Prompt gamma imaging for online monitoring in proton therapy - SiFi-CC project

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PRZYSZŁOŚĆ FIZYKI JĄDROWEJ NISKICH ENERGII W POLSCE
A ROZWÓJ KRAJOWEJ INFRASTRUKTURY BADAWCZEJ
ŚLCJ UW Warszawa 14-15.01.2019

Context: cancer

- 1 in 4 deaths caused by cancer in the EU (Poland close to this average)
- >3.7 million new cases and ~1.9 million deaths/year make cancer the second most important cause of death and morbidity in Europe
- trend: increasing...

¤ src: WHO, Eurostat

Treatment methods:

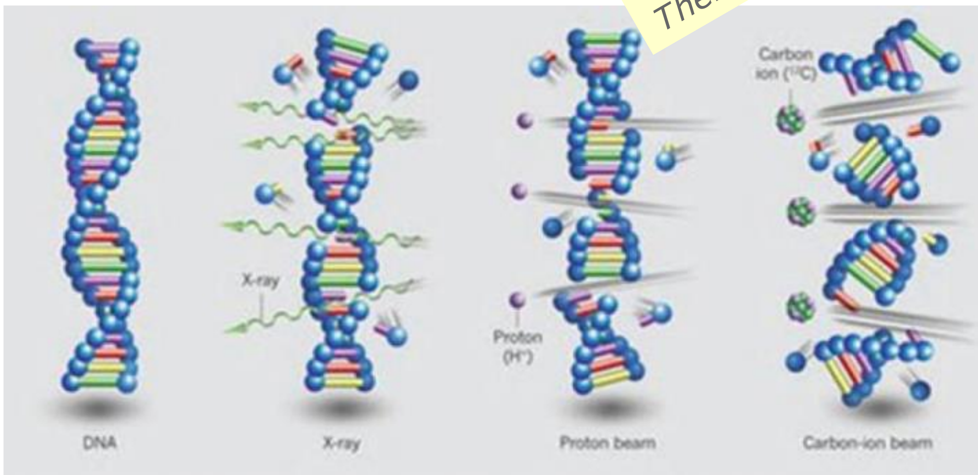
- Surgery
- Chemotherapy
- Immunotherapy (Nobel prize 2018)
- **Radiotherapy**

CCB Kraków launched 2013

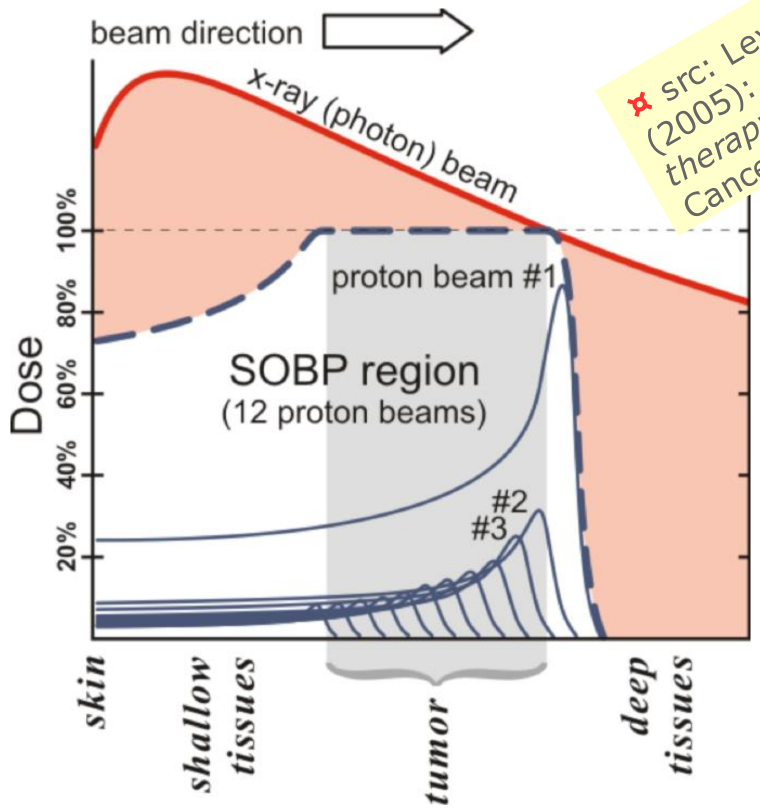
X-ray vs proton therapy

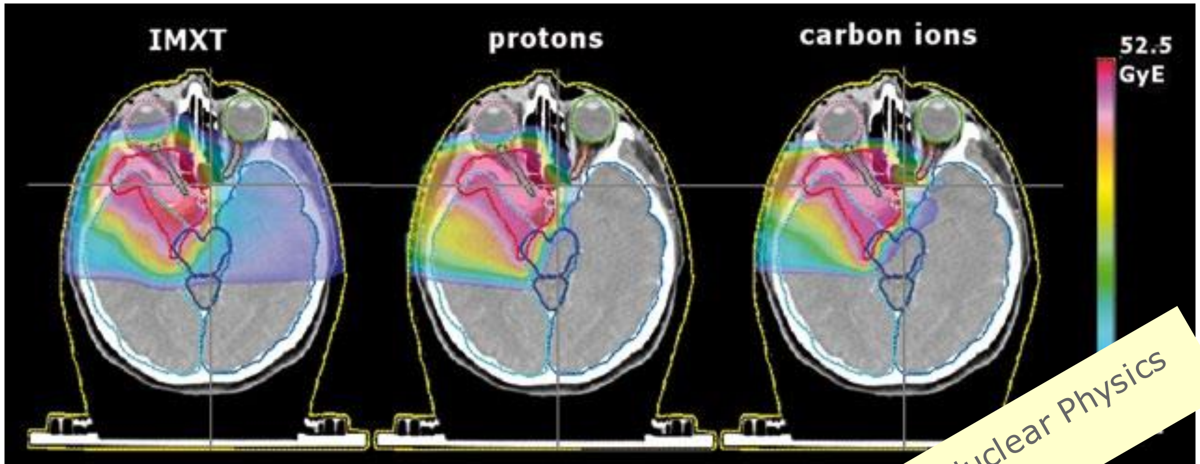
- Tumour irradiation – an important way of treatment
- Advantages of proton therapy compared to X-rays:
  - Conformal dose distribution
  - Biological effectiveness

¤ src: Marcos dÁvila Nunes: Proton Therapy Versus Carbon Ion Therapy Springer 2015



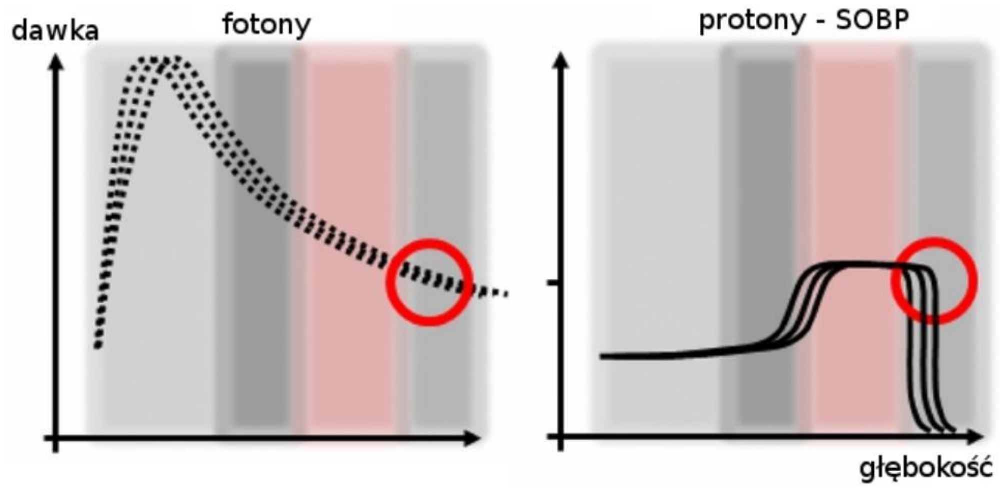
¤ src: Levin et al. (2005): Proton beam therapy in British J. of Cancer





¤ src: Nuclear Physics for Medicine

Why to monitor beam range?



Range effects for
an unmodelled cavity:

- Photons: dose larger by <5%
- Ions: range larger by ~1 cm

¤ src: Knopf, Lomax, Phys.Med.Biol 2013

Proton therapy is a precise and selective treatment method...

... provided you have a perfect 3d map of patient in terms of proton stopping power!

Sources of uncertainties:

- Transformation of imaging info CT→ dE/dx
- Patient positioning
- Anatomical changes
  - Weight loss
  - Change of tumour size/shape
  - Runny nose

¤ src: NuPECC report „Nuclear Physics for Medicine" 2014

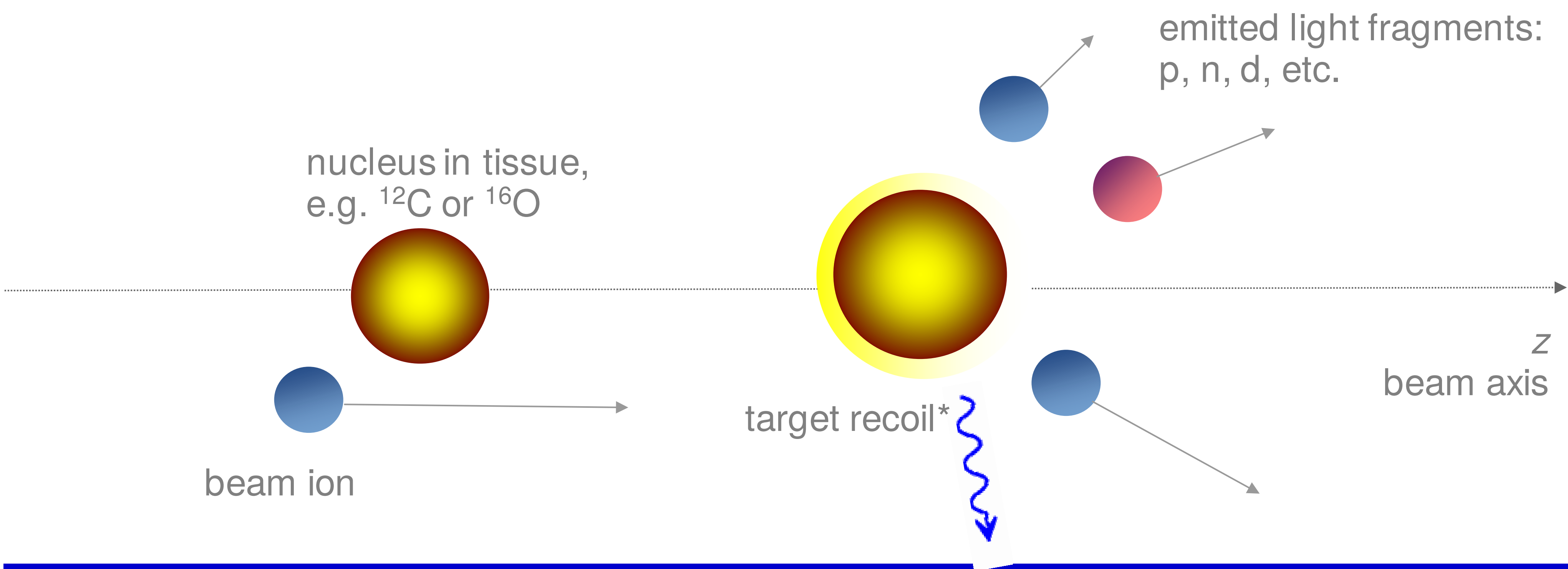
„In-vivo range verification methods would represent an optimal solution for full explotitation of the advantages afforded by the ion beam"

- Reduction of safety margins
- Better/safer treatment plans

Approaches to range monitoring

Idea: exploit by-products of patient irradiation with ion beam:

- Protons
- Neutrons
- β+ emitters (via 511-keV gamma pairs) → PET
- **γ radiation → Prompt Gamma Imaging PGI**
  (γ yield depends on proton energy → correlated with depth)



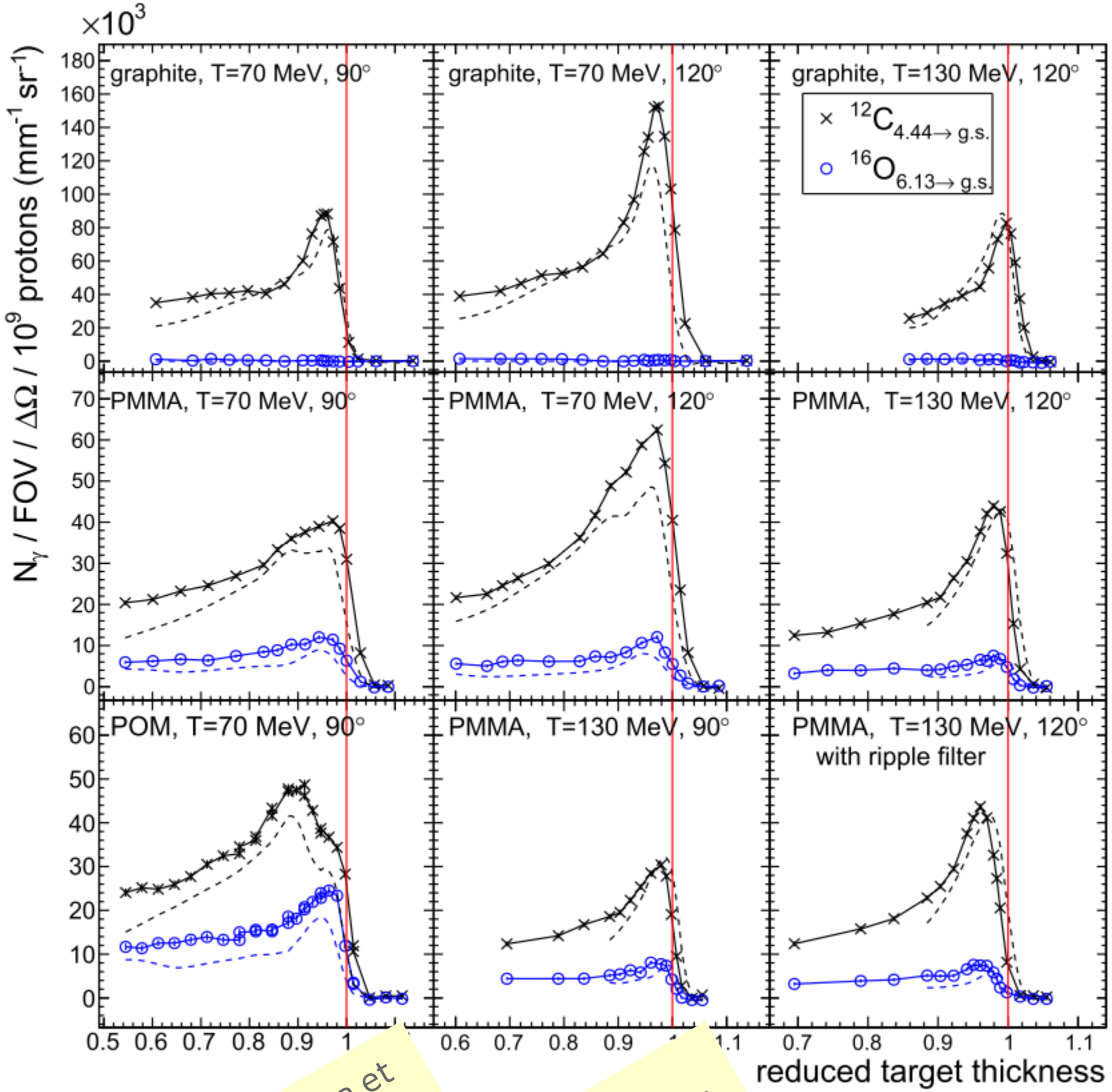
Previous experience

γCCB: Investigation of gamma emission in experimental modelling of hadron therapy

Study dependence σ(depth) for key discrete transitions at

- Various beam energies,
- Various phantom materials,
- Various angles.

financed by FNP as POMOST



¤ src: Kelleter, Wrońska et al., Physica Medica 34 (2017)

¤ also: Rusiecka et al., Acta Phys. Pol. B 49 (2018)

New project: SiFi-CC

SiPM- and heavy scintillation Fiber-based Compton Camera for on-line monitoring of deposited dose distribution in proton therapy

Goal: development of a method for on-line monitoring of deposited dose distribution in proton therapy

Technique: imaging exploiting prompt gamma rays emitted during irradiation

Technology: Detector based entirely on new, heavy scintillating materials read out by SiPMs;
DAQ and (partly) image reconstruction based on FPGA → implantation of HEP technologies to medical application;

Realization: dual-modality setup

- Coded mask **CM**
- Compton camera **CC**

Synergy with J-PET

Financed as SONATA BIS by NCN

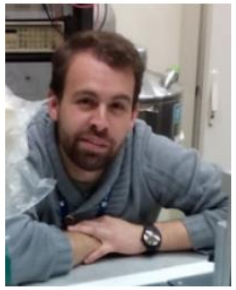
Team

Aleksandra Wrońska[1]
post-doc, PI

Arshiya Anees Ahmed[1]
PhD student

Richard Chomjak[1]
student

Ronja Hetzel[2]
post-doc



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Rafał Lalik[1]
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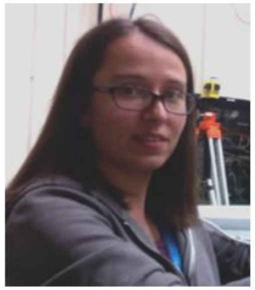

Katarzyna Rusiecka[1]
PhD student

Achim Stahl[2]
professor

Szymon Świstun[1]
student

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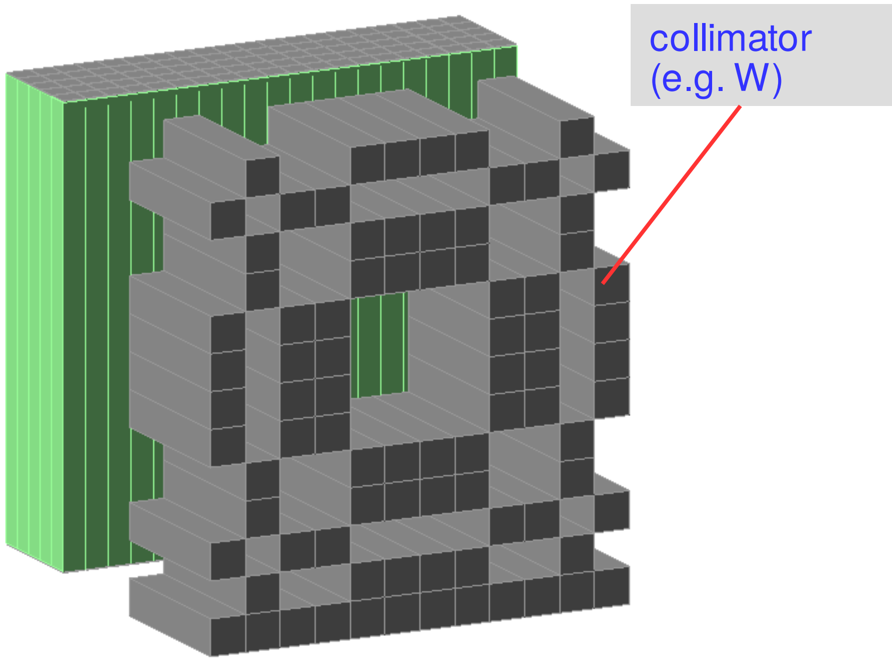
And we keep looking for more people (students, PhD students)…

http://bragg.if.uj.edu.pl/gccbwiki

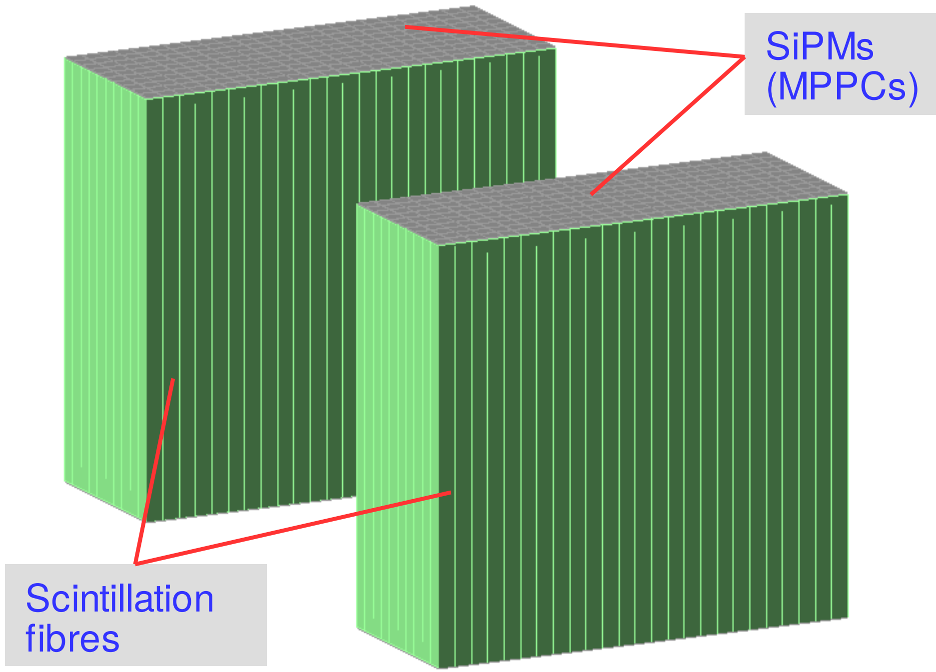
Dual modality - synergy

Coded mask CM



- Technique widely used in astronomy, also for observation of γ sources
- Technique not tested so far for the purpose of proton therapy
- 2d image
- Much larger statistics compared to single-slit detectors without compromising image resolution

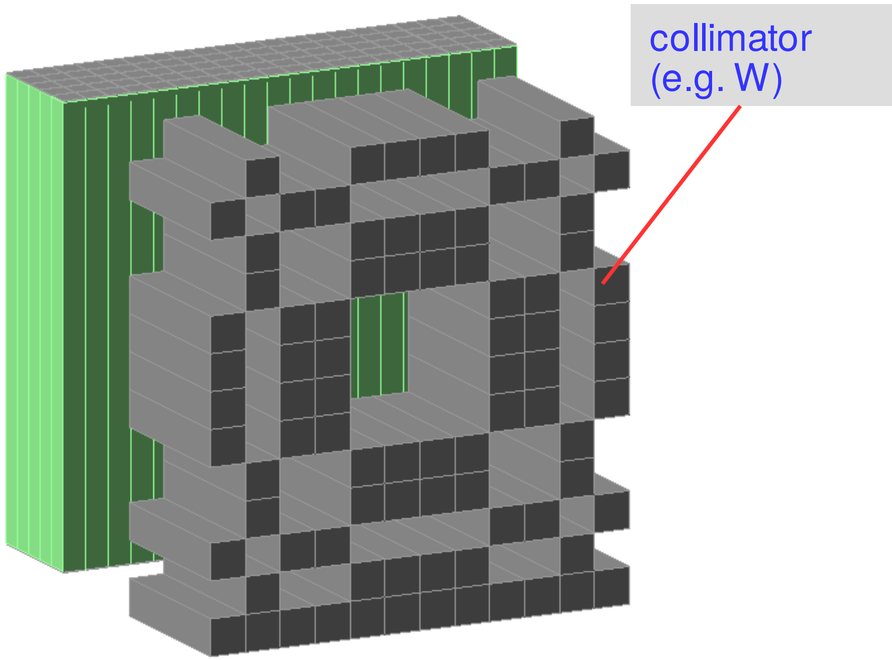
Compton camera CC



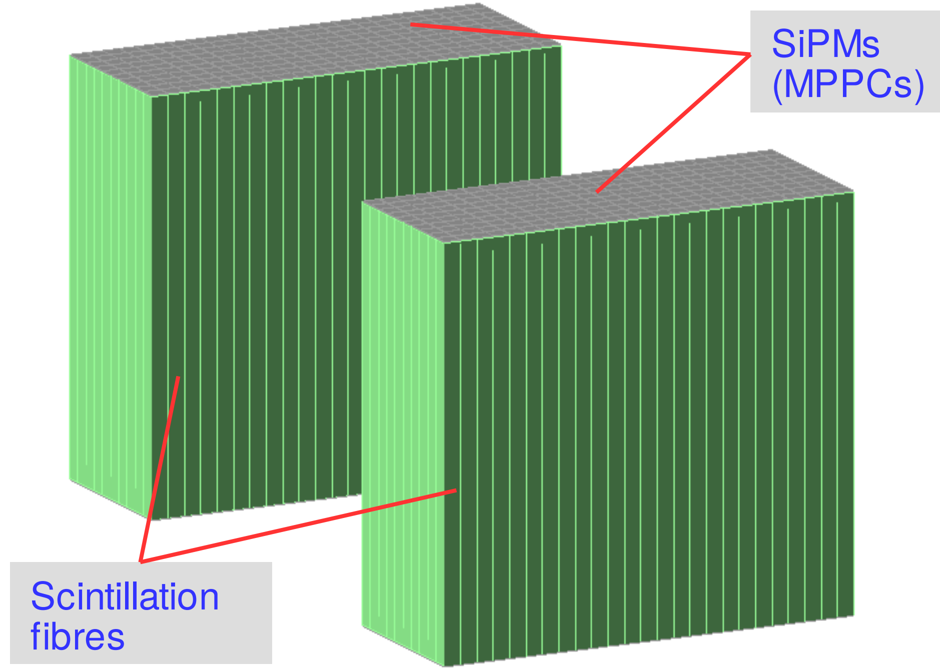
- Solution considered and tested for the use in proton therapy
- 3d image
- Problem faced so far: small statistics (efficiency), background from random coincidences
- Proposed solution: detectors of larger efficiency and better time resolution ($\rightarrow$electronic collimation)

Dual modality - synergy

Coded mask CM



Compton camera CC



Common parts:

- Detection technique
- FEE
- DAQ

→ *expensive hardware*

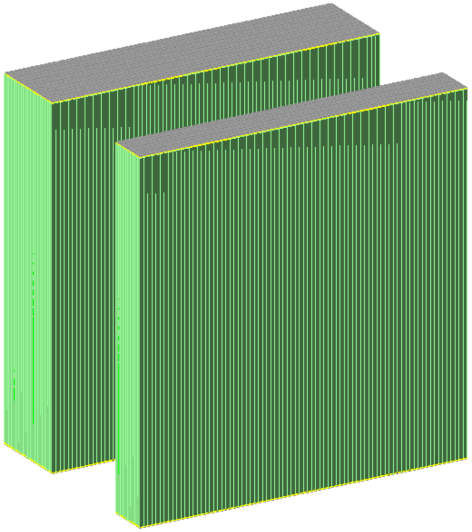
Modality-specific parts:

- Collimation
- Image reconstruction

→ *mostly software (manpower)*

The SiFi-CC setup

- Stacked scintillating fibers
  - Large Z_{eff} and density
  - Large light output O(30000/MeV)
  - Emission spectrum compatible with SiPM
  - Fast rise time and short decay time(s)
  - Attenuation length ~10 cm
  - Small (no?) intrinsic activity
  - Good energy resolution
- SiPMs as size-fitting option
- Aim: high granularity with good energy resolution and fast response
  (rate capability, electronic collimation)



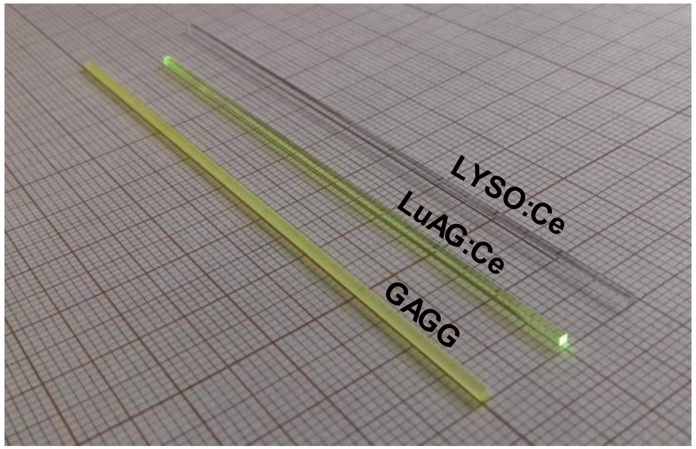
Tasks

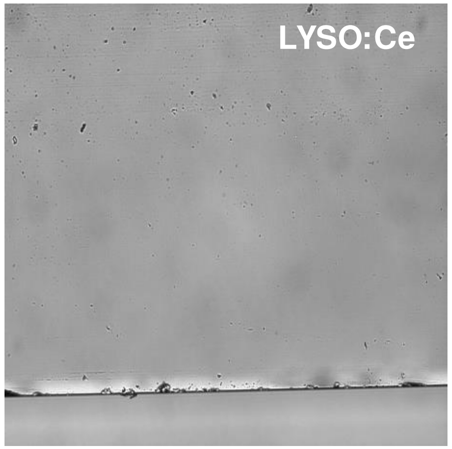
- Optimization of setup design by MC simulations (Geant4) ongoing
- Software development: decoding, calibration, image reconstruction, … ongoing
- Detector development (tests of materials, coating, coupling, etc.) ongoing

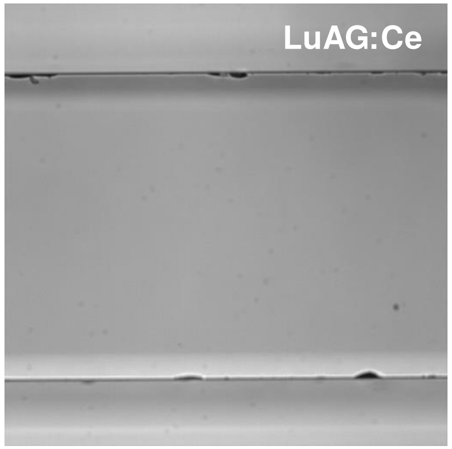
Tasks – tests of detector components

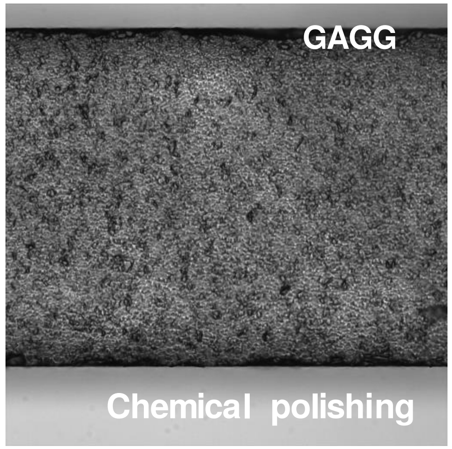
	LuAG:Ce Crytur	LYSO:Ce Epic Crystal	GAGG:Ce,Mg C&A Corporation
Formula	$Lu_3Al_5O_{12}$:Ce	$Lu_{1.8}Y_{0.2}SiO_5$:Ce	$Gd_3Al_2Ga_3O_{12}$:Ce,Mg
Density [g/cm^3]	6.73	7.1	6.63
Z_{eff}	63	65	55
Refraction index	1.84	1.81	-
Maximum of emission [nm]	535	420	520
Decay constant [ns]	70 (44%) 1063 (56%)	40-45	45 (58%) 135 (42%)
Photon yield [ph/MeV]	2.5 x 10^4	3 x 10^4	5.6 x 10^4
Photoelectron yield [% of NaI:Tl]	20	75	-
Radiation length at 511 keV [cm]	1.3	1.2	-
Attenuation length [cm]	5-30	40	-
Energy resolution at 662 keV [%]	8-8.5	7	5-6

src: K. Kamada et al, IE
Trans. Nucl. Sci. 63 (201
443-7







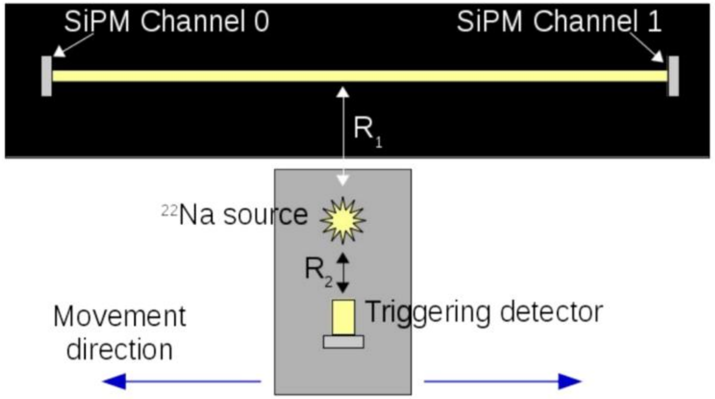


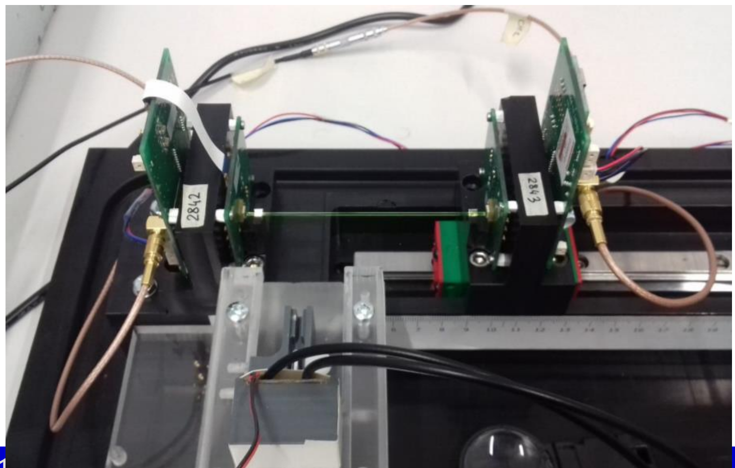
Microscopic pictures: Axio Observer Z1 Zeiss, bright field mode
mgr T. Kołodziej, mgr inż. Z. Baster, Department of Molecular and Interfacial Biophysics of JU

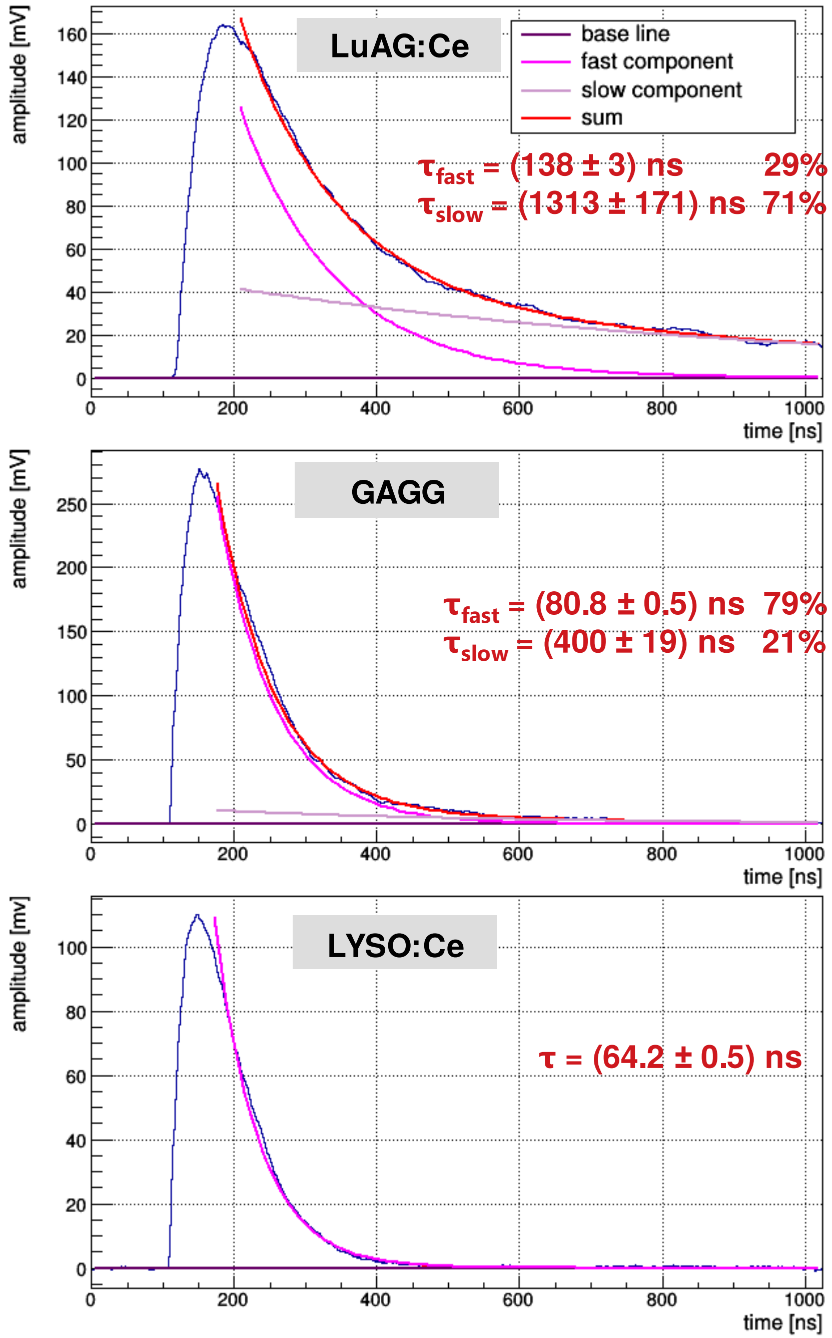
Tasks – tests of detector components

Measurements with fibres on a dedicated test-bench – K. Rusiecka

- Attenuation length
- Light output for 511 keV
- Energy resolution at 511 keV
- Timing properties







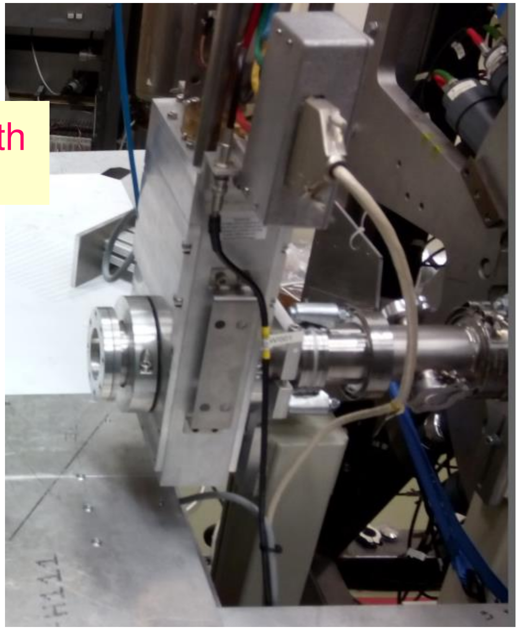
Tasks

- Optimization of setup design by MC simulations (Geant4) ongoing
- Software development: decoding, calibration, image reconstruction, … ongoing
- Detector development (tests of materials, coating, coupling, etc.) ongoing
- DAQ (inc. FEE+slow control) ongoing
- Test measurements (CCB/HIT) in ~2 years

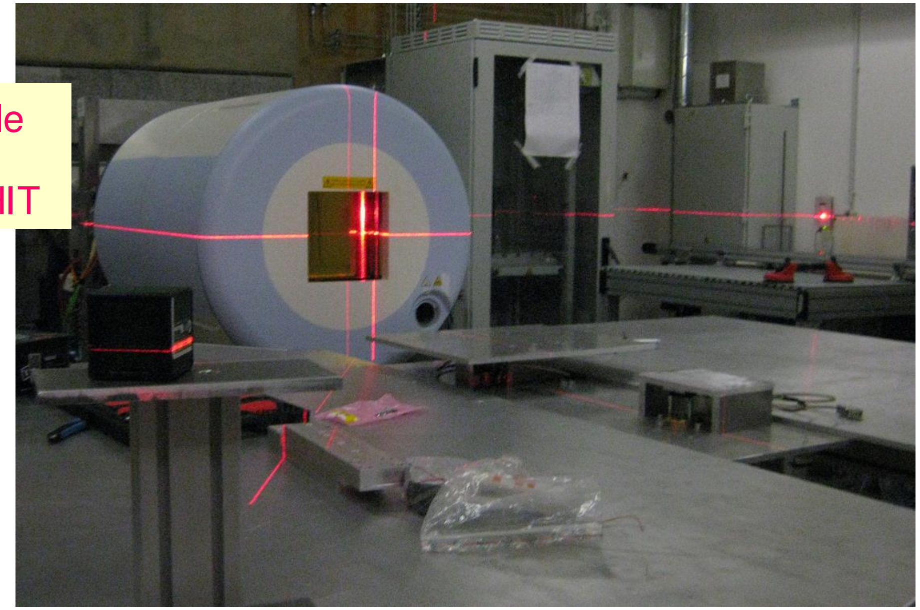
Dreams for test beam time at CCB

- Beam time easier available (T≈150 MeV)
- Beam properties well known (intensity + phase space: distribution of energy, position, angles)
  - Absolute normalization
  - Reliable input for acceptance simulation
- At CCB this is available in treatment rooms, but not in experimental hall
- Maybe a new nozzle for beam pipe?
- ...and a laser positioning system for target alignment?

Ti window with BPM at CCB



Beam nozzle and laser system at HIT



Thank you for your attention ✺

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