AHEAD 2020
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Czech Contribution to AHEAD: Novel/Alternative X-Ray Optics

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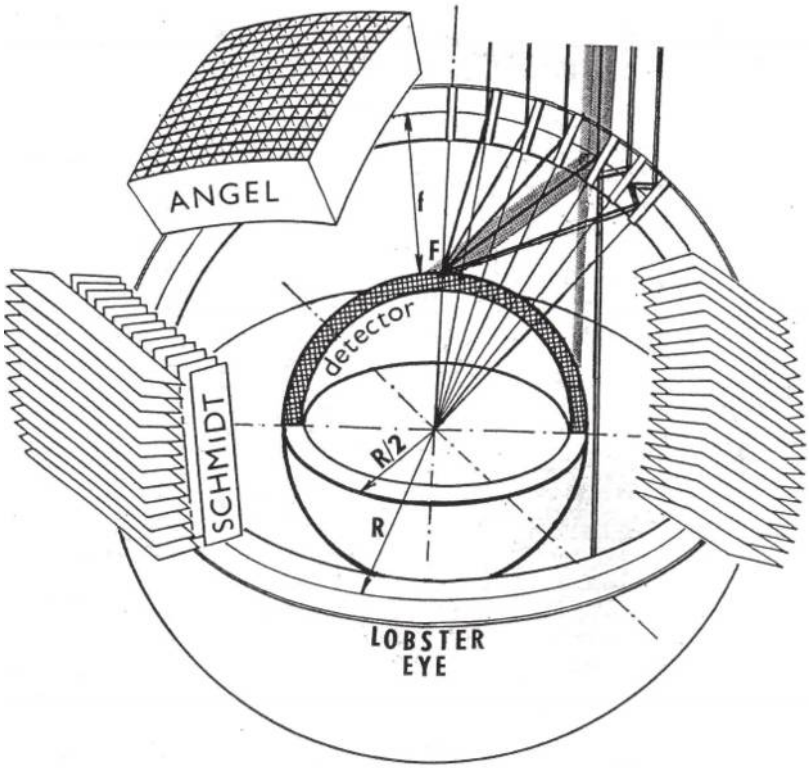
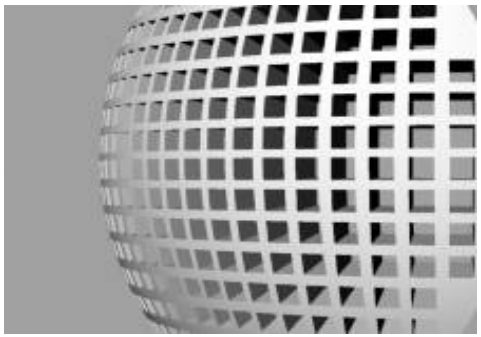
Main activities

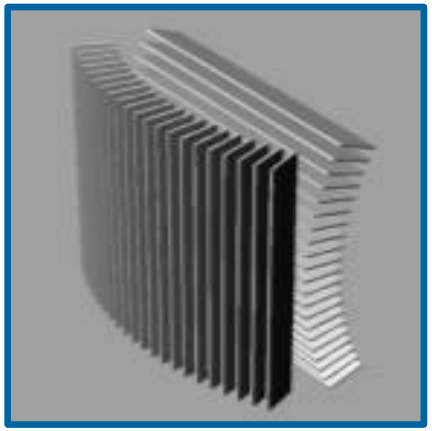
- Simulations and designs of LE (Lobster Eye) and KB (Kirkpatrick-Baez) Systems
- New and alternative simulation/ray tracing methods
- Studies of alternative/improved coatings
- Improved substrates (Si and float glass)
- Design and assembly of new test modules
- Both LE as well as KB test modules
- based on Multi Foil Technology (glass and Si substrates < 1 mm)
- Tests in visible light and in X-rays

Lobster Eye (LE) wide FOV optical systems

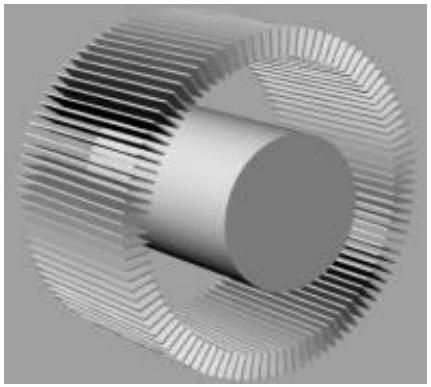




Angel
(Polycapillary Optic)



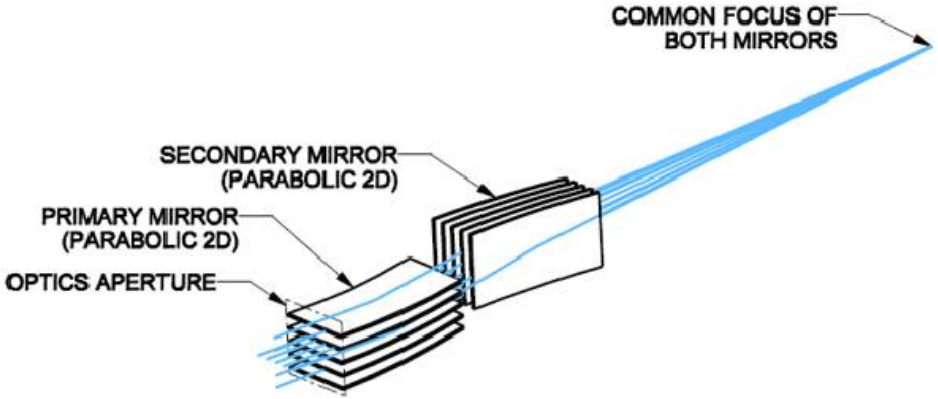
2D Schmidt
(MFO)



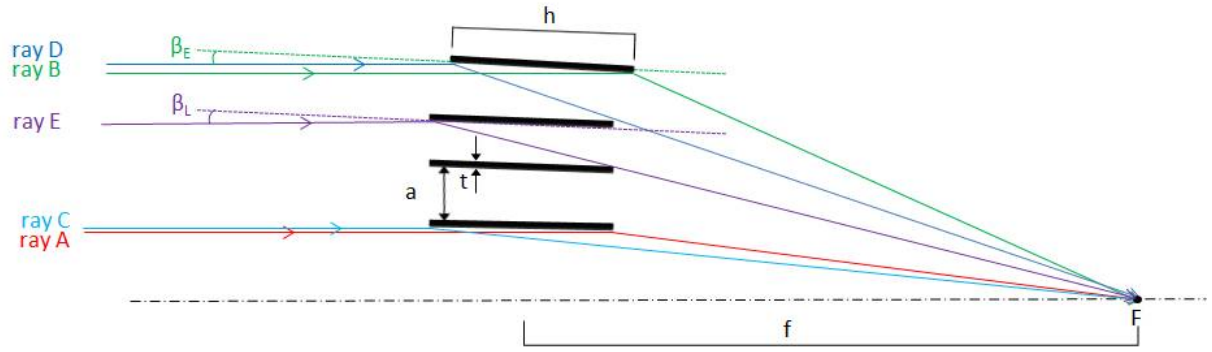
1D Schmidt
(MFO)

These two arrangements studied in AHEAD

Kirkpatrick-Baez (KB) systems



Principle of the X-ray Kirkpatrick-Baez optics in MFO arrangement.



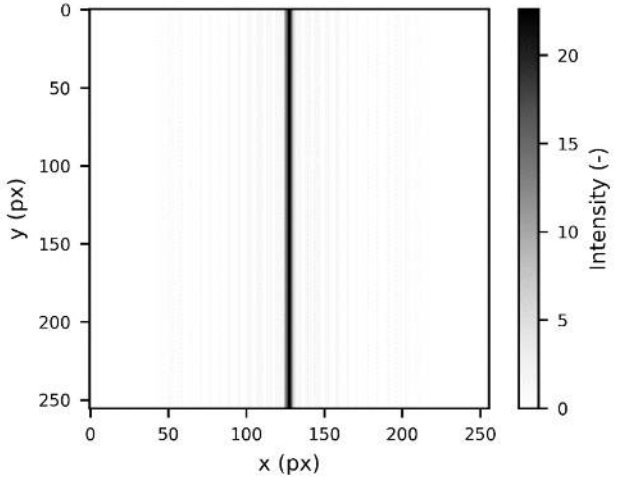
A schematic view of the KB sub-module - all X-rays are reflected to the focal spot F.

Alternative Simulations/Ray Tracing methods

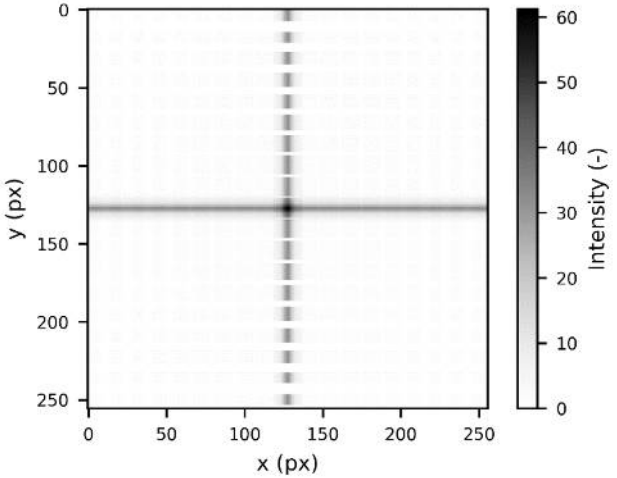
- Alternative simulation and ray tracing methods for LE optics investigated and compared
- Zemax (OpticStudio) based, Matlab (Optometrika toolbox) based, and upgraded Python code PyXLA
- Comparison with LESim Rigaku code
- LOPSIMUL newly developed ray tracing code for multi foil X ray optics
- PyXLA Python X-ray-tracing for Lobster-Eye Simulation

Example: Images from PyXLA

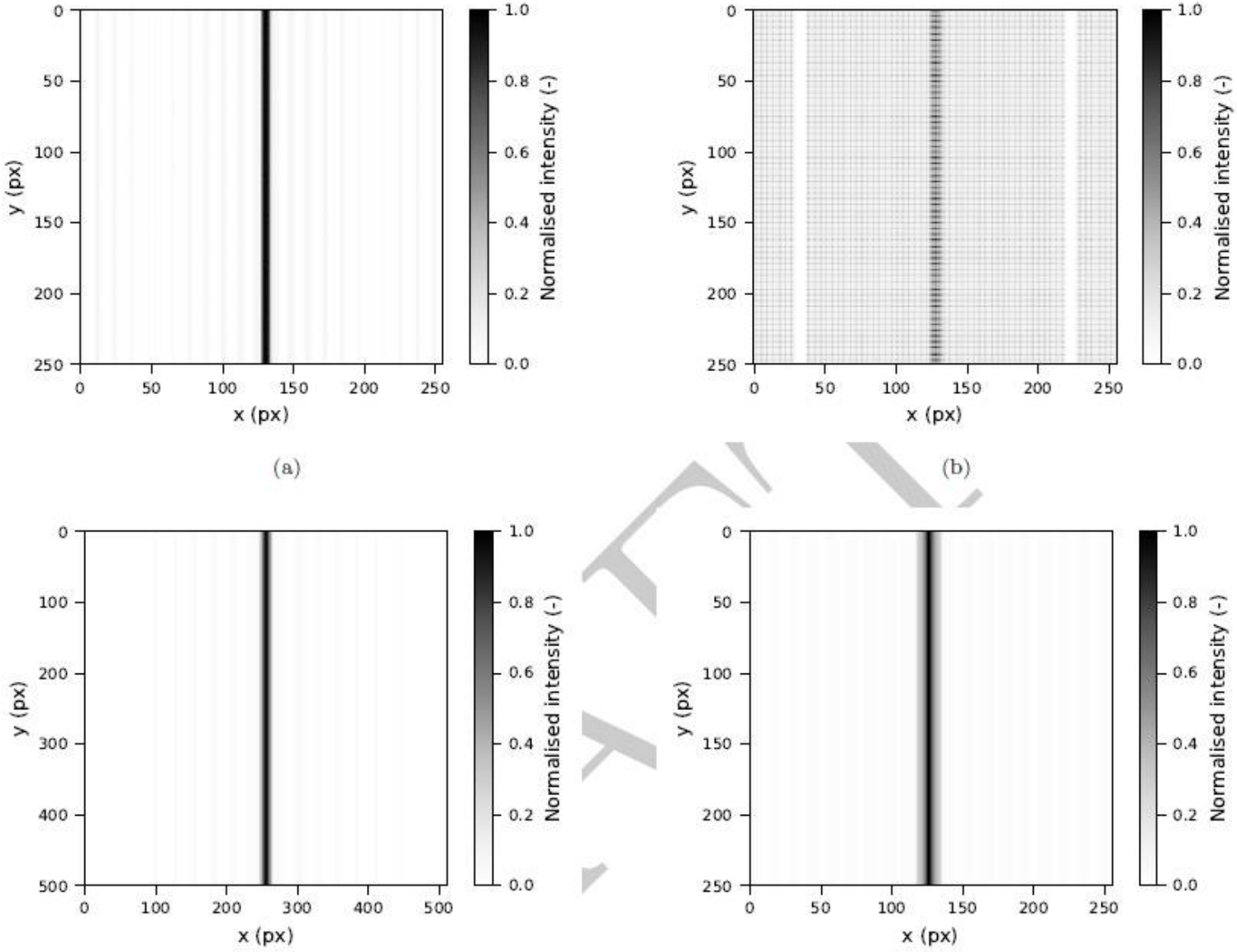
1D optics for 8keV and centre position of point source



2D optics for 8keV and centre position of point source



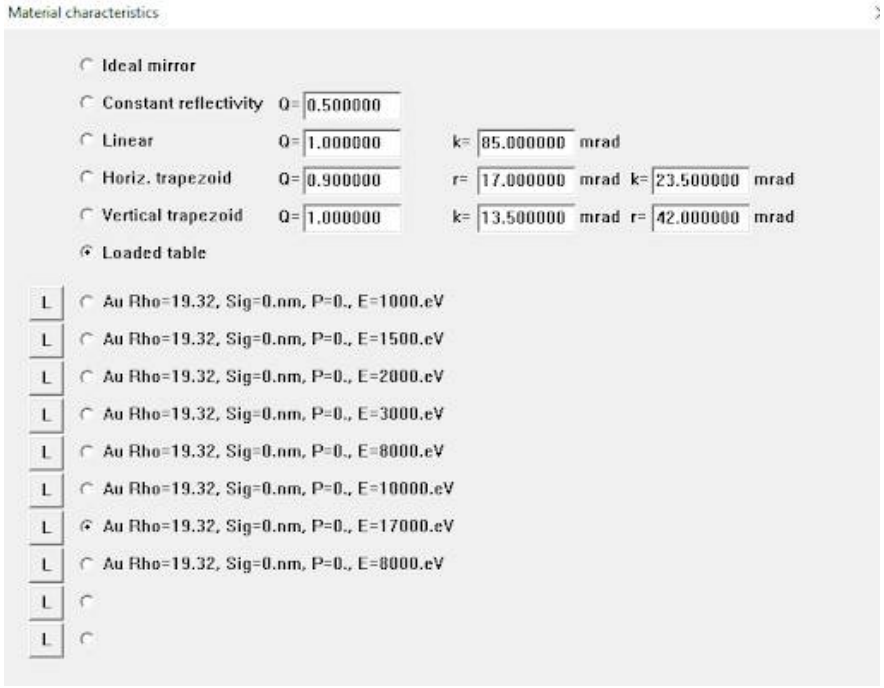
Arrangement with 1D Lobster-eye optics with Timepix detector and incoming rays (green reflected, red direct)



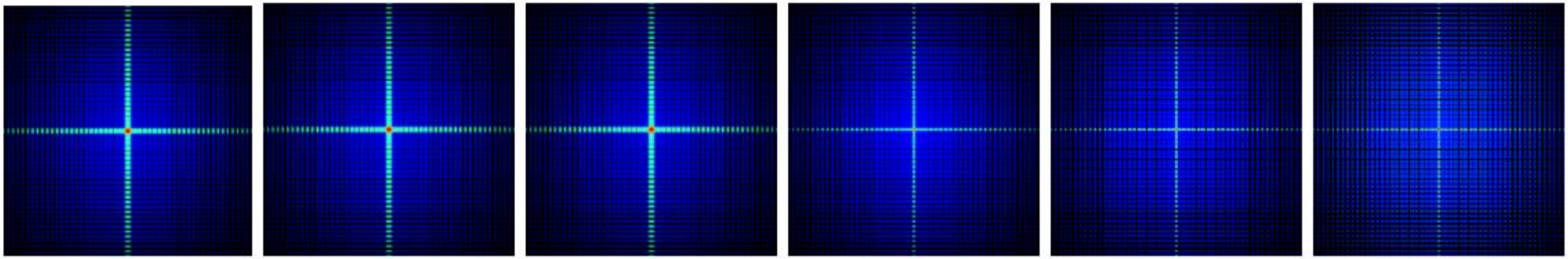
Comparison of 4 ray tracing methods: OpticStudio, Optometrika, LeSim and Python

Figure 10. Result for geometric approach from OpticStudio software (a), Optometrika toolbox for Matlab (b), LeSim (c) and PyXLA software (d) for Lobster-eye optics which does not take into account the reflectivity dependence on the angle of incidence with parameters given in table 2.

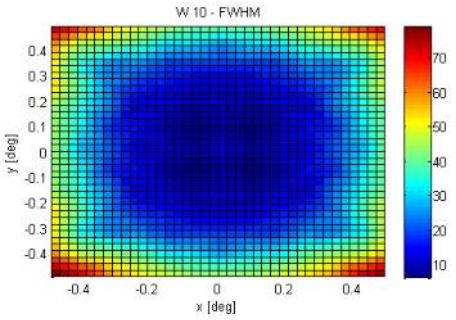
LE ray tracing by LOPSIM



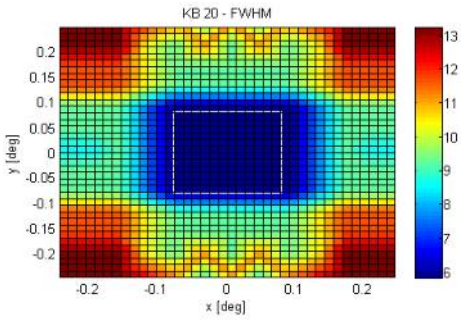
Ray tracing of LE module 1 to 17 keV By LOPSIM .. Newly developed code



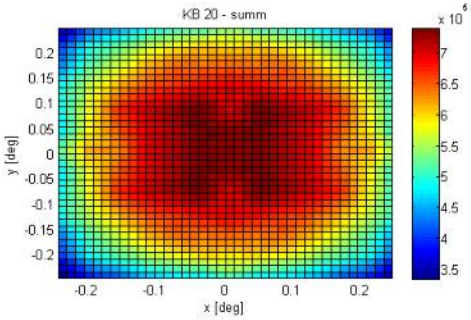
Comparison K-B vs. Wolter



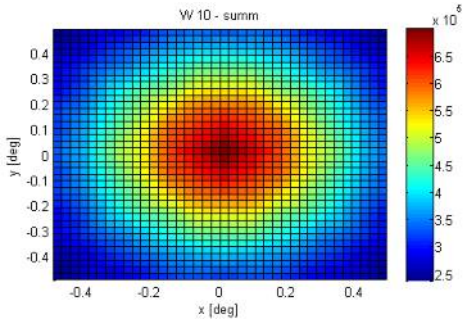
Wolter system - FWHM (F = 20 m)



KB system - FWHM (F = 20 m)



KB system – SUM (F = 20 m)



Wolter systém – SUM (F= 10 m)

	D [m]	A [m²]	F [m]	A_{eff} [m²]*	A_{rel} [%]**	A_{eff} [m²]***	A_{rel} [%]**
W10	dia 1.8	2.6	10	0.70	26.63	0.66	25.11
W20	dia 3.6	10.9	20	2.83	25.89	2.76	25.26
KB20	1.8 x 1.8	3.3	20	0.93	27.80	0.62	18.49
KB40	3.6 x 3.6	13.9	40	3.11	22.33	2.46	17.66

* for detector 100 x 100 mm

** proportion of effective area to aperture

*** for peak (area 4 x 4 mm)

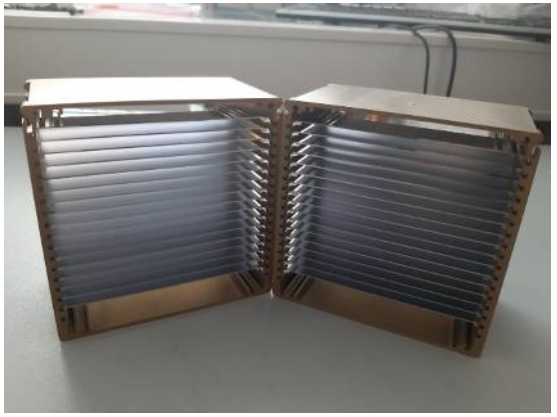
K-B vs. Wolter: comparable ef area at f = 2f, comparable angular resolution

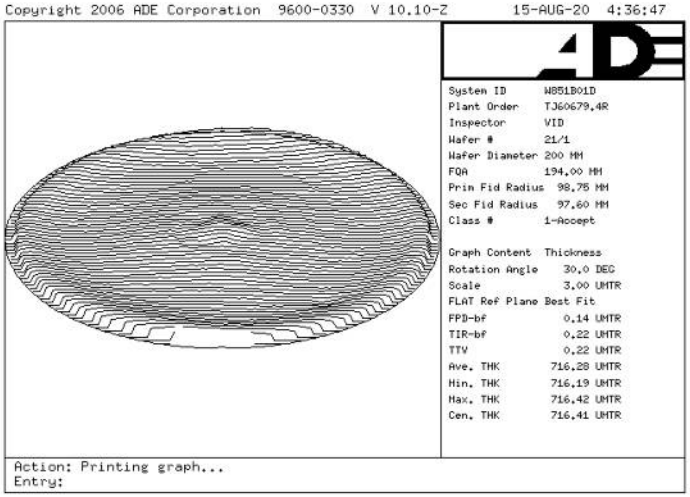
New Test Modules

- LE optics module f 0,9 m
- LE optics module f 0,4 m
- KB optics double test module with Ir/Au coatings
- Large KB module f 6.5 m
- In preparation: KB with superior angular resolution
- Close collaboration with Rigaku Prague, ON Semiconductor, and Aschaffenburg University

MFO Multi Foil Optics

- Both LE in Schmidt design as well as KB optics are assembled from large number of thin (< 1 mm) substrates
- Float glass and/or Silicon wafers
- LE – glass or Si polished from both sides
- KB – glass of single side polished Si





I. LE 2Dmodule with f 0.9 m

	2D optics (F = 890mm)	2D optics (F = 970mm)
Optical aperture	140 x 140 mm	140 x 140 mm
Dimension of foils	148 x 57 x 0.42mm	148 x 57 x 0.42mm
Number of foils	83	83
Spacing	1.26 mm	1.26 mm
Focal length	890 mm (850/930)	970 mm (930/1010)
FOV	4.7 x 4.3 deg	4.3 x 4.0 deg
Angular resolution	5.1 x 4.7 arcmin	4.7 x 4.3 arcmin
Effective area	6.5 cm^2 @ 0.5 keV	6.5 cm^2 @ 0.5 keV
Theoretical Gain	~ 3 500	~ 4 200
Transmission	56%	56%
Energy	0.2 – 10 keV	0.1 – 10 keV
Foil	glass + thin Au layer	glass + thin Au layer
Detector	Quad Timepix (512 x 512 px, 55 µm px, no cooling)	Quad Timepix (512 x 512 px, 55 µm px, no cooling)

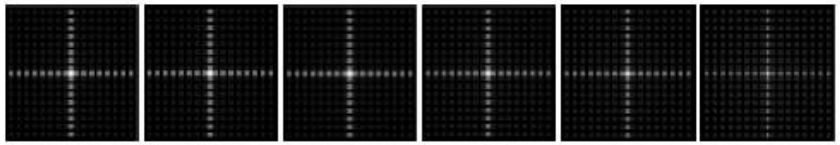
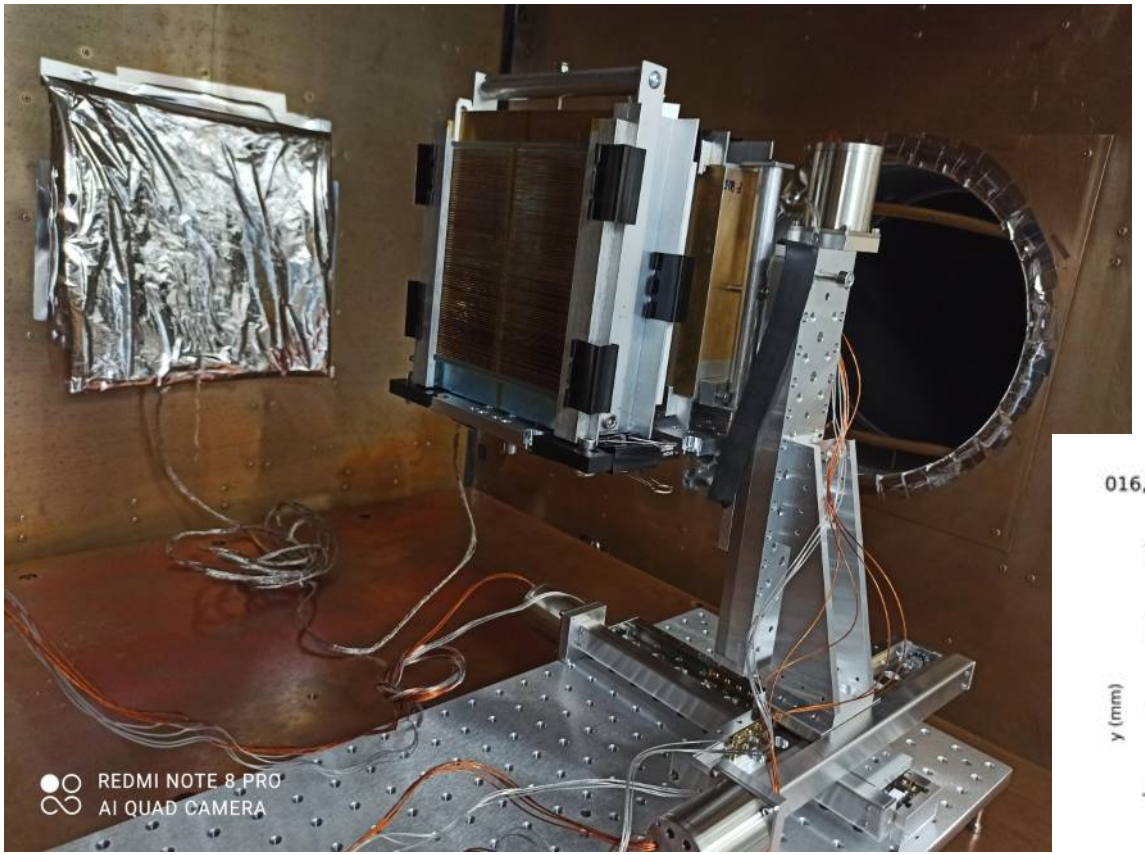
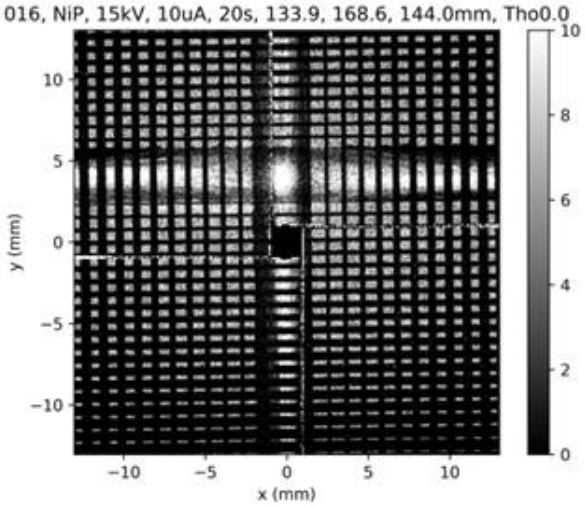


Figure 7. The simulated focal image, 2D arrangement, by ray tracing from 450 eV to 8 keV rays.

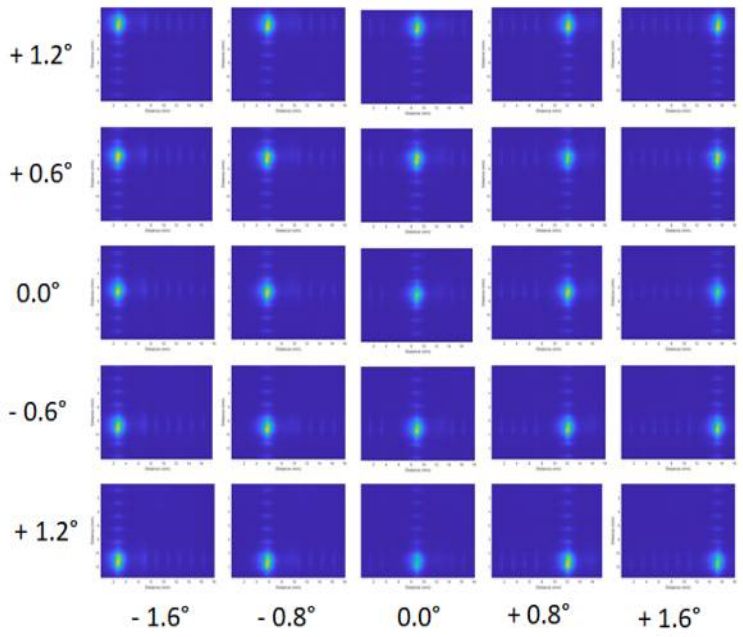
LE test module X-ray tests in Prague, VZLU facility

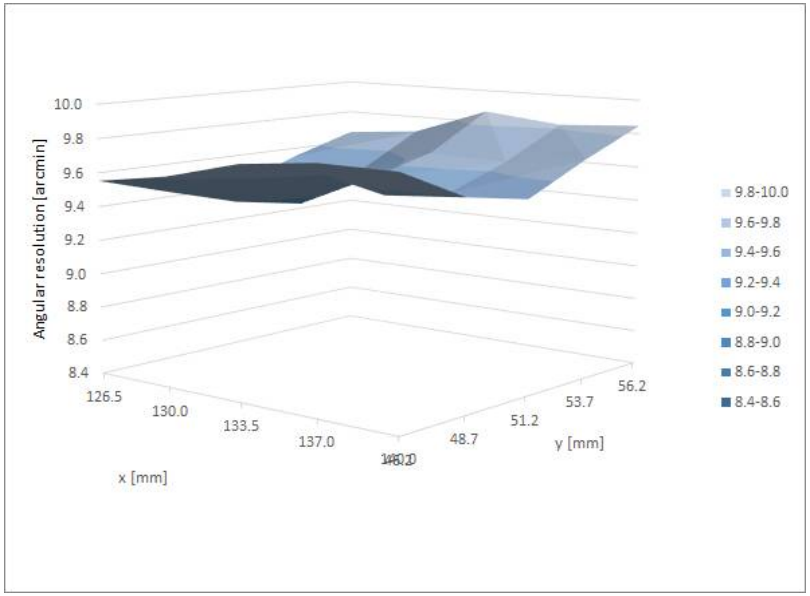


Small X-ray test facility at VZLU in Prague, 10 m long



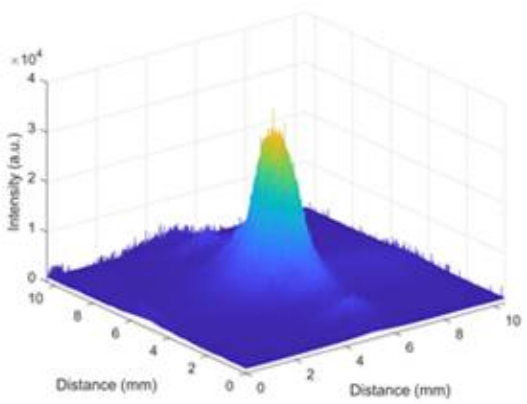
LE X-ray tests in Prague VZLU II

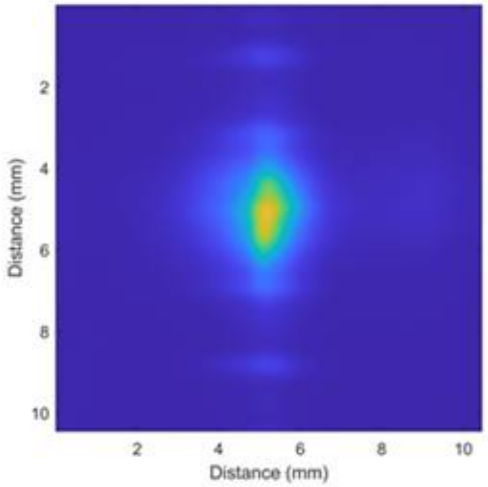


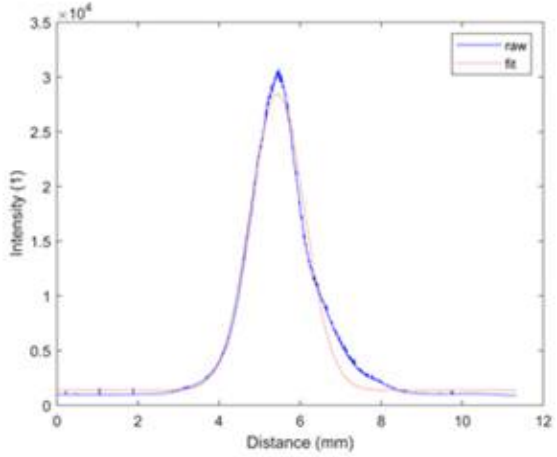


Off axis behaviour of tested LE module (left). Angular resolution dependence on the off axis angle (right).

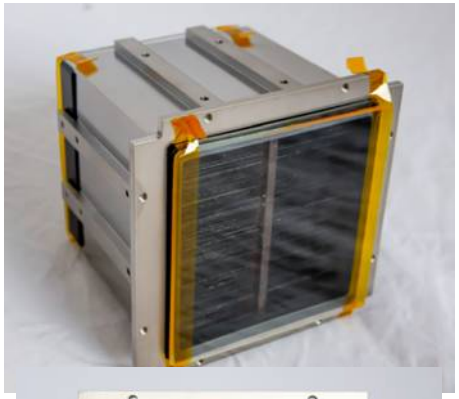
LE X-ray tests in Prague VZLU III

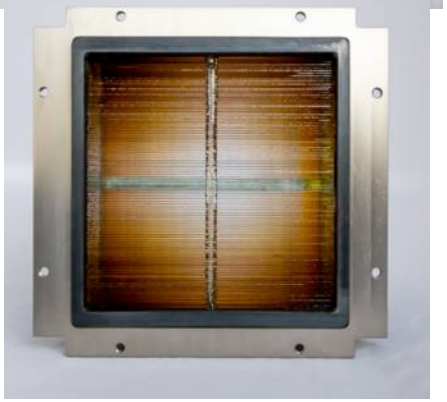




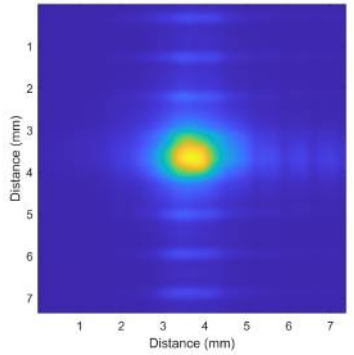


The best focus (left and middle) and the FWHM estimation (right)

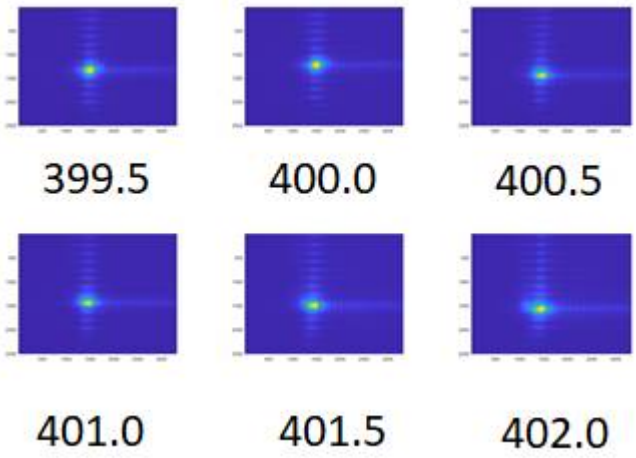


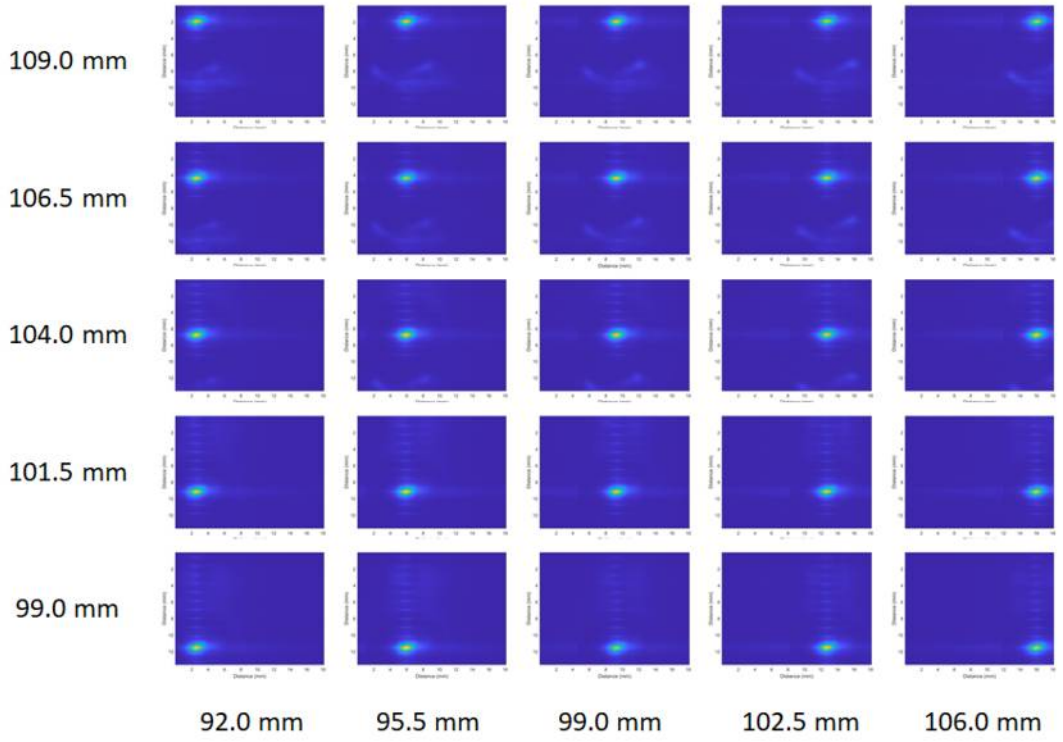


II.LE module f 0,4 m



Aperture 69x69 mm, 150 glass foils length of foils 50 mm

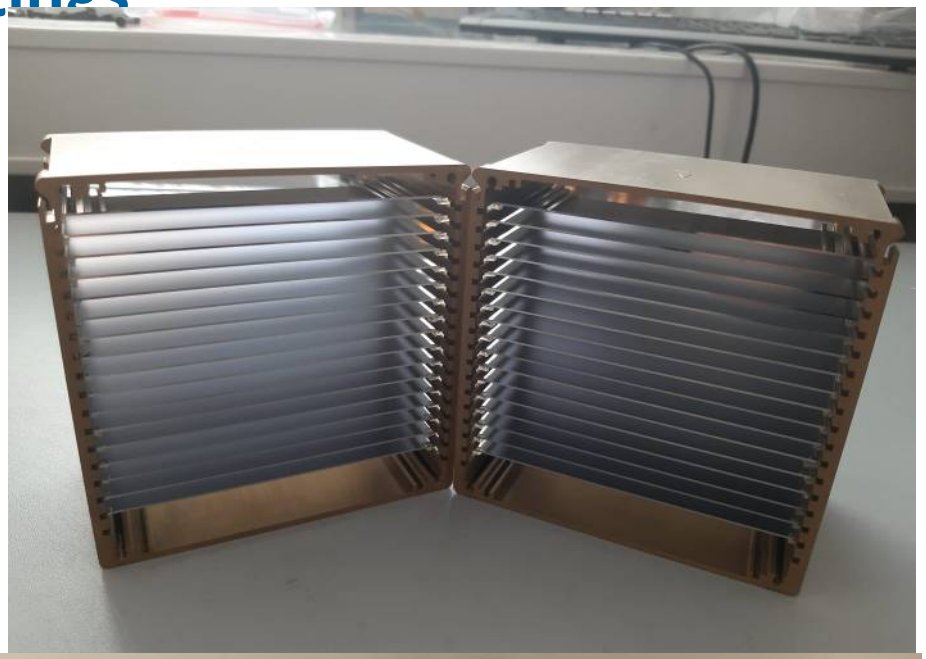




Off axis imaging (±1.6 deg in the horizontal and ±1.2 deg in the vertical direction).

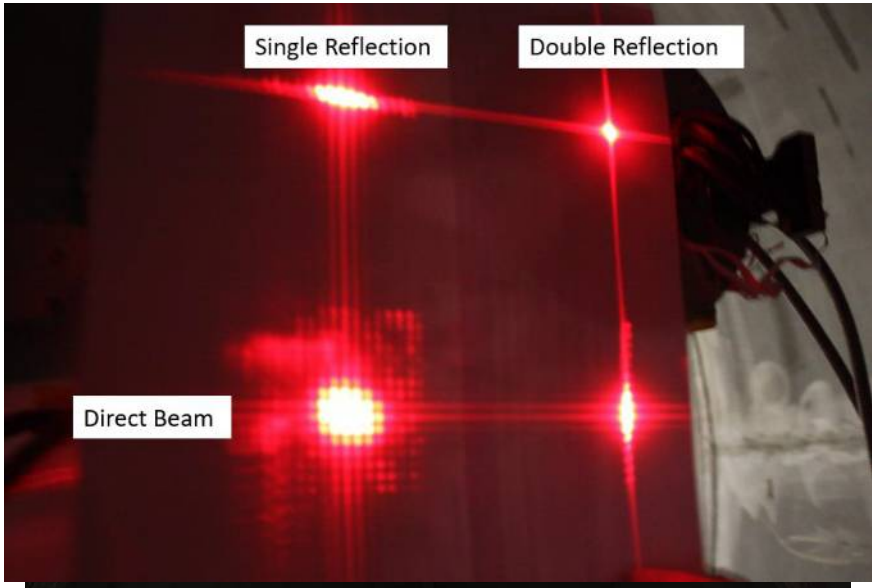
III. HORUS – KB test experiment with Si and different coatings

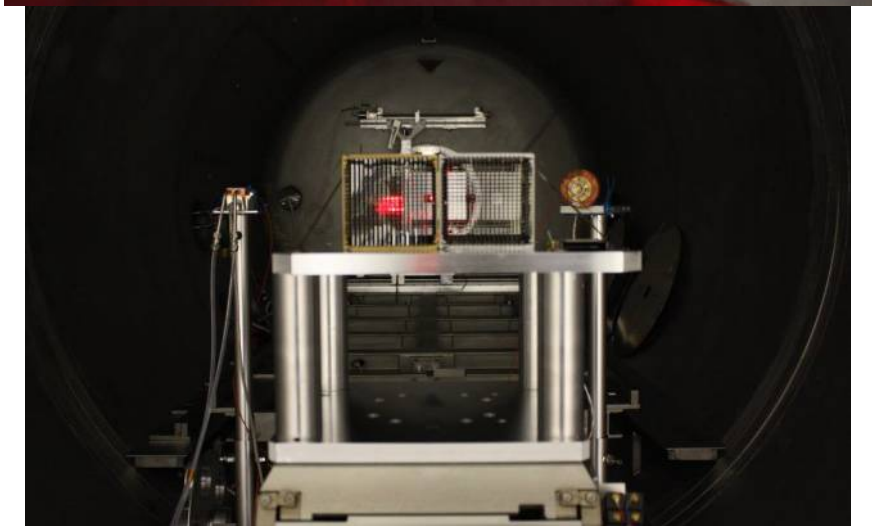
- 4 modules were prepared
  - 2 modules with Au surface
  - 2 modules with Ir surface
  - each module 17 silicon foils
- X-ray tests in preparation
- Goal
  - experimentally compare different reflective layers
  - 4 x 17 Si wafers 0,625 mm thick aperture 85 x 65 mm f 2 m

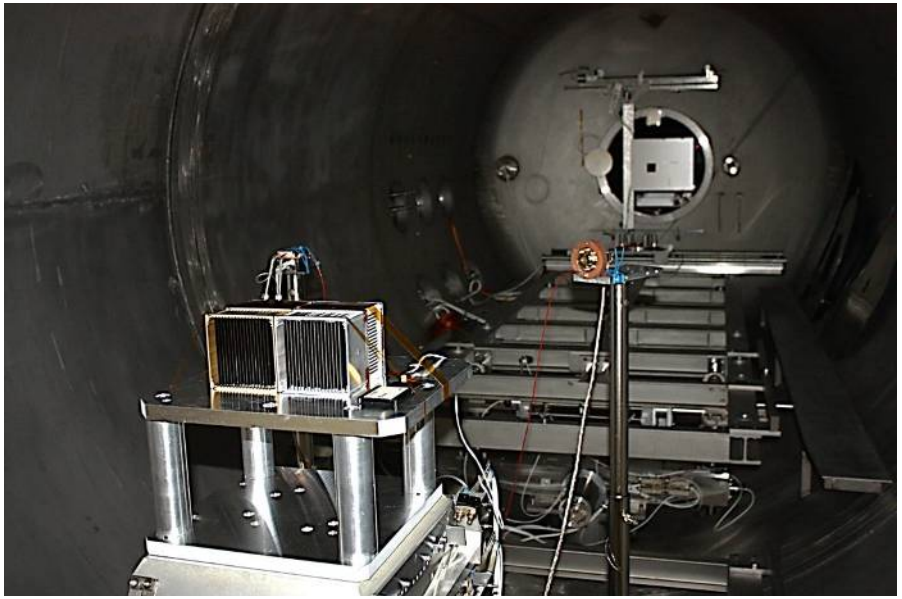


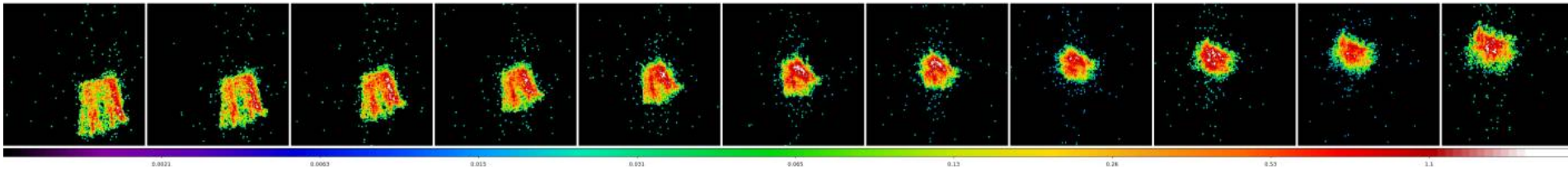
Collaborative effort CTU in Prague, Rigaku Prague, and Aschaffenburg University Student experiment/PhD of Veronika Stehlikova.

HORUS at PANTER

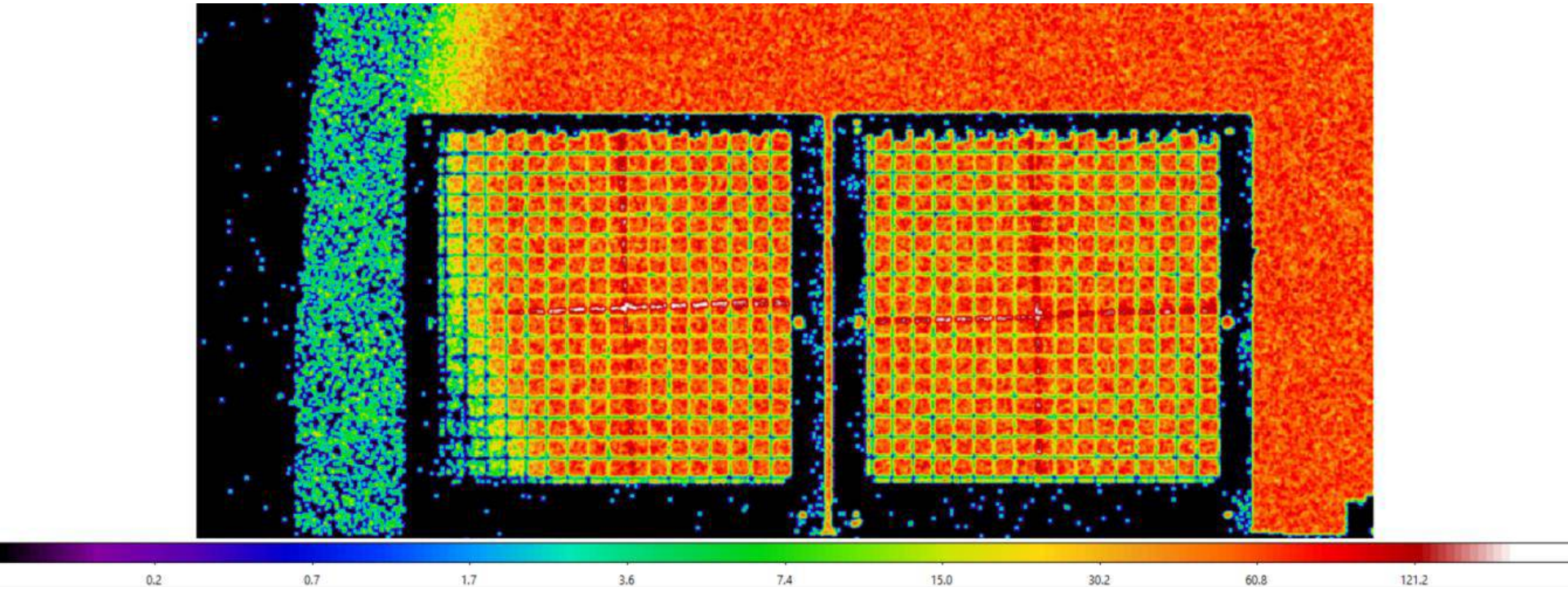








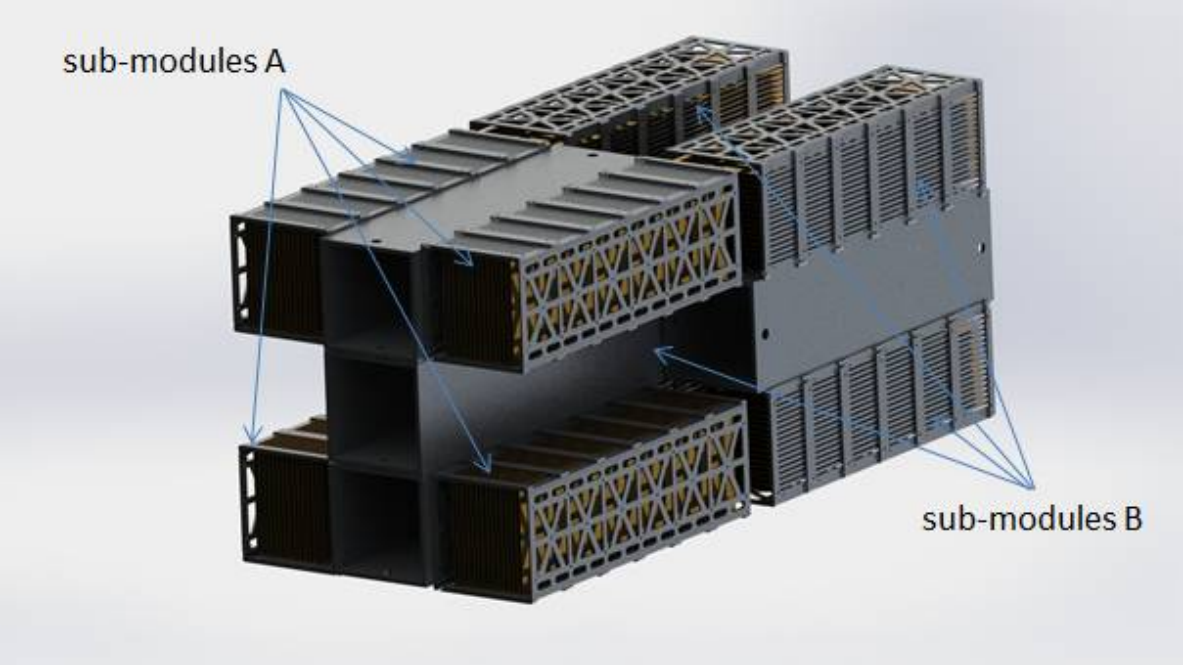
HORUS at PANTER II



Panorama Image of the two modules under X-ray LE Continuum as seen from the detector. PANTER tests in April 2021.

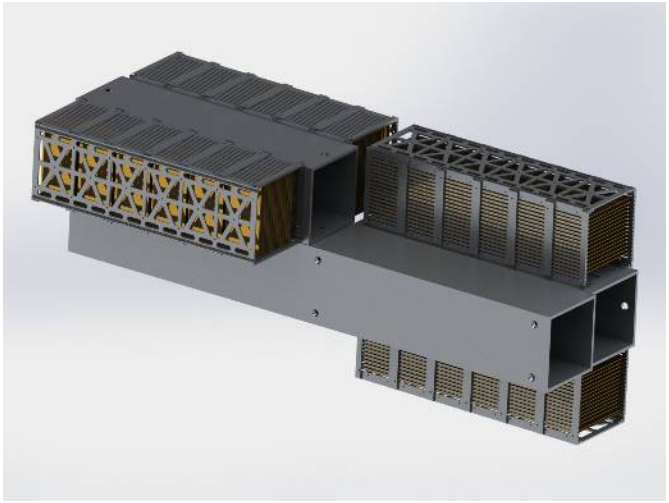
Design of large KB system

The KB optics for the large telescope was designed with focal length 6 155 mm (due to Panter test facility).



Drawing of the X-ray KB optical system for large X-ray telescope. The scheme shows that this KB system consists from 4 sub- modules A and 4 sub-modules B (design and courtesy of Rigaku Prague) .

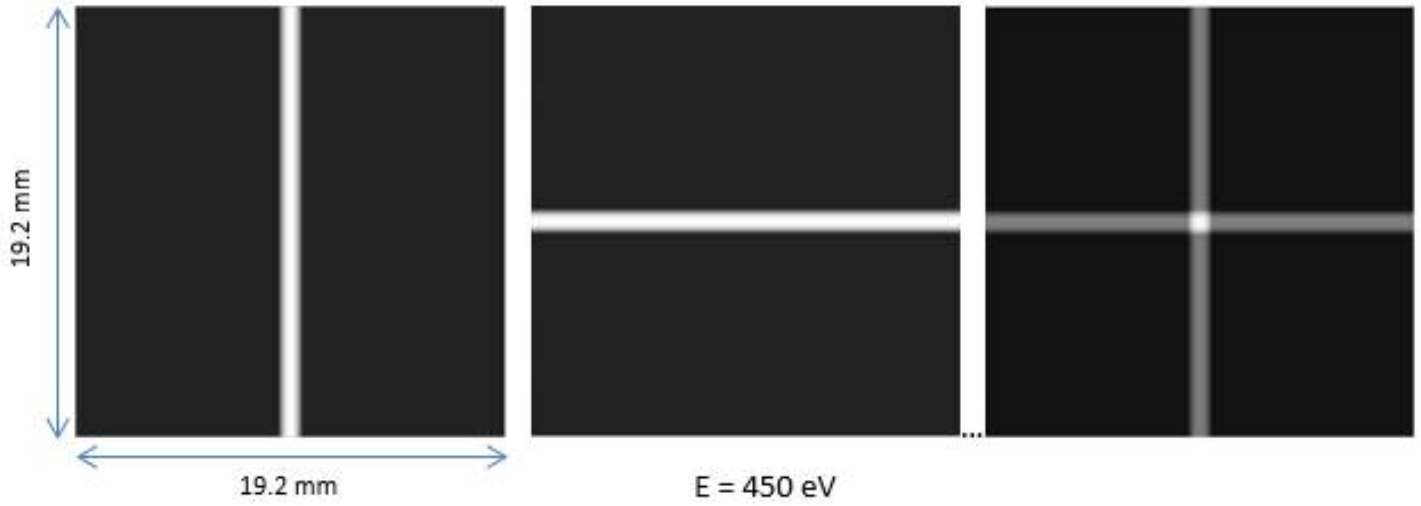
Large KB module: arrangement for PANTER tests



Left - the scheme shows that this KB system is consist of one 2D sub-system (right - up), one 1D sub-module A (left - up) and one 1D sub-module B (right - down).Right - the scheme of the testing KB optics shows input aperture of the KB system with one 2D sub-system (left - up), one 1D sub-module A (left - down) and one 1D sub-module B (right - up).
Module length 330 mm, each module has 15 rows, each row is represented by 6 wafers 100 x 50 mm, aperture 310 x 310 mm in total 360 Si wafers

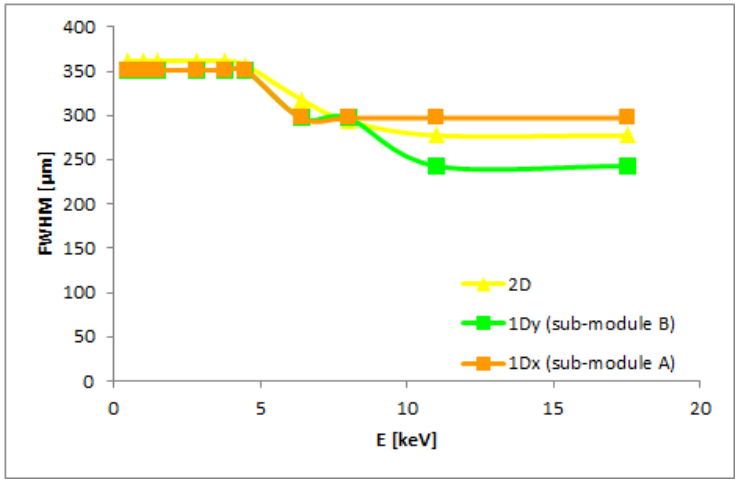
Large KB system with 380 Si substrates

Ray-tracing

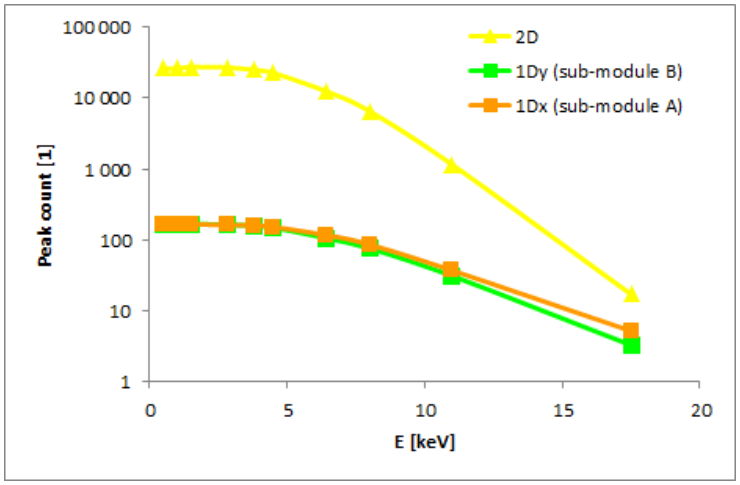


The example of the line focus from horizontal 1D sub-module A (left), line focus from vertical 1D sub-module B (center) and focus from 2D optics (right) in the logarithmic scale. The size of the detector image is 19.2 x 19.2 mm. By Rigaku Prague ray tracing code LeSIM.

Ray-tracing of the large KB module II

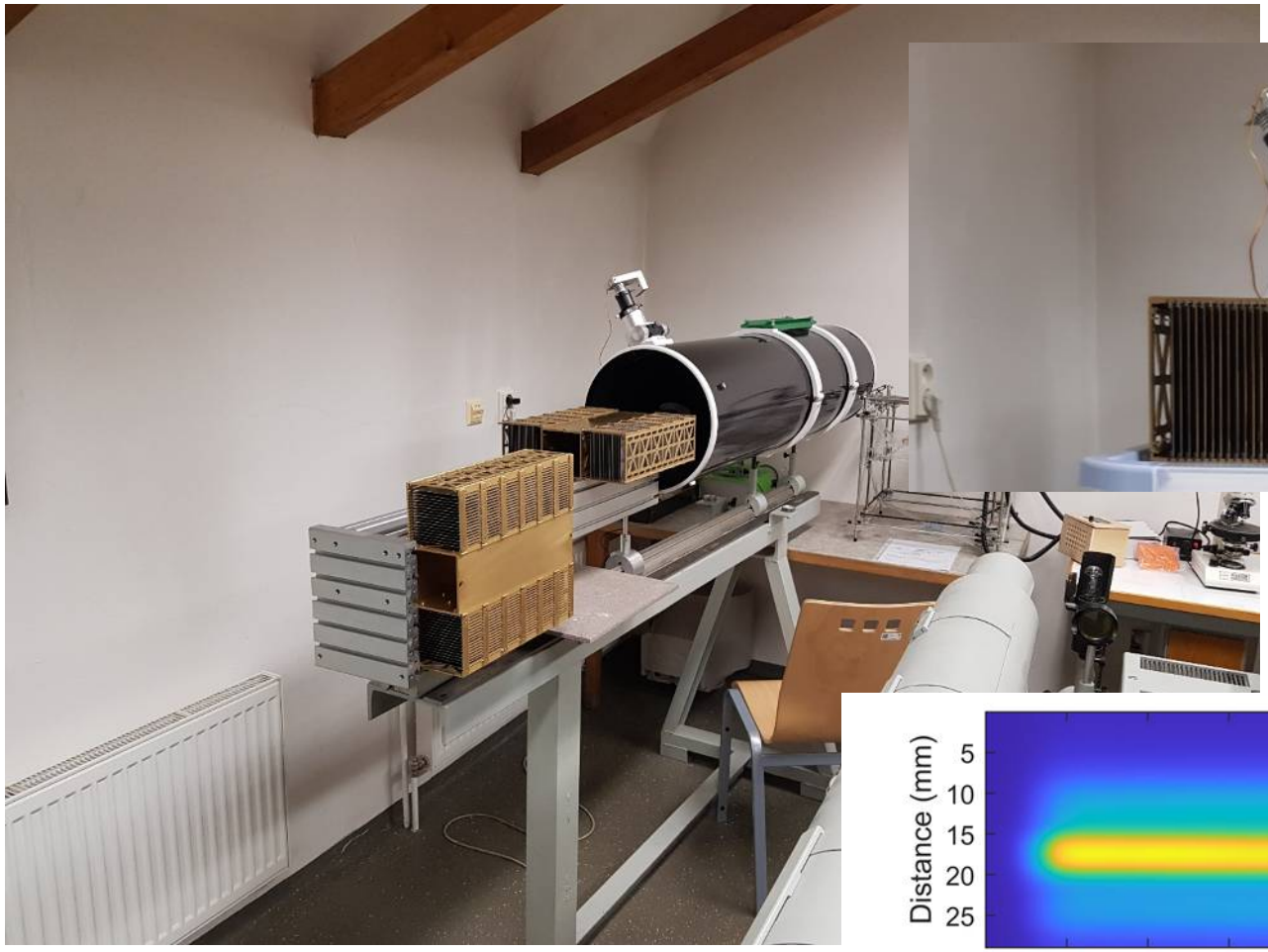


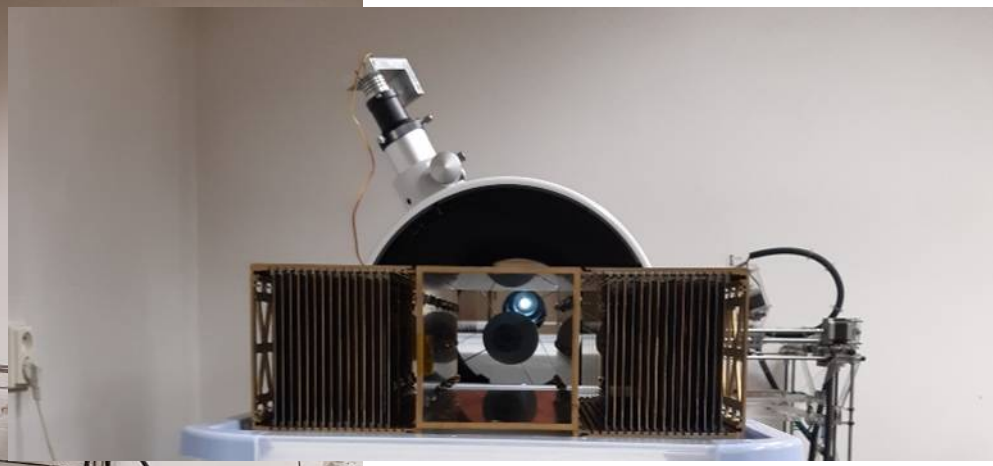
The comparison size of the FWHM (for 1D sub-modules and 2D optics) dependence on the energy. By Rigaku Prague LeSIM.

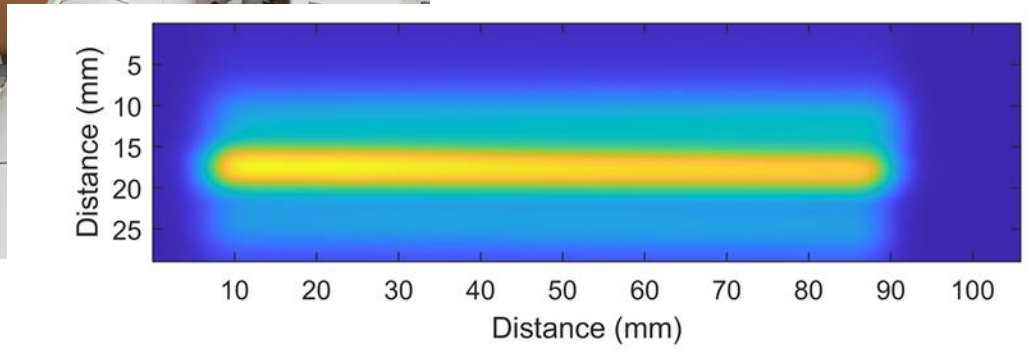


The comparison of the peak count (for 1D sub-modules and 2D optics) in logarithmic scale By Rigaku Prague LeSIM..

KB optical VIS tests at CTU in Prague

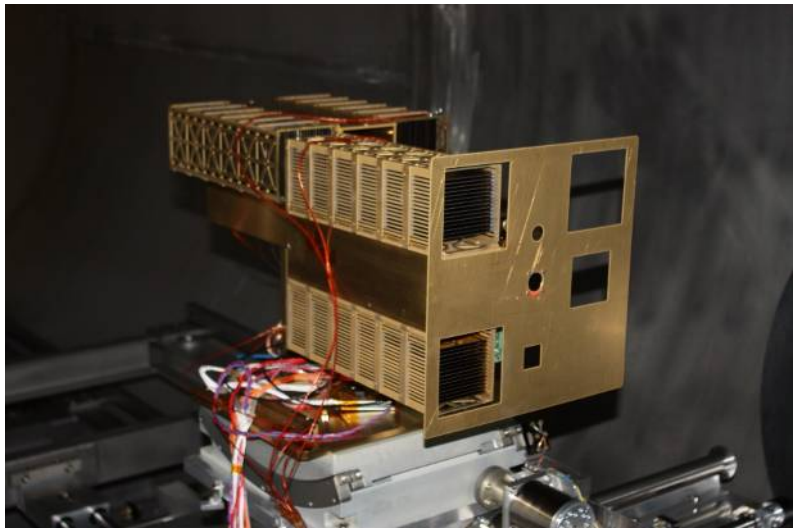


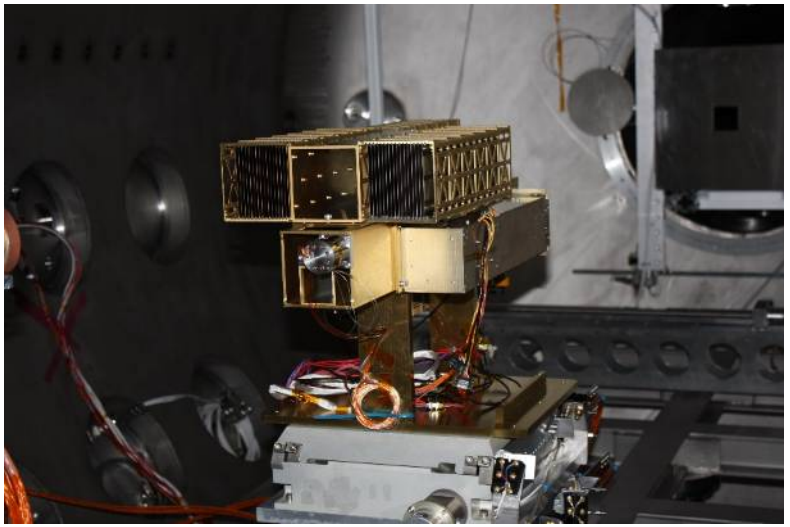


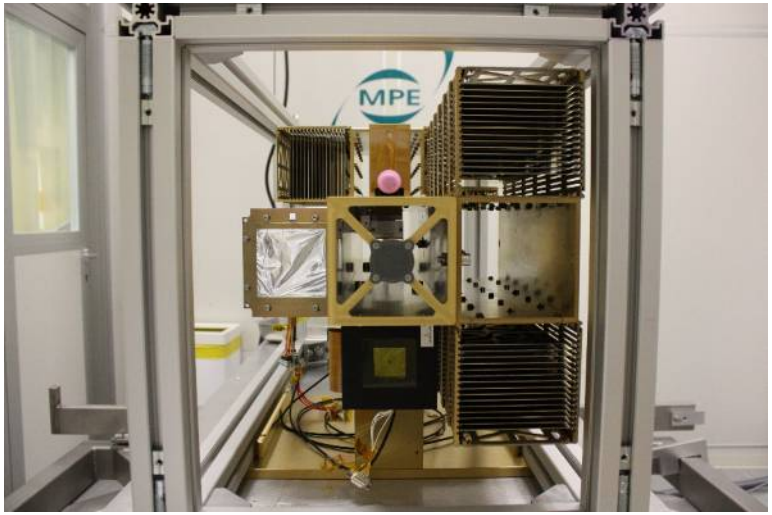


KB module baking off at VZLU Prague

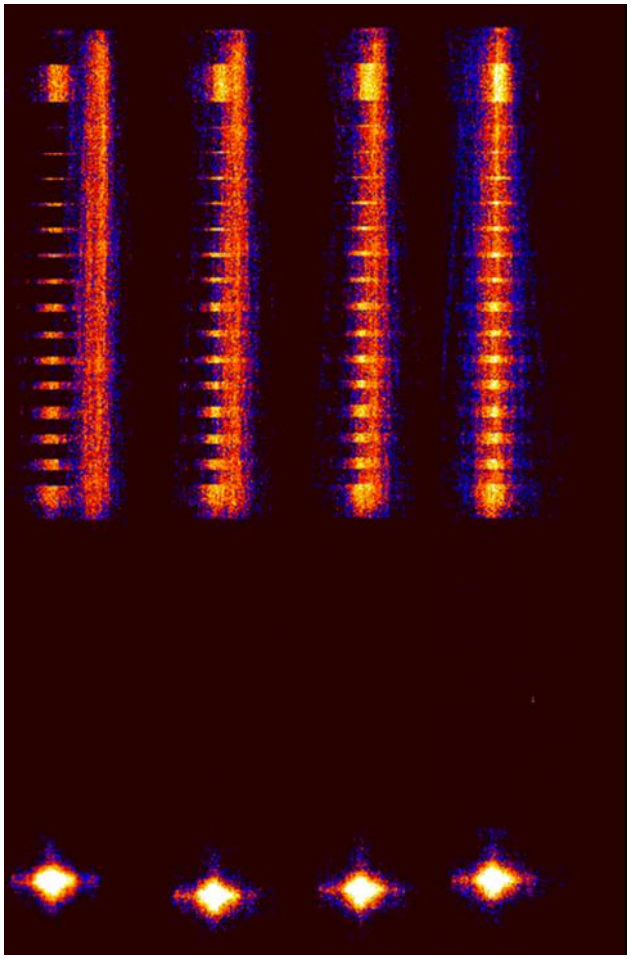
KB module at PANTER



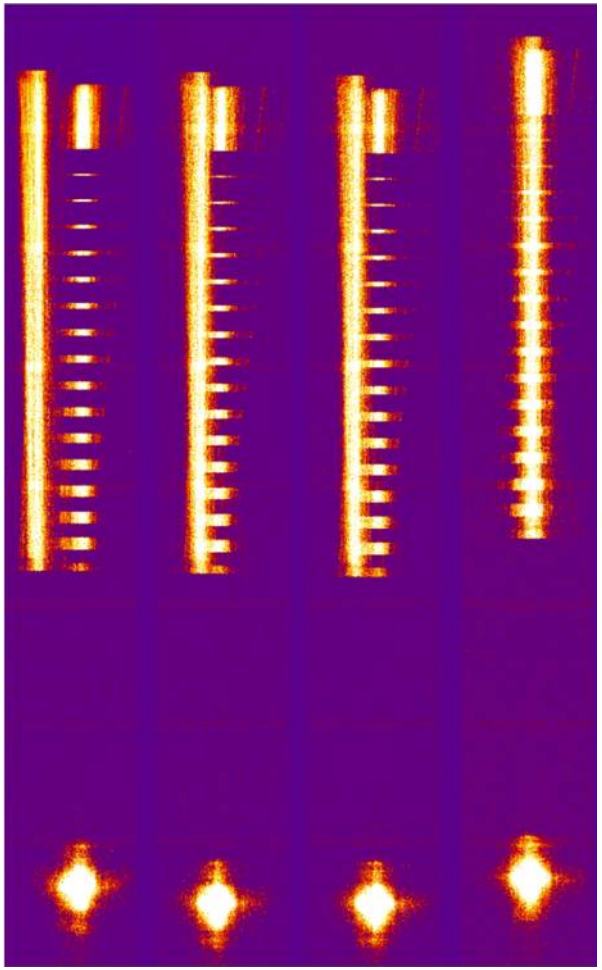




KB PANTER tests



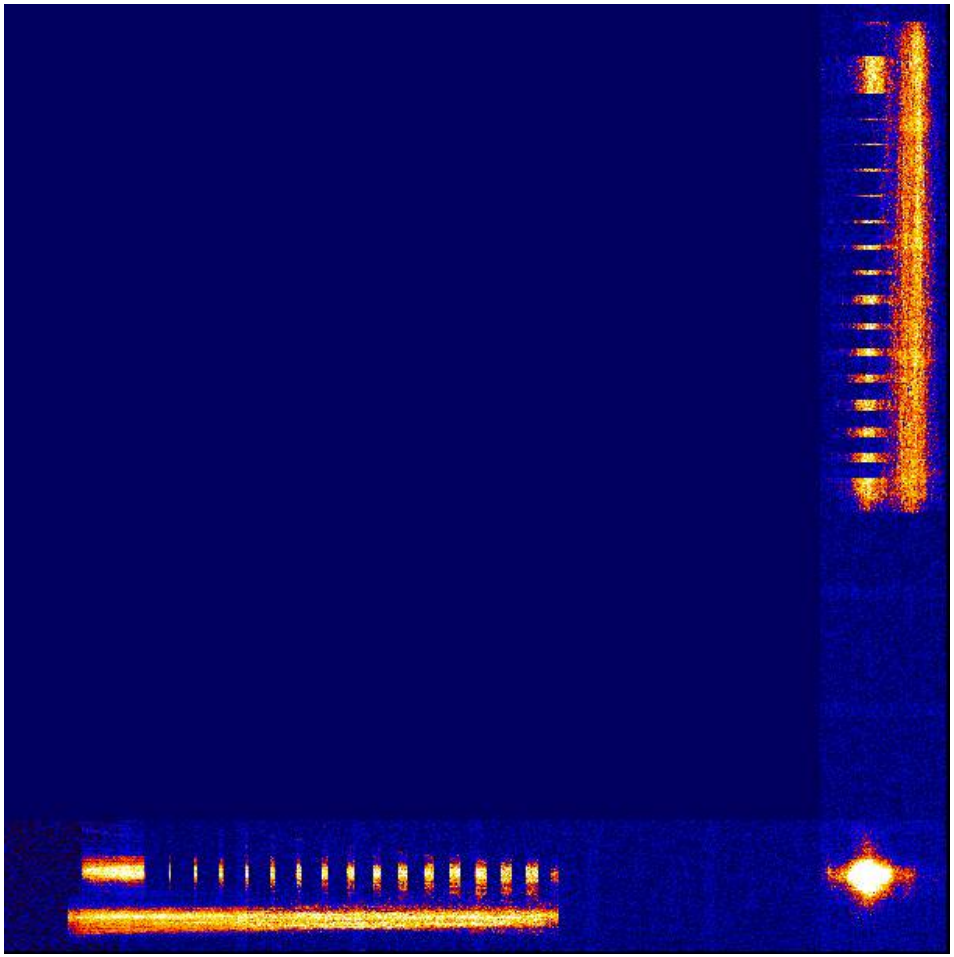
Horizontal and vertical focus searches



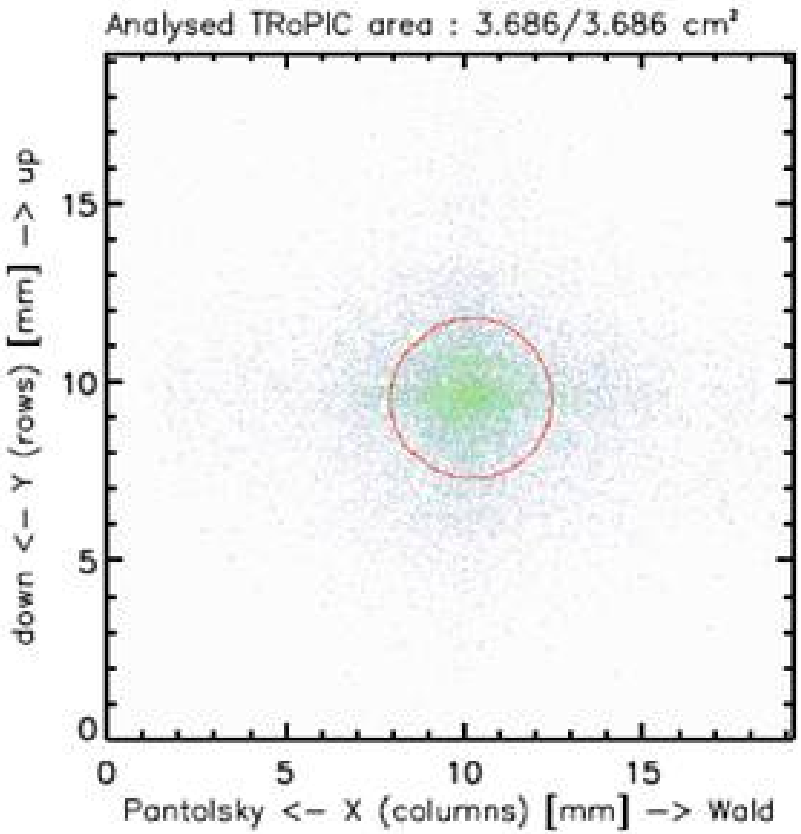
IV. Large KB Module

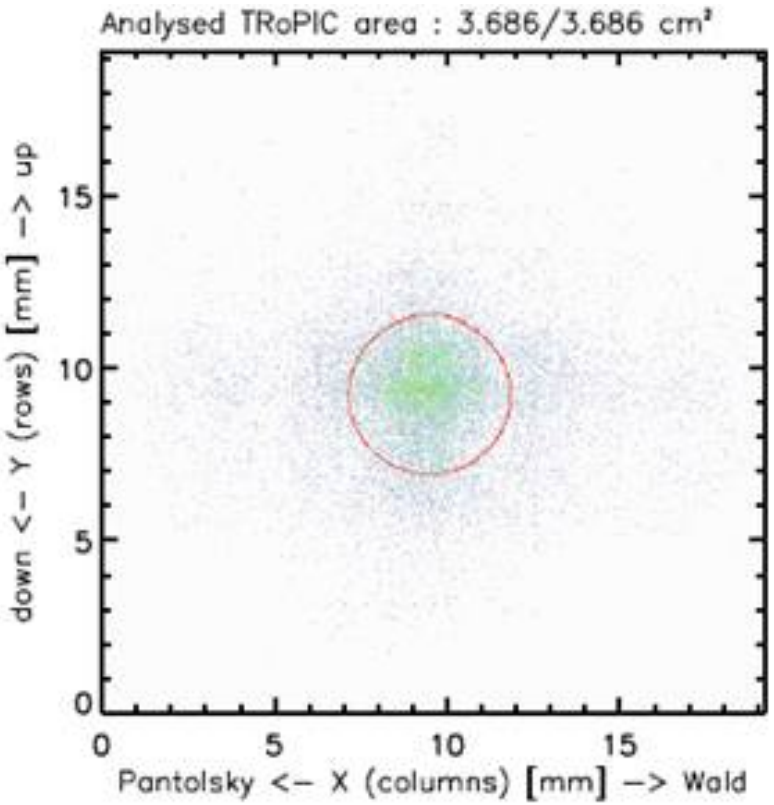
- Developed in collaboration with Rigaku Prague
- Si wafers as substrates, one side polished and coated, in total 380 wafers
- Test of large KB array with large (380) number of substrates

KB 2D image



KB PANTER tests





2D main focus at 4.5 keV (left) and 8 keV (right).
Results still in verification/evaluation.

THANK YOU FOR ATTENTION

Prague