

Studies on x-ray conversion efficiency in Xe cryogenic targets

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Outline of this talk

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- 1) Objectives of the study
- 2) Experimental layout
- 3) Typical angular distribution of EUV emission, plasma particles, and laser scattering from Xe cryogenic target
- 4) Results
 - comparison of Xe EUV emission with Sn EUV emission
 - dependence of EUV emission on laser focus position, laser energy and intensity
 - double pulse effect on EUV emission
 - energy balance in laser heated Xe plasmas
- 5) Summary and conclusion

Objectives of this study

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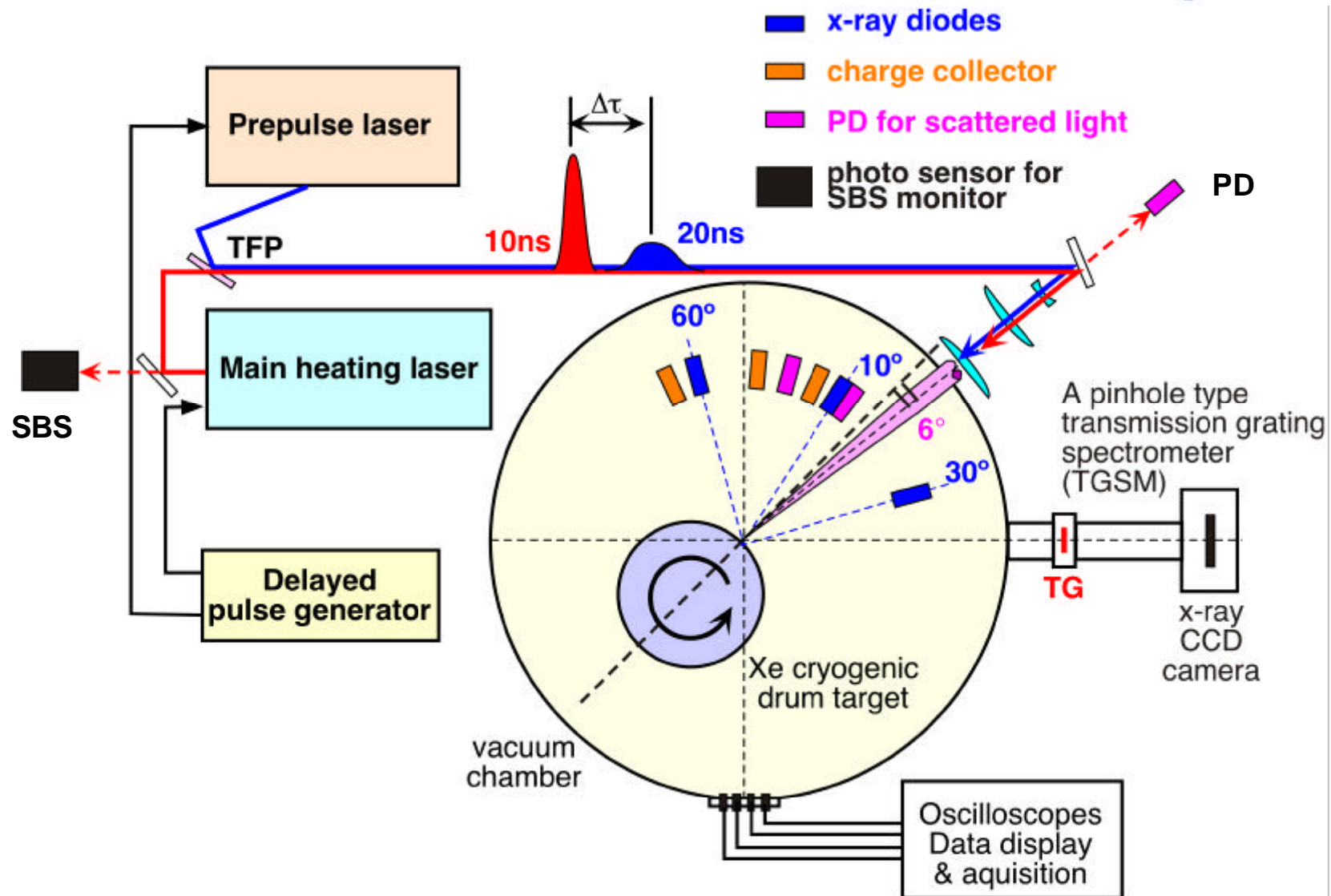
It is to find breakthrough condition of laser and Xe cryogenic target which enables a CE of 2% at 13.5 nm with 2%BW. For this purpose we need to understand the plasma dynamics as much as possible.

The breakthrough condition would be inferred from the knowledge on

- 1) dependence of CE on I_L , focus position and I_L .
- 2) double pulse laser illumination.
- 3) energy balance in target plasmas.

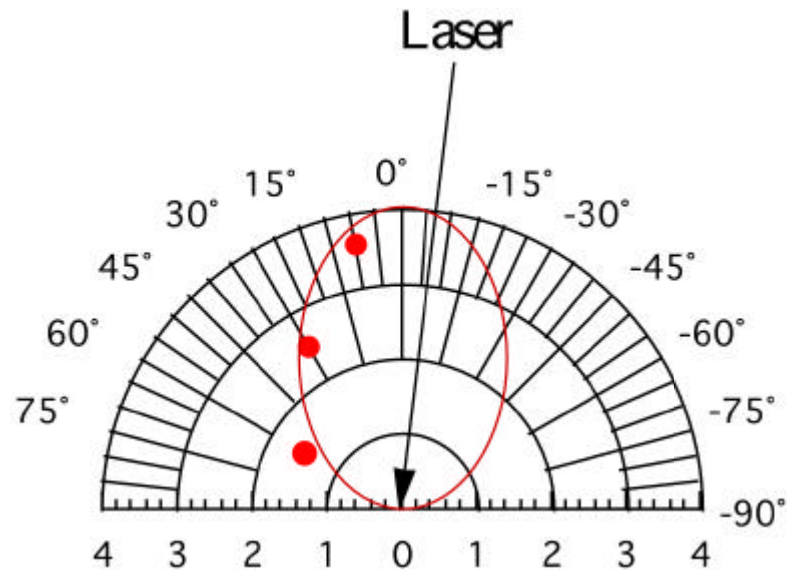
Experimental layout

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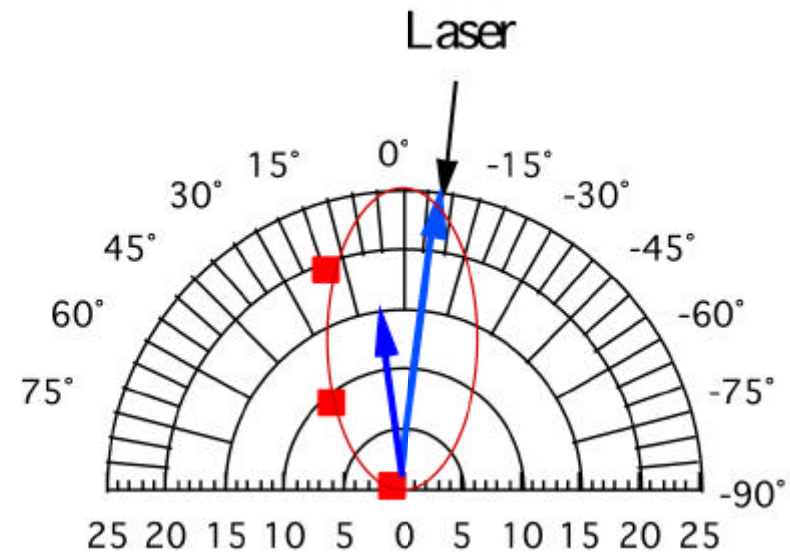


Typical angular distributions of EUV emission, plasma particles and scattered light from Xe cryogenic target

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EUV emission

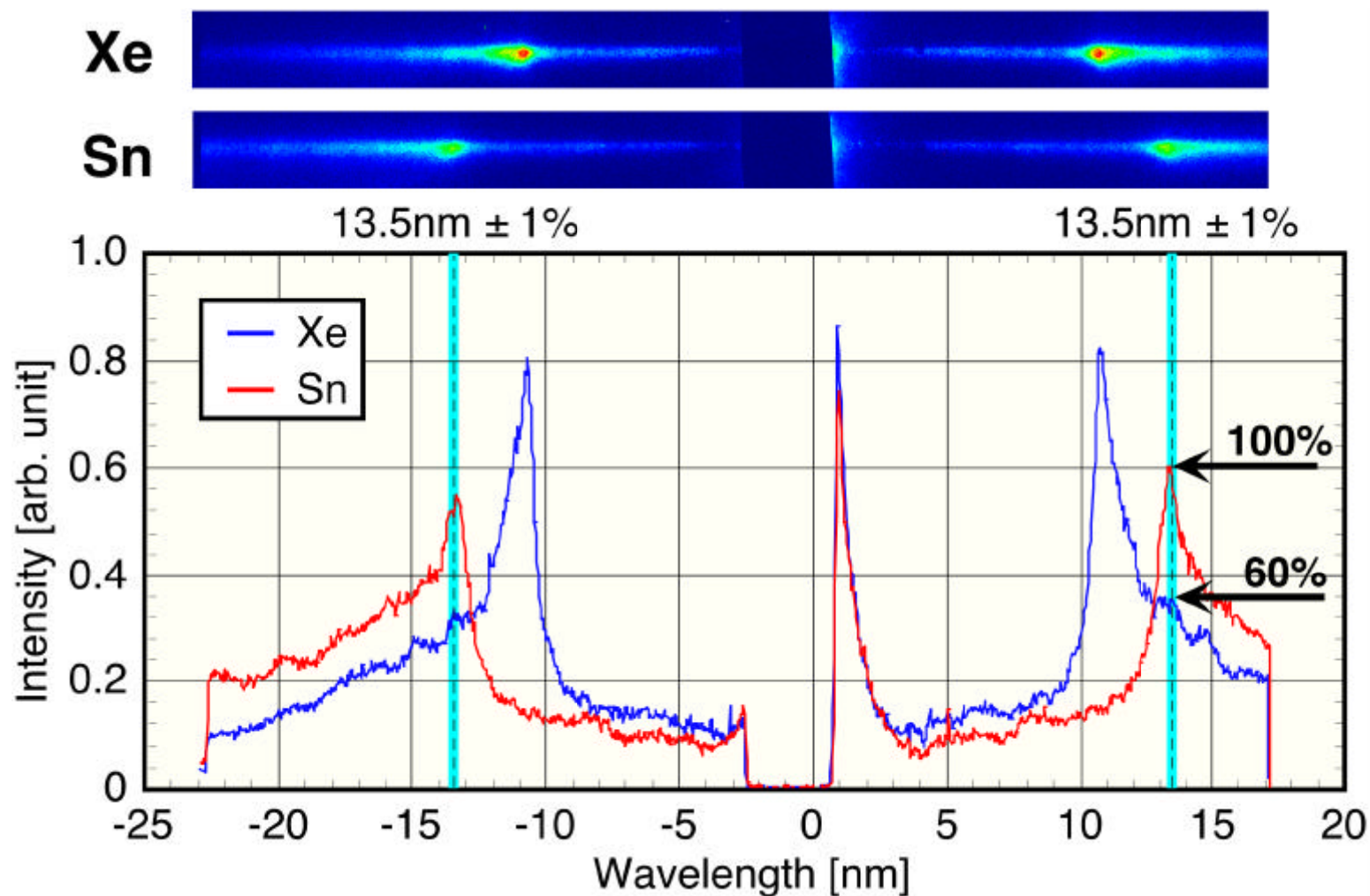


**Plasma particle (square)
Scattered light (arrow)**

Comparison of Xe spectrum with Sn spectrum

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Nd:YAG laser @ $I_L=1064$ nm, $E_L=0.7$ J, $t_L=20$ ns, $I_L \sim 1 \times 10^{12}$ W/cm²

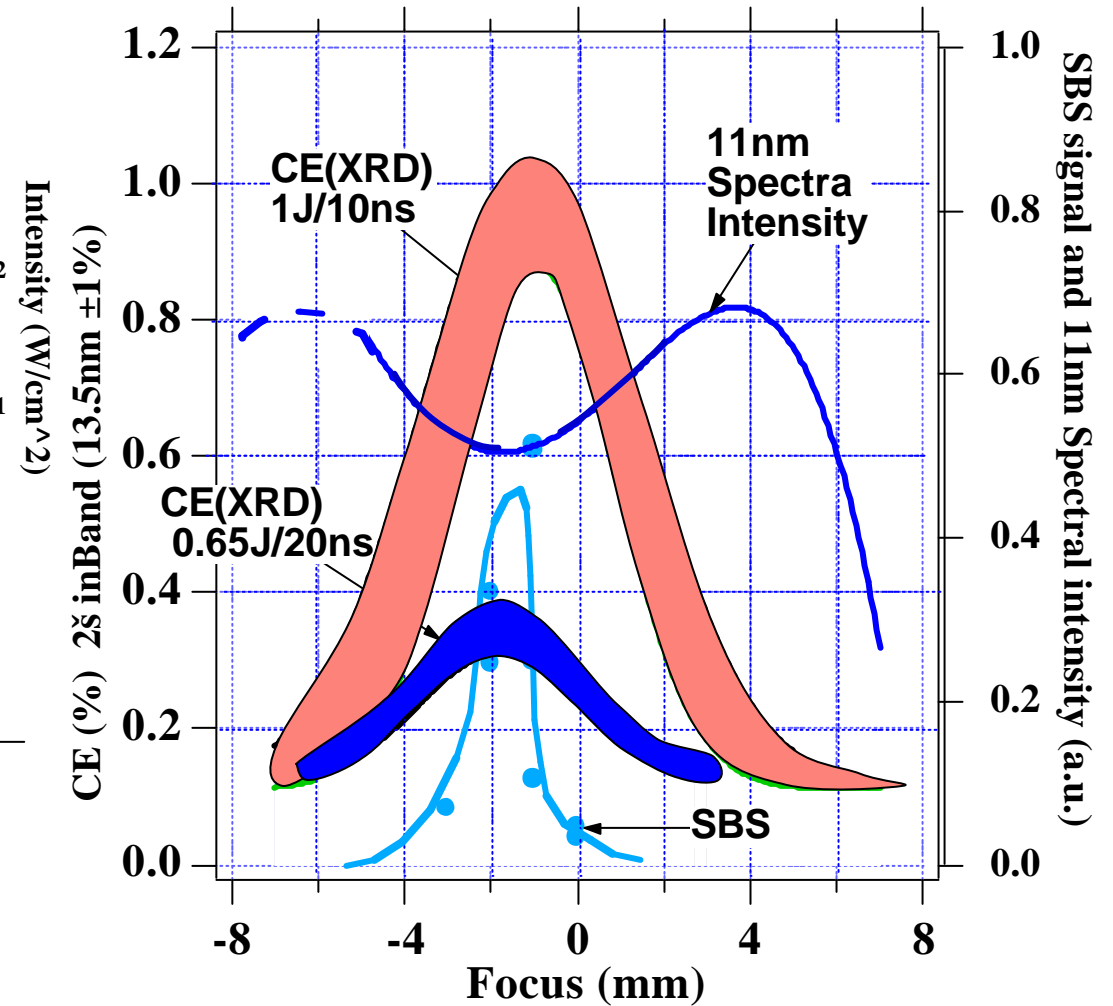
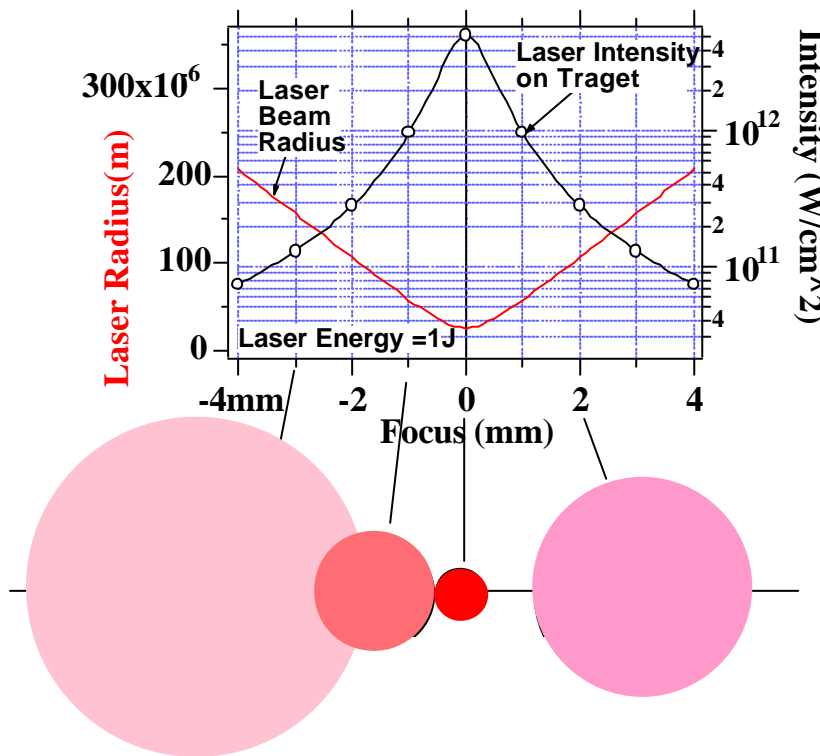


Dependence of EUV intensity on laser focus position 1

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Laser energy = 1J/10ns

CE vs. focus position (3ch XRD)

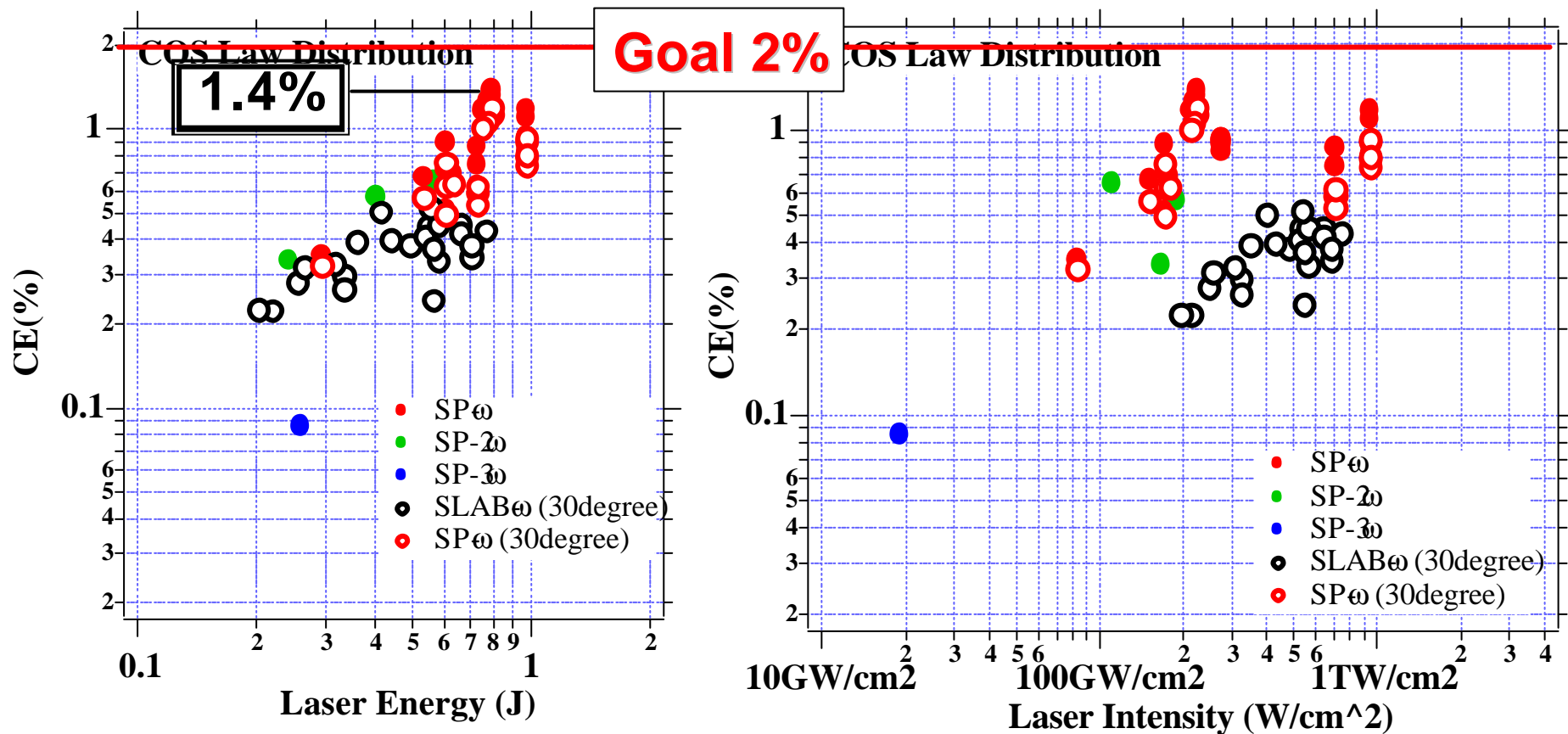


EUV conversion efficiency vs. laser energy and intensity

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Laser Energy

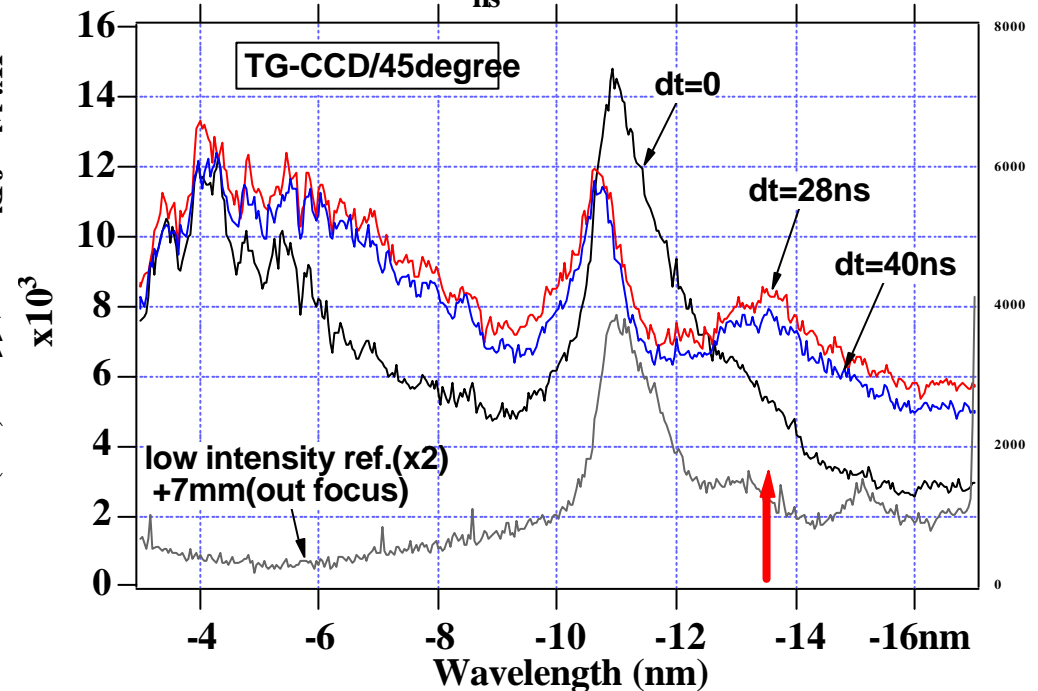
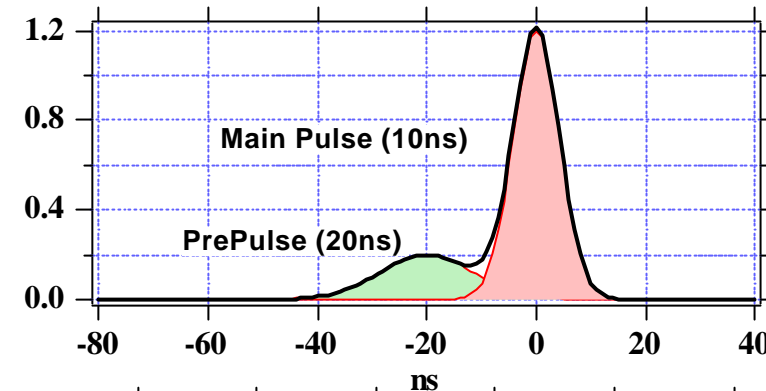
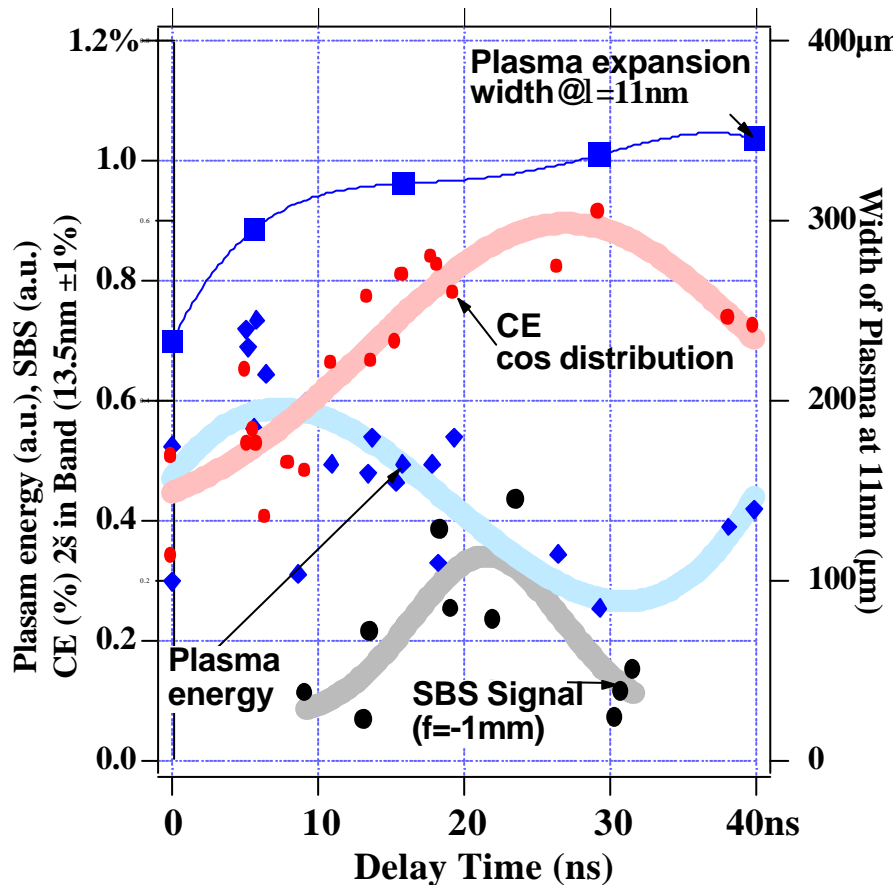
Laser Intensity



Double pulse effect on EUV emission

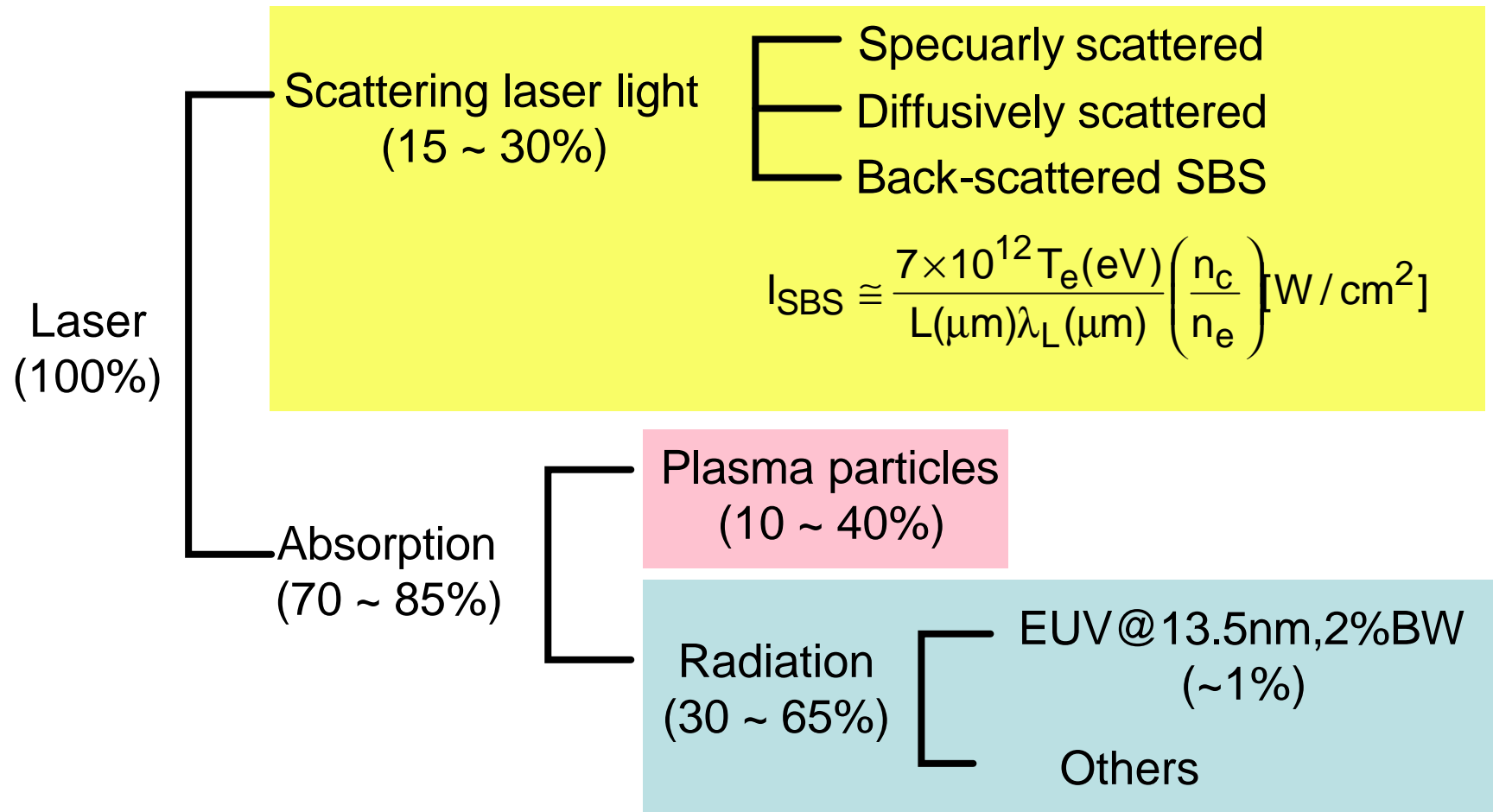
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Pre-pulse 0.16J / 20ns
 Main pulse 1J/10ns
 delay=0-40ns
 Focus position = -2 mm



Energy balance in Xe laser-produced plasma

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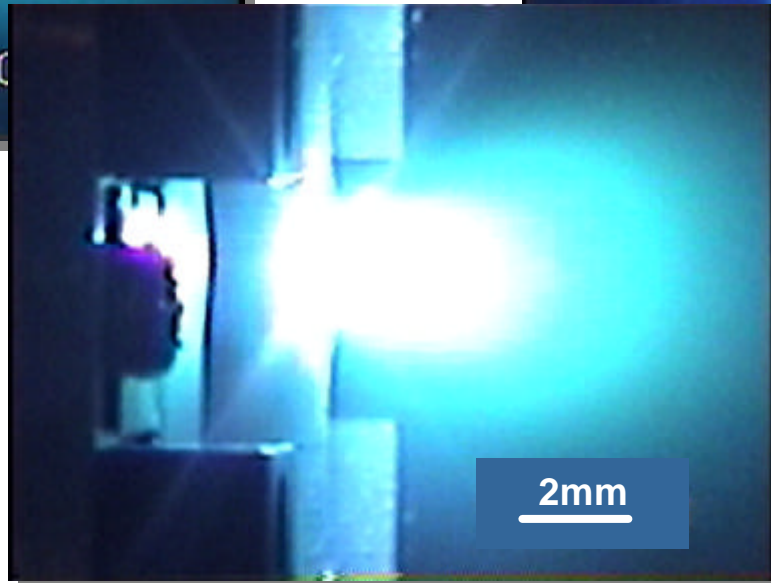
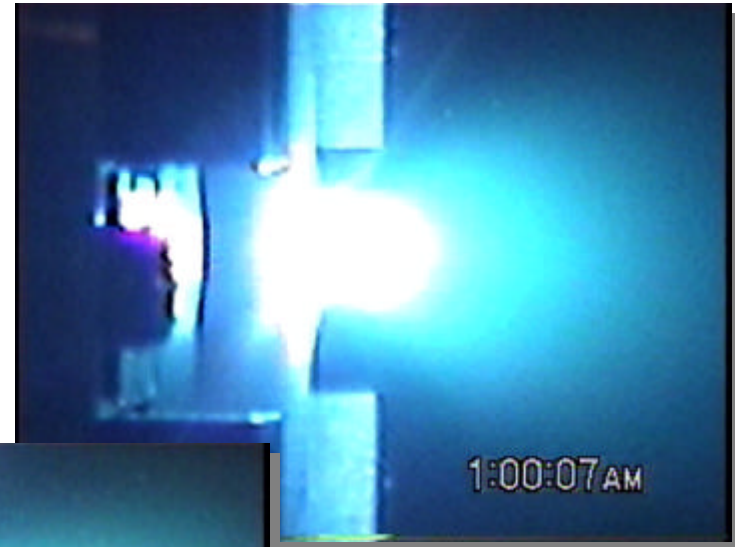
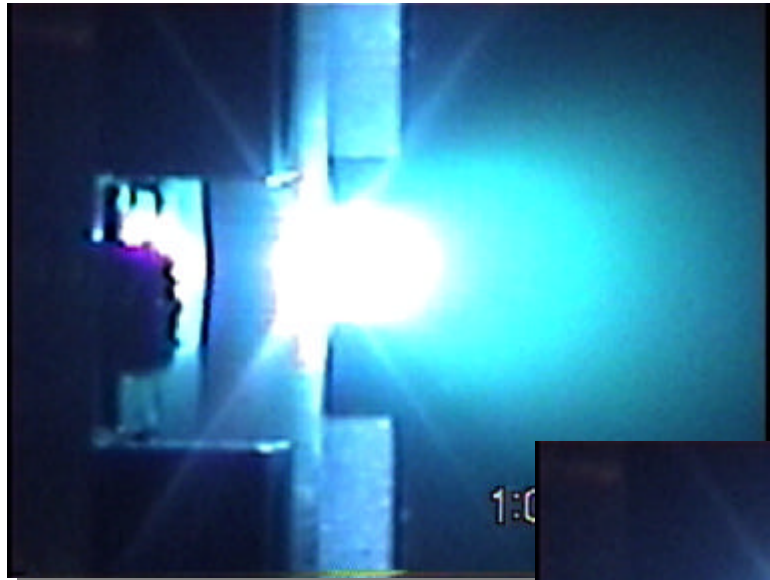
$$I_{\text{SBS}} \cong \frac{7 \times 10^{12} T_e (\text{eV}) \left(\frac{n_c}{n_e} \right)}{L(\mu\text{m}) \lambda_L (\mu\text{m})} [\text{W} / \text{cm}^2]$$

Laser intensity $10^{11} \sim 10^{12} \text{ W/cm}^2$
 Wavelength $1.06 \mu\text{m}$
 Pulse width $10 \sim 20 \text{ ns}$

Examples of high rep-rate shot

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320Hz Optical images



Summary and conclusion

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- 1) An emission ratio Xe/Sn was found to be 0.5 to 0.7 at 13.5 nm @ 0.7 J / 20 ns, 80 μ m ϕ
- 2) An optimum focusing condition exists. The SBS signal indicates production of a long scalelength plasma responsible to enhanced EUV emission.
- 3) The maximum conversion efficiency observed was 1.4 %.
- 4) Double pulse experiment showed increase in CE with a prepulse. This encourages us to survey detailed dynamics to reach the final goal.
- 5) Energy balance suggests us that suppressing plasma particle energy will be helpful to improve CE.

Finally, these knowledge obtained will be extended not only to other planar geometry targets, but also to filament geometry target for improving CE.