

GATE/GEANT4 AS A MONTE CARLO SIMULATION TOOLKIT FOR LIGHT ION BEAM DOSIMETRY

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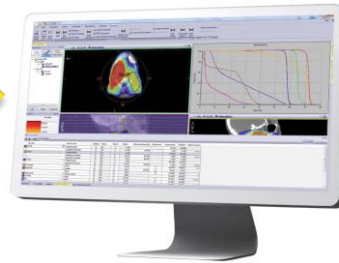
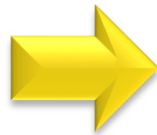
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Motivation

End-to-end testing

- Logistic chain of RT treatment using a phantom containing dosimeters (IC and alanine)
- Alanine dosimetry performed in collaboration with the National Physics Laboratory (NPL) as a **dosimetry auditing** tool



- Several parameters for dose calculation need to be determined

PURPOSE OF THIS WORK:

To use GATE/Geant4 as a toolkit for ion beam dosimetry (protons and carbon ions)

Main focus on the calculation of:

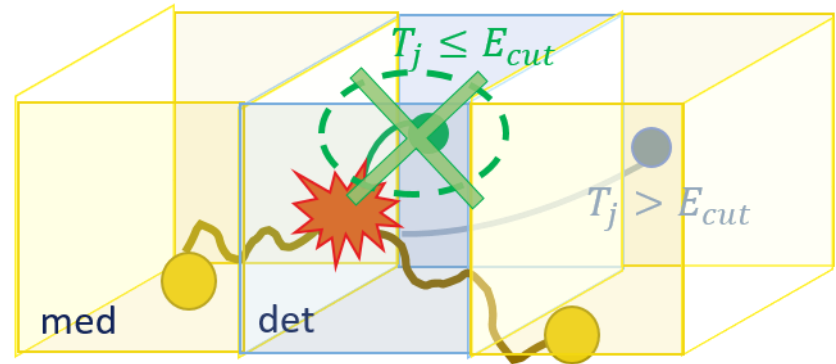
Water-to-medium stopping power ratio (SPR)

Relative effectiveness (RE) of solid-state detectors

Materials and methods

SPR and relative effectiveness determination

❖ “GateRTion 1.0” based on GATE 8.1 and GEANT4 10.03.p03

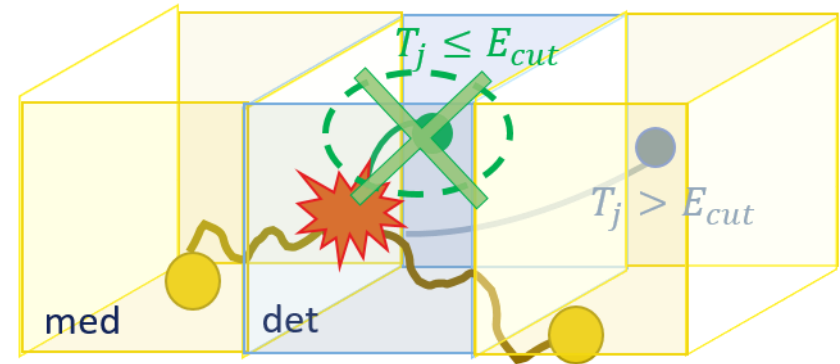


Materials and methods

SPR and relative effectiveness determination

❖ "GateRTion 1.0" based on GATE 8.1 and GEANT4 10.03.p03

$$S_{med,det} = \frac{(E_{dep})_{med} / m_{med}}{(E_{dep})_{med} / m_{med} \left(\frac{(S/\rho)_{det}(T_j)}{(S/\rho)_{med}(T_j)} \right)} =$$

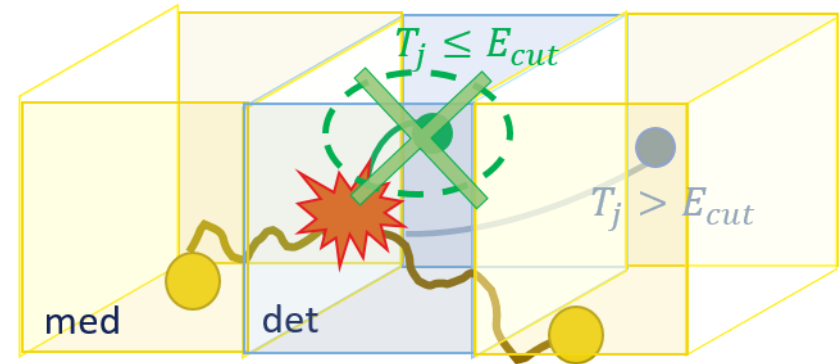


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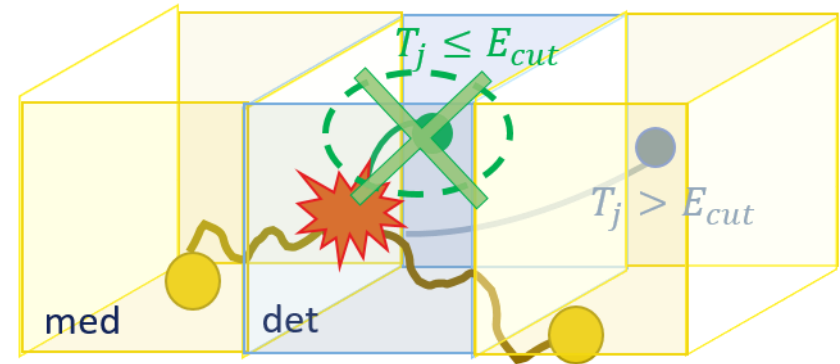
$$\frac{\frac{1}{m_{med}} \left[\sum_{j=0}^N e_j \right]_{T_j > E_{cut}} + \frac{1}{m_{med}} \left[\sum_{j=0}^N T_j \right]_{T_j \leq E_{cut}}}{\frac{1}{m_{med}} \left[\sum_{j=0}^N e_j \frac{(S/\rho)_{det}(T_j)}{(S/\rho)_{med}(T_j)} \right]_{T_j > E_{cut}} + \frac{1}{m_{med}} \left[\sum_{j=0}^N T_j \frac{(S/\rho)_{det}(E_{cut})}{(S/\rho)_{med}(E_{cut})} \right]_{T_j \leq E_{cut}}}$$

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Continuous energy loss $e_j = S_w \cdot \Delta s_j$

S_w = stopping power

Δs_j = track length

! Small stopping power variation along the step !

Materials and methods

SPR and relative effectiveness determination

$\eta_{\text{aln}}(E_j, Z_i)$ as published by R. Herrmann [PhD thesis]
based on “Hansen and Olsen model”

❖ “GateRTion 1.0” based on GATE 8.1 and GEANT4 10.03.p03

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$$\bar{\eta}_{al} = \frac{\frac{1}{m_w} \left[\sum_{j=0}^N e_j \eta_{aln}(E_j, Z_i) \frac{(S/\rho)_{al}(T_j)}{(S/\rho)_w(T_j)} \right]_{T_j > E_{cut}} + \frac{1}{m_w} \left[\sum_{j=0}^N T_j \eta \frac{(S/\rho)_{al}(E_{cut})}{(S/\rho)_w(E_{cut})} \right]_{T_j \leq E_{cut}}}{D_{al}}$$

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For comparison, RE calculations were also done using:

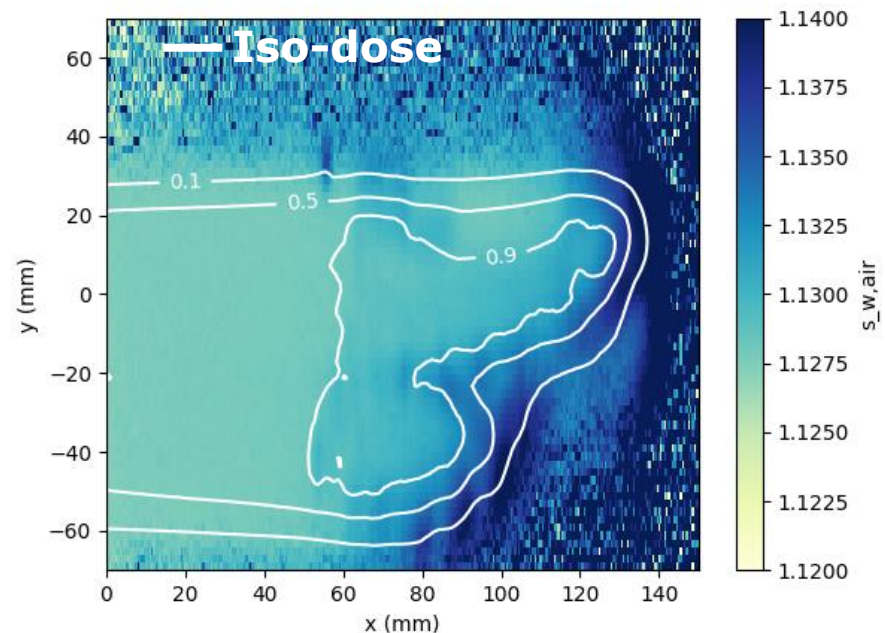
❖ Proton Monte Carlo dose engine of the RaySearch (RS) Treatment Planning System (TPS) (v5.99.50 research version)

Results

Water-to-air SPR (protons)

→ $I_w = 78\text{eV}$

- Treatment plan verification at MA:
 - Patient plan is delivered to a water phantom
 - The dose deposited is measured at different positions with a 3D block of 24 PinPoint IC.
- 1.3% variation in water-to-air SPR



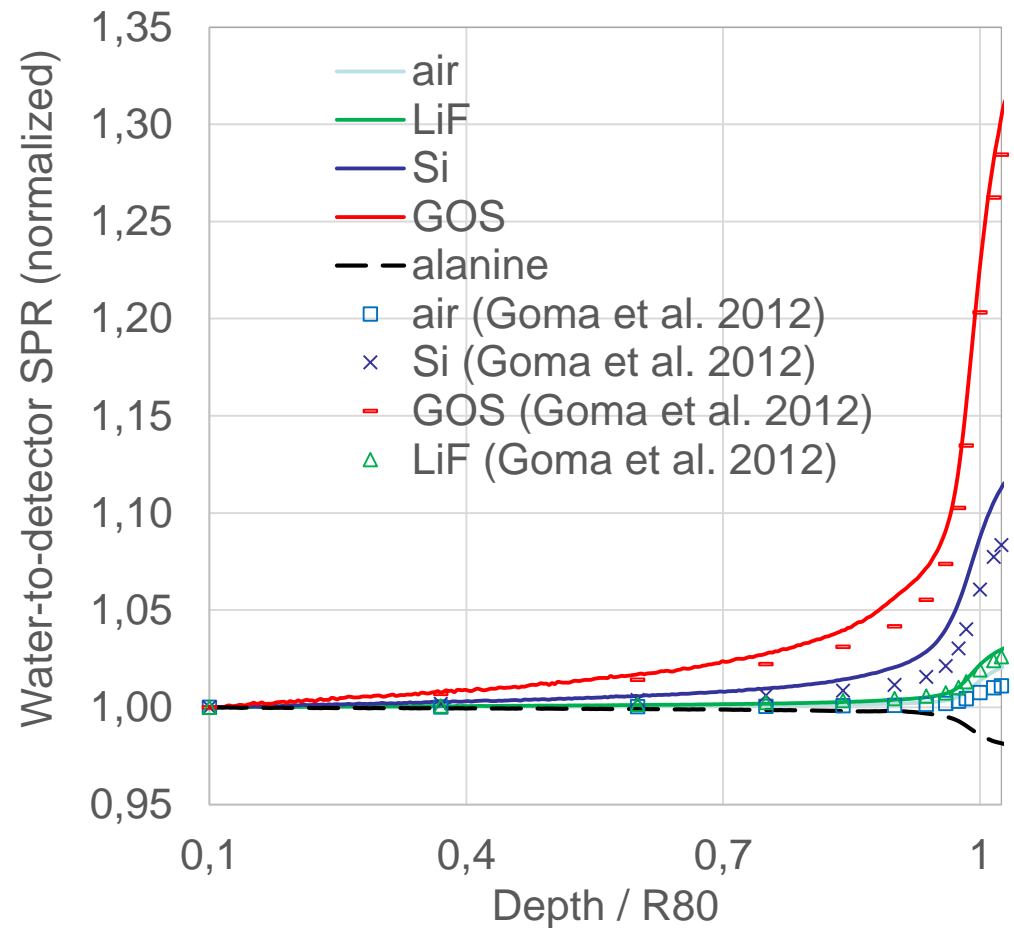
Results.

Water-to-detector SPR (protons)

- Comparison of literature data with GATE calculations

→ 150 MeV proton beam

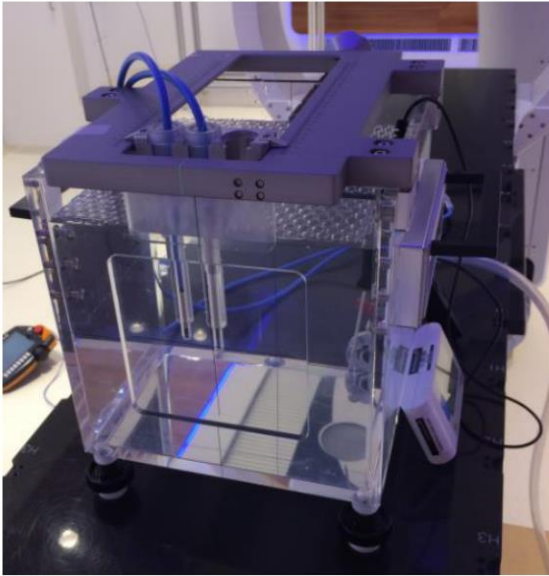
→ 0.5-2.5% difference



Results

Alanine detectors (protons)

- Water phantom



Experimental data from proton beam commissioning at MedAustron 2016/2017

Carlino, A., et al. PMB 63.5 (2018): 055001.

NPL Report IR 48

Ableitinger, A., et al. Radiotherapy and Oncology 108.1 (2013): 99-106.

Results

Alanine detectors (protons)

- Water phantom

	SPR	RE		
	GATE	RS	GATE	Deviation
Square field E=179.2 MeV (entrance)	1.019	1	1.00092	-0.10%
Box $R_{res} = 4\text{cm}$	1.015	0.9908	0.9891	0.18%
Box $R_{res} = 2\text{cm}$	1.014	0.9824	0.9810	0.14%

- Statistical uncertainty in GATE less than 1%
- RE uncertainty $\sim 2.5\%$

Results

Alanine detectors (protons)

- Water phantom

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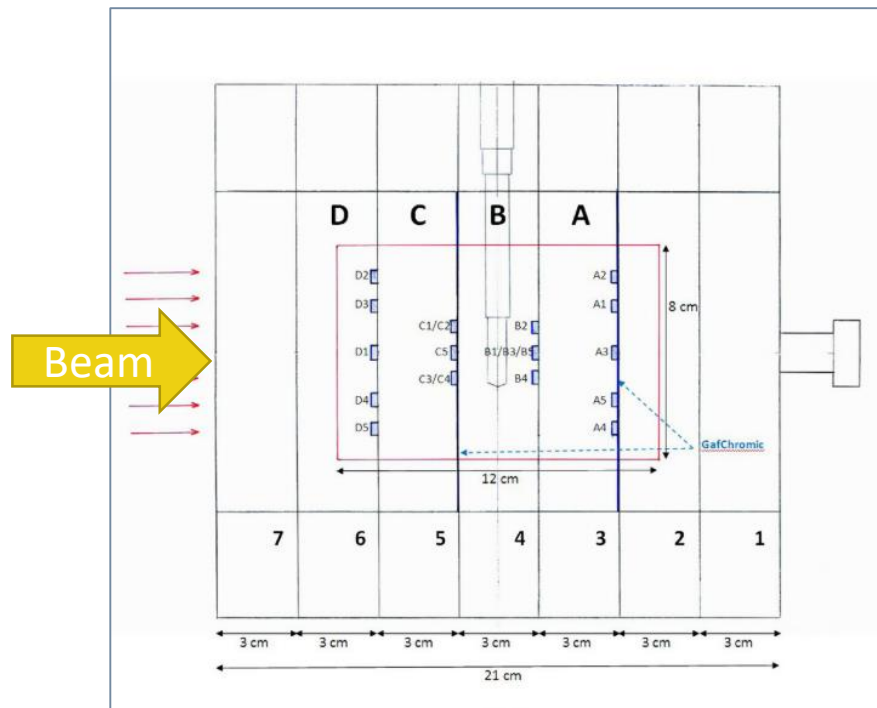
- Comparison of alanine and IC dosimetry using RE calculated with RS or GATE

	Deviation (RS)	Deviation (GATE)
Square field E=179.2 MeV (entrance)	0.61%	-0.34%
Box $R_{res} = 4\text{cm}$	-0.30%	-0.42%
Box $R_{res} = 2\text{cm}$	-1.24%	-0.91%

Results

Alanine detectors (protons)

- Polystyrene phantom



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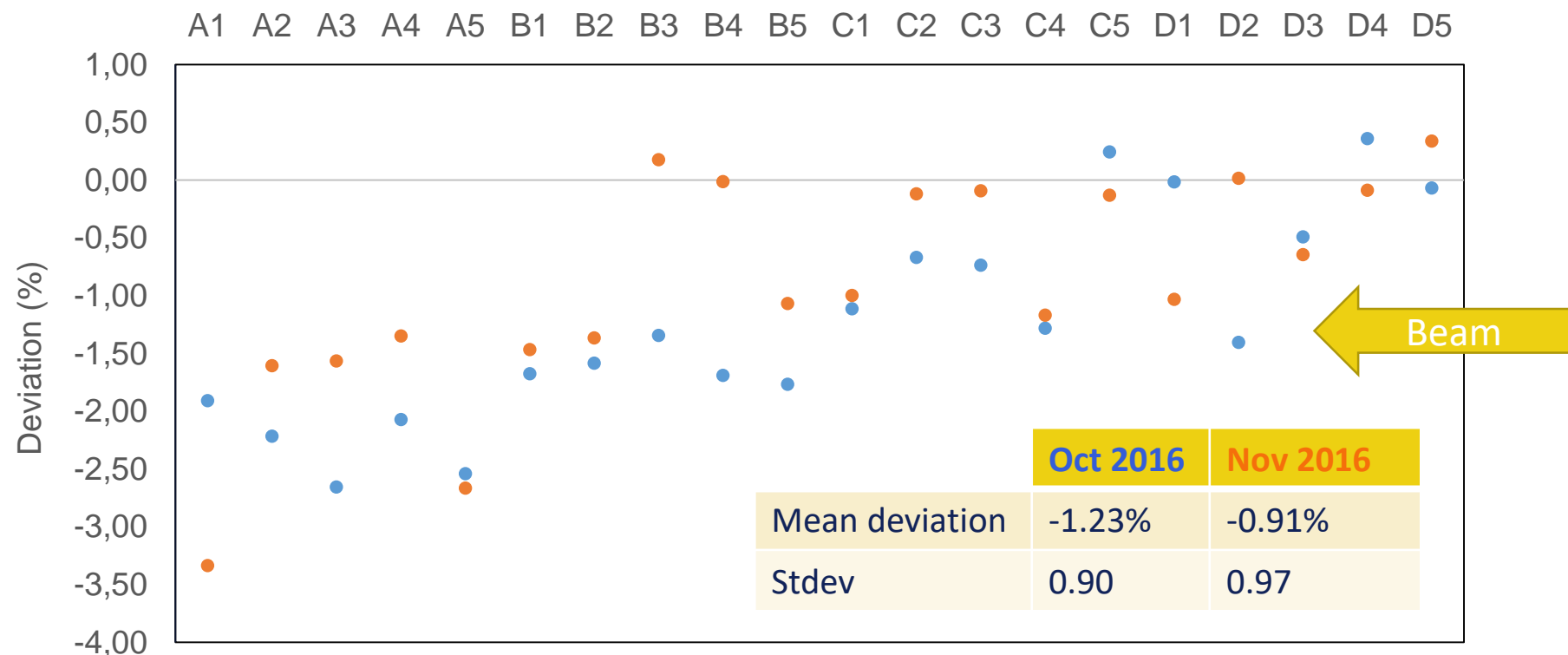
NPL Report IR 48

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Results

Alanine detectors (protons)

- Polystyrene phantom
- Comparison of alanine and IC dosimetry using RE calculated with GATE



Conclusions and perspectives

- Relative effectiveness and stopping power ratio tools were successfully implemented
 - Improvement of RE tools started during Gate Hackathon yesterday!!
- Water-to-medium SPR results for protons has been compared with literature data
- Validation of the RE implementation based on commissioning measurements at MedAustron and comparison with RS was done
 - it will be extended to anthropomorphic phantoms
- Application of these tools to carbon ion end-to-end testing is ongoing
- The use of ICRU 90 for GATE calculations is foreseen

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V. Ivantchenko (CERN)
Geant4 Collaboration

GATE Collaboration

Thanks for your attention