Clinically Ready Simulation Package for Monitoring Gamma Hotspot Emission, and Detection in Patient Anatomy

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AAPM 2025 COMING TOGETHER TO FORGE AHEAD IN MEDICAL PHYSICS
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EXTENDED WORK WILL BE PRESENTED On
Session Title: Therapy SNAP Oral: Functional and Quantitative Image in RT
Date: Wednesday, July 30, 2025
Talk Time: 11:33 AM
Location: Room 209

WELCOME to Prompt Gamma (PG) Station

- **Objective**

Prompt gamma (PG) imaging is a promising modality for proton dose verification. Currently, there is a lack of effective tools to investigate the entire PG imaging process in patient anatomy, from PG emission to camera detection and image reconstruction, to evaluate and optimize its efficacy for dose verification in proton therapy.

- **Approach**

To address this gap, we developed a Monte-Carlo package, POLARIS J Monte Carlo (PJ-MC), that simulates the entire PG emission and imaging workflow in patient anatomy.

- **Main Results**

Mean absolute percentage error analysis showed that PG range verification was more stable when considering the range at 80% or 50% of proton range (D_{max}), as opposed to the range at the D_{max}, where energy gating slightly improves accuracy but may reduce localization due to photon loss.

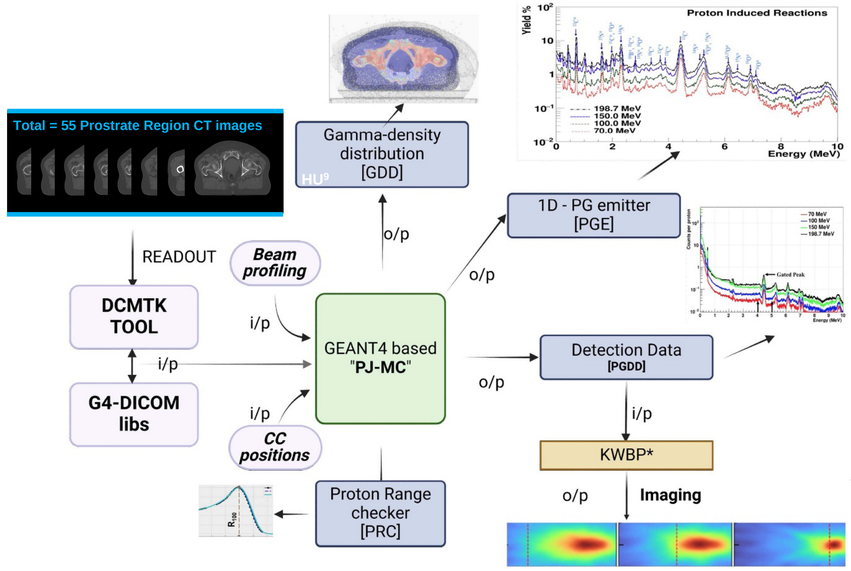
- **Conclusion**

Results showed that patient anatomy can impact the location of hot spot in the PG images, affecting its accuracy for localizing Bragg peak.

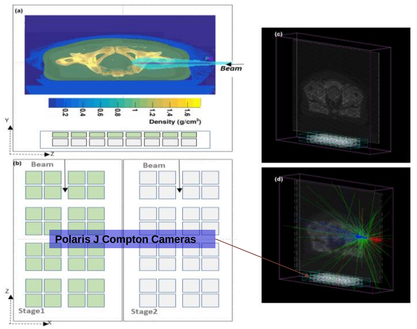
- **Significance.**

Our simulation package provides insights into PG emission and imaging in patient anatomy and serves as a robust tool for evaluating and optimizing PG imaging, enhancing its precision for dose verification in proton therapy.

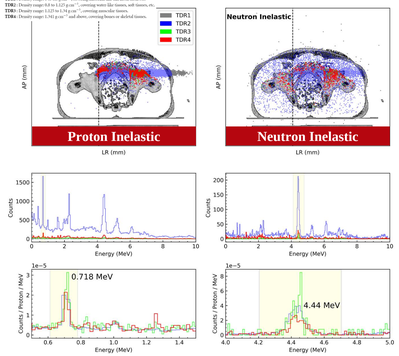
Workflow Illustration using PJ-MC



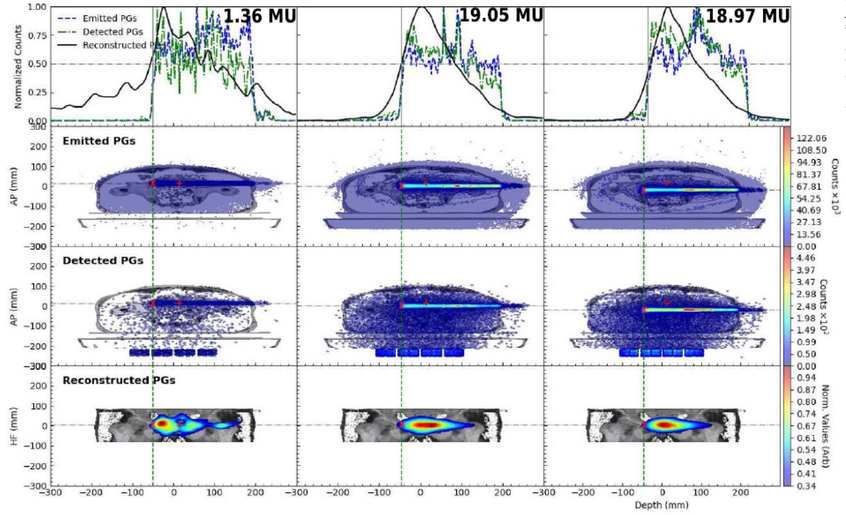
Experimental Set-up



Tissue Dependent Regions (TDR)



Clinical Cases



Proton delivery and plan

Location →	Spot 1	Spot 2	Spot 3
Position X (cm)	3.49	3.49	3.49
Position Y (cm)	14.26	1.04	−18.8
Dose (MU)	1.36	19.05	18.97
Protons ($\times 10^6$)	6.22	87.1	86.7

Total PGs

Emitted	1945 111	27 616 430	28 098 974
Detected	8115	132 995	175 539
Doubles	791	13 821	17 900
Triples	414	7113	9062

Proton range verification at 100% of peak value at D_{max}

Location ↓	G4 Engine (cm)	RAYSTATION (cm)	KWBP (cm)	KWBP EG[a] (cm)
Spot1	24.83	24.56	22.73(↓2.10)	22.53(↓2.20)
Spot2	24.29	24.25	20.15(↓4.14)	21.36(↓2.93)
Spot3	24.69	24.28	19.19(↓5.50)	20.59(↓4.10)

Proton range verification at 80% of peak value at D_{max}

Spot1	24.83	24.56	23.50(↓1.33)	23.62(↓1.21)
Spot2	24.29	24.25	22.20(↓2.09)	21.96(↓2.33)
Spot3	24.69	24.28	21.84(↓2.85)	23.82(↓0.87)

Proton range verification at 50% of peak value at D_{max}

Spot1	24.83	24.56	25.38(↑0.55)	24.73(↓0.1)
Spot2	24.29	24.25	24.29(≈0.00)	24.79(↑0.5)
Spot3	24.69	24.28	25.23(↓0.54)	26.29(↑1.6)

[a] EG = 4.44 MeV PG Signal energy gated Window.
In parentheses → G4Engine—KWBP and/or G4Engine—KWBP EG[a]
↑ Increment by value (cm).
↓ Decrement by value (cm).

Main Results

- The classification of tissues into four density regions (TDR1-TDR4) revealed significant anatomical influences on PG emissions, particularly highlighting the contribution of bone (TDR4) and soft tissue (TDR2) interactions in shaping PG spectra.
- PG-based range verification was assessed using MAPE analysis at 100% and 50% of the peak value of maximum proton range (Dmax). While EG slightly improved accuracy at 100% of Dmax by reducing MAPE from ≈15% to ≈7%–8%), the 80%–50% of peak value at Dmax region showed greater stability
- The findings of this study highlight the critical role of patient anatomy and tissue composition in PG-based range verification, as slight shifts in gamma hotspots appear due to prominent PG signals from denser regions during proton traversal.
- The PJ-MC package provides a robust platform for evaluating PG emissions and secondary gamma interactions in a clinically relevant setting.

Acknowledgements

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References

- Sharma VR, et al., Phys Med Biol. 2025;70(12):125004.
- Jiang Z et al., Phys Med Biol. 2023;68:075001.