Advances in computer simulation tools for plasma-based sources of EUV radiation

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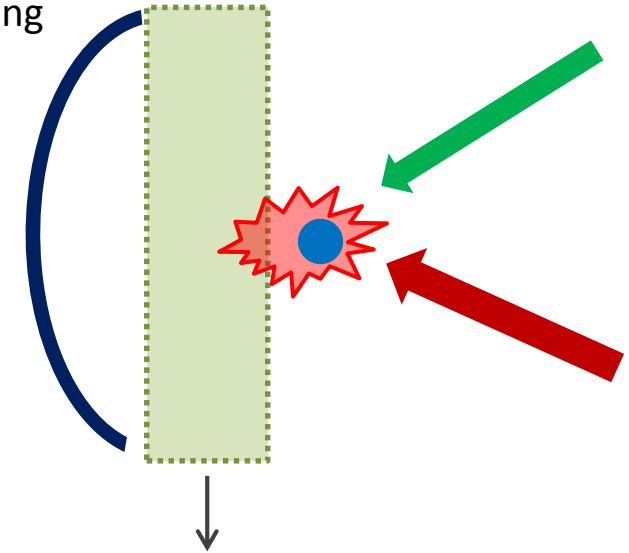
EUV Source from simulation point of view



4. Sn deposition/cleaning for collector mirror

1. Target engineering with laser pre-pulse

2. EUV production with main laser pulse

3. Debris mitigation by buffer gas

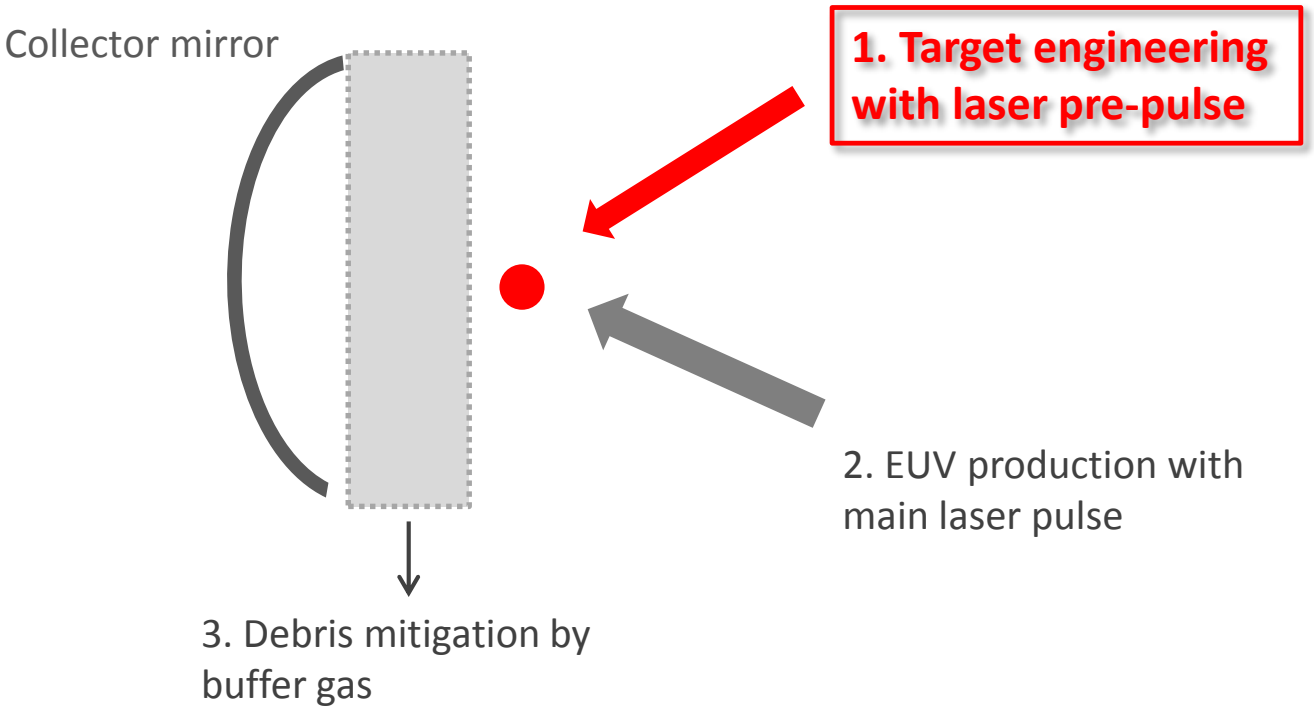
Radiative hydrodynamics codes for plasma

Two RHD codes available – RZLINE and RALEF

List of included physical processes

	RZLINE	RALEF
Plasma hydrodynamics	+	+
Target hydrodynamics	-	+
Plasma thermal conductivity	+	+
Wideband radiation transport	+	+
Laser absorption	+	+
Target ablation	+	+
Nonstationary ionization	+	-
Target geometry	arbitrary RZ	arbitrary 2D (RZ or XY)

Details -> Talk # S23 this conference S36 by M. Basco


Collector mirror
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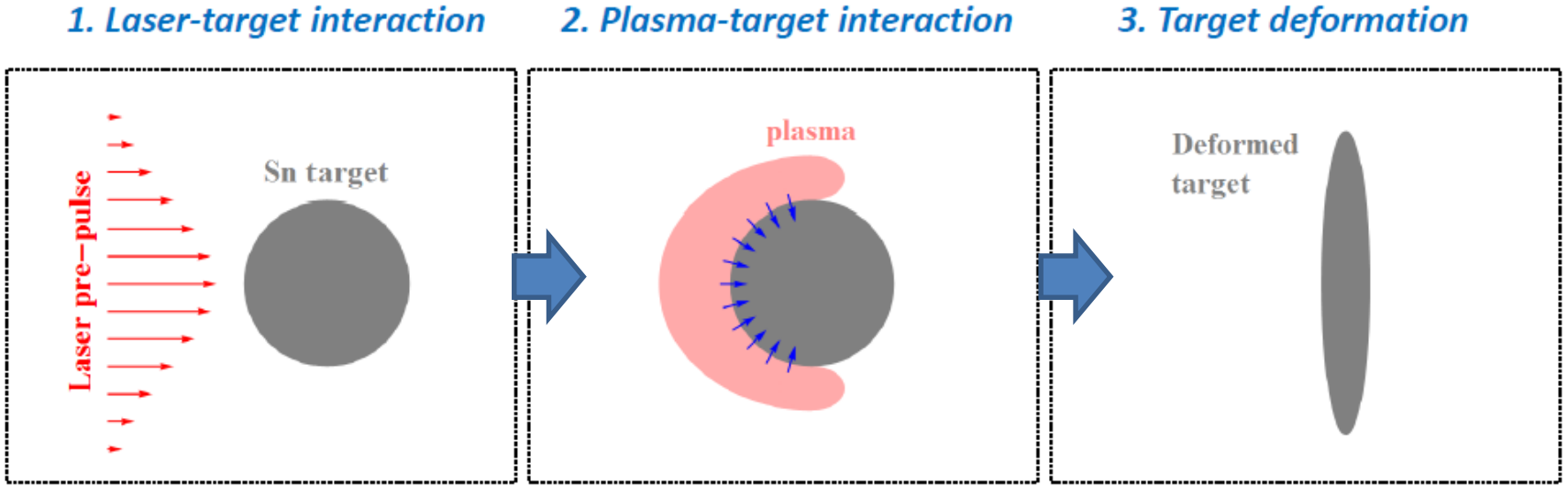
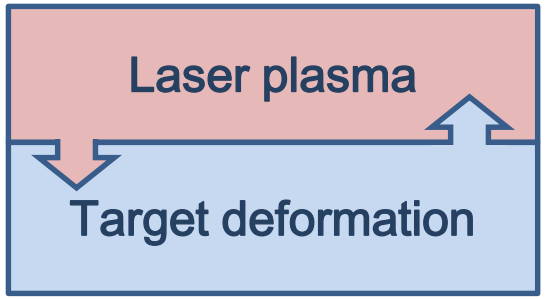
Pre-pulse simulation approaches



Pre-pulse simulation approaches

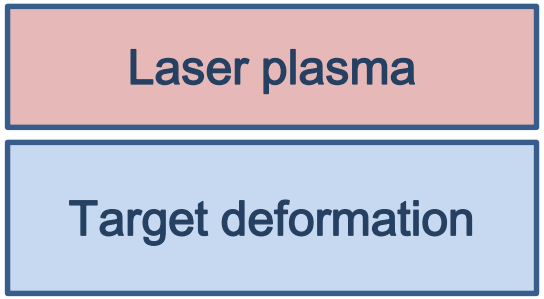
Self-consistent approach



Simulation tools:

- **RALEF** – radiative hydrodynamics of plasma + target

Separated processes

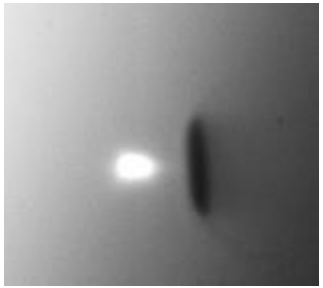


Simulation tools:

- **RZLINE** – radiative hydrodynamics of plasma
- **OpenFOAM** – hydrodynamics of target deformation

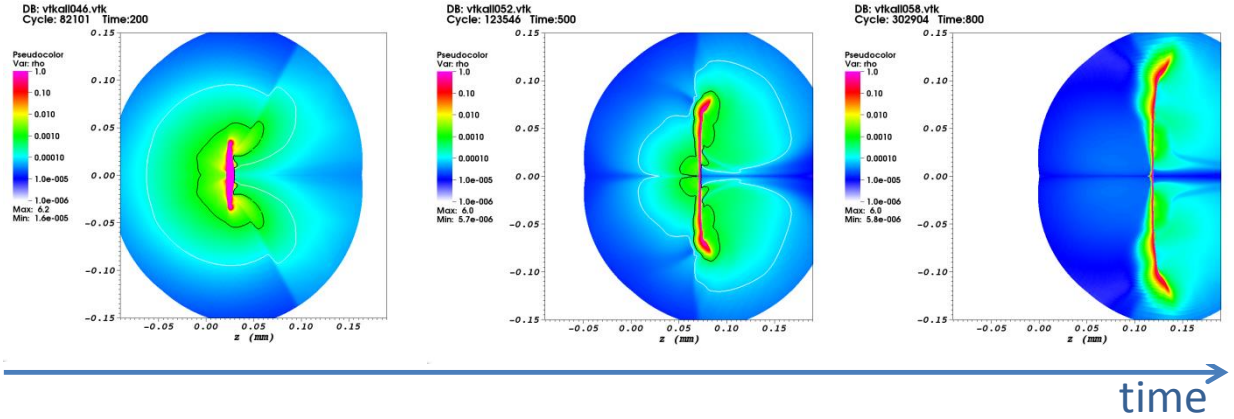
Modeling nanosecond pre-pulses

~ 10 ps pre-pulse
“Disk like target”



H. Mizoguchi, Dublin (2013)

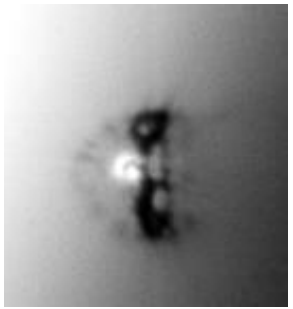
RALEF simulations
Evolution of Sn density profile for 10 ns pre-pulse



Details -> Talk # S23 this conference S36 by M. Basco

Modeling picosecond pre-pulses

~ 10 ps pre-pulse
"Dome like target"



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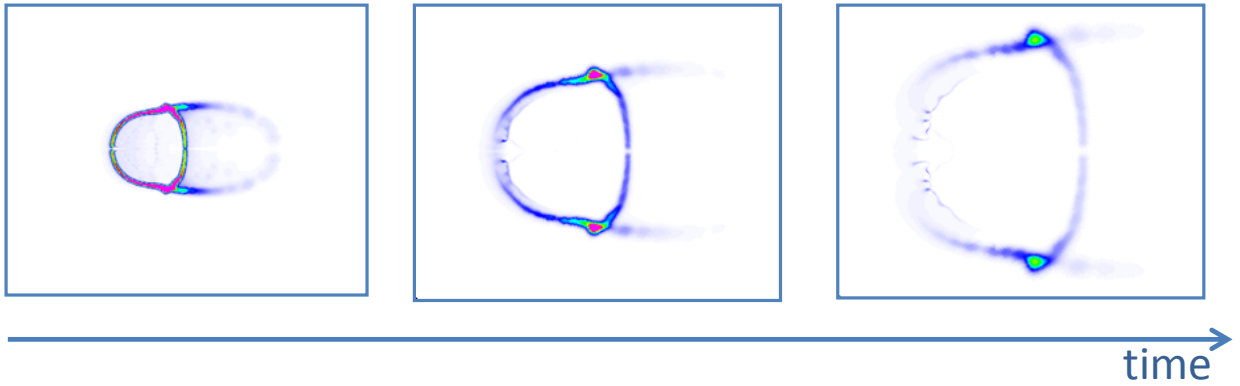
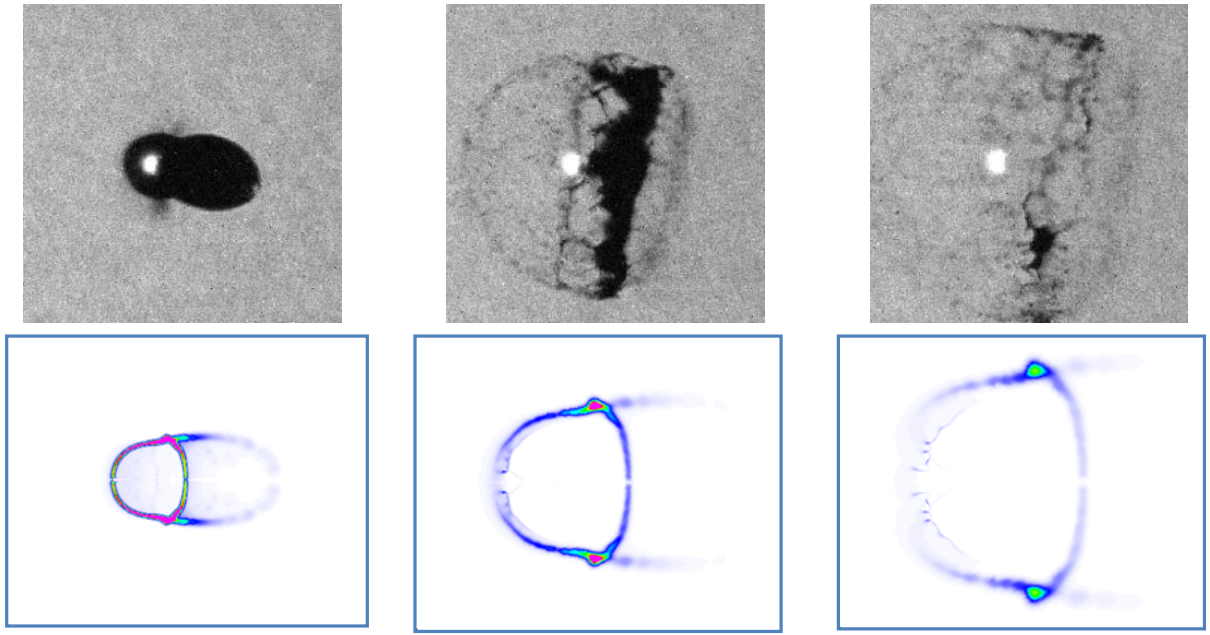


Modeling picosecond pre-pulses

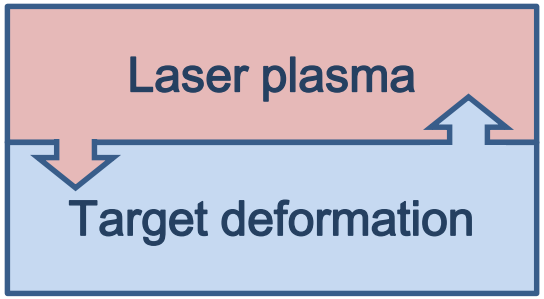
Pre-pulse experiments at ISAN, details -> Talk S72 this conference by A. Vinokhodov



time

Pre-pulse simulation approaches

Self-consistent approach



Simulation tools:

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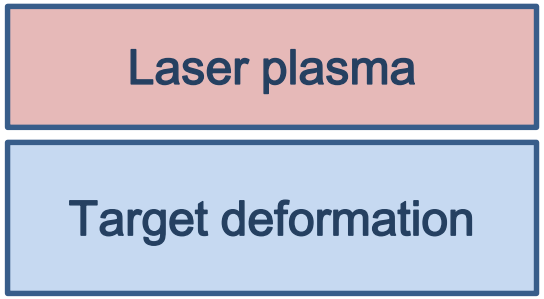


Simulation tools:

- **RZLINE** – radiative hydrodynamics of plasma
- **OpenFOAM** – hydrodynamics of target deformation

Pre-pulse by RZLINE+OpenFOAM

RnD ISAN

+ Volume of Fluid method
+ Two phases (Liquid and Gas)
+ Immiscible fluids
+ Isothermal
+ Viscosity
+ Compressibility

Regular hydrodynamics

+ Surface tension
+ Crushing/merge of droplet(s)
+ Ideal gas equation of state for surrounding gas and constant speed of sound for liquid droplet
+ Surrounding plasma influence through ablation pressure from RZLINE code

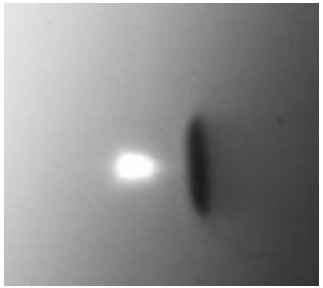
Specific

Details -> Poster S23 this conference

OpenFOAM®

Modeling nanosecond pre-pulses

~ 10 ps pre-pulse
“Disk like target”



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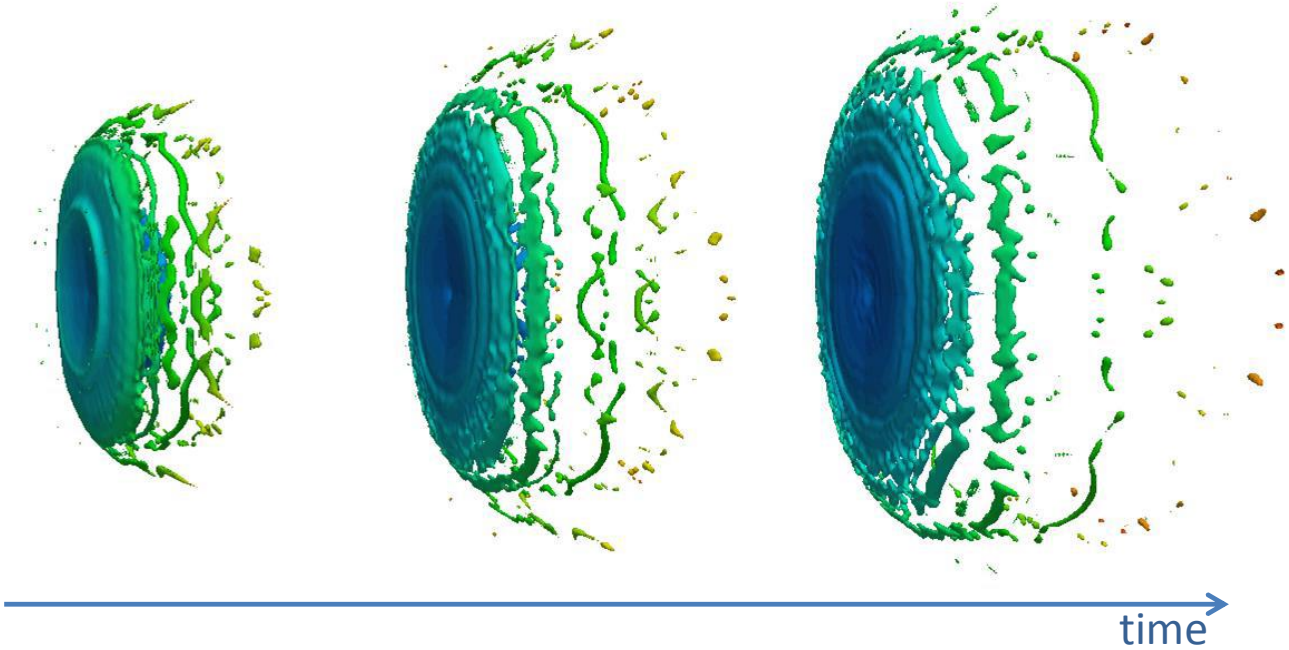

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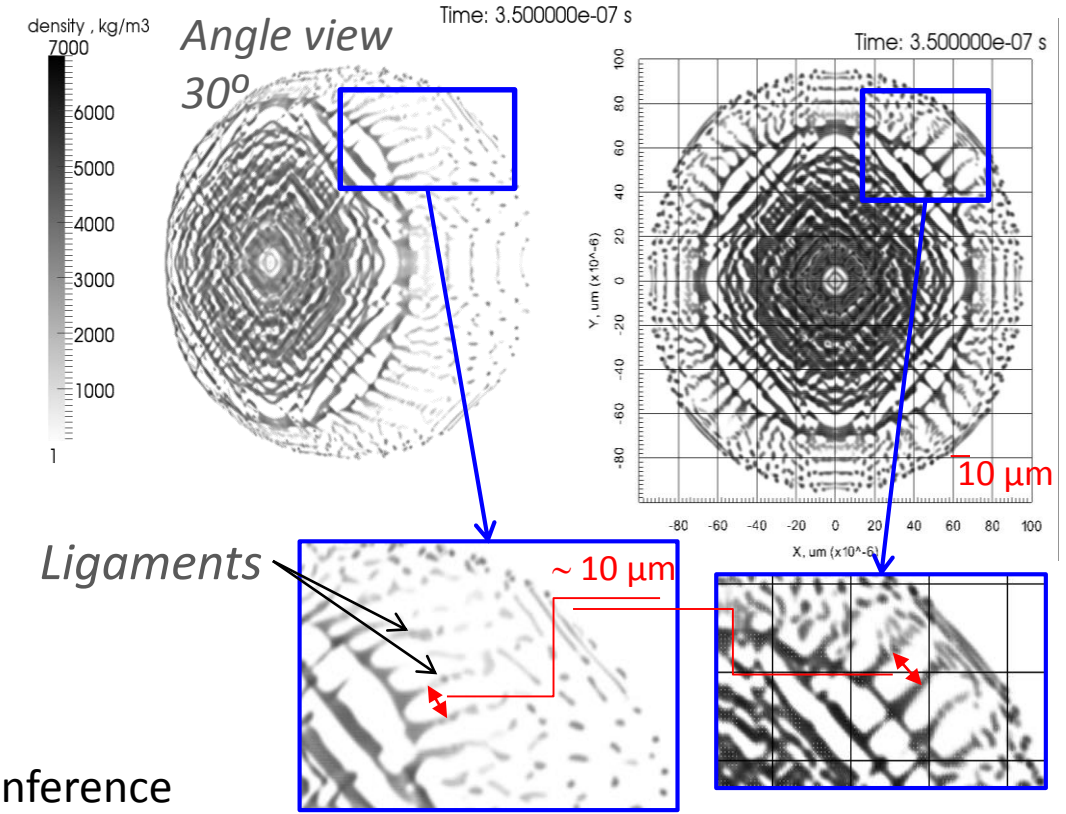
Microparticles produced laser pre-pulse

The ligaments, expelled from the rim, are caused by Rayleigh–Taylor instability localized at the rim.



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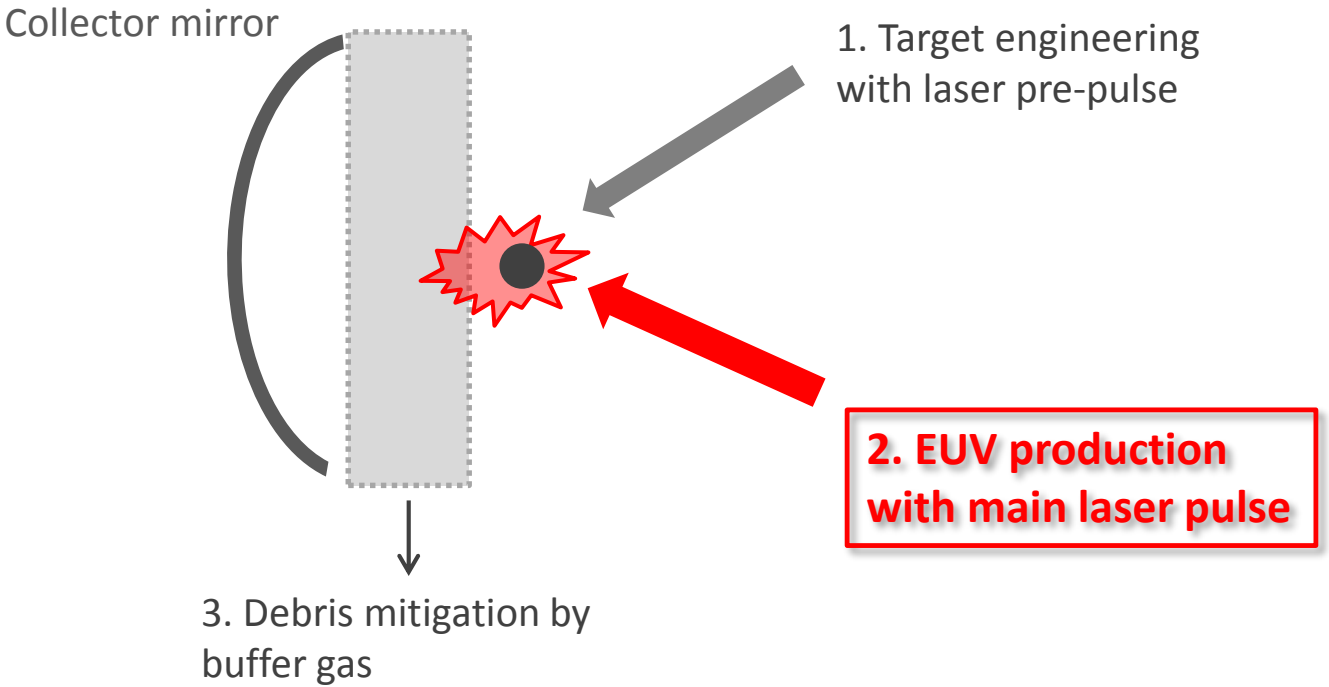
Collector mirror
1. Target engineering with laser pre-pulse
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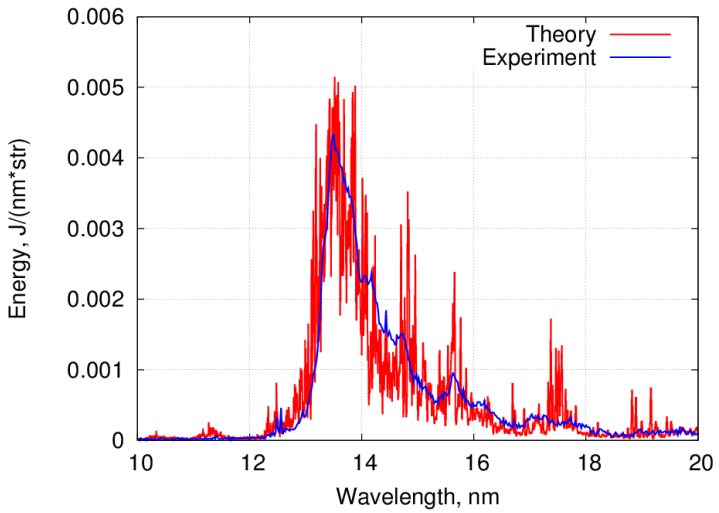
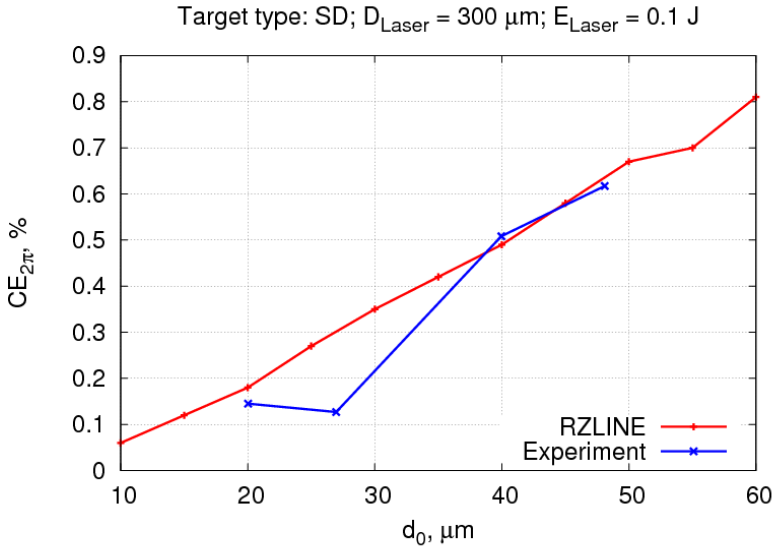
Spectral character

EUV emission spectrum from CO_2-driven LPP with bulk Sn target. Experimental data from ISAN

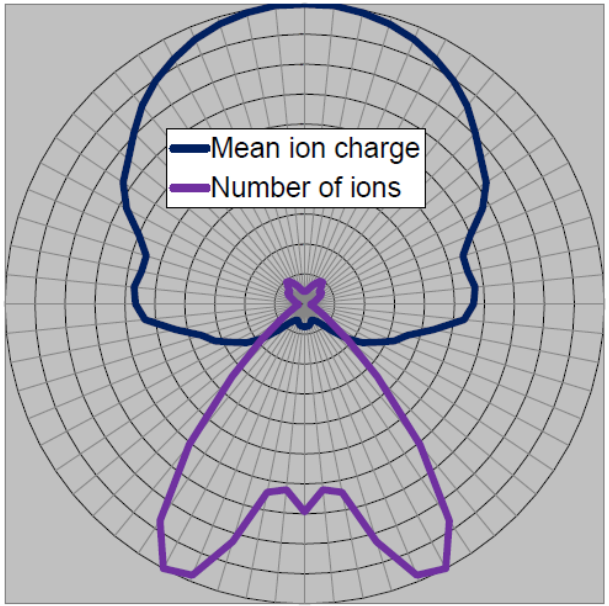


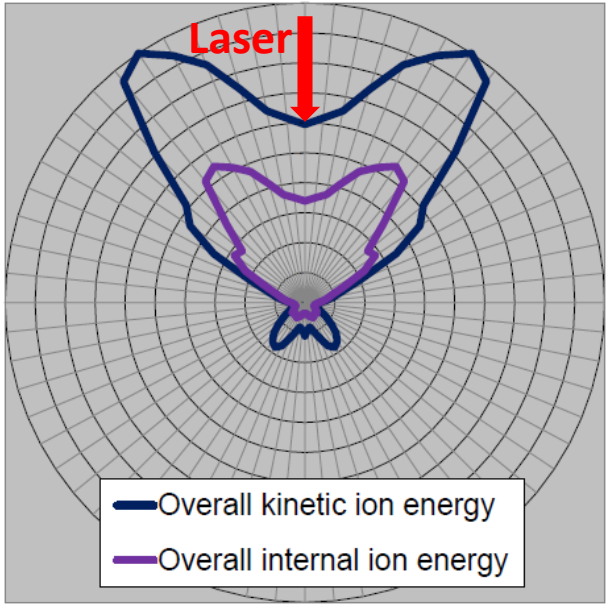
In-band conversion efficiency (CE) for CO_2-driven LPP with Sn droplet targets. Data by Gigaphoton

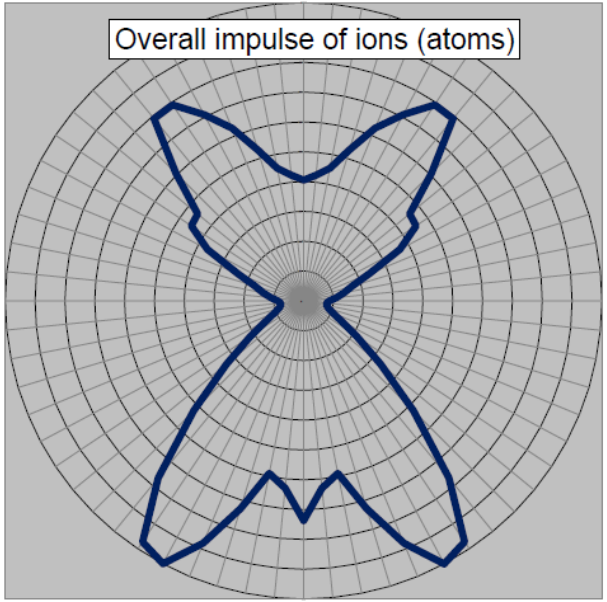


Important ion characteristics of plasma source

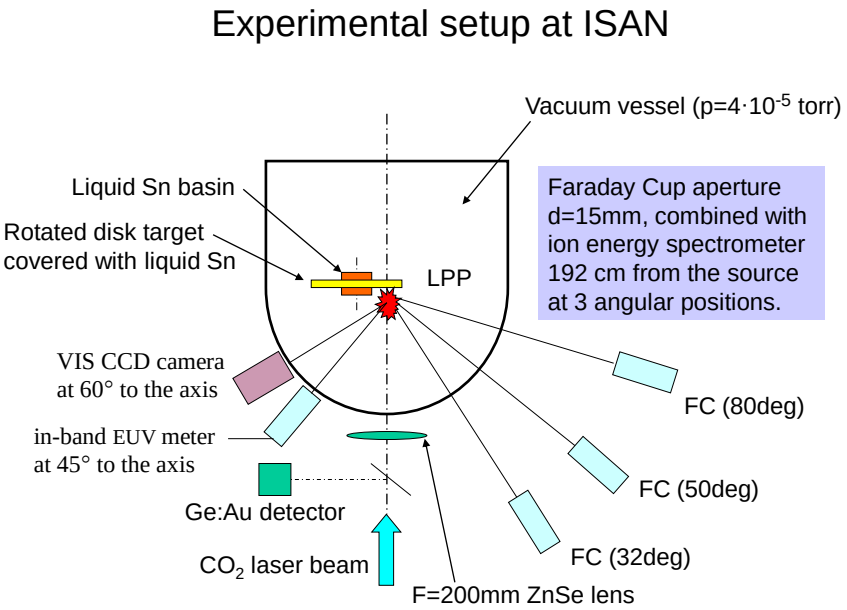
Calculated for CO_2-driven LPP with mass-limited flat disk target

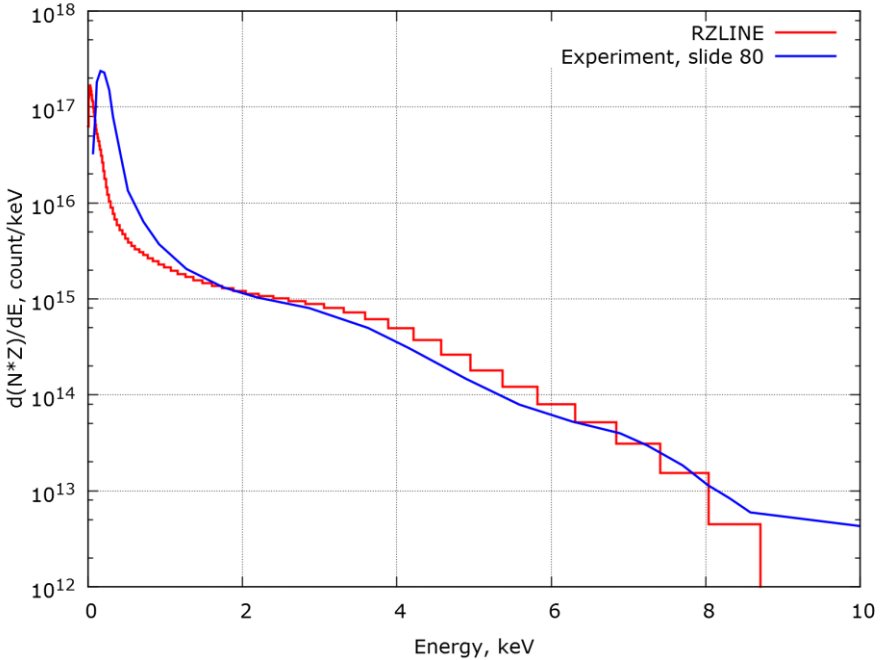






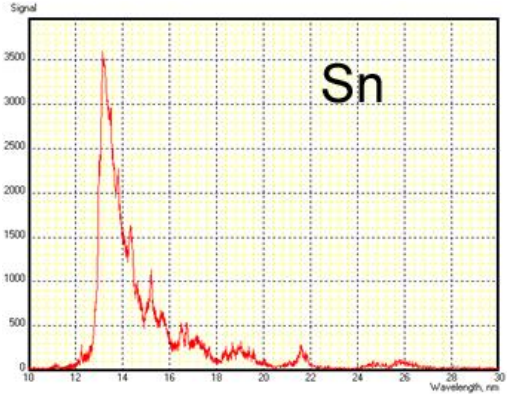
Ion spectra validation

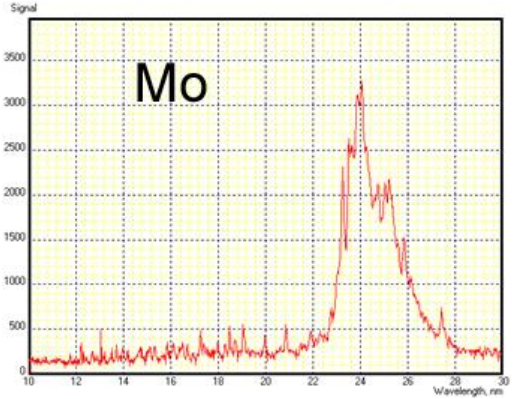




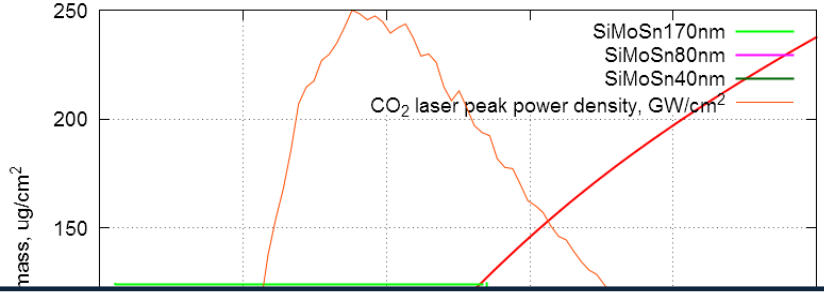
Target ablation rate: how to validate models?

Experiments at ISAN: CO_2-driven LPP with thin Sn films on Mo substrates





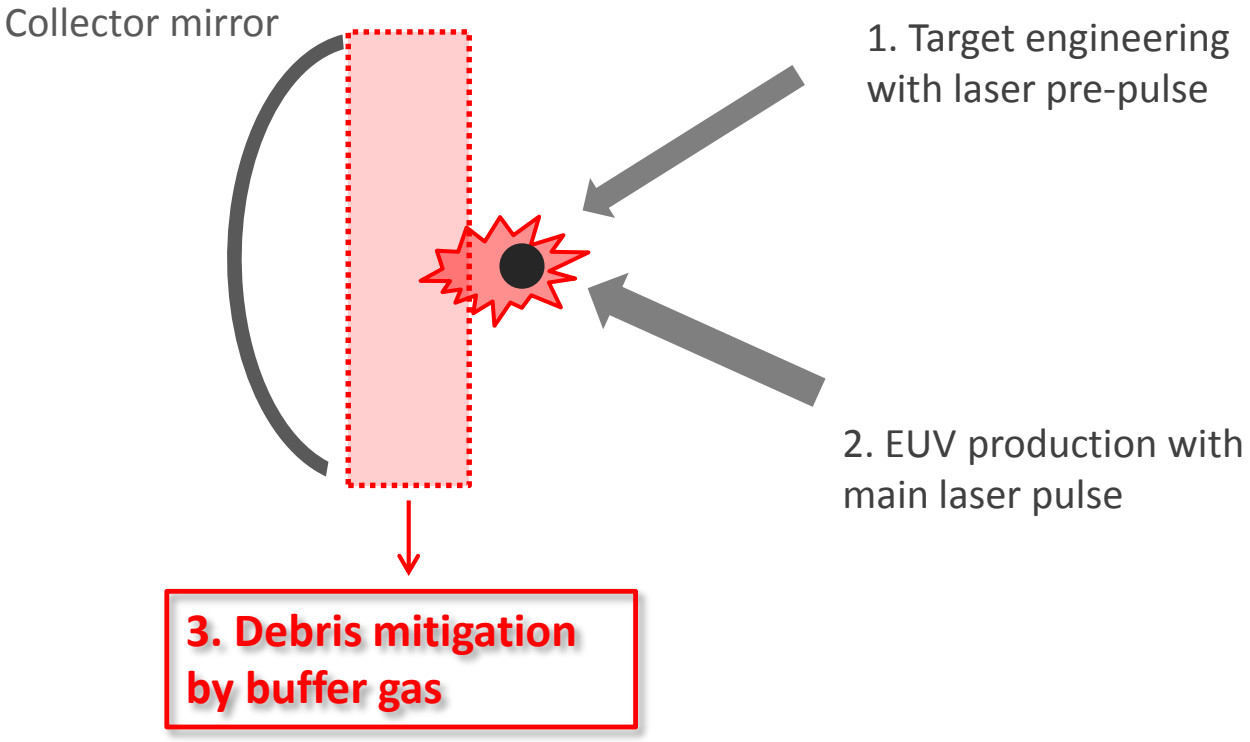
Measured evaporated/ablated mass



Validation of RHD models

- requires introduction of two component model
- calculation of radiation tables for Mo

TBD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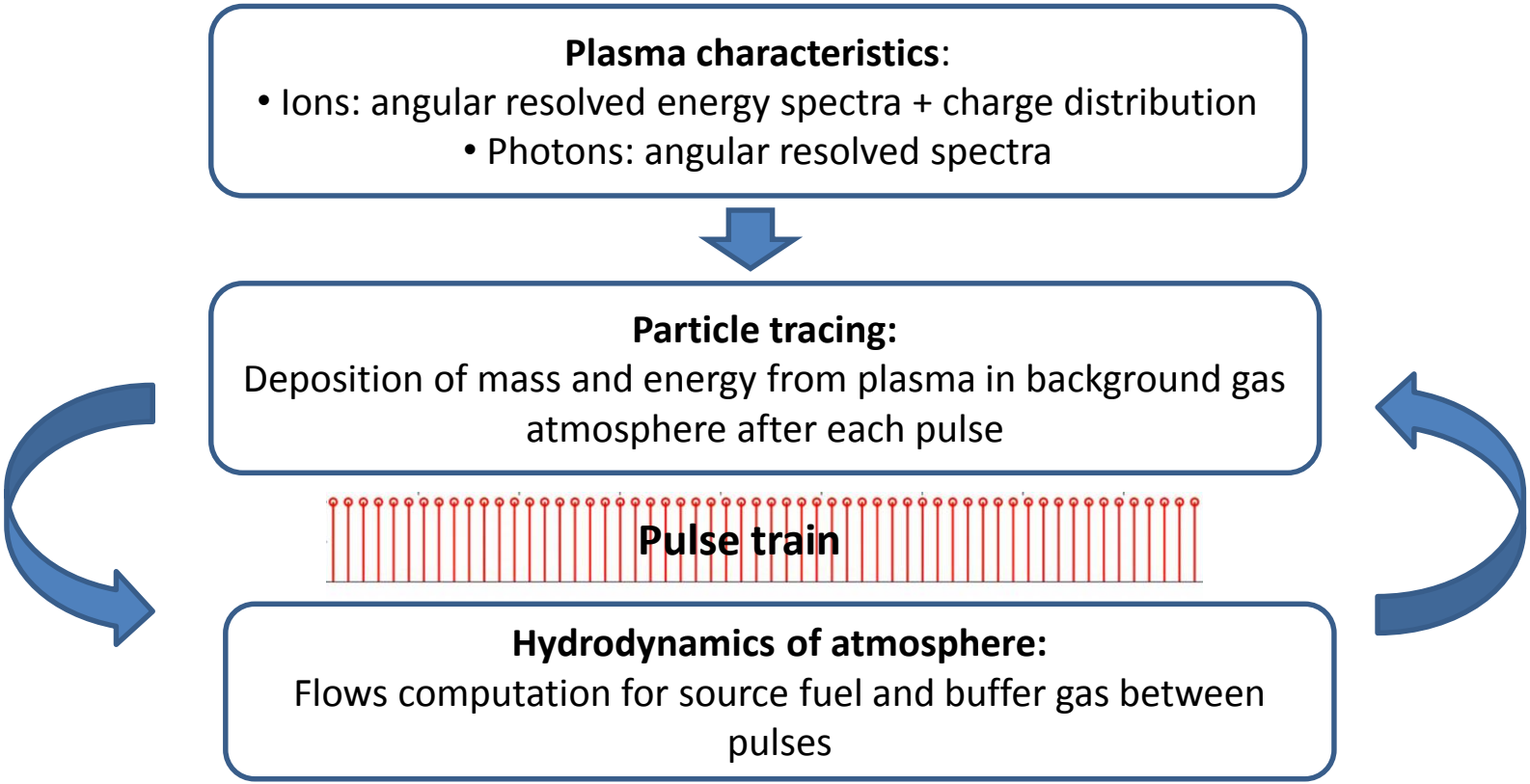
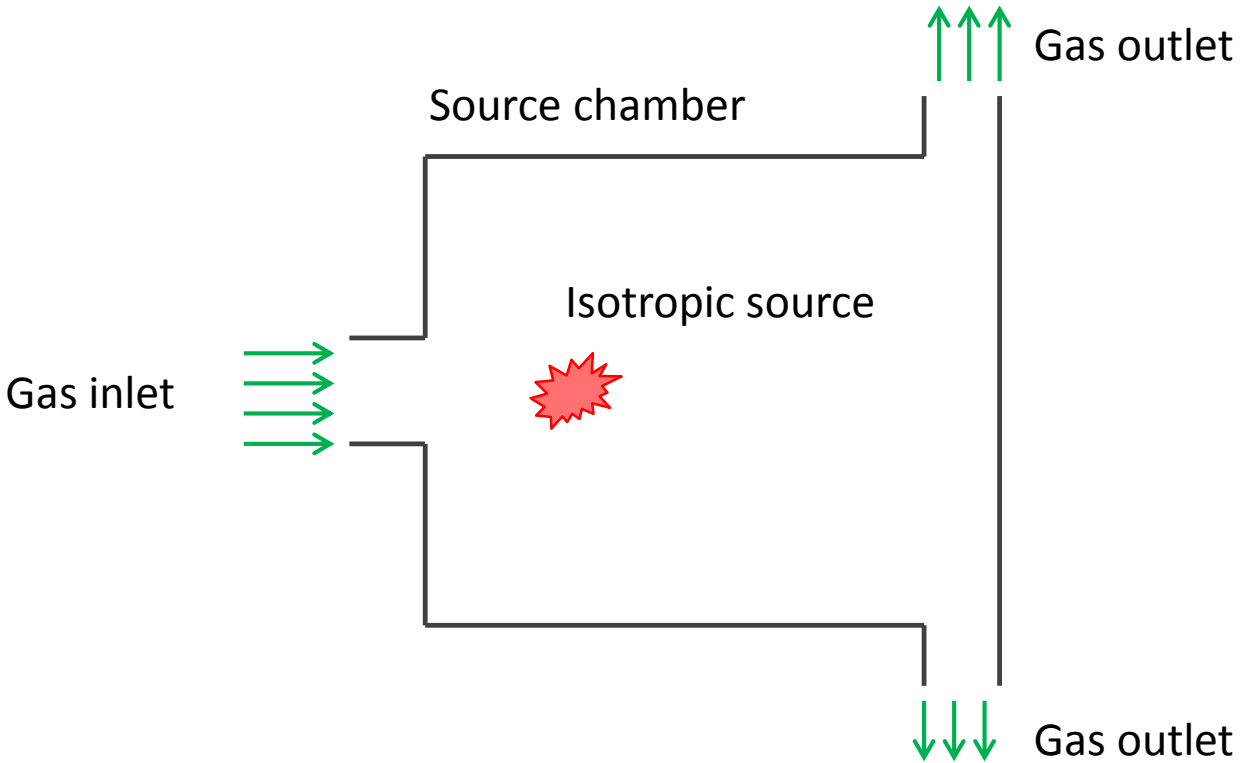
Plasma-gas interaction (PGI) model: approach



PGI model: included processes

- Energy and momentum transfer from ions to buffer gas
- Radiation absorption by buffer gas
- Multi-component gas flow
- Source fuel (Sn) diffusion in buffer gas
- Buffer gas equation of state
- Heat conduction in gas mix
- Dissociation of buffer gas for molecular gases (temperature induced, radiation induced, collision induced)
- Additional species transport (e.g. volatile Sn componds)

PGI example for dummy source geometry



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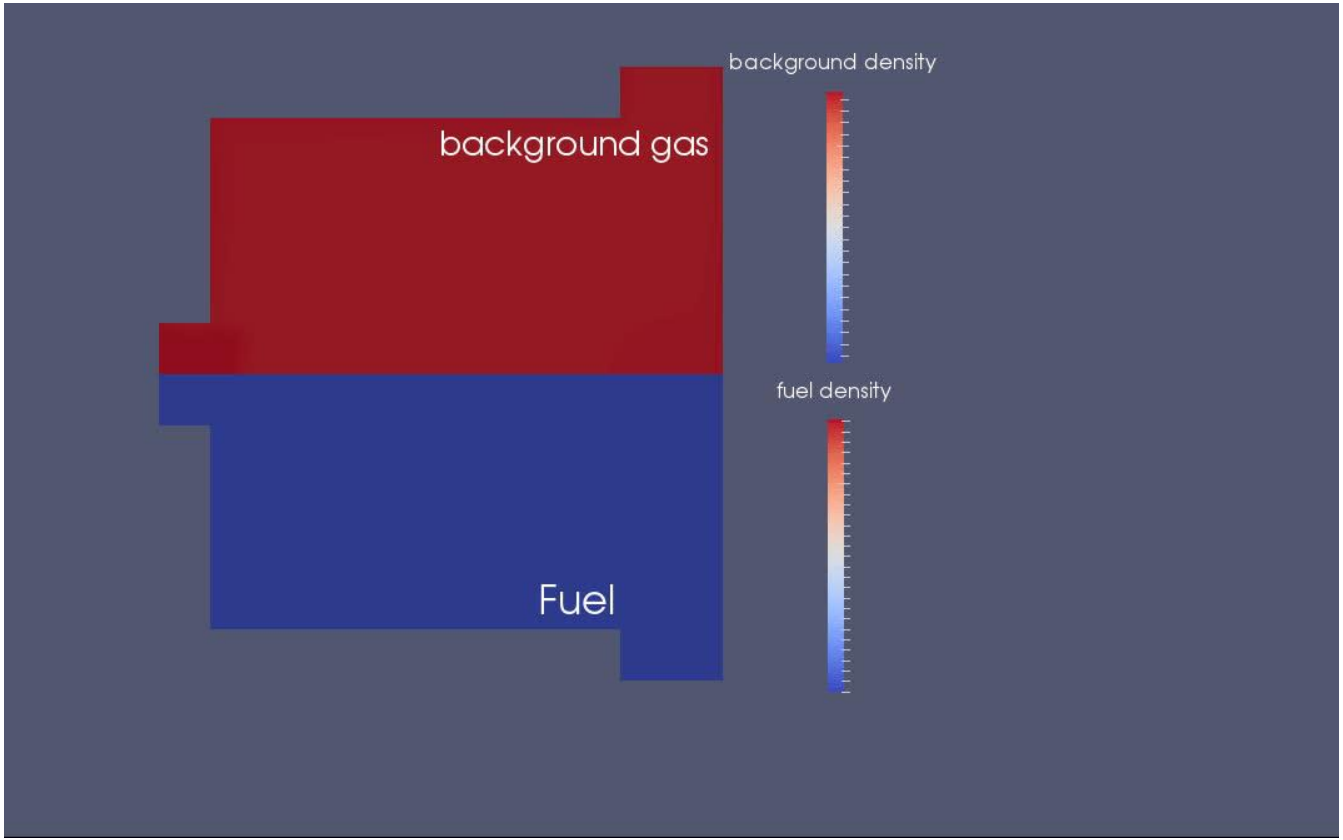

Acknowledgements

ASML

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