HITRI plus
Heavy Ion Therapy Research Integration

Exploring the Role of Artificial Intelligence in Particle Therapy

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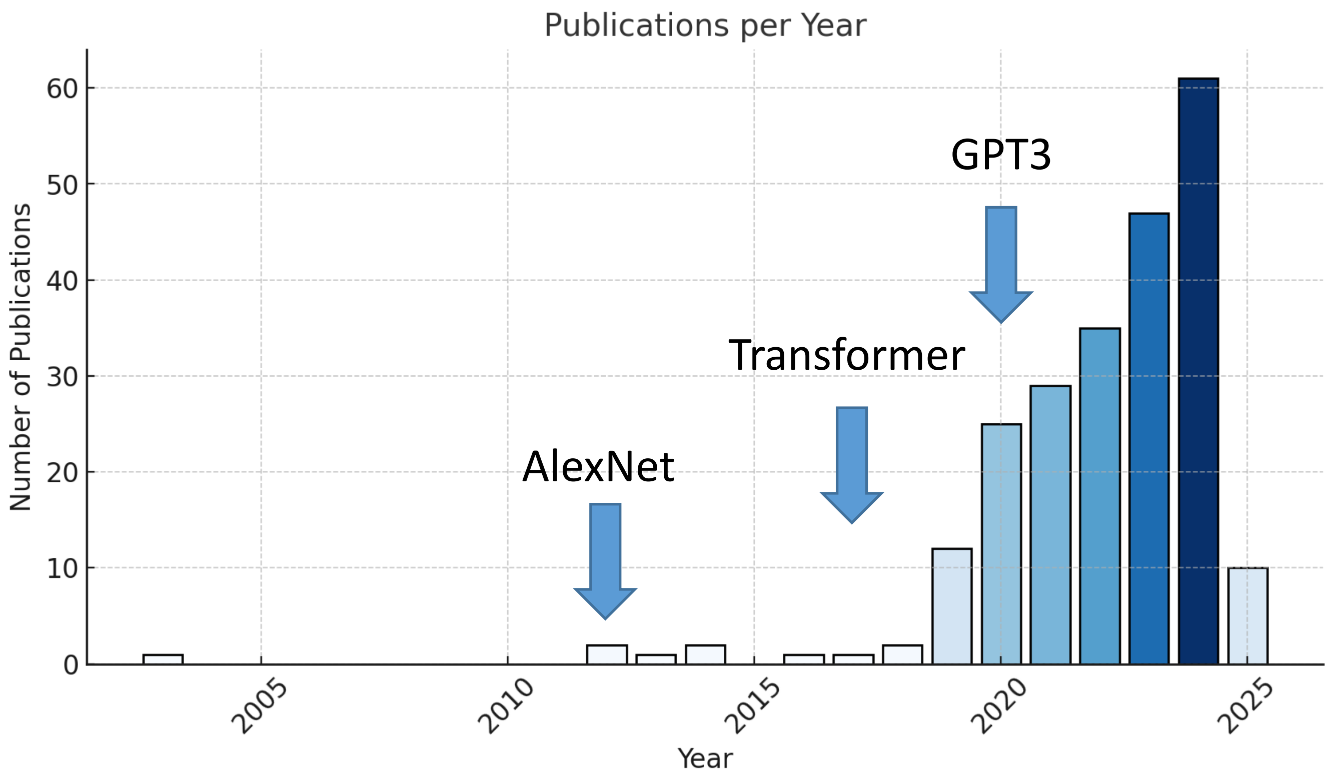
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008548

Overview over AI in particle therapy

- Number of AI publications increaes rapidly
- **2012:** AlexNet is published (Krizhevsky et al.)
- **2017:** “Attention is all you need” (Vaswani et al.)
- **2020:** GPT3 released by OpenAI
- **Current landscape:**
  - Many tools (ChatGPT-o1, githup Copilot, NotebookLM, DeepSeek,…) for efficient workflows
  - Strong libraries for developers (tensorflow, torch), supporting many architectures



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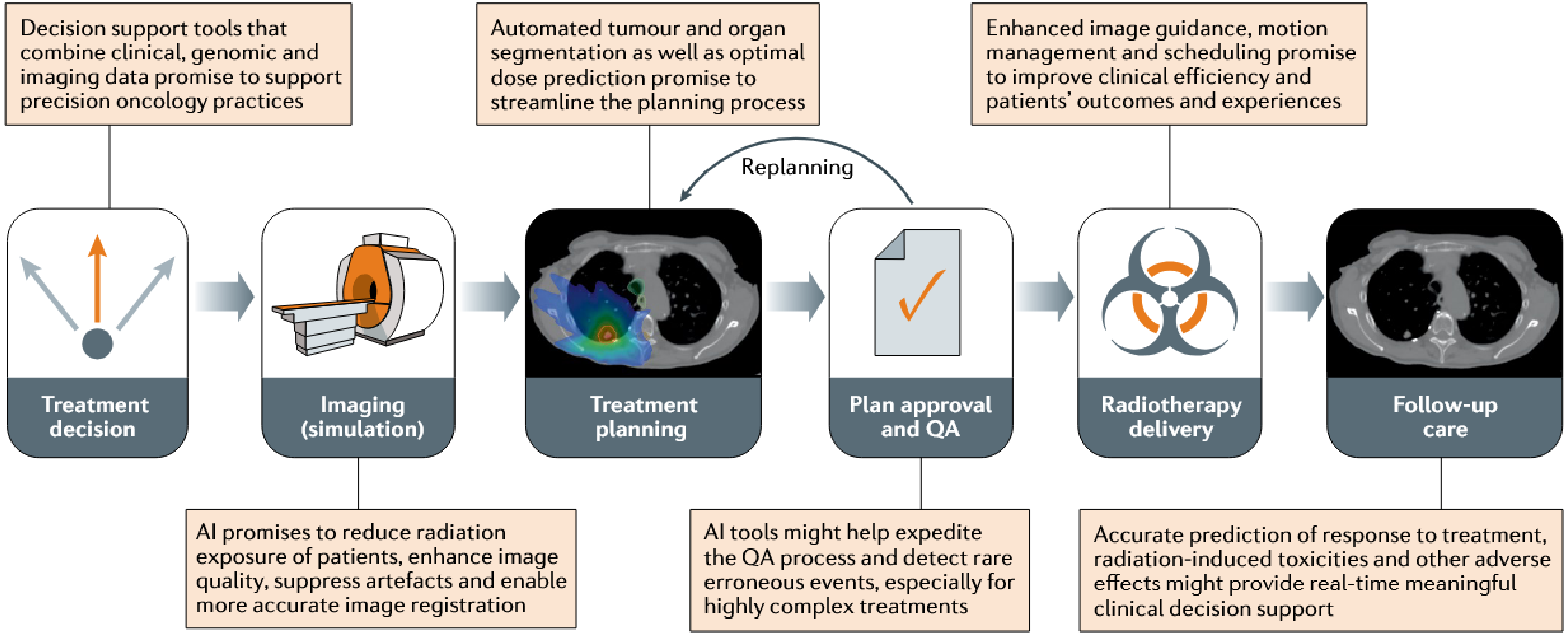
Where can AI help us?



Huynh et al. (2022) Nature Reviews Clin. Onc.

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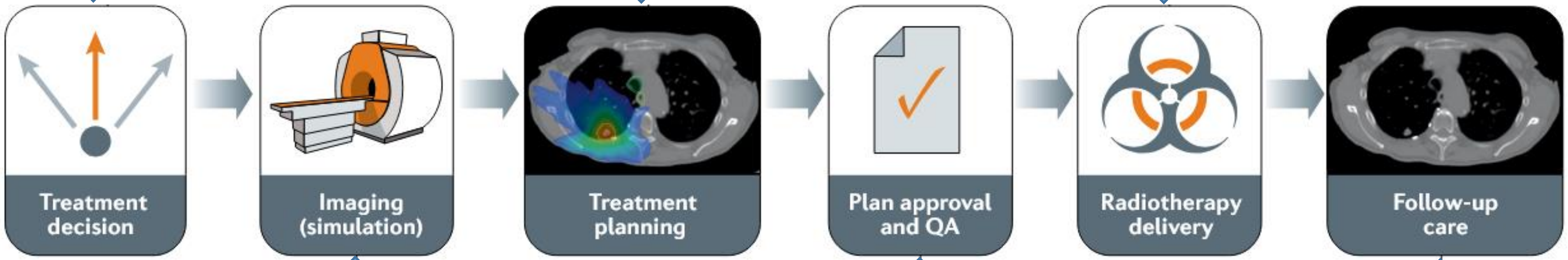
Where can AI help us **specifically in particle therapy**?

Photons or Particles?

- Dose prediction
- Dose calculation
- Workflow efficiency

- Scheduling
- Adaptation
- Motion mitigation



- Stopping power estimation
- Image quality enhancement
- MRI+particles

- Machine QA
- Patient specific QA

- Outcome prediction
- Prediction of adverse effects

Iskasson et al. (2024) Crit. Rev. Oncol. Hematol.

Peng et al. (2022) IEEE Trans. Rad. Plas. Med. Sc.

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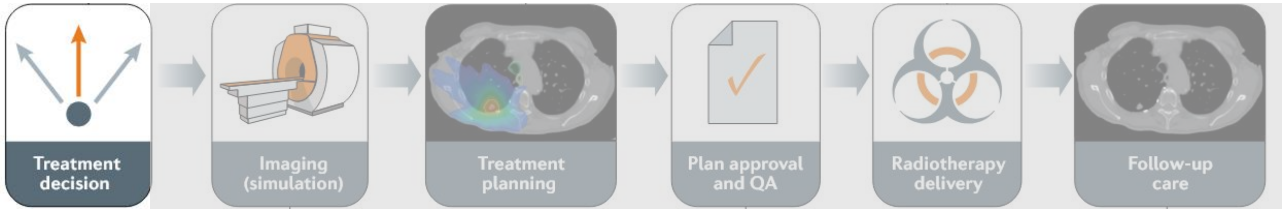
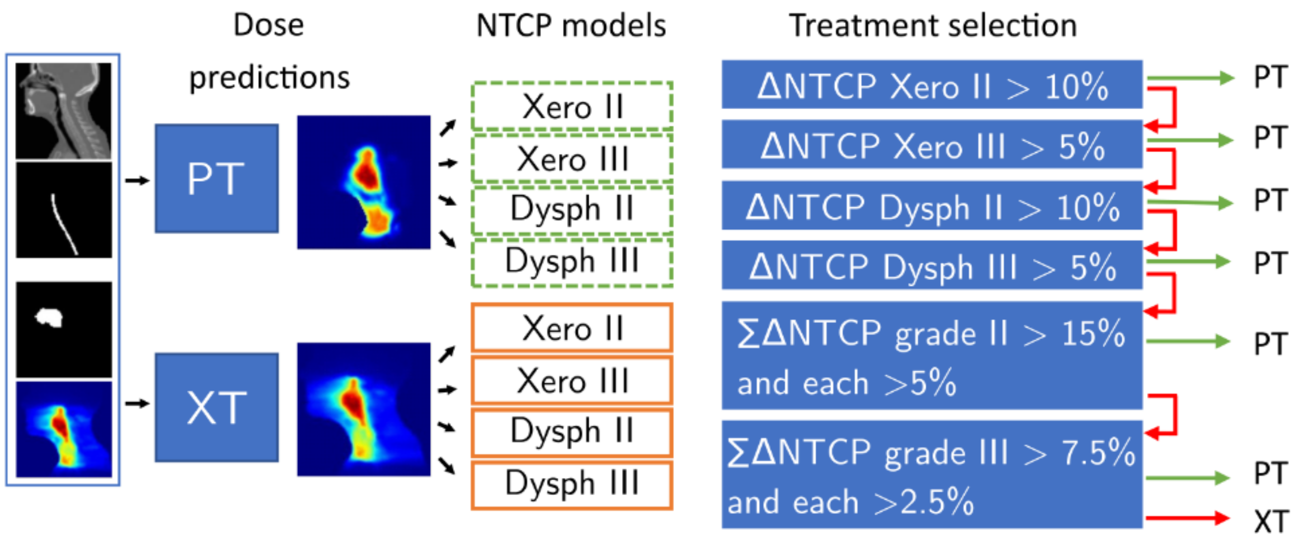


Patient referral

- AI can help find the ideal modality for patients
- **Head&neck:** Gaussian Naïve Bayes classifier using automatic treatment plans (Krouwenberg et al. 2021)
- **Oropharyngeal cancer:** AI-PROTIPP (Huet et al. 2023)
  - 60 patients, HD-UNets for dose prediction
  - Referral accuracy 87% for Dutch model
- **Prostate-cancer:** 3D-Unet dose prediction + NTCP (Chen et al. 2024), NTCP prediction accuracy >90%



Krouwenberg et al. (2021) Green Journal

Huet-Dastarac et al. (2023) Med. Phys.

Chen et al. (2024) Phys. Med. Biol.

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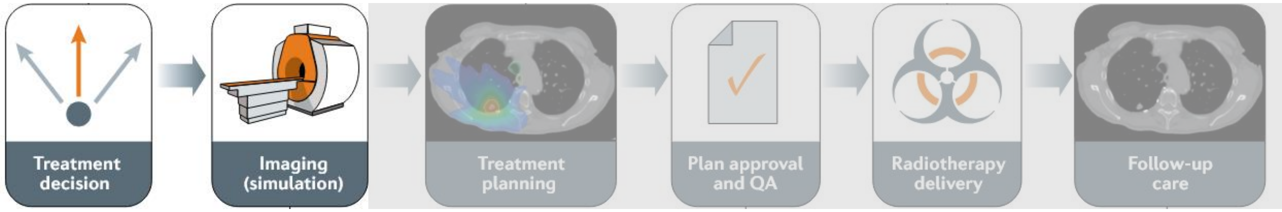
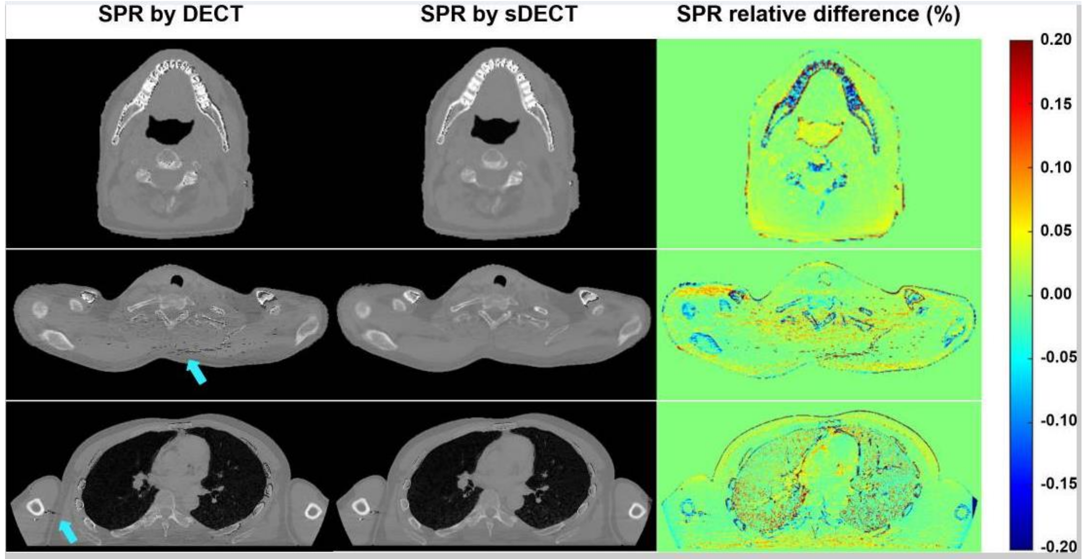
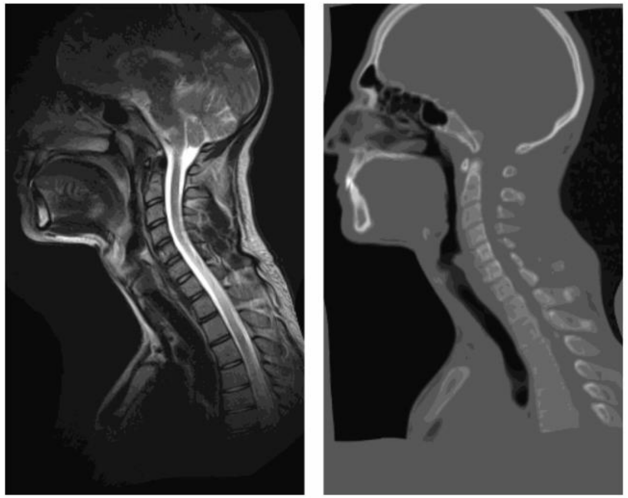


Imaging

- Deformable image registration
- Stopping power prediction
- CBCT to sCT
- MRI to sCT
- Supine to upright
- …





Courtesy Ye Zhang (PSI)
[CPT-DIR (xialipku.github.io)]

Charyyev et al. (2022) BJR

Li et al. (2024) ArXiv

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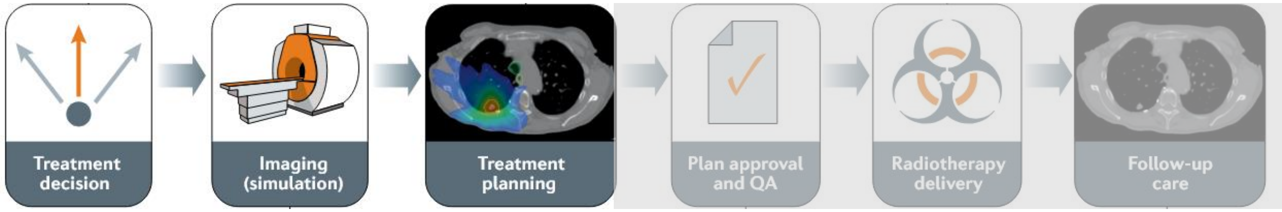
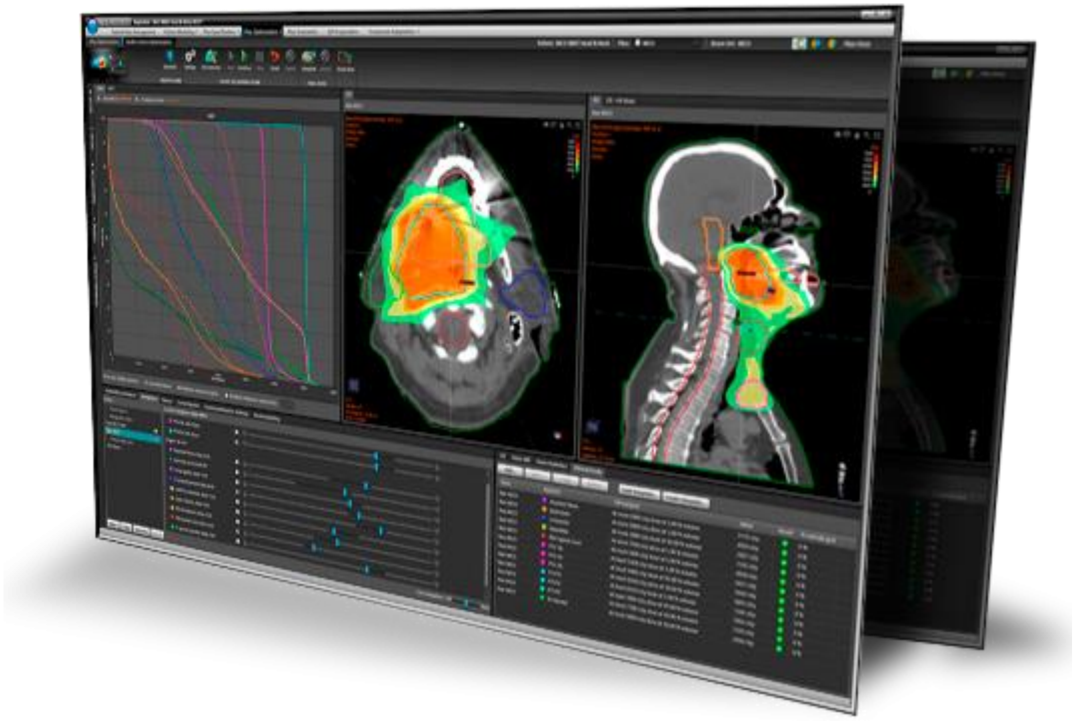


Treatment planning

AI can aid in:

- Beam angle selection
- Dose mimicking
- LETd prediction
- Dose calculation
- Robustness
- Fully automatic treatment planning
- …

➢ Already some AI tools available in commercial platforms (e.g. RayStation)



RaySearch Laboratories, RayStation

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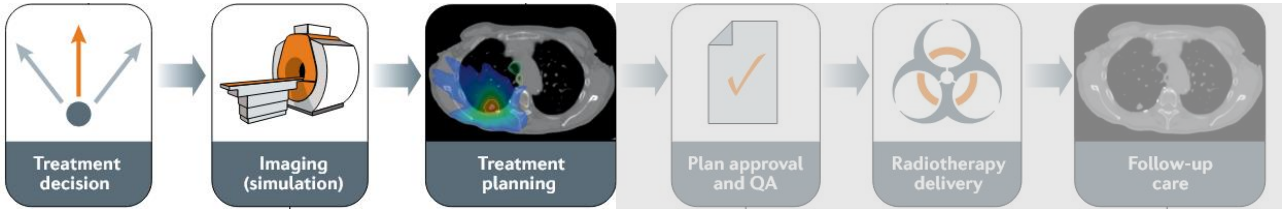
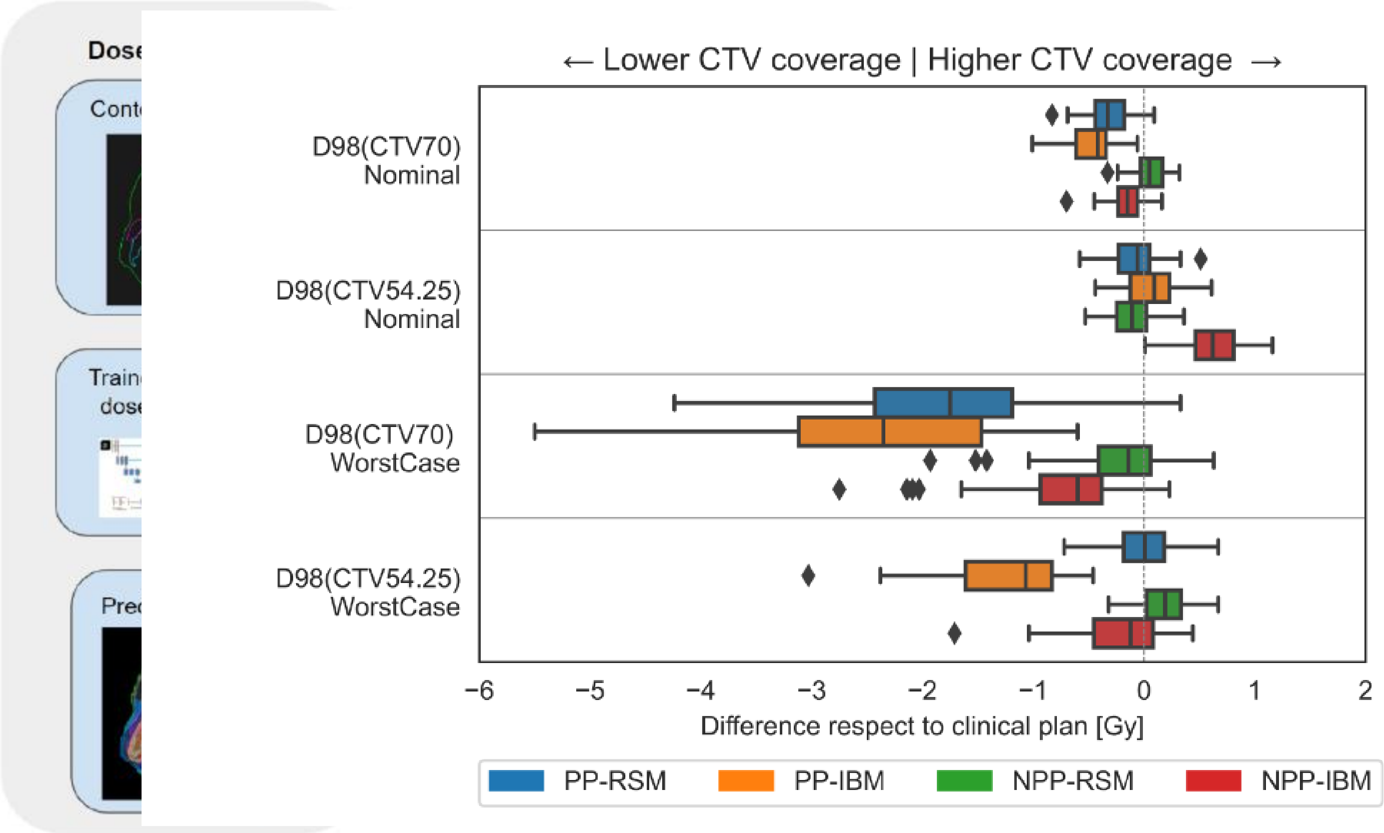


TP: Dose prediction

- Dose prediction and dose mimicking for more efficient workflows
- Borderias-Villaroel et al. (2023): Unet based dose prediction and dose mimicking
- Possibly more standardized plans, less subject to "planner skill"
- Future direction of individualized dose prediction based on population-based outcome models



Borderias-Villaroel et al. (2023) Med. Phys

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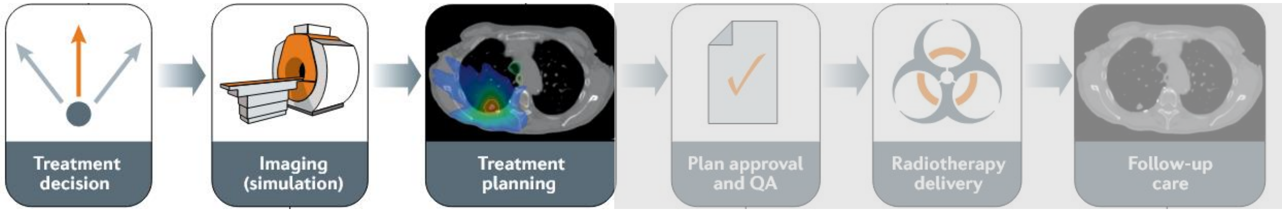
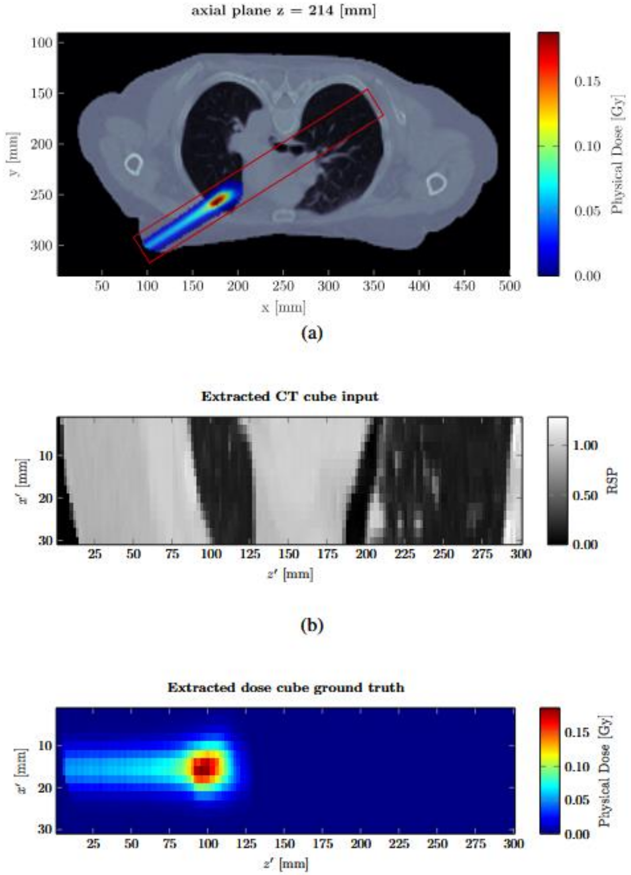
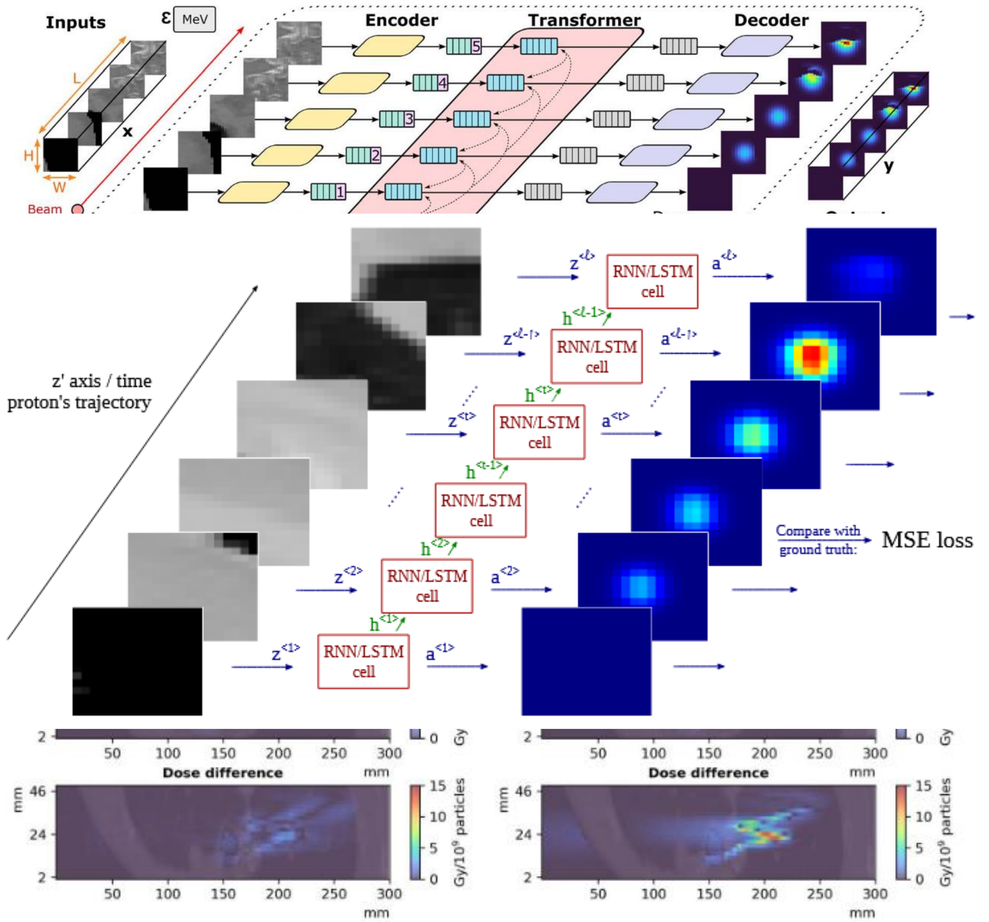


TP: Dose calculation

- Several works on predicting MC dose from pencil beam algorithm dose
- **Neishabouri et al. (2021)** Med. Phys: The beam sees the patient in sequence, so lets treat it like a seq2seq model using an LSTM
- **Pastor-Serrano et al. (2022)** PMB: Use transformer for high accuracy





Neishabouri et al. (2021) Med. Phys.

Pastor-Serrano and Perko (2022) PMB

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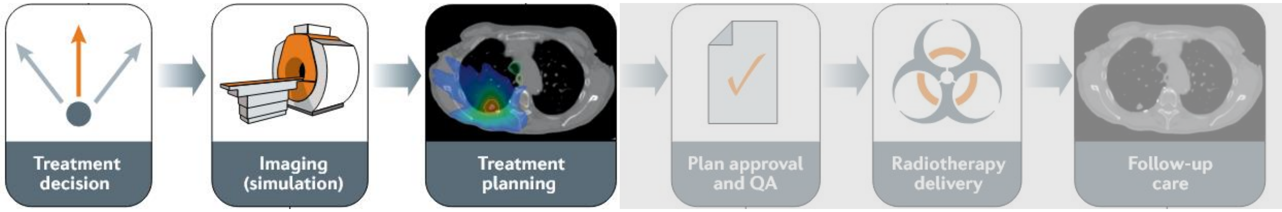
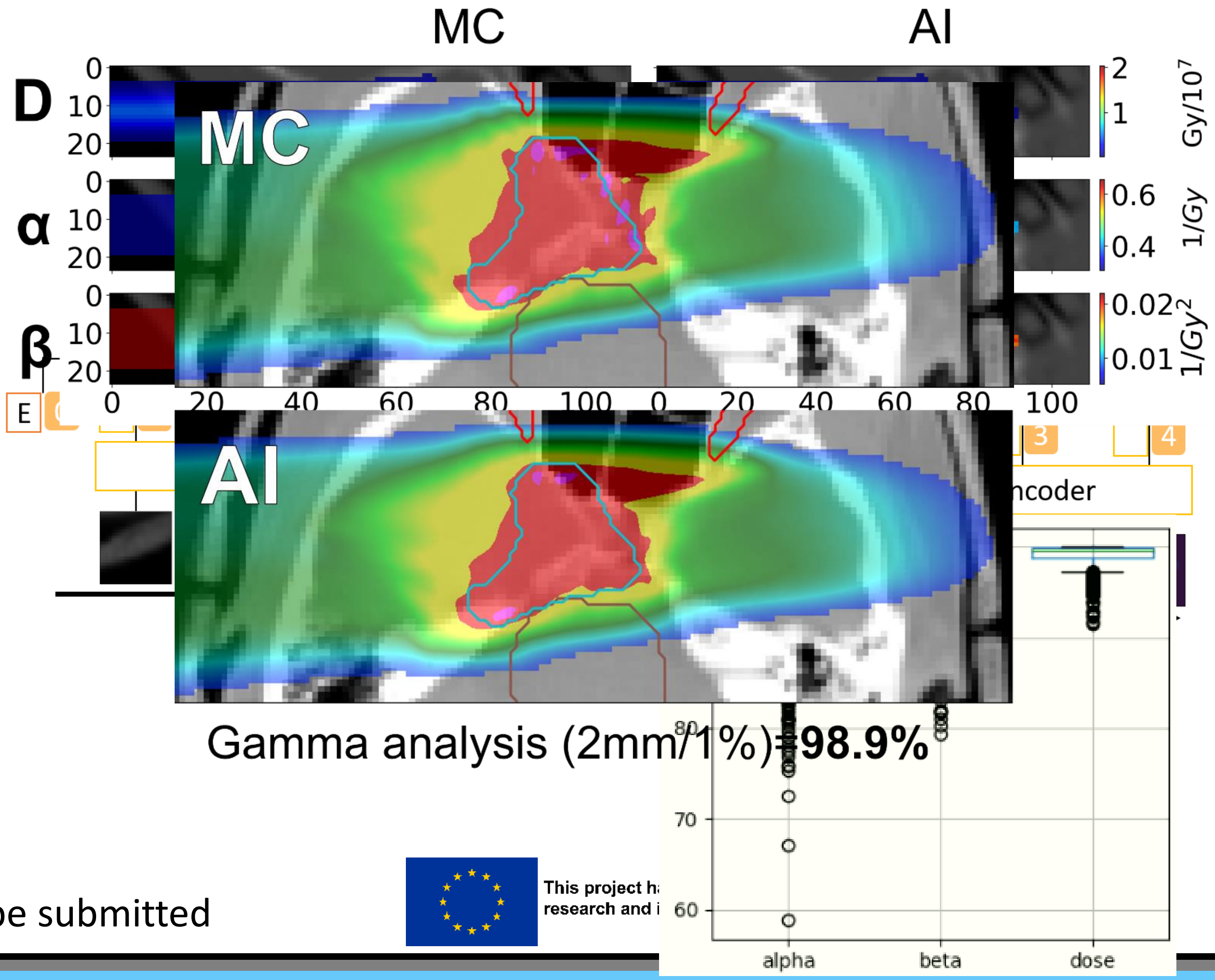
TP: Dose calculation

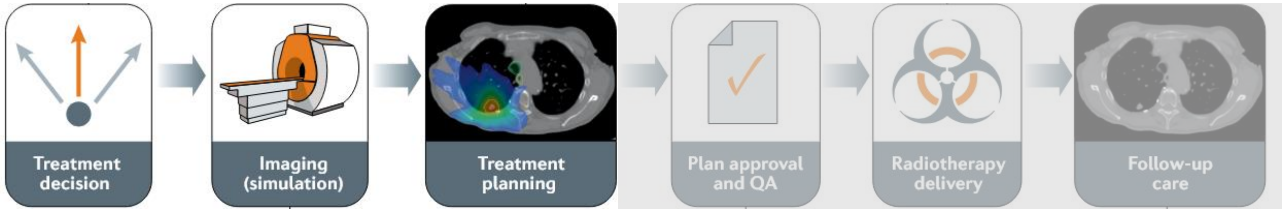


- Recent expansion of DoTA to biological dose calculation in carbon ion therapy (A. Quarz, PhD thesis @GSI)
  - Low-dose approximation of RBE needs alpha and beta parameters
  - DoTa for dose + New two sequence transformer architecture for alpha and beta
  - MC ground truth from FRED GPU, 20k pencil beams



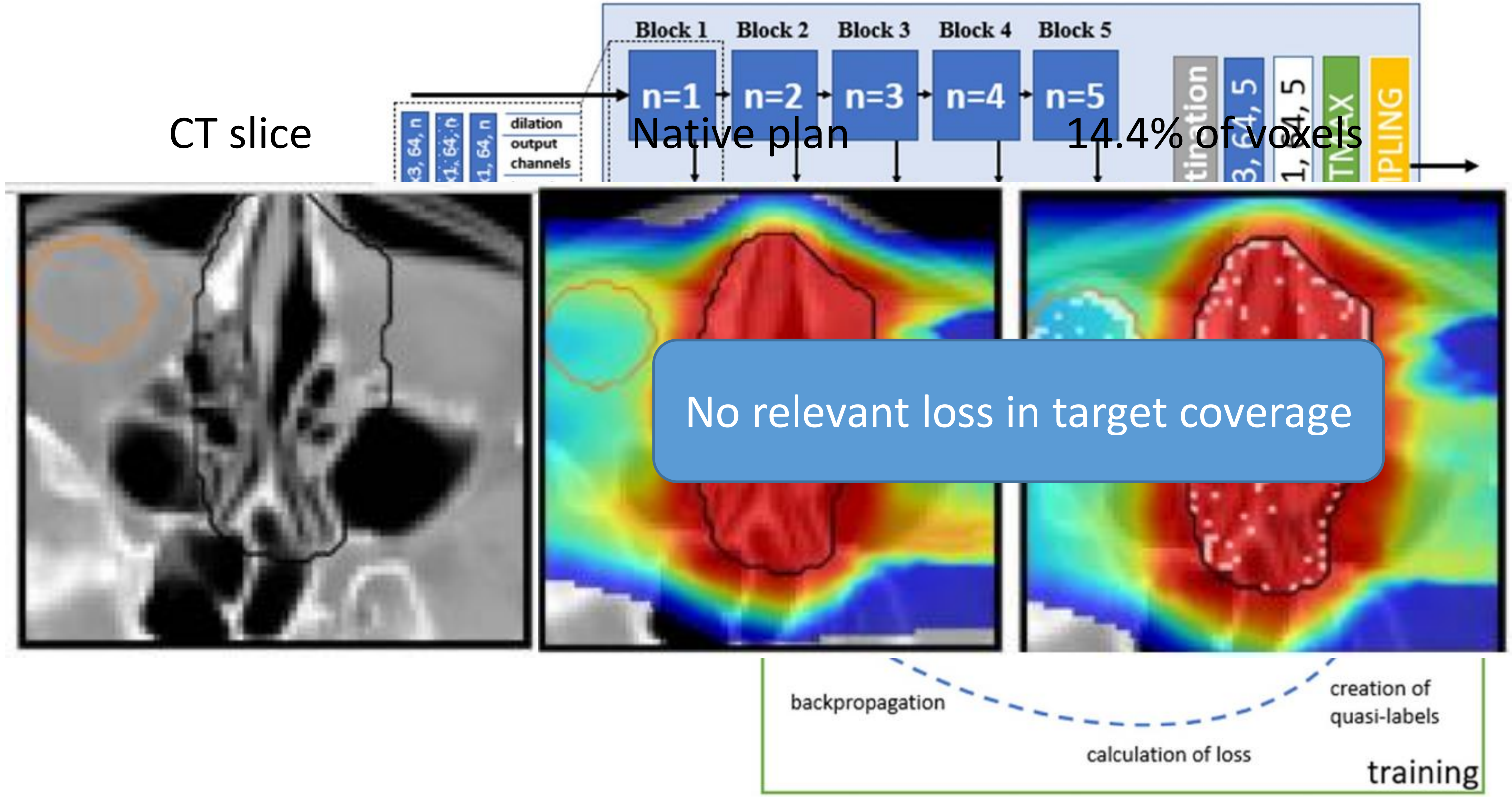
To be submitted

This project h… research and i…



TP: Efficiency

- How can we speed up optimization?
- Do we really need to optimize on all voxels to get a good plan?
- A. Quarz et al. (2024): DeepLearning voxel selection strategies for carbon ion therapy



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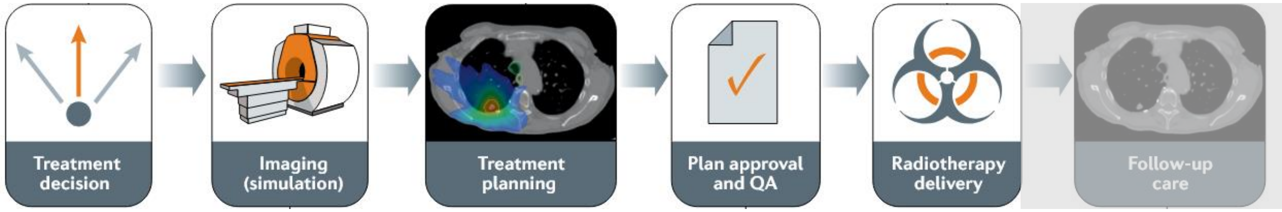

QA and treatment delivery

- Quality assurance:
  - Patient specific QA, e.g. range detection, deep-learning dose calculation for log-file based QA
  - Machine QA, e.g. predicting machine failures
- Delivery:
  - Patient positioning (image guidance)
  - Treatment monitoring
- AI can aid in:
  - More efficient workflows
  - Improved accuracy
  - Detecting issues and provide real-time actionable data

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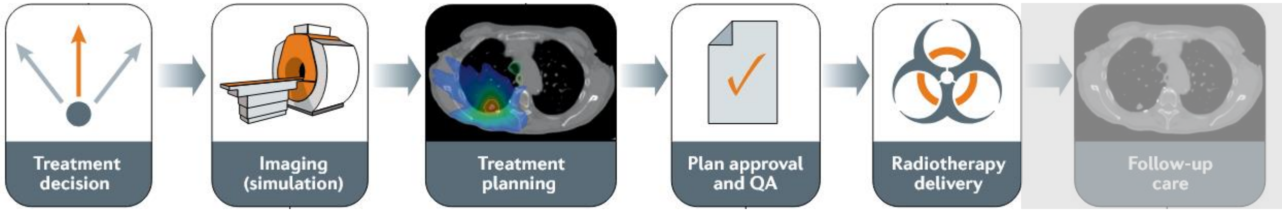
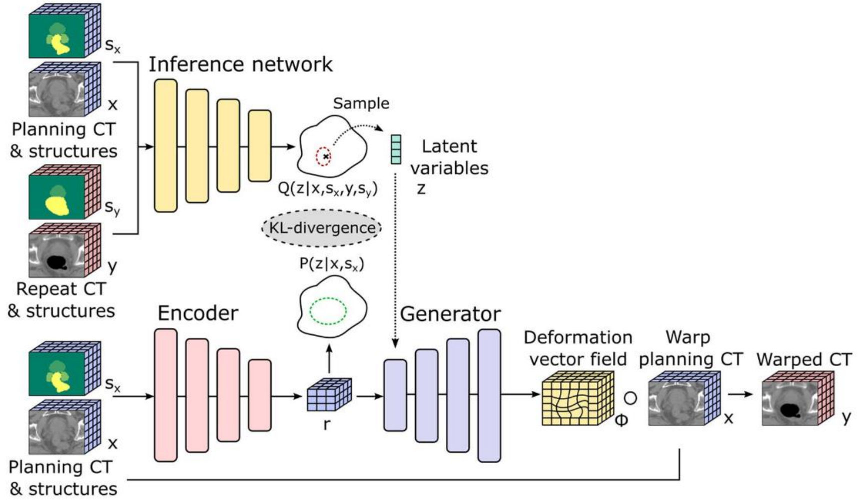


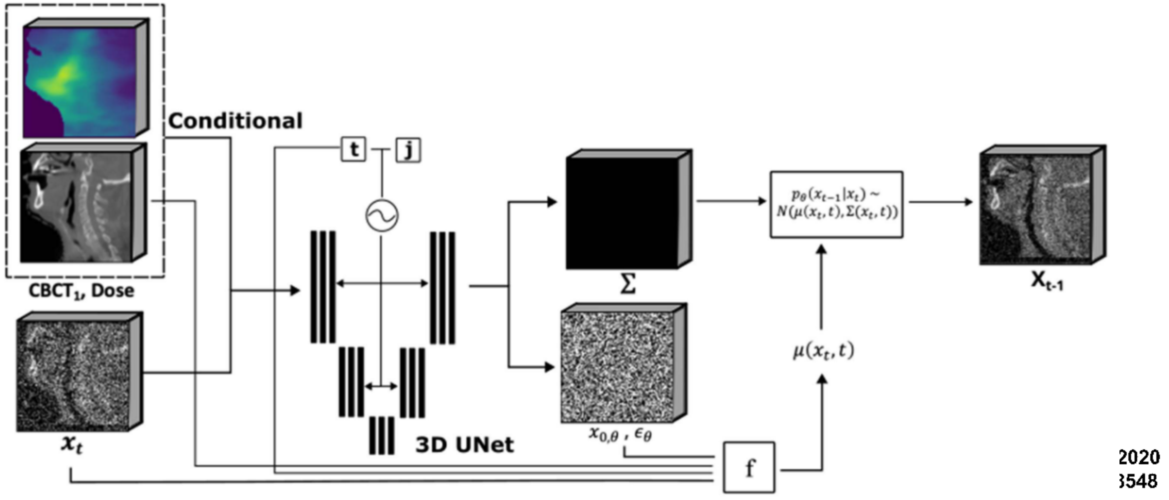
Adaptation

- AI can predict anatomical deformations over the treatment course
  - Enables treatment planning that is robust with respect to these changes
- E.g. Encoder/Decoder architecture by Pastor-Serrano and Perko (2023) PMB for prostate or recently DiffuseRT by Smolders et al. (PMB)

Pastor-Serrano (2023)



Smolders et al. (2024)



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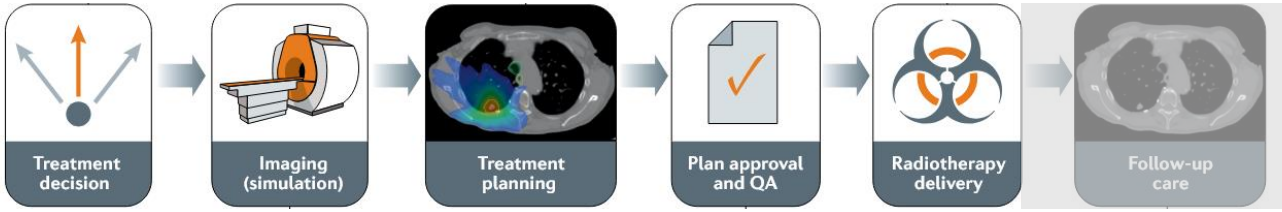
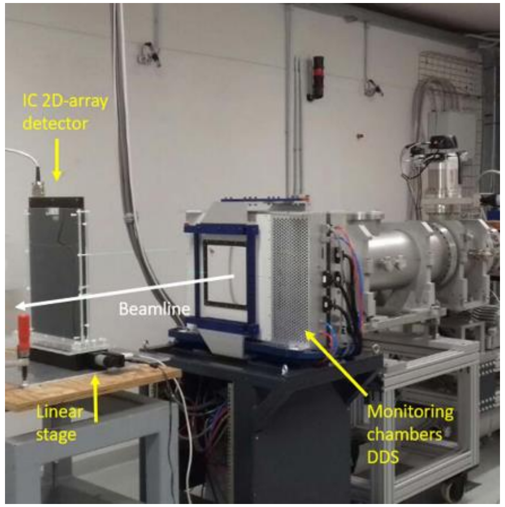
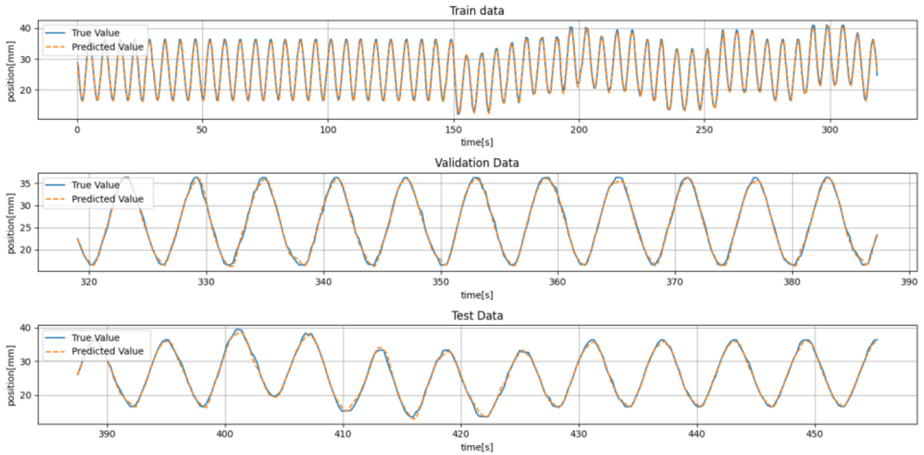
See esp. RAPTOR Project (raptor-consortium.com)



Motion mitigation

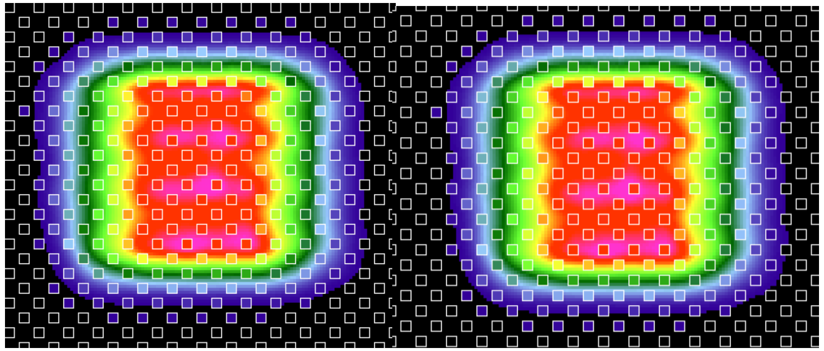
- AI can help in real-time motion monitoring
  - Several projects on X-ray fluoroscopy guided carbon ion therapy (Mori et al.)
- Best motion mitigation strategy is patient specific
  - AI can help in deciding on 4D optimization strategies





4D-RIDOS real time dose reconstruction based on real and AI predicted motion compared to Octavius dose

Real motion LSTM motion



PhD thesis C. Galeone @GSI,
B.Sc. Khaled abu-Mustafa @GSI

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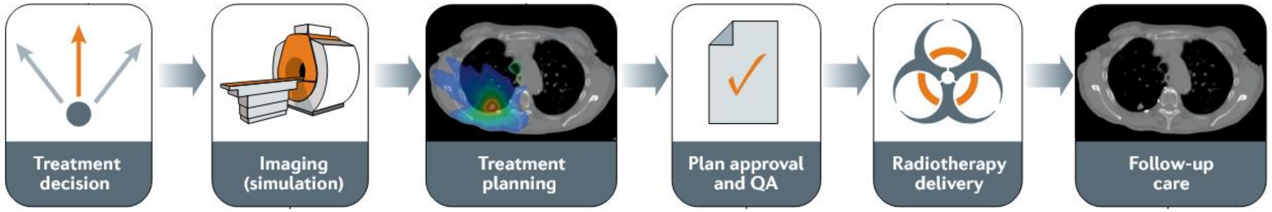
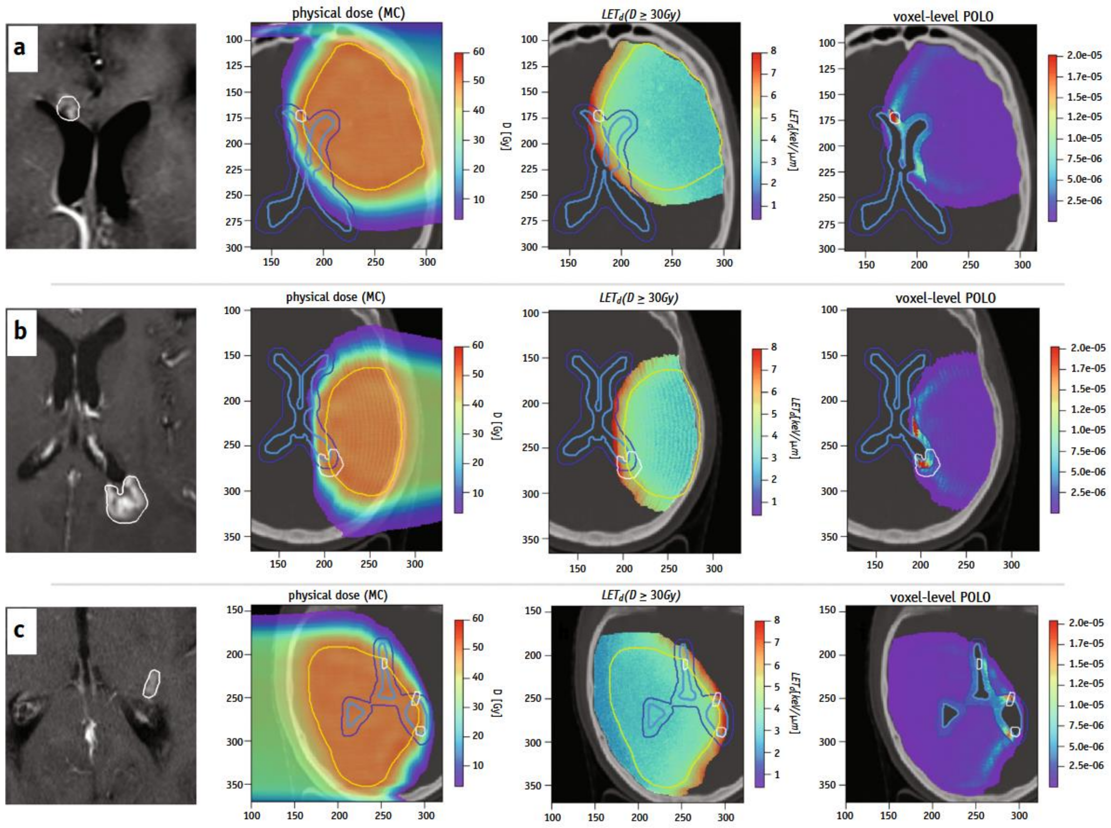
Follow up



- Prediction of toxicity or adverse events
  - E.g. LETd based prediction of brain toxicity
- Scheduling of follow-up appointments
- For re-irradiation: AI based dose accumulation, etc.



MRI contrast enhancement prediction based on LETd, Bahn et al. (2022) IJROBP

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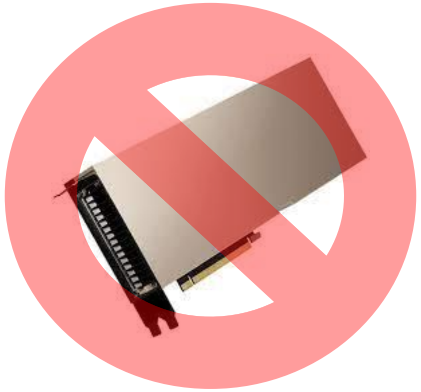
Challenges

- **Data**
  - Clinics often do not want to or cannot share data
  - Online databases, e.g. cancerimagingarchive.net or Proton Collaborative Group
  - We need more joint efforts!
- **Computing power (especially for clinics)**
  - Cloud services may be better than buying GPUs
- Explainability/interpretability of models
- Uncertainty propagation to dose!
- Outlier detection/bias (e.g. ethnicity, gender etc., medical conditions…)



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Conclusions

- ➢ Artificial intelligence in PT is a rapidly increasing field
  - ➢ Auto-segmentation, DIR, dose prediction and dose calculation, auto-planning, adaptation…
- ➢ All aspects of the particle therapy workflow will benefit from AI
  - ➢ Lack of data, lack of model transparency, outlier detection remain challenges
- ❖ Join the PTCOG AI subcommittee, new special issue on "AI in particle therapy" in IJPT

Will AI replace particle therapy medical physicists?

No, [medical physicists] that can use AI will replace those that don't
- Curtis Langlotz as reply to Geoffrey Hinton

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