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Patient Specific Dose Calculation of Circulating Blood

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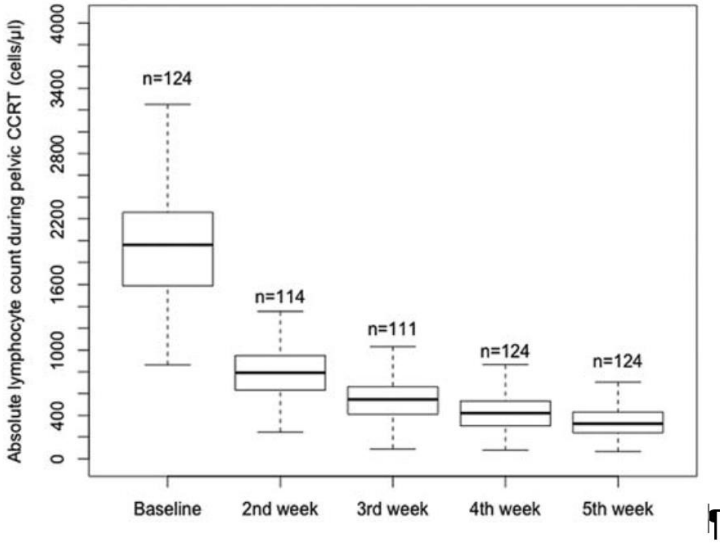
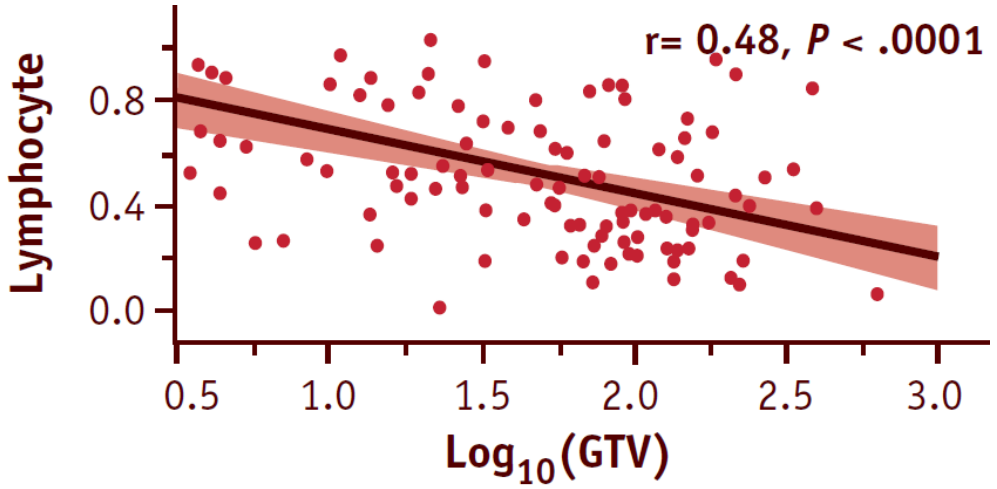
Background

- Radiation therapy influences the patient's immune system, and the immune system influences the response to radiation therapy
  - Radiation Therapy is associated with significant hematologic toxicity, including ***lymphopenia***
  - ***Lymphopenia=*** depletion of the total peripheral lymphocyte count in the blood



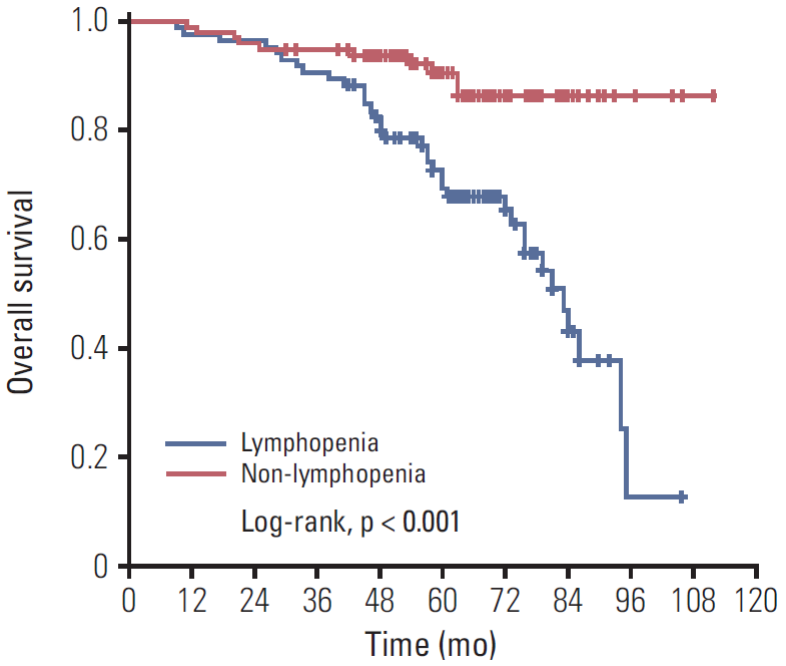
Tang C. et al. Int J Radiat Oncol Biol Phys. 2014



Cho et al. Tumour Biol. 2016

Motivation: Radiotherapy Induces Immunosuppression In Cancer Patients

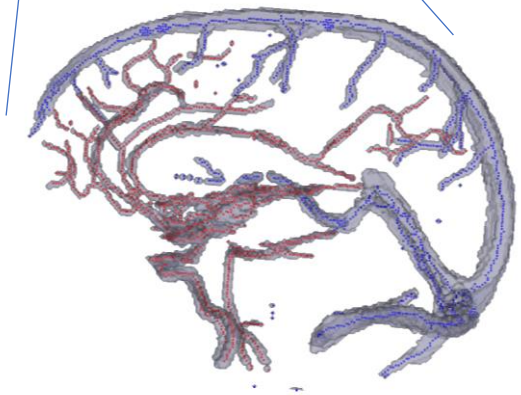
- Treatment-related lymphopenia has been linked to poor outcomes
- Severe lymphopenia has been associated with serious opportunistic infections.
- Prolonged, Treatment-induced lymphopenia (up to 45% of GBM patients) persists for at least one year after treatment RT.
- It is likely that irradiation of circulating lymphocytes in the peripheral blood is a major contributing factor to lymphopenia

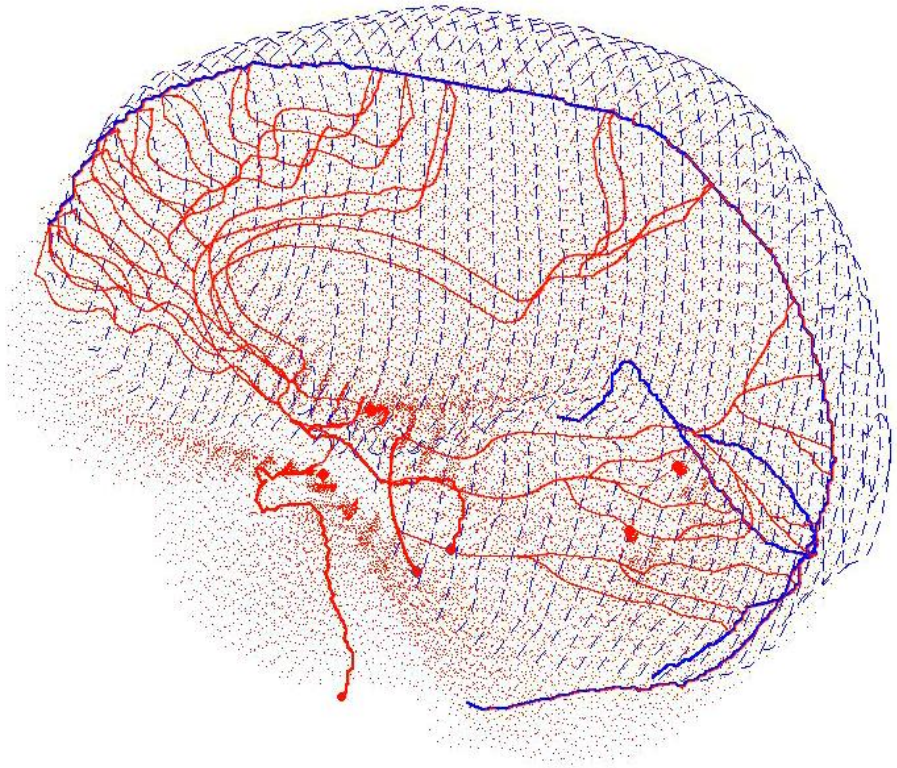


Tang C. et al. Int J Radiat Oncol Biol Phys. 2014

Dose Calculation of the Circulating Blood

- Blood propagation dynamics
  - Spatial information of blood trajectories
    - 8% Anatomical based vessel
    - 92% generic straight lines
  - Hemodynamics
    - $v = \dot{V} * \Delta t$

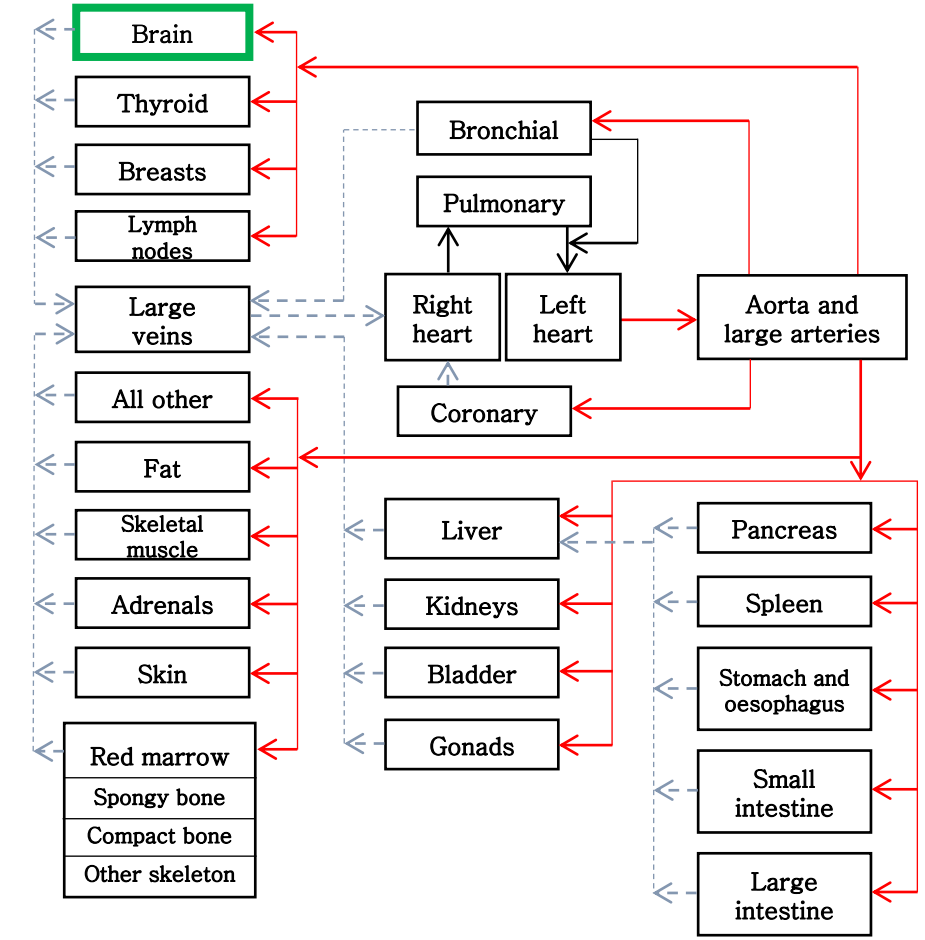




Hammi A. et al. Phys. Med. Biol. 2019

Circulatory System

- Blood propagation dynamics
  - Spatial information of blood trajectories
    - 8% Anatomical based vessel
    - 92% generic straight lines
  - Hemodynamics
    - $v = \dot{V} * \Delta t$
- Blood flow model for the entire human body
  - Based on ICRP data (24 organs)
  - ICRP hemodynamic references (gender, age…)
  - Blood particle tracking (>20 Mio.)



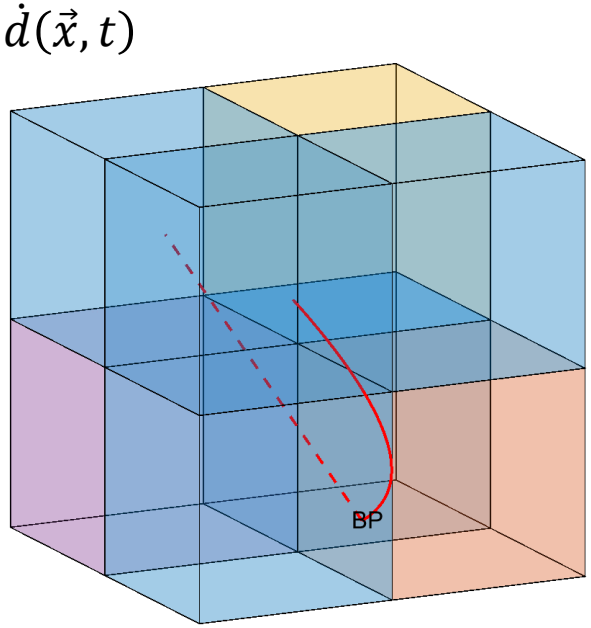
Hammi A. et al. Phys. Med. Biol. 2019

4D Dose Calculation

- Dose scoring

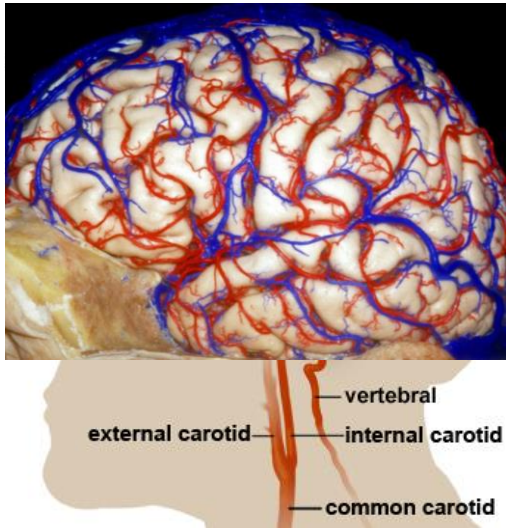
$$D_{ID} = \sum_{id}^{N} \frac{\dot{d}(\vec{x}, t)}{\bar{v}(\vec{x})} \Delta x$$

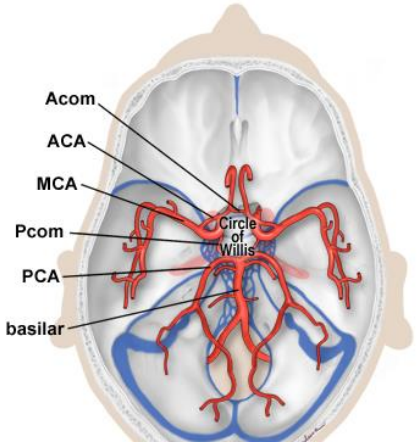
- Wishlist:
  - More realistic spatial presentation of the flow evolution through the brain
  - Higher time resolution



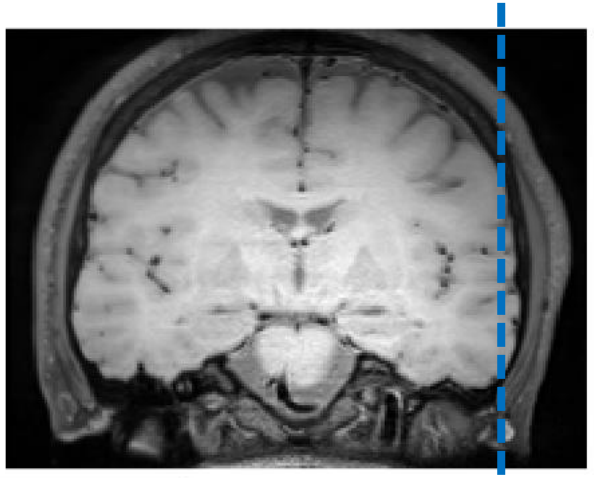
Vascular Architecture

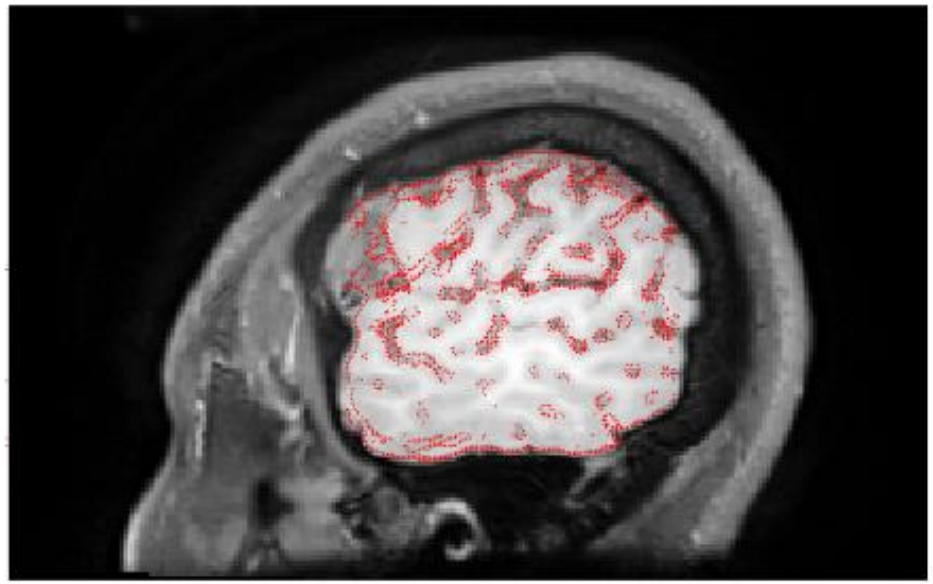
- Realistic vessel boundaries
  - Vessels occupy **convex folds** and **valleys** of the surface of the brain
- Brain Blood Supply
  - Carotid arteries and vertebral arteries
  - Different lobes require different blood supply
  - Communication between major arteries
  - Circle of Willis
  - Venous drainage

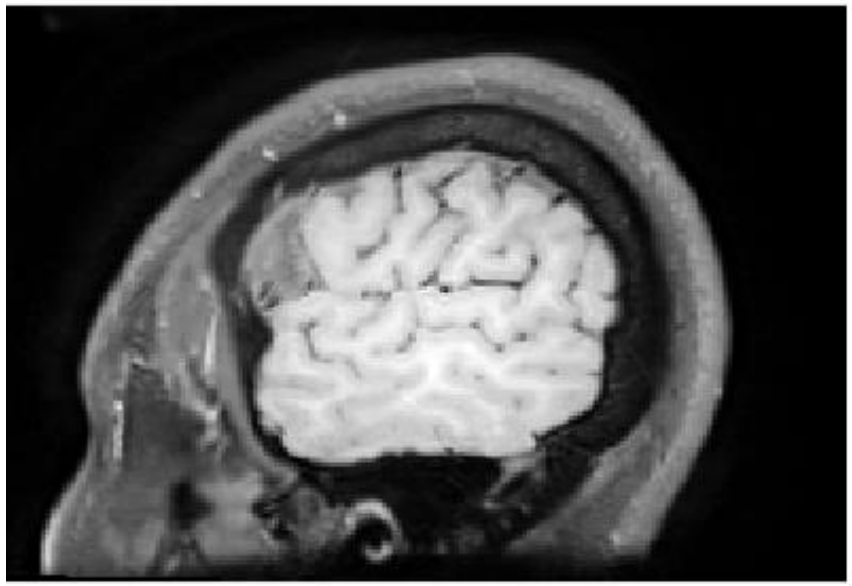




Extraction of vessel boundaries from MRI data

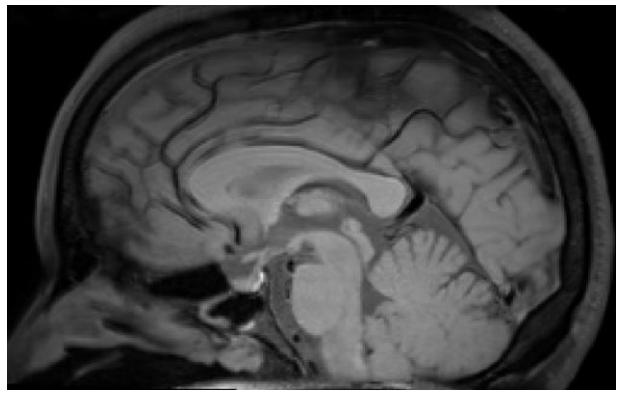


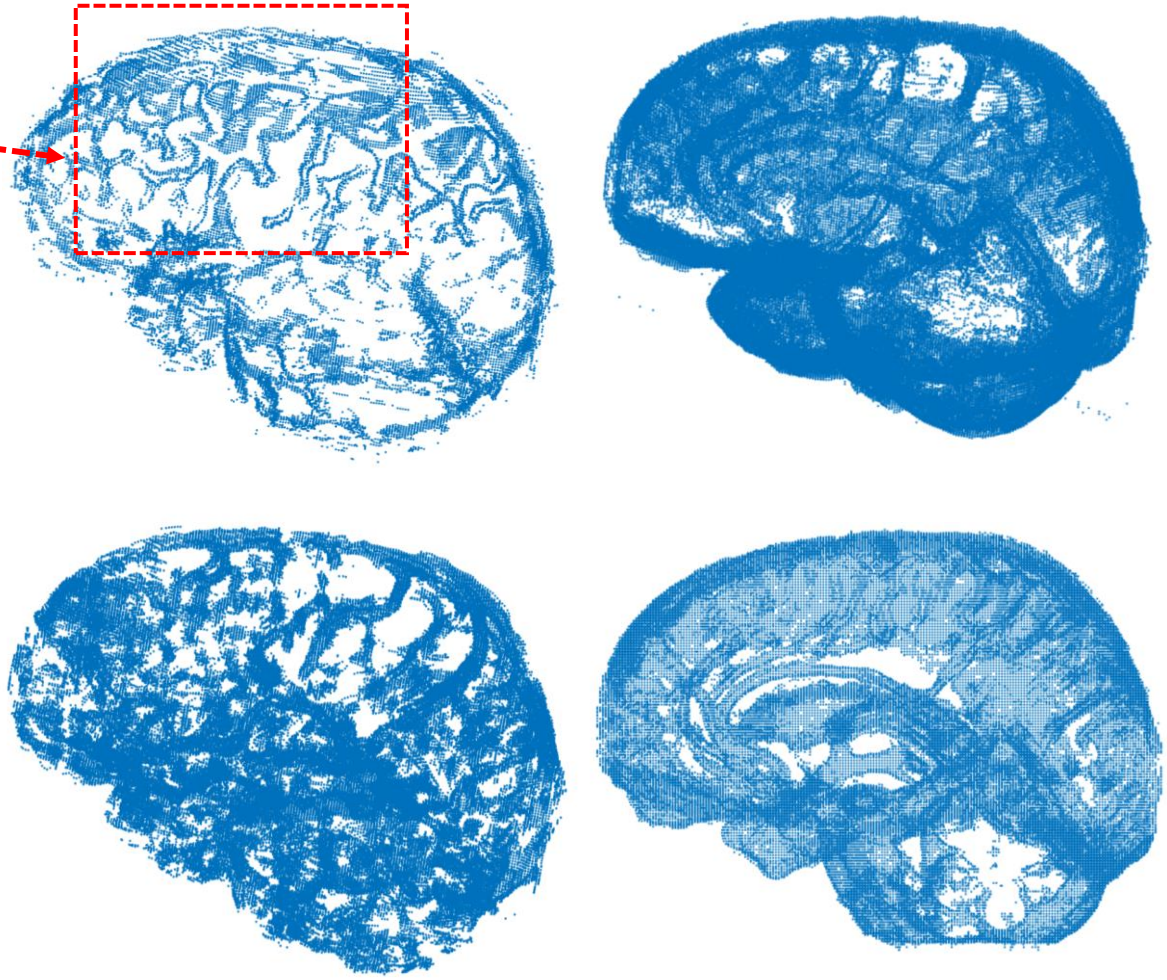




Topographic Map of Vessel Boundaries

- Vessels occupy **convex folds** and **valleys** of the surface of the brain

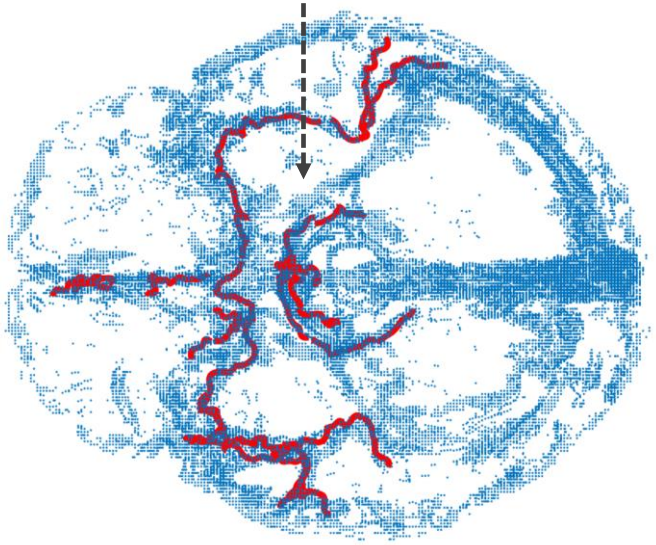


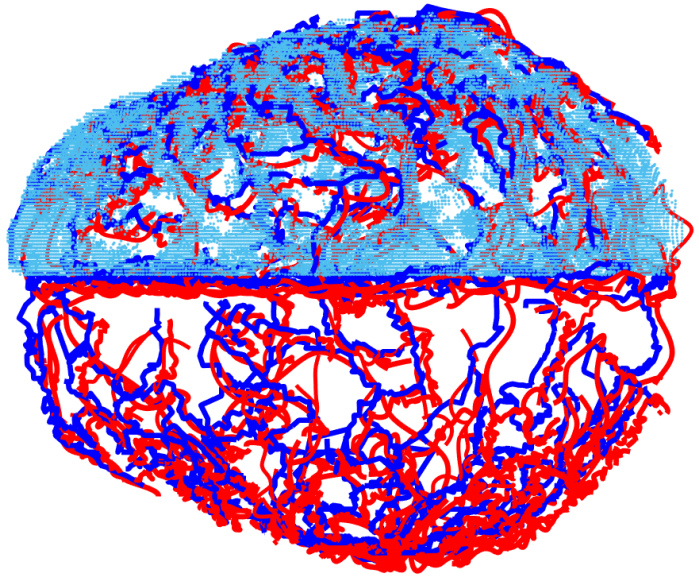


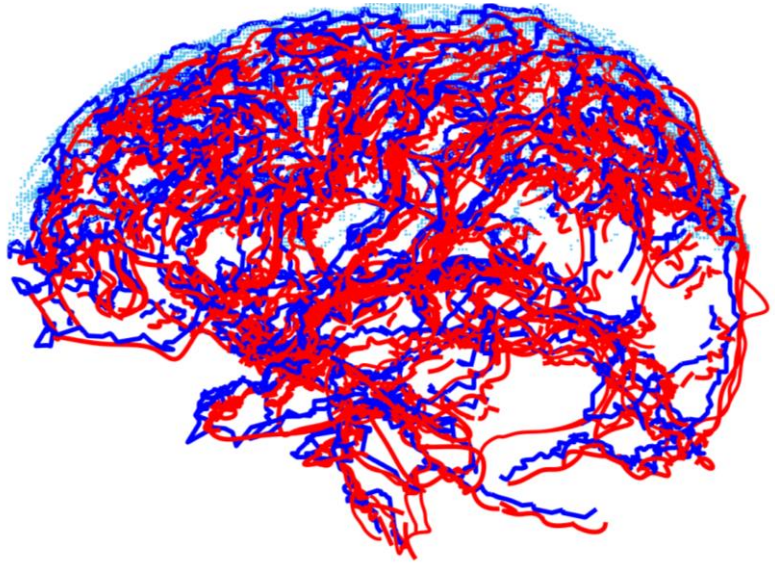
Blood Particles Trajectories

- Connectivity of vertexes set with the shortest distance

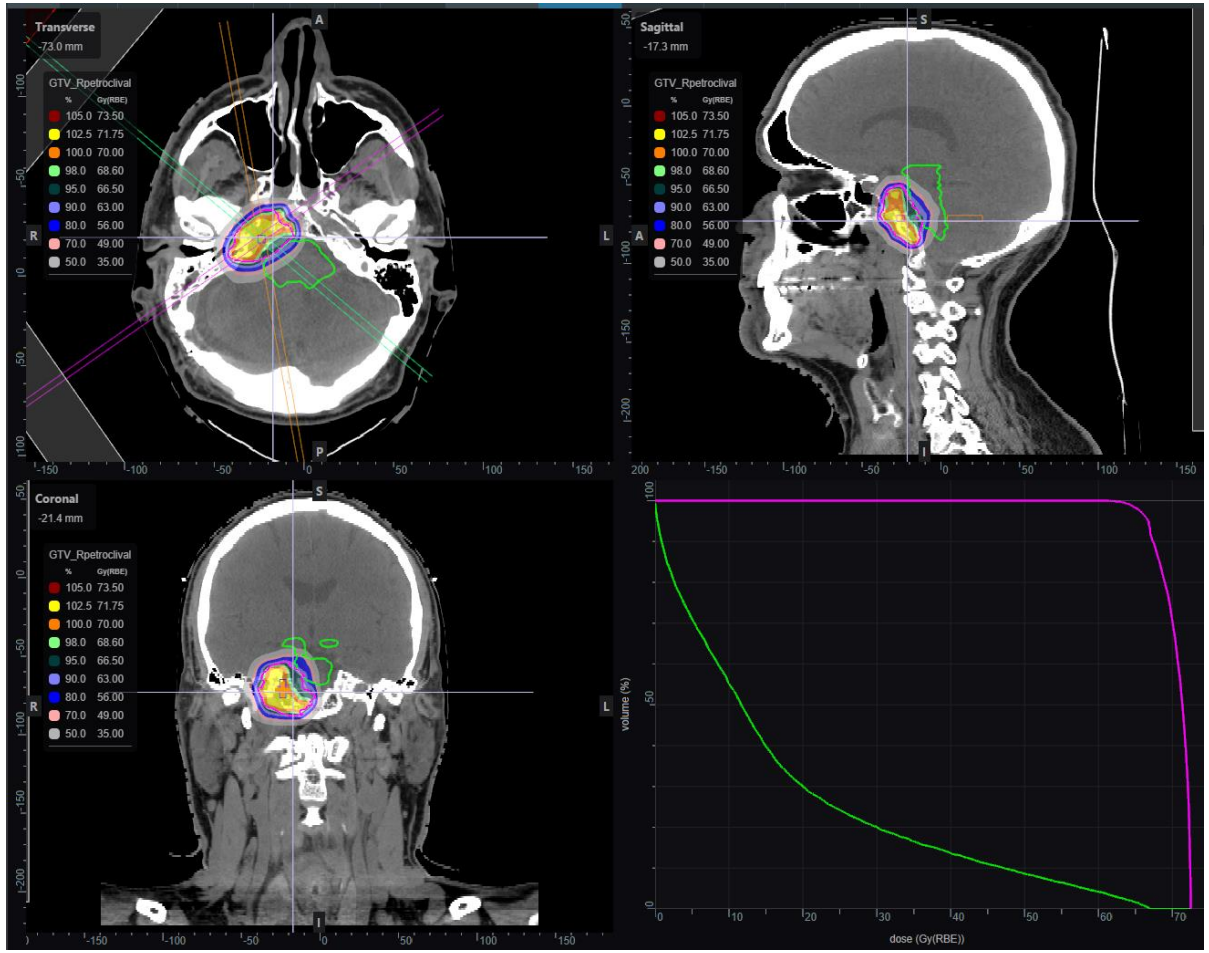
Circle of Willis





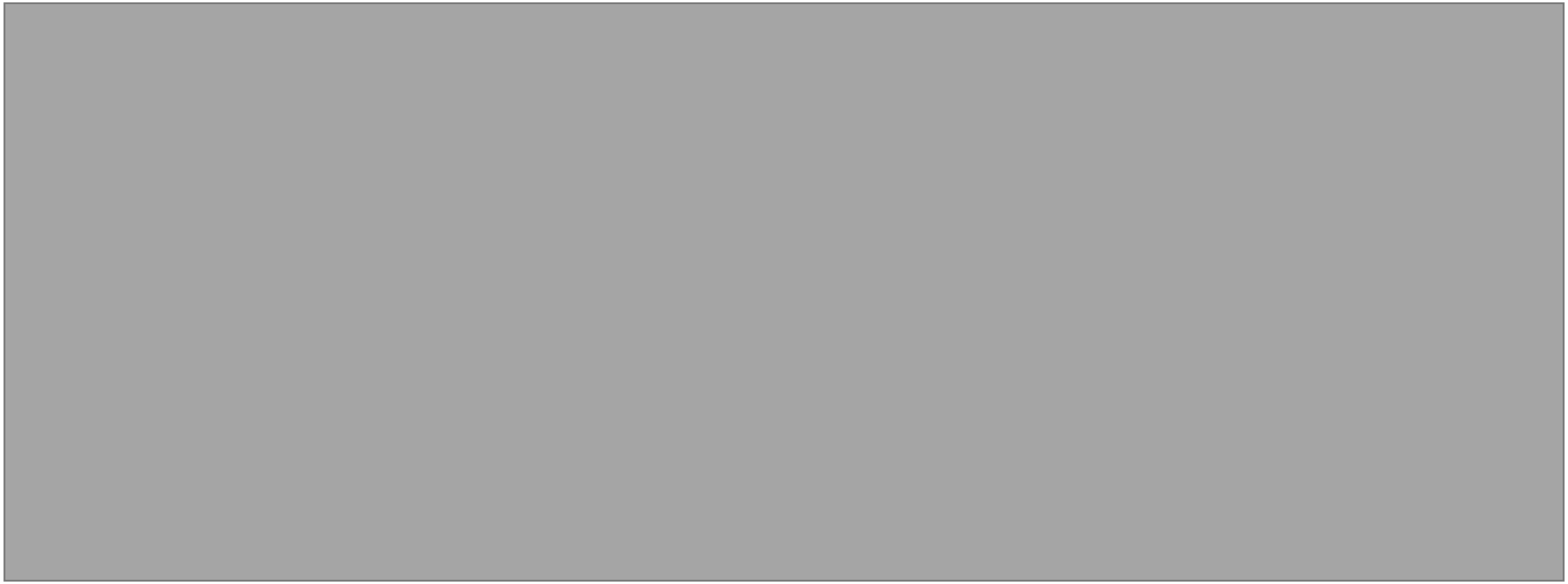


Patient Data



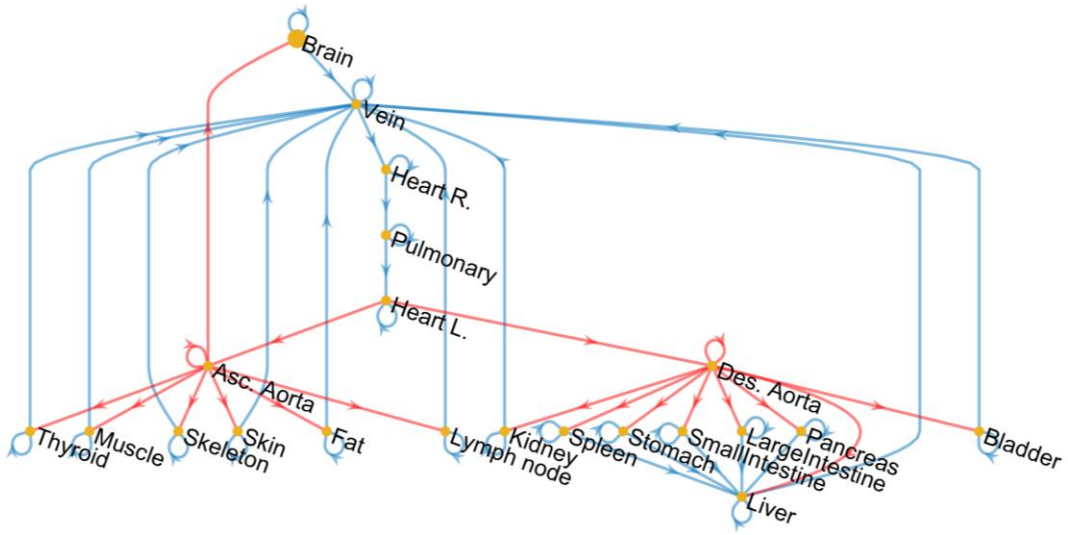
Patient Anatomy

- From generic model to “*Patient Model*”



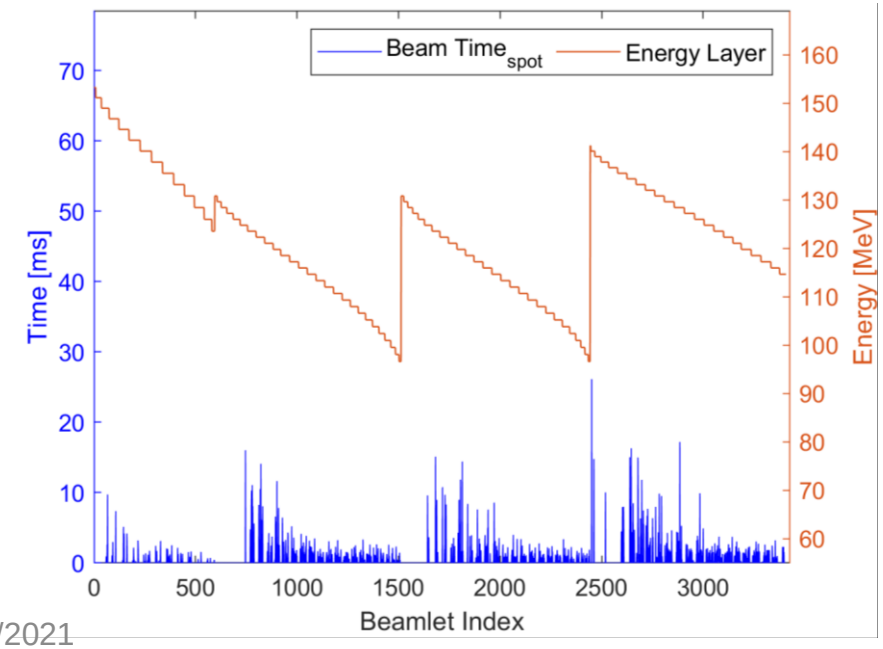
Circulatory System

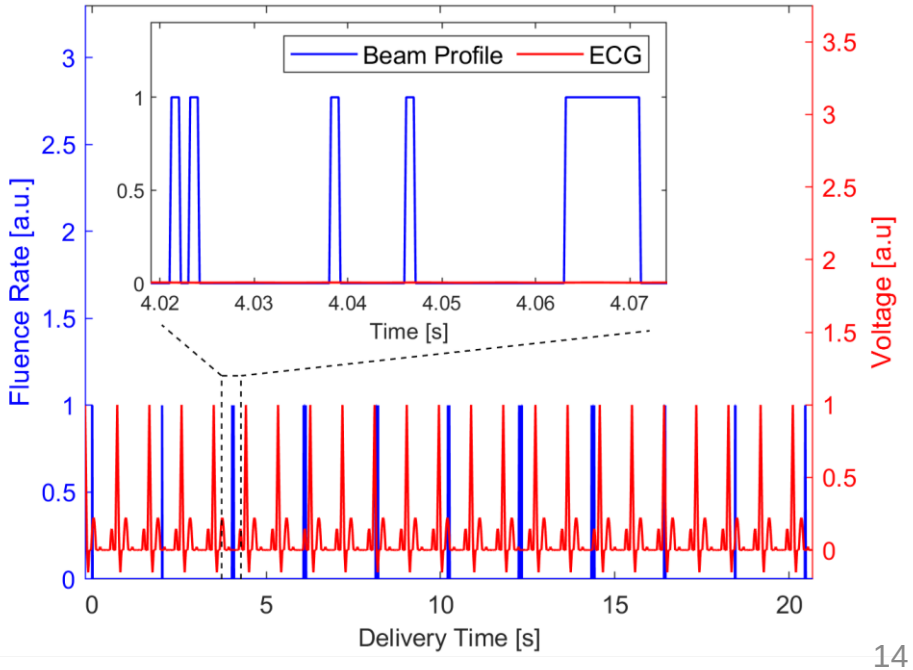
- 30 Compartments organs
- Model 40 Mio BPs
- ΔT= .2*10^{-3}s



Dynamic Beam Delivery I

- Proton Pencil Beam Scanning (PBS)
  - Current ramping up-/down T = 200 ns
  - Energy step ($\Delta E \approx 2MeV$) T = 2 s
  - Sweeping magnet time





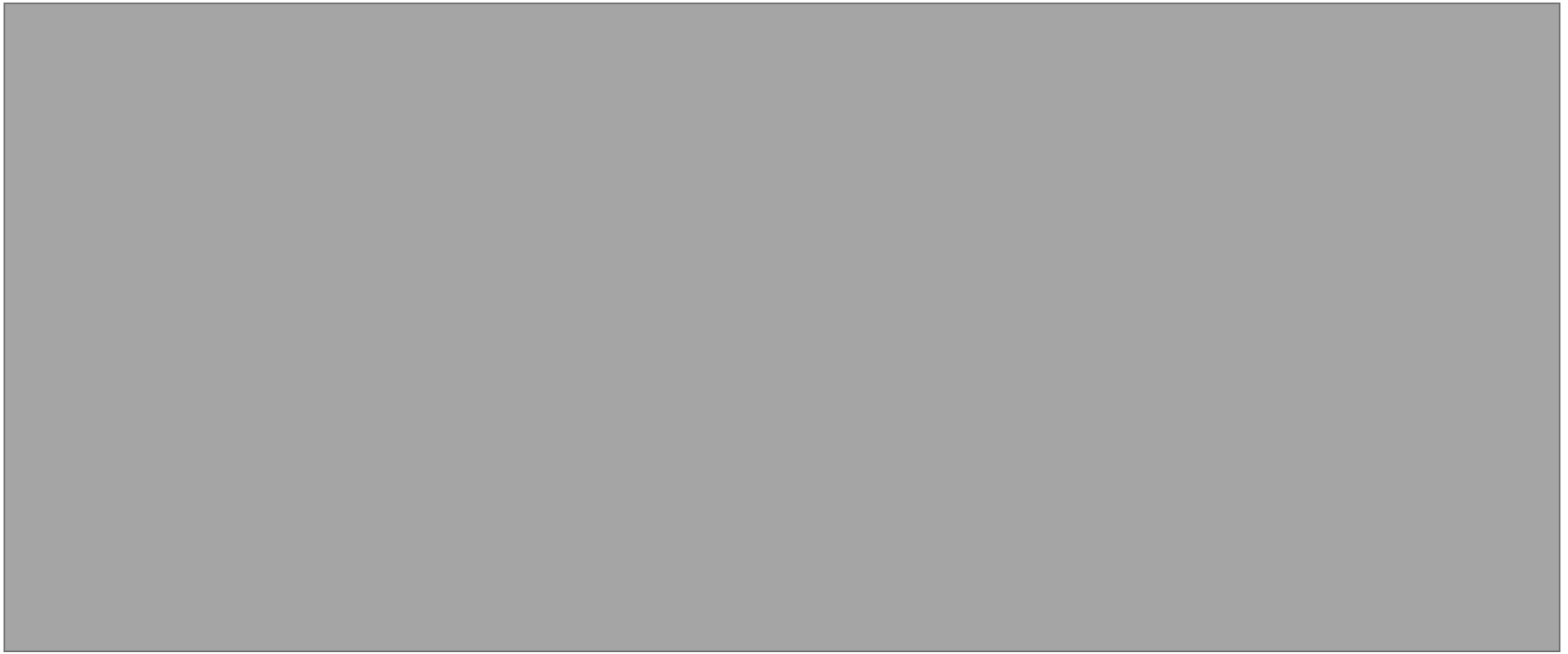
Dynamic Beam Delivery II

- Proton Pencil Beam Scanning (PBS)
  - Current intensity I_m = 2 nA
  - Current ramping up-/down T = 200 ns
  - Energy step ($\Delta E \approx 2MeV$) T = 2 s
  - Sweeping magnet time

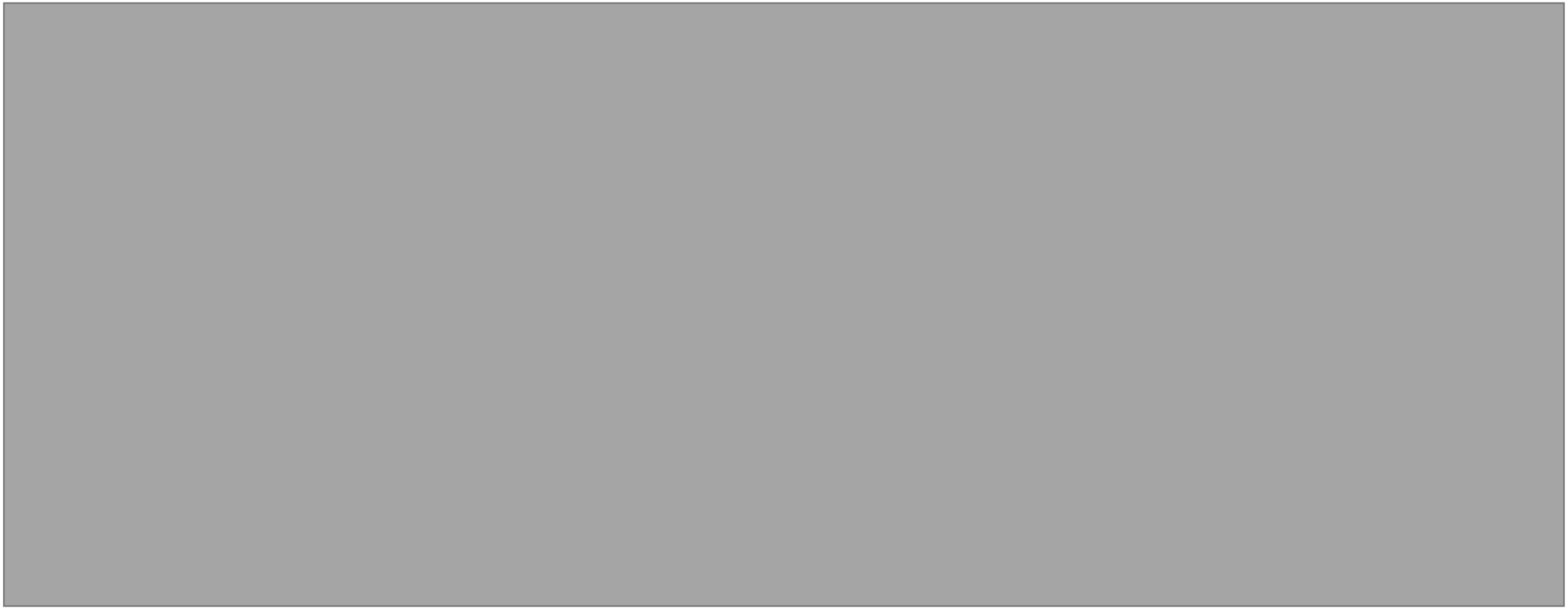
- Proton Passive Scanning (PS)
  - Modulation Wheel 600 rpm
  - Modulation step ~ 2.7 ms

- Photon Therapy
  - Dose-rate
  - Beam-on time
  - Number of segments

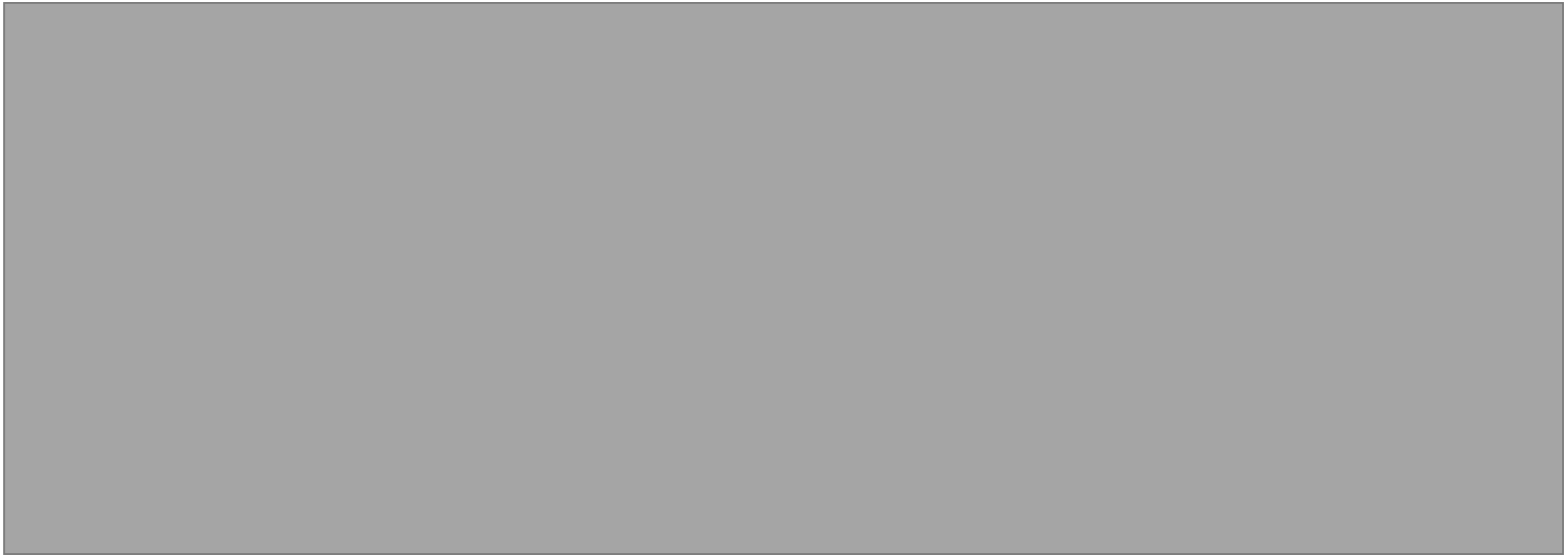
Results: *Effect of Treatment Modality*



Results: *Effect of Current Intensity / Dose Rate*



Results: *Blood Is Not A Solid Organ*



SUMMARY

- Explicit 4D blood flow model including recirculation to estimate radiation dose received by the circulating blood pool
- Model is based on realistic vasculature network of the human brain
- Entire blood dilution and blood flow is considered
- Application to patient case of proton pencil beam scanning, passive scattering and photon-based delivery at various dose rates and fractionations
- Our model considers the total dose over a fractionated treatment but allow to also score cell survival after each fraction

ACKNOWLEDGEMENT

Sebastian Tattenberg

Thank you for your attention!