Laser Acceleration of Protons in Hydrogen Gas Targets using 2 TW laser

Vidmantas Tomkus *[1], Miglė Mackevičiūtė [1], Valdas Girdauskas [1,2], Tomas Rakickas [1], Gediminas Račiukaitis [1], Parvin Varmazyar [3], Tibor Gilinger [3], Károly Osvay [3], Zsolt Lécz [4], Árpád Mohácsi [4], and Christos Kamperidis [4]

[1] FTMC - Center for Physical Sciences And Technology, Savanorių ave. 231, LT-02300 Vilnius, Lithuania; [2] Vytautas Magnus University, K. Donelaičio st.58, LT-44248, Kaunas, Lithuania, [3] National Laser-Initiated Transmutation Laboratory, University of Szeged, 6720 Szeged, Hungary, [4] ELI-ALPS, ELI-HU Non-Profit Ltd., 6728 Szeged, Hungary
(* vidmantas.tomkus@ftmc.lt)

Introduction

In this study, the acceleration of proton beams from gas targets, formed by converging shock nozzles and utilising a 1 Hz laser with limited pulse energy, has been demonstrated. Energetic ion beams are routinely generated in laser-driven ion acceleration experiments in PW-class laser-foil experiments but are limited by slow repetition rate of these laser systems [1-3]. New opportunities of developing more compact ion and neutron sources are offered by emerging multi-terawatt high-repetition rate lasers and utilisation of liquid leaf targets [4]. However, there is still a demand for easy-to-handle and debris-free laser-driven ion acceleration. Therefore, high density gas targets have attracted great attention in recent years [5].

Experimental Setup

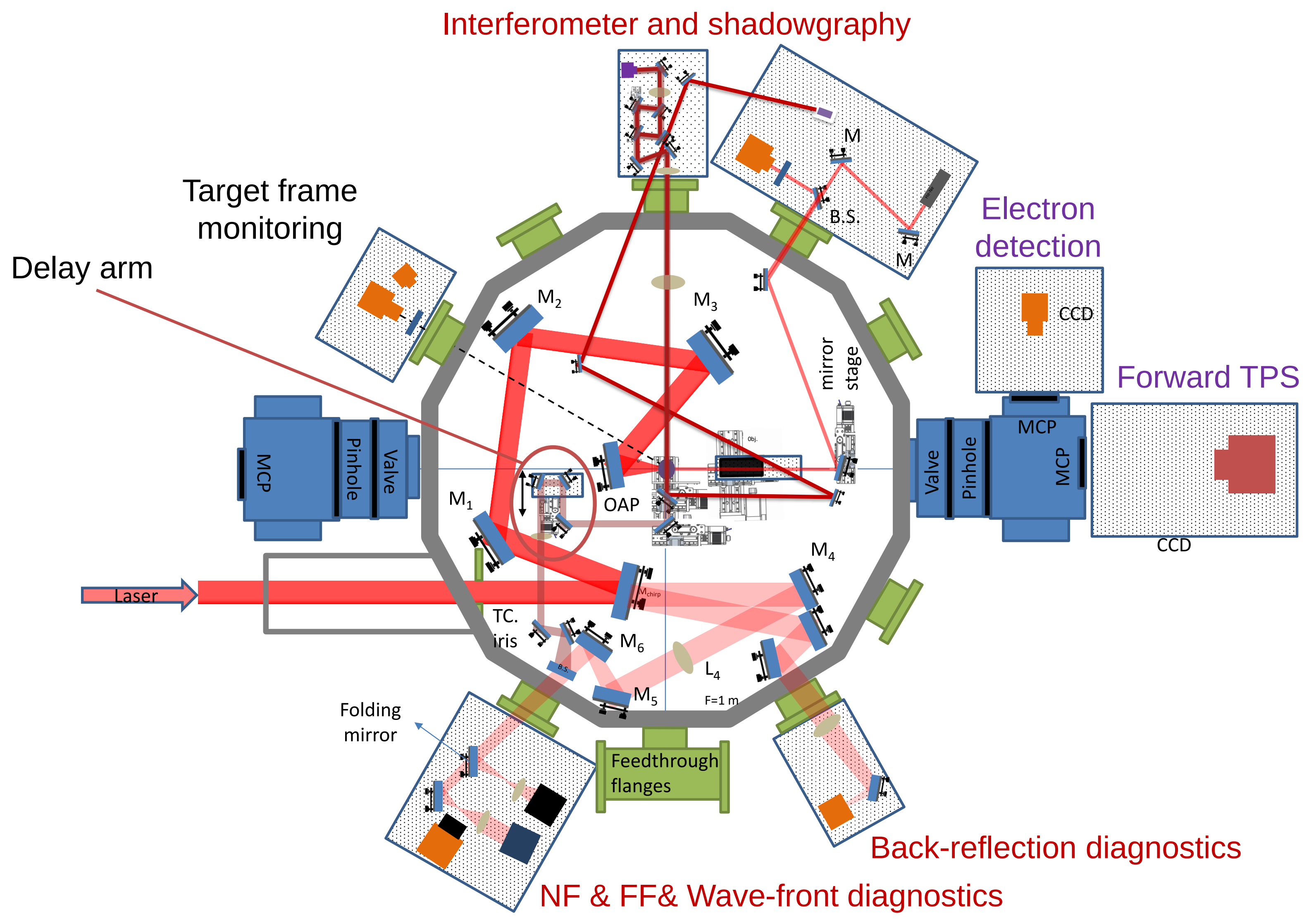

Fig. 1. Schematic diagram of the experimental setup of proton acceleration using 12 fs SEA laser at ELI-ALPS with 8 mJ of pulse energy focused at a spot of 2.9 μm x 2.1 μm.

Gas Target

The gas target formed by converging 820 μm supersonic shock nozzle was simulated using ANSYS CFD software and manufactured using laser bottom-up milling machining technique [6] (Fig. 2a-c). The neutral gas density of $n_{max} \sim 9\times10^{19}$ cm^{-3} at 82 bar of backing pressure of hydrogen was reached. The proton acceleration was simulated using SMILEI PIC software [5] (Fig. 2d-f).

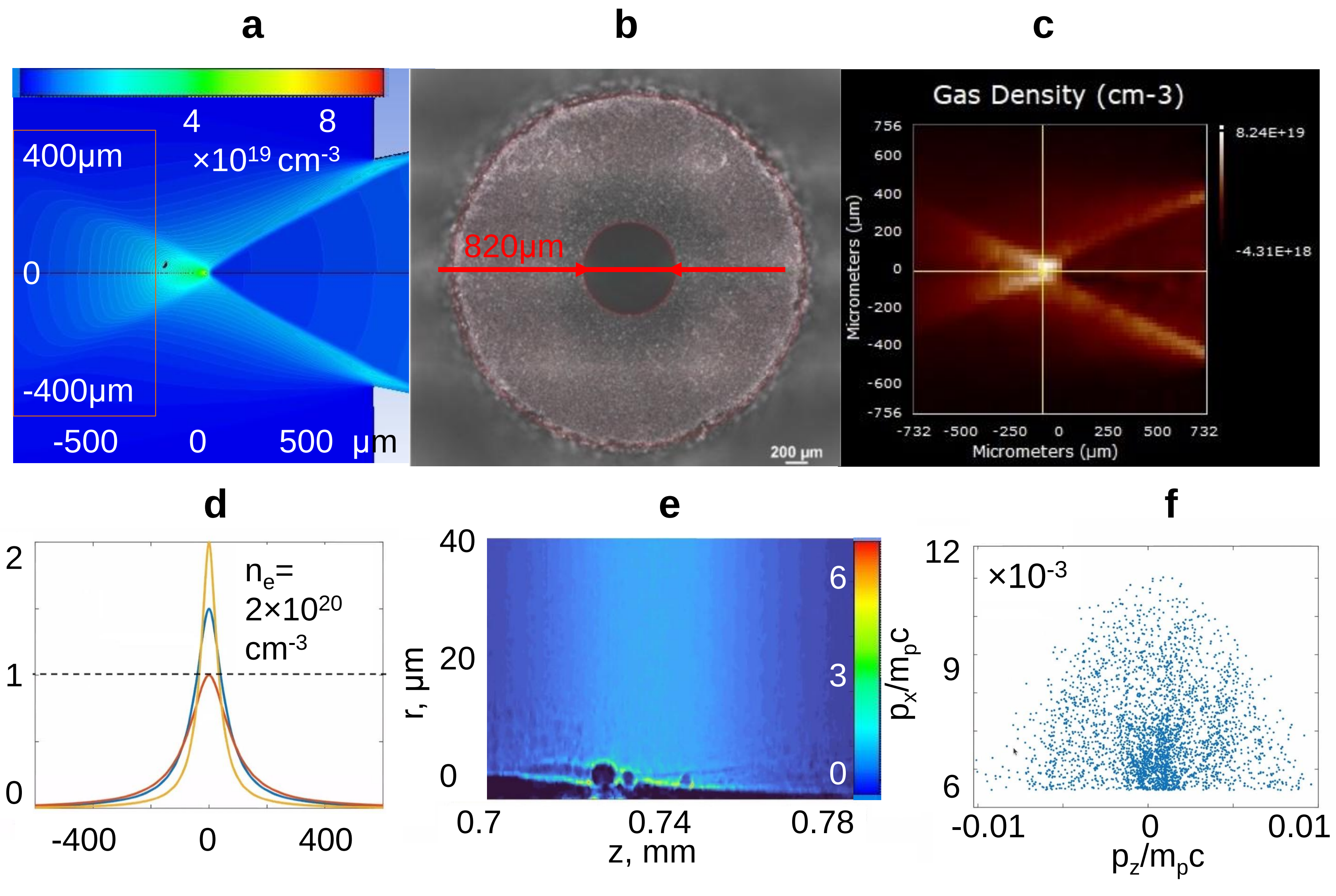

Fig. 2. Simulated (a) and measured (c) neutral gas density at backing pressure of 70 bar of hydrogen of converging 820 μm supersonic shock nozzle (b). Simulated profiles of accelerated proton distribution (e) and phase space (f) of a simplified plasma profile (d).

Experimental Results

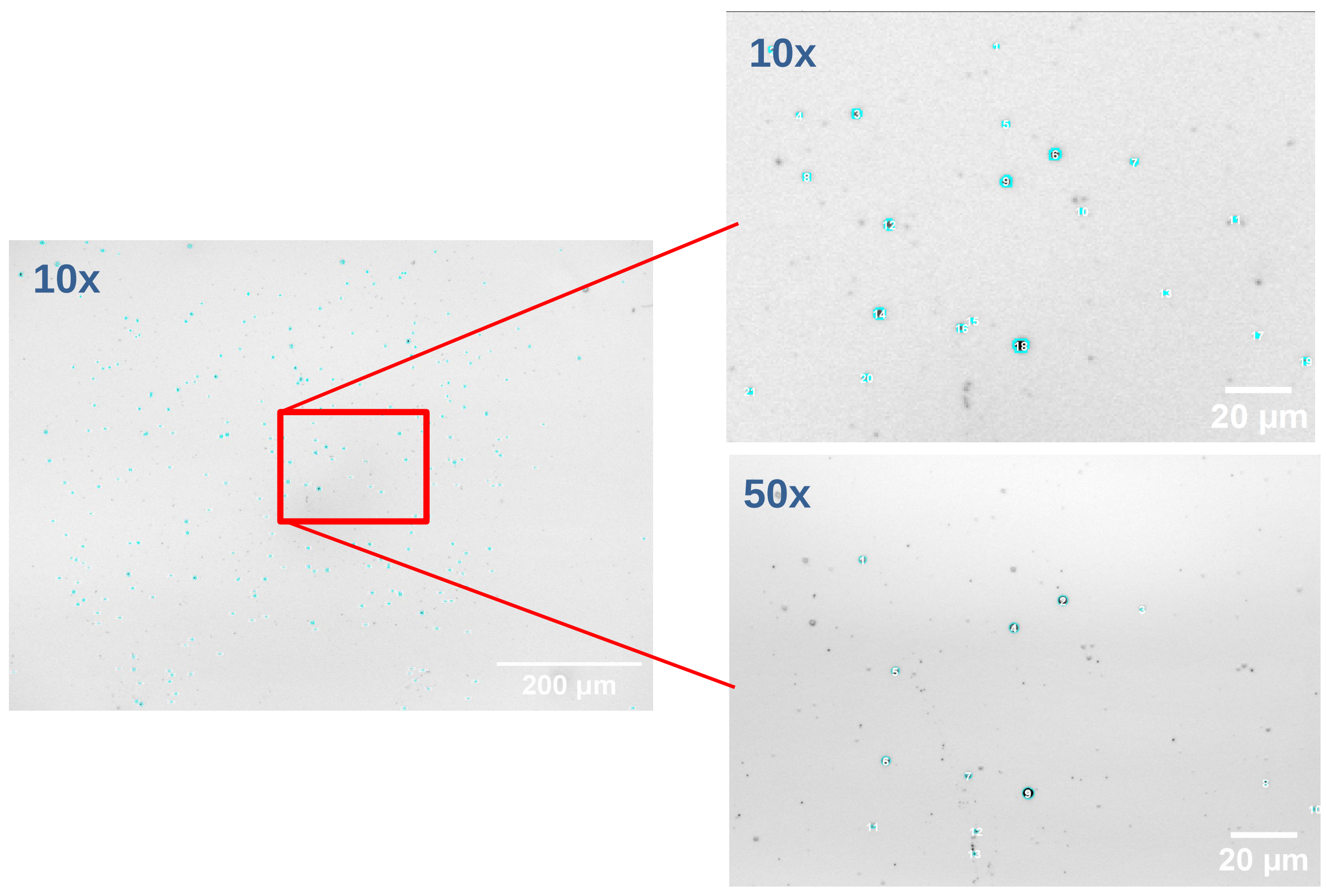

Fig. 3. The images of proton recognition using irradiated CR39 plates at 10x and 50x microscope magnification after etching in 6 N NaOH solution for 40 min.

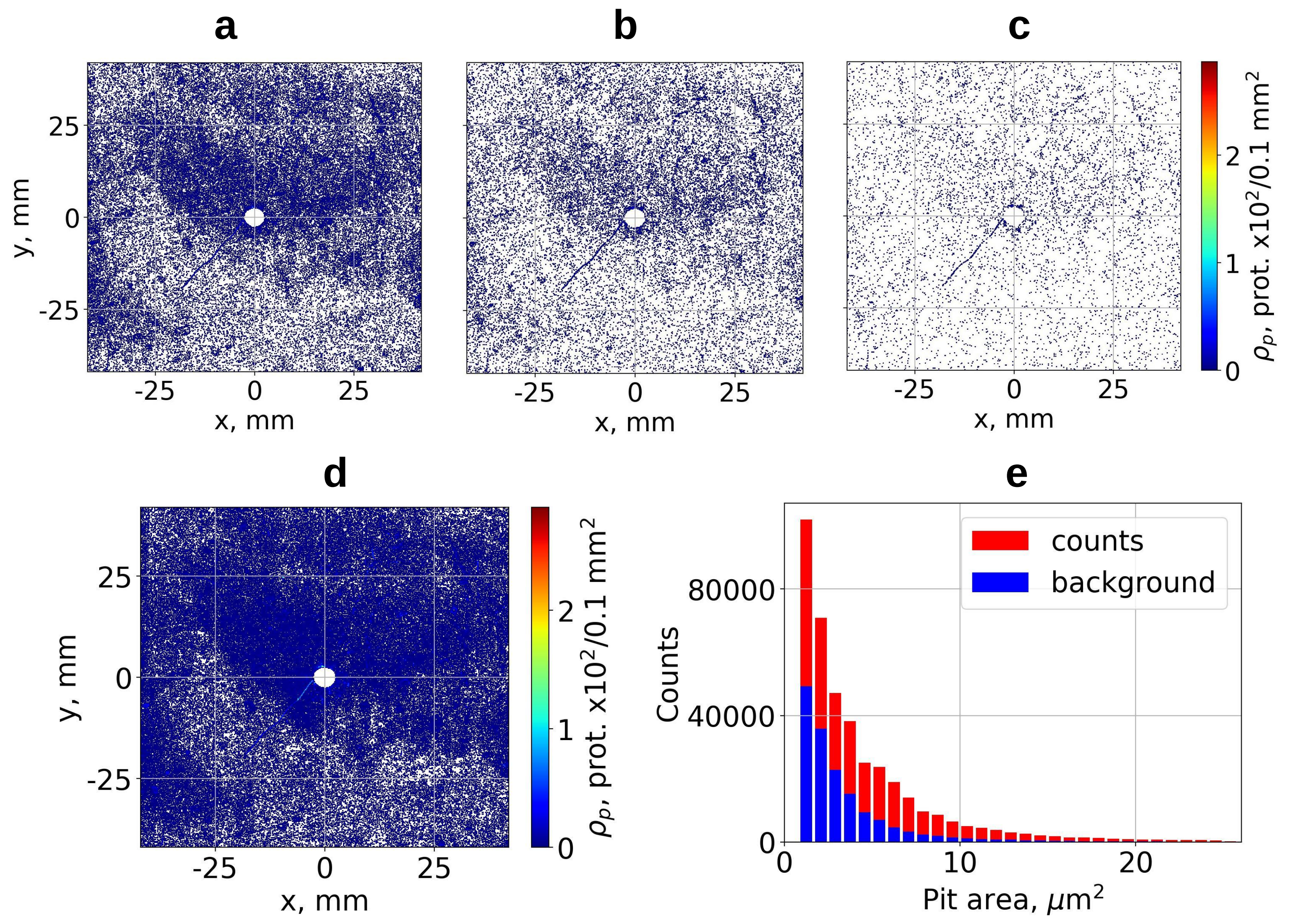

Fig. 4 Images of proton distribution on of an irradiated CR39 plate per 1000 shot of pit area 4-25 μm^2 (a), of pit area 8-25 μm^2 (b), of pit area 20-25 μm^2 (c), of all pits (d), and a number of counts registered depending on the pit area of an irradiated and unirradiated control CR39 plate (e) .

Conclusions

The proton acceleration experiments were performed using a few-cycle 12 fs SEA laser at ELI-ALPS with 8 mJ of pulse energy focused at a spot of 2.9 μm x 2.1 μm FWHM on the target. The high-density region of the 9×10^{19} cm^{-3} hydrogen gas target was formed by intersecting shock waves of a supersonic nozzle manufactured using laser bottom-up milling machining technology from fused silica. 2-3×10^{5} protons per 1000 shots, with an energy of tens keV [7] within the angle of 70 degrees in the propagation direction of the laser beam were registered on CR-39 plates after etching in 6N NaOH solution for 40 min, and the count statistics depending on the pit area was presented.

Bibliography

1. H. Daido et al., Rep. Prog. Phys. 75 056401, (2012);
2. P. Puyuelo-Valdes et al., Physics of Plasmas, 26 (12), 123109 (2019);
3. O. Seemann et al., Phys. Rev. Lett. 133, 025001, (2024);
4. K. Osvay et al., Sci. Rep., 14, 25302 (2024);
5. Zs. Lécz et al., Phys. Rev. Res. 5, 023169 (2023);
6. V. Tomkus et al. Plasma Phys., 90, 965900102, (2024);
7. M.S. Schollmeier, Sci. Rep., 13, 18155, (2023).

The research leading to these results was funded by ELI User Call project ELIUPM3-88 LAPGAST