Kyiv Institute for Nuclear Research

The 6th French-Ukrainian workshop on the instrumentation developments for HEP

'Invisible' beam profile monitor for precision measurements in medical applications

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September 26-28, 2018

Overview

Applying detector technologies originally developed for high energy physics experiments for medical applications

Online monitoring of hadron beams during treatment is of paramount.

To prevent negative effect of treatment a high precision diagnostic systems should be applied.

Beam monitoring system will improve dose calculation accuracy -> Increase treatment efficiency.

To define the dose distribution and its reliability, detector should have good precision of positioning and beam monitoring, as well as high radiation tolerance, since modern radiotherapy seeks to reduce the beam size (thus increasing the intensity of the beam).

Metal Microstrip Detectors (MMD)

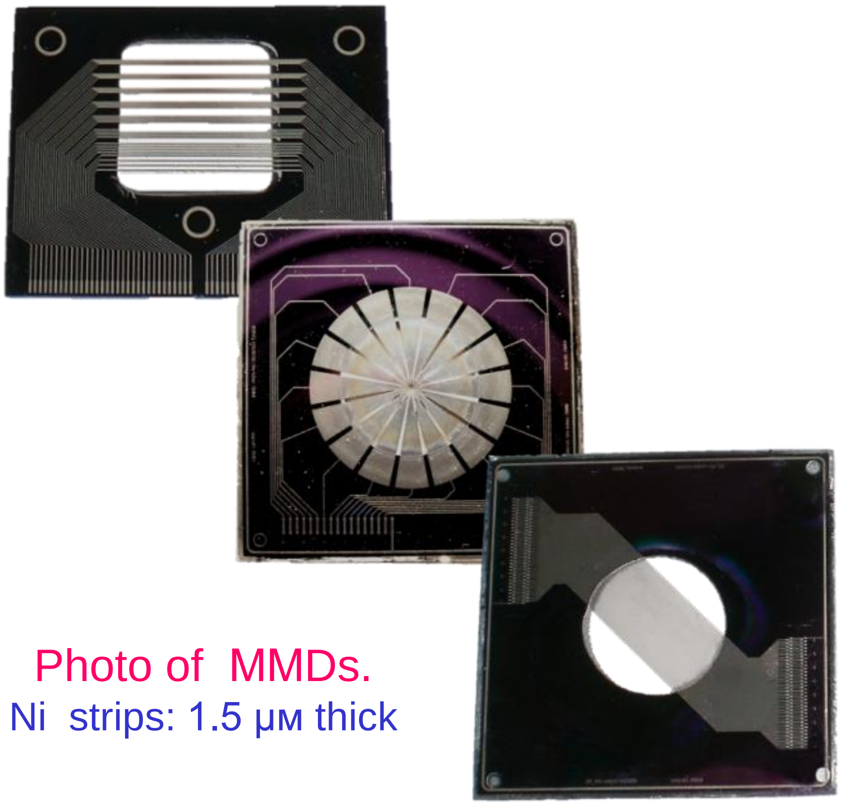


Photo of MMDs.
Ni strips: 1.5 μм thick

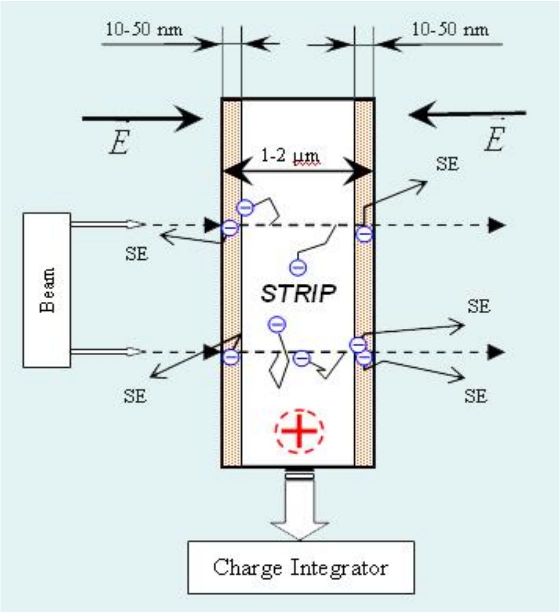
Advantages of the MMD:

- High Radiation tolerance (10-100 MGy)
- Nearly transparent sensor – 1 μm thickness
  the thinnest detector ever made
  for the particle detection
- Low operation voltage (20 V)
- Perfect spatial resolution (10 μm)
- Unique, well advanced production technology
- Commercially available readout hardware
- and software.

MMD applications:

- Non-destructive beam profile monitoring
- Precise dose distribution measurements for micro-biology, medicine etc.
- Imaging X-ray and charged particle beams
- Detectors at the focal plane of mass-spectrometers and electron microscopes

MMD Principle of operation



Signal – positive charge created by the electron emission under the impinging particles.

Conversion factor – electrons/particle: ranges from 0.1 (for MIP) to few hundreds (for the fast Heavy Ion)

Noise – thermoelectric emission, r/f pickup, fluctuation of the leakage current, … Determined by the connecting cable and readout electronics: ENC: (100 – 500) electrons

Thickness – 1 μm (transparent, non-destructive device for the measured beam)

Position resolution – up to 10 μm

This technology works with x-rays, protons and other ion beams!

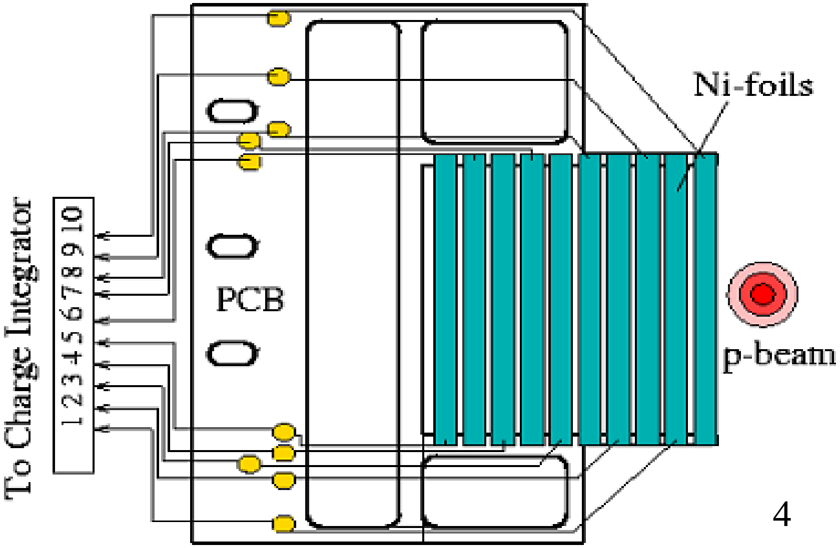
Radiation hardness - more than 100 MGy

Stable operation at X-ray intensity

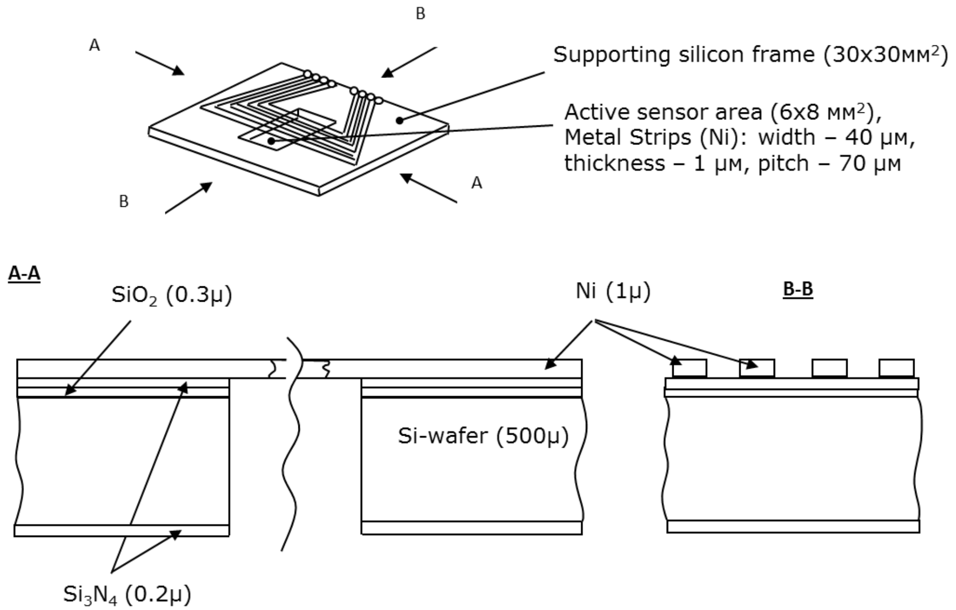
- up to 10^{16} photons·s^{-1}·mm^{-2}

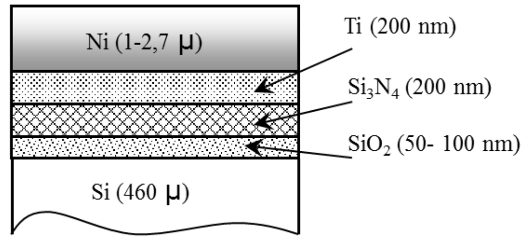
Stable operation at proton beam intensity

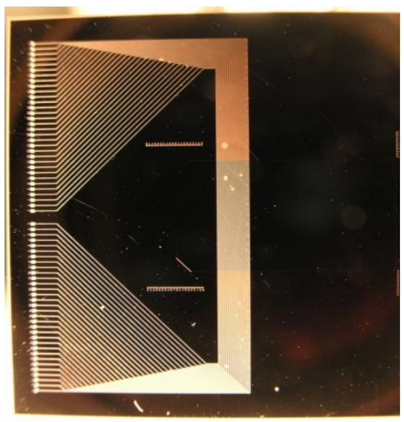
- up to 10^{10} protons·s^{-1}·mm^{-2}

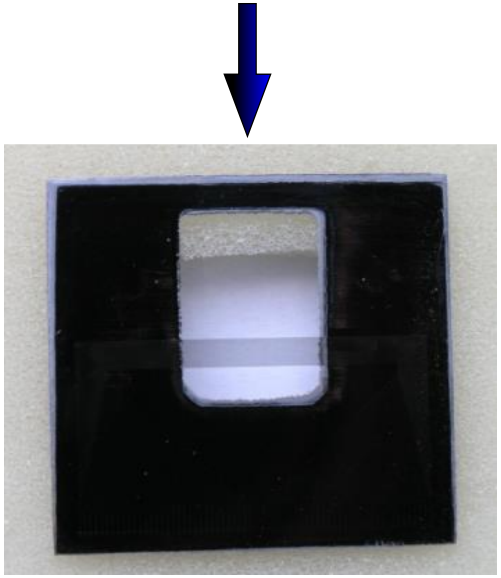


Production technology









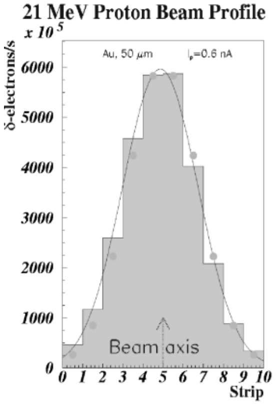
PRODUCTION TECHNOLOGY

The sensors were prepared by means of microelectronics technology and plasma-chemistry etching. Nickel layers served as films for the photo-lithography shaping of the strip pattern as well as contacting lines and pads. From the back side of the sensor a window was created for the plasma-chemistry etching. The KINR plasma-chemical reactor with variable ion energy has been used.

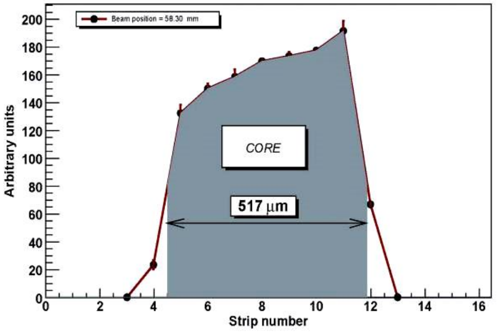
The strips were bonded to the ceramics based pitch adapter and connected by a flexible kapton isolated cable to the 50-pin connector.

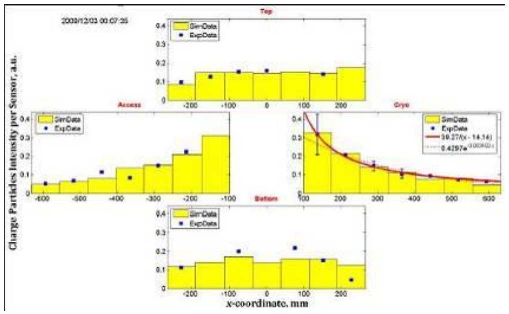
Metal strip sensor is the only object interacting with the radiation beam in the working area

Earlier applications



- HERA-B Luminosity monitoring
- LHCb Radiation Monitoring system
- BPM for 21 MeV proton beam (tandem MPIfK)
- BPM for the LHCb (ST) test beam studies
- 21 keV Synchrotron BPM at HASYLAB





Metal Foil Detector technology allows for Building any size beam monitoring systems

Metal detectors are suitable for measuring and imaging beams of charged particle in the energy range from keV to TeV as well as synchrotron radiation.

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)

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

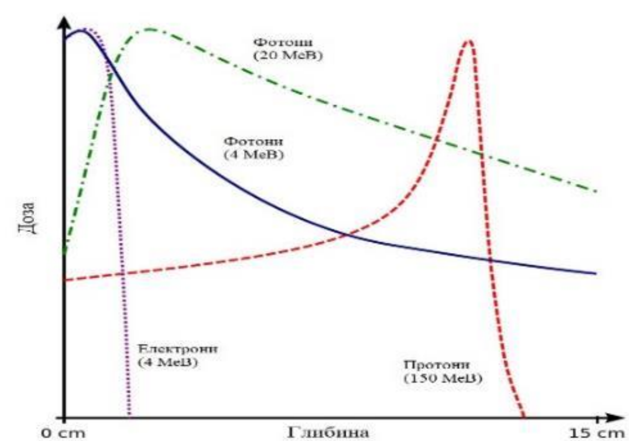
Criteria of profit – **PVDR**

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)

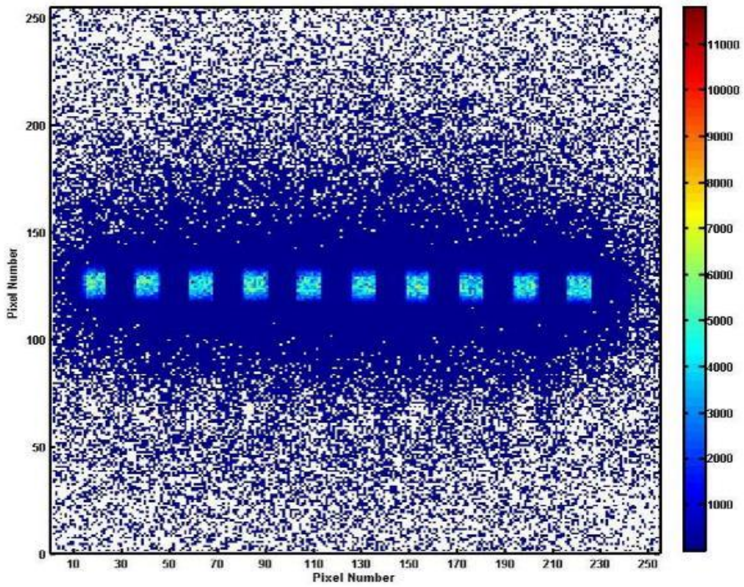
[V. Pugatch, et al. Characterization of equipment for shaping and imaging hadron minibeams. NIM A872 (2017) 119-125.]



TimePix measuring High intensity X-Ray beams

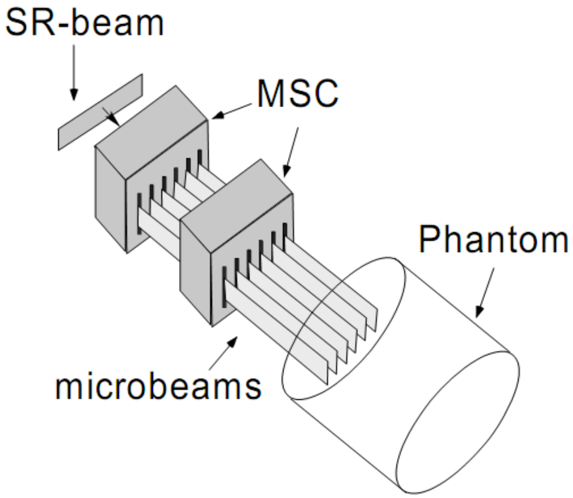
Measurements at the beamline ID17 ESRF (Grenoble)

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

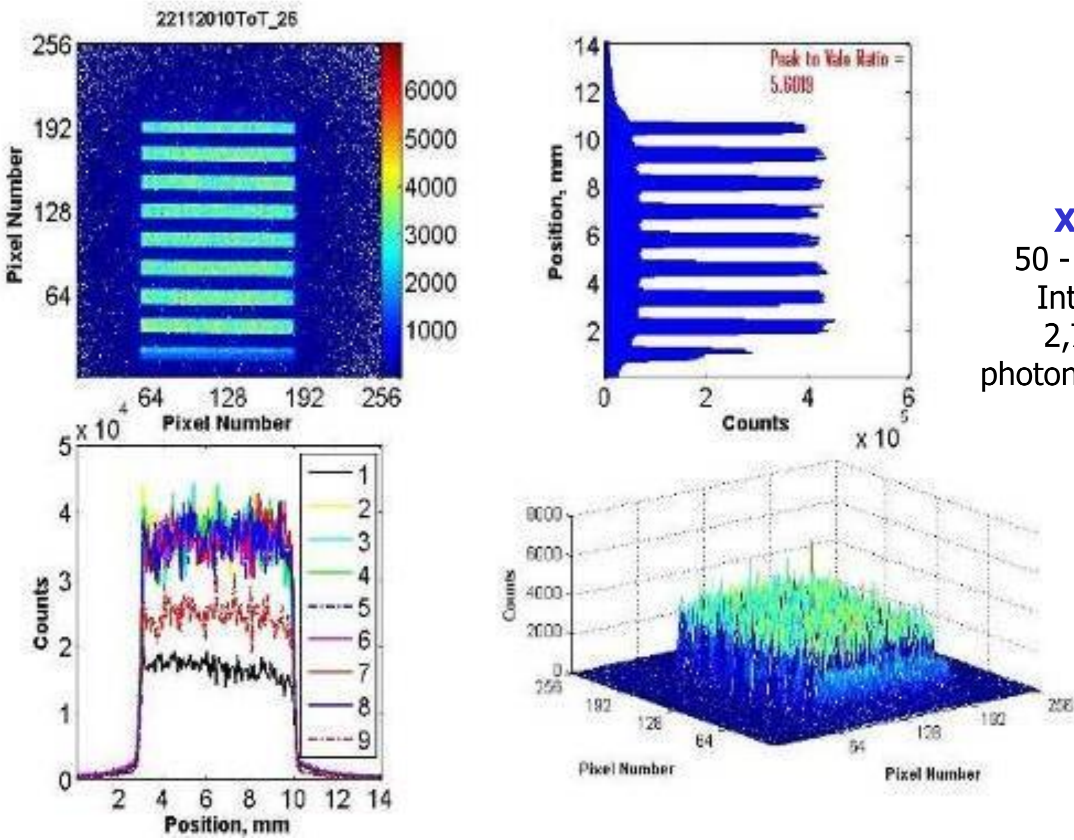


Energy: 150 keV
Intensity: $2{,}7 \cdot 10^{11}$ photons/(c·mm²)

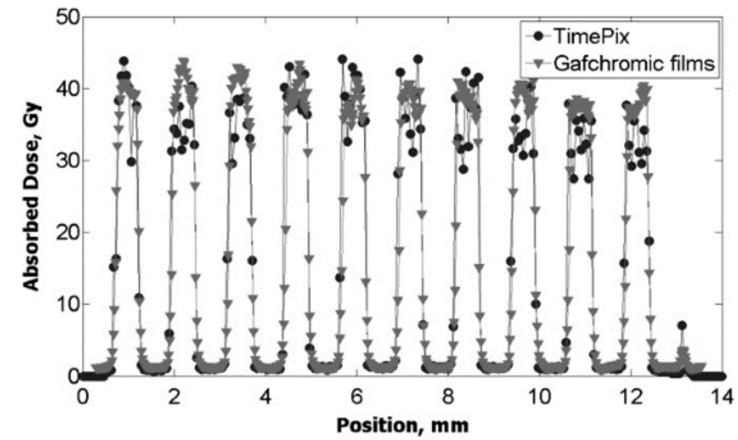
Radiation hard detectors are required!

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×mm²)



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

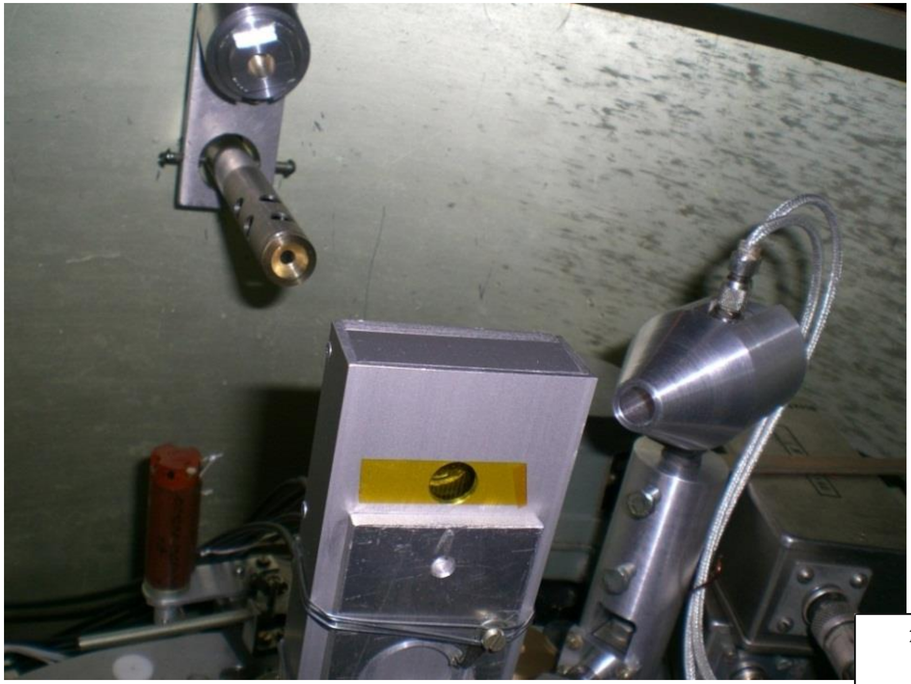
Characterization studies of the Metal TimePix measuring in real time dose distribution at the Mini-beam Radiation Therapy setup (ESRF, Bio-Medical Beamline ID17) were performed.

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) mm² area.

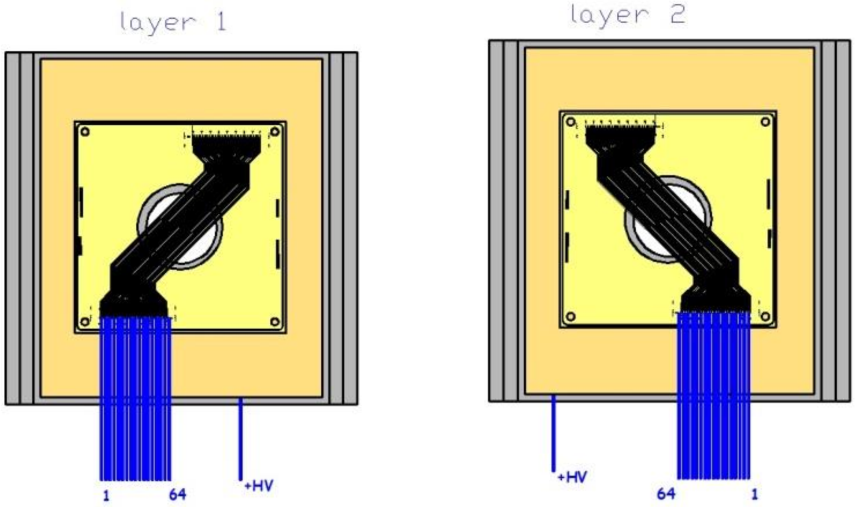
Peak-Valley-Ratios measured by TimePix and gafhromic films agree well.

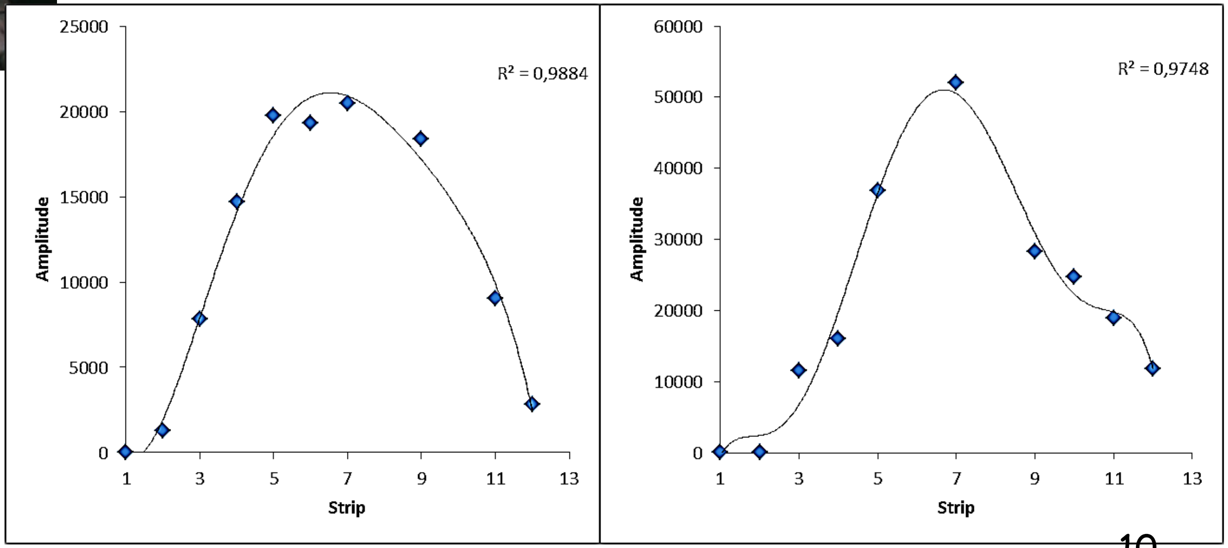
MMD Tests

3 MeV Proton beam profile monitoring. Tandem-generator at INR (Kiev)



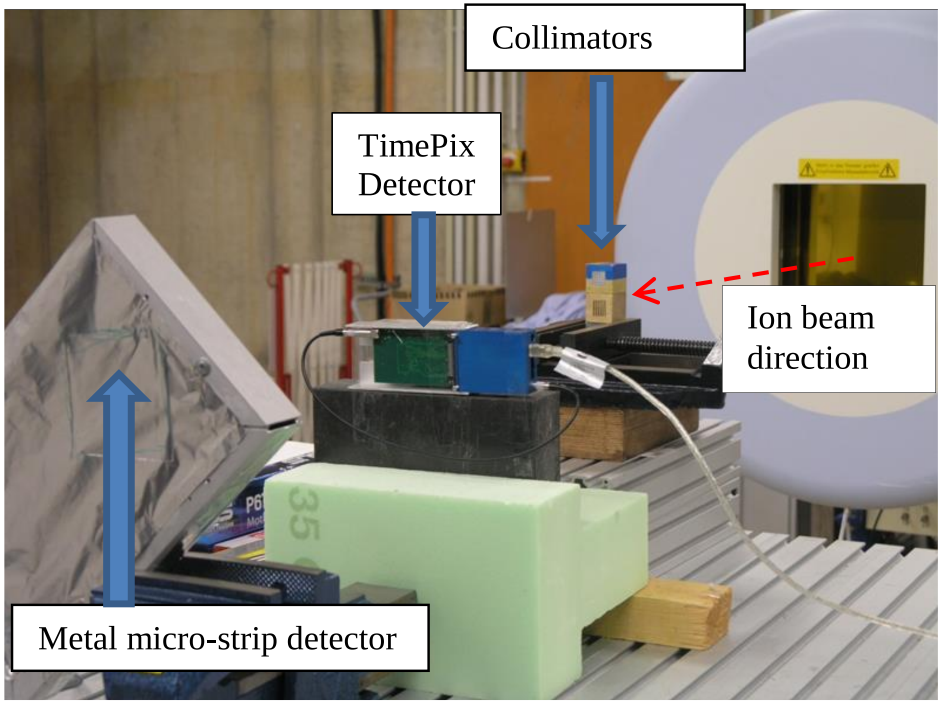
MMD64: 64 strips, 100 μm pitch, 40 μm width, 1 μm thick





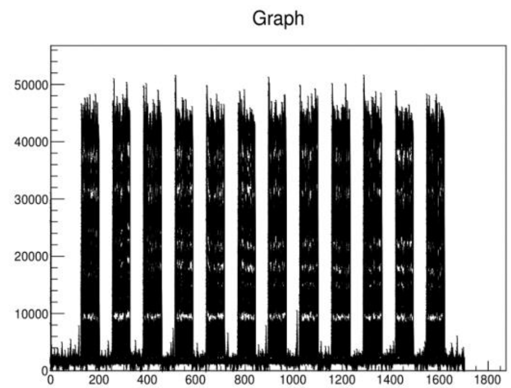
Spatial (Horizontal and Vertical)
Proton Beam Profiles

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

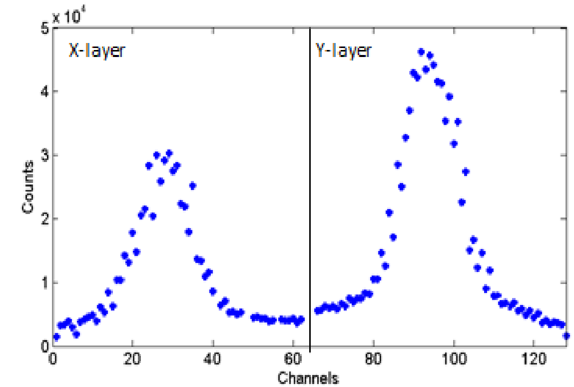


Fixed horizontal beam station of the Heidelberg Ion Therapy center (Germany)

Primary carbon ion beam time and spatial structure measured by MMD



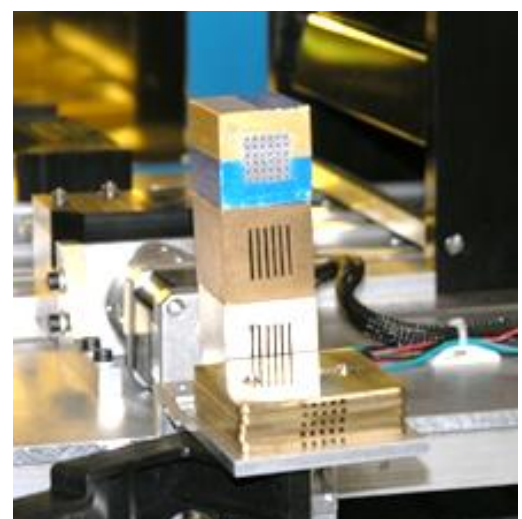
Time structure



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

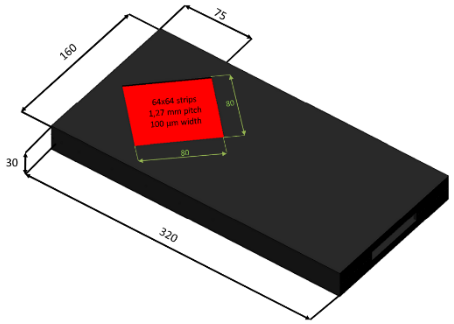


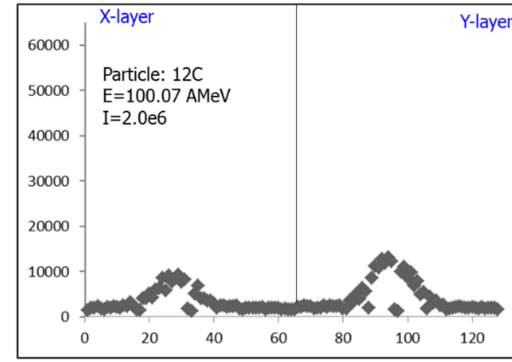
Slit Colimators
(1.0 mm width, 2.5 mm c-t-c distance)

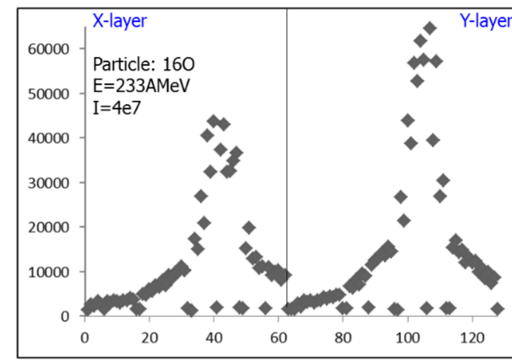
Matrix collimators
(holes of 1.5 x1.5 mm^2 and c-t-c distance of 4 mm)

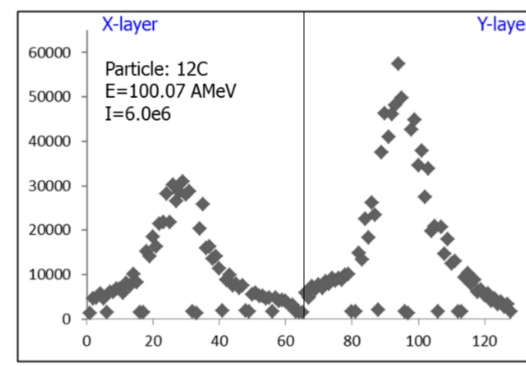
Material: aluminum, brass, lead

HIT. Beam profile monitor

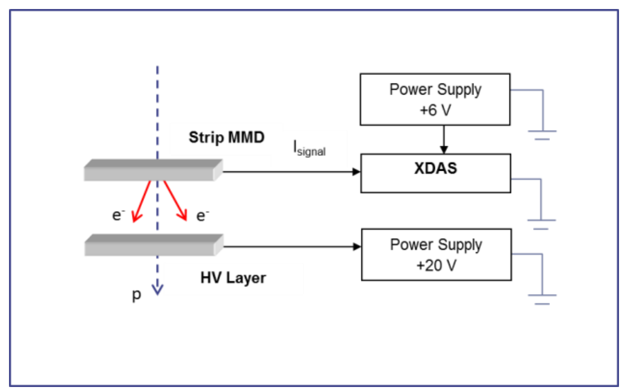








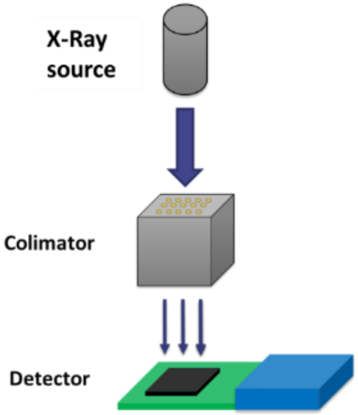
Working area: 80x80 mm^2
Channels: 64+64
Resolution: 0,4 mm
Sensitivity: >10^3 p/(strip*s)
Dynamic range: 10^3



performance of the MMD in measuring and imaging the primary carbon ions beam features

Spatial (Horizontal and Vertical) Ion Beam Profiles

Testing at the Clinac system



Beam Energy: 6-12 MeV

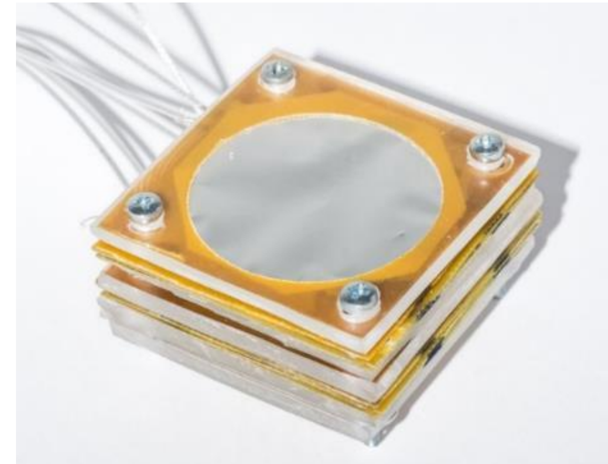
Pulse Width: 5 μs

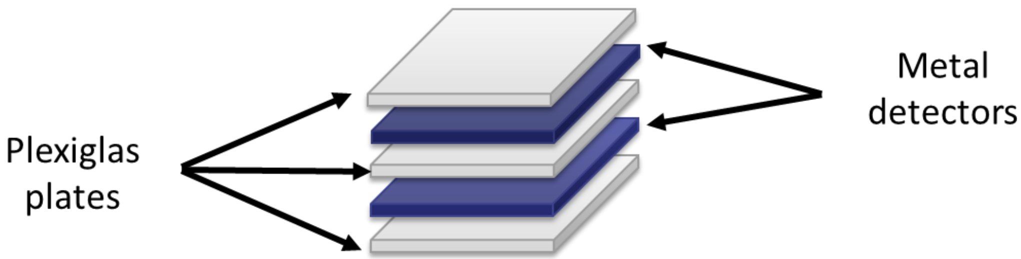
Pulse Repetition Rate: 20-100 Hz

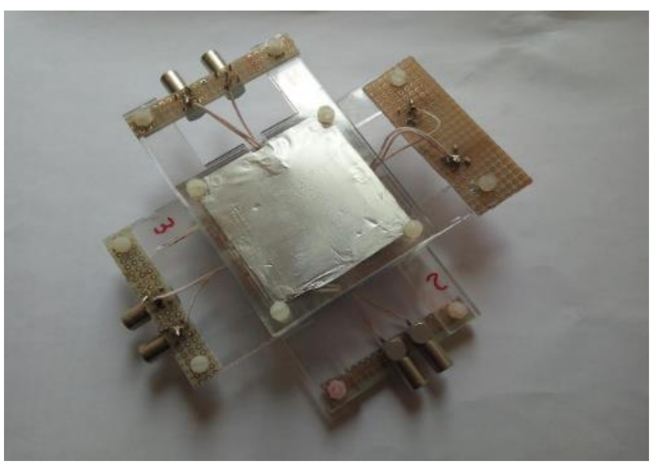
Beam type: Photon, electron

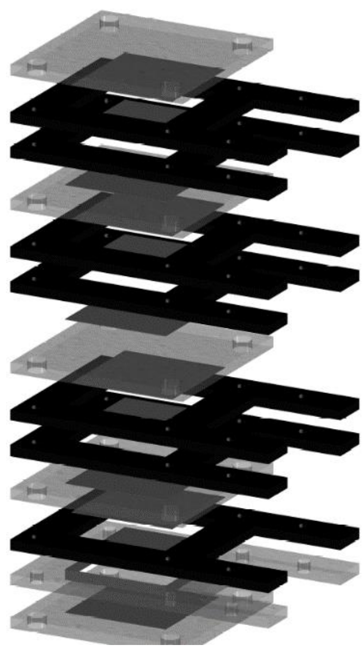
Detectorized Phantom

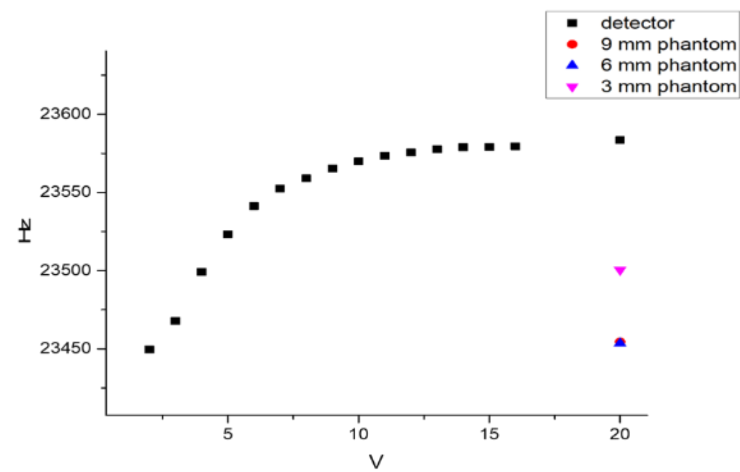
Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).
A few prototype have been produced and tested





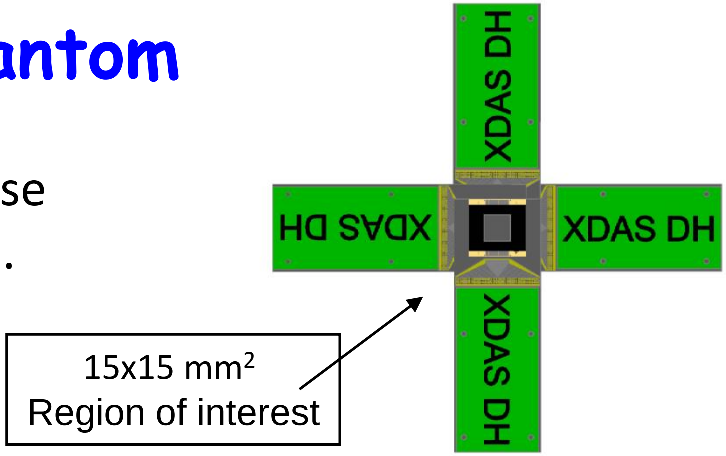


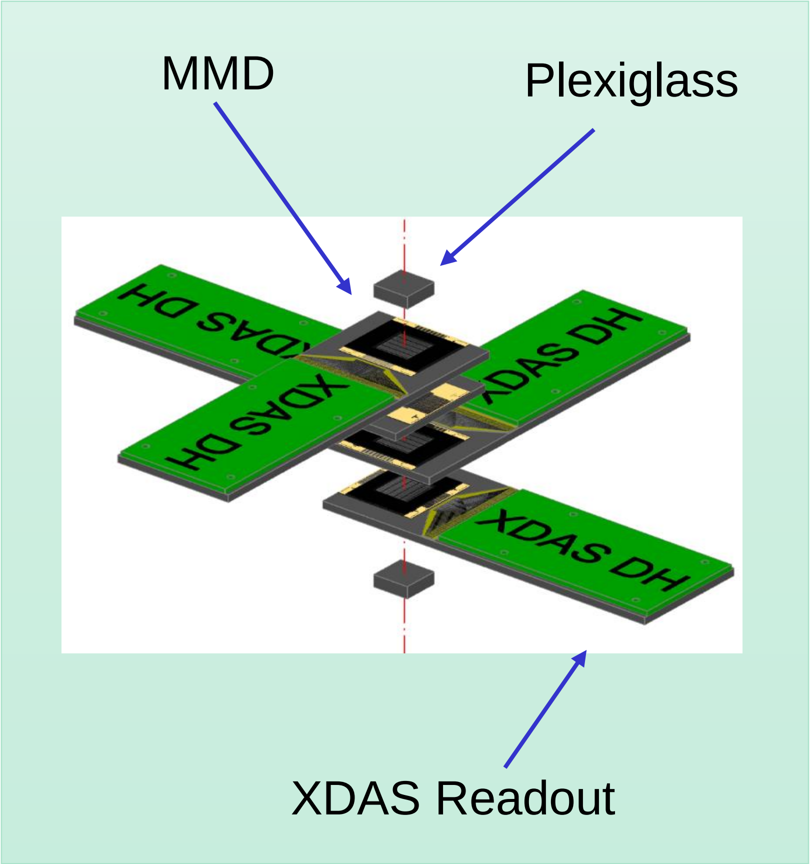




Detectorized Phantom

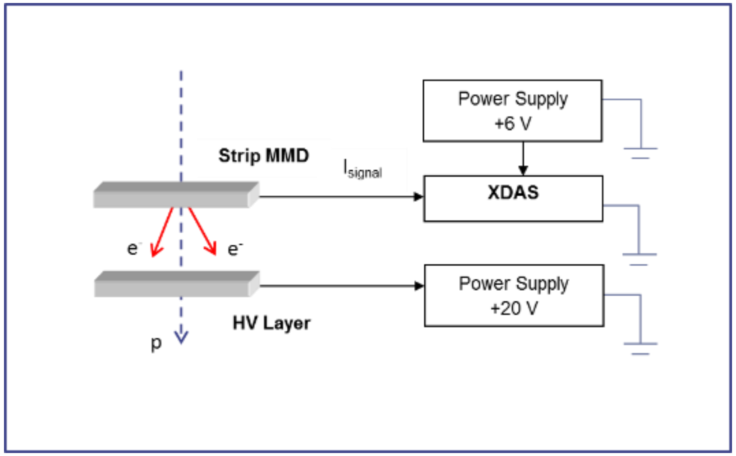
Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).





Modular imaging system (Up to 168 Detector modules).
The layers of the phantom medium (Plexiglas) and “transparent” detectors follow one another

XDAS - data acquisition system (SENS-TECH, UK)



Fractionizing hadron beam

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

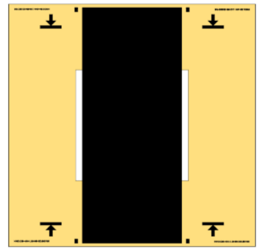
Matrix collimators
(holes of 1.5 x1.5 mm^2 and c-t-c distance of 4 mm)

Material: aluminum, brass, lead

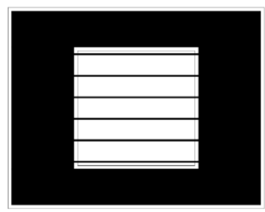
the collimators designed and made in Ukraine – to test the possibility to make multi-beam structure – fractionated hadron therapy.

MMD for Detectorized Phantom

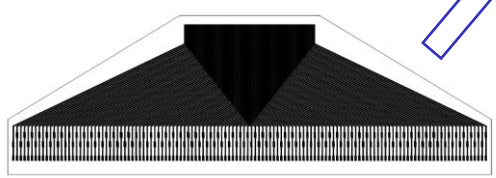
MMD sensor:
- Size – 35x35 mm^2
- Working area – 15x15 mm^2
- Strip thickness – 3um
- Strip width – 90 um
- Strip pitch – 110 um



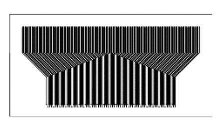
MMD-HV:
- Size – 35x28 mm^2
- Working area – 15x15 mm^2
- Strip thickness – 3um
- Strip width – 200 um
- Strip pitch – 3000 um



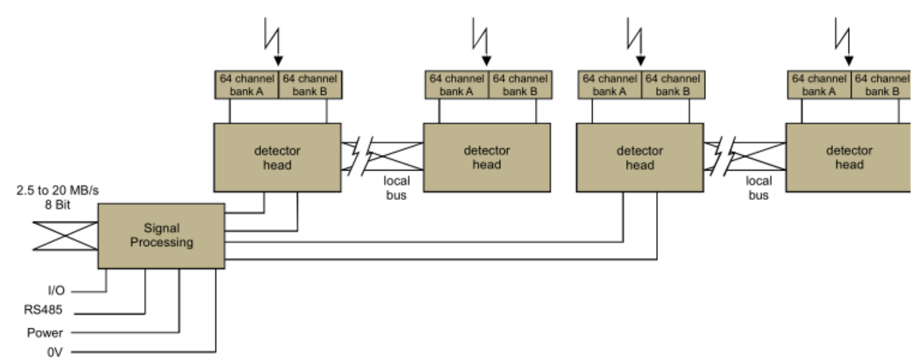
MMD-adapter for XDAS:
- Size – 52x17 mm^2
- Input pitch – 110 um
- Output pitch – 400 um



MMD-adapter for Alibava:
- Size – 16x8 mm^2
- Input pitch – 110 um
- Output pitch – 80 um



Multiple boards can be connected in series and detectors can be butted end-to-end to provide a continuous array.



XDAS

XDAS - X-ray data acquisition system

XDAS is a modular system of boards for use in any X-ray linescan applications. Each board has 64 or 128 channels, corresponding to a detector pitch of 2.5, 1.6, 0.8 or 0.4 mm. Multiple boards can be connected in series and detectors can be butted end-to-end to provide a continuous array.

XDAS (SENS-TECH, UK)

2.5, 1.6, 0.8 or 0.4 mm detector pitch

up to 21504 (128x24DHx7SP) channels in a system

simultaneous data acquisition and read-out

dual energy option

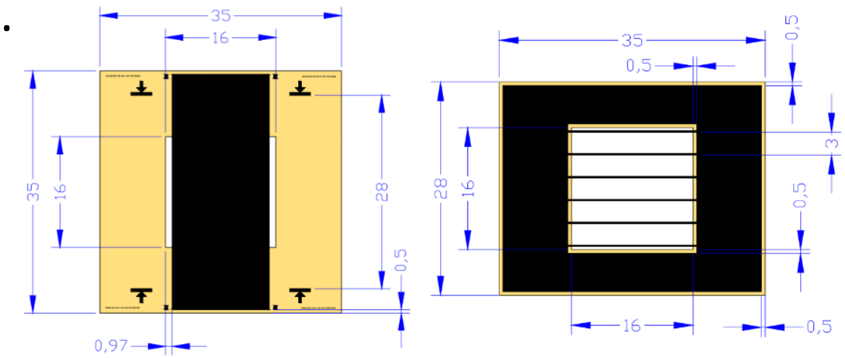
wide dynamic range

16 bit output

high speed USB2 or parallel RS485 link to CPU

Detectorized Phantom. Status

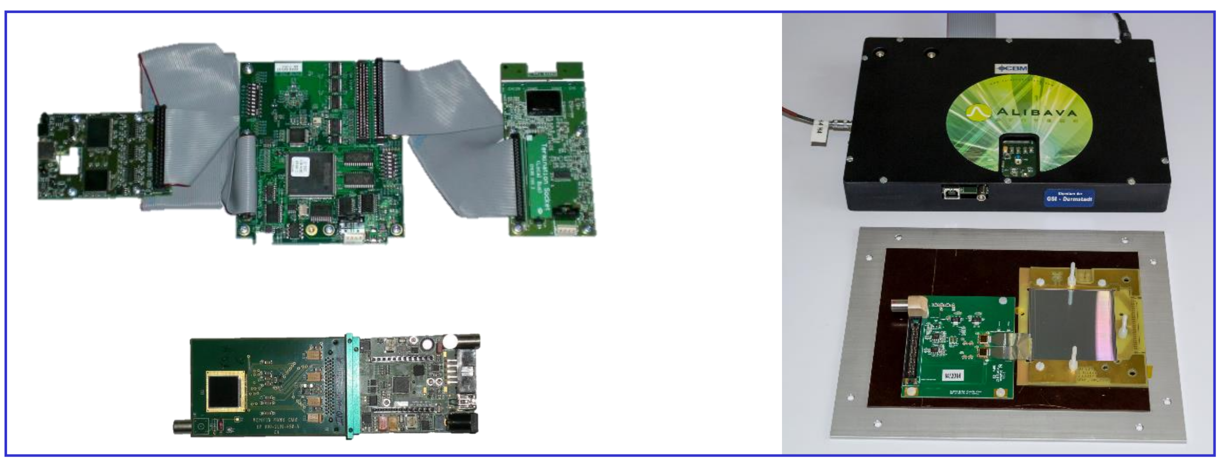
Development of detectorized phantom prototypes for dose delivery verification (heavy-ion radiotherapy in oncology).



The MMD sensor as well as HV-plates and adapters for detectorized phantom are designed. Detector module is designed

First prototypes are under production:
-phololitography – done
-gilding contacts – in work
-plasma etching – in work

Readout system tests:
XDAS – ready to use
Timepix – ready to use
Alibava - testing



Summary

- **Metal Micro-detectors is a reliable tool for online measurements of radiation beam parameters.**
- **Physical features of the MMD makes it applicable for beam diagnostics at any accelerators of charged particles**
- **Main advantages of MMD: transparency, radiation hardness, high position resolution.**
- **MMD have been successfully explored for measuring beam position and beam profile.**
- **Development of the detectorized phantom for dose delivery verification based on MMD has been started.**

Acknowledgements

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

Thank You For Your Attention

Backup slides