SEE Rate Calculation

1. Heavy ion test and rate calculation
2. Single Event Effect rate calculation

SEE Basic Mechanisms and Model

- Charge deposition and collection
  - There are plenty of different SEE that can potentially occur in a device
  - They are all initiated by the same scheme
    - An energetic particle passes through the device
    - Energy is transmitted to the semi-conductor by ionization
    - A large amount of charge is generated on the ion path
    - The generated charge is collected and leads to an event

- SEE are « isolated » events taking place in a device, caused by only one particle strike
  - The SEE sensitivity is not represented by an irradiation level (like for TID/TNID)
  - The SEE sensitivity is represented by a probability of occurrence
    - Specific to the event type
    - Specific to the device

SEE Basic Mechanisms and Model

- This probability is called the device Cross Section
  - The device cross section represents the sensitivity of a device to a given SEE under specific conditions
  - The cross section is represented as a function of
    - The LET under heavy ions
    - The energy under protons

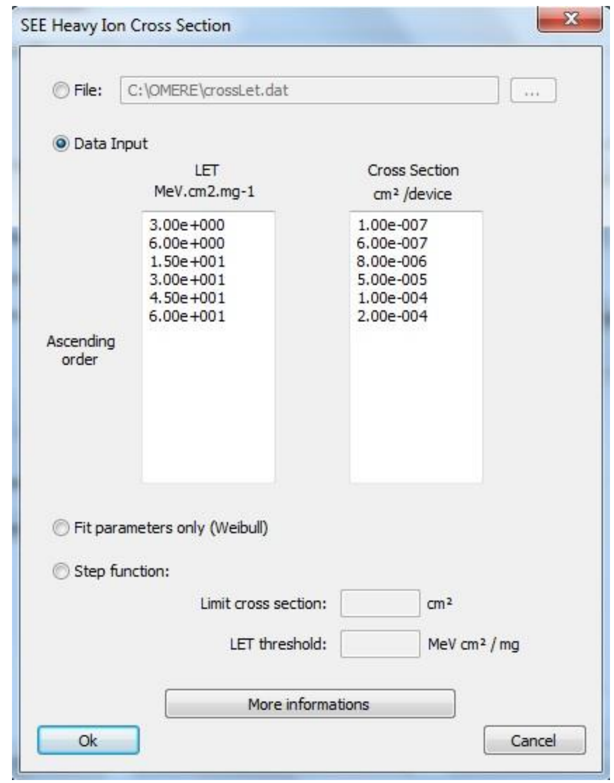
- LET concept
  - Linear Energy Transfer
  - The LET characterizes the amount of energy that a particle yields along its path in the matter
  - The higher the LET, the more the energy deposition in the device is important
  - LET and Energy are two different things…

Cross Section

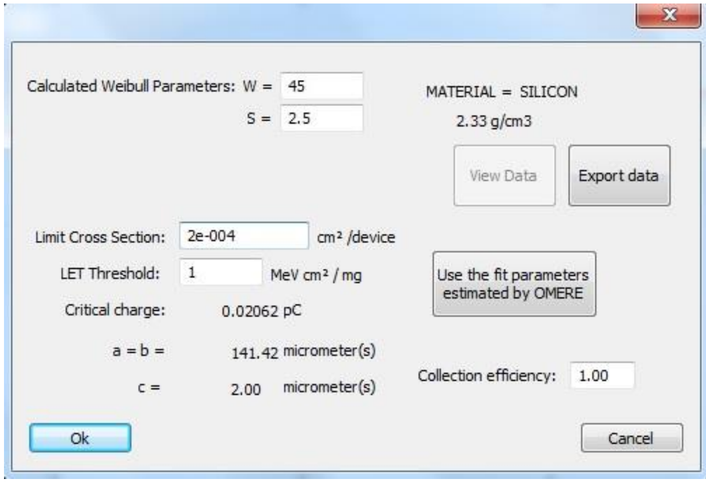
- The Cross Section is the ratio of counted events divided by received ions

$$\sigma = \frac{event\_number}{fluence} = \frac{\#}{\phi}$$

- The Cross Section can be measured
  - It is a test data
  - Events counted under beam for a fixed fluence

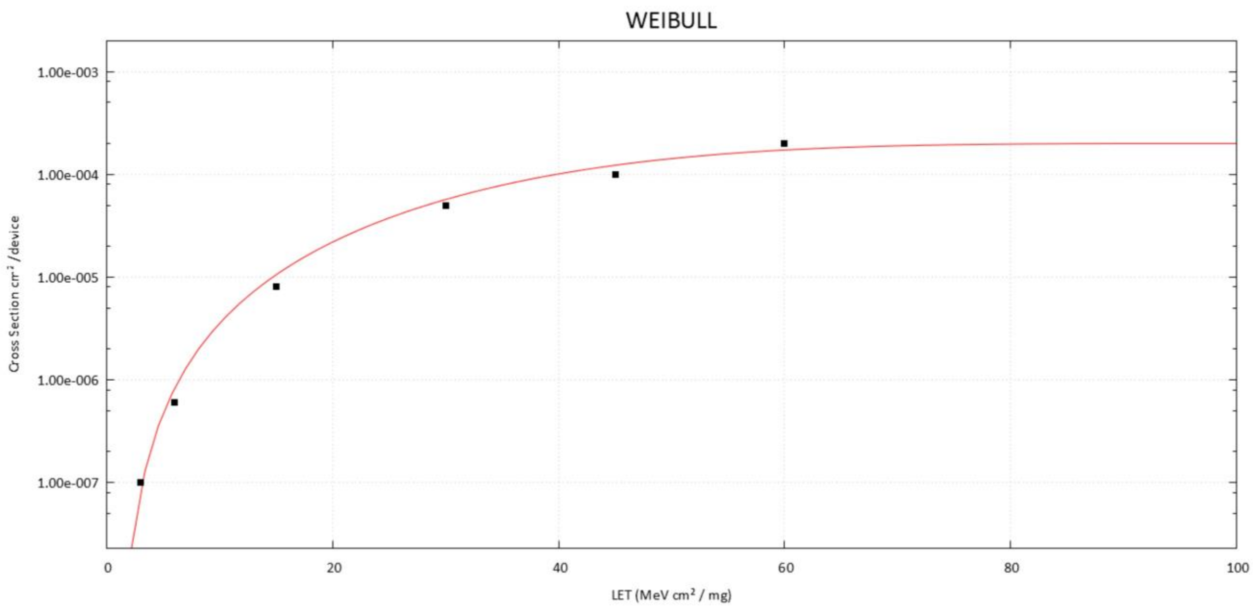


Cross Section



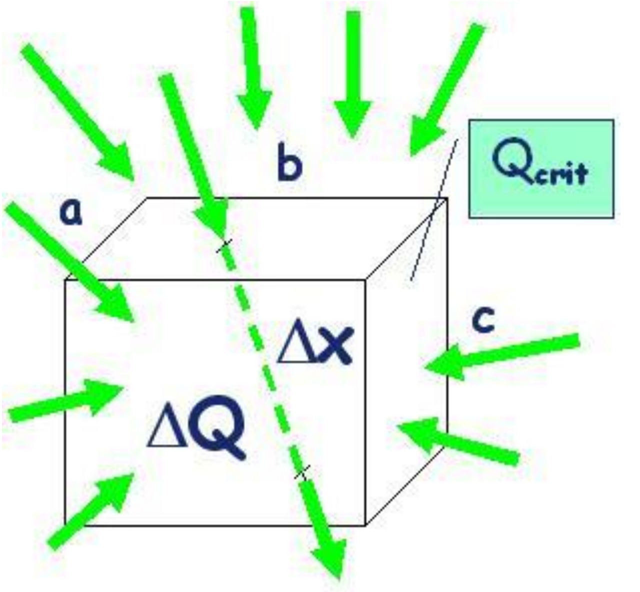
- Weibull fit parameters
  - W (width)
  - S (shape)
  - σ_{SAT} (saturated cross section)
  - L_{th} (threshold LET)

- Weibull curve
  - Weibull distribution (red curve) fitted to the test data (black dots)



CREME and RPP Method

- CREME (Cosmic Ray Effect on Electronics)
  - Adams, 1986
- Assumption
  - Rectangular Parallelepiped (RPP) sensitive volume
  - Constant LET all along ion path
  - Qcrit critical charge of this sensitive volume
  - If $Q_{dep} > Q_{crit}$ then an event occur
- CREME enables to calculate the SEE rate in a given sensitive volume characterized by a specific LET threshold
  - Calculation parameters
    - a, b and c
    - L_{th}



$$\Delta Q \geq Q_{crit}$$

SEE Rate

- For the SEE rate calculation, we assume that an event will occur if the charge deposited in the target by an incident ion is greater than a limit

$$\Delta Q \geq Q_{crit}$$

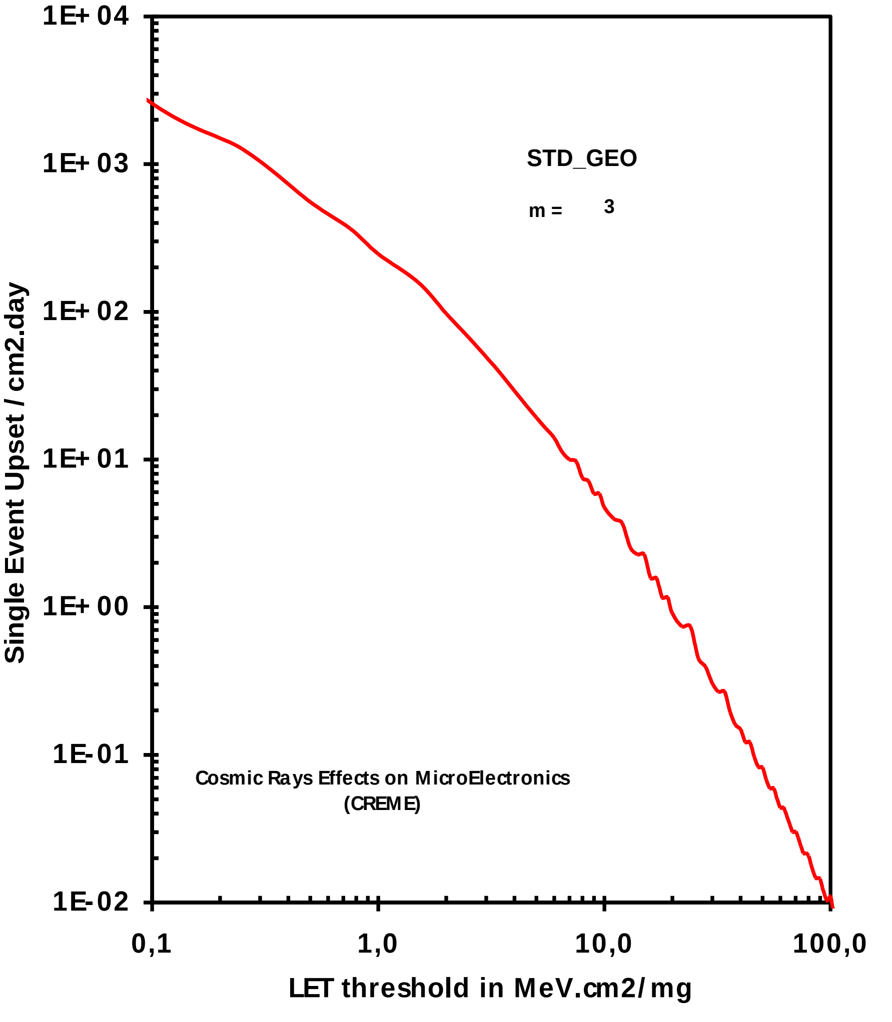
- The deposited charge is proportionnal to the path length Δx in the sensitive volume, and to the LET of the incident particle

- The LET depends on the ion species, the ion energy and the target material

$$\Delta Q \propto \Delta E = LET_{Si}^{ion}(E) \cdot \Delta x$$

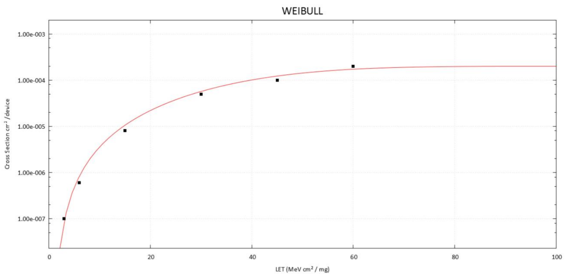
SEE Rate

- For a given sensitive volume
  - The SEE rate is calculated with the UPSET module of CREME86 (included in OMERE)
- For the entire device
  - The single-cell rate is correlated to the device under-irradiation response with OMERE



Interpretation of Data

- LET threshold (or on-set LET)
  - Minimum LET for which an event can occur



- All cells do not have the same LET threshold in a device
  - Progressive increase of the cross section curve

- The information of the SEE susceptibility of the entire device (including all cells) depending on the LET is given by the cross section curve
  - The rate for one sensitive volume (one L_{th}) is calculated at all LET and integrated over the whole cross section curve

- This SEE rate is calculated by OMERE
  - With the CREME rate calculated for one cell with a specific LET threshold
  - Taking into account the whole device sensivity as a function of the LET

Interpretation of Data

- Weibull distribution

$$\Sigma(L)=\Sigma_0\left[1-\exp-\left(\frac{L-L_0}{W}\right)^S\right]$$

- Number of cells for which
  - Lth < L

$$N(L)=N_0\left[1-\exp-\left(\frac{L-L_0}{W}\right)^S\right]$$

- LET threshold distribution

$$\zeta(L)=\frac{dN(L)}{dL}$$

- CREME rate (at each LET)

$$\mathrm{T(L)}\quad \mathrm{CREME}$$

- Device SEE rate
  - Integration over the whole cross section curve

$$\boxed{\tau=\int_{L_0}^{\infty}\mathrm{T}(L)\,\zeta(L)\,dL}$$

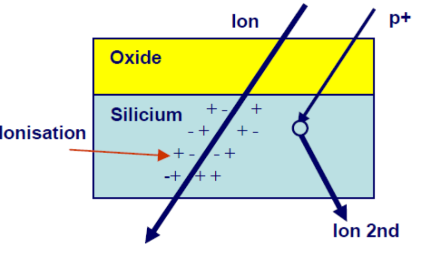
SEE Caused by Protons

- Proton cross section
  - Only one particle type (proton)
  - No need to use the LET
  - Proton-caused SEE are indirect
    - No geometry/angle effect taken into account
  - Cross section expressed as the function of the incident energy

$$\tau_{p+} = \int_{E_0}^{\infty} \varphi(E)\Sigma(E)dE$$

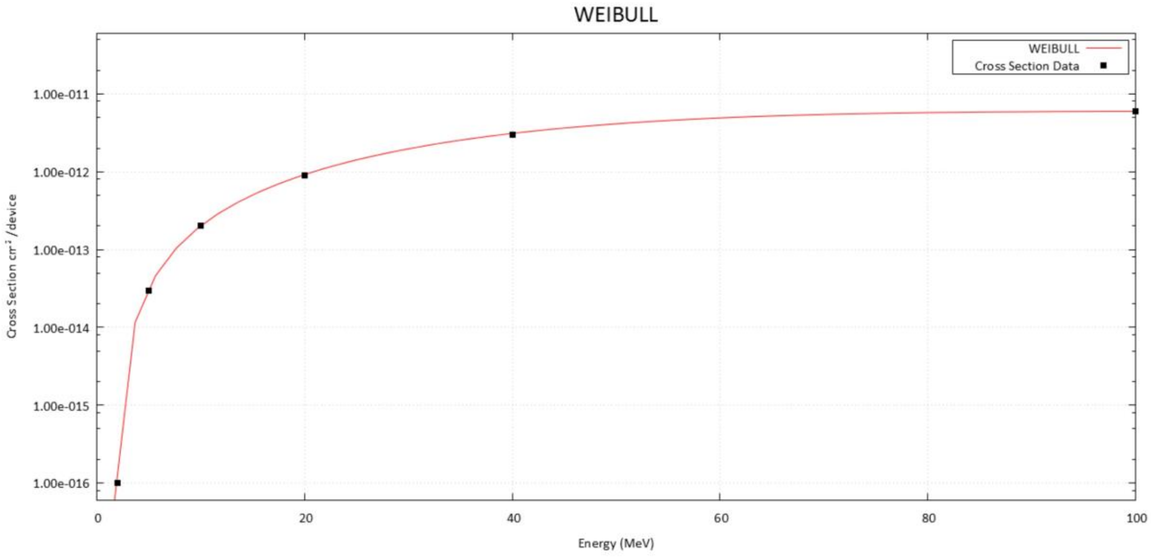
- Proton SEE rate
  - Product of the cross section multiplied by the flux at each energy

- Device considered as potentially sensitive to protons if the heavy ion LET threshold is smaller than 15 $MeV.cm^2.mg^{-1}$

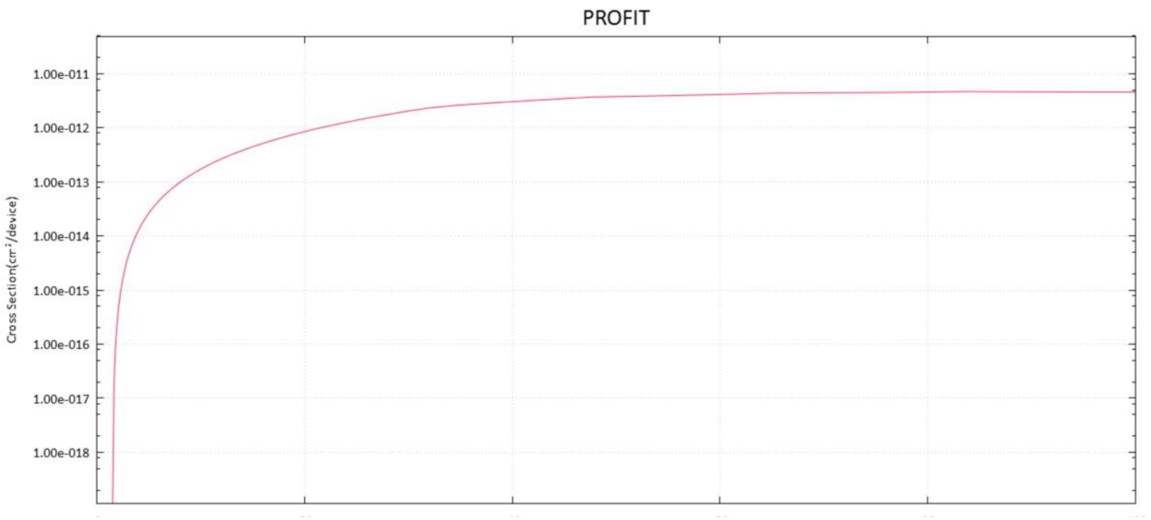


SEE Caused by Protons

- Proton cross section test data (black dots) fitted to a Weibull distribution (red curve)



- The proton cross section can be deduced from the heavy ion cross section
  - PROFIT
  - SIMPA
  - METIS



Heavy Ions Test and Rate Calculation

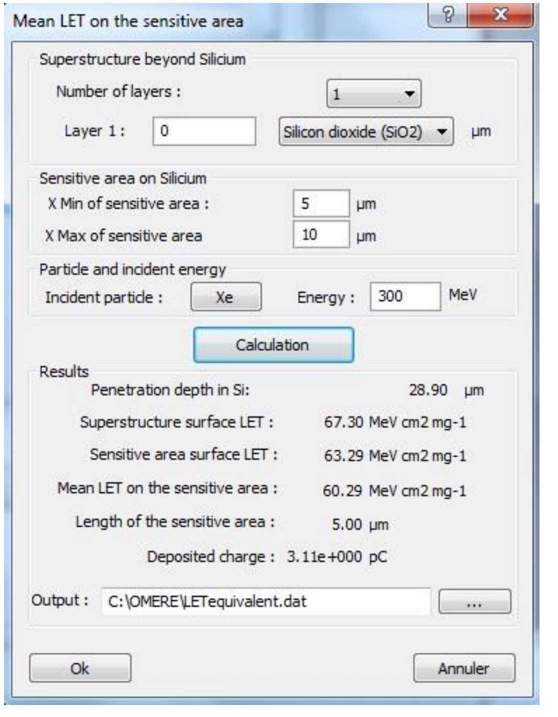
- The heavy ion test is performed to measure the device cross section curve

- The heavy ion test consists in
  - Putting the device under operation
  - Irradiate the device with a specific ion beam
    - Flux
    - Fluence
    - Ion species
    - LET
  - Count the event number with respect to the fluence at several LET
    - LET threshold
    - Saturated cross section
    - Weibull parameters W and S

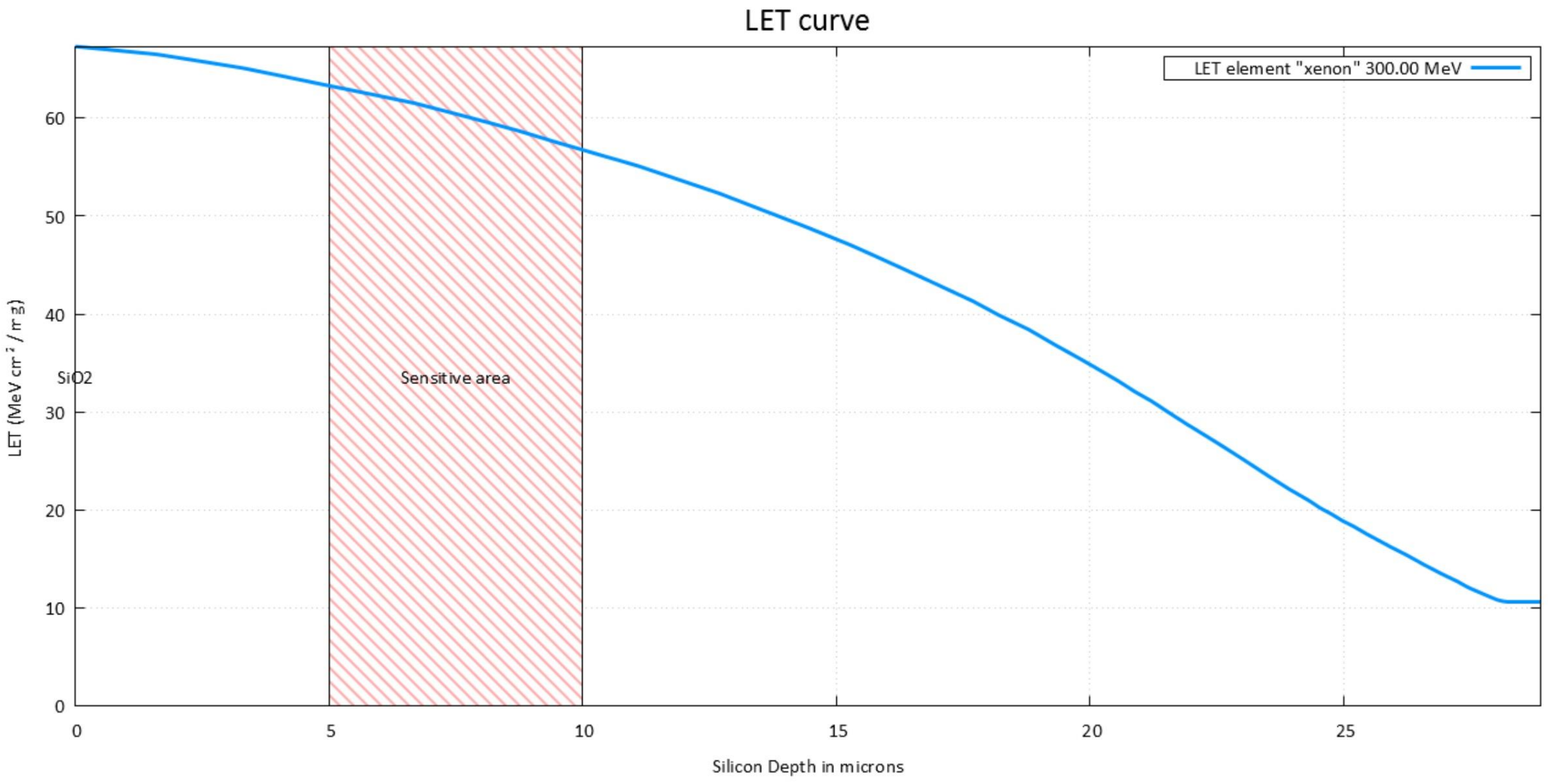
$$\sigma = \frac{\#}{\Phi}$$

Effective LET

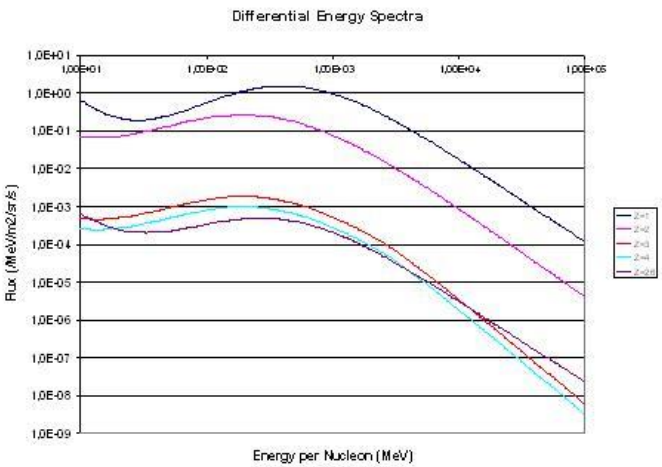
- In a heavy ion test, the LET given by the facility is the surface LET
- The LET does not keep a constant value in the device volume
- If the sensitive volume depth is known, the effective LET can be calculated
  - Averaged LET value in the die



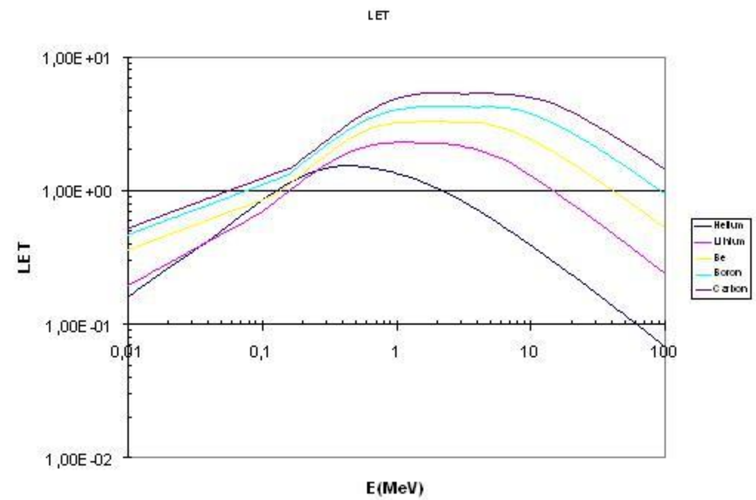
Effective LET



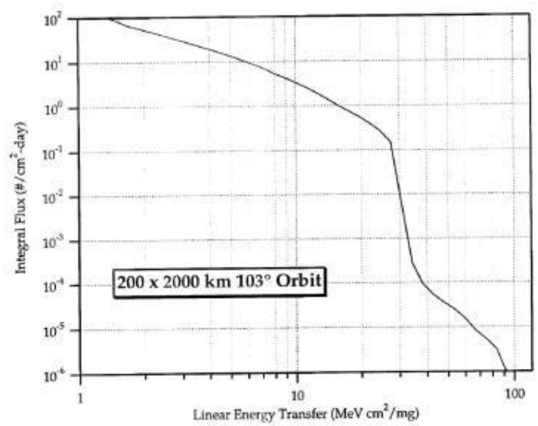
LET Spectrum



Energetic differential flux



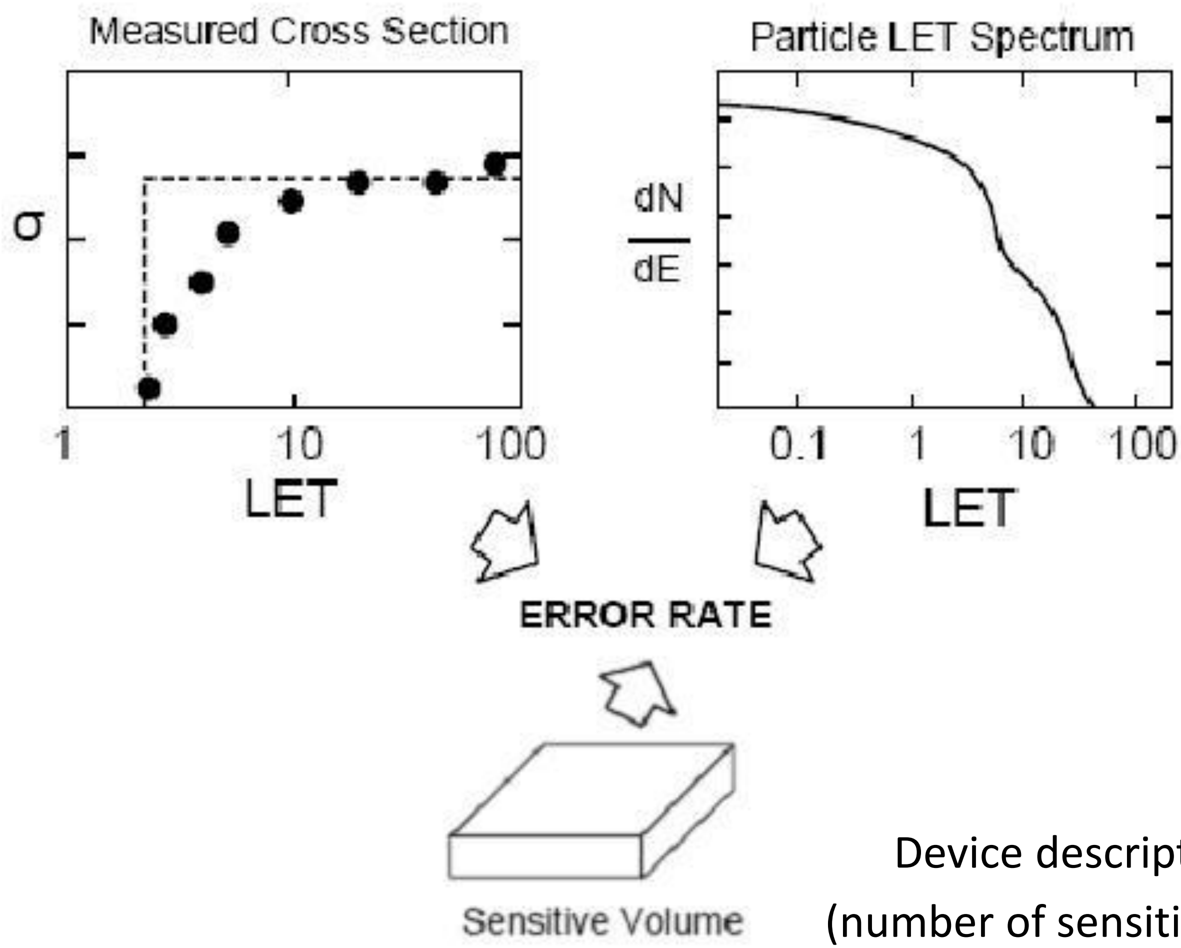
Energetic LET spectrum



Integrated LET spectrum

SEE Rate

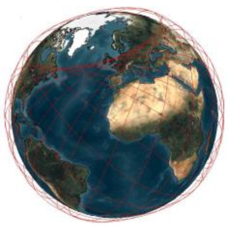
Heavy ion sensitivity (test data)



Space environment (LET spectrum)

Device description (number of sensitive cells and SV depth)

SEE Rate Calculation



Part testing

- Heavy ion test results

OMERE

- Environment
  - Proton belt
  - Solar flares
  - Cosmic Rays

OMERE

- SEE rate calculation
  - Weibull
  - PROFIT
  - SIMPA
  - METIS