Use of FLUKA in hadron therapy

Heavy Ion Therapy Masterclass School
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Sarajevo-Online

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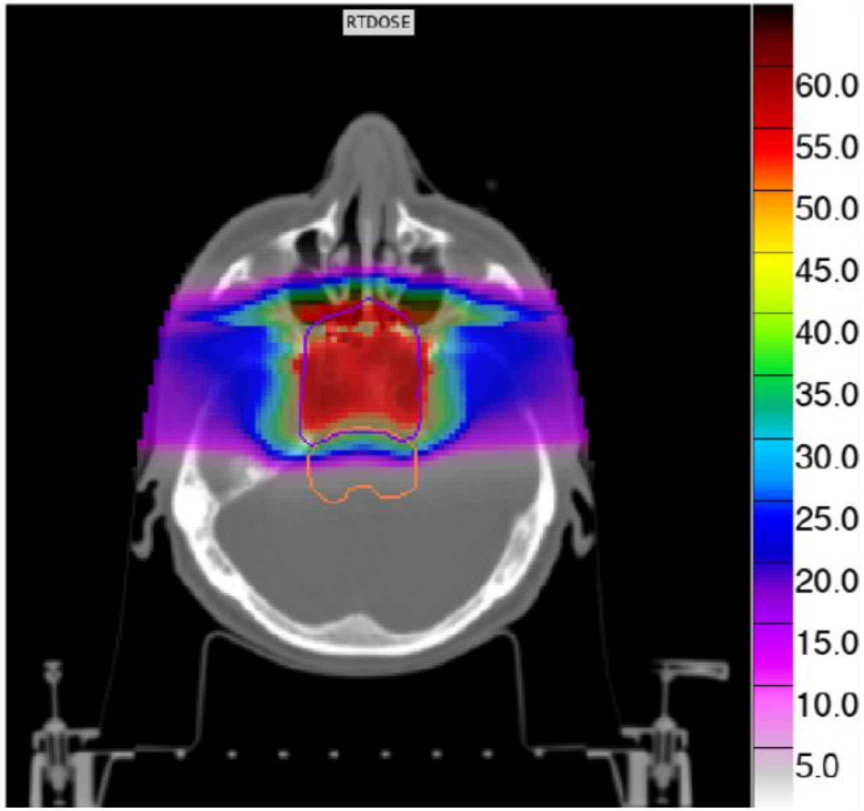
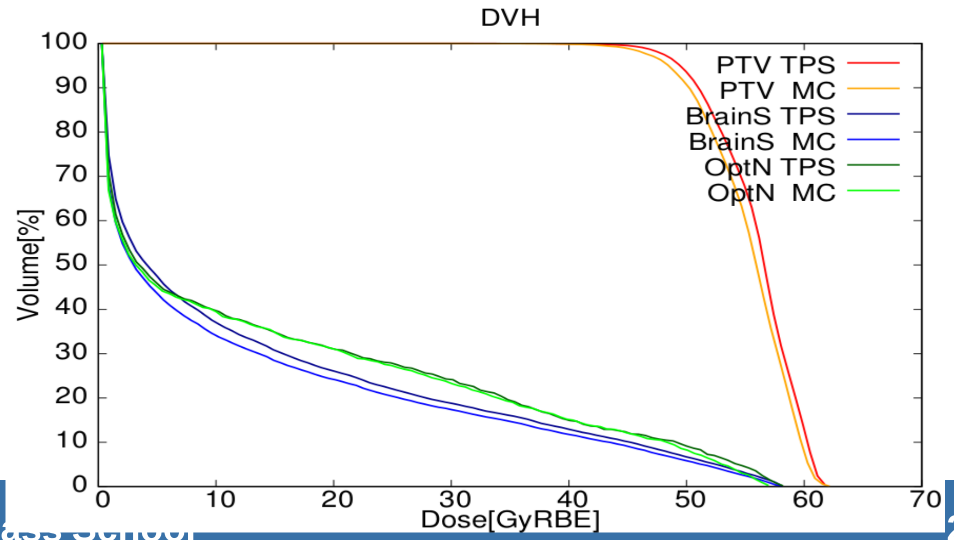
CERN SY-STI-BMI

Monte Carlo in medicine

- MC are increasingly spreading in hadrontherapy community due to their detailed description of radiation transport and interaction with matter
- The suitability of a MC code demands accurate and reliable physical models capable of handling all components of the expected radiation field
- Not only the physics is important
  - but biologically based dose calculations (especially for Ions)
  - accurate prediction of secondary emerging radiation (especially for invivo studies)
  - easy to use interface for a hospital based environments

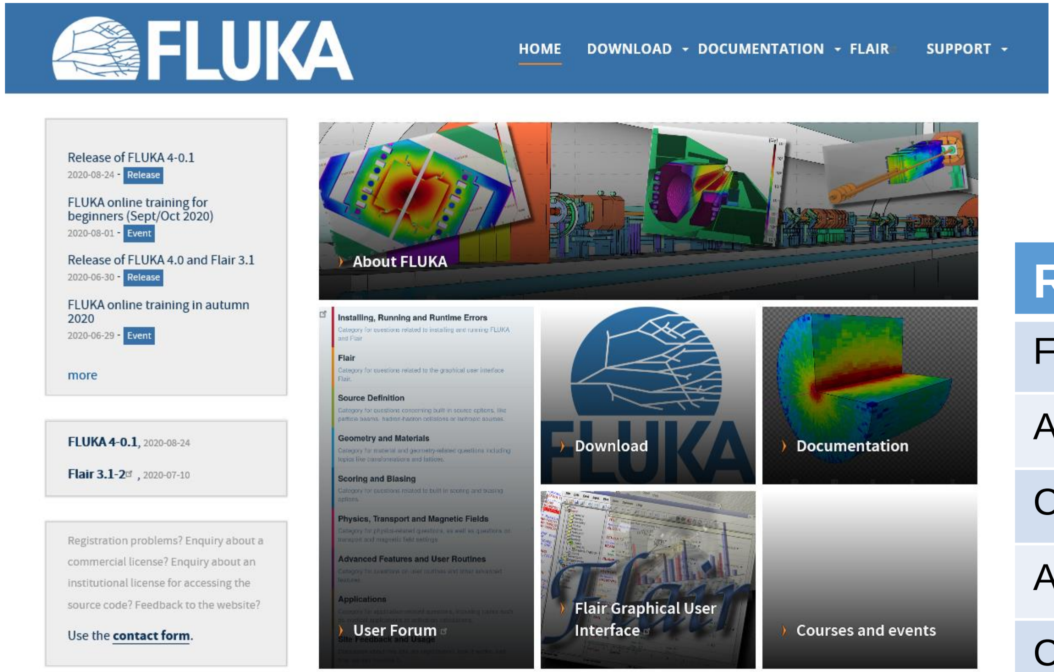




A particle interaction and transport Monte Carlo code

- Born in the 60’s at **CERN** with Johannes Ranft
- Further developed in the 70s and 80s in a collaboration between **Leipzig University**, **CERN** and **Helsinki University** for applications, e.g., at CERN’s high energy accelerators, and in the 90s with **INFN**, among others for the design of SSC and LHC
- From 2003 until August 2019 maintained and developed under a **CERN & INFN** agreement
- From December 2019, new **CERN** distribution aiming to ensure FLUKA's long-term sustainability and capability to meet the evolving requirements of its user community, welcoming contributions by both established FLUKA contributors as well as new partners.
- *Presently a joint development & management team including CERN Engineering Department & Radiation Protection Group and ELI Beamlines (Prague) is in place*

https://fluka.cern



https://cern.ch/fluka-forum

(an independent one time registration is requested to post)

Registration options
FLUKA ***Single User License Agreement***
Affiliates of institutes with a FLUKA ***Institutional License Agreement***
CERN Staff members and Fellows
Affiliates of institutes which signed the FLUKA ***Memorandum of Understanding***
Companies which purchased a FLUKA ***Commercial License Agreement***

FLUKA capabilities

- hadron-hadron and hadron-nucleus interactions
- nucleus-nucleus interactions
- photon interactions (>100 eV)
- electron interactions (> 1 keV; including electronuclear)
- muon interactions (including photonuclear)
- neutrino interactions
- particle decay
- low energy (<20 MeV) neutron library

- ionization and multiple (single) scattering (including all ions down to 250 eV/u)
- combinatorial geometry with lattice capabilities
- voxel geometry and DICOM importing
- magnetic field, and electric field in vacuum
- analogue or biased treatment
- on-line buildup and evolution of induced radioactivity and dose

built-in scoring of several quantities (including DPA and dose equivalent)

✓ Accelerator design ✓ Shielding design ✓ Radiation protection

✓ Dosimetry ✓ Radiation damage ✓ Radiation to electronics effects

✓ Particle physics (calorimetry, tracking and detector simulation, …)

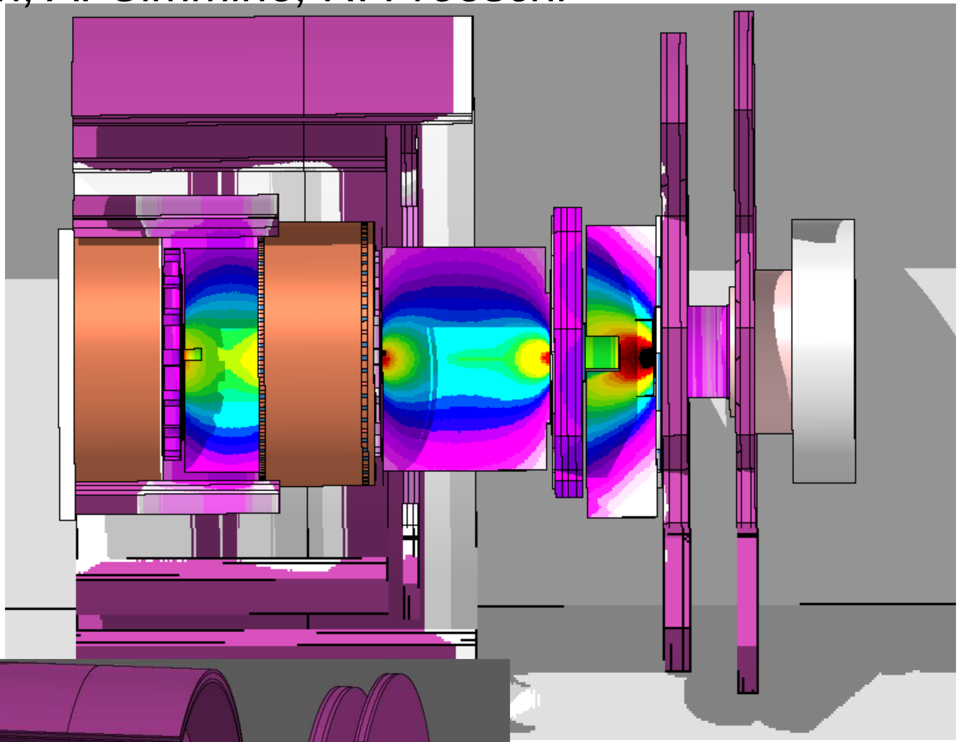
✓ Cosmic ray physics ✓ Neutrino physics ✓ ADS systems, waste transmutation

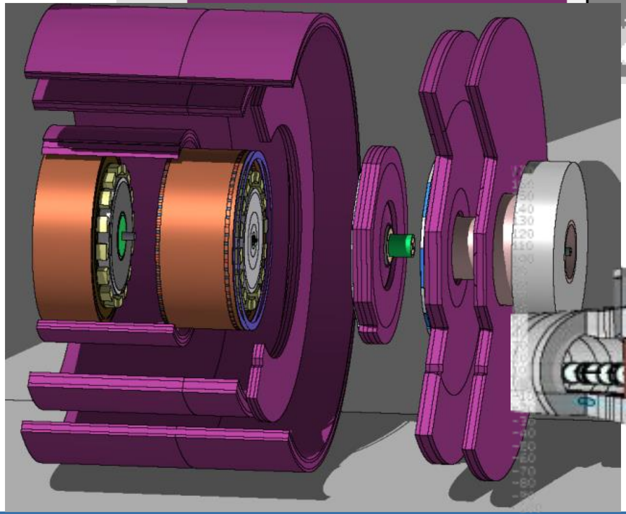
✓ Medical applications, hadrontherapy ✓ Neutronics

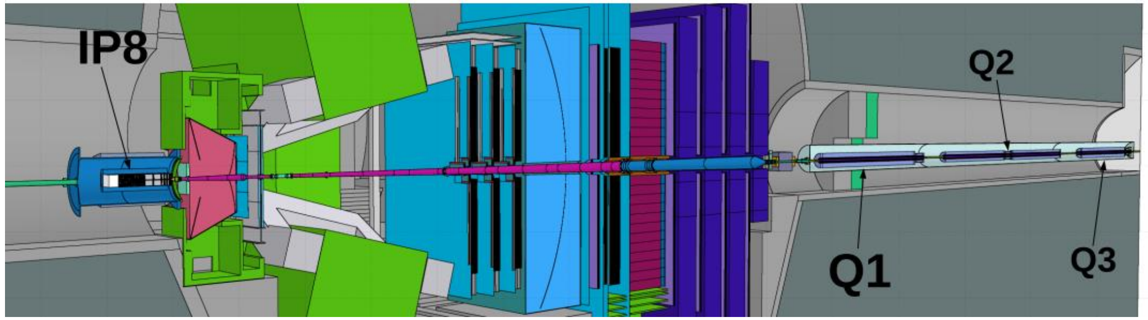
Some pictures to choose for FLUKA

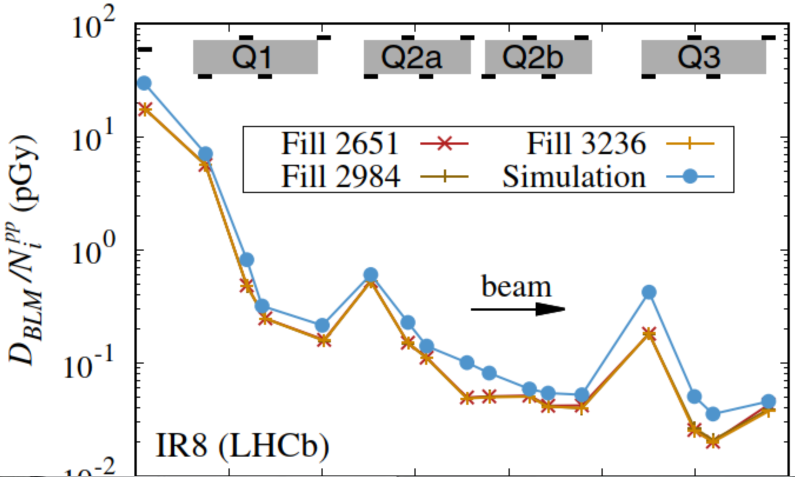
[A. Lechner et al., Phys. Rev. AB 22 (2019) 0710

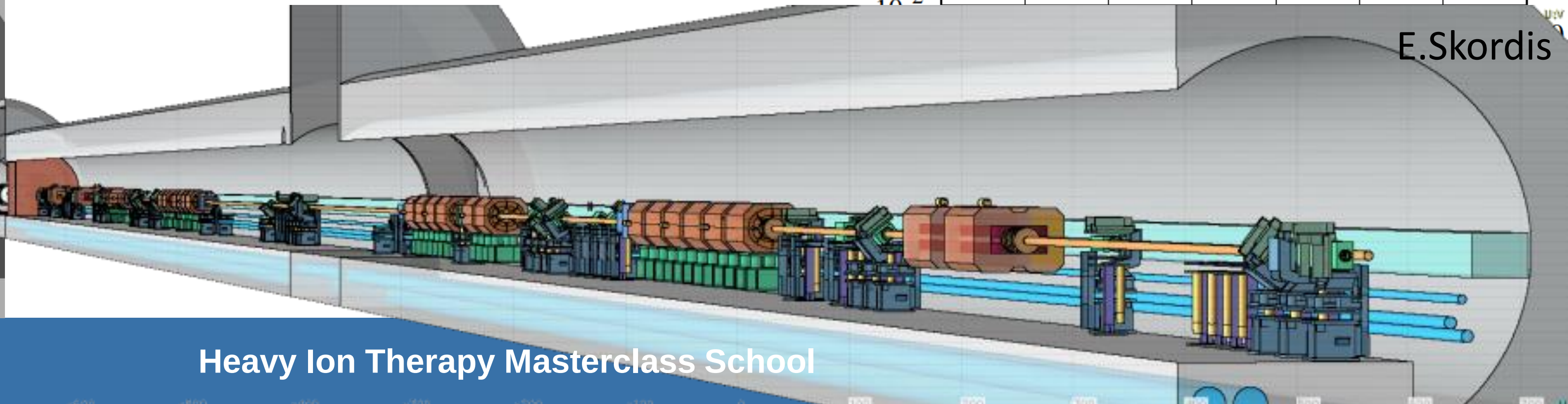
D. Björkman, A. Cimmino, R. Froeschl











flair – fluka advanced interface

http://flair.cern

FLUKA Advanced Interface

- is more than a graphical Interface

- → is a complete integrated working environment for FLUKA

  Greatly enhanced productivity
  → users focus on their problem rather on technicalities

- Without hiding the inner functionality of FLUKA, flair offers all tools for:

Front-end

- Fully featured Input file Editor;
- Geometry: interactive visualization, photo-realistic plots, editing, and debugging;
- Compilation of the FLUKA Executable;
- Running (Spawning on multi-core) and monitoring of the status of one/many run(s)

Back-end

- Post processing of FLUKA output
- Plot generations with gnuplot
- Photorealistic 3D plots with USRBIN data superimposed

Other

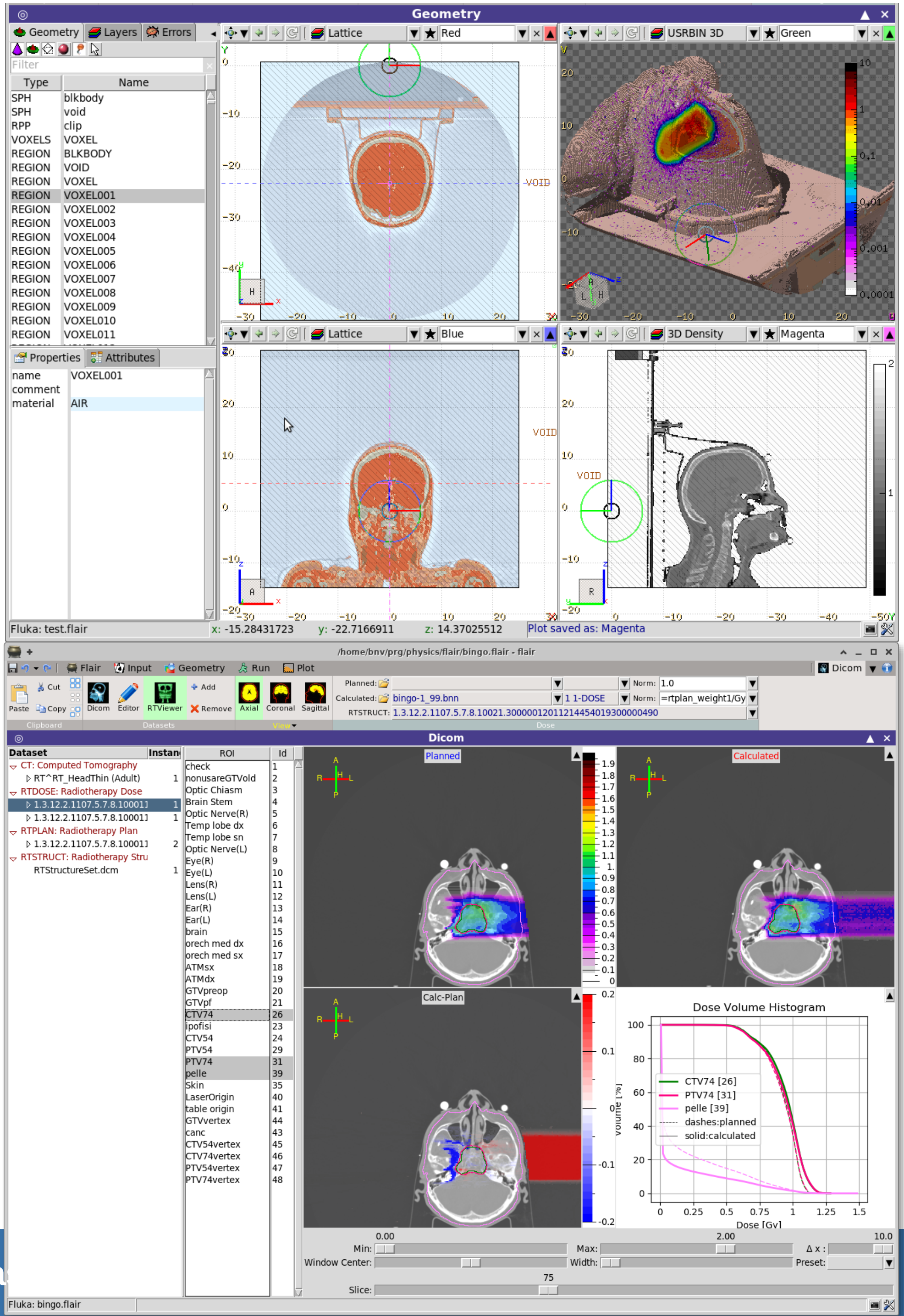
- Database of Materials, Isotopes
- FLUKA hypertext manual
- …

…and many more…

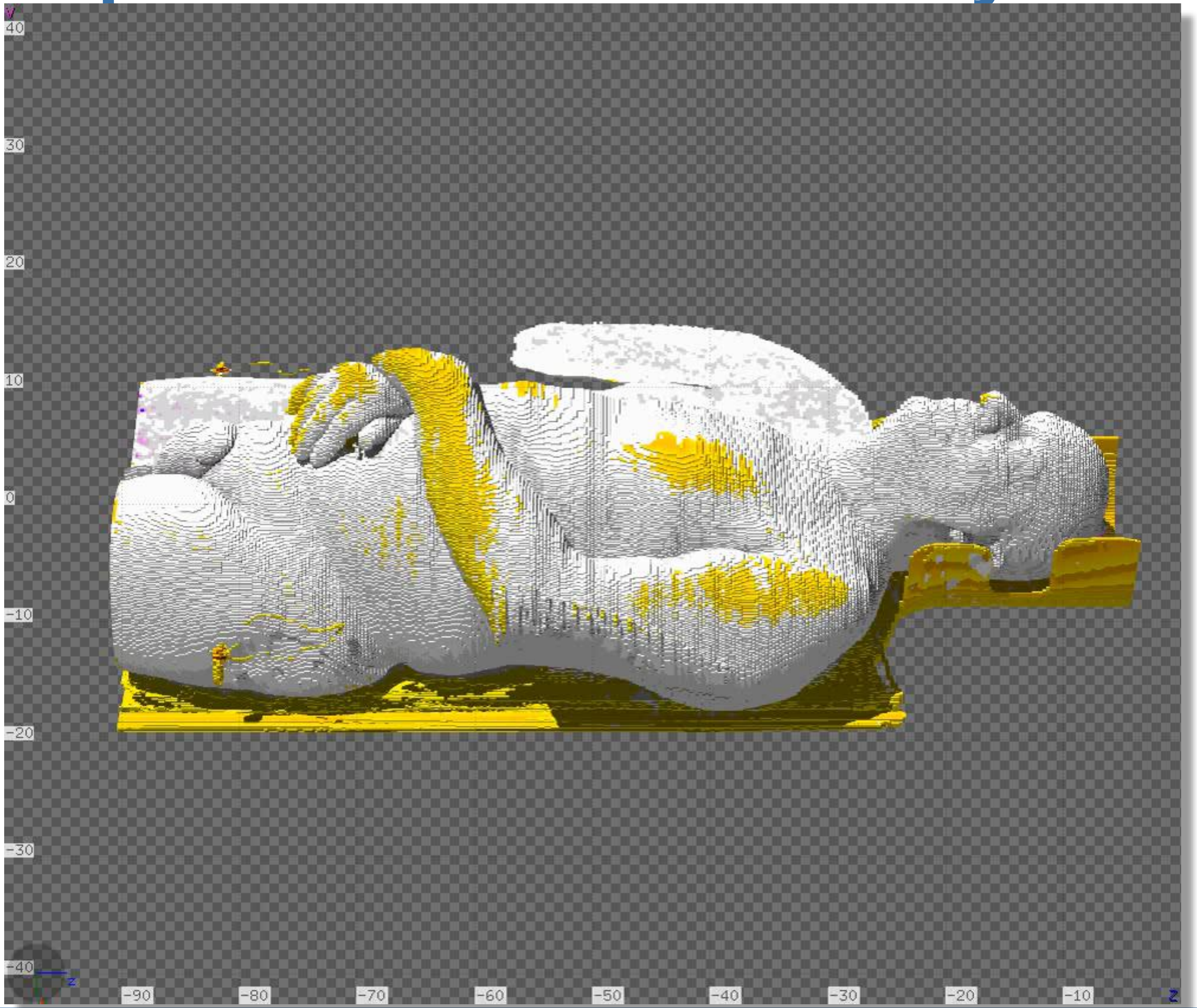
Flair: medical improvements

- Process **DICOM standard files** for radiotherapy purposes
  - DICOM CT, MR, importer
  - Automatic material assignment using the Schneider parameterization
  - Importing ROI RTstructures
- Provides easy-to use tool for **treatment plan re-simulation** and quantitative comparison
  - Importing RTPlan
  - Generation of DVH plots and comparison plots with RTDOSE
  - Enables precise description of patient model and beam delivery system

Running FLUKA simulations …
→ with no programming skill or file editing requirement!



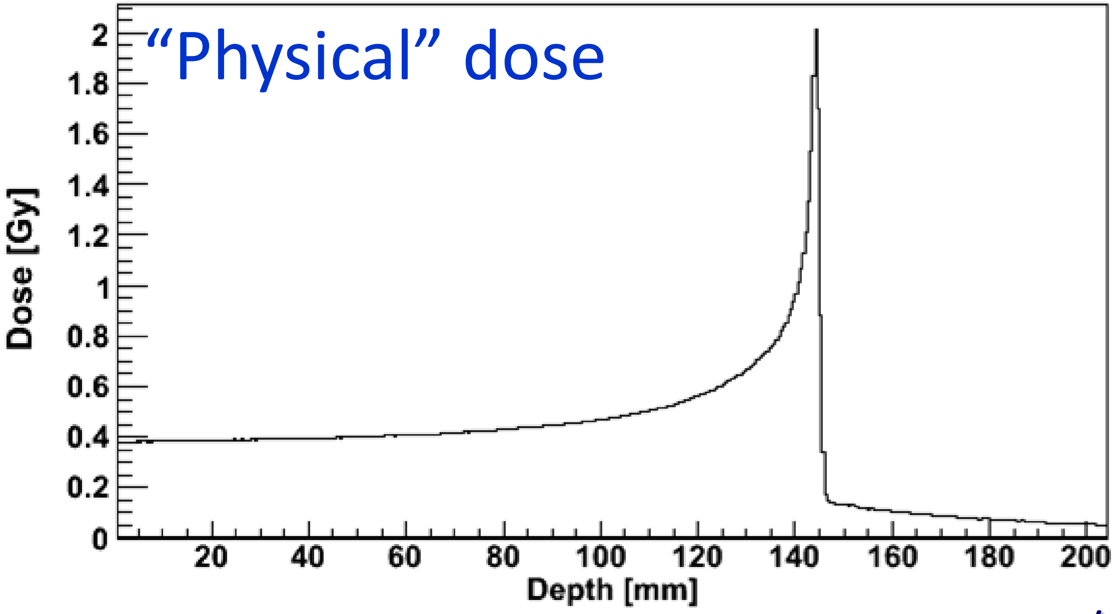
Examples: Nuclear Dosimetry

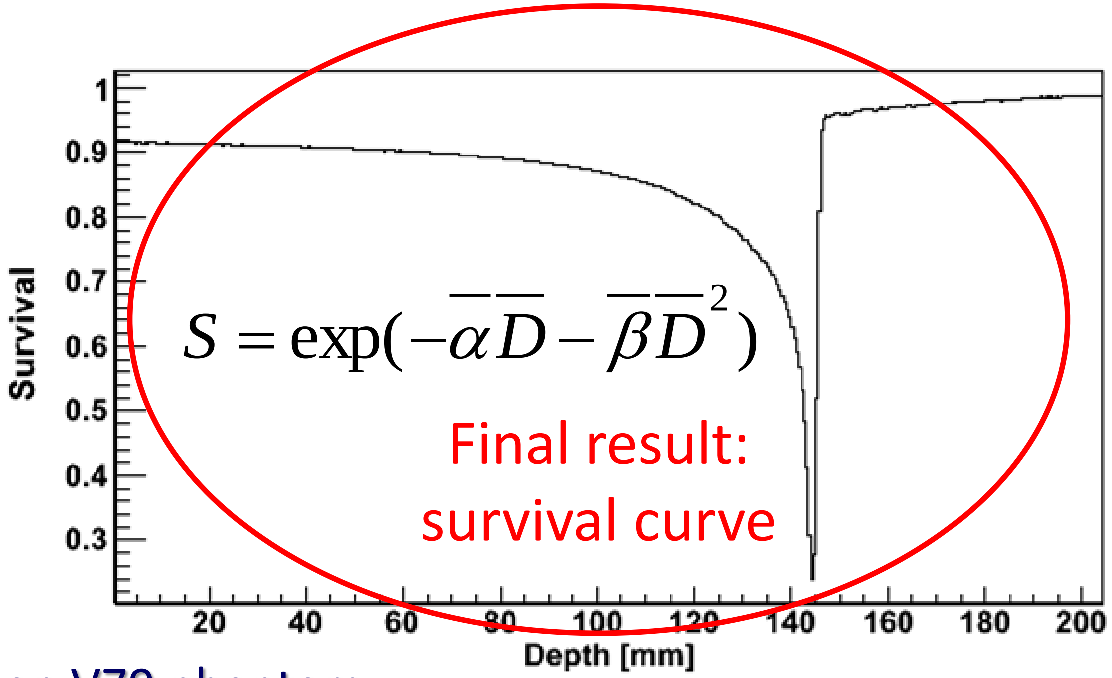


- 3D spatial dose distribution simulated with FLUKA
- Importing the RT DOSE with the activity mapping of ^{68}Ga
- Simulation of the ^{68}Ga decays
- Very fast setup time less than a few minutes with a few clicks from the user

Biologically Oriented Scoring*

- Under the standard assumption of a linear-quadratic dose-effect relationship, for each energy deposition i, FLUKA interpolates from a radiobiological database the $\alpha_{D,i}$ and $\beta_{D,i}$ parameters for the specific ion with a certain charge at a certain energy.
- Then FLUKA sums up properly the mixed radiation effect applying the Kellerer and Rossi theory of dual radiation action

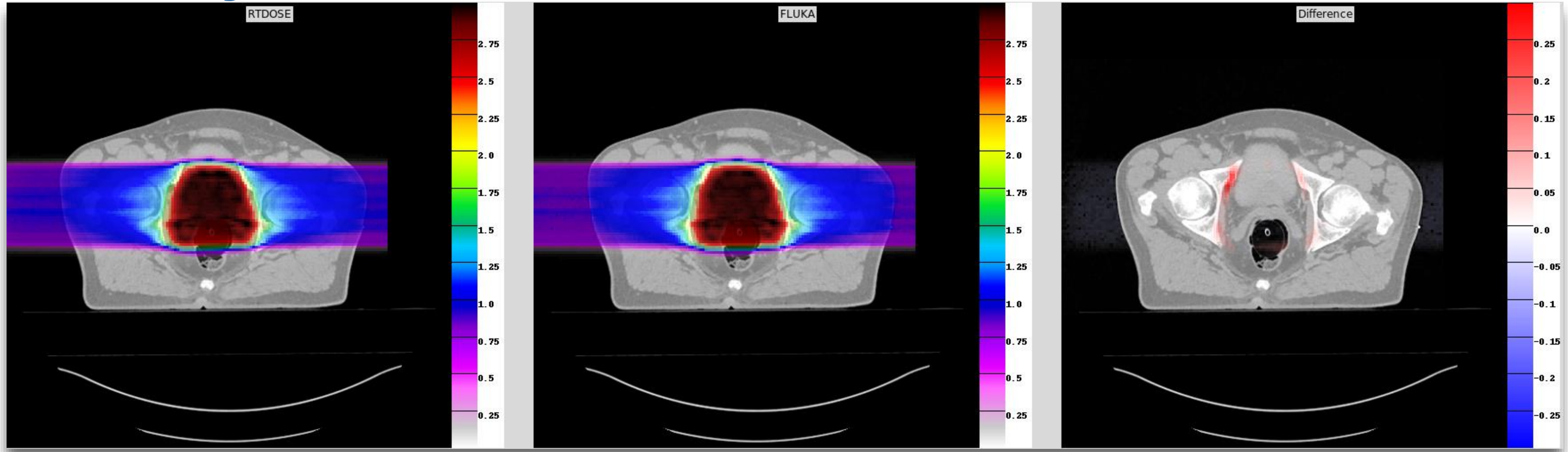




270 MeV/u ^{12}C ions on V79 phantom

*PMB55, 4273 (2010)

Sensitivity studies of Monte Carlo TP recalculations



Proton prostate patient case (MedAustron)
W.Kozlowska PhD

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

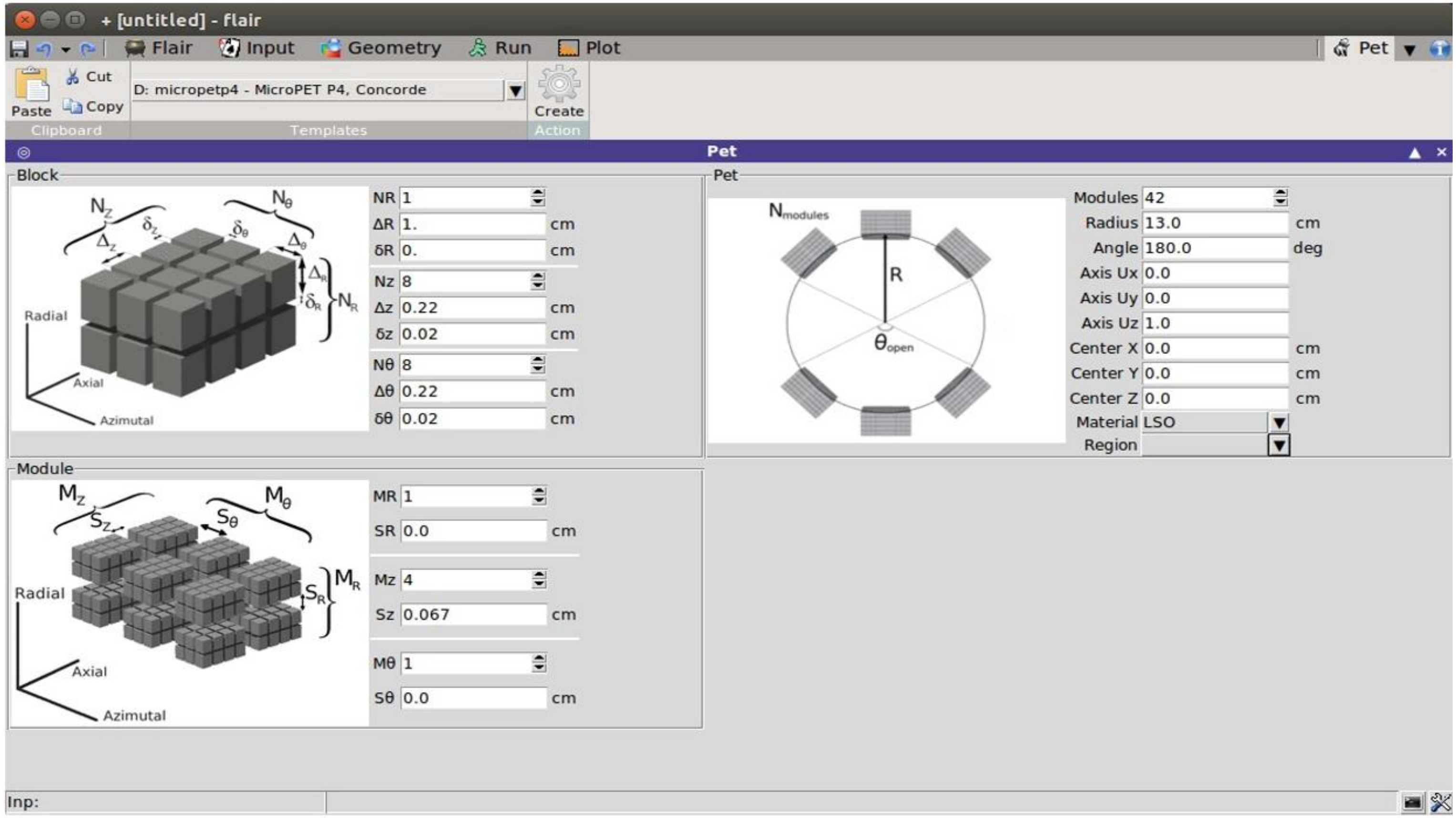
IAEA Human Health Report No.7 Vienna (2013)

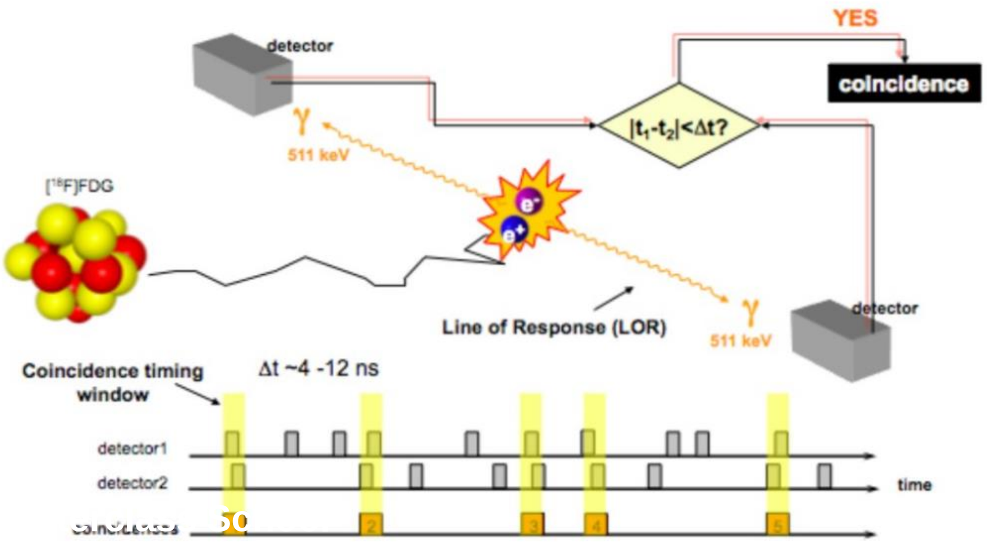
Sensitivity Studies:

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

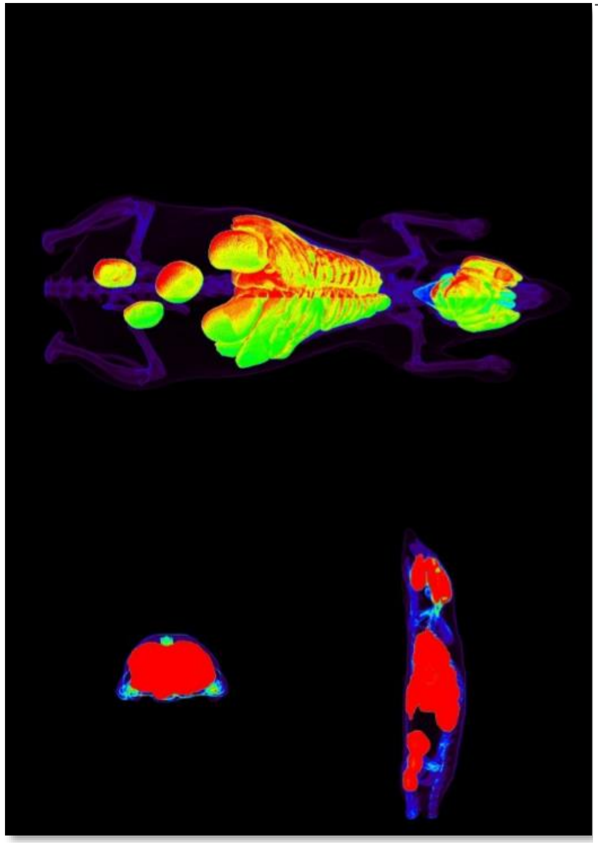
PET Simulations

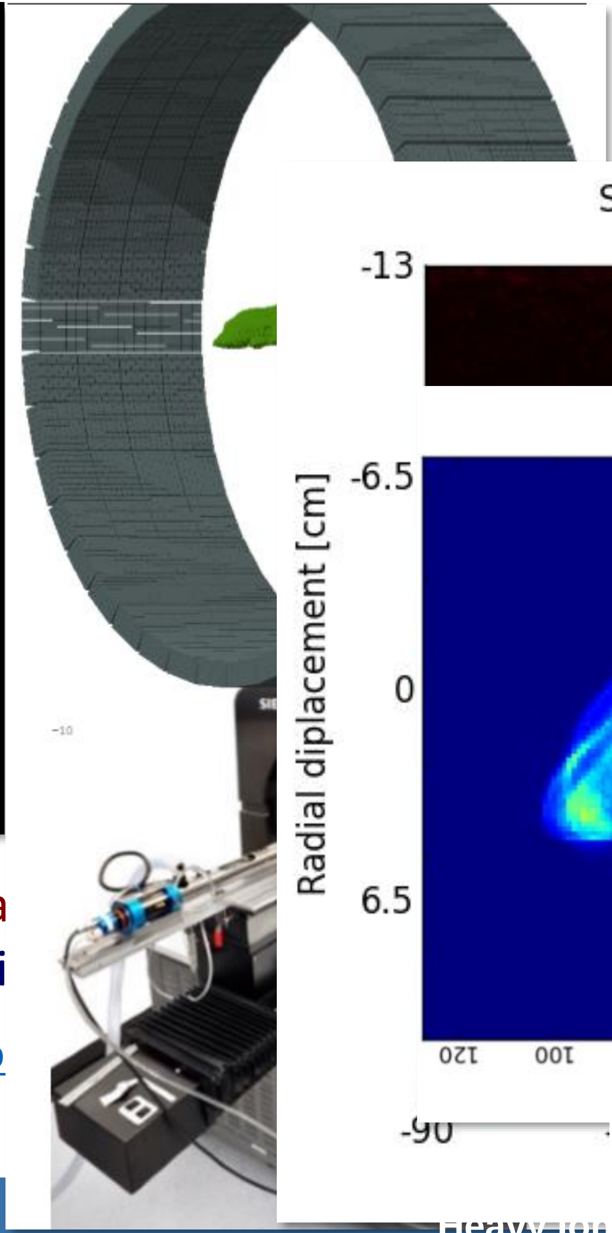
- Automatic PET scanner generation from user provided basic parameters.
- Predefined list of existing commercial scanners
- User defined coincidence scoring routines
- Various algorithms for offline dealing with the coincidences
- Reconstruction algorithms:
  - Filtered Back Projection
  - Maximum Likelihood Expectation Maximization



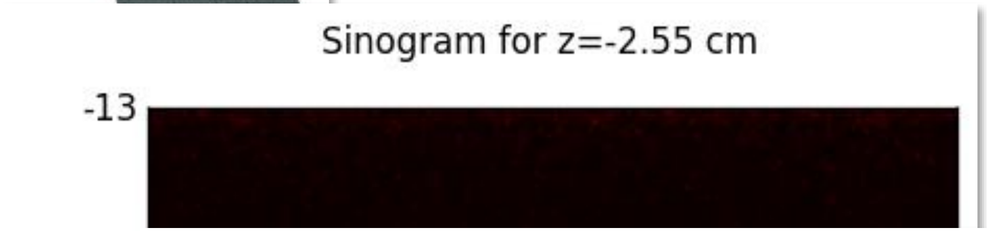


PET: Example of a complex simulation

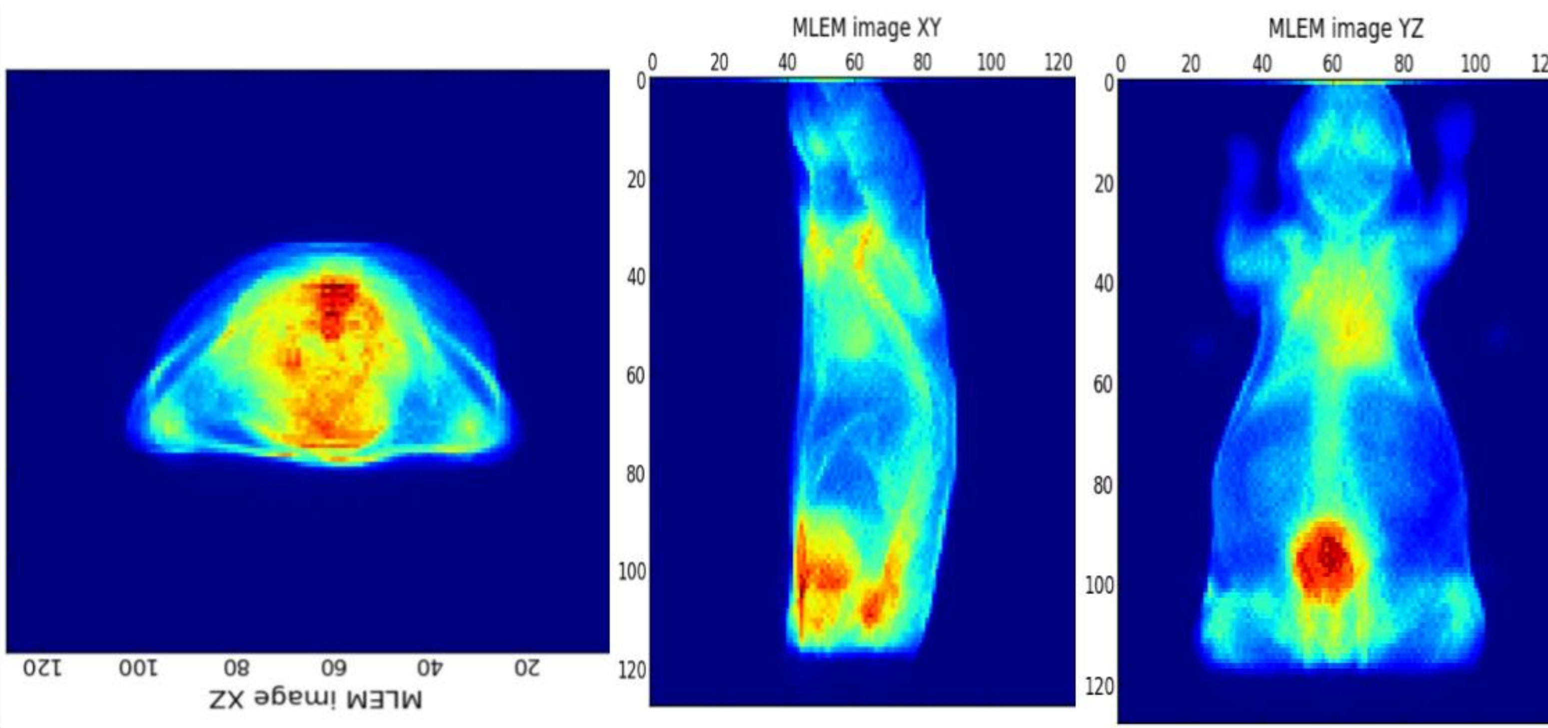




Importing in FLUKA and generating the geometry of MicroPET P4: Scanner for small animals



- Running 5 10^6 primaries (4h) → 20Gb coincidence file
- Sinogram generation



High quality mouse pha
from Univ. of South Cali

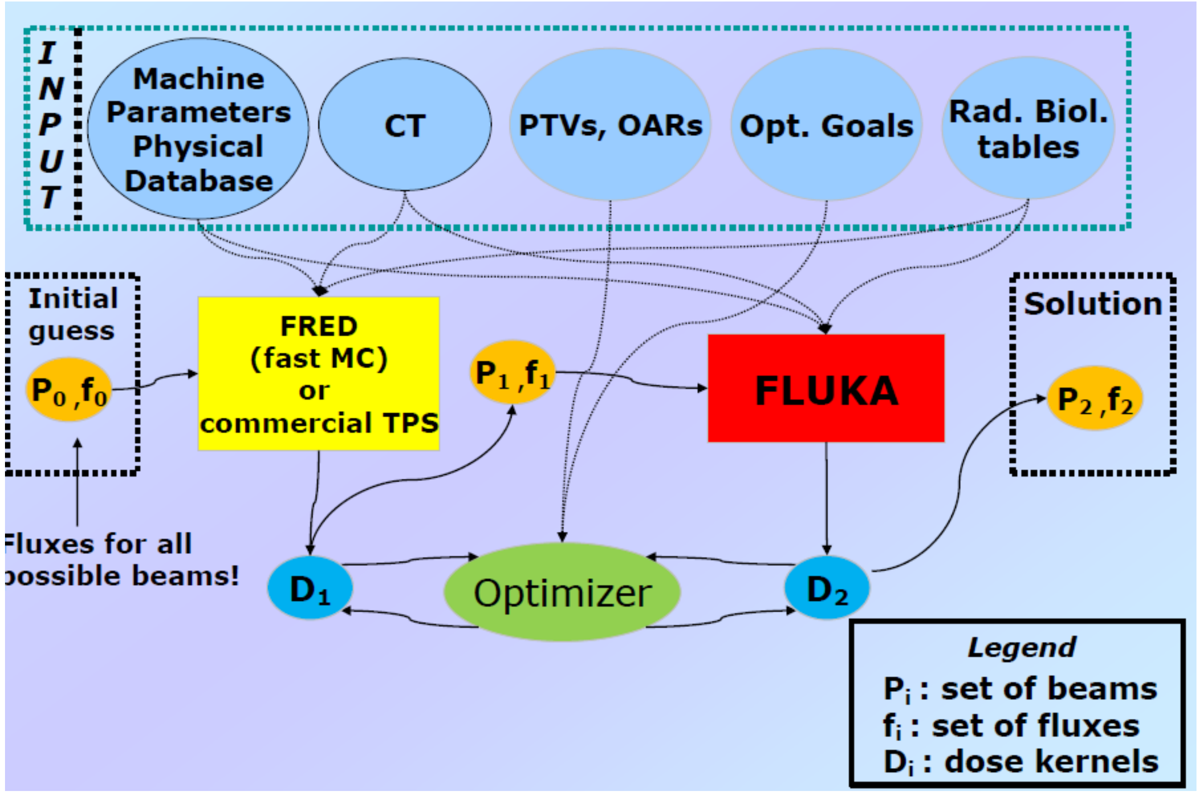
http://neuroimage.usc.edu/neuro/D

Reconstruction with Maximum Likelihood Expectation-Maximization with 70 iterations

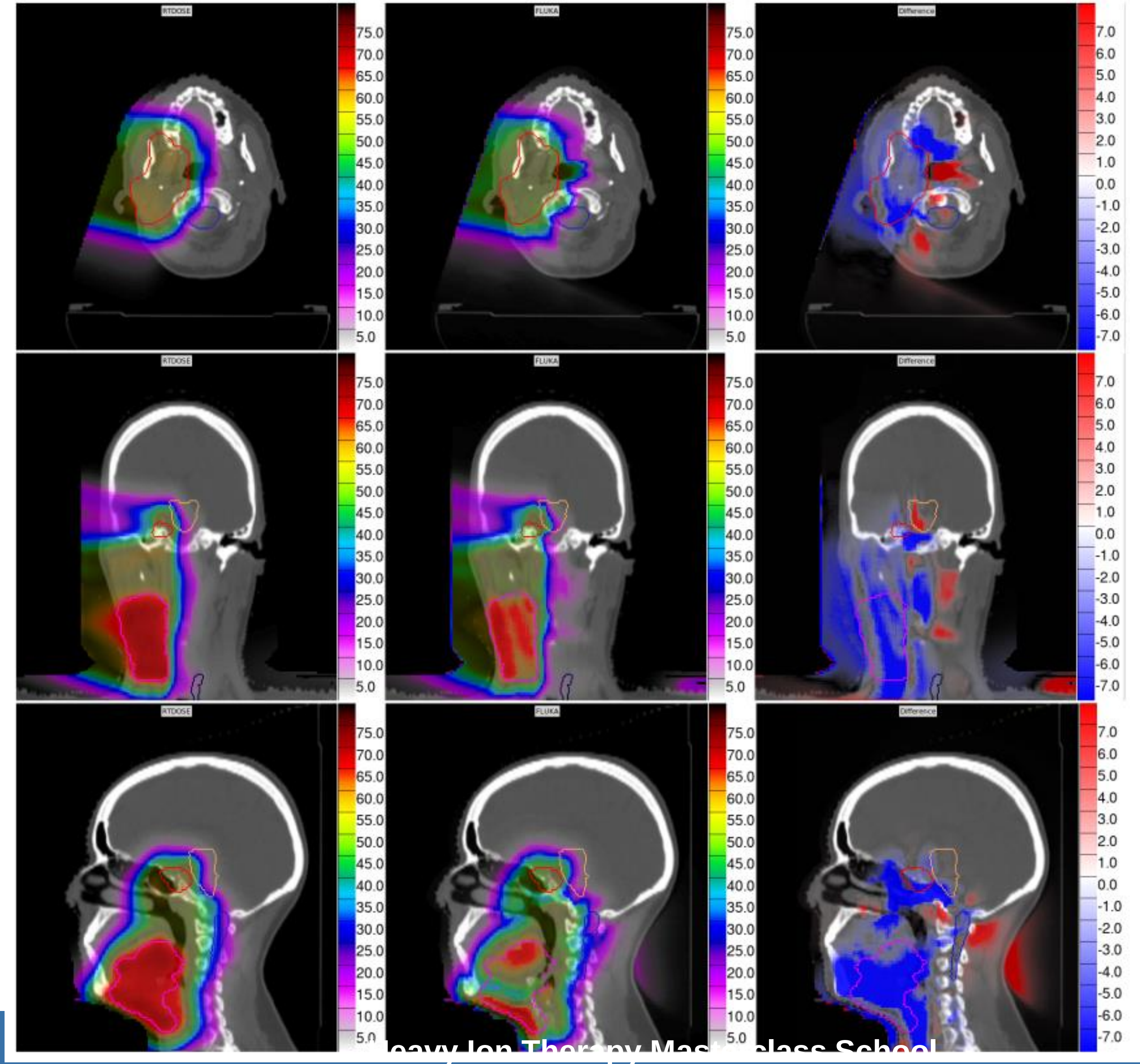
FLUKA

A Monte Carlo based Treatment planning?

- TPS's for h-therapy are based on fast analytic dose engines using Pencil Beam algorithms (using a "physical" database possibly generated by MC)
- MC calculations of doses and fluences are superior in accuracy because they can account for heterogeneities, large densities, geometry details. Moreover, they can predict secondary particle production to be used for imaging, range control, etc.
- However they require much longer execution times…
  - …to account for geometry and material details, overcoming the "water-equivalent" approach
  - …to be applied to realistic treatment conditions within acceptable (?) CPU time
  - …to be applied to treatment planning with all ions with $1 \leq Z \leq 8$ (at CNAO and HIT)
  - … a tool which not only allows to check a given plan, but which also suggests a better solution
  - …to be used stand-alone or as post re-optimization of plans obtained from commercial TPS
  - …to be used in research: New ions and combined ion fields, testing of new bio-models and algorithms, to predict secondary fluxes: β+ emitters, prompt γ, etc.



Head and Neck case



Head and Neck case (CNAO)
W.Kozlowska PhD