A story about Applied Nuclear Physics

Mateusz Sitarz

Open Meeting of SFJ
Student Accelerator Workshop in HIL

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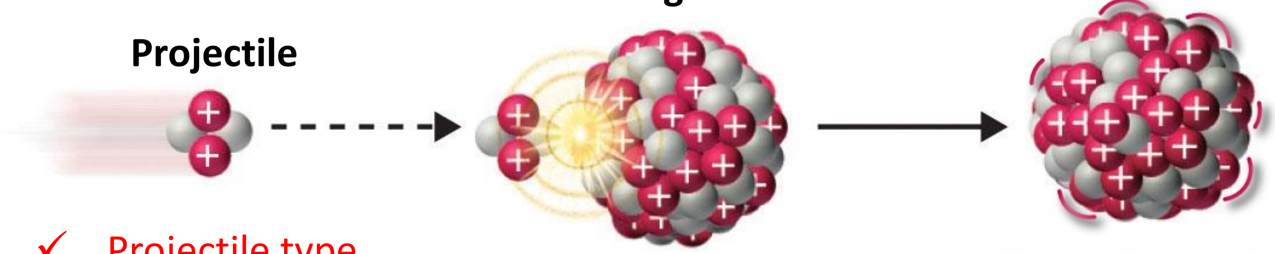
Overview

- Medical radioisotopes (PhD, Warsaw+France)
- Radiobiology and dosimetry (postdoc, Denmark)
- Radiation protection and treatment planning (postdoc, France)

Production of medical radioisotopes

Projectile | Target | Product(s)



- ✓ Projectile type
- ✓ Energy range
- ✓ Beam current

* Physics
* Applications

- ✓ Reaction cross-section (data vs calculations)
- ✓ Target composition
- ✓ Target form
- ✓ Target thickness
- ✓ Target heating

- ✓ Production efficiency
- ✓ Medical properties
- ✓ Activity for patient
- ✓ Radioactive impurities (chelating)

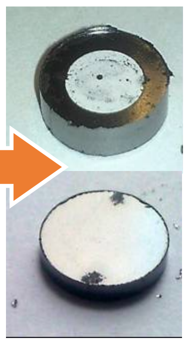
	^{44}Sc	^{68}Ga
OS	+3	+3
$E_{\beta+}$(av)	630 keV	830 keV
$I_{\beta+}$	94%	89%
$T_{1/2}$	3.9 h	68 min

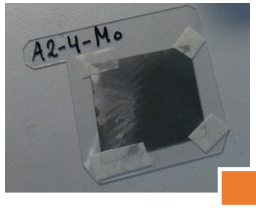
U-200P
SLCJ, Warsaw

C70
ARRONAX, Nantes

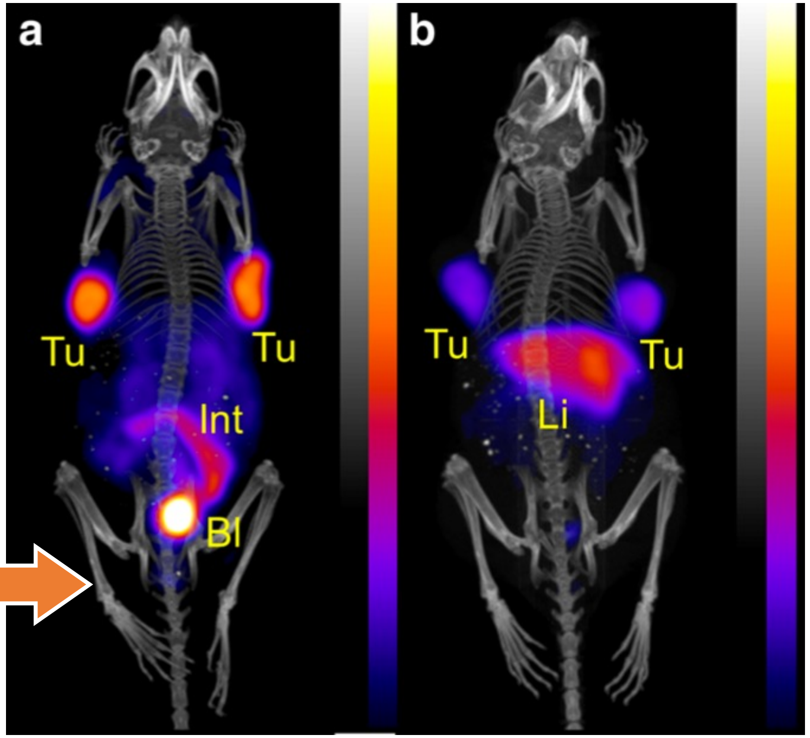
PETtrace
SLCJ, Warsaw

Thick/thin targets





+ separation
+ labeling…



^{44}**Sc**-DOTA-RGD | ^{68}**Ga**-DOTA-RGD

Budget

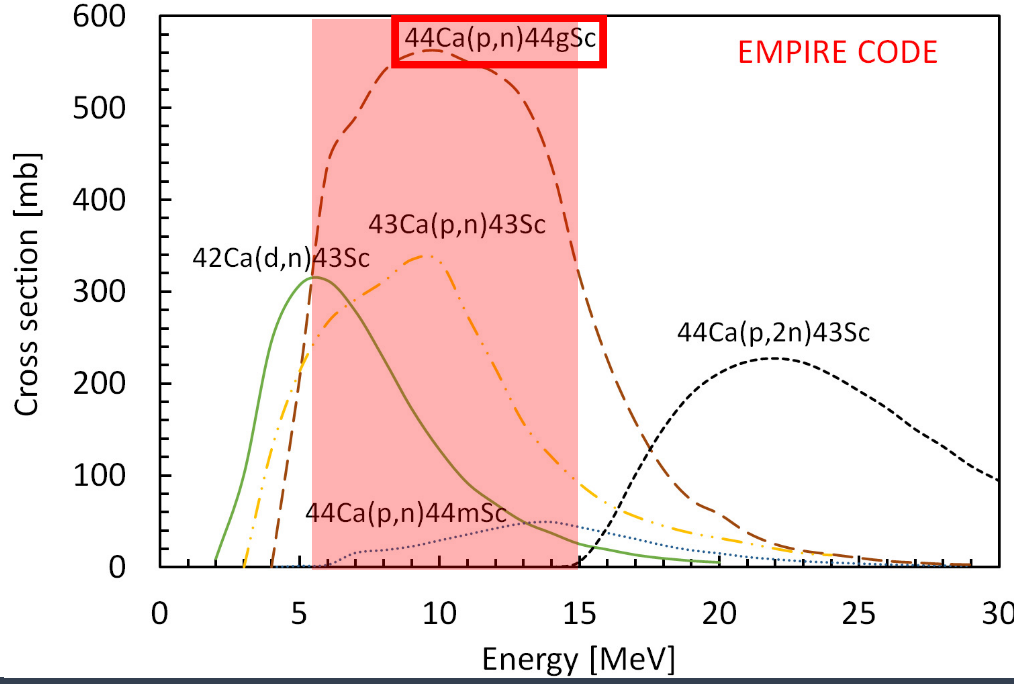
- ➔ Reaction routes
- ➔ Available targets
- ➔ Competitive reactions

$^{44}Ca(p,n)^{44}Sc$

$^{44}Ca(d,2n)^{44}Sc$

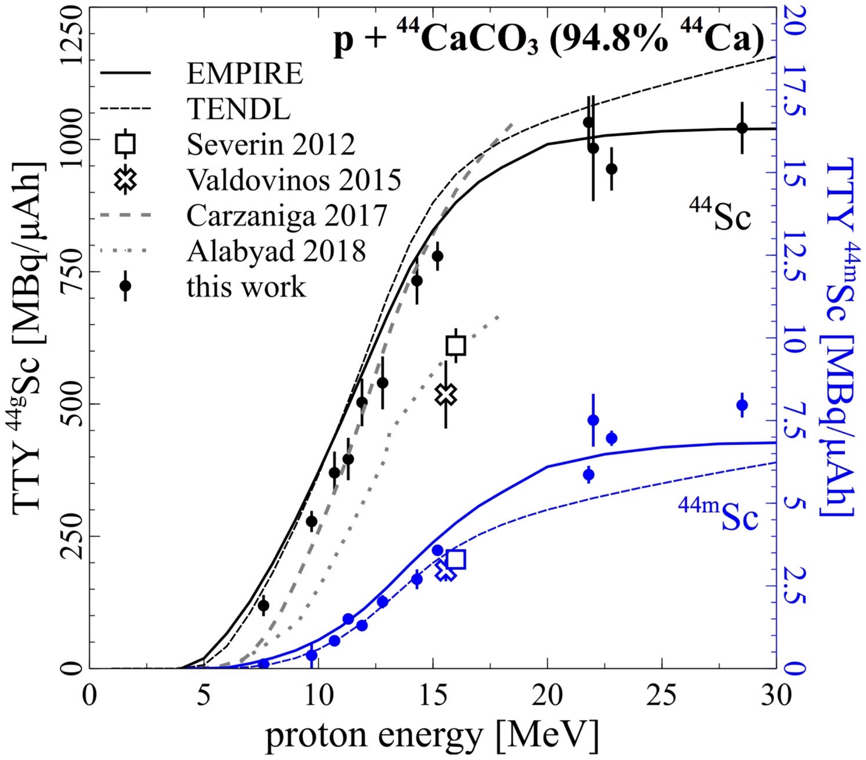
$^{42}Ca(\alpha,np)^{44}Sc$

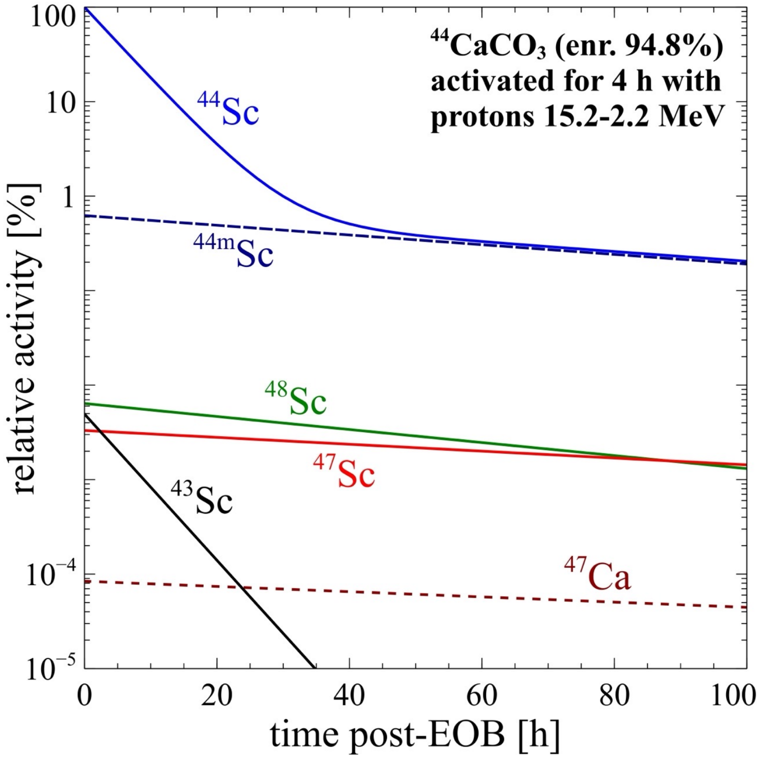
	$^{nat}CaCO_3$	commercially available ($CaCO_3$)	
^{40}Ca	96.9%	99.99%	1.4 $/mg
^{42}Ca	0.65%	68% 95.9%	43 $/mg 81 $/mg
^{44}Ca	2.1%	94.8% 99.2%	20 $/mg 23 $/mg
^{48}Ca	0.19%	69.2% 97.1%	89 $/mg 230 $/mg



Production efficiency

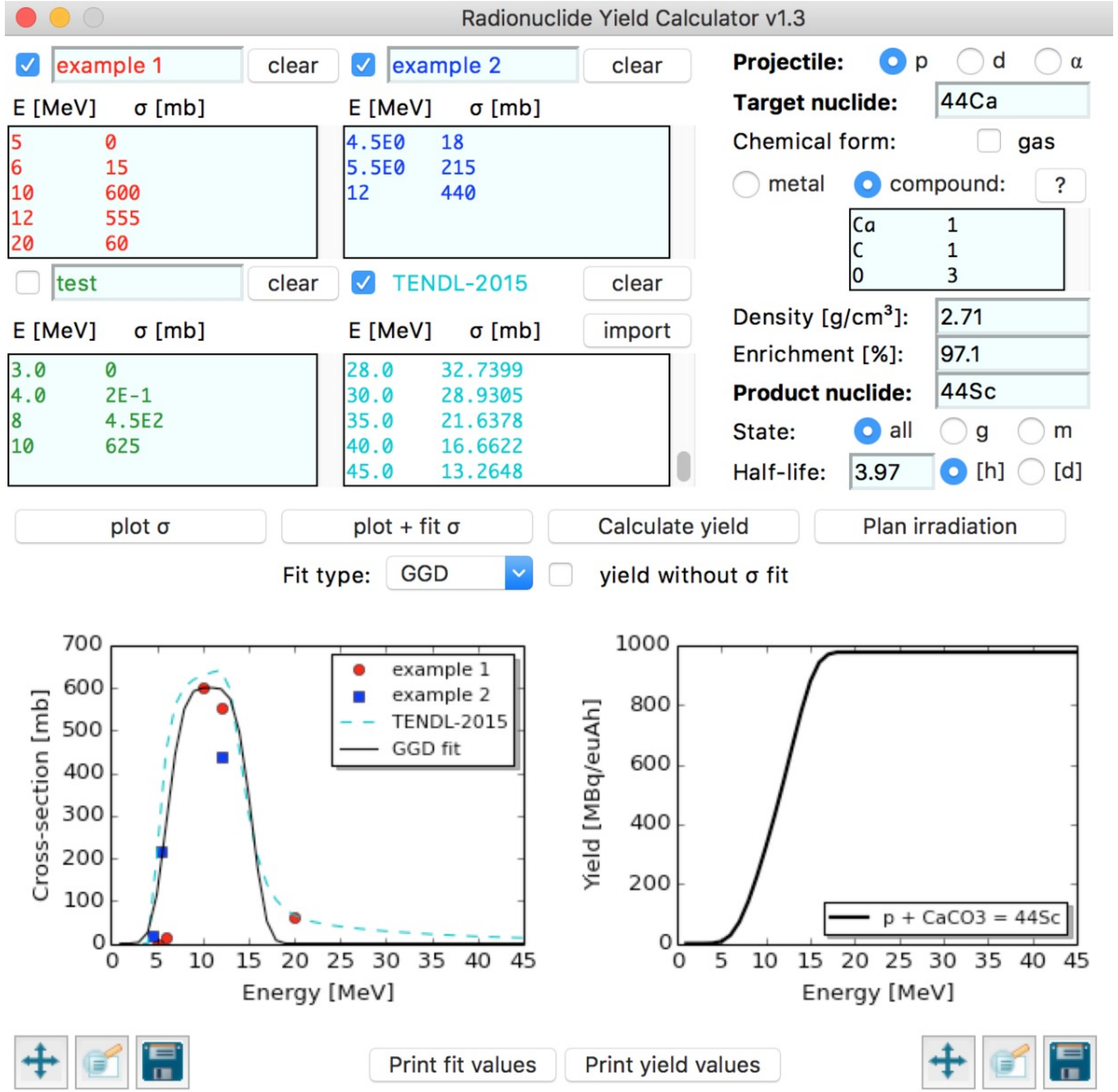
Production yield

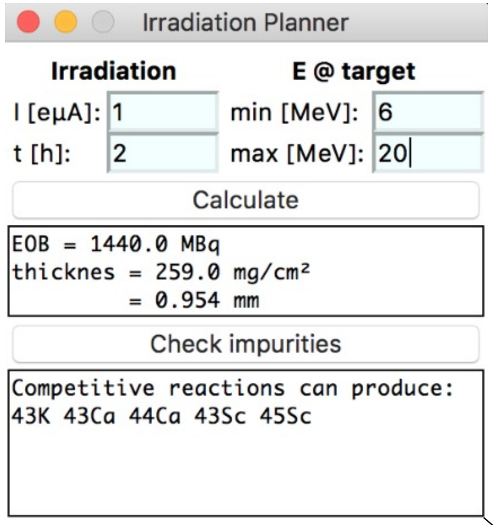




Radioactive impurities

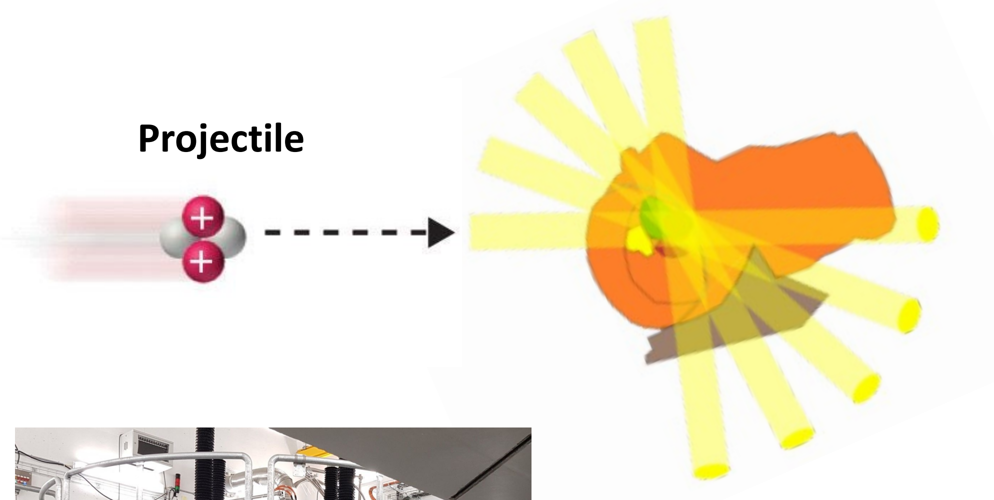
Beam, energy		**p 15-2 MeV**		**d 15-8 MeV**	**α 29-12 MeV**
Target		$^{nat}CaCO_3$	$^{44}CaCO_3$ (94.8%)	$^{44}CaCO_3$ (96.9%)	$^{42}CaCO_3$ (95.9%)
Irradiation: 4 h, 25 μA	^{44}Sc A_{EOB} [GBq]	1.4	63	16	3.3
	Main impurity	^{43}Sc 3.0%	^{44m}Sc 0.7%	^{44m}Sc 2.0%	^{44m}Sc 14%

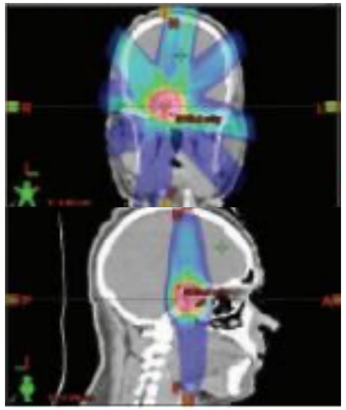




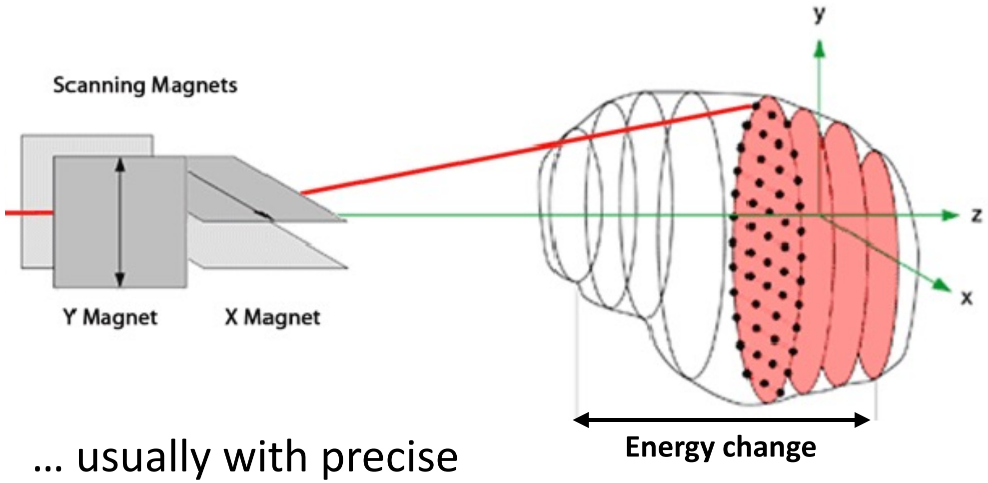
collimator activation
(radioprotection)

Radiotherapy





Deposit prescribed **radiation dose** (energy) in tumor



… usually with precise Pencil Beam Scanning technique

ProBeam: p
Danish Centre for Particle Therapy

Current@target: ~1 nA (~0.1 Gy/s) → Increase to **> 40 Gy/s** → **FLASH effect**
Energy: 70-244 MeV

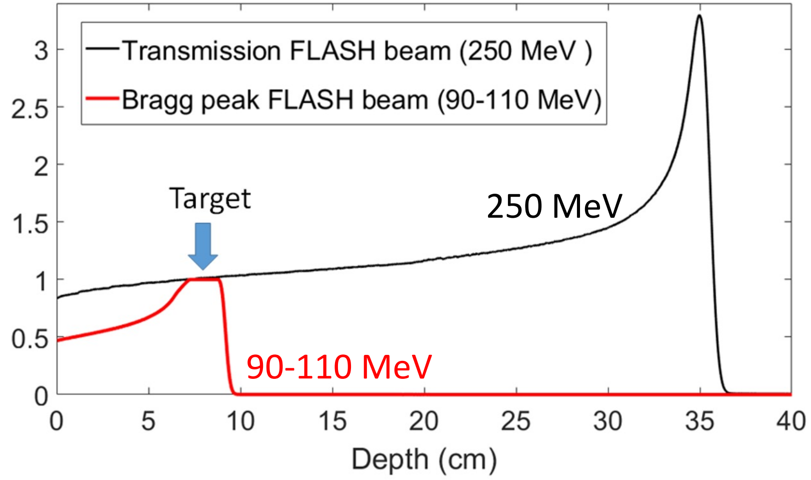
Short treatment times (< 0.5s)
High fraction doses (> ~8Gy)

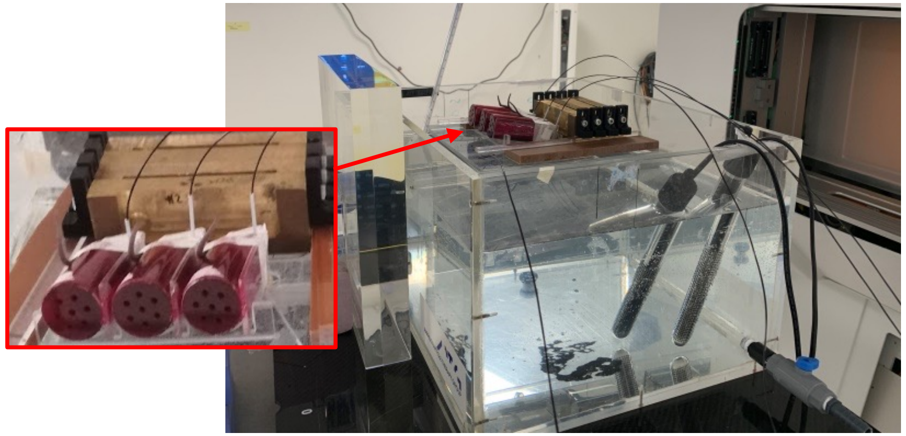
FLASH effect

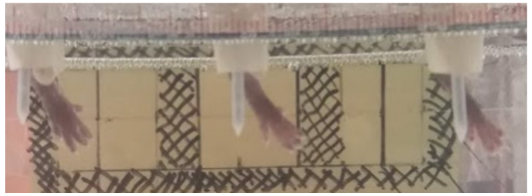
spares healthy tissues
same tumor response

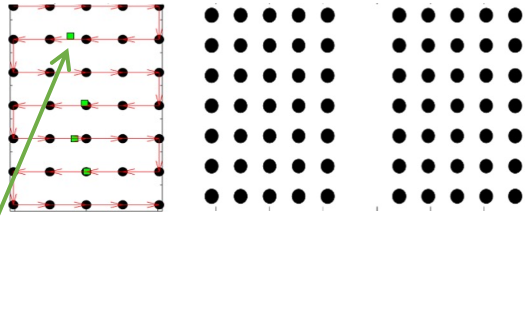
How to trick clinical machine (1 nA =~ 0.1 Gy/s) to deliver FLASH dose rates (40 Gy/s)?

Highest energy (250 MeV) for highest transmission
Highest available cyclotron **current** (550 nA)
Only **one energy** (energy switch = 1 s)
Small treatment **fields** (2x3 cm^2)

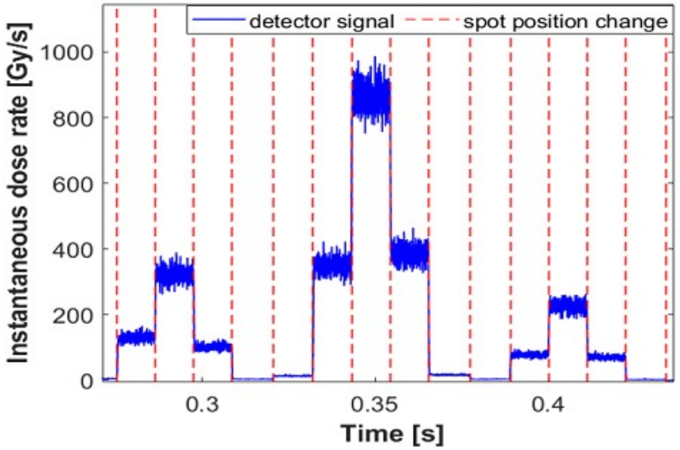








Monitoring with scintillator crystals



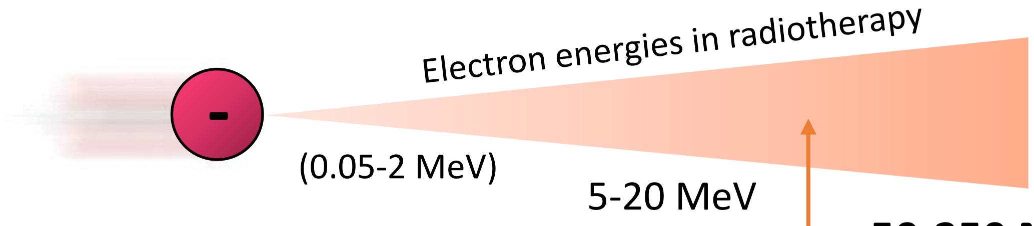
...and other projects

Ridge filters

3D gel dosimetry

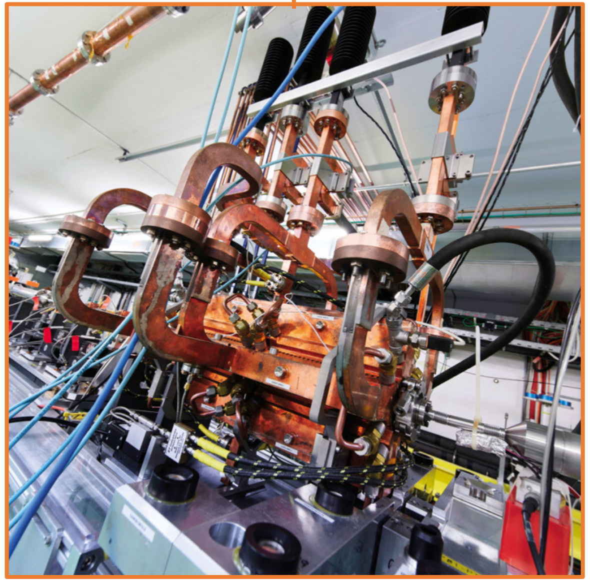
GRID collimators

Very High Energy Electrons (VHEE)



50-250 MeV →

- Deeper penetration
- Sharper transverse penumbra
- Compact technology
- Easily focused
- FLASH dose rates



high-gradient linac

laser accelerated plasma

VHEE modeling

Beam shape:

$$\Phi(z,\rho) = \underbrace{\frac{1-w_B}{\pi r_A^2(z)} e^{-\rho^2/r_A^2(z)}}_{\text{primaries}} + \underbrace{\frac{w_B}{\pi r_B^2(z)} e^{-\rho^2/r_B^2(z)}}_{\text{secondaries}}$$

Radial spread (2-nd Fermi-Eyges moment):

$$r^2(z) = r_0^2 + 2\theta r_0 z + \theta_0 z^2 + \int_0^z (z-u)^2\, T(u)\, du$$

Scattering power:

$$T = \frac{\chi_c^2 B}{l} \qquad \chi_c^2 = \frac{4\,\pi r_e^2 N_A Z^2}{A\,\gamma^2\beta^4}\rho l \qquad B - lnB = ln\frac{6680\rho l(Z+1)Z^{1/3}}{\beta^2 A(1+3.34\alpha^2)}$$

Summary

Applied nuclear/radiation physics in research:

- Production of radioisotopes
- Dosimetry, radiobiology
- Irradiation campaigns
- Beam modeling
- (Programming)