

Electrostatic-Magnetic Deflector and Magnet Power supply for CEPC

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International Workshop on CEPC

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■ Design and progress for electrostatic-magnetic deflector

- Design of electrostatic separator
- Design of dipole magnet
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- Mechanical and Vacuum design

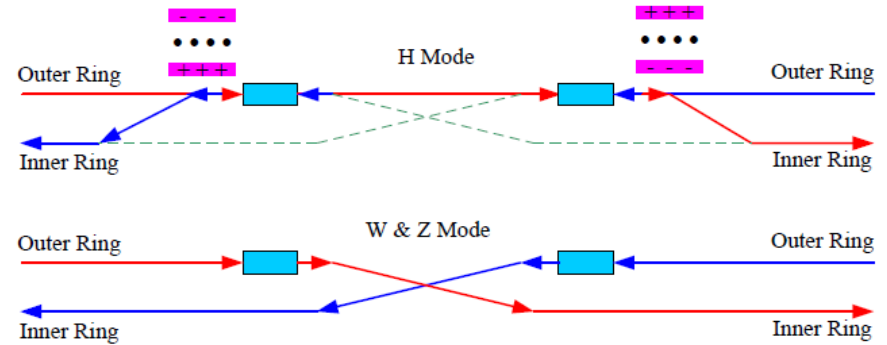
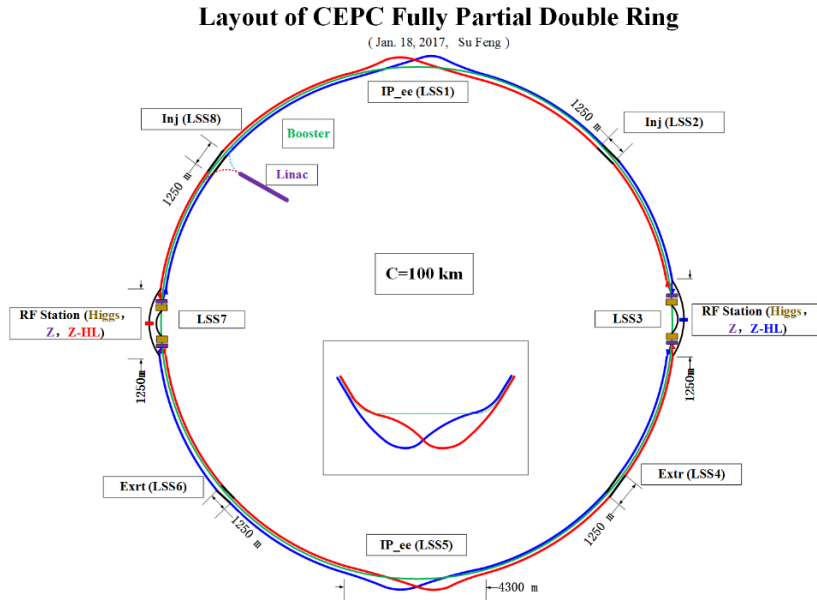
■ Design and progress for power supply

- Design of Booster power supply
- Design of Corrector (Multi-unit combination structure)

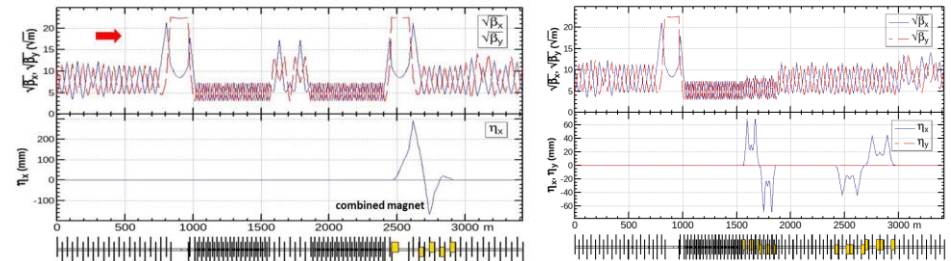
■ Summary

Design and progress for electrostatic-magnetic deflector

Introduction



Layout of RF region



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

In the RF region, A set of electrostatic separators combined with dipole magnet (**Electrostatic-Magnetic Deflector**) are installed downstream of the RF cavities.

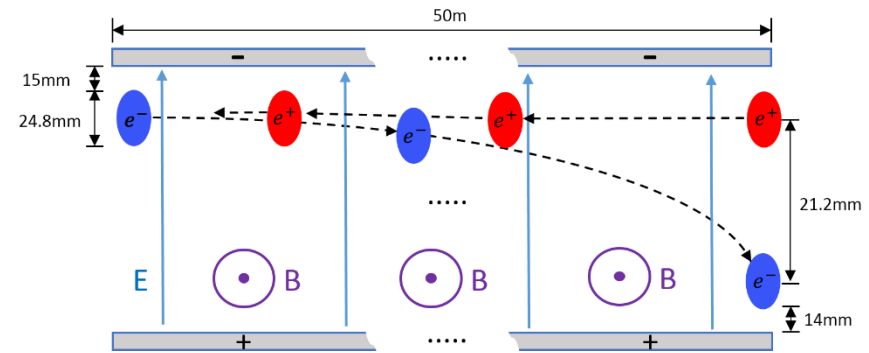
They are used to avoid bending of incoming beam and deflect the outgoing beam in H mode. After the Deflectors, the positive and negative electron beams of the outer ring passing through the RF cavities are deflected to their respective inner rings.

Design and progress for electrostatic-magnetic deflector

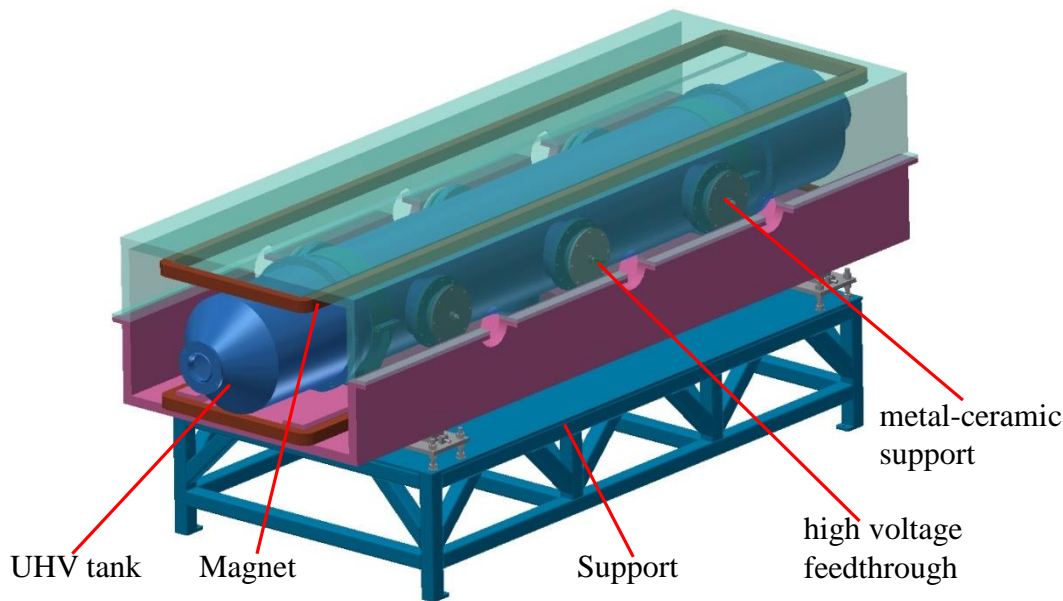
The **Electrostatic-Magnetic Deflector** is a device consisting of perpendicular **electric** and **magnetic** fields.

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

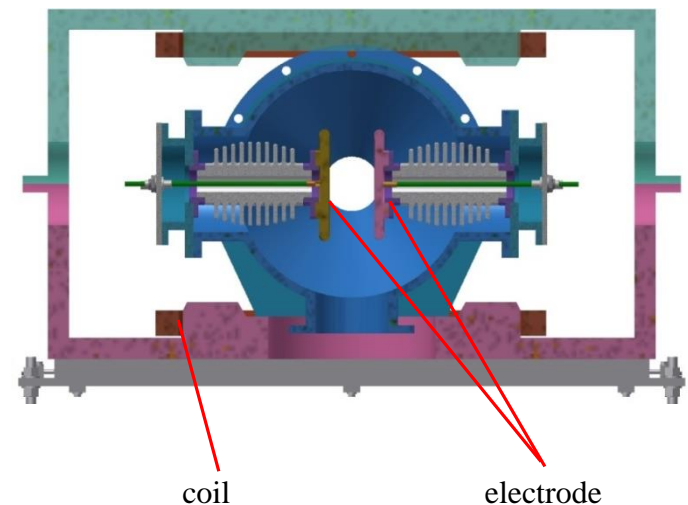
	Filed	Effective Length	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	46mm × 11mm	5×10^{-4}
Dipole	66.7Gauss	4m	46mm × 11mm	5×10^{-4}



Schematic of Electrostatic-Magnetic Deflector



structure drawing of Electrostatic-Magnetic Deflector



coil

electrode

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	4.5m
Inner diameter of separator tank	380mm
Electrode length	4.0m
Electrode width	180mm
Nominal gap	75mm
Maximum operating field strength	2MV/m
Maximum operating voltage	± 75kV
Maximum conditioning voltage	± 135kV
Good field region (0.5‰ limit)	46mm x 11mm
Nominal vacuum pressure	2.7e-8 Pa

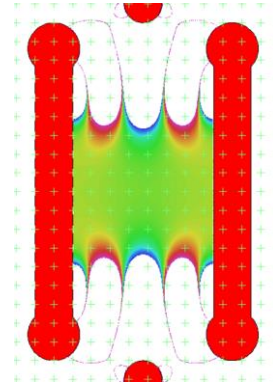
Design of Electrostatic Separator

Electrode (a pair of metal flat plate)

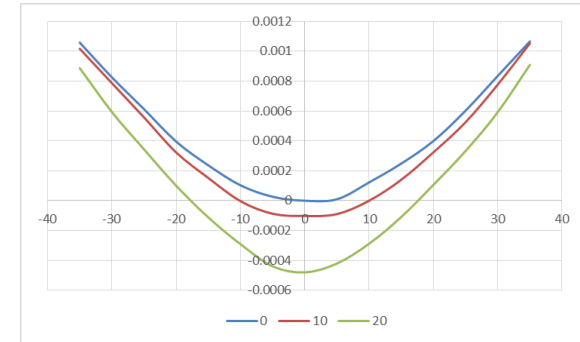
- Dimension : 4m long and 180mm wide
- Material : Pure Titanium
- Field strength : 2MV/m

UHV tank

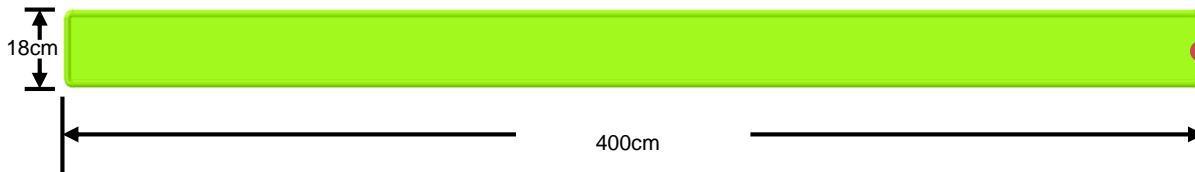
- 4.5m long and 38cm inner diameter
- Material : stainless-steel 316L



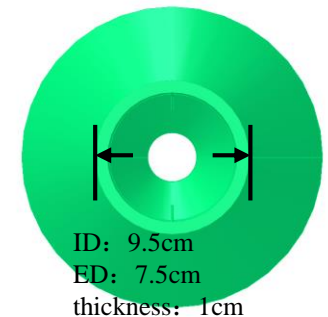
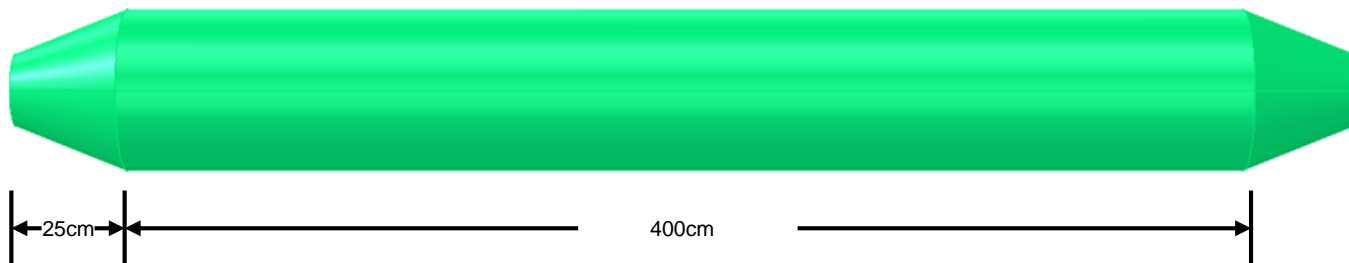
Field homogeneity: 7.5cm*5cm 0.5%



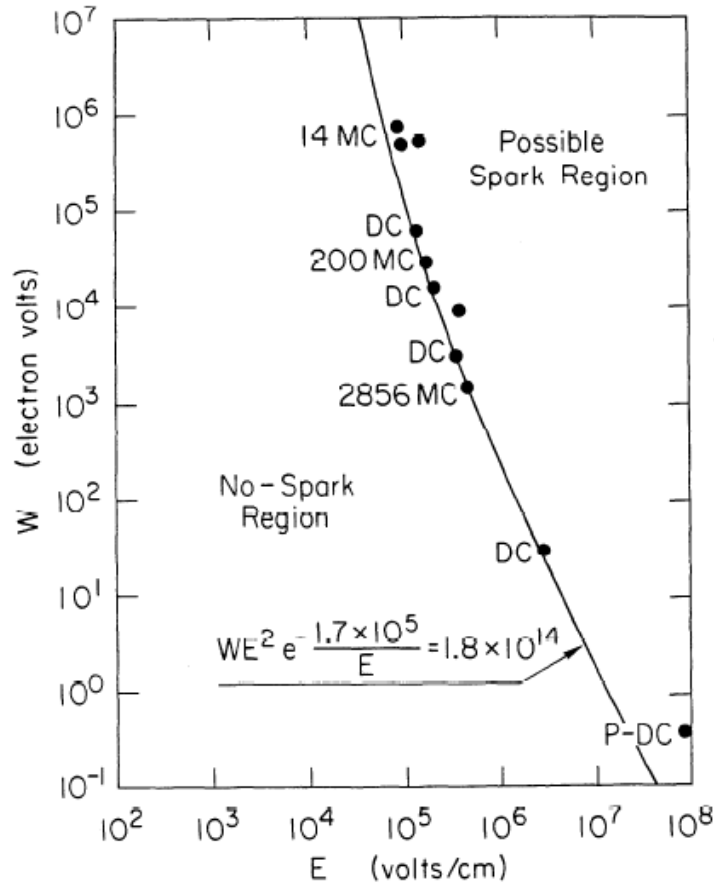
Calculated integrated electrical field uniformity : 4.6cm*3cm 0.5%



Length: 400cm
With: 18cm
Thickness: 2cm
Radius: 1.5cm
Density: 4.54g/cm^3
Weight: $\approx 65\text{kg}$



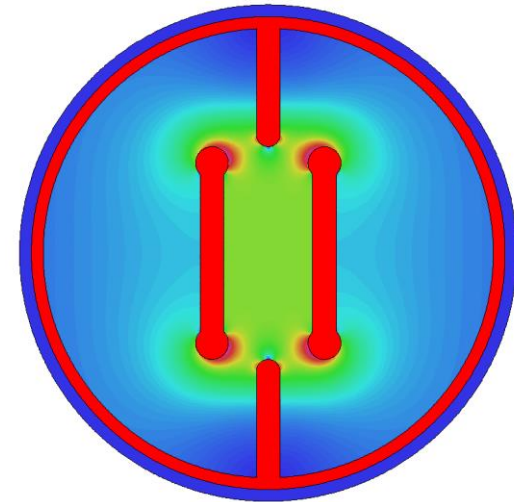
Design of Electrostatic Separator



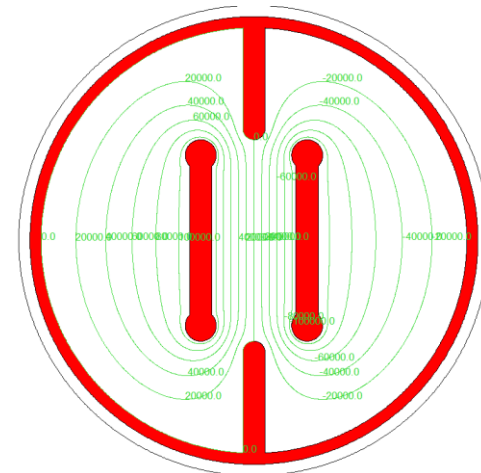
“Kilpatrick's criterion”
基尔帕特里克准则

$$WE^2 \exp(-1.7 \times 10^5 / E) = 1.8 \times 10^{14}$$

@270kV, $E_{\max} = 7.7 \text{ MV/m}$



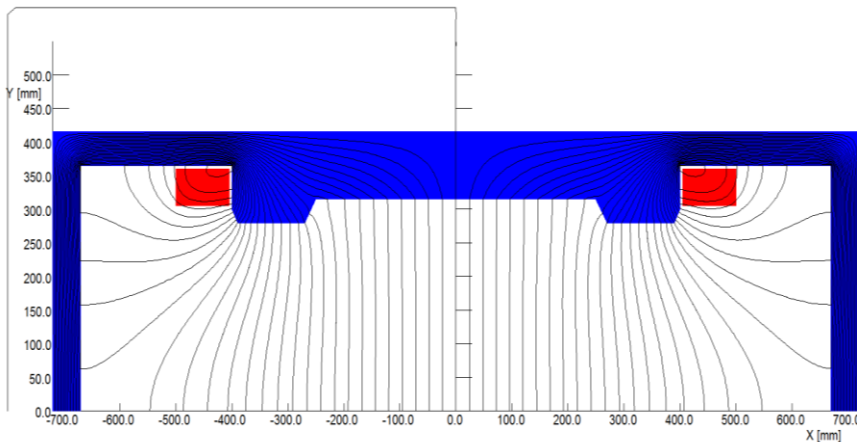
Maximum field strength: 3.86MV/m @150kV
6.95MV/m @270kV



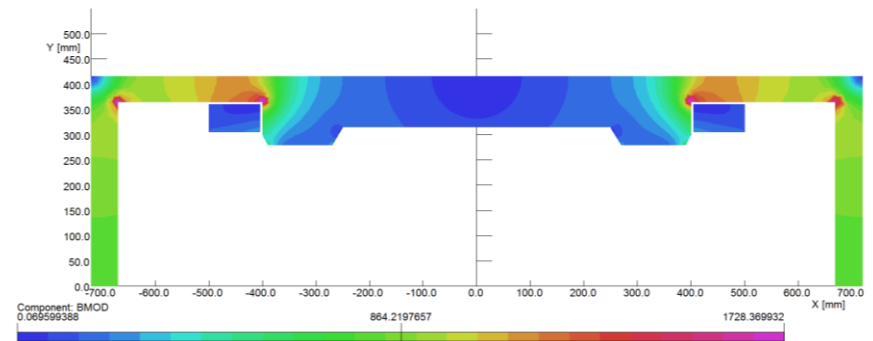
Electric potential line

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 460 mm due to the inner electro-static system size.
- Within the patch of 6cm*11cm, the uniformity of the field integrals reaches $\pm 2E-04$.

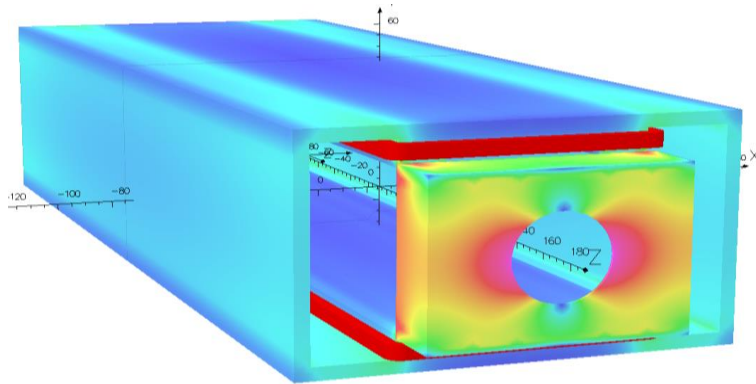
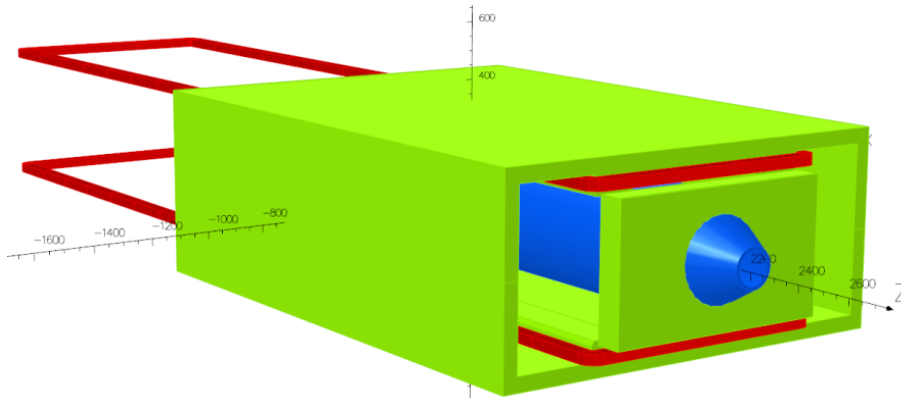


Field Distribution

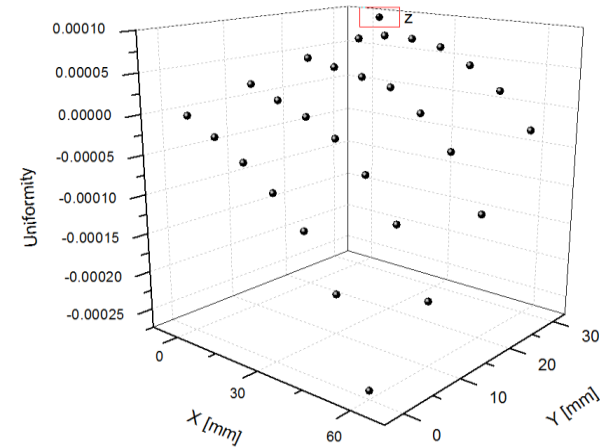


Magnetic flux density distribution in the core

Design of dipole magnet



3D Model and Magnetic flux density distribution



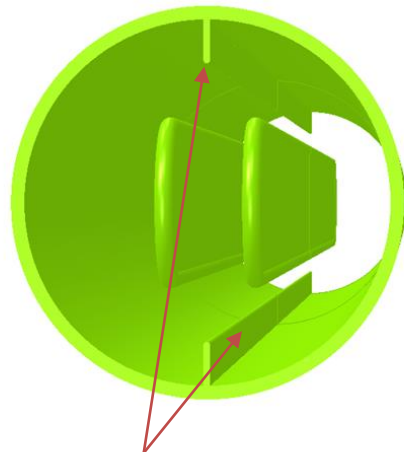
Magnet Name	ESM
Center field [Gauss]	75.5
Magnet Length [m]	4.4
Current [A/turn]	790
Turns [H×V]	1×2
Field Clamp Size [H×V, mm]	780×450
Field Clamp Wall Thickness [mm]	10
Field Clamp Number	2
Coil Number	2
Conductor Size [H×V, mm]	23×35
Current Density [A/mm²]	1
Magnet Resistance [mΩ]	1.42
Magnet Voltage [V]	1.12
Magnet Power [kW]	0.88
Magnet Inductance [mH]	0.45
Cooling Method	Air
Yoke Weight [Ton]	5.1
Coil Weight [Ton,Al]	0.08
Magnet Weight [Ton]	5.18

Parameters of the magnet

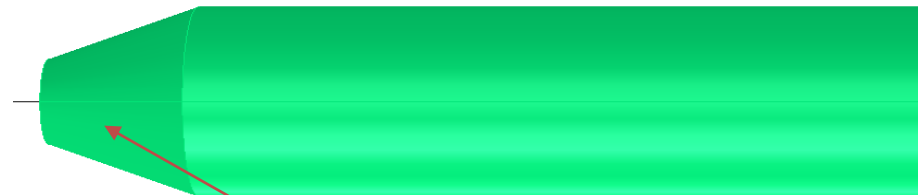
Methods to reduce the Parasitic mode losses

The electrostatic separators are large contributors to the overall impedance. There are two methods implemented in the design of the separator which reduce the loss factor:

- ground electrodes
- tapered ends



Ground electrodes



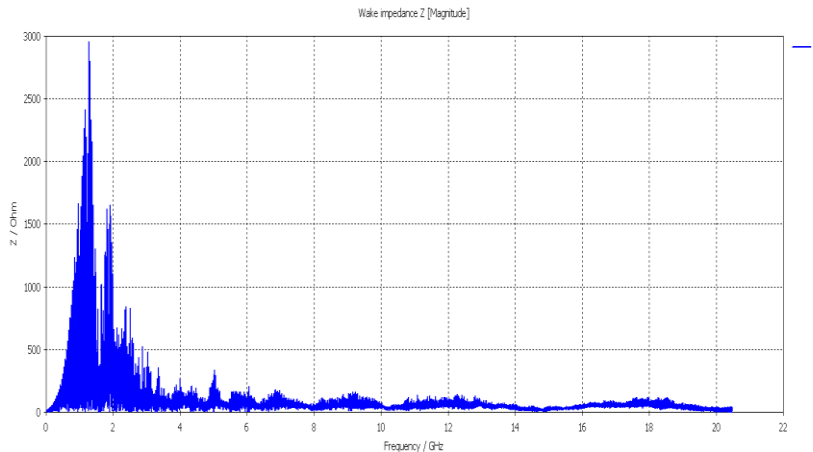
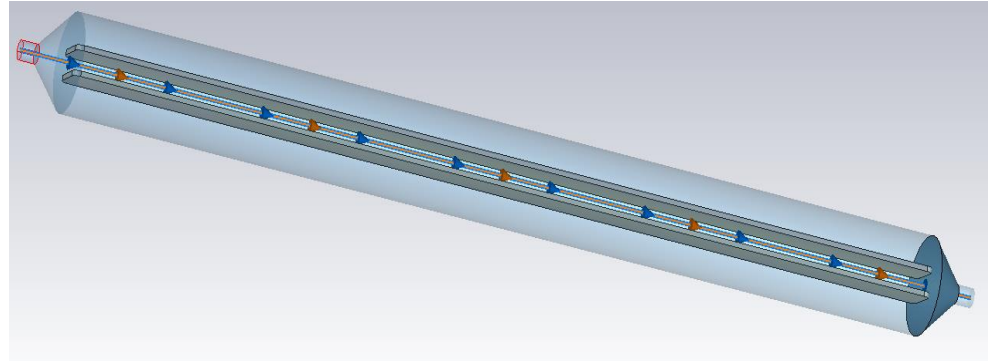
tapered ends

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.

Methods to reduce the Parasitic mode losses

3D tapering, no g.e.

Separator tank length	4000mm
Inner diameter of separator tank	380mm
Electrode height	180mm
Electrode gap	75mm
Electrode thickness	20mm
Transition taper length	52.5mm
Transition pipe diameter	75mm
Ground plate length	×
Ground plate height	×
Ground plate thickness	×



Wake Integration type : Indirect Interfaces

Simulated wake length : 50000 mm

Wake shift x : 0 mm

Wake shift y : 0 mm

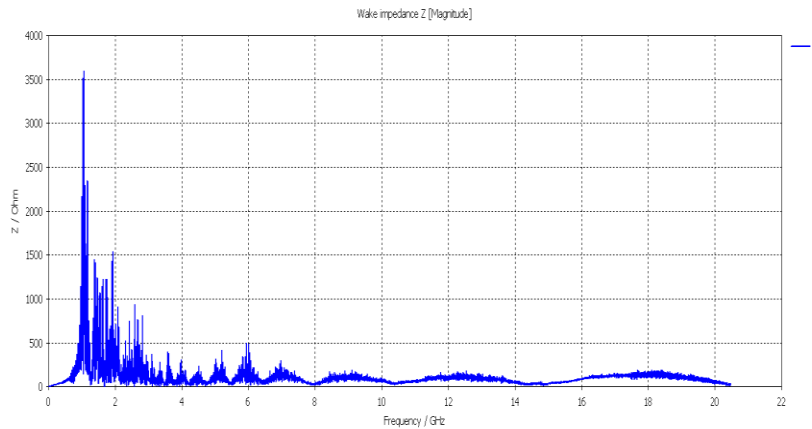
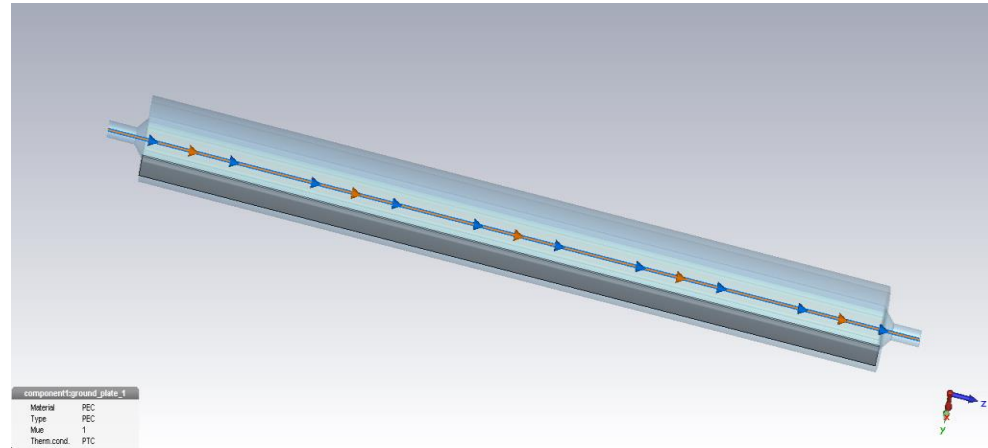
Wake-Loss-Factor : 1.256987e+000 V/pC

$P_{\text{loss}} : 531.5\text{w(Higgs)}/2.12\text{kw(W)}/7.42\text{kw(Z)}$

Methods to reduce the Parasitic mode losses

Partially tapering + g.e.

Separator tank length	4000mm
Inner diameter of separator tank	380mm
Electrode height	180mm
Electrode gap	75mm
Electrode thickness	20mm
Transition taper length	52.5mm
Transition pipe diameter	75mm
Ground plate length	4000mm
Ground plate height	100mm
Ground plate thickness	10mm



Wake Integration type : Indirect Interfaces

Simulated wake length : 50000 mm

Wake shift x : 0 mm

Wake shift y : 0 mm

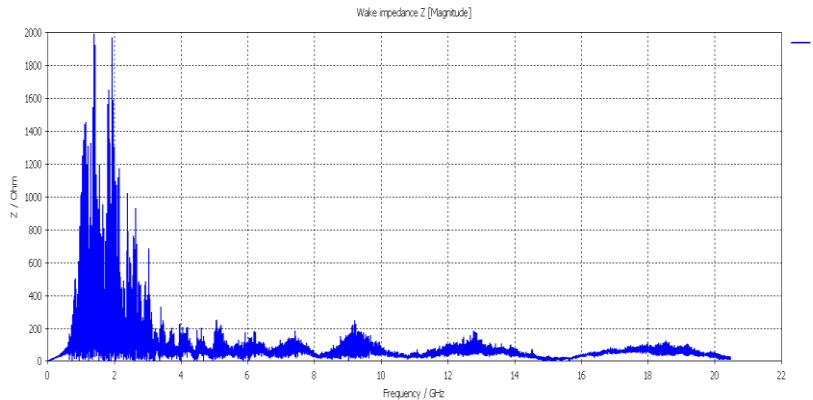
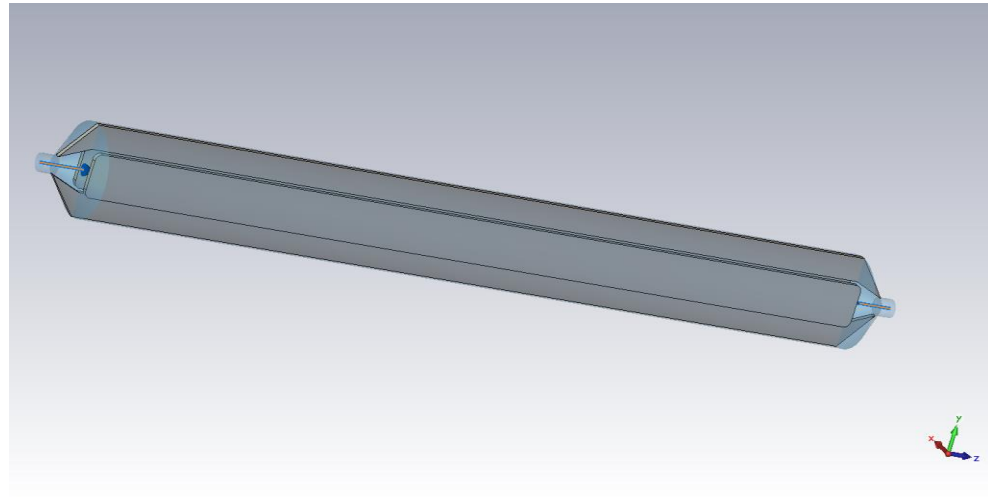
Wake-Loss-Factor : 1.393547e+000 V/pC

$P_{\text{loss}} : 589\text{w(Higgs)}/2.35\text{kw(W)}/8.22\text{kw(Z)}$

Methods to reduce the Parasitic mode losses

3D tapering + g.e.

Separator tank length	4000mm
Inner diameter of separator tank	380mm
Electrode height	180mm
Electrode gap	75mm
Electrode thickness	20mm
Transition taper length	150mm
Transition pipe diameter	75mm
Ground plate length	4300mm
Ground plate height	100mm
Ground plate thickness	10mm



Wake Integration type : Indirect Interfaces

Simulated wake length : 50000 mm

Wake shift x : 0 mm

Wake shift y : 0 mm

Wake-Loss-Factor : 1.170499e+000 V/pC

P_{loss} : 495w(Higgs)/1.98kw(W)/6.91kw(Z)

Methods to reduce the Parasitic mode losses

According to the simulation, there is a relatively strong narrowband impedance below 3GHz (caused by cavity structure).

- The structure of the cavity needs further optimization (increase the thickness of the ground electrode, and make it as close to the beam as possible)
- The absorber maybe necessary to absorb such high power in separator;
- Equipping the electrodes with a simple closed-loop Cooling system.

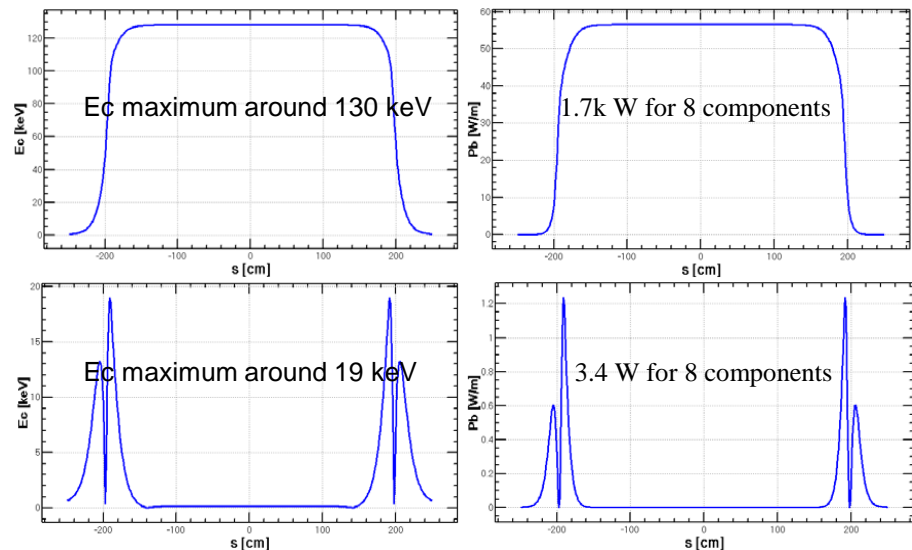
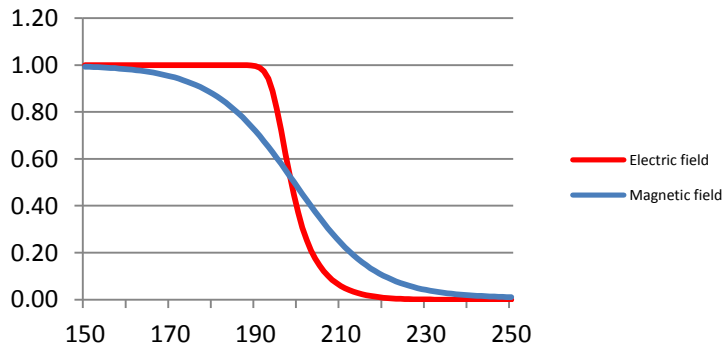
No. Description	K [V/pC]
(1) Partially tapering + g.e.	1.393547
(2) 3D tapering, no g.e.	1.256987
(3) 3D tapering + g.e.	1.170499

Methods to maintain E/B ratio 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

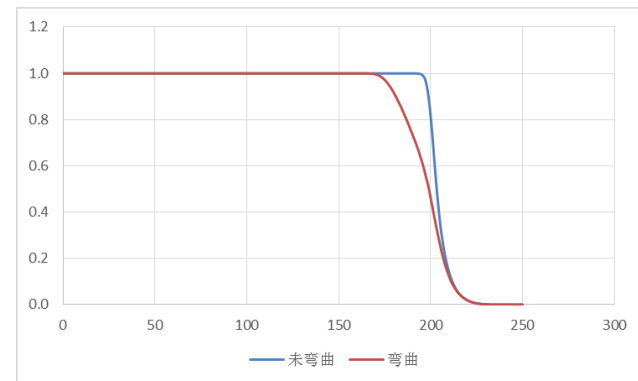
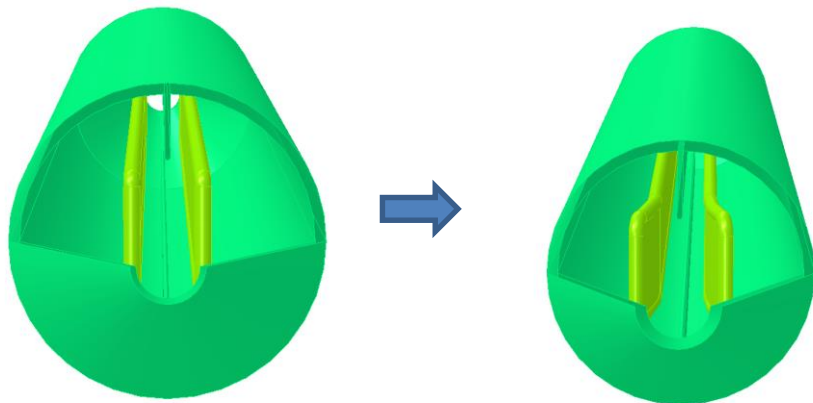
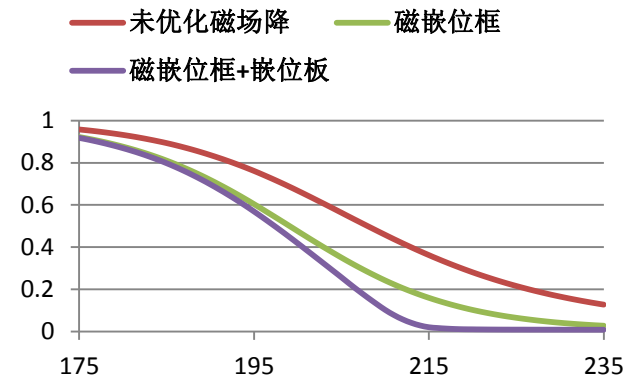
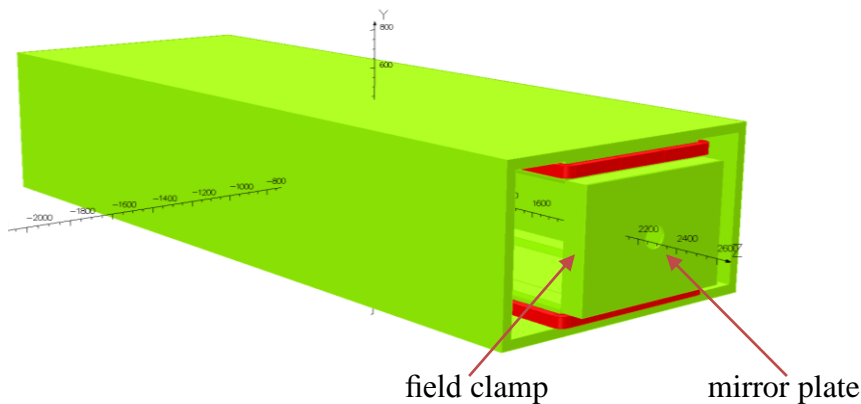
Radiation power

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

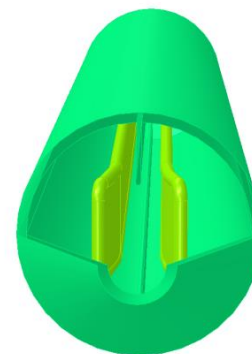
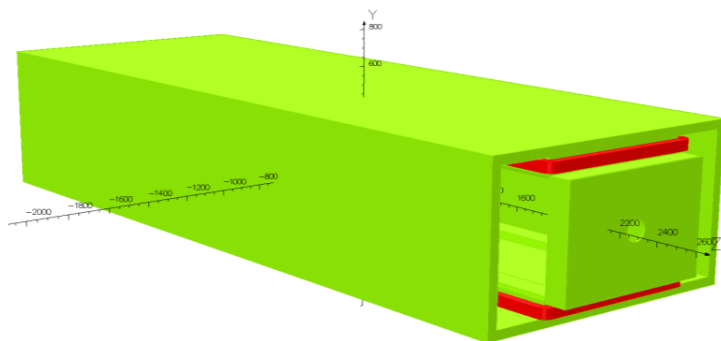
Methods to maintain E/B ratio in fringe field region

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

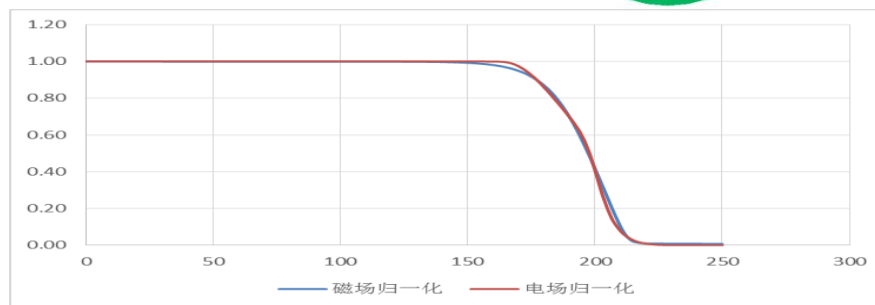
- Magnet: addition of field clamps, along with the mirror plates.
- Separator: flaring open the electrode ends progressively



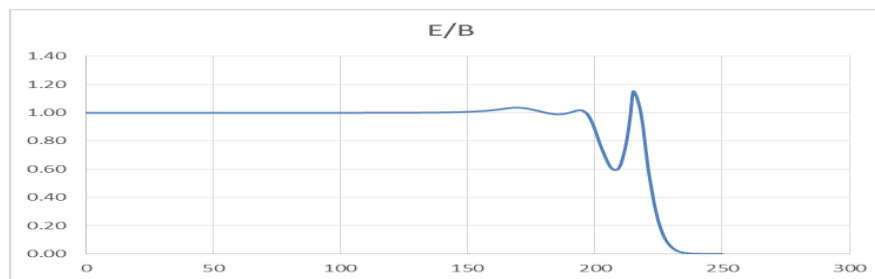
Methods to maintain E/B ratio in fringe field region



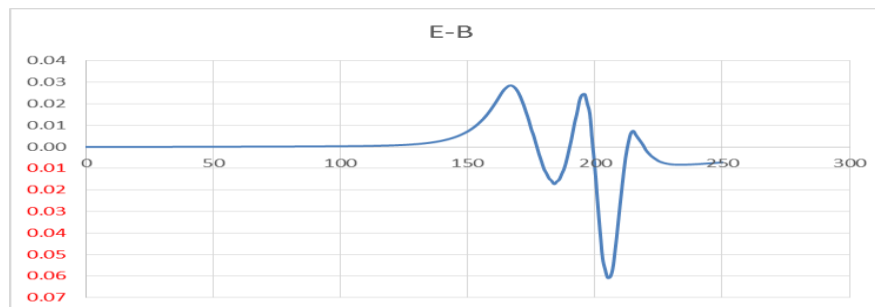
The electric and magnetic fields curve in fringe field region



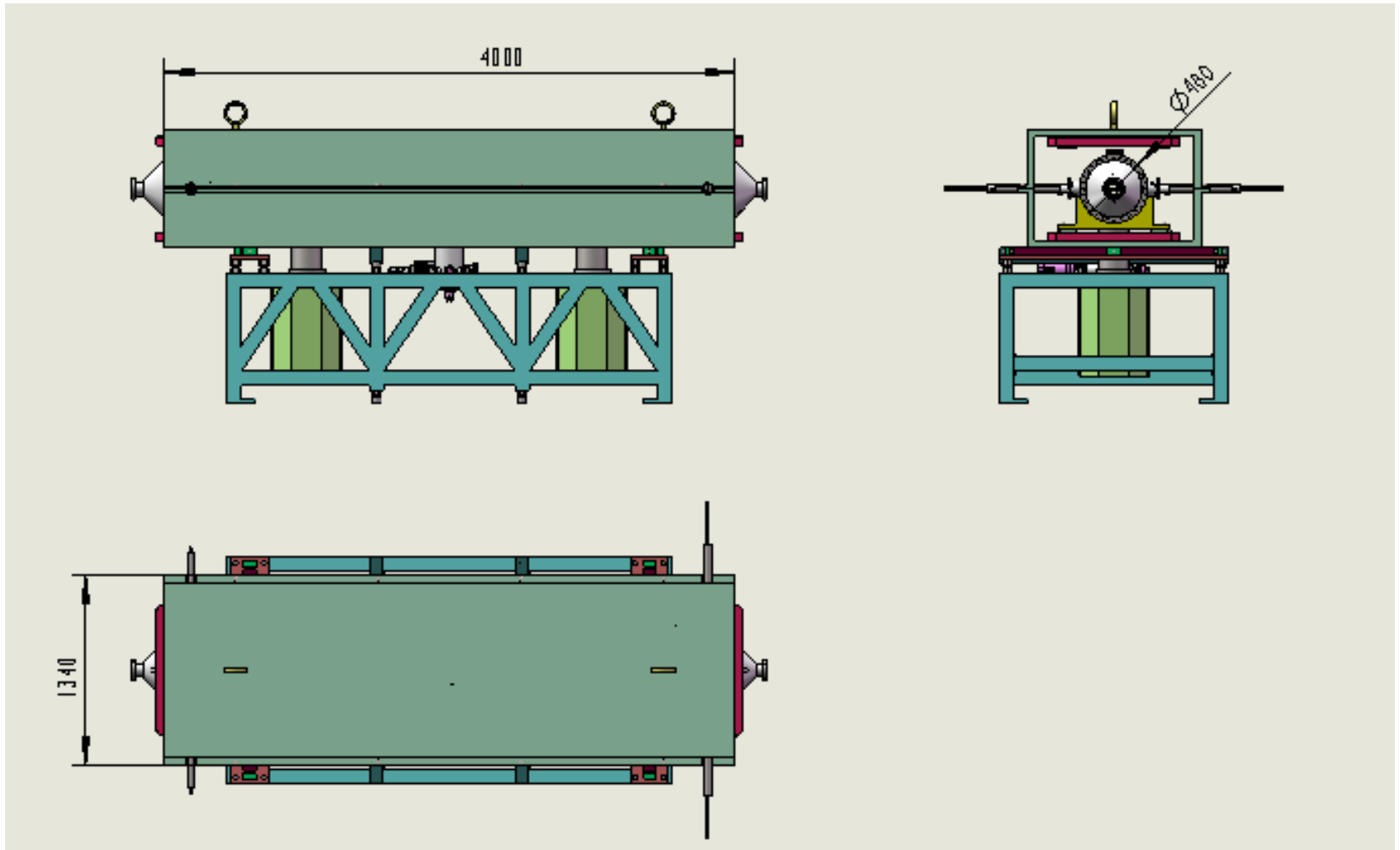
The normalized ratio of electric field to magnetic field



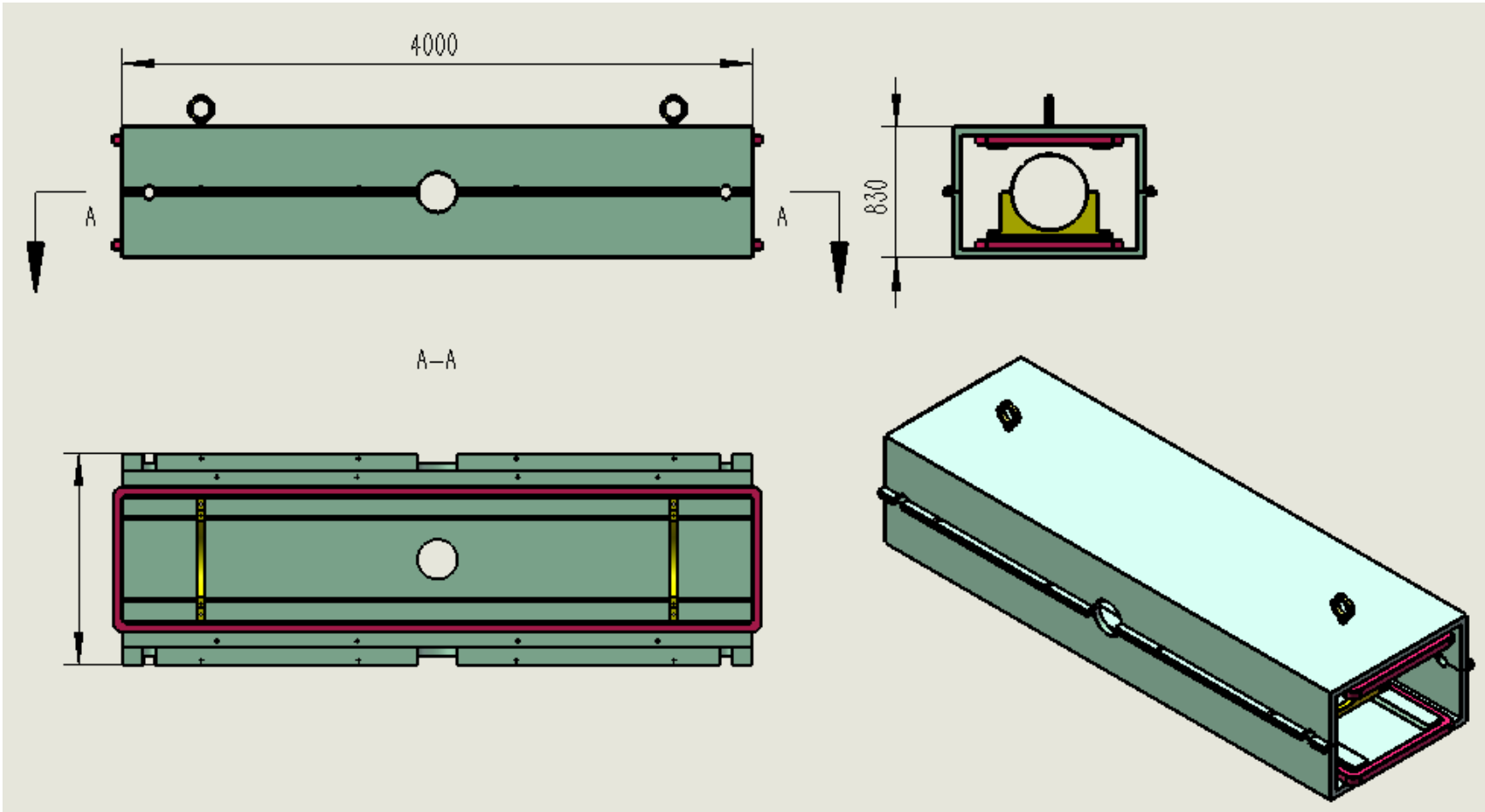
Normalized difference between electric field and magnetic field



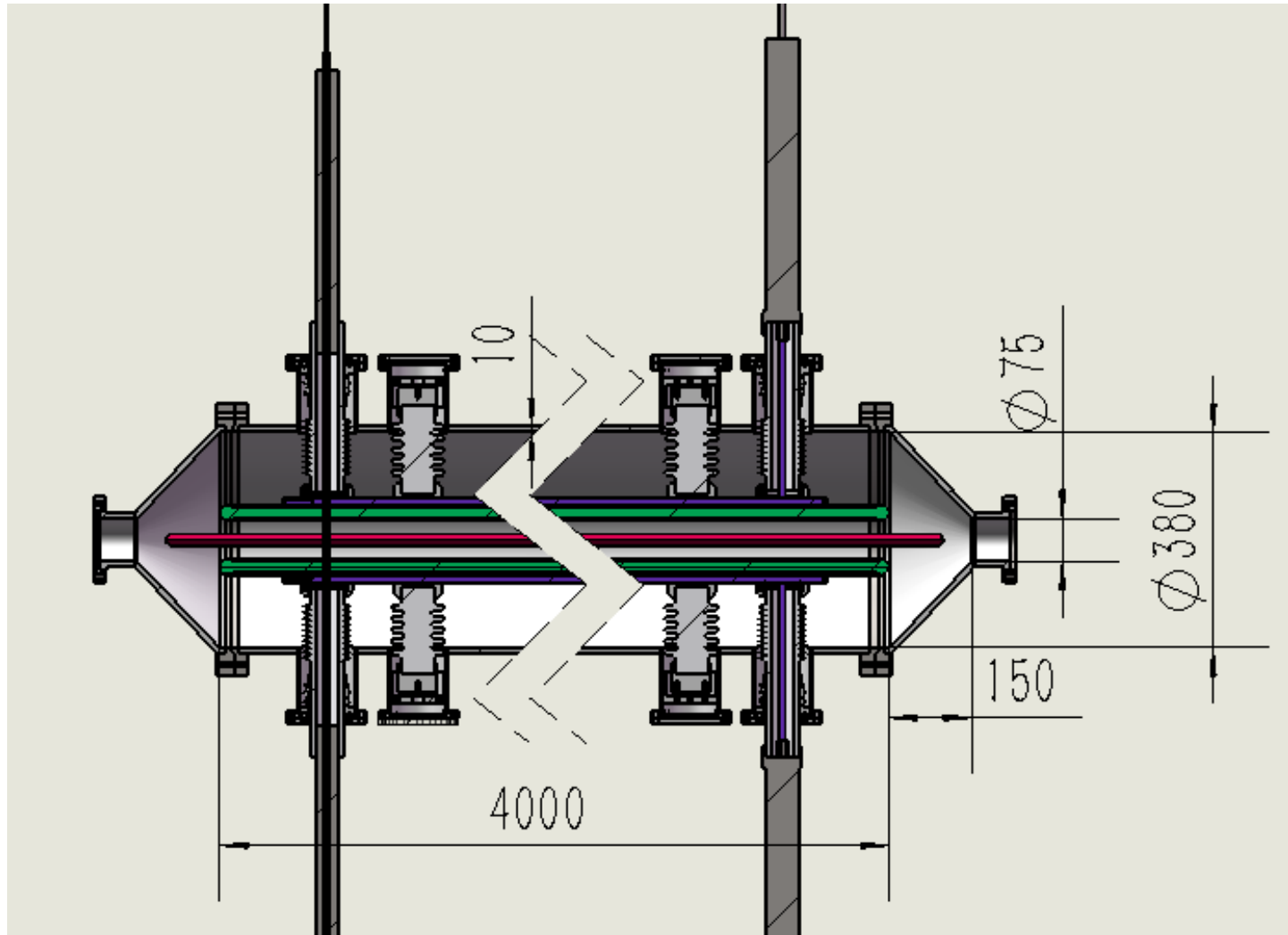
Mechanical design



Mechanical design - magnet

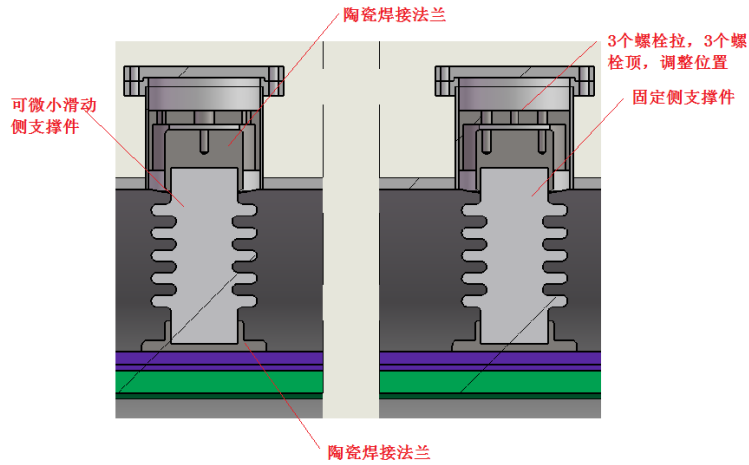


Mechanical design - electrostatic separator

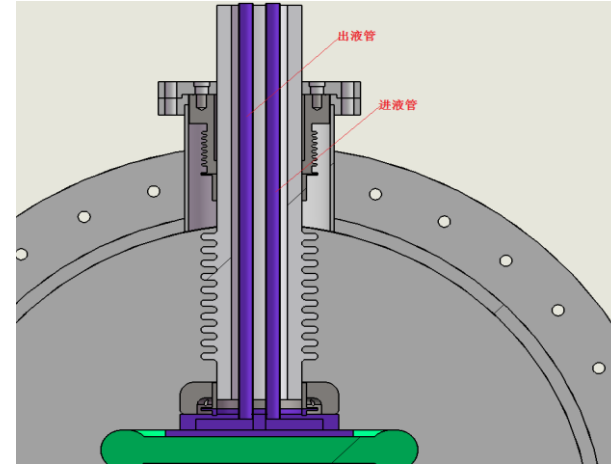


Mechanical design

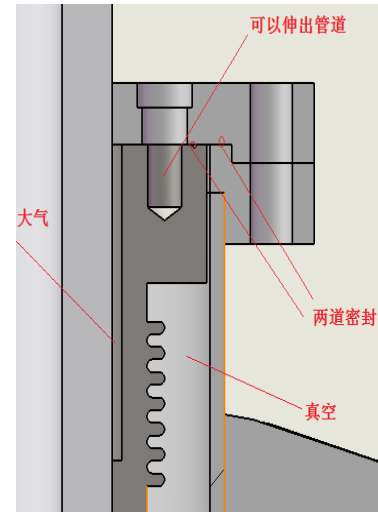
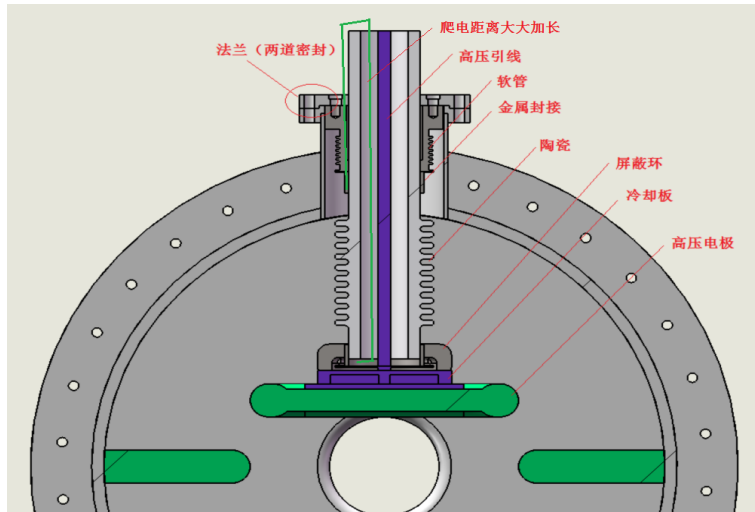
metal-ceramic supports



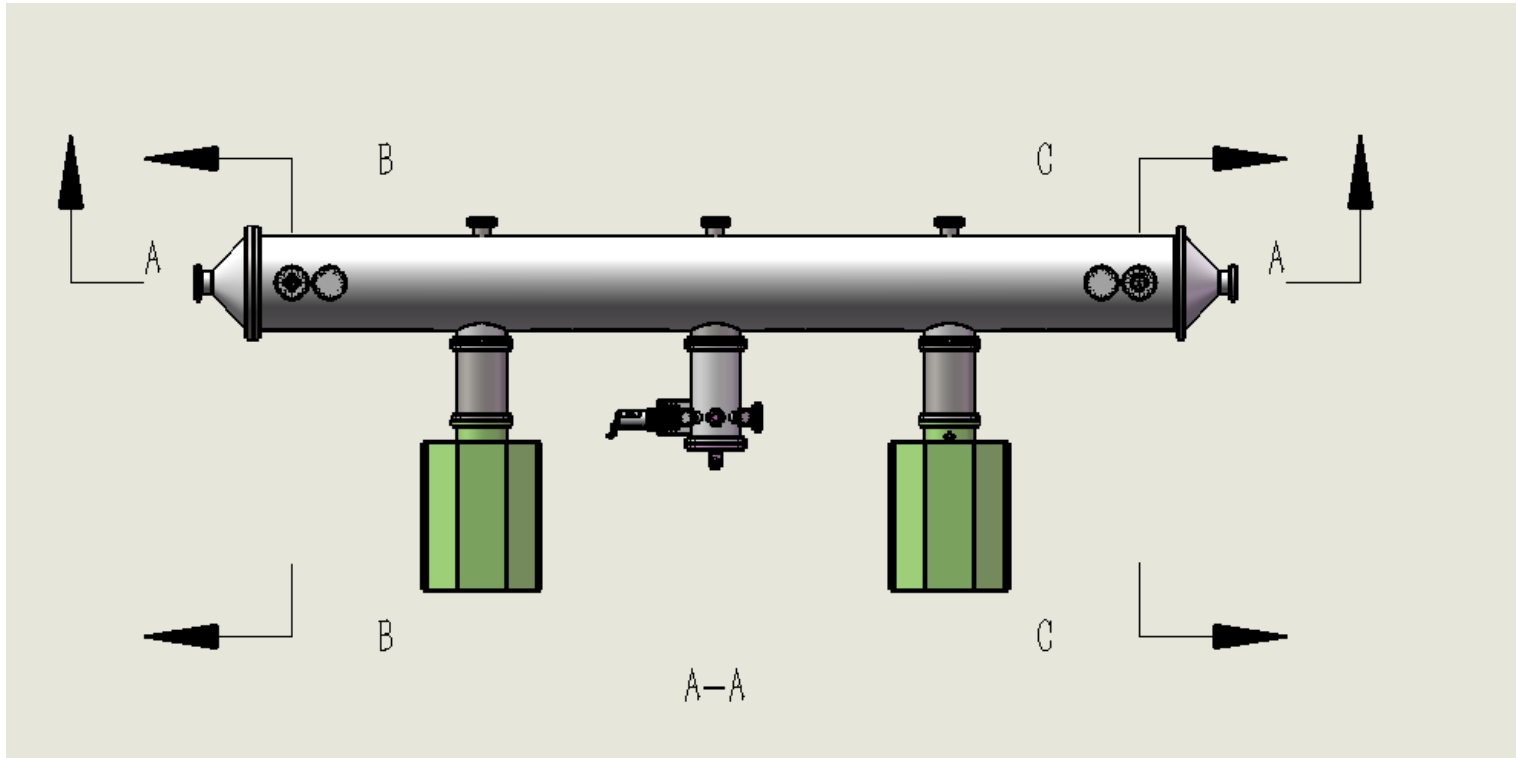
closed-loop cooling system



high voltage feedthrough



Vacuum design



To minimize the breakdown rate, the vacuum in all separators will be kept at the low pressure of about **2.7e-8 Pa**

Including: two sputter ion pump (pumping speed 1000l/s), and one sublimation pump (pumping speed 1300l/s).

Considering add the NEG pump, which maintains a high pumping rate at ultra-high vacuum, especially for hydrogen.

Design and progress for power supply

A large number of power supplies are required for powering the magnets of the Collider ring, the Booster ring, the Transport line, the Linac and the Damping ring.

Focusing on two issues for PS system

- **Prototype of booster Power Supply (600A/600V)**
- **Corrector (Multi-unit combination structure)**

Prototype of booster power supply

■ Requirements of the Power Supply for **Booster Ring**

Power Supply	Quantity	R&L of load	Output Rating
Dipole	16	0.830Ω / 0.089H	940A/820V
Quadrupole	32	6.008 Ω / 1.518H	320A/2100V
Sext.D	16	2.906 Ω / 0.025H	140A/650V
Sext.F	16	3.328 Ω / 0.106H	140A/650V
Corrector	350		25A /20V
Total	430		

Prototype of booster power supply

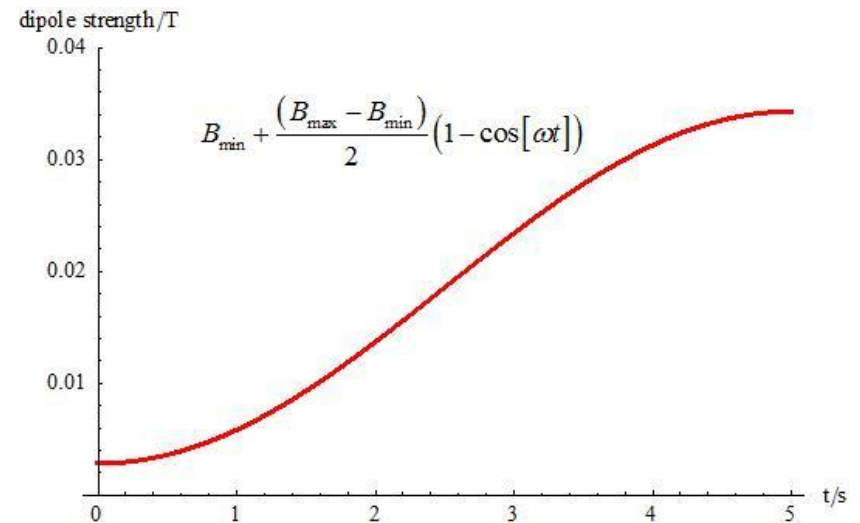
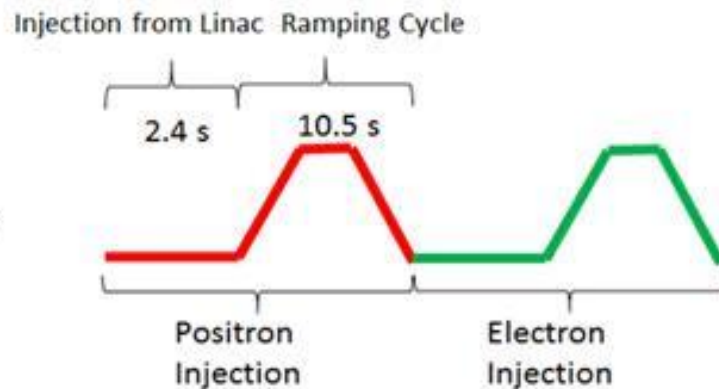
■ Design principles of the booster power supplies:

Based on the current waveform requirement of the dipoles, quadrupoles and sextupoles (as shown below); the rating voltage considering the inductive value caused by the magnet inductance.

Duration of ramp-up and ramp-down are 5s .

Power supply performance: tracking error less than 100ppm .

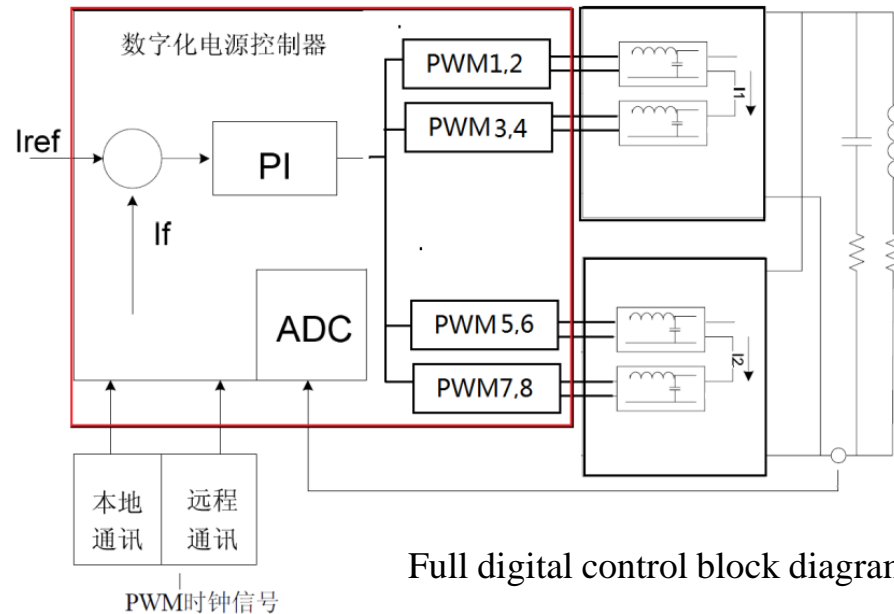
Higgs:



The magnetic field cycle waveform for CEPC booster

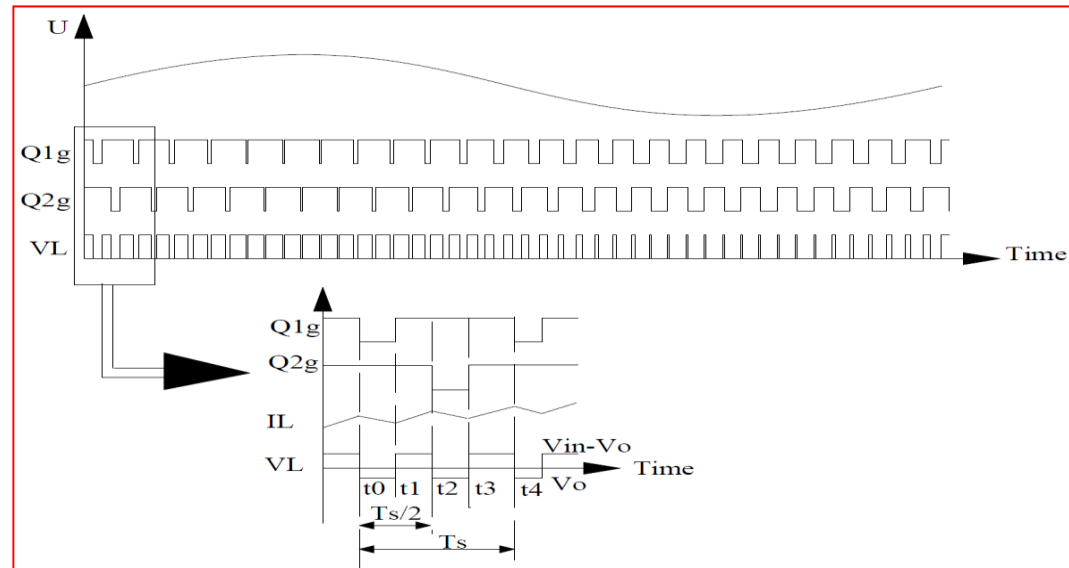
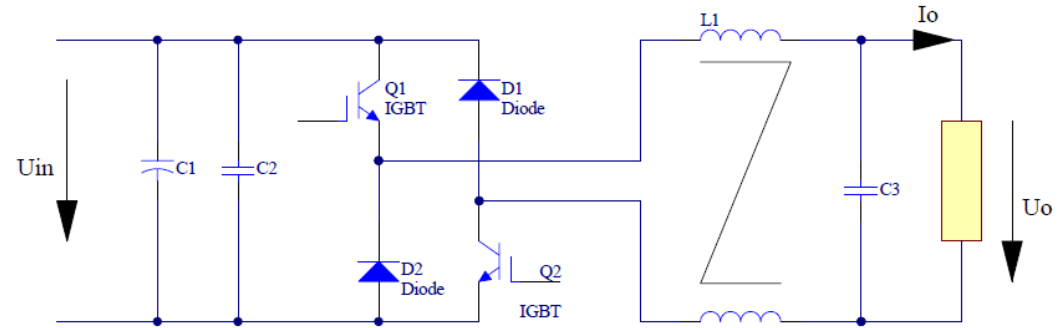
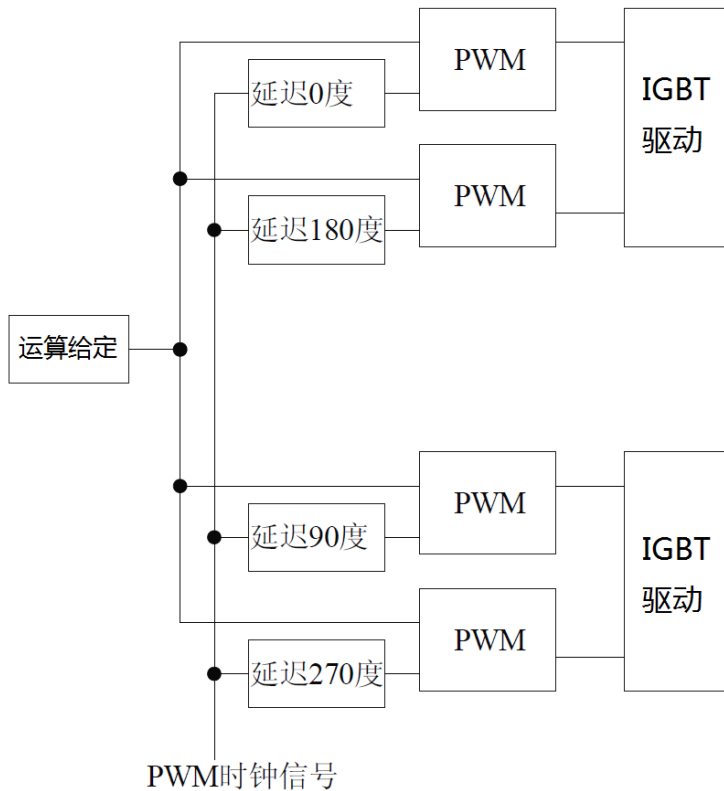
Prototype of booster Power Supply (600A/600V)

- power supply adopts modular structure in order to reduce the volume, improve the efficiency and reliability.
- Series-parallel connection technology of modular will be used in the main circuit structure.
- Switching mode as the main topology for modular, output capacity of single module is 300A / 300V. and The DPSCM-II will be embedded into the power supply.



Prototype of booster Power Supply (600A/600V)

- technology of pulse width multiple stagger phase will be used to decrease the output filter and reduce the output ripple.



Corrector Design - Topology

■ Switching-mode

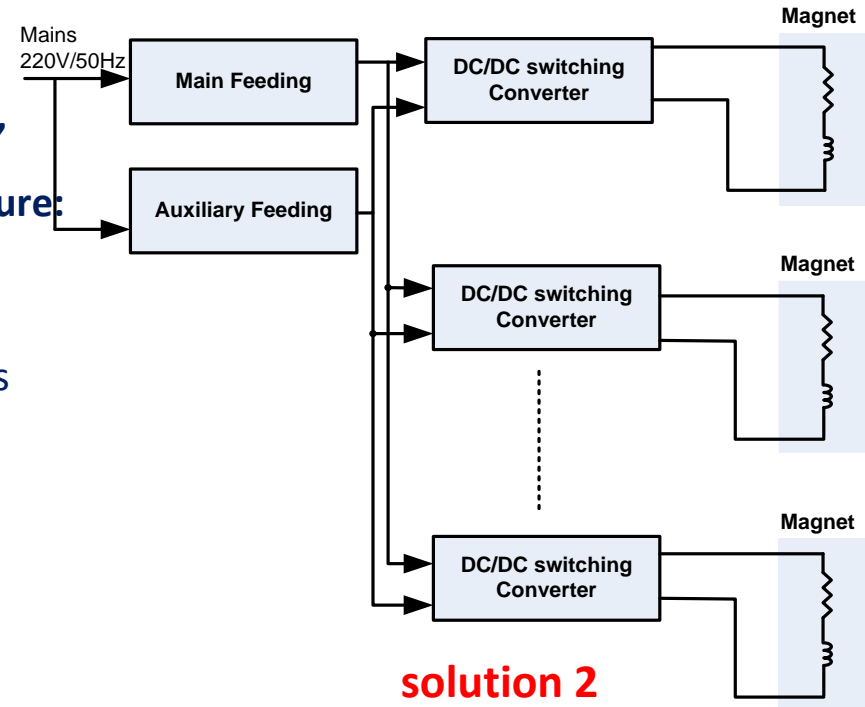
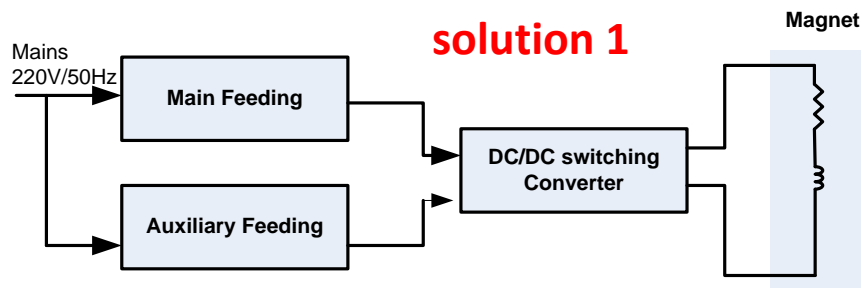
For large number of corrector PS:

Considering the power of these ps is very small,

less than 100W, how to choose the basic structure:

1) each one stand-alone

2) DC-link voltage shared by multi power supplies



Corrector Design - Topology

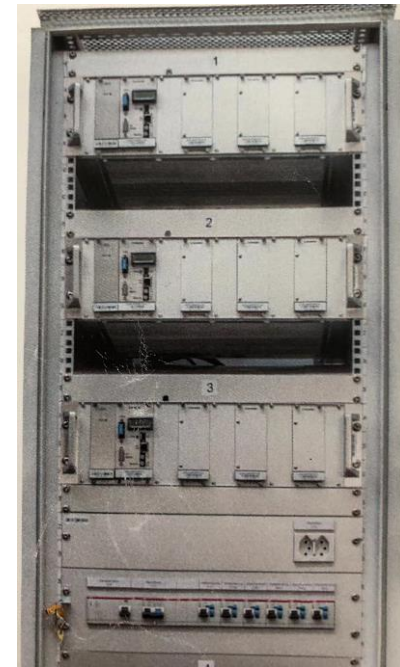
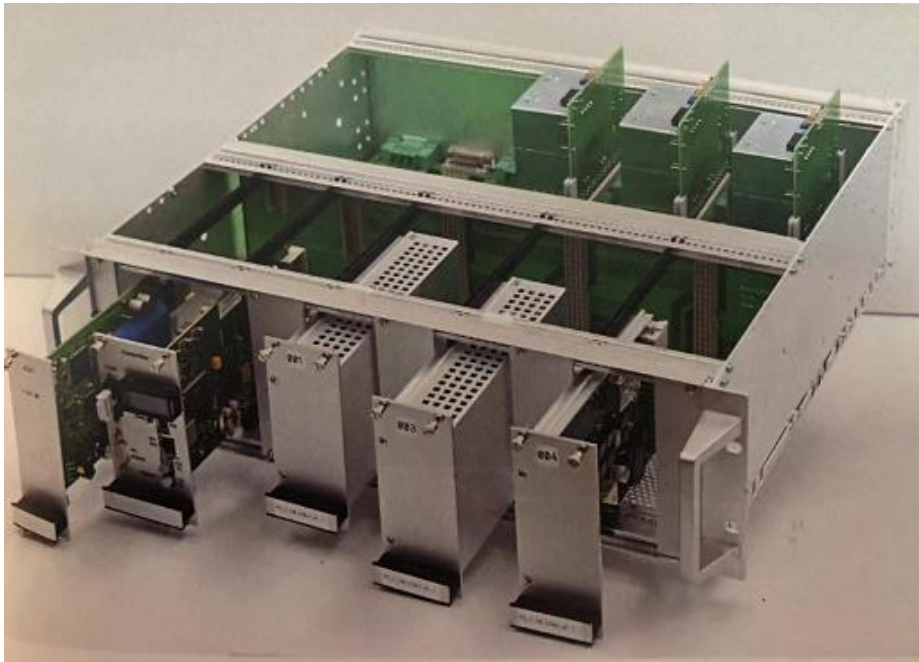
For large number of corrector PS:

- 1) each one stand-alone, but multi power supplies share one chassis;
- 2) power supplies in one chassis share one digital controller

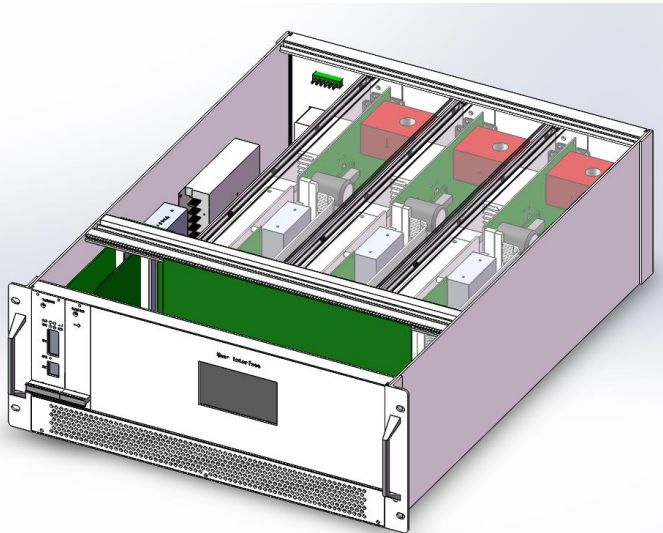
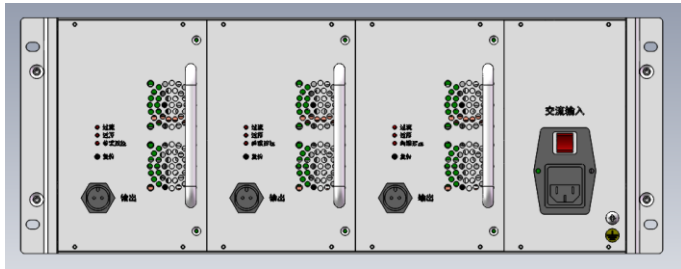
pros:

each power supply can be maintained independently;

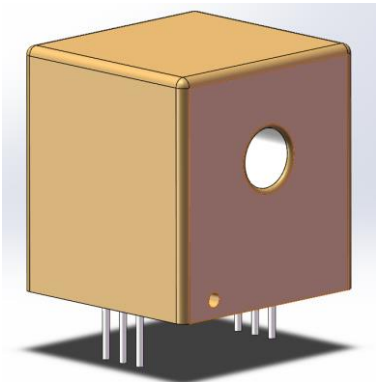
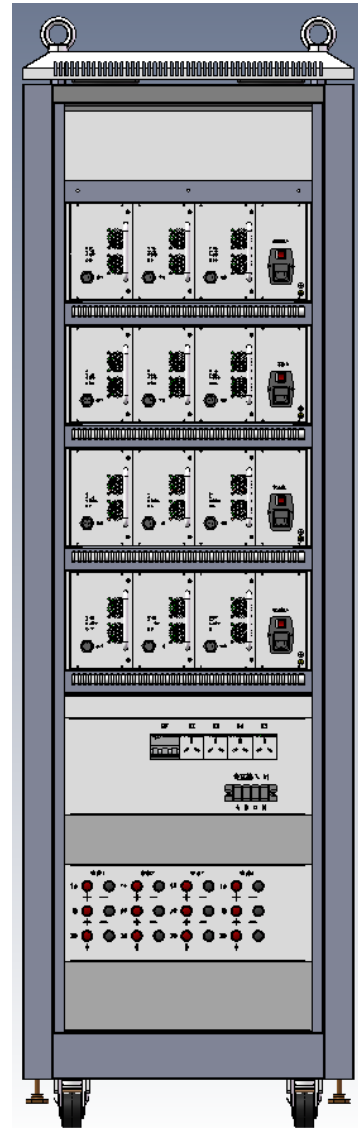
cost effective with respect of chassis and digital controller, and space savings.



Corrector (Multi-unit combination structure)



Structure of correctors



Embedded self-designed DPSCM, and DCCT

Corrector - operation interface

1# 电源

2# 电源

3# 电源

电源已开机

本控 无故障

设定电流: A

输出电流: A

输出电压: V

进入1#电源操控界面

1# 电源操控界面

故障

远控

直流电源

设定电流: A

输出电流: A

输出电压: V

开机

关机

返回主页

输出波形

故障查询

稳定度计算

帮助

1# 电源输出电流波形

返回主页

返回1#电源

2#电源波形

故障时间: - - , : :

1# 电源

DIN_1 正常

DIN_2 正常

DIN_3 正常

DIN_4 正常

DIN_5 正常

DIN_6 正常

DIN_7 正常

DIN_8 正常

DIN_9 正常

DIN_10 正常

返回

复位

故障历史

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 180 mm wide —mounted in an UHV tank of about 380 mm inner diameter.
- The magnet yoke is H-type, the center magnetic field is 66.7 Gauss. Within the patch of 6cm*11cm, the uniformity of the field integrals reaches $\pm 2E-04$.
- There are two methods implemented in the design of the separator to reduce the loss parameter: ground electrodes & tapered ends, but the loss factor is still high. The structure of separator need to be optimized and the absorber maybe necessary
- 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.
- Prototypes for Booster power supply and Correctors with Multi-unit combination structure are under design. The DPSCM-II will be embedded into the prototype.

Thank You!