# LCLS-II FEL Photon Collimators Design

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## Introduction

LCLS-II, a major upgrade of the LCLS machine is being developed as a high-repetition rate X-ray laser with two simultaneously operating FELs.
The LCLS-II presents enormous engineering challenges when it comes to safety, machine protection devices and diagnostic units.
A key component of the beam containment are the FEL beam collimators. The current collimator design is no longer suitable for the high power densities of the upcoming LCLS-II beam and therefore a complete new design has been conceived to satisfy this new constrains.
The design now includes a miss-steering detection system based on a photo diodes array and a CVD Diamond as absorber and collimating element.

## LCLS-II Beam and its power

The LCLS-II beam with high repetition rate up to 1 MHz is an increase of 4 orders of magnitude from the LCLS beam.

**LCLS-II Soft X-ray Beam parameters at 0.1MHz, 300Pc**

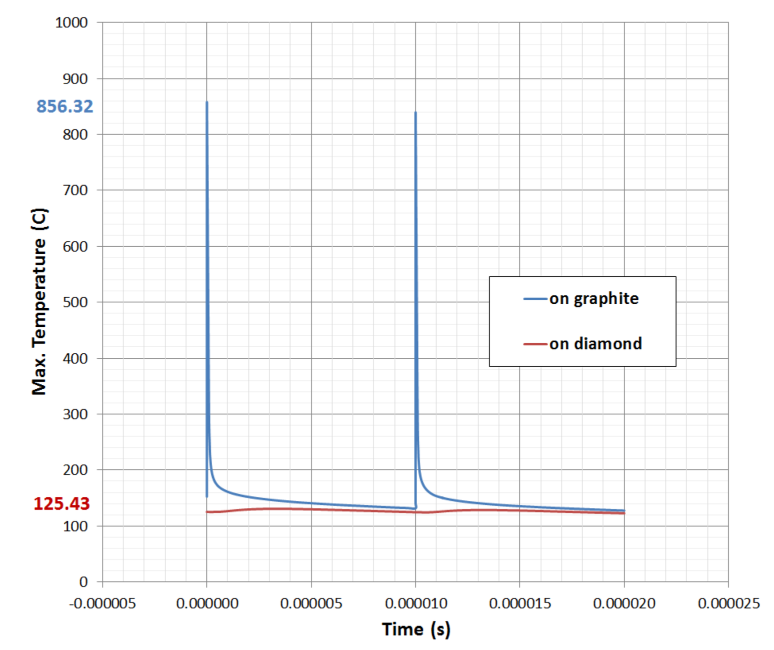
| Energy [eV] | Beam divergence [µrad] | Max integrated power [W] | Max single pulse fluence [mJ] |
|---|---|---|---|
| 250 | 11.8 | 880 | 8.8 |
| 750 | 4.6 | 570 | 5.7 |
| 1250 | 3.2 | 339 | 3.4 |

**LCLS-II Hard X-ray Beam parameters at 0.3MHz, 100Pc**

| Energy [eV] | Beam divergence [µrad] | Max integrated power [W] | Max single pulse fluence [mJ] |
|---|---|---|---|
| 1500 | 2.8 | 519 | 1.73 |
| 3250 | 2.0 | 185 | 0.62 |
| 5000 | 3.3 | 1.8 | 0.06 |

Due to the high power density (W/cm$^2$) and extremely high peak fluence (J/cm$^2$ per pulse) a material with high thermal conductivity and low Z number is required, and the CVD Diamond is the most suitable due to its properties.

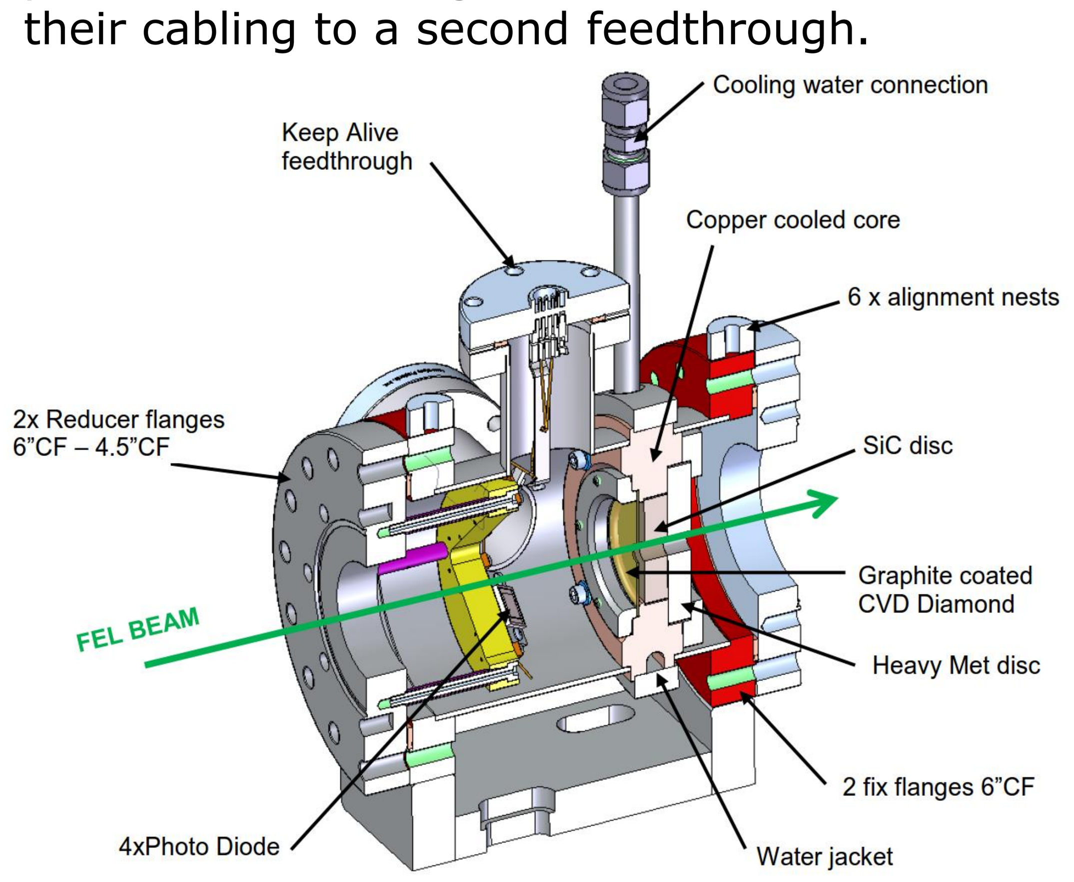
In order to mitigate the damage of the diamond near carbon edge photon energies (~ 283 eV), a pyrolytic graphite coating of 3µm has been applied with chemical vapor deposition.




*The graphite attenuates the x-ray radiation from each pulse and protects the diamond which remains at an almost constant temperature.*

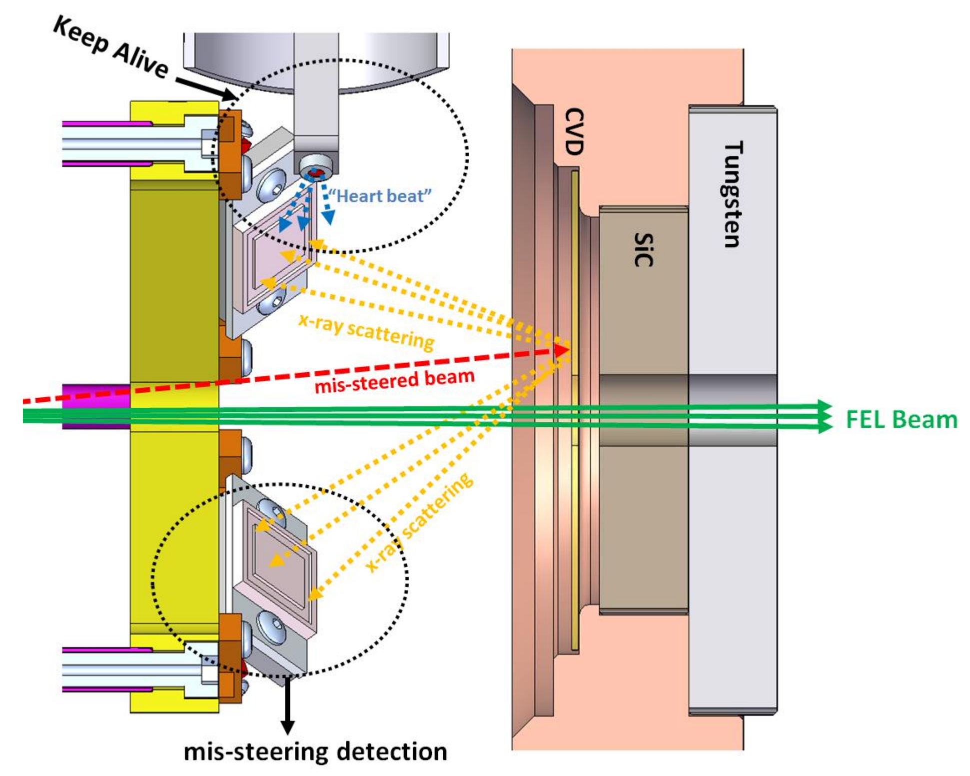
## Design

The photon collimator consists of a vacuum chamber with two fixed DN100CF flanges upstream and downstream and where two zero-length reducers are attached to.
Inside the vacuum chamber there are three main assemblies:
•A 4 AXUV100Al photo diodes array with their holders and cabling to feedthrough.
•A stack of a 750µm thick and Ø55mm CVD Diamond, a 10mm thick SiC disc and a 10mm thick Tungsten disc. All are assembled and clamped to a water cooled OHFC copper brazed body.
•A "keep-alive" system consisting of 2 red pulsed LED working as a heart-beat and with their cabling to a second feedthrough.




*Section view of the Photon Collimator assembly*

In case of a mis-steer of the FEL photon beam this would hit the diamond and create x-ray scattering which will be detected by the diodes and trigger the signal to trip off the beam the beam in less than 100msec.
A pulsed signal from the keep alive LED's will prove the diodes functionality.




*Section of the collimator showing diodes array and keep-alive system*

*Photon Collimator vacuum chamber assembled*

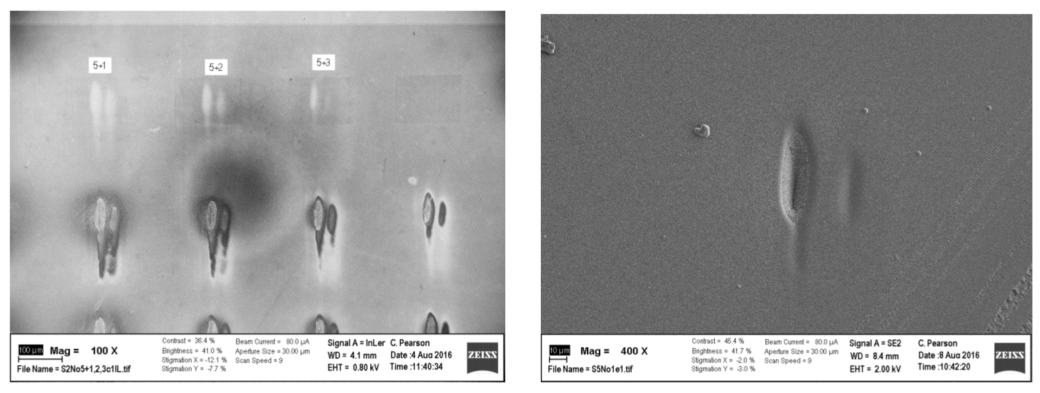
## Simulations and tests

Analysis have been performed taking as worst case the collimator installed at 40m downstream the end of the undulator and taking 400W at 750eV. The simulation has been done with the beam hitting the edge of the aperture where we observe the highest temperature and stress, where 200W are absorbed.

| | PC1S SXR Collimator | PC1H HXR Collimator |
|---|---|---|
| Distance to End of Undulator [m] | 41.1 | 101.5 |
| Photon Energy [eV] | 750 | 1500 |
| Divergence [µrad] | 4.8 | 2.8 |
| Waist location [m] | 20 | 62 |
| Beam size [rms, mm] | 0.3 | 0.38 |
| Incident power [W] | 400 | 519 |
| Surface peak power density [W/mm2] | 712 | 558 |

*Cases of study for SXR and HXR collimators, most upstream collimators in the layout*

We have also performed multi-shot damage tests of graphite coated and uncoated CVD diamond samples at the SXR LCLS beamline at photon energy of 330eV, at dose levels on order of 0.5 eV/atom and up to 100,000 shots. Based on the results we can estimate that the CVD diamond should survive at least a couple of days of continuous irradiations at 100 kHz at this dose level.



*Left, LCLS FEL shots at different dose rates*
*Right, erosion by FEL pulses x1000shots; dose rate @ approx 5eV/atom*

Simulations showed that the diamond may not be safe once the input power exceeds 550W, therefore a ¨bootstrap strategy¨ will be applied by gradually increasing the beam power while monitoring the diamond to define new safe operation conditions.

| Energy / Power | 340W | 550W | 880W |
|---|---|---|---|
| 250 eV | 422°C | 810°C | 1761°C |
| 290 eV | 1479°C | 2386°C | 4123°C |
| 750 eV | 993°C | 1999°C | > 4500°C |

*Combined temperature from steady state and instantaneous for SXR*

For boundary conditions, the peak tensile stress observed is of 57MPa, which is less than the allowable tensile stress of 500MPa.

The peak compression stress is of 665 MPa, which is also below the 1900 MPa of allowable compressive stress.

## Conclusions

A whole new design of photon collimator have been manufactured adding a fault detection mechanism and with a keep-alive system.

Diamond with graphite coating is an appropriate solution to absorb the LCLS-II FEL photon beam.

## Acknowledgments

Armin Busse, Shanjie Xiao, Xavier Permanyer, Stefan Moeller, Tom Rabedeau, Peter Walter, Clemens Weninger, Nina Boiadjieva.



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