IDEAL/GATE-RTion for independent dose calculation in carbon ion beam therapy

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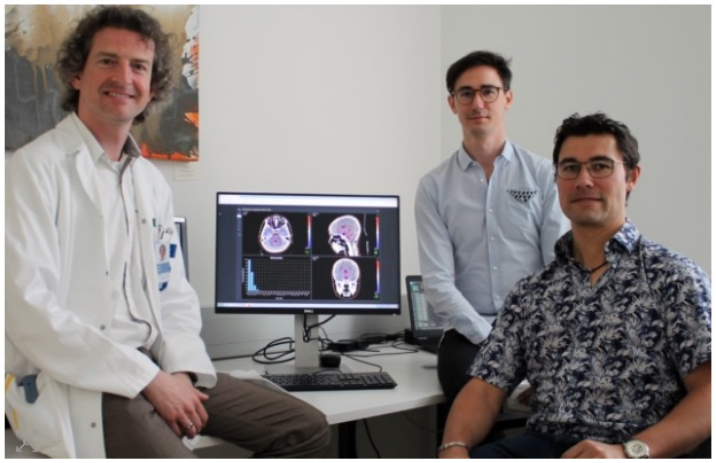
Motivation & Purpose

- Patient specific quality assurance (PSQA)
  - Time consuming measurements:
    - 2023: 350 h/year ≈ 25 treatment days/year for carbon ions
- Goal: replace PSQA by independent dose calculation (IDC) without loss of quality control
  - ✓ **Protons**: measurement time reduction by -87% (2021) ✓
  - ✗ **Carbon ions**: ongoing IDEAL project ✗

Reimagining patient-specific QA in proton and ion therapy facilities

26 May 2021 Sponsored by IBA Dosimetry

Medical physicists from the Austrian particle therapy centre MedAustron explain how – and why – they've put an independent QA solution at the heart of their patient treatment programme



In use since February 2021

First worldwide clinical user of myQA iON for protons!

Purpose:
Develop Independent Dose Calculation System for Light Ion Beam Therapy

GATE-RTion/IDEAL

frontiers in Physics

ORIGINAL RESEARCH
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The GATE-RTion/IDEAL Independent Dose Calculation System for Light Ion Beam Therapy

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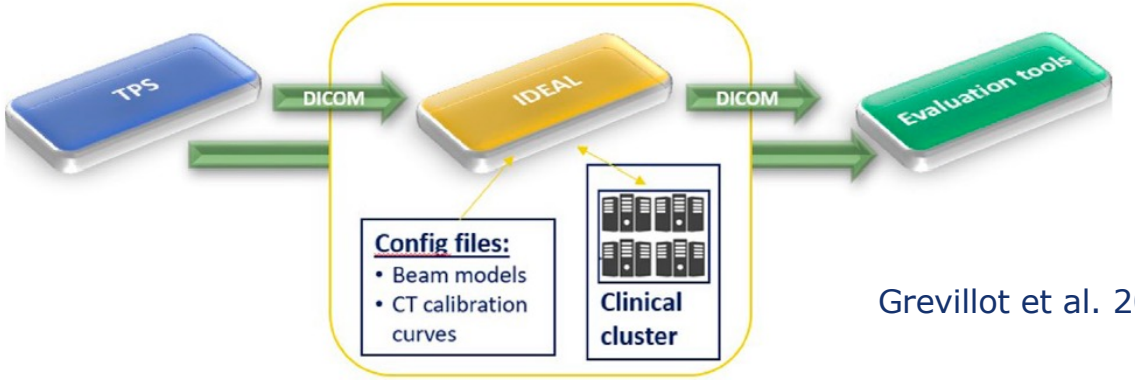
- GATE-RTion:
  - Calculation engine behind IDEAL
  - Uses macro files as input such as GATE
  - New release requires intensive verification process
    - v1.0 well validated: >9 publications using the same version
    - Release cycle ~5 years
- IDEAL/Independent Dose Calculation System for Light Ion Beam Therapy
  - DICOM in / DICOM out
    - Retrieves all information from DICOM, sets up MC simulation and post-processes output automatically
    - Open source: https://github.com/OpenGATE/IDEAL



Grevillot et al. 2021

FIGURE 1 | High level workflow of IDEAL. It shows that IDEAL was conceived in a DICOM-in/DICOM-out fashion, to ease the use of GATE-RTion for IDC in LIBT.

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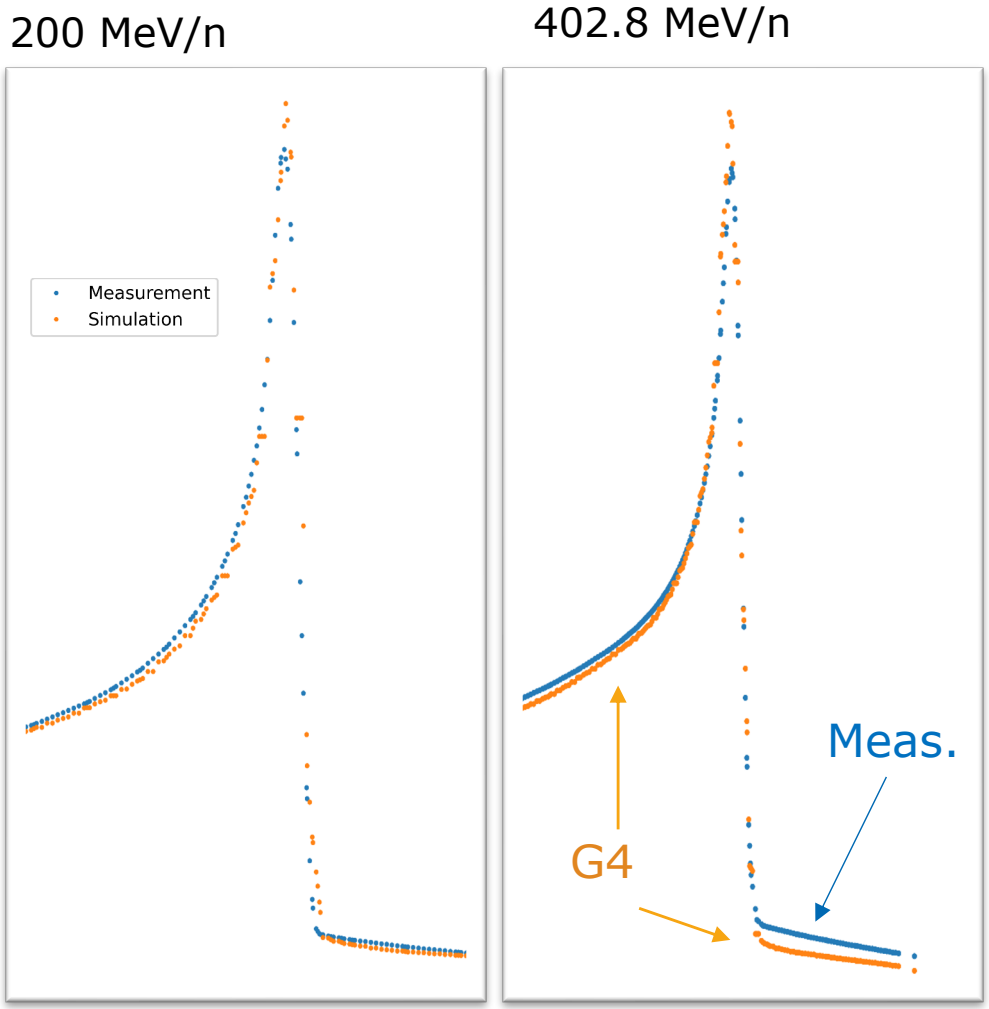
IDEAL/GATE-RTion v1.0 commissioning results
Carbon ion beams

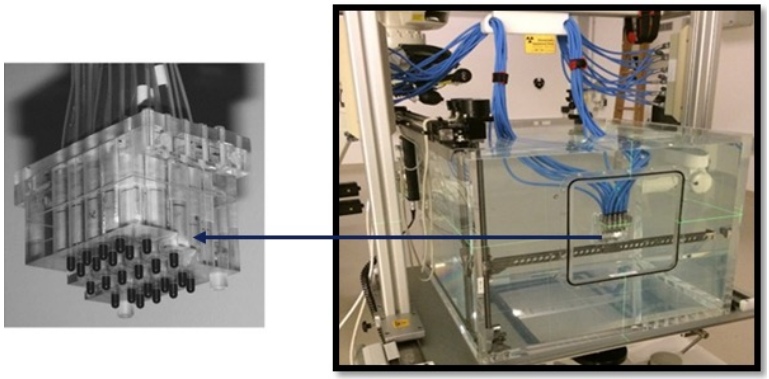
- Commissioning results
  - Beam ranges in water $\Delta_{R80} \leq 0.3\,mm$
  - Peak widths $\Delta_{W50} \leq 0.3\,mm$
  - Spot sizes in air $\Delta_{FWHM} < 8\,\%$
  - HU to material conversion $\overline{\Delta_{\rho_m}} < 0.1\,\%$
- Single energies
  - Notable local dose deviations (tail)

  ➔ Better agreement in more recent/future Geant4 versions?
- Spread out Bragg peaks, local dose deviation
  - Per plan $\overline{\Delta_{all}} \leq 2\,\%$
  - Within target $\overline{\Delta_{SOBP}} < 1\,\%$



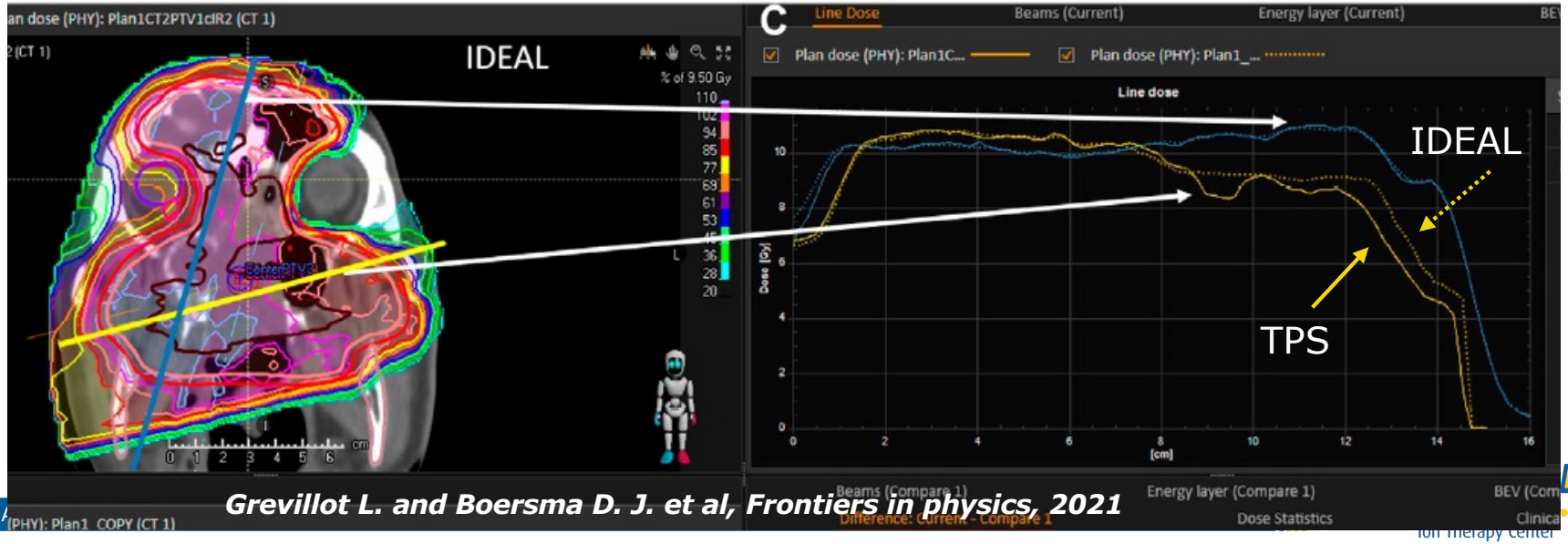
Patient Specific Quality Assurance (PSQA)

- Experimental PSQA
  - Measurement in homogeneous water geometry ✓
  - Measurement quantity: dose to water ✓
- Independent dose calculation
  - Dose calculation in patient geometry ✓
  - Clinical quantity: RBE * dose ✗
  - ➔ RBE model needed ✗



Measurement set-up using 3D-block

Such effects are not visible in a water tank! (exp. PSQA)



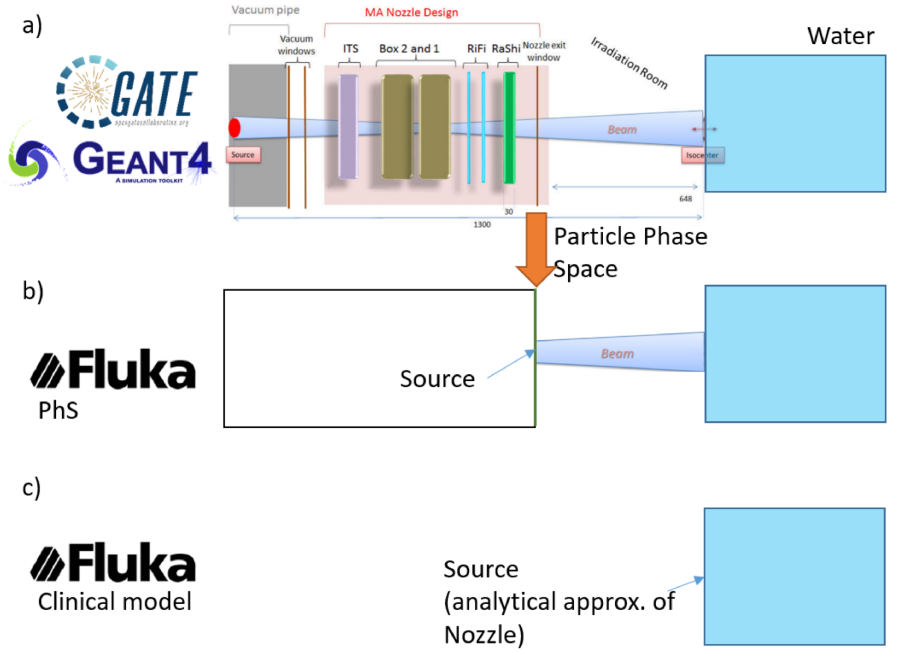
Grevillot L. and Boersma D. J. et al, Frontiers in physics, 2021

Proof of concept: Geant4 for LEM I

RBE study within the TPS

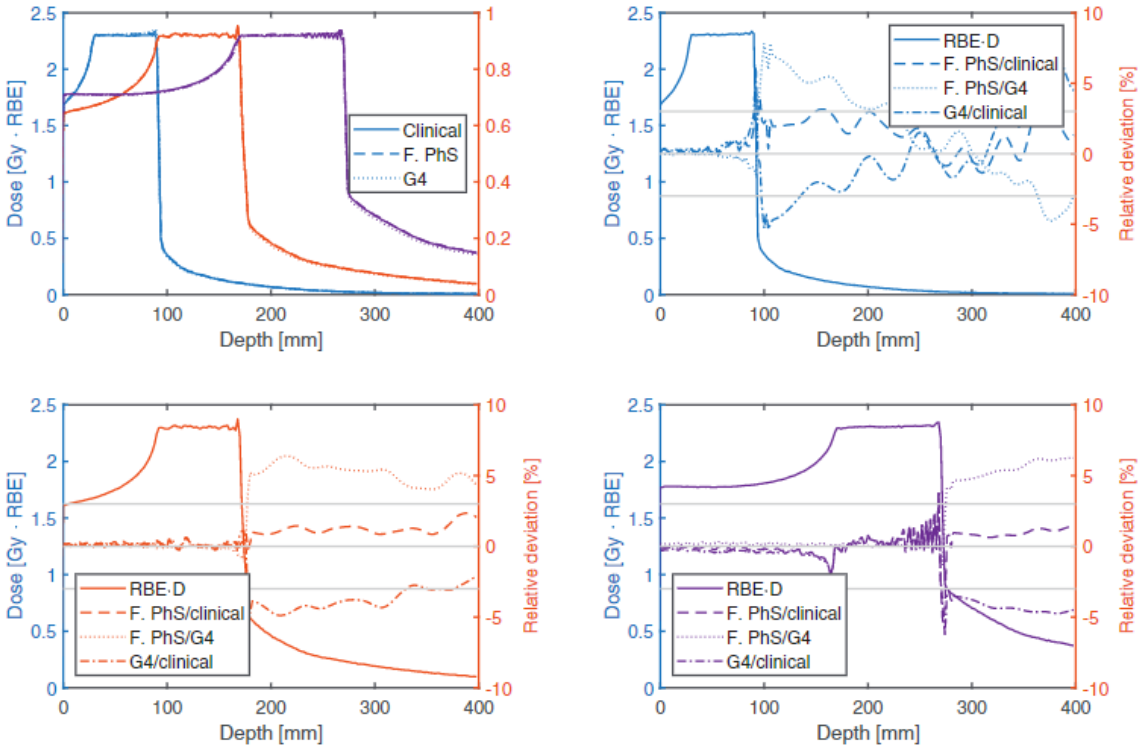
- Fluence tables generated with GATE-RTion or FLUKA (two different setups)
- Evaluated 3 water & 10 patient cases

  ➔ Good agreement of RBE weighted dose $\overline{\Delta_{target}} < 1\%$



Simulation setup

Results



Resch et al. 2022

Next Steps

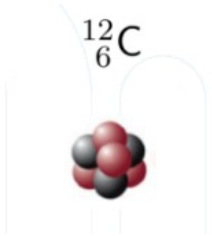
2022/2023: MyDEAL v1: integration of IDEAL v1.0 into myQA iON, IBA Dosimetry

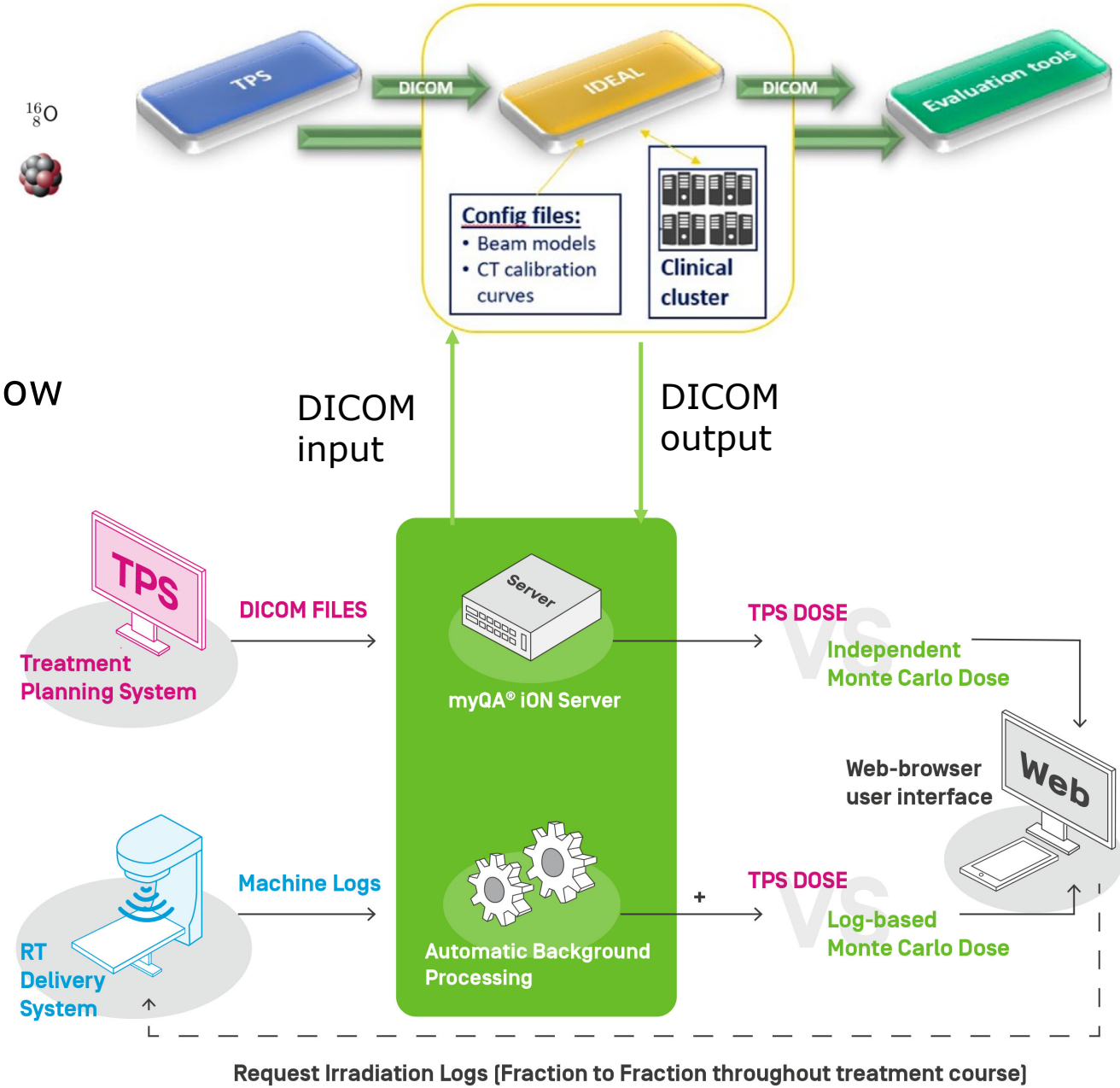
2023/2024: GATE-RTion v2.0

Interfacing IDEAL v1.0 with myQA iON
myDEAL 1.0

- Research workflow

- Towards clinical workflow
  - Develop interface
  - Acceptance tests
  - Commissioning





New features for GATE RTion v2.0

- **Linear energy transfer (LET) calculation**
  - Transfer implementation from GATE ✓
    - See earlier talk Resch et al. "Benchmarking LET …"
- **Source/beam modeling improvements**
  - Movable snout
  - Bind beam model and nozzle geometry ✓
  - Support (energy dependent) dose correction factors ✓
- **Relative biological effectiveness (RBE) models**
  - RBE varies in the order of about 1.5 to 3 in clinical scenarios
  - modified Microdosimetric Kinetic Model (mMKM)
    - Transfer from GATE develop branch ✓
      - See talk Lydia Maigne "Biological dose estimation for proton and carbon ion treatment plans using the GATE platform"
  - Local effect model I (LEM I)
    - Classical approach: Implemented in TPSs
    - Low dose approximation: available e.g. in FLUKA (Mairani et al.)

New architecture for GATE RTion v2.0

- **Simplify use**
  - Replace **macro** interface with **python interface**
    - See talk *David Sarrut and Lydia Maigne*
    - Allows significant simplification of IDEAL v2.0
- **Simplify installation**
  - pip install
- **Automatize & advance verification**
  - Dose
    - Comprehensive measurement set available
    - Multi-center approach?
  - RBE, LET
    - Consistency checks
  - Geometry

  ➔ Simplify code upgrades

Inspired by*: Arce et al. 2021, Report on G4-Med, a Geant4 benchmarking system for medical physics applications developed by the Geant4 Medical Simulation Benchmarking Group*

Summary

- IDEAL v1.0 was released in April 2021
  - Extensive validation
- IDEAL v1.0 was accepted and partially commissioned at MedAustron:
  - For scanned proton & carbon ion beams

Perspectives

- Clinical implementation
  - Integration of IDEAL v1.0 into myQA iON
    - Collaboration between IBA dosimetry and MedAustron
    - Goal: 2023
  - IDEAL v2.0
    - New features: LET, RBE for proton & carbon ions
    - New architecture: python binding

Questions or interested?

Do not hesitate to contact:

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Thank you for your attention!

- **Loic Grevillot:** IDEAL project initiator
- **David Boersma**: Former IDEAL v1.0 main developer
- **Martina Favaretto:** Current IDEAL v1.0 main developer
- **MedAustron medical physics team**: for providing measurements
- **OpenGate collaboration** for development and maintenance of GATE
- **Geant4 collaboration** for providing frequent Geant4 updates
- **Fonds** for financial support for 3 years

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