Development of the nuclear interaction models for hadrontherapy in the FLUKA Monte Carlo code

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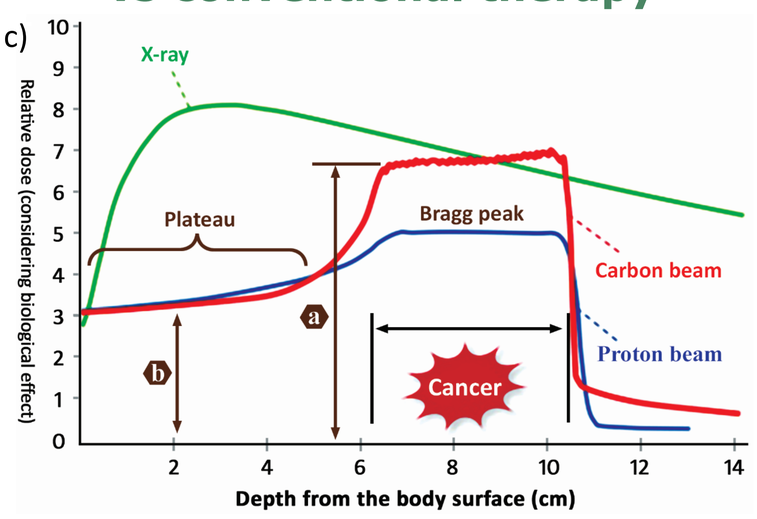
Overview

The main challenge in radiotherapy is the killing of all malignant cells in a cancer patient, with minimum damage to the healthy tissues. Hadrontherapy utilizes charged particles like proton and carbon ions that, in comparison to photons, are more favorable to treat deep-seated tumors.

Before each patient treatment, simulations of the delivered dose (energy/mass) are performed to identify the optimal treatment plan. Monte Carlo codes like FLUKA[a),b)] are used as a support for the treatment planning. For accurate and precise predictions of the delivered dose, particle fragmentation, particle scattering and the biological effectiveness need to be well understood and considered in the simulations.

Advantages of hadrontherapy vs conventional therapy

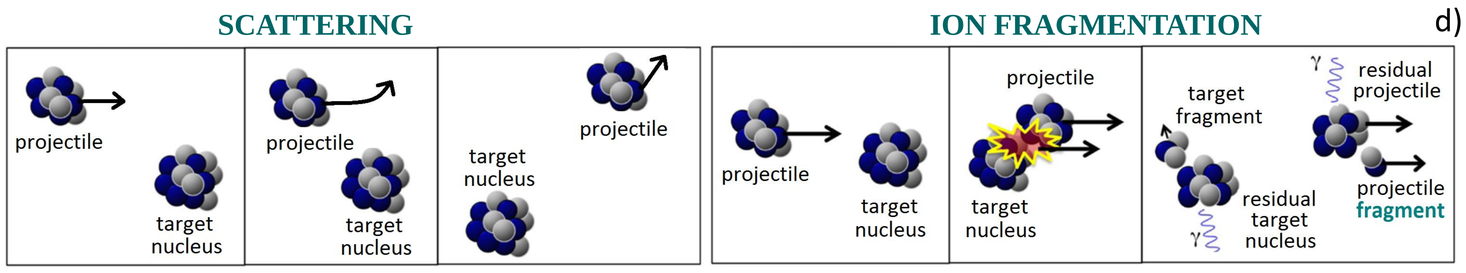
c)



- MORE CONFORMED DOSE TO THE TUMOR.
- BETTER SPARING OF HEALTHY TISSUES IN FRONT AND BEHIND THE TUMOR (higher a/b ratio, see Figure).

Drawbacks of hadrontherapy

- NUCLEAR INTERACTIONS MAY OCCUR BETWEEN THE PRIMARY PARTICLES (e.g. protons and carbon ions) AND THE NUCLEI OF THE PATIENT TISSUES.
- NUCLEAR INTERACTIONS MAY RESULT IN:

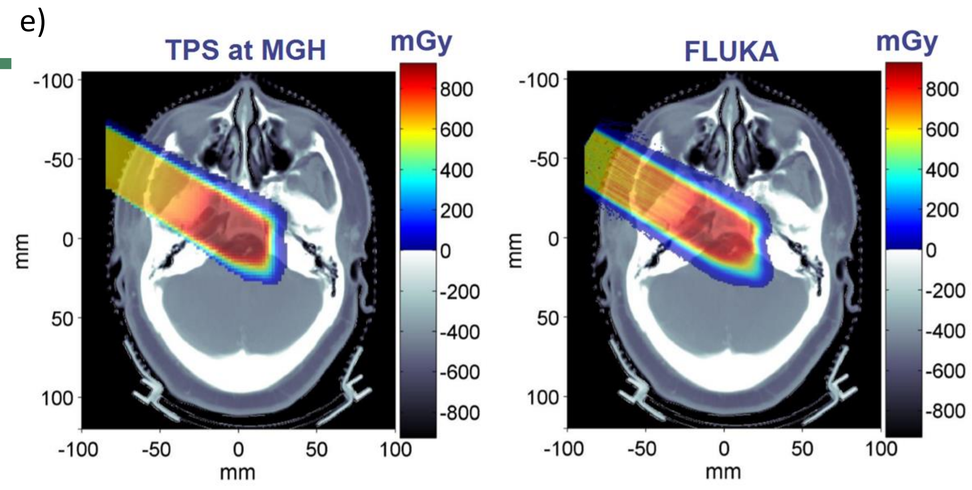


Role of Monte Carlo simulations

MONTE CARLO CODES LIKE FLUKA ARE USED :

- TO GENERATE INPUT DATA FOR THE TREATMENT PLANNING SYSTEMS (TPS)
- TO VALIDATE THE TPS DOSE CALCULATIONS (see Figure)
- FOR TREATMENT VERIFICATION EXPLOITING THE SECONDARY FRAGMENTS (e.g. PET, prompt, …)

e)



Aim of the project

IMPROVEMENT OF THE NUCLEAR INTERACTION MODELS TO BE USED IN FLUKA, TO GET MORE ACCURATE PREDICTIONS OF

- THE DOSE DISTRIBUTION FOR THE TPSs
- THE SECONDARY RADIATION FOR BEAM MONITORING

Method

- BENCHMARKING FLUKA RESULTS AGAINST EXPERIMENTAL DATA
- TUNING OF THE MODELS
- VALIDATION OF THE NEW RESULTS IN CLINICAL SCENARIOS

Main issue

LACK OF EXHAUSTIVE EXPERIMENTAL DATA IN THE ENTIRE ENERGY RANGE AND IN ALL CONFIGURATIONS NEEDED, FOR COMPARISON WITH THE FLUKA SIMULATIONS

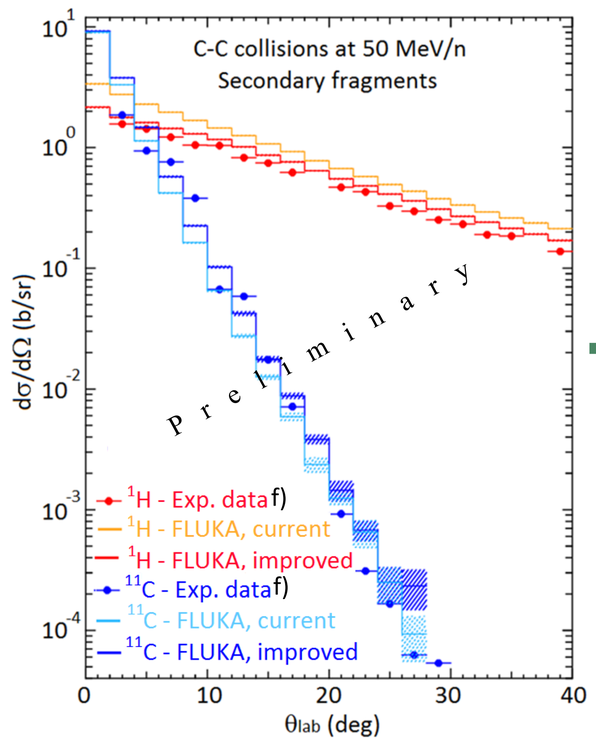
Preliminary Results

COMPARISON BETWEEN EXPERIMENTAL MEASUREMENTS AND FLUKA SIMULATIONS OF SECONDARY FRAGMENTS PRODUCED BY CARBON ION BEAMS :

✓ THE ANGULAR DISTRIBUTIONS OF THE FRAGMENTS ARE IN GENERAL WELL REPRODUCED BY THE FLUKA PHISICS MODELS
→ see ^{11}C as an example in the Figure (light blue line)

✗ AN OVERESTIMATION IN THE AMOUNT OF SECONDARY PROTONS WAS OBSERVED AT ENERGIES BELOW 100 MEV/n
→ see Figure for an example (orange line)

IMPROVEMENTS IN FLUKA ALLOW TO BETTER REPRODUCE THE EXPERIMENTAL DATA
→ dark colour lines in the Figure



Summary

ACCURATE INTERACTION MODELS ARE REQUIRED IN MONTE CARLO CODES TO PREDICT PRECISELY THE ION FRAGMENTATION OCCURRING IN CANCER PATIENTS DURING RADIOTHERAPY TREATMENTS.

Conclusions

WE ARE IMPROVING THE PHYSICS MODELS IN FLUKA TO INCREASE THE ACCURACY OF THE TREATMENT PLANNING SYSTEMS AND DOSE VERIFICATION METHODS BASED ON FLUKA.

References:
a) Ferrari A *et al*, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
b) Böhlen TT *et al*, Nucl. Data Sheets 120 (2014) 211-214
c) http://www.bestcyclotron.com/particletherapy/
d) https://www.frontiersin.org/articles/10.3389/fonc.2015.00150/full
e) Parodi K *et al*, JPCS 74 (2007) 012013
f) Divay C *et al* 2017, Phys. Rev. C **95** 044602

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