Gate RTion v1/IDEAL v1 for independent dose calculation in carbon ion beam therapy

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MedAustron Ion Therapy Center

Motivation & Purpose

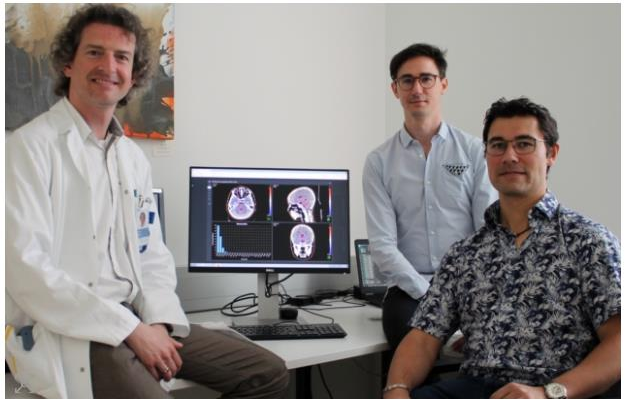
- Replace PSQA by independent dose calculation (IDC) without loss of quality
  - ✓ **Protons**:
    - Commercial software available (myQA-iON, IBA Dosimetry)
    - measurement time reduction by -87% (2021) ✓
  - ✗ **Carbon ions**: ✗
    - No commercial software available

      ➔ **IDEAL project**
    - Using GATE-RTion/Geant4
    - 2023: 350h beamtime ≈ 25 treatment days
- Benefits:
  - - Reduce measurement time
  - - Reduce manpower

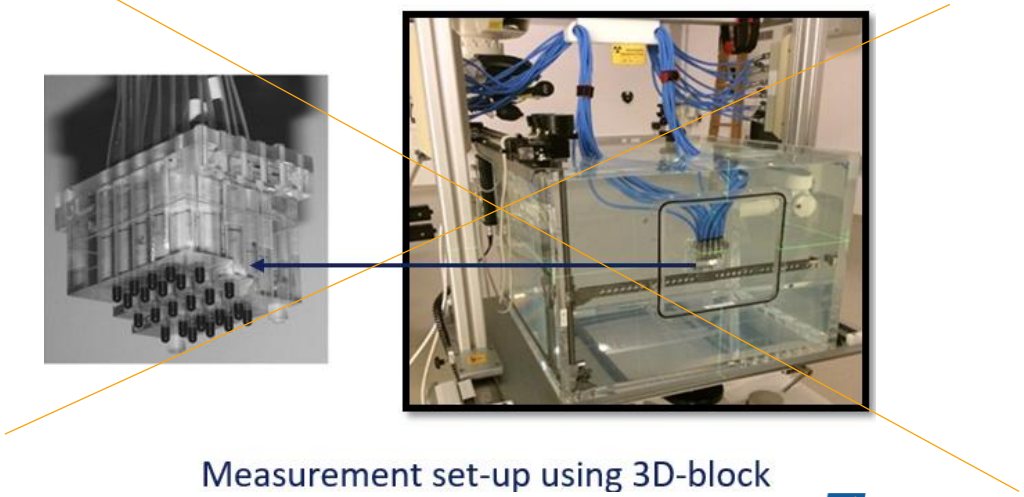
Reimagining patient-specific QA in proton and ion therapy facilities

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

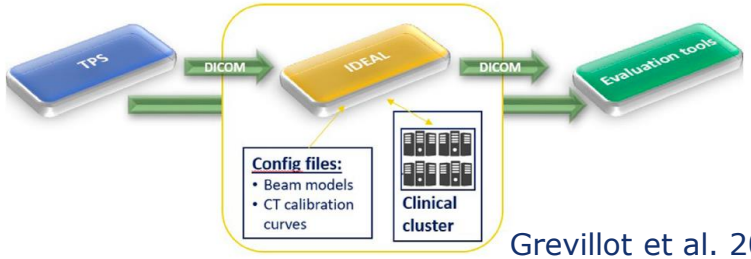


Proton IDC in use since February 2021



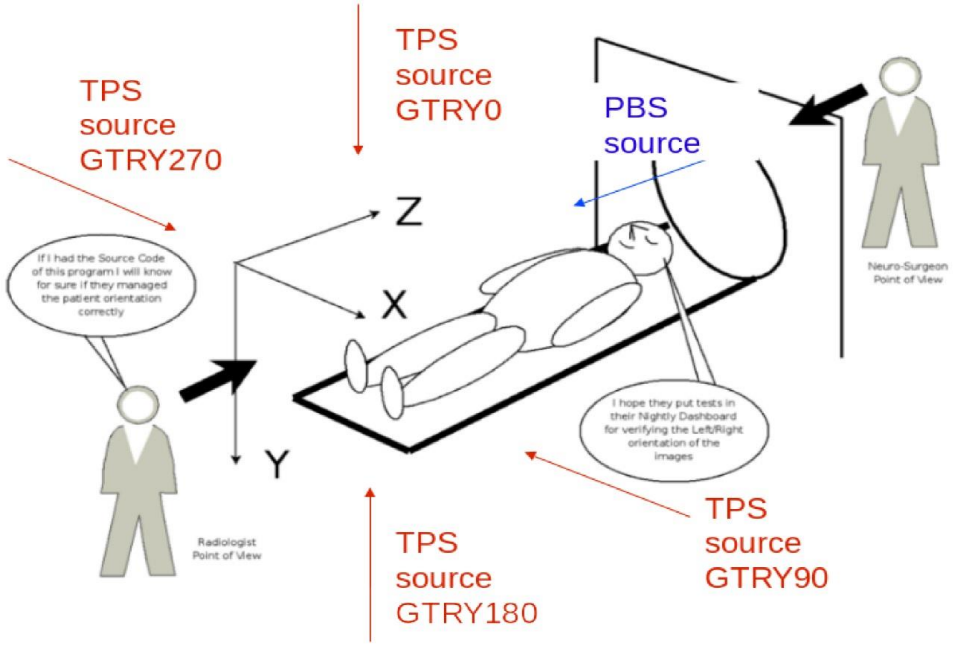
Measurement set-up using 3D-block

GATE-RTion/IDEAL



Grevillot et al. 2021

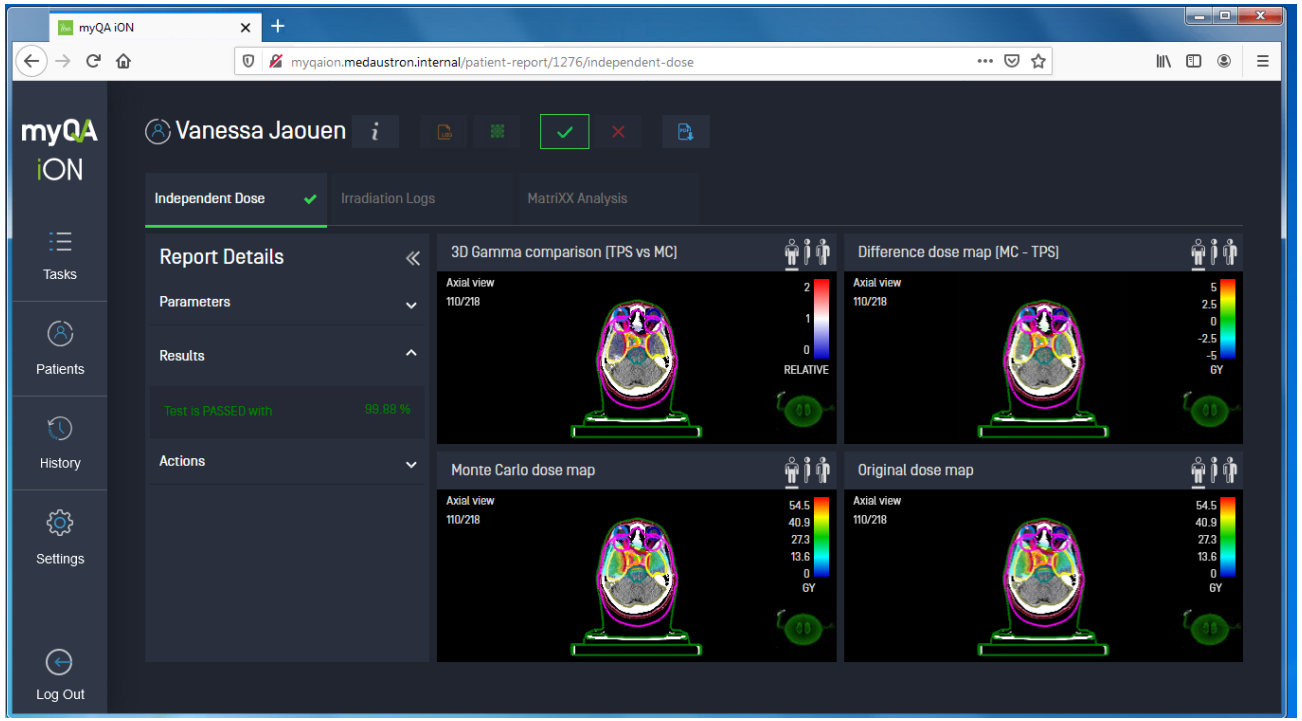
- Independent Dose Calculation System for Light Ion Beam Therapy
  - DICOM in / DICOM out
    - CT (HU map, Scanning protocol)
    - Structure (External to crop CT, organ material overwrite)
    - Plan (Patient position, gantry angle, beam positions and intensities, beamline)
    - Dose (Dose grid size and position)
  - Conversion table database
    - HU material conversion for each scanning protocol
    - Beamline settings
  - Create mac files, start simulations (HTCondor queuing system)
  - Combine simulations, DICOM out
  - Open source: https://github.com/OpenGATE/IDEAL
- GATE-RTion v1 (Geant4 10.3):
  - Calculation engine behind IDEAL
  - Uses macro files as input
  - New release requires intensive verification process
    - v1.0 well validated: >9 publications using the same version
    - Release cycle ~5 years



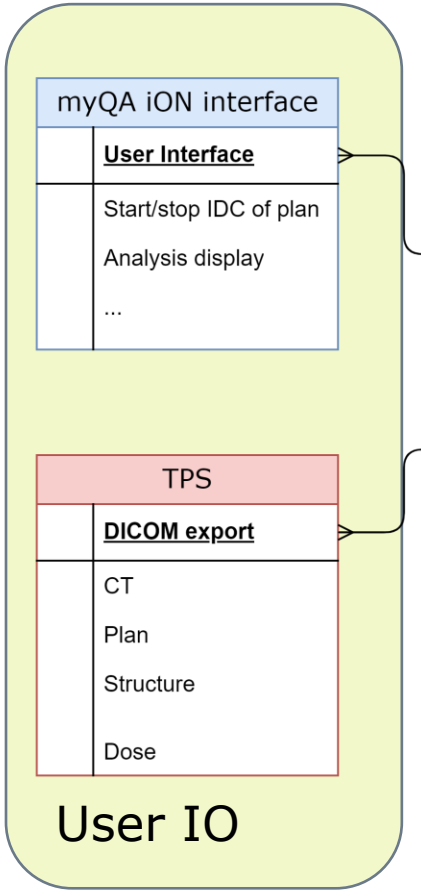
Goal

- Q1/Q2 2024: Clinical use of IDC for carbon ion beams
  - CE required
  - Useability for daily routine

➔ Integration of IDEAL/GATE RTiON into myQA iON, IBA Dosimetry



MyQA iON workflow



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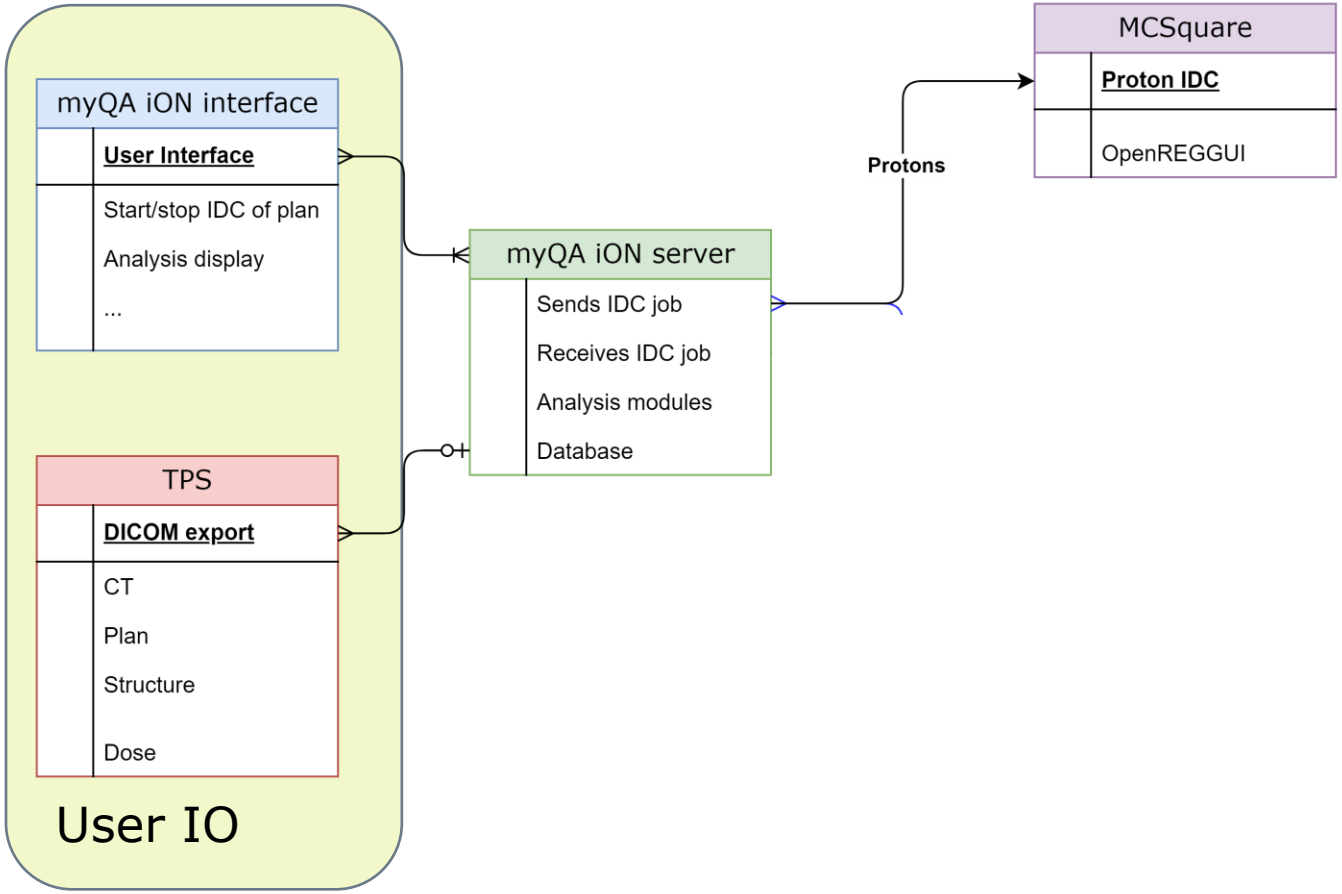

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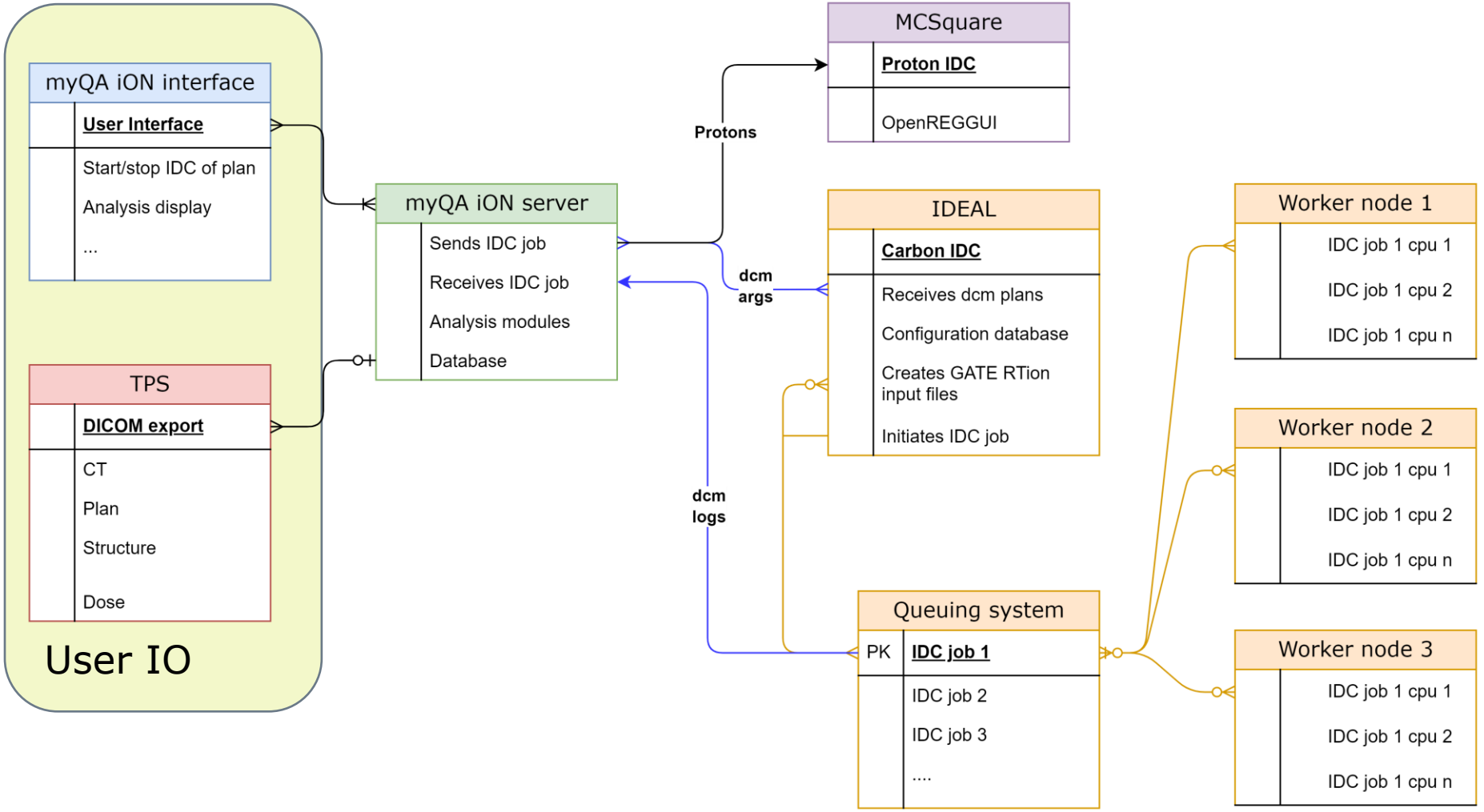


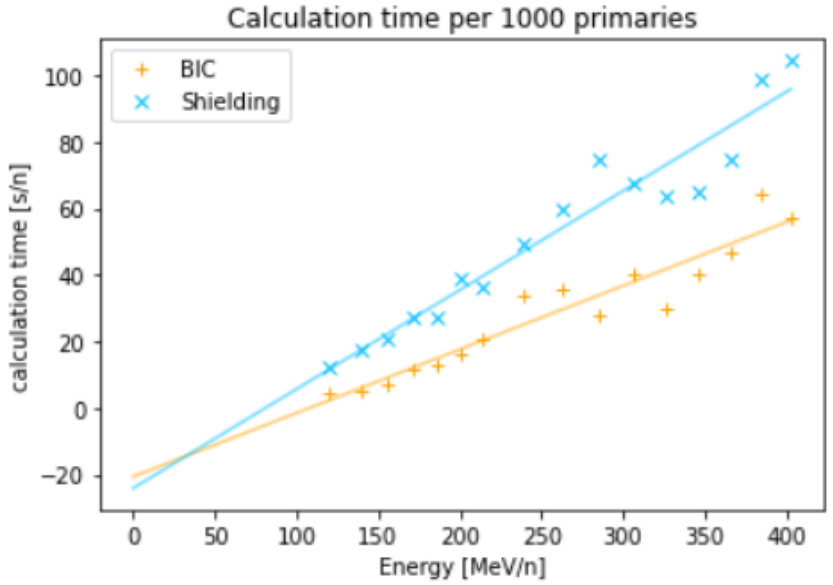
IDEAL 1.1 developments

- **GATE RTion 1**
  - No changes
- **Minor code changes in IDEAL 1.1**
  - Code reorganization
  - Bug fixes
- **User interfaces:**
  - Command line interface
  - Python Module (new)
  - http API (new)
    - Going to be used by myQA iON
    - Functional requirements defined together with IBA Dosimetry
    - Restricted settings available

Calculation time reduction

- Example: Patient Calculation time
  - Treatment volume: 1l
  - 48 CPU cores
  - 2 mm dose voxel size, 1% stat. uncert., IDEAL 1: ~33h
- Calculation time dependency
  - Volume: $t \sim V_{target}$
  - Energy: $t \sim \frac{8}{400\frac{MeV}{n} - \frac{120MeV}{n}} E_{nom}$
  - Number CPUs: $t \sim \left(\frac{1}{N_{CPU}}\right)^{0.99}$
  - Statistical uncertainty: $t \sim \left(\frac{1}{\sigma}\right)^2$
  - Dose voxel size: $t \sim \left(\frac{1}{a}\right)^3$
  - Physics settings

Nr Cores		48
Vox Size [mm]	**Stat uncertainty [%]**	**Calc time [h]**
2	1	33
3	1	18
3	2	4
2	2	8
2	3	4



Calculation time reduction

- Electromagnetic options
  - Marginal difference between EMY and EMZ
- HP
  - ~30% reduction
- Nuclear scattering models
  - BIC and INCLXX similarly fast
  - Shielding ~ factor 2 slower
- Secondary particle production cut
  - Up to factor 5 slower for low pc

t_0

	Time [s/ 1e3 events]		Ratio [t/t0]	
SOBP range [cm]	**9**	**28**	**9**	**28**
BIC_EMZ	6	42	1.00	1.00
BIC_EMY		40		0.96
BIC_HP_EMZ	8	51	1.36	1.23
INCLXX_HP_EMZ	8	59	1.37	1.41
Shielding_EMZ	14	84	2.30	2.03
BIC_EMZ_inklEl	50	417	8.34	10.02
Shielding_EMZ_inklEl	62	469	10.33	11.28

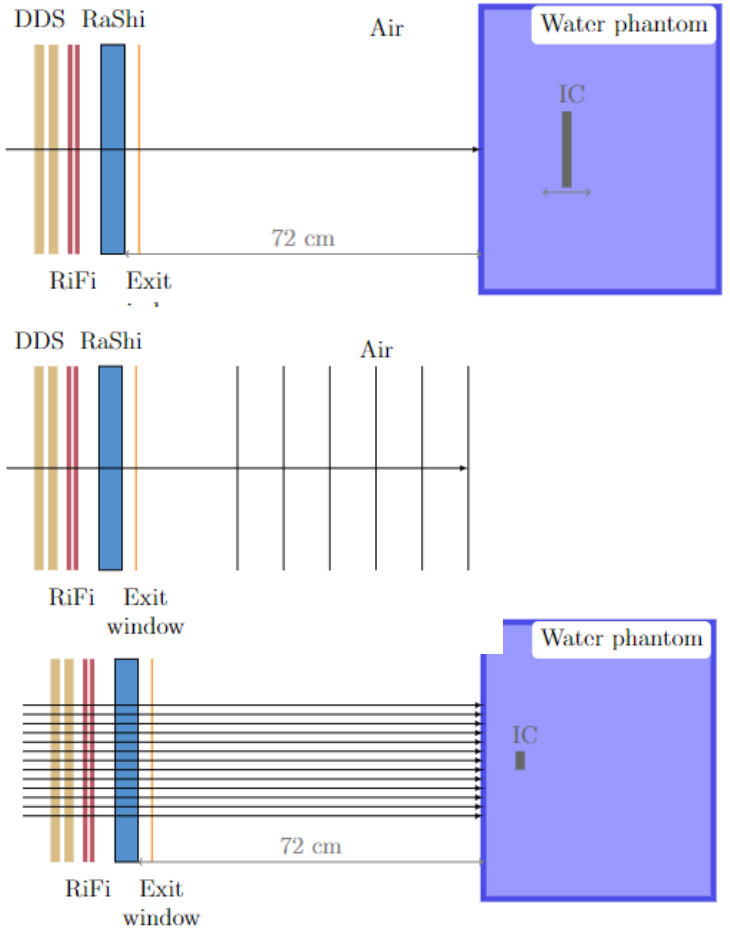
Nr Cores		48
Vox Size [mm]	**Stat uncertainty [%]**	**Calc time [h]**
2	1	~~33~~
3	1	18
3	2	4
2	2	8
2	3	4

➔Combined effect ~ factor 10 calculation time reduction
➔Patient plan re-calculation within 1-3 h seems possible

Experimental validation

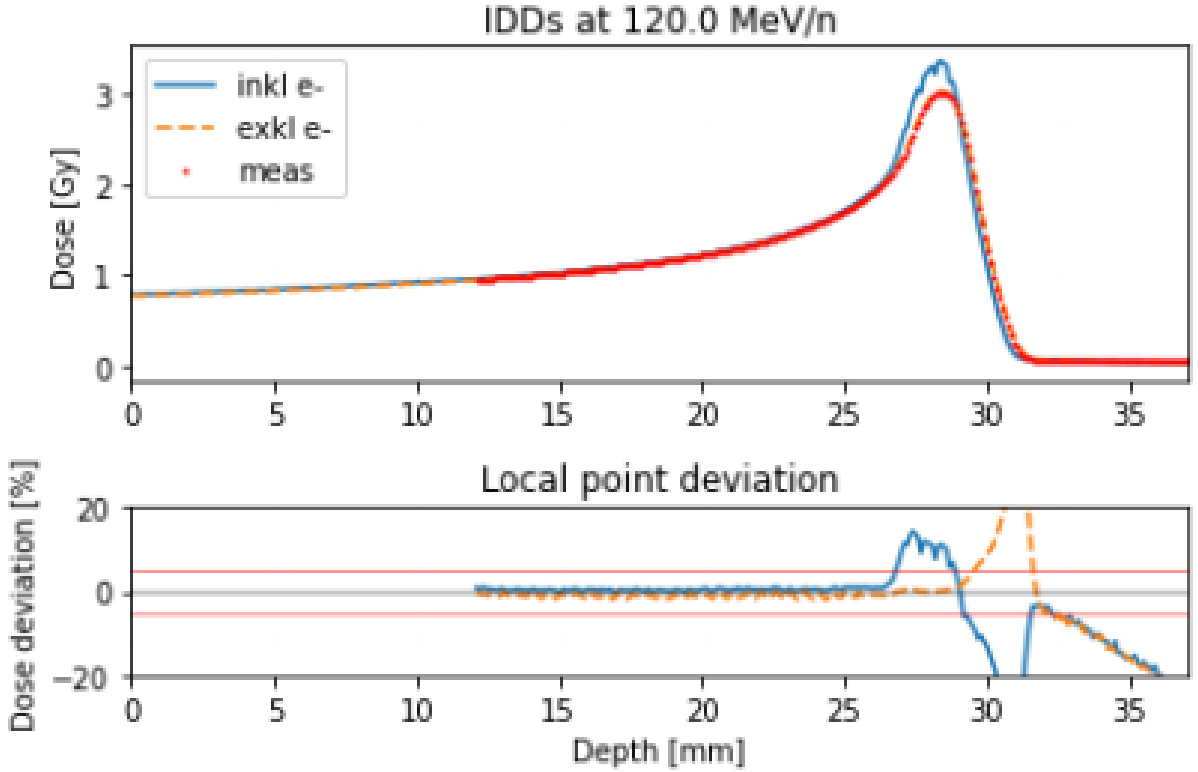
Overview validation

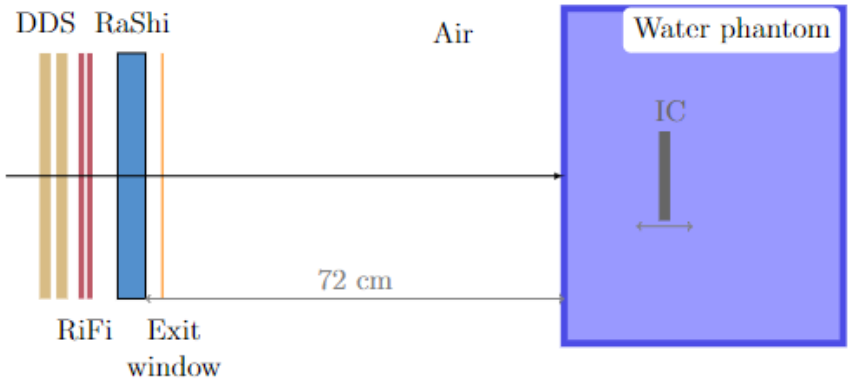
- Validation
  - Dose calculation accuracy
    - Commissioning data
      - Depth dose profiles in water ✓
      - PB sizes and positions in air ✓
      - Reference dose in water ✓
      - Dose in SOBPs in water (work in progress)
  - HU to material conversion
    - rWET of calibration tissue equivalent material
    - rWET of animal tissue
  - Functional tests
    - Alignment (CT, beam, dose grid)
    - Selection of correct settings (HU to material, beamline, …)
- Automatic verification tool
  - Continuous testing of software development



Secondary e- production cut

- Validation against depth dose profiles in water with and without range shifter
- Comparing e-, e+, gamma production cut
  - 0.5 mm (~ with e-)
  - 100 m (~ no e-)
- Results
  - Interference of transport and production cut
  - Systematic difference in non- and voxelized geometry
  - High e- production cut feasible





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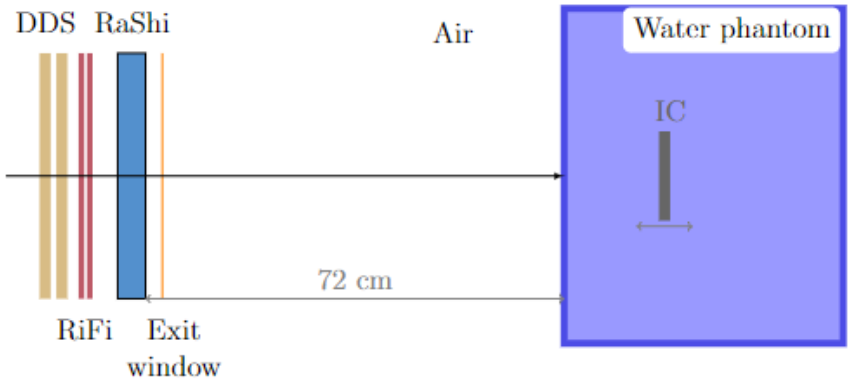
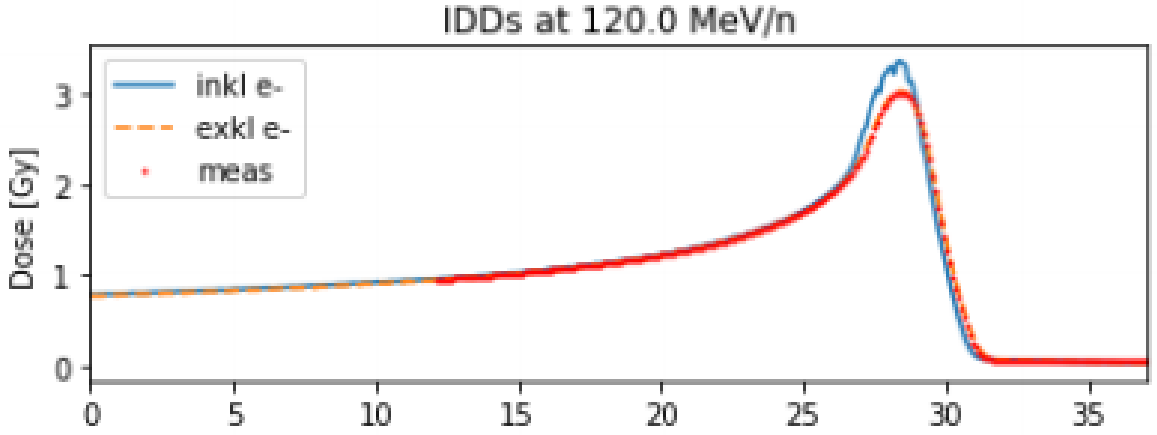
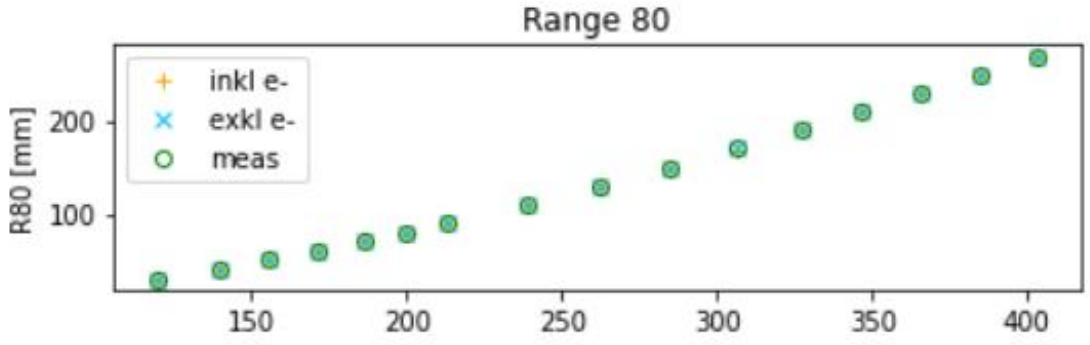
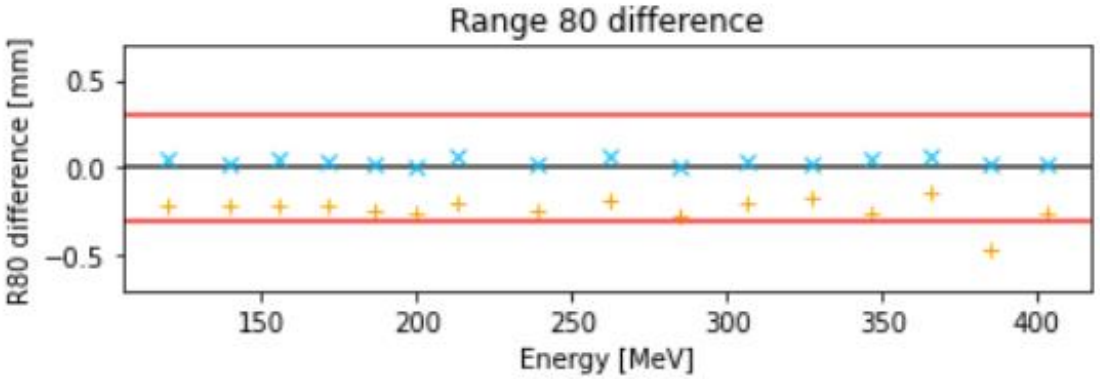


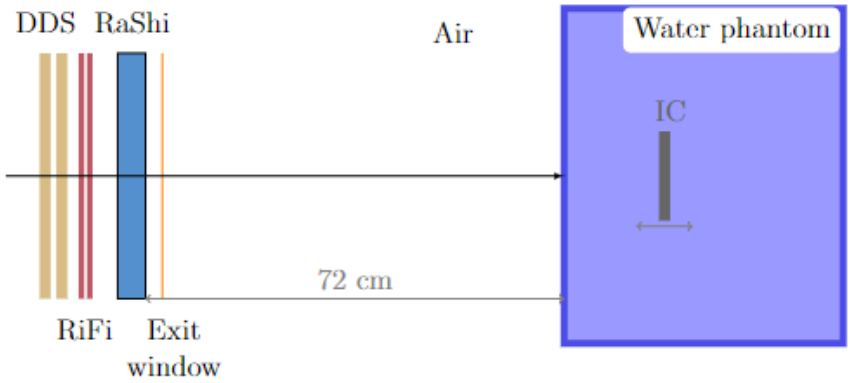


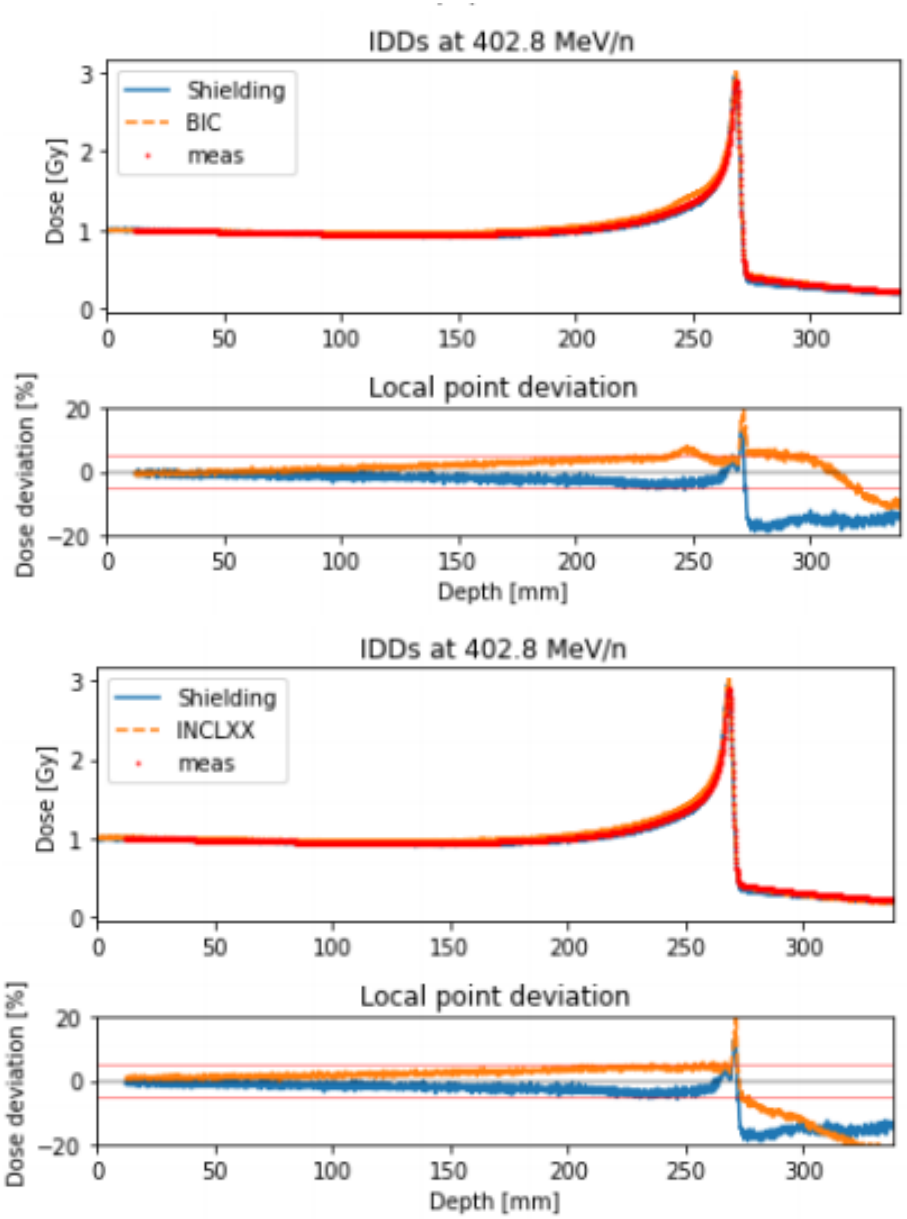




Nuclear scattering models

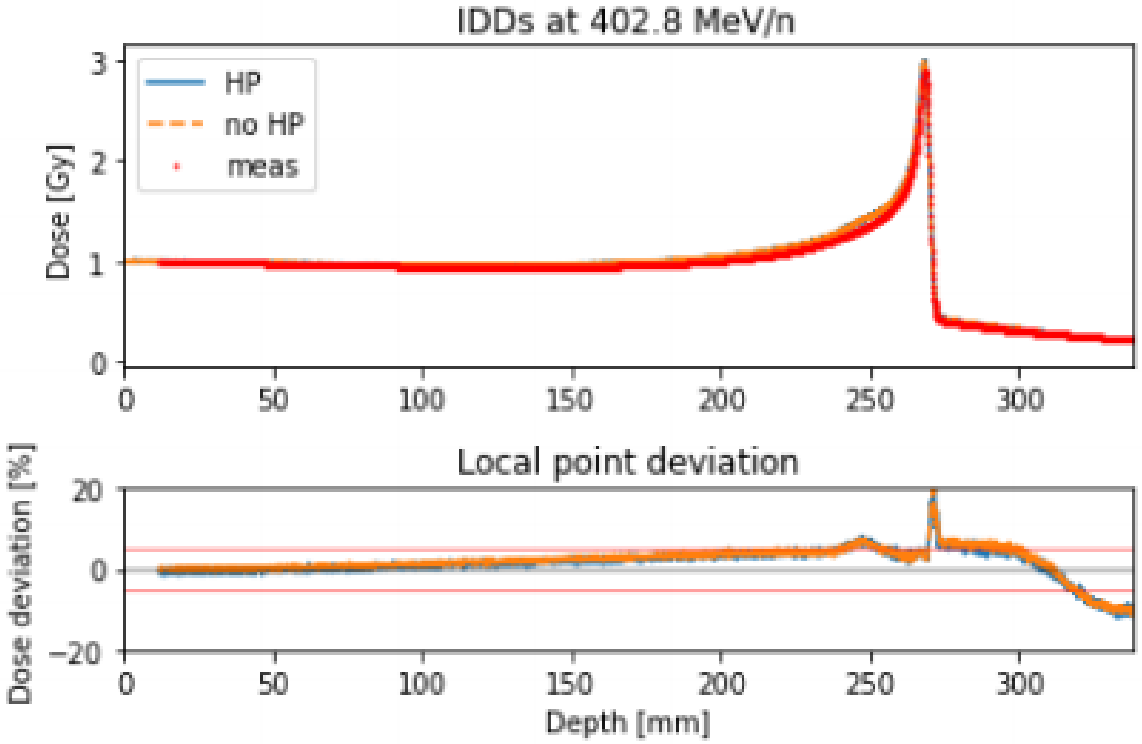
- Validation against depth dose profiles in water with and without range shifter
- Comparing
  - BIC
  - Shielding
  - INCLXX
- Accuracy energy and depth dependent
  - ➔no evident optimal setting ➔ BIC
  - ➔Consistent with recent literature (Arce 2021 et al.)

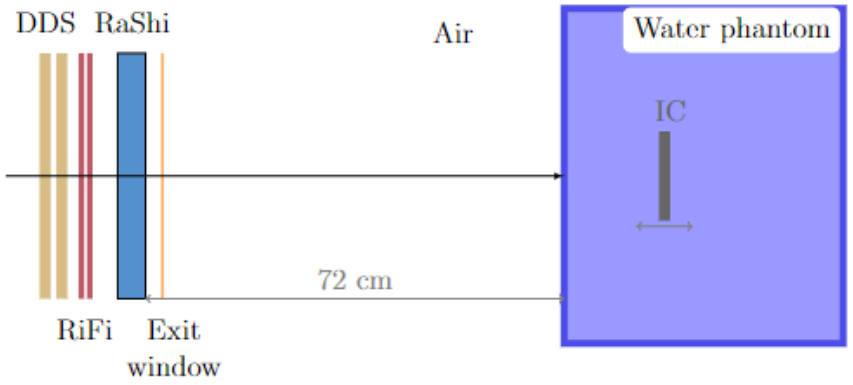




High Precision (HP) option

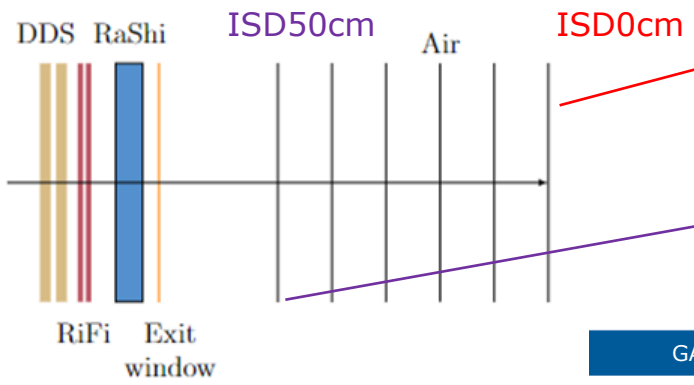
- Validation against depth dose profiles in water with and without range shifter
- Comparing
  - With HP
  - Without HP
- Result:
  - No difference detectable

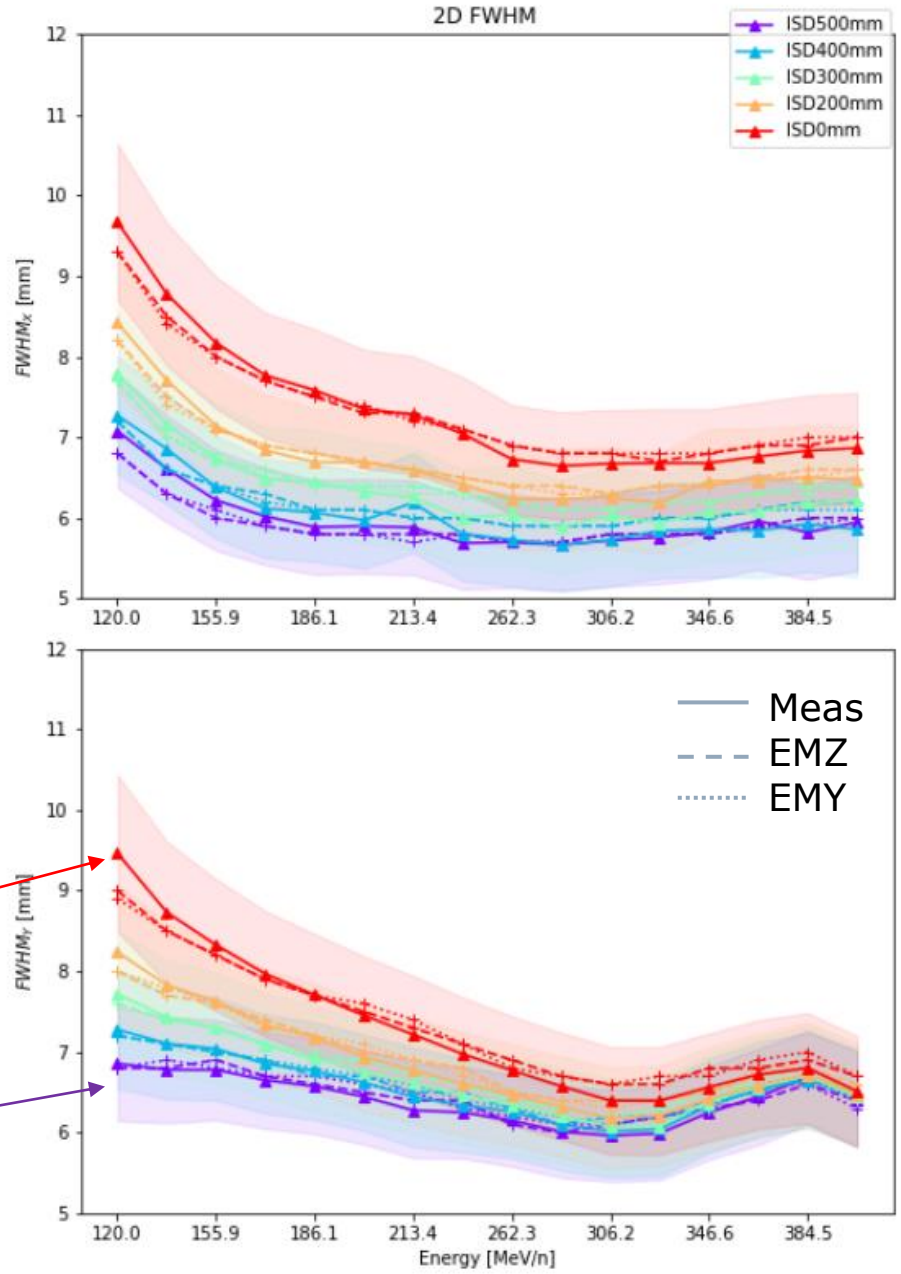




Electromagnetic options

- Validation against dose profiles at different air gap distances
- Comparing
  - EMY (option 3)
  - EMZ (option 4)
- Result:
  - No significant difference ➔ both options can be used

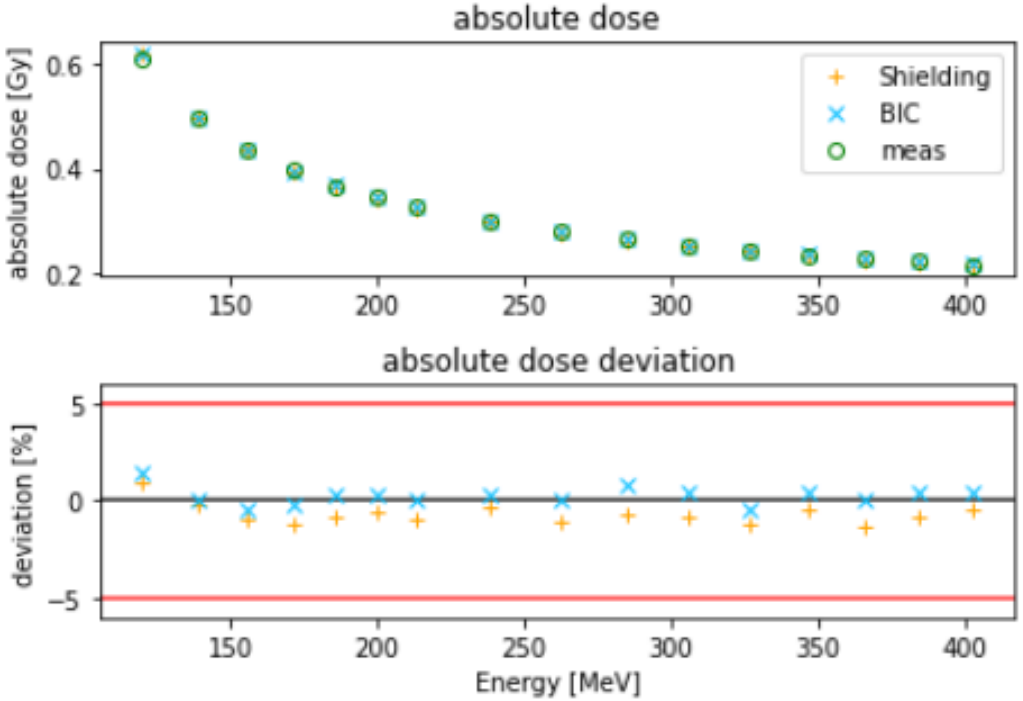


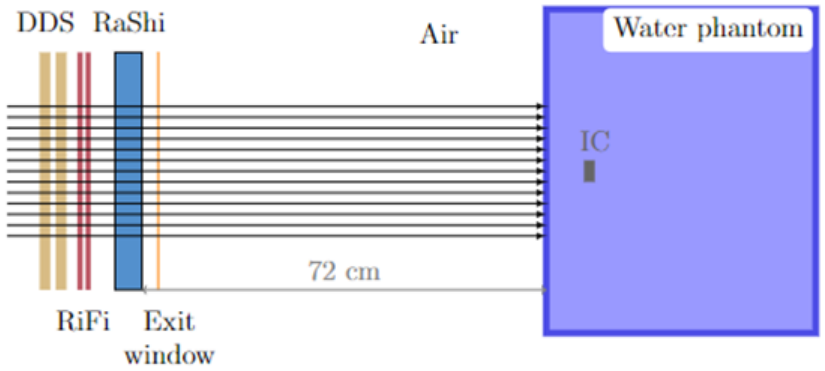


Absolute dose validation

- Validation against dose profiles at different air gap distances
- Comparing
  - EM options
  - Nuclear models
- Result:
  - No significant difference

  ➔ All options can be used



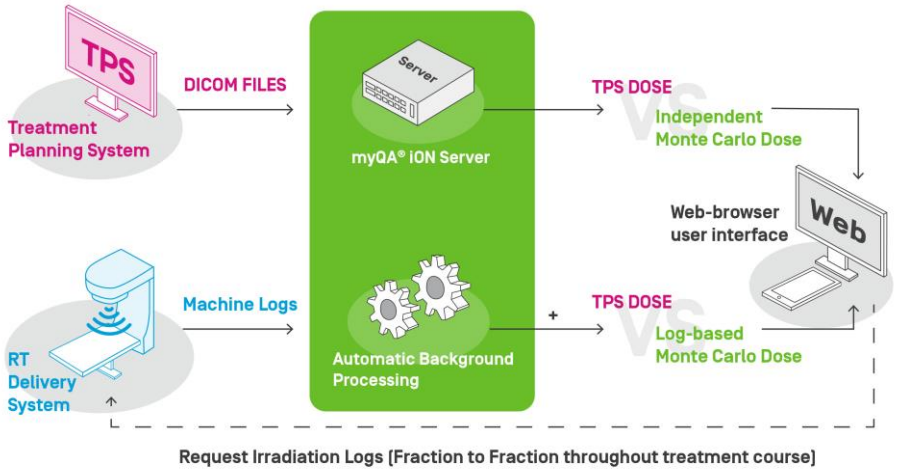


Summary & Conclusions

- **IDEAL v1.0**
  - Released in April 2021, Extensive validation
  - IDEAL v1.0 was accepted and partially commissioned at MedAustron:
  - For scanned proton & carbon ion beams
- **IDEAL v1.1**
  - Release planned for summer 2023
  - Minor changes
  - Additional features: new interfaces: python module, http API
- **IDEAL v1.1 @MedAustron**
  - Optimized physics settings for physical dose calculation accuracy and time
    - ➔ Release candidate: QGSP_BIC_EMZ(/Y)
    - ➔ Factor ~10 calculation time improvement seems feasible
  - Ongoing commissioning
  - Non-clinical use for research (open source)
  - Clinical use: interface to commercial software MyQA iON, IBA Dosimetry
- **IDEAL v2:**
  - Based on Gate10: see talk M. Favaretto

Outlook
Integration of IDEAL v1.1 into myQA iON

- **10/2023: Release of myQA-iON with IDEAL v1.1 for carbon ions**
  - Non clinical version
  - CE with a patch: Q4/2023 - Q1/2024
- **Q1/Q2 2024 Clinical release at MedAustron**



Thank you for your attention!

David Boersma
David Sarrut
IBA Dosimetry
All the others

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MedAustron Ion Therapy Center

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