CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

"MAPS characterization by measuring spatial 2D-distributions of ions or photons".

KINR

INTRODUCTION OF POSSIBLE CONTRIBUTION TO WP7 Project

VALERY PUGATCH

Institute for Nuclear Research
National Academy of Sciences of Ukraine

WP7 kick-off meeting , Sept. 4th., 2020

CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

The goal: To characterize MAPS features measure 2D spatial distribution of ions or photons beams; compare the results obtained for irradiated/non-irradiated devices.

- **Low energy (<100 keV) ions or photons:**
  - **Laser Mass-Spectrometer**
  - **X – ray facility, Difractometer**

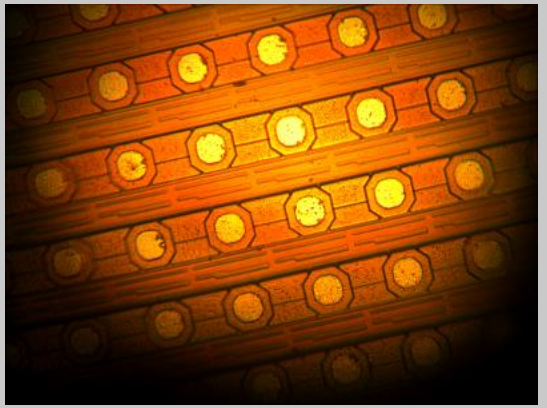
- **Low and Medium energy ions and electrons:**
  - **1 – 28 MeV – Tandem generator, Cyclotron U-120**
  - **40 -140 MeV - Isochronous Cyclotron U-240,**
  - **Electrons beams, 1-5 MeV – e-LINAC, 5-15 MeV -CLINAC**

- **Irradiation:**
  - **neutrons reactor WWR-10**
  - **HI - Isochronous Cyclotron U-240**
  - **X-rays, electrons - X – ray facility, e-LINAC**

Illustration of proposed approach to characterization of MAPS

TimePix (MEDIPIX, CERNHybrid pixel detector n-Silicon sensor chip and the electronics chip connected via bump bonds.

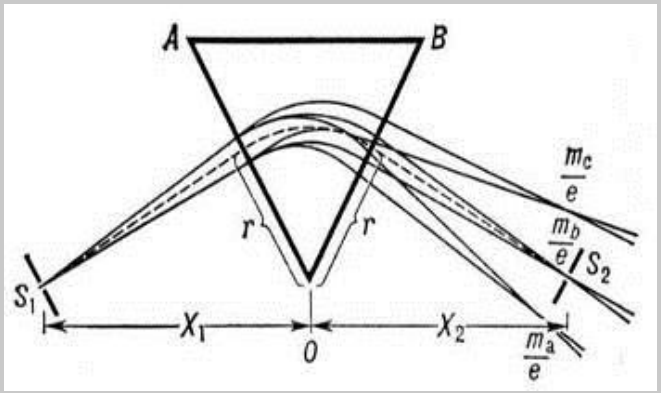
- 256 x 256 pixels
- 55 x 55 µm ^{2}
- 3 modes:
  - Single particle counting,
  - Time over Threshold
  - Time of Arrival

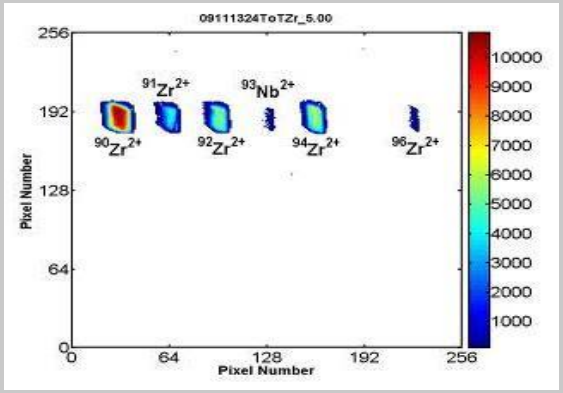


A bare TimePix readout chip with its input contact pads used as metal micro-detector

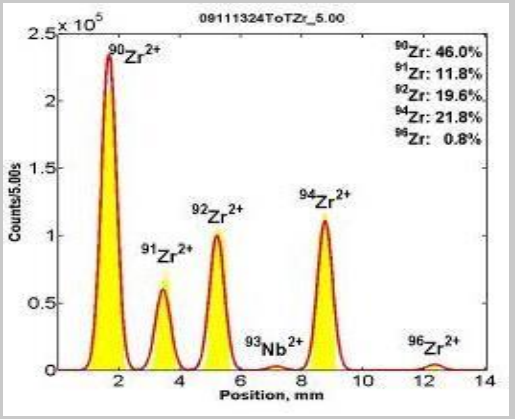
A positive voltage has been applied to a mesh over the chip area – to collect secondary electrons emitted by metal surface of the chip under the impact of impinging ions.

Medipix detector in a Laser Mass-Spectrometer. Institute of Applied Physics NAS Ukraine, Sumy





mass spectra of sample with Zr^{2+} – isotopes . Energy of ions 12,3 keV



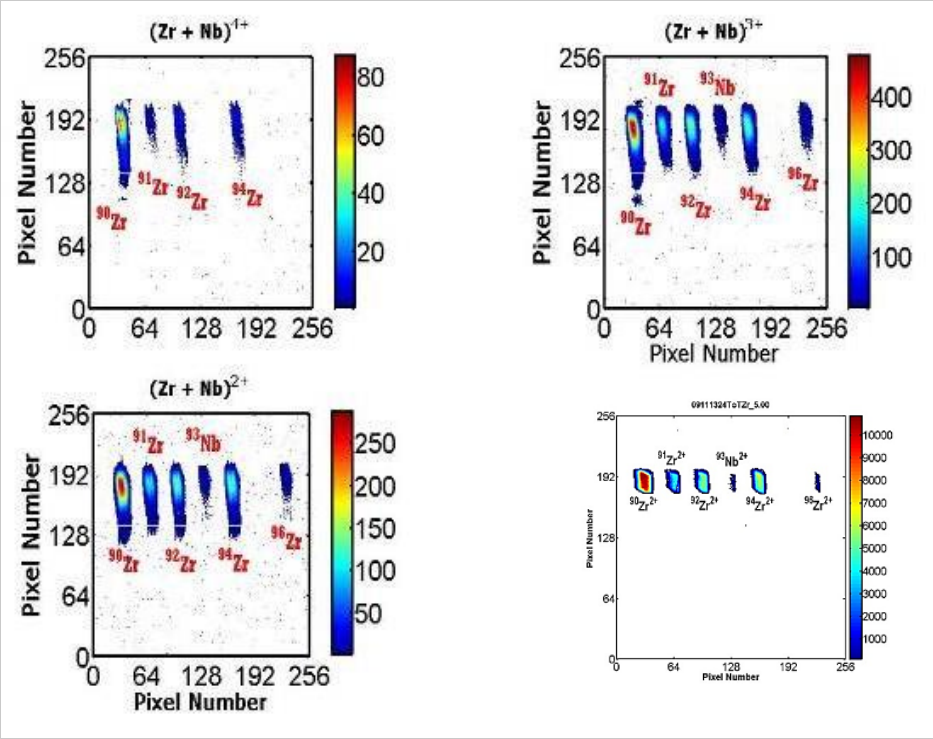
Ion beam has been generated at the sample-target by the infrared (1064 nm) laser (15 ns, 50 Hz).

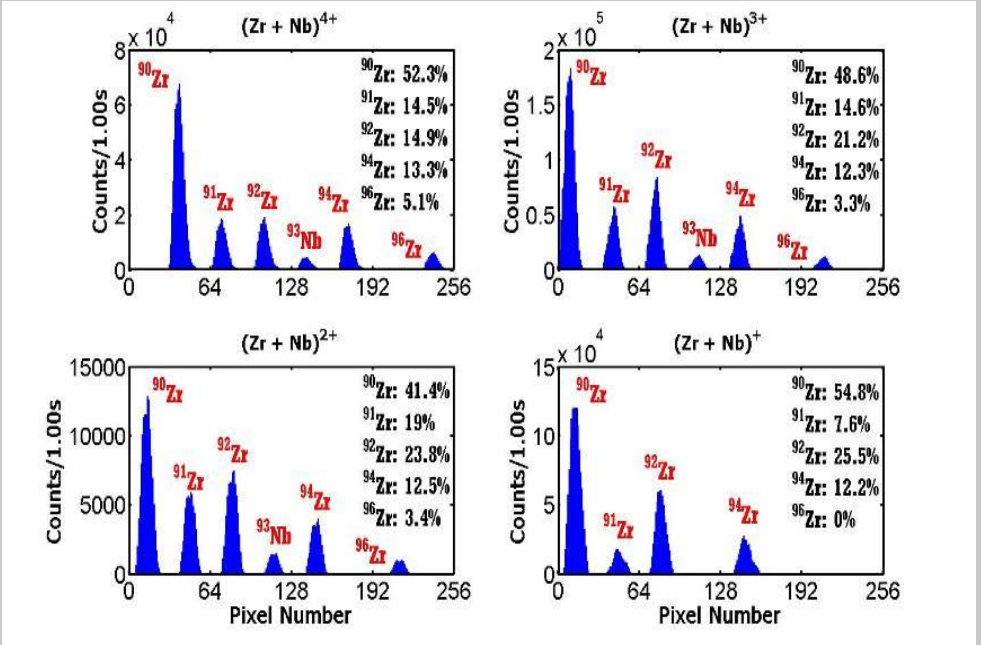
Passing through the magnetic sector ions were focused accordingly to their mass over charge ratio in a focal plane (210 mm long) of the mass-spectrometer.

For each bunch of ions detected by a pixel a triangular pulse is formed with a height proportional to a number of ions in a bunch. Whenever the new bunch of ions arrives at the pixel its counter content is increased accordingly to the number of ions in the bunch.

TimePix chip was readout by the PIXELMAN hardware/software (IEAP, Prague) via USB-connection to PC.

TimePix measuring low energy ion beams





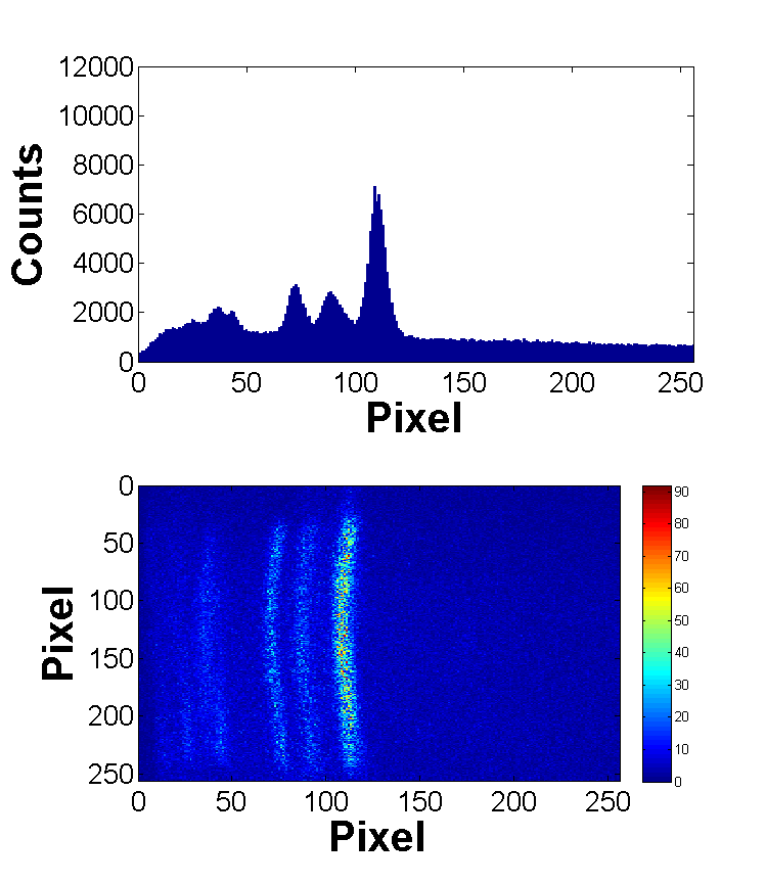
Two dimensional data on-line –
'electronic photo-plate' – for alignment, focusing, testing stability of electric and magnetic fields etc.,)

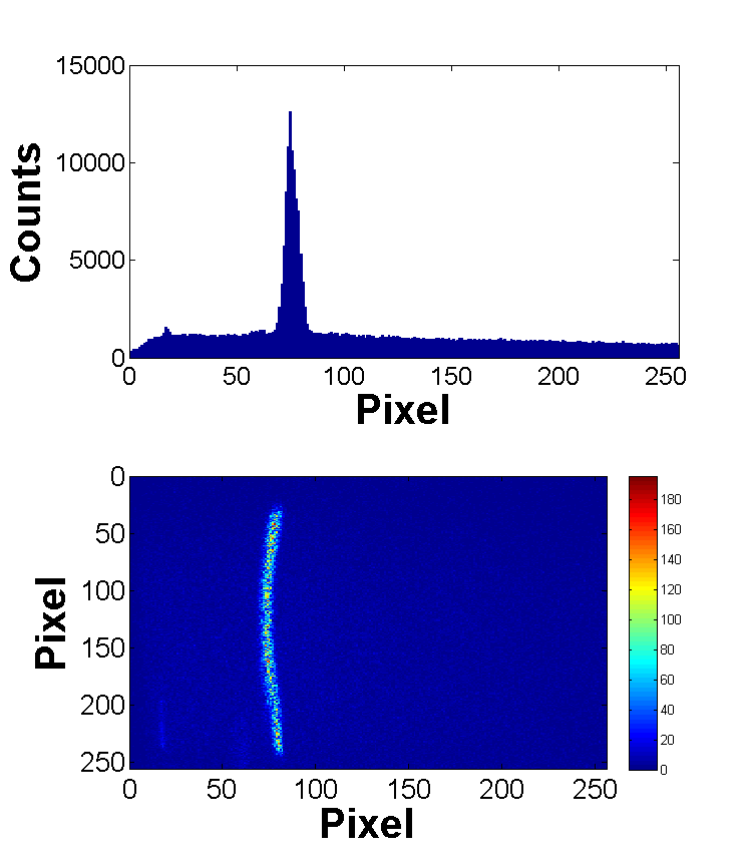
A powerful tool in a feedback system
for fine tuning of a mass-spectrometer and similar devices.

Uniformity of response is a crucial feature for a sensor.

Timepix measuring diffraction of x-rays by metals

- Institute for Problems of Material Science NASU (Kyiv)





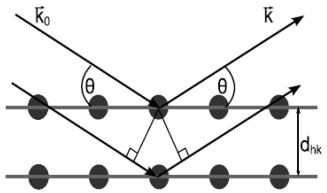


Figure 2.2: Bragg's law. Diffraction from crystallographic planes (hkl) at the Bragg angle θ. The lattice plane spacing is d_{hkl}, and the incident and scattered wave vectors are $\vec{k}_0$ and $\vec{k}$

$$2\, d_{hkl}\, \sin\theta = \lambda$$

The diffraction peak position was determined ‘
from two-dimensional distribution of X-rays scattered by metal sample

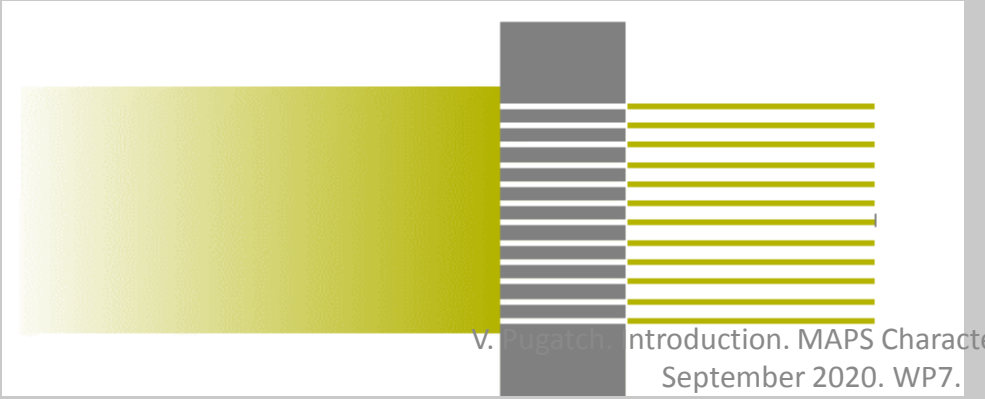
Shaping and monitoring of mini-beams of charged particles and gamma-rays for spatially fractionated radiation therapy

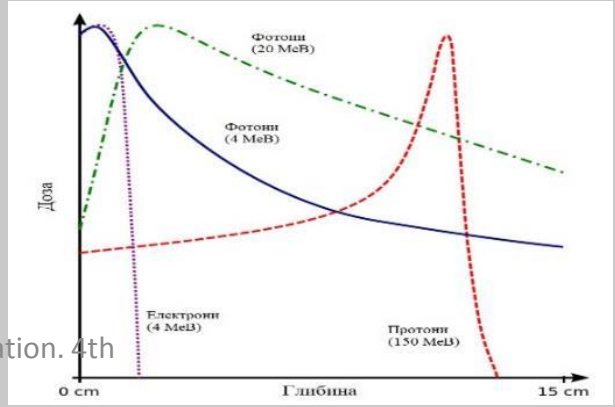
•**Make Irradiation field inhomogeneous:**

- **Shape it as mini-beams (0.6 mm width and 1.2 mm periodical structure) or micro-beams (50 µm and 100 µm periodical structure)**
- **Developed for the synchrotron radiation at ESRF (Grenoble)**
- **Measured for the first time in real time in 2011 in Collaboration KINR_ESRF_Medipix(CERN) – spatial dose distribution in agreement with gafchromic films (off-line, time consuming procedure, yet with a perfect position accuracy – few micrometers).**

•**New idea (IMNC, Yolanda Prezado) – to implement it for the hadron beams (feasibility studies started at HIT – Heidelberg in 2014 (KINR-IMNC-CERN)**

•***[V. Pugatch, et al. Characterization of equipment for shaping and imaging hadron minibeams. NIM A872 (2017) 119-125.]***

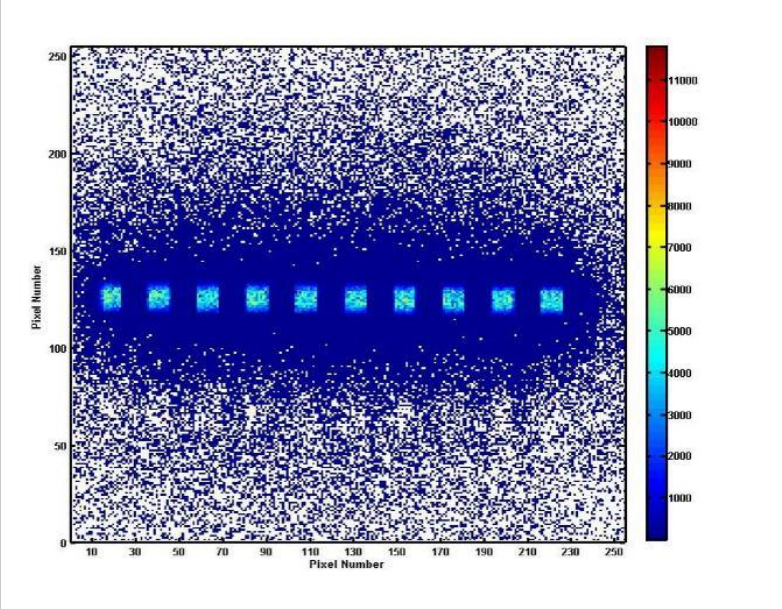




TimePix measuring High intensity X-Ray beams

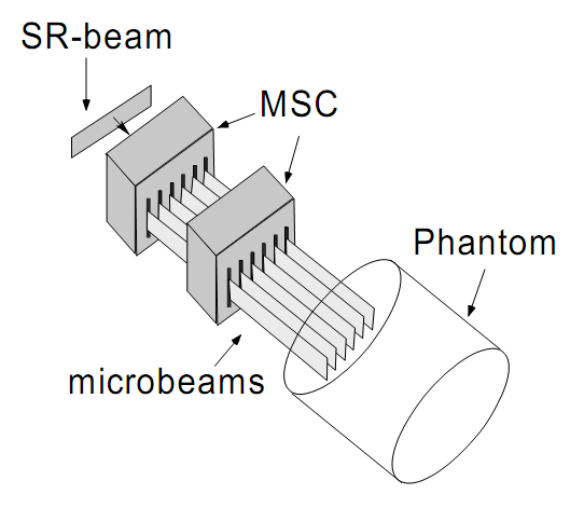
Measurements at the beamline ID17 ESRF (Grenoble)

The experiment (ESRF, MI1056) was carried out at the beamline ID17 with closed wiggler gap (24.8 mm) in the 16-bunches mode and with 200 mA electron beam current in the storage ring with the electrons energy of 6 GeV. X-rays with peak energy of 150 keV (ranging from 20 to 500 keV) were produced with intensity of 2,7×109 photons/(c×mm2×mA).



2D image of the 10 X-ray beams measured by the TimePix (Metal) detector.

The spatially fractionated mini-beam

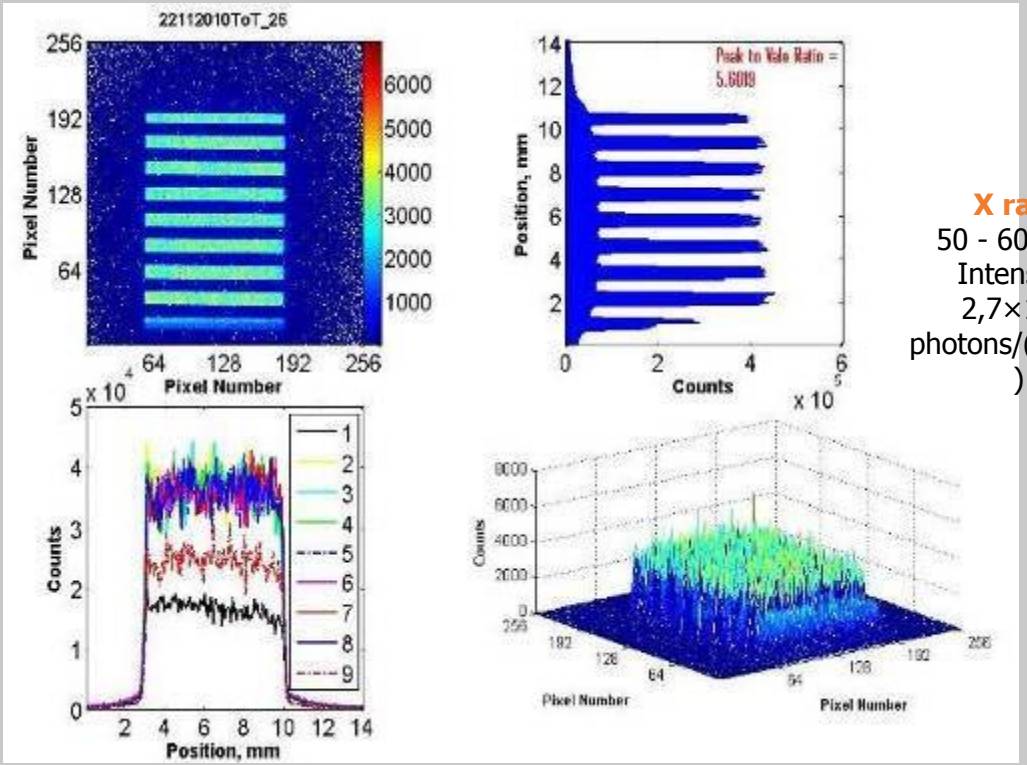


Energy: 150 keV
Intensity: $2,7 \cdot 10^{11}$ photons/(c·mm²)

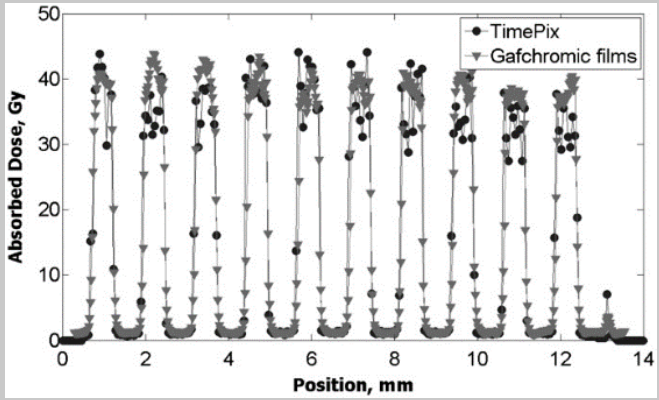
Metal TimePix detector imaging the X-ray beam.

Color grade indicates the relative beam intensity.

Metal TimePix imaging X-rays beams at the Bio-medical beamline ID17 (ESRF, Grenoble).



X rays
50 - 600 keV
Intensity:
$2{,}7\times10^{11}$ photons/(s×mm^2)



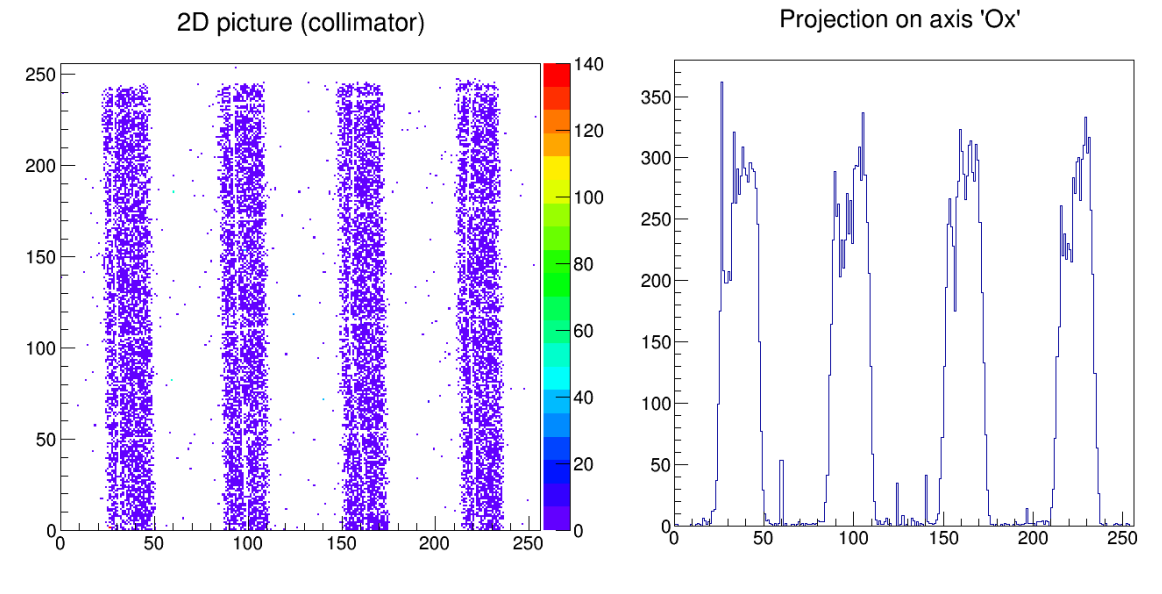
Conventional dose measurement (gafchromic films) using microscope technique takes up to 24 hours.

Characterization studies of the Metal TimePix measuring in real time dose distribution at the Mini-beam Radiation Therapy setup (ESRF, Bio-Medical Beamline ID17) were performed.

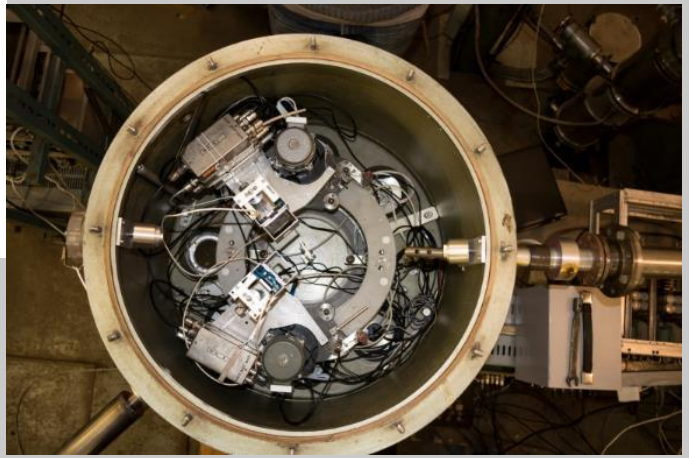
The results obtained for high intensity synchrotron radiation mini-beams illustrate an excellent performance of the TimePix providing 2D image of the high level dose distribution over many beams in (14 x14) mm^2 area.

Peak-Valley-Ratios measured by TimePix and gafhromic films agree well.

Feasibility studies of the spatially fractionated hadron therapy. KINR (Ukraine)

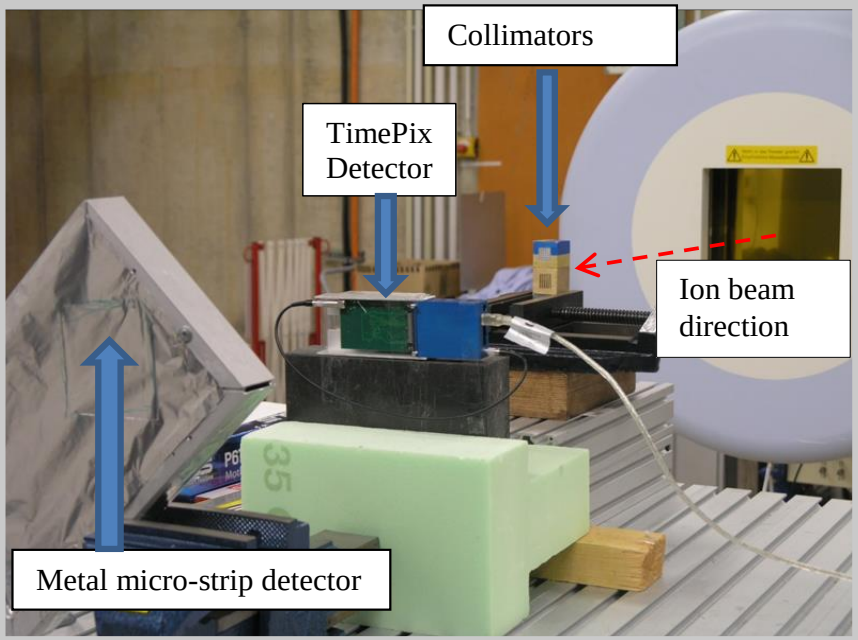


Metal TimePix detector

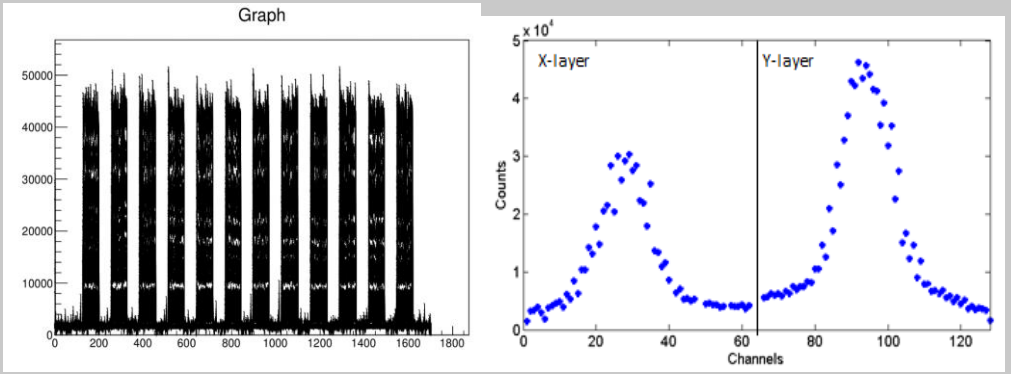


Left: 2D distribution of the of the proton beam intensity (color scale at the right side) measured by metal TimePix detector (X- and Y-axis – pixel number). Slit collimator was installed in front of the TimePix detector. Right: Projection of the data onto X-axis.

Feasibility studies of the spatially fractionated hadron therapy. HIT (Heidelberg)



Primary carbon ion beam time and spatial structure measured by MMD



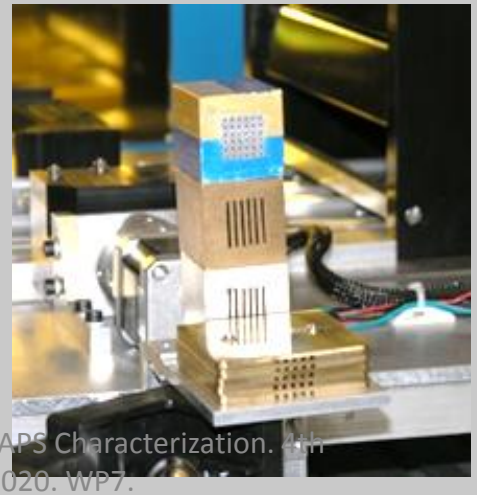
Time structure

Spatial distribution of the intensity of the primary beam in X- and Y-direction.

Fixed horizontal beam station of the Heidelberg Ion Therapy center (Germany)

Setting up the collimators designed and made in Ukraine – to test the possibility to make multi-beam structure – fractionated hadron therapy.

MMD was installed for monitoring of the overall beam profile monitoring



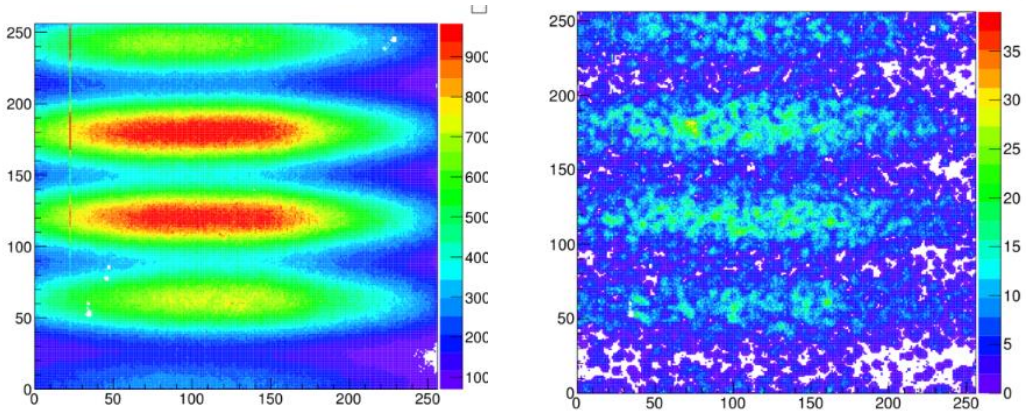
Slit Collimators
(1.0 mm width, 2.5 mm c-t-c distance)

Matrix collimators
(holes of 1.5 x1.5 mm^2 and c-t-c distance of 4 mm)

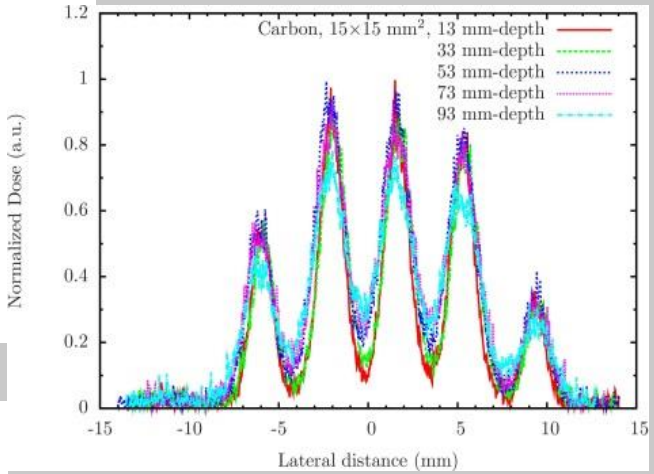
Material: aluminum, brass, lead

Feasibility studies of the spatially fractionated hadron therapy. HIT (Heidelberg)

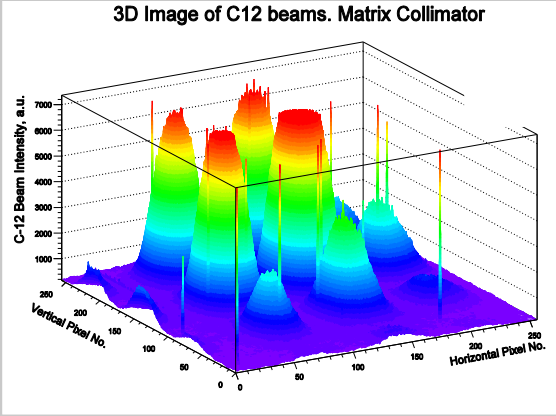
2D images of carbon mini-beams shaped by the **slit collimator** (brass) with five slits (1.0 mm width, 2.5 mm c-t-c distance)

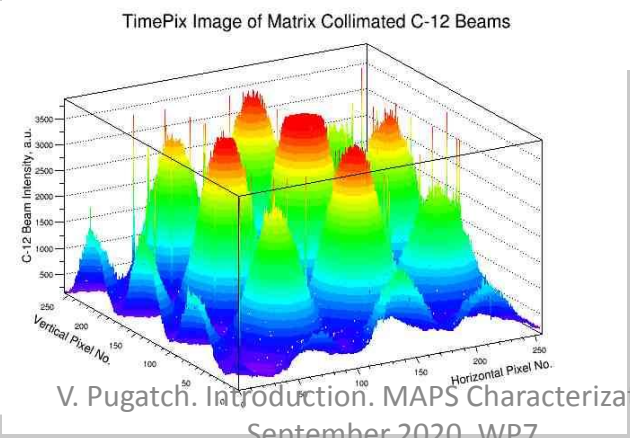


The lateral dose (normalized, a.u.) profiles for carbon ions measured at several depths (13, 33, 53, 73 and 93 mm-depth) in a RW3 solid-water phantom. The irradiation field size was 15×15 mm^2.

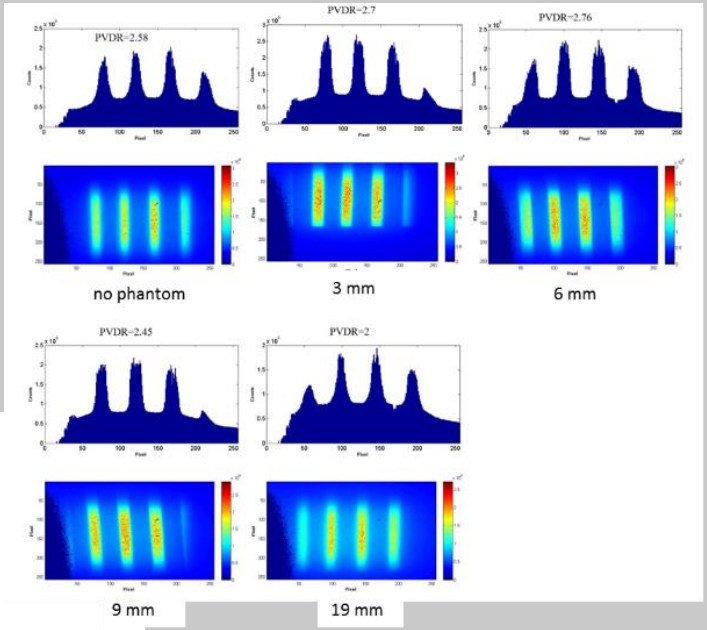


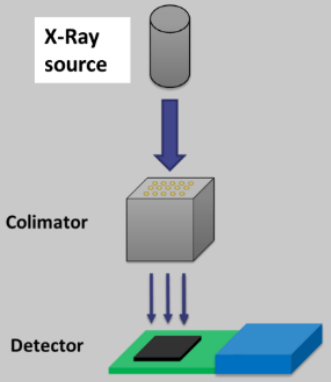
Images of carbon mini-beams shaped by a **matrix collimator** made out of 40 mm thick brass: 1.5 x1.5 mm^2 holes with c-t-c distance of 4 mm





Testing at the Clinac system



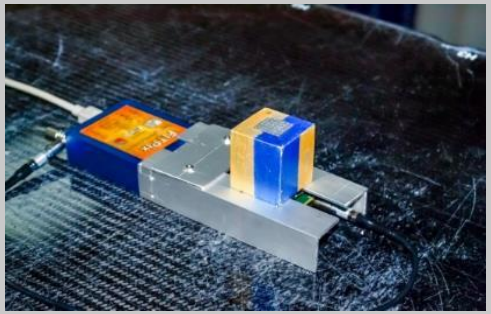


Beam Energy: 6-12 MeV

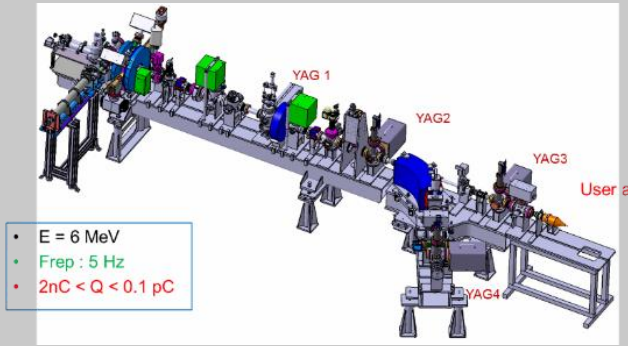
Pulse Width: 5 µs

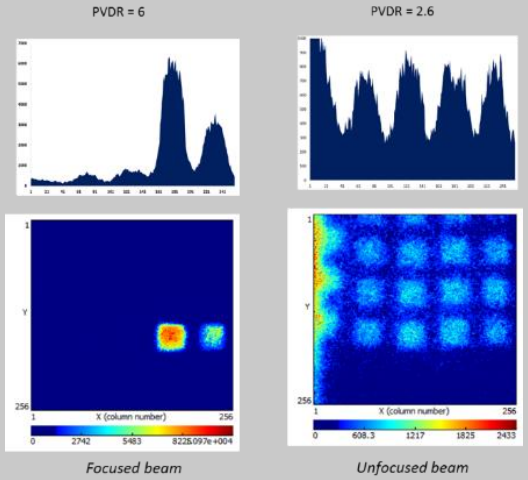
Pulse Repetition Rate: 20-100 Hz

Beam type: Photon, electron

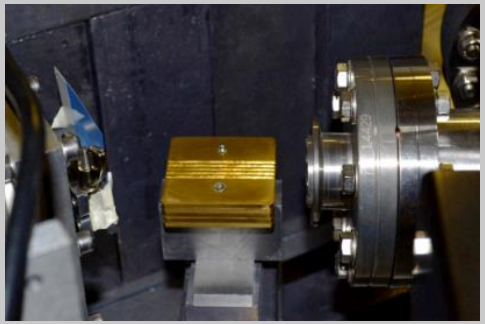


Testing at the PHIL

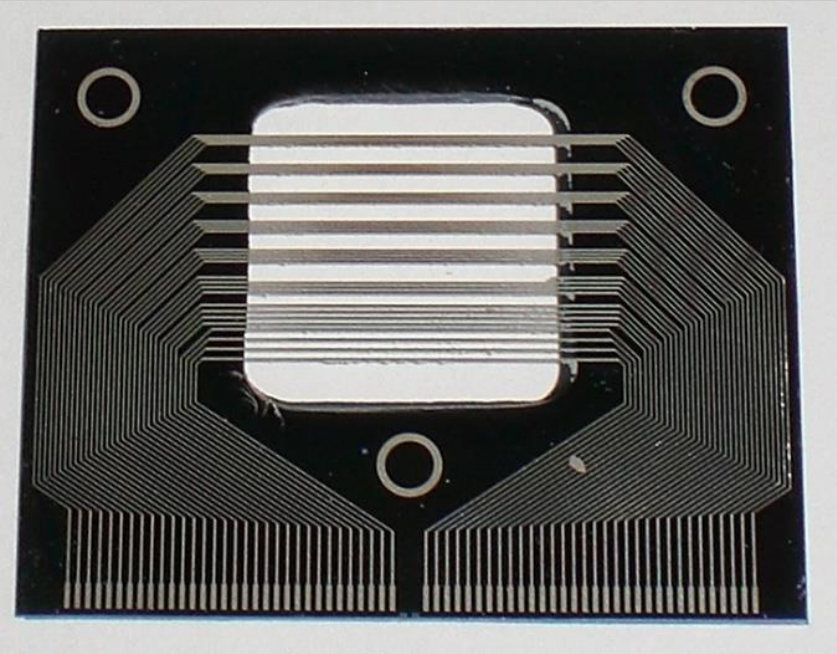




Focused beam *Unfocused beam*



MMD WITH VARIABLE PITCH – A TOOL FOR MEASURING SPATIAL RESOLVING POWER



Variable Distance between strips – from 100 to 2 µm.

Thickness - 2 µm.

Summary

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  - **neutrons reactor WWR-10**
  - **HI - Isochronous Cyclotron U-240**
  - **X-rays, electrons - X – ray facility, e-LINAC**

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

•We highly appreciate MEDIPIX Collaboration (CERN) for the introduced opportunity to carry out studies with Timepix detector.

•Part of these studies were carried out in frames of the LIA IDEATE activity.

•Related projects have been financially supported by CNCP (UK) and NAS of Ukraine grants.