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

CEPC Circular Electron Positron Collider

Preliminary study of the global collimators arrangement for CEPC

Yuting Wang, Xiaohao Cui, Dou Wang, Haoyu Shi, Guangyi Tang, Yiwei Wang, Haijing Wang, Sha Bai and Yuhui Li

CEPC day, Mar 23, 2023, IHEP

AGENDA

- **Introduction to beam abort**
- **Collimator design**
- **Summary**

Introduction to beam abort

- Machine protection of the CEPC becomes extremely challenging due to unprecedented energies stored in the magnets and circulating beams.
- Machine protection: powering failures of normal conducting magnets, quenches of the superconducting magnets, critical RF failures …

Table 1: Parameters for CEPC beam dump

	Higgs	W	Z	ttbar
Beam Energy [GeV]	120	80	45.5	180
Bunch Population/10^{10}	13	21.4	13.5	20
Number of bunches	446	13104	2162	58
Total Energy [MJ]	1.1	3.7	20	0.33
Beam life time [min]	20	80	55	18

Introduction to beam abort

- The priority consideration of machine protection:
  - IP regions, RF region, superconducting magnet…

Table 2: Beam Losses and Protection Strategies for Different Operation and Failure Scenarios

Beam life time	Scenario	Strategy
20 min (Higgs)	Operating conditions	Collimators must be sufficient and absorb most of the beam energy
~ms (multi-turns)	Fast beam loss Fast equipment failure	Detect the failure or beam loss. Beam dump response as fast as possible Active protection
~ µs (~ turns)	Several-passages beam loss	Passive protection relies on collimators Passive protection

Collimator design

Constraints on collimator design

- ✓ The half width of a collimator should be small enough to shield the particles that may reach the IR (±10 m from IP).

$$d_c \leq r_{IR}\sqrt{\frac{\beta_c}{\beta_{IR}}}$$

$$(s, \beta_x) = (\pm 6.2, 374.601) \qquad (s, \beta_y) = (\pm 3.2, 6547.64)$$

- ✓ Limit from the collective beam instabilities

- ✓ Injection requirement

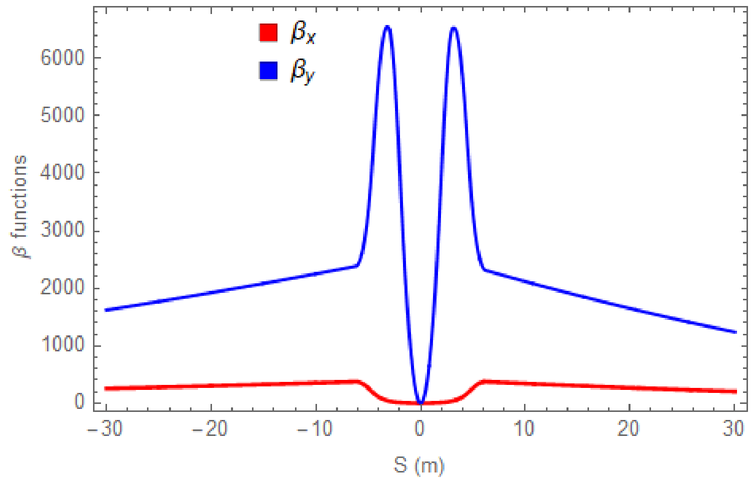

Fig 1: β functions in IP

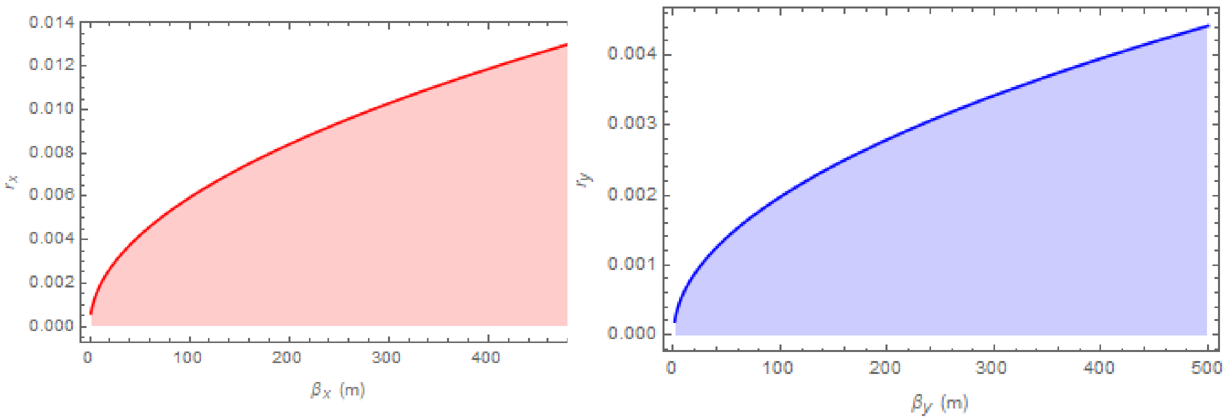

Fig 2: Collimators radius

Layout of the global collimators

Collimators locate at the regions with large β functions or large dispersion functions

16 collimators for MDI
Total number of collimators: 54

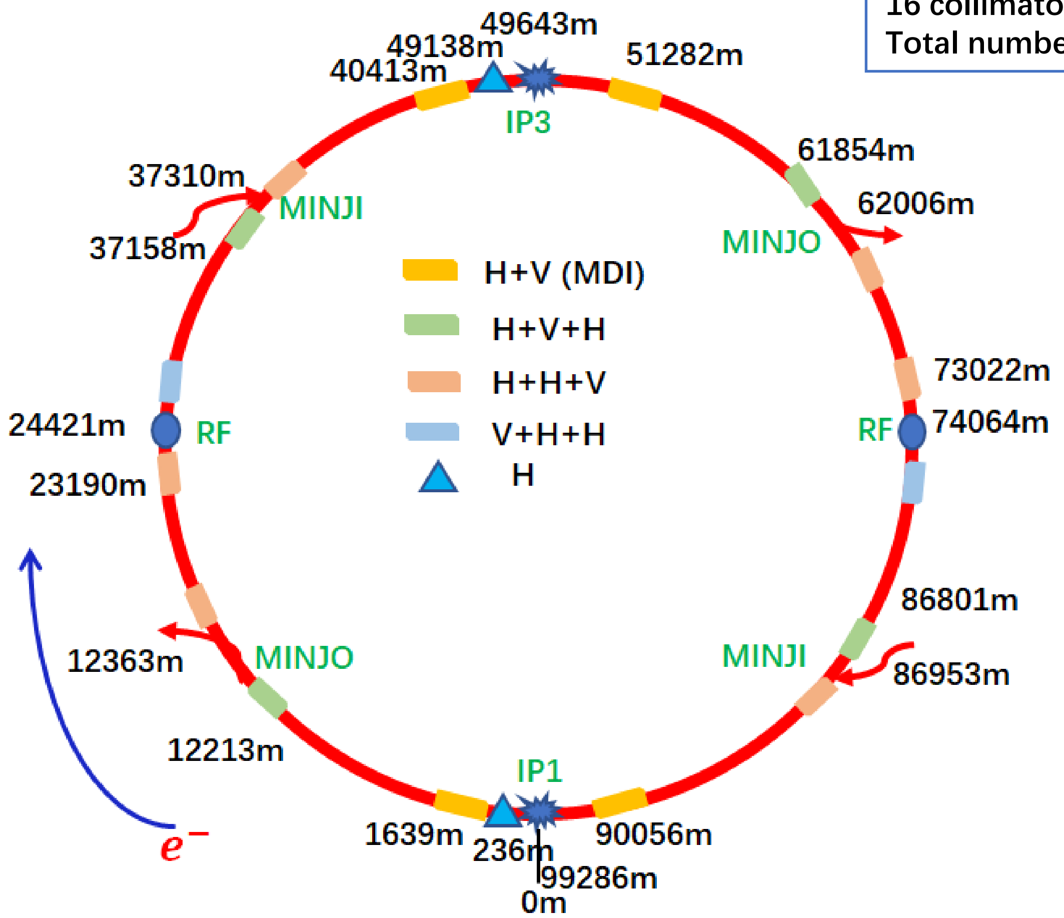

Fig 1: Layout of the global collimators

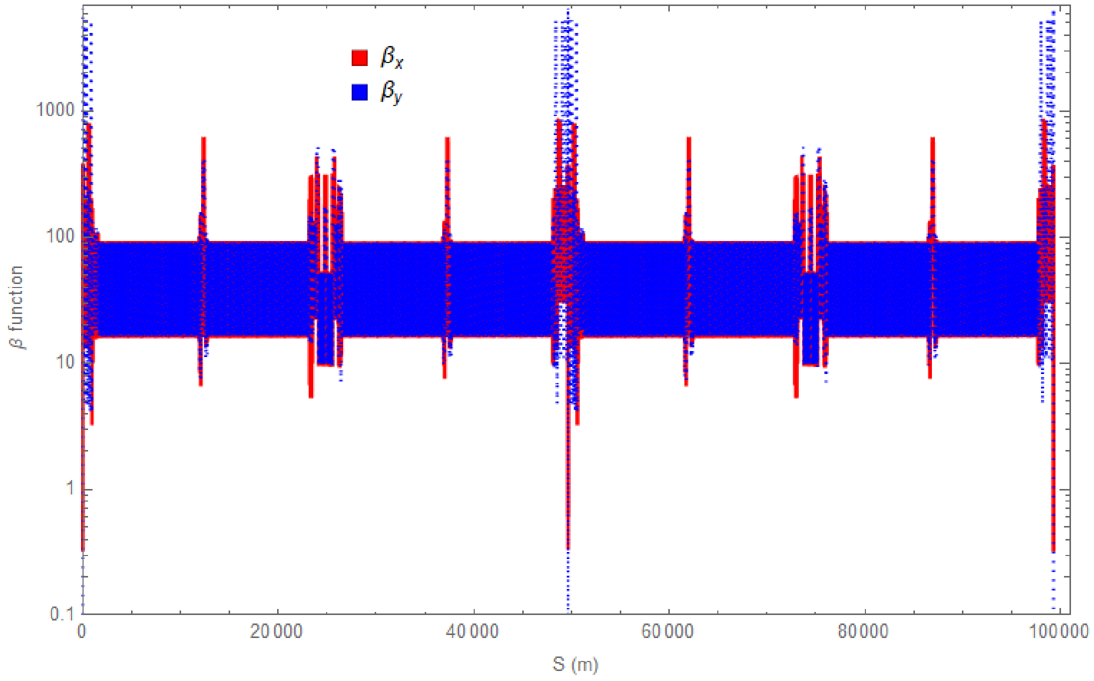

Fig 2: β functions along the collider ring

Serious beam loss

J.Y Zhai

- **In the condition of critical RF failures, the most serious beam loss occurs.**

$$V = V_0 e^{-t/\tau}$$

where $\boldsymbol{V_0 = 4.01 \times 10^7}$ is the voltage of the RF cavity , $\boldsymbol{\tau \approx 773\ \mu s}$.

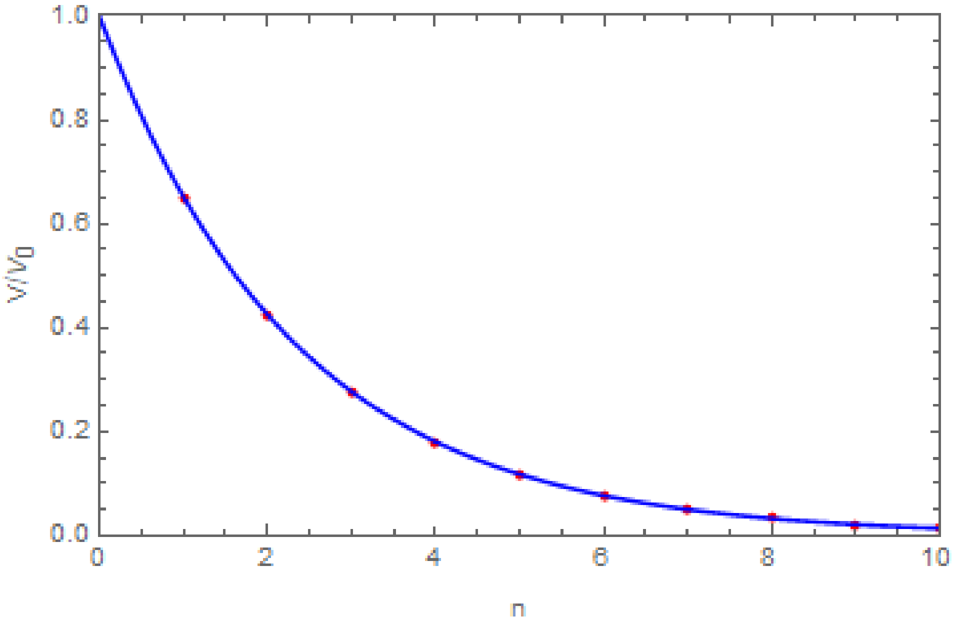

Fig.1 Voltage decays as n varies

Single passage at CEPC ~ 331 $\boldsymbol{\mu s}$

Simulation

- Simulation tool: SAD

- Beam distribution: Gaussian distribution, start from injection point

- Parameters of collimators:
  - 24 horizontal collimators with radius 3 mm
  - 12 vertical collimators with radius 3 mm
  - 2 horizontal collimators with radius 18 mm
  - 16 collimators for MDI(Horizontal radius with 4 mm and vertical radius with 3 mm)

Parameters	Values
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3
β_x/β_y (m/m)	604.7/202.0
Bunch length (mm)	2.3
Energy spread (%)	0.10

synchrotron radiation

Acceleration by CAVI

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CTIME= 284.308   sec   DT= 284.308        sec
RAD      RFSW     RADCOD  COD      NOINTRA RING     NOEMIOUT         GAUSS    BIPOL    CELL     NOFFSPRMPT       NODAPERT         FIXSEED
REAL     CODPLOT  CALC4D  NOPOL    FLUC     K64      NOFOURIER        NOTRACKSIZ        SIMULATE          ABSW     JITTER   TRGAUSS NOLWAKE
NOTWAKE BARYCOD BATCHSTA           CONV     STABLE   NOSPAC   NORADLIGHT       GEOCAL   NOPHOTONS         NOWSPAC NOSELFCOD        NOPSPAC
CONVCASE          NOPRSVCASE        LOSSMAP ORBITCAL          RADTAPER          NOSORG   INTRES   HALFRES SUMRES   NODIFFRES
CHARGE=1          CONVERGENCE=NaN DP=.017 DP0=0    EMITDIV=1        EMITDIVB=1        EMITDIVQ=1        EMITDIVS=1        EMITX=6.51E-10
EMITY=1E-12       GCUT=1E35         MINCOUP=.01       MOMENTUM=1.2E11 PBUNCH=1E10       NBUNCH=1          XIX=0    XIY=0    NP=   1000
MAXITERATION=   40
FIT $$$ $$$       MEA_SURE $$$      ORG IP1 DISP_LAY IP1 $$$
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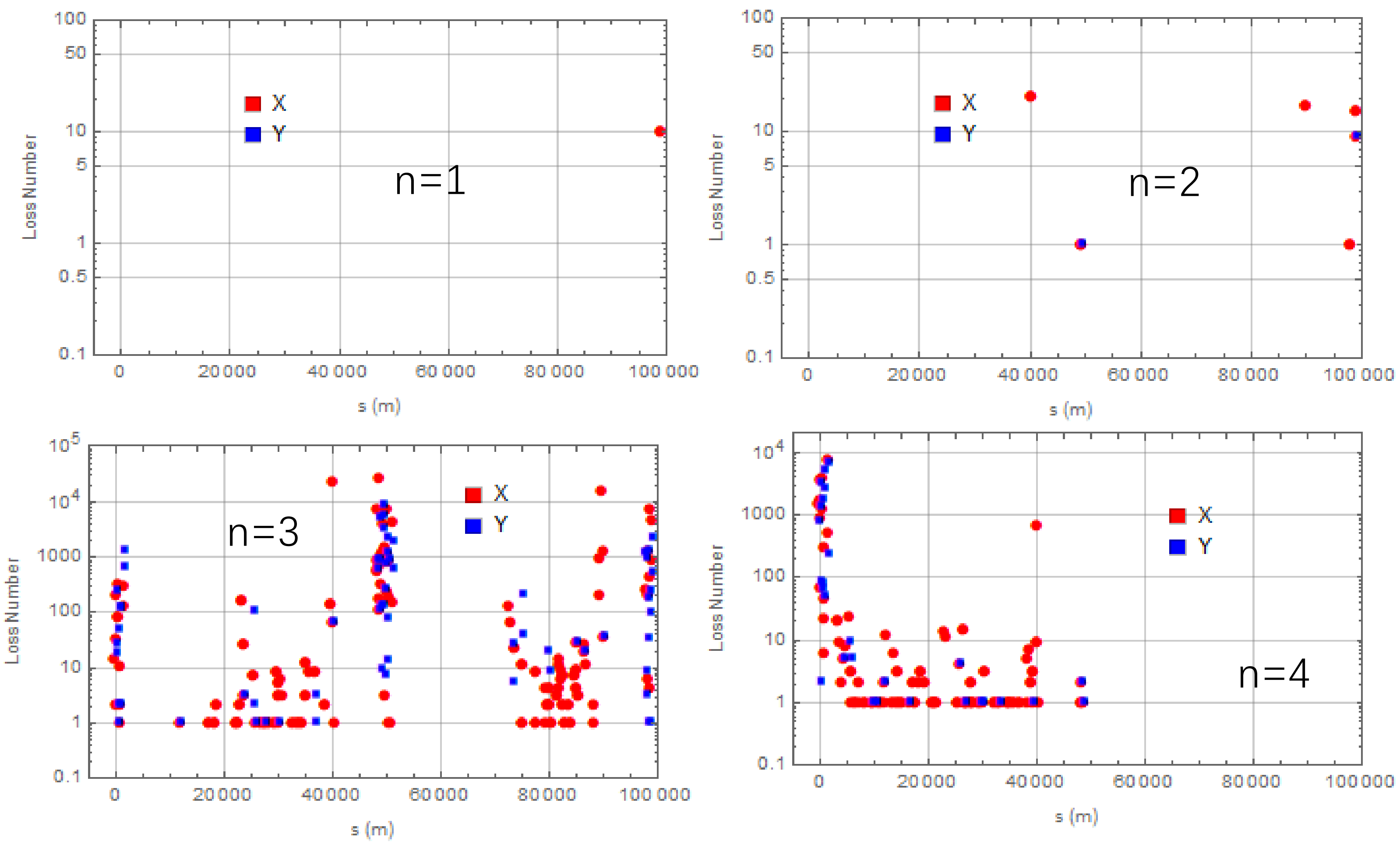
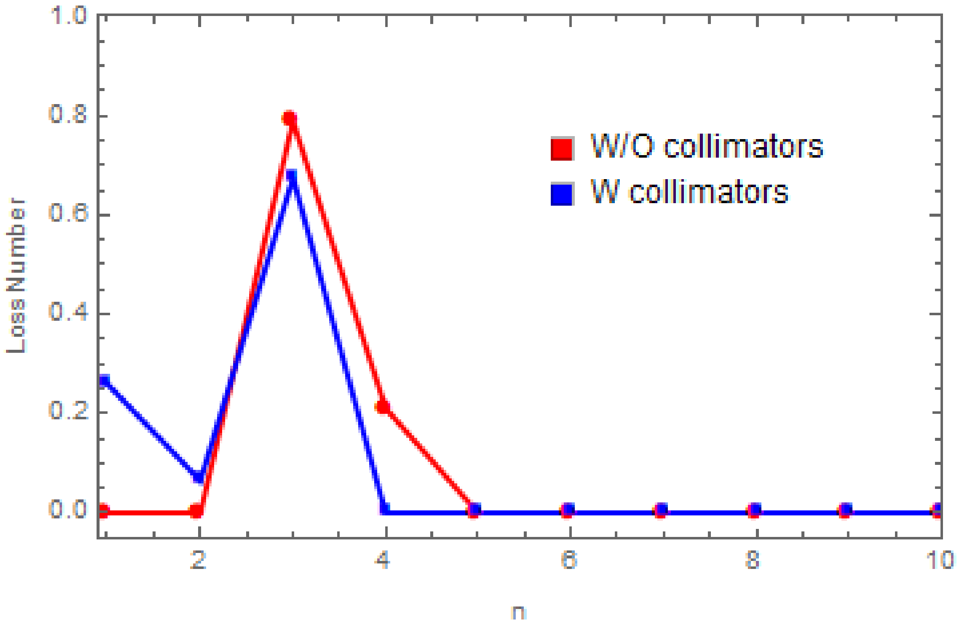
Loss number turn by turn (Only 16 collimators for MDI)

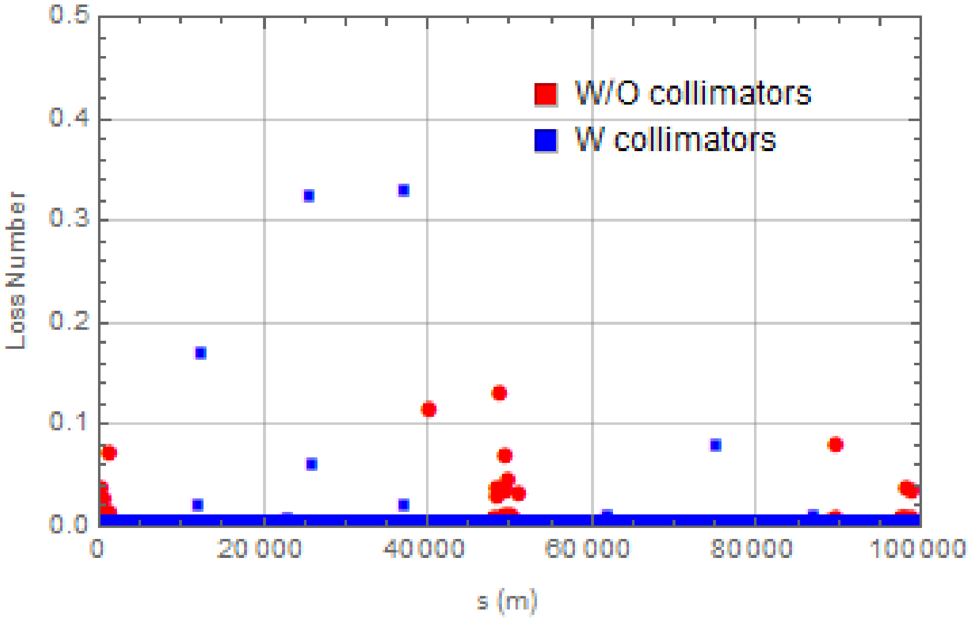


Without additional collimators, beam loss rapidly when the quench of RF occurs. Meanwhile, the a large amount particles are lost near IP and RF region.

Beam loss distribution

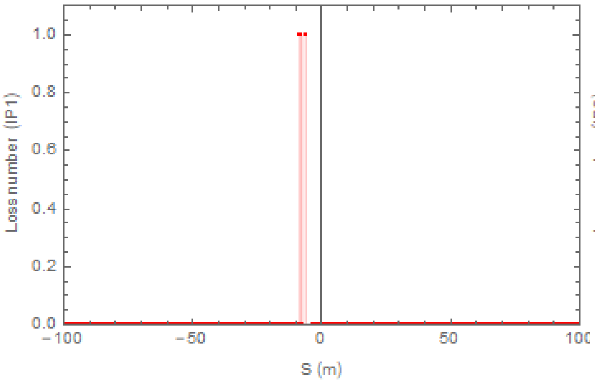
Simulation result shows that the beam losses rapidly, even that beam dump system hasn't enough time to response.

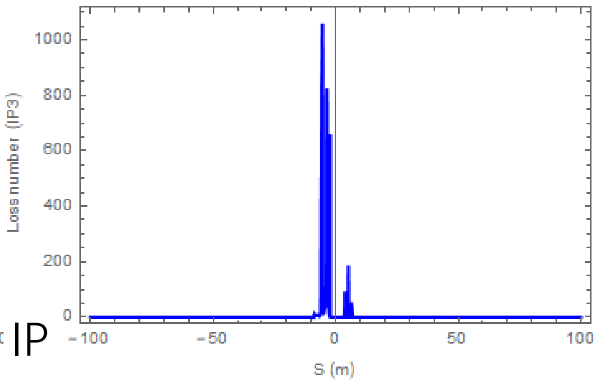




Beam loss in condition of critical RF failure

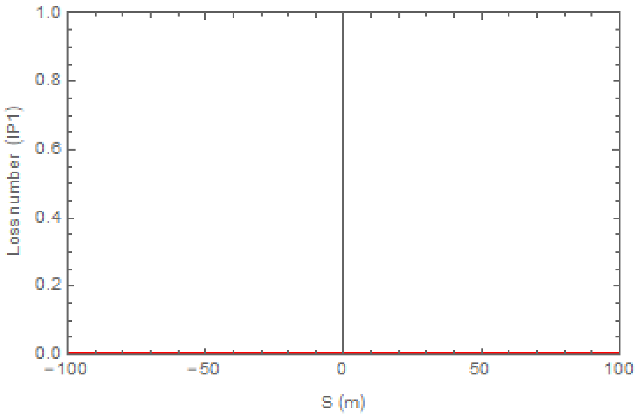
Simulation result suggest:
In condition of MDI collimator, particles will loss near IP region and RF region (20000 particles in simulation)

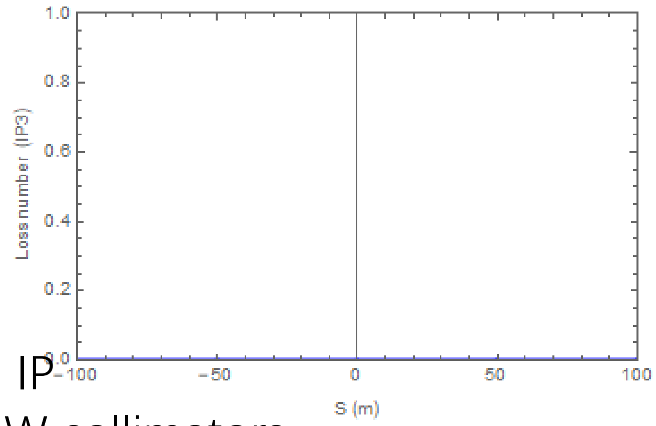




IP

W/O collimators

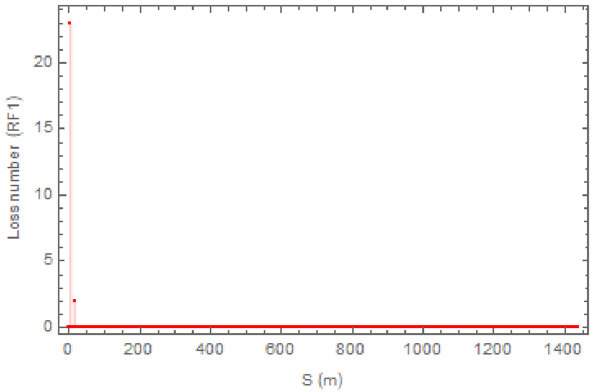


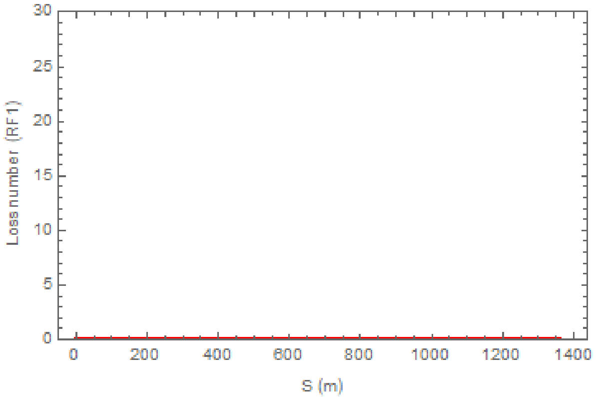


IP

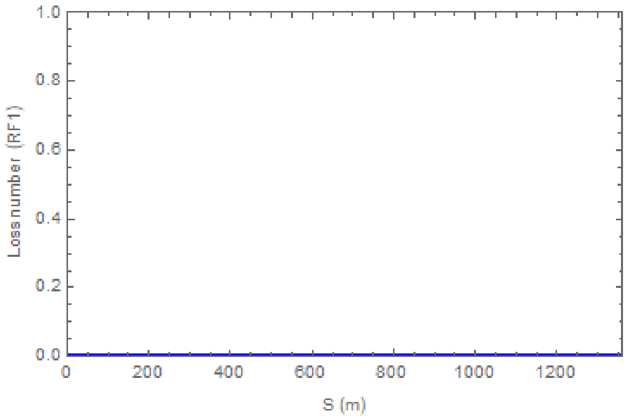
W collimators

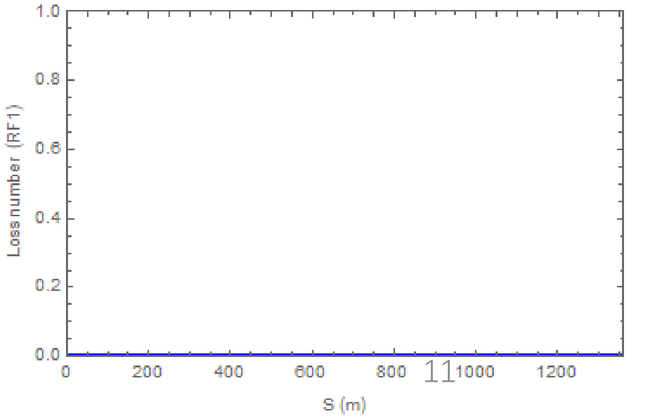
RF





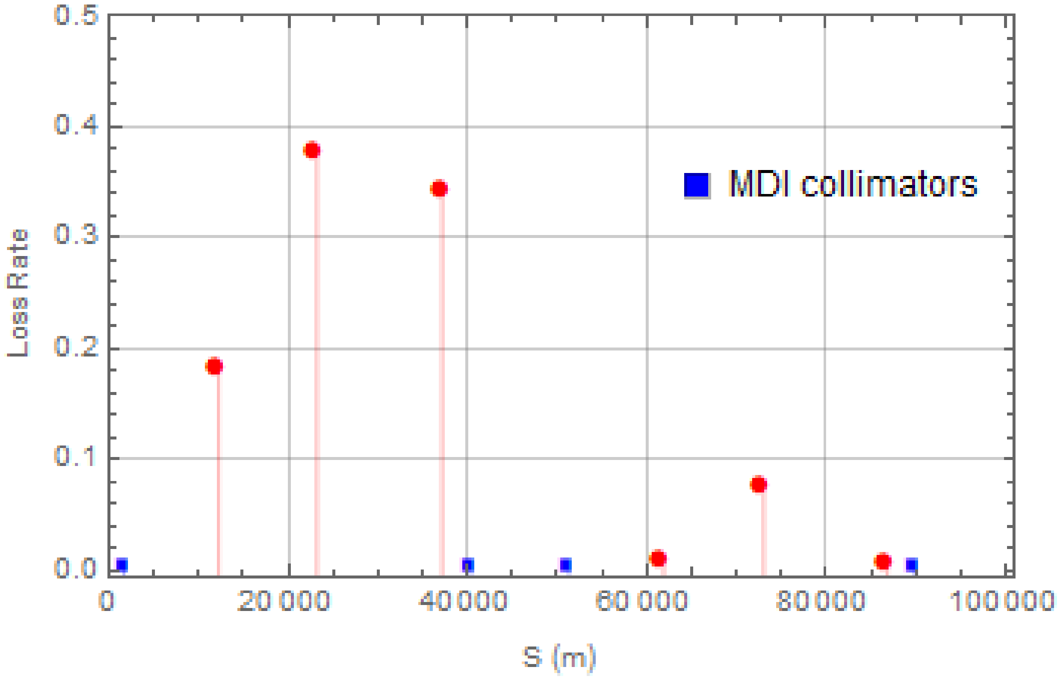
RF

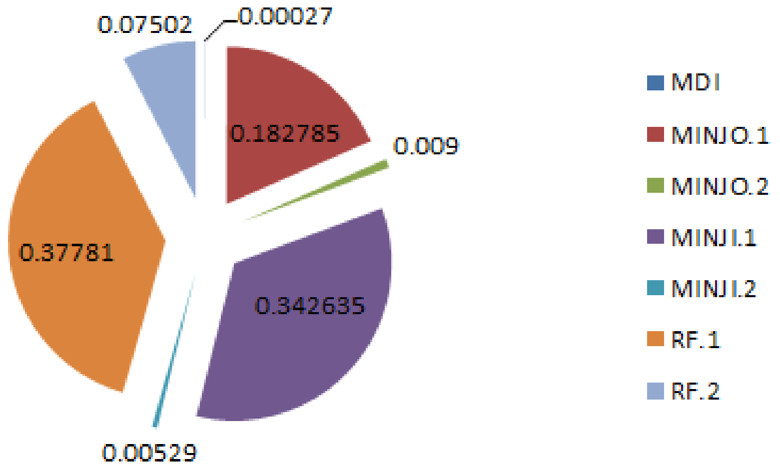




Loss distribution in different collimators

- There are 99.28 % beam loss in all collimators
- Less than 0.1% beam loss in collimators for MDI
- For now, collimators upstream IP1 absorb most of the beam loss
- Residual beam loss near collimators and upstream IP1





Detailed beam loss in collimators

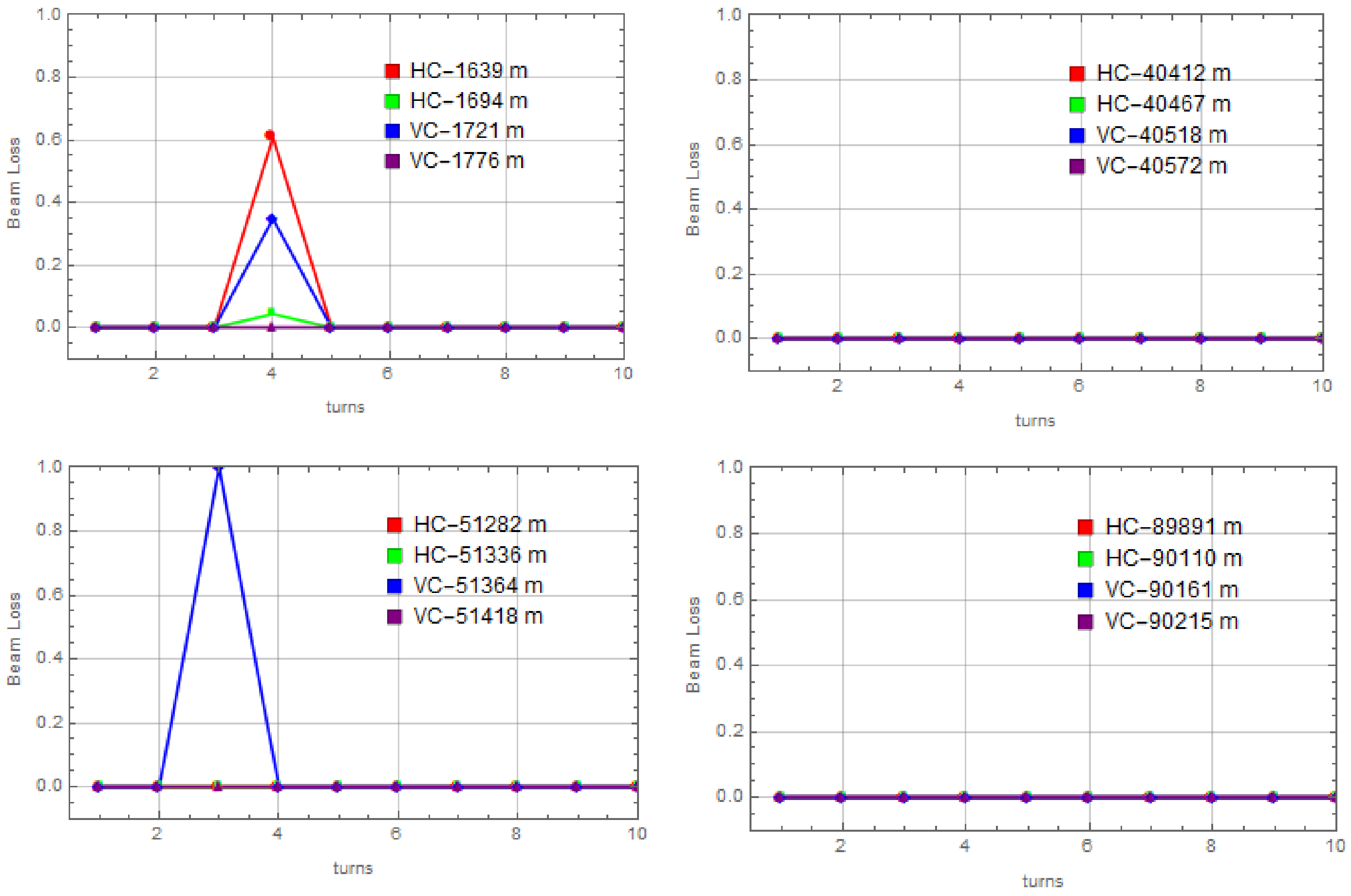


Fig.1 Beam loss distribution in 16 collimators for MDI

- Small amount of beam loss in collimators region
- 8 collimators upstream IP contribute less to beam abort

Detailed beam loss in collimators

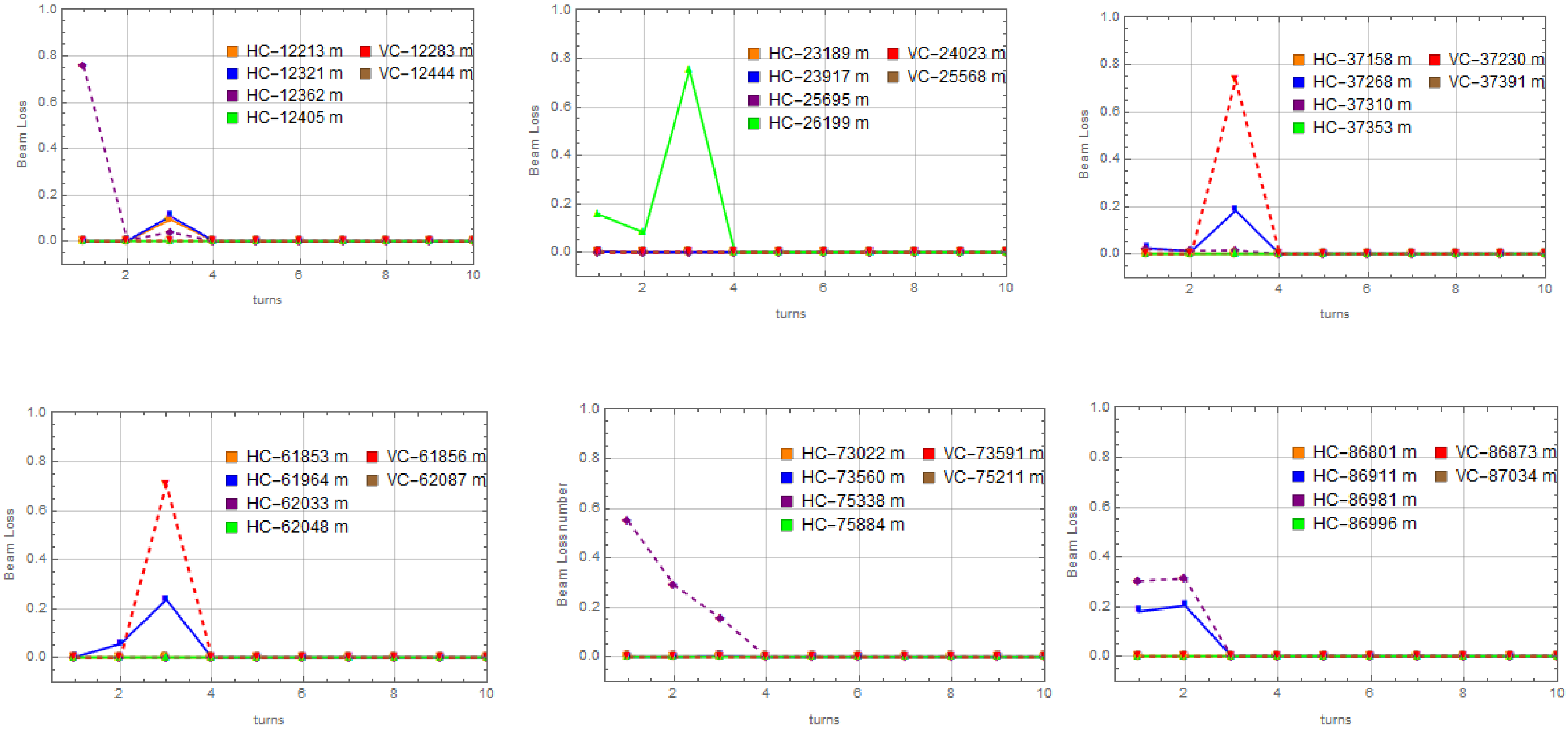
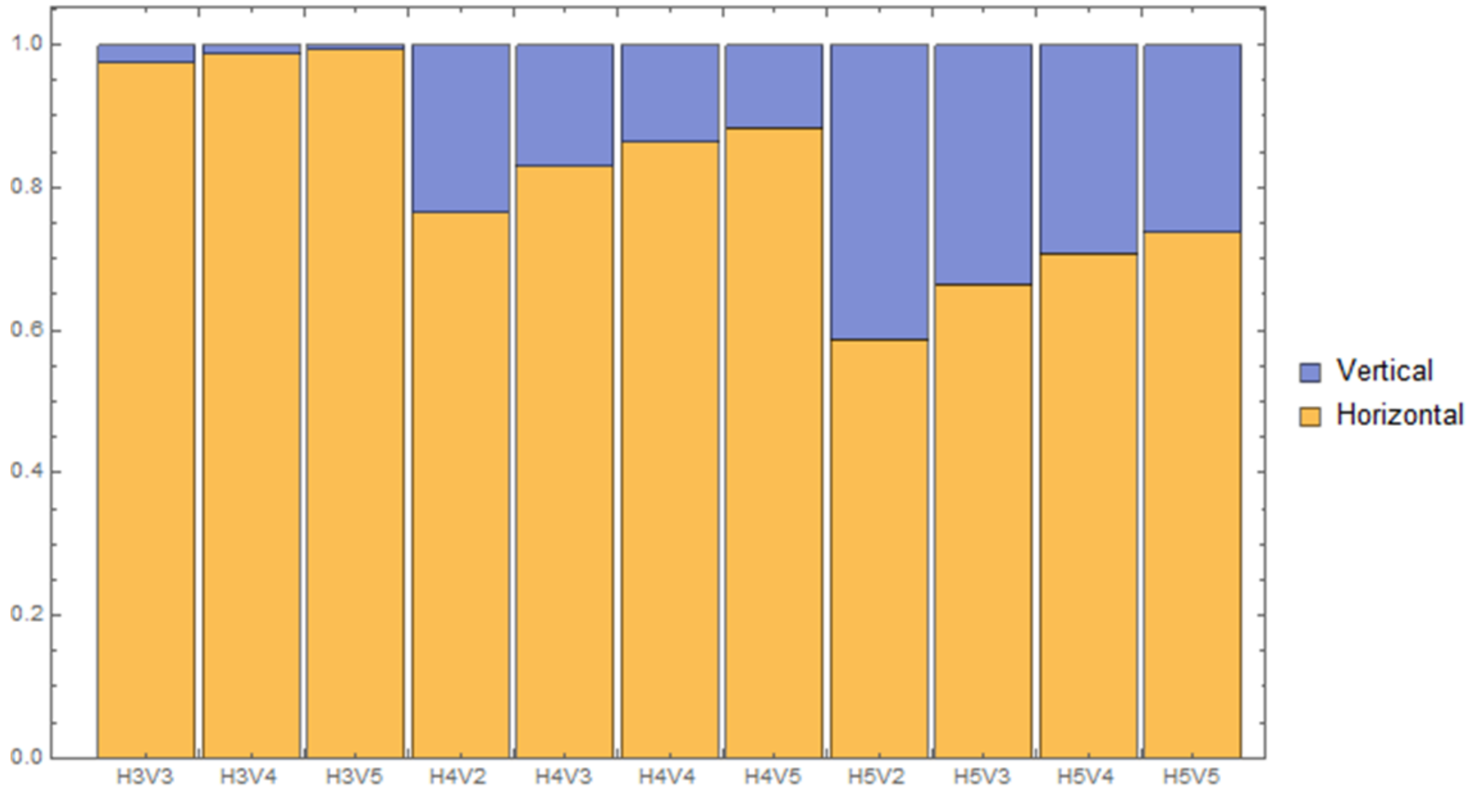


Fig.1 Beam loss distribution in 38 collimators

- ➢ Most of beam loss in collimators near injection region and RF region
- ➢ Though these collimators can sufficiently absorb beam loss, some collimators maybe damage due to high energy
- ➢ More particles loss in horizontal collimators rather than vertical collimators

Beam loss in two directions

Change the radius of the collimators in RF region and injection region



Simulation results indicate:

- Beam loss in horizontal collimator is more sensitive to the radius of horizontal collimator
- Small gap of vertical collimator causes more beam loss in vertical direction

Summary

The global collimators arrangement are studied

- All the collimator could protect IP region and RF region in the disaster condition
- For now, collimators near RF and injection region absorb most of the beam loss
- 2 collimators near IP1 and IP3 are expect to absorb the beam in case of beam loss near IP region
- Beam loss in horizontal collimator is more sensitive to the radius of horizontal collimator

Problems:

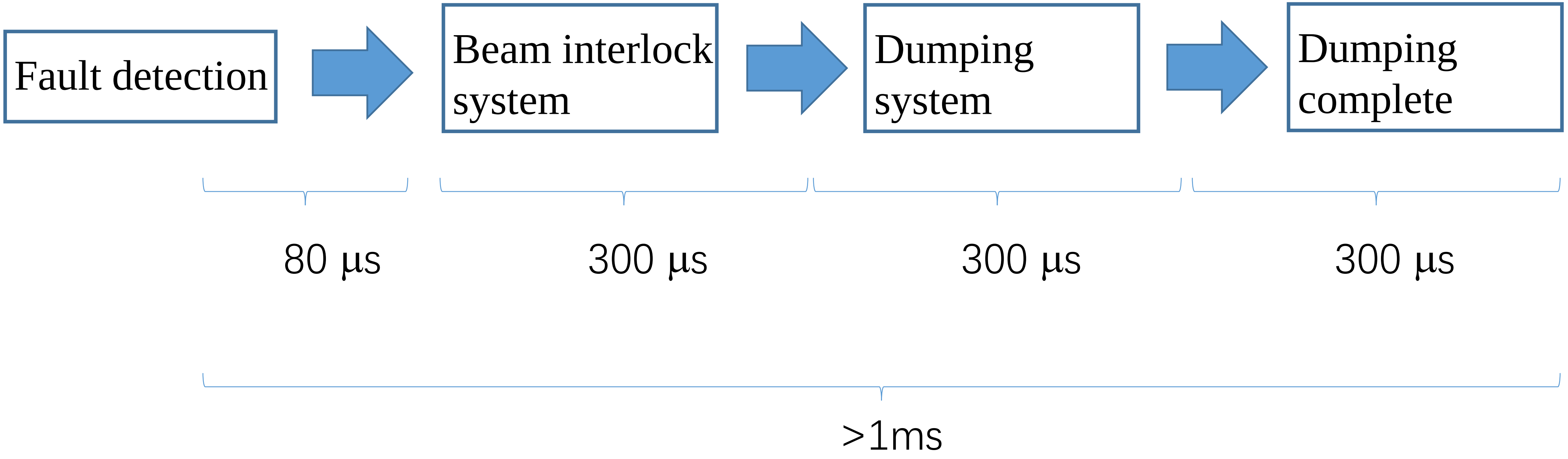
- Collimators in MINJO.1, RF.1 and MINJI.1 face high pressure due to large amount of beam loss
- Preliminary arrangement of the collimators doesn't match the impedance budget
- More conditions should be included:
- Powering failures of normal conducting magnet
  - Quenches of superconducting magnets
  - Potential damage of equipment
  - Powering failures of kicker
  - ......

Backup

Introduction to Machine Protection

X.H Cui

- Process of active machine protection



CEPC active machine protection system can only work for beam failure of time scale larger than 1 ms

Ref: Y. Nie, TUPVA012, IPAC17, FCCee CDR

Operation

Active protection

Passive operation

Table 1: Beam Losses and Protection Strategies for Different Operation and Failure Scenarios

Beam Lifetime	**Beam Power into Environment**		**Scenario**	**Strategy & Remark**
	LHC	**FCC**		
100 h	1 kW	23 kW	Optimum operating conditions	(Possible) upgrade of the collimation system after some years of operating experience
10 h	10 kW	236 kW	Acceptable operating conditions (expected during early operation)	Operation acceptable, collimators must absorb large fraction of beam energy
12 min	500 kW	11806 KW	Particular operating conditions (during change of optics, tuning, collimator aperture setting, etc)	Operation only possible for short time (~10 seconds), collimators must be very efficient
1 s	362 MW	8500 MW	Fast beam loss (standard equipment failures)	Detection of failure, beam must be dumped rapidly
A few ms (multi-turns)	~100 GW	~ TW	Very fast beam loss (fast equipment failures, e.g., magnet powering failures or quenches)	Detection of failure or beam losses, beam dump as fast as possible
1 turn	4 TW	26 TW	Single-passage beam loss (failures at injection or during beam dump, potential damage of equipment)	Beam dump not possible, passive protection relies on collimators, absorbers (sacrificial materials)