AAC'22 Advanced Accelerator Concepts Workshop

November 6 - 11, 2022

Hyatt Regency Long Island, NY

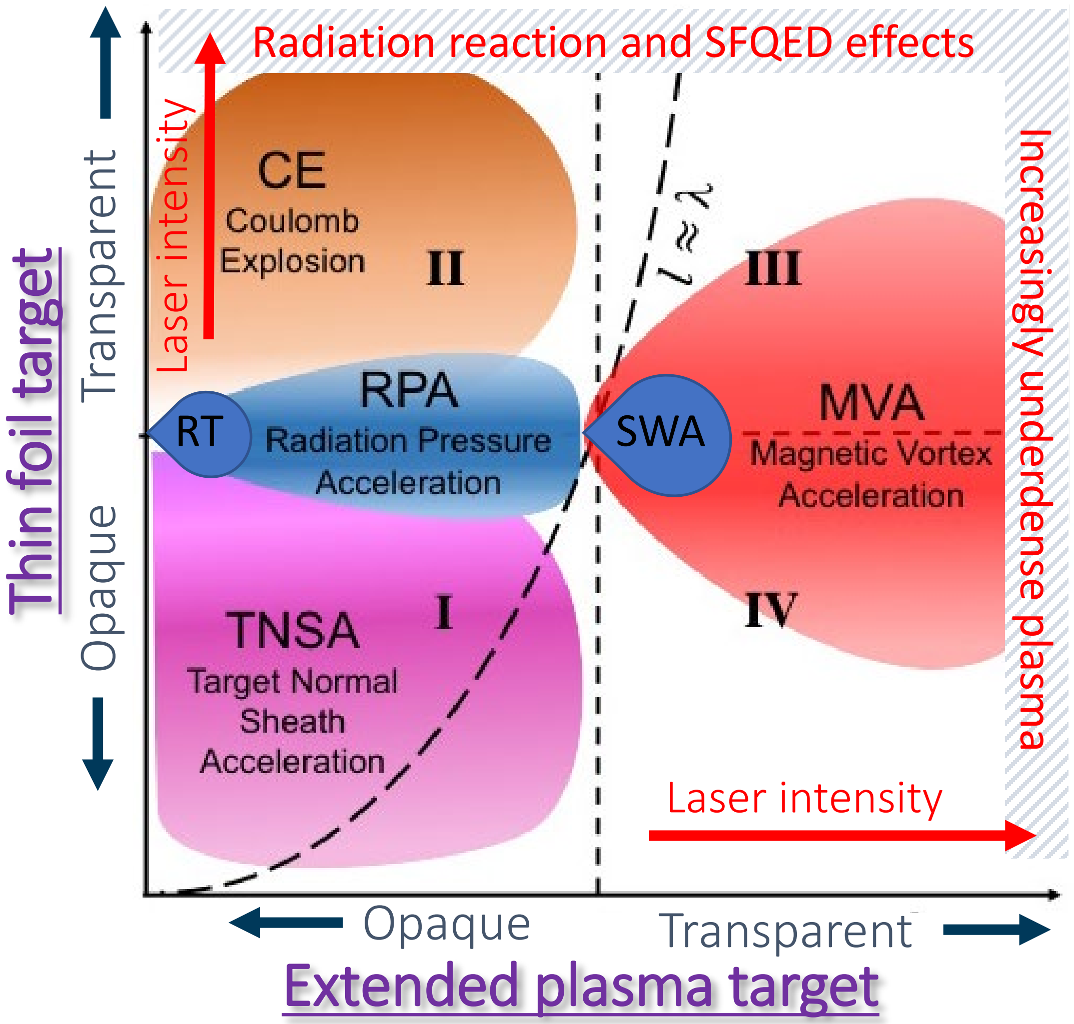
WG 6: Laser-Plasma Acceleration Ions, Summary

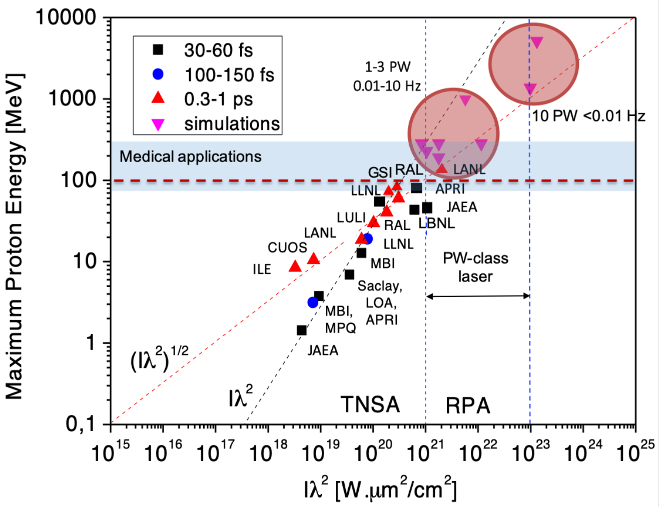
Lieselotte Obst-Huebl (LBNL), Igor Pogorelsky (BNL), Mamiko Nishiuchi (KPSI)

Summary WG6 Laser Acceleration Ions

- Advanced Ion acceleration mechanisms
  - Radiation pressure acceleration, magnetic vortex acceleration, relativistic transparency, shock acceleration studied both in simulations and experiments. > 100 MeV protons reported in experiments.
  - Advanced targets (ultrathin/curved/foams/jets/mico-3D-printed) and laser parameters (few cycle/short and long wavelength/with prepulse/circularly polarized) used to access advanced regimes.
- Applications
  - Radiobiology - first mouse irradiation
  - Fast neutron generation at 1 Hz repetition rate
  - Fusion: pB reactions and proton fast ignition

Advanced Acceleration Mechanisms are needed to generate ion beams with energies exceeding 100 MeV/u





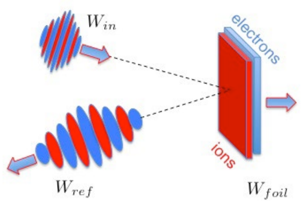
Radiation Pressure Acceleration

Laser: High Intensity

Target: Thin solid density foils

Ion Energy: hundreds of MeV

Ion Energy ~ Laser Power



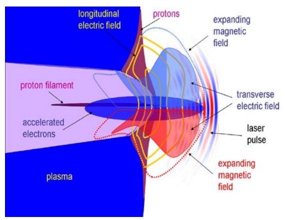
Magnetic Vortex Acceleration

Laser: High Intensity

Target: Near Critical Density slab

Ion Energy: hundreds of MeV to GeV

Ion Energy ~ Laser Power$^{2/3}$

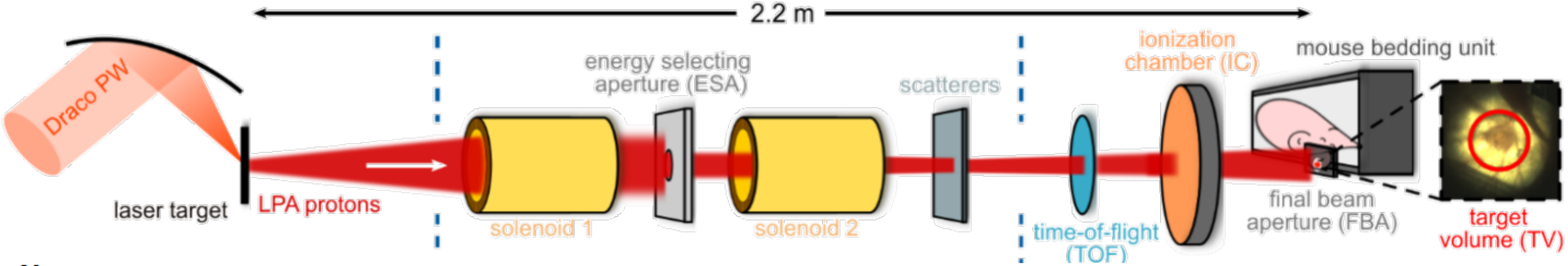


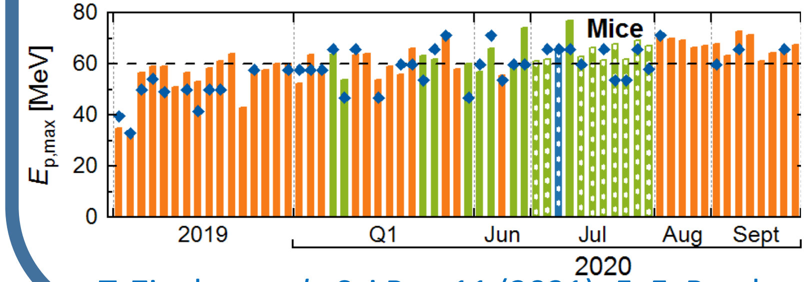
1. **The Radiation Pressure Acceleration and Magnetic Vortex Acceleration are the most promising candidates among advanced acceleration mechanism to generate ions with energy >100 MeV/u**
2. **The concept of target transparency plays the central role in analyzing the efficiency of advanced ion acceleration mechanisms**
3. **Optimization of acceleration mechanisms is needed to overcome different limiting factors and generate ion beams with required for application properties: Composite targets for RPA and MVA & Laser pulse and target shaping**

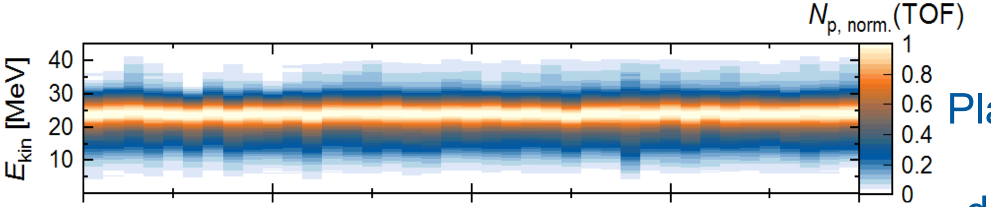
S. S. Bulanov, "**Advanced Ion Acceleration Mechanisms**"

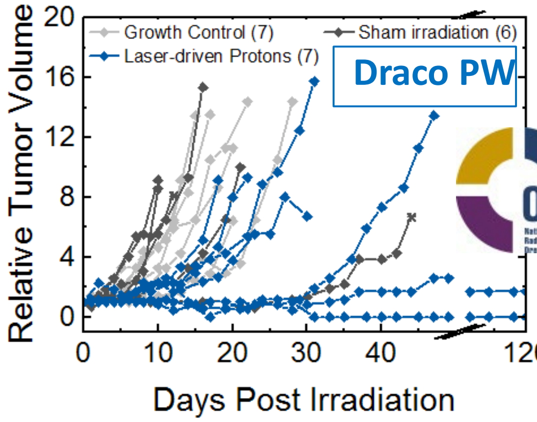
Karl Zeil: High energy proton acceleration at DRACO-PW and radio-biological applications

Stable TNSA beams enabled first volumetric in-vivo irradiation of mice





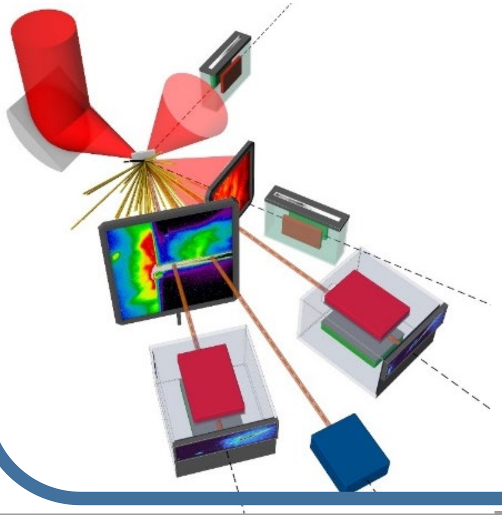


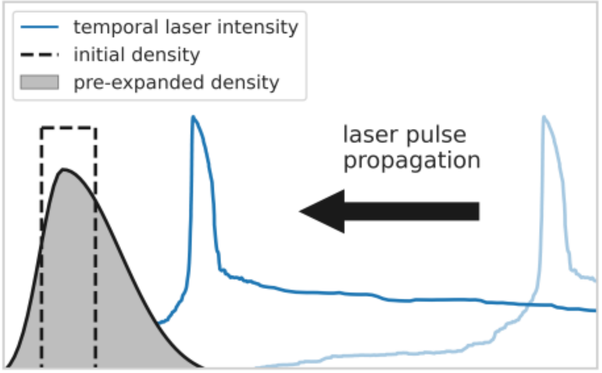


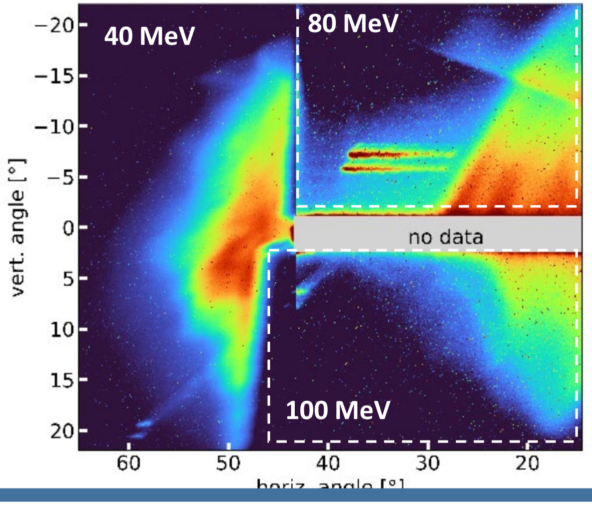
T. Ziegler *et al.*, Sci Rep 11 (2021); F.-E. Brack *et al.*, Sci Rep 10 (2020), F. Kroll *et al.* Nat. Phys. 18, 316 (2022)

Platform enabling single-shot delivery of mm-scale 3D tumor-conform dose distributions making perfect use of the broadband LPA proton spectrum

High-energy (> 100 MeV), bandwidth limited proton pulses from rep-rate capable laser system







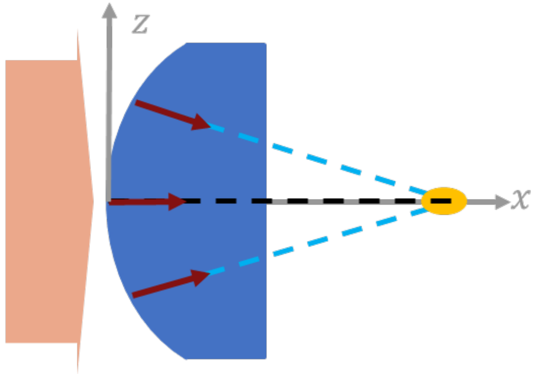
Combination of multiple detector systems based on different principles to confirm energies >100 MeV in pre-expanded foils with well characterized intrinsic contrast

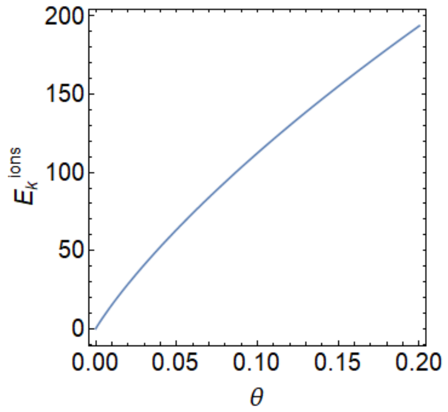
Understand and mitigate strong fluctuation is work in progress

HB-RPA+ Parabolic front Surface=Focused monoenergetic ion beam

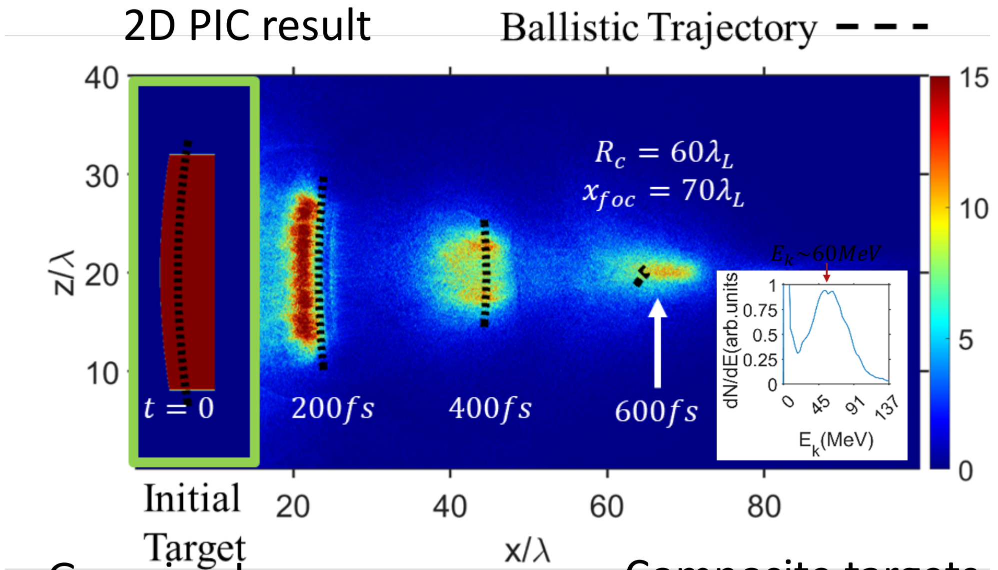
Jihoon Kim (Cornell University)

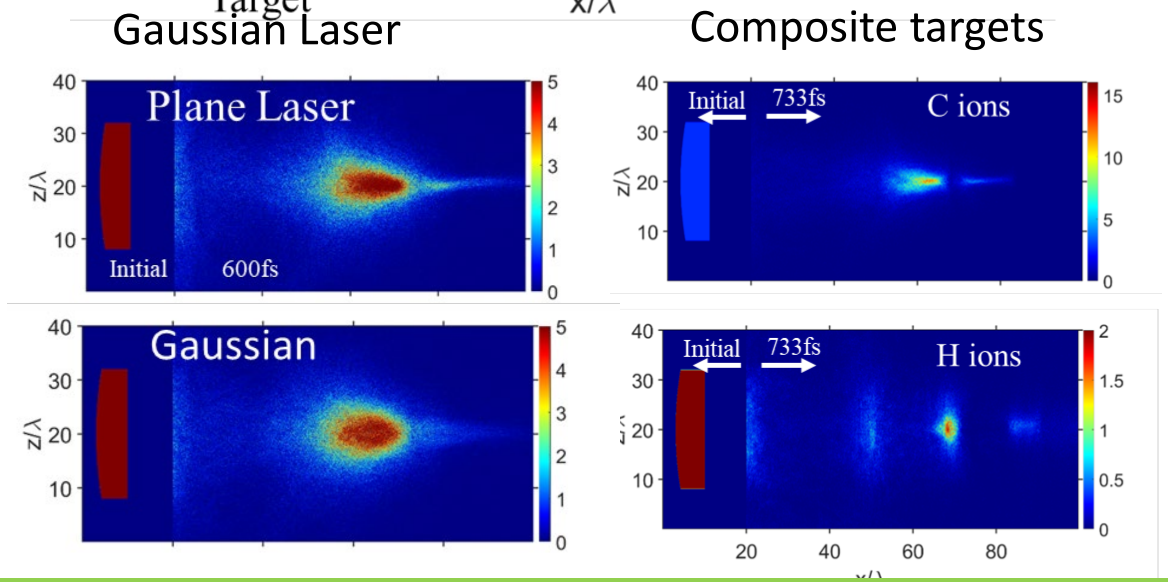
Analytical Model and 2D PIC

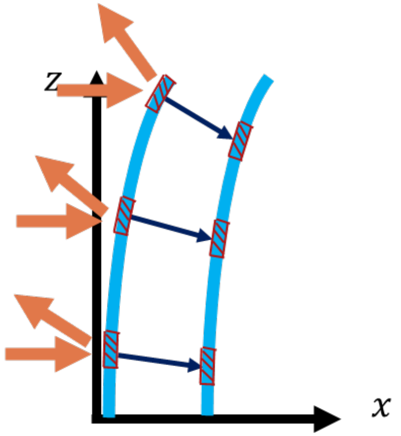


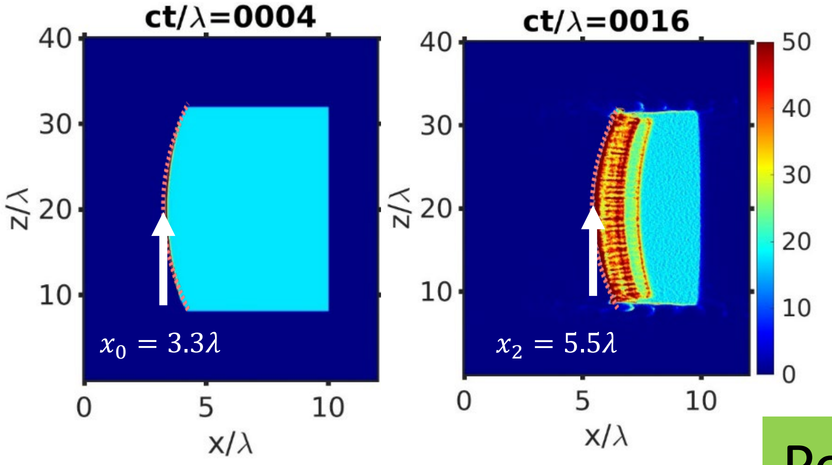


- Parabolic front surface = Ion Focusing
- Relatively flat front surface=
- 1D theory applicable*









- Surface shape retained over several microns

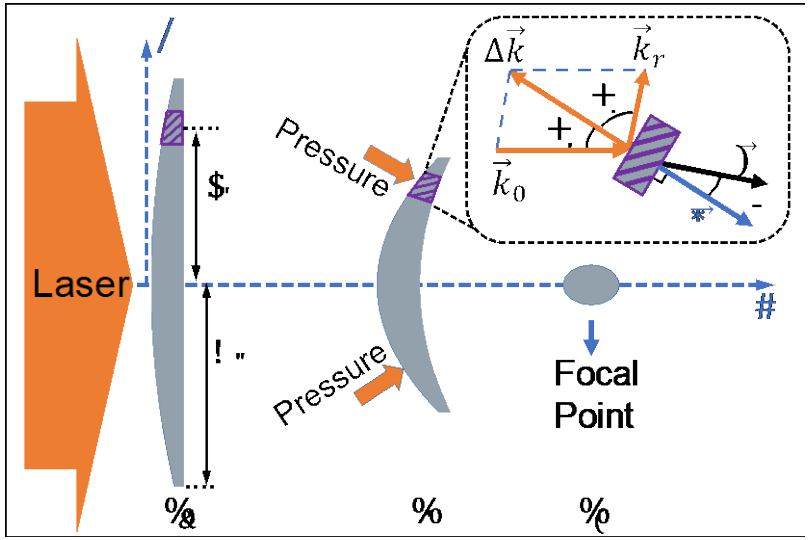
Potential application to fast ignition of ICF targets

Naumova, PRL 102 025002(2009)*

Roopendra S. Rajawat, T. Wang, G. Shvets
Cornell University

Structured targets work efficiently with elliptically polarized lasers

Target focusing is insensitive to laser polarization.

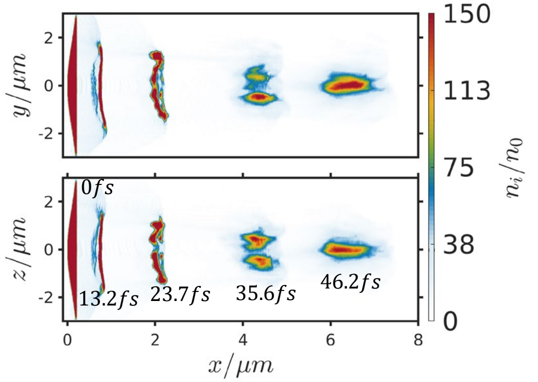


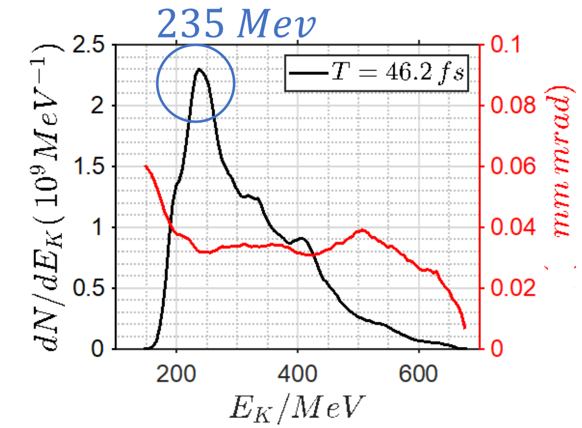
T. Wang et. al. PRL, 126, 024801 (2021); Rajawat et. al. (in preparation)

3D PIC Ion Density

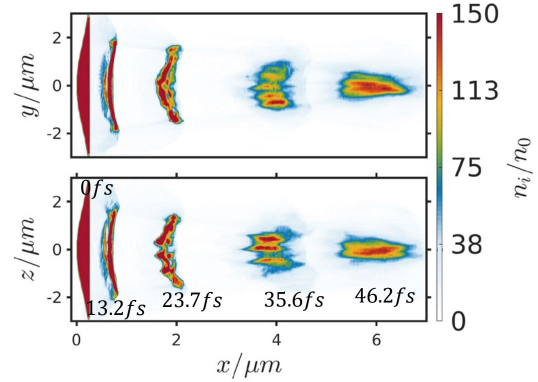
Ion Energy spectrum

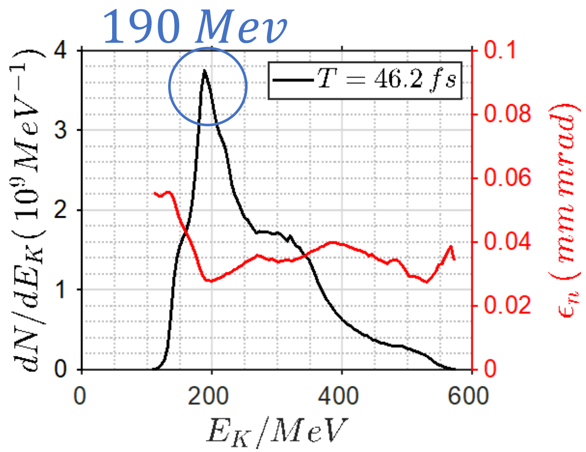
CP



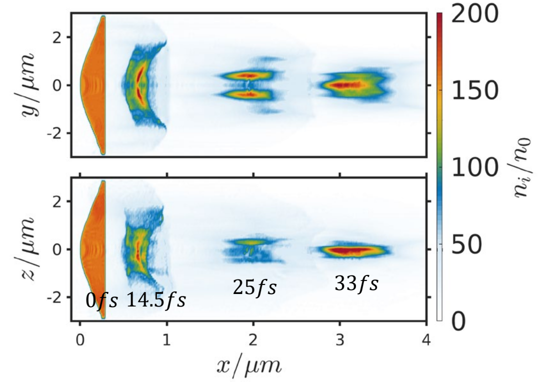


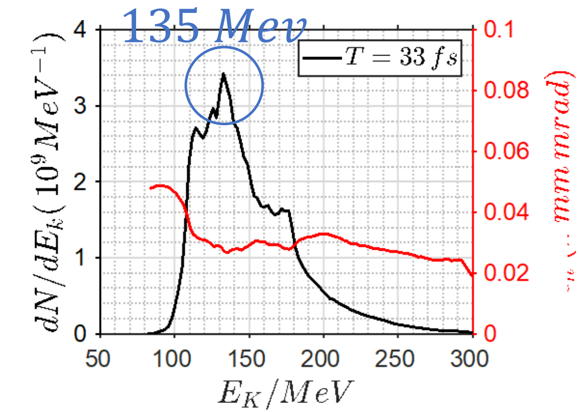
EP





LP

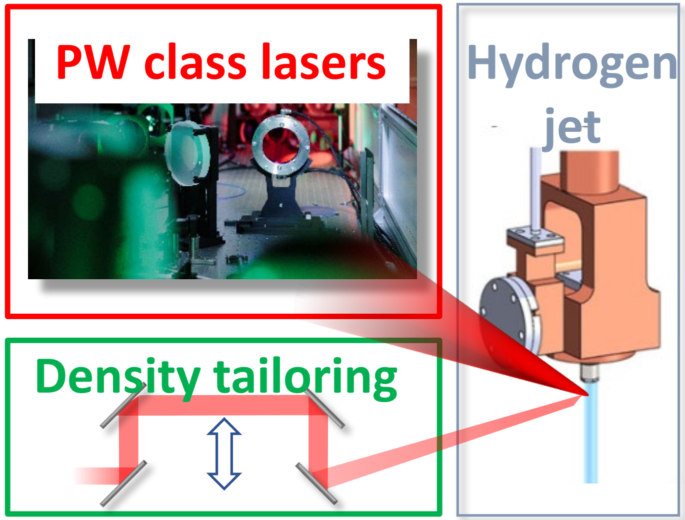




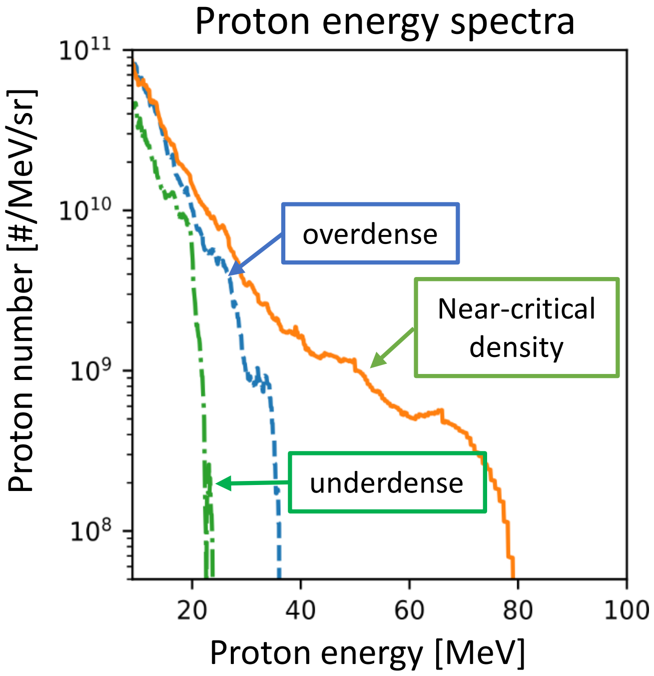
Ultra-short pulse laser-driven acceleration of protons to 80 MeV from density tailored cryogenic hydrogen jets

M. Rehwald, C. Bernert, F.-E. Brack, M. Bussmann, T. E. Cowan, C. B. Curry, F. Fiuza, M. Garten, L. Gaus, M. Gauthier, S. Göde, I. Goethel, S. H. Glenzer, A. Huebl, J. B. Kim, T. Kluge, S. Kraft, F. Kroll, J. Metzkes-Ng, M. Loeser, L. Obst-Huebl, M. Reimold, H.-P. Schlenvoigt, C. Schoenwaelder, U. Schramm, M. Siebold, F. Treffert, T. Ziegler, and K. Zeil

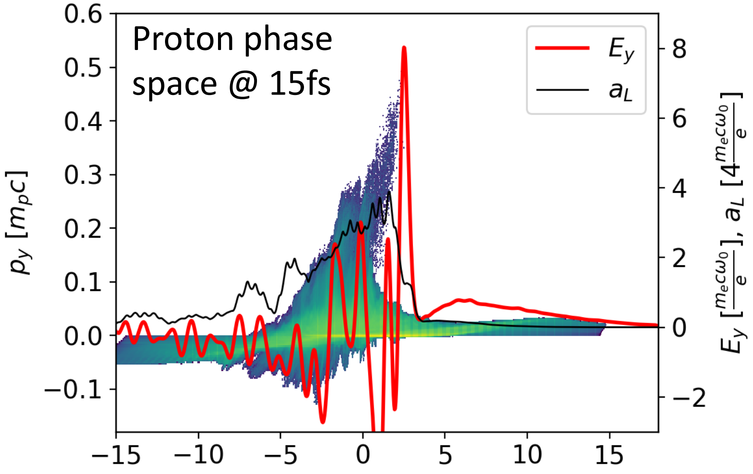
- **Proof-of-concept study:** density tailored cryogenic hydrogen jets and repetition rate capable PW class lasers allow to study different target density dependent **advanced acceleration mechanisms**



- High energy proton beams of **80 MeV** in the **near-critical regime** measured



- Simulations (3D PIC + Hydrodyn.) suggest enhanced **proton acceleration at the relativistic transparency front** for the optimal case

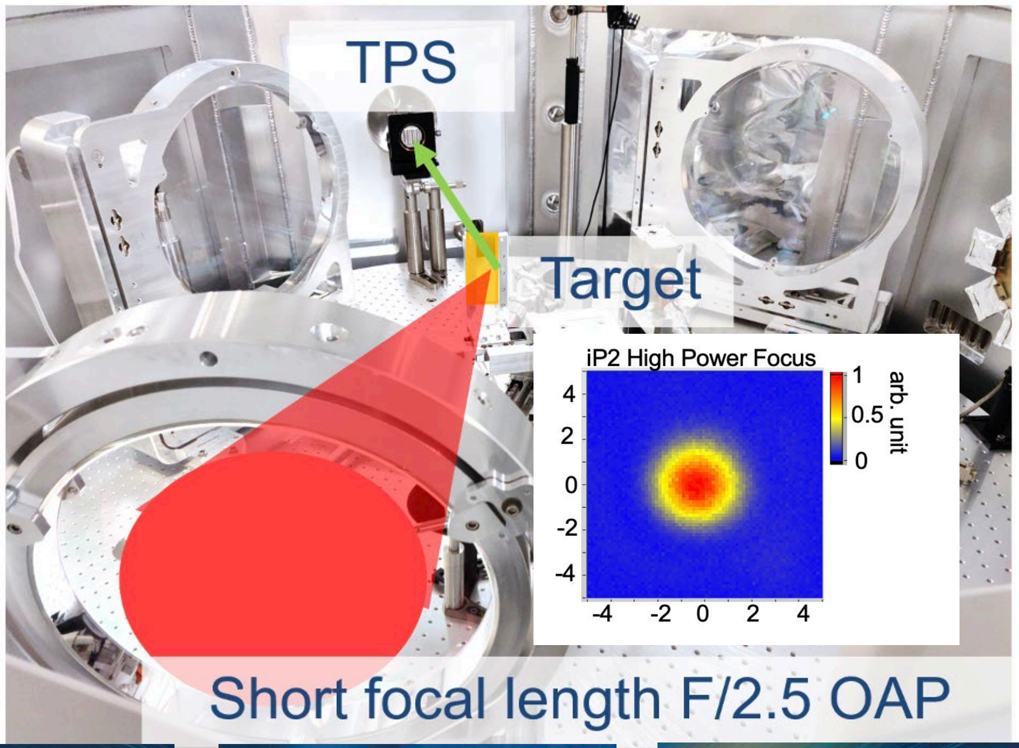


New capabilities of the iP2 beamline for laser-solid interaction studies at the BELLA PW facility

Sahel Hakimi, Lieselotte Obst-Huebl, Kei Nakamura, Axel Huebl, Stepan Bulanov, Anya Jewell, Jared De Chant, Antoine Snijders, Csaba Toth, Anthony Gonsalves, Carl Schroeder, Jeroen van Tilborg, Jean-Luc Vay, Eric Esarey, Cameron Geddes

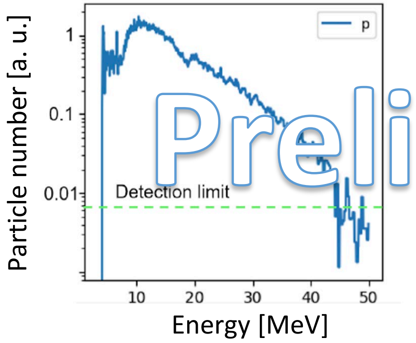
iP2 beamline at the BELLA Center for ultra high intensity laser-plasma interactions

iP2: New short focal length F/2.5

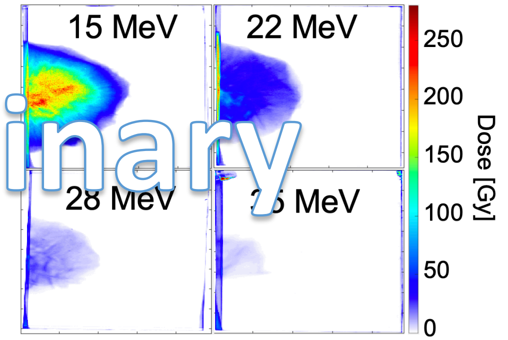


Commissioning experiments at the iP2 beamline generated high charge, > 40 MeV proton beams at 17 J

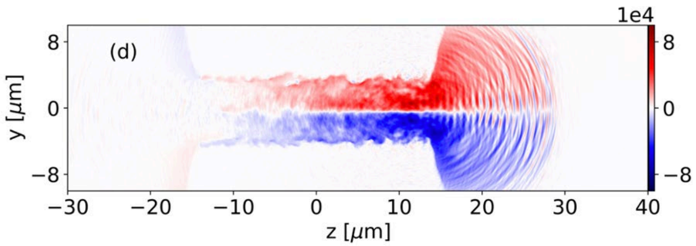
Preliminary proton spectrum



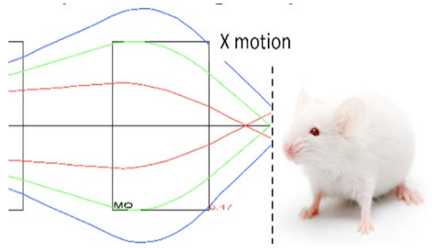
Preliminary proton beam profile



LaserNetUS iP2 experiments in the near future



Magnetic Vortex Acceleration (MVA) mechanism



Radiobiological studies

Theoretical and numerical investigation of ion acceleration in the interaction of high energy and high intensity attosecond pulses with solid targets

E. d'Humières[1], X. Ribeyre[1], R. Capdessus[1], F. Brun[1], J. Wheeler[2] and G. Mourou[2]
[1]CEntre Laser Intenses et Applications, Univ. Bordeaux-CNRS-CEA, UMR 5107 Talence 33405, France
[2]DER-IZEST, Ecole Polytechnique, 91128 Palaiseau Cedex, France

2D PIC simulations

$\boldsymbol{\lambda_L} = \mathbf{10\ nm}$ $\quad I_L = 2.71 \times 10^{26}\ \mathrm{W.cm^{-2}}$

$a_L = 140$

$\mathrm{FWHM_{(intensity)}} = 330\ \mathrm{as}$ & $\mathrm{Spot} = 10\lambda_L$

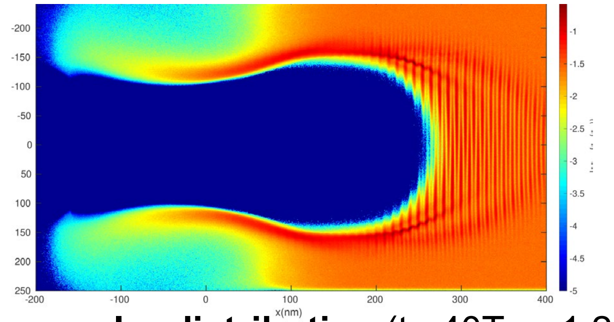
$\mathcal{E}_L = 10\ \mathrm{J}$

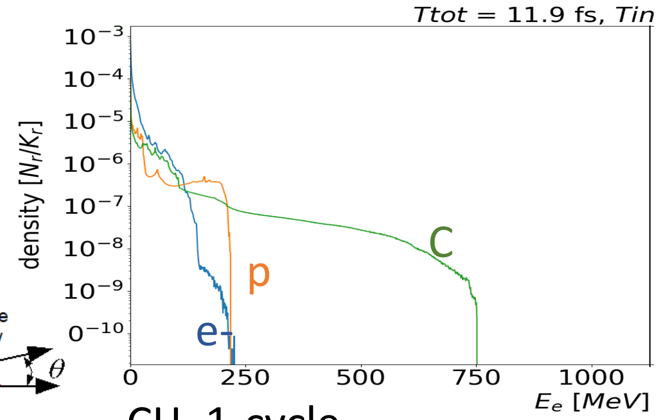
Solid pB target

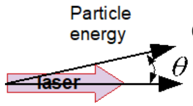
B & H target $n_{e0} = 3 \times 10^{23}\ \mathrm{cm^{-3}} \simeq 0.03 n_c$

X. Ribeyre et al. Scientific Reports 12:4665 (2022)

Electron density (t= $40T_L$ = 1.2 fs)

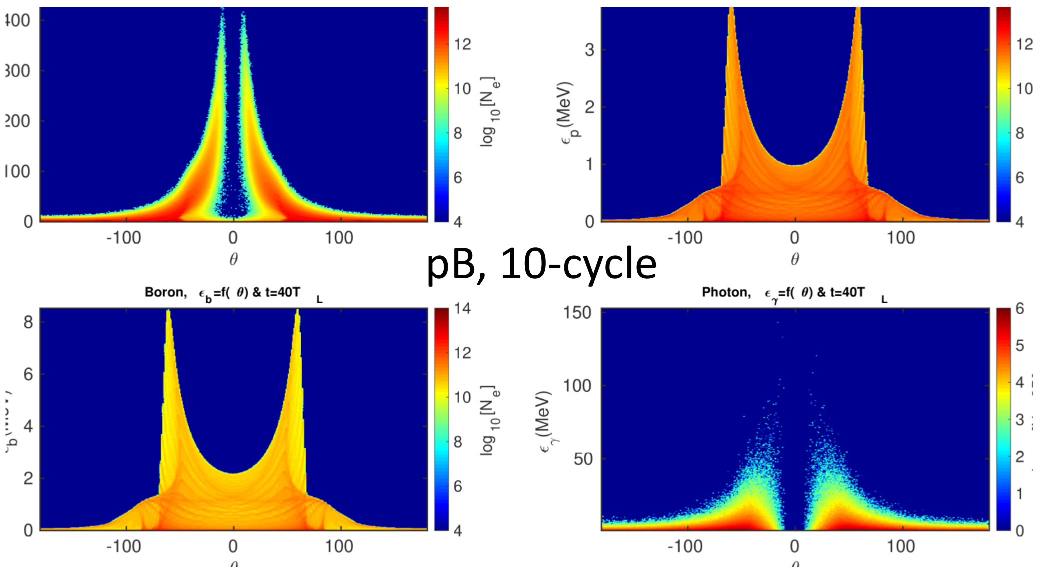




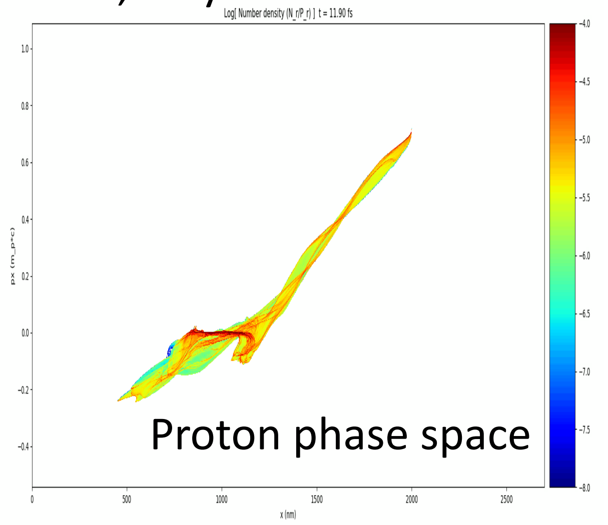


CH, 1-cycle

Energy angular distribution (t= $40T_L$ = 1.2 fs)



pB, 10-cycle

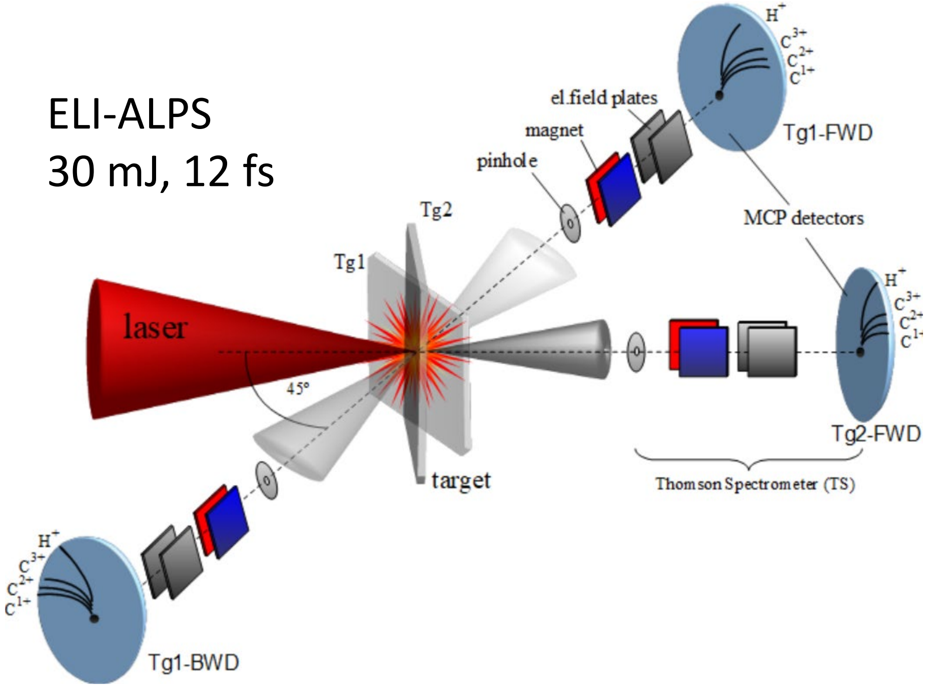


- **Efficient ion acceleration in the transverse and longitudinal directions**
- **More efficient for single-cycle pulses**
- **Potential application to pB fusion**

Ion acceleration and neutron generation with few-cycle, relativistic intensity laser pulses

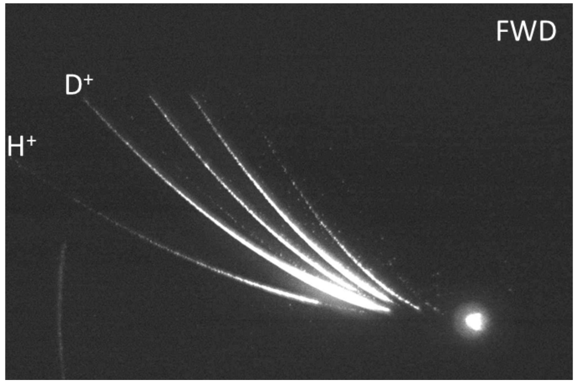
Karoly Osvay, M. Füle, T. Gilinger, B. Kis, P. K. Singh, S. Ter-Avetisyan, P. Varmazyar, B. Biro, L. Csedreki, S. Dombrádi, Z. Elekes, A. Fenyvesi, Zs. Fülöp, Z. Halasz, Z. Korkulu, I., Kuti, L. Stuhl, A. Bembribe, J. Benlliure, J. Penas, A. Borzsonyi, J. Csontos, A. Farkas, A. Mohacsi, T. Somosköi, G. Szabó, Sz. Tóth

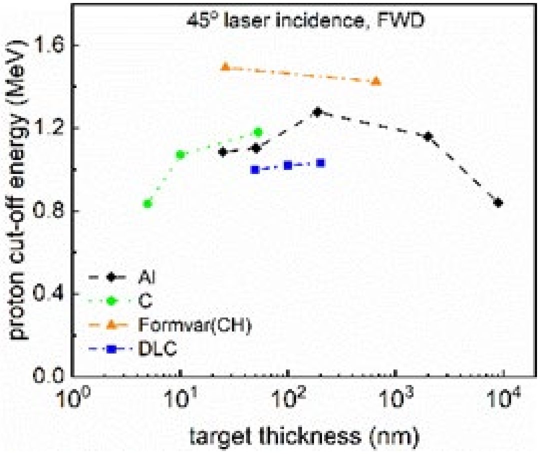
ELI-ALPS
30 mJ, 12 fs



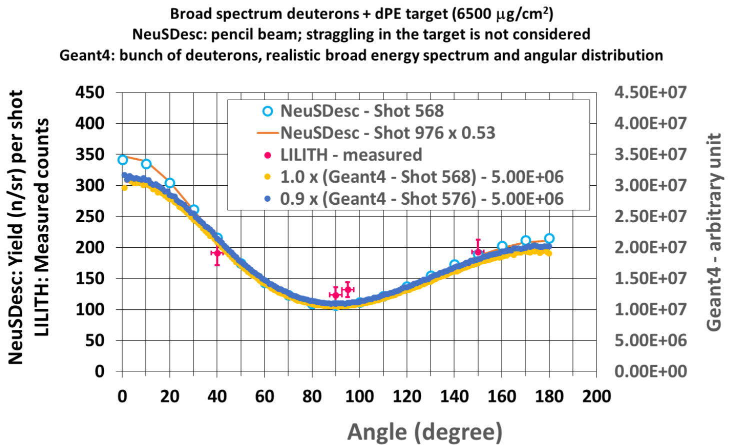
Proton and Deuteron acceleration acceleration at 1 Hz repetition rate

up to 1.5 MeV, 1.5% laser-protons conversion efficiency, proton beam emittance 0.00032 π-mm-mrad





Fast neutron production (>3500/shot) in secondary target

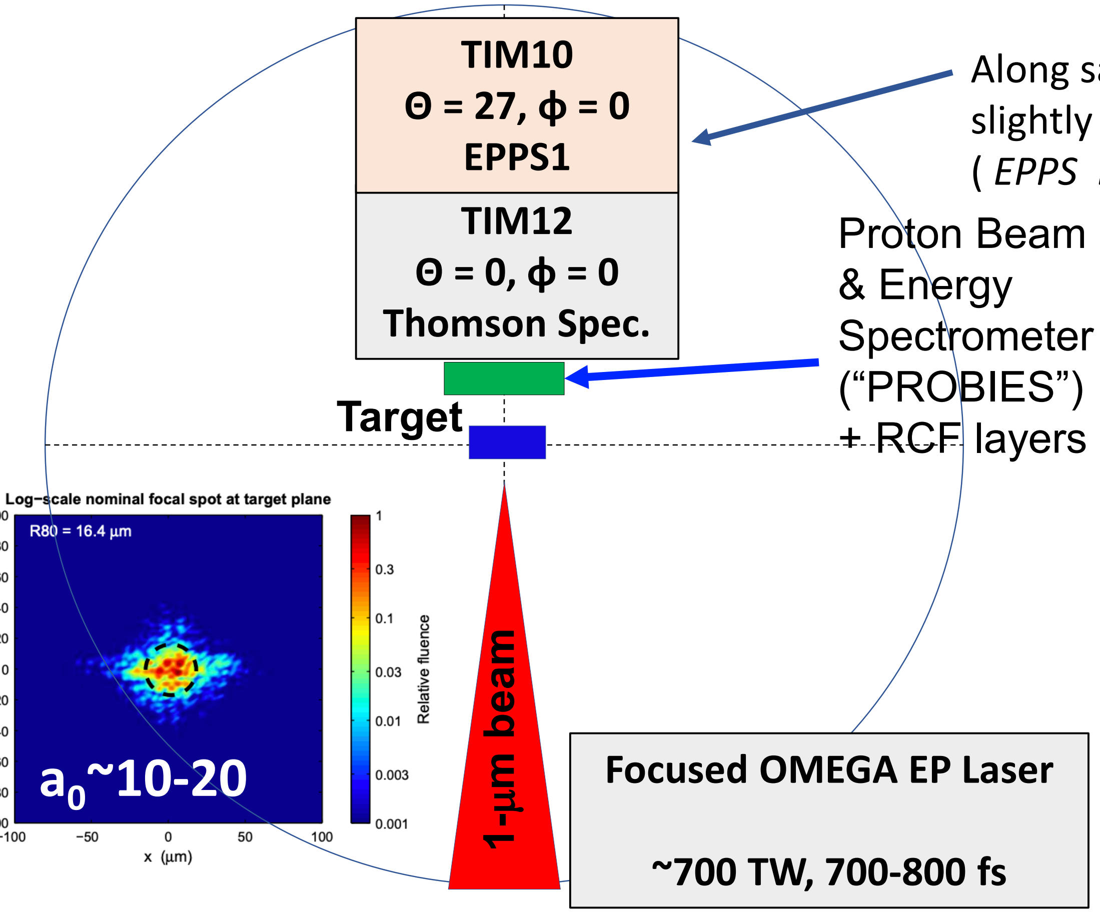


National Laser-Initiated Transmutation Laboratory
University of Szeged

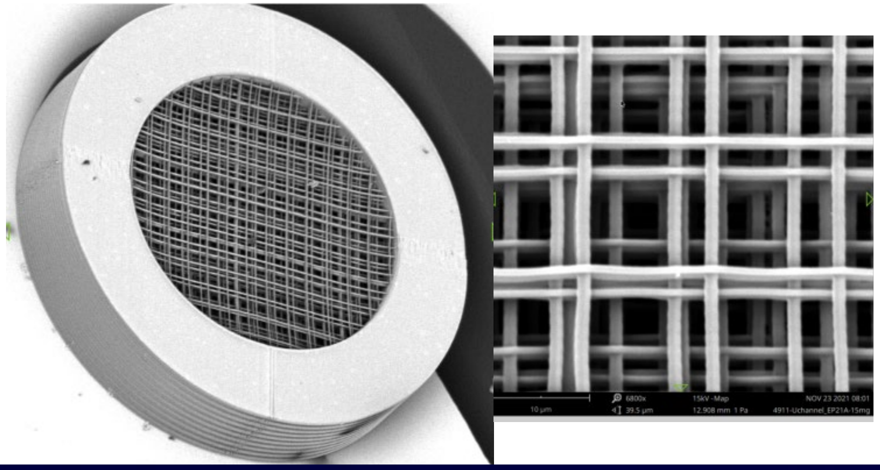
HUNGARIAN NATIONAL LABORATORY

New ion acceleration platform: printed targets

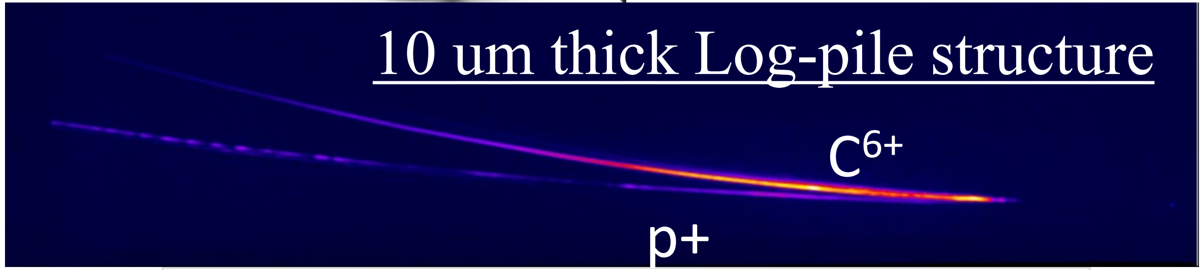
Sergei Tochitsky (UCLA)

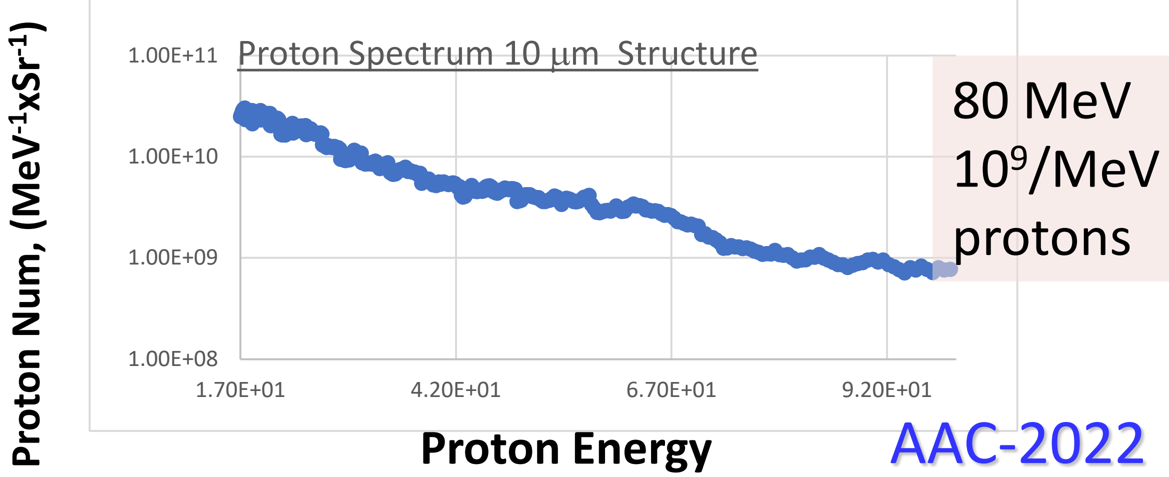


General Atomics 3D Laser Printed target



1 µm WIRES 2-10 µm Period





OMEGA EP UCLA+LLNL+LLE+GA NLUF experiments 2022-2023.

AAC-2022

OPPORTUNITIES FOR ADVANCED ACCELERATOR RESEARCH WITH FEMTOSECOND LONG-WAVELENGTH LASERS

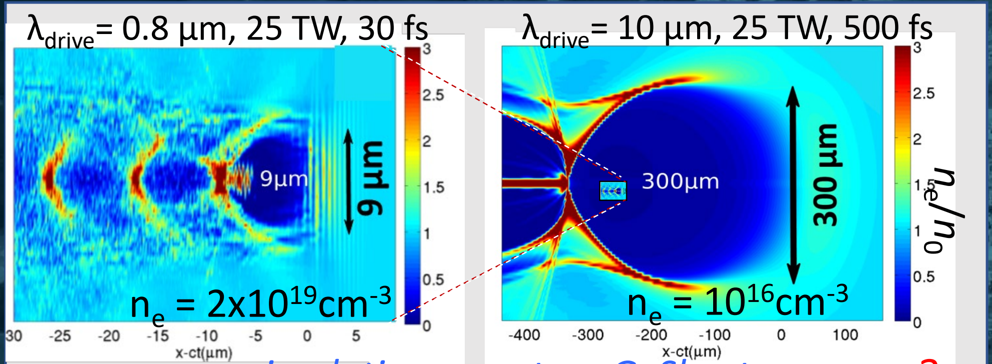
I. Pogorelsky, M. Babzien, M. Fedurin, W. Li, M. N. Polyanskiy and M. A. Palmer (ATF)
N. Vafai-Najafabadi (Stony Brook University)

Brookhaven National Laboratory

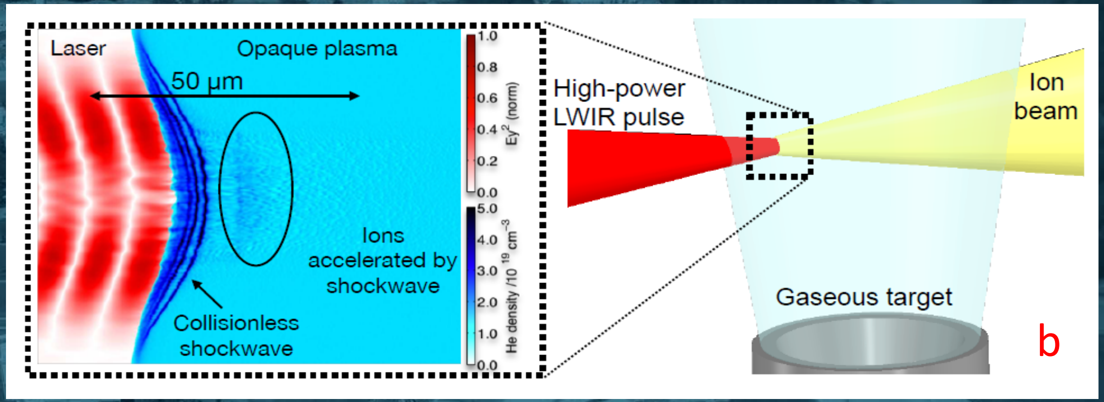
U.S. DEPARTMENT OF ENERGY

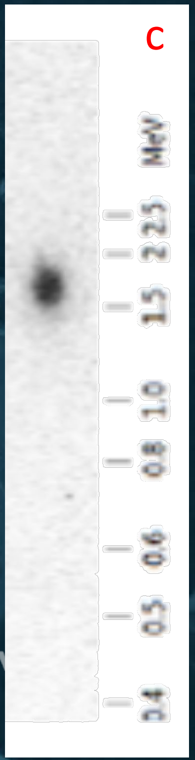
Favorable wavelength scaling $a_o = eE_L/m\omega c$ $E_p \propto I_L/n_{cr}$ $n_{cr} = m_e\omega^2/e^2$

allows producing gigantic plasma bubbles for LWFA and driving mono-energetic Shock Wave Acceleration of ions from gas jets

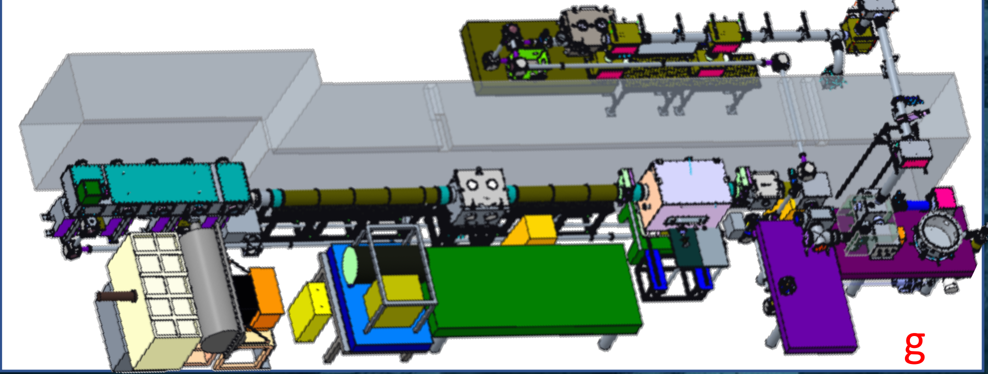


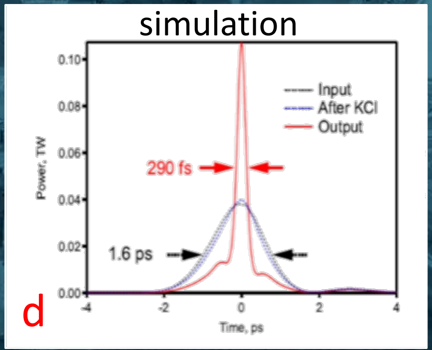
simulations courtesy G. Shvets

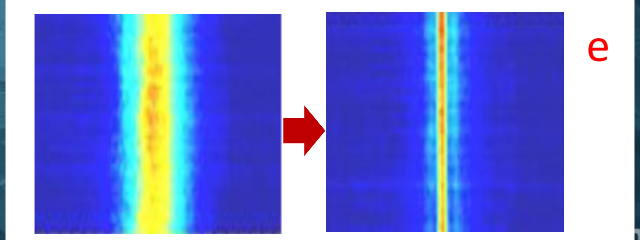




Ongoing 10-µm laser upgrade to >20 TW @ 300 fs



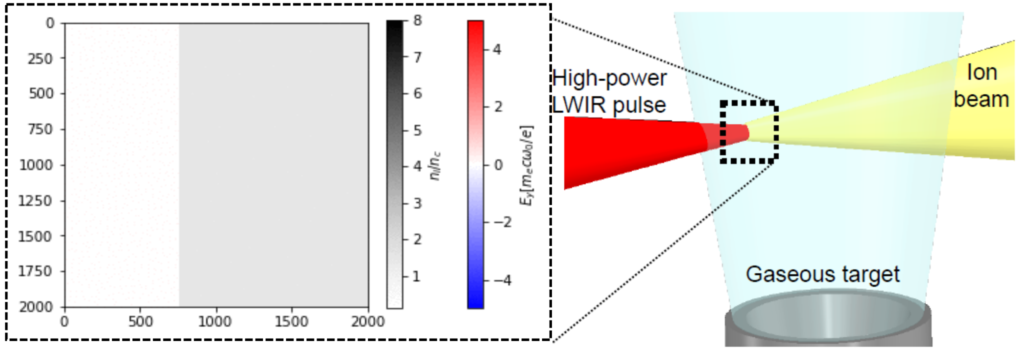


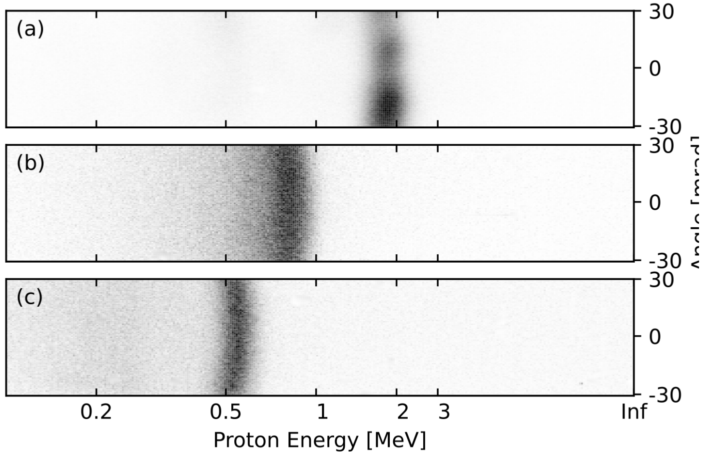


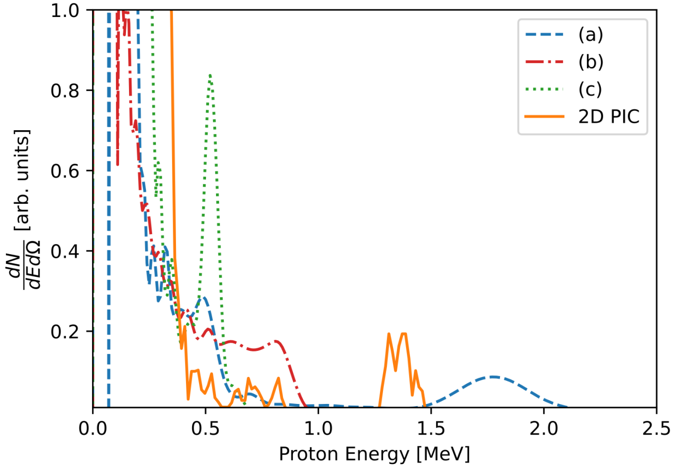
Pop experiment: Pulse compressed from 2 ps to 290 fs (autocorrelation)

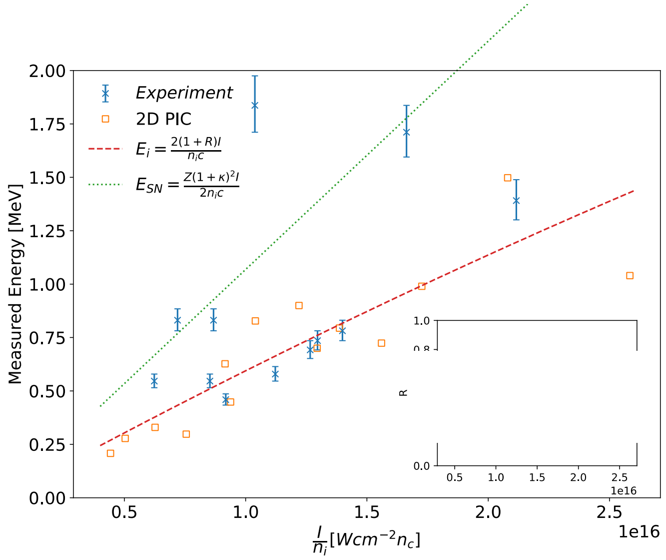
Proton acceleration with a CO_2 laser at the ATF

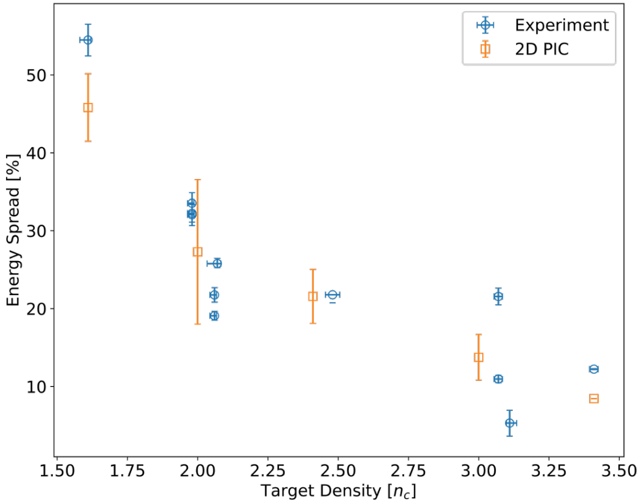
O.C.Ettlinger, N.P.Dover, E.-J. Ditter, Z.Najmudin (Imperial College London)
I. Pogorelsky, M.N.Polyanskiy, M.Babzien, M.Palmer (BNL/ATF)











- CO_2 lasers offer a unique platform to study shock based ion acceleration mechanisms
- Narrow energy spread of shock accelerated protons in HB-RPA and CSA regimes.
- Target density dependence on the proton bunch energy spread - still trying to understand this.
- Laser diagnostic at optical wavelength offers interesting probing opportunities to study plasma dynamics in interaction region.

Summary WG6 Laser Acceleration Ions

- Advanced Ion acceleration mechanisms
  - Radiation pressure acceleration, magnetic vortex acceleration, relativistic transparency, shock acceleration studied both in simulations and experiments. > 100 MeV protons reported in experiments.
  - Advanced targets (ultrathin/curved/foams/jets/mico-3D-printed) and laser parameters (few cycle/short and long wavelength/with prepulse/circularly polarized) used to access advanced regimes.
- Applications
  - Radiobiology - first mouse irradiation
  - Fast neutron generation at 1 Hz repetition rate
  - Fusion: pB reactions and proton fast ignition