Università degli Studi di Pavia **INFN - Pavia** **Ludwig-Maximilians-Universität München**

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Implementation of an analytical lateral dose model in the proton TPS- CERR

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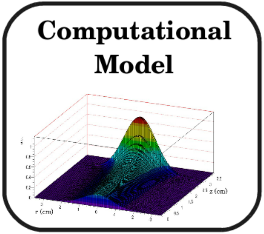
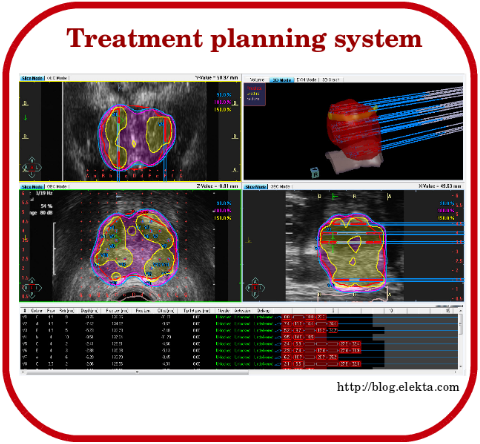
on behalf of
Università degli Studi di Pavia,
Istituto Nazionale di Fisica Nucleare INFN- Pavia
Ludwig-Maximilians-Universität München groups

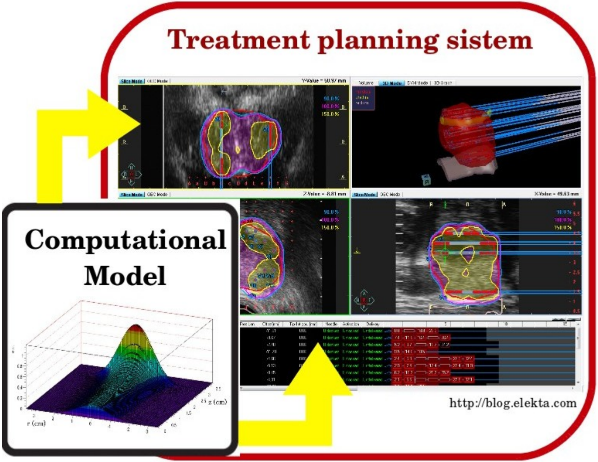
Goal


Computational Model
r (cm)
z (cm)


Treatment planning system
http://blog.elekta.com

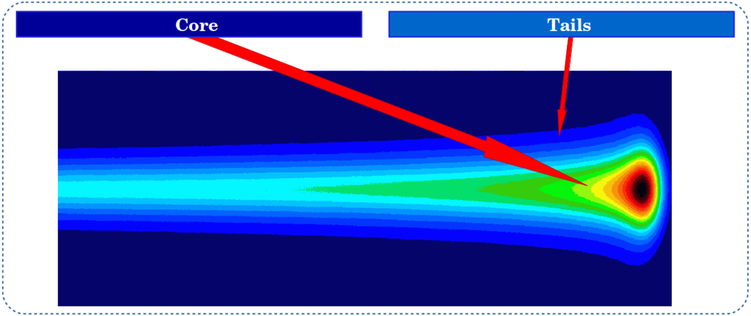
Goal

Implementation of a new computational model
to overcome limitations of current approximated models



A computational model for dose deposition evaluation

Bellinzona E.V.et al., Phys. Med. Biol. 61
doi:10.1088/0031-9155/61/4/N102-7 (2016)



Lateral profile: Electromagnetic core

Core

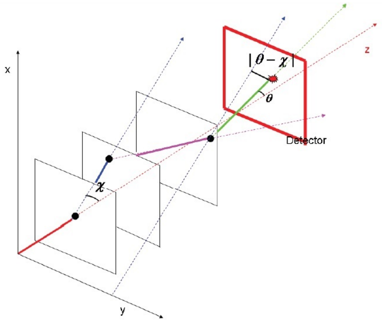
Multiple coulomb scattering :

$$f(\theta)\theta d\theta = f_M(\theta)d(cos\theta)d\phi/2\pi$$

Calculation of χ_c^2 , χ_α^2

Lateral profile: Electromagnetic core

The Coulomb scattering distribution is well represented by the theory of Molière.
χ stands for an angle related to single scattering event;
θ stands for a net angle after multiple scattering events;



The theory predicts the probability that a particle is in the angular interval $d\theta$ after traversing a thickness t [1]

$$f(\theta)\theta d\theta = f_M(\theta)d(cos\theta)d\phi/2\pi$$

[1] H. A. Bethe, Phys.Rev.89, 1256,(1953)

Lateral profile: Electromagnetic core

The crucial factors of Molière's theory are two parameters:

- $\chi_{\mathbf{c}}^{\mathbf{2}} = 0.1569 \cdot 10^{-6} Z^2 z^2 \frac{x}{A} \frac{1}{p^2 \beta^2}$
  that is related to the scattering angle RMS

- $\chi_{\alpha}^{\mathbf{2}} = \mu^2 \chi_0^2$
  with

$$\begin{cases} \mu^2 = \left(1.13 + 3.76 \dfrac{z^2 Z^2}{137^2 \beta^2}\right) \\ \chi_0^2 = \left(\dfrac{\hbar}{p} \dfrac{Z^{1/3}}{0.468 \cdot 10^{-8} (cm)}\right)^2 \end{cases}$$

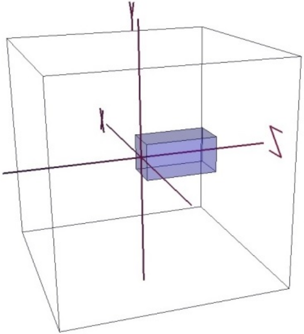
  This parameter explains the Coulomb potential screening

Lateral profile: Electromagnetic core

Some results of the comparison between the model and FLUKA[2,3] simulation

Experimental set up:

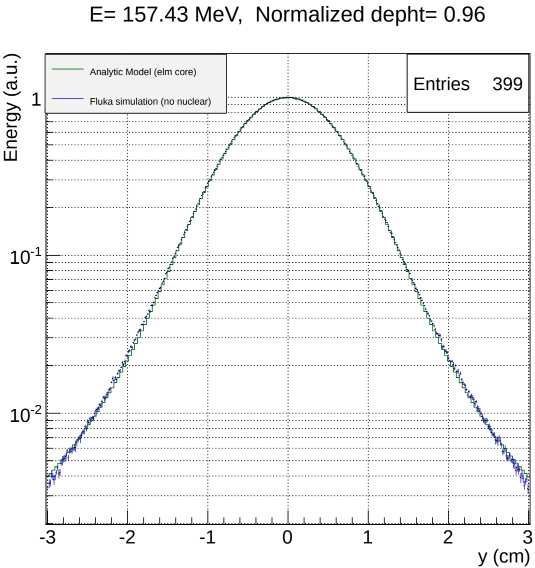
- proton beam
- homogeneous water phantom
- $x[(5cm, 5cm); 1bin]$
  $y[(5cm, 5cm); 400bins]$
  $z[(0cm, 30cm); 3000bins]$
- Heidelberg Ion Beam Therapy Center (HIT) phasespace



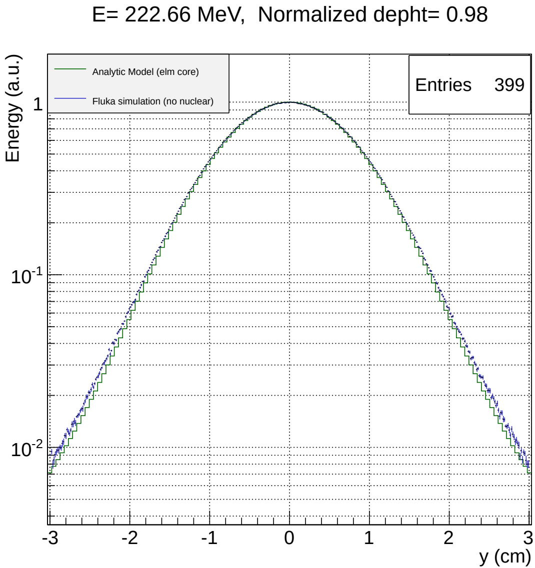
[2] T.T. Bohlen et. all,Nuclear Data Sheets 120, 211-214 (2014)

[3] A. Ferrari et. all, CERN-2005-10 (2005), INFN/TC05/11, SLAC−R−773

Lateral profile: *Electromagnetic core*



Lateral profile: Electromagnetic core



Lateral profile: Nuclear Tails

Core	Tails
Multiple coulomb scattering : $f(\theta)\theta d\theta = f_M(\theta)d(cos\theta)d\phi/2\pi$ Calculation of χ_c^2 , χ_α^2	Nuclear interaction : $(1 - W_p)\frac{t(x)}{\int_{-\infty}^{+\infty} t(x)\mathrm{d}x}$ Calculation of W_p

Lateral profile: *Nuclear Tails*

To take into account also nuclear collision (of hadrontherapy interest), a modified Cauchy-Lorentz[4,5] distribution is applied:

$$f(x)_{x,y} = W_p f_M(x) + (1 - W_p)\frac{t(x)}{\int_{-\infty}^{+\infty} t(x)\mathrm{d}x}$$

$f_M(x)$ = Molière electromagnetic theory
$t(x)$ = Cauchy-Lorentz distribution
W_p = fraction of events without nuclear interactions

[4] Soukup M, Fippel M and Alber M 2005 Phys. Med. Biol. 50 5089104
[5] Li Y et al 2012 Phys. Med. Biol. 57 98397

Lateral profile: Nuclear Tails

W_p is the percentage of particles that have only had electromagnetic interactions, i.e. no nuclear interactions, as a function of the traversed thickness, for protons of incident kinetic energy E and range R in water, at a certain water thickness x[6]

$$W_p = \frac{1}{2}\left[1 - \left(\frac{E - E_{th}}{m}\right)^f \frac{x}{R}\right]\left[1 + \text{erf}\left(\frac{R - x}{\tau}\right)\right] ,$$

with

- erf $f = 1.032$ error function
- m proton mass (MeV)
- $E_{th} = 7$ MeV ^{16}O threshold energy of the Coulomb barrier.

[6] W. Ulmer 2007, Rad. Phys. and Chem. 76 1089-107

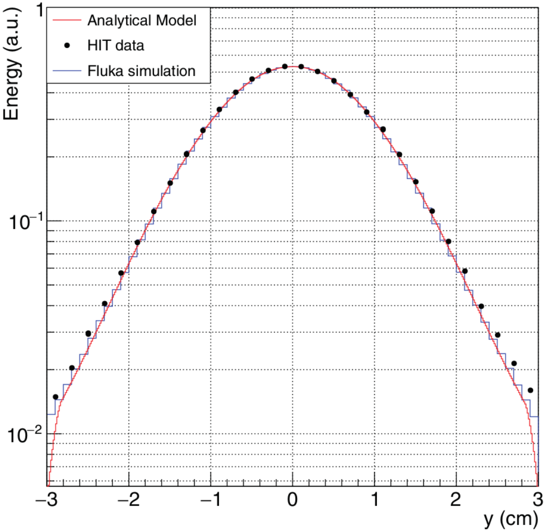
Lateral profile: Complete

Core	**Tails**
Multiple coulomb scattering : $f(\theta)\theta d\theta = f_M(\theta)d(cos\theta)d\phi/2\pi$ Calculation of χ_c^2 , χ_α^2	Nuclear interaction : $(1 - W_p)\dfrac{t(x)}{\int_{-\infty}^{+\infty} t(x)\mathrm{d}x}$ Calculation of $\boldsymbol{W_p}$

$$f(x)_{x,y} = W_p f_M(x) + (1 - W_p)\frac{t(x)}{\int_{-\infty}^{+\infty} t(x)\mathrm{d}x}$$

Lateral profile: Validation[7]

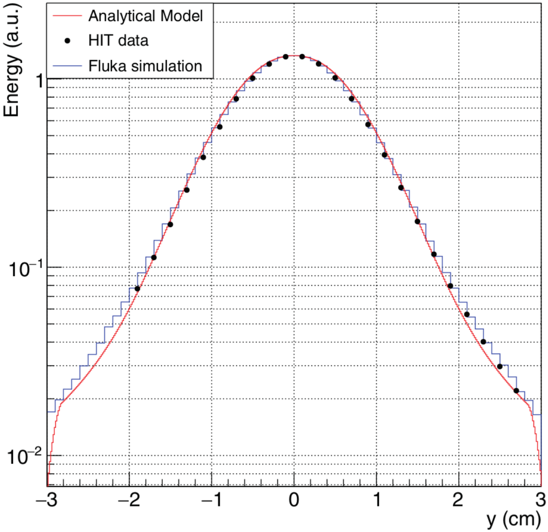
$$E = 81.49 MeV \ , z = 1.57 cm$$



[7] Data courtesy of Heidelberg Ion Therapy Center (HIT)

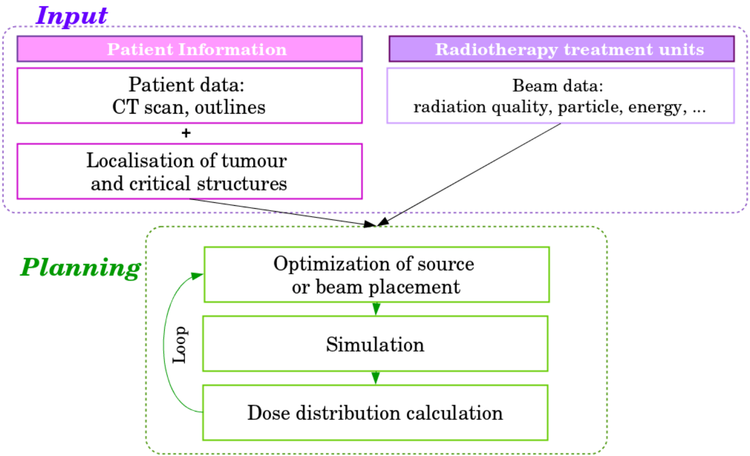
Lateral profile: Validation[8]

$$E = 158.8 MeV \ , \ z = 16.55 cm$$

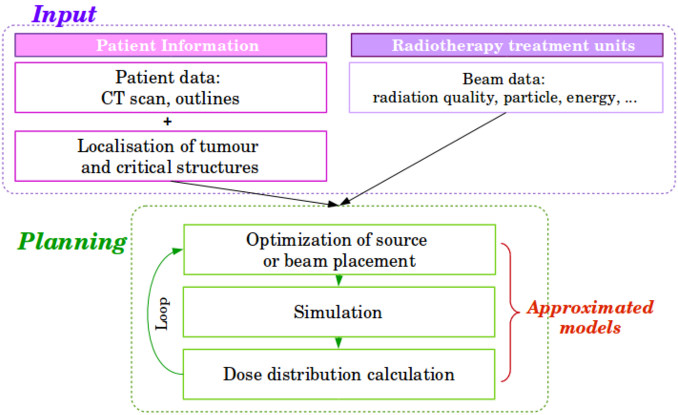


[8]Data courtesy of Heidelberg Ion Therapy Center (HIT)

Treatment planning system: Overview



Treatment planning system: Overview



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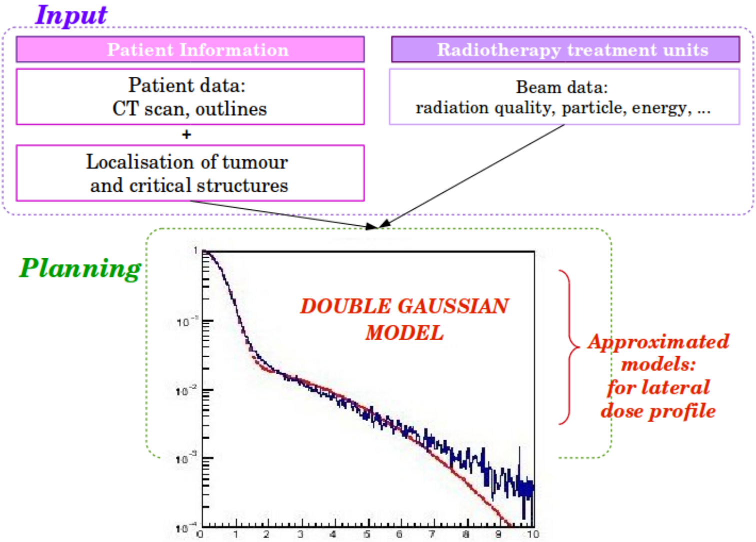
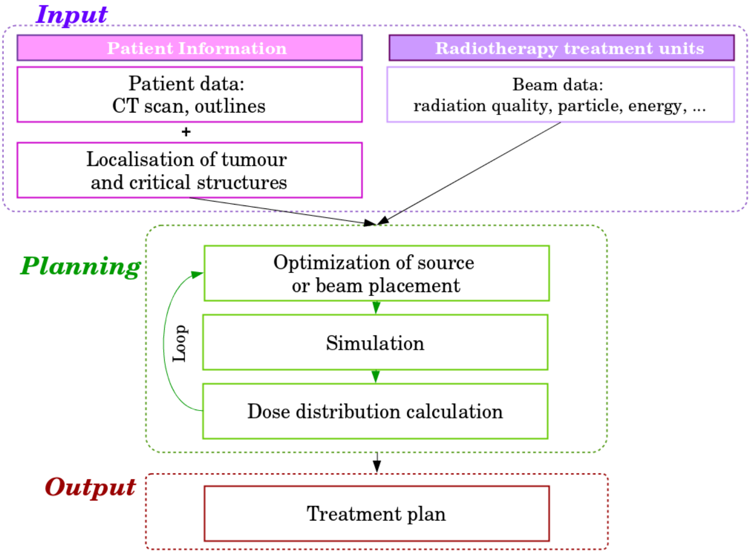
[9] Bellinzona V. E. et al., Physica Medica doi: 10.1016/j.ejmp.2015.05.004

Treatment planning system: Overview

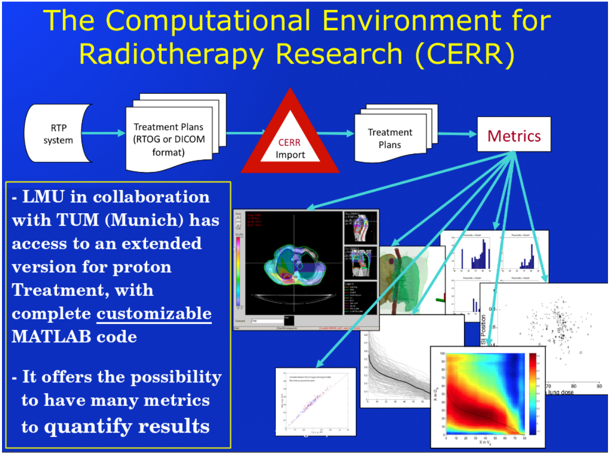


Treatment planning system: Overview



CERR:

A Computational Environment for Radiotherapy Research[10] [11]



[10] Deasy JO et. al, Med Phys. 2003 May;30(5):979-85.

[11] Schell S. and Wilkens J. J., Med Phys 2010, 37(10):533040.

CERR:

Dose calculation

For each beam (many depths and energies):

- ↦ The longitudinal dose
  is evaluated by using database of GEANT4 simulations
- ↦ The lateral dose (normalized by the area) is calculated by
  1. a double gaussian parametrization in which σ_1 and σ_2 are read from another database
     $D_{xy} = \frac{1}{2\pi\sigma_1} * \exp\left[\frac{(-(X^2+Y^2))}{2\sigma_1^2}\right] + \frac{1}{2\pi\sigma_2} * \exp\left[\frac{(-(X^2+Y^2))}{2\sigma_2^2}\right]$

  or

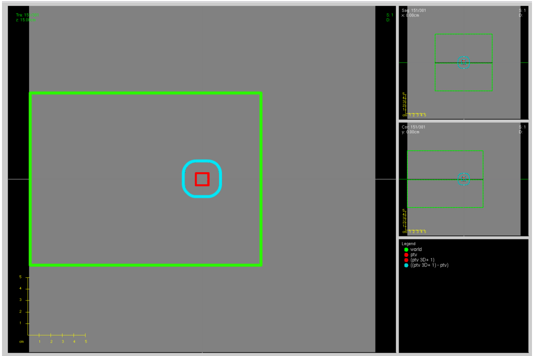
  2. the model code
- ↦ So the total dose is the result of multiplication
  $D_{tot} = D_{xy} * D_z$

Preliminary Results

Preliminary comparison between the treatment plan lateral dose obtained with the model and with the Double Gaussian parametrization.

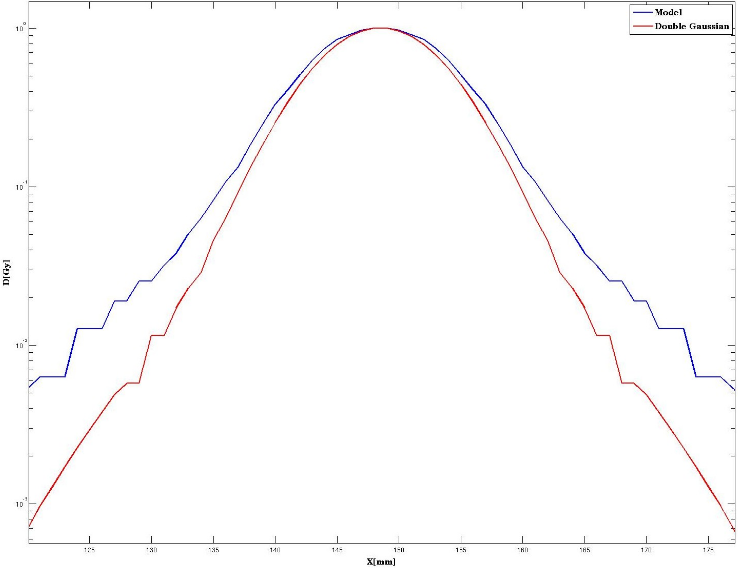
Experimental set up:

- proton pencil beam $\sigma_0 = 0.4cm$
- homogeneous water phantom
- (note that x axis is a beam-relative axis)



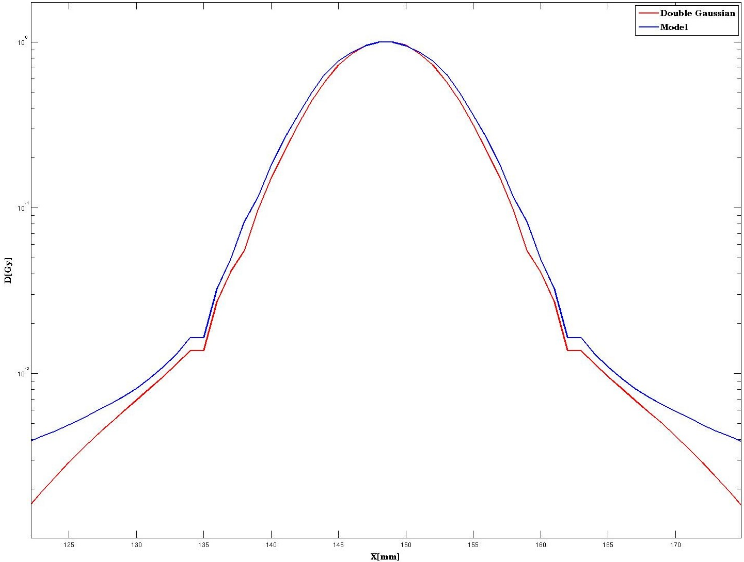
Preliminary Results

$$E = 148MeV \;\; z_{rel} = 95\%$$



Preliminary Results

$$E = 148MeV \;\; z_{rel} = 65\%$$



Conclusion and outlooks

- *Conclusion*
  - First investigations show an improvement in accuracy of lateral dose evaluation using the new analytical model
  - the computational time is comparable, even though the process still has to be optimized
  - the model can be considered competitive to full Monte Carlo evaluation, and also to Double Gaussian method in accuracy.
- *Future perspectives and forthcoming steps*
  - evaluation of a full treatment in water phantom
  - time optimization
  - other materials will be taken into account

Thanks for your attention, I warmly ask questions

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