RADIATION HARD MICRODETECTOR SYSTEM FOR PRECISION MONITORING OF IONIZING RADIATION BEAMS

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

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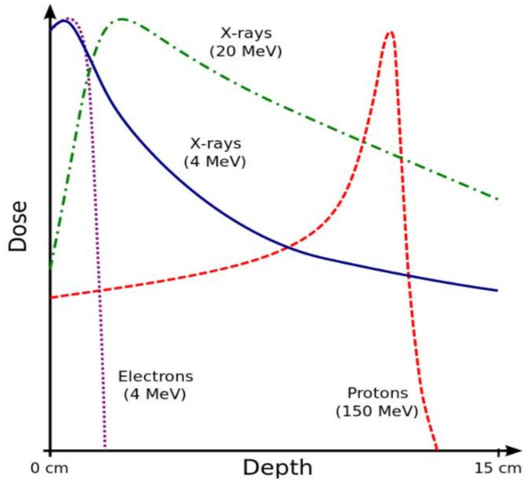
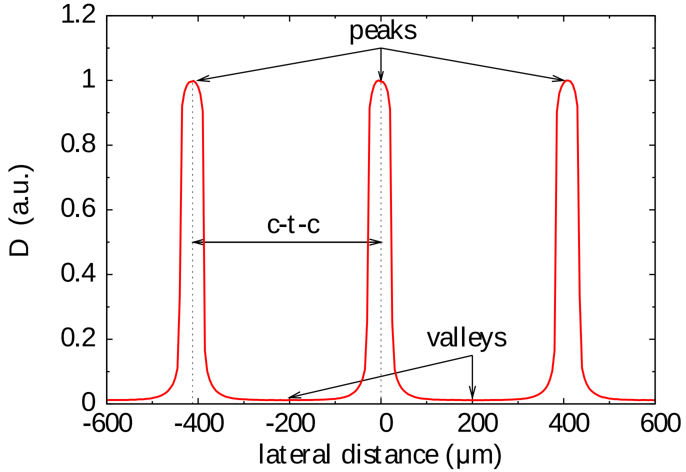
- **Make Irradiation field inhomogeneous:**
- **Shape it as mini-beams (0.6 mm width and 1.2 mm periodical structure) or micro-beams (50 µm and 100 µm periodical structure)**

- **Measured for the first time in real time in 2011 in Collaboration KINR_ESRF_Medipix(CERN) – spatial dose distribution in agreement with gafchromic films *[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)**

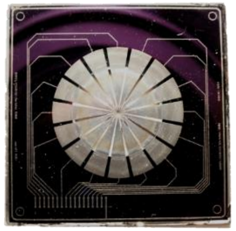
•***[V. Pugatch, et al. Characterization of equipment for shaping and imaging hadron minibeams. NIM A872 (2017) 119-125.]***



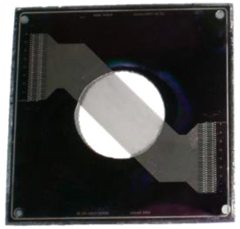


Criteria of profit – PVDR (peak to valley dose ratio)

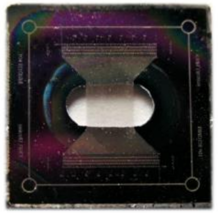
Metal Microstrip Detector



MMD: 16 sectors, 1 µm thick

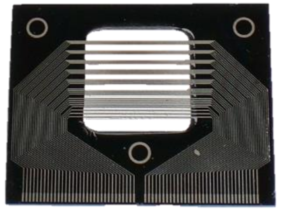


MMD: 64 strips, 100 µm pitch, 40 µm width, 1 µm thick



MMD: 128 strips, 30 µm pitch, 10 µm width, 1 µm thick

MMD: 1024 strips, 60 µm pitch, 40 µm width, 1,5 µm thick



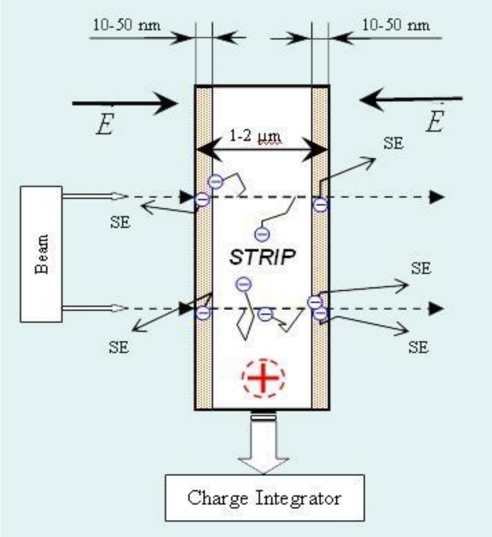
MMD Variable Step: 32 strips, 8 groups, 2-300 µm dist., 100 µm width, 1,5 µm thick

- 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)

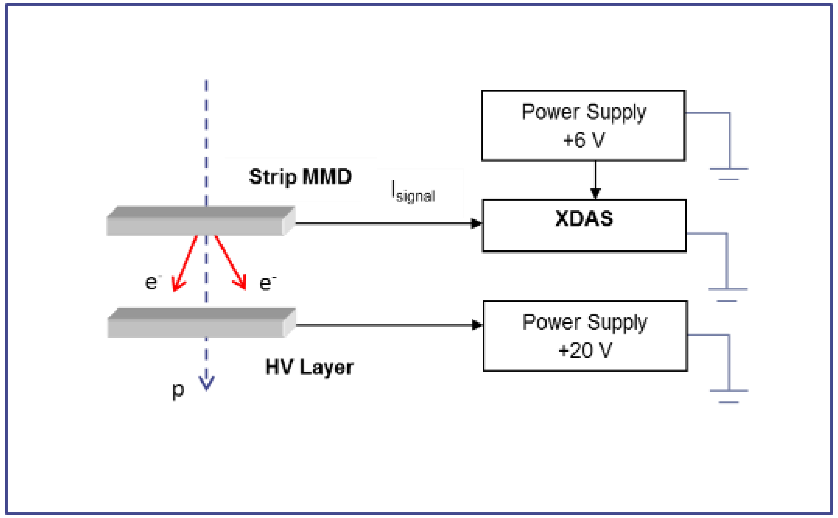
Position resolution – up to 10 µm

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

Radiation hardness - more than 100 MGy

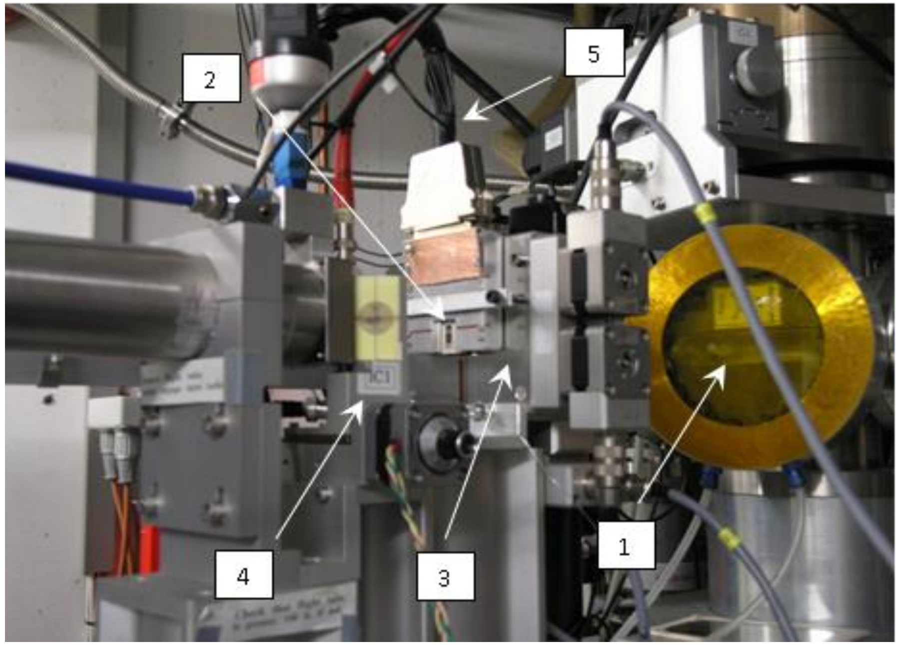
Stable operation at X-ray intensity - up to 10^{16} photons·s^{-1}·mm^{-2}

Stable operation at proton beam intensity - up to 10^{10} protons·s^{-1}·mm^{-2}



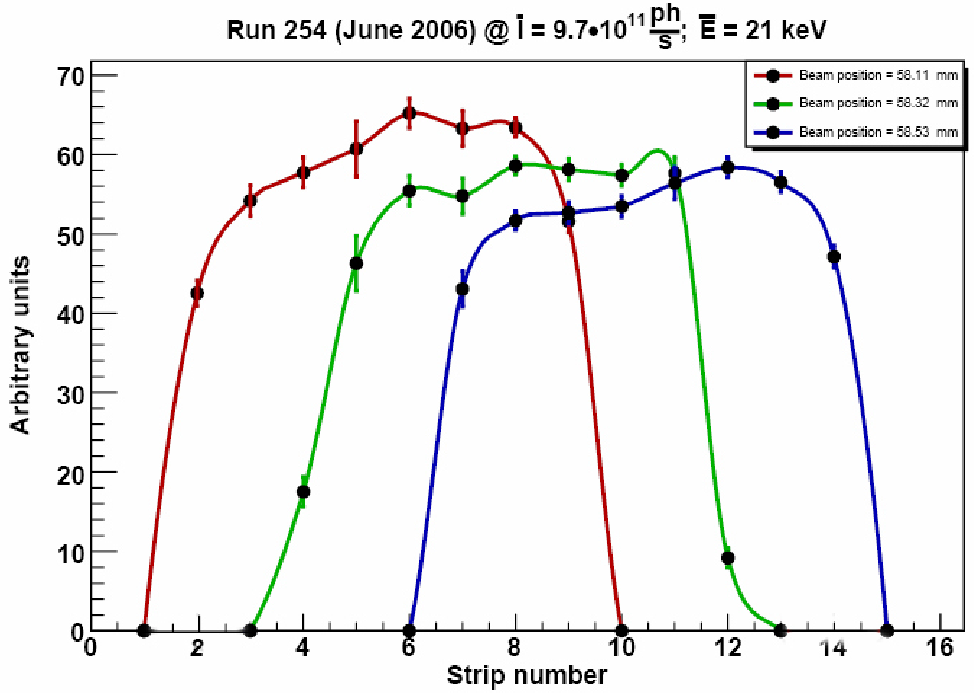
MMD on synchrotron DESY (Hamburg)

MMD tests on 20 KeV synchrotron beams at the DESY research center (Hamburg, Germany)

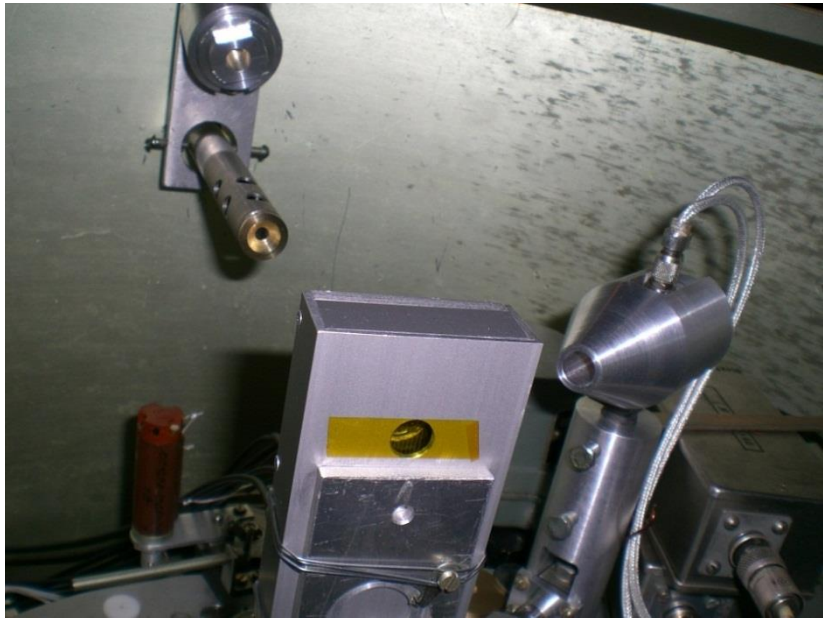


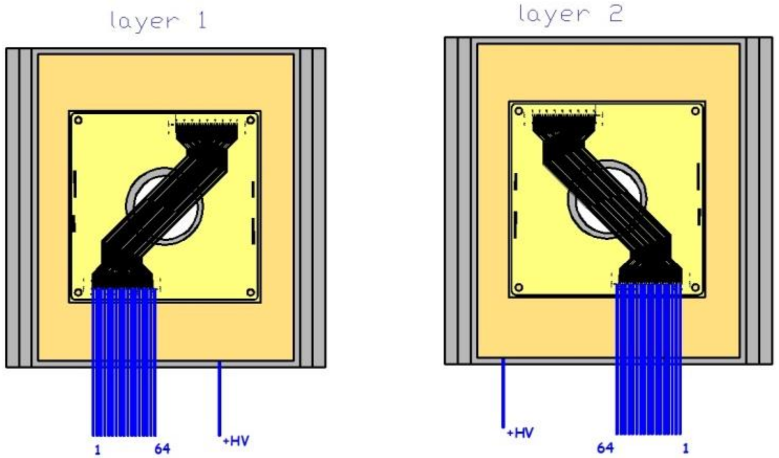
Experimental installation:
1 - beryllium window, 2 - MMD, 3 - fixed platform, 4 - ionization chamber, 5 - cable for reading data

MMD 32:
strips thickness 1.5 µm;
width 40 µm;
step 70 µm.

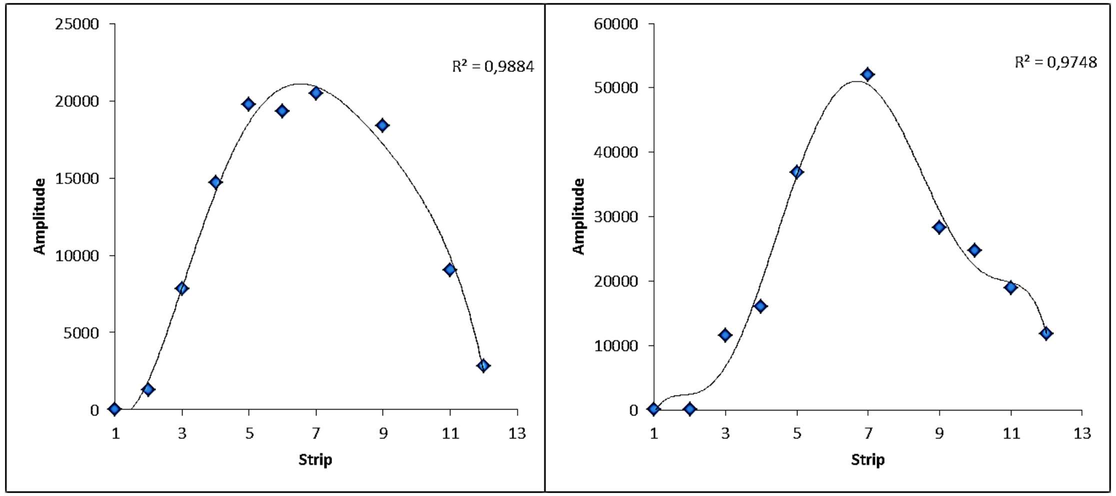


3 MeV Proton beam profile monitoring. Tandem-generator at INR (Kiev)





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



Spatial (Horizontal and Vertical) Proton Beam Profiles

Sens-Tech XDAS

XDAS is a modular system of boards for use in any X-ray lines can 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 built end-to-end to provide a continuous array.

data processing board

Detector head

USB adapter

XDAS (SENS-TECH, UK)

- Simultaneous data collection and reading
- 2,5, 1,6, 0,8 or 0,4 mm channel step
- Up to 21504 (128x24DHx7SP) channels in a system
- Low electronic noise
- 60μs minimum signal integration time
- 16 bits on the output
- USB 2.0 port

MMD (KINR) for Detectorized Phantom

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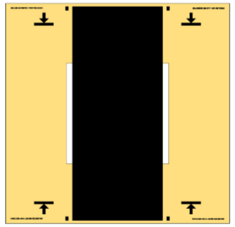
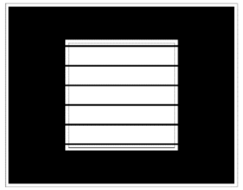
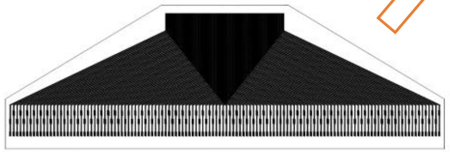
MMD sensor:
- Size – 35x35 mm^2
- Working area – 15x15 mm^2
- Strip thickness – 2um
- Strip width – 90 um
- Strip pitch – 110 um



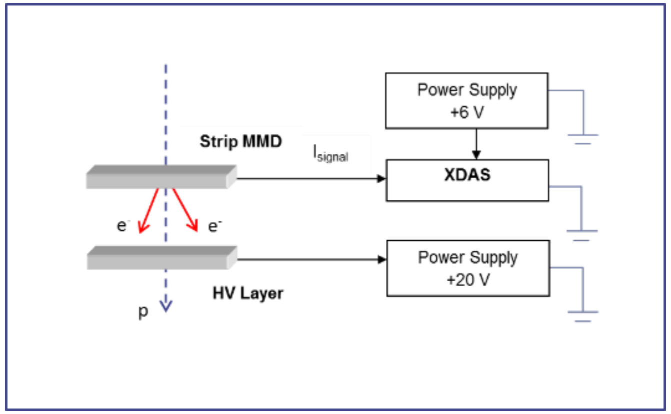
MMD-HV:
- Size – 35x28 mm^2
- Working area – 15x15 mm^2
- Strip thickness – 3um
- Strip width – 200 um
- Strip pitch – 3000 um

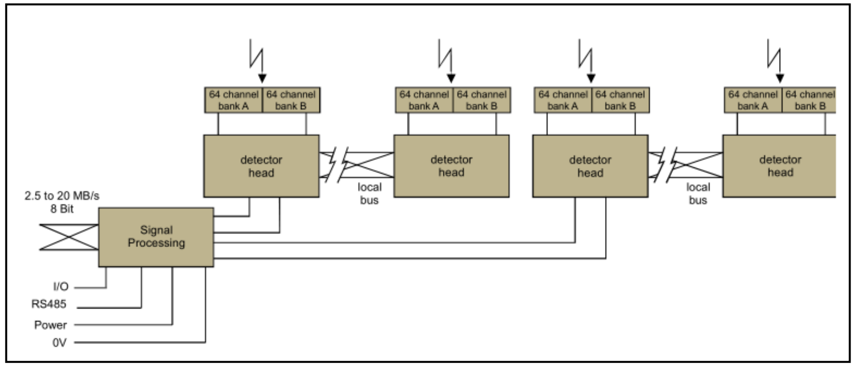


MMD-adapter for XDAS:
- Size – 52x17 mm^2
- Input pitch – 110 um
- Output pitch – 400 um



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





New prototype of beam profile monitor for detectorized phantom

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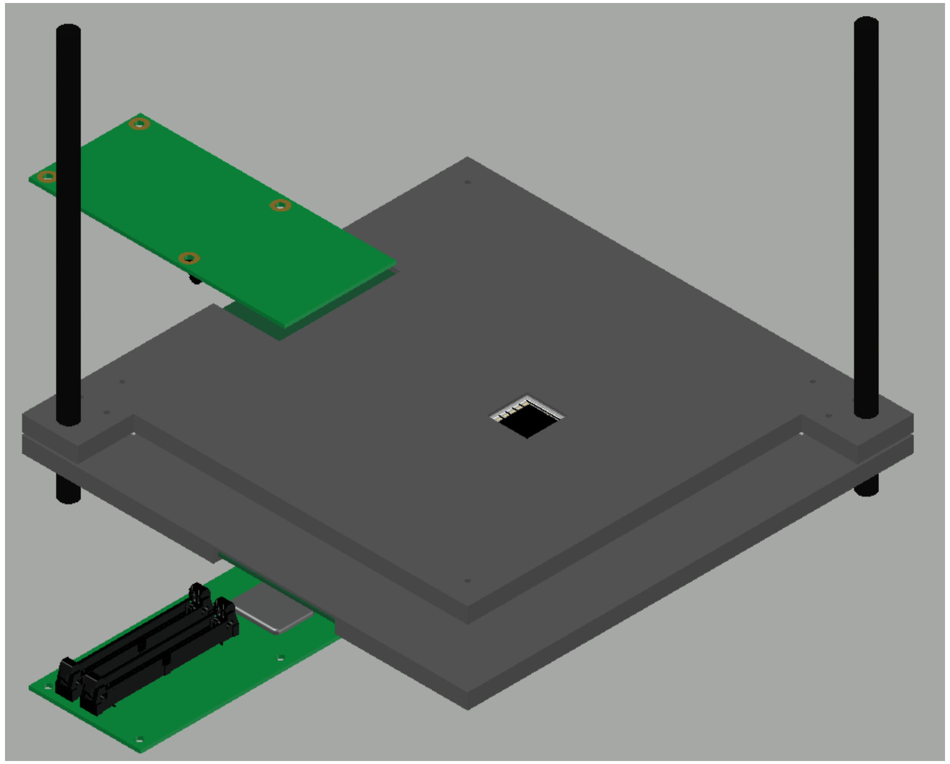

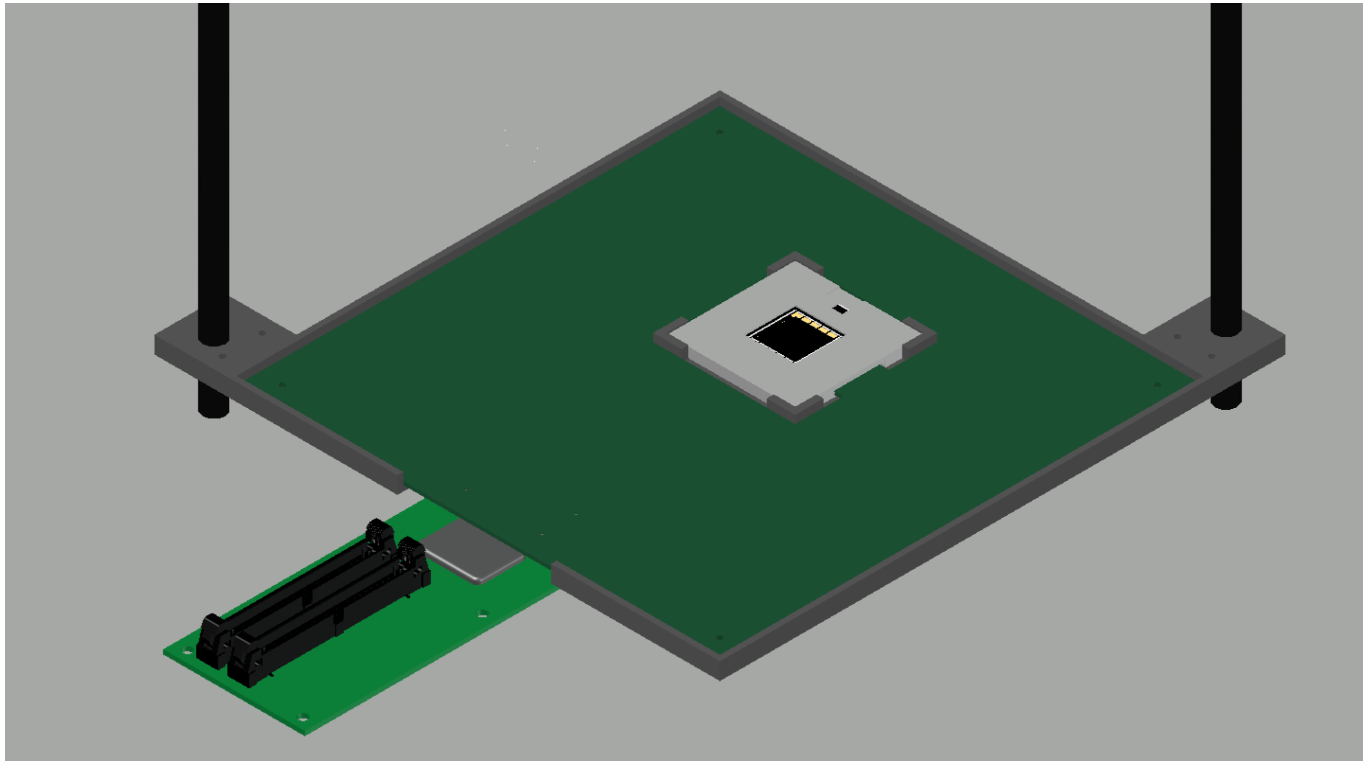

Detector module size is 176x170x9mm

New prototype of beam profile monitor for detectorized phantom

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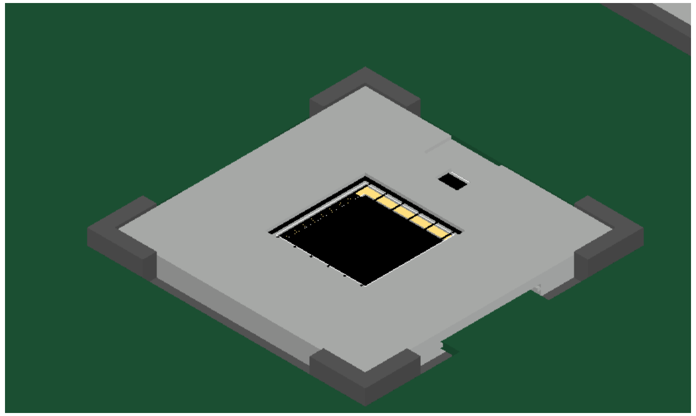
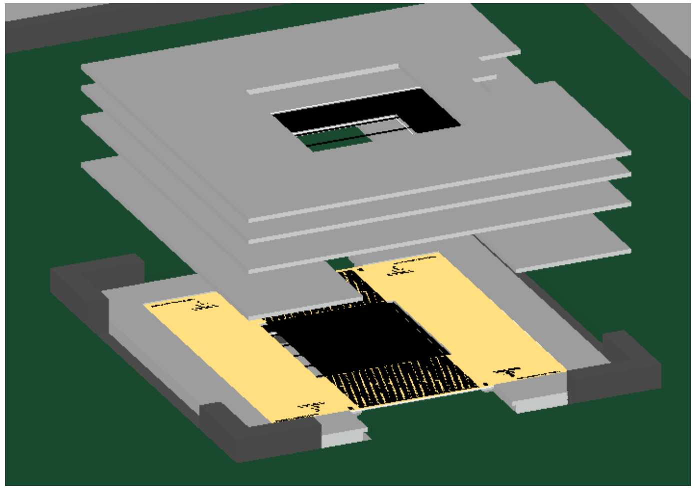
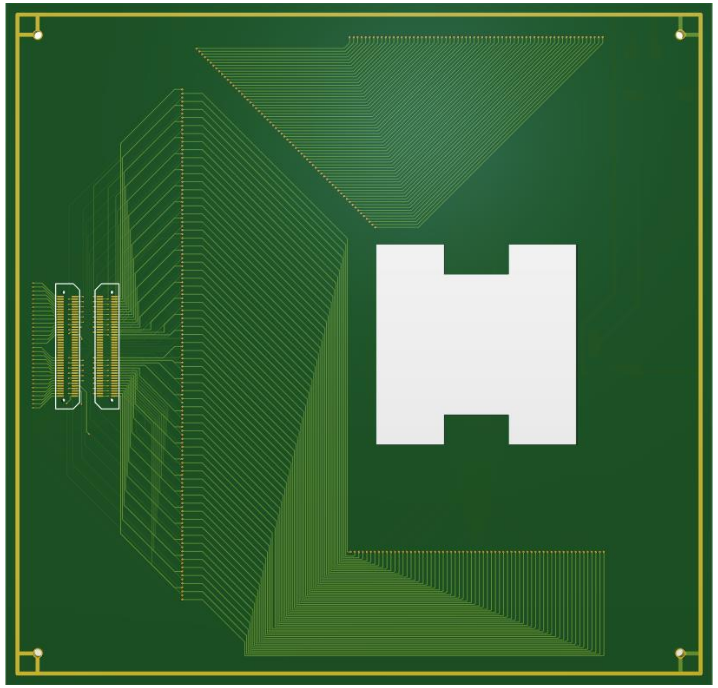
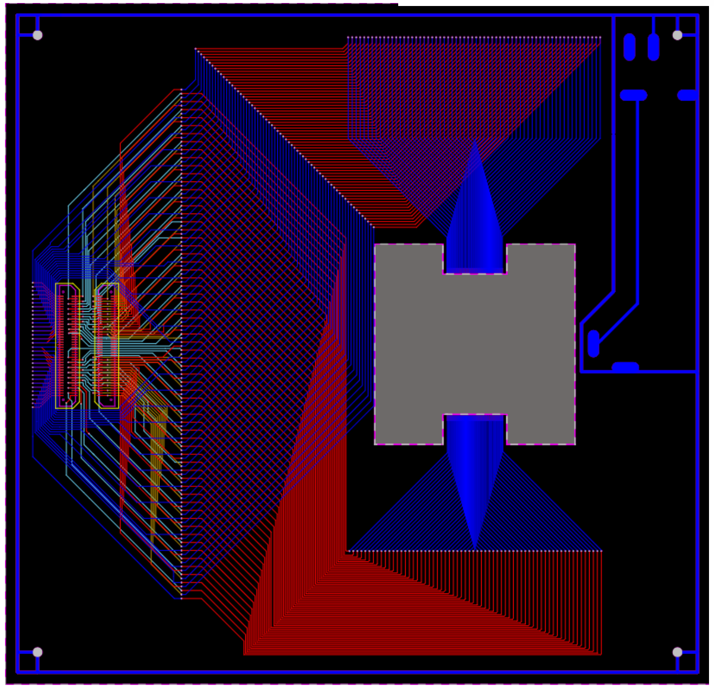
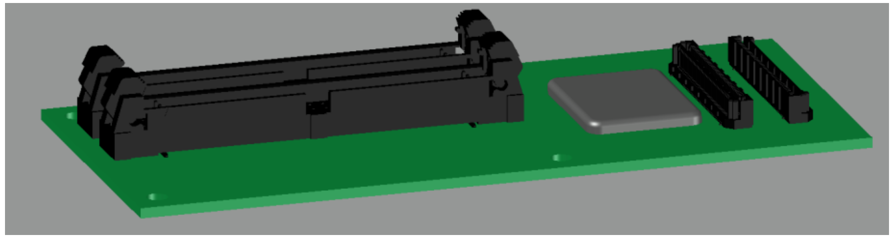








PCB adapter for MMD128 XDAS readout electronics



The sensor(MMD) is fixed in the frame using ceramics, which also serves as an insulator for leakage currents from HV Layer

Readout electronics Sens-Tech XDAS V3 has 128 reading channels and special connectors which allows to configure detection system

Matrix collimators made of different materials

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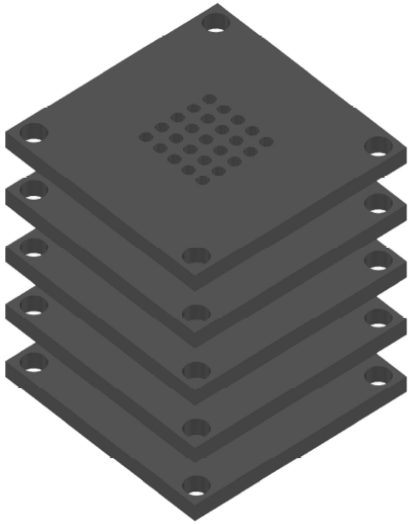
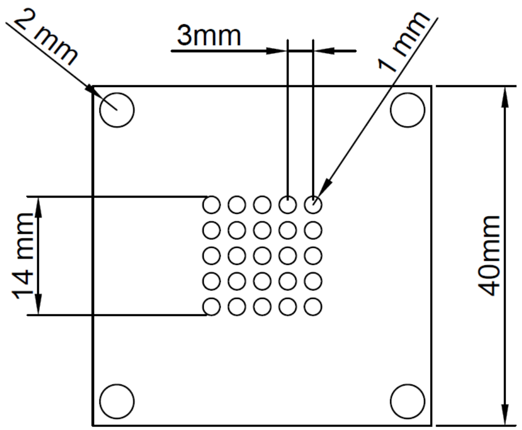
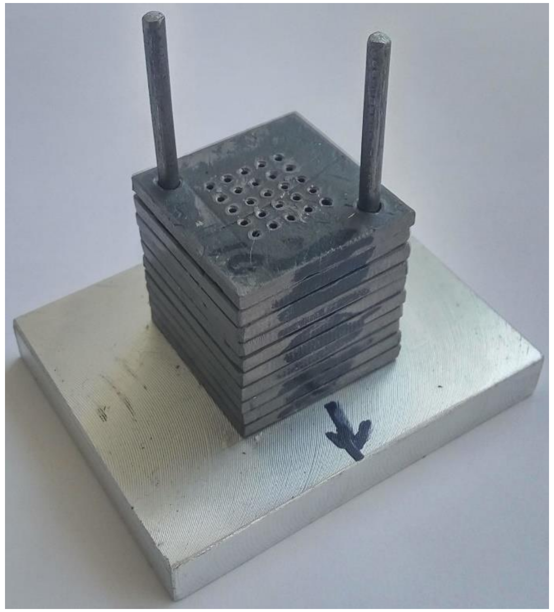
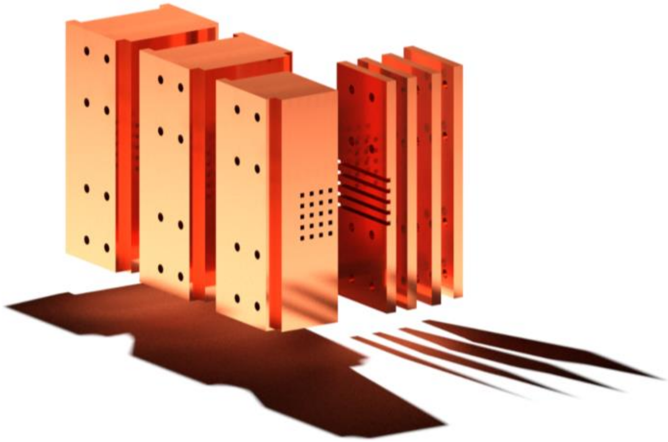
Modular lead collimator

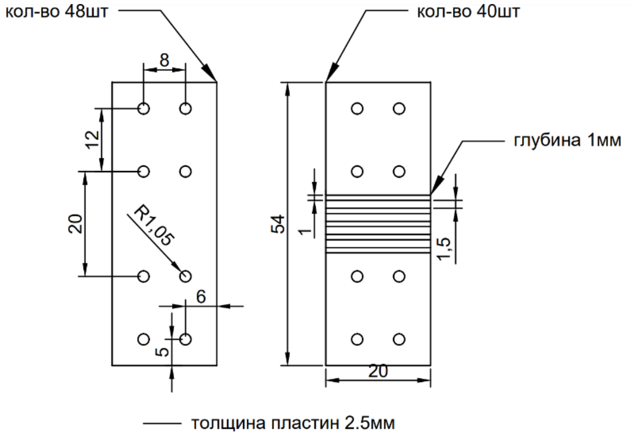






Modular copper collimator





Concept of Matrix collimator made of Tungsten

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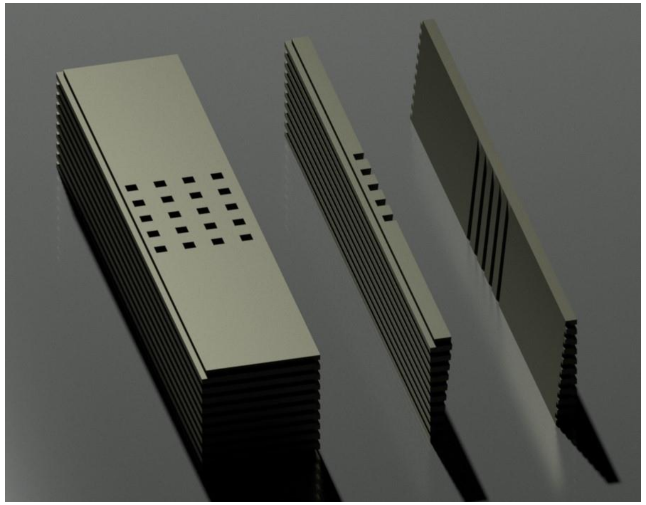
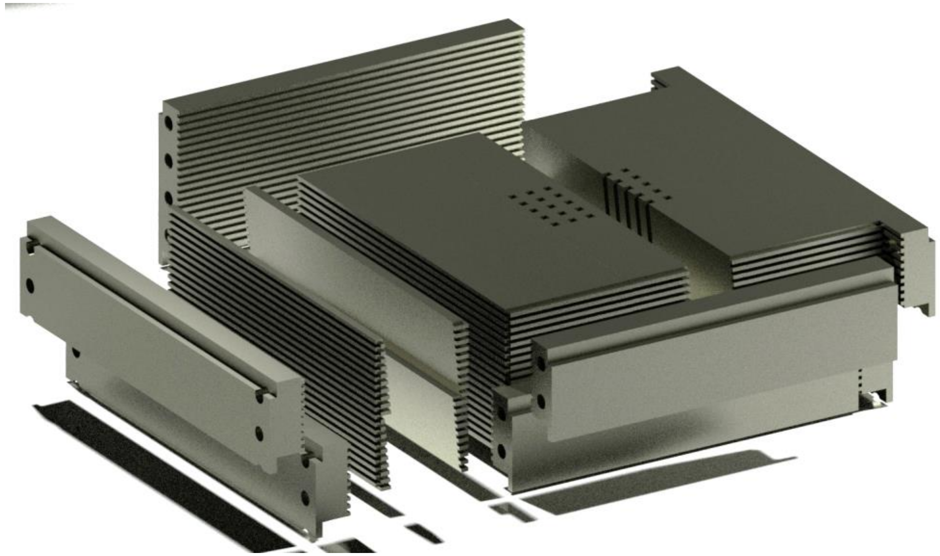
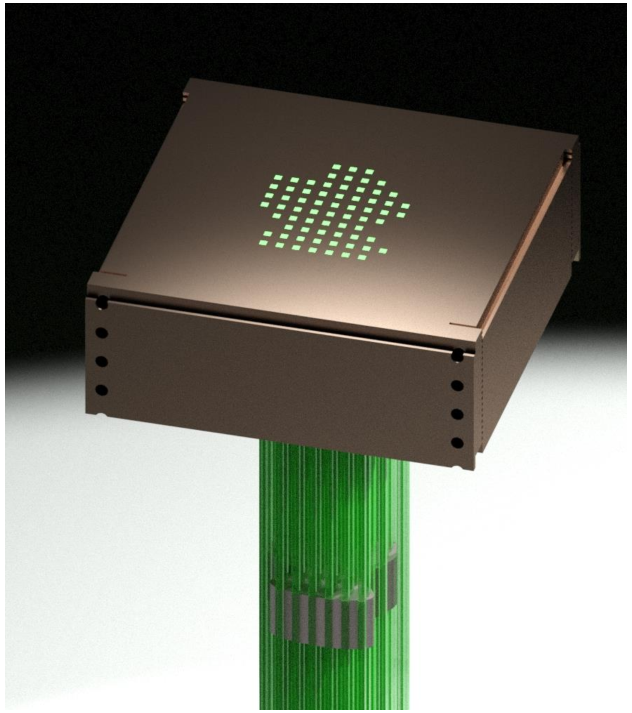
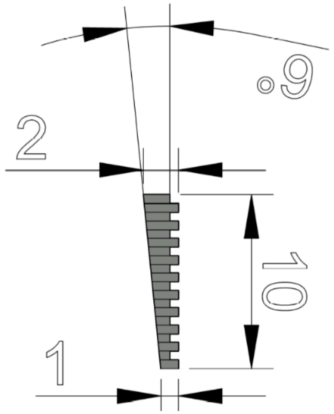
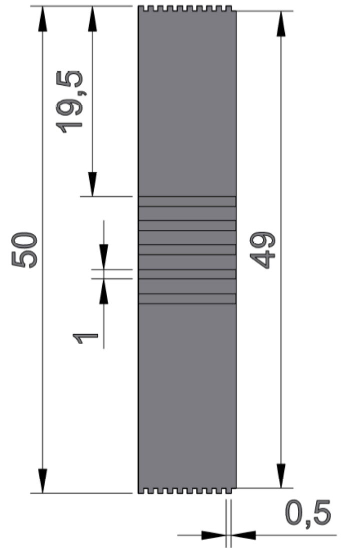
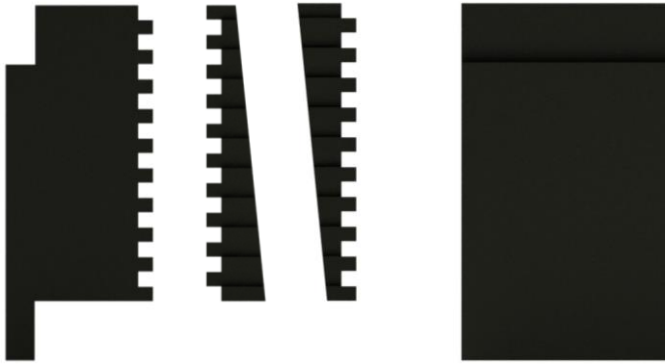




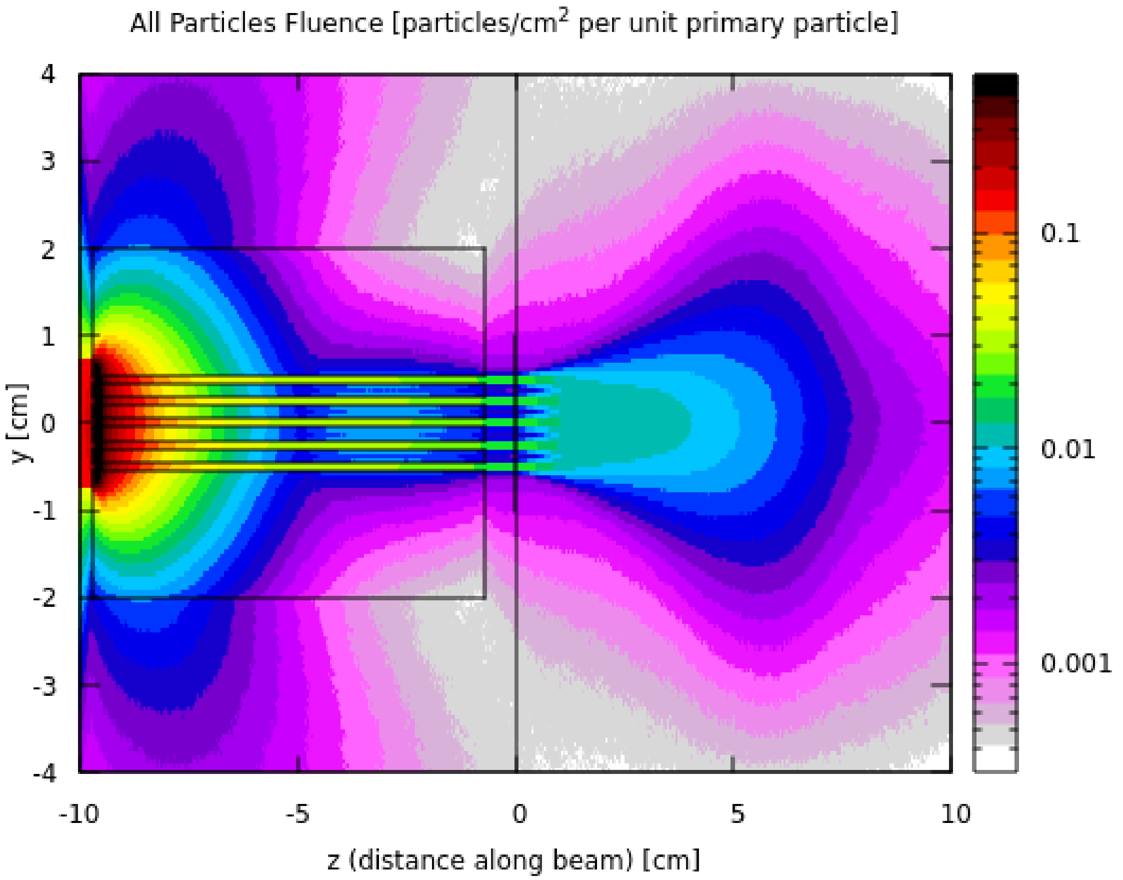




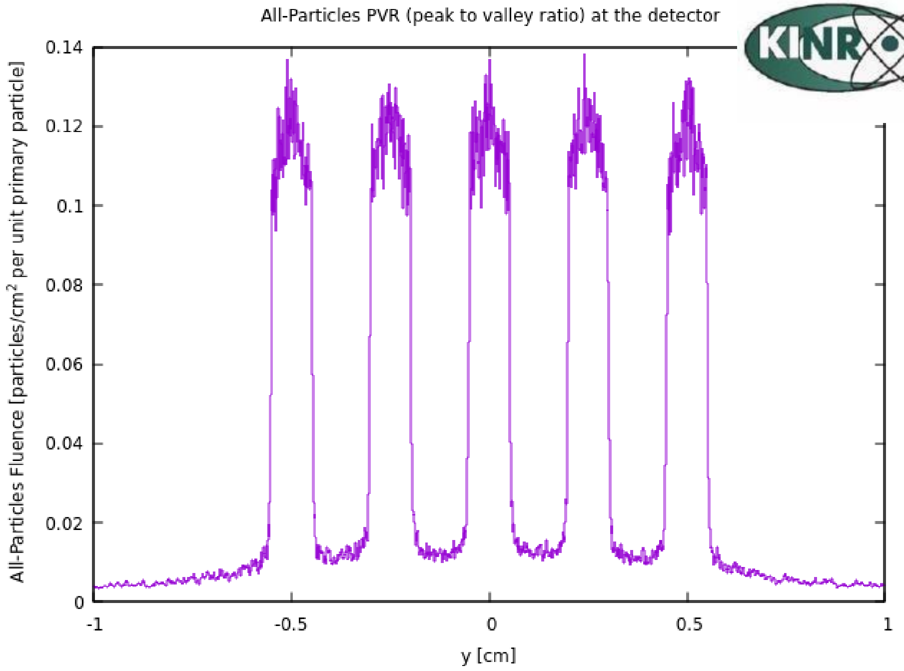


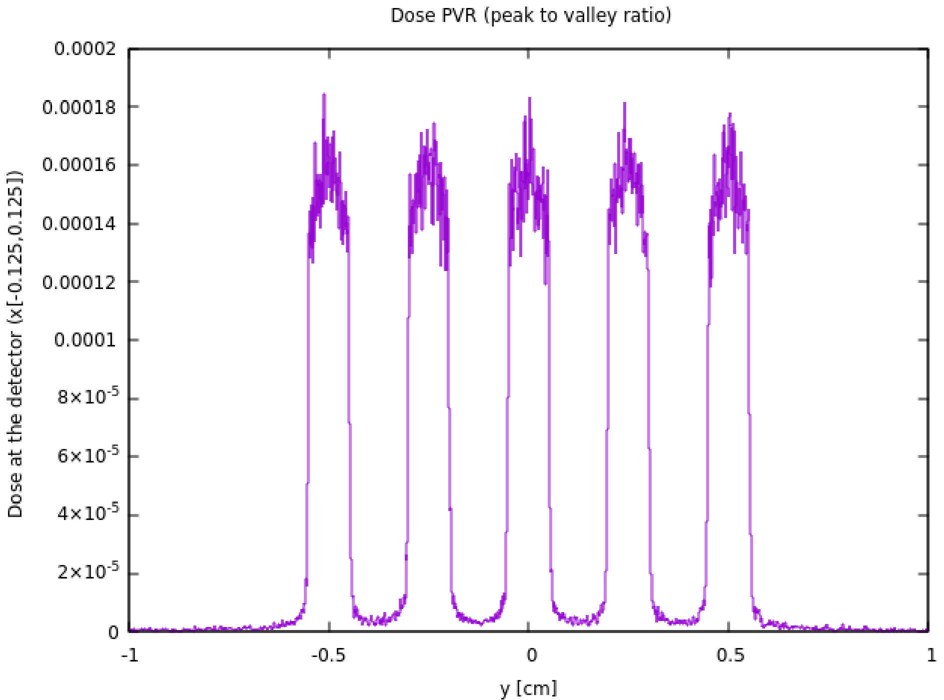


Dose distribution in phantom. Electron beam E=18 MeV



Tungsten collimator [4cm×4cm×width] 9cm length, Beam [1,5cm × 1,5cm] × 10^7 particles





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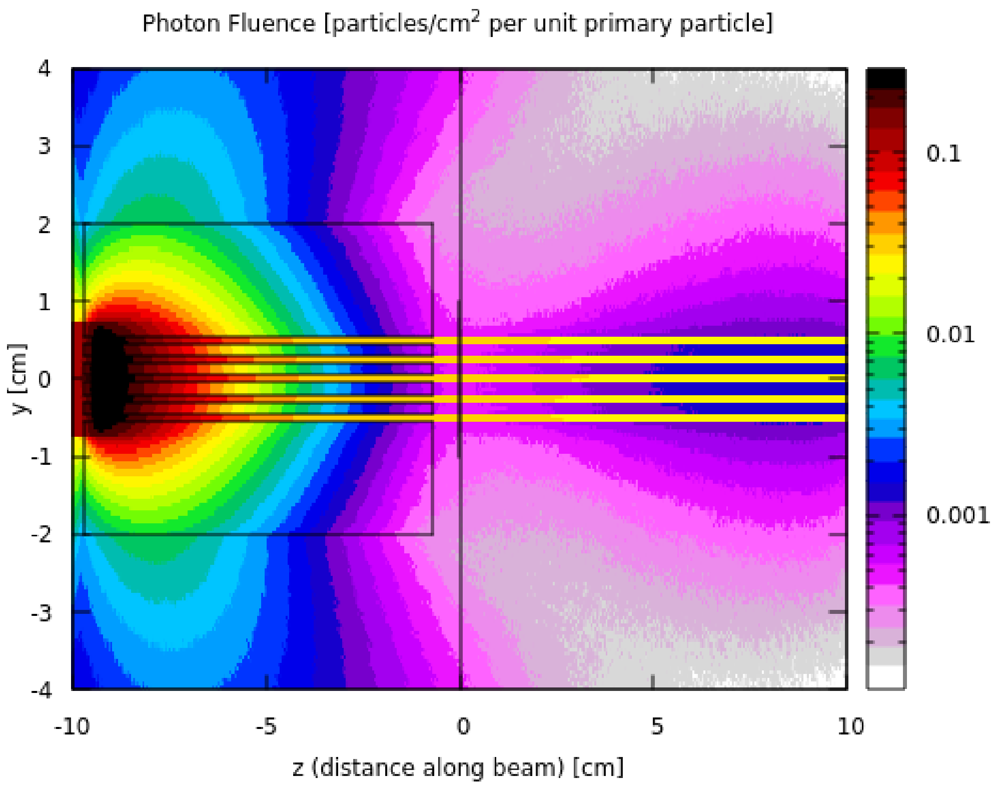
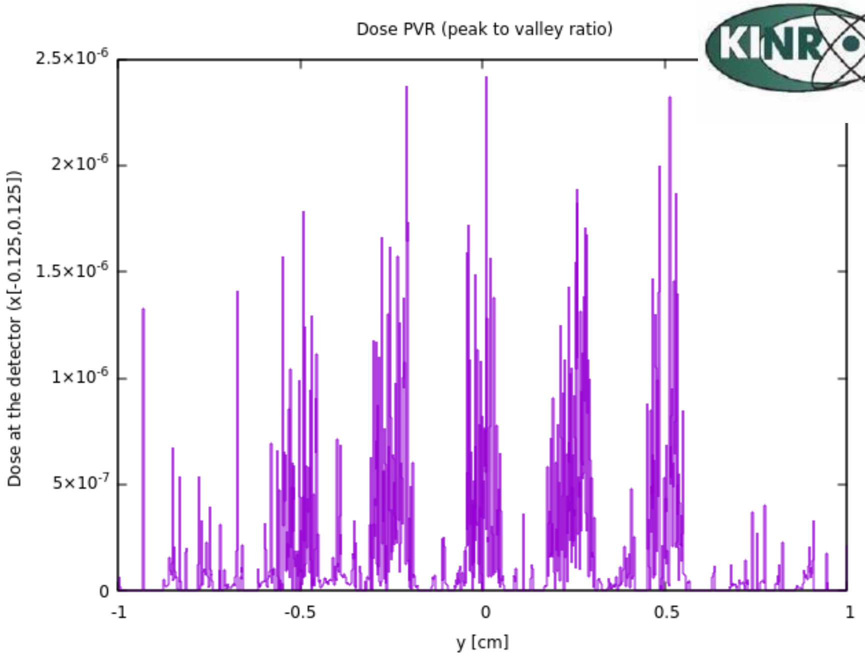
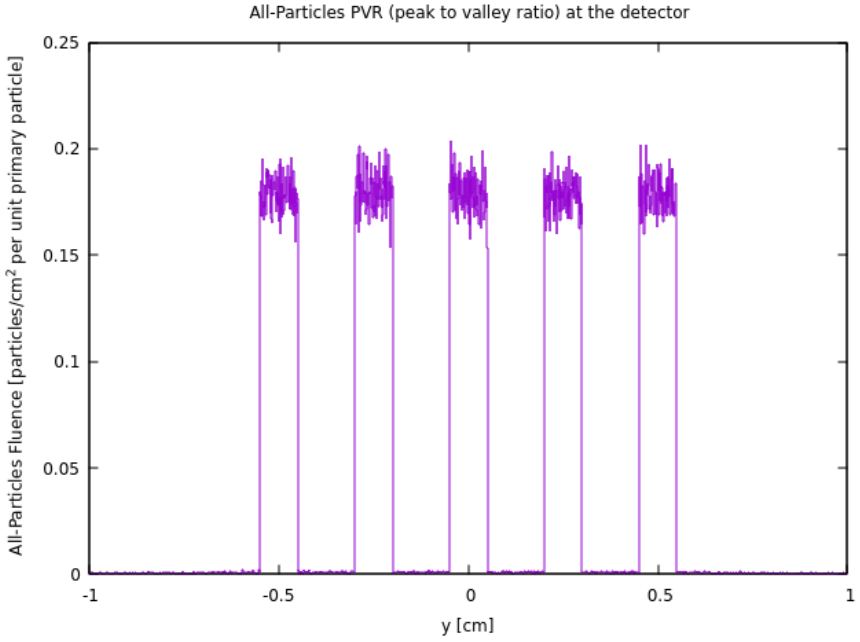
Dose distribution in phantom. X-ray beam E=25 MeV







Tungsten collimator [4cm×4cm×width] 9cm length, Beam [1,5cm × 1,5cm] × 10^7 particles

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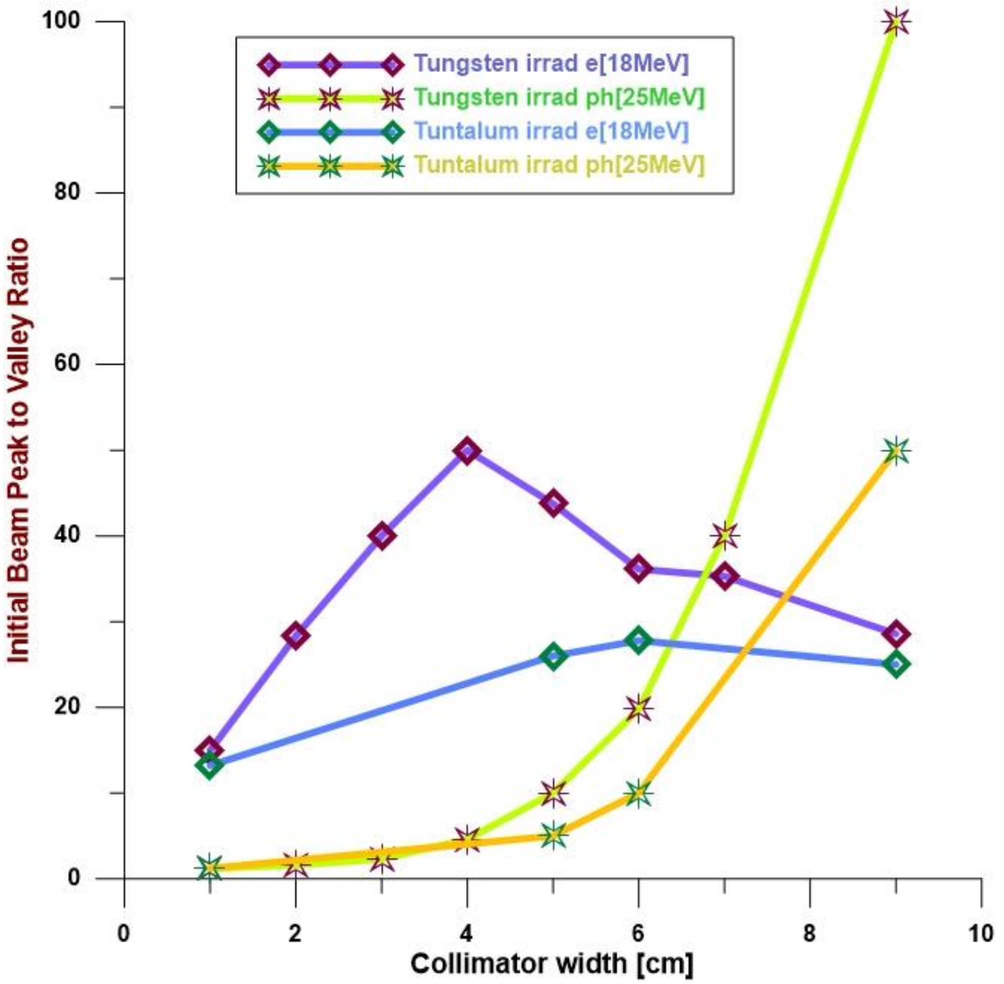
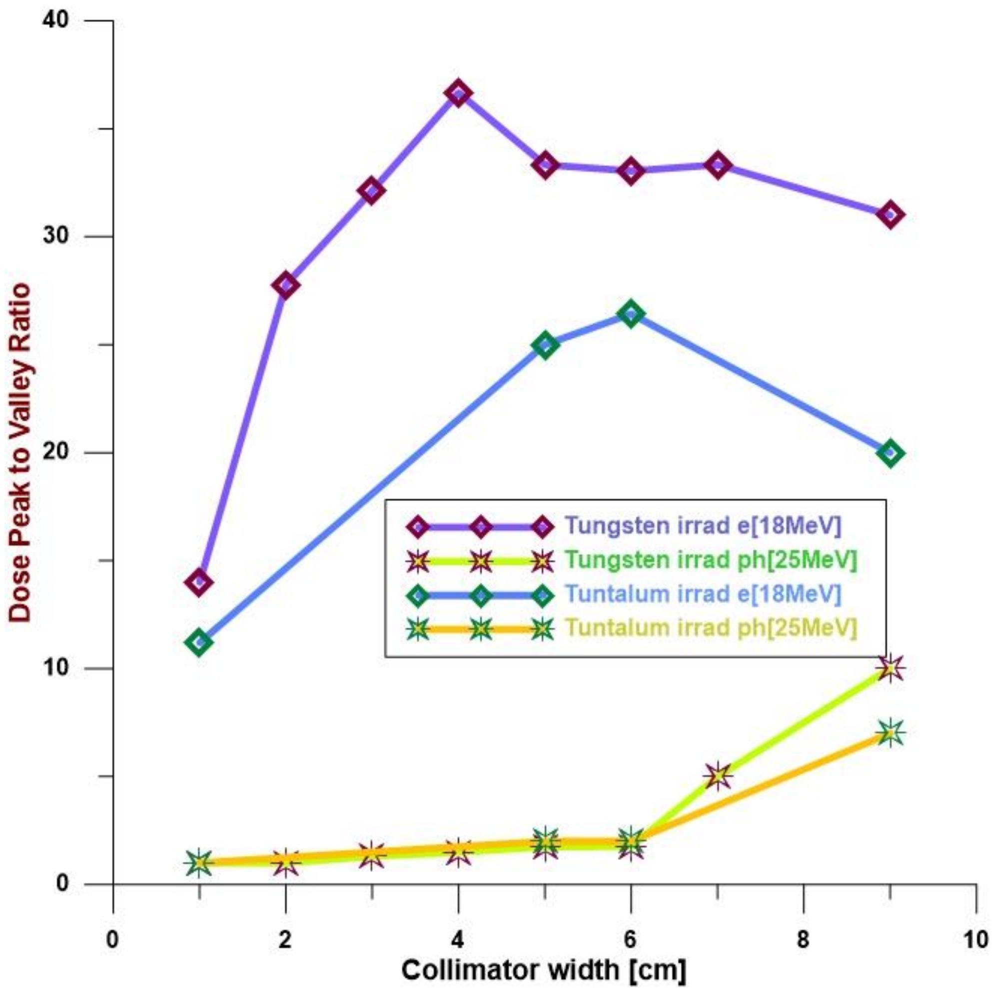
PVDR





The dependences of the initial beam peak to valley fluence ratio and peak to valley dose ratio for tantalum and tungsten collimators the collimator thickness for electron and photon medical beams are presented in the two final graphics.

SUMMARY

- Micro-strip metal detectors of various shapes and types for measuring the profile and position of charged particle beams in the atmosphere and in vacuum have been developed and manufactured.

- Test setups for Detectorized phantom studies of the mini-beams approach in the spatially fractionated radiation therapy were developed at KINR. Monte Carlo simulations have been performed for optimization of multi-beam structures for spatially fractionated radiation therapy.

- The possibility of using mmd with a commercially available multi-channel X-DAS reading system has been tested.

- Equipment for shaping and monitoring of mini-beams has been designed and produced. New collimators for shaping mini-beams for different types of ionizing radiation have been designed, produced and qualified.

Acknowledgements

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