Fred 3.0
status report

A. Schiavi

SBAI - URLS - 29/11/2019

Fast paRticle thErapy Dose evaluator

Collaboration network

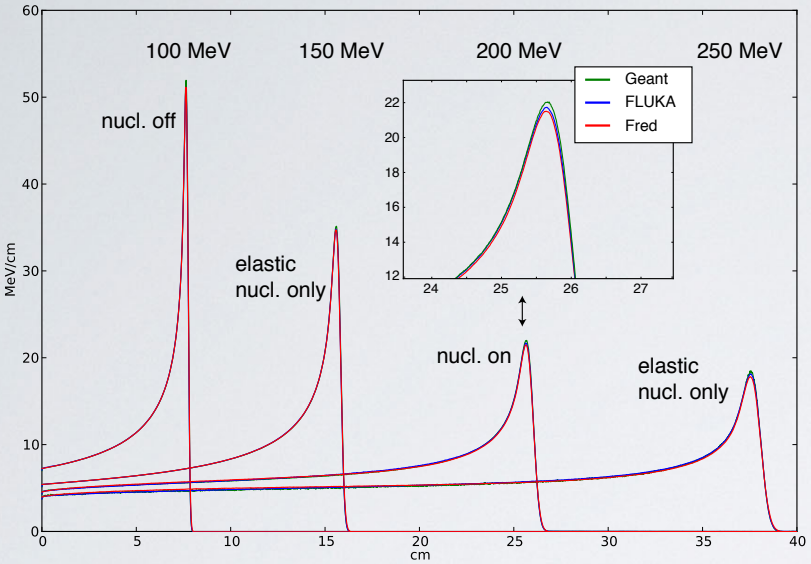
- A. Schiavi, V. Patera, A. Sarti, M. De Simoni, M. Fischetti, M. Pacitti, G. Acciaro, G. Traini, G. Battistoni, Univ. La Sapienza Roma and INFN (Italy)
- N. Krah - CREATIS, CNRS/University Lyon (France)
- A. Rucinski, J. Gajewski, M. Garbacz, A. Skrzypek, J. Baran - PAN, Krakow (Poland)
- I. Rinaldi - Maastro clinic, Maastricht (Netherlands)

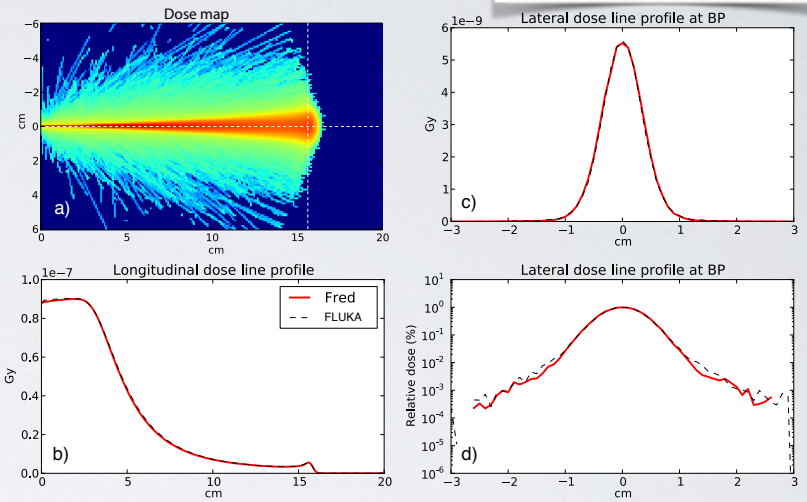
FRED fast-MC platform

- particle tracking with class II MC algo in voxelized geometry
- Tabulated total stopping power in standard materials (PSTAR-NIST), energy straggling (Gaussian and Landau-Vavilov regimes)
- MCS models: single-,double-,triple-gaussian, gauss+Rutherford
- Nuclear interactions: elastic and inelastic; fragmentation; local deposition of heavy ions; tracking of secondary particles (e.g. protons and deuterons)
- HU to density conversion (Schneider) and stoppow calibration
- MC-TPS: dose optimization using DDO (Lomax)
- RBE models = fixed 1.1, LETd-based (Wedenberg, Carabe, Wilkens, Chen,McNamara), table-based (LEM1, MKMPIDE)

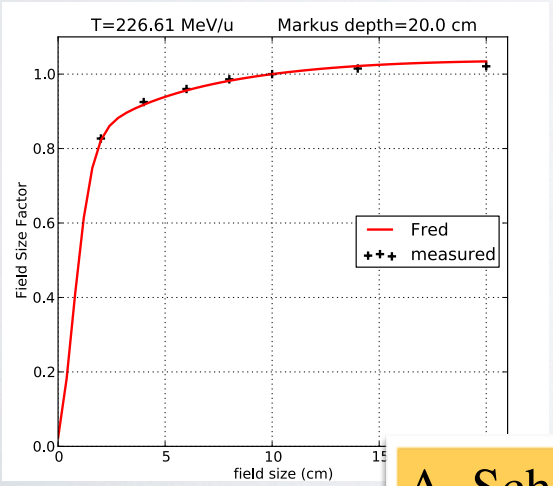
Water model

150 MeV protons in liquid water





Field size factor

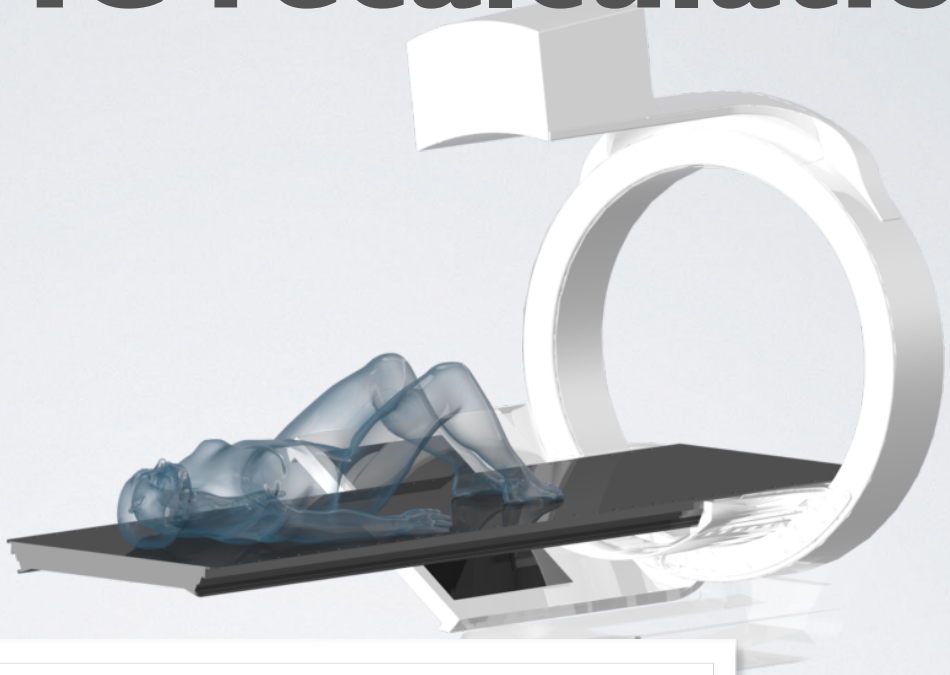


- ddd within 1.5% of full-MC codes
- lateral tails matched at 4 orders of magnitude
- nuclear tails within 1.5% of data at 20 cm away from axis in the F.S.F.

A. Schiavi et al, *PMB* **62** (2017) 7482–7504

fast-MC recalculation

In-room imaging for patient positioning (CBCT)



- patient positioning
- geometry match
- delivery uncertainties

we need also **dosimetric** verification of TP on the day of treatment

Parallel execution model in Fred

Extranode
MPI

Intranode
POSIX
Multi-threads

Fred
front-end

Intranode
Multi-GPU
OpenCl

Tracking performance

Benchmark = dose calculation for 150 MeV protons
in liquid water phantom with 2 mm voxel resolution.

	Hardware	primary/s	Patient plan recalculation*
FLUKA/GEANT4	single CPU core	750	16 days
FRED	single CPU core	15000	19 hours
FRED	single GPU card	10 mln	**2,3 min**
FRED	cluster of 144 GPU cards	300 mln	3 s

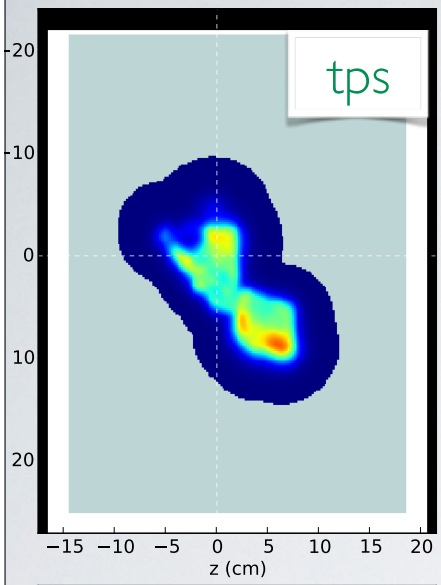
* Patient case: 3-fields Head-Neck plan at 1% of total protons = 700 mln primaries

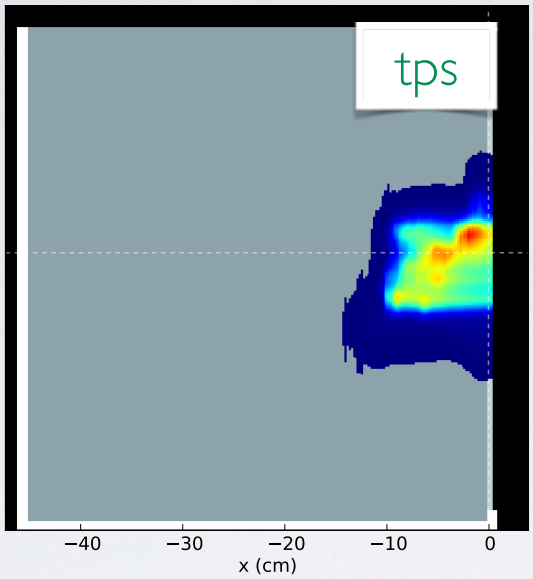
Examples of applications in ongoing collaborations

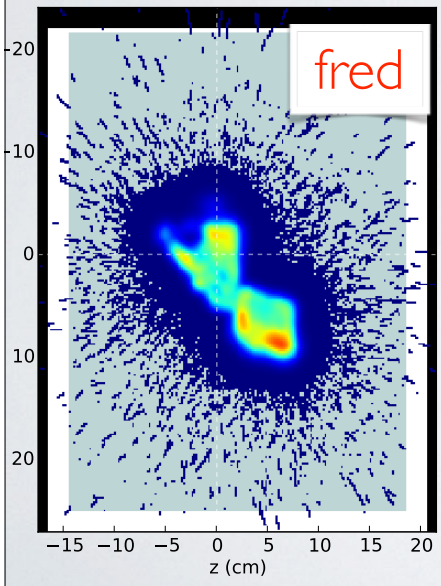
- verification plan and patient plan recalculation (CNAO - Pavia)
- commissioning and RBE models (CCB - Krakow)
- Complex delivery sequence (Maastro)
- Half-Head experiment at CCB
- Carbon fragmentation
- Electromagnetic Fred (plugin development)

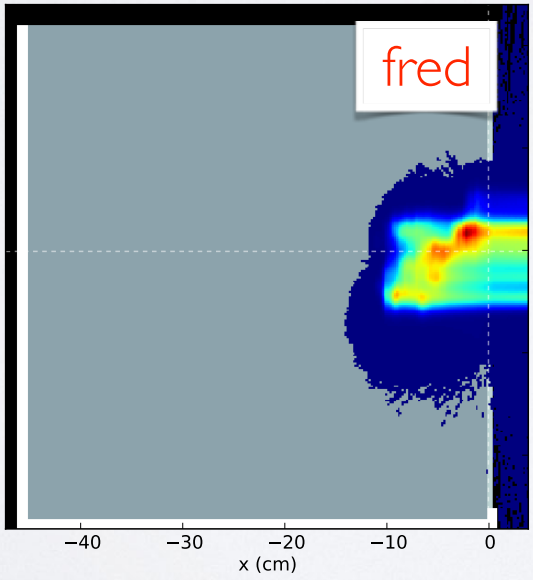
Patient verification plan

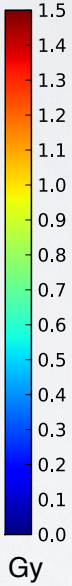
fondazione CNAO
Centro Nazionale di Adroterapia Oncologica

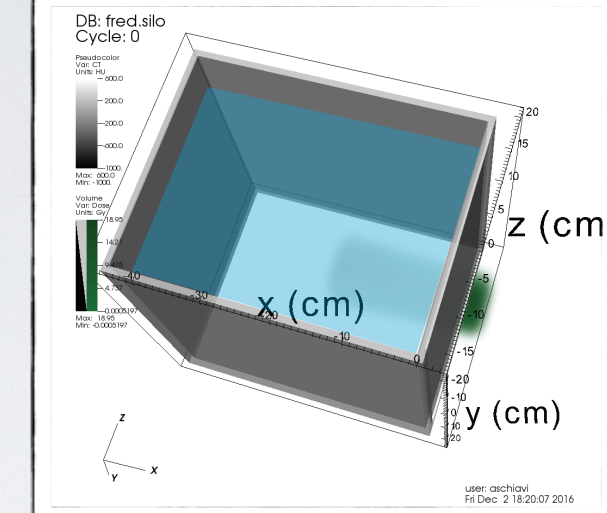












γ-index pass rates

99.6% @ 2mm/2%

96.7% @ 1mm/1%

head-on

side-on

9

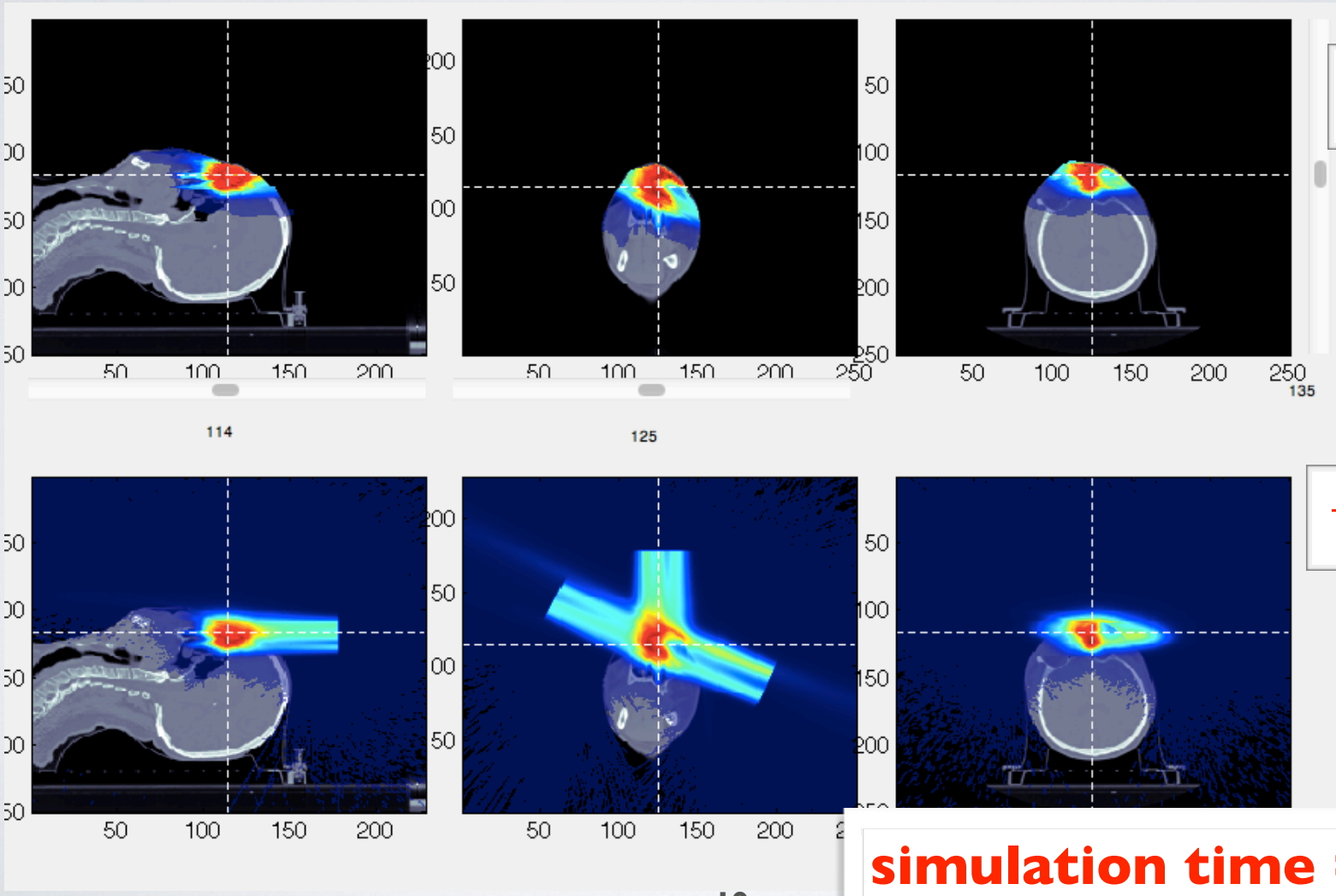
Patient recalculation plan

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica

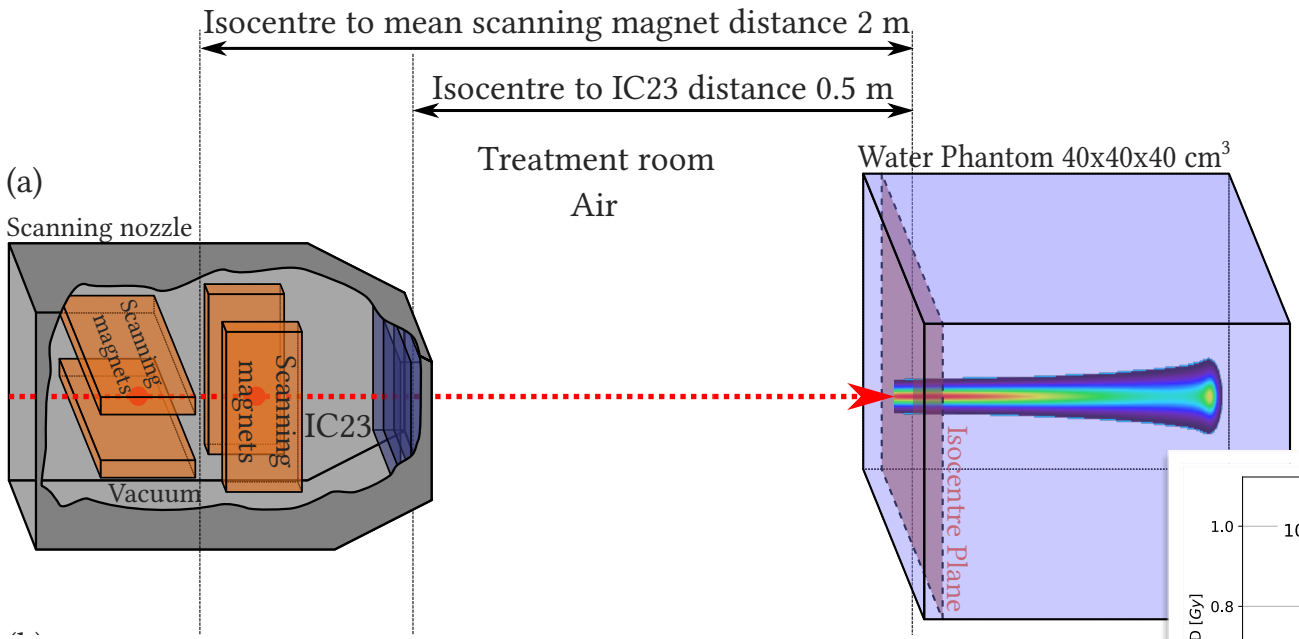
recalculation at 1% = 700 million primary protons

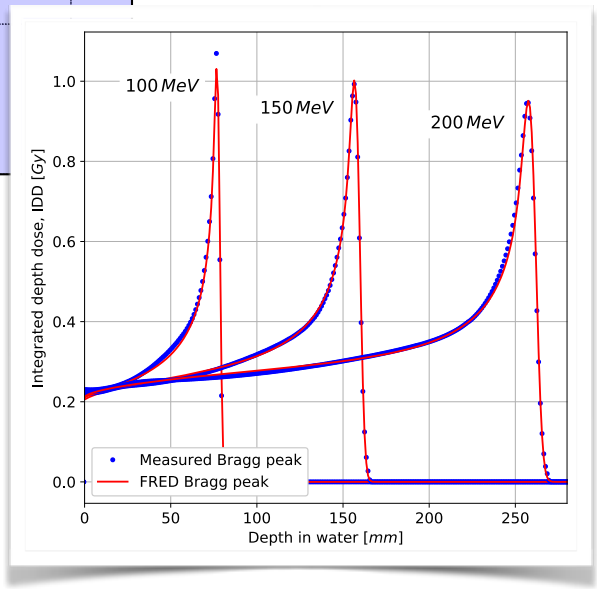
gamma-index 97% @ 2mm/2%

gamma-index 92% @ 1mm/1%



Implementation and validation of the clinical beam model

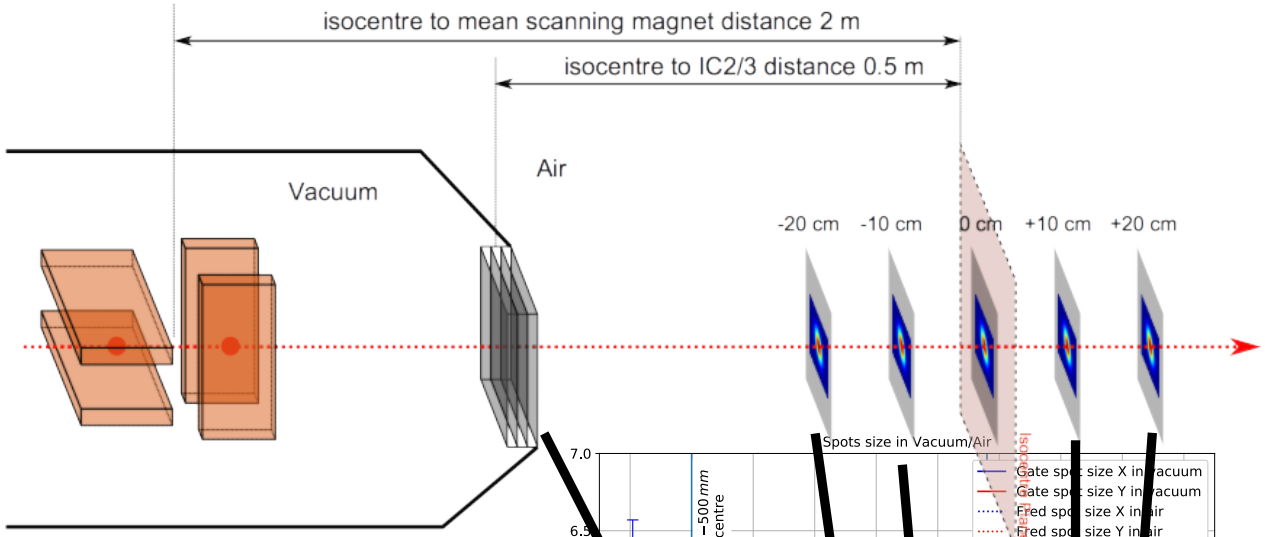


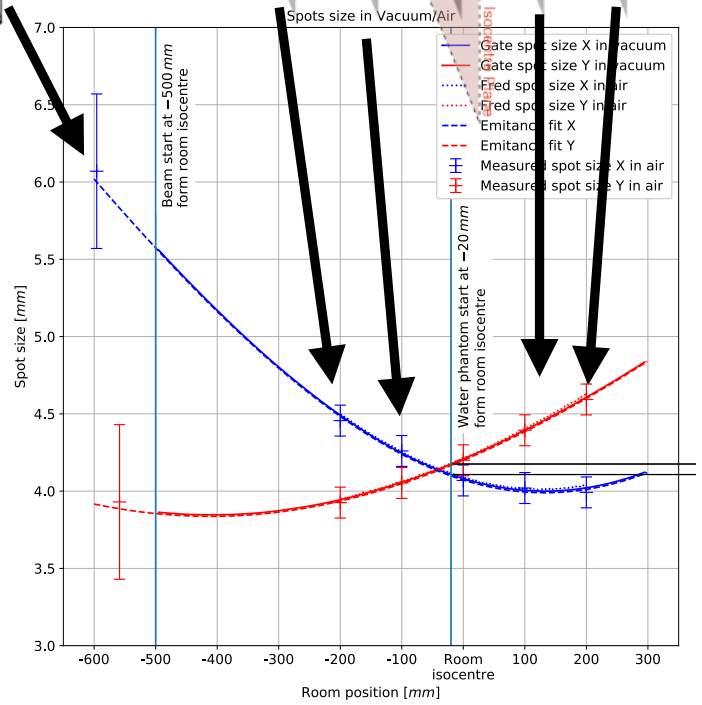


70-230 MeV in 10 MeV steps

Energy & energy spread & dosimetric calibration

Implementation and validation of the clinical beam model





The emittance formalism:

$$\sigma^2_{x/y}(z) = \epsilon_{x/y} \cdot \left(\beta_{x/y} - 2 \cdot \alpha_{x/y} \cdot z + \frac{1+\alpha^2_{x/y}}{\beta_{x/y}} \cdot z^2 \right)$$

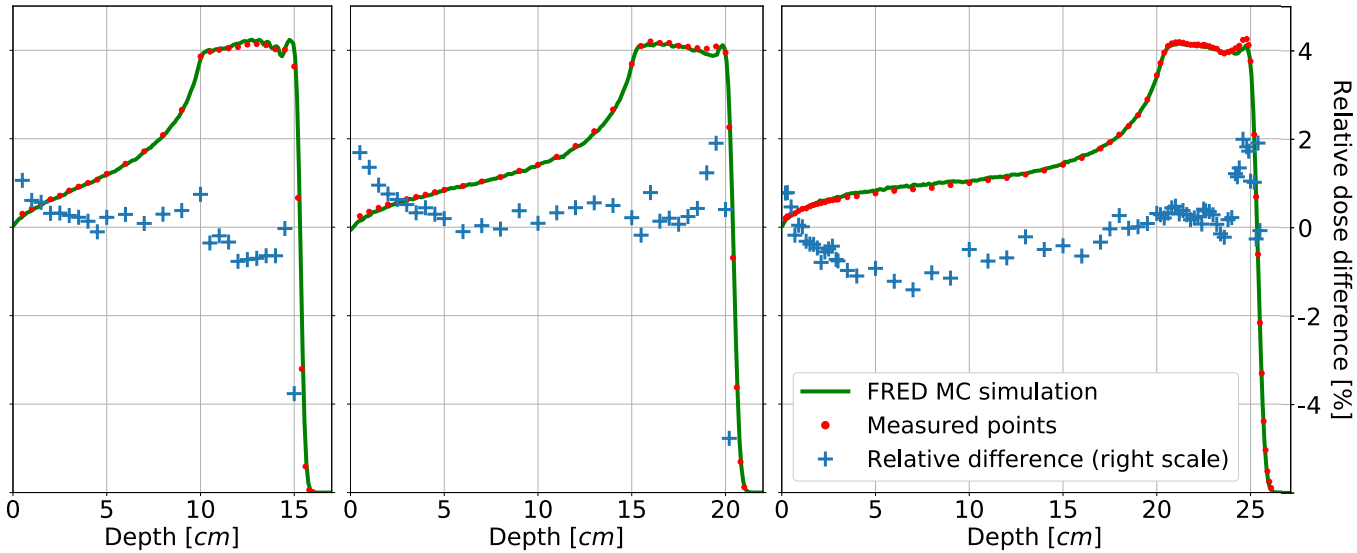
[Twiss et al. 1949]

$\varepsilon_{x/y}$ - emittance
α - de/focusing
β - length over which beam changes its transversal shape

Implementation and **validation** of the clinical beam model

DATA

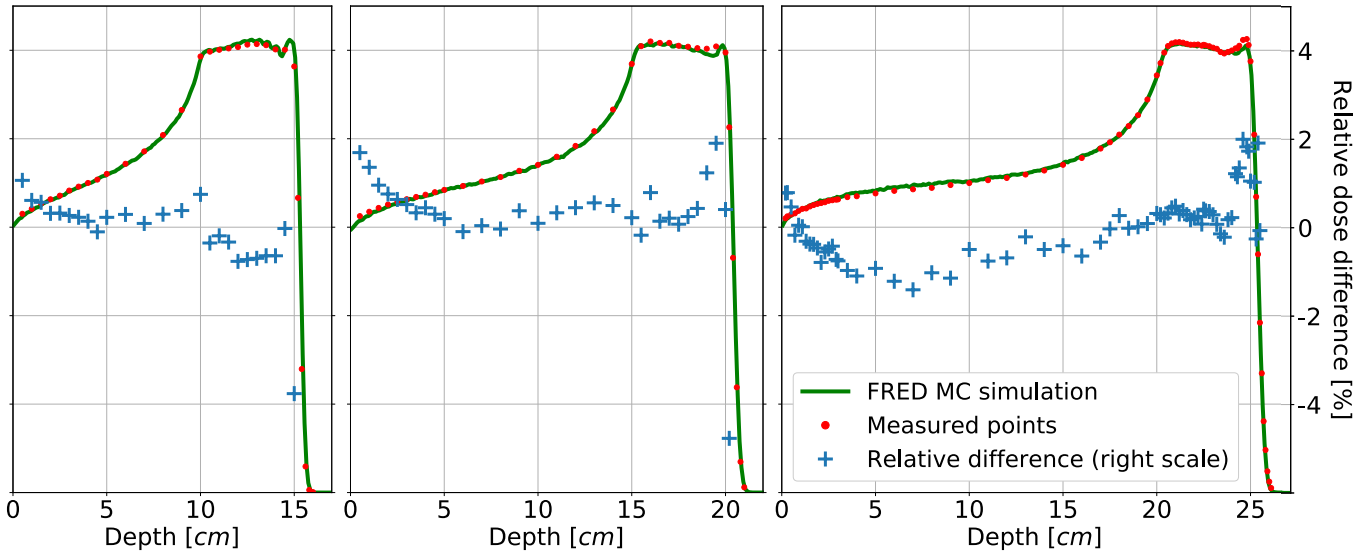
FRED

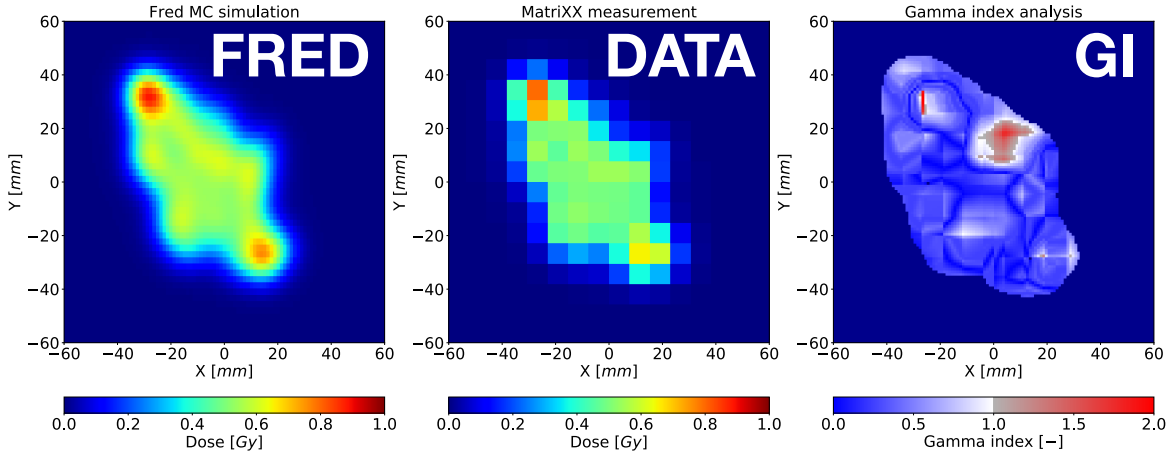


Implementation and **validation** of the clinical beam model

DATA

FRED

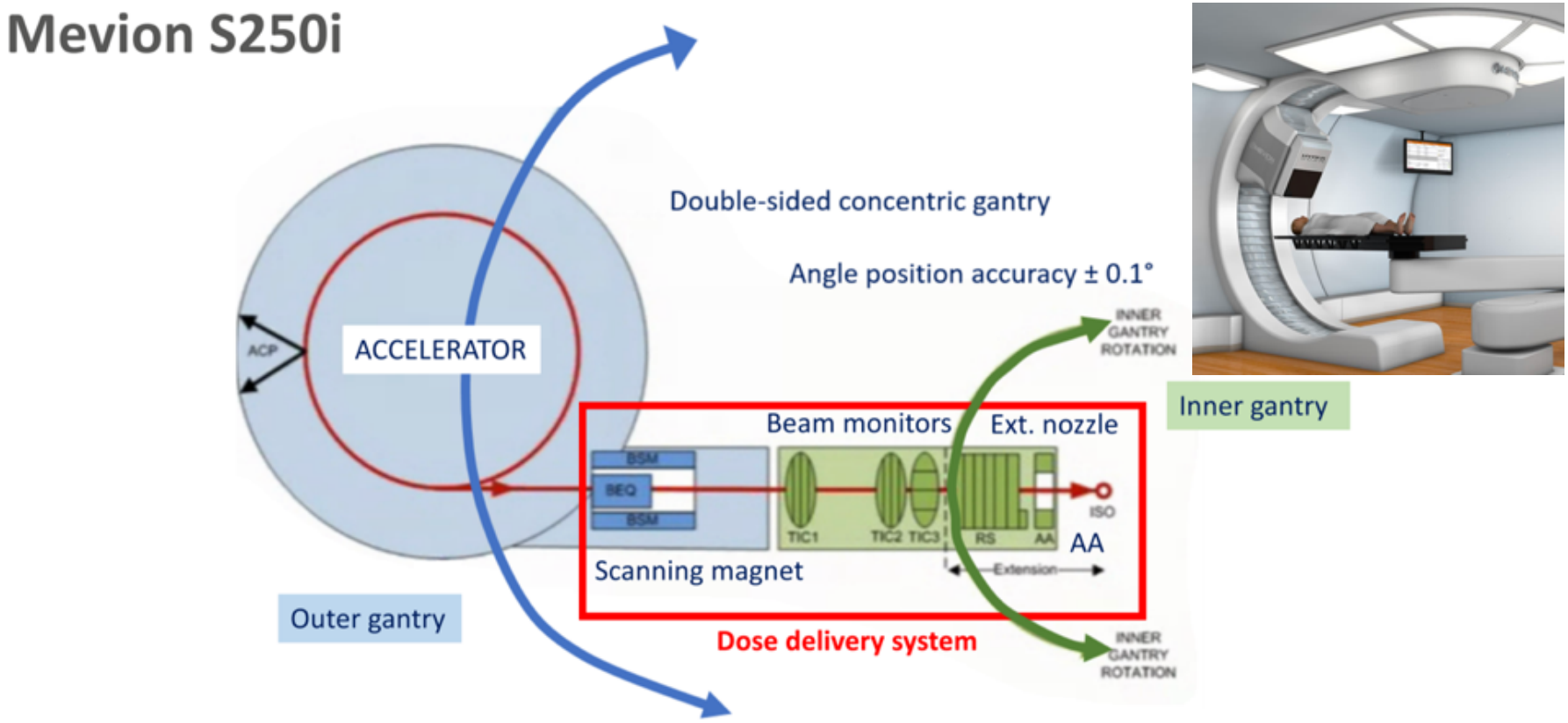




$$\gamma - index = 2mm/3\%$$

182 patient verification fields
GI: 97.9 (3.3)% (1σ)
3'28 (1'41) min (1σ)

Beam model and delivery manager for Maastro



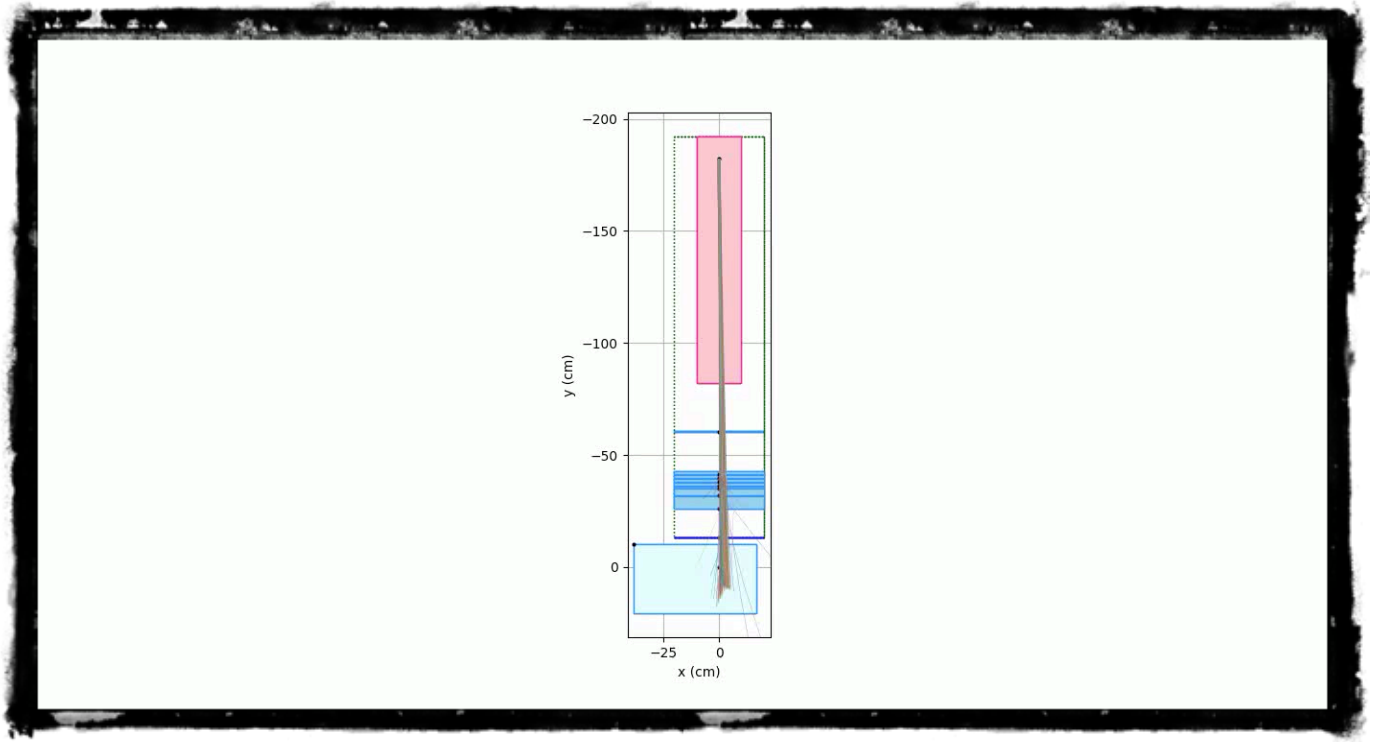
Maastro GROW Maastricht UMC+ Maastricht University

Beam model and delivery manager for Maastro

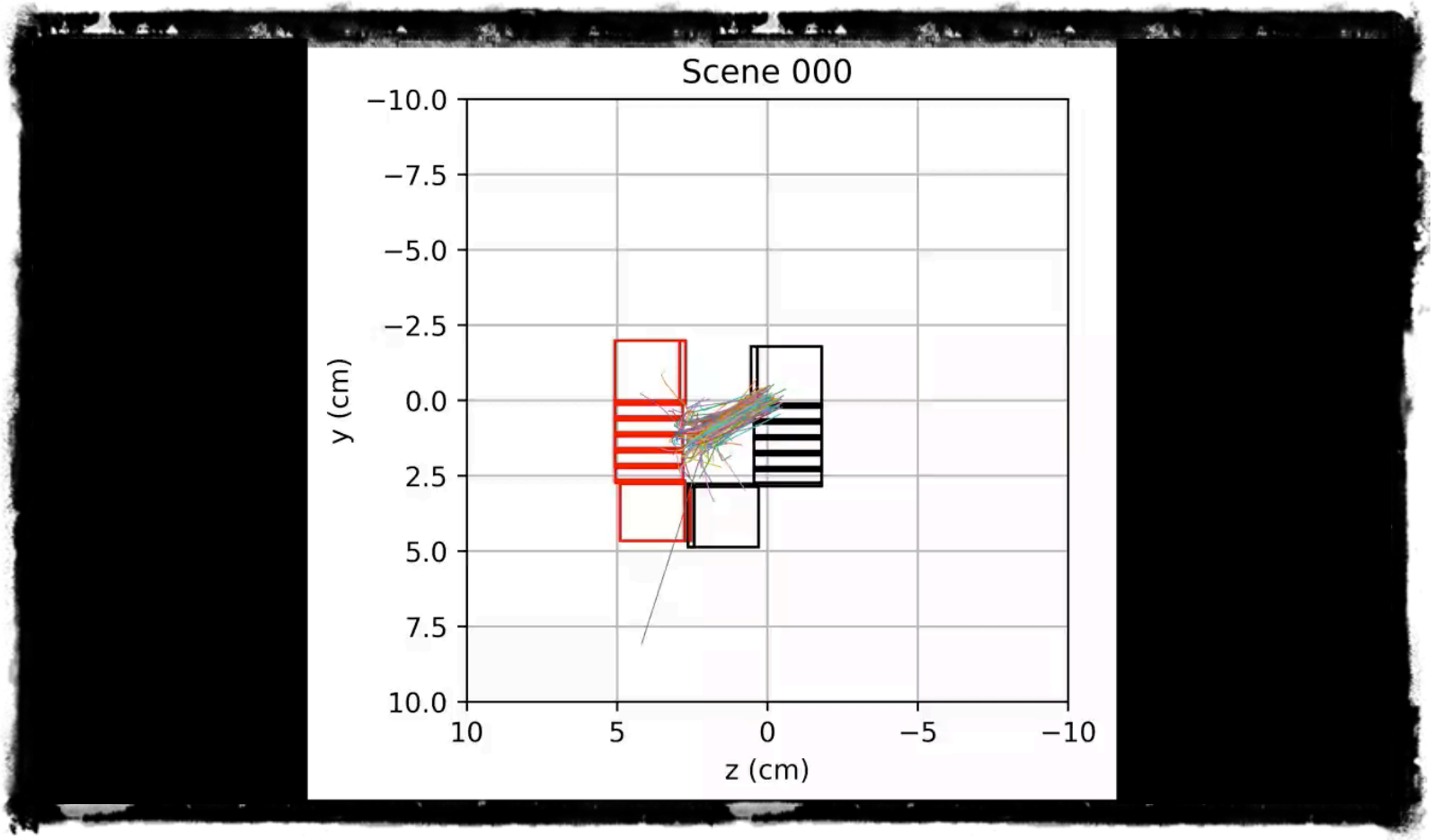
```
# delivery sequence
transform: gantry rotate 37 y self
transform: nozzle shift_by 12.2 z gantry
activate: phantom field_1 gantry
activate: RS1

deactivate: ErgBlades
activate: EB1 EB3 EB12
deliver:  pb 1:34 1

deactivate: ErgBlades
activate: EB1 EB7 EB9
deliver:  pb 35:67 1
…
```



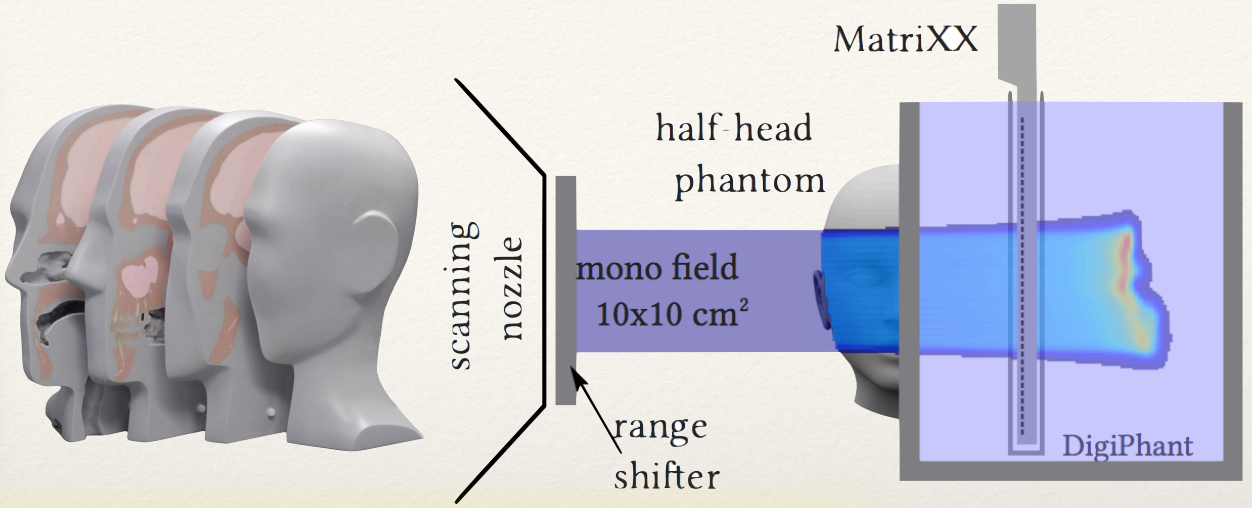
Adaptive Aperture movements from log files

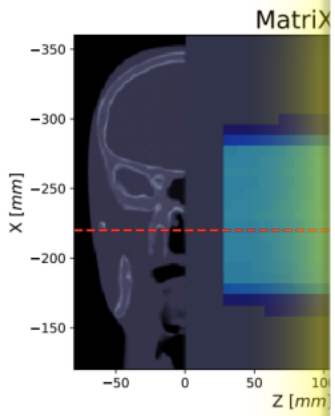


THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

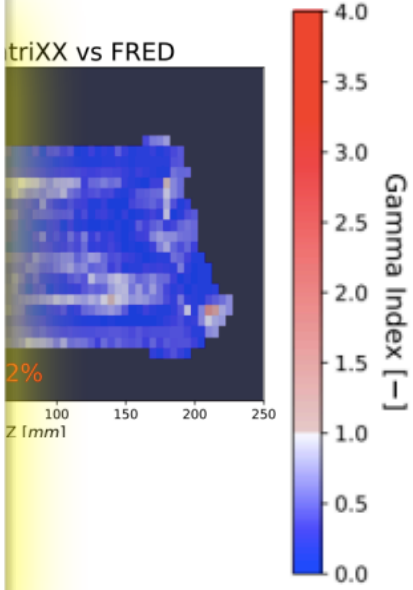
Validation in heterogeneous media

- Heterogeneous head phantom
- MatriXX measurement in water
- Single energy: 100, 150 and 200 MeV
- Range shifter





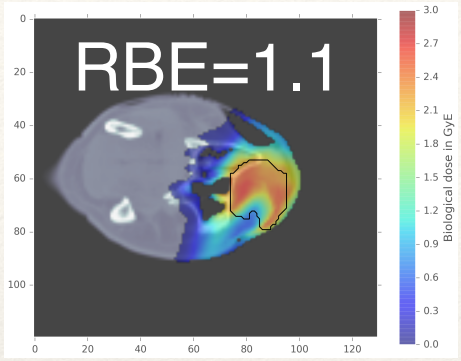
Energy(RS)	GI (2%/2mm/1%)
100	99.97%
100RS	98.93%
150	99.64%
150RS	99.44%
200	98.88%
200RS	99.44%



3D Gan
rate for

Biological modelling

Generic RBE clinic

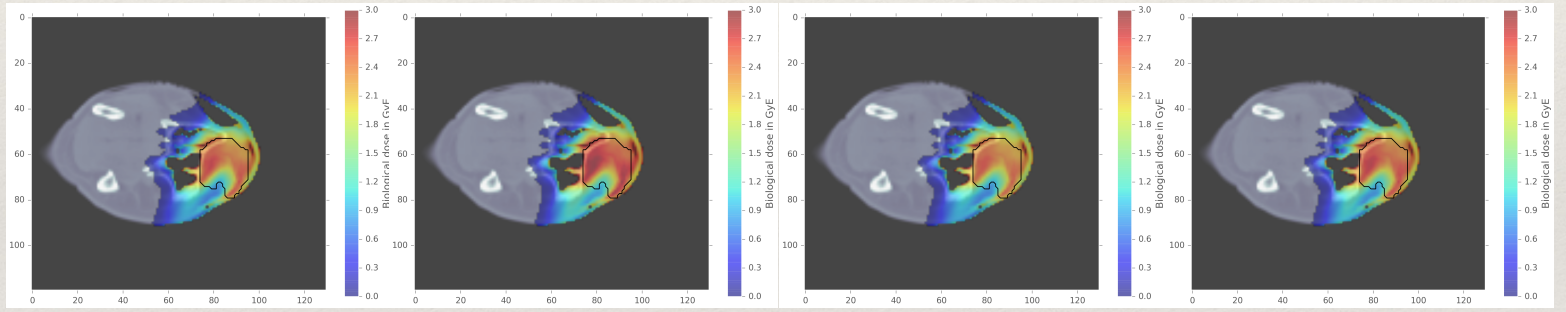


The user can chose several RBE models at once to get a comparative BioDose report

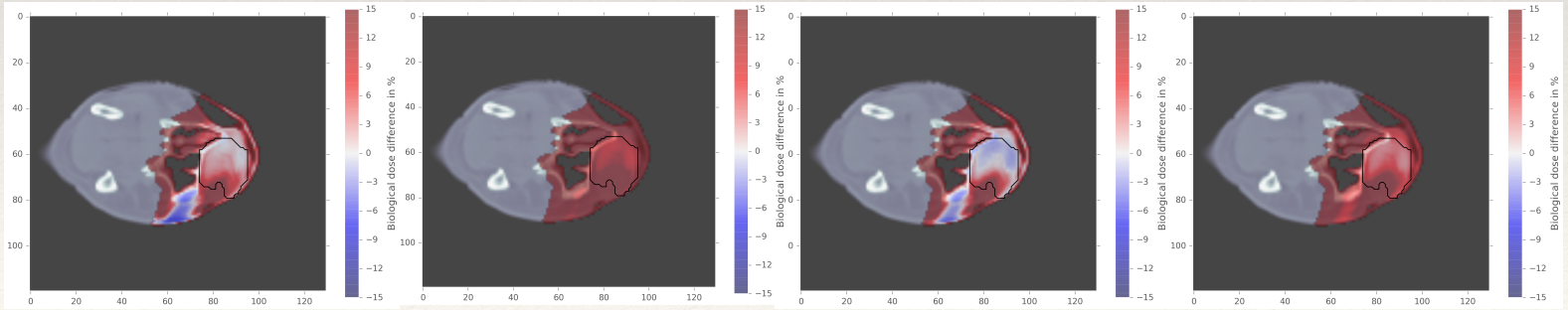
Variable RBE models:
Wedenberg (Wedenberg et al. 2013)
Wilkens (Wilkens and Oelfke 2004)
Chen (Chen and Ahmad 2012)
Carabe (Carabe at al. 2012)
McNamara (McNamara et al. 2015)

Variable RBE

Carabe | Chen | Wedenberg | Wilkens



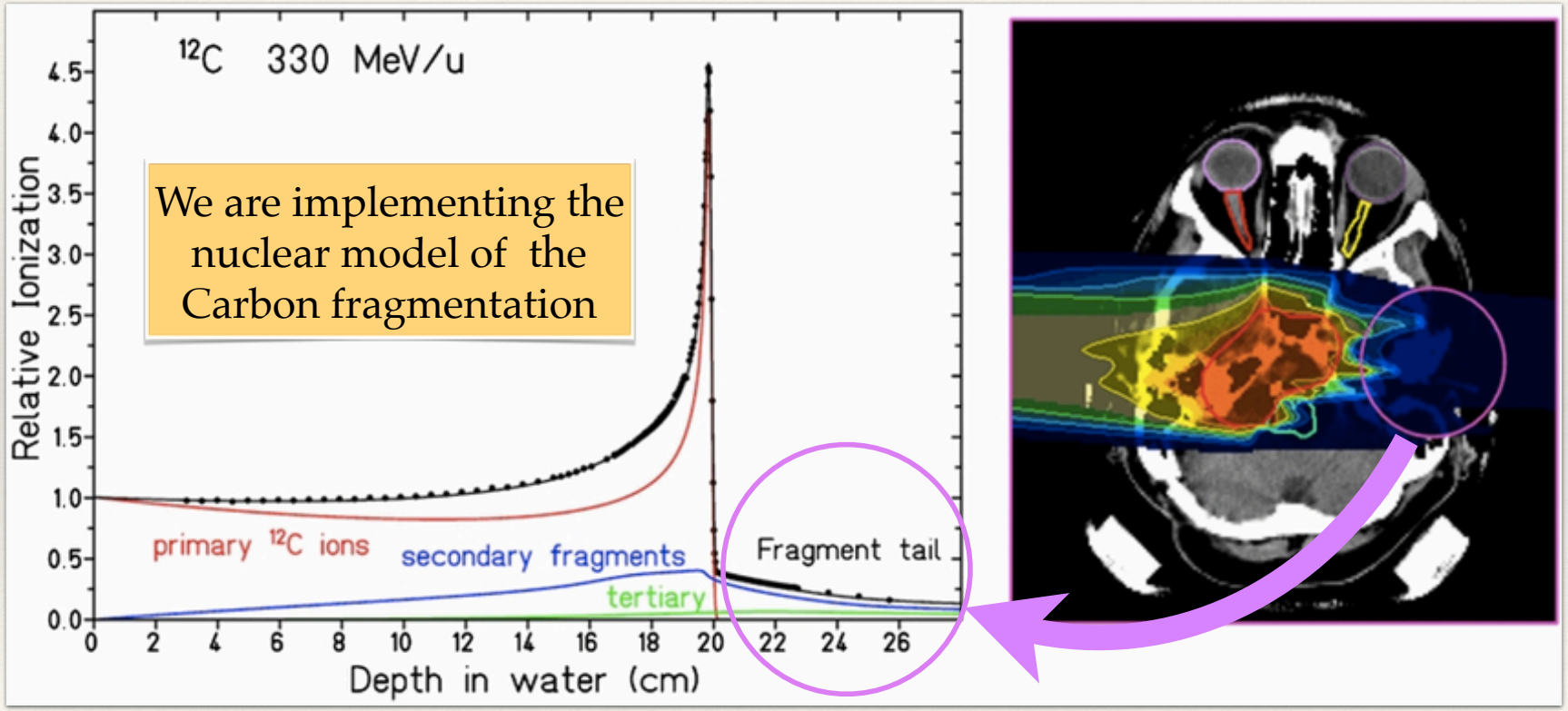
Biological dose in Gy



Biological dose difference in %

Tumor Treatment with Light Ion Beams

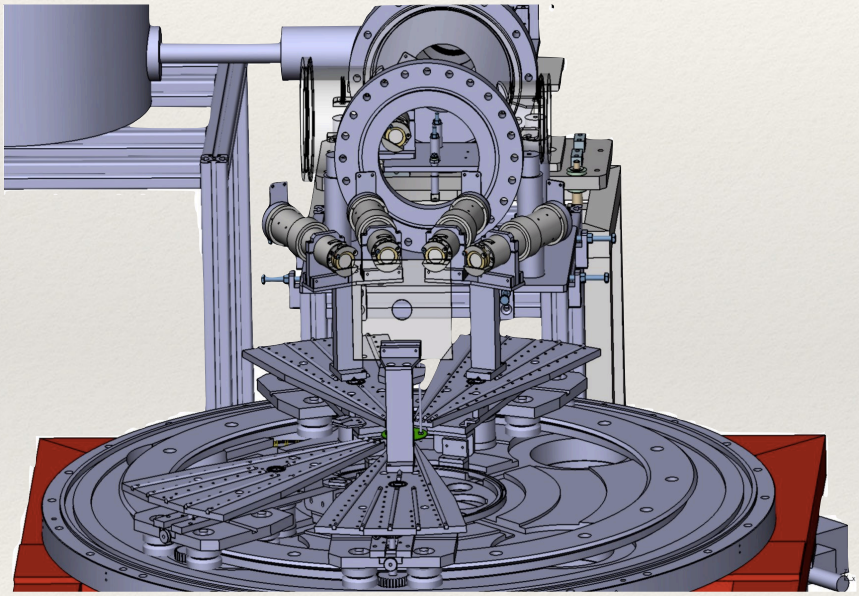
The simulation of light ion nuclear fragmentation, presently not included in the code, gives a significant contribution to the dose deposited inside the patient in the distal region.

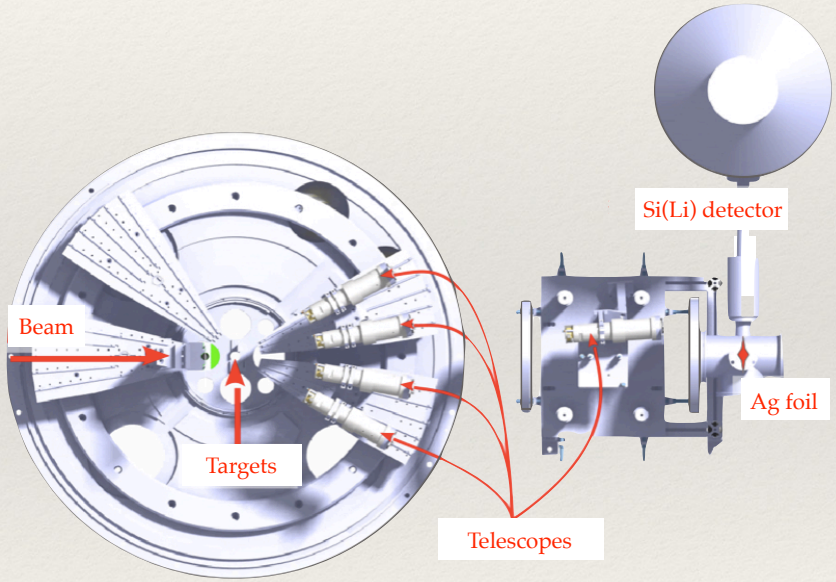


Ganil Experiment

Development of the model using data taken during experiments to study the fragmentation of ^{12}C beams on thin targets at GANIL (laboratory of CAEN, France, 2011-2017).

Data consist on: **energy and angular cross-section** distributions on H, C, O, Al, and Ti with beams of ^{12}C with energies of 50 and 95 MeV/n with a detection angle [-43°,+43°]



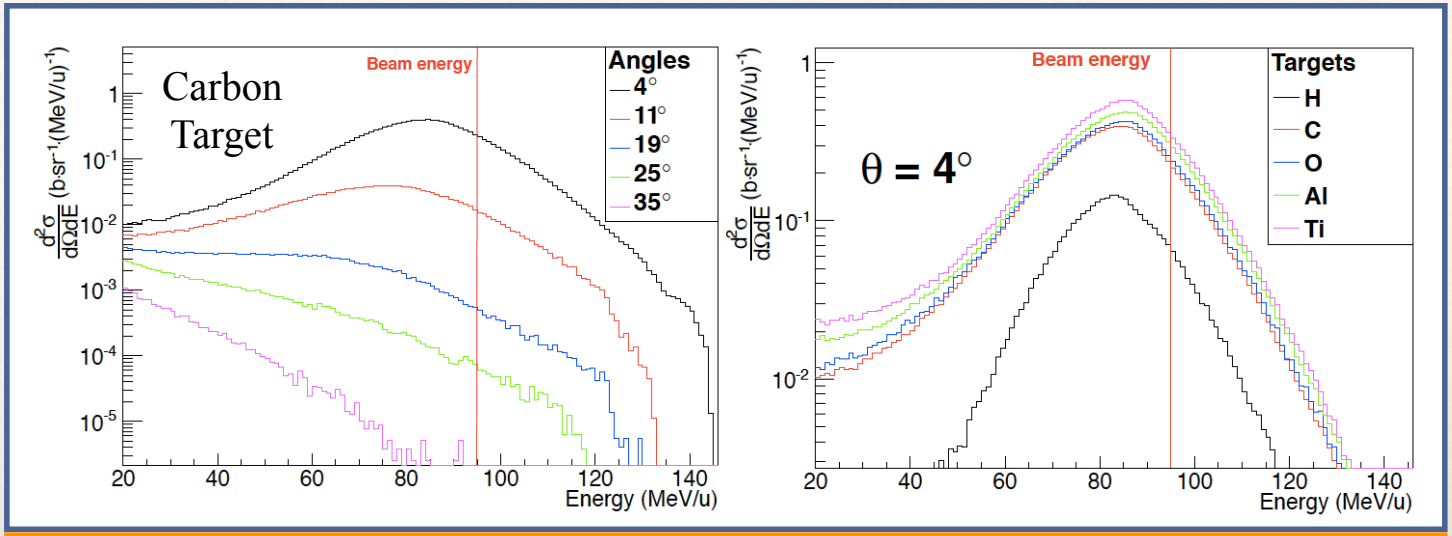


J. Dudouet, et al, C, PHYSICAL REVIEW American Physical Society, 2013

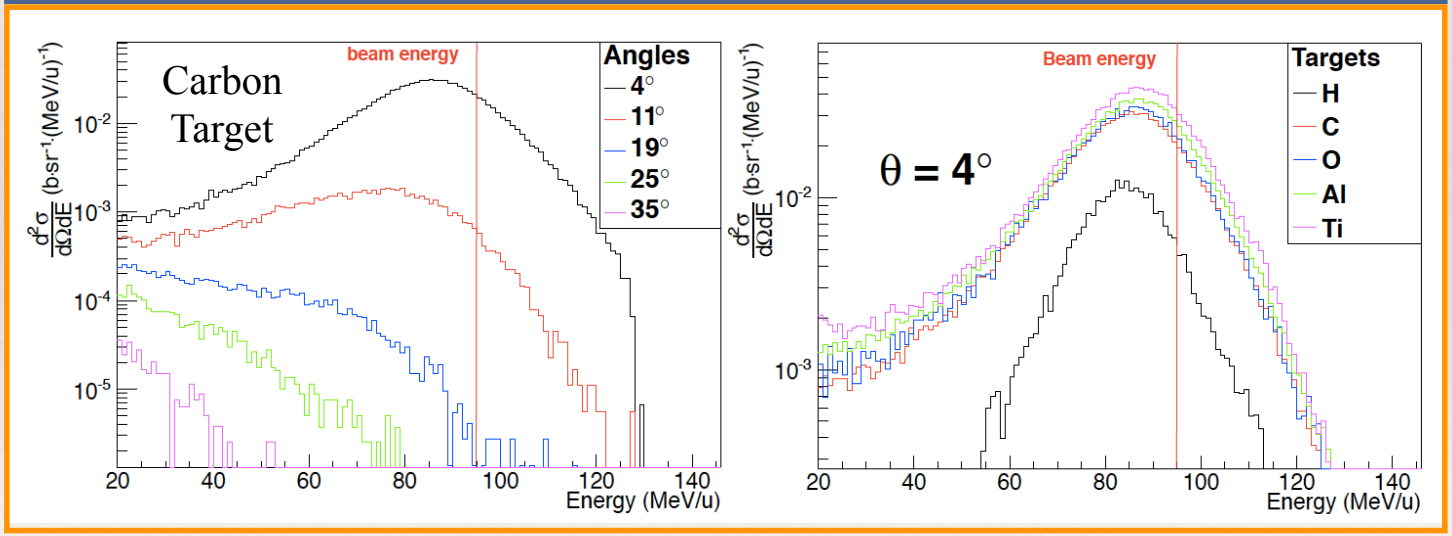
C. Divay et al, PHYSICAL REVIEW C 95, 044602 (2017)

Implementation of ion fragmentation

^{4}He energy distribution
Beam:
^{12}C [95MeV/u]

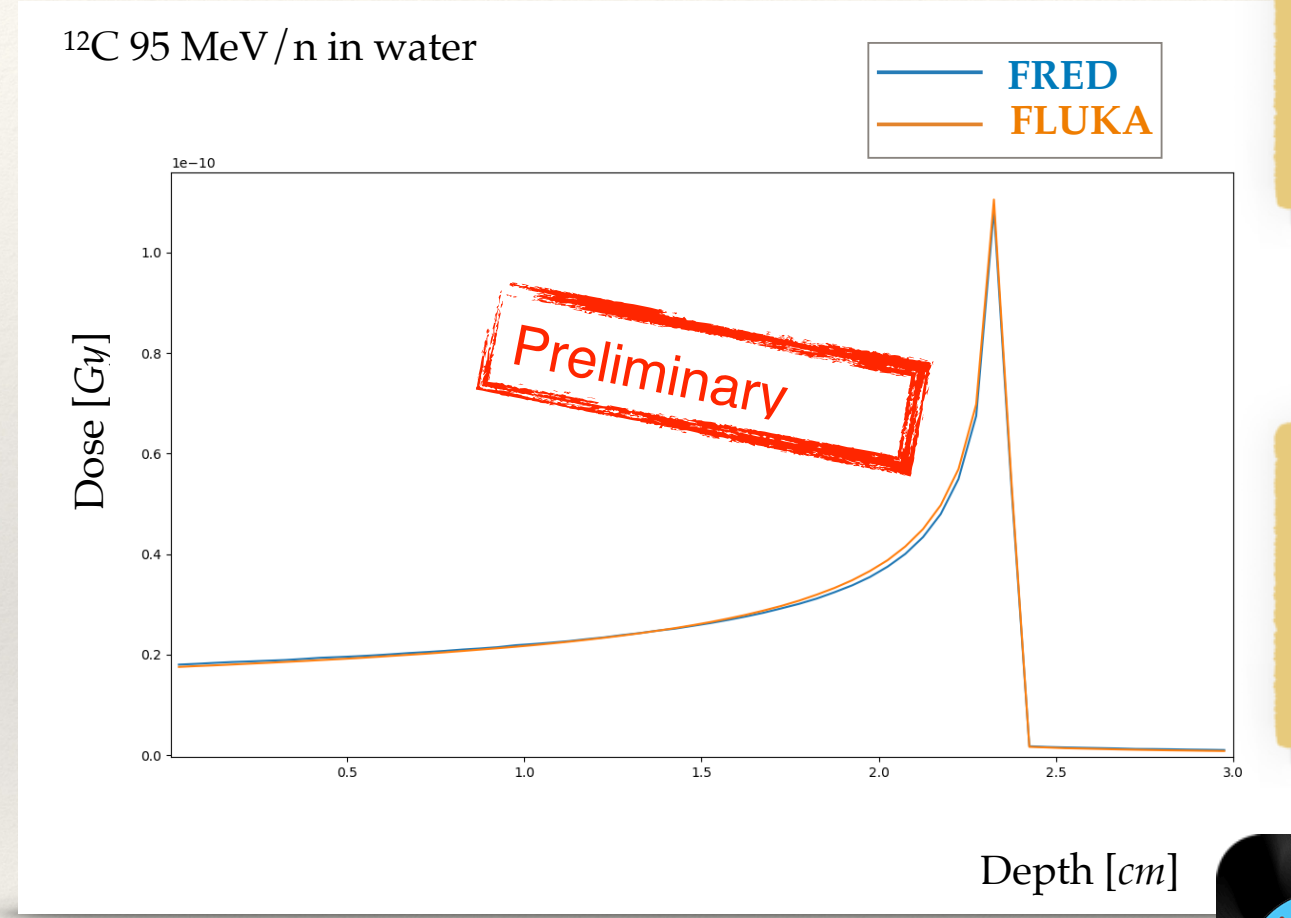


^{6}Li energy distribution
Beam:
^{12}C [95MeV/u]



J. Dudouet, et al, C, PHYSICAL REVIEW American Physical Society, 2013

Waiting for new data

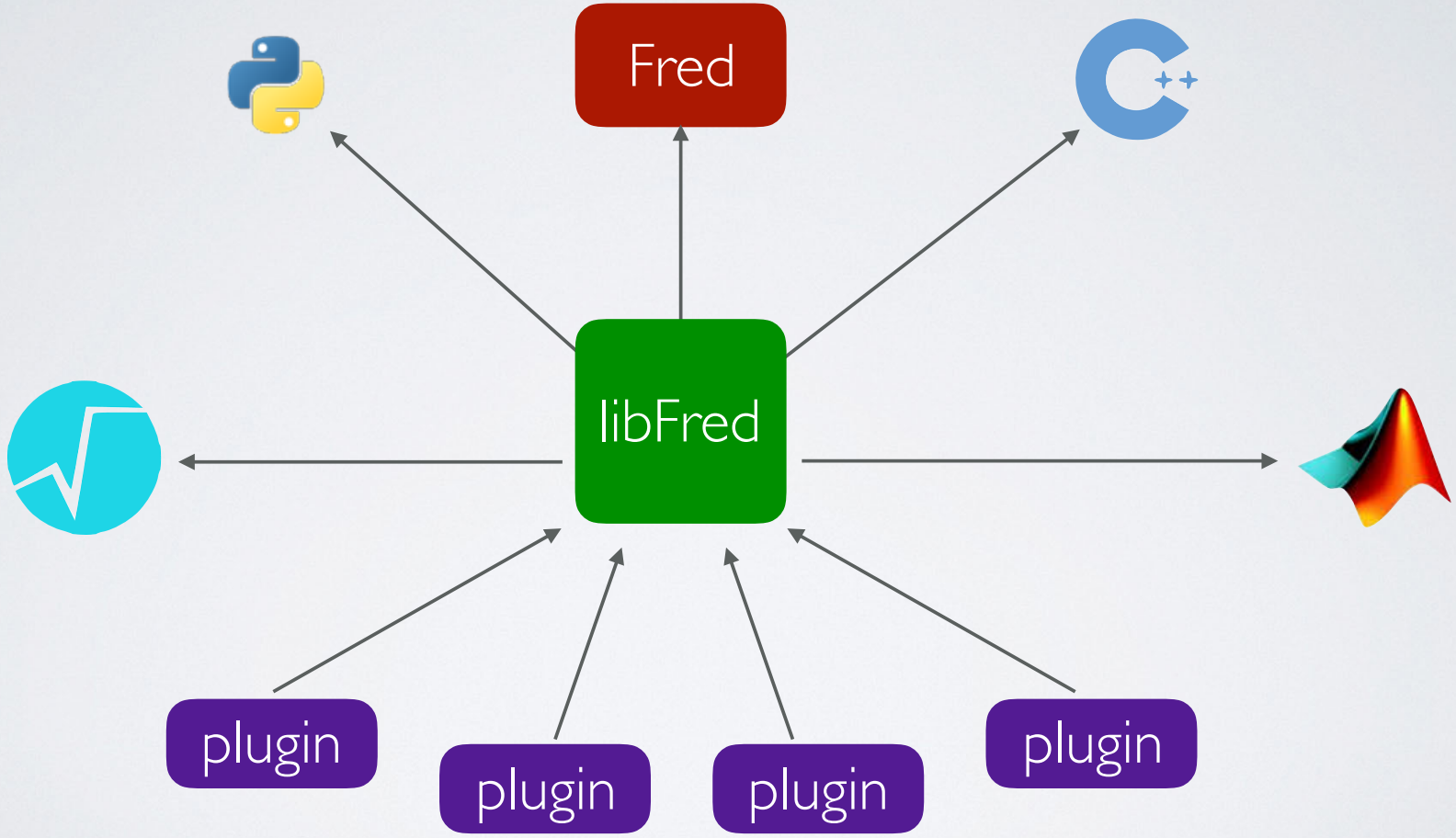


We are presently tuning fragmentation on full-MC codes

New data are expected from a dedicated expt on nuclear fragmentation

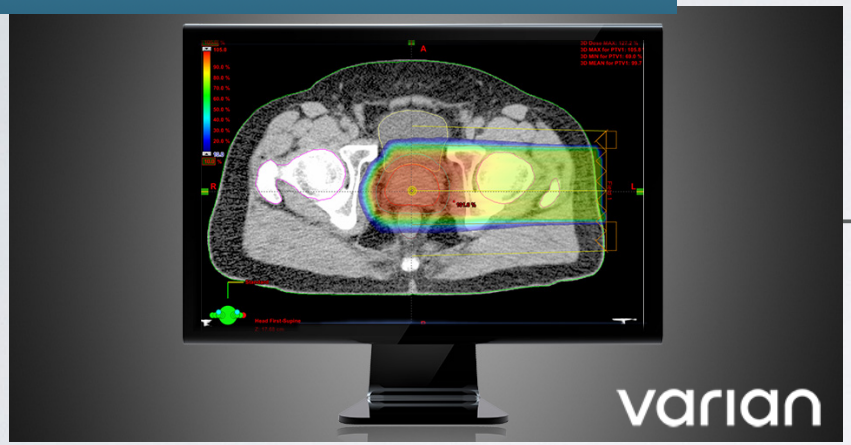
FOOT (FragmentatiOn Of Target)

LIBRARY



EMBEDDING FRED

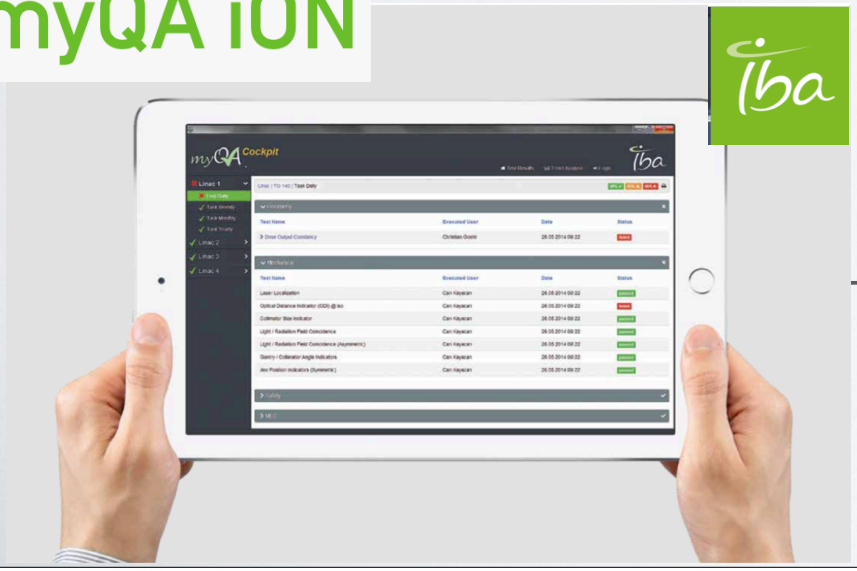
ECLIPSE FOR PROTON



libFred

CCB

myQA iON



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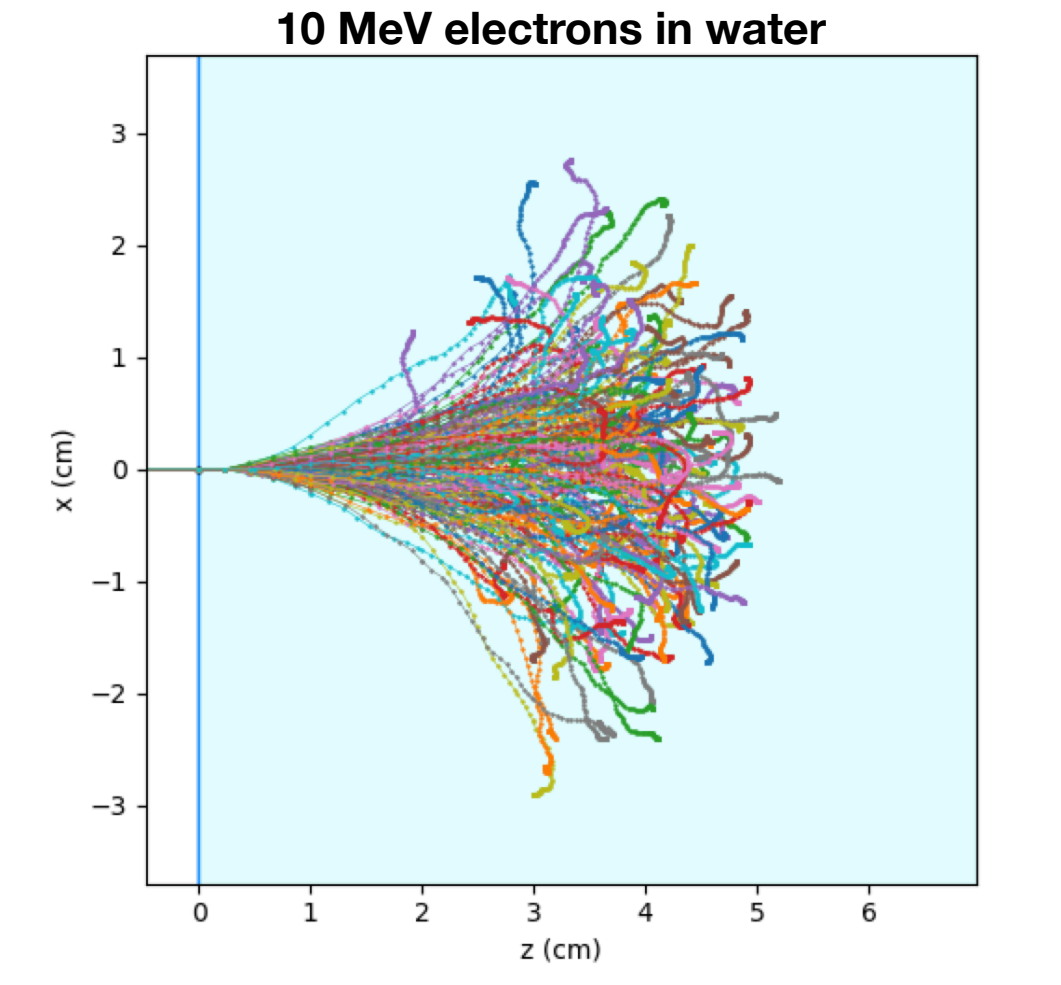
Maastro

Plugin interface for development



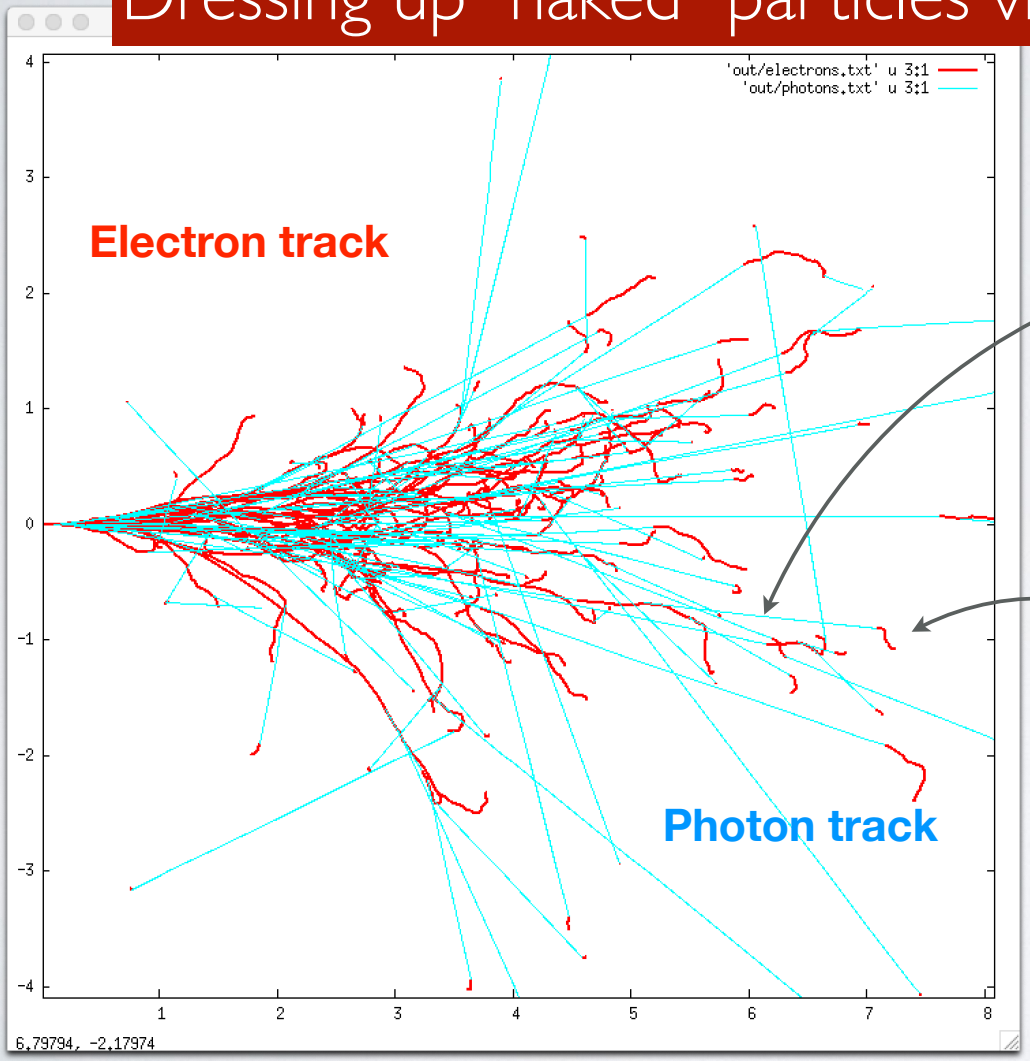
Very simple model for electrons

Energy loss using NIST ESTAR stopping power

Multiple Coulomb Scattering using single Gaussian approx

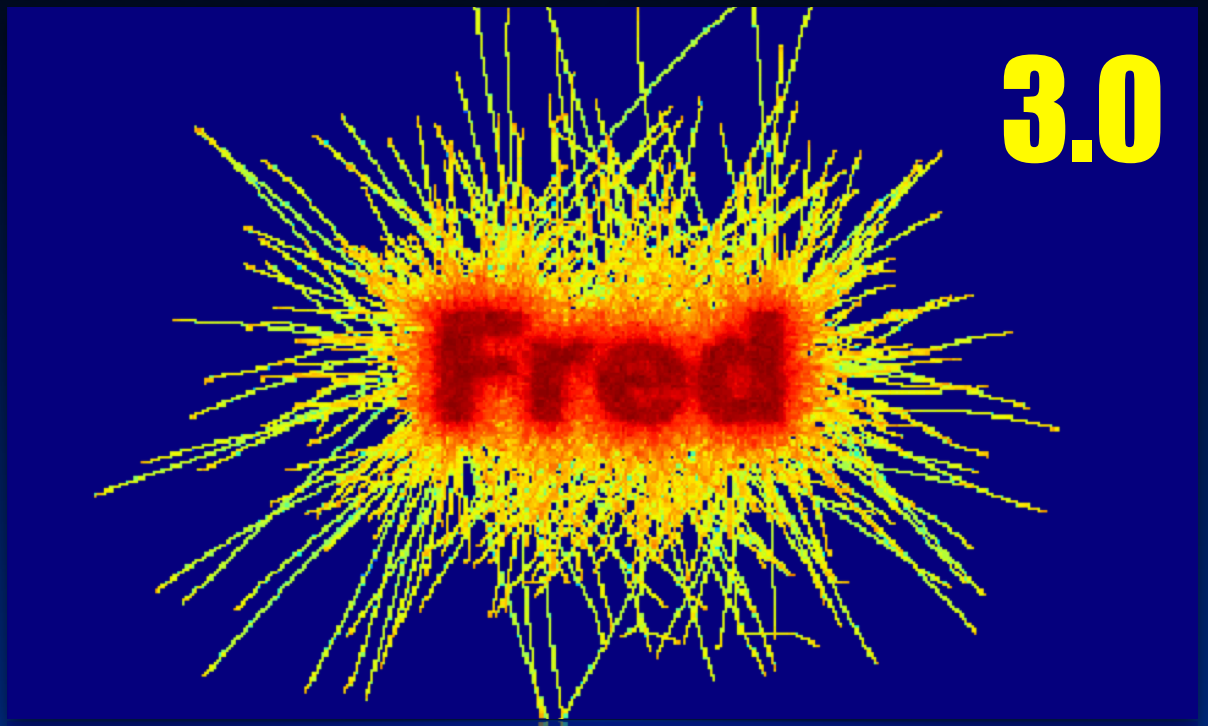
Plugin interface for development

Dressing up "naked" particles via plugin interface



Primary electron generates photon via Bremsstrahlung

Photon kicks out an atomic electron via photoelectric effect



COMING SOON!