中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

RADIATION AND PROTECTION ISSUE STUDIES IN CEPC

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CEPC workshop, 2022

OUTLINE

- Introduction
- Synchrotron radiation shielding
- Radionuclides productions in the tunnel
- Linac beam losses shielding
- Summary and outlook

Using FLUKA & Flair. (applies to: Synchrotron radiation shielding; Radionuclides productions in the tunnel; Linac beam losses shielding)

RADIOLOGICAL IMPACT

- Main consideration aspects

Impact factors	Characteristics
Synchrotron radiation	Radiation damage to magnets coils; Over heat load to ventilation system; Formation of ozone and nitrogen oxides in the air; Slightly activation to the material around;
Random beam loss	Cause secondary radiation inside the tunnel; Determine the bulk shielding thickness;
Hot spots	MDI, Collimation locations, collider/linac dumps, injection/extraction points;
Radiological impact on environment	Dose from stray radiation emitted during machine running Radionuclides in the cooling water, underground water, tunnel air, soil. Radioactivity analysis for the solid components and waste
Machine protection	Active/passive protection

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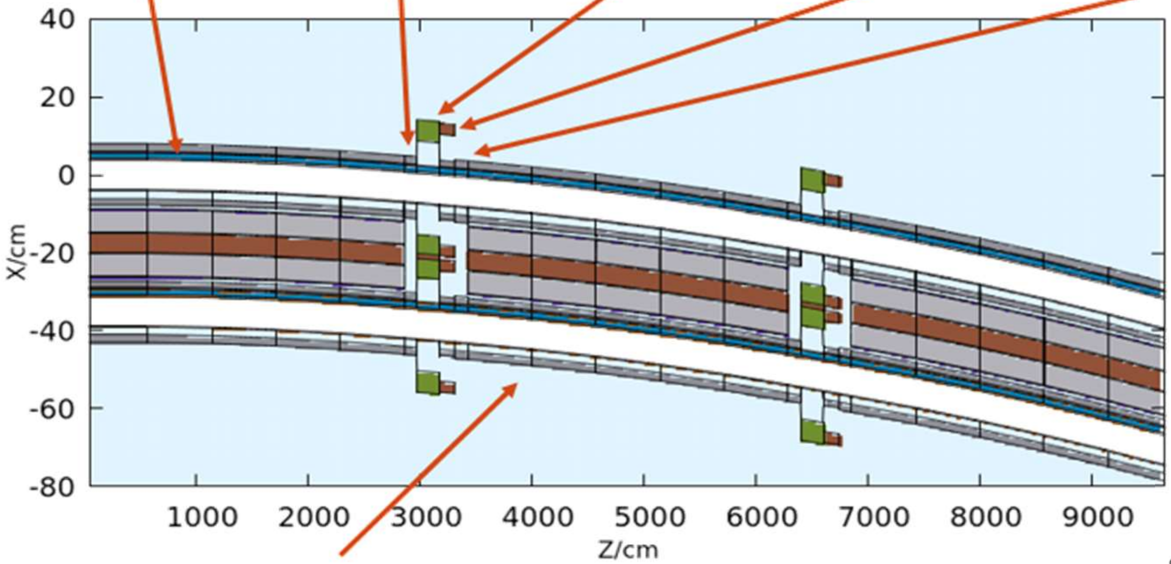
- Radionuclide productions
- Linac beam losses shielding
- Summary and outlook

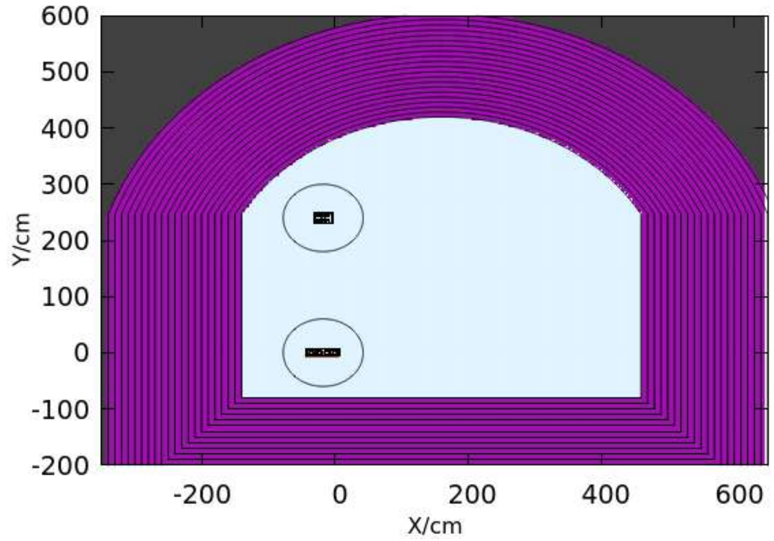
SIMULATION SETUP

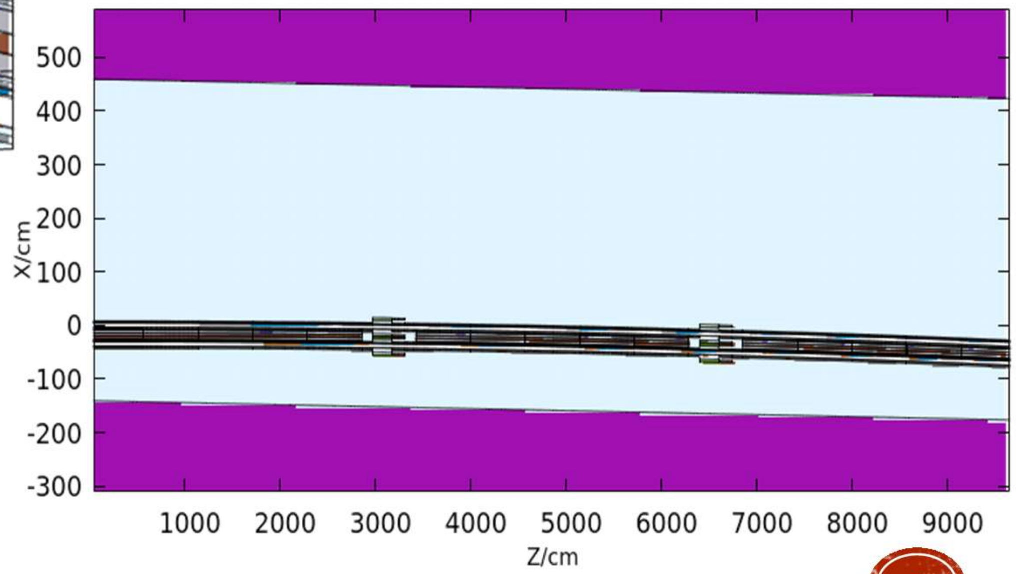
- Tunnel geometry

- 28m dipole -> 1.1m drift chamber -> 2m quadrupole -> 1.4m sextupole -> 1.1m drift



chamber -> 28m dipole -> ......

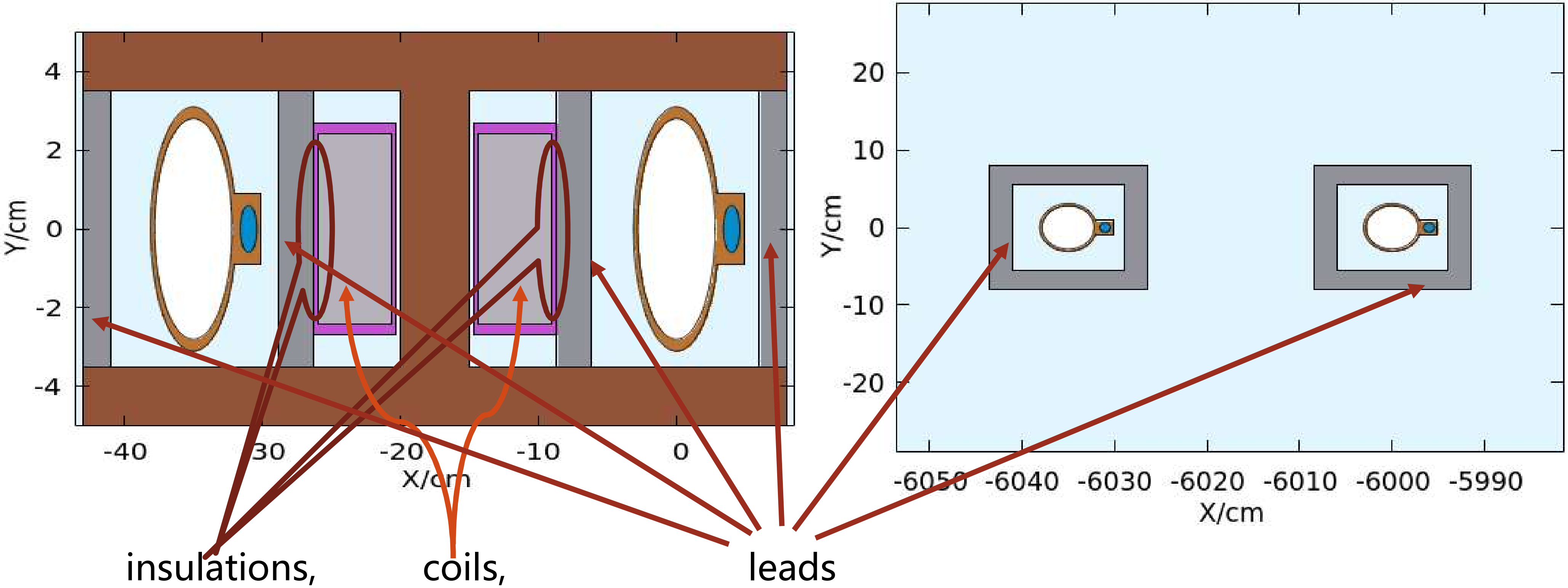




- Length: 100m;
  - 3 dipoles;
  - 2 quadrupoles;
  - 2 sextupoles;

SIMULATION SETUP

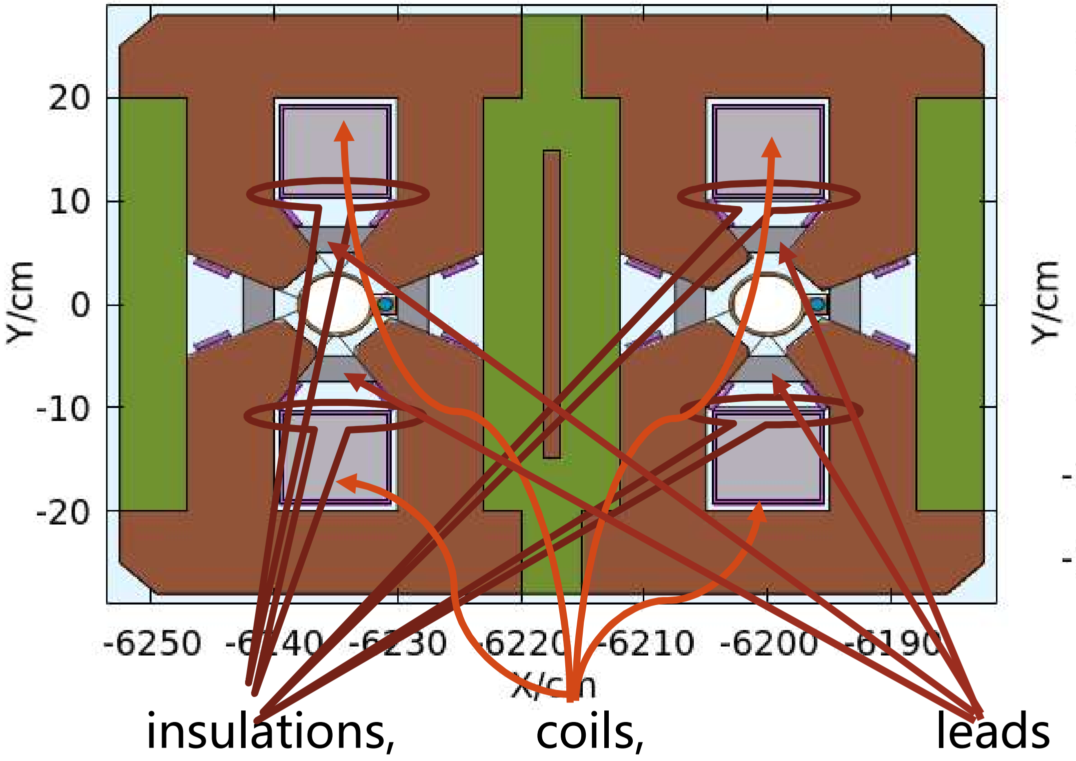
- Dipole
- Drift chamber



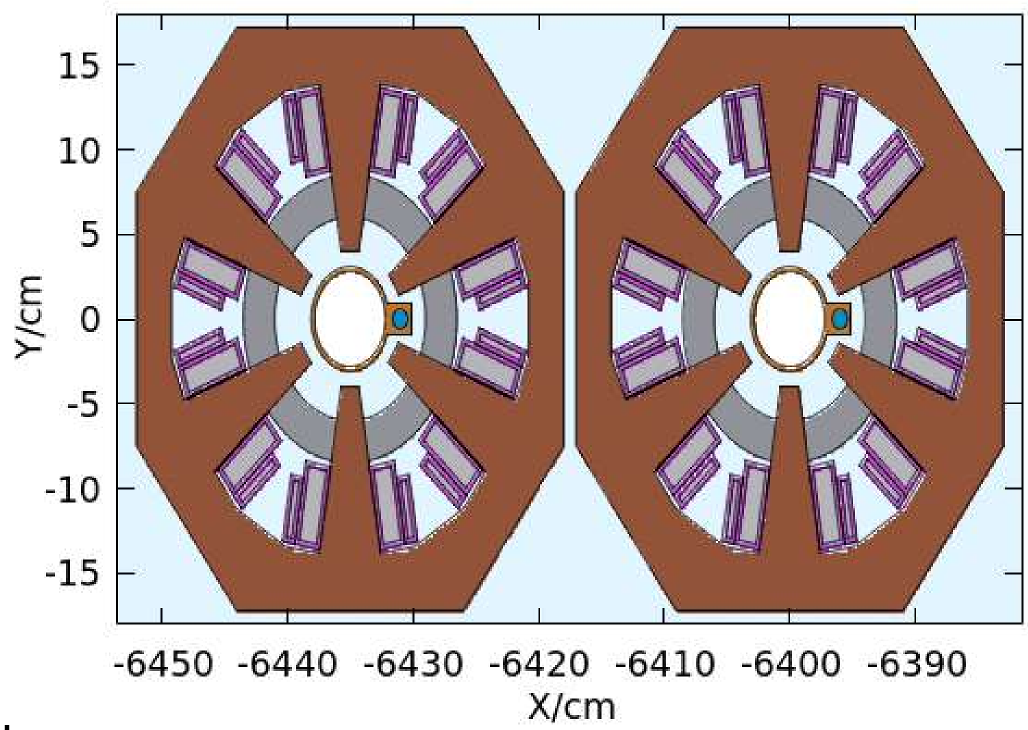
- Insulations is added in the model. Both beam-pipes are made of copper.
- In the cross-section, area of lead: $56cm^2$
- area of lead: $216cm^2$

SIMULATION SETUP

- Quadrupole



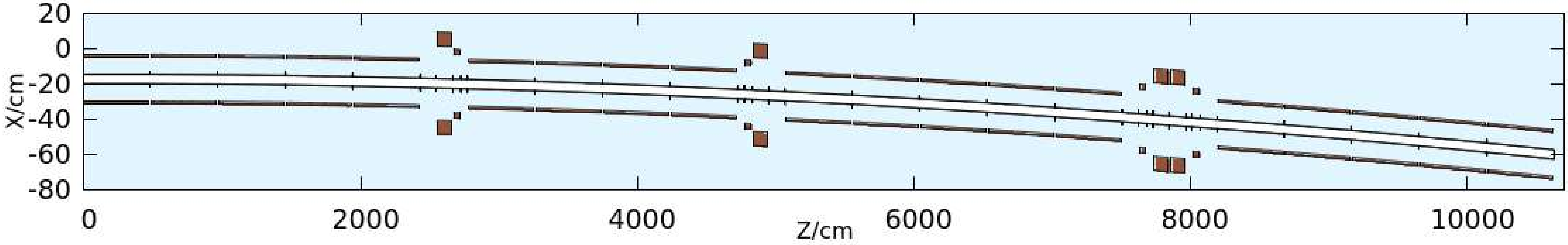
- Sextupole



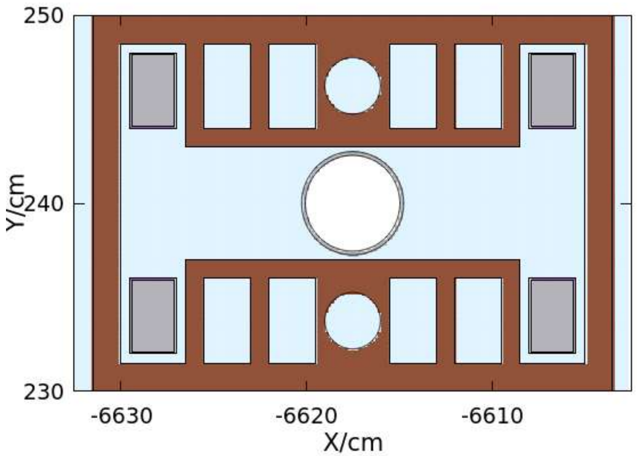
- area of lead : $96cm^2$
- area of lead : $100cm^2$

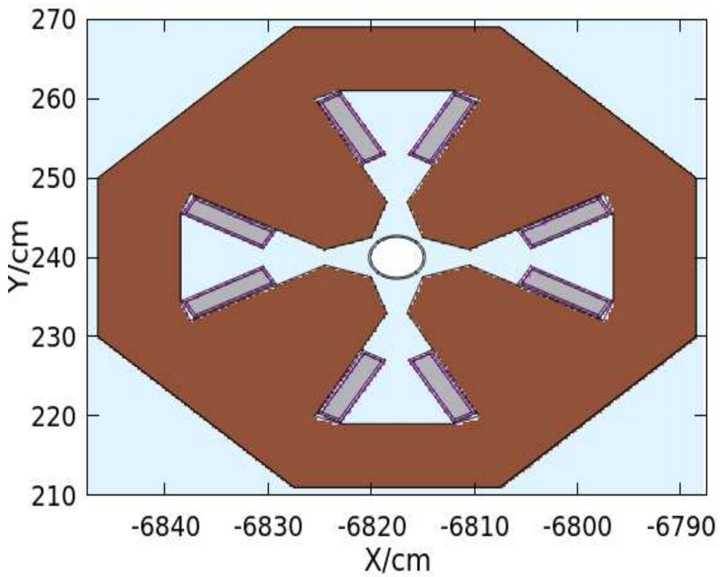
BOOSTER

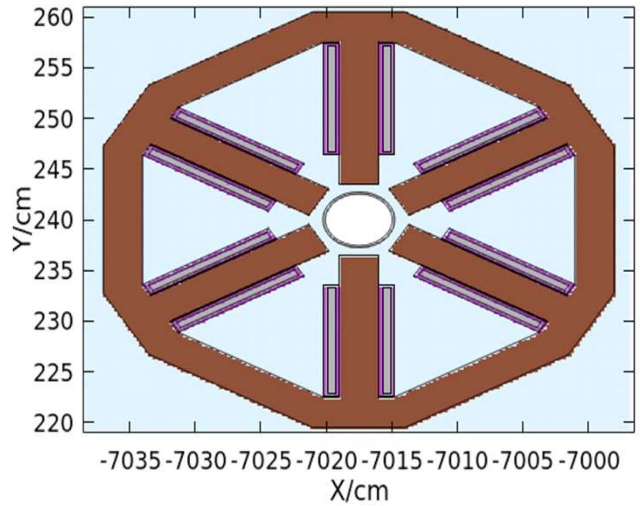
- dipole ->drift chamber ->quadrupole -> sextupole ->drift chamber ->dipole …



- Magnets







PARAMETERS: 50MW

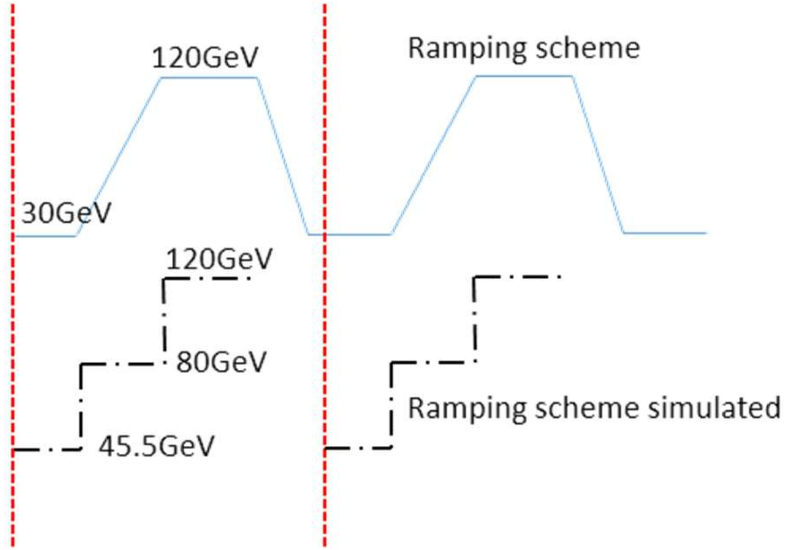
- Collider

	Higgs	WW	Z	ttbar
Beam energy/GeV	120	80	45.5	180
Ne/bunch/10^{10}	14	13.5	14	20
Number of bunches	415	2162	19918	58
Number of photons/114m	4.7e18	1.6e19	8.4e19	1.4e18

- Booster

	Higgs	WW	Z	ttbar
Current(mA)	0.98	2.85	14.4	0.11
Injection duration(s)	31.8	38.1	134.4	29.2
Injection interval(s)	38	155	153.5	65

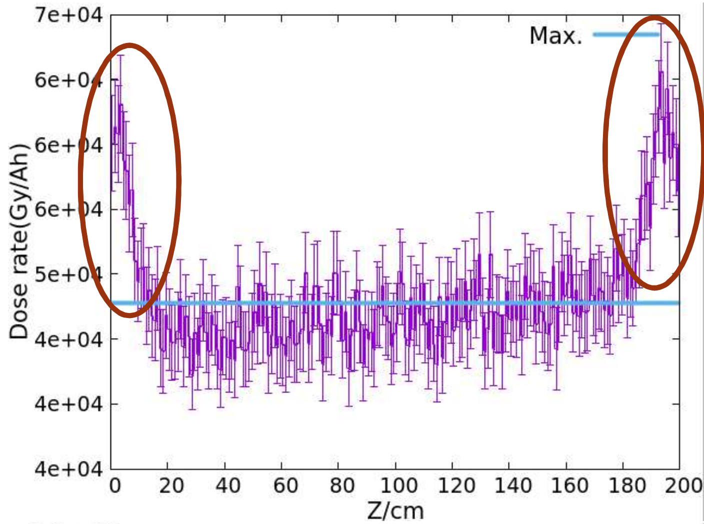
- Ramping simulation: example @higgs

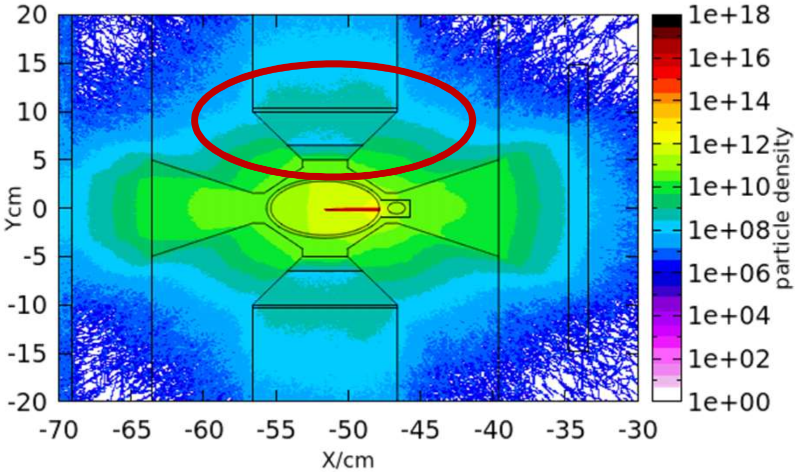


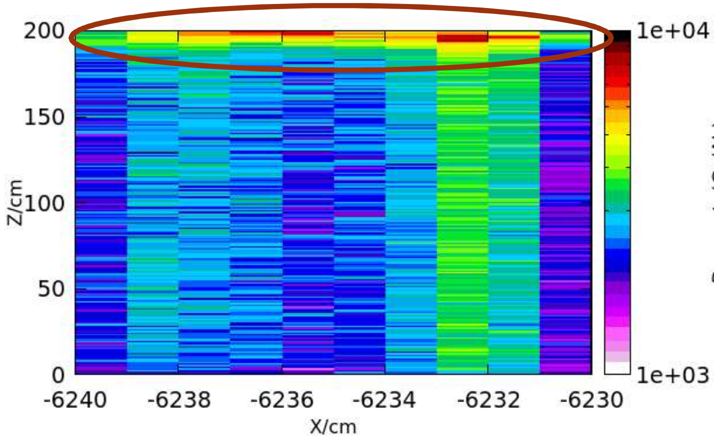
- The ramping simulation is more critical than reality.
  - Overestimate dose in booster

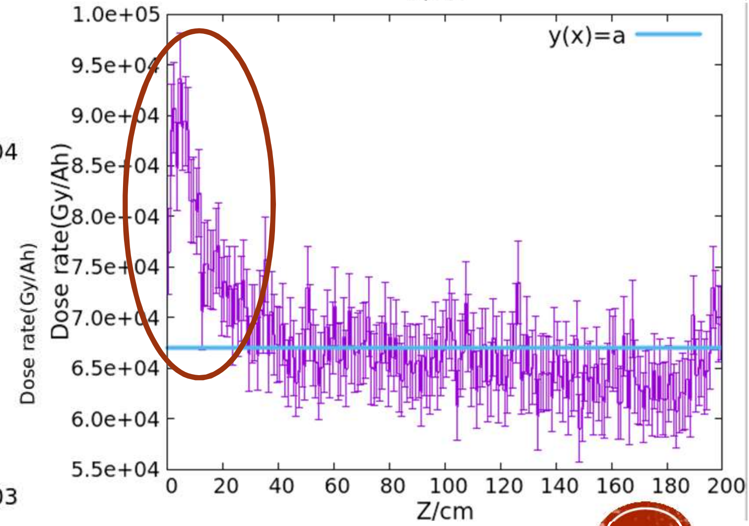
DOSE TO INSULATIONS

- along beam direction, dose is a constant in middle of magnets, but not in both sides of magnets.
- “Hot spots” in insulation because:
  - The shielding between magnets are not matched very well.
  - SR hits the iron close to beam pipe and bypasses lead.
- Hot spots shielding will be considered in next stage.
- Dose in uniform regions are summarized in the following pages.



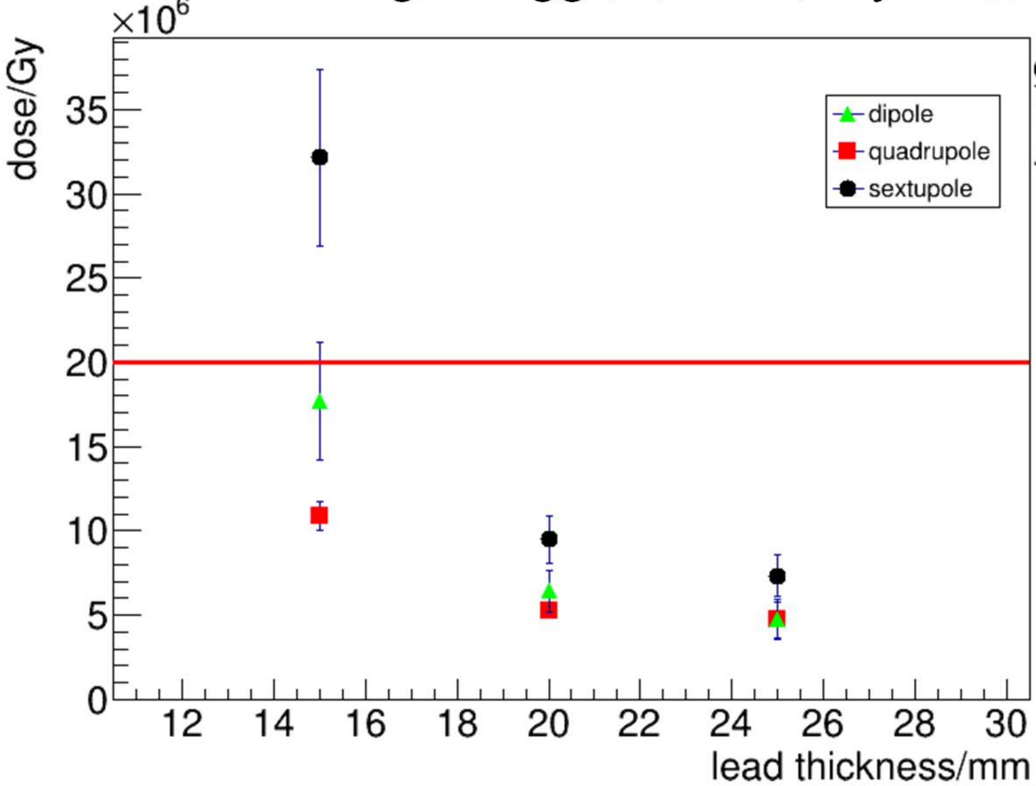






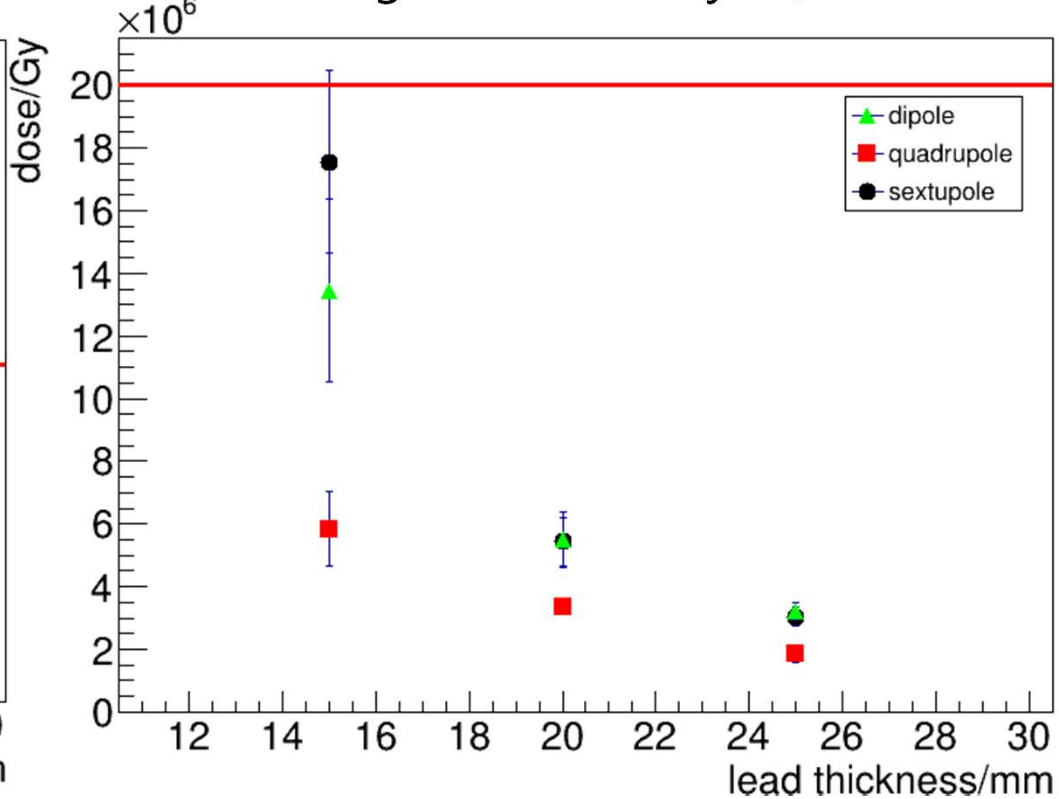
DOSE VS LEAD THICKNESS: 50MW

- While running @Higgs/Z/WW (10 years),



  - Possible to reduce 2cm lead if no ttbar run;

- While running @ttbar for 1 year,

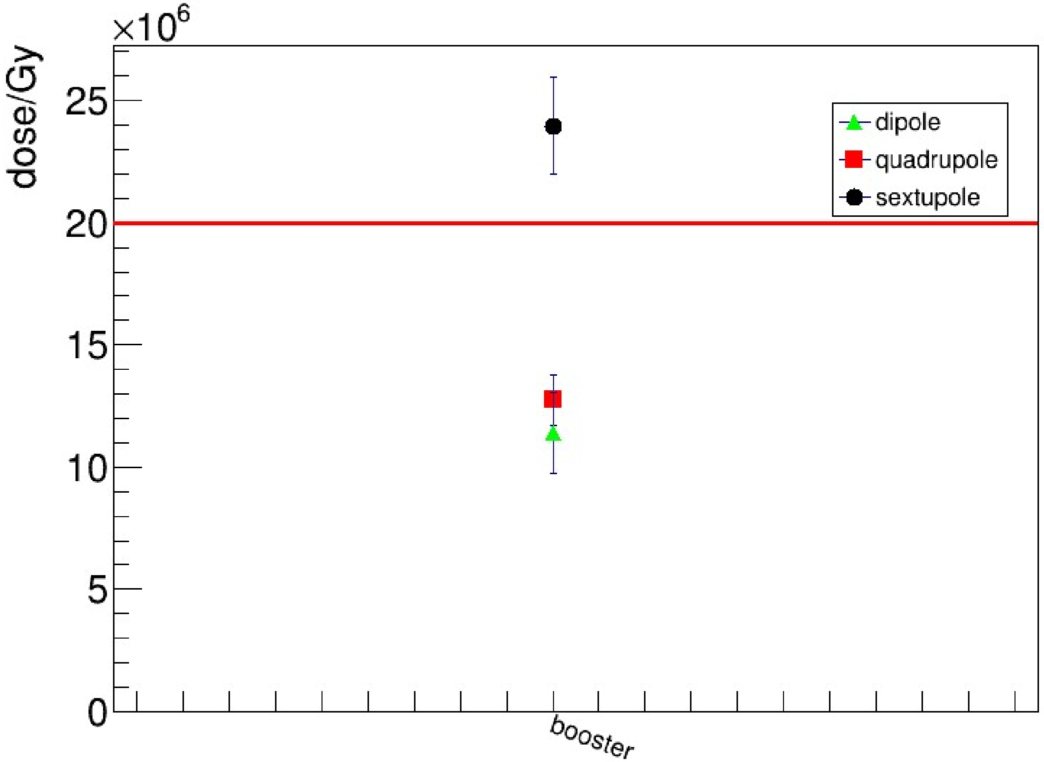


  - May run another 2 years for dipole, quadrupole and sextupole

- Lead thickness is constrained by the operation plan.

DOSE IN BOOSTER INSULATION: 50MW

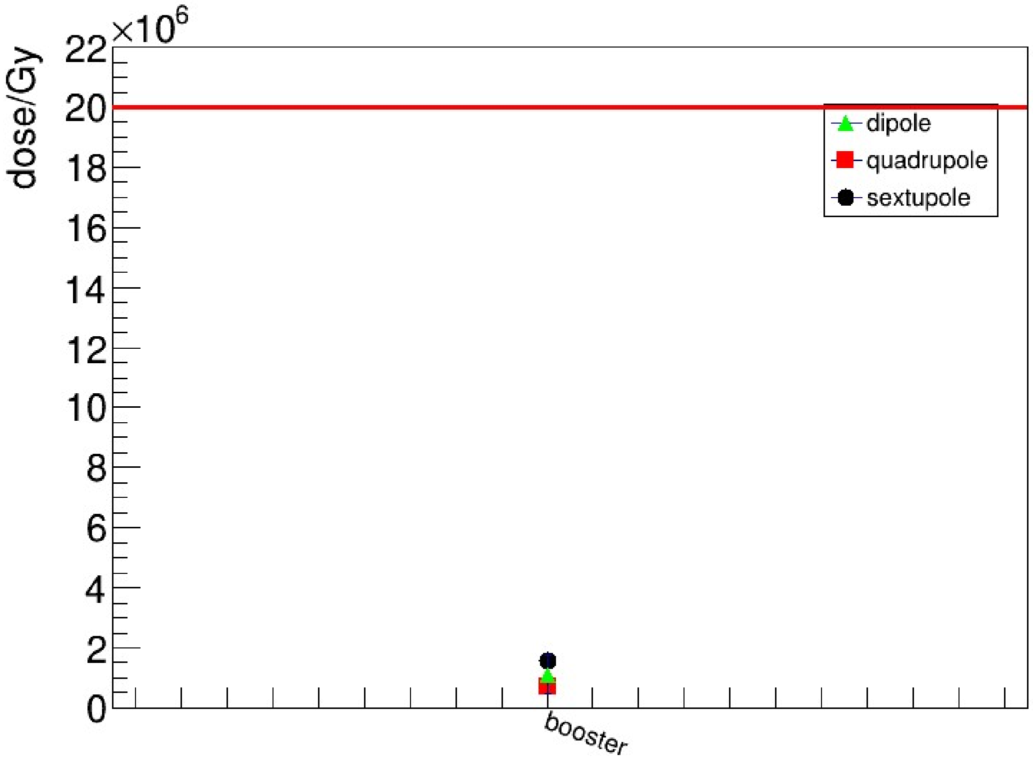
- While running Higgs/Z/WW (10 years),



- Carefully assesse dose in sextupole

- Pay attention to sextupole. Simulate more precisely.

- While running @ttbar for 1 year,

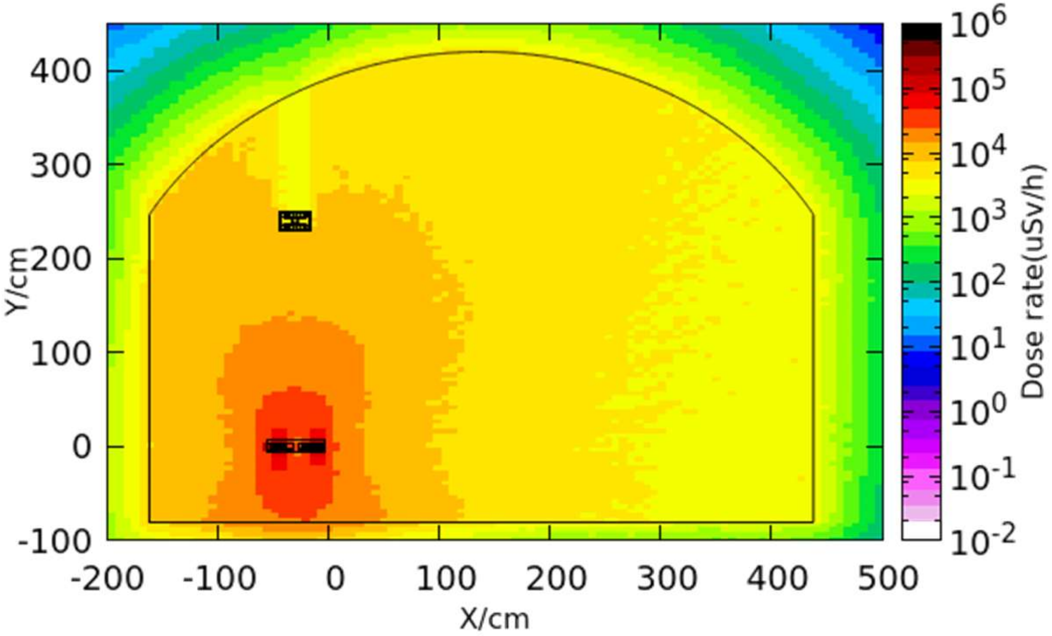


- May run another 5 years for booster dipole and quadrupole

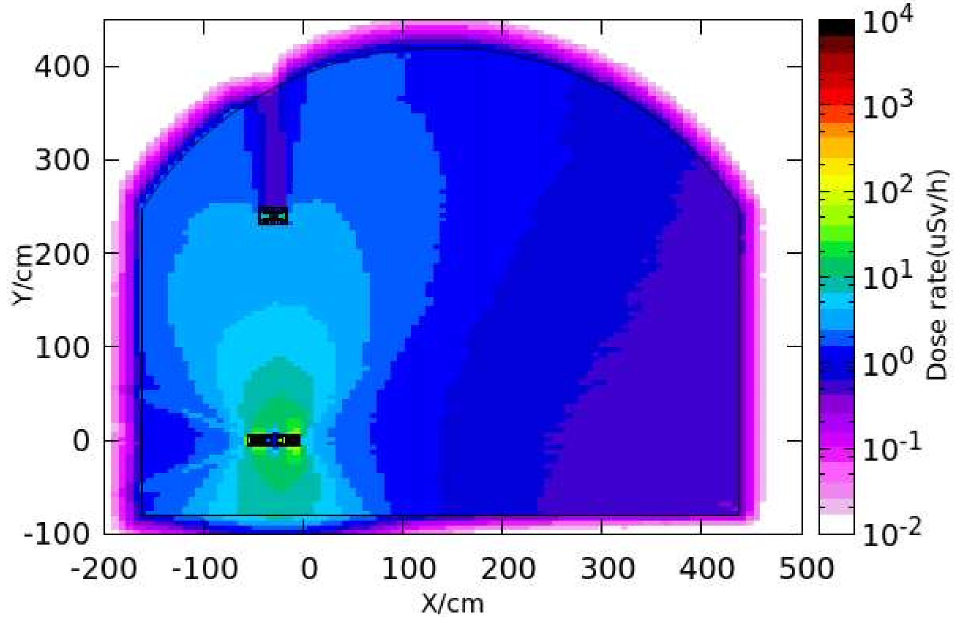
DOSE-EQ IN THE TUNNEL

In the arc section of the ring, the most important two radiation sources are from synchrotron radiation and random beam losses.

- Secondary radiation components from random beam losses is harder and more liable to produce radioactivity in the material surrounded, Should be assessed.



Prompt radiation dose-eq caused by random beam loss



Prompt radiation dose-eq caused by synchrotron radiation

RADIONUCLIDES SIMULATION

- Beam losses & SR photon of energy >6MeV

		Higgs	WW	Z	ttbar
Beam energy/GeV		120	80	45.5	182.5
Ne/bunch/10^{10}		14	13.5	14	20
Number of bunches	50MW	415	2162	19918	58
Number of SR photons >6MeV	50MW	1.4e10	1e-7	negligible	1.3e15
Life time	50MW	0.33	0.91	1.33	0.30
Beam losses/114 m	50MW	5.5e7	1.0e8	6.7e8	1.2e7

- Two critical cases are simulated.

- FLUKA options

- Wall material:
  - Case1: water as wall
  - Case2: rock as wall

SOIL/ROCK

- In previous study, use soil as tunnel wall.
- Now use average components of different kinds of rock.
- Simulate productions of residual nuclei after 1 year running in:
  - Cooling water
  - Air in tunnel
  - Water outside tunnel
  - Rock (leachable isotopes)

		Soil	average components of different rocks
density		1.6g/cm^3	1.2~3.3g/cm^3
Major element (wt%)	C	1.0	---
	N	0.12	---
	O	34	30~70
	Na	0.50	0.1~2.9
	Mg	0.52	0.4~3.7
	Al	8.0	3.5~9.7
	Si	40	26~39
	P	---	0.02~0.16
	K	2.36	1.8~3.7
	Ca	2.26	0.2~4.8
	Ti	1.0	0.09~0.8
	Mn	0.24	0.02~0.12
	Fe	9.6	0.8~6.3

RADIONUCLIDES PRODUCTION

- Concentrations of Long half-life isotopes are lower than mandatory standard, GB18871.

		Half-life	Cooling water: Specific activity/GB 18871	Cooling water: Stat. error (%)
Beam losses @Z-pole	O15	122s	2.44	10
	C14	5700 a	3.5e-7	23
	Be7	53d	1.3e-2	34
	H3	12a	2.3e-6	22
SR @ttbar	None			

		Half-life	Air in tunnel: Specific activity/GB18871	Air in tunnel: Stat. error (%)
Beam losses @Z-pole	O15	122s	2.7e-4	52
	C14	5700a	7.7e-7	1
	Be7	53d	1.1e-5	57
	H3	12a	3.5e-9	32
	P33	25d	1.9e-8	100
	Ar37	35d	6.1e-9	59
	Ar41	2h	1.4e-3	12
SR @ttbar	C14	5700a	6.5e-6	2
	Ar41	2h	1.5e-2	20

RADIONUCLIDES PRODUCTION

- Densities of Long half-life isotopes are lower than mandatory standard.
- Only leachable isotopes are listed:
  - ^{3}H, ^{22}Na, ^{45}Ca, ^{54}Mn

		Half-life	Water wall	
			Specific activity/ GB18871	Stat. error (%)
Beam losses @Z-pole	O15	122s	2e-3	2
	C14	5700a	5e-10	4
	Be7	53d	3e-5	5
	H3	12a	6e-9	3
	F18	2h	5e-6	52
SR @ttbar	C14	5700a	2e-12	99
	H3	12a	1e-10	71

		Half-life	Rock wall	
			Specific activity/ GB18871	Stat. error (%)
Beam losses @Z-pole	Mn54	312d	6.94E-04	1.8
	Ca45	163d	5.49E-06	0.3
	Na22	2.6y	7.20E-04	1.4
	H3	12a	5.90E-09	0.9
SR @ttbar	H3	12a	1e-10	71

- Should investigate if radionuclides would transport to drinking water.

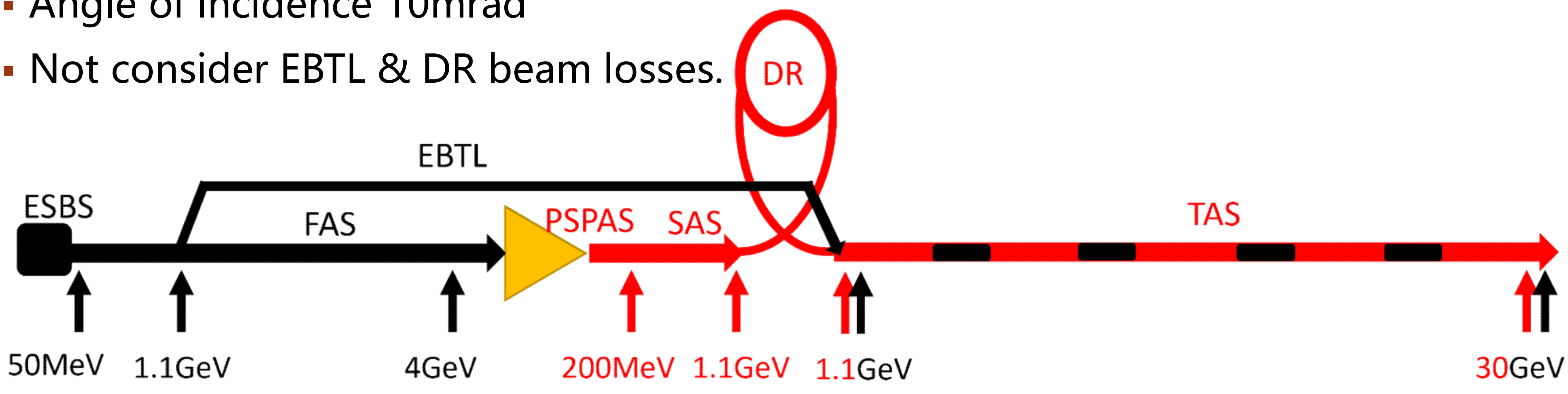
OUTLINE

- Introduction
- Synchrotron radiation shielding
- Radionuclide productions
- Linac beam losses shielding
- Summary and outlook

LINAC BEAM LOSSES ASSUMPTIONS

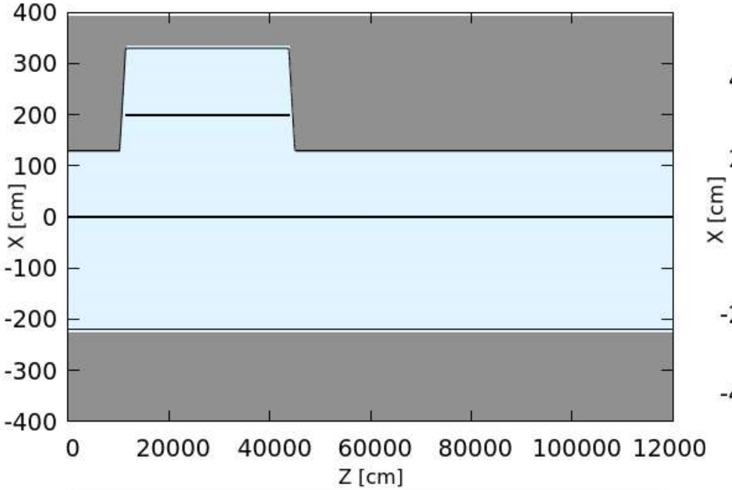
Position	Length	Beam energy	Number of bunches [s^{-1}]	Beam losses/bunch [nC]	Number of particles [10^{10}/s]
FAS	100m	300MeV	200	0.5	62.5
Positron target	15mm	4GeV		10	1250
PSPAS	15m	5~200MeV		10	1250
SAS	3m	300MeV		2	250
	30m	600MeV		0.2	25
TAS	1163m	1.1~30GeV		0.1	12.5

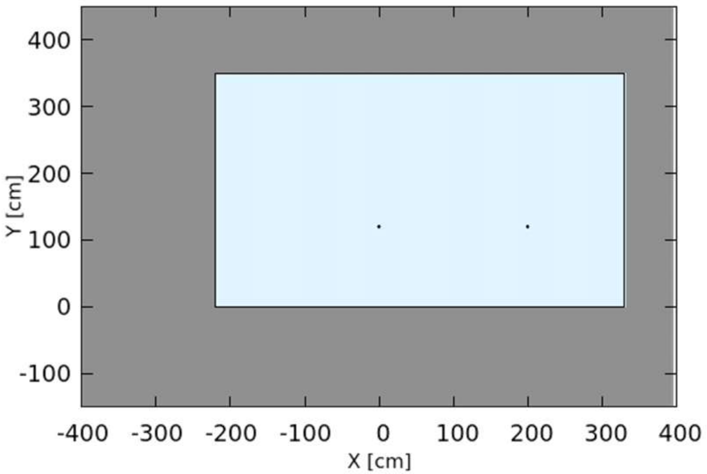
- Angle of incidence 10mrad
- Not consider EBTL & DR beam losses.



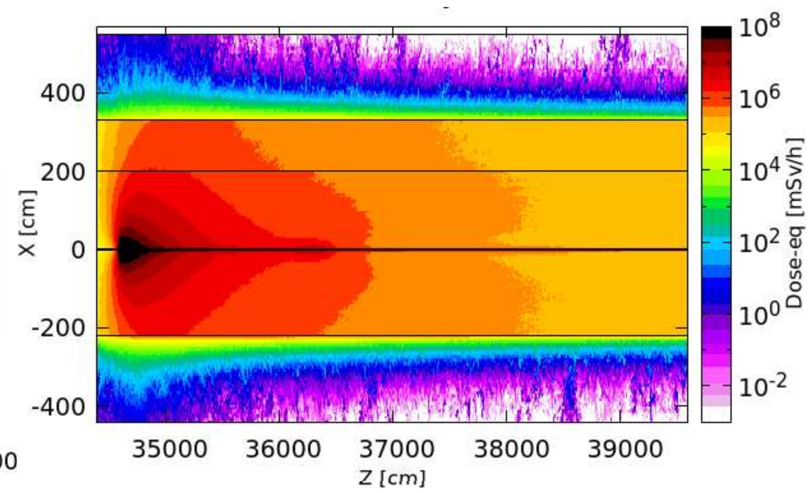
SIMULATION SETUP & BULK SHIELDING

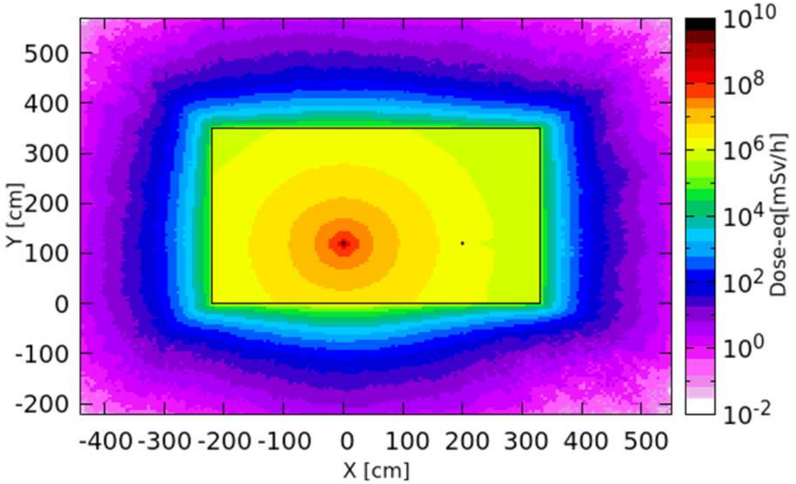
- Beam pipes and concrete wall
- Top/side view





- Dose-eq distribution example: SAS





- Thickness of Shielding wall according to upper limit 5.5mSv(left/right/bottom) /2.5uSv(top).

Wall thickness	FAS	SAS	TAS
Left	0.3m	1.9m	0.3m
Right	0.2m	1.9m	0.3m
Bottom	0.3m	2.1m	0.3m
Top	1.3m	4.1m	2.0m

SUMMARY & OUTLOOK

- Lead shielding seems well. Further optimize SR shielding design
  - Unequal dose distribution in the insulations.
  - Precise simulation for booster.
- Radionuclides productions are studied.
  - If necessary, all running modes can be simulated.
- The thickness of Linac walls are designed.
- Go on:
  - Activation transport assessment.
  - Shielding around experiment hall (around MDI).

Thank you

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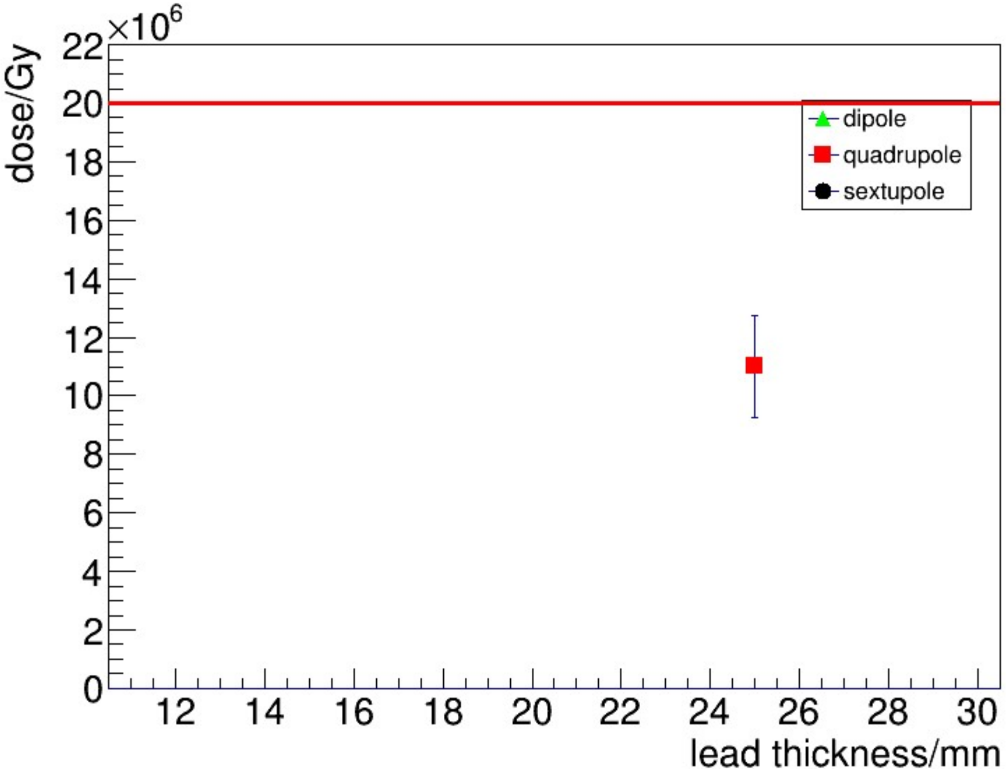
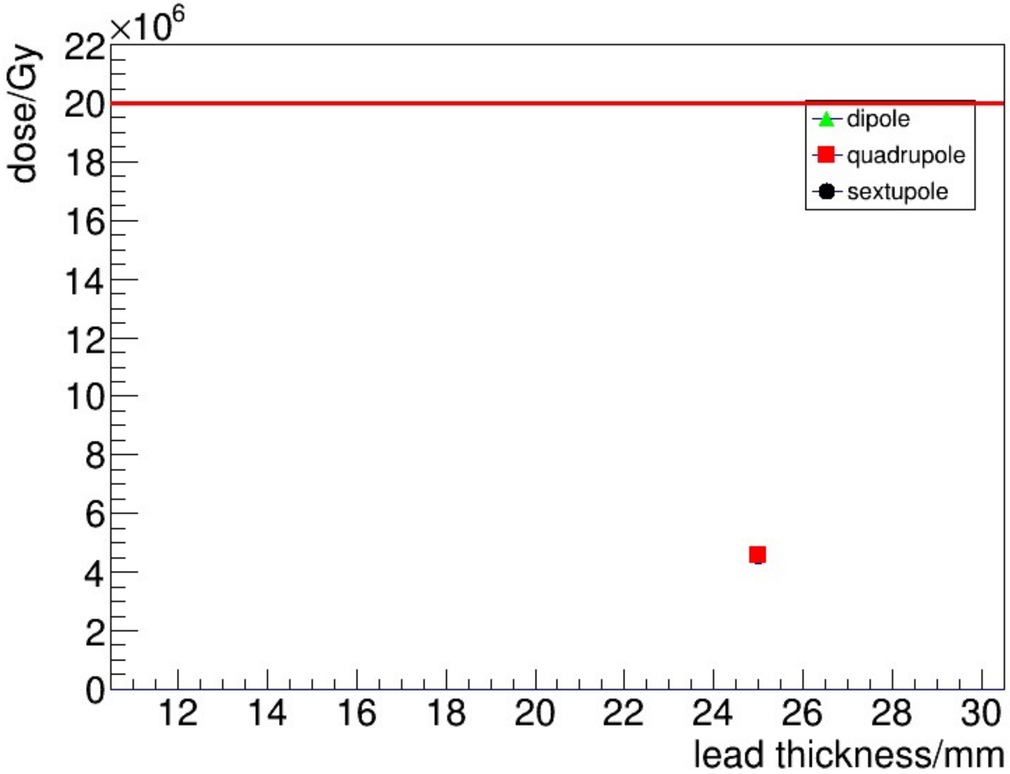
BACKUP

DOSE TO TRIM INSULATION: 50MW

- While running Higgs/Z/WW (10 years),



- While running @ttbar for 1 year,
  - May run another 2 years for quadrupole trim coil

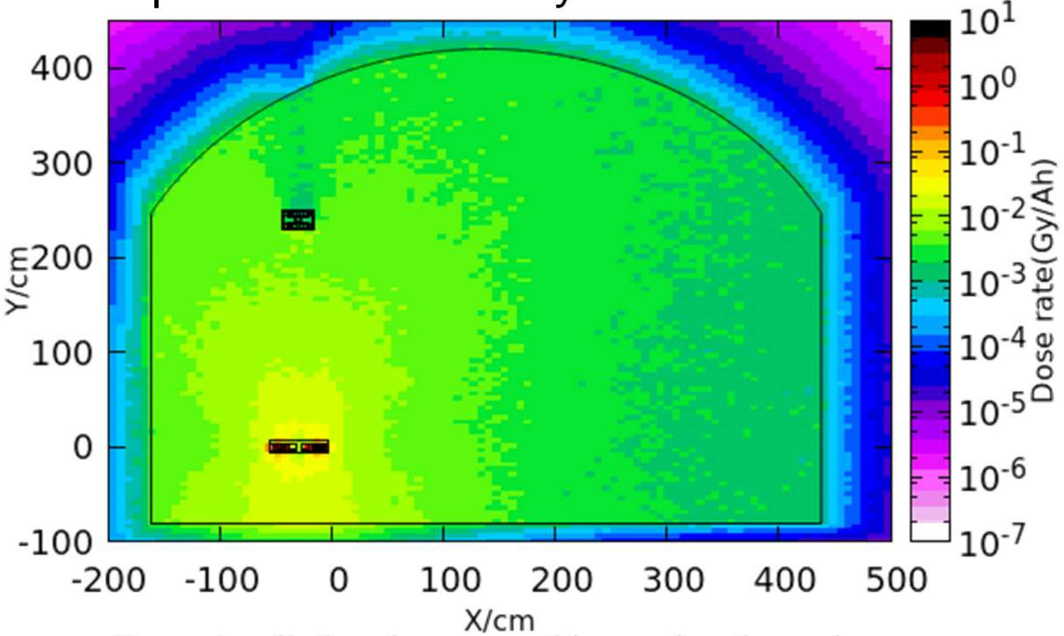


- Lead thickness is constrained by the operation plan.

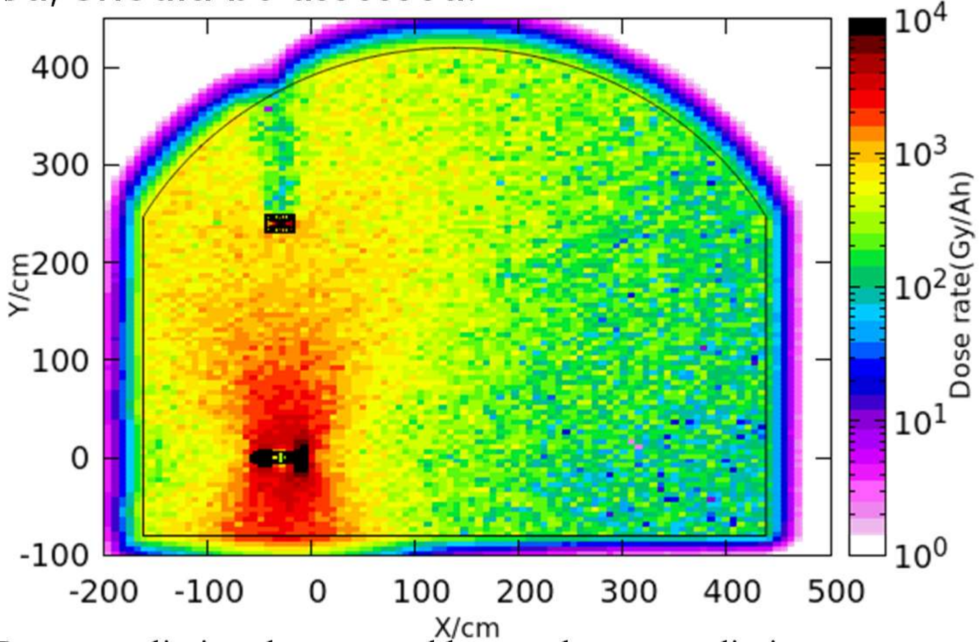
DOSE IN THE TUNNEL

In the arc section of the ring, the most important two radiation sources are from synchrotron radiation and random beam losses.

- Radiation caused by synchrotron is more serious than beam losses
- Secondary radiation components from random beam losses is harder and more liable to produce radioactivity in the material surrounded, Should be assessed.



Prompt radiation dose caused by random beam loss



Prompt radiation dose caused by synchrotron radiation

PARAMETER

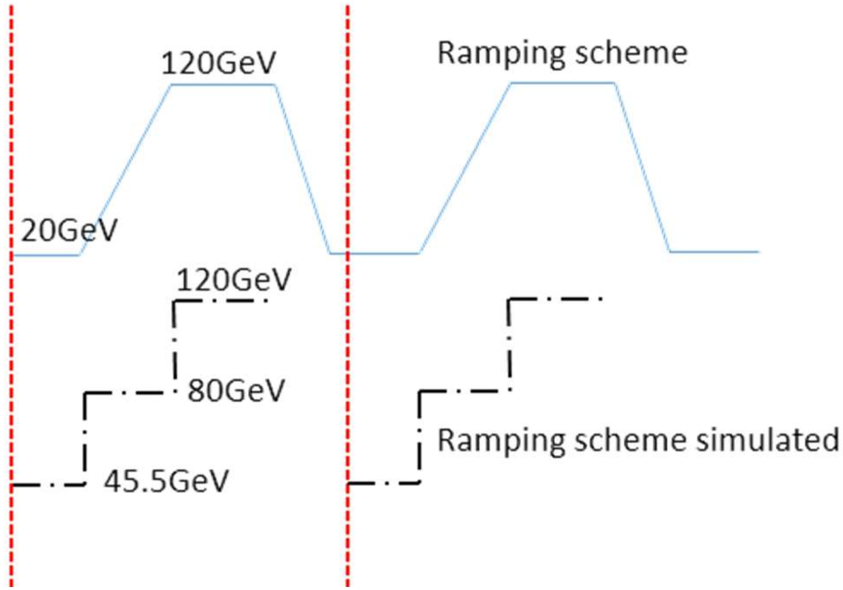
- Collider

		Higgs	WW	Z	ttbar
Beam energy/GeV		120	80	45.5	182.5
Ne/bunch/10^{10}		14	13.5	14	20
Number of bunches	30MW	249	1297	11951	35
	50MW	415	2162	19918	58
Number of photons/114m	30MW	2.8e18	9.2e18	5.0e19	8.4e17
	50MW	4.6e18	1.5e19	8.4e19	1.4e18
Life time	30MW	0.33	0.91	1.33	0.30
	50MW				
Beam losses/114m	30MW				
	50MW	5.5e7	1.0e8	6.7e8	1.2e7

- Booster

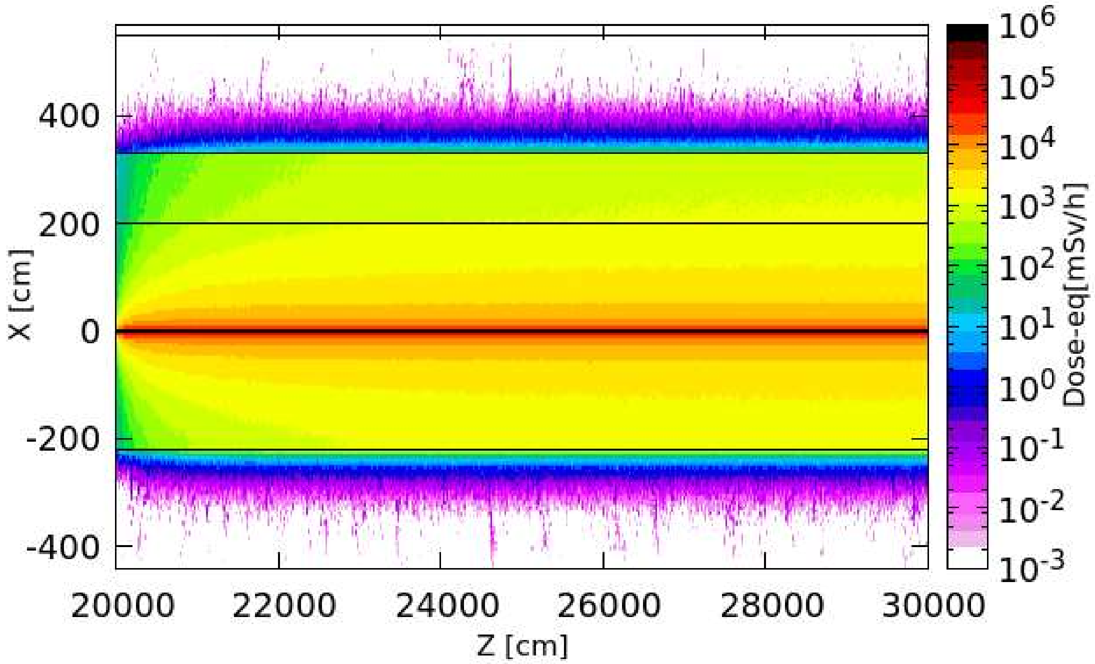
	Higgs On	WW	Z	ttbar
Current(mA)	1	2.69	14.4	0.12
Injection duration(s)	32.8	39.3	134.7	30
Injection interval(s)	38	155	153.5	65

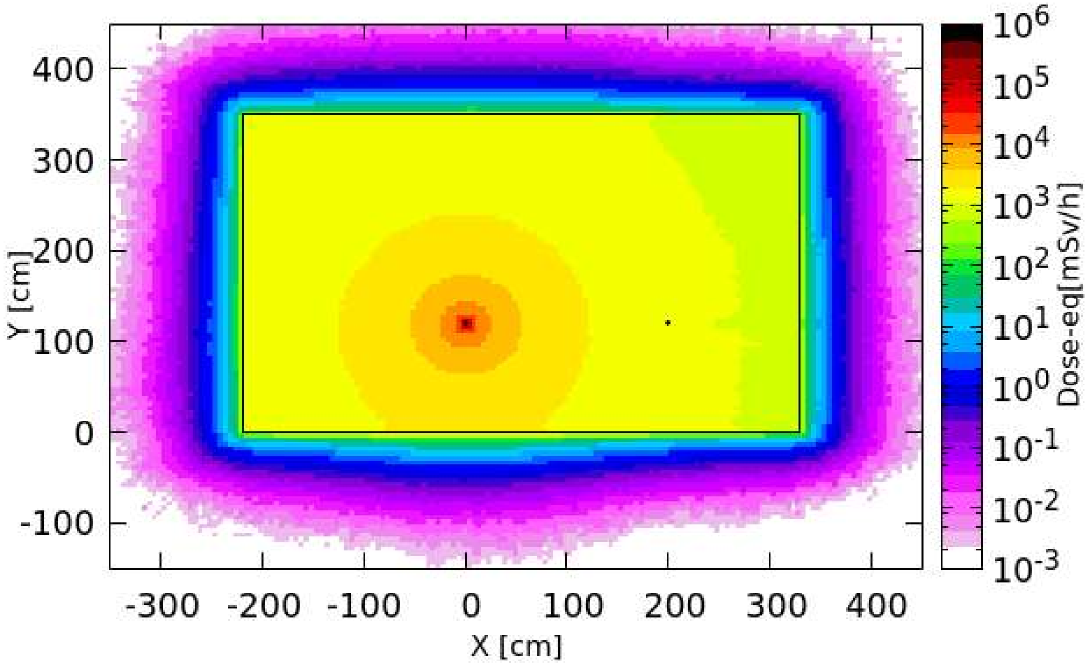
- Ramping simulation



DOSE-EQ: FAS

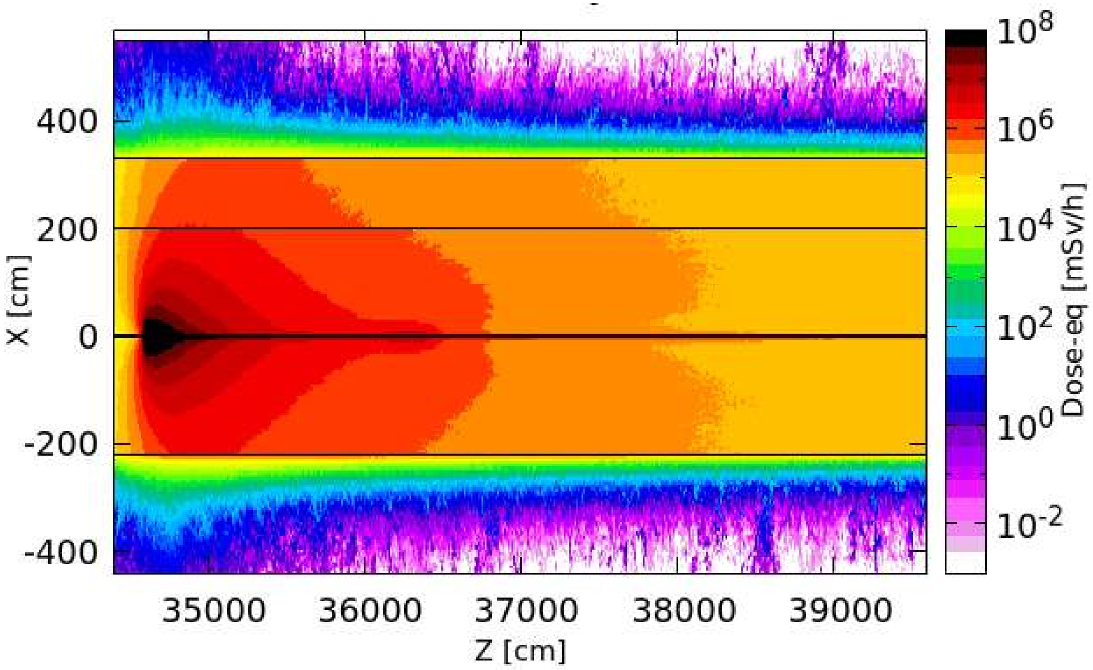
- 束流管所在水平面内剂量当量约1~100Sv/h
- 以5.5mSv限值（土壤中）估计，左/右/下侧混凝土墙厚度约30cm/20cm/30cm。
- 以2.5uSv限值（空气中）估计，顶部混凝土厚度1.3m。

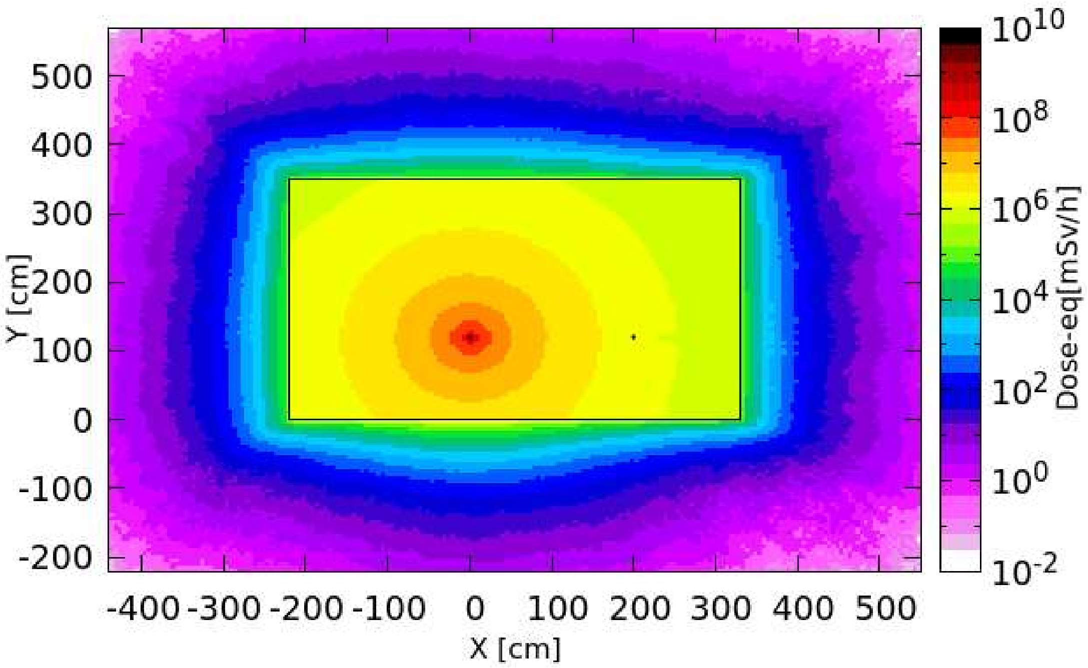




DOSE-EQ: PSPAS ~ SAS

- 束流管所在水平面内剂量当量约10~1000Sv/h
- 以5.5mSv限值（土壤中）估计，左/右/下侧混凝土墙厚度约1.9m/1.9m/2.1m。
- 以2.5uSv限值（空气中）估计，顶部混凝土厚度4.1m。

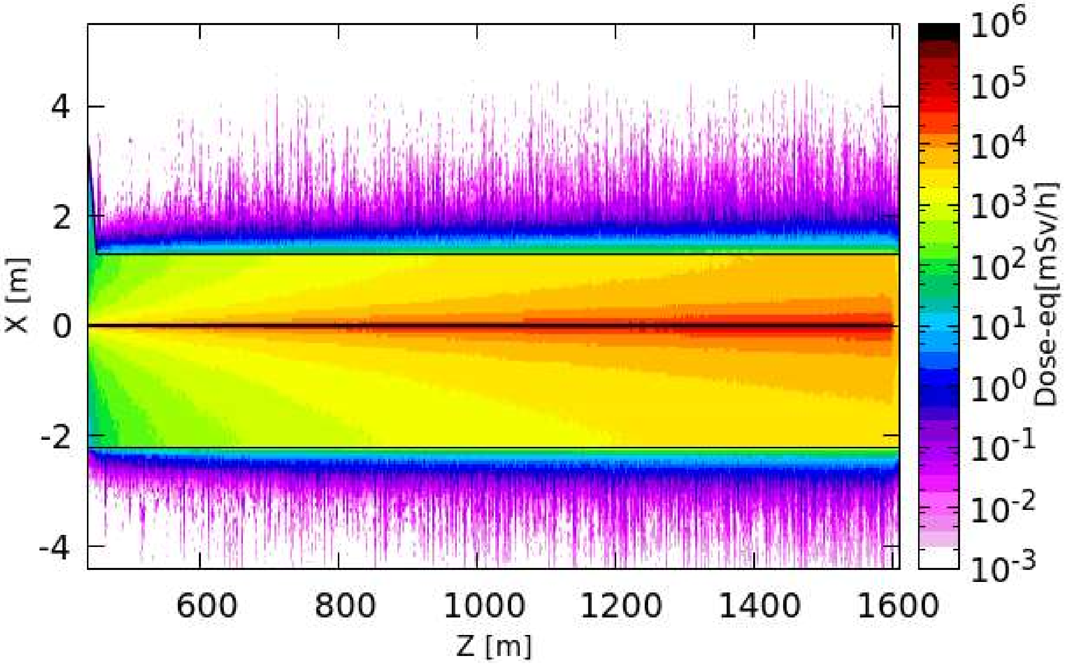


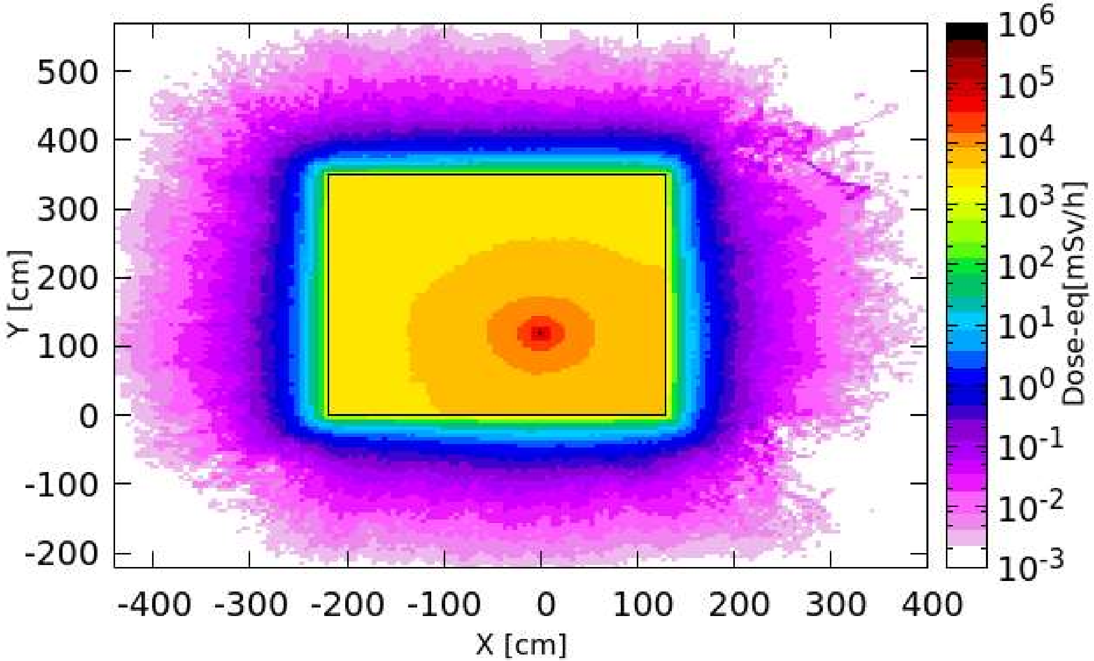


DOSE-EQ: TAS

- 束流管所在水平面内剂量当量约0.1~100Sv/h

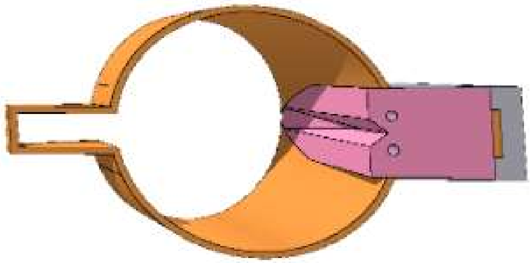
- 以5.5mSv限值（土壤中）估计，左/右/下侧混凝土墙厚度约30cm/30cm/30cm。
- 以2.5uSv限值（空气中）估计，顶部混凝土厚度1.6m。





VACUUM CHAMBER: FCC-EE, TWO SCHEMES

Absorbers (ABS)



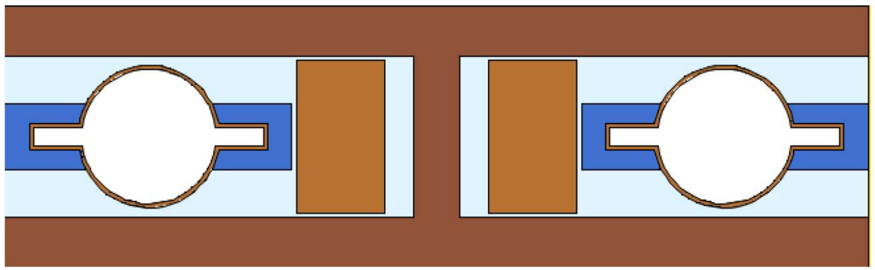
- CuCrZr alloy
- Length: 30cm
- 5-6m distance
- Angled surfaces for even power
- Water cooled
- 25 ABS in each beam (MBs, MQs)

(Design and initial placement by R. Kersevan)

Barbara Humann, FCC week 2021 talk

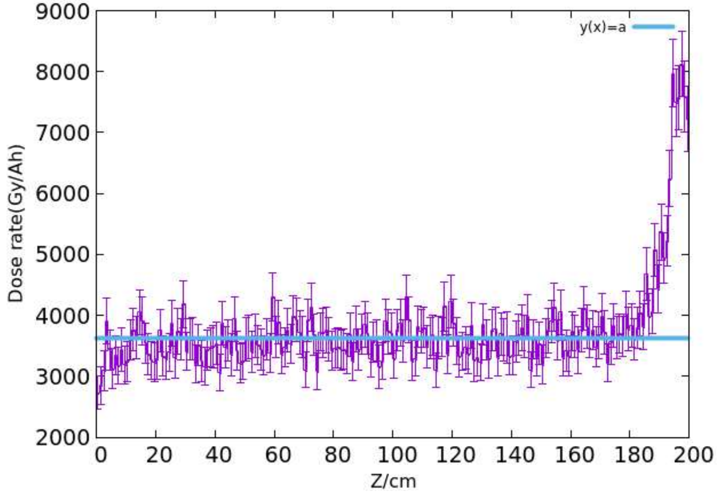
Continuous shielding

- Equivalent to LEP layout
- Continuous shielding around VC in MBs
  - Due to space restrictions from yoke and coils respectively, no shielding in MQs and MSs.
- Intermet180 (Tungsten alloy)
- Shielding thickness:
  - Top/bottom: 1cm
  - Sides: 1.3cm

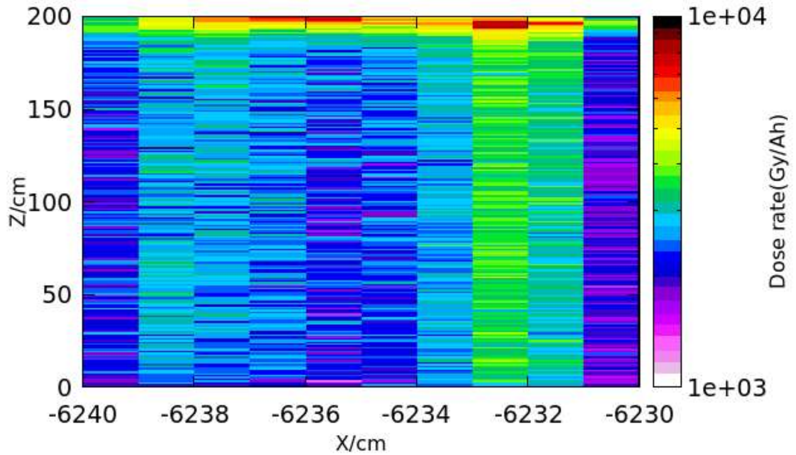


HOT POINTS (2CM LEAD)

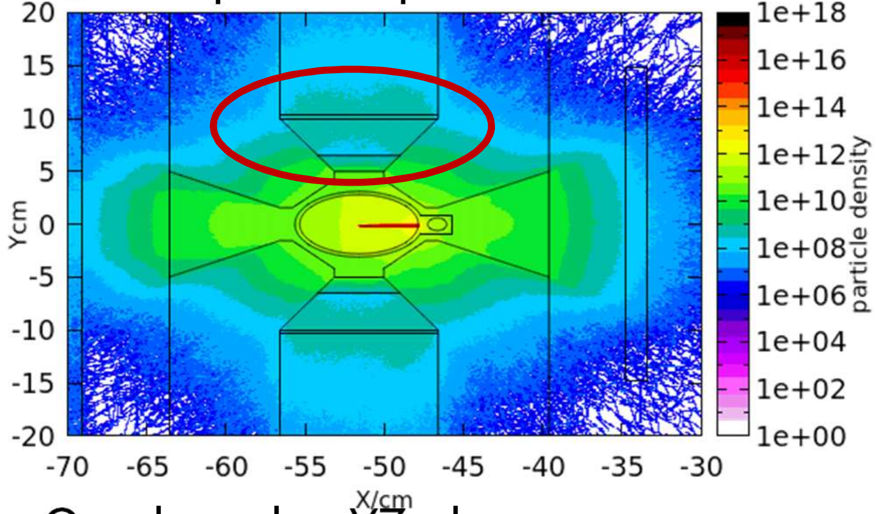
- Dose hot points caused by particles bypassing lead shielding.



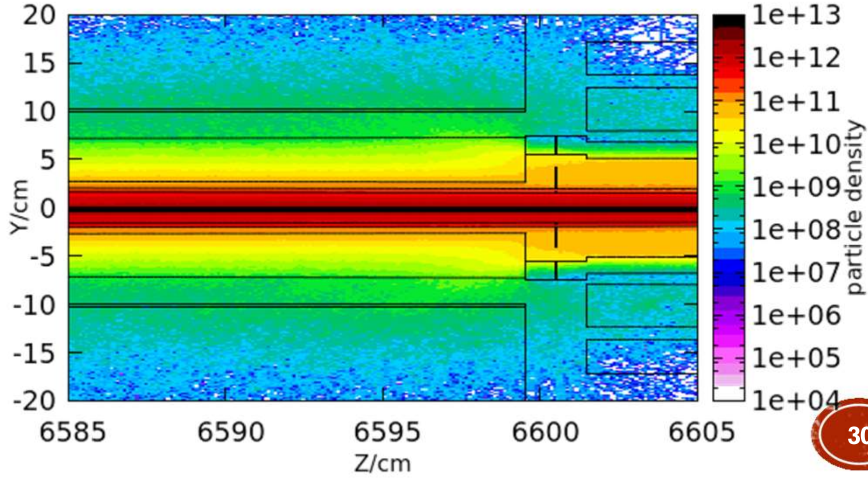
- 2D dose distribution on the surface of insulator



- Quadrupole XY plane

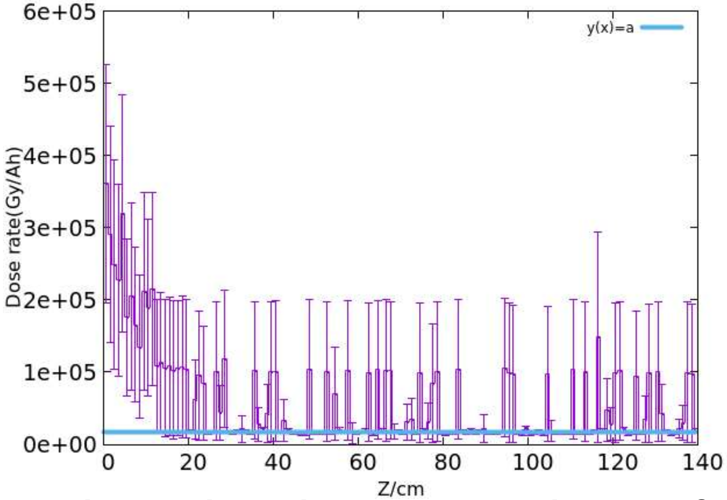


- Quadrupole : YZ plane

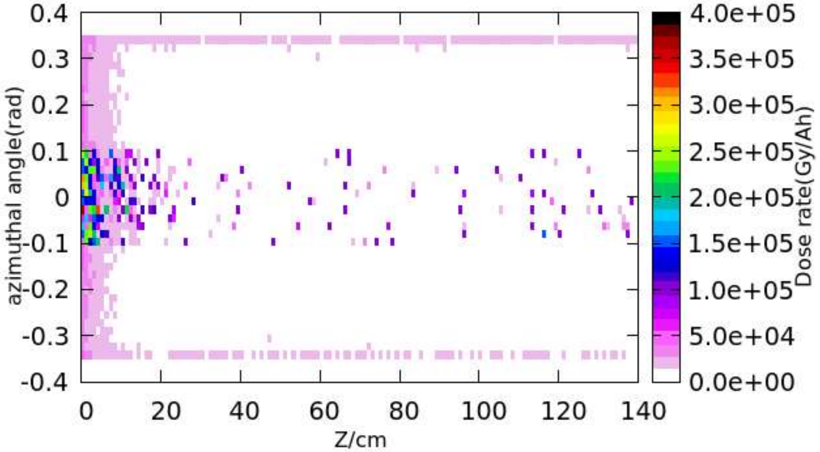


HOT POINTS (2CM LEAD)

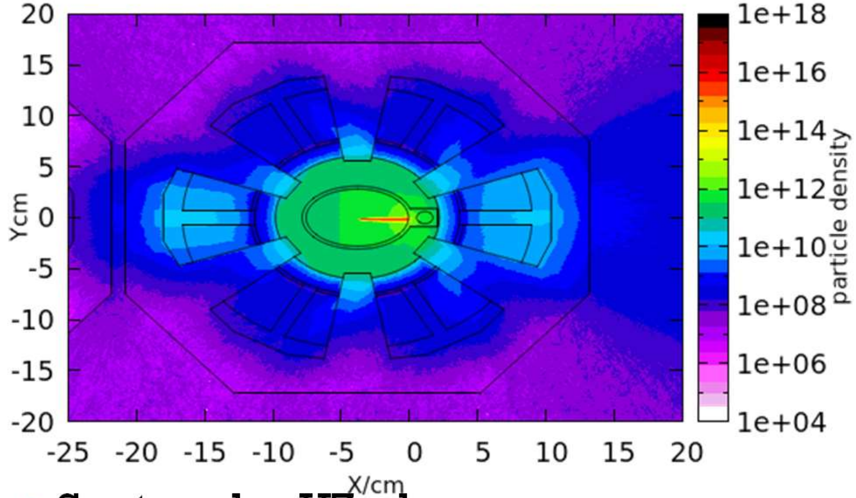
- Dose hot points caused by particles bypassing lead shielding.



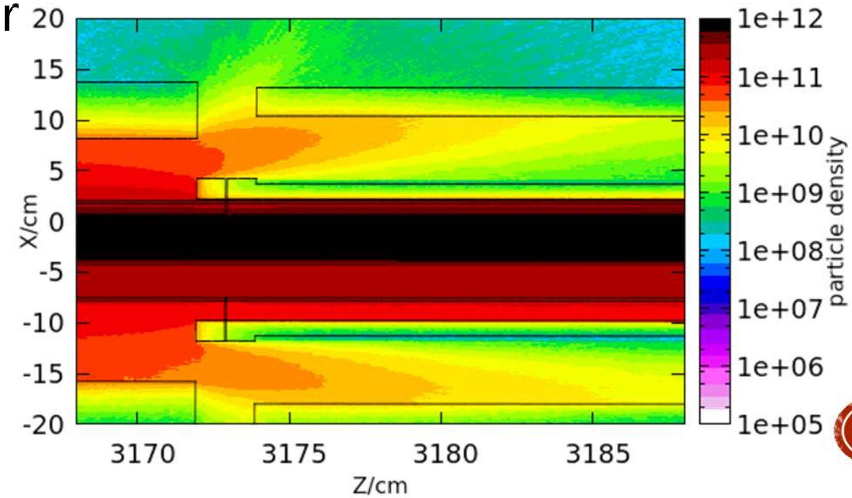
- 2D dose distribution on the surface of insulator



- Sextupole XY plane



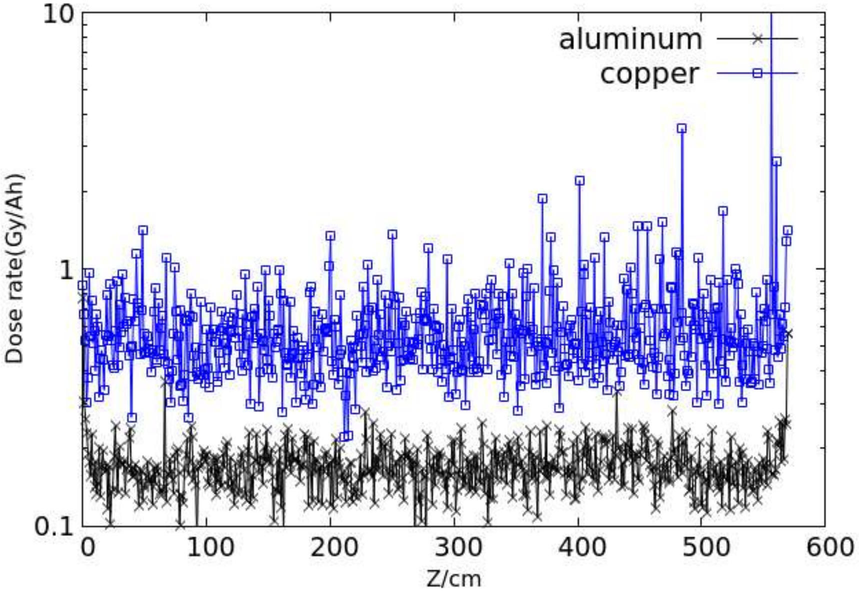
- Sextupole :YZ plane



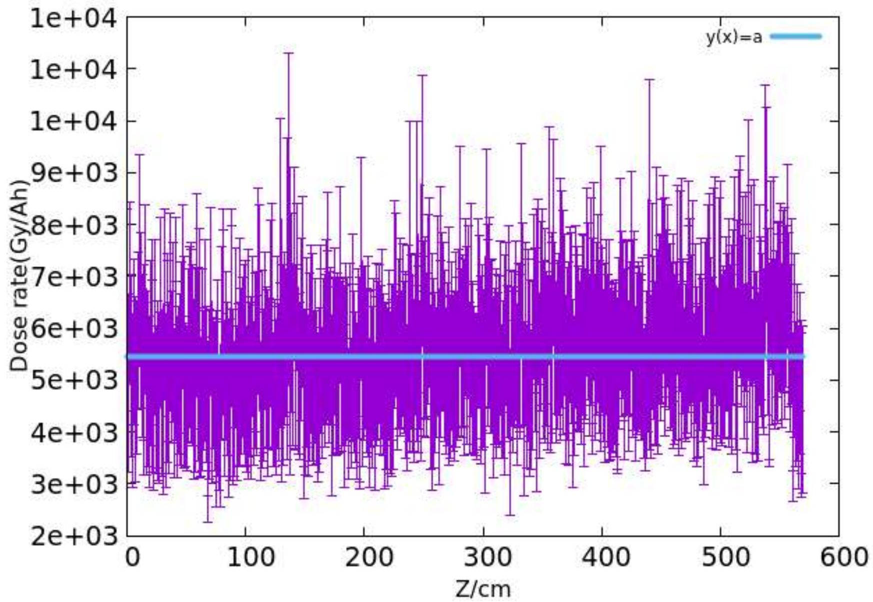
DOSE AROUND INSULATORS

In the arc section of the ring, the most important two radiation sources are from synchrotron radiation and random beam loss.

- Around coils, dose caused by SR is more serious than by beam loss.



Prompt radiation dose caused by random beam loss



Prompt radiation dose caused by synchrotron radiation