Institute of High Energy Physics
Chinese Academy of Sciences

CEPC 环形正负电子对撞机 Circular Electron Positron Collider

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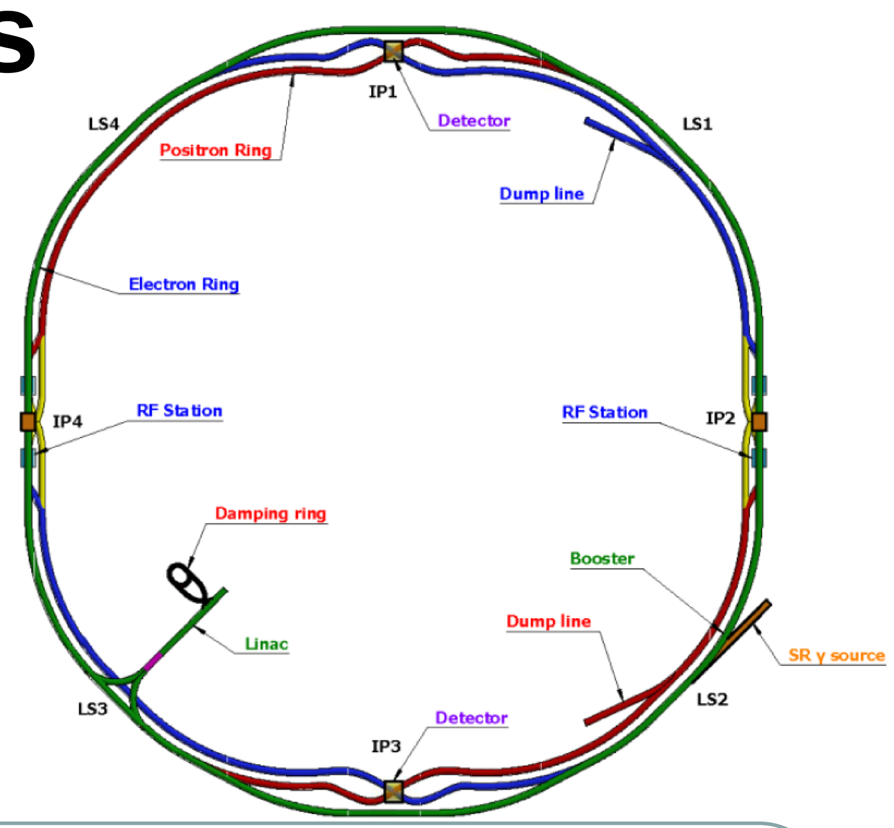
The CEPC radiation protection issues

G. Y. Tang#, 1), H. Y. Shi1), Q. Y. Liu1), Z. J. Ma1)

1) Institute of High Energy Physics, CAS, China



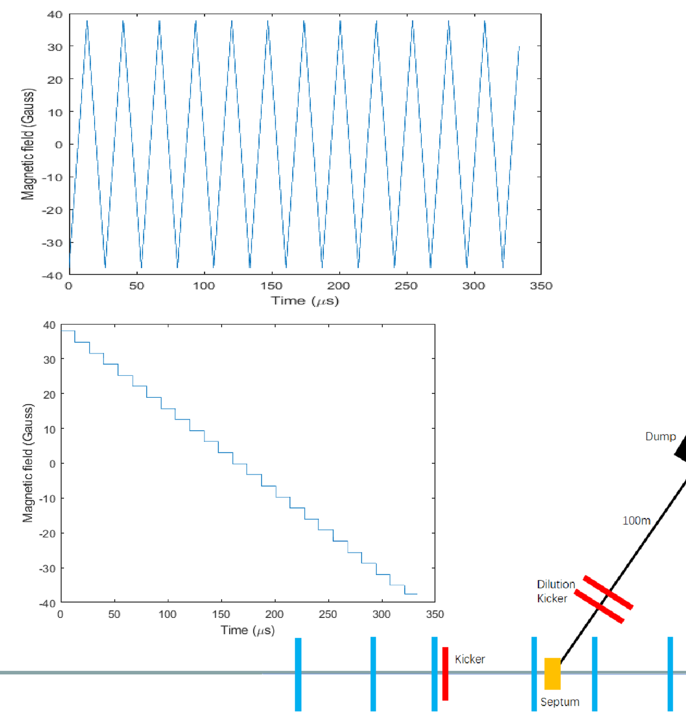
Circular Electron-Positron Collider (CEPC) is a 100 km circumference double-ring Collider. The radiation protection issues are complicated topics at the CEPC. The CEPC machine will operate at different beam energies, from 45.5 GeV up to 180 GeV and at beam currents, from 3.3 mA to 1340.9 mA. The collider dumping system, synchrotron radiation shielding, the linac bulk shielding, the linac dump dimensions and the radioactivity productions are introduced.

1. The Collider dump

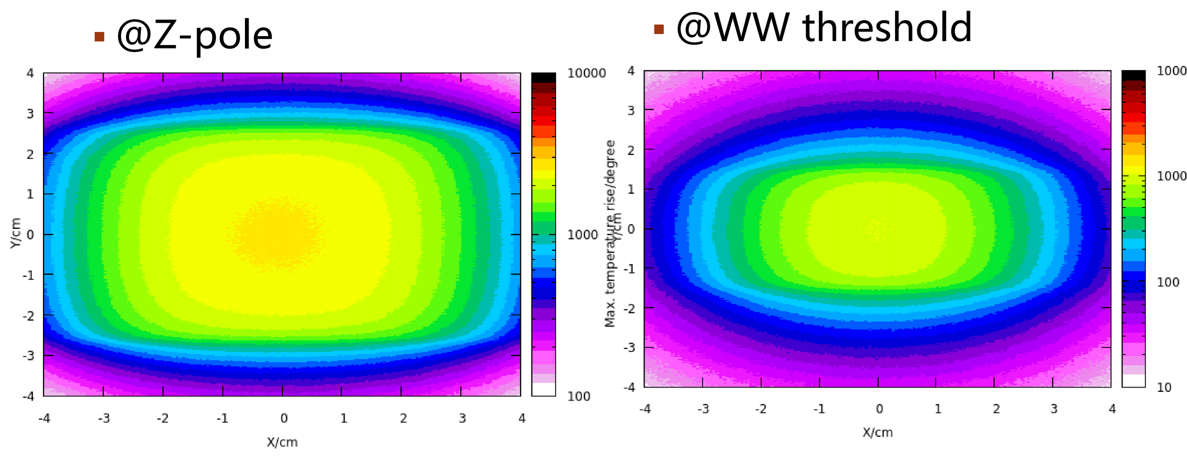
- Besides a kicker and septum, two dilution kickers are used to dilute the beam horizontally and vertically.
- The dump core is made of graphite, covered by a iron shell.

		Extraction kicker	Septum	Dilution kickers
Length (m)		2	20	10
Magnetic flux density (Gauss)	Z	280	2600	40 (Max.)
	WW	493	4700	
	Higgs	740	7000	
	ttbar	1110	10500	

- The wave forms of dilution kickers are in the figures below.



- When dumping once, the instantaneous temperature rise is in the figures below.
  - @Z-pole
  - @WW threshold

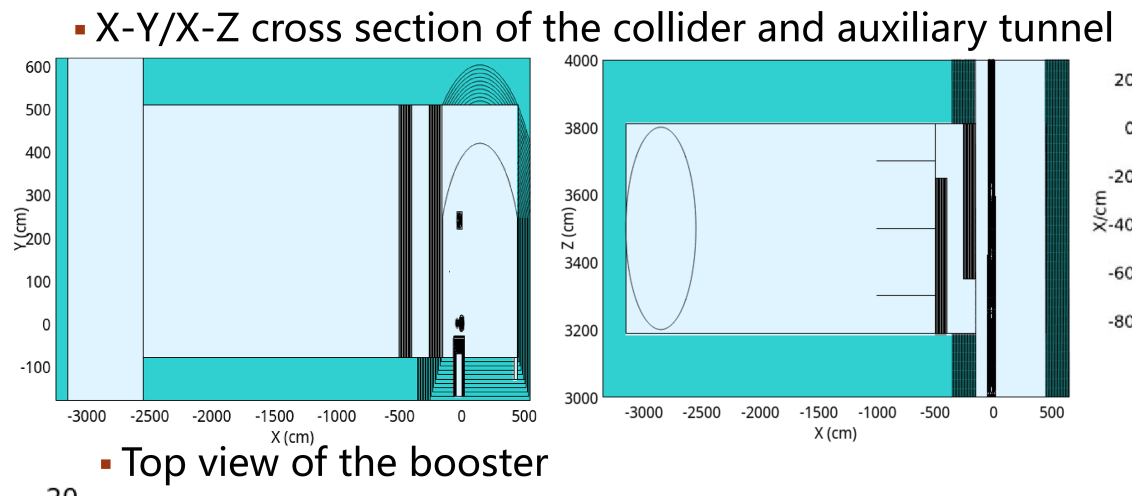


	Higgs	WW	Z	ttbar
Beam energy/GeV	120	80	45.5	180
Ne/bunch/ 10^{10}	14	13.5	14	20
Bunch number (50MW)	415	2162	19918	58
Max. temperature rise	510 $\pm$ 15℃	1020 $\pm$ 30℃	2620 $\pm$ 15℃	194 $\pm$ 2℃

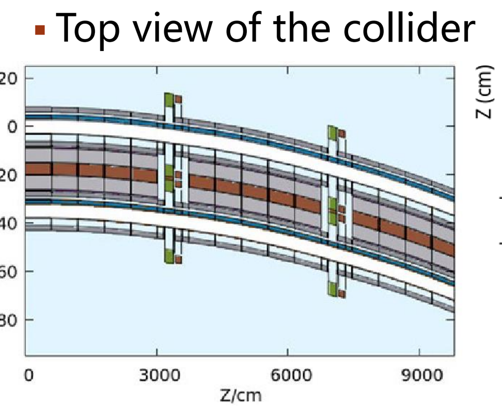
- The max. temperature rises are shown in the table.
- Dimension (graphite + Iron): R~2.3m, L~8m; Constrained by dose-eq < 5.5mSv/h.
- Max. temperature rise is smaller than graphite melting point. Inert gas will be used to stop fire and chemical reaction.

2. Synchrotron Radiation in the tunnel

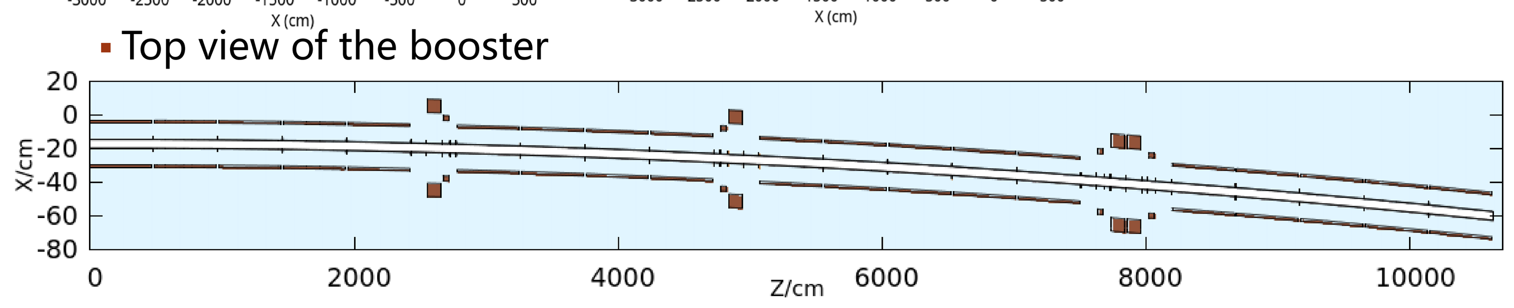
- The tunnel geometry is shown in the figures below.
  - X-Y/X-Z cross section of the collider and auxiliary tunnel



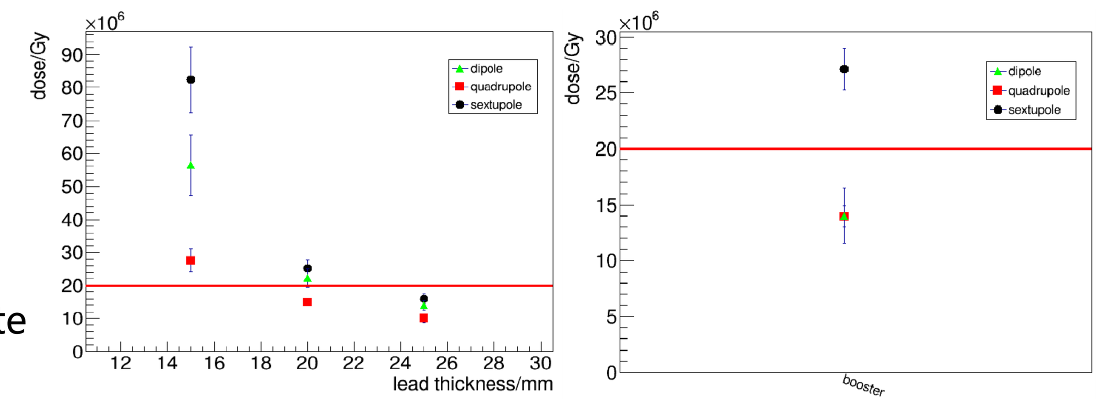
- Top view of the collider



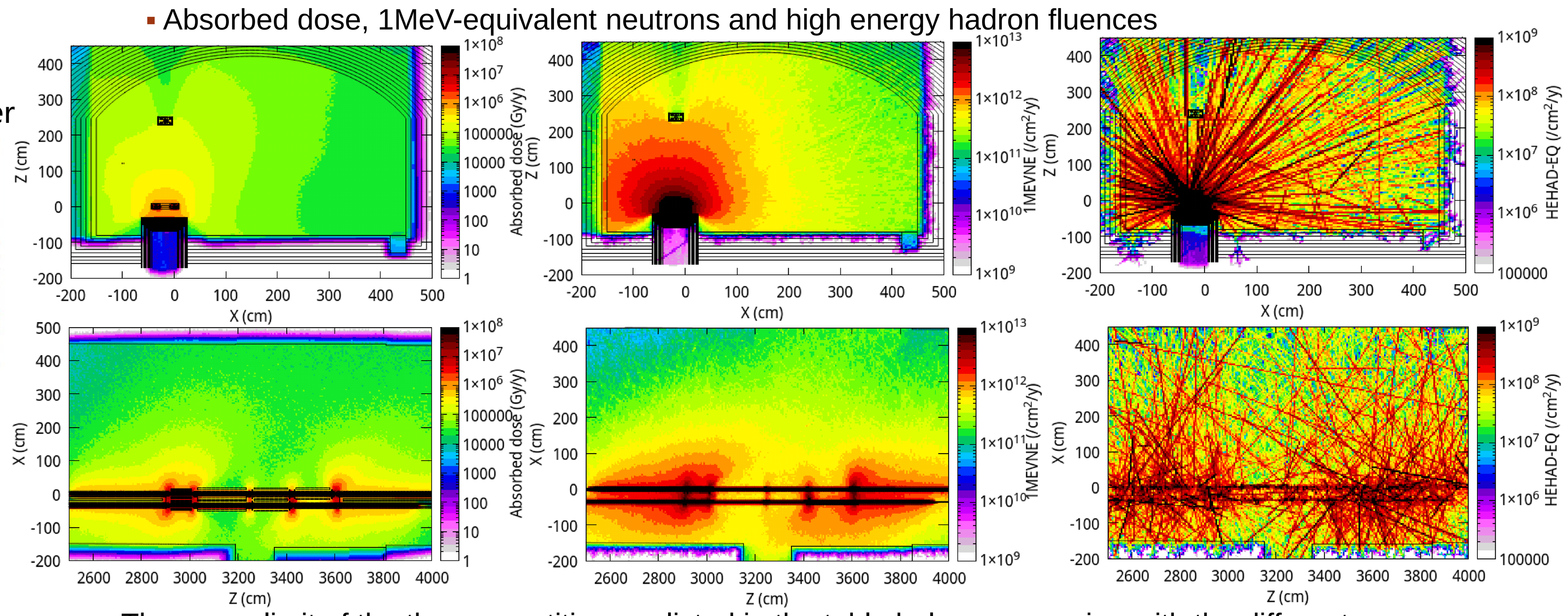
- Top view of the booster



- Operation scenarios: 10-year Higgs + 2-year Z + 1-year W + 5-year ttbar
- Put lead between coils and beam-pipes for collider. The absorbed doses to the coil insulations are shown in the below figures.
- 2.5-cm lead for collider dipole, quadrupole and sextupole seem enough.
- The dose to booster dipole and quadrupole is not too high, but neither for sextupole. Should simulate more precisely, with accurate ramping scheme.



- For the electronics shielding, we choose three quantities to assess the radiation exposure levels:
  - Absorbed dose, 1MeV-equivalent neutrons and high energy hadron fluences



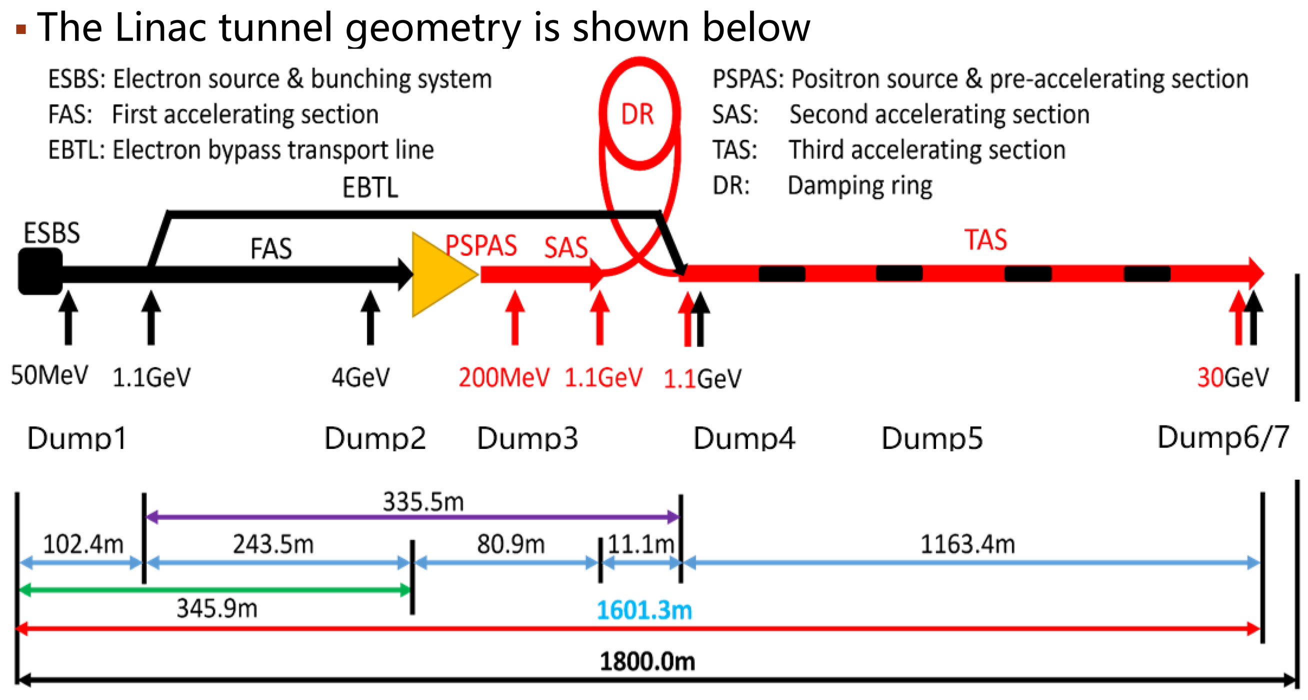
- The upper limit of the three quantities are listed in the table below, comparing with the different shielding materials.
  - Concrete, iron, lead and their combination.

	Upper limit	3-leg maze with 1m-thick concrete wall	20-cm iron	20-cm lead	20-cm concrete	80-cm concrete	20-cm lead and 20-cm concrete
High energy hadron fluence $(cm^{-2}\ y^{-1})$	2×10^{10}	$< 3 \times 10^{6}$	$< 10^{9}$	$< 6 \times 10^{8}$	$< 4 \times 10^{9}$	$< 2 \times 10^{8}$	$< 1 \times 10^{8}$
Absorbed dose (Gy/y)	20	< 10 (1m away from entrance)	< 60	< 6	< 4000	< 10	<6
1MeV equivalent neutron fluence $(cm^{-2}\ y^{-1})$	2×10^{11}	$< 3 \times 10^{8}$	$< 10^{12}$	$< 3 \times 10^{11}$	$< 2 \times 10^{11}$	$< 2 \times 10^{9}$	$< 1 \times 10^{11}$

- 3-leg maze work fine so all electronics in auxiliary tunnel are safe.
- For electronics in the tunnel, need more optimization to find reliable and feasible design.

3. Linac Bulk shielding & Dumps

- The Linac tunnel geometry is shown below



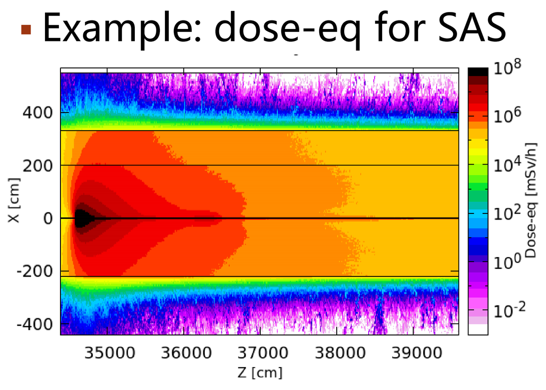
- Beam loss assumptions

Position	Length	Beam energy	Number of bunches [s-1]	Beam loss/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

- Thickness of bulk shielding

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

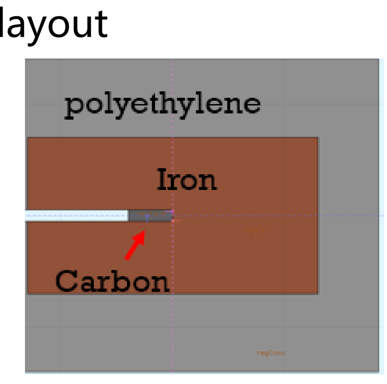
- Example: dose-eq for SAS



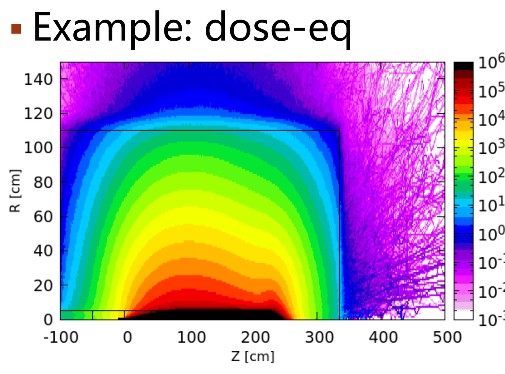
- Dump structure: carbon +Iron +polyethylene

Beam energy	Number of particles [10^{10}/s]	C R/m	C Length/m	C+Fe R/m	C+Fe Length/m	C+Fe+Polyethylene R/m	C+Fe+Polyethylene Length/m
60 MeV	12.5	0.05	0.15	0.7	1.0	---	---
4 GeV	12.5		1.25	1.1	2.4	1.2	2.6
250 MeV	6.3		0.4	0.5	0.9	0.55	1.0
1.1 GeV	6.3		0.75	0.75	1.6	0.85	1.7
6 GeV	3.7		1.45	0.9	2.4	1	2.5
30 GeV	3.7		2.6	1.2	3.7	1.3	3.8

- layout



- Example: dose-eq



4. Radioactivity productions

- In/around circular tunnel, the densities of Long half-life isotopes are lower than mandatory standard, GB18871.

		Half-life	Cooling water: Specific activity/GB 18871
Beam losses @Z-pole	O15	122s	2.44
	C14	5700a	3.5e-7
	Be7	53d	1.3e-2
	H3	12a	2.3e-6
SR @ttbar	None		

		Half-life	Water wall: Specific activity/GB 18871
Beam losses @Z-pole	O15	122s	2e-3
	C14	5700a	5e-10
	Be7	53d	3e-5
	H3	12a	6e-9
	F18	2h	5e-6
SR @ttbar	C14	5700a	2e-12
	H3	12a	1e-10

		Half-life	Rock wall: Specific activity/GB 18871
Beam losses @Z-pole	Mn54	312d	6.94E-04
	Ca45	163d	5.49E-06
	Na22	2.6y	7.20E-04
	H3	12a	5.90E-09
SR @ttbar	H3	12a	1e-10

		Half-life	Air in tunnel: Specific activity/GB18871
Beam losses @Z-pole	O15	122s	2.7e-4
	C14	5700a	7.7e-7
	Be7	53d	1.1e-5
	H3	12a	3.5e-9
	P32	14d	---
	P33	25d	1.9e-8
	Cl36	3e5a	---
	Cl38	37m	---
	Ar37	35d	6.1e-9
	Ar41	1.8h	1.4e-3
SR @ttbar	C14	5700a	6.5e-6
	Ar41	2h	1.5e-2

- In linac tunnel air, the densities of Long half-life isotopes are lower than mandatory standard, GB18871.

	Half-life	Air in Linac: Specific activity/GB18871
Ar41	1.8h	0.13
Ar37	35d	3.4×10^{-7}
Cl38	37m	0.41
Cl36	3e5a	3.1×10^{-10}
S35	88d	3.4×10^{-5}
P33	25d	4.6×10^{-6}

	Half-life	Air in Linac: Specific activity/GB18871
P32	14d	4.6×10^{-5}
Si31	2.6h	4.3×10^{-4}
F18	1.8h	2.7×10^{-4}
O15	2.0m	2.58
C14	1.2m	7.8×10^{-5}
Be7	53d	3.8×10^{-2}
H3	12a	1.3×10^{-5}

- Toxic gases is also lower than mandatory standard.
  - In circular tunnel air, O_3: $8.3 \times 10^{-6} \mu g/m^3$. In linac tunnel air, O_3: $1.0 \times 10^{-6} \mu g/m^3$.
  - Both of them << mandatory standard: O_3: $160\ \mu g/m^3$.
  - Also, the density of NO_X is smaller than mandatory standard.

#tanggy@ihep.ac.cn