UNIVERSITATEA DIN BUCUREȘTI

VIRTUTE ET SAPIENTIA

Facultatea de Fizică Universitatea din București

Spectral distribution of laser accelerated protons by multilayer CR-39 nuclear track detectors

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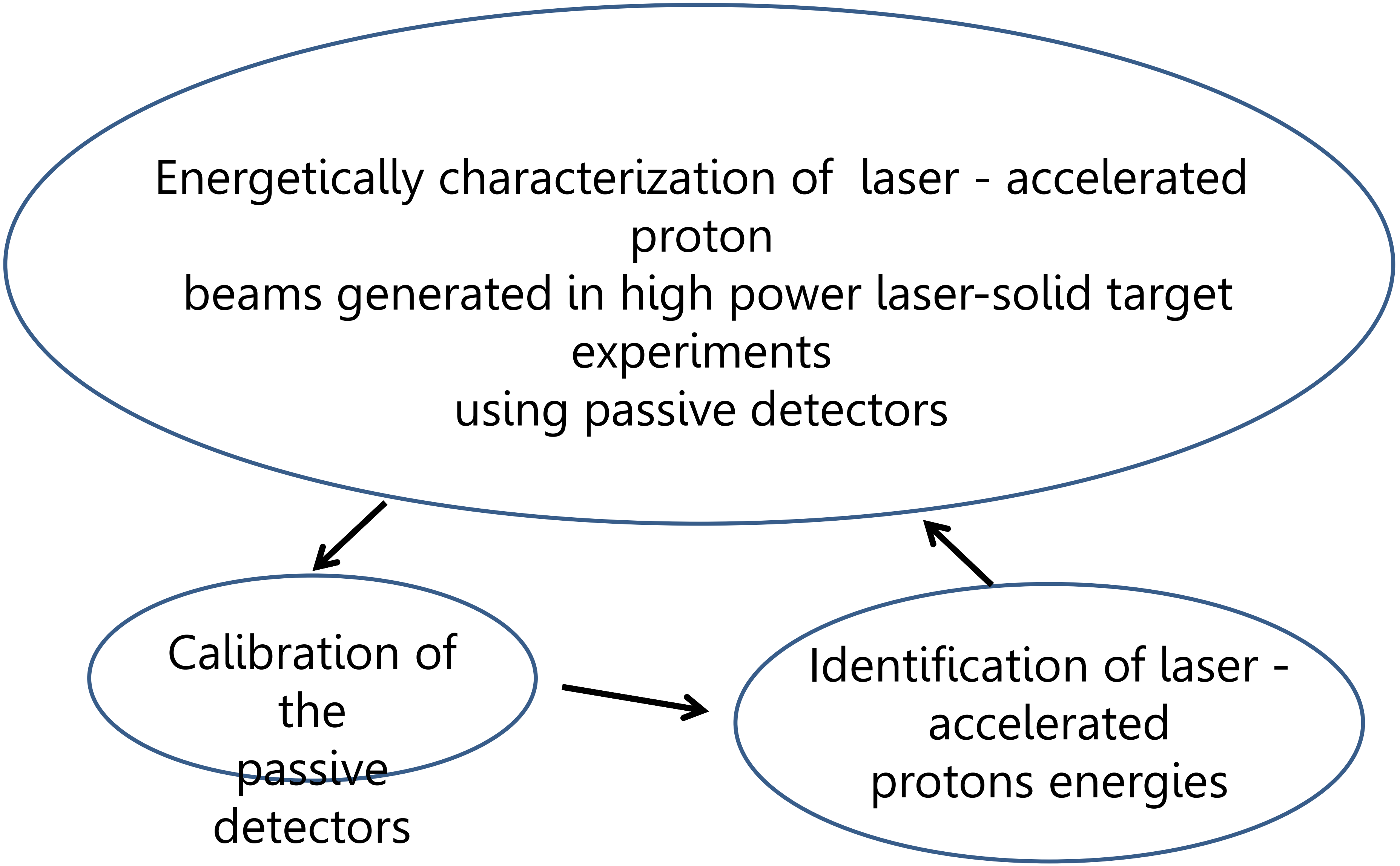
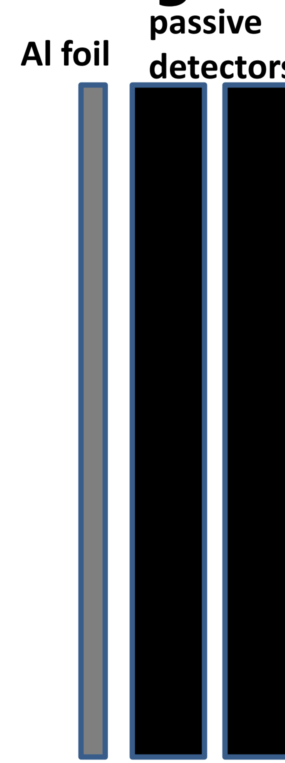
Motivation


Energetically characterization of laser - accelerated proton
beams generated in high power laser-solid target experiments
using passive detectors
Calibration of the passive detectors
Identification of laser - accelerated protons energies

Summary

- Target Normal Sheath Acceleration Mechanism
- Experimental Set-up
- Calibration of passive detectors using monoenergetic proton beams and dedicated software codes
- Atomic force microscopy analysis of laser accelerated proton tracks in CR-39 detectors stack
- Conclusions
- Acknowledgments

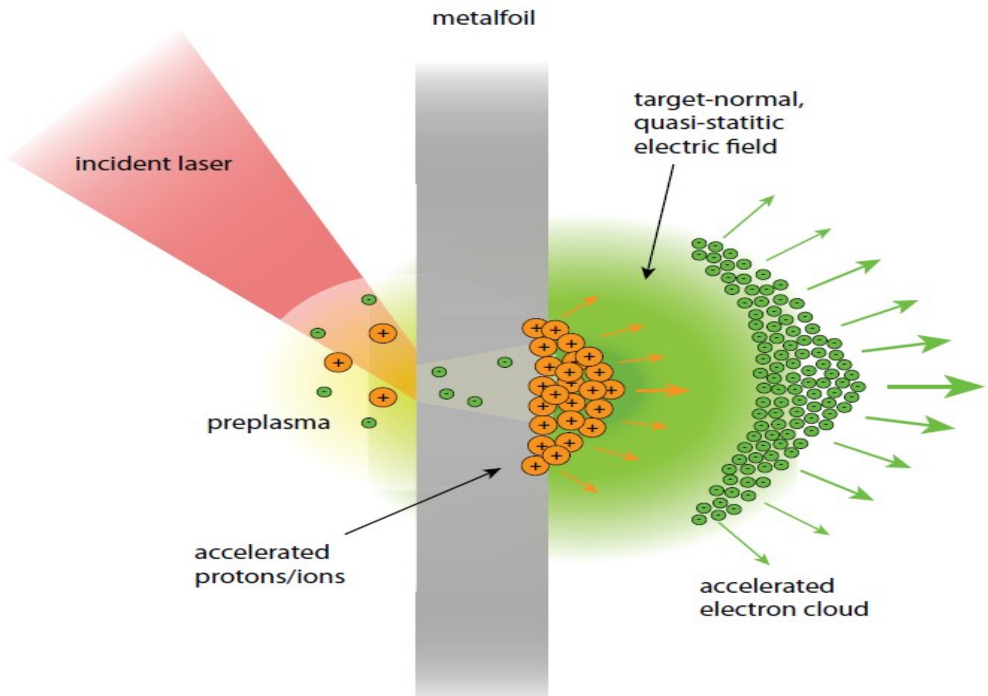
Target Normal Sheath Acceleration mechanism in high power laser - solid target interaction



I > 10^{18} W/cm^2

The energy deposits by the laser pulse at the target surface is partially absorbed (conversion eficency factor η) into the hot electrons

$$N_e \approx \frac{\eta E_L}{k_B T}$$



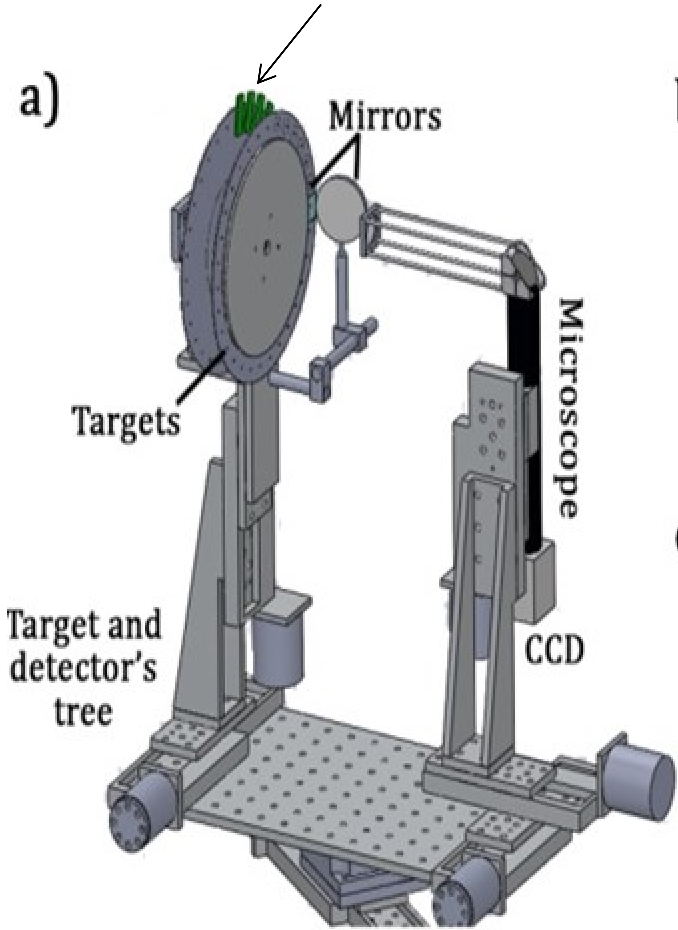
the most energetic electrons accelerated in the forward direction escape from the rear side of the target and form an electron sheath resulting in an electric field of TV/m on the rear surface

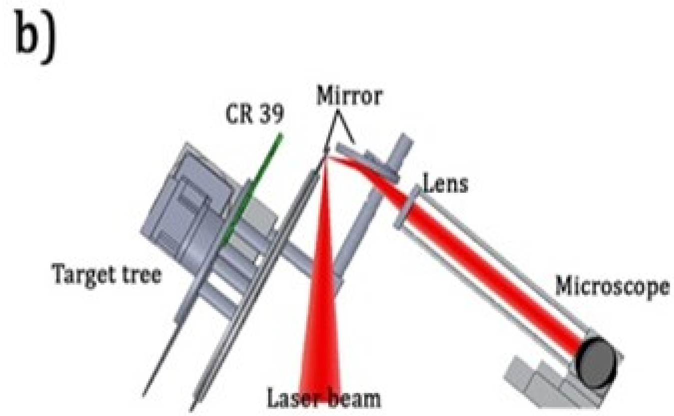
protons from impurities on the target rear surface are field ionized and accelerated normal to the surface in vacuum along the electric field line

J. Fuchs, et all Nature Phys., 2, 48–56, 2006.
M. Roth, M. Schollmeier, "Laser-Plasma Interactions and Applications", Scottish Graduate Series Springer International Publishing, 2013

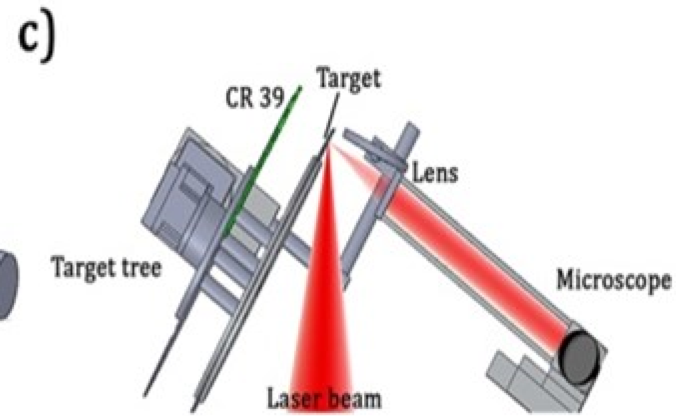
Experimental Set-up

detectors stack





for laser beam focal point profile analysis



to visualize the reflected laser light on target

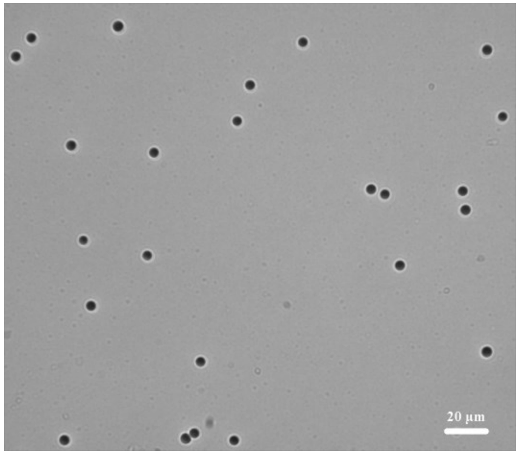
5 and 10 μm thick targets was prepared by magnetron sputtering technique

Laser parameters in focus:
laser energy 8 J
45^0 laser incidence angle on the target
laser spot dimensions 9 x 23 μm^2
$I = 5 \times 10^{19}$ W/cm^2

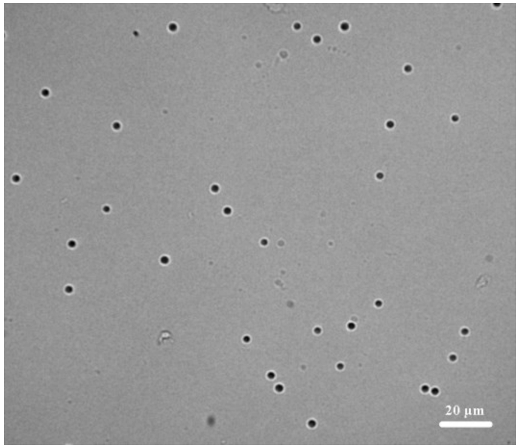
Calibration of CR-39 nuclear track detectors used for laser accelerated proton track analysis

-irradiation of CR-39 detectors with monoenergetic proton beams
-estimation of bulk etching rate of the CR-39 detectors in specific etching conditions
-calculation of proton range and proton track diameter using dedicated numerical codes
-finding of the correspondence between the proton incident energy on the detector stack and the proton incident energy on the second CR-39 detector
-established of a calibration curve that relates proton track diameter with proton energy

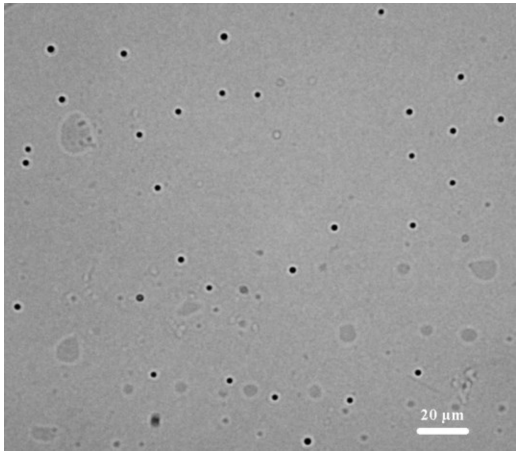
Experimental results on the irradiation of CR-39 detectors with monoenergetic proton beams



2 MeV
D=5.5 μm



3 MeV
D=4.5 μm



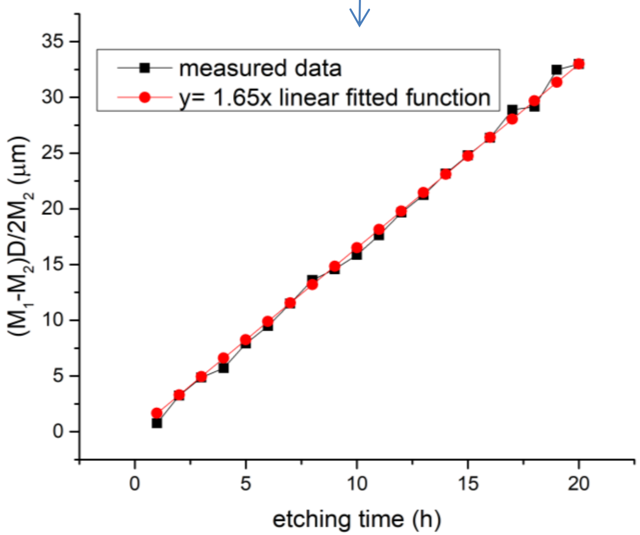
5 MeV
D=3 μm

-the black circular tracks are attributed to protons
-the spots with irregular shapes and sizes are due to the chemical etch of the detector’s material
- similar results obtained from AFM investigations

proton track diameter depend on the chemical etching condition of the detectors

determination of the bulk etching rate of CR-39 detectors

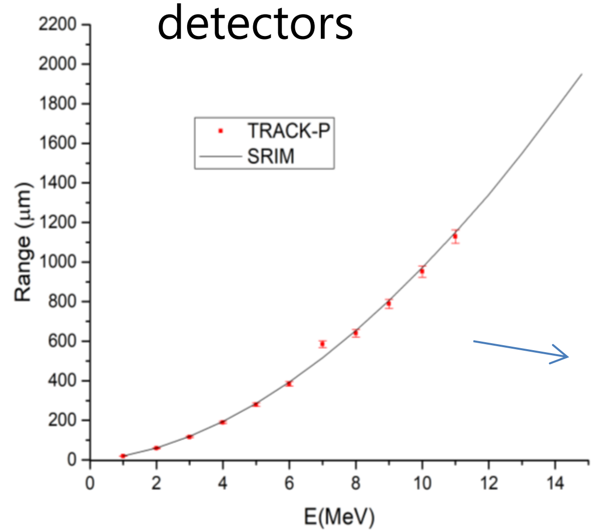
$$(M_1\text{-}M_2)D/2M_1 = v_b\, t$$



essential in the finding of the correspondence between proton track diameter and proton energy

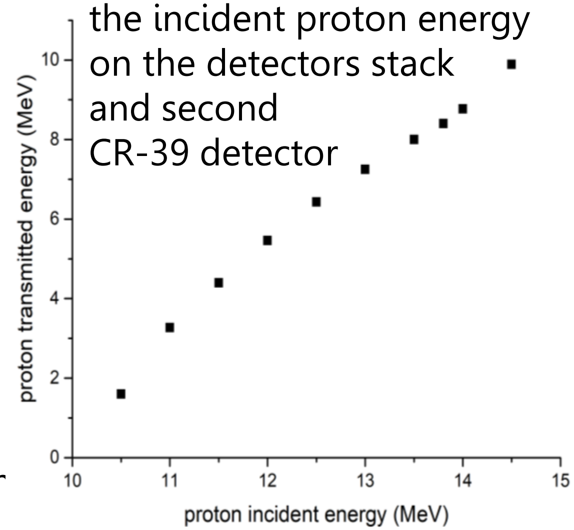
bulk etch rate of 1.65 ± 0.05 µm/h over an etching tim

proton range in CR-39 detectors

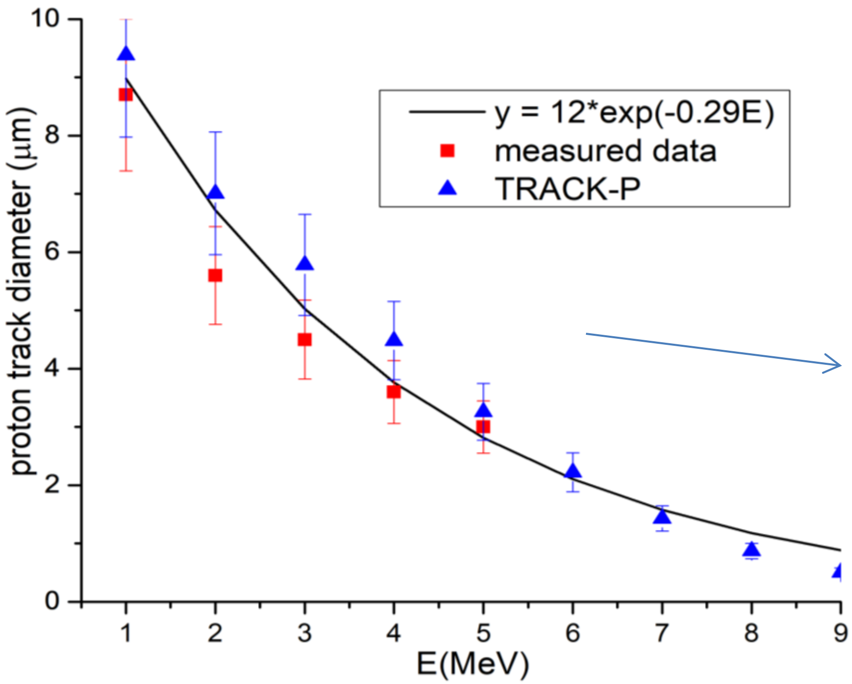


protons with maximum energy of 14.5 MeV can be stopped in the second CR-39 detector of the stack

correspondence between the incident proton energy on the detectors stack and second CR-39 detector



Evolution of the proton track diameter in CR-39 detector as function of proton energy



minimum proton track diameter that can be observed on a CR-39 detector is 0.8 µm which correspond to 9 MeV proton energy

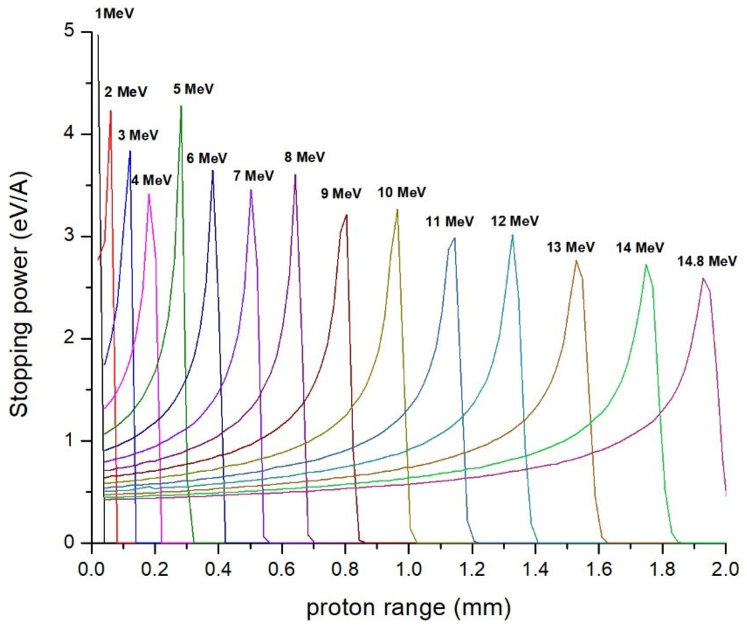
9.38 µm (for 1 MeV proton energy) 0.8 µm (for 9 MeV proton energy)

comparison between experimental data and the computed one considering the etching parameters of the CR-39 detectors

a fitted curve and a fitted function

Data obtained from SRIM simulation of the detector stack.

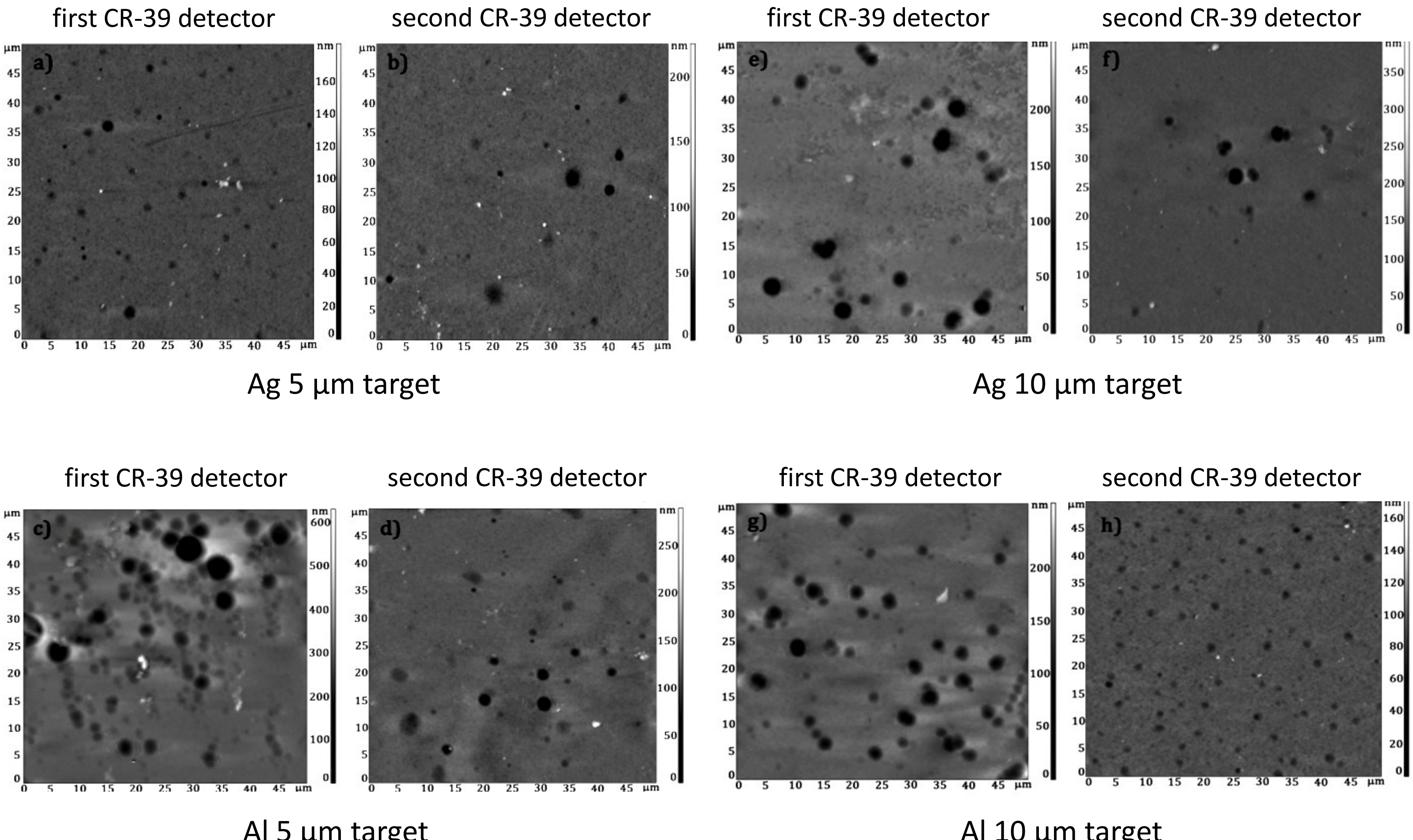
Layer No.	Energy (MeV)	Proton range (mm)	Stopping power intensity(eV/A)	Simulation structures of the experimental stack (10 μm Al +2 mm of the CR-39 detectors)
1	1	$15.5 \cdot 10^{-3}$	4.96	5.9 μm
2	2	$55.3 \cdot 10^{-3}$	4.23	layer 1 + 40.5 μm
3	3	$115 \cdot 10^{-3}$	3.85	layer 2+ 58.5 μm
4	4	$187 \cdot 10^{-3}$	3.41	layer 3 + 76 μm
5	5	$279 \cdot 10^{-3}$	4.27	layer 4 + 93.5 μm
6	6	$386 \cdot 10^{-3}$	3.65	layer 5 + 109 μm
7	7	$508 \cdot 10^{-3}$	3.45	layer 6 + 124 μm
8	8	$646 \cdot 10^{-3}$	3.6	layer 7+ 142 μm
9	9	$797 \cdot 10^{-3}$	3.22	layer 8 + 153 μm
10	10	$962 \cdot 10^{-3}$	3.25	layer 9 + 168 μm
11	11	1.14	2.97	layer 10+ 178 μm
12	12	1.33	3.02	layer 11 + 200 μm
13	13	1.53	2.76	layer 12+ 205 μm
14	14	1.76	2.72	layer 13 + 230 μm
15	14.8	1.95	2.59	layer 14 +200 μm



protons with energies higher than 10.5 MeV can fully deposit their energies in the second CR-39 detector

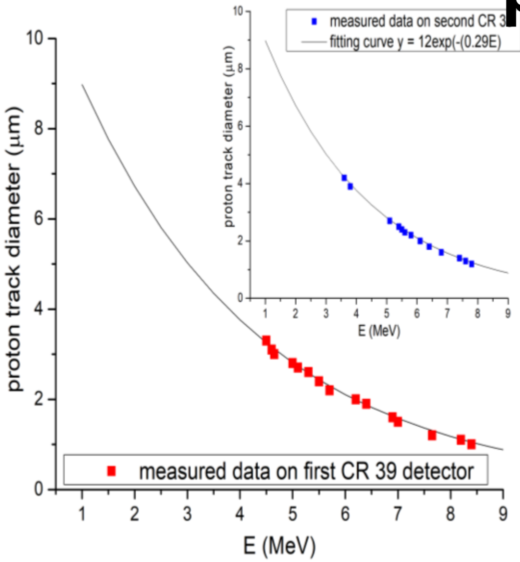
Bragg peak positions in CR-39 detector stack

Analysis of the laser driven proton tracks in CR-39 detectors by atomic fo

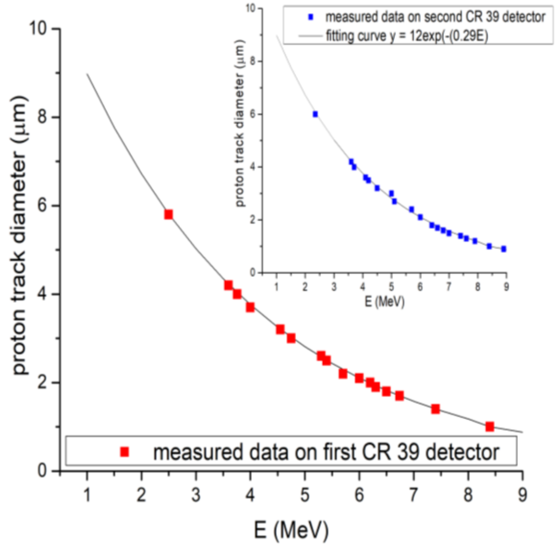


- minimum track diameter that can be attributed to protons Is about 0.8 µm

Evolution of proton track diameters on first and second post etched CR-39 detector



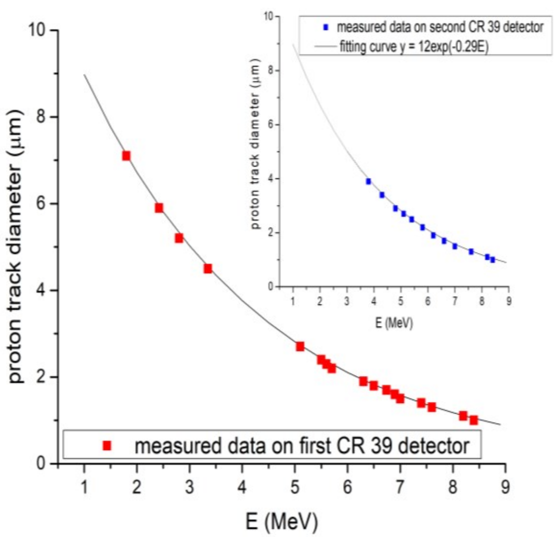
Ag 5 µm target



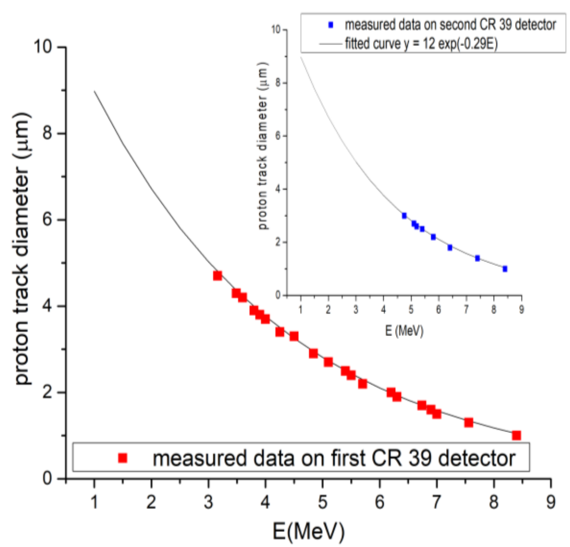
Ag 10 µm target

establish of proton energies
resulted as a consequence of
high power laser - solid targe
interaction

maximum proton energy
of 13.8 MeV within
±15 % error



Al 5 µm target



Al 10 µm target

minimum track diameter
that can be attributed
to protons
Is about 0.8 µm

Conclusions

We propose a method to assess the energy of the laser-accelerated proton beams within the 1-15 MeV range, by investigating the tracks left in a stack made of two CR-39 detectors. All issues that occur after the exposure of CR-39 type to laser- accelerated proton beams, followed by etching in specific physical and chemical conditions was analysed and discussed.
Only individual tracks with circular or elliptic shapes, with very well defined edges and diameters in the 0.8 – 8 μm range, which are theoretically established, are assigned to protons.

The most important step consists in the calibration of the CR-39 detectors and finding of an analytical expression of the calibration curve in the 1-9 MeV energy range.

Estimation of the proton energy from the track diameter measured by AFM in each dete
that compose the irradiated stack.

Acknowledgements

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