ENHANCEMENT OF ION ACCELERATION BY LASER-PULSE SHAPING VIA PLASMA SHUTTER

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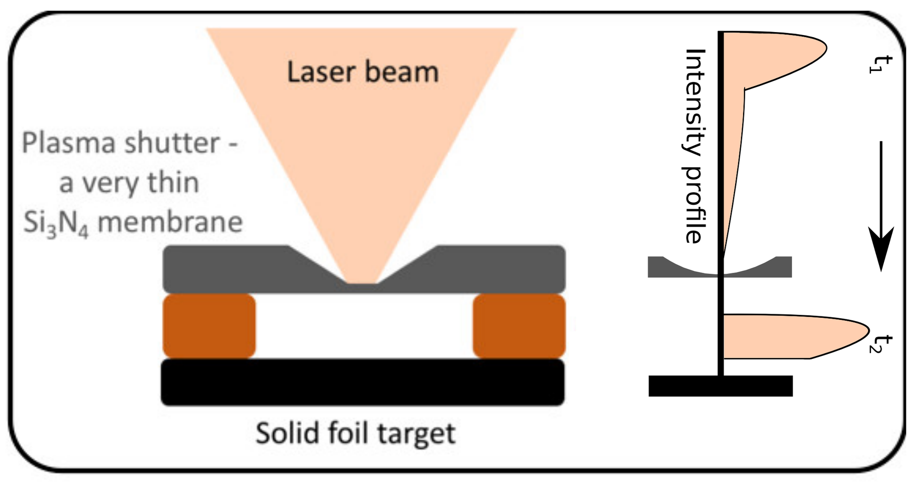
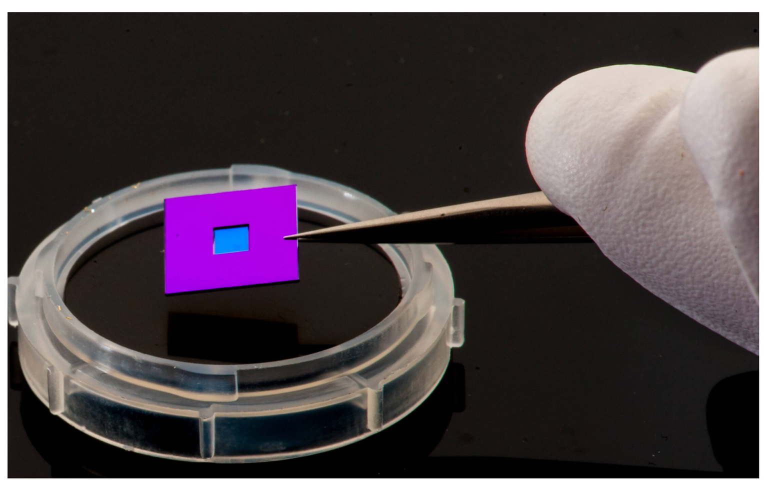
Introduction and Simulation Parameters

- A plasma shutter is usually a thin solid foil or membrane which is placed in front of the main target in the laser-matter interaction. The laser pulse then needs to burn through the plasma shutter, which leads to the modification of its intensity profile. The concept was proposed in theory and proved in various experiments and simulations [1-3].
- In this work we study the usage of a commercial silicon nitride membrane as the plasma shutter in the interaction with a PW-class laser (corresponding to systems like ELI Beamlines) and subsequent interaction of the transmitted laser pulse with a silver foil [4, 5]. Several 2D and 3D particle-in-cell simulations using the code EPOCH [6] and 2D hydrodynamic simulations done by the code PALE [7] were employed.
- Laser pulse: $\sin^2$ intensity temporal profile, duration 64 fs, wavelength $\lambda = 1 \mu$m , spot diameter 3 μm, peak intensity 1×10^{22} W/cm^2 ($a_0 \approx 85$), linear polarization
- Plasma shutter: Si_3N_4, thickness $d = 20$ nm, position $x = 0$, electron density $n_e = 835\, n_c$
- Main target: silver Ag^{40+}, $d = 20$ nm, $x = 5$ μm, $n_e = 2100\, n_c$, ($n_c = 1.115 \times 10^{21}$ cm^{-3})

Utilization of the Plasma Shutter

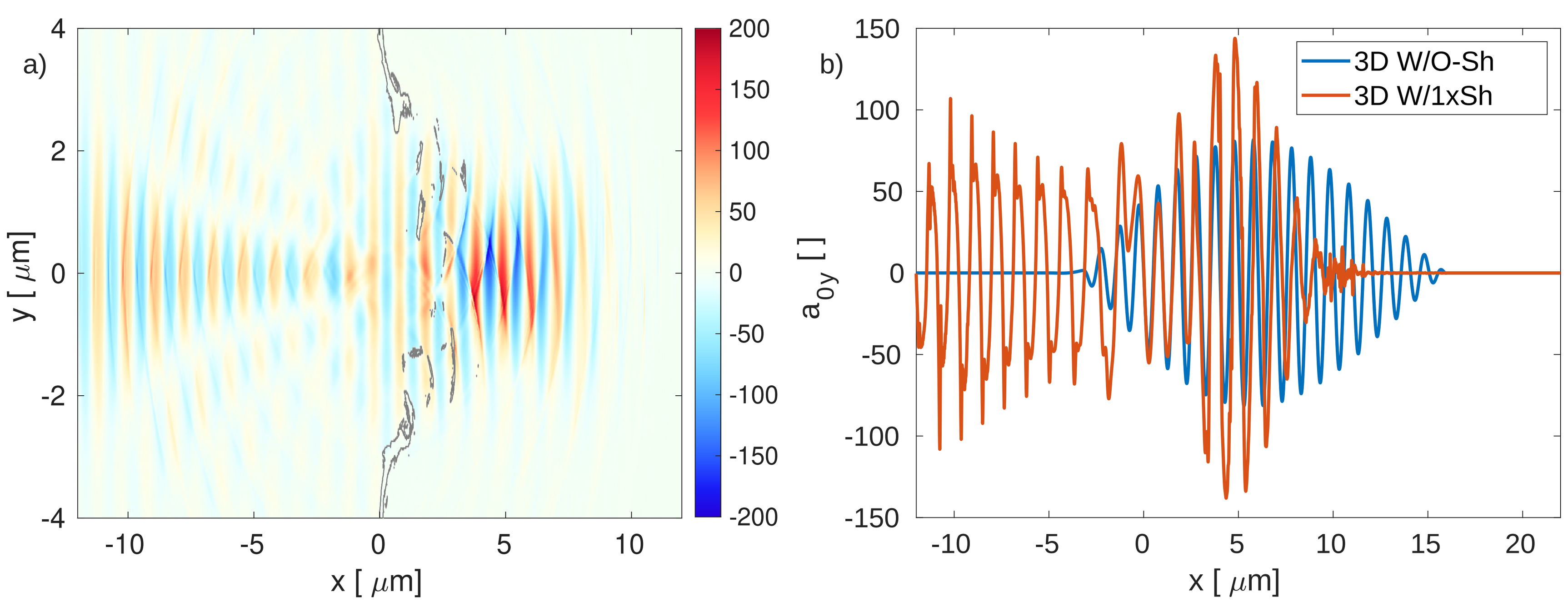


- Scheme of the plasma shutter application



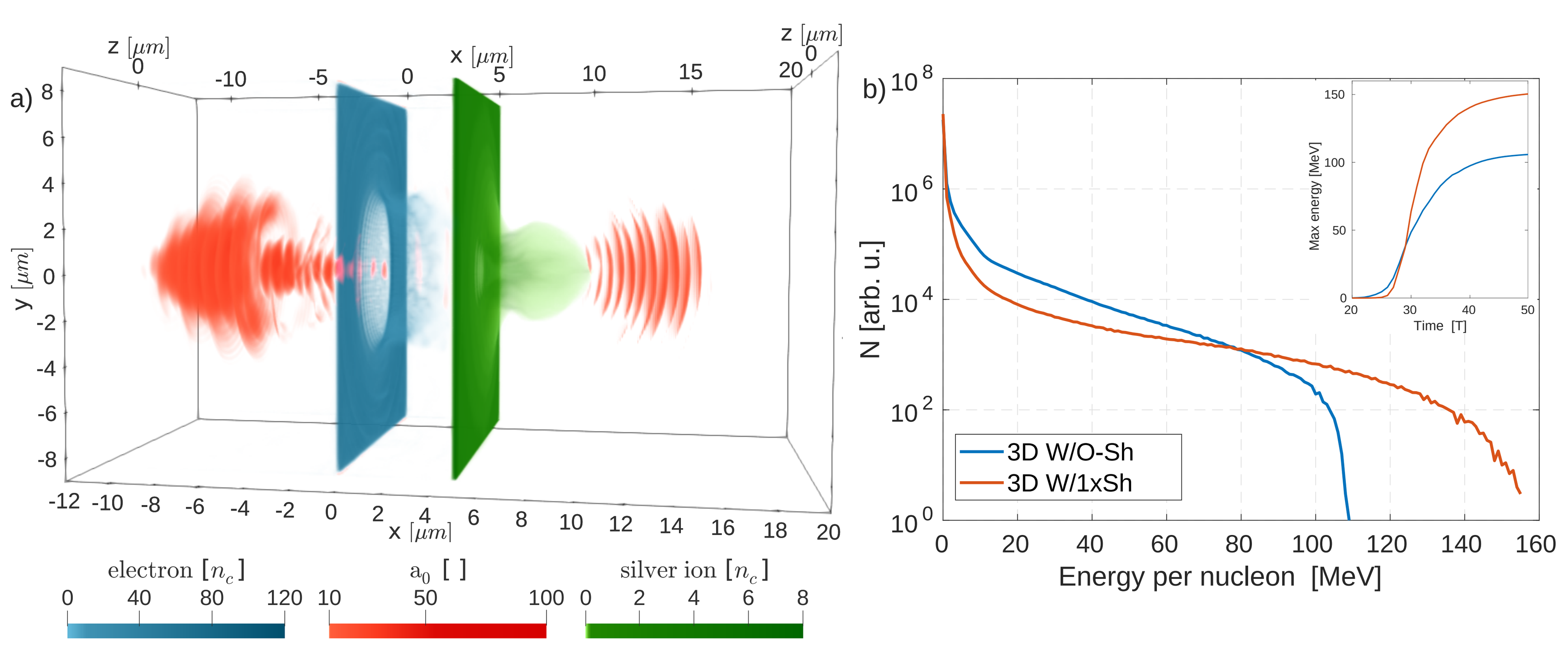
- Example of the plasma shutter [8]

Laser Pulse Transmission Through the Plasma Shutter



- a) 2D, b) 1D slices of the 3D electric field
- Local increase of a_{0y}: from 85 to over 200
- Maximum at $x \approx 5$ μm → target spot
- Pulse ≈ 5 T shorter with a steep rising front

Effects on Heavy Ion Acceleration

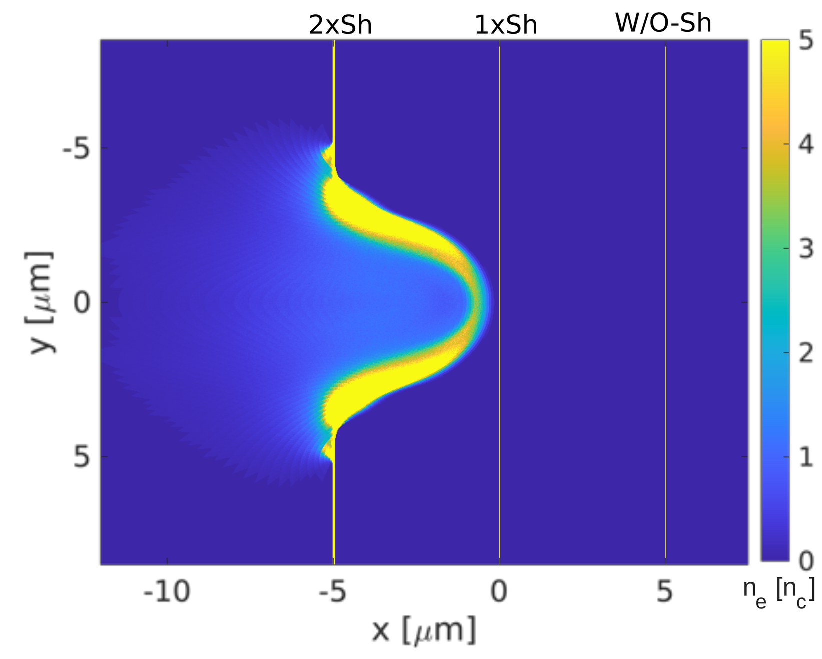


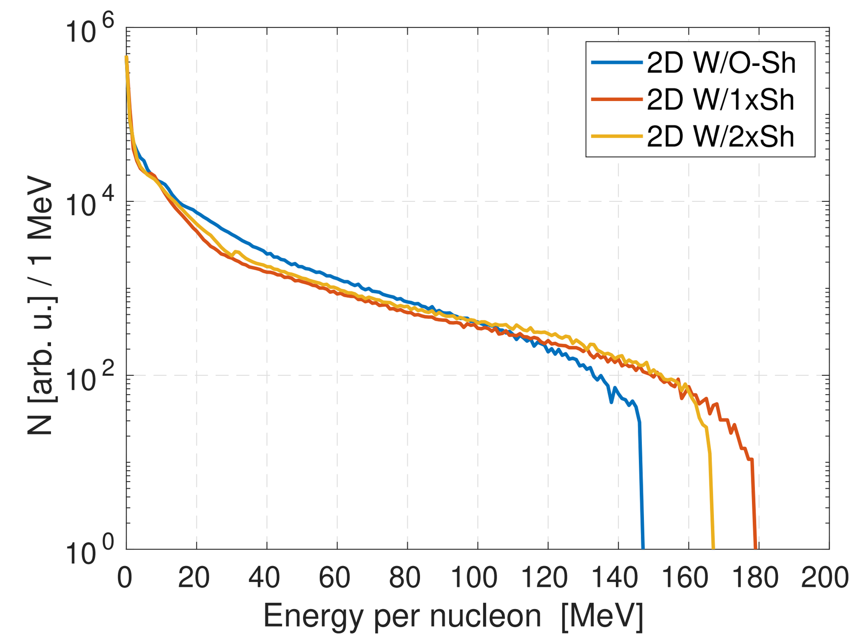
- a) Target becomes Relativistically Transparent to laser pulse (onset of RIT at $t = 30\, T$)
- b) Plasma shutter included → silver ion energy increases (109 → 155 MeV/A)
- The rise of maximal ion energy changes from exponential to logarithmic (inset of b)
- Acceleration scenario changes from RPA to hybrid RPA-TNSA induced by RIT [9]

Conclusion

- The interaction of a PW-class laser pulse with the plasma shutter led to a local intensity increase and creation of a steep rising front of the laser intensity profile
- The subsequent interaction of the transmitted laser pulse with the main target resulted in increase of maximal silver ion energy by 42.2 % (from 109 MeV/A to 155 MeV/A) compared to the case without the plasma shutter in our 3D simulations
- The scheme employing double plasma shutter, which consider the plasma pre-expansion caused by prepulses, was proposed. The scheme also provided significant increase of maximal ion energy compared to the case without any plasma shutter
- Our data were visualized using a web-based application with a Virtual Reality (VR) mode, which can be used for both scientific study and popularization of science for general public

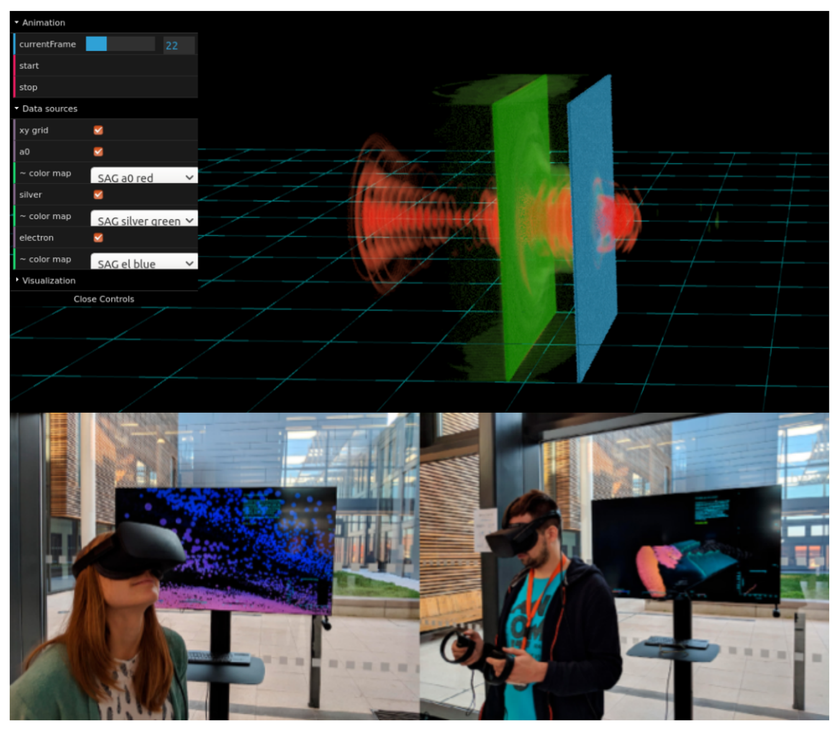
Taking Prepulses into Account



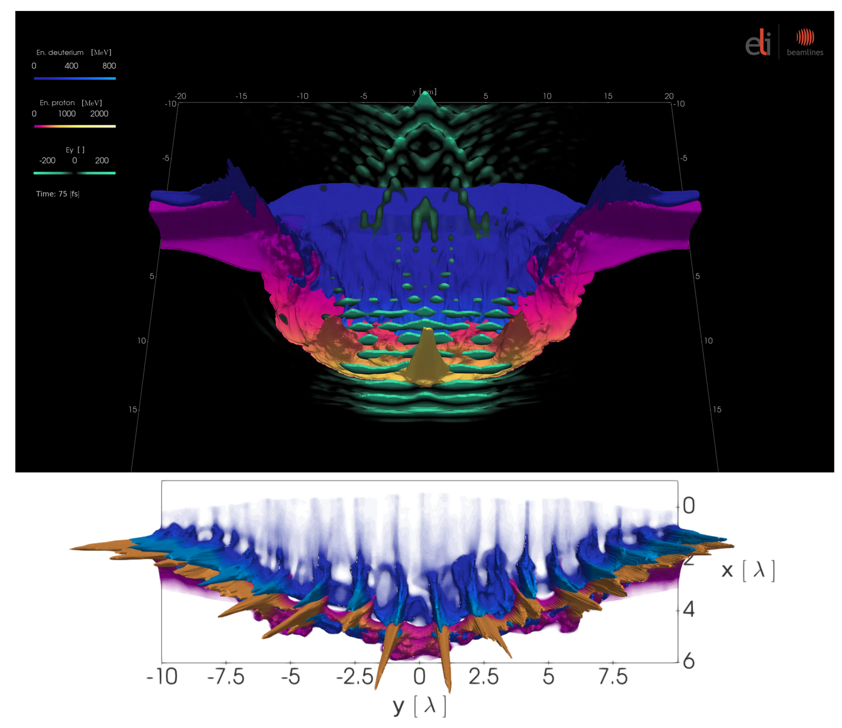


- 2D hydrodynamic simulation with plasma shutter and prepulse: 10^{12} W/cm^2, 125 ps
- Density profile of expanded shutter added into PIC simulation (2 x Shutter + Target)
- Electron density above n_c → expanded shutter can filter out the prepulse of this duration
- Silver ion energy increases also in this case: 147 MeV/A → 167 MeV/A

Visualizations and related work



- Interactive web-based application [10]
- Enable real time viewing of prepared time frames, zoom, rotation, VR mode



- Utilization of laser steep rising front
- 100 PW class laser pulse and double-layer target with interface modulation [11]

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Acknowledgement

This work has been supported by projects High Field Initiative (CZ.02.1.01/0.0/0.0/15_003/0000449) from the European Regional Development Fund, by Czech Science Foundation project (18-09560S), The Photon and Neutron Open Science Cloud - PaNOSC (No. 823852), Center of Advanced Applied Natural Sciences (CZ.02.1.01/0.0/0.0/16_019/0000778), ELI Beamlines: International Center of Excelence (LQ1606) and by the GA of the CTU in Prague, grants (SGS19/192/OHK4/3T/14) and (SGS19/191/OHK4/3T/14). Computer resources were provided by IT4Innovations National Supercomputing Center (LM2015070). Visualizations were created jointly with our colleagues from Virtual Beamline team at ELI Beamlines.