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Dose computation for radiotherapy with deep learning

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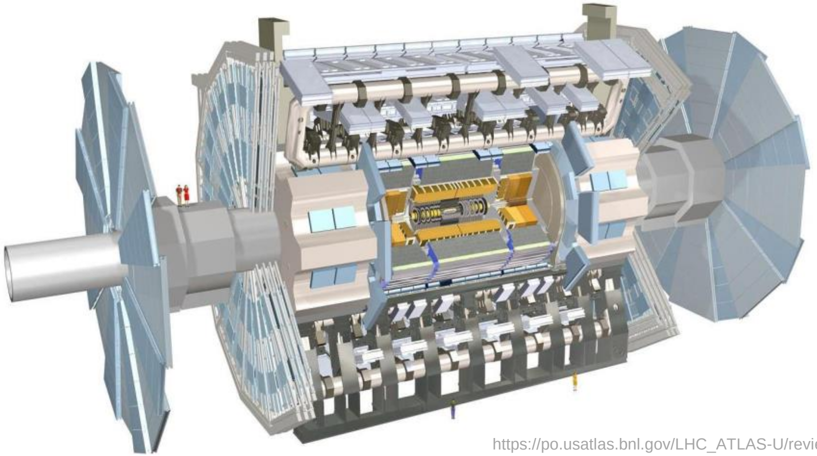
DoDSc Kolloquium – 11.01.2022

AG Kröninger – From High Energy Physics (HEP) to the Hospital

- Our group: detector development and data analysis at ATLAS experiment at CERN



https://po.usatlas.bnl.gov/LHC_ATLAS-U/reviews/
DOE_Status_Review_Dec_2015/

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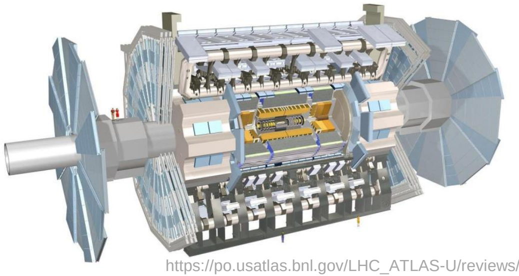
AG Kröninger – From High Energy Physics (HEP) to the Hospital

- Our group: detector development and data analysis at ATLAS experiment at CERN
- Silicon pixel and strip detector development
  - ➡ High precision small field dosimetry for proton therapy
- Detector and particle interaction simulations
  - ➡ Studies on proton radiography and computed tomography
- Machine learning analysis in searches for new physics phenomena
  - ➡ Information gains in radiation protection dosimetry
  - ➡ Fast dose predictions for novel radiotherapy treatments



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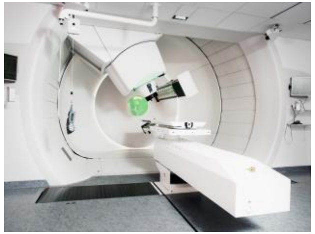
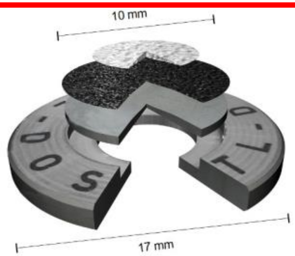
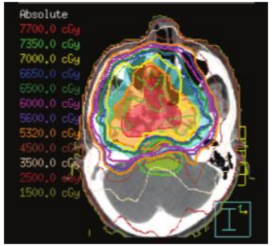


https://www.primomedico.com/de/spezialist/prof-timmermann-protonentherapie-essen/



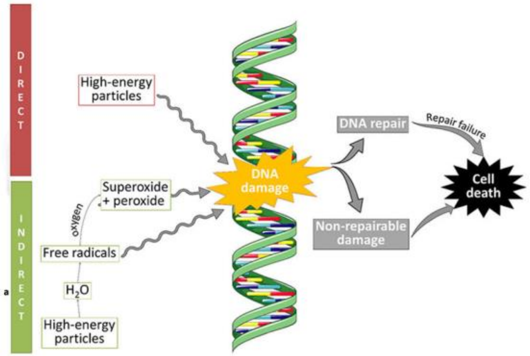
Courtesy by MPA NRW



https://www.researchgate.net/figure/The-NPC-treatment-plan-for-Pinnacle-planning-system-of-Philips-Radiation-Oncology-System_fig3_311447422

Radiotherapy treatment planning and machine learning

- Concept radiotherapy: destroy DNA of cancerous cells with ionizing radiation
  - Before delivering radiation therapy to patient: treatment planning
  - Optimization: many computations energy deposition computations required
- Full Monte Carlo (MC) slow for treatment planning
  - Many clinical treatments: fast(er) approximations available
  - Machine learning studies: promising but mostly based on existing treatment plans
- Not applicable to novel treatments in development: MC often only option



https://www.cancer.gov/news-events/cancer-currents-blog/2021/avasopasem-cancer-radiation-more-effective

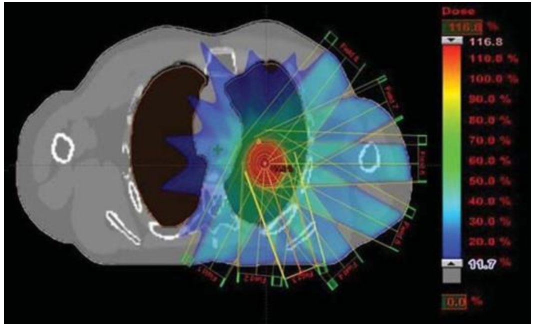


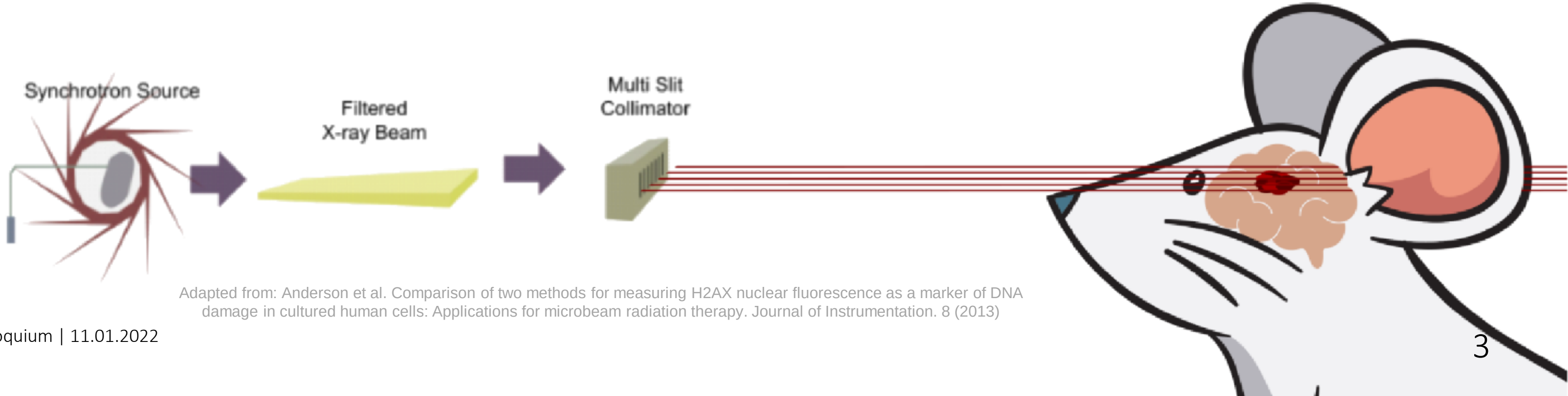
Image: http://www.albahyperthermia.com/hyperthermia-treatment-planning-system.html

Microbeam radiation therapy (MRT)

- Novel treatment using array of sub-millimetre sized radiation beams
  - Experiments with synchrotron gamma sources and proton beams
- Potential use cases include brain tumours: good healthy tissue sparing

http://www.delta.tu-dortmund.de/cms/de/DELTA/

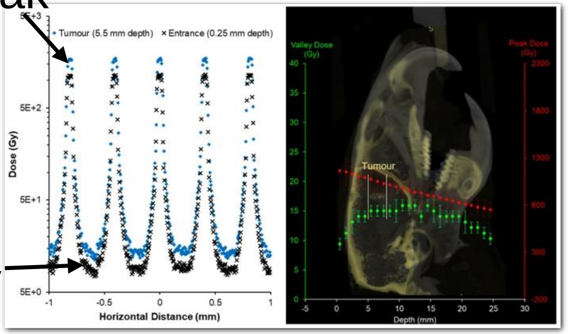
This contains a synchrotron.
Not used for MRT though.



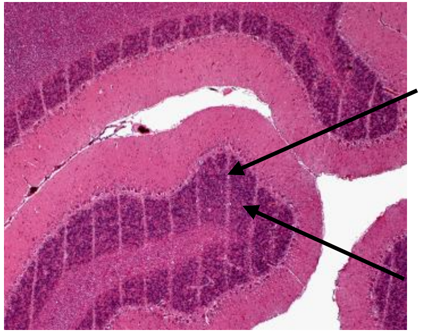
Adapted from: Anderson et al. Comparison of two methods for measuring H2AX nuclear fluorescence as a marker of DNA damage in cultured human cells: Applications for microbeam radiation therapy. Journal of Instrumentation. 8 (2013)

Microbeam radiation therapy (MRT)

- Novel treatment using array of sub-millimetre sized radiation beams
  - Experiments with synchrotron gamma sources and proton beams
- Potential use cases include brain tumours: good healthy tissue sparing
  - Current status of treatment: pre-clinical
  - Current status of treatment planning: Monte Carlo simulations



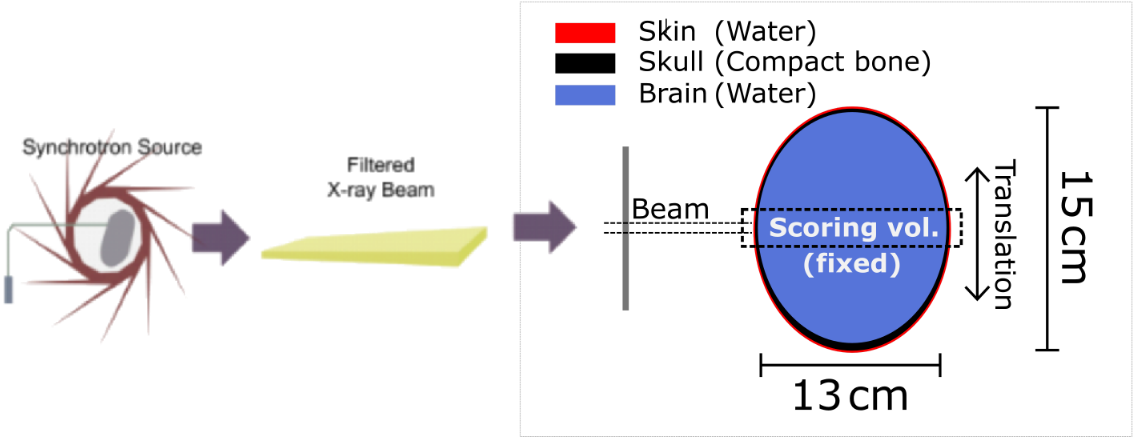
E. Engels et al., Toward personalized synchrotron microbeam radiation therapy. Scientific Reports volume 10, Article number: 8833 (2020)



F. Studer et al., Synchrotron X-ray microbeams: A promising tool for drug-resistant epilepsy treatment. European Journal of Medical Physics 31(6), 2015

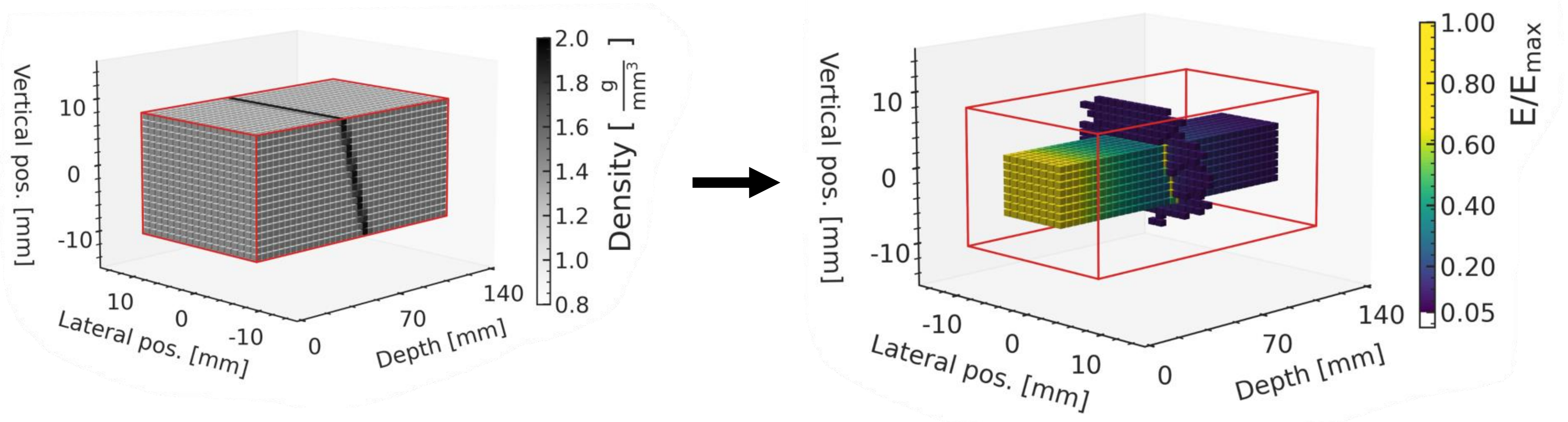
Initial exploration: Bone slab in water

- Current treatment planning with Monte Carlo simulations: up to 50 h/CPU per configuration
  - Simulation modelled after Imaging and Medical Beamline at the Australian Synchrotron
- Goal of study: Train deep learning algorithm to mimic Monte Carlo dose prediction
  - Proof of concept: 8mm broad beam on slab phantom and simplified head phantom (shown here)



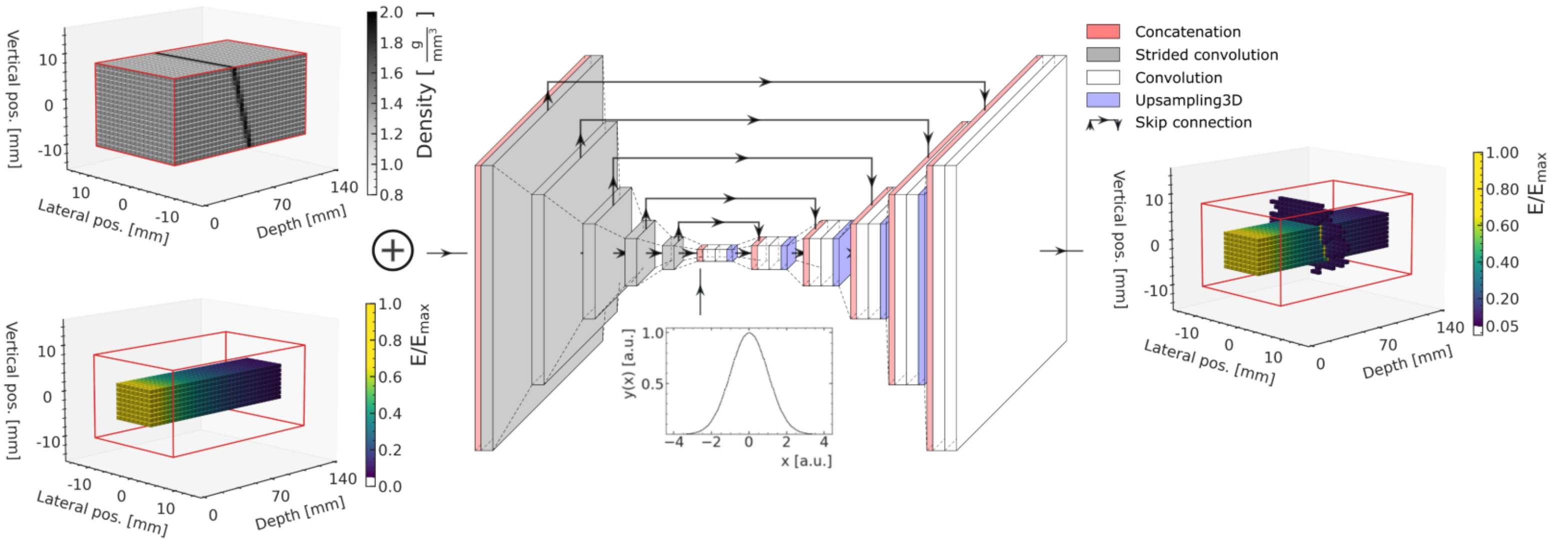
Initial exploration: Bone slab in water

- Simulation output: 140x18x18 mm³ voxel matrices: density + E_{dep}
  - Larger than beam (8x8 mm²): include out-of-field dose
- Learning task: "translate" given density matrix to 3D E_{dep} matrix
  - Approach: use 3D convolutional network for maximum prediction speed



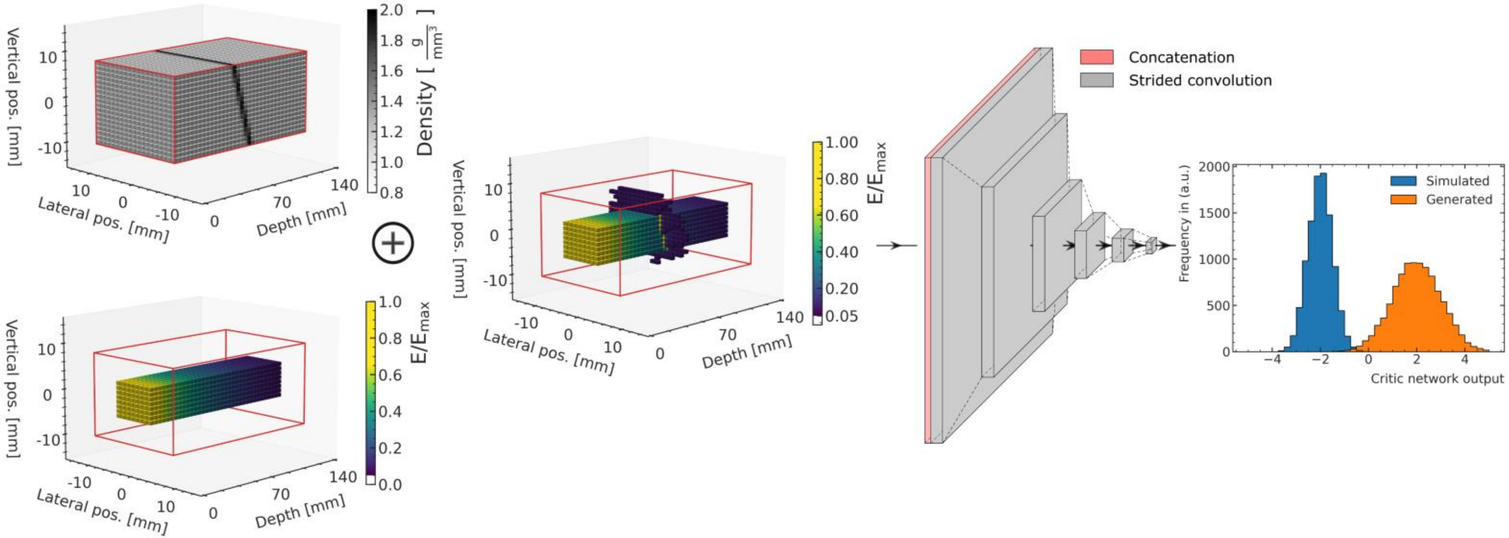
Machine learning dose **generator**: „3D U-Net“

- Input matrices: phantom density + E_{dep} in water (beam characteristic) + noise
- Output matrix: E_{dep} in phantom



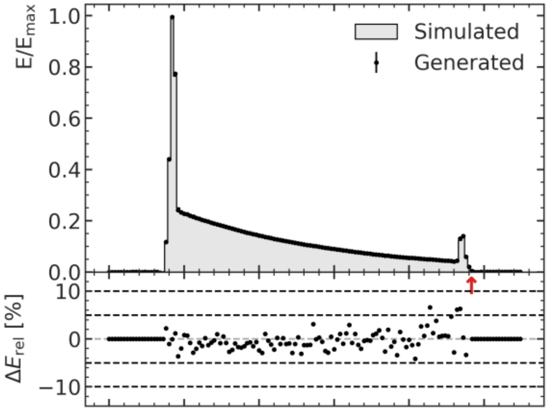
Critic (**adversarial**) network

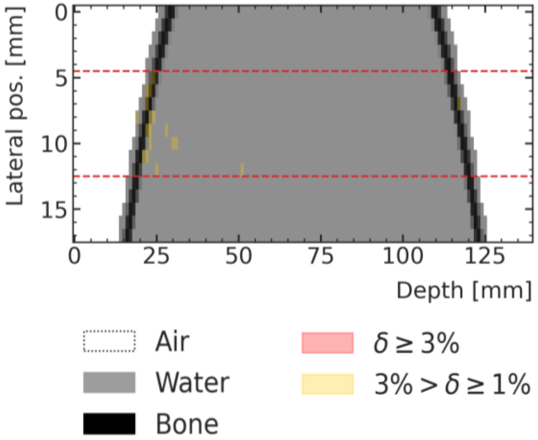
- Input matrices: phantom density + E_{dep} in water + E_{dep} in phantom (Geant4/Generator)
- Output: rating → cost function for generator network optimization
  - Advantage over „normal“ loss like MSE: can evaluate on a volume level, not voxel-by-voxel

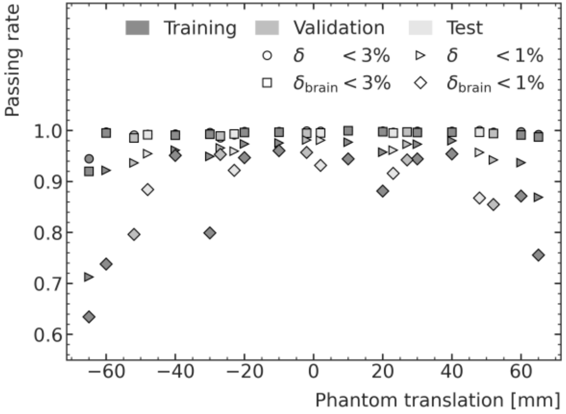


Validation of concept: Increased geometry complexity

- Performance measures: fraction of in-field voxels with $\delta < 3\%$ and $\delta < 1\%$ with $\delta = \frac{\Delta D}{D_{max}}$
- First tests: fixed size, phantom translation
  - High accuracy except at extreme cases due to high bone proportion
  - Deviations mainly 1-3% of maximum dose to brain
  - Important: Dose near material boundaries predicted accurately







Summary and outlook

- Presented ML model accurately predicts dose in simple scenarios
  - On average, more than 98% of the in-field voxels pass $\frac{\Delta D}{D_{max}} < 3\%$
- Comparison of generation time:
  - GAN generator: ~0.25s / dose distribution on 6 CPU
  - Geant4: ~1 h / dose distribution on 50 CPU

Summary and outlook

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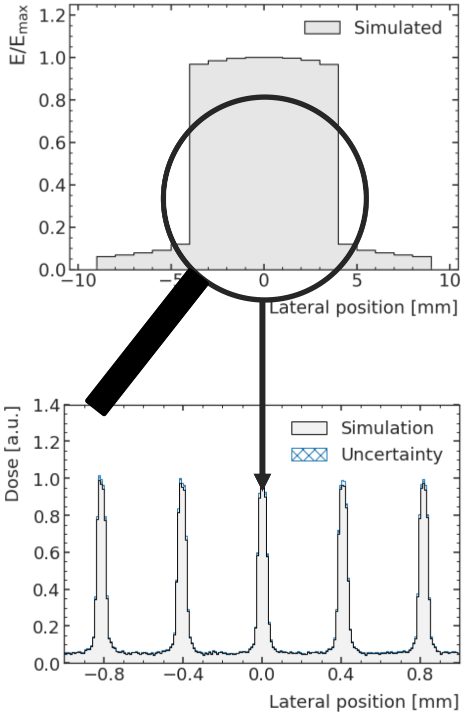
- Comparison of generation time:
  - GAN generator: ~0.25s / dose distribution on 6 CPU
  - Geant4: ~1 h / dose distribution on 50 CPU
- Focus of current research:
  - Transition to X-ray microbeams
  - Expand to proton microbeams
  - Experiment with transformers for CT to dose „translation"



Thank you for your attention