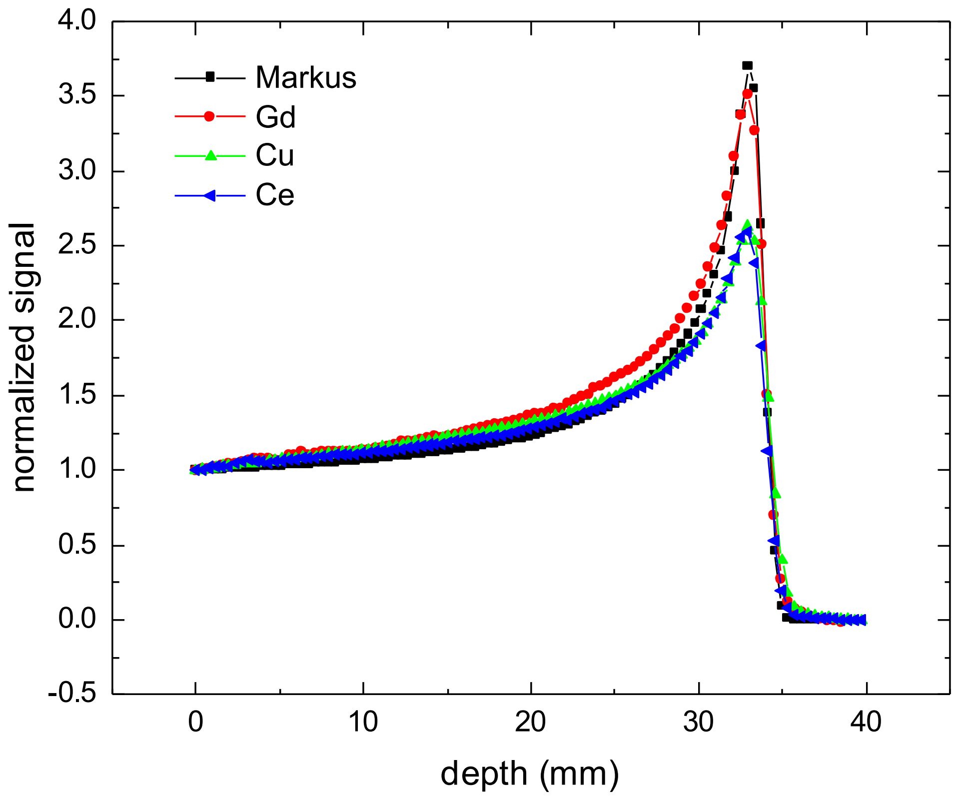
$$\frac{dL}{dx} = \frac{S\frac{dE}{dx}}{1 + k_B\frac{dE}{dx} + C\left(\frac{dE}{dx}\right)^2}$$

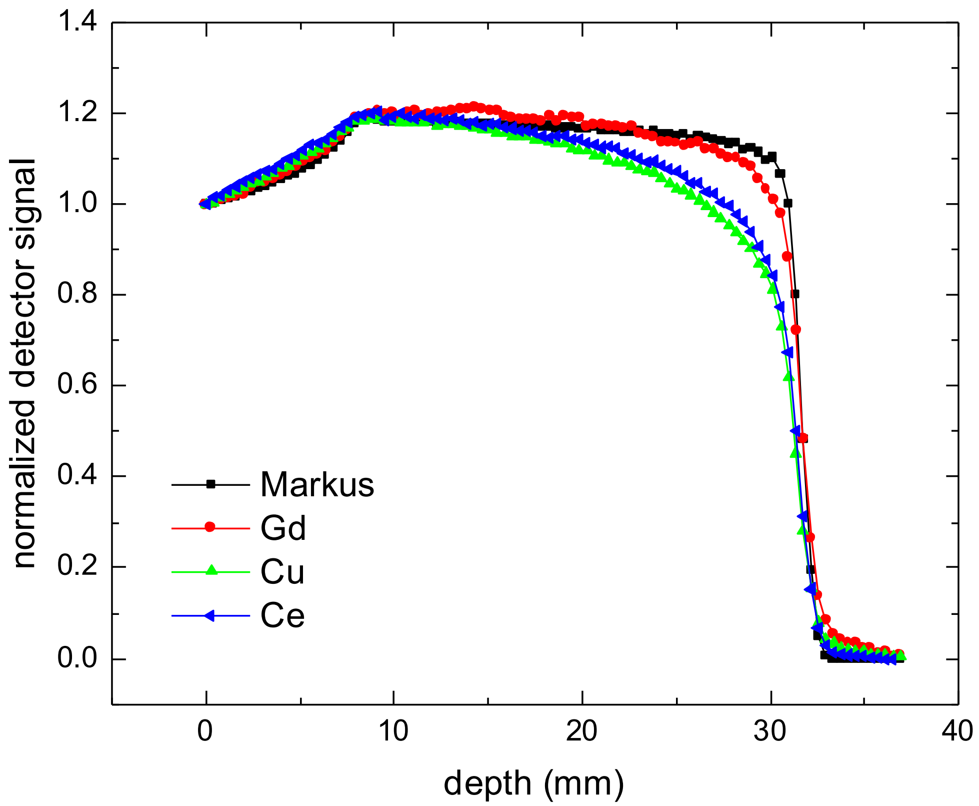
- Empirical Craun-Birks equation
- Correction of quenching
- Not practical for Proton Therapy!



Physics in Medicine and Biology, 63 095016 (2018)

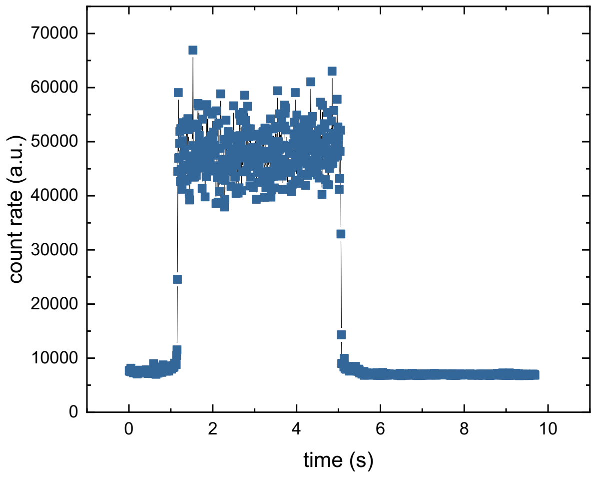
Energy Dependence



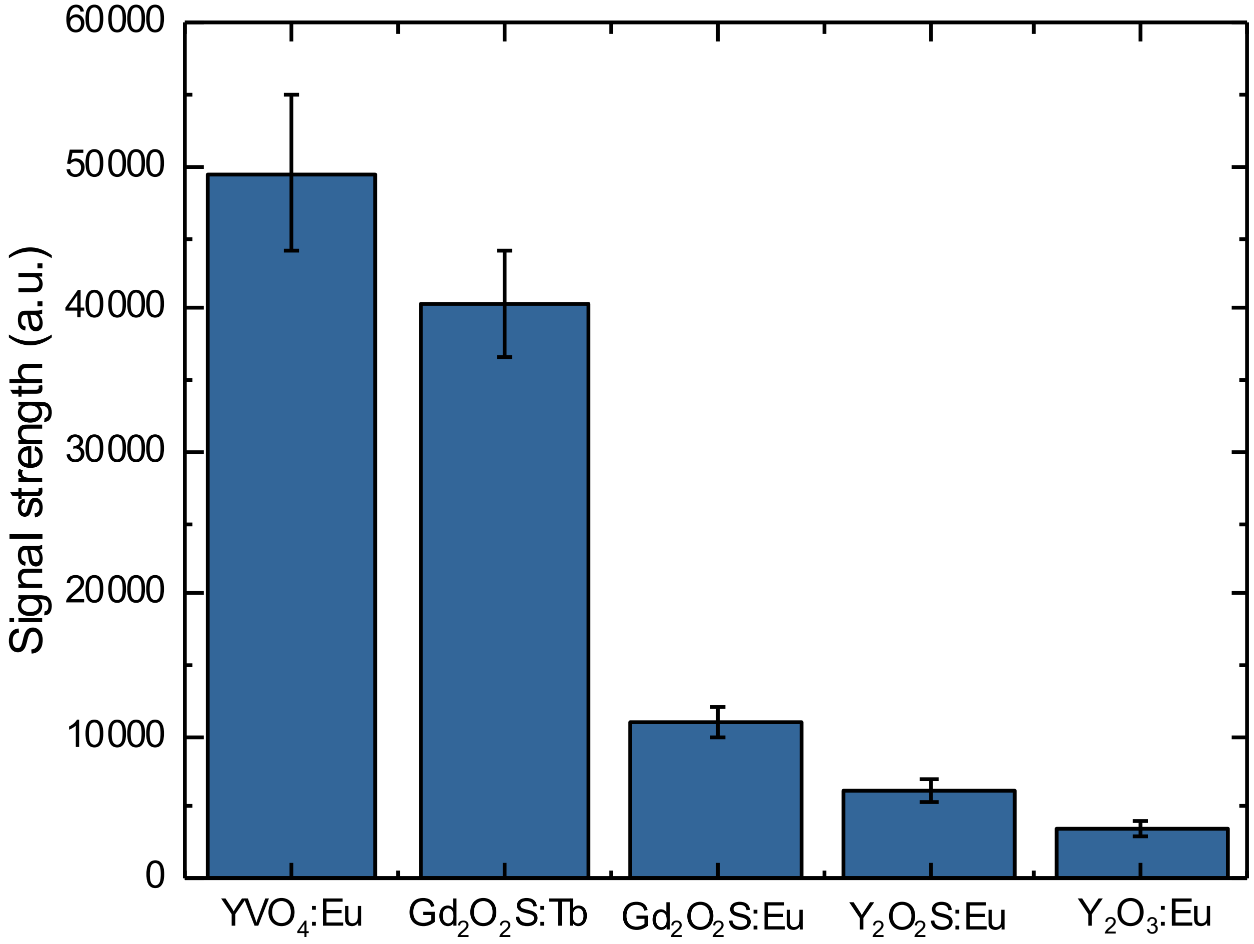


- Markus: 3.7
- **Gd doped fiber: 3.5!**

Neutron beam



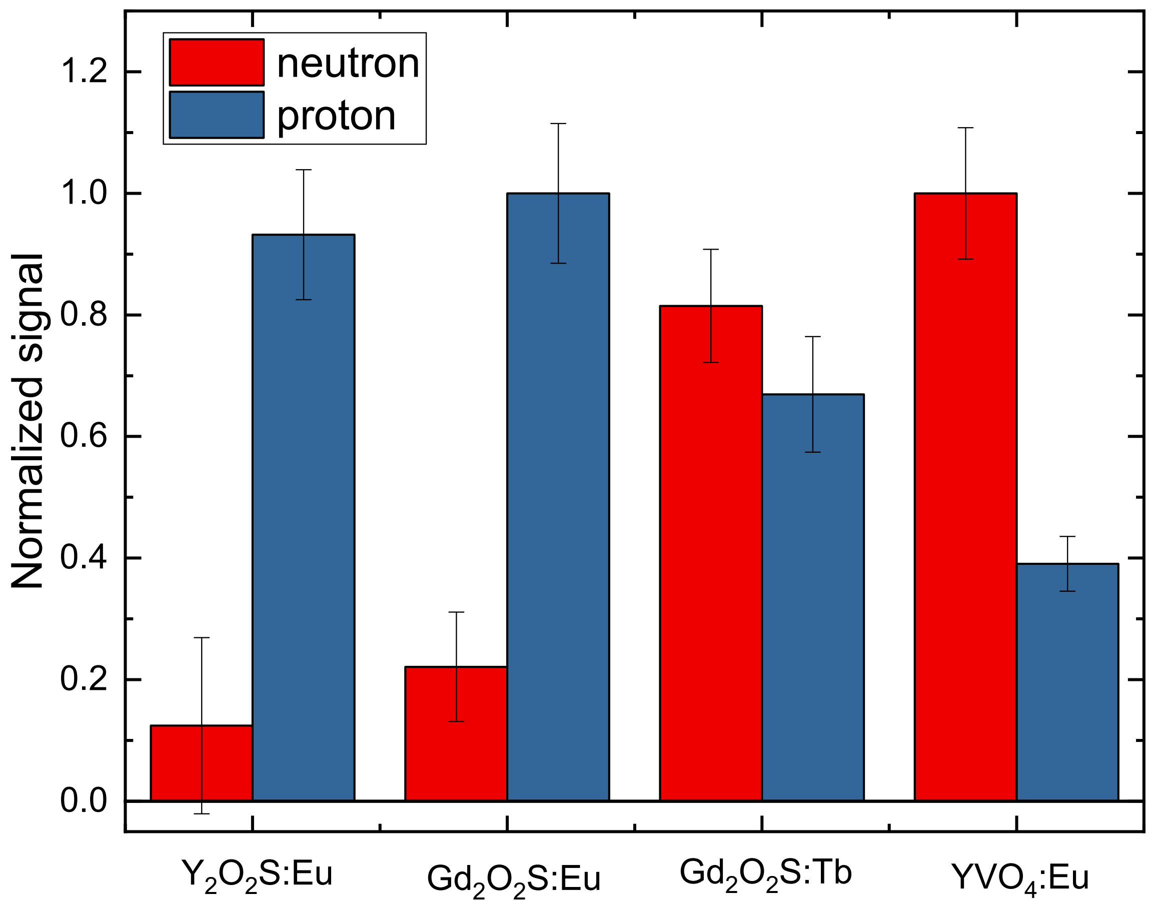
- Neutron beam at TNF (TRIUMF Neutron Facility) at the end of beam line 1A
- Different scintillators have different response



Particle Sensitivity – biological dose

- Hadron therapy always produces secondary neutrons – with different biological effectiveness for same physical dose

- Scintillators show different response due to neutrons v. protons
- Combination could be used for particle determination
- Biological dose measurement

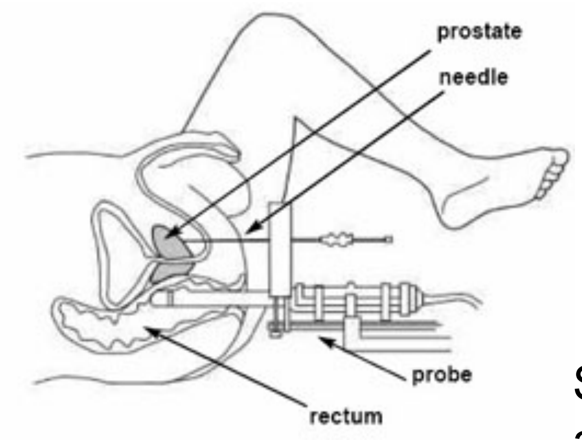


Medical Physics 46 (2019)

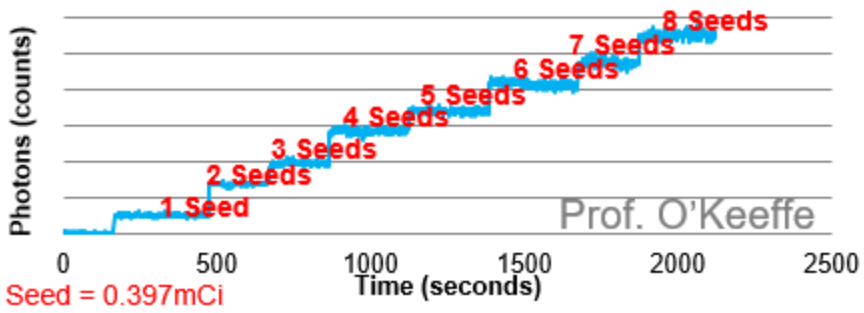
IEEE Transactions on Optical Sensors, 18 1513 (2017)

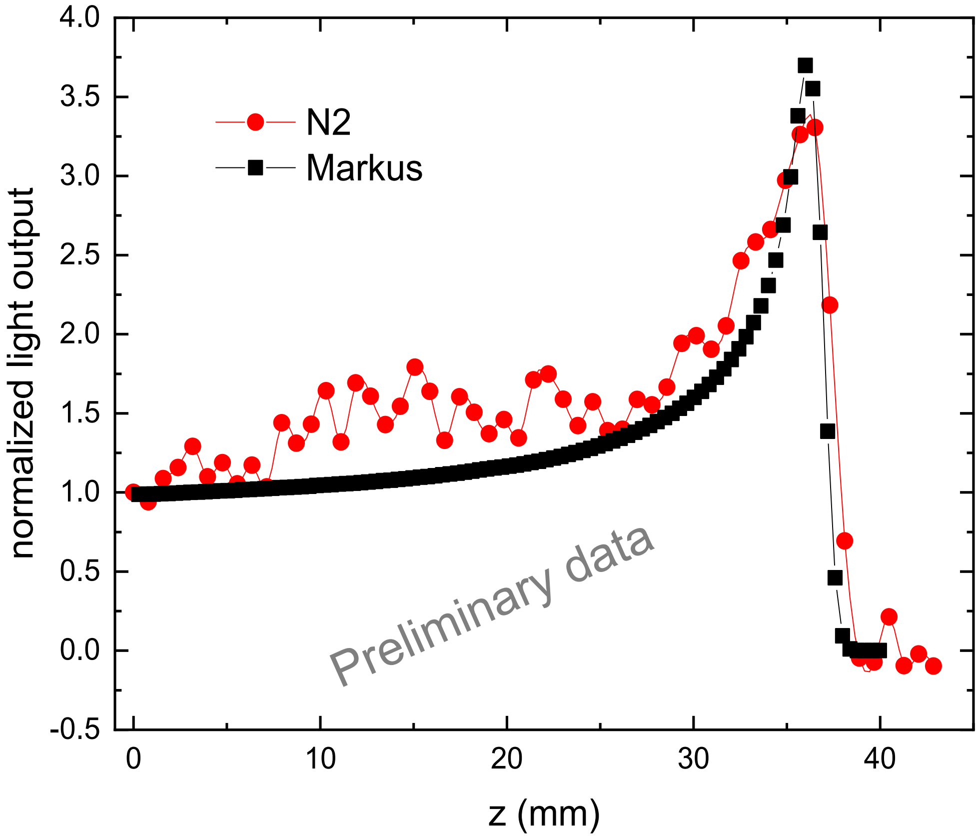
Spatial resolution – in-vivo dosimetry

Prostate cancer treatment with ^{131}I seeds.
Monitor seed placement with optical fiber inserted instead of one seed.



Sensor very large and invasive





5 um thin N-doped silica fiber able to resolve Bragg peak

Medical Physics 46 (2019)

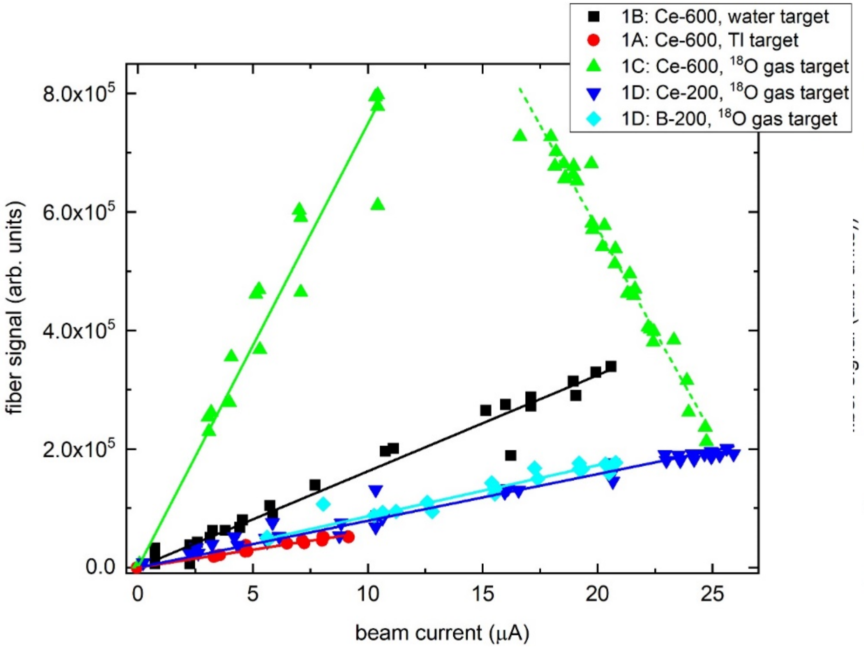
Medical Isotopes for Nuclear Imaging & Targeted Radiation Therapy

- Medical isotopes produced in solid, liquid or gaseous targets
  - TR13 cyclotron: ^{11}C, ^{13}N, ^{18}F, ^{44}Sc, ^{45}Ti, $^{52,54}Mn$, ^{55}Co, $^{64,67}Cu$, ^{68}Ga, ^{86}Y, ^{89}Zr, ^{94}Tc, ^{119}Sb, ^{197}Hg, ^{203}Pb
  - ISAC: ^{155}Tb, ^{165}Er, ^{211}At, ^{225}Ac
  - IPF (Isotope Production Facility at 1A): ^{212}Pb, ^{213}Bi, ^{225}Ac
- Extreme environment with high radiation field, high temperature, potentially high pressure
- Pressure and temperature important observables for target integrity to avoid escape of potentially highly radioactive and costly material – difficult to measure
- Need small and radiation hard detector → inorganic optical fibers

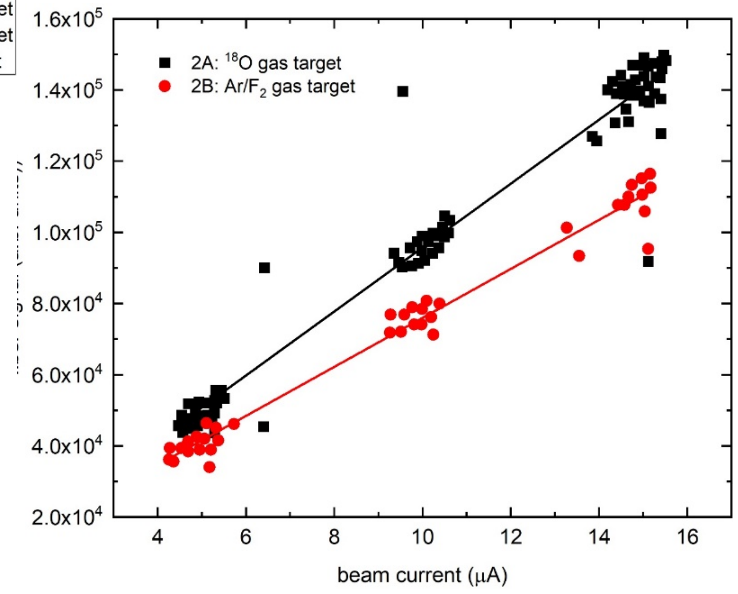
Nuclear Physics News, 30 28 (2020)

Proton beam and target monitoring

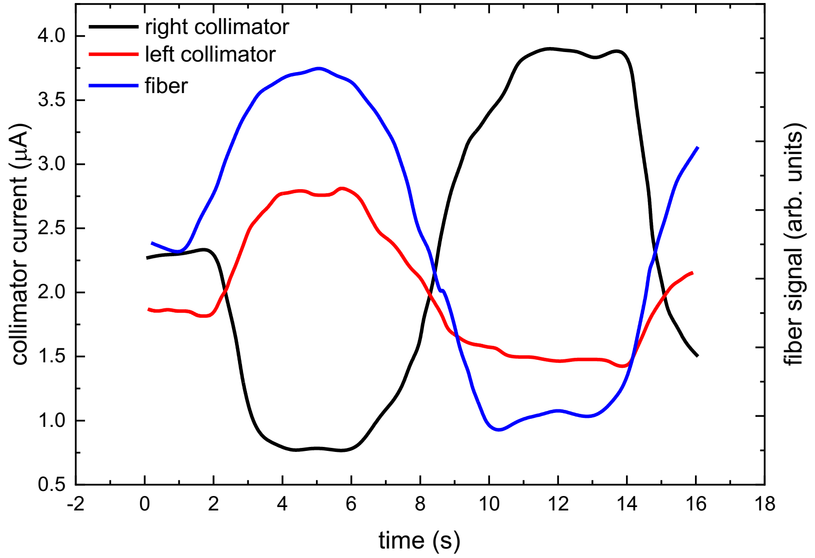
Solution: Surround target with fibers to measure secondary particles (here: gas targets at TR13 cyclotron)



Beam intensity



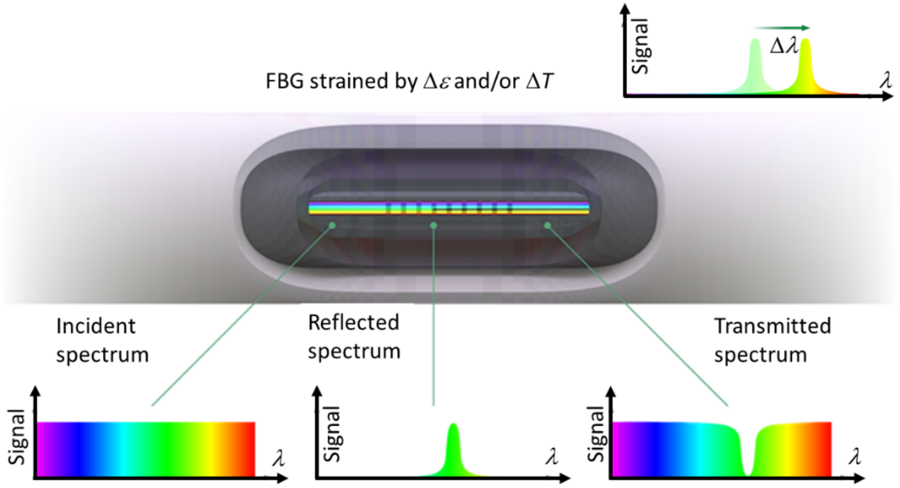
Target material

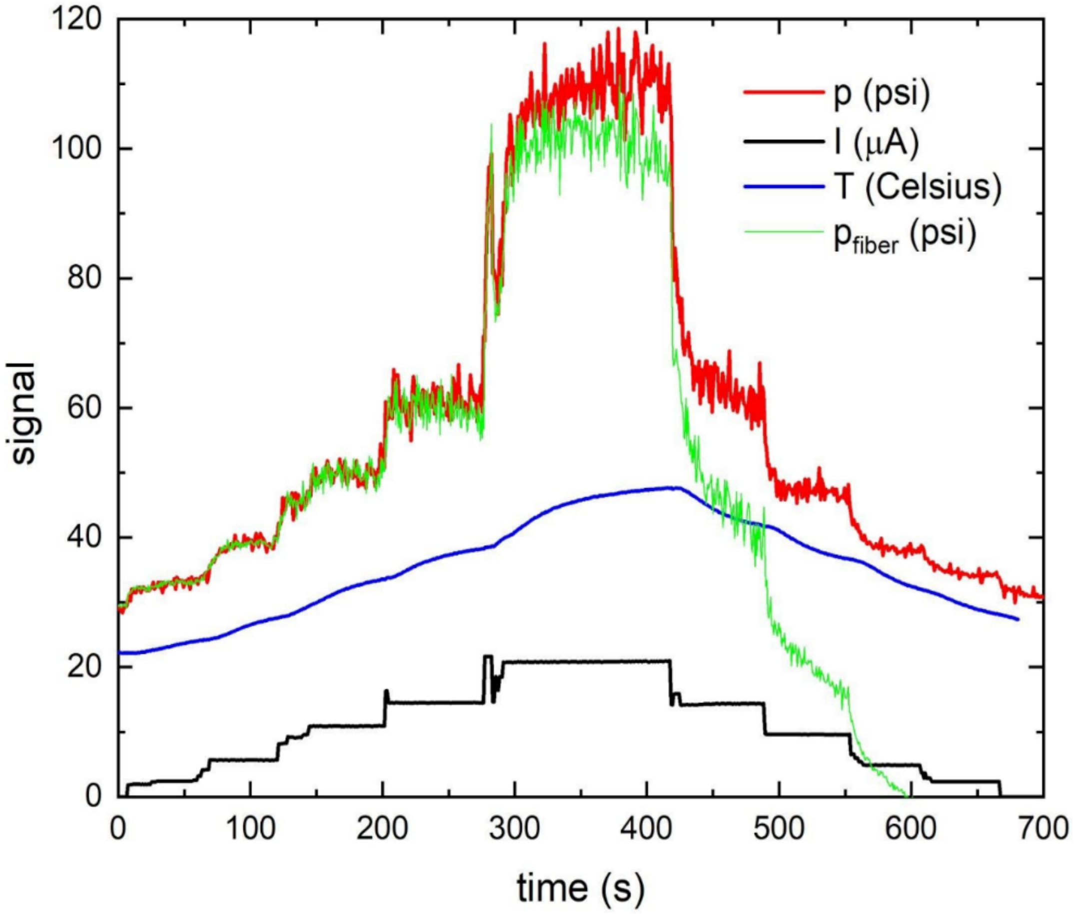


Beam steering

Temperature measurement

Solution: Insert inscribed silica fiber with FBG (Fiber Bragg Grating) into target to measure temperature and pressure change (here: water target at the TR13 cyclotron)





FBG successfully tracks temperature change inside the target cavity

Applied Science, 10 4610 (2020)

Future directions – medical applications

Radiotherapy – improving the therapeutic index for cancer therapy with optimized beam delivery and novel modalities

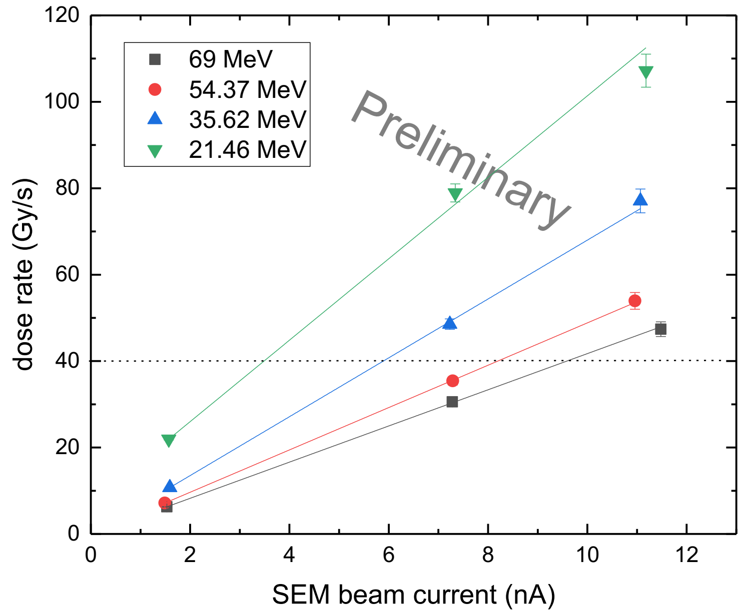
Beam delivery

- Dosimetry with novel detectors and techniques
- Physical beam delivery verification with novel detector solutions
- Biological delivery verification with novel detector solutions
- Novel accelerator technology for radiotherapy

Novel modalities

- Exploit TRIUMF infrastructure for novel modalities: photon/proton FLASH, neutron therapy
- Combine different beam modalities
- Combine with nano-technology

➡ **Translate into clinic**



First FLASH dose rates at our proton therapy facility this Tuesday!

Future directions – medical applications

Medical isotopes – improving the therapeutic index for cancer therapy with optimized and novel radioisotopes

Improved isotope and tracer production

- Novel target monitoring
- Novel target technologies
- Novel detection solutions for Targeted-Radiation-Therapy (TRT) tracer development
- Novel accelerator technology for isotope production

Novel therapy with radioisotopes

- Exploit TRIUMF infrastructure for therapeutic isotopes
- Combine theranostics with external beam therapy
- Combine with nano-technology

→ **Translate into clinic**

Acknowledgment

- **Life Science Division**
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Thank you
Merci

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