Optimizing x-ray mirror thermal performance using variable-length cooling for high-repetition-rate FELs.

Corey Hardin, Venkat N. Srinivasan, Lope Amores, Nicholas M. Kelez, Daniel S. Morton, Peter M. Stefan, Daniele Cocco

August 28th, 2016

Thanks to: J. Krzywinski, E. Ortiz, G. Gassner, M.L. Ng, L. Zhang, D. Rich, M. Rowen, M. Idir, Jtec, Axilon, D. Flath, A. Wallace, T. Pardini, L. Christensen, K. Alano, L. Raimondi, T. Rabedeau, L. Ladao, M. Church, L. Lee, D. Stefanescu, D. Fritz, A. Catalano…....

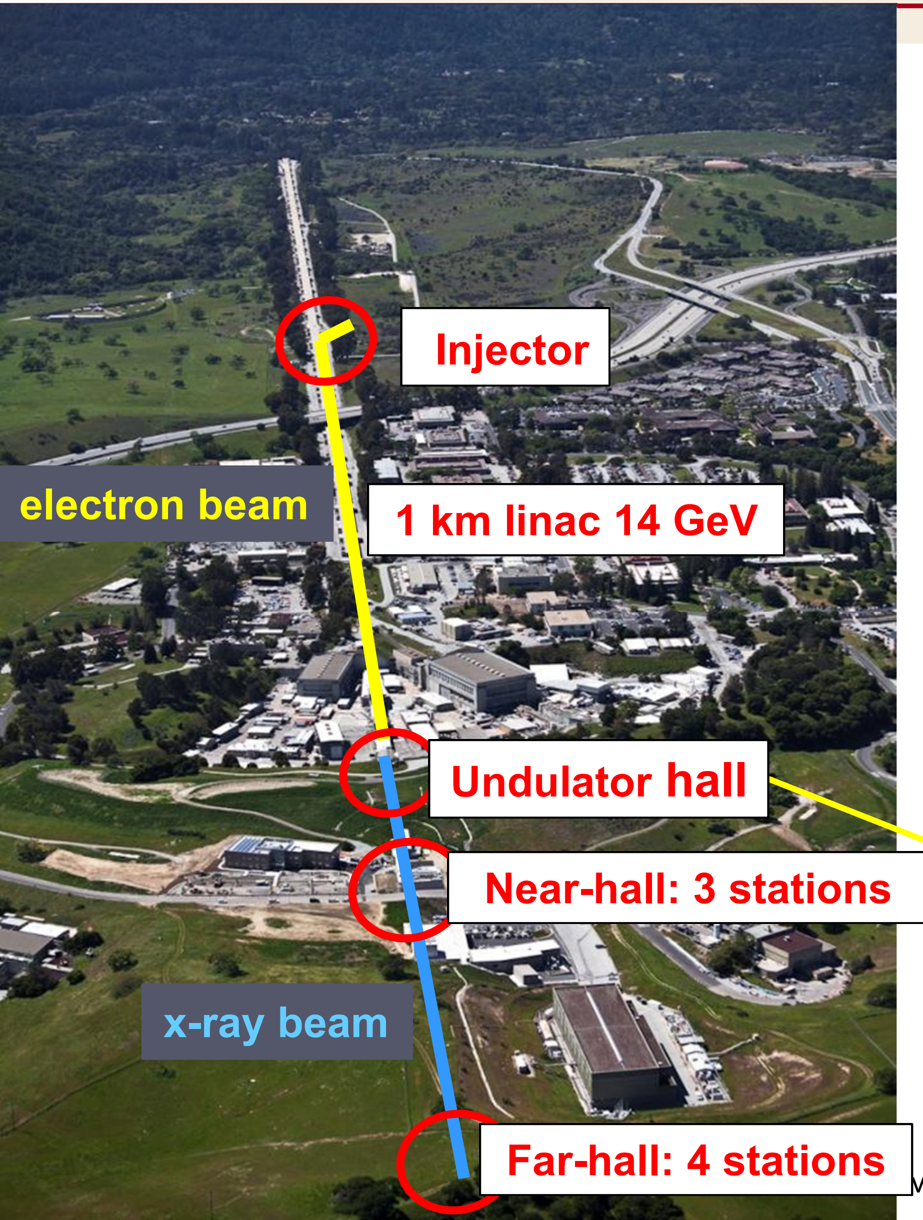
U.S. DEPARTMENT OF ENERGY Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

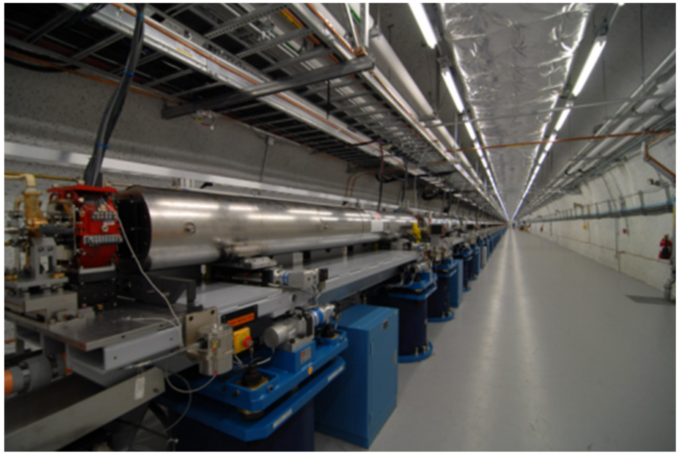
Linac Coherent Light Source

LCLS is part of the SLAC National Accelerator Laboratory located within the Stanford University campus in Menlo Park, CA.

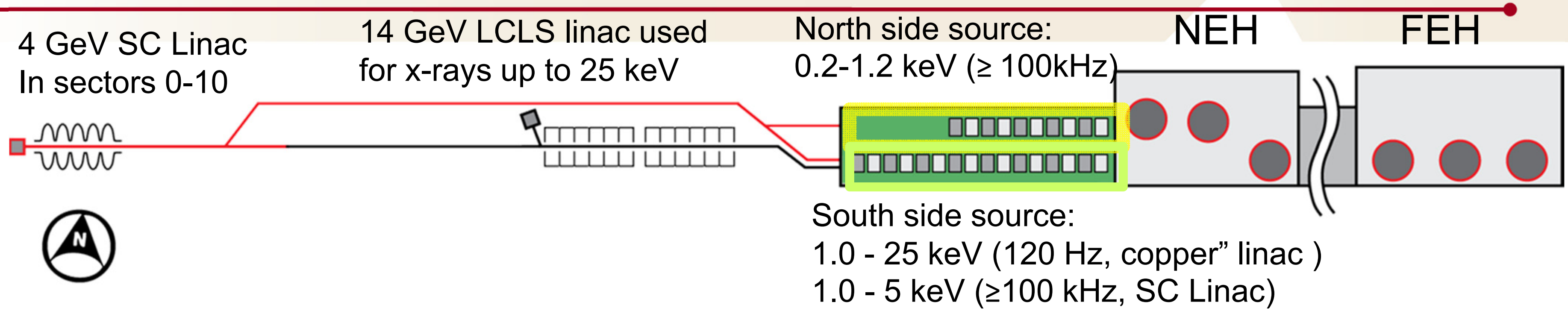
Linac Coherent Light Source



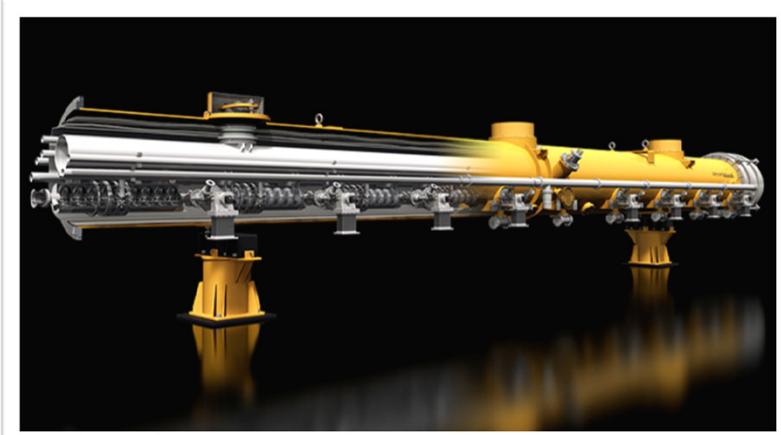
- Uses last 1 km of 3-km linac
- e-beam energy: 2-14 GeV
- X-rays produced by ~100 m undulator
- Photon energy range: 250 eV-10 keV
- Pulse length: 1 -100 fs
- 6 experimental stations
- >600 On Site Users per from over 30 countries



LCLS - II



SLAC NATIONAL ACCELERATOR LABORATORY
BERKELEY LAB
Argonne NATIONAL LABORATORY
Cornell University Founded A.D. 1865
Fermilab
Jefferson Lab



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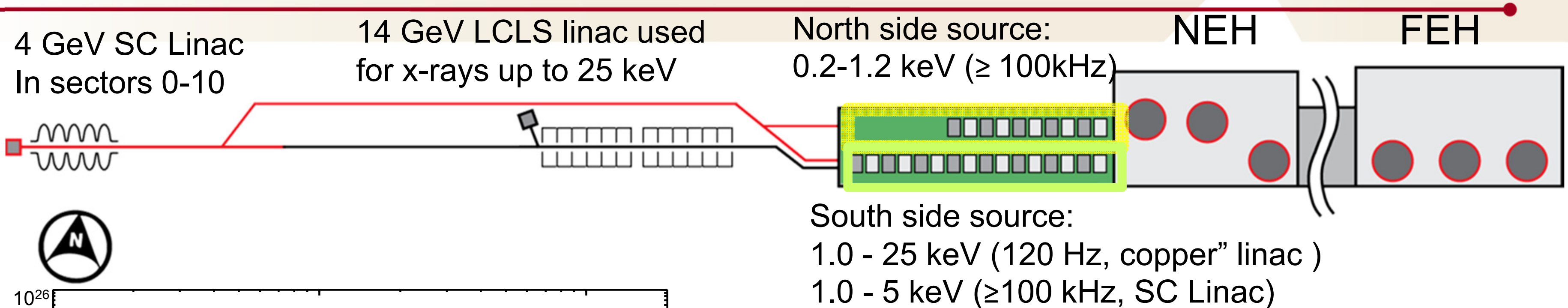

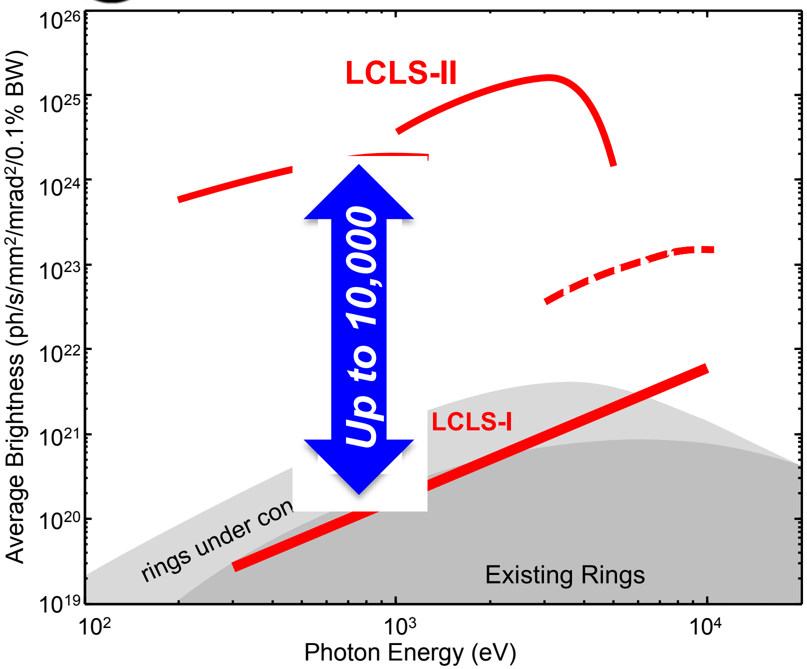

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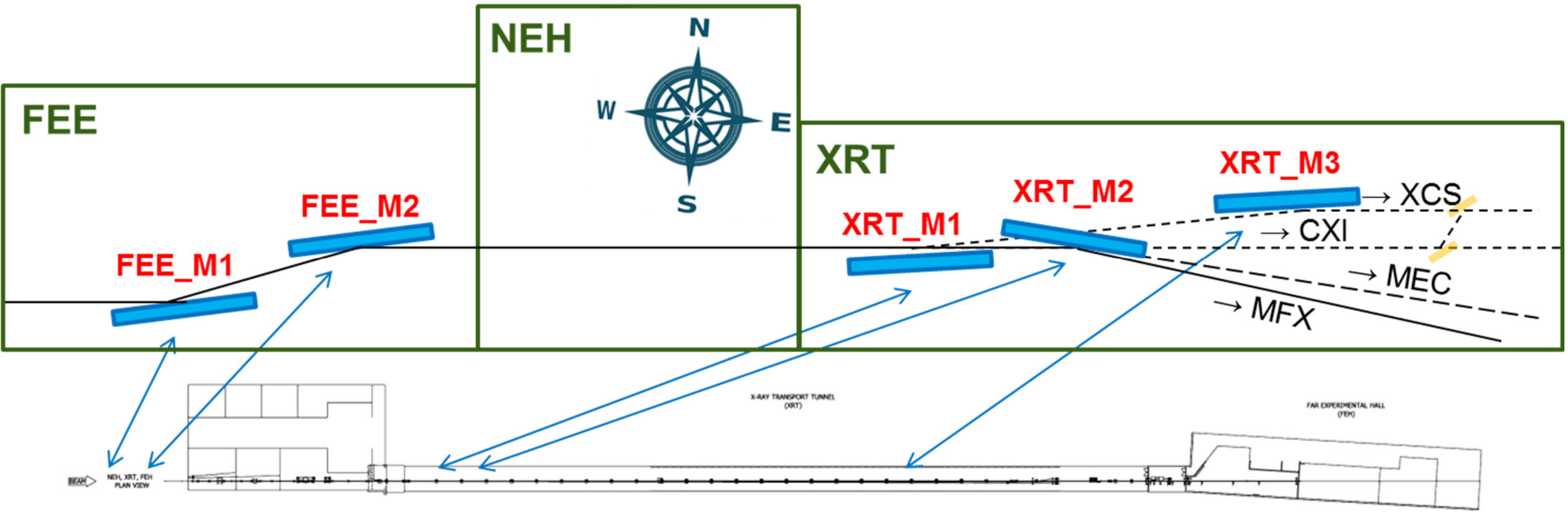
From the current 2-300 mW to up to 600 W on the optics

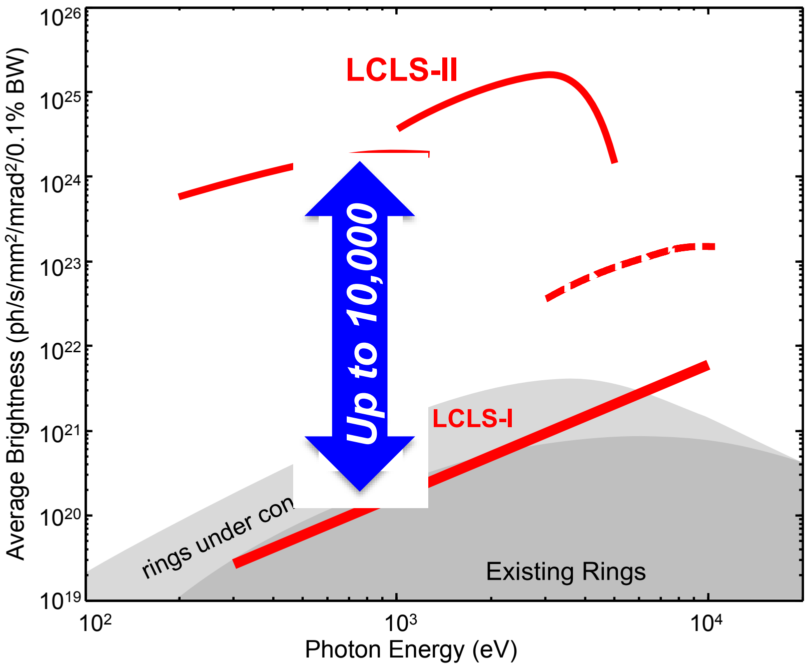
LCLS-I Flat Mirror System Locations



Ack: D. Cocco

LCLS Flat Mirror System Upgrade

- We need to upgrade the flat mirrors at LCLS to accommodate LCLS II upgrade
- Mirror Requirements:
  - Preserve wavefront in and out of focus
  - Optimized for lower power but with good performance at higher power (200 W)
  - Accommodate Variable beam footprint (from 70 to 400 mm FWHM)
  - Limit induced vibration
  - Avoid LN2, to limit contamination absorption

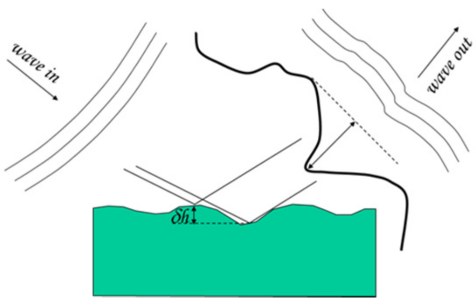


From the current 2-300 mW to up to 600 W on the optics

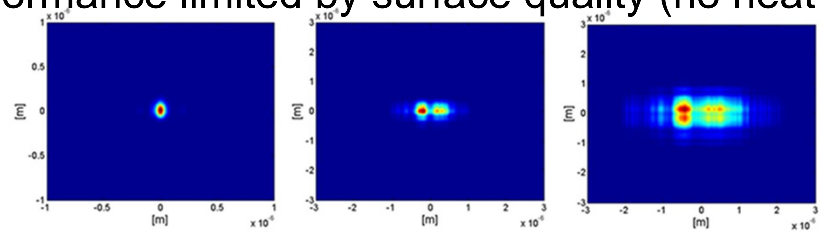
Motivation - Mirror shape errors requirements

- Preserve wavefront in and out of focus
- Optimized for lower power but with good performance at higher power (200 W)

From what we have now (1-2 nm rms shape error mirrors, limited acceptance)



Performance limited by surface quality (no heat load)



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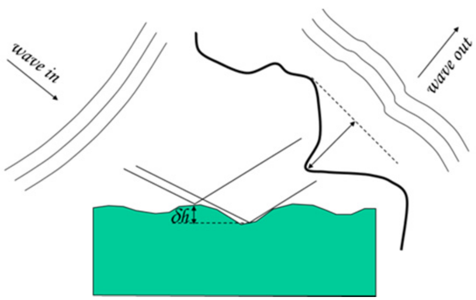

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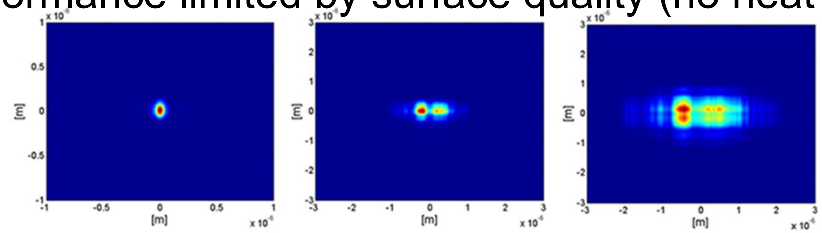
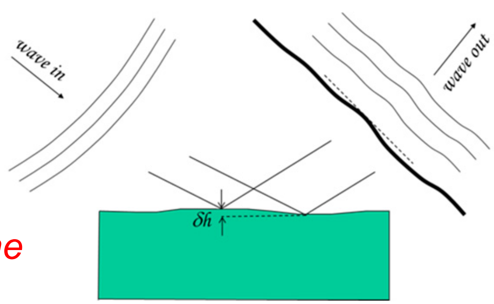
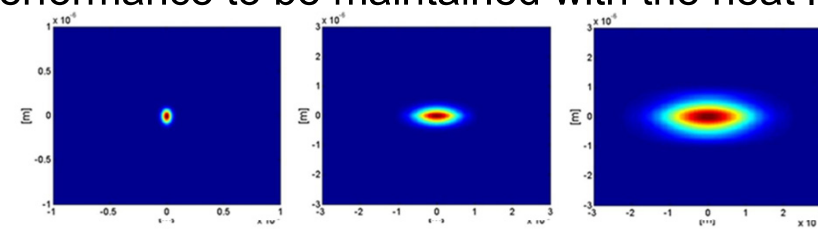


In focus | 1 mm out of focus | 2 mm out of focus

..to what we need to have (< 0.5 nm rms, 2 FWHM acceptance) *with up to 200 W on the mirror*



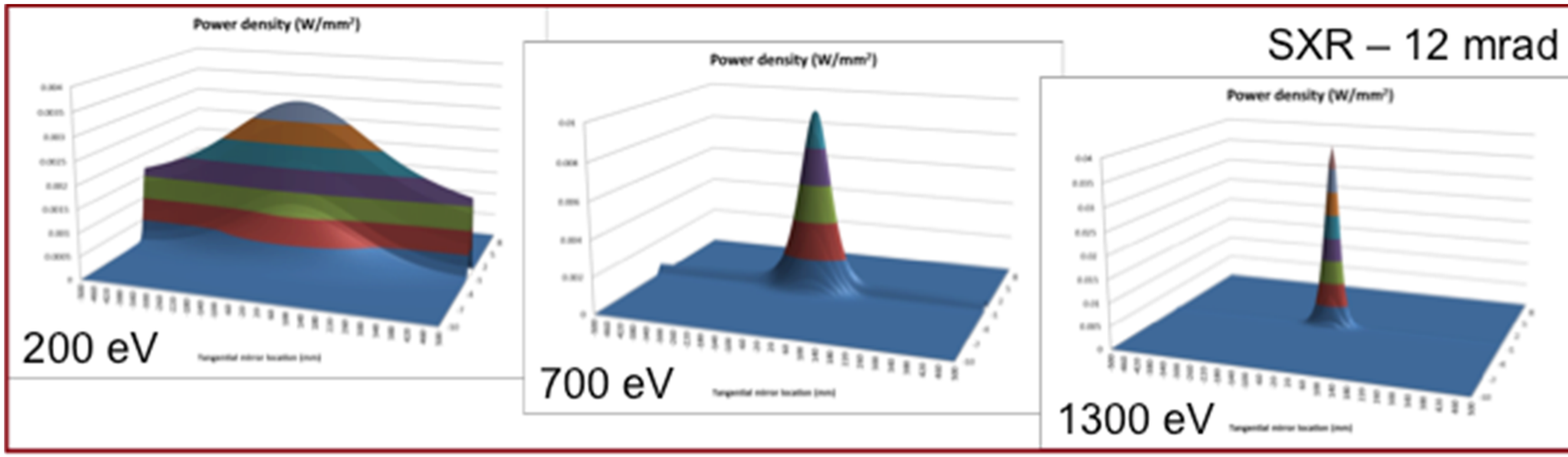
Performance to be maintained with the heat load

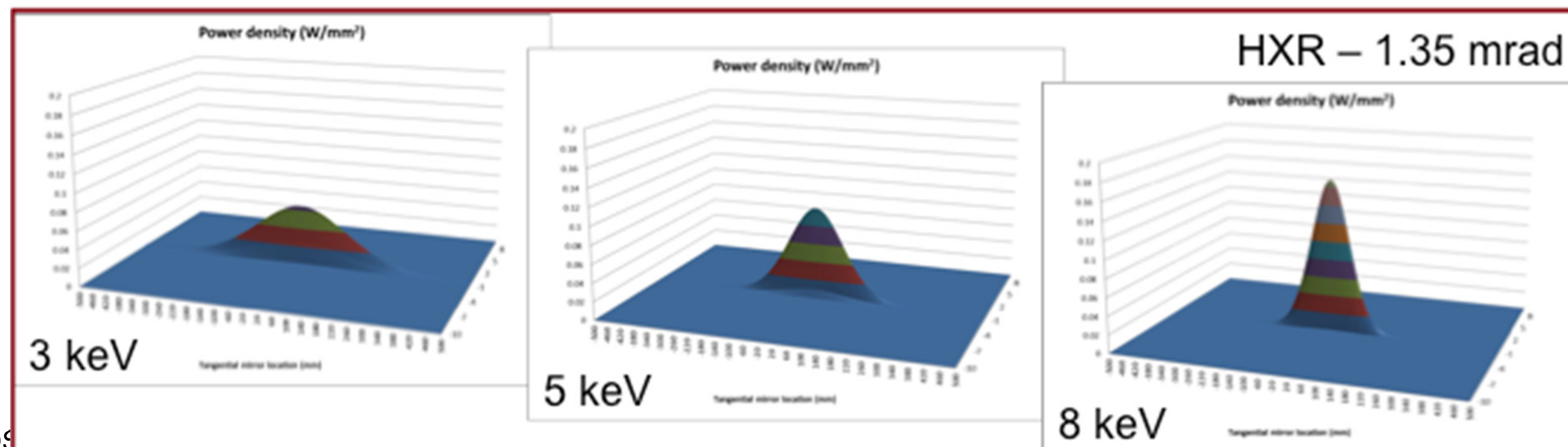


In focus | 1 mm out of focus | 2 mm out of focus

Absorbed power profiles – Flat mirror case

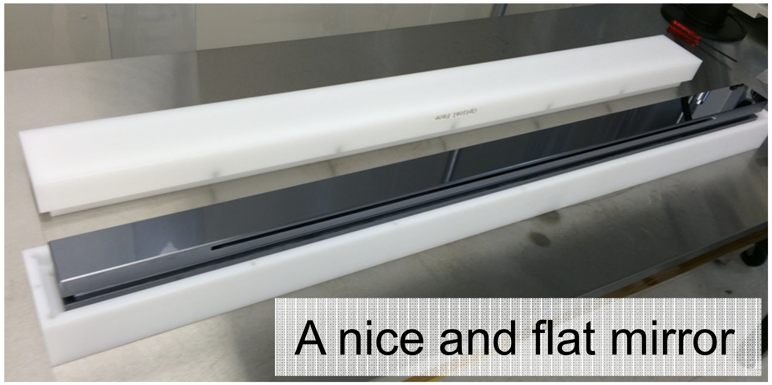
Wide energy range leads to a highly variable beam footprint (from 70 to 400 mm FWHM)

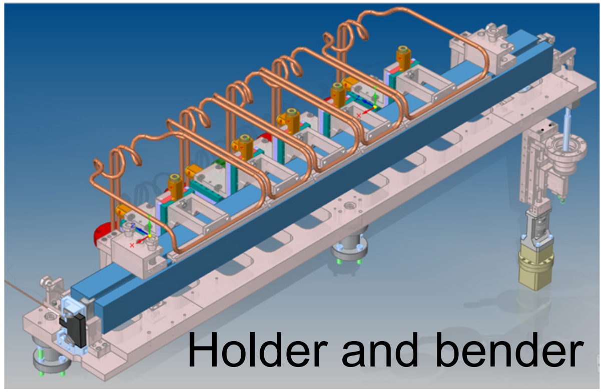




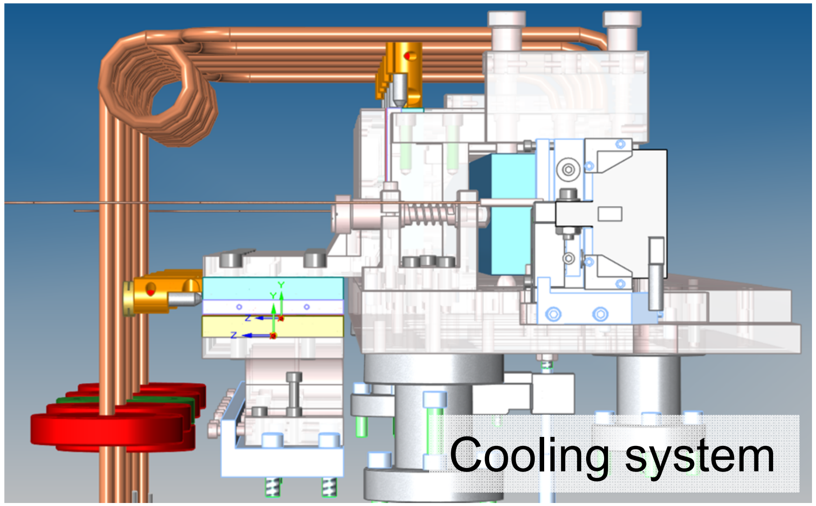
Introduction to the Flat mirror system

It is composed by:





Design, assembled and tested in house (an entire unit has been realized and tested)



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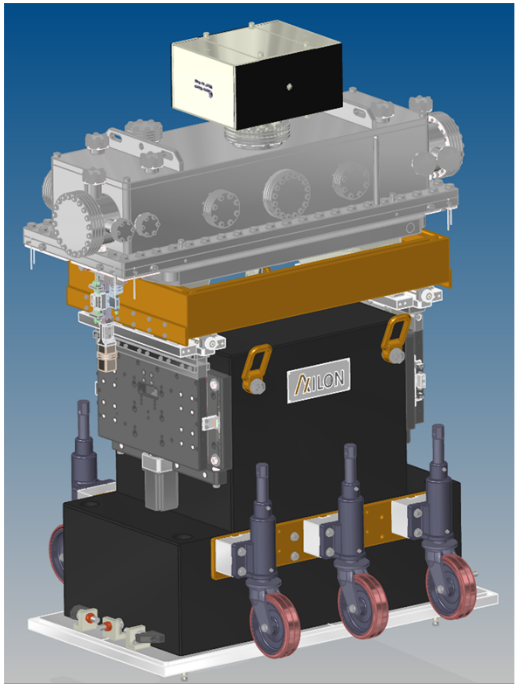
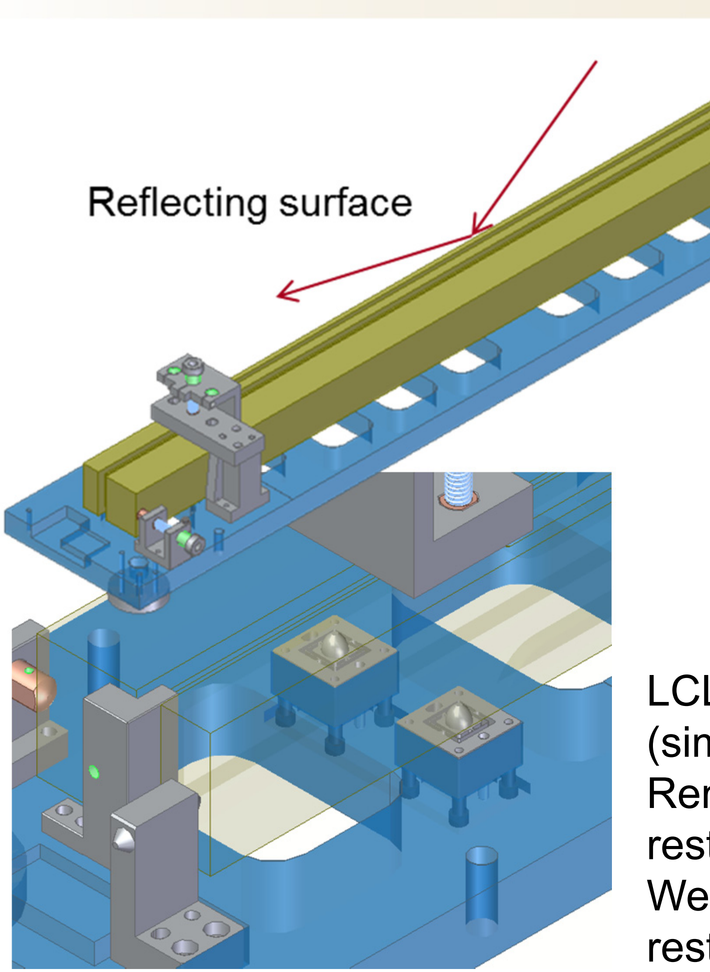
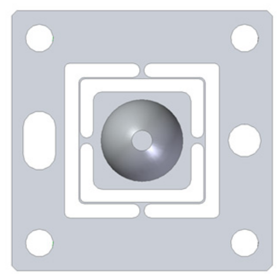


A robust and stable vacuum and mover system (identical system has been procured for the HOMS upgrade project of LCLS) Build to specs.

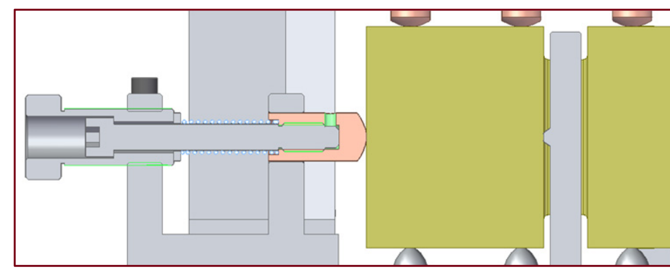
Flat Mirror - Holder



3 Vertical and 2 horizontal restraints
Positioned outside the Bessel points, to minimize the induced deformation in the central area



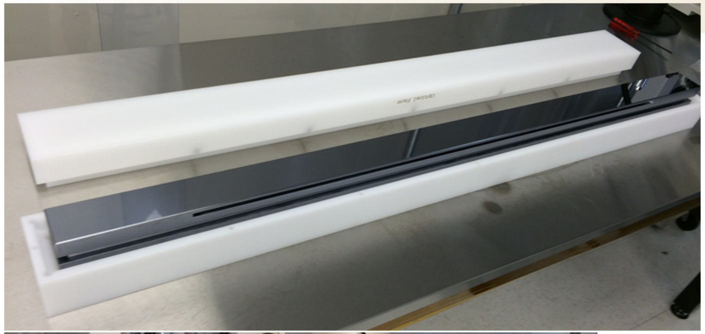
LCLS –I flexure design
(similar to the McCarville design)
Removable, to accommodate different restraints
We will use the higher compliance restrains to reduce deformation

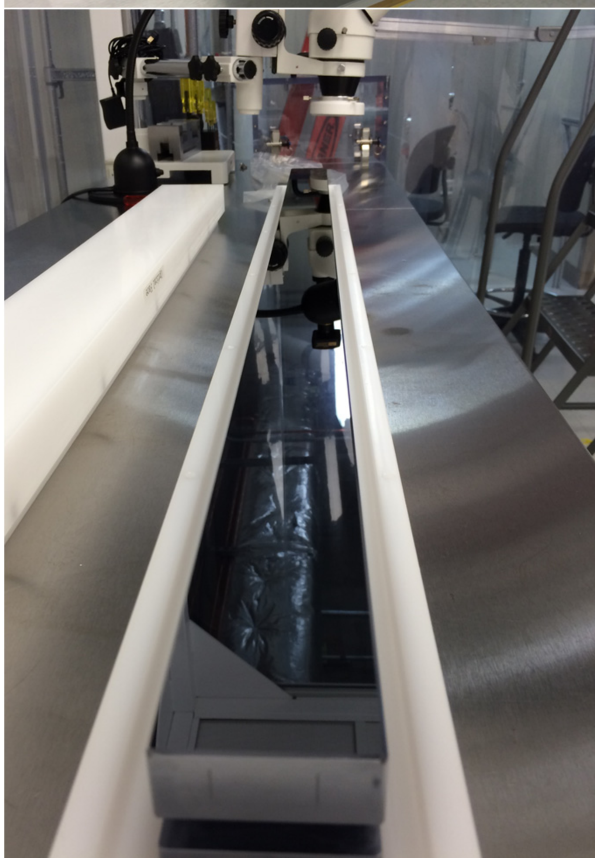


Horizontal pusher
Using the notch around the mirror

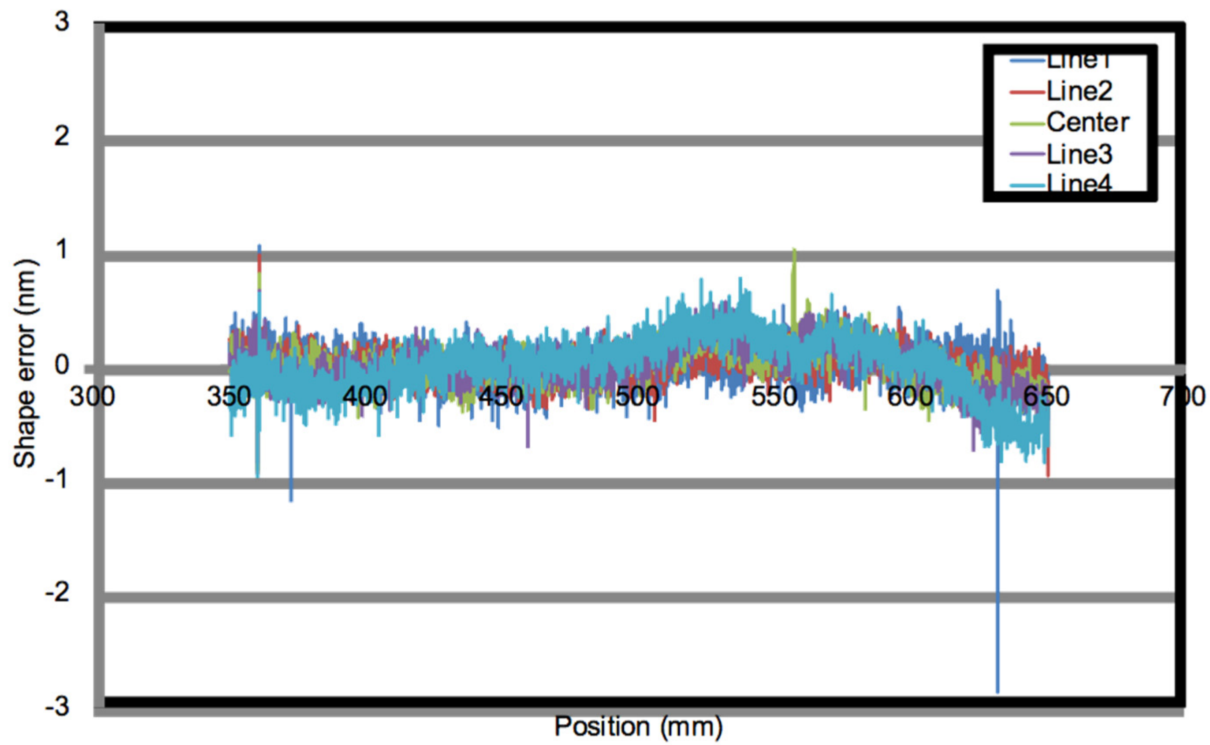
System tested with Jtec mirrors. No appreciable deformation seen.
Careful installation procedure has to be followed

The mirrors exist!



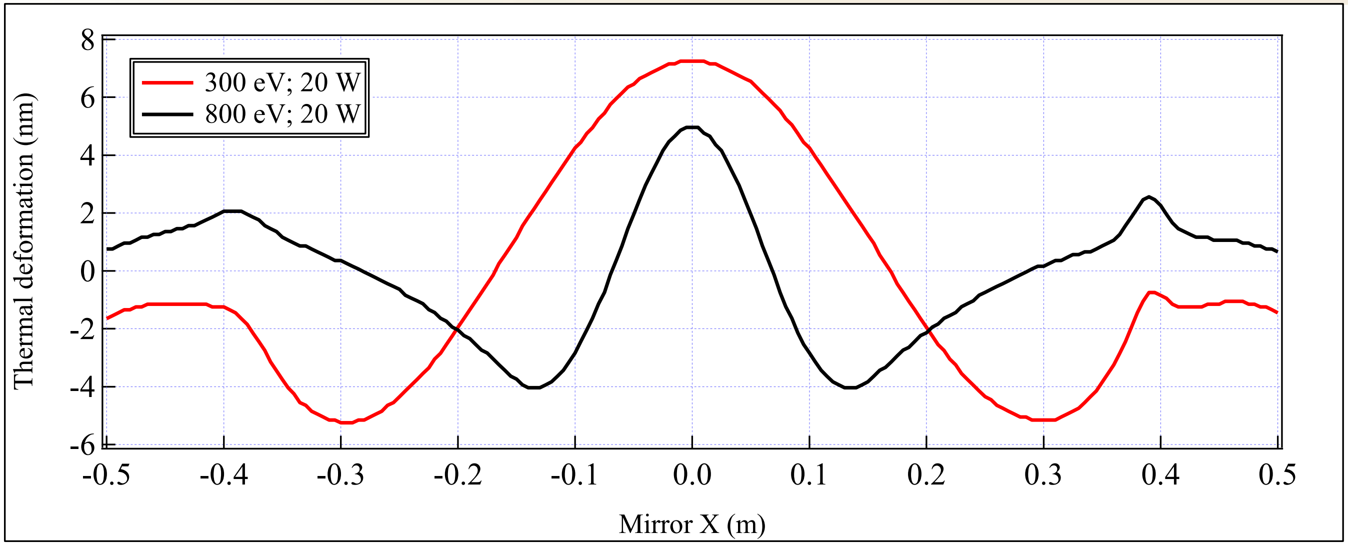


- First three (3) 1-m long mirrors for HOMS upgrade received in May 2016 at SLAC
- They are the <u>best mirrors ever manufactured in the world</u>!
- < 0.2 nm rms in the central 300 mm and < 0.6 overall
- R >900 Km

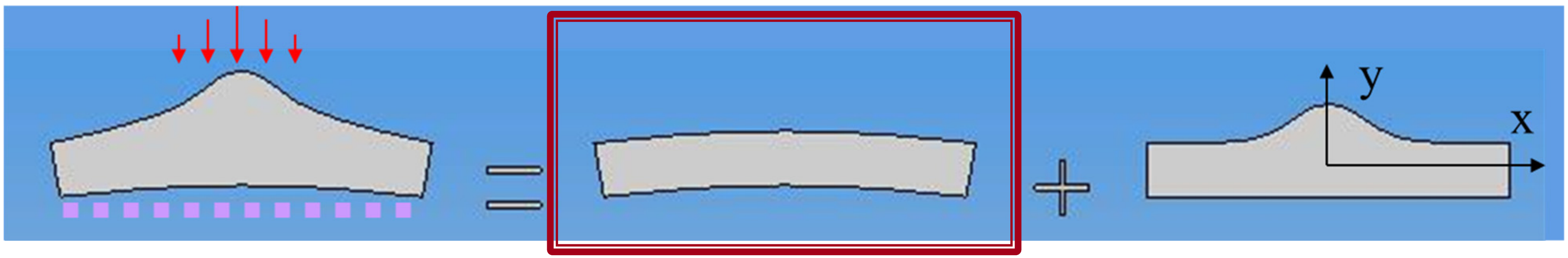


Measured shape errors at parallel lines at the vendor premise

Thermal deformation – spherical part



The deformation include a spherical thermal bump (dash lines) and residual shape errors

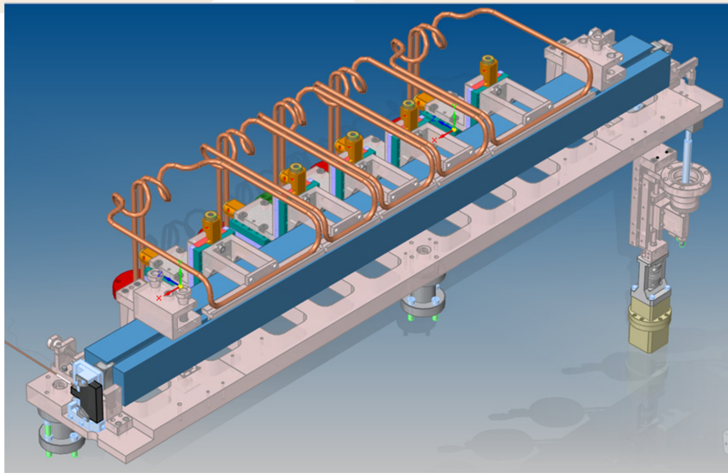


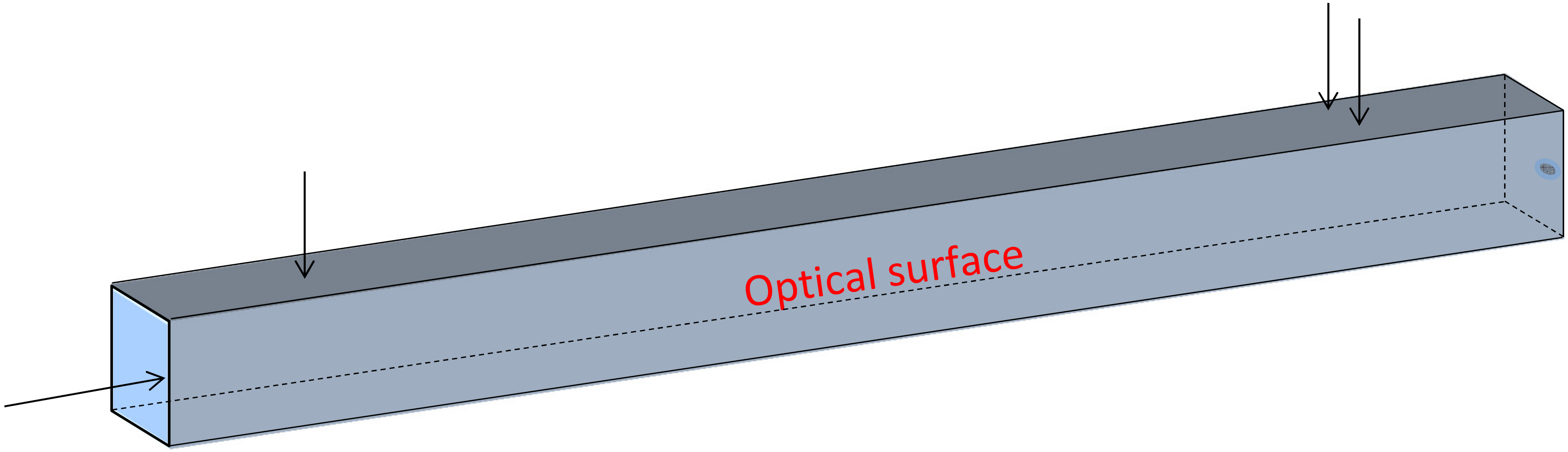
Flat Mirror - Bender

We Need to preserve the flatness – R>900 Km

(with and without heat load)

- Successfully optimized installation procedure to do not introduce stress on the mirror (measured R > 1000 km!)
- Tested effect of each restrain (no visible mirror deformation)
- Tested the bender reproducibility (impressive preliminary results)





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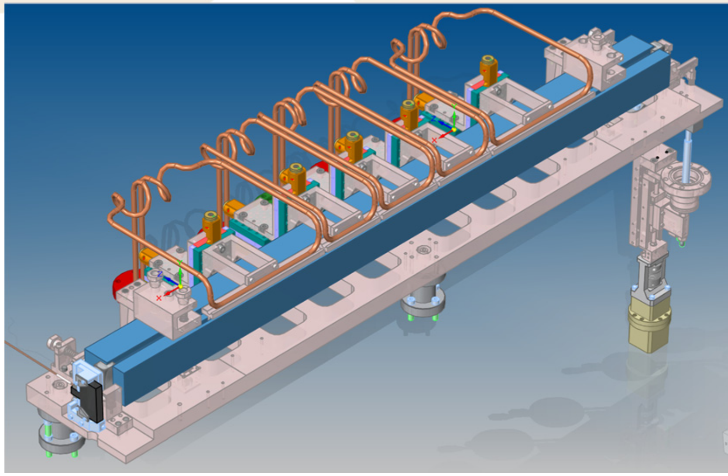
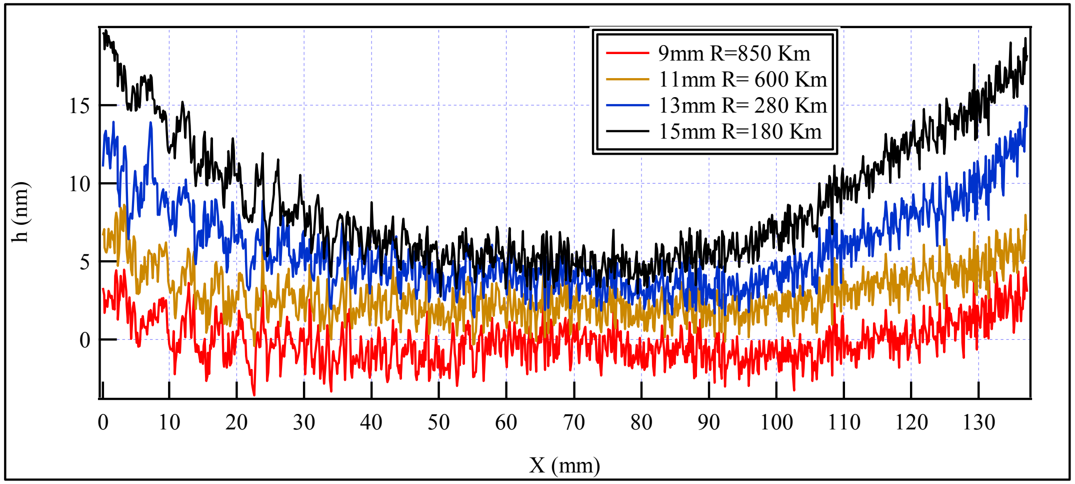
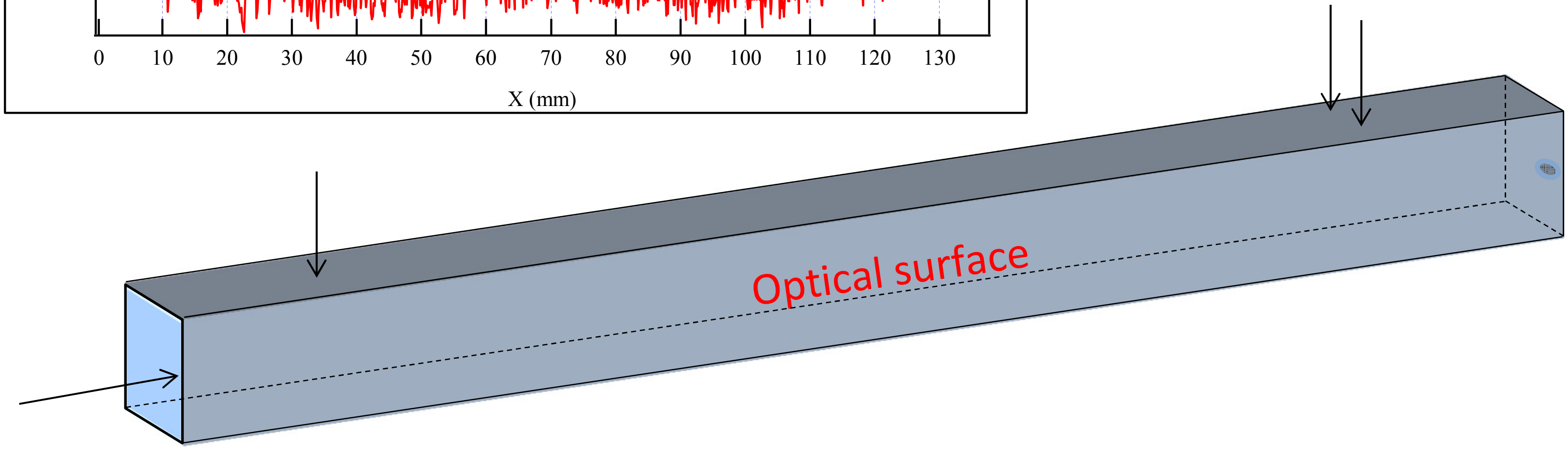
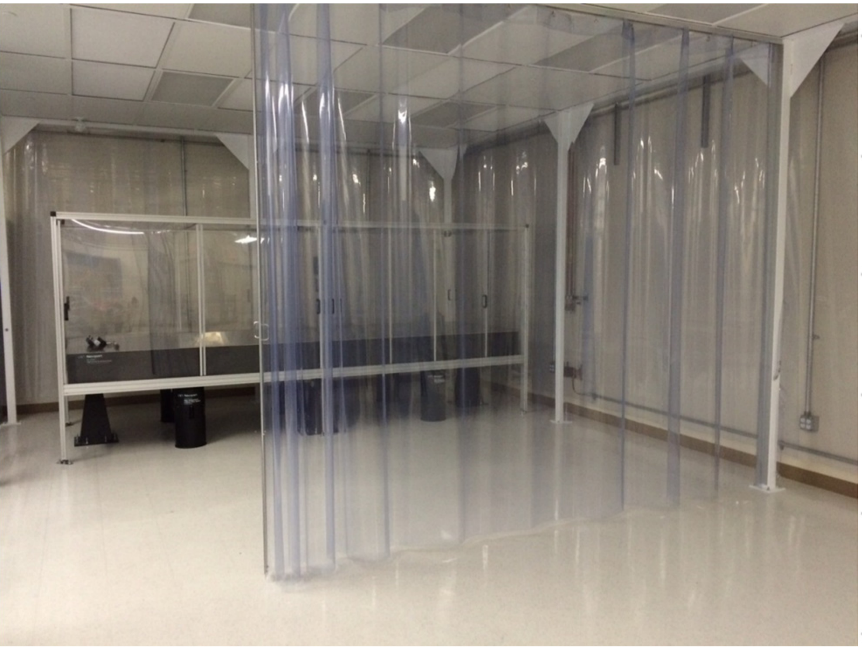


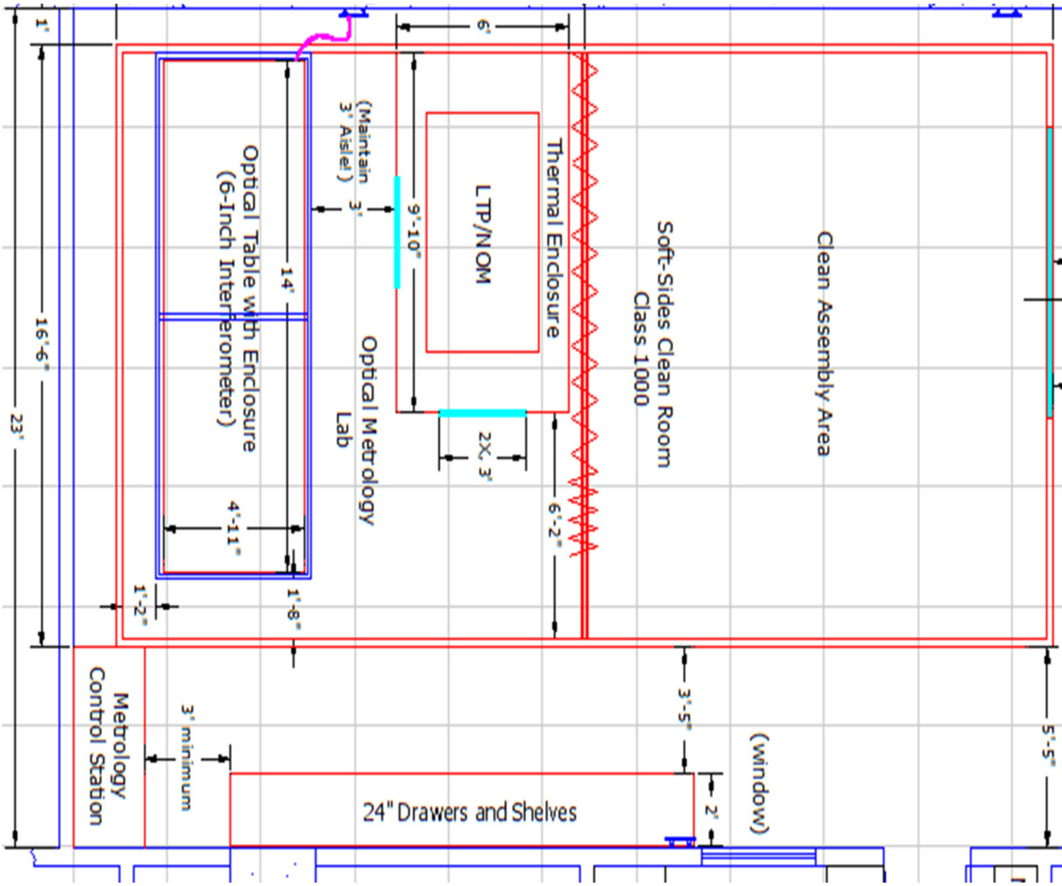




Metrology Laboratory

Class 1,000
Based on 16 HEPA filter
Enclosure provided by
clear vinyl curtain

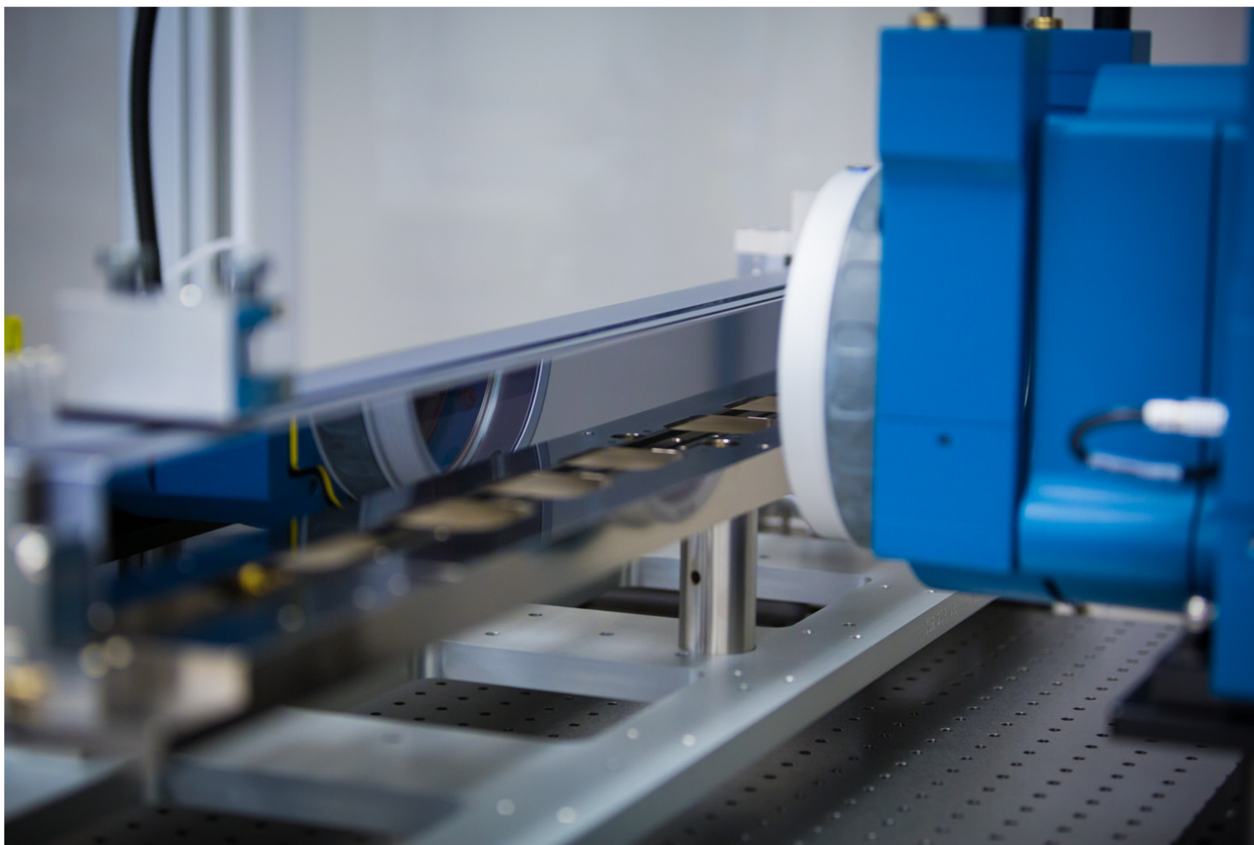


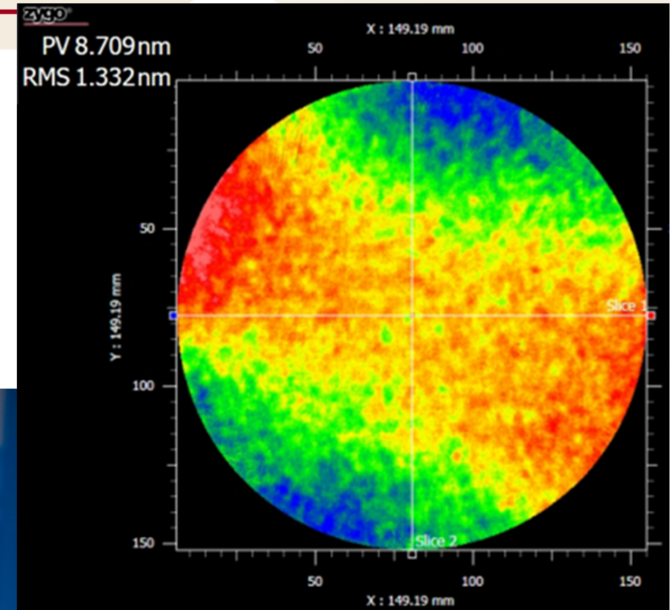


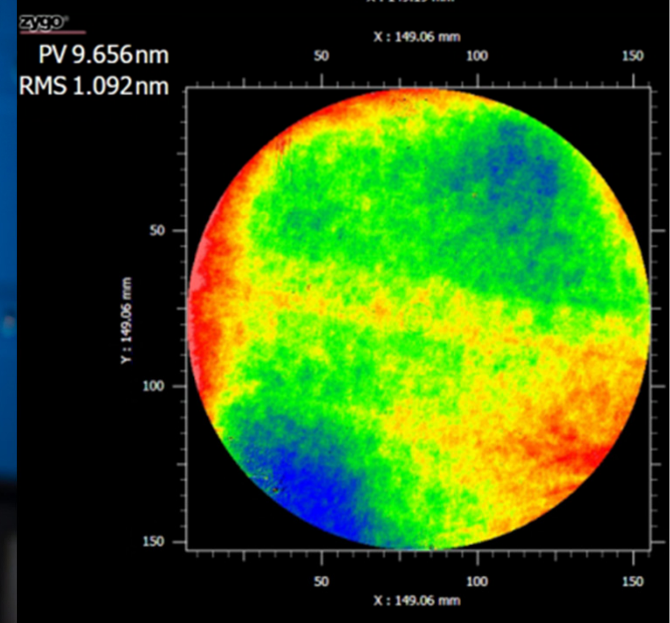
Humidity and temperature controlled by maintaining stable the circulating air.
Temperature stability: +/- 0.1^{o}C with up to 8 people in the room (by design) at 85^{o}F
Humidity: +/- 2.5% at 50%

Fizeau Interferometer

- We have 3 thick, very flat references for our interferometer.
- 1 λ/300, 1 Dynaflect λ/300 (4%LT), and one λ/50.

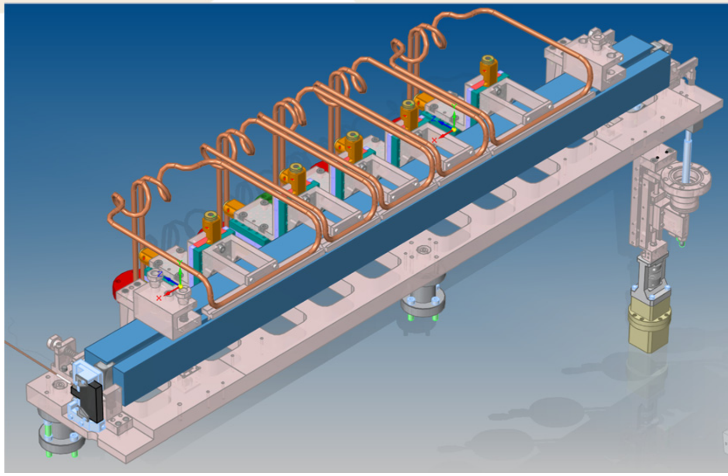


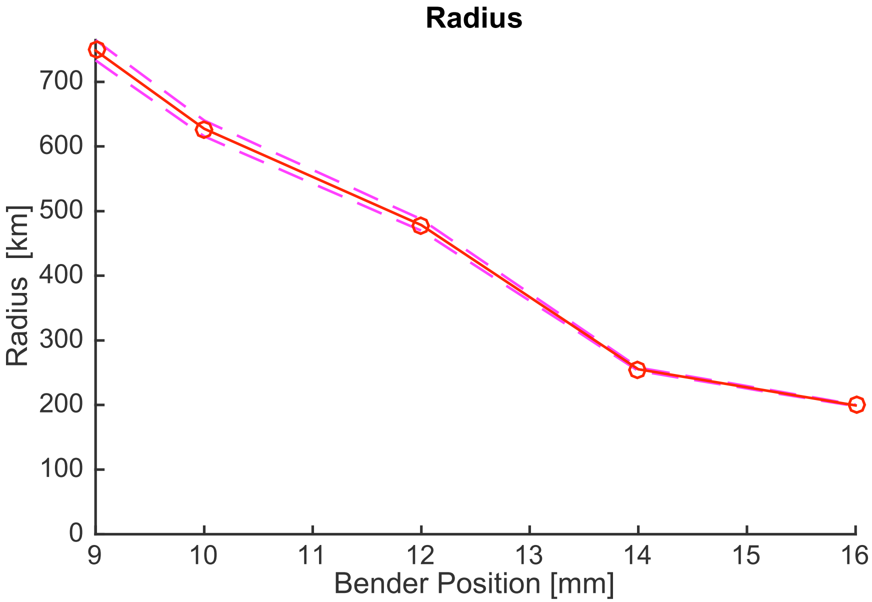


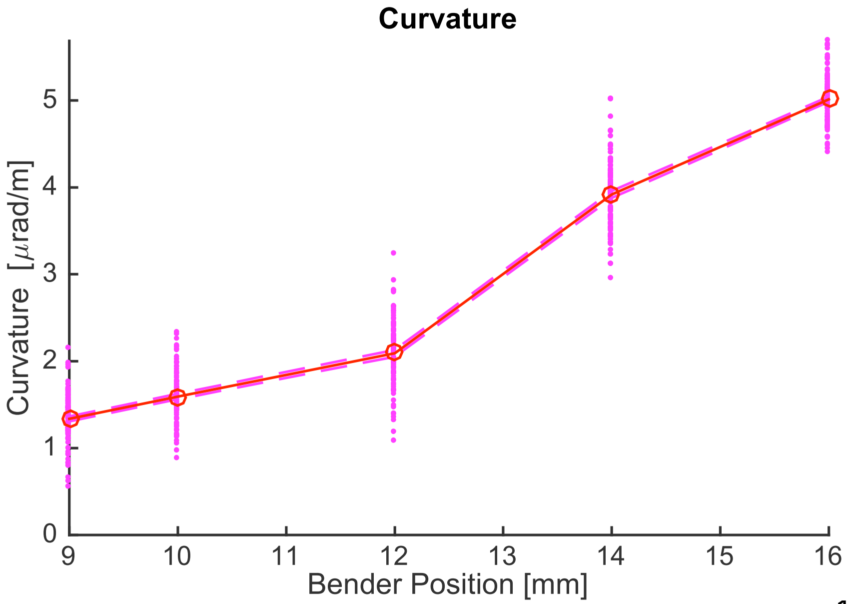


Test results on the bender

Several rounds of measurements performed (>1000 measurements)
Designed to compensate radius of 250 Km (expected to be able to compensate radius as short as 150 Km)



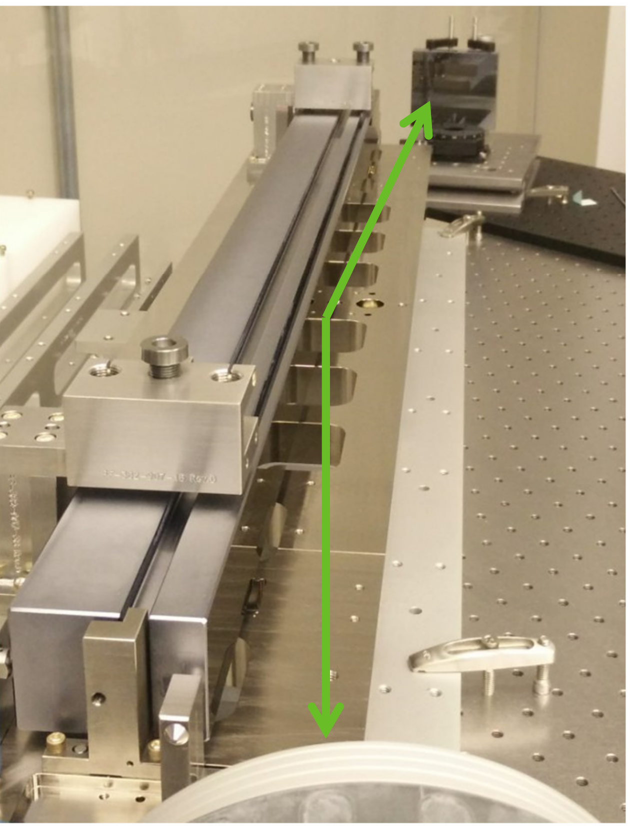


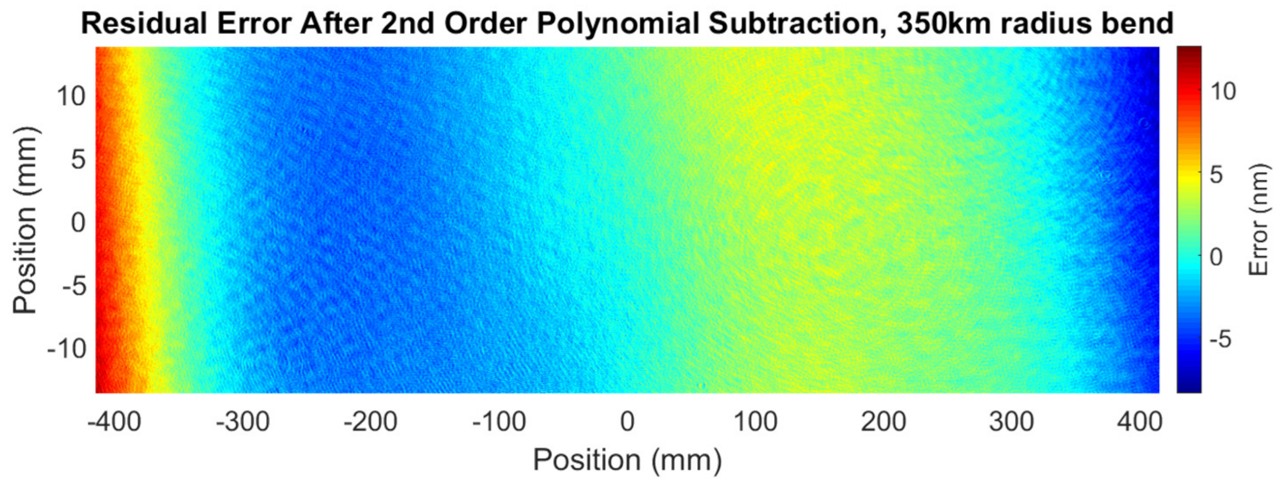


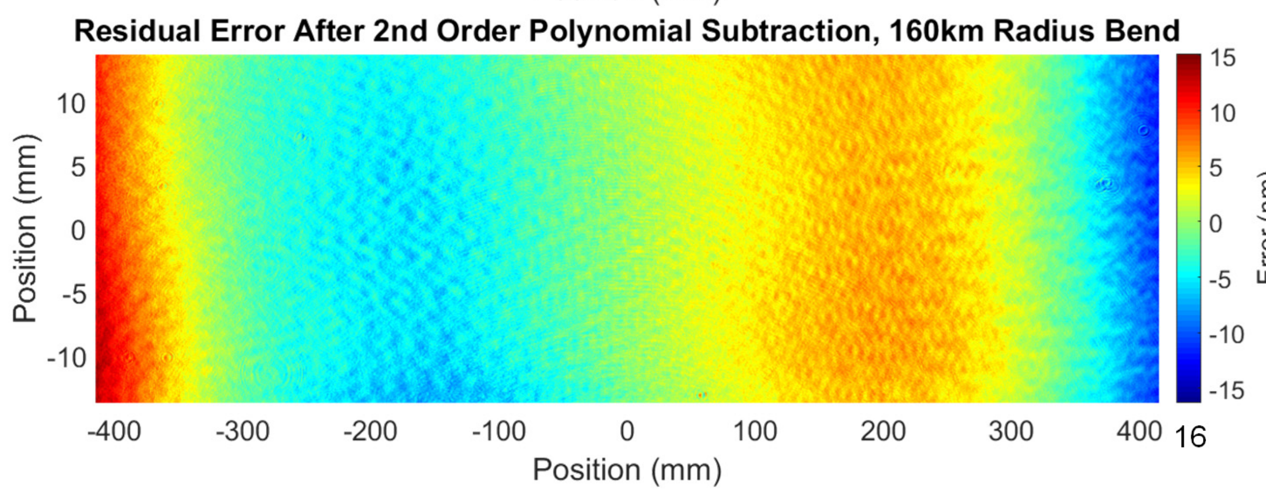
Grazing Incidence Measurements

The bender induces a small, low special frequency residual cubic error term measured in grazing incidence (~10nm PV)

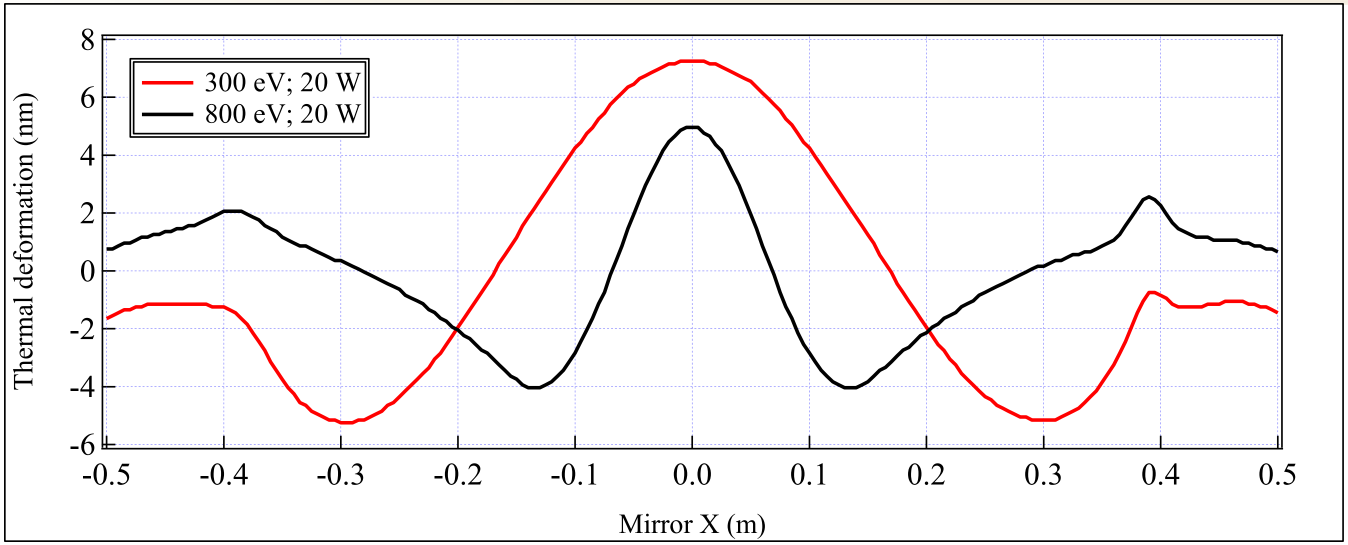
Resolution is ~1/5th Normal Incidence at a Grazing Angle of 5.6 degrees (~0.5nm)





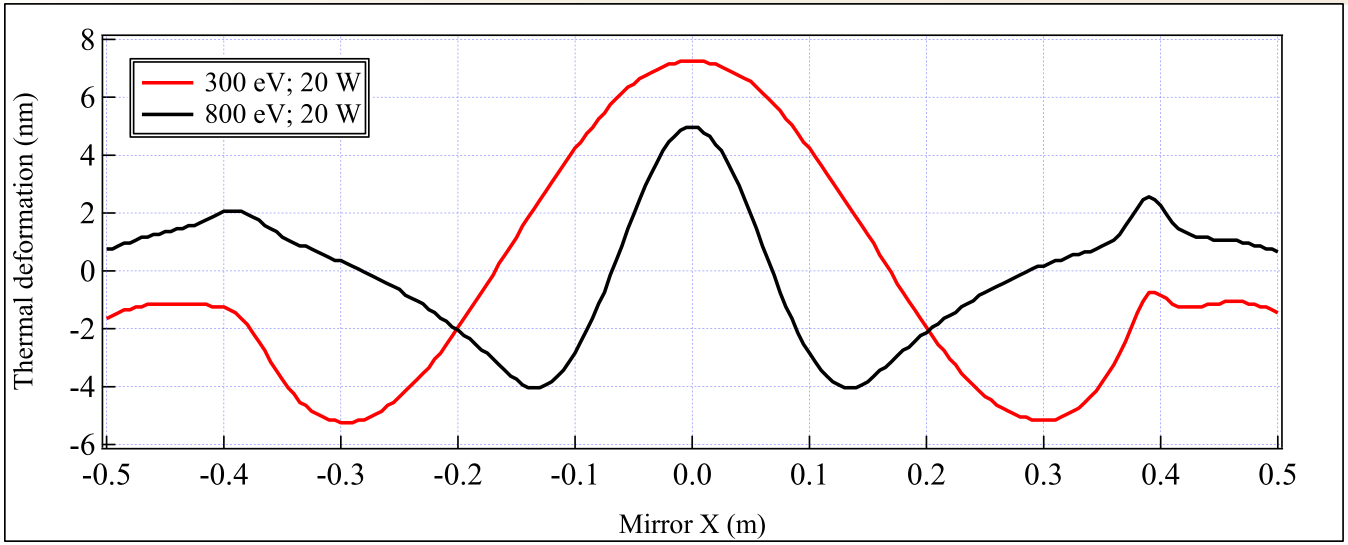


Thermal deformation – aspherical part



Photon Energy (eV)	Power (W)	Radius (km)
300	20	1,800
800	20	920
200	200	~470
1300	200	~200

Thermal deformation



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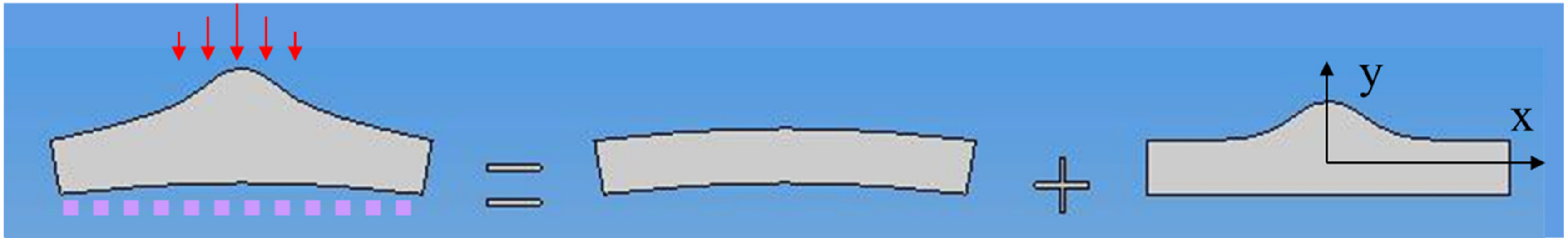
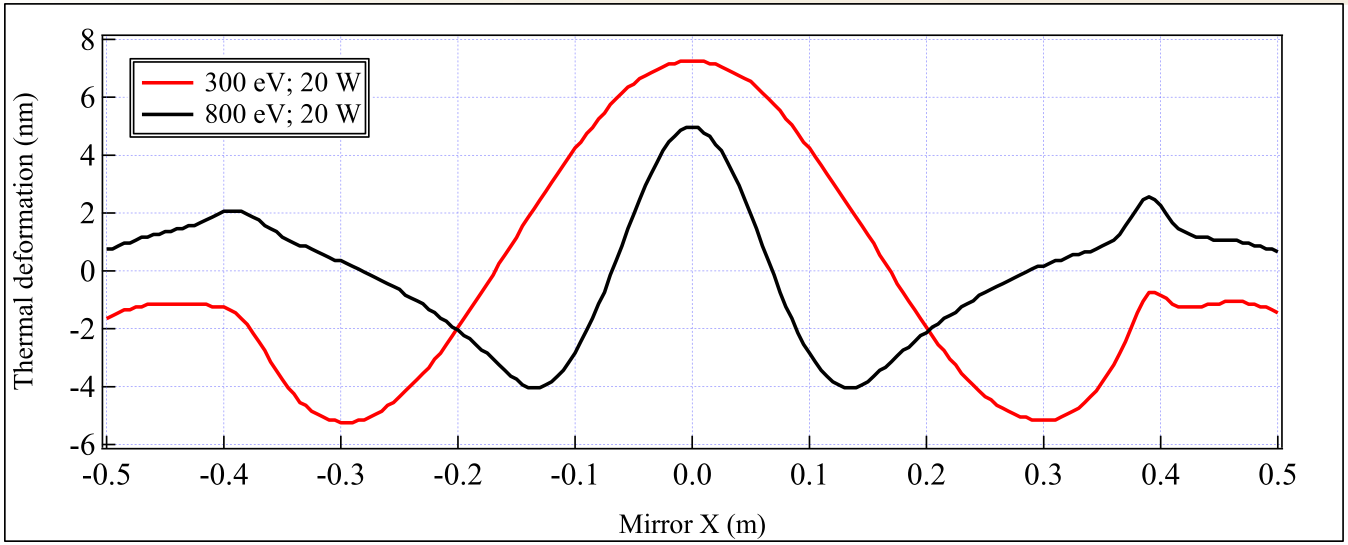


Thermal deformation



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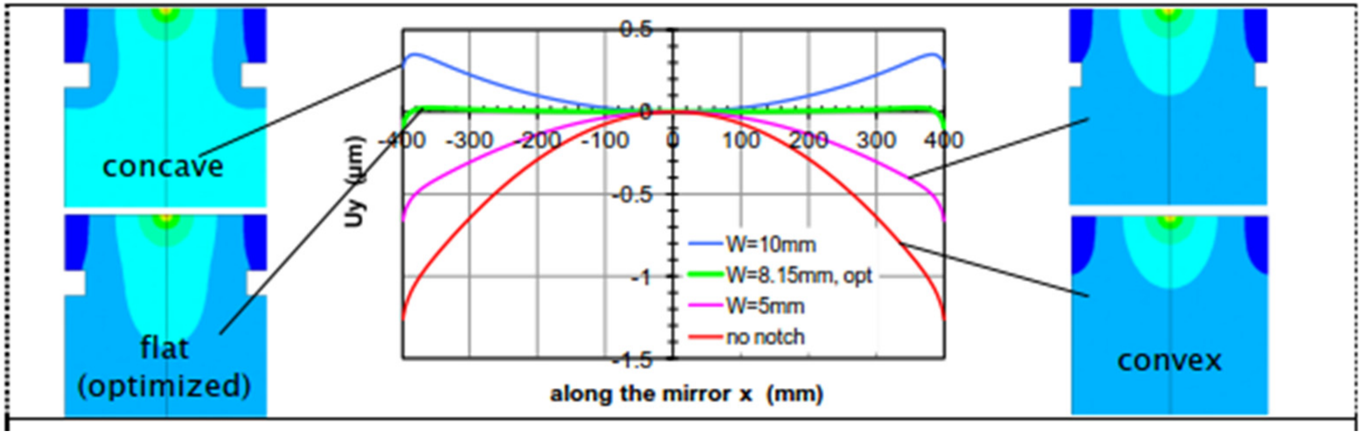
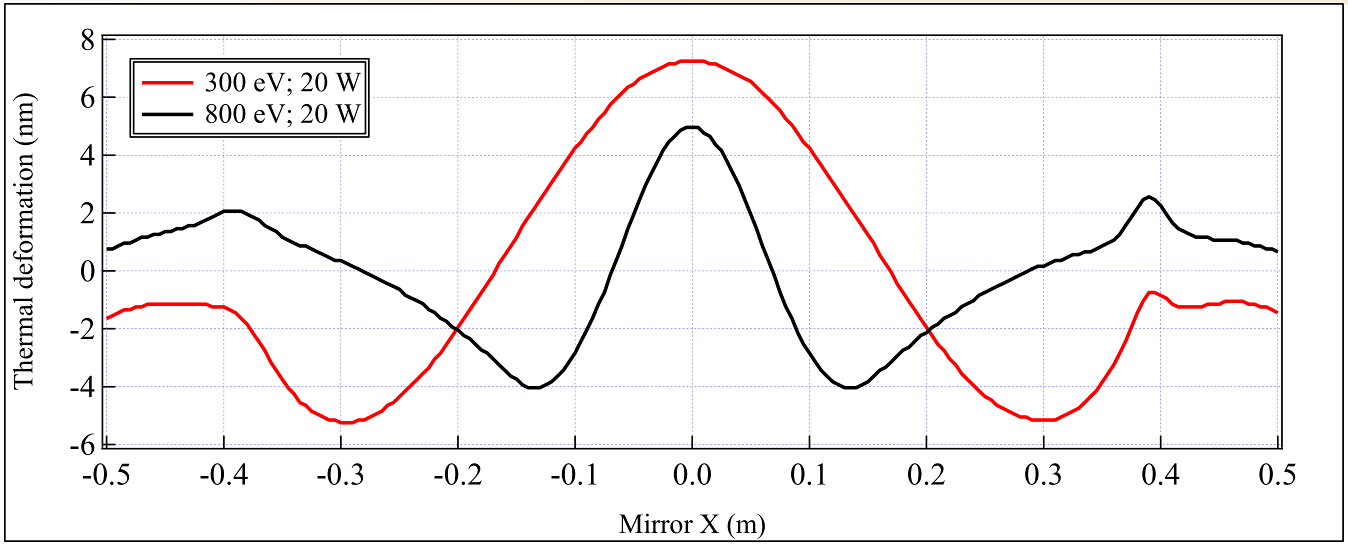


Thanks to the notch, the induced spherical thermal bump can be minimized for a range of beam footprints

Thermal deformation



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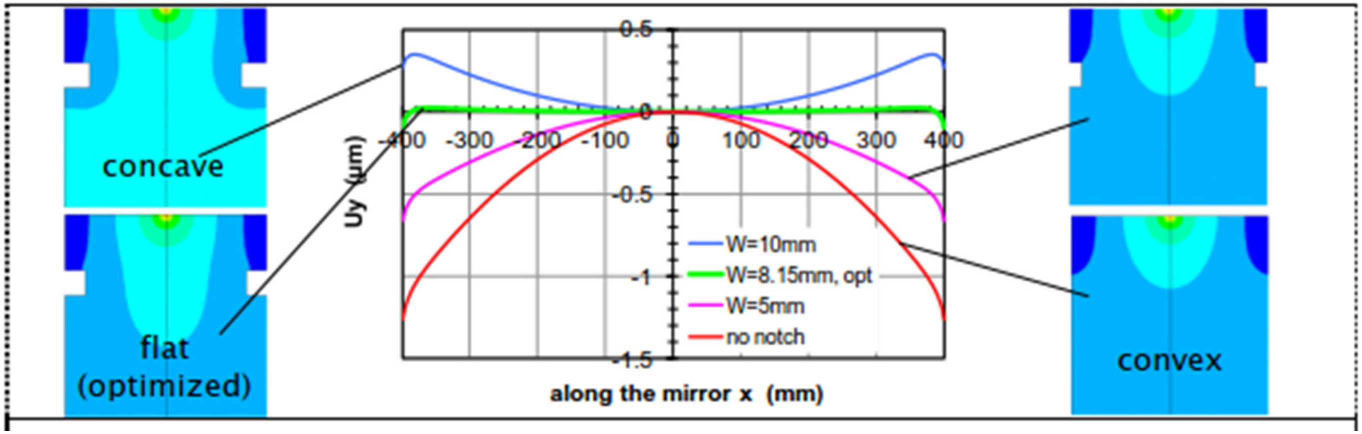
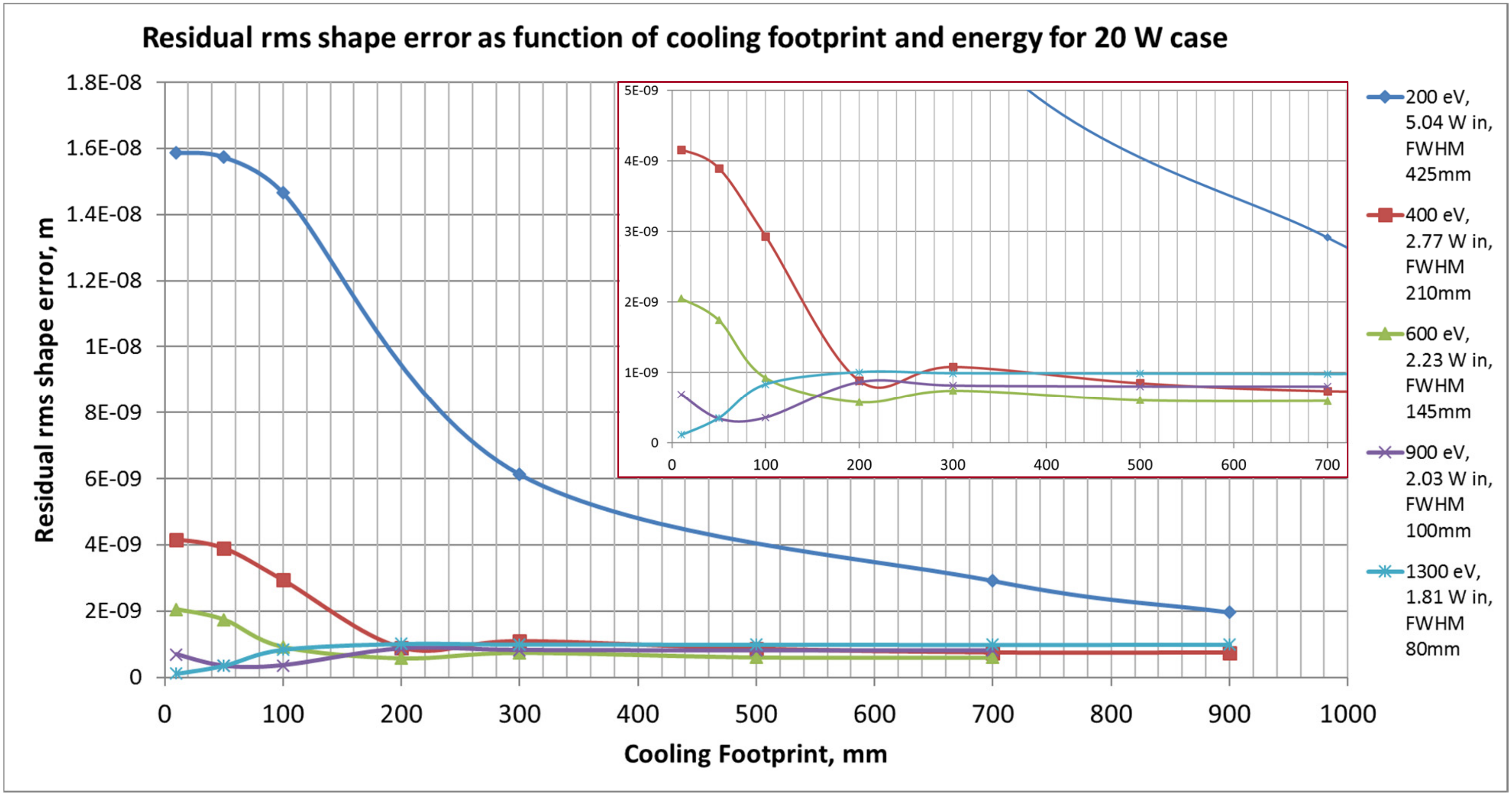


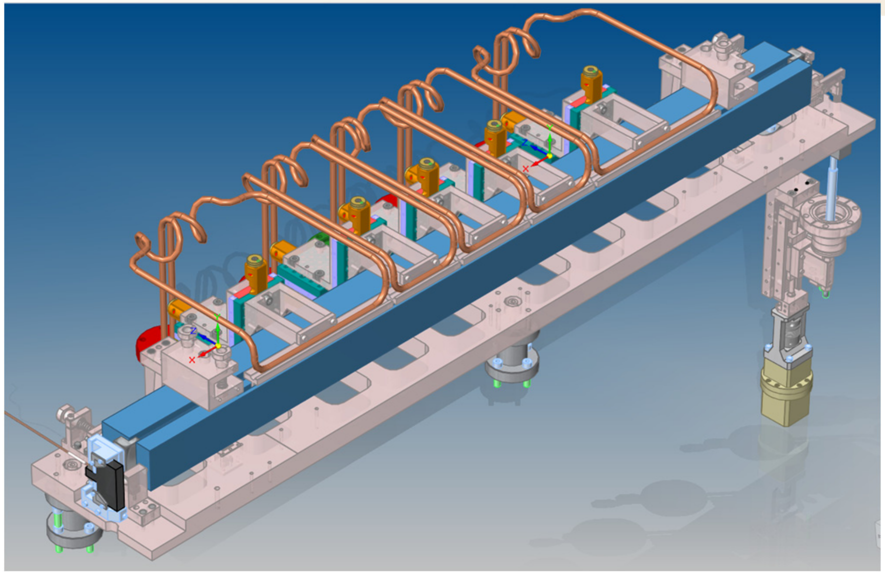
Thanks to the notch, the induced spherical thermal bump can be minimized for a range of beam footprints

Effect of Cooling Footprint on Performance

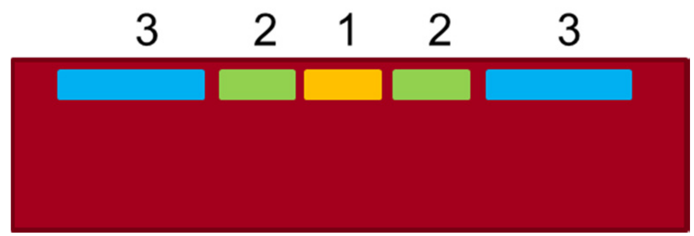
The ideal scenario is when the cooling length matches the beam FWHM.



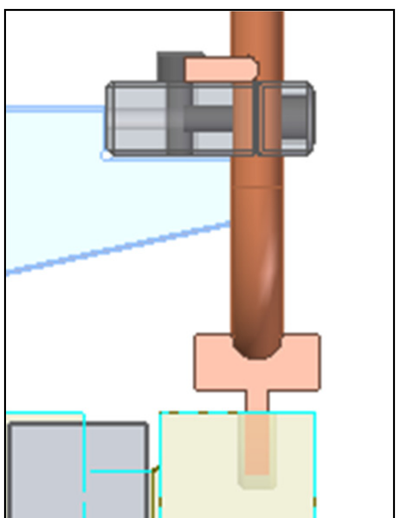
Cooling scheme

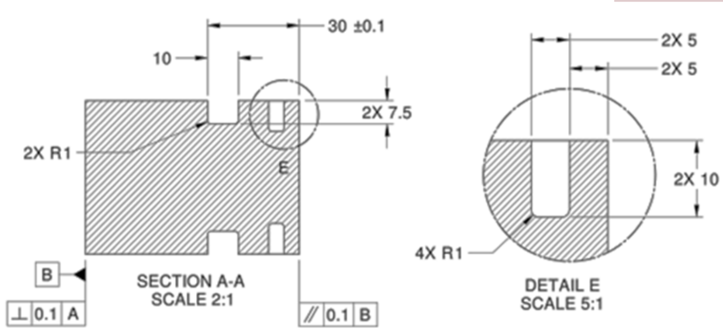


A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint



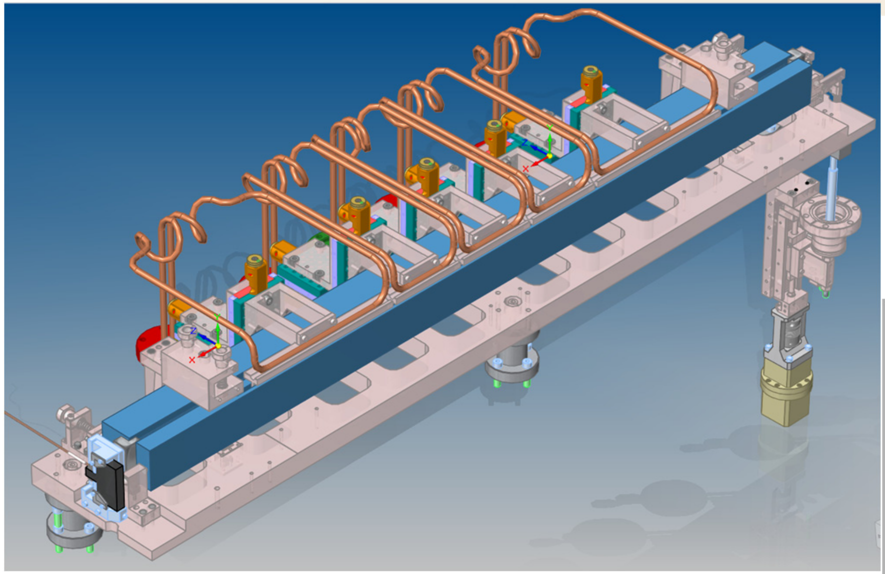
Energy Range (eV)	Cooling Footprint (mm)
< 400	700
~ 400 – ~ 800	300
> 700	100





The mirror is cooled from one side only. It has a trough located 5 mm from the surface hosting the GaIn eutectic. A notch, 20 mm from the surface, is used to reduce the thermal bump, and hold the mirror

Flat Mirrors (HOMS/SOMS) design – in focus



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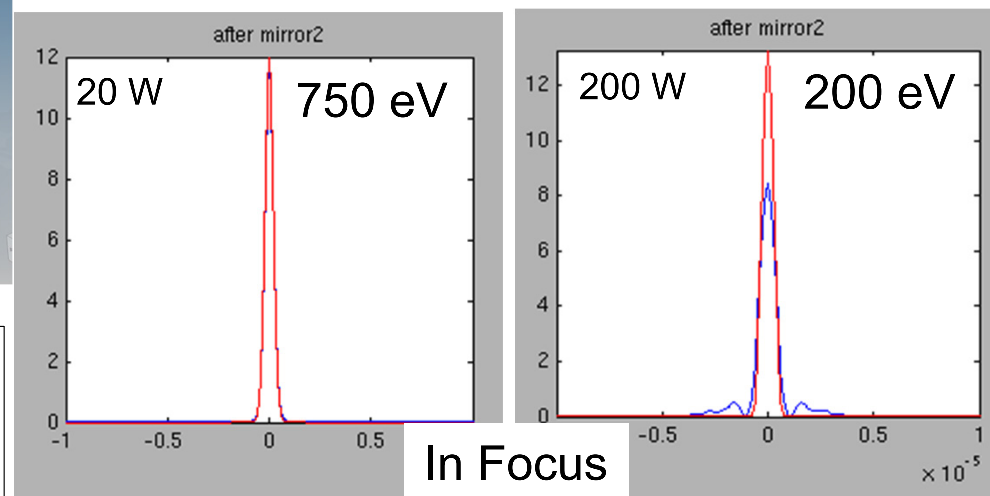
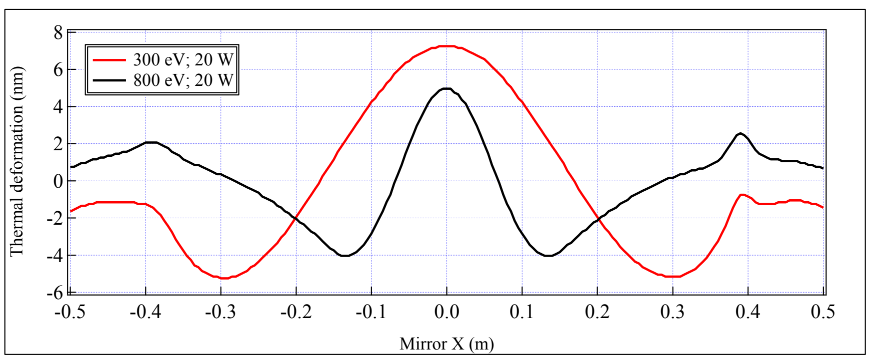
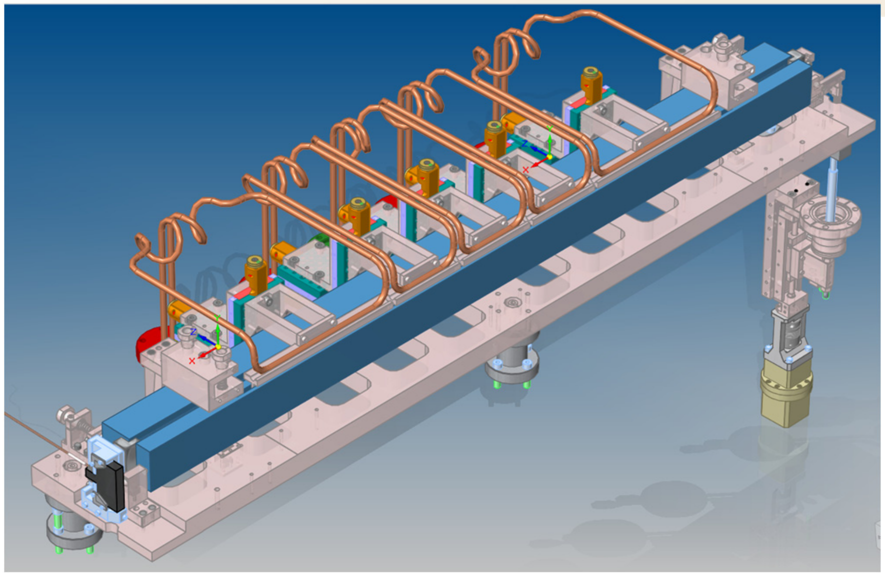
A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint

Red=perfect mirrors; Blue=with thermal deformation

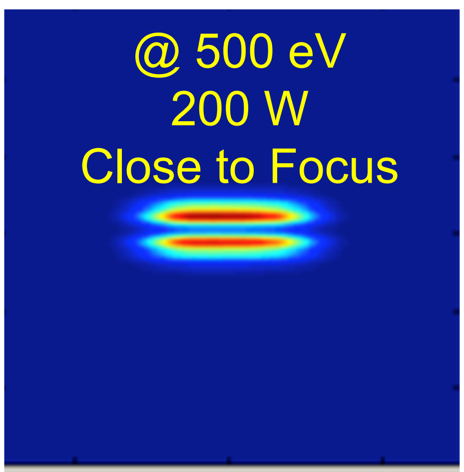


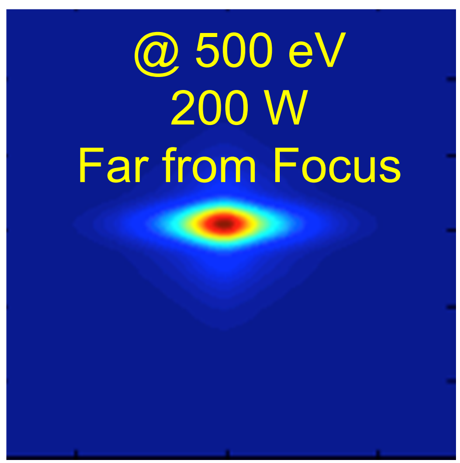


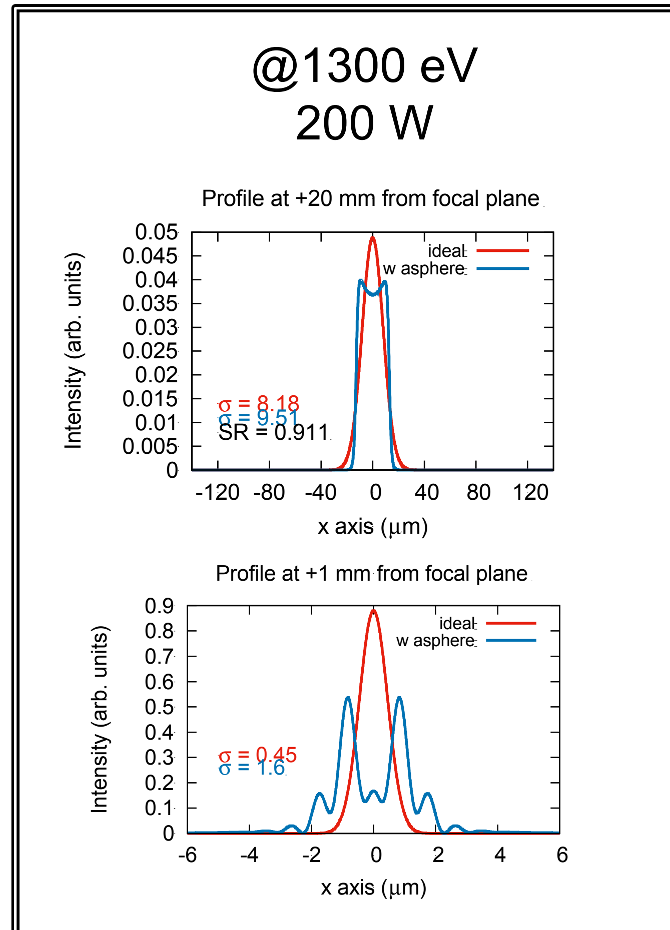
Flat Mirrors (HOMS/SOMS) design - out of focus



The ideal scenario is when the cooling length matches the beam FWHM.
A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint

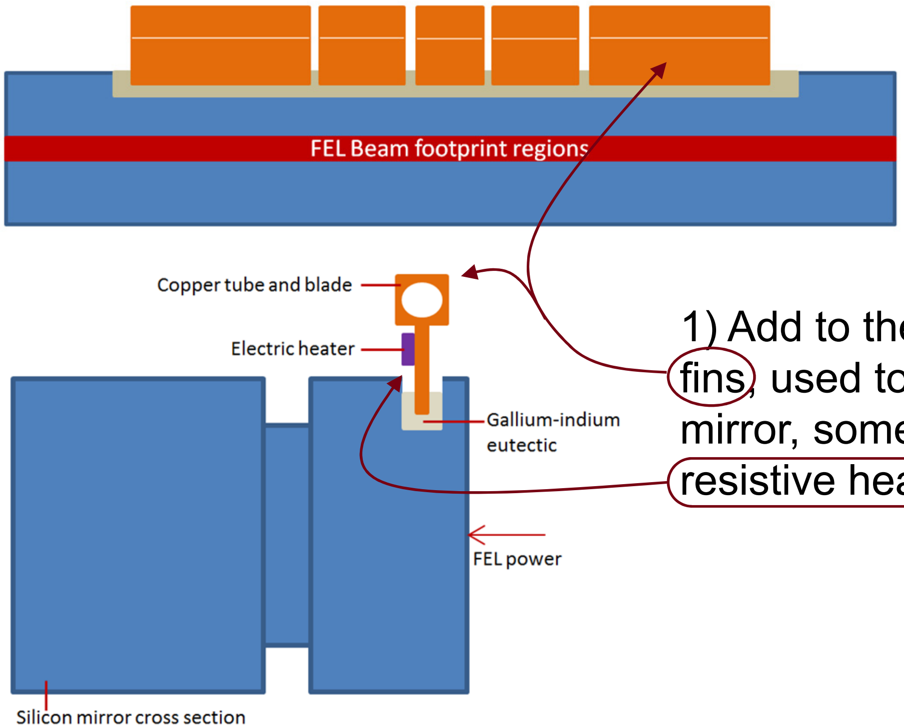




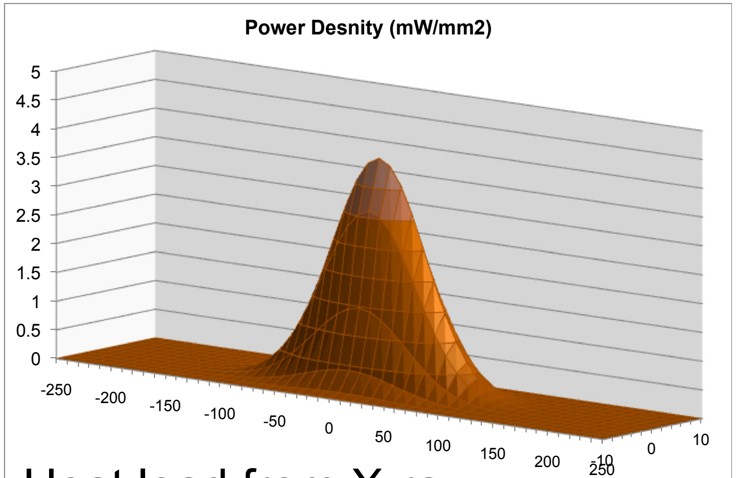


Future development:
REAL (Resistive Element Adjustable Length) Cooled Optics

Project funded by BES over two years



1) Add to the existing fins, used to cool the mirror, some resistive heaters



Heat load from X-ray

Future development:
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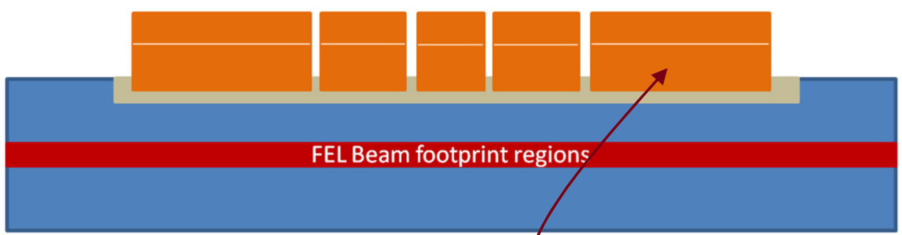
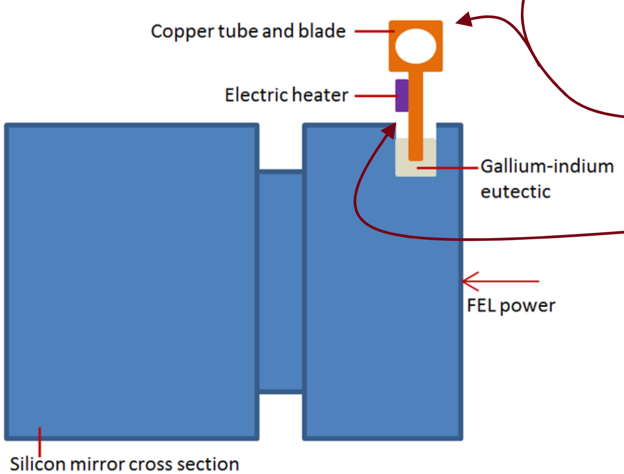
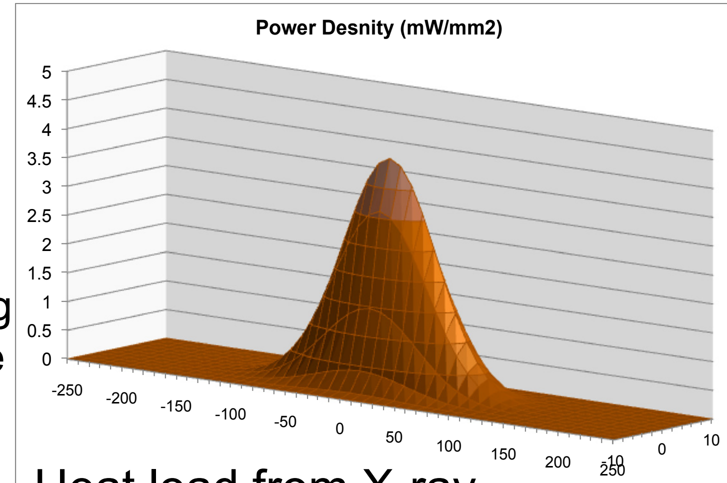


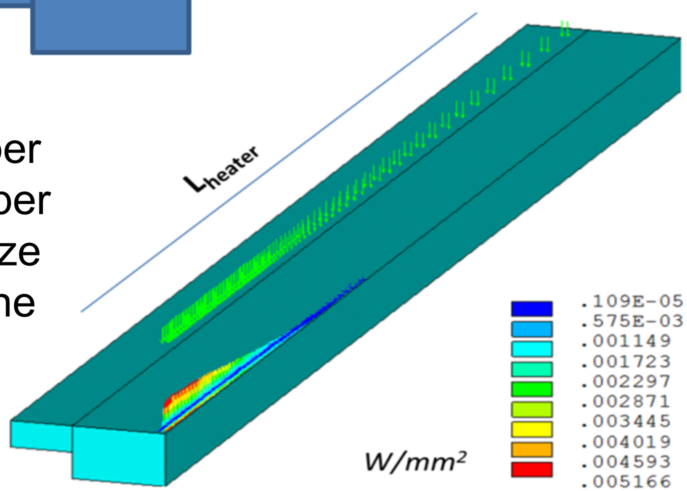


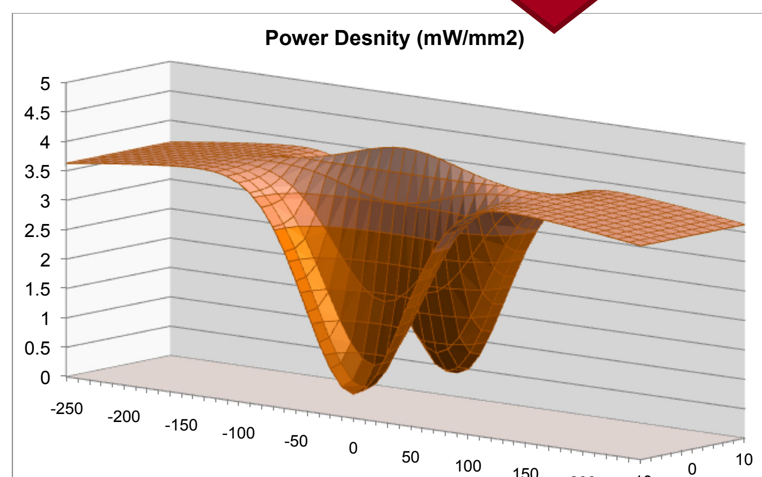
1) Add to the existing fins, used to cool the mirror, some resistive heaters



Heat load from X-ray

2) Apply the proper power to the proper heaters to equalize deformation on the mirror

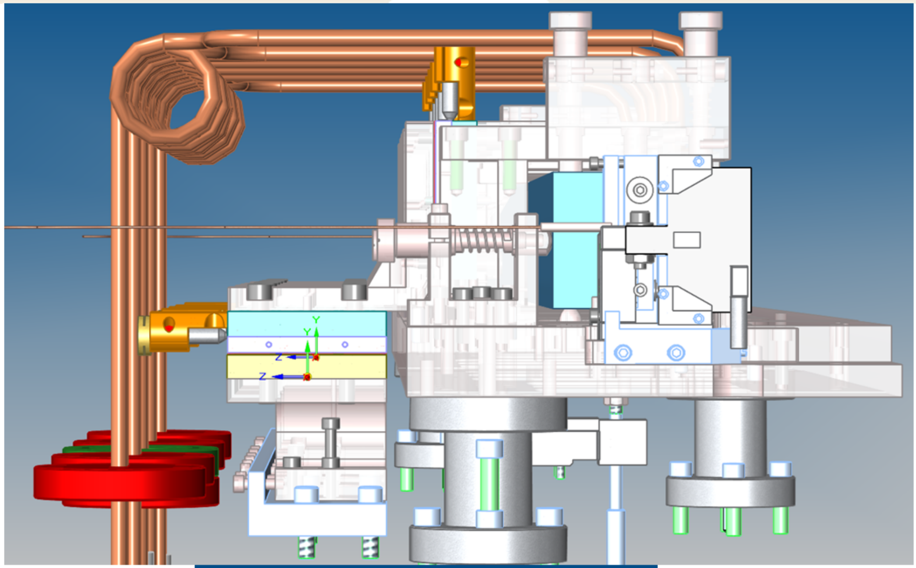


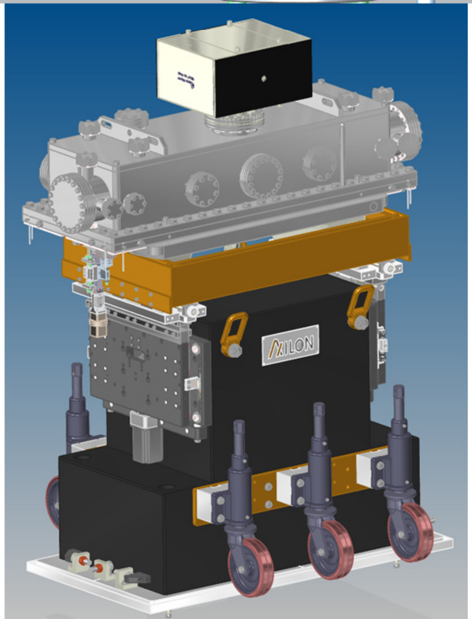


Combined power load

Next steps

- Test prototype mirror with Gallium indium
  - Measure static vibration performance
  - Measure influence of cooling on vibration
    - Ensure proper chiller performance
- Test REAL cooling technique
- Install mirrors in LCLS I with no cooling in March 2017
- Full LCLS II upgrade with cooling beginning ~June 2018





Acknowledgements

The majority of the work on this project was done by Venkat N. Srinivasan Under Daniele Cocco

May Ling Ng
Josep Nicolas
Jacek Krzywinski
Peter M. Stefan
Lope Amores
Daniel S. Morton
Tony Catalano
Nicholas M. Kelez

Eliazar Ortiz
Lin Zhang
Dave Rich,
Michael Rowen
Jtec
Axilon,
And many others….

Questions?

U.S. DEPARTMENT OF ENERGY
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