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Computational and experimental methods applied for treatment planning, quality assurance, and research at the clinically operating proton-therapy facility

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In this contribution, I will review technologies and applied translational research activities ongoing at the R&D lab of the Cyclotron Centre Bronowice (CCB), proton therapy center in Krakow, Poland. I will show examples of clinical translation of developed technologies to routine proton treatment planning and quality assurance (QA). Individual projects presented here have been conducted in close international collaborations with research partners, a.o., PSI and Maastro Clinic proton centers, the Sapienza University of Rome, and TIFPA (Italy), as well as commercial partners.

To support the clinical operation of the CCB proton center, we commissioned computational methods based on Monte Carlo simulations in GATE/Geant4 running on a computational cluster and GPU-accelerated proton dose engine FRED. For both codes, we developed and automated advanced proton beam modeling and validated the physics models against measurements [1]. Prospectively, FRED and GATE are used for the evaluation of LET and variable RBE distributions in proton treatment plans. Thanks to its excellent time performance, FRED is now integrated into the clinical environment to support and eventually replace patient QA measurements, while the spared QA beamtime can be used for patient treatments [2]. Since the R&D lab is in the clinical environment, we established a large database of patients treated in Krakow to study physical and biological range uncertainties in patients and new treatment planning protocols [3,4]. To verify the simulations, we employ quantum sensitive pixelated detectors TimePix (ADVACAM) for measuring dose and LET in a water phantom with single particle sensitivity [5,6]. Further research activities conducted in the proton center R&D lab include the development of a proton beam range monitoring system based on a PET detector built from plastic scintillators (J-PET technology) [7,8], prompt gamma measurements, investigation of non-clinical irradiation conditions with low and flash dose rates, development of new proton treatment plan optimization techniques, as well as nano-scale approaches to biologically weighted treatment planning [9].

[1] Gajewski et al. 2021 https://doi.org/10.3389/fphy.2020.567300
[2] Krzempek et al. 2023 (see PTCOG 61 oral presentation)
[3] Garbacz et al. 2021 M. Garbacz, https://doi.org/10.1016/j.radonc.2021.08.015
[4] Garbacz et al. 2022 https://doi.org/10.1186/s13014-022-02022-5
[5] Stasica et al. 2020 https://doi.org/10.3389/fphy.2020.00346
[6] Stasica et al. 2023 (under review in PMB)
[7] Borys et al. 2022 https://doi.org/10.1088/1361-6560/ac944c
[8] Brzezinski et al. 2023 (under review in PMB)
[9] Rucinski et al. 2021 https://doi.org/10.1088/1361-6560/ac35f1

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