Dose, Flux and LET Measurements of Scattered Radiation in Proton Therapy Using Timepix3 Detectors

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Disclosure

Cristina Oancea, Lukas Marek, Jiri Pivec, Carlos Granja, Jan Jakubek are employed by

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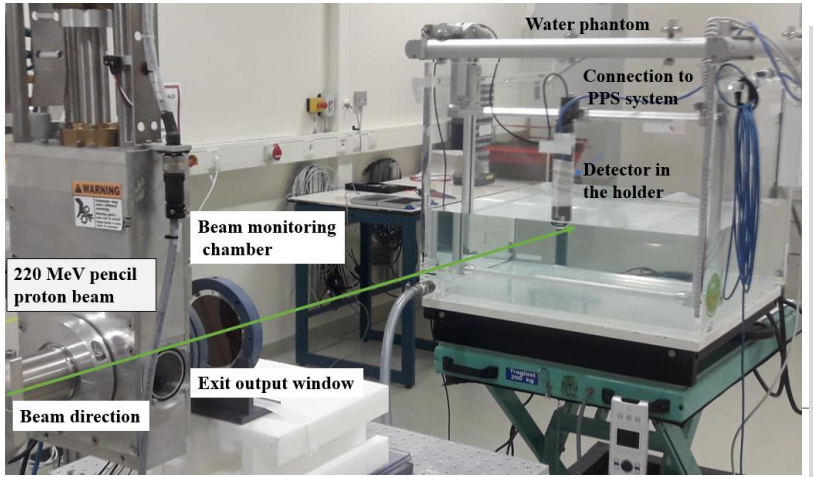
Motivation

- **Aim:** Spectral and component characterization of secondary particles produced in proton beams using a pixel detector
- Spectral tracking and **LET measurements** of **light** and **heavy charged particles** in a water-phantom
- Flux and dose rate of the **scattered radiation** (protons, electrons, X rays, gamma, neutrons)

Experimental setup

Experimental setup

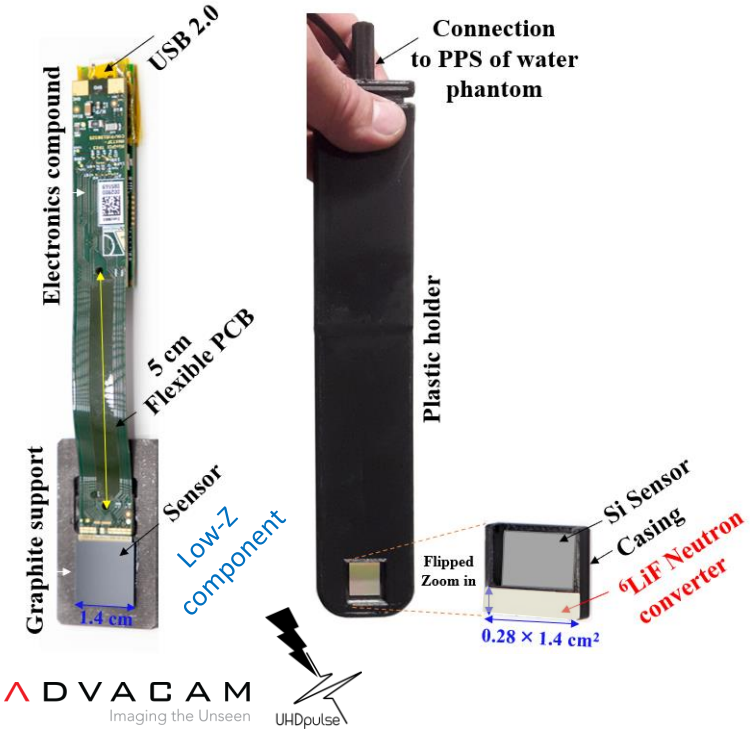


University Proton Therapy Dresden, horizontal research beamline (IBA cyclotron)

- **Stationary 220 MeV proton pencil beams**
- Pulsed beam structure with specified dose rates from **0.01 to 360 Gy/s**
- Timepix3 placed laterally (24 positions) perpendicular to the beam direction
- Multiple depth measurements ranging from the entry region to distal of the Bragg peak (BP).

Experiment Setup: Mini*PIX* Timepix3-Flex pixel detector

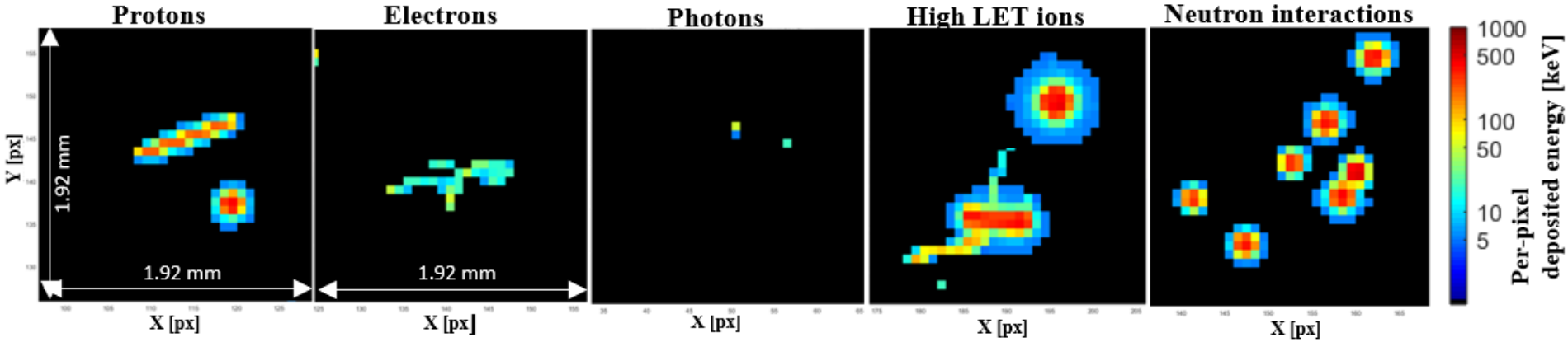
Timepix3 Si 500 µm



- Customized **waterproof miniaturized radiation detector**
- ASIC chip with Si sensor in **low-Z** chipboard and **support**
- Sensor area: **14 mm × 14 mm = 65 k pixels** (55 µm x 55 µm)
- Simultaneous measurement of **deposited energy** and **time**
- **100%** detection efficiency for charged particles, wide FoV
- **Thermal neutrons** detected with ^{6}LiF converter

Spectral tracking and imaging of single particles

- Precise measurement of position, deposited energy, time, direction



- Different particles make characteristic tracks

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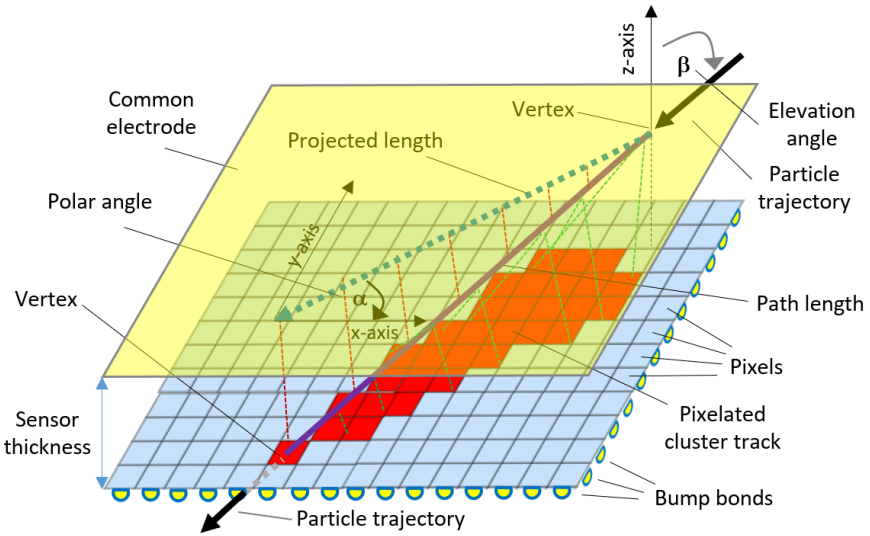
LET, flux and dose rate measurements



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❑ **LET** in silicon

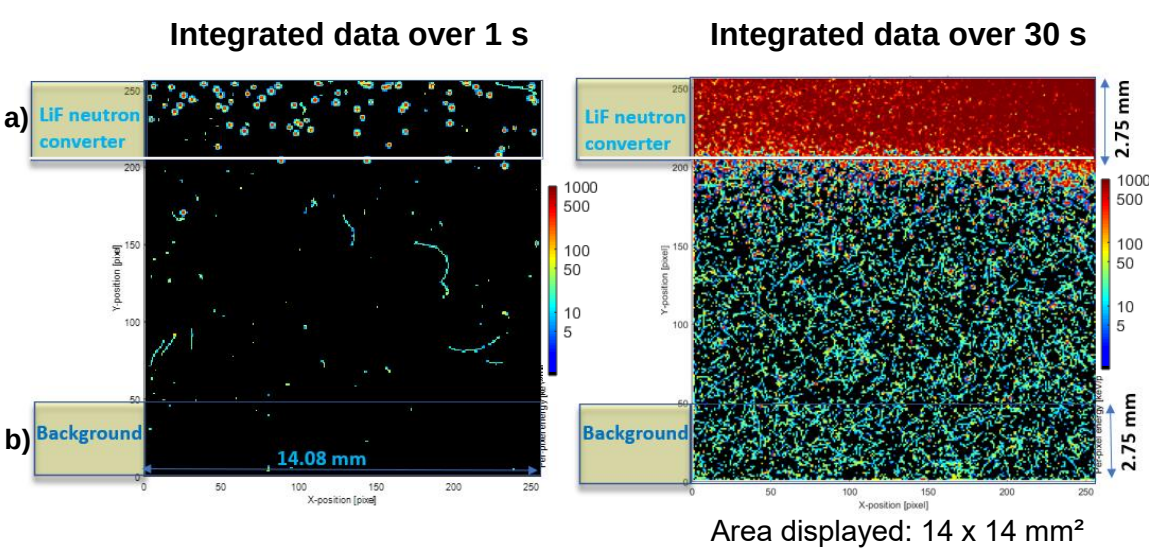
- **Wide range** (0.1 to >100 keV/μm)
- **Wide Field of View** (2π)

$LET = \frac{E}{x}$, **E** = cluster energy,
x = 3D length

❑ **Particle flux and DR**

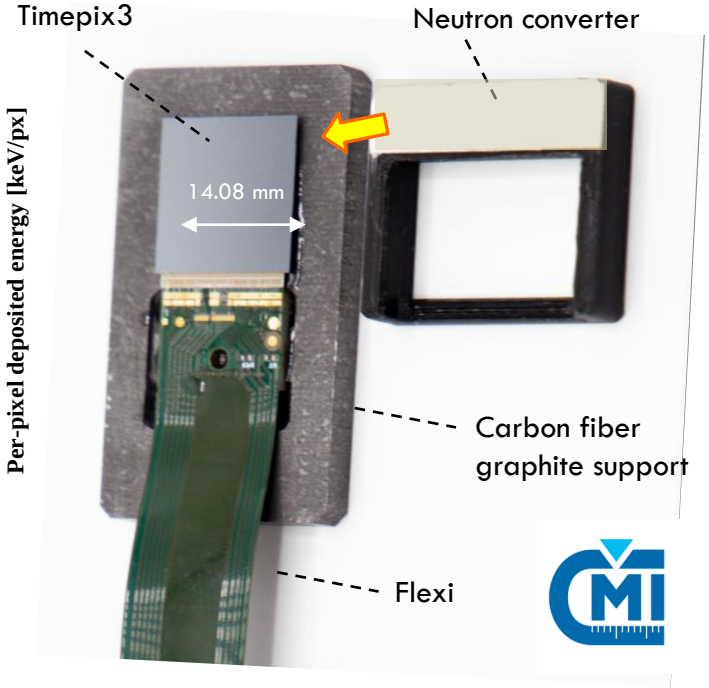
- Per-pixel deposited energy
- Time of arrival of each particle

Calibration of Timepix3 detector for thermal neutrons



Area displayed: 14 x 14 mm²

$k = (\Phi_a - \Phi_b) / \Phi_{ref}$



- Thermal neutron detection efficiency, k = 1.15% ± 0.038%

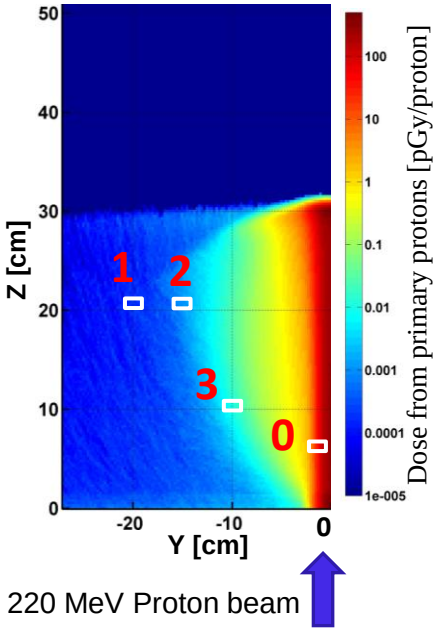
Results

Results: Deposited energy of scattered radiation

MC simulation 2D dose

from primary protons normalized

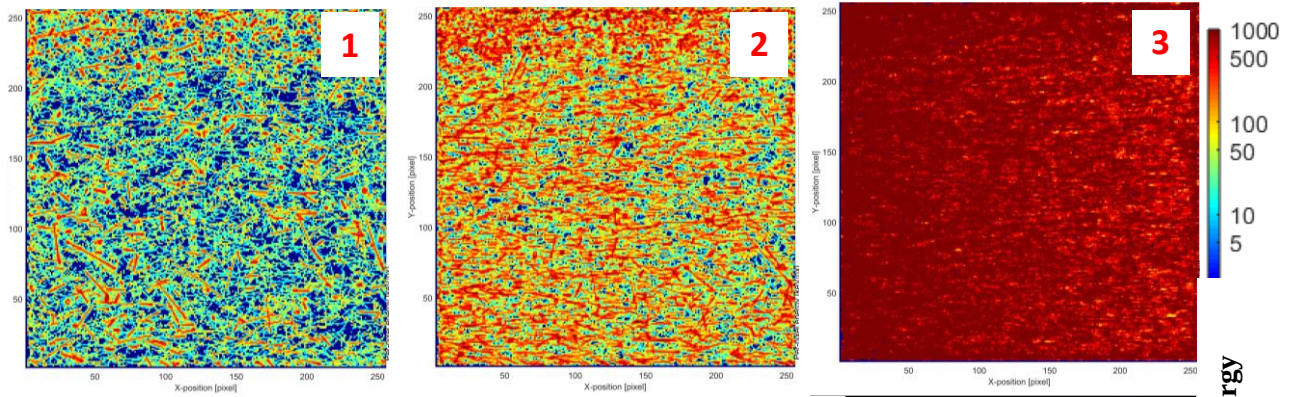
Water-phantom: 50 x 50 x 50 cm³



Measured deposited energy by Timepix3 detector

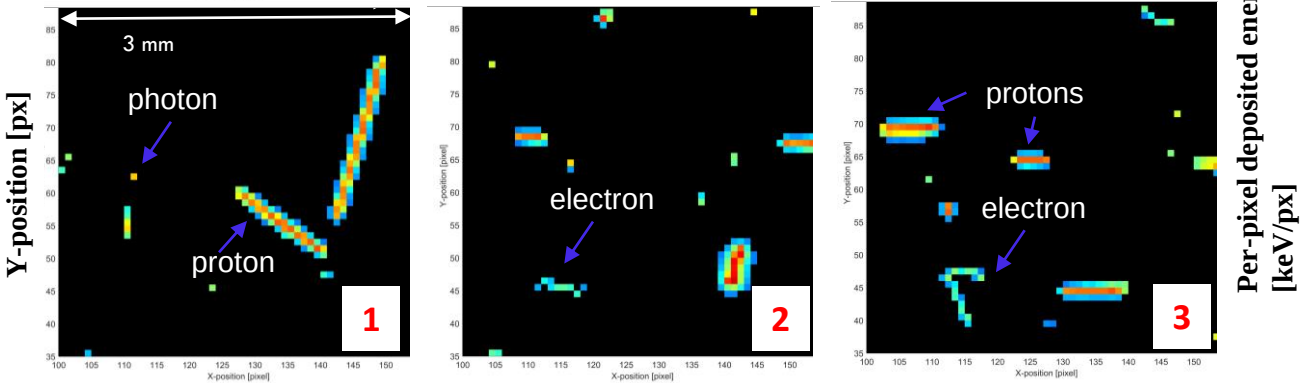
Integrated frame, 10 s

Entire sensor region = 2 cm²



Single frame, 0.1 s

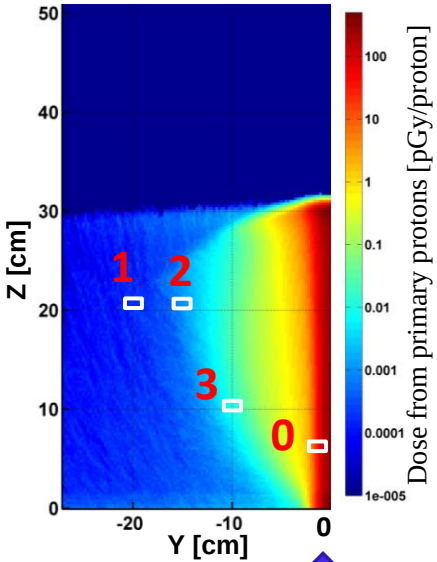
Small region of sensor: 4%



Results: Flux & DR of scattered particles

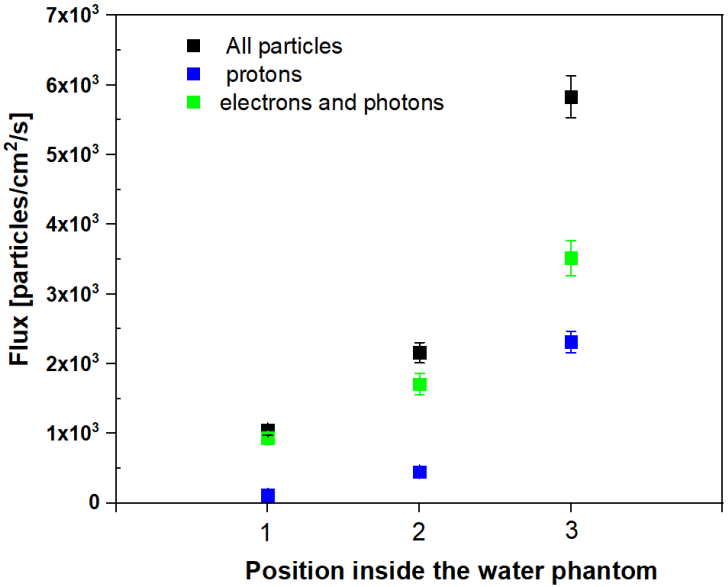
MC simulation 2D dose

from primary protons normalized

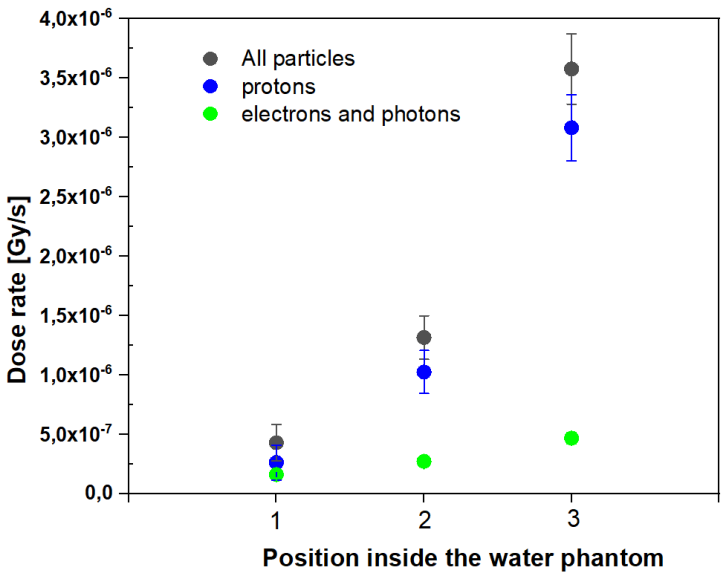


220 MeV Proton beam
DR at 0 = 0.14 Gy/s

Particle flux



Dose rate

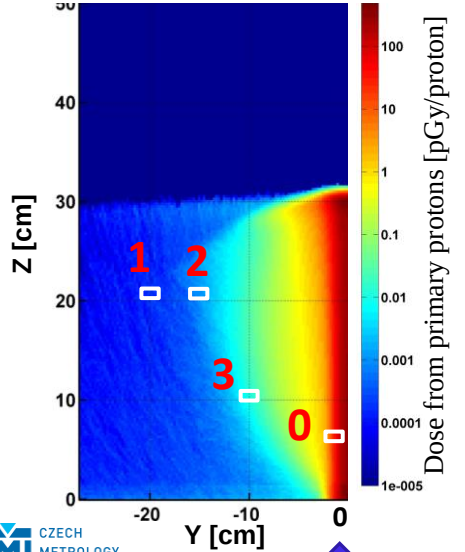


- *In agreement with MC simulations*

Results: LET histograms of stray radiation

MC simulation 2D dose

from primary protons normalized*



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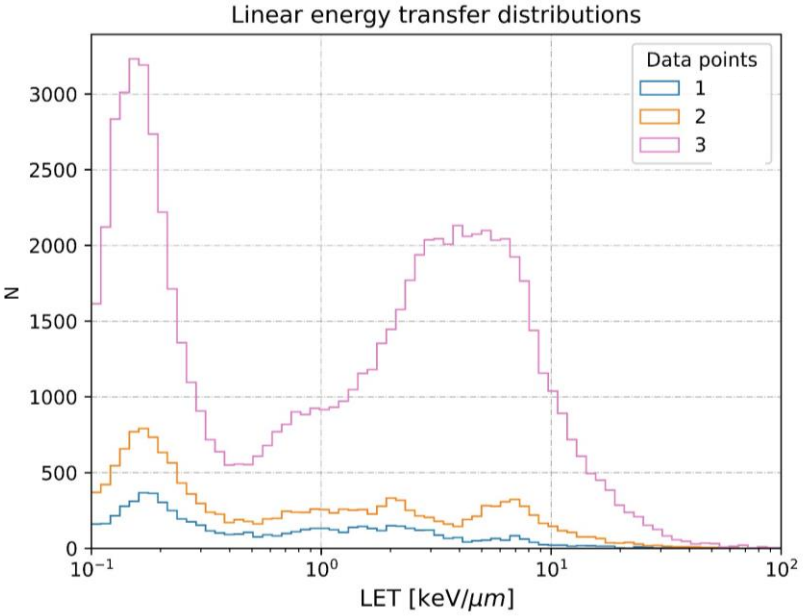
*Provided by CMI

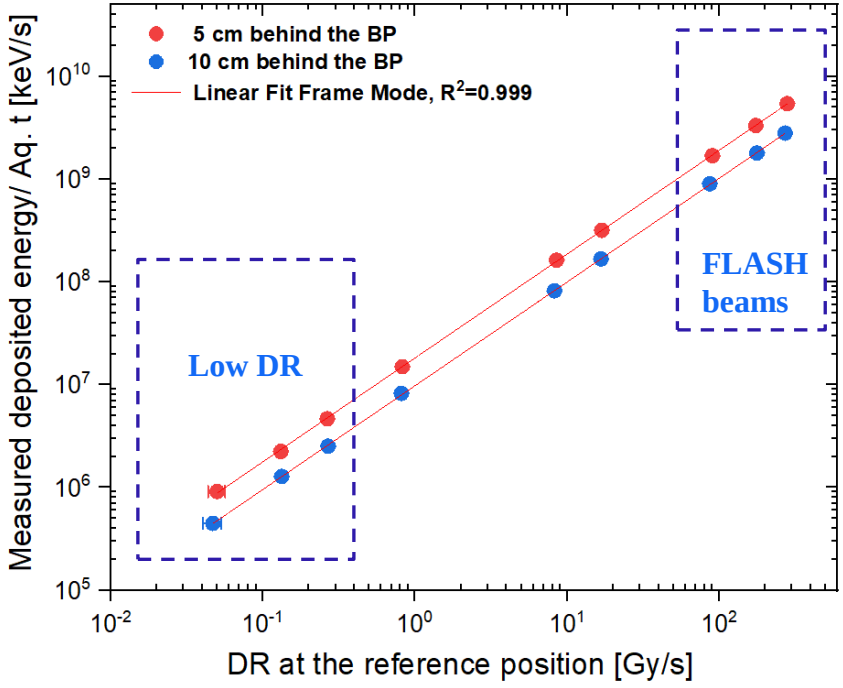
DR at 0 = 0.14 Gy/s



- *Predominantly low-LET particles*
- *At position 3 scattered particles with high-LET*

Linear deposited energy response for wide range of dose rates (DR)

from conventional to FLASH-like proton beams



- *Linear response of deposited energy*
- *Conversion from deposited energy to dose in Si and dose in water*

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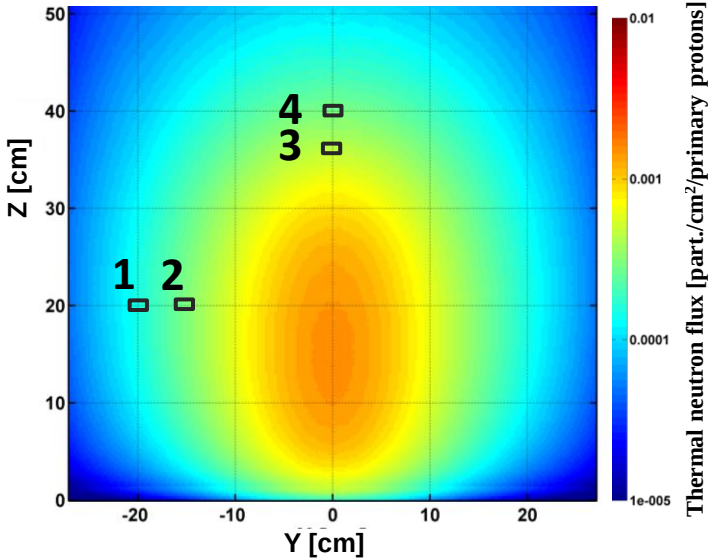
Preliminary results: thermal neutron flux in proton beams

MC simulation of spatial distribution of thermal neutron fluence*



*MC simulation provided by CMI

Measured thermal neutron flux
for a DR at the reference point of 0.27 Gy/s

Position inside water	Φ with detection efficiency constant [particles/cm²/s]
1	1.2E+04
2	2.7E+04
3	4.1E+04
4	2.5E+04

- *Thermal neutron flux in a water phantom should be an unneglected component*

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Summary

- The newly developed MiniPIX TimePIX3-Flex was used to characterize the stray radiation fields of conventional and UHDR proton beams produced in a water phantom
- A methodology for the characterization of secondary radiation produced in proton beams (composition, flux, deposited energy and dose rate) in water was developed
- Linear response of deposited energy in silicon over a wide range of DR (from 0.14 Gy/s to 270 Gy/s)
- A new method for measuring the thermal neutron flux in proton beams was established.

Acknowledgments

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- http://uhdpulse-empir.eu/
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Thank You!