Studies on Extreme Ultraviolet Sources

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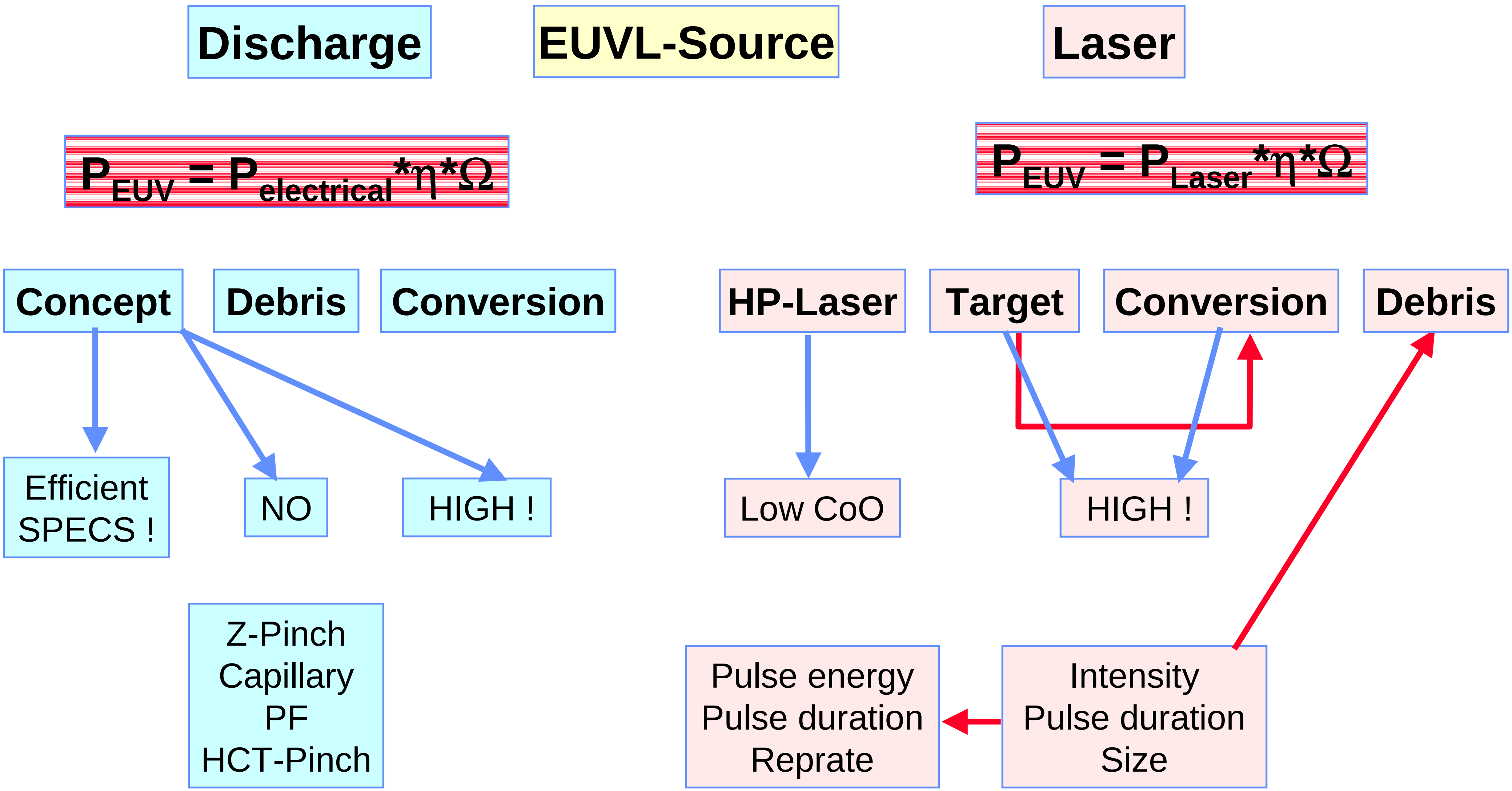
- EUVL Source Development
- LPP Conversion Efficiency
- Development of a high Power Laser
- Discharge Sources

Key Issues of EUVL Source Development



Key issues addressed in the German scientific program

Source Metrology
Tool-Set for source characterization
Comparison of sources (coordinated with ASML Flying Circus)

Key experiments on LPP
- Optimization of Conversion (fs-ps-ns),
- LPP at High Repetition rate,
Influence of laser wavelength, Influence of target

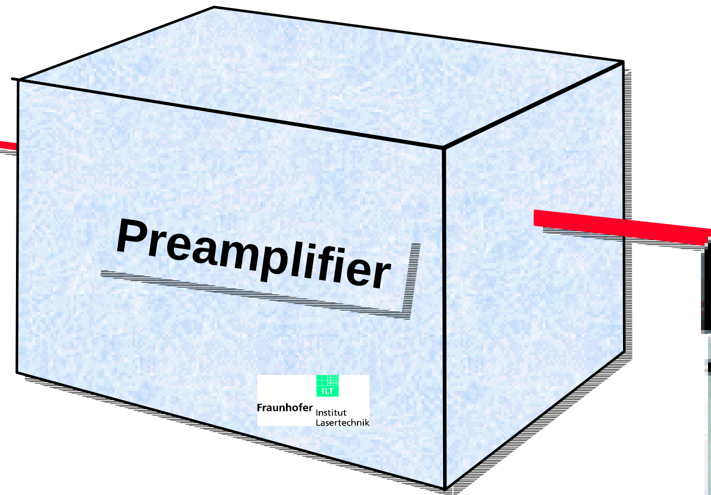
Concepts for high power lasers
based on commercially available components
Studies of new laser concepts

Evaluation of limits of gas discharge based EUVL sources
Evaluation Discharge Concepts
Operation with high repetition rate and high power

High Power Laser Development: based on commercial components.

OSCILLATOR | **PRE-AMPLIFIER** | **POWER AMPLIFIER**

P_{cw} = 4.4 kW
Diode lifetime > 20,000 h exp.
Price < 1 M$



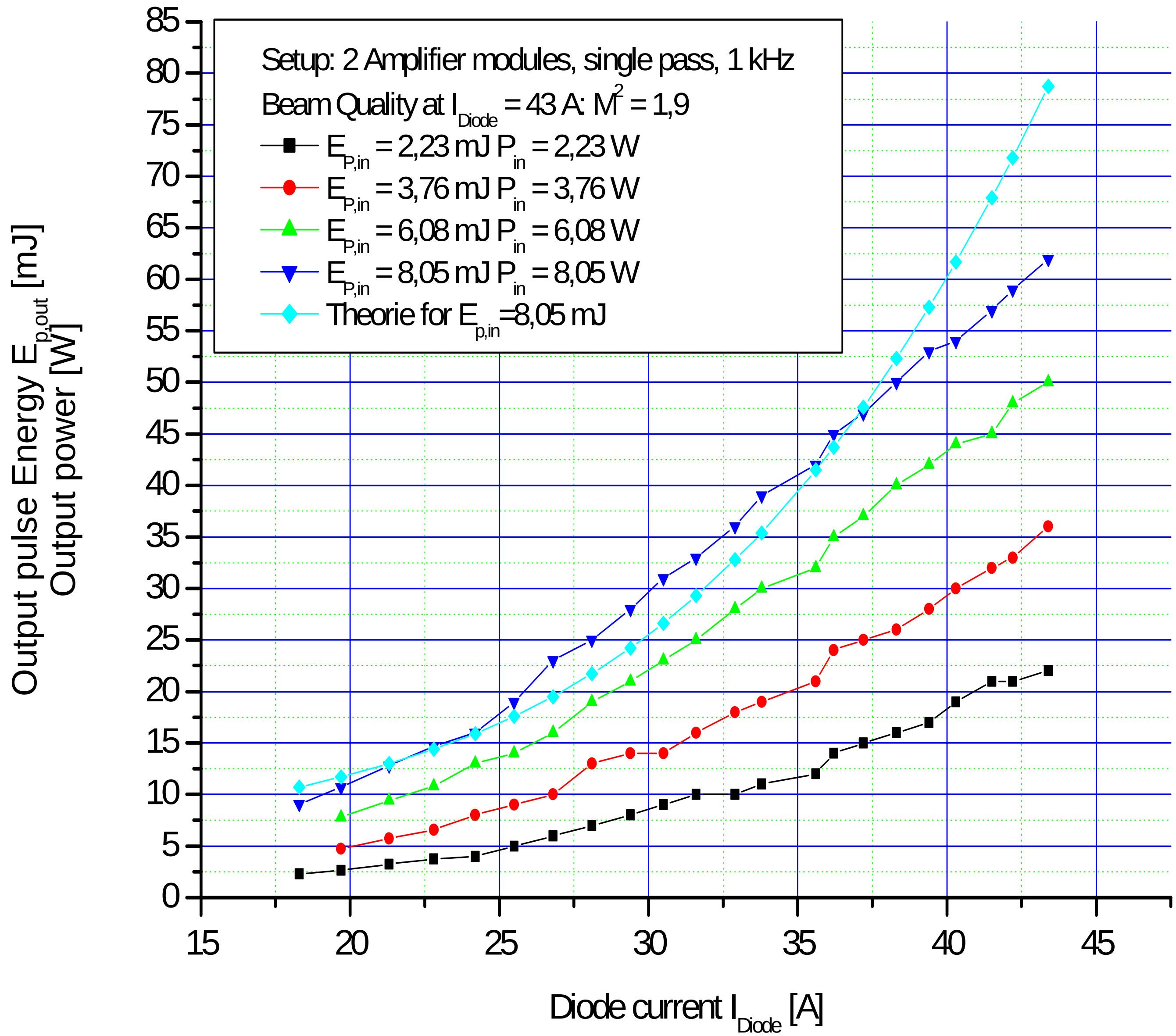
lifetime > 10,000 h
price < 200 k$

commercial diode modules
lifetime > 10,000 h
price < 300 k$

High Power Laser Development : RSL-DY-Laser based pre-amplifier

Pulse energy after single pass pre-amplifier as a function of the diode laser current

- E_{p_in} : 2.2 3.8 6 and 8 mJ
- max pulse energy: 63 mJ
- Repetition Rate : 1 kHz
- output power : 63 W
- Beam quality at max. pump power : M²=1,9



LPP Conversion : Dependence on Intensity

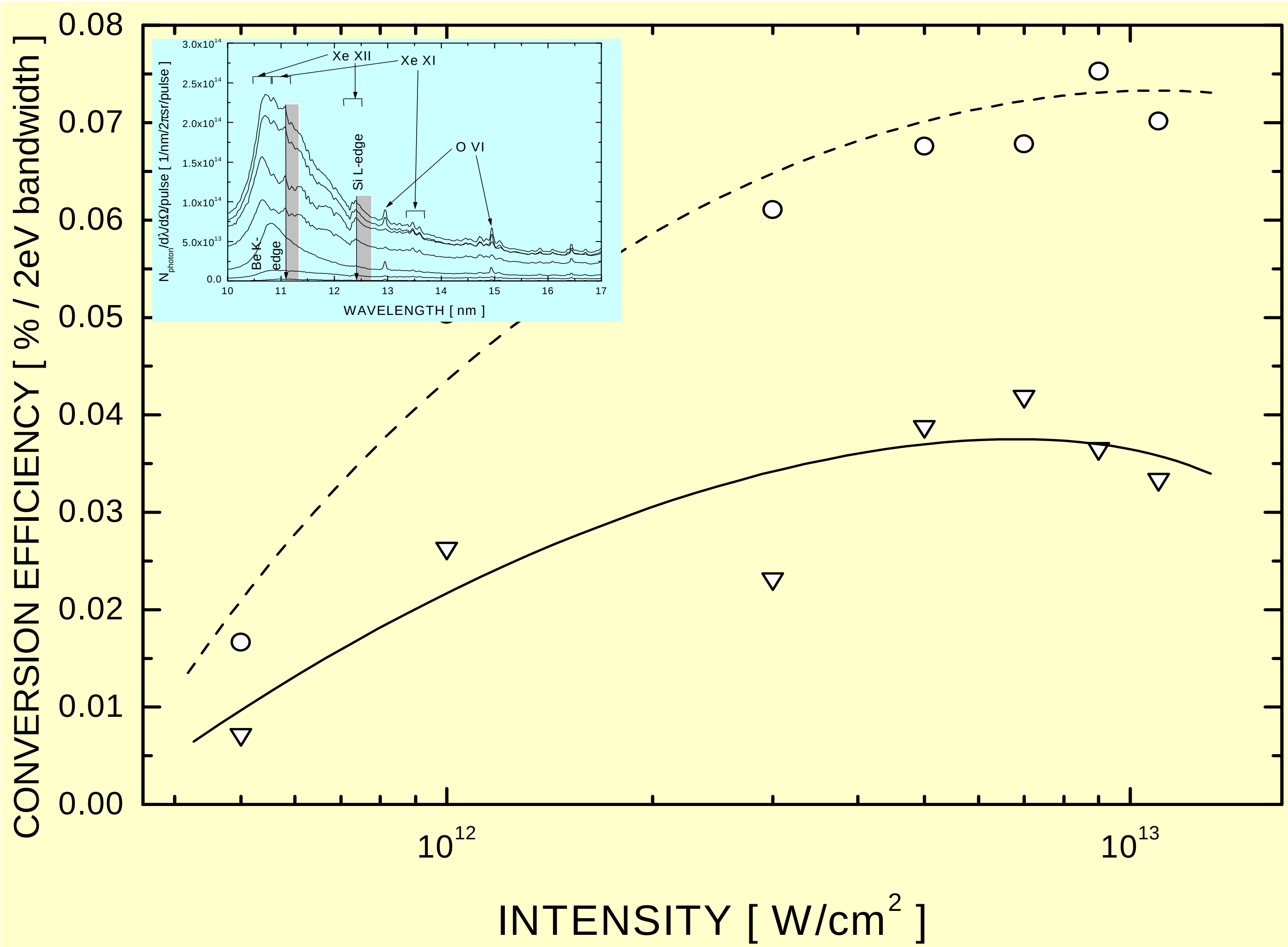
Target: frozen Xe

Focus : r_F = 25 µm

Laser : 10 ns

: 12 W

: 1,2 J / pulse



Optimized Intensity is close to 10^{13} W/cm² for 10 ns laser pulses

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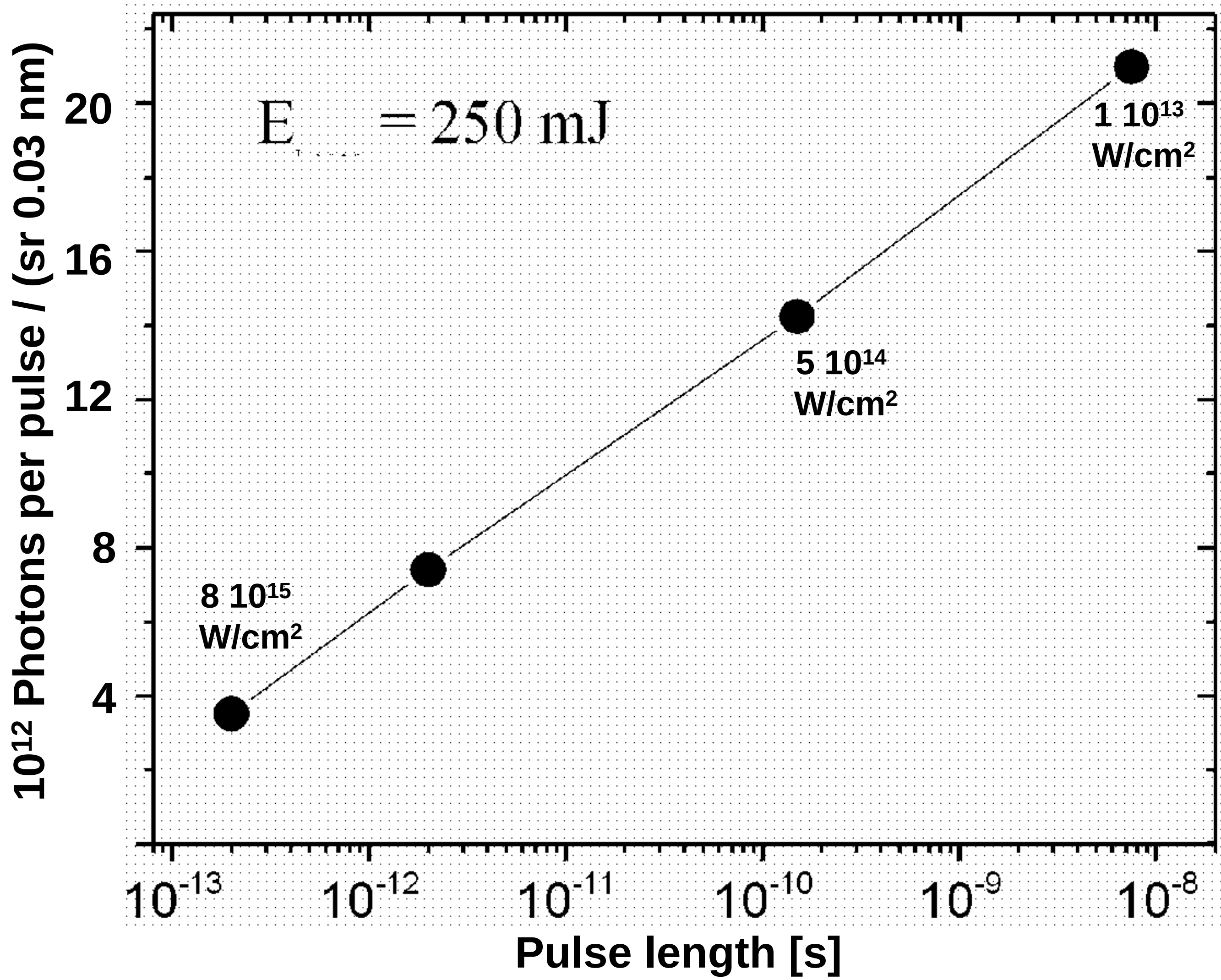
LPP conversion : Dependence on Pulse Duration : Solid Target

Target : glass solid state
Focus : r_F = 10 µm
Energy : 250 mJ / pulse
Laser : Jena multi-TW



- **Conversion efficiency increases by a factor of 5 from 100 fs to 8 ns**

Conversion efficiency = 0,15 % / sr

? Dependence on intensity
==> lower pulse energy
==> larger source

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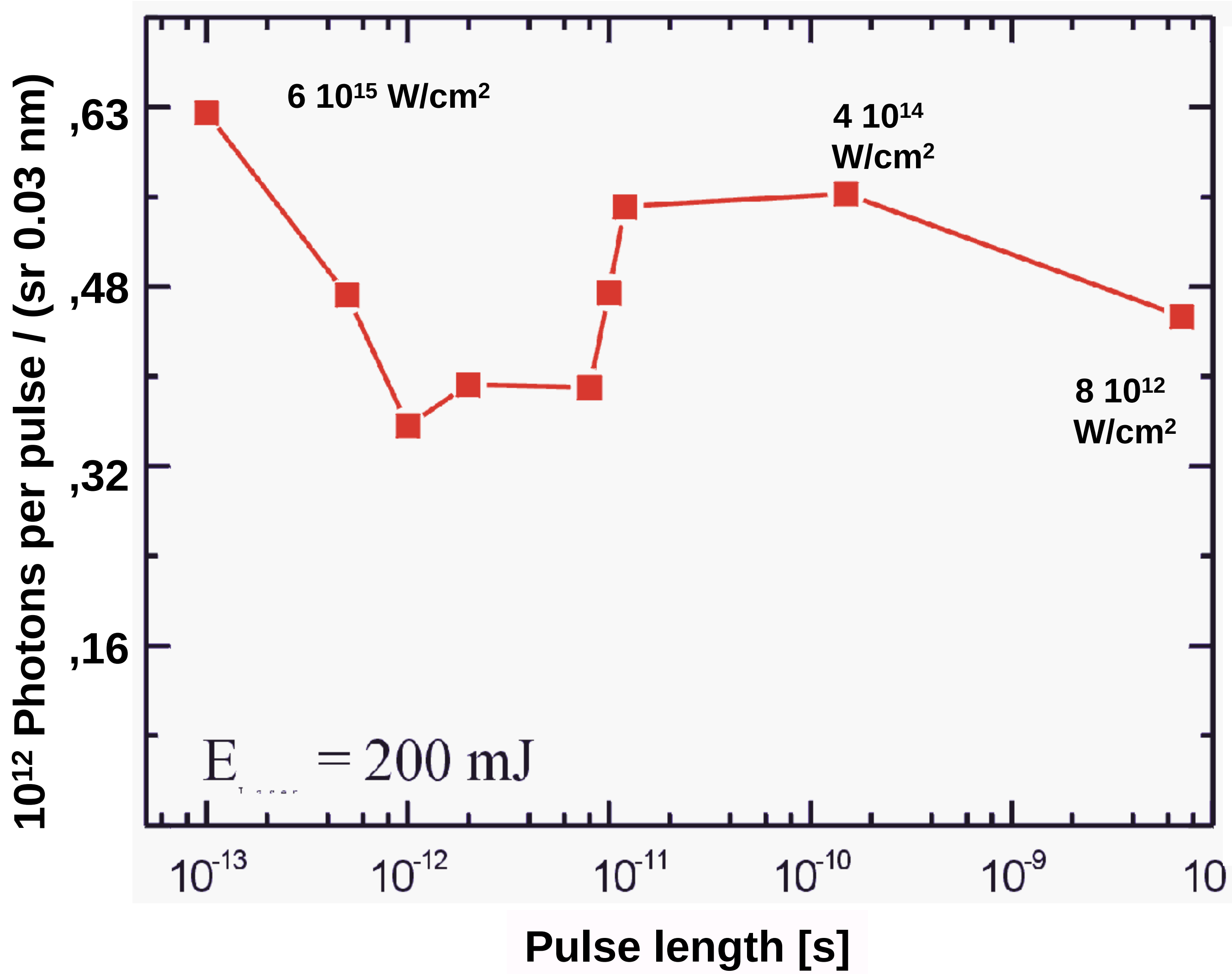
LPP conversion : Dependence on Pulse Duration: Droplet Target

Target : Water droplet
Focus : r_F = 10 µm
Energy : 200 mJ / Pulse
Laser : Jena multi-TW

- **Conversion efficiency is nearly constant**
- **worst for 1 - 10 ps**
- **Low h due to high pulse energy and small source size**

==> better laser-droplet match necessary
==> lower pulse energy
==> larger source



Conversion efficiency = 0,005 % / sr

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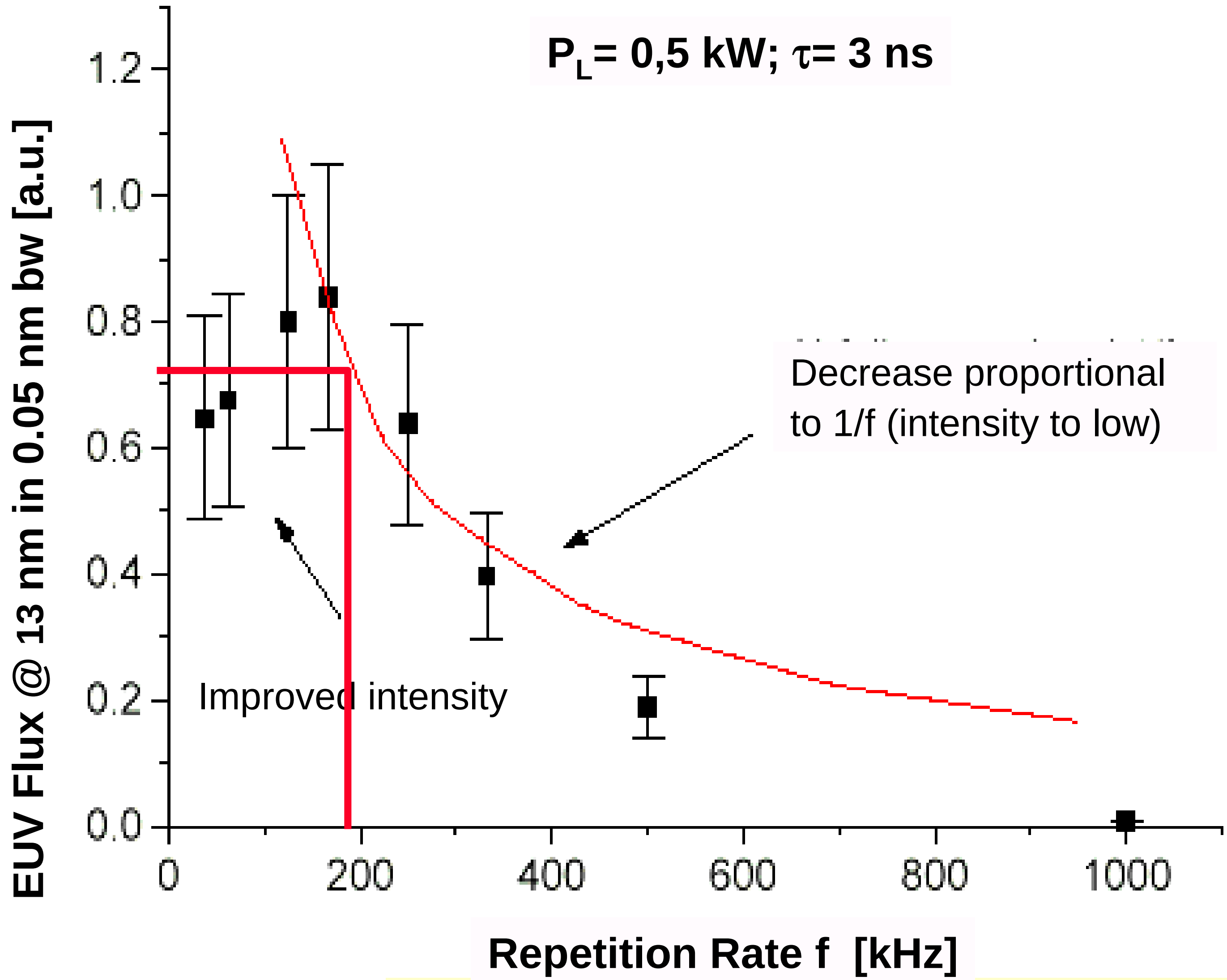
LPP conversion : Dependence on repetition rate : Waterjet with ns

$P_{EUV} = P_{Laser} * \eta_{Pulse}(I,\tau)$

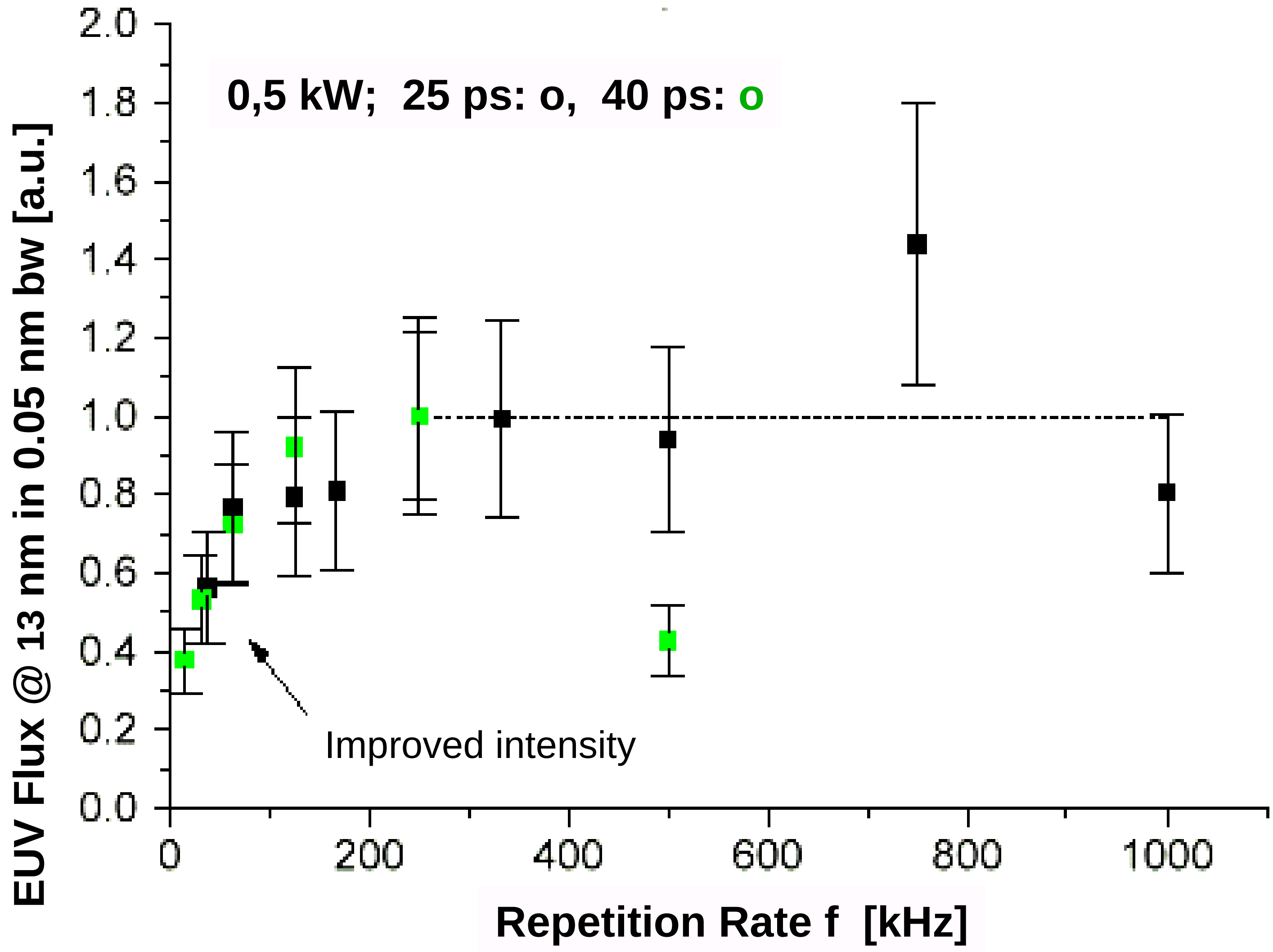
$P_{Laser} = f_{laser} * E_{Pulse}$



Target: Waterjet
Focus : r_F = 10 µm
Laser : ns
: 0,5 kW
: 0.5 µJ - 50 mJ

f_{opt} = 180 kHz ==> I_{opt} = 3*10^{11} W/cm^2

LPP conversion : Dependence on repetition rate : Waterjet with ps

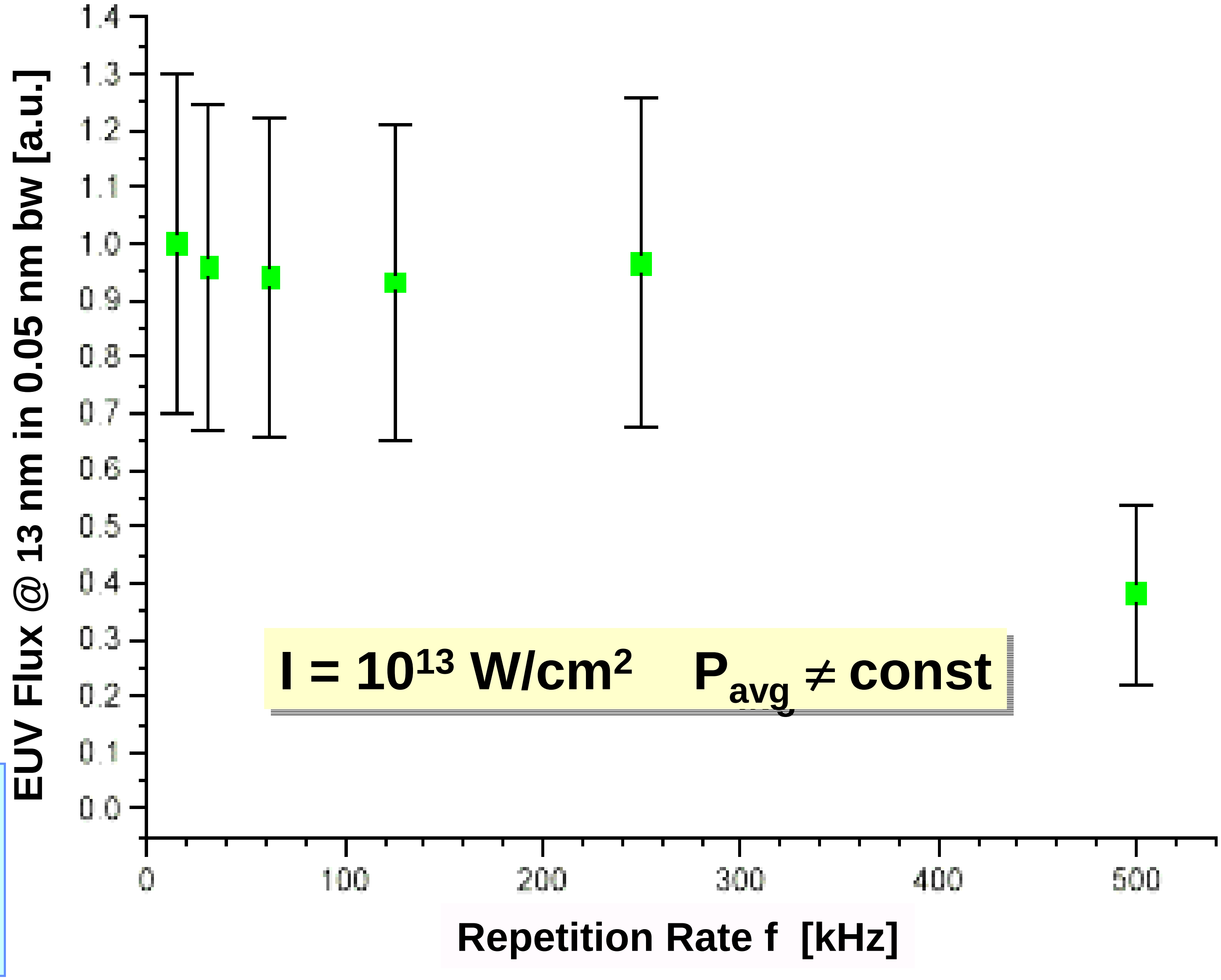


Target : Waterjet
Focus : r_F = 10 μm
Laser : 25, 40 ps
: 0,5 kW
: 0.5 mJ - 50 mJ

F_{opt} = 320 kHz ==> ==> I_{opt} = 1,7*10^{13} W/cm^2

LPP Conversion : Hydrodynamic Stability of Targets

Conversion is independent from reprate up to 250 kHz ==> Jet target is hydrodynamical stable

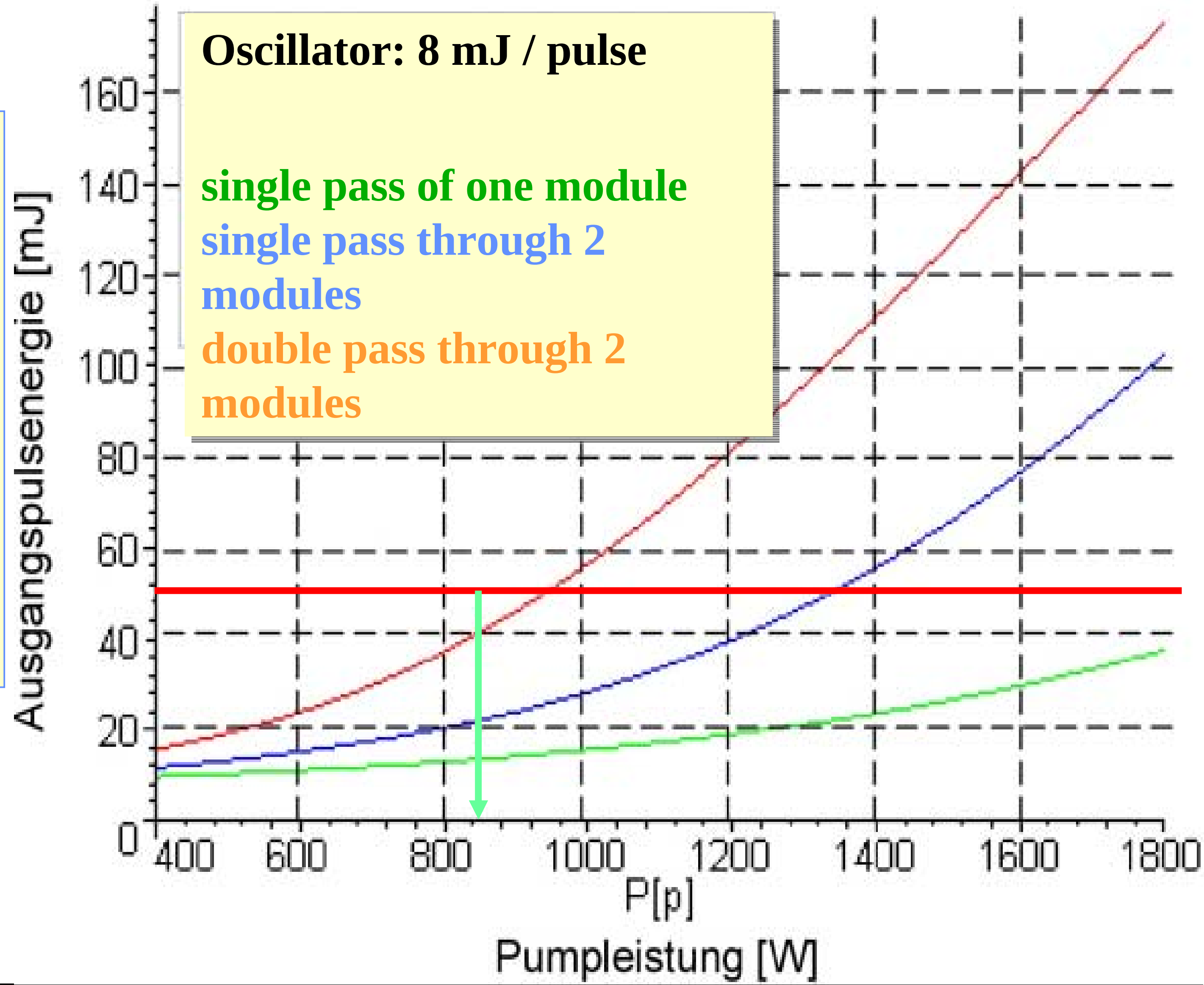


Target : Waterjet
Focus : r_F = 10 µm
Laser : 25 ps pulses
: 20 W-0,5 kW

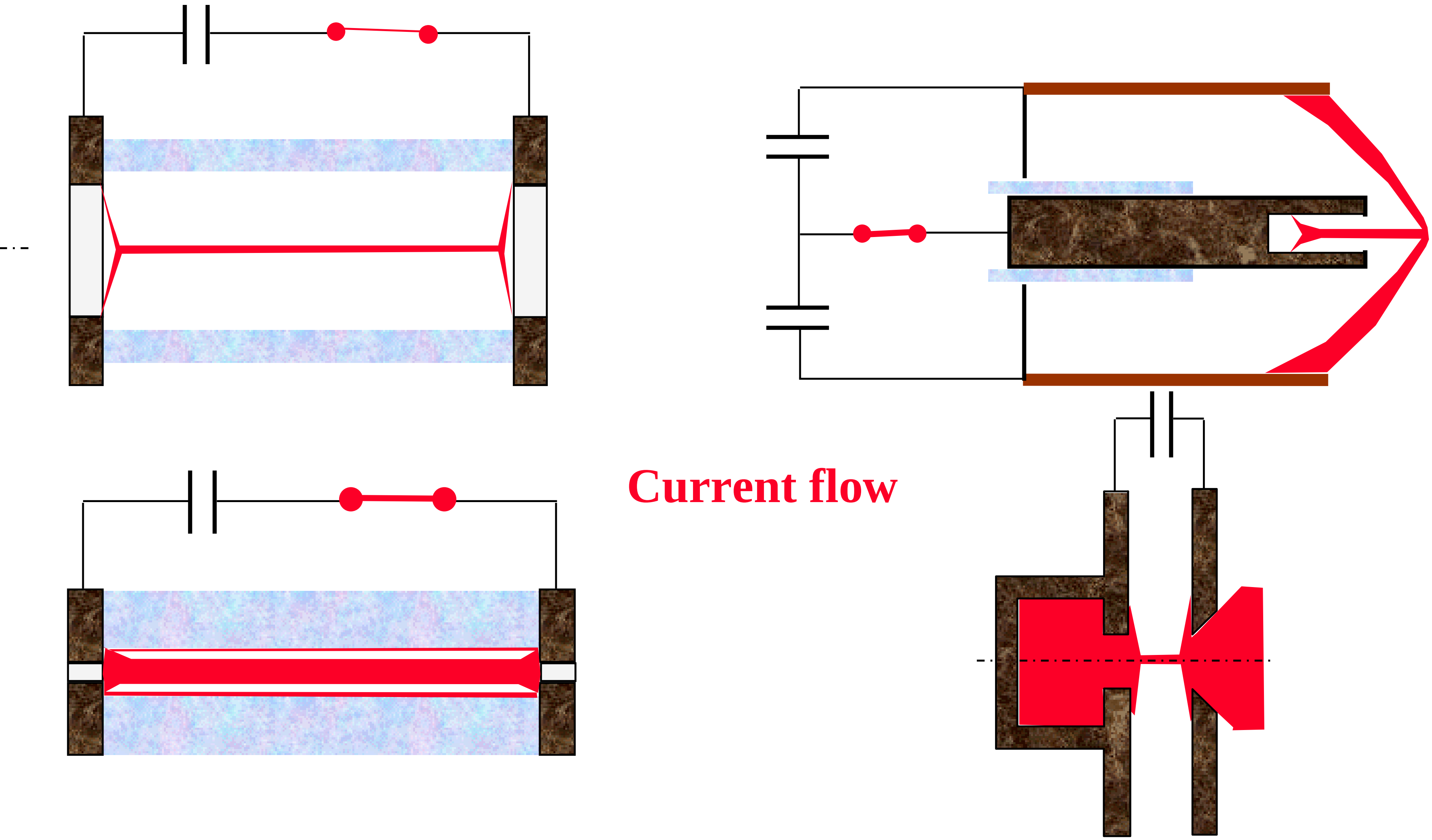
High Power Laser Development : Expected pre-amplifier power

In double pass operation
2 modules reach the
desired power

and are still operated
in the
long lifetime mode



Discharge Plasmas as EUVL Sources



$$\eta_{EUV} = \eta_{Pinch} * \eta_{Generator} * \eta_{Output}$$

Preliminary Rating of EUVL Source candidates

	LPP fs	LPP ps	LPP ns	Capillary pinch	PF-pinch	Z-Pinch	HCT Pinch	Synchr.
Function	+	+	+	+	+	+	+	?
Acceptance	+	+	+	+	+	+	+	-
Economic	low medium	medium	medium	+	+	+	+	?
Key issue	HPL-CoO	HPL-CoO	HPL-CoO	Debris Power	Debris Stability Power	Power Reprate	Power Convers.	Concept
F&E -duration	long	medium	shorter	medium	medium	medium	medium	long
Show-Stopper	Stability ?	-	-	-	-	-	-	Size

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Outlook: best numbers combined and outlook

Approach	Input Power	Conversion	Ω	Yield into condenser
Laser produced	2 kW	η = 0.03 %/sr	2 sr	1.2 W
	5 kW	η = 0.10 %/sr	2 π sr	30 W
	10 kW	η = 0.15 %/sr	2 π sr	90 W
Gas discharge	5 kW	η = 0.03 %/sr	1 sr	1.5 W
	30 kW	η = 0.10 %/sr	2 sr	60 W

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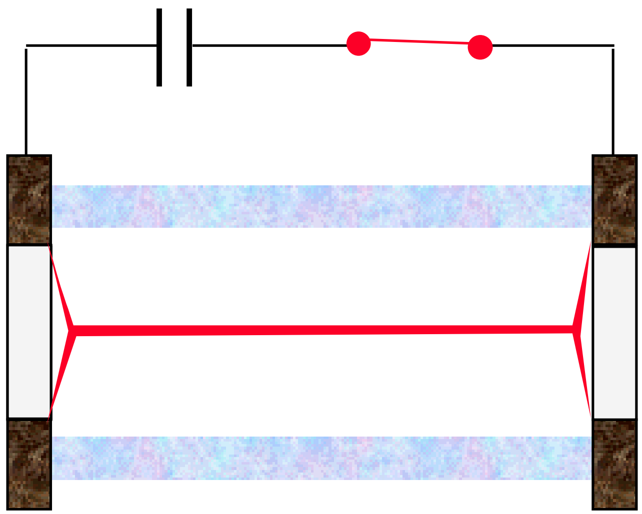
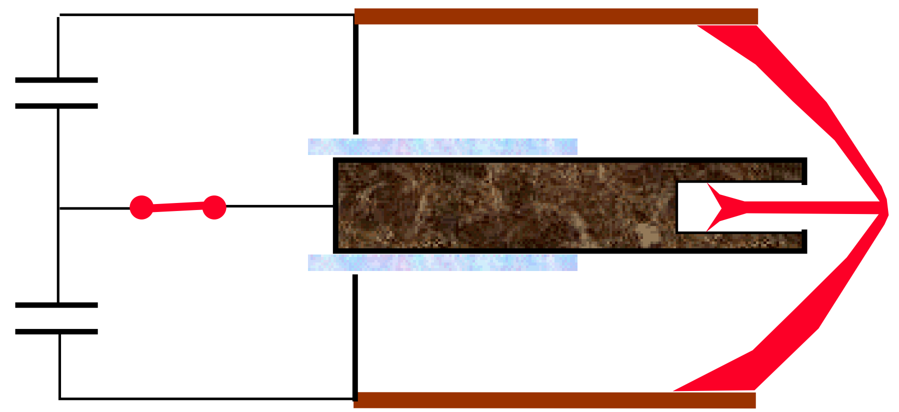
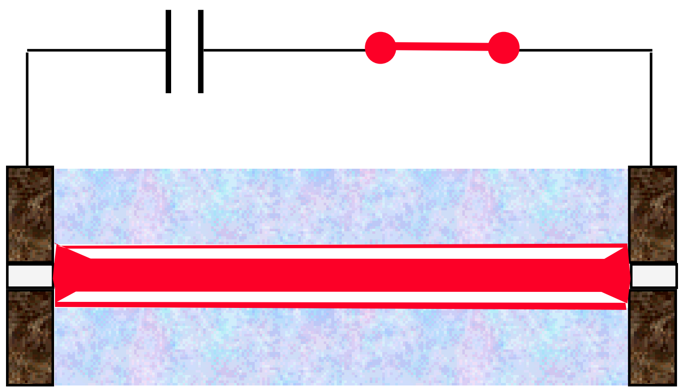
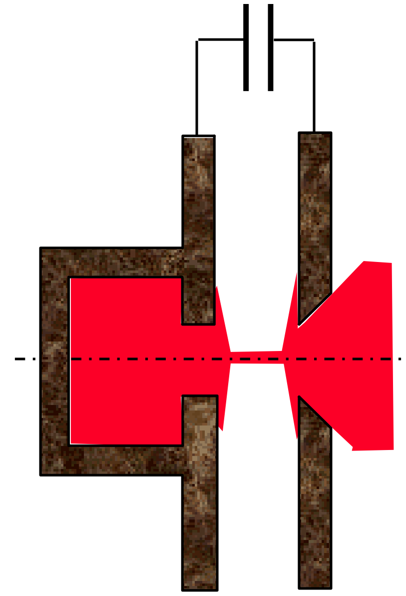
Current Flow



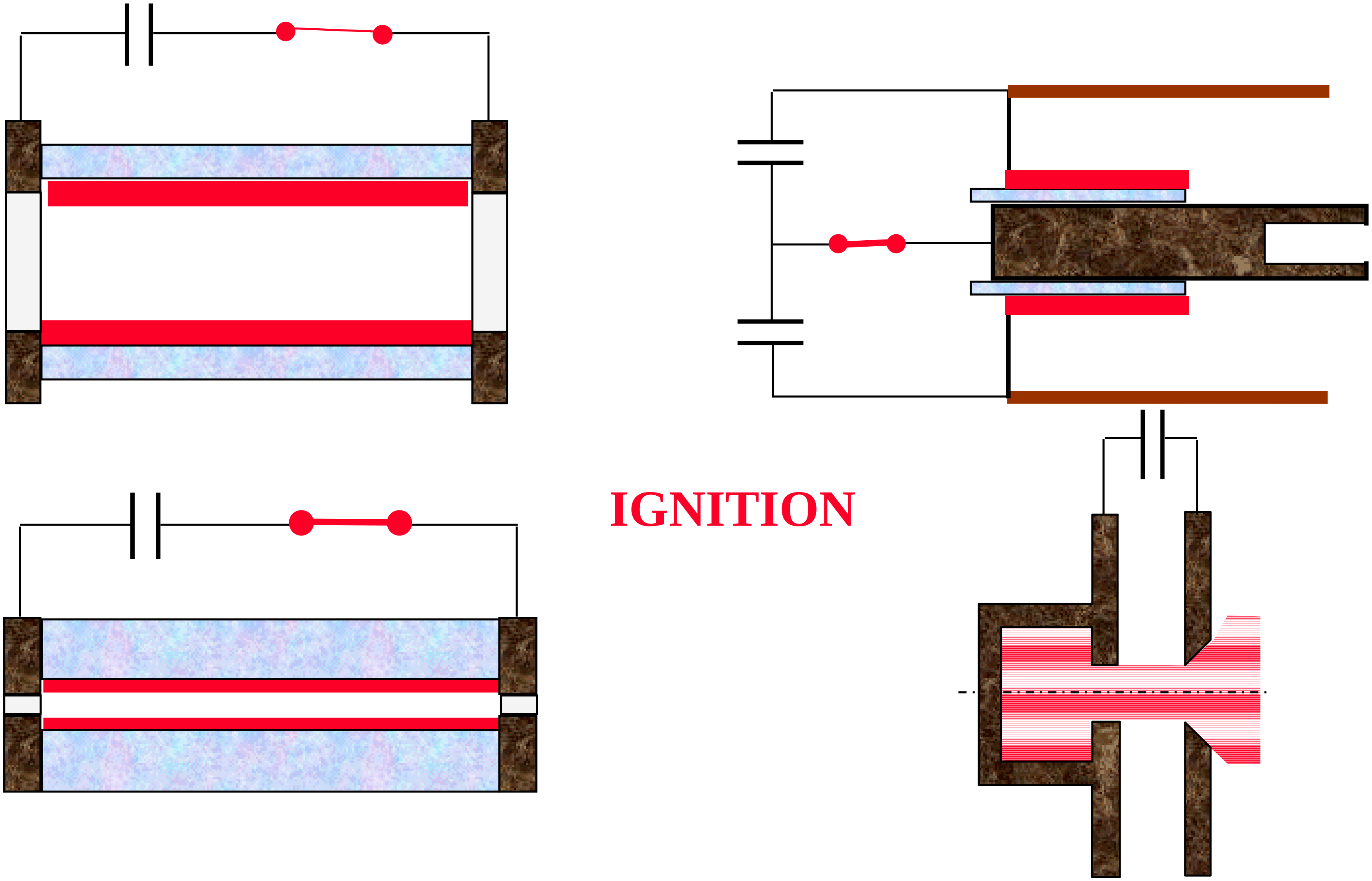


Current flow





Pinch Ignition



Sources for EUV-Lithography : Source development

Approach	Basic Research	Development	Tools
Laser produced	Conversion Efficiency Debris free target	High power laser High Reprate Target	Laser CoO Target lifetime mtf
Gas discharge	Conversion efficiency Debris free discharge	High Power device High Reprate device	CoO lifetime mtf
System	Spectral distribution Suited emitters Emission characteristics	Coupling to Optics	Degradation Contamination

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