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Theme: Physics / Abstract No.: PTCOG-AO2025-ABS-0131

Abstract Title: Analytical Simulation of Adjacent Spot Distinction in PBS Proton Therapy: Effects of Spot Size, Inter-Spot Spacing, and Detector Pitch

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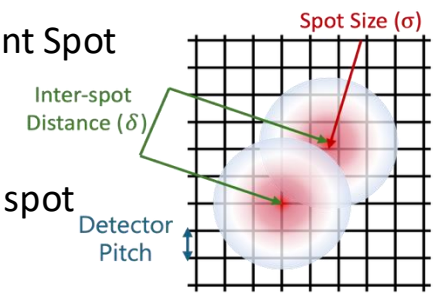
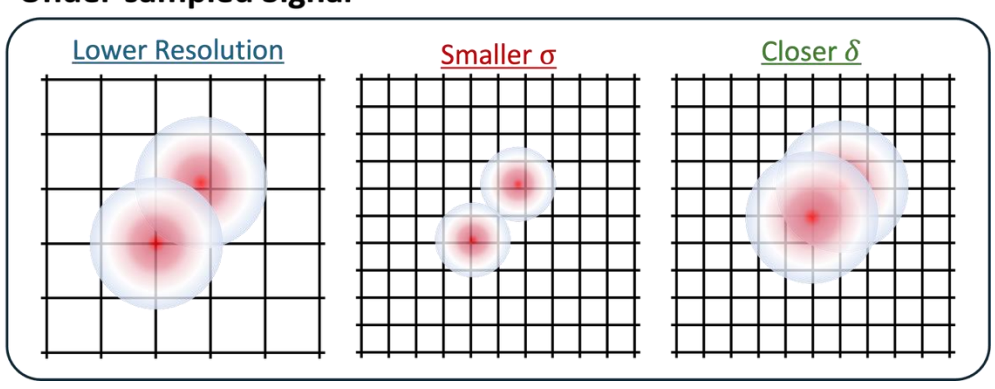
Background & Aims

- Spot Size (σ) of PBS Proton Therapy Beam: 2.6-13.0 mm
- Typical IC Array for PBS QA: 7.1-7.6 mm-pitch
- (AAPM TG-224) Proton Therapy PBS QA Tolerance for Spot Measurement: 1 mm (position), 10% (σ)
- Under-sampling Case for Adjacent Spot
  1. Lower number of samples
  2. Detector pitch ≫ σ
  3. Too-close δ looks like merged spot



Under-sampled Signal

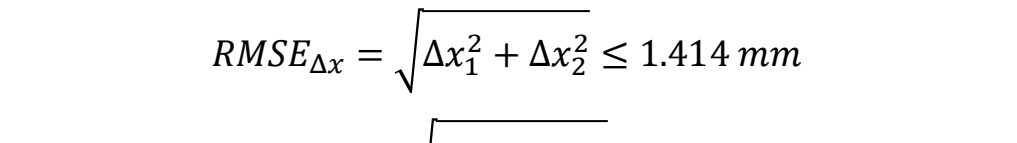


This study analytically investigates adjacent-spot distinction in PBS proton therapy by varying spot size (σ), inter-spot spacing (δ), and detector pitch.

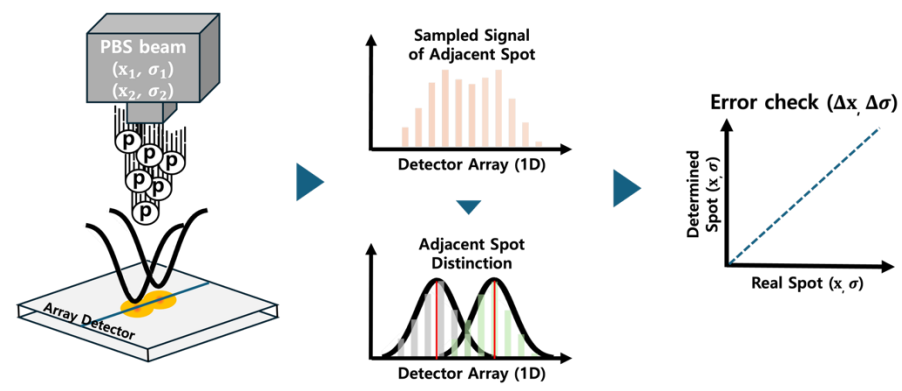
Materials & Methods

Simulation Condition for Adjacent Spot Distinction:

- Ideal Point Sensor 1D Array (0.25-10 mm Pitch)



- Adjacent Spot: 2 Equal-amplitude Single-Gaussian Spots (σ =2.6-13 mm, δ=0.1-30 mm)



- Non-linear Least Squares fitting

$$S = \Sigma S = S_1(x_1, \sigma_1) + S_2(x_2, \sigma_2) \xrightarrow{NLLS}$$

$$\hat{S} = \hat{A} \cdot \left[exp\left[-\frac{(x-\hat{x}_1)^2}{2\hat{\sigma}_1{}^2} \right] + exp\left[-\frac{(x-\hat{x}_2)^2}{2\hat{\sigma}_2{}^2} \right] \right]$$

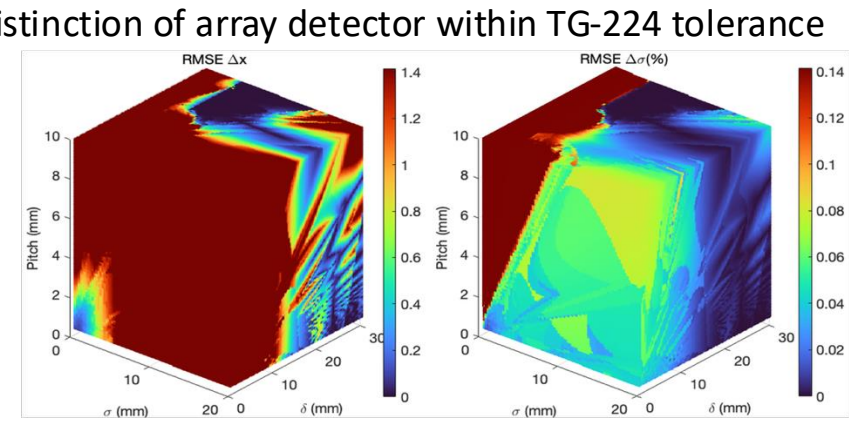
Root-mean-square-error (RMSE) Heatmaps for Accuracy Quantification of Adjacent Spot Distinction:

$$RMSE_{\Delta x} = \sqrt{\Delta x_1^2 + \Delta x_2^2} \leq 1.414\, mm$$

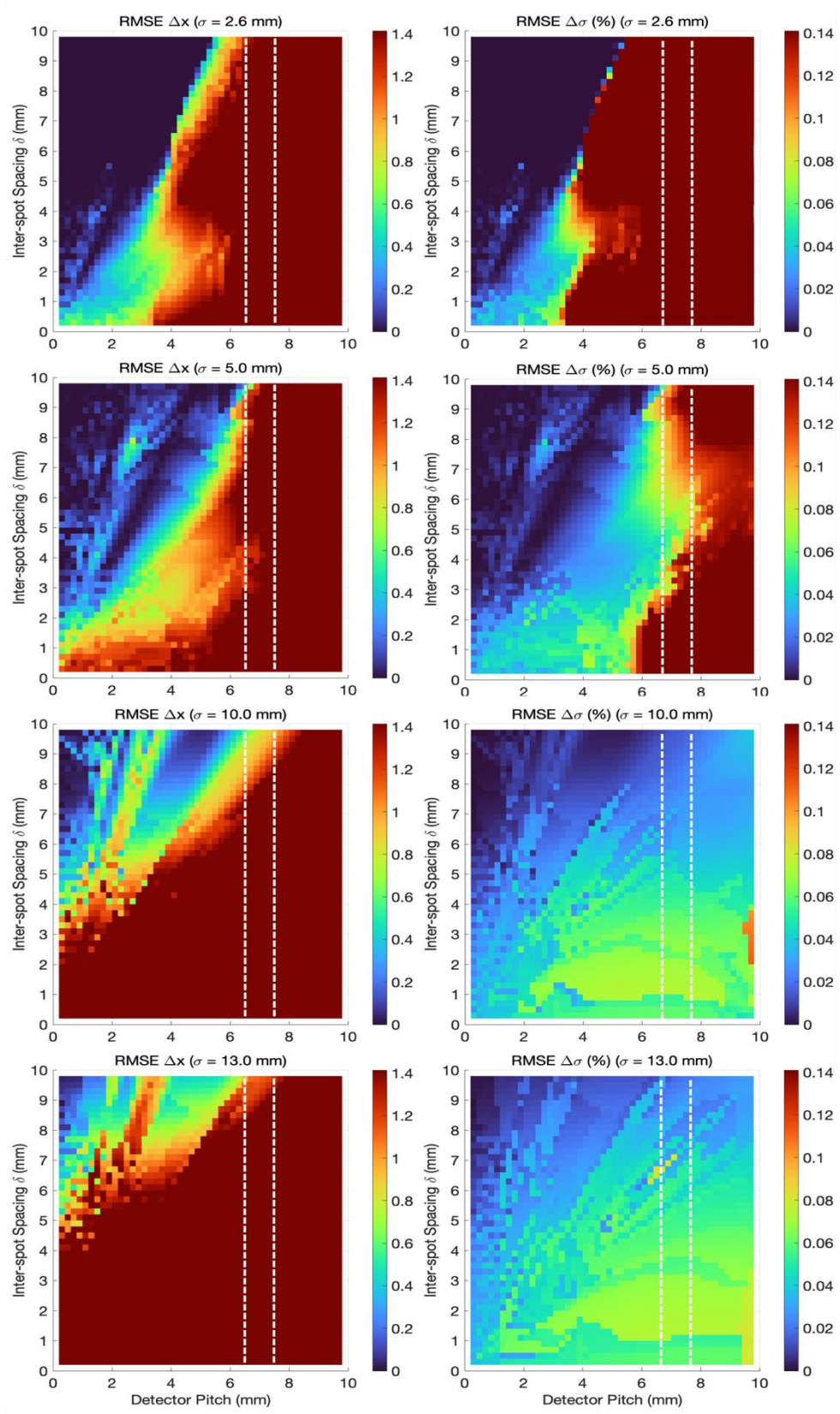
$$RMSE_{\Delta \sigma} = \sqrt{\Delta \sigma_1^2 + \Delta \sigma_2^2} \leq 14.14\ \%$$

Results & Discussion

- RMSE 3D heatmap (x: σ, y: δ, z: pitch) shows adjacent spot distinction of array detector within TG-224 tolerance



- 6.5-7.6 mm-pitch array (white dash) only resolve overlapped spots when σ ≳ 10 mm & δ > 9 mm
- Arrays (< 3 mm-pitch) distinguish overlapped spots (σ = 2.6-13 mm, optionally δ ∝ 0.1σ-0.5σ)



Conclusion

- Conventional detectors are sufficient for gamma analysis, but higher-resolution detectors are required to verify individual spot assignments in PBS proton therapy plans
- Limitation: only considered ideal point detector and two spot distinction, assumed single-Gaussian dose distribution of PBS Proton Therapy beam spot

Acknowledgement

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