SPECTRAL- AND INTENSITY-SENSITIVE CHARACTERIZATION OF PULSED FLASH PROTON FIELDS WITH THE PIXEL DETECTOR TIMEPIX3

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C. Oancea, J. Pivec, C. Granja, S. Polansky, L. Marek, J. Jakubek are affiliated at ADVACAM, Prague, Czechia.
➢ Provide and test a detector able to satisfy requirements of ultra-high dose rate (UHDR) particle beams

➢ MiniPIX TimePIX3 detector was tested for its suitability of use in high-intensity proton beams

➢ Establish a methodology for the characterization of secondary radiation produced in UHDR beams using Timepix3 detectors (e.g. composition, flux, deposited energy)

➢ Quantify the scattered radiation (protons, electrons, gamma, neutrons, other charged particles) and estimate its effect on the surrounding healthy tissue

➢ Particle tracking and cluster parameters: deposited energy, area, length, Linear Energy Transfer (LET) spectra measurement in a water-phantom.
MiniPIX TimePIX3 detector for UHDR beams

**Detector features:**
- Miniaturized radiation cameras
- All metal parts are removed
- Graphite support and chiller for sensors
- Temperature stabilization < 20 s
- Holder to connect to the IBA phantom PPS
- Event-by-event spectral tracking
- Matrix of **256x256 pixels (~1.4 x 1.4 cm²)**
- Pixel size 55 µm
- Time resolution of **1.6 ns**
- Threshold < 5 keV

**Sensors and thicknesses:**
- Si (100, 500, 650 µm)
- GaAs (550, 650 µm)
- CdTe (1000, 2000 µm)
- **Without sensor** (Naked)

**Optimized detectors for characterization of UHDR proton beams**
All electronic/metallic compounds were removed from the sensor

MiniPIX TimePIX3 Flex (right) with sensor placed in an extruded graphite support 5 cm distance from the electronics, (left) waterproof holder.

C. Oancea | FRPT | MinipIX TimePIX3 Flex
Experimental setup at the University Proton Therapy, Dresden

- Pencil proton beam of 220 MeV energy
- Delivery of beam pulses with specified dose (monitor chamber unit (MU)) MU=\~ 0.33 nAs
- 9 beam intensities/dose rates (DR) were studied
- Two MiniPIX TimePIX 3 detectors Si sensors
- An ionization chamber placed between the 2 detectors
- Detectors placed inside water-phantom (size: 50 x 50 x 50 cm³)
- Angles of measurement: 0°, 45°, 90°
- Operation modes:
  - data-driven (ToT+ToA, “.t3pa”)
  - frame (iTToT+Event, “.txt”)

<table>
<thead>
<tr>
<th>pulse length [s]</th>
<th>Beam current [nA]</th>
<th>DR [Gy/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>0.38</td>
</tr>
<tr>
<td>0.005</td>
<td>60</td>
<td>230</td>
</tr>
<tr>
<td>0.003</td>
<td>97</td>
<td>363</td>
</tr>
</tbody>
</table>

DR [Gy/s] at the Bragg peak (BP)* provided by J. Solc, CMI
Particle tracking in data-driven mode (low-intensity)

**MC simulation of 2D dose from primary protons norm.**

Proton beam  
E=220 MeV

**Measured deposited energy behind BP**

Scattered particles due to neutron production

$^6$LiF convertor partially covered the sensor

Minipix Timepix3 Si 500 μm

High-LET charged particles

Minipix Timepix 3 Flex , Si 500 μm

MC simulations provided by J. Solc, CMI

Measurements performed using Minipix Timepix3 Flex, Si 500 μm

C. Oancea | FRPT | MinipPIX TimePIX3 Flex
Particle tracking in data-driven mode (low-intensity beams)

Absorbed dose from secondary neutrons

Area

Energy

Height

Length

Linear Energy Transfer

C. Granja, et al., NIM-A, 2018

C. Granja, C. Oancea et al. NIM-A, 2021

MiniPIX TimePIX3 Si 500 µm
The response of MiniPIX TimePIX3 Si 500 µm at various intensities of UHDR, MU ~0.3 nAs

- At high intensity the detector was operated in frame mode (Event+iToT)
- The integrated per-pixel deposited energy was measured at >25 positions inside the water-phantom
- The same number of monitor units was delivered at various intensities (e.g. from 0.1 to 100 nA)
- Constant response of the detector in terms of energy and event rate
- A rescaling factor of data measured in data-driven mode can be applied.

Integrated deposited energy by a single pulses of 3 ms at I= 100 nA

![Deposited Energy vs beam intensity](image)

Illustration of measured points

![Illustration](image)
Study of the sensor’s thickness sensitivity in frame mode

A thinner sensor (100 µm) provides a radiation sensitive volume of smaller dimensions which thus:

- Reduces the detection efficiency for high energy X-rays and gamma rays
- Reduces the event count rate
- Reduces the amplitude* (charge created per px) of the detected signals
- Reduces the pixel size of the signal, allowing to register higher event rates

* signals of smaller amplitude are collected faster and allows to register more particles

The detector based on Si 100 µm sensor could be more suitable for UHDR proton beams measurements.
 Prototype detectors MiniPIX TimePIX3-Flex with silicon sensors of various thicknesses (100, 500, 650 µm) were tested in stray radiation fields of UHDR proton beams

➢ The detector’s response was successfully tested up to ~100 nA (~ 370 Gy/s at the Bragg peak), no saturation was seen

➢ A constant deposited-energy was measured with the MiniPIX TimePIX3 detector for a constant delivered MU by adjusting the pulse durations and beam current

➢ Detailed spectral particle tracking based on clustering can be made at small intensities (0.1 nA)

➢ The biological impact of UHDR scattered radiation to be quantified

Further work

• Calibrate the detectors using convertors for fast and thermal neutron fields at the CMI.
• Test the detectors at higher intensities/DR of UHDR proton and electron beams.
• Test the detectors in laser-driven proton beams and improve the shielding, if necessary.
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Thank You!

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