Metal microdetectors test with spatially fractionated gamma-ray beam at the Kyiv Institute of Cancer

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Principle of the 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)
- Tested at animals – positive effect due to the increased dose in the open area of the collimator.

- Criteria of profit – PVDR (peak to valley dose ratio)

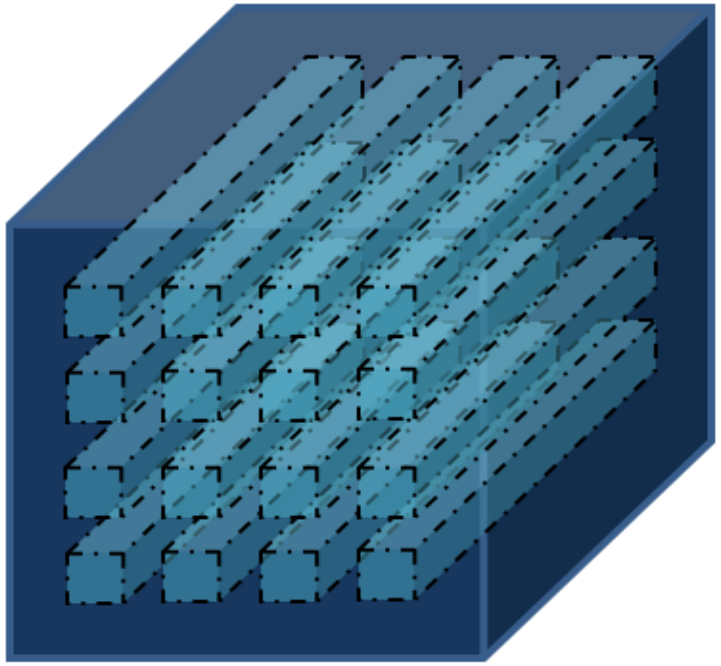
- Measured for the first time in real time in 2011 in Collaboration KINR_ESRF_Medipix(CERN) – spatial dose distribution in agreement with gafchromic films (off-line, time consuming procedure, yet with a perfect position accuracy – few micrometers).

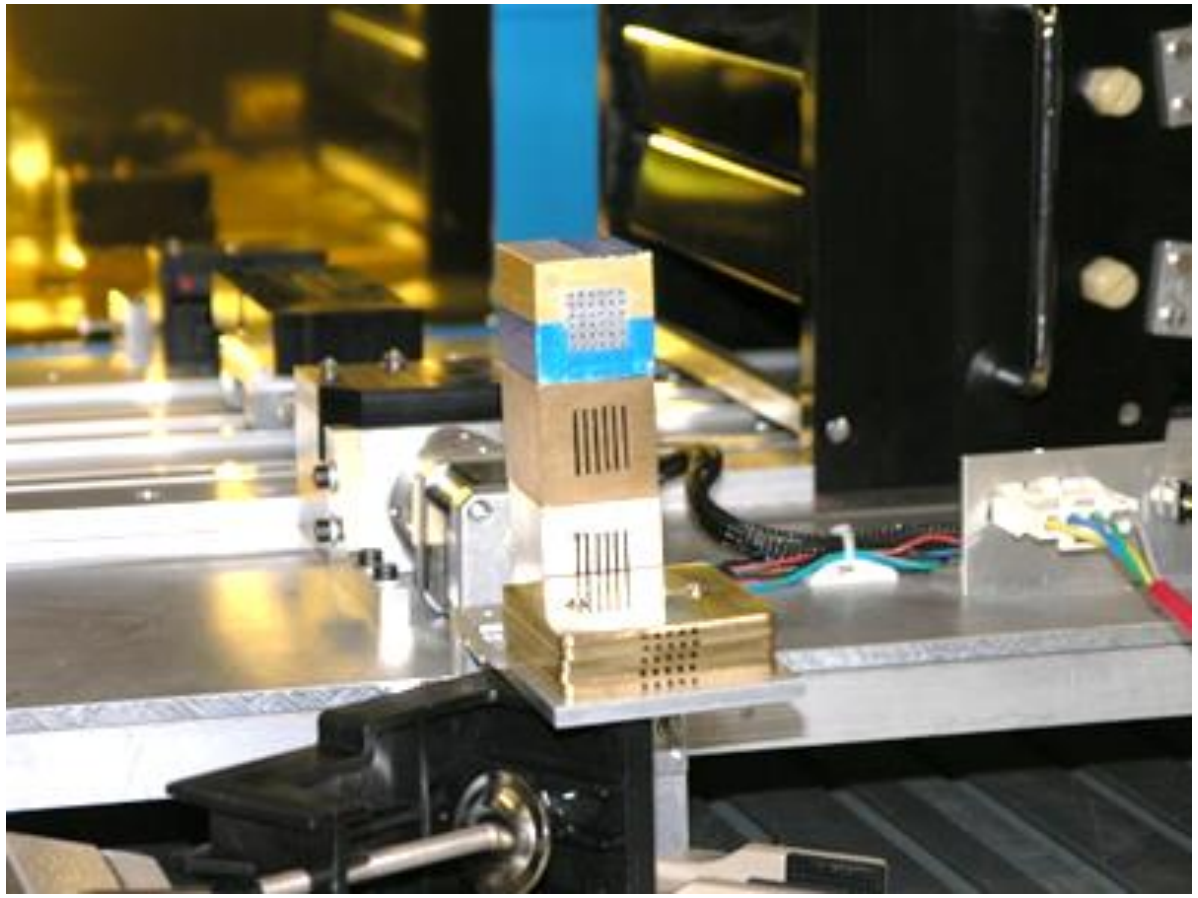
- New idea (IMNC, Yolanda Prezado) – to implement it for the hadron beams (feasibility studies started at HIT – Heidelberg in 2014 (KINR-IMNC-CERN)
- *[V. Pugatch, et al. Characterization of equipment for shaping and imaging hadron minibeams. NIM A872 (2017) 119-125.]*

Goal

- Study the property of different materials for collimators and dose distribution using different type of collimators
- Archive the best value of PVDR
- Use for shaping and dose measurement of radioactive beam different detector types
- Compare collimator fractionated beam with the pencil beam

Equipment for shaping





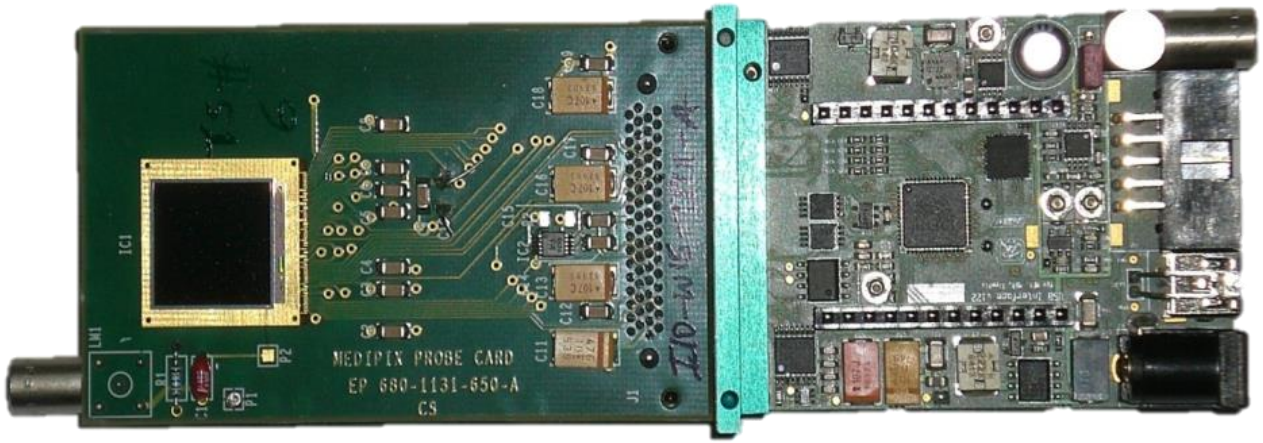
Matrix collimators
(holes of 1.5 x1.5 mm^2 and c-t-c distance of 4 mm)

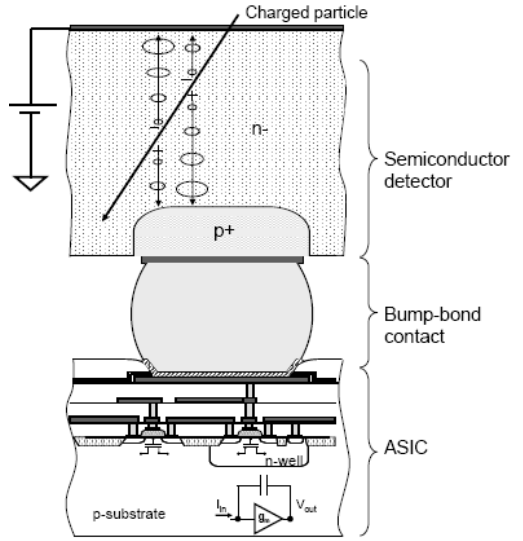
Slit Collimators
(1.5 mm width, 2.5 mm c-t-c distance)

Material: aluminum, brass, copper

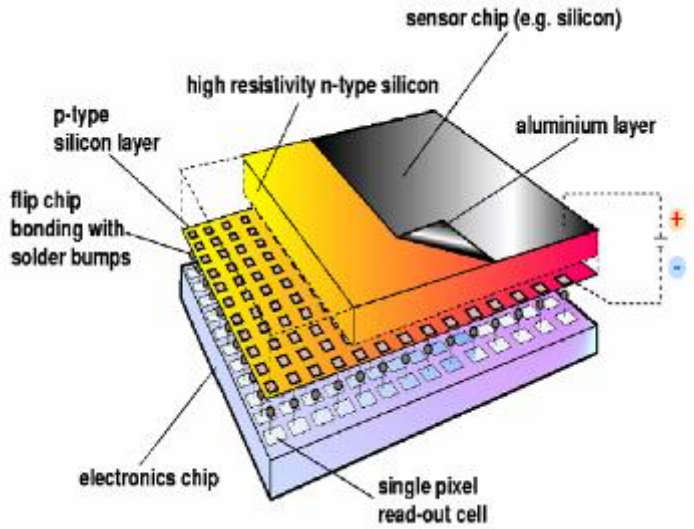
Equipment for imaging. TimePix

Hybrid pixel detector with the n-Silicon sensor chip and the TimePix electronics chip connected via bump bonds

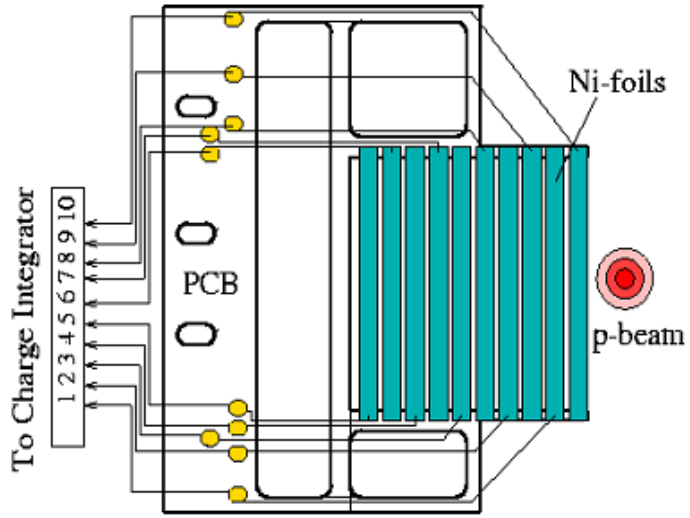




- 256 x 256 pixels
- 55 µm side length
- Direct X-ray conversion
- positive or negative charge input
- single energy threshold.
- 3 modes: Single particle counting, Time over Threshold or Arrival time mode.
- 13-bit counter per pixel.
- Parallel and serial read-out are realised.



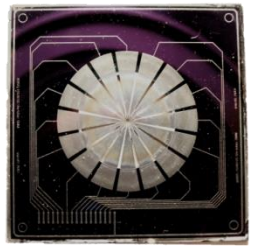
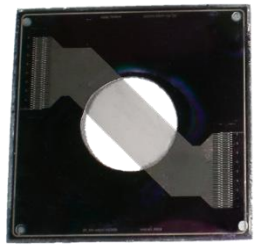
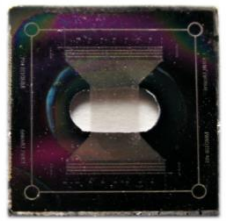
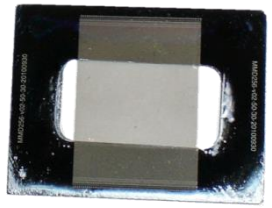
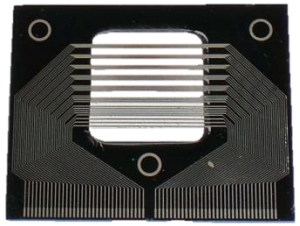
Equipment for imaging. MMD



- High Radiation tolerance (more than 100 MGy)
- Nearly transparent sensor – 1 μm thickness

MMD applications

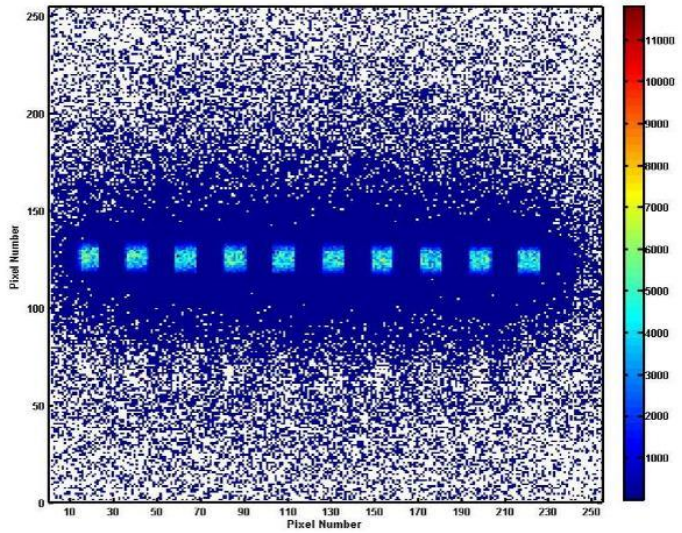
- Micro-beam Profile Monitoring for Charged Particles and Synchrotron Radiation
- Detectors at the focal plane of mass-spectrometers and electron microscopes
- Imaging sensors for X-ray and charged particle applications
- Precise dose distribution measurements for micro-biology, hadron-therapy etc.
- Industrial applications: micro-metallurgy, micro-electronics, etc.

TimePix measuring High intensity X-Ray beams

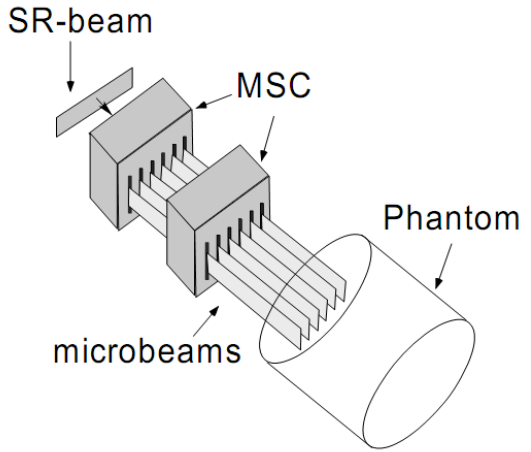
Measurements at the beamline ID17 ESRF (Grenoble)

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 $2{,}7\times10^{9}$ photons/(c×mm2×mA).



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

The spatially fractionated mini-beam

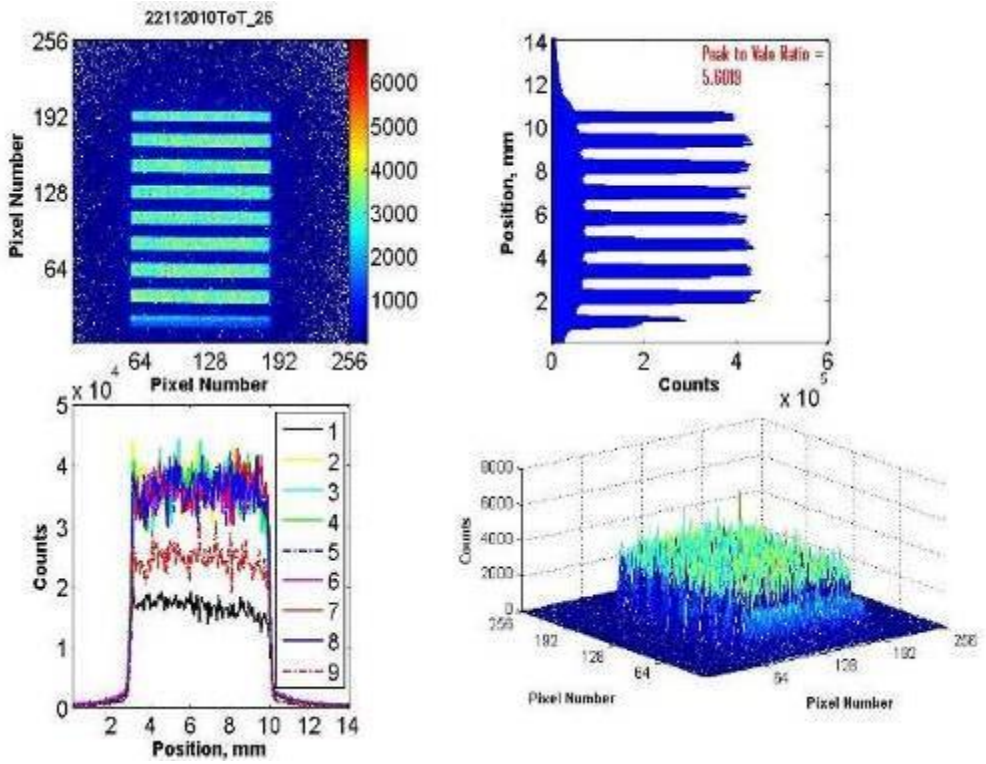


Energy: 150 keV
Intensity: $2{,}7\cdot10^{11}$ photons/(c·mm^2)

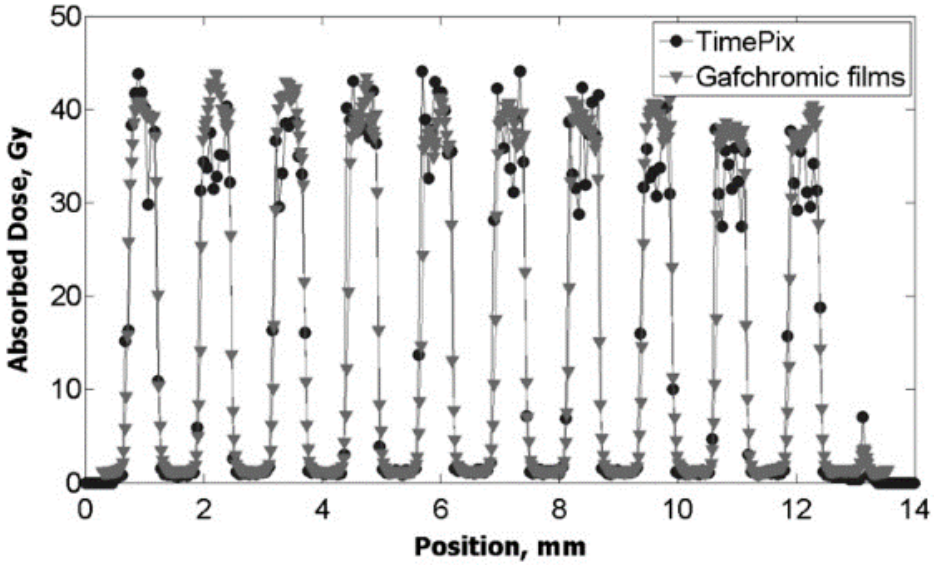
Radiation hard detectors are required!

Metal TimePix detector imaging the X-ray beam.
Color grade indicates the relative beam intensity.

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.

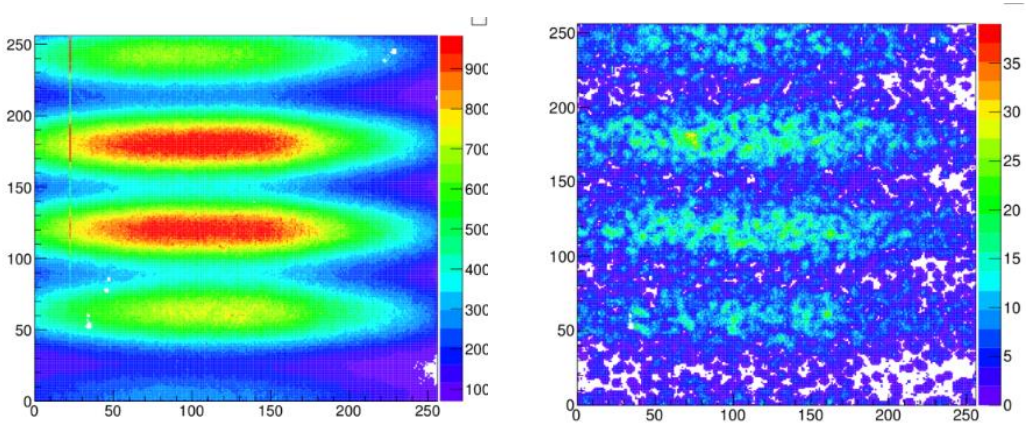
Characterization studies of the TimePix measuring in real time dose distribution at the Mini-beam Radiation Therapy setup (ESRF, Bio-Medical Beamline ID17) were performed.

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.

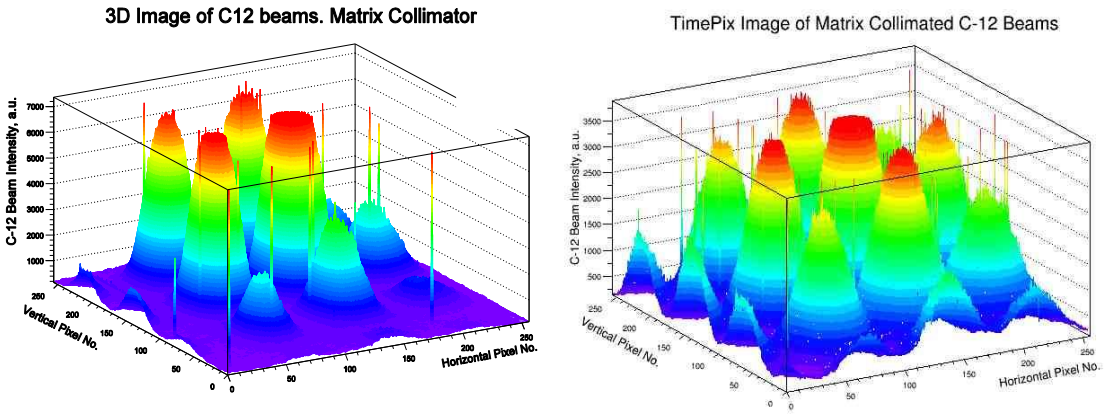
Peak-Valley-Ratios measured by TimePix and gafhromic films agree well.

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

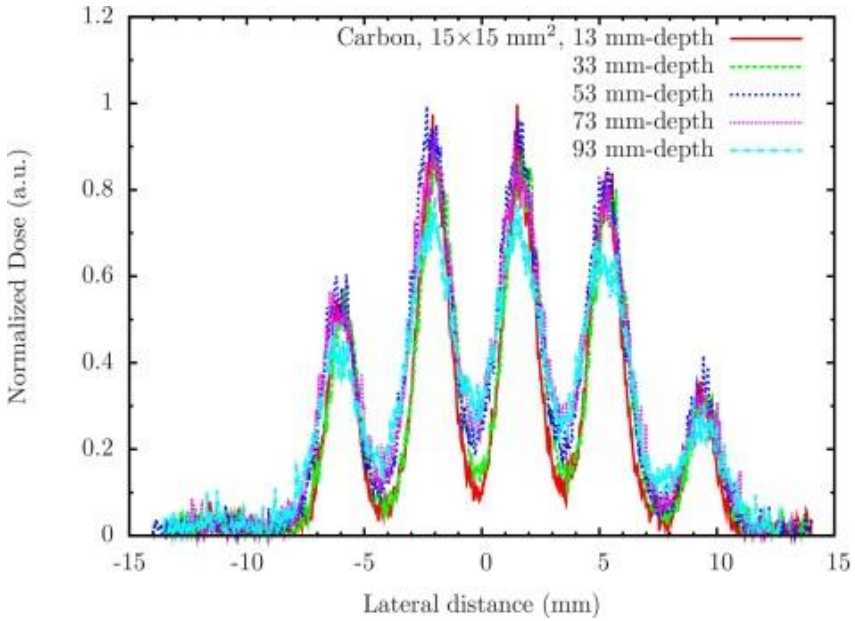
2D images of carbon mini-beams shaped by the **slit collimator** (brass) with five slits (1.5 mm width, 2.5 mm c-t-c distance)



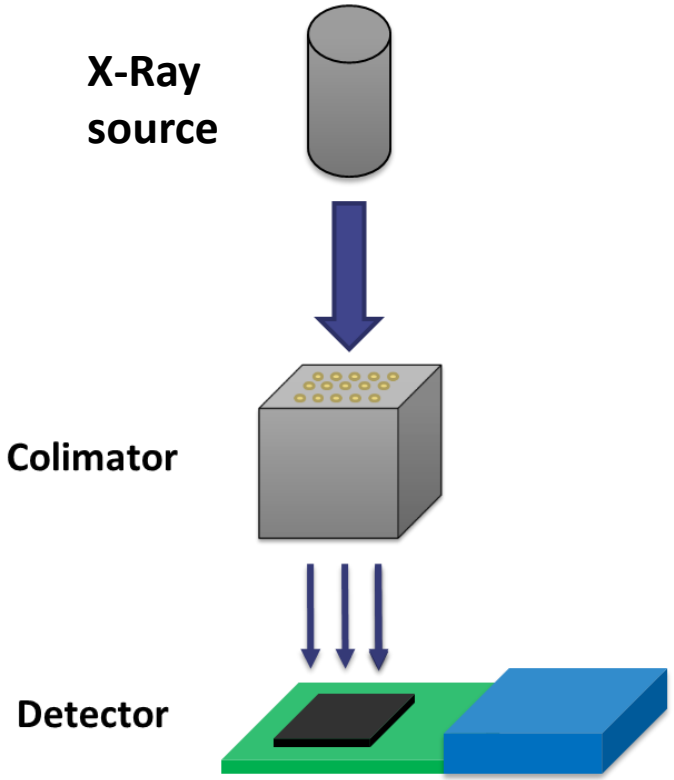
Images of carbon mini-beams shaped by a **matrix collimator** made out of 40 mm thick brass: 1.5 x1.5 mm^2 holes with c-t-c distance of 4 mm



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.



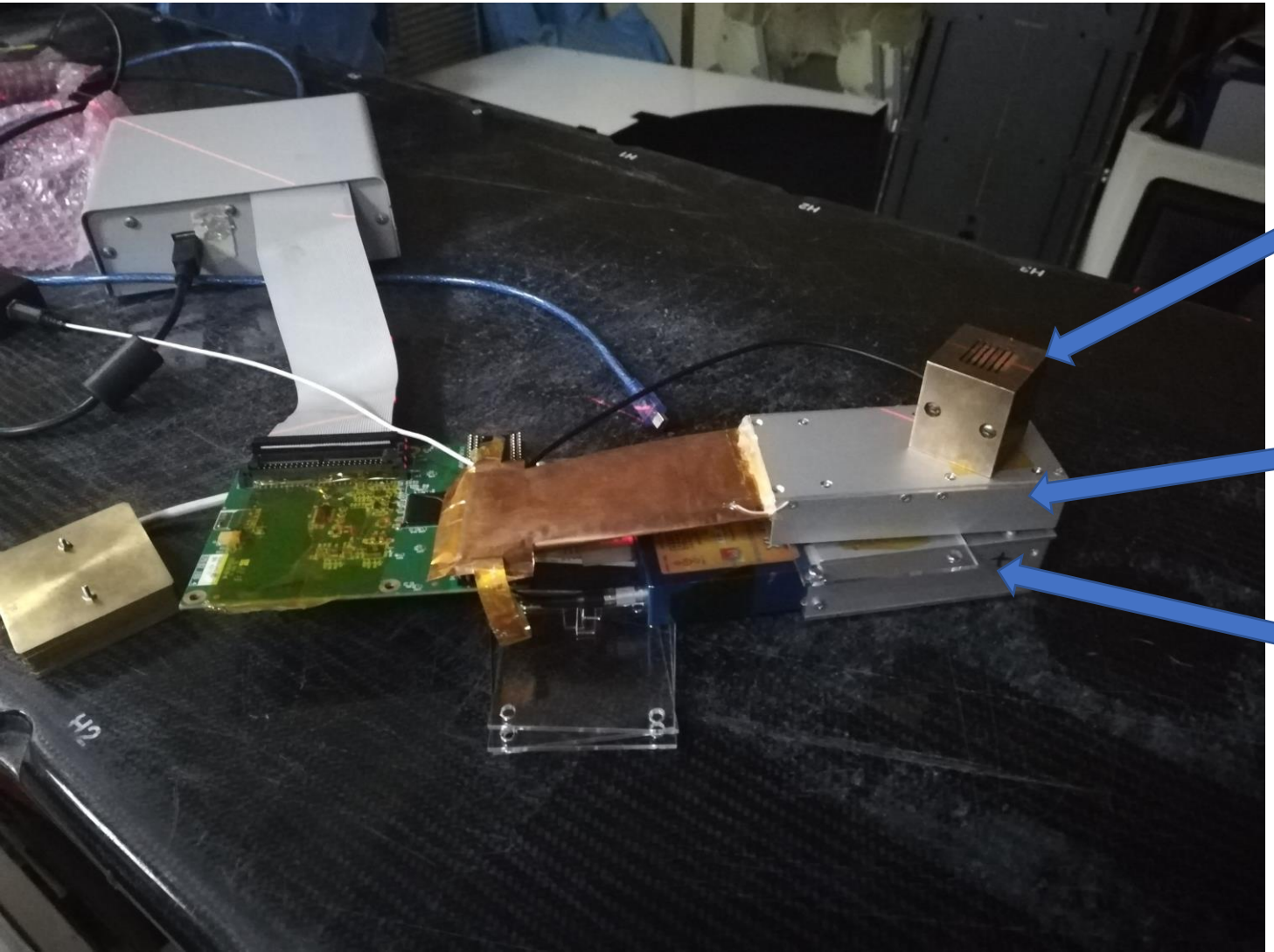
Experimental setup for shaping and monitoring mini-beams



The experimental setup for testing various types of micro-detectors and read-out electronics on charged particles and gamma-rays at the accelerator Clinac-2100 CD "VARIAN"

Beam Energy: 6, 15 MeV
Pulse Width: 5 μs
Pulse Repetition Rate: 20-100 Hz
Beam type: Photon, electron

Positioning and parallel measurements

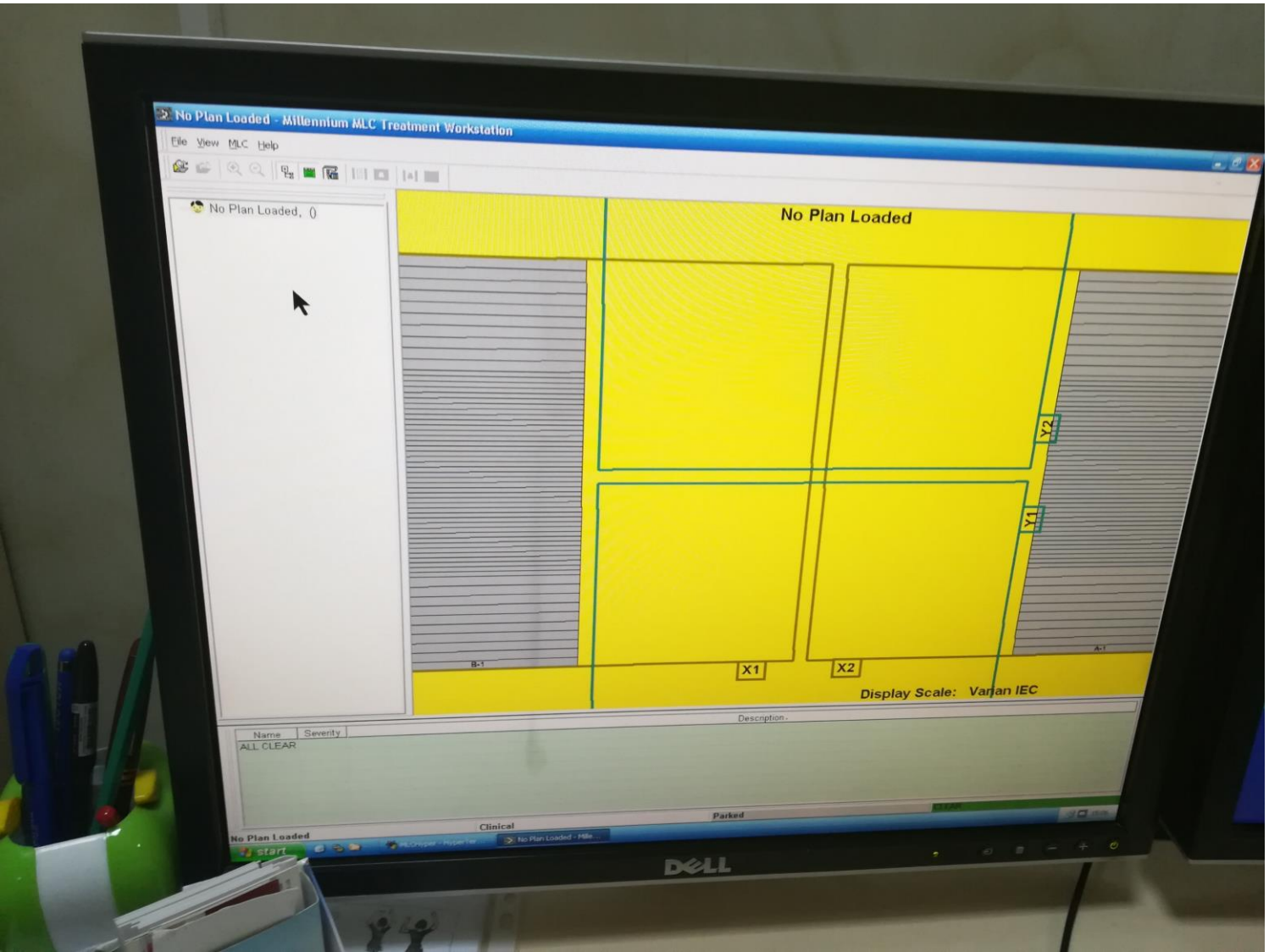


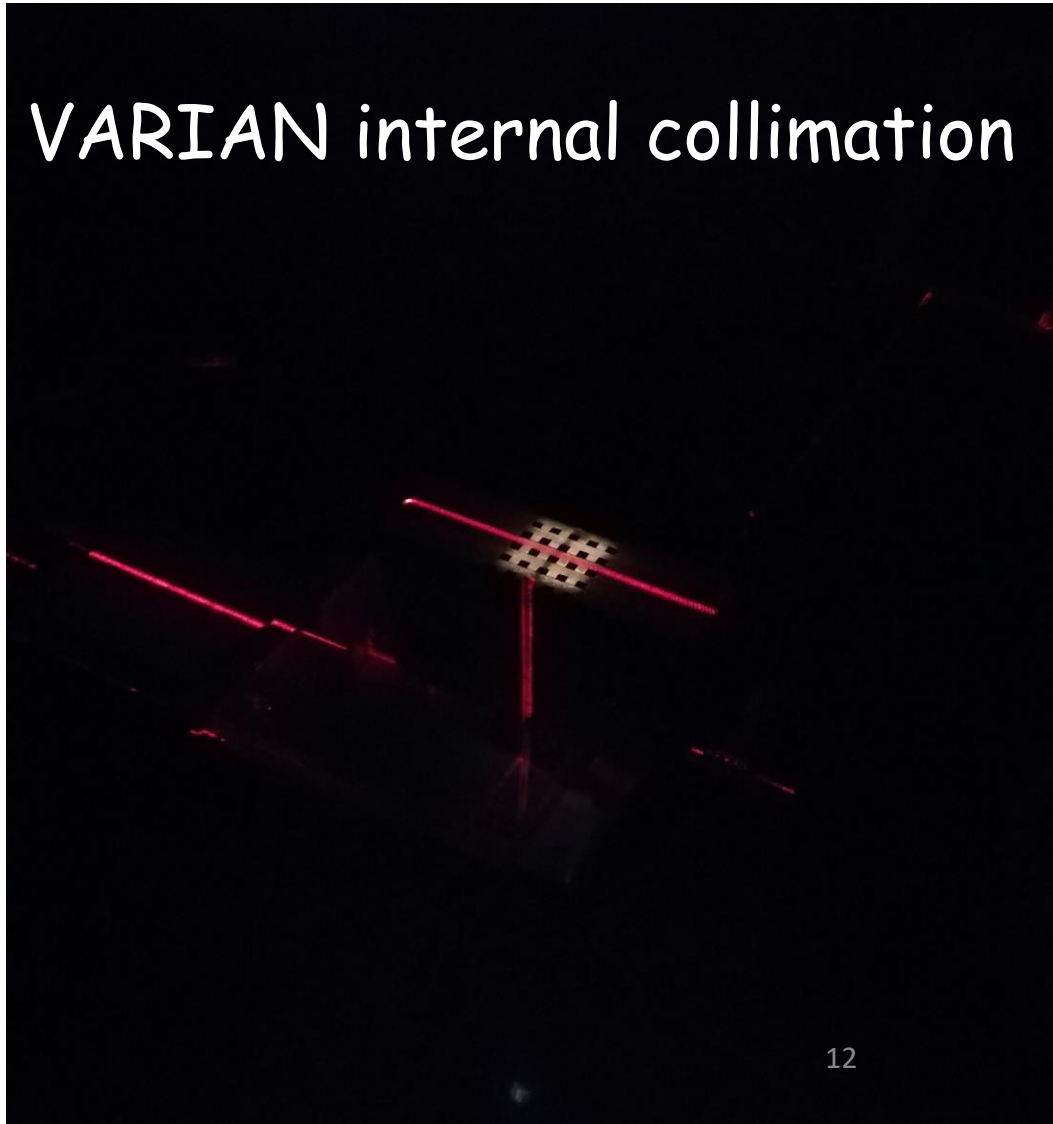
Collimator

MMD

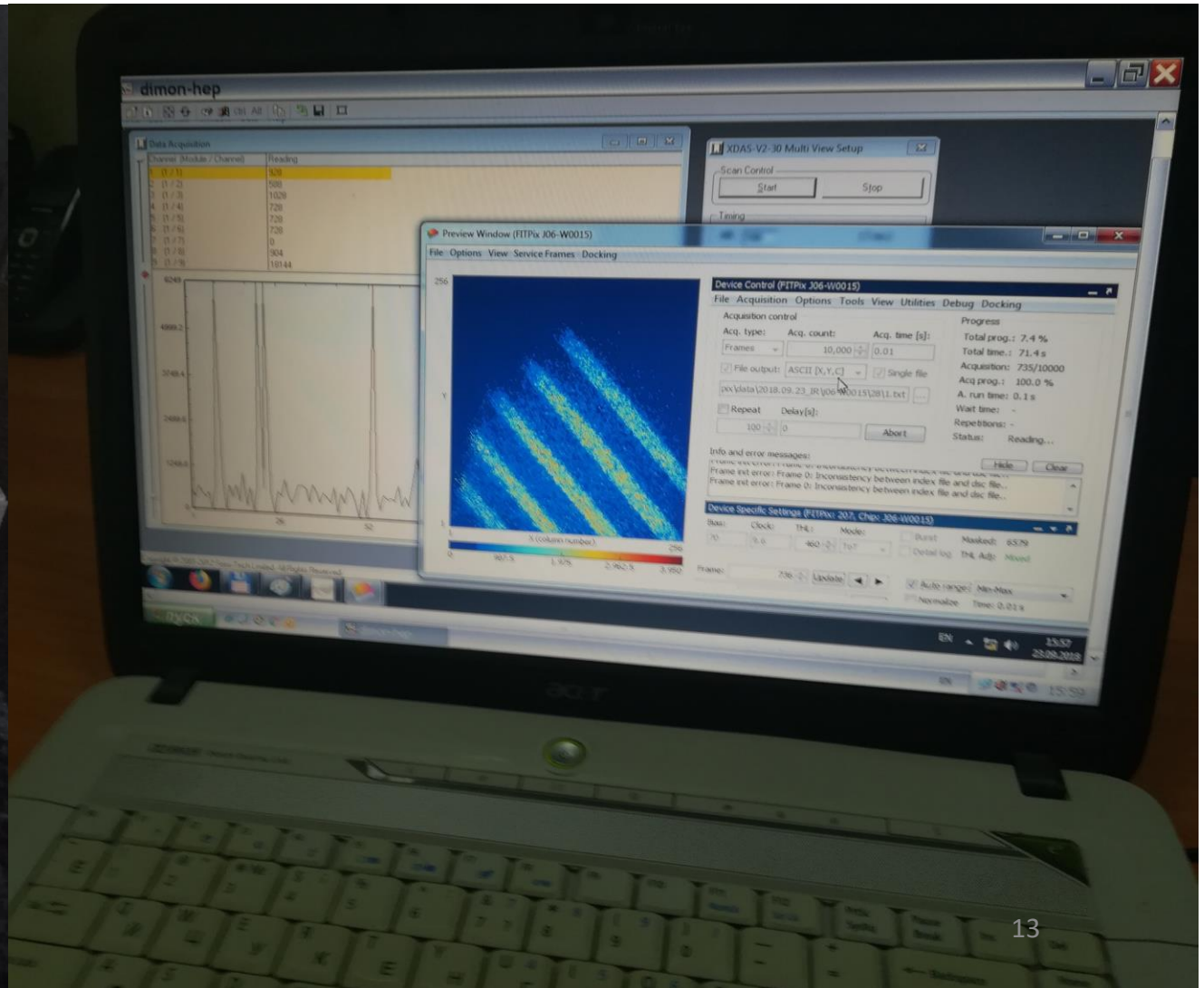
TimePix

Positioning and parallel measurements



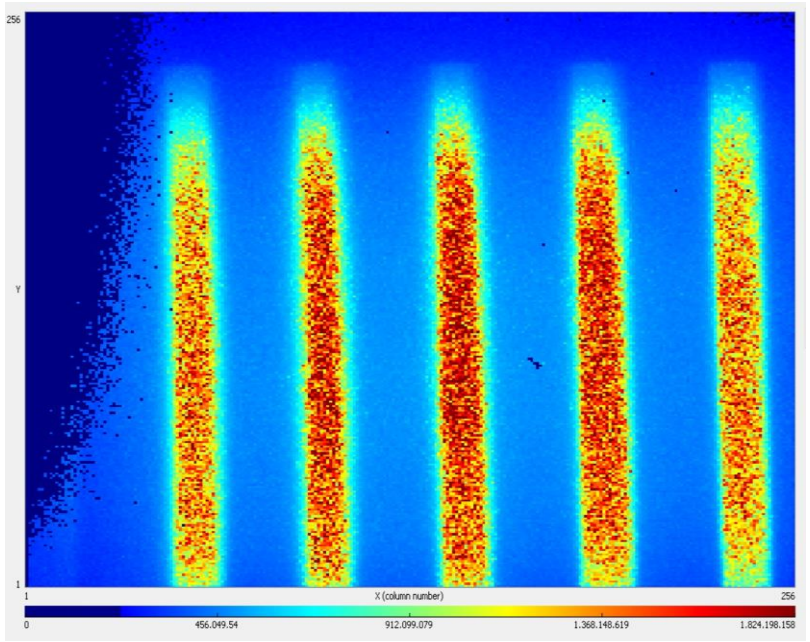


Positioning and parallel measurements



Beam fractionated by brass slit collimator

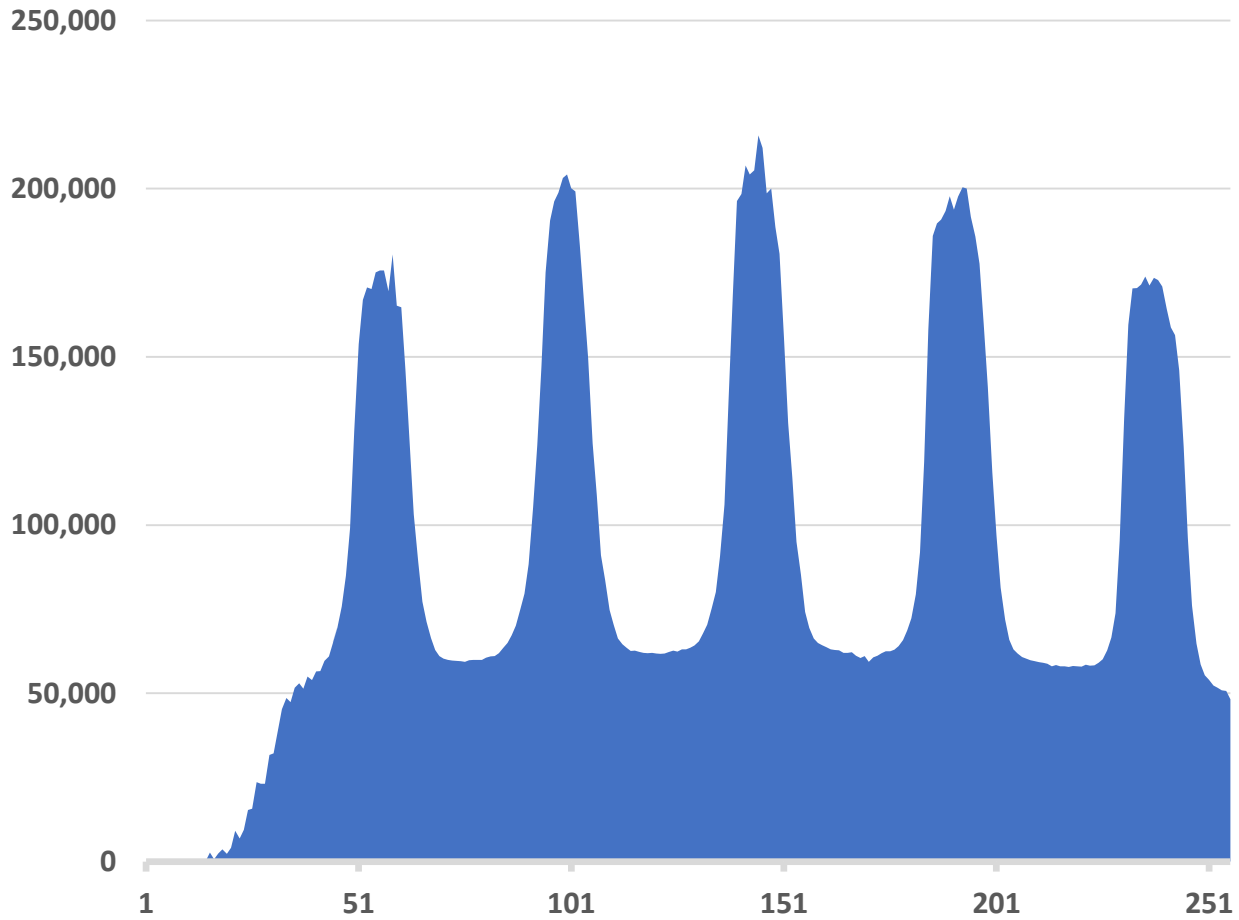
2D dimension distribution



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

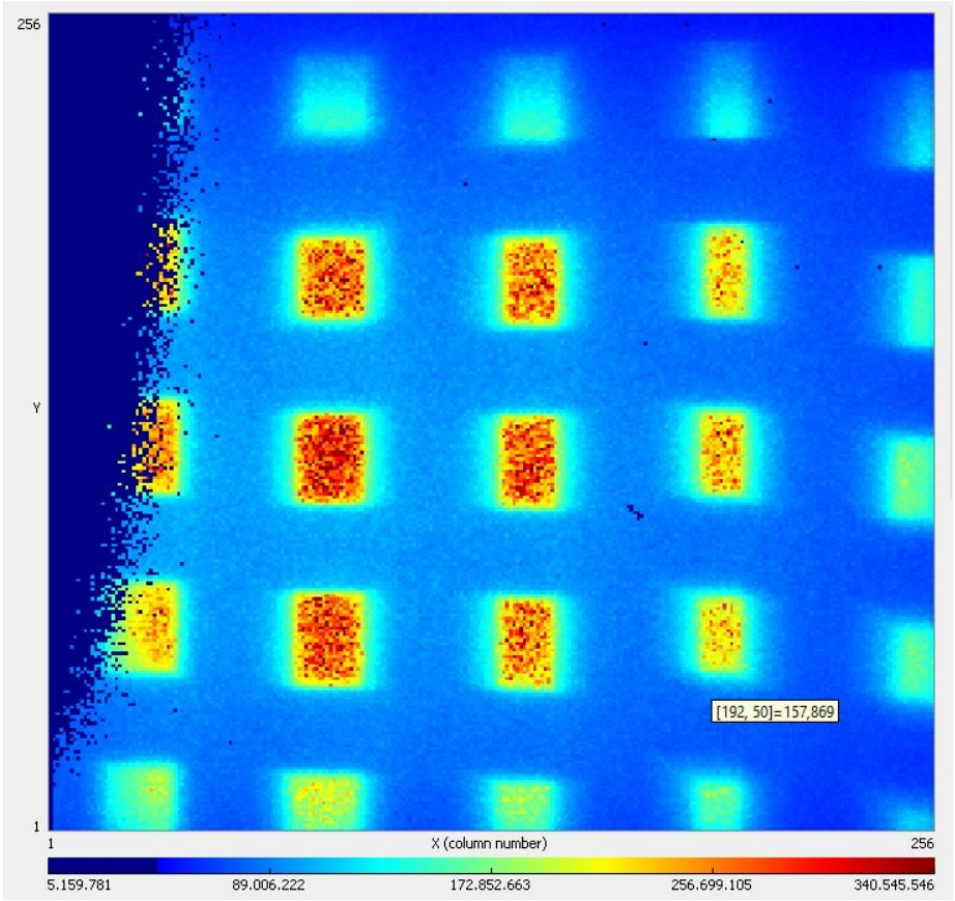
PVDR: ~3.45

1D dimension distribution



Beam fractionated by brass matrix collimator

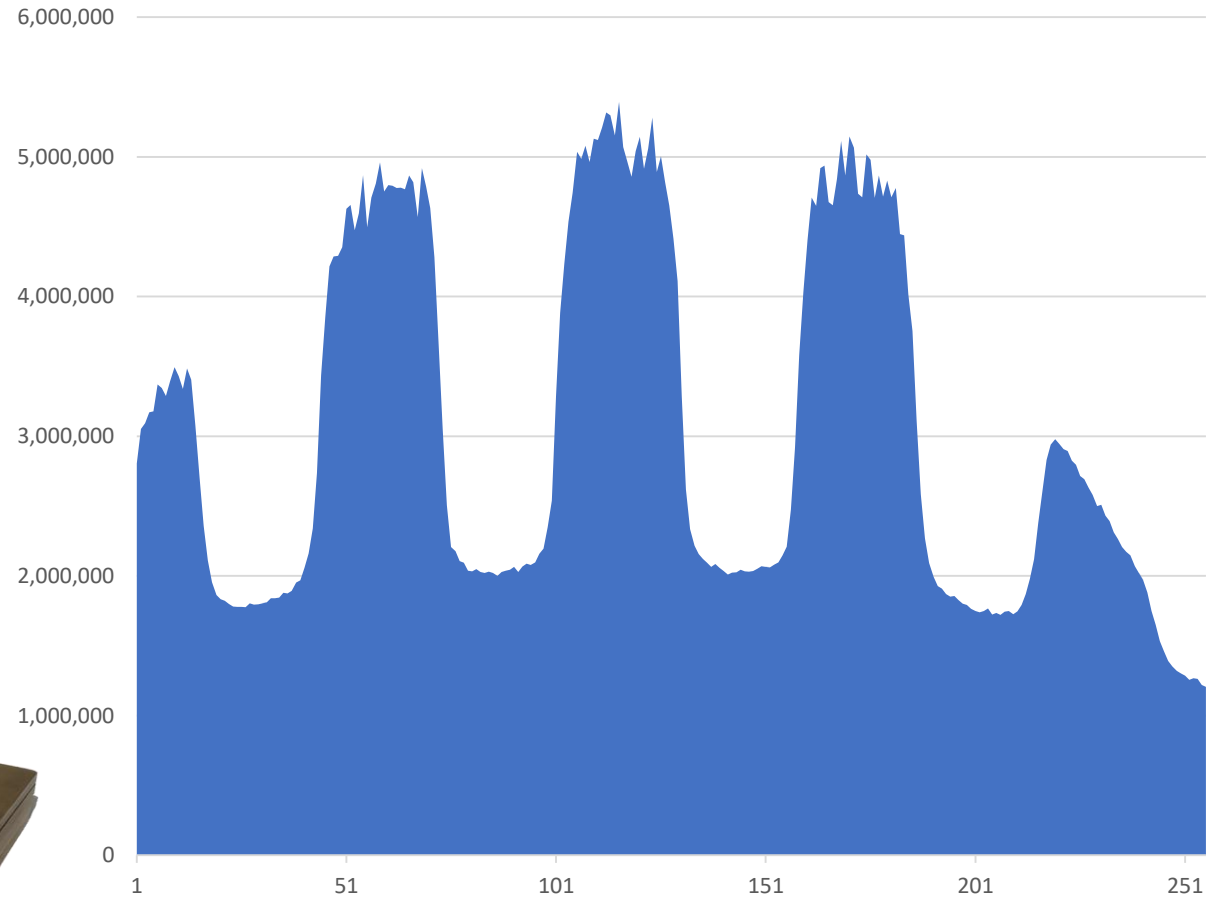
2D dimension distribution



Matrix collimators

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

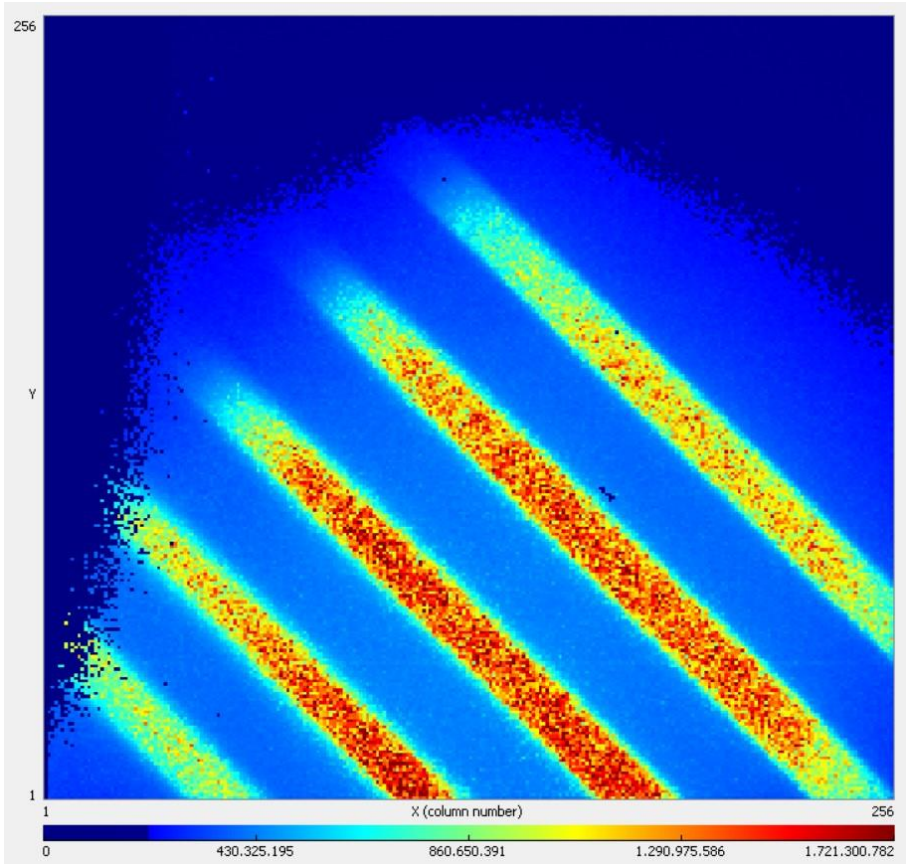
1D dimension distribution



PVDR: ~2.5

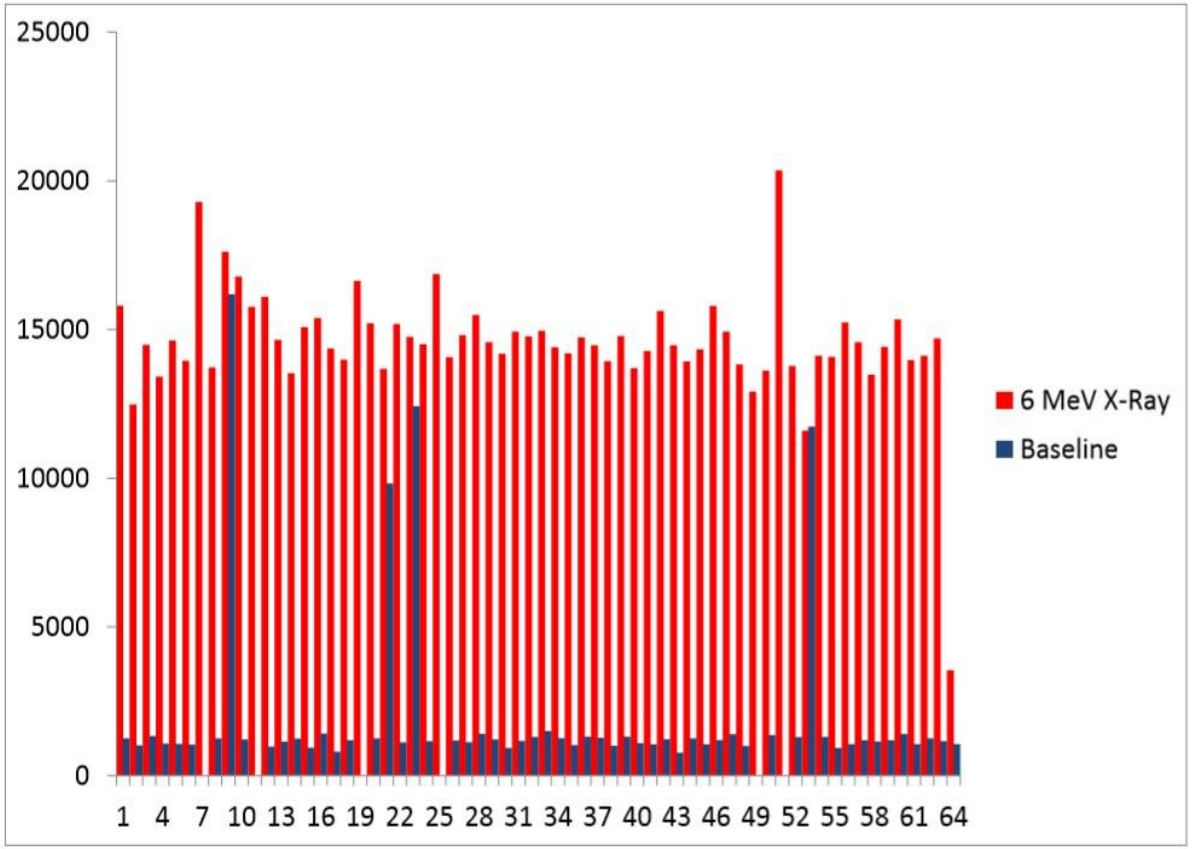
Beam fractionated by brass slit collimator and MMD detector

2D dimension distribution



PVDR: ~3.5

1D dimension distribution
measured by MMD detector



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

Summary and Outlook.

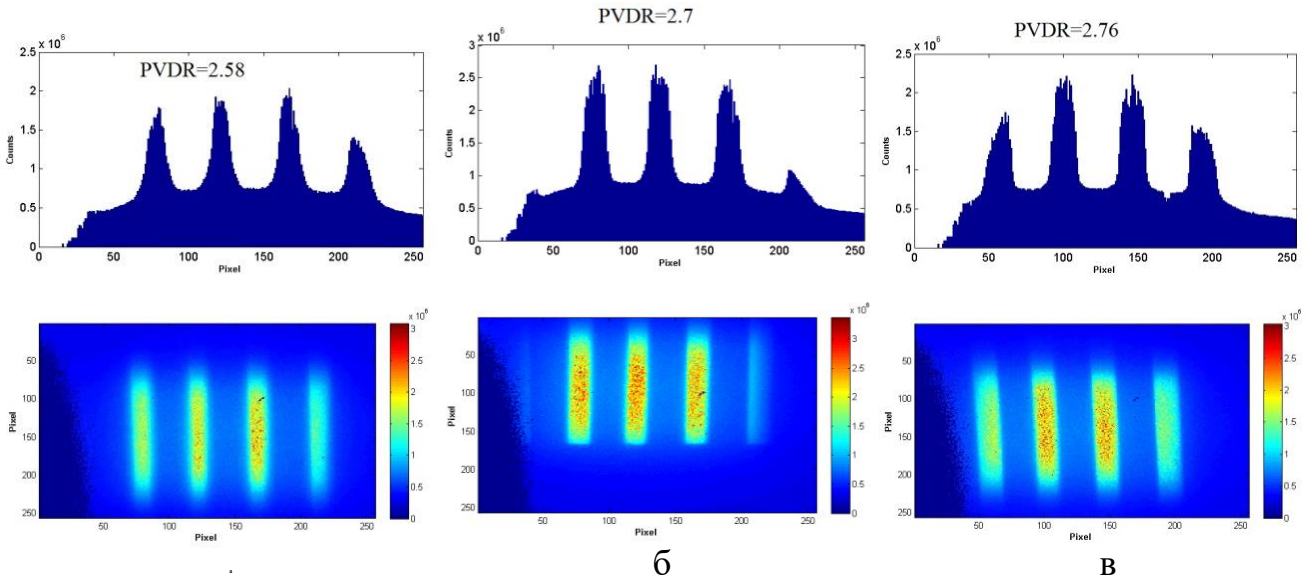
- Matrix and slit collimators for such application were designed and produced
- The whole set of the equipment for shaping and imaging mini-beams has been tested with gamma rays at accelerator Clinac-2100 CD "VARIAN"
- Timepix detectors in a hybrid mode have demonstrated perfect performance for imaging minibeams in real time. Response of MMD was shown. Preliminary results were presented.
- It would be great to perform feasibility studies at CPO (Orsay) with 105 MeV protons in collaboration with LAL and CPO colleagues.
- It would be also nice to test shaping and monitoring equipment built at KINR at ALTO facility with 75 MeV electrons.

Acknowledgements

These studies were carried out in frames of the LIA IDEATE activity and financially supported by CNCP (project No. P9903)

Backup slides

Testing at the Clinac system

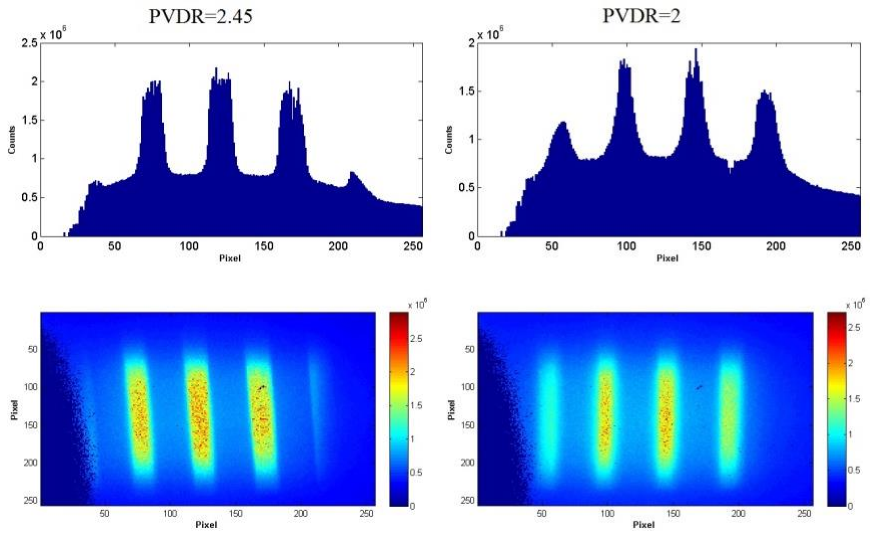


а – без фантому,
б – товщина фантому 3 мм,
в - товщина фантому 6 мм,
г - товщина фантому 9 мм,
д - товщина фантому 19 мм.

а

б

в



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