Significant Increase in the Number of Energetic Protons with Two Hot Temperatures of 1 and 4 MeV During the Interaction of an Ultra-Intense Laser with a Foam Target Near the Critical Density and Coulomb piston signature in foil target.

G. Malka,[1] P. Raczka,[2] H. Larreur,[1,3,4] D. Molloy,[4,5] Y. Fukuda,[6] K. Batani,[2] D. Singappuli,[1] Bing Liu,[7] Dong Ao,[7] Wei Kang,[8] S. Pikuz,[3] A. Martynenko,[9] N. Borisneko,[10] T. Pikuz,[11] W.Nazarov,[12] G.Giuntelli,[5] T. Hayakawa,[5] A. Yogo,[6] Z. Lan,[6] Y. Arikawa,[6] A. Morace[7], D.Mancelli, [1,14,15] A. Aliverdiev,[13] D. Batani,[1]

1) Université de Bordeaux, CNRS, CEA, CELIA, Unité Mixte de Recherche 5107, Talence 33400, France

2) Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warszawa, Poland

3) Departamento de Física Fundamental, Universidad de Salamanca, 37008 Salamanca, Spain

4) HB11 Energy Holdings Pty, Freshwater 2096, Australia

5) Centre for Light-Matter Interactions, Queen's University, Belfast, Belfast BT7 1NN, United Kingdom

6) Institute of Laser Engineering, Osaka University, 2-6, Yamadaoka, Suita, Osaka, Japan.

7) ENN Fusion Technology R&D Center (ENN-FTRC), Langfang, China

8) HEDPS, Center for Applied Physics and Technology, Peking University, Beijing 100871, China

9) Plasma Physics Department, GSI Helmholtzzentrum fur Schwerionenforschung, 64291 Darmstadt, Germany

10) Lebedev, Russia

11) Institute for Laser Technology, 2-6, Yamadaoka, Suita, Osaka, Japan&

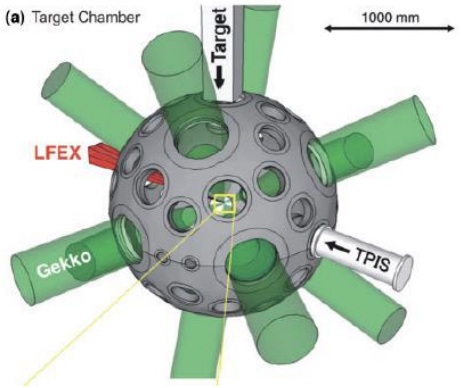
12) Wigen Nazarov

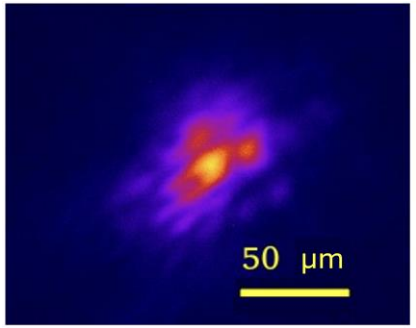
13) IGRRE JIHT RAS, Makhachkala, Russia

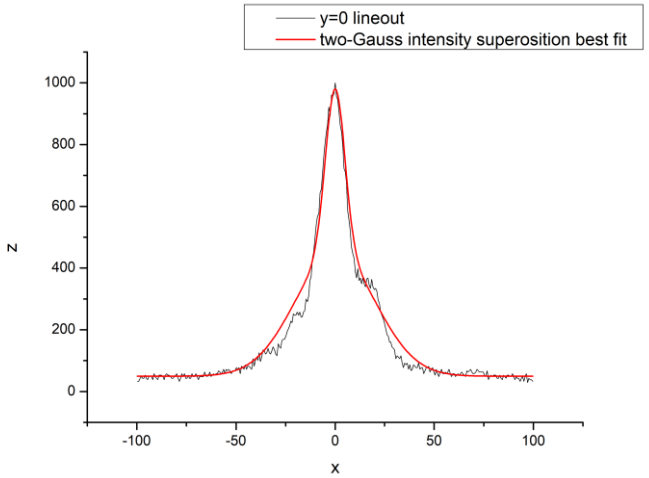
14) Institute of Plasma Physics and Lasers-IPPL, University Research and Innovation Centre, Hellenic Mediterranean University, 74100 Rethymno, Greece

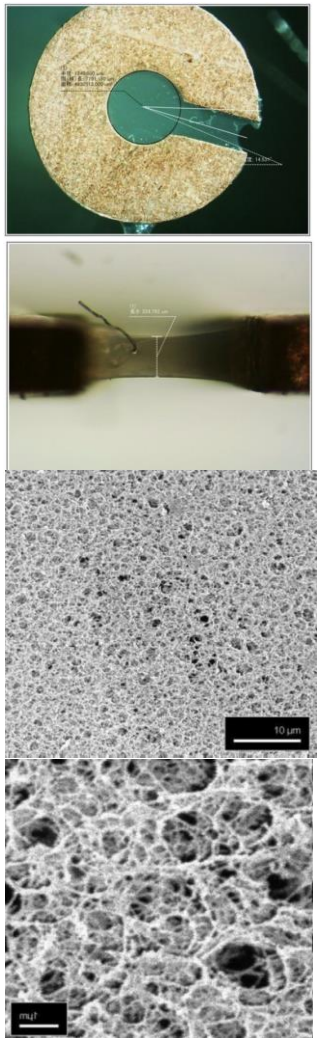
15) Department of Electronic Engineering, Hellenic Mediterranean University, 73133 Chania, Greece

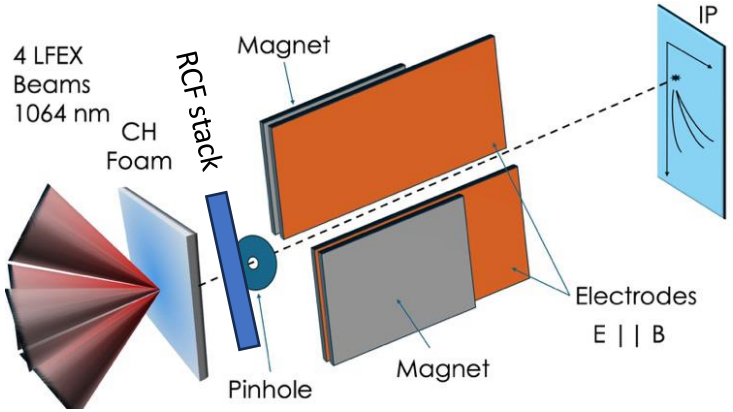
EXPERIMENTAL SET UP

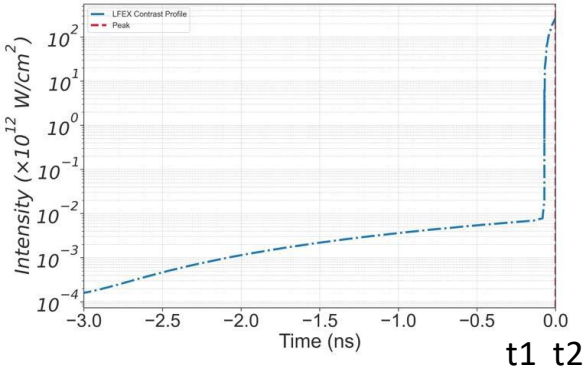












t1 t2

LFEX 1.2 kJ, 1,4 ps with 10^{-9} ASE of 2 ns, 360 J
on the 50 µm diameter focal spot, I = 1.5×10^{19} W/cm².

Time profile: - 0 to 0.1 ns ramp from 0 to $3 \cdot 10^{10} Wcm^{-2}$;
- from 0.1 ns to t1=2.116 ns constant ns prepulse $3.10^{10} Wcm^{-2}$;
- from t1=2.116 to t2=2.196 ns (80 ps) exponential ramp to $3 \cdot 10^{15}\ Wcm^{-2}$

$$I/I_0 = [b_1 \exp\left(-\frac{r^2}{\sigma_1^2}\right) + b_2 \exp(-\frac{r^2}{\sigma_2^2})]^2,$$

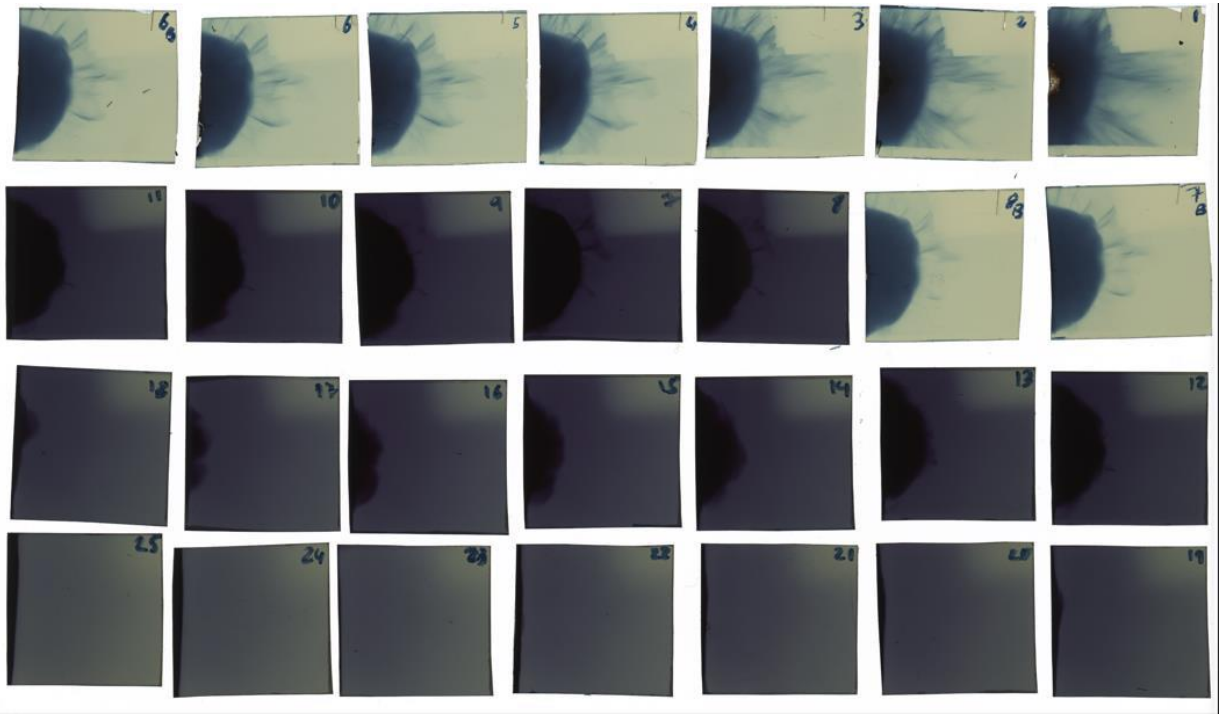
where σ_k are the waist parameters of the intensity distributions and
$b_2 = 1 - b_1, r^2 = (x - x_c)^2 + (y - y_c)^2$,
$b_1 = 0.41964$,
$\sigma_1 = 47.80$ µm, $\sigma_2 = 11.60$ µm,
$x_c = 0, y_c = 1.39$ µm

Targets :
$C_3H_4O_2$ foam, 3, 8 and 16 mg/cc density, 200 μm wide, 250 μm thick,
CH 6 μm thick thin foil target

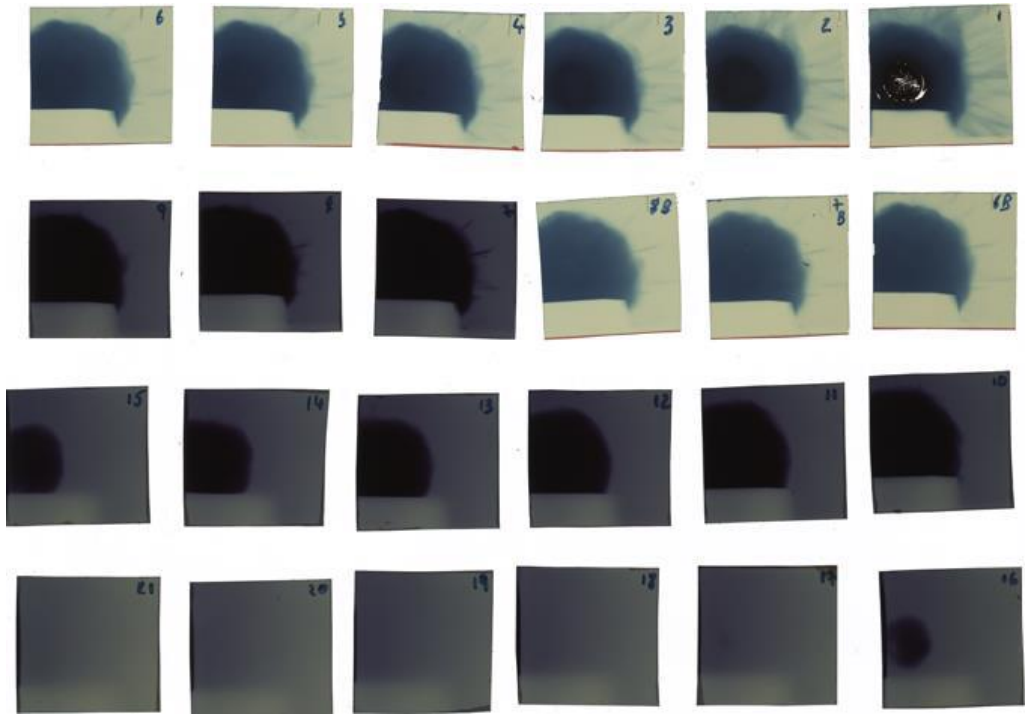
RCF STACK WITH FOAM TARGET

RCF Stack proton spectrum half spatial distribution: the p beam is normal to the target's rear side

I = 0°



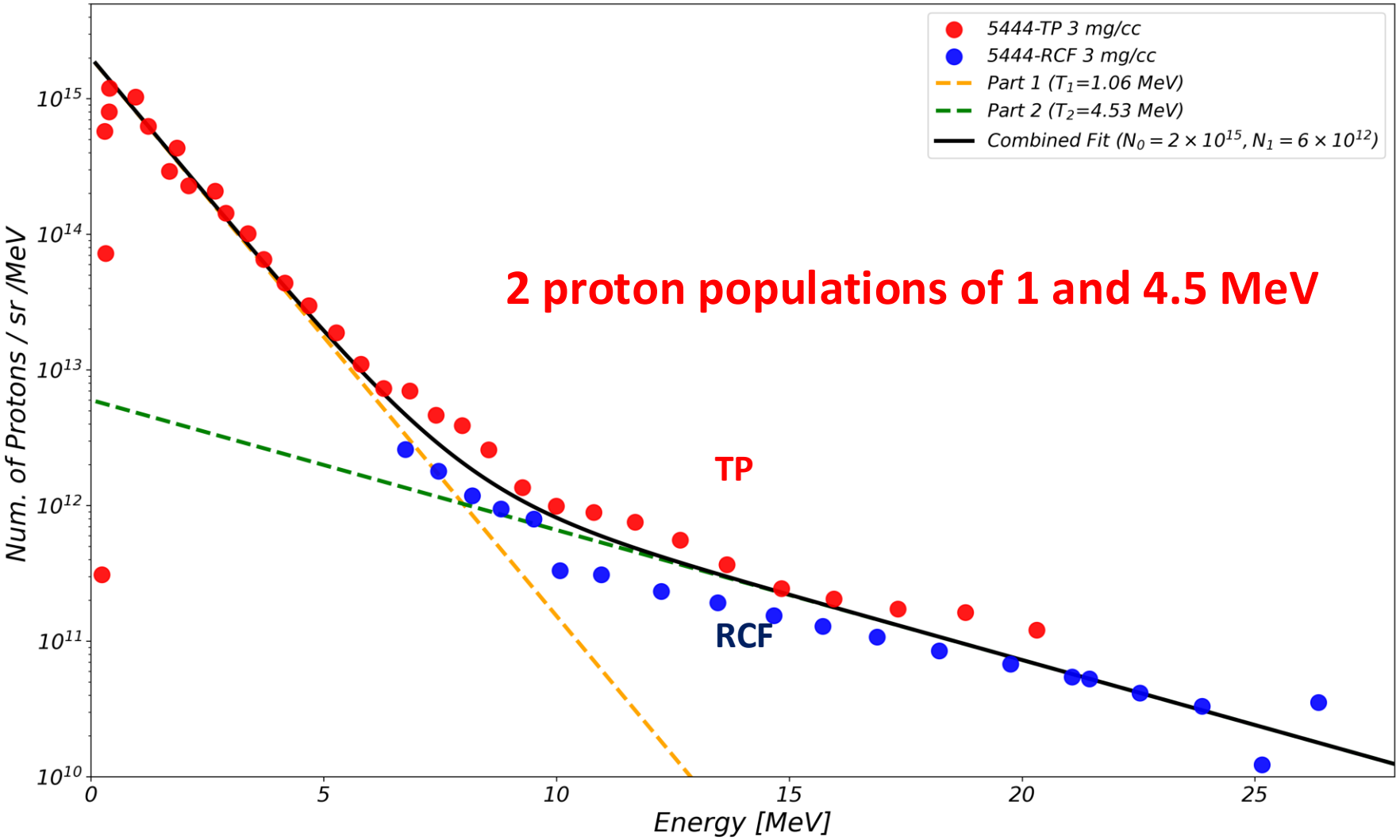
I = 15°



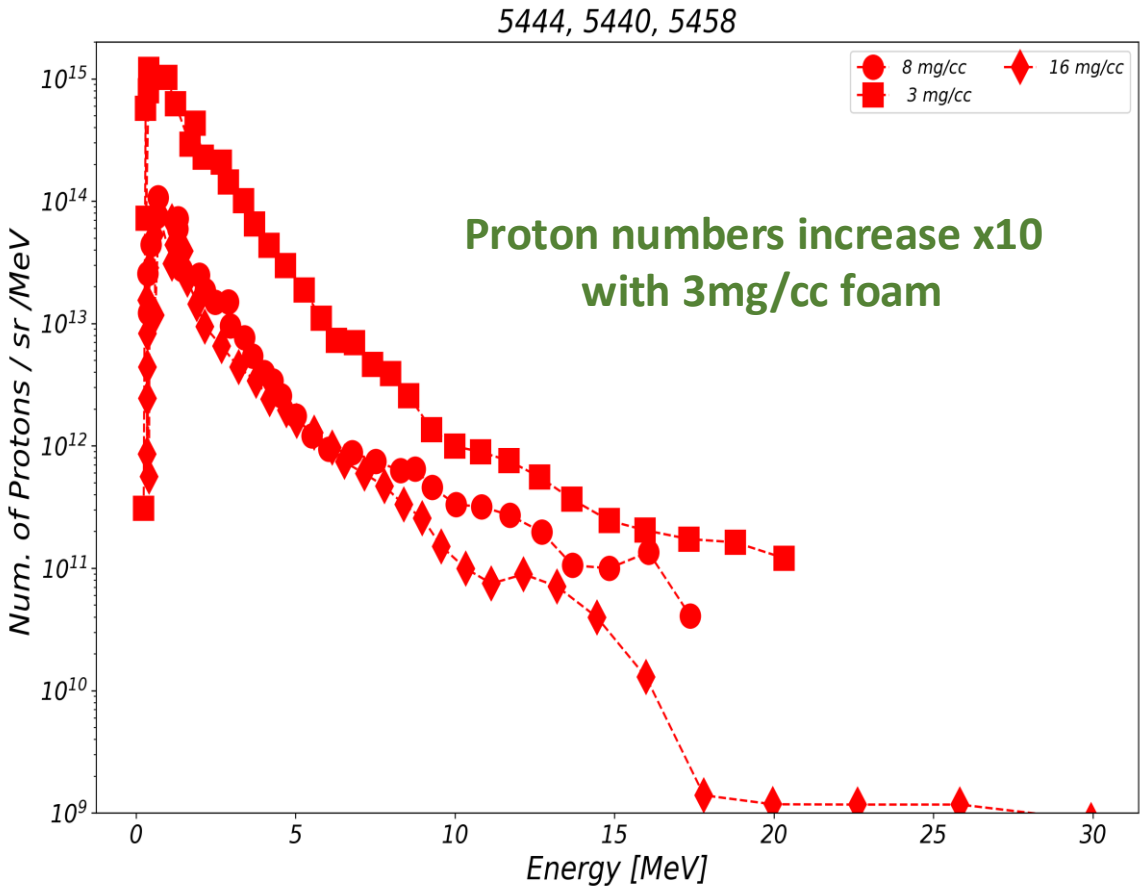
Signature of TNSA

PROTON SPECTRUM WITH TP/RCF STACK, 3 mg/cc FOAM TARGET

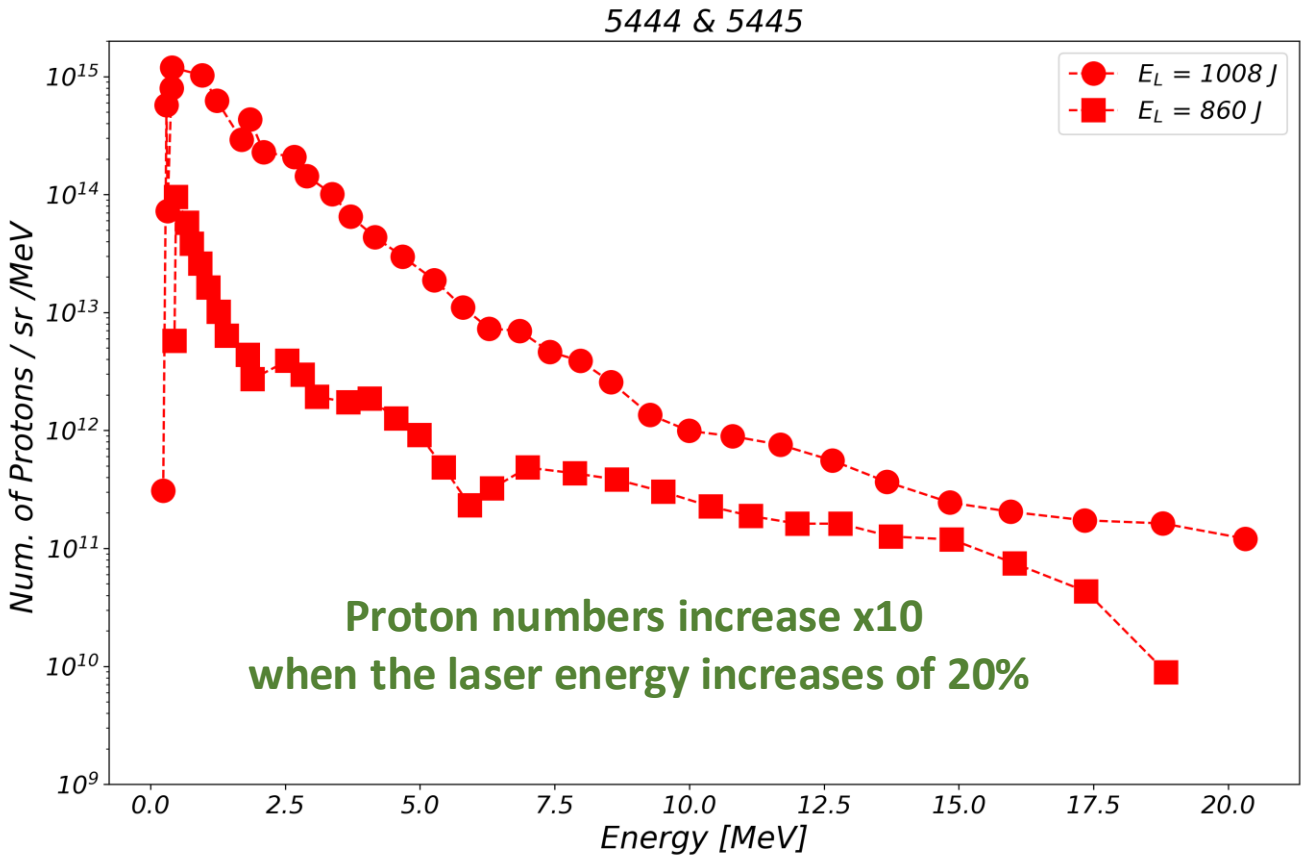
High efficiency > 10 % of laser conversion to protons 0.5-5MeV protons in 2024 but not in 2025, need to be confirmed using other diagnostics



PROTON SPECTRUM 3, 8 and 16 mg/cc FOAM TARGET

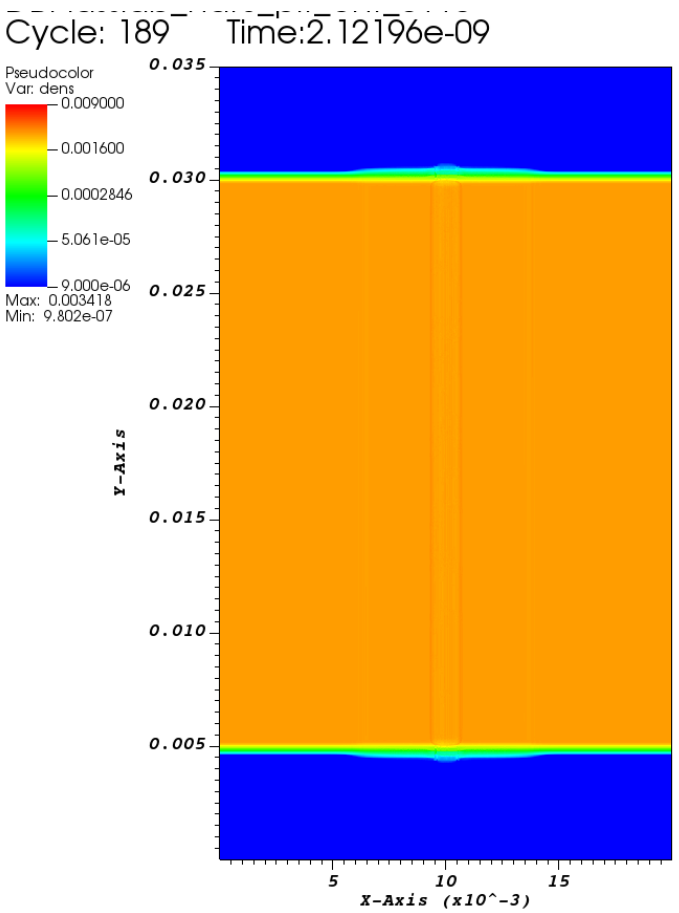


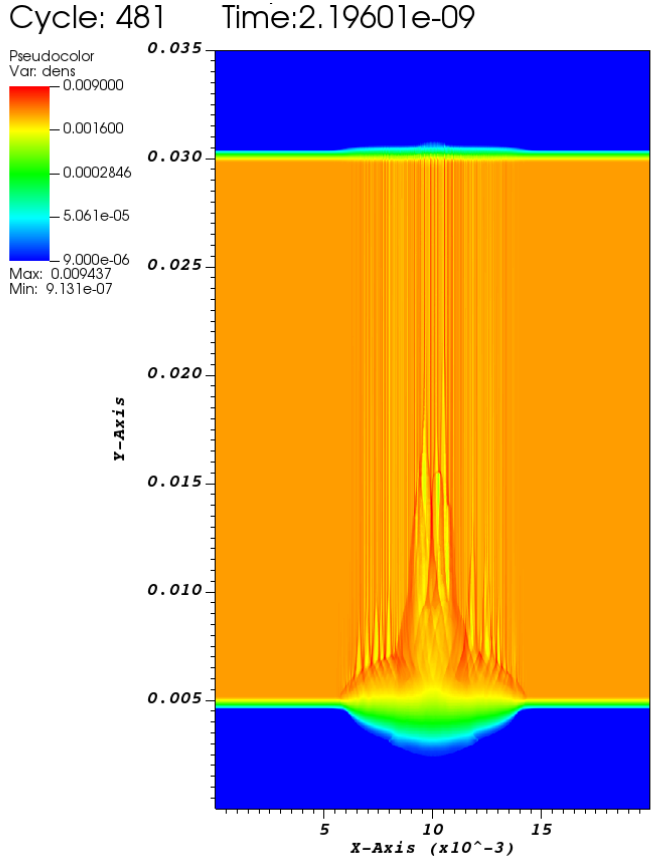
Signature of better laser coupling in the near critical plasma induced by the ASE



Signature of the relativistic self-focusing threshold in the near critical plasma induced by the ASE

2D FLASH HYDRODYNAMIC SIMULATION OF THE PREPULSE
3 mg/cc UNIFORM DENSITY TARGET, *Piotr RACZKA et al IPPLM, Warsaw*





Mass density

End of the 2 ns prepulse (t1)

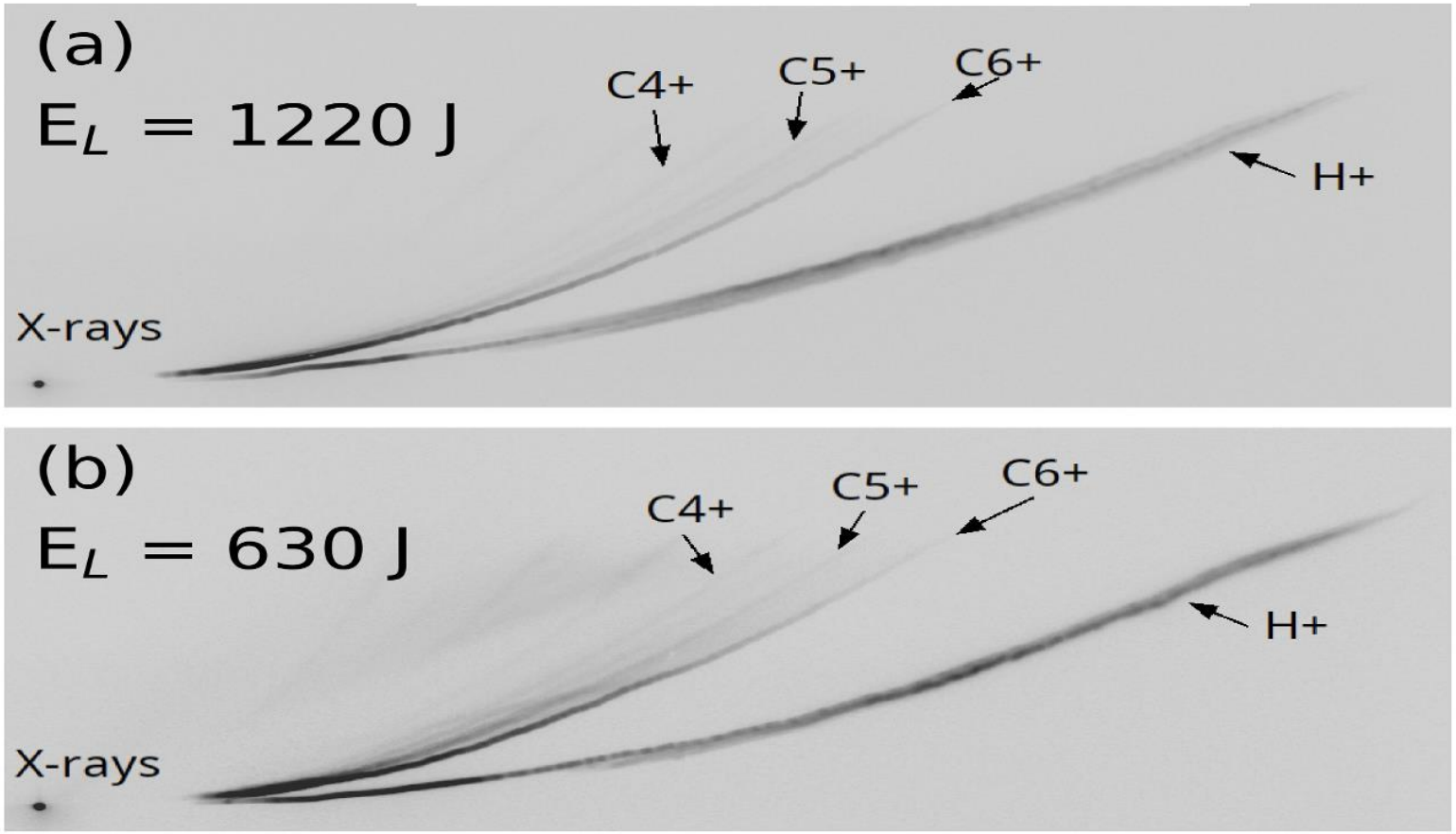
End of the 80 ps prepulse (t2)

- Time profile: - 0 to 0.1 ns ramp from 0 to $3 \cdot 10^{10} Wcm^{-2}$;
- from 0.1 ns to 2.116 ns constant ns prepulse $3.10^{10} Wcm^{-2}$;
- from 2.116 to 2.196 ns (80 ps) exponential ramp to $3 \cdot 10^{15}\ Wcm^{-2}$

2D PIC simulations still in progress

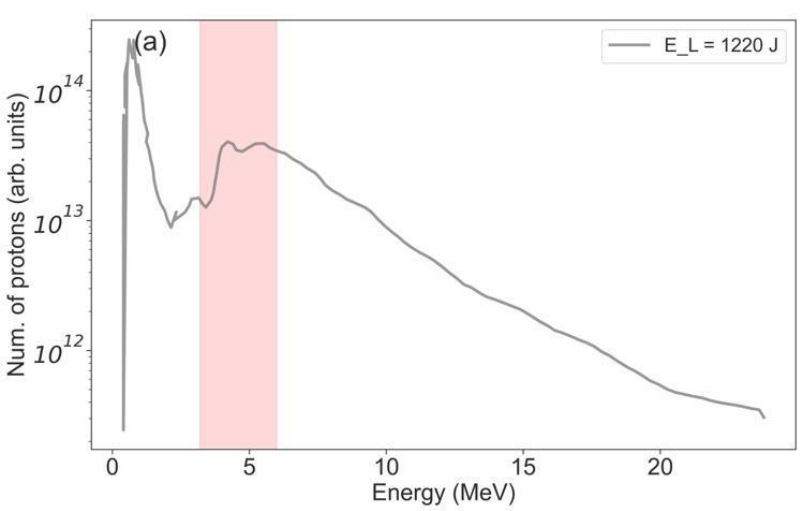
PROTON AND CARBON LINES ON TP WITH A 6 MICRONS CH FOIL TARGET

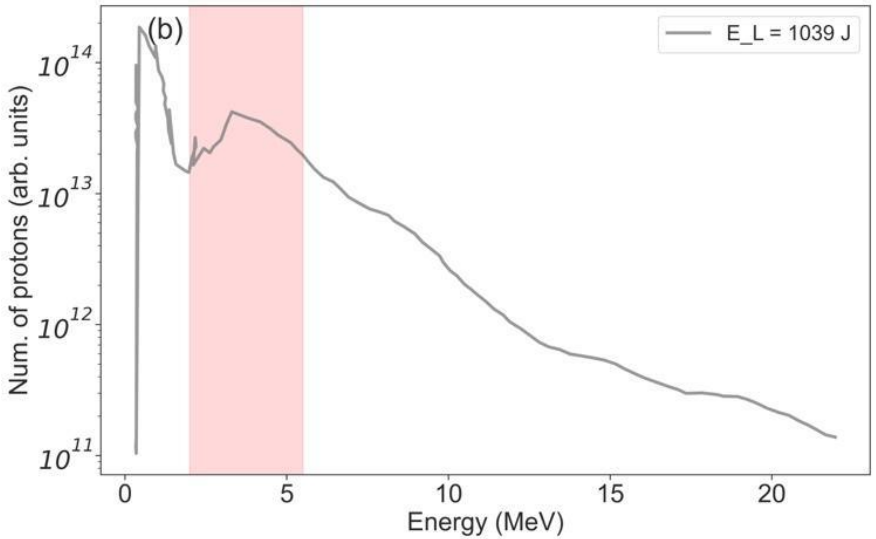
Coulomb piston signature

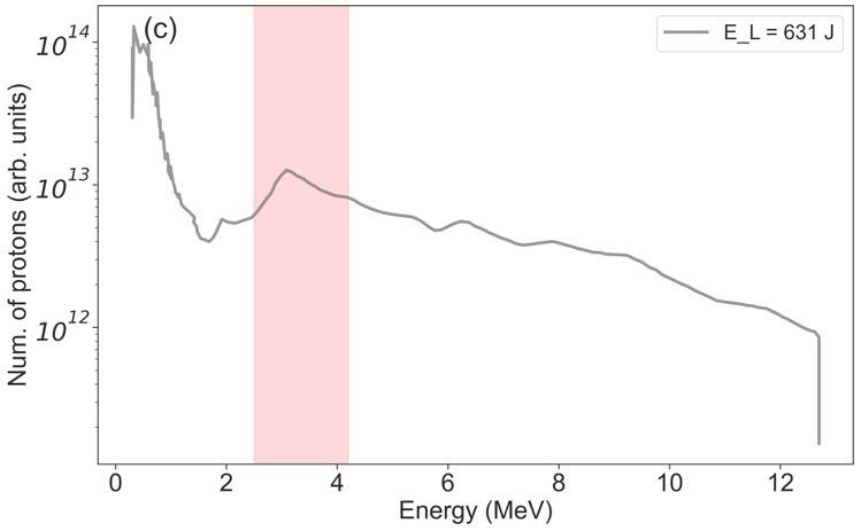


PROTON SPECTRUM 6 MICRONS CH FOIL TARGET :

SIGNATURE OF THE COULOMB PISTON



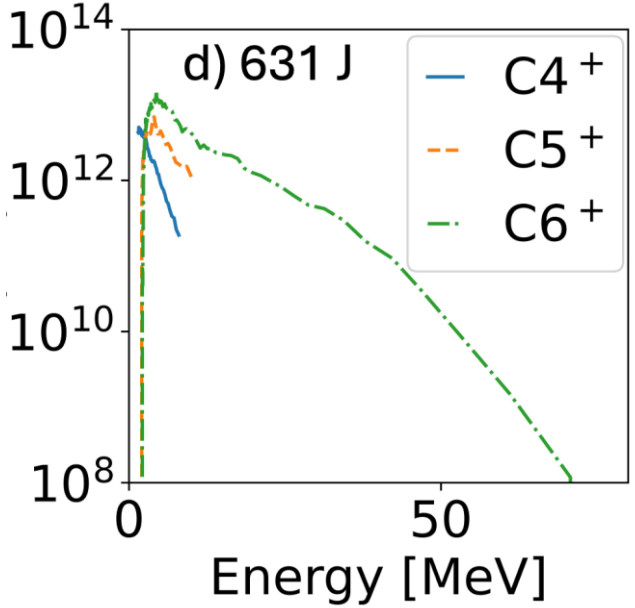


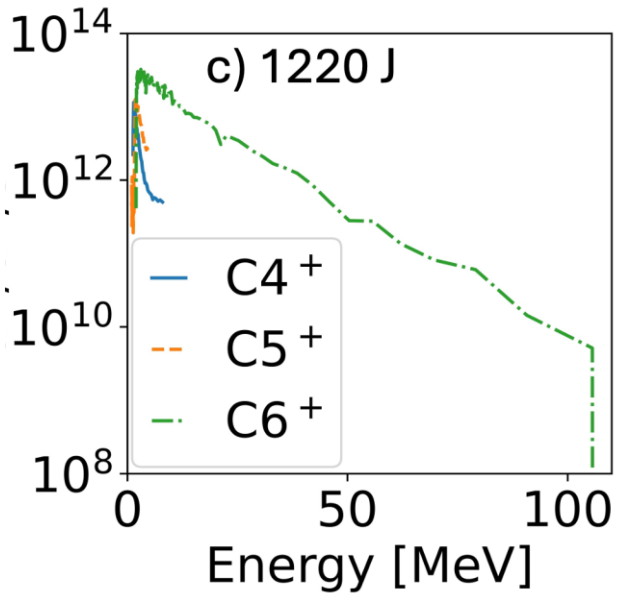


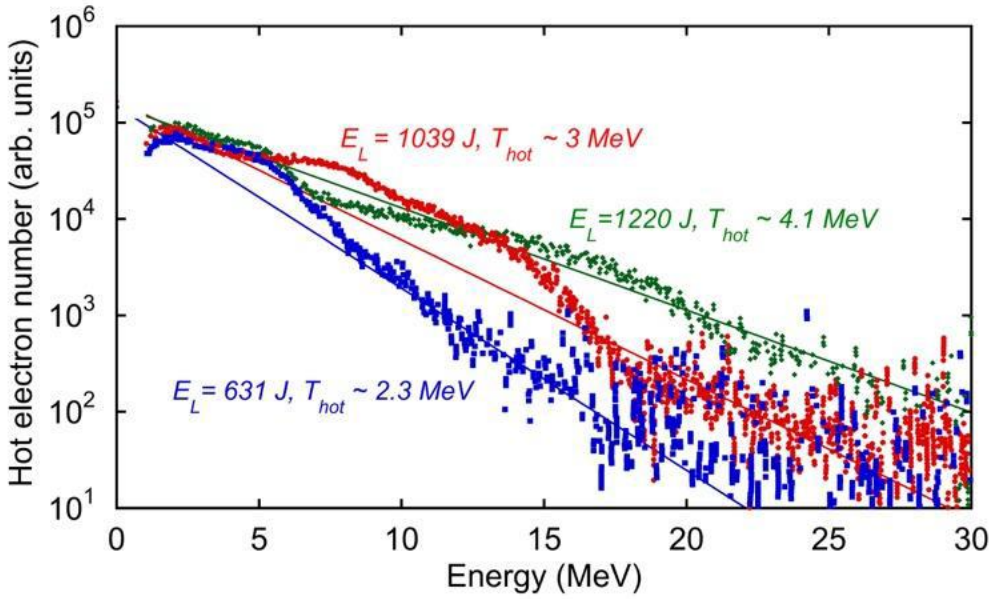
A proton peak appears around 5 MeV,
The energy of the peak decreases linearly with the laser energy.
This is due to carbon ions with a similar proton velocity, pushing protons during the time of flight between the target and the TP
For larger thicknesses, there is no proton peak (TNSA dropps)

Experimental Investigation of laser driven proton bunching with plastic foil targets
D.Batani et al, accepted in HPLSE 2026&

CARBON AND ELECTRON SPECTRUM 6 MICRONS CH FOIL TARGET



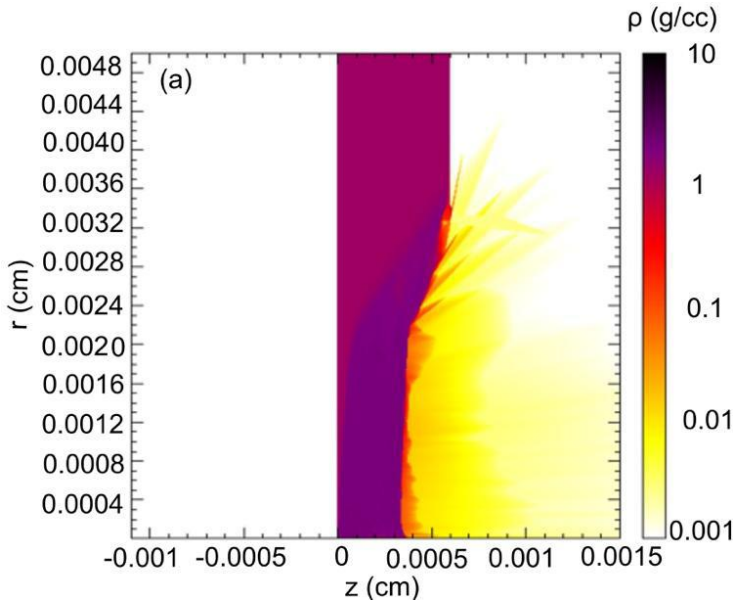




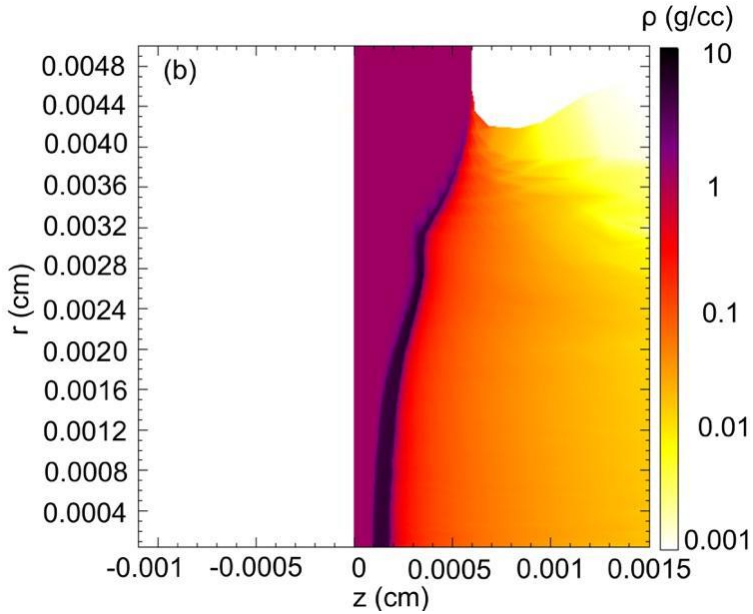
Physical quantity	Model by Bychenkov et al. (Ref. [25])	Model (1220 J)	Experimental results (1220 J)	Model (631 J)	Experimental results (631 J)
Hot electron temperature			4.1 MeV		2.3 MeV
Maximum Proton energy	$E_{p+} = T_{hot} ln^2\left(\frac{t}{t_0}\right)$	21 MeV	24 MeV	12 MeV	13 MeV
Maximum Carbon energy	$E_{C6+} = Z\, E_{p+}$	126 MeV	105 MeV	72 MeV	70 MeV
Position of bunching peak in proton spectrum	$E_{peak} = \frac{m_p}{m_C} E_{C6+}$	8.7 MeV	5-7 MeV	5.8 MeV	3-4 MeV

Table 1: Comparison of model predictions and experimental results

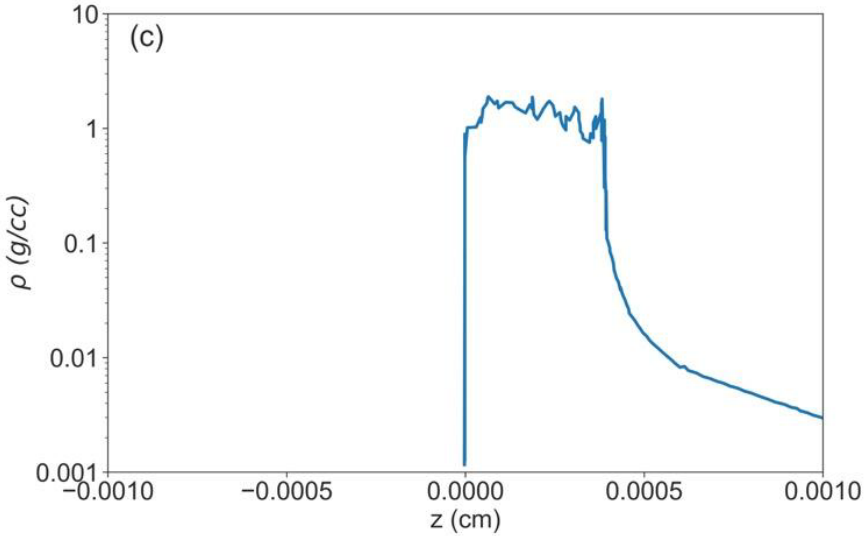
2D MULTI CODE PREPLASMA PROFILE 6 microns CH foil

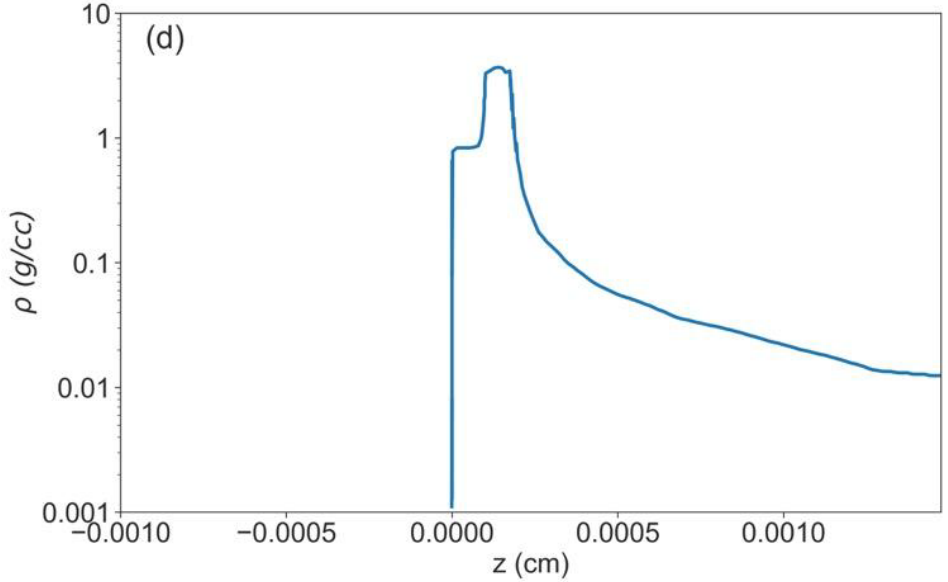


t1



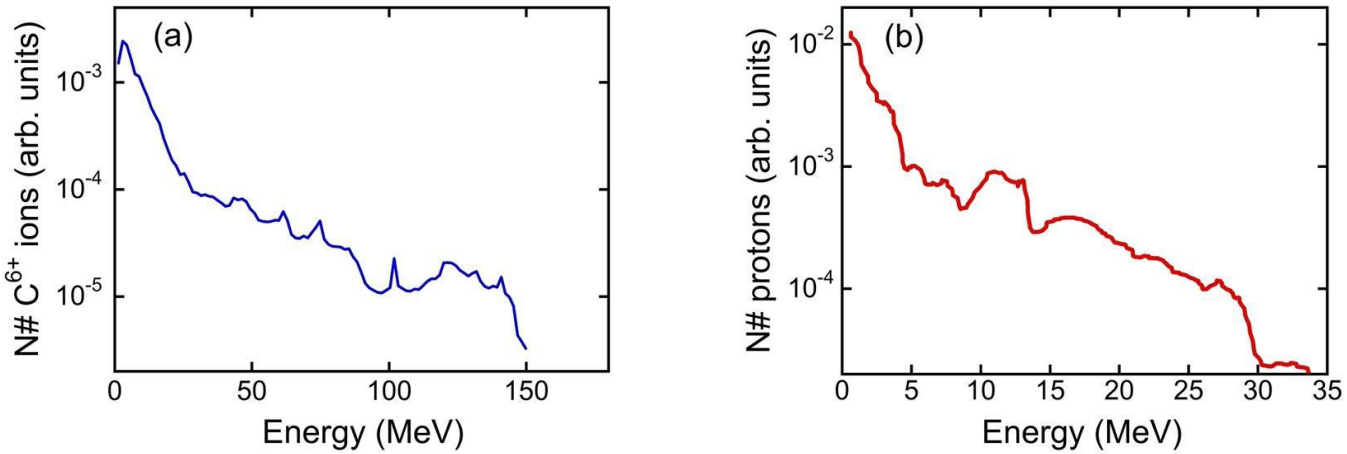
t2



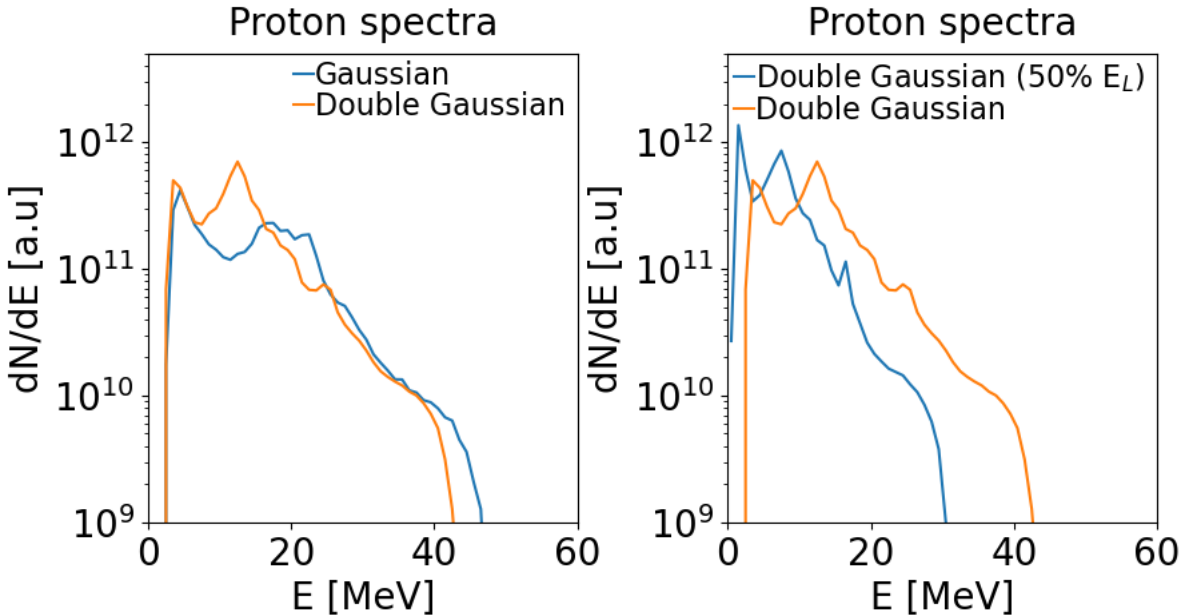


a) at the end of the prepulse plateau, and b) just before the arrival of the main short pulse laser,
c) and d) corresponding density profiles along the axis.

Energy spectrum for carbon ions and for protons from 1D PIC SMILEI simulations, showing a distinct peak at energies ~ 10-15 MeV.

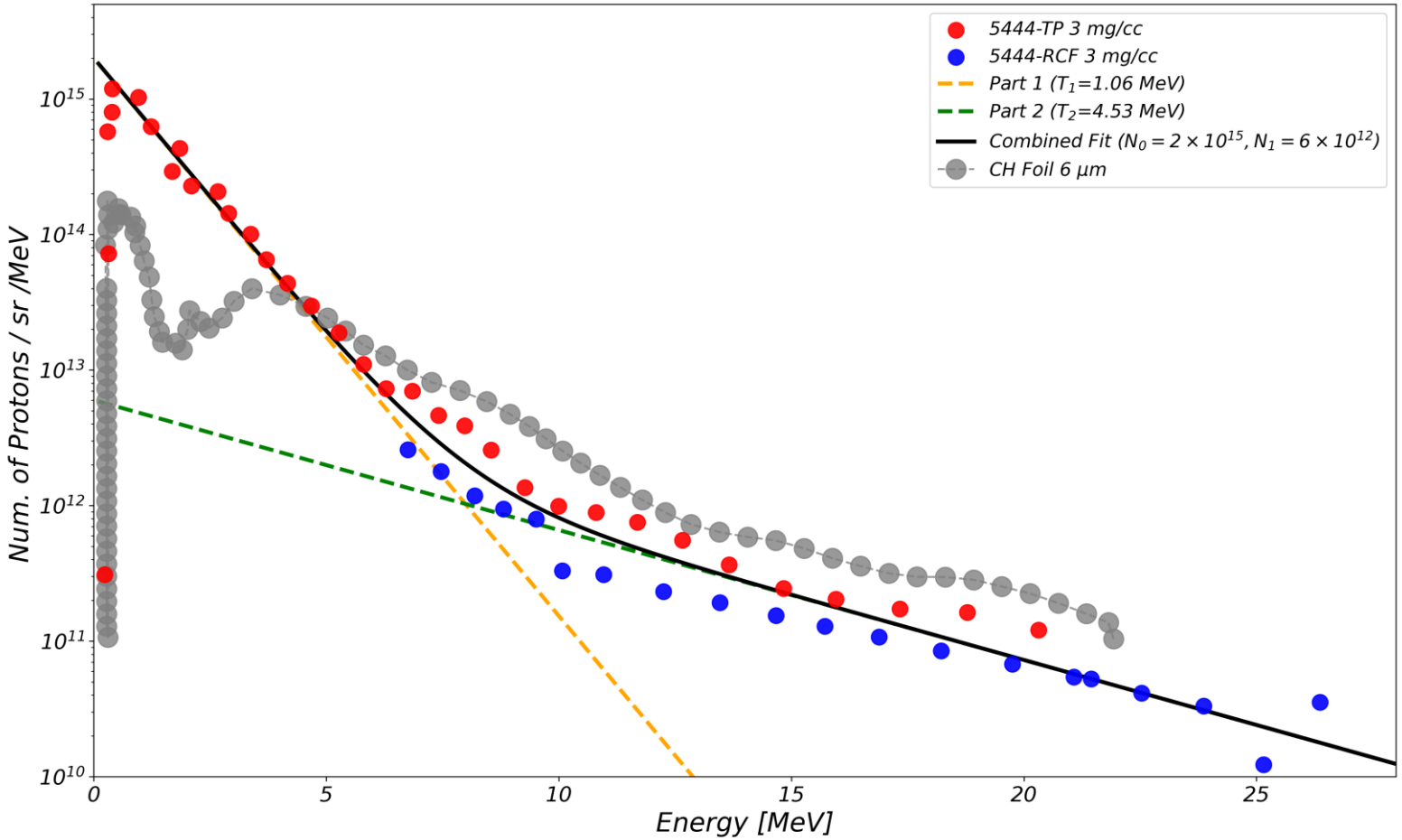


See also 2D PIC CHIC simulations : Numerical Investigation of laser-driven proton bunching with multi-species CH targets using high-energy, long-pulse lasers, accepted in Pop 2026 M. Huault et al.

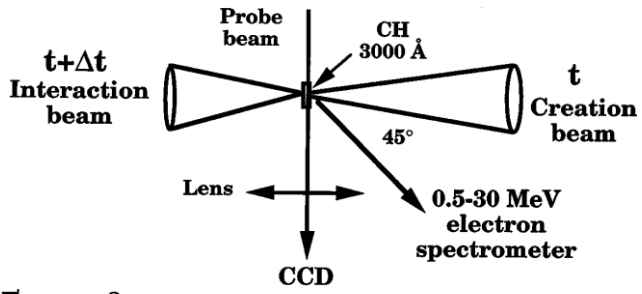


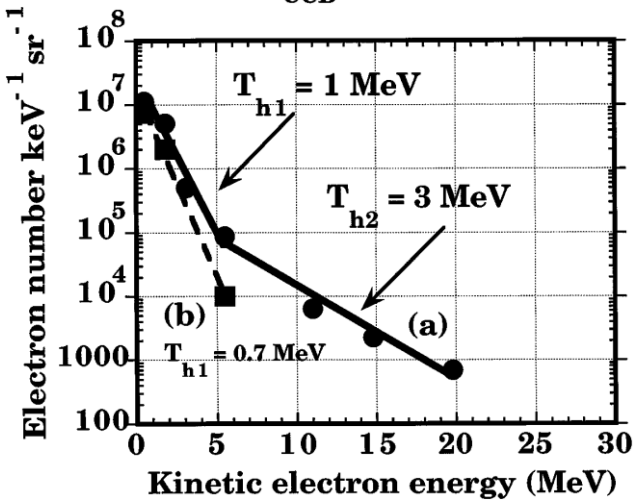
Comparison of the proton spectrum obtained with the 3mg/cc foam and foil targets

For high-energy protons, their number are quite similar, but for energies below 5 MeV, the conversion sharply increases with the 3mg/cc foam target.



30 years ago !

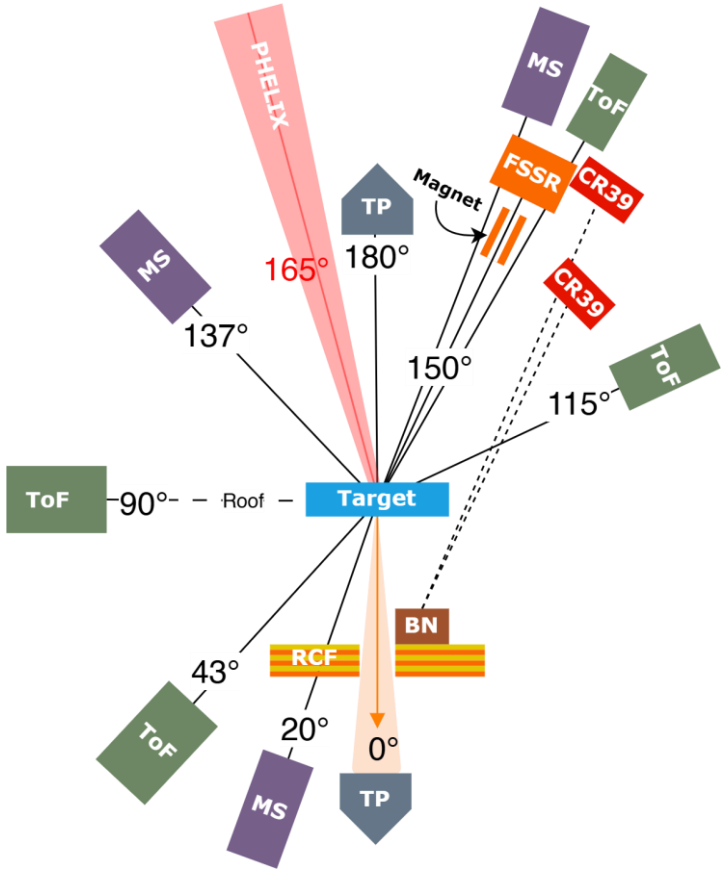


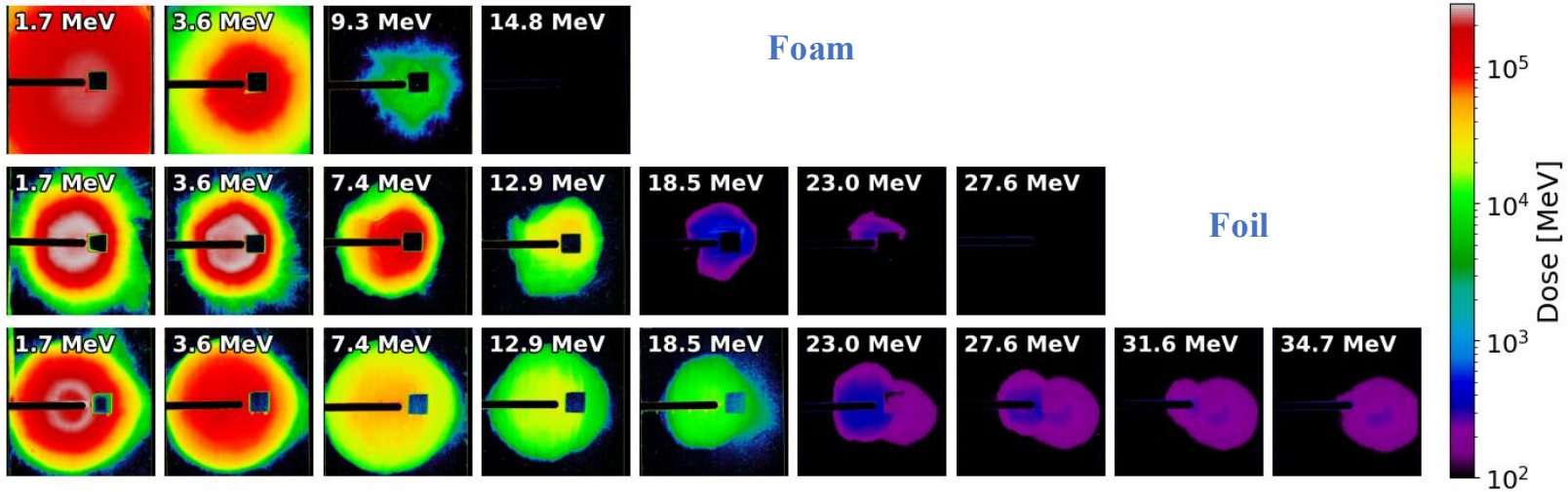


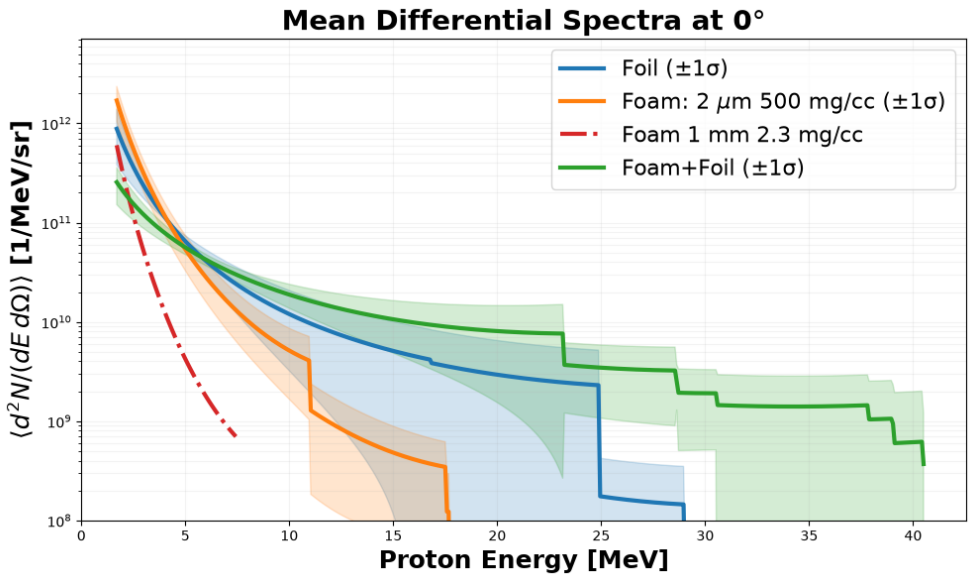
G.Malka et al , PRL 79, 11, 1997, 300fs, 15J, 5x10 μm² with 3J, I = 10^{19} W/cm².

OTHER EXPERIMENT IN PHELIX GSI : < 1%, collaboration with Olga Rosmej et al,

Anton Moroz, Alessandro Milani PhD students from the Aufrande program







Need to be confirmed?