Physical design of electrostatic deflector in CSNS muon source

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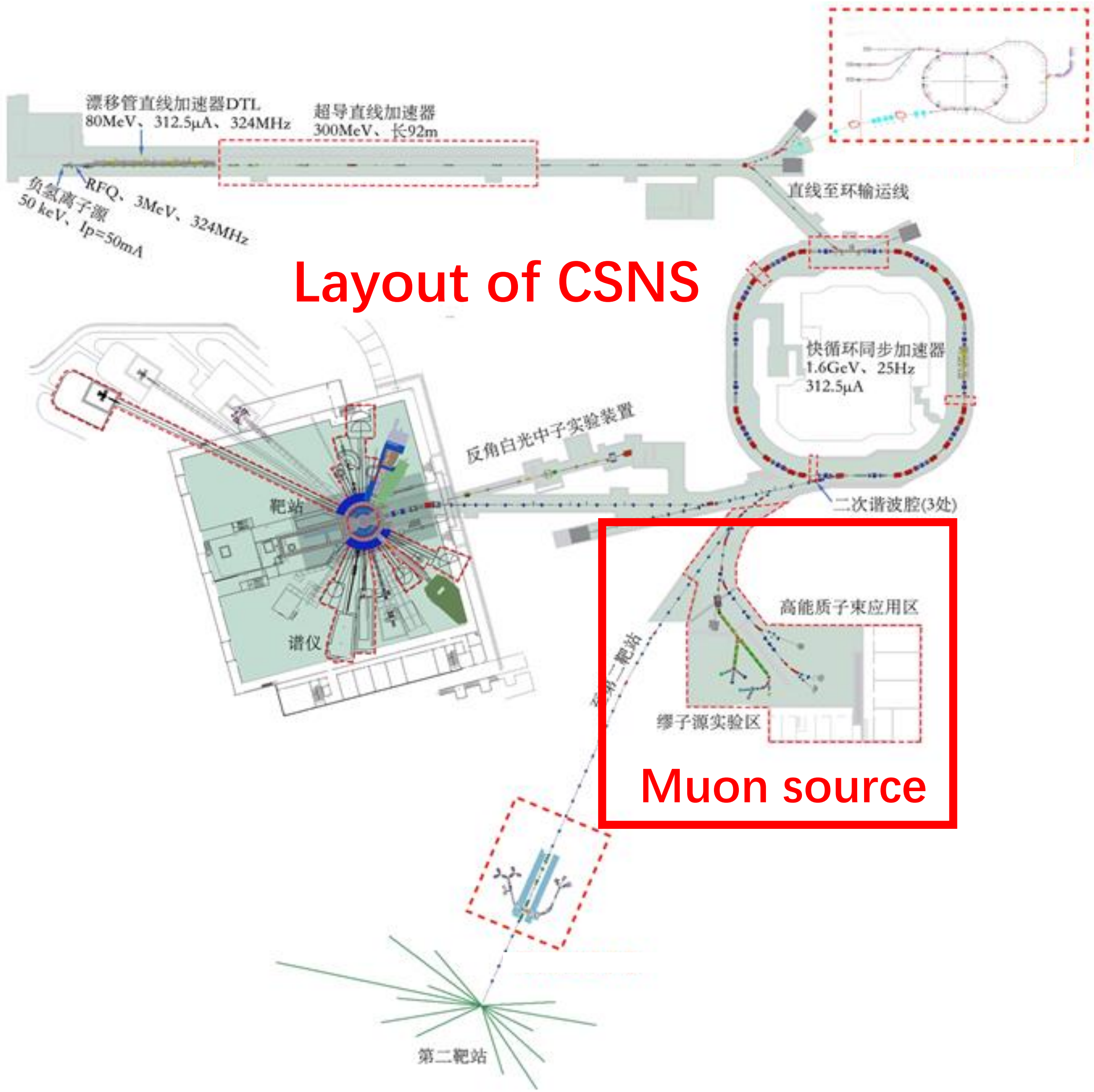
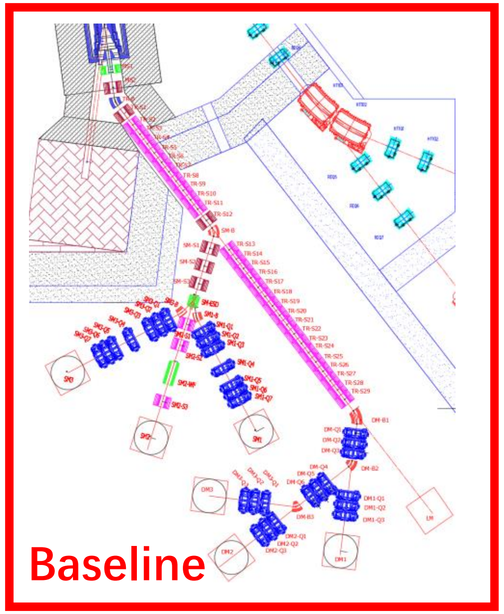
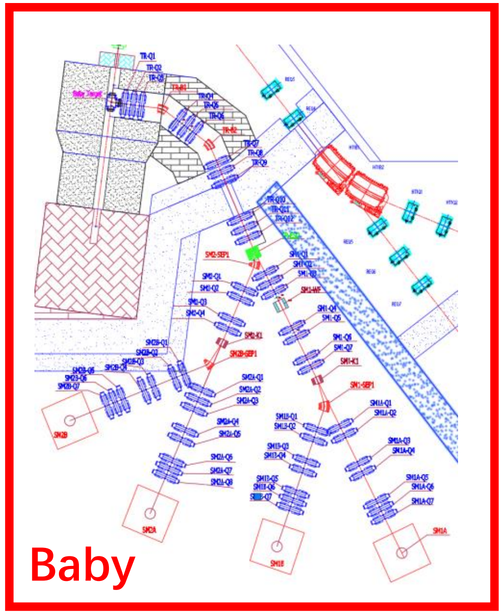
Abstract



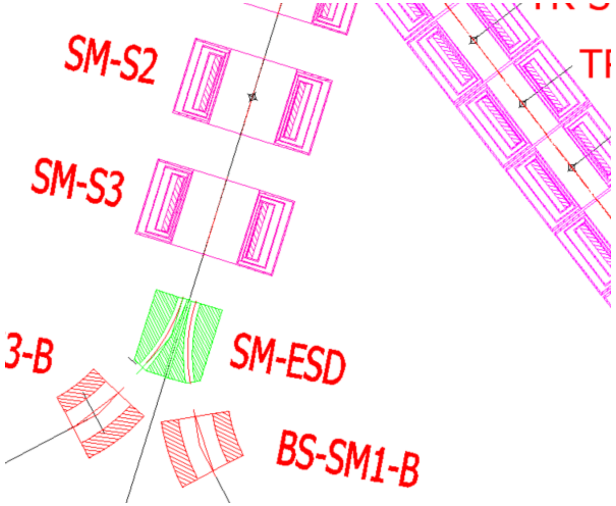




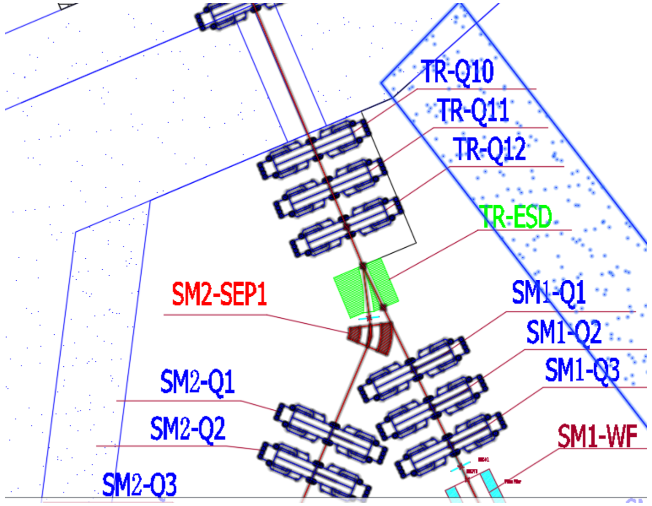
CSNS will build a muon source at the end of the RTBT. In the current design, the muon source propose two schemes, namely the baseline scheme and the baby scheme. High voltage electrostatic deflectors (ESD) are used to deflect the beam in the two schemes. A three-channel ESD with 400 kV HV is employed in the baseline scheme and a 210 kV dual-channel ESD in the simplified scheme.

According to physical requirements, the electric field concentration factor is introduced, and the electrode of ESD is theoretically designed. 2D and 3D simulations are carried out to analyze the characteristics of electric field distribution by OPERA. The geometry of the electrodes also met the requirements of electric field uniformity, high voltage resistance and mechanical strength at the same time. In the baseline scheme and the baby scheme, the ESD electric field concentration factors are 1.36 and 1.53, and the maximum electric field is 6.78MV/m and 4.6MV/m, respectively. The design meets the requirements and is reasonably feasible.

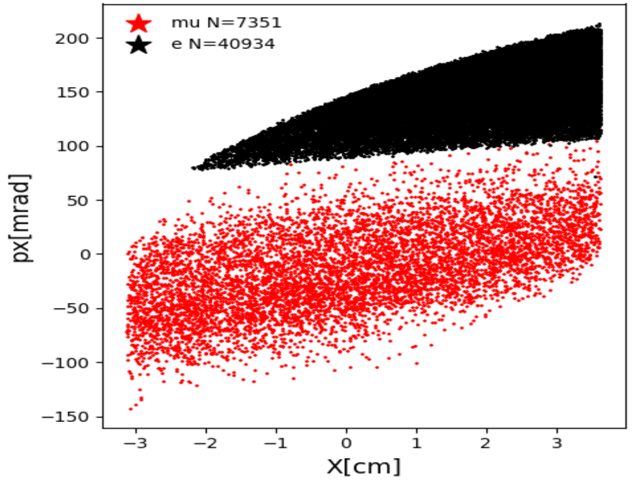
Physical considerations



Three-channel ESD for baseline scheme



Combination of dual-channel ESD and setpum magnet for baby scheme



phase spaces of muons and the positrons are separated by ESD in baby scheme

scheme	baseline	baby
quantity	1	1
deflection angle (deg)	25	15.6
field area gap(mm)	80	50
field-free gap/entrance(mm)	24	140
field-free gap/exit(mm)	322	
electric field strength(MV/m)	5	3
voltage(kV)	400	210
effective length(m)	0.7	0.66
electrode width(mm)	300	200
power source	1	1

A spatial splitting method based on arc-shaped ESD is phase spaces of muons and the positrons are separated adopted on EMuS, which not only removes positrons, but also allows simultaneous beam supply for multiple end-stations. After the ESD, a septum magnet is placed to further deflect beam to ensure sufficient space for layout.

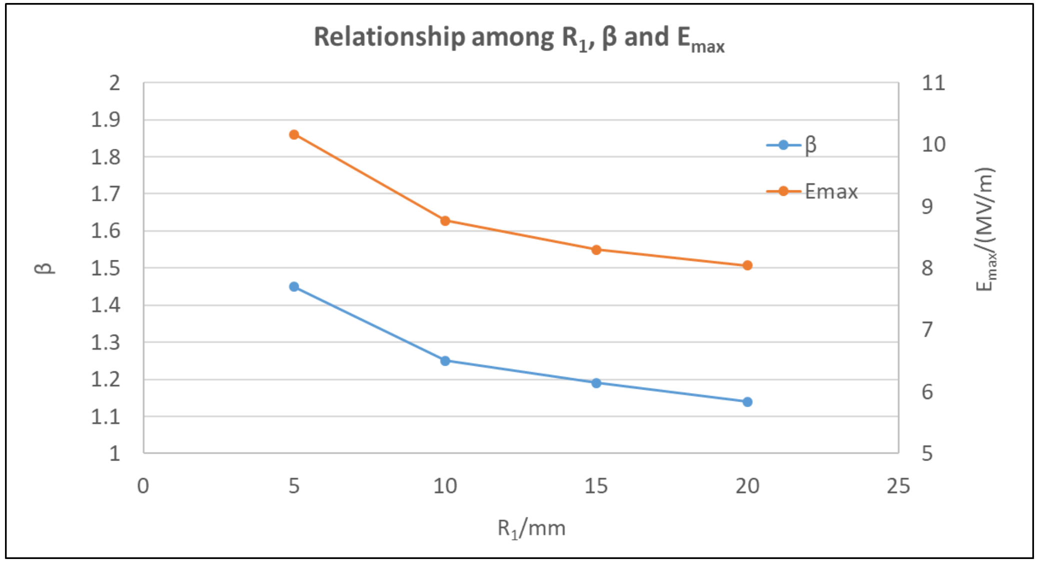
For the baby scheme, limited by the layout, we plan to use a dual-channel ESD, with one channel straight and field-free, and the other channel located in a field area produced by arc-shaped electrodes. For the baseline scheme, we plan to design a three-channel ESD, with symmetrical arc-shaped electrodes on both sides, and a narrow field-free straight-through channel in the middle.

We can estimate that the strength of electric field is around a few MV/m, and the specific value is given by g4beamline simulation. In the baby scheme, positrons are about 14 times more than muons. The effective length of the separator is set to 0.66 m. When the deflection angle reaches 15.6 degrees, phase spaces of muons and the positrons are separated well enough. As for the baseline scheme, superconducting solenoids collects positrons about 60 times of muons. With 0.7 m long separator, and 25 degrees deflection angle, phase spaces can be effectively separated. But now the voltage has reached 400 kV. Electrodes with such high voltage will bring huge challenge for operations.

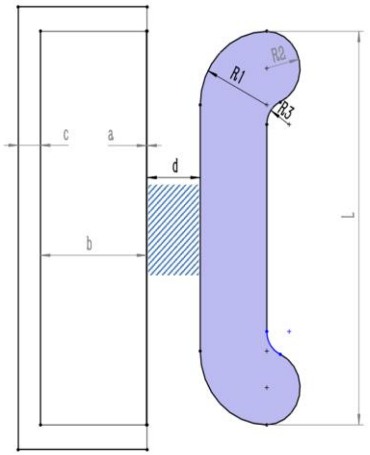
Electrode design

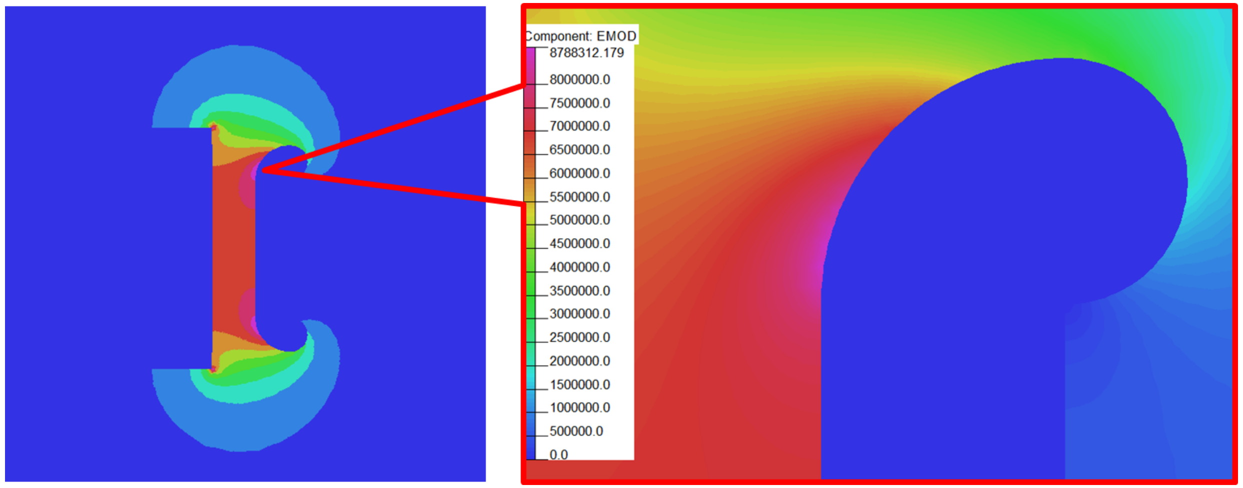
$$\beta = \frac{E_{max}}{E_0}$$

The electric field concentration factor β is introduced, which is defined as the ratio of the maximum field strength to the field strength in the central area. Empirically, it is required that $\beta < 2$, and the smaller β, the better the stability of the electric field between electrodes.

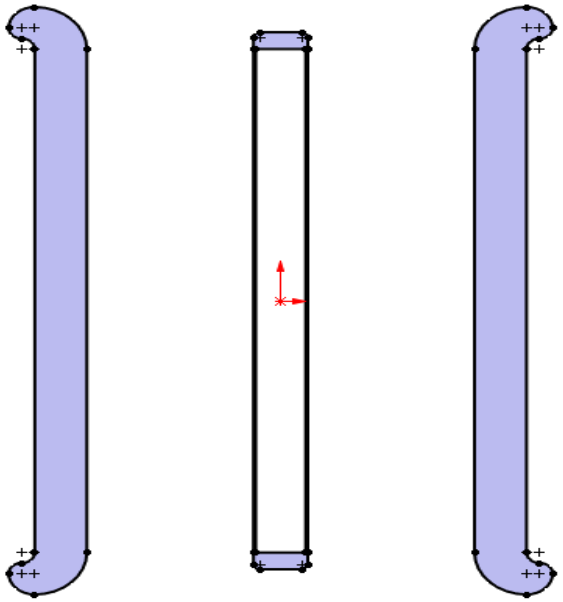


Source: NewRT-ESD, internal document





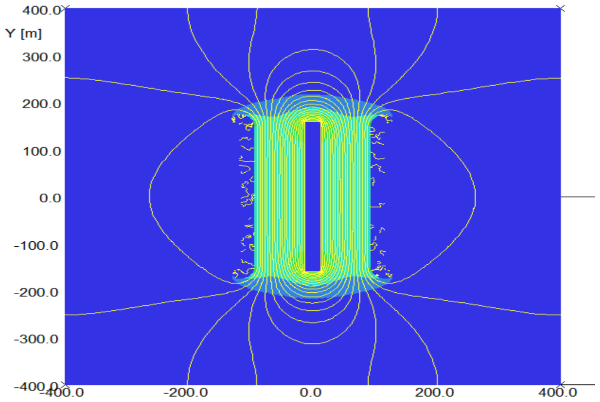
The maximum field intensity is concentrated at the end of the electrode. The larger the chamfer radius R_1, the smaller the maximum electric field intensity and the smaller the electric field concentration factor.

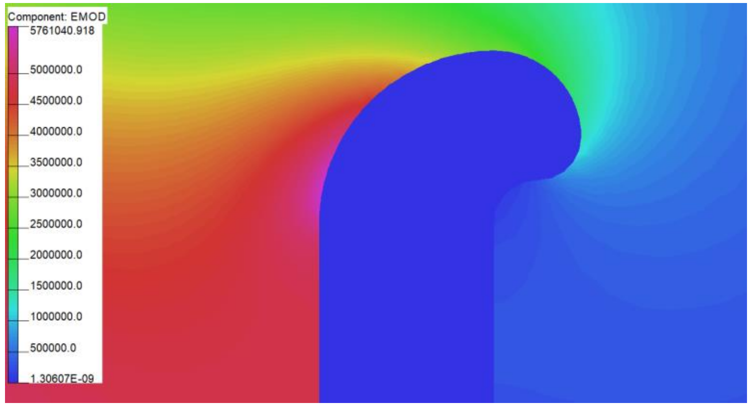


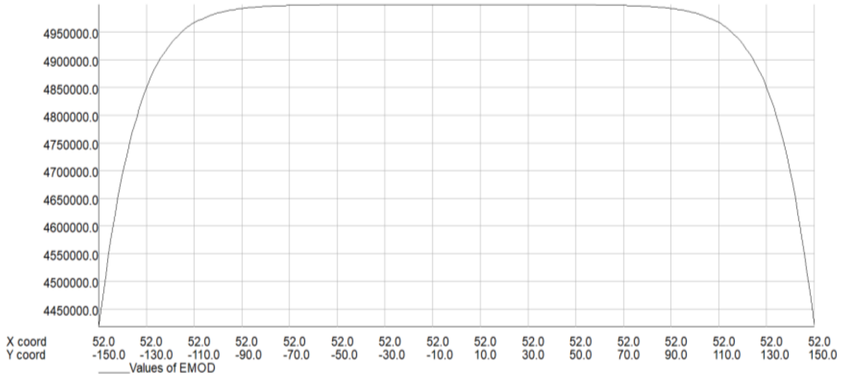
The cross section at the entrance of three-channel ESD for baseline scheme

R_1:25mm	L:300mv
R_2:12.5mm	d:80mm
R_3:6.25mm	a:0.1mm
R_4:6.25mm	b:24mm

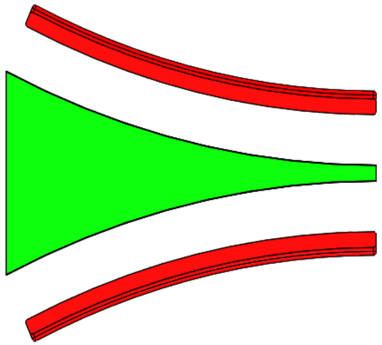
Electric field simulation-baseline scheme

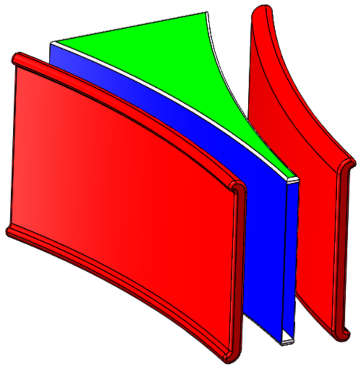


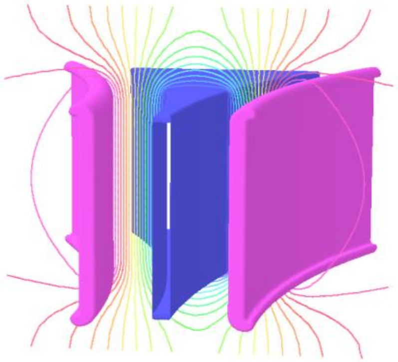


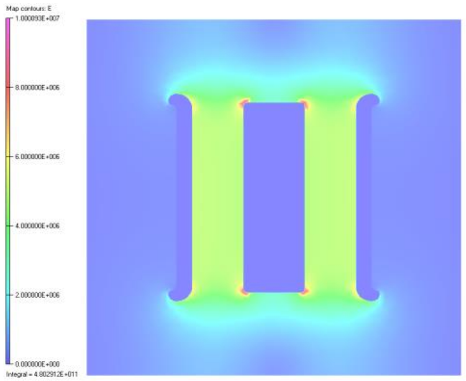


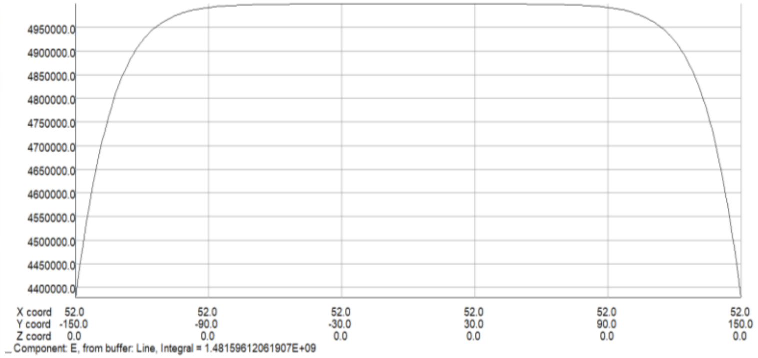
2D simulation: E_0=5MV/m, E_{max}=5.76MV/m, β = 1.15





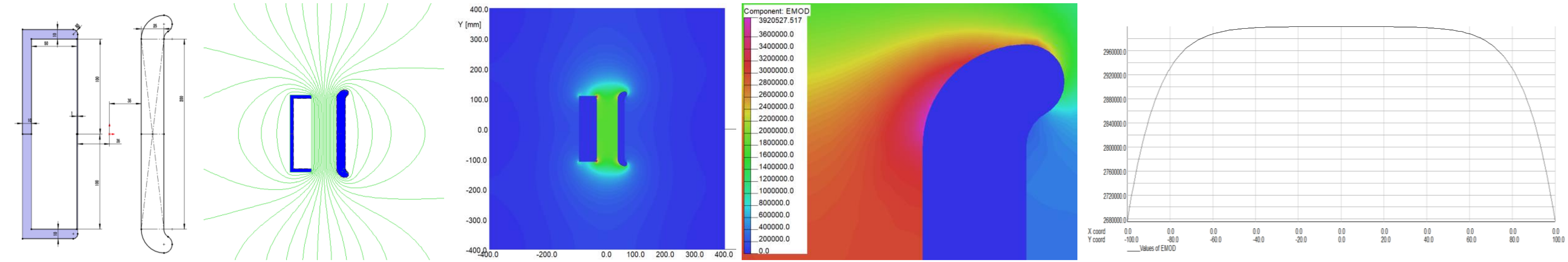




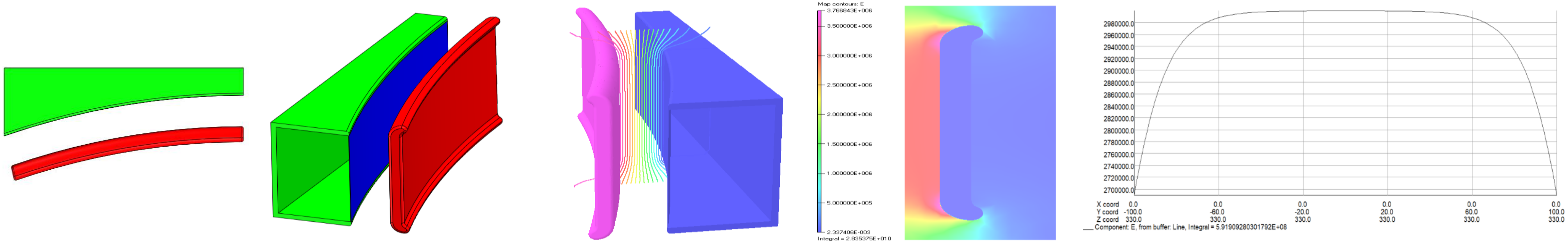


3D simulation: E_0=5MV/m, E_{max}=6.58MV/m, β = 1.32

Electric field simulation-baby scheme



2D simulation: E_0=3MV/m, E_{max}=3.92MV/m, β = 1.31



3D simulation: E_0=3MV/m, E_{max}=3.77MV/m, β = 1.26

Summary

- The baseline scheme and the baby scheme are introduced and the physical requirements are summarized.
- The design of electrode is introduced.
- 2D and 3D simulations are carried out, and ESD with electric field concentration factor < 2 are designed.
- The voltage of ESD for the baseline scheme is up to 400 kV, which will bring challenges to the design and operation.
- The preliminary physical design has been completed. The difficulty lies in the mechanical design (high vacuum and high voltage), and further refinement and advancement are needed.