The FLUKA Monte Carlo code at CNAO

An overview on its applications in Medical Physics

Giuseppe Magro

Medical Physics Unit – CNAO

XV Seminar on Software for Nuclear, Subnuclear and Applied Physics

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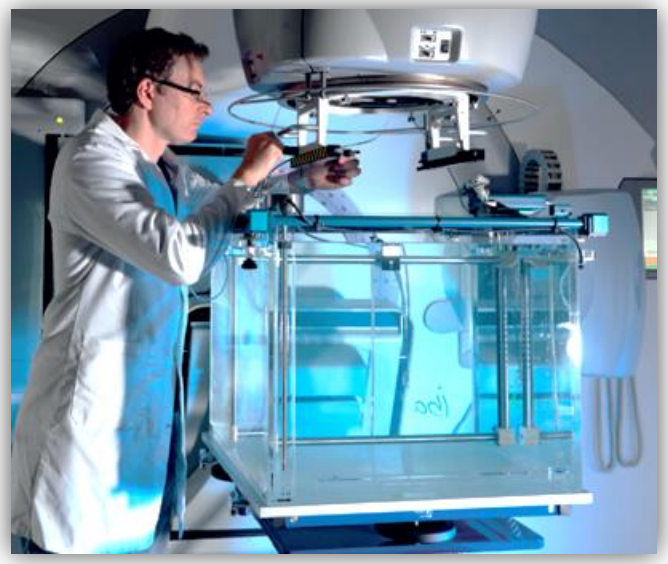
fondazione CNAO
Centro Nazionale di Adroterapia Oncologica

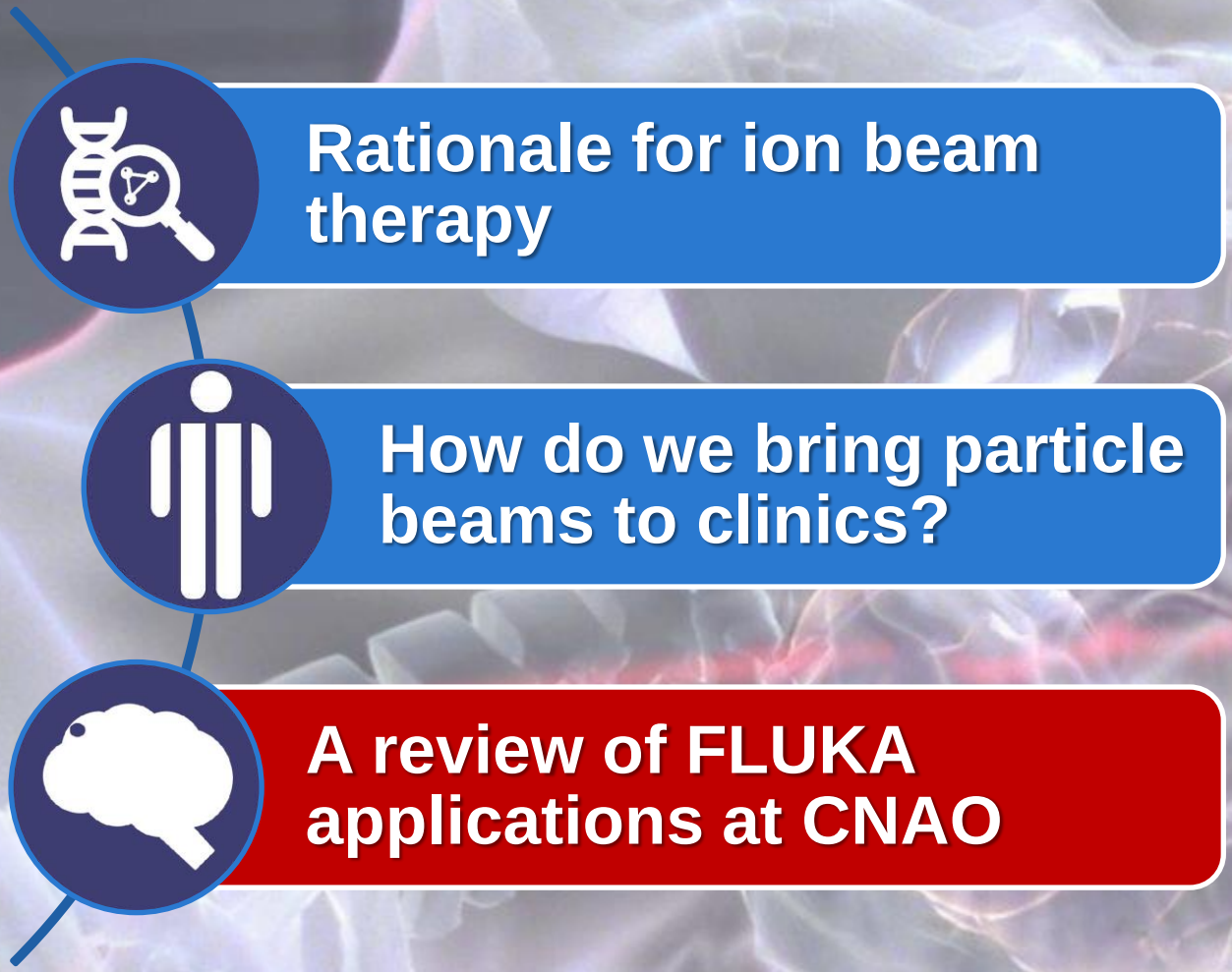
… on behalf of the CNAO Medical Physics Unit

- ✓ Mario Ciocca (Head)
- ✓ Alfredo Mirandola
- ✓ Silvia Molinelli
- ✓ Edoardo Mastella
- ✓ Stefania Russo
- ✓ Alessandro Vai
- ✓ Davide Maestri

- ✓ Andrea Mairani
- ✓ Giuseppe Magro (*)



Outline



- Rationale for ion beam therapy
- How do we bring particle beams to clinics?
- A review of FLUKA applications at CNAO

Rationale for ion beam therapy

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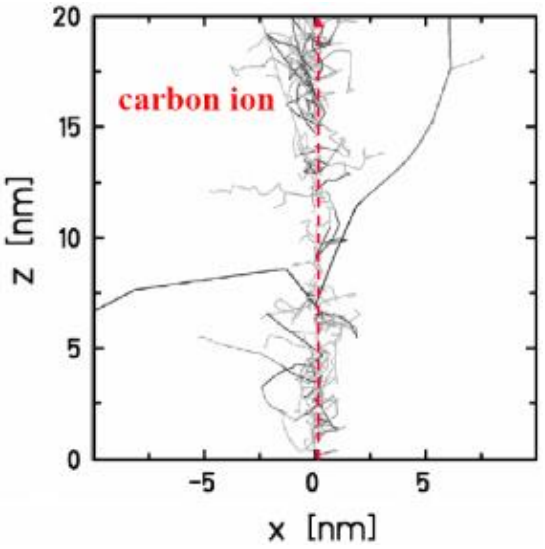
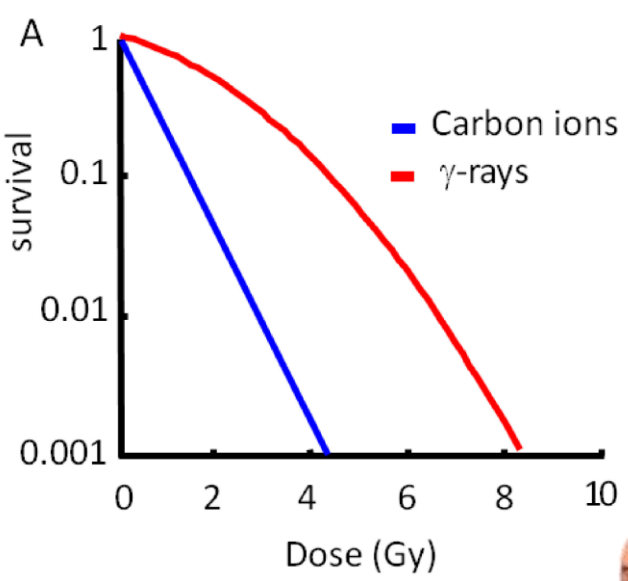
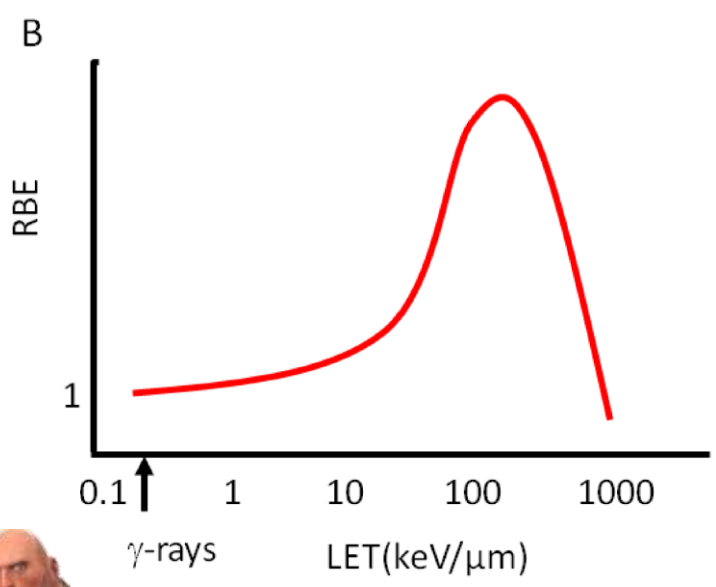
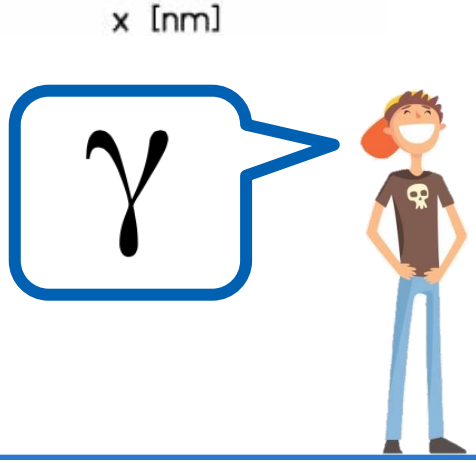
Rationale for ion beam therapy

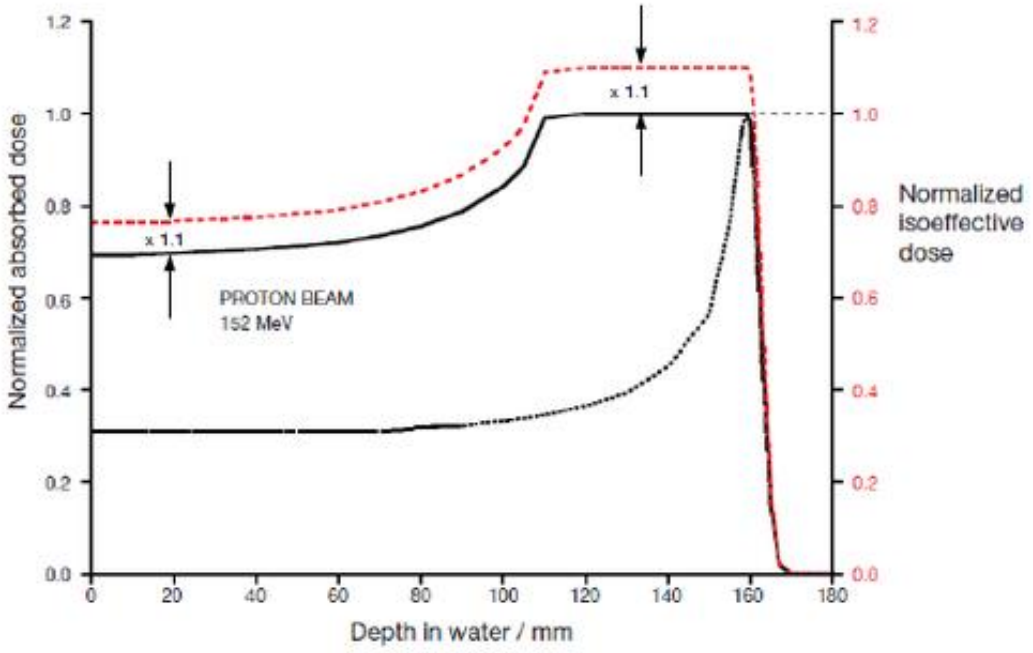


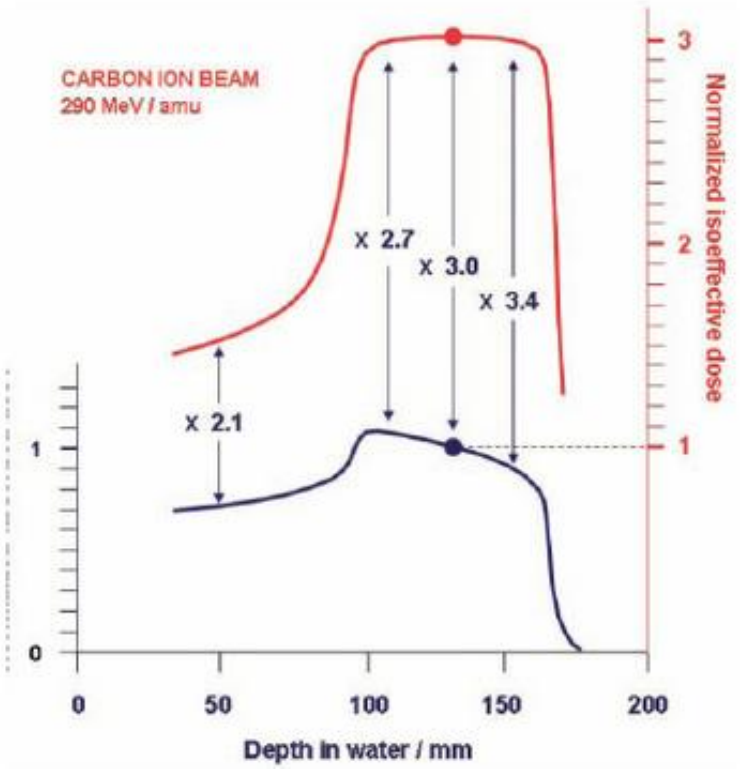




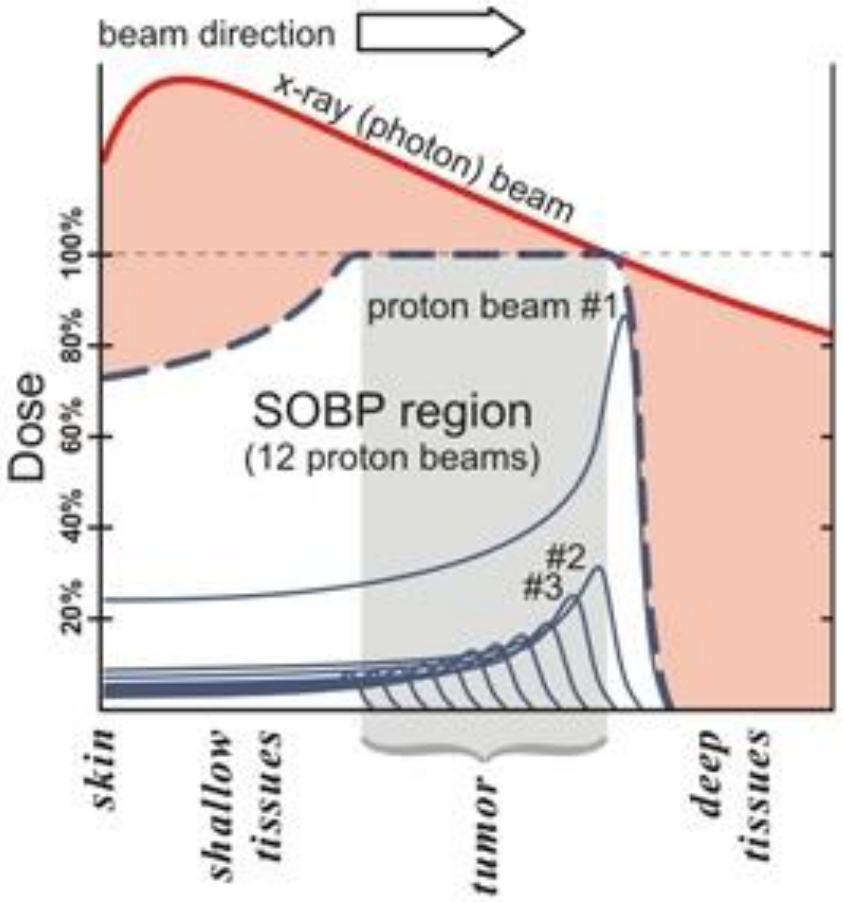


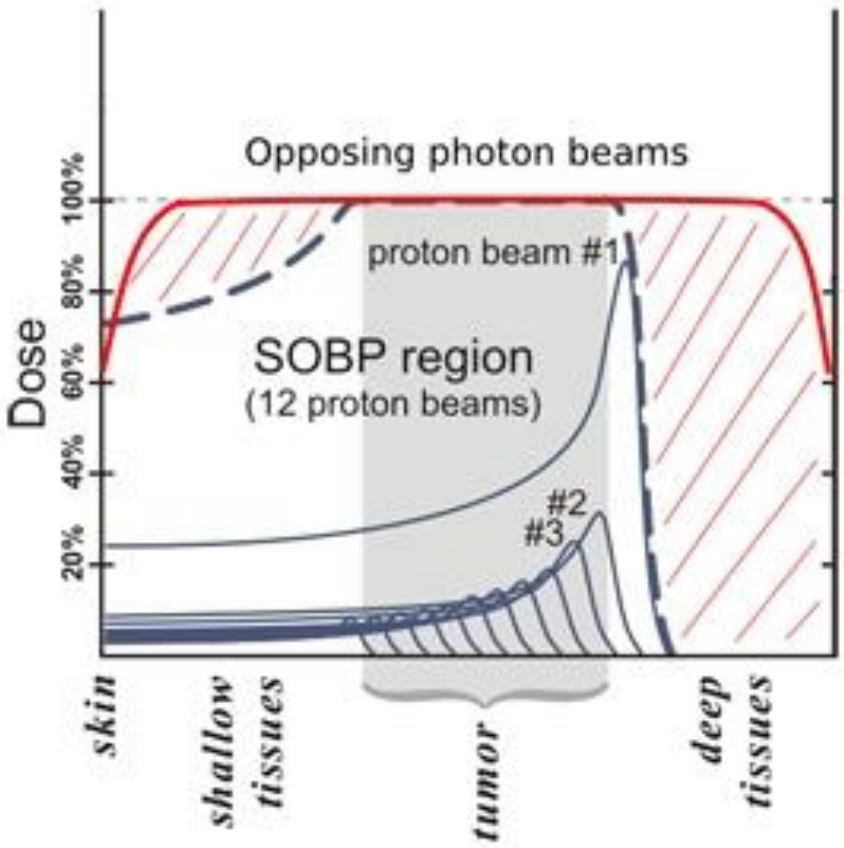
Rationale for ion beam therapy



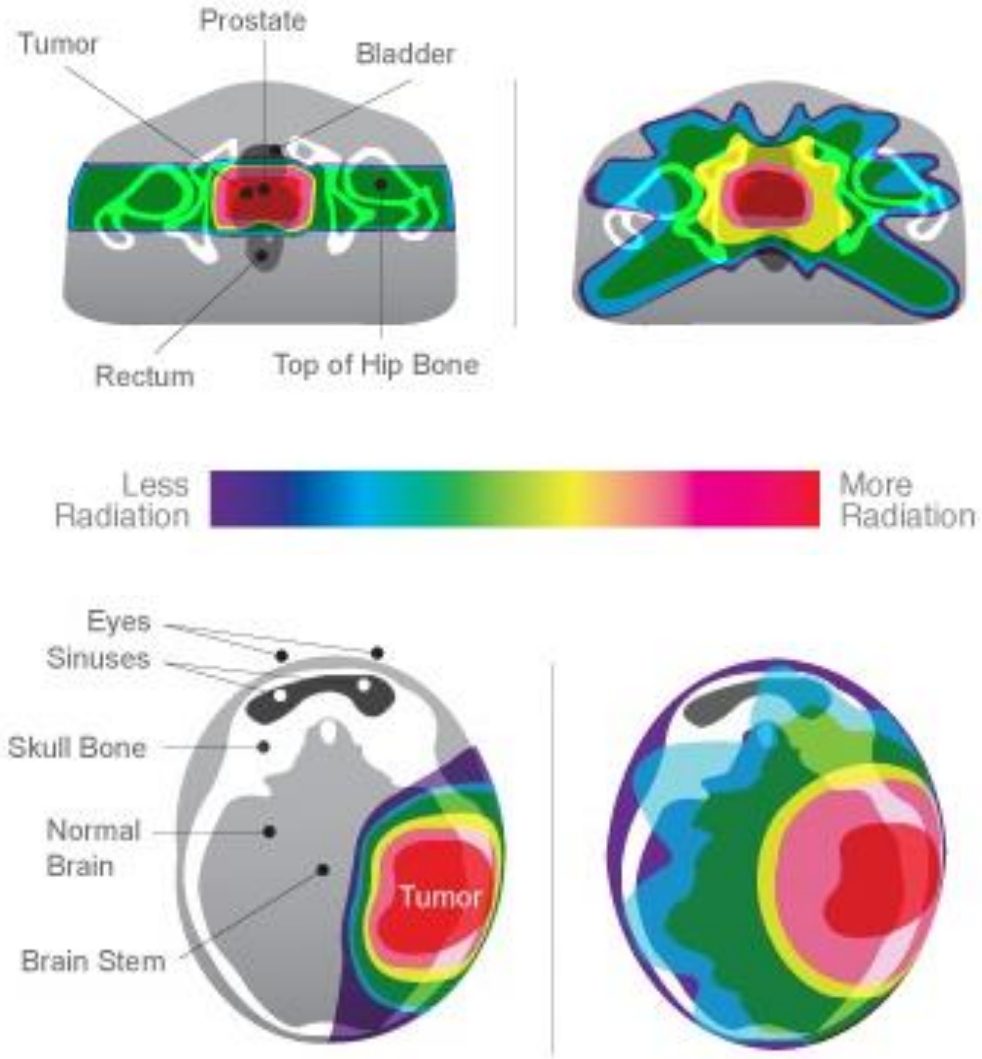


Rationale for ion beam therapy

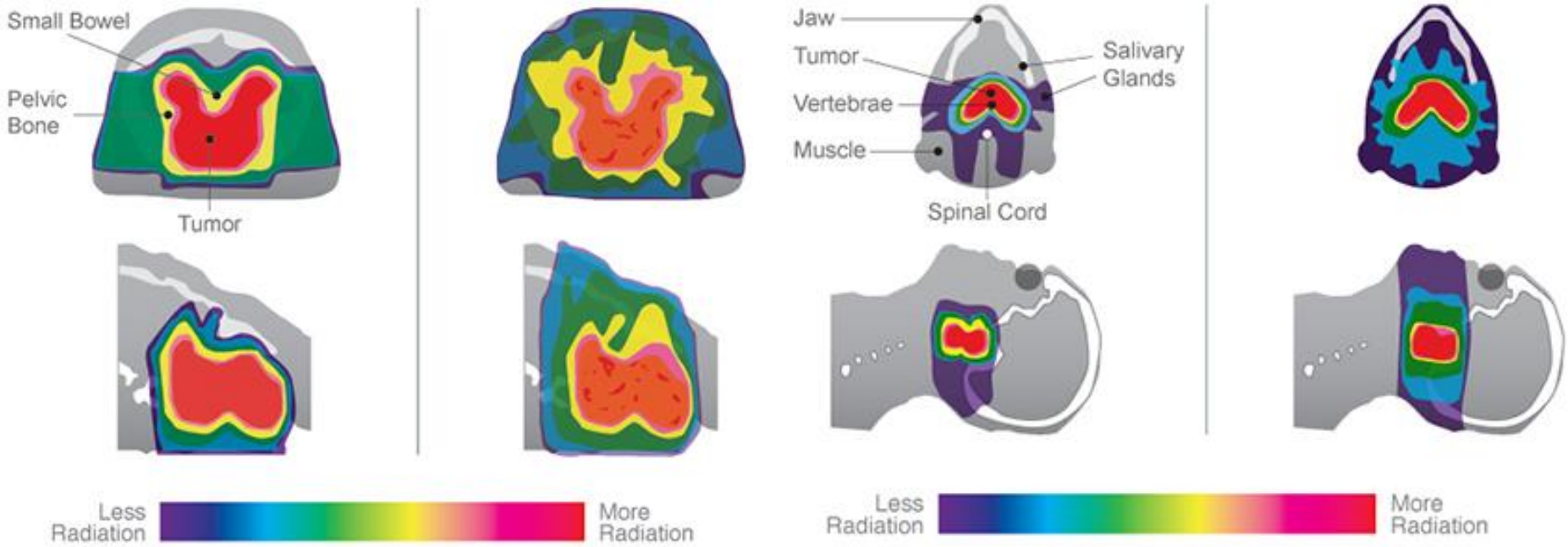


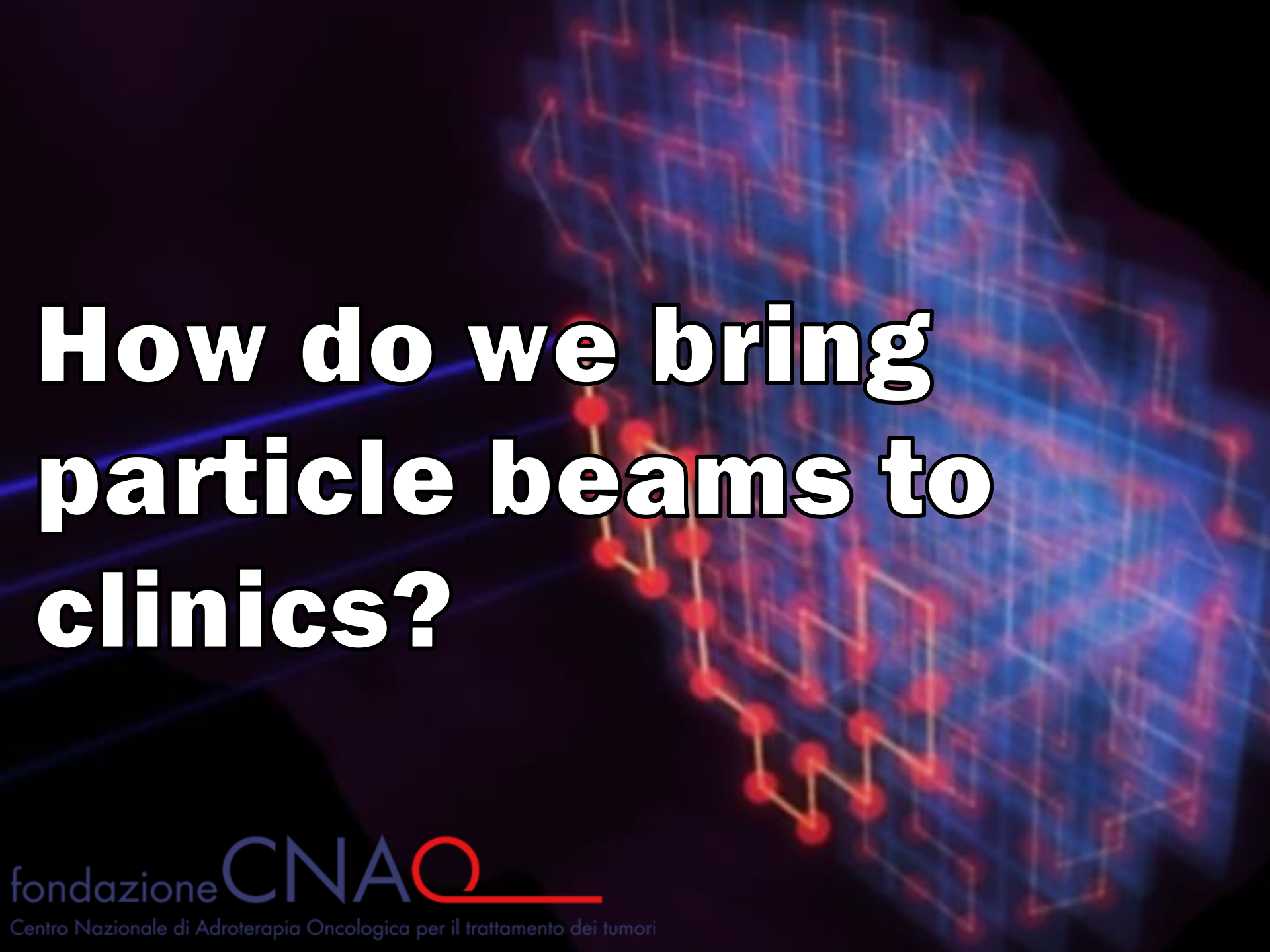


Rationale for ion beam therapy



Rationale for ion beam therapy





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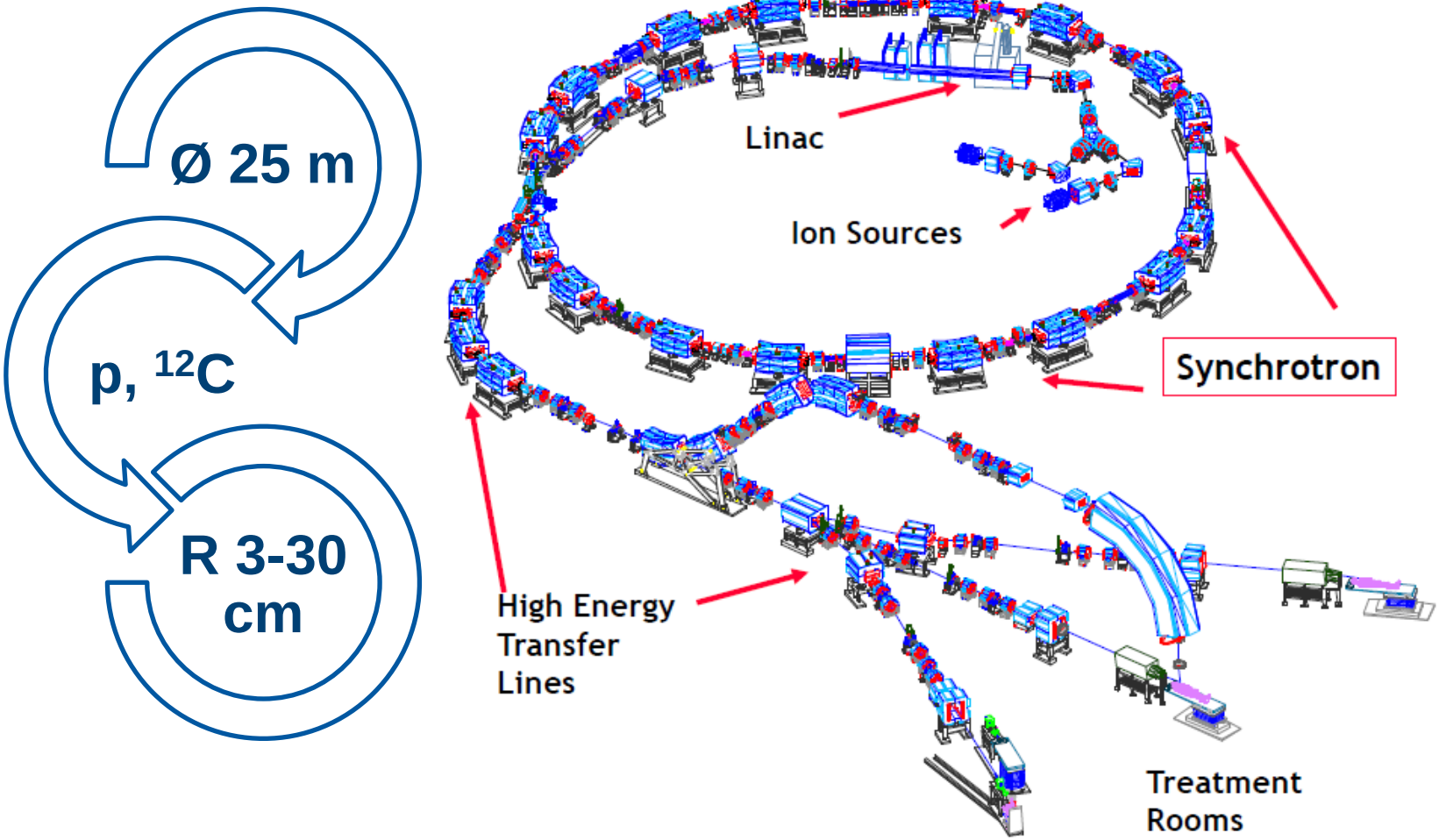
How do we bring particle beams to clinics?



How do we bring particle beams to clinics?

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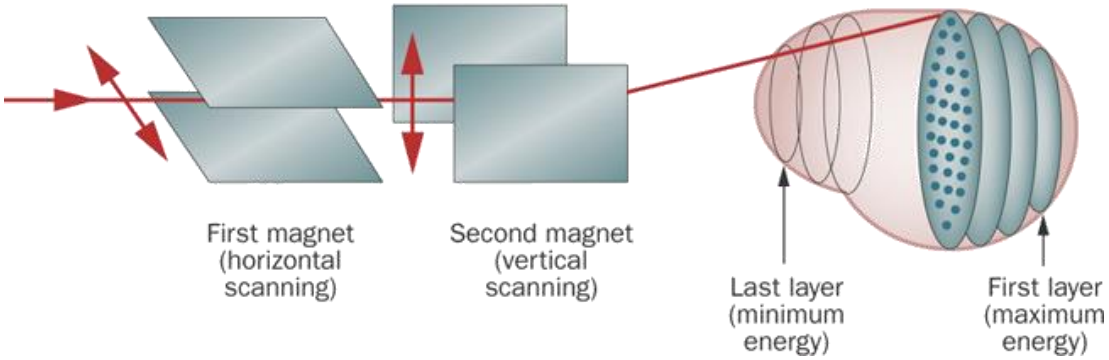
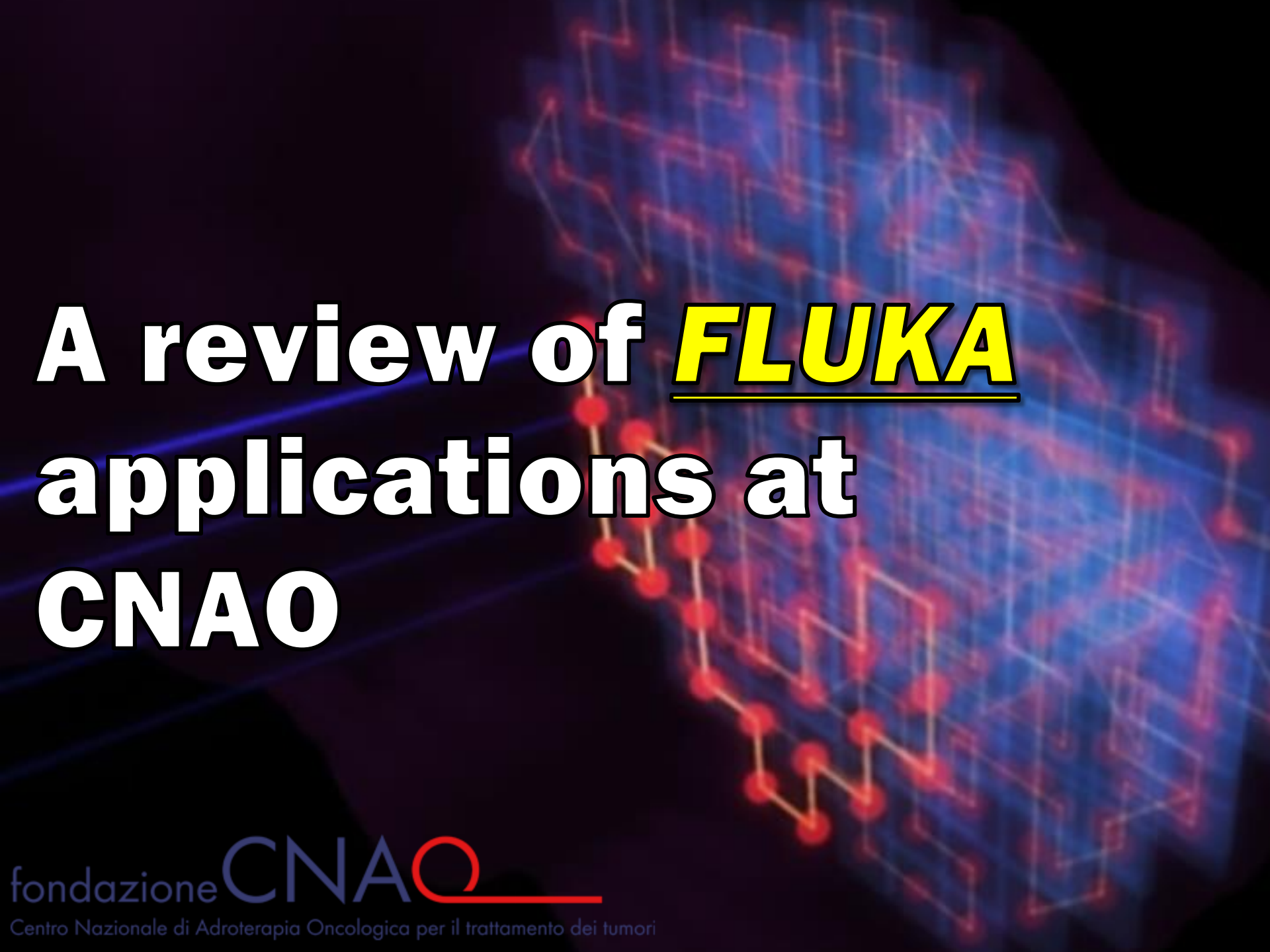


A review of FLUKA applications at CNAO



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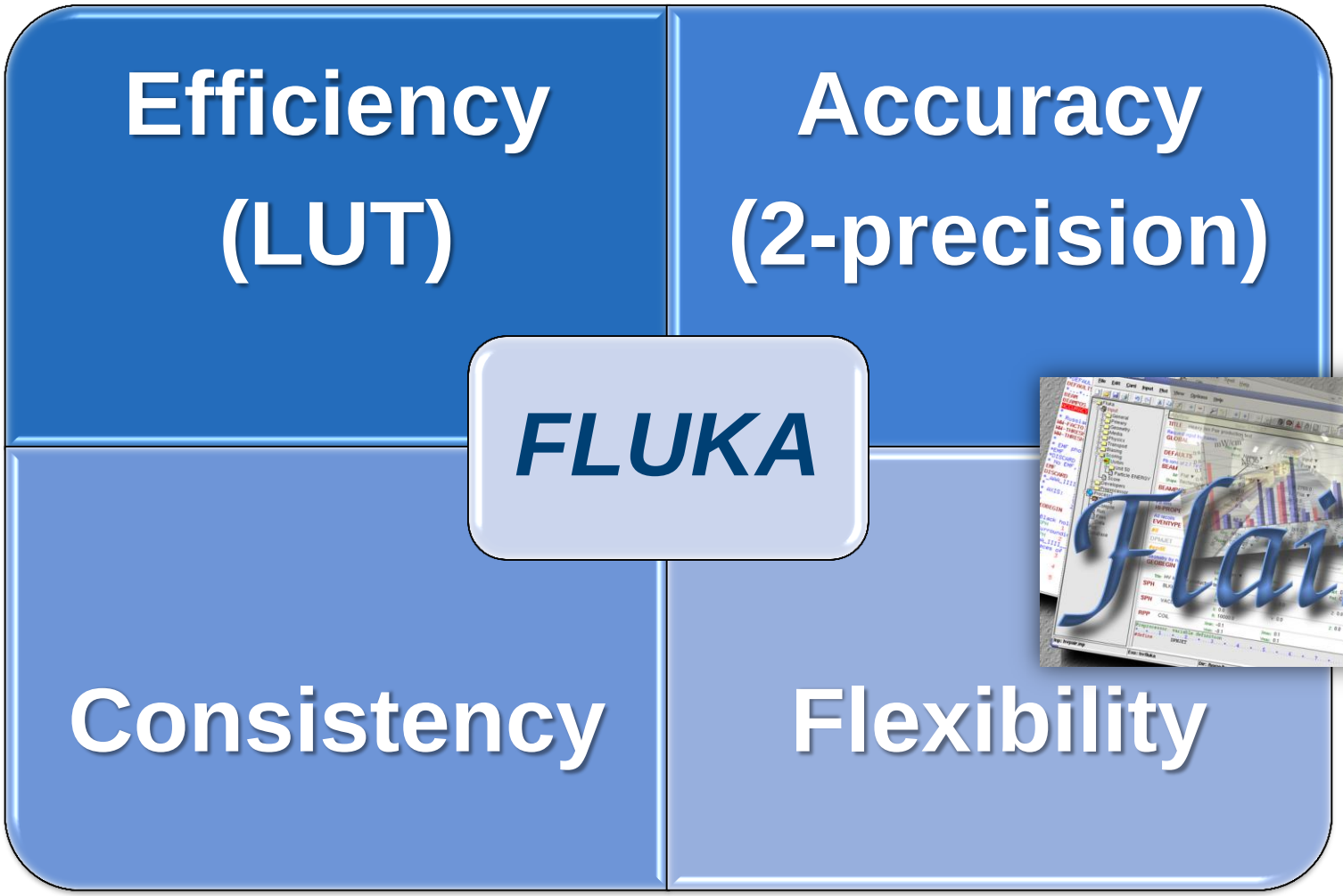
www.fluka.org/fluka.php www.fluka.org/FLUKA/flair/



FLUKA

...

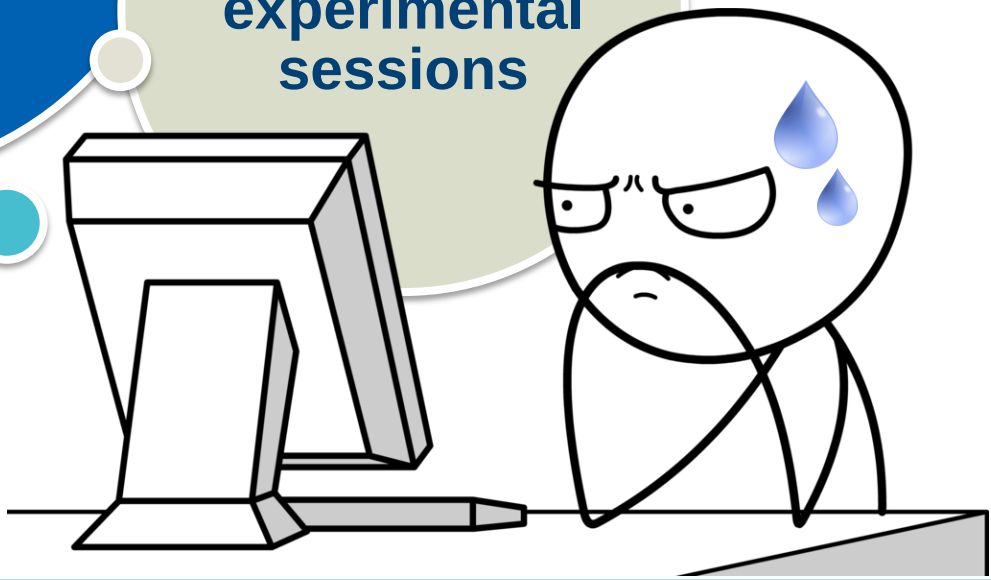
TPS input data

FLUKA Monte Carlo code

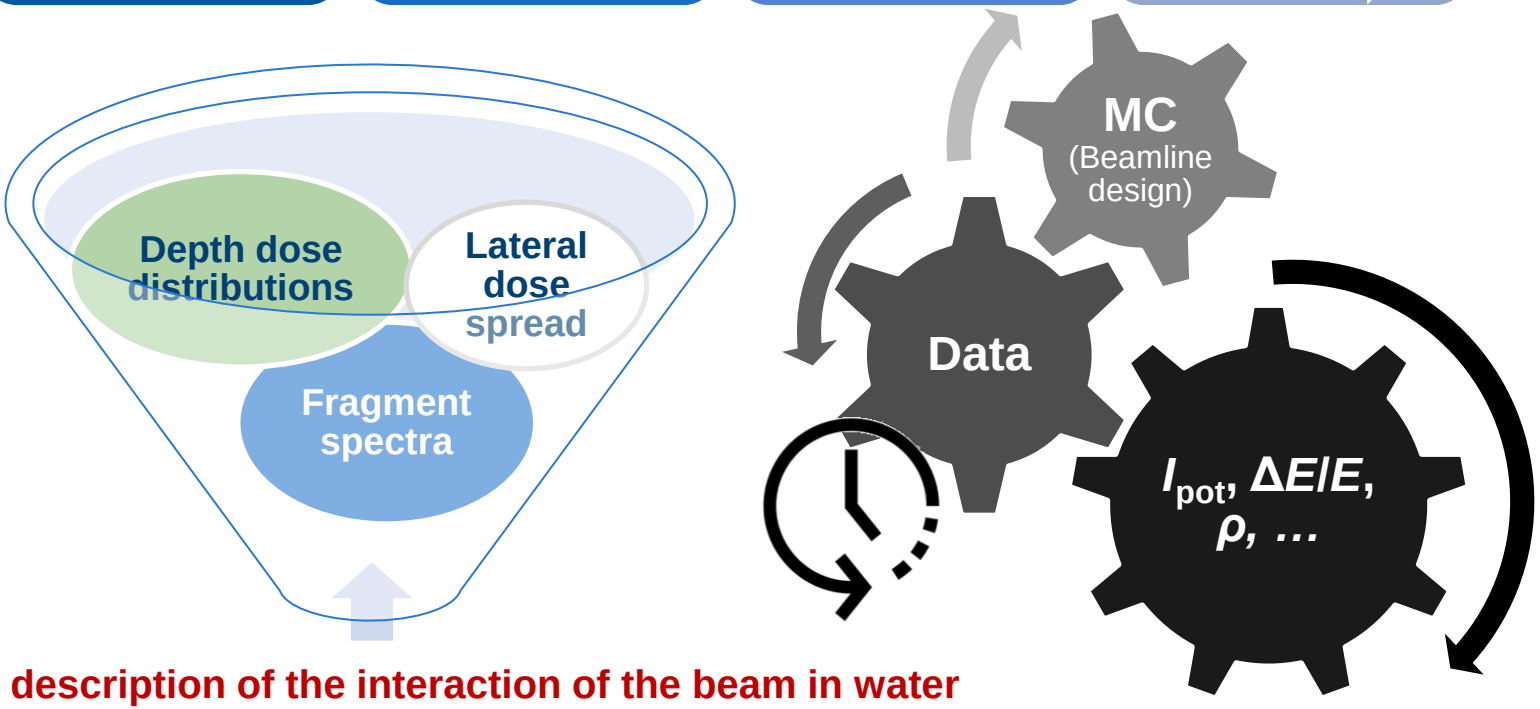
Dosimetric comparisons

Support to experimental sessions

Research topics



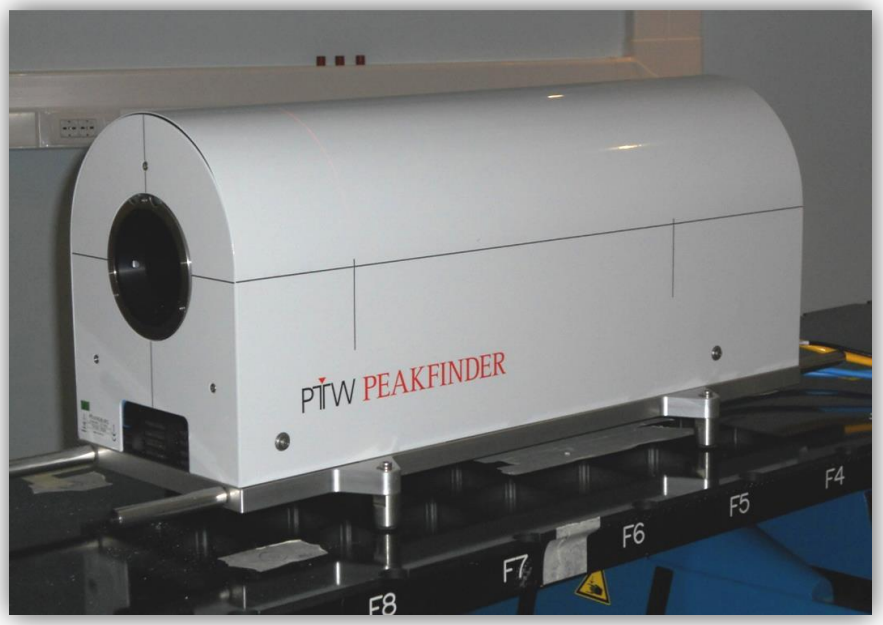
Treatment Planning System (TPS) input data

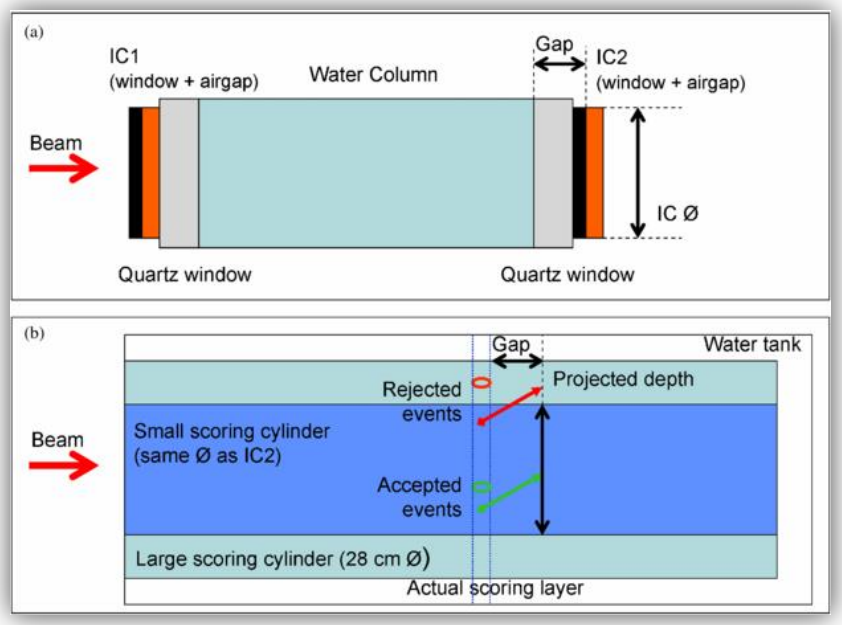


MC-based description of the interaction of the beam in water

Treatment Planning System (TPS) input data

Depth Dose Distributions



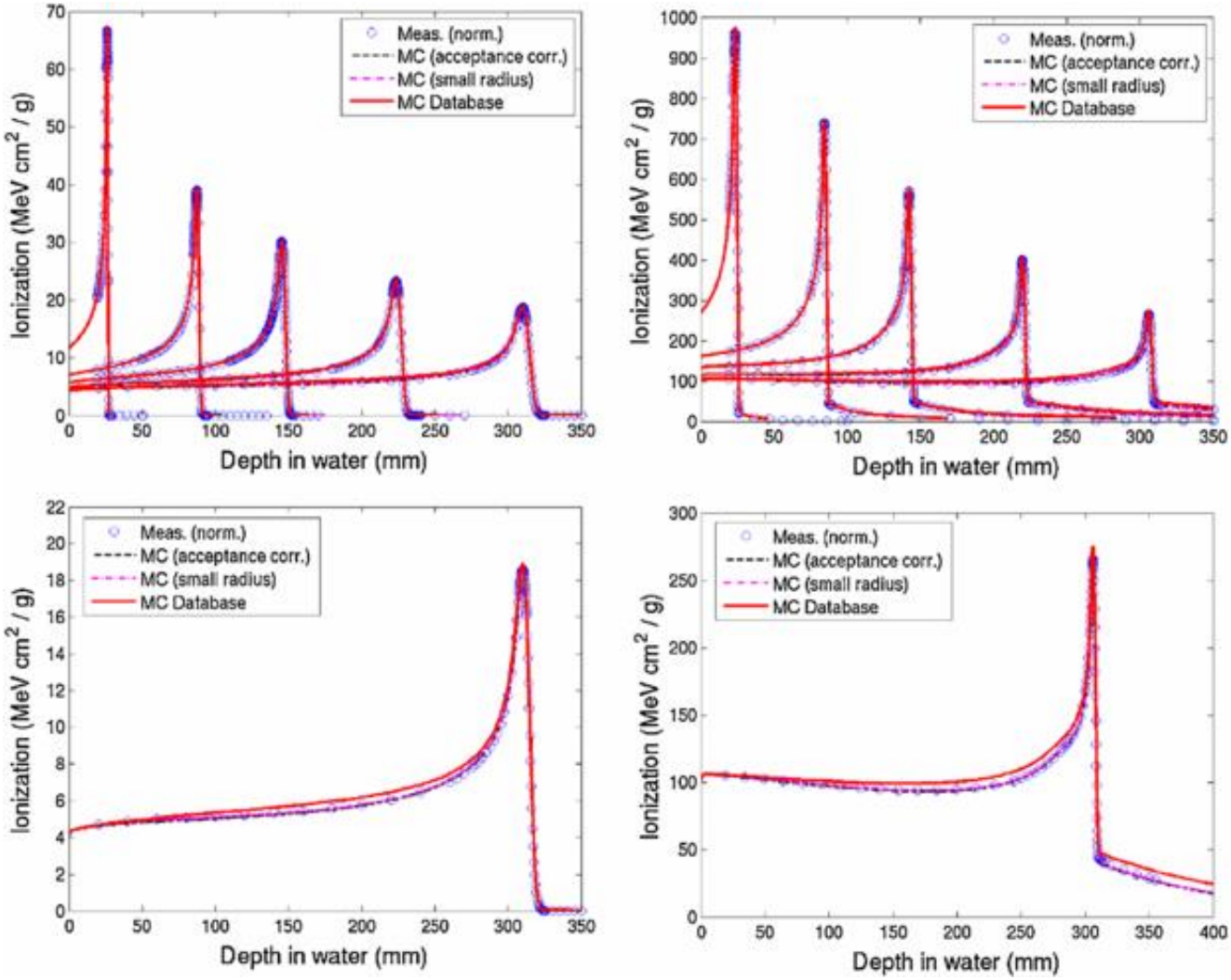


Parodi et al. "Monte Carlo simulations to support start-up and treatment planning of scanned proton and carbon ion therapy at a synchrotron-based facility." *Physics in Medicine & Biology* 57.12 (2012): 3759.

Treatment Planning System (TPS) input data

Depth Dose Distributions

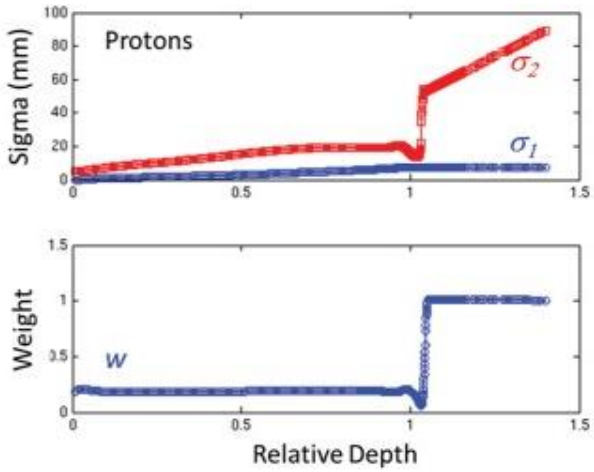
Parodi et al. (2012)

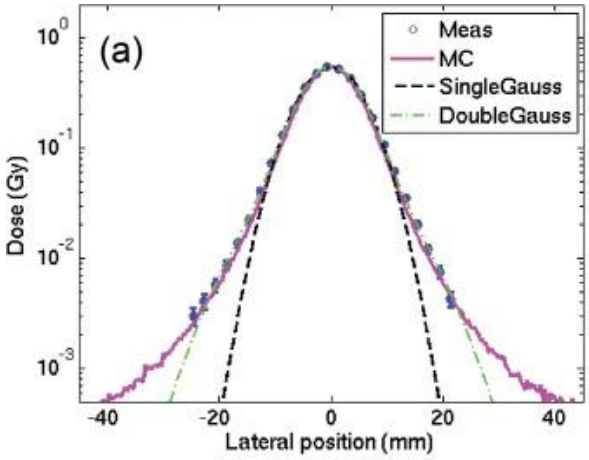


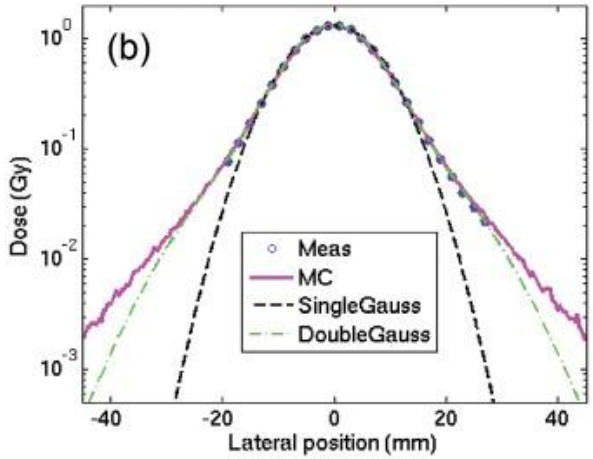
Treatment Planning System (TPS) input data

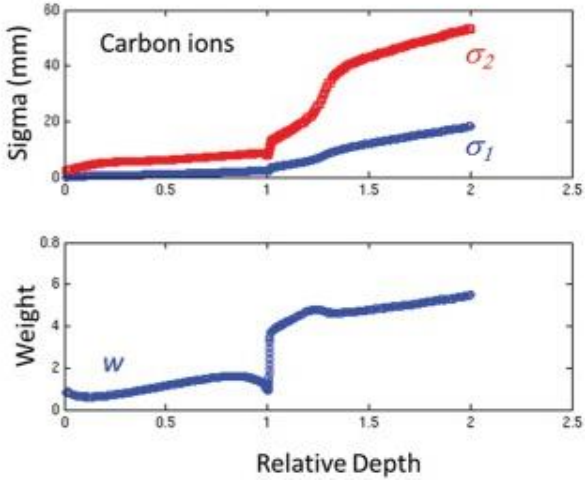
Lateral dose distributions

$$f(y) = N\left\{(1-W)\frac{1}{\sqrt{2\pi}\sigma_1}\exp\left[-\frac{y^2}{2\sigma_1^2}\right] + W\frac{1}{\sqrt{2\pi}\sigma_2}\exp\left[-\frac{y^2}{2\sigma_2^2}\right]\right\}$$









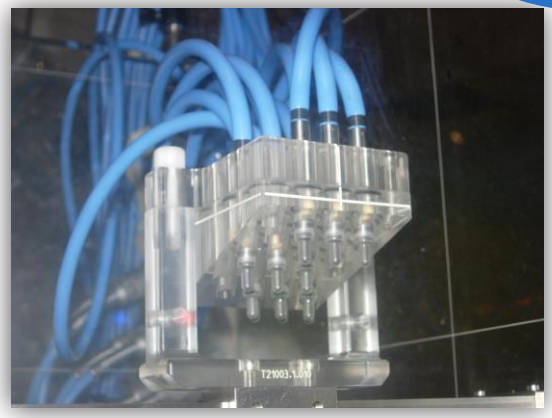
Parodi at al. "Monte Carlo-based parametrization of the lateral dose spread for clinical treatment planning of scanned proton and carbon ion beams." *Journal of radiation research* 54.suppl_1 (2013): i91-i96.

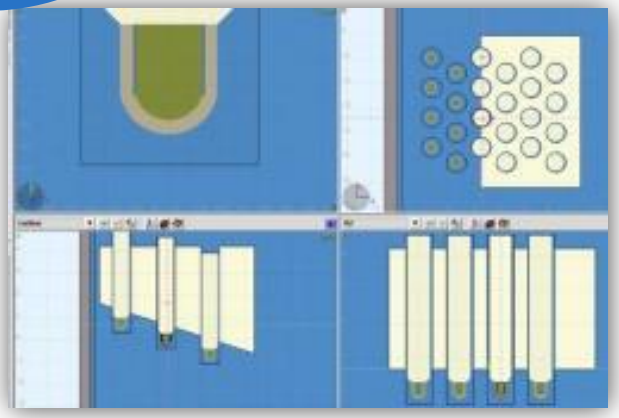
Dosimetric accuracy of the plan verification system

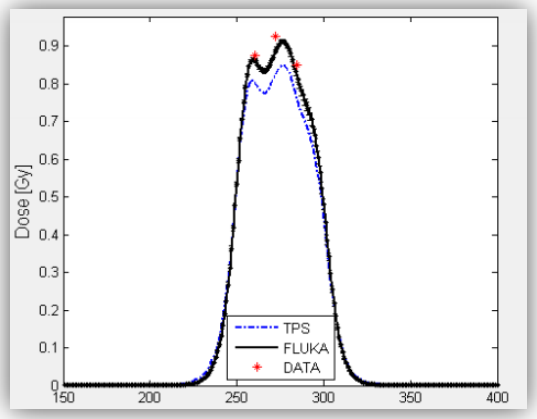
Planning

Verification

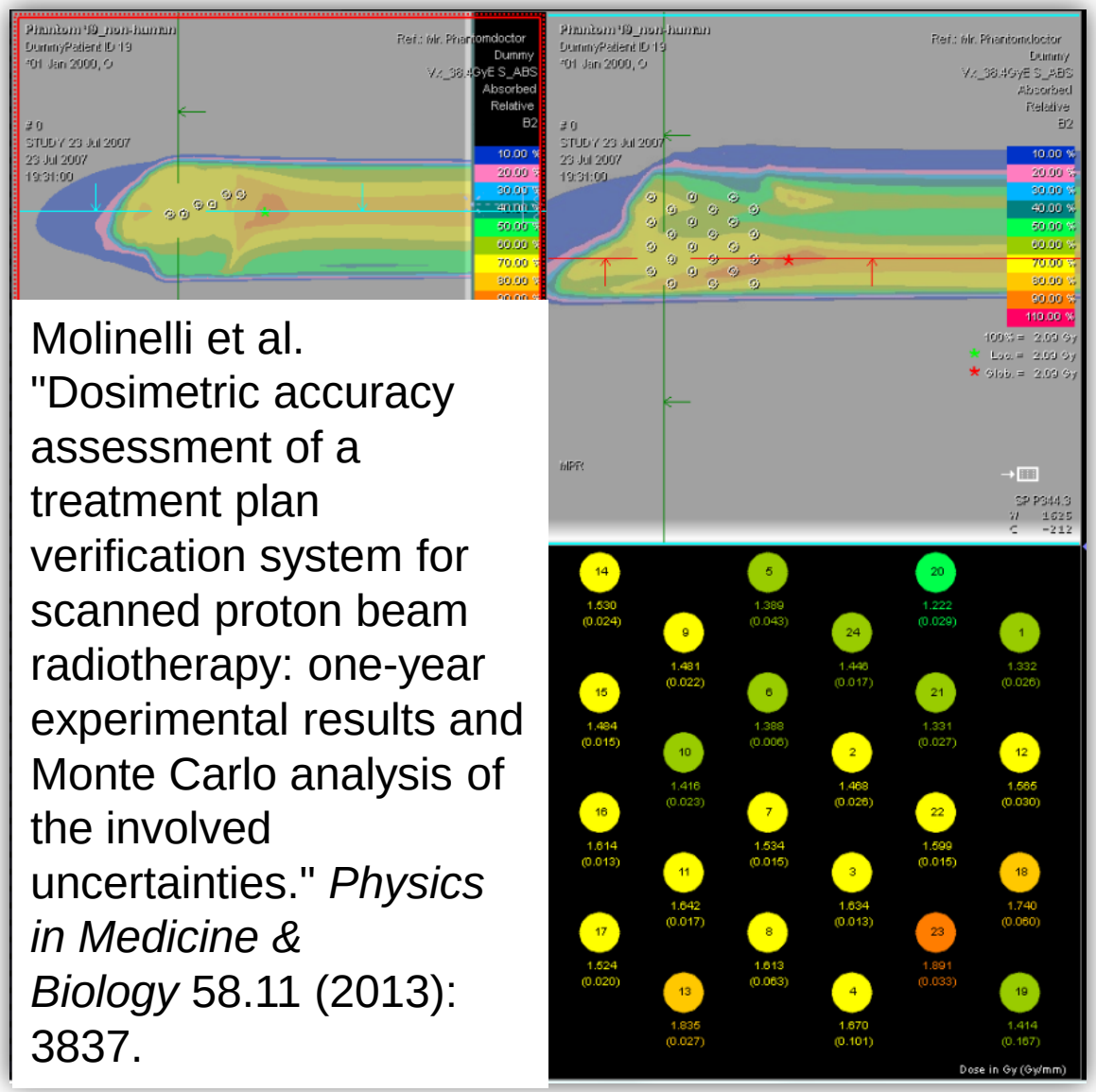
Delivery







Dosimetric accuracy of the plan verification system



Molinelli et al. "Dosimetric accuracy assessment of a treatment plan verification system for scanned proton beam radiotherapy: one-year experimental results and Monte Carlo analysis of the involved uncertainties." *Physics in Medicine & Biology* 58.11 (2013): 3837.

TPS

(4.2 ± 0.8)%

h.s. ±7%

MC

(3.5 ± 1.1)%

h.s. ±7%

MC + DDS

(2.4 ± 0.7)%

h.s. ±7%

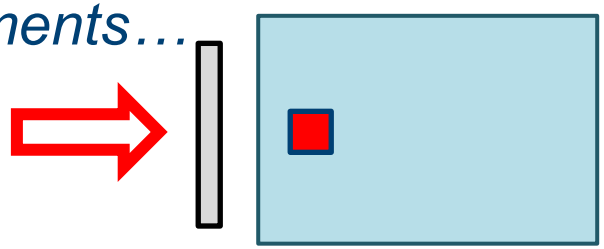
MC + DDS + setup

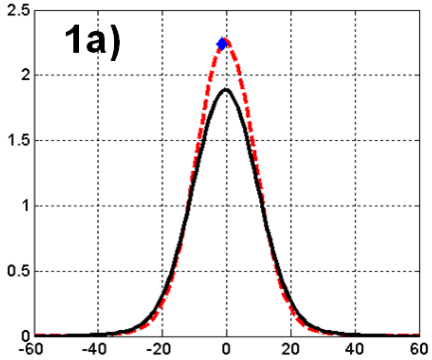
< 2.5%

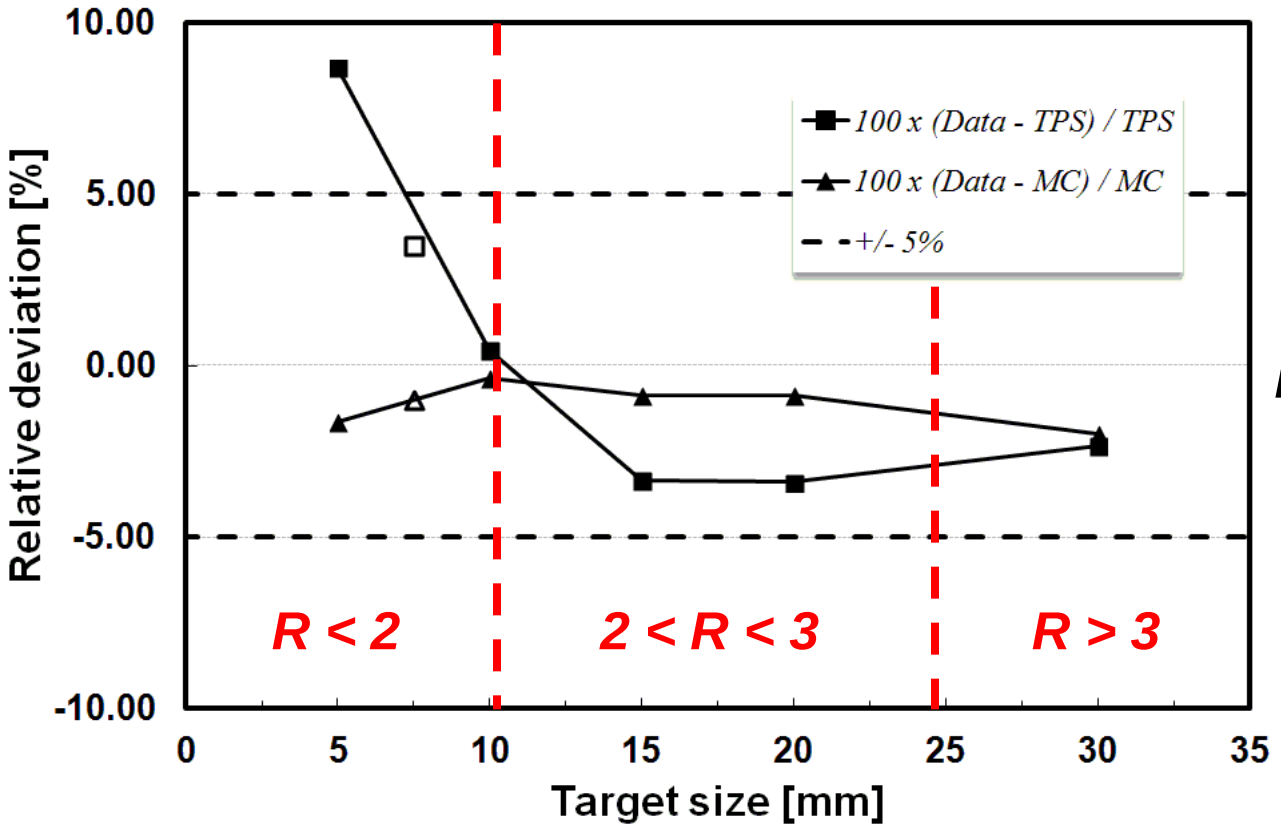
h.s. ±5%

Dosimetric accuracy on small superficial targets

Looking towards eye treatments…



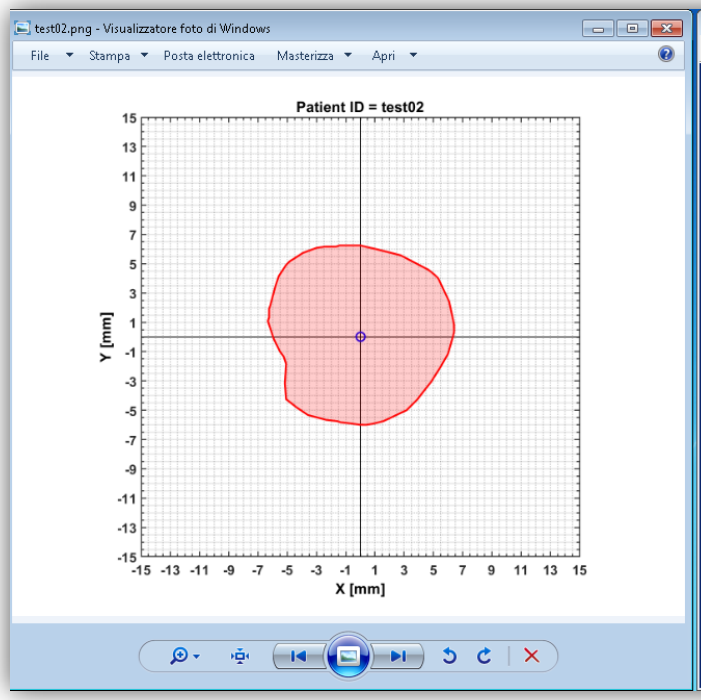


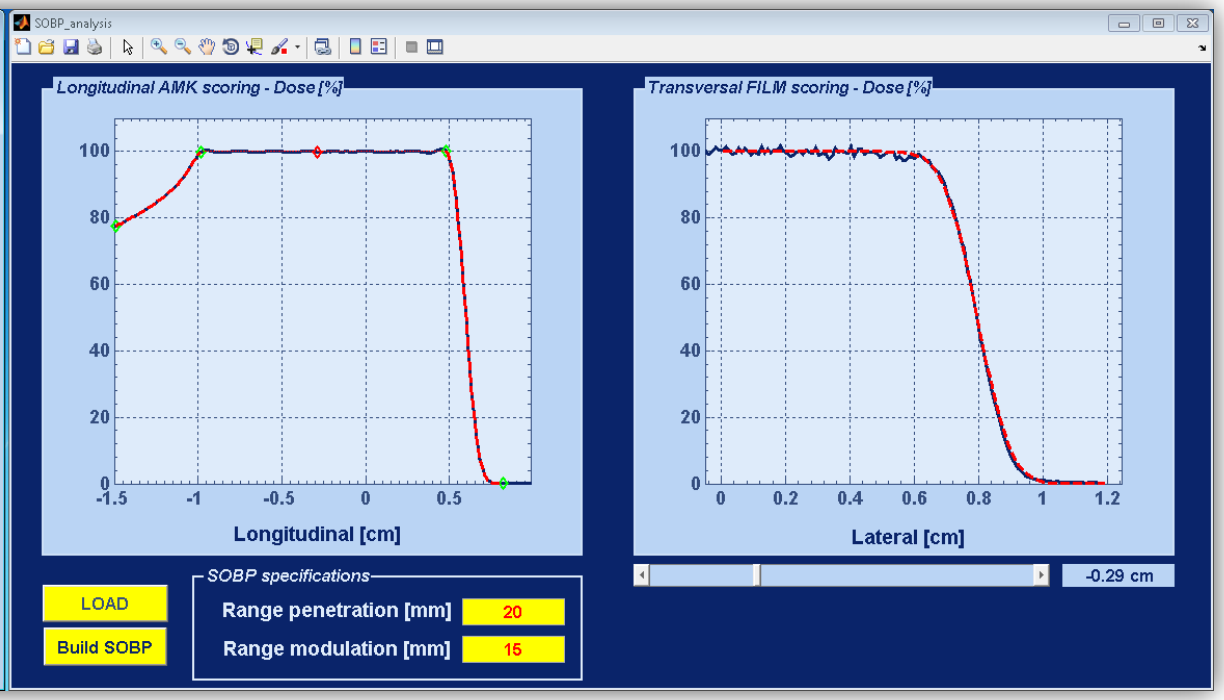


Magro et al. "Dosimetric accuracy of a treatment planning system for actively scanned proton beams and small target volumes: Monte Carlo and experimental validation." *Physics in Medicine & Biology* 60.17 (2015): 6865.

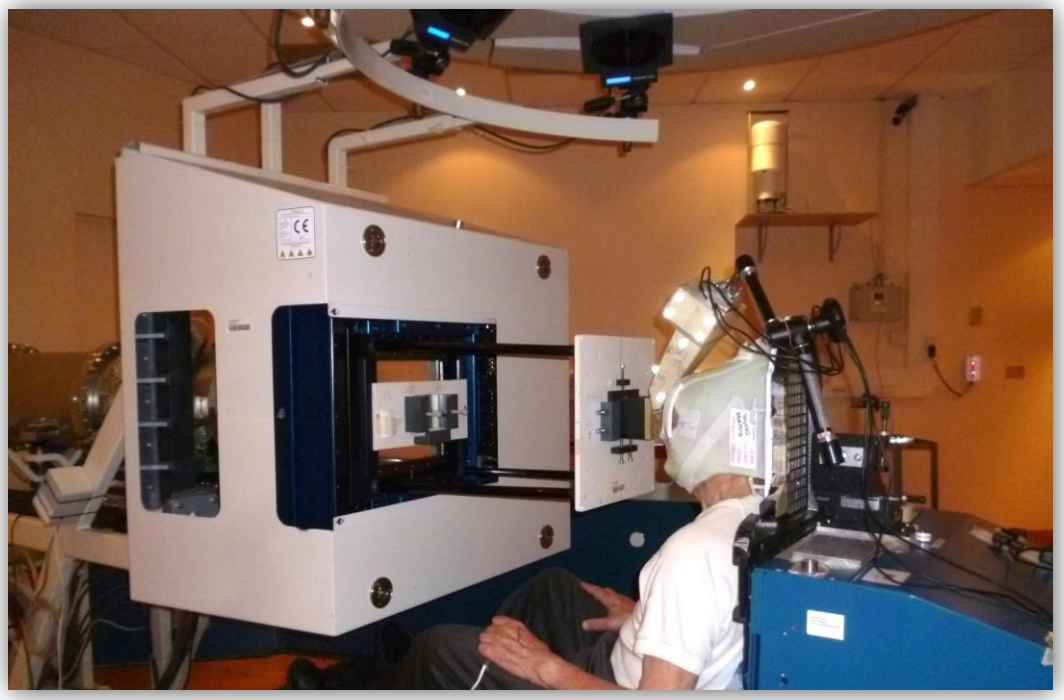
Optimization of an eye-dedicated beamline

Not only Monte Carlo …

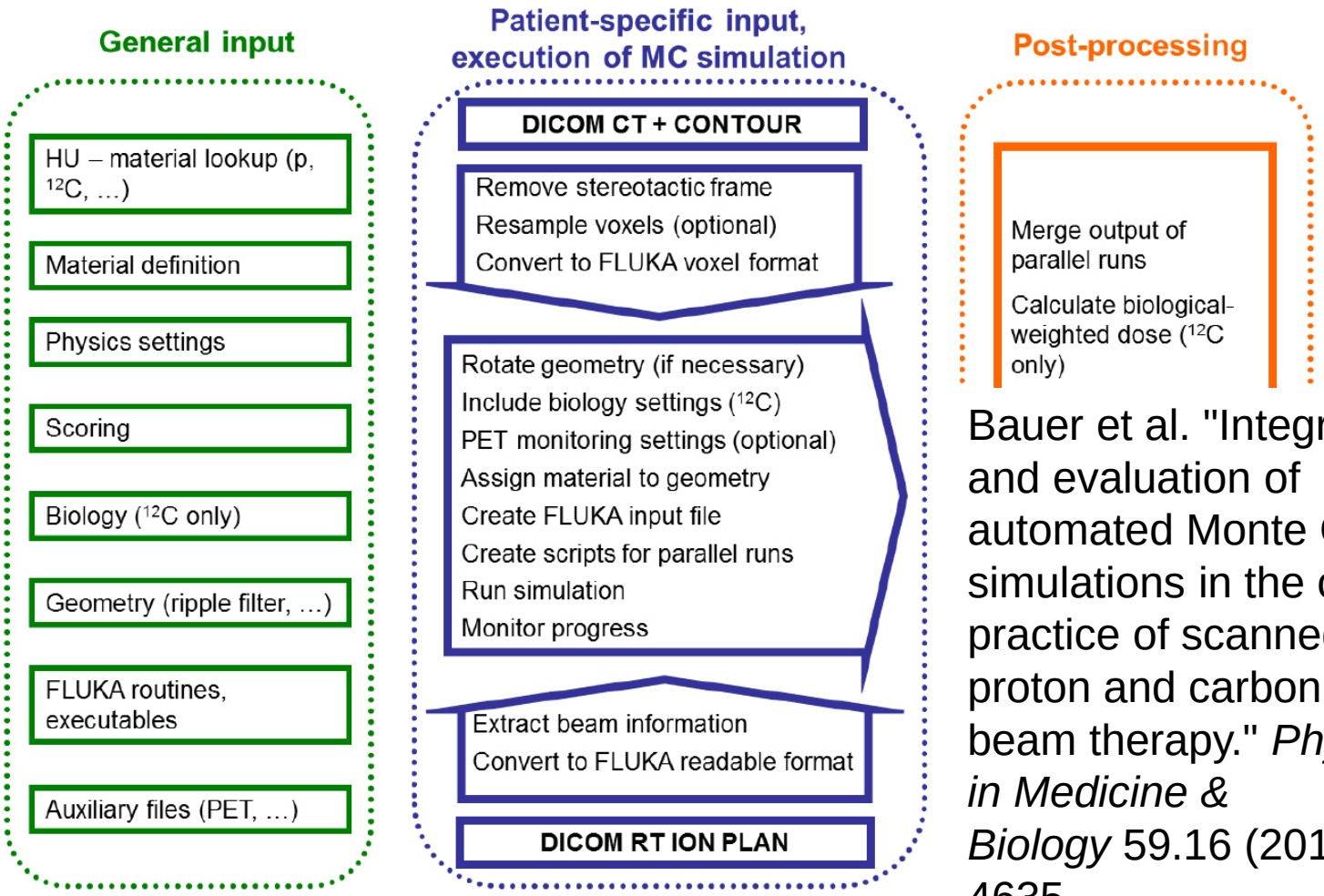




Optimization of an eye-dedicated beamline

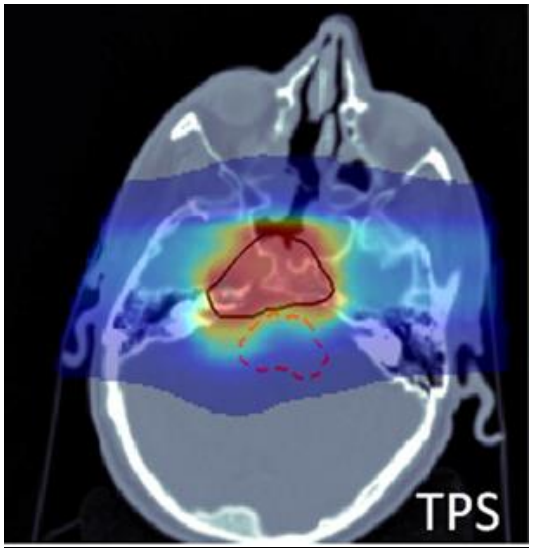


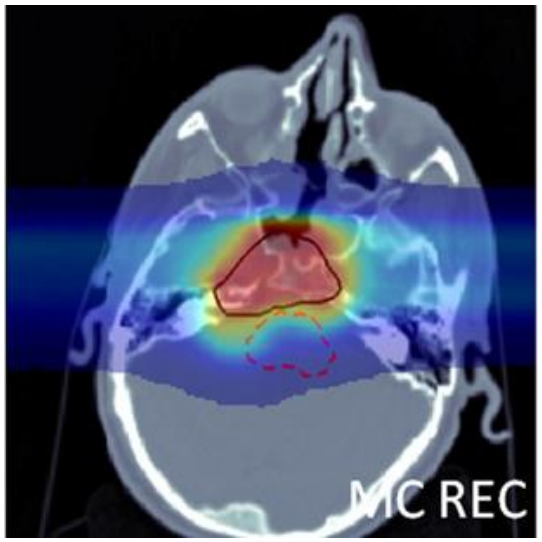
Support to the clinics: patient plan recalculations

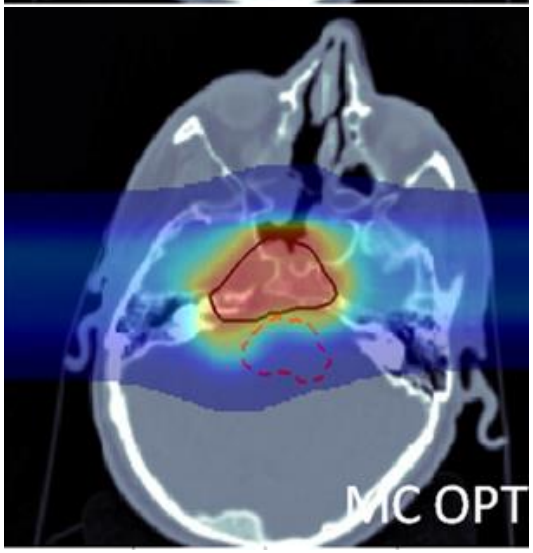


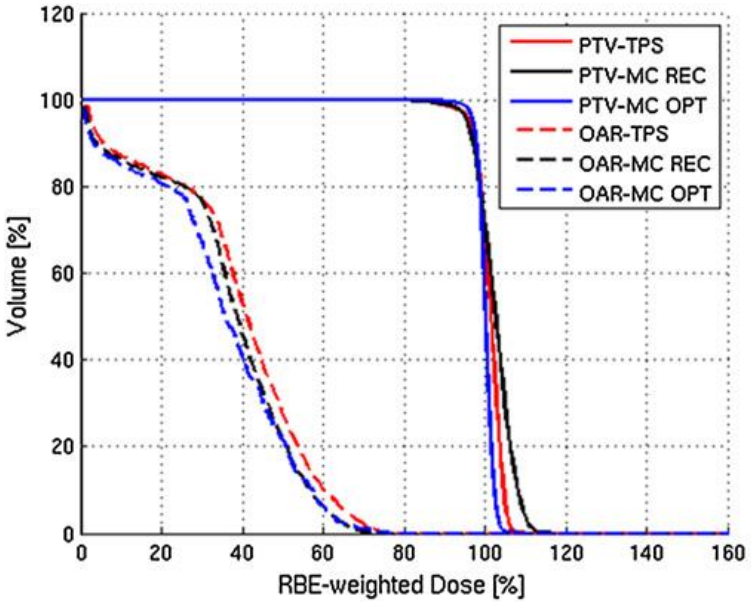
Bauer et al. "Integration and evaluation of automated Monte Carlo simulations in the clinical practice of scanned proton and carbon ion beam therapy." *Physics in Medicine & Biology* 59.16 (2014): 4635.

Support to the clinics: patient plan optimization





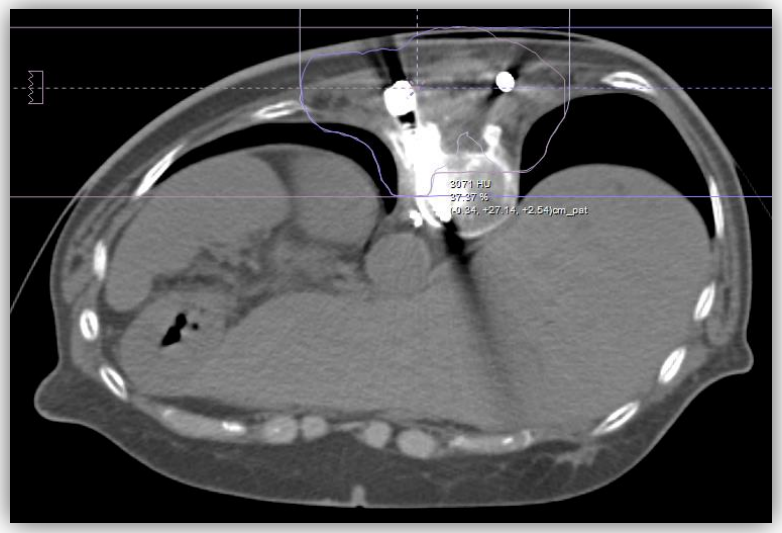


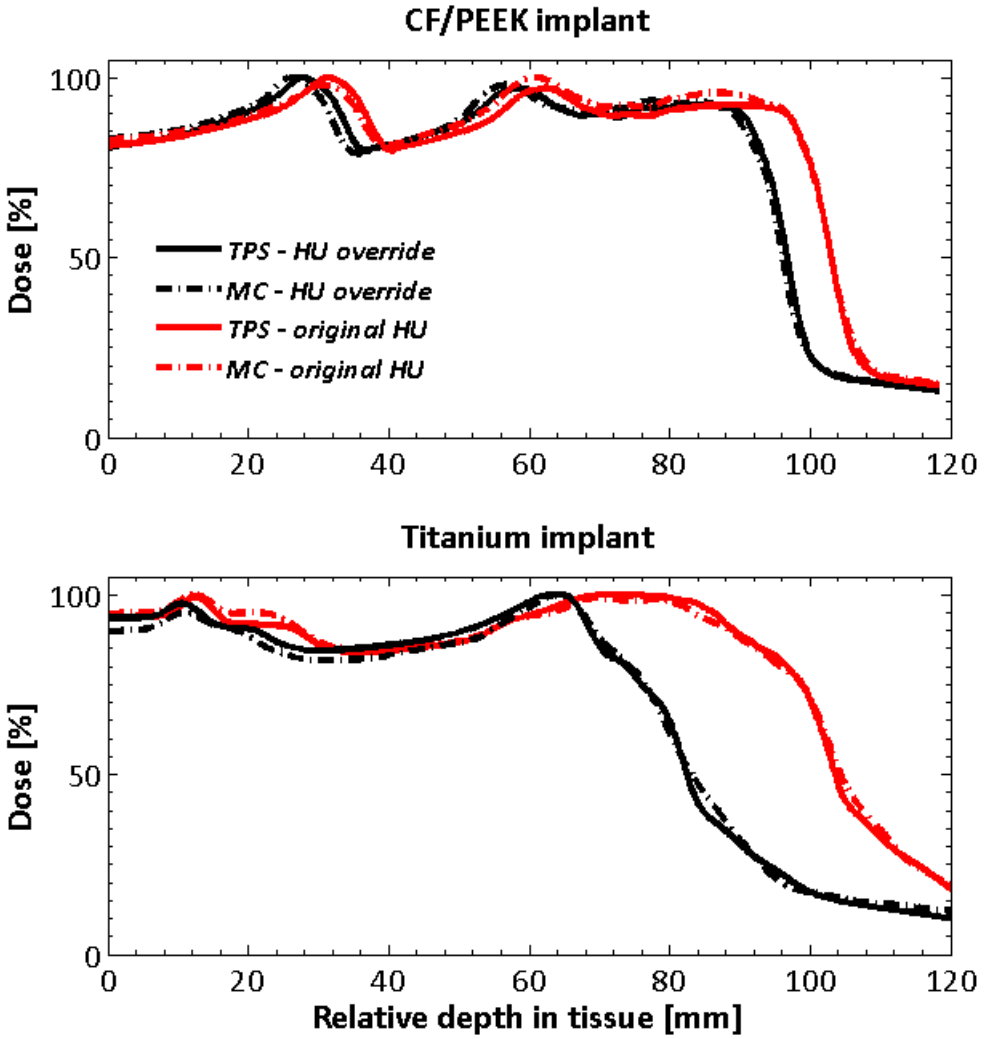


Mairani et al. "A Monte Carlo-based treatment planning tool for proton therapy." *Physics in Medicine & Biology* 58.8 (2013): 2471.

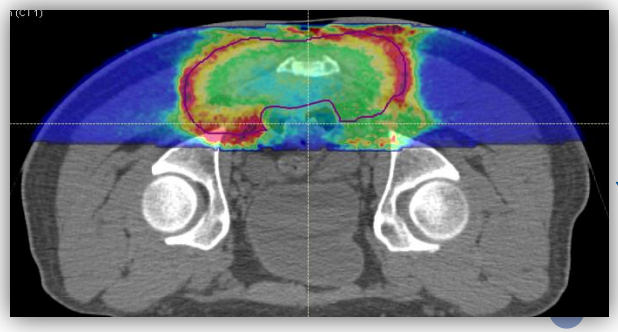
Support to the clinics: plan robustness

Mastella et al. "Dosimetric characterization of carbon fiber stabilization devices for post-operative particle therapy." *Physica Medica: European Journal of Medical Physics* 44 (2017): 18-25.





Biological dose prescription in C-ion RT



Higher LET

Lower physical dose

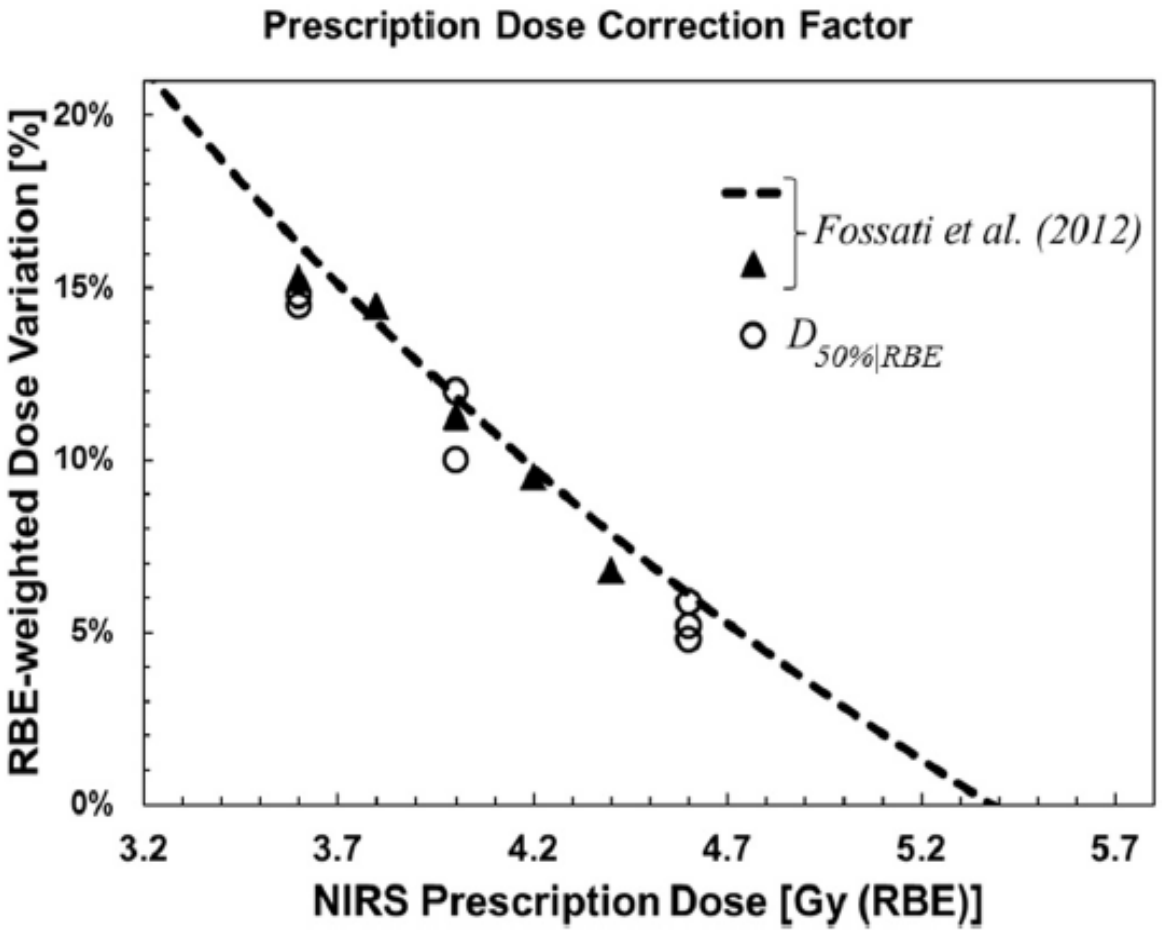
MKM

1994

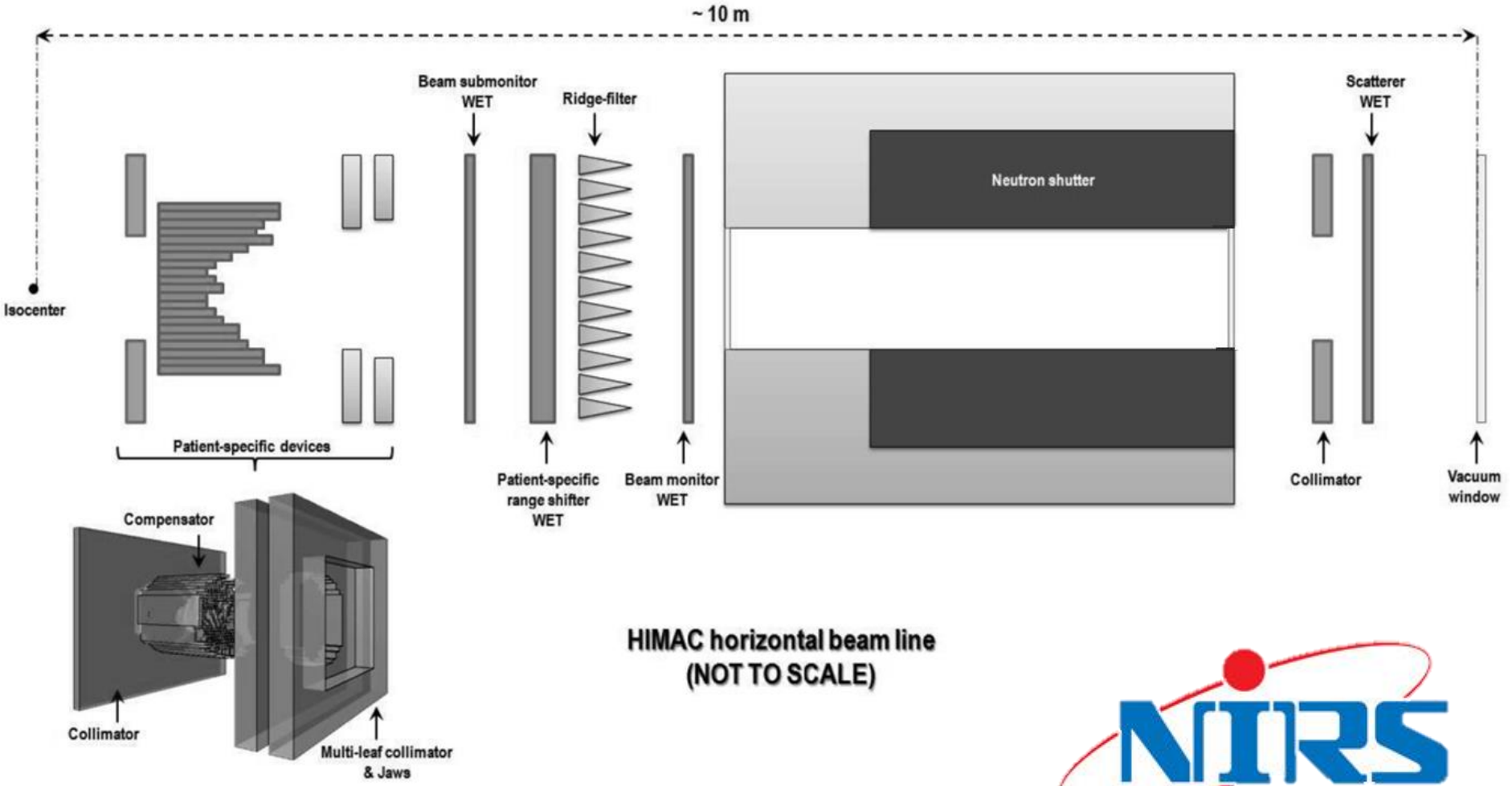
LEM

Biological dose prescription in C-ion RT

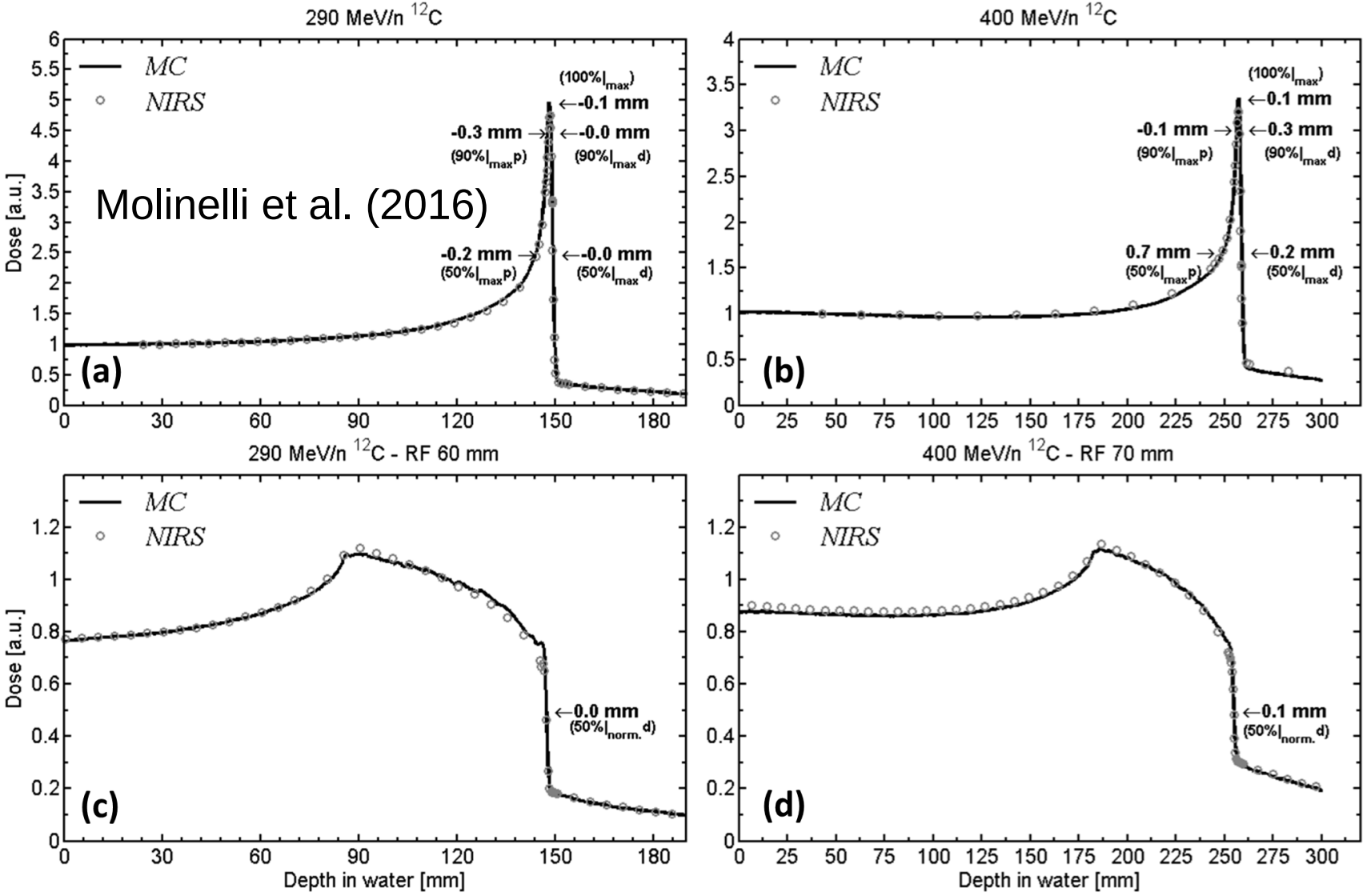
Molinelli et al. "Dose prescription in carbon ion radiotherapy: How to compare two different RBE-weighted dose calculation systems." *Radiotherapy and Oncology* 120.2 (2016): 307-312.



Biological dose prescription in C-ion RT



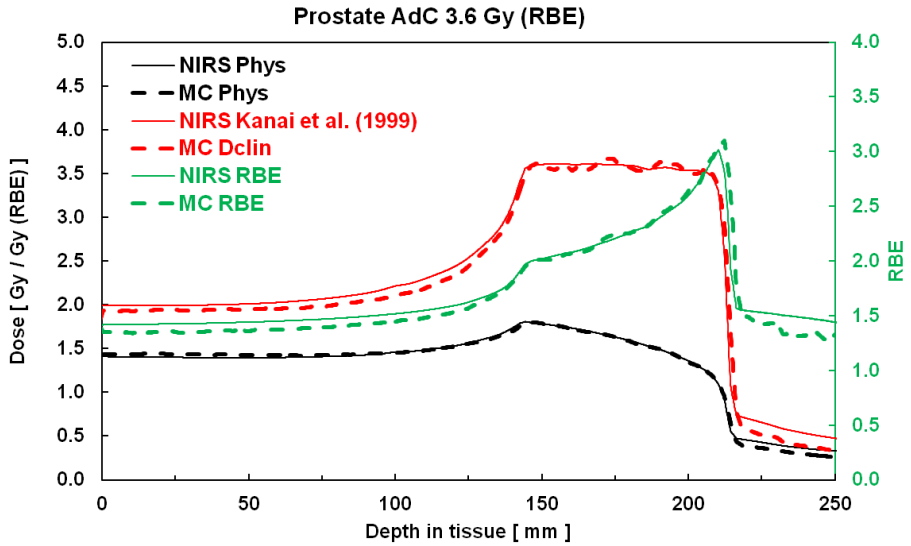
Biological dose prescription in C-ion RT



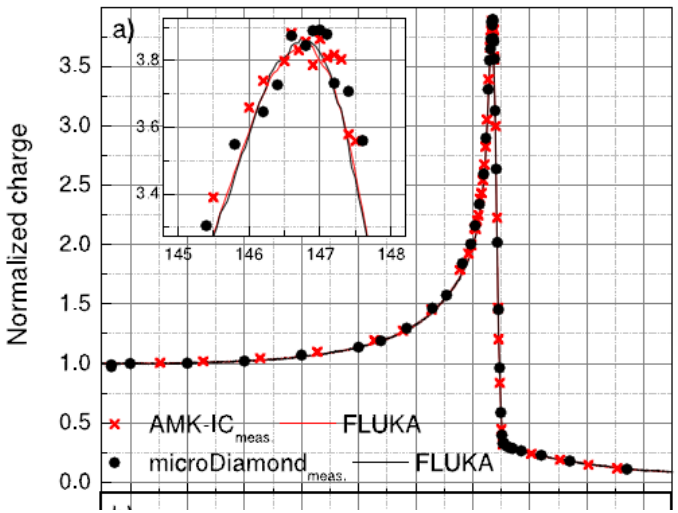
Biological dose prescription in C-ion RT

FLUKA coupled with LEM and MKM

Magro et al. "The FLUKA Monte Carlo code coupled with the NIRS approach for clinical dose calculations in carbon ion therapy." *Physics in Medicine & Biology* 62.9 (2017): 3814.



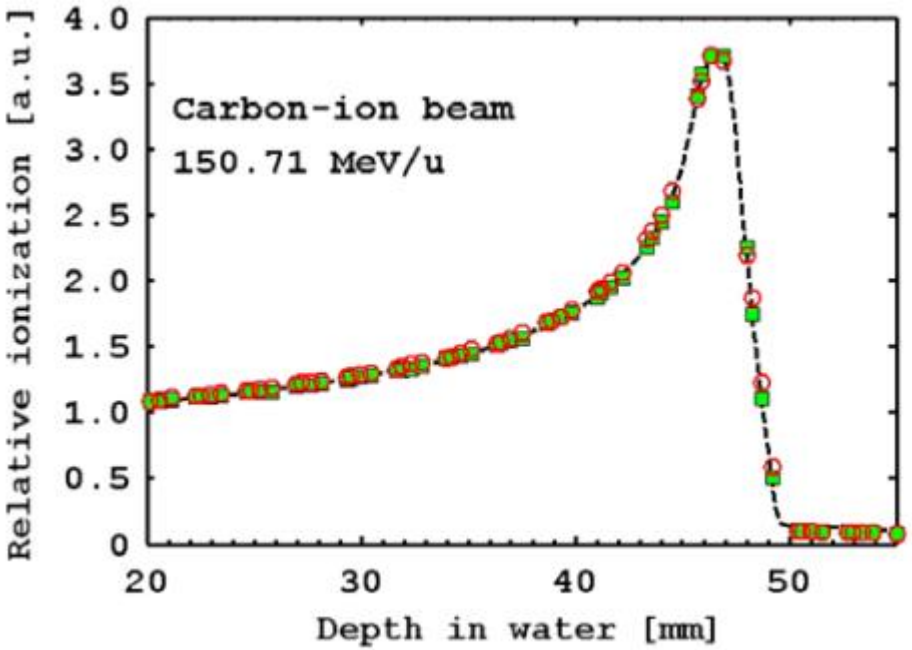
Support to experimental sessions



Marinelli et al. "Dosimetric characterization of a microDiamond detector in clinical scanned carbon ion beams." *Medical physics* 42.4 (2015): 2085-2093.

Mirandola et al. "Characterization of a multilayer ionization chamber prototype for fast verification of relative depth ionization curves and spread-out-Bragg-peaks in light ion beam therapy." *Medical physics* 45.5 (2018): 2266-2277.

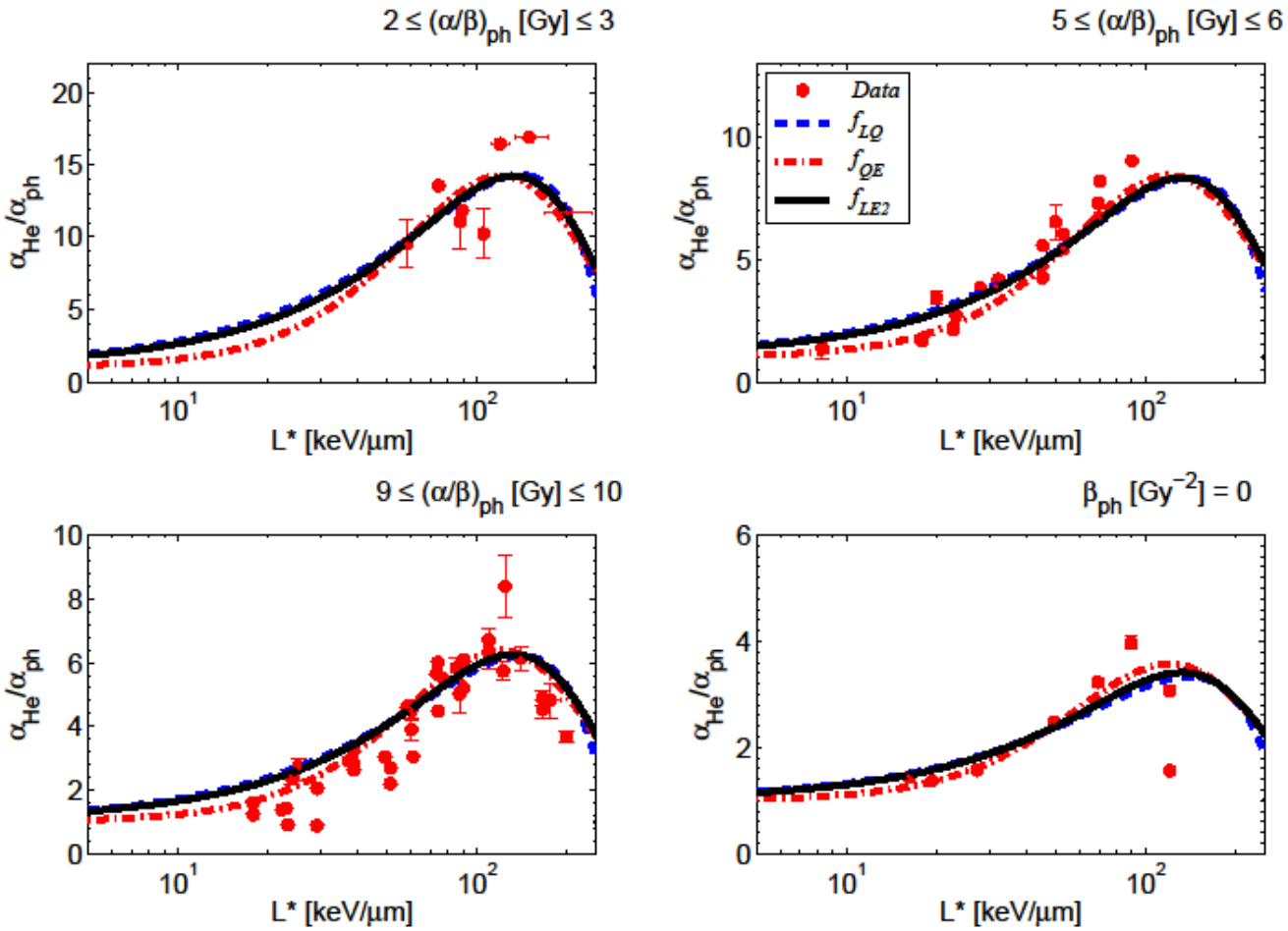
DEVICES AND TECHNOLOGIES TORINO



Research topics (radiobiology)

In-house RBE model for He-ion beams

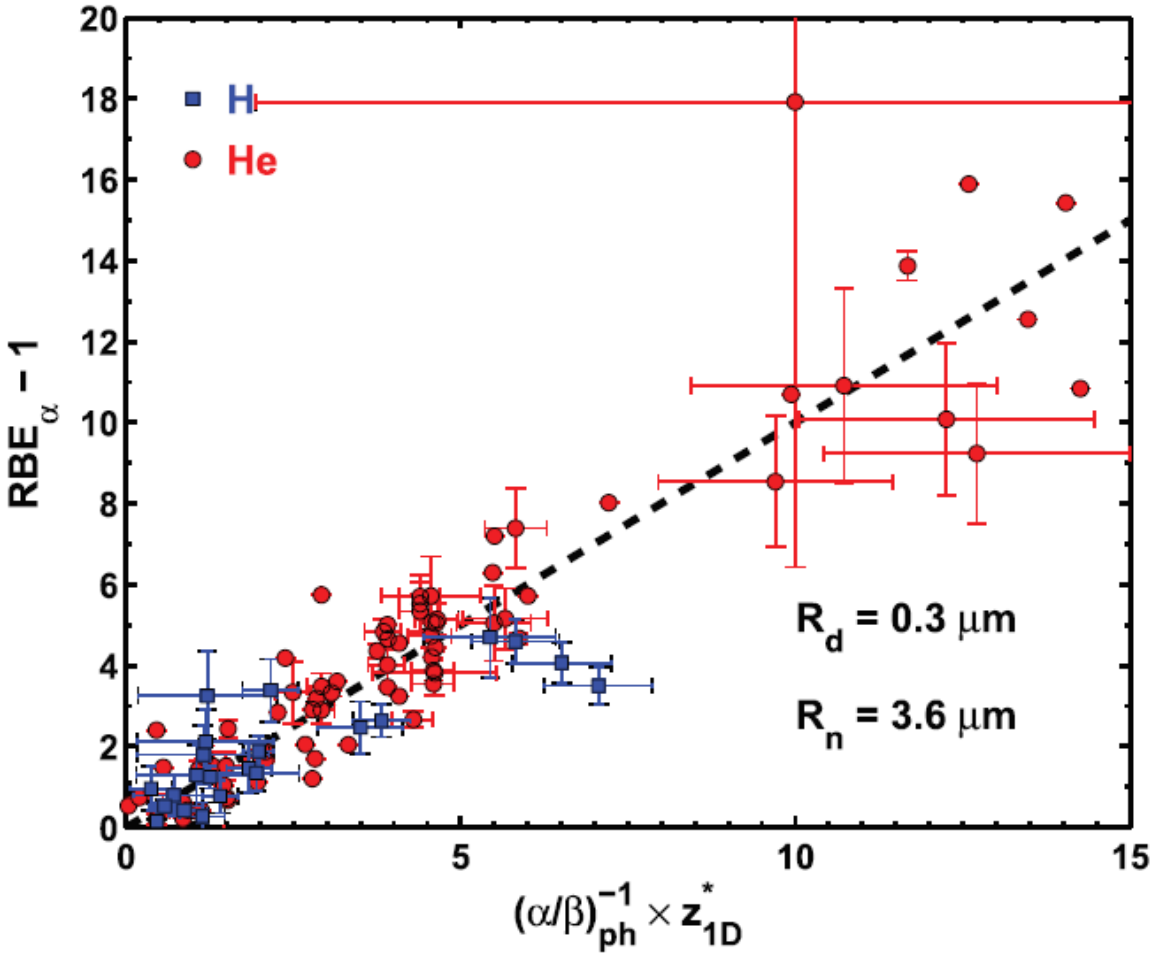
Mairani et al. "Data-driven RBE parameterization for helium ion beams." *Physics in Medicine & Biology* 61.2 (2016): 888.



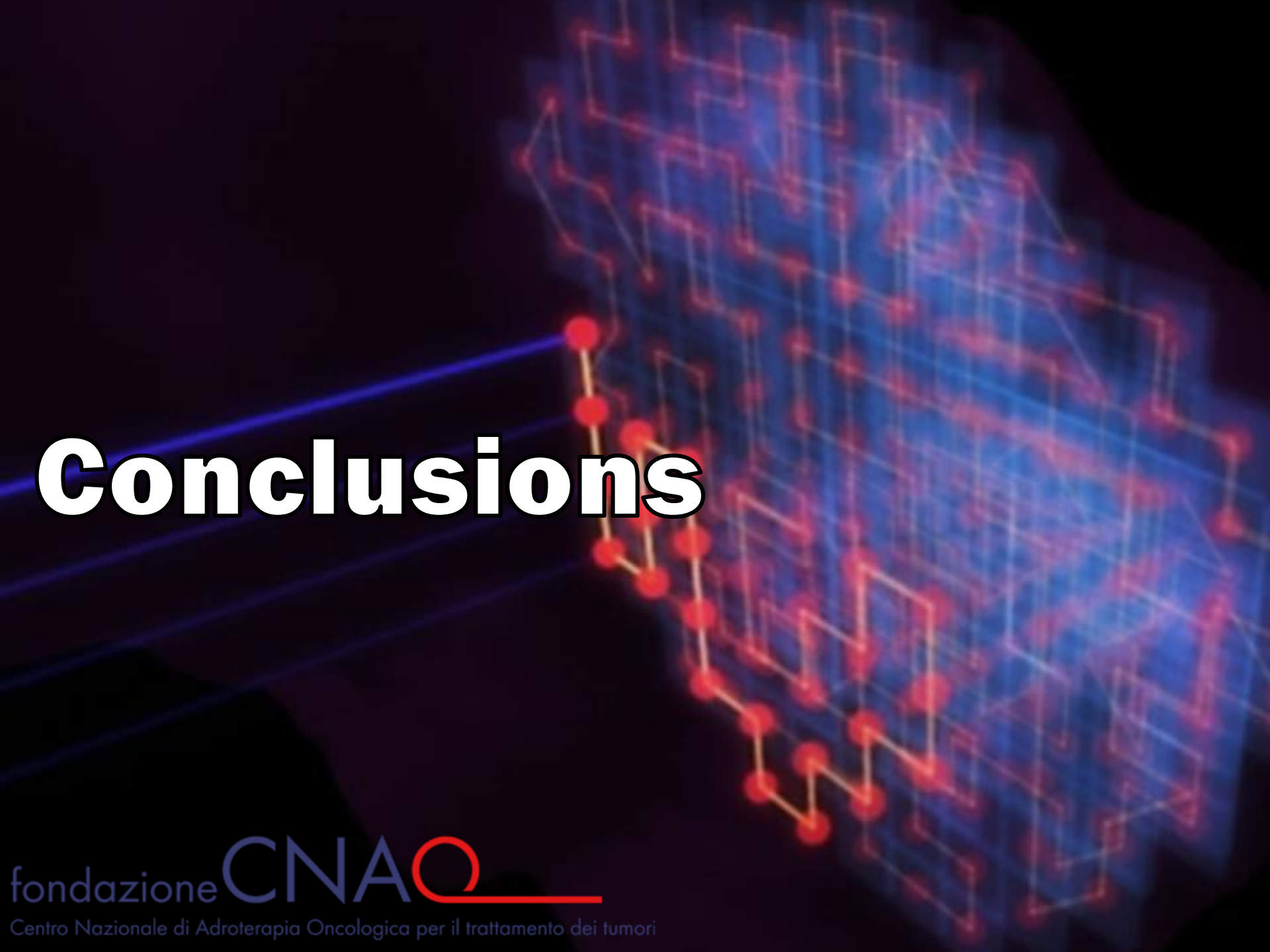
Research topics (radiobiology)

Tuning MKM input parameters for a variable RBE in proton therapy

Mairani et al. "Optimizing the modified microdosimetric kinetic model input parameters for proton and 4He ion beam therapy application." *Physics in Medicine & Biology* 62.11 (2017): N244.



Conclusions



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TPS using as input MC-calculated dosimetric database are a standard in particle therapy

More than 4000 patients worldwide have been treated using the developments based on the MC activity

Each hadron therapy facility has its MC expert

MC calculations are an asset for daily support of the clinical activity

Introduction of new ion modalities and RBE approaches in clinical practice will be strongly based on MC calculations

Thank you

"There is real progress only when the advantages of a new technology become for all."

- Henry Ford -

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giuseppe.magro@cnao.it