Simulation studies of the beam monitor for the CSR external-target experiment

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Introduction

- A gaseous beam monitor is being developed for the cool storage ring (CSR) external-target experiment (CEE) at the Heavy Ion Research Facility in Lanzhou (HIRFL).
- Its purpose is to track the beam particles and aid in reconstructing the primary collision vertex.
- The main requirements of CEE on the beam monitor are:
  - spatial resolution of less than 50 μm;
  - time resolution of less than 1 μs.

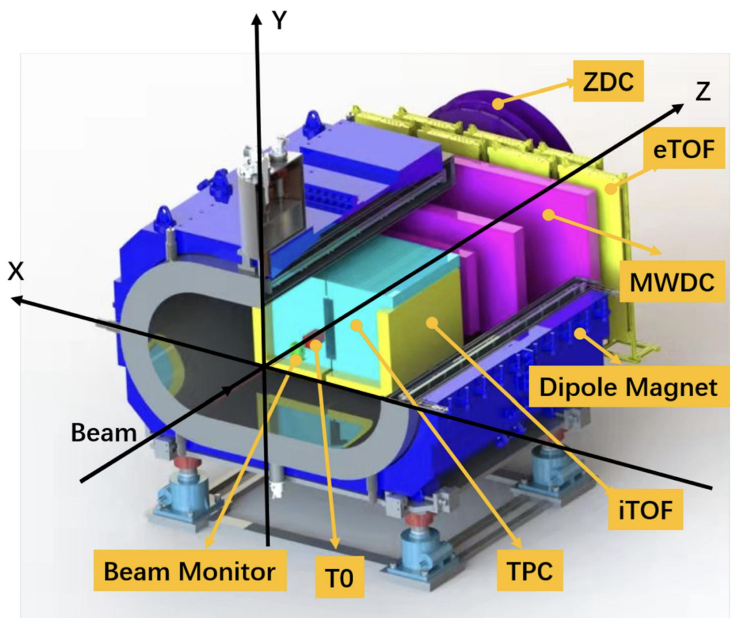

Fig.1 Schematic layout of the CEE spectrometer

Simulation of drift electric field

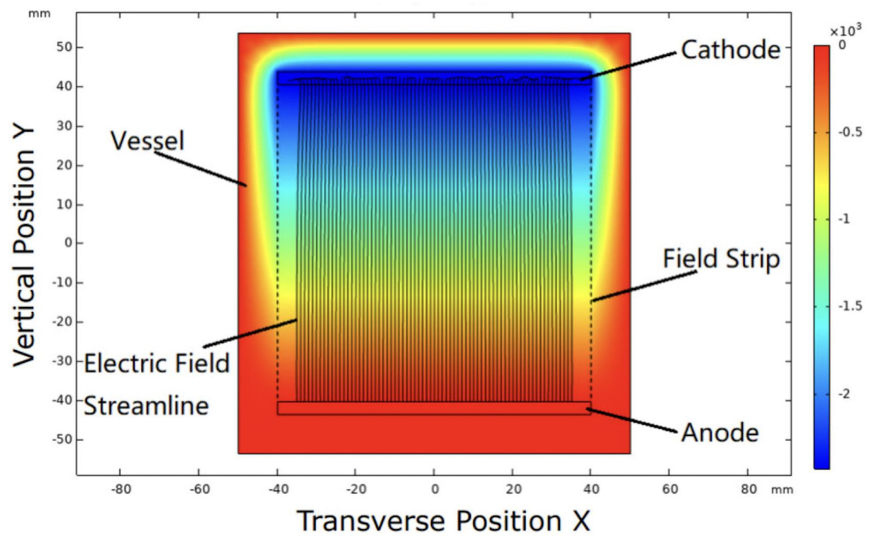

Fig. 4 2D COMSOL Model of one field cage for electric field calculation.

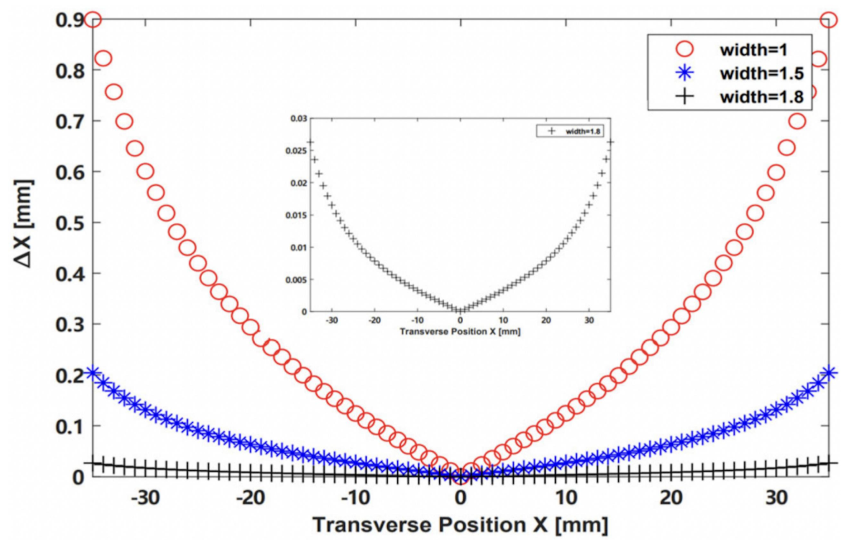

Fig. 5 Maximum deviation between the starting and ending positions of the electric field lines .

The maximum deviation is less than 10 μm in the sensitive volume from -15 to 15 mm in the X-axis with a field cage strip width of 1.8 mm and a pitch of 2 mm.

Effect of space charge

- Space charge produced by the beam particles can be modeled to the volume charge at equilibrium. The volume charge density for 1MHz U ion is $7.41 \times 10^{-8} \times \frac{1}{\sigma x\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma x^2}} \times \frac{1}{2} \times (1+\mathrm{erf}(\frac{y}{\sigma y\sqrt{2}}))\ \mathrm{C/m^3}$.
- Space charge is added to 3D COMSOL field cage model. The deviation between the starting and ending positions of the electric field lines is used to quantify space charge effect.

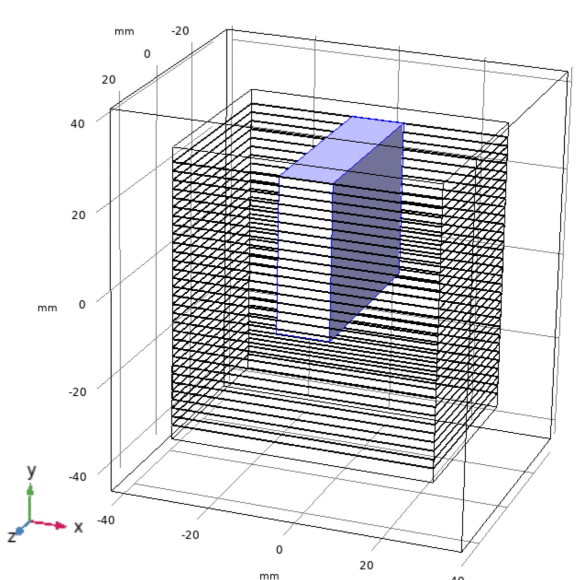

Fig.7 COMSOL field cage model with space charge (blue box)

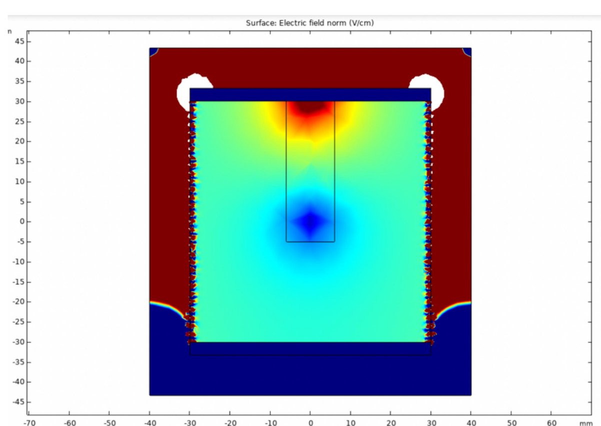

Fig.8 Distribution of electric field in COMSOL model

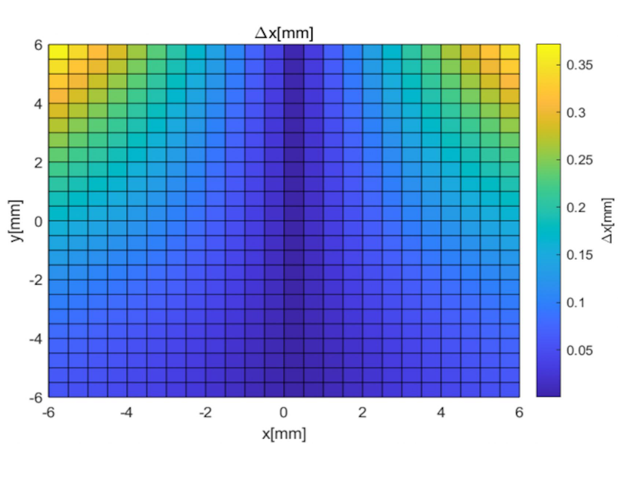

Fig.9 Deviation between the starting and ending position of electric field lines in Z =0 mm plane.

Conclusion

- The beam monitor of the CEE experiment tracks beam particles at rates up to 1MHz on an event-by- event basis to monitor the beam profile and reconstruct the main collision vertices.
- The preliminary simulation studies of the drift electric field, gas properties, space charge effect and the predicted spatial resolution have been performed, which shows the beam detector can achieve the desired position resolution (< 50 um).

Detector design

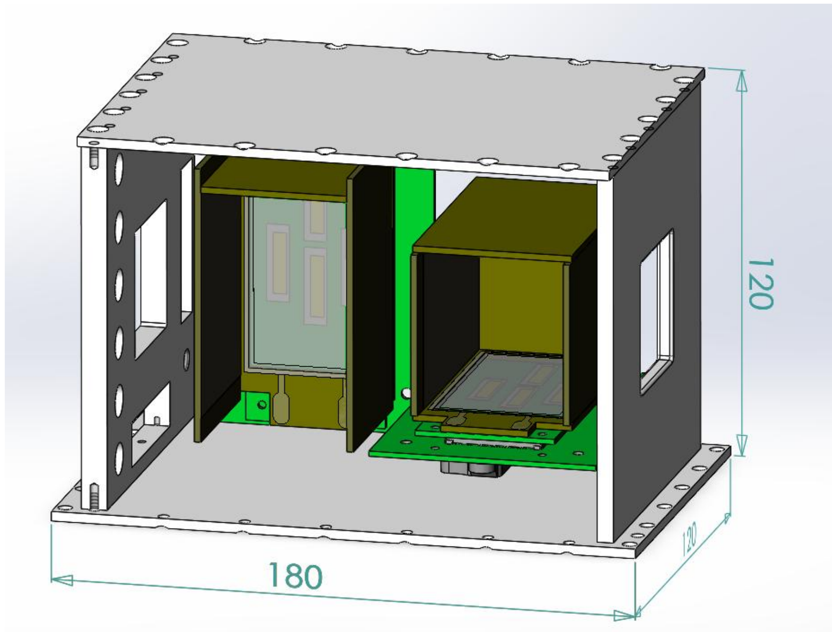

Fig.2 Basic structure of the beam monitor. The size of the beam monitor is 120 (X) × 120 (Y) × 180 (Z) mm^3. Two cubic field cages are inside the gastight vessel. GEM is used for beam particles with less ionization.

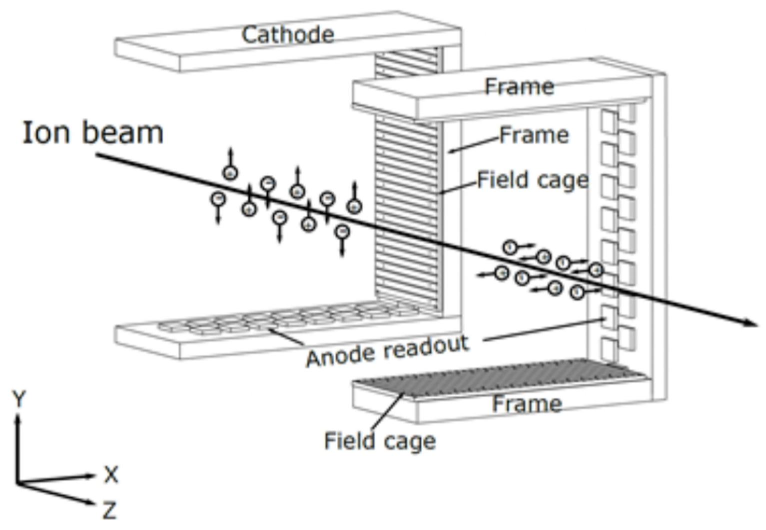

Fig.3 Working principle of the beam monitor.

Simulation of spatial resolution

Tab .1 Gas selection for the target beam particles in the CEE and the properties of the gases in the electric field 300 V/cm.

Beam particles	Gas	Drift velocity of ions [cm/ms]	Drift velocity of electrons [cm/μm]	Transverse diffusion coefficient [μm/sqrt (cm)]	Mean ionization energy W [eV]	Energy loss [MeV/cm]	Electrons produced [e^-/cm]
500MeV/u ^{238}U	$He-CO_2$(90:10)	1.74	1.04	189	36.7	6.91	1.88×10^5
600MeV/u ^{129}Xe	$He-CO_2$(80:20)	1.18	0.76	161	35.2	3.47	9.86×10^4
600MeV/u ^{12}C	Ar$-CO_2$(80:20)	0.47	1.04	166	27.9	0.11	3.94×10^3

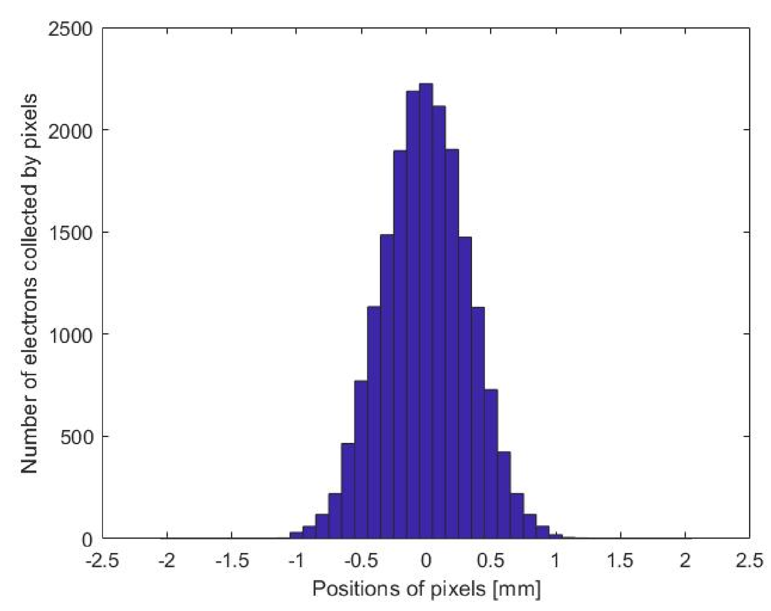

Fig.6 The number of electrons collected by pixel array for U at 500MeV/u.

Tab .2 Expected spatial resolutions of U

Pixel Noise (e-)	spatial resolution (um)
0	2.9
100	8.8
200	16.5
300	25.3
400	34.5
500	43.9
600	51.9

Calibration of space charge effect

- Build the mapping of real positions and measured positions of the particles based on 3D COMSOL model containing two field cages.
- Use Delaunay triangulation to interpolate linearly.

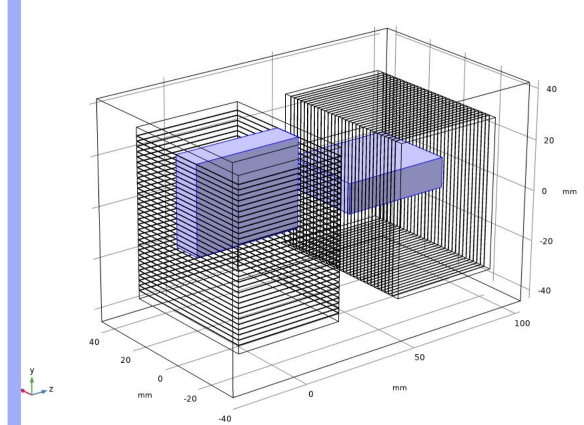

Fig.10 3D COMSOL model containing two field cages

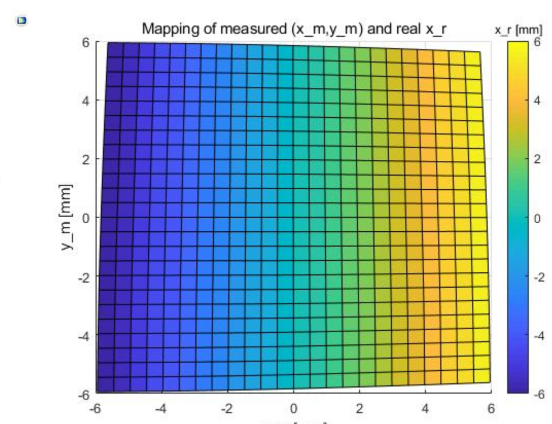

Fig.11 Mapping of real positions and measured positions of the particles

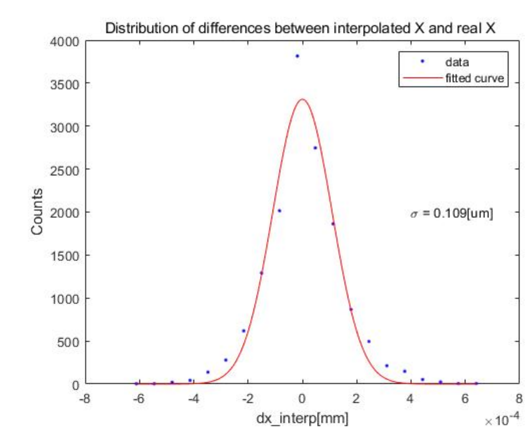

Fig.12 Distribution of differences between interpolated X and real X

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