Using Resistive Element Adjustable Length (REAL) Cooling to Increase Optical Design Flexibility in High Power XFELS

Corey Hardin, May Ling Ng, Daniel S. Morton,
Lin Zhang, Josep Nicolas, Daniele Cocco

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U.S. DEPARTMENT OF ENERGY
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SLAC NATIONAL ACCELERATOR LABORATORY

LCLS - II

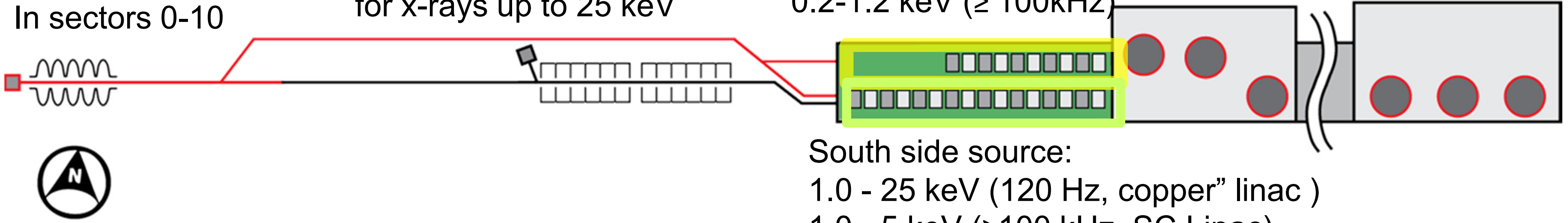
4 GeV SC Linac
In sectors 0-10

14 GeV LCLS linac used
for x-rays up to 25 keV

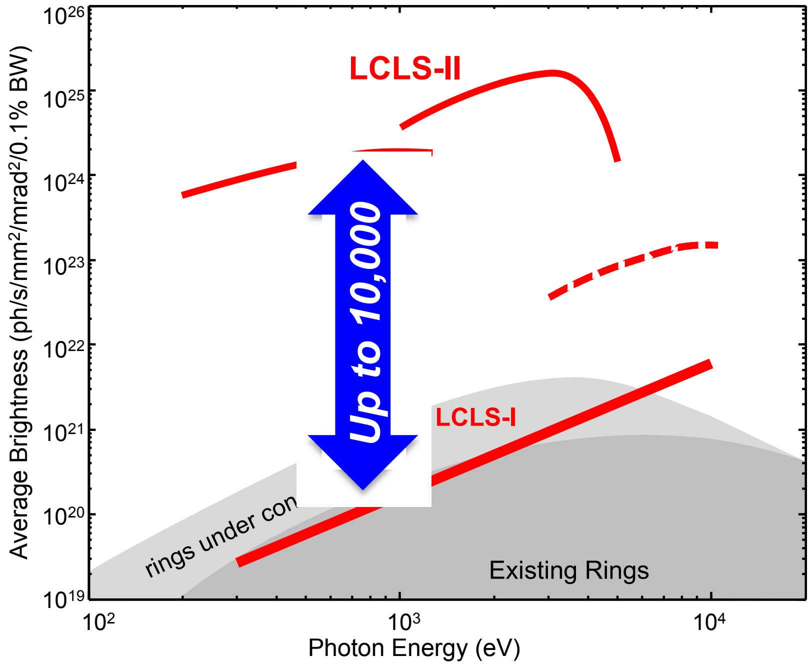
North side source:
0.2-1.2 keV (≥ 100kHz)

NEH

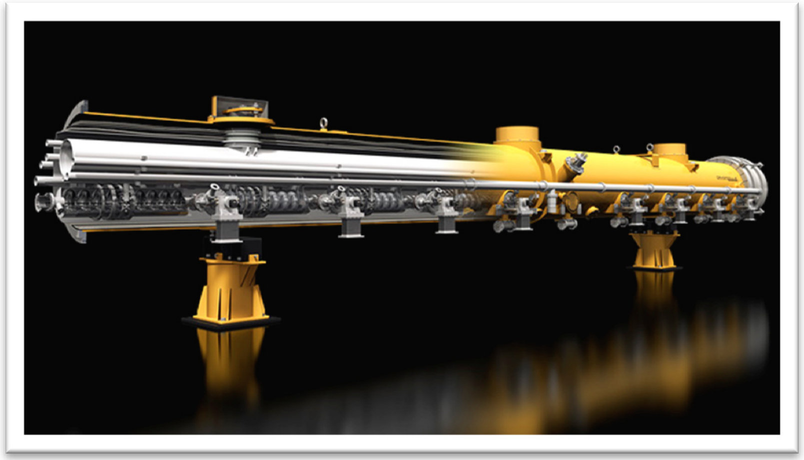
FEH



South side source:
1.0 - 25 keV (120 Hz, copper” linac)
1.0 - 5 keV (≥100 kHz, SC Linac)

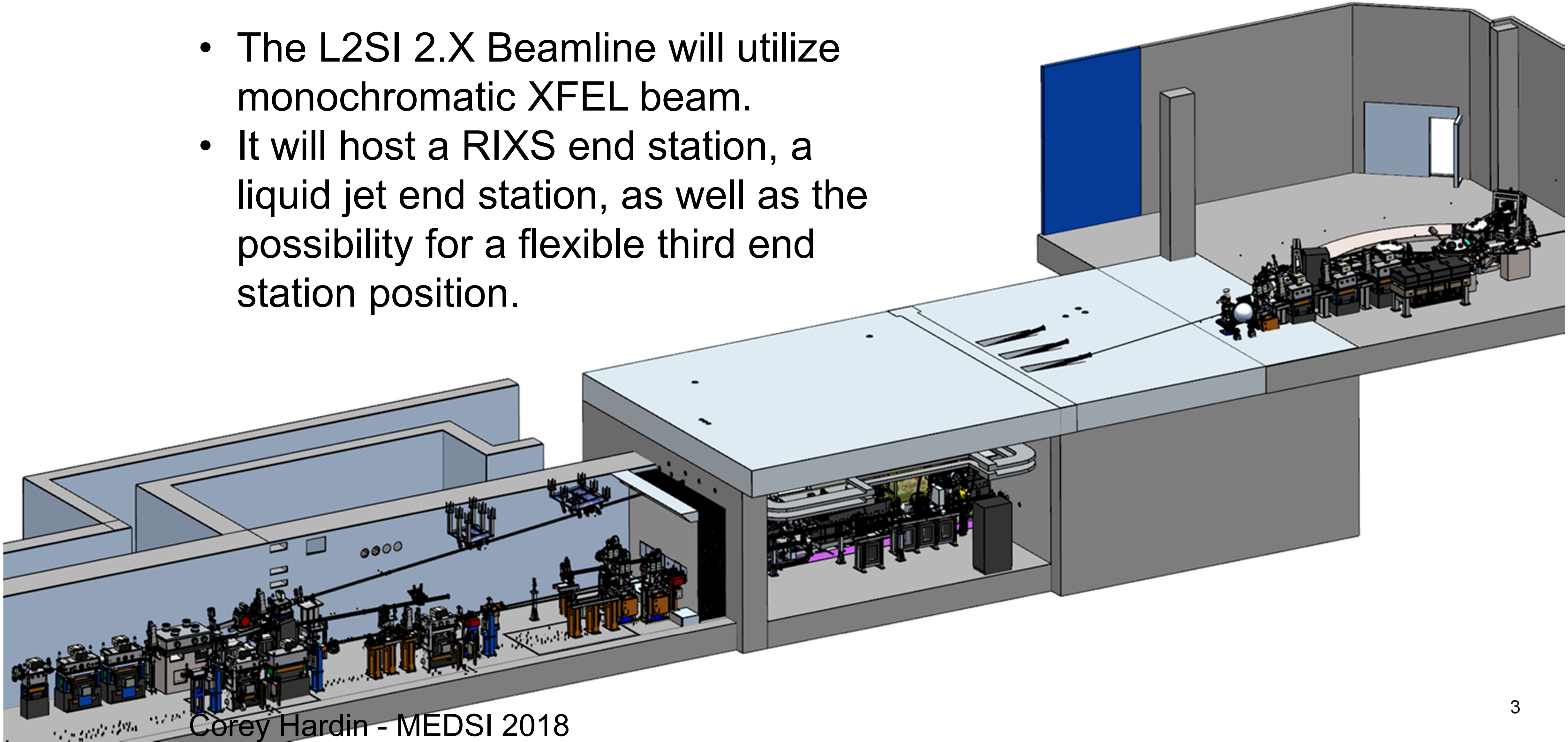


From the current 2-300 mW to up to 600 W on the optics



2.2 Layout

- The L2SI 2.X Beamline will utilize monochromatic XFEL beam.
- It will host a RIXS end station, a liquid jet end station, as well as the possibility for a flexible third end station position.



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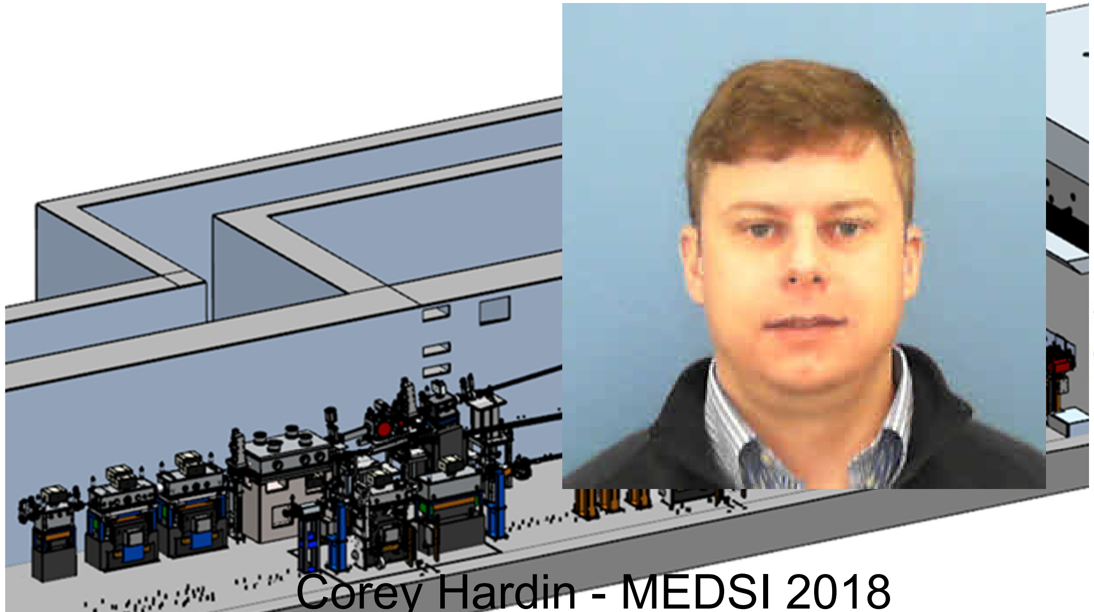
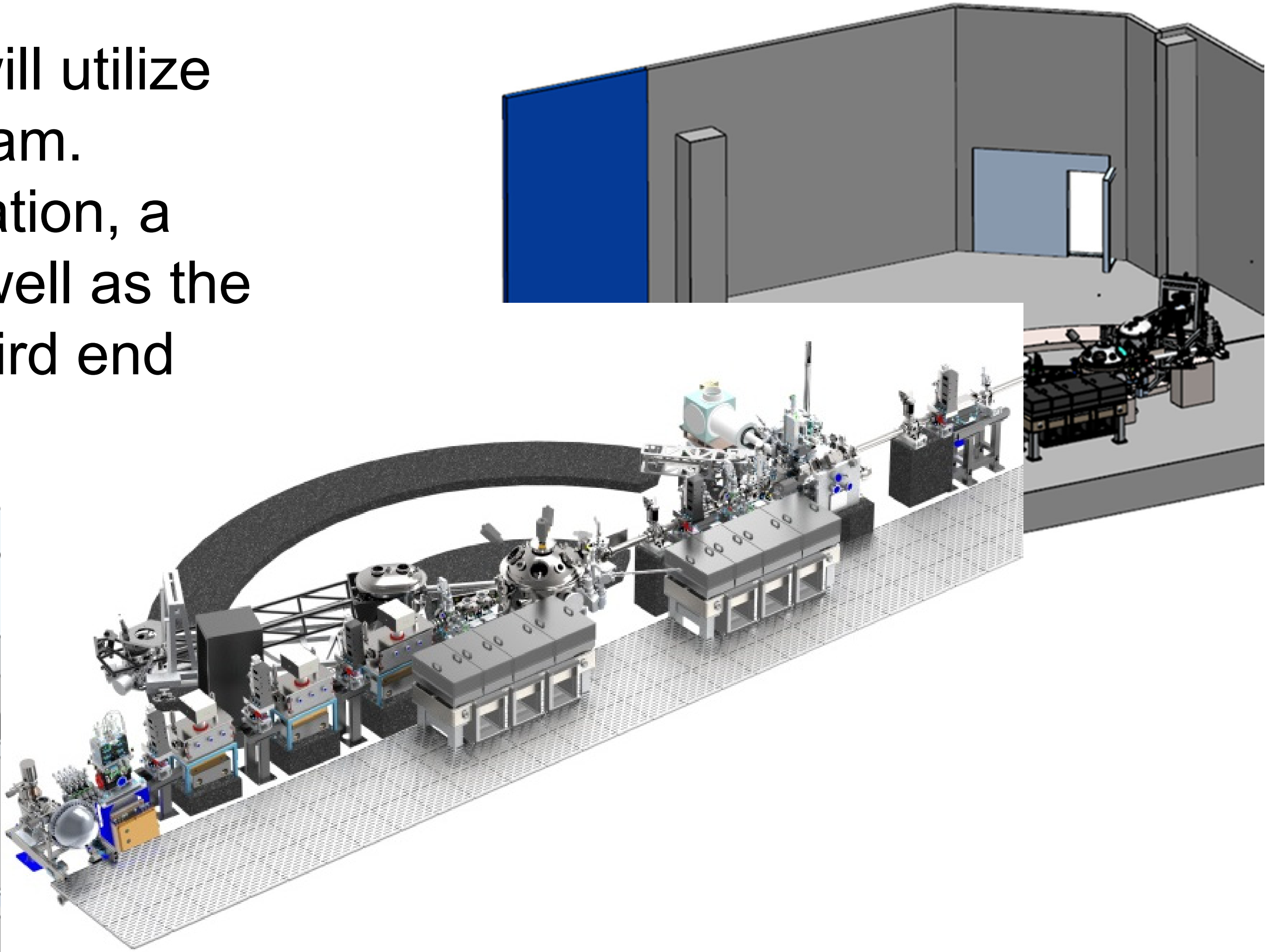
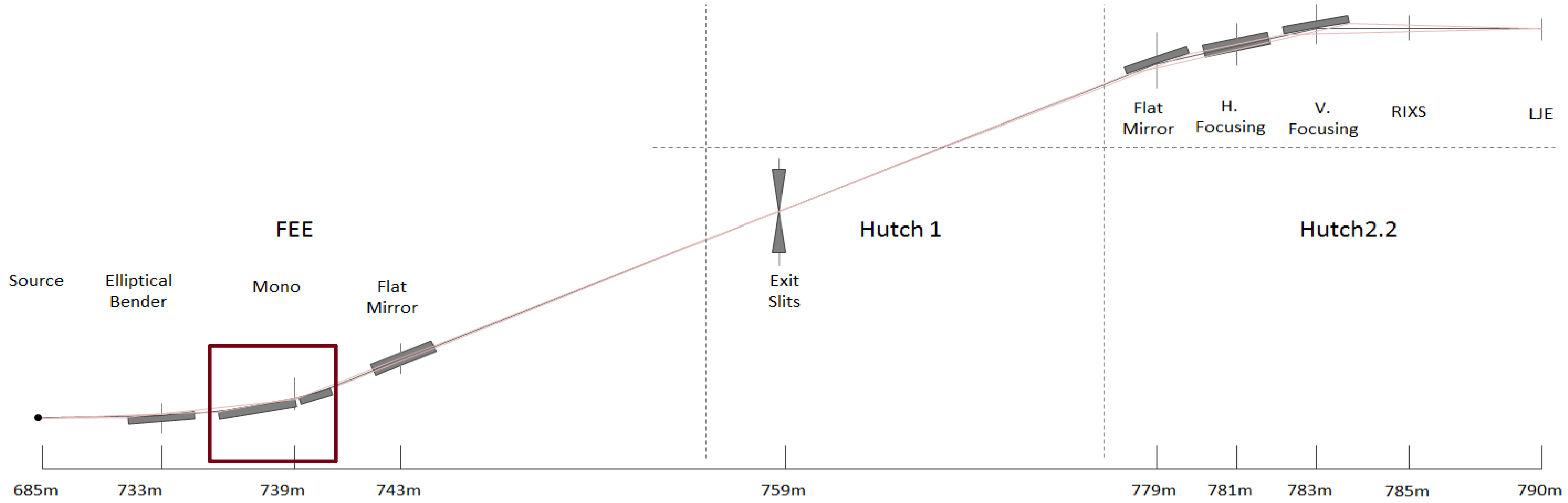


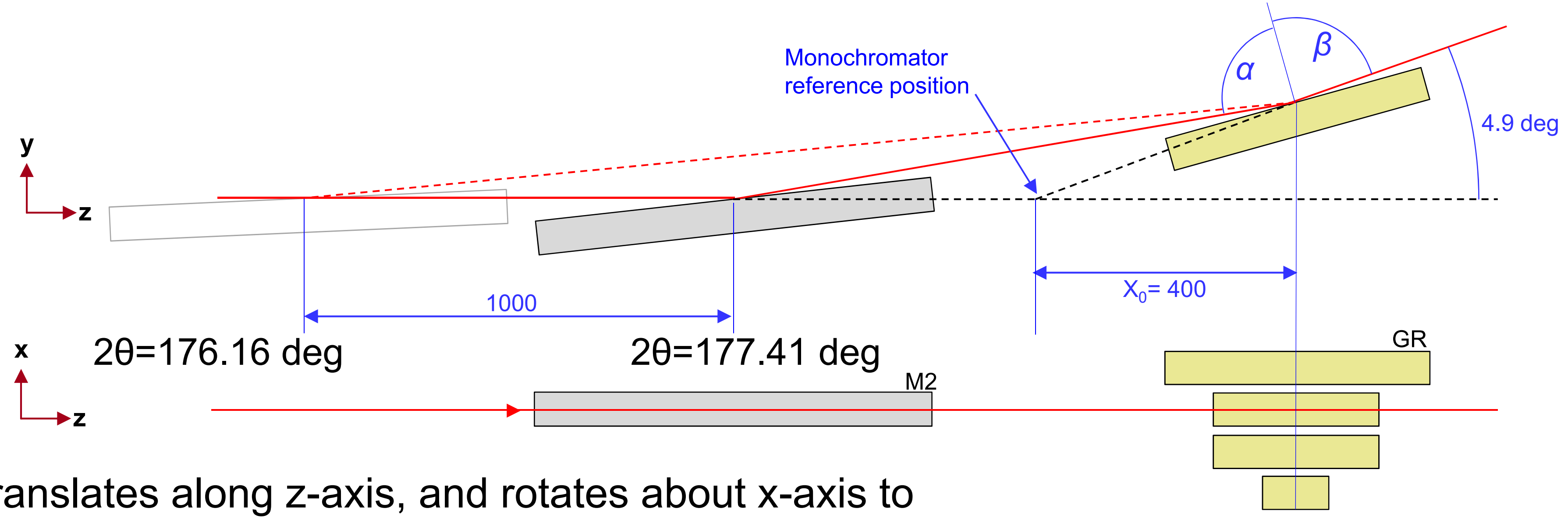


See Frank O'Dowd's Poster this afternoon for more detail

2.X Optical Layout

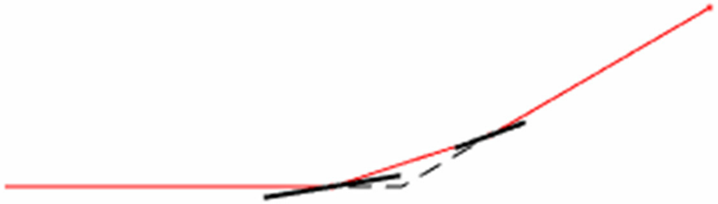


Monochromator layout



1) Mirror translates along z-axis, and rotates about x-axis to keep the beam aligned downstream of the grating.
2) Each position of the mirror corresponds to a different *included angle* (=α+β).
3) The grating rotates about the x-axis to select photon energy.
4) Translation along x-axis to select the grating.

E = 1227, d = 0.72 m



Maintaining optical quality

Being able to obtain the proper “image” of what you are intending to study

Without having the “images” distorted by your optics at a level preventing the experiment to be successful

Monochromator Requirements

Experimental Technique	Rep Rate	Pulse Energy	Average Power	Photon Energy Range	Resolving Power (E/ΔE)
Absorption spectroscopy	100 kHz	30 uJ*	3 W*	250 – 1350 eV	**<5,000**
Resonant coherent scattering and imaging	10 kHz	30 uJ*	0.3 W*	250 – 1300 eV	**<5,000**
RIXS - low resolution (high through-put) [surfaces]	100 kHz 1 MHz‡	30 uJ* 3 uJ*‡	3 W*	250 – 1300 eV	**5,000**
XMCD	100 kHz 1 MHz‡	30 uJ* 3 uJ*‡	3 W*	250 – 1300 eV	1,000-5,000
Absorption spectroscopy	100 kHz	30 uJ*	3 W*	250 – 1600 eV	**10,000-50,000**
RIXS - high resolution q-resolved	1 MHz‡	0.2 uJ*	0.2 W*	250 – 1600 eV	**10,000-50,000**
RIXS - high resolution vibrational	1 MHz‡	1 uJ*	1 W*	250 – 1600 eV	**10,000-50,000**
XPCS-soft	10 kHz	30 uJ*	0.3 W*	250 – 1600 eV	**10,000-50,000**

≈ 40 W @ 500 eV; 30 W @ 1300 eV
with Seeded beam
> 600W for SASE beam

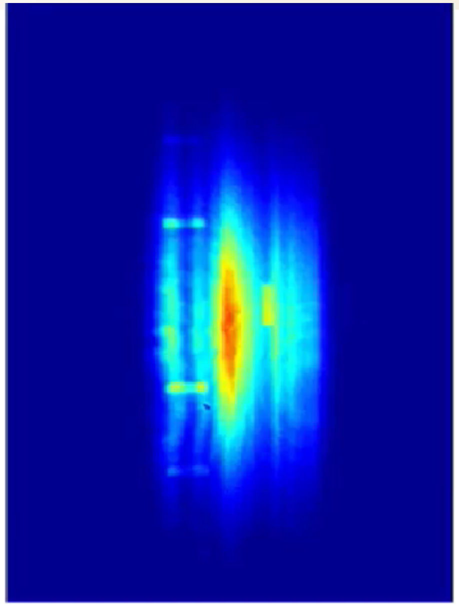
≈ 4 W @ 500 eV; 3 W @ 1300 eV
with Seeded beam
≈ 90 W @ 500 eV; 70 W @ 1300 eV
with SASE beam

≈ 160 W @ 500 eV; 190W@1300 eV
with Seeded beam
> 600W for SASE beam

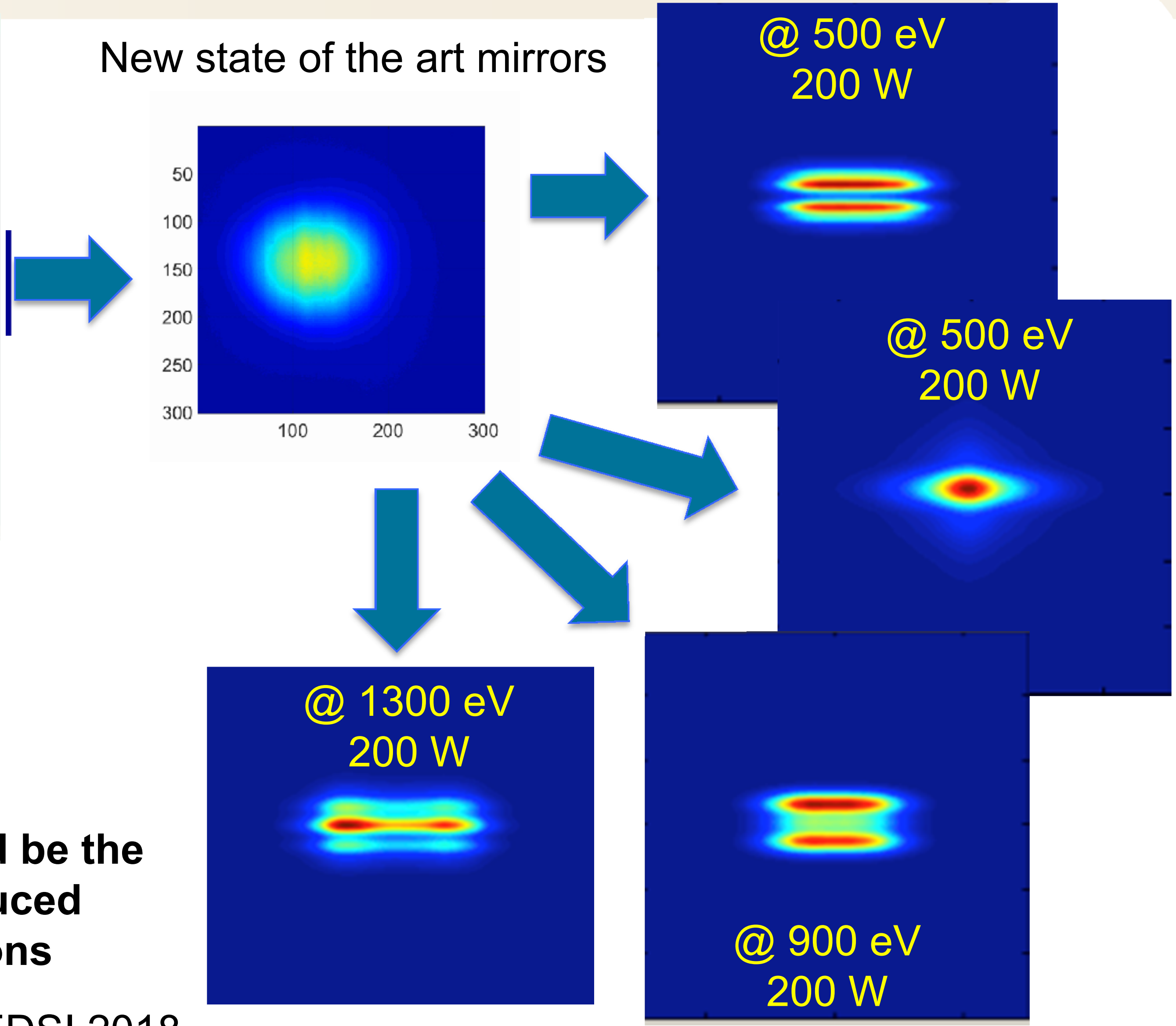
≈ 10 W @ 500 eV; 12 W @ 1300 eV
with Seeded beam
> 200W for SASE beam

*After the exit slit

Maintaining optical quality



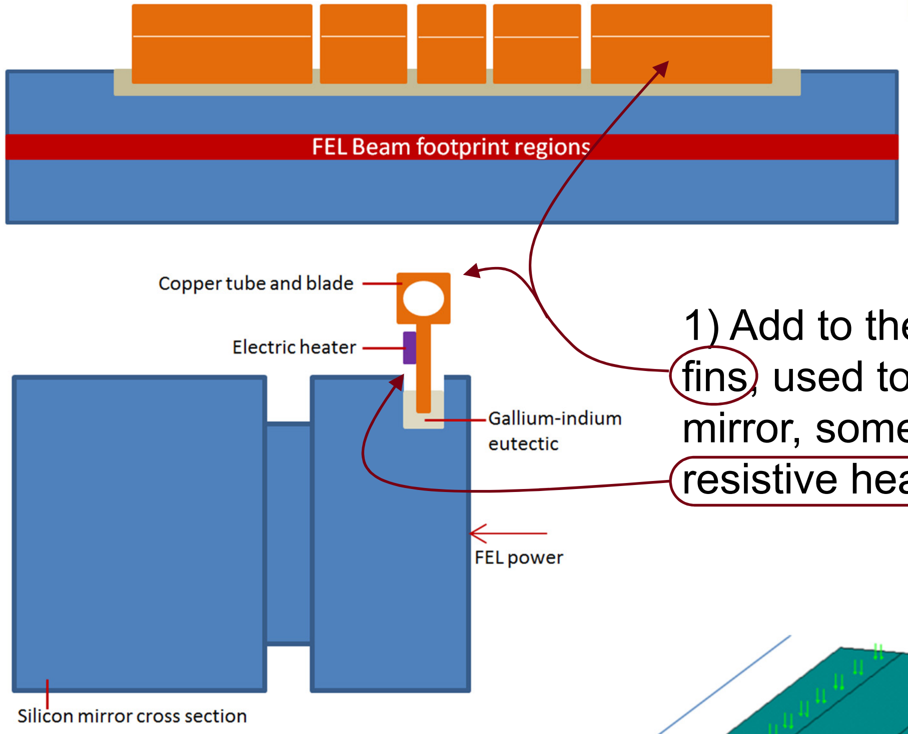
Old Mirror limit
shape errors



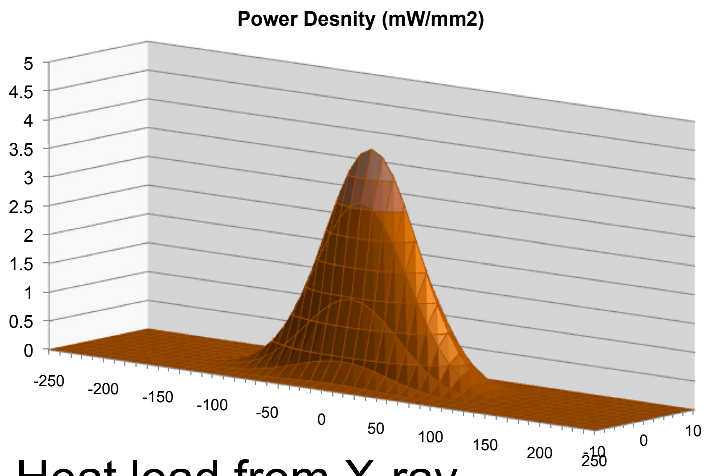
Next limit could be the thermal induced deformations

Corey Hardin - MEDSI 2018

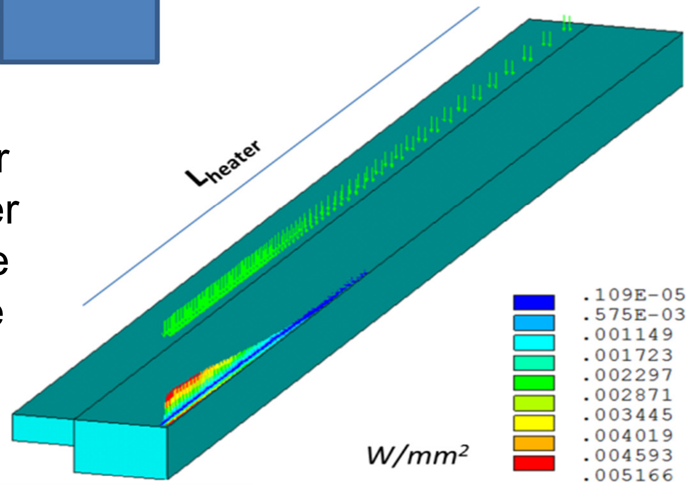
REAL (Resistive Element Adjustable Length) Cooled Optics



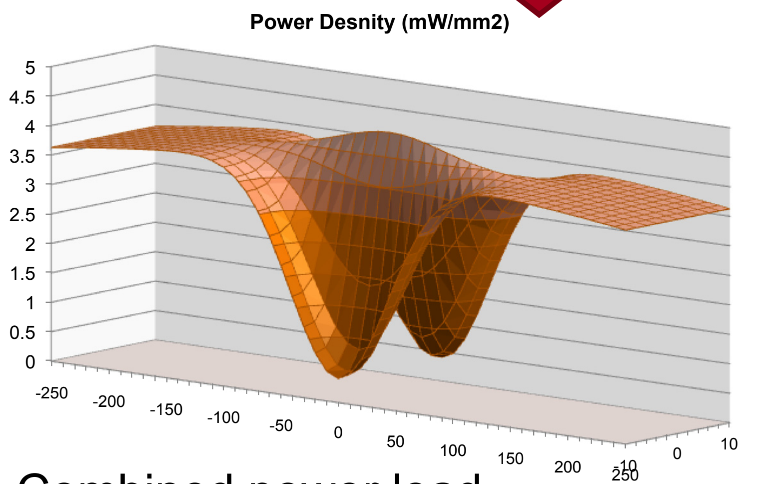
1) Add to the existing fins, used to cool the mirror, some resistive heaters



Heat load from X-ray



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



Combined power load

DOE/BES Funded Project

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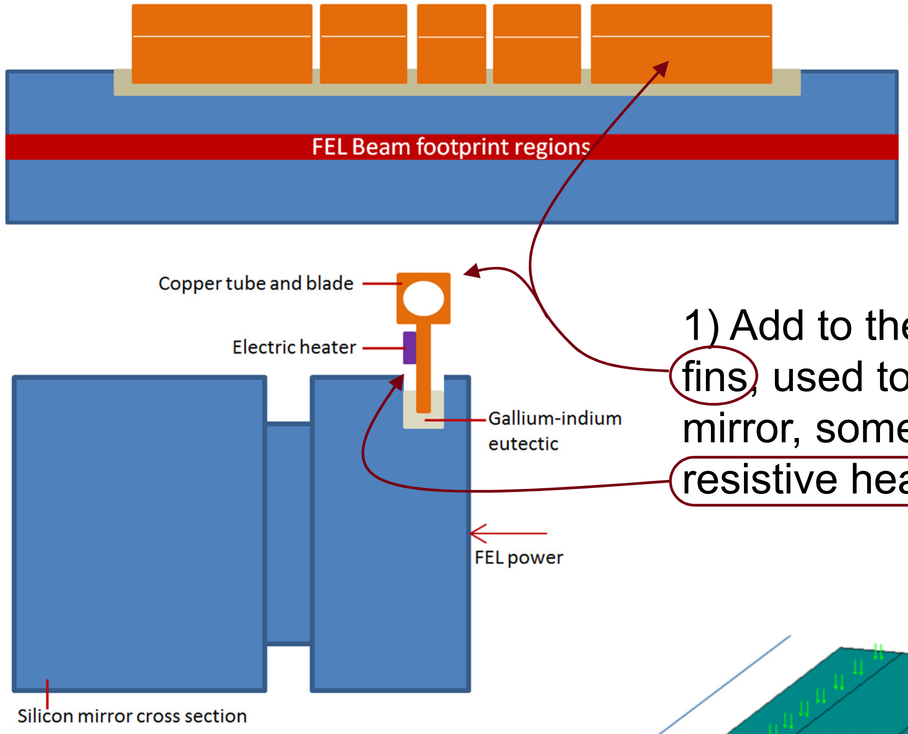

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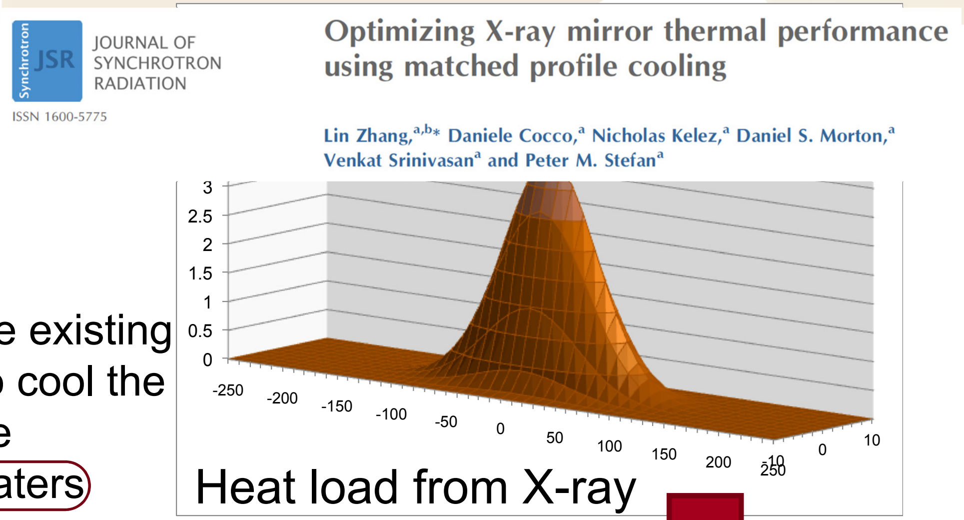

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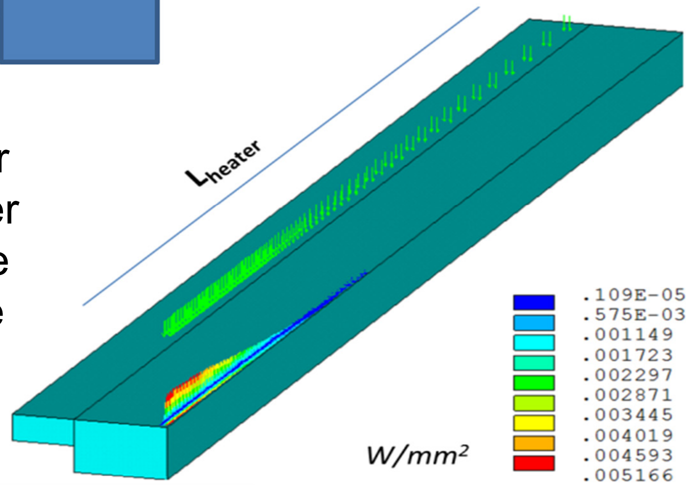
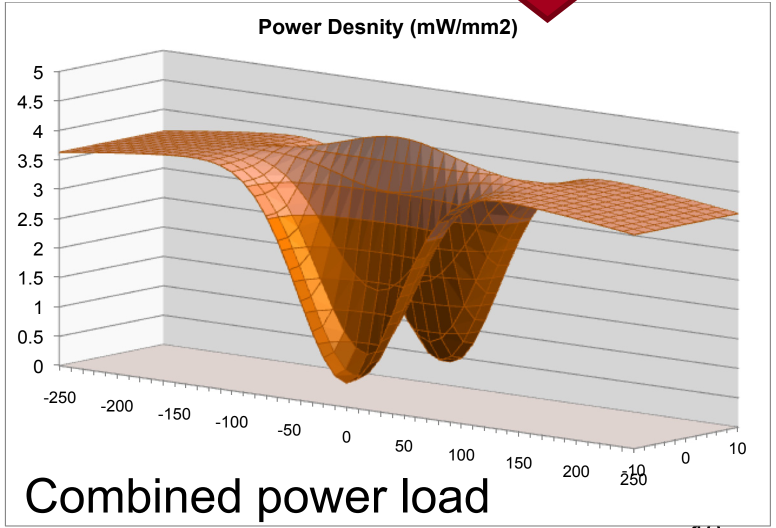
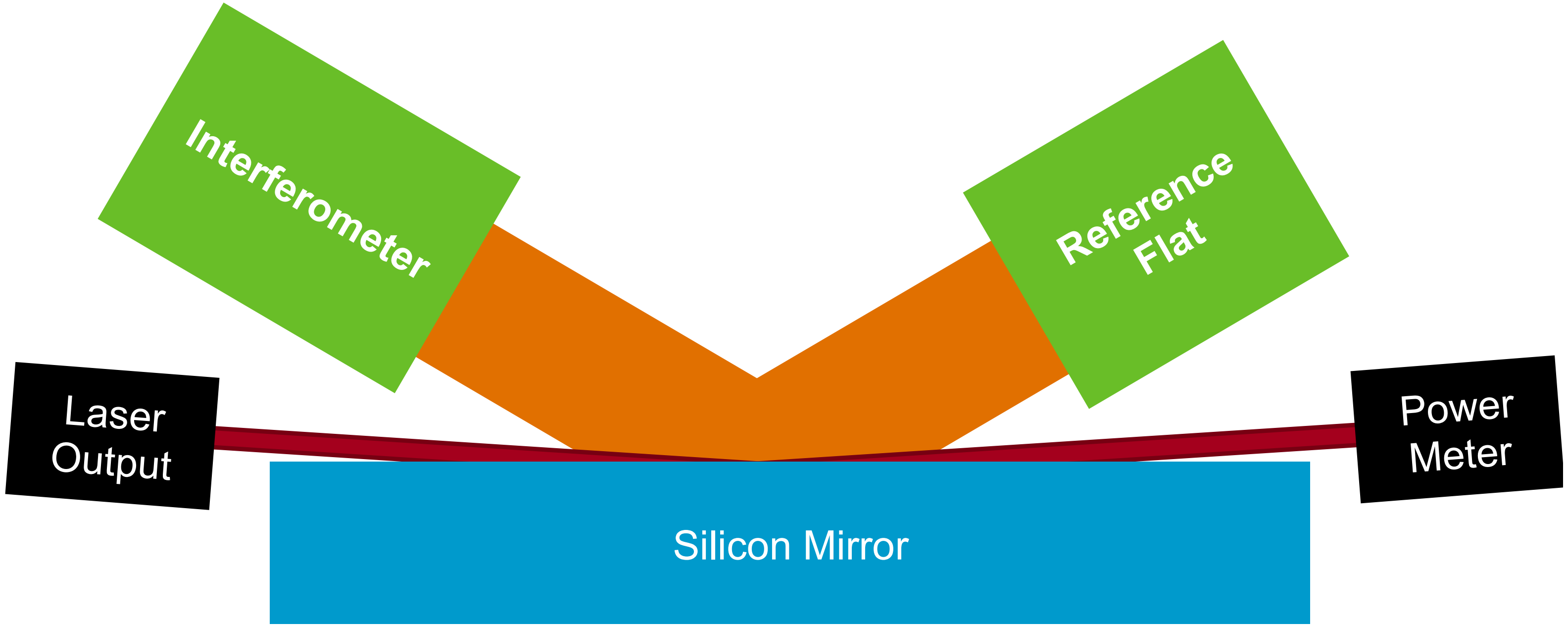




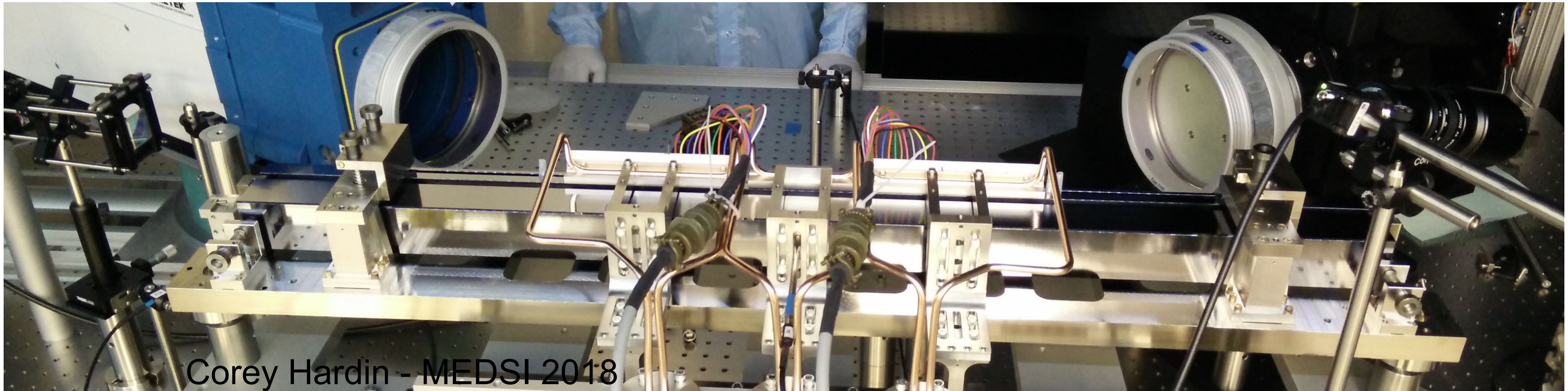
Combined power load

DOE/BES Funded Project

Measurement Layout

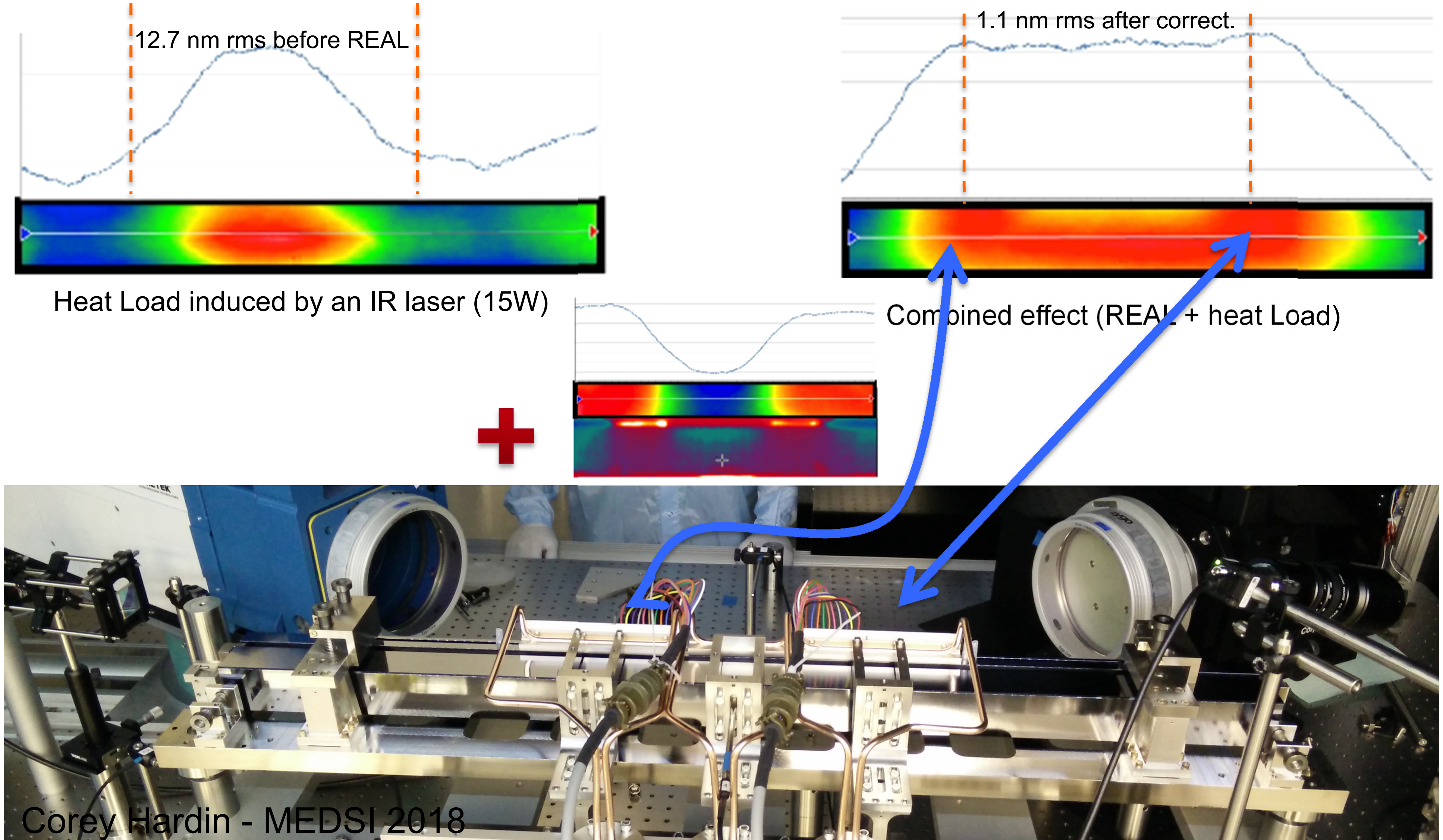


Measuring in double bounce, reference flats are λ/300
Laser starts as 2mm round beam, telescope expands horizontal axis to 20mm, Interferometer incidence angle is ~25^0, Laser angle 11^0

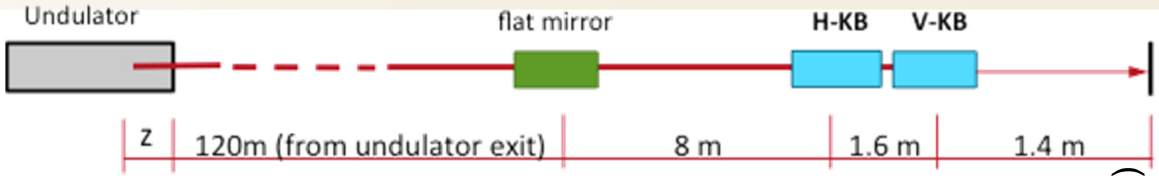


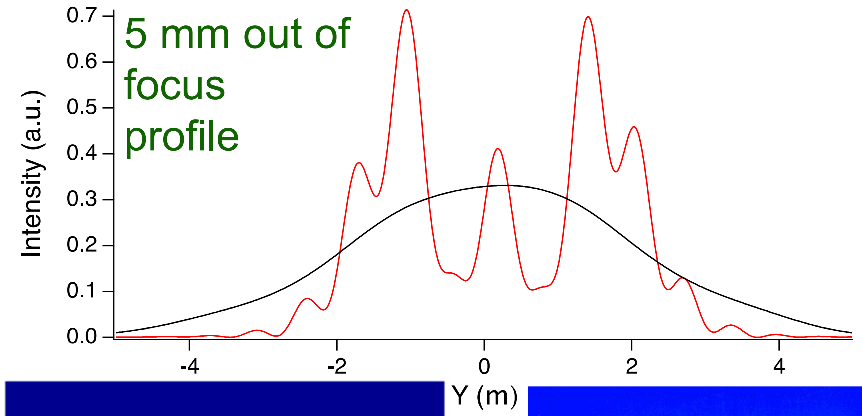
REAL test

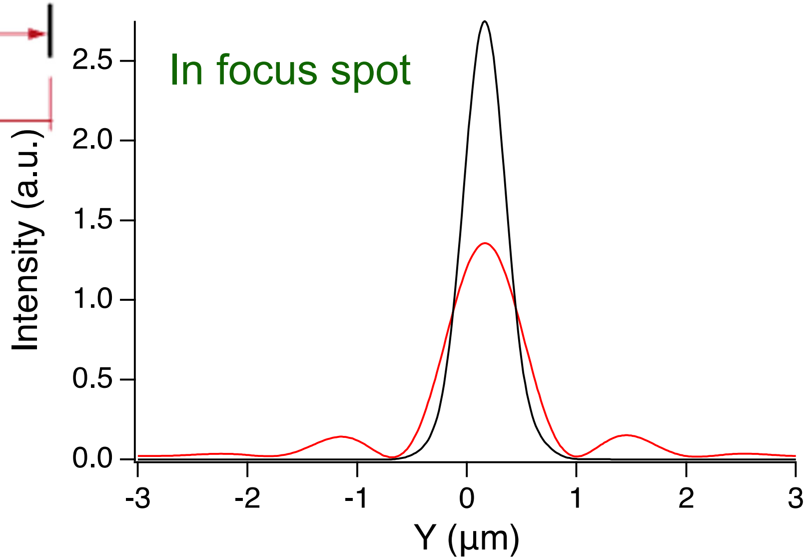
1st demonstration of X-ray mirror shaping (correction) using heaters



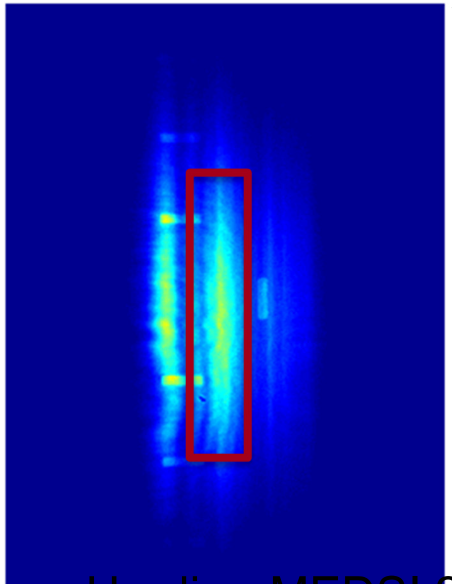
Expected performance improvement - a REAL example

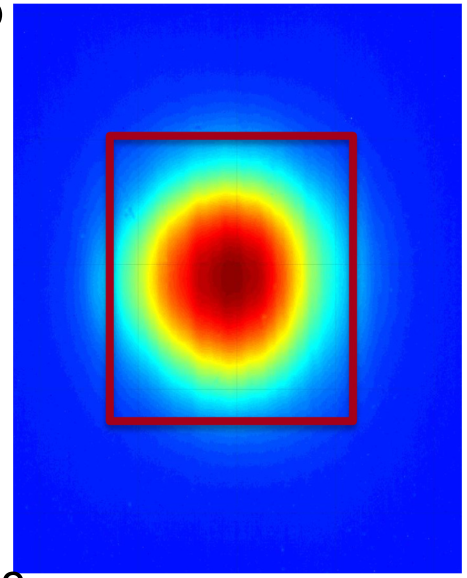






There is a gain of a factor 2 in peak power (or fluence) in focus

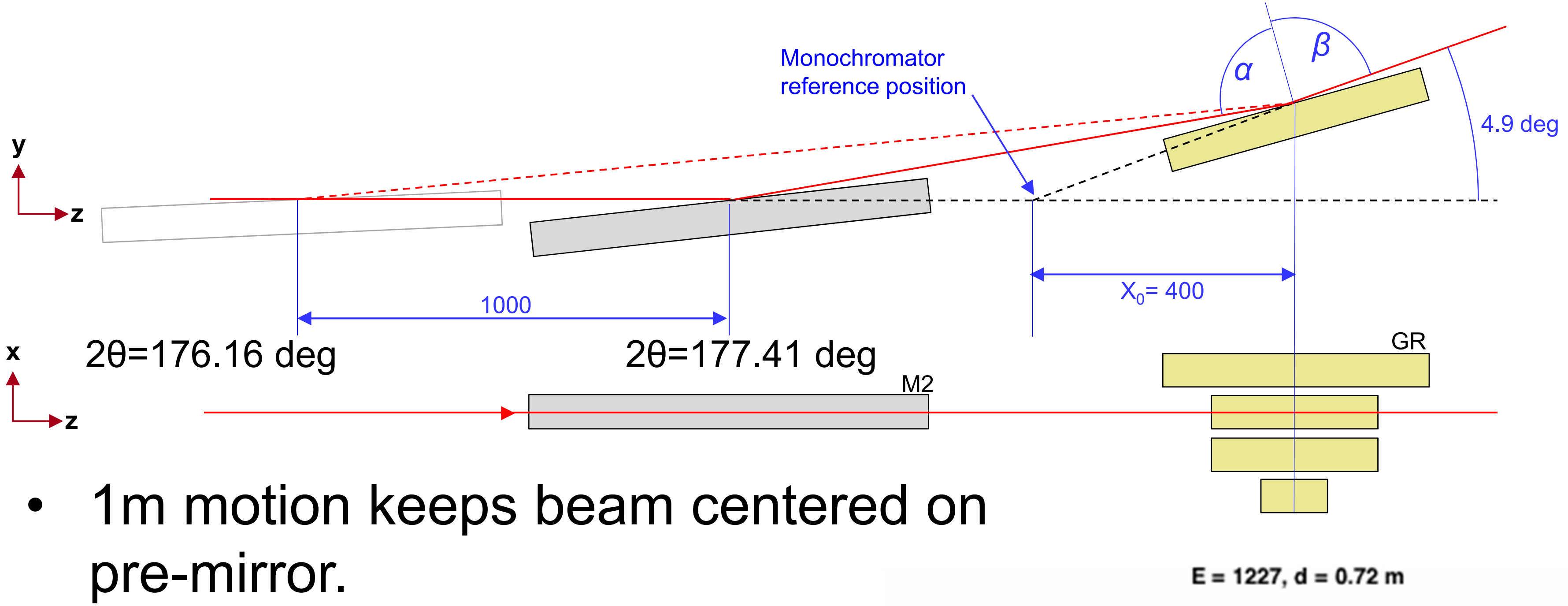




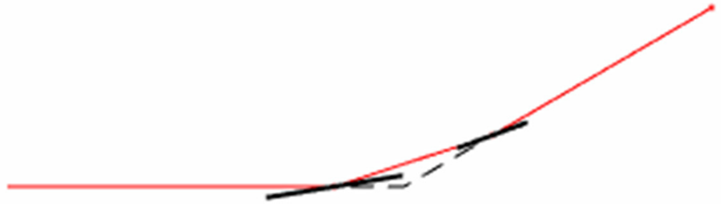
🡐 and much more out of focus

Let's compare the effort/cost for this mirror with the investment to double or triple the power from the source… $$$

Monochromator layout

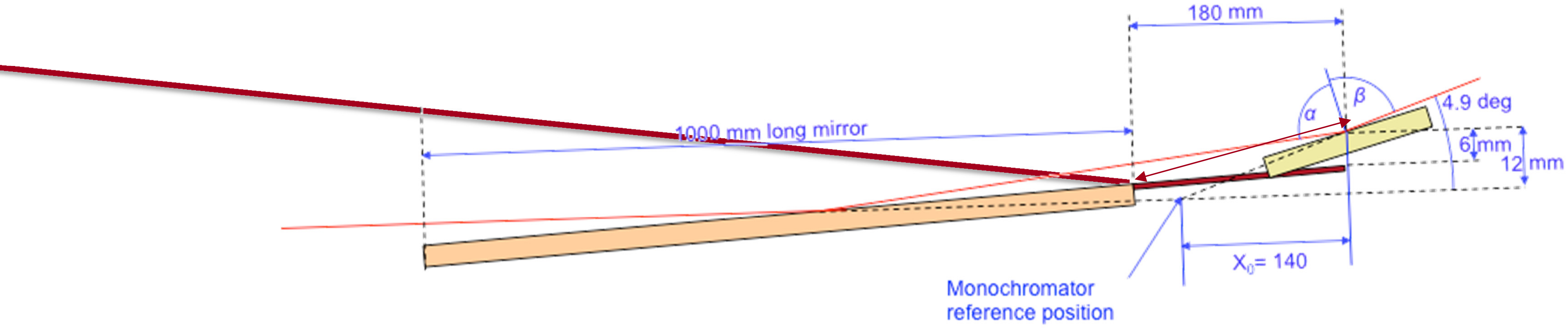


- 1m motion keeps beam centered on pre-mirror.
- Accuracy of <70nrad across 1m stroke required. Very difficult to achieve even with interferometric measurements.



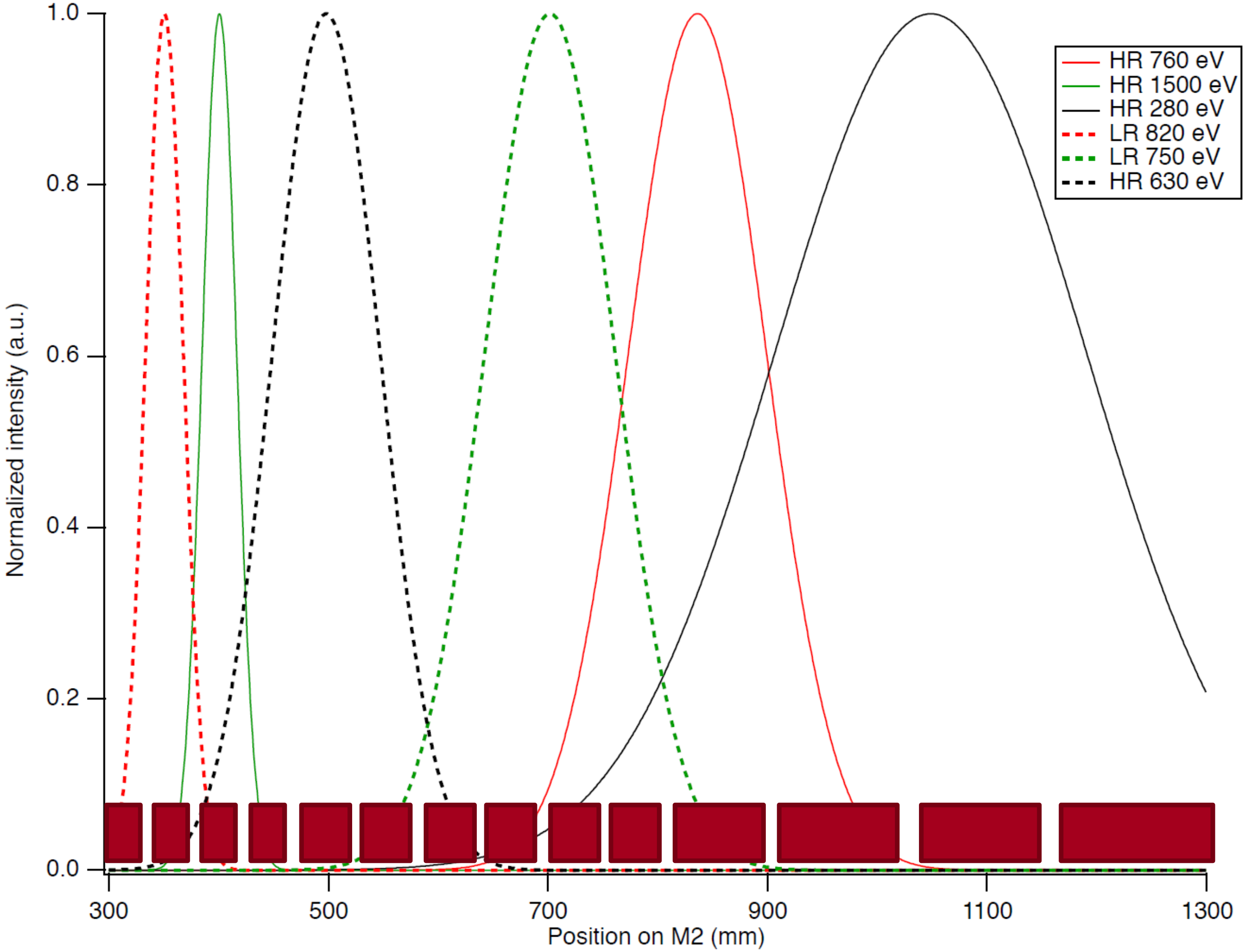
New Monochromator Design

- Since adaptive cooling is already required, we can utilize it to remove the requirement of keeping the beam centered on the pre-mirror
- As a result, the linear motion of the pre-mirror can be eliminated if we replace it with a longer mirror that only requires a pitch about a point below the grating.



Beam Footprint on Mono Pre-Mirror

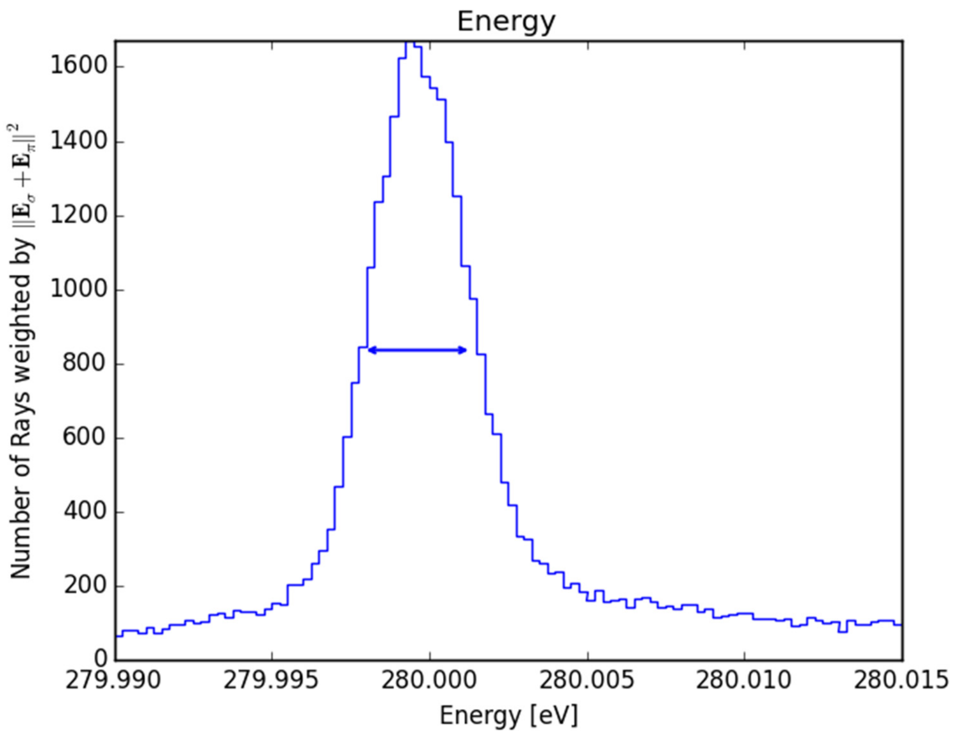
- Heater spacing can be tapered to match changing beam size as beam moves along mirror
- FEA/Analytical study to optimize spacing is in progress

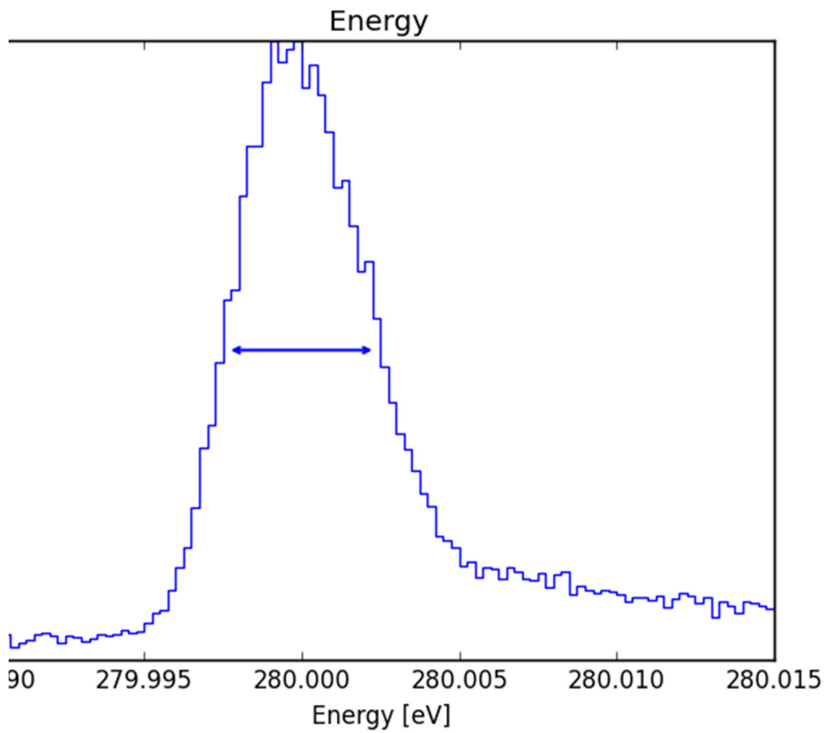


High Resolution 300 l/mm D1 = 2.57 l/cm^2 280 eV

M1 focal distance: 14.0 m
D_2 ideal: 0.007 l/cm^3
D_3 ideal -0.001 l/cm^4
No thermal deformation
ΔE=3.5 meV
E/ΔE=80,000

M1 focal distance: 14 m NO CORRECTION
D_2 ideal: 0.007 l/cm^3
D_3 ideal -0.001 l/cm^4
Thermal deformation – 200 W @ source
ΔE= 4.7 meV
E/ΔE=60,000





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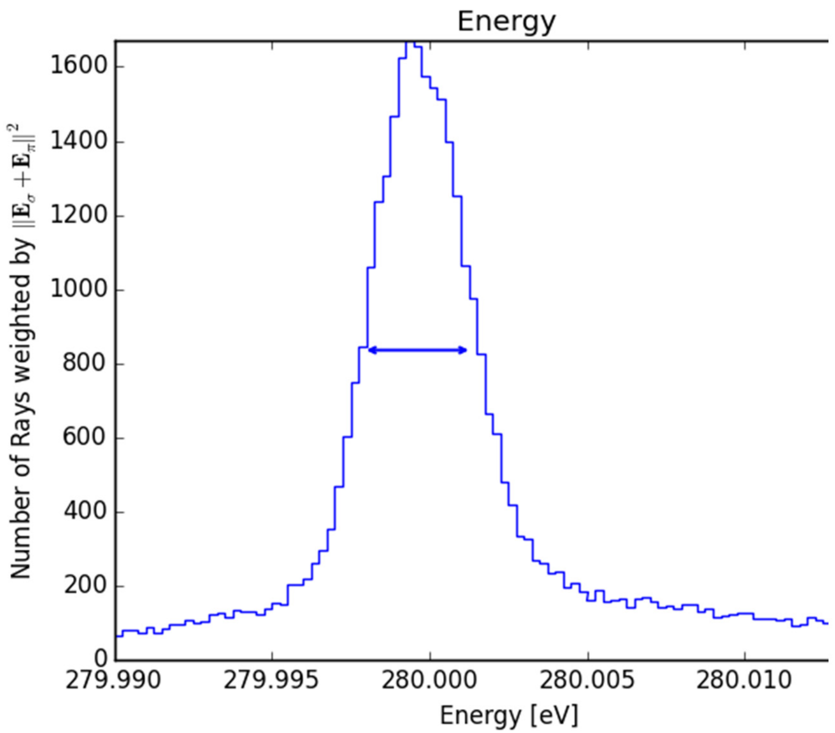
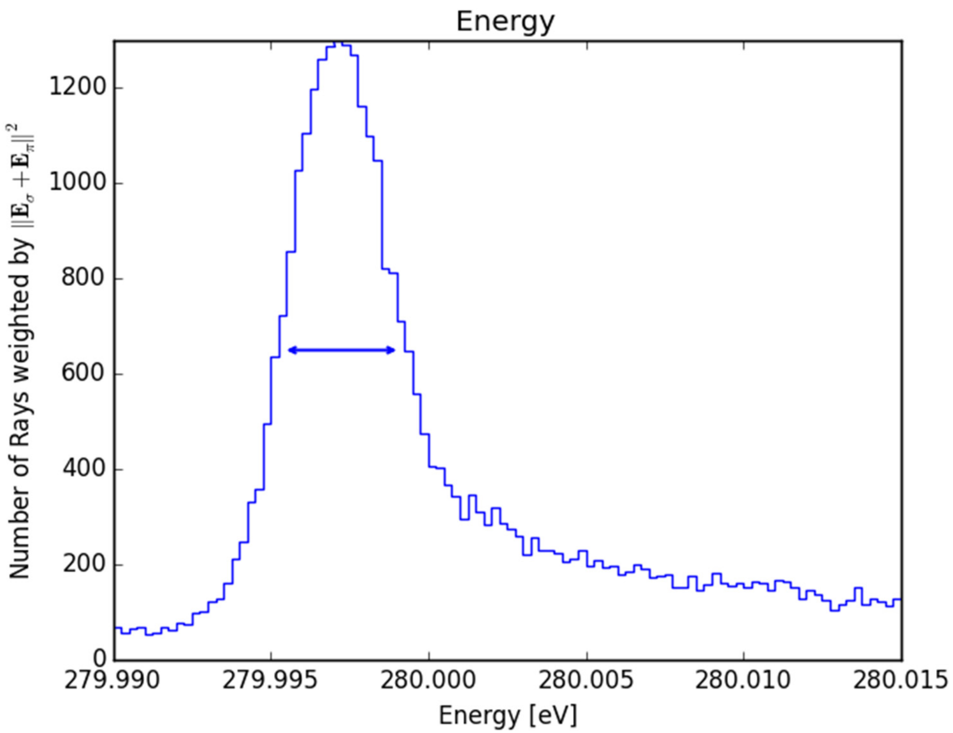


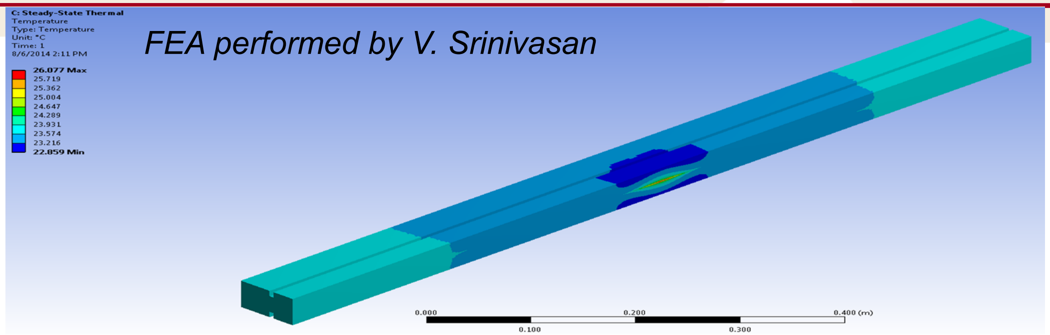
M1 focal distance: 14.1 m corrected
D_2 ideal: 0.007 l/cm^3
D_3 ideal -0.001 l/cm^4
Thermal deformation – 200 W @ source
ΔE= 3.7 meV
E/ΔE=75,000

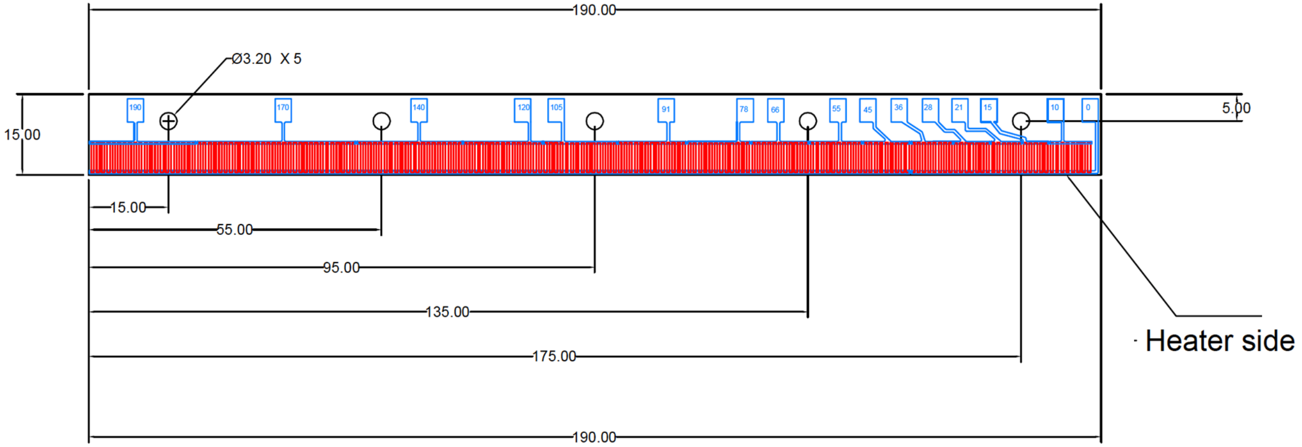


Something about the heaters

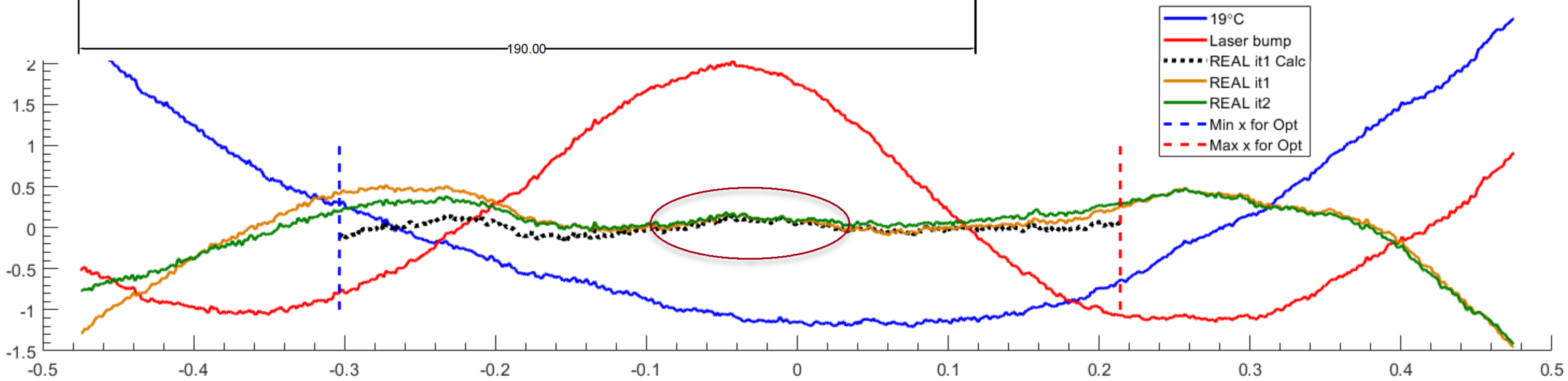
For long mirrors, with variable footprint you need a lot of wire (at least one per channel plus one for each ground)

This means a lot of wires, and possibly hydrocarbons in the mirror chamber

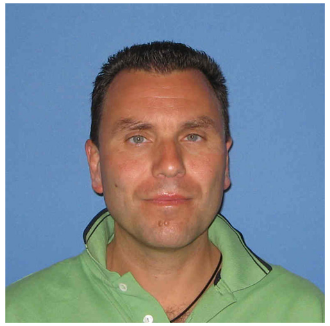




Add in vacuum multiplexing circuit?

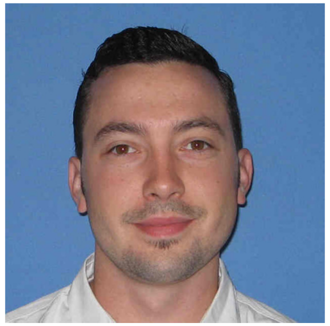


Acknowledgements



Daniele Cocco
(Optics group leader)

Daniel Morton
(precision mechanics)



Lin Zhang
(Inst. Dev.
Group Leader)

Daniele Spiga
(optics and metrology)

Josep Nicolas
(optics and metrology)
Returned to Alba 2017

Peter Stefan
(optics and mechanics)

May Lin Ng
(Metrology)

Lance Lee
(mechanics and
vibration)

And many others!

Thanks for your kind attention

Stanford University

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