Thermal bump removal
by designing an optimised crystal shape

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French CRG-IF BM32 at ESRF

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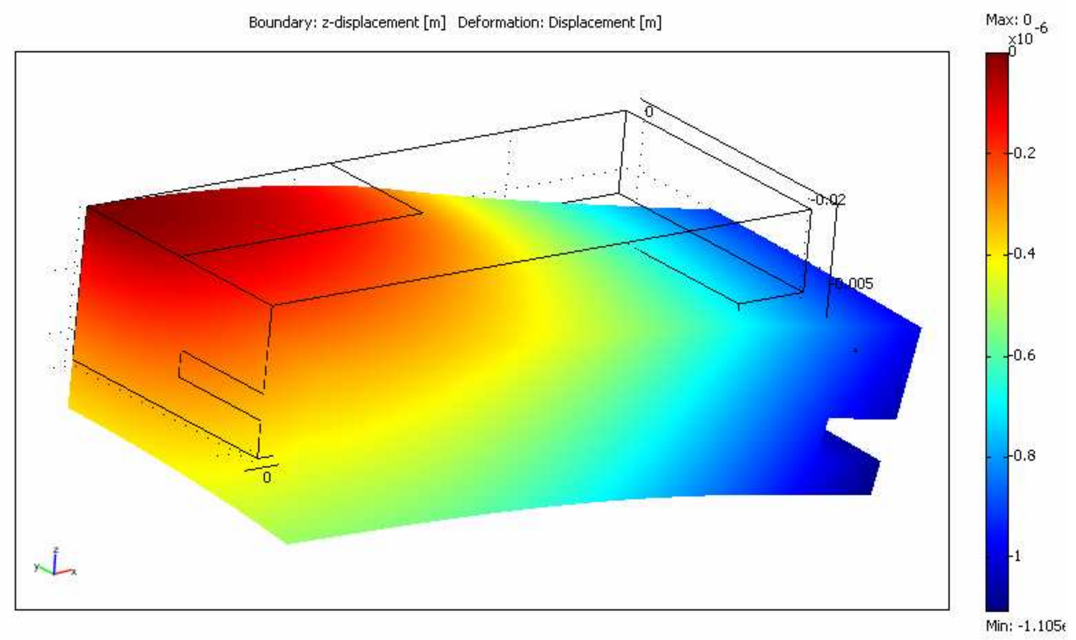
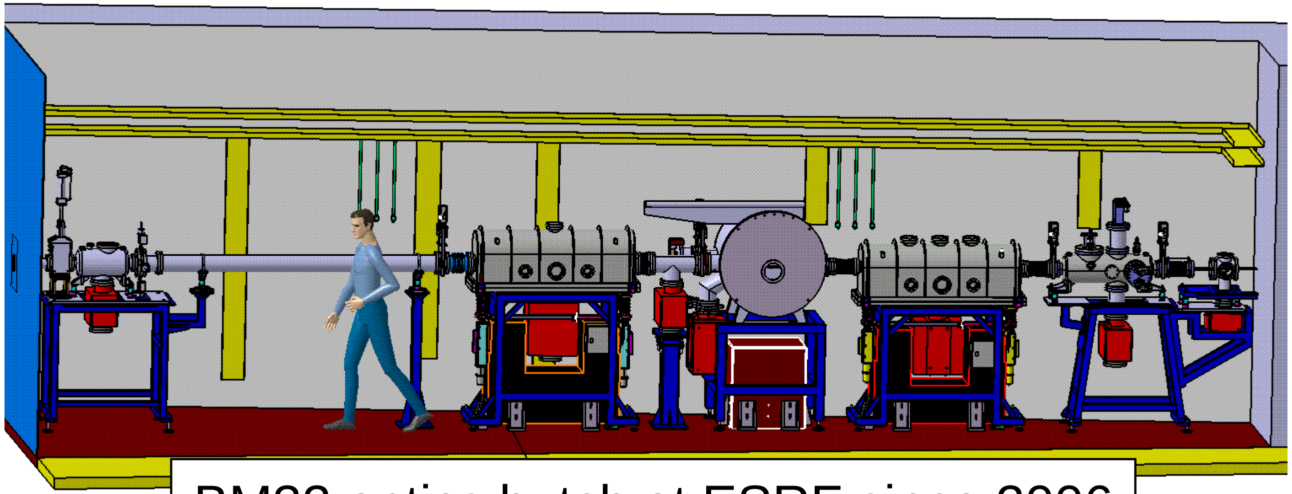
Outline

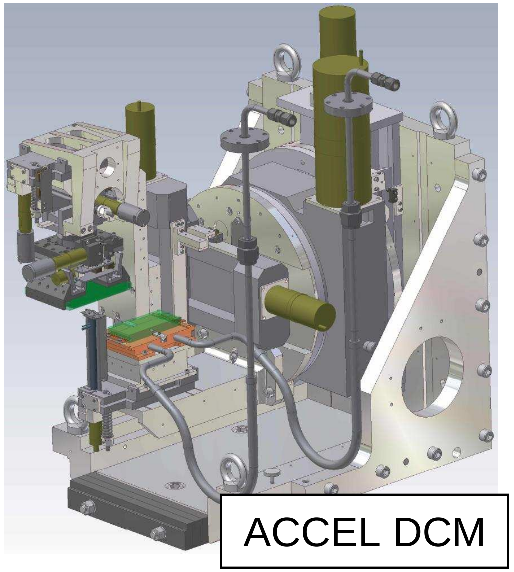
- Motivations
- Modelling
- Results
- Conclusions



Motivations

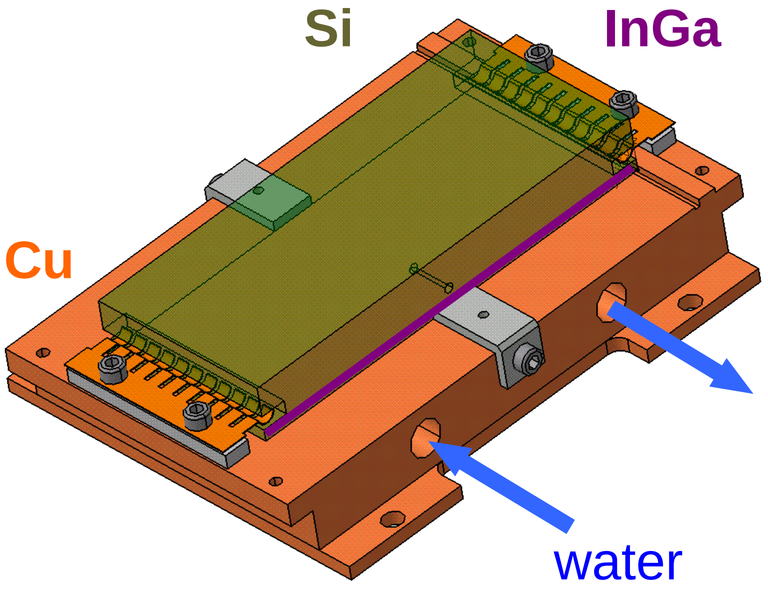


BM32 optics hutch at ESRF since 2006



ACCEL DCM

- *Bending Magnet at ESRF*
  - heat power : 300W
  - acceptance: horiz. >1.5mrad, vert. 0.1 mrad
- *New Double Crystal Monochromator*
  - Si(111)
  - from 5 to 30 keV
- *keep cheap and simple cooling design*
  - water (avoid LN2)
  - indirect cooling (simple + less vibrations)

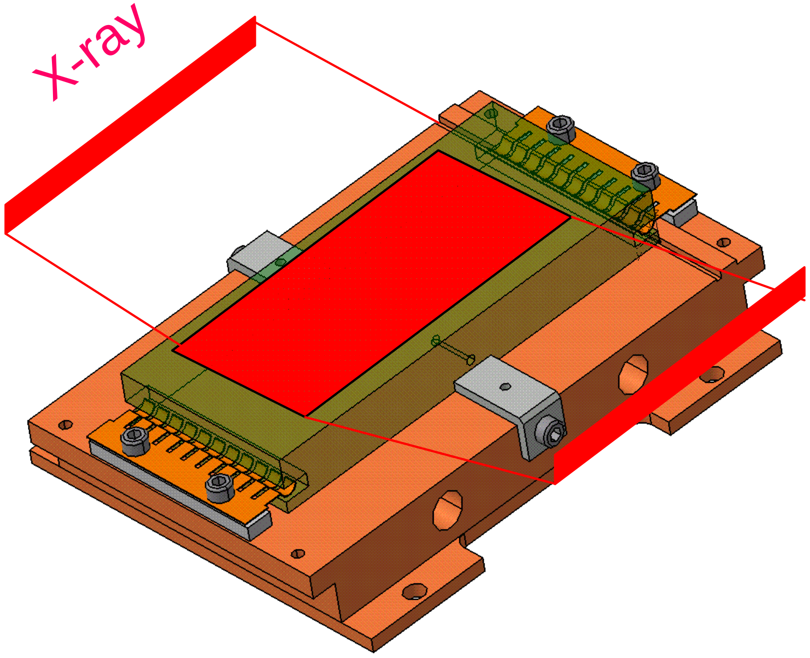


Block crystal

Modelling : FEA - Heat

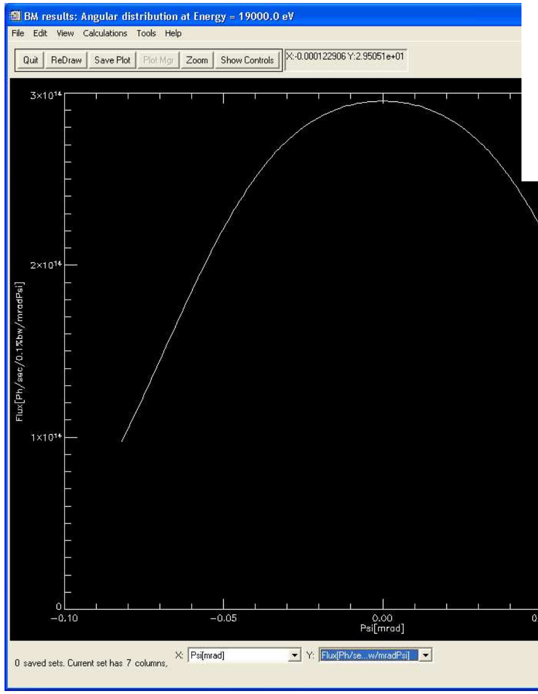
- ***Heat source***:
  2D domain incoming power
  ~ 100-150 W on 40x50 mm
  ~ 50-130 mW/mm^2 (on mono)

- Spatial distribution (uniform, gaussian-like)
- current in storage ring
- crystal inclination (working energy)
- Slits aperture (hxv), illuminated area



XOP
E=6.04 GeV
R=25m
B=0.8T

H accept= 2.09 mrad
(mono. 26.9m
Slits 23.9m)

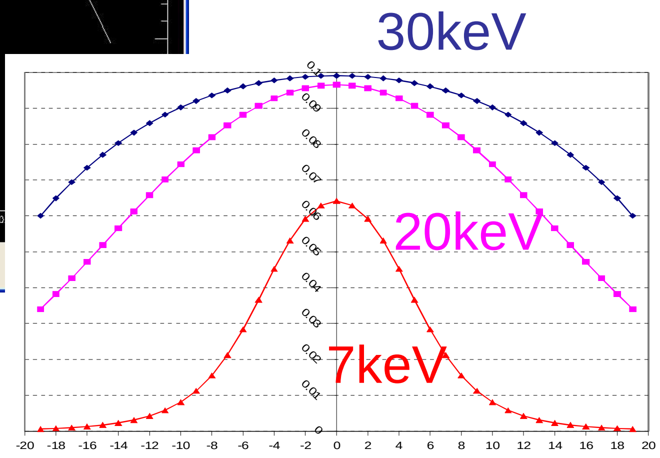

BM results: Angular distribution at Energy = 19000.0 eV

X:-0.000122906 Y:2.95051e+01

0 saved sets. Current set has 7 columns,

X: Psi[mrad]

Y: Flux[Ph/se...w/mradPsi]



0.1 W/mm$_v^2$

- ***Cooling power***:
  - convective transfer: water/Cu
    h = 5000W/mm^2/K
  - heat resistance Si/InGa/Cu

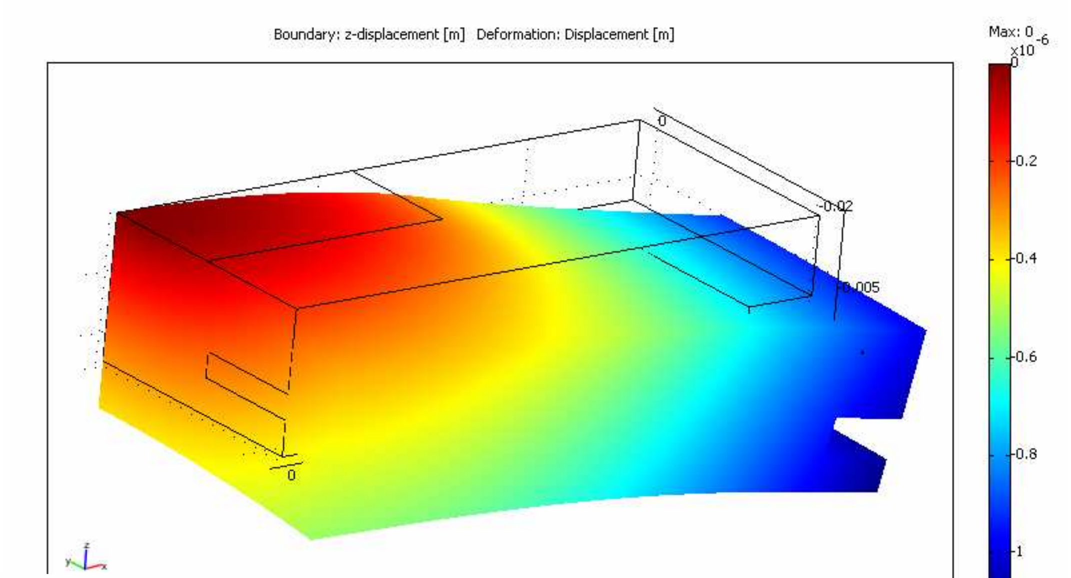
Modelling : FEA - deformation

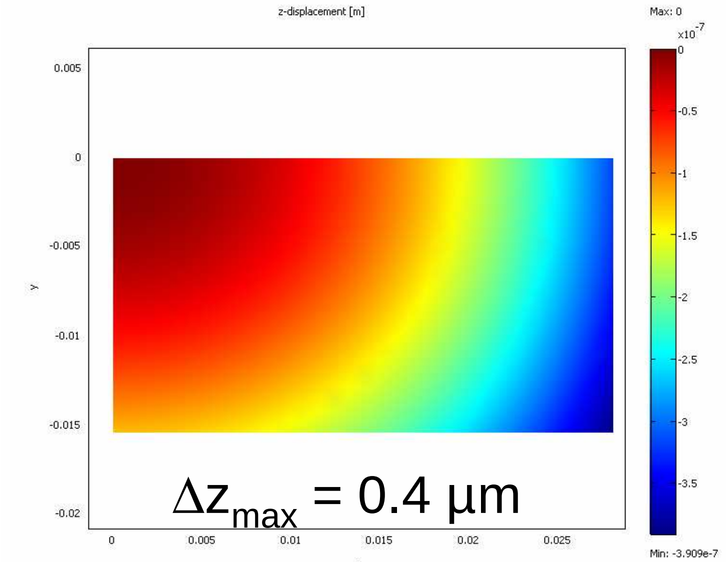
Get at (reflective) domain surface:
uz vertical displacement along z => derivative of uz along y (// x-ray beam)
=> µ longitudinal slope errors

FEA with COMSOL multiphysics
(ex FEMLAB)

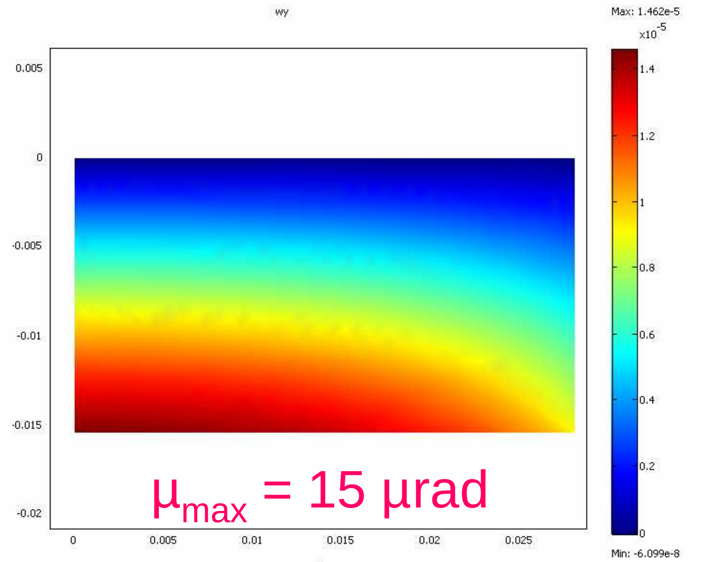
Standard block Si crystal

E =18keV
$\Delta\omega$ = 16 µrad
I = 200mA





Δz_{max} = 0.4 µm



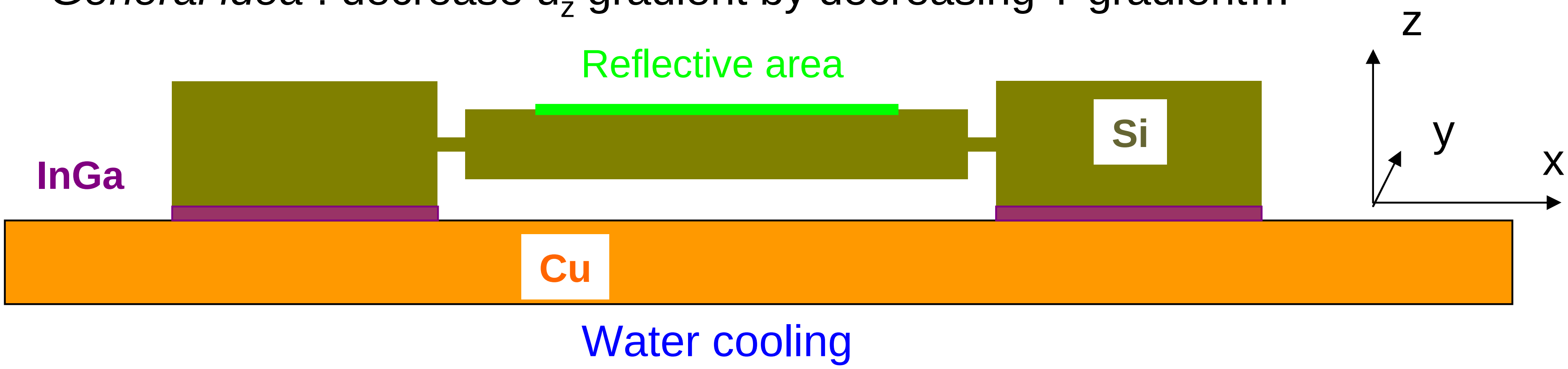
μ_{max} = 15 µrad

R_{int} = 50%

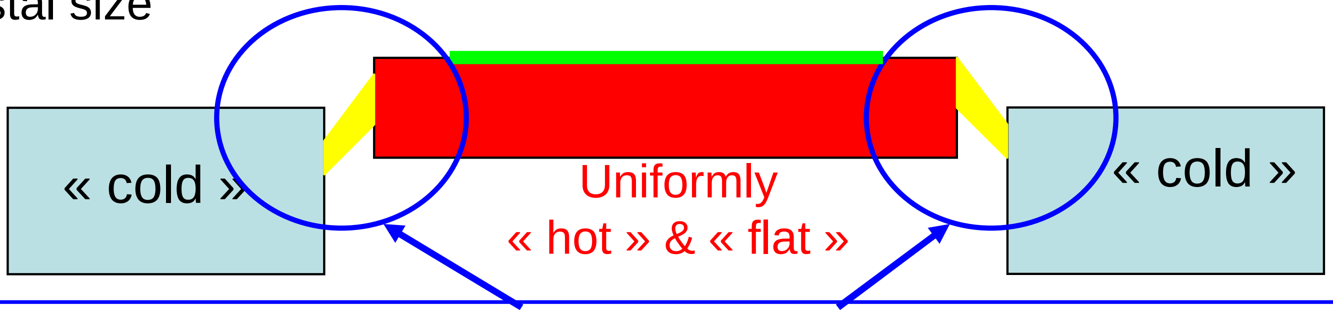
Less than to 25%
with I = 350mA

Modelling : design of an optimised shape

- *Previous works* : side cooling better than bottom cooling
- *General idea* : decrease u_z gradient by decreasing T gradient…



- *First simulations* : possibility to reverse the bump curvature !
- *For a given heat load*: possibility to remove longitudinal uz gradient (smooth profile)
- *add deformation sources*
- Constraints to the design:
  - several optics configurations
  - limited crystal size

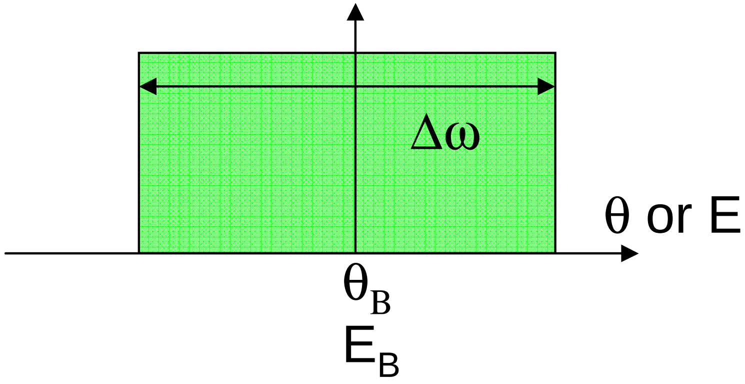


Strain and ***temperature gradient*** are outside the reflective domain

Reflectivity Model – surface bump

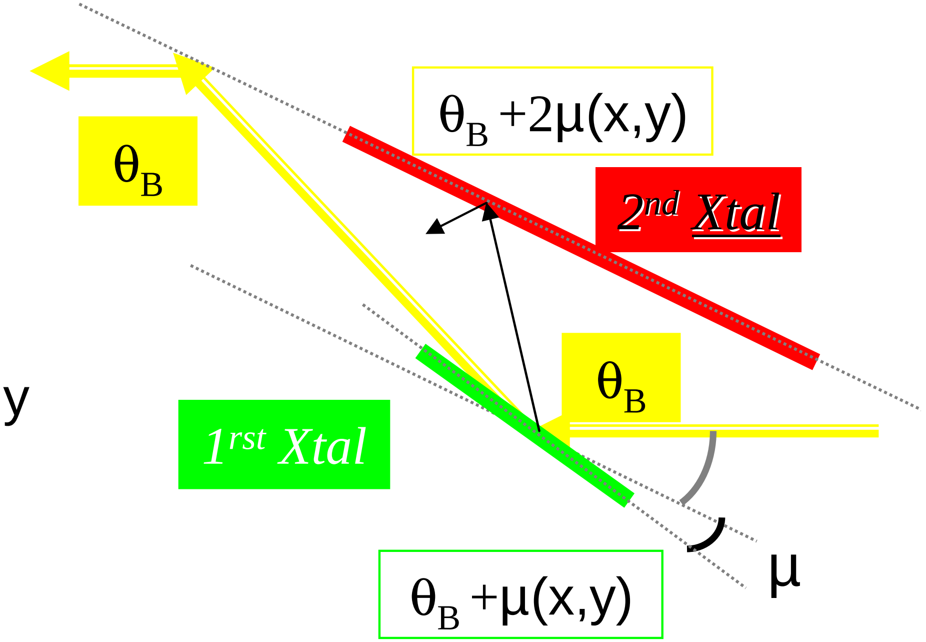
Simple Model: *μ : Slope error at (x,y) on 1^{rst} crystal / flat 2^{nd} crystal*
$\Delta\omega$: *Darwin width*

Bragg reflectivity ~ gate function $\Delta\omega$ or ΔE width



DCM reflectivity per unit area: **R(x,y)**

$$\mathbf{R(x,y)} = \begin{cases} 1-|\mu_{(x,y)}|/\Delta\omega & \textbf{if } |\mu_{(x,y)}|<\Delta\omega \\ 0 & \textbf{else} \end{cases}$$



Integrated reflectivity :

$$R_{int} = \int_{area} \mathbf{R}_{(x,y)}\, dxdy$$

- Objective function to optimise
- two inputs:
  - local slope error $\mu(x,y)$ from FEA
  - Darwin width $\Delta\omega$ (working energy)

Reflectivity Model – thermal lattice expansion

Two origins of lattice planes strain at illuminated surface:

- slope errors (longitudinal z-displacement gradient)
- thermal lattice spacing expansion

$$\boxed{\Delta\theta_B=\alpha_{expansion}.\tan\theta_B\ \Delta T=\mu_{th}}$$

@20 keV, $\alpha_{Si}=2.66\ 10^{-6}\ K^{-1}$

$\Delta T=1°C \Leftrightarrow \Delta\theta_B=1/4\ \mu rad$

$\Delta T=60°C \Leftrightarrow \Delta\theta_B=\Delta\omega$

- If T1(x,y) uniform => perfect tuning with tilted 2nd Xtal by $\Delta\theta_B$ with $\Delta T = T_2-T_1$
- if T1(x,y) non uniform => best tuning with tilted 2nd Xtal by $\Delta\theta_B$ with $\Delta T = T_2$-mean(T1)
  equivalent slope error ~ $\mu = \alpha_{expansion}.\tan\theta_B\ \Delta T_{Max}/2$

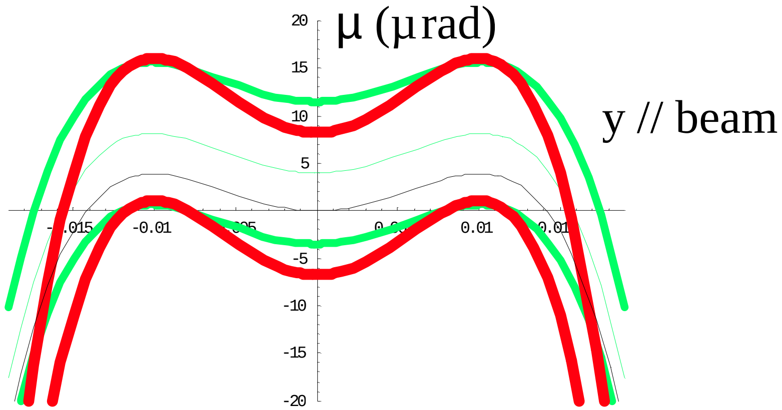
For our heat load range, d-spacing variation can be omitted

- A more accurate computation can be done:

$$\mu_{th}=(T_2-T_1(x,y)).\alpha_{Si}.\tan\theta_B$$

Gate function Xtal 1 with $\mu+\mu_{th}$

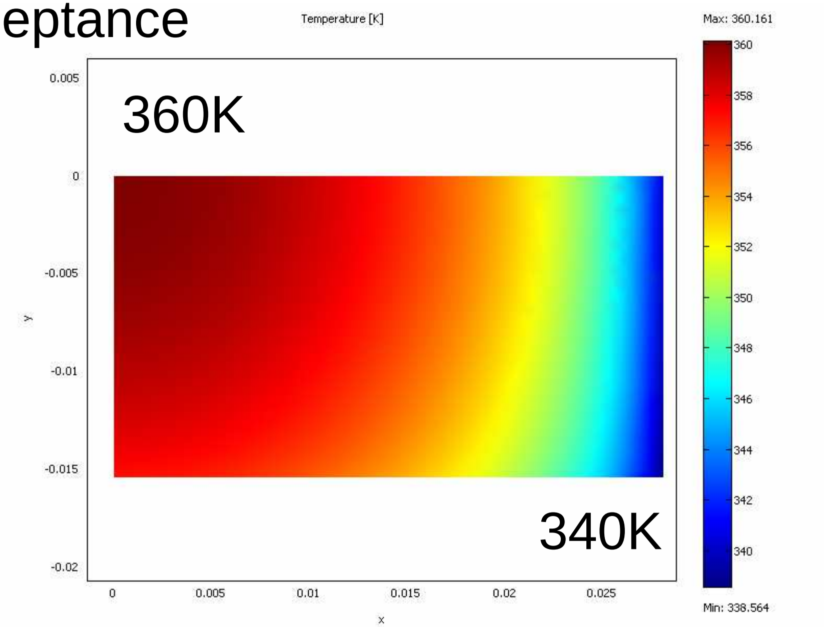
Gate function Xtal 2 with 2μ+offset



=> offset for highest R_{int}

Results

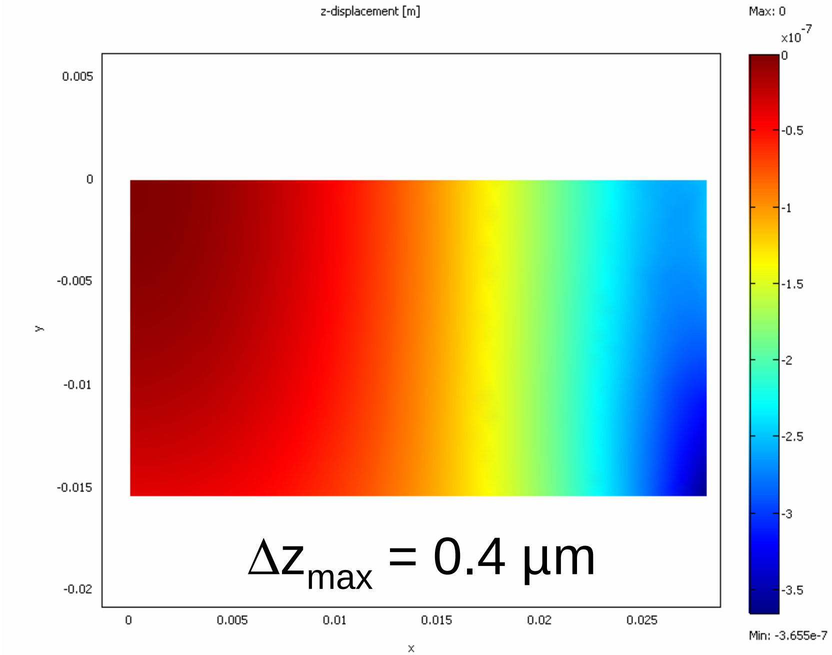
Optimised shape for 3 Energies X 3 horiz. acceptance



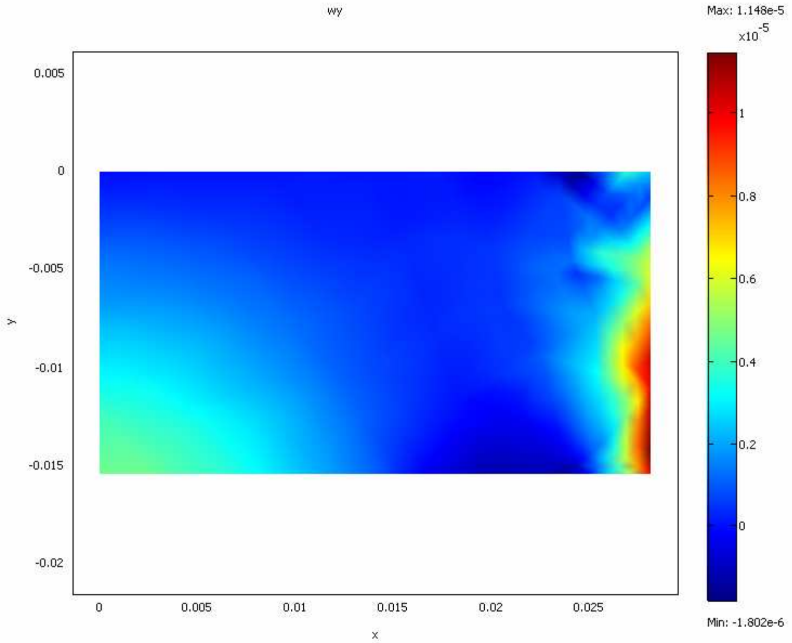
360K

340K

E =18keV
Δω = 16 µrad
I = 200mA



$\Delta z_{max} = 0.4\ \mu m$



Rint = 90%

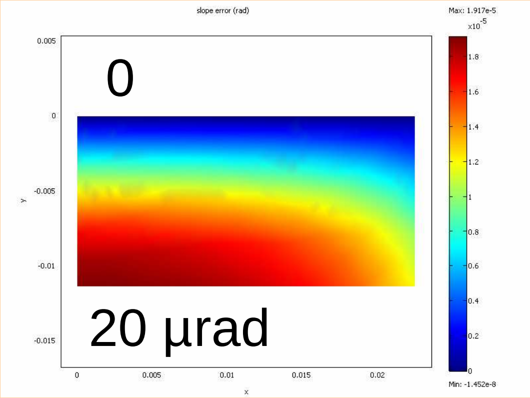
Gradient is along x !

µ = -2 to 11 µrad µmean =2 µrad !

Results: comparison old-new crystal

Old Xtal

New Xtal

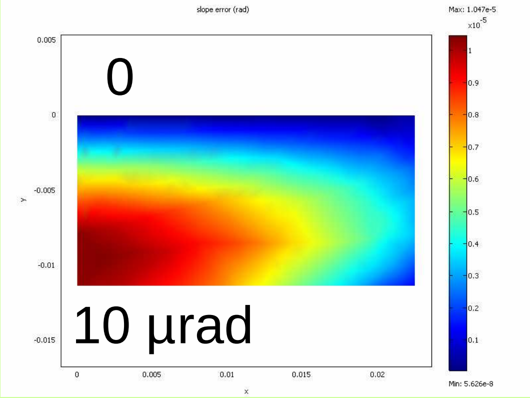


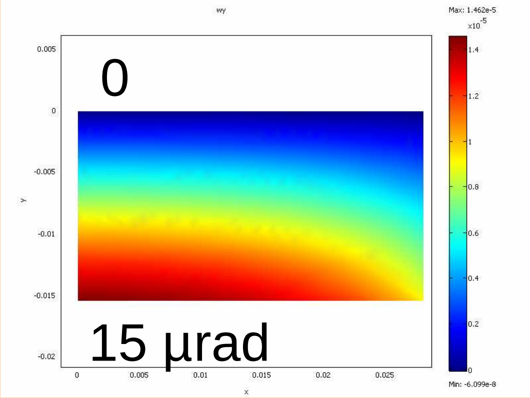
8 keV 40x5 mm $\Delta\omega = 40$ µrad

Total power 129.25 W

in rectangle h= 45.02 mm and v= 22.64 mm on monochromator

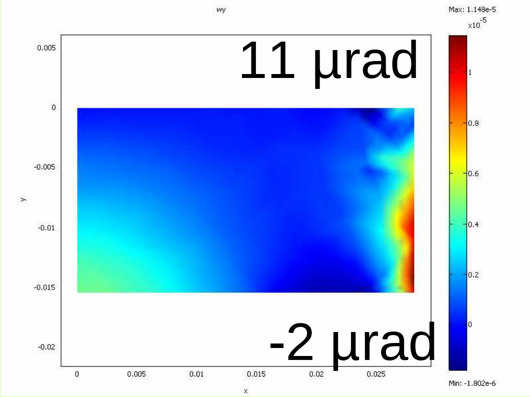
mean power density 0.127 W/mm^2 (mono), 0.5 W/mm^2 (HxV)

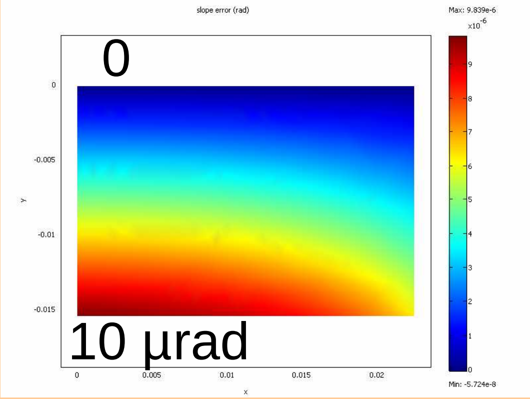




18 keV 50x3 mm $\Delta\omega = 16$ µrad

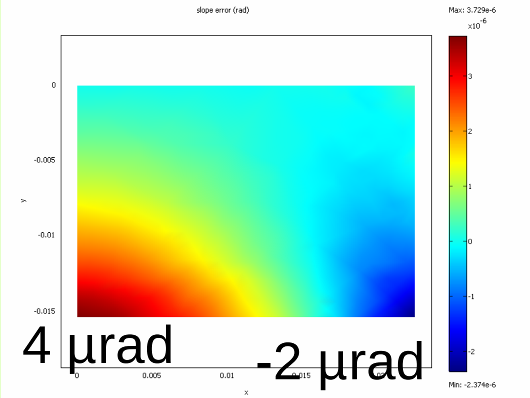
Total power 122.8 W
in rectangle h= 56.28 mm and v= 30.36 mm on monochromator
mean power density 0.072 W/mm^2, 0.1 W/mm^2 (HxV)





27 keV 50x3 mm $\Delta\omega = 10$ µrad

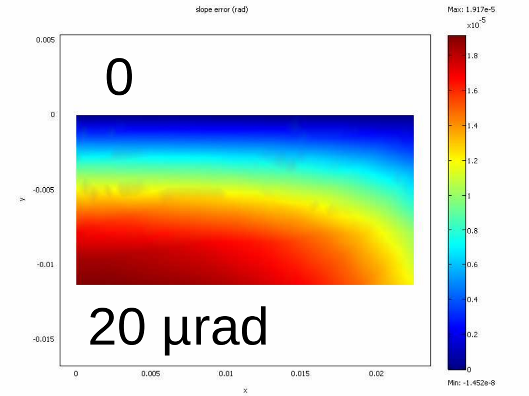
Total power 98.24 W
in rectangle h= 45.02 mm and v= 45.55 mm on monochromator
mean power density 0.048 W/mm^2 or 0.66 W/mm^2 (hxv)



Results: comparison Exp. - FEA

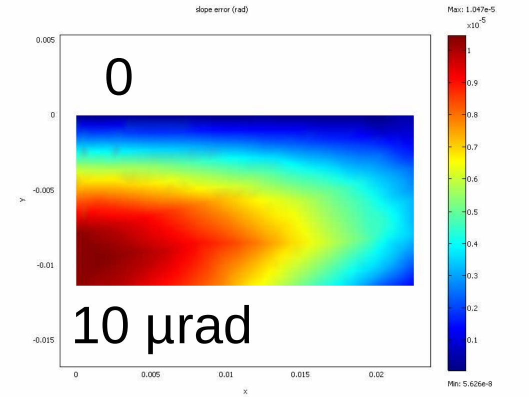
Old Xtal

New Xtal



8 keV 40x5 mm

$\Delta\omega = 40$ µrad

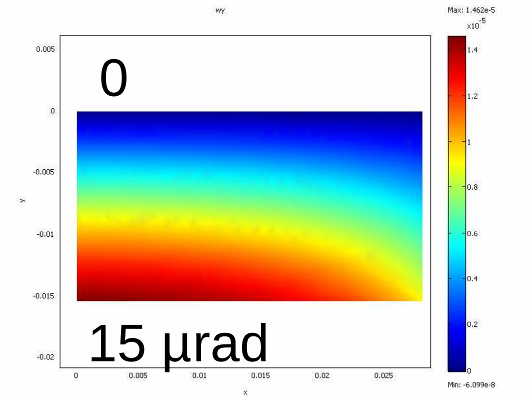


R_{int}=70%

R_{int}=85%

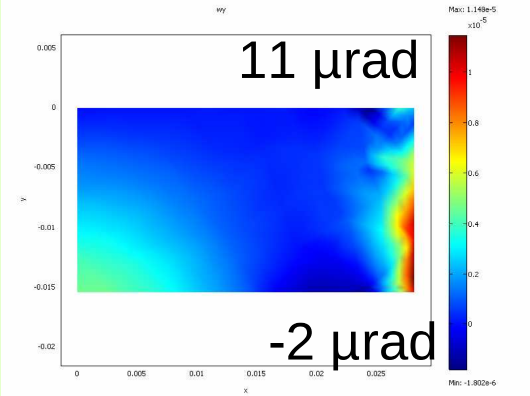
0.5 10^{11} ph/s/200mA

0.7



18 keV 50x3 mm

$\Delta\omega = 16$ µrad

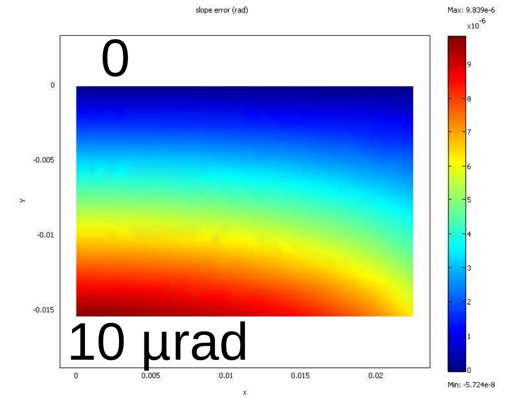


R_{int}=56%

R_{int}=90%

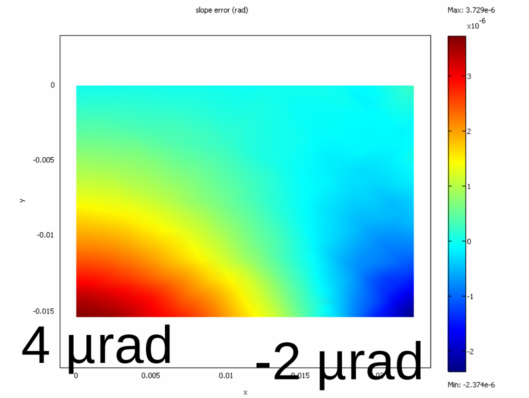
4.32

8.0



27 keV 50x3 mm

$\Delta\omega = 10$ µrad



R_{int}=56%

R_{int}=92%

5.36

8.74

Conclusions

- Optimised crystals mounted on BM32 and BM02 at ESRF

- Photons flux at sample is very close to the theoretical flux
- FEA predicts high R_{int} even for higher storage ring current

Advantages

- Longitudinal bump removed
- Self-tuning crystal
- For one optics configuration => it should exist an optimised shape
- Cheap (indirect cooling + water)
- Simple to design & simple iterative converging methodology
- Standard manufacturing and tailoring
- Easy to mount & not sensitive to mounting defaults

Drawbacks (?)

• Increase of temperature	(but whole setup might be cooled down anyway)
• Weak sagittal bump	(but could be compensated)

Outlook

- Automatic iterative method, use ray-tracing method
- Install on other BM beamline @ ESRF, SOLEIL (DIFFABS,…), etc…
- Apply on Ge/Si (Smart Cut)
- Apply on other reflective surfaces:
    - monochromator with higher power load (wiggler, ondulator)
    - mirror
    - other spectral range (laser)

Thank you for your attention