CEPC mechanics design

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IAS Mini-workshop: Accelerator Physics - Key Beam Physics and Technologies Issues for Colliders

1.13-1.14, 2022

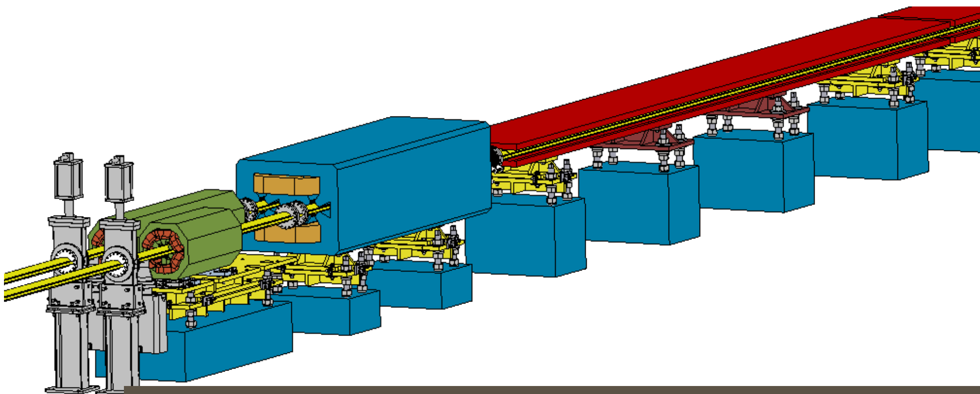
Outline

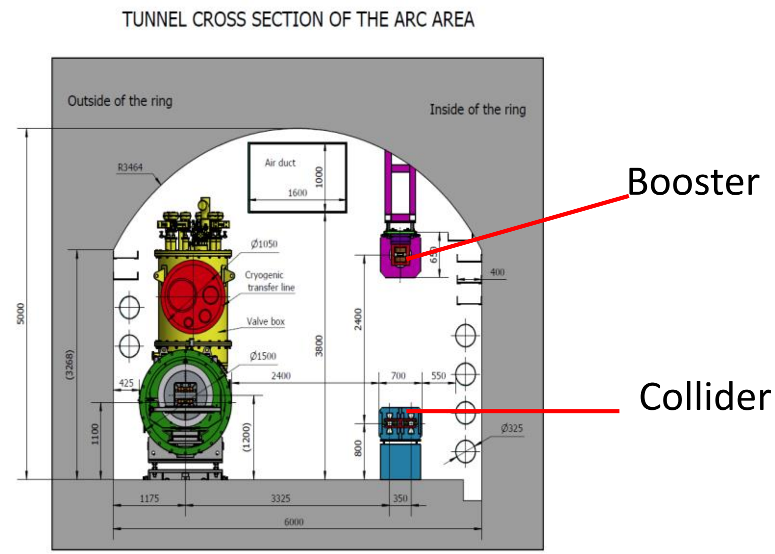
- Magnet supports
- MDI mechanics
- Collimators and machine protection scheme
- Summary

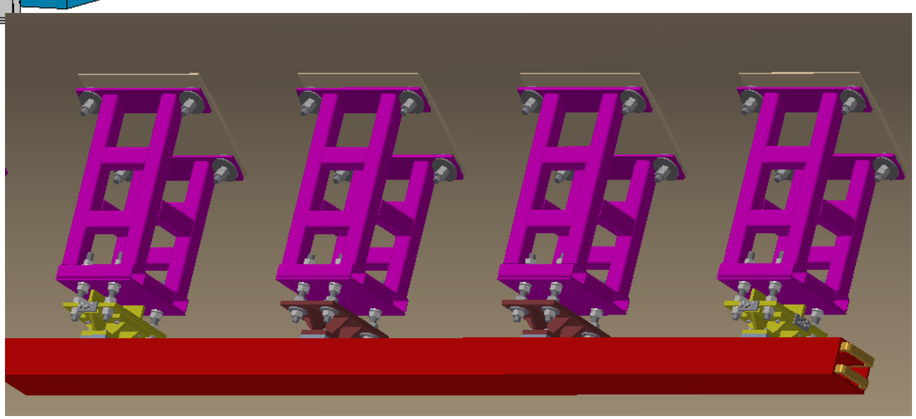
Magnet supports

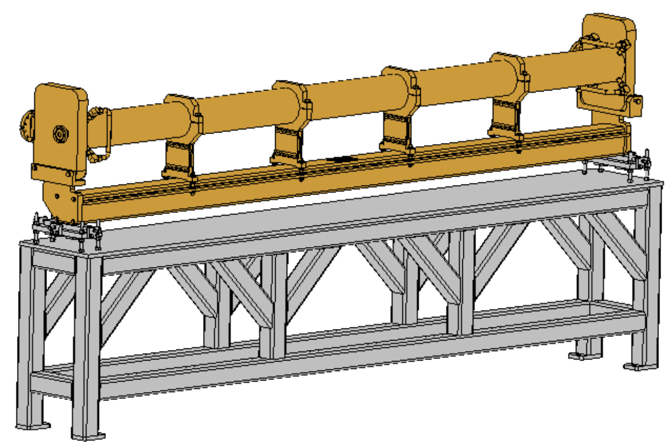
- Over 80% of the length is covered by magnets of about 138 types.

Adjustment Ranges of magnets			
X	≥±20 mm	Δθx	≥±10 mrad
Y	≥±30 mm	Δθy	≥±10 mrad
Z	≥±20 mm	Δθz	≥±10 mrad



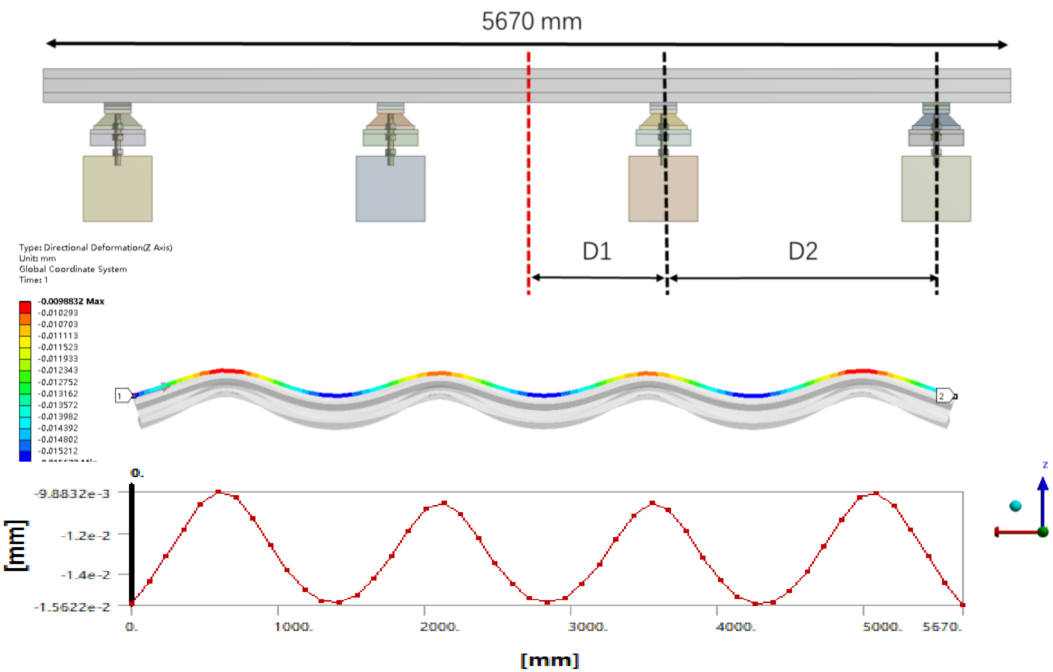




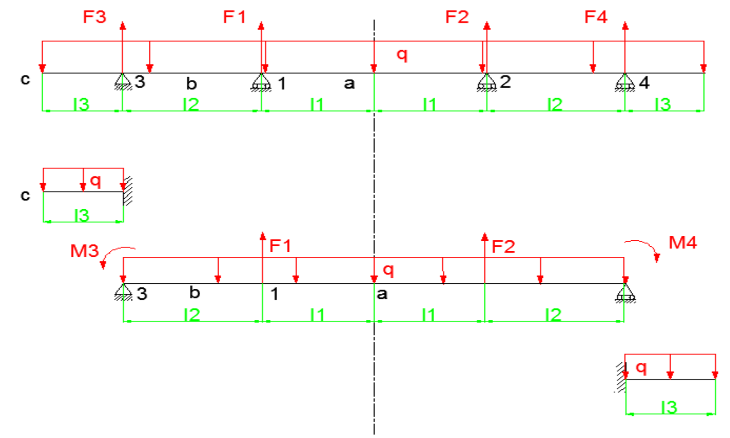


Magnet supports

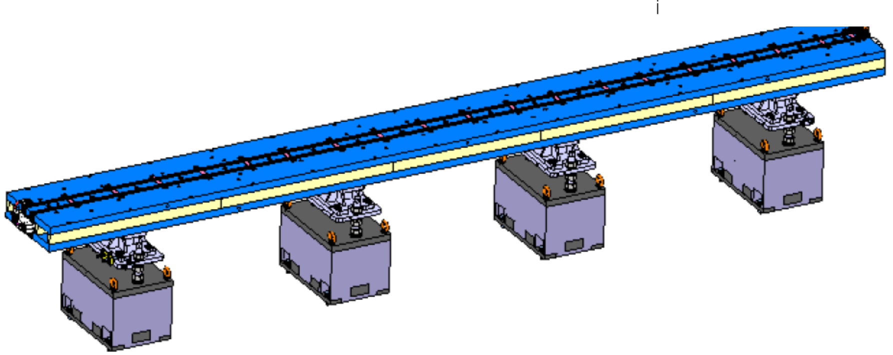
Optimization for dipole supports



No. of supports	Max. deformation (um)
3	19
4	7
5	5

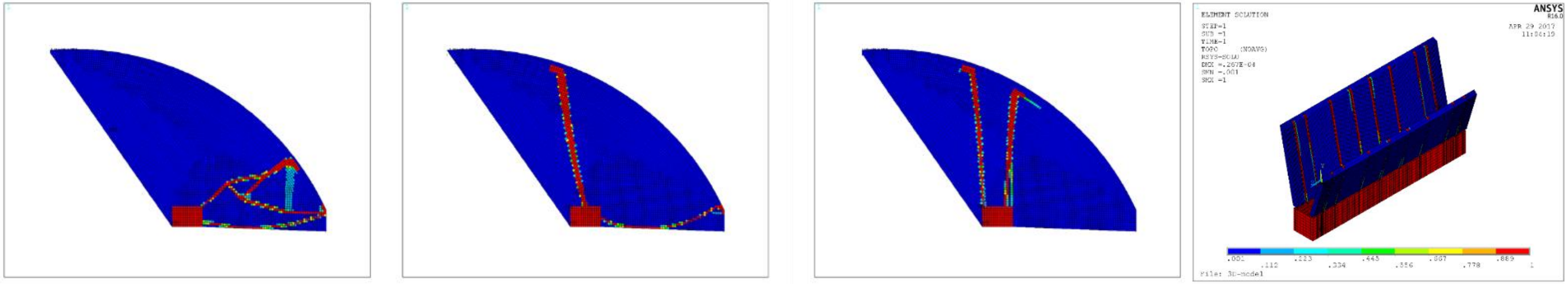


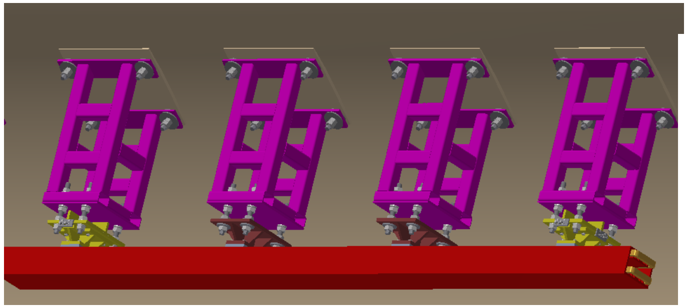
- Methods:
  - Theoretical derivation
  - Deformation optimization
- Tools:
  - Matlab
  - Workbench-Response surface
  - Inventor

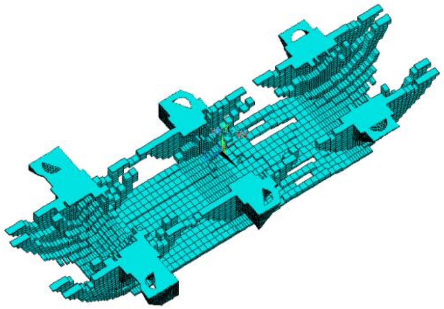


Magnet supports

Optimization for dipole supports in Booster





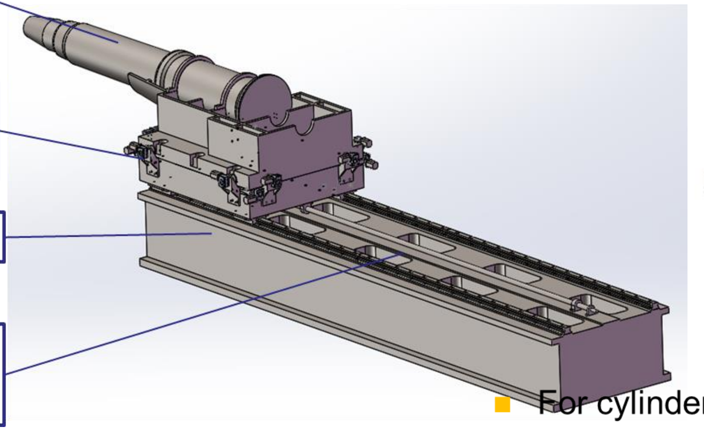


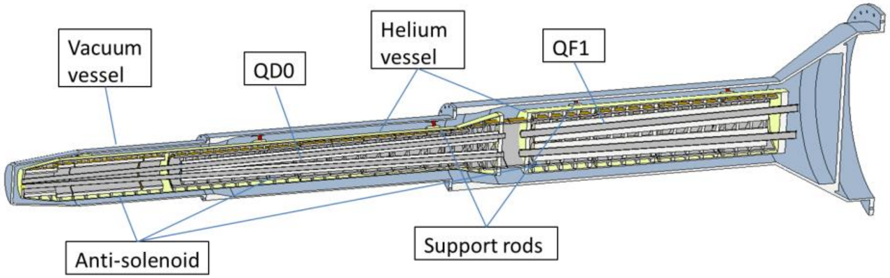
- Methods:
  - Theoretical derivation
  - Deformation optimization
  - Topology optimization
- Tools:
  - Matlab
  - Workbench-Response surface
  - ANSYS APDL
  - Inventor

Topology optimization was first used in girder design by our team on HEPS-TF

Magnet supports

Optimization for SC magnet supports





- For cylinder cantilever under gravity
  - Max. deformation $y_{\max}$
  - First natural frequency ω_1

$$y_{\max} = -\frac{ql^4}{8EI} = \frac{64l^4\rho}{\pi ED^2} \quad \omega_1 = 3.5\sqrt{\frac{EI}{\rho Al^4}} = \frac{3.5D}{4l^2}\sqrt{\frac{E}{\rho}}$$

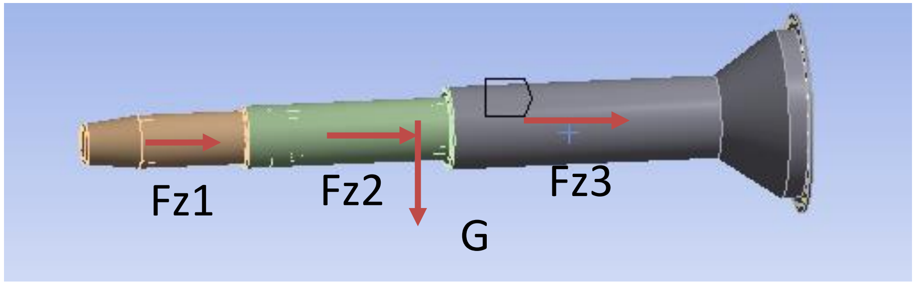
  - Shape factors: l, D; material factors: E/ρ

- For concentric cylindrical cantilever under gravity

$$y_{\max} \sim \frac{\rho l^4}{32\text{EI}}(D^2 - d^2 + \frac{\rho'}{\rho}d^2)$$

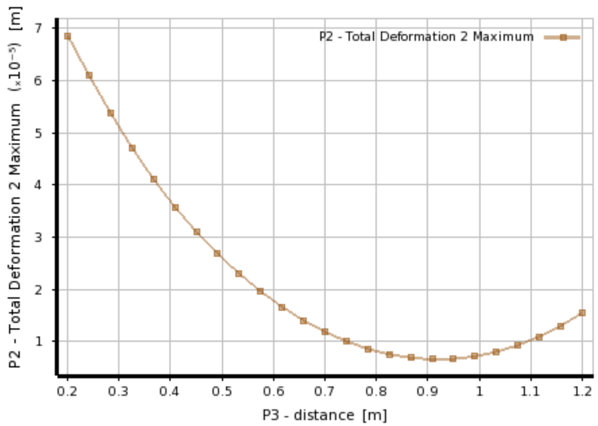
- ρ': equivalent density of inside cylinder

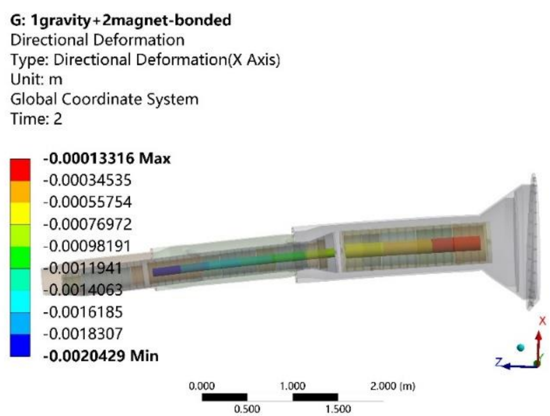
- Methods:
  - Theoretical derivation
  - Deformation optimization
  - Stability optimization
  - Material optimization
- Tools:
  - Matlab
  - Workbench
  - Inventor

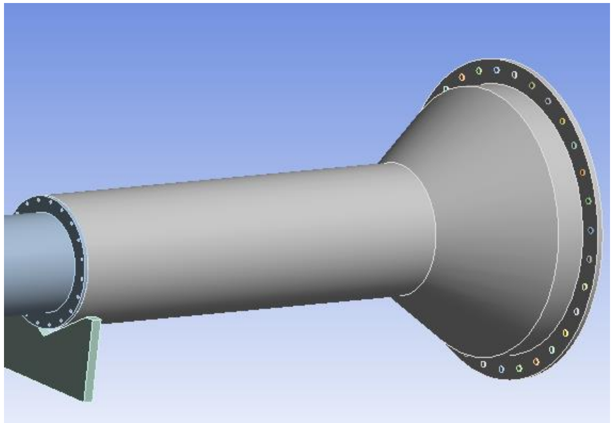


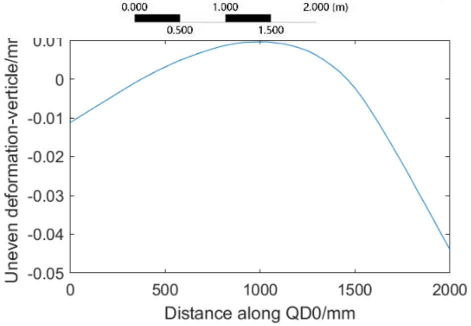
Magnet supports

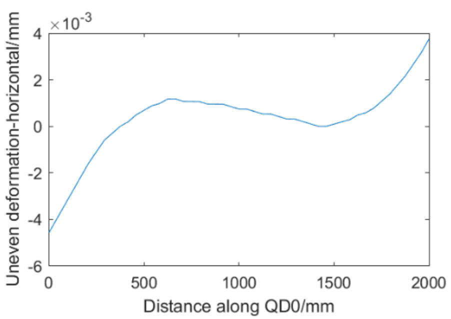
Optimization for SC magnet supports



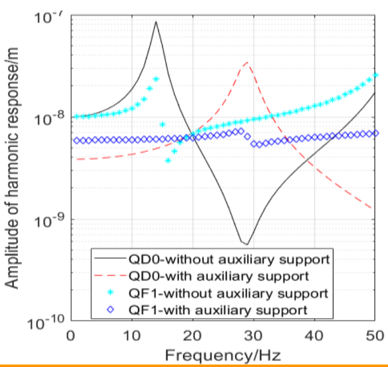


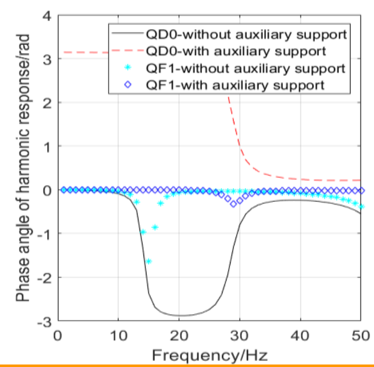






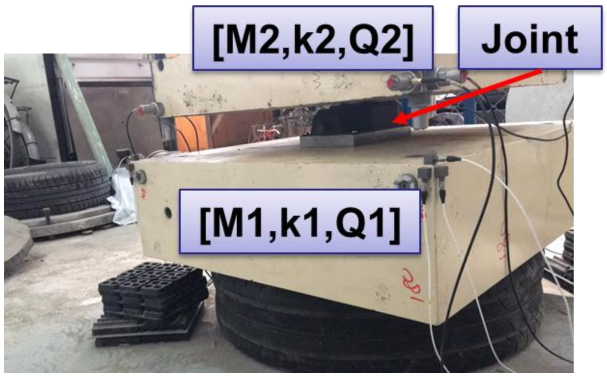
- Methods:
  - Theoretical derivation
  - Deformation optimization
  - Stability optimization
  - Material optimization
- Tools:
  - Matlab
  - Workbench
  - Inventor

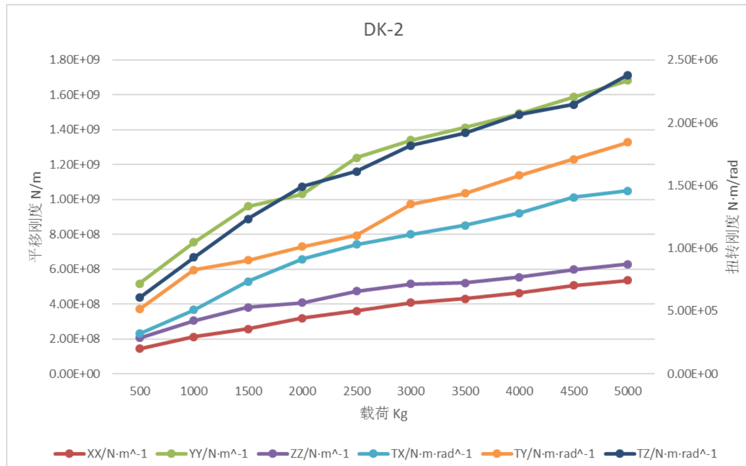




Magnet supports

Stiffness study for adjusting joints: very important for stability evaluation





A new method used in HEPS

- High efficiency
- High accuracy
- Simple

- Methods:
  - FEA-based hammering method
- Tools:
  - ANSYS APDL
  - Matlab
  - Test devices

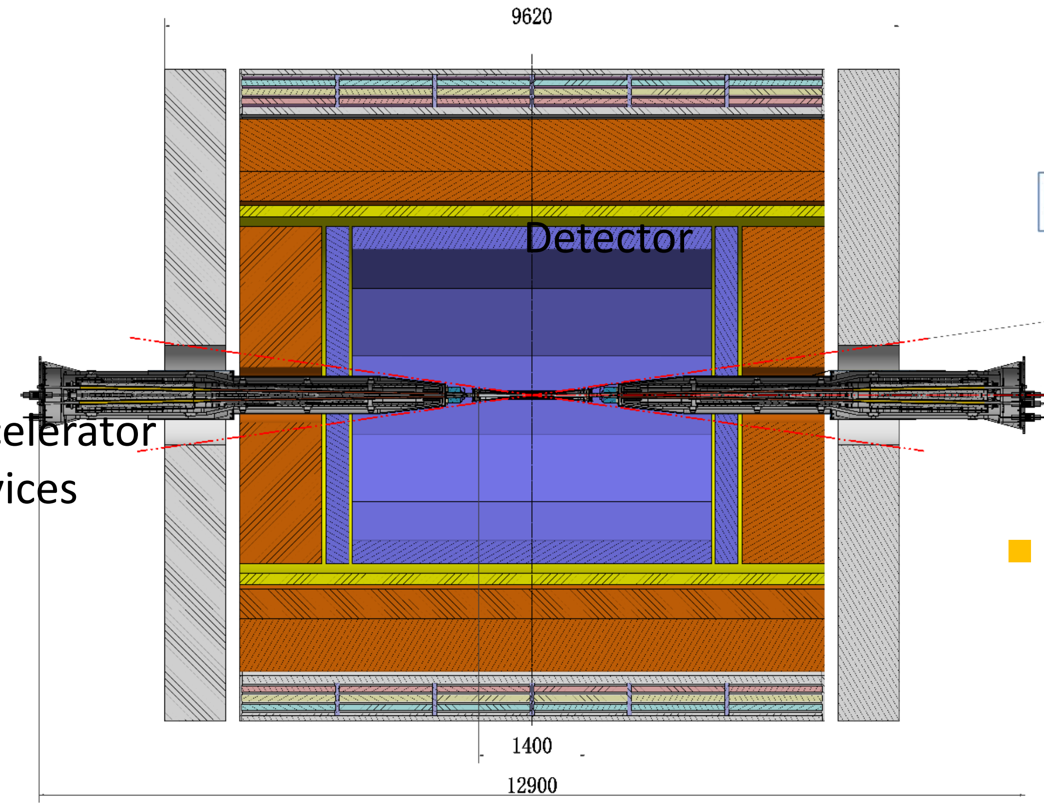
载荷KG	XX/%	YY/%	ZZ/%	TX/%	TY/%	TZ/%
500	1	2	2	19	1	2
1000	3	4	0	23	8	6
1500	0	2	3	28	3	8
2000	2	0	5	20	0	5
2500	0	1	2	15	3	5
3000	2	0	5	10	1	6
3500	1	4	6	9	0	3
4000	2	5	9	6	0	2
4500	3	7	8	8	0	1
5000	5	8	10	4	1	0

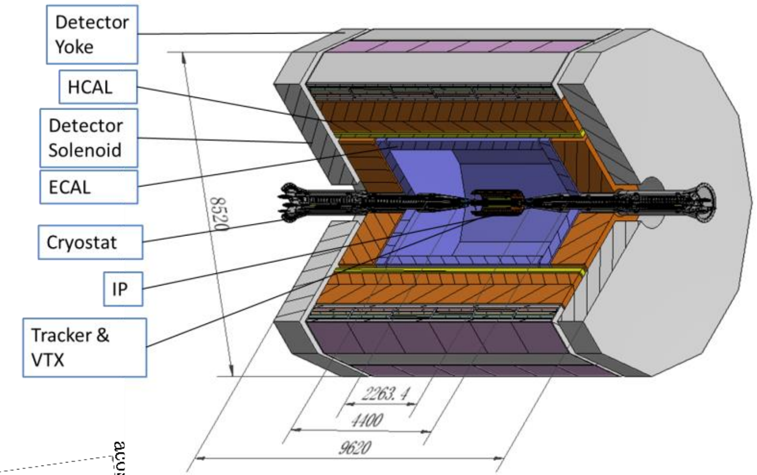
Magnet supports

- Main parameters obtained in analysis
  - Regular dipoles in Collider: 5670 mm long, uneven deformation ＜10um (under gravity)
  - QD0: 2000 mm long, uneven deformation ＜30 um (under gravity and Lorentz force in anti-solenoid)
- More detailed works are under-going
  - Further optimization in SC magnet support
  - Common girder design for regular quadrupoles and sextupoles, and optimization

MDI mechanics

MDI layout: Continue to be updated

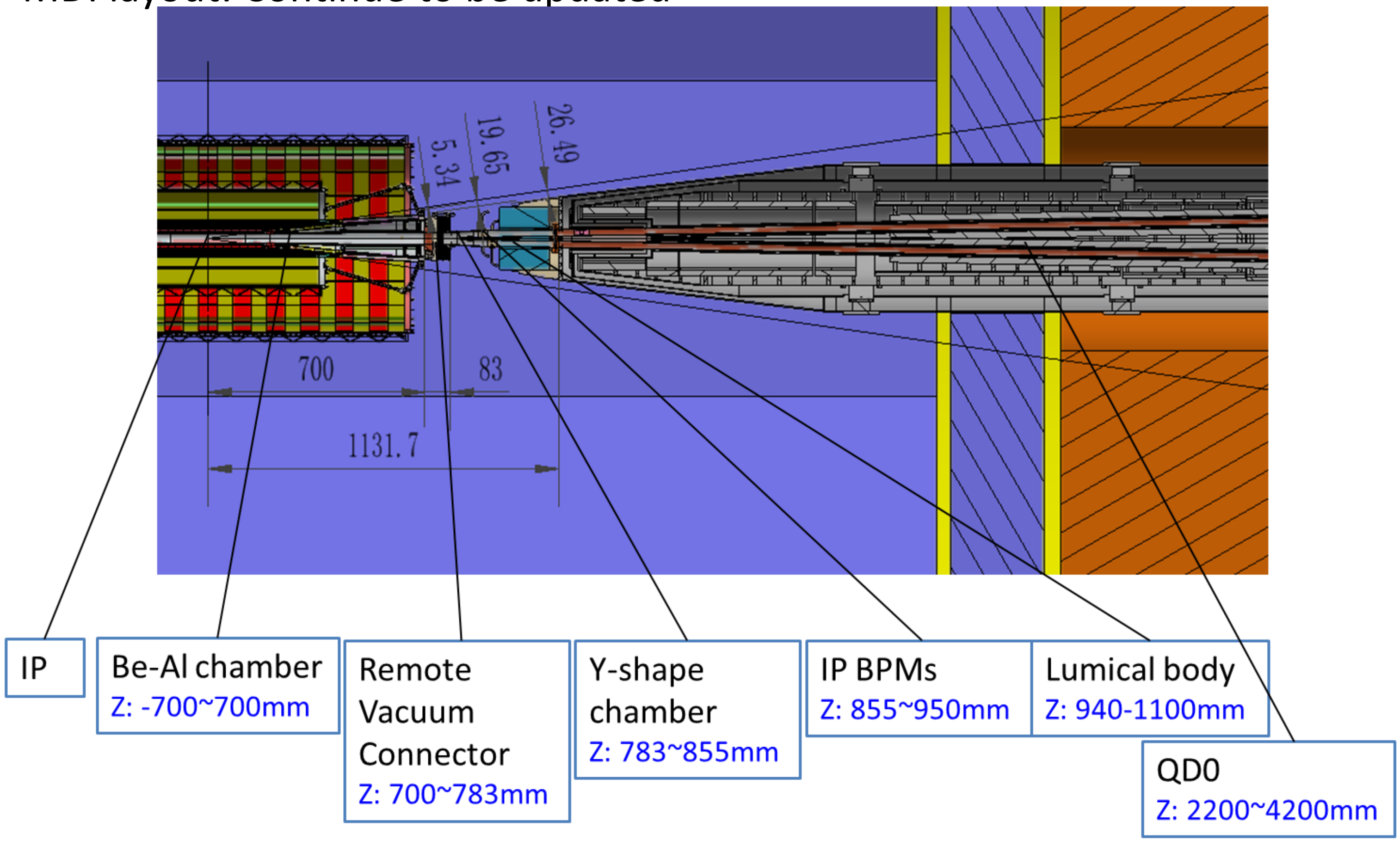




- Collaboration from several systems:
  - Accelerator: physics, mechanics, SC magnets, vacuum, cryogenic, instruments…
  - Detector: physics, mechanics, VTX, Yoke, shielding…

MDI mechanics

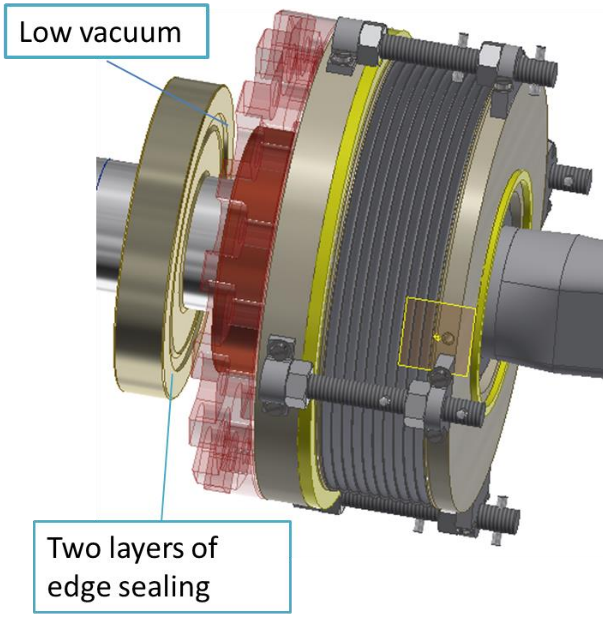
MDI layout: Continue to be updated

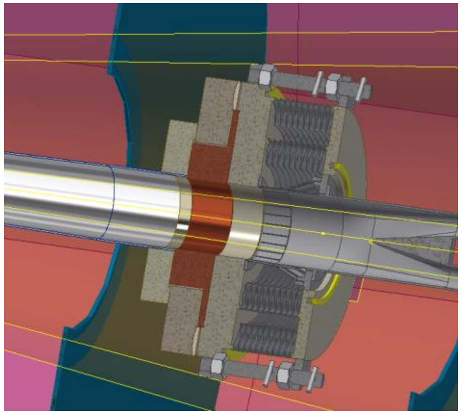


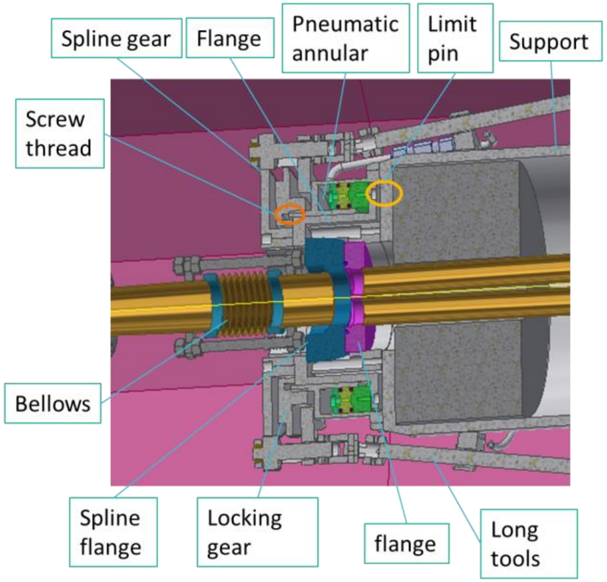
- Tools: Inventor, solidworks…
- Phased achievements: a workable layout for CDR

MDI mechanics

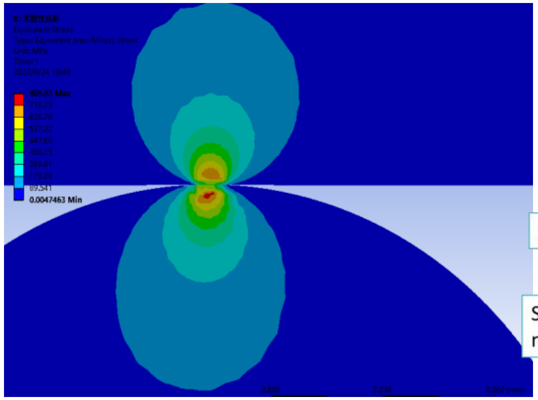
Remote vacuum connector

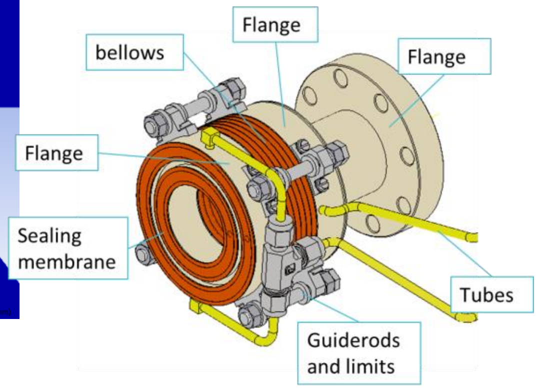






- Methods:
  - ➢ Theoretical derivation
  - ➢ Two layers of edge sealing
  - ➢ Space optimization
  - ➢ FEA
- Tools:
  - ➢ Workbench
  - ➢ Inventor





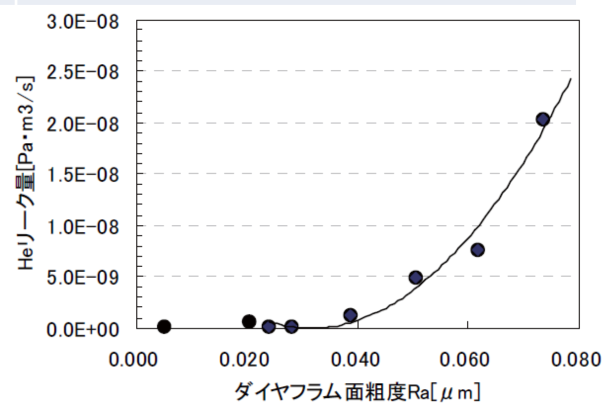
MDI mechanics

Remote vacuum connector

- Difficulties:
  - Space limitation, leak rate, thermal dissipation…

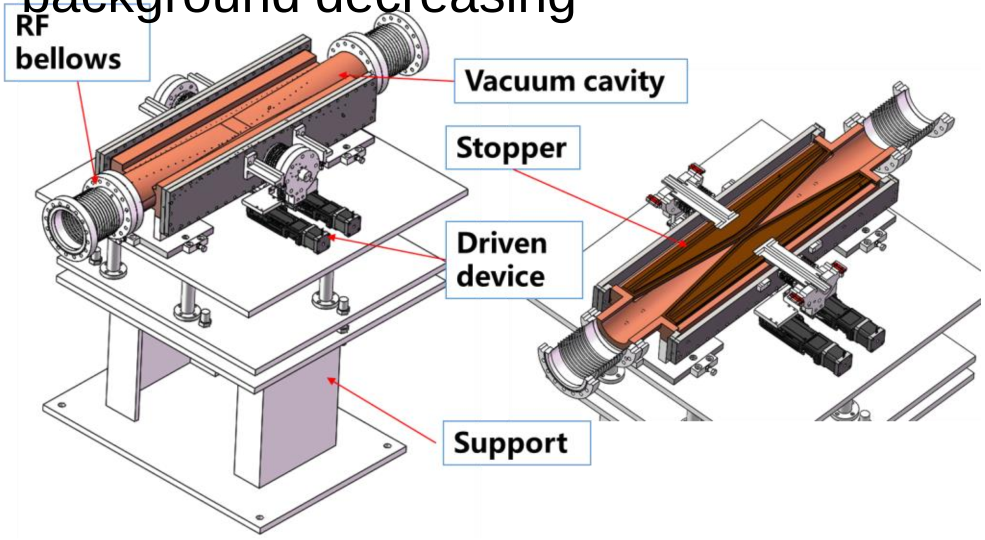
Sealing methods	Within detection angle	Leak rate estimation	Remarks
RVC	NO	★★★★	Successful used in S-KEKB
Remote chain	Yes	★	Eliminated
Inflatable seal*	Yes	★★	Experience from CSNS
Improved inflatable seal	Yes	★★★	Mainly focused on

- Our experience:
  - Single-layer → double layer, leak rate can be improved from 1e-6 Pa.m3/s to 8.5e-10 Pa.m3/s.
  - Replace membrane sealing by edge sealing



Collimators and machine protection scheme

- 4 collimators per IP per ring for background decreasing

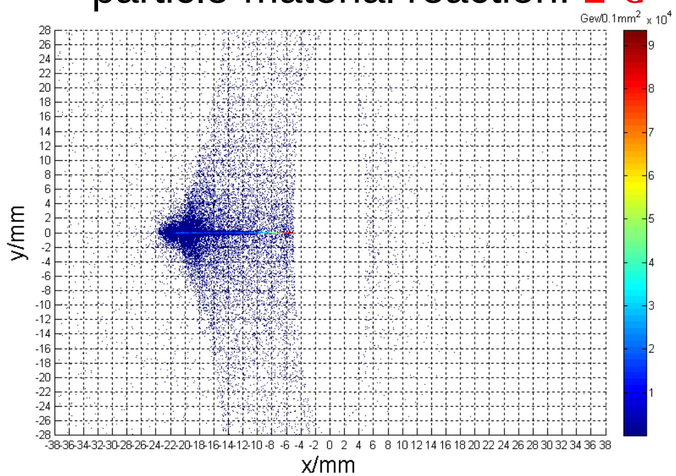


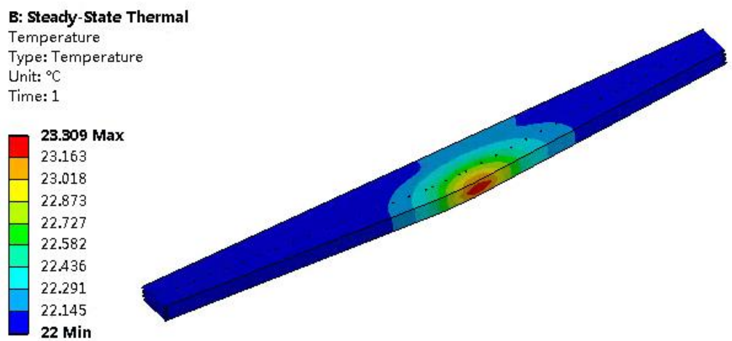
- Horizontal aperture
  - 4.4 mm~20 mm
- Methods:
  - FEA
  - Thermal deposition analysis
  - Impedance analysis
  - Kinetic design
- Tools:
  - ANSYS/Workbench
  - Inventor
  - Geant4
  - CST

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m
APTX1	D1I.1897	2139.06	113.83	0.24
APTX2	D1I.1894	2207.63	113.83	0.24
APTX3	D1O.10	1832.52	113.83	0.24
APTX4	D1O.14	1901.09	113.83	0.24

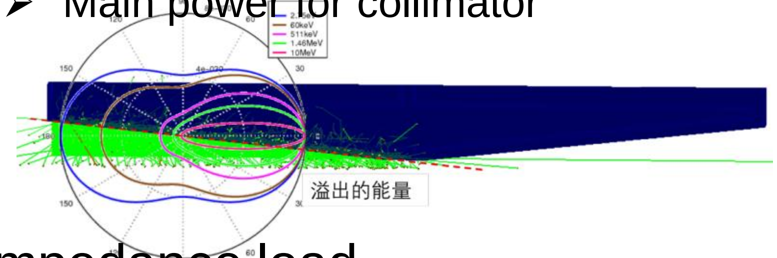
Collimators and machine protection scheme

- Particle deposition
  - Jaw material: Cu
  - Total heat generation: 91.6 W
  - Maximum temperature raise by particle-material reaction: 2℃

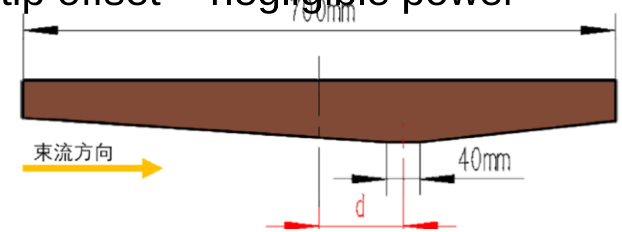


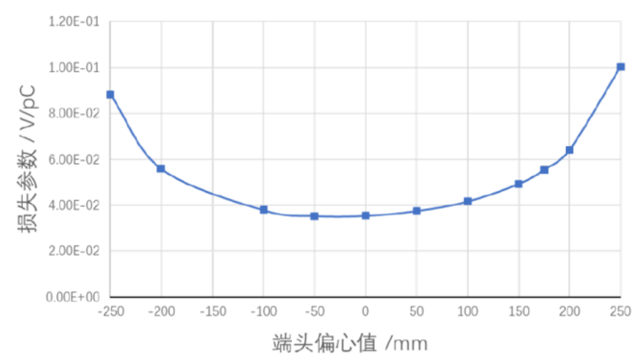


- SR load
  - 9.3 kW@30 MW, Higgs
  - Main power for collimator



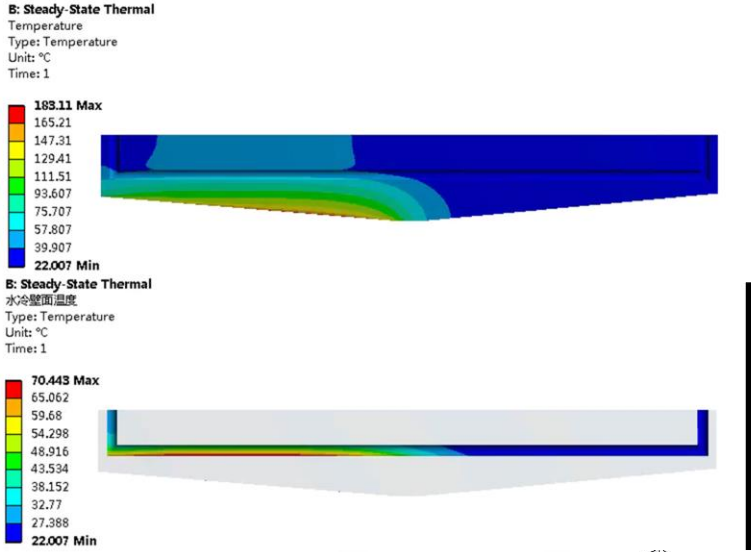
- Impedance load
  - Loss factor can be optimized with tip offset ~ negligible power

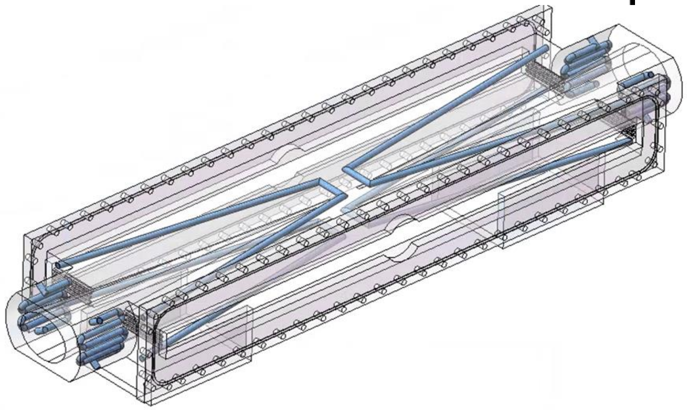


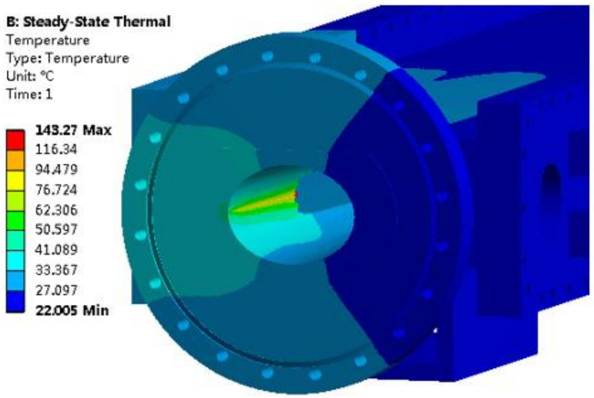


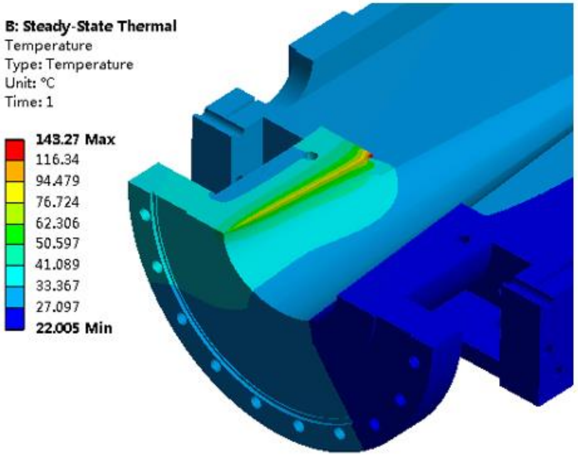
Collimators and machine protection scheme

- Highest temperature in jaws: 183 ℃
- Highest temperature in chamber: 143 ℃



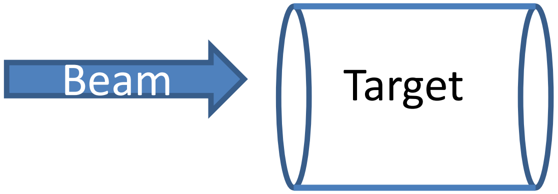






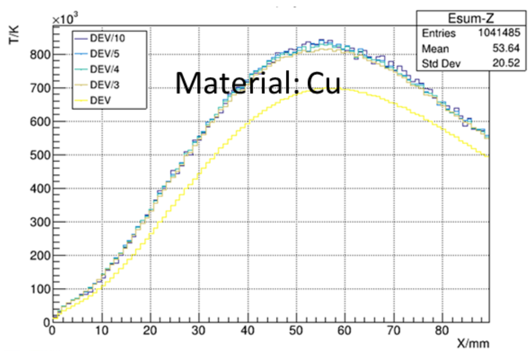
Collimators and machine protection scheme

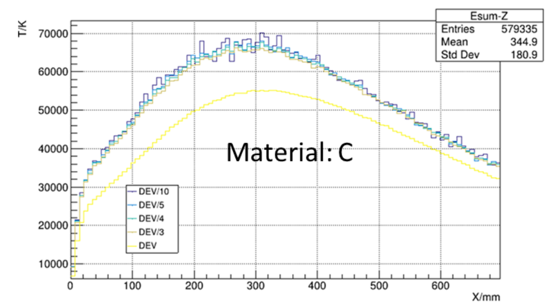
- If the beam loss happens:
  - ➢ 242 bunches, 15e10 particles per bunch, 120 GeV. From CDR.
  - ➢ 242*15e10*1.602e-19*120e9 =697.831kJ
  - ➢ Equal to ~1.7kg copper from 20 ℃ to melting point or ~131g copper to gasification point.
  - ➢ 4.6 m long copper of the cross section (165, 35.7) um will be gasified.
  - ➢ $\Delta T = Q/(c \cdot m)$ ⇒ $\Delta T = q * \frac{V}{(c \cdot \rho \cdot V)} = \frac{q}{\rho} * \frac{1}{c} = \frac{D}{c}$
  - ➢ ~0.3 bunches for copper melting
  - ➢ The facility should be protected from the mad beams, especially at IR.

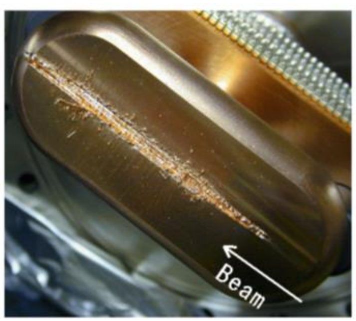


Collimators and machine protection scheme

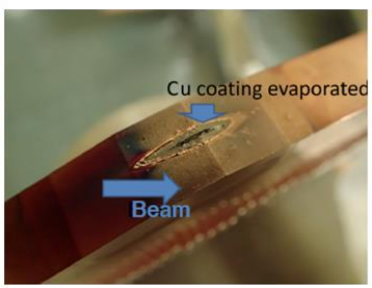
- Beam loss failure of CEPC
  - If dipoles have powering failure, The beam will be lost in 1 turn, on collimators or on vacuum chamber. From accelerator physics.



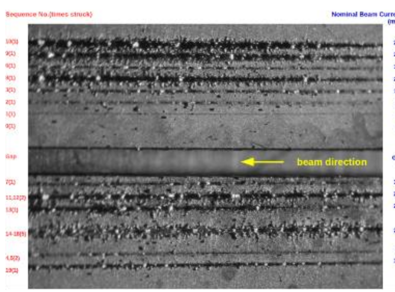




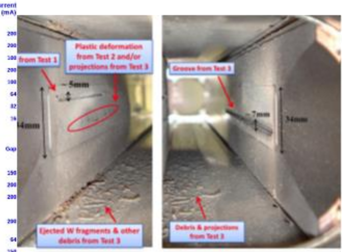
Broken collimator of KEKB



Broken collimator of Super KEKB



Experiments of APS-U



Experiments of LHC

  - Beam loss failure on vacuum chamber or magnets should be avoided.

Preliminary design on machine protection

- Machine protection—KEKB
  - Beam abort system, to avoid direct hit on movable collimators.
  - Response time: ~100 us (~10 turns).
- Machine protection —Super KEKB
  - Deliver the stored beam into a beam dump and prevent spewing beam everywhere in the ring.
  - Response time: less than 20 us. (~2 turns)
- Machine protection-LHC
  - Collimators are used for passive protection. 99.99% of the lost protons were intercepted. 100 collimators.
  - Dump delay: 270 us (3 turns)

Abe, Tetsuo, et al. "**Achievements of KEKB**." *Progress of Theoretical and Experimental Physics* 2013.3 (2013).

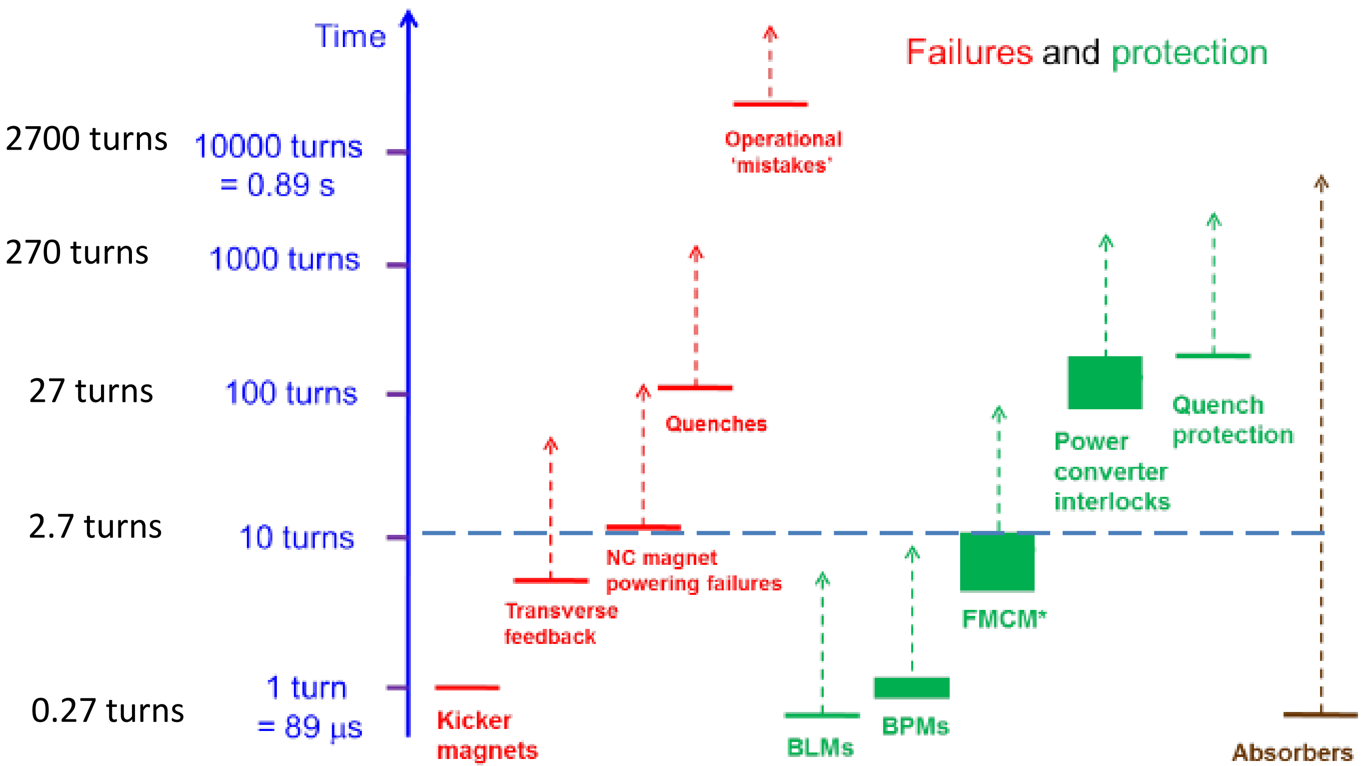
Akai, Kazunori, Kazuro Furukawa, and Haruyo Koiso. "SuperKEKB collider." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 907 (2018): 188-199.

Mimashi, Toshihiro, et al. "SuperKEKB beam abort system." *Proc. IPAC* 14 (2014): 116.

Wenninger, Jörg. "Machine protection and operation for LHC." *arXiv preprint arXiv:1608.03113* (2016).

Preliminary design on machine protection

- Preliminary scheme



Beam abort system, to beam dump

Passive protection
- Collimators
- Reverse switching solenoids

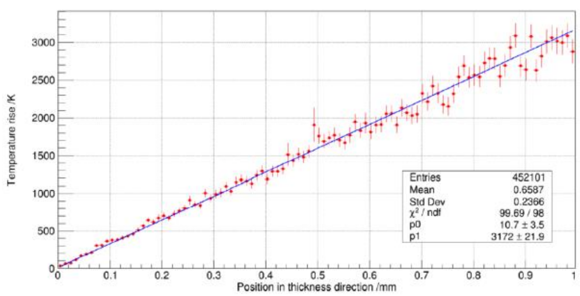
…

Picture from: Wenninger, Jörg. "Machine protection and operation for LHC." *arXiv preprint arXiv:1608.03113* (2016).

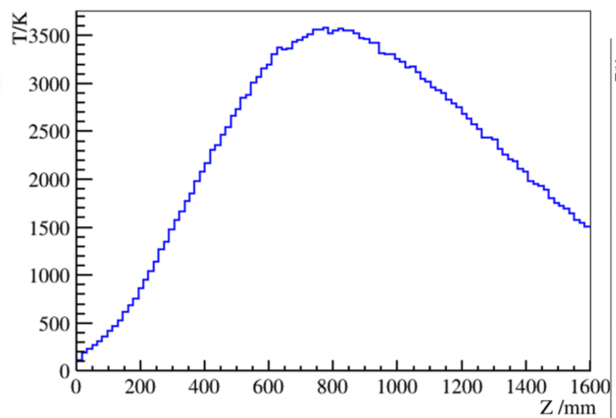
Preliminary design on machine protection

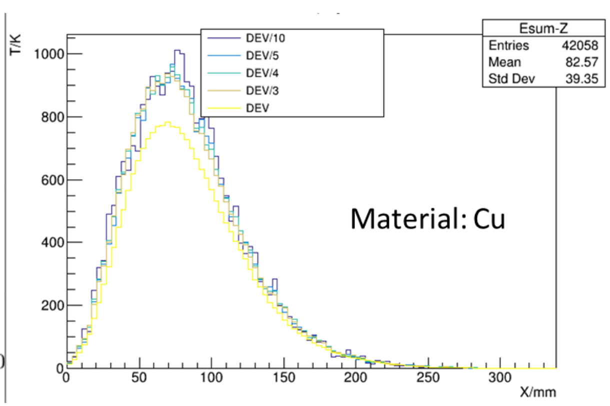
Possible method for passive protection

- By collimators
  - Primary collimator: diamond, 1 mm in thickness
  - Secondary collimator: graphite, 200 meters after
  - The collimators can endure the 242 bunches without melting.
  - Collimator distribution and impedances haven't been studied.
- By reverse switches
  - Scale up the beam size three times larger, the copper chamber will not melt.
  - Auxiliary solenoids on the vacuum chamber with a reverse switching with dipoles may be used to dilute each bunch.
  - Response time and technical flexibility should be studied.



Temperature in 1 mm diamond





Temperature in graphite

Summary

- Theoretical derivation, deformation optimization, topology optimization have been adopted in the magnet girder design, more detailed optimization works are on-going.
- We have made a workable MDI layout. Some key devices such as remote vacuum connector are designed.
- The collimators for background decreasing are designed. The beam loss failure has been considered and preliminary protection scheme with abort system, collimators and reverse switching solenoids are considered.

Thanks for your attention!