“Metal Mode MAPS for Measuring Time Stamped Spatial Distributions of Ions or Photons".

VALERY PUGATCH

Kyiv

Institute for Nuclear Research
National Academy of Sciences of Ukraine

EURIZON

WP7 meeting , Feb. 9th., 2023. GSI. Darmstadt

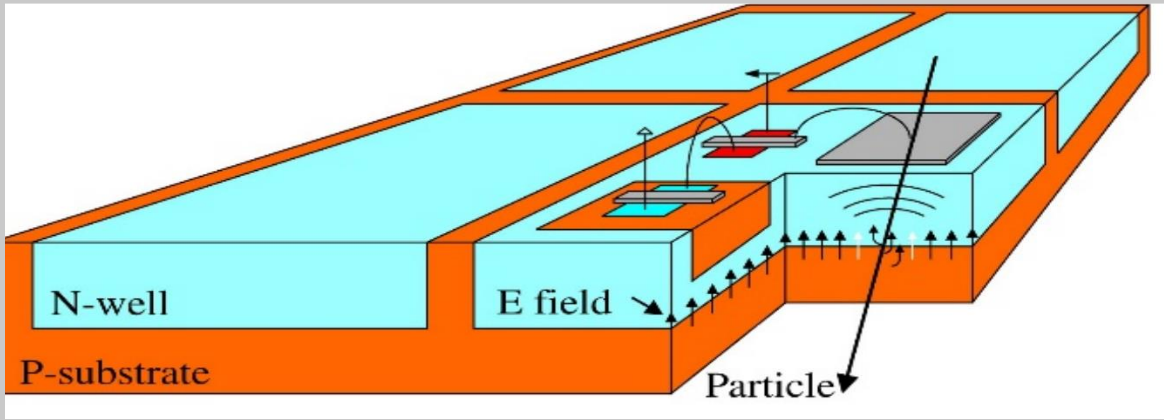
On a possibility to build Superthin Radiation Hard Detector of Ions or X-Rays Beams

Let us consider:

- **CMOS Pixel Readout Chip (25 μm)**
- **Metal Micro strips (2 μm)**
  - **Combined to get METAL MPS Detector, which might become a new**

Superthin Radiation Hard Detector of Ions or X-Rays Beams

1. CMOS Pixel Readout Chip



LOW THICKNES MAPS (30-50 µm)

- ➢Extremely low noise (~20 e^-).
- 28 nm CMOS technology – time stamp of ~ 25 ps .

➢The idea is to produce a chip with readout pixels only, making input pads of preamplifier open to allow SEE caused by incident ions be collected by closely placed metal microstrips (Metal Foil Detector principle)

MFD principle: SEE electrons are measured

NIM A 650 (2011) 194

2. METAL Micro Strips

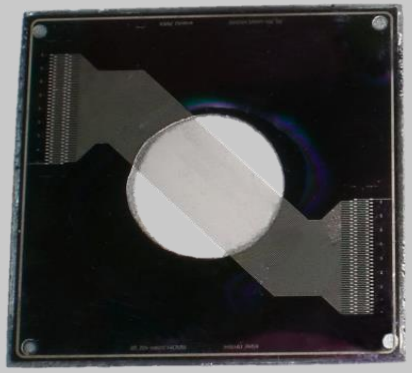
Metal Micro Strip Detectors (MMD) – Original production Technology developed at KINR allows to produce 1-2 µm thick microstrip sensors.

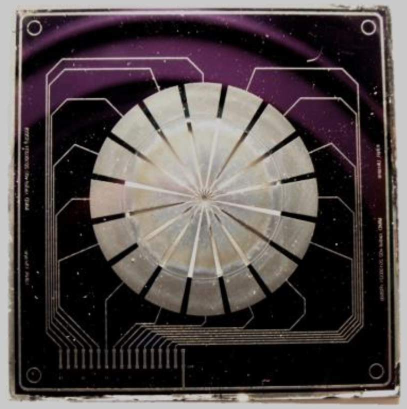
(Ref. Problems of Atomics Sciens and Technologies, 6(87) (2012) 196)

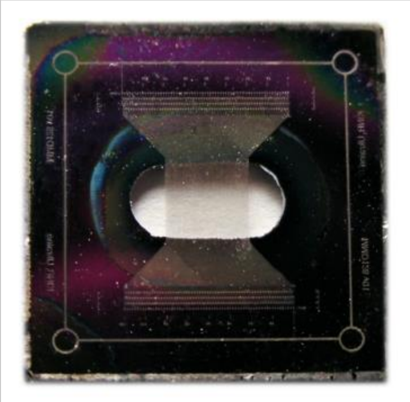
Various layouts and strips pitch (2, 30, 60 µm) are available. (Right hand photos)

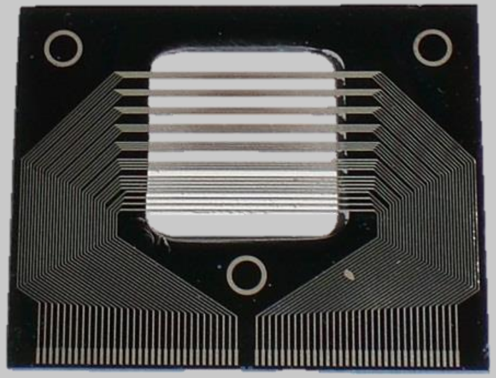
Ref. Journal NPAE, v.17(2016) 92-97;

- **Science and Innovatiobs, v.10 (2014) 25-30**
- **Journal NPAE, v.13/4 (2012) 382**

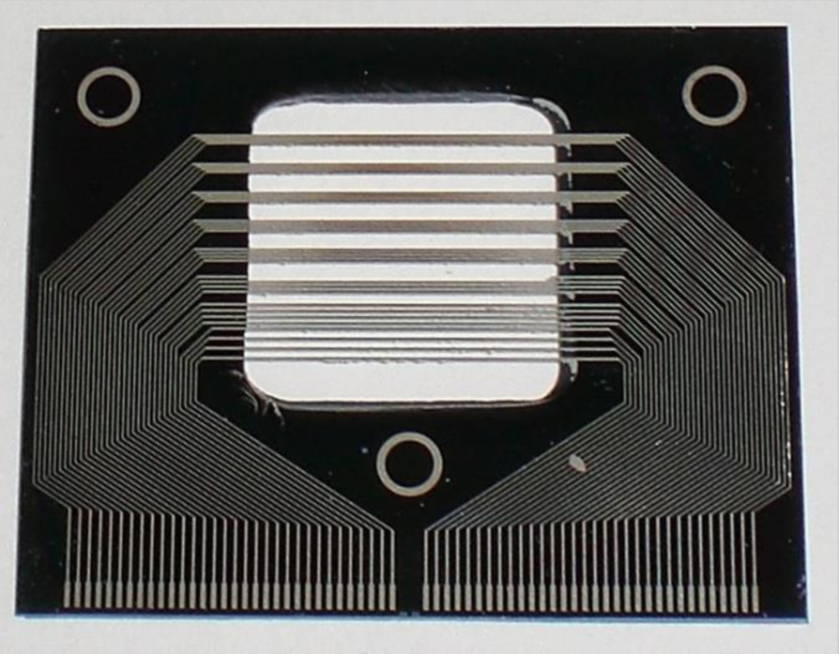








MMD WITH VARIABLE PITCH –
A TOOL FOR MEASURING SPATIAL RESOLVING POWER



Variable Distance between strips – from 100 to 2 µm.

Thickness - 2 µm.

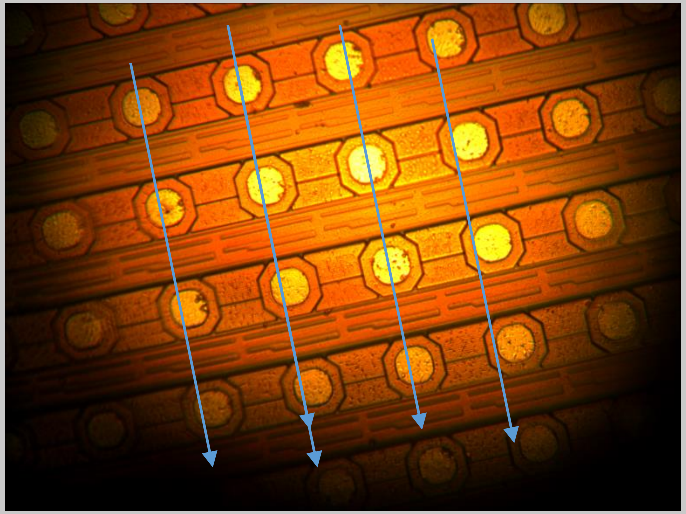
Proof of the Principle :
Timepix (CERN) detector operation in a metal mode

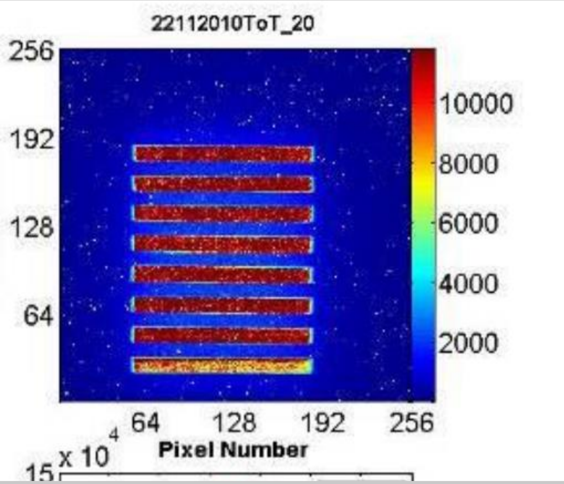
- Timepix detector "readout chip, only", implementing the principle of Metal fFoil Detectors MFD), was successfully tested by the KINR and CERN teams in a set of applications.

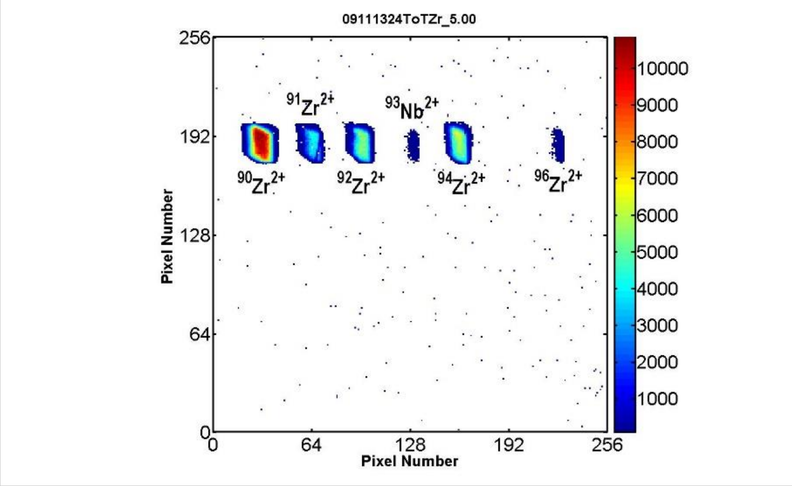
- The response to charged particles occurs in metal sensors due to secondary electron emission (SEE) from metal contact micro-pads connected to the inputs of charge amplifiers.

Timepix testing team in Sumy (Ukraine). Institute of Applied Physics. September 2008.

Metal mode Timepix operation.
MFD principle:
Integrate positive charge in a metal contact pad caused by SEE.







MFD principle: SEE electrons are emitted from input pads of a chip:
-> collect them applying positive voltage to a mesh (1 µm thick Ni strips) mounted over the chip area at ~ 3 mm.

NIM A 650 (2011) 194

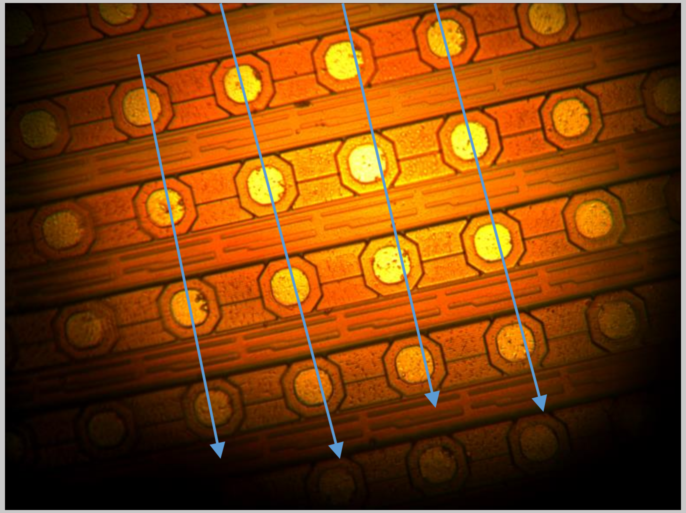
Response to X-rays . ESRF-2011
NIM, A 682. – 2012. P. 8–11

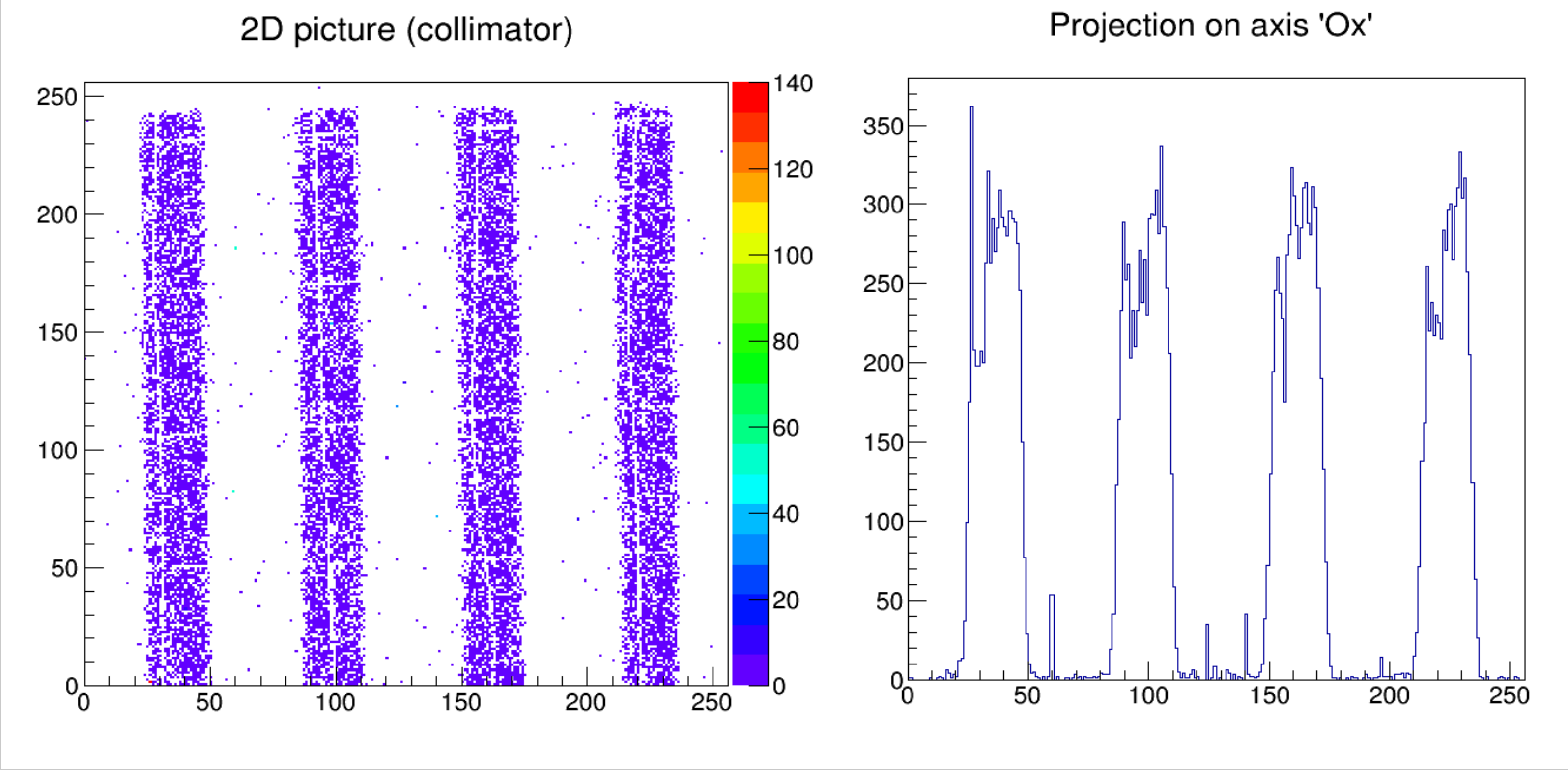
Similar results:
Journal NPAE, v.17 (2016) 92-97;
Science and Innovatiobs, v.10 (2014) 25
PAST, 6(87) (2012) 196
Journal NPAE, v.13/4 (2012) 382

Metal Timepix Response:
-to low energy ions. (Laser mass-pectrometer. NIM A 650 (2011) 194, Journal NPAE, v.10 (2009) 424)

-to Heavy ions (200 MeV) at HIT:
NIM A872 (2017) 119-125

Metal Mode Timepix –
measuring proton beam (2.65 MeV)
shaped by the slits collimator at KINR' Tandem Generator





Metal Mode Timepix – making SELFI picture of collecting electrodes (white lines inside the irradiated areas defined by collimator' slits.

CMOS-28 nm –MetMPS.
Superthin Radiation Hard Detector

By the analogy, we propose to develop a metal mode of MAPS, excluding in their construction a silicon sensitive layer ("P-substrate").

- **A grid of 1 micron thick collecting electrodes made by MMD technology will be installed on top of the entire plane of the read-out chip at a distance of about 0.5 mm.**
- **A positive voltage of about 5 V will provide a collection of SEE electrons (the maxiμm of their energy distribution is at 3 eV [Nucl. Instr. Meth., A535 (2004) 566]).**
- **Such a detector would operate as Metal Monolithic Pixel Sensor (MetMPS).**

CMOS-28 nm –MetMPS. Superthin Radiation Hard Detector

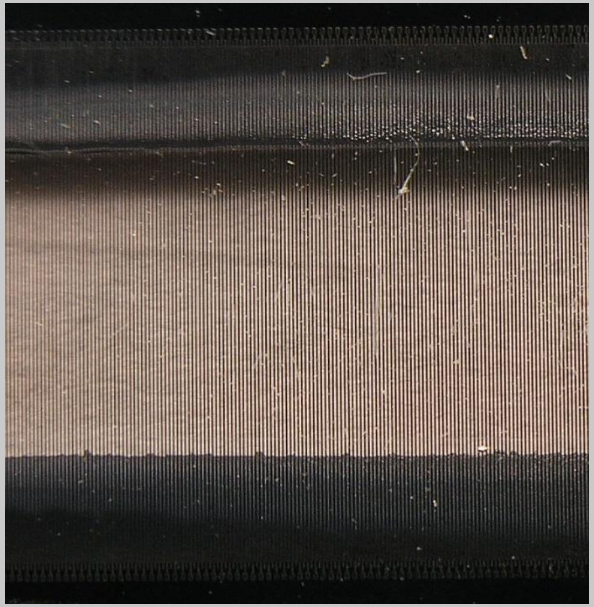
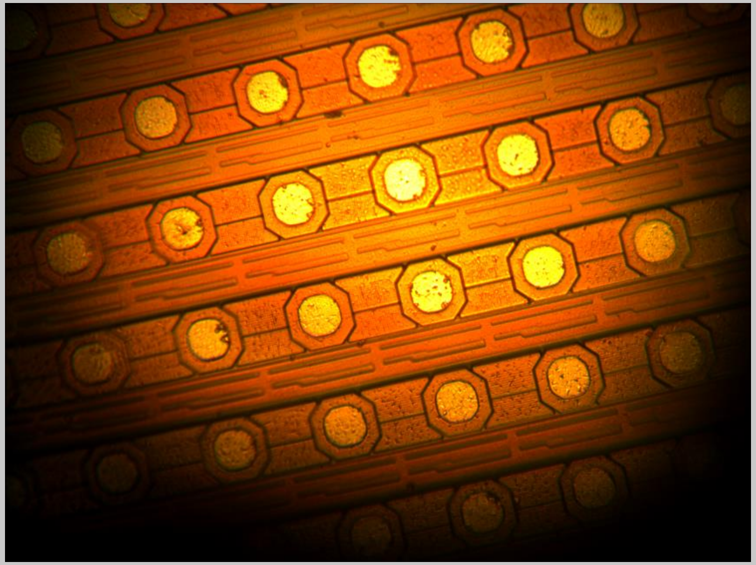


Photo of MMD- 1024 Ni strips:
1.5 µм thick, 40 µм wide, 60 µм pitch



A grid with 1 µм thick electrodes be mounted over the read-out chip at a distance of about 0.5 mm.

CMOS-28 nm –MetMPS.
Superthin Radiation Hard Detector

Some of the expected benefits of modifying MAPS to MetMPS:

- **Fabrication of the read-out chip, only**

  ->Commercial CMOS nm technology (low resistivity silicon).
- **Increase of radiation hardness.**
- **Reduction of the thickness of the detector.**
- **Low biasing voltage.**
- **No noise caused by reverse current**
- **and capacitance at the input of the amplifier.**
- **Low cost**

CMOS-28 nm –MetMPS.
Superthin Radiation Hard Detector

- **The extremely low noise (10 e) makes it possible to detect not only fluxes of minimally ionizing particles (1 SEE electron per 10 MIPs), but also individual heavy ions, provided that they generate SEE electrons in the amount of few tens electrons. Such SEE yields were observed in studies with Xe ions.**

- **Possible application of MetMPS (Metal Monolithic Pixel Sensor) - "in-situ" monitoring of heavy-ion beams (e.g., “pencil beams” for the purposes of spatially fractionated radiation therapy).**

- .

Summary and Outlook

- **We propose to develop a Superthin Radiation Hard Detector, MetMPS**

- **That might be accomplished by combining the MAPS read-out chip**

with a grid of 1 micron thick electrodes (KINR production) at a distance of about 0.5 mm biased by a positive voltage of about 5 V.

- **Development of a compact DAQ board for the MAPS is an essential prerequisite for its characterization and further applications.**

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THANK YOU FOR YOUR ATTENION !

Acknowledgements

The results presented in this talk were obtained due to inspiring and pleasant collaboration with colleagues from *INR NASU (Kyiv), MEDIPIX Collaboration (CERN)*, IAP NASU (Sumy), *IEAP (Prague), IPMS NASU* (Kyiv).

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- **Our special thanks to MEDIPIX Collaboration for introducing a possibility to carry out studies with a state-of-the art Timepix devices.**

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BACKUP SLIDES

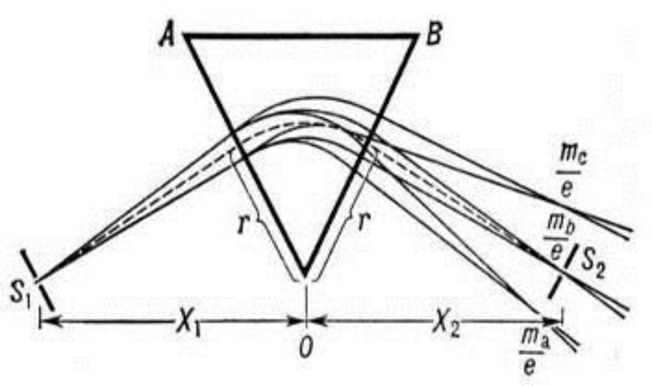
KINR Team - characterization of MAPS
measuring 2D spatial distribution of ions or photons beams;
comparing the results obtained for irradiated/non-irradiated devices.

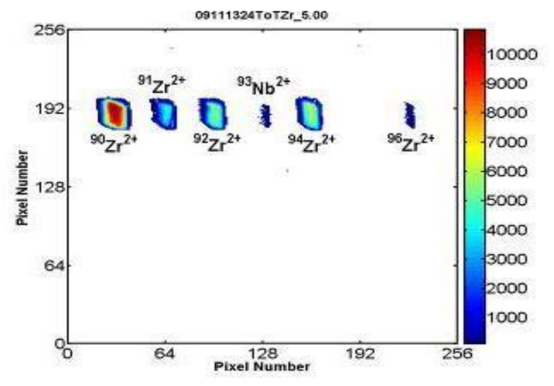
- **Low energy (<100 keV) ions or photons:**
  - **Laser Mass-Spectrometer**
  - **X – ray facility, Difractometer**

- **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**

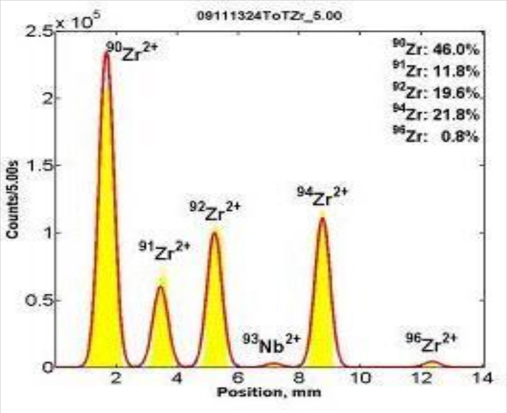
- **Irradiation:**
  - **neutrons reactor WWR-10**
  - **HI - Isochronous Cyclotron U-240**
  - **X-rays, electrons - X – ray facility, e-LINAC**

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).

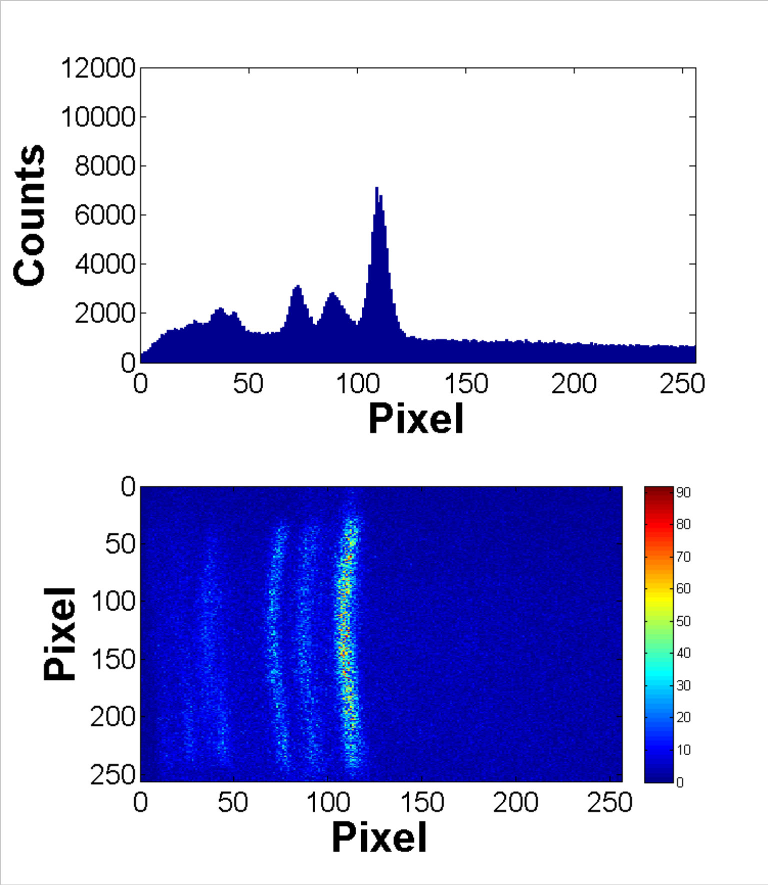
Passing through the magnetic sector ions were focused accordingly to their mass over charge ratio in a focal plane (210 mm long) of the mass-spectrometer.

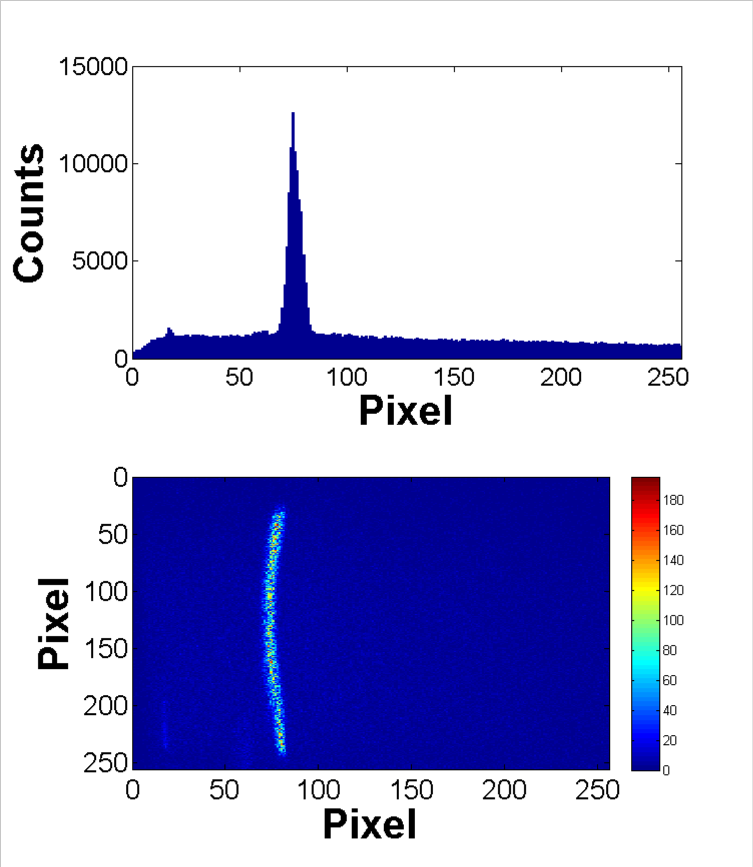
For each bunch of ions detected by a pixel a triangular pulse is formed with a height proportional to a number of ions in a bunch. Whenever the new bunch of ions arrives at the pixel its counter content is increased accordingly to the number of ions in the bunch.

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

Timepix measuring diffraction of x-rays by metals

- Institute for Problems of Material Science NASU (Kyiv)





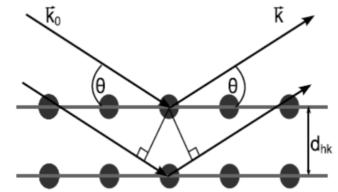
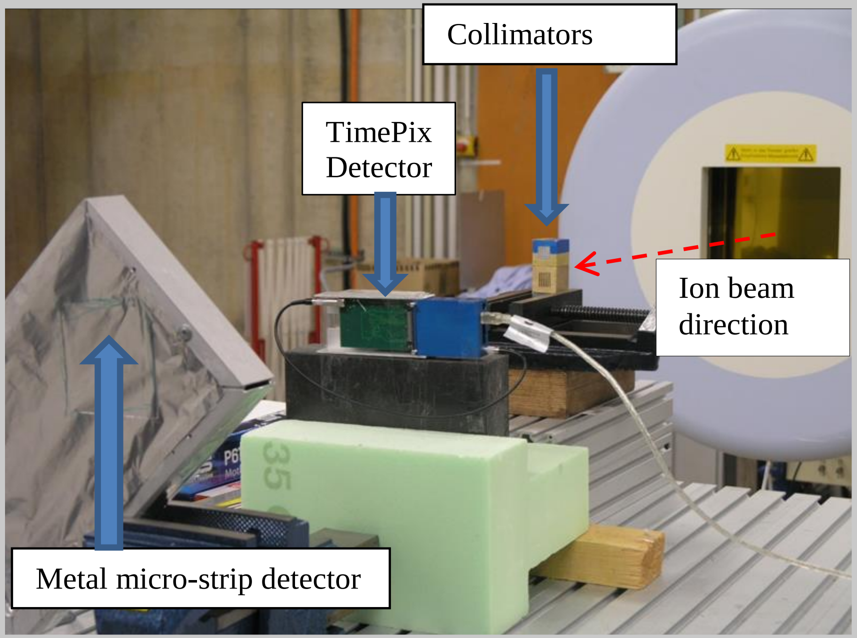


Figure 2.2: Bragg's law. Diffraction from crystallographic planes (hkl) at the Bragg angle θ. The lattice plane spacing is d_{hkl}, and the incident and scattered wave vectors are $\vec{k_0}$ and $\vec{k}$

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

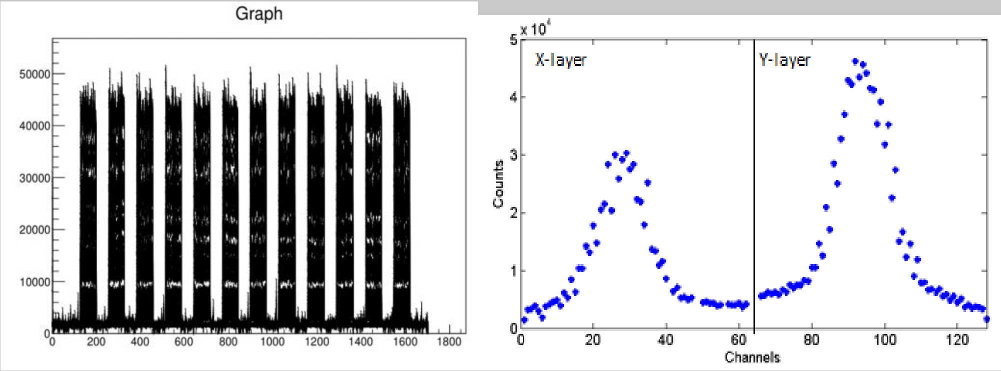
The diffraction peak position was determined ‘
from two-dimensional distribution of X-rays scattered by metal sample

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



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

Primary carbon ion beam time and spatial structure measured by MMD

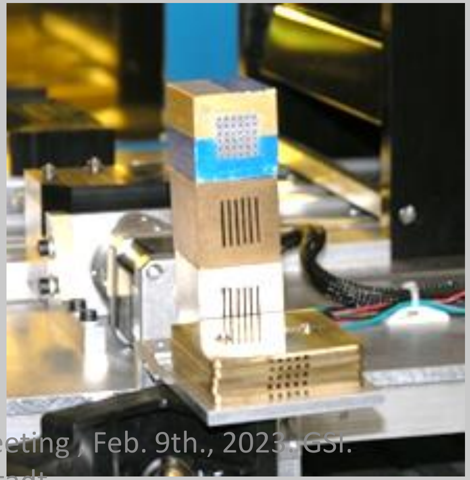


Time structure

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

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



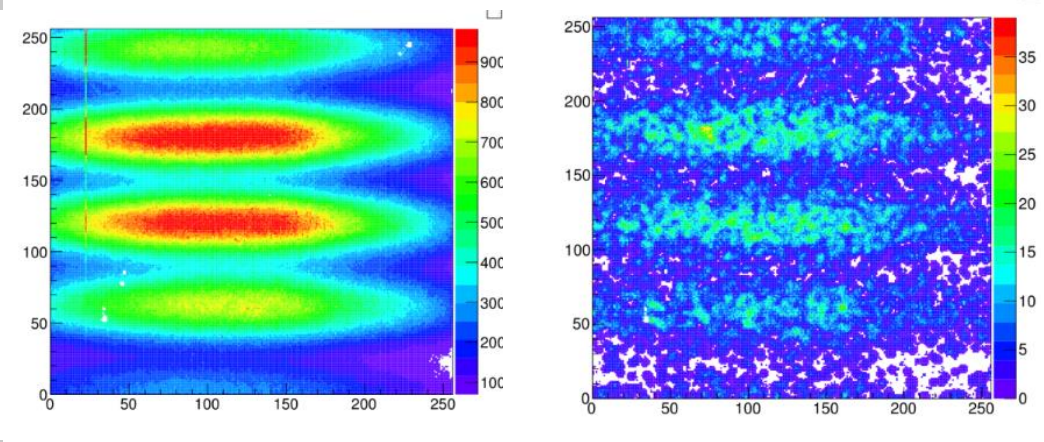
Slit Colimators
(1.0 mm width, 2.5 mm c-t-c distance)

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

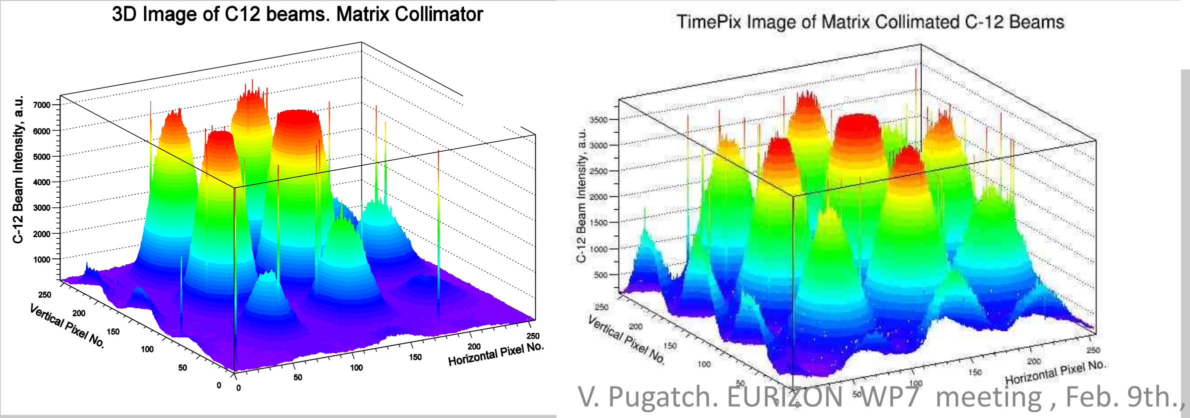
Material: aluminum, brass, lead

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

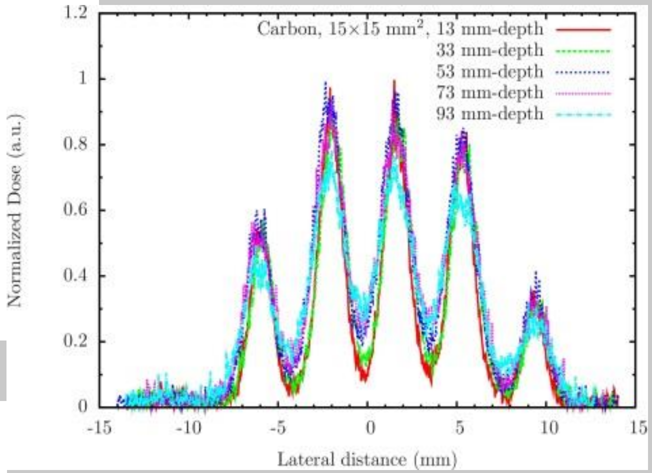
2D images of carbon mini-beams shaped by the **slit collimator** (brass) with five slits (1.0 mm width, 2.5 mm c-t-c distance)



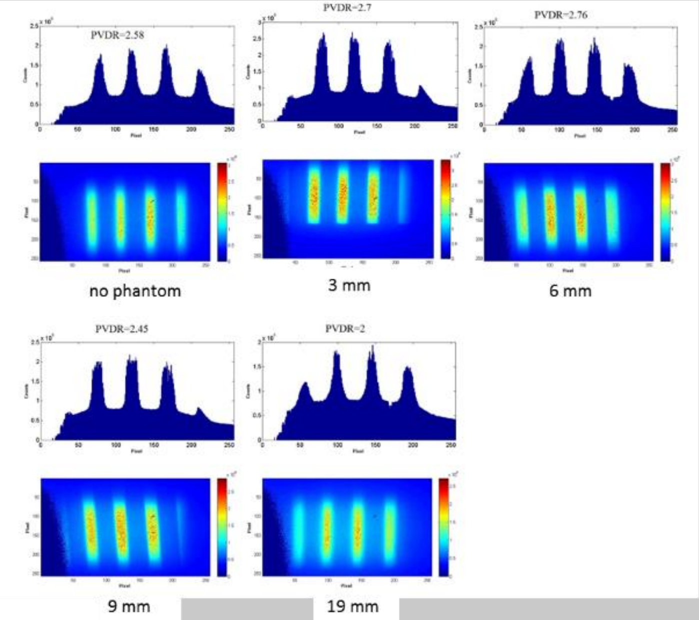
Images of carbon mini-beams shaped by a **matrix collimator** made out of 40 mm thick brass: 1.5 x1.5 mm^2 holes with c-t-c distance of 4 mm

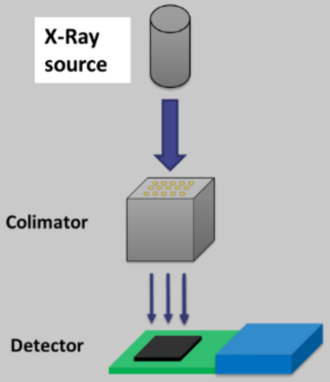


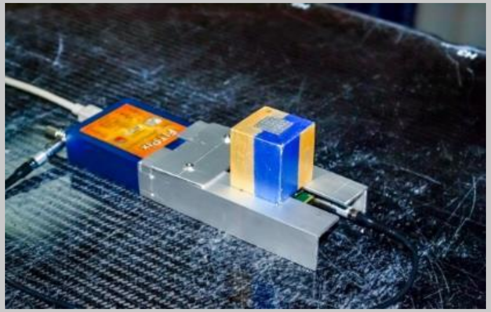
The lateral dose (normalized, a.u.) profiles for carbon ions measured at several depths (13, 33, 53, 73 and 93 mm-depth) in a RW3 solid-water phantom. The irradiation field size was 15×15 mm^2.



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