Prompt Gamma Emission Prediction using an LSTM Network

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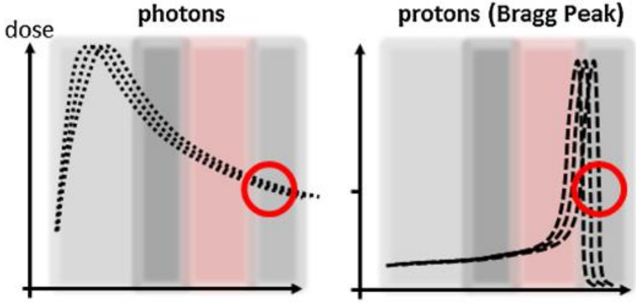
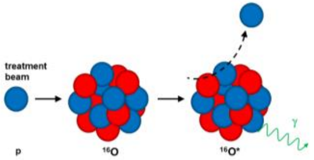
Background
Proton therapy & Prompt gamma(PG) imaging

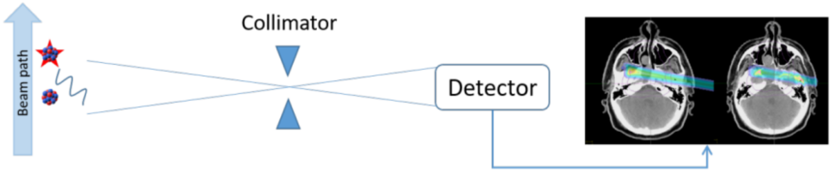
- **Proton therapy**
  - Superior dose conformity compared with photon therapy
    - Limited dose range/reduced exposure to normal tissues
  - Limitations due to **range uncertainty**
    - Non-optimal dose coverage of targets/overdose of healthy tissues



Influence of a density heterogeneity to depth dose curves[1]

- **Prompt gamma (PG) imaging**
  - PG signals are highly correlated to proton dose distributions
  - Potential for **real-time** range monitoring





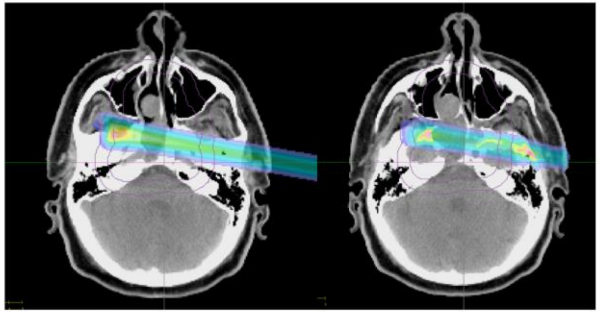
Schematic setup of PG based proton range verification[2]

[1] Knopf AC, Lomax A. In vivo proton range verification: a review. *Phys Med Biol*. 2013;58(15):R131-R160.
[2] Tian, Liheng (2020): A new treatment planning concept accounting for prompt gamma imaging for proton range verification. Dissertation, LMU München

Background & Motivation

Fast calculation of expected PG distributions

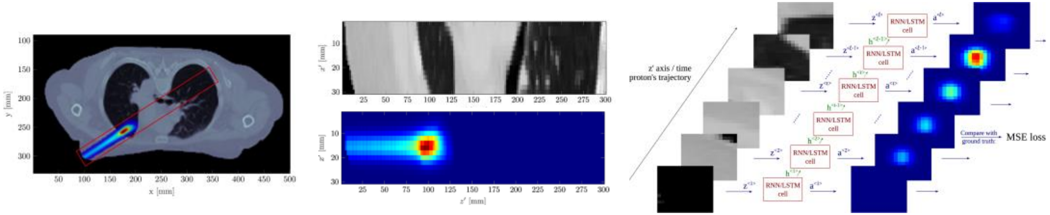
- **The PG fall-off does not explicitly match the therapeutic dose fall-off[2]**



Dose delivery PG emission

- **PG emission calculation methods**
  - MC simulation (slow)
  - Analytical dose filtering methods

Fast and accurate prompt gamma calculation

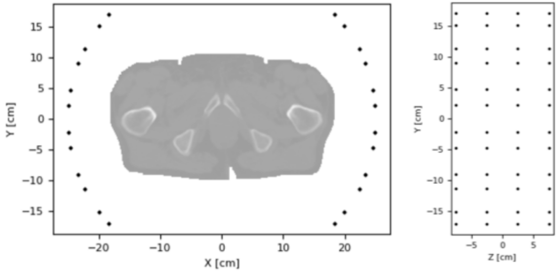


Long short-term memory (LSTM) network-based proton dose calculation[3]

[2] Tian, Liheng (2020): A new treatment planning concept accounting for prompt gamma imaging for proton range verification. Dissertation, LMU München
[3] Neishabouri A, et al. Long short-term memory networks for proton dose calculation in highly heterogeneous tissues. *Med Phys.* 2021;48(4):1893-1908.

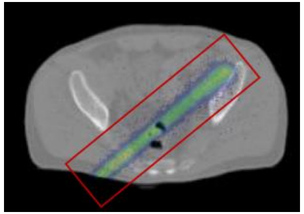
Materials & methods
Patient datasets & MC simulation

- **Patient datasets**
  - 33 prostate patients treated at LMU University Hospital
  - Planning CT scans (resampled voxel size: $1.5\times1.5\times1.5$ mm^3)
  - Dataset split: training/validation/testing=20/3/10

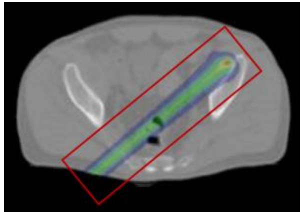


- **Geant4 MC simulation for PG and dose distributions**
  - Convert CT to relative stopping power (RSP) with respect to water
  - Number of histories for each PB: **10M**[4] (20-30 hours)
  - Recorded PG threshold: **above 3 MeV**[5]
  - Angular region: $[40°,140°]\cup[220°,320°]$, $\Delta\alpha=16.6°$
  - PB number simulated per patient: 96
  - Cuboid extraction: from patient surface
  - Cuboid dimension/resolution: $320\times24\times24/1\mathrm{x}2\mathrm{x}2$ mm^3

MC PG on RSP

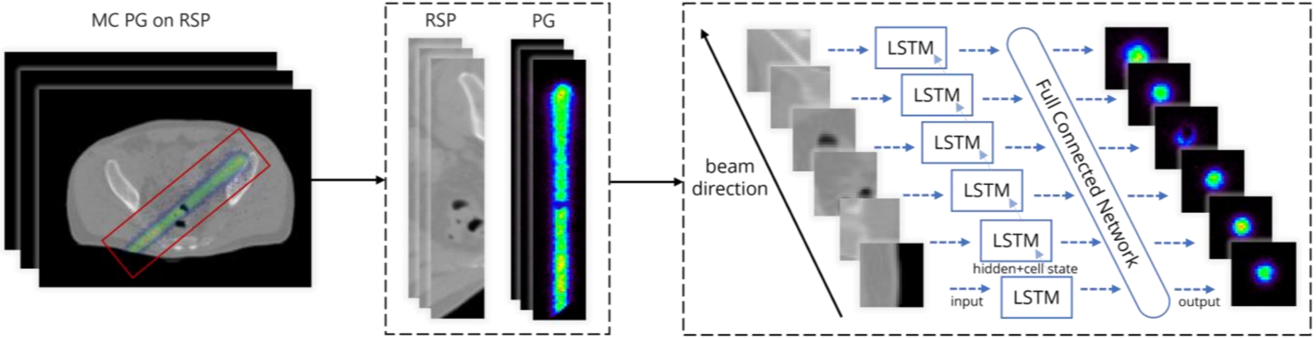


MC Dose on RSP

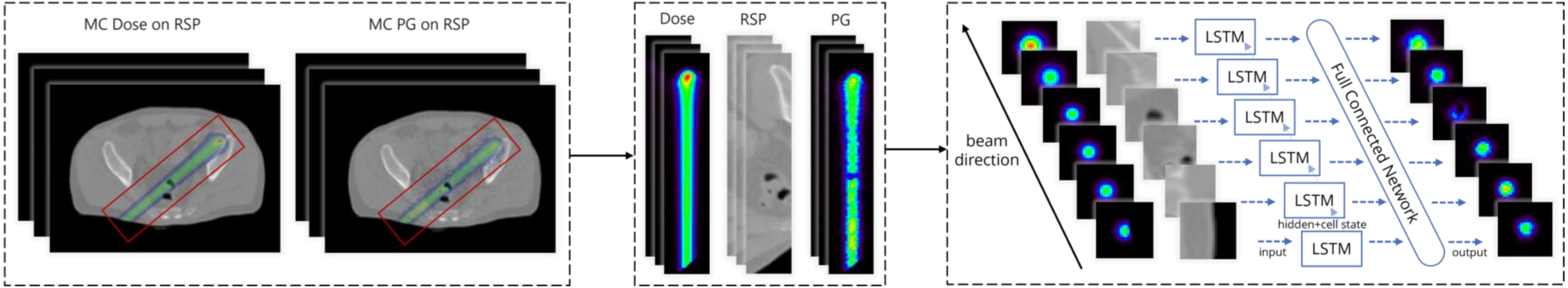


[4] Souris K, et al (2016). Fast multipurpose Monte Carlo simulation for proton therapy using multi-and many-core CPU architectures, *Med Phys*.
[5] Sterpin E, et al (2015). Analytical computation of prompt gamma ray emission and detection for proton range verification, *Phys Med Biol*.

Materials & methods
LSTM-based PG prediction framework



RP (RSP to PG) model: input RSP, output PG



RDP (RSP and dose to PG) model: input RSP and dose, output PG

Materials & methods
Experiments & Metrics

- **Experiments**
  - SE: single energy; ME: multi-energy

Cuboid Dataset [energy (PB number)]

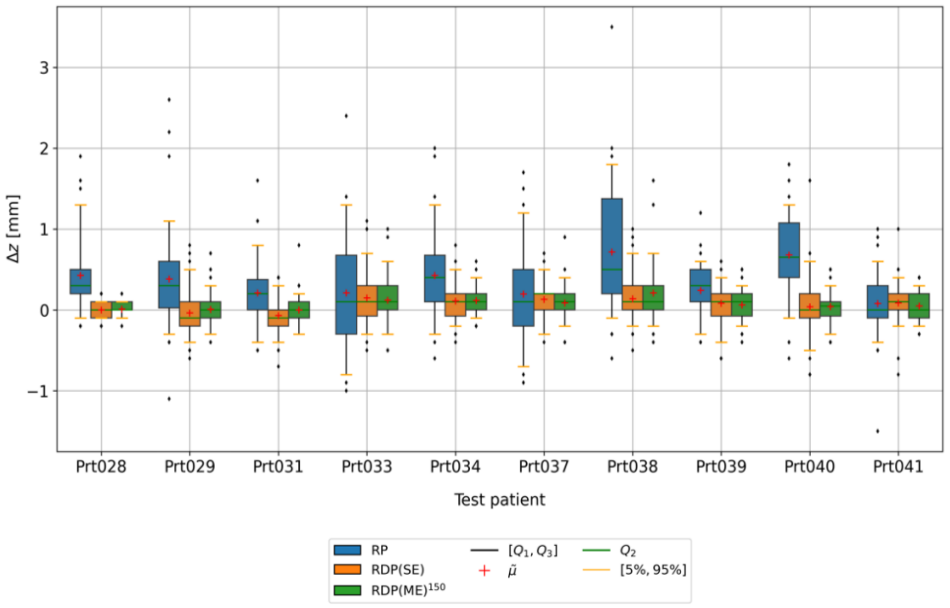
Model	Training	Validation	Test
RP	150 MeV (1920)	150 MeV (288)	150 MeV (540)
RDP (SE)	150 MeV (1920)	150 MeV (288)	150 MeV (540)
RDP (ME)	150 MeV (1920), 175 MeV (1920), 200 MeV (1920)	125-200 MeV (288×3)	150 MeV (540), 175 MeV (540), 200 MeV (540), 125-210 MeV (540)

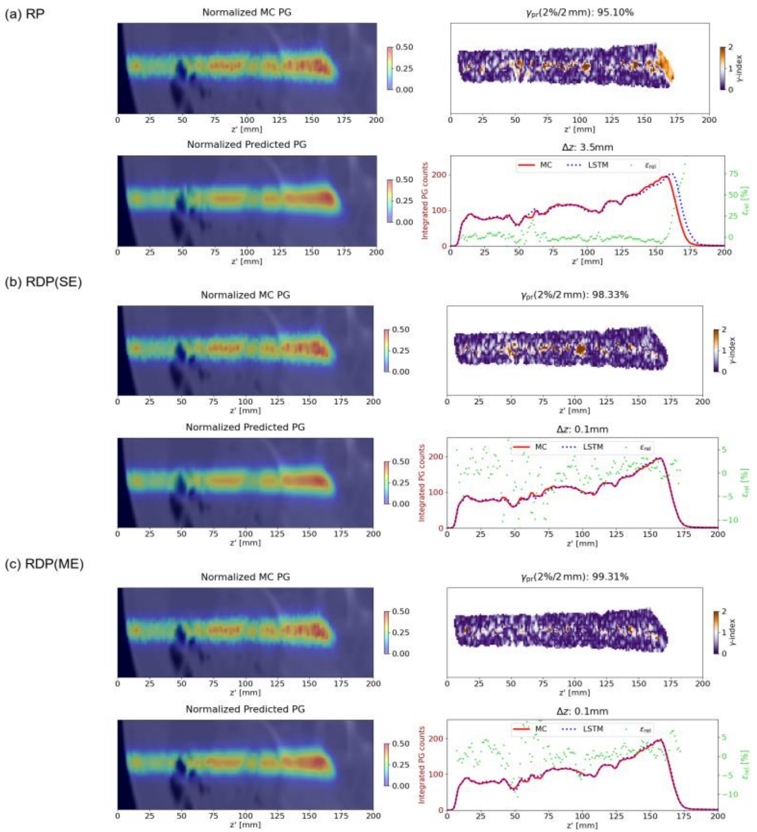
- **Metrics**
  - Gamma passing rate $\boldsymbol{\gamma_{pr}}$ (2%/2mm, PG count>10% of the maximum PG count)
  - Laterally integrated PG profiles with relative count differences $\boldsymbol{\epsilon_{rel}}$ (%)
  - Range shift $\boldsymbol{\Delta z}$[6] of two laterally integrated PG-depth profiles

[6] Knopf, A., et al. (2008). Quantitative assessment of the physical potential of proton beam range verification with PET/CT, *Phys Med Biol.* 53(15): 4137.

Results
RP, RDP (SE) and RDP (ME) model comparison

- The RDP(SE) model has smaller Δz than the RP model in the same test dataset (150 MeV)
- Mean γ_{pr} of RDP model (99.1%) is higher than RP model (98.1%)

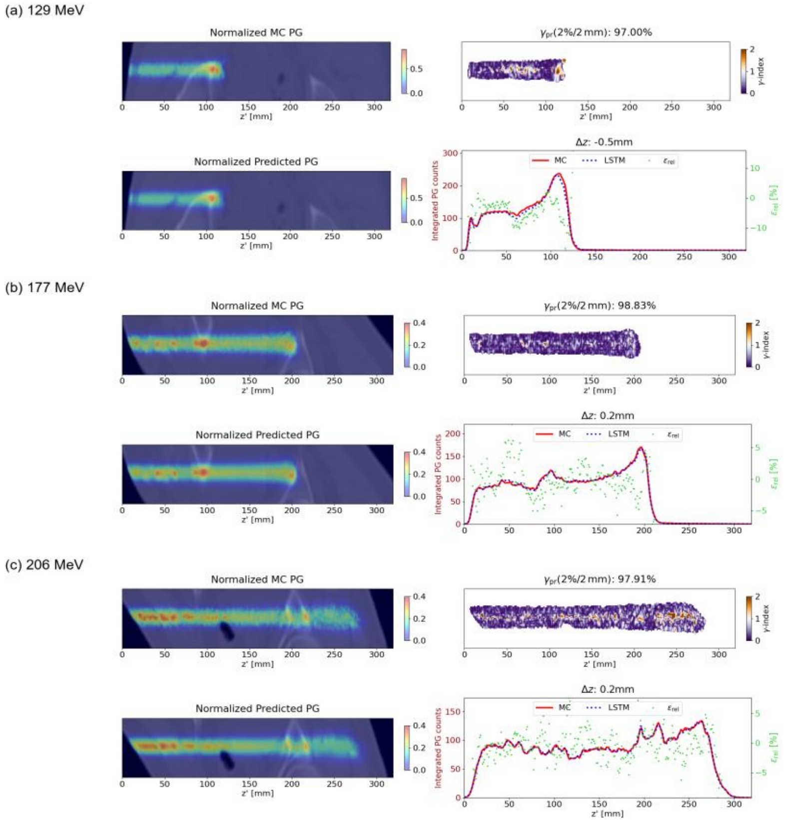


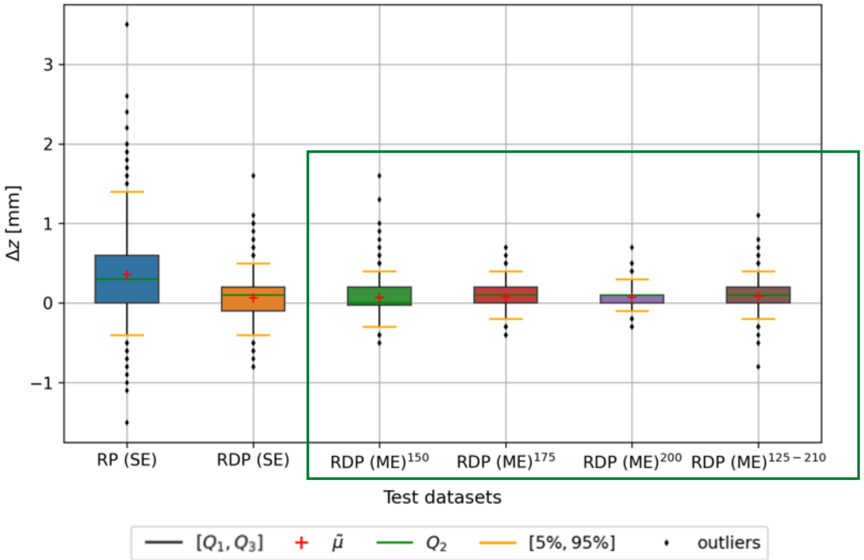


Results

RDP (ME) model on four test datasets

- The Δz of test cases from RDP(ME) model is all within 1 mm (except for three outliers)





Results
Runtime

- All computation measurements were carried out on a workstation equipped with an Intel(R) Xeon(R) Gold 6354 3.00 GHz CPU and an NVIDIA RTX A6000 GPU.

Model	Cuboid extraction time (ms)	Model inference time (ms)
RP	55	10
RDP	55x2	11

Conclusions

- A sub-second LSTM-based PG emission prediction method was developed
- Combining RSP and **dose** improves the accuracy of PG range predictions and helps the model generalize to unseen energies

Outlook

- Extend to more treatment sites and spot sizes
- Validation with PG detection data from experimental PG camera needs to be explored

LMU KLINIKUM
Gemeinsam. Fürsorglich. Wegweisend.

Thank you for your attention!

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