LASER-DRIVEN ION ACCELERATION FROM CRYOGENIC LOW-Z JETS

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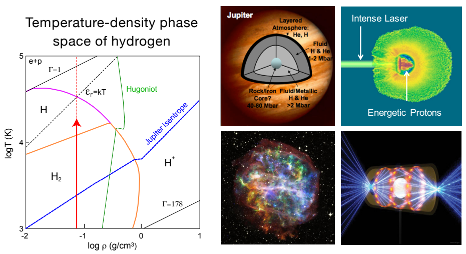
Abstract

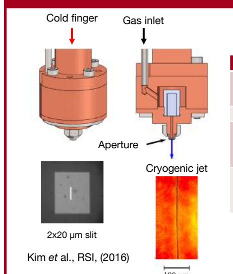
Particle-in-cell (PIC) simulations have identified more favorable regimes for ion acceleration, such as Enhanced Sheath Field Acceleration (ESF) acceleration, using higher peak laser intensities and advanced target designs.

Cryogenic low-Z jets, with tunable thickness and near-critical density, can be used to systematically investigate most of these alternative acceleration regimes. Here, we present our experimental results of laser-driven proton and deuteron acceleration from 150TW to 1PW using cryogenic low-Z jets.

High intensity lasers allow us to explore the phase space of hydrogen plasmas

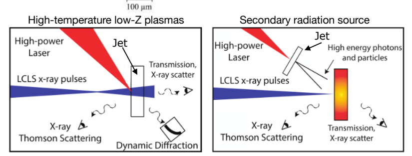


Cryogenic jets address many challenges of laser driven ion acceleration

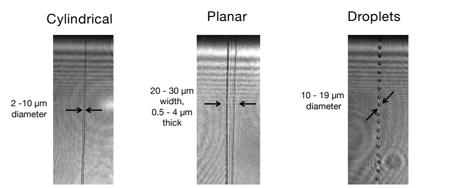


Kim et al., RSI, (2016)

Challenge	Solution
High repetition rate	Continuous target up to 1kHz Debris free
Contaminants	Single species
Versatile Target	Compatible with other gases (D_2, Ar, Ne, CH_4) Adaptable target geometry
Maximum energy Energy bandwidth Emittance	Low density can favor alternative acceleration mechanisms ($30n_c$ at 800nm)

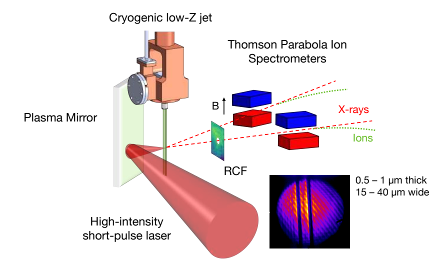


Cryogenic jets can be designed for experimental needs

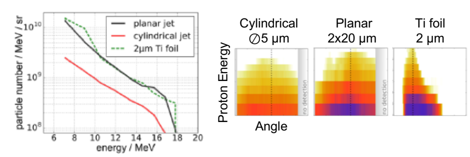


- The density and flexibility of the cryogenic jets (e.g. H_2, $30n_c$ at 800nm) is ideal for studying different acceleration mechanisms

Proton beam is characterized using Thomson Parabolas and Radiochromic Film (RCF) Stacks



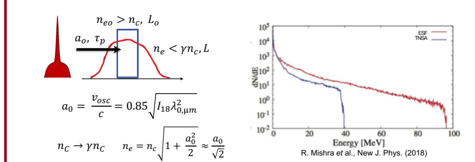
Ion acceleration from planar jets and 150 TW laser is comparable to TNSA from metallic foils



Obst et al., Sci. Rep, (2017)

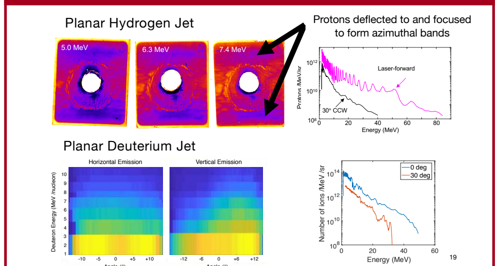
- Contrast enhancement was required to optimize ion acceleration from near-critical density cryogenic hydrogen jets
- Proton cut-off energy, flux, and emittance from planar hydrogen jets are similar to conventional metallic foils

Transition to Enhanced Sheath Field (ESF) acceleration from near critical density targets and 1 PW laser

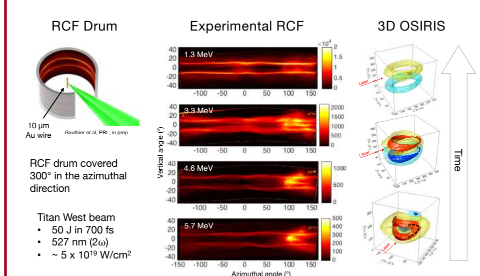


- TNSA is enhanced if the target becomes relativistically transparent near the peak of the laser pulse
- Two-fold increase in proton cut-off energy observed in 2D OSIRIS simulations

Preliminary results of pure proton/deuteron acceleration using the Texas Petawatt laser

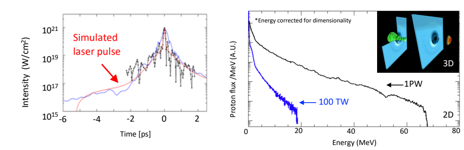


Magnetic fields observed to deflect proton beam characterized and interpreted using self-generated proton radiography model



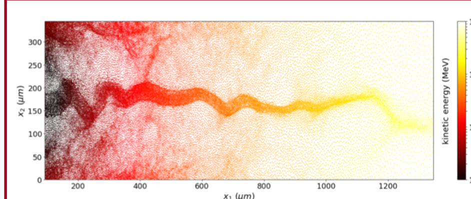
Gauthier et al., PRL, in prep. Mishra et al., PoP, in prep.

2D/3D PIC simulations accurately predict ion energies when picosecond pre-pulse is included



- Pre-pulse can induce a significant pre-expansion before main pulse interacts with the target and enter into a different regimes for proton acceleration
- Critical to accurately model the pre-pulse in high intensity interactions

Pinching due to magnetic fields leads to the formation of an unstable ion filament



- Long range spatial modulation of the proton beam has been observed in 2D PIC simulations.
- Filament instability may explain the well-defined modulations observed experimentally in the proton energy spectrum.

Conclusions and Outlook

- Cryogenic jets are debris free and compatible with high-repetition rate petawatt lasers
- Protons have been accelerated to >80 MeV energies with the Texas Petawatt laser
- Follow up experiments and detailed simulations have been performed to understand the proton beam spatial and energy distribution
- Future experiments will use cryogenic deuterium jets to generate a high-repetition rate pulsed neutron source
- Next generation particle accelerator coupling the proton beam from the cryogenic hydrogen jet with a compact RF accelerator has been proposed

Acknowledgements

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