Hadrontherapy Treatment Planning with FLUKA Monte Carlo Code

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Treatment Planning Systems for Hadrontherapy

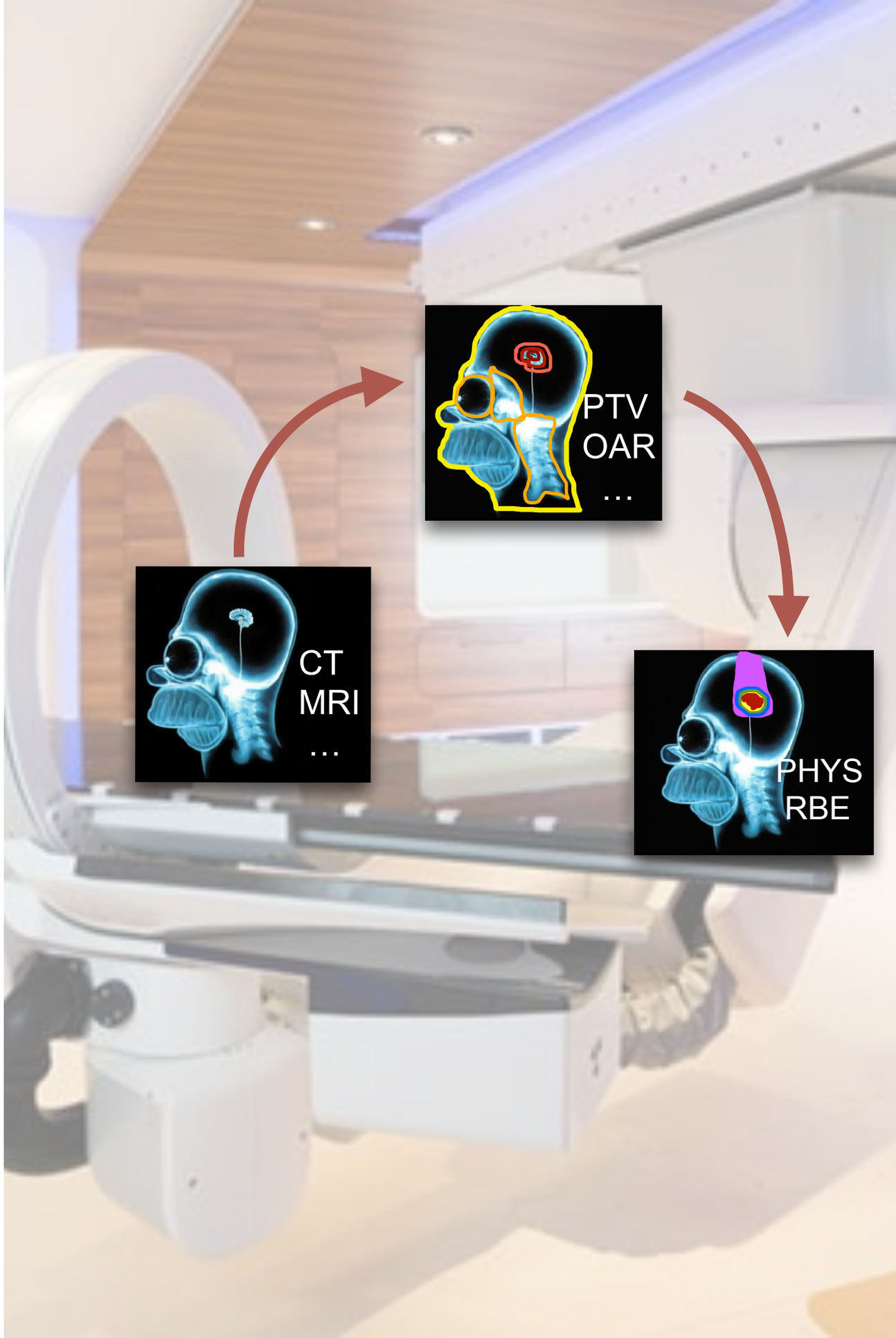
Commercial TPS typically use **pencil beam scanning algorithms**

Range of the proton/ion beam is mainly based on the **water equivalent depth**

Lateral beam shape is described by Gaussian or double-Gaussian **parametrization**

Analytical TPS enables **fast** dose calculations and **fast** optimization

Why do we need Monte Carlo TPS?



Monte Carlo for Treatment Planning

- Provides faithful consideration of **radiation transport and interactions with matter** which is particularly important for precise ion therapy
- Gives possibility for **combined ion treatment planning**
- Uses **realistic atomic composition** of the patient tissue limited only by the HU (Hounsfield Unit) to tissue conversion method
- Able to score not only physical dose, but also **RBE (relative biological effective) weighted dose, LET (linear energy transfer)** and emerging secondaries for a real time dose delivery …

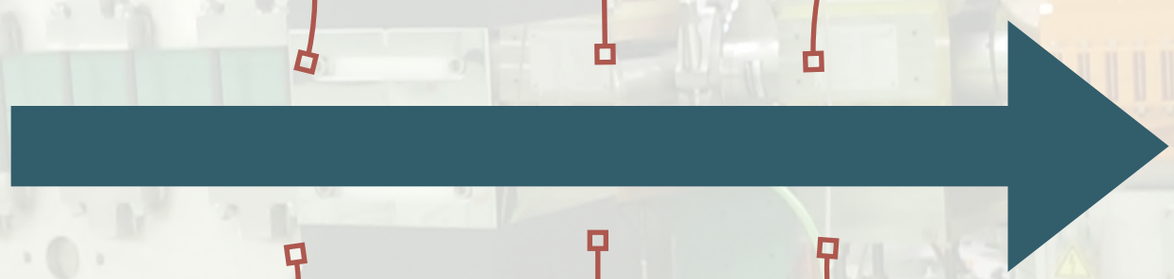
Monte Carlo Simulations are considered as a gold standard for treatment planning systems, although time is the main issue

More precise and fast verification tools

Fully independent recalculation of Treatment Plan

Complex patient geometries, heterogeneous tissues

Research



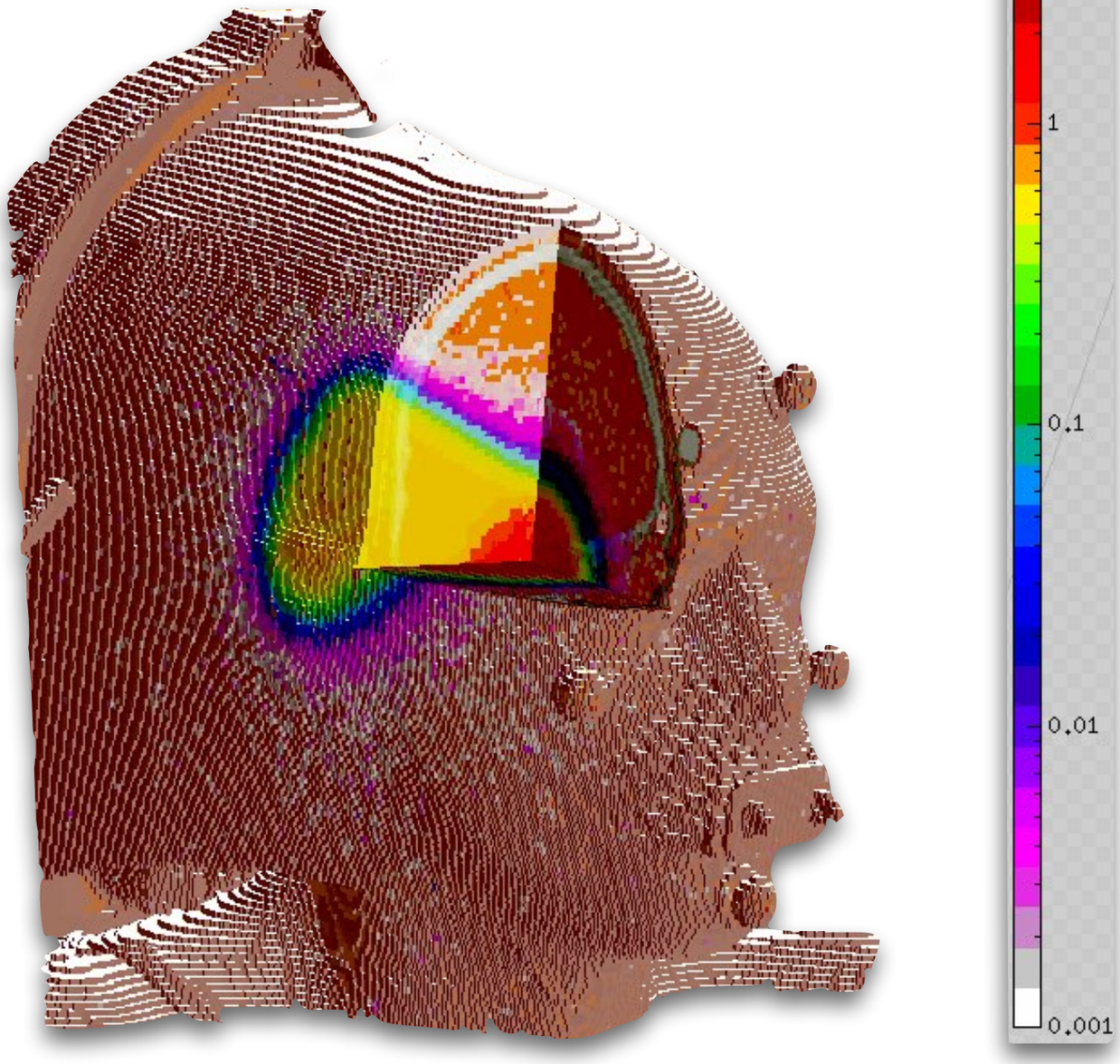
Clinical technologies

Real-time dose delivery verification using emitted $\beta+$ or prompt-γ

Treatment optimization for RBE, LET …

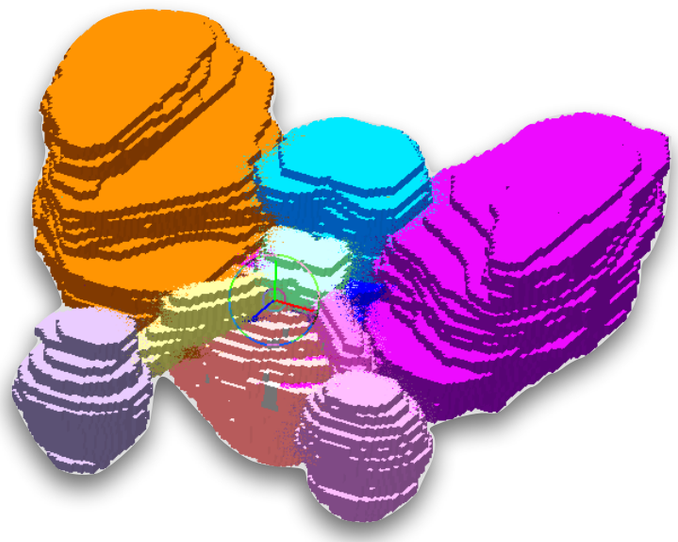
Additional treatment information - different RBE models, LET..

Dose deposition in patient



One of the **major contribution factor to the accidents** in the radiation therapy related to the TPS derives from **lack of independent calculations** for beam intensities [4]

Regions of interest (ROI)



FLUKA and its GUI Flair for Hadrontherapy TPS

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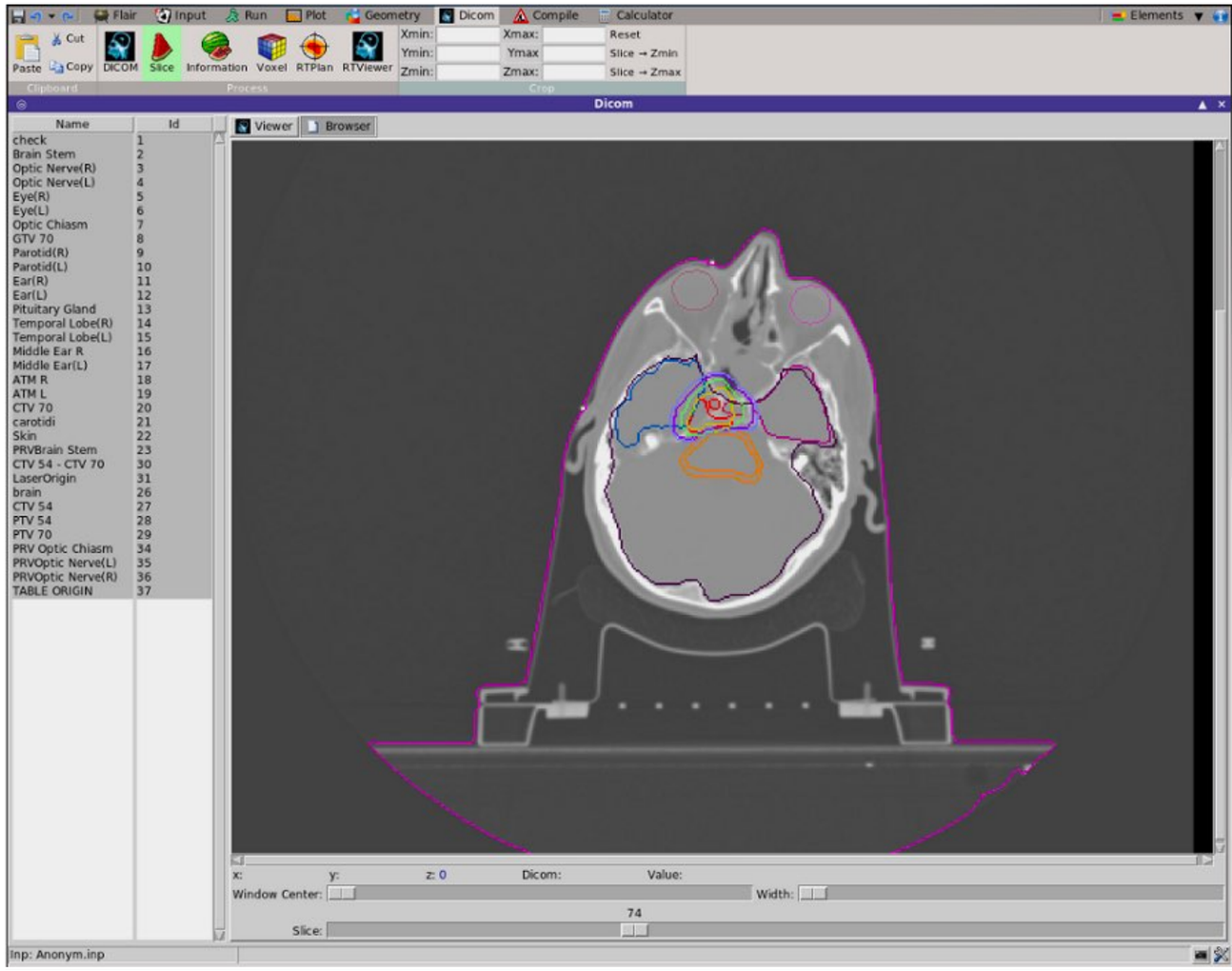
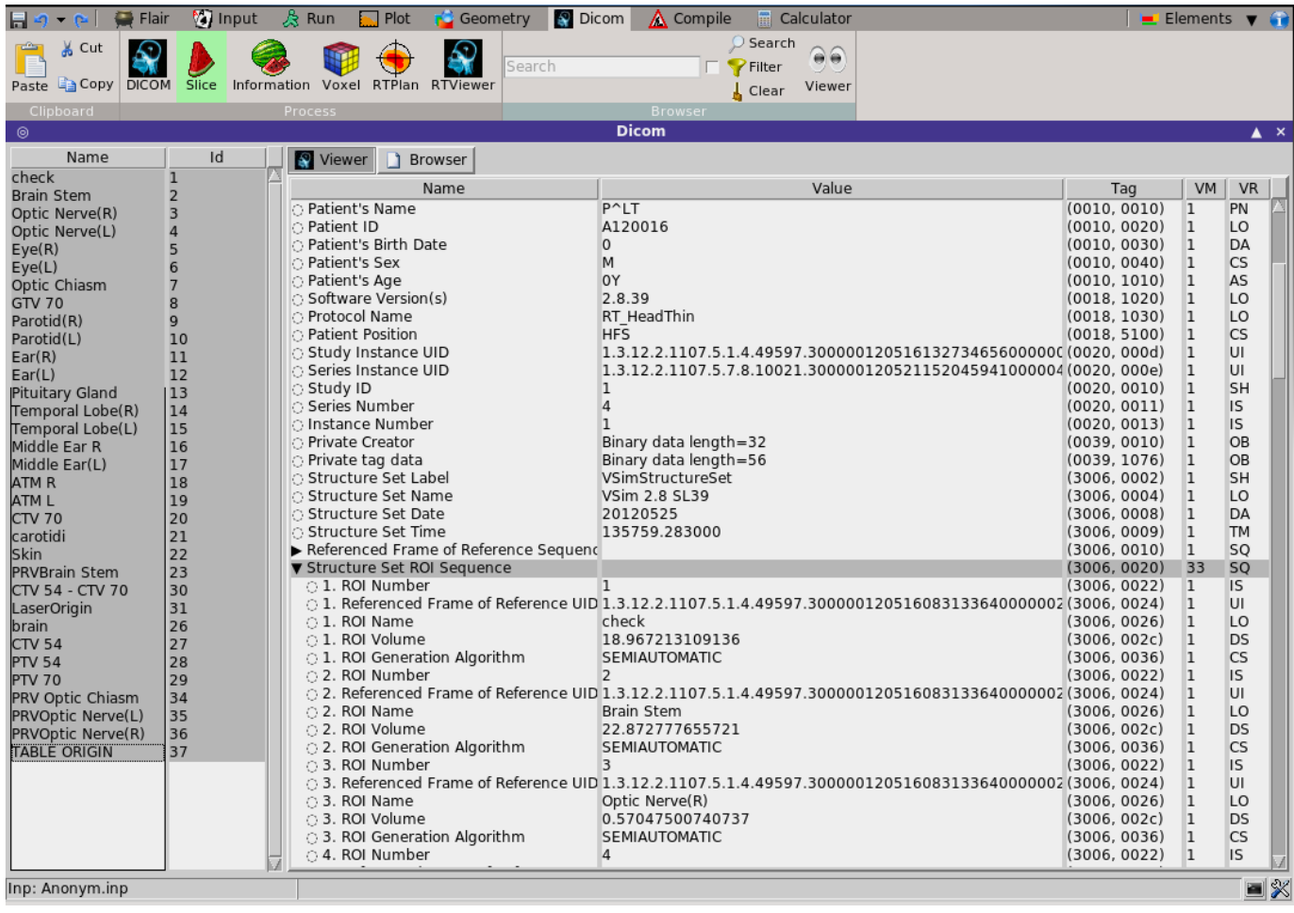
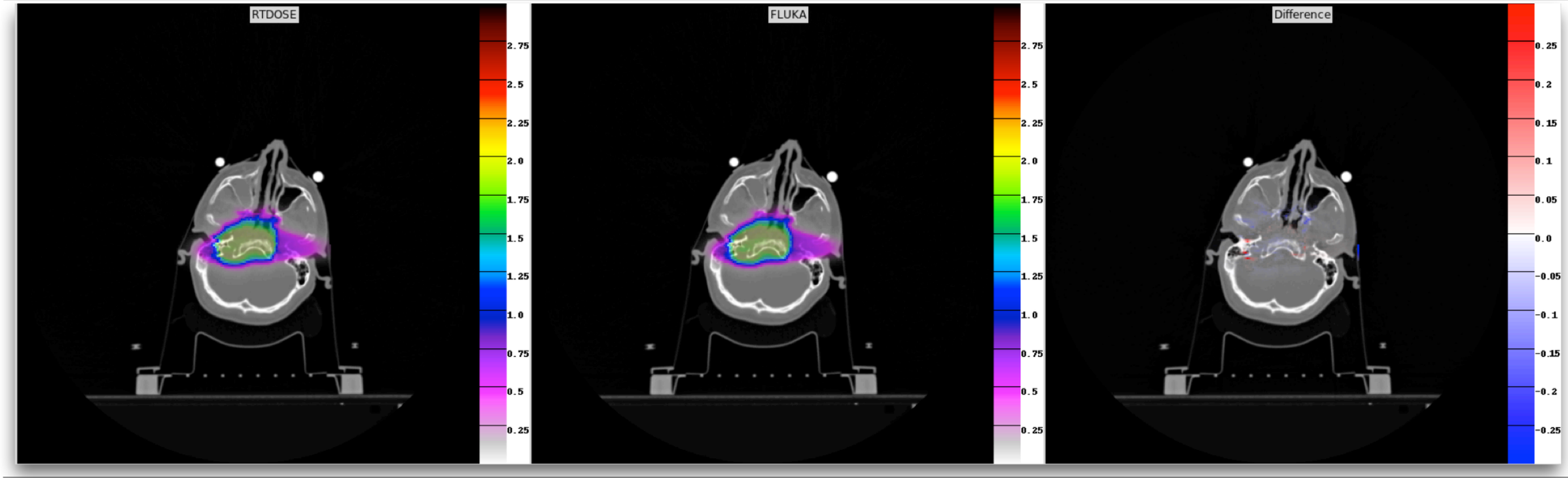
- **Flair** provides an IDE for all stages of **FLUKA simulations** (input, debugging, visualization)
- Process **DICOM standard files** for radiotherapy purposes
- Provides easy-to use tool for **treatment plan re-simulation** and quantitative comparison
- Enables precise description of patient model and beam delivery system

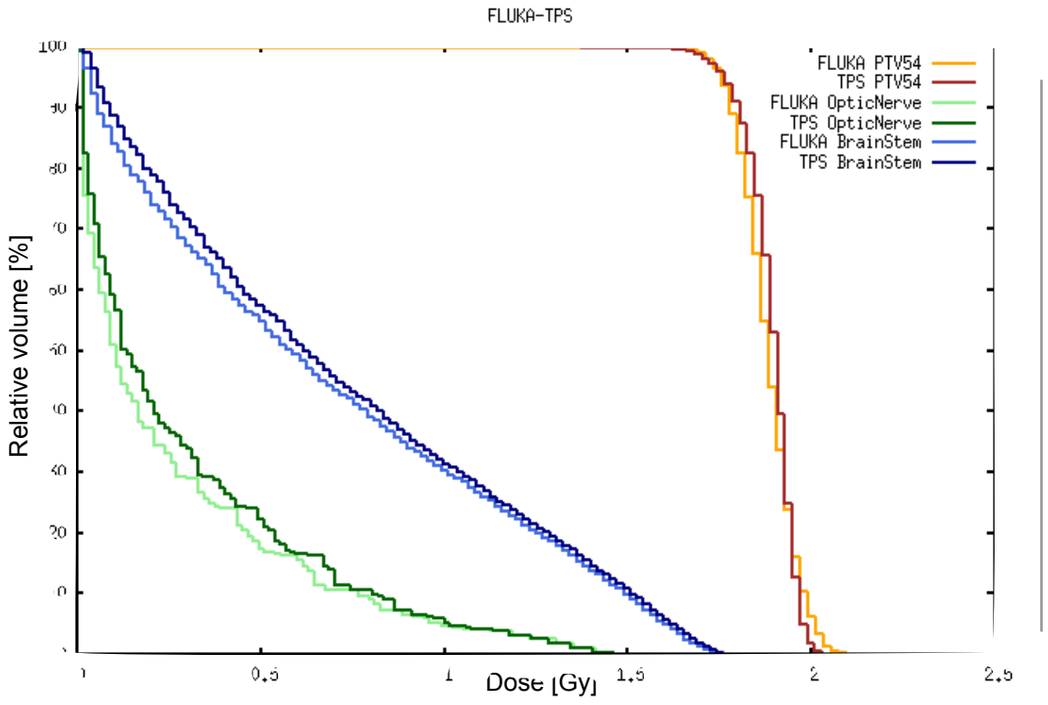




Monte Carlo Treatment Plan recalculations



Proton chordoma patient case (CNAO)



Highly conformal dose distribution gives advantage for **refining treatment margins** by decreasing uncertainties in TP calculations

Proton calculation typical uncertainty margins -3,5% of the range +1mm [5]

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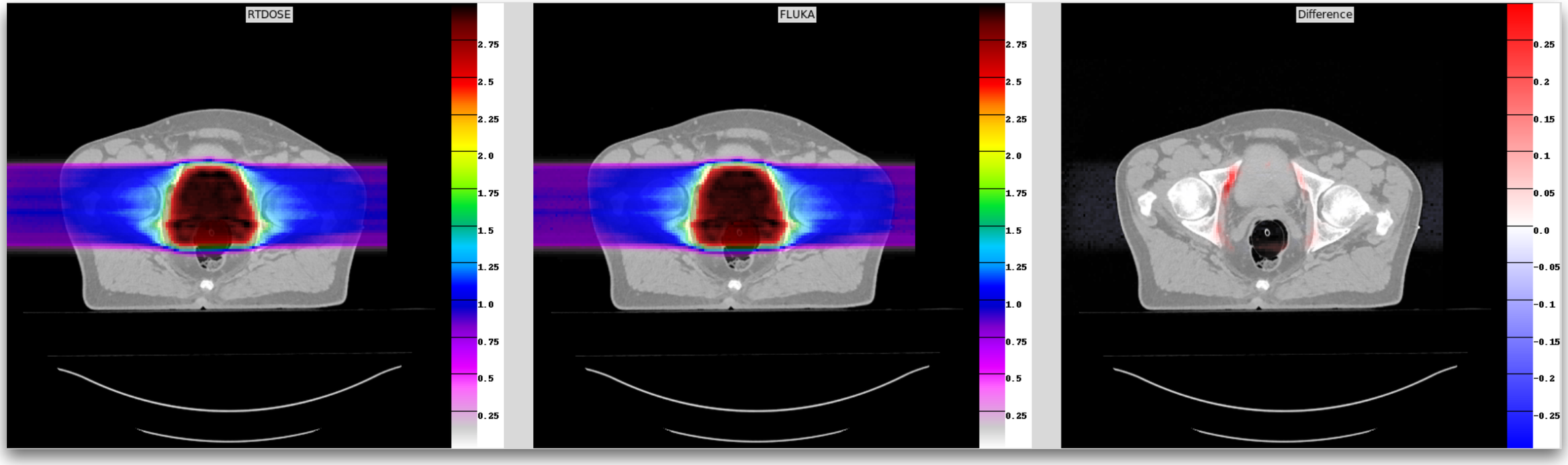
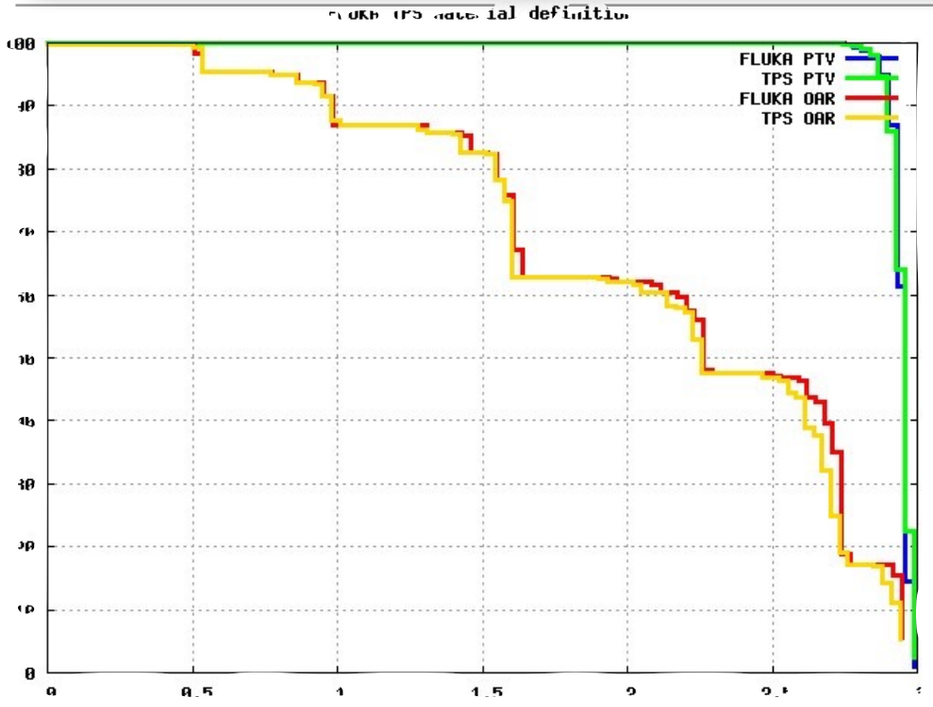
Sensitivity studies of Monte Carlo TP recalculations

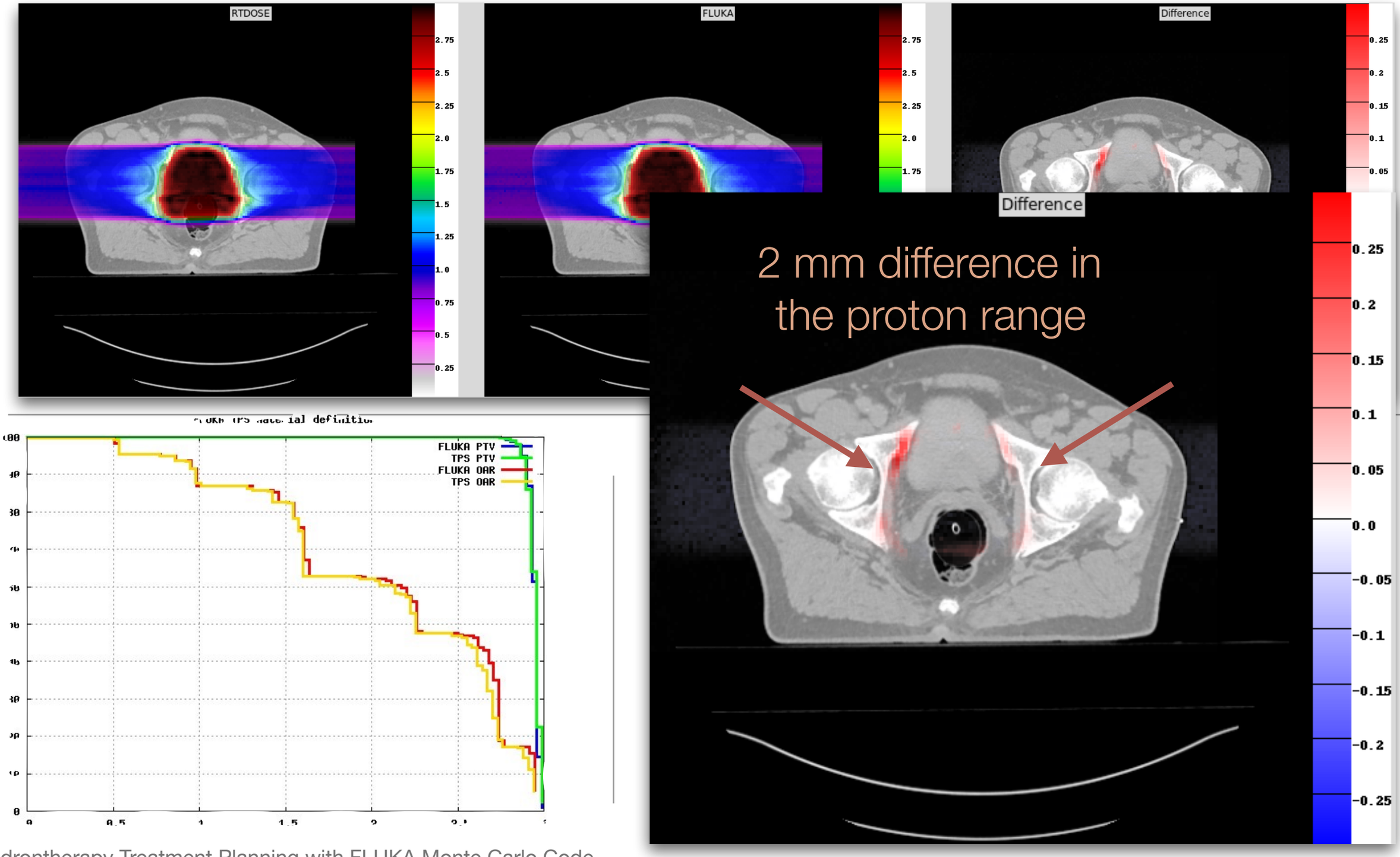




Proton prostate patient case

- Calibration of CT HU to density values
- HU to tissue conversion methods
- Size of the scoring grid
- Ionization potentials of tissue materials
- Accuracy of primary beam description
- …

Sensitivity studies of Monte Carlo TP recalculations



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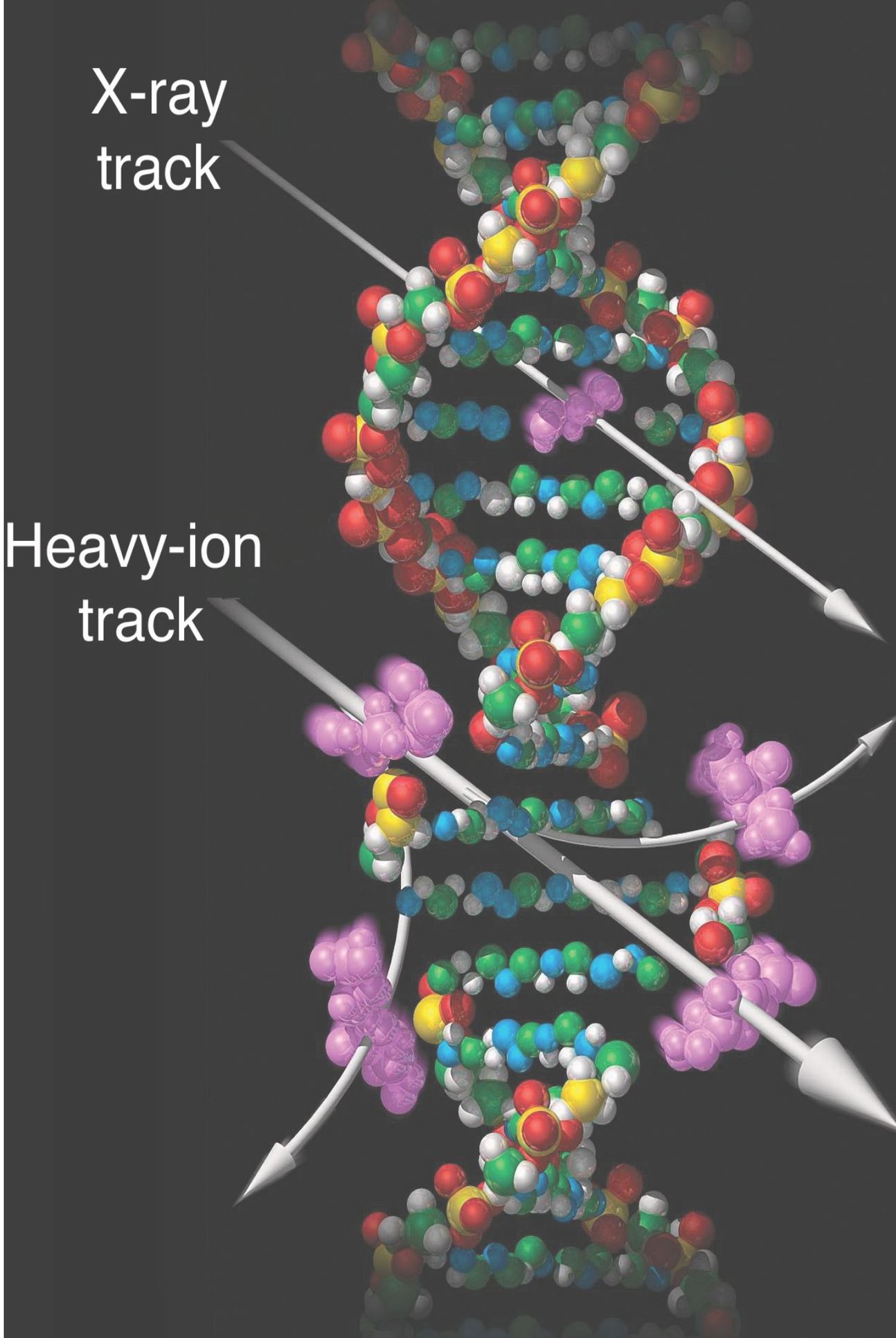
Relative Biological Effectiveness (RBE)

- Ratio of a dose of photons to a dose of any other particle to produce the same **biological effect** [6]

- Experimental measurement by means of the cell survival fraction

- RBE for protons is fixed to 1.1 [7], RBE for ions is parameterized in radiobiological databases

- FLUKA enables combining **biophysical models (such as LEM)** for the mixed radiation fields and calculate RBE-weighted dose distributions [9]



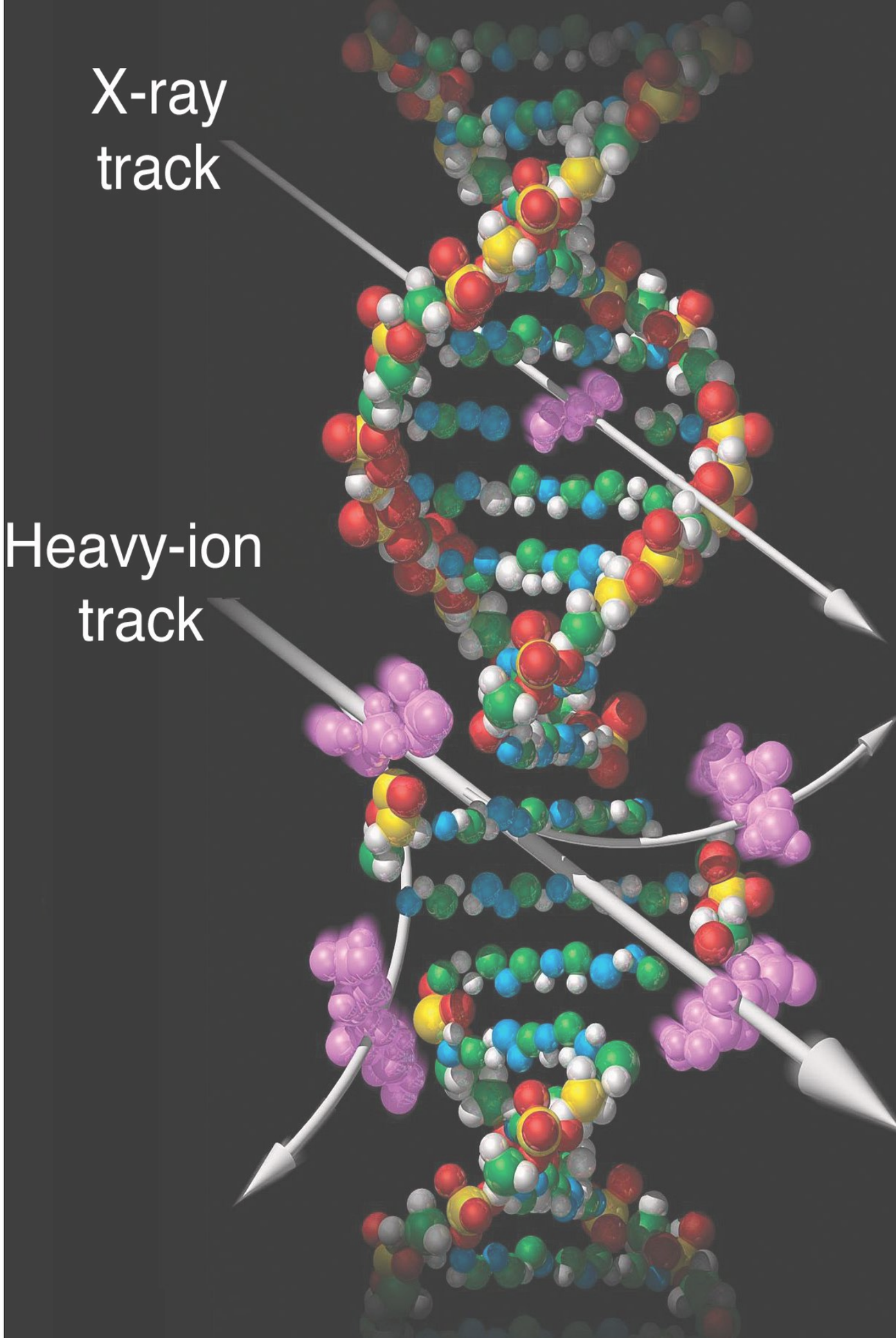
Linear Energy Transfer (LET)

- LET is average amount of energy a particular radiation imparts to the local medium per unit length

- Can be estimated by Monte Carlo simulations

- Significant correlation between the dose-averaged LET and RBE

- High-LET particles can **reduce the response factor OAR** (oxygen enhancement ratio) leading improvement of the treatment outcome for hypoxic - radioresistive tumors



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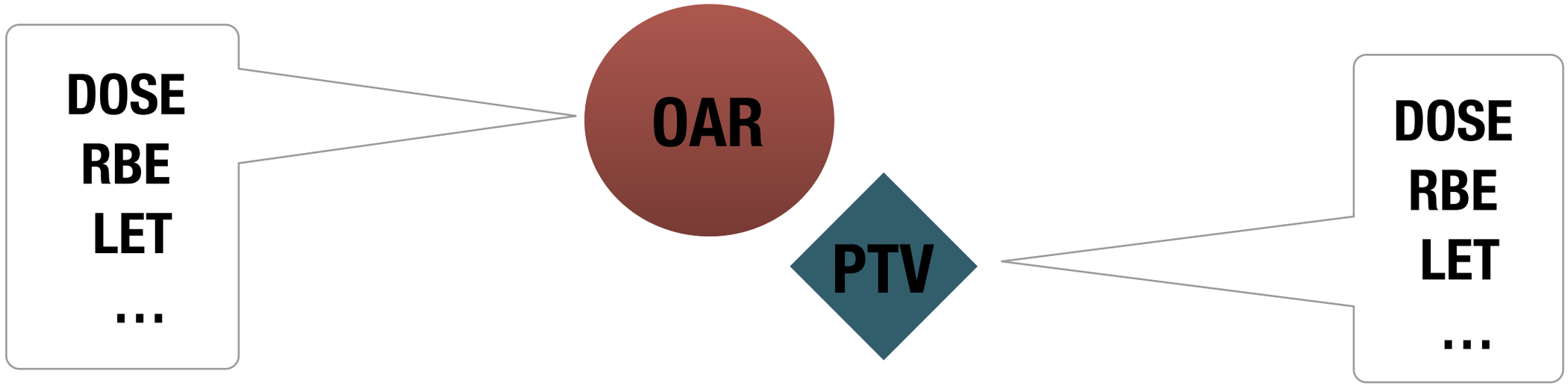
Aim of the MC Treatment Plan Optimization

- Based on the **preliminary optimization** from analytical TPS
- **Re-simulation** and validation of the Treatment Plan



- Development of **algorithms for optimization** based on MC output
- Ability for using different **radiobiological datasets**

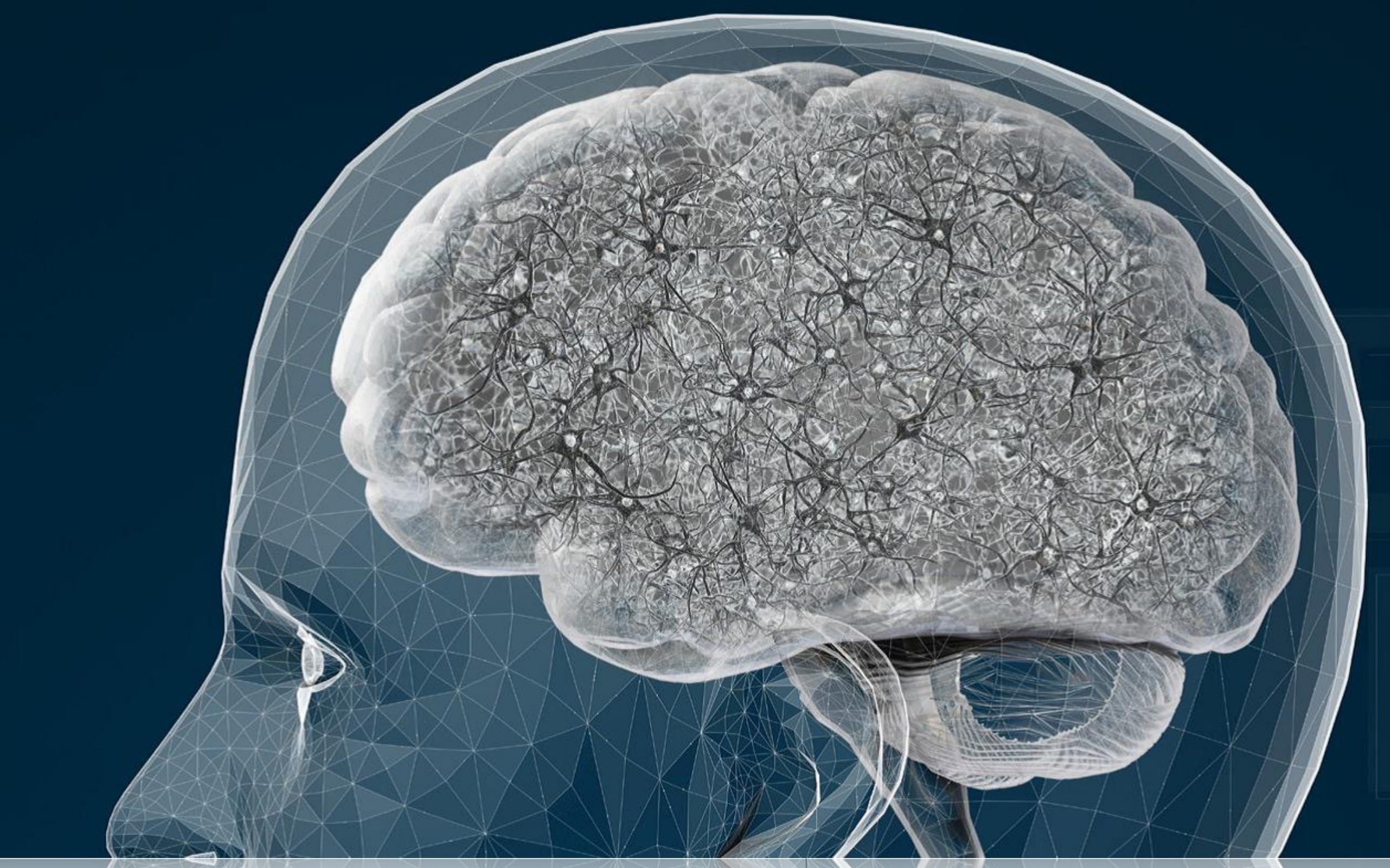
My current work and further plans

- Development and constant improvement of the FLUKA and Flair for **fully independent Treatment Planning recalculations**

- Examining **uncertainties on the proton and ion** (currently carbon-12) treatment planning for **Quality Assurance purposes**

- Full integration of the **MC optimizer with the FLUKA** interface, and further work on the different optimization algorithms for **dose / RBE / LET 'painting'** ideas

- Examining sensitivity of the treatment plan to the different biophysical datasets applied to the different ROI, providing **robust optimized plan**



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