An iterative approach to shielding the first carbon facility in the US by means of Geant4

D. Bolst[1], J. M. Dougherty[2], K. Furuntani[2], S. Guatelli[1], A. B. Rosenfeld[1], C. J. Beltran[2]

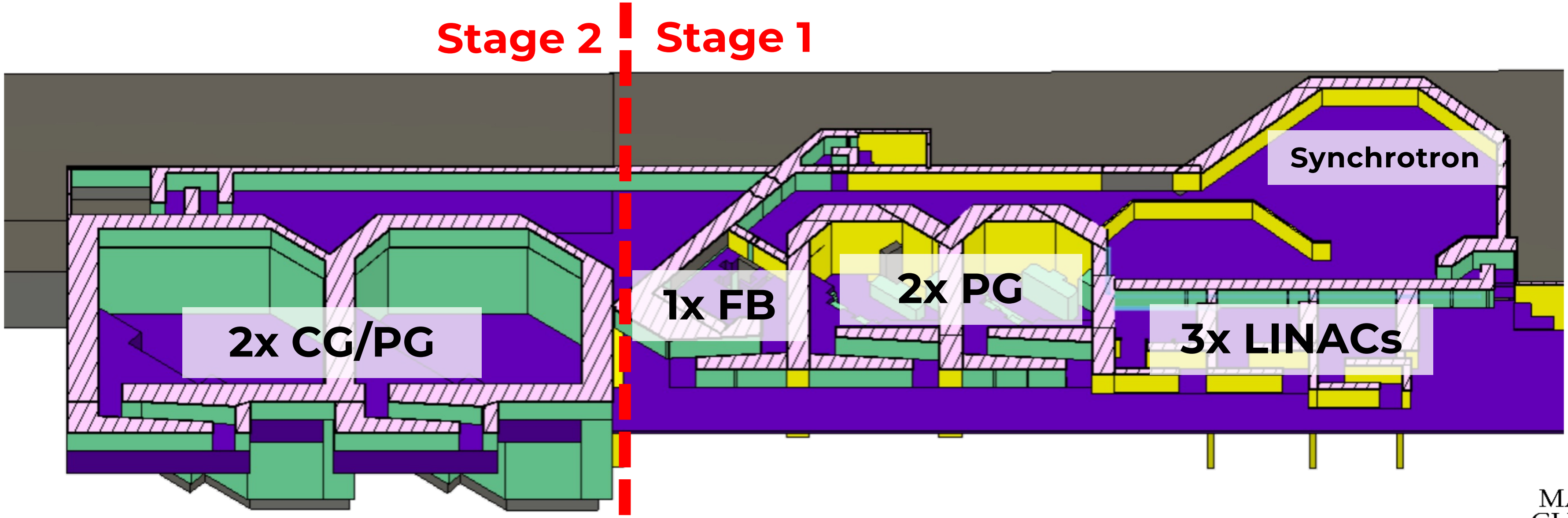
[1]Centre for Medical Radiation Physics, University of Wollongong, Australia

[2]Division of Medical Physics, Department of Radiation Oncology, Mayo Clinic, Jacksonville, Florida, USA

Geant4 Users Meeting 2022 - Napoli

First* clinical carbon ion facility in the US

- Mayo Clinic is constructing the first US carbon ion therapy facility in Jacksonville, Florida
- Stage 1 consist of two proton gantries, a fixed beam room (proton + carbon)
  - Construction started 2022
  - Stage 1 construction planned to be complete in 2024
  - Proton therapy patients treated from 2025
  - Carbon ion therapy patients treated by 2027
- Stage 2 consists of two carbon + proton gantries



*Not counting the Lawrence Berkeley National Accelerator Laboratory due to it being pre-clinical research

Typical approach for radiation shielding of a facility in the US

Reference shielding design from vendor

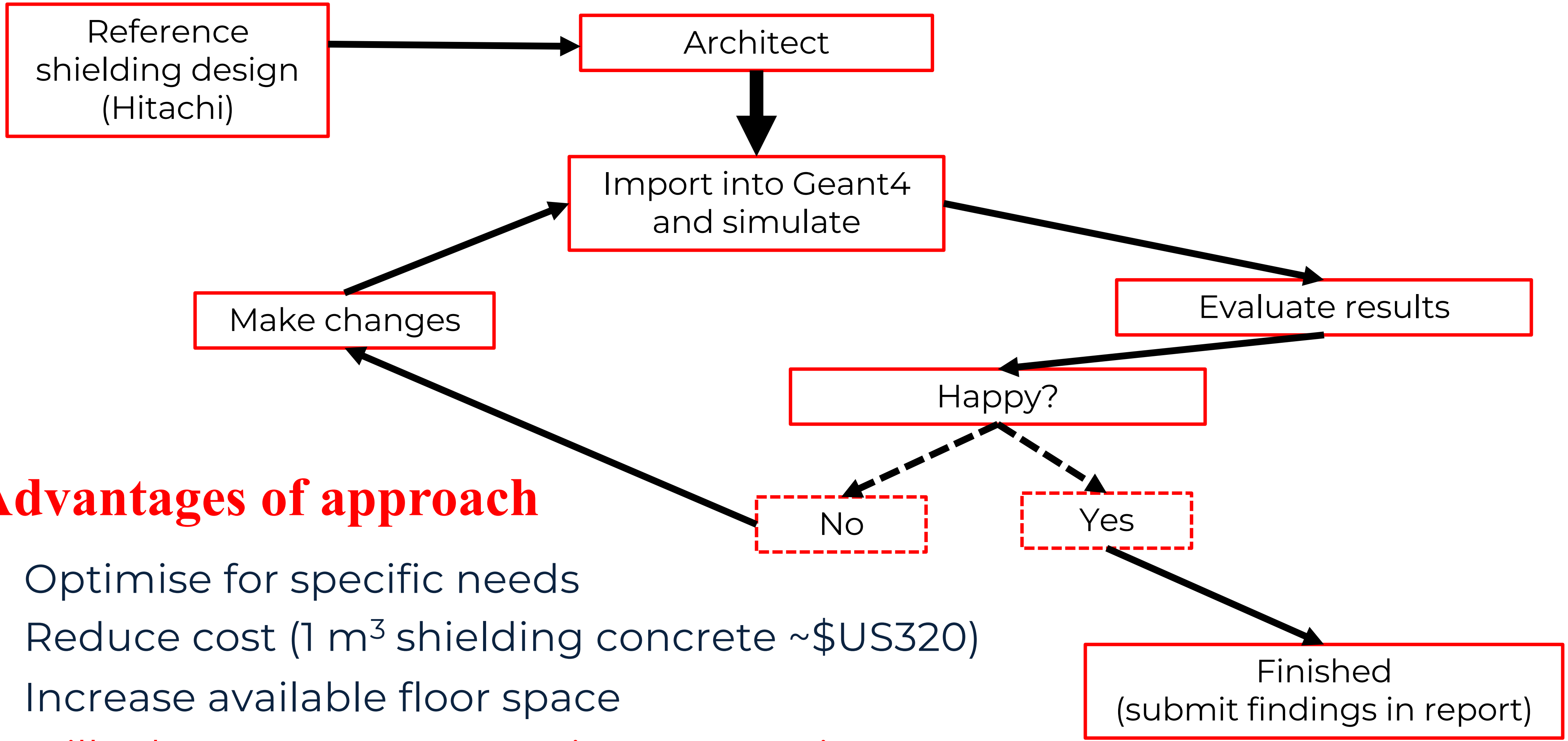
→ Architect makes some alterations to fit specific site plan and need

→ Shielding consultant
Tests provided plan
Checks whether meets regulation

→ Consultant makes recommendation

→ Findings submitted with building proposal to regulators

Approach adopted for this project

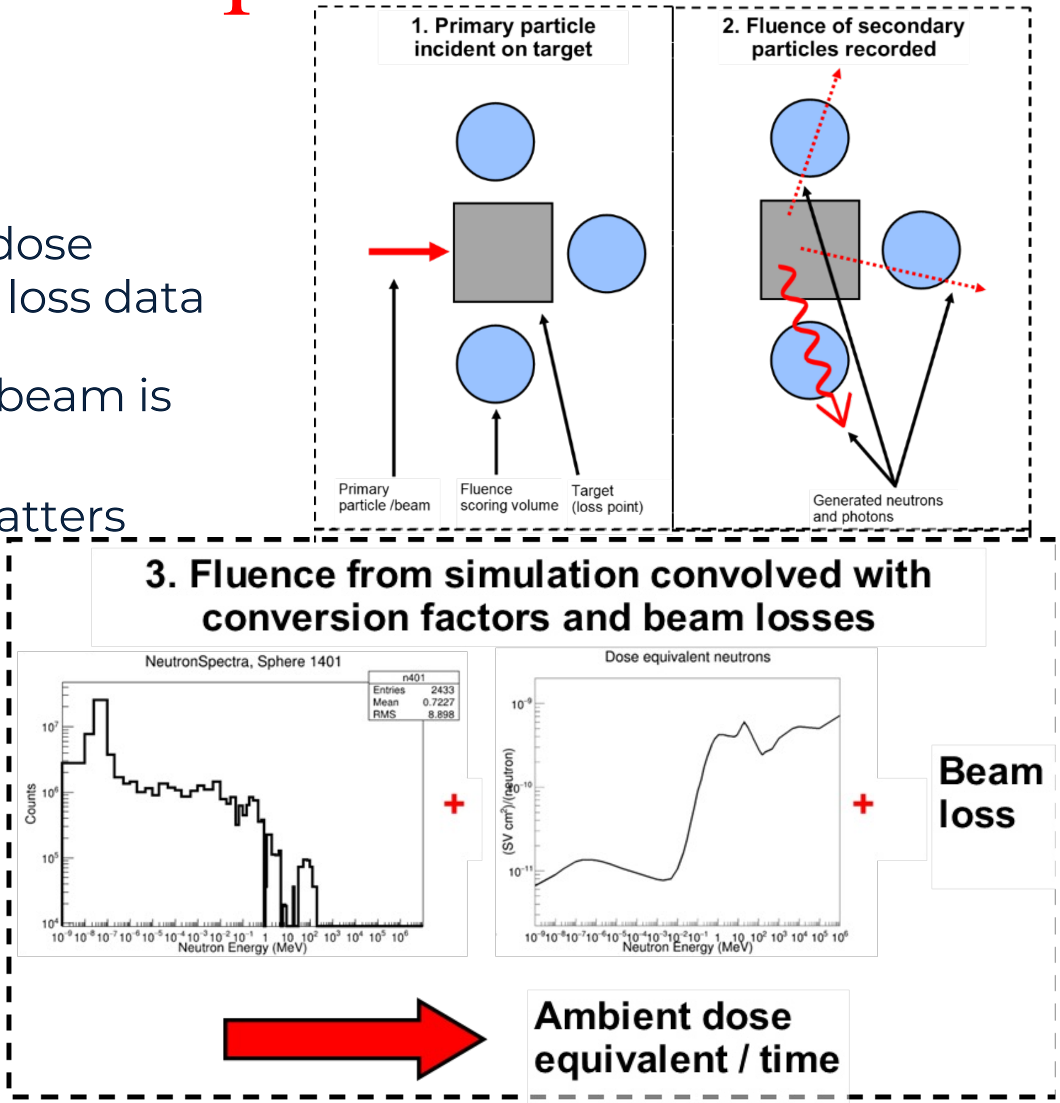


Advantages of approach

- Optimise for specific needs
- Reduce cost (1 m^3 shielding concrete ~$US320)
- Increase available floor space
- Still adopt many conservative assumptions

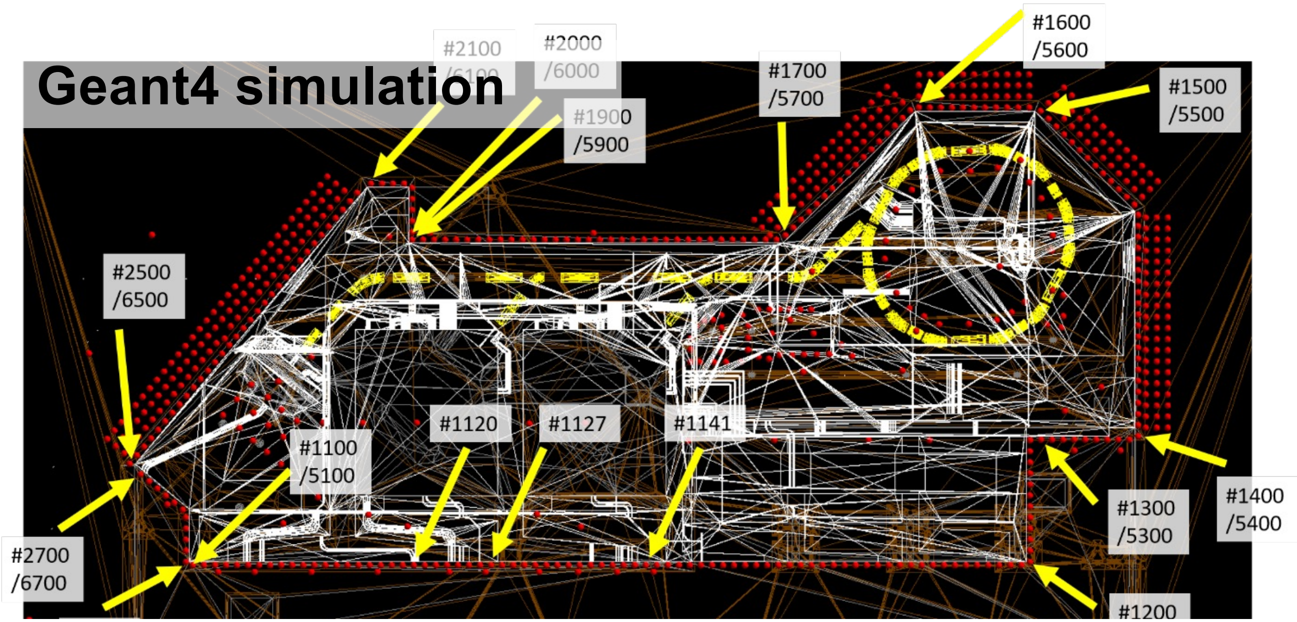
Brief overview of simulation process

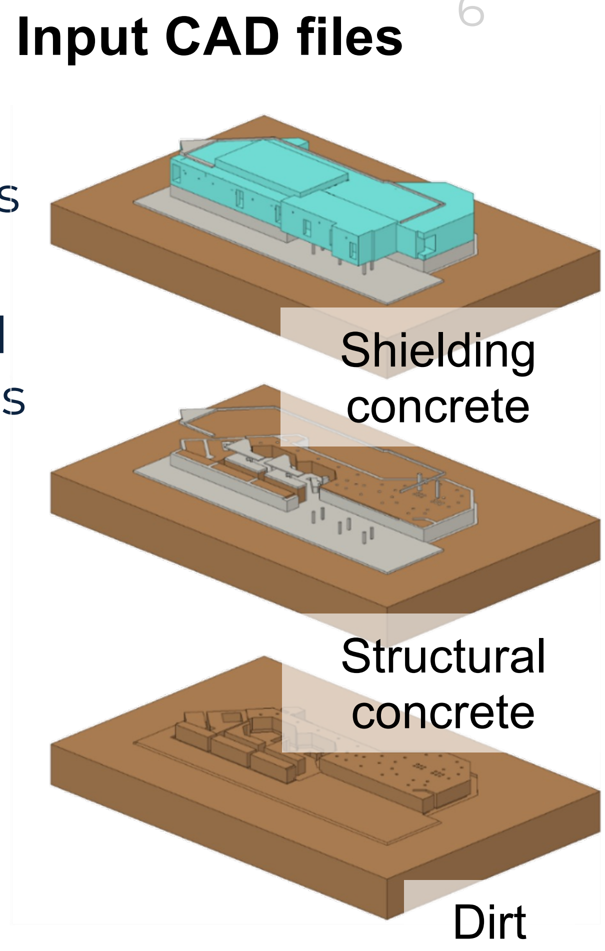
- Simulation consist of:
  - Generating primary proton/carbons
  - Score neutron and photon fluence
  - Convolve recorded energy fluence with dose equivalent conversion factors and beam loss data
- “Beam loss” refers to when some amount of beam is “lost”
  - (undergoes inelastic nuclear reaction, scatters from beam line
- Beam losses have been provided by Hitachi
  - Assumes 16000 treatments a year in each room, with 50 Gy delivered to 250 mL target per treatment
- Maximum beam energy:
  - 230 MeV proton
  - 430 MeV/u carbon ions



Simulation

- Version 10.6 of Geant4 with Bertini cascade
- Fusion 360 used to change CAD files and export as STL files
- CADMesh used to import STL files into Geant4
- 60 cm diameter air spheres were placed throughout world (red volumes) to score the fluence of neutrons and photons
- Fluence also scored in 25 cm cube voxels

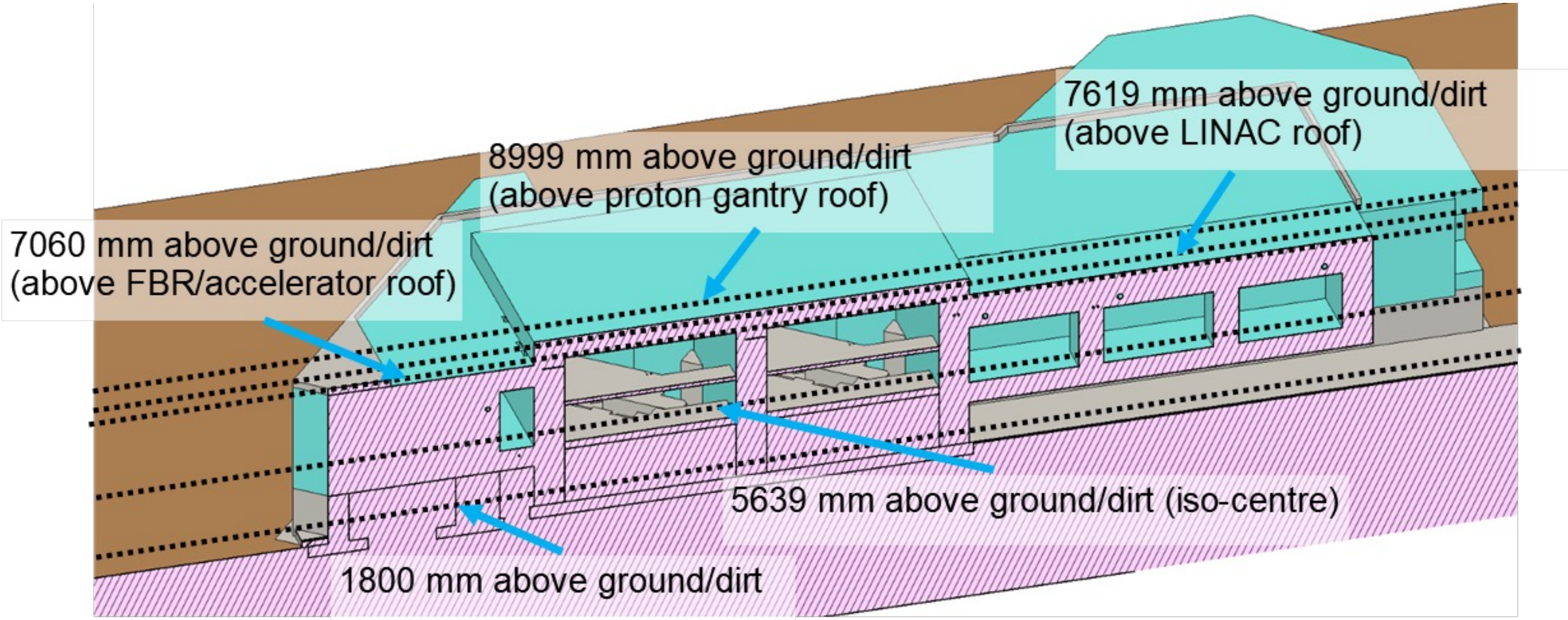




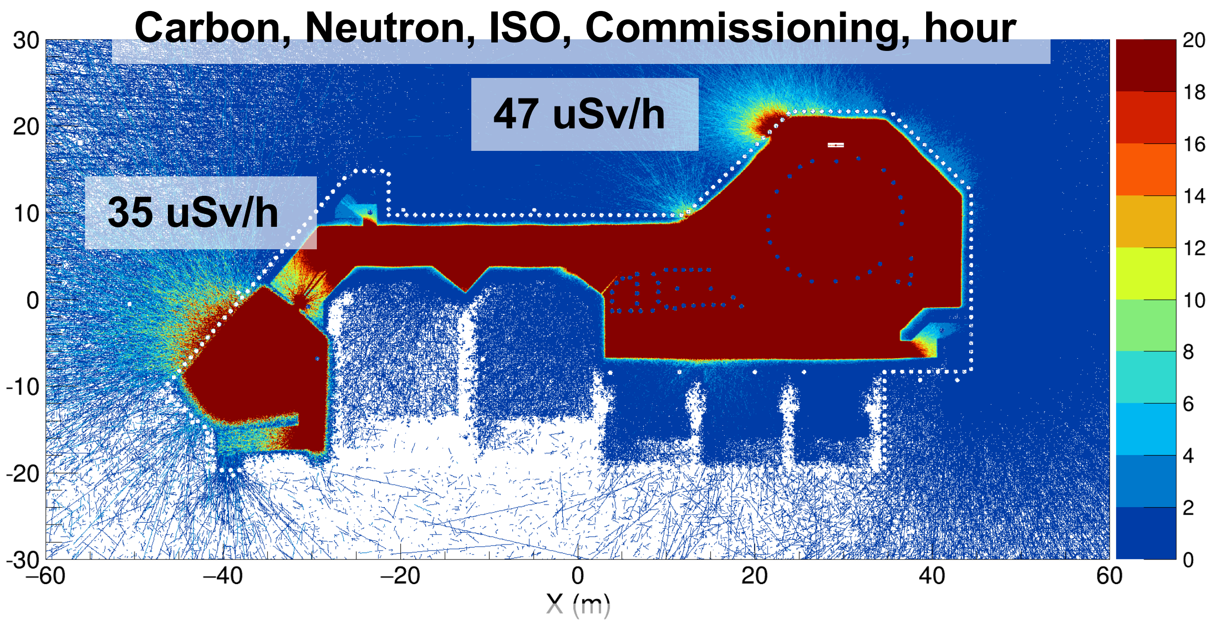
MAYO CLINIC
CENTRE FOR MEDICAL RADIATION PHYSICS
UNIVERSITY OF WOLLONGONG AUSTRALIA

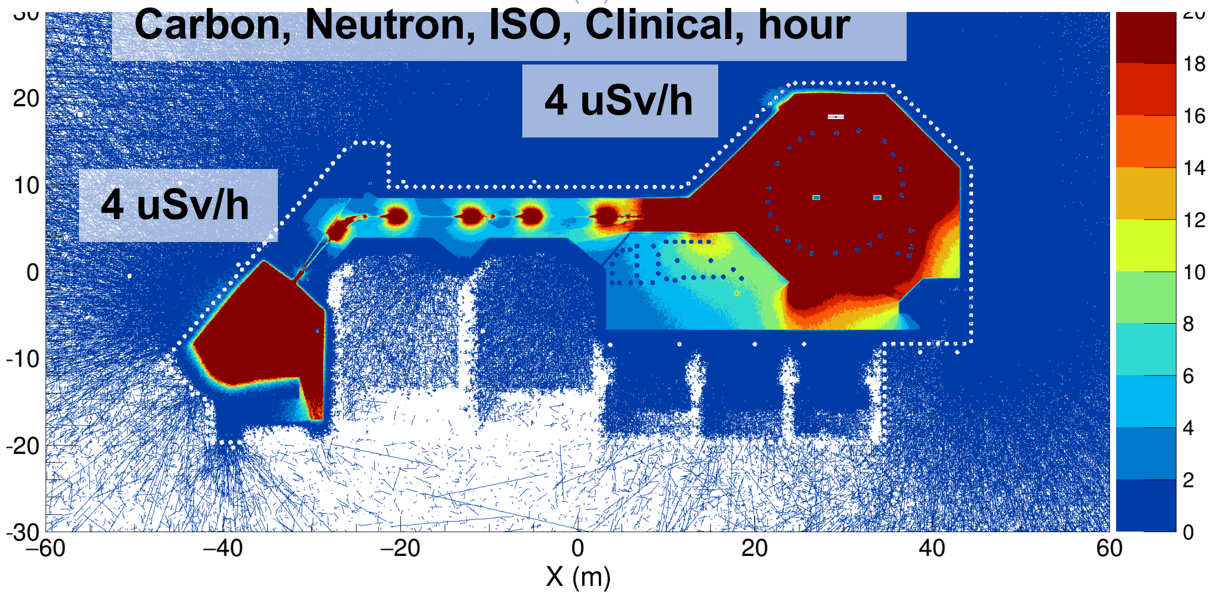
Results

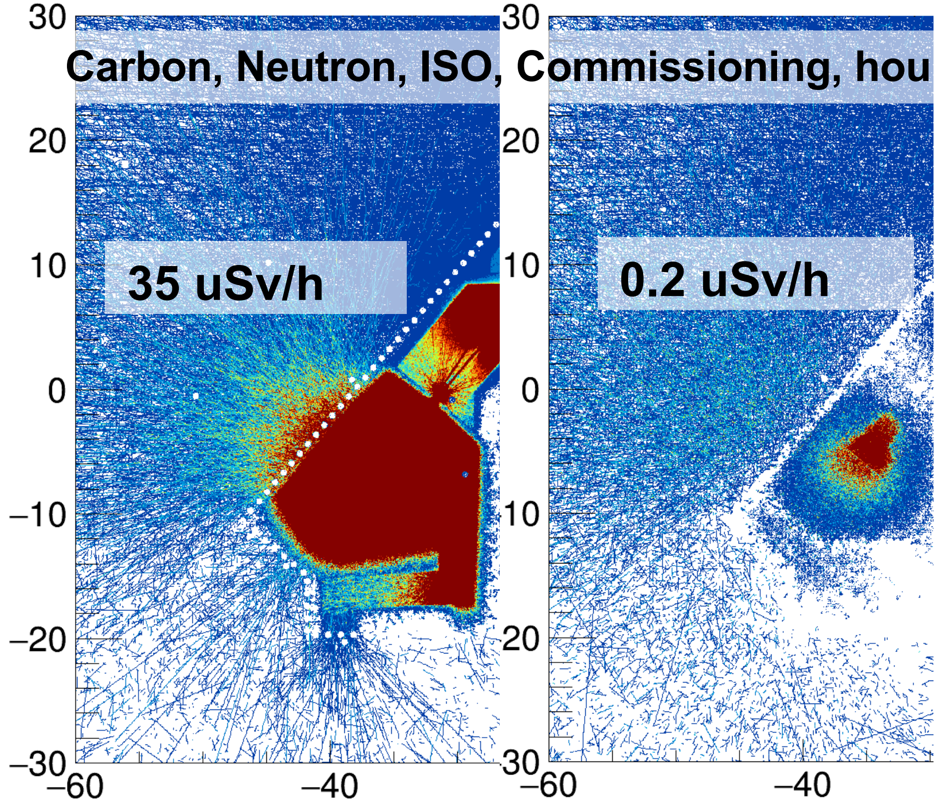
- Showing dose equivalent values calculated from 25 cm cube voxels over an hour period, units of uSv/h
  - limit = 20 uSv/h, cannot be scaled based on occupancy
- Focusing mostly on fluence at iso-centre height (5.6 m above ground)
- Only showing carbon ion losses
- Results shown are from “final” iteration



MAYO CLINIC
CENTRE FOR MEDICAL RADIATION PHYSICS
UNIVERSITY OF WOLLONGONG AUSTRALIA







ISO-centre
5.6 m above ground

1.8 m above ground

MAYO CLINIC

CENTRE FOR MEDICAL RADIATION PHYSICS

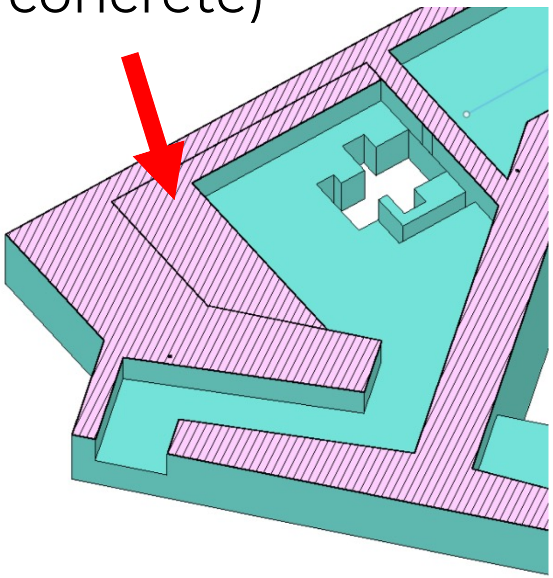
UNIVERSITY OF WOLLONGONG AUSTRALIA

Some notable changes through the iterations

Fixed beam room's "wedge" reduced from 7 m to 4 m thick

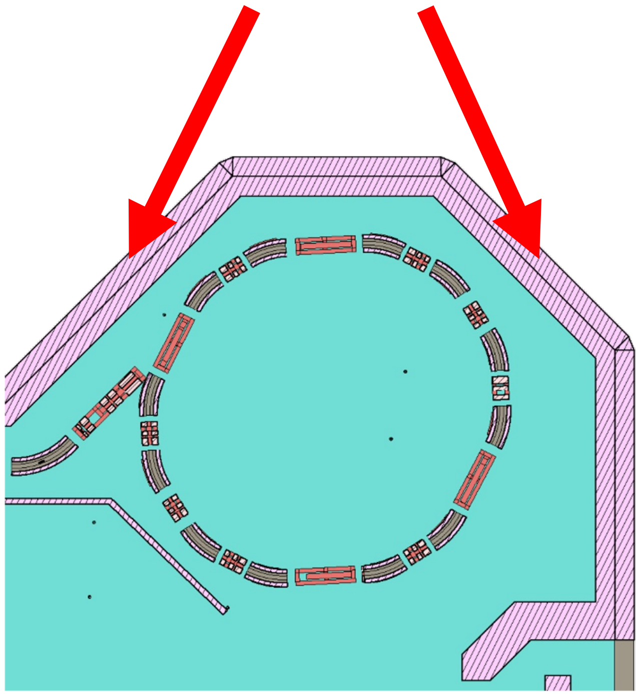
Increasing available floor space by 33 m^2

Saving $52k (163 m^3 of concrete)



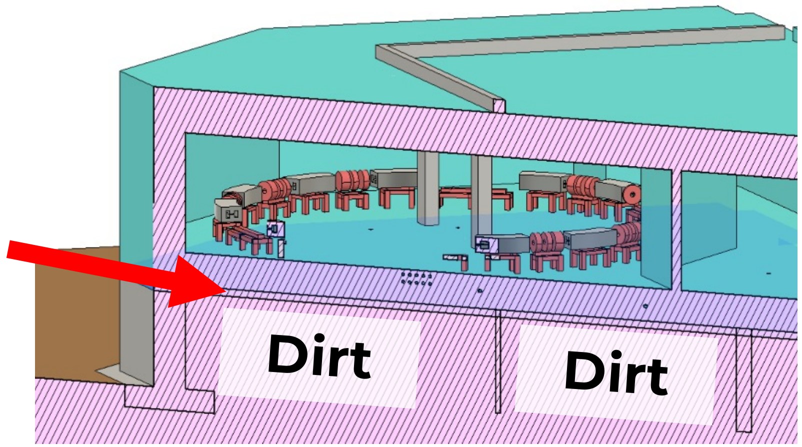
Surrounding walls of synchrotron reduced from 2 m to 1 m thick

Saving $236k (739 m^3)



Reducing synchrotron/beam transport's floor of 30 cm

Saving $98k (307 m^3)

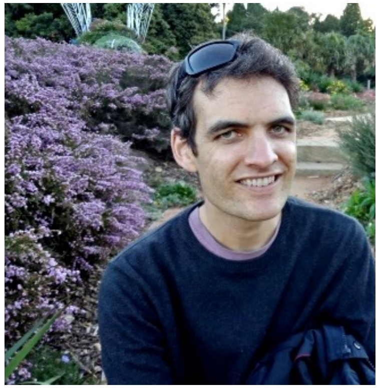


Summary

- Jacksonville, Florida, will be the site of first carbon ion facility in the US
- Design/shielding approach followed an iterative approach using Geant4
- Proton shielding component didn't show any major surprises
- Carbon gave values which exceeded the 20 uSv/h limits during commissioning ~5 m above the ground at the synchrotron and
  - Temporary fence being erected at simulated hotspots
  - Despite conservative assumptions made (such as physical dose instead of biological dose be prescribed) clinical operations were below limits
- Approach helped save ~$US400k in concrete compared and increasing treatment room size compared to the starting reference design

MAYO CLINIC
CENTRE FOR MEDICAL RADIATION PHYSICS
UNIVERSITY OF WOLLONGONG AUSTRALIA

Thank you



David Bolst

Susanna Guatelli

Anatoly Rosenfeld

Jingjing (Michele) Dougherty

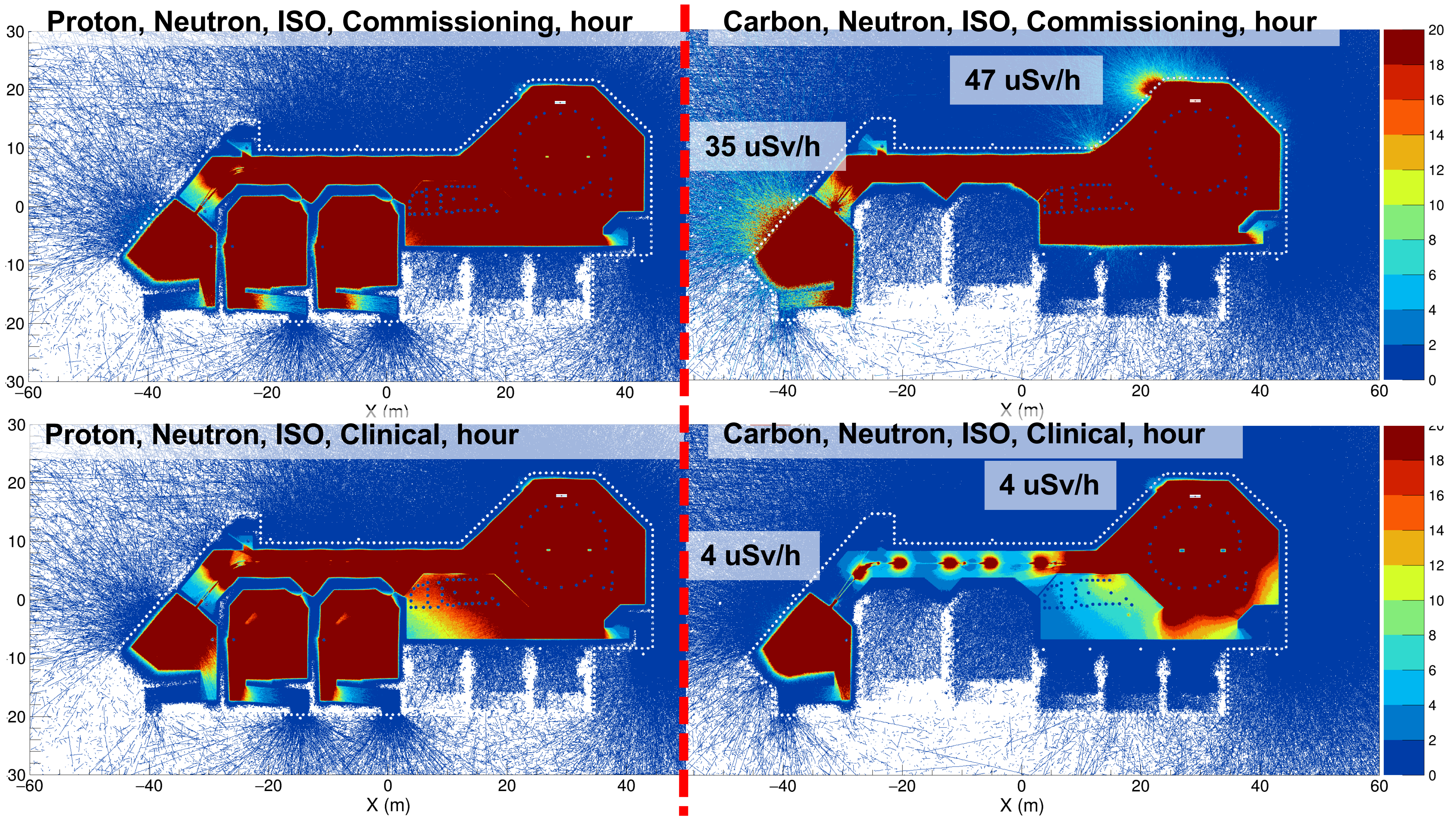
Keith Furuntani

Chris Beltran

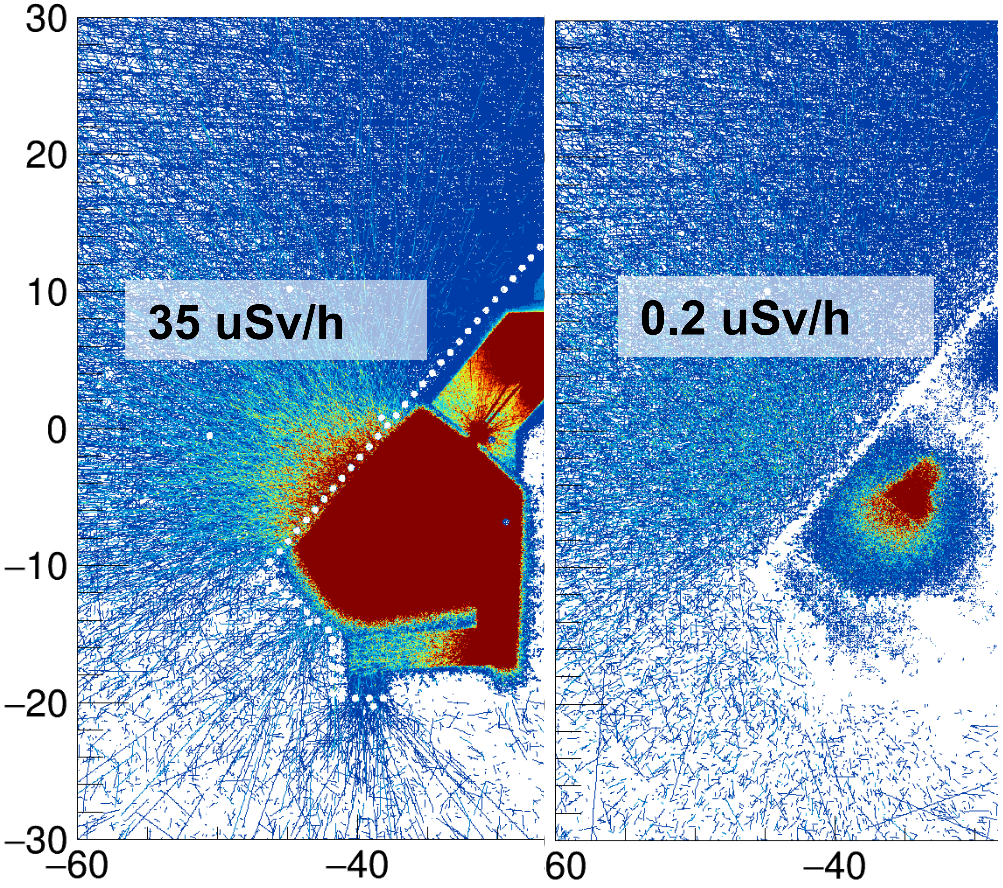
MAYO CLINIC

CENTRE FOR MEDICAL RADIATION PHYSICS

UNIVERSITY OF WOLLONGONG AUSTRALIA

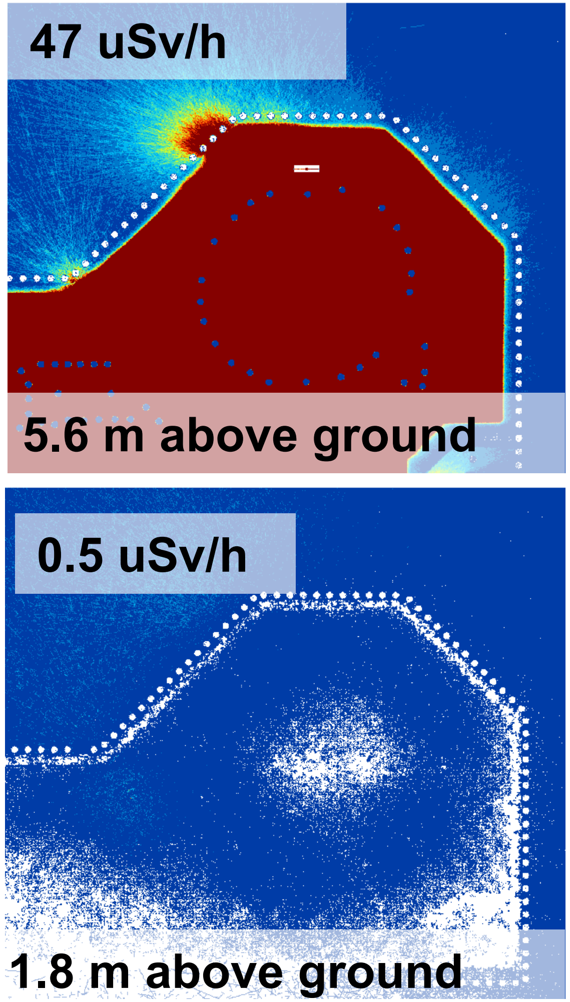

Proton, Neutron, ISO, Commissioning, hour
Carbon, Neutron, ISO, Commissioning, hour
47 uSv/h
35 uSv/h
Proton, Neutron, ISO, Clinical, hour
Carbon, Neutron, ISO, Clinical, hour
4 uSv/h
4 uSv/h
X (m)

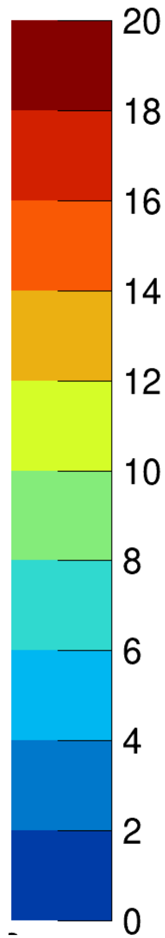
Different height: Carbon, Commissioning, hour



ISO-centre, 5.6 m above ground

1.8 m above ground





MAYO CLINIC

CENTRE FOR MEDICAL RADIATION PHYSICS

UNIVERSITY OF WOLLONGONG AUSTRALIA

Brief overview of beam losses

- Beam consists of four regions:
  - Injector hall (low energy, 7 MeV, 4 MeV/u)
  - Synchrotron (medium to high, 50-230 MeV/u, 100-430 MeV)
  - High energy beam transport (high energy-230 MeV, 430 MeV/u)
  - Treatment rooms (high energy-230 MeV, 430 MeV/u)
- Beam losses vary between commissioning and clinical operations