Track detector development for neutron and mixed field dosimetry

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ARDENT
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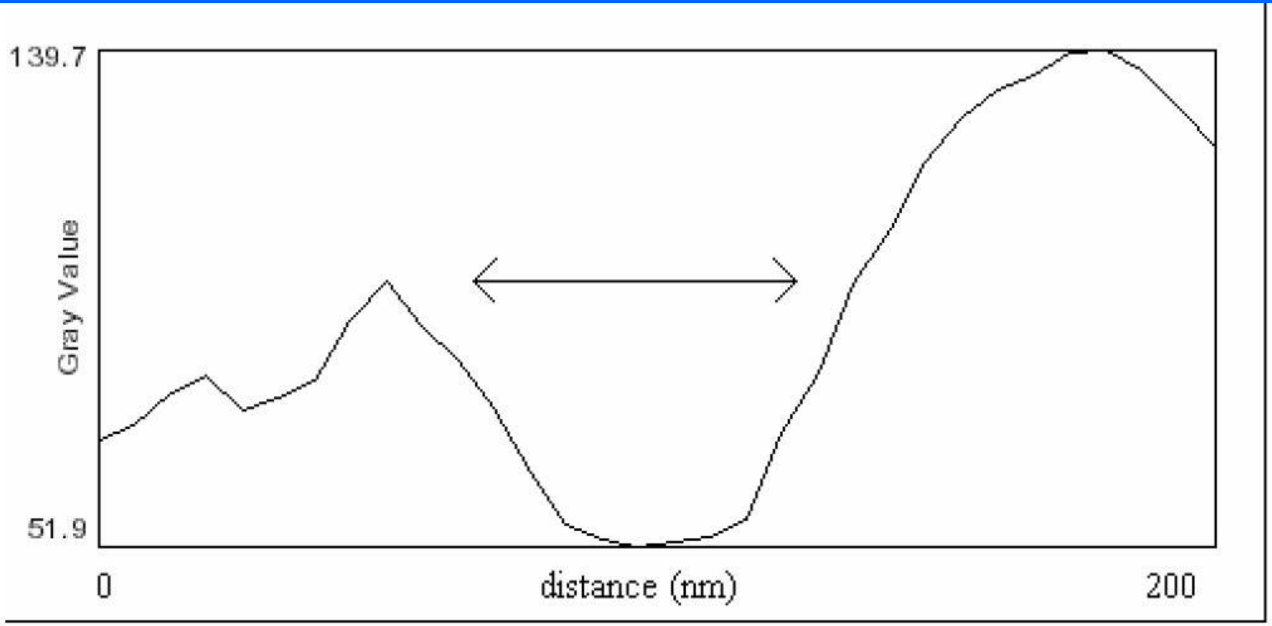
MARIE CURIE ACTIONS

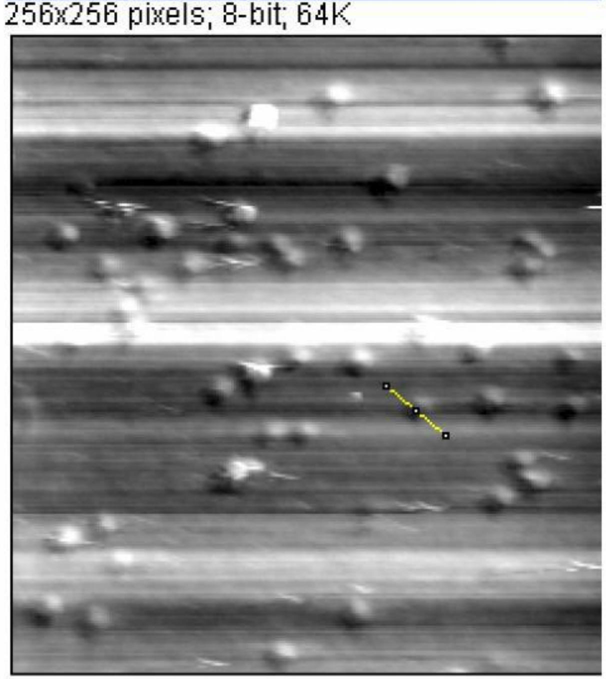
mi.am
strumentazione e dosimetria radon

CNAO

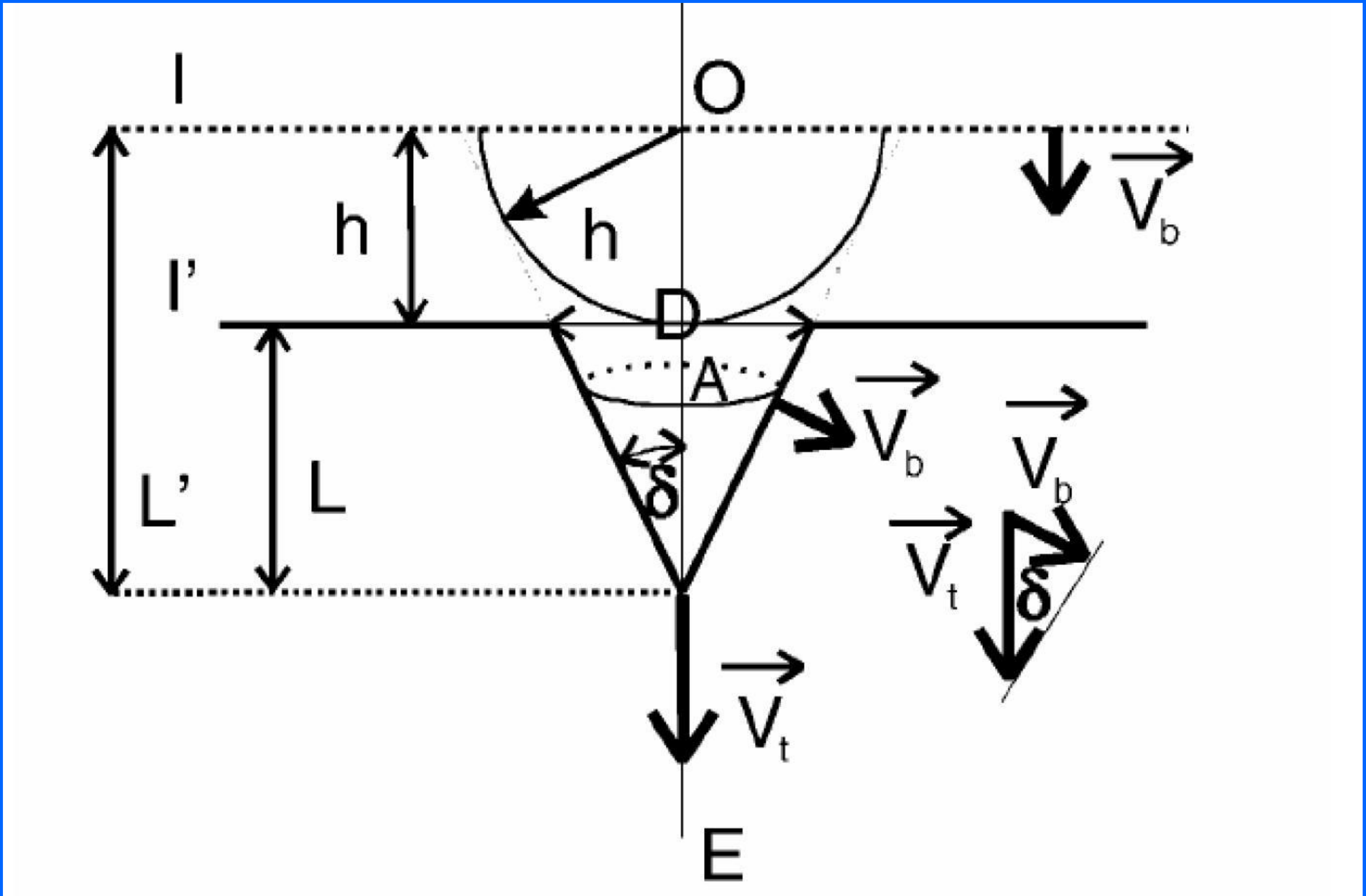
Nuclear track detectors

- ✓ Sensitive to high LET radiation ⇔ heavy charged particles

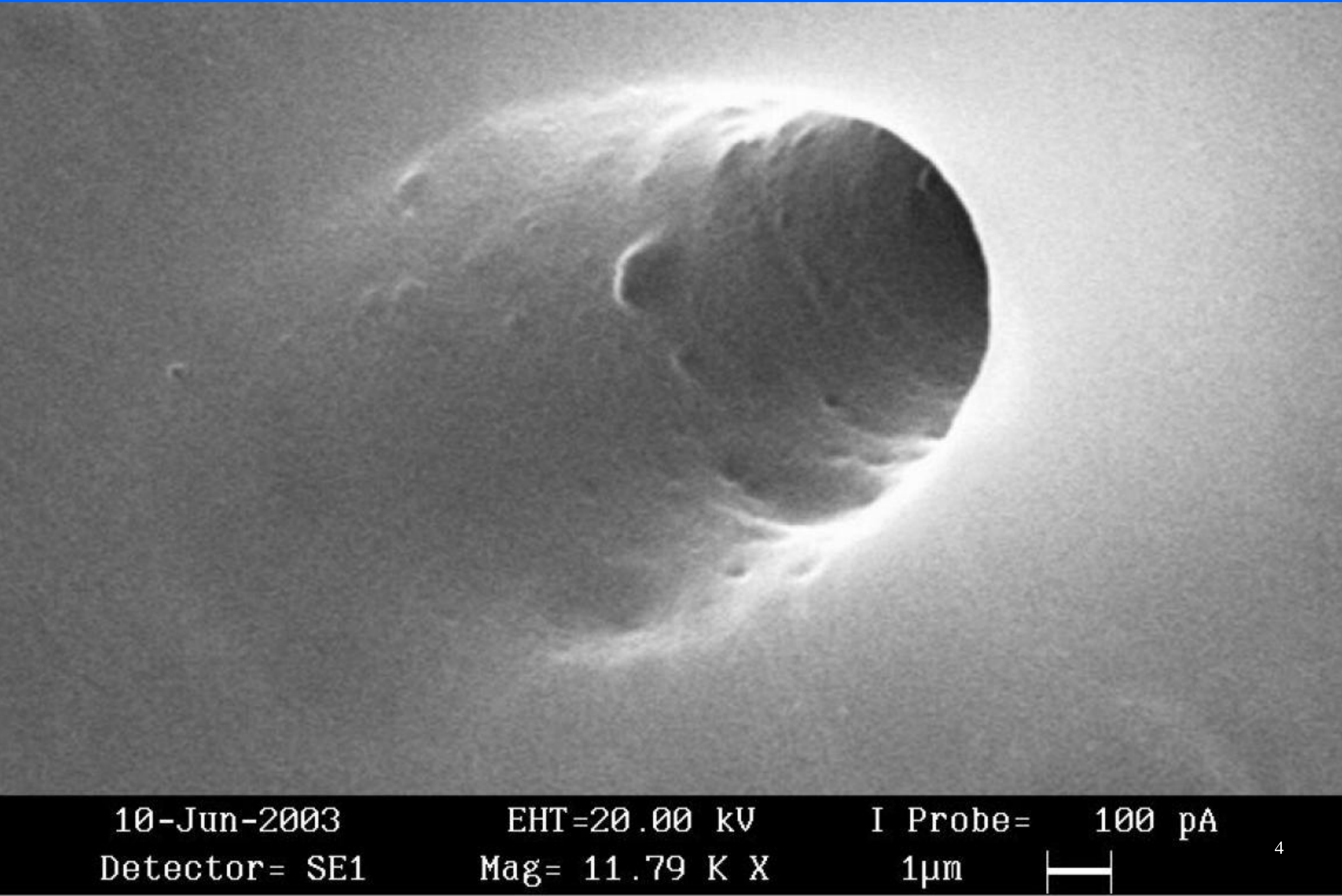




The damaged material is removed with Vt, the bulk material with Vb



Etching: the few nm track is enlarged up to a few microns

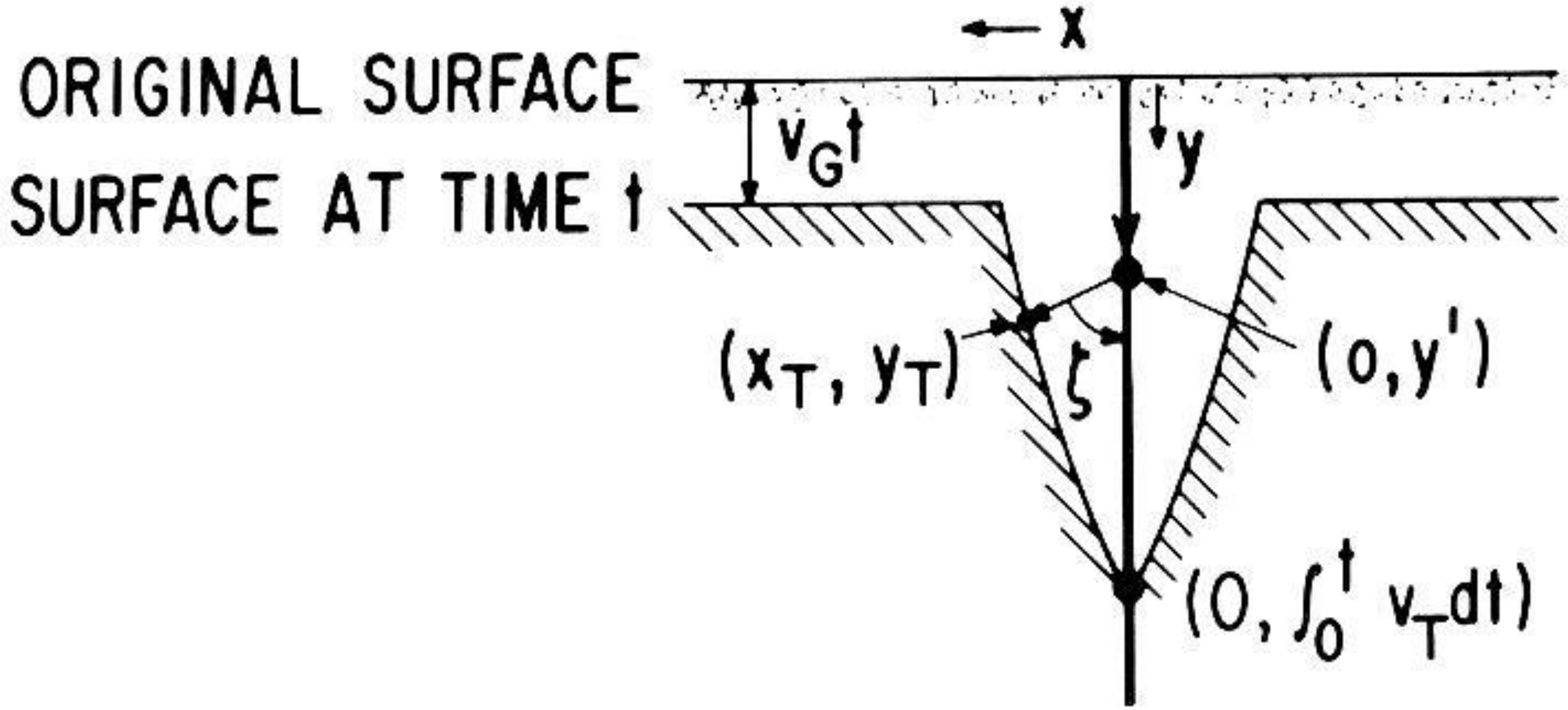


The real shape of the etched track depends on a few parameters:

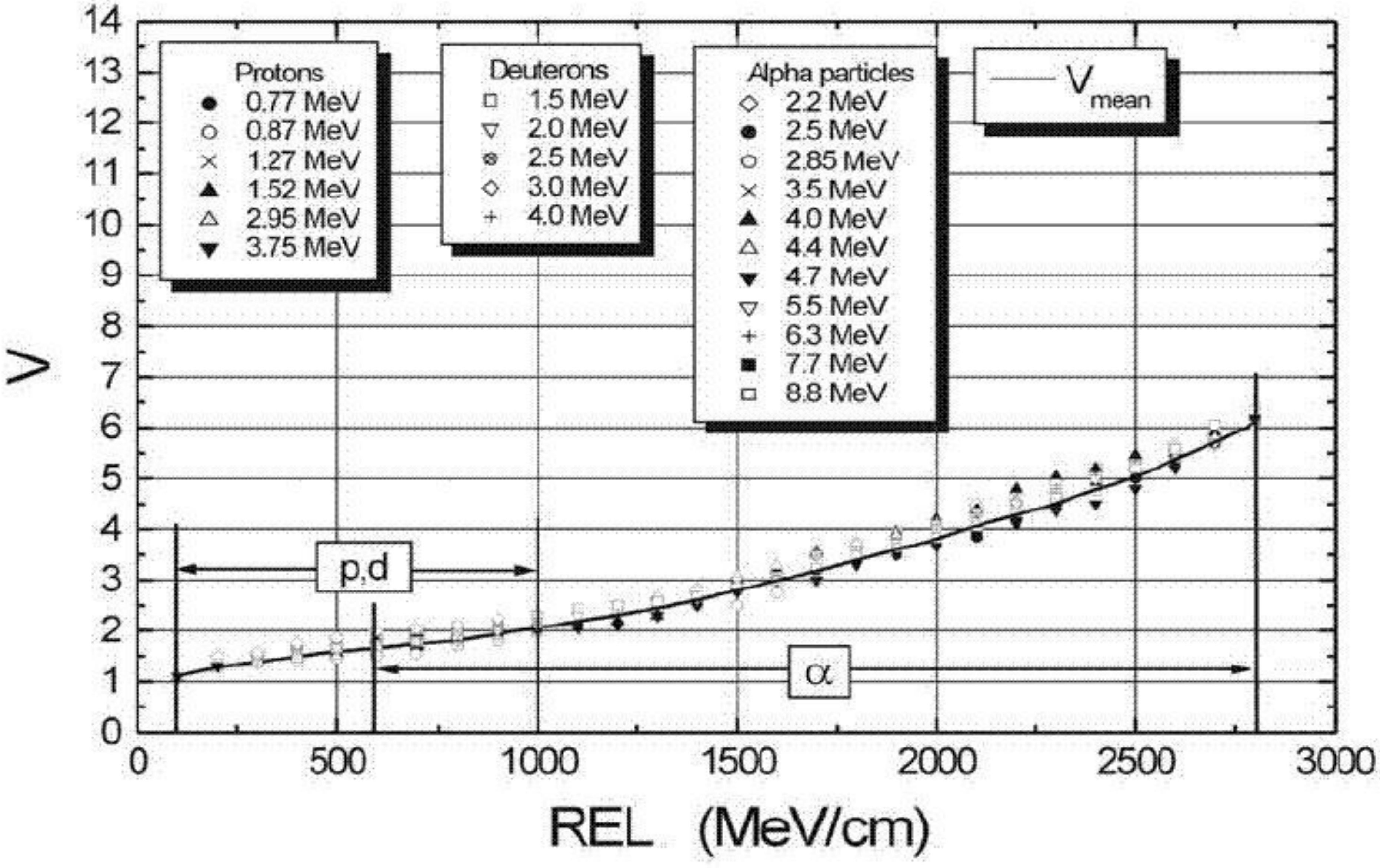
$V=Vt(LET)/Vb$

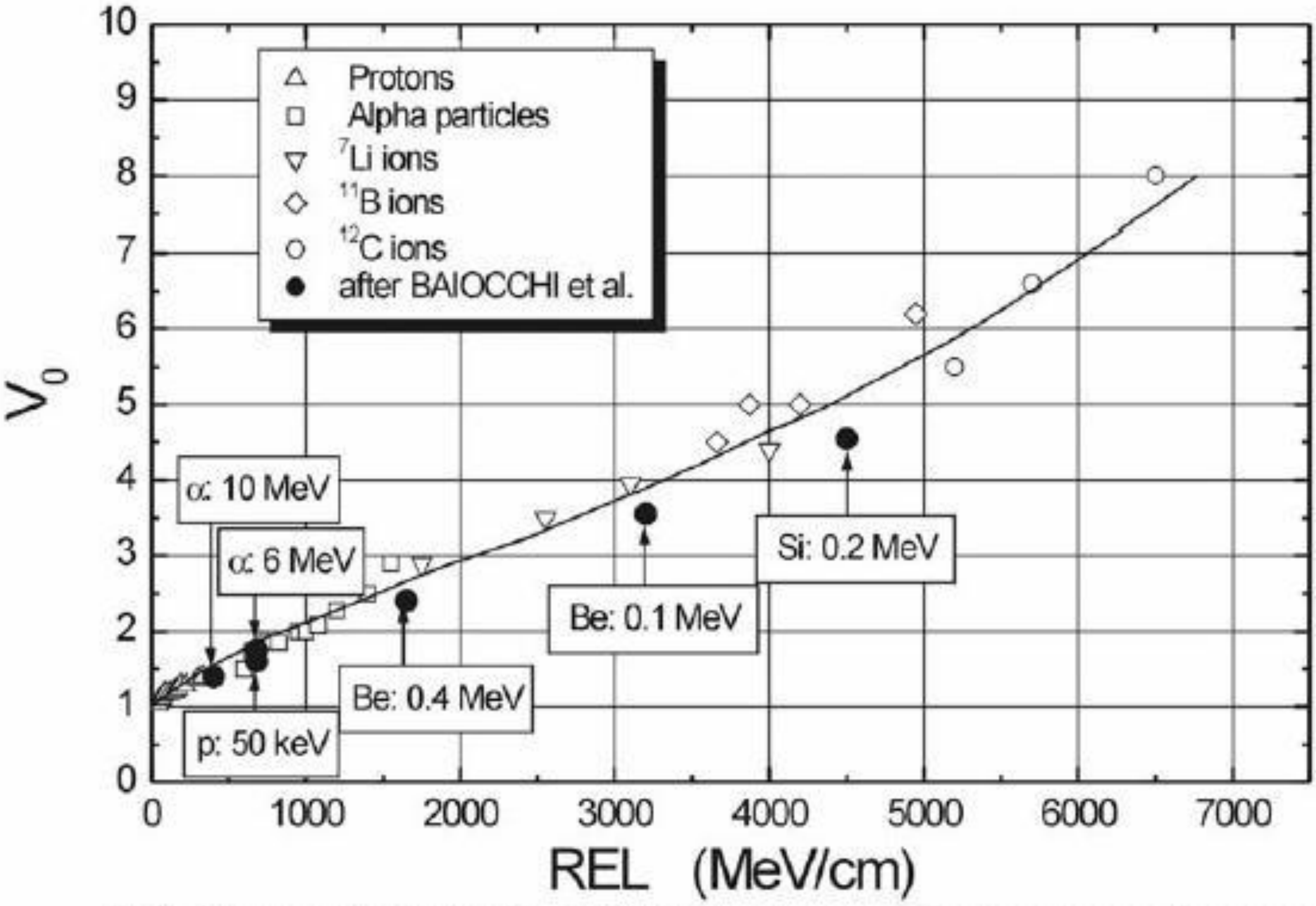
θ= incidence angle

LET = LET(y)



CR39 – most used track detector

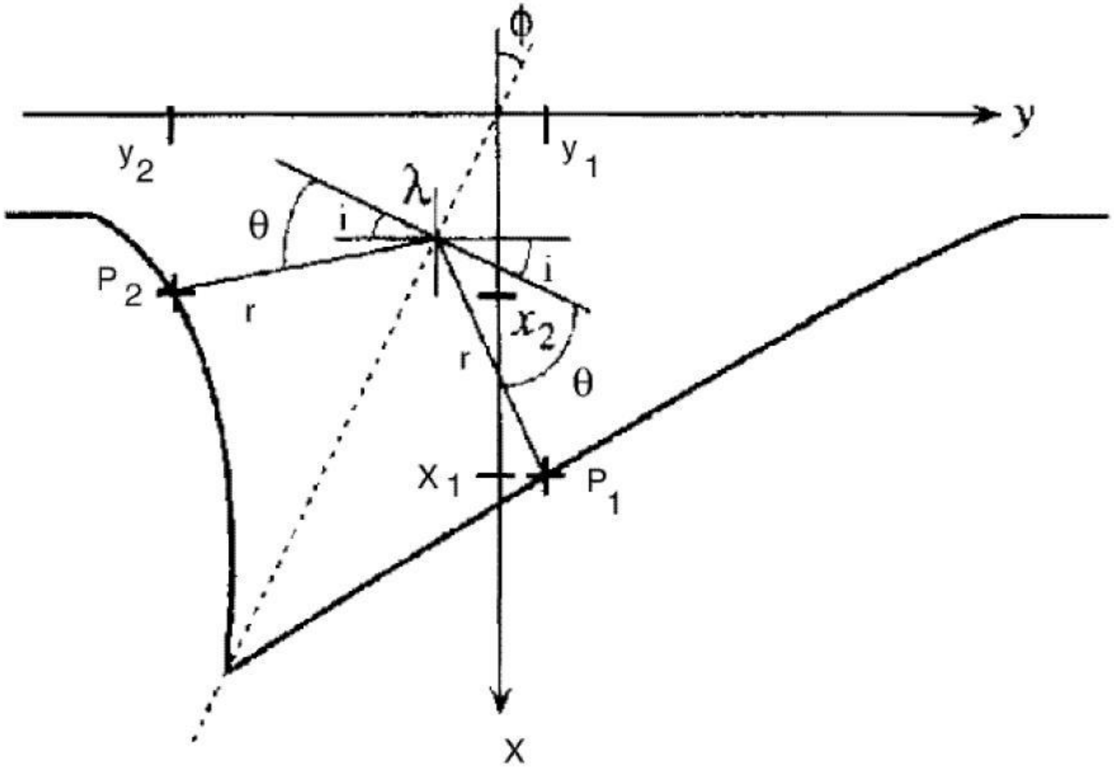


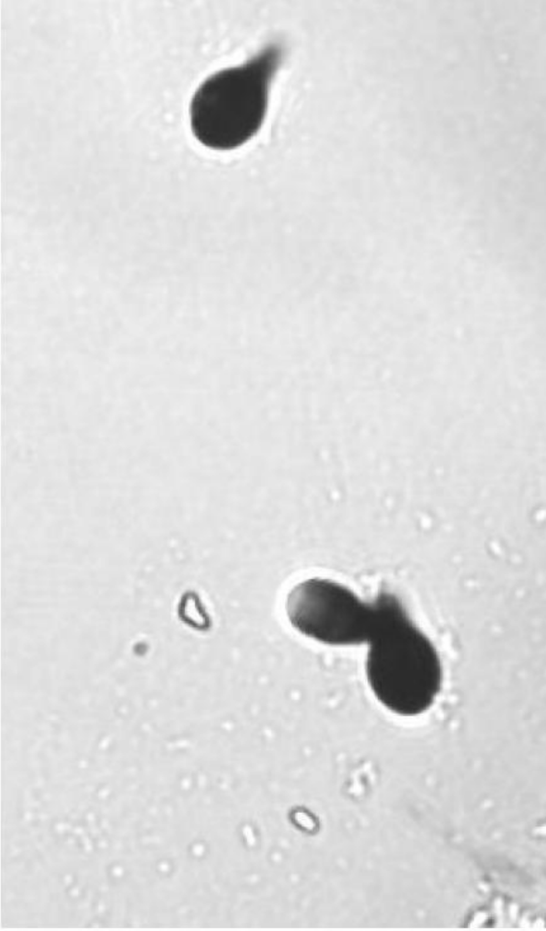


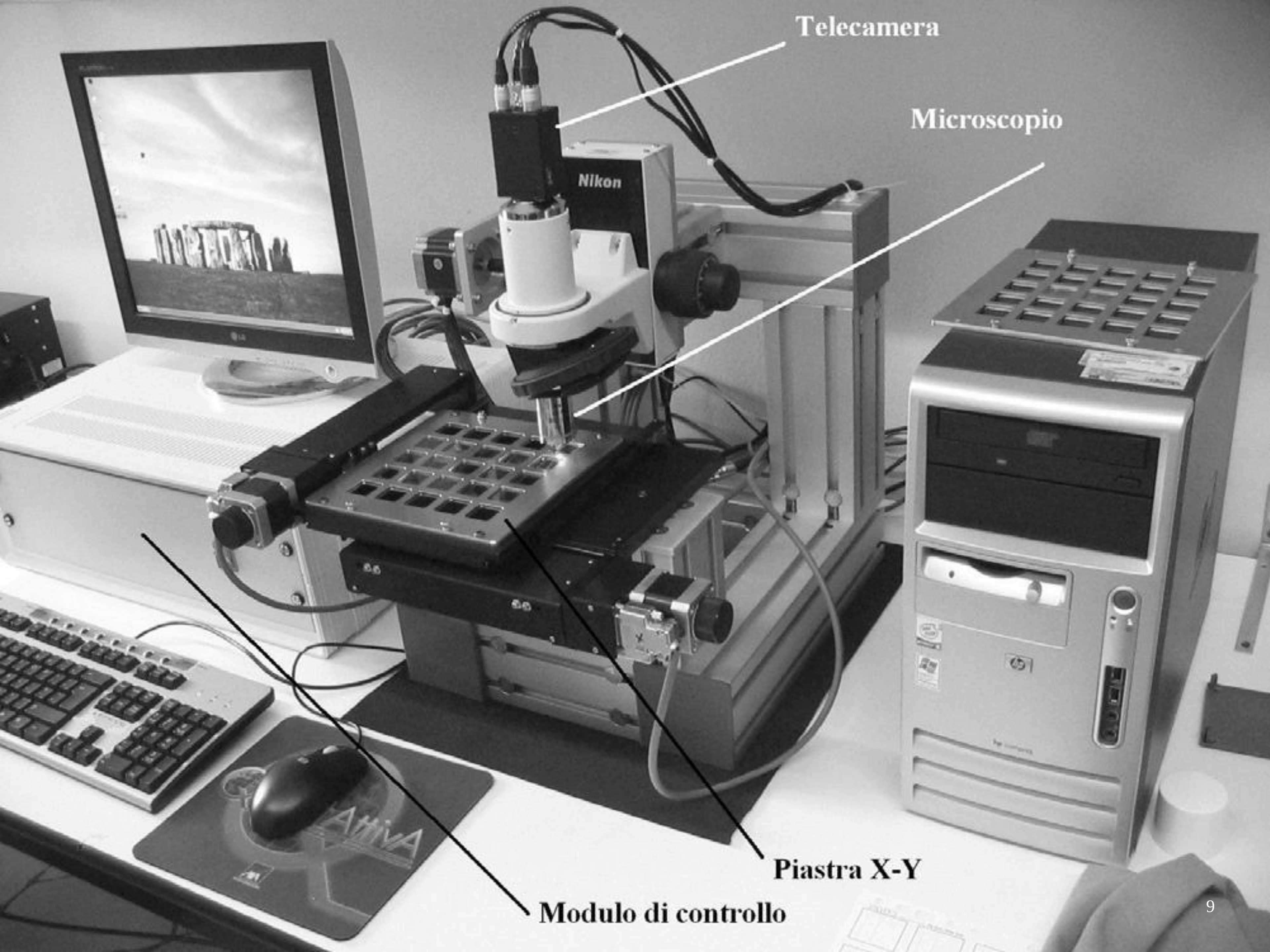
Many formulas are available to calculate V(LET)

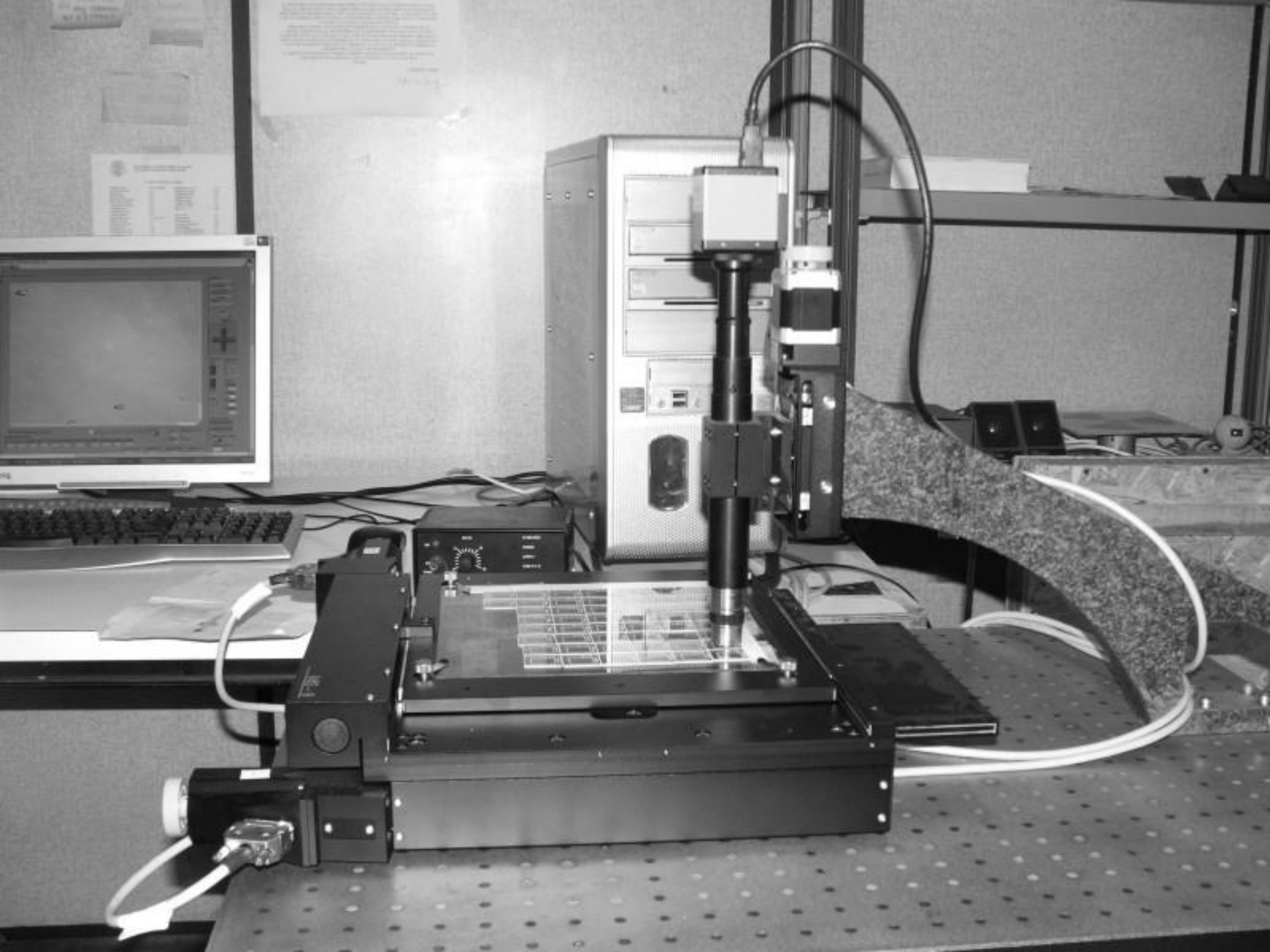
The track is read by a microscope.

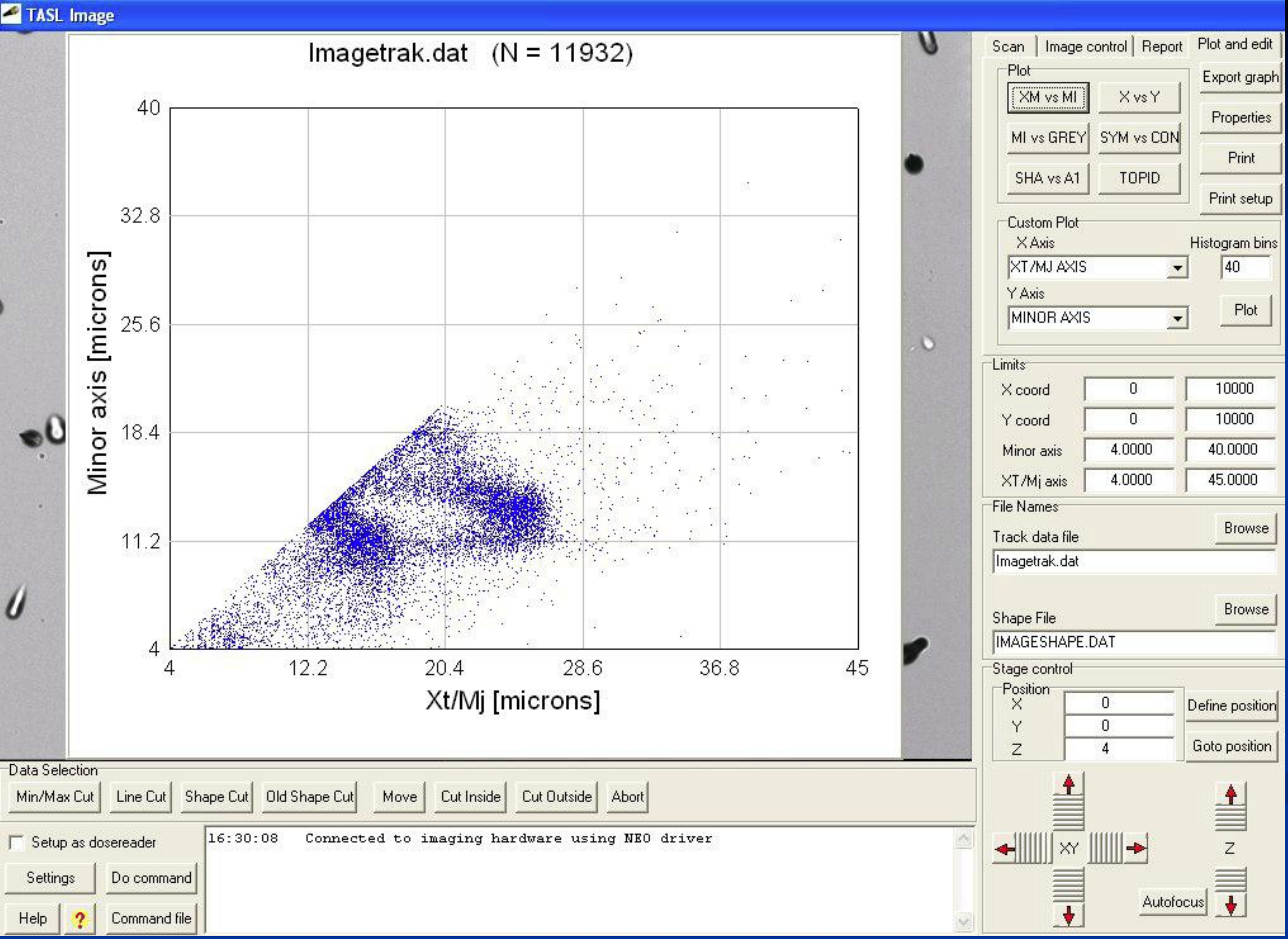
Its shape also depends on the etching procedure (etchant, etchant temperature, etching duration etc…)






Telecamera
Microscopio
Piastra X-Y
Modulo di controllo
Nikon





X Axis: XT/MJ AXIS

Histogram bins: 40

Y Axis: MINOR AXIS

Limits

X coord	0	10000
Y coord	0	10000
Minor axis	4.0000	40.0000
XT/Mj axis	4.0000	45.0000

File Names

Track data file: Imagetrak.dat

Shape File: IMAGESHAPE.DAT

Stage control

Position

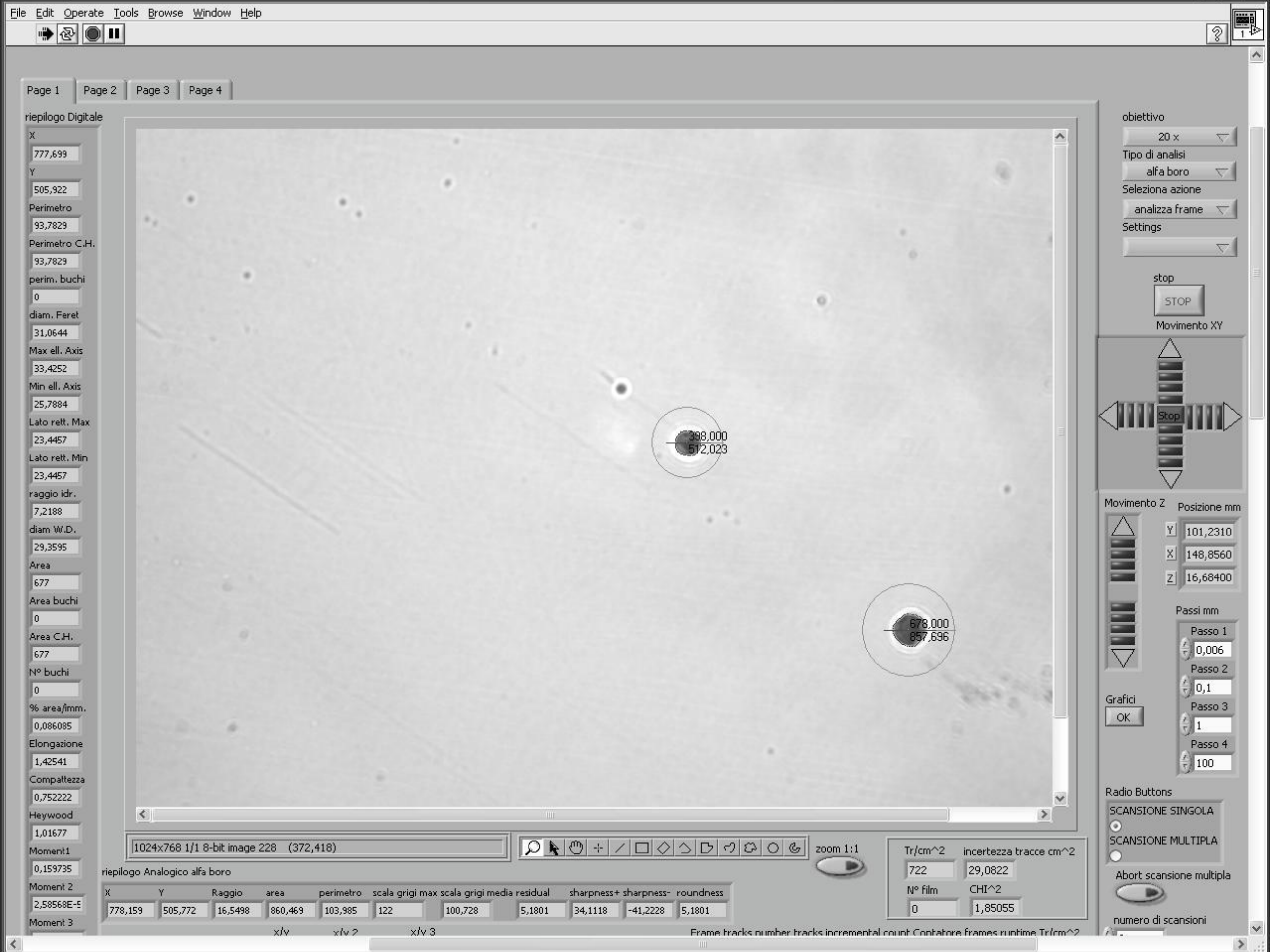
X: 0

Y: 0

Z: 4

☐ Setup as dosereader

```
16:30:08    Connected to imaging hardware using NEO driver
```



riepilogo Digitale

X	777,699
Y	505,922
Perimetro	93,7829
Perimetro C.H.	93,7829
perim. buchi	0
diam. Feret	31,0644
Max ell. Axis	33,4252
Min ell. Axis	25,7884
Lato rett. Max	23,4457
Lato rett. Min	23,4457
raggio idr.	7,2188
diam W.D.	29,3595
Area	677
Area buchi	0
Area C.H.	677
N° buchi	0
% area/imm.	0,086085
Elongazione	1,42541
Compattezza	0,752222
Heywood	1,01677
Moment1	0,159735
Moment 2	2,58568E-5
Moment 3	

obiettivo: 20 x

Tipo di analisi: alfa boro

Seleziona azione: analizza frame

Settings:

Posizione mm

Y	101,2310
X	148,8560
Z	16,68400

Passi mm

Passo 1	0,006
Passo 2	0,1
Passo 3	1
Passo 4	100

Radio Buttons

○ SCANSIONE SINGOLA

○ SCANSIONE MULTIPLA

numero di scansioni

1024x768 1/1 8-bit image 228 (372,418)

riepilogo Analogico alfa boro

X	Y	Raggio	area	perimetro	scala grigi max	scala grigi media	residual	sharpness+	sharpness-	roundness
778,159	505,772	16,5498	860,469	103,985	122	100,728	5,1801	34,1118	-41,2228	5,1801

Tr/cm^2	incertezza tracce cm^2
722	29,0822

N° film	CHI^2
0	1,85055

x/y x/y 2 x/y 3

Frame tracks number tracks incremental count Contatore frames runtime Tr/cm^2

It is possible to:

- Count the tracks
- Count the tracks by filtering the tracks with certain parameters (⇔reduce background)
- Calculate for any track the LET (discriminate the particles) and the impinging angle

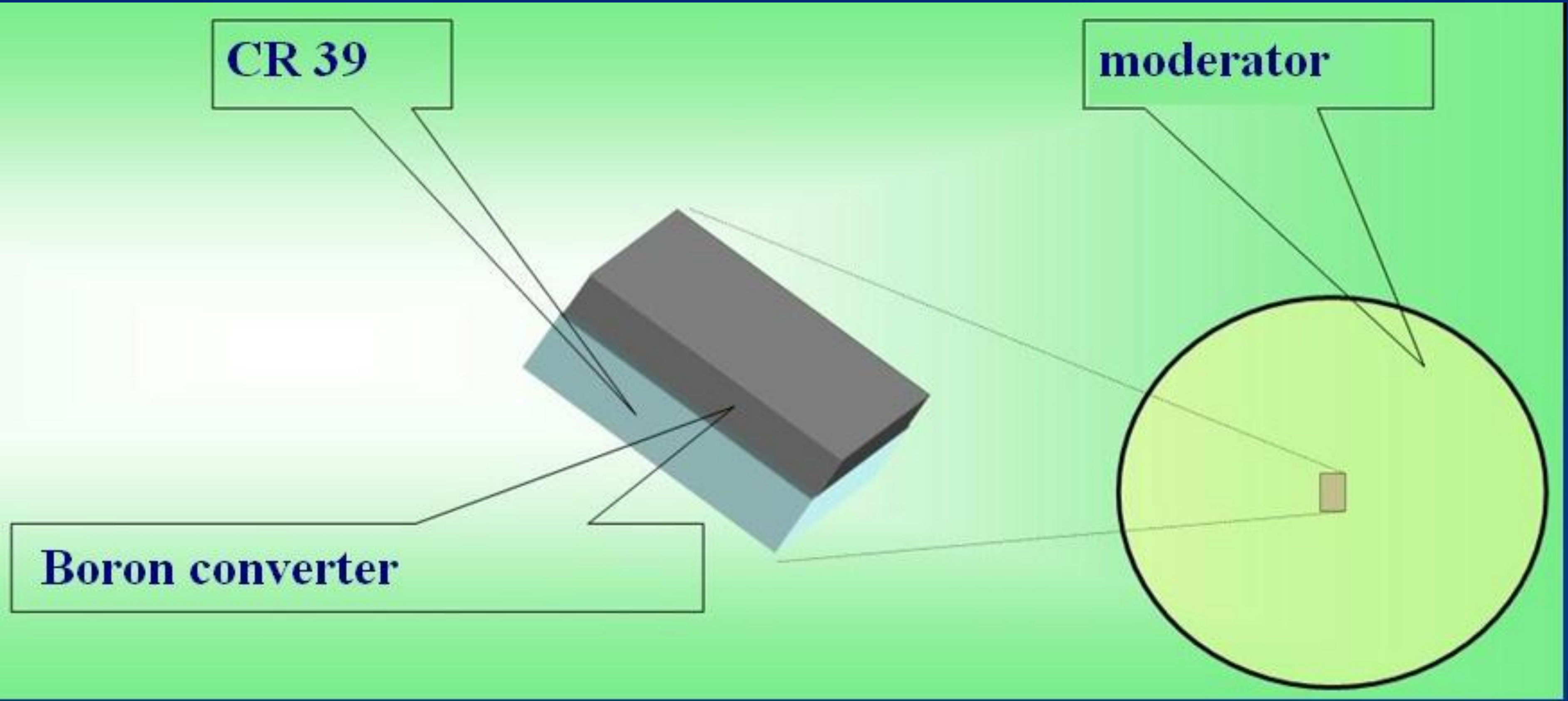
Neutron and mixed field dosimetry and spectrometry

- Use the track detector coupled to a boron converter, as thermal neutron detector (expoiting the n,α reaction on 10B). The neutron is detected by the 1.47 MeV α particle. The number of tracks is proportional to the thermal neuton fluence (inside Bonner spheres and Rem counters)

- Use the recoil protons (radiator-degrader technique). The number of tracks is proportional to the fast neutron fluence. The detection efficiency depends on the neutron energy.

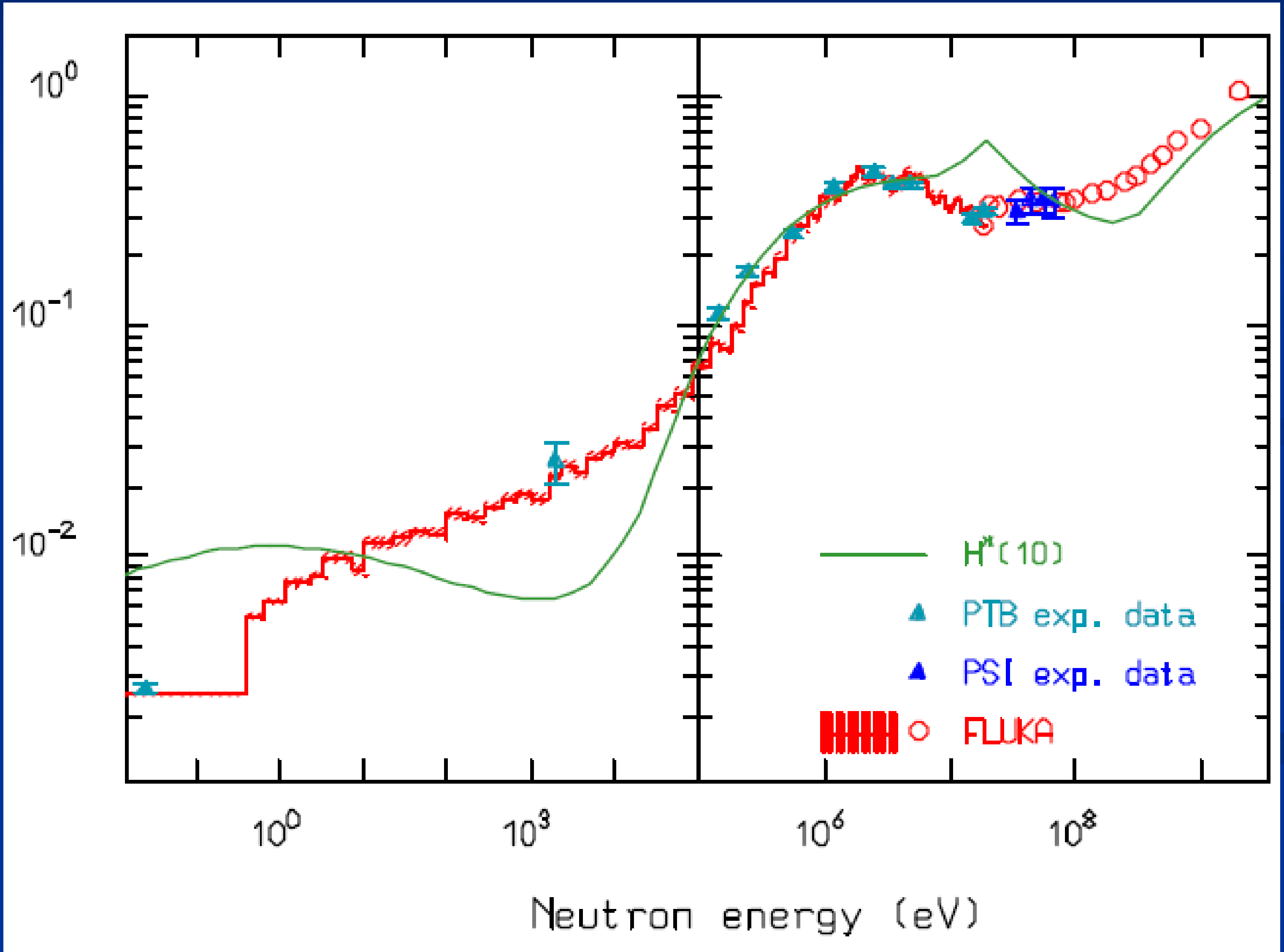
- Calculation of particle LET and impinging angle. Direct estimate of the equivalent dose by calculating, for any particle the dose and the quality factor Q(LET) .

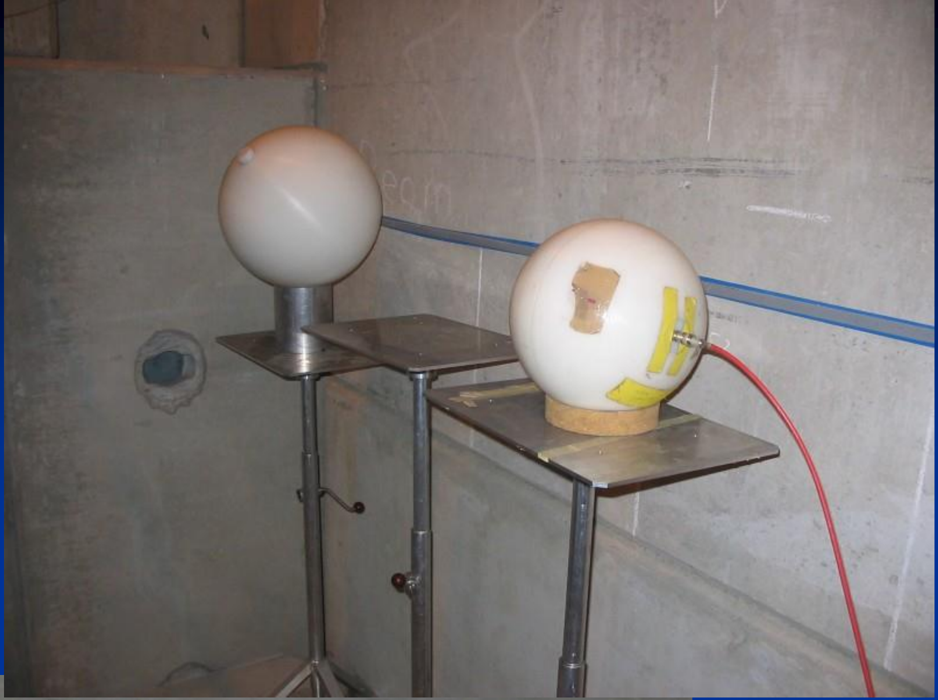
Use of CR39 as thermal neutron detector

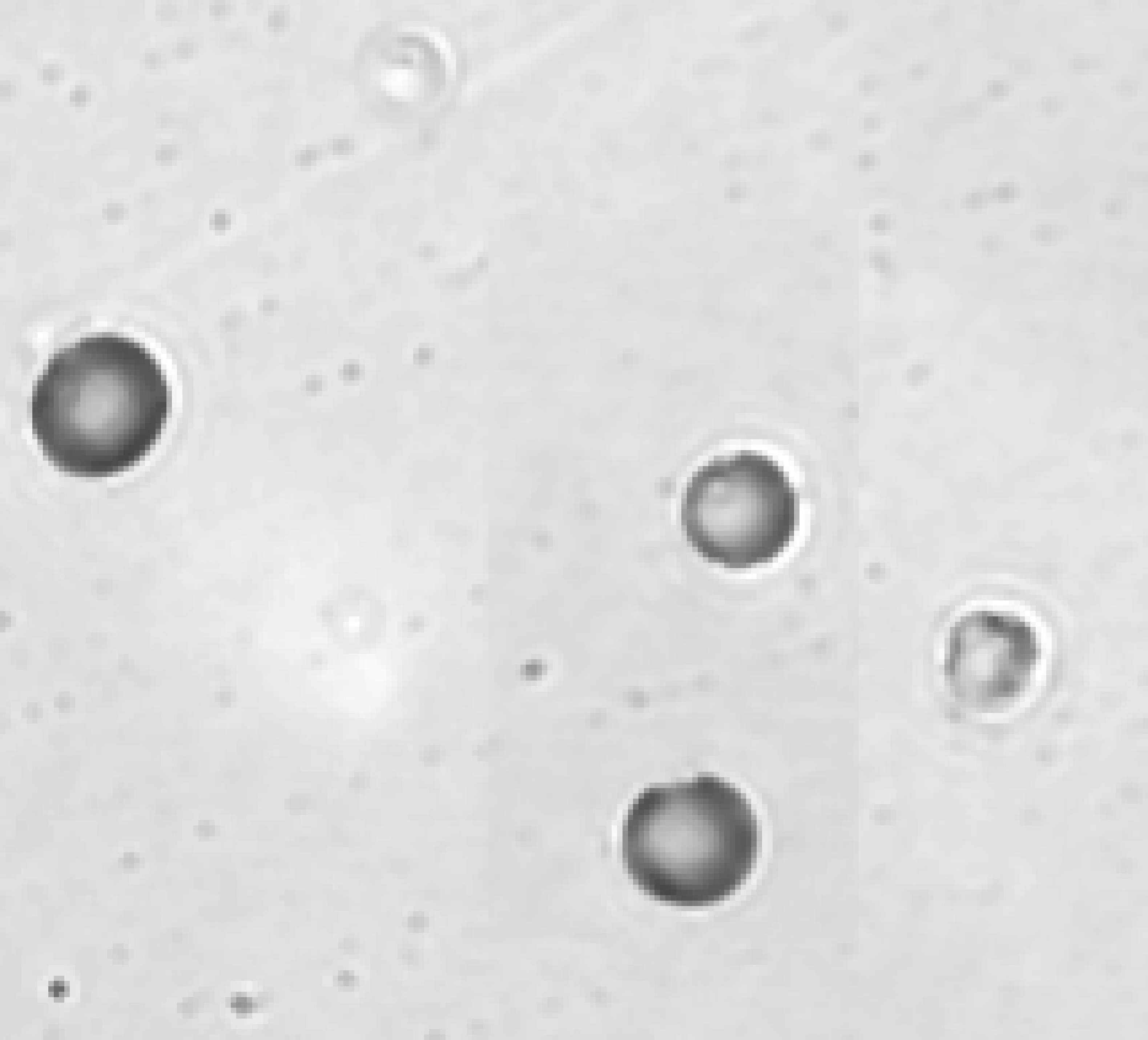


Passive REM counter

The number of tracks is proportional to the ambient dose equivalent



Passive REM counters:

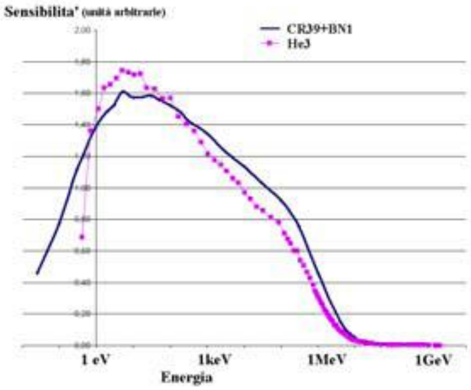
- Independent from field time structure (e.g. pulsed fields)
- Low background (few tracks/cm2) independent from exposure time and high sensitivity (5 tracks/cm2 per microSievert)
- Low lower detection limit (2 μSv)
- This is how the passive neutron dosimetry is done here!

Z1-009A-EDF_4
ITALY

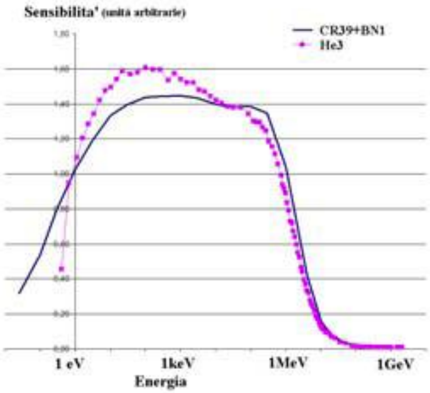
Bonner spheres

Spectral response of various spheres

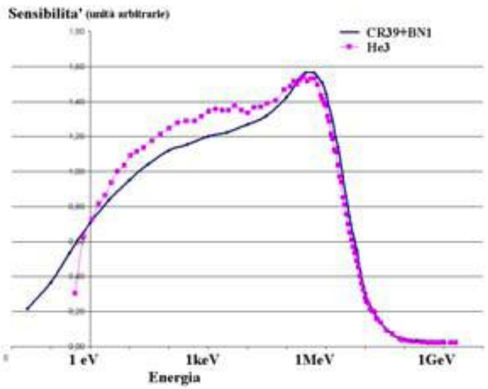
81 mm



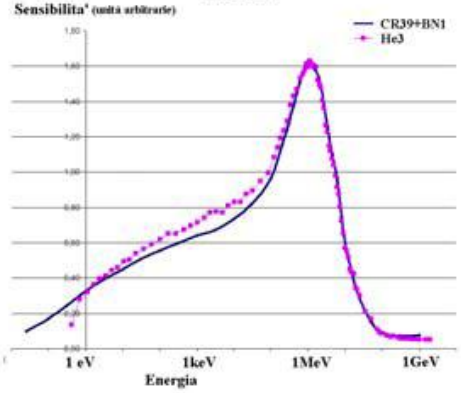
108 mm



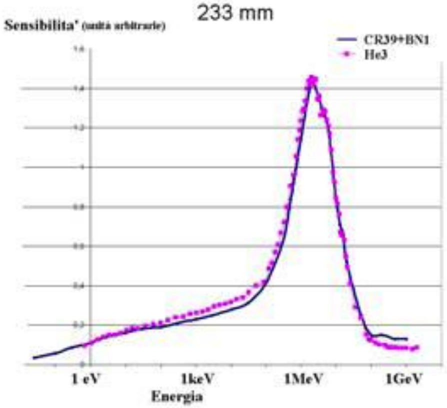
133 mm



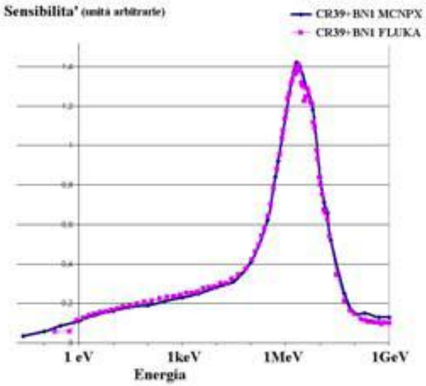
178 mm



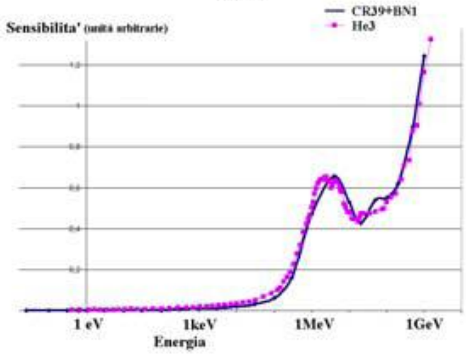
233 mm



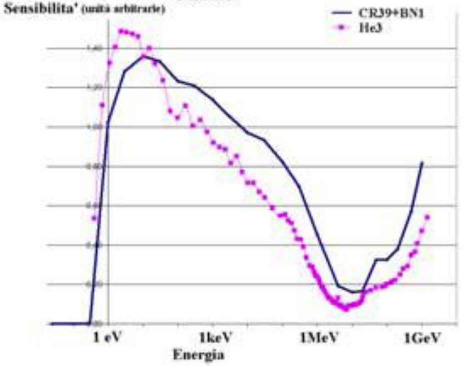
233 mm FLUKA-MCNPX



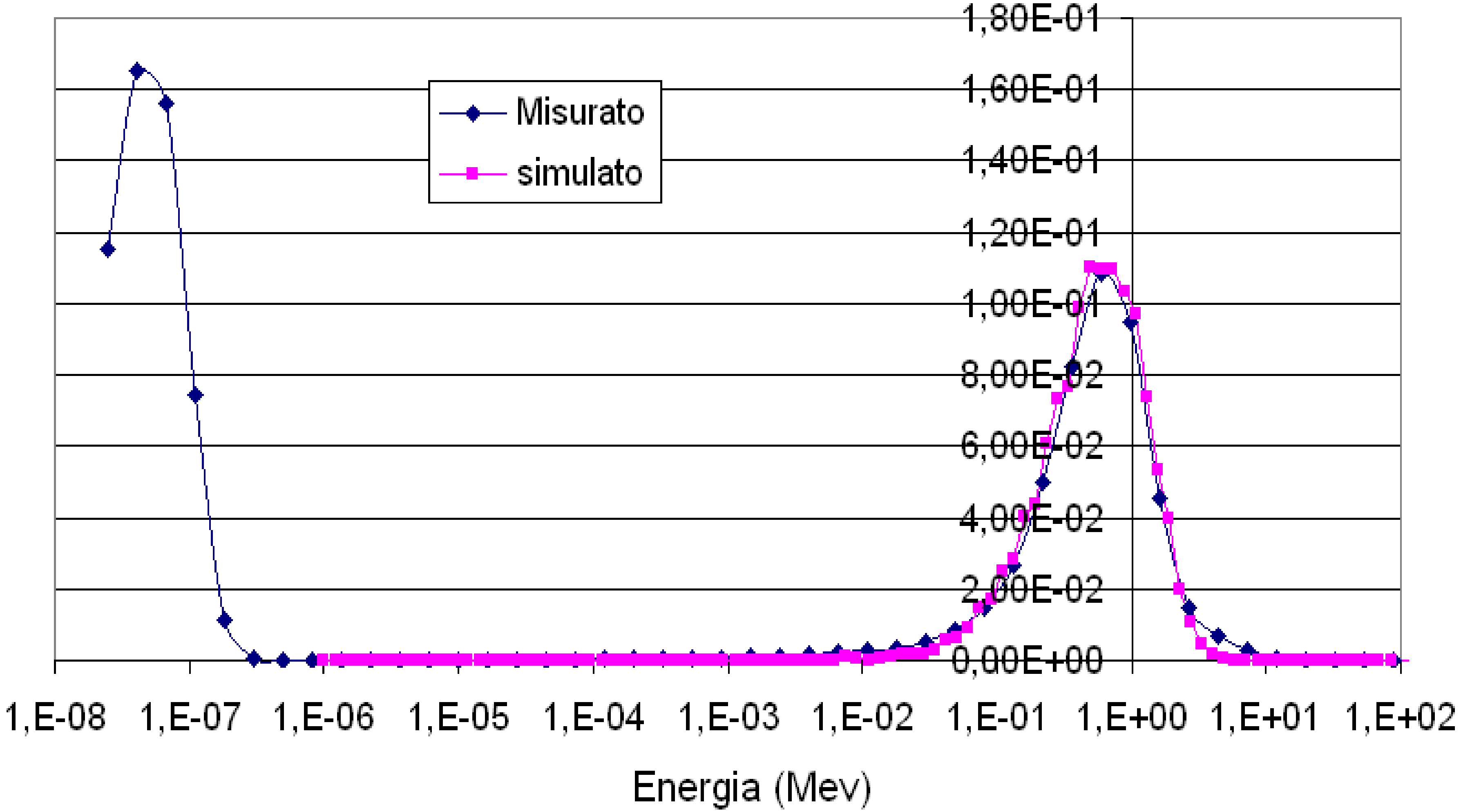
Ollio



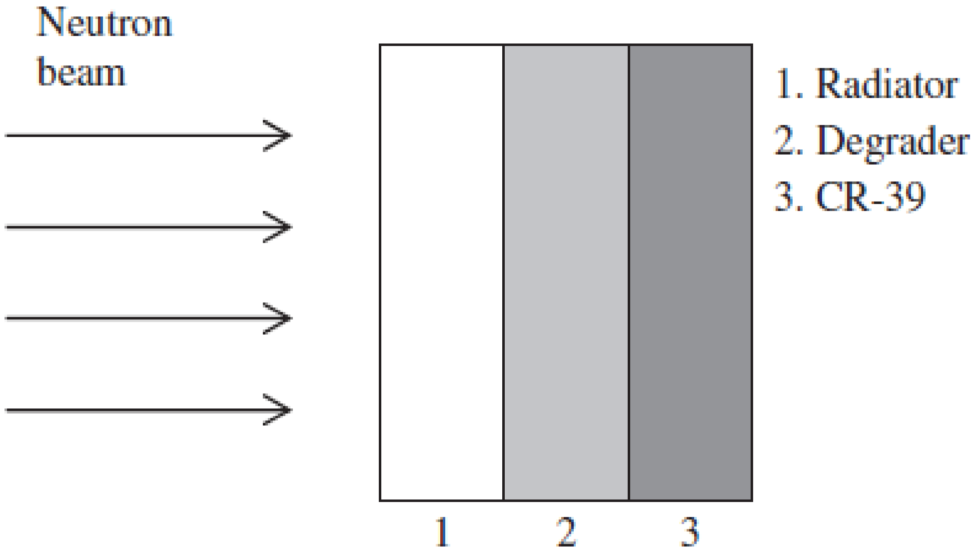
Stanlio



Neutron spectrum (LINAC)



Radiator Degrader Neutron Spectrometer (RDNS)



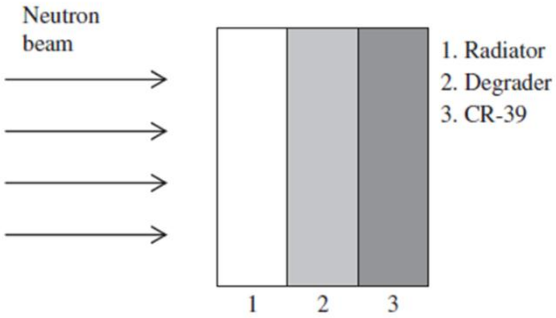
Radiator:

high density (0.95 g·cm^{-3}) polyethylene,

Degrader:

aluminum (purity 99.0%)

Detector sensitivity

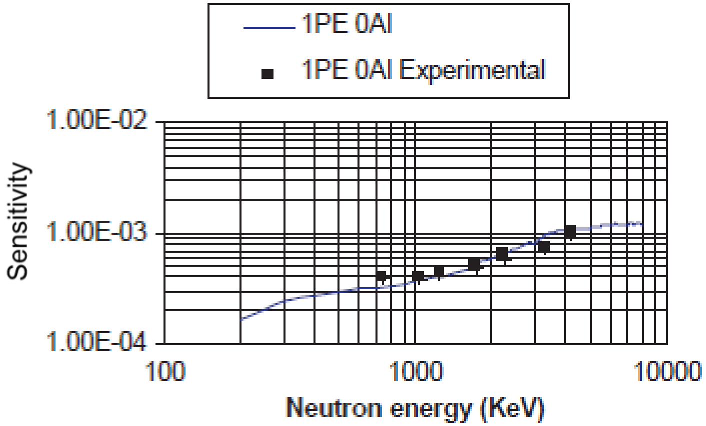


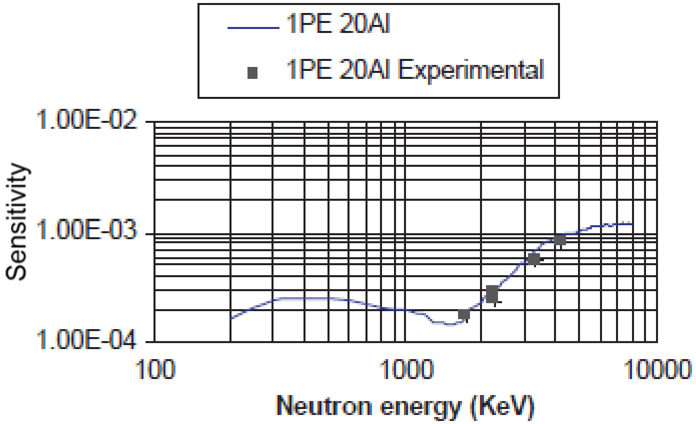
(1) Recoil protons generated inside the radiator(external radiation component).

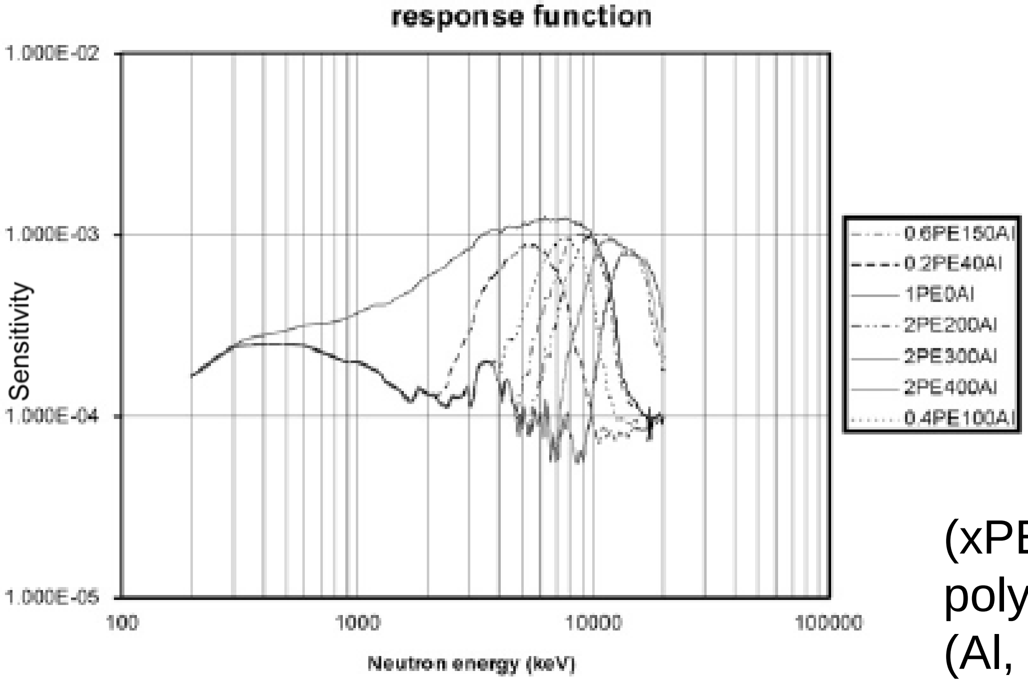
(2) Recoil protons generated inside the detector(proton self radiator).

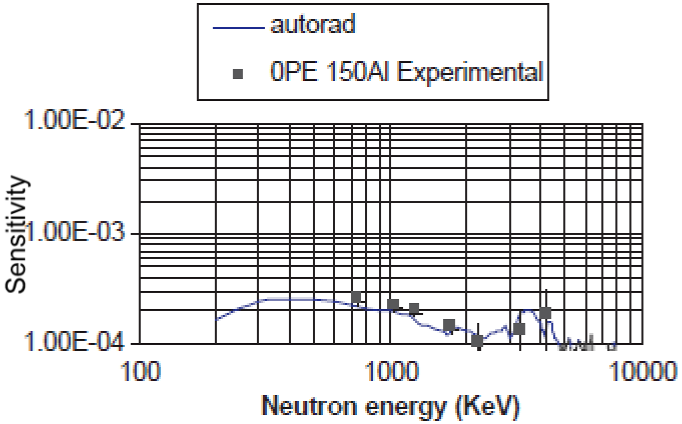
(3) Carbon and oxygen recoil nuclei generated inside the detector (ion self radiator).

Sensitivity experimental verification



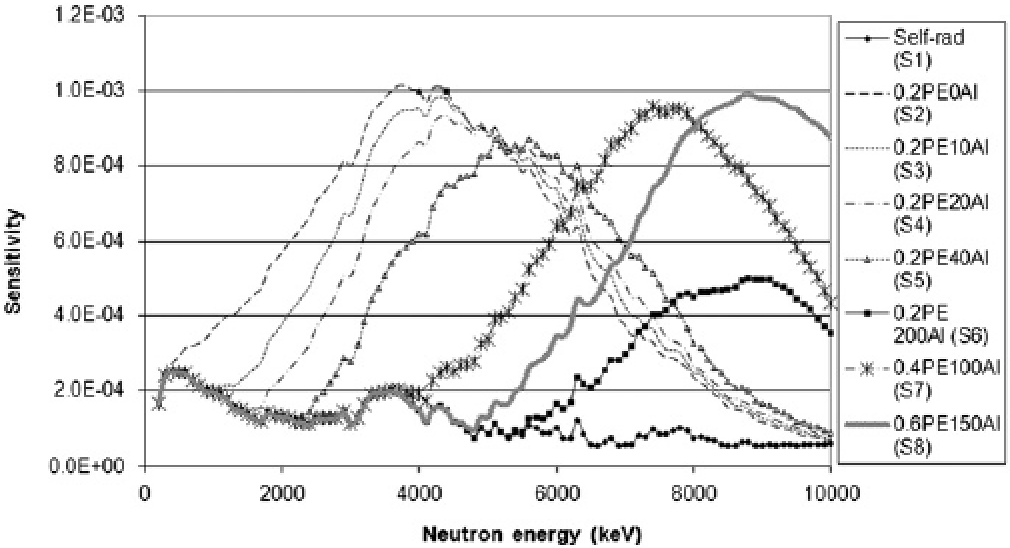


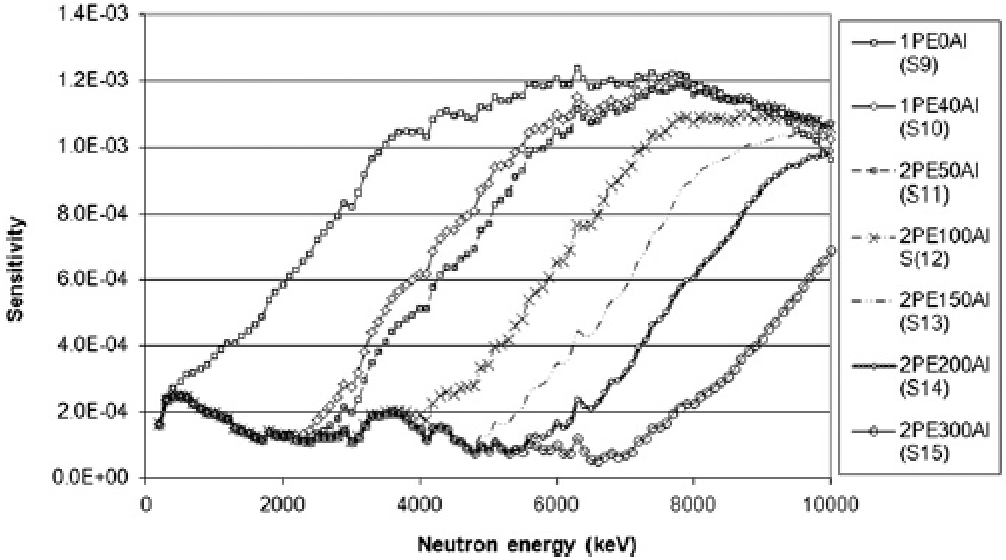




(xPEyAl), where x and y indicate the polyethylene (PE, mm) and the aluminum (Al, µm) thickness,respectively.

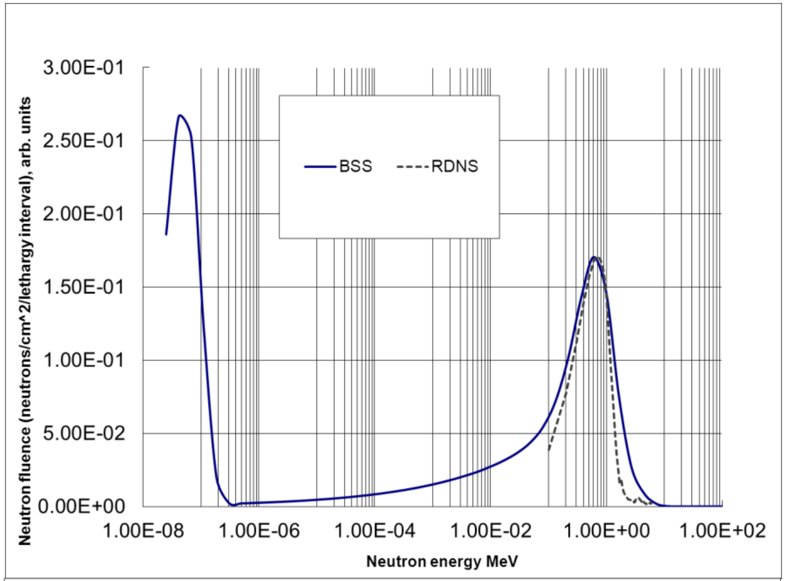
Evaluation of the unfolding capability

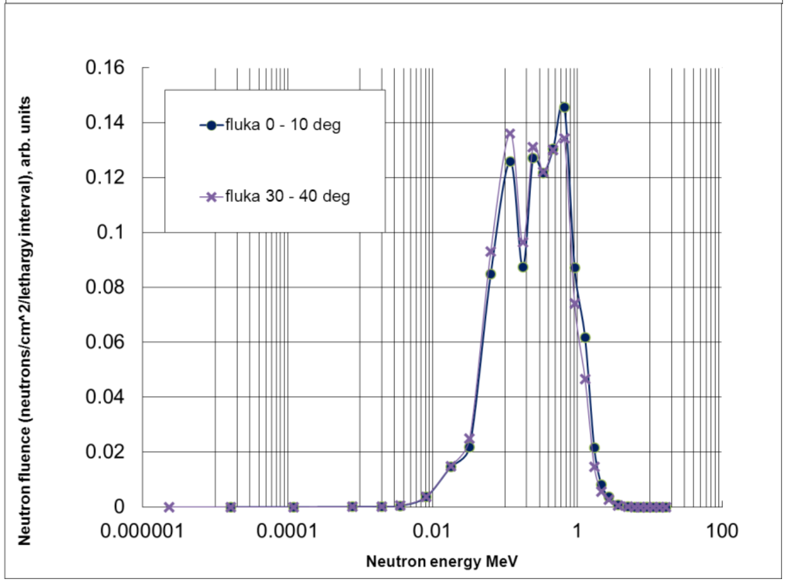




RDNS with 15 configurations was tested both with simulated and experimental irradiation with a neutron Pu-Be source

Spectrometric capability
Experimental data





Conclusions

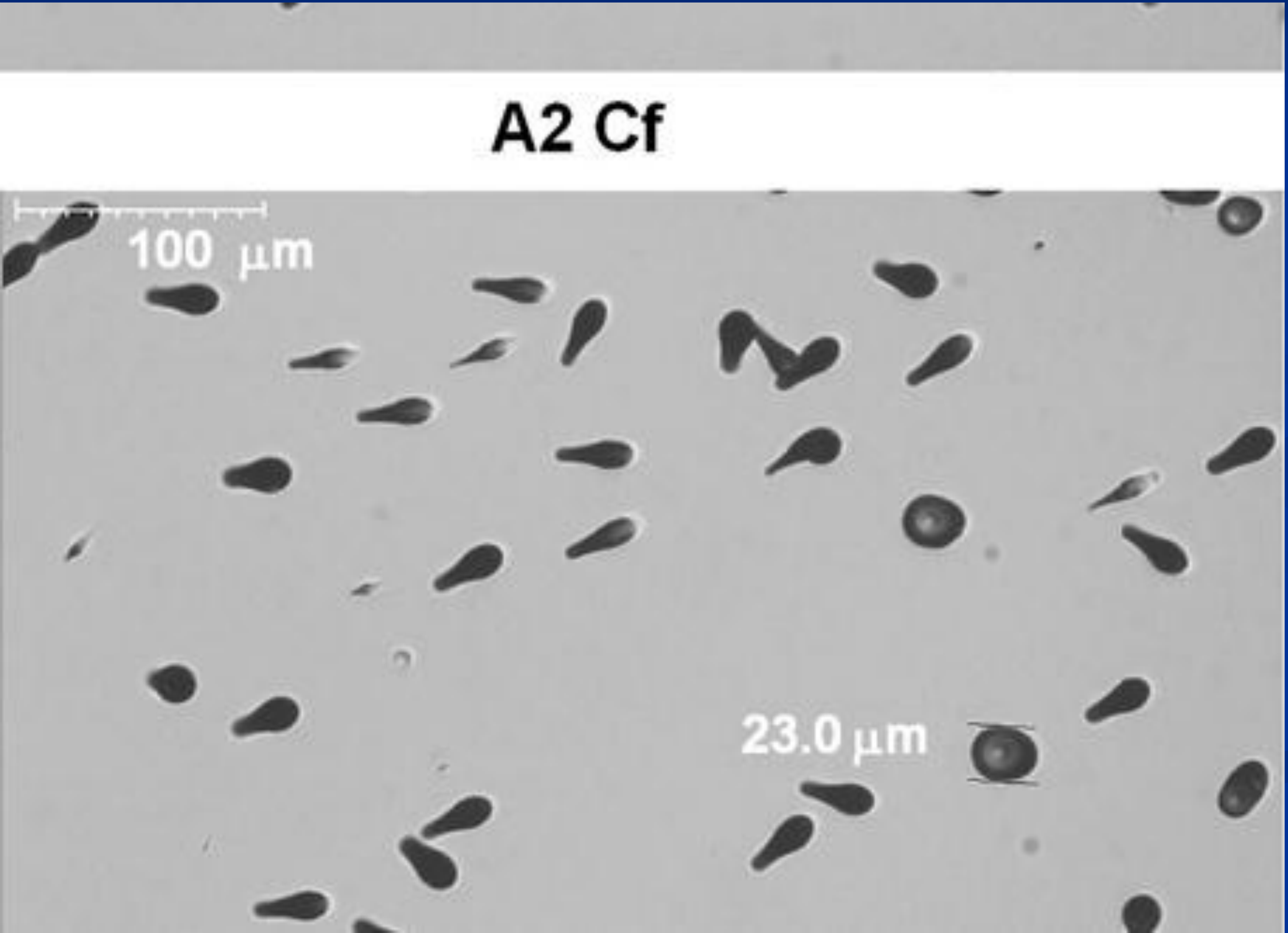
Advantages

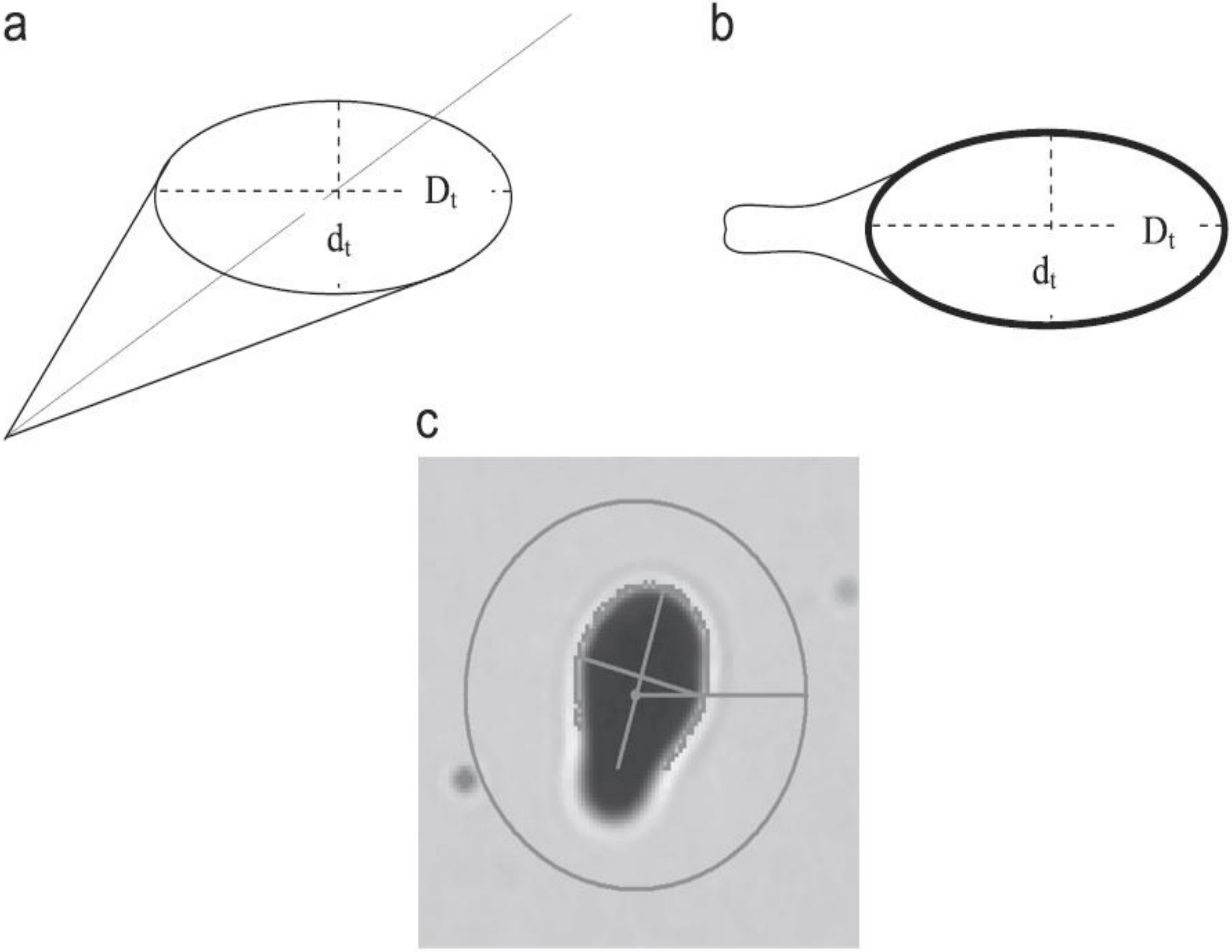
- Possibility to make simultaneous measurement in several configurations because the detectors can be placed side by side without an appreciable cross scattering;
- The presence of a small amount of moderating material which, produces negligible perturbation in the measured neutron field;
- The small dimension allows measurements also in very narrow sites where a moderator based spectrometer cannot be used.

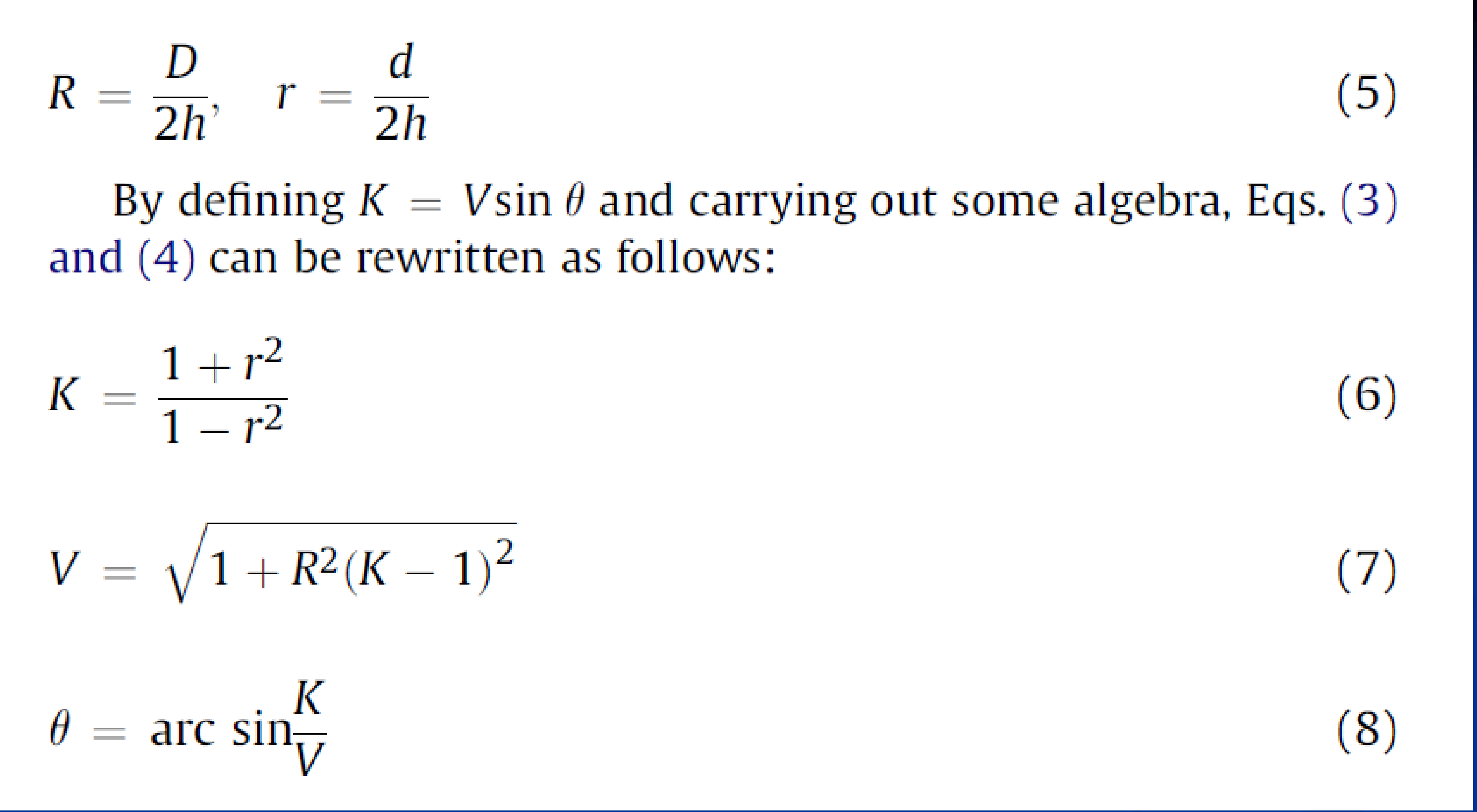
Disadvantages

- Insensitivity to the thermal neutrons, even if this fact can be bypassed by introducing a PADC detector coupled with a boron converter. This solution has not been characterized yet;
- The response functions are angular dependent. The RDNS was characterized for normal impinging neutrons only. The angular dependence has not been studied yet;
- Low sensitivity when compared with moderation based fast neutron detectors. This fact is intrinsic in detectors based on protons recoil detection

Neutron dosimetry based on LET spectrometry




a
D_t
d_t
b
D_t
d_t
c



$$R = \frac{D}{2h}, \quad r = \frac{d}{2h} \tag{5}$$

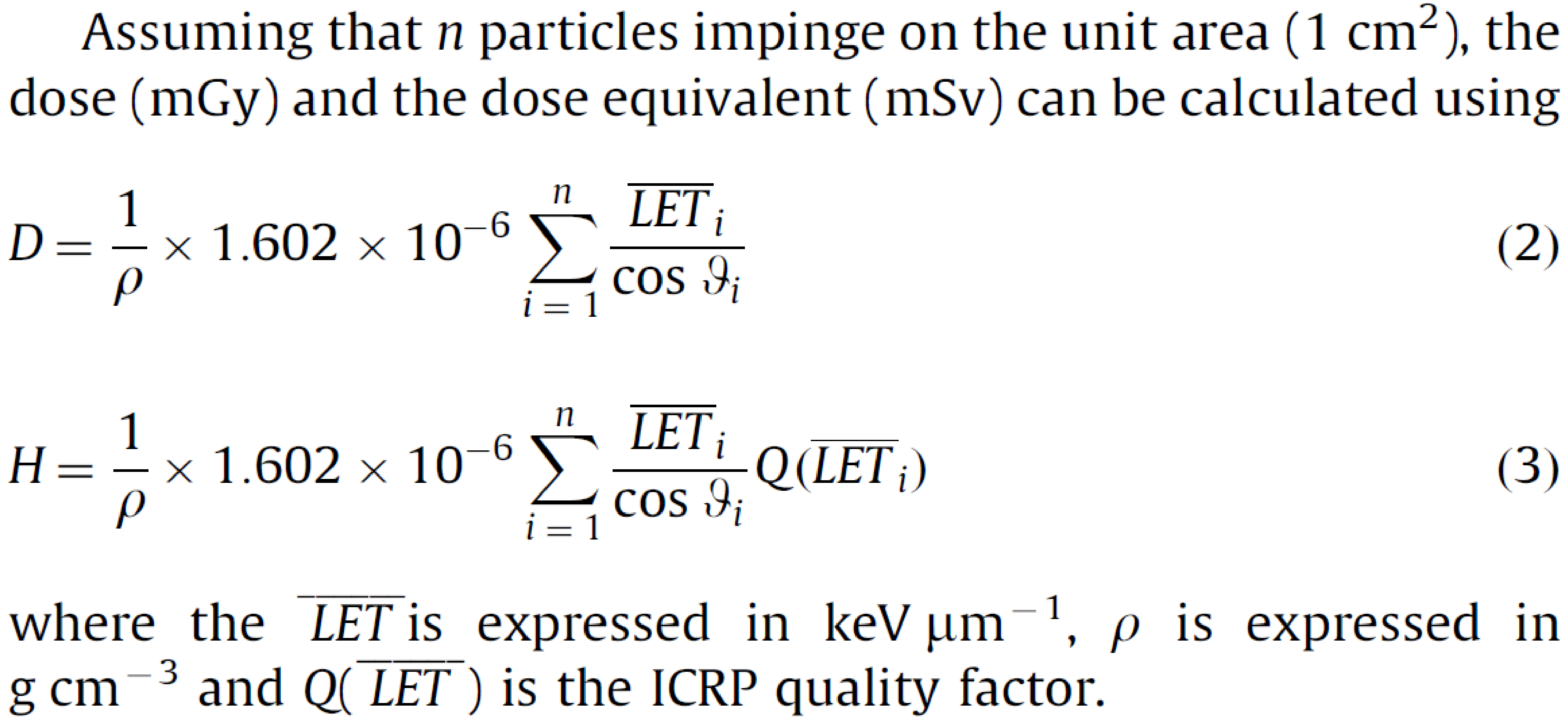
By defining $K = V\sin\theta$ and carrying out some algebra, Eqs. (3) and (4) can be rewritten as follows:

$$K = \frac{1 + r^2}{1 - r^2} \tag{6}$$

$$V = \sqrt{1 + R^2(K - 1)^2} \tag{7}$$

$$\theta = \text{arc sin}\frac{K}{V} \tag{8}$$

It is possible to calculate V and θ from the track parameters. LET= LET (V)



Assuming that n particles impinge on the unit area (1 cm^2), the dose (mGy) and the dose equivalent (mSv) can be calculated using

$$D = \frac{1}{\rho} \times 1.602 \times 10^{-6} \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos \vartheta_i} \qquad (2)$$

$$H = \frac{1}{\rho} \times 1.602 \times 10^{-6} \sum_{i=1}^{n} \frac{\overline{LET}_i}{\cos \vartheta_i} Q(\overline{LET}_i) \qquad (3)$$

where the $\overline{LET}$ is expressed in keV $\mu\mathrm{m}^{-1}$, ρ is expressed in g cm^{-3} and $Q(\overline{LET})$ is the ICRP quality factor.

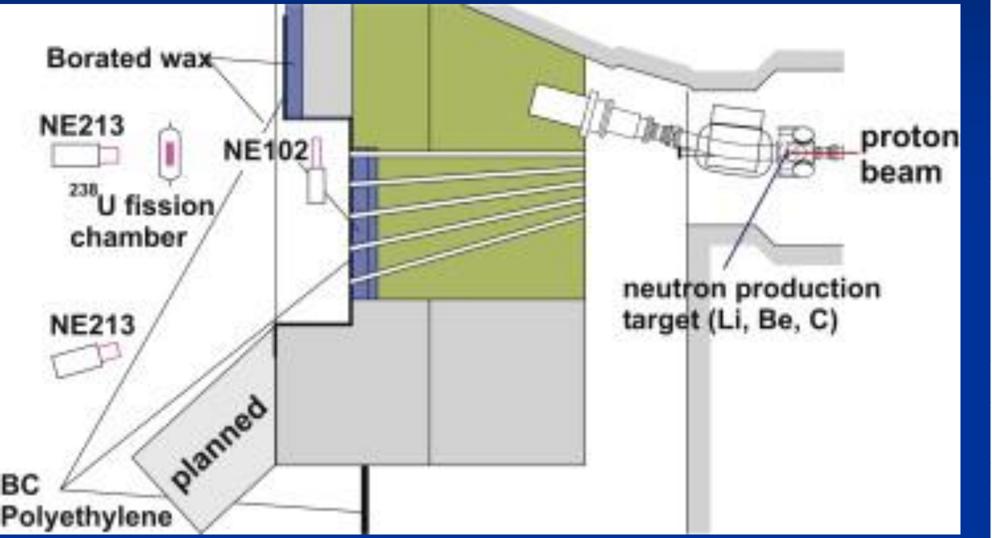
From LET and θ it is possible to calculate the dose and the dose equivalent.
If a 1 cm PMMA radiator is used, H is a good approximation of H*(10).
This is almost independent from the impinging particle.

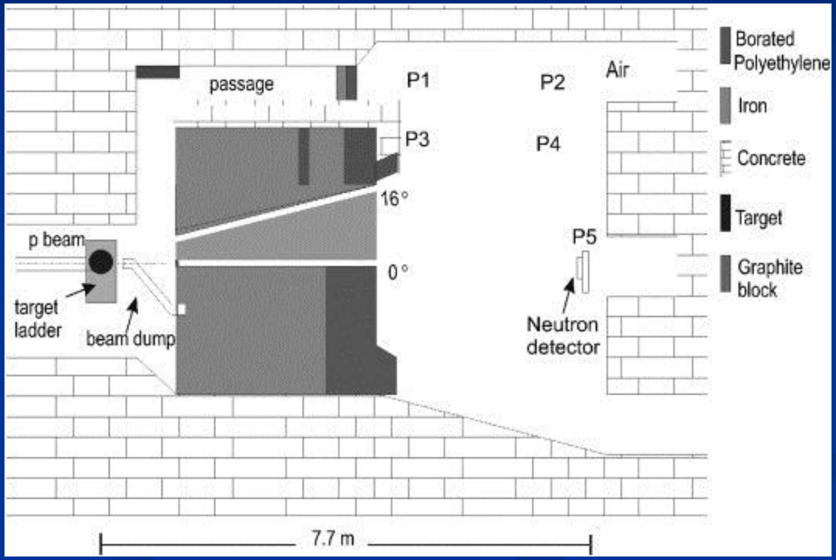
Any energy, but not any LET or any impinging angle.

These contributions are lost:

- low LET particles (electrons, but also protons with E>10 MeV)
- low energy particles (e.g. protons below 0.5 MeV)
- particles impinging below the critical angle - the critical angle is a function of LET.

High energy quasi monoenergetic beams tested

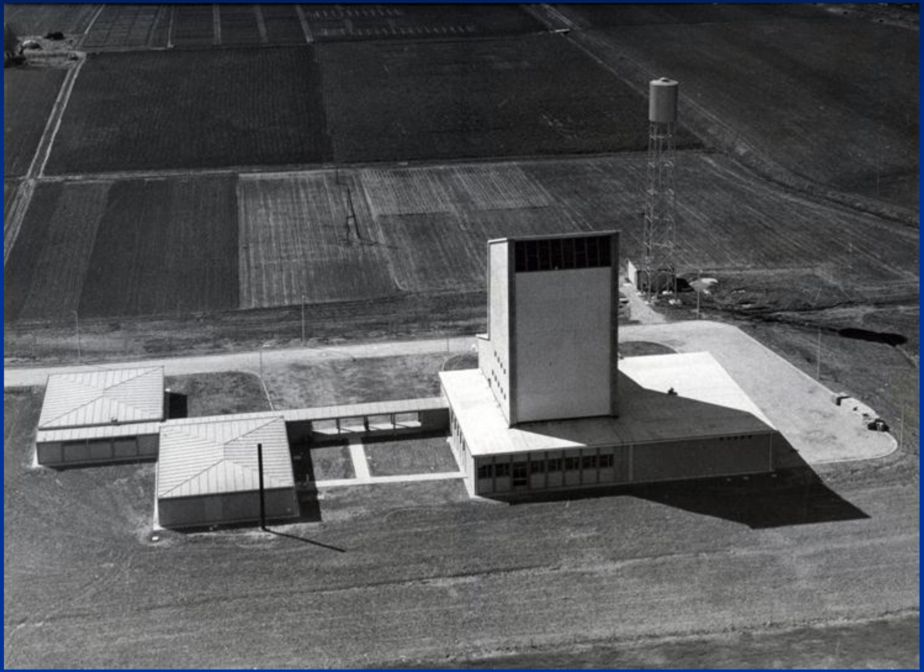




- Uppsala, SE (21, 46.5, 96, 175 MeV)
- Ithemba labs, ZA, 100 and 200 MeV

(results on their way)

Quasi monoenergetic fields



- PTB

19.0 MeV

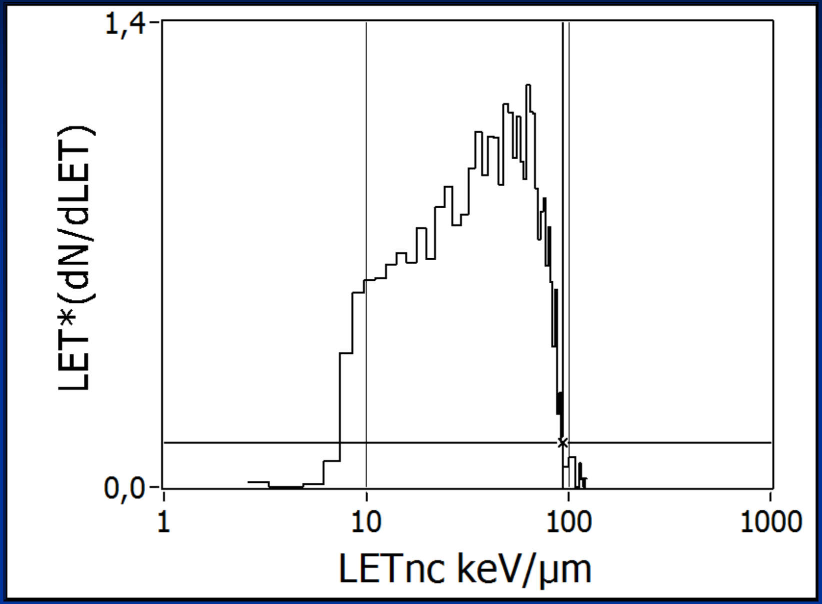
14.8 MeV

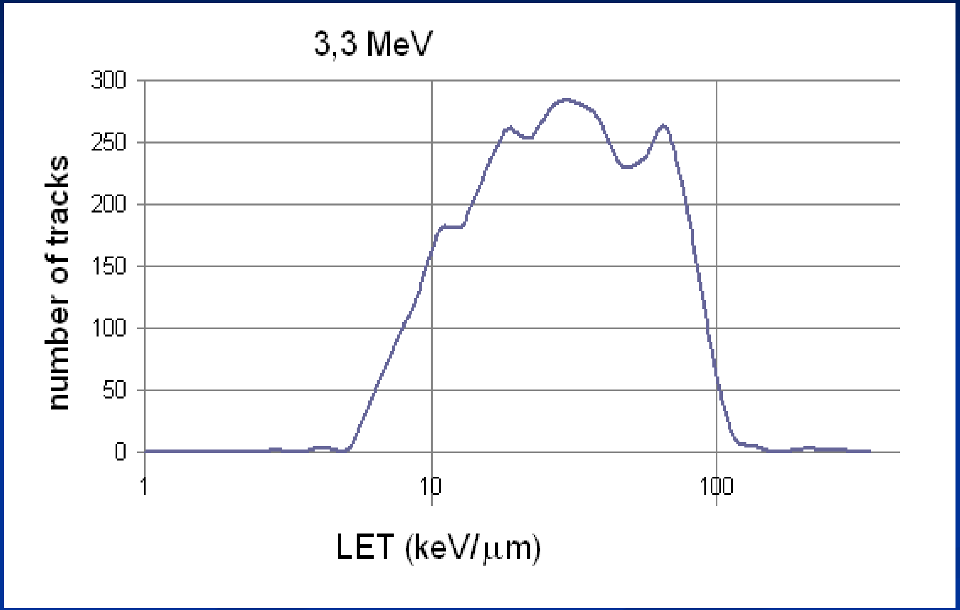
0.535 MeV

- LNL

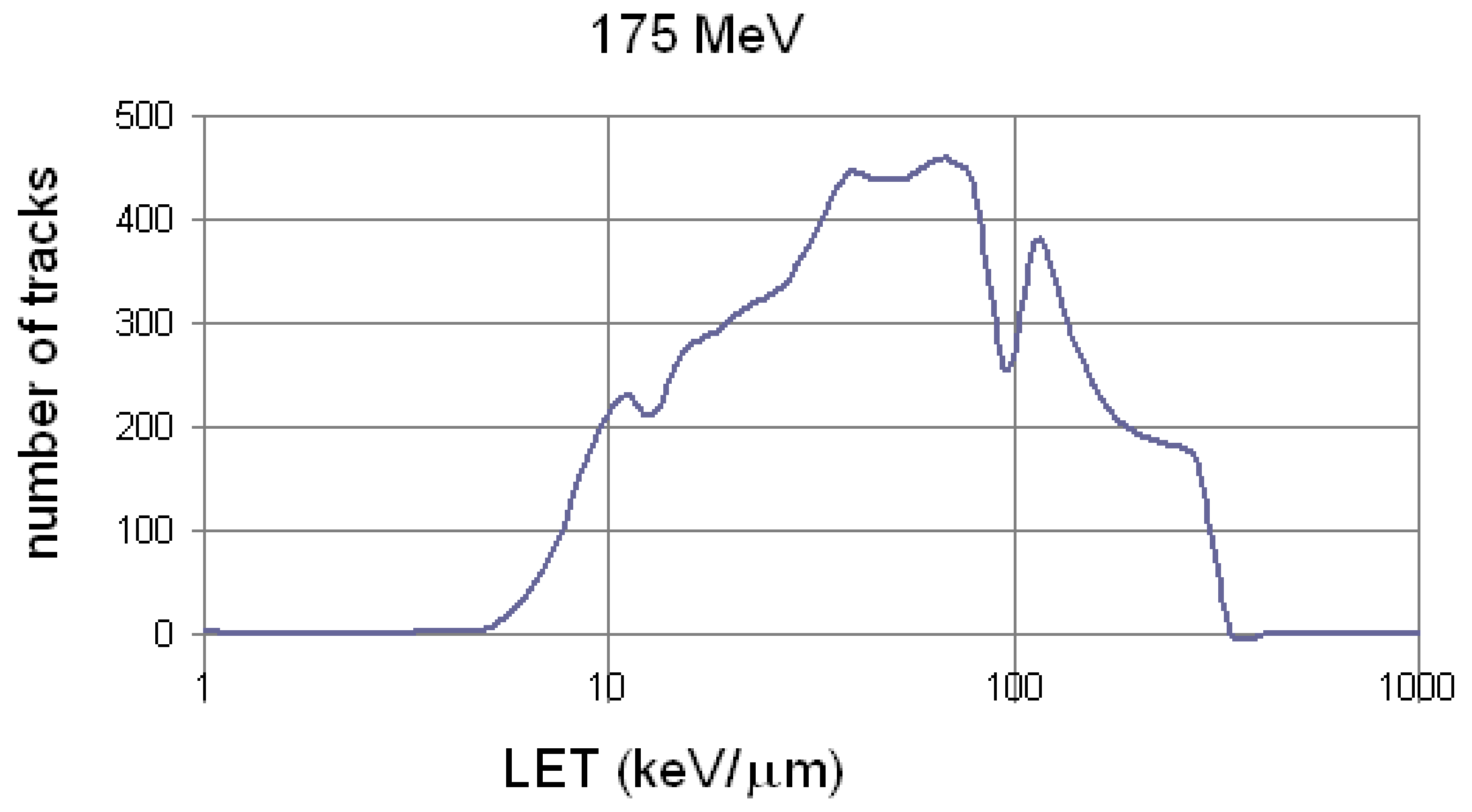
2.0 MeV

3.3 MeV

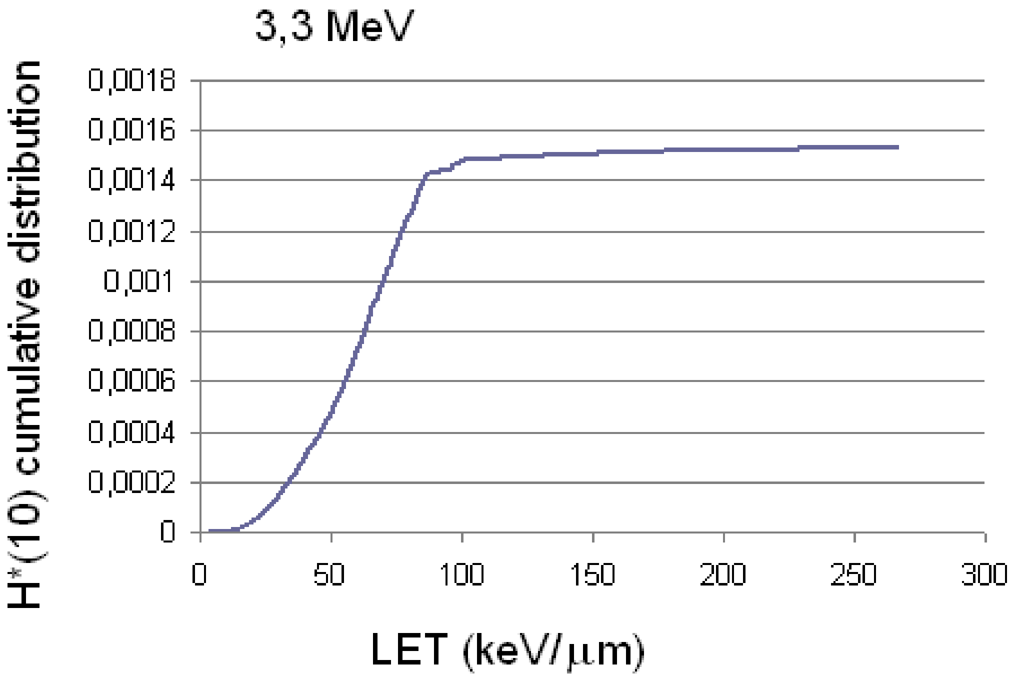


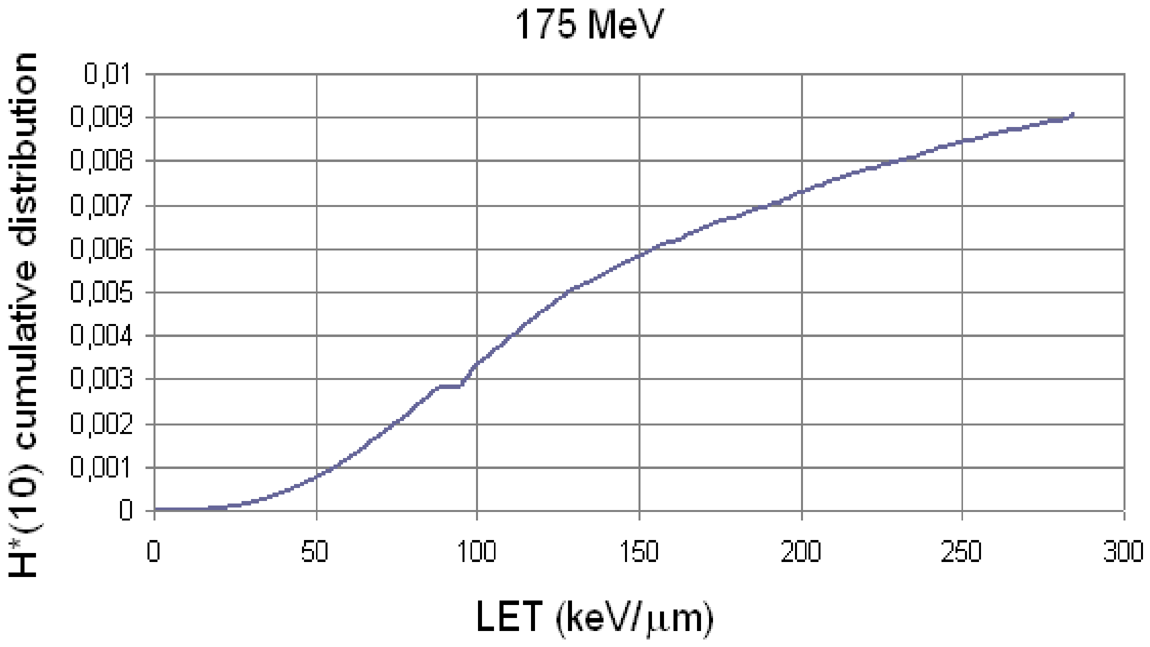


- 2 MeV neutrons
- 3.3 MeV neutrons
- Signal only due to protons



For any energy between 2.0 and 175 MeV neutrons the ratio between the measured dose and the reference value ranges between 0.6 and 0.9. The efficiency for 0.535 MeV neutrons drops to less than 0.4

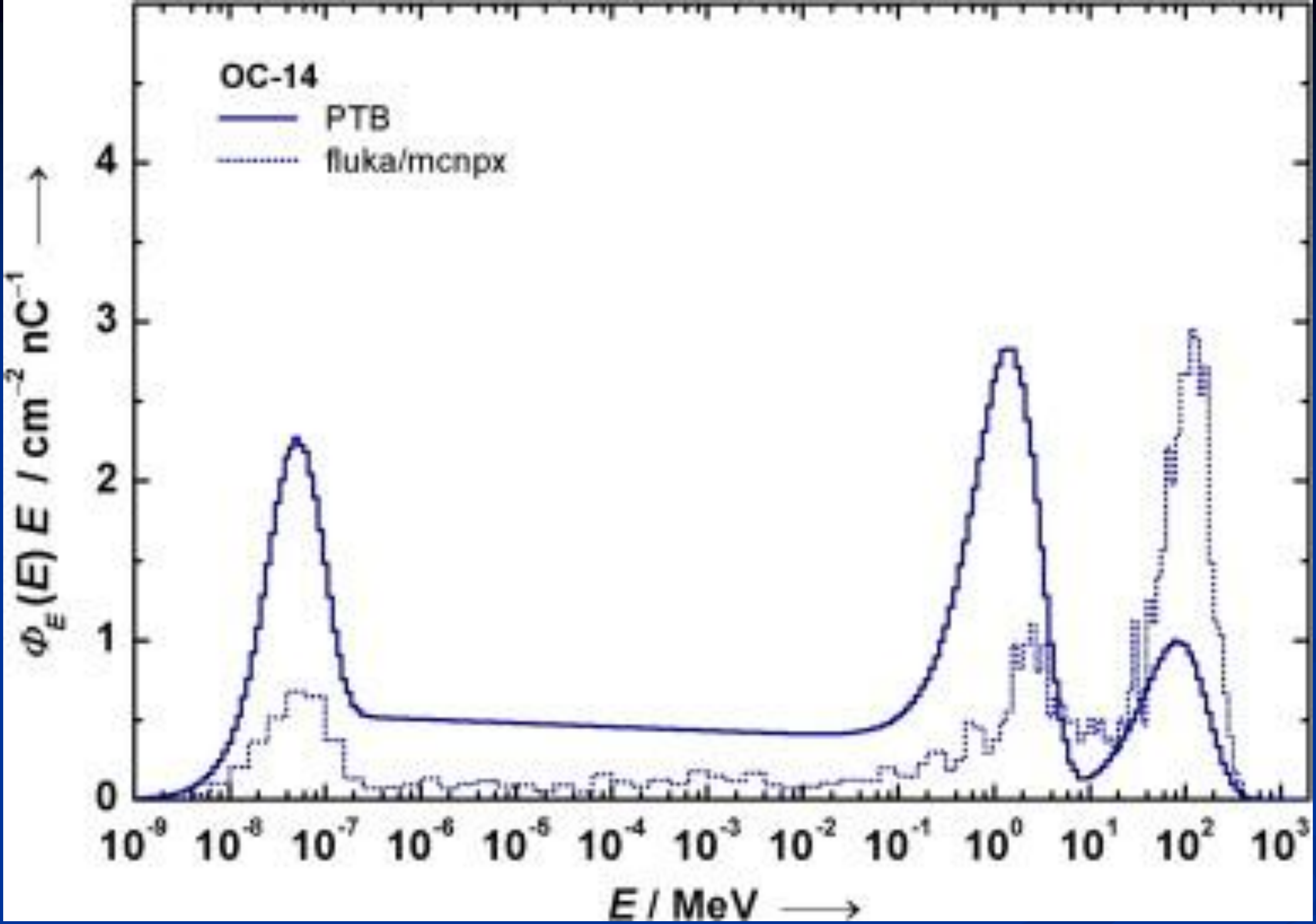




At 3.3 MeV all the dose is due to protons

At 175 MeV more than 60% of the dose is due to recoils heavier than protons.

The technique may also be used to measure charged fragments, ions, etc…



The majority of the dose in accelerator environment is due to neutrons from 1 to a few hunderd MeV

What is left to do?

- 1) Some work about the quality of measurements is still necessary for the first two applications, that are at a much more advanced stage.
- Metrological characterization

- 2) Much is left to do for the LET spectrometry technique.
  A full Monte Carlo characterization of the dosemeters is still in progress (MCNPX? FLUKA?)
  - Angular response still to be understood

  - Metrological characterization for personal and environmental dosimetry

  - Medical physics application (?) : secondary dose evaluation due to fragments, with LET spectrometry

- S. Agosteo, F. Campi, M. Caresana, M. Ferrarini, A.Porta M.Silari, (2007), Sensitivity study of CR39 track detector in a system of extended range Bonner spheres, Radiat. Prot. Dosimetry vol.126, No. 1-4 pp.310-313
- •M. Silari, et al. (M.Ferrarini), Intercomparison of radiation protection devices in a high-energy stray neutron field. Part III: Instrument response Radiation Measurements 44 (2009) 673–691
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