Calculation of microdosimetric quantities of proton track segments with Geant4-DNA

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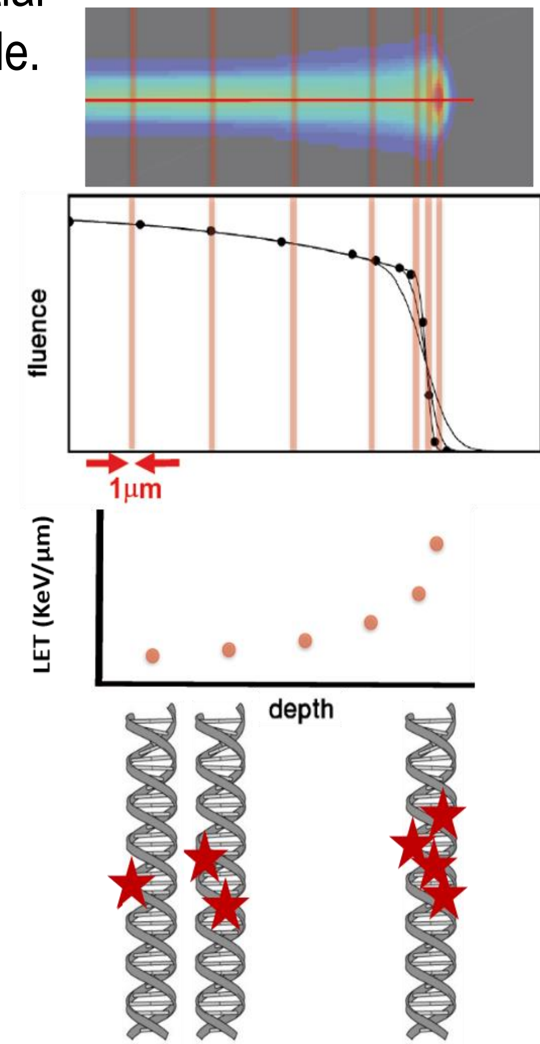
Introduction

The spatial distribution of energy deposition events is an essential aspect in the determination of the radiobiological effects at cellular scale.

Can be described by **MICRODOSIMETRY**



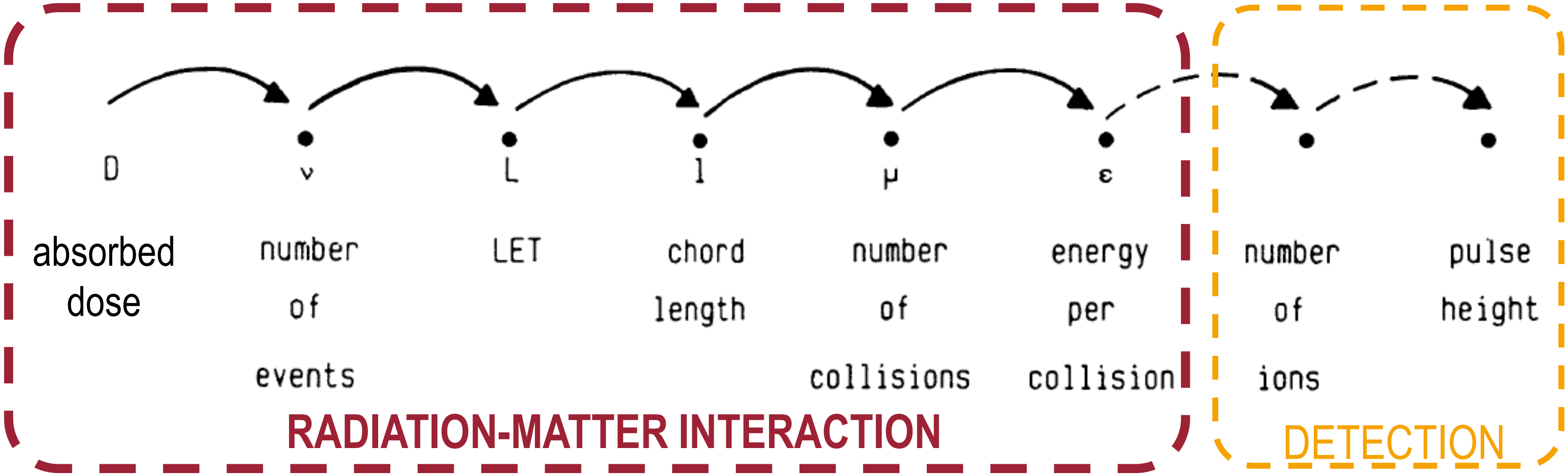
In particle therapy the formalism of microdosimetry can be used to address problems such as:

- characterization of Linear Energy Transfer (LET)
- Derivation of Relative Biological Effectiveness (RBE)

We present a track structure Monte Carlo application, developed for the computation of microdosimetric quantities of protons track segments in liquid water with Geant4-DNA

Single-Event Distributions

An **event** in a **site** is the deposition of energy due to particles that are statistically correlated. The **single event distribution** reflects various stochastic factors.



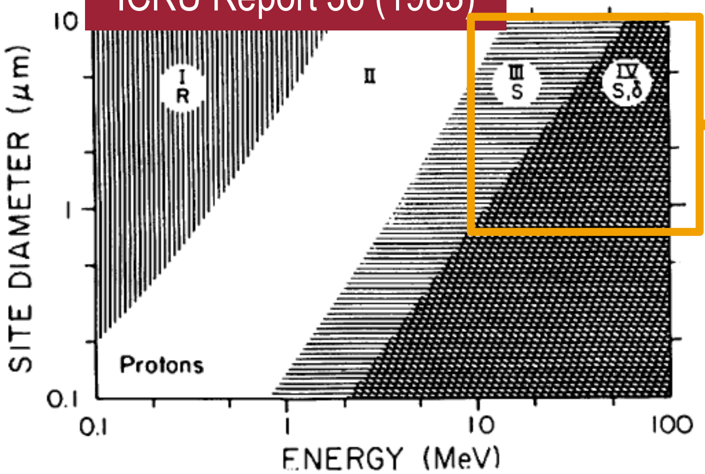
The impact of each random factors on the single event distribution (V_1) can be assessed in terms of the **relative variances** of the LET distribution (V_L), the chord length distribution (V_l) and the straggling distribution (V_s):

$$\boldsymbol{V_1 = V_L + V_l + V_L V_l + V_s},$$

Assumptions:
- primary particle range considerably larger than site dimensions;
- straight track segments.

Connection of LET with microdosimetric quantities

ICRU Report 36 (1983)



The formula for the relative variance leads to:

$$\bar{L}_D = \frac{\bar{l}_F}{\bar{l}_D}\bar{y}_D - \frac{\delta_2}{\bar{l}_D}$$

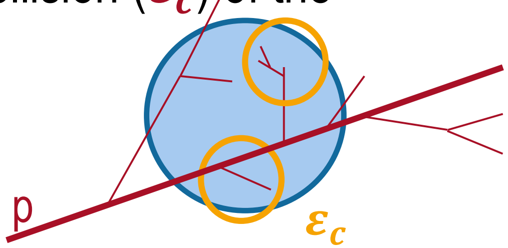
A. M. Kellerer, "Fundamentals of microdosimetry" (1985)

- $\bar{l}_F$ and $\bar{l}_D$ obtained from the first and second momentum of the chord length distribution.
- $\bar{y}_D$ is the dose mean lineal energy:

$$\bar{y}_D = \frac{1}{\bar{l}}\frac{\int \epsilon_i^2 f(\epsilon_i)\mathrm{d}\epsilon_i}{\int \epsilon_i f(\epsilon_i)\mathrm{d}\epsilon_i}.$$

- δ_2 is the weighted average of the energy imparted to the site per collision (ε_c) of the traversing charged particle:

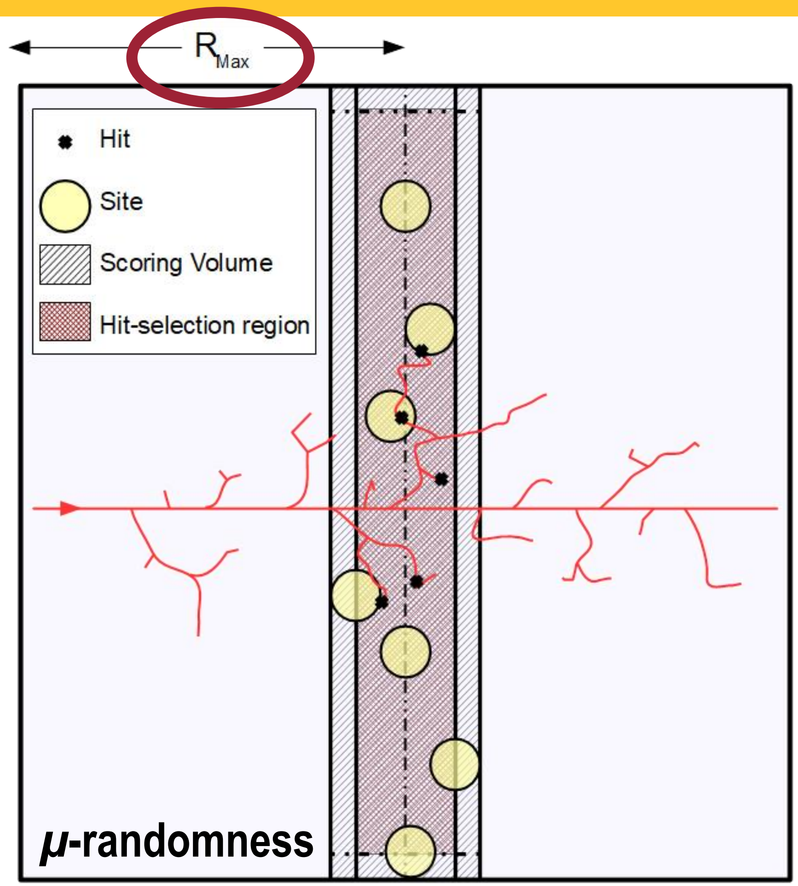
$$\delta_2 = \frac{\int \varepsilon_c^2 f(\varepsilon_c)\mathrm{d}\varepsilon_c}{\int \varepsilon_c f(\varepsilon_c)\mathrm{d}\varepsilon_c}.$$



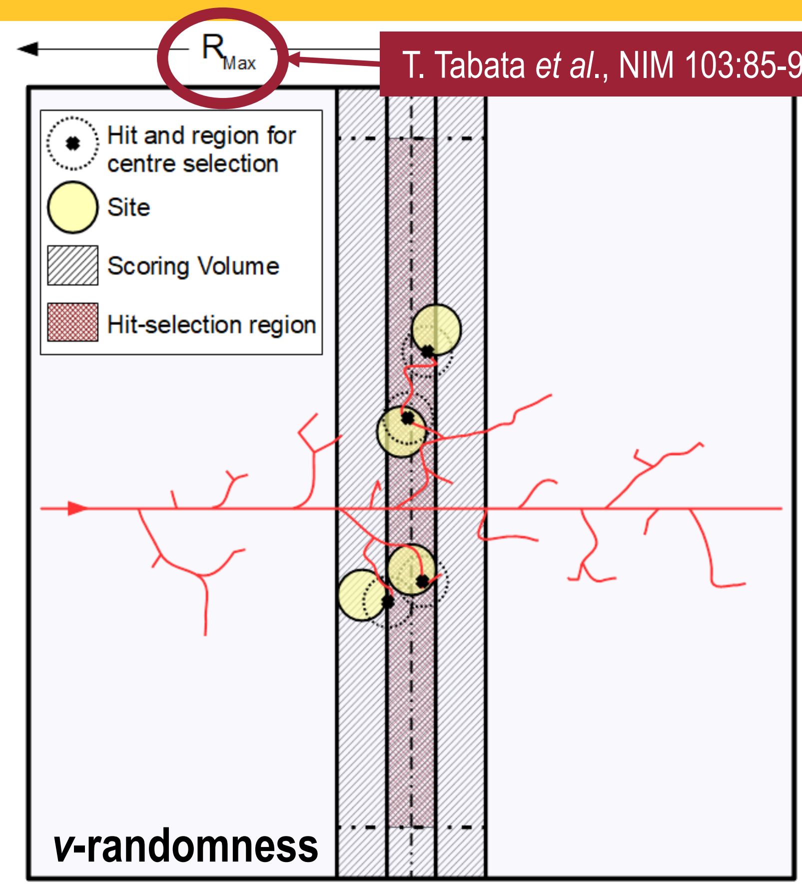
Calculation Approach

T. Tabata *et al.*, NIM 103:85-91 (1972)

UNIFORM SAMPLING



WEIGHTED SAMPLING

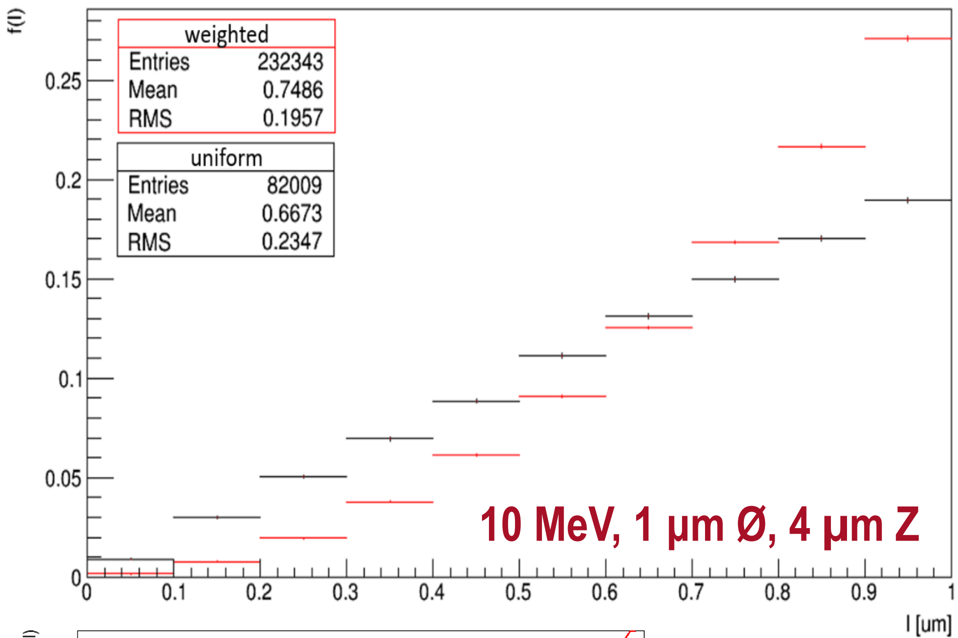


UI commands to select:

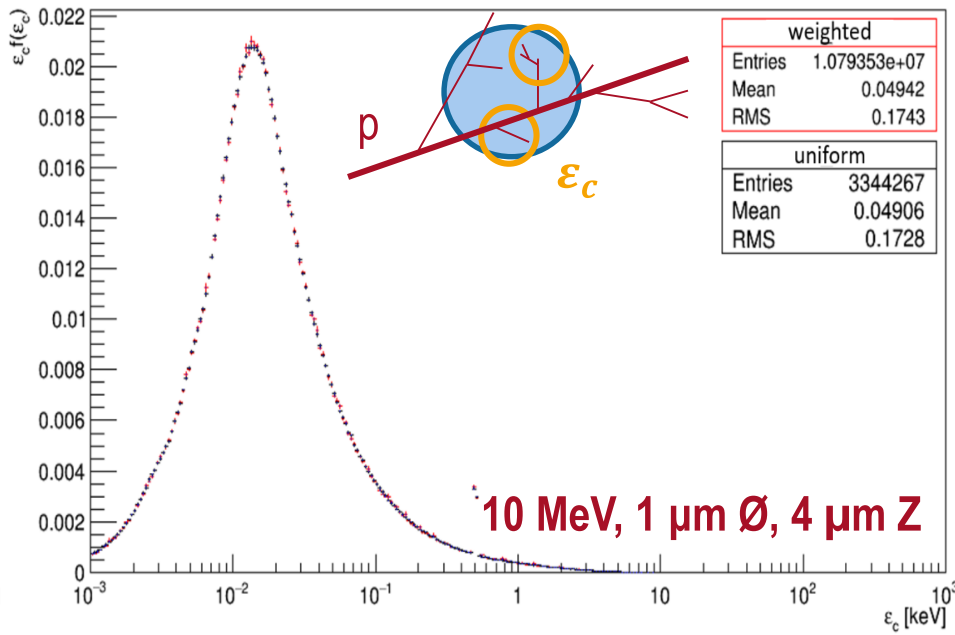
- Dimensions of scoring volume, hit selection region and site.
- Beam characteristics (energy distribution).
- Type of sampling (uniform or weighted sampling).

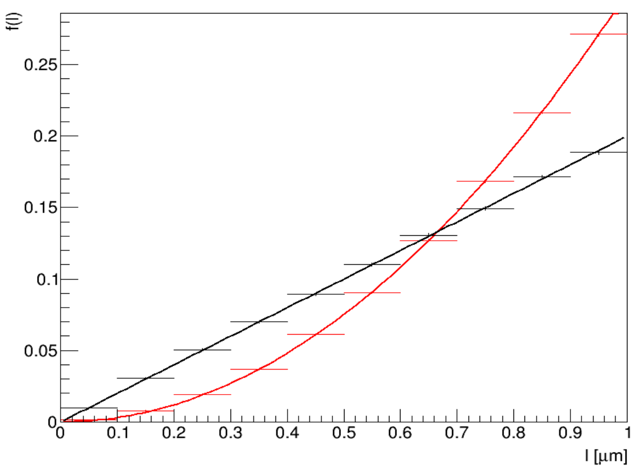
Results – Weighted & Uniform Sampling

Chord length distribution f(l)



Energy imparted per collision f(ε$_c$)

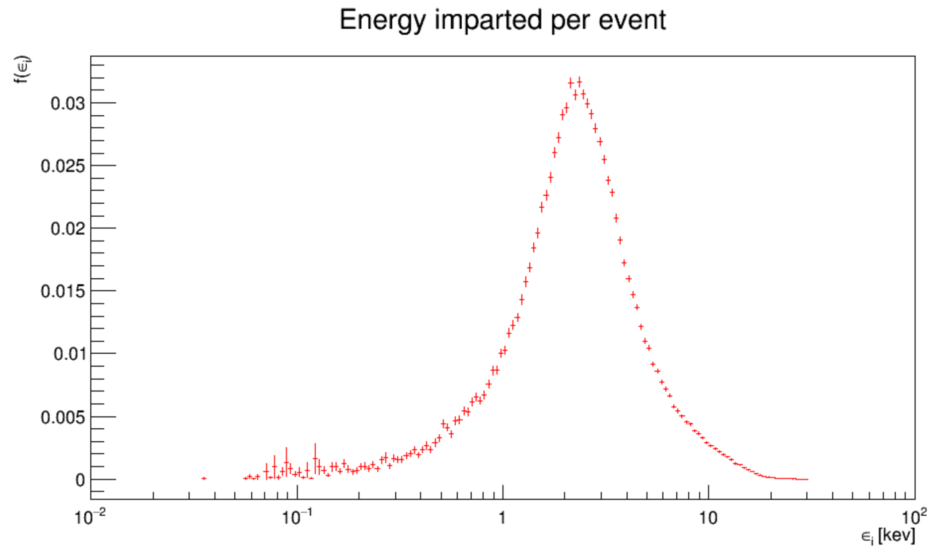


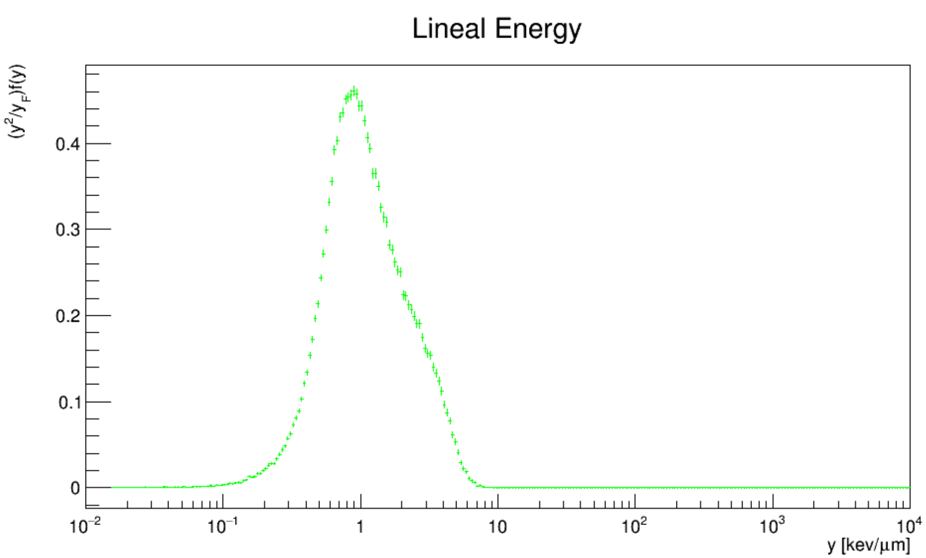


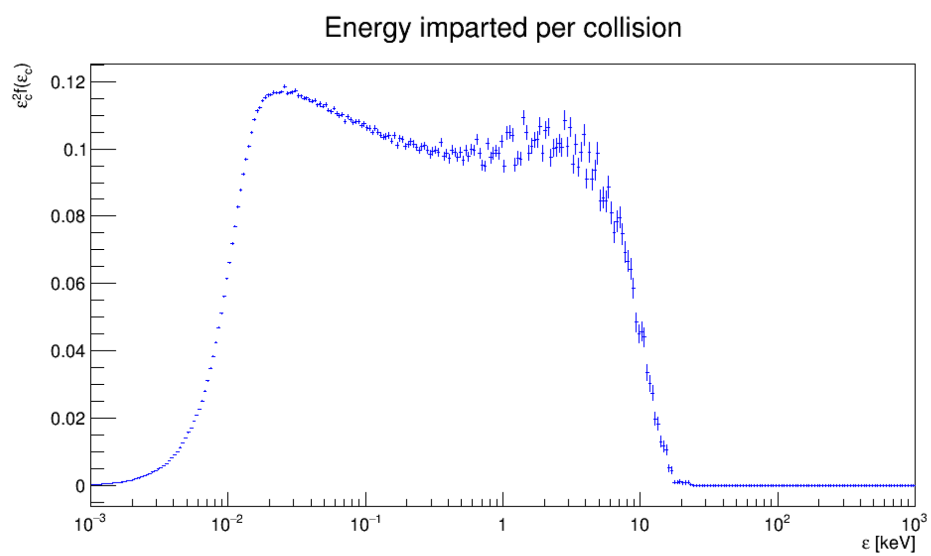
Uniform sampling:	**Weighted sampling:**
$f(l) = \frac{2l}{d^2}$	$f(l) = \frac{3l^2}{2d^3}$
$\Rightarrow \bar{L}_D = \frac{8}{9}\bar{y}_D - \frac{4}{3}\delta_2$	$\Rightarrow \bar{L}_D = \frac{15}{16}\bar{y}_D - \frac{5}{4}\delta_2$

Results – Microdosimetric Distributions p @ 70 MeV, sites of 2.5 μm diameter

- **Output modes available:**
  - **ROOT ntuplas** (big storage needs!)
  - **ROOT histograms**







Conclusions

- Application code for the calculation of microdosimetric quantities of **proton track segments**.
- It is illustrated how to compute the **energy imparted per individual electronic collision** of the proton ($\boldsymbol{\varepsilon_c}$), needed to get LET using microdosimetry.
- Uniform and weighted sampling techniques give generally comparable results. The uniform sampling, as expected, is more robust with respect to changes in the geometrical parameters, but less efficient.
- A special attention must be paid to the **chord length distribution** which **varies depending on the sampling method used**.
- We propose this work to be included as example.

Acknowledgments

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