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Combined proton-photon radiotherapy

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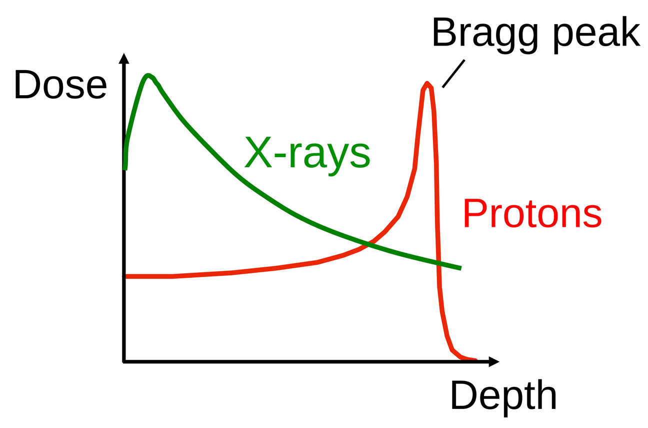
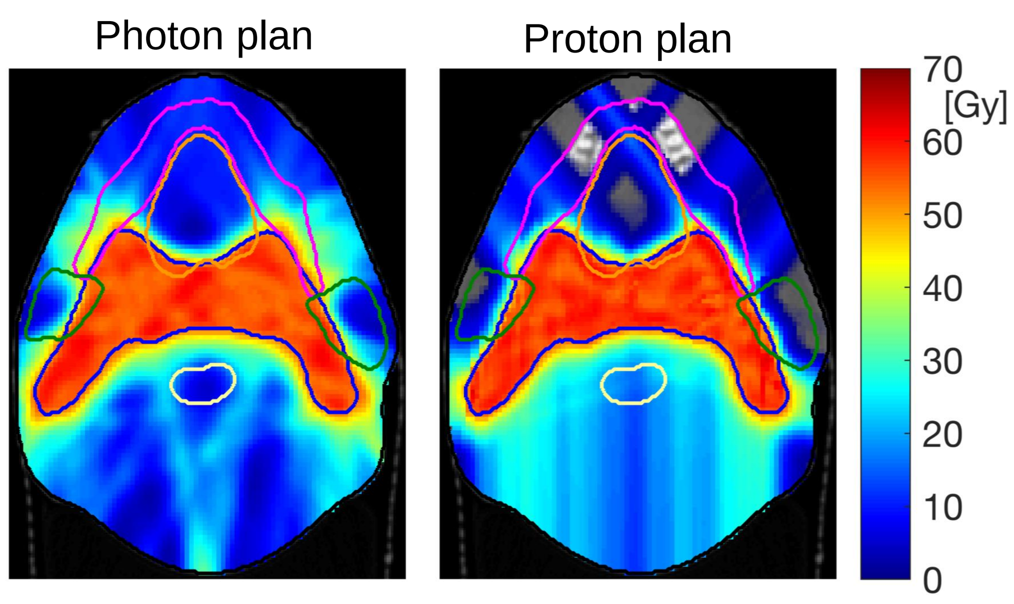
Background

- **Proton therapy allows for a better dose distribution compared to photon therapy**
  - ➢ integral dose reduction in normal tissues by a factor of 2-3
- **Proton therapy is a limited resource**
  - ➢ 80 proton therapy facilities with a total of 211 treatment rooms
  - ➢ 12000 linear accelerators (Linacs) for X-ray therapy
- **Proton therapy is bulky and costly**
  - ➢ Proton gantries cannot be installed in treatment rooms for photon therapy
  - ➢ Ratio of costs of about 2.4

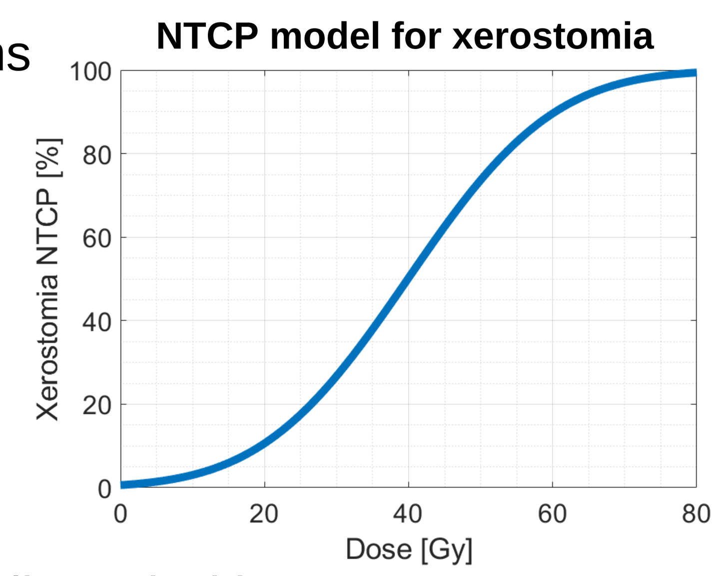




How can limited proton slots be optimally distributed over a patient cohort?

Material

- 45 Head & Neck (HNC) cancer patients from Dresden University Hospital
  - ➢ Photons (IMRT) and protons (IMPT) plans
  - ➢ 70/54 Gy prescribed to GTV/PTV in 30 fractions
- Normal Tissue Complication Probability (NTCP) models for relevant side-effects (e.g. xerostomia)



- Limited proton resources
  - ➢ Only 20% of all fractions (1350) can be delivered with protons
- Investigate the benefit of combined photon-proton treatments
  - ➢ Some fractions are delivered with protons and the rest with photons

Methodology

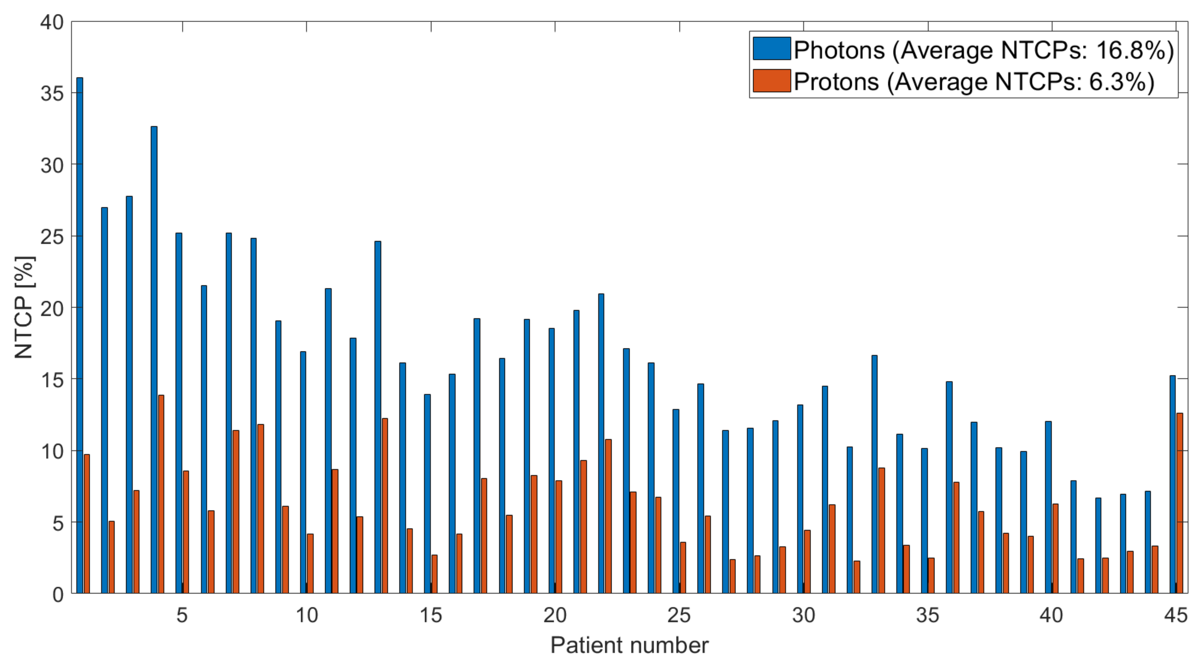
Minimize the sum of complication risks over the patient cohort

$$\underset{n_j^p}{\text{minimize}} \quad \sum_{patient\, j} NTCP\left(n_j^p\right) = \sum_j \Phi\left(\frac{n_j^p d_{p,j}^{mean} + (30-n_j^p) - D_{50}}{D_{50}\cdot m}\right)$$

$$\text{subject to} \quad \sum_j n_j^p = 20\% \text{ of all fractions}$$

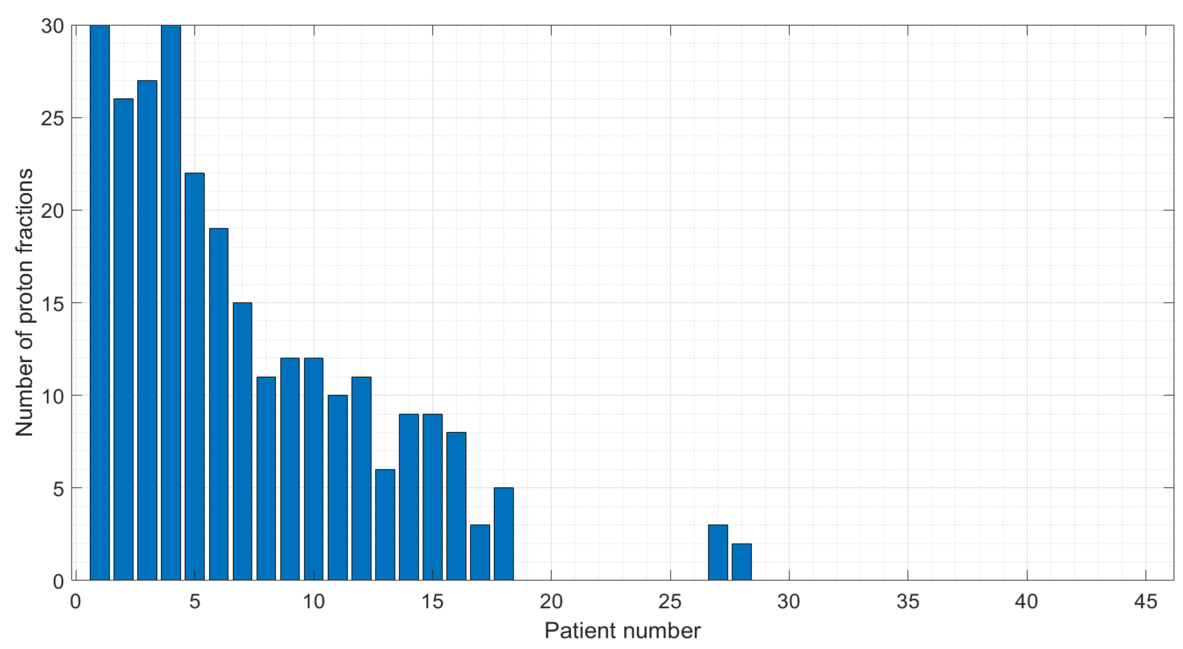
Results

- **NTCP values for xerostomia from the IMRT and IMPT plans**



➢ Protons therapy reduce the risk for xerostomia over the patient cohort

- **Optimal allocation of proton slots over the patient cohort**



➢ The patients with the highest ΔNTCP value ($NTCP_{IMRT}$-$NTCP_{IMPT}$) receive the largest number of proton fractions

➢ Patients not receiving protons receive photons

Conclusion

Combined proton-photon treatments with an optimized allocation of proton slots increase the benefit of proton therapy on the population level. Limited PT resources can be more efficiently used, from a global health system perspective.

How can we make proton therapy more available?

Treatment room design

- A horizontal proton beam line (FBL) with pencil beam scanning
- A conventional Linac for advanced X-ray therapy
- A robotic couch for treatments in lying position
  - ➢ Protons and photons delivered in the same treatment session

Rationale

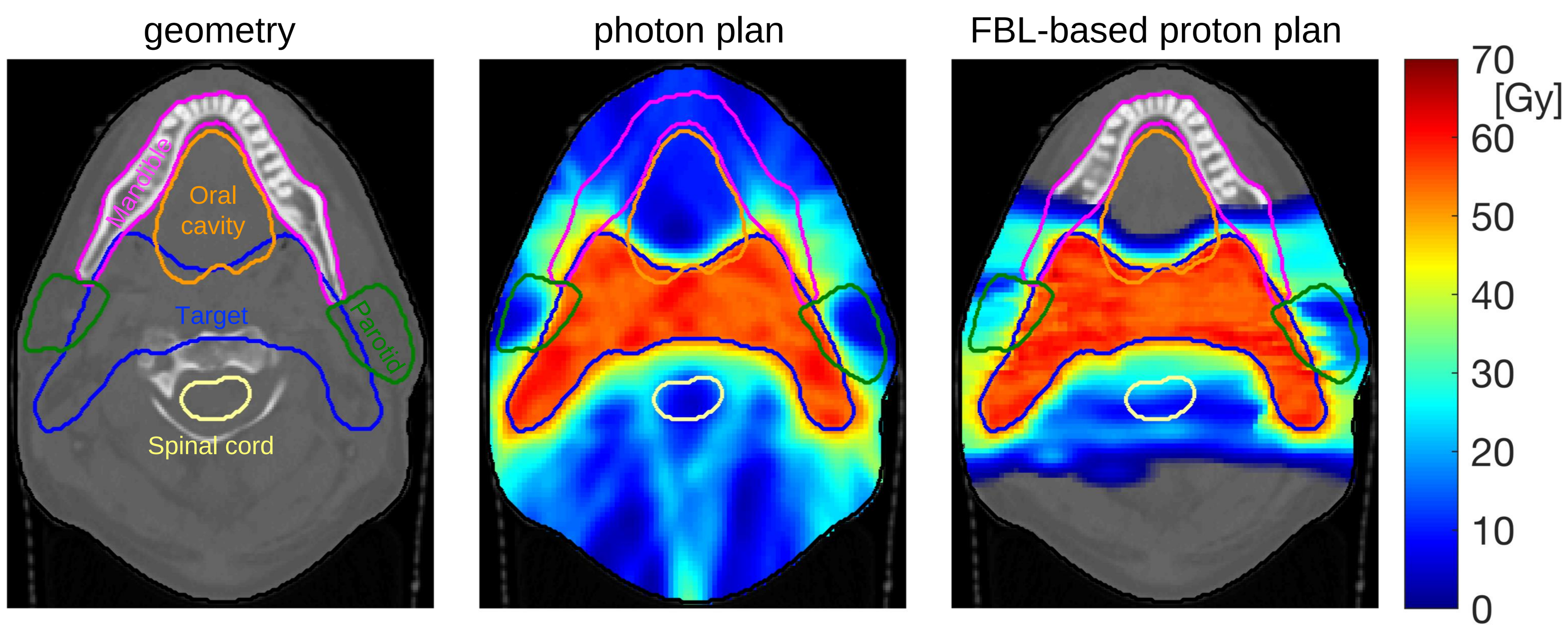
- Proton units can be installed into a conventional treatment room
- Building and equipment costs are substantially reduced
- Proton beams limited to a coronal plane may lead to sub-optimal plans for some tumor sites. However, this can be compensated for by a photon component

Treatment planning

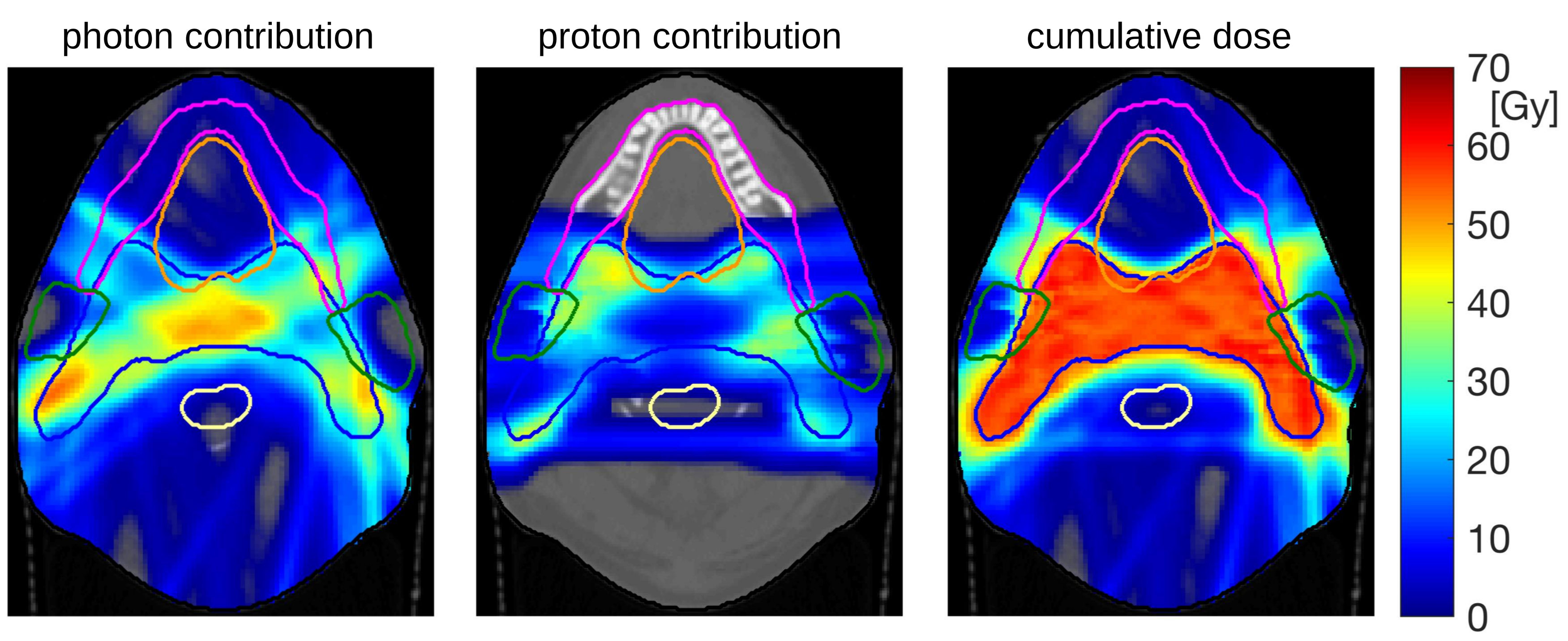
Simultaneous optimization of photons and protons plans based on their cumulative physical dose

$$\underset{x^\gamma, x^p}{\text{minimize}} \quad f(D^\gamma x^\gamma + D^p x^p)$$

Application to a head & neck cancer case



➢ IMPT with horizontal beams leads to high doses in the parotids



- ➢ The combined plan uses both photons and protons to optimally conform the dose distribution
- ➢ The combined plan maintains most of the integral dose reduction of the protons-only plan in normal tissues

Conclusion

Fixed proton beamlines in bunkers for conventional radiotherapy may allow the widespread use of protons. When plan quality for protons alone is sub-optimal due to limitations in the available beam directions, a photon component may allow achieving high-quality treatment plans.