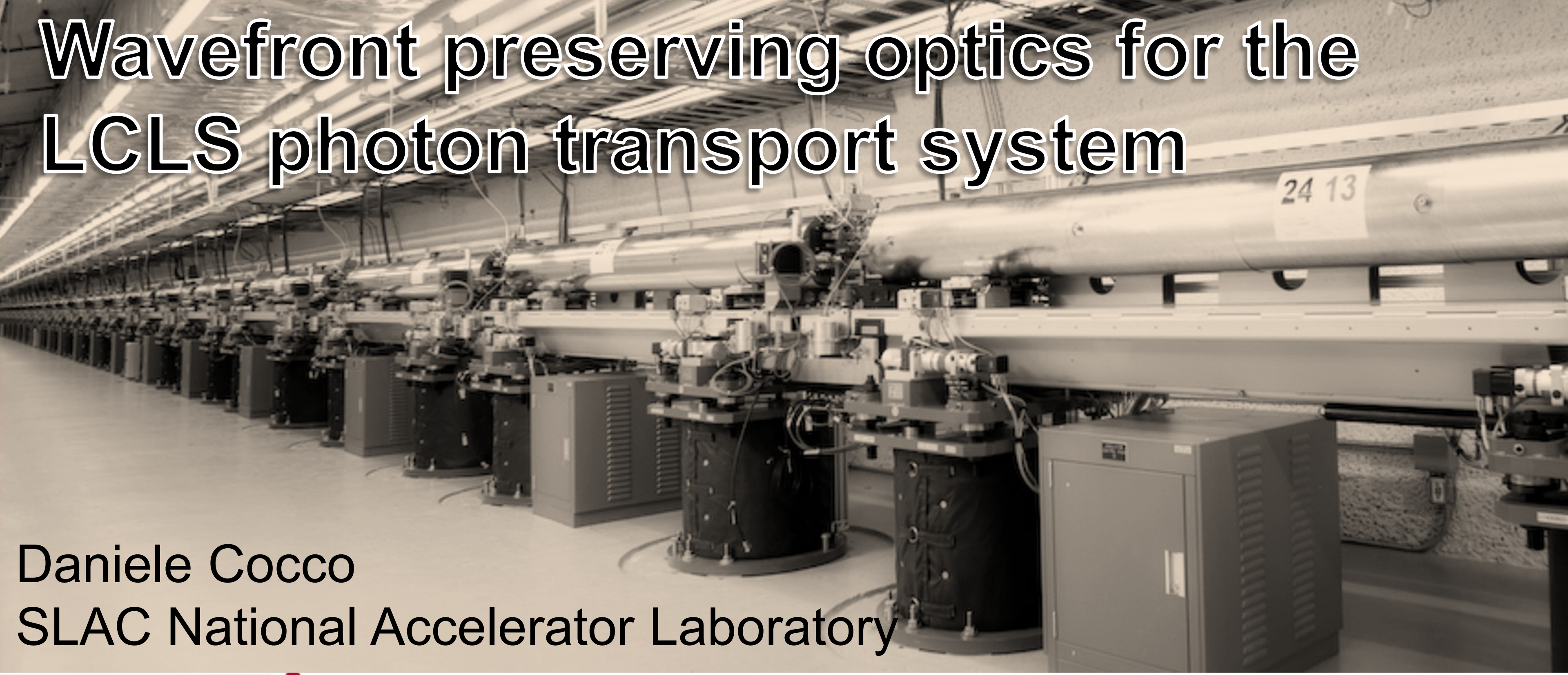
Wavefront preserving optics for the LCLS photon transport system



Daniele Cocco
SLAC National Accelerator Laboratory

Contributors

Corey Hardin
Daniel Morton
Tom Pardini
Lance Lee
Josep Nicolas
May Ling Ng
Lin Zhang
....

L. Assoufid — Argonne National Laboratory
M. Idir — Brookhaven National Laboratory
K. Goldberg — Berkeley Lab, Lawrence Berkeley National Laboratory

FEL 2017 Santa Fe, NM

U.S. Department of Energy
Office of Science

Stanford University

SLAC National Accelerator Laboratory

Outlook/abstract

The Linac Coherent Light Source (LCLS) of SLAC is upgrading the facility to an High Repetition Rate mode and to a higher quality of the wavefront. This poses extreme challenges to the optical components. **A new approach to beamline design** is needed, starting from a new way to assess the effect of slope and shape errors, to **the need of taking into account any potential source of distortion**. Among the technical novelties the LCLS X-ray optics team is introducing, the most important are **a novel cooling scheme** to maintain the mirror shape within 0.5 nm rms under heat load, **the study of the effect of the cooling interface** to the mirror surface, and **new diagnostic systems**. Ultra-flat mirrors with **novel holder/bender mechanisms** have been recently installed. First results, showing the improvement of the beam quality, are expected in mid-June 2017. Another important aspect, is the **cleaning process to remove, in situ, carbonaceous contamination** from carbon based coatings. A controlled method has been developed and successfully implemented in the SXR mirrors to remove the carbon without affecting the coating. **All the above tests and studies will be presented, as well as the effect seen on a six-year old mirror exposed to FEL for his entire lifetime.**

Outlook/abstract

The Linac Coherent Light Source (LCLS) of SLAC is upgrading the facility to an High Repetition Rate mode and to a higher quality of the wavefront. This poses extreme challenges to the optical components. **A new approach to beamline design** is needed starting from a new way to assess the effect of slope and shape errors, to **the need of taking into account any potential source of distortion**. Among the technical novelties the LCLS X-ray optics team is introducing, the most important are **a novel cooling scheme** to maintain the mirror shape within 0.5 nm rms under heat load, **the study of the effect of the cooling interface** to the mirror surface, and **new diagnostic systems**. Ultra-flat mirrors with **novel holder/bender mechanisms** have been recently installed. First results, showing the improvement of the beam quality, are expected in mid-June 2017. Another important aspect, is the **cleaning process to remove, in situ, carbonaceous contamination** from carbon based coatings. A controlled method has been developed and successfully implemented in the SXR mirrors to remove the carbon without affecting the coating. **All the above tests and studies will be presented, as well as the effect seen on a six-year old mirror exposed to FEL for his entire lifetime.**

A bit too ambitious for a 15 minutes talk!!

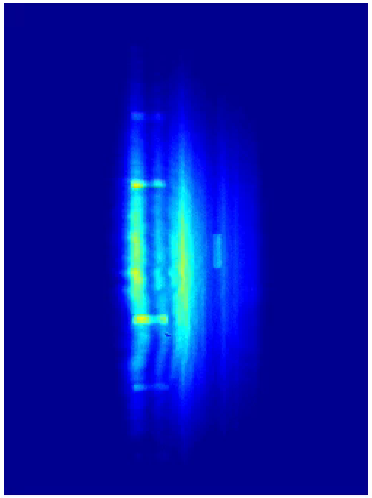
Outlook/abstract

SLAC

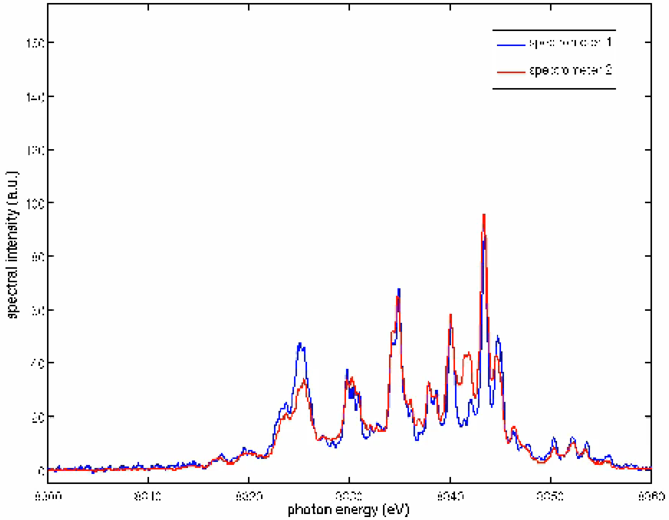
The Linac Coherent Light Source (LCLS) of SLAC is upgrading the facility to an High Repetition Rate mode and to a higher quality of the wavefront. This poses extreme challenges to the optical components. **A new approach to beamline design** is needed, starting from a new way to assess the effect of slope and shape errors, to **the need of taking into account any potential source of distortion**. Among the technical novelties the LCLS X-ray optics team is introducing, the most important are **a novel cooling scheme** to maintain the mirror shape within 0.5 nm rms under heat load, **the study of the effect of the cooling interface** to the mirror surface, and **new diagnostic systems**. Ultra-flat mirrors with **novel holder/bender mechanisms** have been recently installed. First results, showing the improvement of the beam quality, are expected in mid-June 2017. Another important aspect, is the **cleaning process to remove, in situ, carbonaceous contamination** from carbon based coatings. A controlled method has been developed and successfully implemented in the SXR mirrors to remove the carbon without affecting the coating. **All the above tests and studies will be presented, as well as the effect seen on a six-year old mirror exposed to FEL for his entire lifetime.**

LCLS is cool, but not perfect (yet)

Spatial



Spectral



- Spectral profile can "improve" by using the existing and/or planned self seeding scheme (yesterday morning talks)
- Spatial distribution "inhomogeneity" is, mostly, dominated by the optics
  - The mirrors and holders we have are better than (or equal to) the best mirrors in the Synchrotron Facility
    - Not good enough
  - How can we do better

Understand what you really need

Optical designer in SR are use to specify mirrors in slope. This modus operandi has been transferred to the FELs

Only recently, it has been demonstrated that SHAPE is important, not slope

It was, actually, embedded into a 20 years old precursor article (it was just too advanced, at that time, for the SR needs)

Effect of slope errors on the performance of mirrors for x-ray free electron laser applications

Dec. 2015

Tom Pardini,[1,*] Daniele Cocco,[2] and Stefan P. Hau-Riege[1]

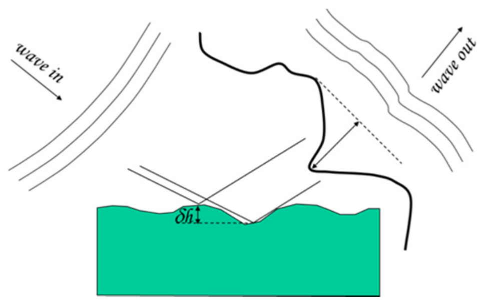
[1] *Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, California 94566, USA*

Specification of glancing- and normal-incidence x-ray mirrors

Eugene L. Church, FELLOW SPIE
Peter Z. Takacs, MEMBER SPIE
Brookhaven National Laboratory
Upton, New York 11973

1995

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



$$\text{Strehl Ratio} \approx e^{-(2\pi\varphi)^2} \approx 1-(2\pi\varphi)^2$$

The Strehl Ratio (SR) is defined as a ratio of the maximum intensity in the focus, with and without wave front distortions which are introduced by the optics

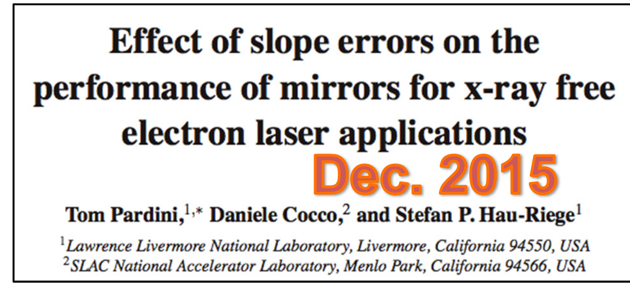
$$\delta h = \lambda \frac{\sqrt{1-Strehl \quad Ratio}}{4\pi \sin\vartheta}$$

SR ≥ 0.8 (according to the Marechal Criterion) is necessary to have "good" optical system

Understand what you really need

Optical designer in SR are use to specify mirrors in slope. This modus operandi has been transferred to the FELs

Only recently, it has been demonstrated that SHAPE is important, not slope



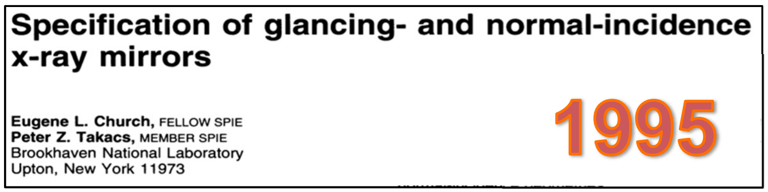
Effect of slope errors on the performance of mirrors for x-ray free electron laser applications

Dec. 2015

Tom Pardini,[1,*] Daniele Cocco,[2] and Stefan P. Hau-Riege[1]

[1] *Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, California 94566, USA*

It was, actually, embedded into a 20 years old precursor article (it was just too advanced, at that time, for the SR needs)

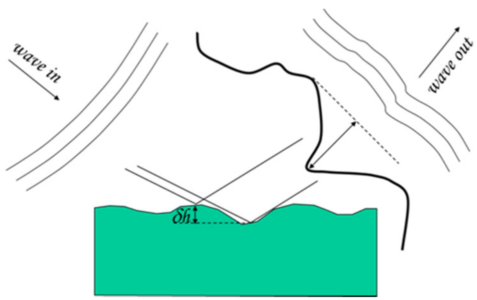


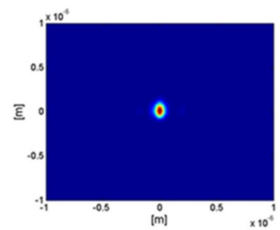
Specification of glancing- and normal-incidence x-ray mirrors

1995

Eugene L. Church, FELLOW SPIE
Peter Z. Takacs, MEMBER SPIE
Brookhaven National Laboratory
Upton, New York 11973

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





In focus

SR ≥ 0.8 (according to the Marechal Criterion) is necessary to have "good" optical system

Understand what you really need

Optical designer in SR are use to specify mirrors in slope. This modus operandi has been transferred to the FELs

Only recently, it has been demonstrated that SHAPE is important, not slope

It was, actually, embedded into a 20 years old precursor article (it was just too advanced, at that time, for the SR needs)

Specification of glancing- and normal-incidence x-ray mirrors

Eugene L. Church, FELLOW SPIE
Peter Z. Takacs, MEMBER SPIE
Brookhaven National Laboratory
Upton, New York 11973

1995

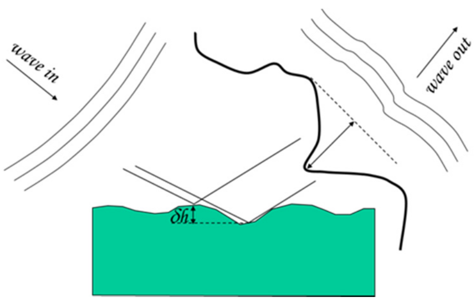
Effect of slope errors on the performance of mirrors for x-ray free electron laser applications

Dec. 2015

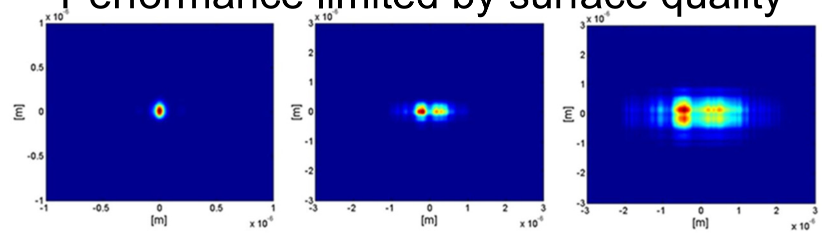
Tom Pardini,[1,*] **Daniele Cocco,**[2] **and Stefan P. Hau-Riege**[1]

[1] *Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, California 94566, USA*

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



Performance limited by surface quality



In focus — 1 mm out of focus — 2 mm out of focus

SR ≥ 0.8 (according to the Marechal Criterion) is necessary to have "good" optical system

Understand what you really need

Optical designer in SR are use to specify mirrors in slope. This modus operandi has been transferred to the FELs

Only recently, it has been demonstrated that SHAPE is important, not slope

It was, actually, embedded into a 20 years old precursor article (it was just too advanced, at that time, for the SR needs)

Specification of glancing- and normal-incidence x-ray mirrors

Eugene L. Church, FELLOW SPIE
Peter Z. Takacs, MEMBER SPIE
Brookhaven National Laboratory
Upton, New York 11973

1995

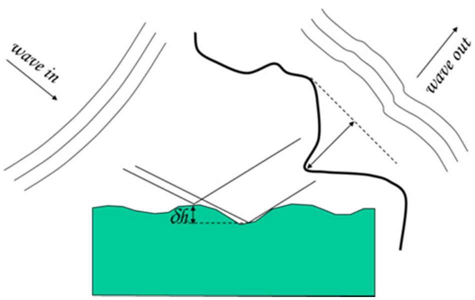
Effect of slope errors on the performance of mirrors for x-ray free electron laser applications

Dec. 2015

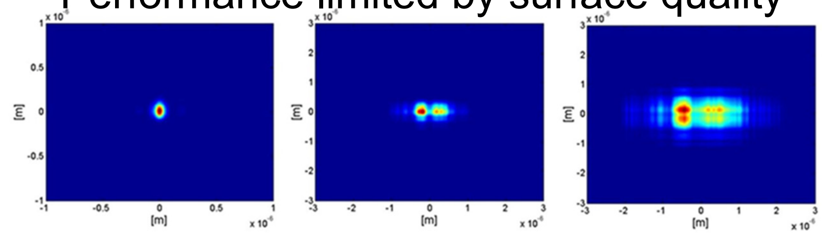
Tom Pardini,[1,*] Daniele Cocco,[2] and Stefan P. Hau-Riege[1]

[1] *Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, California 94566, USA*

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

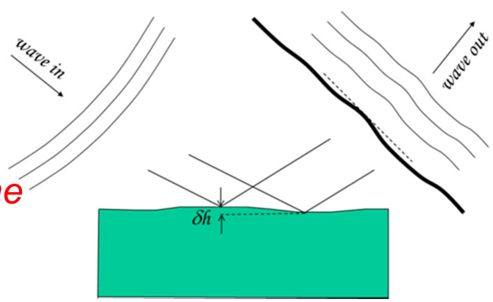


Performance limited by surface quality

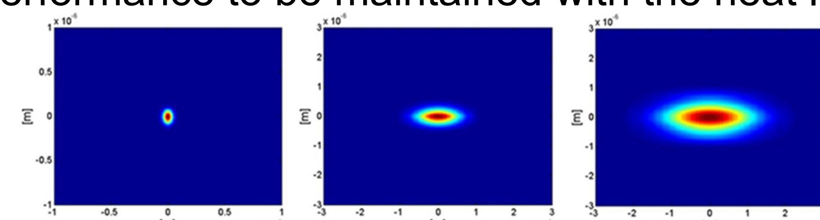


In focus | 1 mm out of focus | 2 mm out of focus

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

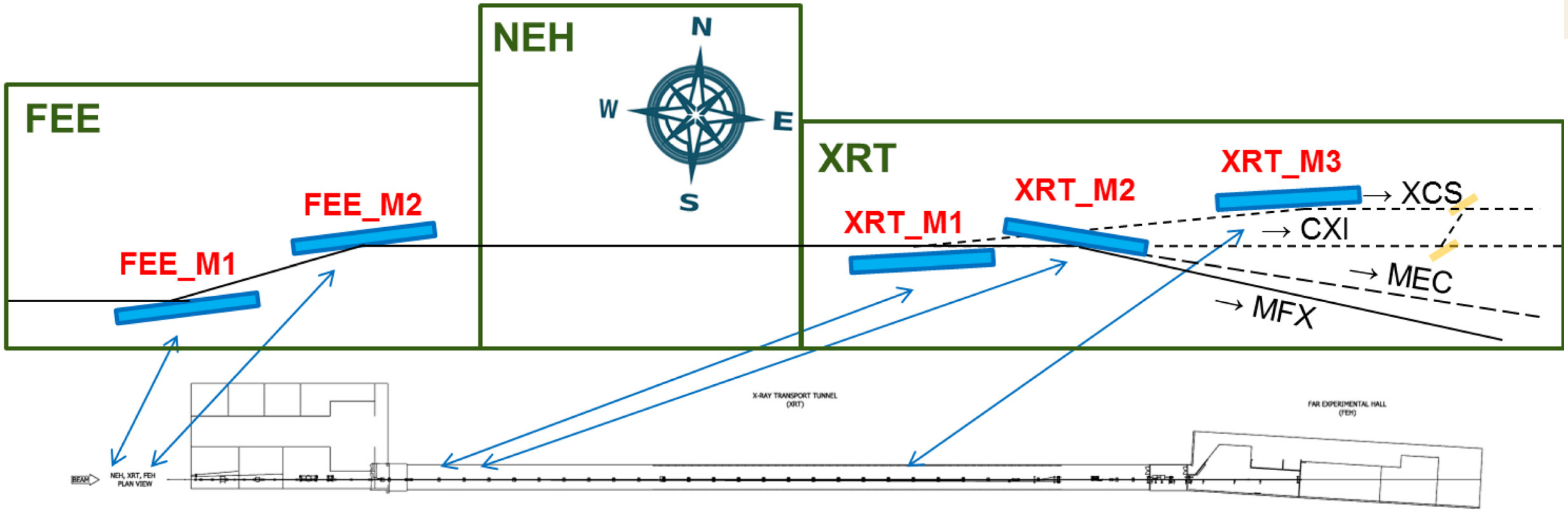


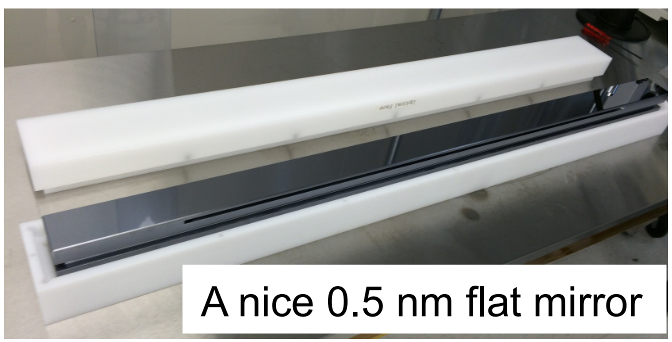
Performance to be maintained with the heat load



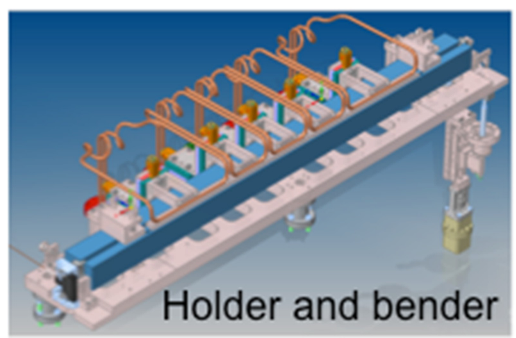
In focus | 1 mm out of focus | 2 mm out of focus

HOMS (HXR mirror system) upgrade



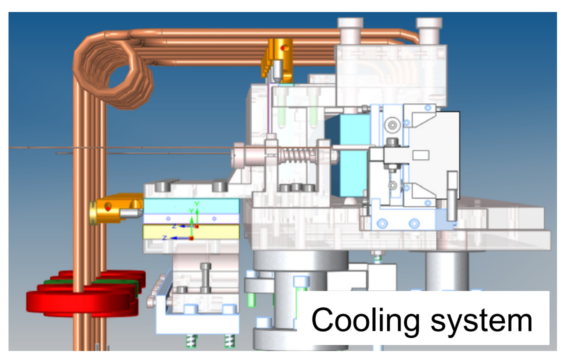


A nice 0.5 nm flat mirror

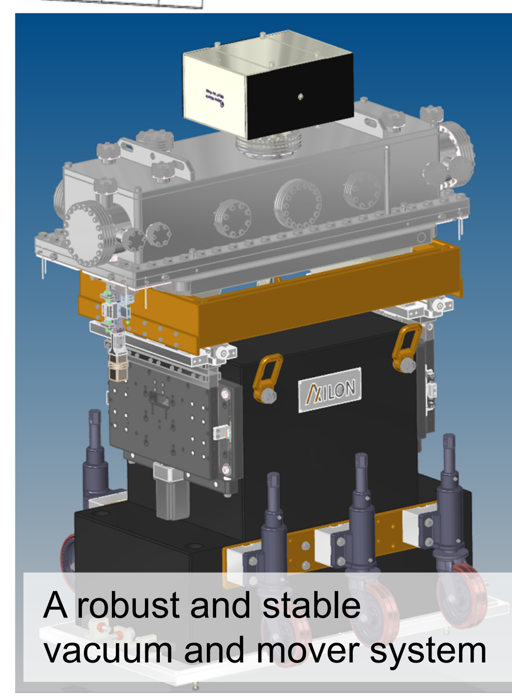


Holder and bender

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

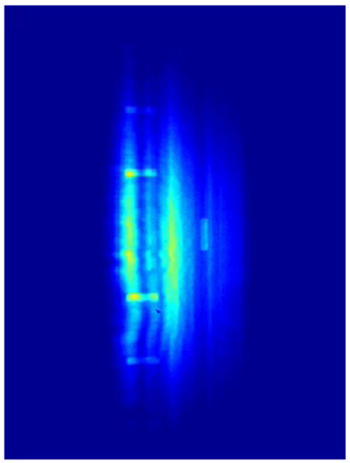


Cooling system



A robust and stable vacuum and mover system

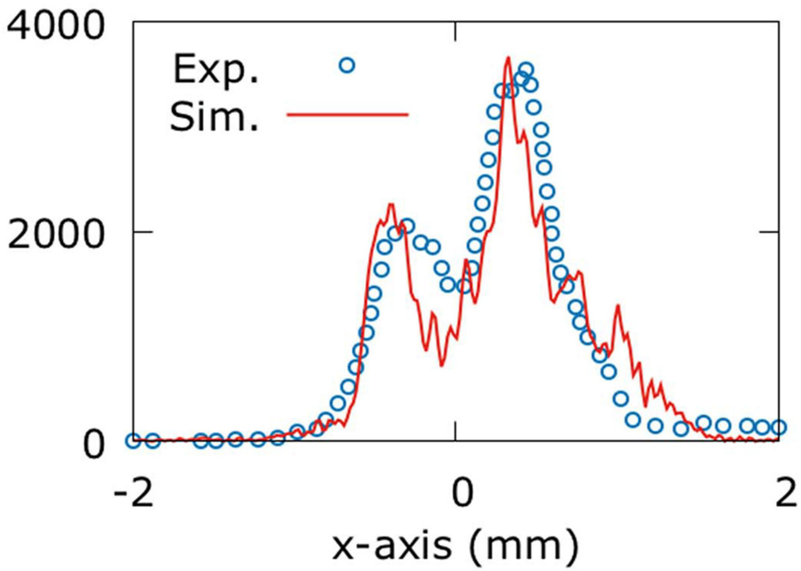
Measured beam profile before and after upgrade

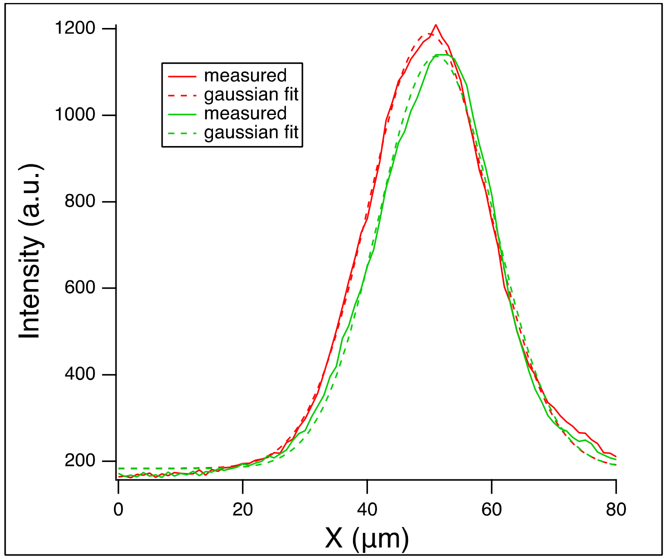


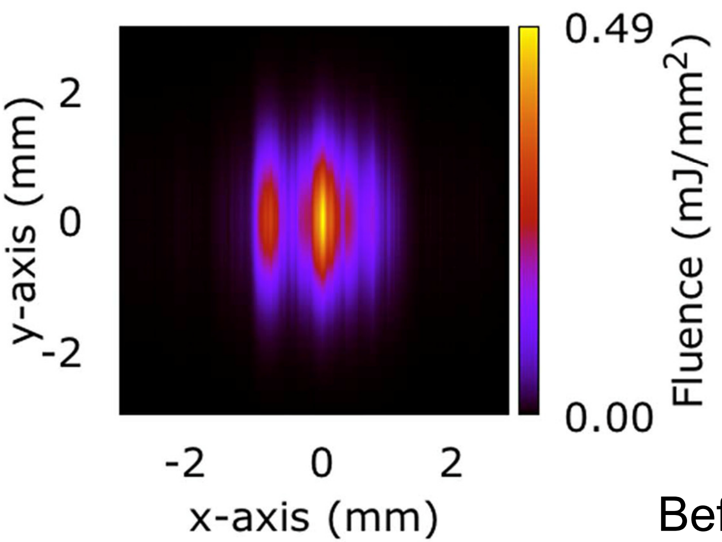
Beam profile after 2 old mirrors

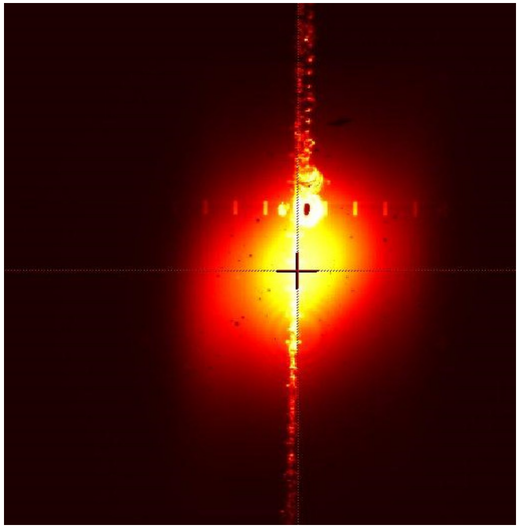
Beam profile after 2 new mirrors
(images taken in the very first days of operation with the machine not perfectly tuned

Measured beam profile before and after upgrade





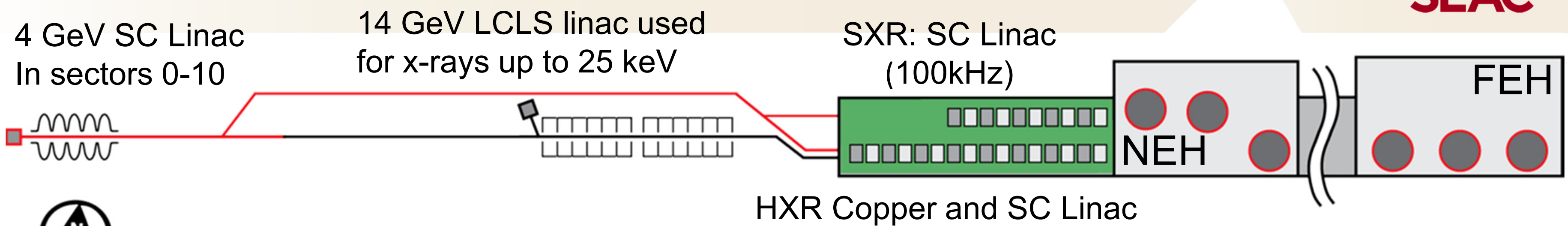


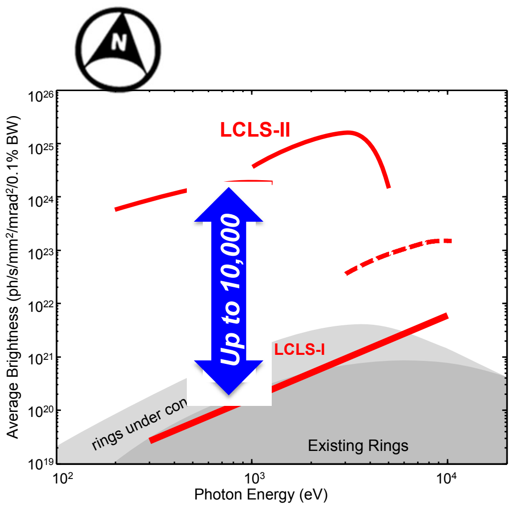


Before and after (measured)

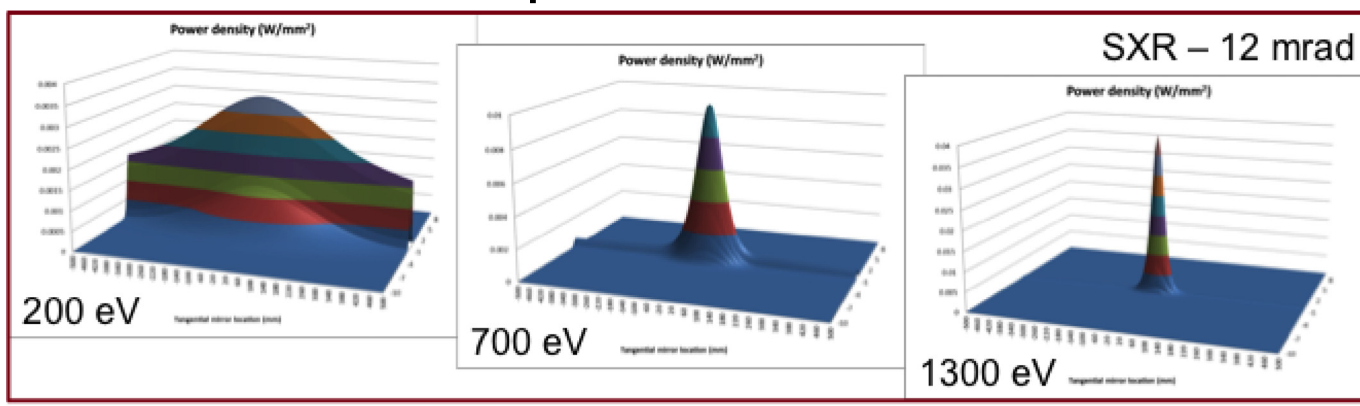
LCLS - II

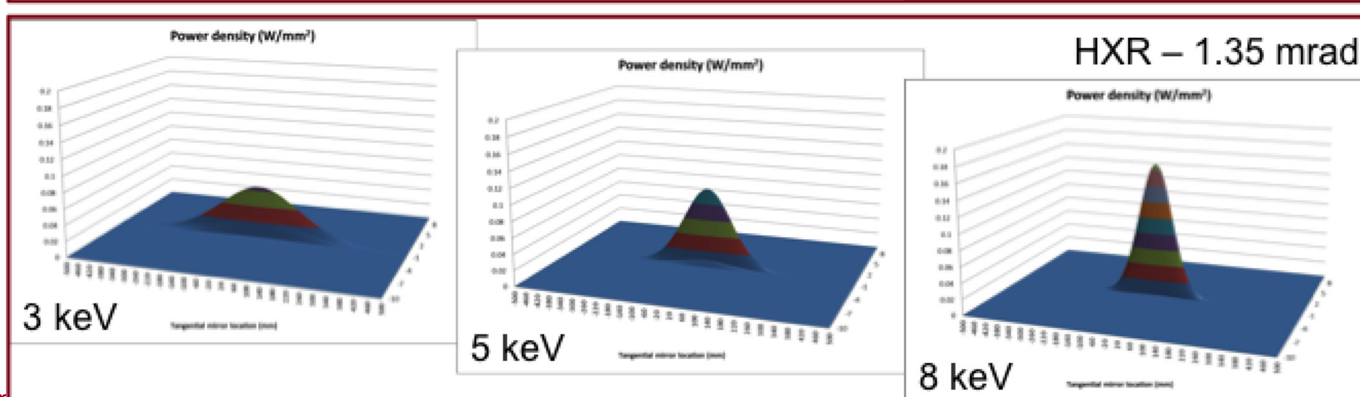
SLAC





Wide energy range leads to a highly variable beam footprint and **power absorbed**

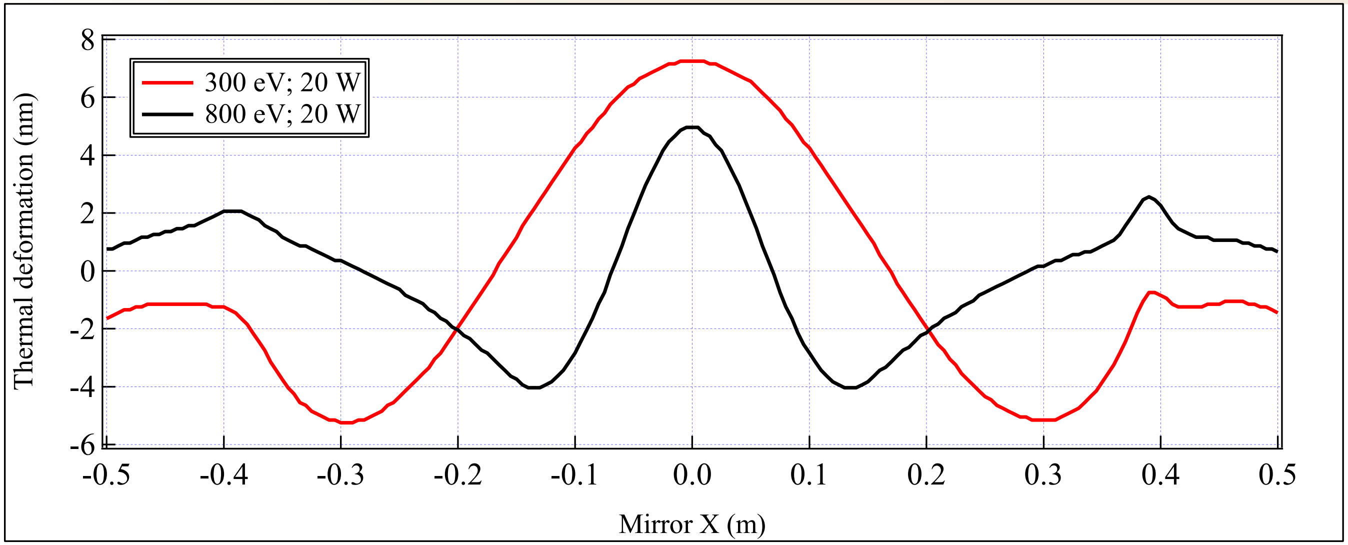




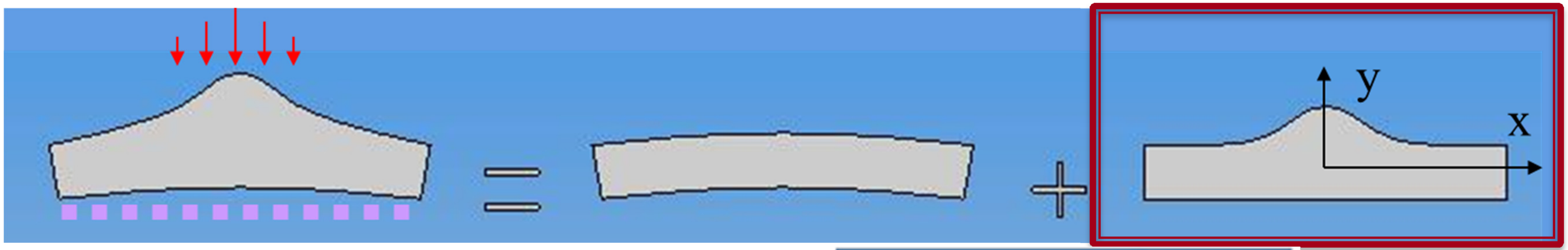
From the current 2-300 mW to up to 600 W on the optics

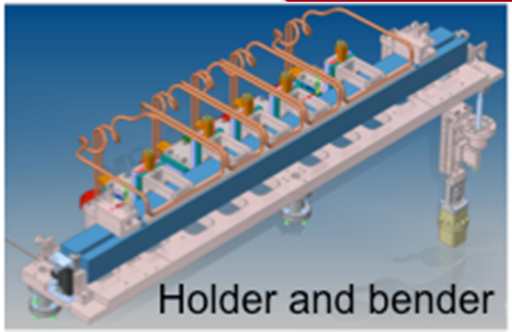
P. Emma (SLAC) "Status of the LCLS-II project at SLAC (Monday afternoon)

Thermal deformation – aspherical part

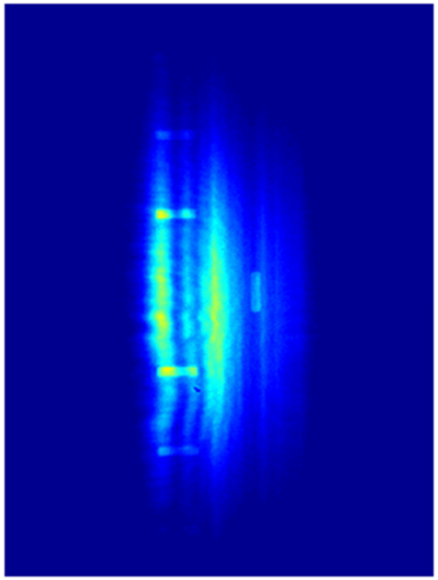


The deformation include a spherical thermal bump and a residual shape errors. Profile change with energy.
Spherical part can be eliminated with benders or moving the focal spot.
Higher orders has to be minimized by the cooling scheme





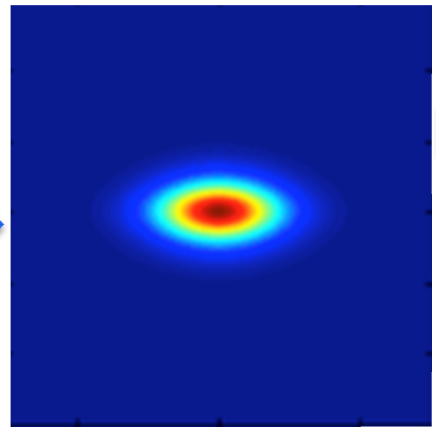
Out of focus beam profile

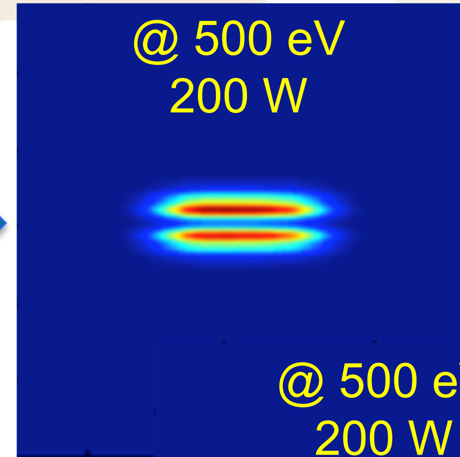


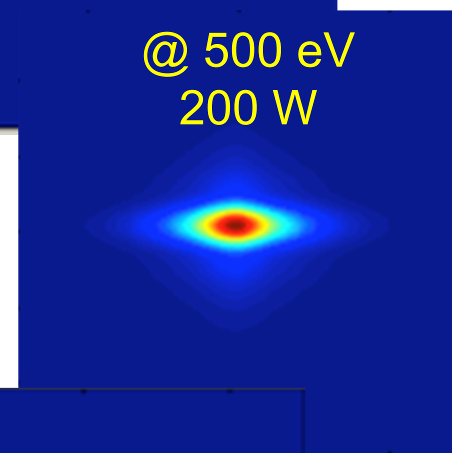
Old Mirror limit shape errors

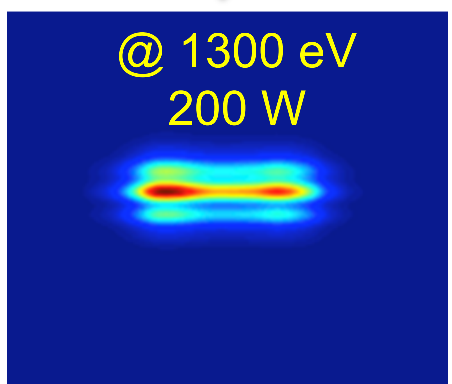
Next limit could be the thermal induced deformations

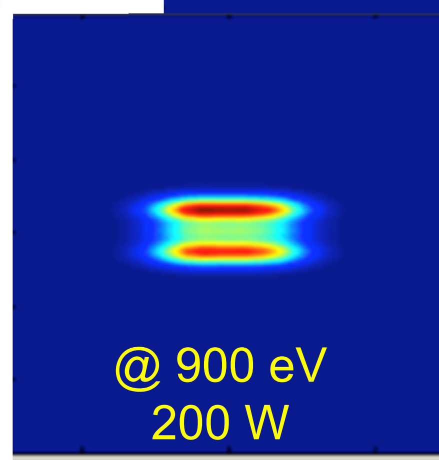
New state of the art mirrors











Wavefront preserving mirrors – DOE/BES ADR project

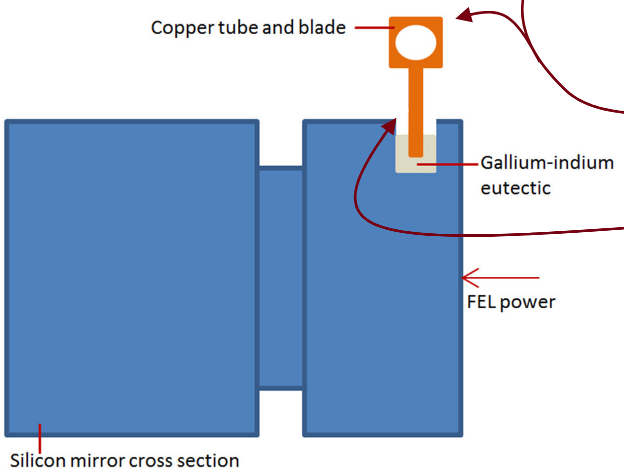
WAVEFRONT PRESERVING MIRRORS – ABSTRACT

Daniele Cocco, SLAC National Accelerator Laboratory (Principal Investigator)
Lahsen Assoufid, Argonne National Laboratory (Co-Investigator)
Kenneth Goldberg, Lawrence Berkeley National Laboratory (Co-Investigator)
Mourad Idir, Brookhaven National Laboratory (Co-Investigator)

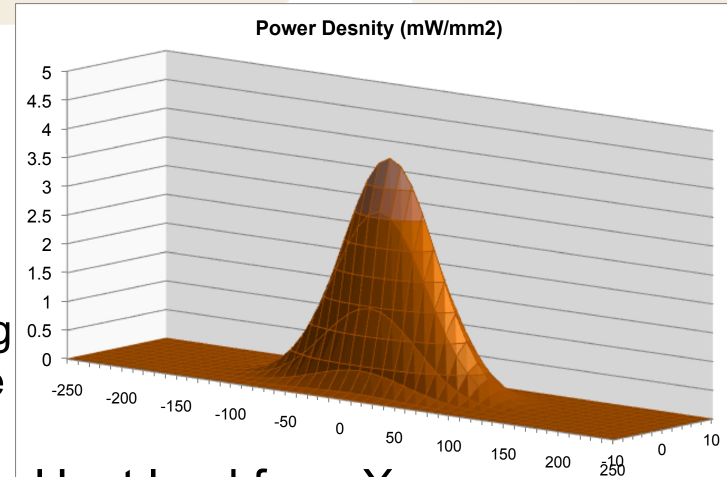
Abstract
This proposal brings together teams from the four major, large scale facilities operated under the auspices of the Department of Energy, Basic Energy Science; ………………… The development of a novel room-temperature mirror cooling system with in-situ, at-wavelength testing, and the study of non-invasive wavefront sensing are aimed at preserving the wavefront and the beam quality of Free Electron Lasers (FELs) and Diffraction Limited Storage Rings (DLSR).

- 2 years project:
- Deliverables:
  - ***SLAC:*** Development and demonstration of the novel cooling scheme
  - ***BNL:*** Implementation of an “invasive” wavefront sensor to test REAL sustaining 50-100 W
  - ***LBNL:*** Study of “non invasive” beam diagnostics (WS) for SXR
  - ***ANL:*** Study of “non invasive” beam diagnostics (WS) for HXR

REAL (Resistive Element Adjustable Length) Cooled Optics

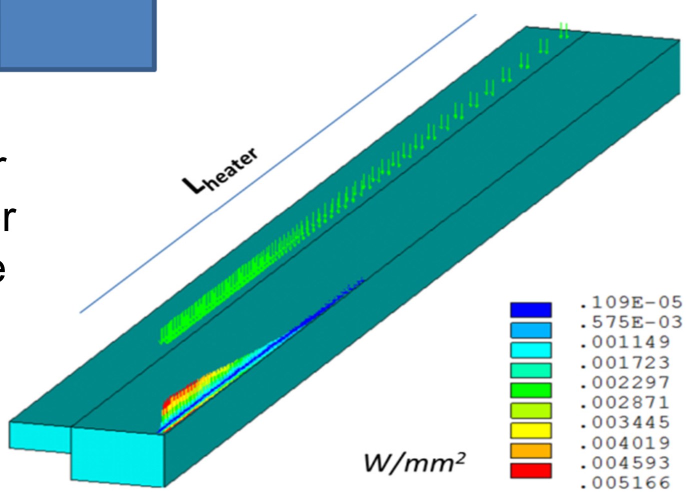


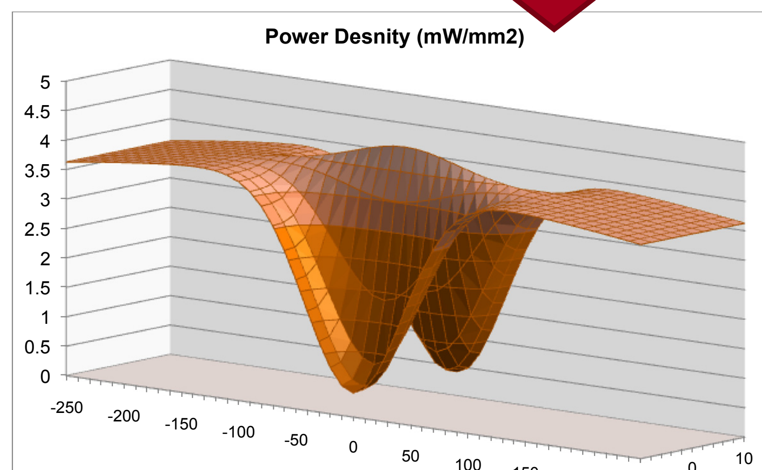
1) Add to the existing fins, used to cool the mirror, some resistive heaters



Heat load from X-ray

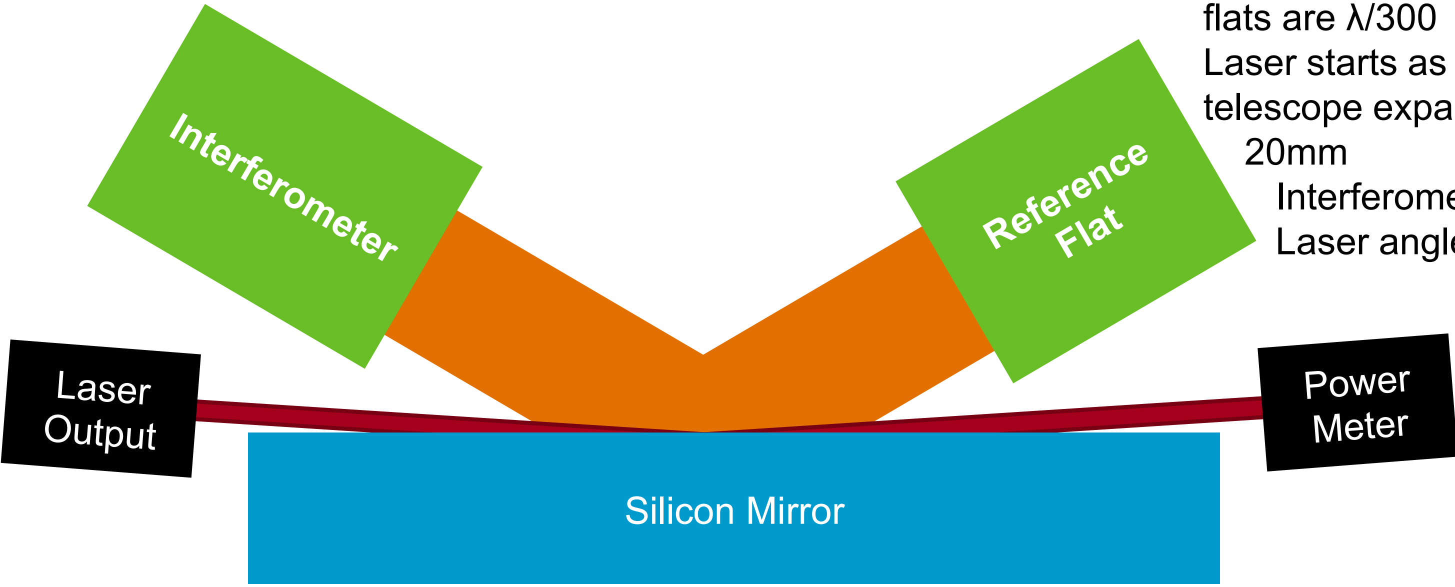
2) Apply the proper power to the proper heaters to equalize deformation on the mirror



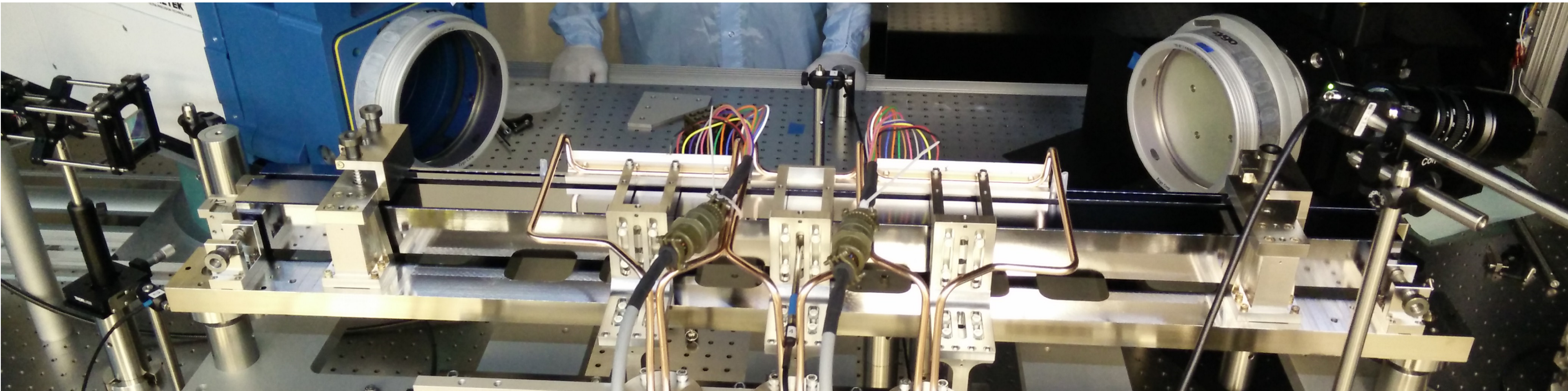


Combined power load

Measurement Layout

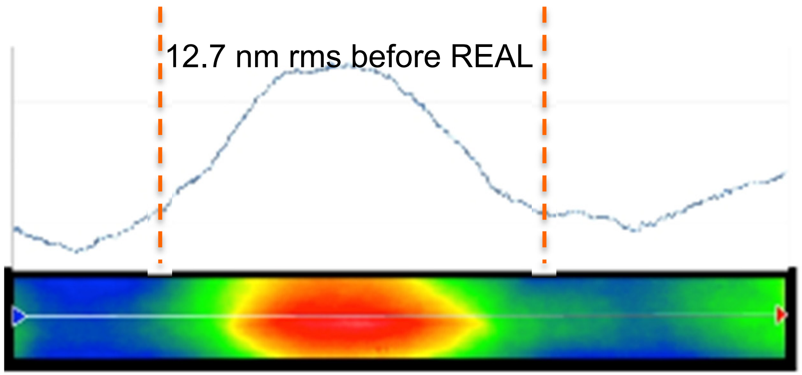


- Measuring in double bounce, reference flats are λ/300
- Laser starts as 2mm round beam, telescope expands horizontal axis to 20mm
  - Interferometer incidence angle is $\sim 25^0$
  - Laser angle 11^0

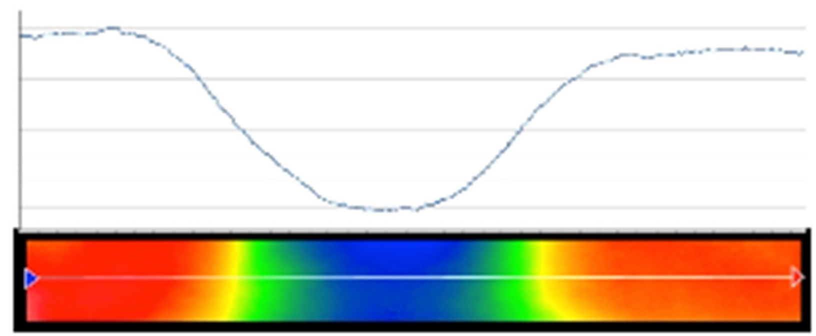


First compensation test, August 7th 2017

Metrology measurements - 2D map and central line profile (≈ 12 W absorbed)

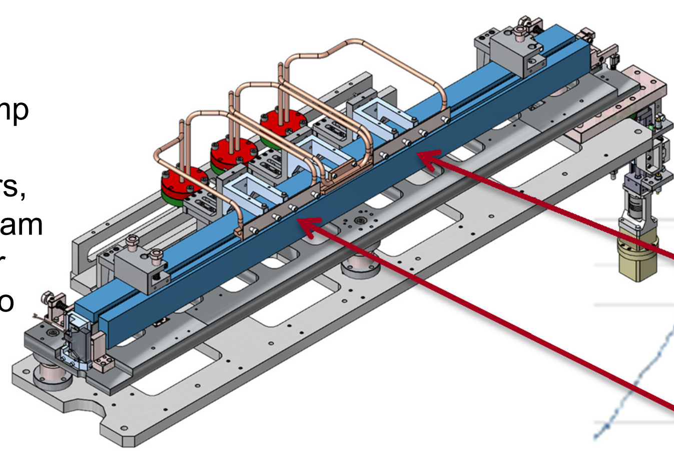


Heat Load induced by an IR laser (15W)

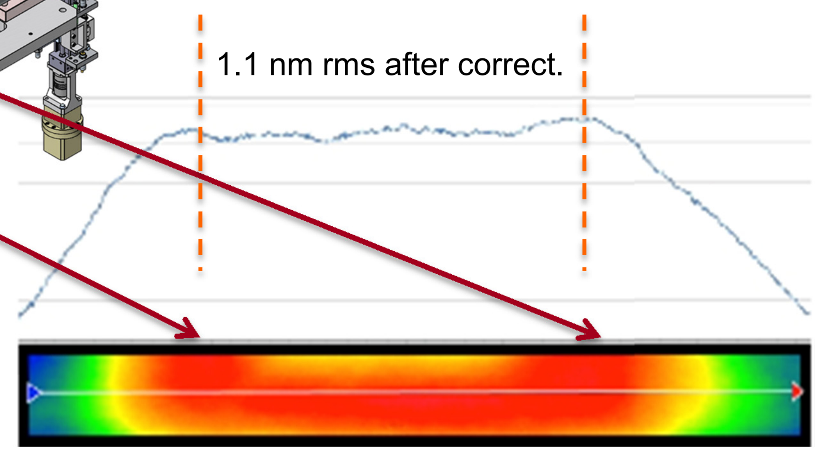


“counter” profile produced by 14 heaters

NOTE:
The effect of a thermal bump is not comparable with the high frequency shape errors, in terms of effect on the beam
Also, the 1.17 nm rms after correction are mainly due to the native surface of the “cheap” prototype mirror



One side cooling and heating
Evident in the 2D map profile

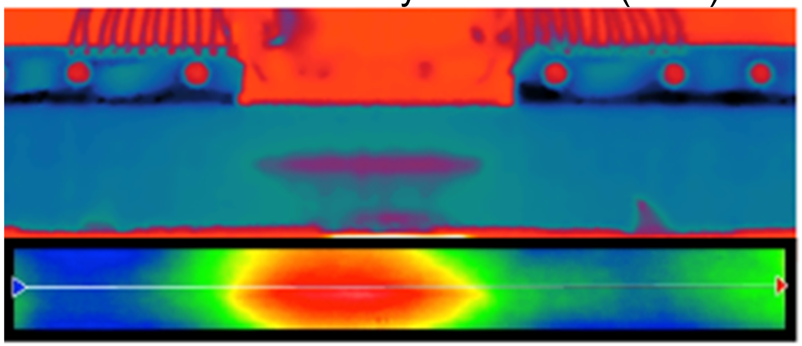


Combined effect (REAL + heat Load)

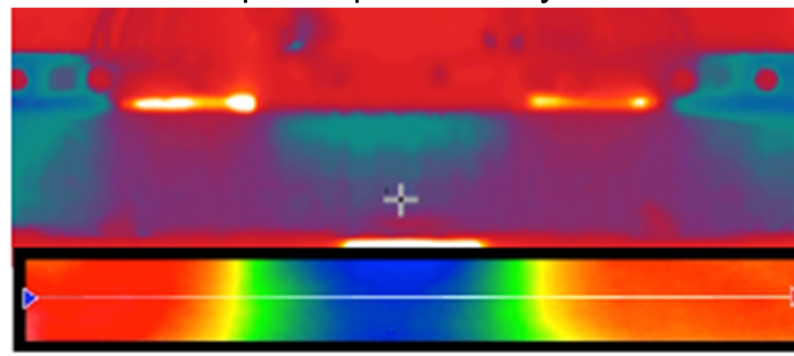
First compensation test, August 7th 2017

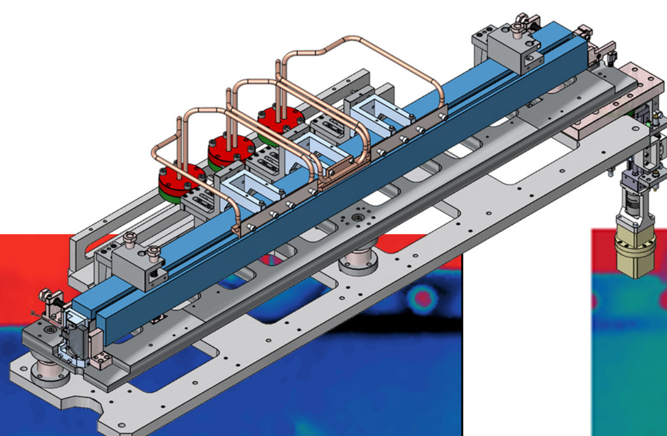
Thermal measurements (temperature in °C) map

Heat Load induced by an IR laser (15W)

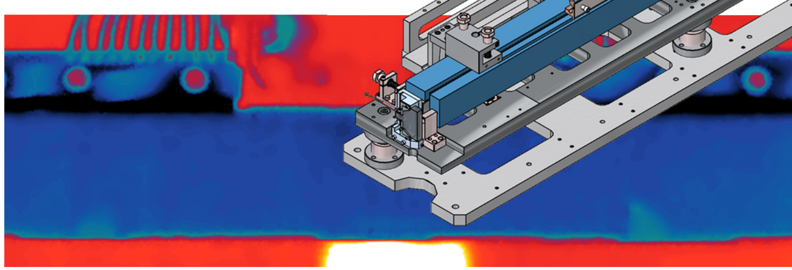


“counter” profile produced by 14 heaters

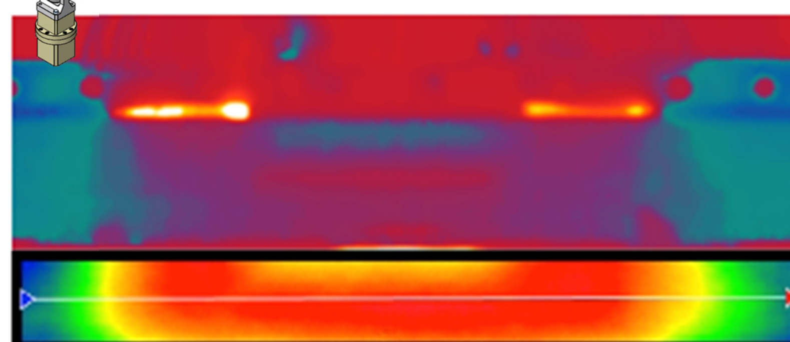




False color map scale changed to highlight the temperature distribution



No heat load / no heater / cooling only



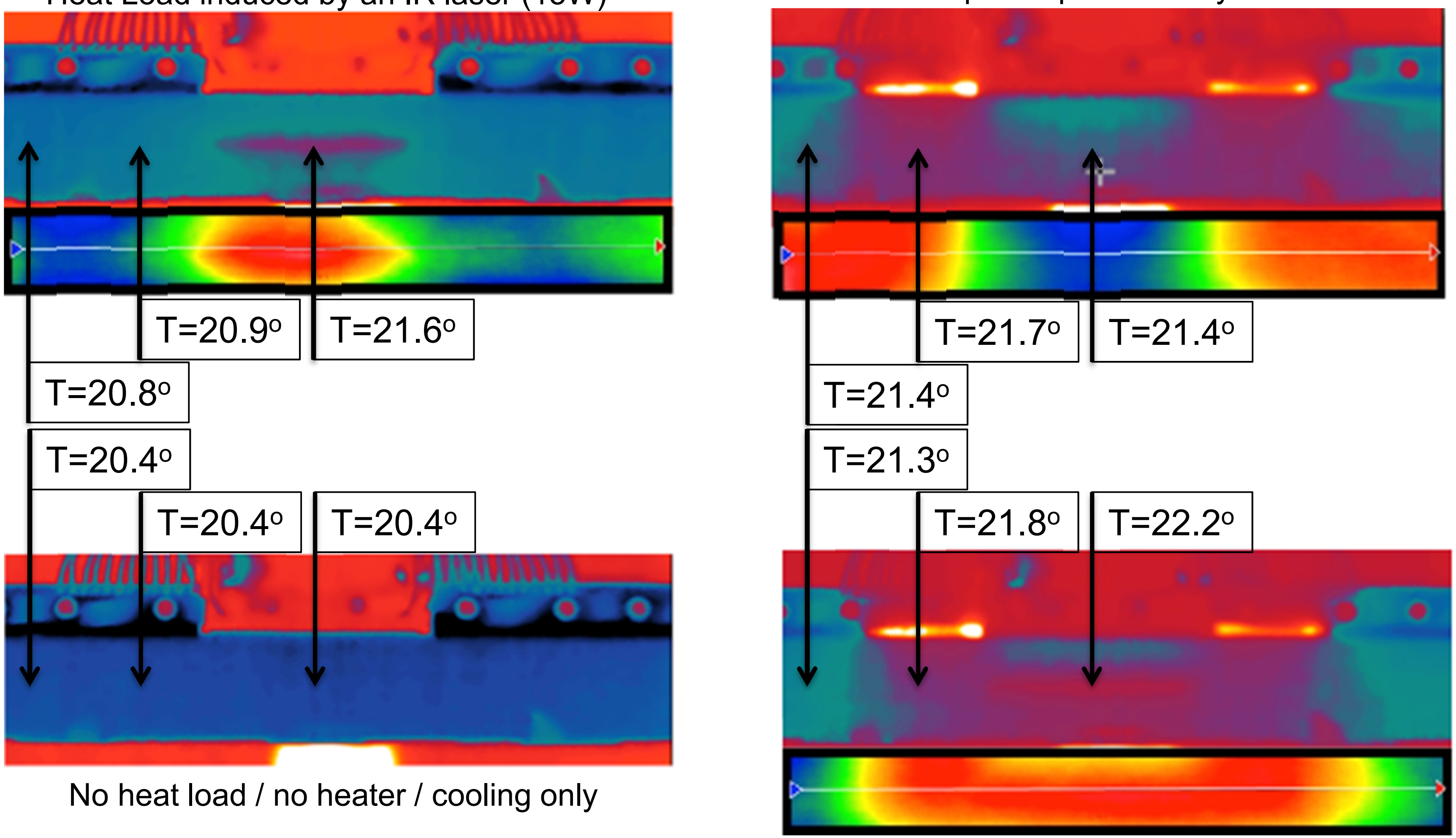
Combined effect (REAL + heat Load)

First compensation test, August 7th 2017

Thermal measurements (temperature in °C) map

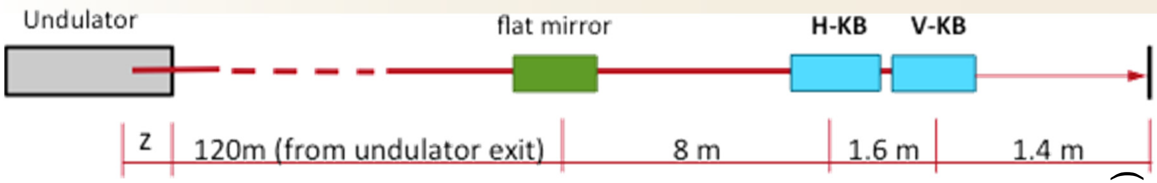
Heat Load induced by an IR laser (15W)

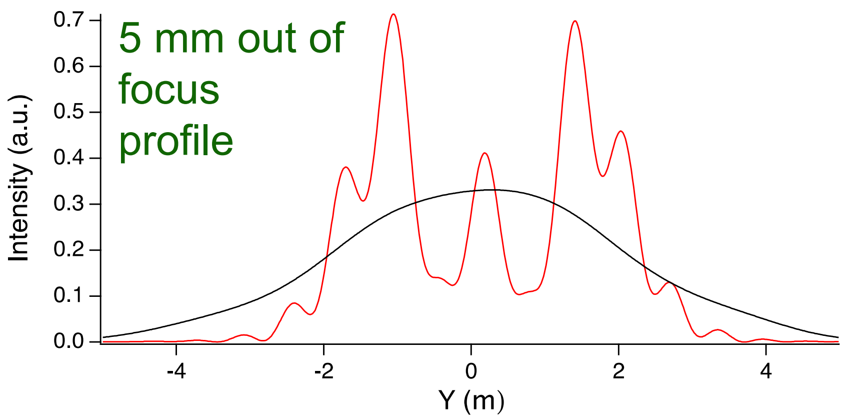
“counter” profile produced by 14 heaters

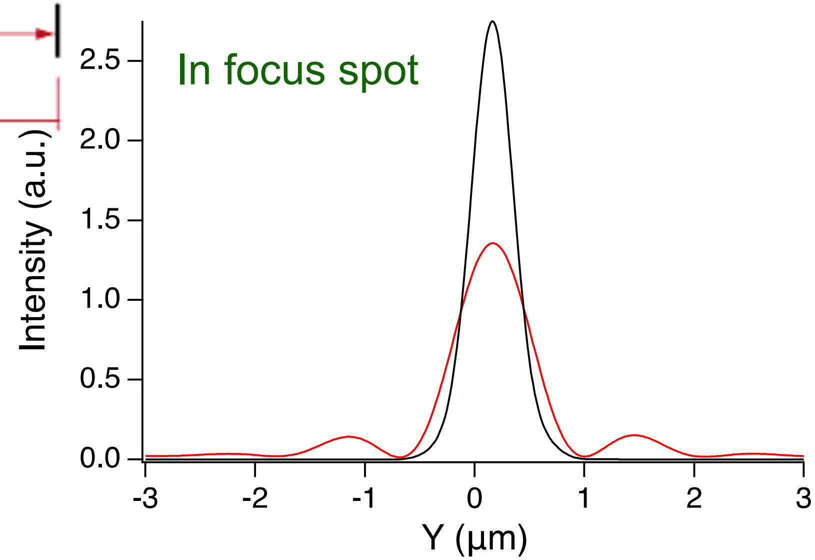


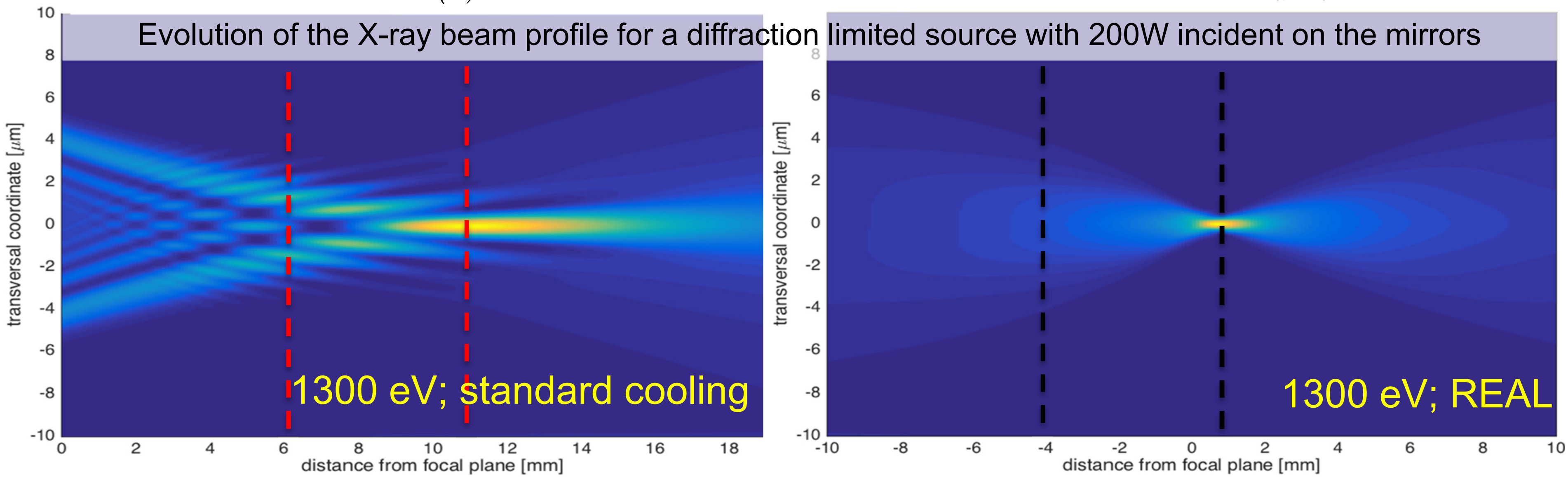
Combined effect (REAL + heat Load)

Expected performance improvement - a REAL example









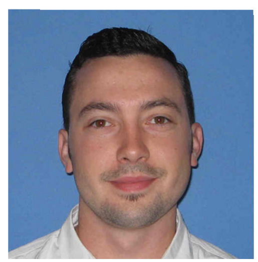
I haven't discuss most of the topics but, I'm happy to do it off line (with slides and pictures)

The Linac Coherent Light Source (LCLS) of SLAC is upgrading the facility to an High Repetition Rate mode and to a higher quality of the wavefront. This poses extreme challenges to the optical components. **A new approach to beamline design** is needed, starting from a new way to assess the effect of slope and shape errors, to **the need of taking into account any potential source of distortion**. Among the technical novelties the LCLS X-ray optics team is introducing, the most important are **a novel cooling scheme** to maintain the mirror shape within 0.5 nm rms under heat load, **the study of the effect of the cooling interface** to the mirror surface, and **new diagnostic systems**. Ultra-flat mirrors with **novel holder/bender mechanisms** have been recently installed. First results, showing the improvement of the beam quality, are expected in mid-June 2017. Another important aspect, is the **cleaning process to remove, in situ, carbonaceous contamination** from carbon based coatings. A controlled method has been developed and successfully implemented in the SXR mirrors to remove the carbon without affecting the coating. **All the above tests and studies will be presented, as well as the effect seen on a six-year old mirror exposed to FEL for his entire lifetime.**

X-ray optics team

Peter Stefan

Daniel Morton

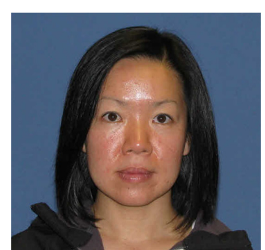


Lin Zhang

Venkat Srinivasan (Left on June'17)

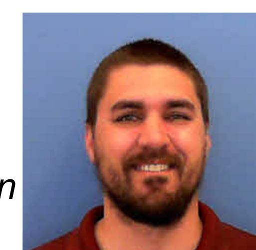
Josep Nicolas (Returned to ALBA)

Lance Lee



May Lin Ng

Corey Hardin



Thanks for your kind attention