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

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On behalf of co-authors

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Spatially fractionated radiation therapy

Radiation therapy is one of the main methods of treating malignancies. Almost 60-70% of cancer patients apply irradiation in terms of independent, combined (irradiation + operation) or complex (irradiation + chemotherapy) treatment.

Laboratory studies with synchrotron radiation beams and clinical applications of GRID beams of gamma rays have demonstrated the promise of such a direction of work. Fractionation can significantly increase local doses in the tumor, while providing tolerant doses for healthy tissues.

The thorough researches were carried out, in particular, on the biomedical line ID-17 (ESRF, Grenoble), including the participation of several authors of this project using the technique of so-called mini-beams and micro-beams of synchrotron radiation. Apply various technical solutions for spatial fractionation of the dose absorbed in the tumor: passive multi-slit collimator, complex systems of synchronized movement of the collimator and patient, and others.

A significant problem exists in measuring and monitoring real-time distribution of the dose delivered to a tumor and absorbed in the whole body. Existing detector systems cannot withstand high radiation exposure (semiconductor detectors and ionization chambers) or do not provide the required spatial resolution (scintillator detectors), or their processing require unaffordable time (~ 24 hours - gafchromic films). Experimental dosimetry in Minibeam radiation therapy (MBRT) is challenging due to the high spatial resolution needed and the high dose rates used. Until now, no a perfect detector able to cope with all the special features of MBRT has been available. Metal Micro-detectors developed at KINR might become a suitable device for that goal providing currently the highest radiation tolerance.

Spatially fractionated relativistic hadron beams are considered as new promising tool for cancer treatment. Spatial fractionation of the hadron mini-beams (center-to-center distance between adjacent beams about 0.5 mm) allows to increase the dose delivered to tumor while dose absorbed by healthy tissue will be still tolerable due to the so called volume-dose effect.

Spatially fractionated radiation therapy

Studies are in progress with mini-, and micro-beam irradiation fields exploring synchrotron radiation. There are different technical solutions to provide spatial fractionation of the dose delivered to tumor: passive multi-slits collimators, sophisticated systems for synchronized movement of collimator and patient, and so on. Recently, similar technique has been evaluated for hadron therapy applications. Feasibility studies have been carried out at the Heidelberg Ion Therapy Centrum (Germany).

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

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.

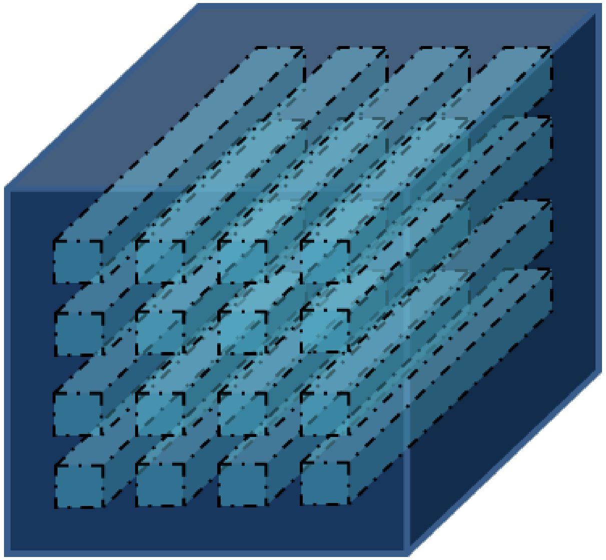
- Criteria of profit – PVDR

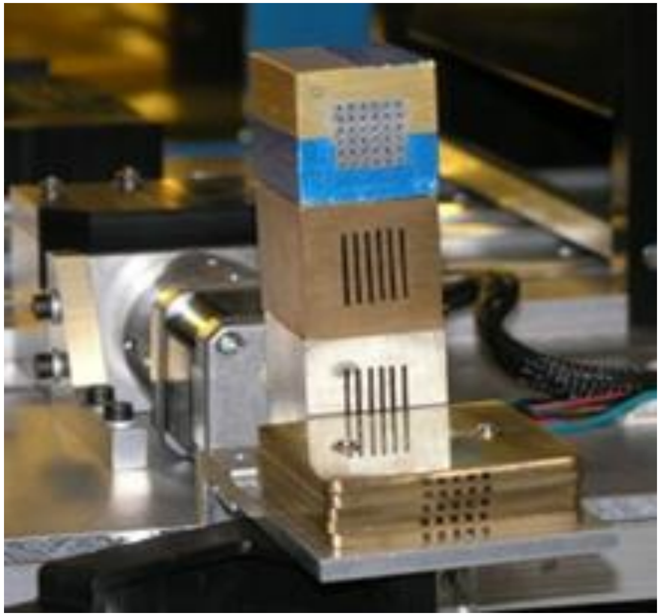
- Measured for the first time in real time in 2011 in Collaboration KINR_ESRF_Medipix(CERN) – spatial dose distribution in agreement with gafchromic films (off-line, time consuming procedure, yet with a perfect position accuracy – few micrometers).

[V. Pugatch et al. Nucl. Instr. and Meth. A682 (2012) 8-11]

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

Equipment for shaping





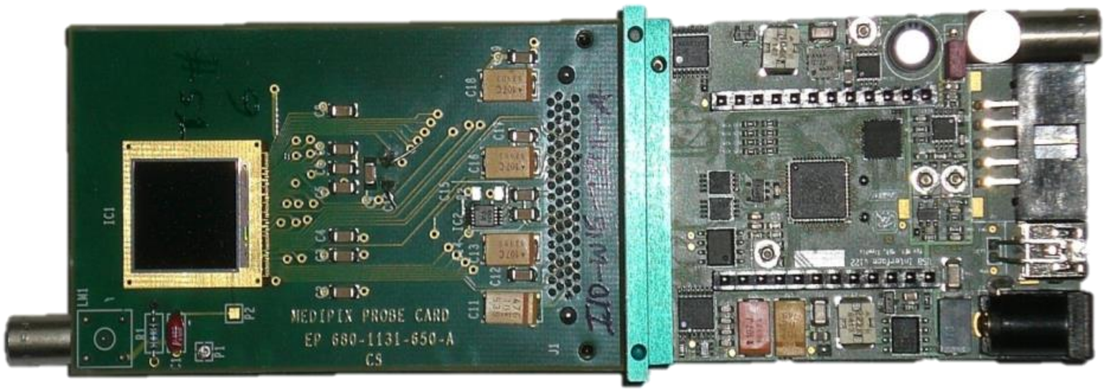
Matrix collimators
(holes of 1.5 x1.5 mm^2 and c-t-c distance of 4 mm)

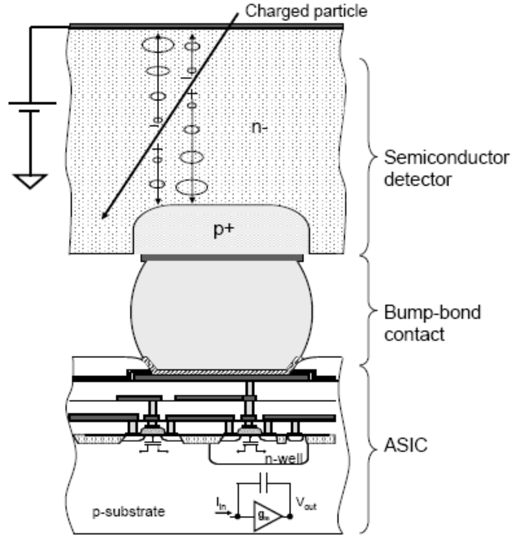
Slit Collimators
(1.0 mm width, 2.5 mm c-t-c distance)

Material: aluminum, brass, lead

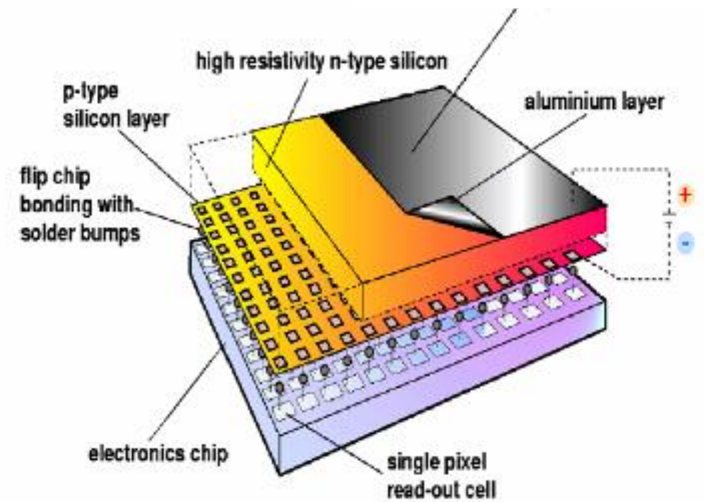
Equipment for imaging. TimePix

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

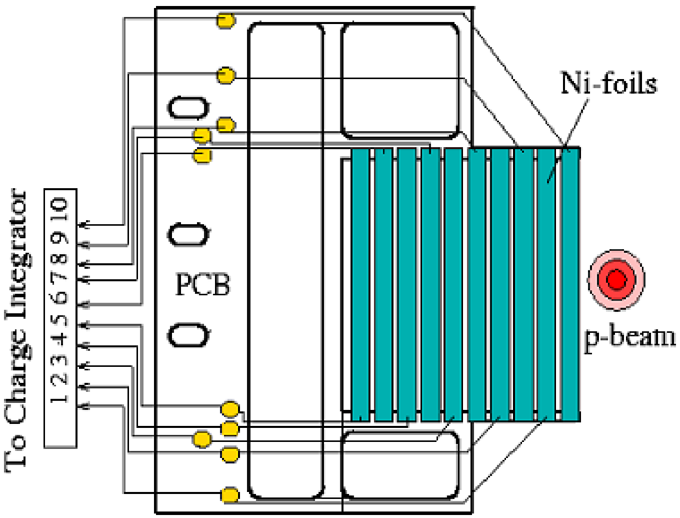




- 256 x 256 pixels
- 55 µm side length
- Direct X-ray conversion
- positive or negative charge input
- single energy threshold.
- 3 modes: Single particle counting, Time over Threshold or Arrival time mode.
- 13-bit counter per pixel.
- Parallel and serial read-out are realised.



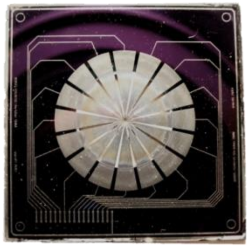
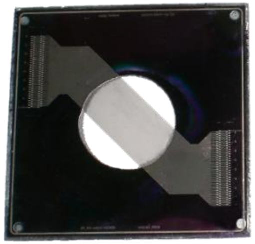
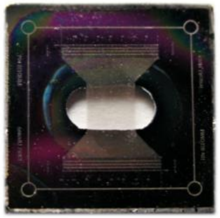
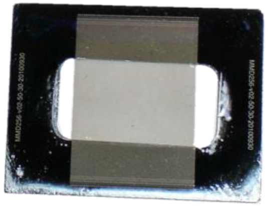
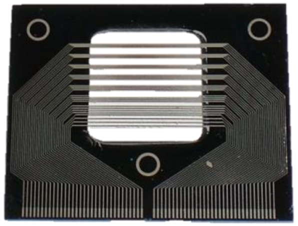
Equipment for imaging. MMD



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

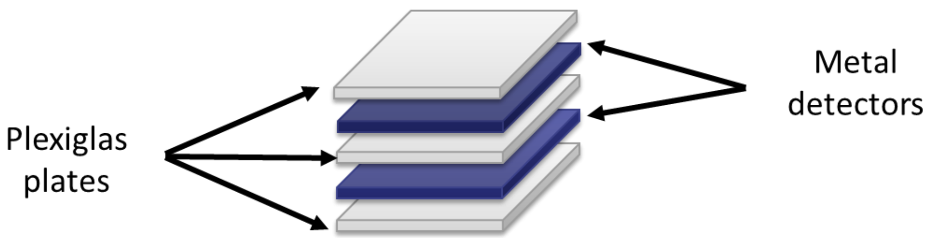
MMD applications

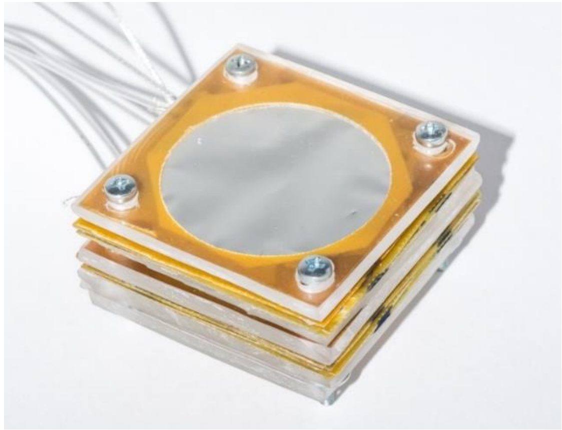
- Micro-beam Profile Monitoring for Charged Particles and Synchrotron Radiation
- Detectors at the focal plane of mass-spectrometers and electron microscopes
- Imaging sensors for X-ray and charged particle applications
- Precise dose distribution measurements for micro-biology, hadron-therapy etc.
-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

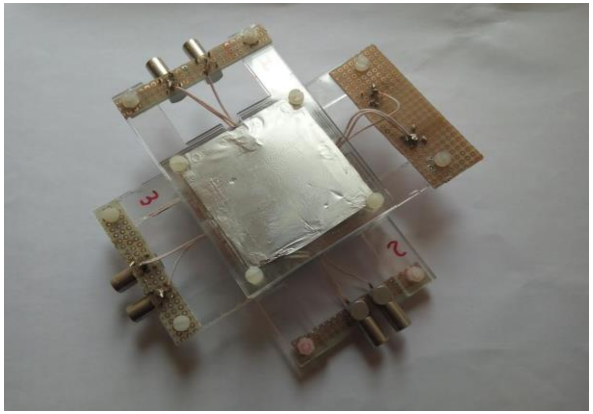






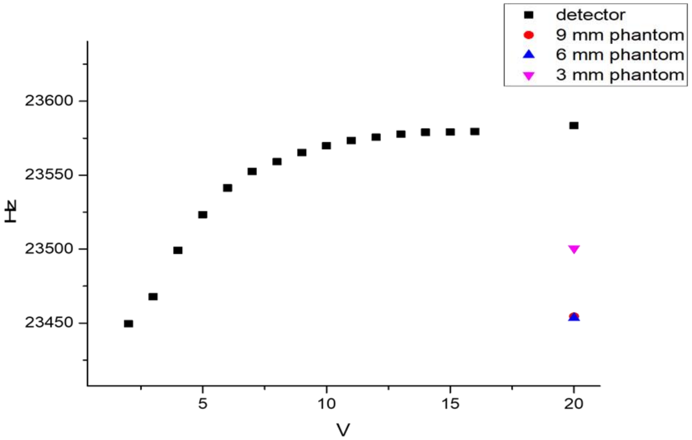
Detectorized Phantom

Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).
A few prototype have been produced and tested

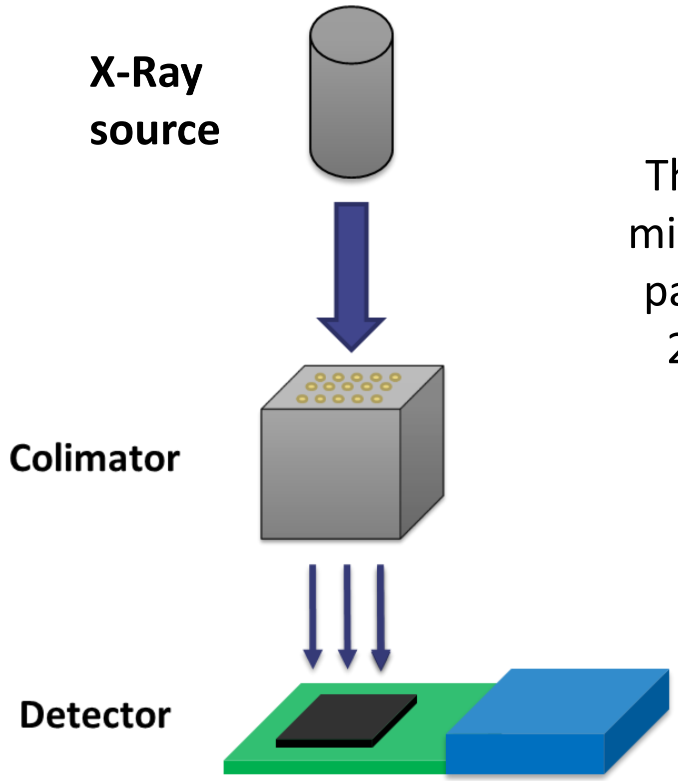








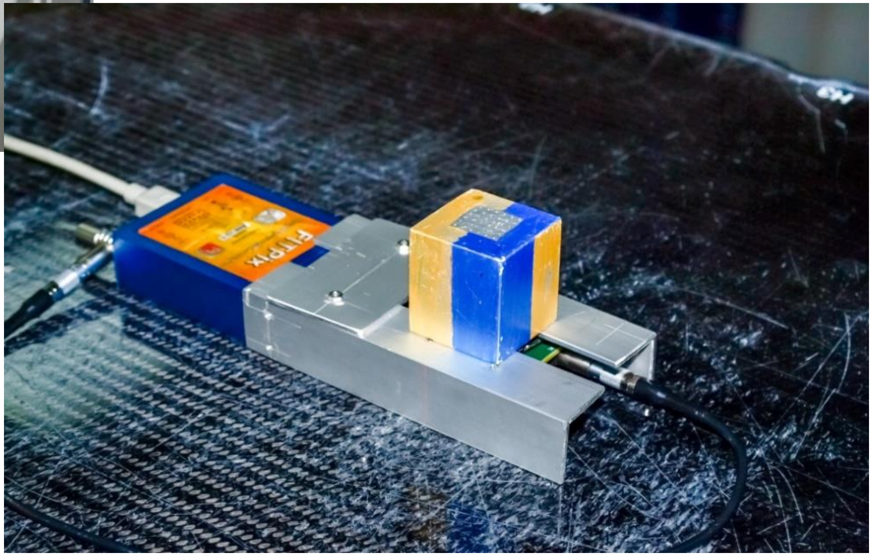
Experimental setup for shaping and monitoring mini-beams



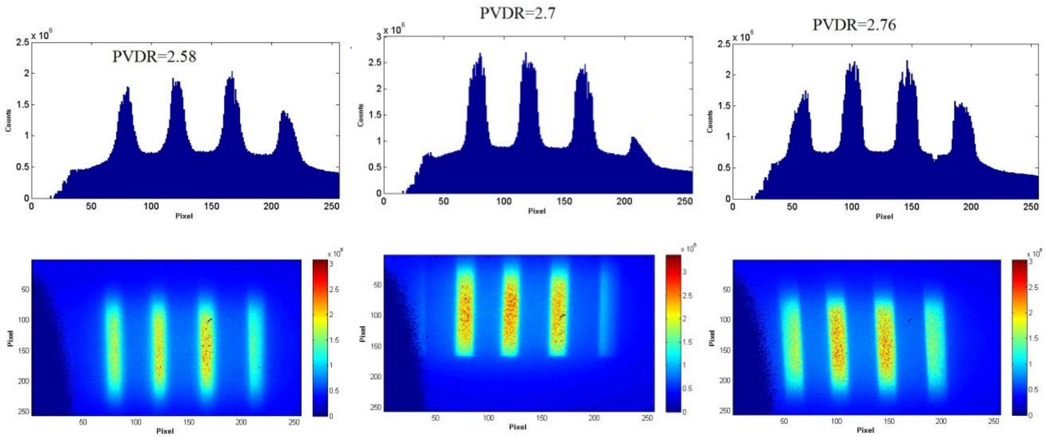
The experimental setup for testing various types of micro-detectors and read-out electronics on charged particles and gamma-rays at the accelerator Clinac-2100 CD "VARIAN" and PHIL (LAL, Orsay, France).

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 Clinac system



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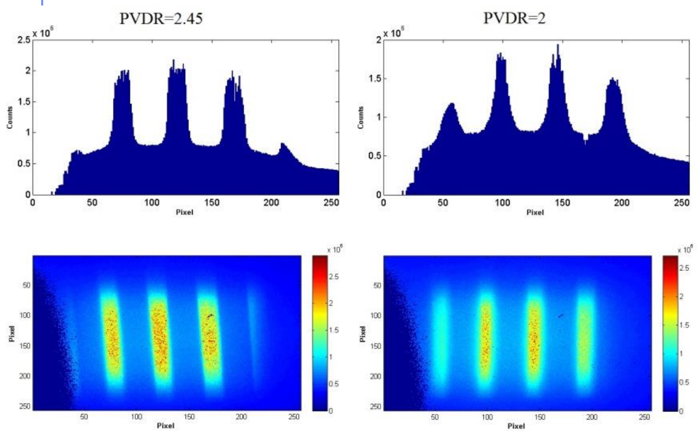
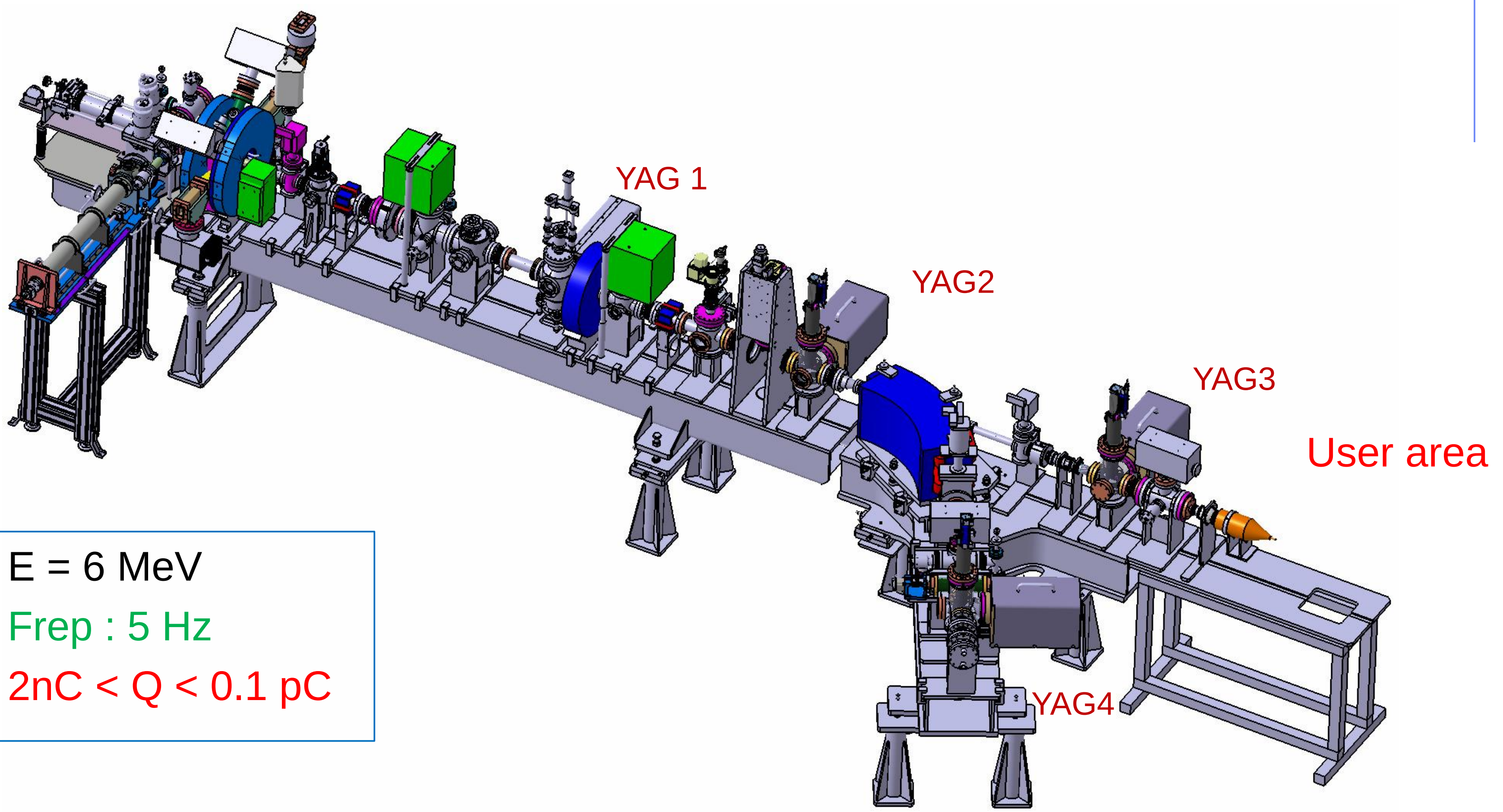


г д

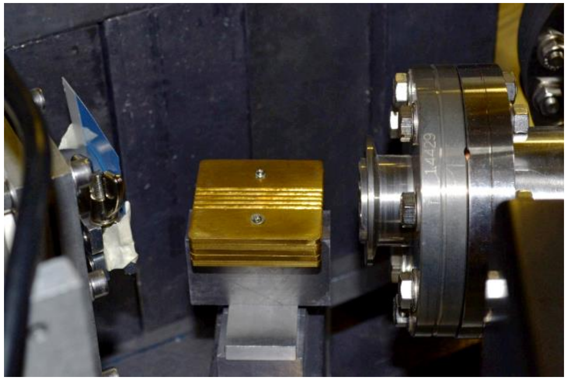
а – без фантому,
б – товщина фантому 3 мм,
в - товщина фантому 6 мм,
г - товщина фантому 9 мм,
д - товщина фантому 19 мм.

Testing at the PHIL (LAL, Orsay, France).

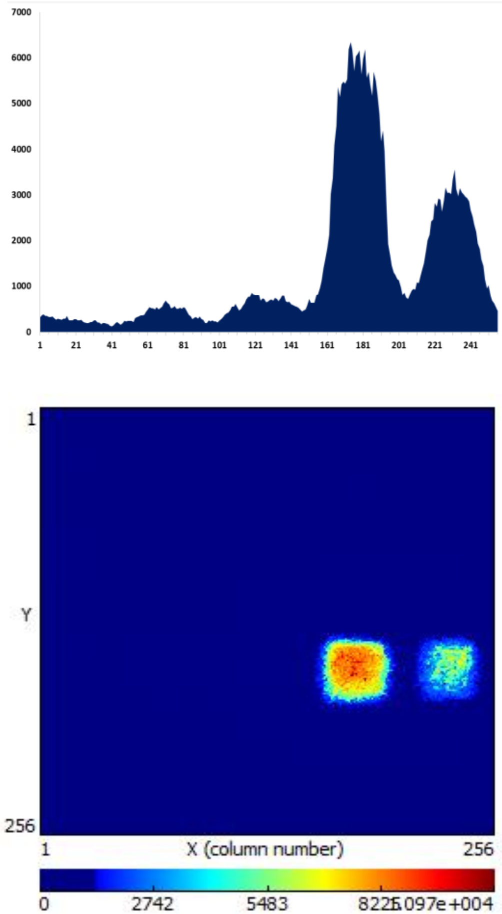


- E = 6 MeV
- Frep : 5 Hz
- 2nC < Q < 0.1 pC

Testing at the PHIL (LAL, Orsay, France).

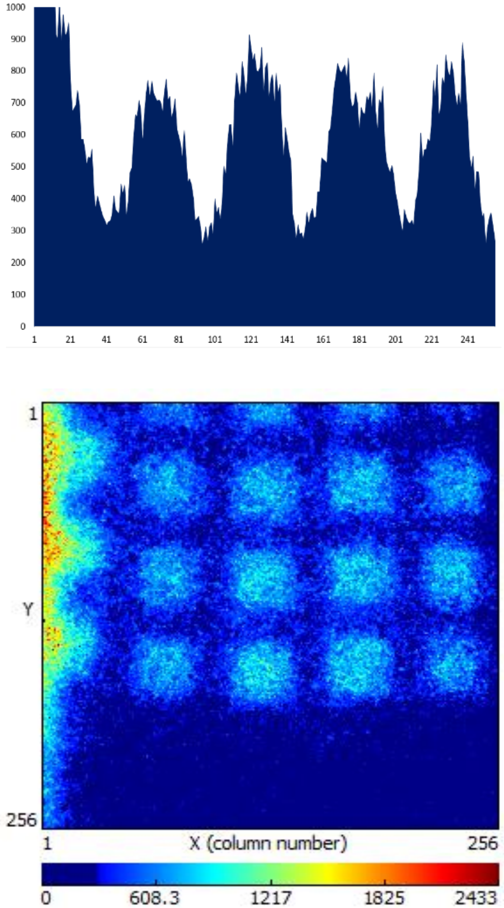


PVDR = 6



Focused beam

PVDR = 2.6



Unfocused beam

Summary and Outlook.

- Aiming for studies at CPO (Orsay) MC simulations have ben performed for 105 MeV protons. The calculations illustrate possibility to shape mini-beams with reasonable PVDR values
- Matrix and slit collimators for such application were designed and produced
- The equipment for shaping and imaging mini-beams has been tested at the accelerator Clinac-2100 CD "VARIAN" and PHIL (LAL, Orsay, France)
- Timepix detectors in a hybrid and metal mode have demonstrated perfect performance for imaging minibeams in real time.
- Metal Microstrip detectors have been successfully applied for production detectorized phantom prototypes for dose delivery verification.
- Characterization studies of the detectorized phantom will be performed soon.

Acknowledgements

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Thank You For Your Attention