Monte Carlo research activities at the Institute of Nuclear Physics PAS in Kraków

Jan Gajewski

THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

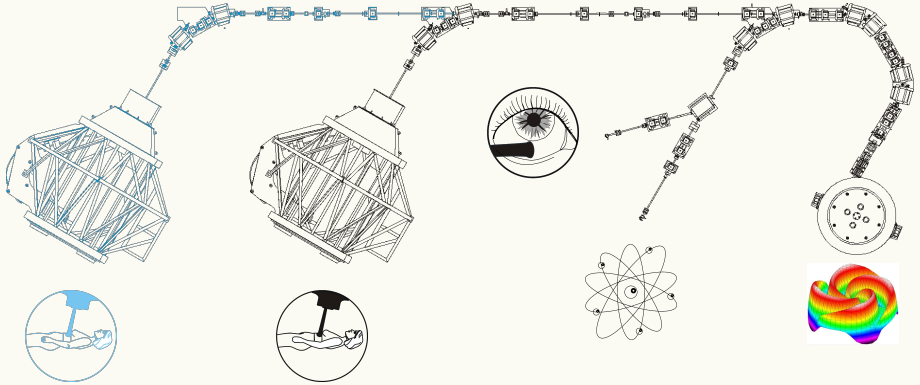
CCB Cyclotron Centre Bronowice

European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund
SCIENCE FOR THE SOCIETY

GATE Scientific meeting 2023
Kraków, 26.04.2023

Cyclotron Centre Bronowice IFJ PAN

Cyclotron Centre Bronowice



- IBA Proteus C-235
- Clinical operation from Oct 2016
- 2 x gantry (841 patients treated)
- Eye treatment room (330 patients)
- Experimental hall (0 patients)

Cyclotron Centre Bronowice

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Medical Physics Department

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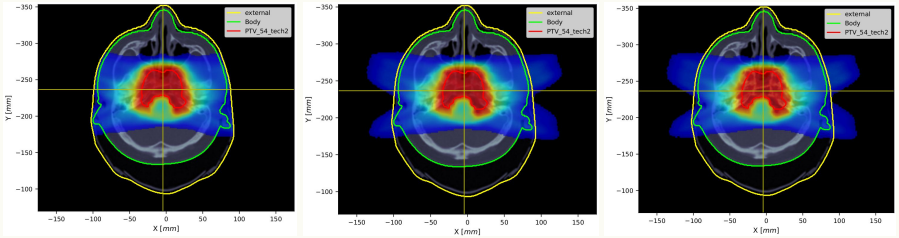
Research and Development Lab.

dr inż. Antoni Ruciński (head)
dr inż. Jan Gajewski
mgr inż. Katarzyna Krzempek
dr Majid Kazemi Kozani
dr Damian Borys
dr hab. Justyna Miszczyk
dr Anna Zając-Grabiec
mgr inż. Paulina Stasica (PhD student)

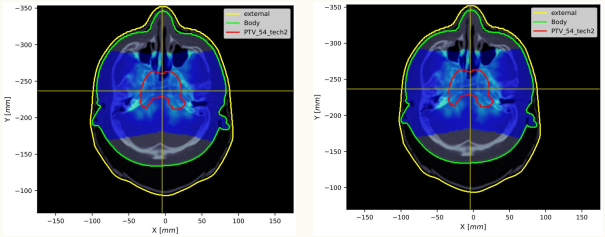
Monte Carlo applications

- **Patient Quality Assurance**

Dose TPS vs GATE vs FRED



LETd GATE vs FRED

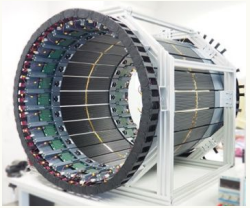


- **Support treatment planning**

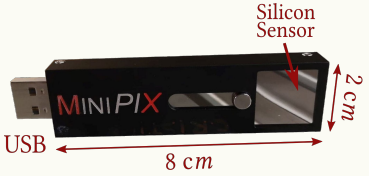
- **Treatment planning studies**
  database of 100 patient treatment plans
  for Monte Carlo recalculations

- **Detector development**

J-PET



TimePix

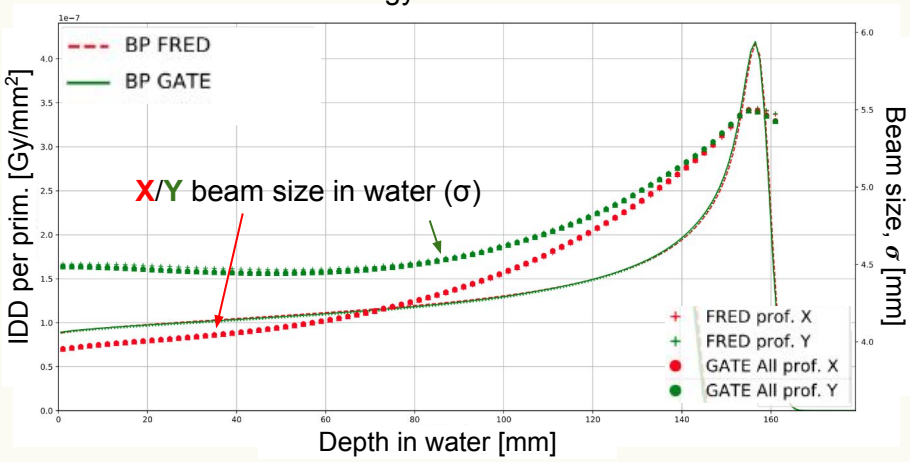


Beam modeling in FRED and GATE

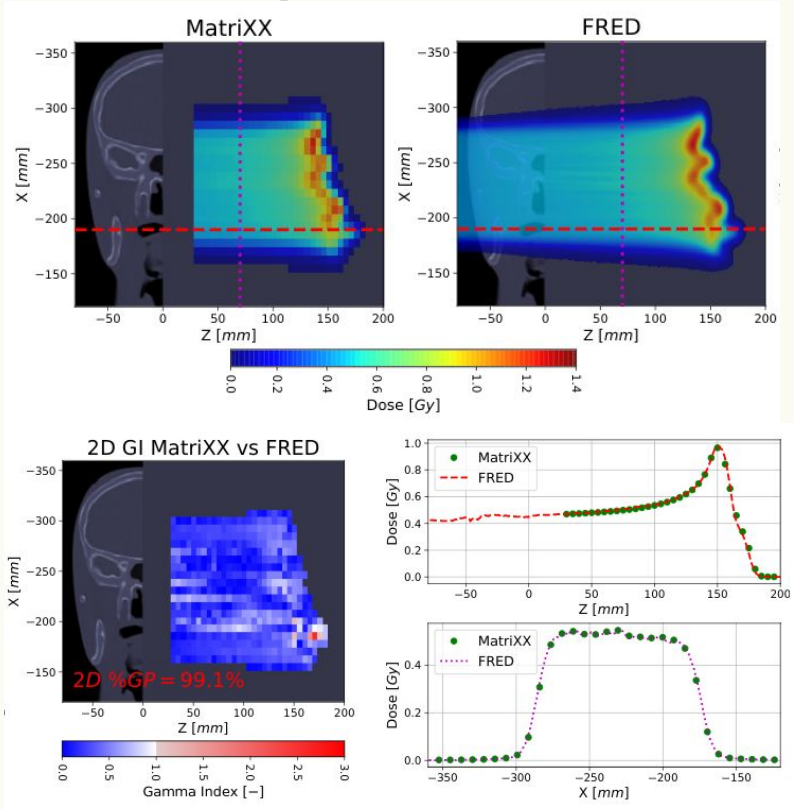
Beam model based on 9 parameters for 17 beam energies:

- initial energy, energy spread
- lateral propagation (6 emittance parameters)
- dosimetric calibration
- including range shifters
- implemented: gantry/patient rotations + isocenter shifts

Nominal energy: 150 MeV in water



Experimental validation

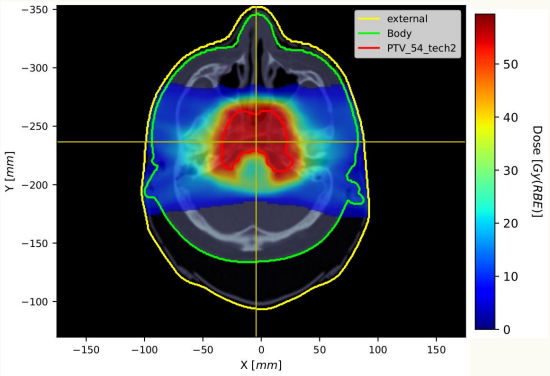


J. Gajewski, et al., *Front. in Phys.* (2021)

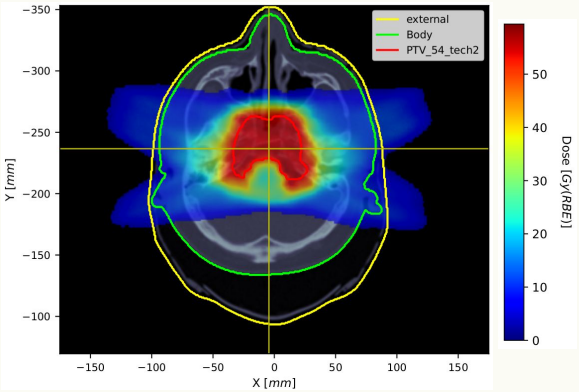
Dosimetric cross-validation TPS-GATE-FRED

- 35 treatment plans
- precise physics
  - *QGSP_BIC_HP_EMZ*
  - *0.1 mm prod. cuts*
- GATE on ZIEMOWIT cluster

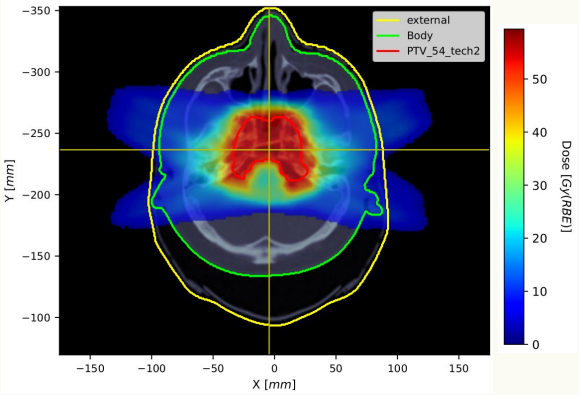
TPS



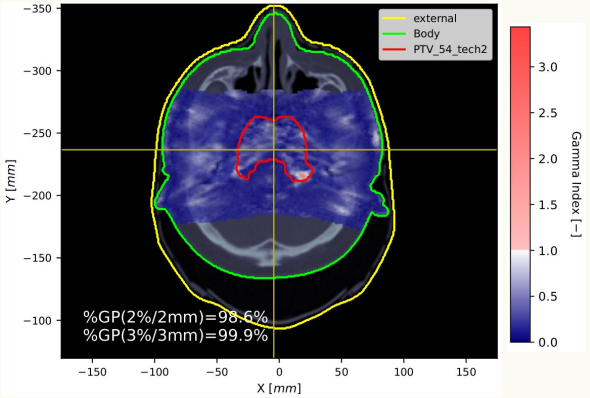
FRED



GATE



Gamma Index (*3mm/3%*)



Collaboration

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PSI

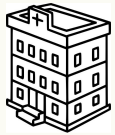
Silesian University of Technology

HPC Ziemowit

SAPIENZA UNIVERSITÀ DI ROMA

Paper under preparation…

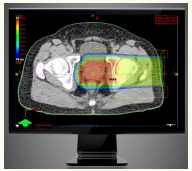
Computational Patient QA with FRED and GATE



Diagnosis and treatment protocol

Computed tomography

CT calib. (HU to RPSP)



Treatment planning

Beam model (commissioning)

Experimental dose measurement

Time consuming process

Plan verification

Plan irradiation

Computational patient QA

Log-based patient QA

Monte Carlo calculations

GATE

Fred

SCIENCE FOR THE SOCIETY

Grant for computational patient QA workflow implementation

+

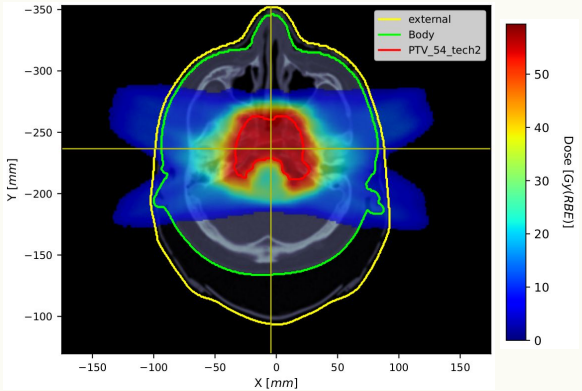
simultaneous LET and Dose optimisation

myQA iON

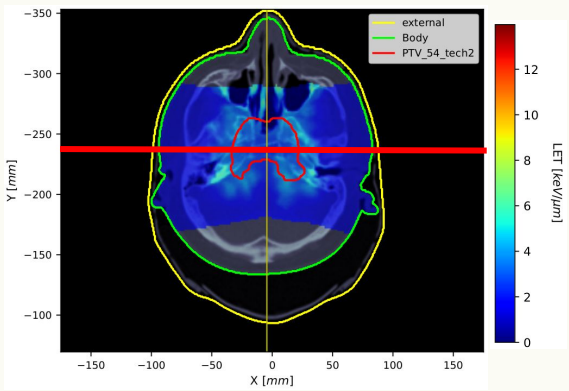
iba

Monte Carlo to support proton planning

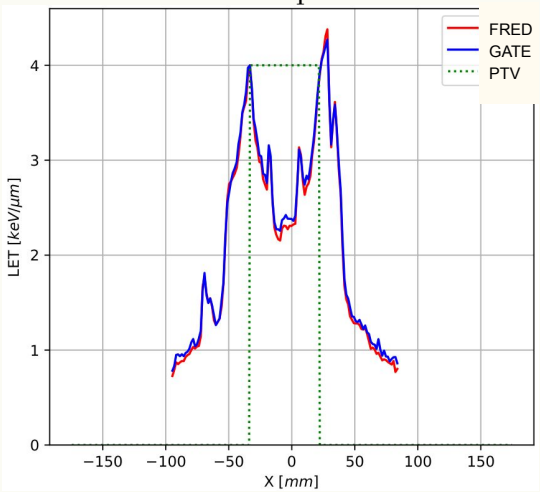
Dose FRED



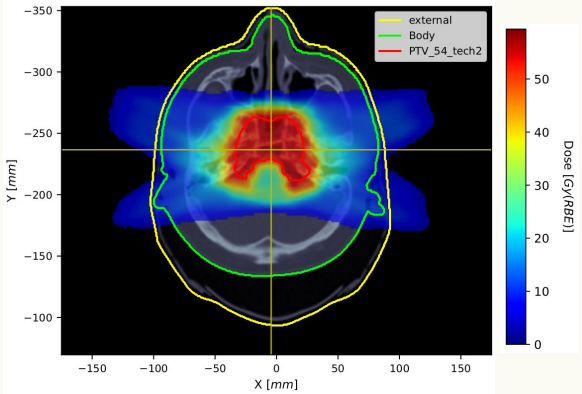
LETd FRED



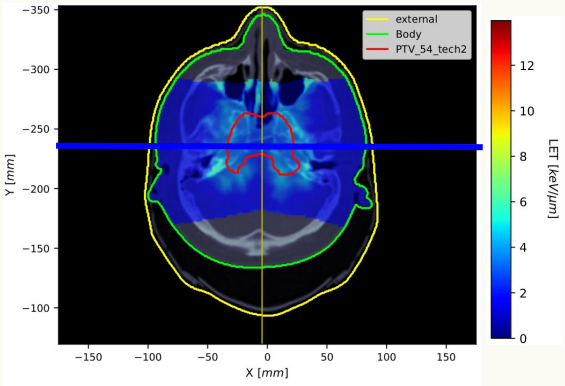
LETd X profile



Dose GATE



LETd GATE



Collaboration

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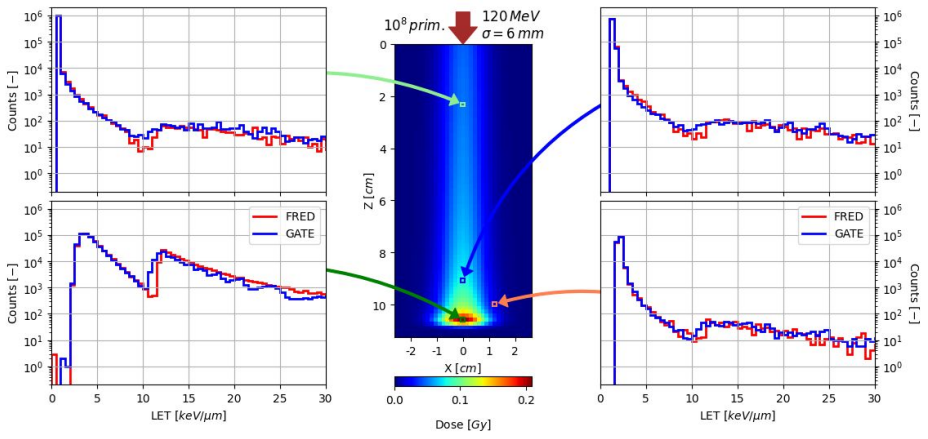
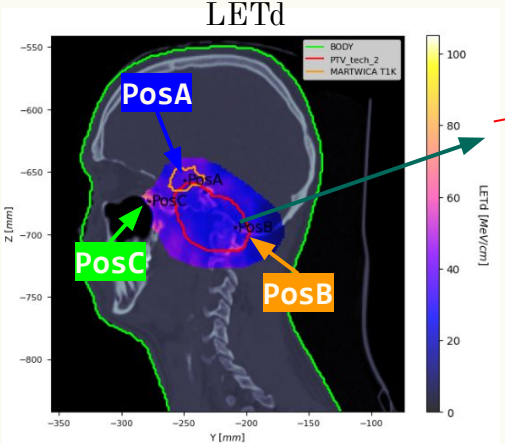
Paper under preparation…

Computational LET QA

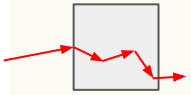
Not only the **averaged LET** (e.g. LETd) but
the whole **LET spectra** in a voxelized geometry



LETd



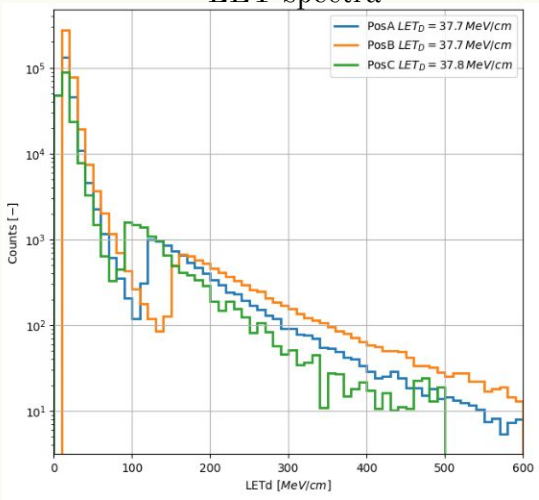
CT voxel



LET scored for each particle depositing energy

Spectra stored in Multi-component image (each voxel is a histogram)

LET spectra



Fred

GATE

Collaboration

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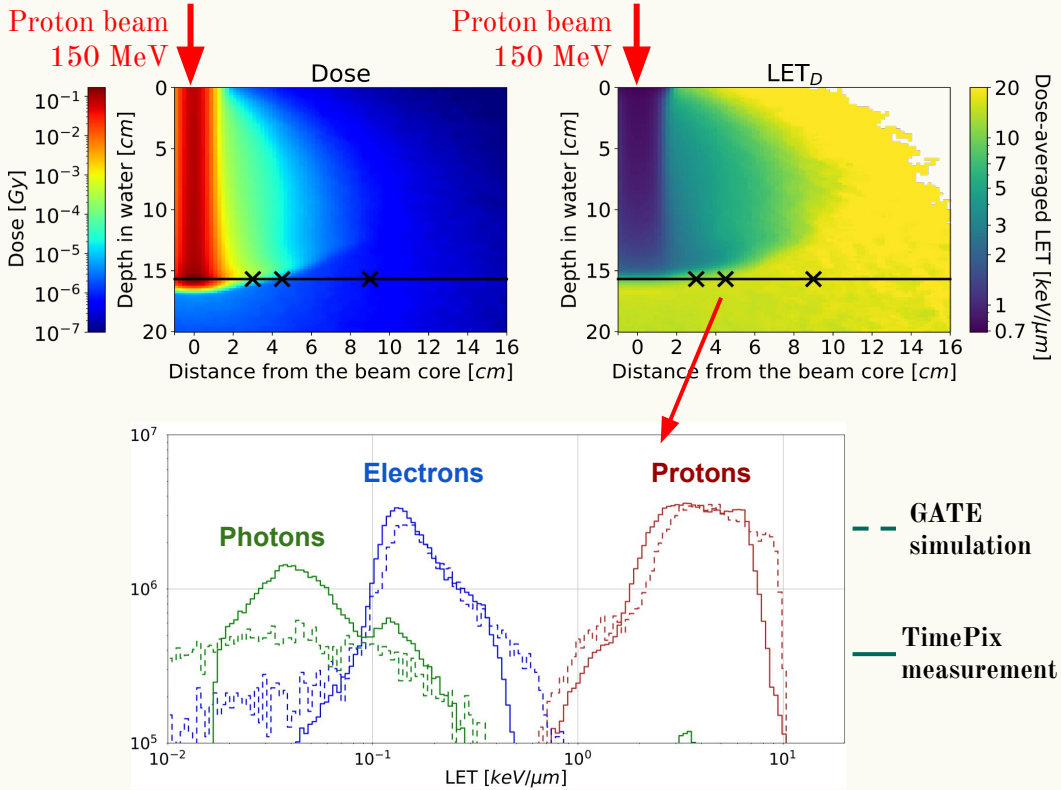
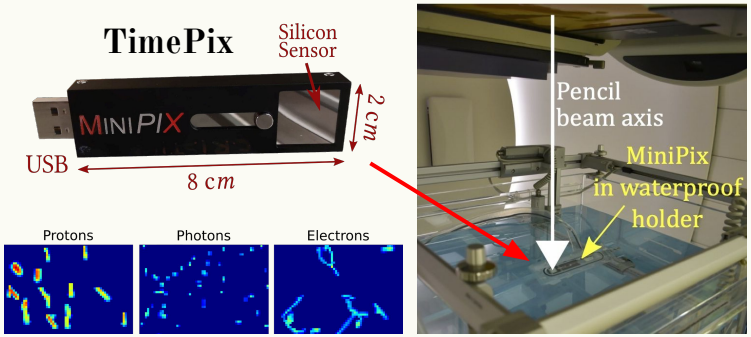
The National Centre for Research and Development

Grant for characterisation of mixed radiation fields in proton therapy

Experimental LET QA





Monte Carlo for detector development

- Depositions in TimePix simulated in GATE and FRED
- TimePix response with Geant4-based AllPix^2

Collaboration

ADVACAM
Imaging the Unseen

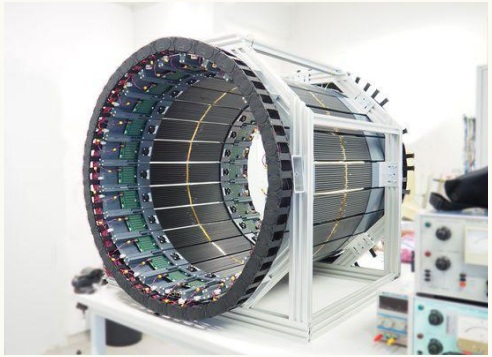
The National Centre for Research and Development

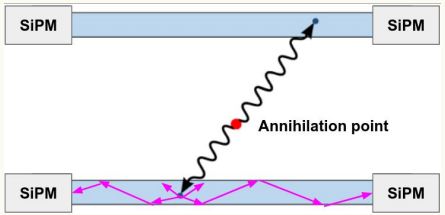
Grant for characterisation of mixed radiation fields in proton therapy

P. Stasica, et al., *PMB* (2023), accepted

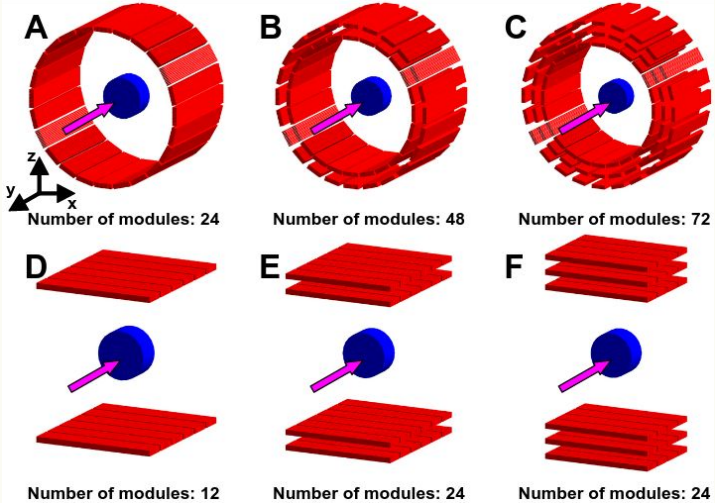
J-PET for range monitoring in PT

J-PET operation principle





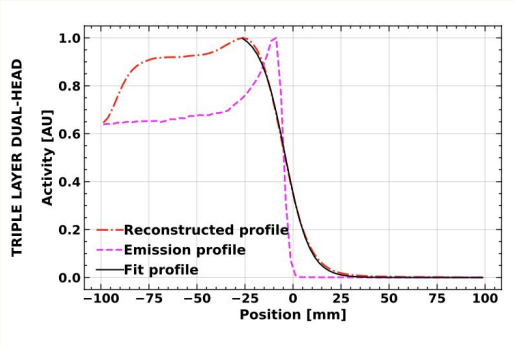
Sensitivity



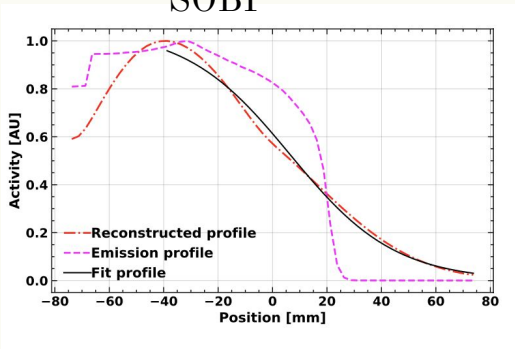
Setup	SPB			SOBP		
	$\eta[10^{-6}]$	$\sigma(\eta)[10^{-6}]$	$\overline{H}$	$\eta[10^{-6}]$	$\sigma(\eta)[10^{-6}]$	$\overline{H}$
Single layer cylindrical	9.45	0.29	1.0	3.64	0.22	1.0
Double layer cylindrical	27.41	0.80	2.9	10.76	0.65	2.9
Triple layer cylindrical	45.72	1.26	4.8	18.00	1.11	5.0
Single layer dual-head	3.79	0.13	0.4	2.45	0.19	0.7
Double layer dual-head	10.55	0.35	1.1	7.21	0.56	2.0
Triple layer dual-head	10.22	0.26	1.1	8.92	0.78	2.4

Range estimation

SPB



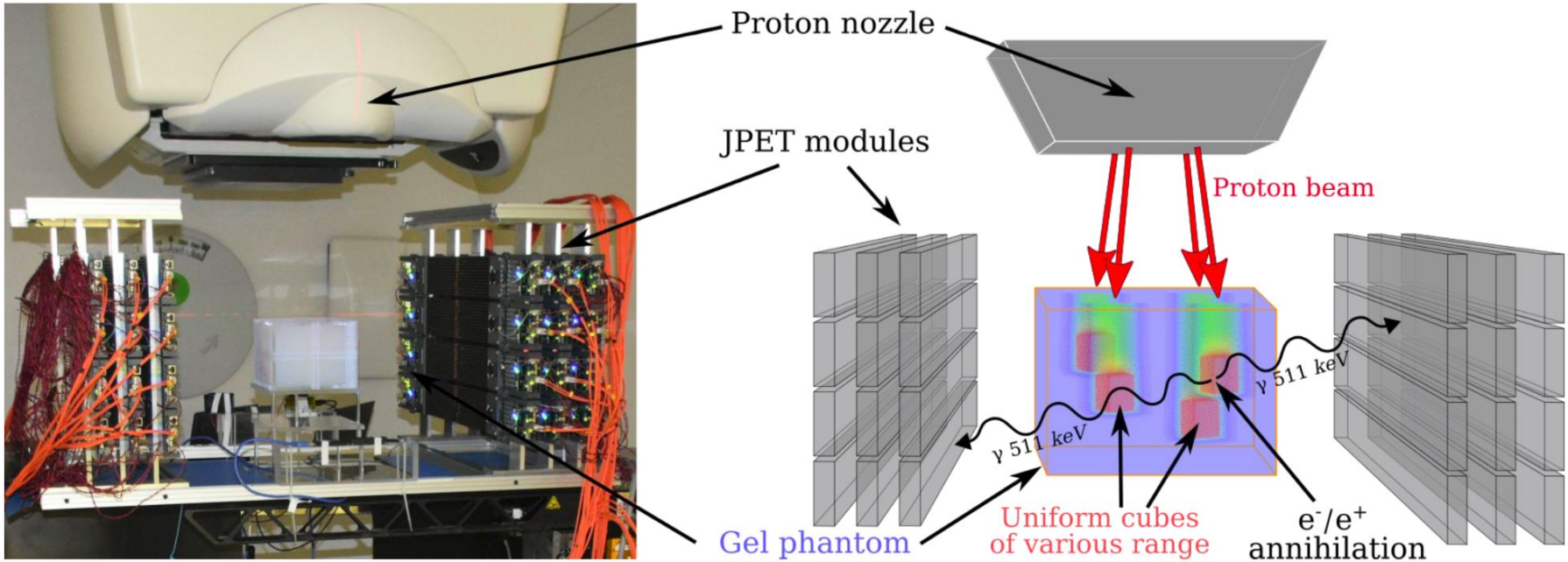
SOBP



J. Baran, et al. 2023 under review

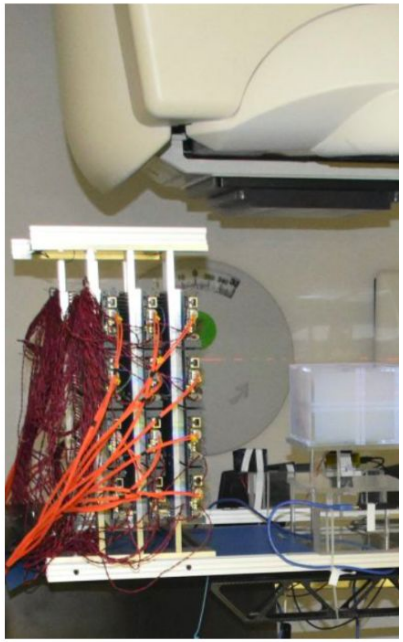
J-PET for range monitoring in PT

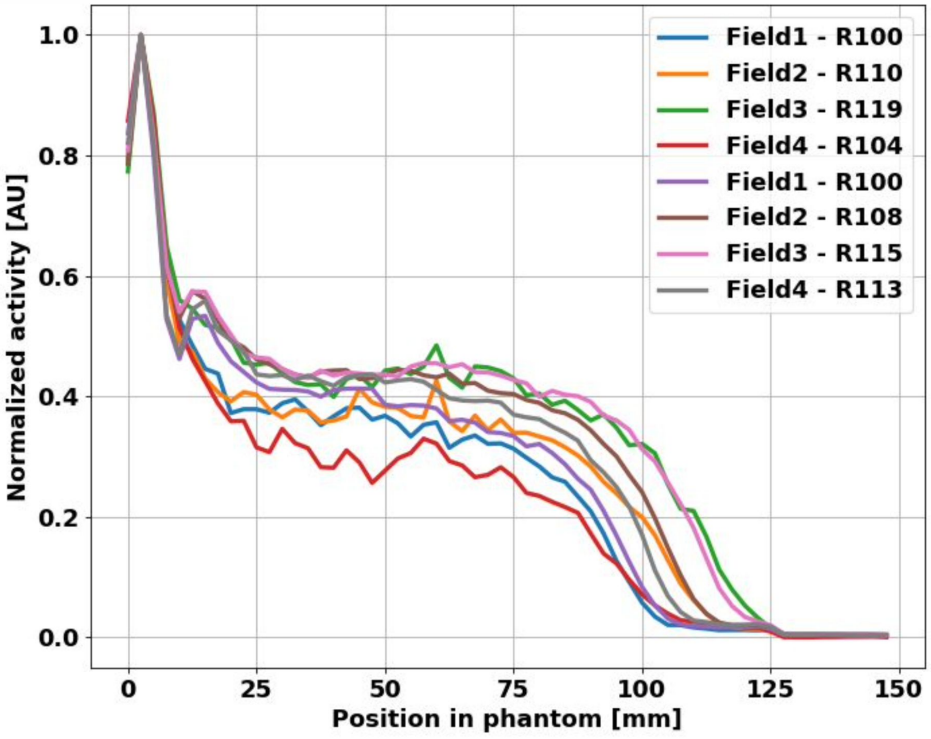
Experimental validation with proton beams at CCB

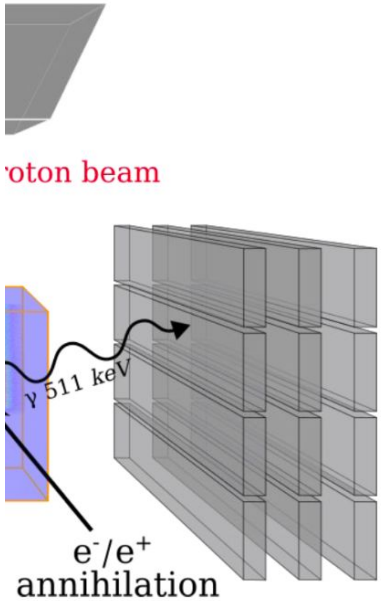


J-PET for range monitoring in PT

Experimental validation with proton beams at CCB







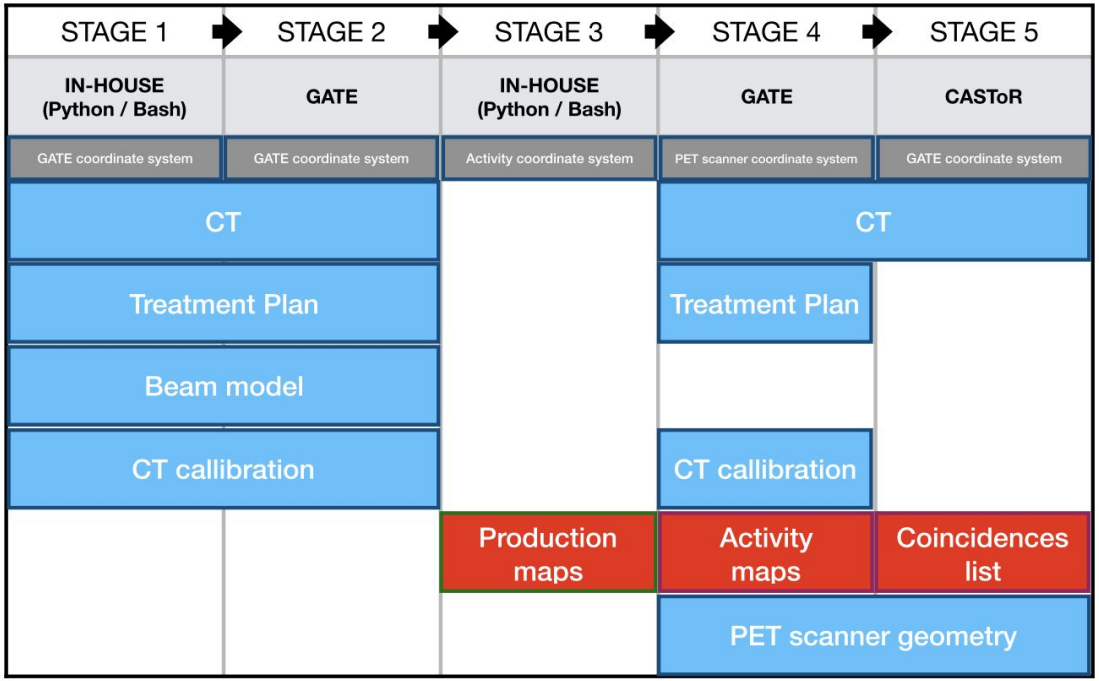
ProTheRaMon

Proton Therapy Range Monitoring

https://github.com/borysd/ProTheRaMon

Open source software package for characterizing and optimizing the performance of a PET scanner for proton therapy range monitoring.

- Automated and time-efficient
- Flexible protocols and geometries
- Geant4/**GATE** Monte Carlo
- **CASToR** PET image reconstruction
- in-house implemented scripts.



Silesian University of Technology

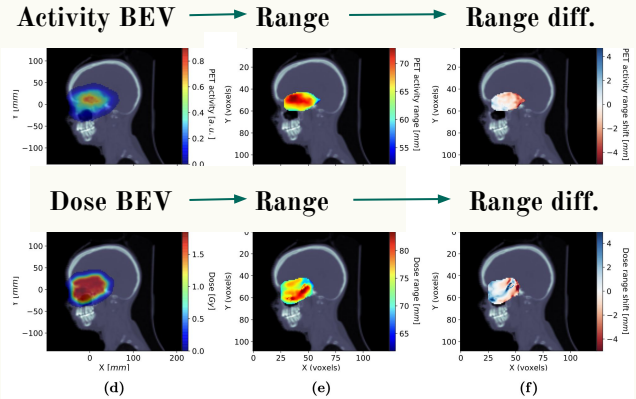
HPC Ziemowit

D. Borys, et al., PMB (2022)

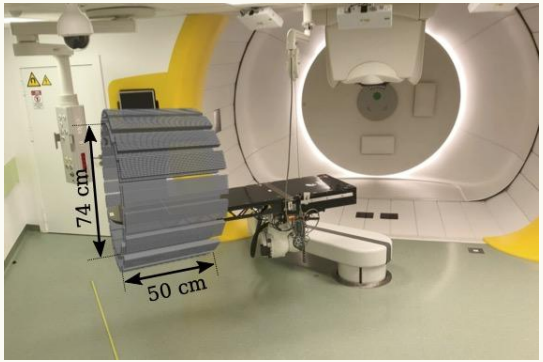
Range shift detection in patients

Simulation studies with J-PET

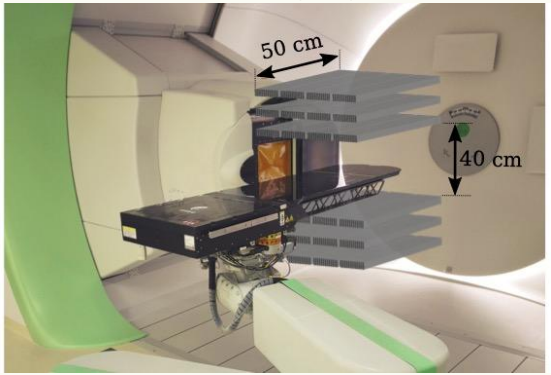
94 patients x 27 scenarios
(24 shifts + 2 CT cal. + reference)



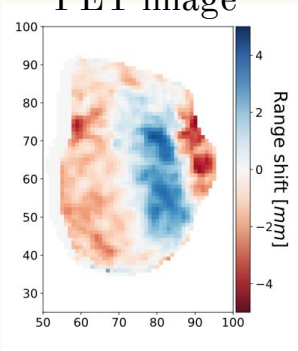
In-room PET imaging protocol



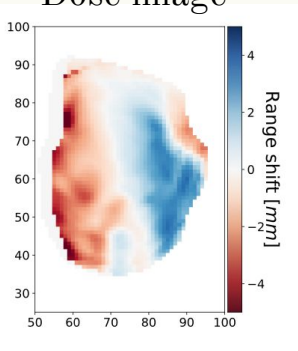
In-beam PET imaging protocol

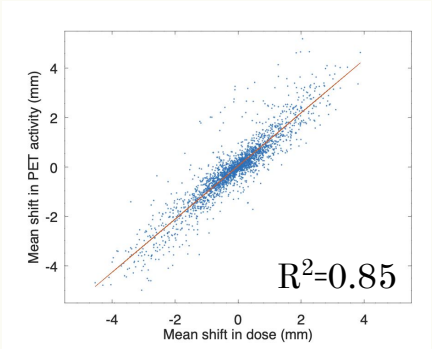


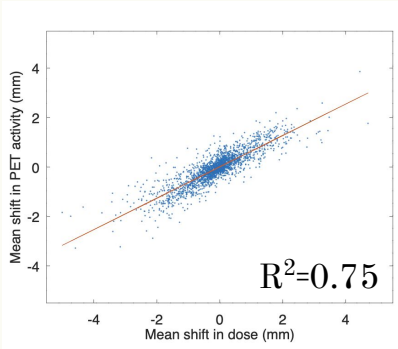
PET image



Dose image







K. Brzezinski, et al., PMB (2023) provisionally accepted

Summary

Monte Carlo medical physics applications in Kraków proton therapy centre:

- Computational patient **Quality Assurance** - Dose evaluation
- Support treatment planning - **LET evaluation**
- Detector development - **J-PET** and **TimePix**
- Analysis of large patient dataset

Thank You for Your attention

M. Bałamut, D. Borys, K. Brzeziński, M. Garbacz, W. Komenda, R. Kopeć, M. Kozani, D. Krzempek, K. Krzempek, G. Mierzwińska, J. Miszczyk, N. Mojżeszek, M. Rydygier, P. Stasica, A. Zając-Grabiec, A. Ruciński

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C. Granja, C. Oancea, L. Marek — ADVACAM Imaging the Unseen

N. Krah — CREATIS

D. Borys — Silesian University of Technology

C. Winterhalter, K. McNamara, A. Lomax, D. C. Weber, S. Zürrer — PAUL SCHERRER INSTITUT PSI

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