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Radiation Shielding Analysis for New 4th Generation Storage Ring (4GSR) Tunnel in Korea

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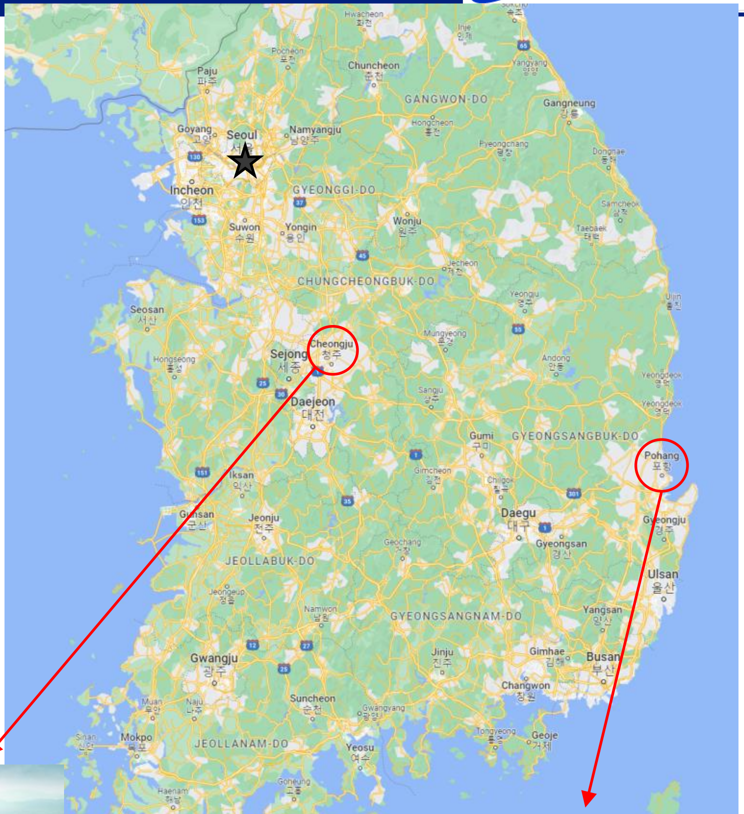
4GSR project in Korea

❑ History

- 2019. 10 : Start a Conceptual Design of 4GSR by PAL/KBSI*/KAERI** collaboration
- 2020. 5 : Determine a construction site as ‘Cheongju’
- 2020. 6 : Publish a Conceptual Design Report (CDR)[1]
- 2021. 7 : Determine an institution to conduct the construction project as KBSI
- 2021. 7 (~ 2027. 6) : Start a construction project, ‘Multipurpose Synchrotron Radiation Construction Project’
- 2029.11 : Finishing project construction
- 2030.1 : Operation of synchrotron radiation accelerator (might be changed)

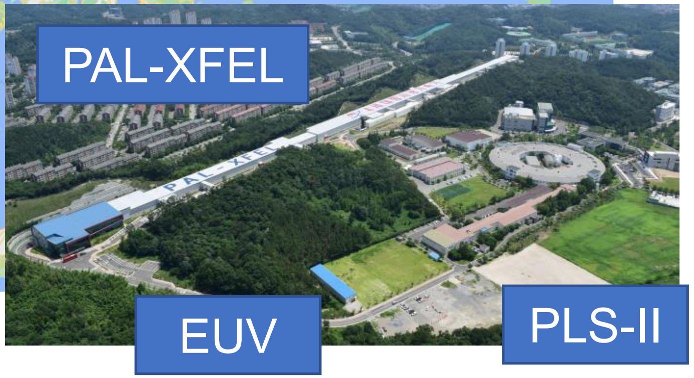


- Counterpart in the construction project

KBSI : Project Instruction → Building & Infrastructure

PAL : Accelerator & Beamline

(+ Radiation Shielding, Radiation Protection System)



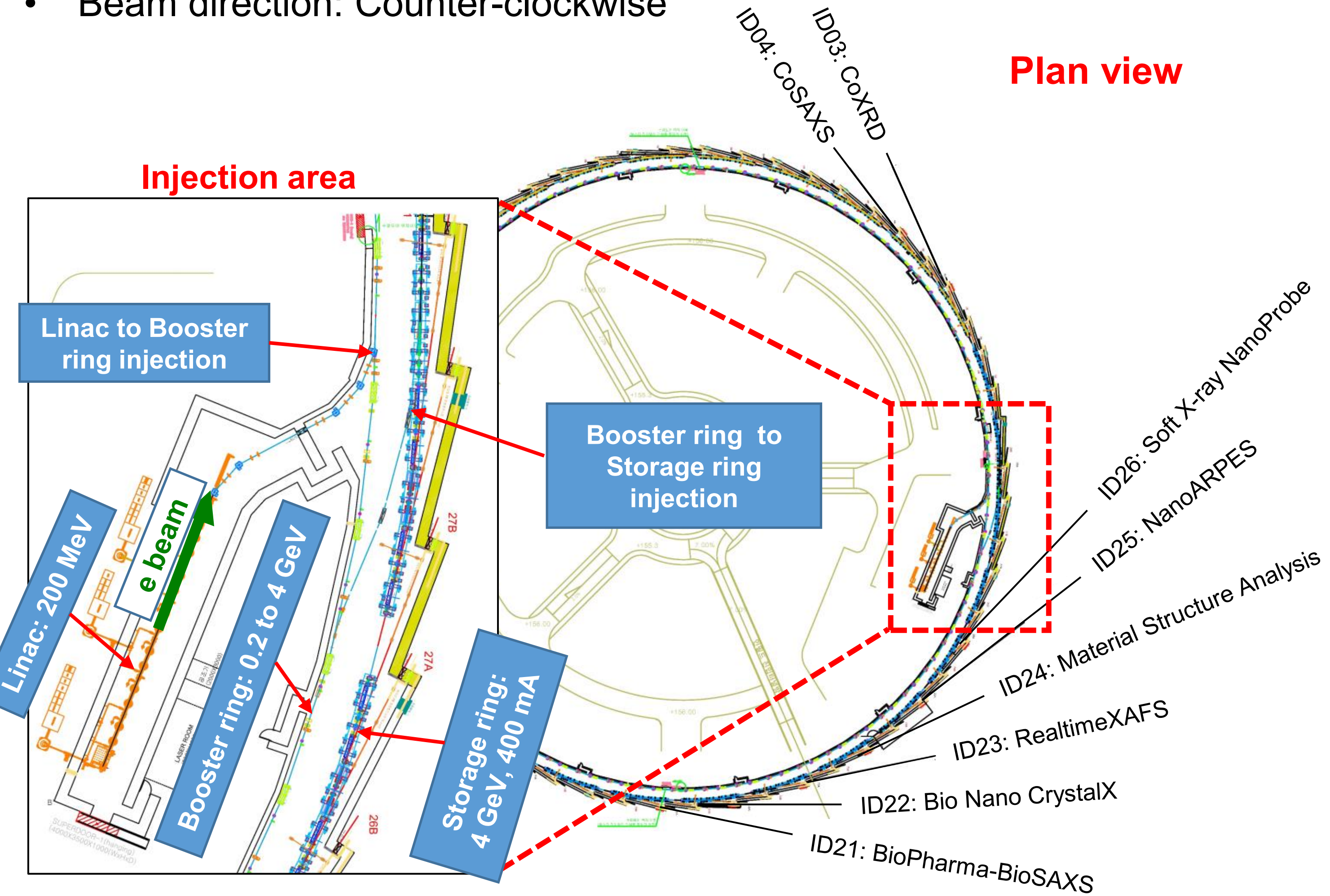
*Korea basic science institute
** Korea atomic energy research institute

[1] Pohang Accelerator Laboratory, “Conceptual Design Report of 4GSR”, PAL-PUB-2000-004, 2000.

Specification and layout of 4GSR in Korea

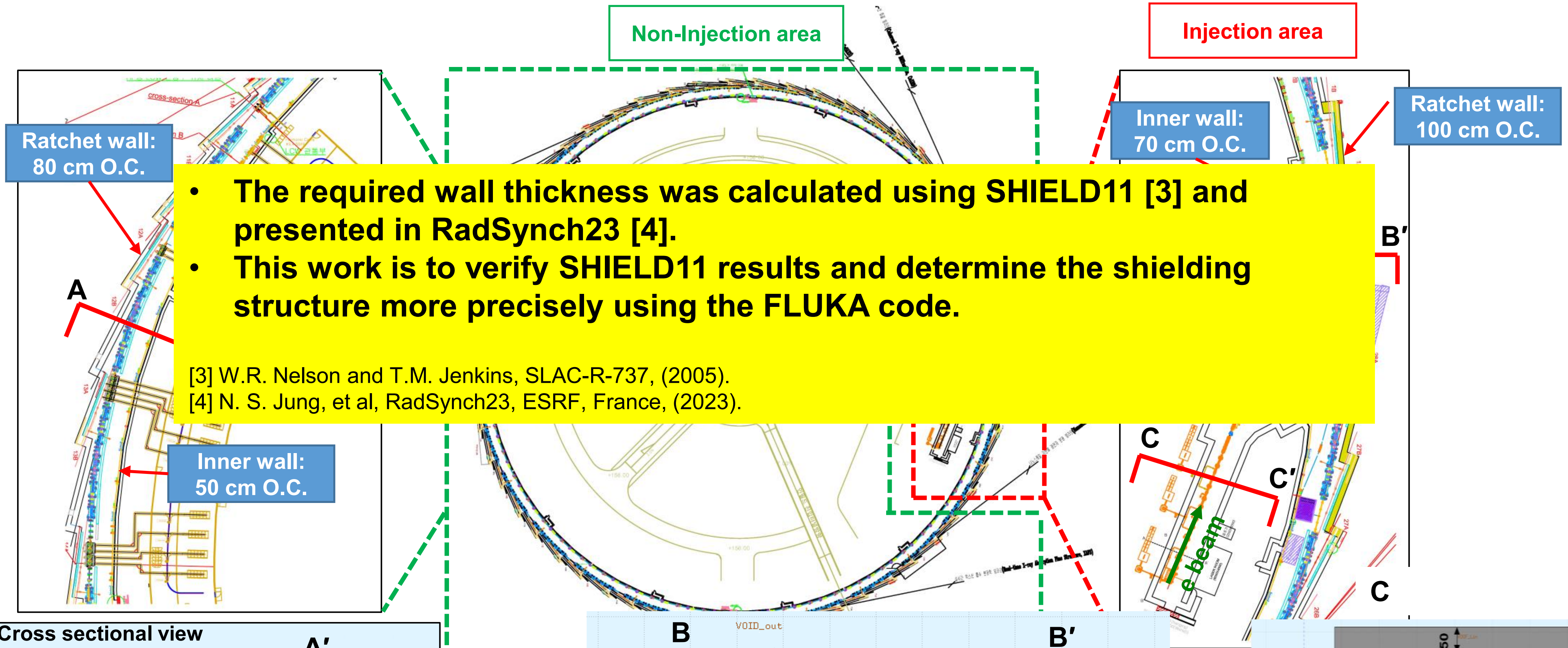
Position	Parameter	Value in TDR [1]
Storage ring (SR)	**Beam energy**	**4 GeV**
	Stored current	**400 mA**
	Ring circumference	**799.297 m**
	Symmetry	28
	Straight section No.	28
	Straight section length	**6.06 m**
	Emittance	**62 pm.rad**
Booster ring	**Energy**	**0.2 GeV to 4 GeV**
	Circumference	**772.893 m**
Linac	**Energy**	**200 MeV**
	Reputation rate	2 Hz
	Pulse charge	1 to 3 nC (Multi-bunch) 0.01 to 1 nC (Single-bunch)
	Pulse length	≈128 ns (Multi-bunch) 6~8 ps FWHM (Single-bunch)

- Booster ring & storage ring in the same tunnel
- **10 beamlines will be constructed at the end of the first construction phase.**
- Beam direction: Counter-clockwise



[1] Multipurpose synchrotron radiation accelerator (Korea-4GSR) detailed design report (2023), In Korean

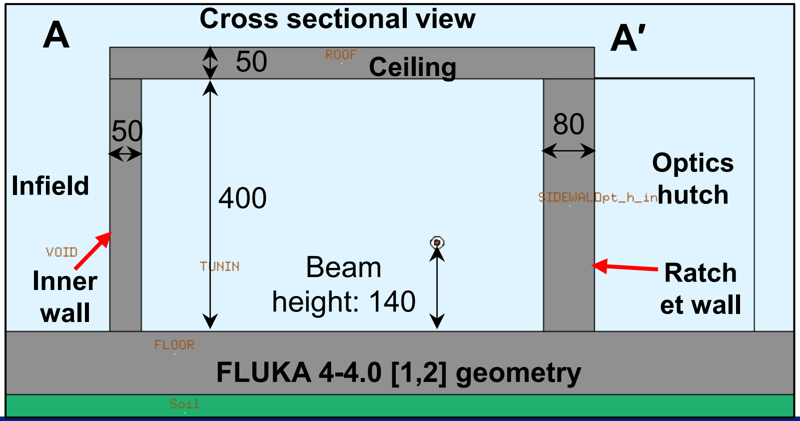
Specification and layout of 4GSR in Korea

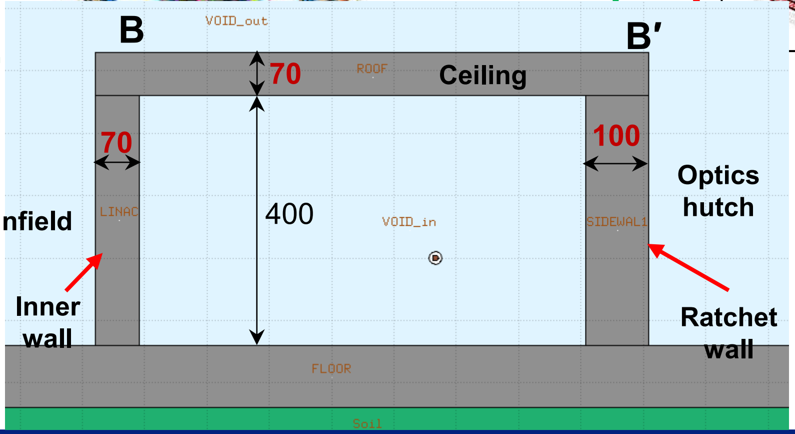


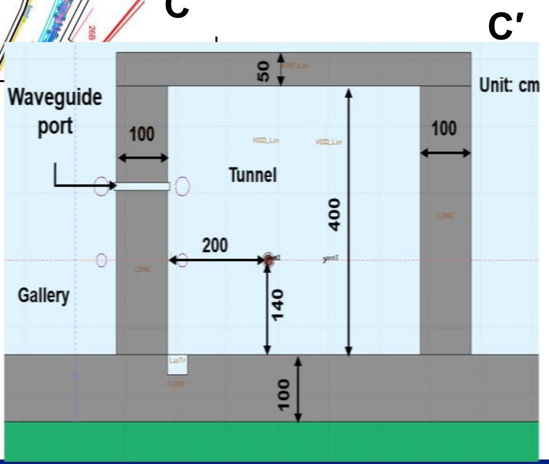
- **The required wall thickness was calculated using SHIELD11 [3] and presented in RadSynch23 [4].**
- **This work is to verify SHIELD11 results and determine the shielding structure more precisely using the FLUKA code.**

[3] W.R. Nelson and T.M. Jenkins, SLAC-R-737, (2005).
[4] N. S. Jung, et al, RadSynch23, ESRF, France, (2023).

Unit: cm







[1] C. Ahdida et al, Frontiers in Physics 9, 788253 (2022). [2] G. Battistoni et al, Annals of Nuclear Energy 82, 10-18 (2015).

Radiation safety control policy

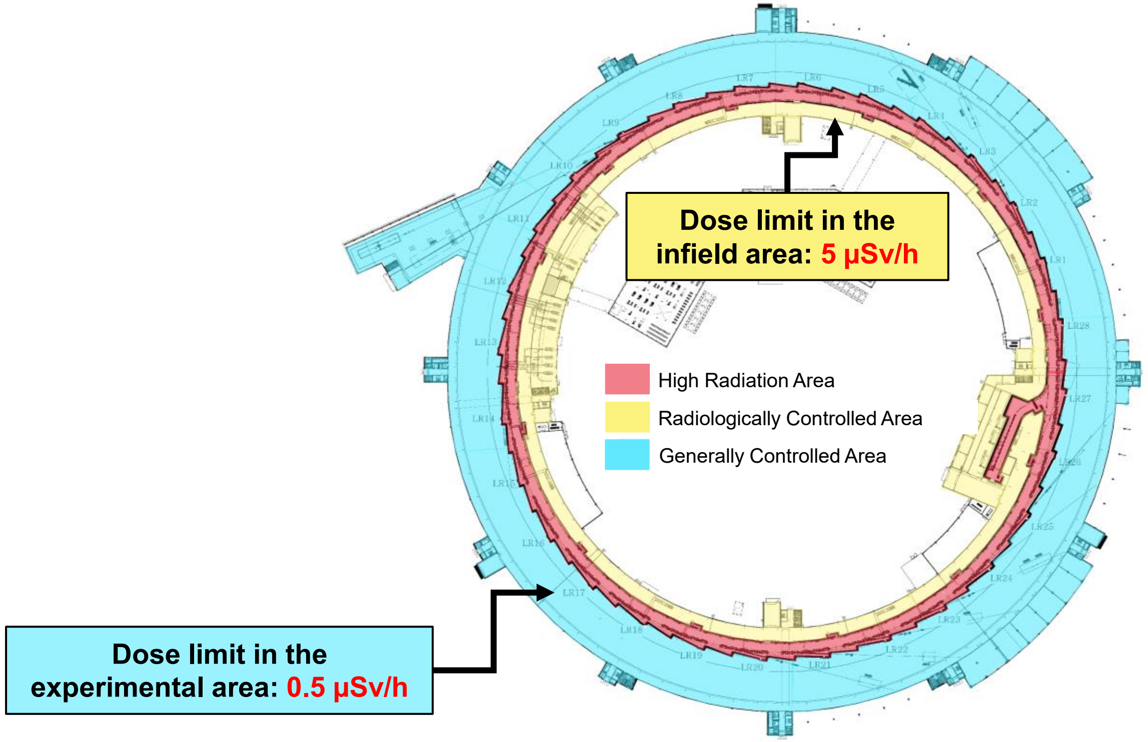
❑ **Dose criteria**

- **Same safety control policy as PAL**

Dose Limit (based on Korean Regulation)	Dose
Radiation Workers (RW)	20 mSv/y
Frequent Visitors	6 mSv/y
Public (including User)	1 mSv/y
Site Boundary	0.25 mSv/y

Shielding Criteria	Dose	Note
Radiation worker accessible area	**10 mSv/y, (5 μSv/h)** ½ of dose limit based on ALARA	Normal operation
User accessible area	**1 mSv/y (0.5 μSv/h)**	Normal operation
(In accident)	**1 mSv within 1 h for single event**	

Area (Zone) Classification	Dose
Restricted Area	0.25 mSv/y ≤ Dose < 1 mSv/y
Generally-Controlled Area	1 mSv/y ≤ Dose < 20 mSv/y
Radiologically-Controlled Area	20 mSv/y ≤ Dose < 1 mSv/h
High Radiation Area	Dose ≥ 1 mSv/h (No Access)



FLUKA calculation conditions

- **Evaporation Option**: Used for particle evaporation and photonuclear reaction simulations.
- **Photonuclear Reactions**: Includes GDR, QD, and high-energy (>0.7 GeV) photonuclear reactions.
- The **JEFF-3.3 neutron data library [1]** was utilized as the default library for neutrons below 20 MeV.
- **Energy Cut-off Settings**:
  - Neutrons: 10^{-11} MeV
  - Electrons and positrons: 1 MeV
  - Photons: 10 keV
- **Biasing Techniques**:
  - Recommended FLUKA options (**EMF-BIAS, LAM-BIAS**) were applied for photonuclear reaction calculations.
- **Scoring Methods**:
  - **Radiation Flux Distributions**: Scored using USRBIN cards (mesh size 10 × 10 × 10 cm^3)
  - **Effective Dose Conversion Coefficients**: ICRP74 and Pelliccioni using Anterior-Posterior (AP) irradiation geometry [2].
  - **Radiation Dose Distributions**: Computed by folding USRBIN data with dose conversion factors via the AUXSCORE scoring card.

Material information used in FLUKA.

Material	Density [g/cm³]	Mass Fraction					
		Element	Ratio	Element	Ratio	Element	Ratio
Iron (Fe)	7.874	Fe	1				
Copper (Cu)	8.96	Cu	1				
Aluminum (Al)	2.699	Al	1				
Concrete (FLUKA Portland)	2.3	H	0.1	C	0.001	O	0.529107
		Na	0.016	Mg	0.002	Al	0.033872
		Si	0.337021	K	0.013	Ca	0.044
		Fe	0.014				
Stainless Steel (FLUKA ANSI316LN)	7.8	Fe	0.67145	Cr	0.185	Ni	0.1125
		Mn	0.02	Si	0.01	P	0.00045
		S	0.0003	C	0.0003		
Soil (PAL-XFEL Soil)	1.83	H	0.0014	C	0.0036	O	0.5017
		Mg	0.0011	Al	0.0956	Si	0.3276
		K	0.0317	Ca	0.0373		
Polyethlyene (PE)	0.94	H	0.143711				
		C	0.143711				
Graphite	2.00	C	1				
Tungsten (W)	19.30	W	1				
Lead (Pb)	11.35	Pb	1				

[1] A. J. M. Plompen et al., European Physical Journal A, 56 (2020).

[2] M. Pelliccioni, Radiation Protection Dosimetry, 88 (2000).

Radiation sources and electron beam loss scenarios

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❑ Source of radiation:

- **Normal operation:**
  - **Electron beam loss inside the tunnel**
  - **High-energy Bremsstrahlung photons:** as a result of stored electrons interaction with the storage ring components.
  - **Photoneutrons:** Generated from Bremsstrahlung photons with matter [1]
    - Giant dipole resonance (GDR)
    - Quasi-deuteron (QD)
    - High-energy neutrons
  - **Additional radiation sources for beamline shielding design [2]**
    - **Gas Bremsstrahlung**: Produced by stored electrons interacting with residual gas in a vacuum chamber.
    - **Synchrotron radiation**: Generated when electrons travel through a bending magnet, wiggler, or undulator.
- **Abnormal operation**:
  - Electron beam accidentally strikes the storage ring components, and intense **Bremsstrahlung photons and photoneutrons** are generated.

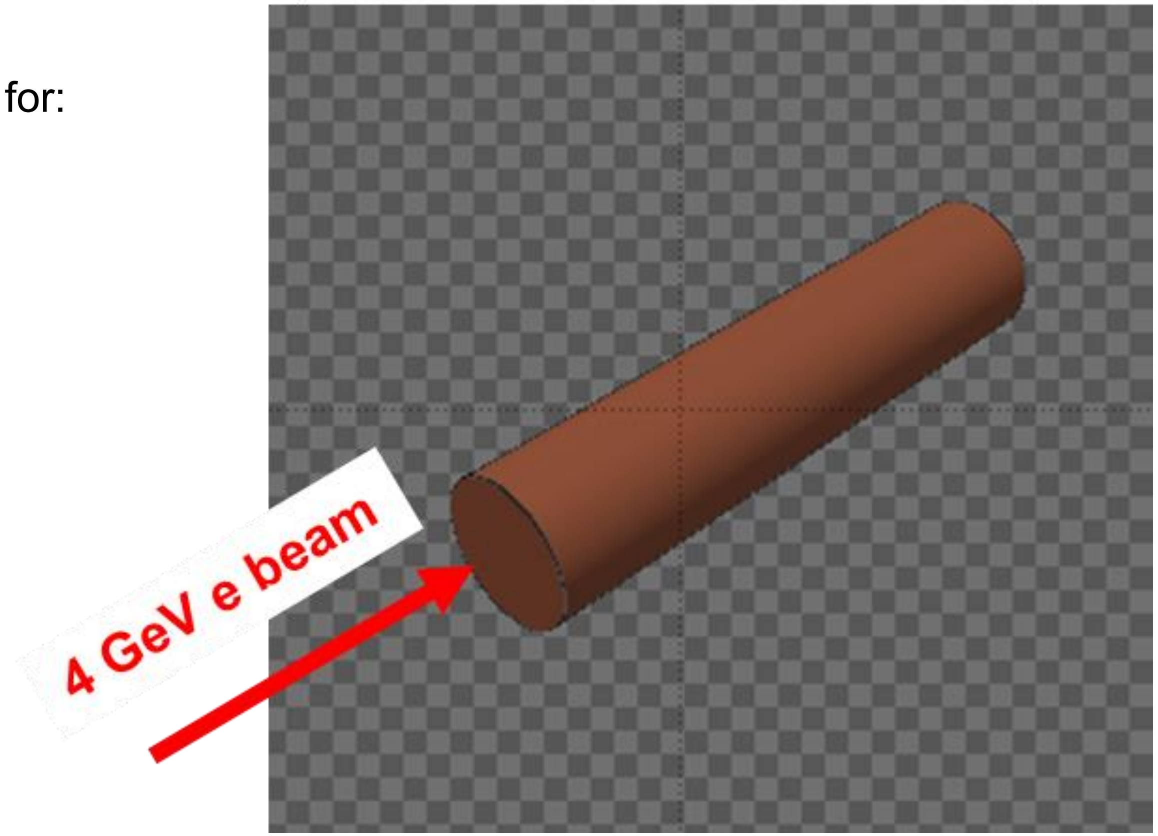
➢ **These radiations need to be suitably shielded.**

[1] M. Bakhtiari, et al. Contribution of compound, preequilibrium and direct reactions to photoneutron emission spectrum from various targets induced by 16.6-MeV monoenergetic photons. **Nucl. Instrum. Methods Phys. Res. B**, 521, 2022.
[2] M. Bakhtiari, et al. Radiation shielding analysis for synchrotron radiation beamlines of 4th generation storage ring in Korea, SATIF16, INFN-LNF-Italy, 2024.

❑ Radiation production yields calculations

- Photons, neutrons, and muons production yields were calculated for:
  - Target: Fe
  - Φ: 4 cm
  - Thickness: $3X_0$, $5X_0$, $10X_0$, $20X_0$
  - Electron energy: 4 GeV
  - Angles: 0 and 90 degrees

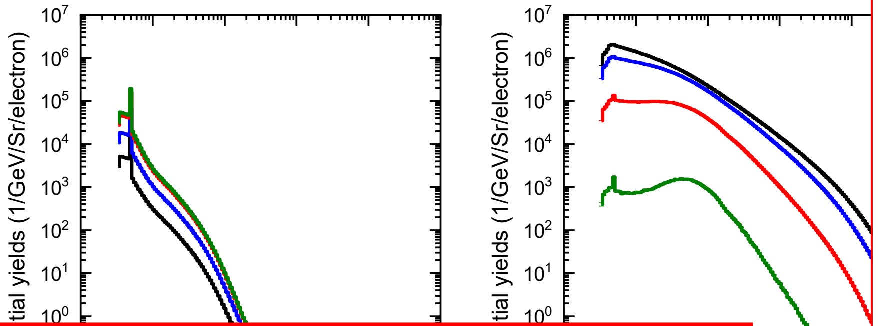
X_0: Radiation length



Radiation sources and electron beam loss scenarios

- **Radiation production yields calculations**
  - **Photons**
    - are forward-peaked
    - are attenuated significantly in the target

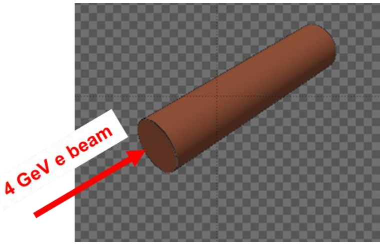
Photon production yields

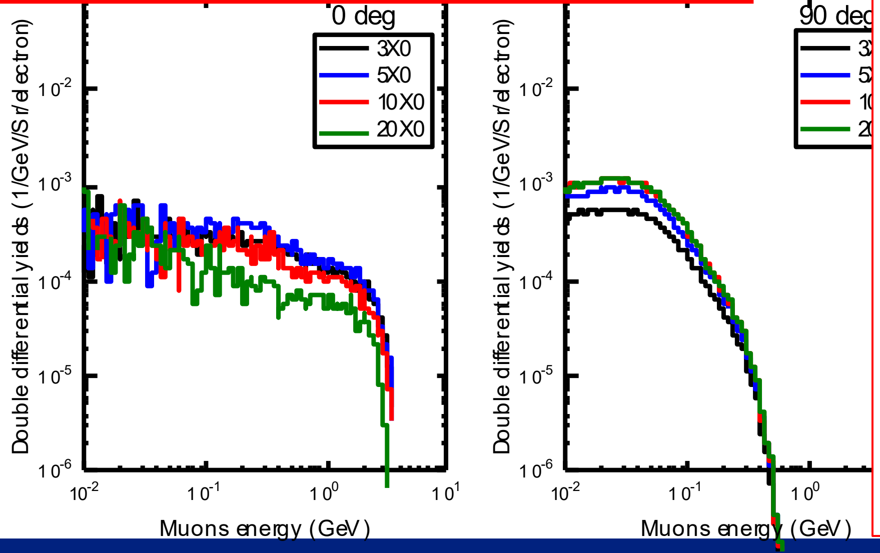


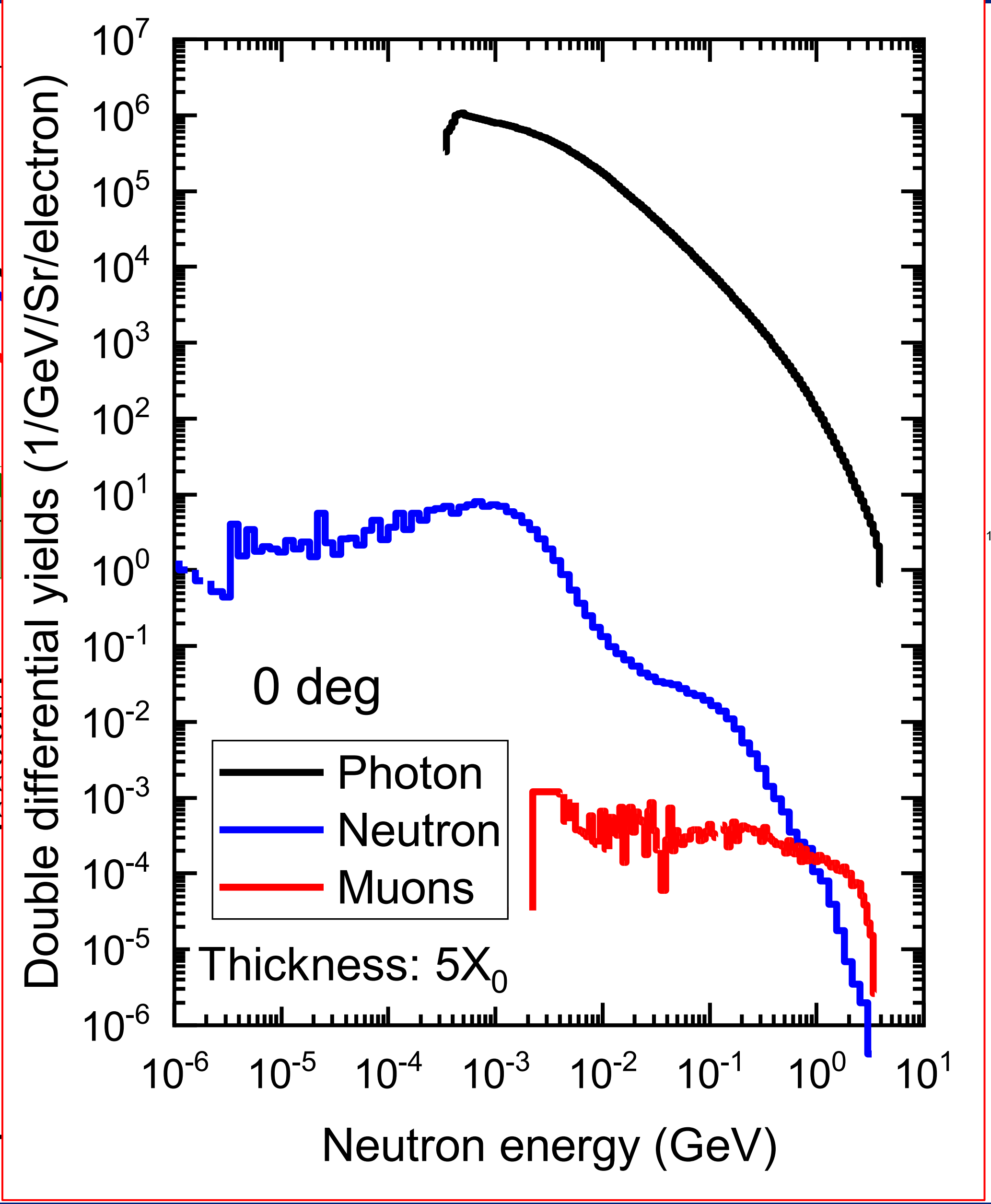
- Muons production yields are lower than those of photons and neutrons by several order of magnitude.
- Muons effective dose rate was calculated and was negligible.

    - are less attenuated in the target

Target: Fe
Φ: 4 cm
Thickness: $3X_0$, $5X_0$, $10X_0$, $20X_0$





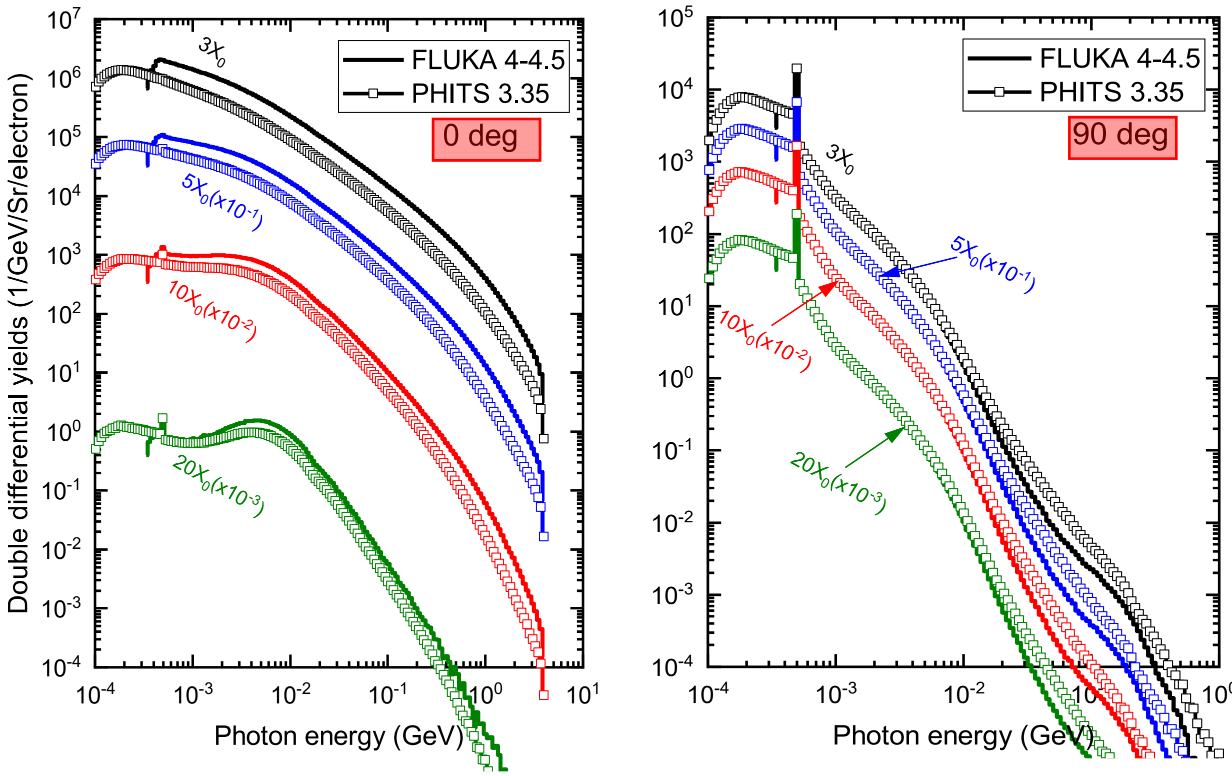


Radiation sources and electron beam loss scenarios

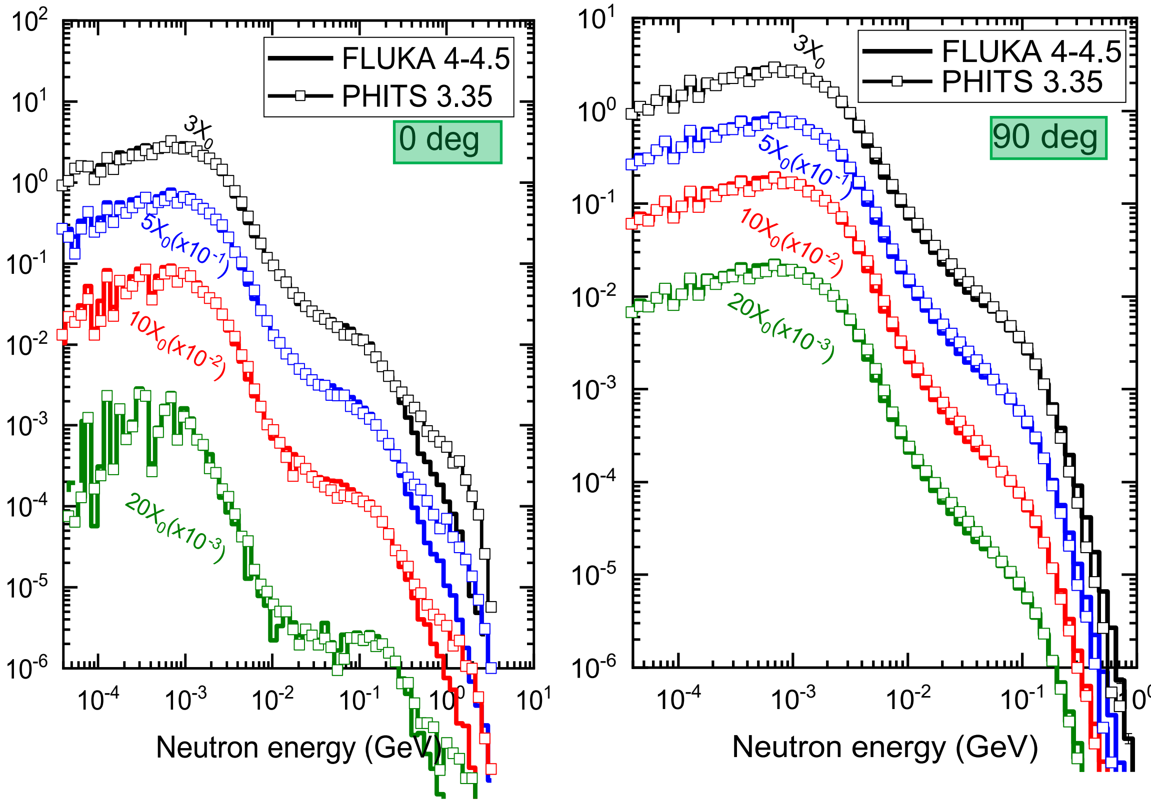
❑ Radiation production yields calculations

- **Cross comparison FLUKA results with the PHITS [1] code**
  - Generally, the radiation production yields calculated by FLUKA and PHITS are consistent.
  - **A discrepancy is seen for photons at 0 deg.→ can be a subject for further study.**

Photon production yields



Neutron production yields

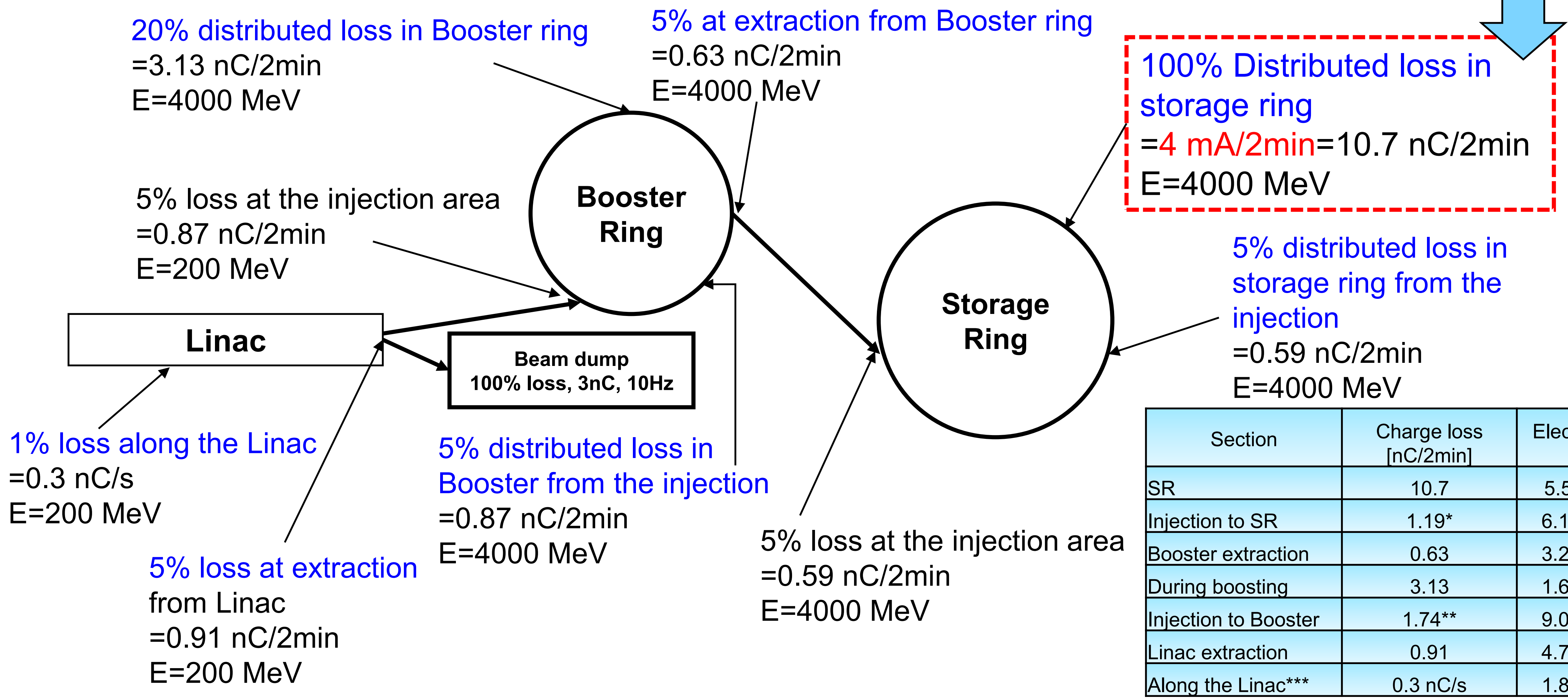


[1] T. Sato et al, J. Nucl. Sci. Technol. 61, 127-135 (2024)

Radiation sources and electron beam loss scenarios

❑ **Schematic drawing of beam loss under normal operation**

As the stored electron beam decreases over time, the 4 mA electron beam is injected every 2 minutes to compensate it.



Section	Charge loss [nC/2min]	Electron loss [e/s]	Loss [%]
SR	10.7	5.57×10^{8}	100
Injection to SR	1.19*	6.19×10^{7}	10
Booster extraction	0.63	3.26×10^{7}	5
During boosting	3.13	1.63×10^{8}	20
Injection to Booster	1.74**	9.05×10^{7}	10
Linac extraction	0.91	4.76×10^{7}	5
Along the Linac***	0.3 nC/s	1.88×10^{9}	1

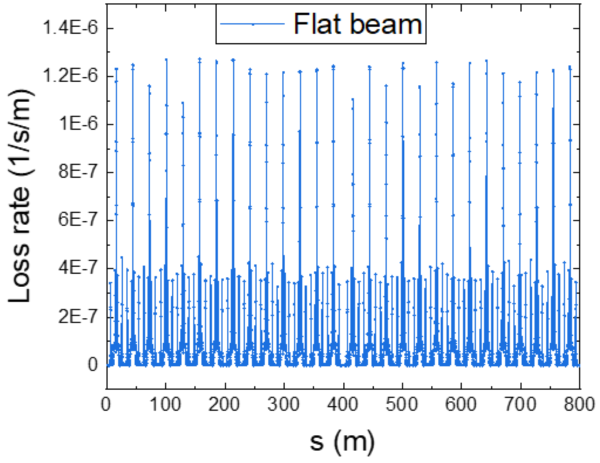
* Half is lost locally, half is lost uniformly in SR

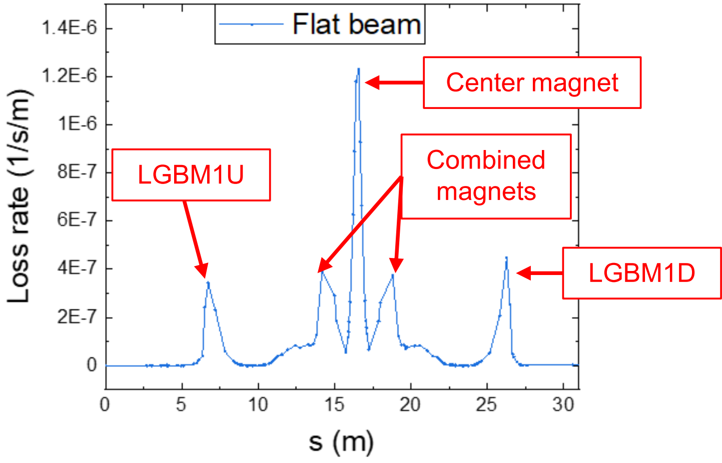
** Half is lost locally, half is lost uniformly in Booster

❑ Normal operation

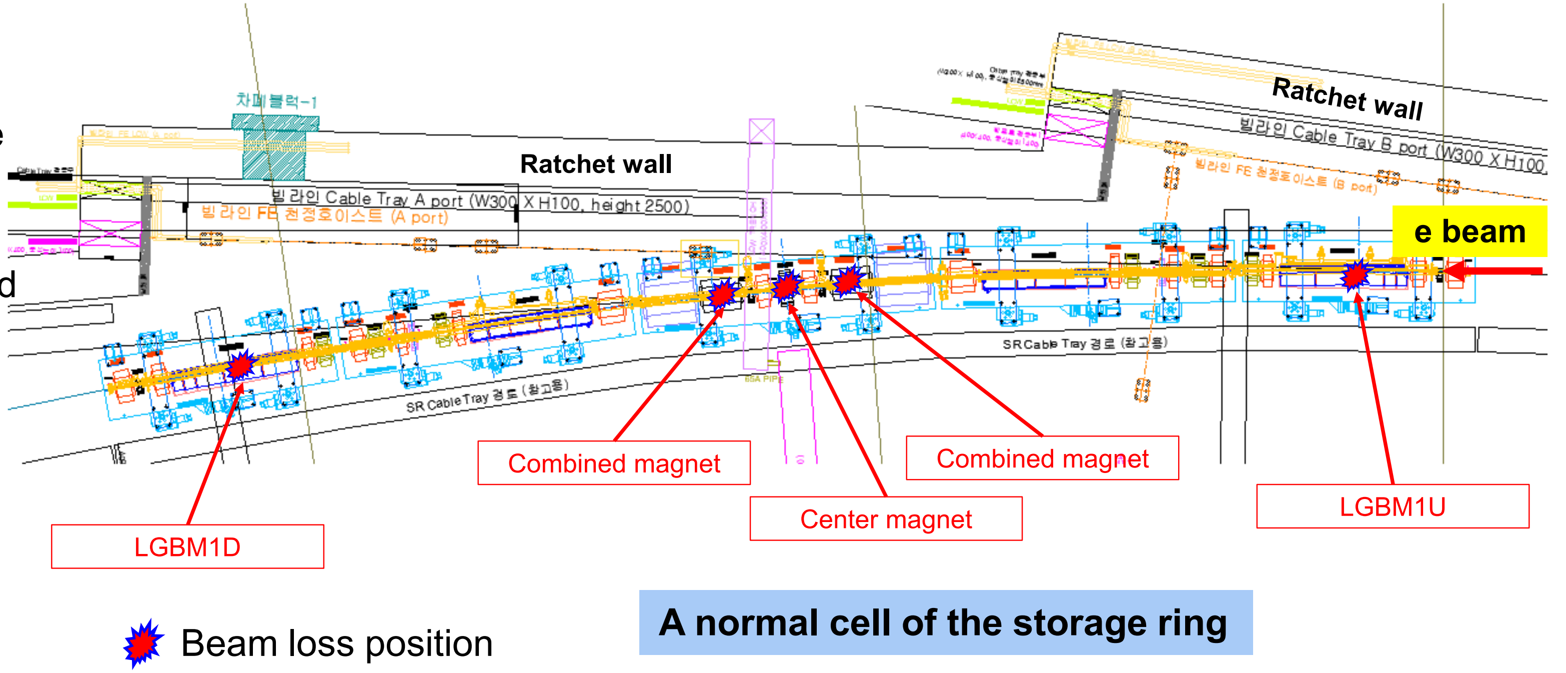
- **Beam Loss position in storage ring:**
  - Electron beam loss in the storage ring is primarily caused by the Touschek effect during normal operations (RF on).
  - Major loss locations in a normal cell include LGBM1U*, the center magnet, two combined magnets, and LGBM1D (**According to beam dynamic simulations**).

RF on: Touschek loss rate





- **Targets in FLUKA:**
  - **5 targets** were defined in each cell to evaluate dose rates for a uniformly distributed beam loss scenario.
  - In the simulations, an equal beam loss was assumed at every 5 positions.

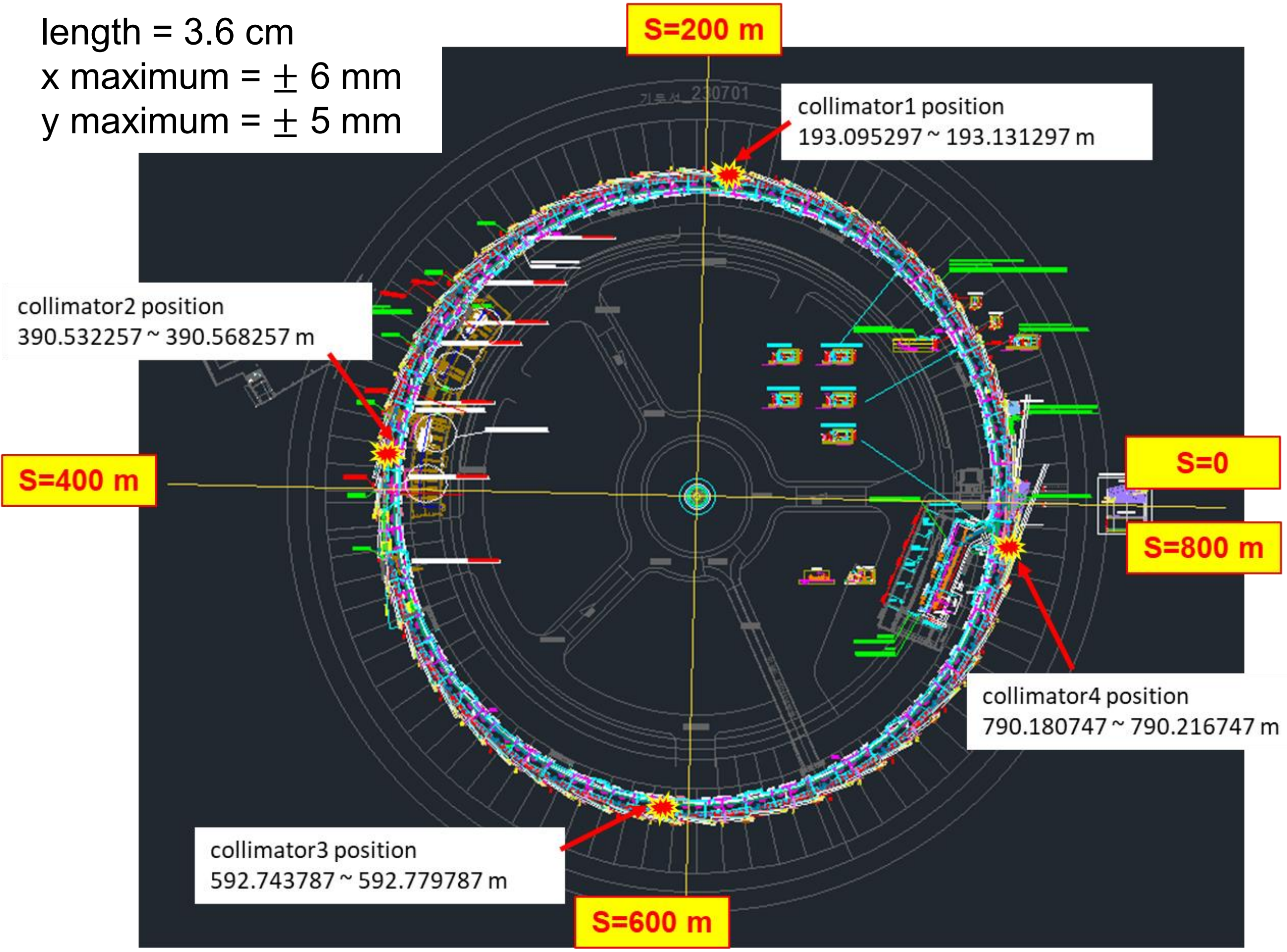


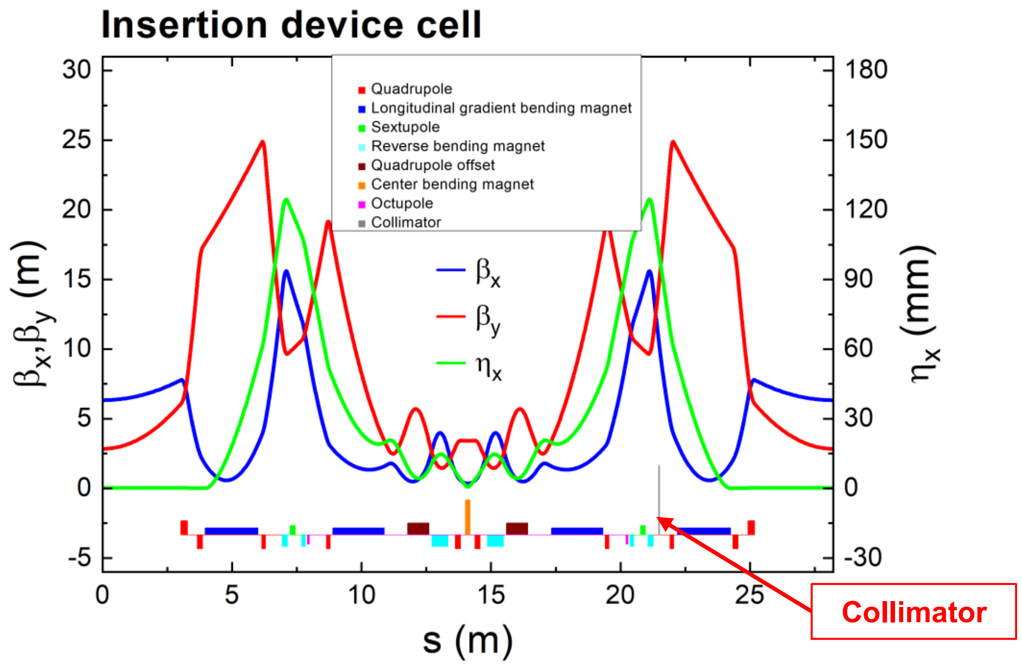
A normal cell of the storage ring

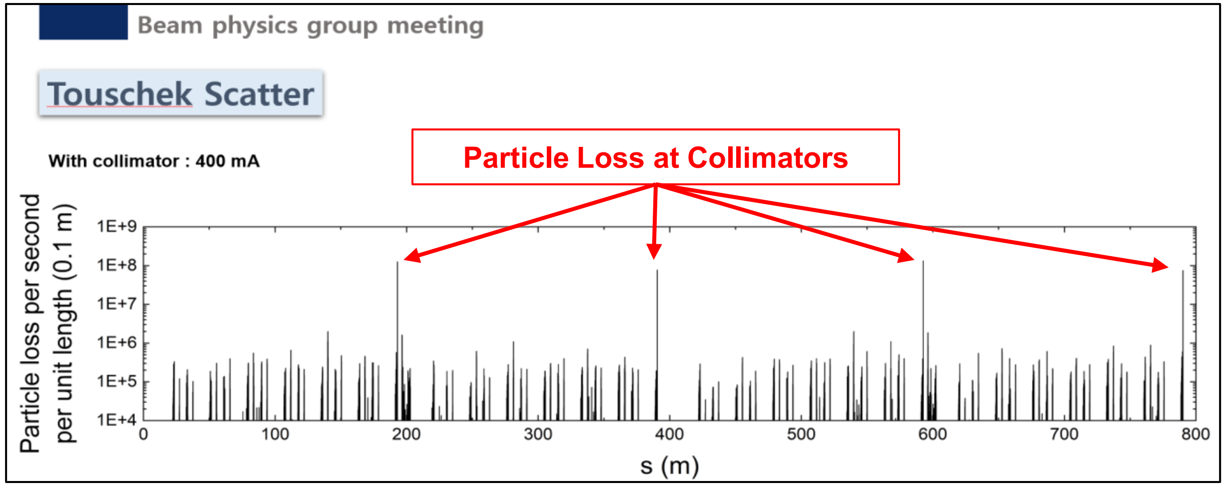
* LGBM: Longitudinal Gradient Magnet

Radiation sources and electron beam loss scenarios: With collimator

- **Normal operation**
  - **4 collimators are being considered in the storage ring (Not fixed yet)**
  - **76.7% of beam loss occurs at the collimators.**

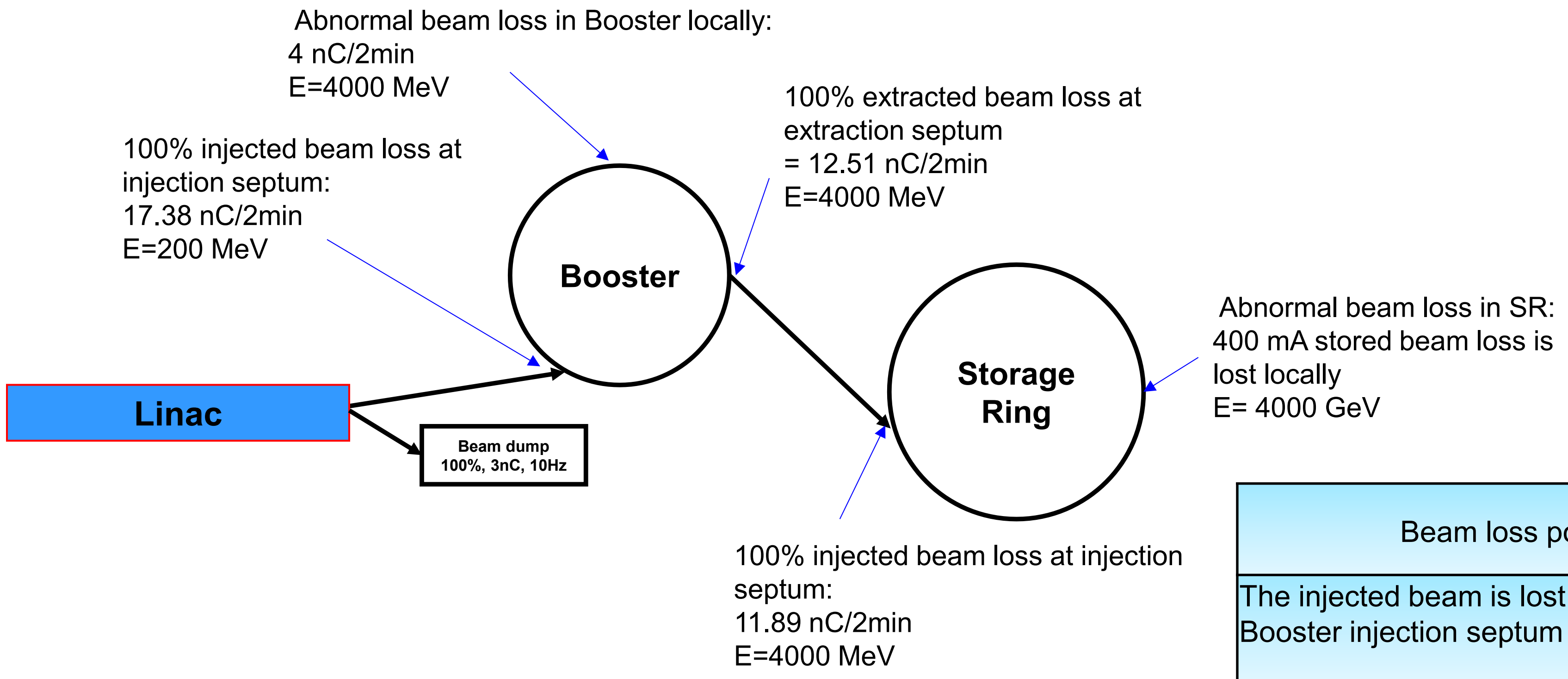






Electron beam loss scenarios

- **Abnormal operation**
  - Several abnormal beam loss scenarios were considered

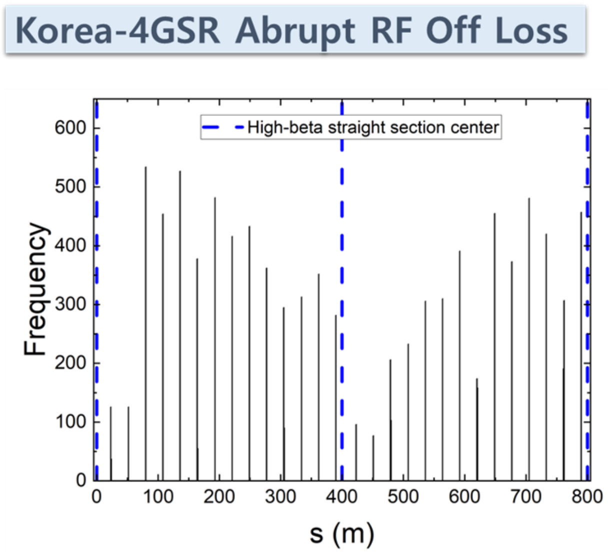


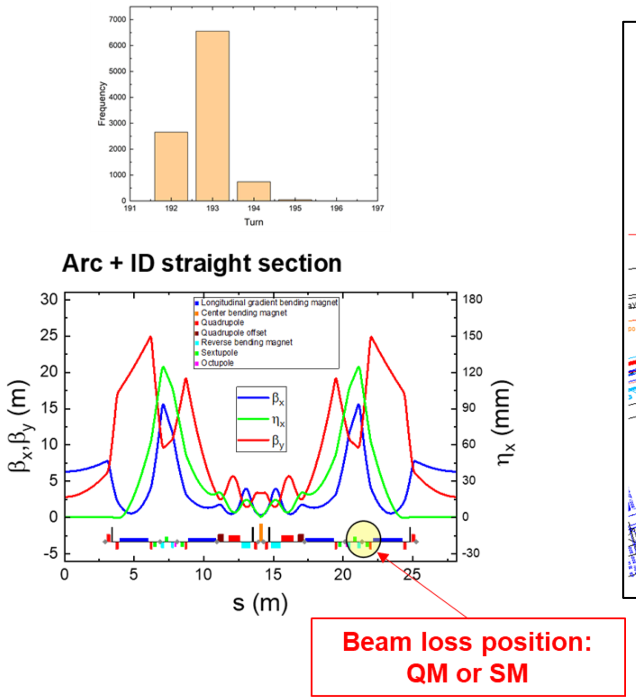
Beam loss position	Charge loss [nC/2min]	Electron loss
The injected beam is lost entirely at the Booster injection septum	17.38 nC/2min	9.05×10^8 e/s
Beam lost in the Booster ring near the mazes	4 nC/2min	2.08×10^8 e/s
The injected beam is lost entirely at the Booster extraction septum	12.51 nC/2min	6.52×10^8 e/s
The injected beam is lost entirely at the storage injection septum	11.89 nC/2min	6.19×10^8 e/s
Stored electron beam is lost at a quadrupole magnet	1.07×10^3 nC (400 mA)	6.67×10^{12} e

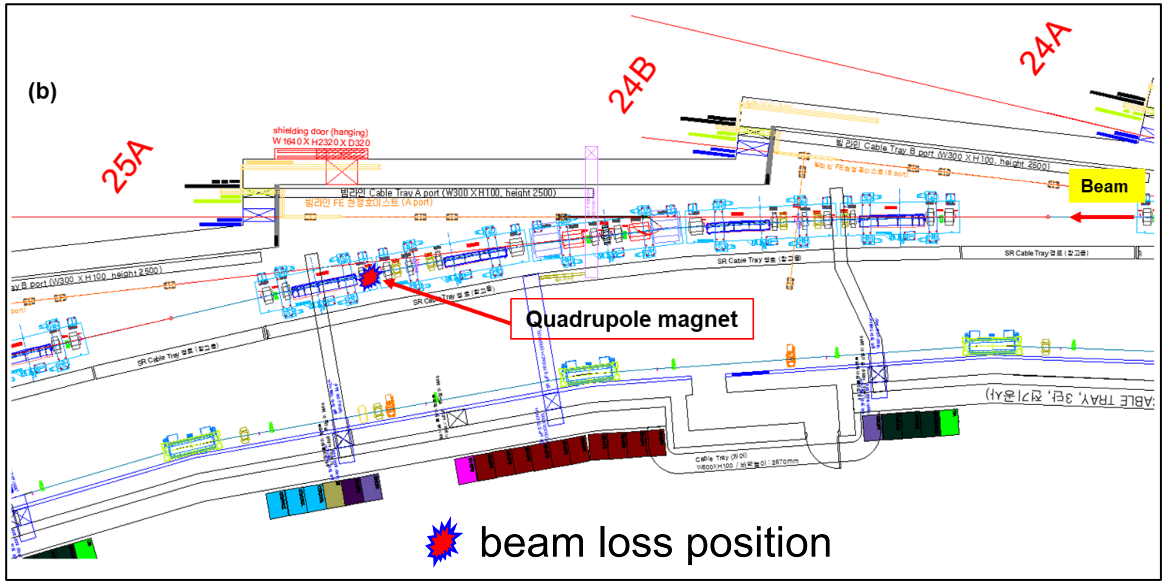
❑ Abnormal operation

- Once the RF power is off:
  - The beam loss around the storage ring **is not uniform**.
  - The position of beam loss is at **the second dispersion** bump which is a QM or SM.

(a)





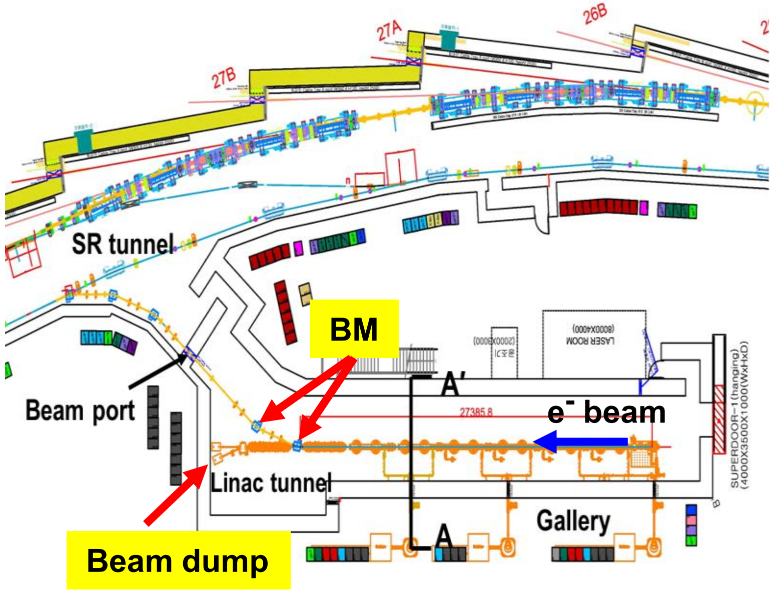


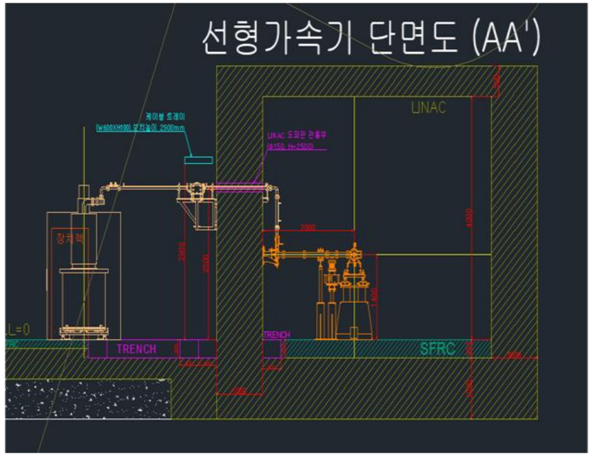
- The beam loss simulations are performed only for storage ring by the beam physics group.

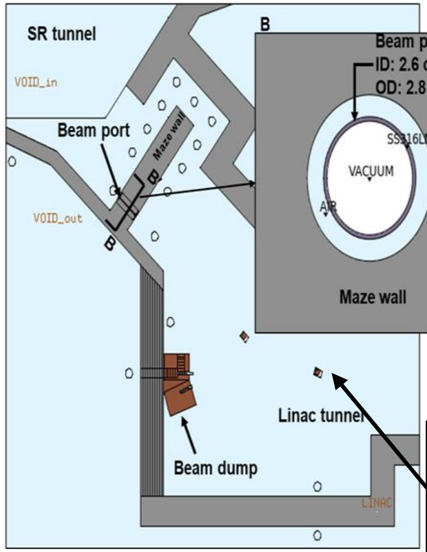
Shielding calculations of linear accelerator

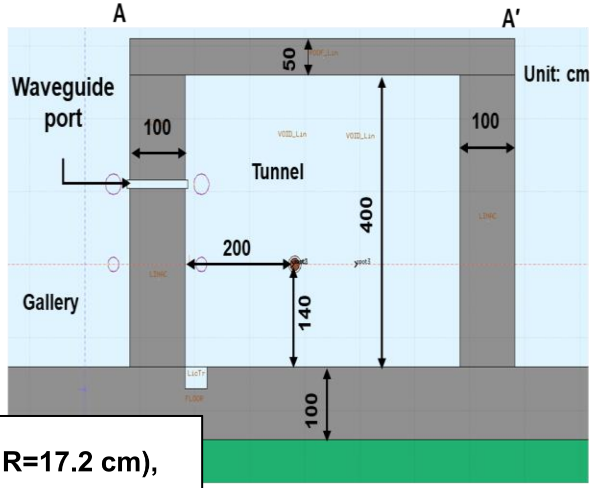
❑ Tunnel wall structure

- The Linac accelerates electrons up to 200 MeV.
- Repletion rate: 2 Hz during top-operation, 10 Hz when dump is used (3 nC/pulse)
- Tunnel walls are 100 cm thick, ceilings are 50 cm thick, and the beam is 120 cm away from the wall facing the gallery. with a beam height of 140 cm and a tunnel height of 400 cm.
- The Linac-to-Booster beam port uses a stainless steel pipe with an inner diameter (ID) of 2.6 cm and an outer diameter (OD) of 2.8 cm.
- A beam dump is required to stop 200-MeV electron beam
- **Modeled Geometry:**
- Shielding structures, tunnel walls were modeled in FLUKA for accurate shielding calculations.









Target: Fe (Φ=5MR=17.2 cm),

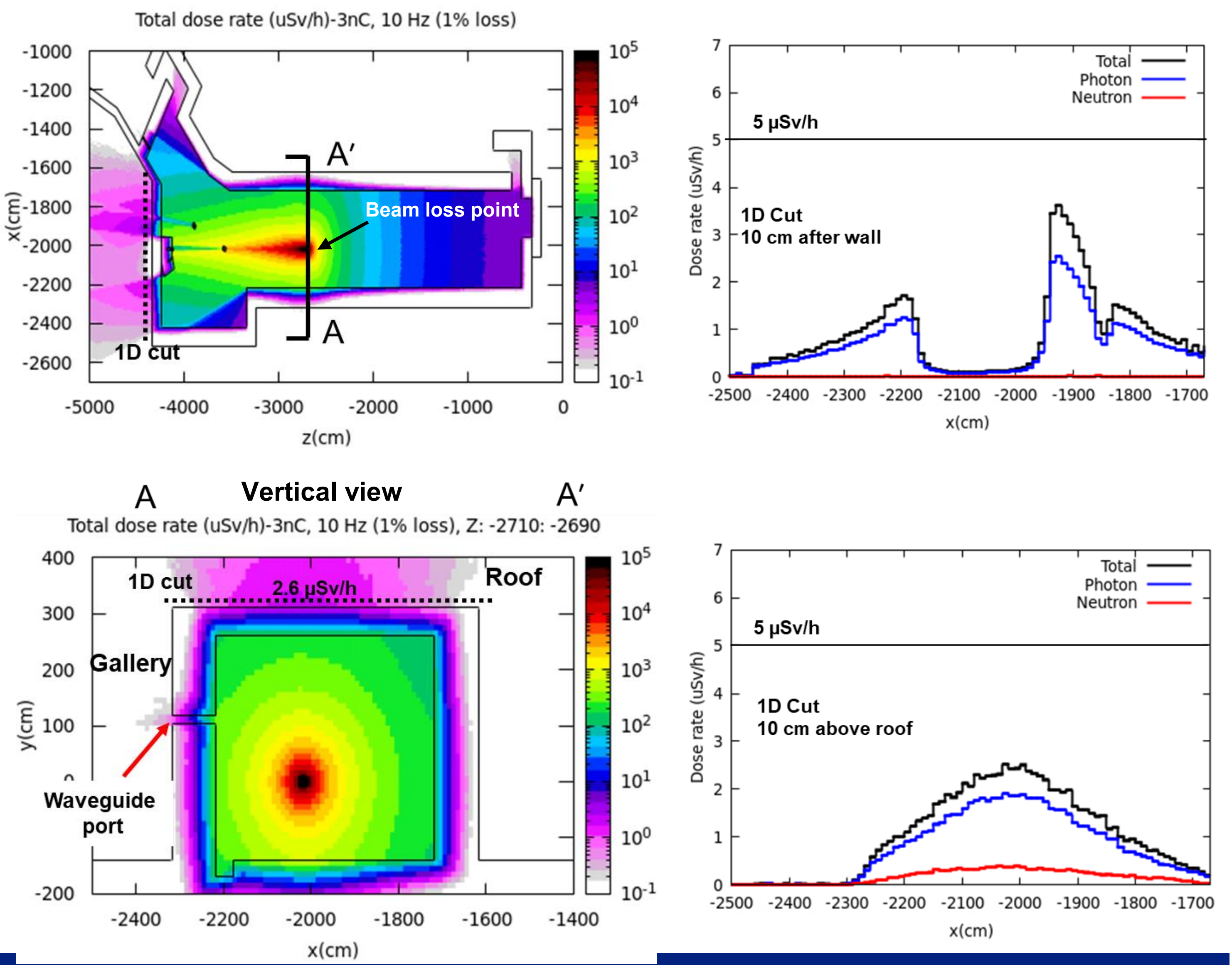
Thickness= $10X_0$=17.57 cm)

- Normal operation

(**Only Linac operation, 10 Hz, 3 nC/s, 1% loss**)

- The photon dose rate dominates in the forward direction, with the neutron dose being isotropic and negligible in comparison.
- At 10 cm beyond the wall (behind the beam dump), the total dose rate is around 4 μSv/h, primarily from photons, with minimal contribution from neutrons.

Total dose rate (Top view), 10Hz, 3nC/s,1% loss



❑ Normal operation

(Linac injection mode, 2 Hz, 5% extraction loss)

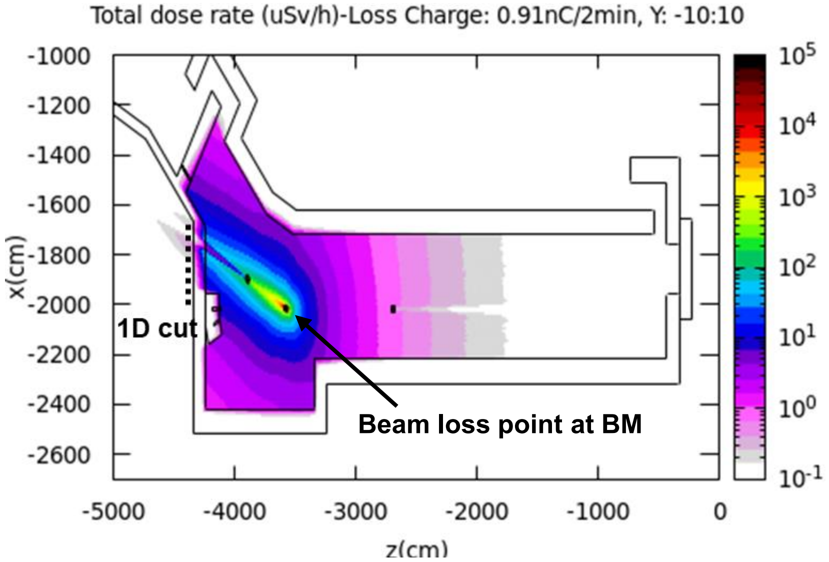
- The total dose rate around the Linac tunnel is less than 0.5 μSv/h, with photon contributions significantly exceeding neutron contributions.

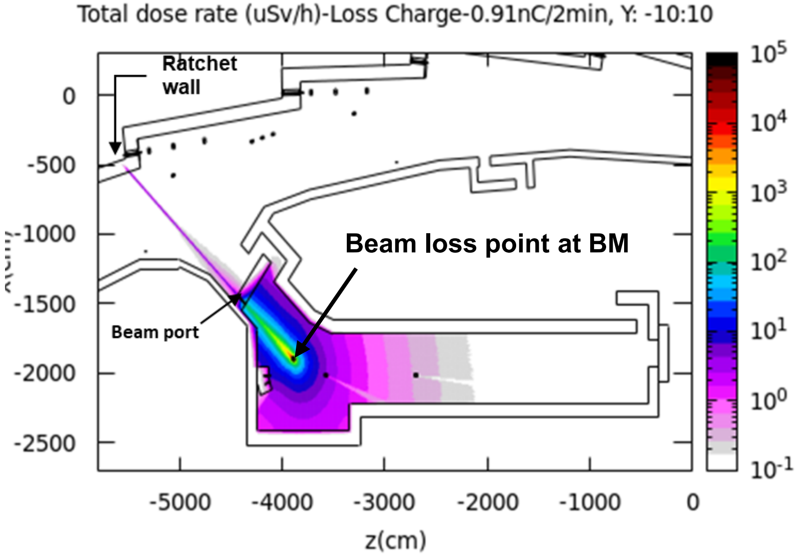
- The total dose rate around the Linac tunnel is below 0.2 μSv/h.

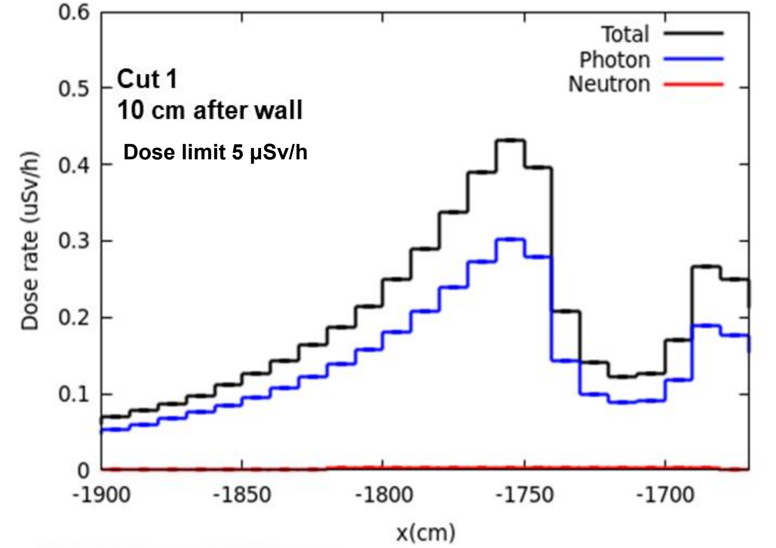
- Streaming radiation through the beam port is attenuated by the SR ratchet wall, maintaining dose rates below 0.2 μSv/h.

➢ **The Linac tunnel wall's shielding effectiveness is sufficient to maintain dose rates within dose limits for these beam loss scenarios.**

Total dose rate (Top view), 2 Hz, 5% extraction loss



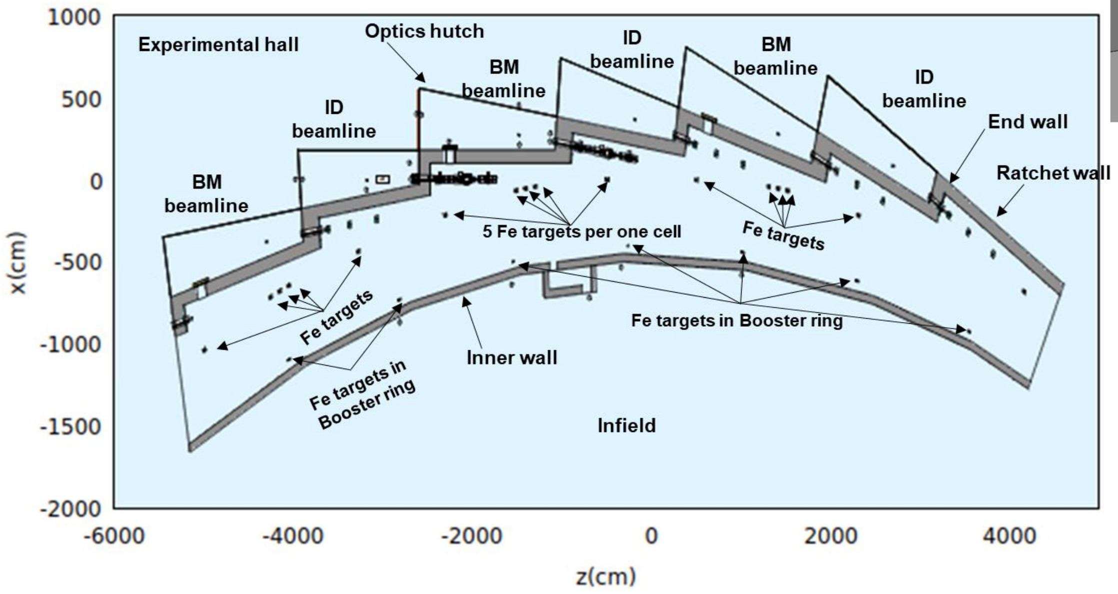


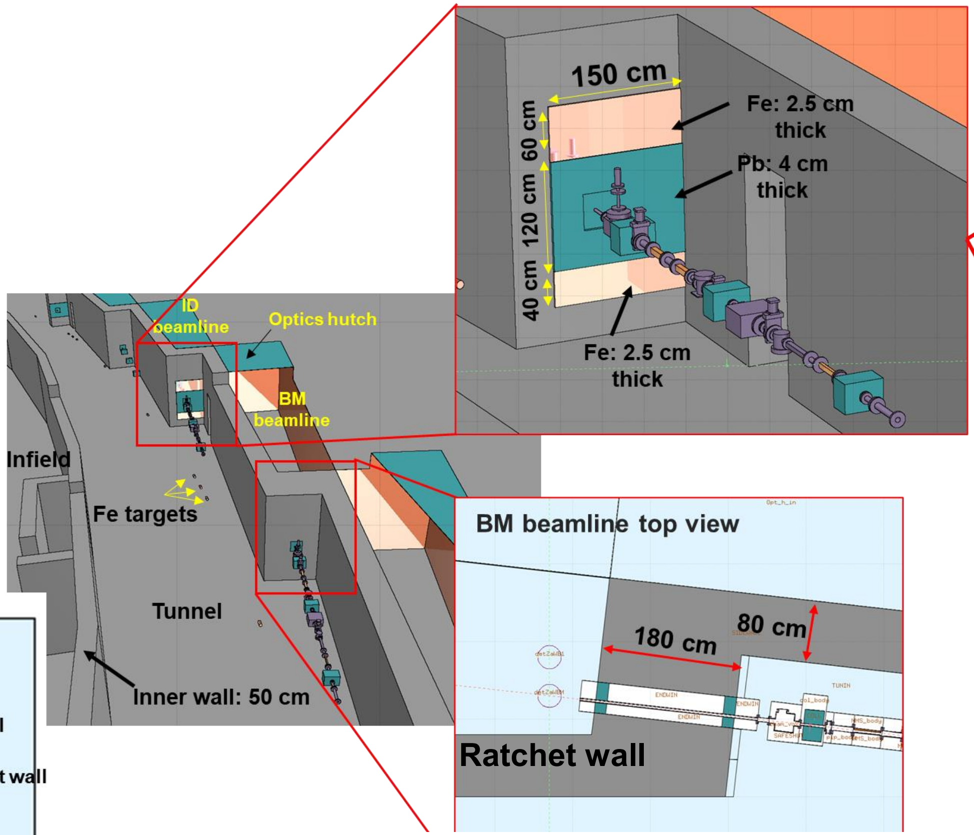


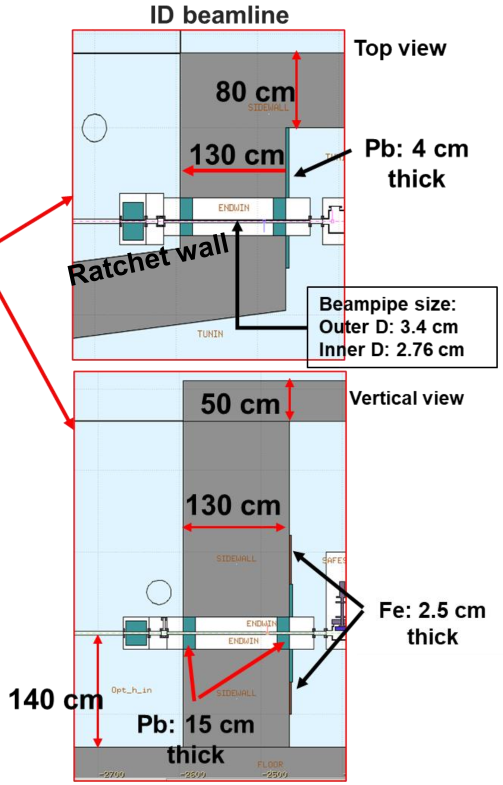
- Tunnel wall structure and target positions in storage ring and booster ring

Position	Shielding material and thickness
Ratchet wall	80 cm O.C
Inner wall	50 cm O.C.
End wall	ID beamline: 130 cm O.C.+ 4 cm Pb with two 2.5 cm Fe plates
	BM beamline: 180 cm O.C.
Ceiling	50 cm O.C.

*O.C (ordinary concrete) density: 2.3 g/cm^3
**ID: Insertion device, ***BM: Bending magnet







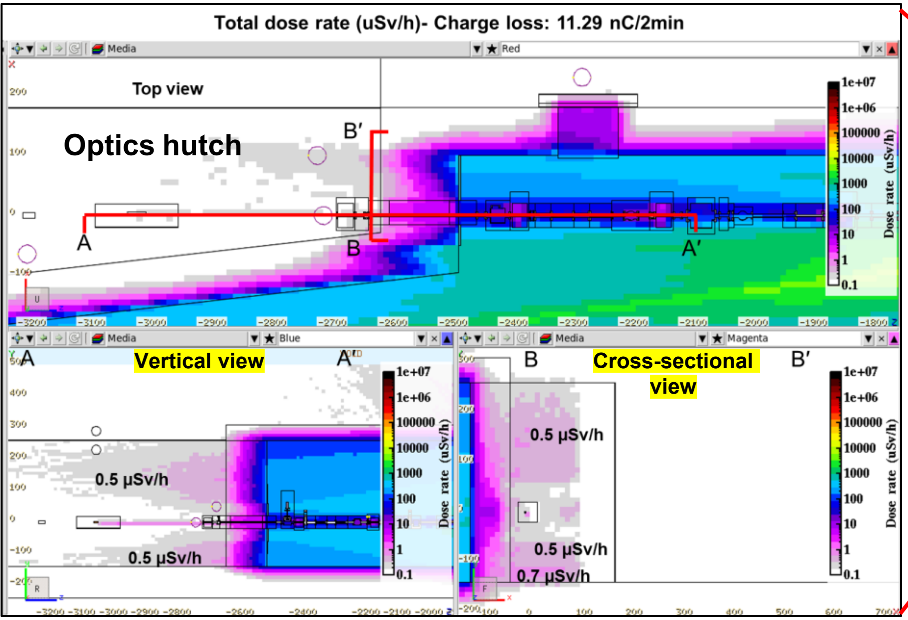
Targets:

- In storage ring: 5 Fe targets for each cell
  - Fe: 10 X0 = 17.57 cm
  - Φ: 8.7 cm
- In booster ring: 1 Fe target at a dipole magnet position
  - Fe: 10 X0 = 17.57 cm
  - Φ: 4 cm

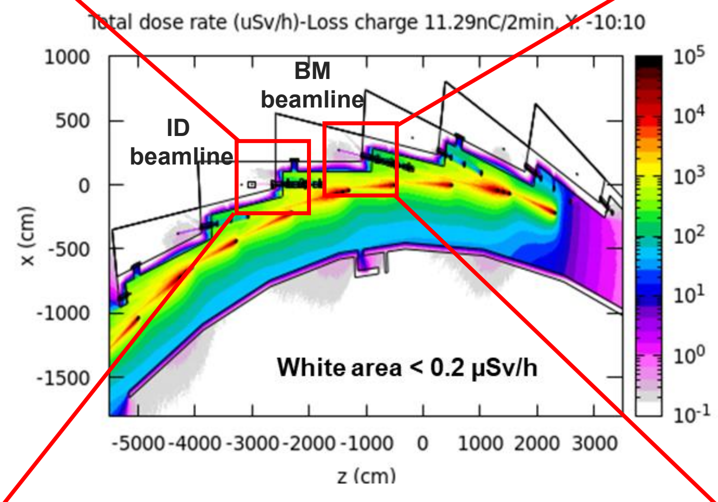
Shielding calculations for non-injection area

❑ Uniformly distributed beam loss along the storage ring

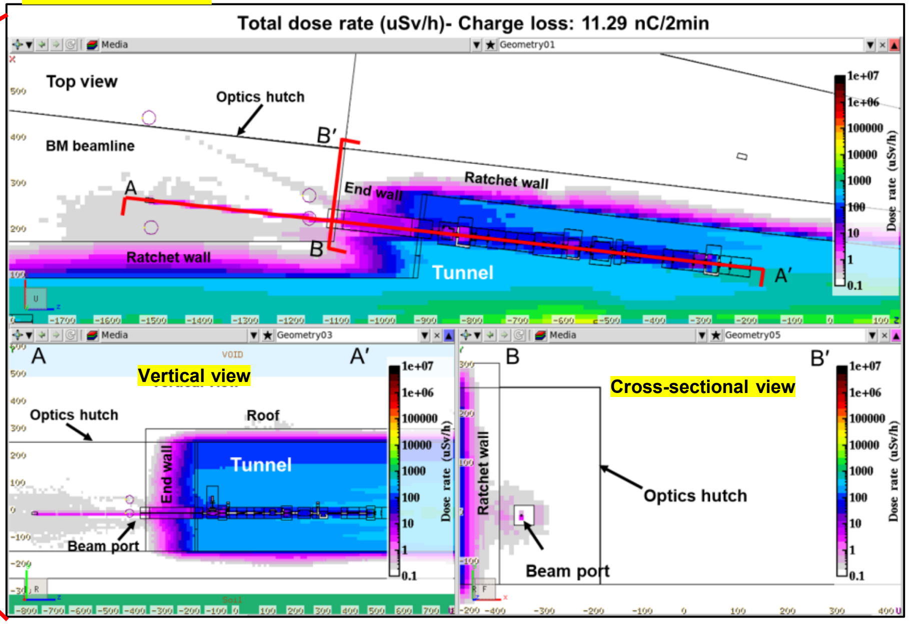
ID beam line



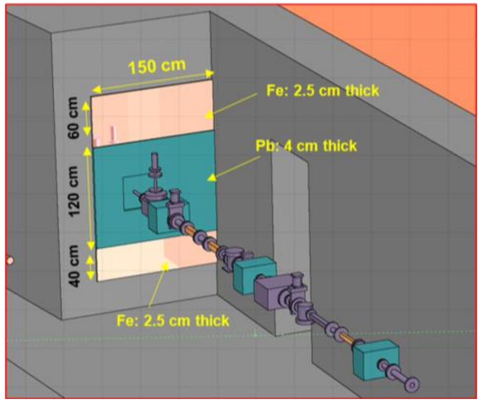
Effective dose rate top view



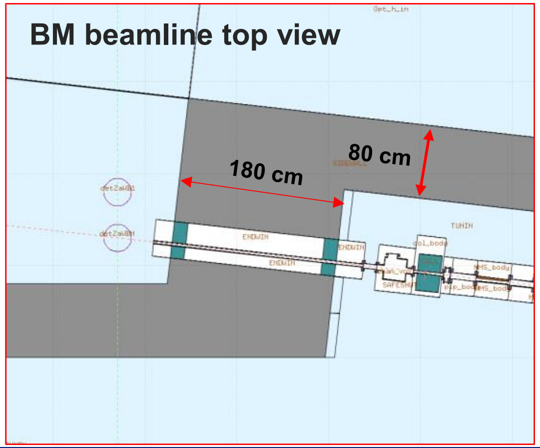
BM beam line



ID beamline



- The total dose rate does not exceed 0.5 μSv/h in the experimental area; only at a point of a corner near the floor is 0.7 μSv/h.

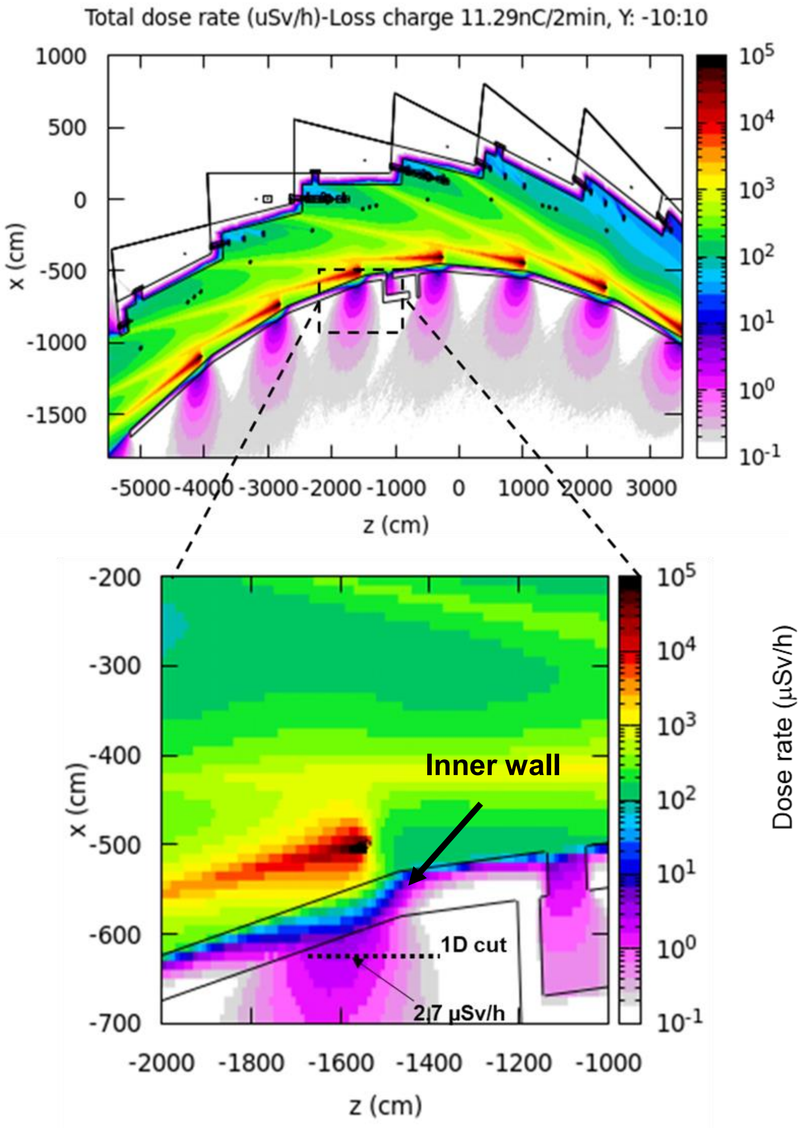


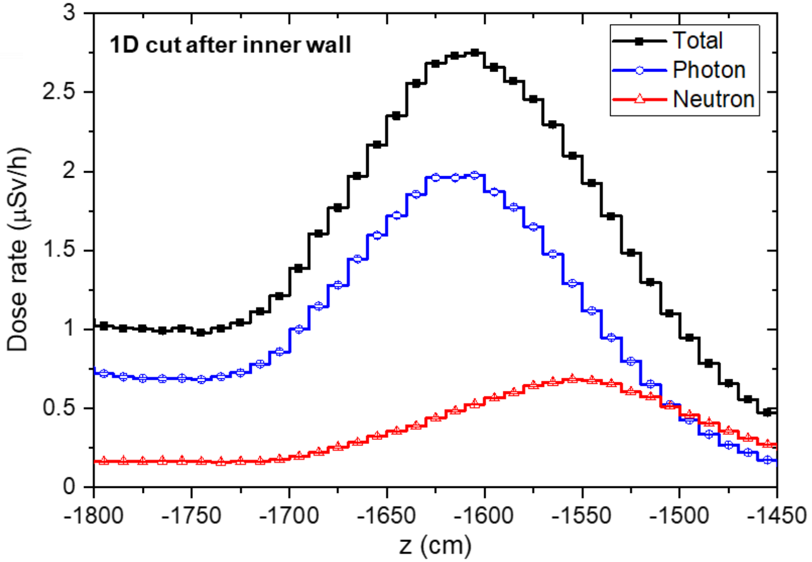
Shielding calculations for non-injection area

❑ Uniformly distributed beam loss along the booster ring

- Total dose rate after the inner wall is 2.7 μSv/h (which is less than 5 μSv/h) dominated by the photon dose rate contribution.
- Photon contribution to the total dose rate is dominant after the inner wall.

Effective dose rate top view



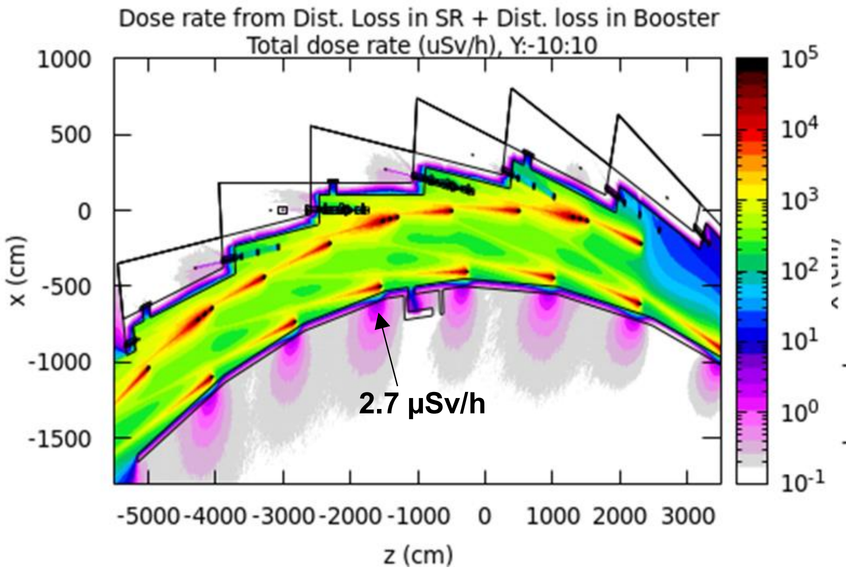


❑ Summing 2 beam loss scenarios-top view

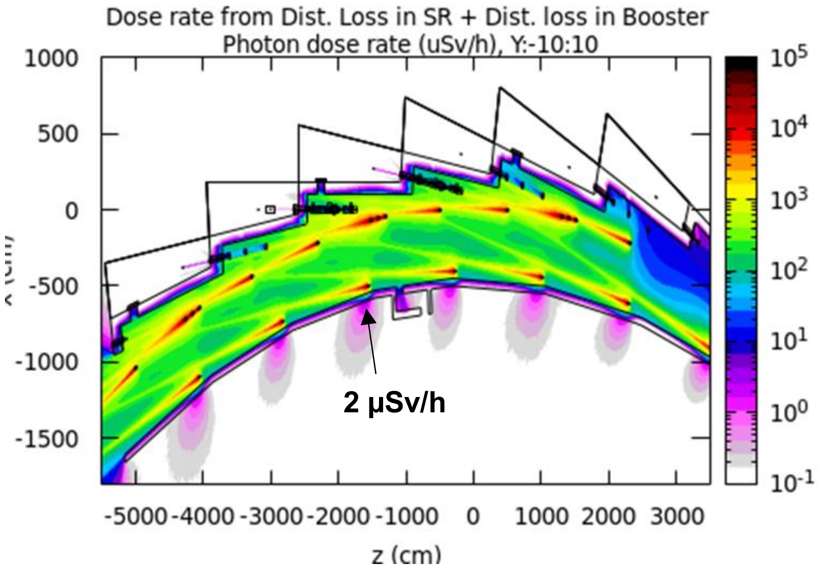
- Dose rate from uniformly distributed beam loss along the storage ring is added to the dose rate from uniformly distributed beam loss along the booster ring.

- The dose at the infield outer wall is within the design limit (5μSv/h), and the dose outside the building remains well below acceptable levels.

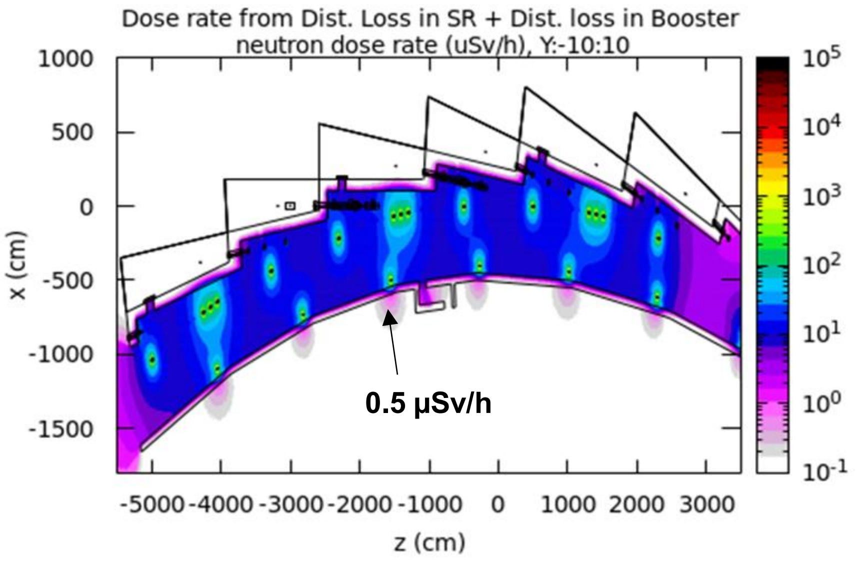
Total dose rate (all particles)



Photon dose rate



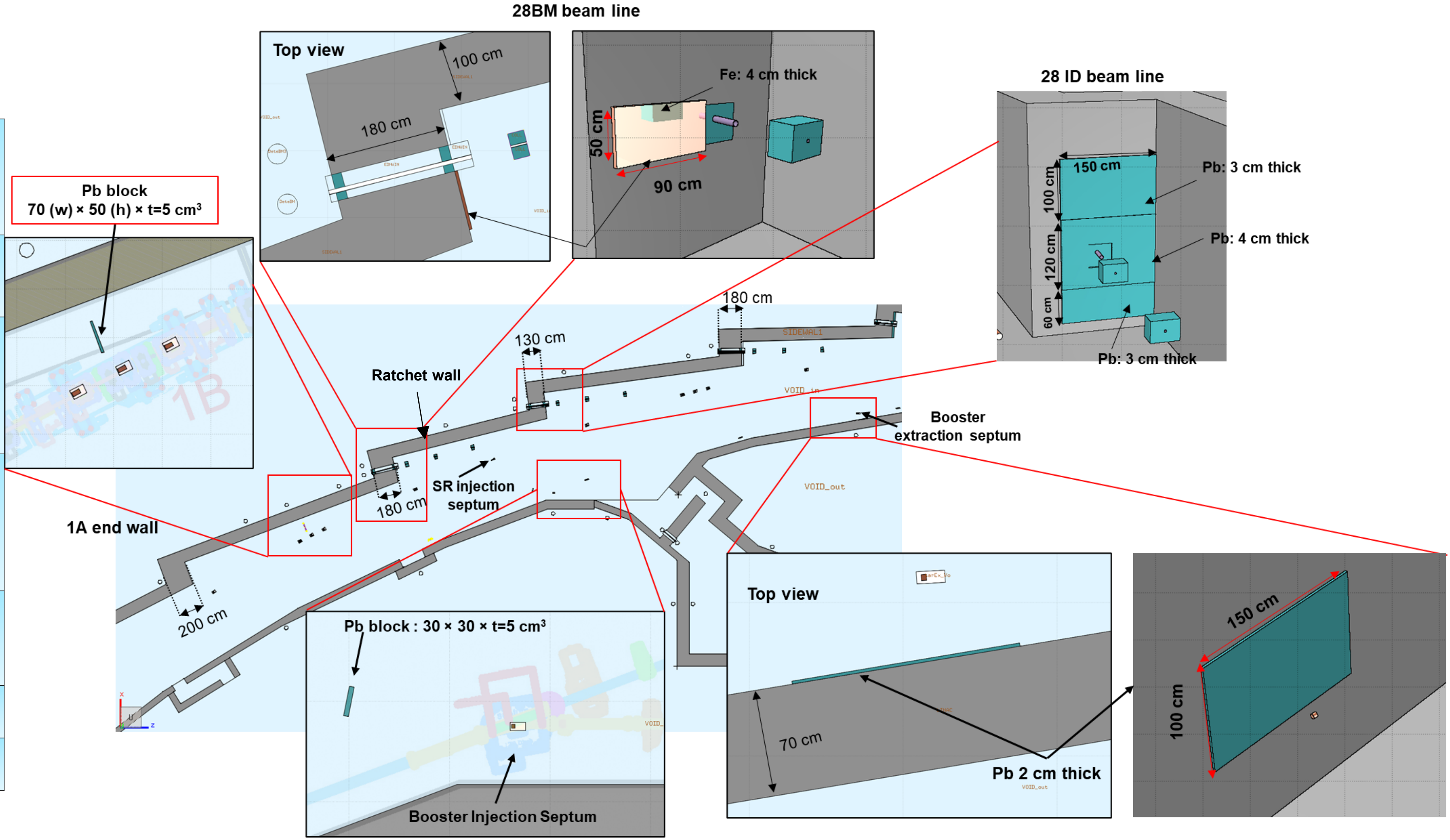
Neutron dose rate



Shielding calculations for injection area

❑ Tunnel wall structure

Position [injection area]	Shielding material and thickness
Ratchet wall	100 cm O.C.*
Inner wall	- Near Booster extraction septum: 70 cm O.C + 2 cm Pb plate - Other areas: 70 cm O.C.
End wall	ID** beamline: 130 cm O.C. + 4 cm thick Pb with 3 cm-thick Pb plates up and down
	28 BM*** beamline: 180 cm O.C. + 4 cm thick Fe
	1A end wall: 200 cm O.C.
Ceiling	70 cm O.C.



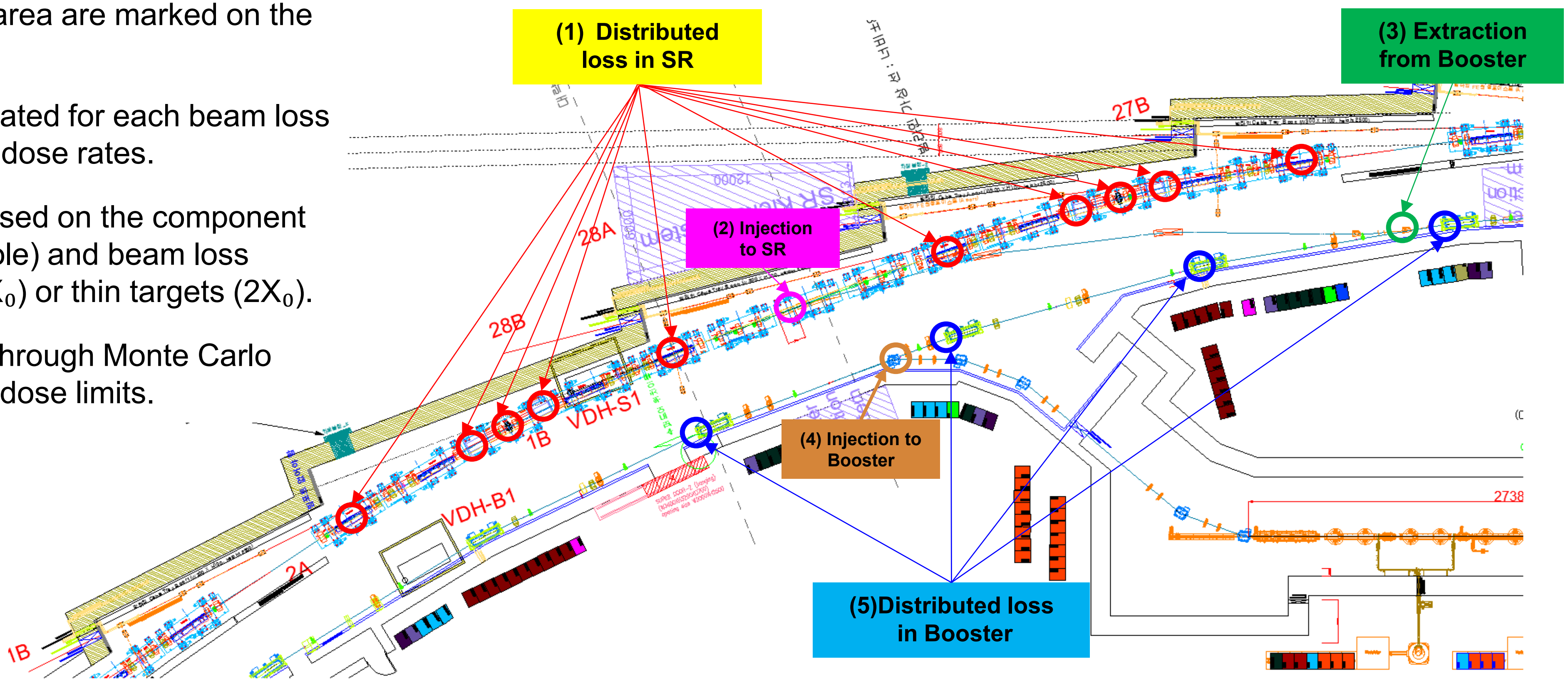
*O.C (ordinary concrete) density: 2.3 g/cm^3

**ID: Insertion device (undulator or wiggler), ***BM: Bending magnet

Shielding calculations for injection area

❑ Beam loss positions

- Beam loss locations in the injection area are marked on the CAD drawing for clarity.
- Separate FLUKA input files were created for each beam loss scenario to compute radiation flux and dose rates.
- Target thicknesses were selected based on the component type (e.g., septum magnet or quadrupole) and beam loss location, using either thick targets ($10X_0$) or thin targets ($2X_0$).
- Tunnel wall structure was validated through Monte Carlo simulations to ensure compliance with dose limits.



(1) Distributed loss in SR

(2) Injection to SR

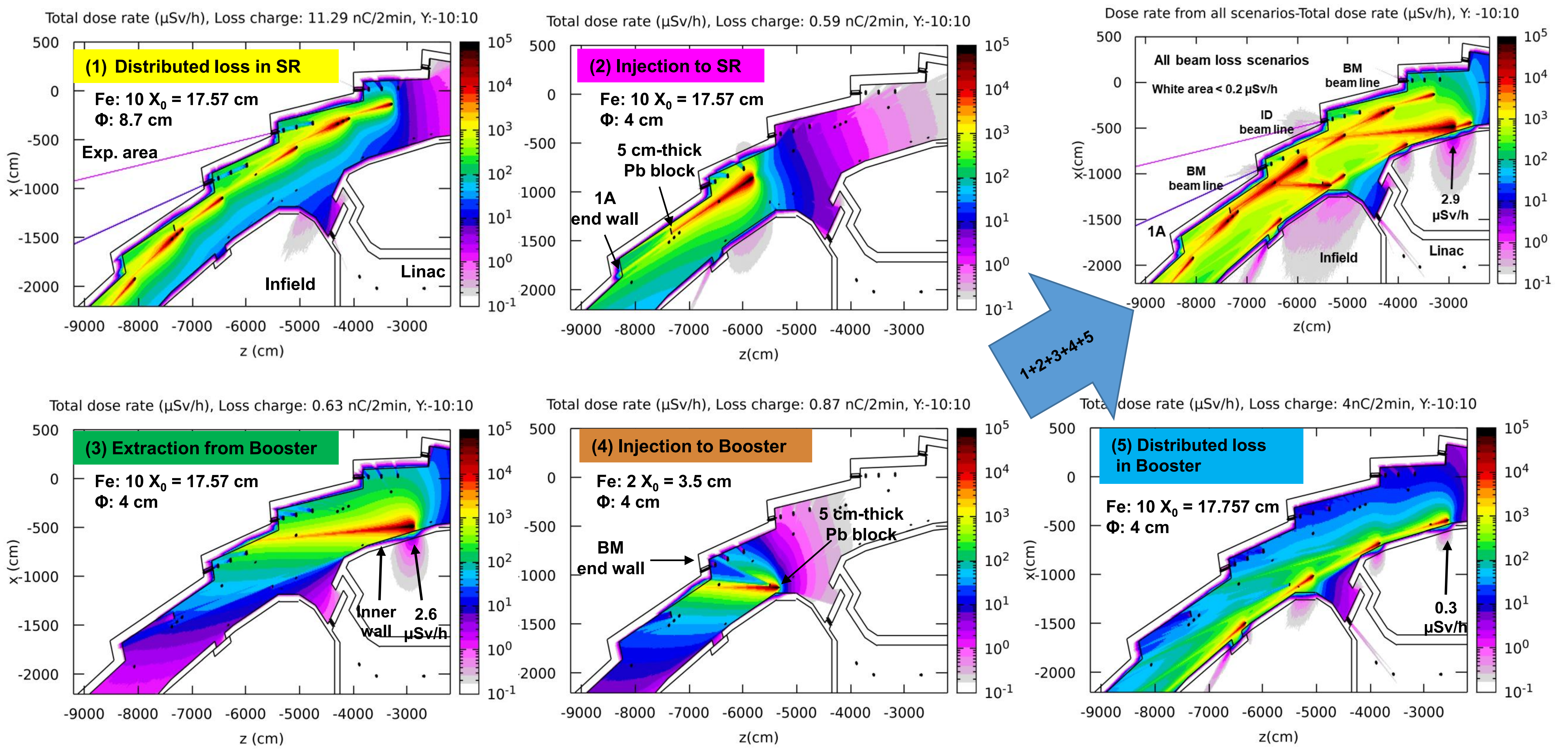
(3) Extraction from Booster

(4) Injection to Booster

(5) Distributed loss in Booster

Resultant dose rate = (1)+(2)+(3)+(4)+(5)

Summing all 5 beam loss scenarios-Top view



Summing all 5 beam loss scenarios-Top view

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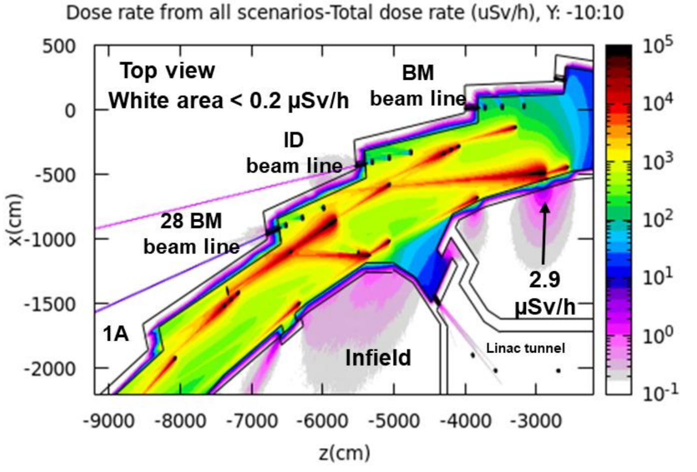
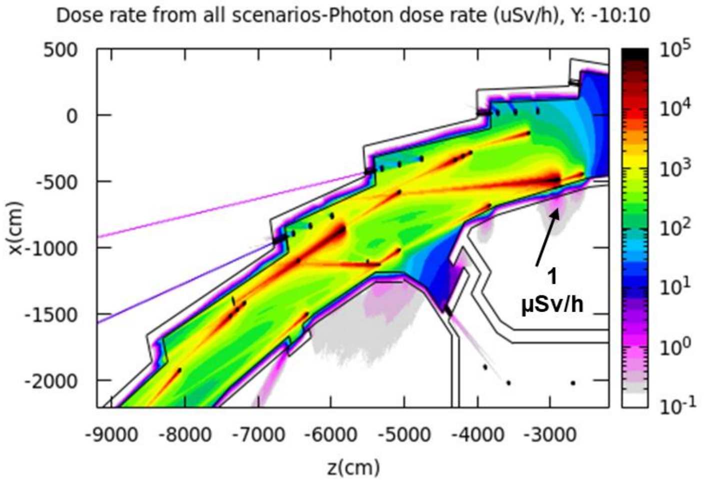
- Neutron dose rate is higher than the photon dose rate after the inner wall.
- Photon dose rate is higher than the neutron dose rate above the roof.

- Roof with 70 cm thick O.C. is enough to keep the dos e rate below the 5 μSv/h limit.

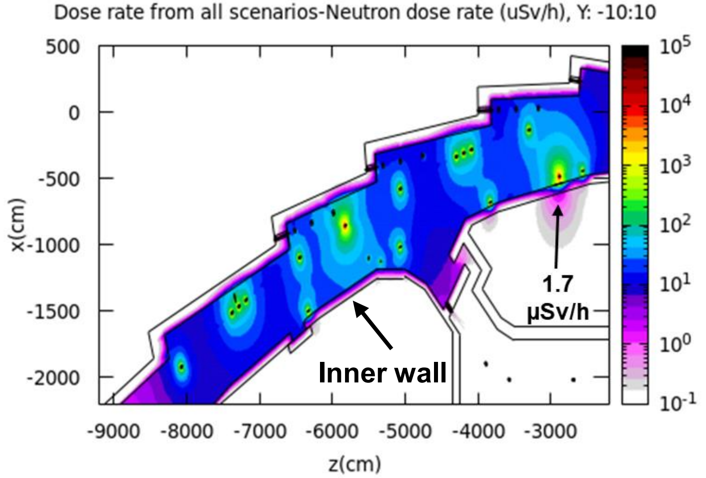
Total dose rate (all particles)

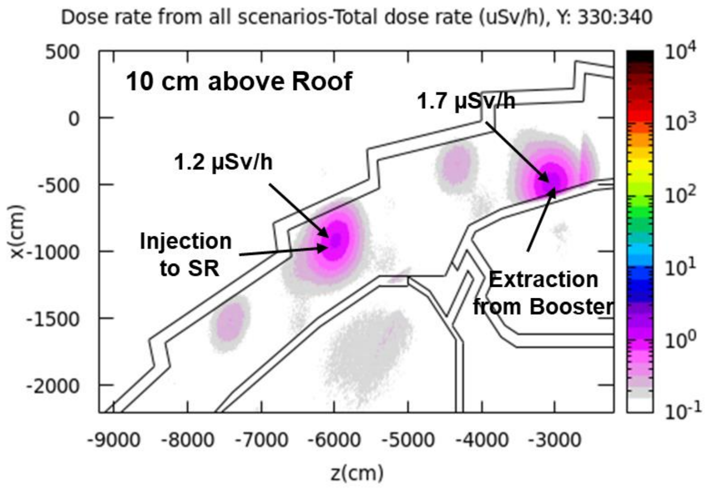


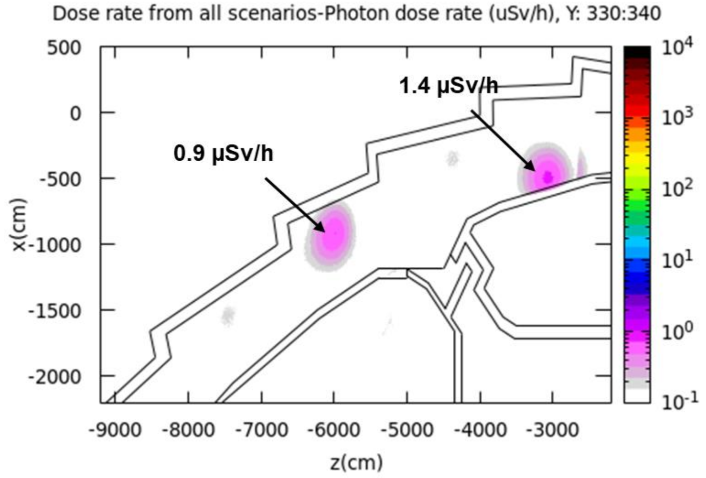
Photon dose rate

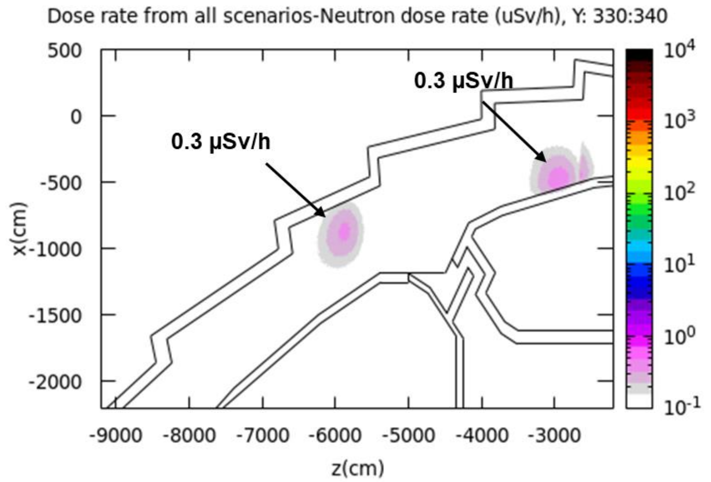


Neutron dose rate



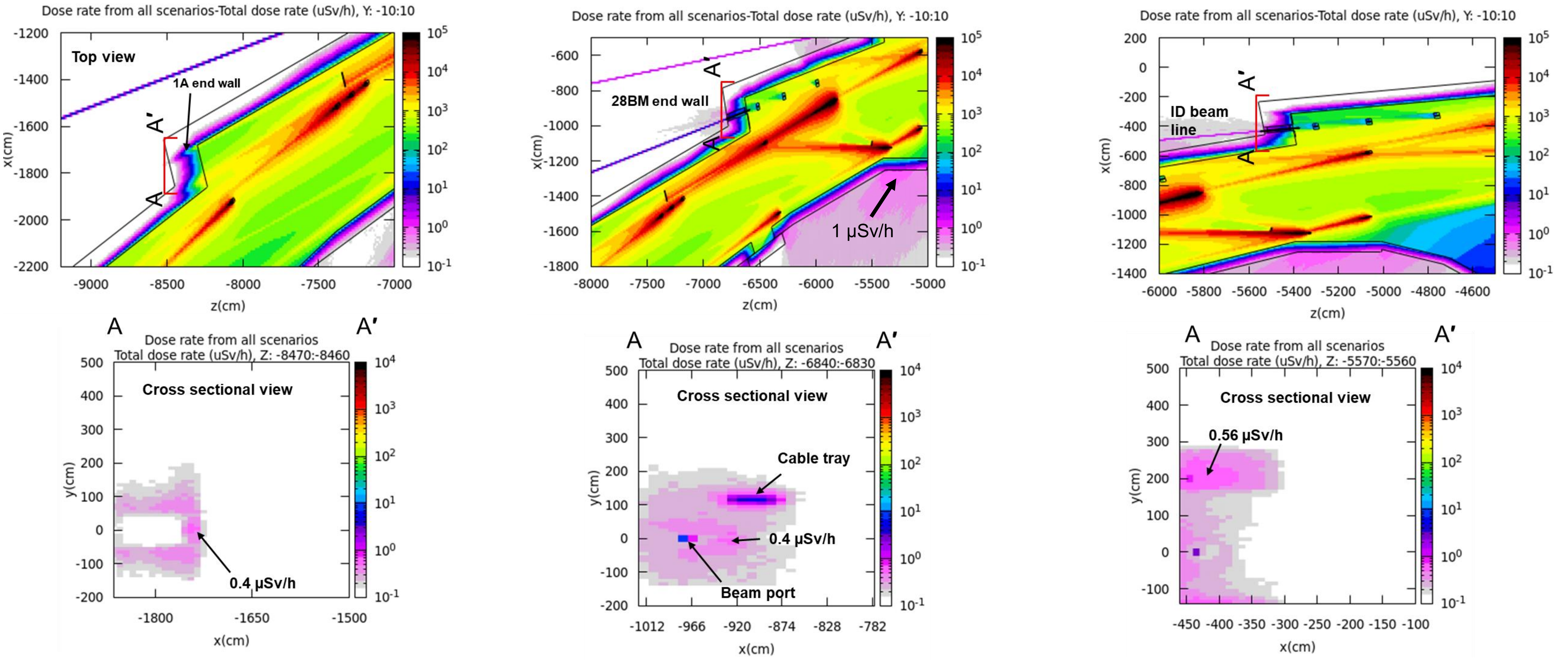






Summing all 5 beam loss scenarios-Top and vertical views

- Total dose rate < 0.2 μSv/h in the experimental area.
- The shielding structures of the end wall is sufficient to keep the total dose rate below the limit of 0.5 μSv/h.



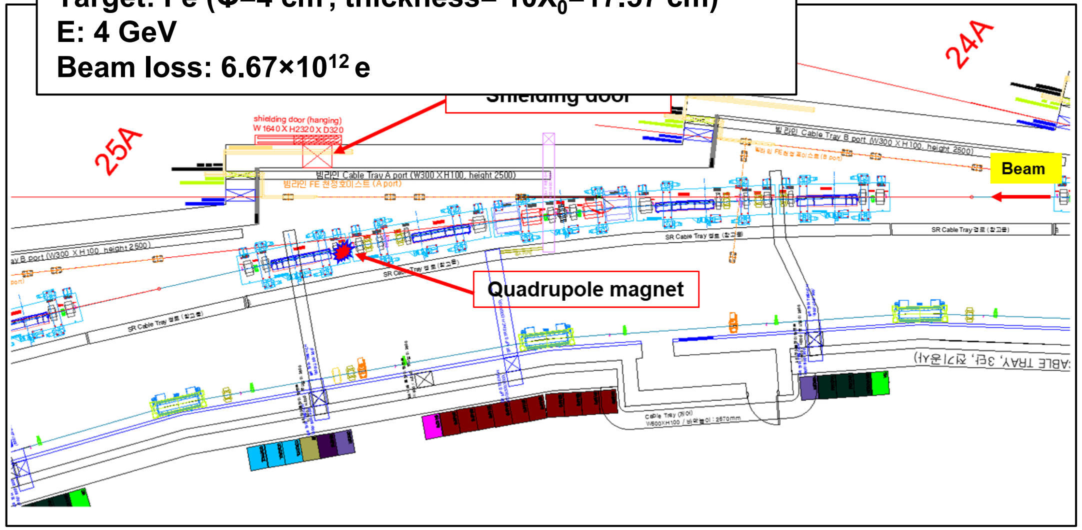
❑ Abnormal beam loss scenarios in storage ring

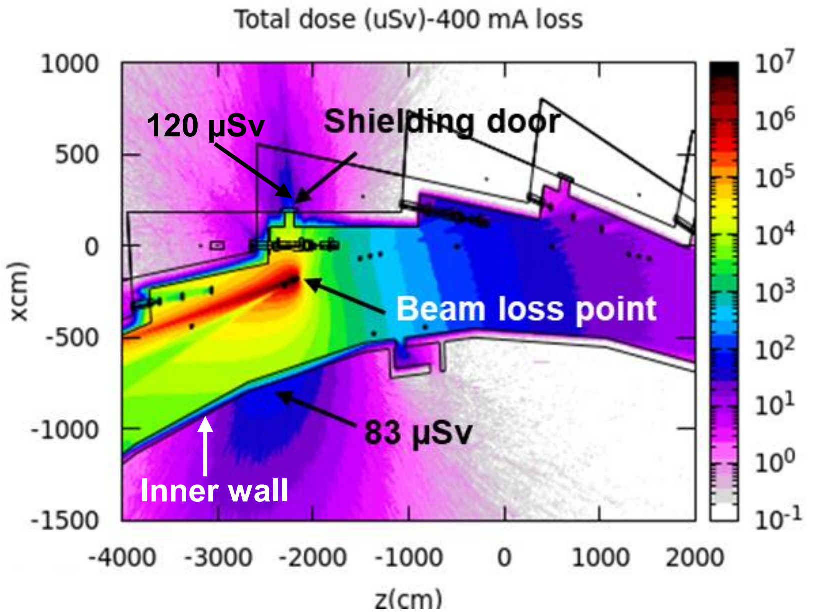
- Beam loss at Quadrupole magnet in storage ring.
  - Beam loss: 400 mA (6.67×10^{10} e) is lost.
  - The dose is around 120 μSv 10 cm after the shielding door.
    - Neutron dose is slightly higher than the photon dose.
  - The total dose is 83 μSv after the inner wall.
    - Photon dose is higher than the neutron dose after the inner wall.

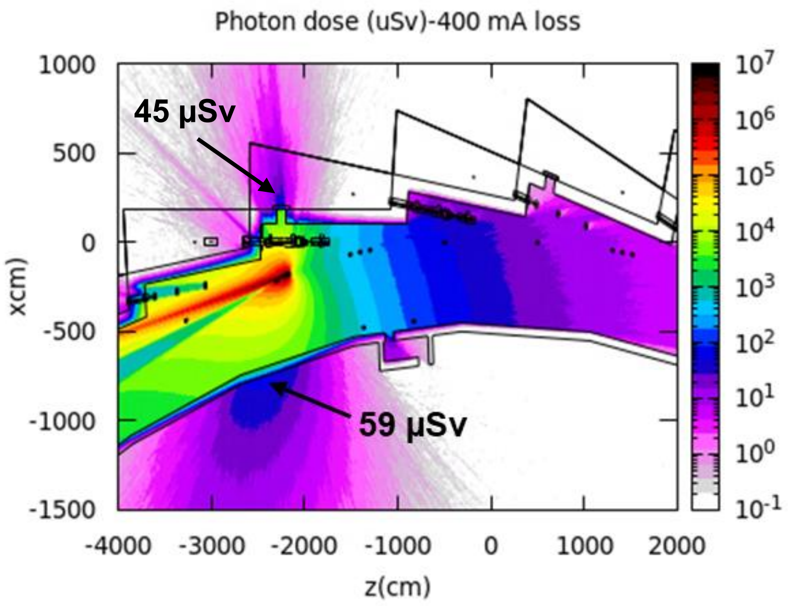
➢ **Dose limit for accident cases: 1 mSv (1000 μSv) for one event.**

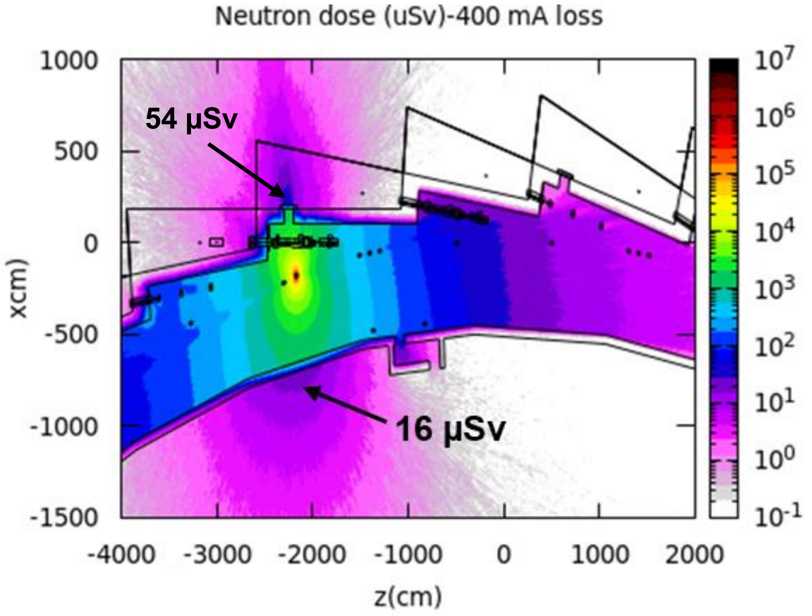
➢ **The dose rate is below 1000 μSv.**

Target: Fe (Φ=4 cm , thickness= $10X_0$=17.57 cm)
E: 4 GeV
Beam loss: 6.67×10^{12} e









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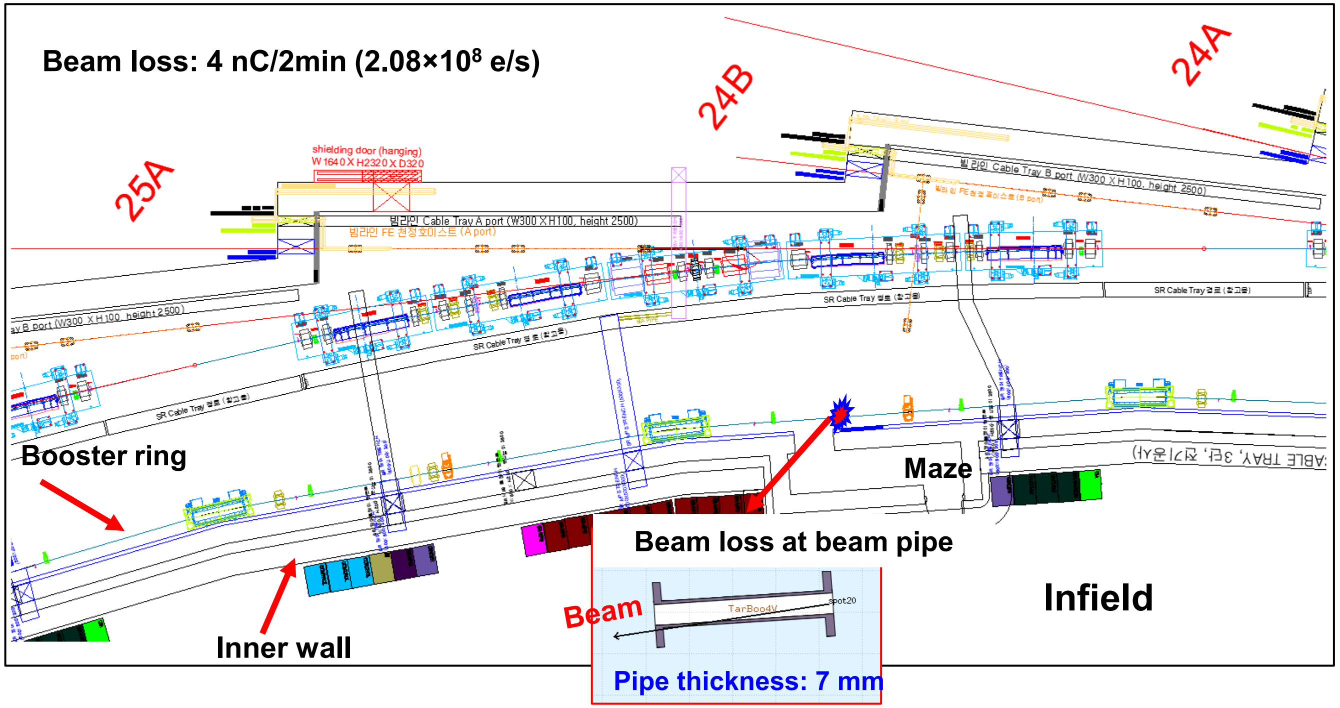
❑ Abnormal beam loss scenarios in booster ring

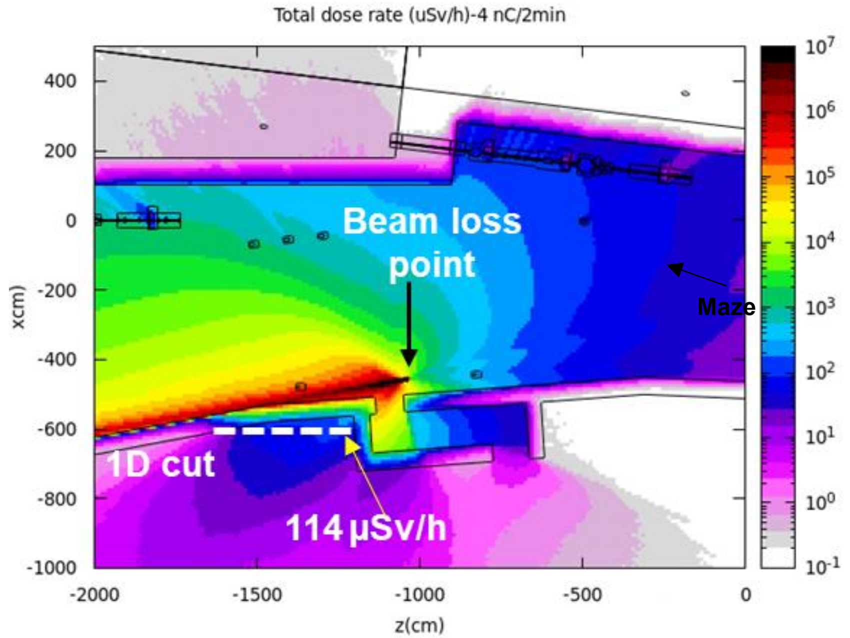
Beam loss at beam pipe (Beam incident angle: 5 deg)

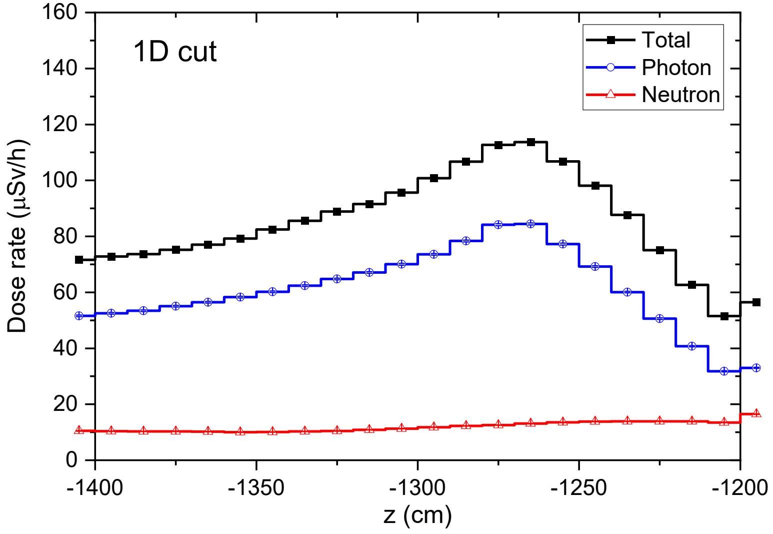
- The dose rate is 114 μSv/h in the infield area after the inner wall.

➢ **Dose limit for accident cases: 1 mSv (1000 μSv) for one event.**

➢ **The dose rate is below 1000 μSv.**







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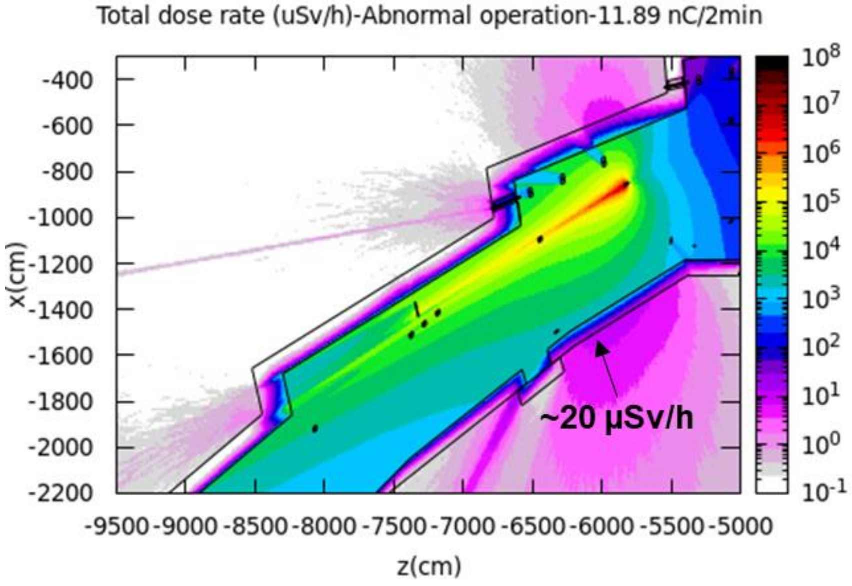
❑ Abnormal beam loss scenarios

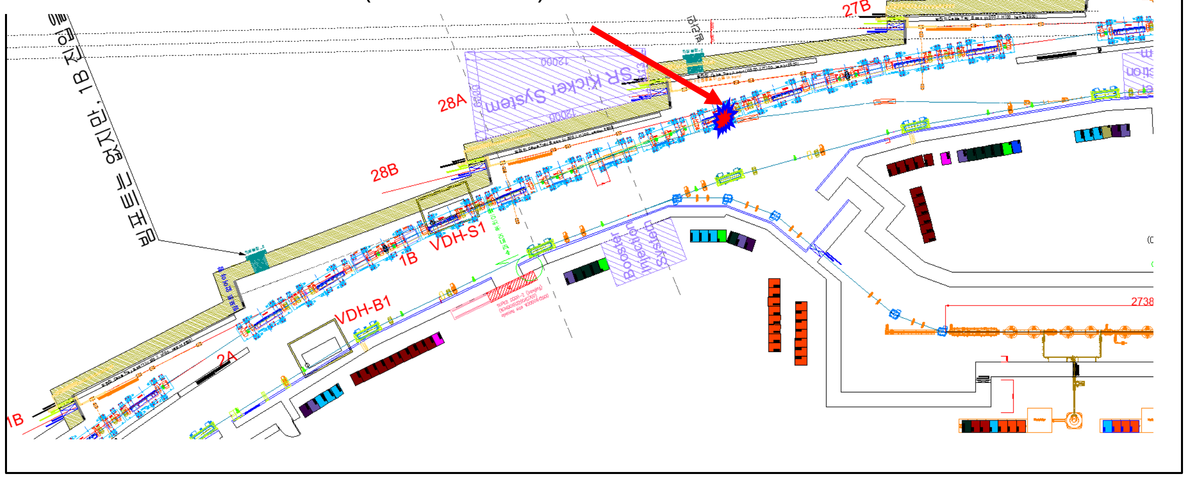
1. At SR septum magnet:
   - The dose rate is around 20 μSv/h in the infield area and 22 μSv/h on the roof.

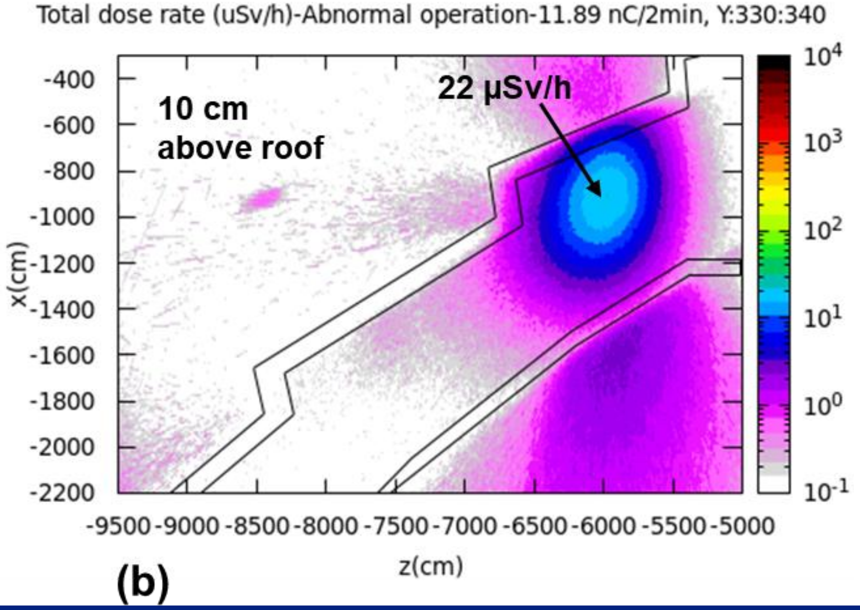
➢ **Dose limit for accident cases: 1 mSv (1000 μSv) for one event.**

➢ **The dose rate is below 1000 μSv.**



(1) Injection to SR
E= 4GeV
Target: Fe (Φ=4 cm, thickness= $10X_0$=17.57 cm)
Beam loss: 11.89 nC/2min (6.19×10^{8} e/s)





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❑ Abnormal beam loss scenarios

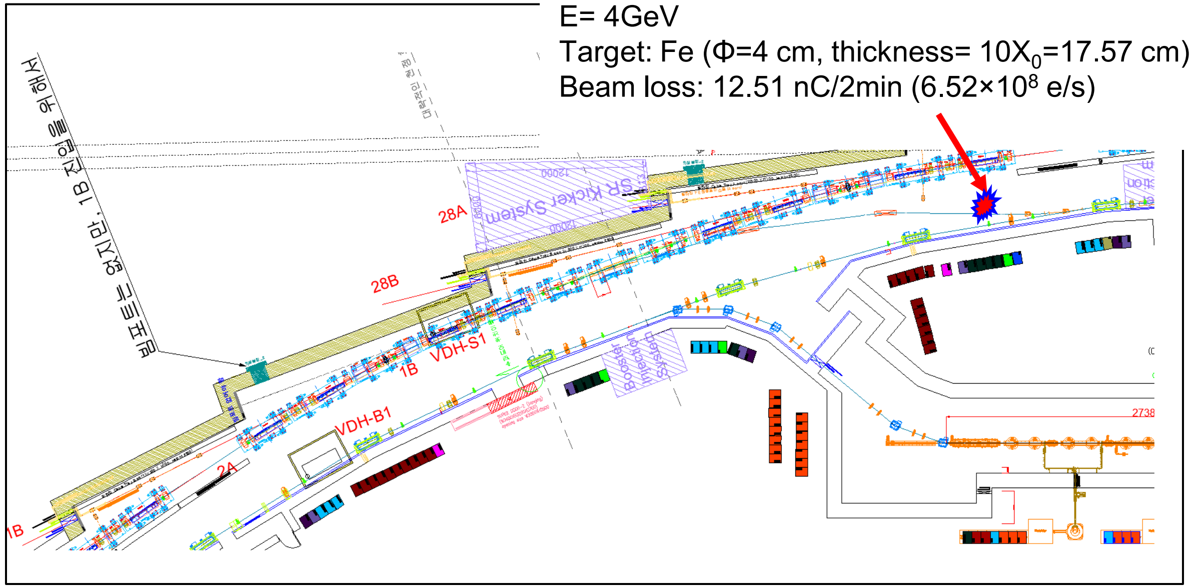
2. At Booster extraction septum:

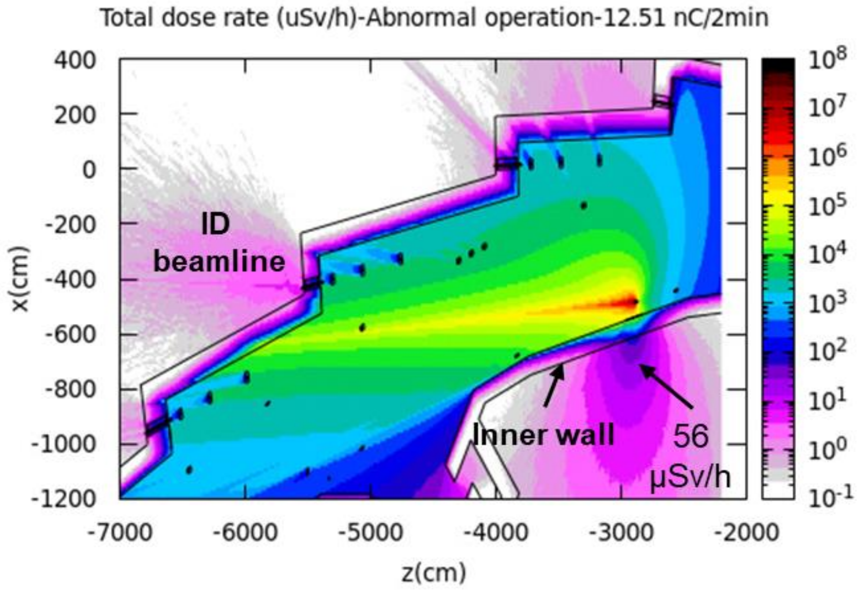
- The dose rate is around 56 μSv/h in the infield area close to the extraction point and 23 μSv/h on the roof.

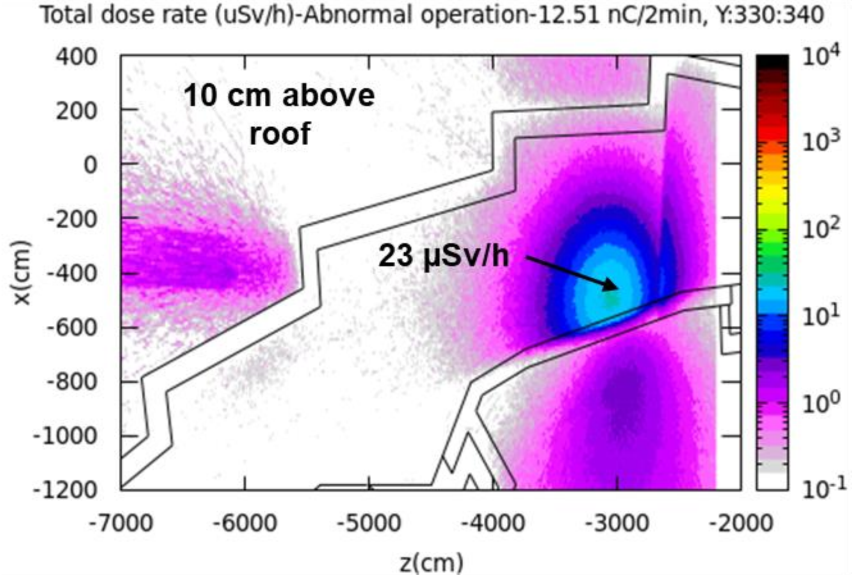
➢ **Dose limit for accident cases: 1 mSv (1000 μSv) for one event.**

➢ **The dose rate is below 1000 μSv.**

(2) Extraction from Booster
E= 4GeV
Target: Fe (Φ=4 cm, thickness= $10X_0$=17.57 cm)
Beam loss: 12.51 nC/2min (6.52×10^8 e/s)







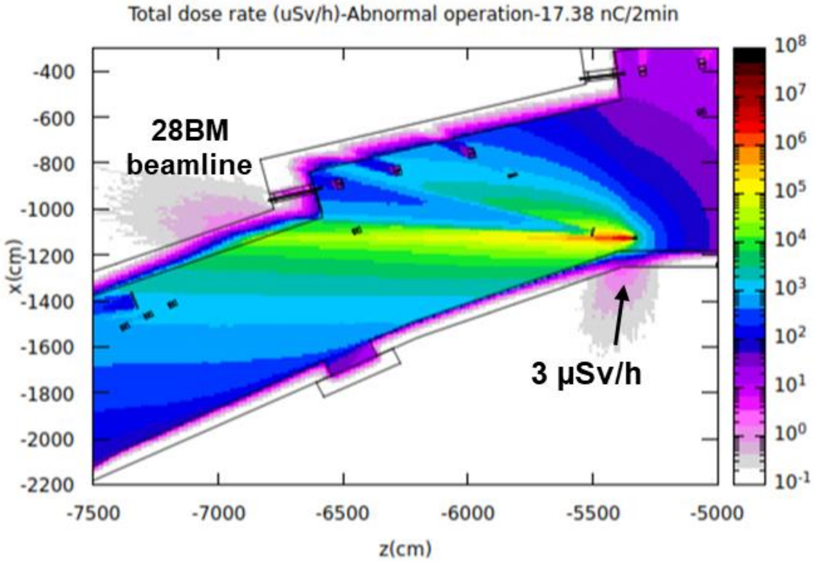
❑ Abnormal beam loss scenarios

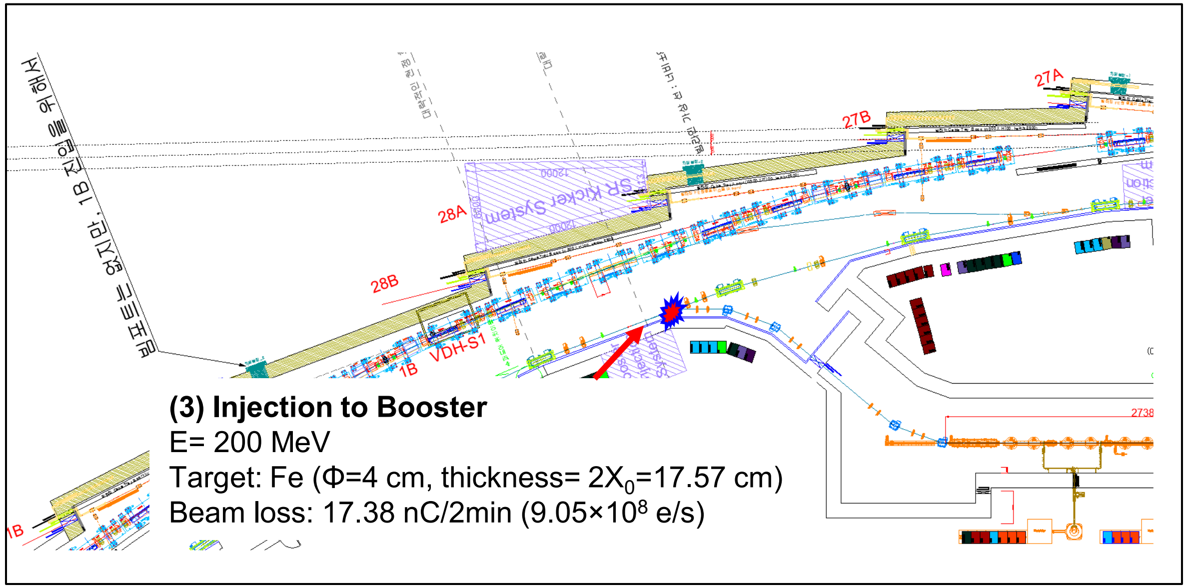
3. At Booster injection septum:

- The dose rate is around 3 μSv/h in the infield area close to th e extraction point.

➢ **Dose limit for accident cases: 1 mSv (1000 μSv) for one event.**

➢ **The dose rate is below 1000 μSv.**





(3) Injection to Booster
E= 200 MeV
Target: Fe (Φ=4 cm, thickness= $2X_0$=17.57 cm)
Beam loss: 17.38 nC/2min (9.05×10^8 e/s)

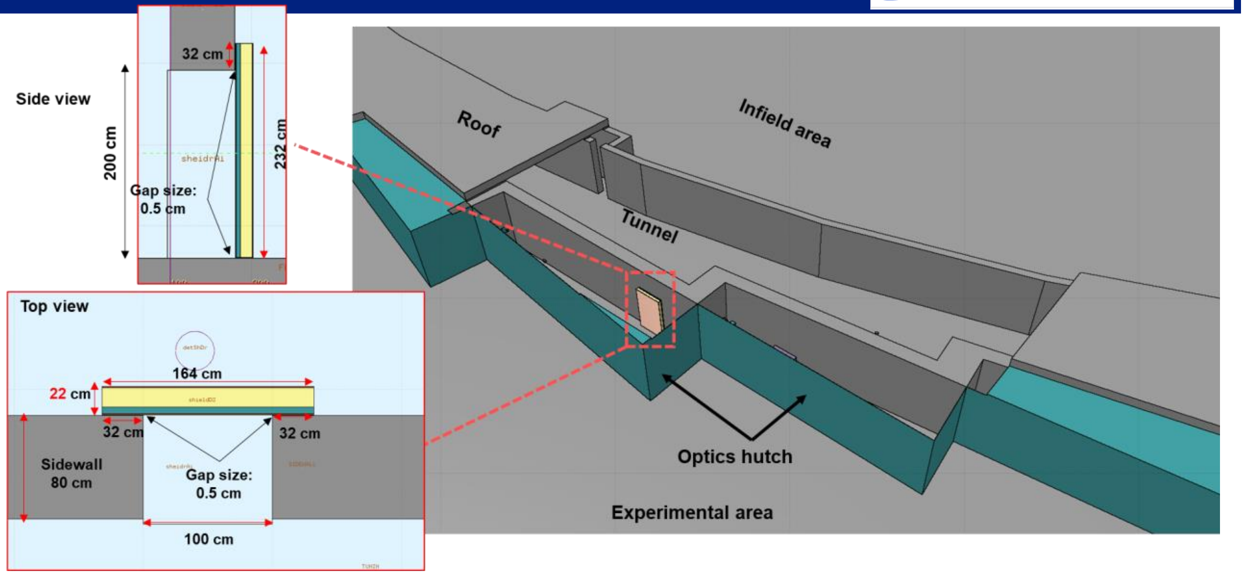
Shielding door design

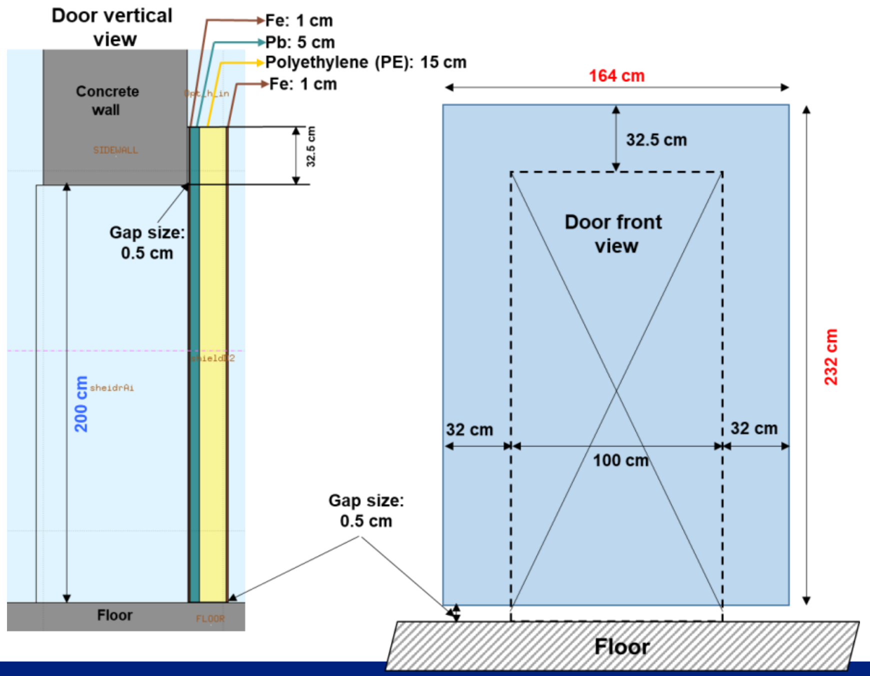
❑ Components of the shielding door from inside to outside

- 1 cm Iron (Fe)
- 5 cm Lead (Pb)
- 15 cm polyethylene (PE)
- 1 cm Iron (Fe)
- Total thickness: 22 cm

❑ Additional requirements

- Gap between the door and wall is 0.5 cm
- Gap between the door and floor is 0.5 cm
- Door overlap on the top is 32.5 cm
- Door overlap on the left side is 32 cm
- Door overlap on the right side is 32 cm
- Door height is 232 cm
- Door width is 164 cm





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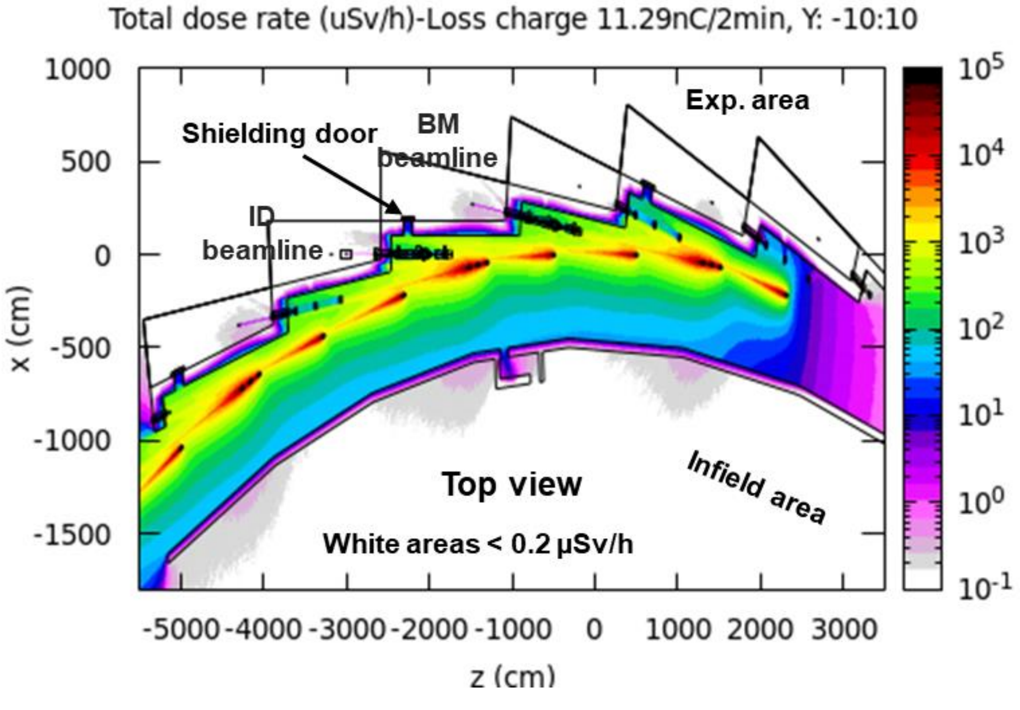
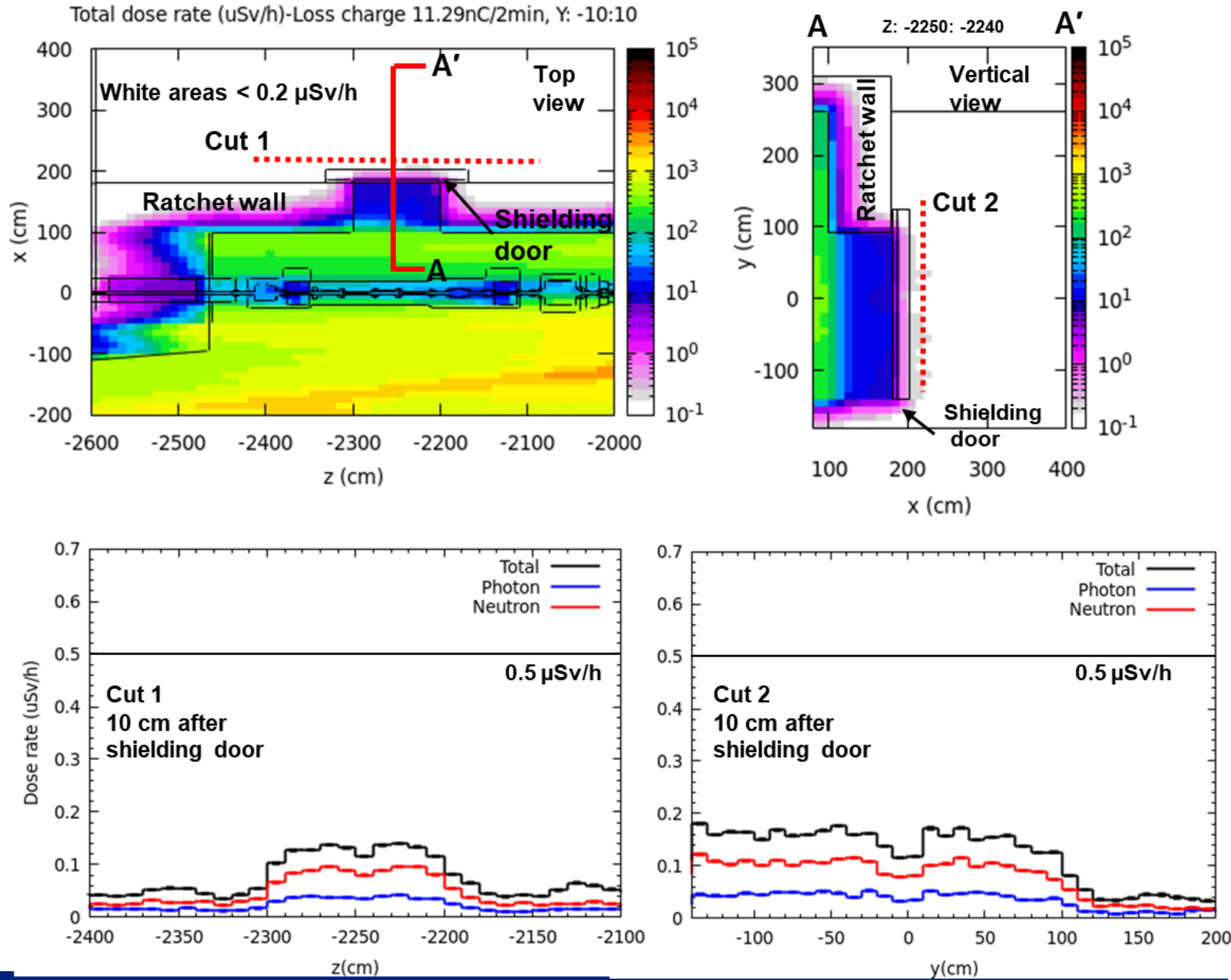
❑ Normal operation

- **Uniformly distributed beam loss along storage ring**
  - The designed shielding door effectively keeps the dose rate below 0.2 μSv/h in the experimental area for normal operation beam loss scenario.





Shielding door design

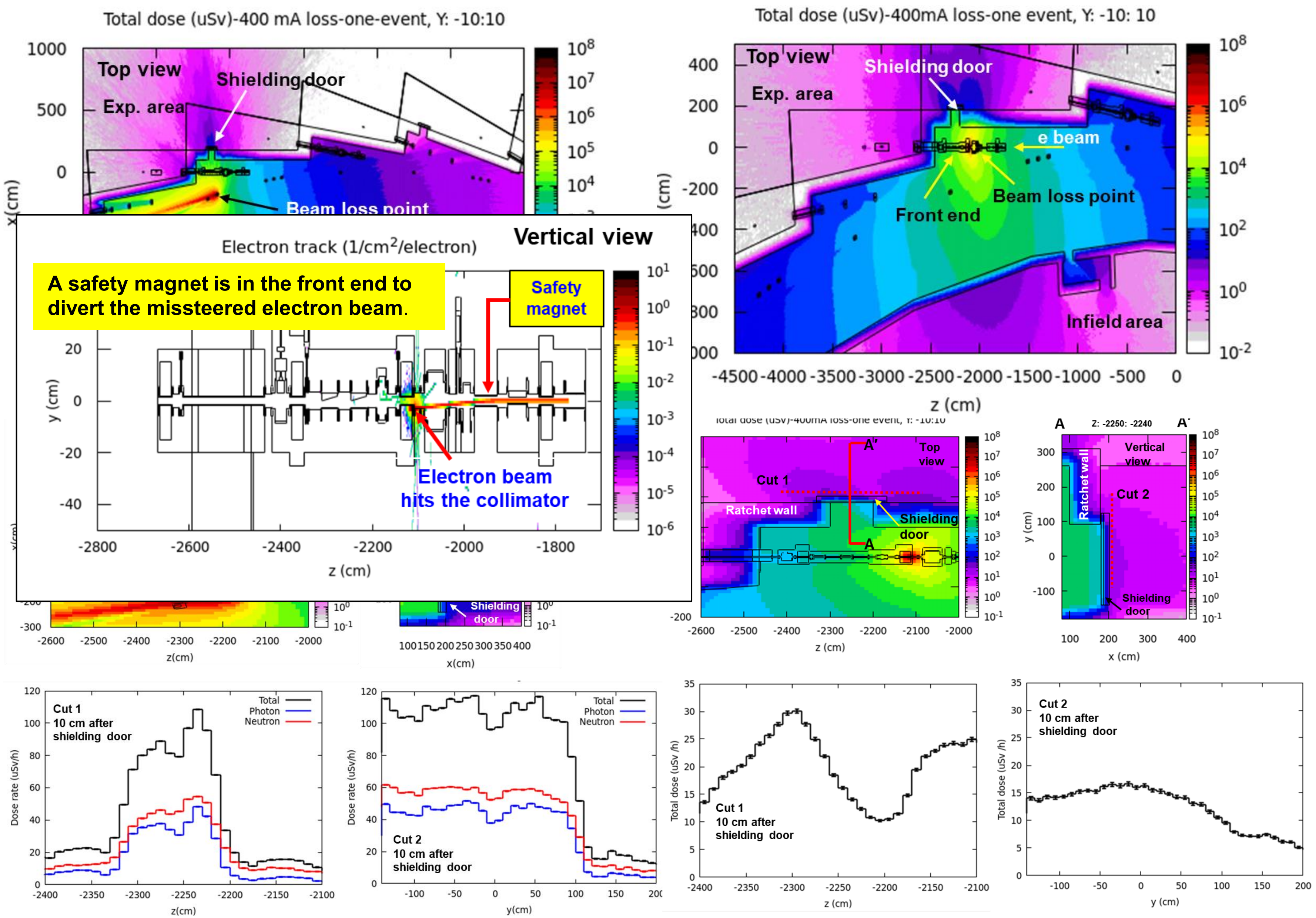
❑ Abnormal operation

I. Stored beam is lost at a quadrupole magnet in SR

- Dose limit for accident cases: 1 mSv (1000 μSv) for one event.
- The dose beyond the shielding door is 110 μSv which is far below 1000 μSv for this beam loss position.

II. The whole stored beam is lost at the dump collimator after the safety magnet.

- The dose beyond the shielding door is less than 30 μSv which is far below 1000 μSv for this beam loss position.



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- Preliminary shielding calculations were performed using the FLUKA 4-4.0 Monte Carlo code to determine the tunnel wall structures for the Linac, injection and non-injection areas.

- **Normal** and **abnormal** beam loss scenarios were considered to ensure the shielding are sufficient to keep the dose rate below the limit in accordance with Korean regulations.

- The calculations were performed assuming **90% injection efficiency and 4mA/injection every 2 min**.
- A layered **shielding door** of 1 cm-thick Fe+5 cm-thick Pb+15 cm-thick PE+1 cm-thick Fe was designed.
- The preliminary designed shielding structures are sufficient to keep the dose rate below the criteria for the current design.

Plans:

- Shielding calculations will be performed considering more detailed geometry using **unstructured mesh feature** in FLUKA 4-4.5.
- Calculations will be performed using **PHITS Monte Carlo** code to compare with the FLUKA calculations.
- Beam line shielding calculations are ongoing using **STAC8 [1]** code:
  - Results will be compared with **FLUKA 4-4.5** and **FLUKA 2025.1** [2].

[1] Y.Asano and N.Sasamoto, Radia. Phys. Chem. Vol.44 p133 (1994)
[2] F. Ballarini et al., EPJ Nuclear Sci. Technol. 10, 16 (2024)

More details can be found in our publications

Journal paper: Will be published online soon

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RESEARCH - PARTICLES AND NUCLEI

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Radiation shielding aspects and Monte Carlo analysis of the 4th generation storage ring in Korea

Mahdi Bakhtiari[1] · Nam-Suk Jung[1] · Hee-Seock Lee[1]

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Abstract
The 4th generation storage ring (4GSR) facility is under construction in Korea. The facility includes a 200-MeV Linac, a booster ring operating from 200 MeV to 4 GeV, and a storage ring. Storage ring circumference is 799.297 m, stored electron energy and current are 4 GeV and 400 mA, respectively. Both storage ring and booster ring are located in the same tunnel. Shielding assessment was performed using the FLUKA 4−4.0 Monte Carlo code to determine the required thickness and shielding structure of the Linac and storage ring tunnels. Various beam loss scenarios under normal and abnormal operations were considered for the shielding analysis. The injection efficiency from booster ring into storage ring was assumed as 90%. For the shielding calculations, it was assumed that 4 mA beam current is injected into the storage ring every 2 min. The electron beam injection from Linac to booster ring, beam extraction from booster ring, and injection from booster ring to storage ring are all located near each other. Thus, the shielding calculations were categorized for the injection area and non-injection area so that for each area different tunnel wall thicknesses were considered. The shielding criteria were based on the Nuclear Safety Act in Korea and the As Low As Reasonably Achievable (ALARA) principle. These simulations will provide an overall radiological framework for shielding the 4GSR in Korea based on the present design conditions.

Keywords Shielding calculations · FLUKA Monte Carlo code · 4th generation storage ring · Synchrotron radiation

1 Introduction

The 4th generation storage ring (4GSR) facility has been planned and launched in Korea since July 2021. Storage ring circumference is 799.297 m and is composed of 28 symmetrical cells with a beam emittance of 62 pm.rad. The stored electron energy and current are 4 GeV and 400 mA, respectively. The facility includes a 200-MeV Linac, a booster ring, and a storage ring. Both storage ring and booster ring are located in the same tunnel. In the Korea-4GSR facility, beamlines are numbered based on their synchrotron radiation sources. The storage ring comprises 28 cells. Beamlines utilizing bending magnets (BM) are labeled 1B through 28B, while those employing insertion devices (ID), such as undulators, are designated 1A through 28A. Therefore, "1A" refers to the first beamline position. However, due to spatial constraints and other devices, a beam port will not be installed at the end wall of 1A beamline.

The radiation control policy of Korea-4GSR follows the Nuclear Safety Act of Korea, setting annual effective dose limits for workers, the public, and site boundaries accordingly. However, shielding criteria based on the As Low As Reasonably Achievable (ALARA) principle is applied to limit dose rates on the outer shielding walls to 10 mSv/year for radiation workers (half the permitted average). The radiation fields and shielding requirements have been calculated for the anticipated beam loss scenarios. These estimates are based on conservative assumptions, accounting for various operational modes that include normal beam loss mechanisms as well as specific abnormal beam loss scenarios. Shielding specifications for the Linac, storage ring, and booster ring are designed to limit personnel exposure to less than 10 mSv/year, assuming a worker is present for 2000 h annually. This corresponds to the dose rare of 5 μSv/h. In the accessible area for the public including beam line users, the exposure of 1 mSv/year is considered, corresponding to 0.5 μSv/h. The dose limit for an abnormal operation is 1 mSv/incident. The details of the shielding policy and area

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PAL-PUB-2025-001
Apr. 2025

Preliminary Shielding Calculations for the 4th Generation Storage Ring (4GSR) in Korea Using FLUKA Monte Carlo Code

Mahdi Bakhtiari, Hee-Seock Lee

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