Memorial Sloan Kettering
Cancer Center

Automated proton treatment planning with robust optimization using constrained hierarchical optimization

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Robust optimization

- Intentionally impose errors
- Stochastic and the worst-case approach
  - **Worst-case:**

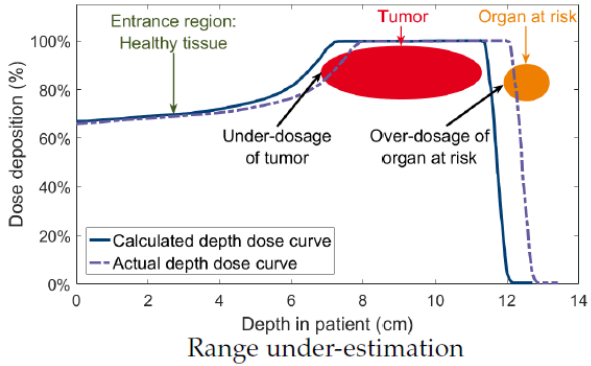
$$\min_x \left(\max_s (f_s(x)) \right)$$

With x the proton spot weights, and s the scenario index

  - **Stochastic:**

$$\min_x \left(\mathbb{E}(f_s(x)) \right) = \min_x \left(\sum_s w_s \cdot f_s(x) \right)$$

with $\mathbb{E}$ the expectation value, and w_s an importance weight (or probability) for scenario s



$$\min_x \left(\max_s (w_s \cdot f_s(x)) \right)$$

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Robust optimization

Stochastic:
- Includes all scenarios
- Focuses on the average scenario

Worst-case:
- Includes only one scenario
- Focuses on worst scenario

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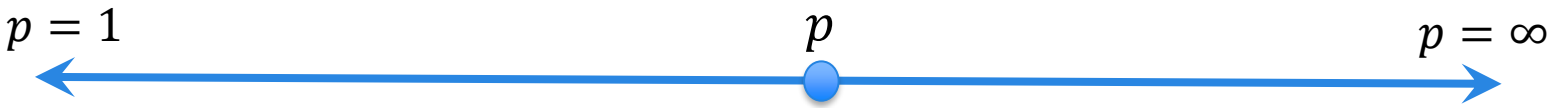
Robust optimization – our approach



Stochastic:
- Includes all scenarios
- Focuses on the average scenario

Worst-case:
- Includes only one scenario
- Focuses on worst scenario

- Robust optimization:

$$\min_x \left(\sum_{s \in S} \left(f\left(d(x,s)\right) \right)^p \right)^{\frac{1}{p}}$$

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ECHO (Expedited Constrained Hierarchical Optimization)

- Constrained optimization
  - Max and mean doses are strictly fulfilled
  - Tuning of objective weights (b_w) is avoided
- Hierarchical optimization
  1. Target coverage
  2. OAR sparing

} Robustness is included in both steps

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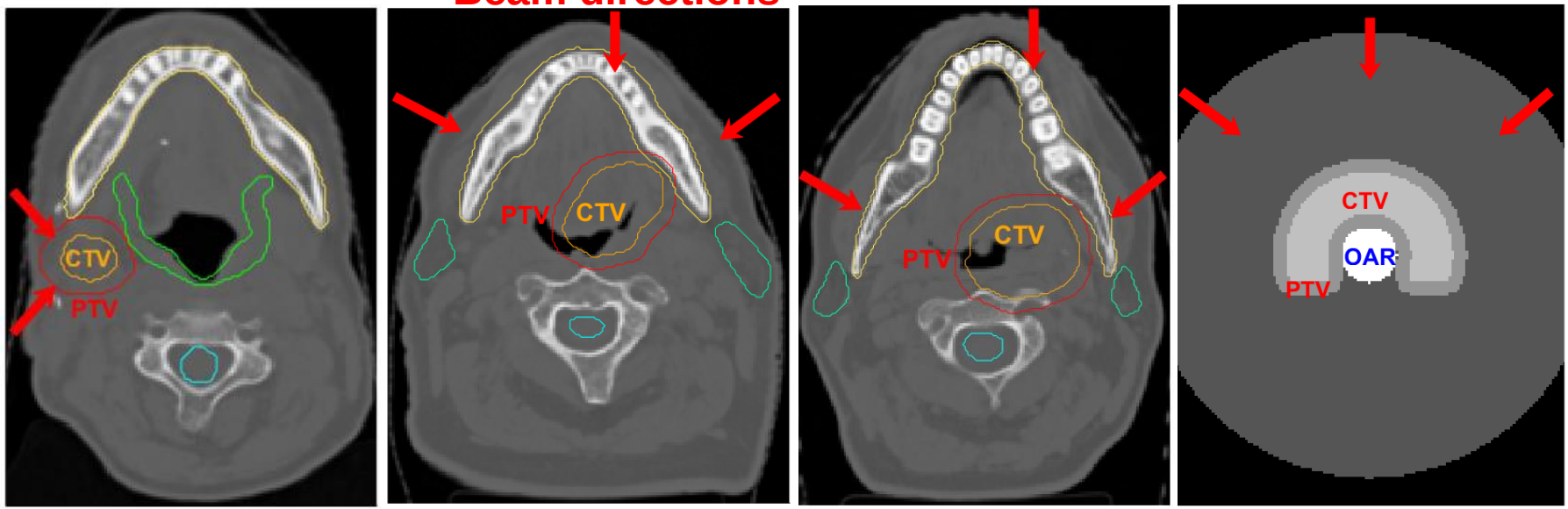
Patients

Scenarios:
1 nominal
6 x 3 mm setup error + 3.5% range error
6 x 3 mm setup error + -3.5% range error

Beam directions



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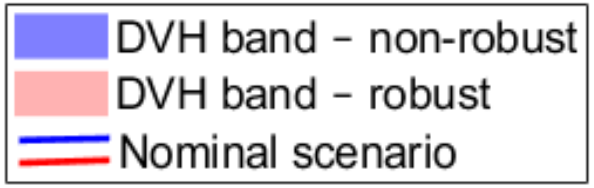
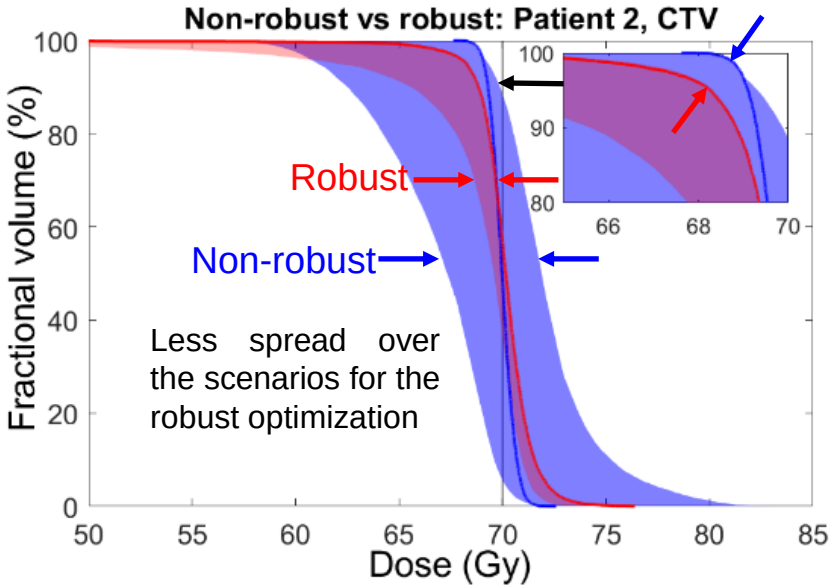
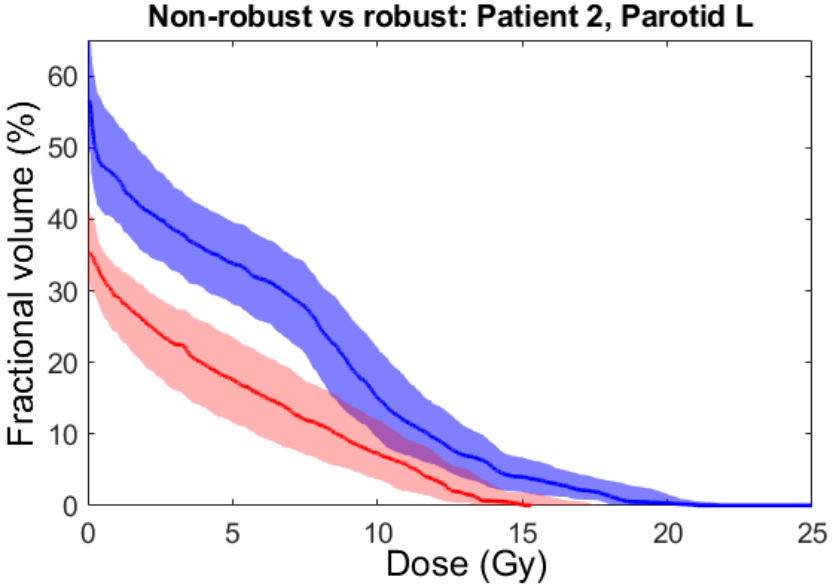
Robust vs non-robust



Nominal scenario better for the non-robust optimization





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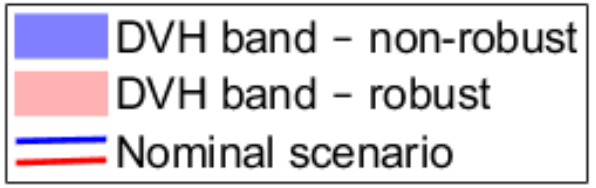
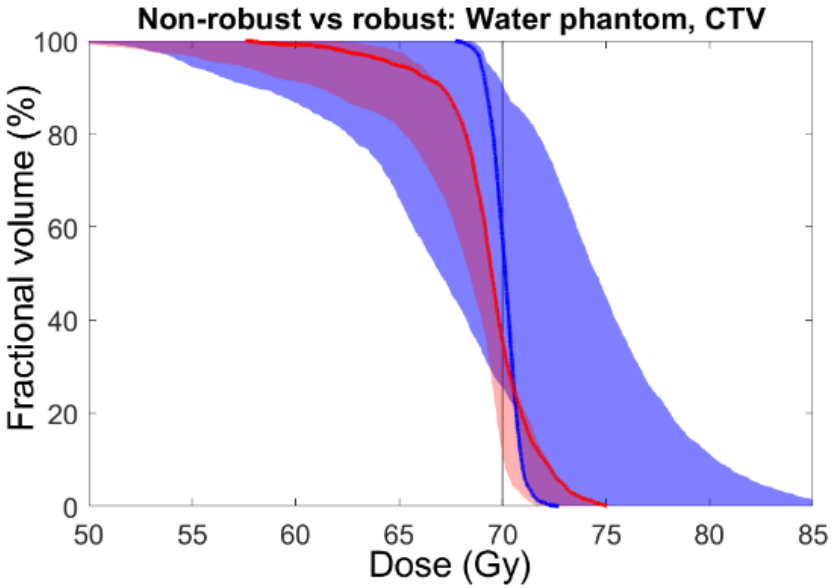
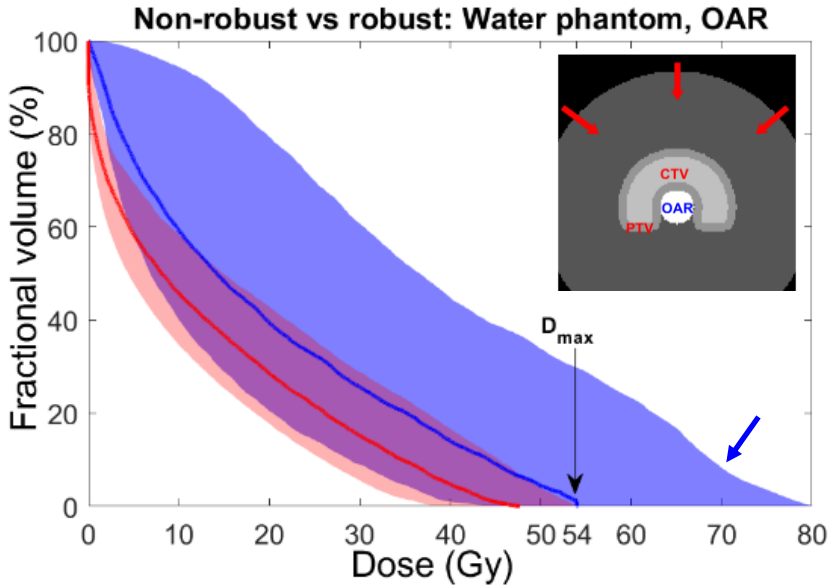
Robust vs non-robust







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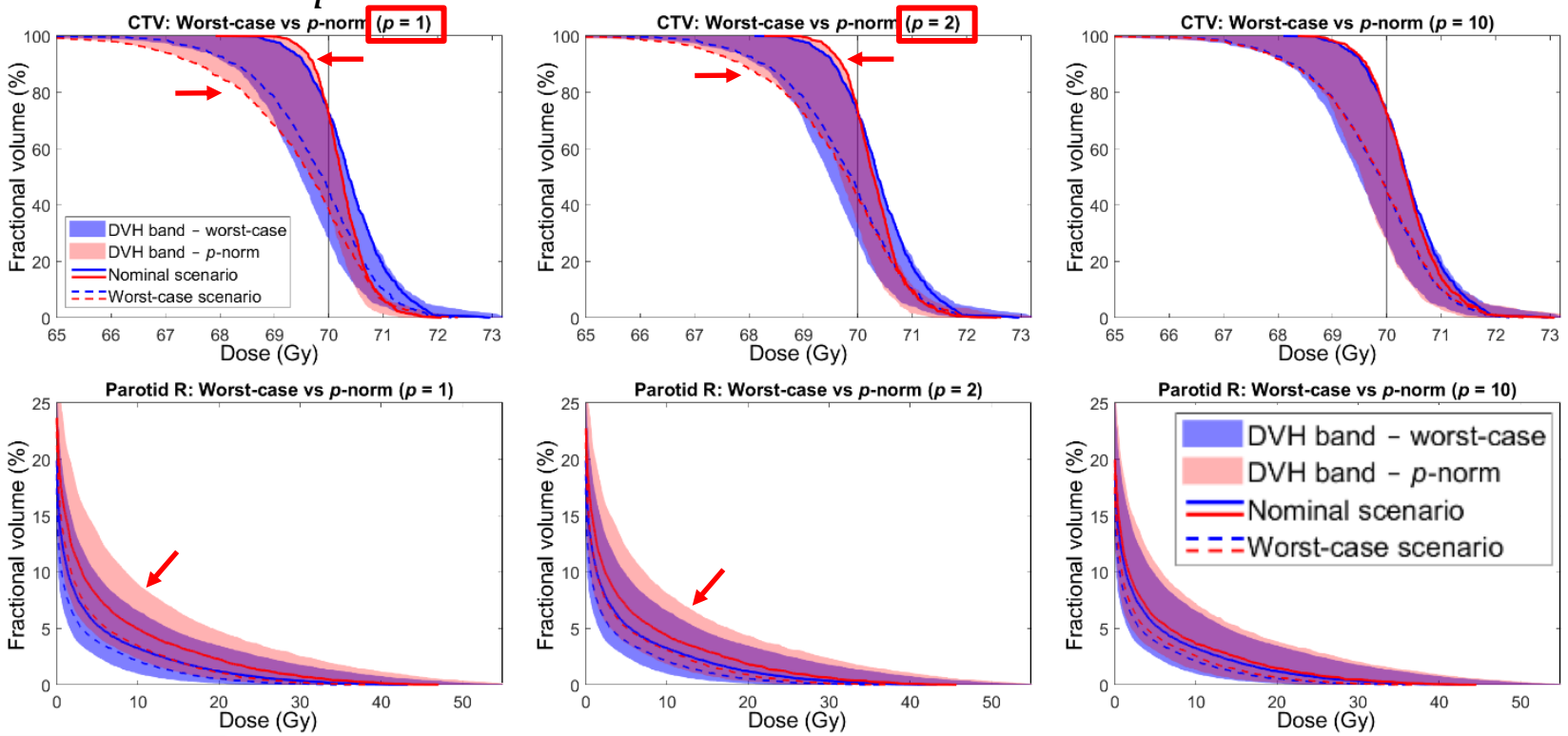
p-norm (and stochastic) vs worst-case

Stochastic: $p = 1$



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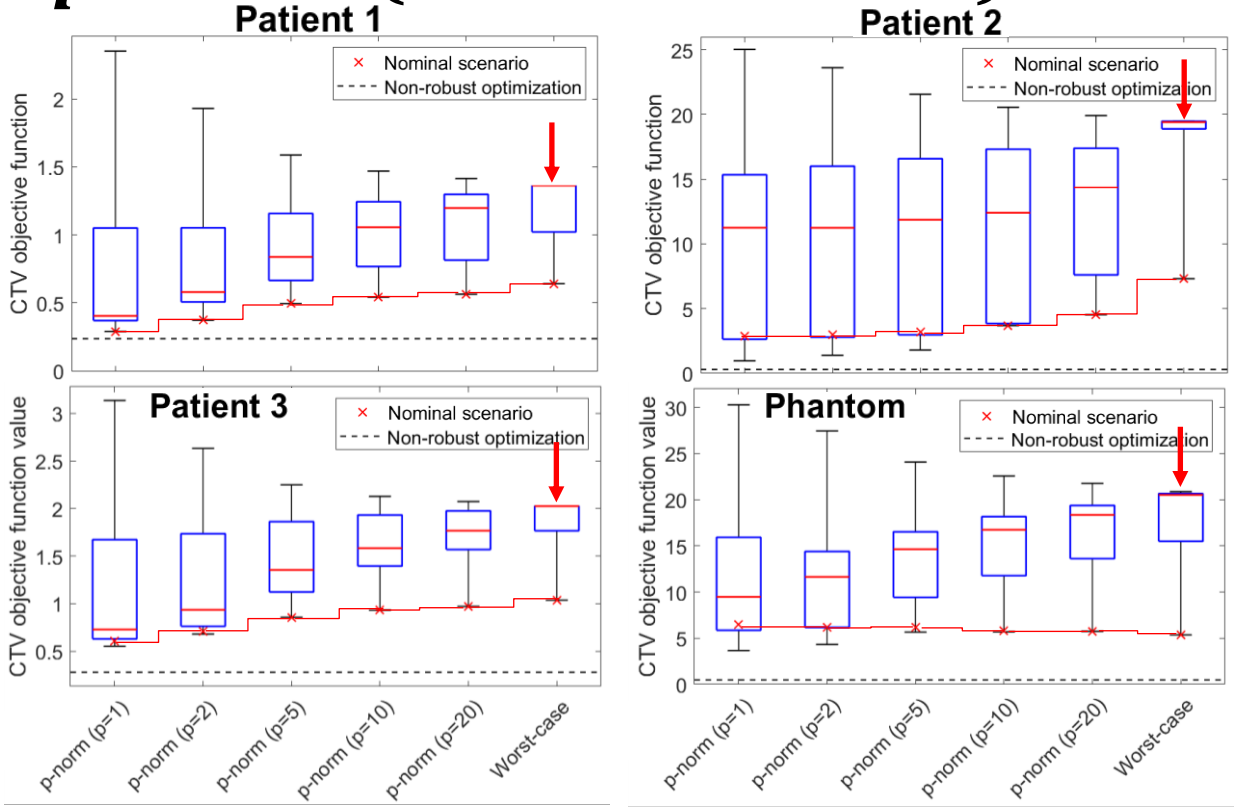
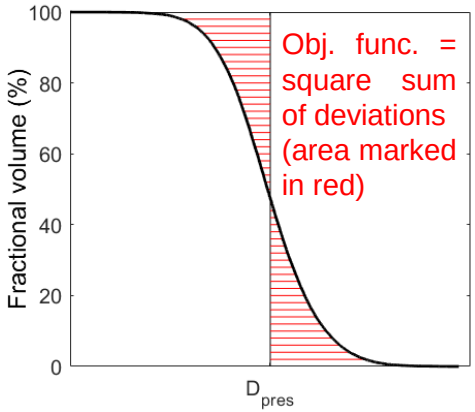
p-norm (and stochastic) vs worst-case





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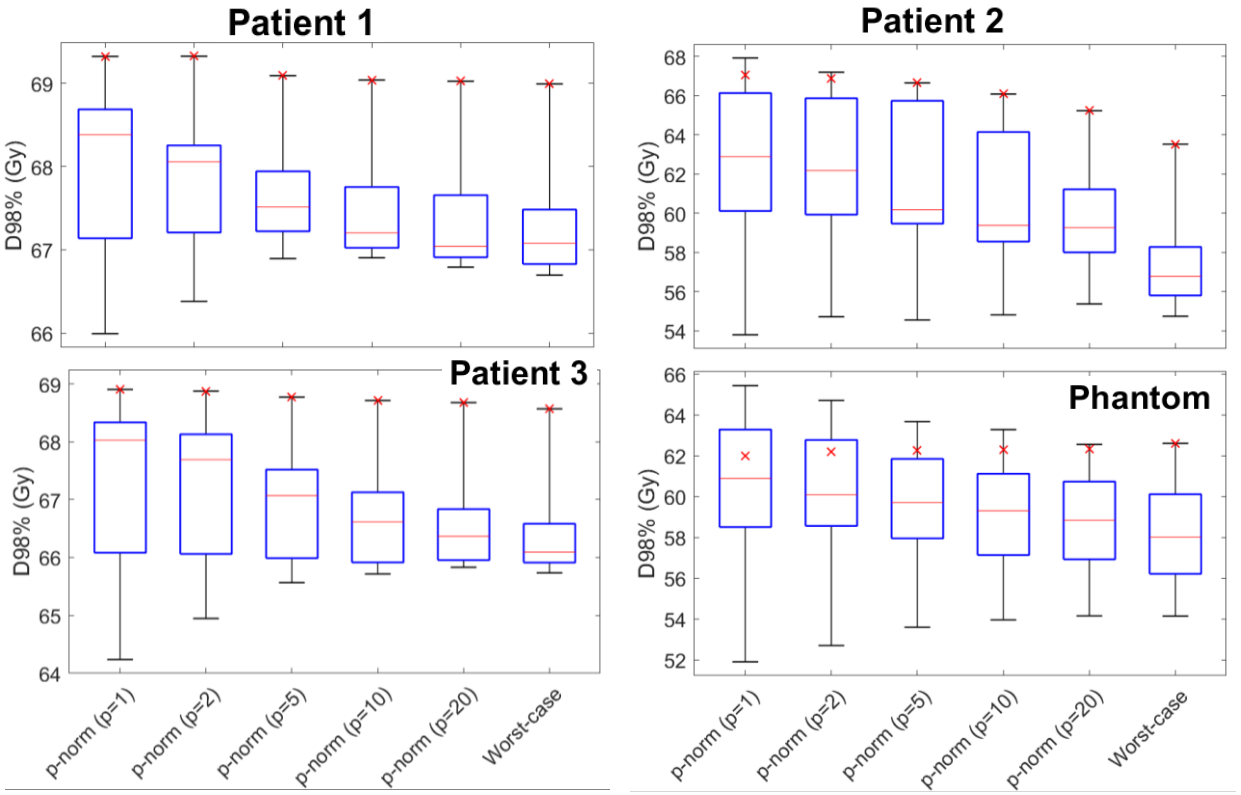
p-norm (and stochastic) vs worst-case



Prescription dose = 70 Gy

Worst-case approach:

- ↑ Less variation among the scenarios
- ↑ Better in the worst scenario
- ↓ Worse median value

***p*-norm approach:**

- Full flexibility to focus on the most important criteria

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Summary

- ECHO – automated treatment planning for protons
- Robustness approach in-between extreme approaches
- Flexibility to balance between the nominal and the worst scenario

Thank you very much for your attention

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References

- VT Taasti, L Hong, JO Deasy, M Zarepisheh. Automated proton treatment planning with robust optimization using constrained hierarchical optimization. *Med Phys.* 2020.
- VT Taasti, L Hong, JS Shim, JO Deasy, M Zarepisheh. Automating proton treatment planning with beam angle selection using Bayesian optimization. *Med Phys.* 2020.
- Zarepisheh M, Hong L, Zhou Y, Hun Oh J, Mechalakos JG, Hunt MA, Mageras GS, Deasy JO. Automated intensity modulated treatment planning: The expedited constrained hierarchical optimization (ECHO) system. *Med Phys*. 2019;46:294-2954.
- Integrating soft and hard dose-volume constraints into hierarchical constrained IMRT optimization. S Mukherjee, L Hong, JO Deasy, and M Zarepisheh. *Med Phys*. 2020;47:414-421.

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