Maria Ilaria Besana :: Paul Scherrer Institut

Shielding Calculations for the Swiss Light Source Upgrade

SATIF16 Workshop, 29 May 2024

Outline

- Introduction
- Losses at the dump region
  - Energy density on the dump
  - Load on permanent magnets
- Losses at the collimation region
  - Load on undulator
  - Dose outside the SLS bunker
- Accidental loss scenario for a working gallery below the bunker

Simulations performed with FLUKA 4.3 Monte Carlo code

Introduction

The Swiss Light Source (SLS) synchrotron facility began operation in early 2001

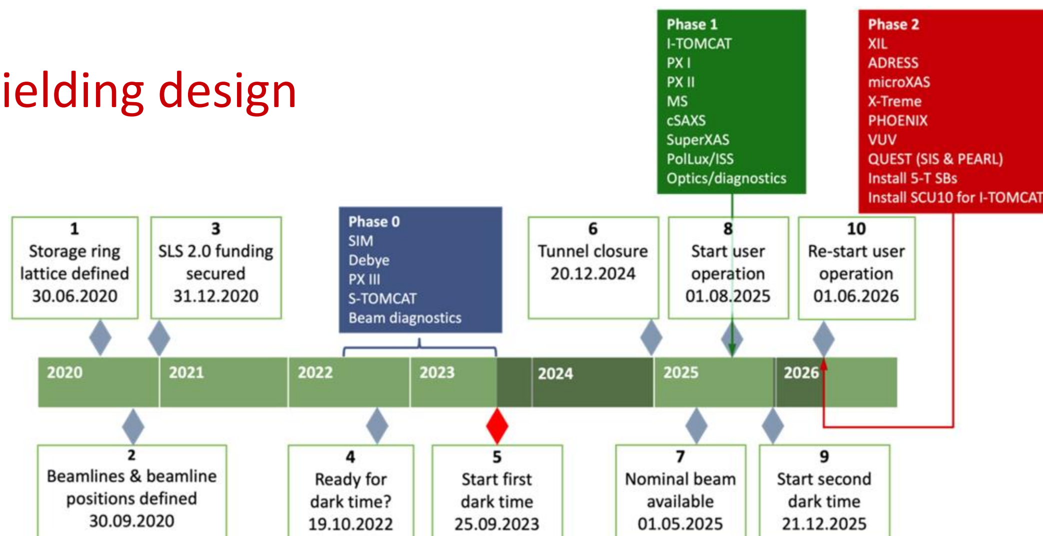
Upgrade ongoing for SLS 2.0

<u>Key changes</u> from SLS to SLS 2.0

- Reduced electron beam emittance from 5500 pm to 157 pm
- Energy increase from 2.4 GeV to 2.7 GeV

+ Intercepting devices added to localize the losses:
  – Collimators
  – Dump

→ challenges for shielding design



SLS 2.0 – The Upgrade of the Swiss Light Source
P. R. Willmott & H. Braun

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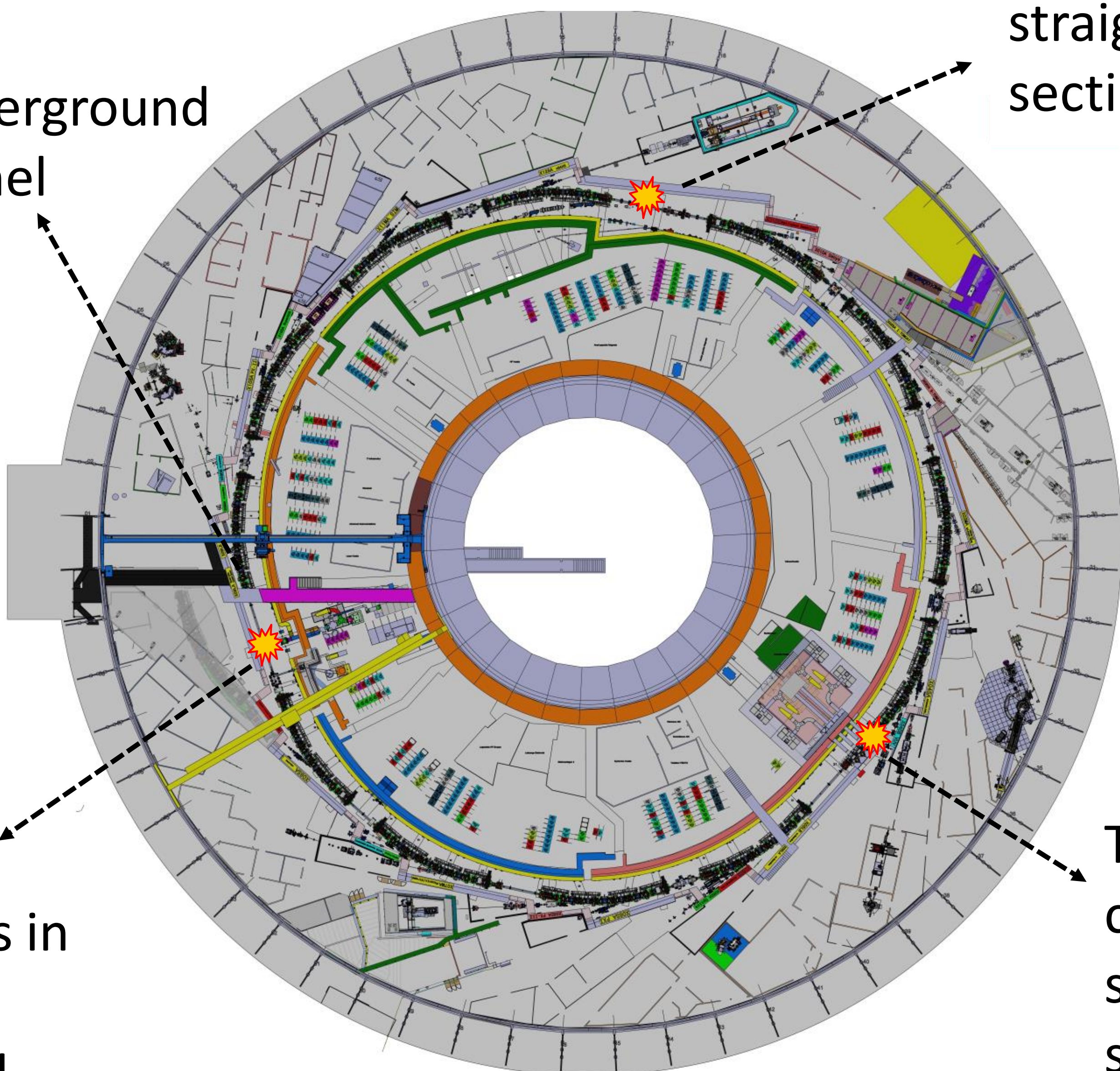
SLS 2.0 Layout



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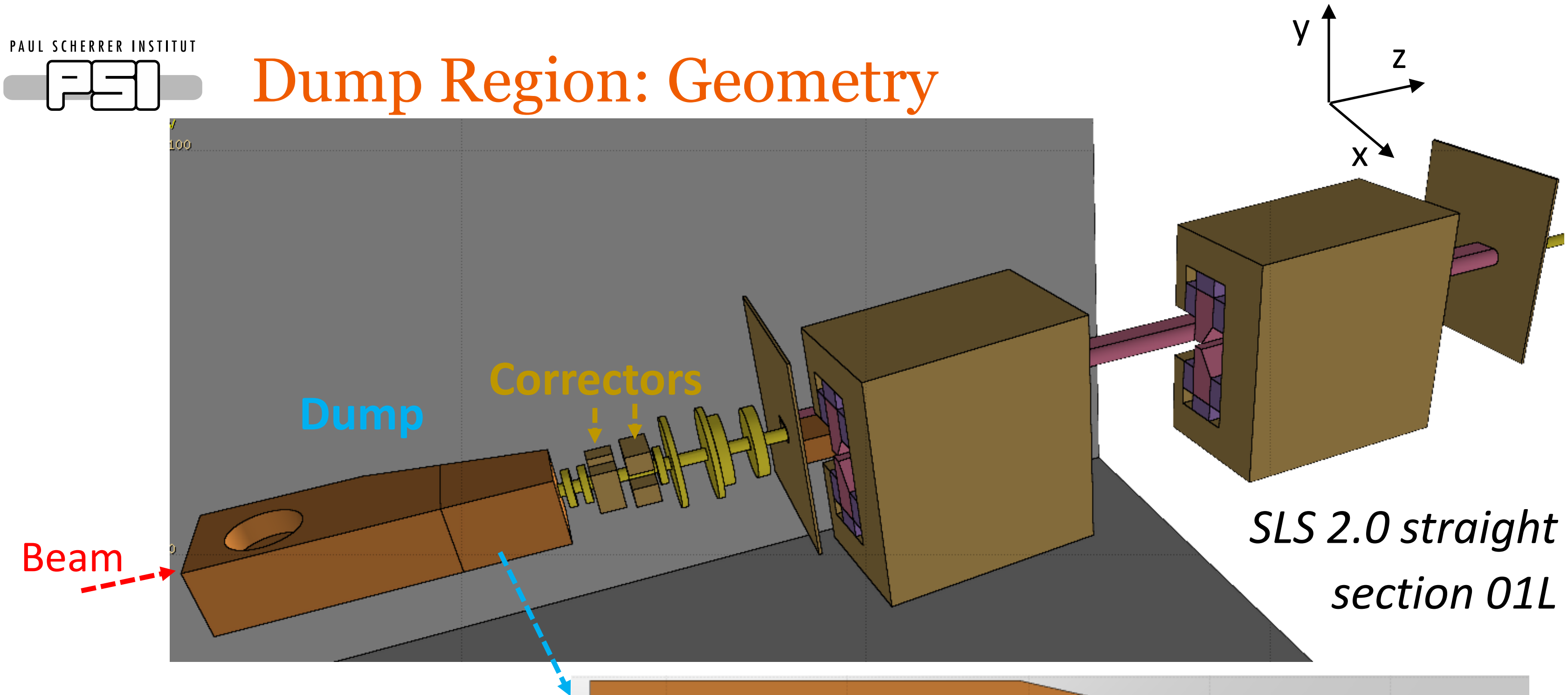
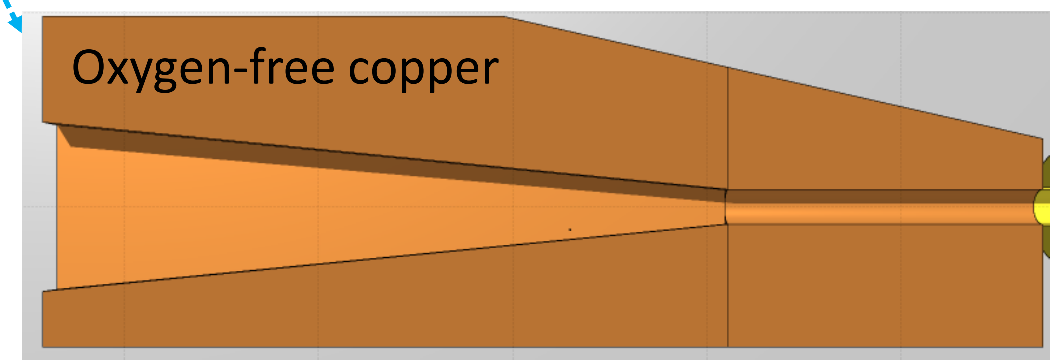
Simulations performed with FLUKA 4.3 Monte Carlo code

Dump Region: Geometry

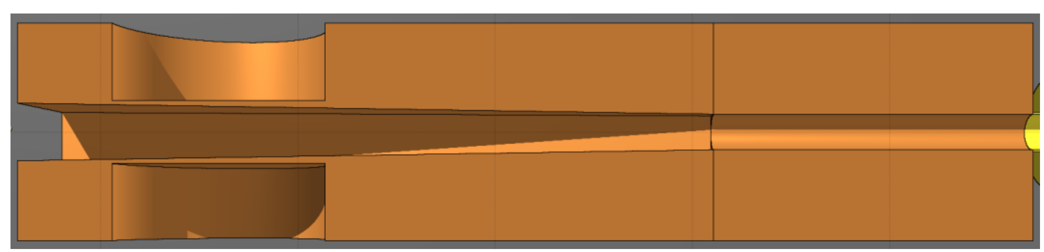


Dedicated dump located upstream of the thick septum assembly

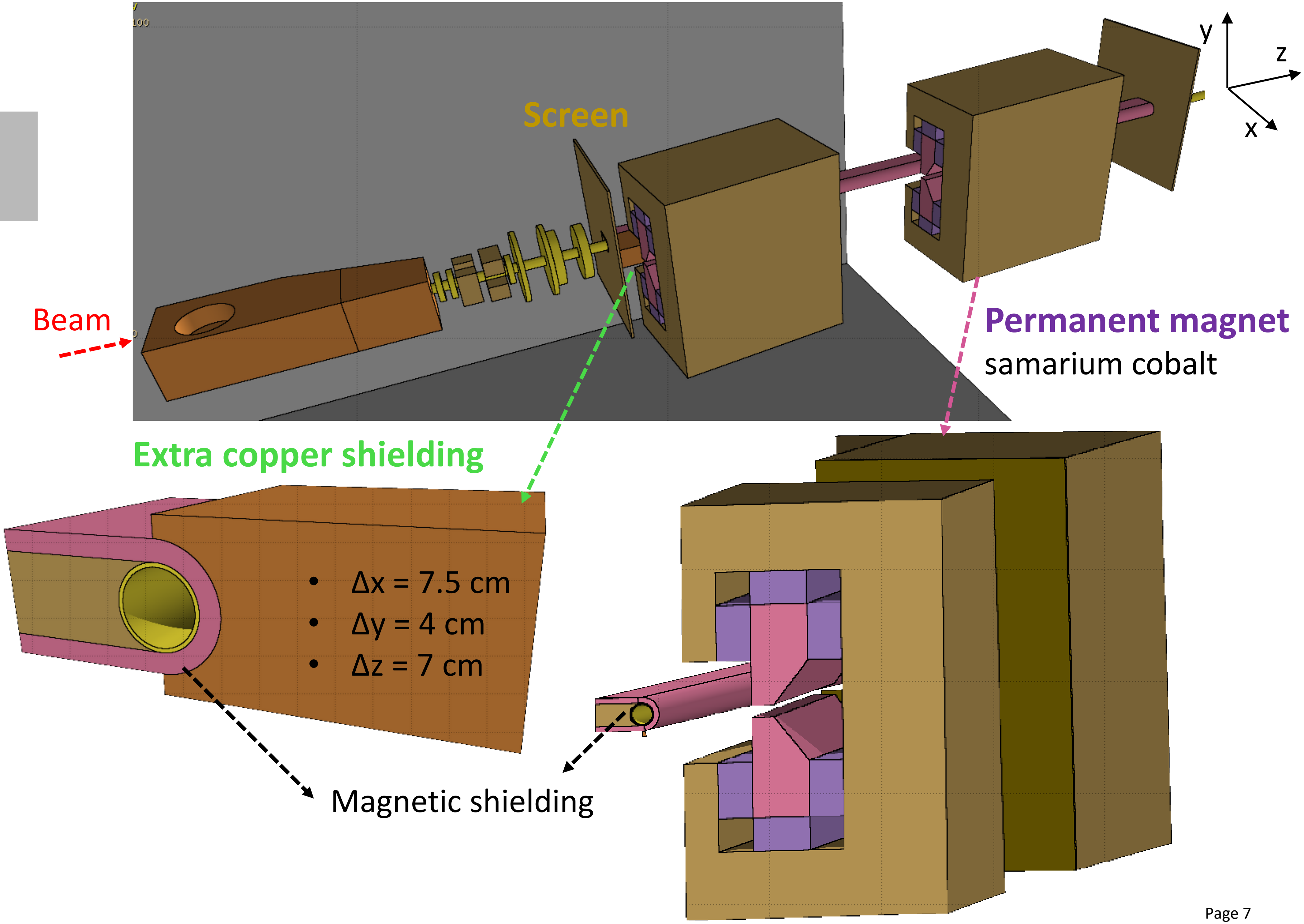


- Top view at beam height

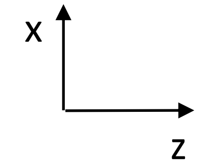
- Side view at beam position



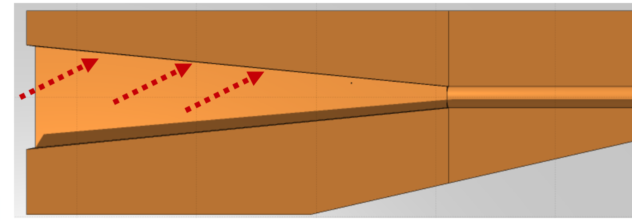
Geometry

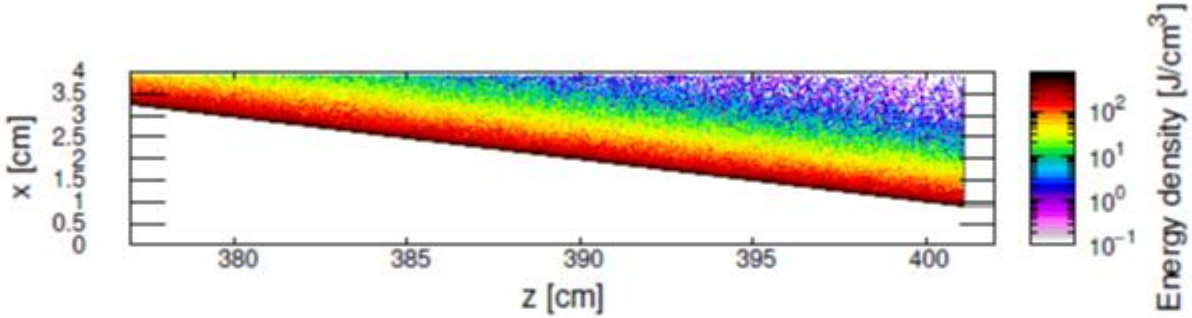

Screen
Beam
y
z
x
Permanent magnet
samarium cobalt
Extra copper shielding
• Δx = 7.5 cm
• Δy = 4 cm
• Δz = 7 cm
Magnetic shielding

Energy Density on the Dump



Normal operation: full beam (400 nC) swept uniformly on the beam dump aperture



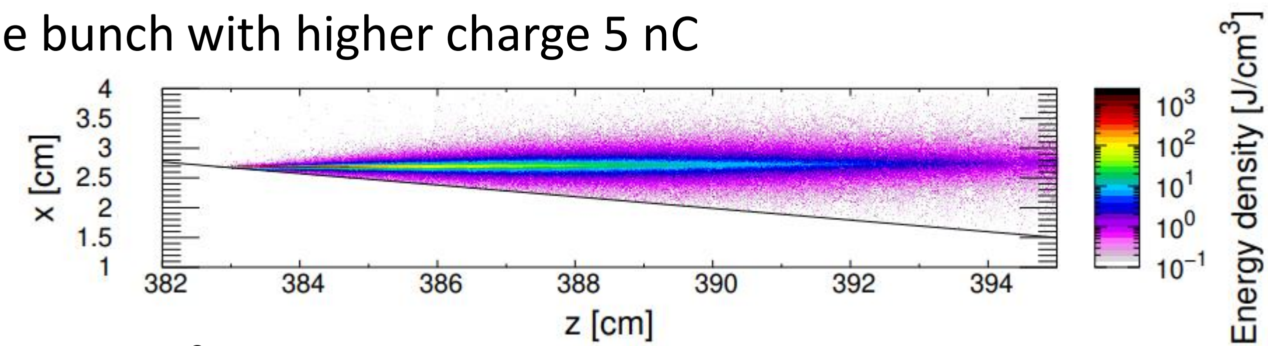


Maximum density on the surface < 1000 J cm^{-3}

- User routine “source_newgen.f” used
- Refined binning for scoring: 20 μm X 10 μm X 100 μm
- Single Coulomb scattering activated

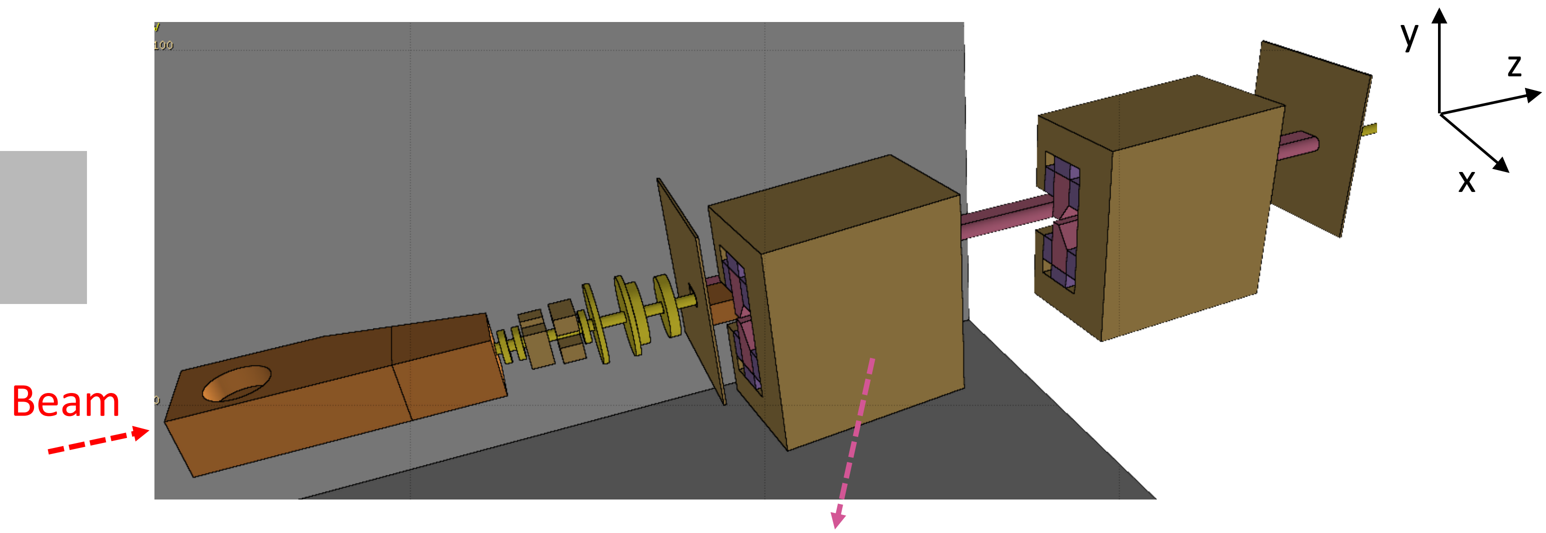
Worst case scenario: one bunch with higher charge 5 nC

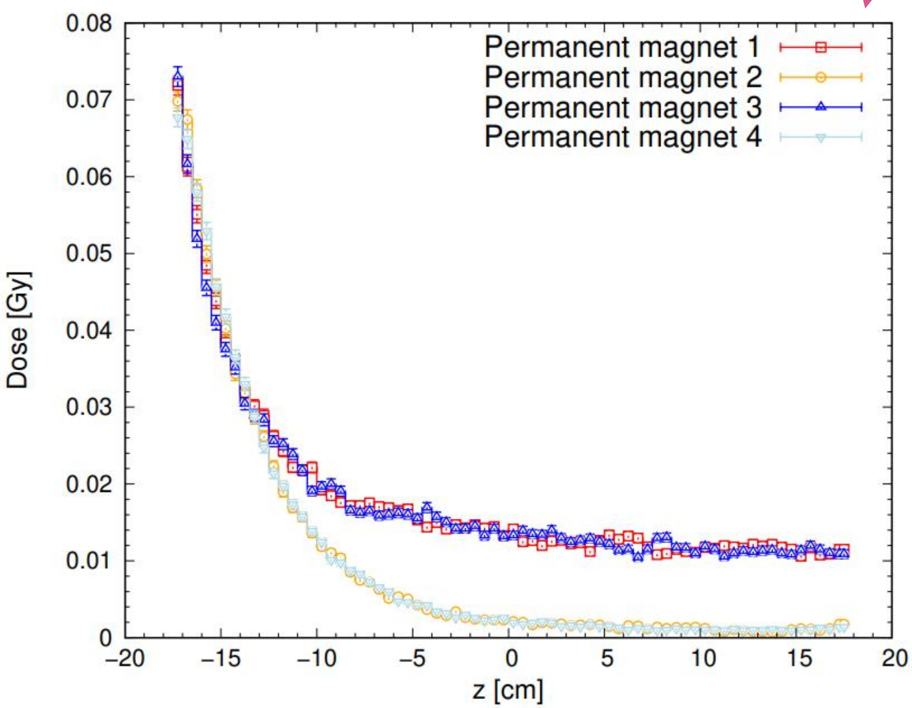
Beam size = σ_x = 35 μm and σ_y = 11 μm



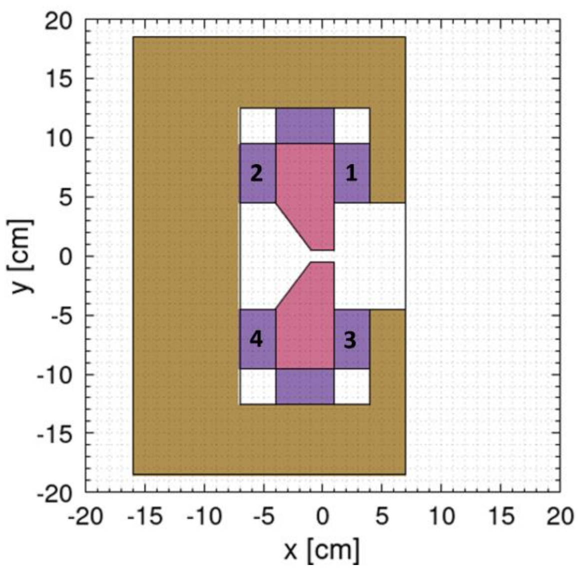
Peak energy density of 2500 J cm^{-3}
Limit = 3600 J cm^{-3}

Load on Permanent Magnets

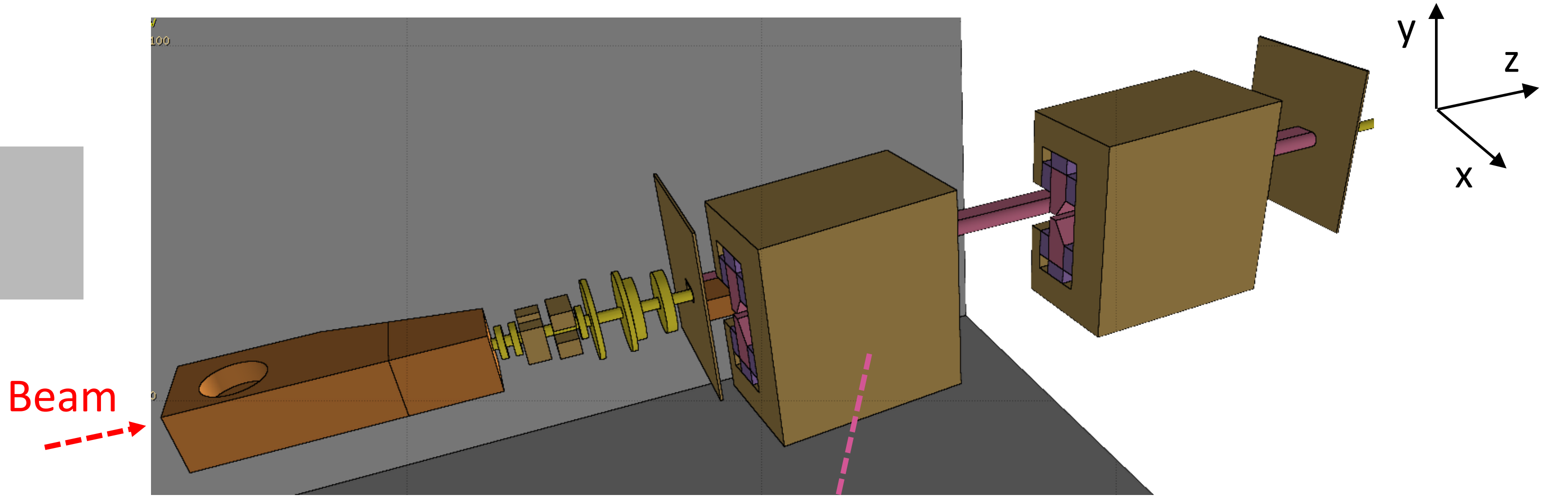


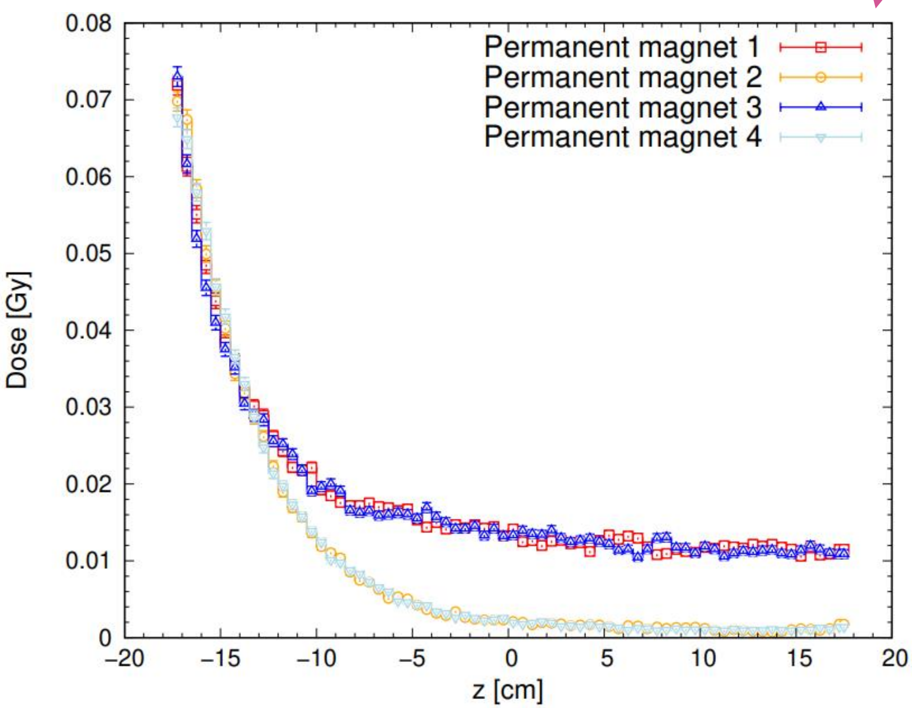


Average dose on the permanent magnets, per full beam dump (400 nC)



Load on Permanent Magnets





Average dose on the permanent magnets, per full beam dump (400 nC)

Acceptable dose values

- Number of interlock beam dumps per year ~210
- Demagnetization expected for accumulated doses above 70 MGy

Outline

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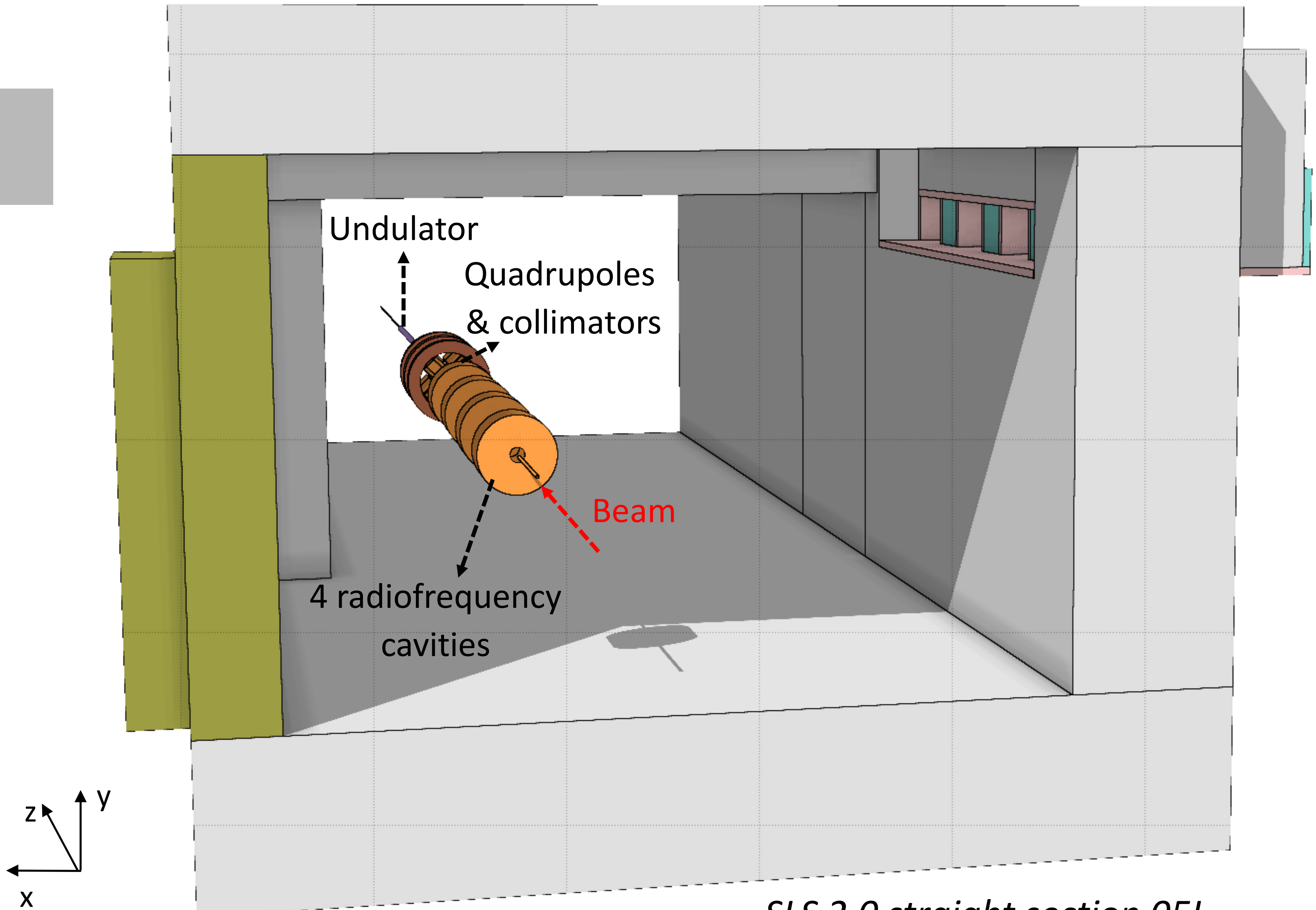
Simulations performed with FLUKA 4.3 Monte Carlo code

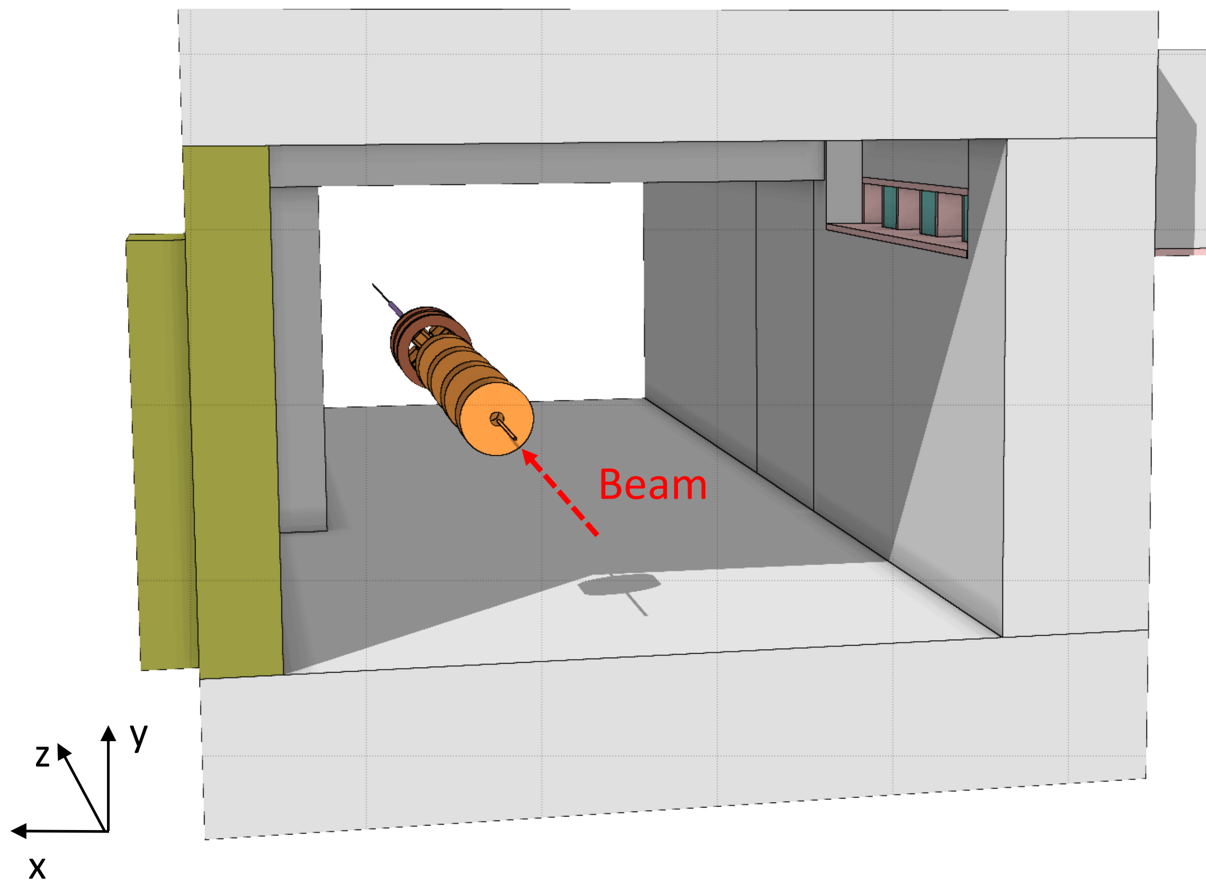
Collimation Region: Geometry



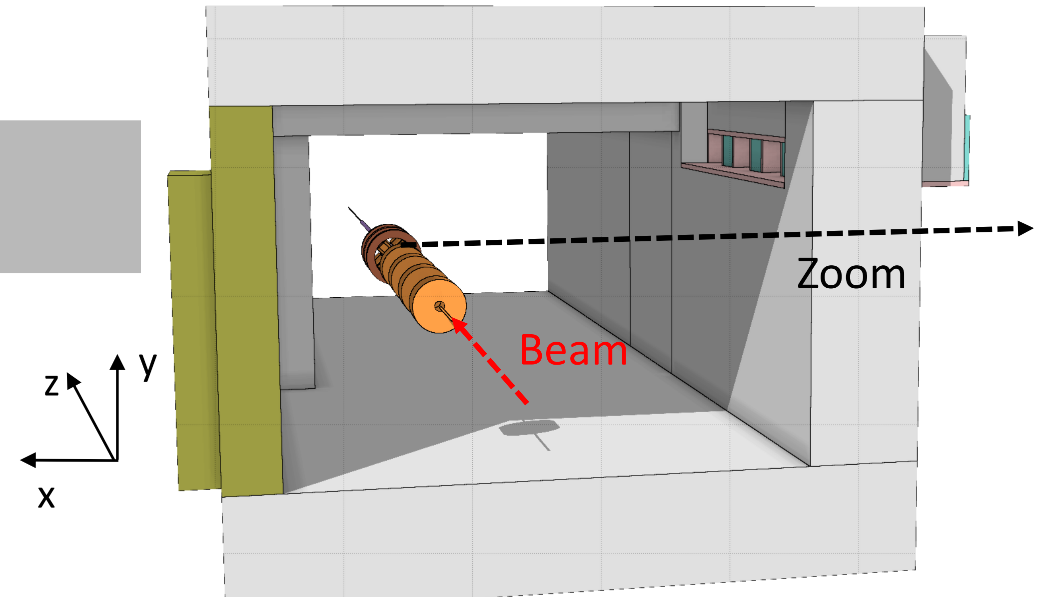
SLS 2.0 straight section 05L

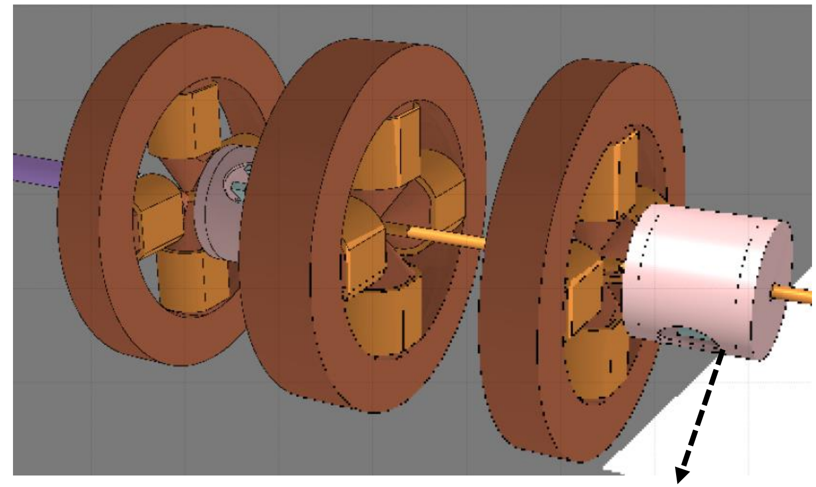
Losses at the collimation region

- Source terms considered:
  - Regular losses at the horizontal collimator
  - Regular losses at the vertical collimator
  - Dark current from RF cavities (not discussed in this talk)



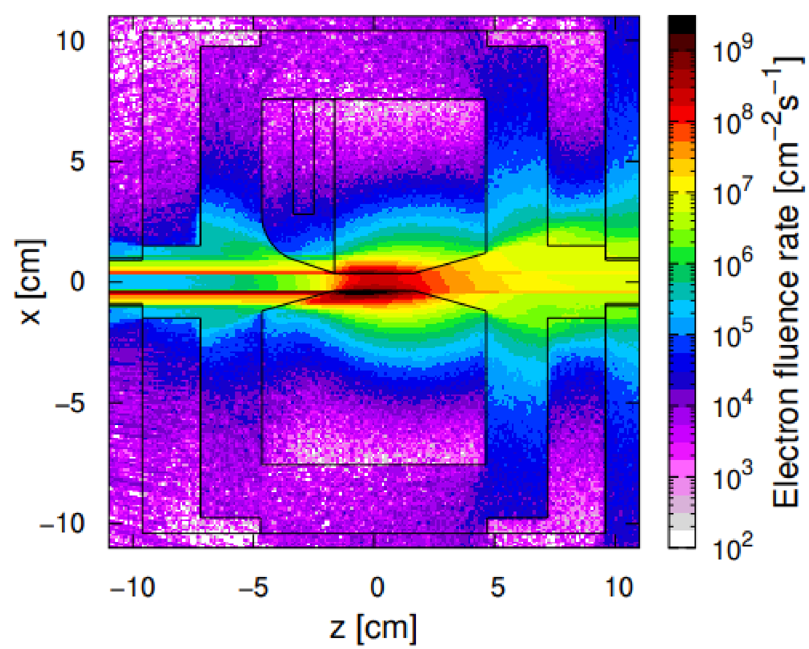
Losses at Horizontal Collimator

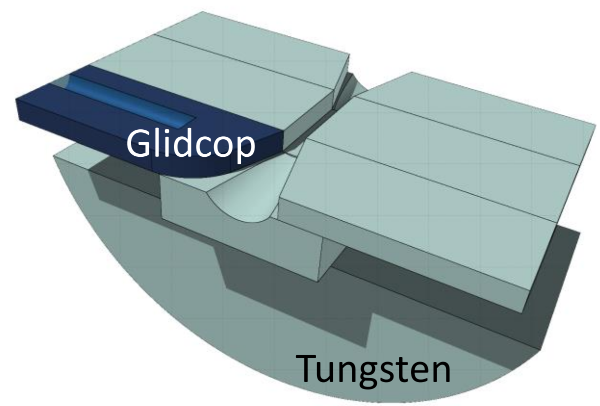




Inner part of the horizontal collimator:

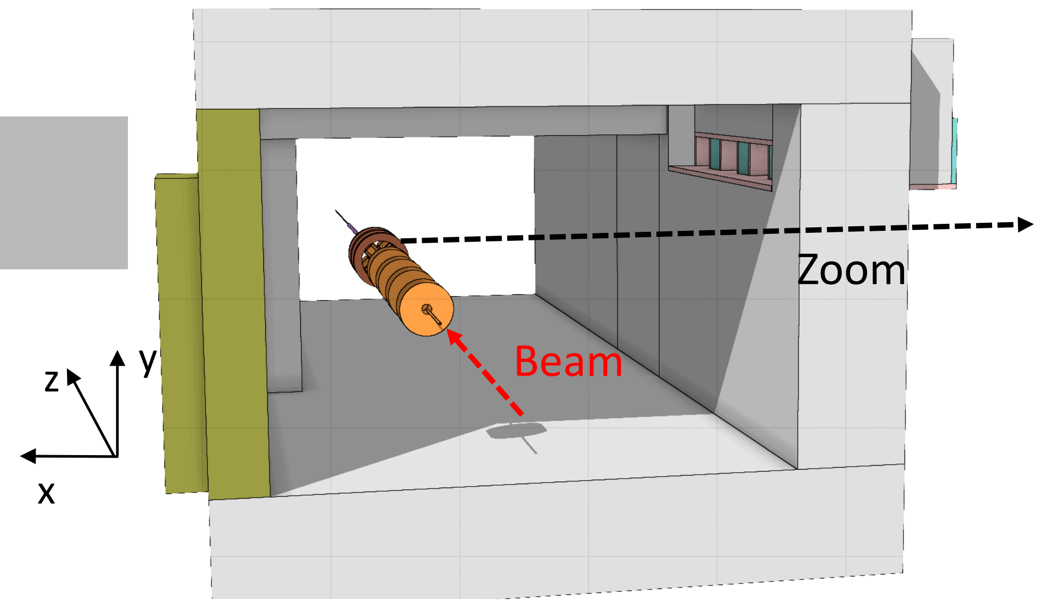
- Half gap = 0.361 cm

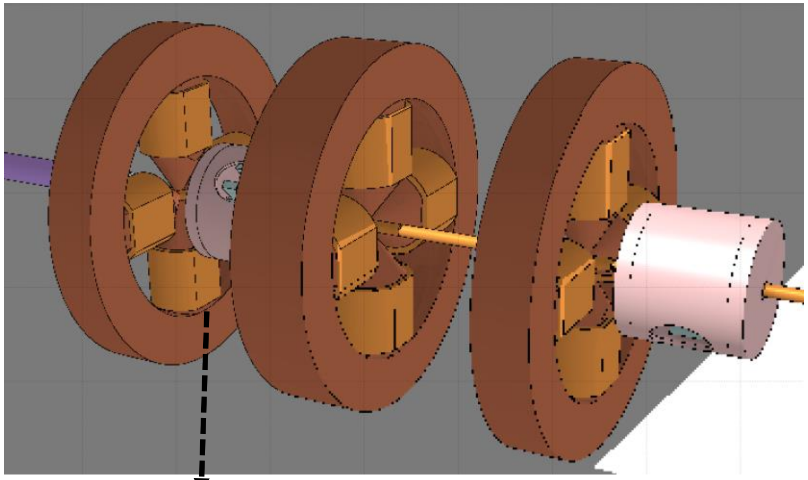




- Source term from tracking simulations (elegant), read in FLUKA through a user routine
- Lost charge rate = 7.5 nC/h

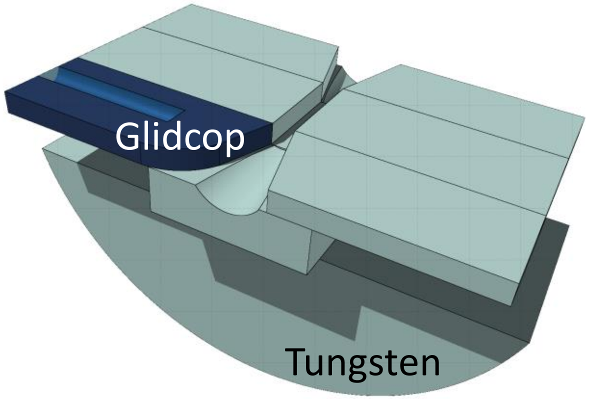
Losses at Vertical Collimator

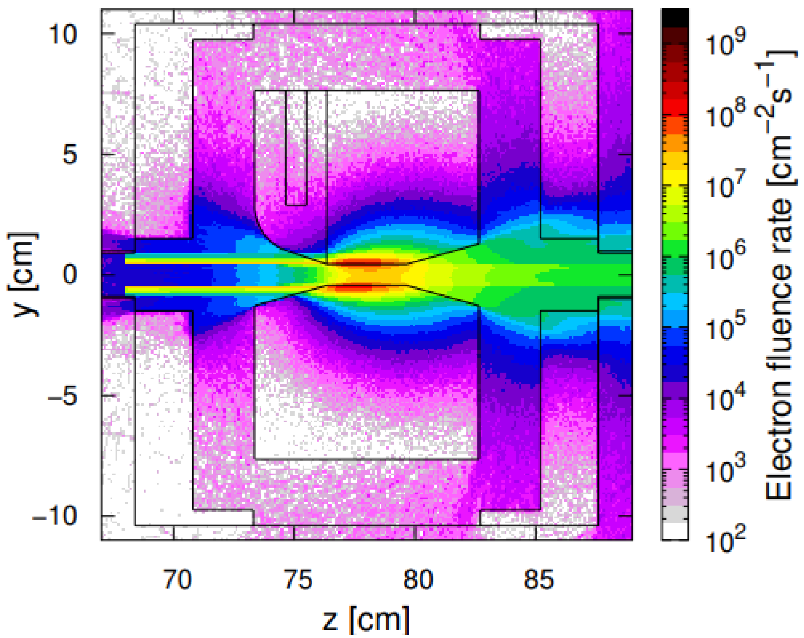




Vertical collimator rotated by 90 degrees:

- Half gap = 0.443 cm



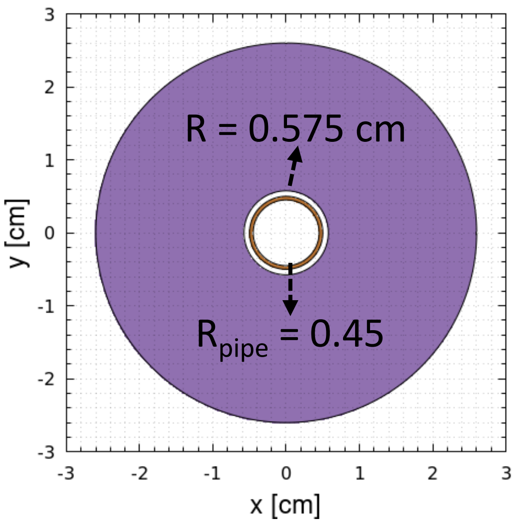


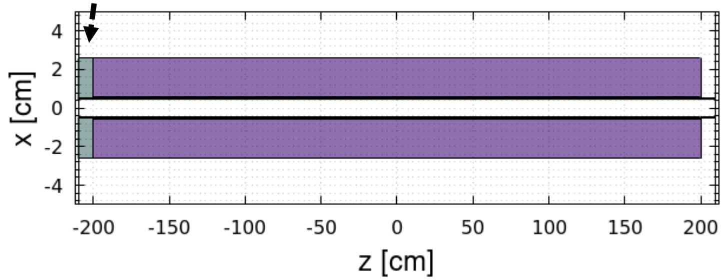
- Source term from tracking simulations (elegant), read in FLUKA through a user routine
- Lost charge rate = 1 nC/h

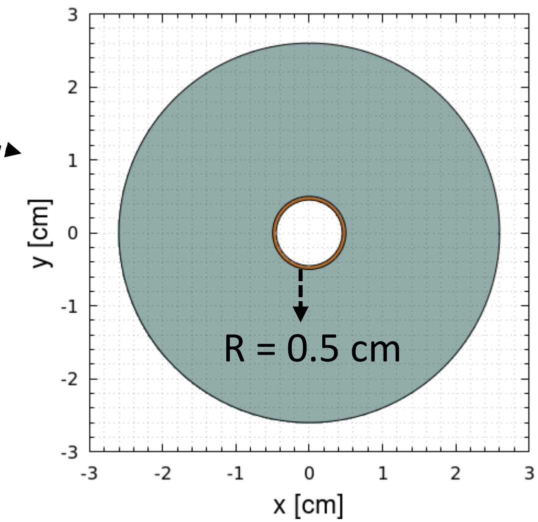
Load on the Undulator

Undulator is more exposed to radiation, because of its small aperture

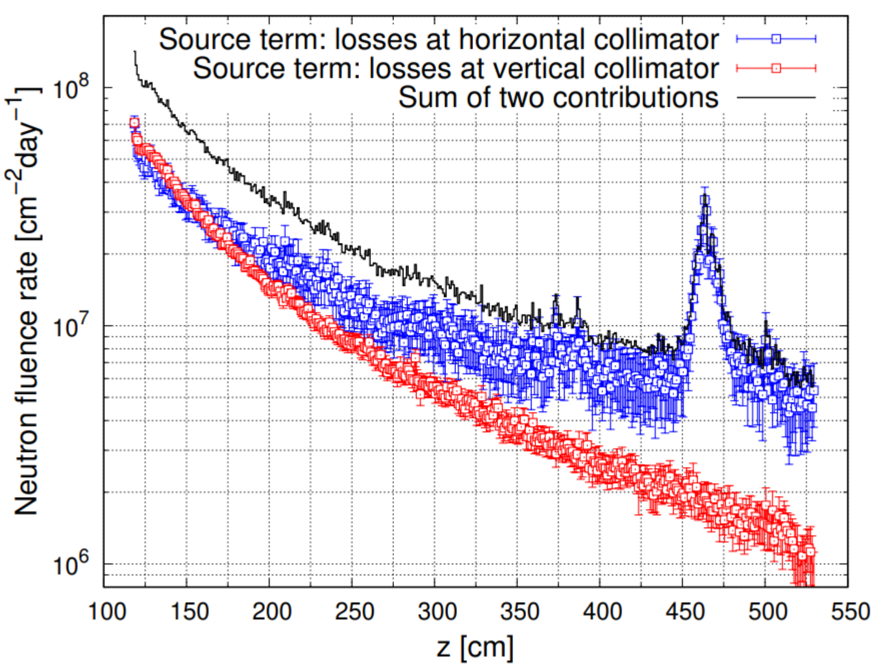
- ➢ Tungsten mask in front

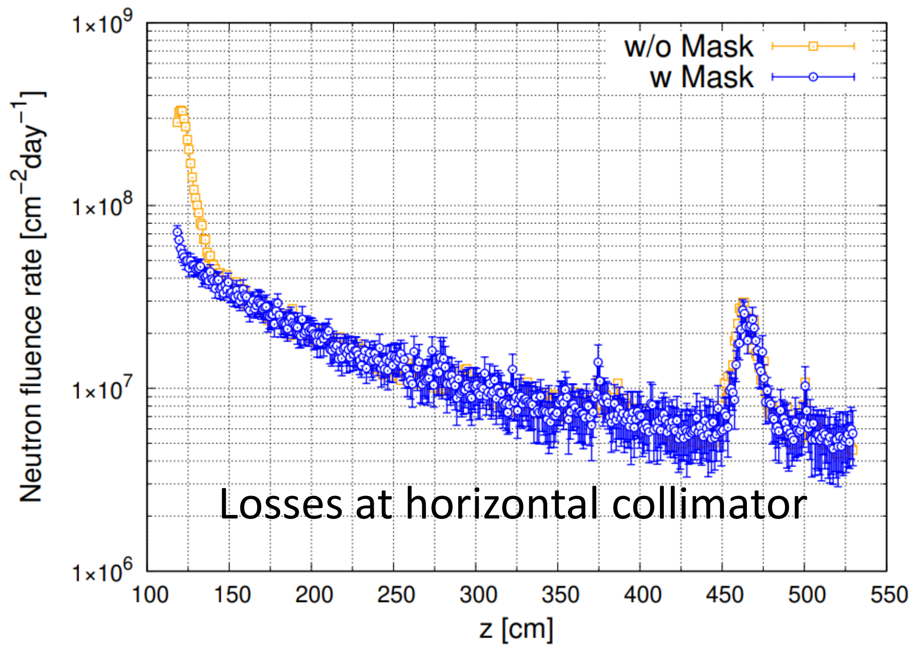




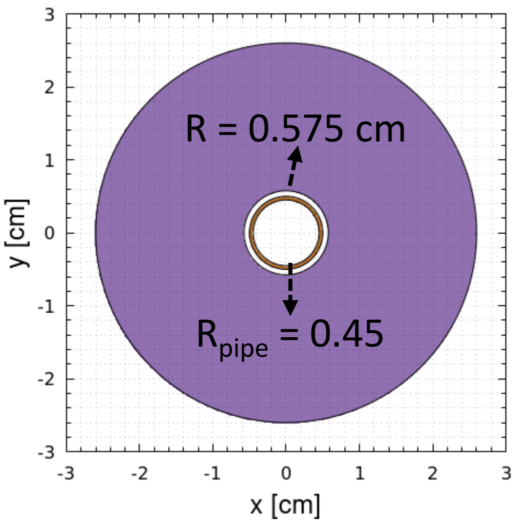


Ex. Neutron fluence rate



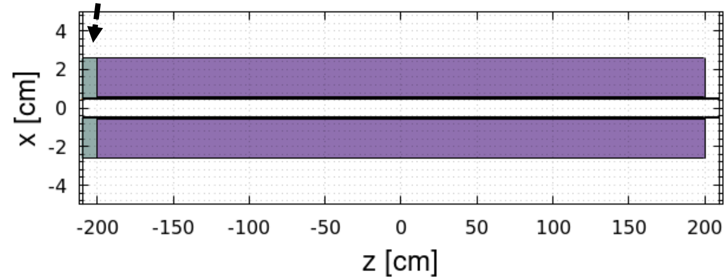


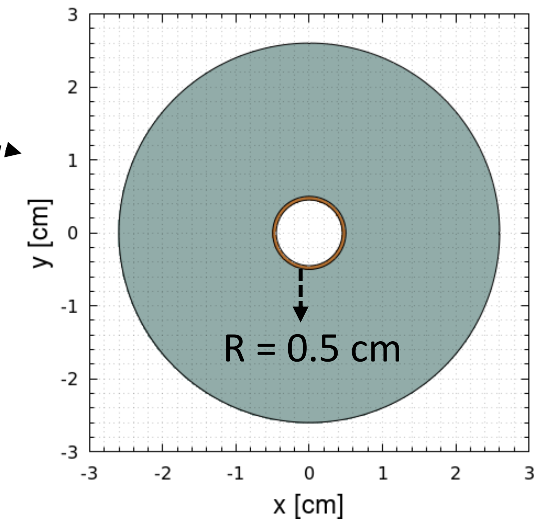
Load on the Undulator



Undulator is more exposed to radiation, because of its small aperture

- Tungsten mask in front





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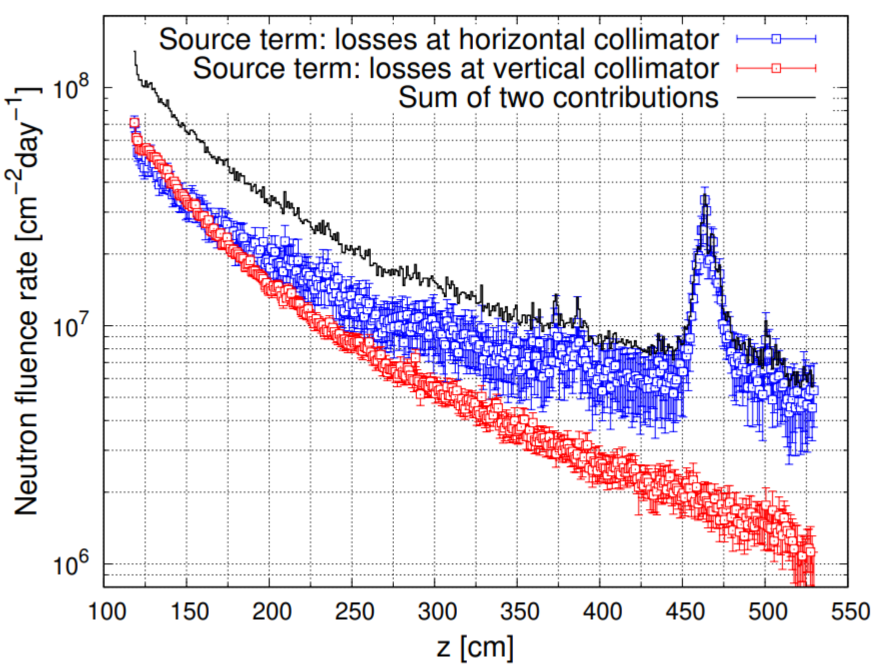
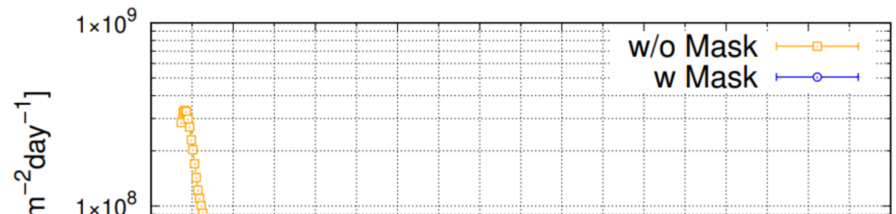




Maximum = 2 10^8 neutrons cm^{-2} day^{-1}

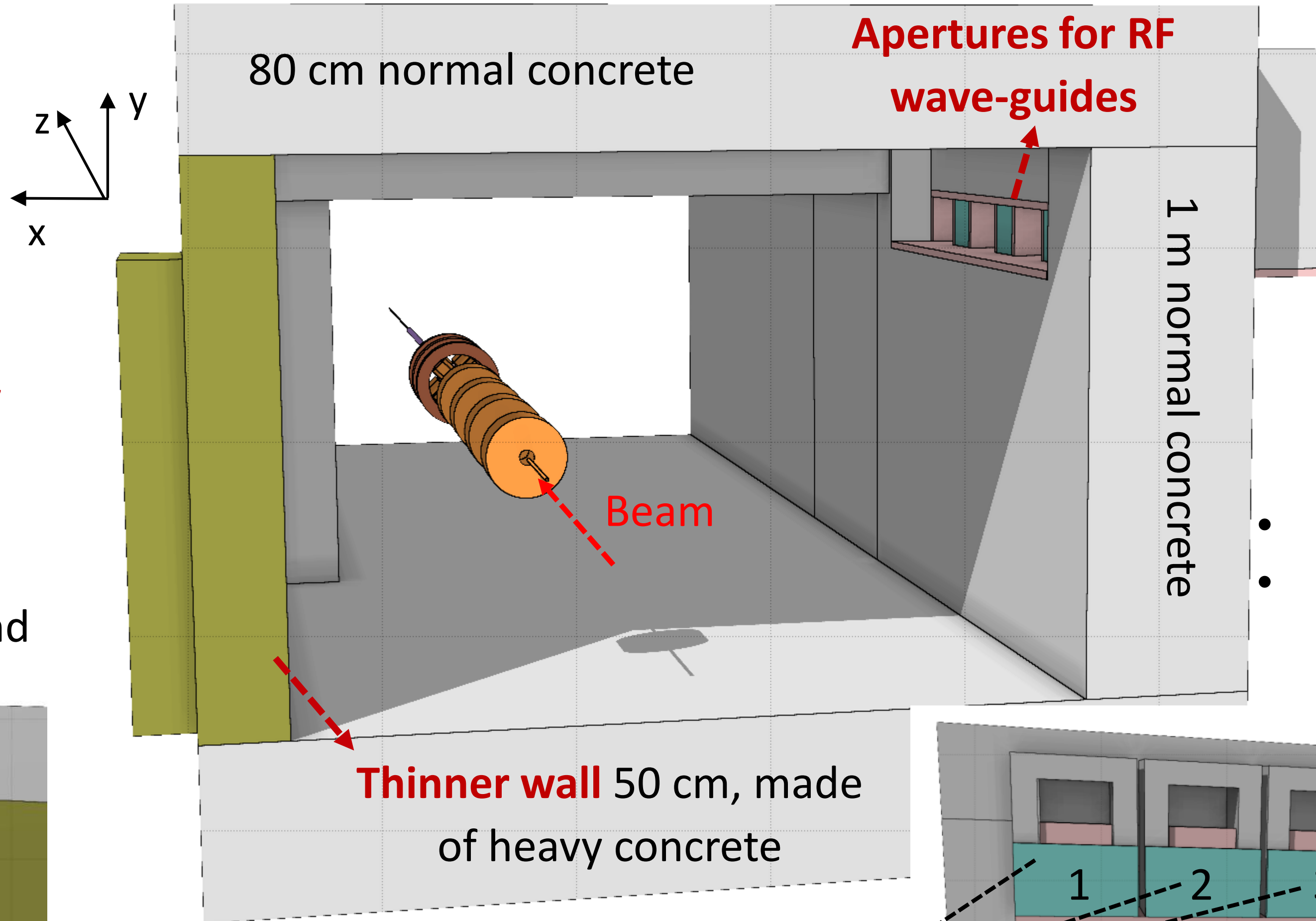
→ Not dangerous value

Demagnetization expected after an integrated neutron fluence

- of 10^{18} neutrons cm^{-2} for SmCo
- of 10^{12} neutrons cm^{-2} for NdFeB

Conservative values

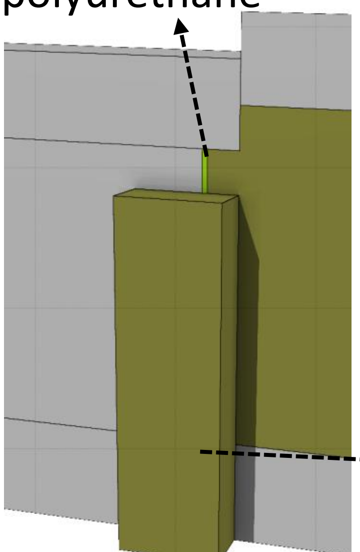
Shielding Critical Points



- 10 cm steel
- 10 cm polyethylene

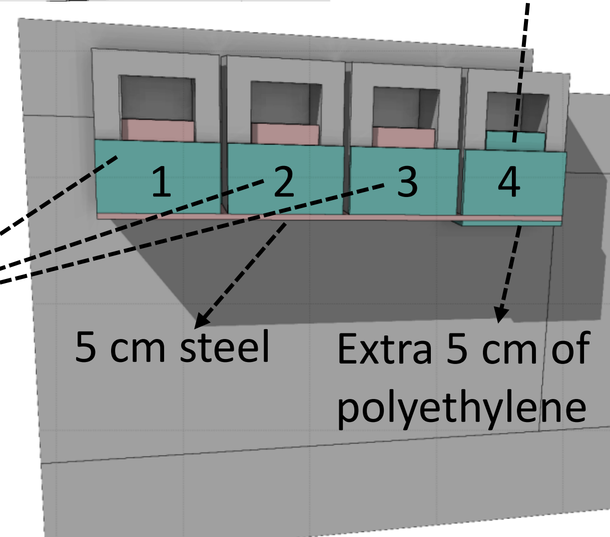
Thinner wall 50 cm, made of heavy concrete

Possible gaps between heavy and normal concrete
→modelled as layer of steel and polyurethane

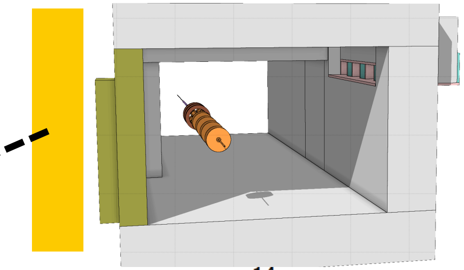


50 cm thick reinforcement pillar

- 5 cm steel
- 5 cm polyethylene

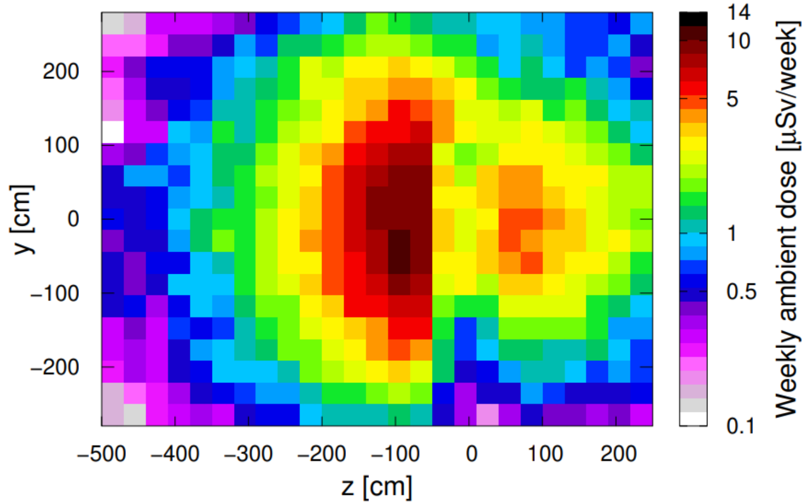


Dose Outside Outer Wall

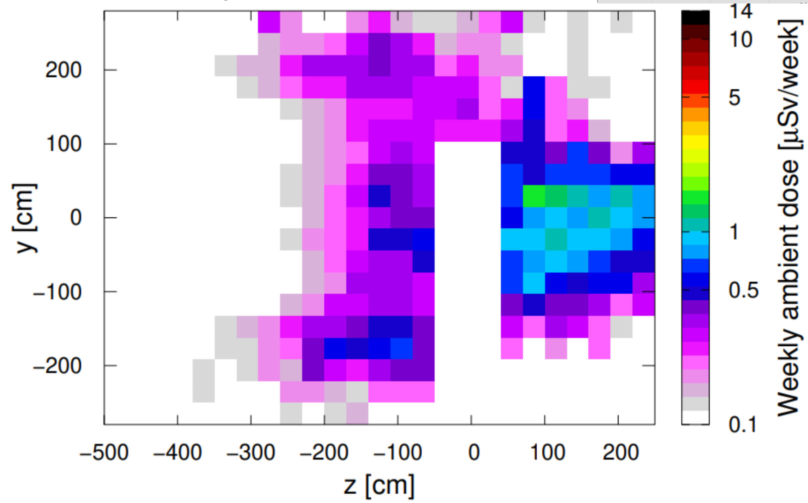


Losses @h-collimator:

neutrons

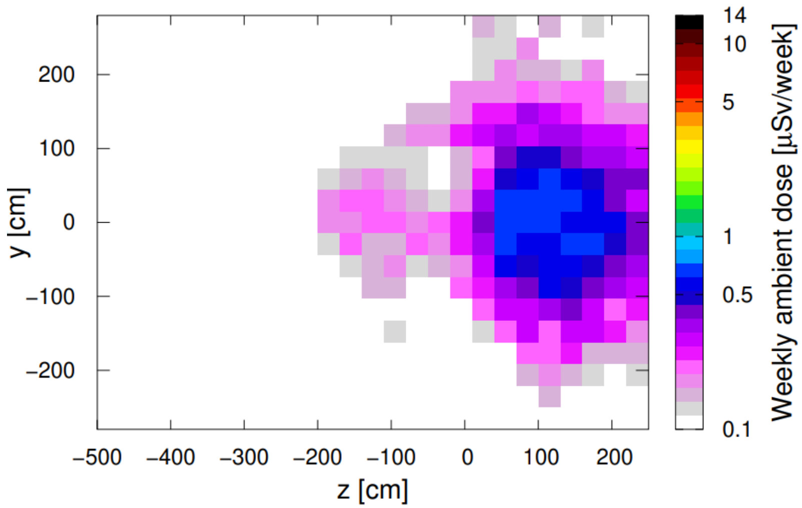


photons:

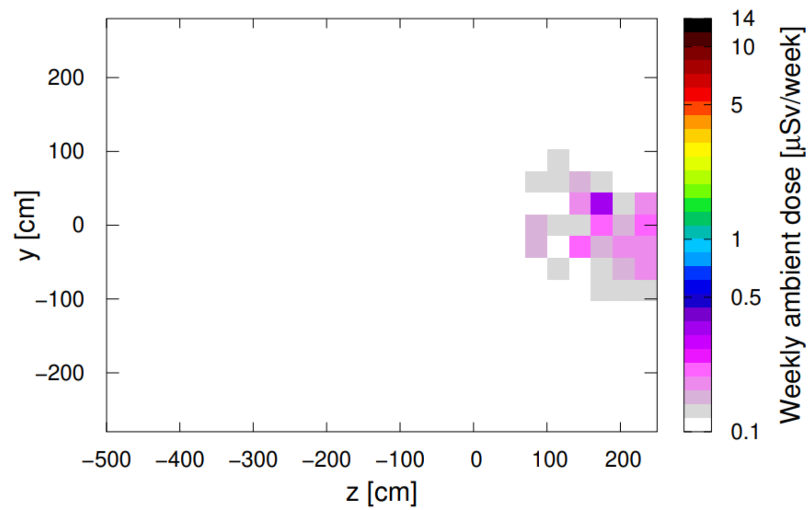


Losses @v-collimator:

neutrons



photons:



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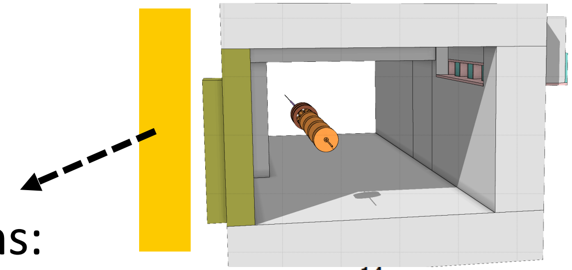
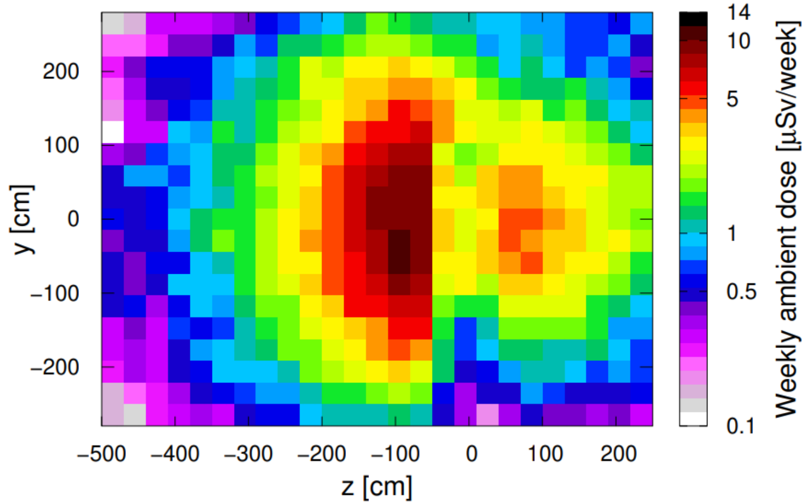
Dose Outside Outer Wall

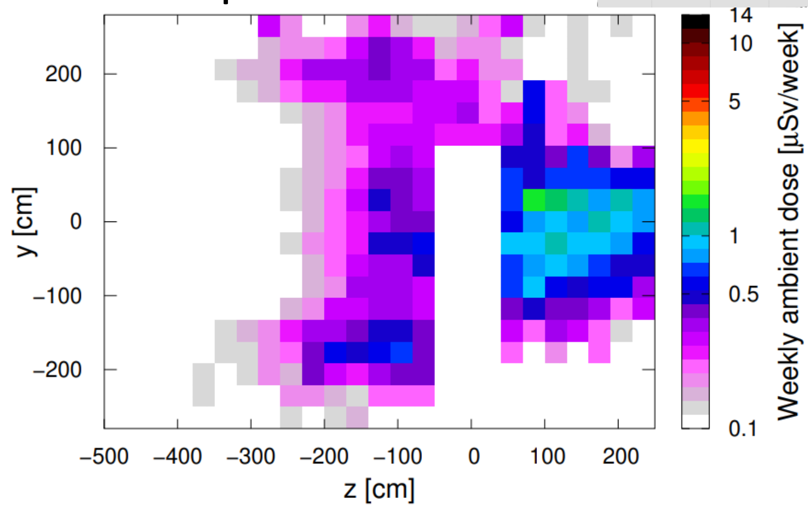


Losses @h-collimator:

neutrons

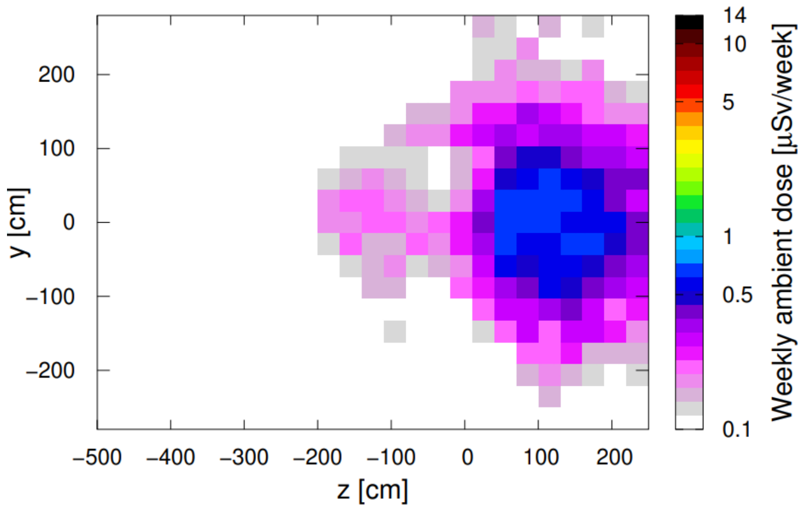


photons:

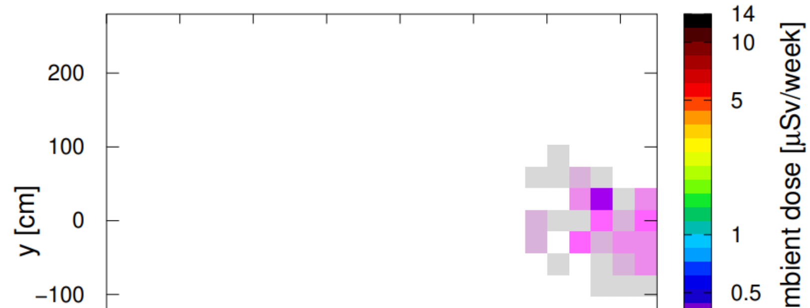


Losses @v-collimator:

neutrons



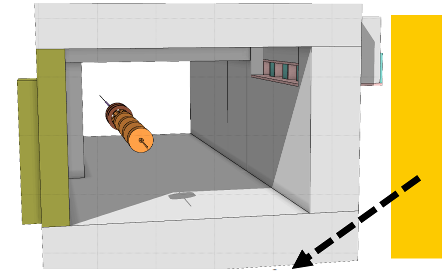
photons:



- Peak behind heavy concrete wall
- Below 14 μSv/week

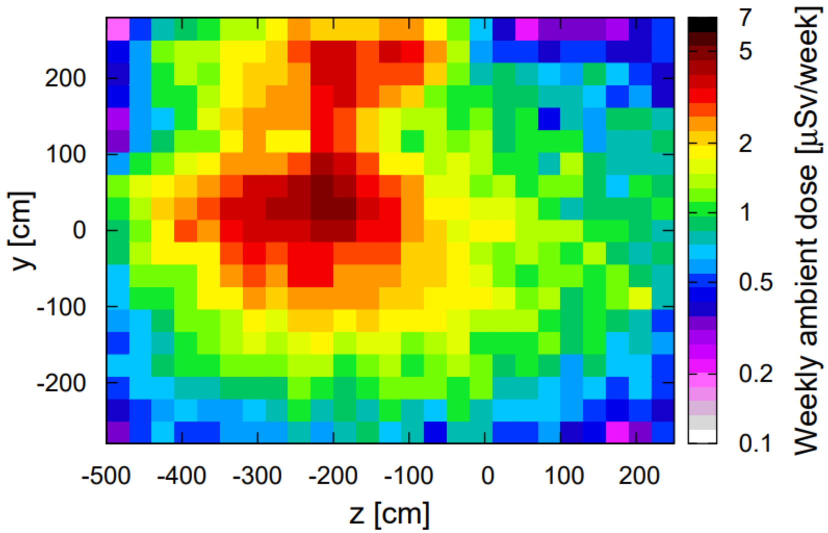
z [cm]

Dose Outside Inner Wall

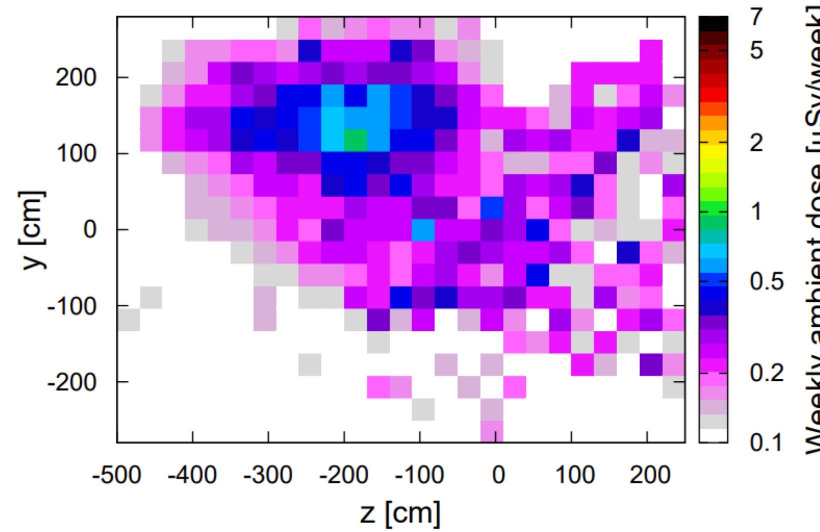


Losses @h-collimator:

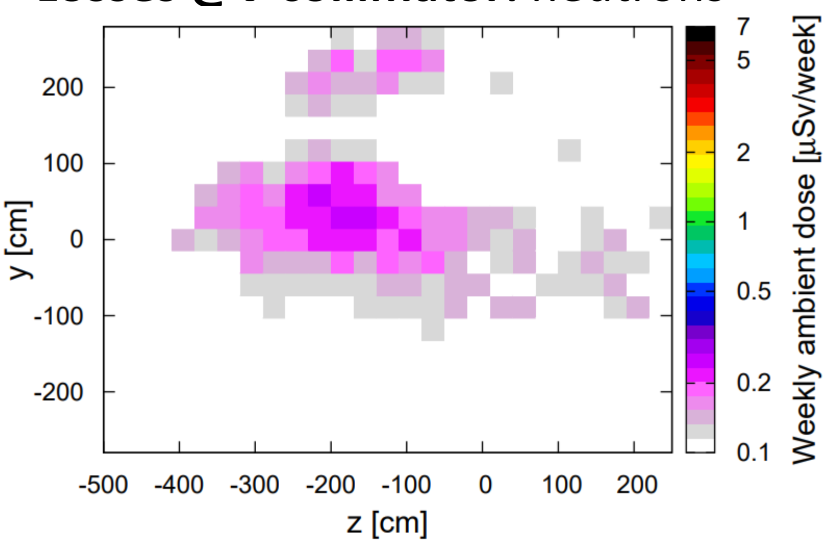
neutrons



photons:

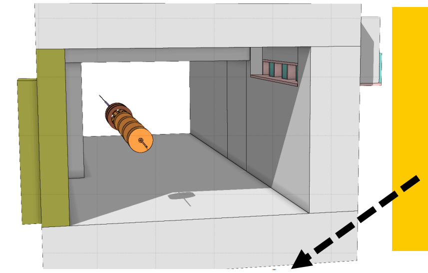


Losses @v-collimator: neutrons



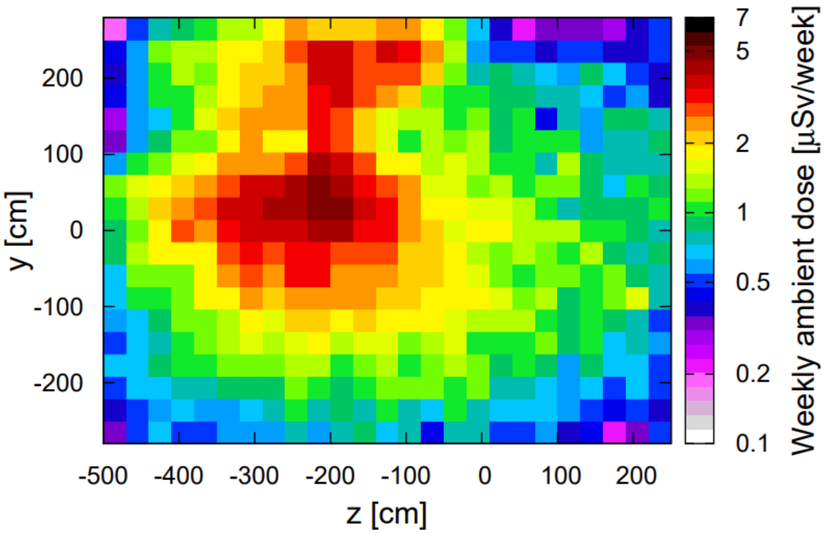
photons contribution negligible

Dose Outside Inner Wall

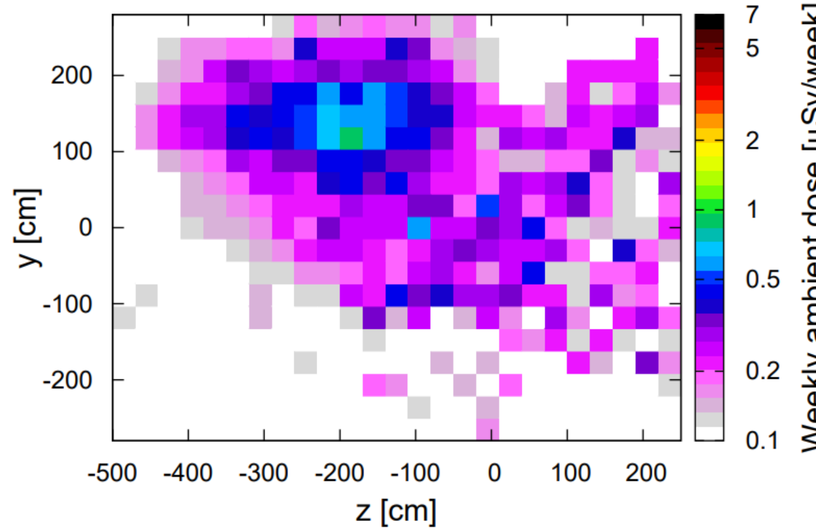


Losses @h-collimator:

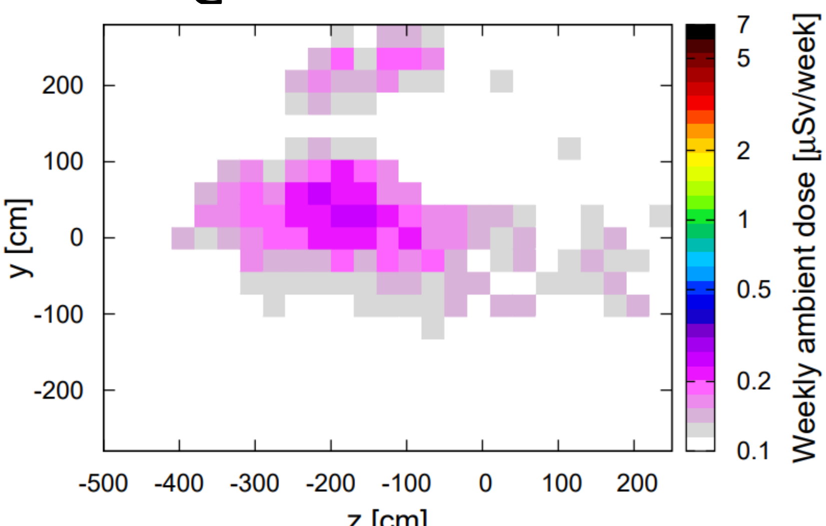
neutrons



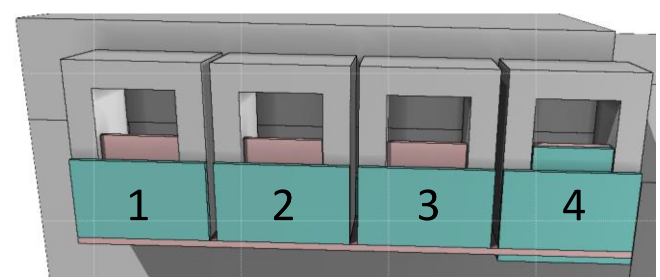
photons:



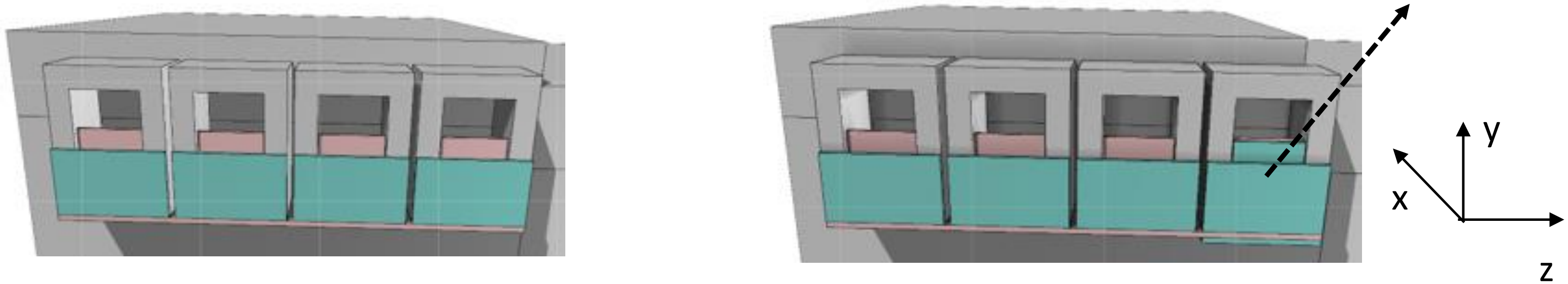
Losses @v-collimator: neutrons

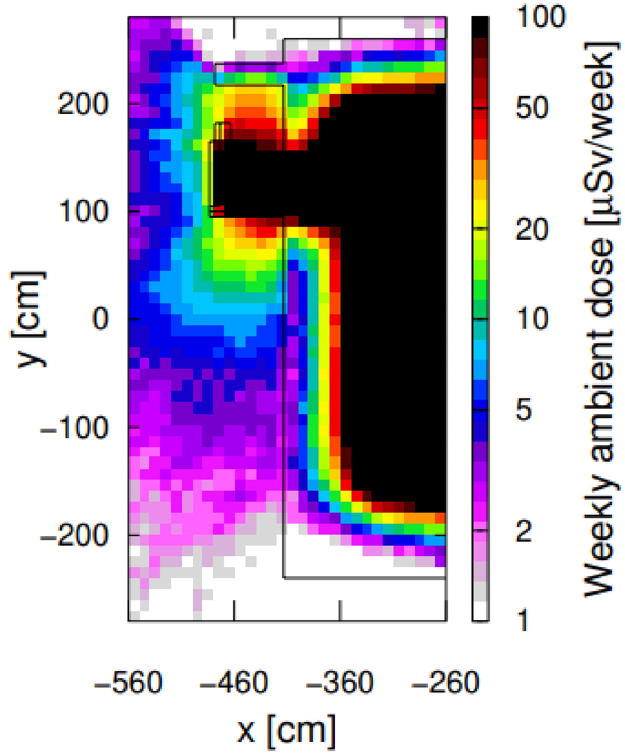


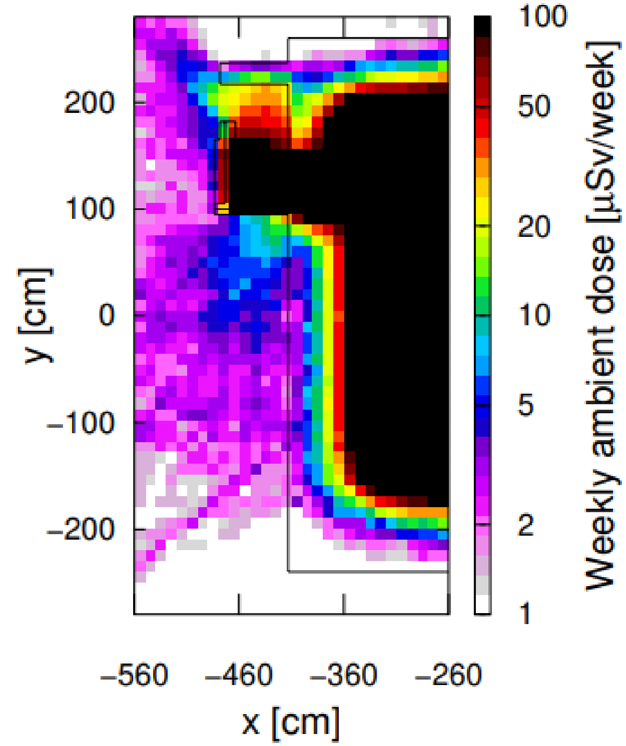
- Below 10 µSv/week
- Peak behind 3rd RF opening
  - the 4th opening has a shielding reinforcement



Why Shielding Reinforcement?







- Dose outside the bunker reduced by a factor of 5, thanks to reinforcement
- In the final design all apertures will have thicker shielding, as the 4th one

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  - Energy density on the dump
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- Losses at the collimation region
  - Load on undulator
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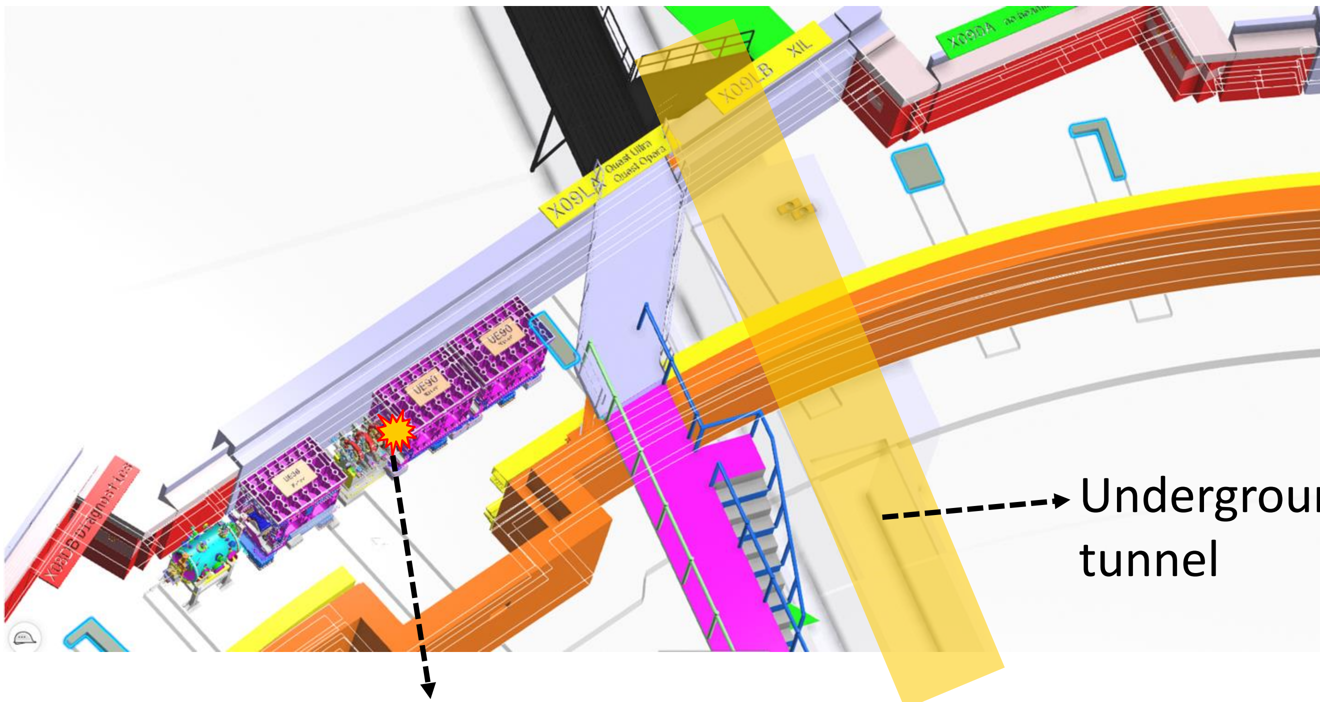
- Accidental loss scenario for a working gallery below the bunker

Simulations performed with FLUKA 4.3 Monte Carlo code

Working gallery below the bunker

Technical gallery below the SLS bunker about 10 m downstream the collimators in 09L



Underground tunnel

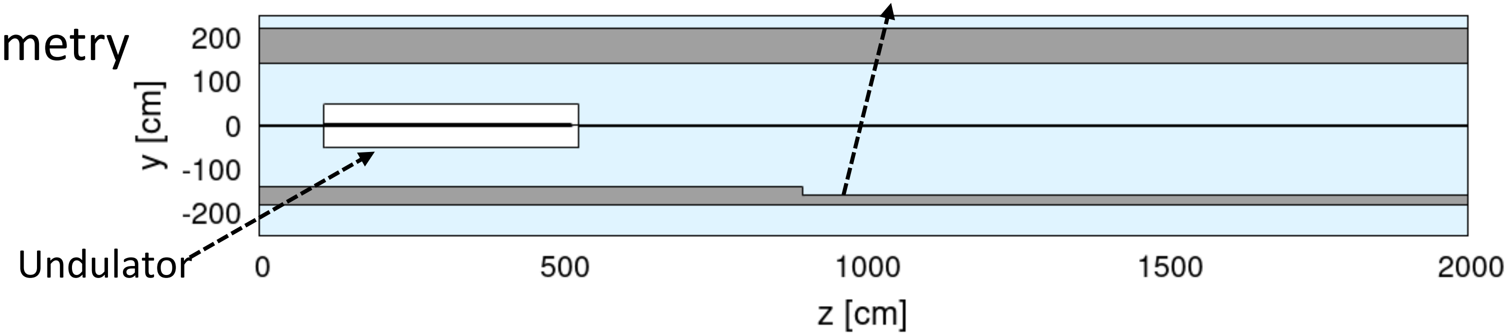
Worst case scenario = Accidental beam dump at the undulator (extremely unlikely but possible)

Two possible cases identified, through closed orbit bump calculations → Lost particles distribution read in FLUKA with user routines

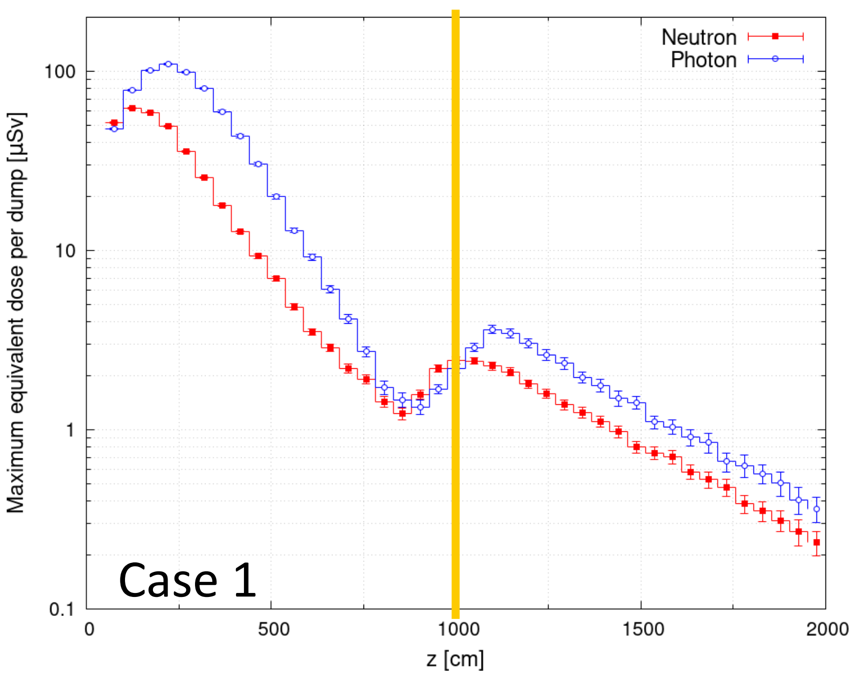
Dose Values

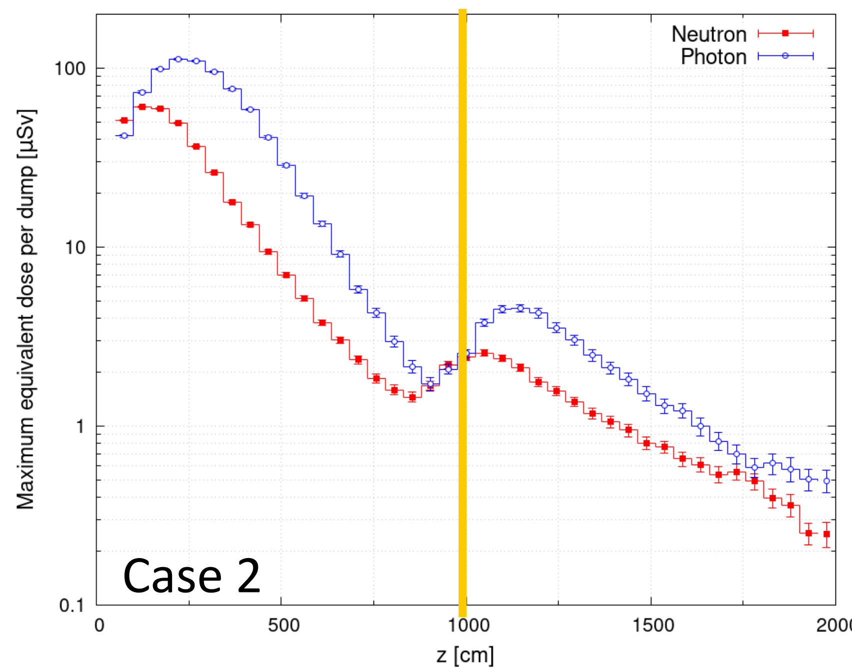
FLUKA geometry

Floor thickness reduced, because of floor channels for cables



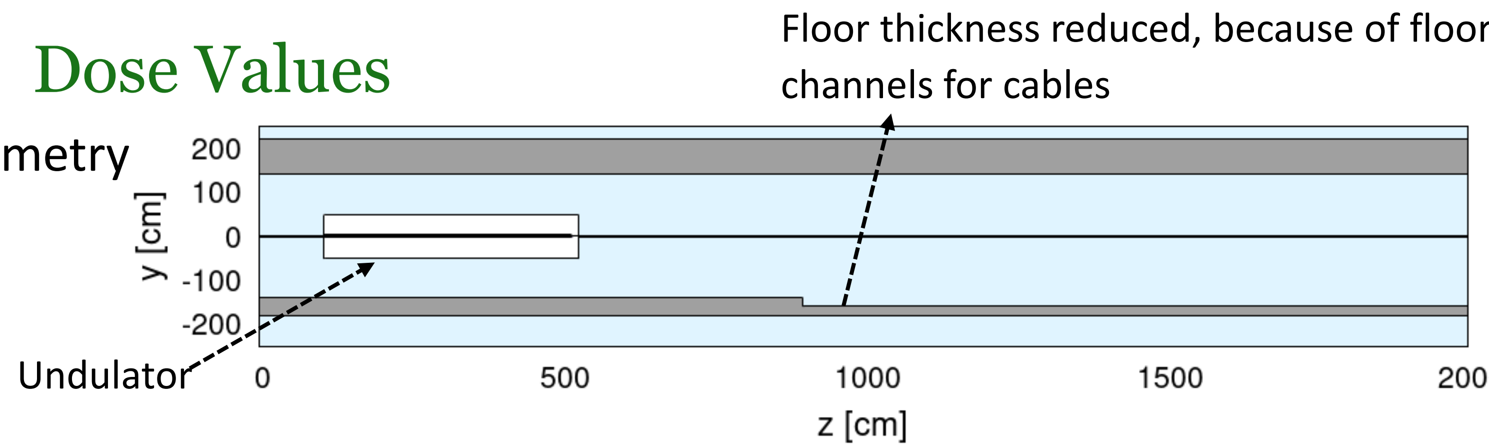
Peak dose profile as a function of z below the floor:



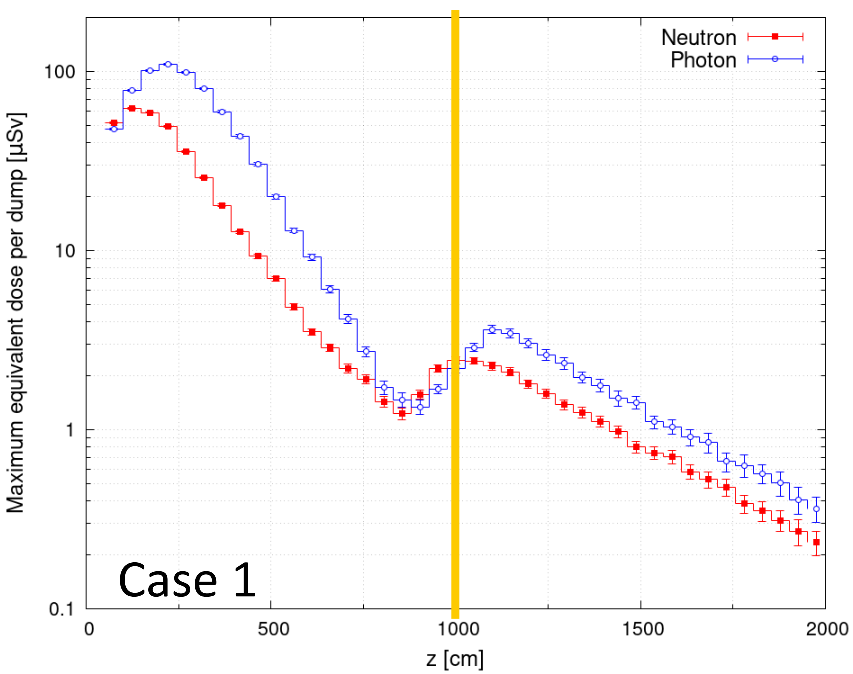


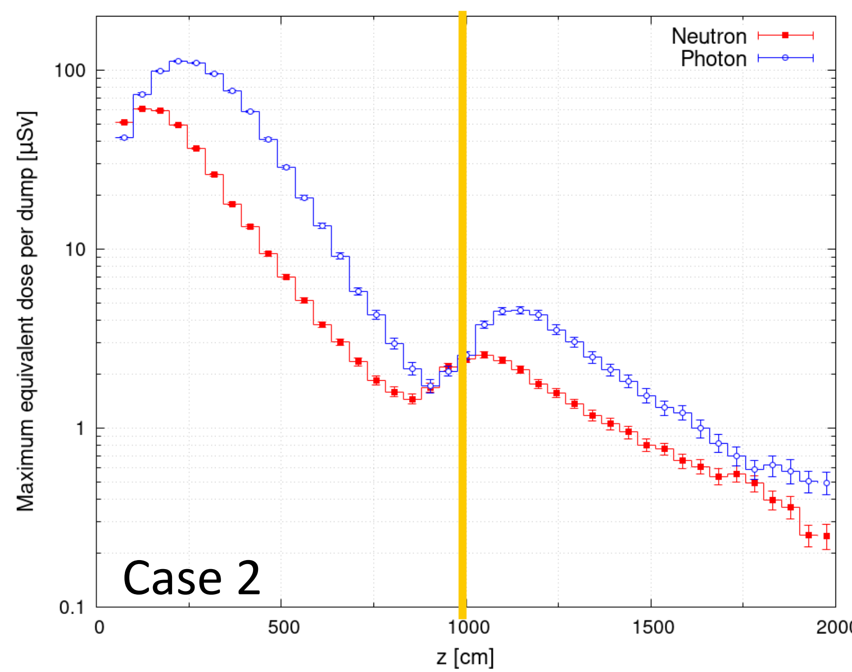
Dose Values

FLUKA geometry



Peak dose profile as a function of z below the floor:





Total dose around 5 µSv/event

Summary

- Changes in the SLS 2.0 storage ring pose challenges to the shielding design
- Studies performed with FLUKA Monte Carlo to assess:
  - the load on critical accelerator components
  - dose maps outside the SLS bunker
- Settings optimization for the different simulations
- A variety of source terms has been considered
  - input from tracking simulations
  - use of user routines
- Worst case scenarios identified
- Strategies conceived to mitigate the radiation
- Estimated values look acceptable
- The upgrade from SLS to SLS 2.0 is currently ongoing → goal for nominal beam 01/05/2025

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Thanks for your attention!

My thanks go to

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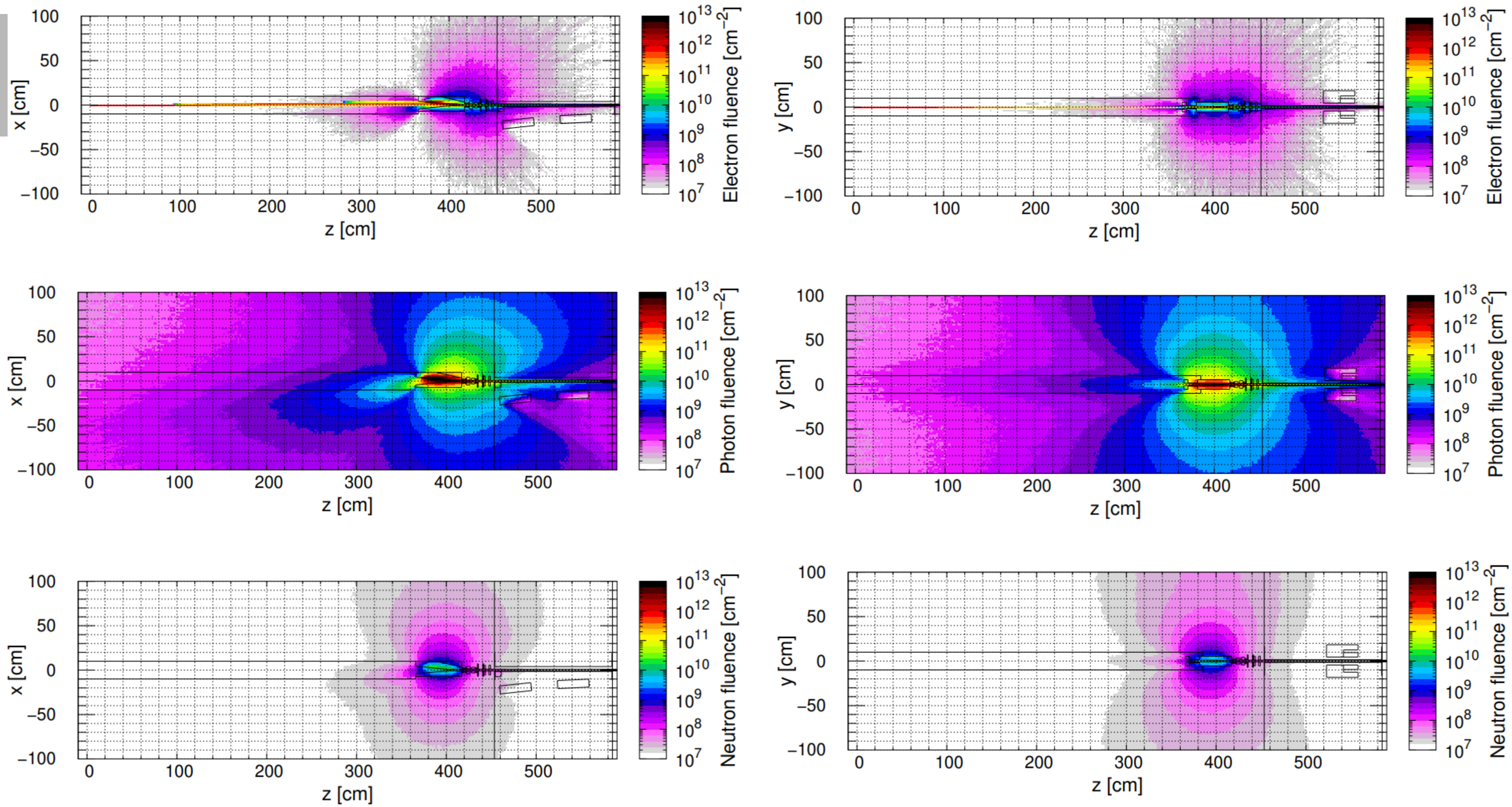
CERN-SY/STI

Beam Dump: Particle Fluence

Particle fluence maps



Dose outside the SLS Bunker

Dominated by neutrons