Design of the Electrostatic-Magnetic Deflector for CEPC

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IAS Program on High Energy Physics 2019

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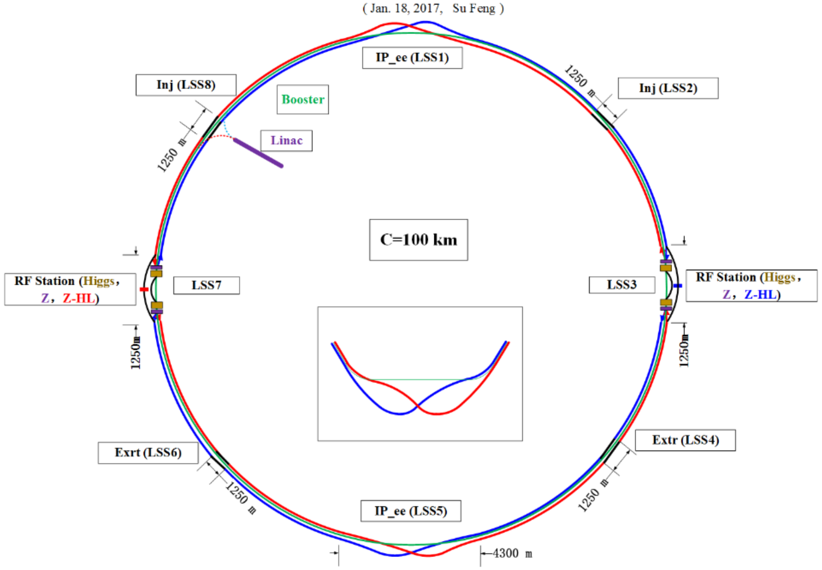
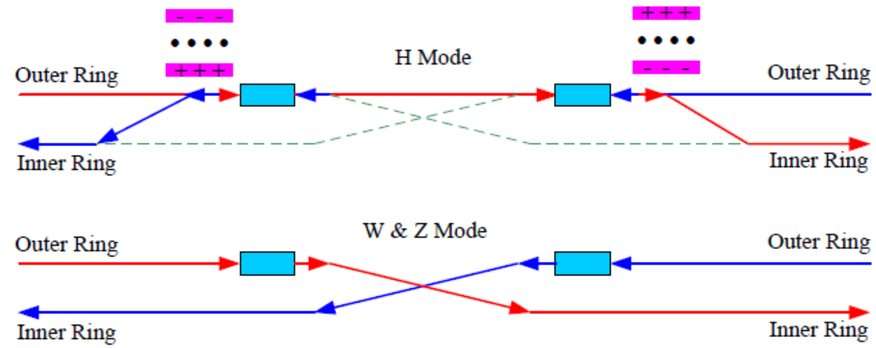
Introduction

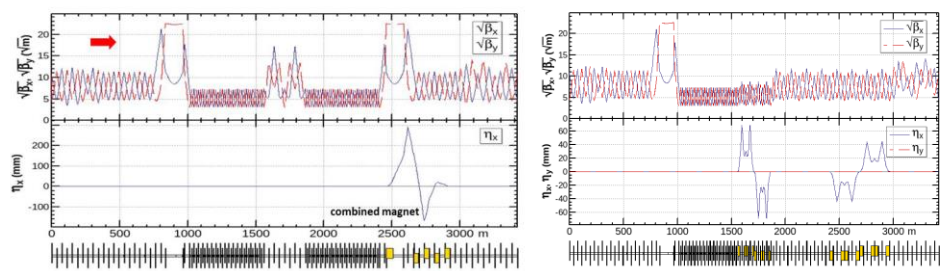
Layout of CEPC Fully Partial Double Ring

(Jan. 18, 2017, Su Feng)





Layout of RF region



Optics of the RF region for Higgs (left), W and Z (right) modes

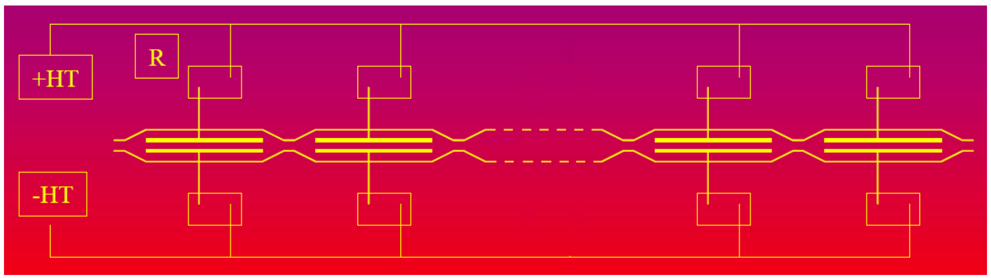
In the RF region, the RF cavities are shared by the two rings. Each RF station is divided into two sections for bypassing half numbers of cavities in W and Z modes.

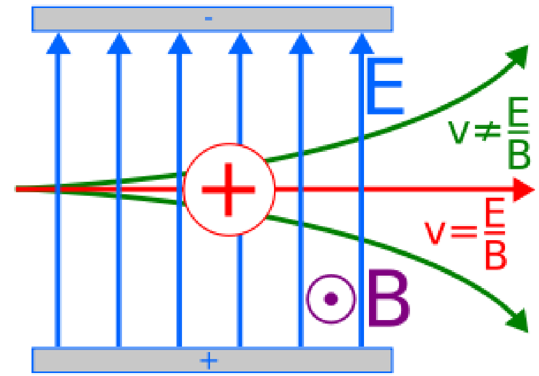
A set of electrostatic separators combined with dipole magnet (**Electrostatic-Magnetic Deflector)** are used to avoid bending of incoming beam and deflect the outgoing beam in H mode. After the Deflectors , there is a drift as long as 75m to make the two beam distance as large as 10cm at the entrance of quadrupole.

Introduction

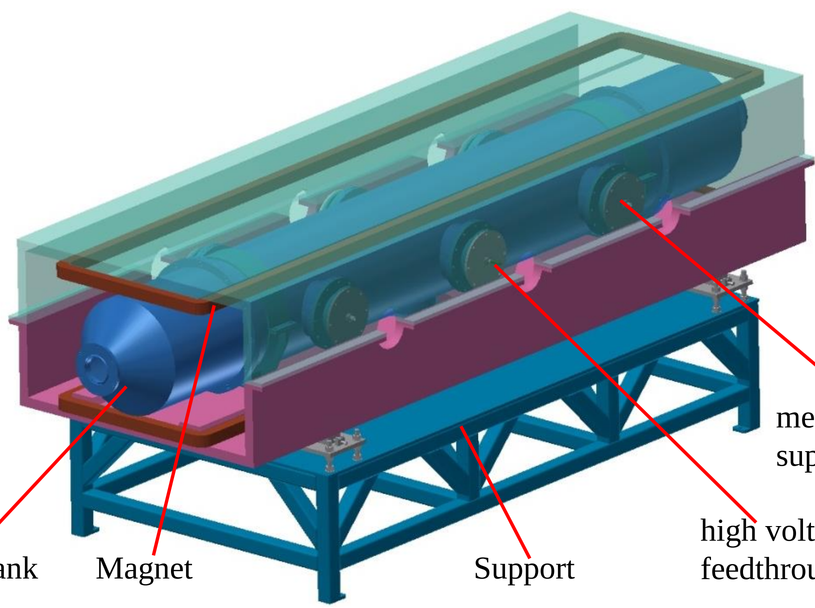
The **Electrostatic-Magnetic Deflector** is a device consisting of perpendicular **electric** and **magnetic** fields, just like **Wien filter**.

One set of Electrostatic-Magnetic Deflectors including 8 units, total 32 units will be need for CEPC.

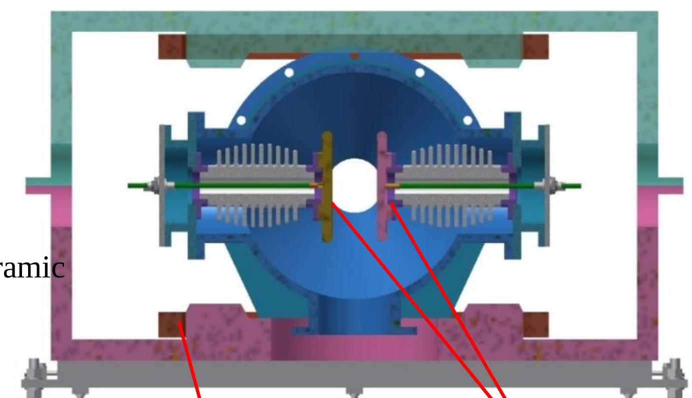




A Wien filter



structure drawing of Electrostatic-Magnetic Deflector



Introduction

Parameters of Electrostatic-Magnetic Deflector

	Filed	Effective Length	Gap	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	110mm	70mm x 30mm	5×10^{-4}
Dipole	66.7Gauss	4m	600mm	70mm x 30mm	5×10^{-4}

Challenges

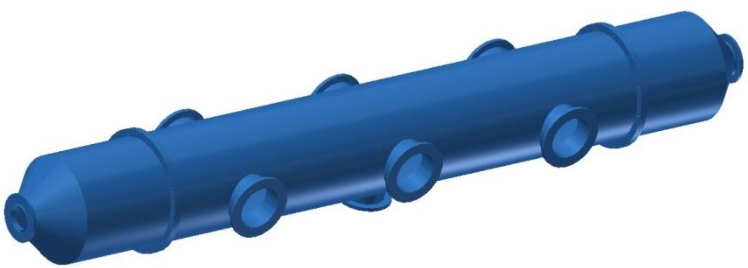
- Homogeneous Field design
- To maintain E/B ratio in fringe field region
- Reduce the impedance and loss factor of the separator
- Mechanical structure design

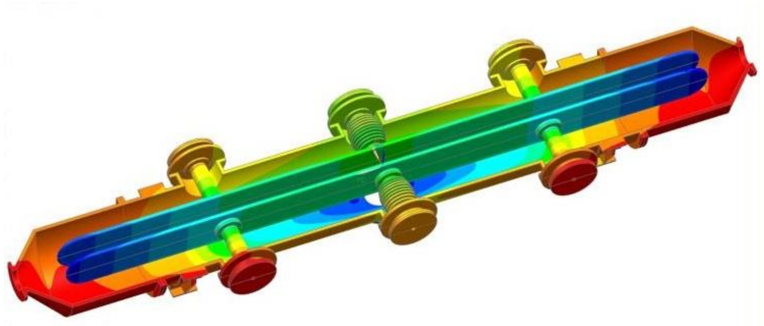
Design of Electrostatic Separator

An electrostatic separator comprise a pair of electrodes, UHV tank, metal-ceramic supports, high voltage feedthrough, High voltage circuit and vacuum system, etc.

Parameters of electrostatic separator

Separator length	**4.8m**
Inner diameter of separator tank	**540mm**
Electrode length	**4.0m**
Electrode width	**260mm**
Nominal gap	**110mm**
Maximum operating field strength	**2MV/m**
Maximum operating voltage	**±110kV**
Maximum conditioning voltage	**±160kV**
Good field region (0.5‰ limit)	**70mm x 30mm**
Nominal vacuum pressure	**2.7e-8 Pa**

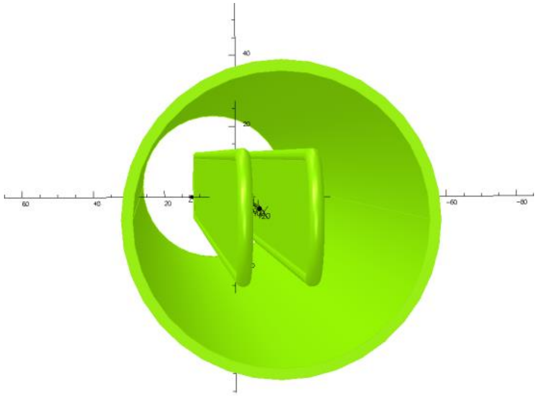


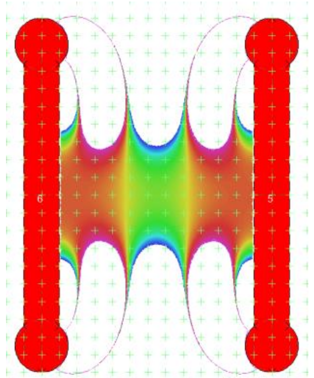


Design of Electrostatic Separator

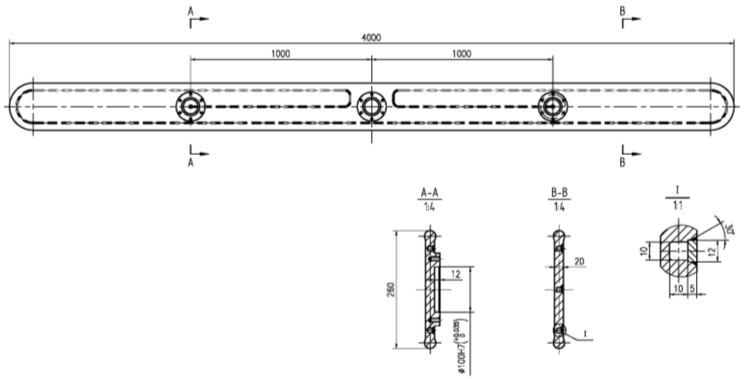
Electrode (a pair of hollow metal flat plate)

- Dimension : 4m long and 260mm wide
- Material : Pure Titanium
  - Titanium to obtain good local vacuum; lightweight good for horizontal application to reduce stress on insulators
- Separated direction : Horizontal
- Field strength : **2MV/m**
  - Since any HV breakdown between the Electrodes can cause an important reduction in luminosity or even a complete loss of the stored beam, the electrostatic field in the electrode gap is limited to 2MV/m.
- Cooling :
  - Parasitic mode losses
  - Equip with a simple closed-loop Cooling system





Field homogeneity：11cm*6cm 0.5‰



Design of Electrostatic Separator

Electrode support

- Each electrode is supported by two metal-ceramic supports, which insulate the electrode from the vacuum tank
- Electrode cooling liquid channel
- Material : Stainless steel
  Metal-ceramic (99.5% Al_2O_3)

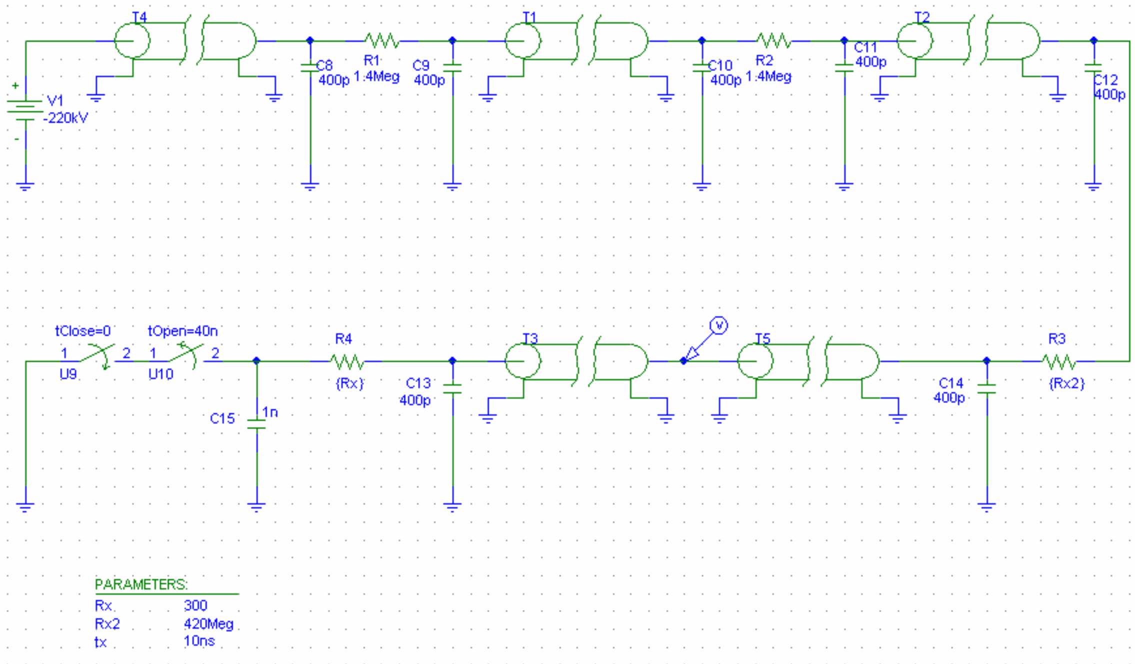
HV feedthrough

- Each electrode can be charged to its nominal voltage via a high voltage feedthrough
- design voltage : up to 160 kV
- Modular design: can be exchanged in case of failure without removal of separator from beam line

Design of Electrostatic Separator

HV power supplies

- Including : two HV supplies of maximum 160kV, 3mA output – one positive and one negative polarity.
  - Voltage margin for conditioning, Current margin to cope with dark current / beam loading / recovery after sparking
- discharge resistor : 10MΩ
- Stability of power supply : 0.5‰



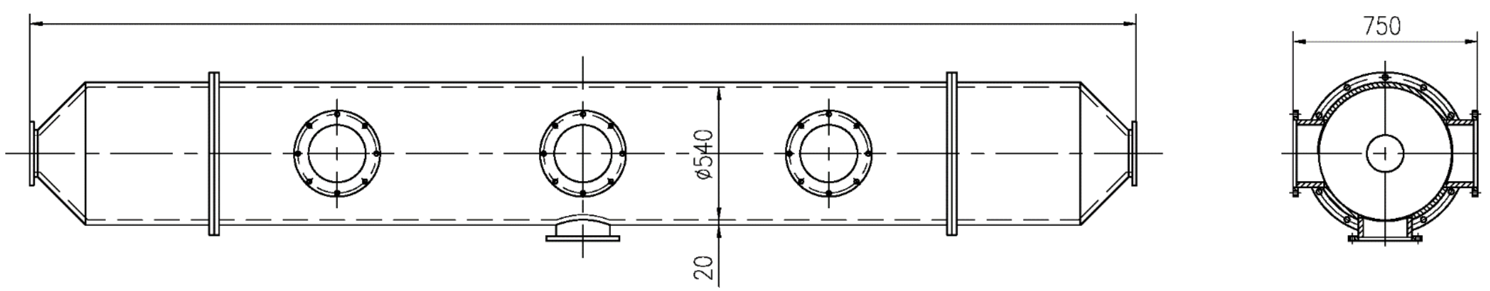
Design of Electrostatic Separator

Vacuum System

- To minimize the breakdown rate, the vacuum in all separators will be kept at the low pressure of about **2.7e-8 Pa**
- Including: tow sputter ion pump (pumping speed 800l/s), and two sublimation pump (pumping speed 1300l/s).
- Bake out at a temperature of up to 300℃.

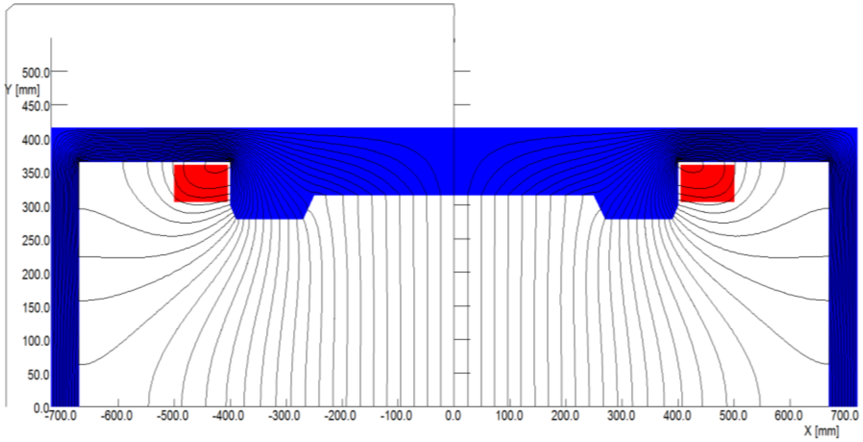
UHV tank

- Dimension : 4.8m long and 540mm inner diameter
- Material : stainless-steel

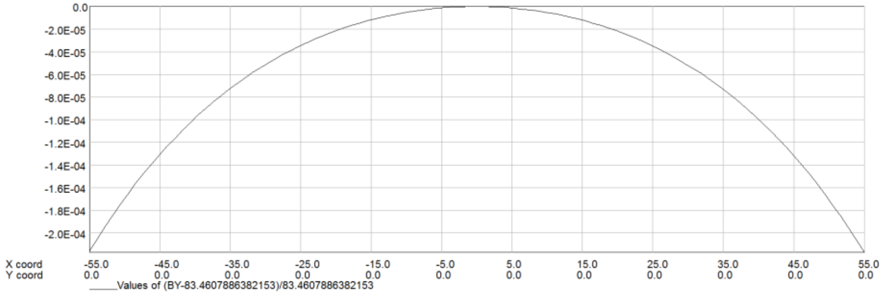


Design of dipole magnet

- The magnet yoke is H-type, because of the higher field integrals uniformity and installation consideration of the electro-static system.
- According to the Lorentz force equation, the center magnetic field needs to reach 66.7Gauss.
- The magnet aperture arrives at 600 mm due to the inner electro-static system size.
- Within the patch of 6cm*11cm, the uniformity of the field integrals reaches ±2E-04.

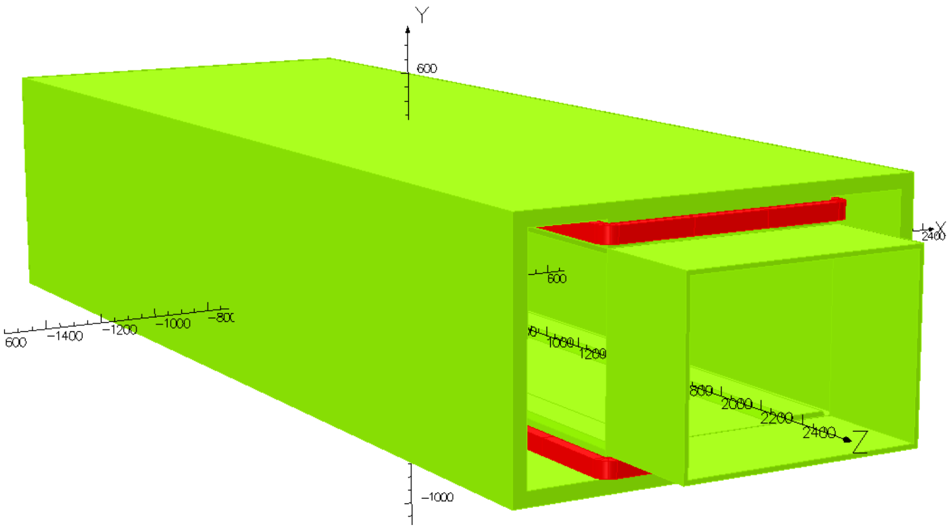


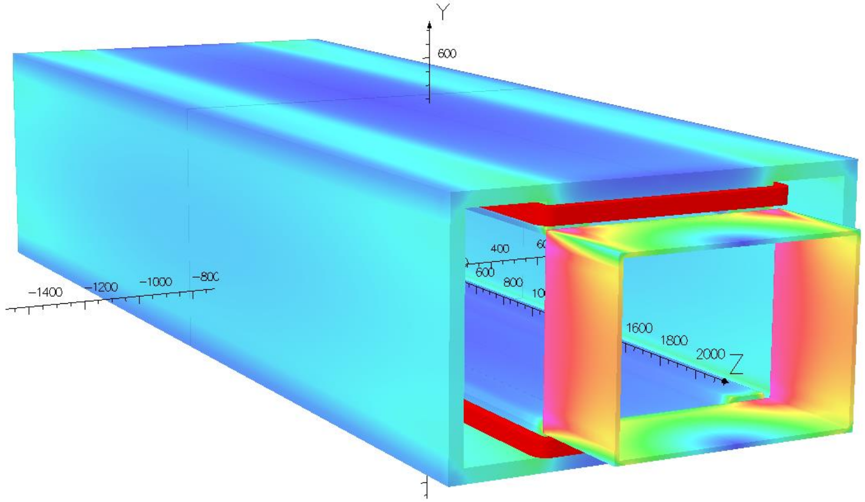
Field Distribution



Field homogeneity

Design of dipole magnet





3D Model

Magnet Name	ESM
Center field [Guass]	75.5
Magnet Length [m]	4.4
Current [A/turn]	10.8
Turns [H×V]	12×17
Field Clamp Size [H×V, mm]	830×610
Field Clamp Wall Thickness [mm]	10
Field Clamp Number	2
Coil Number	2
Conductor Size [H×V, mm]	3×3
Current Density [A/mm^2]	1.2
Magnet Resistance [Ω]	7.82
Magnet Voltage [V]	84.4
Magnet Power [W]	660
Magnet Inductance [H]	2.42
Cooling Method	Air
Yoke Weight [Ton]	11
Coil Weight [Ton]	0.328
Magnet Weight [Ton]	11.328

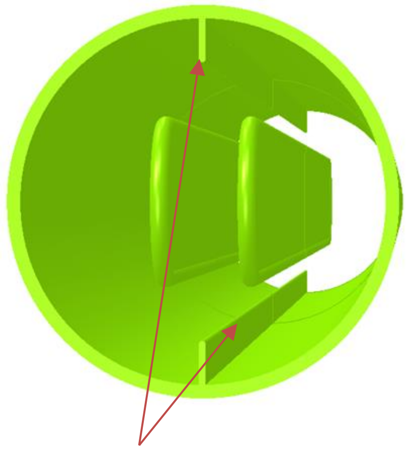
Parameters of the magnet

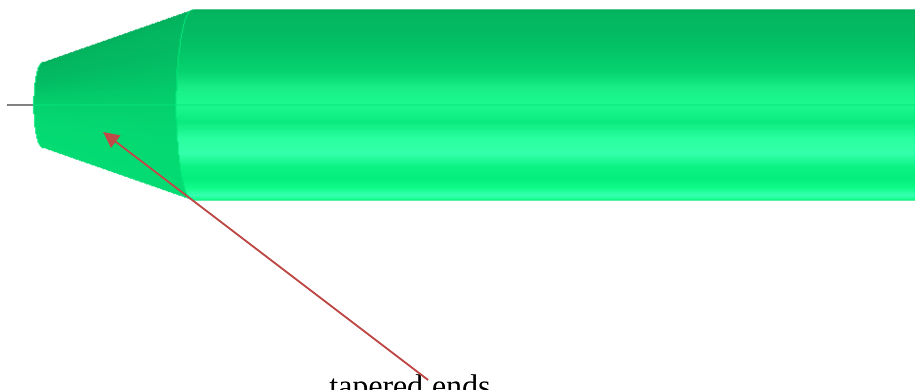
Methods to reduce the Parasitic mode losses

The electrostatic separators are large contributors to the overall impedance. In addition, the RF fields generated by the beam passing through the separators have seriously degraded the high voltage performance.

There are two methods implemented in the design of the separator which reduce the loss factor:

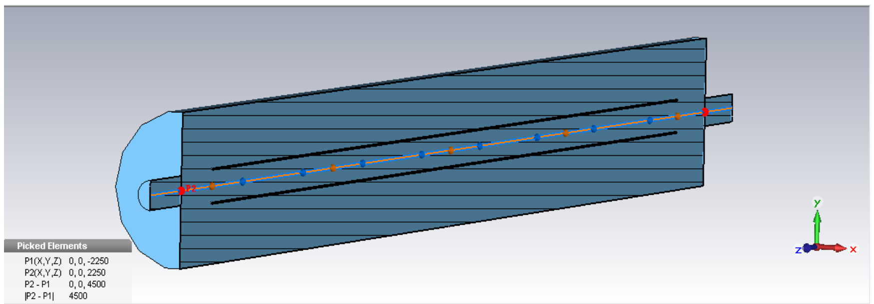
- ground electrodes
- tapered ends

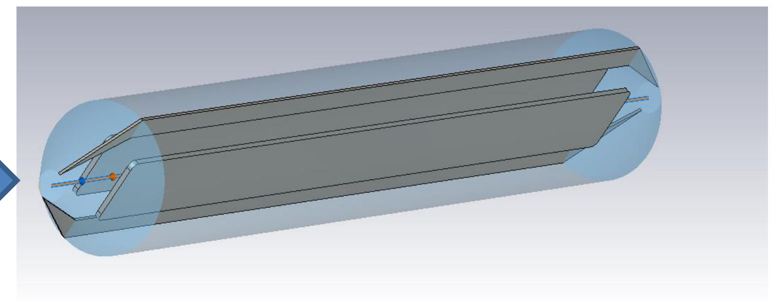




Methods to reduce the Parasitic mode losses

These two methods are merged in one unusual surface which smoothly guides the field energy from a normal vacuum chamber geometry to the multiple electrode geometry and then back to the normal vacuum chamber.





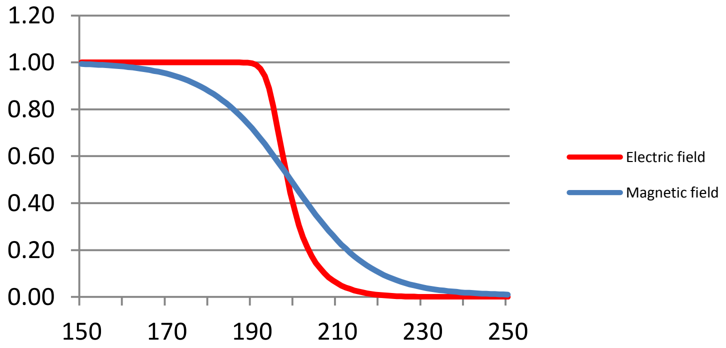
Initial design				optimization design		
Loss factor p_{loss}	8.947095e-001 V/pC			2.620589e-001 V/pC		
Power(H/W/Z)(kw)	0.3734	1.5131	5.2855	0.1094	0.4432	1.54

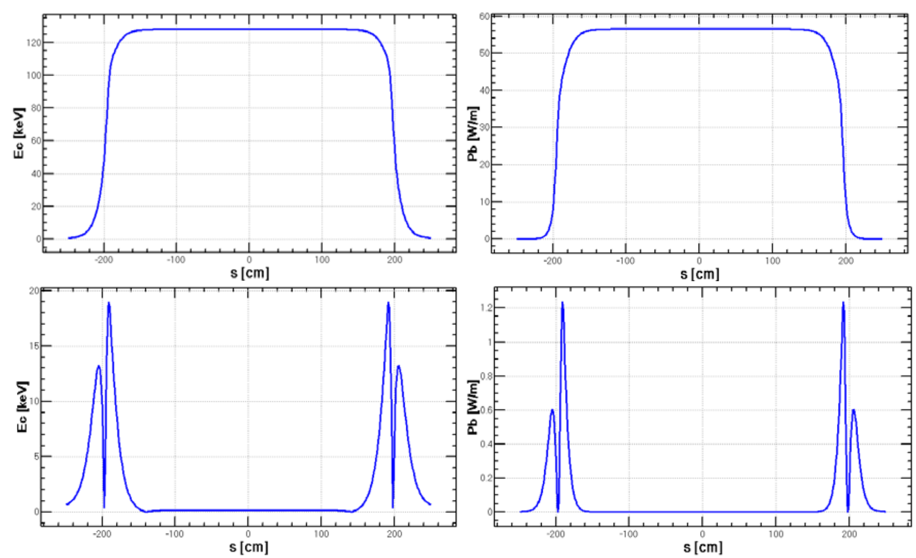
Methods to maintain E/B ration in fringe field region

Another challenge in designing deflector is the spatial difference in electric and magnetic fringe fields. Because of the large gap, the magnetic fringe field extends over a larger distance than the electric fringe field.

In this fringe field region, the ratio of E/B differs from that inside the deflector, and this can result in a synchrotron radiation from the Separation Region, which will affect the down stream RF cavities.

For the coming-in beam, the radiation power **of 3.4 W is significant if it point to one cavity**.





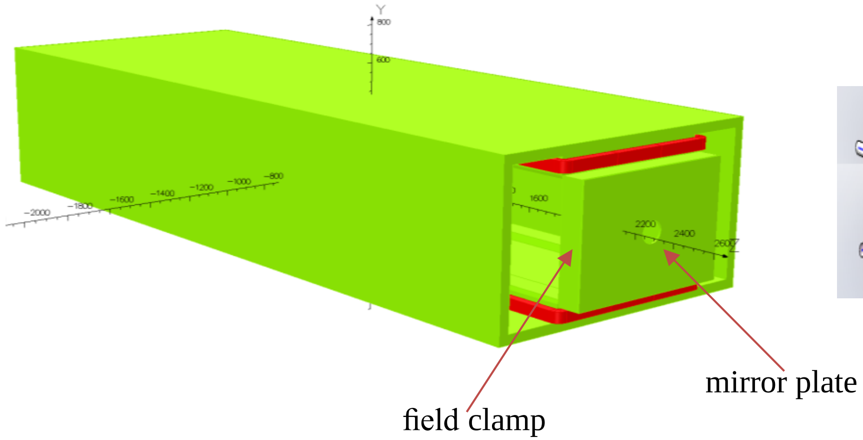
Critical energy of photons Radiation power

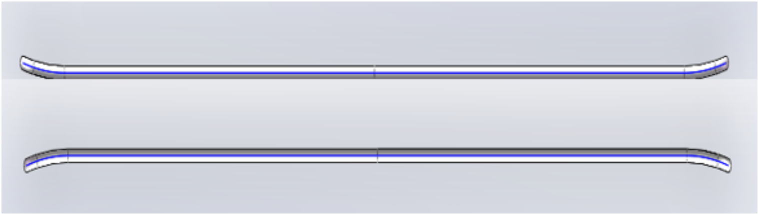
Upper figures for out-going beam Lower figures for coming-in beam

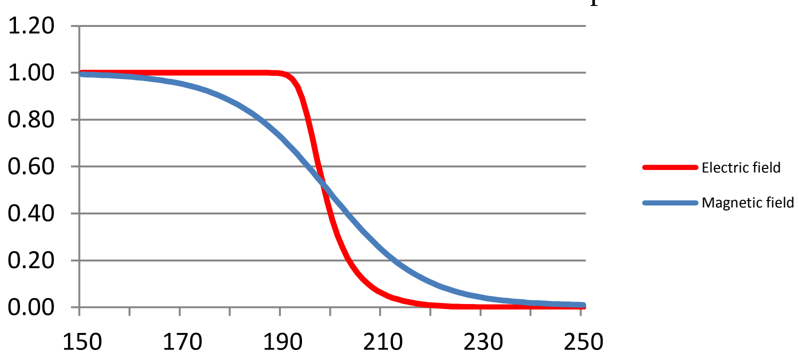
Methods to maintain E/B ration in fringe field region

Several Methods have been incorporated into the design of the deflector in an effort to minimize the distortions in the fringe field region.

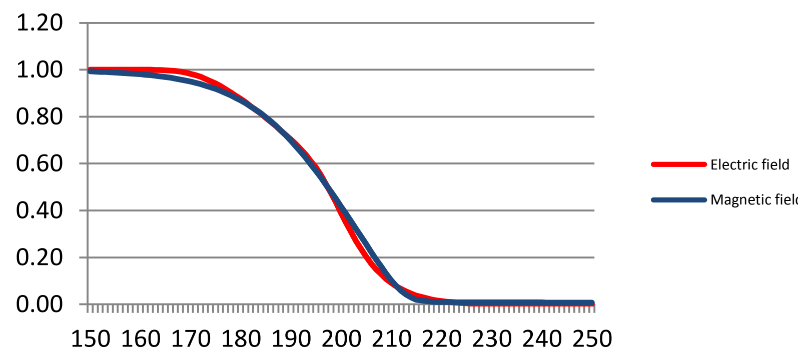
- Magnet: addition of field clamps, along with the mirror plates.
- Separator: flaring open the electrode ends progressively





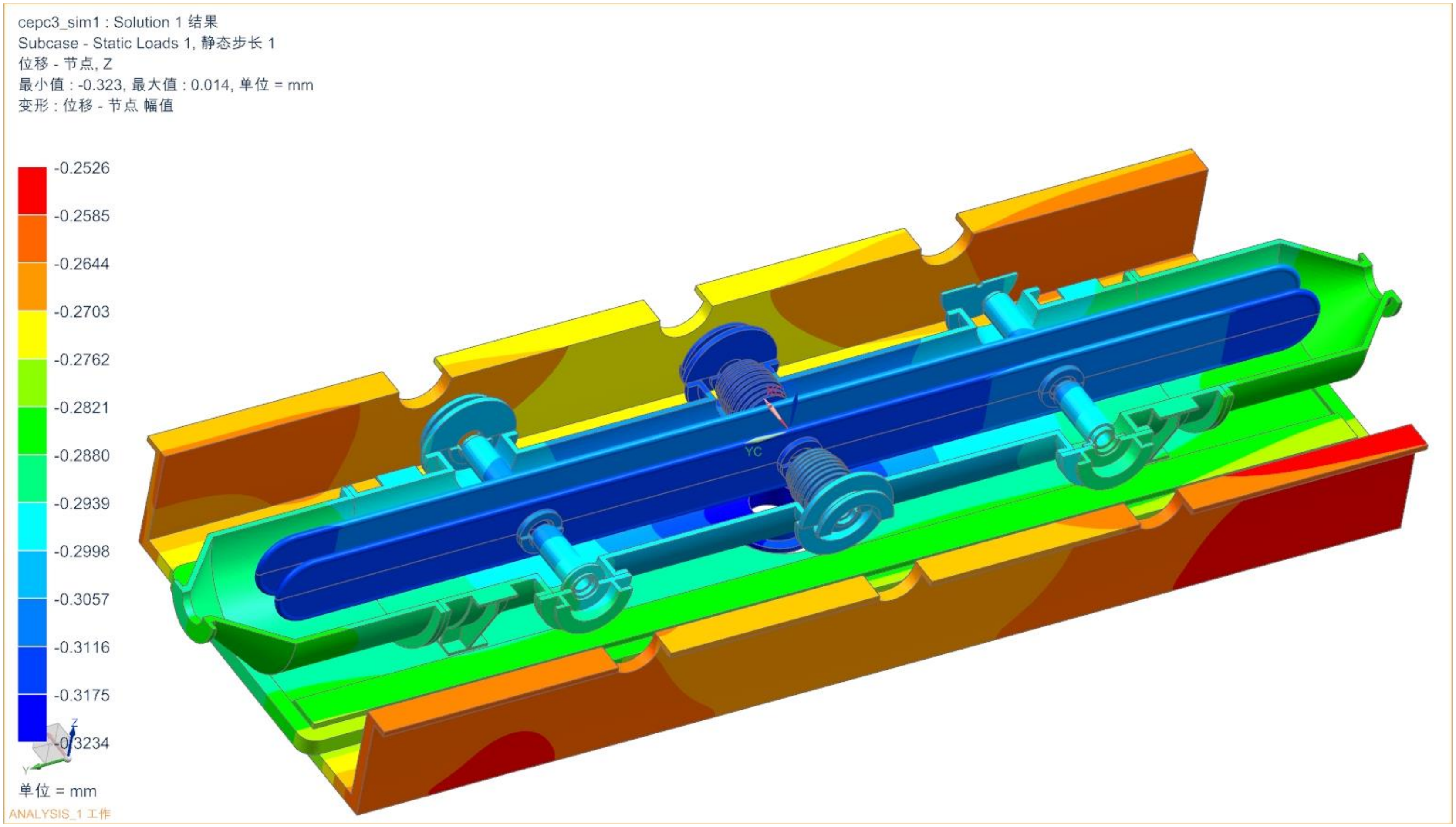


Initial design

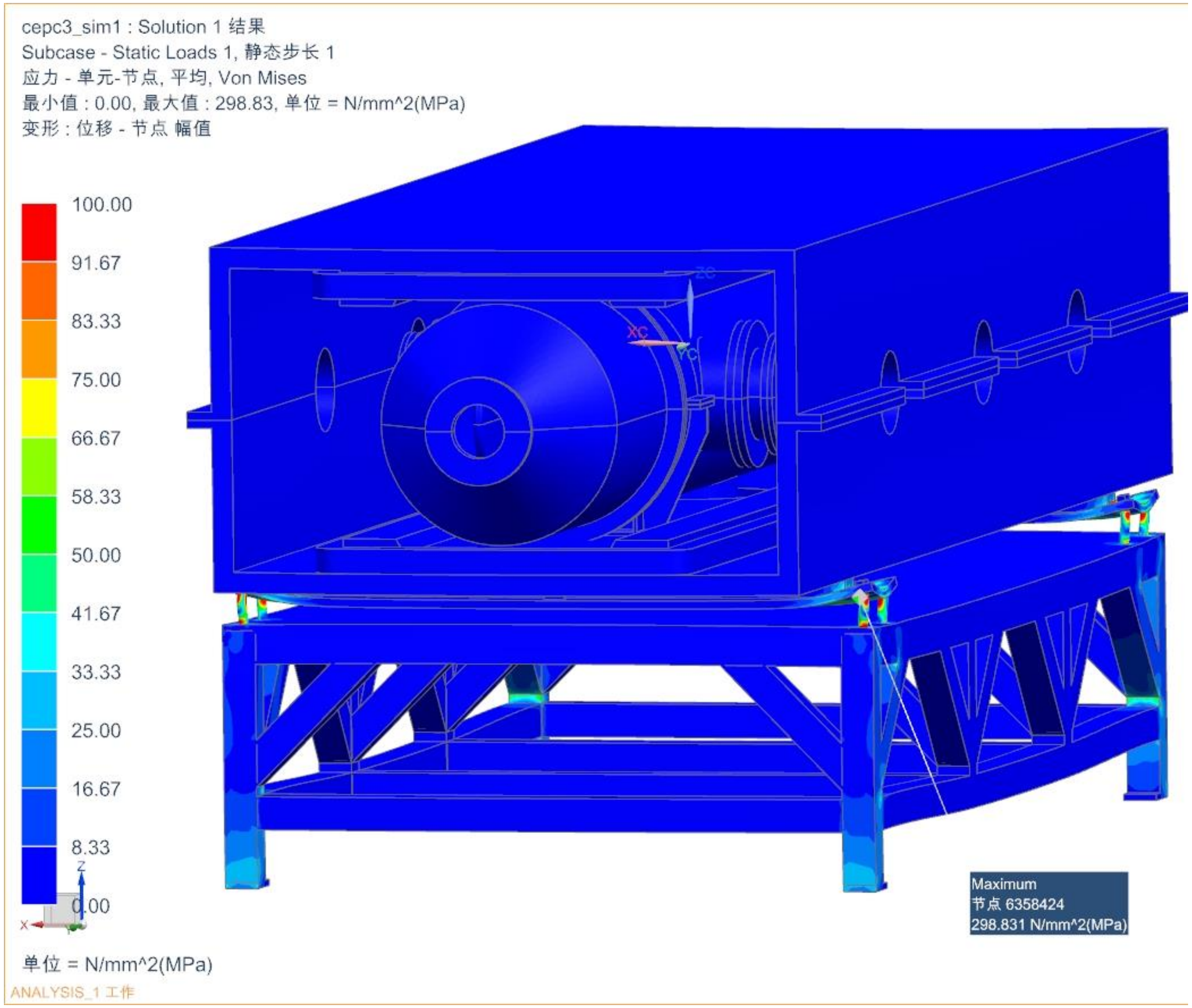


optimization design

Simulation- mechanical deformation ≤0.323mm



Simulation- mechanical stress



Summary

- The Deflector including two part: **Electrostatic Separator** and **Dipole Magnet**
- A separator unit consists of a pair of pure Titanium electrodes — each 4 m long and 260 mm wide —mounted in an UHV tank of about 540 mm inner diameter.
- The magnet yoke is H-type, the center magnetic field is 66.7 Gauss, and the magnet gap is 600 mm. Within the patch of 6cm*11cm, the uniformity of the field integrals reaches ±2E-04.
- There are two methods implemented in the design of the separator to reduce the loss parameter: ground electrodes & tapered ends
- we use the field clamps, along with the mirror plates and flaring open the electrode ends progressively to minimize the distortions in the fringe field region.
- The simulation result of the mechanical structure design show that the mechanical deformation is less than 0.323mm and the mechanical stress is less than 27.7MPa.

Thank You!