The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2139-5

School on Synchrotron and Free-Electron-Laser Sources and their Multidisciplinary Applications

26 April - 7 May, 2010

Special optical devices: from micro-focusing to FEL optics

Daniele Cocco
Sincrotrone Trieste SCpA

Strada Costiera 11, 34151 Trieste, Italy - Tel.+39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it

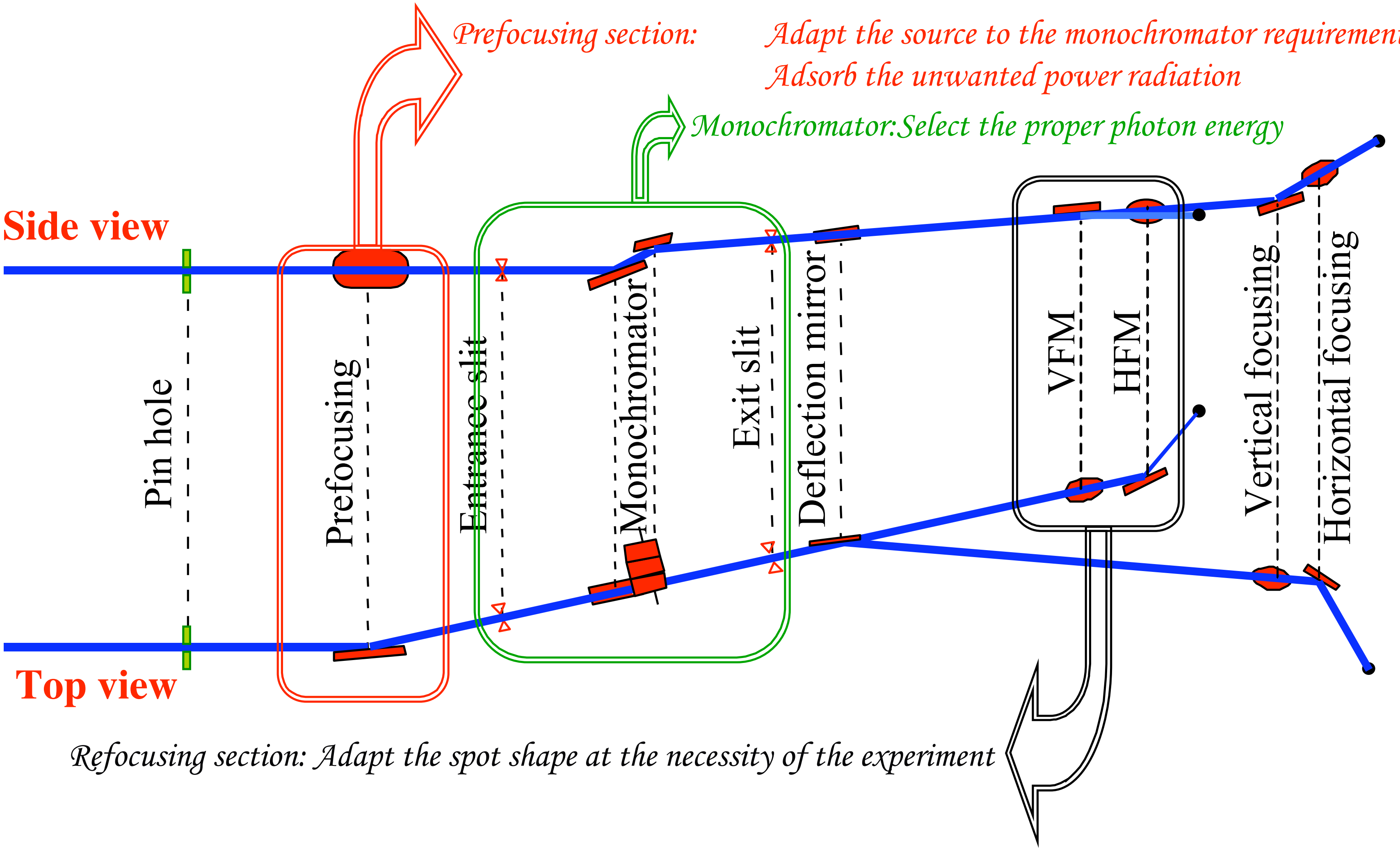
Special optical devices: from micro-focusing to FEL optics

Daniele Cocco

Sincrotrone Trieste ScpA, S.S. 14 Km 163.5 in Area Science Park, 34012 Trieste, ITALY

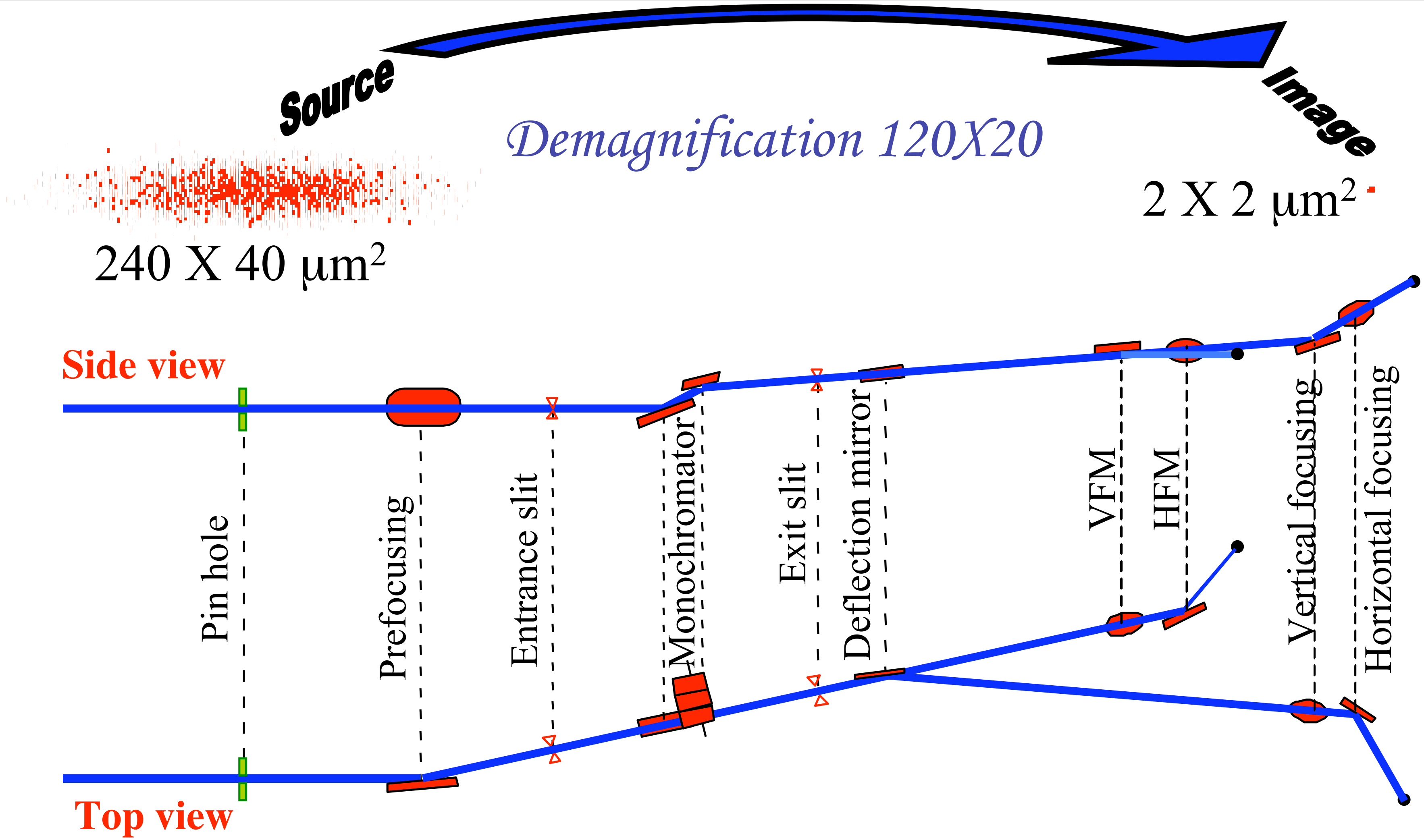
School on Synchrotron and Free-Electron-Laser Sources and their Multidisciplinary Applications
April 26 - May 7 2010
ICTP Trieste ITALY

Beamline

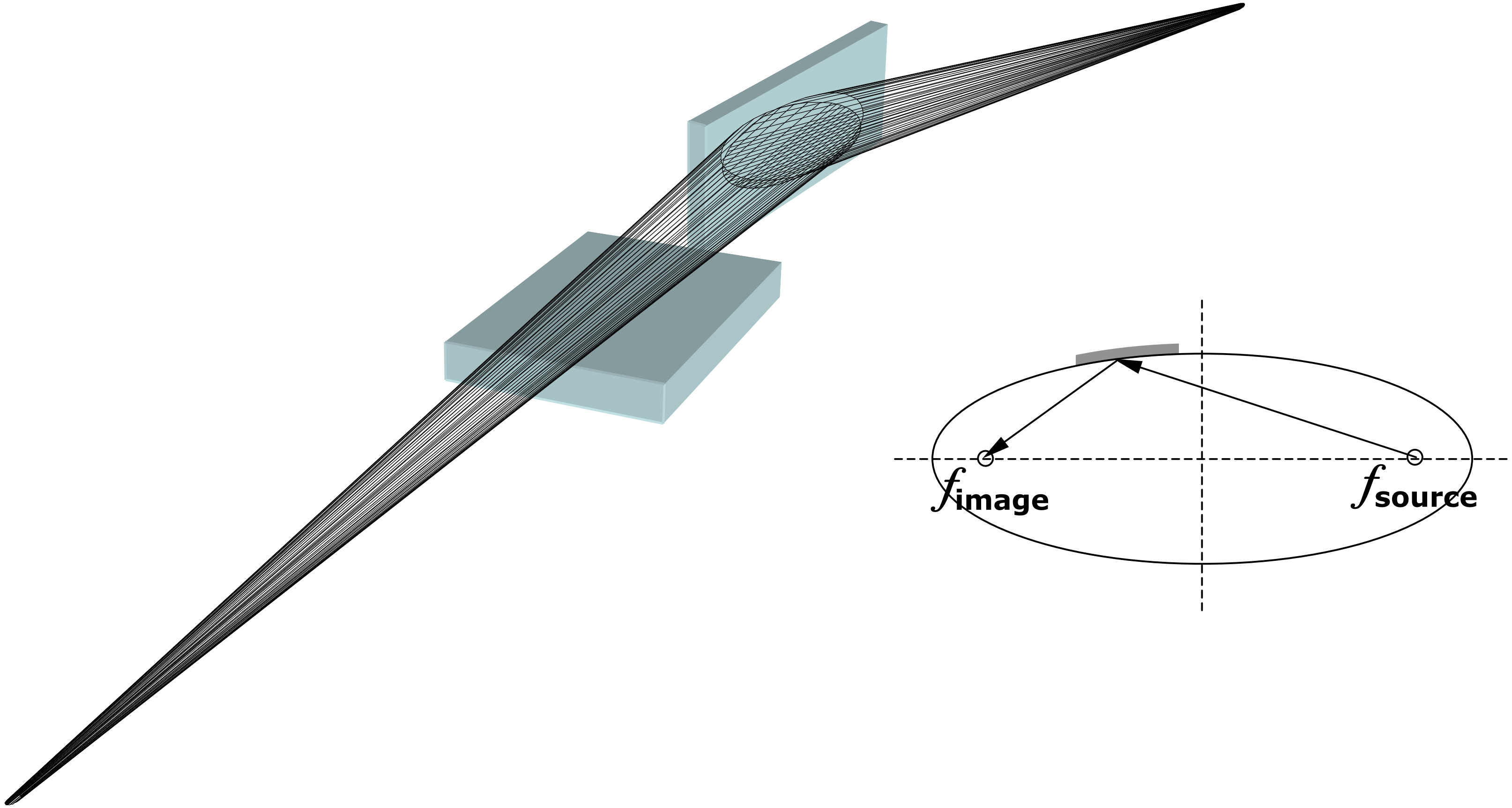


Prefocusing section:
Adapt the source to the monochromator requirements
Adsorb the unwanted power radiation
Monochromator:Select the proper photon energy
Side view
Top view
Pin hole
Prefocusing
Entrance slit
Monochromator
Exit slit
Deflection mirror
VFM
HFM
Vertical focusing
Horizontal focusing
Refocusing section: Adapt the spot shape at the necessity of the experiment

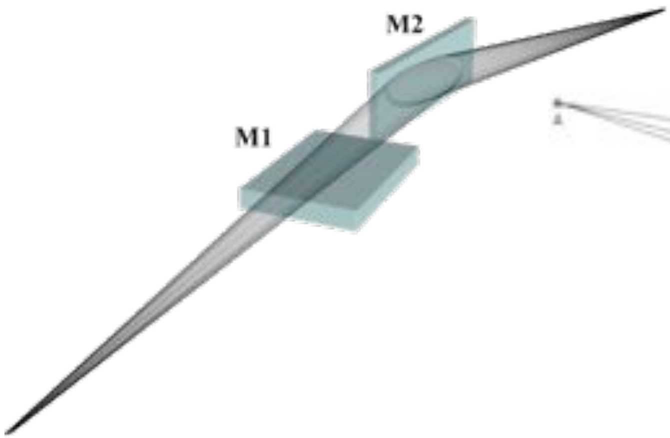
Small spot = Large demagnification

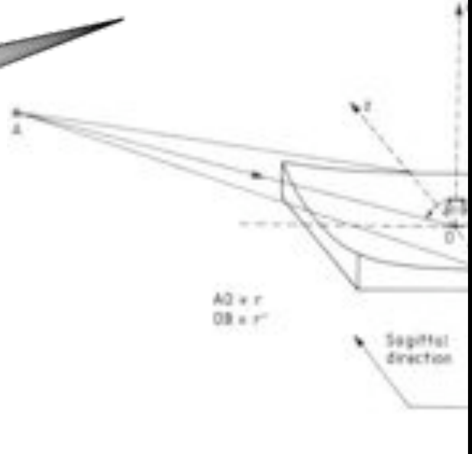


KB mirrors

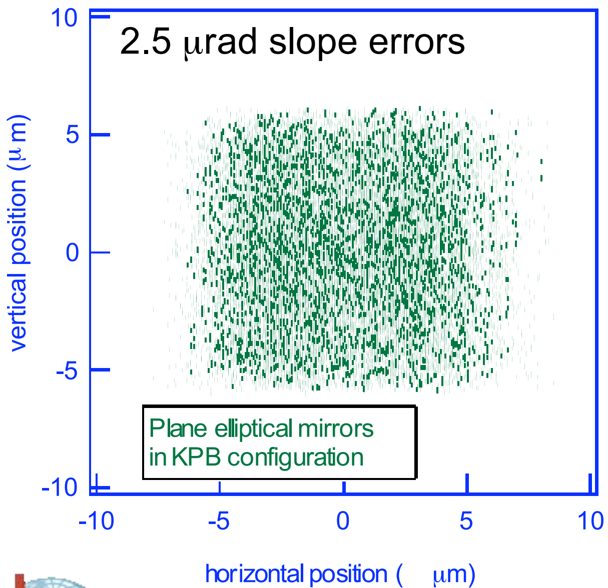


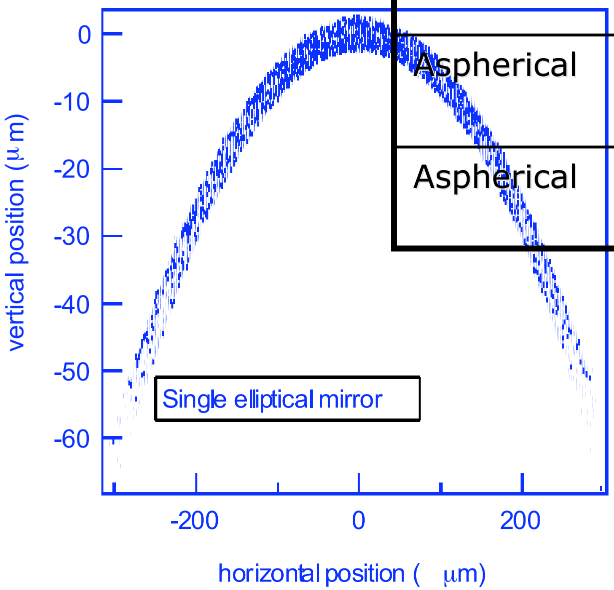
Small spot with KB system

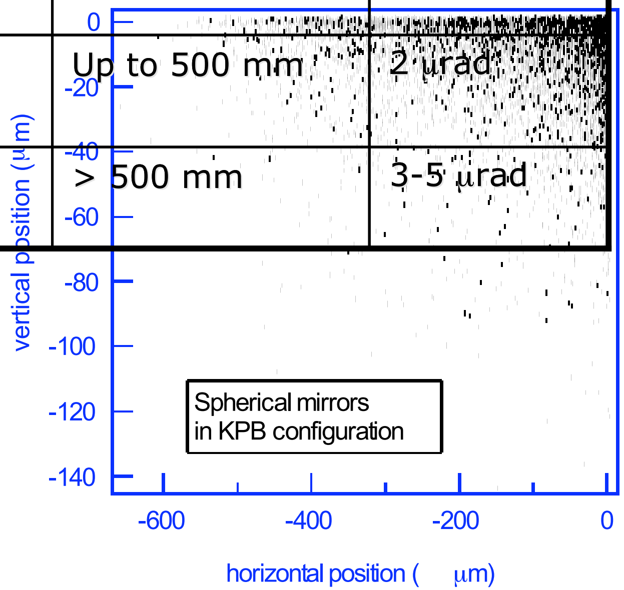




Shape	Length	rms errors
Spherical/flat	Up to 500 mm	< 0.5 μrad
Spherical/flat	> 500 mm	1-2 μrad
Toroidal	Up to 500 mm	< 1 μrad
Toroidal	> 500 mm	> 1 μrad
Aspherical	Up to 500 mm	2 μrad
Aspherical	> 500 mm	3-5 μrad





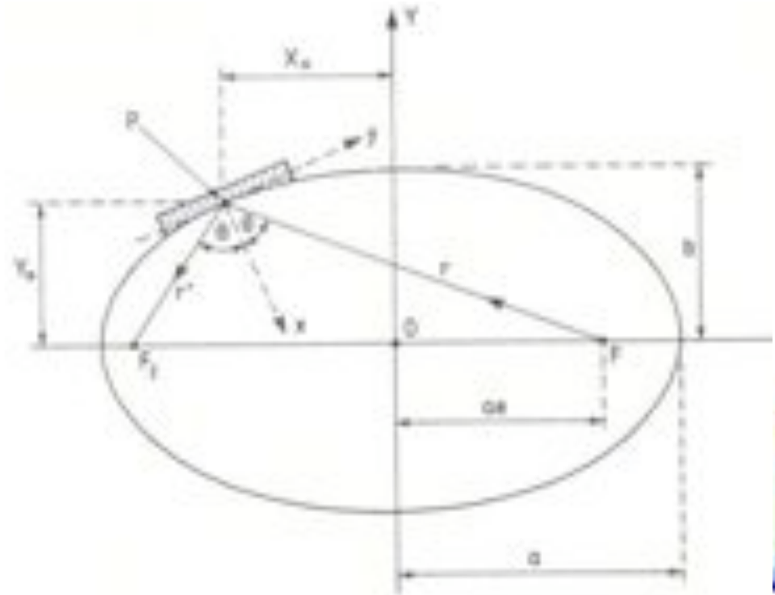


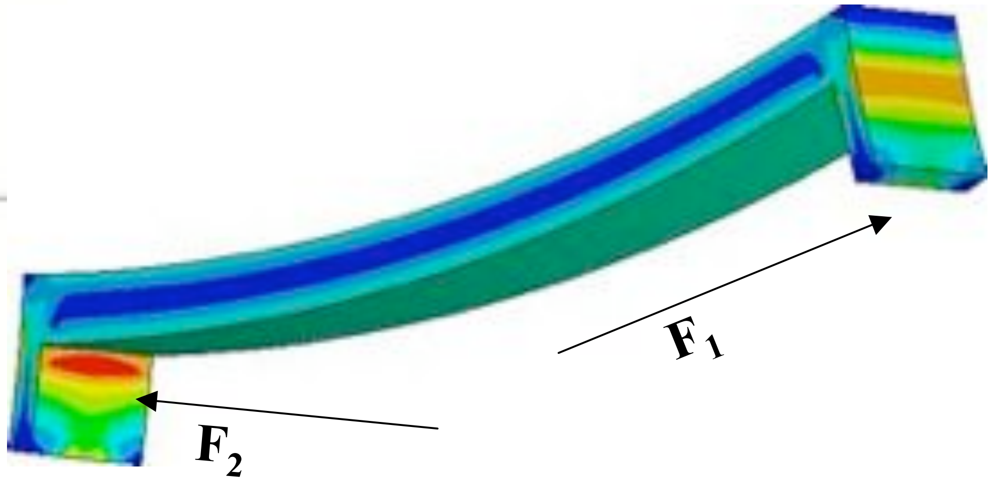
Approach best ellipse

$$x^2\left(\frac{\sin^2\vartheta}{b^2}+\frac{1}{a^2}\right)+y^2\left(\frac{\cos^2\vartheta}{b^2}\right)-x\left(\frac{4f\cos\vartheta}{b^2}\right)-xy\left[\frac{2\sin\vartheta\sqrt{e^2-\sin^2\vartheta}}{b^2}\right]=0$$

where: $f=\left(\frac{1}{r}+\frac{1}{r'}\right)^{-1}$

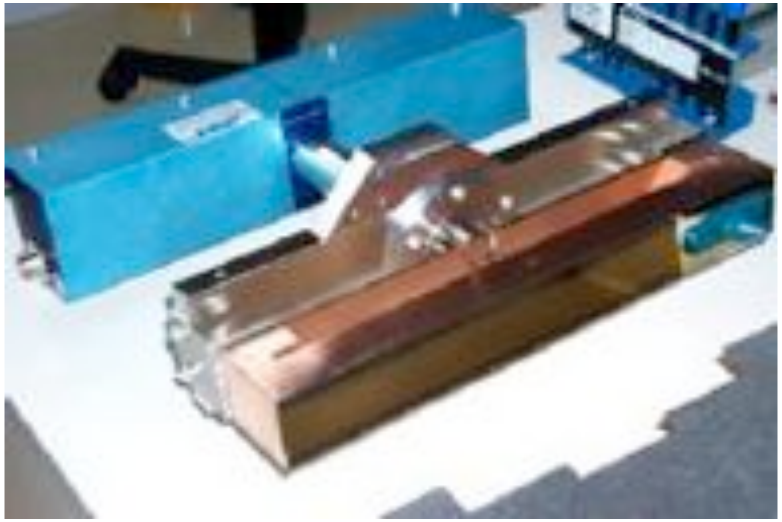
Needs a 3rd order approximation in shape

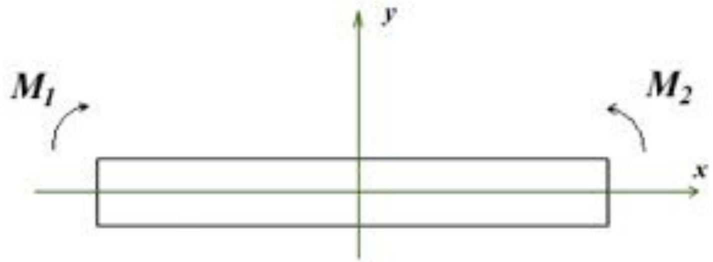


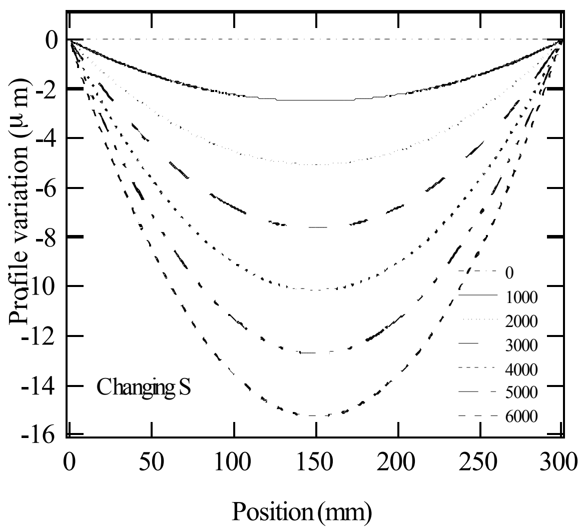


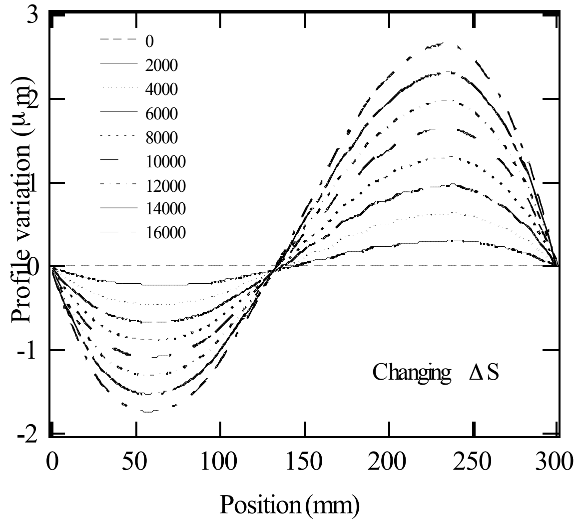
Two unequal moment applied at the edges

Correction by polishing

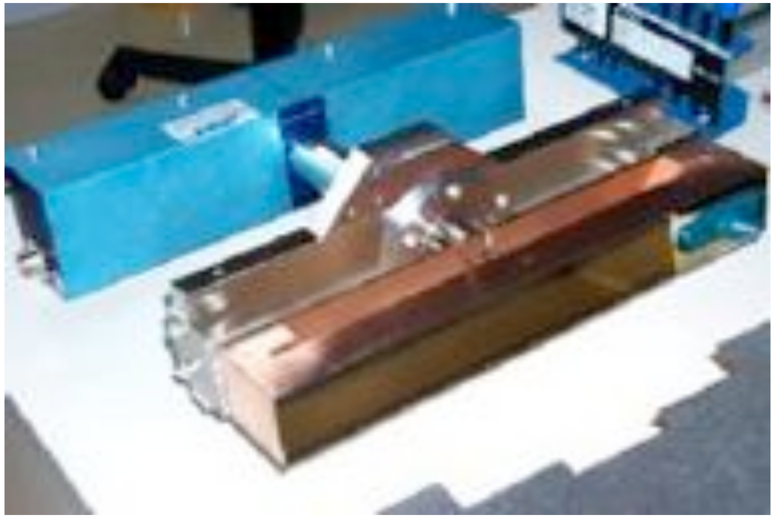


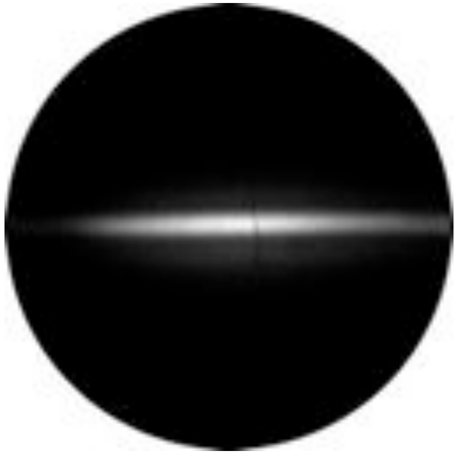






Correction by polishing

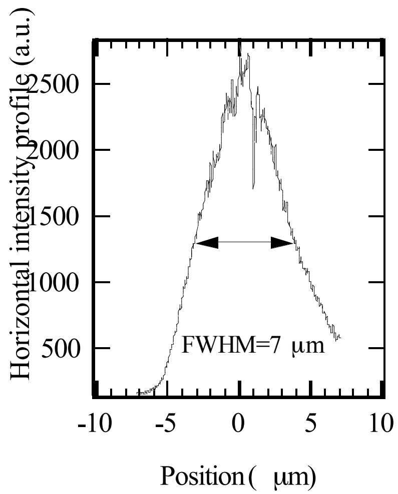


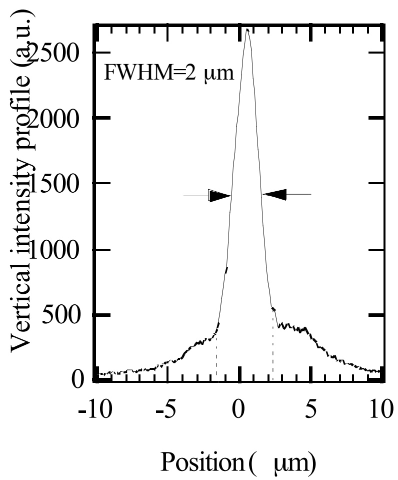


Sample tilted by 76°

2X7 μm^2

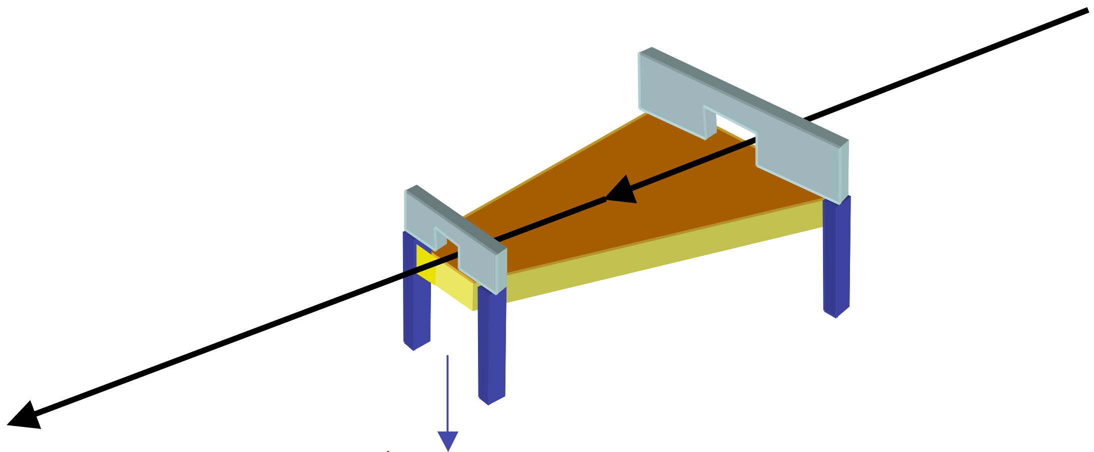
Flux $1x10^{13}$ ph/sec





Corrected by variable width

micro-fluorescence & micro-diffraction (HXR)



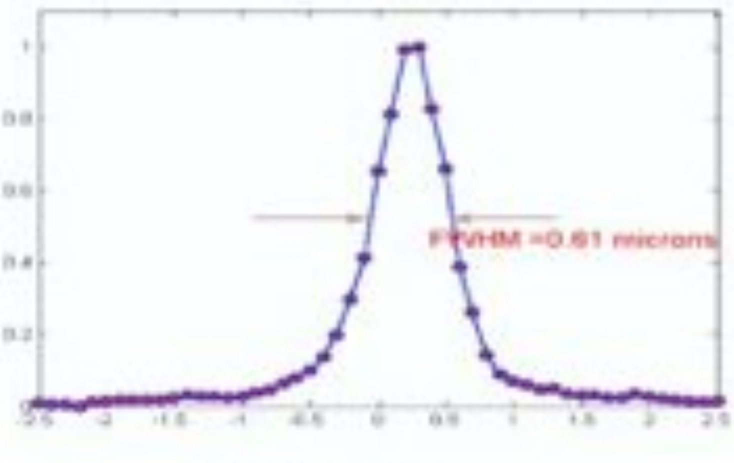
Bending system

The mirror must be shaped according to the required working distance and angle of incidence constant thickness but linear width variation.

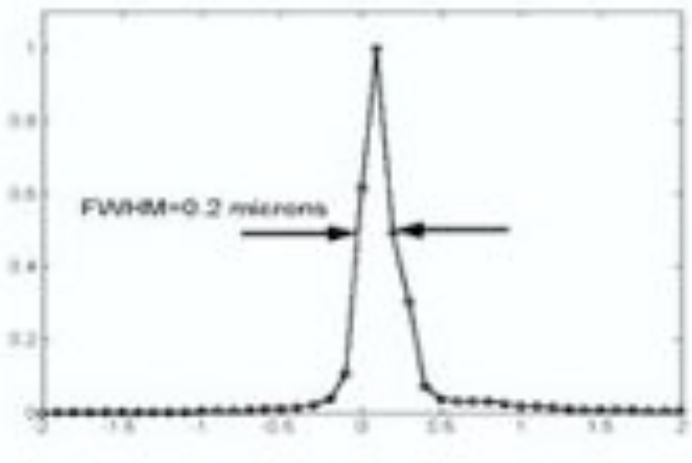
Open clamping system to let the beam pass trough

Picomotors for the bending driving system (2 for each mirror)
Two different moments are applied at the end of the flat polished substrate

Corrected by variable width



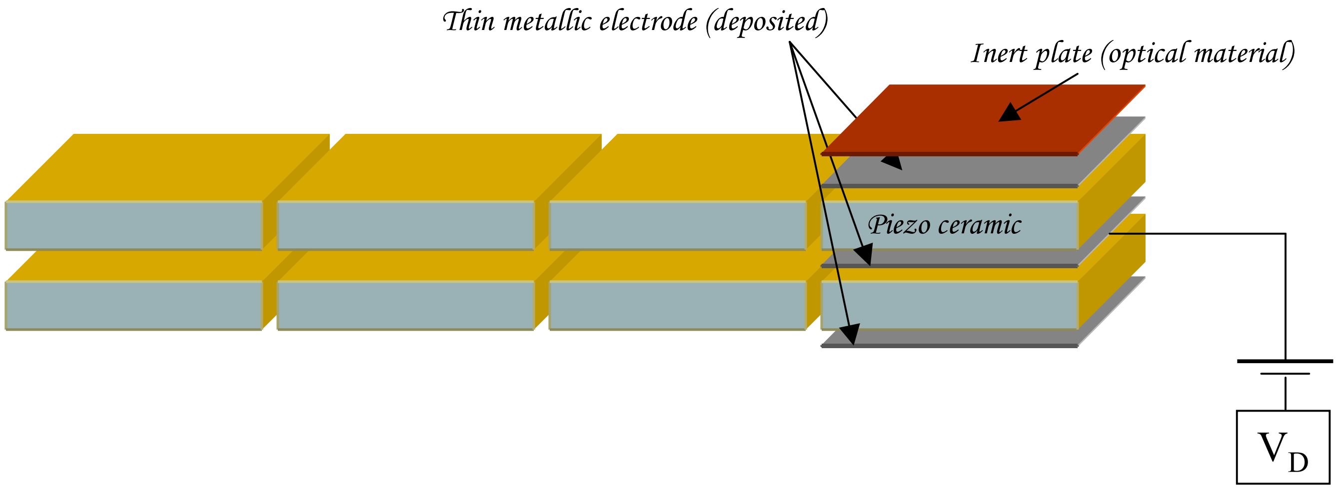
Vertical scan

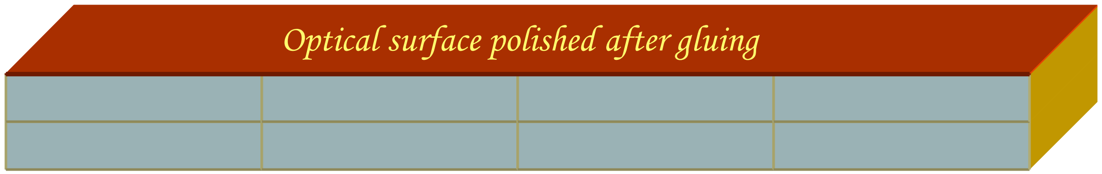


Horizontal scan

2001 **Beamline: ID 19**
Energy 19 KeV
Gain 3.5 10^5

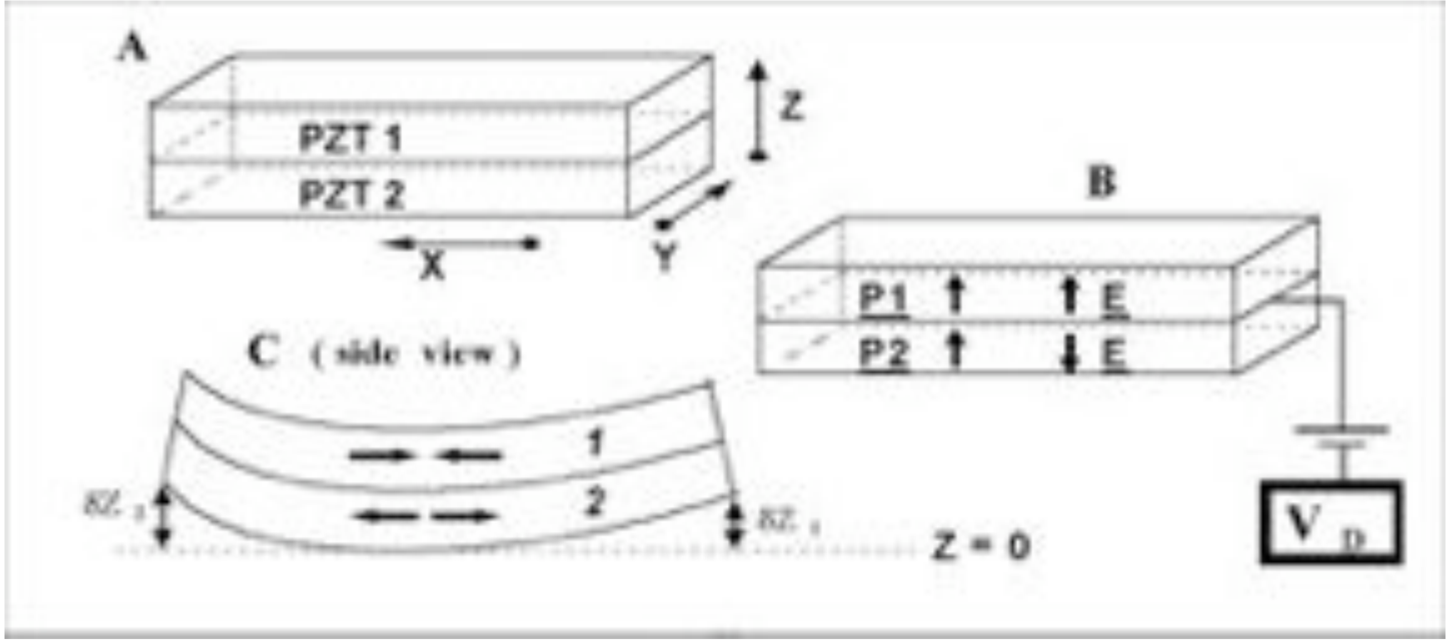
Bimorph mirror





Bimorph mirror

Dimension: from 150 mm (single element) to 1400 mm.

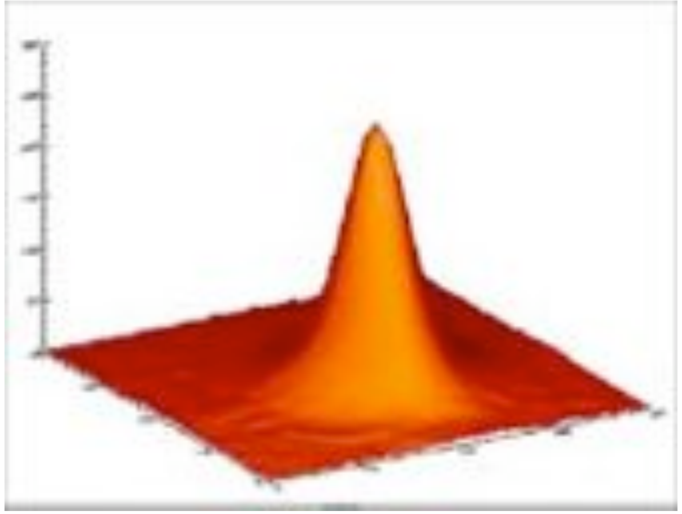


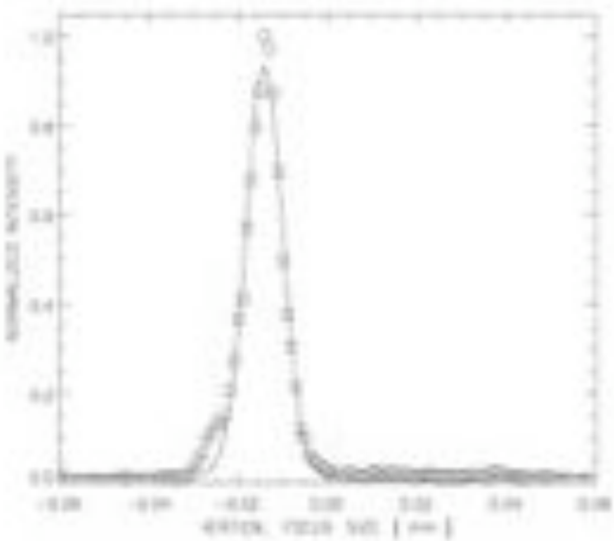
Radius variation: 370 m (+1500V) to 2300 m (-1500V)

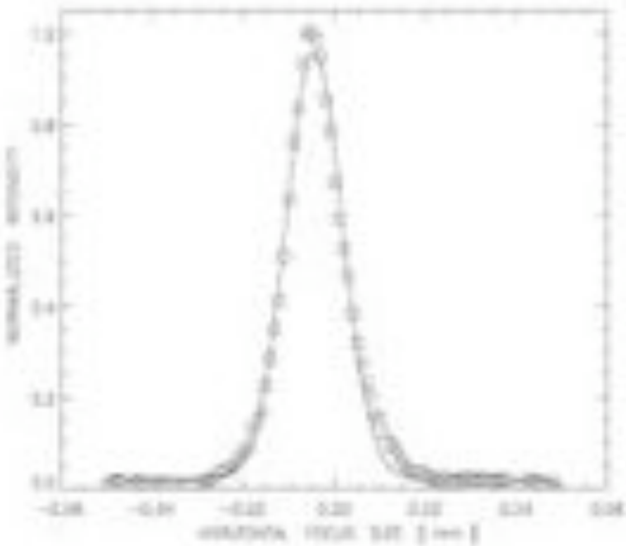
Stability: $\Delta R/R \cong 0.8\%$ on 1 day scale
$\Delta R/R \cong 2.0\%$ on 10 day scale

Bimorph mirror

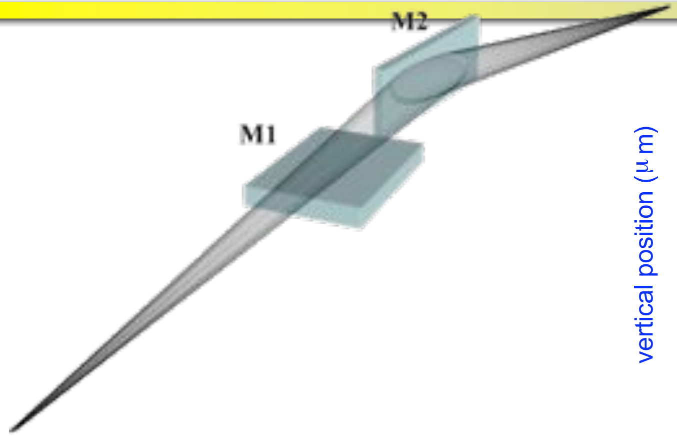
Photon Energy	33.167 KeV
Grazing angle	2 mrad
Coating	Pt
Source size	510 X 30 μm^2
Footprint	260 mm
VFM Demag	40
HFM Demag	62
Spot dimension	8.5 X 6.0 μm^2

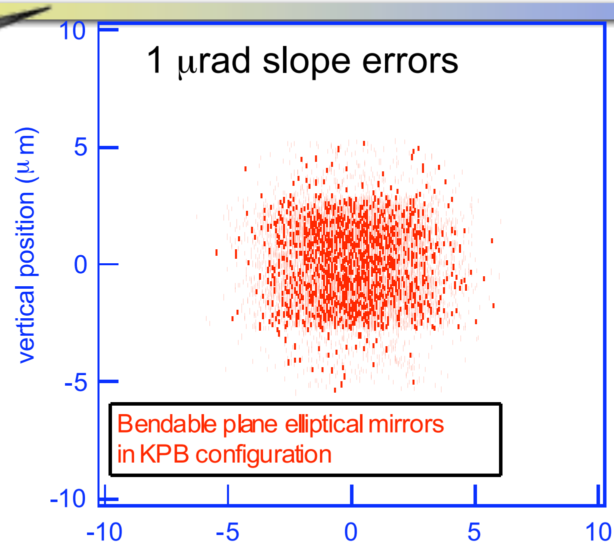




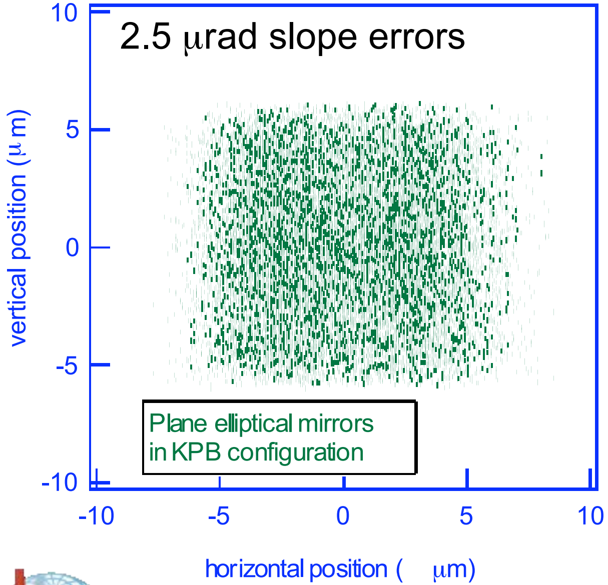


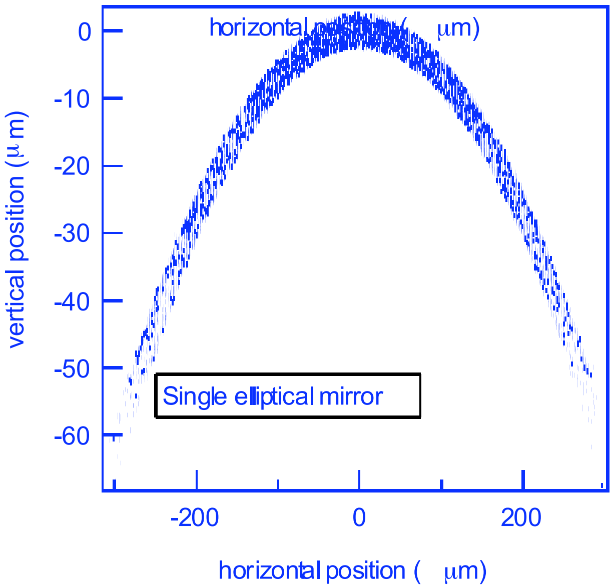
Small spot comparison

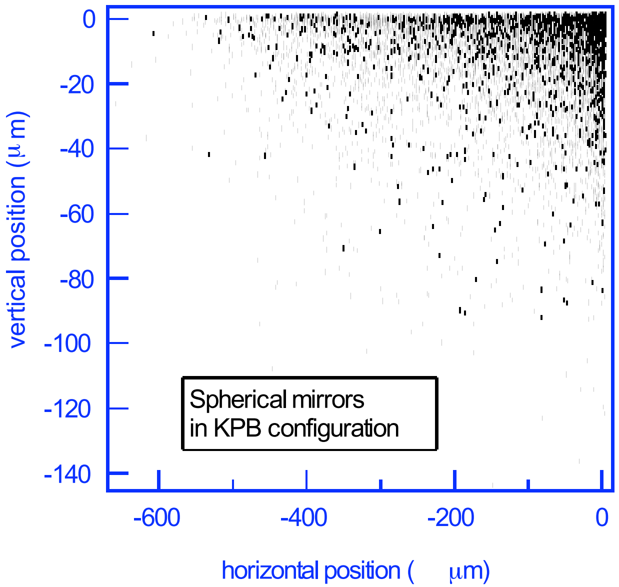




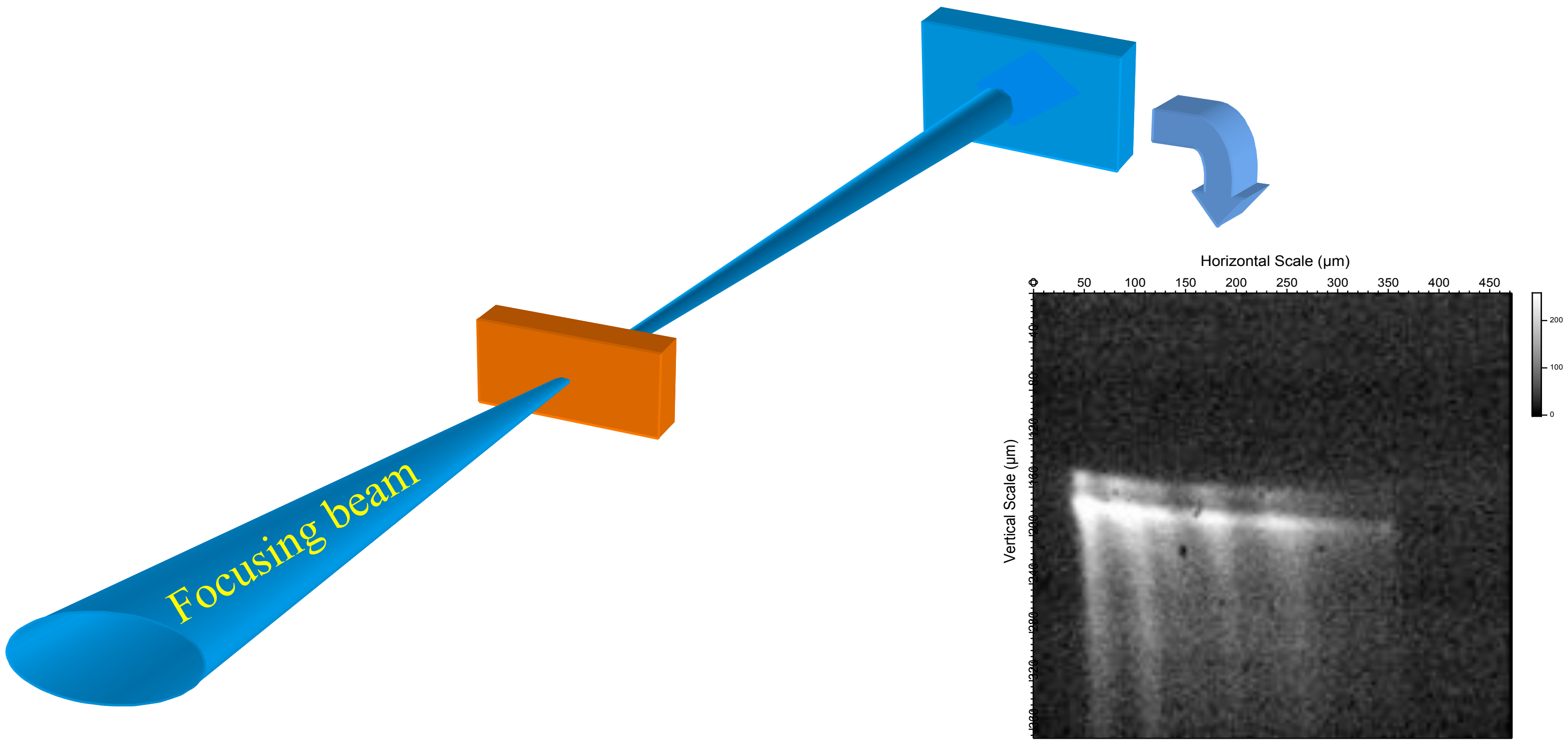
The only way to have a real micro-focus is to start from a flat or spherical surface and bent it to an mono dimensional ellipse



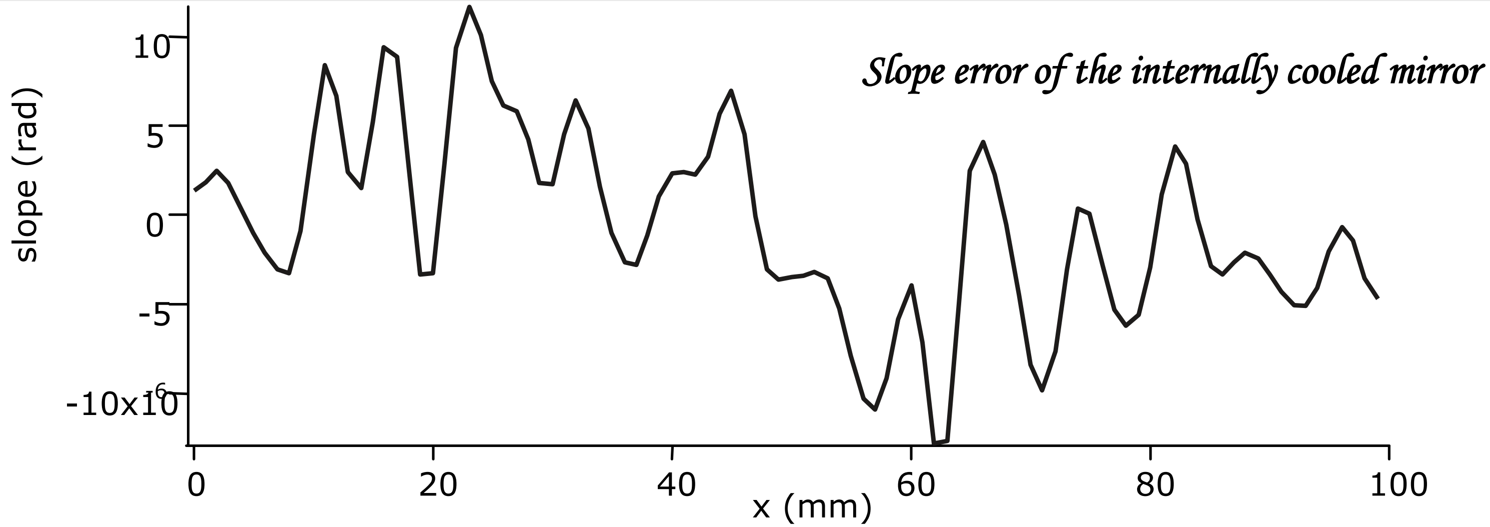


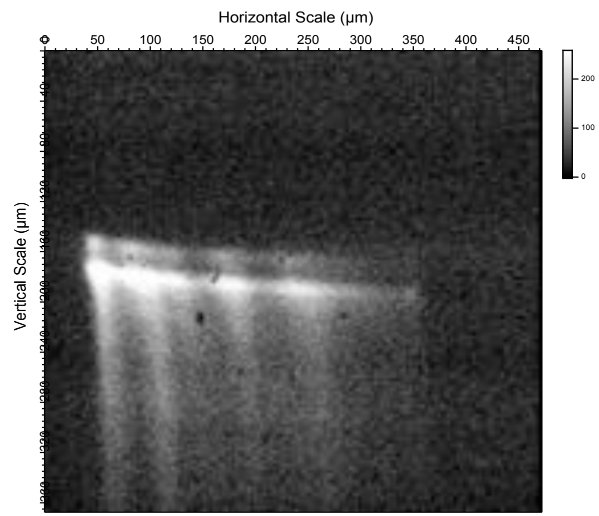


Out of focus spot

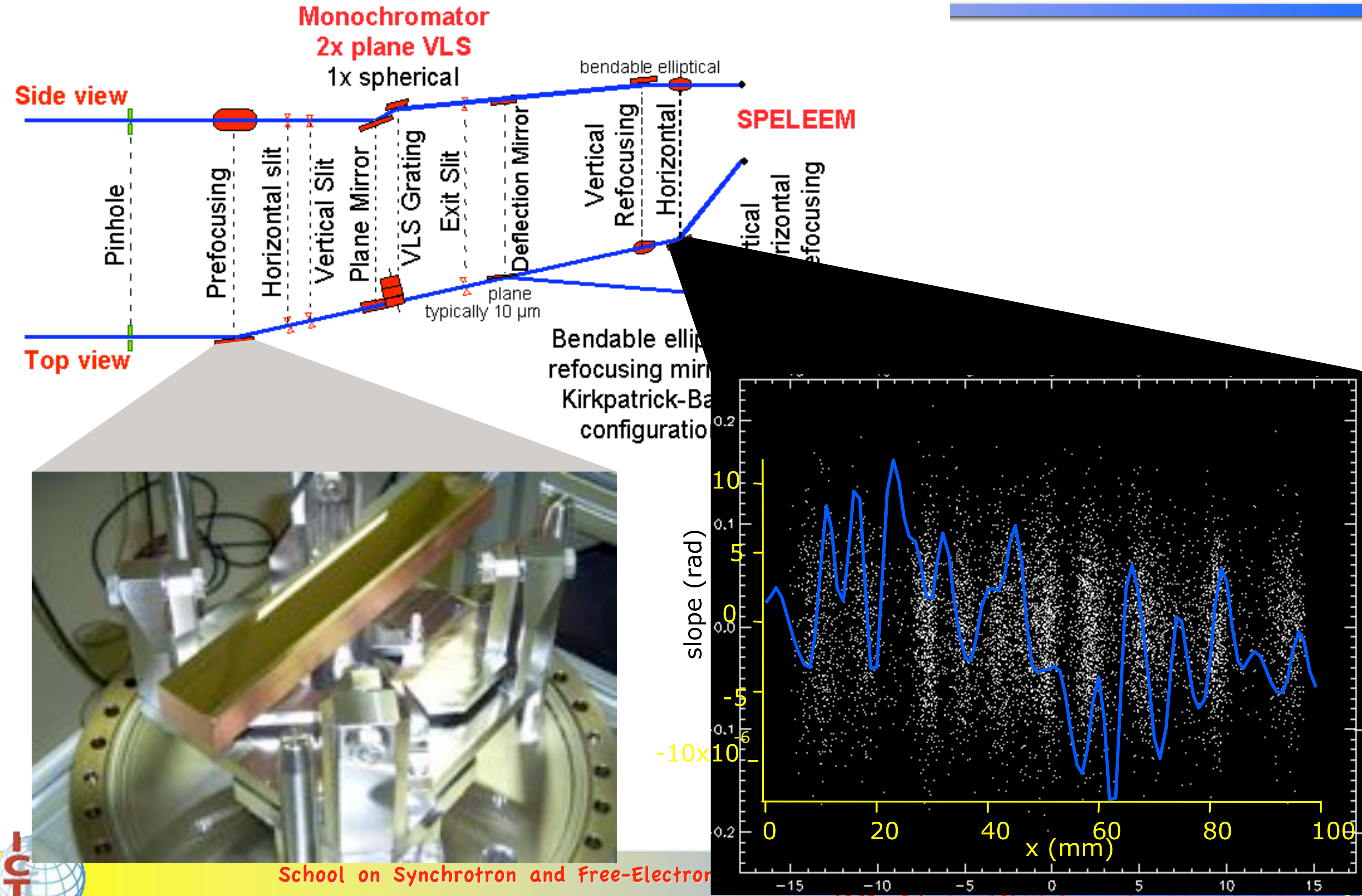


Out of focus spot

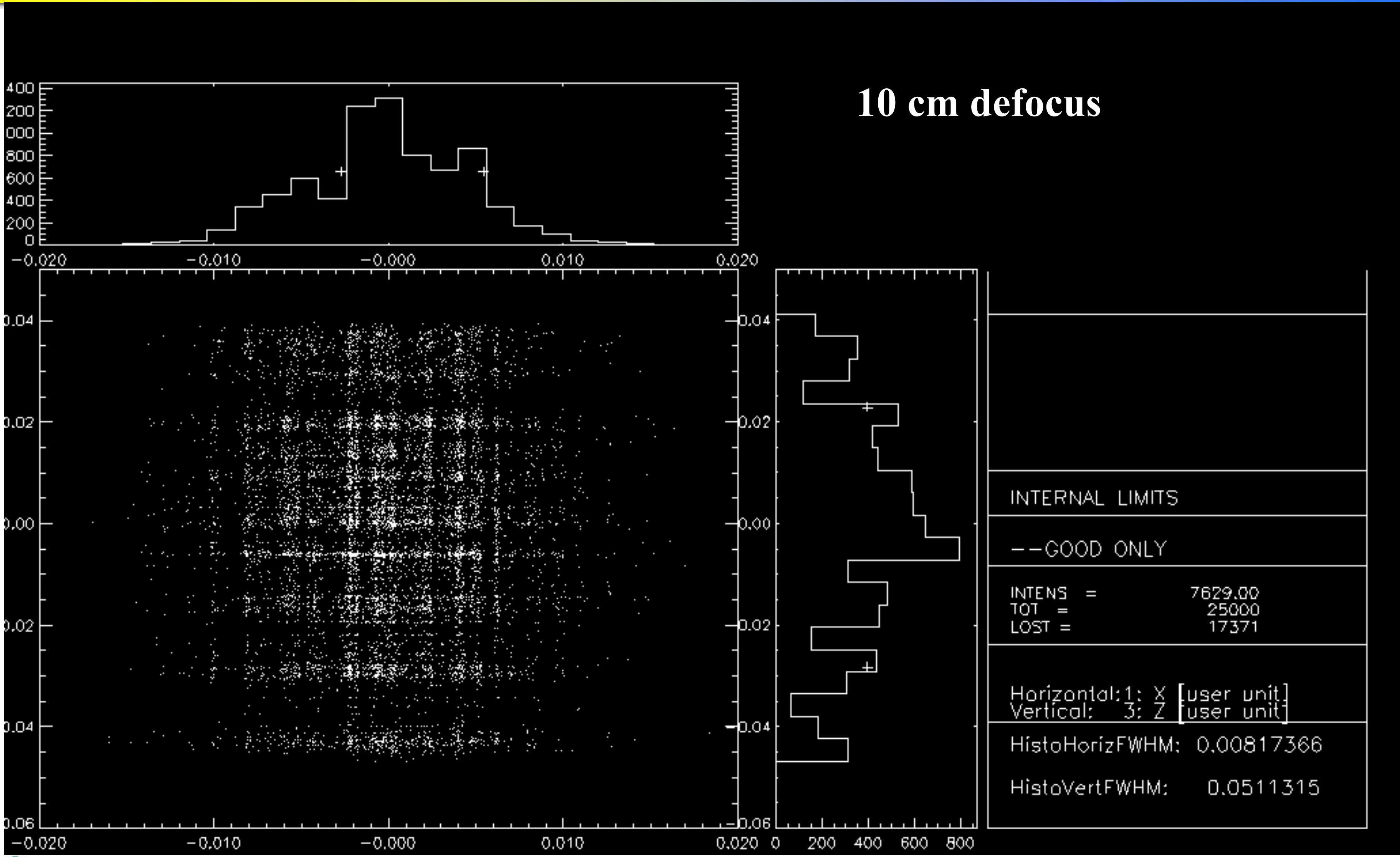




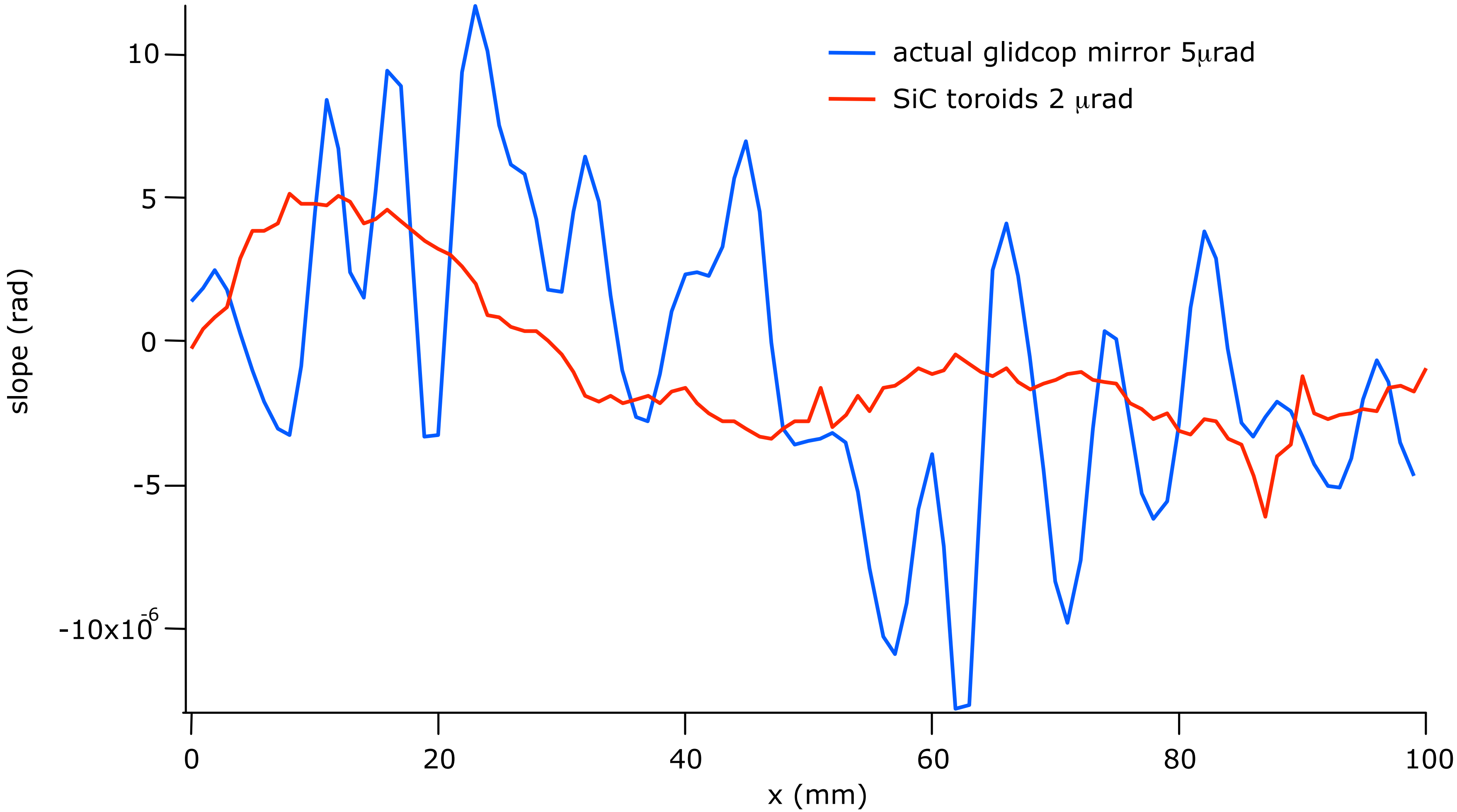
Out of focus spot



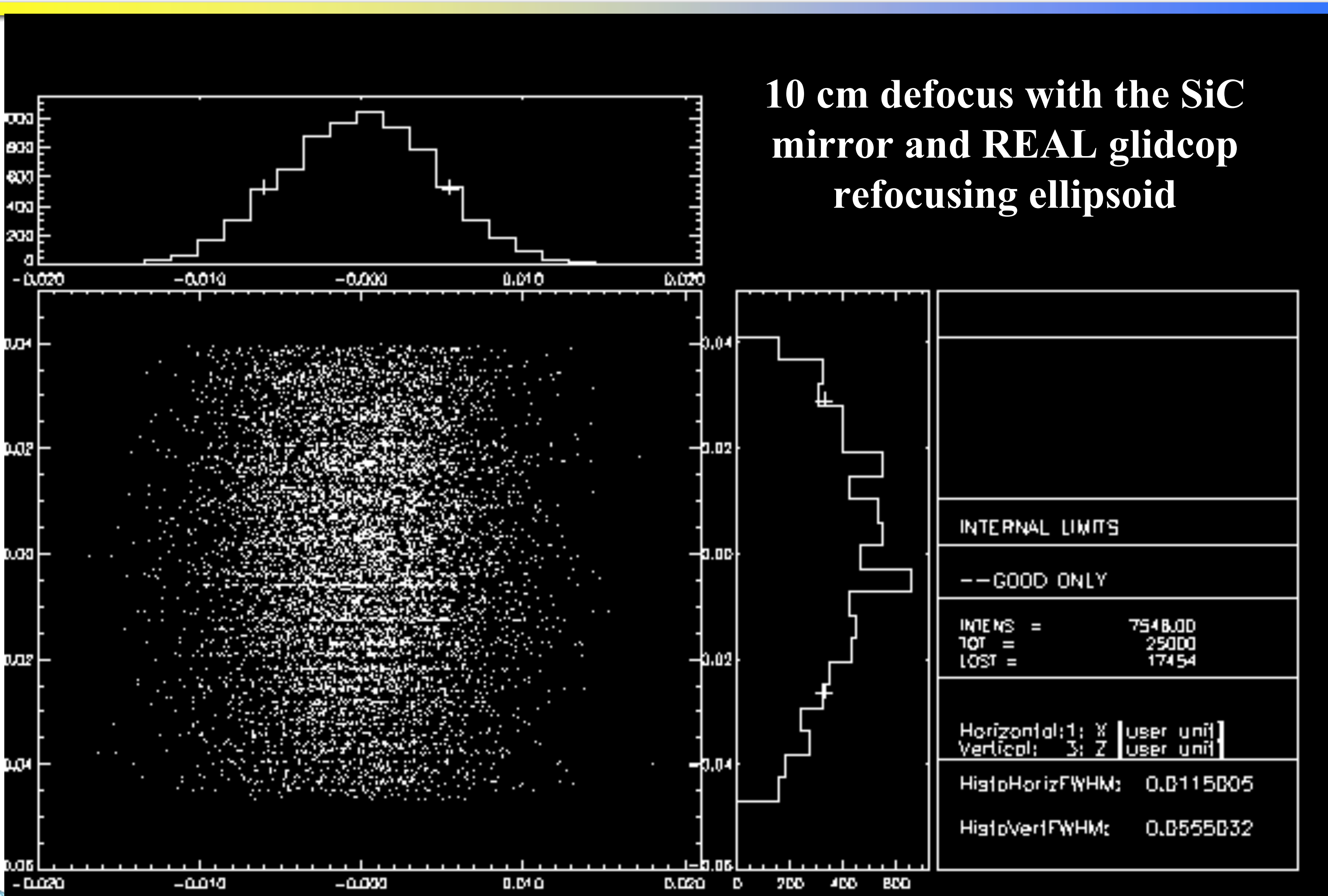
Out of focus spot



Different mirror material

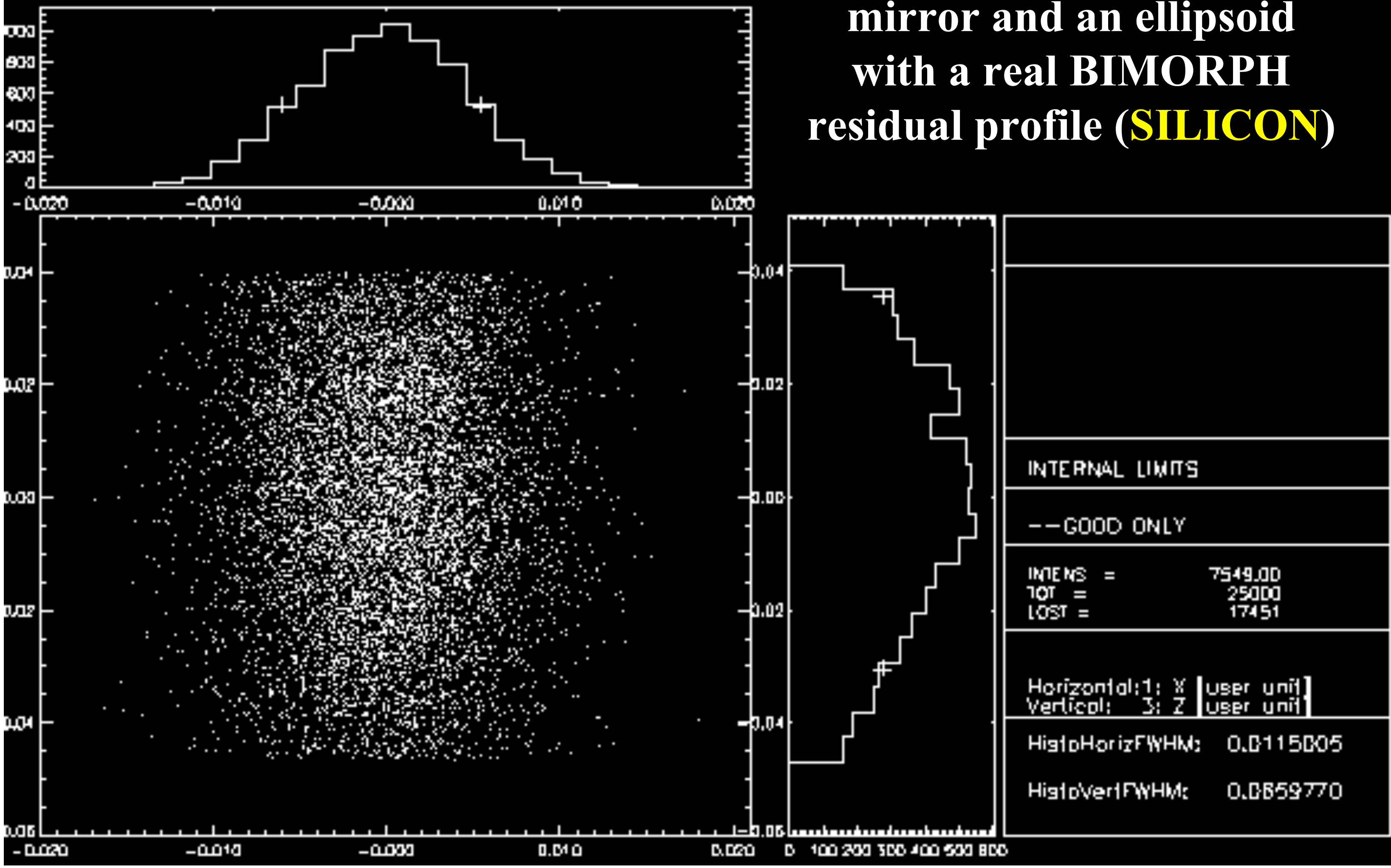


Out of focus with SiC

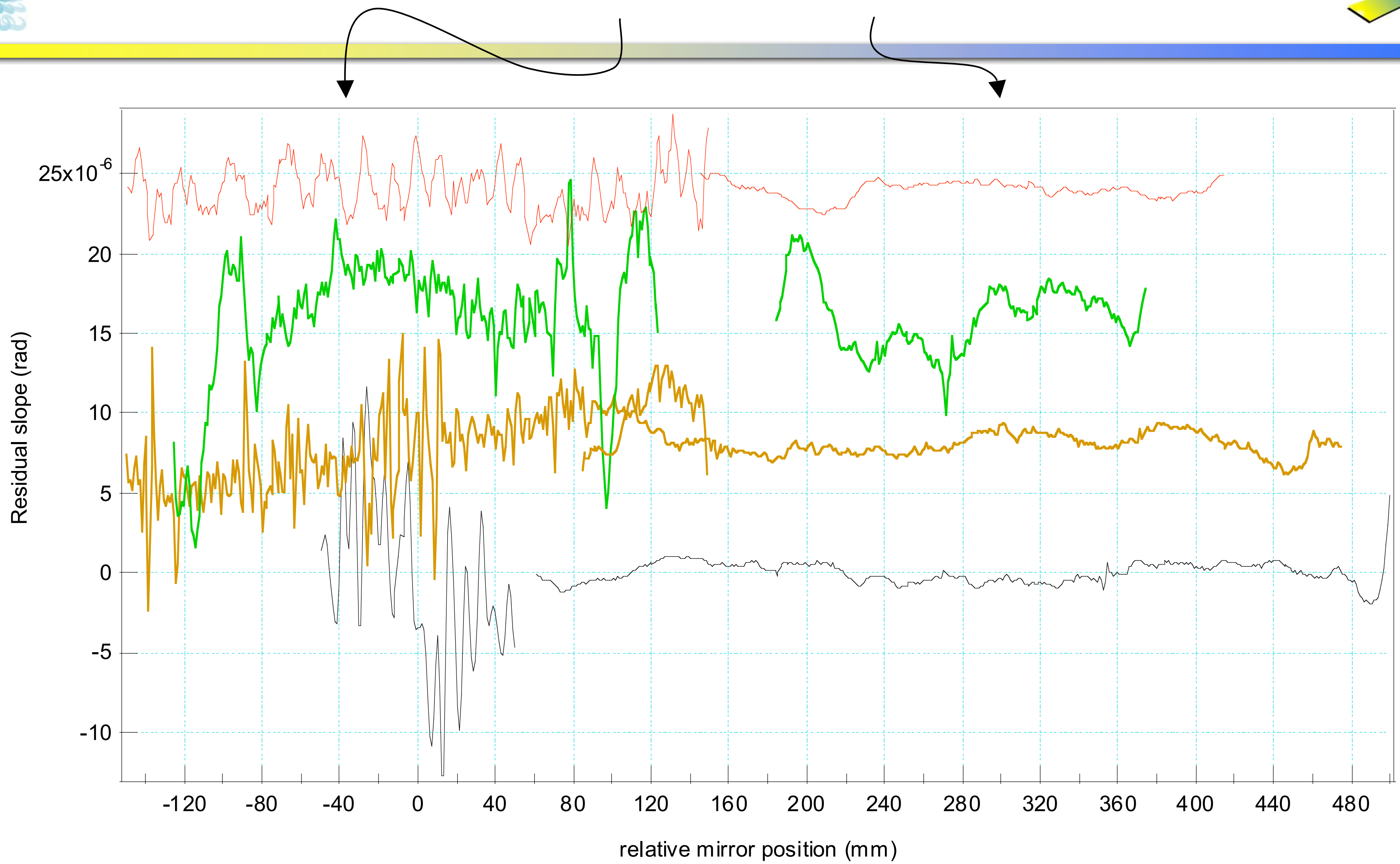


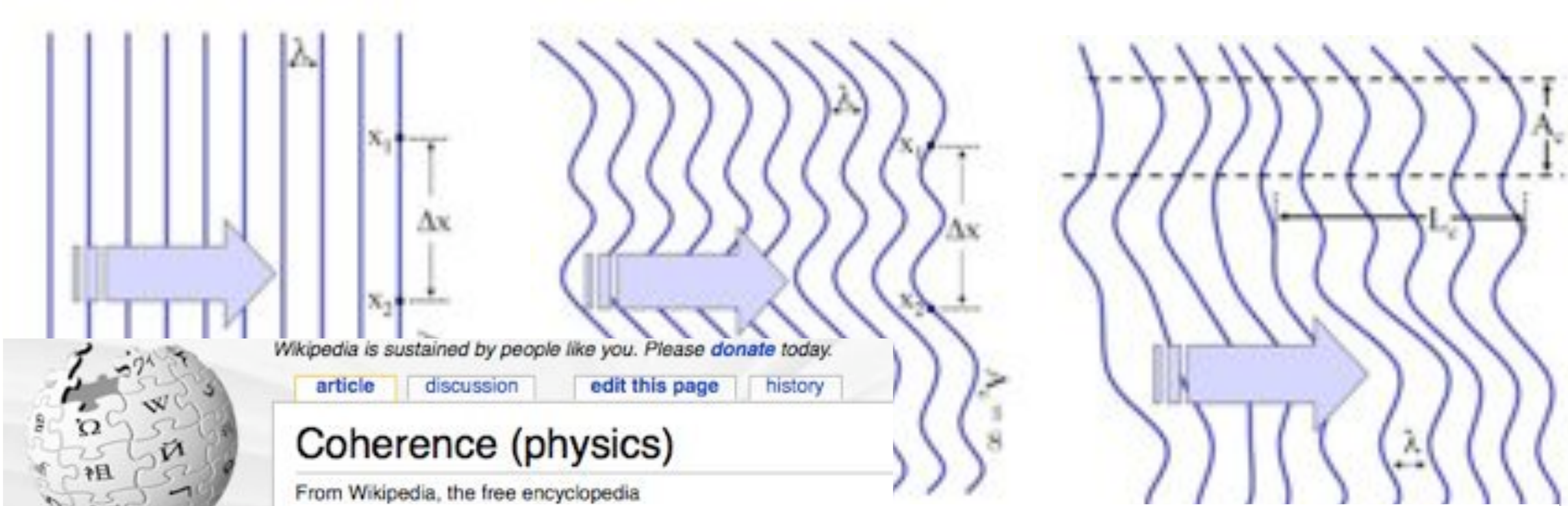
Out of focus with silicon mirrors

10 cm defocus with the SiC mirror and an ellipsoid with a real BIMORPH residual profile (SILICON)



Metallic vs Silicon





Wikipedia is sustained by people like you. Please donate today.

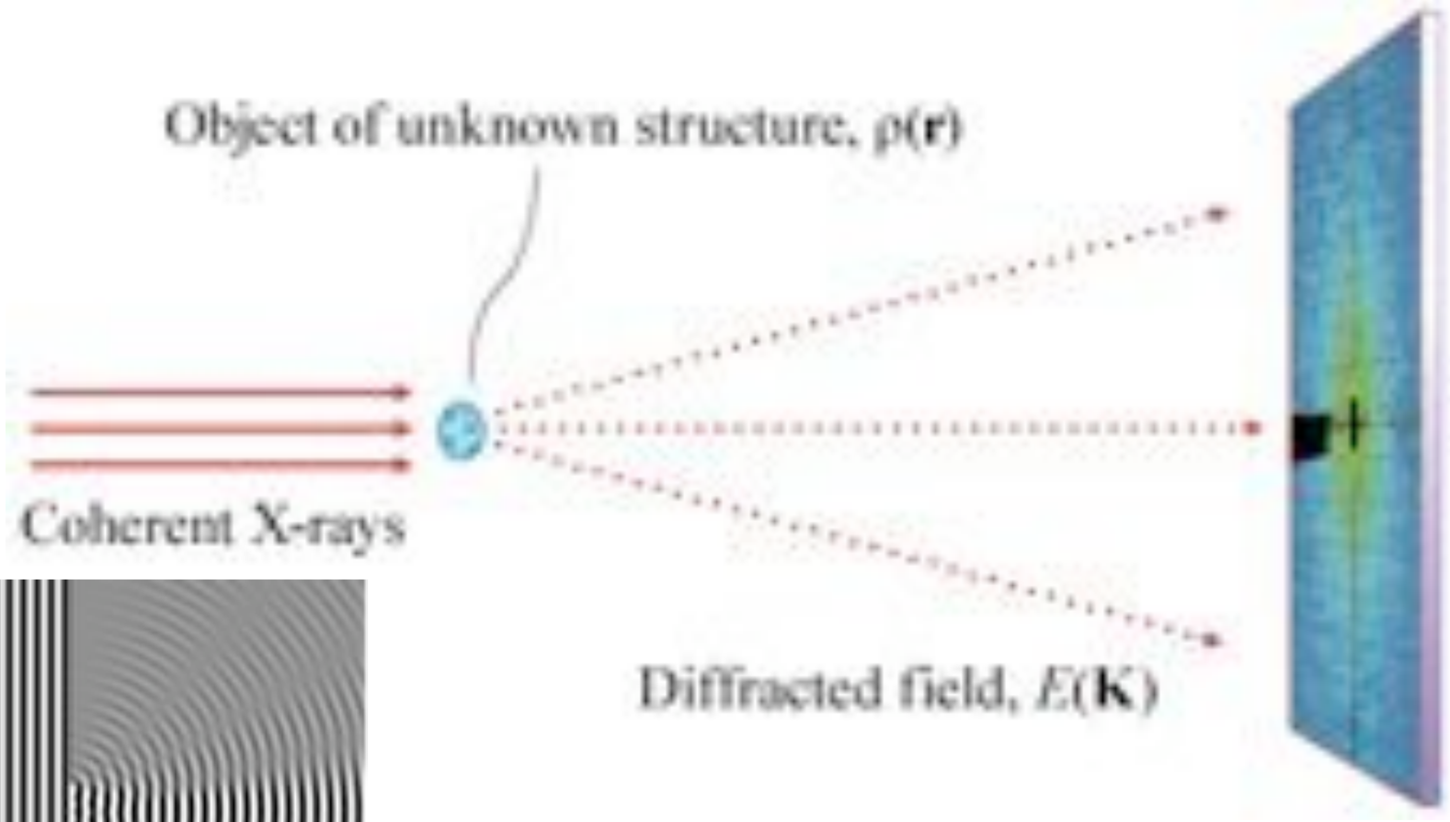
article | discussion | edit this page | history

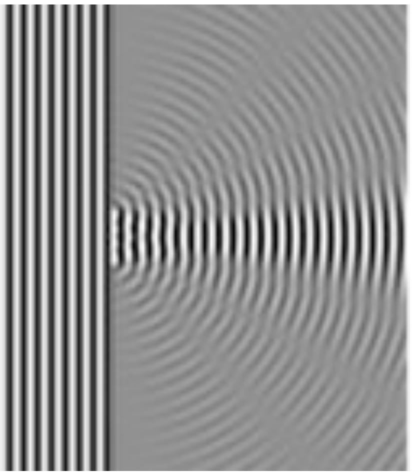
Coherence (physics)

From Wikipedia, the free encyclopedia

In physics, coherence is a property of waves, that enables stationary (i.e. temporally and spatially constant) interference. More generally, coherence describes all correlation properties between physical quantities of a wave.

Coherence

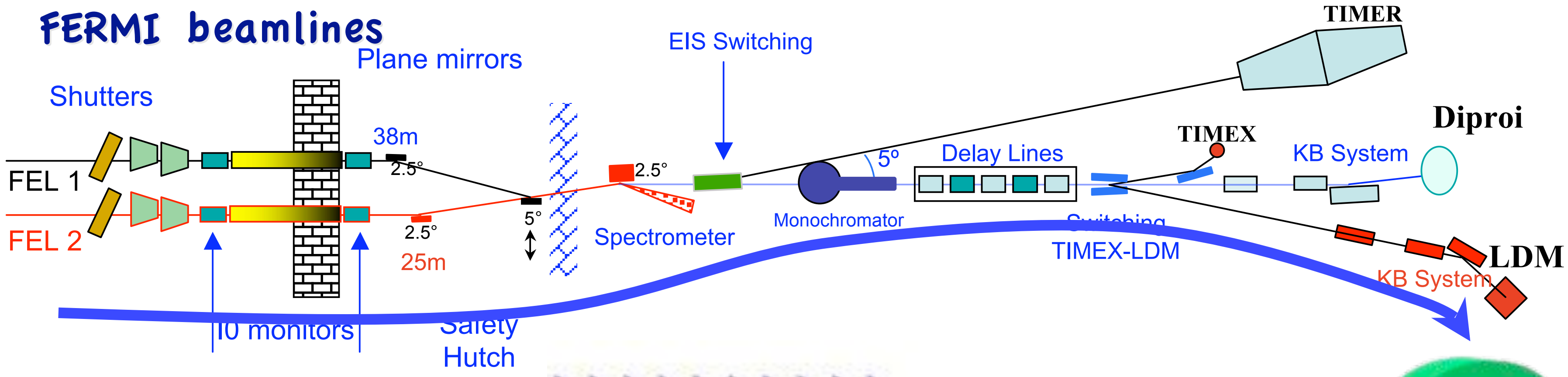


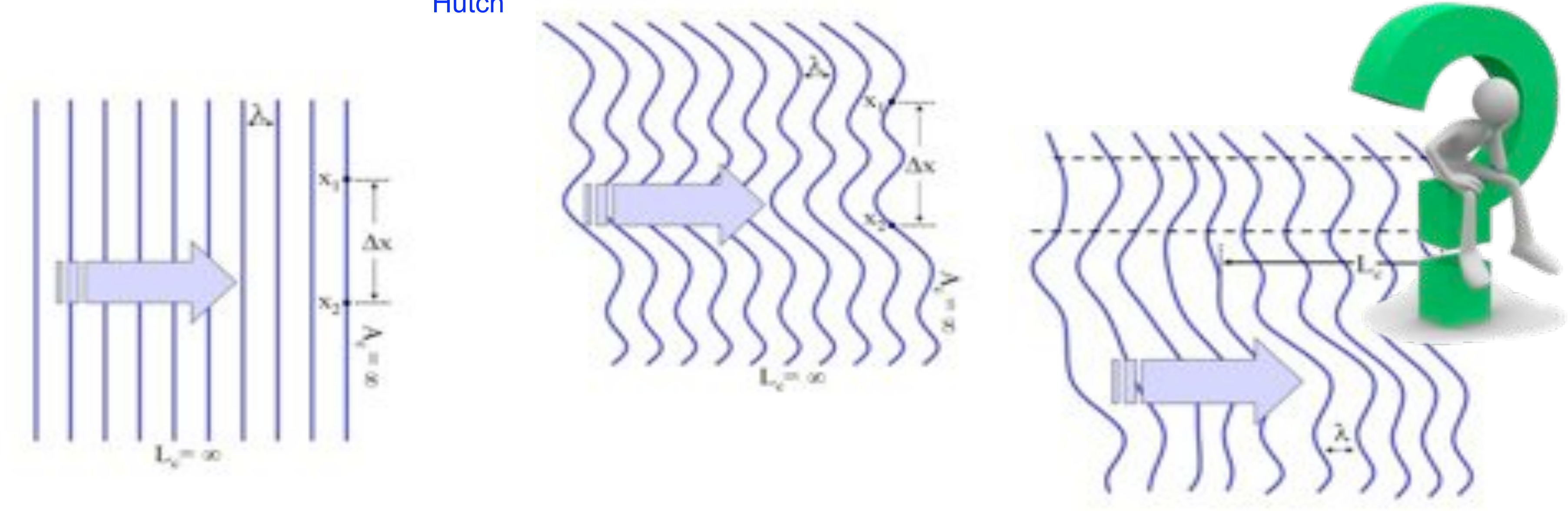


H. Chapman et al. Nature Physics 2, 839 - 843 (2006)

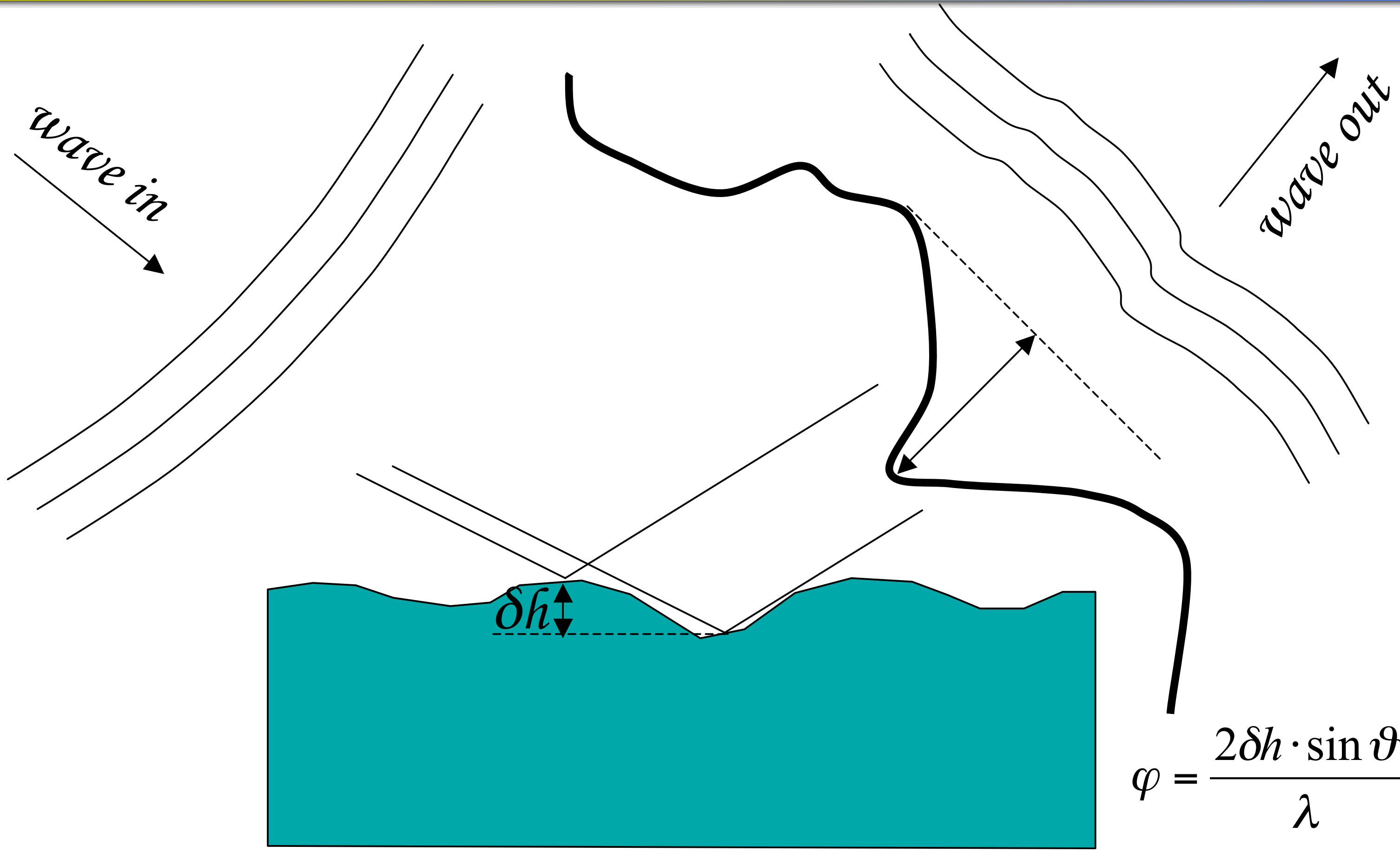
Cherence/wave front preservation

FERMI beamlines





Coherence (wavefront) preservation



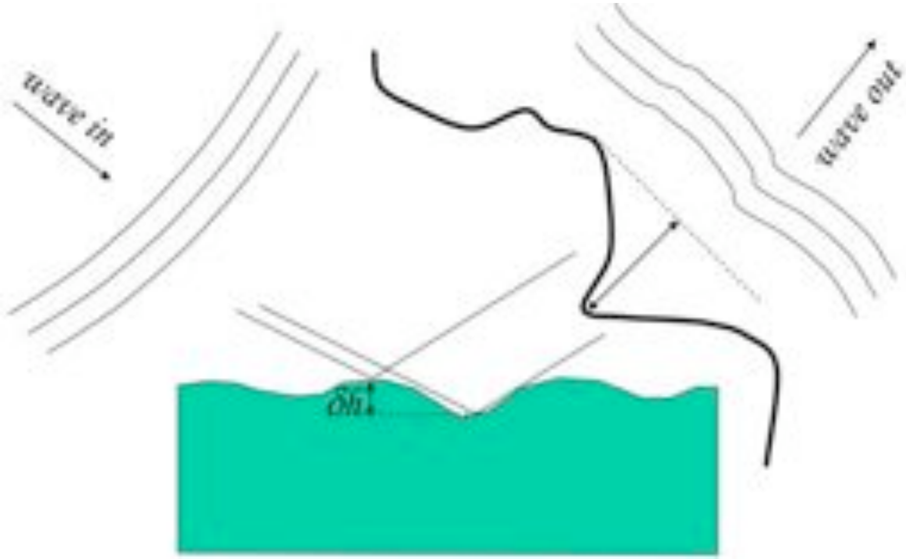
$$\varphi = \frac{2\delta h \cdot \sin\vartheta}{\lambda}$$

λ/4 deformation (after <u>all</u> mirrors) needed
λ/10 deformation (at <u>each</u> mirrors) acceted

Coherence (wavefront) preservation

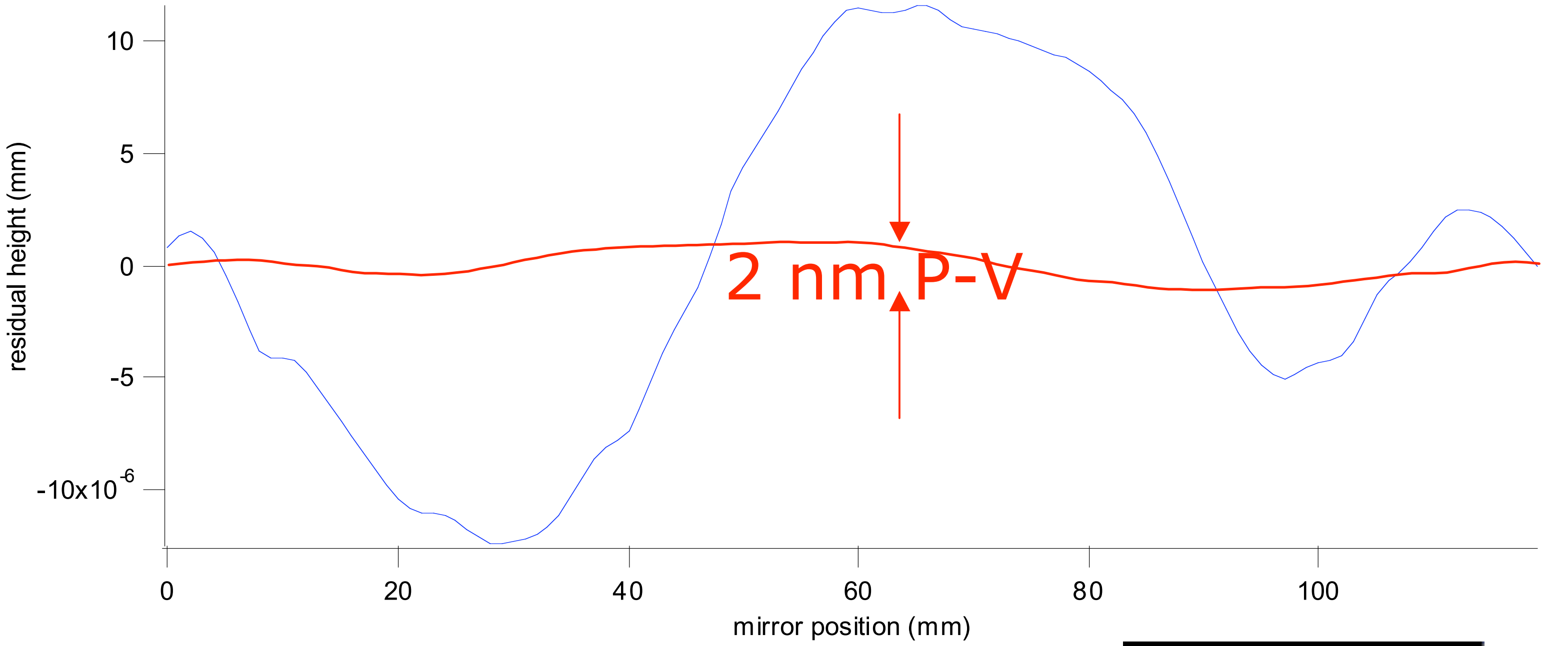
Fermi@elettra case			
Wavelength	Angle of incidence	shape error p-v φ =**0.25**	shape error p-v φ =**0.1**
40 nm	6°	47	18
40 nm	3°	95	38
40 nm	1.5°	191	76
10 nm	3°	23	9
10 nm	2°	35	14
10 nm	1°	71	28
5 nm	3°	12	5
5 nm	2°	18	7.2
5 nm	1°	36	14
1.67 nm	3°	4	2

Xfel(s) case			
Wavelength	Angle of incidence	shape error p-v φ =**0.25**	shape error p-v φ =**0.1**
1 nm	1°	7	3
0.5 nm	1°	3.6	1.4
0.1 nm	0.33°	2	<1



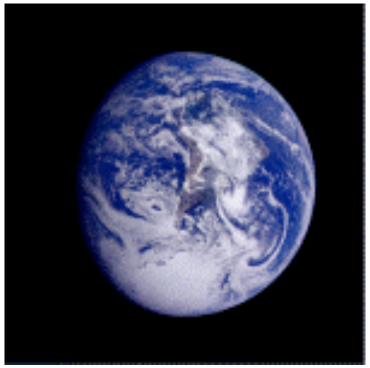
$$\varphi = \frac{2\delta h \cdot \sin\vartheta}{\lambda}$$

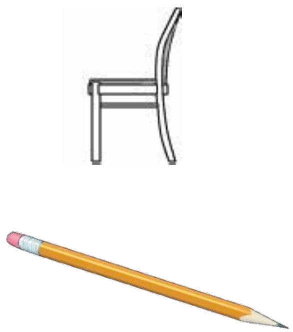
Mirror shape error



Typical SR mirrors

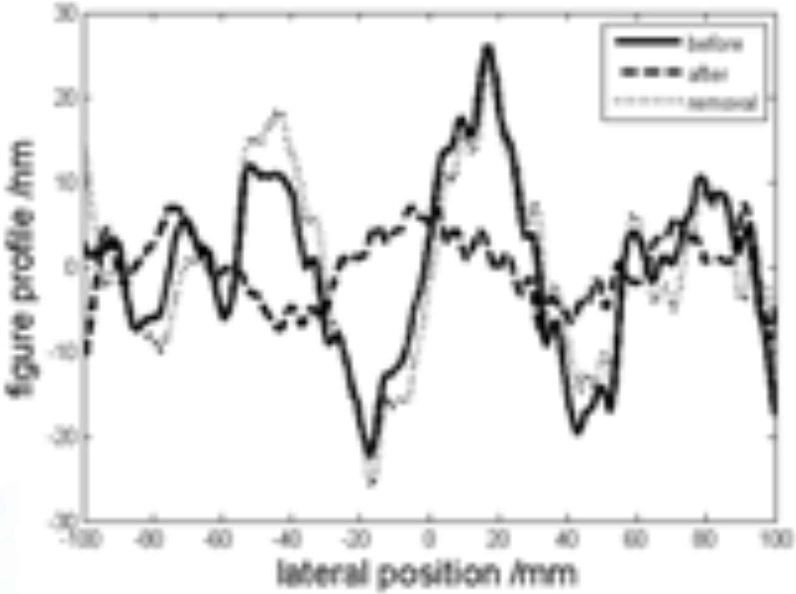
Required FEL mirrors



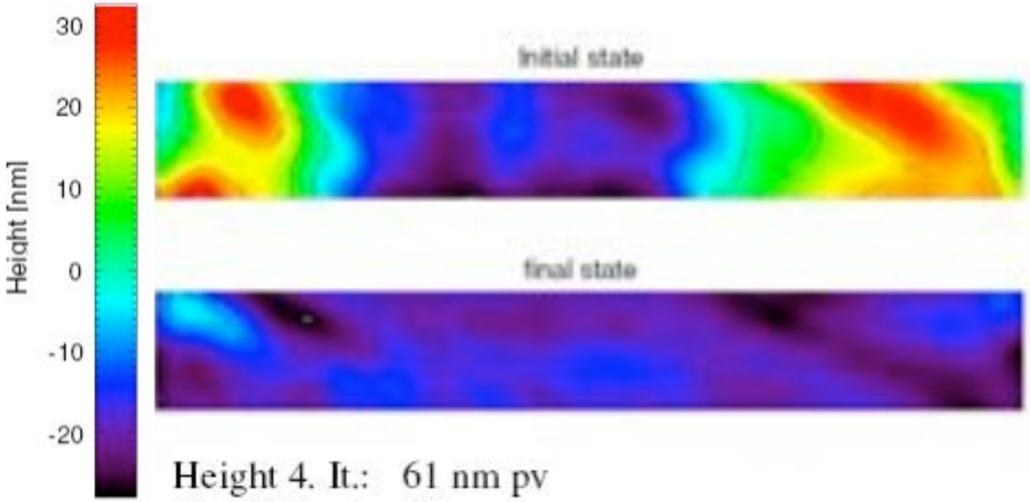


"Classical" polishing with "good" metrology (H. Thiess-Zeiss, F. Siewert-HZB)

1) Classical polishing (Computer Controlled Polishing-CCP)
2) High precision metrology (NOM-Bessy)
3) Ion Beam Figuring or CCP
4) Second itaration with metrology
5) Second IBF or CCP
6) Third.....
7) ......
8) ....

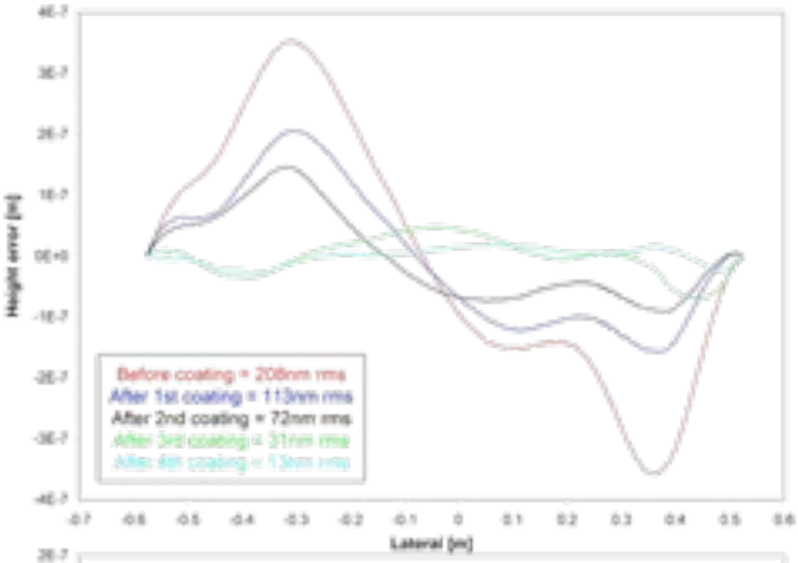


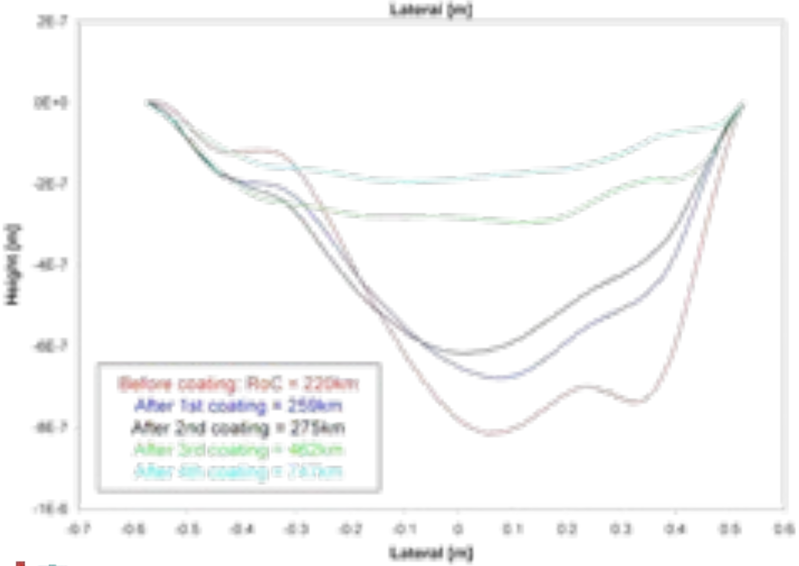
	PV /nm	RMS /nm	slope RMS /arcsec
before	48.4	10.3	0.37
after	14.9	3.9	0.22
after -0.5mm	13.9	3.6	0.17
after +0.5 mm	18.5	4.4	0.31

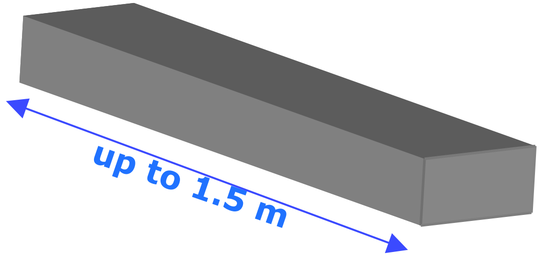


Height 4. It.: 61 nm pv
Height final.: 22 nm pv

Preferential coating technique
(S. Alcock-Diamond, S. Cockerton-Crystal Scientific)





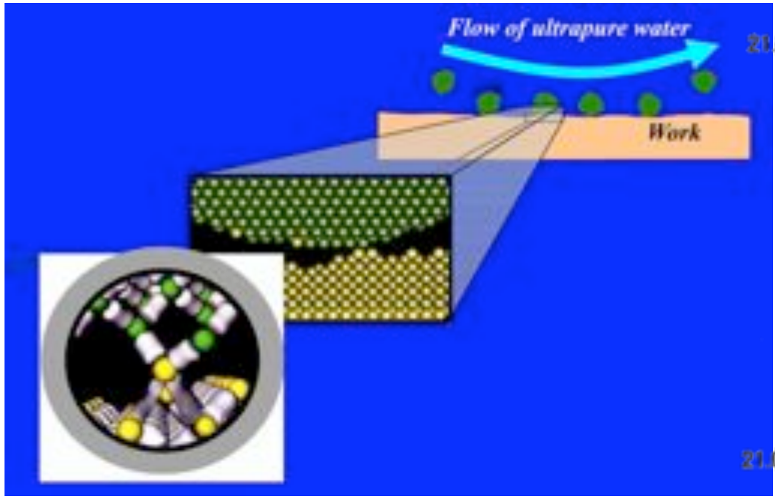


1) **Classical polishing**
2) **High precision metrology**
3) **Error correction by Rh controlled deposition**
4) **Second itaration with metrology**
5) **Second differential coating deposition**
6) **Third.....**
7) **......**
8) **.......**
9)

nn) Final required slope/shape error reched (hopefully)

Elastic Emission Machining
(Jtec, K. Yamauchi-Osaka Univ.)

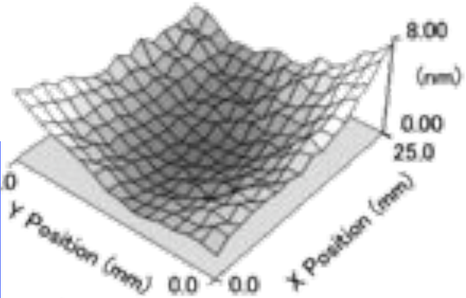
JTEC CORPORATION



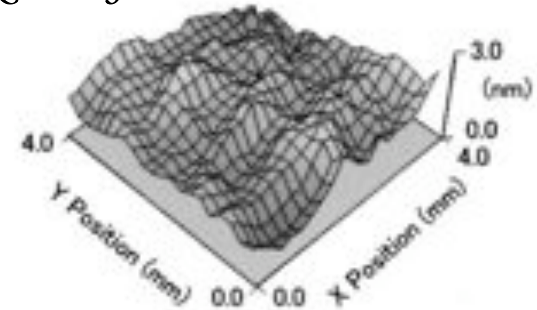
Chemical reaction are induced between top-site atoms of mirror and fine powders

Problem: max dimension 100mm (400 with lower precision)

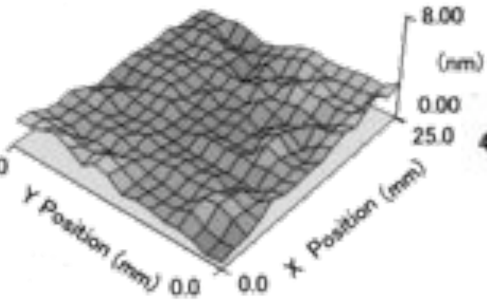
*mirror substrate :*Quarz Glass Silicon



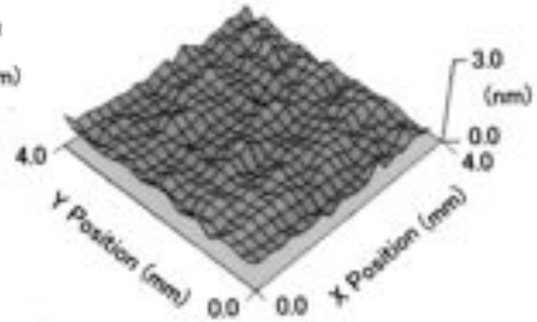
Before machining
1.3 nm rms



Before machining
0.32 nm rms



after machining
0.3 nm rms



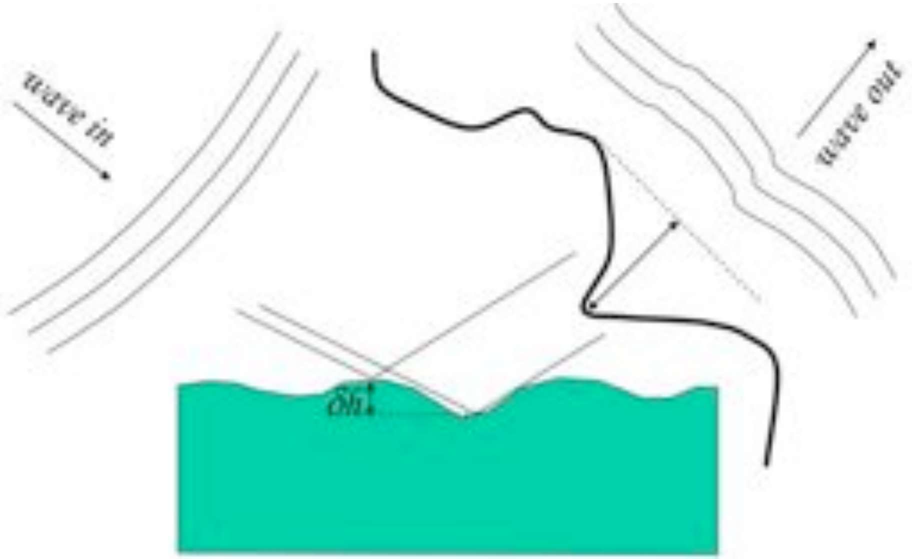
after machining
0.14 nm rms

Powder used: 0.1μm size SiO2 2μm size SiO2

Optical quality: resume

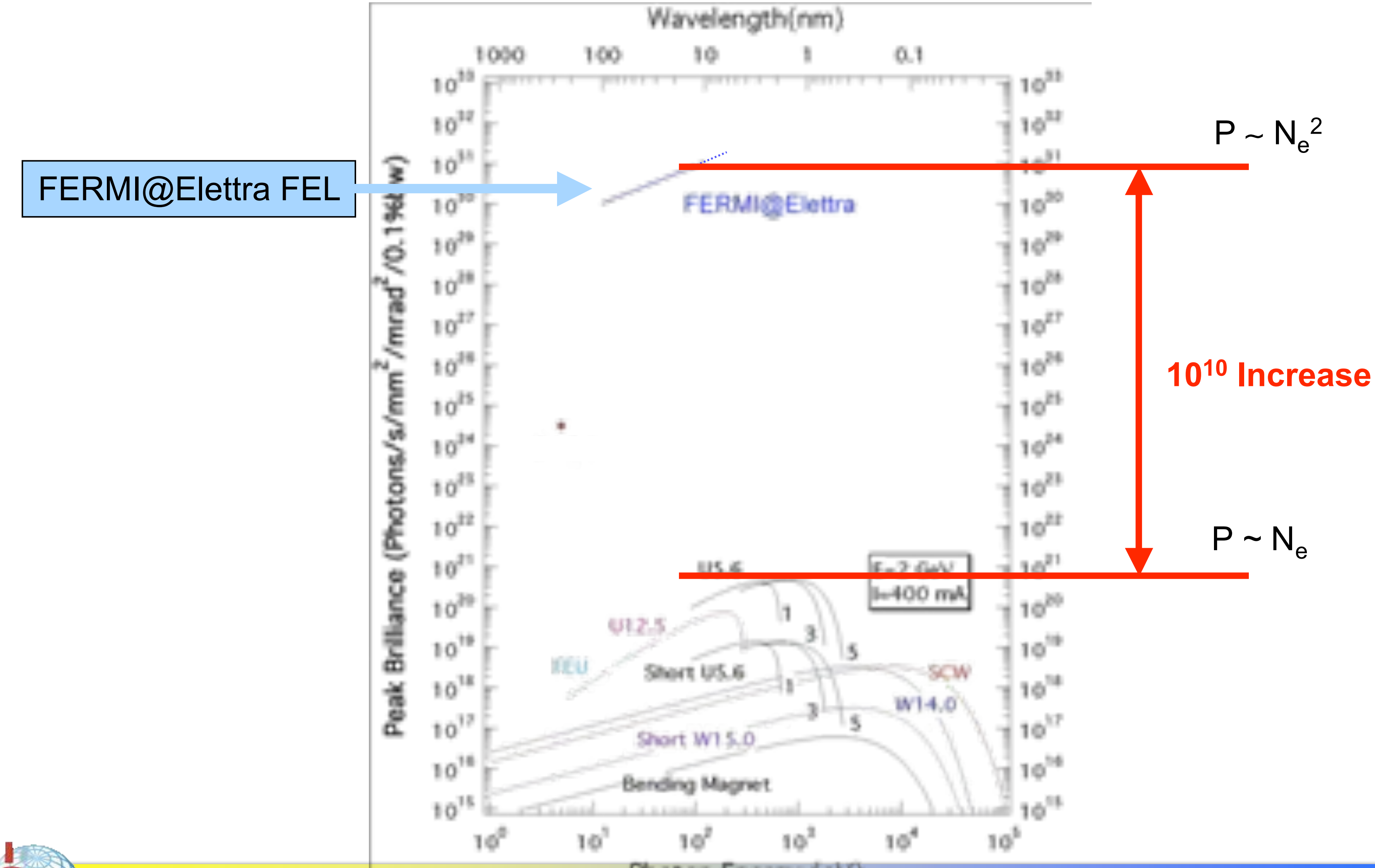
Fermi@elettra case			
Wavelength	Angle of incidence	shape error p-v φ =0.25	shape error p-v φ =0.1
40 nm	6°	47	18
40 nm	3°	95	38
40 nm	1.5°	191	76
10 nm	3°	23	9
10 nm	2°	35	14
10 nm	1°	71	28
5 nm	3°	12	5
5 nm	2°	18	7.2
5 nm	1°	36	14
1.67 nm	3°	4	2

Xfel(s) case			
Wavelength	Angle of incidence	shape error p-v φ =0.25	shape error p-v φ =0.1
1 nm	1°	7	3
0.5 nm	1°	3.6	1.4
0.1 nm	0.33°	2	<1



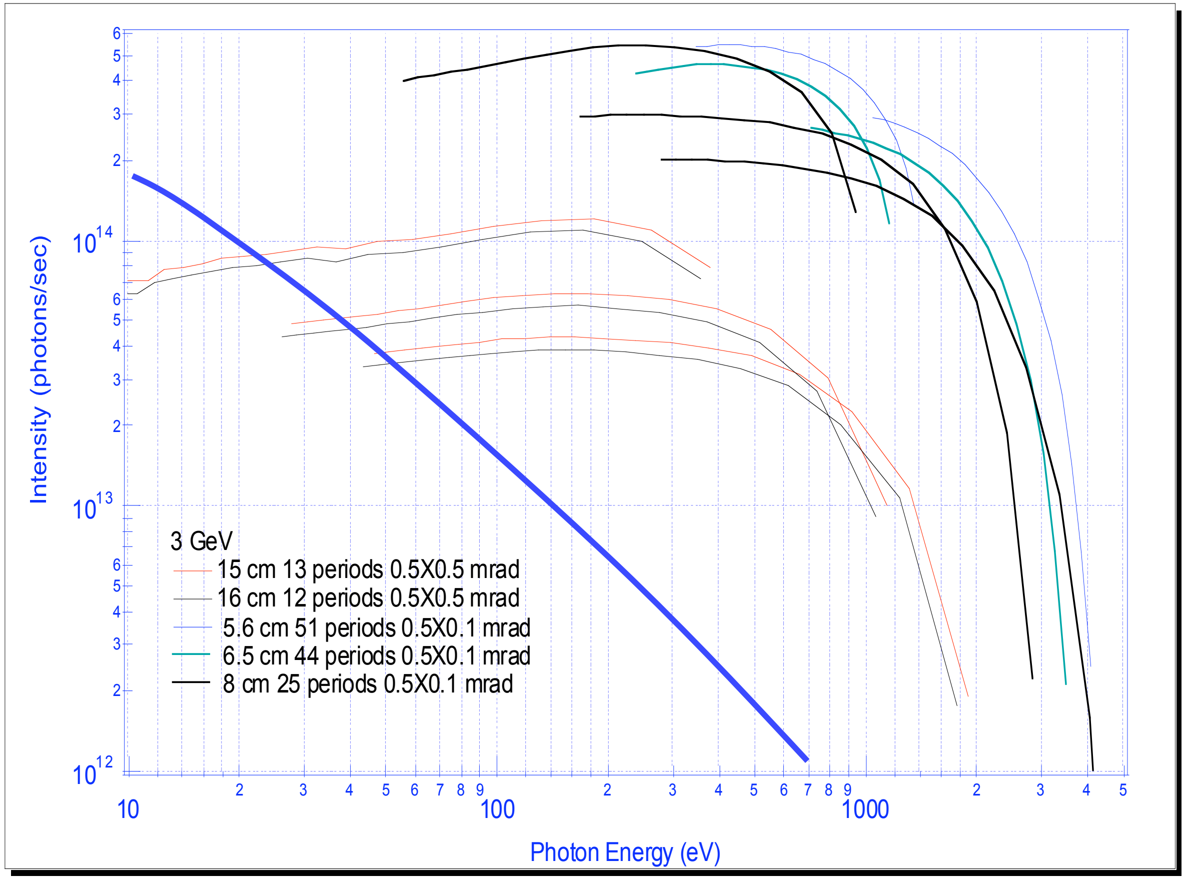
Manufacturer are not ready for the challenging short wavelength request, or, we must relax ur expectation for a while!

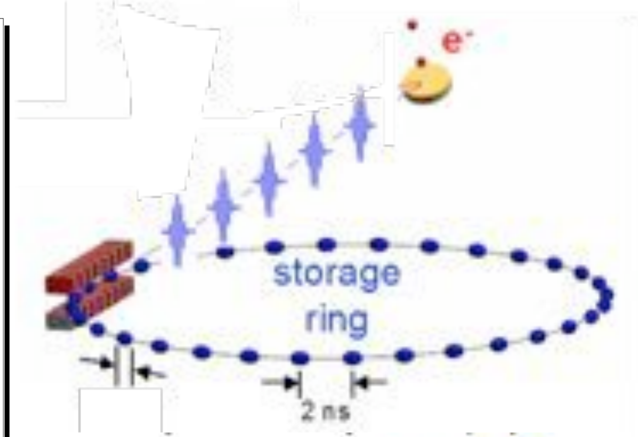
Brilliance

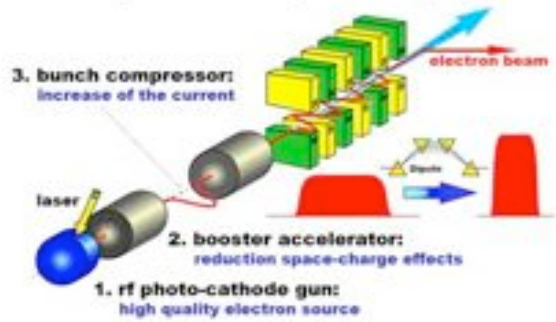


FERMI@Elettra FEL
Wavelength(nm)
1000
100
10
1
0.1
FERMI@Elettra
Peak Brilliance (Photons/s/mm²/mrad²/0.1%bw)
Photon Energy (eV)
U12.5
Short U5.6
Short W15.0
SCW
W14.0
Bending Magnet
I=400 mA
P ~ Ne²
10¹⁰ Increase
P ~ Ne

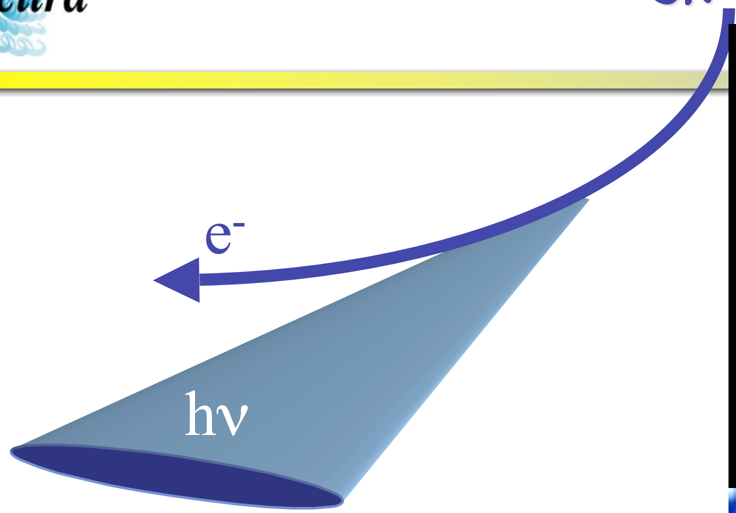
Difference with SR sources

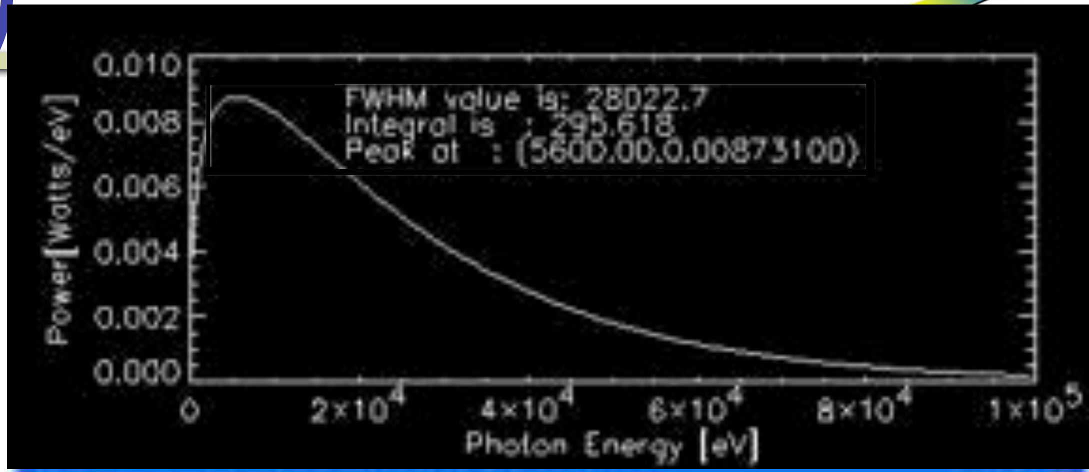


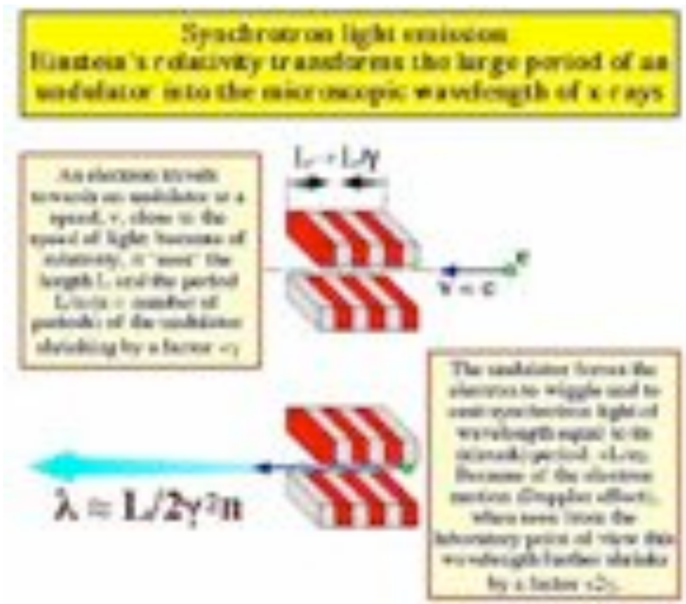


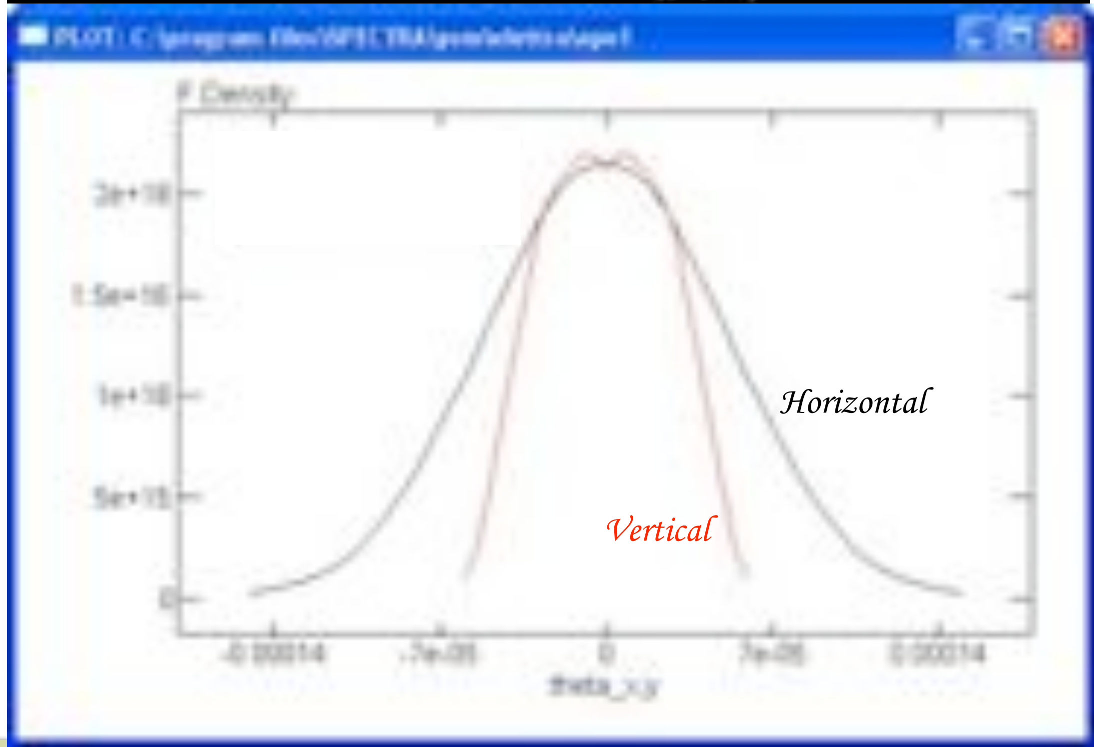


SR characteristics

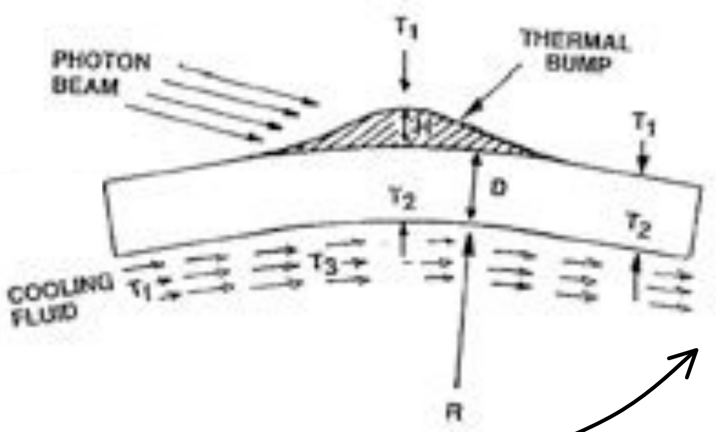


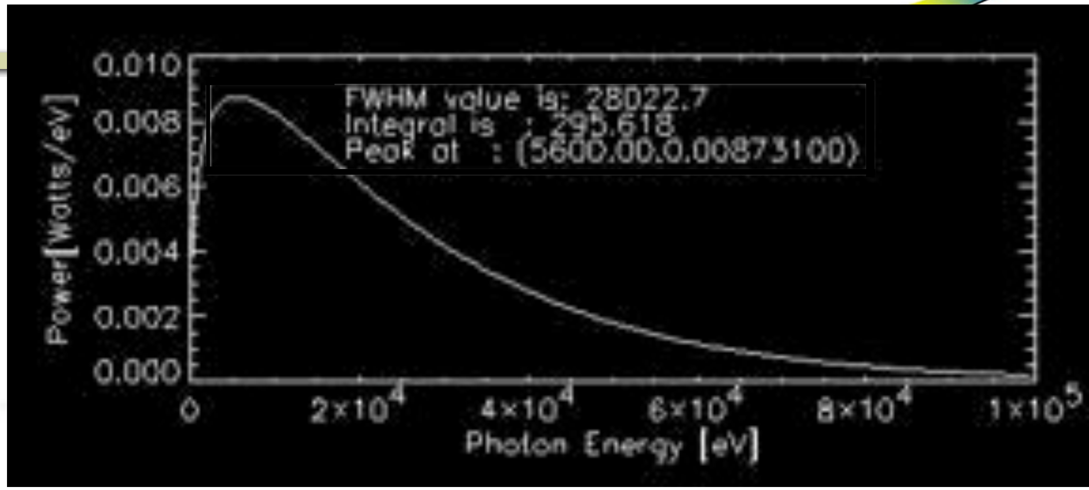






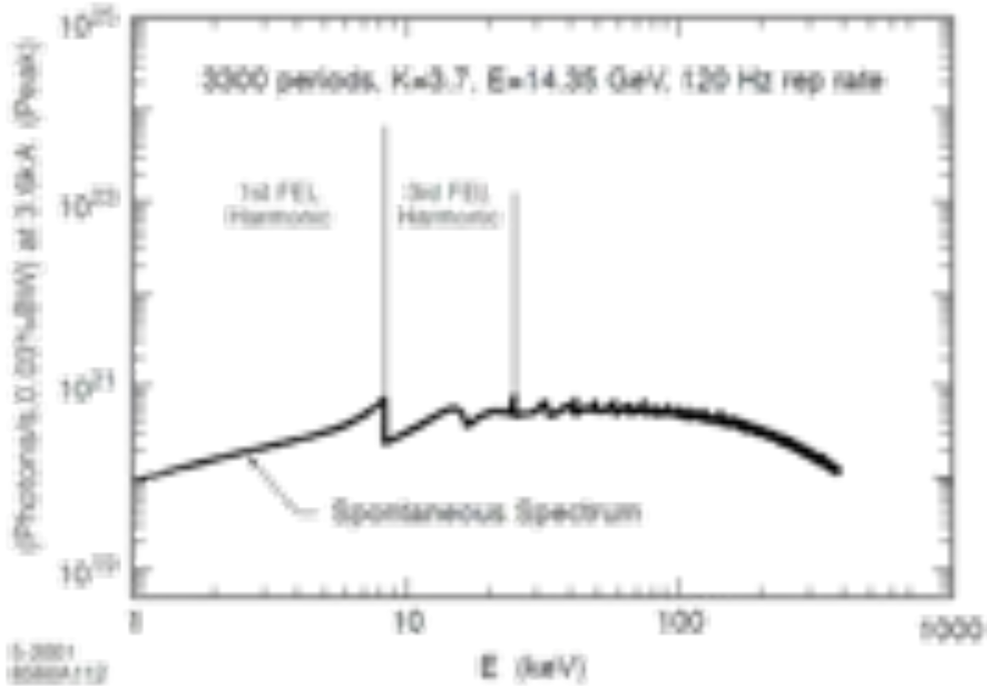
Thermal deformation



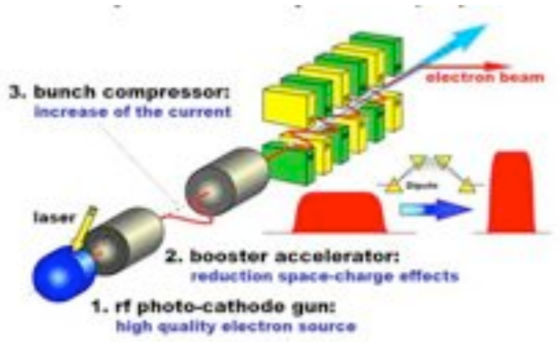


100W --> kW

From μW or mW



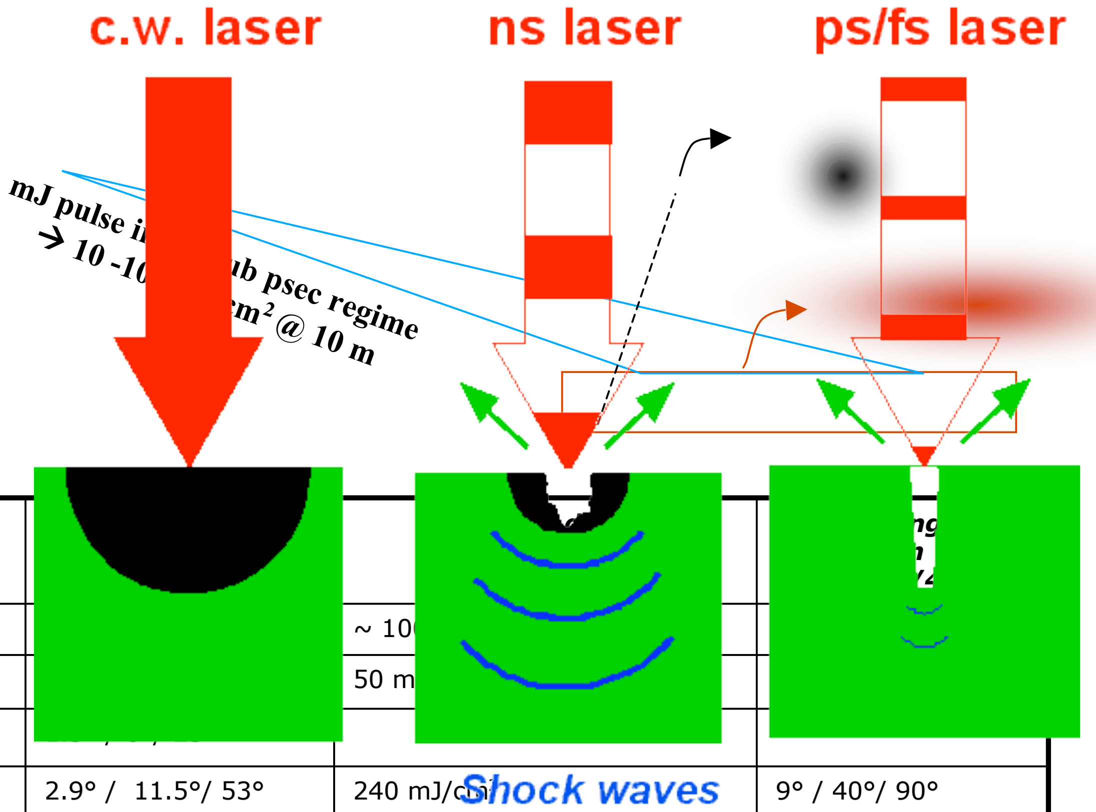
Fluence & Damage threshold



Fluence (Joules/cm^2) = laser pulse energy (J) / focal spot area (cm^2)
Intensity (Watts/cm^2) = peak power (W) / focal spot area (cm^2)
Peak power (W) = pulse energy (J) / pulse duration (sec)

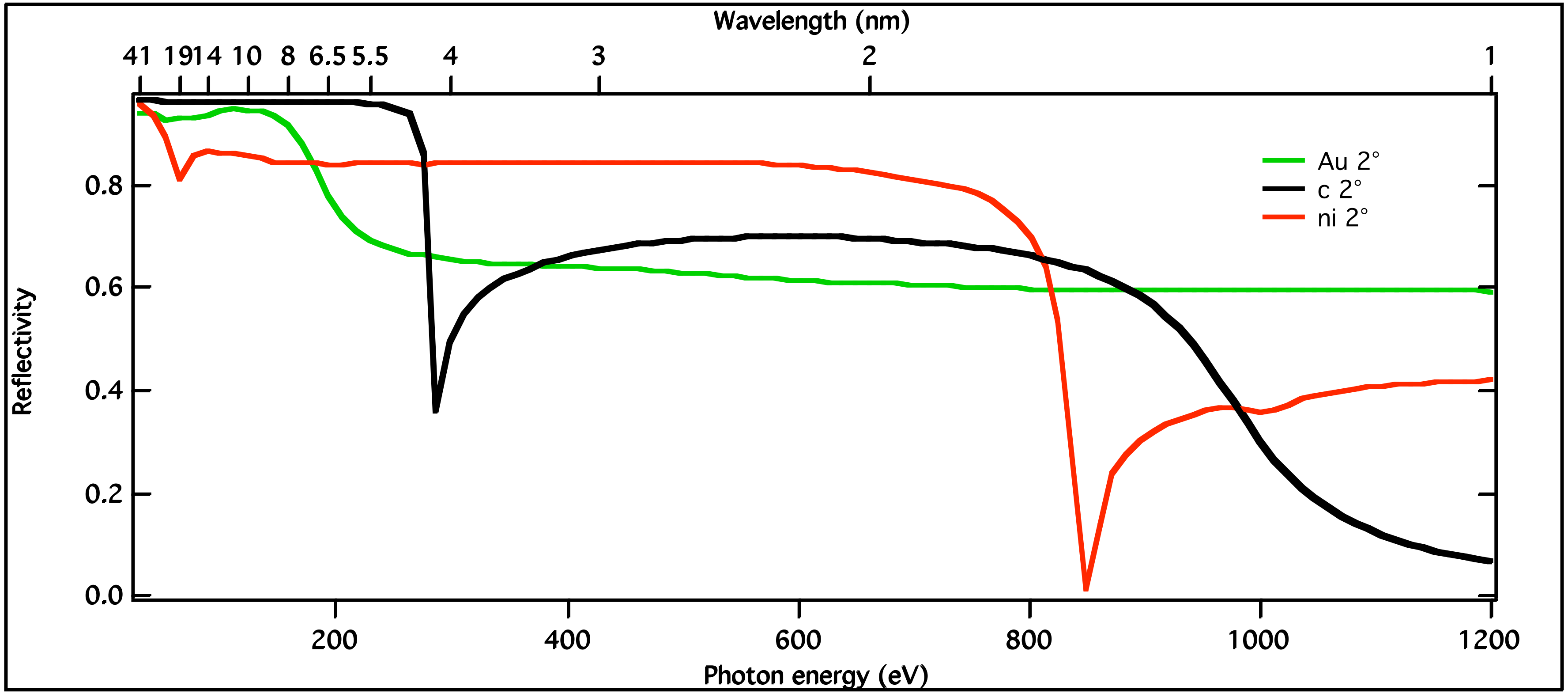
FEL 1:
100 fsec; 5 GW → ~ 0.5 mJ

FEL 2:
200 fsec; 1 GW → ~ 0.2 mJ



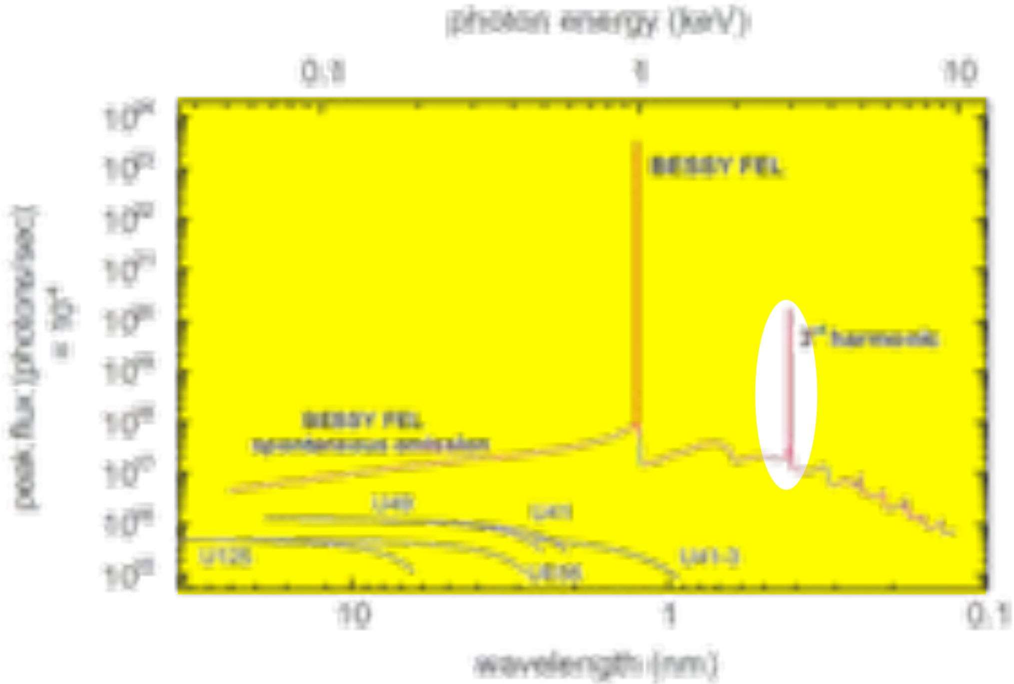
Matrial	Damage threshold @ 90 nm			
Cu/Glidcop bilk	~ 500 mJ/cm²		~ 10	
Au coating	40 mJ/cm²		50 m	
Silicon bulk	30 mJ/cm²			
Graphite coating	60 mJ/cm²	2.9° / 11.5°/ 53°	240 mJ/cm	9° / 40°/ 90°
YAG bulk	70 mJ/cm²	3.3° / 13.4°/ 68°		

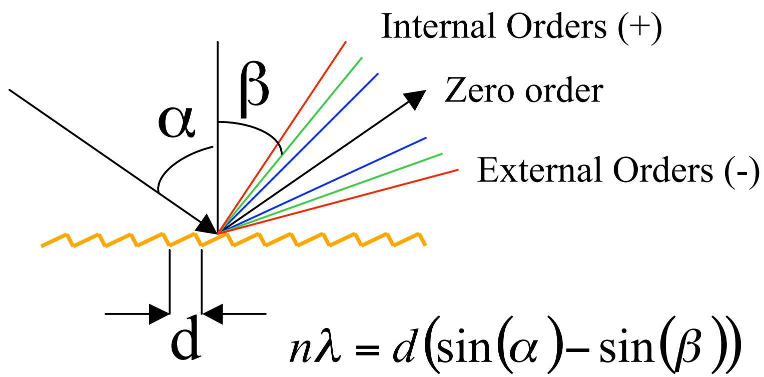
High density carbon (or B4C) are very "strong" materials but…



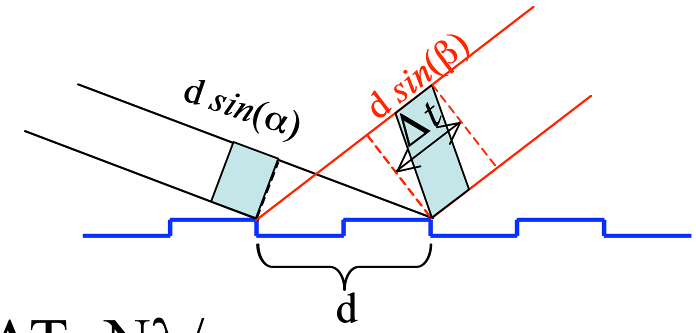
Gold or platinum are "soft" or "tender" materials…..
Therefore, the only way to substain such a strong energy density is to stay far away from the source and work in grazing incidence mode.
Sometimes it is not possible →

Harmonic rejection





$$n\lambda = d\left(\sin(\alpha) - \sin(\beta)\right)$$



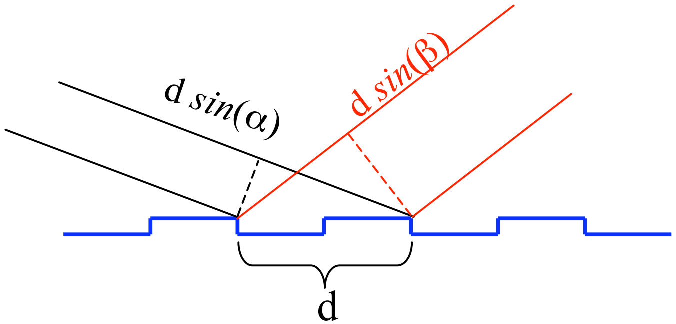
ΔT=Nλ/c

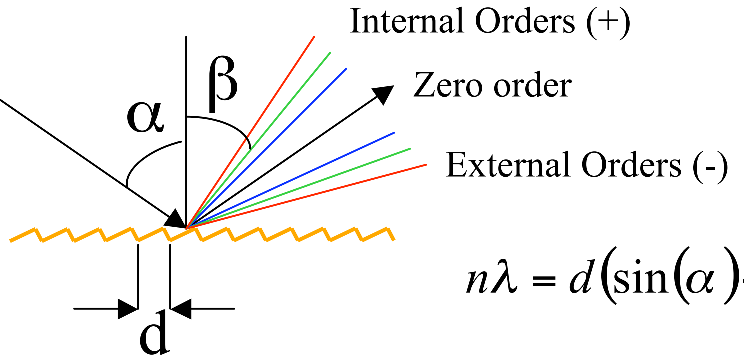
Examples:

100 nm cff 0.98 α 80.41 11.1 l/mm Δt=74 fsec FWHM
40 nm cff 0.93 α 81.8 33.3 l/mm Δt=65 fsec FWHM
30 nm cff 1.25 α 82.65 150 l/mm Δt=300 fsec FWHM
10 nm cff 1.73 α 85.5 600 l/mm Δt=236 fsec FWHM

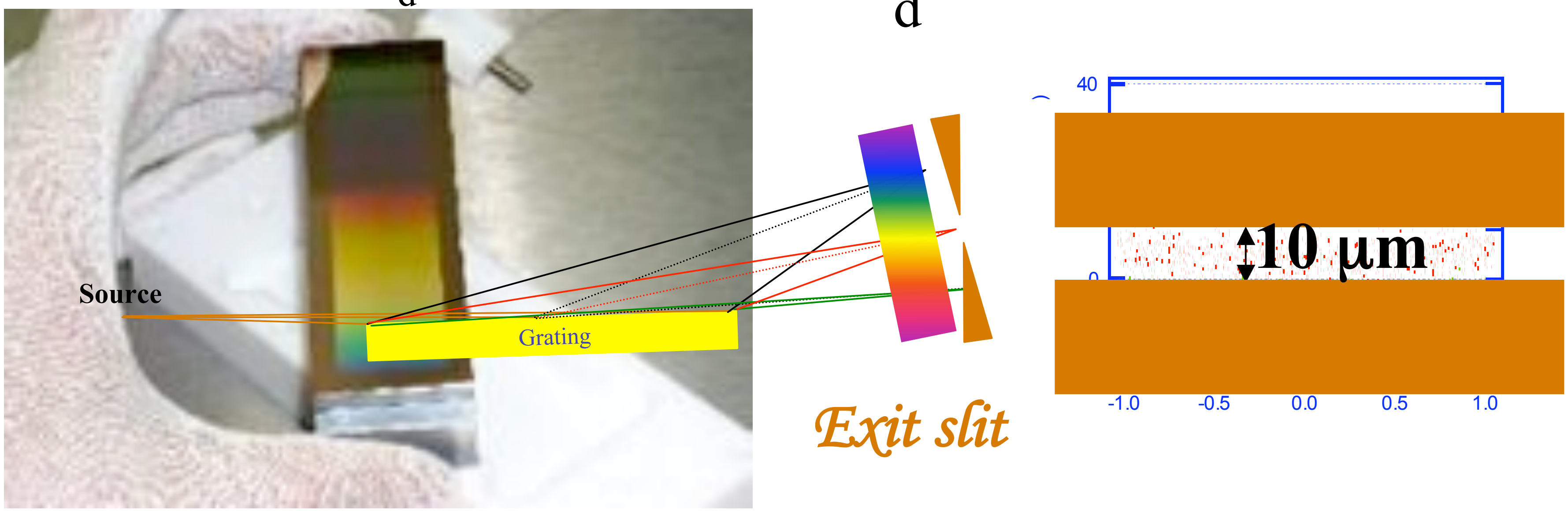
Diffraction gratings

Micro wave	I.R.	Visible	U.V.	Soft X-ray	Hard X-ray



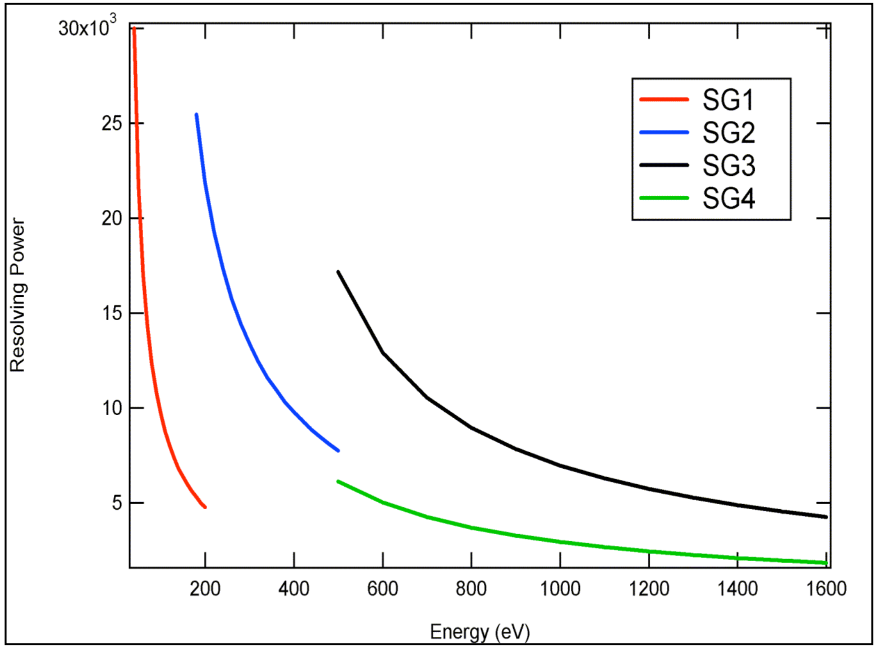


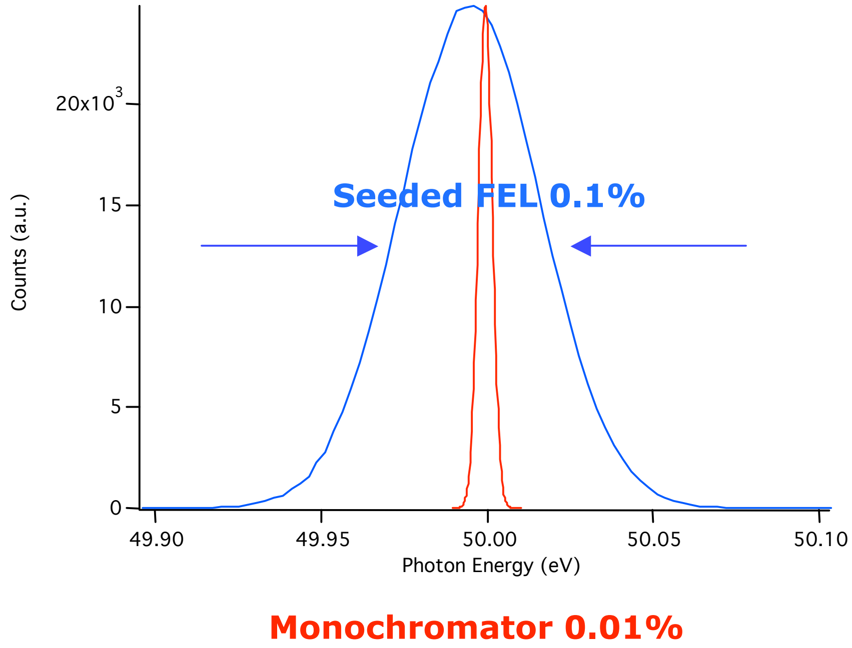
$$n\lambda = d\left(\sin(\alpha) - \sin(\beta)\right)$$



Why gratings?

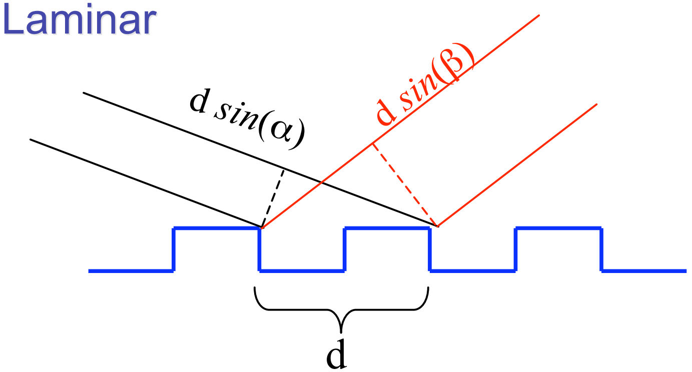
Resolving power = E/ΔE



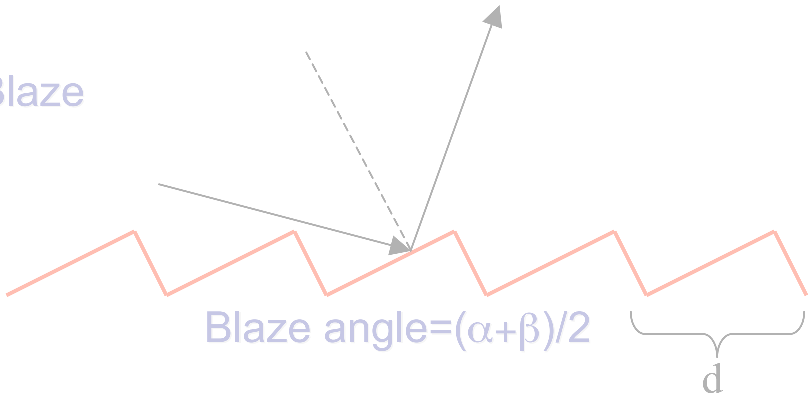


Groove profile

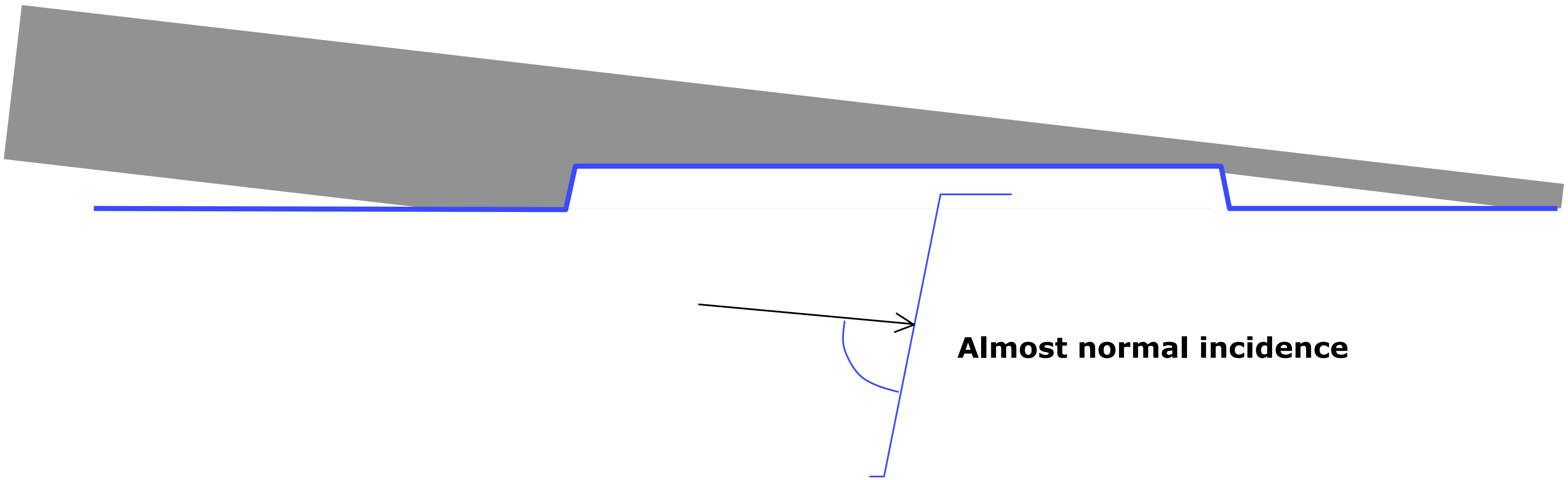
Laminar

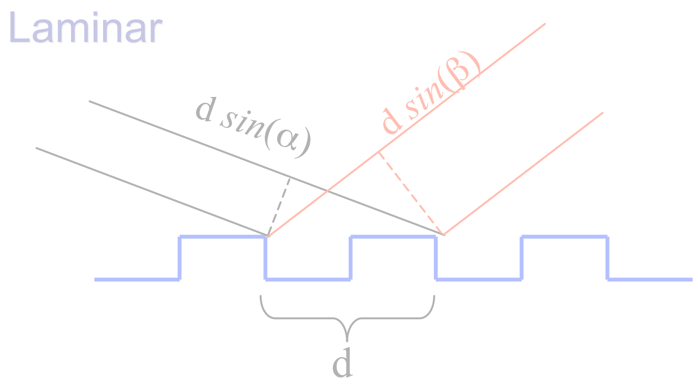


Blaze

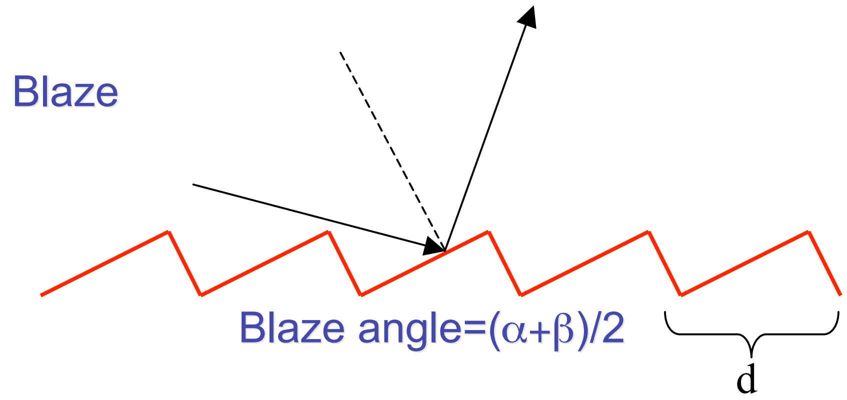


A lot of energy deposited on the grating facet

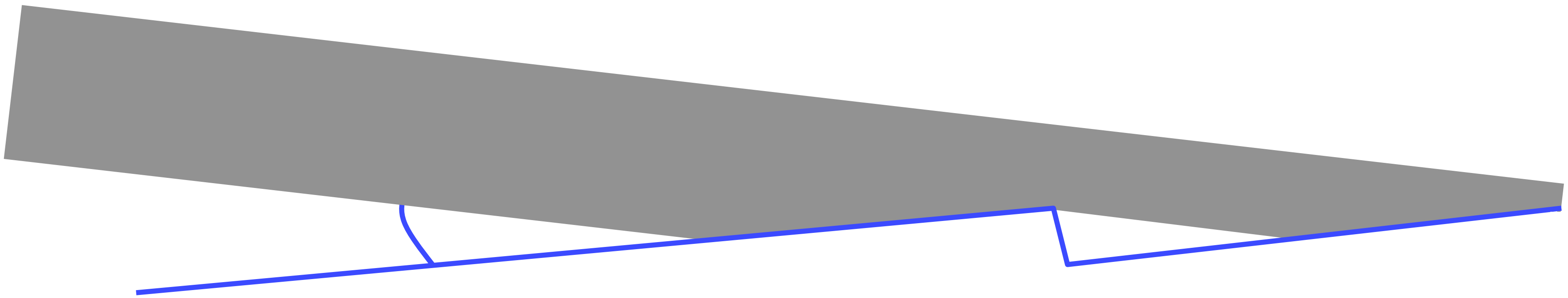




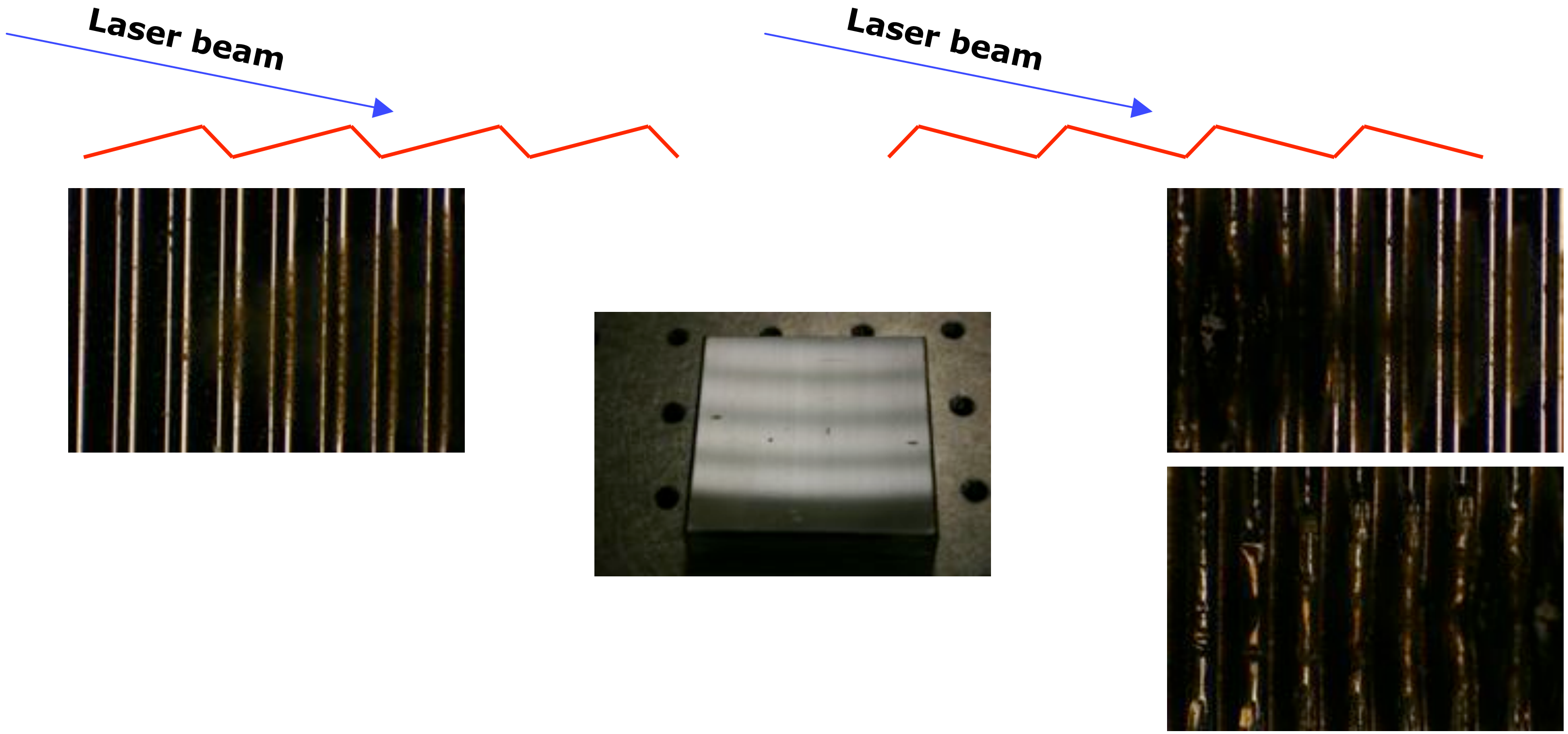
A lot of energy deposited on the grating facet



Energy distributed on the grating facet

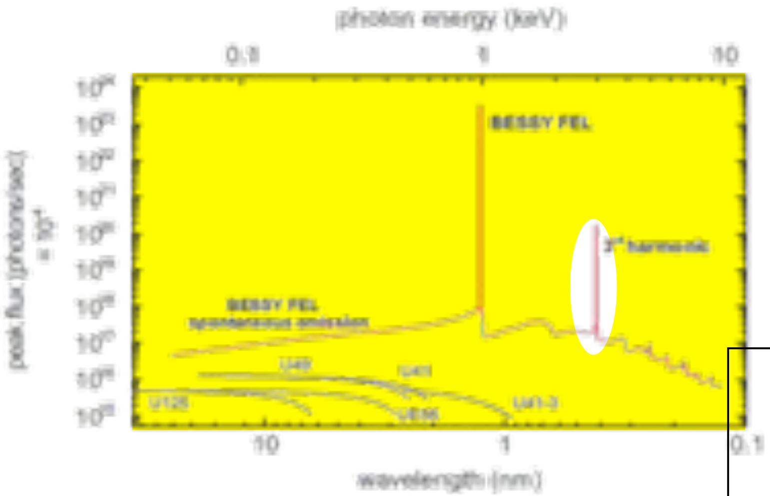


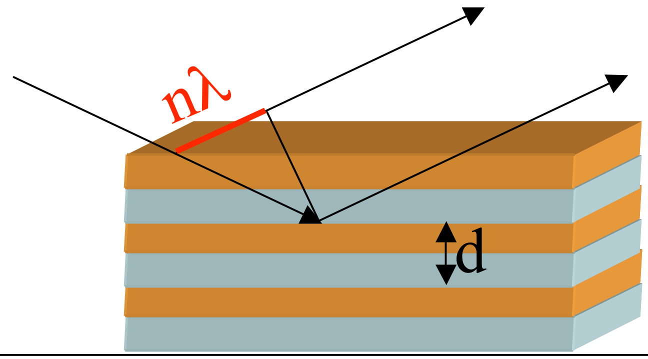
Grating damage test

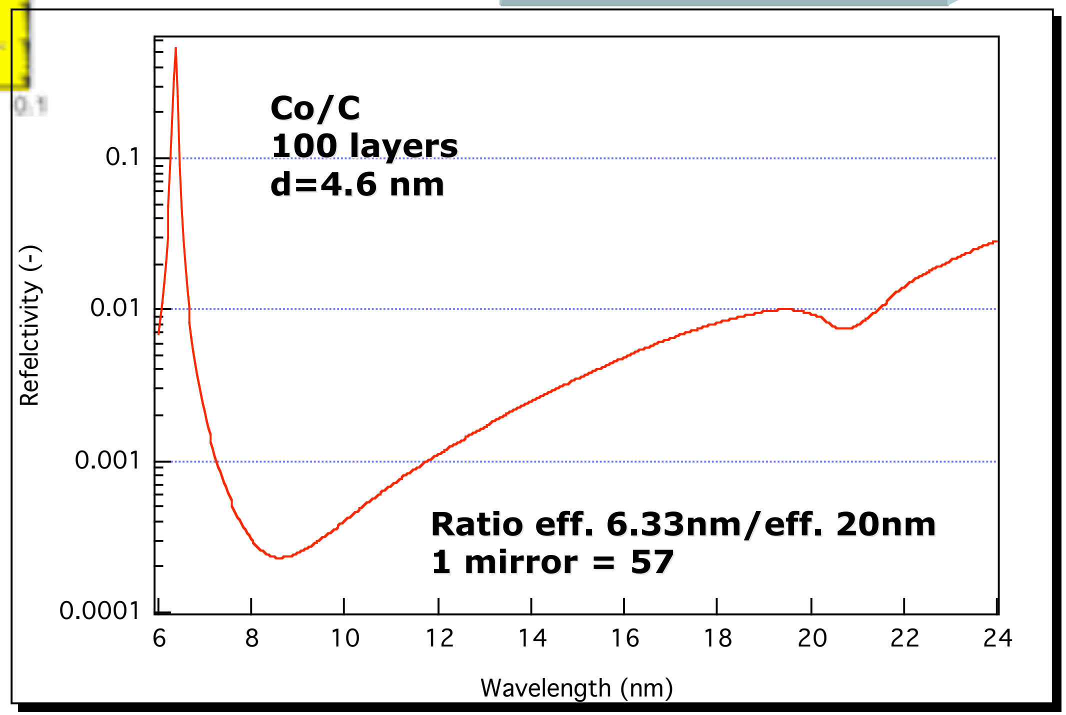


Grating can be used, but only with blaze profile and in very grazing incidence mode

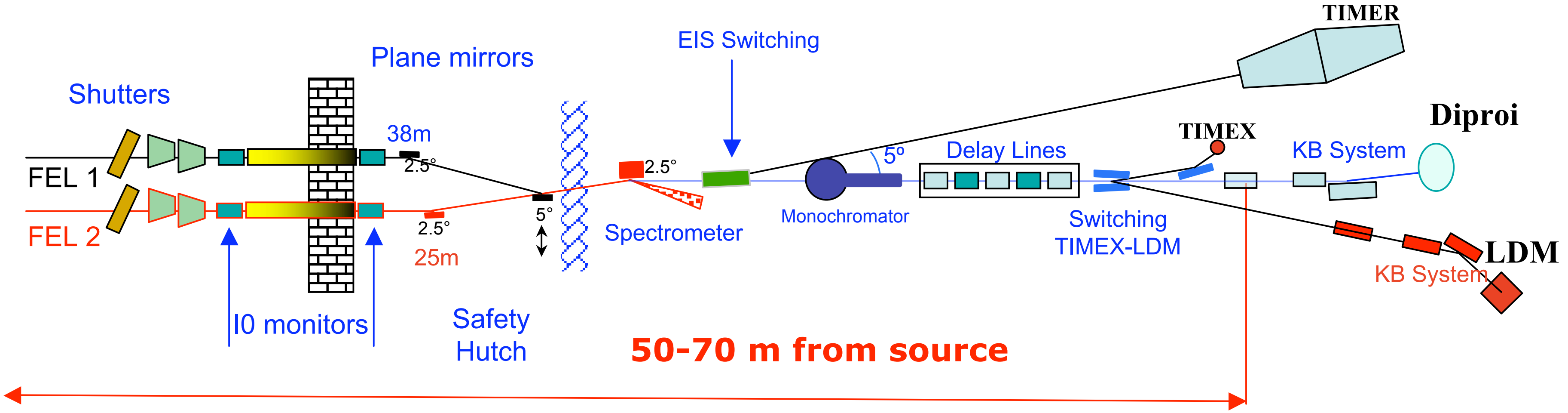
Multilayer for harmonic rejection







Multilayer for harmonic rejection

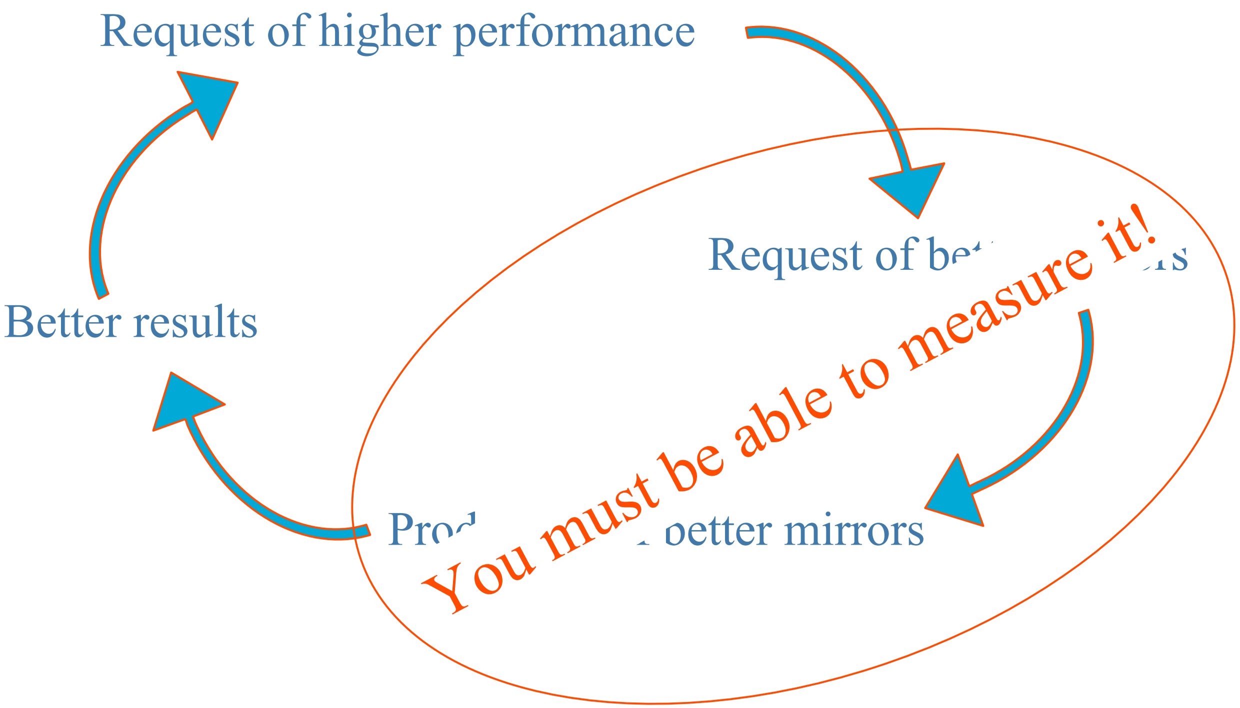


0.9-1.8 mJ/cm² on the 45° mirror surface at 20 nm
0.9-1.8 mJ/cm² adsorbed

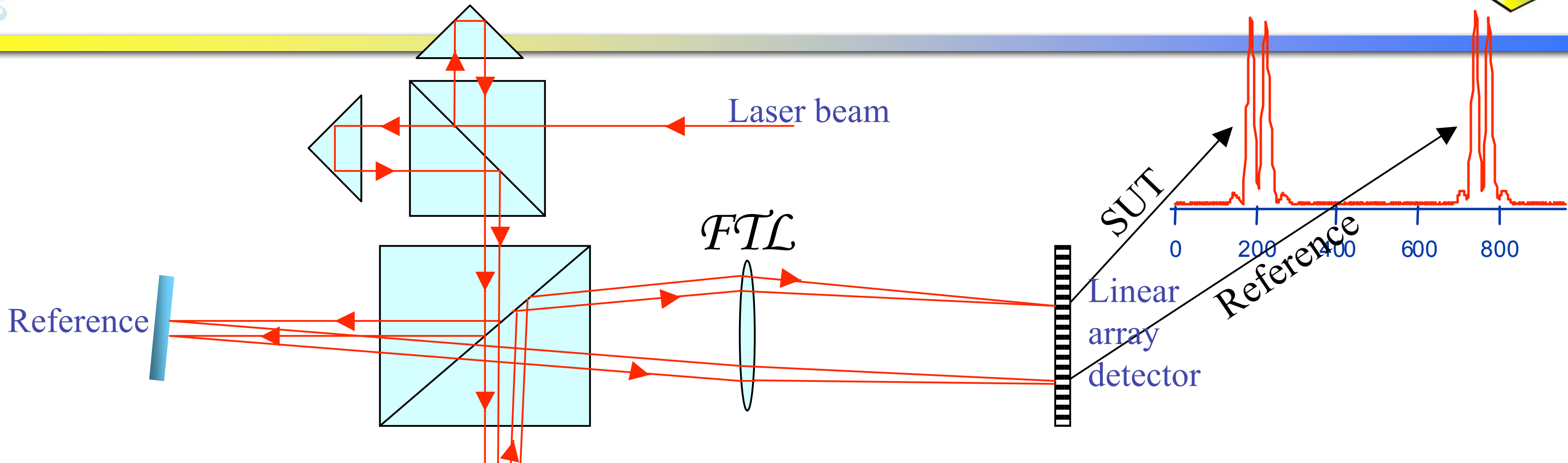
Multilayers suffer from fast aging effect

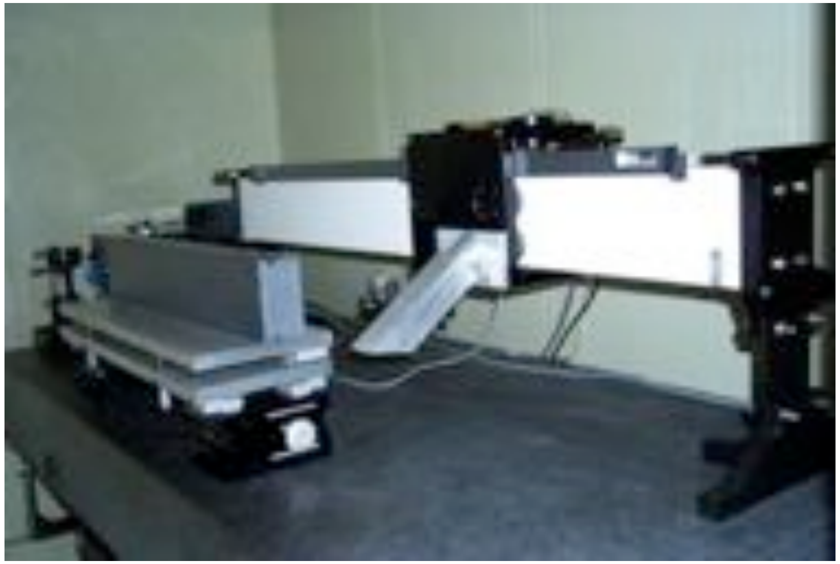
Matrial	*Damage threshold @ 32 nm*	*Safety margin @ 50 m, 45° Full beam Absorbed*
Silicon bulk	87 mJ/cm^2	48 - 48
α-C	60 mJ/cm^2	33 - 33
SiC	140 mJ/ cm^2	77 - 77
B4C	200 mJ/cm^2	111 – 111

Metrology

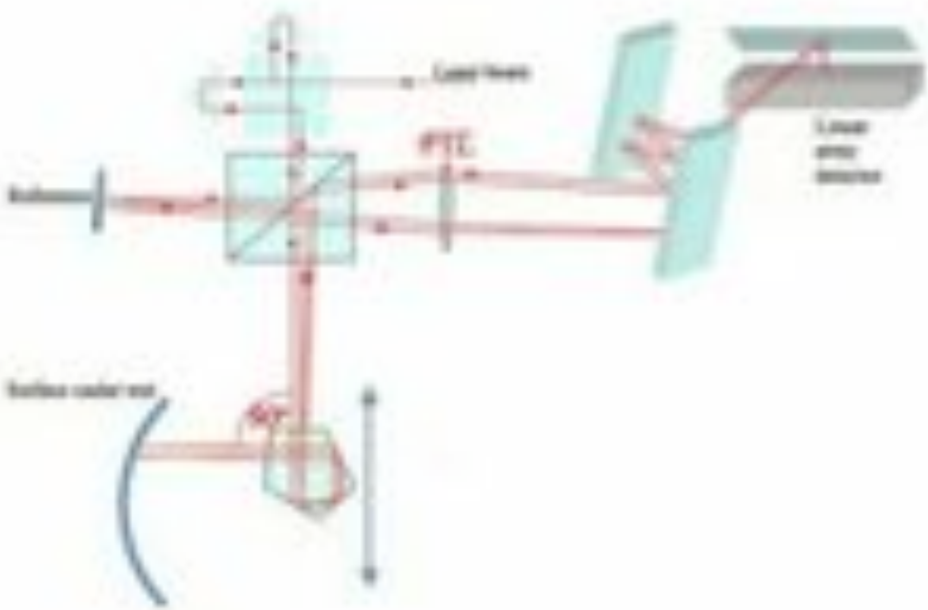

Request of higher performance
Better results
You must be able to measure it!

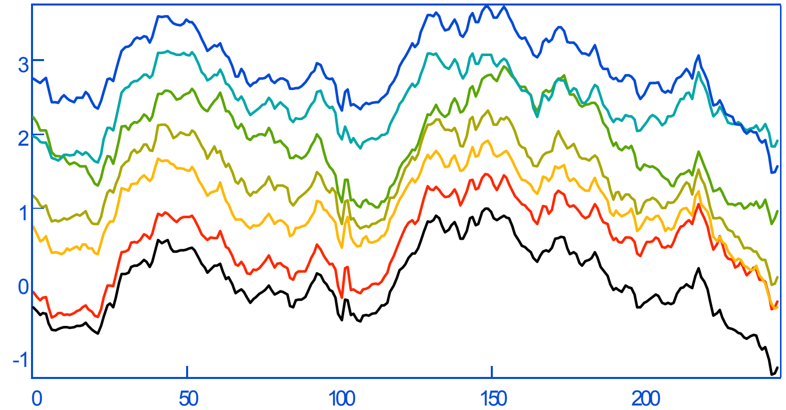
Long trace profiler

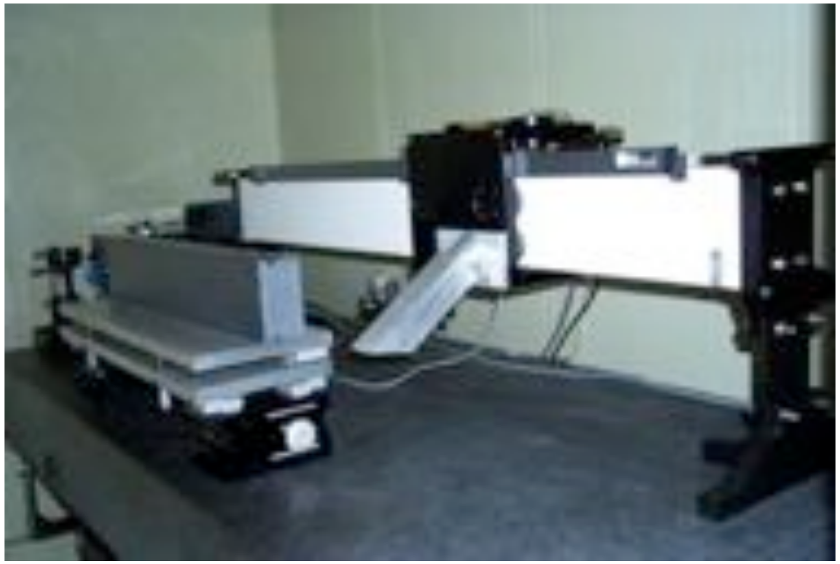




Long trace profiler

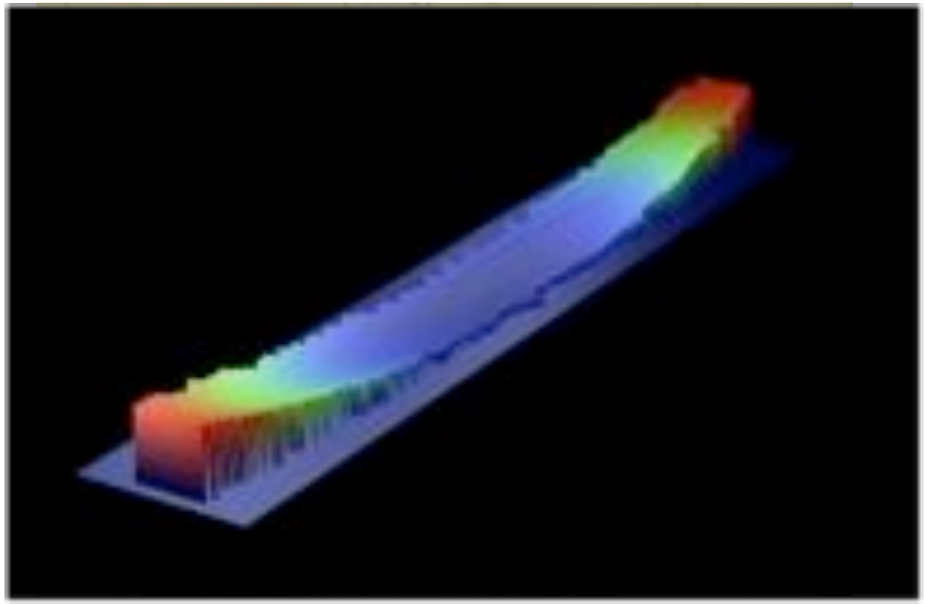






Precision: better than 0.5 μrad (a pencil on earth)

Fizeau interferometer



3D measurement of optical surfaces

λ/100 precision

λ/2000 repeatability

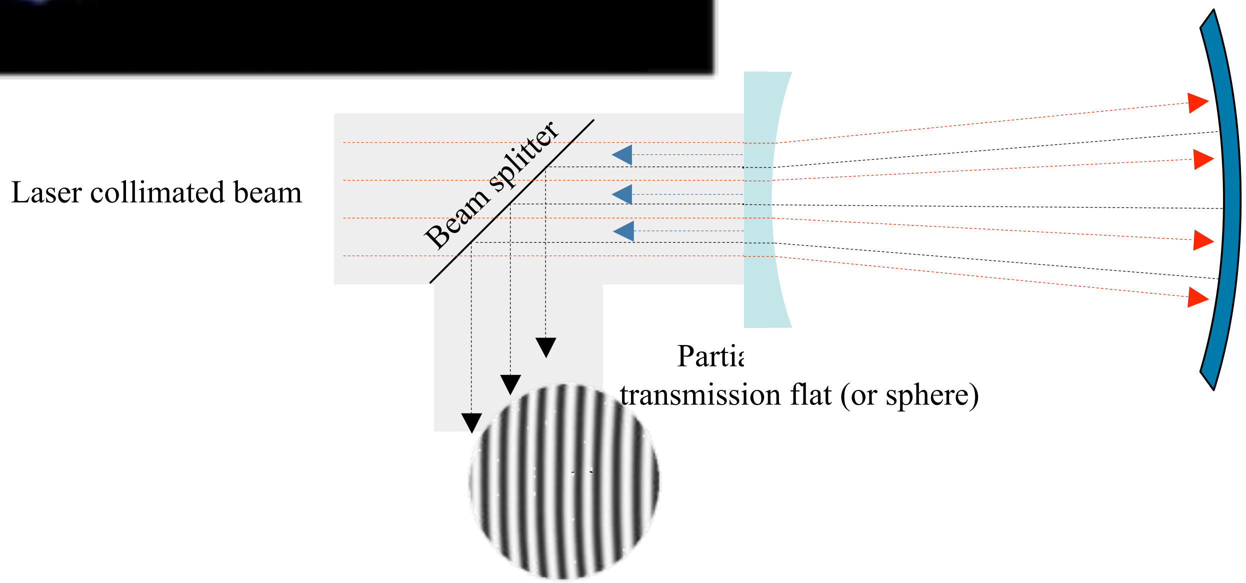
λ usually 632.8 nm or 1100 nm

Accessories

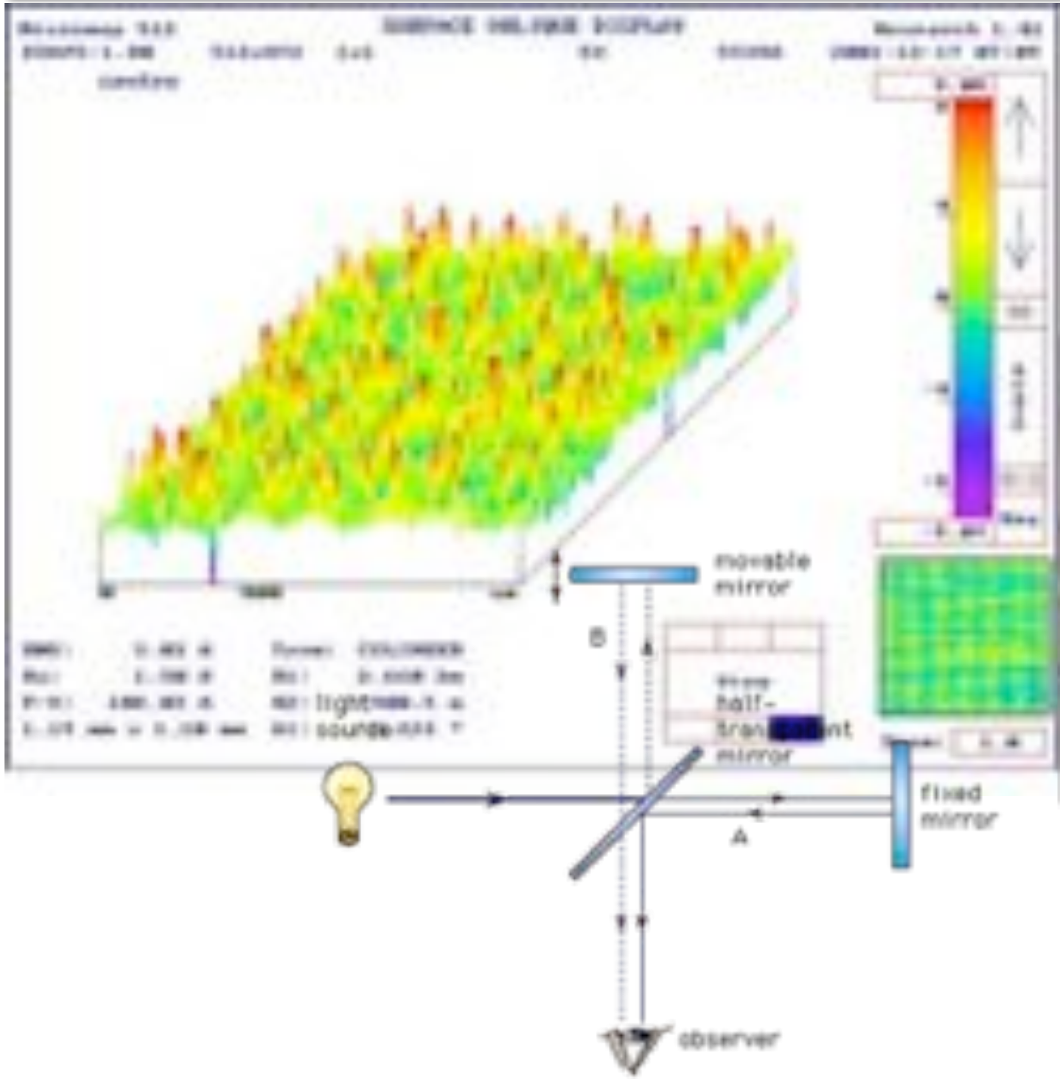
Transmission spheres

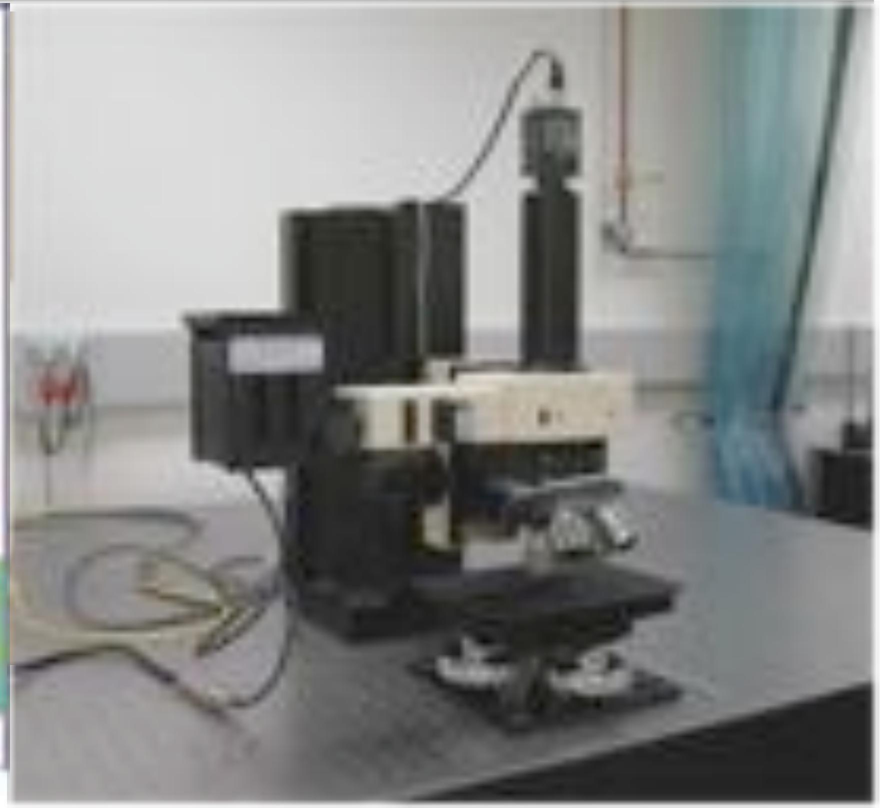
Converger for sagittal radii and NI mirrors

Diverger for NI mirrors with R>2 m



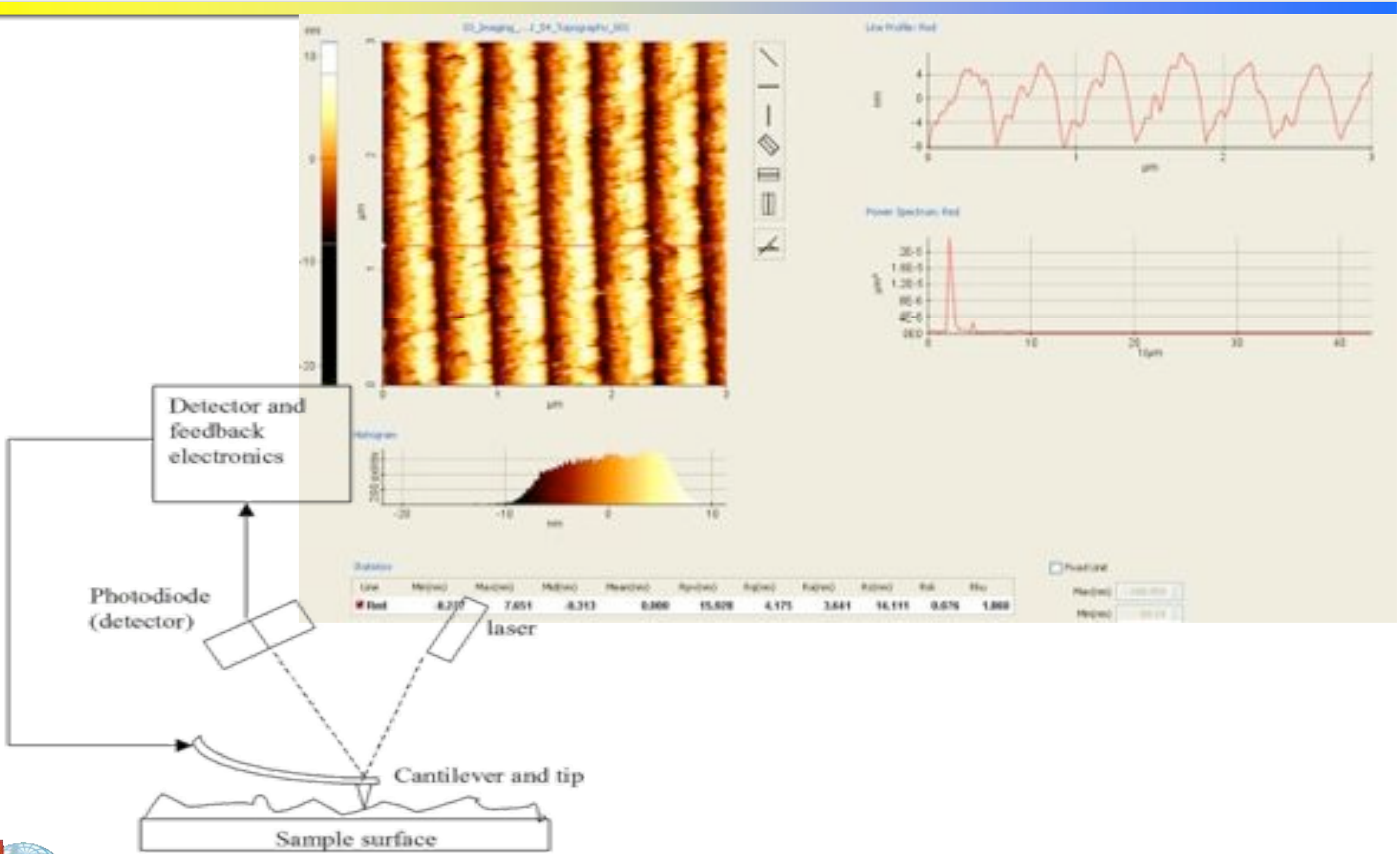
Roughness measurement



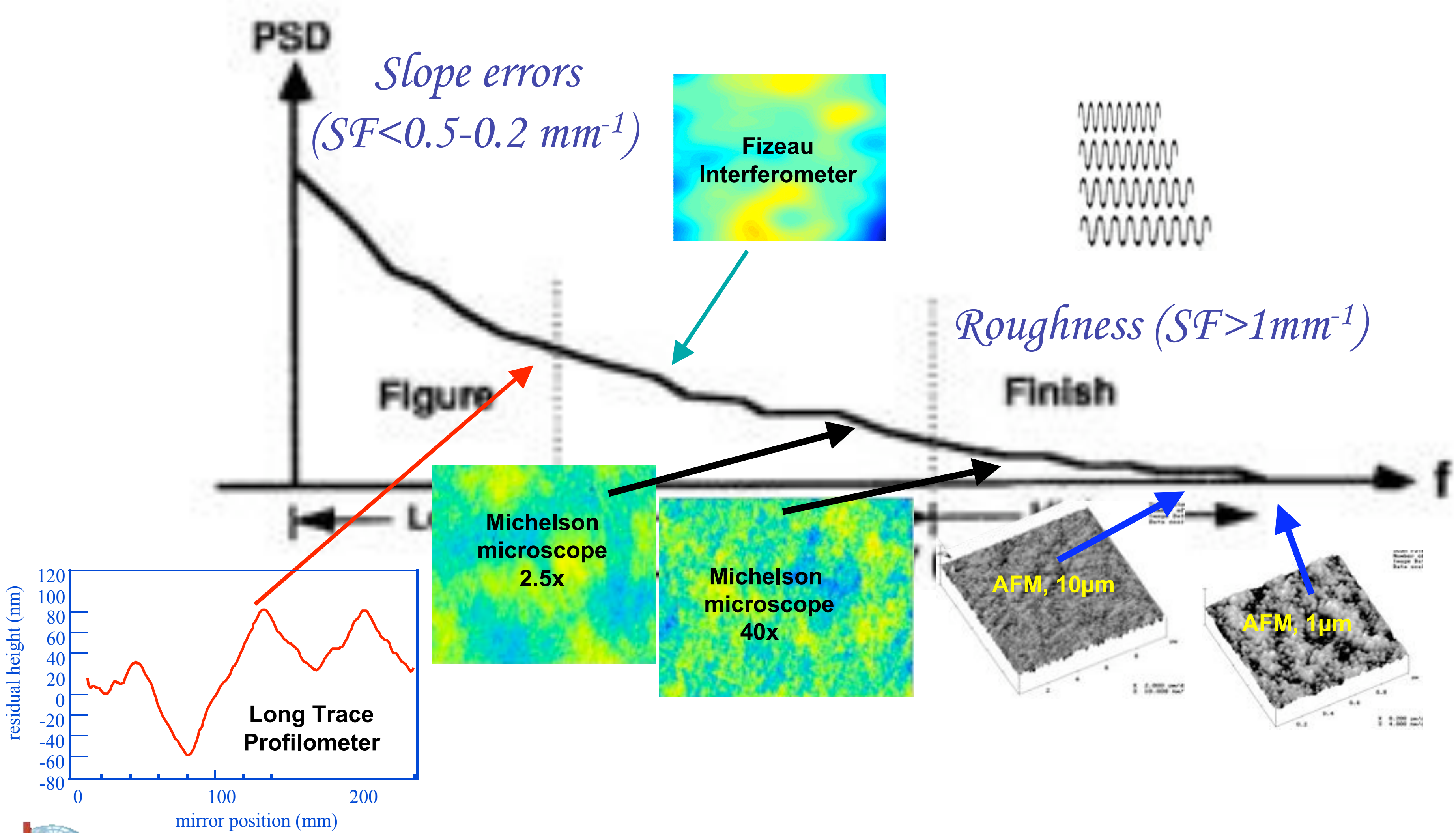


Michelson Interferometer

Atomic Force Microscope



Power spectral density



Bibliography

Books:

W. B. Peatman: **Gratings Mirrors and Slit** Gordon Sci. Publ. Amsterdam (1997) (Soft X.ray opitcs, introduction to SR sources)
D. Attwood, **Soft X-Rays and Extreme Ultraviolet Radiation**, Cambridge University Press (Interaction radiation-matter, SR sources, UV and Soft X-Ray optics)
A.A. **Modern Developments in X-ray and Neutron Optics** (Recent achievment in multilayer, metrology, ray tracing and X-ray lenses)
CXRO **X-ray data booklet** Lawrence Berkeley Nat. lab. (2001) free (general information and table useful when using X-ray)

Programs:

Shadow (ray tracing) http://www.nanotech.wisc.edu/shadow/shadow.html
XOP (general optical calculation) http://www.esrf.fr/computing/scientific/xop
SPECTRA (synchrotron source) http://radiant.harima.riken.go.jp/spectra/index_e.html

Links:

Centre for X-ray Optics http://www-cxro.lbl.gov/ *(general information and on line software)*
The international society for Optical Engineering http://www.spie.org
Optics.org http://optics.org
Photonics.com http://www.photonics.com/