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Multi-Start Likelihood Reconstruction with Bayesian Penalisation for Low-Statistic Positronium Lifetime Imaging

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We explore the adaptive algorithm in Positronium Lifetime Imaging (PLI), a new technique that analyses the local behaviour of positronium (Ps) – a quasi-stable electron-positron (e^-e^+) compound [1]. Voxel-dependent Ps lifetime spectra can be acquired using Positron Emission Tomography (PET) with specific $\beta^+\gamma$ sources that emit an additional prompt gamma photon. But mostly due to a need for 3-photon coincidence data, the sensitivity is much lower than in standard PET [2].

Based on the previous development of PLI algorithms based on non-linear fitting of noisy voxel-dependent Ps lifetime spectra [3], we further address the challenge of low-count data. A multi-variable Bayesian penalisation factor is added to the negative log-likelihood minimisation, using prior information from the approximate low-resolution image. There is a major issue that the multi-channel Ps decay model tends to overfit and converge to local minima. A proposed solution is a multi-start optimisation with random initial guesses, split into two stages – each with different variables fixed or penalised from priors.

We also conduct an inferential analysis of the initial guess distributions and their adjustment to the regions that converge best. That allows for a decrease in their minimal number for successful minimisation and for a performance boost of the PLI algorithm.

[1] Deutsch M. Phys.Rev. 82 455 (1951)

[2] Huang B et al. Comm.Phys. 8 1 (2025)

[3] Shopa RY, Dulski K. BAMS 19 54 (2023)

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