Laser accelerated ion beam diagnostics

Bc. Boris Odložilík

Czech Technical University in Prague
Department of Dosimetry and Application of Ionizing Radiation

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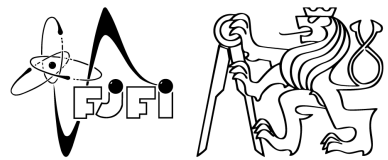
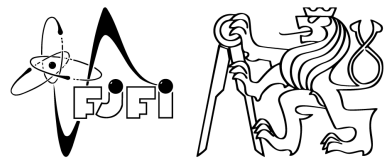
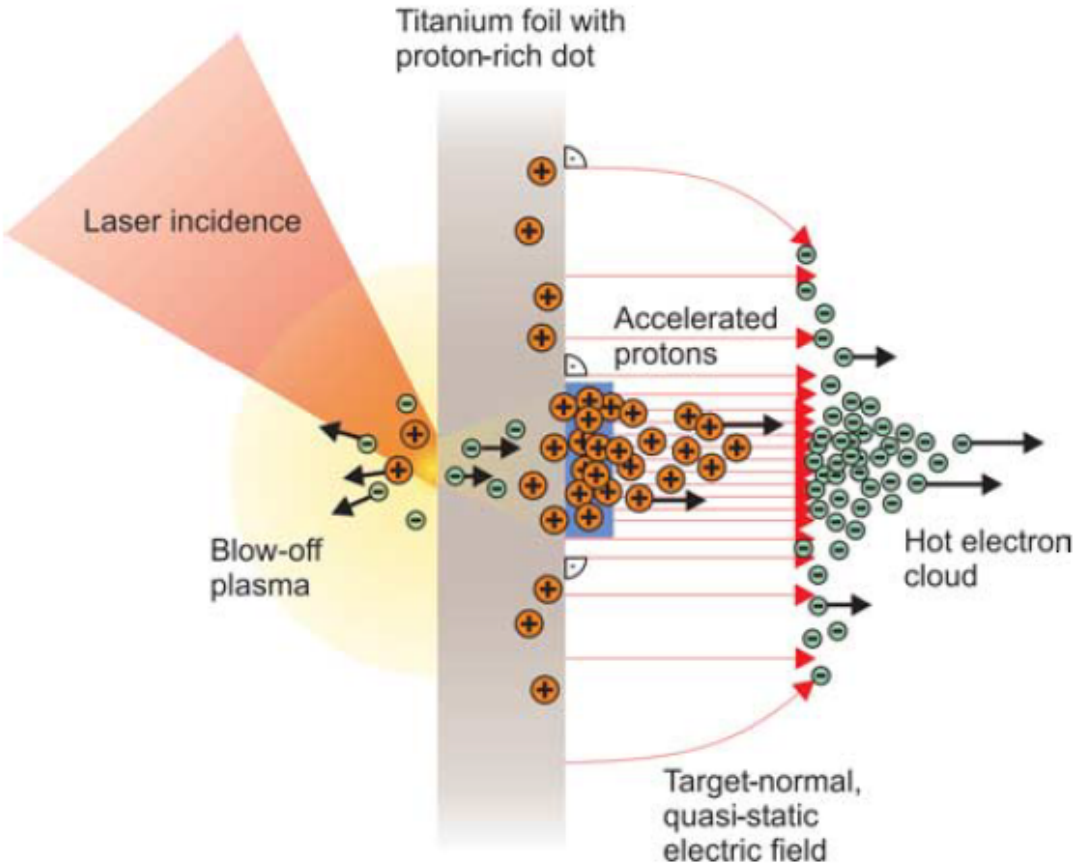


Content of the presentation

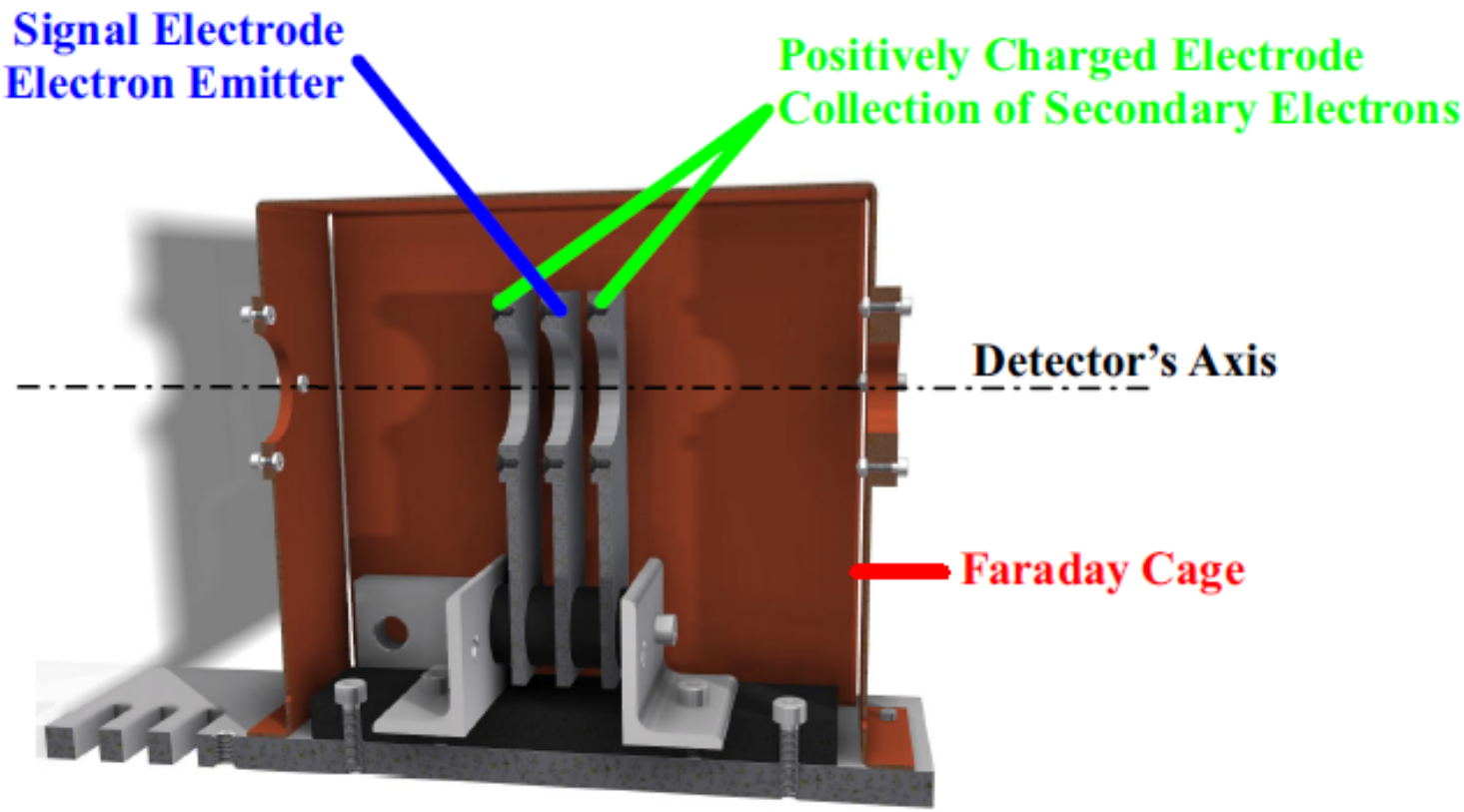
- Short introduction to laser-driven ion acceleration.
- Diagnostics of accelerated ion beams.
- Radiochromic films stack detectors.

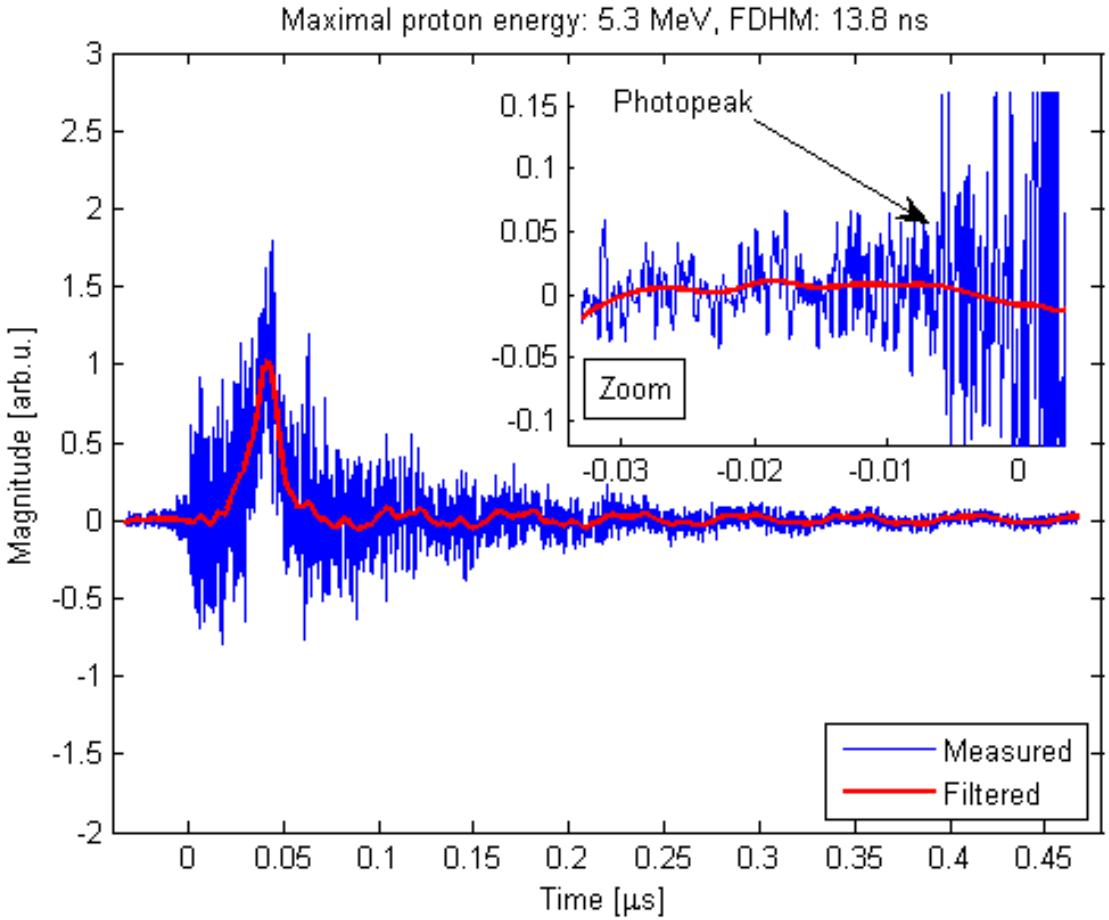
- Target Normal Sheath Acceleration (TNSA)
- Radiation Pressure Acceleration (RPA)
- Magnetic Vortex Acceleration (MVA)
- Directed Coulomb Explosion (DCE)
- Break-Out Afterburner (BOA)
- Coulomb Explosion (CE)
- Shock Acceleration (SA)

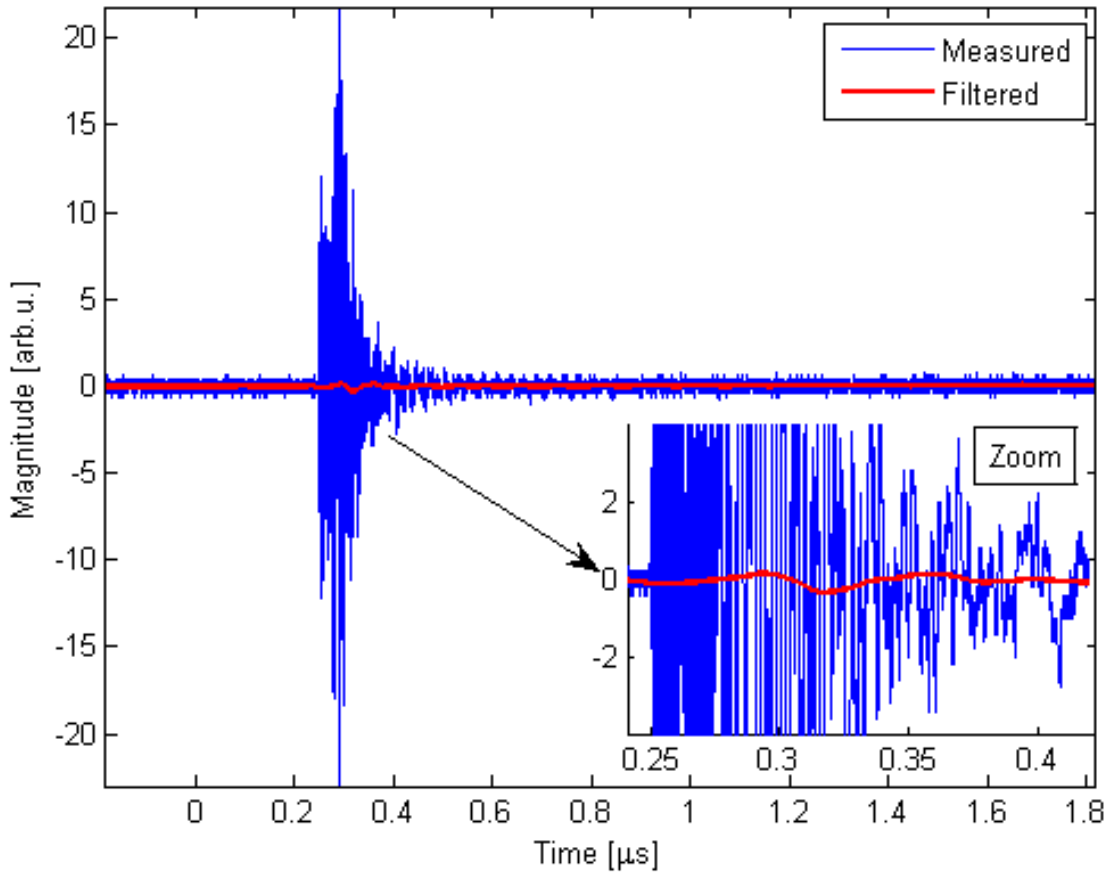



Titanium foil with
proton-rich dot
Laser incidence
Accelerated
protons
Blow-off
plasma
Hot electron
cloud
Target-normal,
quasi-static
electric field

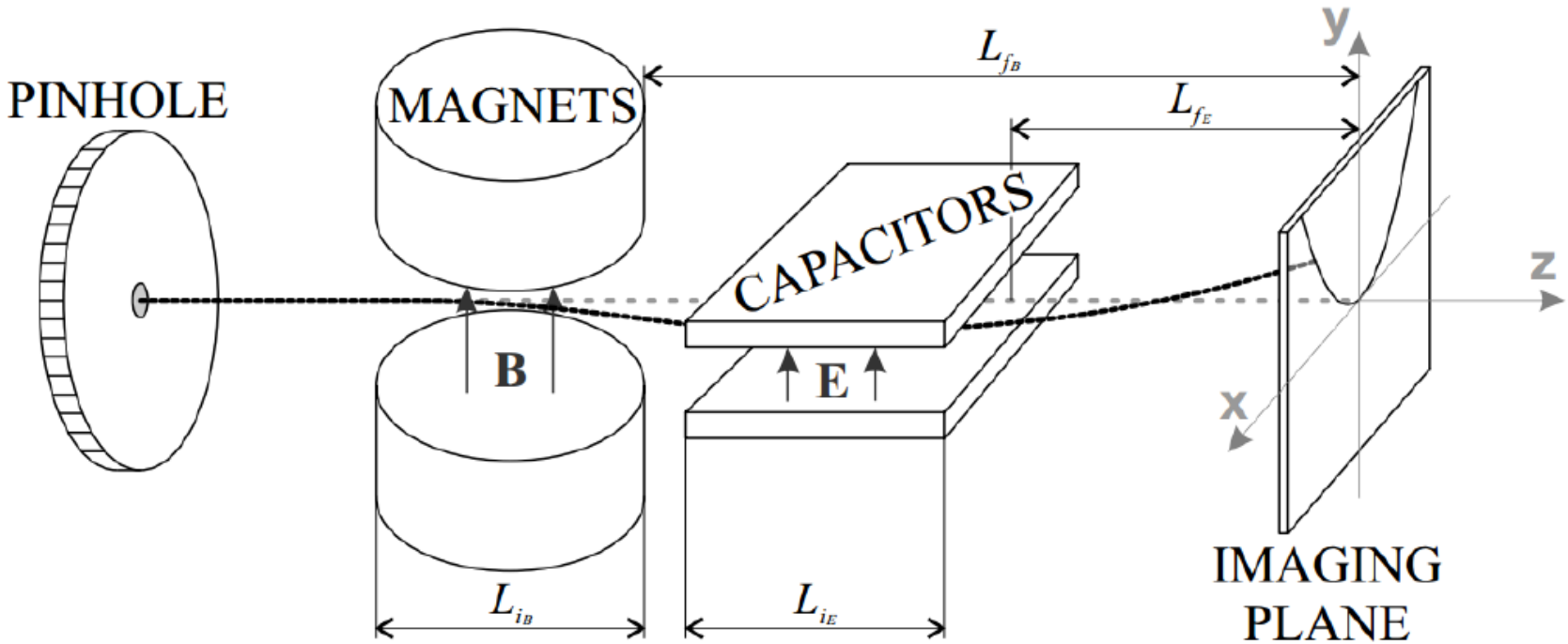
SEM-0


Signal Electrode
Electron Emitter
Positively Charged Electrode
Collection of Secondary Electrons
Detector's Axis
Faraday Cage


Maximal proton energy: 5.3 MeV, FDHM: 13.8 ns
Photopeak
Zoom
Measured
Filtered
Magnitude [arb.u.]
Time [μs]


Measured
Filtered
Zoom
Magnitude [arb.u.]
Time [μs]
20
15
10
5
0
-5
-10
-15
-20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
-2
0.25
0.3
0.35
0.4

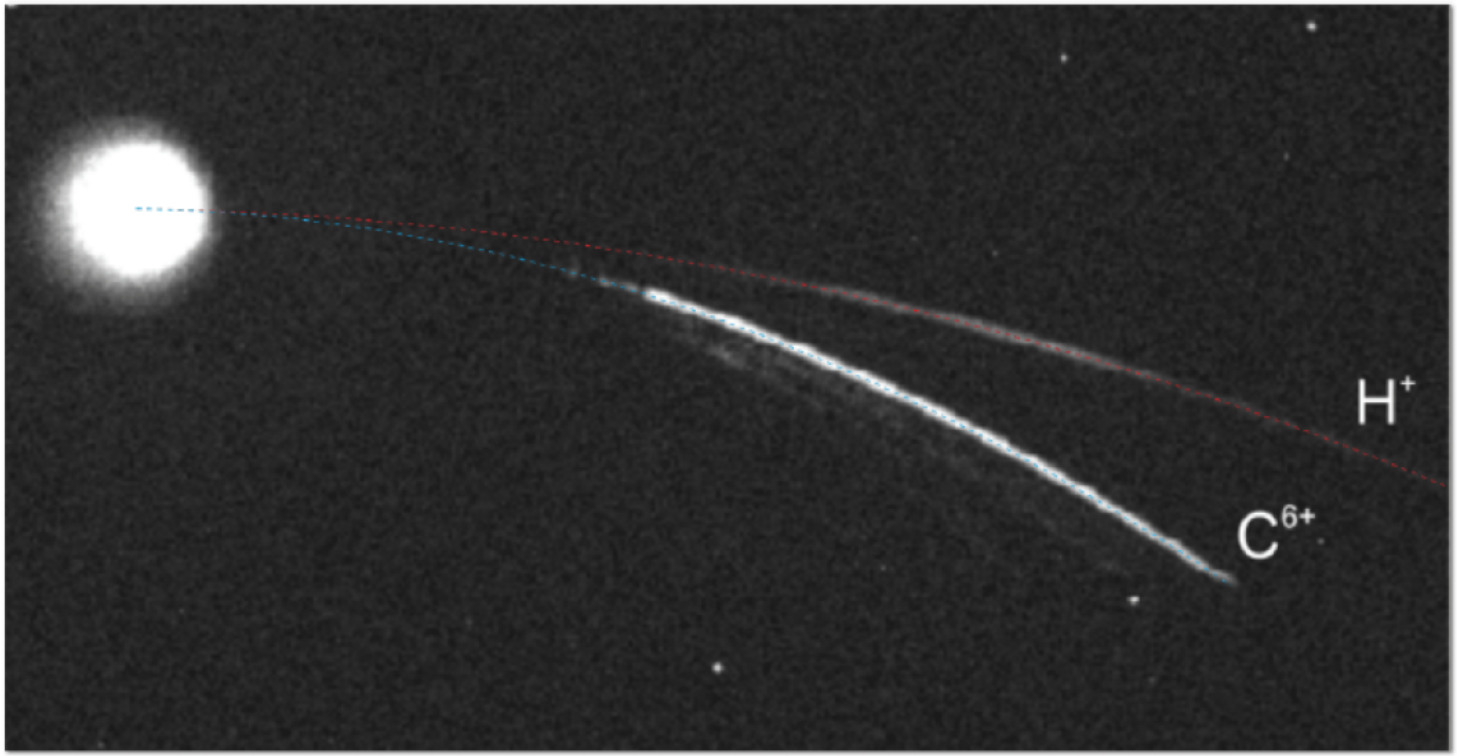
Thomson parabola



$$x = \frac{qBL_{iB}}{mv}\left(\frac{L_{iB}}{2} + L_{fB}\right)$$

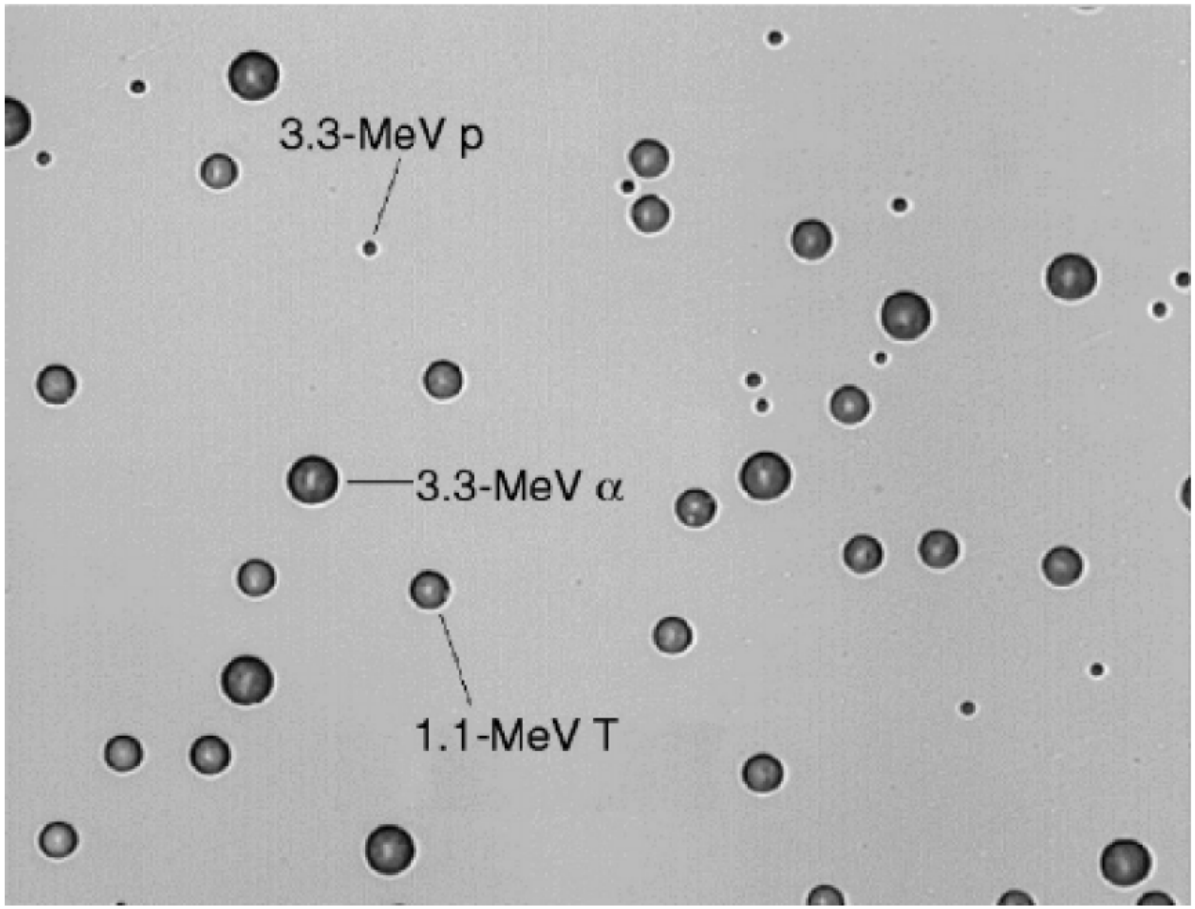
$$y = \frac{qEL_{iE}}{mv^2}\left(\frac{L_{iE}}{2} + L_{fE}\right)$$

$$y = \frac{mEL_{iE}\left(\frac{L_{iE}}{2} + L_{fE}\right)}{qB^2L_{iB}^2\left(\frac{L_{iB}}{2} + 2L_f\right)^2} \cdot x^2$$


H+
C6+

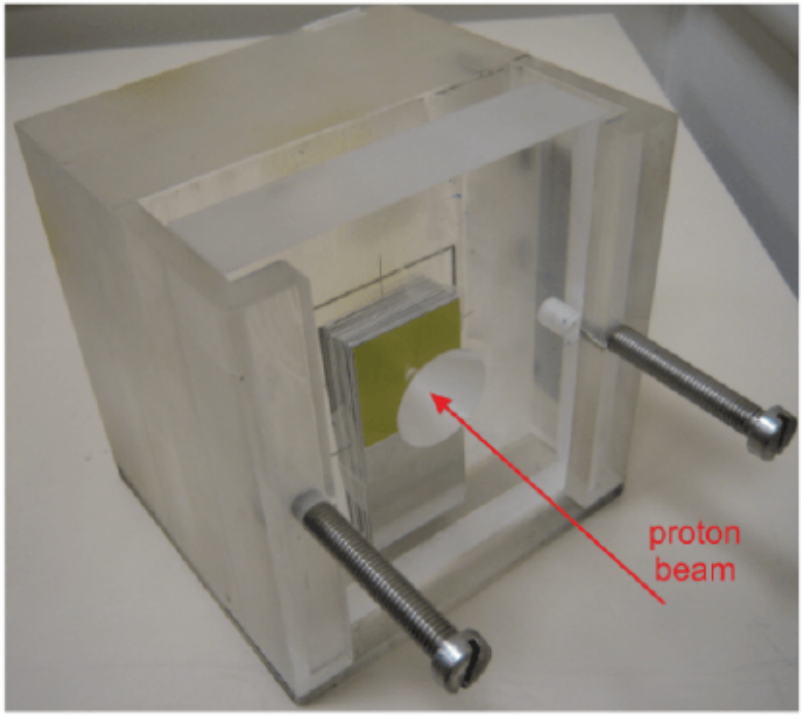
CR39

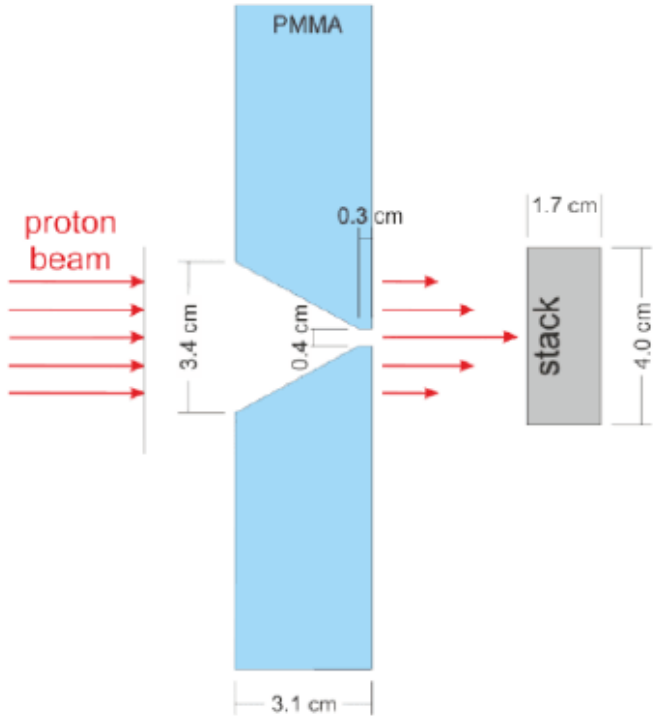
- Polymer solid state nuclear track detector.
- Sensitive only to charged particles.
- Etching makes tracks visible (optical microscope).
- Different crater sizes allow to characterize particles.

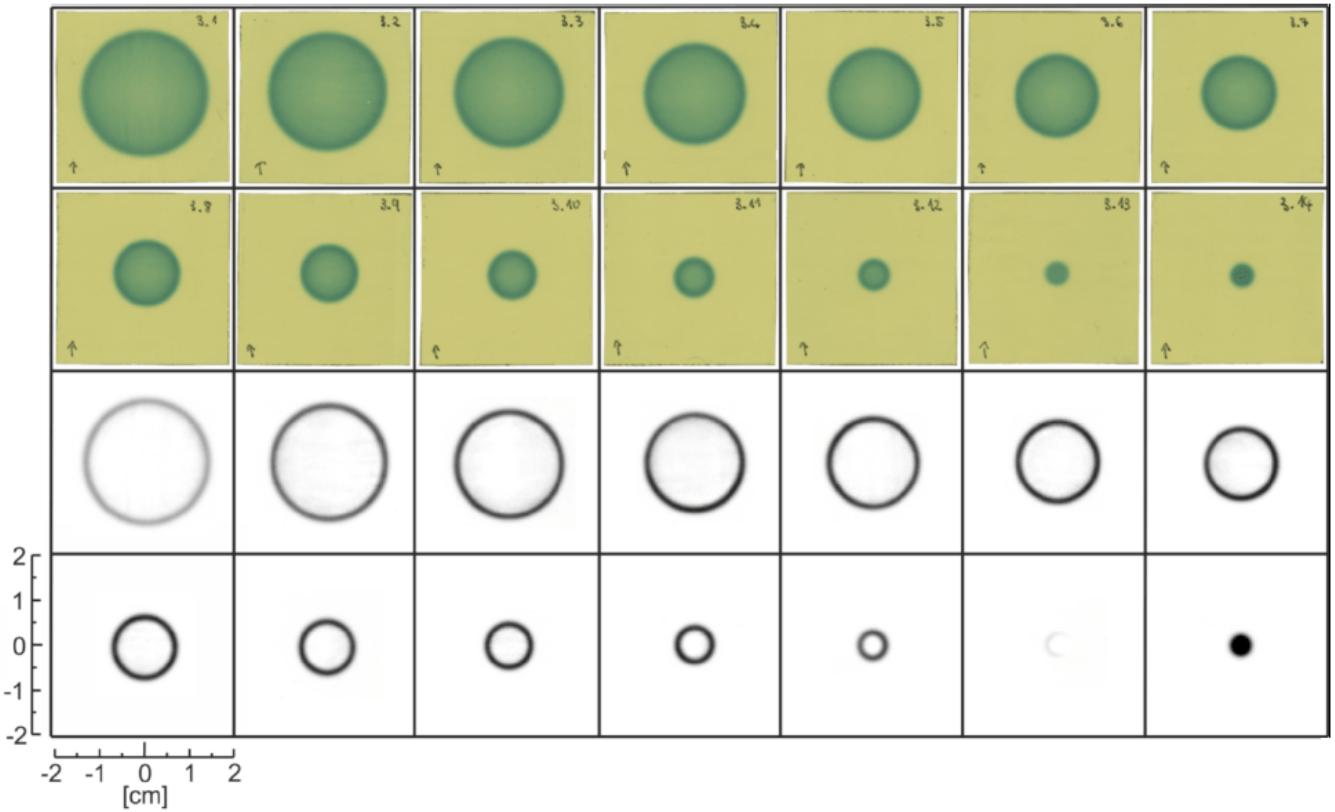

3.3-MeV p
3.3-MeV α
1.1-MeV T

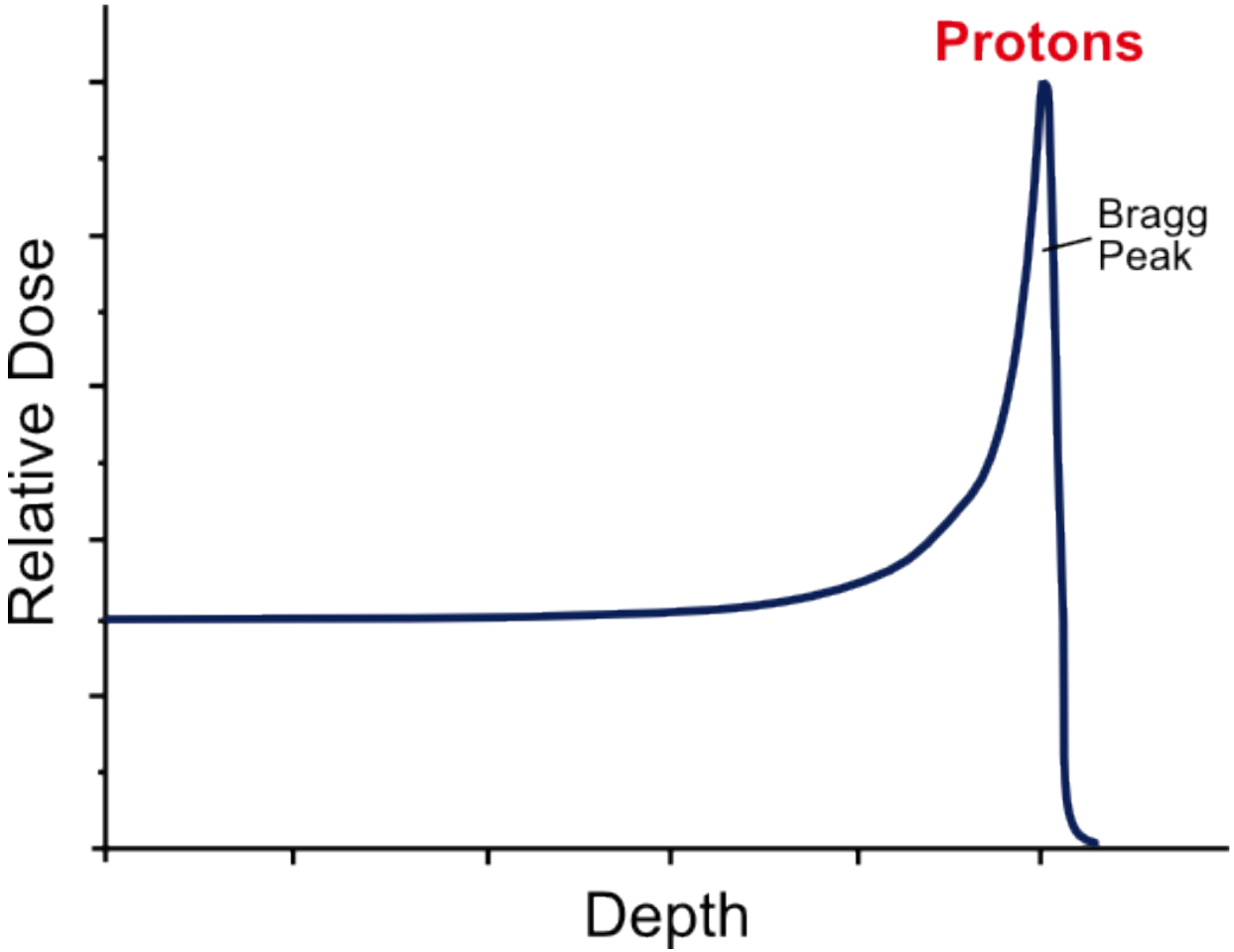
Radiochromic films

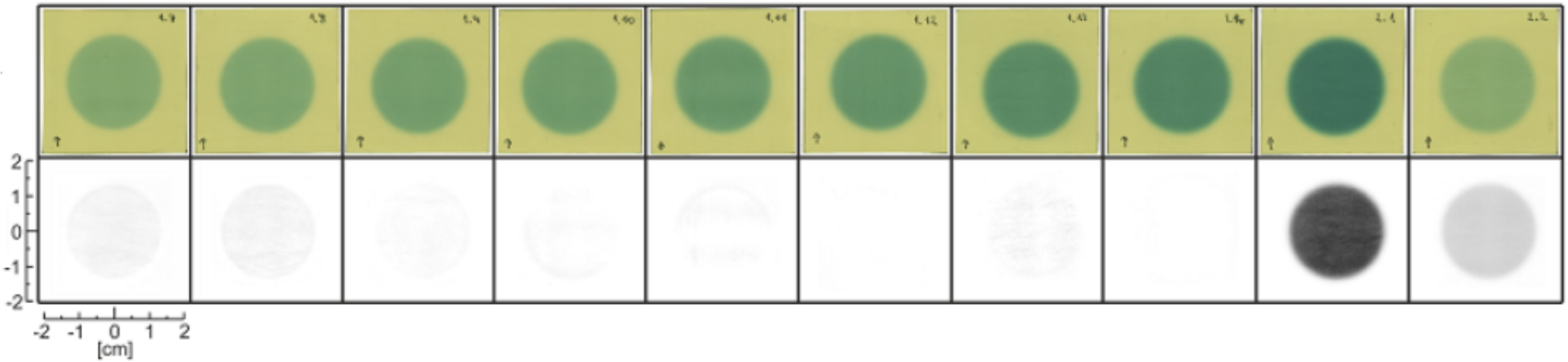
- Optical density change dependent on the received dose.
- Chemical processing is not needed.
- Polymerization of organic monomer in active layer.
- Optical density is proportional to polymer density.
- Polymer density is proportional to the received dose.

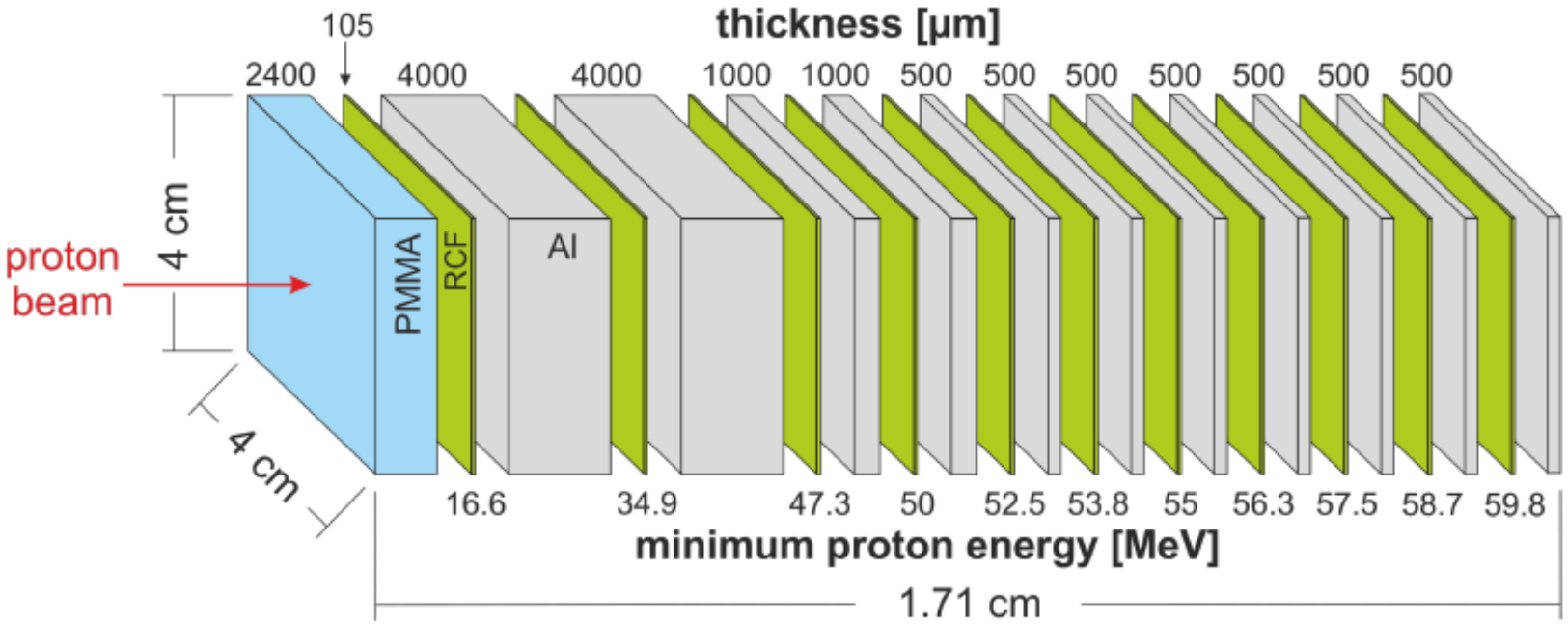

proton
beam

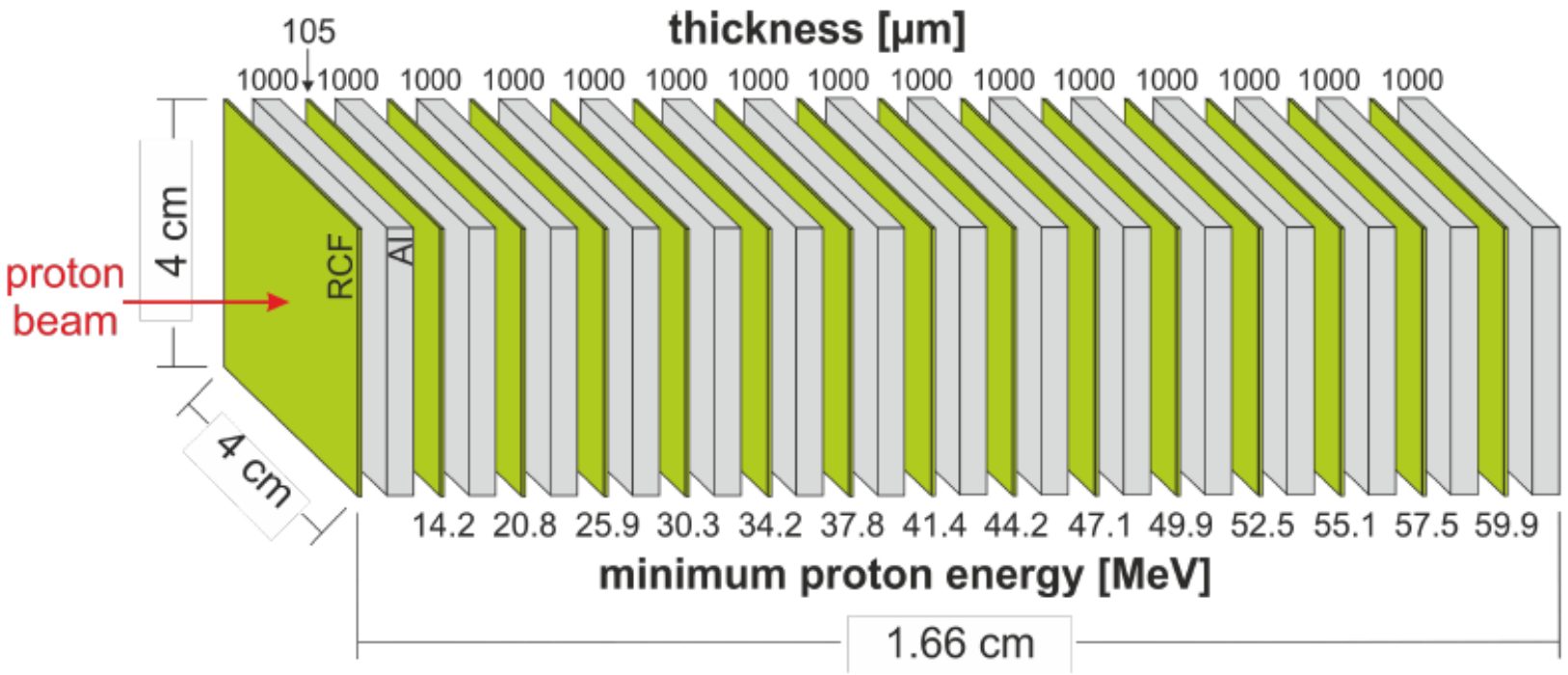

PMMA
proton
beam
0.3 cm
1.7 cm
3.4 cm
0.4 cm
stack
4.0 cm
3.1 cm


2
1
0
-1
-2
-2 -1 0 1 2
[cm]

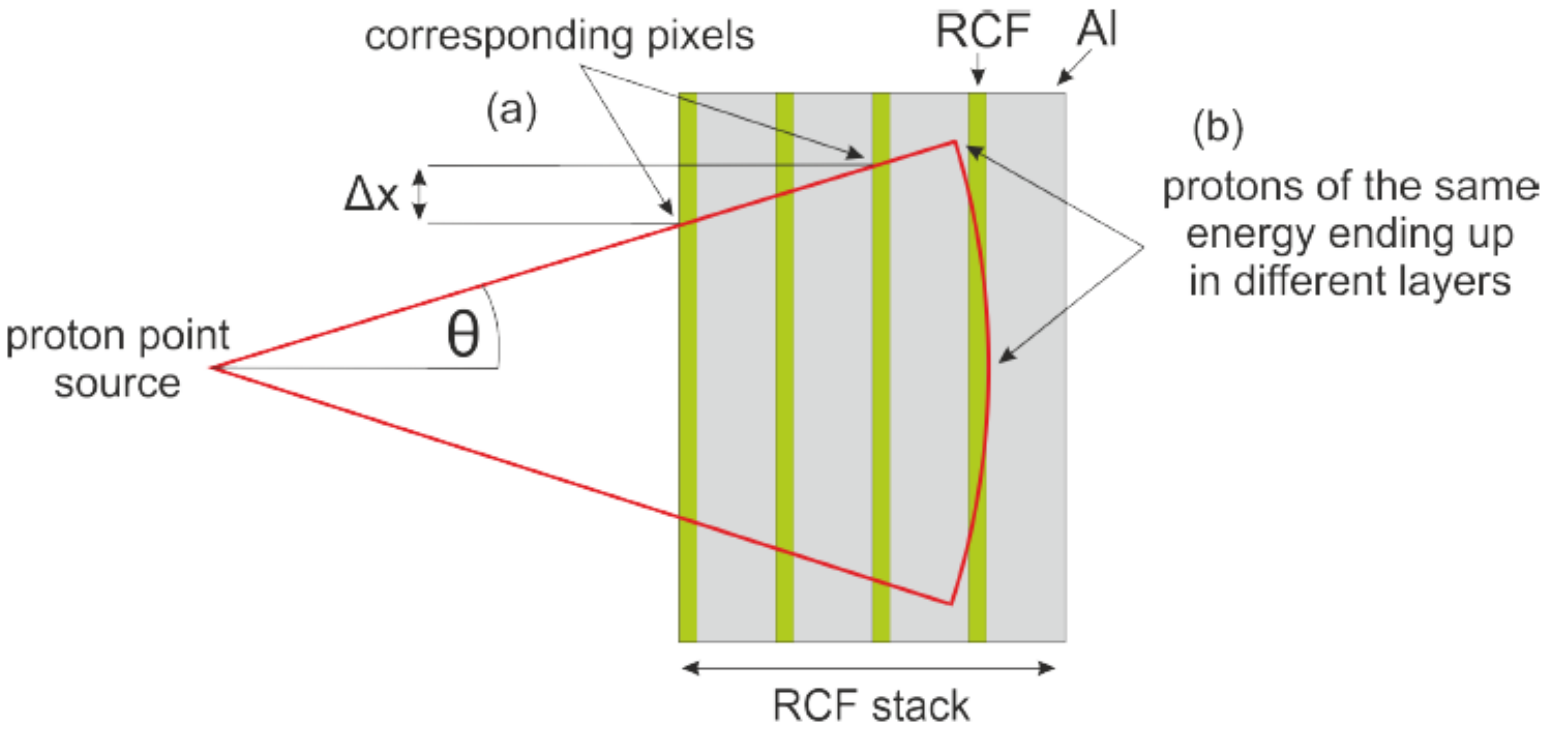

Protons
Bragg
Peak
Relative Dose
Depth

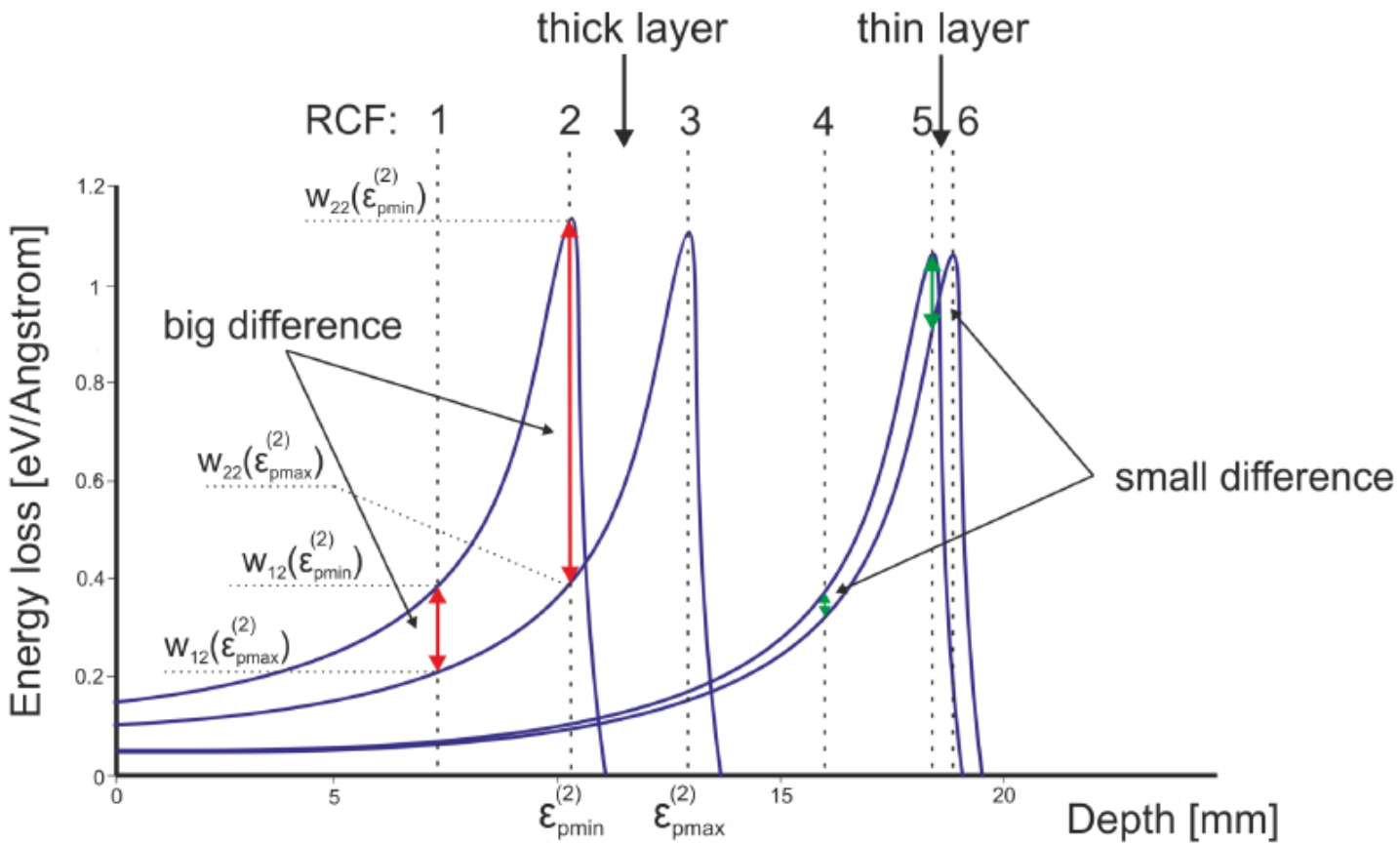

2
1
0
-1
-2
-2 -1 0 1 2
[cm]

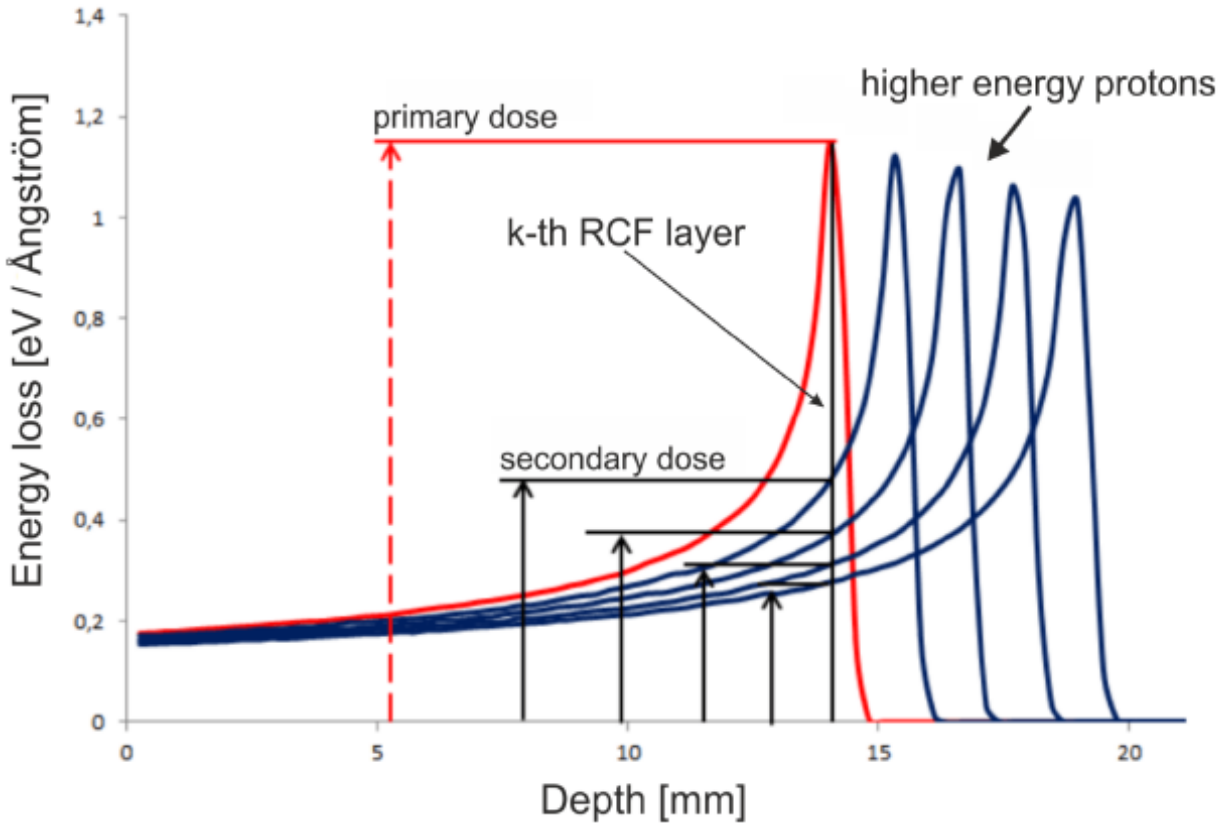

thickness [µm]
105
2400
4000
4000
1000
1000
500
500
500
500
500
500
500
proton
beam
4 cm
PMMA
RCF
Al
4 cm
16.6
34.9
47.3
50
52.5
53.8
55
56.3
57.5
58.7
59.8
minimum proton energy [MeV]
1.71 cm


thickness [μm]
105
1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000
proton beam
4 cm
RCF
Al
4 cm
14.2 20.8 25.9 30.3 34.2 37.8 41.4 44.2 47.1 49.9 52.5 55.1 57.5 59.9
minimum proton energy [MeV]
1.66 cm

Do not forget that...




thick layer
thin layer
RCF: 1 2 3 4 5 6
$w_{22}(\varepsilon^{(2)}_{pmin})$
big difference
$w_{22}(\varepsilon^{(2)}_{pmax})$
$w_{12}(\varepsilon^{(2)}_{pmin})$
$w_{12}(\varepsilon^{(2)}_{pmax})$
small difference
Energy loss [eV/Angstrom]
1.2
1
0.8
0.6
0.4
0.2
0
0
5
15
20
$\varepsilon^{(2)}_{pmin}$
$\varepsilon^{(2)}_{pmax}$
Depth [mm]

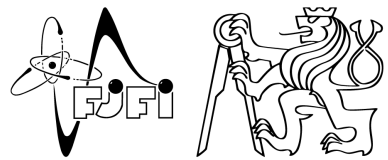

Energy loss [eV / Ångström]
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0
5
10
15
20
Depth [mm]
primary dose
higher energy protons
k-th RCF layer
secondary dose

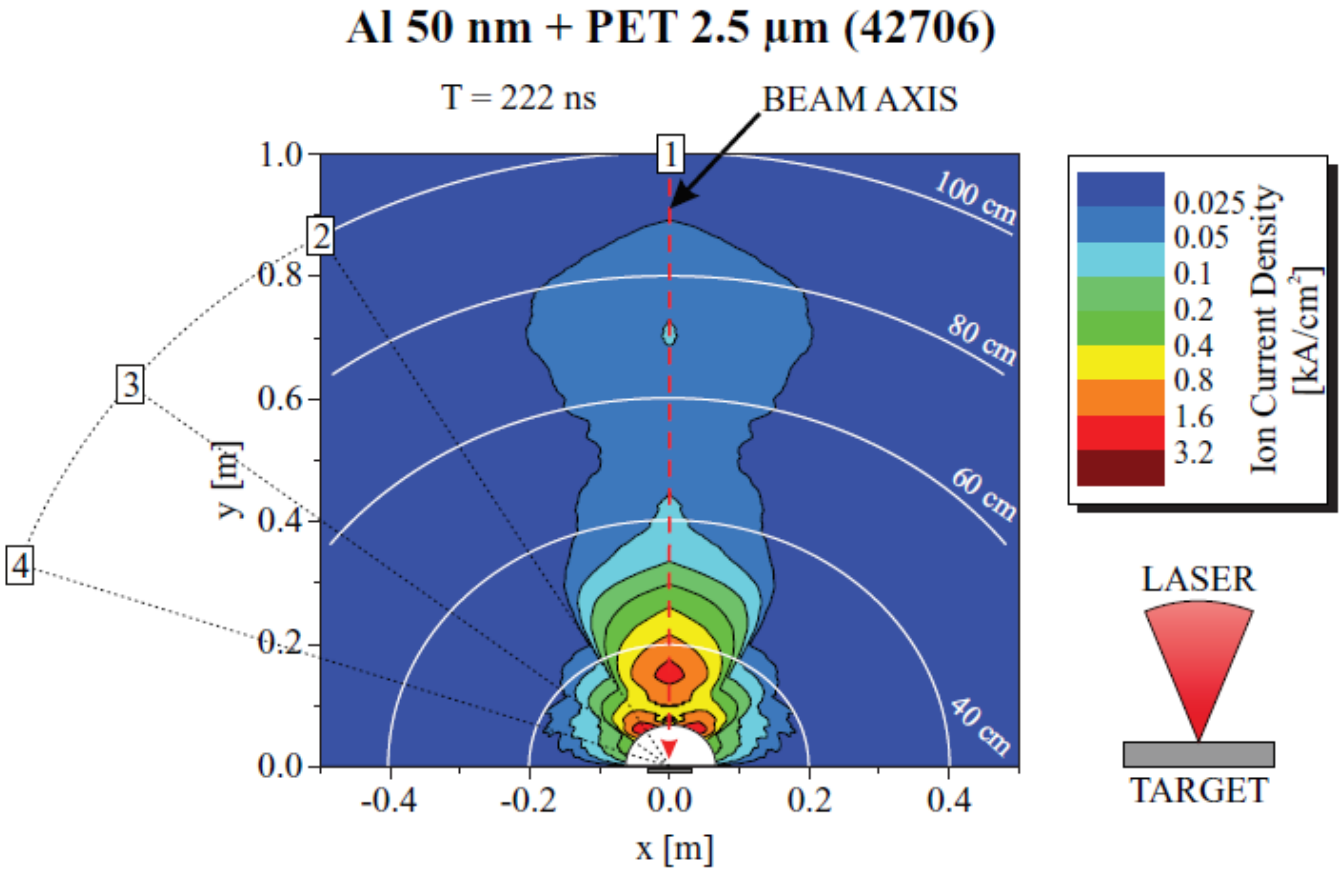
- Primary dose in the k^{th} RCF layer:

$$\mathbf{D}_{prim}^{(k)}\,[\mathrm{Gy}] = \mathbf{D}_{tot}^{(k)}\,[\mathrm{Gy}] - \sum_{i=k+1}^{N_T} \mathbf{D}_{prim}^{(i)}[\mathrm{Gy}]\,\frac{w_{ki}\,[\mathrm{eV/Angstrom}]}{w_{ii}\,[\mathrm{eV/Angstrom}]}$$

- Calibration is made for water phantom $\rightarrow$ correction.

Thank you!




Al 50 nm + PET 2.5 µm (42706)
T = 222 ns
BEAM AXIS
1
2
3
4
100 cm
80 cm
60 cm
40 cm
1.0
0.8
0.6
0.4
0.2
0.0
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
0.025
0.05
0.1
0.2
0.4
0.8
1.6
3.2
Ion Current Density [kA/cm²]
LASER
TARGET

(a) ELI-NP

(b) ELI-Beamlines

(c) ELI-ALPS