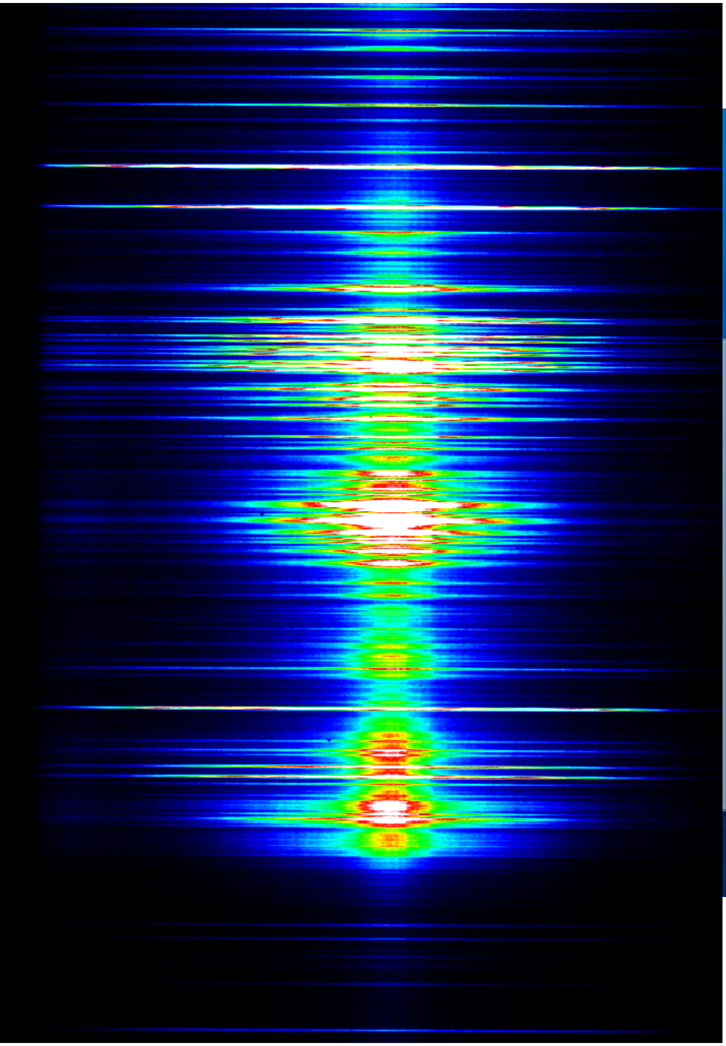

The Request for High-brilliant XUV Sources: A First Principle Approach

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(3) Fraunhofer Institute for Laser Technology
(4) Max-Born-Institute

High brightness demand in Nanoscopy

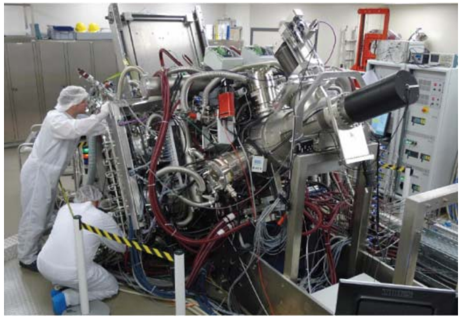
Nanoimaging	**Scanner**
Nanoimaging with pixel resolution of 10 nm	18 nm
Wavelength 13.5 nm → NA @ 0.54→ 0.25 sr	13.5 nm → NA @ 0.3; 0.07 sr
CCD with 1000*1000 Pixel → 100 µm^2 F 4*4 MPx: 1600 µm^2	625 mm^2 Field ?
Good Image: Noise < 1 % → 1000 Photons (=0.15 µJ)	10 mJ/mm^2 ?
Optical System (type. 1 % EUV transmission) → 15 µJ + etendué 4*10^{-5} mm^{2}sr → 0.6 J/(mm^2 sr)	1 % transm. → etendué: 1 mm^{2}sr → 10 J/(mm^2 sr
Throughput ABIT: 1 s → 0.5 W/(mm^2 sr) APIT: 36 µs/image → 16.214 W/(mm^2 sr) →1.000 W/(mm^2 sr) → < 25 mW resp. < 2 W /(2 π sr) source	Throughput 1 s→ >100 W/(mm^2 sr) → > 500 W/(2 π sr) source

Summary of requirements for metrology sources

	Etendué	Brightness	Power
HVM Requirement:	1-3 mm^2 sr	<100 W/(mm^2 sr)	> 1 kW inband > 200 mW on Resist
ABIT	**> 0.1 mm^2 sr**	**< 1** W/(mm^2 sr)	< 50 mW inband < 100 µW on mask blank
AIMS	< $1\ 10^{-4}$ mm^2 sr	> 100 W/(mm^2 sr)	< 200 mW inband < 1 mW on blank
APIT	< $1\ 10^{-4}$ mm^2 sr	1.000 W/(mm^2 sr)	< 2 W inband < 10 mW used on mask

Status Sources

SEE TALK of Klaus Bergmann

	Xe-EUV-Lamp	Xe-Energetic	Xe-FhG-ILT	Sn-Xtreme/Ushio	Sn-Cymer
					
	1 W/(2 π sr)	10 W/(2 π sr)	17 W/(2 π sr)	650 W/(2 π sr)	170 W/(2 π sr)
Source Diameters:	0,4 mm	0,5 mm	0,17 mm	1 mm	0.1 mm
Avg. Brightness:	**1 W/mm^2/sr**	**8 W/mm^2/sr**	**119 W/mm^2/sr**	**530 W/mm^2/sr**	**3.400 W/mm^2/sr**

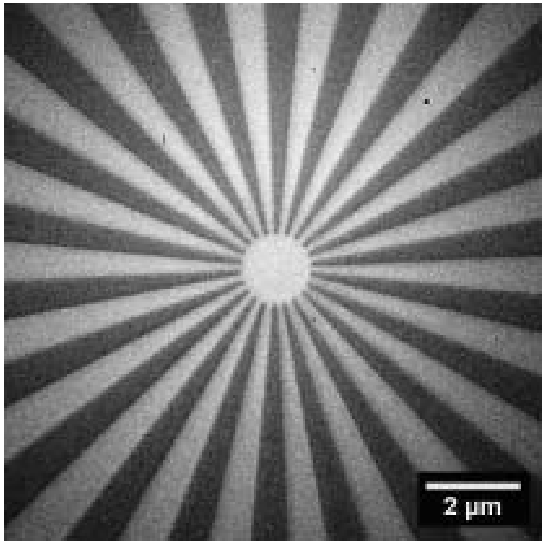
Example: X-ray Microscopes (“Water window” $2.4 < \lambda < 4.4$ nm)

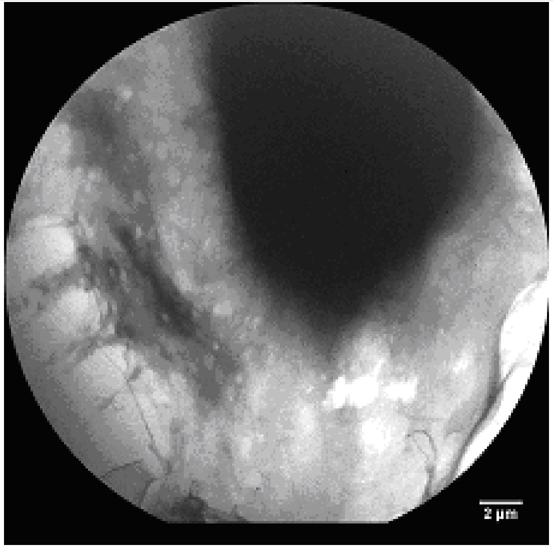
Experience with the demands of Mask Metrology
(Source & Optics Integration and Alignment; Nanometer Sample Positioning, UHV, Mechanical Stability; Vibration controlled architecture, Detectors etc.)

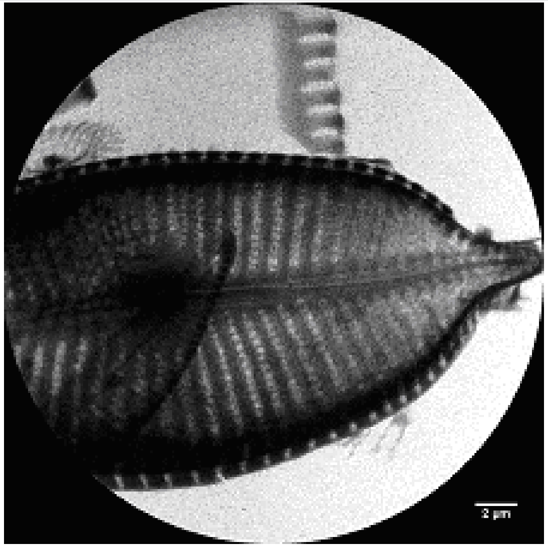
- German Research Network (Coordinator: Bruker ASC)
- High brightness LPP and DPP sources
- Grazing incidence, multilayer, and diffractive (zone plate) optics
- Resolution ~30nm, ~20µm field
- Tomography, Cryo

BESSY
MBI Max-Born-Institut
ENGENE
IOF Institut Angewandte Optik und Feinmechanik
ILT Institut Lasertechnik
KTH
microliquids
fg
Rhein Ahr Campus
BASF The Chemical Company
Laser-Laboratorium Göttingen e.V

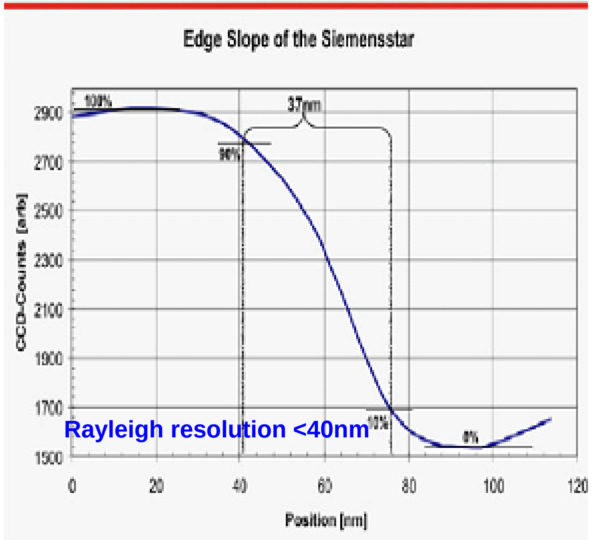
Results from X-Ray Microscopy







1000 x magnified diatoms



M. Benk, K. Bergmann, D. Schäfer (2008)

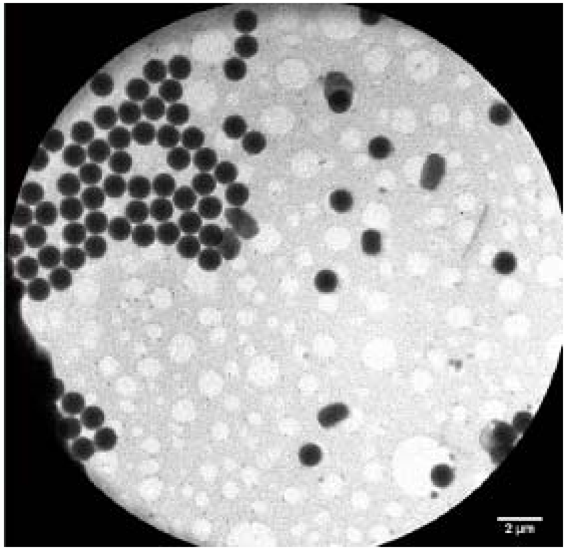
40 nm Rayleigh Resolution demonstrated

Single Line (< 0.5 % bandwidth) brightness of

- >7 W/mm²/sr with DPP

and

> 150 W/mm²/sr with LPP



1000 x magnified diatoms and 80 nm latex spheres

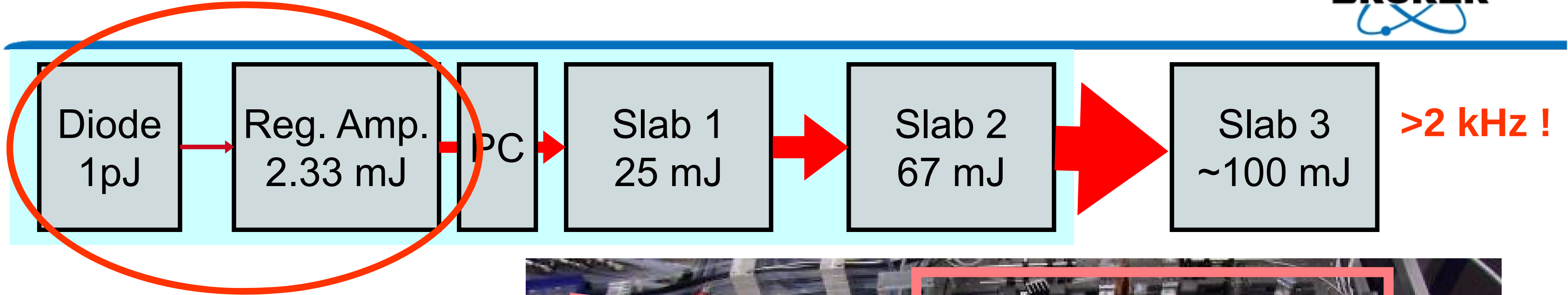
Soft-X high Brightness Sources → EUV

Experience with using high brightness DPP and LPP sources were obtained in R&D Project on Laboratory Transmission Soft-X-Ray Nanoscopy

	DPP-Sources	LPP-Sources
Technology	Xenon DPP; Concepts similar to Philips-EUV and BASC / AIXUV Sources	Droplet & Jet Targets Laser Focus
Developed with	Fraunhofer-ILT	MBI, KTH Stockholm, RAC, FhG ILT
Driver	HV-Capacitor Charger developed and build at Fraunhofer-ILT used by Philips-EUV	Special Short Pulse Laser developed, build and shipped by Fraunhofer-ILT

	Reported	**Extrapolated**	**Reported Soft x < 0.2 % BW**	**Extrapolated > 2% BW**
Power	17 W/2πsr inband	> 20 W/2πsr inband	> 0.25 W/2πsr inband	> 0.8 W/2πsr inband
Source Size	340 µm FWHM	< 200 µm FWHM	< 30 µm FWHM	< 20 µm FWHM
Brightness	7,5 W/sr/mm^2 inband	100 W/sr/mm^2 inband	> 120 W/mm^{2}sr inband	> 200 W/mm^{2}sr inband

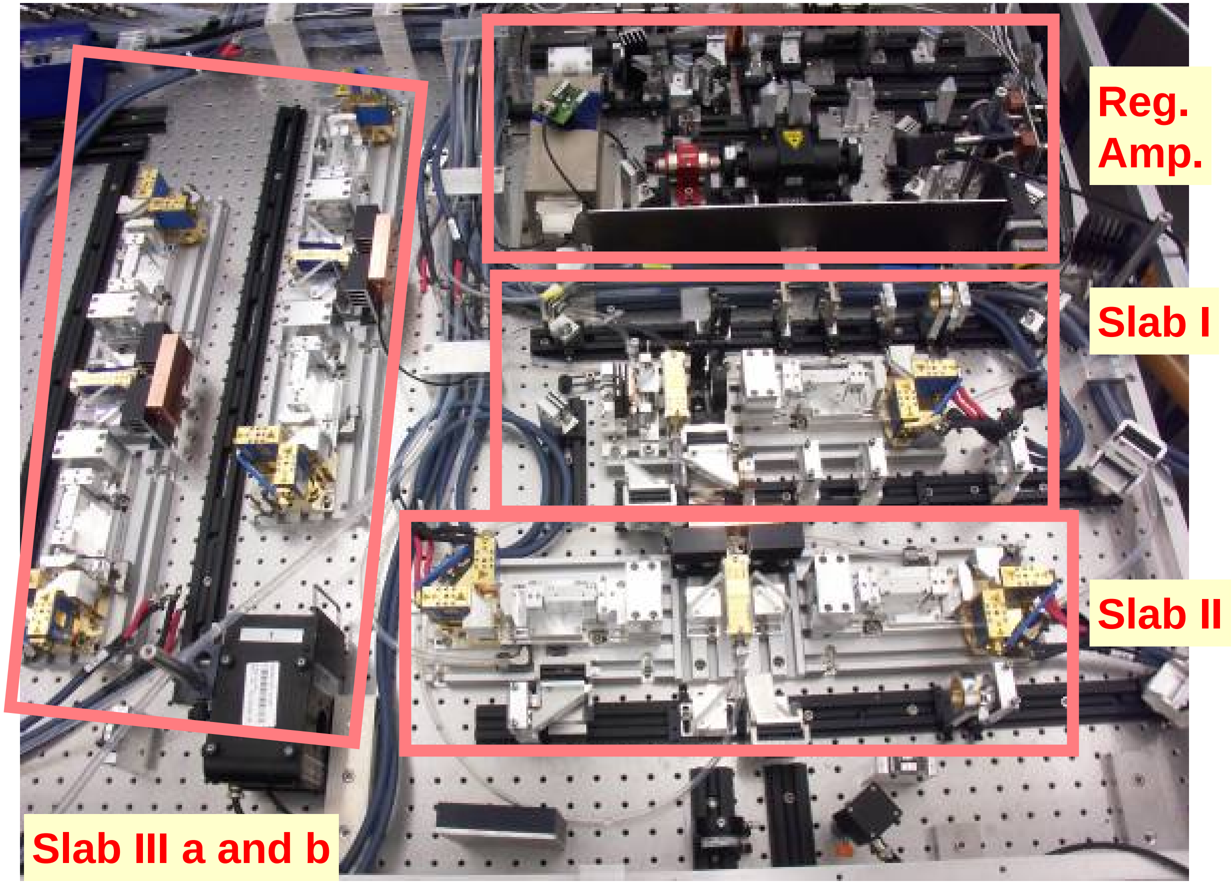
Laser Development for HB-LPP source at FhG-ILT



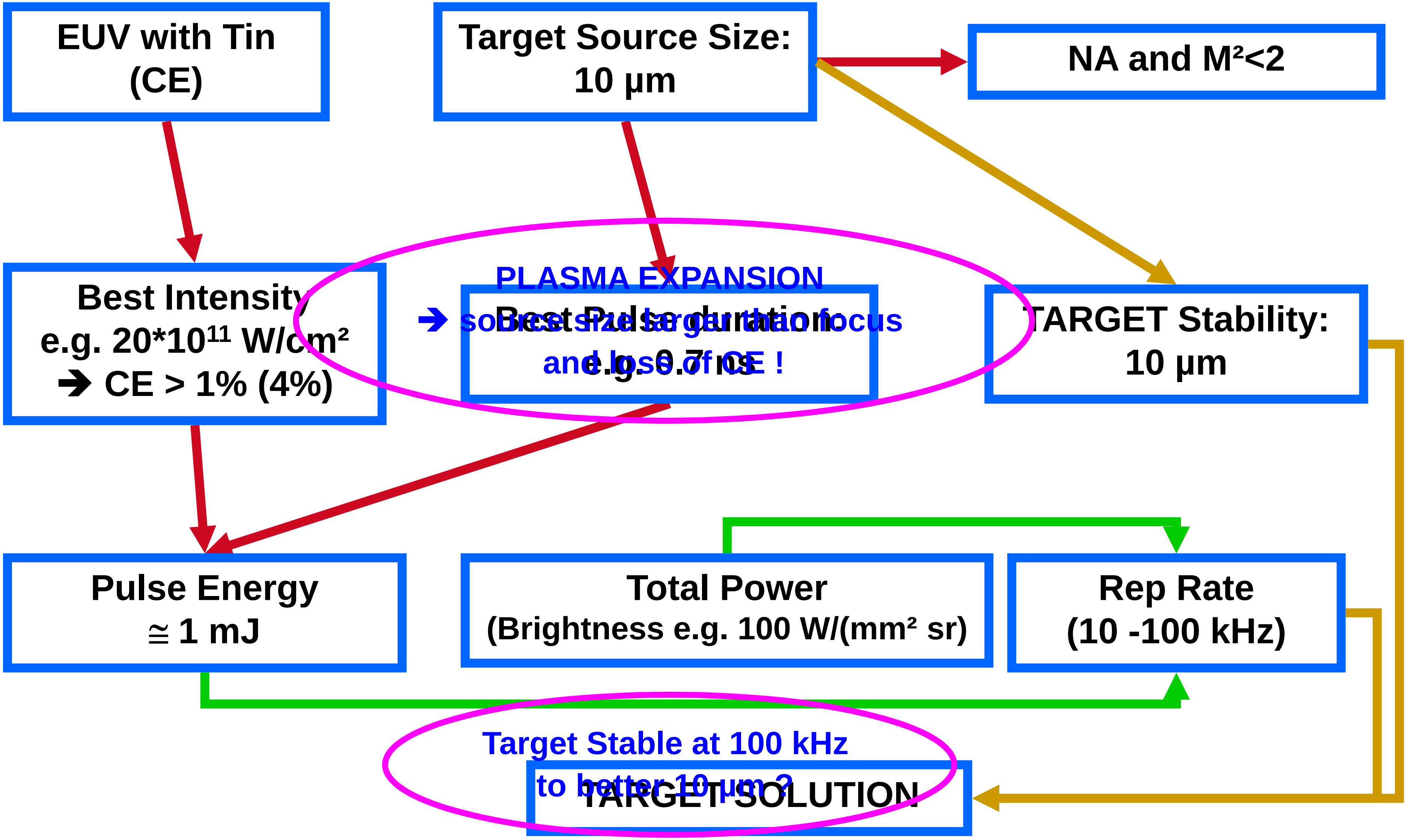
Laser for HB-LPP
EUV-Source !

SEE TALK of
PETER LOOSEN
(Advanced INNOSLAB Solid-state-lasers for XUV/EUV-generation (P37)

Fraunhofer Institut Lasertechnik



Path to “optimized” HB-LPP source



EUV with Tin (CE)

Target Source Size: 10 µm

NA and $M^2<2$

Best Intensity e.g. $20 \cdot 10^{11}$ W/cm²
➔ CE > 1% (4%)

PLASMA EXPANSION
➔ source size larger than focus and loss of CE !

Best Pulse duration: e.g. 0.7 ns

TARGET Stability: 10 µm

Pulse Energy ≅ 1 mJ

Total Power (Brightness e.g. 100 W/(mm² sr)

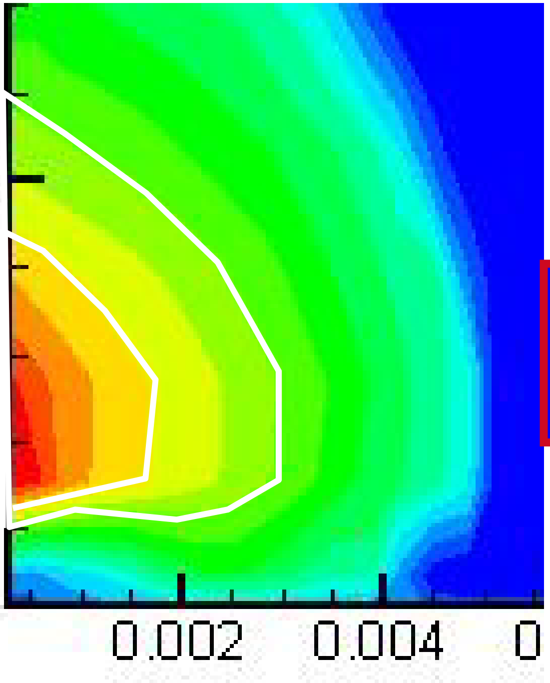
Rep Rate (10 -100 kHz)

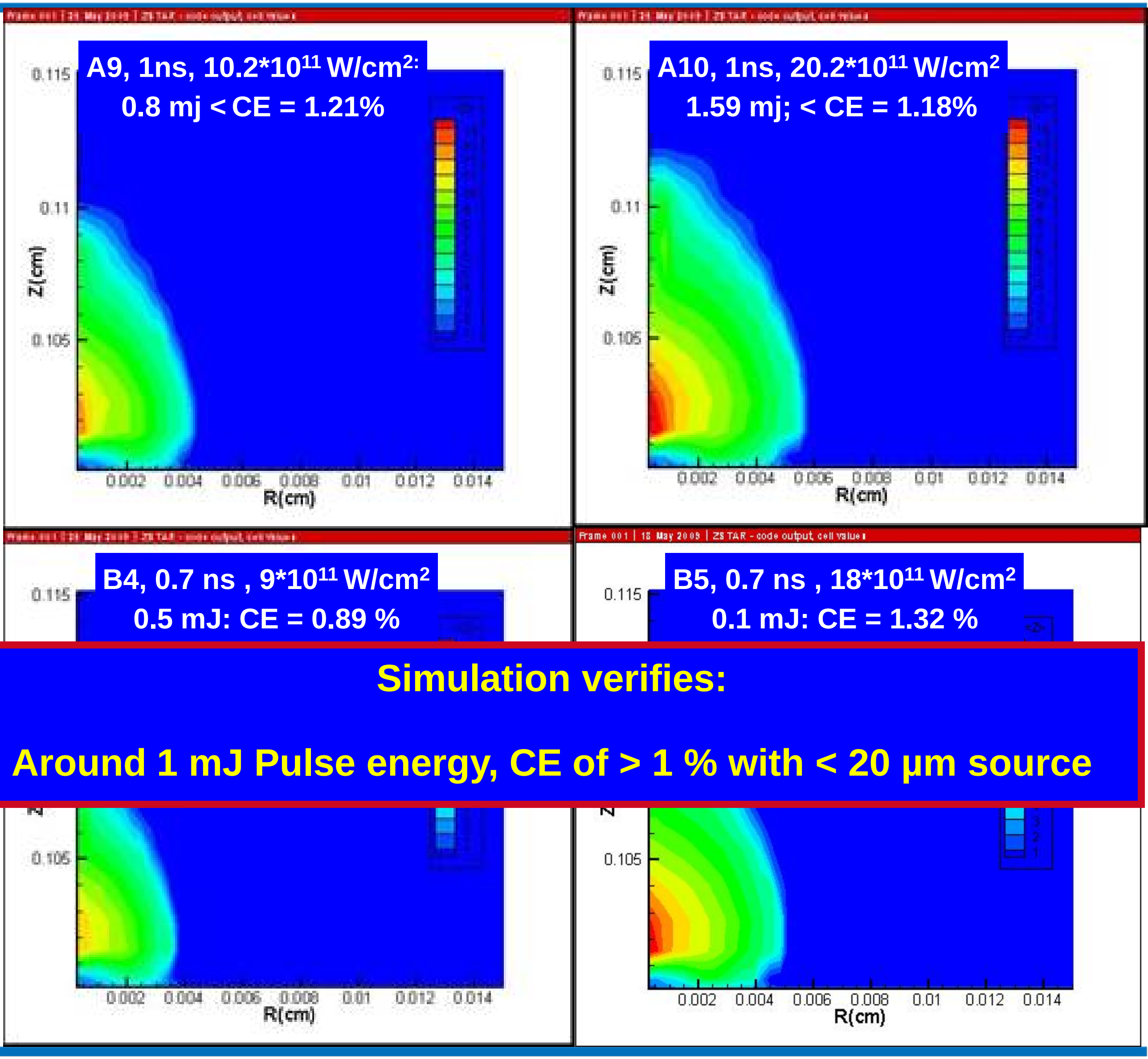
Target Stable at 100 kHz to better 10 µm ?

TARGET SOLUTION

Simulation of Low Pulse Energy EUV Generation

- No Brightness evaluation, yet.
- Representative for source Size: Average Charge distribution





A9, 1ns, 10.2*10^{11} W/cm$^{2:}$
0.8 mj < CE = 1.21%

A10, 1ns, 20.2*10^{11} W/cm^{2}
1.59 mj; < CE = 1.18%

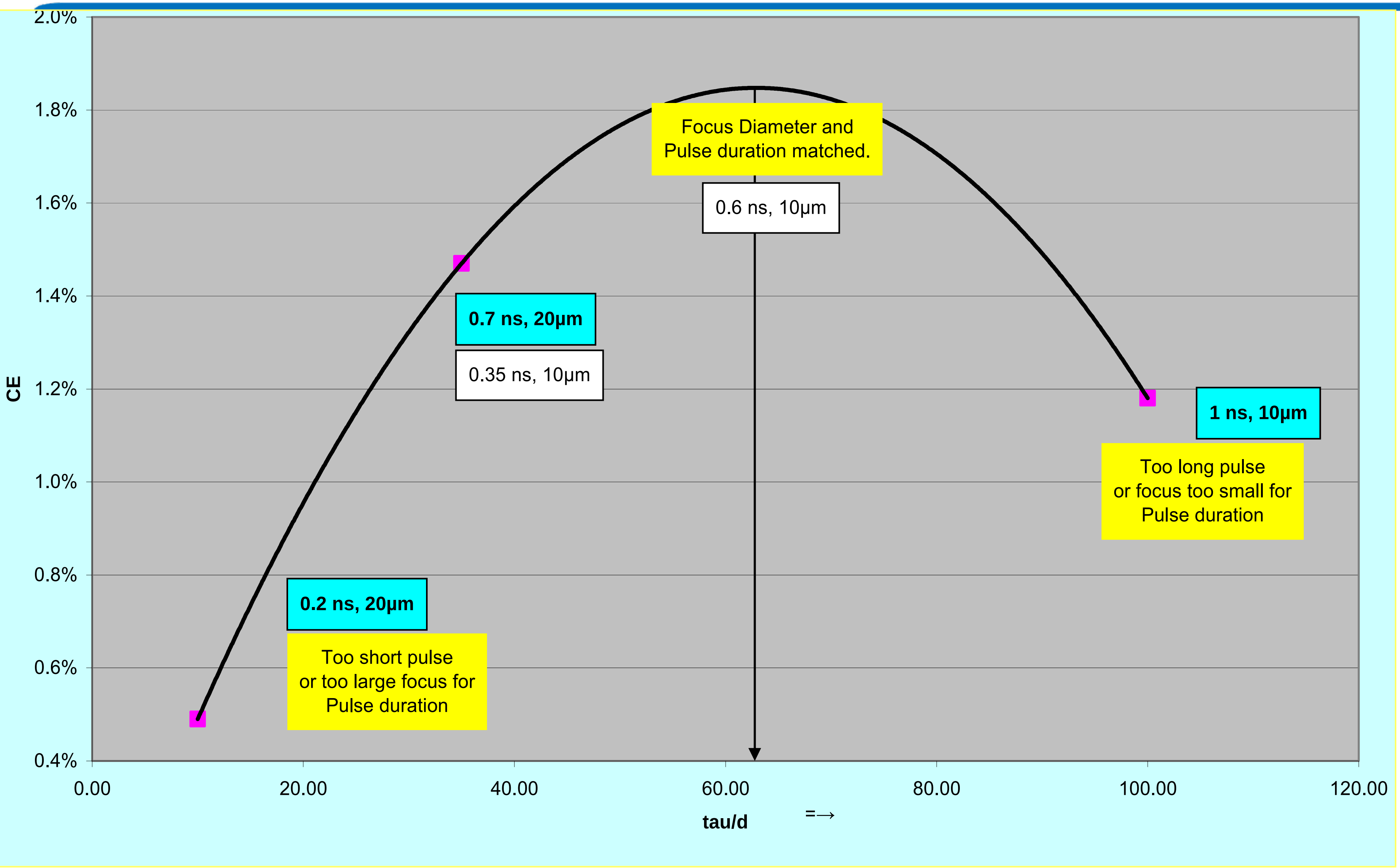
B4, 0.7 ns , 9*10^{11} W/cm^{2}
0.5 mJ: CE = 0.89 %

B5, 0.7 ns , 18*10^{11} W/cm^{2}
0.1 mJ: CE = 1.32 %

Simulation verifies:

Around 1 mJ Pulse energy, CE of > 1 % with < 20 µm source

Understanding CE



Focus Diameter and
Pulse duration matched.

0.6 ns, 10µm

0.7 ns, 20µm

0.35 ns, 10µm

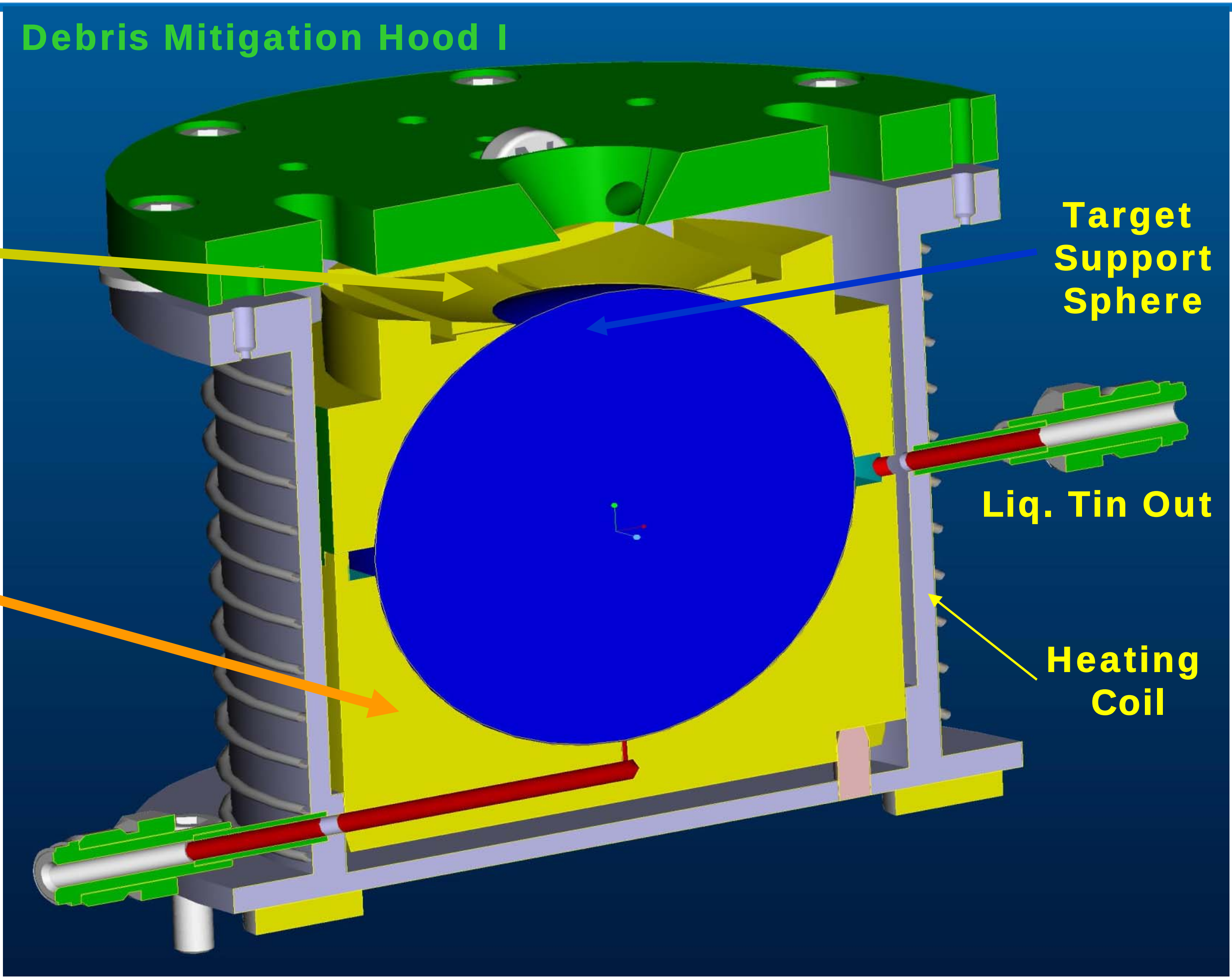
1 ns, 10µm

Too long pulse
or focus too small for
Pulse duration

0.2 ns, 20µm

Too short pulse
or too large focus for
Pulse duration

HB-LPP Target Liquid Tin Target V_0 Designed



Debris Mitigation Hood I

Wave Control Surface

Target Support Sphere

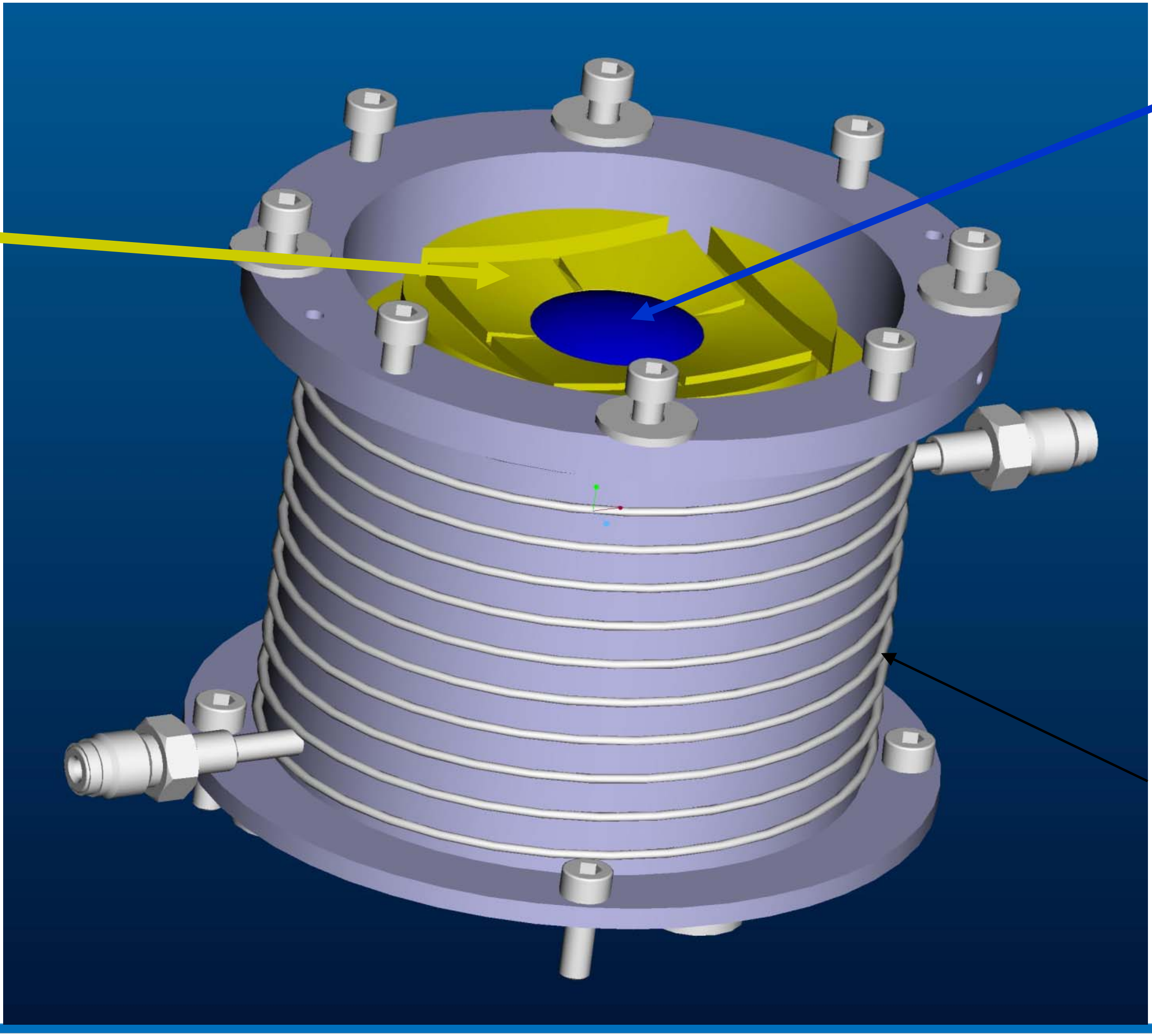
Sphere & Flow Control Body

Liq. Tin Out

Heating Coil

Liq. Tin In

HB-LPP Target Liquid Tin Target V_0 Designed and in manufacture



Wave Control Surface

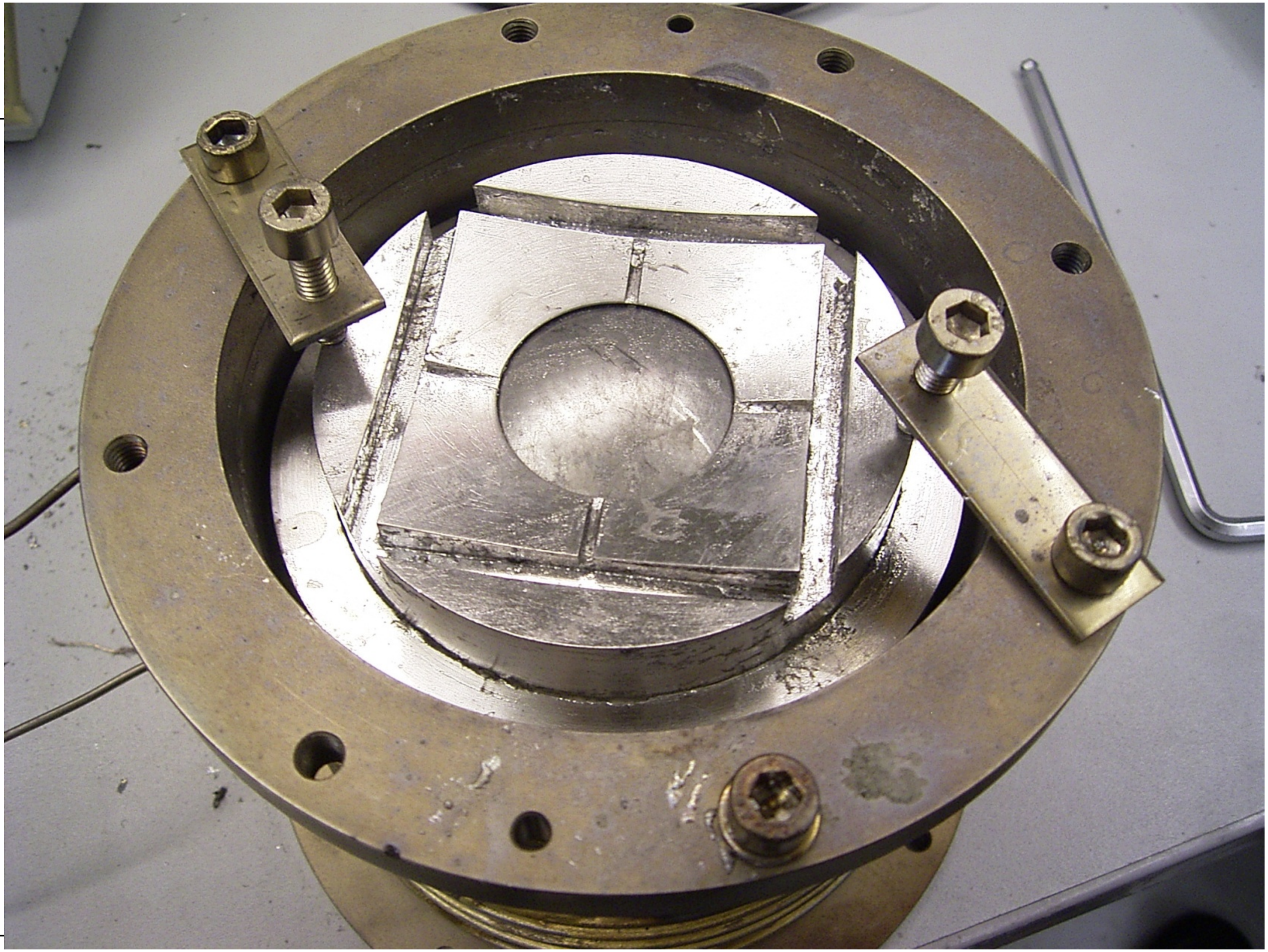
Target Support Sphere

Liq. Tin Out

Liq. Tin In

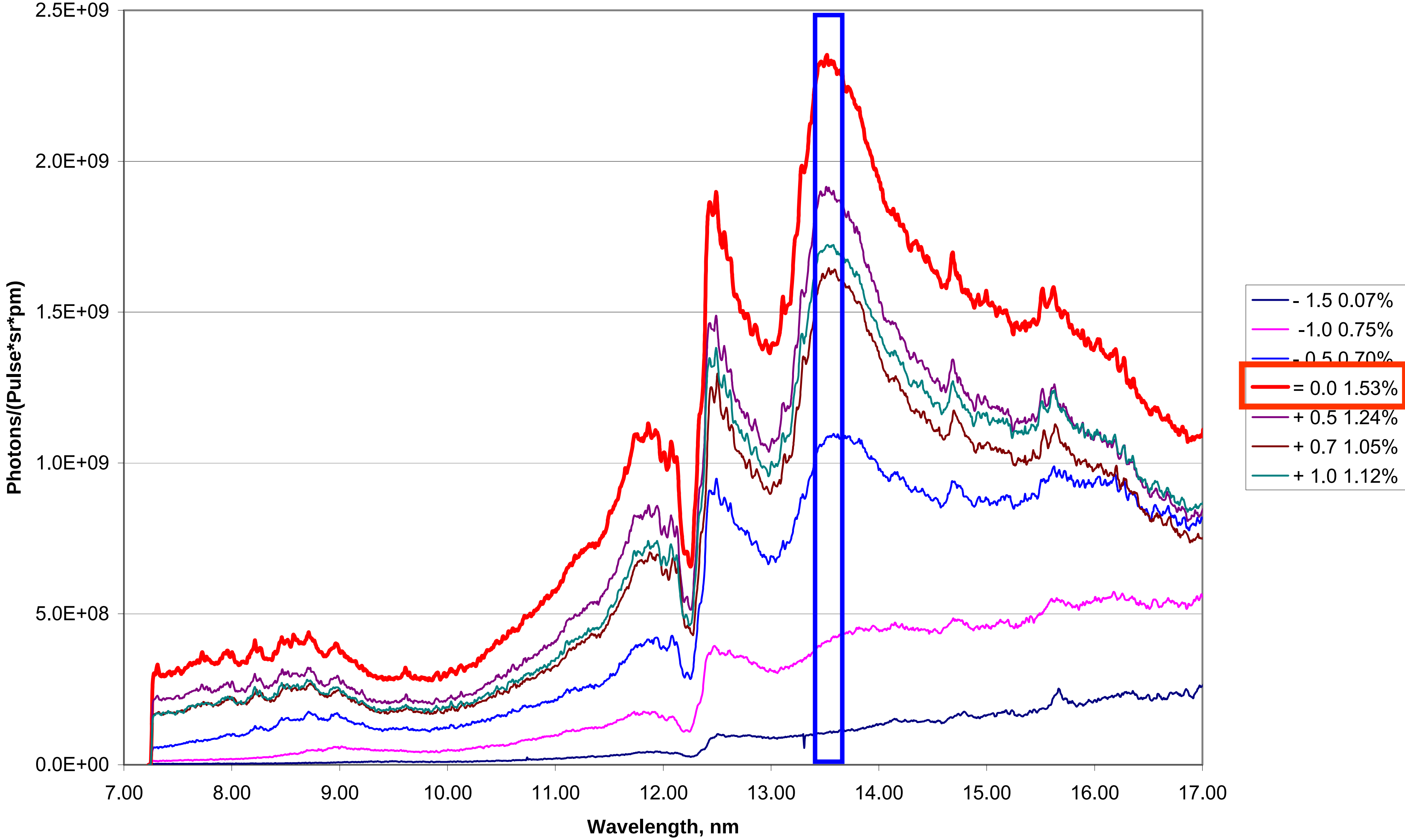
Heating Coil

Target Hardware

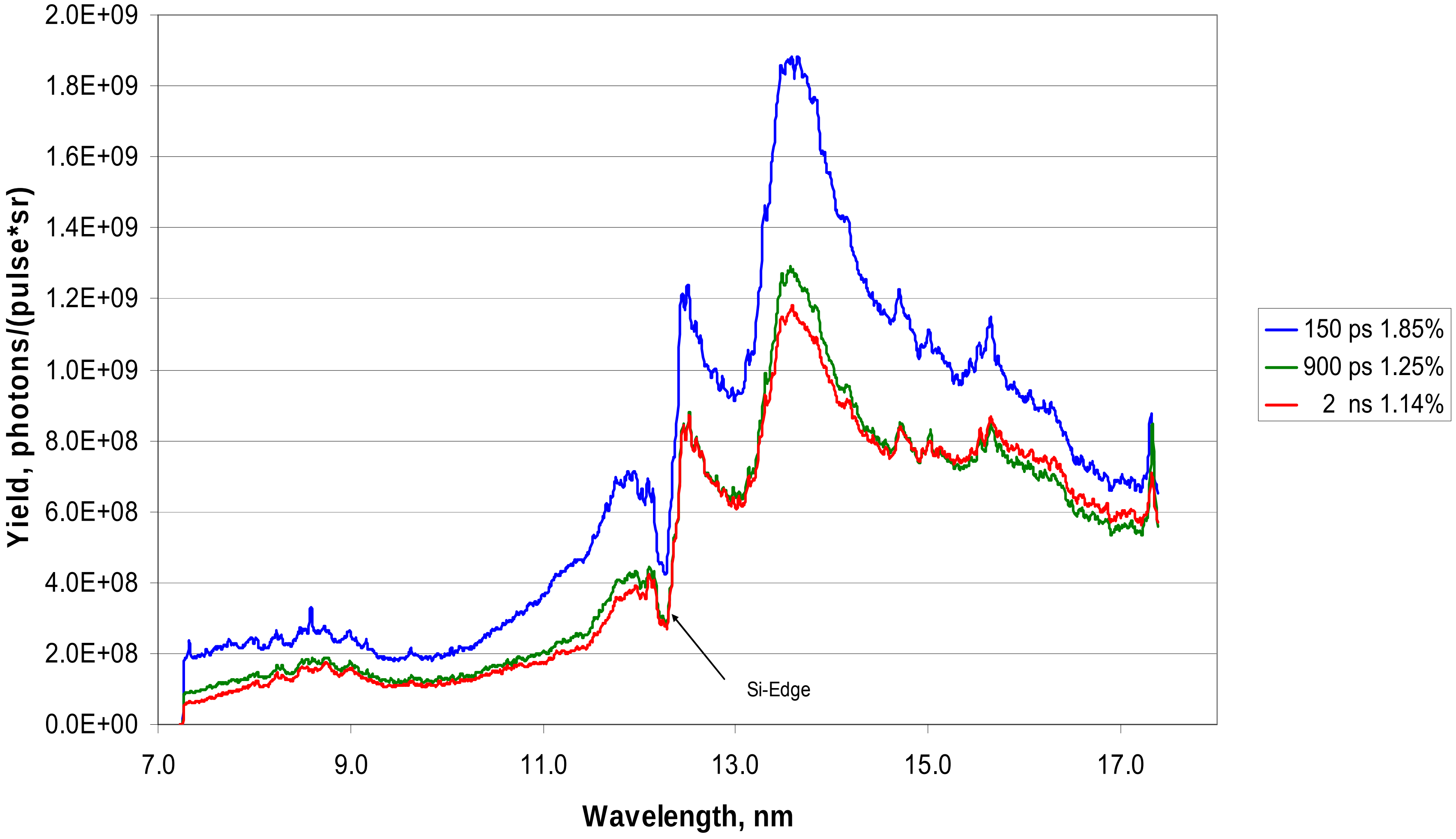


Liquid Tin Target in Vacuum Proof of concept

CE with Focusing (Intensity, Source Size)



CE with Pulse duration (Intensity)



Source Magnified Imaging

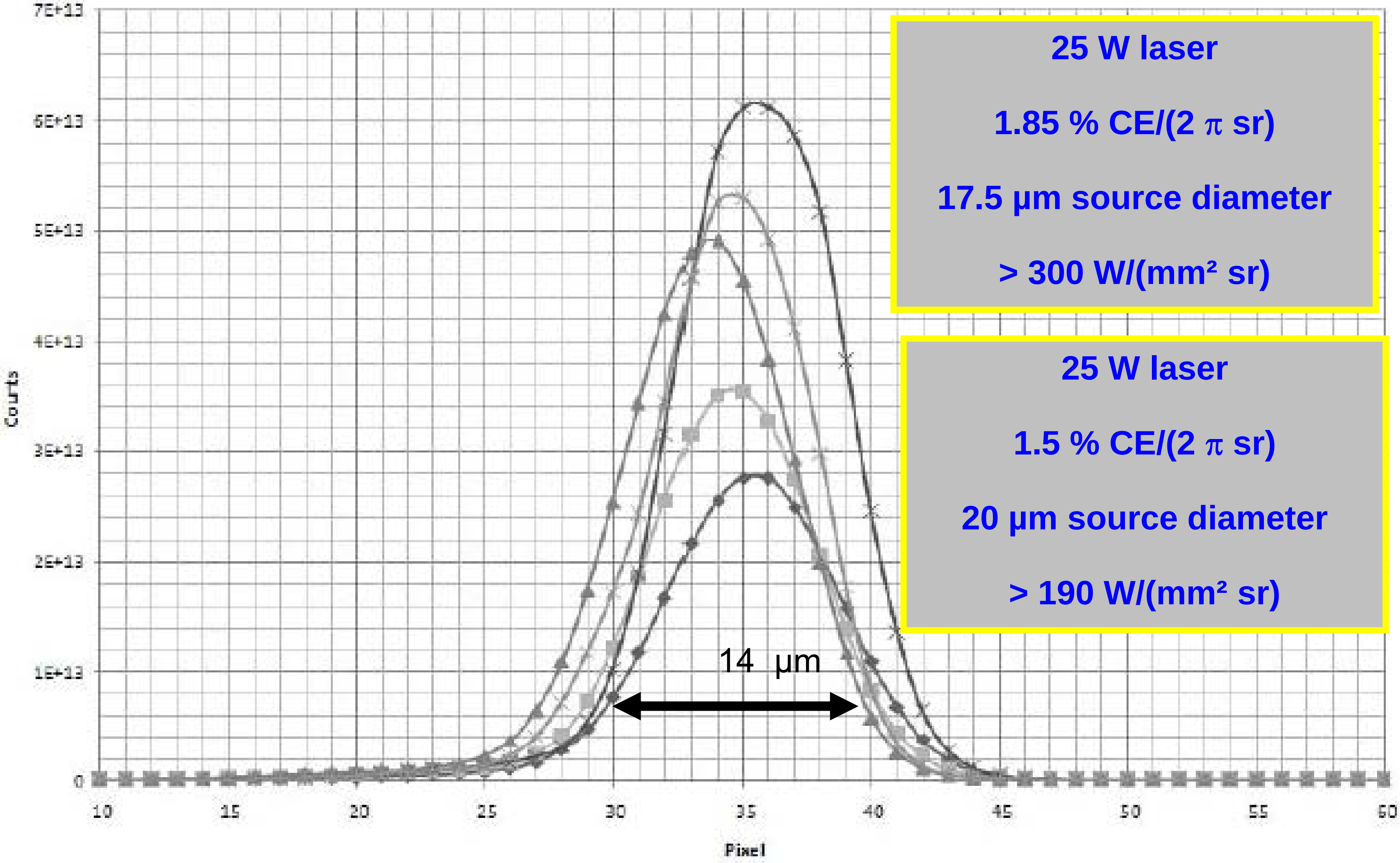
CCD-Camera

Source Imaging Optics

Infinity Laser

Target chamber

Source Sizes: < 20 µm (M=9; Px: 13µm)



25 W laser

1.85 % CE/(2 π sr)

17.5 µm source diameter

> 300 W/(mm² sr)

25 W laser

1.5 % CE/(2 π sr)

20 µm source diameter

> 190 W/(mm² sr)

SUMMARY

- Fulfilling high brightness demands of EUV-Metrology with discharge plasmas is limited or requires high-power HVM-like sources.

- LPP sources with dedicated lasers is the more effective approach
- We have demonstrated > 200 W/mm²/sr in a fast, low budget experiment with a compact set-up. Components used are:
  - Laser with < 1 ns, 2.5 mJ, 10 kHz and $M^2 \cong 2$
  - Stationary liquid tin bath target, with immanent easy cooling and regeneration.

- With a clear path for source development (based on experience) a partnership to laser development and companies allows for fast commercialization and potential up-scaling by a factor 10 in brightness (25 W ➔ >250 W as laser for microscopy !) by only frequency scaling

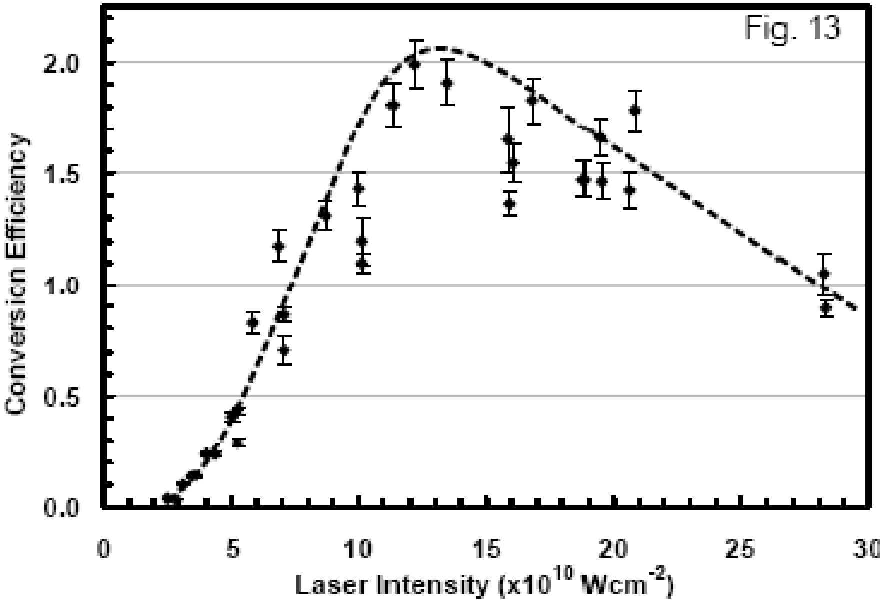
Thanks for the attention

BRUKER ASC

Former ACCEL Instruments & *AIXUV* Business

www.bruker-asc.com

Conversion: match Intensity



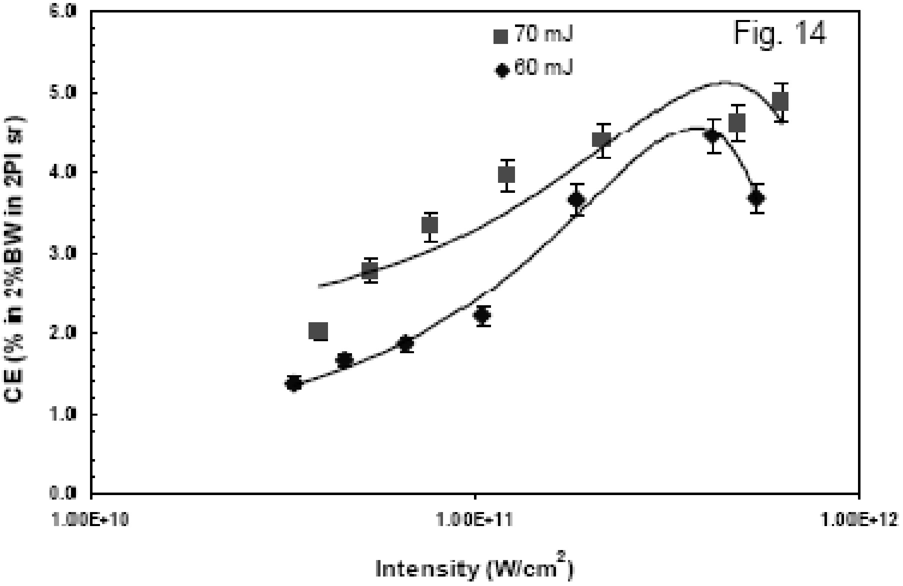


Figure 13: Conversion efficiency of the tin-doped droplet target laser plasma source as a function of laser intensity.
Figure 14: Conversion efficiency of the solid tin planar target as function of laser intensity.

High conversion efficiency microscopic tin-doped droplet target laser-plasma source for EUVL

Chiew-Seng Koay, Simi George, Kazutoshi Takenoshita, Robert Bernath, Etsuo Fujiwara**, Martin Richardson*, Vivek Bakshi***

Laser Plasma Lab, College of Optics: CREOL & FPCE, University of Central Florida, Orlando, FL 32816

Droplet target is only stable close to Nozzle; at usable distances the budget is exceeded.

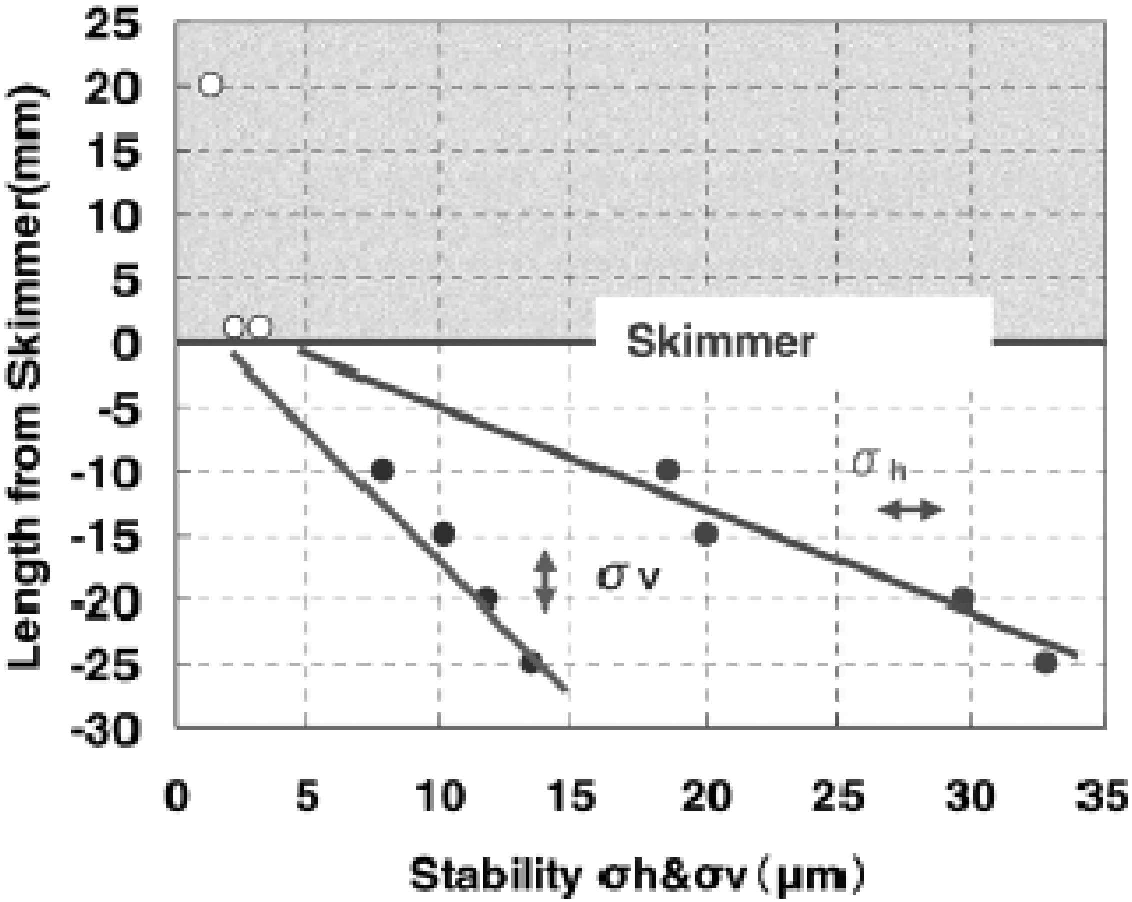
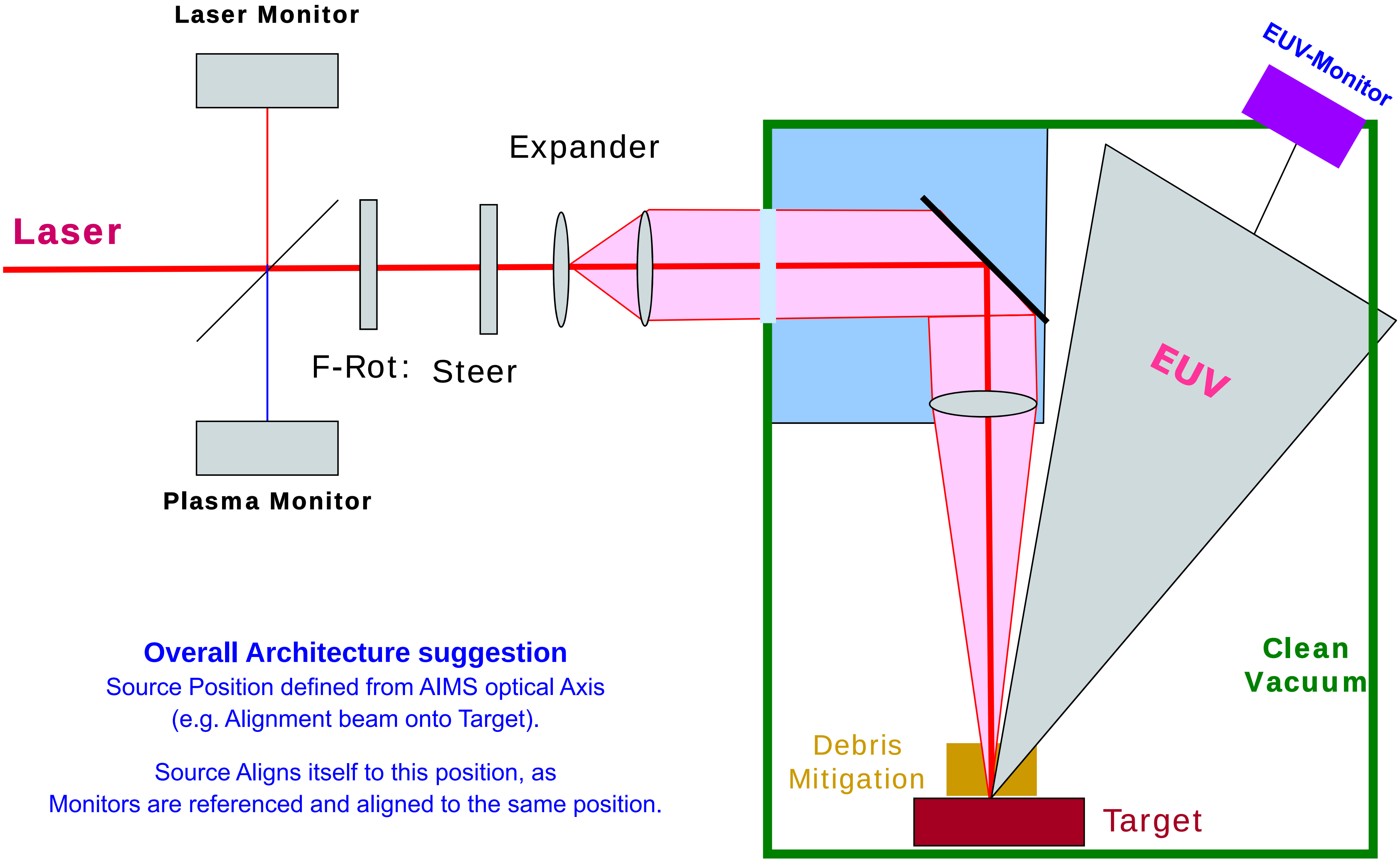


Fig. 18. Vertical and horizontal stability of the Xe droplet chain in 20-kPa He and vacuum.

Total System with Control



Overall Architecture suggestion

Source Position defined from AIMS optical Axis
(e.g. Alignment beam onto Target).

Source Aligns itself to this position, as
Monitors are referenced and aligned to the same position.

Source Size with frequency