Optimization of GATE/Geant4 settings

Monte Carlo simulations of Pencil Beam Scanning in protontherapy

PARTNER
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21 May 2010

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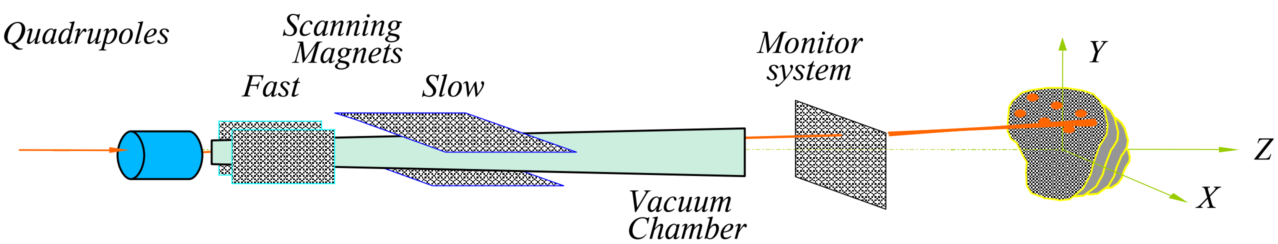
Highlights of the project

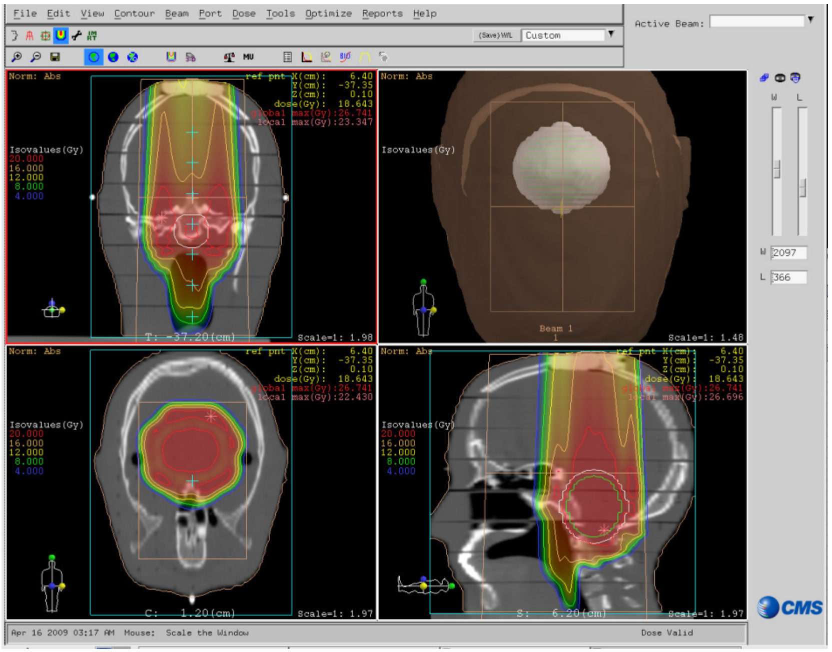
Pencil **B**eam **S**canning delivery technique.



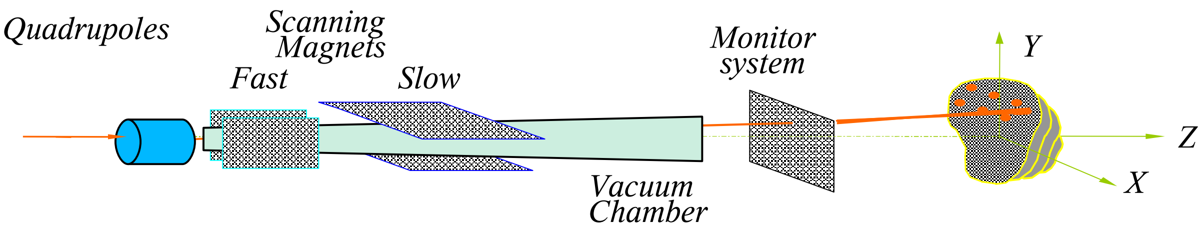
www.opengatecollaboration.org

A **Geant4-based Monte Carlo platform** for **medical physics** applications.

TPS benchmarking:
Comparing dose distributions from **XiO** (Elekta CMS software) with **GATE**.

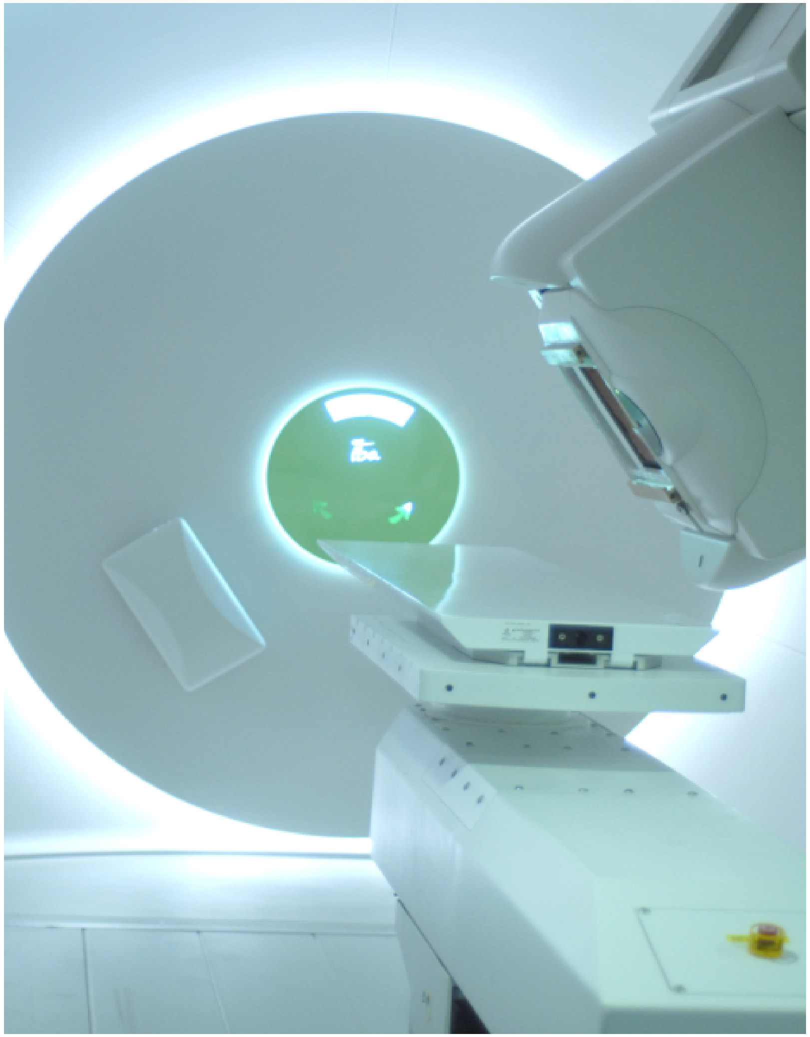


Presentation plan



(I) Simulation settings
- Importance of the MC parameters

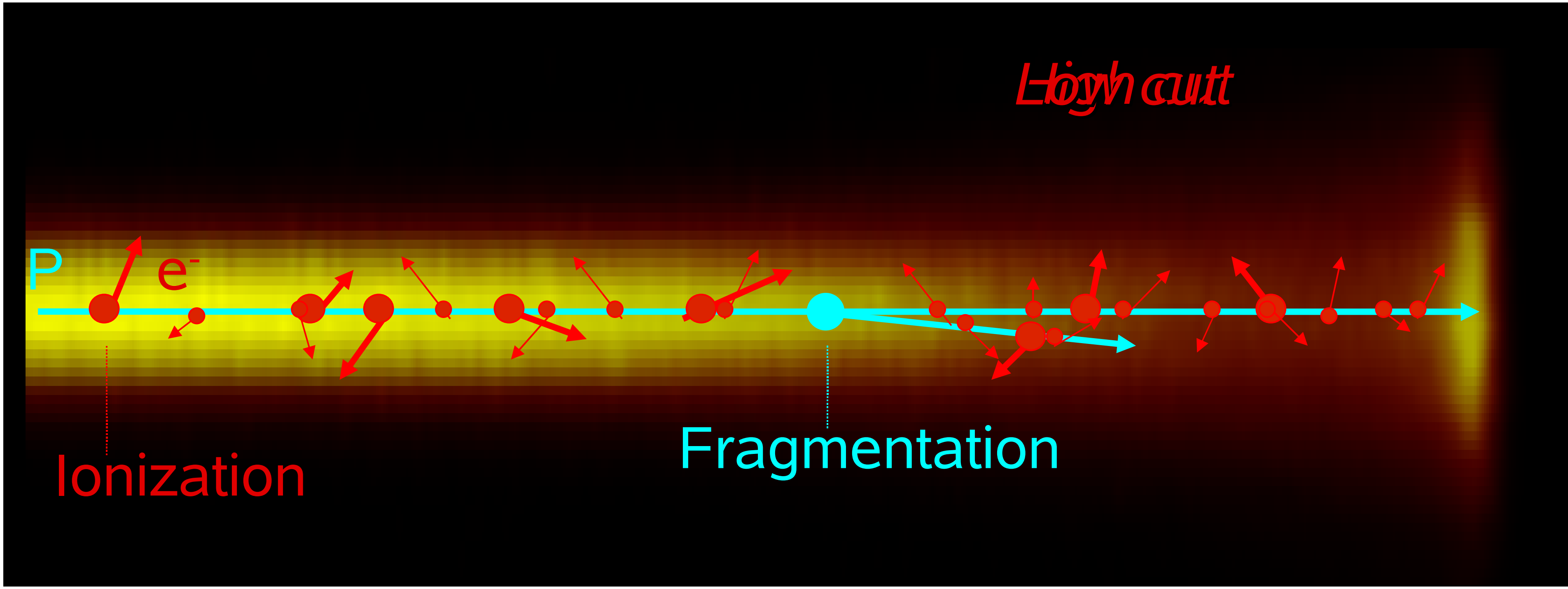
(II) Experimental validation
- Simulation accuracy
- Limits of the models



The new IBA PBS dedicated nozzle

Simulation settings

Defining the simulation in Geant4



- *Hadronic (HAD) :*
  - Elastic collision
  - Inelastic collision => fragmentation
- *Electromagnetic (EM) :*
  - Ionization
  - Coulomb scattering

- Step
- Range cut
- EM table binning

See also a previous study for carbon ions: (Zahra et al. 2010, Physica Medica)

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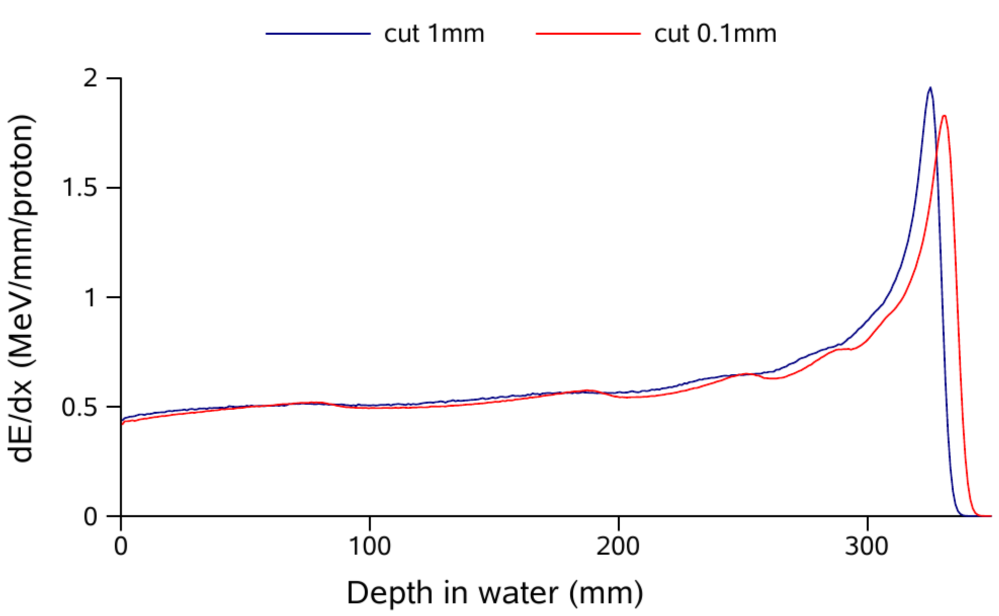
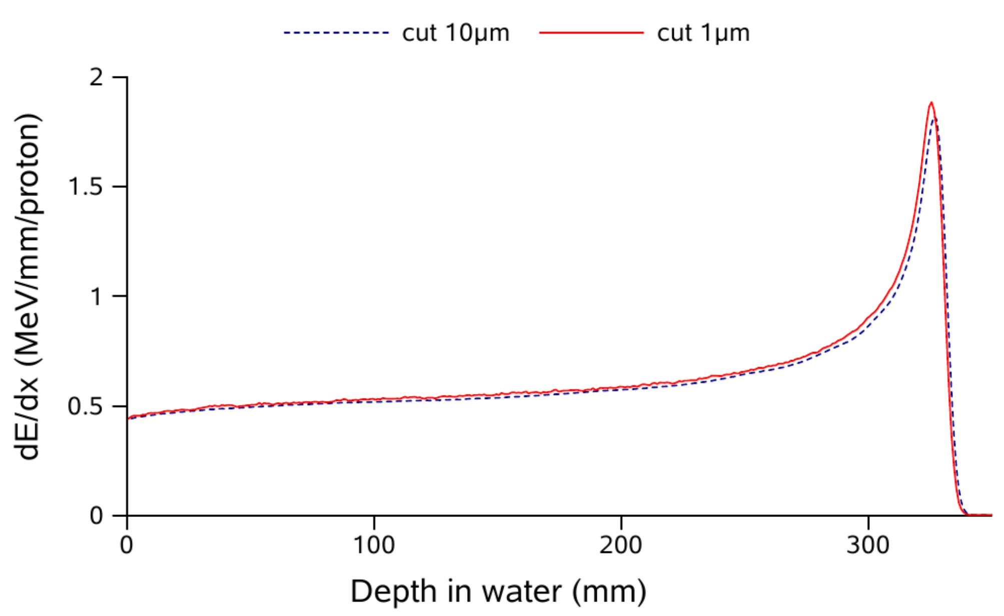
Influence of the simulation parameters (I)

Comparison of pristine Bragg Peak with MC simulation
with a **default binning:** 7 Bins/decade

High cut:
- Fluctuations
- Unstable range
- 6 mm range shift

Low cut:
- No fluctuations
- Stable range
- Still some discrespancies





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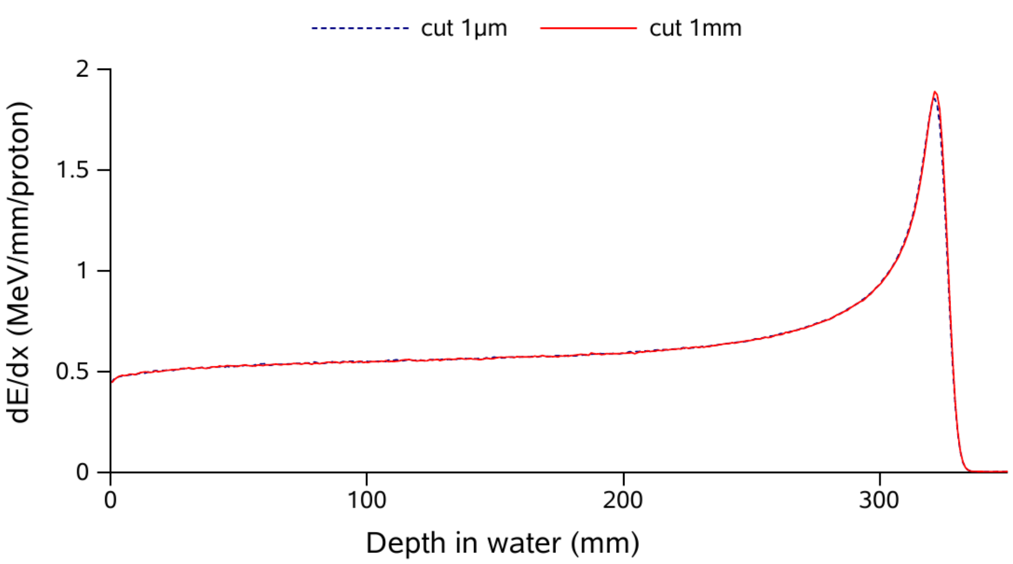
Influence of the simulation parameters (II)

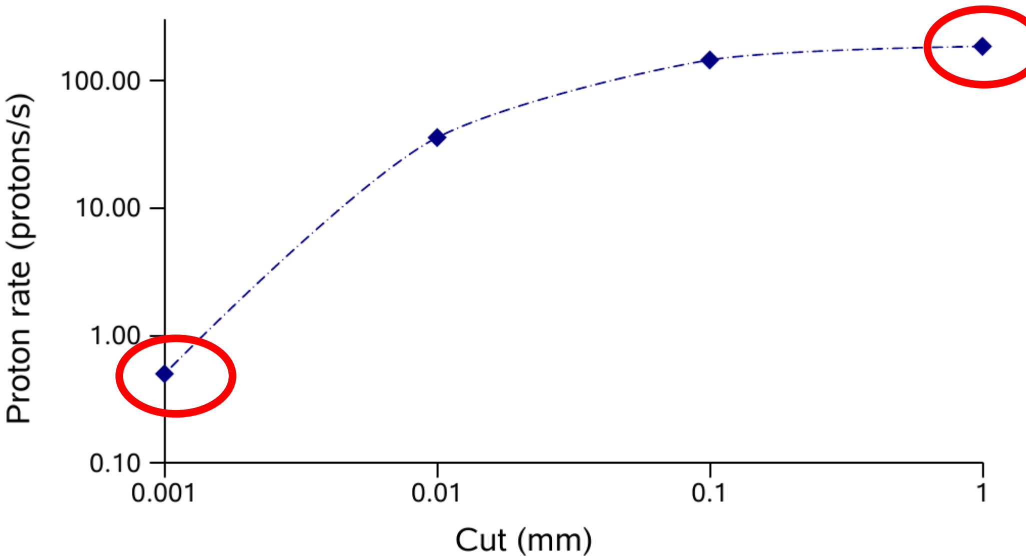
Comparison of pristine Bragg Peak with MC simulation
with a **high binning:** 50 Bins/decade

- No fluctuations
- Stable range
- Immune to step and cut variations

- Optimisation of simulation time (T) and efficiency (η)



Simulation time



➔ **Robust parametrization!**

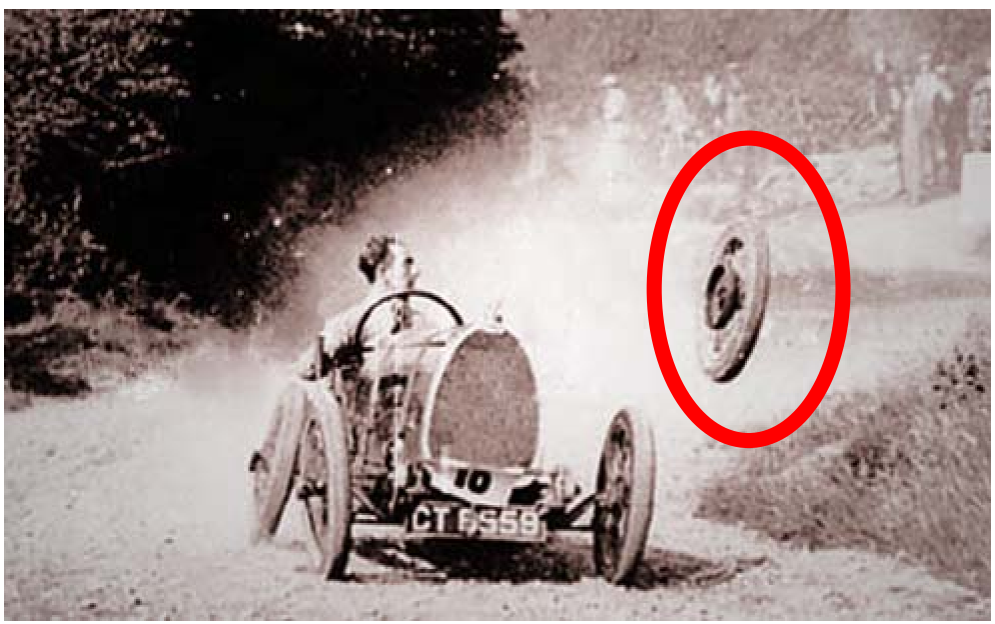
1mm vs. 1µm cut values:
=> 350 times faster!
=> 430 times more efficient!

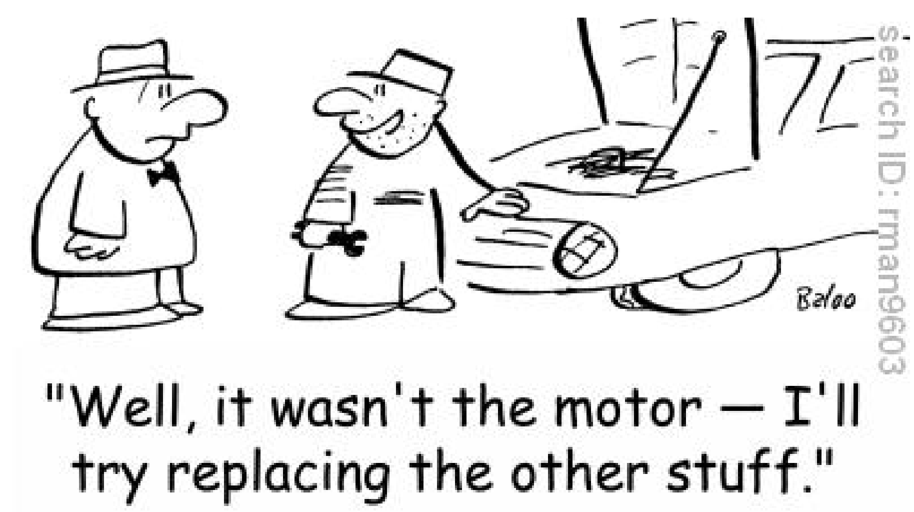
Influence of the simulation parameters (III)

Simulation parameters are numerous,

not always physical,

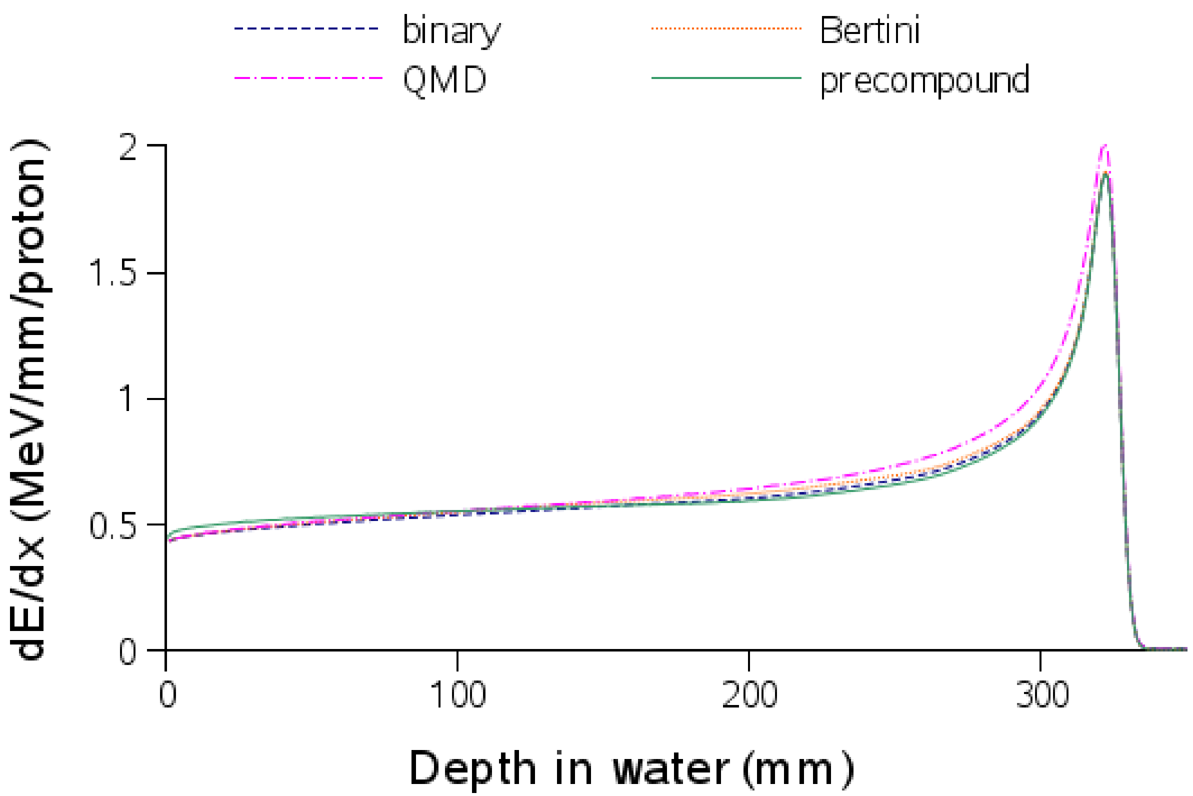
but are however of primary importance!





Physical processes

- Electromagnetic: **standard EM** library
- Hadronic elastic: G4UHadronElasticProcess
- Hadronic inelastic: **Precompound** model

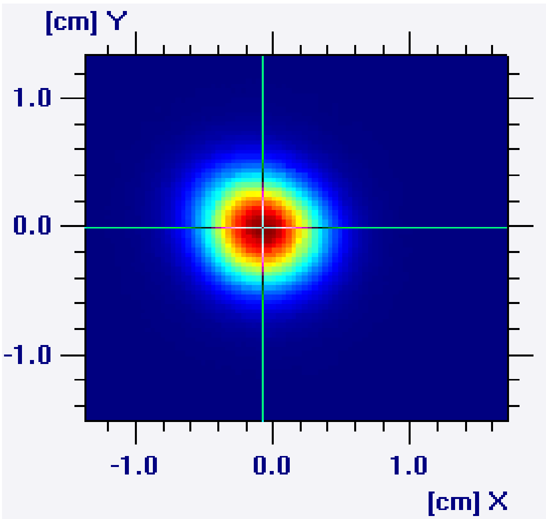


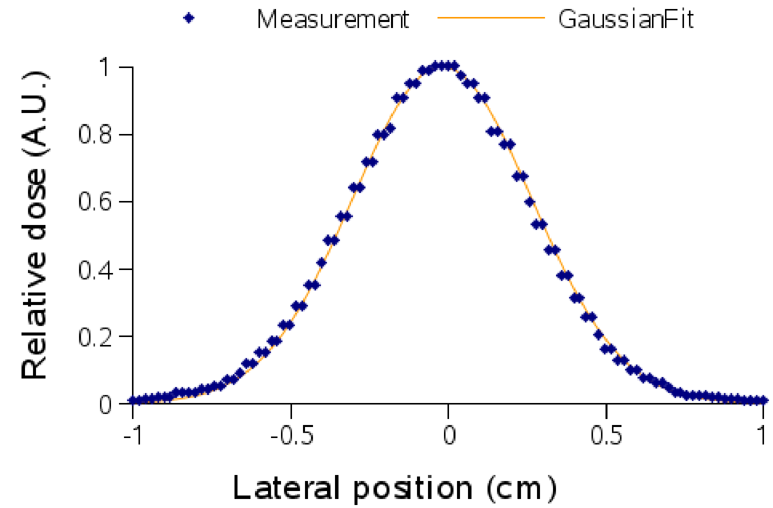
Key references : *C. Z. Jarlskog and H. Paganetti., IEEE Trans. Nucl. Sc. 2008*
S. W. Peterson et al. PMB 2009
J. C. Polf et al. PMB 2009

Experimental validations

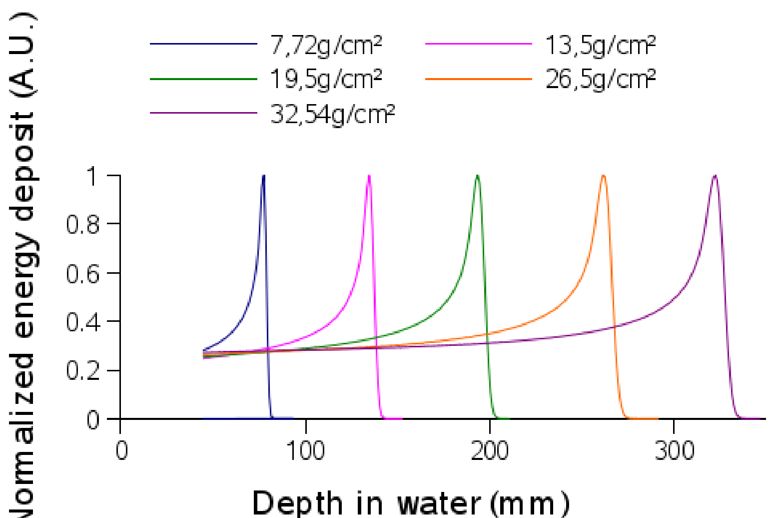
A Monte Carlo pencil beam model

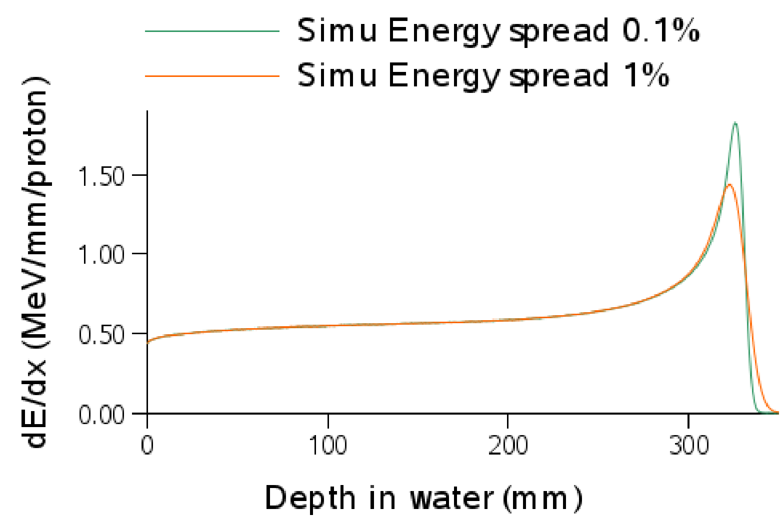
- **Gaussian spot size:** adjusted over reference measurements in air at isocenter





- **Gaussian energy spread:** adjusted over reference measurements in water





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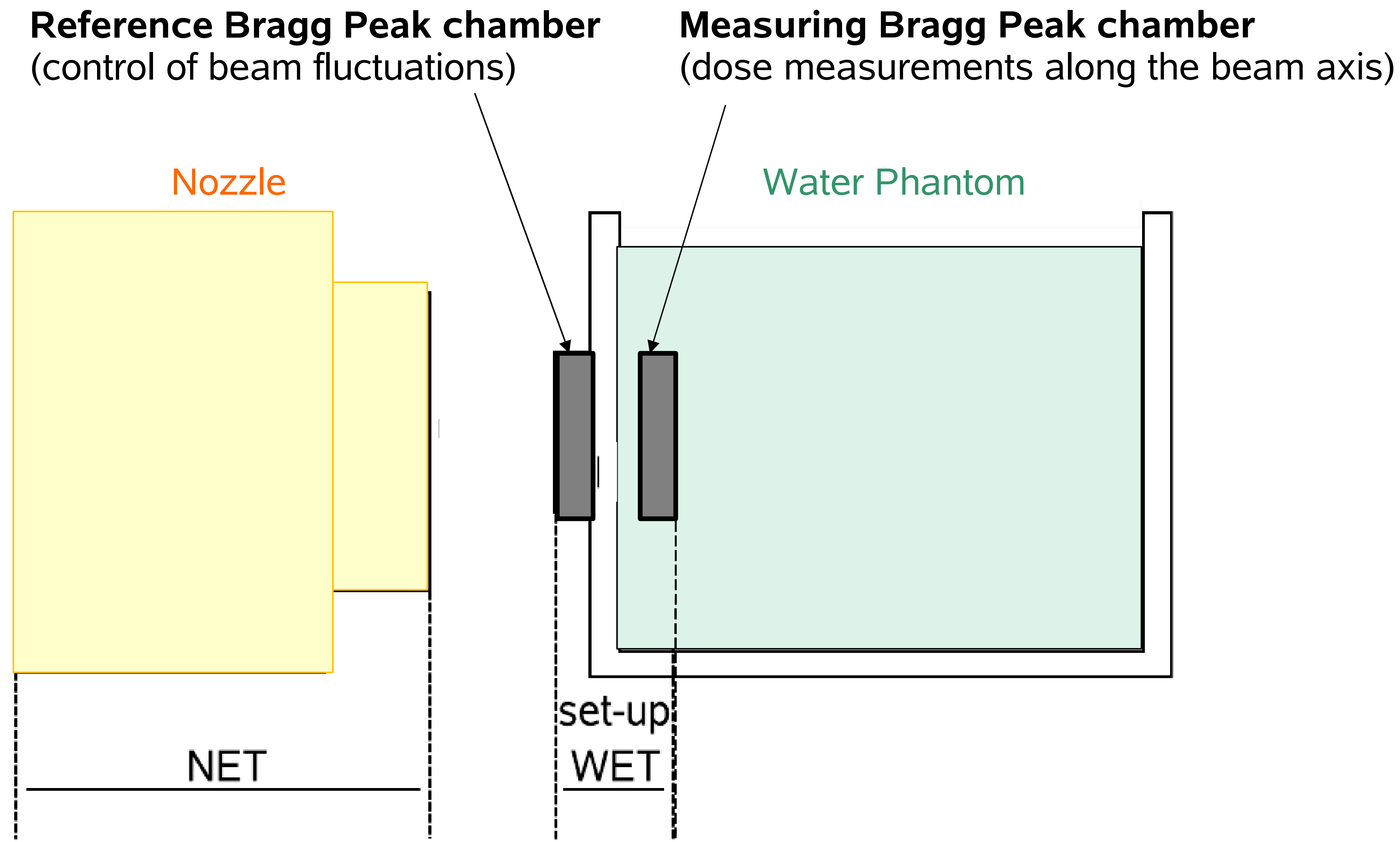
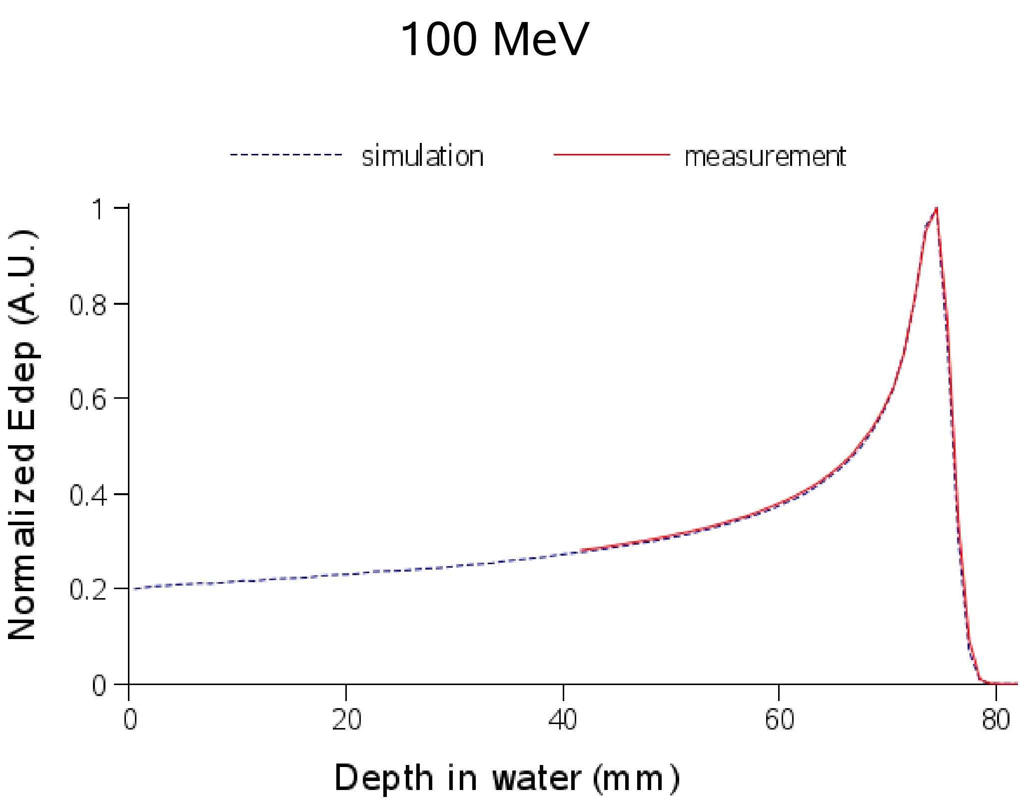
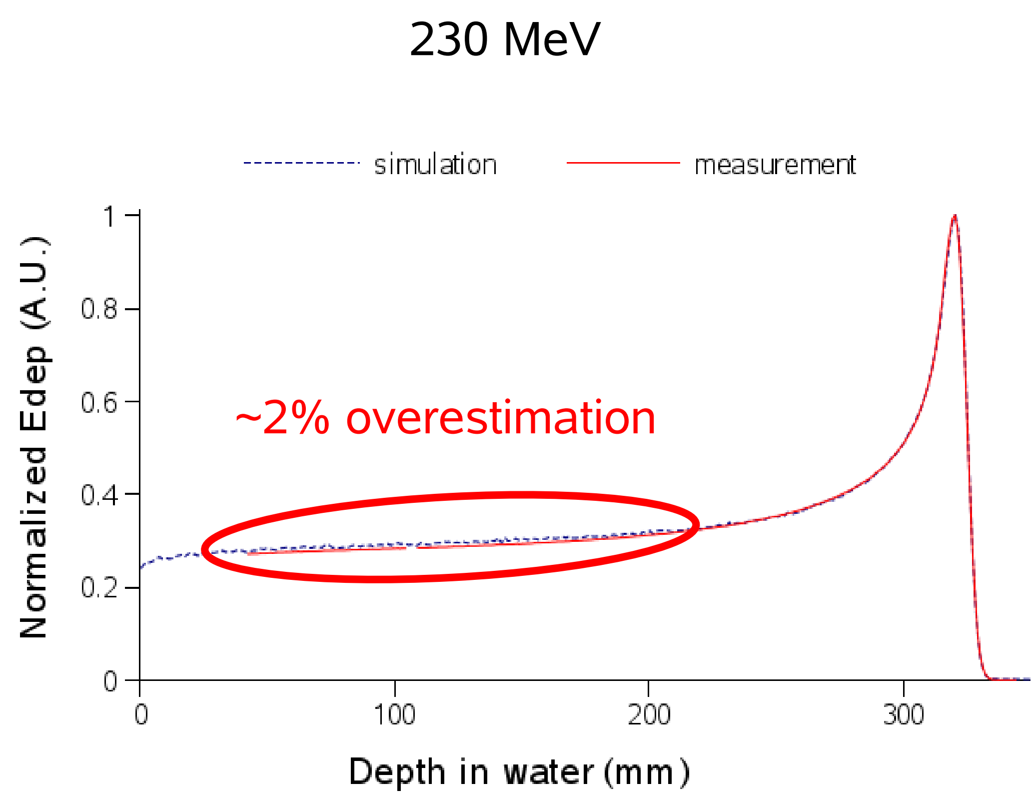
Experimental setup for depth-dose measurements in water



Setup corrections: Nozzle Equivalent Thickness (NET) : beam modification due to nozzle components
Water Equivalent Thickness (WET) : beam modification due to the chambers and phantom wall

Depth dose profiles in water

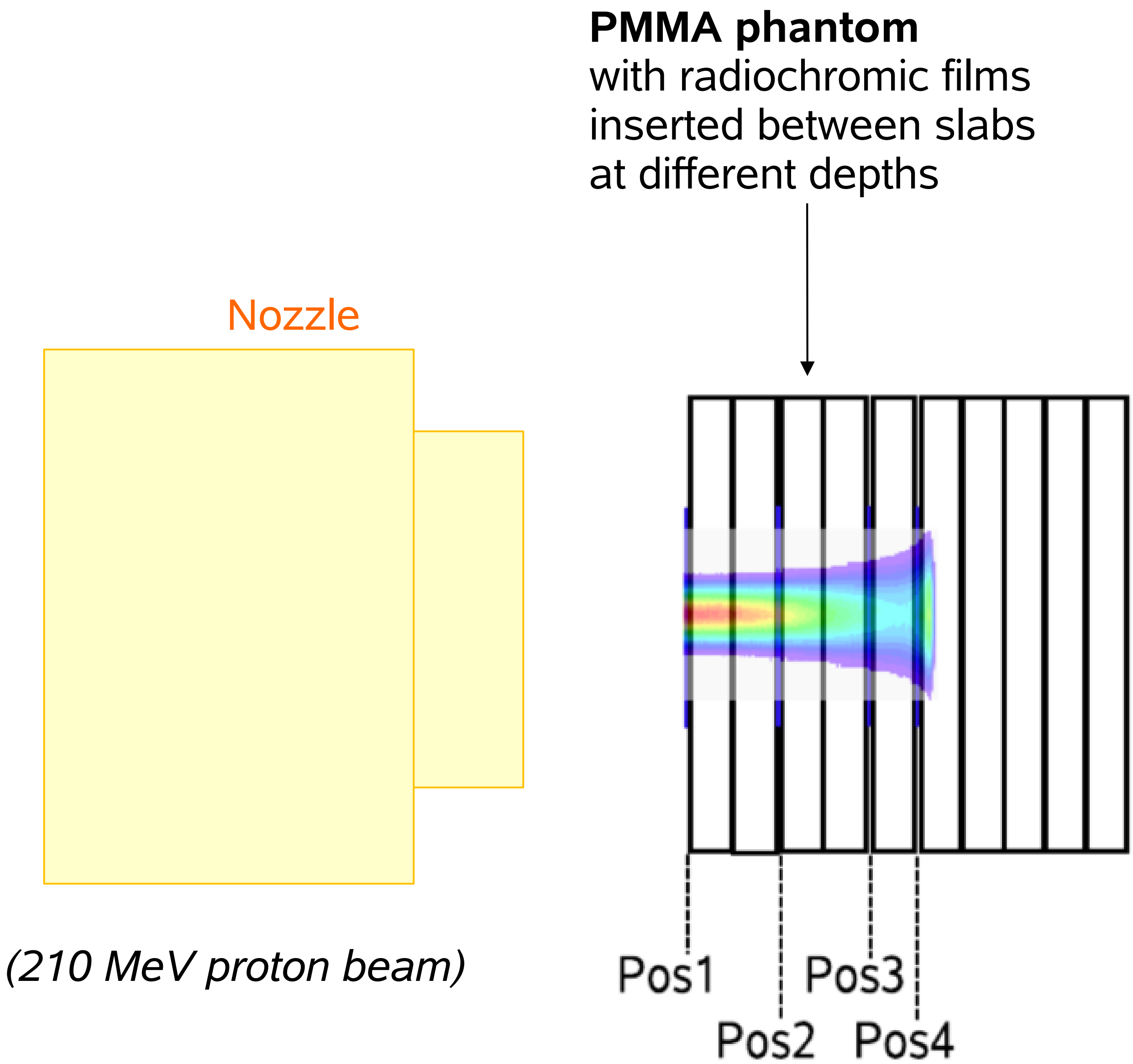




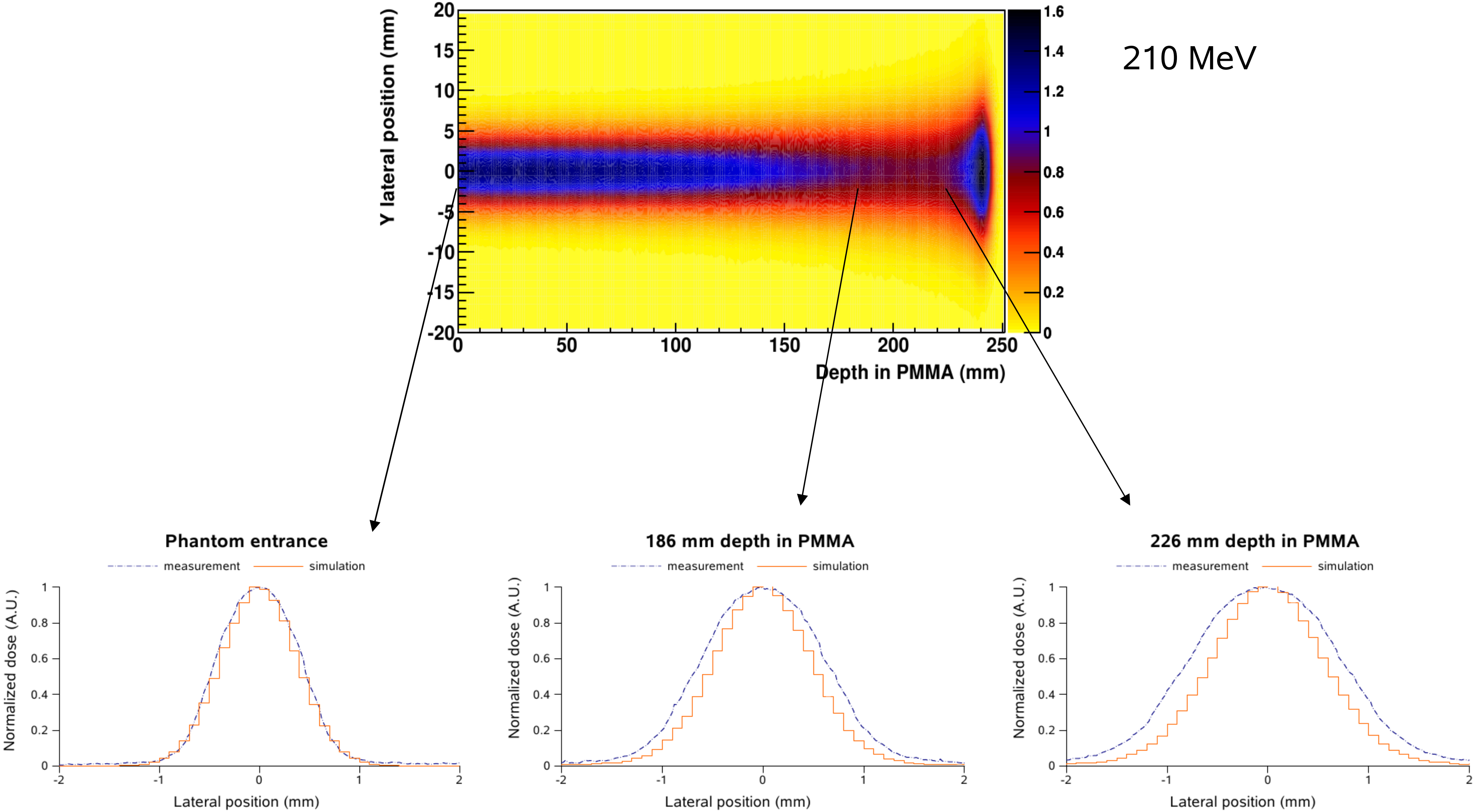
Comparisons:

	Mean deviation	~ 1%
	Range accuracy	~ 0.3 mm (compared to NIST PSTAR database)

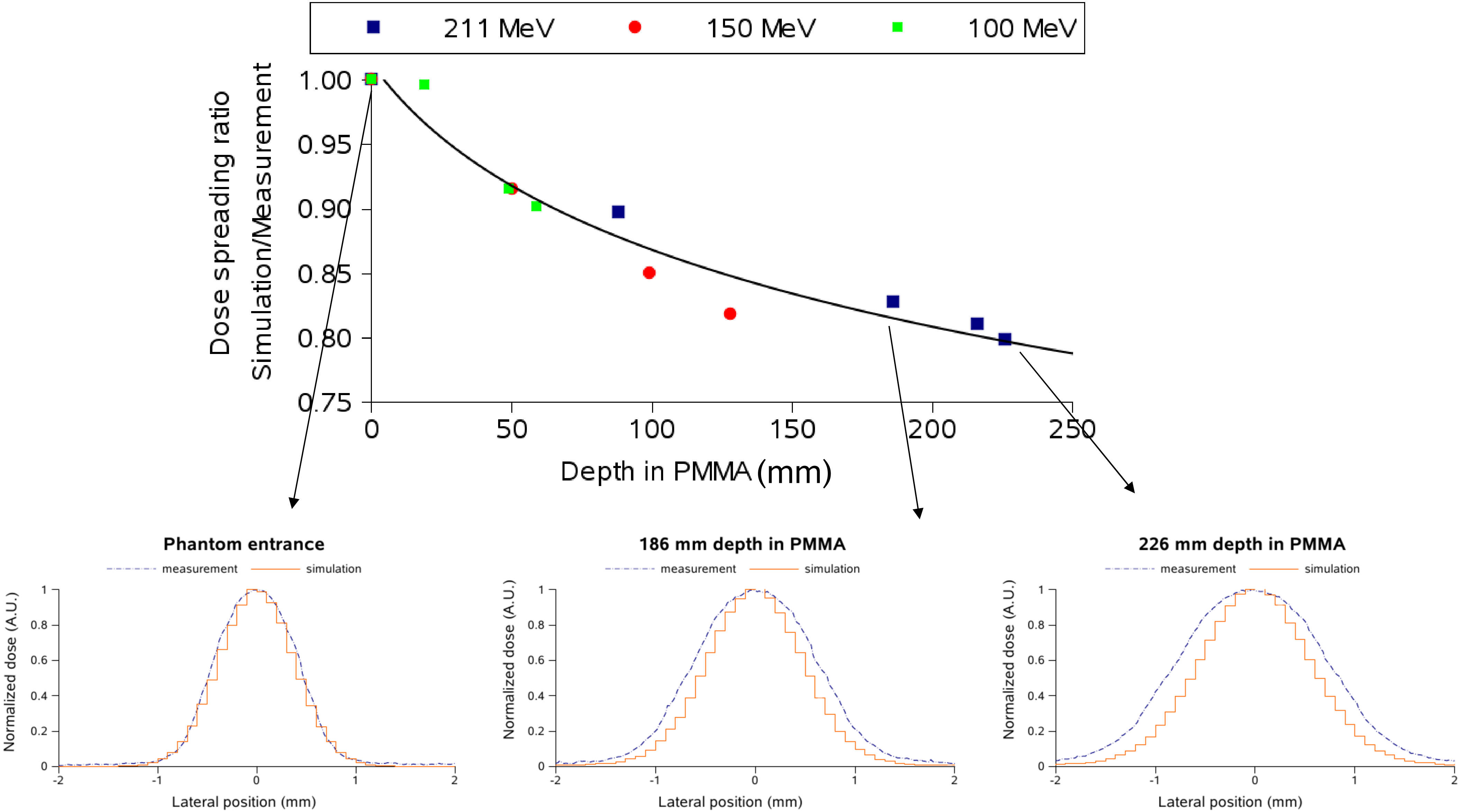
Experimental setup for transverse measurements in PMMA



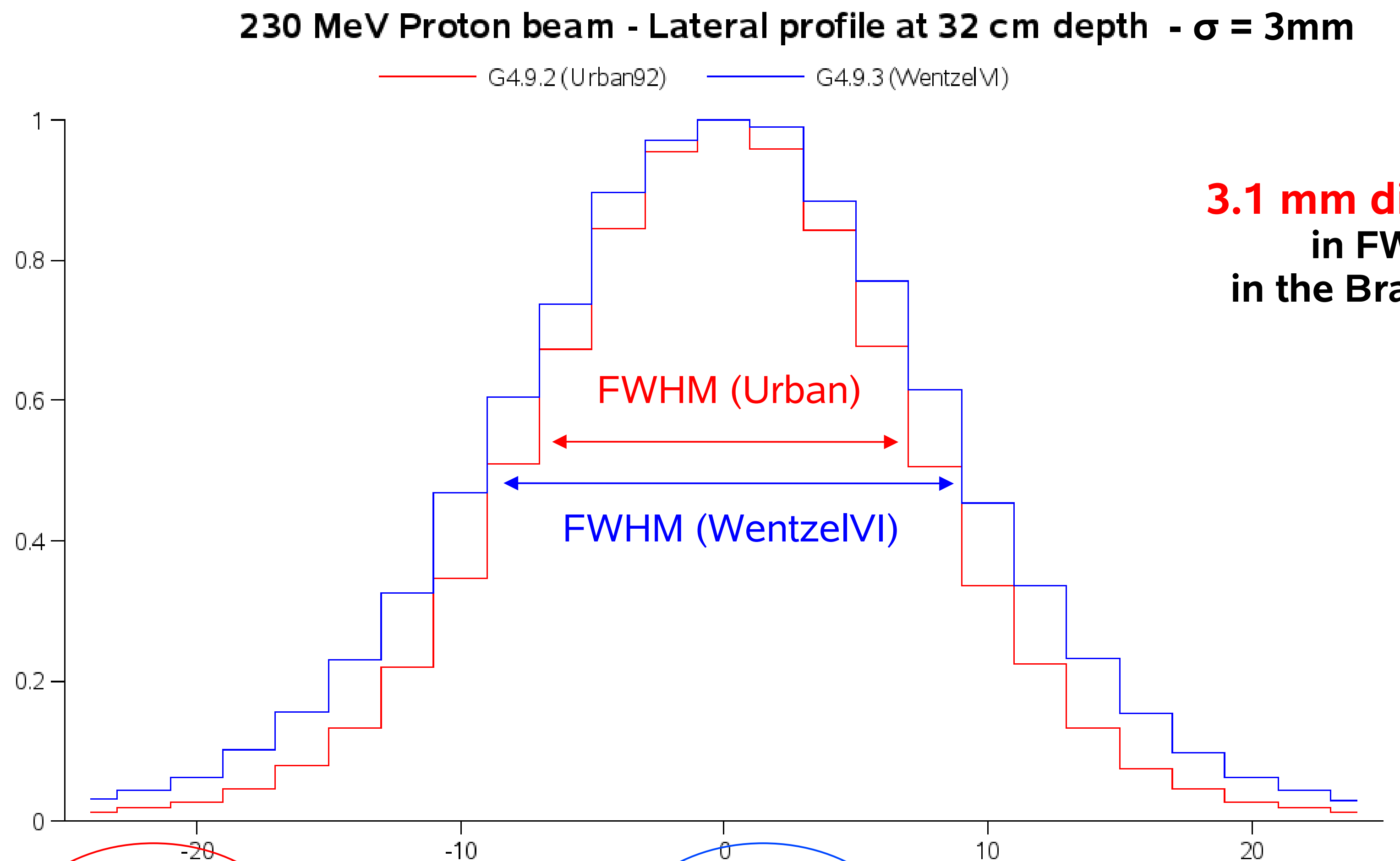
Transverse profiles in PMMA



Transverse profiles in PMMA



Additional comparisons in water



Szymanowski et al., Med Phys 2001

	Geant4.9.2 Urban92 MS model	Geant4.9.2 Coulomb Scattering SS model	Geant4.9.3 WentzelVI MS model	MCNPX2.5.0 MS model	PHITS2.14 MS model	Szymanowski Analytical
$FWHM_{32cm}$ (mm)	16.2	17.6	19.3	19.0	17.2	18.3

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Conclusion

- **Importance of preparing Monte Carlo simulation**
  - Simulation translates reality (measured databases) and theoretical physics (models) into the computing world: this inherently yields some deviations to be assessed and minimized
  - Every MC code has its own methodology, that needs to be understood before entering into complex simulations

- **Validation of the simulation environment for pencil proton beams**
  - 🙂 Integral depth-dose of pristine Bragg peaks : **mean error ~ 1%**
  - 🙂 Range comparison with NIST PSTAR database : **0.3 mm accuracy**
  - ☹ Transverse profiles in materials: large discrepancies between simulations and measurements… but also between different MC codes: **multiple scattering still poorly accounted for**

  => Currently the limitting factor for dosimetric accuracy

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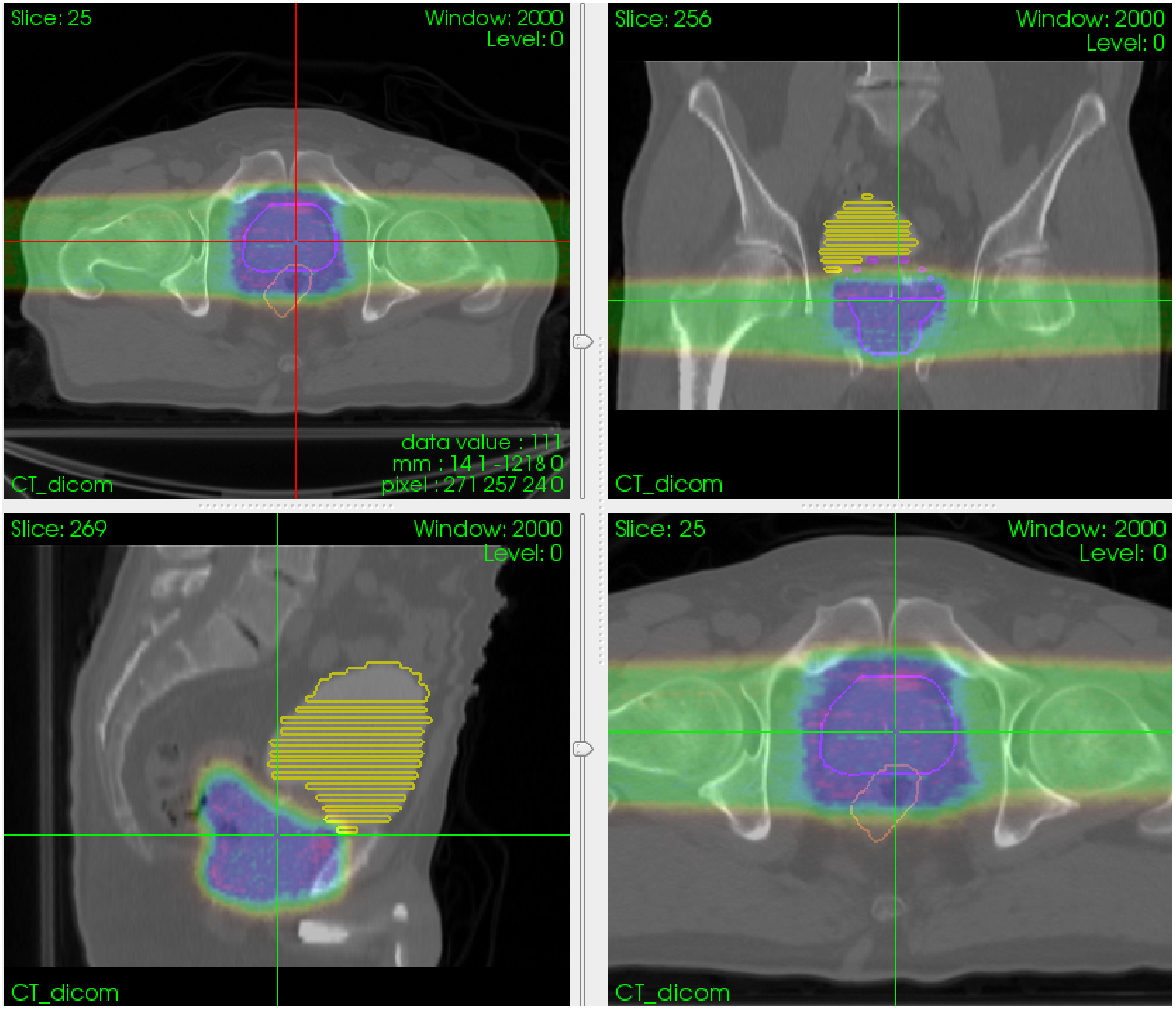
Perspectives

- Deeper investigations of the transverse profile issues
- Preparations towards patient dose calculation
  - HU to tissues conversion
  - Treatment plan processing
  - PBS model validation
  - …
- Treatment plan computations and dose comparisons between GATE/Geant4 and Xio.



Thank you!

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Nicolas Freud
Thibault Frisson
Nabil Zahra

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Damien Betrand
Frédéric Stichelbaut

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The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 215840-2.