Activity on LET Calculation and Hadrontherapy

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LOW ENERGY GROUP ACTIVITY
Open questions

► Which contribute from our group?

- ……………………..
- ……………………..
- Optimisation for medical physic (……………..)
  - ☺ …………………………………
  - ☺ LET and LEM calculation
  - ☺ ……………………………………

LOW ENERGY GROUP ACTIVITY
LET studies

LET calculation for clinical proton beams

• LET definitions (ICRU 16 vs ICRU 60)
• Monte Carlo calculation (*)
• Inplementation inside Hadrotherapy

LET model calculation for carbon ions:

➢ Ions LET definitions
➢ Multifragmentation contributions
➢ Monte Carlo calculation (**)
➢Implementation in a new explames (??)

(*) **J. J. Wilkens and U. Oelfke - Medical Physics, Vol. 30, No. 5, May 2003**
(**) Kempe, Medical Physics, Vol. 34, No. 1, January 2007

LET calculation for clinical proton beams

The physical dose is not the only parameter one should look at in treatment planning
(→ the biological effect does not depend on the physical dose alone)

At least the increased effectiveness at the end of the range of proton beams should be accounted for in treatment planning

In protontherapy a constant relative biological effectiveness (RBE) is widely used (the effects of a variable RBE would be clinically significant????????????)

It could be to develop very efficient models for RBE calculation (NOT only costant value!?!?!)

The RBE depends on dose, tissue type, the biological endpoint and the local energy spectrum. The latter is often referred to as ‘‘radiation quality’’ characterized by the Linear energy transfer (LET)

It is reasonable to provide 3D LET distributions (in addition to the physical dose distributions). **This might help to localize high LET regions, where the greatest variations in RBE are expected** (RBE is surely not a linear function of LET (not a function of LET alone))

LET calculation for clinical proton beams

The LET for monoenergetic protons is easily obtained from tables!

The calculation of the mean local LET for realistic clinical proton spectra (SOBP) is a more complicated task

This can be accomplished by Monte Carlo simulations

All LET definitions are based on the stopping power……….

$$S_{tot}=S_{col}+S_{rad}=S_{el}+S_{nuc}+S_{rad}$$

ICRU report 60 defines the linear energy transfer as the restricted linear electronic stopping power L_Δ

The unrestricted linear energy transfer $L_\infty = S_{el}$

The term LET is also employed to describe a mean value of the stopping power. This mean can be calculated either along the track of a single particle or by averaging the stopping powers of all particles at a certain point in a radiation field.

$$L_t(\mathbf{x}) = \frac{\int_0^\infty \varphi_r(\mathbf{x}) S(r) \mathrm{d}r}{\int_0^\infty \varphi_r(\mathbf{x}) \mathrm{d}r} \qquad L_d(\mathbf{x}) = \frac{\int_0^\infty \varphi_r(\mathbf{x}) S^2(r) \mathrm{d}r}{\int_0^\infty \varphi_r(\mathbf{x}) S(r) \mathrm{d}r}$$

LET CALCULATION & HADRONTHERAPY

HADRONTHERAPY == CATANA proton beam line simulation

OUTPUT == 3D dose distribution in an uniform phantom (FP and SOBP)

LET INPLEMENTATION INSIDE HADRONTHERAPY

Two new class: LET.cc and LET.hh

INPUT: ICRU49 Proton Stopping Power Tables

OUTPUT:
- Proton Fluence vs depth
- LET dose (depth function)
- LET track (depth function)

RESULTS

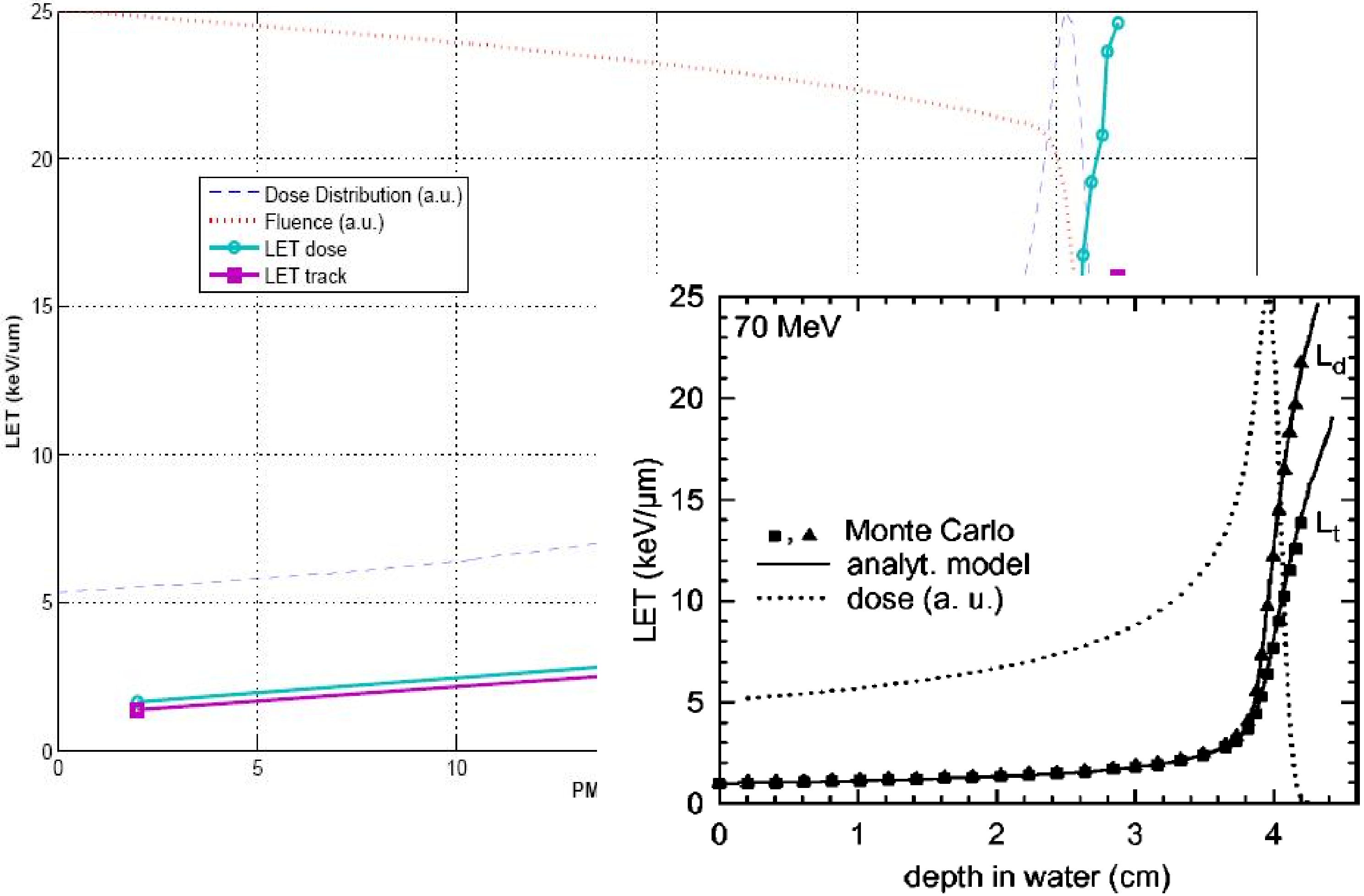
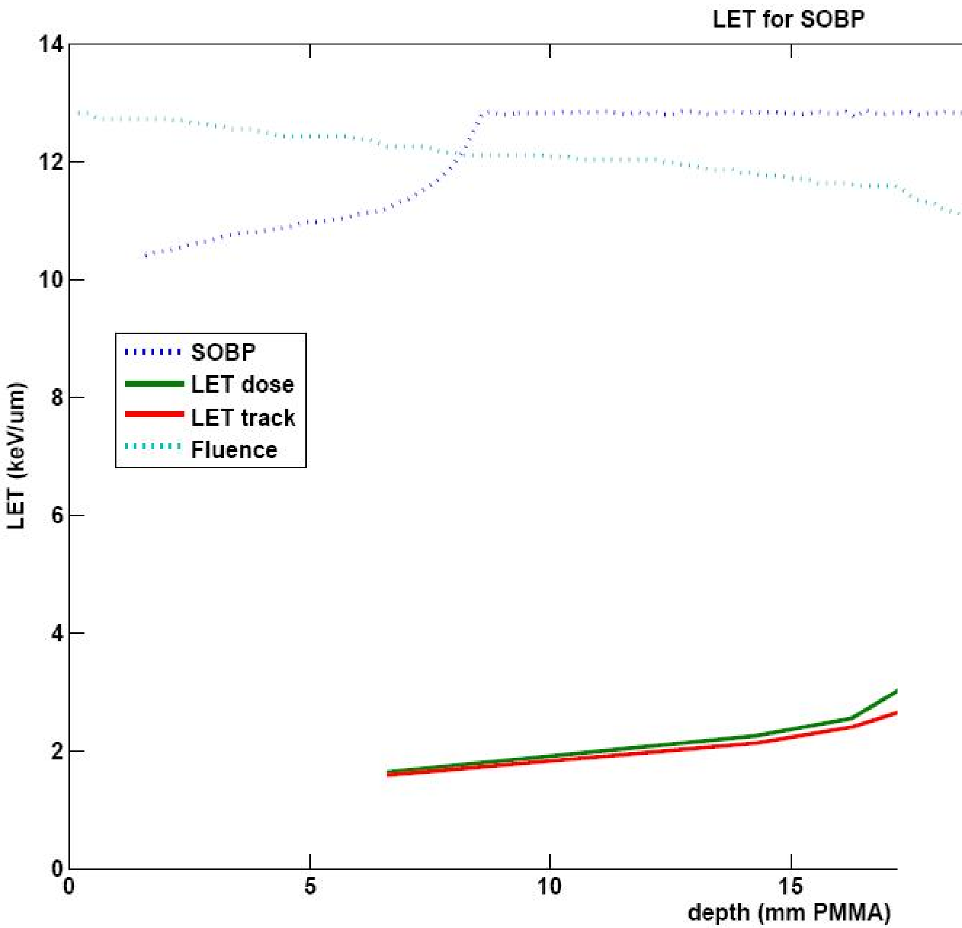


FIG. 4. LET distributions for a broad beam of 70 MeV protons in water ($\sigma_E = 0.5$ MeV). Track averaged and dose averaged LET obtained by Monte Carlo simulations (squares and triangles) are compared with the analytical model (lower and upper solid line, respectively). The relative dose distribution is given in arbitrary units (dotted line).

Medical Physics, Vol. 30, No. 5, May 2003

RESULTS



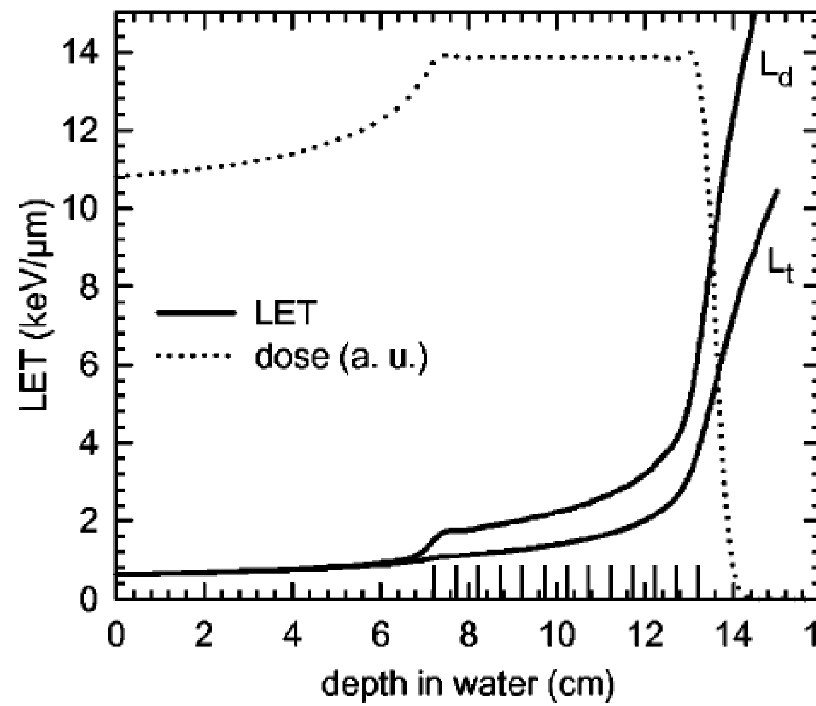


FIG. 7. LET distributions for a spread-out Bragg peak, which consists of 13 single peaks. The positions of the peaks are indicated by the small vertical lines. The track averaged and dose averaged LET (lower and upper solid line, respectively) are calculated with the analytical LET model. The dotted line shows the dose distribution in arbitrary units.

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LET model calculation for carbon ions

Fast protons in soft tissue reach a local LET maximum of about 80 eV/nm over a few microns just before the particle comes to rest

However, since this high LET track segment is very short compared to the range straggling, the RBE of high energy protons is very close to that of photons

Heavy ions are tested mainly due to the low oxygen enhancement ratio OER. These ions have a high LET and high RBE in the beam entrance and the plateau region

The nuclear fragmentation processes of these heavier ions increase with atomic number and the produced secondary particles will also give an increasing dose of high LET behind the target

Various investigations on ion beam radiation quality have been carried out considering the absorbed dose and LET distributions as well as fragmentation processe

Ions LET definitions????????

…Restricted LET…

Δ = ????

$$\overline{L_{\Delta}^{\Phi}(z)} = \frac{\int_{\Delta}^{\infty} L_{\Delta}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E + \int_{0}^{\Delta} L_{\infty}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E}{\int_{0}^{\infty} \mathbf{\Phi}_{E}(z)\mathrm{d}E}$$

$$\overline{L_{\Delta}^{D}(z)} = \frac{\int_{\Delta}^{\infty} L_{\Delta}^{2}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E + \int_{0}^{\Delta} L_{\infty}^{2}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E}{\int_{\Delta}^{\infty} L_{\Delta}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E + \int_{0}^{\Delta} L_{\infty}(E)\mathbf{\Phi}_{E}(z)\mathrm{d}E}$$

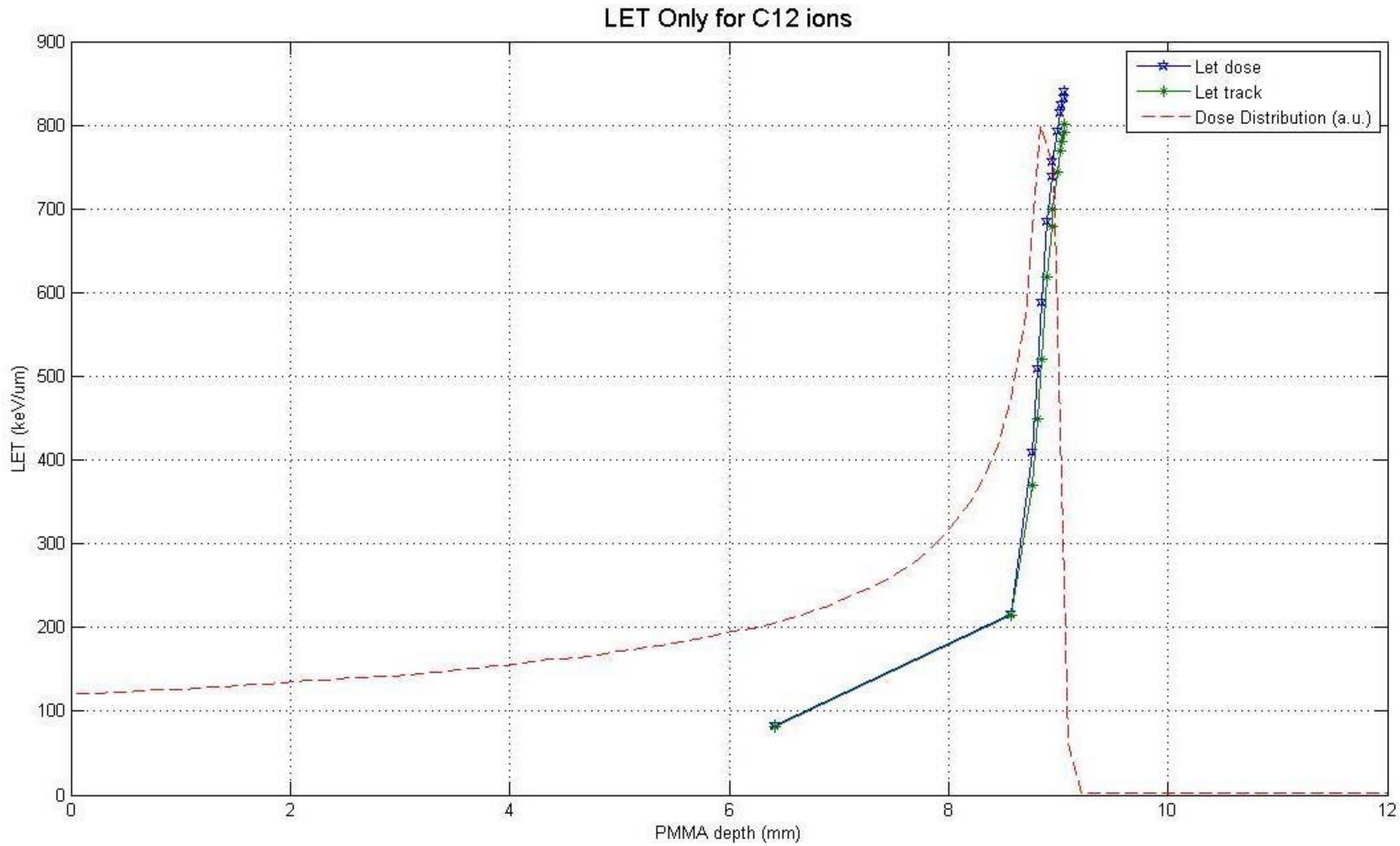
…Unrestricted LET…

Correct????

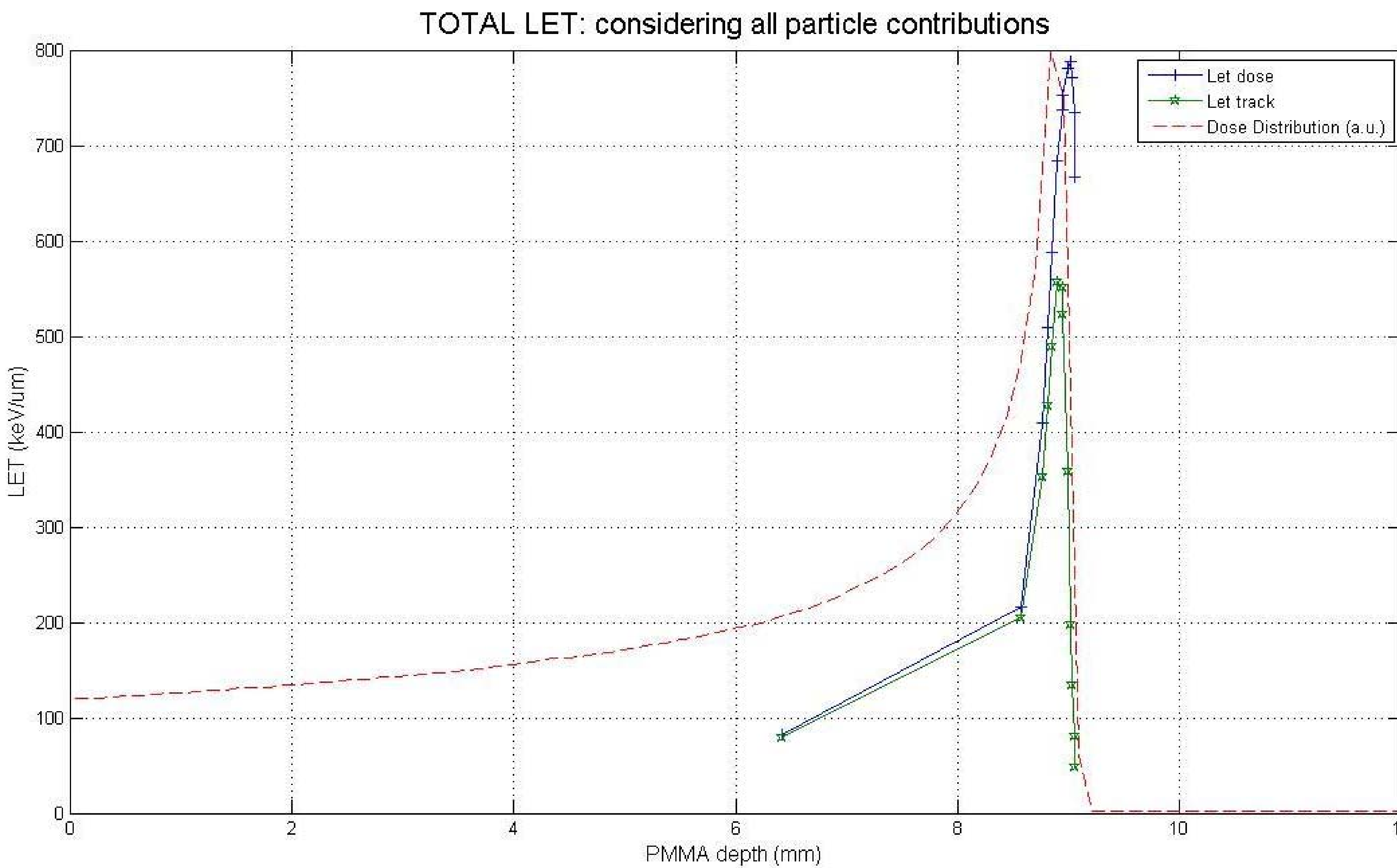
$$L_{t}(\mathbf{x}) = \frac{\int_{0}^{\infty} \varphi_{r}(\mathbf{x}) S(r)\mathrm{d}r}{\int_{0}^{\infty} \varphi_{r}(\mathbf{x})\mathrm{d}r}$$

$$L_{d}(\mathbf{x}) = \frac{\int_{0}^{\infty} \varphi_{r}(\mathbf{x}) S^{2}(r)\mathrm{d}r}{\int_{0}^{\infty} \varphi_{r}(\mathbf{x}) S(r)\mathrm{d}r}$$

RESULTS



?????Multifragmentation contributions?????????????



TOTAL LET: considering all particle contributions
LET (keV/um)
PMMA depth (mm)
Let dose
Let track
Dose Distribution (a.u.)
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12