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Optimization study of the drift field for TPC detector in CEPC

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Background

• The Time Projection Chamber is one of the options for the CEPC outer tracker (Circular Electron Positron Collider). In the baseline design, TPC should provides a resolution of 100μm in R-Φ direction and 500um in Z direction.

• Most CEPC TPC operating parameters have already been determined as shown in the list except for the drift field which requires further optimization to improve TPC's performance.

Table 1 The characteristics and requirements of TPC in CEPC

Half-length	2.35m	Outer radius	1.8m
Inner radius	0.3m	Magnetic field	3.0T
Momentum resolution(1/pT)	$10^{-4}GeV^{-1}$	Spatial resolution in R-Φ	<100μm
Spatial resolution in Z	<500μm	Spatial points	220 per track

Objective and Method

• Our objective is to optimize the drift field for CEPC

-The drift field directly determines the drift velocity and diffusion of electrons

-The drift velocity and diffusion affect the spatial resolution

-Thus, the drift field is optimized according to the requirement of CEPC TPC resolution

• Simulation, Analytic analysis & Experiment

-Simulate working gas (T2K) properties

-Find the optimum value based on analytic formula for spatial resolution in R-Φ and Z direction

-Develop a new TPC prototype to verify the result and do further study
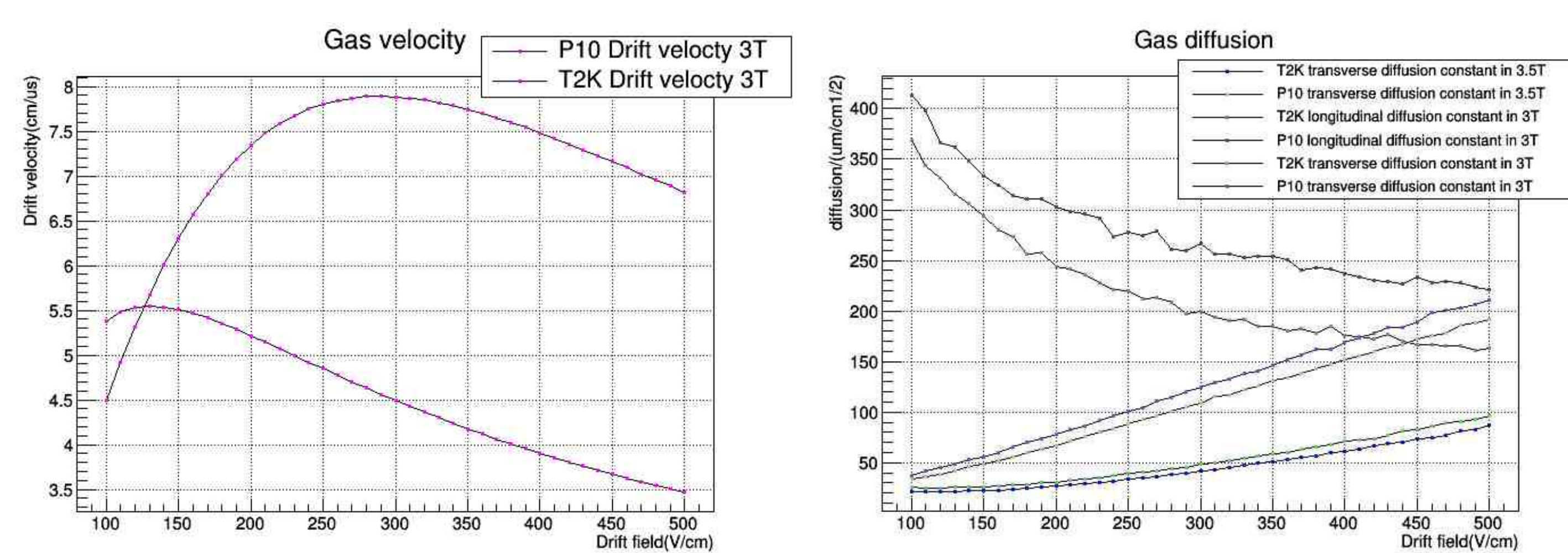
Discussion and Result

Fig. 1 The properties of T2K and P10 gas

The plateau region of the drift velocity is in the drift field range from 240V/cm to 400V/cm. It is suitable to set drift field in this range to limit drift velocity's deviation caused by inevitable drift field's shift.

$$\sigma_{r\varphi}^2 = (B_0^2 + D_T^2)/N_{eff}$$

B_0 Constant term, depends on pad size, electonic noise and mechanical distortion
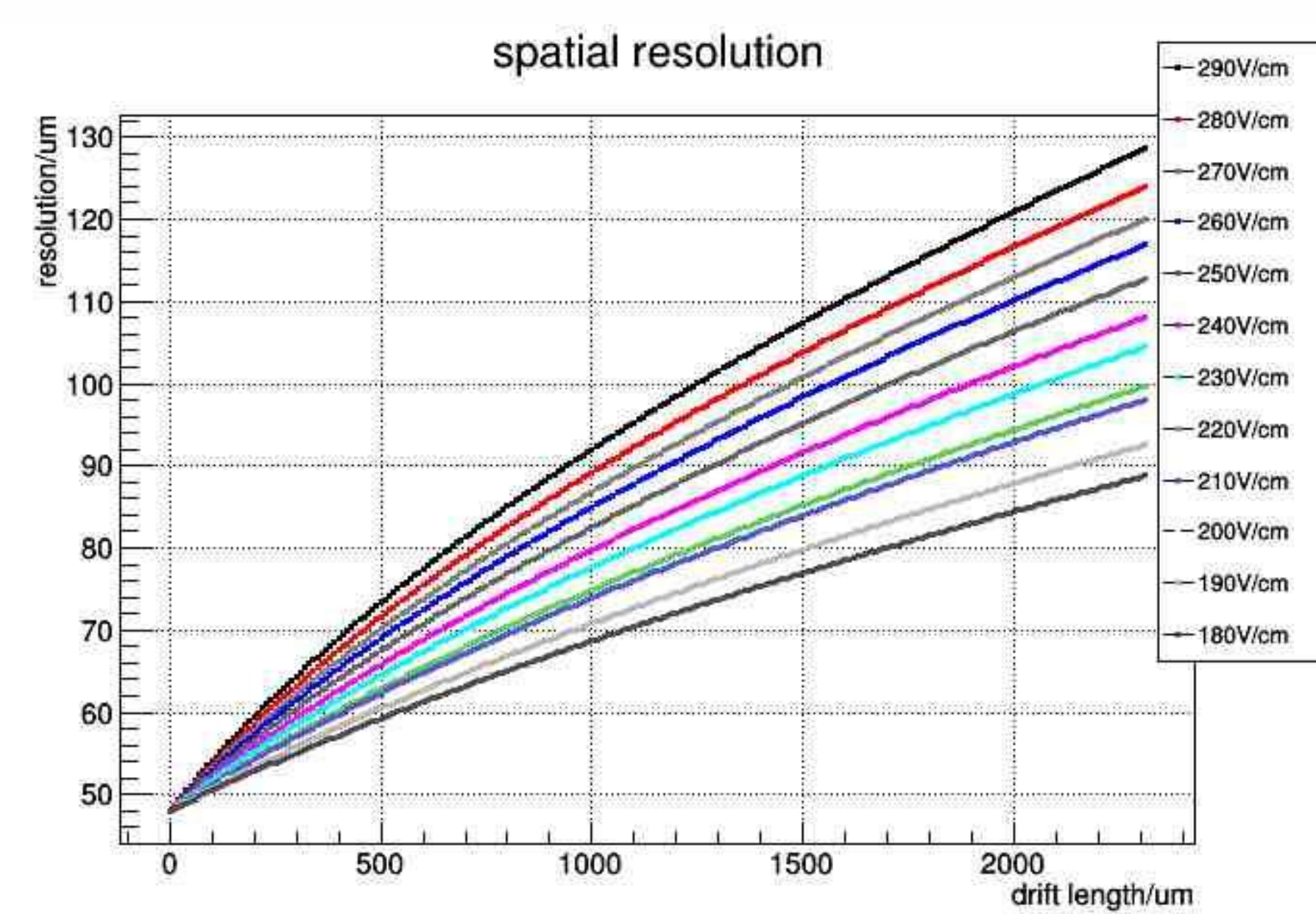N_{eff} effective number

Fig. 2 Dependence of resolution in Z direction for T2K gas

The drift field should be less than 220V/cm so that the spatial resolution in R- Φ direction is less than 100μm in the full drift length .

$$\sigma_z^2 = (\sigma_v^2/v_{true}^2 + \sigma_t^2/t_{true}^2)z_{true}^2$$

σ_v, the drift velocity error, is composed of 2 parts-σ_m (measurement error) and σ_{fl} (drift velocity fluctuation)
σ_t, the drift time error that mainly depends on TPC readout electronics' time resolution

The dependence of drift velocity error and drift time error has to be carefully studied with a high-precision TPC prototype that will be introduced below.
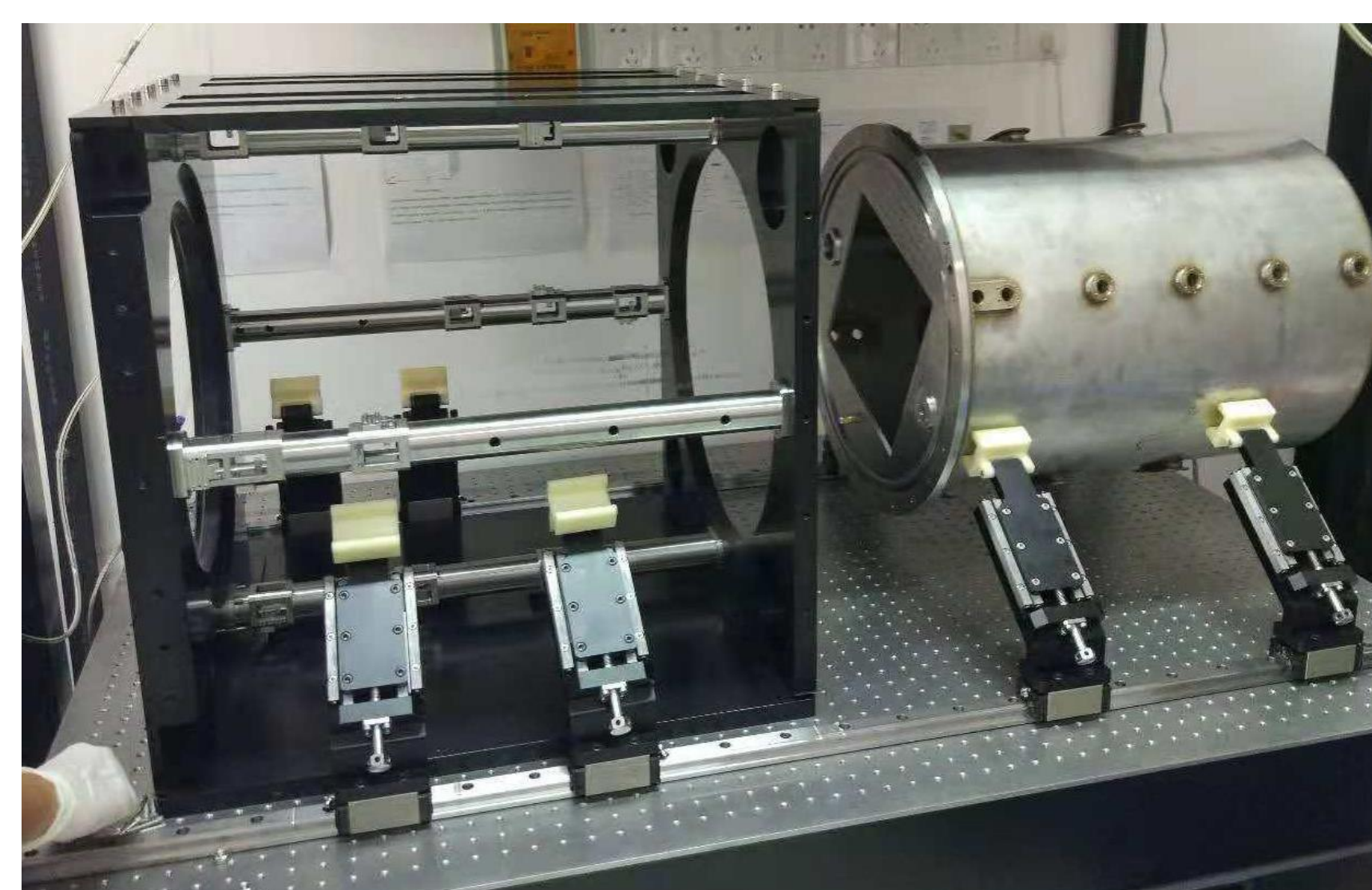

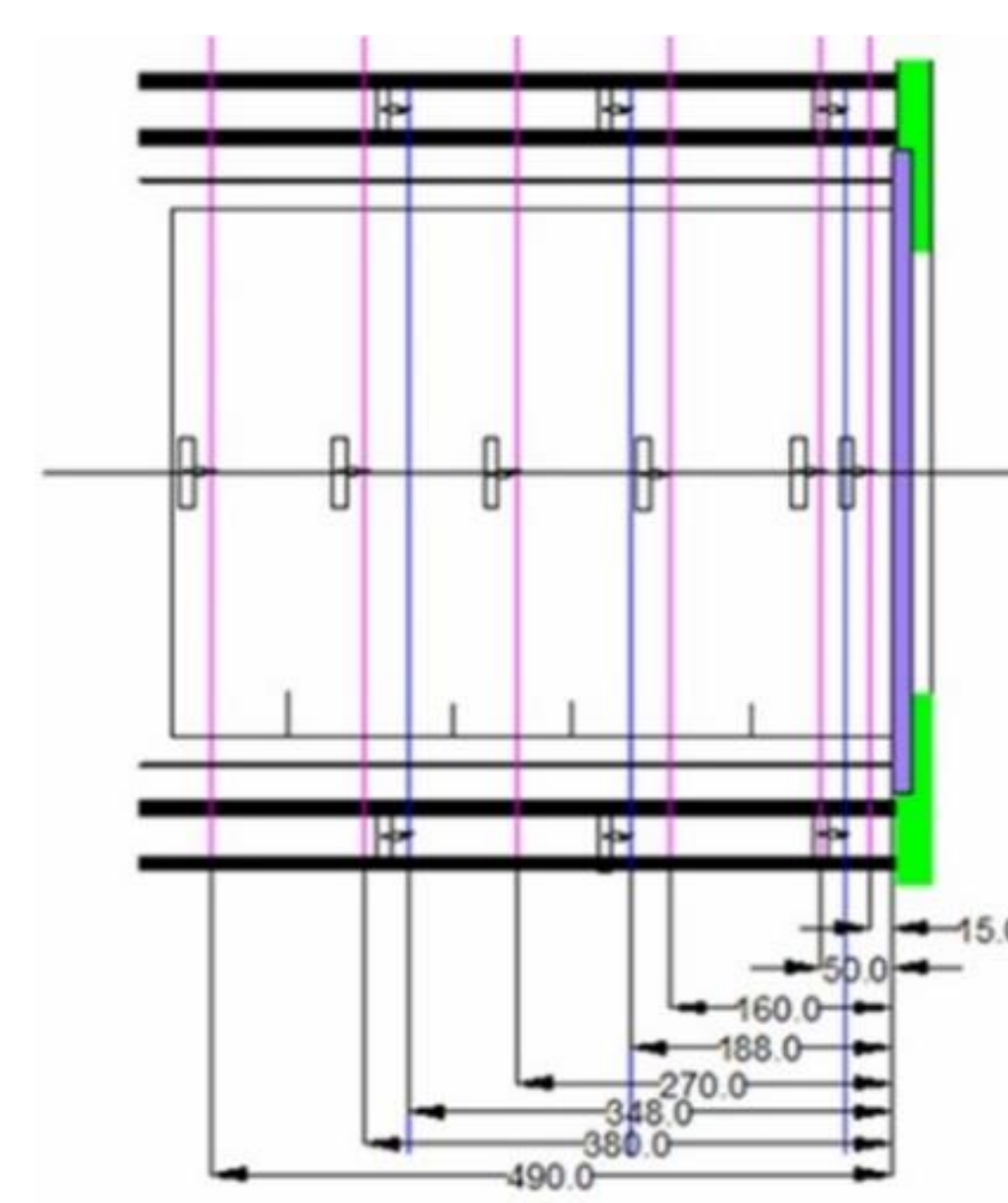Fig. 3 A new TPC prototype with laser calibration system   Fig. 4 Laser configuration

A TPC prototype with laser calibration system is being developed by gaseous sub-group of Tsinghua University and IHEP used for calibration and distortion measurement. With this high-precision TPC prototype, the parameters' value used in analytic formula can be verified. Also, the drift velocity error and drift time error can be measured precisely so that the dependence of drift field on spatial resolution in z direction is clear.

Nine layers of narrow laser beam are at predefined position inside the TPC (shown in Fig.4) to measure and correct the distortion to improve the spatial resolution. The detector can also examine electronics performance, measure drift velocity and diffusion at high precision in real time and align the readout modules.

Conclusion

The purpose of optimization of drift field is to improve the TPC's resolution to reach 100μm in R-Φ direction and 500μm in Z direction as well as to reduce negative effects caused by inevitable drift deviation. For the former goal, the analytic formula is deduced and an upper limit of 220V/cm is found. For the latter goal, the drift field should be in the interval from 240V/cm to 400V/cm.

It seems that the study so far doesn't give the optimal value of drift field. On one hand, the parameters used in the formula refer to ILD TPC, however, in CEPC TPC, the distortion can be corrected with laser calibration system so that the upper limit of drift field may be higher than 220V/cm. On the other hand, a compromise may have to be made towards the spatial resolution that the drift field should be set as 240V/cm.

The TPC prototype with laser calibration system is being assembled and tested and the further optimization result of drift field will be published in the near future

Reference

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