High energy proton detection by PADC track etch detectors.

(Results from Loma-Linda, NSRL-BNL proton ICHIBAN exposures and experiments at TSL accelerator, Uppsala, Sweden.)

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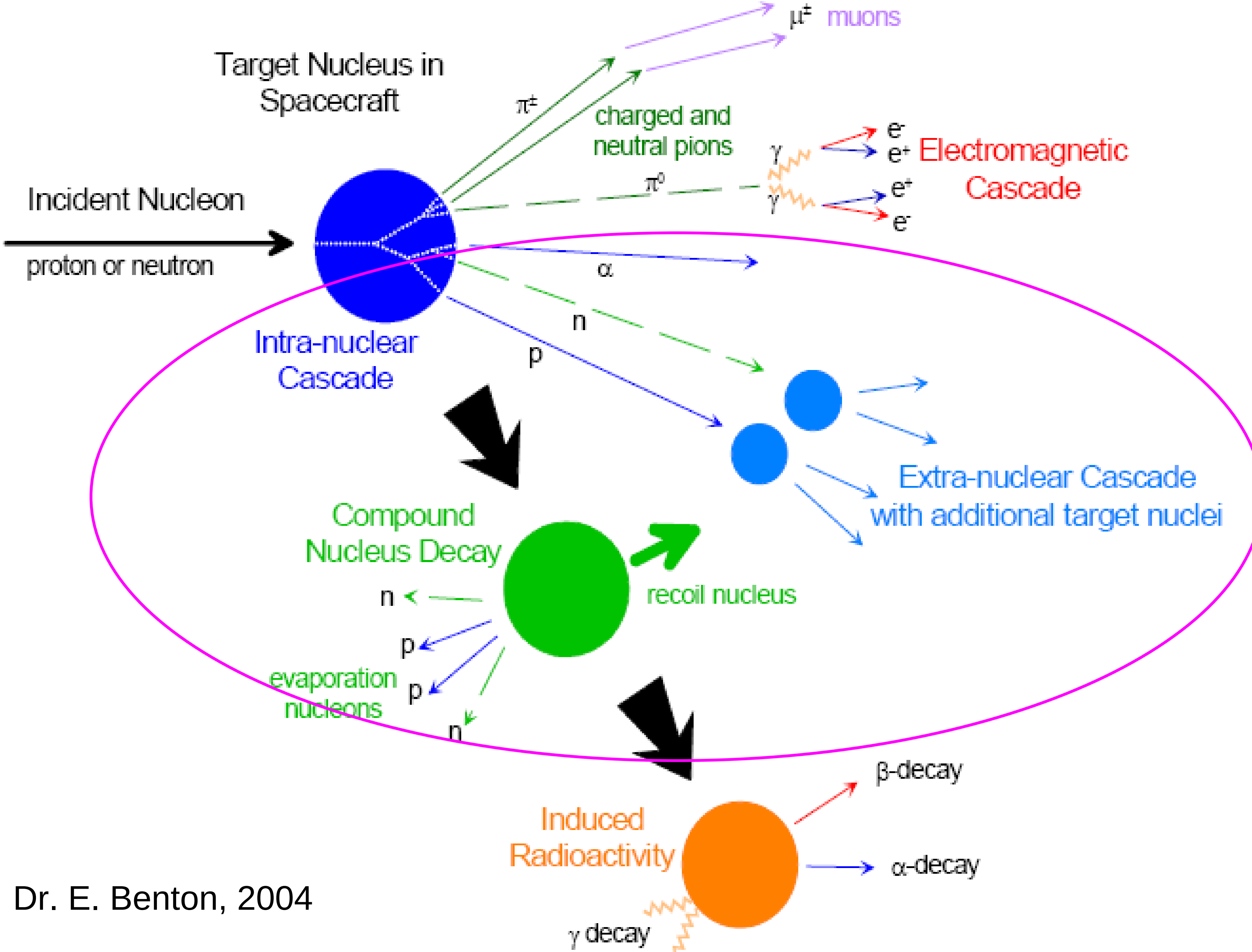
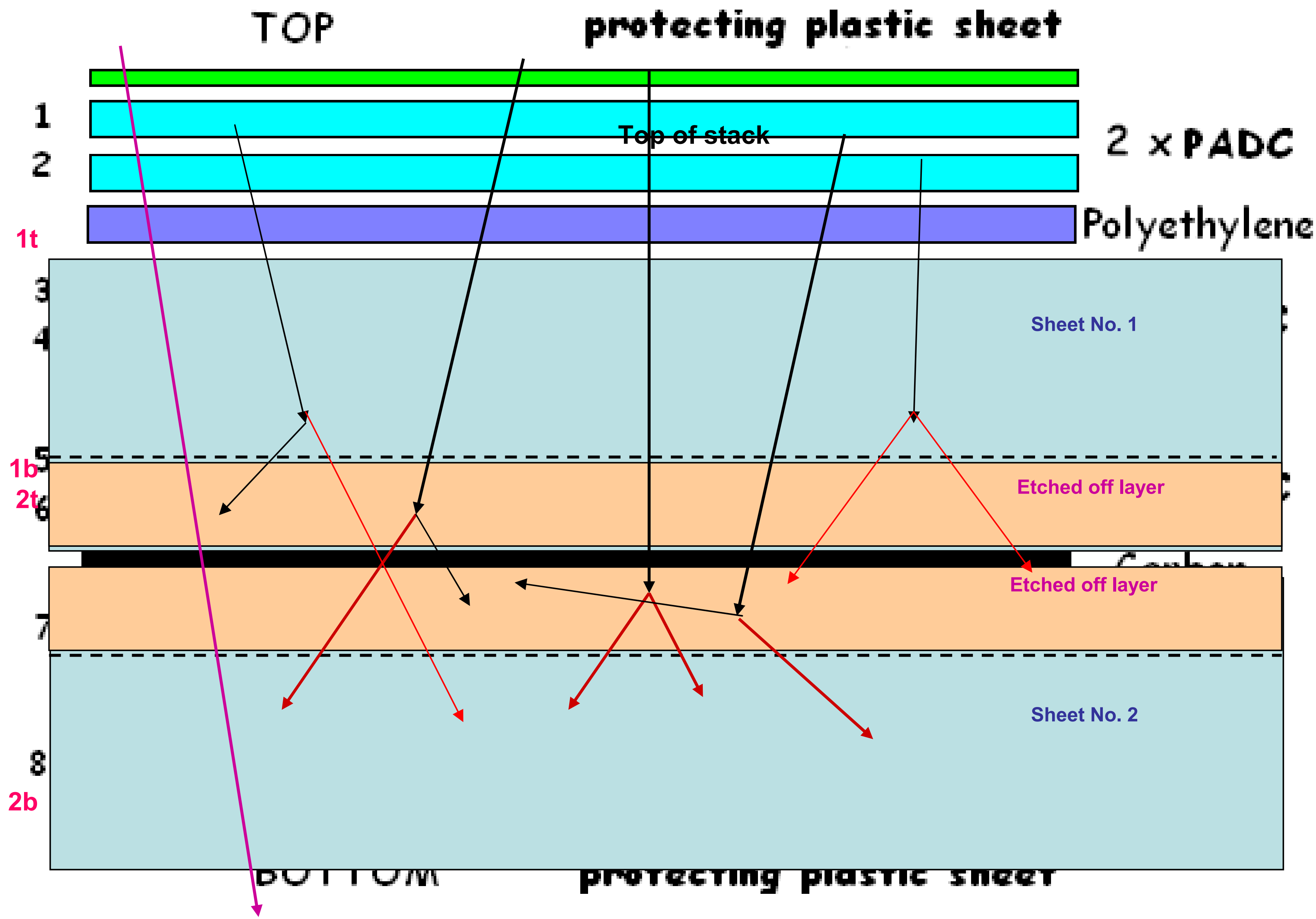


Dr. E. Benton, 2004

Proton induced ^{12}C fragmentation

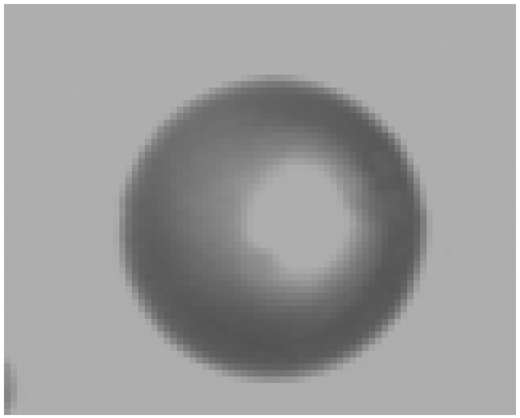
	^{6}Li +	^{7}Li+	^{7}Be+	^{9}Be+	^{10}Be+	^{10}B+	^{11}B+
Possible Coupled particles	^{7}Be	α+2p	α+D	^{3}He+p	3p	^{3}He	2p
Cross section, mb	9.8	7.8	12.2	2.5	1.8	19	63
Rel. probability, %	8.46	6.73	10.5	2.17	1.57	16.3	54.3
E_{my}, MeV	~5	~6	~7	~9	~6	~6	~6
Max. range, μm	~13	~16	~13	~17	~11	~9	~8

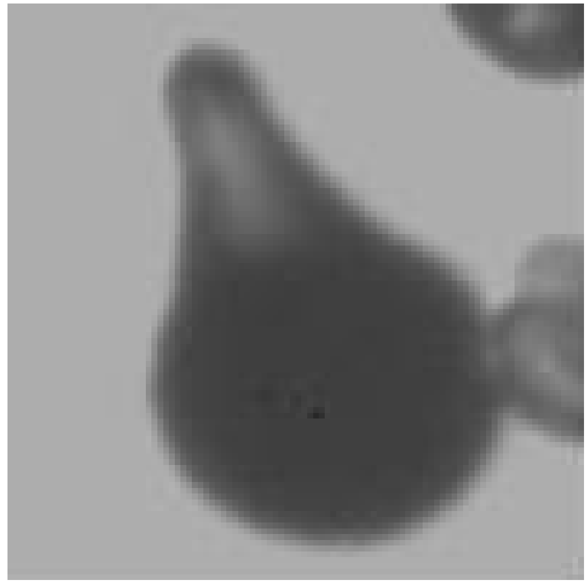
The weighted averaged range R_e = ~ 10 μm

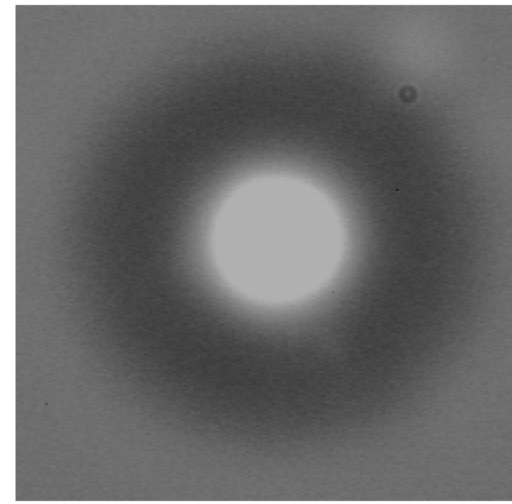


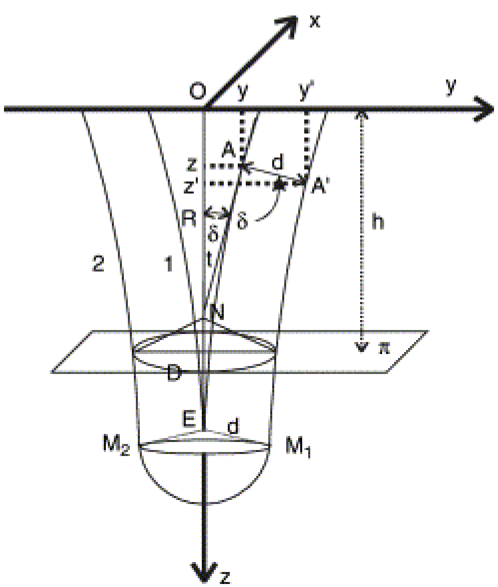
TOP
protecting plastic sheet
1
2
Top of stack
2 x PADC
Polyethylene
1t
Sheet No. 1
1b
2t
Etched off layer
Etched off layer
Sheet No. 2
8
2b

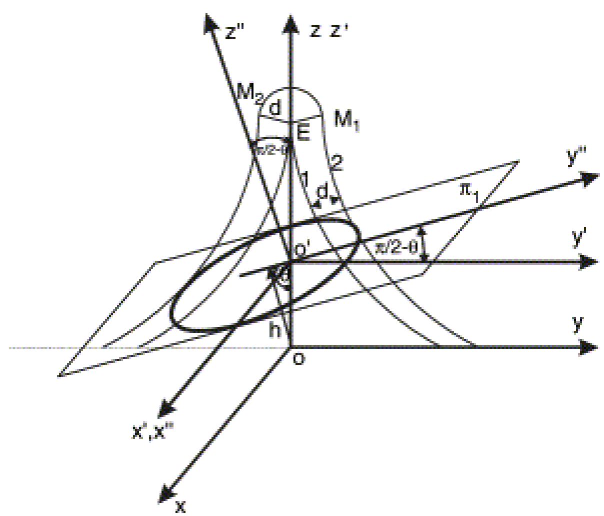
3DTrack formation dynamics, after Nikezic, 2003.

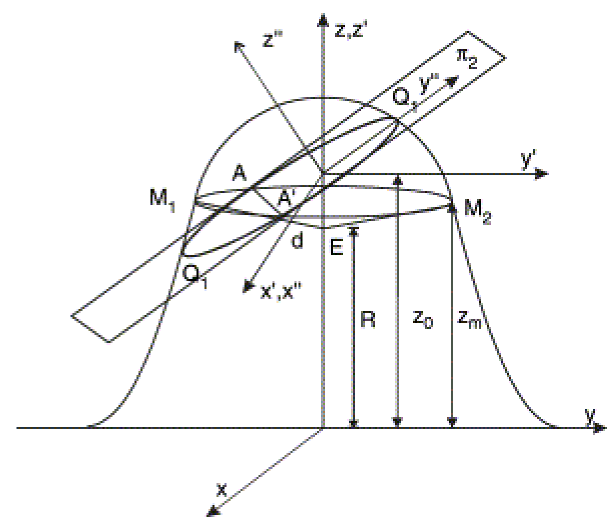


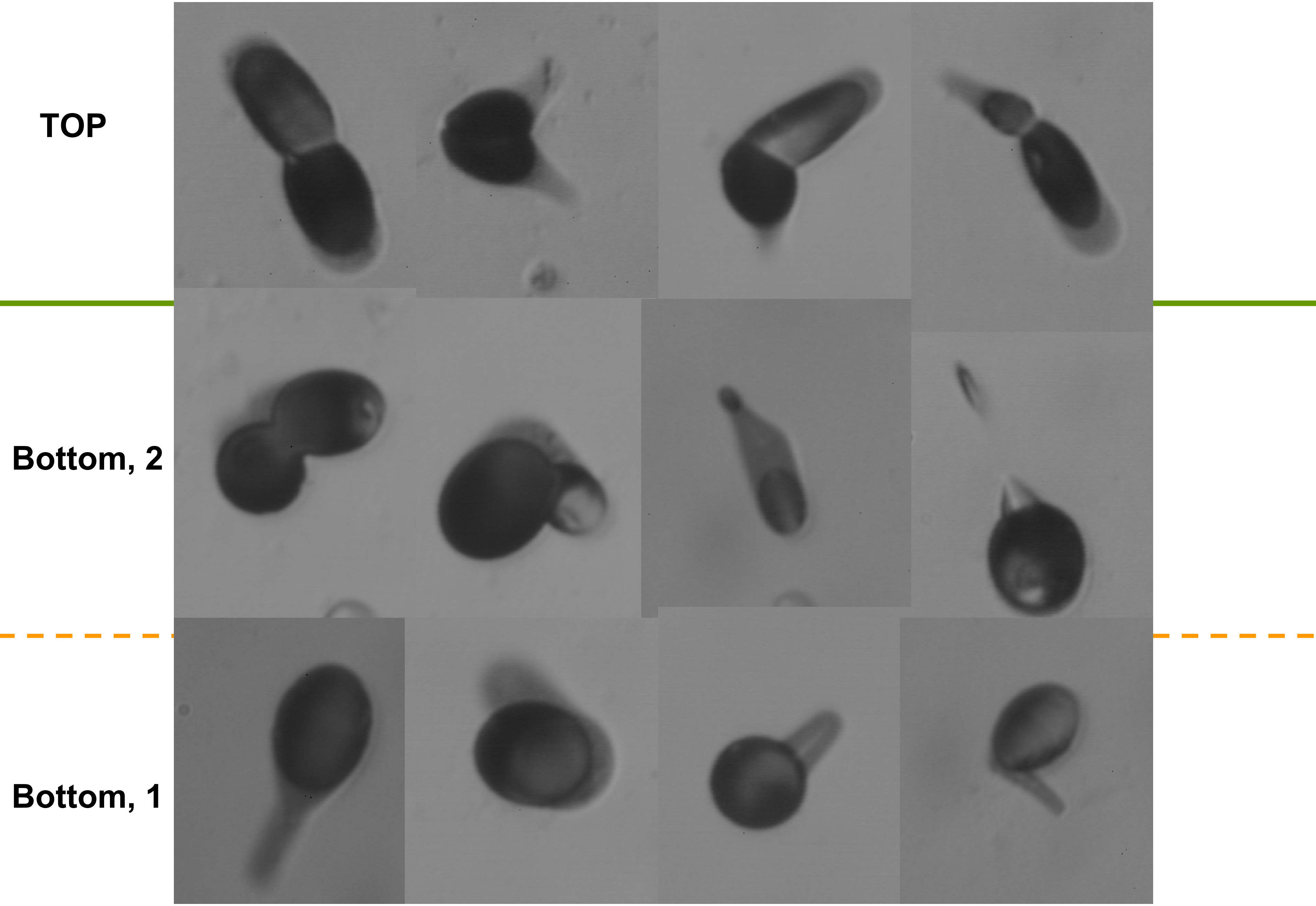






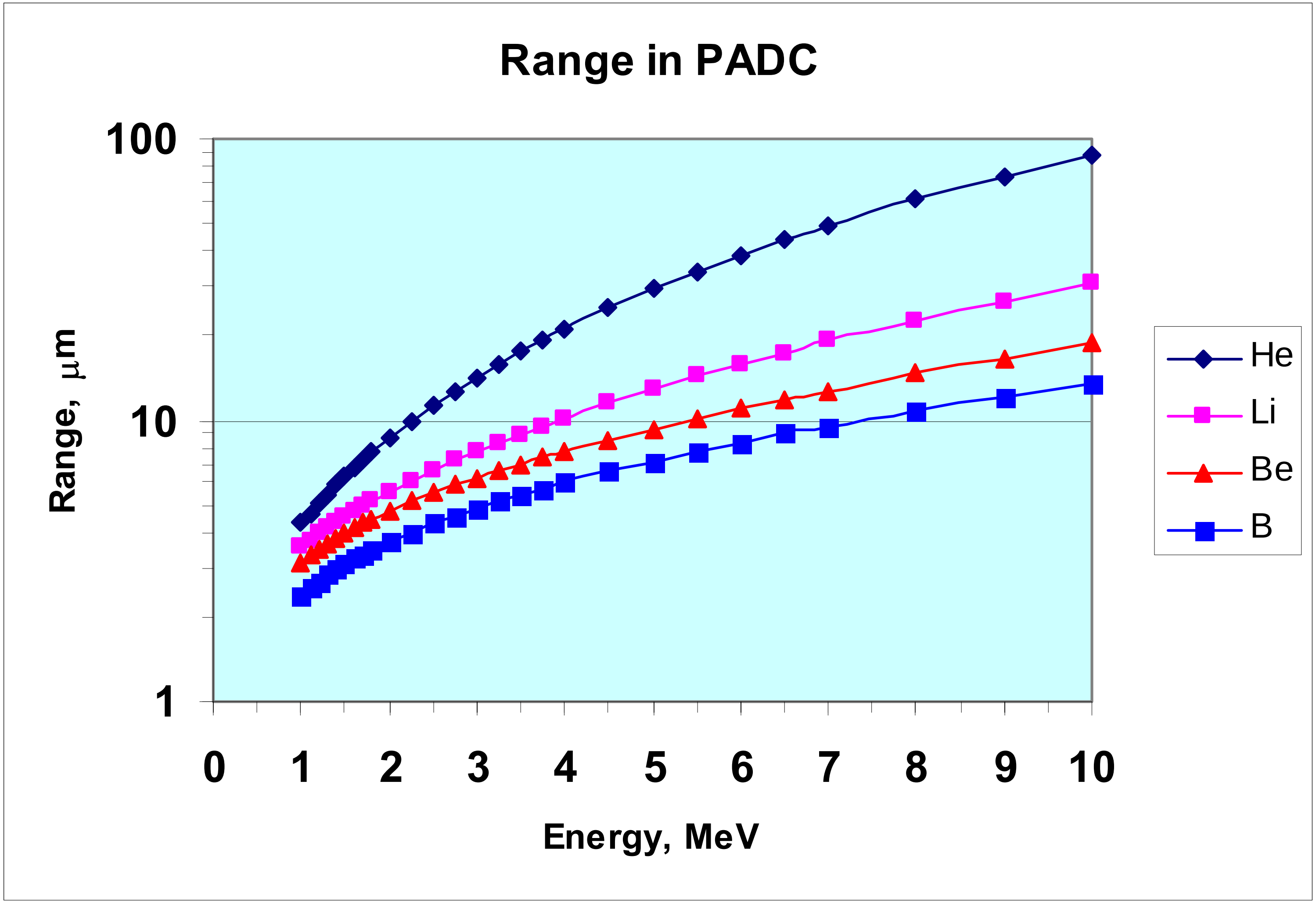


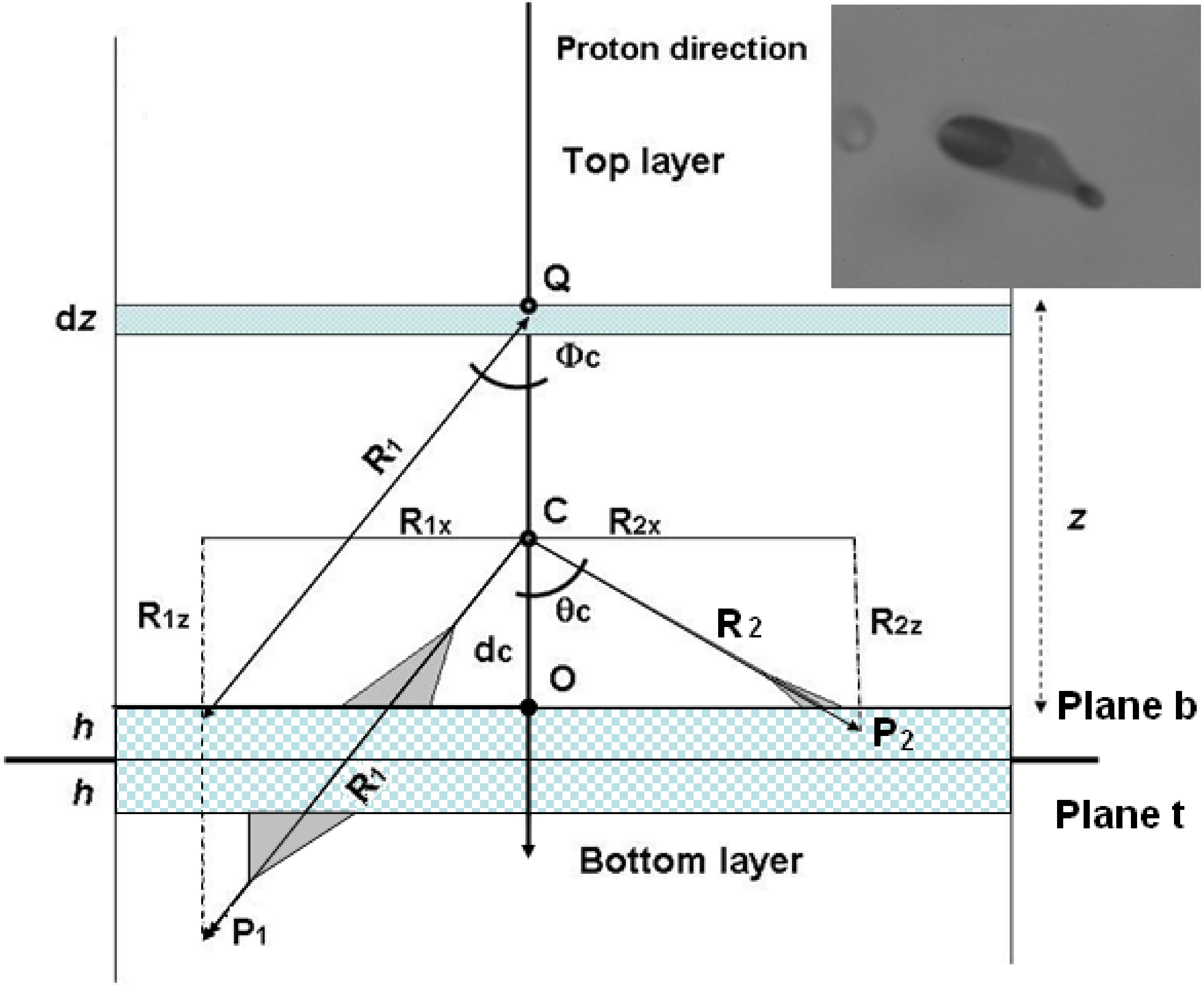




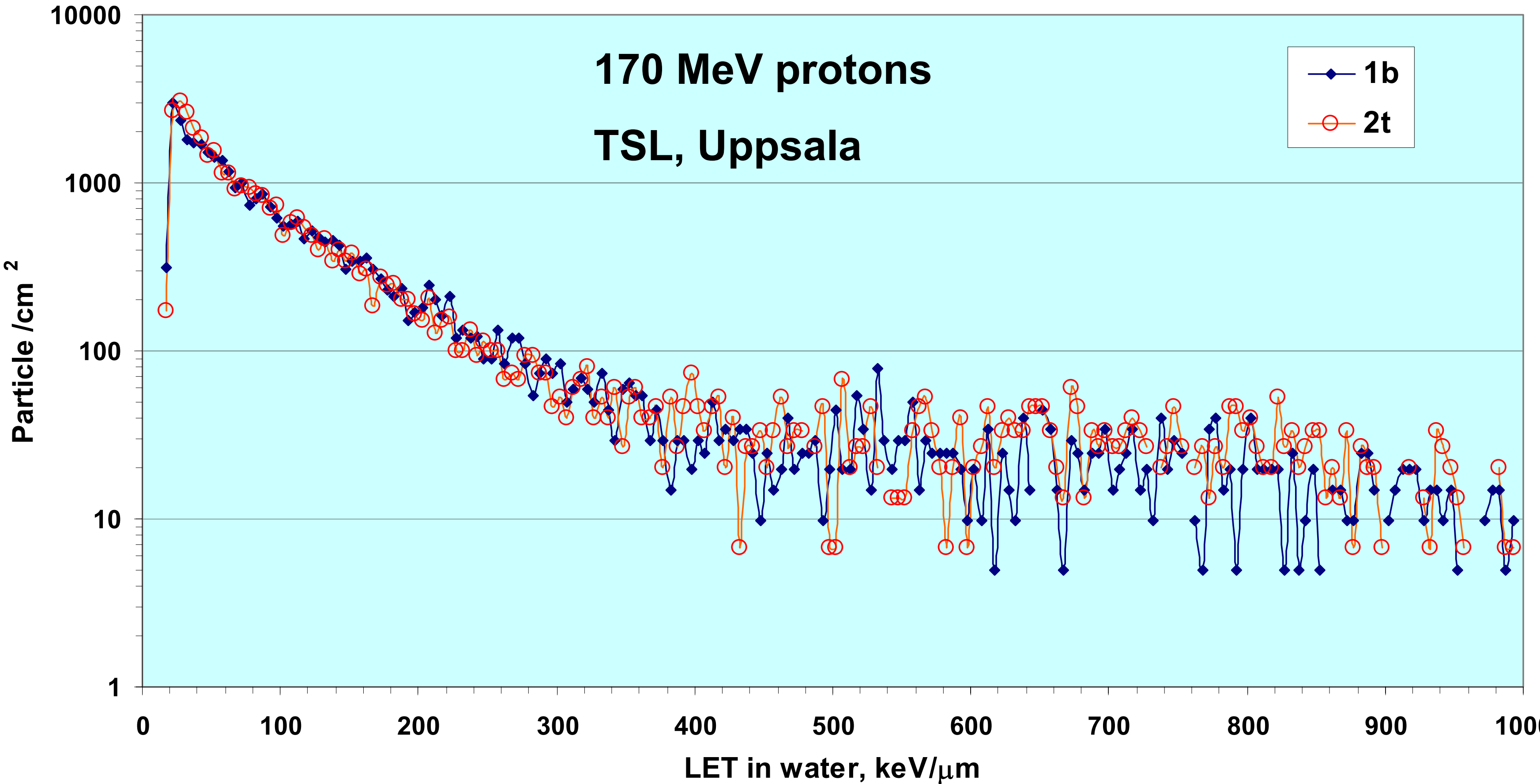
TOP
Bottom, 2
Bottom, 1

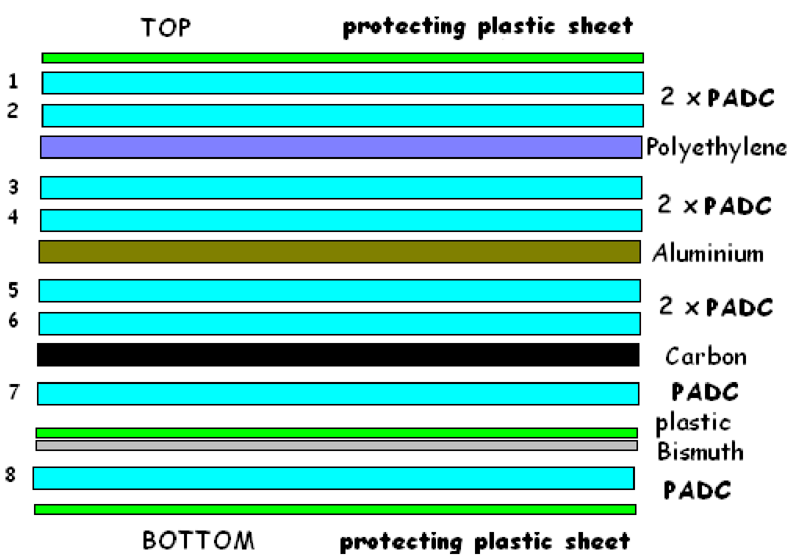
The purpose of the investigations was to estimate the real number and LET of secondary particles (fragments) produced by high energy trapped and GCR protons in a close tissue equivalent solid state nuclear track detector material (PADC) material composed of $C_{12}H_{18}O_7$, which indicates that ($p \rightarrow {}^{12}C$) is the most important fragmentation interaction.





Proton direction
Top layer
Q
dz
Φc
R1
C
R1x
R2x
z
R1z
θc
R 2
R2z
dc
O
Plane b
h
P2
h
R1
Plane t
Bottom layer
P1





No significant difference between LET spectra on top & bottom surfaces

TASTRAK, 1 mm

6 h etching , 8 mm removal

If *n* is the fragmentation event producing two fragments in a unit volume then the number of tracks detected on unit detector surface (called track density, *T*) can be expressed as

$$T = T_1 + T_2 = \frac{1}{2} n \times (R_1 \sin^2 \Phi_c + R_2 \sin^2 \Theta_c)$$

where T_1 and T_2 are the track densities of the two different types of fragments (^3He and ^{10}B, for instance) having ranges R_1 and R_2, with critical detection angles Φ_c and Θ_c, respectively.

The number of the tracks of detected twins is: $2T_2 = n \times R_2 \sin^2 \Theta_c$

and number of the lost heavier particles is then:

$$N_L = T - 2T_2 = \frac{1}{2} n \times (R_1 \sin^2 \Phi_c - R_2 \sin^2 \Theta_c)$$

Let us define the efficiency ε as the ratio of the measured track density over the generated particle number (2n) :

$$\varepsilon = \frac{T}{2n} = \frac{1}{4}(R_1 \sin^2 \Phi_c + R_2 \sin^2 \Theta_c)$$

If R_2 = 10 µm is the averaged ranged of heavy products as estimated above and R_1 = 300 µm is the averaged range of lighter particles, as well as, averaged Φ_c and Θ_c, are 70° and 45°, respectively, then

$$\varepsilon = \frac{1}{4}(0.03 \sin^2 70 + 0.001 \sin^2 45)$$

briefly $\varepsilon = 6.8 \times 10^{-3}$

~ 75 fragmentation events within a unit volume produce a single, visible track on the surface (assuming forward moving fragments).

EXAMPLE

The detector stack was exposed perpendicularly to 170 MeV protons with a fluence of 5.5 x 10^8 cm^{-2}, the measured track density on the bottom side of the first detector sheet was found to be T=3.8 x 10^4 cm^{-2}. Then, the number of fragmentation events in unit volume (1 cm^3) is

$$n = \frac{T}{2\varepsilon}$$

numerically n = 2.8 x 10^6, which is 0.5 % of the proton fluence,

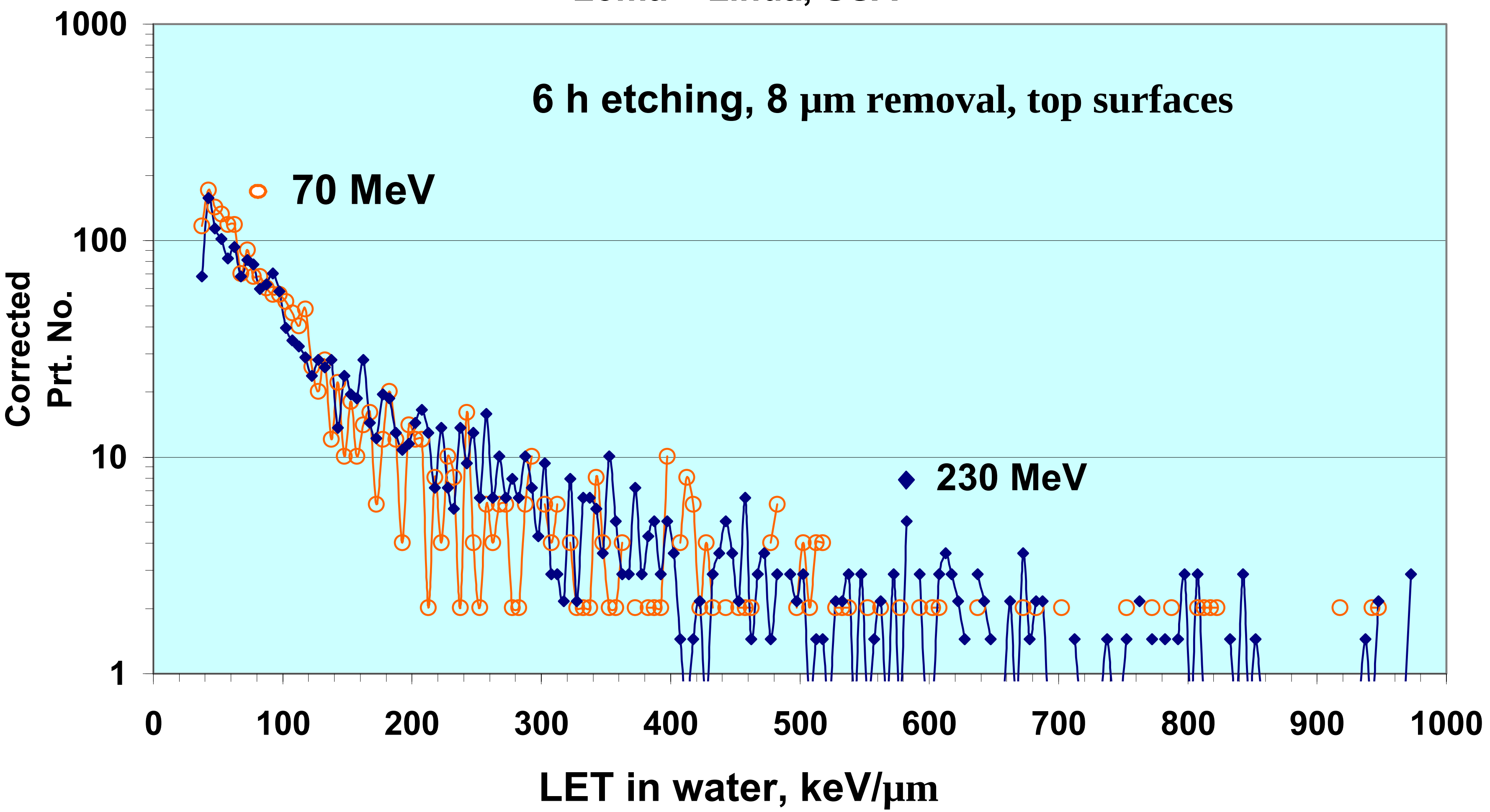
Protons trespassing without interaction should be neglected!

The number of the lost (not detected) particles (heavy products), *N_L*, then can be calculated as:

$$N_L = \frac{1}{2}\times 2.8\times 10^6 (0.03\sin^2 70 - 0.001\sin^2 45) = 3.6\times 10^4$$

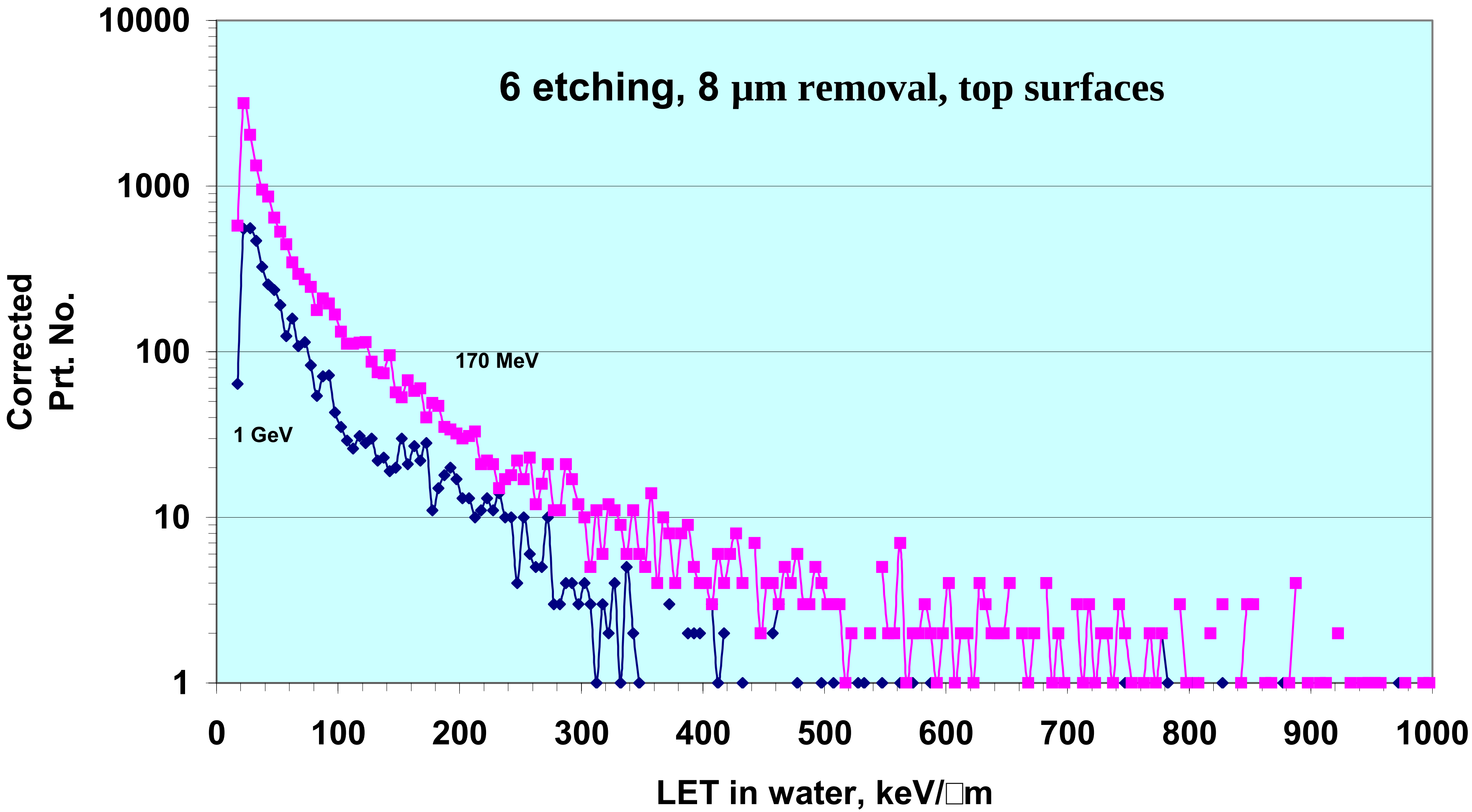
70 & 230 MeV protons

Loma – Linda, USA



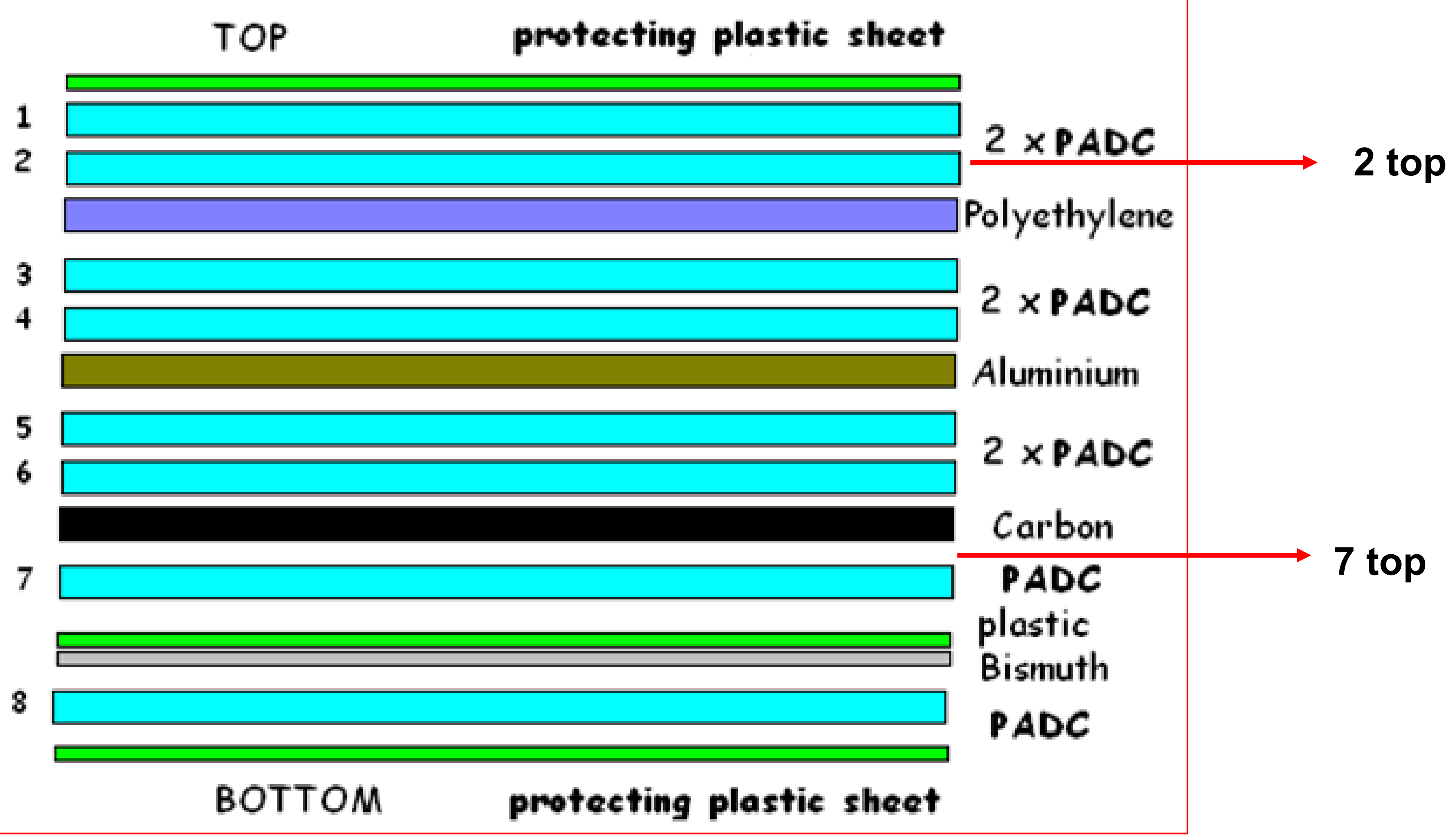
No significant difference between LET spectra of different proton energies

1 GeV & 170 MeV protons

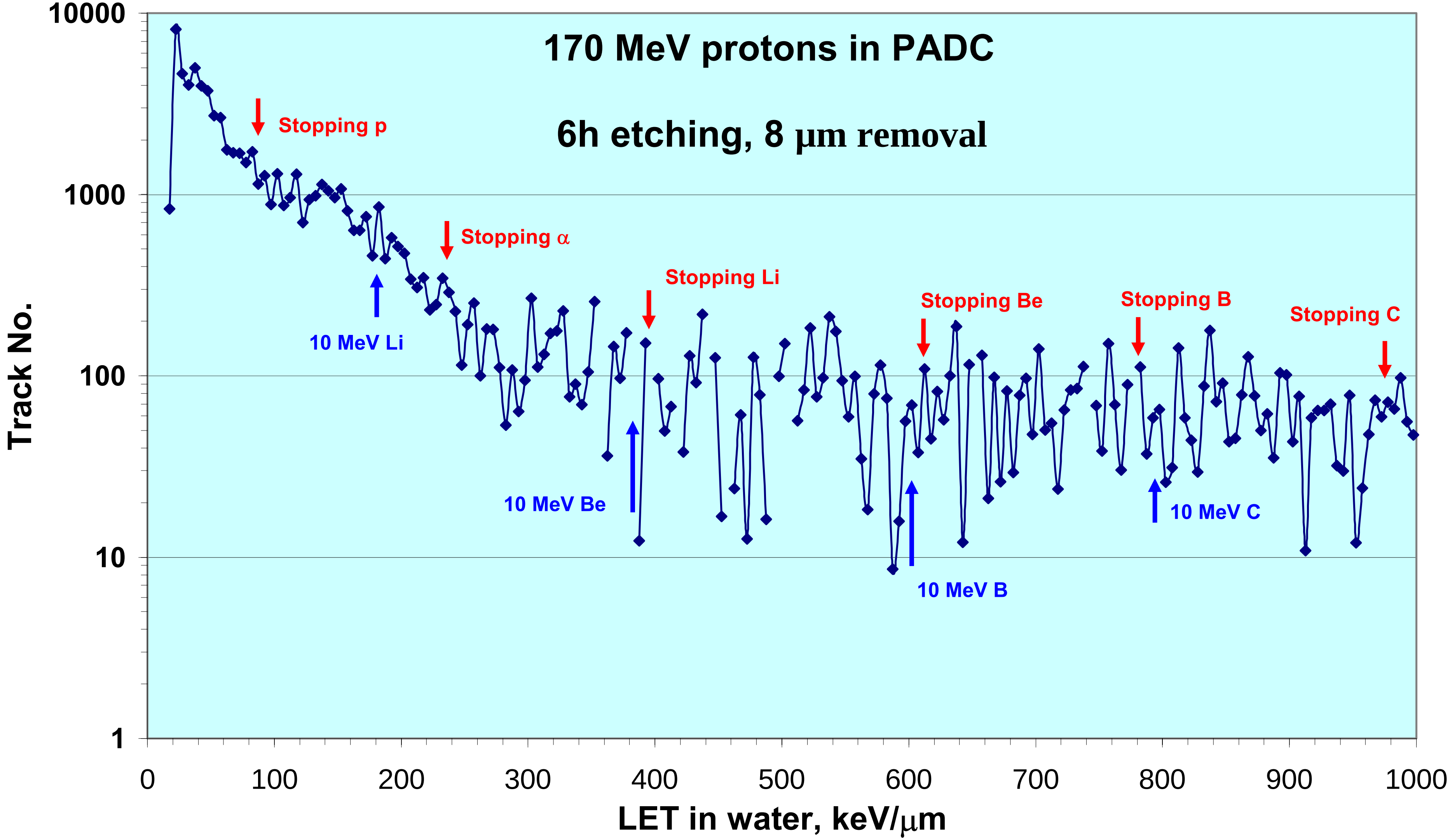


Exposures at NSRL-BNL (USA) and TSL (Sweden)

No significant difference between LET spectra of different proton energies

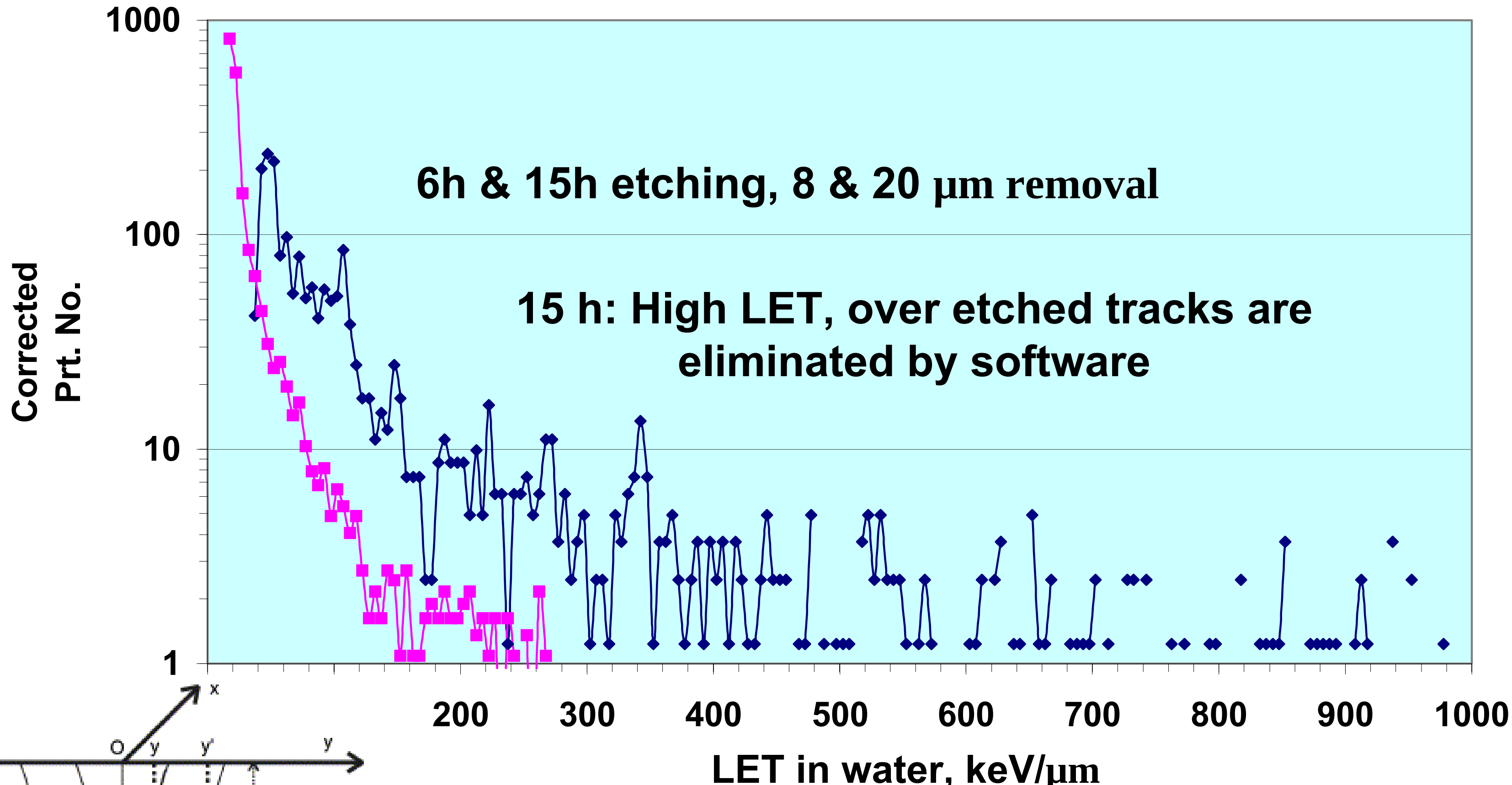


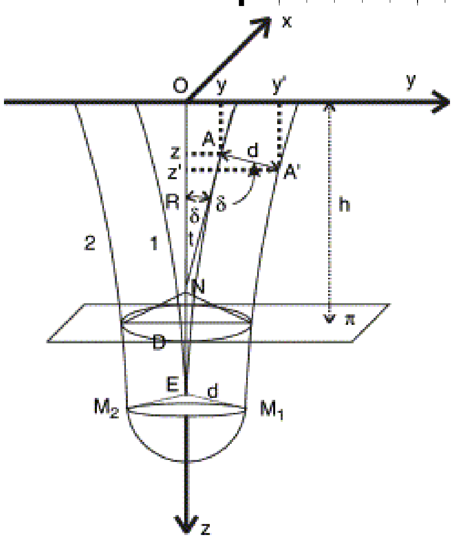
Difference of LET spectra (7t – 2t) provide info on ^{12}C spallation



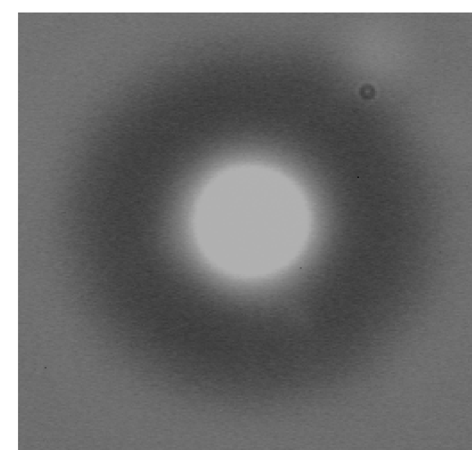
Short range target fragments Z>2 are registered with LET > ~230 keV/μm

230 MeV protons, under carbon, 6 &15h





Nikezic model



SUMMARY

If short range target fragment and GCR particle tracks can be separated (multi-layered stack, multiple etching, track recognition program) then:

1. **External (to detector) GCR (or projectile fragment) particle fluence and dose can be "easily" calculated from track parameter measurements. Traditional way! Calibration! Correction! LET spectrum!**
2. **Proton induced target fragment event & particle No. can be determined. Detection efficiency! Correction for the LET spectrum above ~230 keV/μm (???) needed. HOW?**
3. **The total dose is the sum of GCR and target fragment doses.**

The authors wish to express their apretiation and thanks to the ICCHIBAN working group, for making possible to participate in the intercomparison experiments, and

especially to Eric Benton for taking care of the AERI detectors during the proton experiments at Loma Linda and NSRL-BNL.

Thanks for your attention