МНИЦ «КОГЕРЕНТНАЯ РЕНТГЕНОВСКАЯ ОПТИКА
ДЛЯ УСТАНОВОК КЛАССА МЕГАСАЙЕНС»

БФУ

БАЛТИЙСКИЙ
ФЕДЕРАЛЬНЫЙ УНИВЕРСИТЕТ
ИМЕНИ ИММАНУИЛА КАНТА

РАЗРАБОТКА ОПТИКИ ДЛЯ КОМПТОНОВСКИХ ИСТОЧНИКОВ ЖЕСТКОГО РЕНТГЕНОВСКОГО И ГАММА ИЗЛУЧЕНИЯ

Дмитрий ЗВЕРЕВ
Анатолий СНИГИРЕВ

21.03.2022

Калининград

Immanuel Kant Baltic Federal University

Международный научно-исследовательский центр БФУ *«Когерентная рентгеновская оптика для установок Мегасайенс»*

Head: Prof. Anatoly Snigirev
https://www.researchgate.net/profile/A-Snigirev
http://xoptics.ru

2014-2018
Лаборатория рентгеновской оптики БФУ
Постановление 220 – Мегагрант
«Исследоование и разработка новых принципов управления рентгеновским излучением на основе наноструктурированных материалов »

2019 – 2021
Лаборатория мирового уровня
«Когерентная рентгеновская оптика и методы на ее основе для дифракционно-ограниченных источников»

РНФ
ПРЕЗИДЕНТСКАЯ ПРОГРАММА ИССЛЕДОВАТЕЛЬСКИХ ПРОЕКТОВ

2022 – 2025 «Приоритет 2030»

2021 – 2023 Программа развития синхротронных и нейтронных исследований

2022 – 2024 Разработка и изготовление оптики для станций СКИФ

Our team

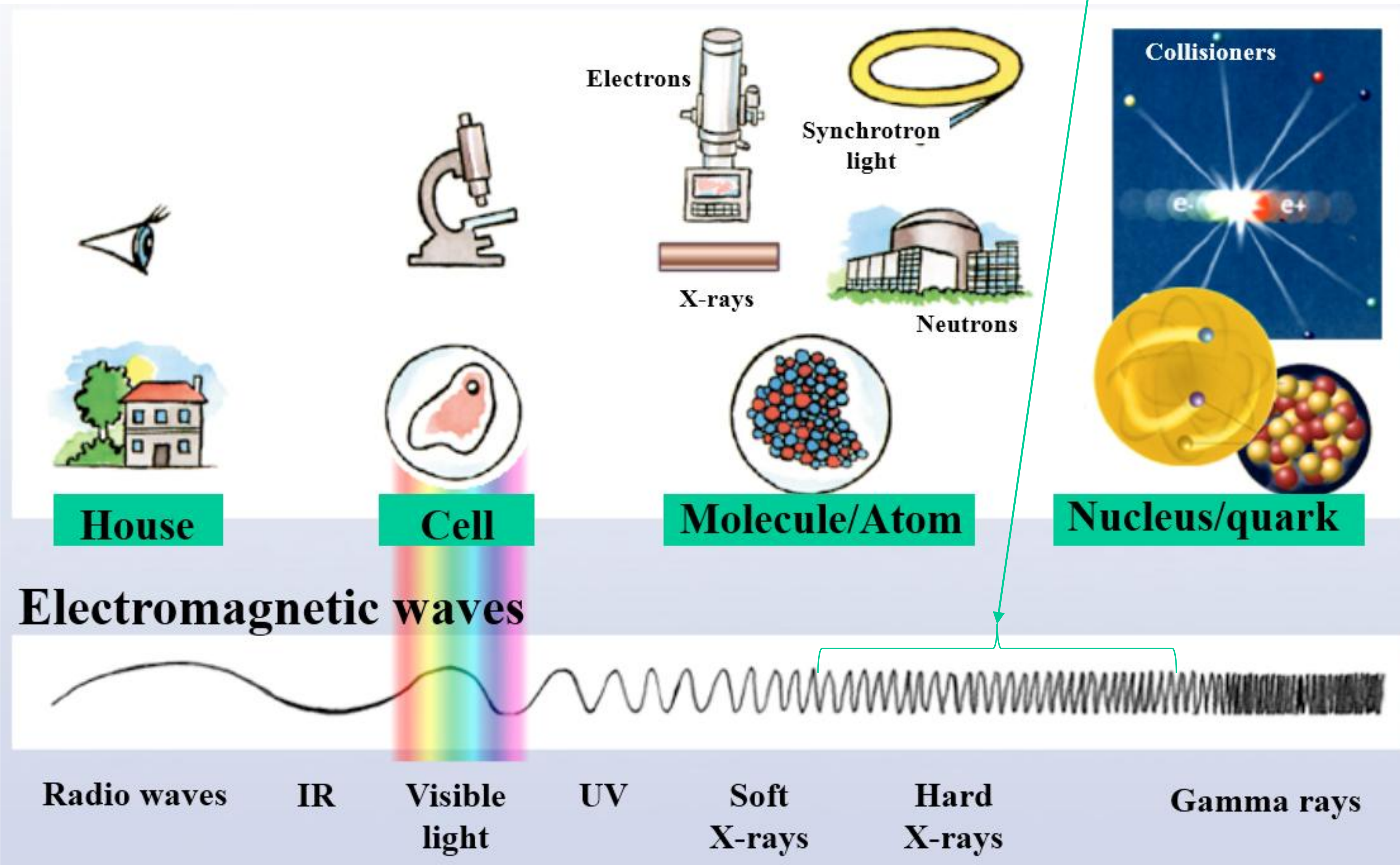
International research centre
“Coherent X-ray optics for Megascience facility”

- **2 professors**
- **2 senior researcher**
- **4 PostDocs**
- **5 young researchers**
- **4 PhD students**
- **4 engineers**

Head: Prof. Anatoly Snigirev
https://www.researchgate.net/profile/A-Snigirev
http://xoptics.ru

To see invisible

1 - 250 keV (1 MeV ?)



ESRF, Grenoble, France

PETRA III @ DESY,
Hamburg, Germany

European XFEL

XFEL @ DESY,
Hamburg, Germany

Источники СИ в России (планы)

СИЛА

Источник Специализированный
Синхротронного Излучения

СИЛА, Протвино

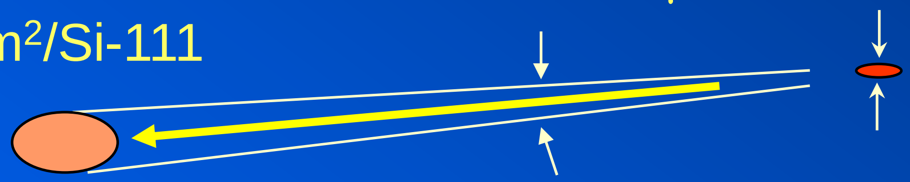
+

Перестройка КИСИ (Сибирь-2)

СКИФ

Сибирский Когерентный Источник Фотонов СКИФ (SKIF), Новосибирск ~ 40 млрд рублей!

Diffraction limited SR sources



wavelength / source size ~ beam divergence

For 12.4 keV

$\lambda = 10^{-10}$ m

s = 10 µm

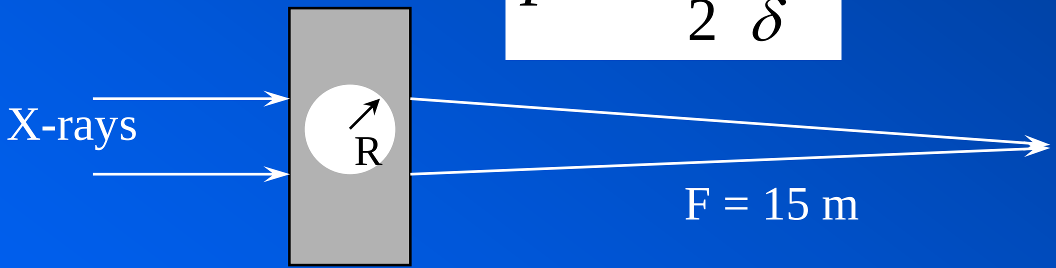
λ/s = 10 µrad !

X-ray Compound Refractive Lenses

$Re(n) = 1-\delta + i\beta < 1$

$1-n \sim 10^{-5}\text{-}10^{-6}$

$$F = \frac{R}{2\delta}$$



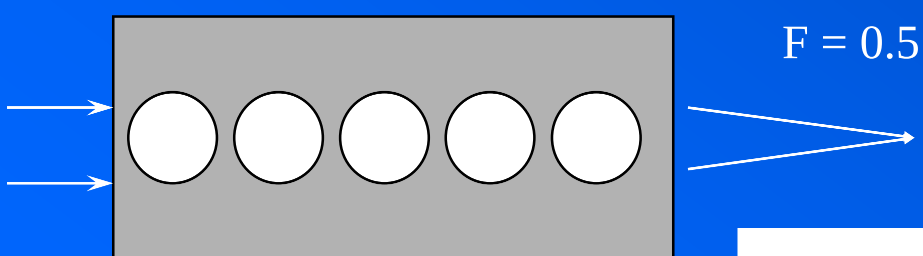
x N

Be

E = 10 keV

$\delta = 3.4 \cdot 10^{-6}$

$R = 100\ \mu m$



N = 30

$$F = \frac{R}{2N\delta}$$

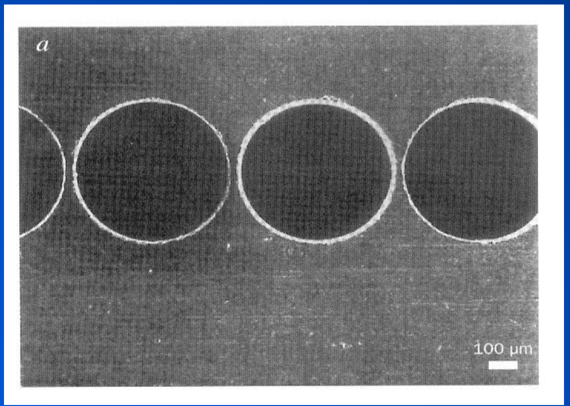
NATURE · VOL 384 · 7 NOVEMBER 1996

A compound refractive lens for focusing high-energy X-rays

A. Snigirev*, V. Kohn†, I. Snigireva* & B. Lengeler*‡

* European Synchrotron Radiation Facility, BP220, F-38043 Grenoble Cedex, France

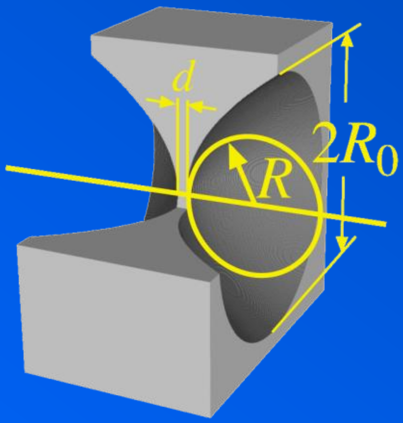
† Kurchatov, I. V., Institute of Atomic Energy, 123182 Moscow, Russia

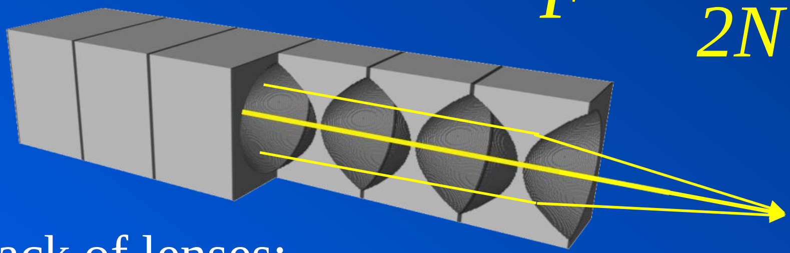


Al, $R = 300\mu m$

X-ray Refractive Optics

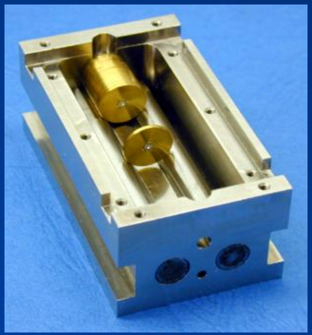
single parabolic lens





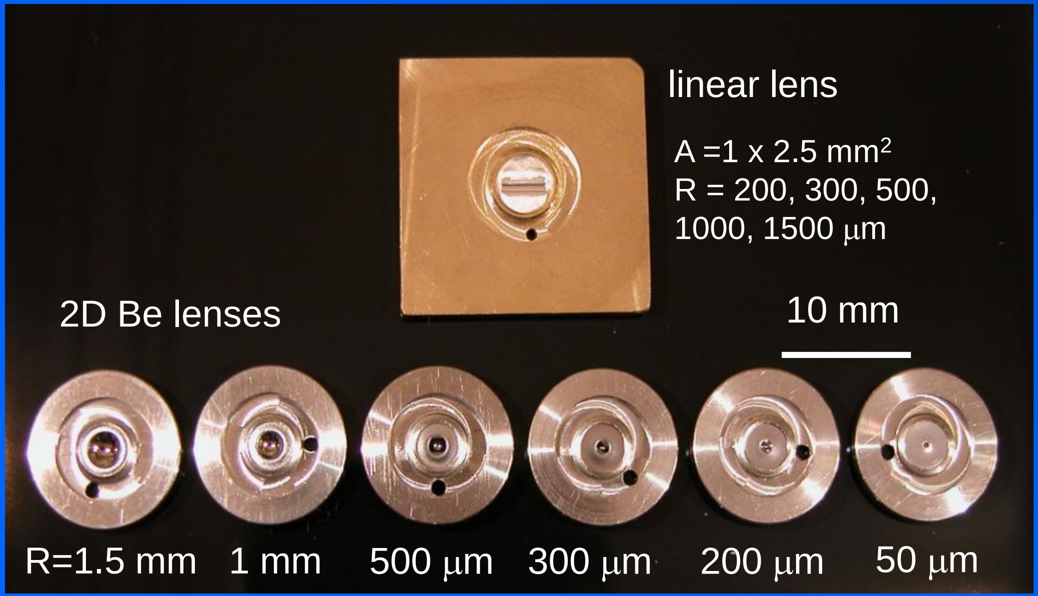
$$F = \frac{R}{2N\delta}$$

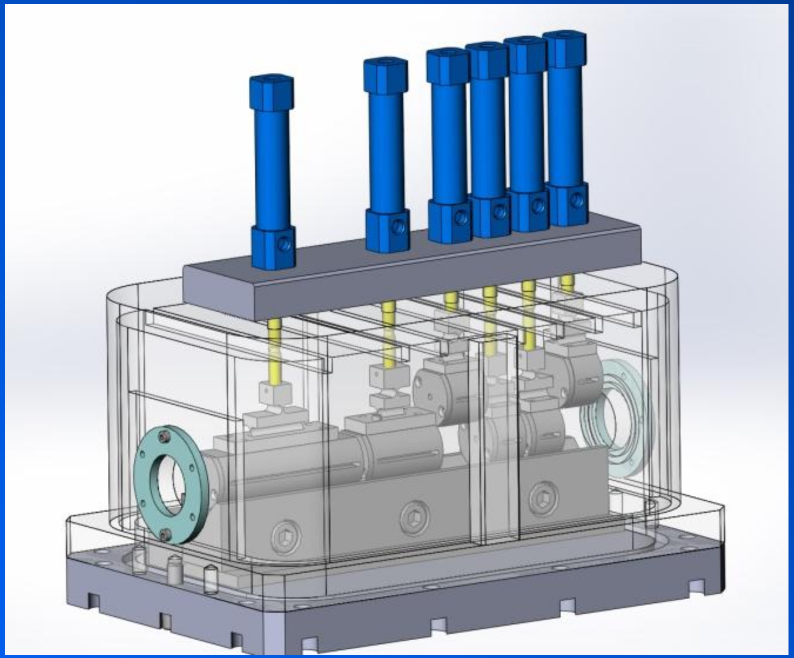
stack of lenses:
compound refractive lens (CRL)



CRL transfocator

Parabolic lenses (RXOPTICS)





Use of Refractive Optics Worldwide

15 synchrotrons in 10 countries

France	ESRF, Soleil
Germany	PETRA III, ANKA
Spain	ALBA
Switzerland	SLS
UK	Diamond
US	APS, NSLS, SSRL, LCLS
Japan	SPring-8
South Korea	PLS
China	BSRF
Russia	Kurchatov synchrotron, SSRC (BINP)
THOM-X	France, LURE

Major users are large high-energy facilities: ESRF, Spring-8, APS and PETRA-III
Half of the ESRF and all PETRA-III beamlines are equipped with refractive optics

X-ray Free Electron Lasers

US	LCLS, Stanford
Japan	SACLA, Hyogo
Germany	XFEL, Hamburg
Switzerland	XFEL,

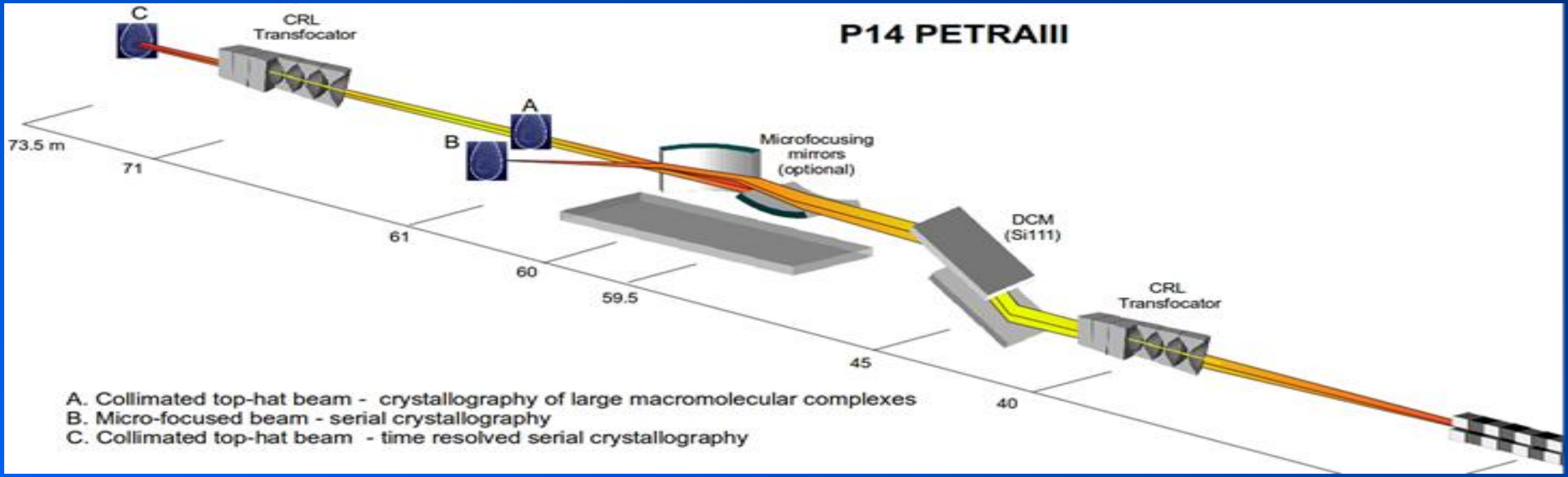
Применения

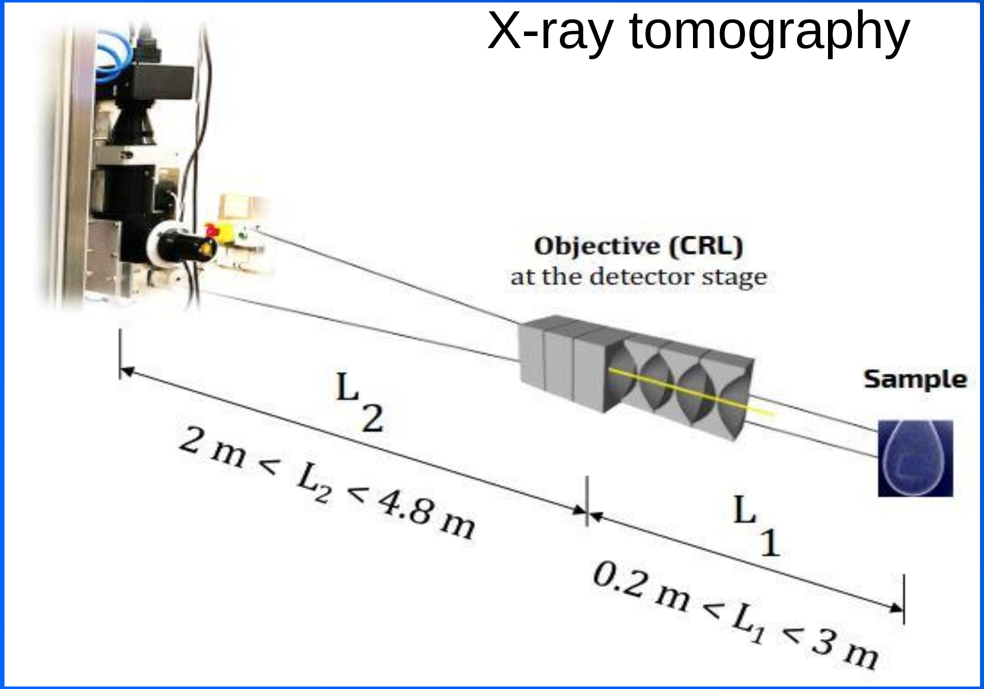
- Оптика формирования/кондиционирования пучка *(Beam conditioning optics)*
  - ✓ конденсоры (*condensers*)
  - ✓ коллиматоры (*collimators*)
  - ✓ монохроматоры (*monochromators*)
  - ✓ подавители гармоник (*harmonics rejecters*)
  - ✓ расширитель пучка (beam expanders)
- Мико-(нано-)фокусировка (*micro (nano)-beam*)
  - ✓ дифракция, спектроскопия, микроскопия (diffraction, scattering, microscopy & spectroscopy)
- Диагностика пучка (*Beam/emittance diagnostics*)

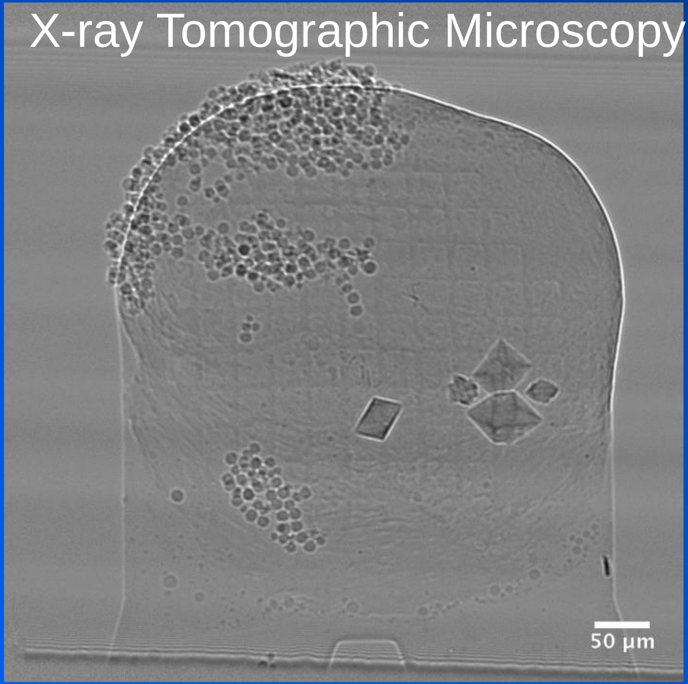
Новые методы (*New techniques*)

- ✓ Когерентная полно-польная и дифракционная микроскопия (Coherent full-field imaging and diffraction microscopy)
- ✓ Темнопольная микроскопия (Dark-field microscopy)
- ✓ Интерферометрия (In-line interferometry)

Macromolecular beamline P14@ PETRA III

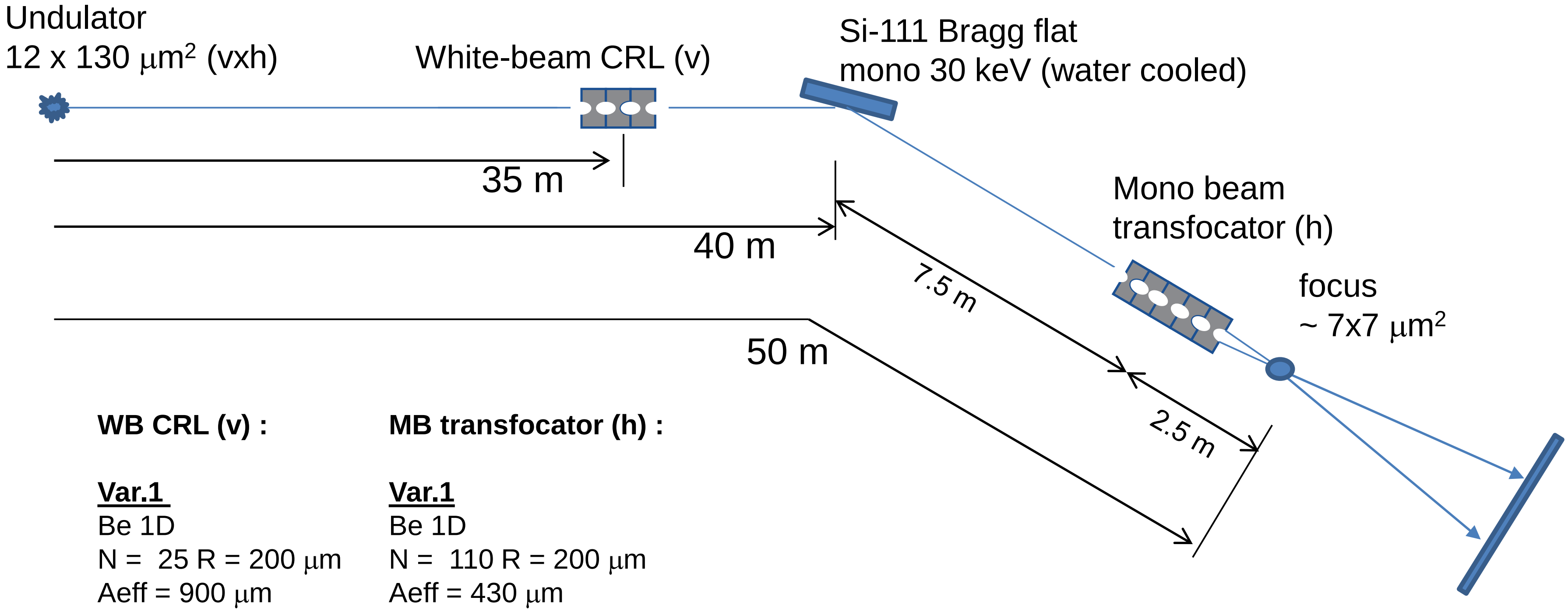






M. Polikarpov, G. Burenkov, T. Schneider *(EMBL, Hamburg)*, **A. Snigirev** *(IKBFU, Kaliningrad)*

Proposal for BL layout for High Preasure BL



WB CRL (v) :

<u>Var.1</u>
Be 1D
N = 25 R = 200 μm
Aeff = 900 μm

<u>Var.2</u>
Al 1D
N = 16 R = 200 μm
Aeff = 380 μm

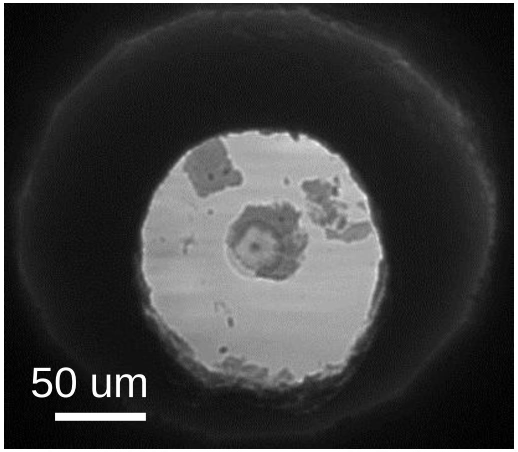
MB transfocator (h) :

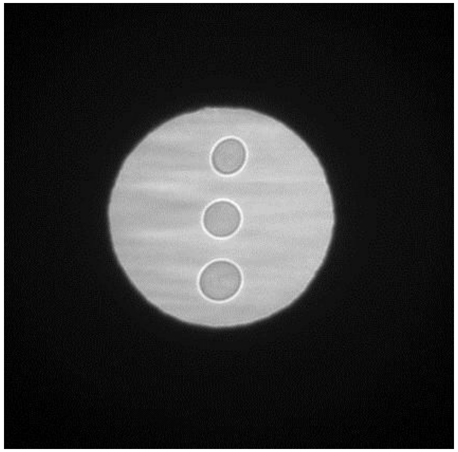
<u>Var.1</u>
Be 1D
N = 110 R = 200 μm
Aeff = 430 μm

<u>Var.2</u>
Al 1D
N = 70 R = 200 μm
Aeff = 180 μm

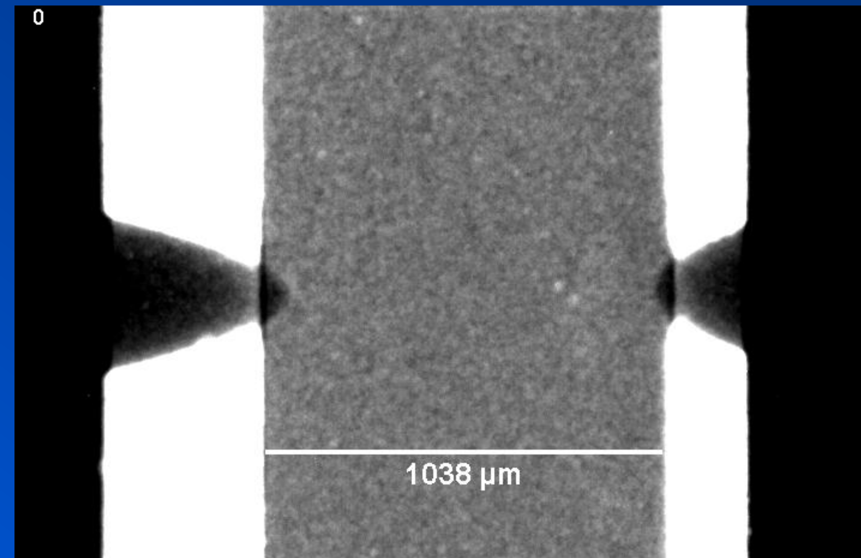
var.1 versus var.2
factor > x5 flux in focus

flux gain in focus
compare with ID9 HP : X 10!

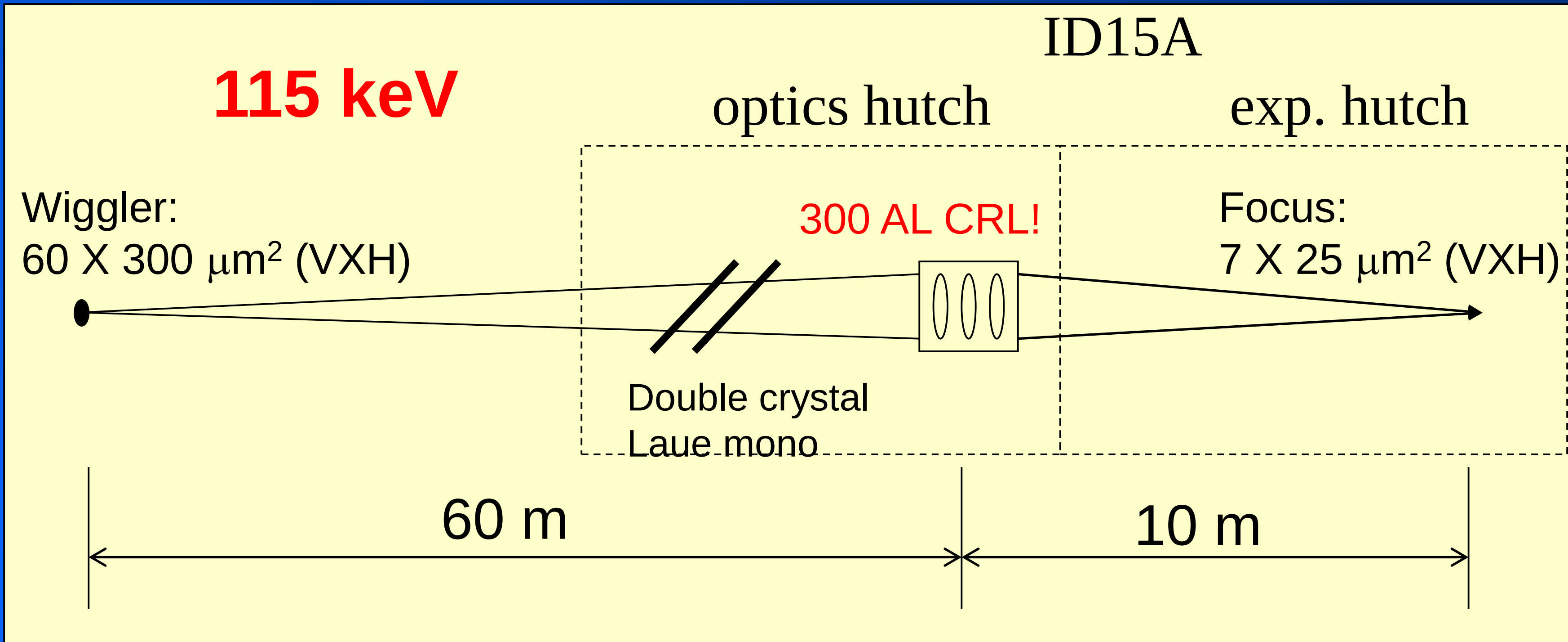


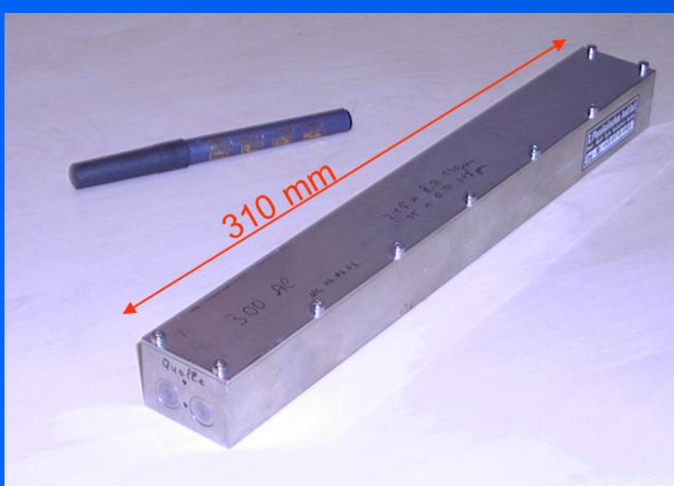


Insitu контроль за прессованием линз

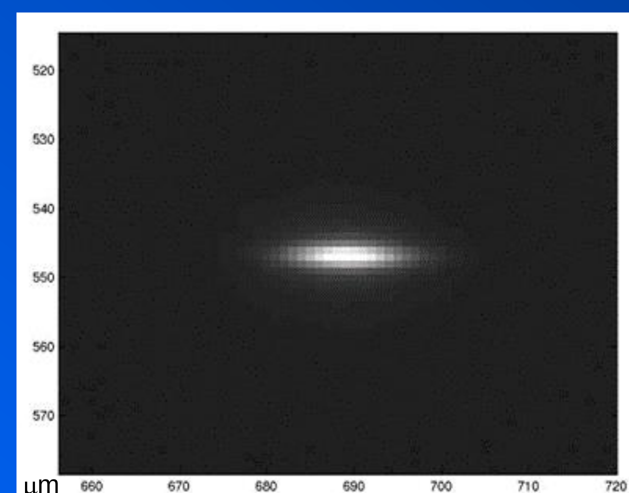


High Energy Focusing





<u>115 keV</u>
$7 \times 25\ \mu m^2$ (VXH)
10^9 ph/s



High Energy X-ray focusing test of Ni lenses

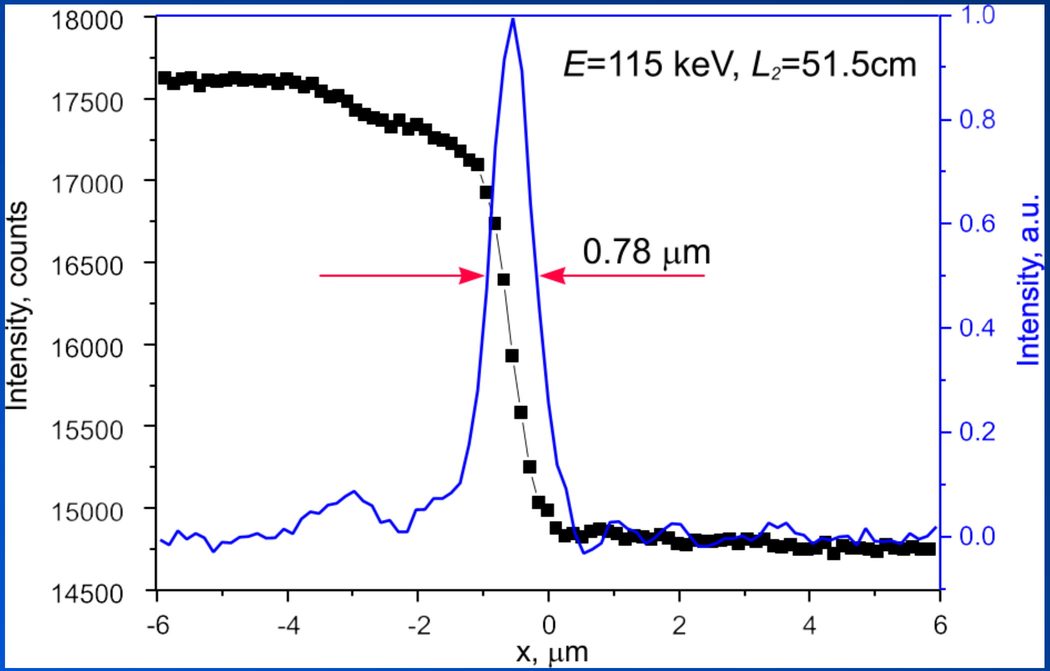
ID15

E = 40 –150 keV

L_1 = 60 m

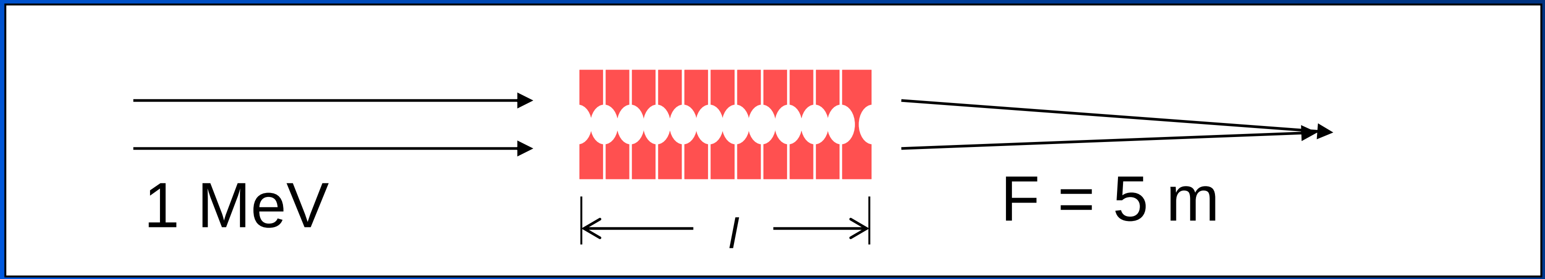
F = 0.5 – 5 m

Res = 0.75 μm at 50 keV
0.9 μm at 150 keV



E, keV	L_2, cm	Number of lenses	Aperture, μm	Radius, μm	FWHM, μm
46	51	13	94.3	12.5	0.75
78	225	13	94.3	12.5	1.3
82	270	8	80.4	10.8	1.8
86	90	34	109.1	13.9	1.4
86.5	66	50	118.7	15.3	1.1
115	51	98	98	12.8	0.78
144	51	117	74	9.6	0.9

1 MeV focusing



Al lenses
R = 200 μm
N = 40 000 l ~ 40 m !

A_{eff} ~ 100 μm

Ni lenses
R = 200 μm
N = 12 500 l ~12.5 m !

A_{eff} ~ 100 μm

Ni lenses
R = 50 μm
N = 3000 l ~ 3 m !

A_{eff} ~ 100 μm

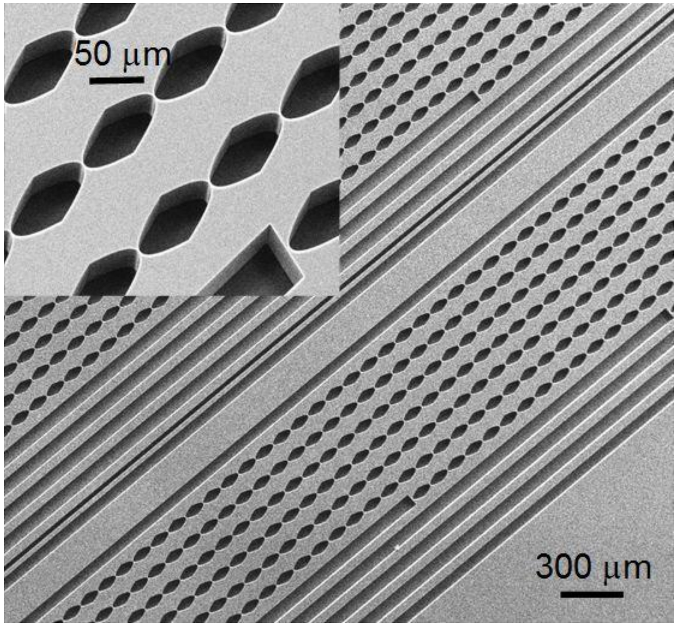
Ni planar lenses
R = 5 μm
N = 300 l ~ 5 cm !

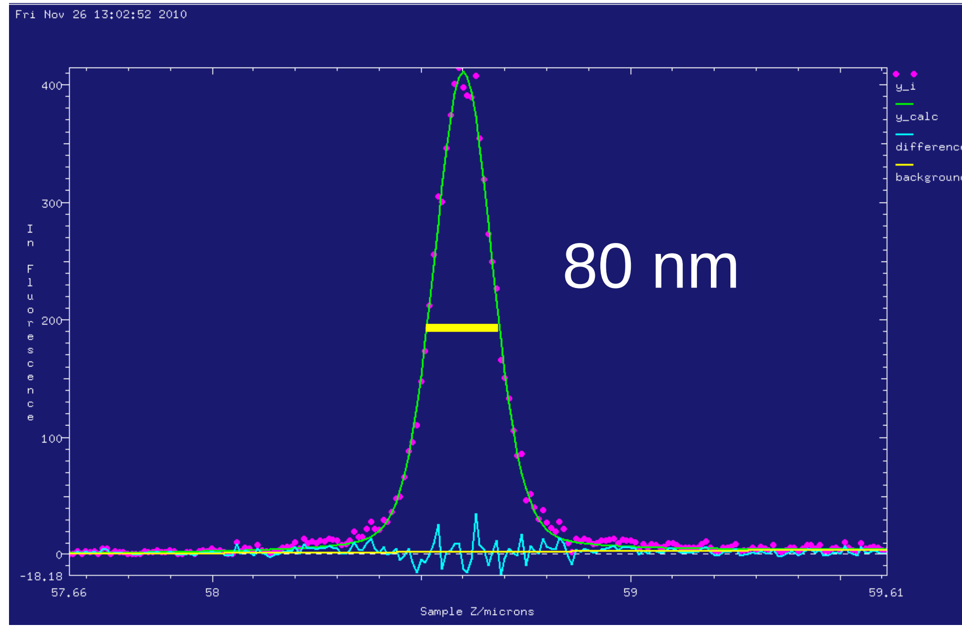
A_{eff} ~ 100 μm

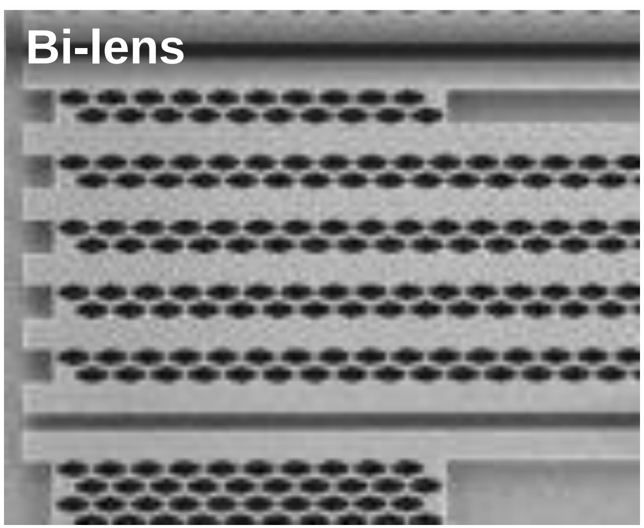
Au, Pt, U

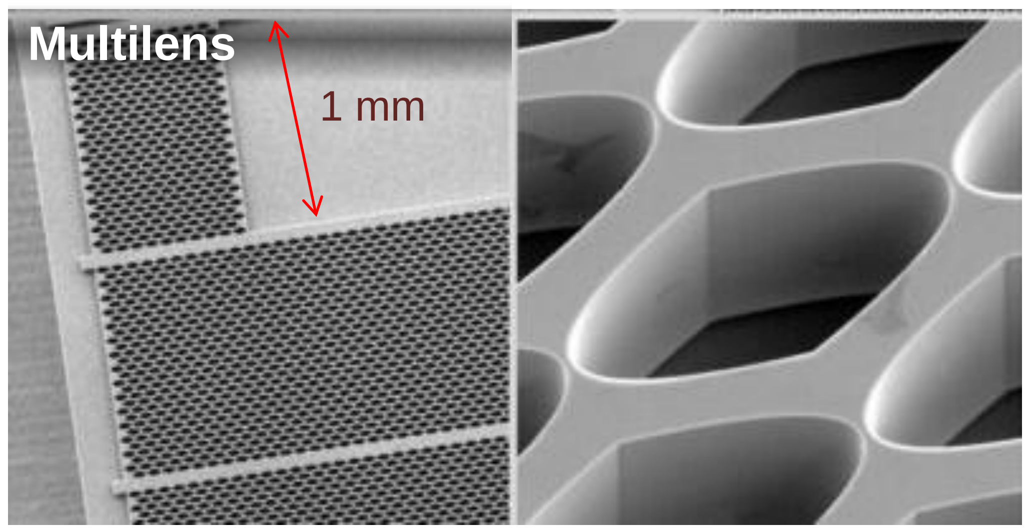
ID11 Toward the < 100 nm Frontier

From 30 to 100 keV!!!



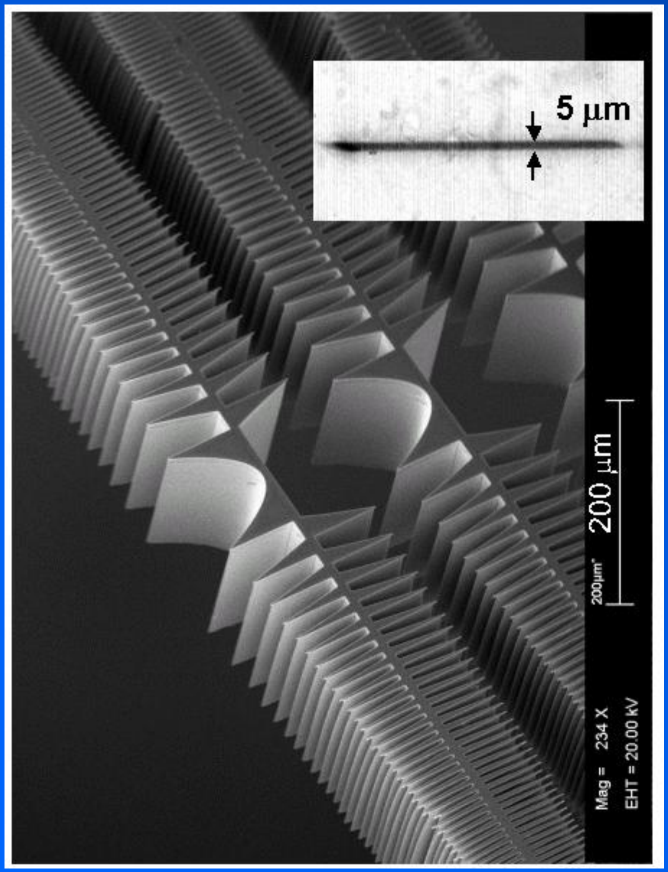


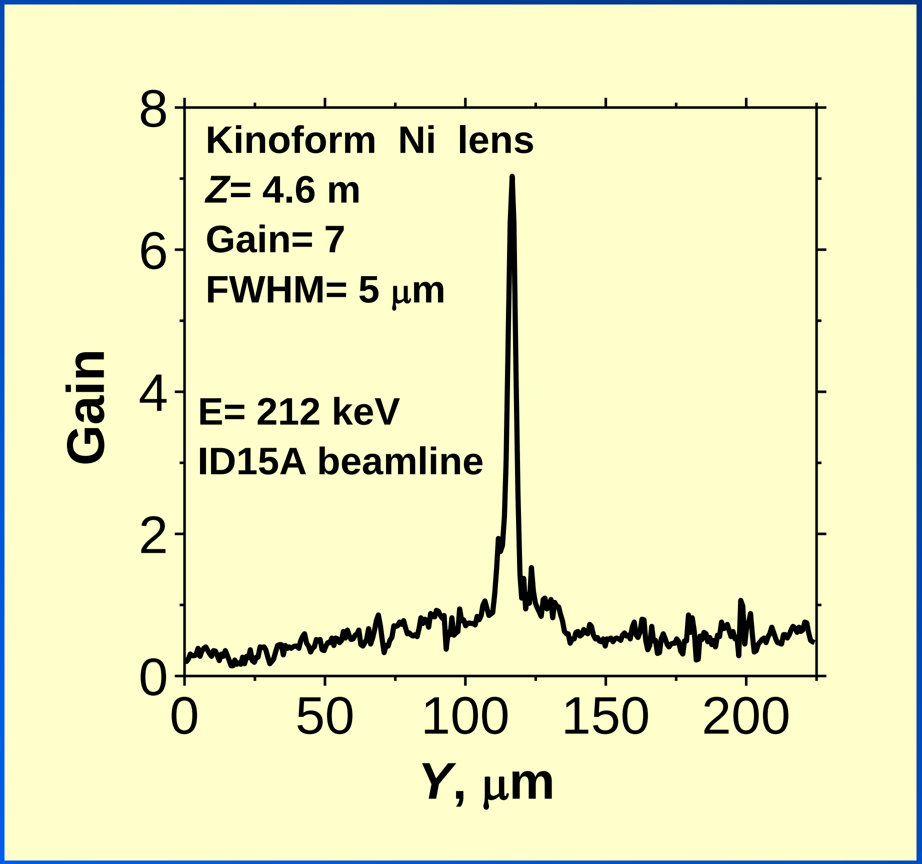




High Energy X-ray focusing test of Ni kinoform lenses

5µm @ 212 keV !





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2021, AHEAD-OF-PRINT, 1-9
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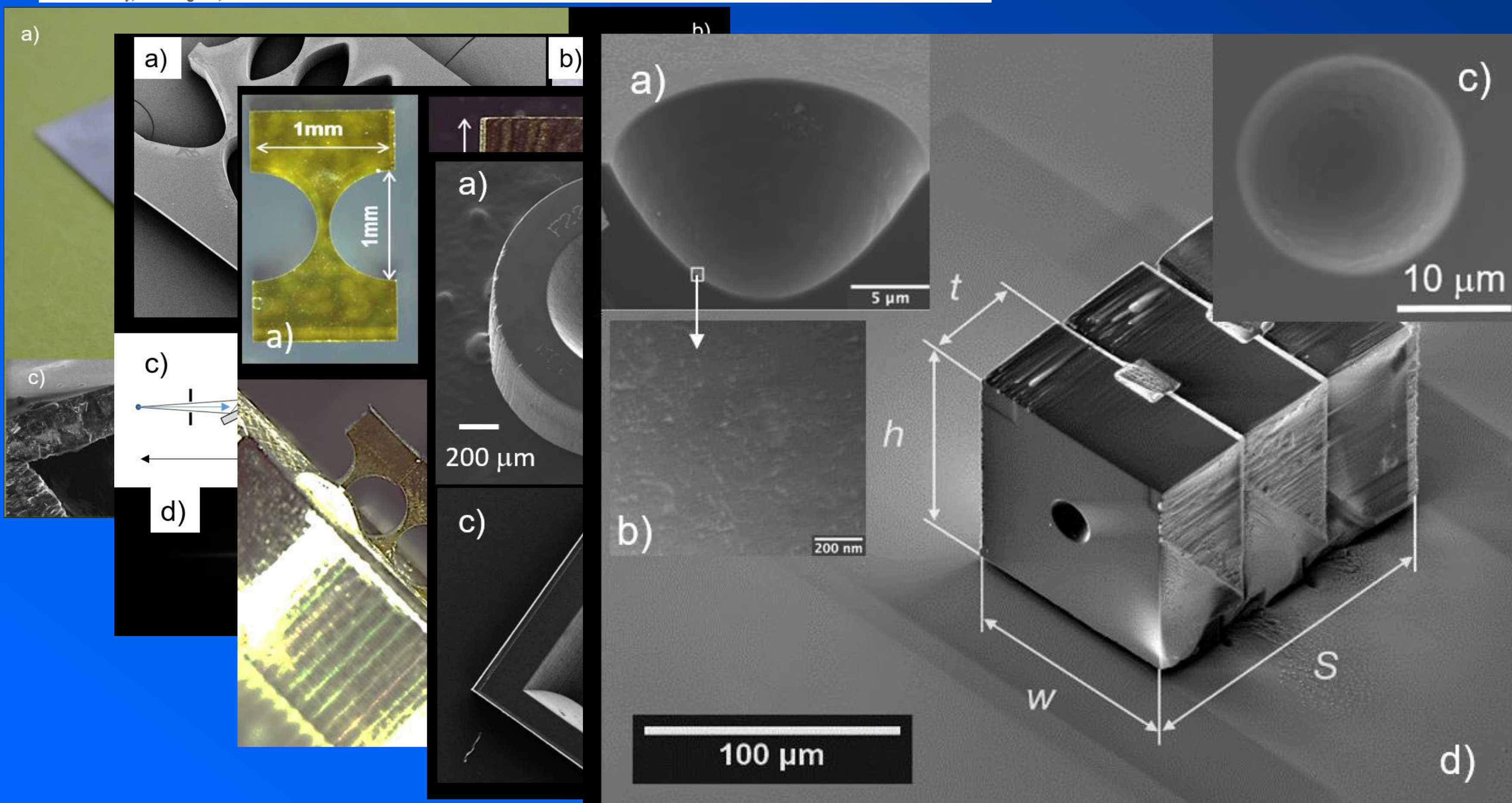
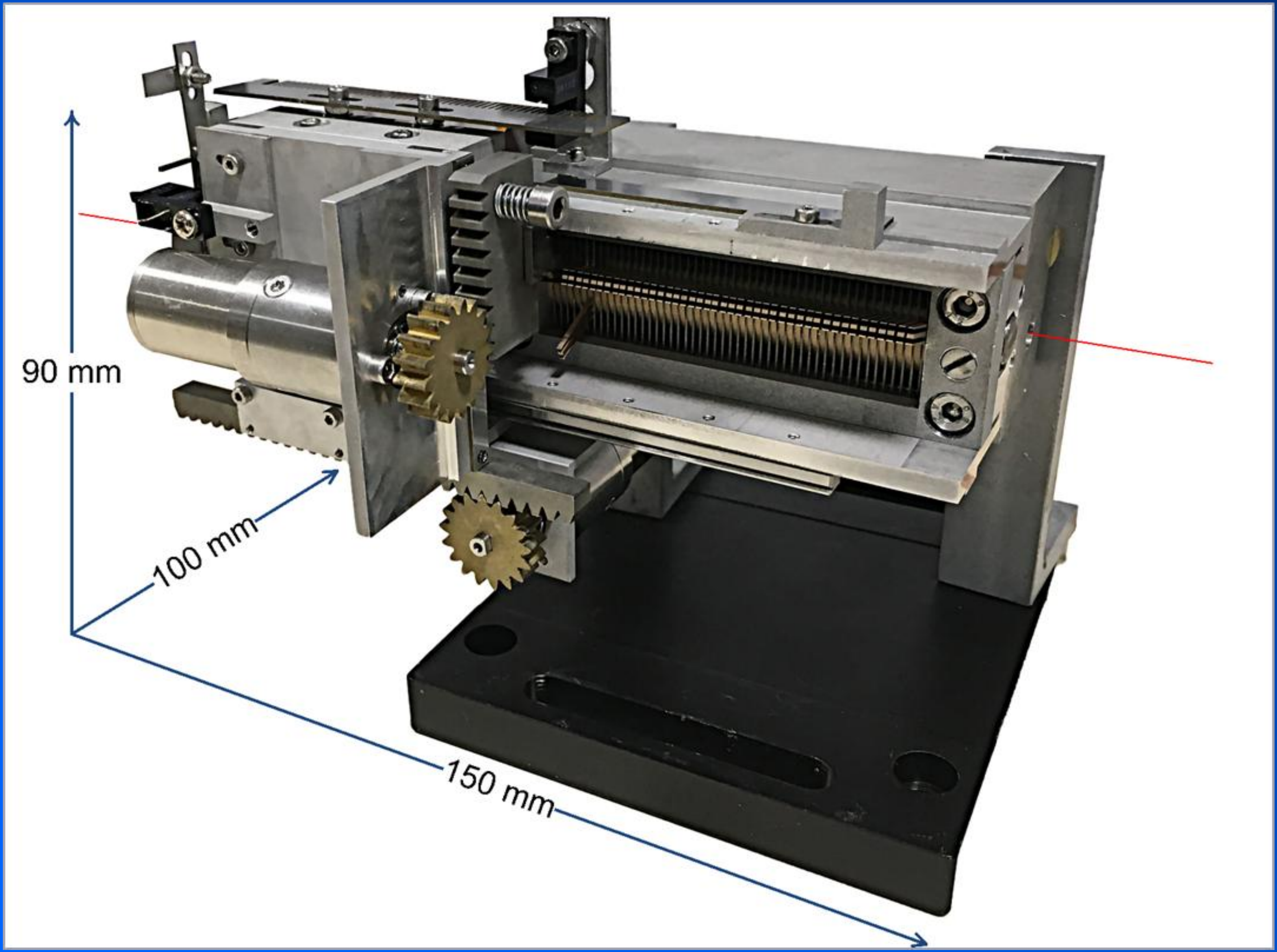
Diamond X-Ray Refractive Optics

Irina Snigireva[1] , Maxim Polikarpov[2] , and Anatoly Snigirev[3]

[1] European Synchrotron Radiation Facility, Grenoble, France [2] ETH Zurich, Zurich, Switzerland [3] Immanuel Kant Baltic Federal University, Kaliningrad, Russia

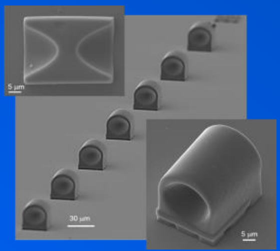


Компактный трансфокатор

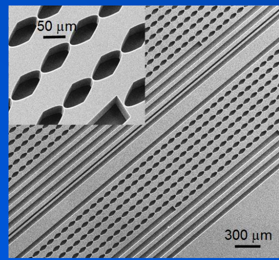


Implementation of X-ray Refractive Optics

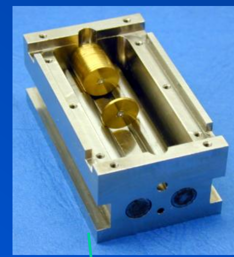
Refractive Optics - the most versatile and adaptable optics for wide energy range: 2 – 200 keV



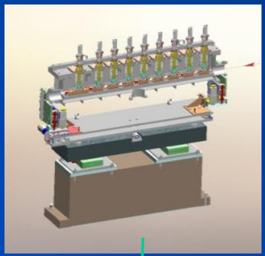
micro-lenses

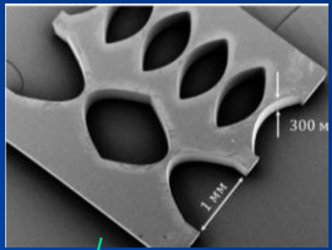


nano-lenses

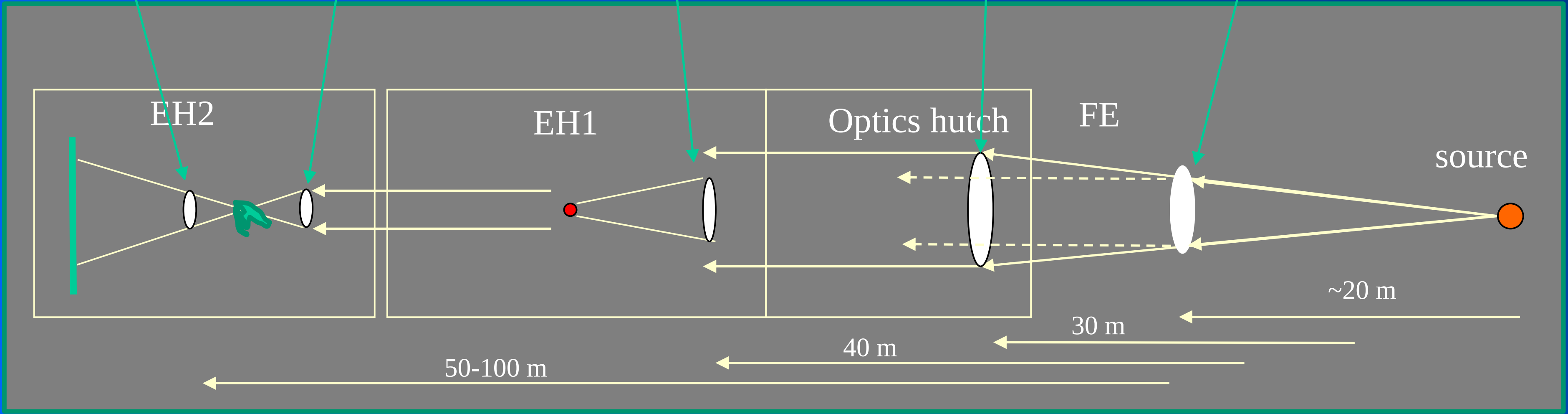


micro-optics





front-end lenses/transfocators



mode of use	*focal length*	*resolution*
condensers/collimators	F ~ 10 m	10 µm
micro-optics	F ~ 1 m	1 µm
nano-optics	F ~ 10-100 mm	50 – 100 nm

Microoptics test bench based on X-ray micro-focus Metal-Jet source