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

ELECTRON DUMP SYSTEM AND SAFETY ISSUES

Guangyi Tang, Haoyu Shi and Zhongjian Ma

CEPC workshop, 2021/11/11

OUTLINE

- Introduction
- Dump system
  - Collider ring dumps
  - Linac hot spots
- Safety issues
  - SR shielding
  - Dose distribution
- Summary and outlook

RADIOLOGICAL IMPACT

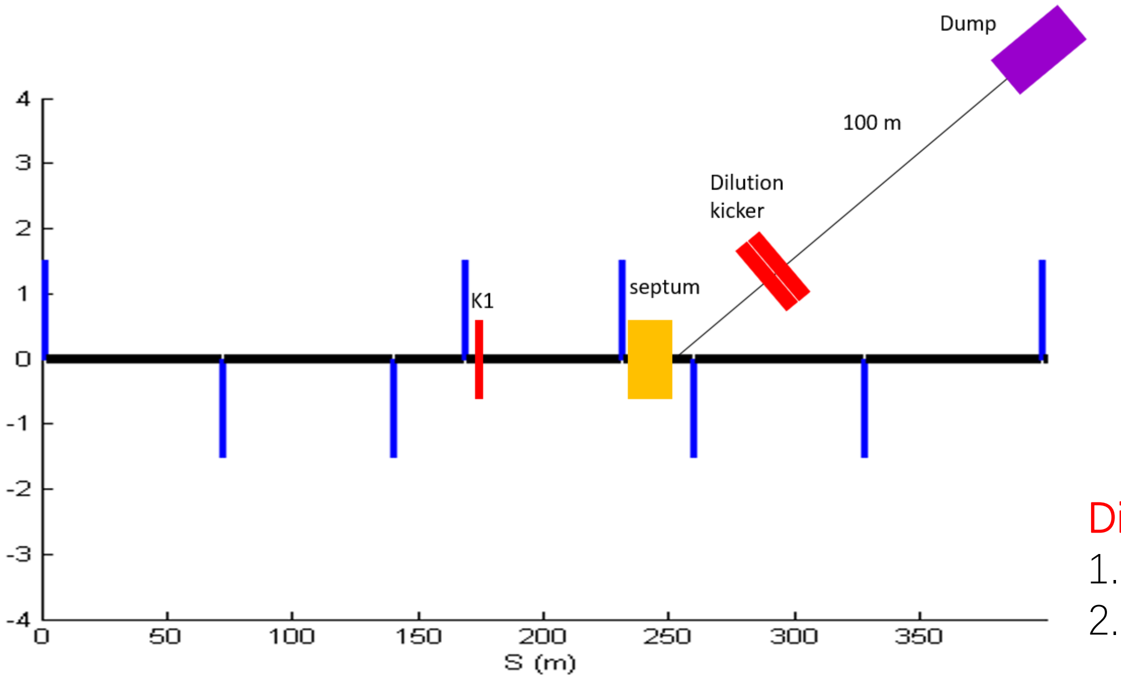
- Main consideration aspects

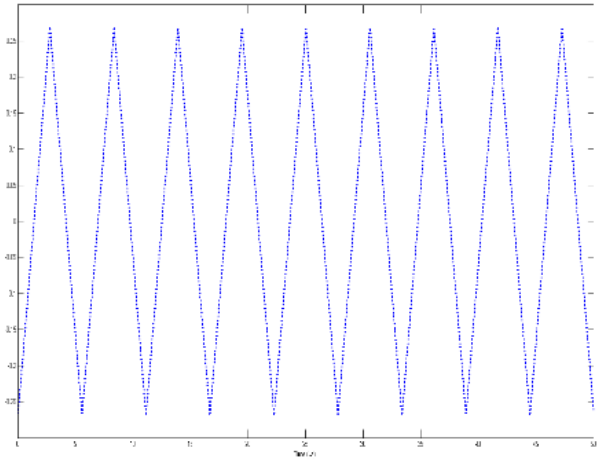
Impact factors	Characteristics
Synchrotron radiation	Radiation damage to magnet coil; Over heat load to ventilation system; Formation of ozone and nitrogen oxides in the air; Slightly activation to the material around;
Random beam loss	Cause secondary radiation inside the tunnel; Determine the bulk shielding 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

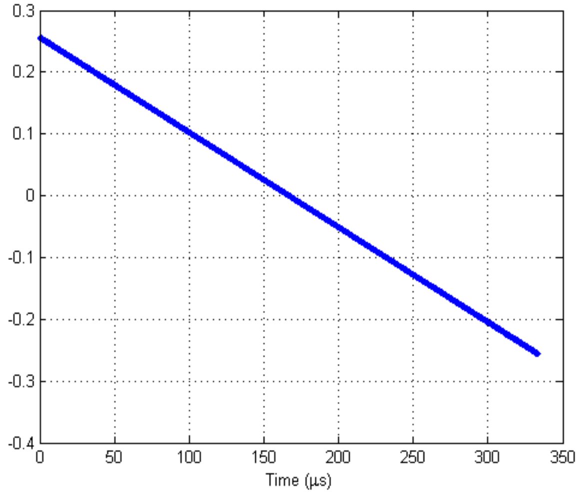
COLLIDER RING DUMP

- A set of kicker magnets has been used to dilute the beam horizontally and vertically;
- The area of bunch distribution in front of dump is assumed to be 25cm x 25cm; These dimensions haven’t been optimized yet.
- The length of transfer tunnel is about 100m; the diameter is about 2m, considering the vacuum equipment, pipe installation.

		Extraction kicker	Dilution kickers
Length (m)		2	10
Magnetic flux density (Gauss)	Z	281	197
	WW	494	347
	Higgs	741	520
	ttbar	1110	781







Dilution kicker requirement:

1. Horizontal kicker should periodic oscillate 50 times in 300 us
2. Vertical kicker should reduce from max value to minimum in 300 us

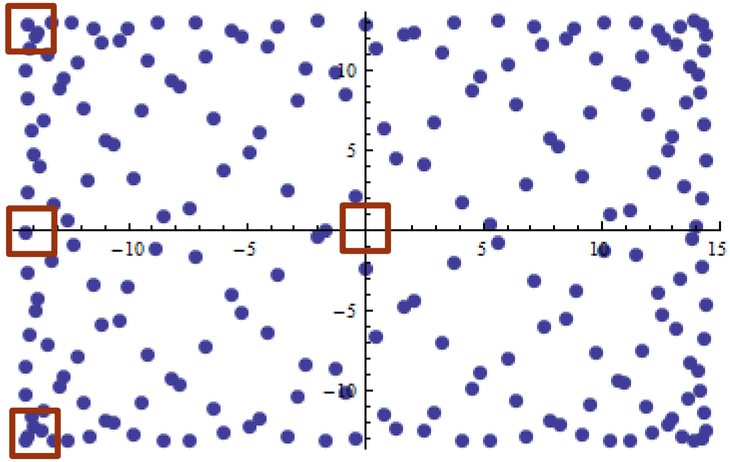
From Xiaohao Cui

BUNCH DISTRIBUTION

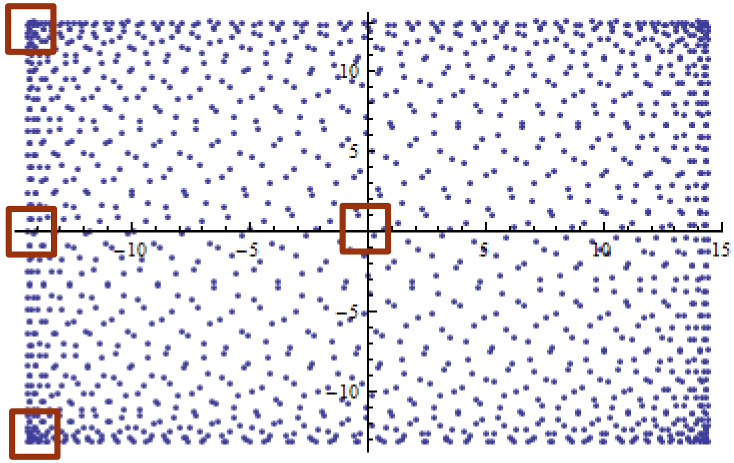
- The bunch distributions on the dump surface for 5 operation models is simulated.
  - Bunch size: $\sigma_x > 600\mu m; \sigma_y > 30\mu m;$

From Xiaohao Cui

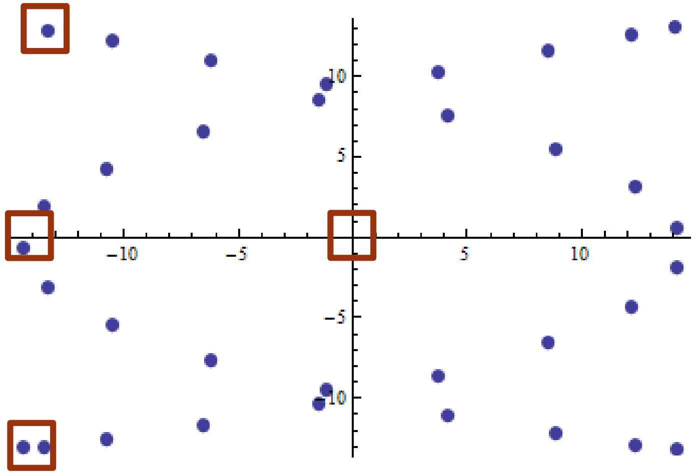
① Focus on 4 sub regions because the bunches in these regions are smaller and more concentrated than any others.
② Find the maximum energy deposition. Optimize dimensions
③ Import to ANASYS to analyze the deformation. (ongoing)



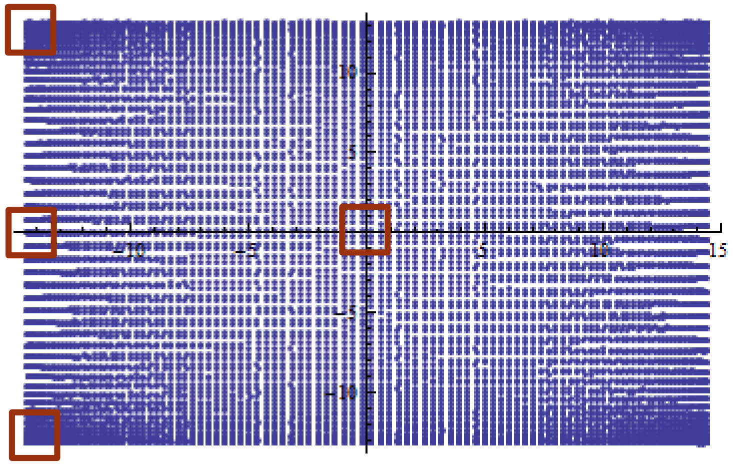
Higgs



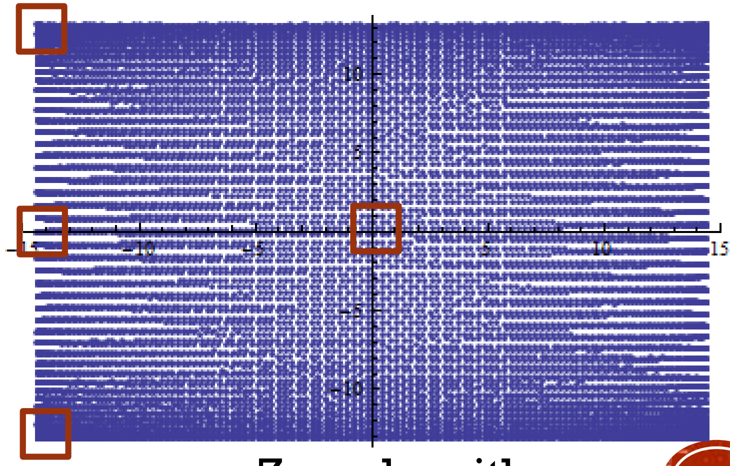
WW



ttbar



Z mode with 12k bunches



Z mode with 15k bunches

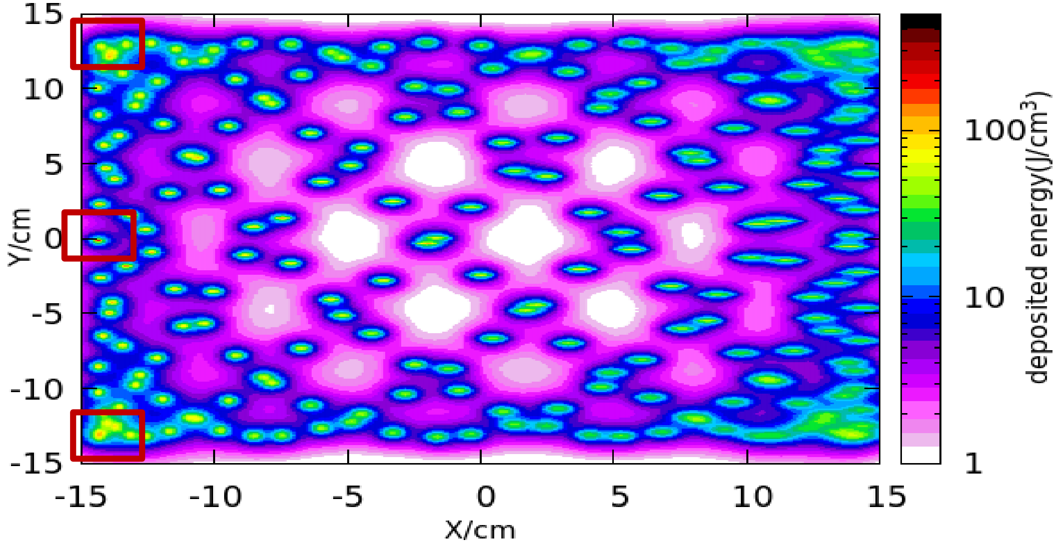
MAX. TEMPERATURE RISE

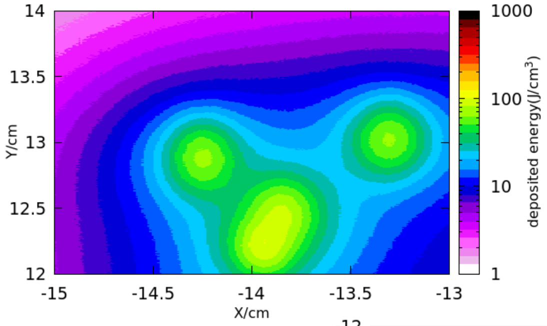
- Example: aluminum core

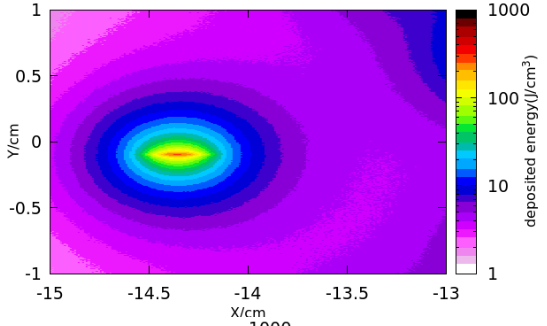
	ttbar	Higgs	WW	Z
Beam energy/GeV	175	120	80	45.5
Ne/bunch/ 10^{10}	24	17	12	15
Bunch number	34	218	1569	15000
Total energy/MJ	0.2	0.7	2.4	16.4
Maximum temperature rise	234 ± 3℃	154 ± 5℃	103 ± 1℃	714 ± 12℃

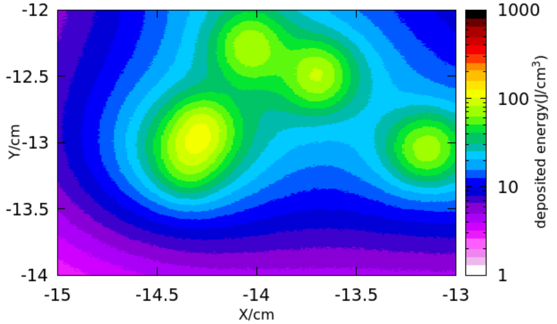
- Max. temperature rise @Z mode can decrease by increasing the bunch distance on the dump surface.

- Energy deposition @Higgs mode









MORE ISSUES

- External dumps with dilution systems can be built around 4 straight sections. Number of dumps depends on machine requirement and reliability.
- Active/passive protection is needed.

5.3.1.2 LHC beam dump scenario: active surveillance

The beam dump system and clean dump action depend on a number of conditions that must be monitored. If these conditions degrade, a dump is issued while the conditions are still sufficient for a clean dump. Examples are:

- failures of general services (electricity, vacuum, cooling, ethernet, . . .);
- bad beam position in dump region;
- magnet powering failure of extraction equipment.

5.3.1.3 LHC beam dump scenario: passive protection

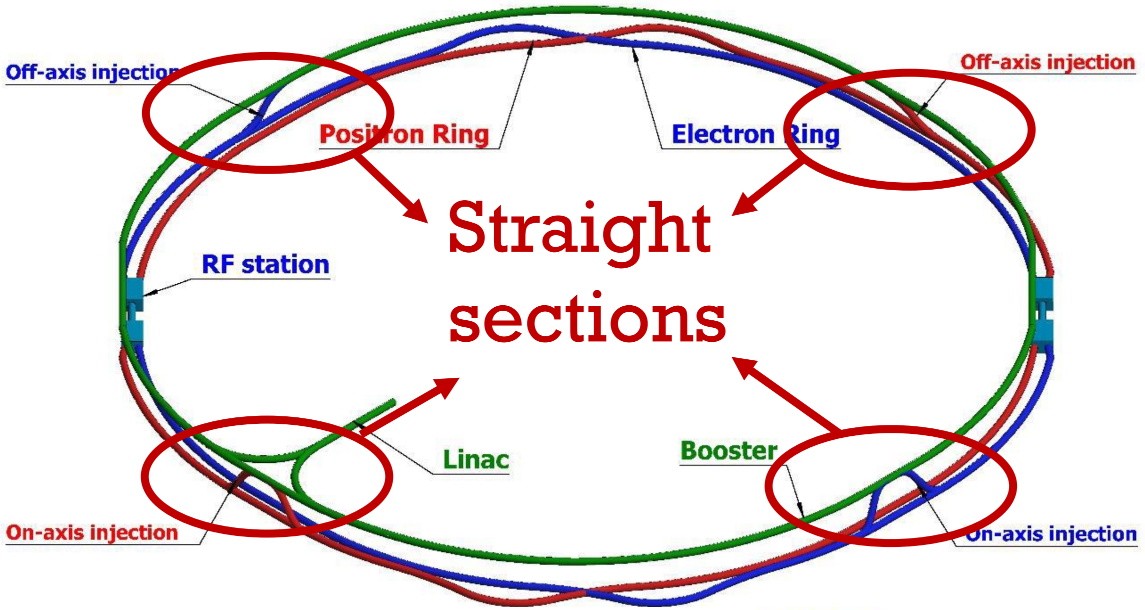
This category of failures cannot be prevented by surveillance systems and involve failures of the kicker systems. Redundancy has been built into the number of required dump kickers to ensure correct extraction. These failures can be tolerated and will not cause damage:

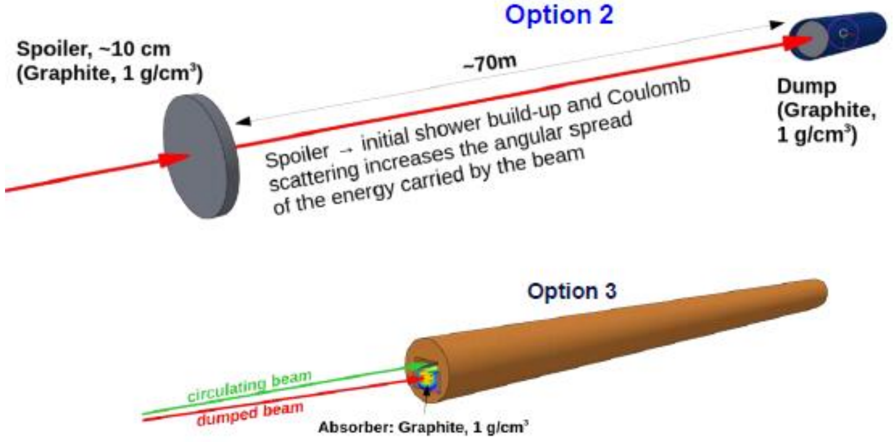
- one missing extraction kicker magnet;
- missing dilution kicker magnets;
- erratic behaviour of a dilution kicker magnet.

Finally there is a set of possible kicker failures where passive protection is required. They cannot be tolerated without correct settings of the passive protection element TCDQ:

- erratic behaviour of an extraction kicker magnet (spurious asynchronous trigger).

V. Kain, Beam Transfer and Machine Protection





Alexander Krainer, talk in FCC week 2021.

- More safety issues are in our schedule.
  - Passive/internal dump
  - Deal with fast beam loss
  - ……

HOT SPOTS INSIDE LINAC

Radiation hot spots, such as beam energy analysis stations, collimators, positron targets, dumps, should be shielded in order to protect equipment and people and minimize the thickness of the wall of Linac tunnel.

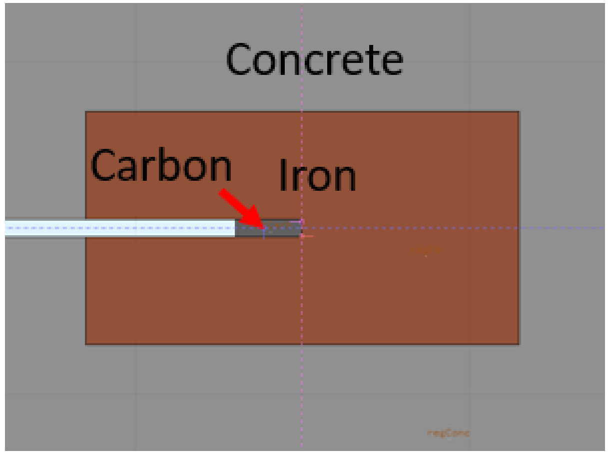
- Two kinds of prompt radiation inside Linac tunnel: radiation from hot spots and from beam loss
- Many hot spots inside Linac are used for beam energy analysis in different locations.

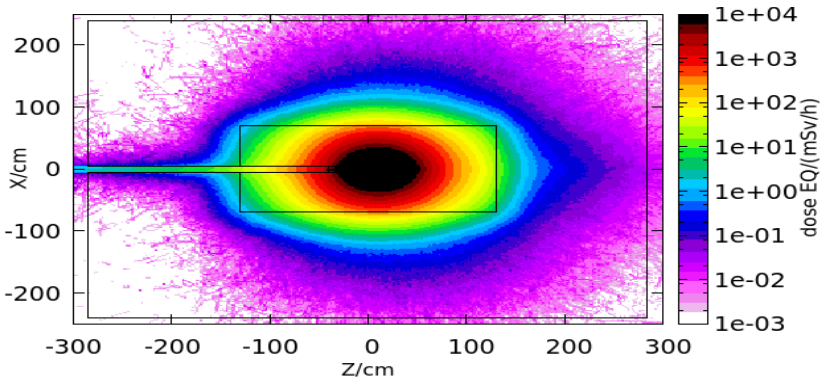
No.	Purpose of dumps	Beam energy	Bunch size/mm	Frequency/Hz	Charge/nC	Bunch popolartion/ 10^{10}
1	Beam Energy Analysis	60MeV	2/1	1	10	6.3
2	Beam Energy Analysis	1.2GeV	0.5/0.5	1	10	6.3
3	Beam Energy Analysis	250MeV	1.5/1.5	1	5	3.2
4	Positron target position	4GeV	-	-	-	6.0
5	Dump for Linac beam	11GeV	0.5/0.5	1	3	1.9

For 20GeV linac, there are more hot spots and will be updated soon.

LOCAL SHIELD DESIGN FOR HOT SPOTS

- Carbon and iron is selected as the absorber material, surrounded by the concrete as local shielding.
- 5.5mSv/h dose-equivalent is set as upper limit to decide the thickness of local shielding .





Beam energy	Trans. Area $/m^2$	Length/m
60MeV	0.75*0.75	1.36
1.2GeV	1.56*1.56	3.05
250MeV	0.98*0.98	1.56
11GeV	2.10*2.10	3.36

Absorber geometry and local shielding:
Size for carbon and iron for different beam energy, adopt from other projects, is suitable but haven't been optimized.

Local size selection (11GeV dump as example):
2D map of dose distribution was simulated by FLUKA, the dose rate alone Z or X axis was averaged by 10*10cm^2 area, the shielding size can be selected by the setting dose rate limit.

Preliminary design results for different beam energy analysis station:
Radiation level nearby each energy analysis station was figured out, also specify a roughly space for the future local shielding.

- The thickness of shielding will be optimized so that the dose-eq out of dumps is in the same order of dose-eq by beam loss.

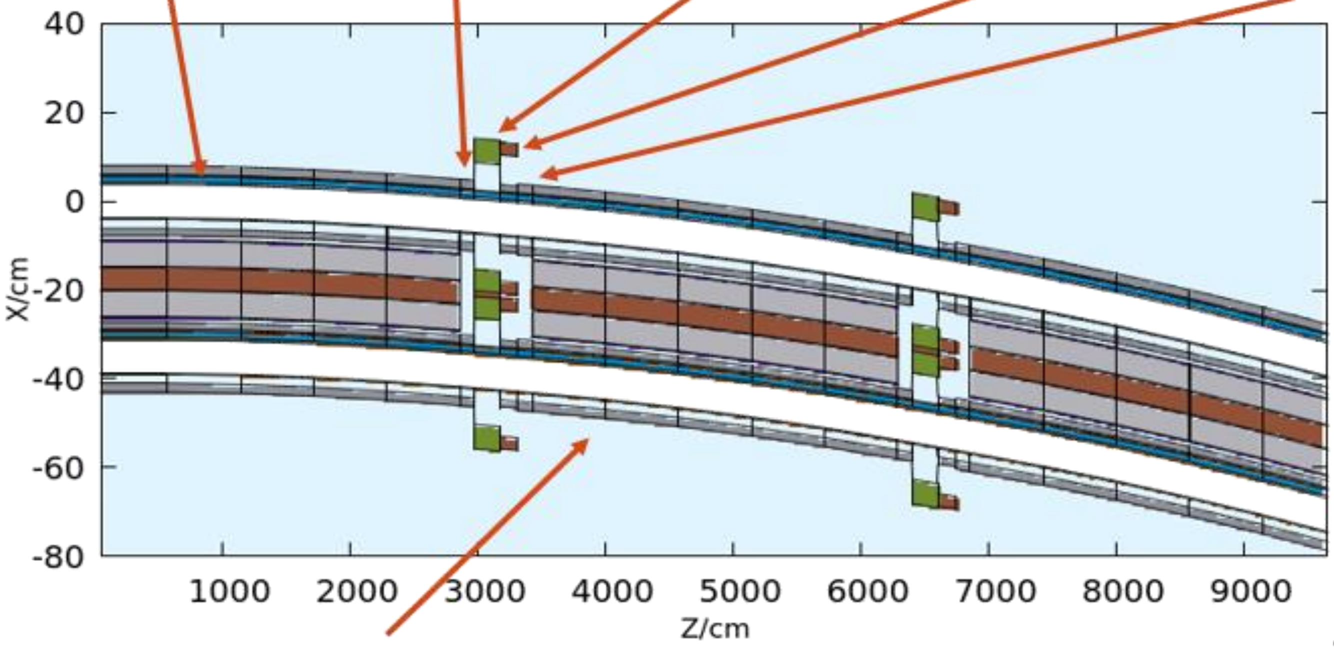
OUTLINE

- Introduction
- Dump system
  - Collider ring dump
  - Linac dump
- Safety issues
  - SR shielding
  - Dose distribution
- Summary and outlook

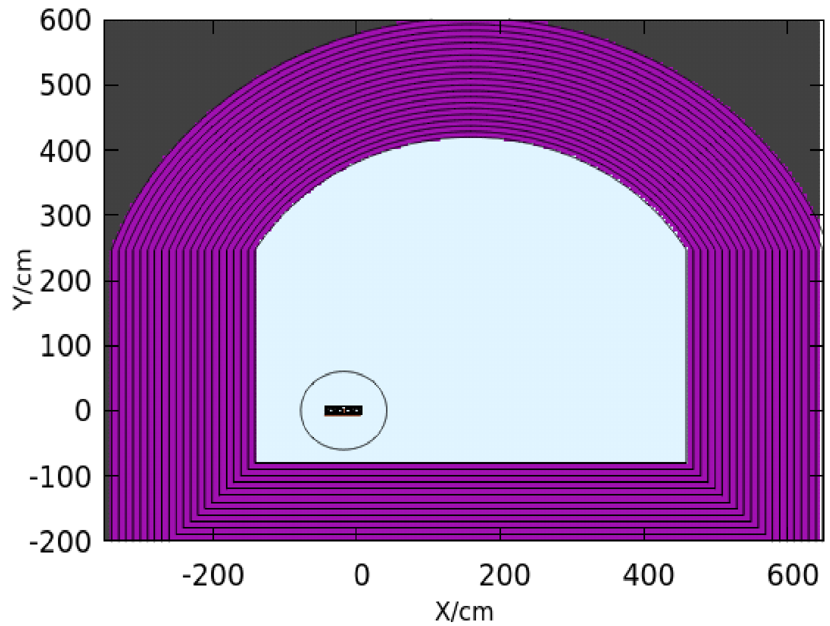
SIMULATION SETUP

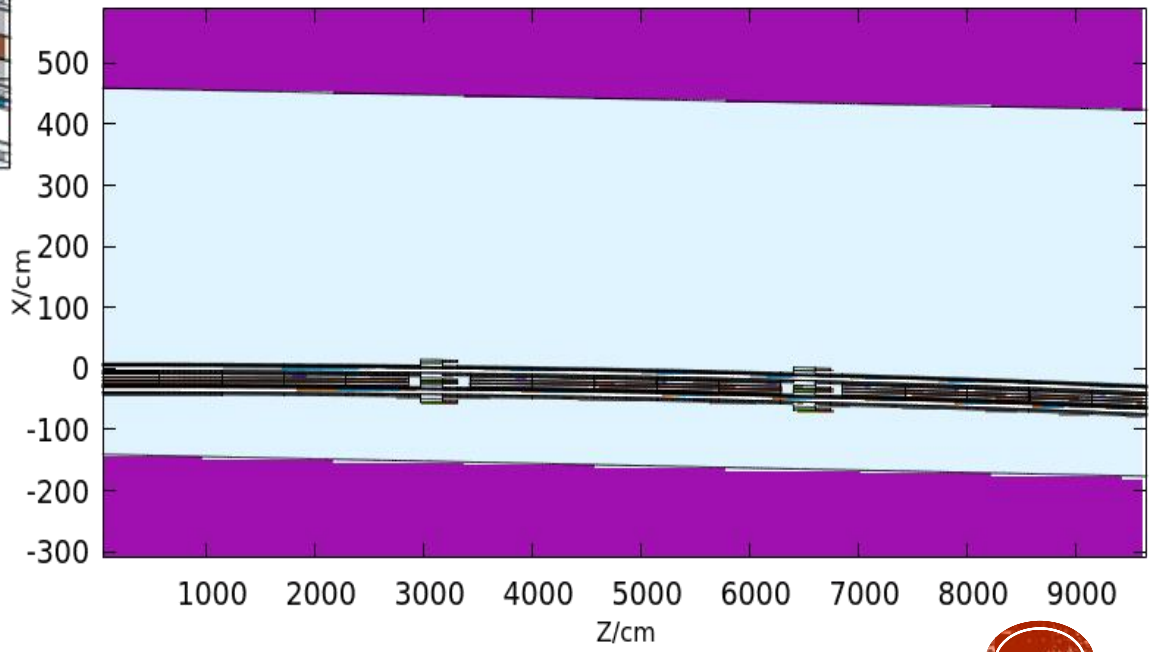
- Tunnel geometry

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



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

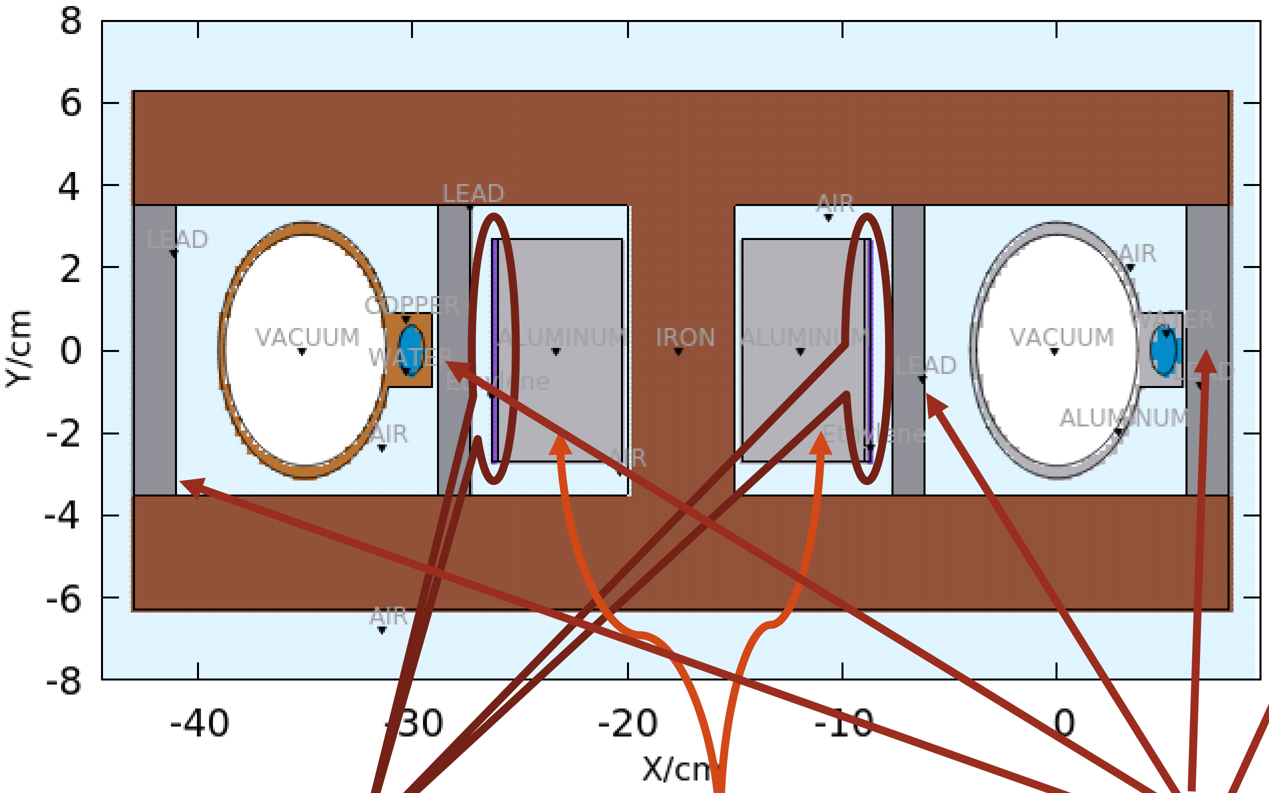




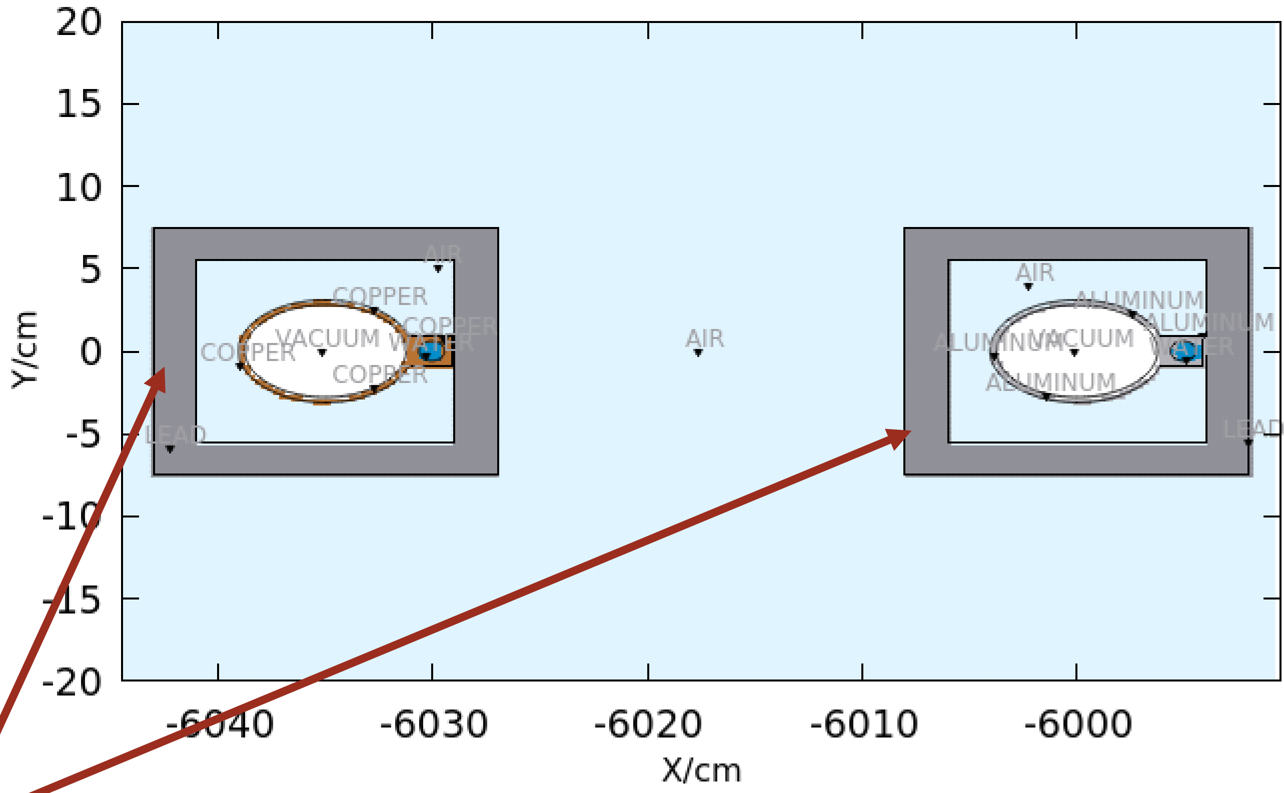
- Length: 100m;
  - 3 dipoles;
  - 2 quadrupoles;
  - 2 sextupoles;

SIMULATION SETUP

- Dipole



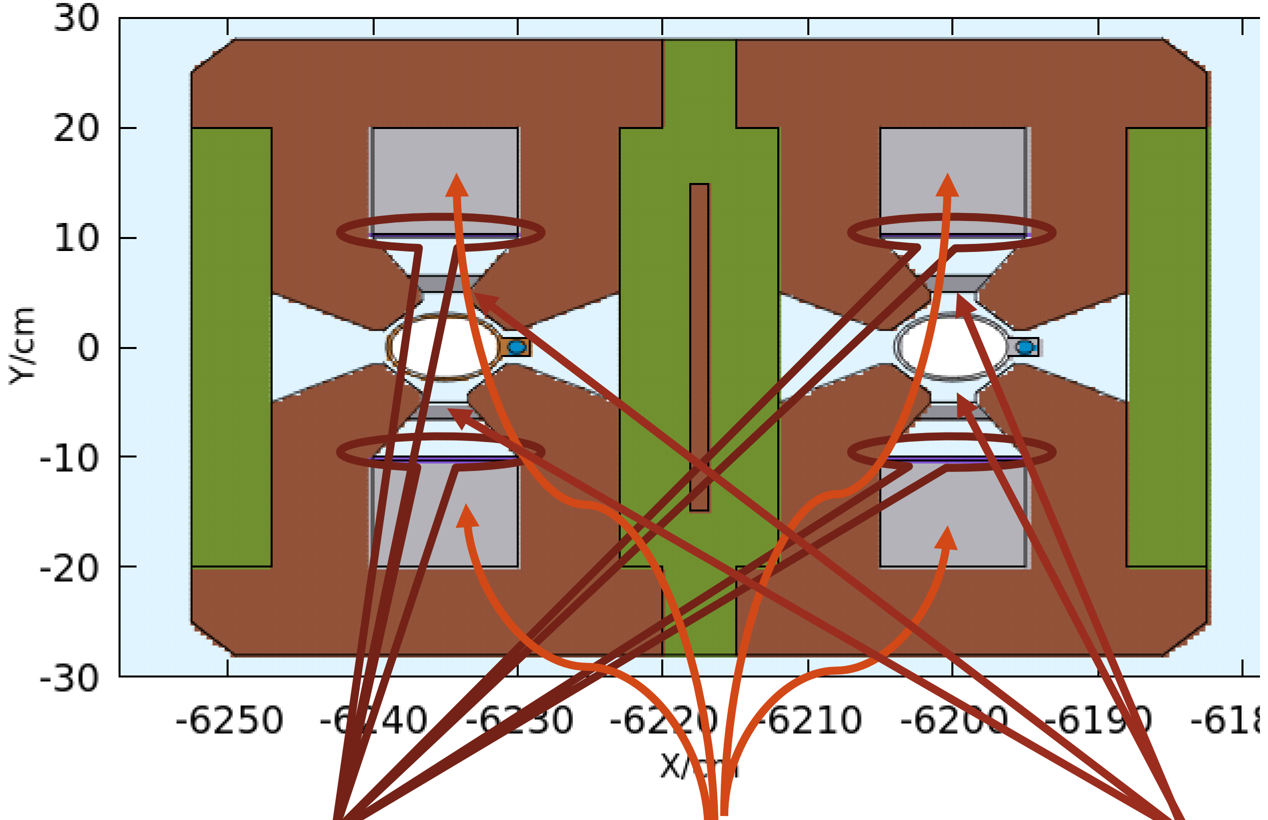
- Drift chamber



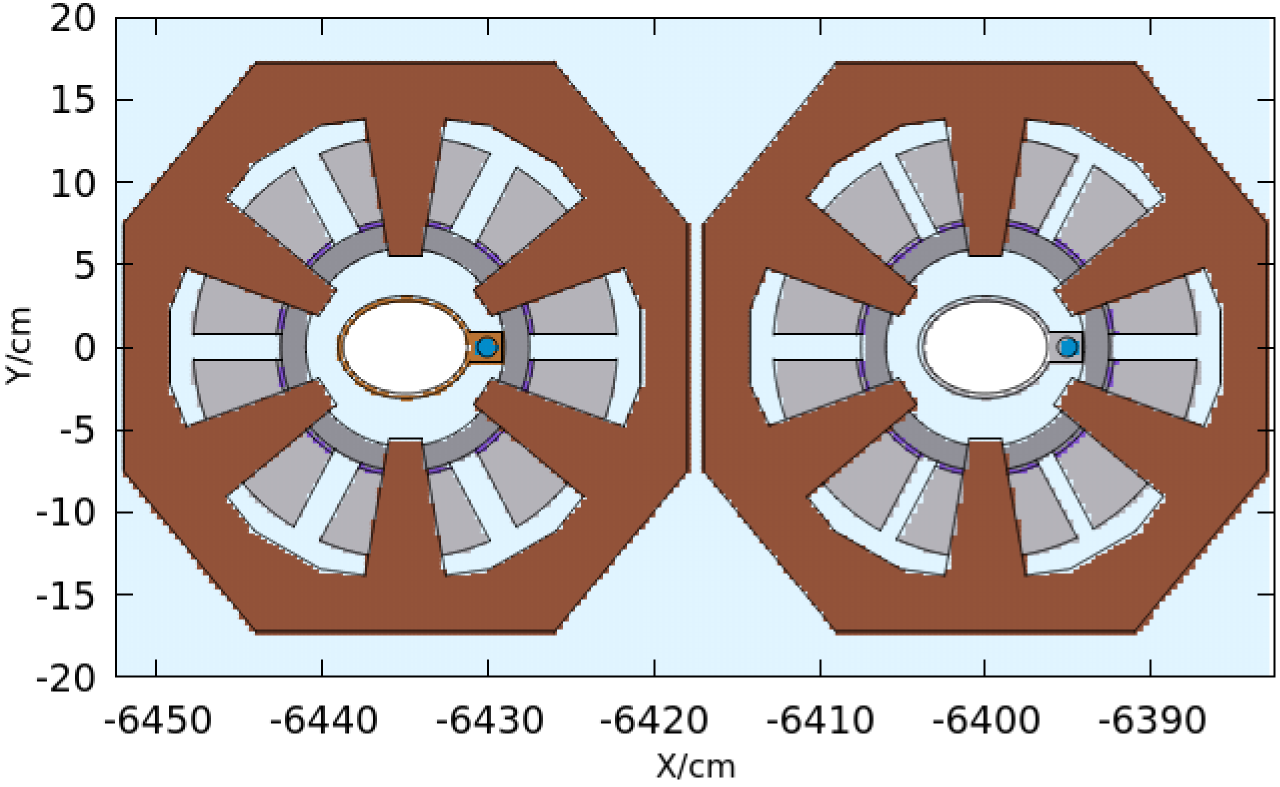
- insulator, coils, lead
- Insulator is added in the model.
- In cross-section, area of lead: $56cm^2$
- area of lead: $216cm^2$

SIMULATION SETUP

- Quadrupole



- Sextupole



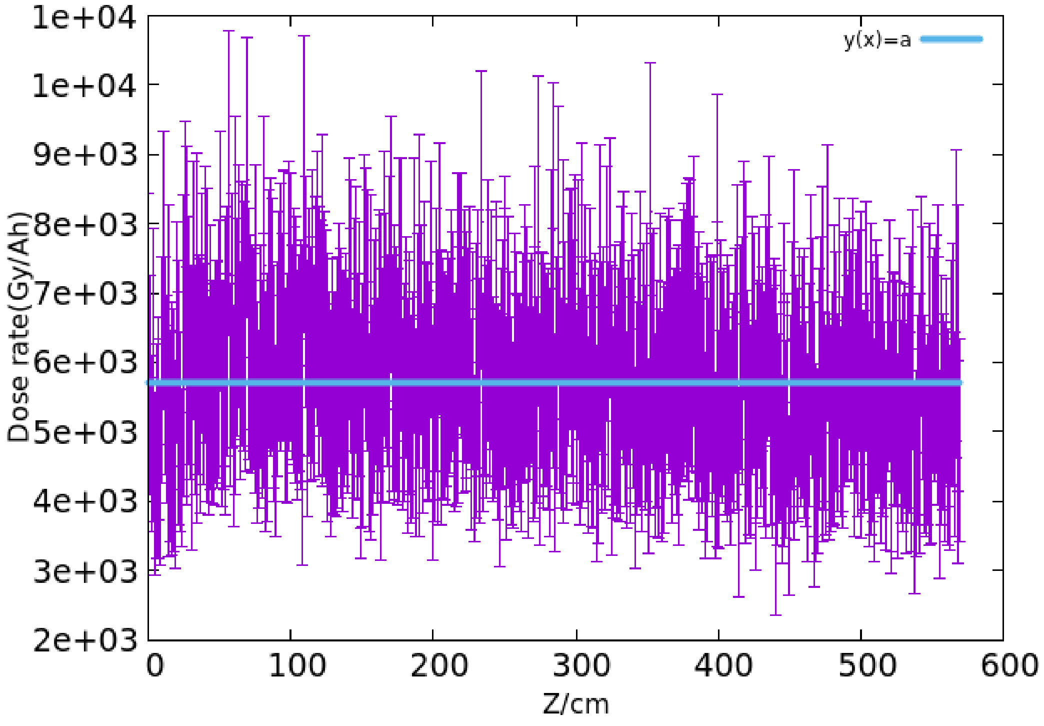
- insulator, coils, lead
- Insulator is added in the model.
- area of lead : $48cm^2$
- area of lead : $100cm^2$

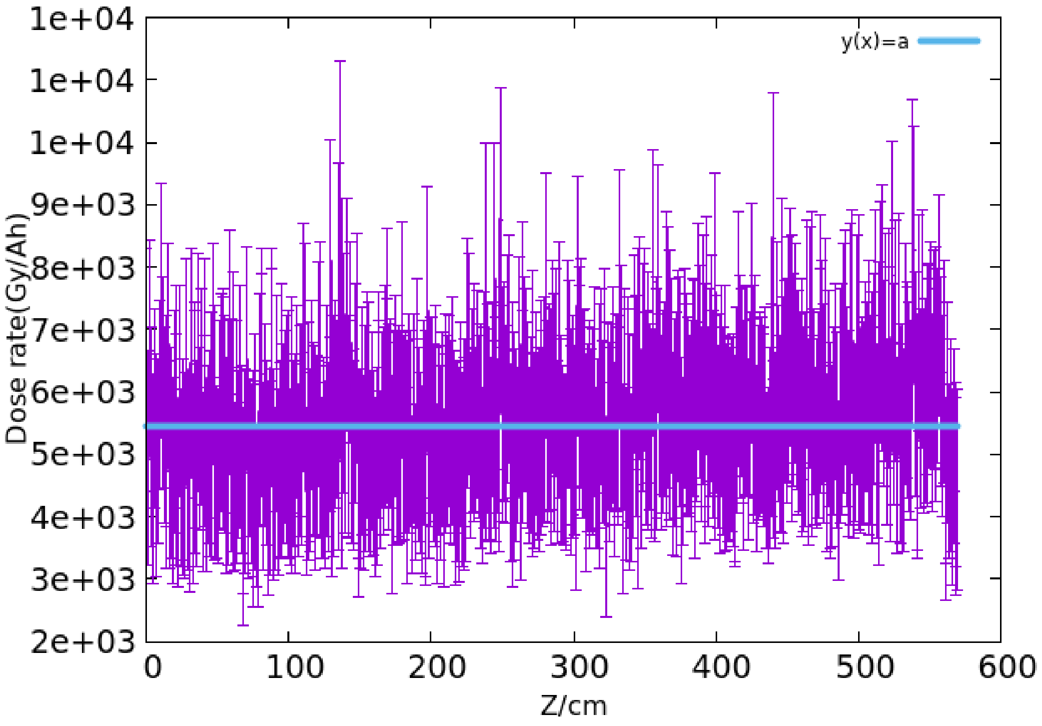
DOSE AROUND INSULATORS (2CM LEAD)

- For dipole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Al	0 ± 0	129 ± 4	5695 ± 30	$(1.89 \pm 0.02) \times 10^5$
Cu	0.42 ± 0.32	53 ± 3	5473 ± 32	$(1.91 \pm 0.02) \times 10^5$

- Fit dose distribution to get values in above table, example @120GeV





DOSE AROUND INSULATORS (2CM LEAD)

- Quadrupole:

		Dose(Gy/Ah)			
		Z	WW	Higgs	ttbar
Quadrupole	Top right	0 ± 0	131 ± 4	5621 ± 42	$(9.21 \pm 0.08) \times 10^4$
	Bottom right	0 ± 0	153 ± 5	5697 ± 41	$(8.44 \pm 0.08) \times 10^4$
	Top left	0 ± 0	77 ± 4	3714 ± 92	$(6.58 \pm 0.13) \times 10^4$
	Bottom left	0 ± 0	90 ± 4	3660 ± 89	$(6.96 \pm 0.13) \times 10^4$
Sextupole	Left	0 ± 0	359 ± 14	$(1.65 \pm 0.03) \times 10^4$	$(3.23 \pm 0.07) \times 10^5$
	right	0 ± 0	195 ± 7	$(9.3 \pm 0.2) \times 10^3$	$(2.20 \pm 0.05) \times 10^5$

- Running schedule

	Higgs	Z	WW
Running time (yr)	7	2	1

- Dose:
  - 10y H/Z/WW

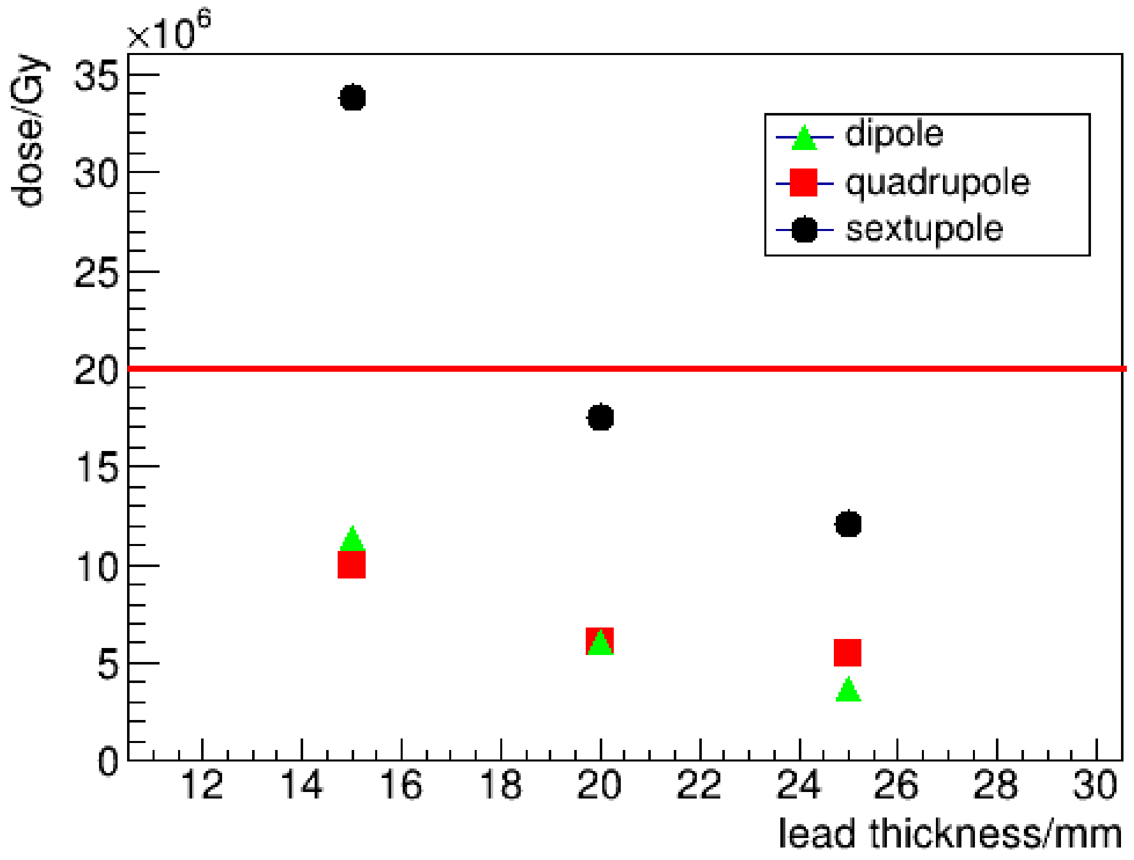
	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	6.05 ± 0.04	6.06 ± 0.05	17.5 ± 0.4

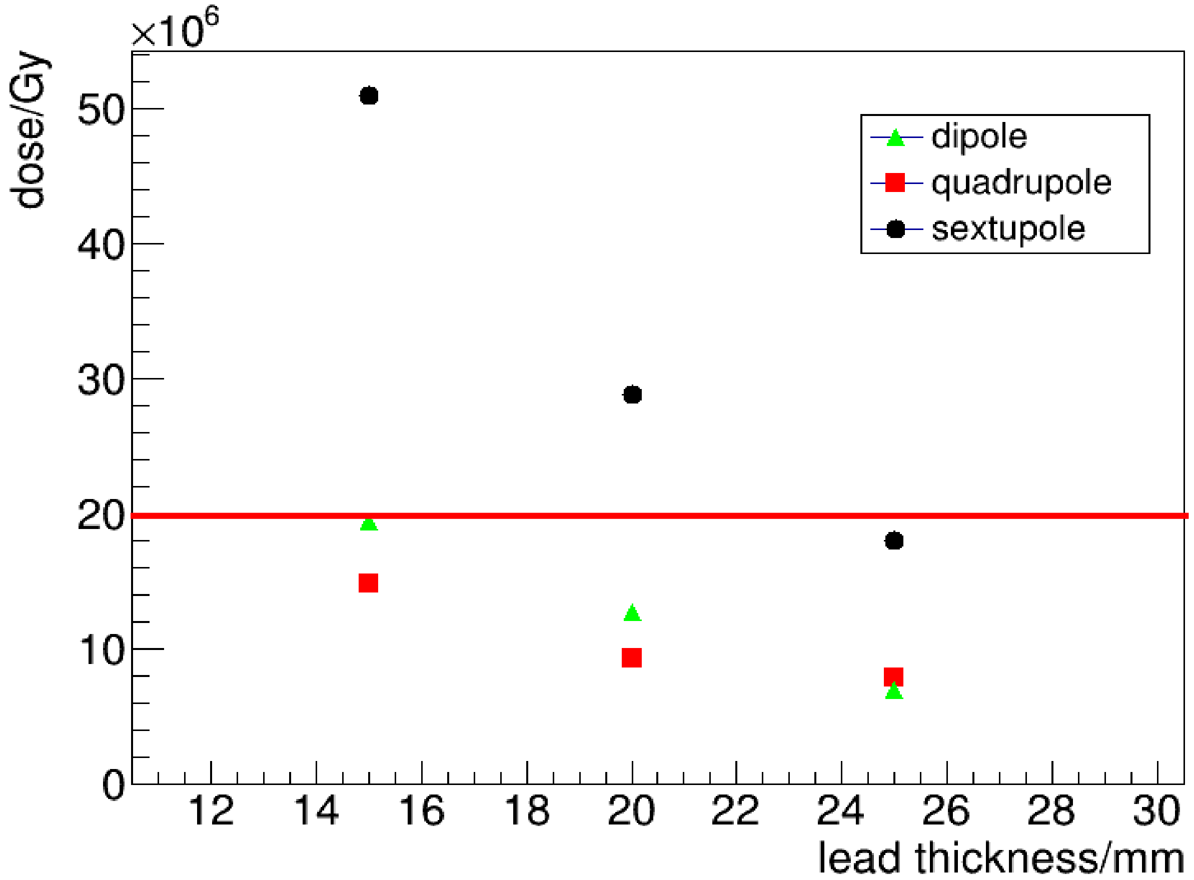
  - One year running ttbar

	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	6.62 ± 0.07	3.23 ± 0.03	11.3 ± 0.3

DOSE VS LEAD THICKNESS

- While running Higgs/Z/WW (10 years),
  - possible to reduce usage of lead for dipole and quadrupole;
  - but not for sextupole;
- While running 10+1 year,
  - close to upper limit for dipole and quadrupole;
  - Exceed upper limit for sextupole.



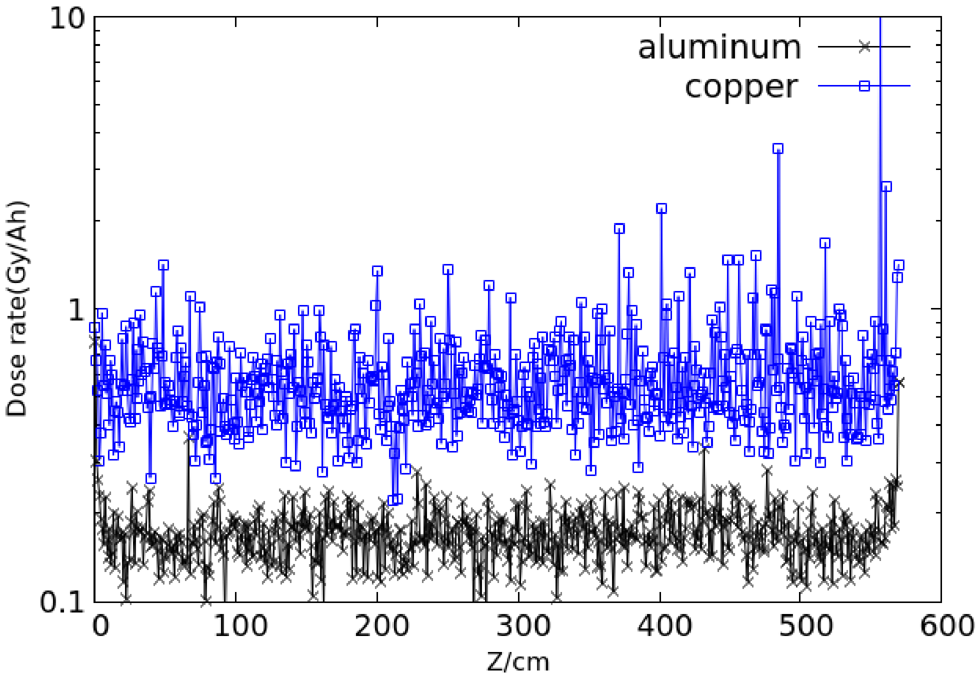


- Lead shielding works well. Will update while magnet design is updated.

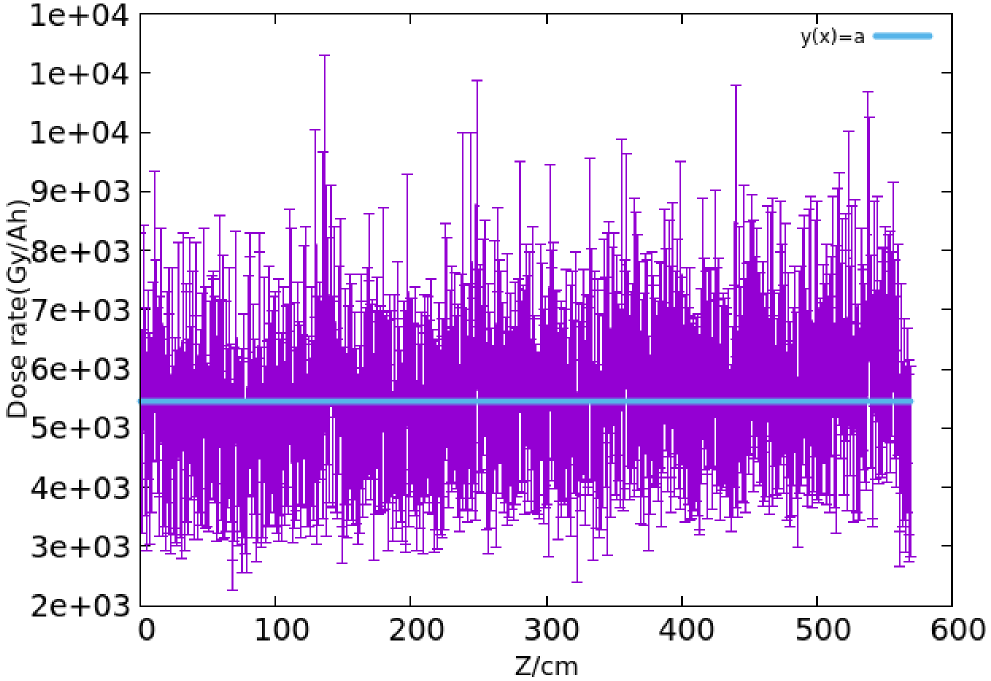
DOSE AROUND INSULATORS

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

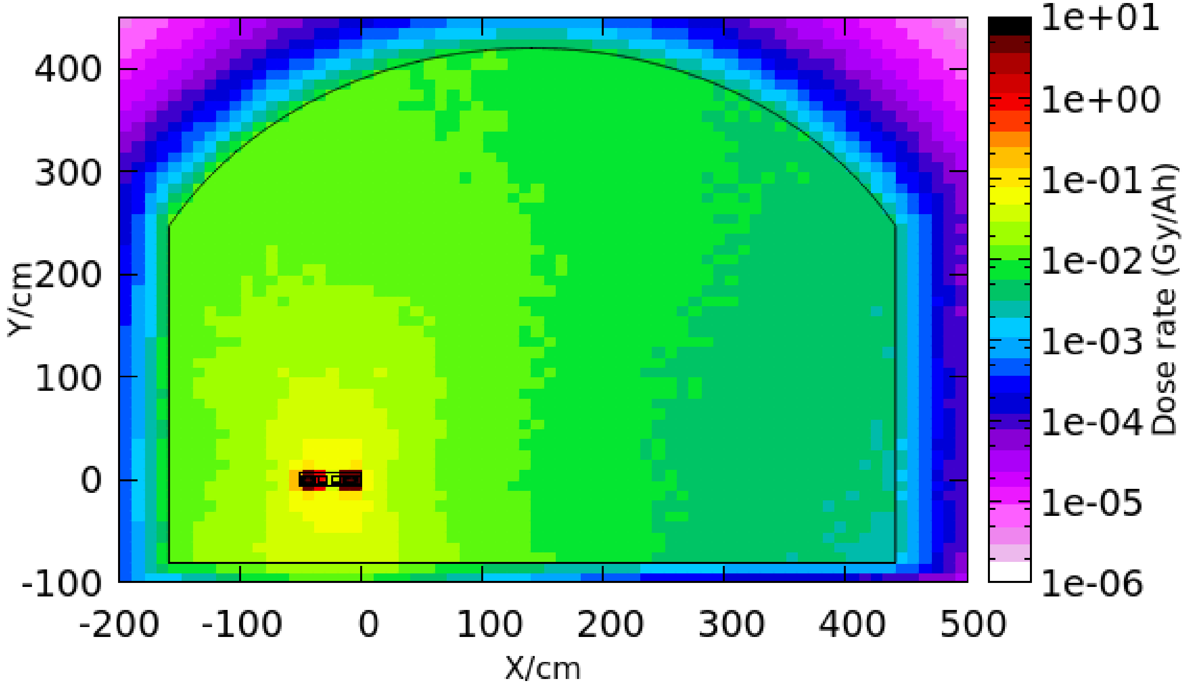


Prompt radiation dose caused by synchrotron radiation

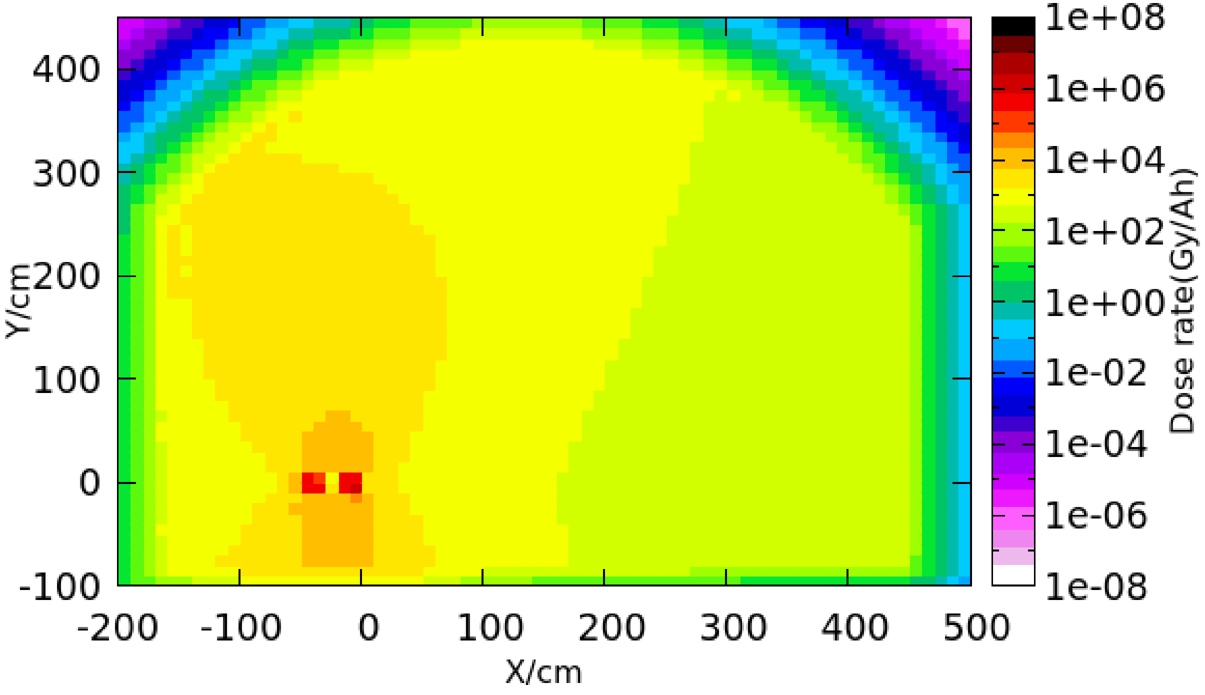
DOSE IN THE TUNNEL

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

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



Prompt radiation dose caused by random beam loss

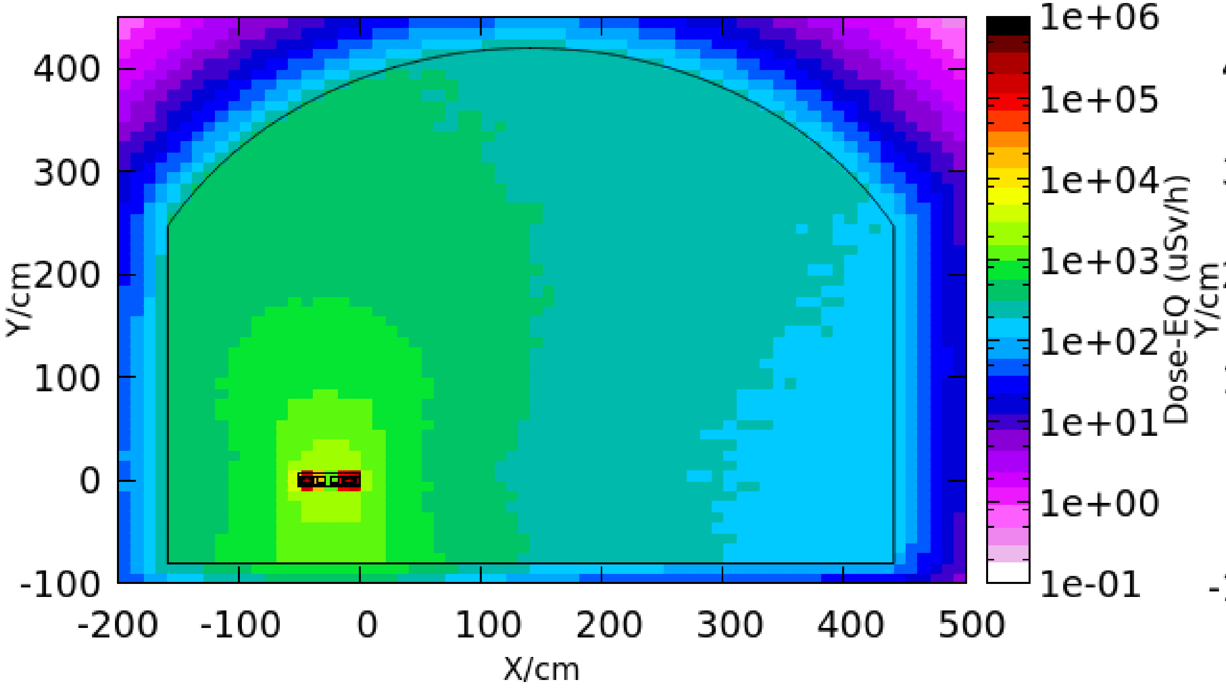


Prompt radiation dose caused by synchrotron radiation

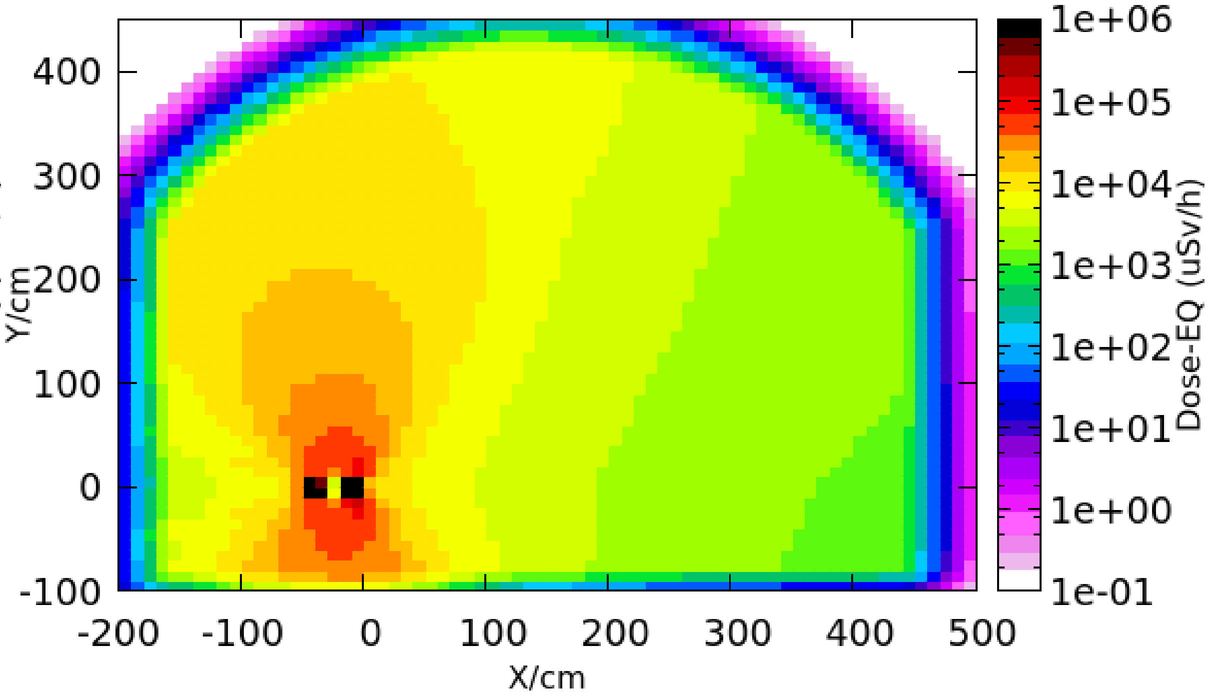
DOSE-EQ IN THE TUNNEL

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

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



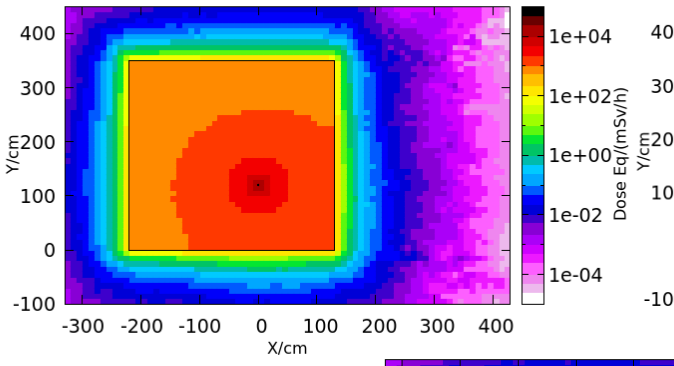
Prompt radiation dose-eq caused by random beam loss

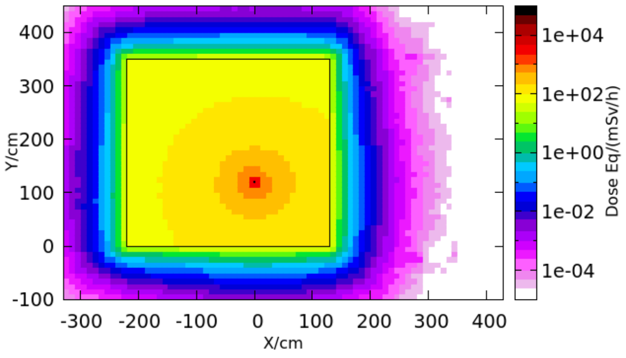


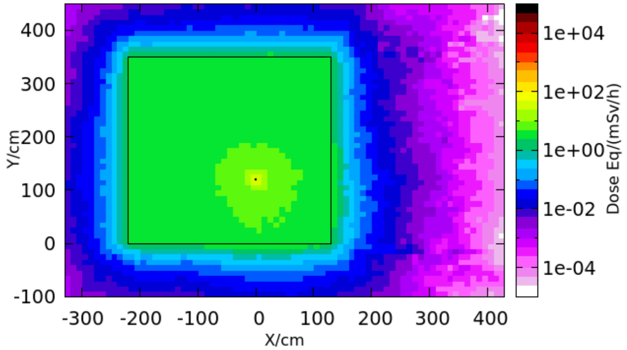
Prompt radiation dose-eq caused by synchrotron radiation

DOSE-EQ IN LINAC TUNNEL

- Dose-eq inside Linac tunnel is important to determine the local shielding thickness.
- Assume that leptons will be lost alone the beam-pipe. About 10% leptons with energy 10GeV is lost alone the beamline.
- Dose-eq: total, gamma, neutron



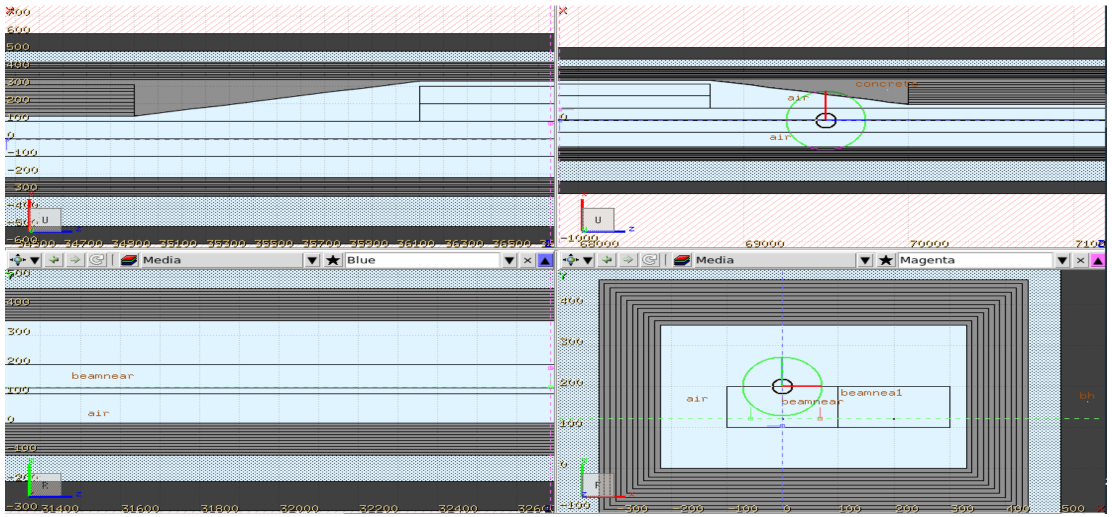




- Linac parameters

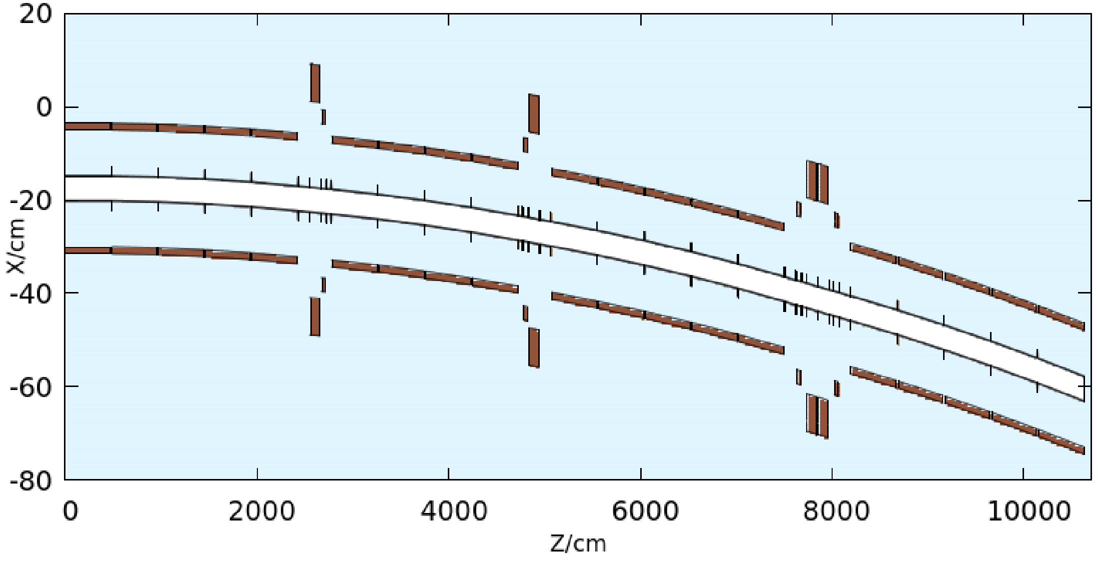
Parameter	Symbol	Unit	Value
e^- /e^+ beam energy	E_{e^-}/E_{e^+}	GeV	10
Repetition rate	f	Hz	100
e^- /e^+ bunch population	N_{e^-}/N_{e^+}		>9.4×10^9
	N_{e^-}/N_{e^+}	nC	>1.5
Energy spread (e^- /e^+)	σ_E		<2×10^{-3}
Emittance (e^- /e^+)		nm	<120
e^- beam energy on Target		GeV	4
e^- bunch charge on Target		nC	10
Length	L	m	1200

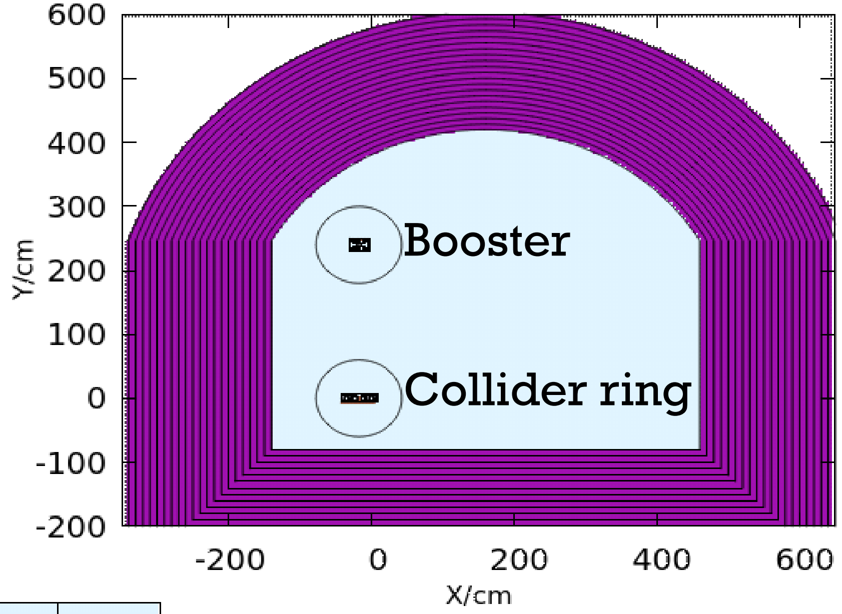
- Linac simulation setup

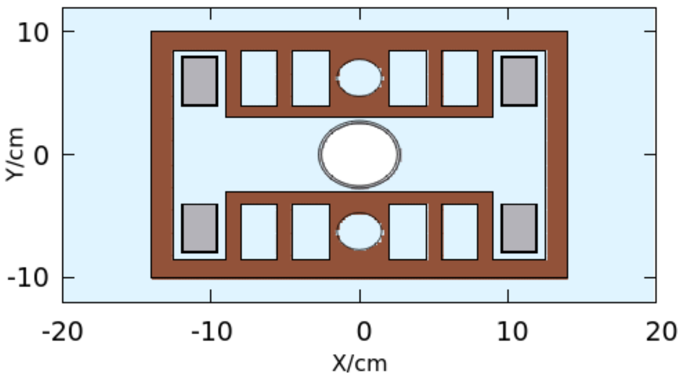


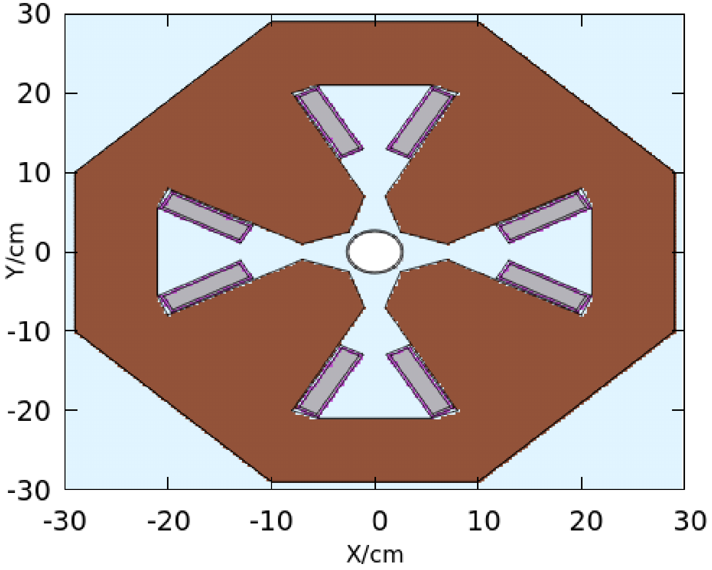
OUTLOOK

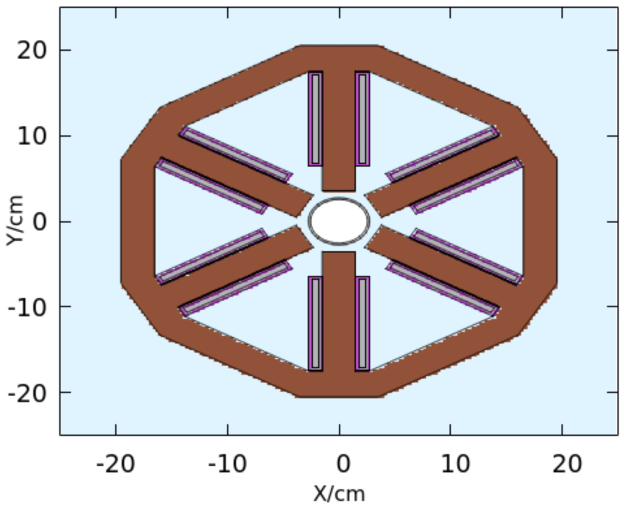
- Booster is added in the simulation. More results are on the way.





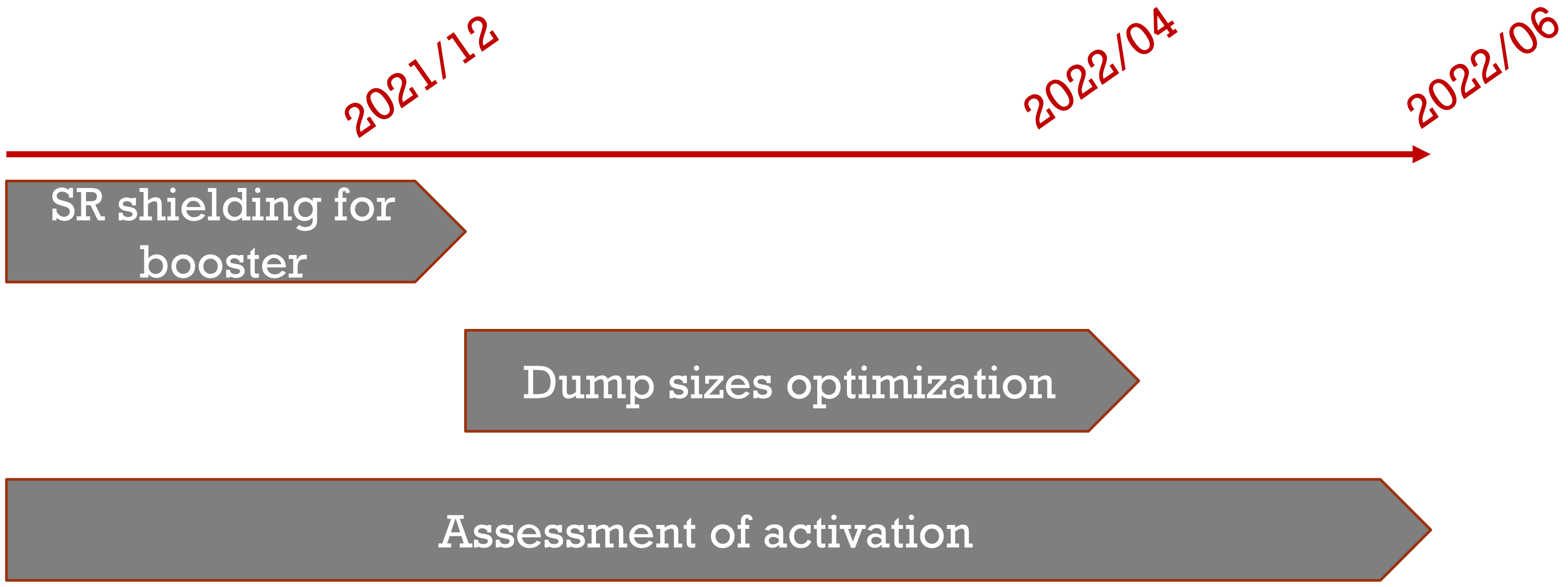






SUMMARY & OUTLOOK

- Preliminary dump designs for ring and linac are done. Optimizations are going on.
- SR shielding for collider ring has been checked. SR shielding for booster will be finished soon.
- Dose distribution for collider and linac is obtained based on CDR paras. As linac design is updated, we will update soon.
- Careful assessment of activation is needed.



Thank you

23

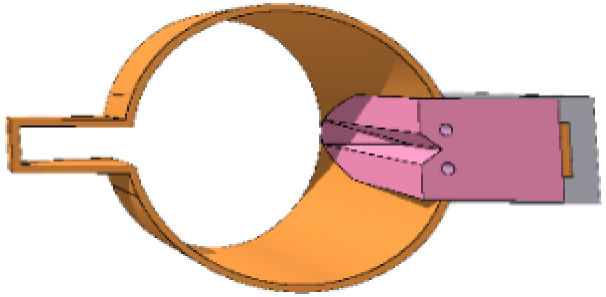
BACKUP

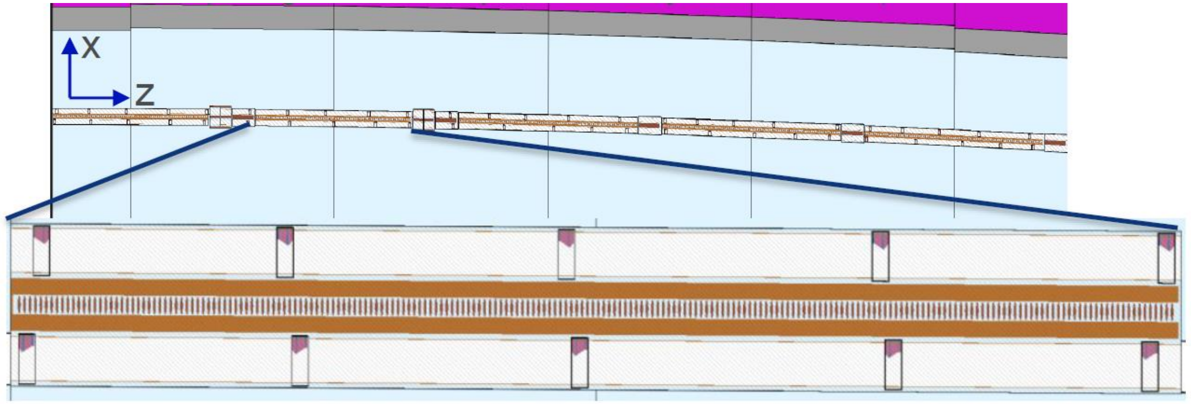
VACUUM CHAMBER: FCC-EE, TWO SCHEMES

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)

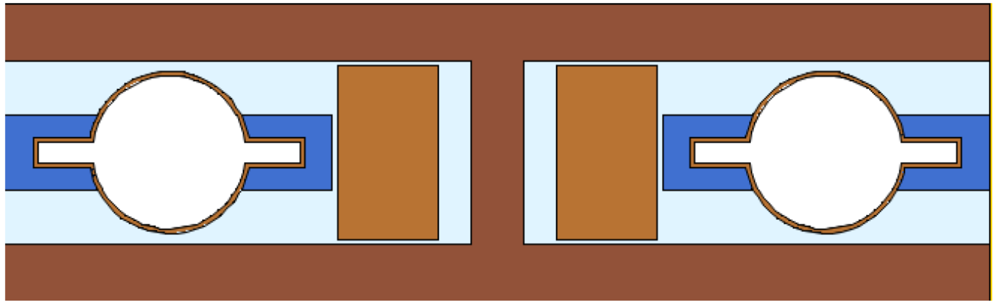




Barbara Humann, FCC week 2021 talk

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



DEPOSITED ENERGY

- The energy deposited in air and wall is less than 5%.
- Energy deposited in dipole and beam-pipe is quite large.

- 2cm-lead shielding

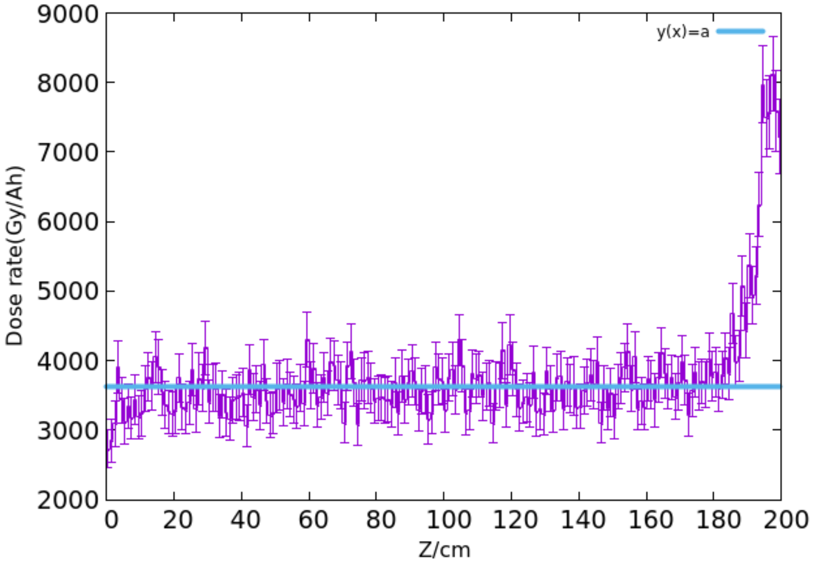
	Z	WW	Higgs	ttbar
Beam pipe (Al)	50.0%	45.9%	38.5%	36.0%
Beam pipe (Cu)	46.7%	27.4%	23.0%	26.8%
Lead	1.1%	9.6%	14.9%	14.5%
Iron of dipole	1.9%	14.5%	18.7%	16.4%
Iron of quadrupole	0.1%	0.9%	1.4%	1.4%
Iron of sextupole	0.1%	0.6%	0.9%	0.8%
Air	0.0005%	0.01%	0.03%	0.04%
Wall	0.0004%	0.03%	1.8%	3.1%

CEPC PARAMETERS

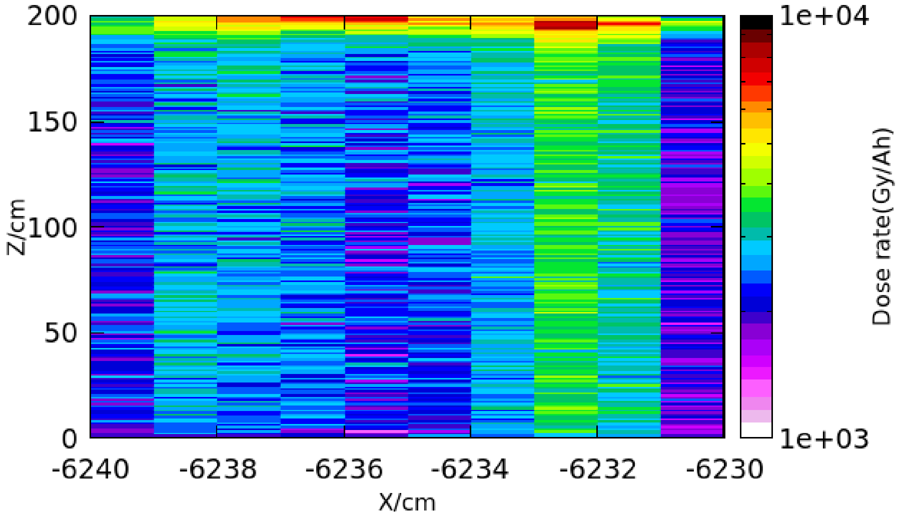
	Higgs	WW	Z	Z (high lum.)	ttbar
Beam energy (GeV)	120	80	45.5		182.5
SR loss/turn (GeV)	1.73	0.34	0.036		9.15
Particles/bunch (10^{10})	15	12	8	15	20
Bunch number	242	1524	12000	15000	35
Beam current (mA)	17.4	87.9	461.0	1081.4	3.36
SR power/beam (MW)	30	30	16.5	38	30
Bending radius (km)	10.72				
Critical energy(keV)	358	106	19		1258
Ave. energy/photon (keV)	110.1	32.6	6.0		387.3
Photons/57.2m dipole	1.44×10^{18}	4.83×10^{18}	1.44×10^{19}	3.38×10^{19}	4.2×10^{17}

HOT POINTS (2CM LEAD)

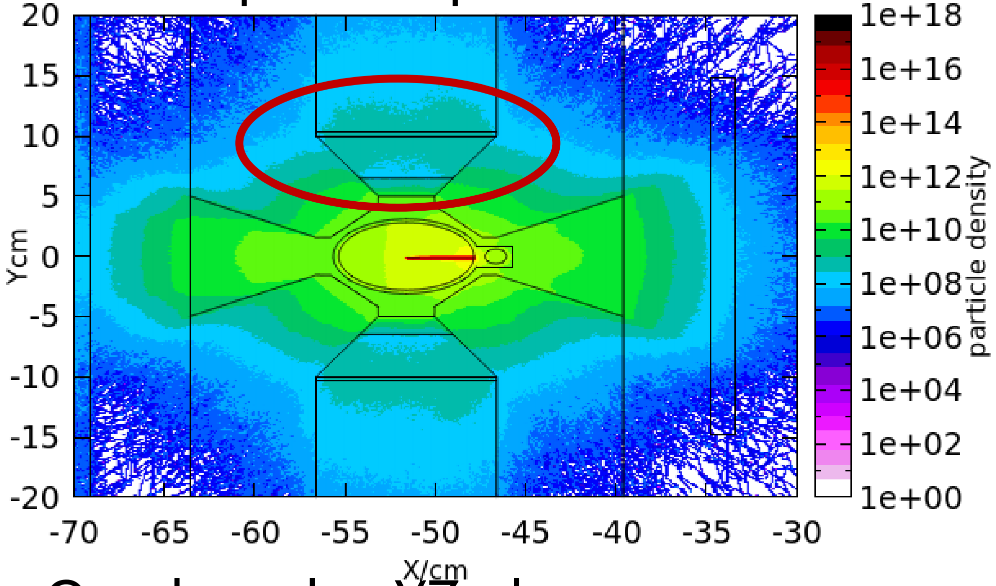
- Dose hot points caused by particles bypassing lead shielding.



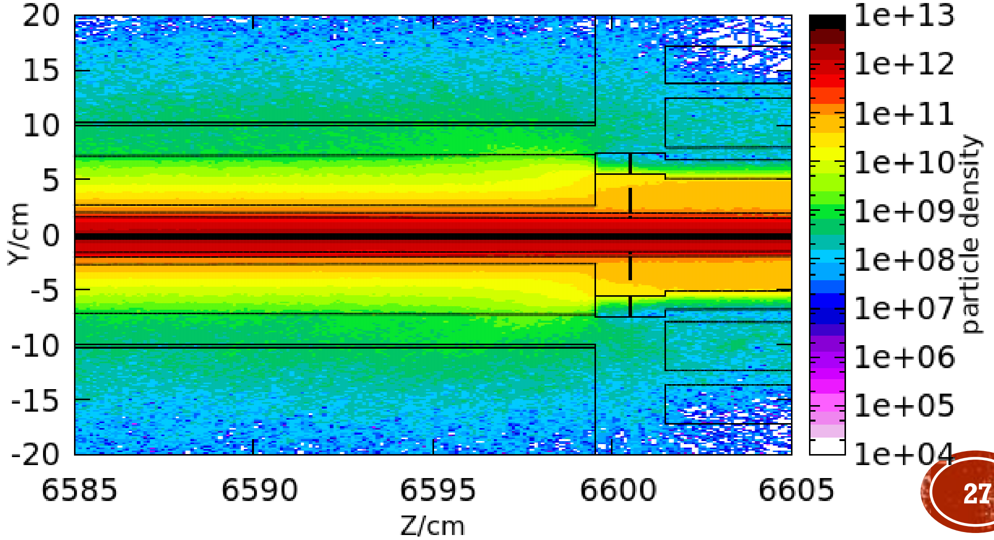
- 2D dose distribution on the surface of insulator



- Quadrupole XY plane

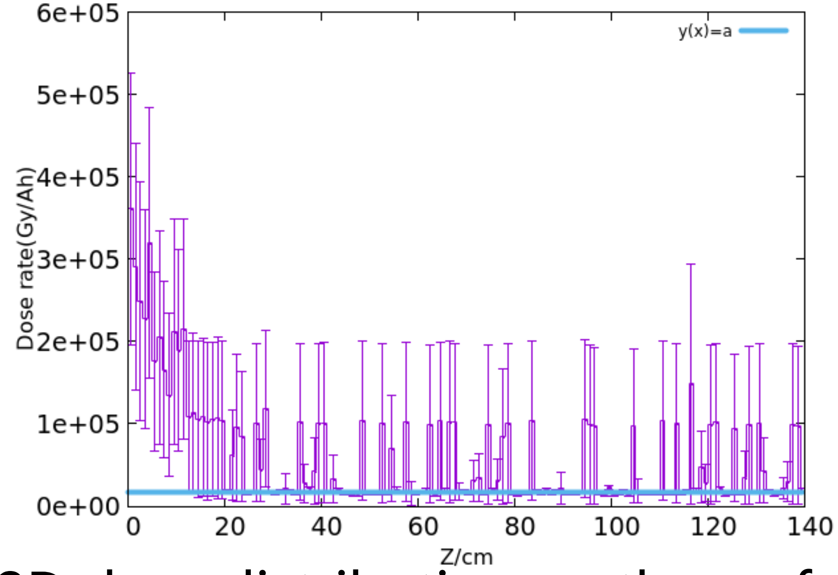


- Quadrupole : YZ plane

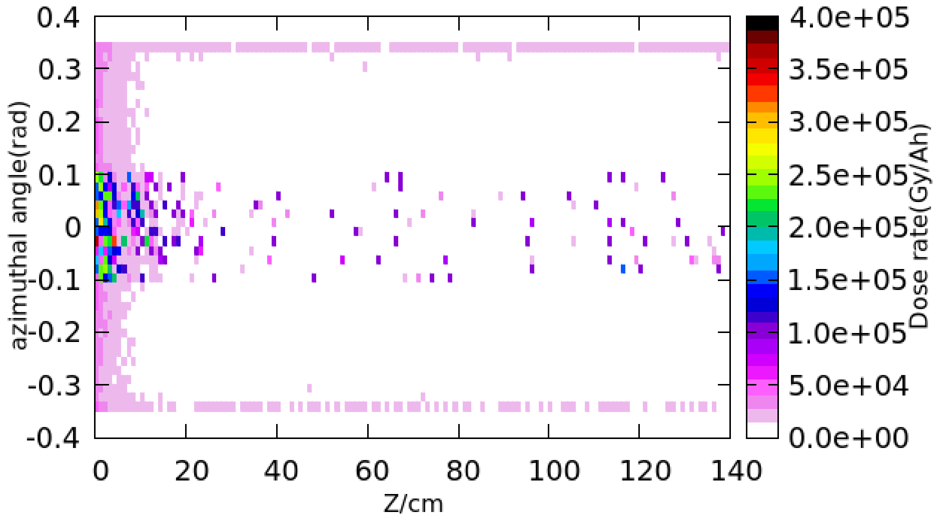


HOT POINTS (2CM LEAD)

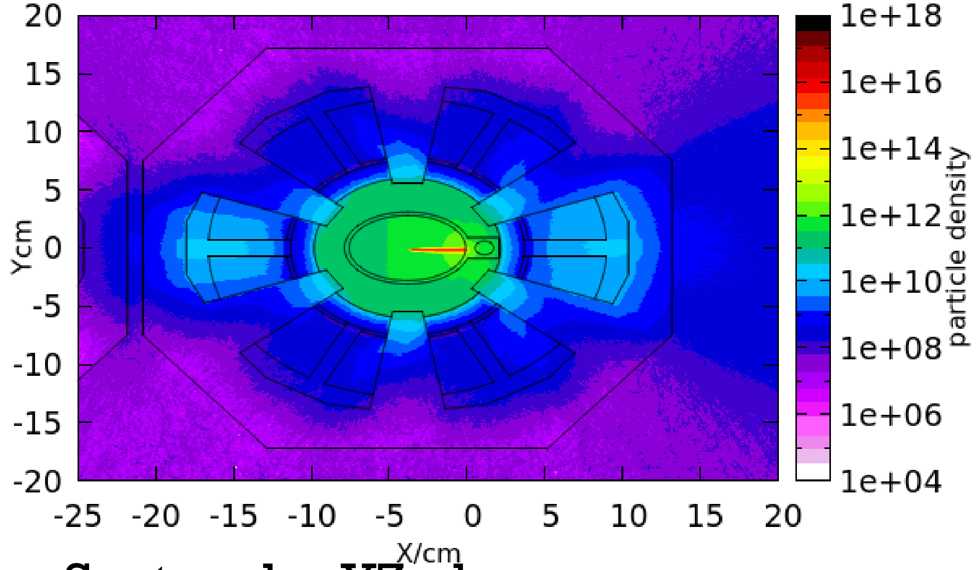
- Dose hot points caused by particles bypassing lead shielding.



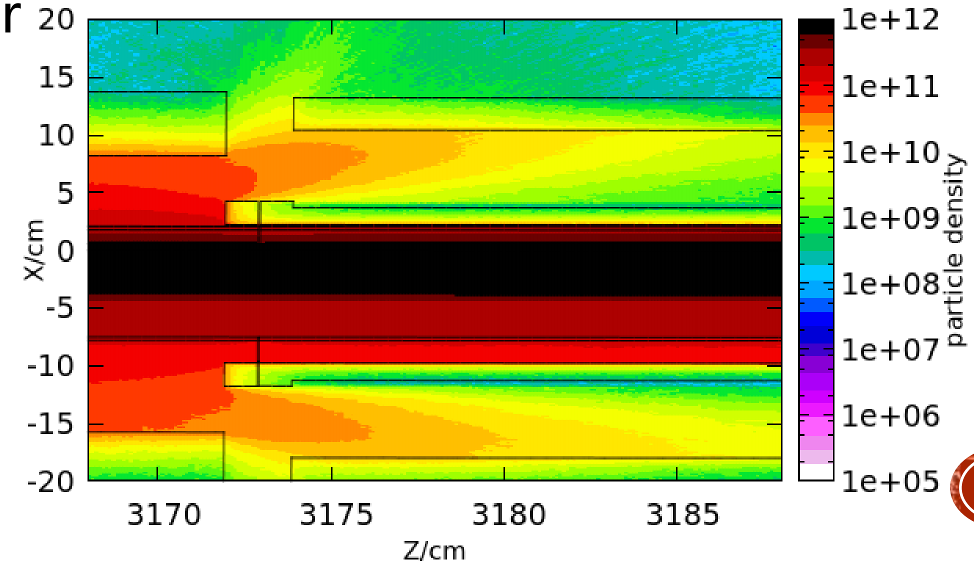
- 2D dose distribution on the surface of insulator



- Sextupole XY plane



- Sextupole : YZ plane



DOSE AROUND INSULATORS

- Lead thickness: 1.5cm
- Dipole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Al	0 ± 0	257 ± 4	10673 ± 46	$(2.23 \pm 0.01) \times 10^5$
Cu	0.42 ± 0.32	201 ± 4	10151 ± 47	$(2.30 \pm 0.01) \times 10^5$

- Quadrupole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Top right	0 ± 0	221 ± 4	9367 ± 99	$(1.41 \pm 0.02) \times 10^5$
Bottom right	0 ± 0	216 ± 4	9249 ± 97	$(1.31 \pm 0.02) \times 10^5$
Top left	0 ± 0	121 ± 2	6070 ± 58	$(9.94 \pm 0.10) \times 10^4$
Bottom left	0.11 ± 0.04	117 ± 2	5924 ± 54	$(9.56 \pm 0.09) \times 10^4$

DOSE AROUND INSULATORS

- Lead thickness: 1.5cm
- Sextupole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Left	0 ± 0	651 ± 17	$(3.19 \pm 0.05) \times 10^4$	$(4.93 \pm 0.08) \times 10^5$
right	0 ± 0	325 ± 8	$(1.80 \pm 0.03) \times 10^4$	$(2.95 \pm 0.05) \times 10^5$

- Running schedule

	Higgs	Z	WW
Running time (yr)	7	2	1

- Dose:
  - 10y H/Z/WW

	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	11.33 ± 0.05	9.94 ± 0.11	33.76 ± 0.6

  - One year running ttbar

	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	8.06 ± 0.04	4.94 ± 0.07	17.3 ± 0.3

DOSE AROUND INSULATORS

- Lead thickness: 2.5cm
- Dipole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Al	0 ± 0	12 ± 1	3421 ± 23	$(9.26 \pm 0.06) \times 10^4$
Cu	5 ± 2	0 ± 0	2914 ± 22	$(8.36 \pm 0.06) \times 10^4$

- Quadrupole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Top right	0 ± 0	99 ± 2	4806 ± 48	$(6.66 \pm 0.08) \times 10^4$
Bottom right	0 ± 0	126 ± 2	5166 ± 55	$(6.64 \pm 0.08) \times 10^4$
Top left	0 ± 0	50 ± 1	2795 ± 27	$(4.48 \pm 0.04) \times 10^4$
Bottom left	0.29 ± 0.07	67 ± 1	3029 ± 30	$(4.67 \pm 0.04) \times 10^4$

DOSE AROUND INSULATORS

- Lead thickness: 2.5cm
- Sextupole:

	Dose(Gy/Ah)			
	Z	WW	Higgs	ttbar
Left	0 ± 0	243 ± 9	$(1.13 \pm 0.02) \times 10^4$	$(1.69 \pm 0.03) \times 10^5$
right	0 ± 0	114 ± 6	$(6.65 \pm 0.11) \times 10^3$	$(1.09 \pm 0.02) \times 10^5$

- Running schedule

	Higgs	Z	WW
Running time (yr)	7	2	1

- Dose:
  - 10y H/Z/WW

	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	3.62 ± 0.03	5.49 ± 0.06	12.0 ± 0.2

  - One year running ttbar

	Dipole	Quadrupole	Sextupole
Dose(10^6 Gy)	3.24 ± 0.02	2.33 ± 0.03	5.9 ± 0.1

TEMPERATURE RISE

- Simulate only one bunch whose width is minimum

		ttbar	Higgs	WW	Z(2T high lumi.)
Beam energy/GeV		175	120	80	45.5
Ne/(bunch· 10^{10})		24	17	12	15
Bunch number		34	218	1569	15000
Total energy/MJ		0.2	0.7	2.4	16.4
Maximum temperature rise	Fluka	229 $\pm$ 3℃	138 $\pm$ 4℃	103 $\pm$ 1℃	714 $\pm$ 12℃
	One bunch	227.7 $\pm$ 0.5℃	140.8 $\pm$ 0.3℃	78.5 $\pm$ 0.3℃	88 $\pm$ 29℃