Development of Cylindrical Drift Chamber for COMET Phase-I

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Abstract

COMET is an experiment to search for μ^- – e^- neutrinoless conversion with a single-event sensitivity of 3 x 10^{-15} for Phase-I and 3 x 10^{-17} for Phase-II which is a factor of 10,000 better than the current upper limit. In COMET Phase-I, the Cylindrical Drift Chamber (CDC) is the main part of the detection system. To decide the parameters for CDC development, prototype of CDC II and III were built and an experiment was performed at Research Center for Electron Photon Science of Tohoku University (RCEP). The purpose of this study was to finalize the parameters of CDC and to evaluate the detector performance of the CDC prototype under two kinds of anode wires and three kinds of gas types.

Motivation of Beam Test

Measurement
- Gas gain (gain curve)
- Distance to time relation (x-t curve)
- Spatial resolution (σ)
- Hit efficiency (plateau curve)

Development
- Decision of parameters for CDC and Prototype IV

Beam Test

Beam Profile
- Electron Beam (σ_x: 8mm ; σ_y: 6mm)
- Beam time : 1st~12th December,2014
- Electron momentum : 460MeV/*c*
- Beam rate : 1.1kHz with PMT coincidence

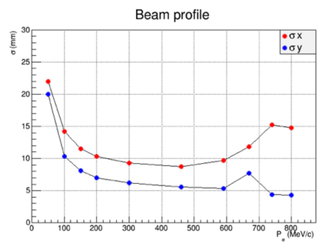


Fig.1 Beam profile of electron beam in ELPH

Setup of Beam Test

Chambers determine tracks (Tracking Chambers X&Y)
- 4 chambers
- Sense wire : Au-W $\varphi 30\mu m$
- Field wire : Al $\varphi 80\mu m$
- Ar:CH4 (90:10)
- 3 cells

CDC Prototype Chambers II & III
- Sense wire : Au-W $\varphi 25\mu m$ /$\varphi 30\mu m$
- Field wire : Al $\varphi 80\mu m$
- Stereo-angle : 65 mrad

Gas mixture
- He:iC_4H_{10} (90:10)
- He:C_2H_6 (50:50)
- He:CH_4 (73:27)

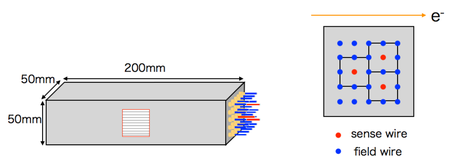
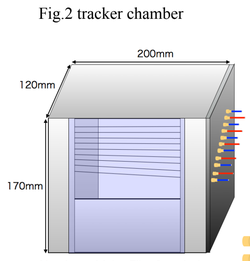
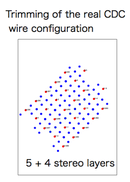


Fig.2 tracker chamber





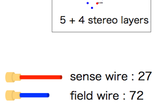


Fig.3 prototype CDC chamber

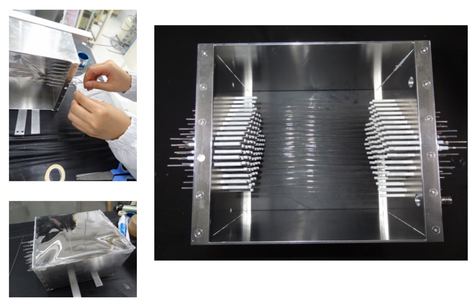
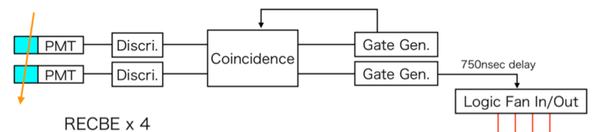


Fig.4 Prototype chamber construction



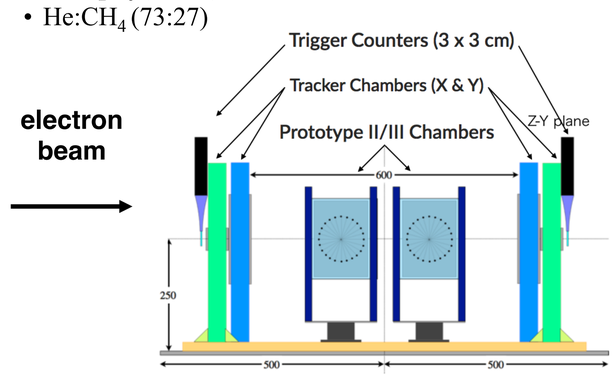


Fig.5 Experimental setup in Tohoku Beam test

Fig.6 DAQ logic block Diagram

Analysis Method

1. Two Scintillators as trigger for readout board
2. Four tracking chamber coincidence
3. Noise cut by ADC value
4. Drift distance restricted to cell boundary (8mm)
5. Calculation of y-z, x-z directions individually
6. $\chi^2 < 7$ for tracking chamber X
7. 3-dimentional track is reconstructed
8. Selection Efficiency ~ 25%

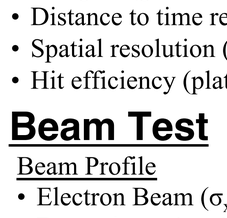


Fig.7 χ^2 distribution of X&Y tracking chamber

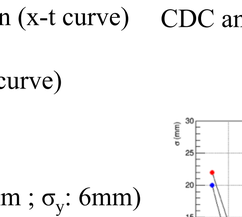


Fig.8 Beam spot of selected events at Upstream tracker

Distance to time relation (x-t curve)

- Using the closest approaches between the track and sense wires at prototype chambers, drift distance and time curve (x-t curve) are plotted.
- Fitting x-t curve bin by bin, the spatial resolution can be obtained.
- Spatial resolution is obtained by fitting with Gaussian function.
- Hit efficiency is counting hit within 600μm.
- Distance dependency of spatial resolution and hit efficiency are obtained with 1mm step.

- He:C_2H_6 = 50:50
- High Voltage : 2500V
- Threshold: 3730mV

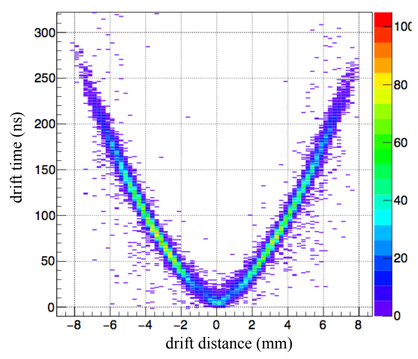


Fig.9 Typical drift time and distance relation of centre wire

A: Near sense wire

B: Near boundary of the cell

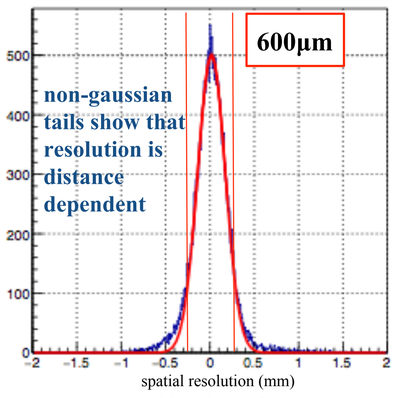


Fig.10 Typical spatial resolution of centre wire

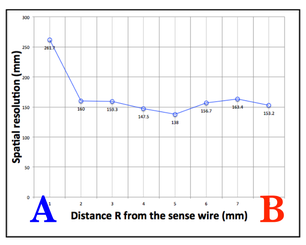


Fig.11 Spatial resolution and distance relation

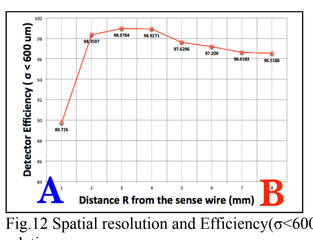


Fig.12 Spatial resolution and Efficiency(σ<600μm) relation

Spatial Resolution and Hit Efficiency

- The high voltage scanning was performed.
- The threshold of Belle II RECBE board scanning was performed.
- Efficiency/Spatial resolution and High Voltage dependence are obtained

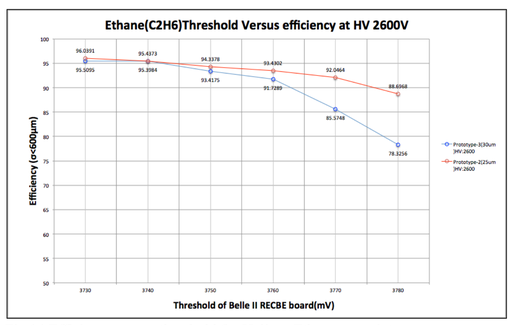


Fig.14 Efficiency versus threshold for Helium-Ethane gas mixture

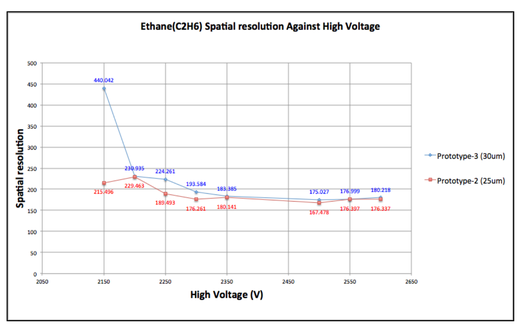


Fig.13 Spatial resolution versus High voltage for Helium -Ethane gas mixture

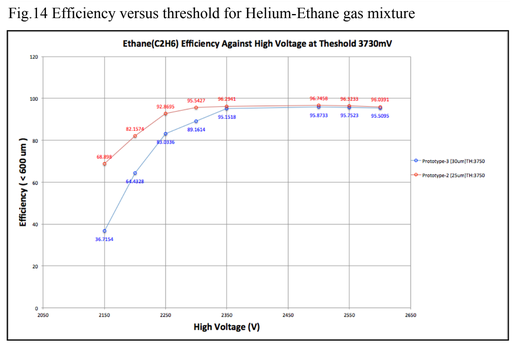


Fig.15 Efficiency versus High voltage for Helium-Ethane gas mixture

Gain Curve

- Fitting the ADC sum, the gain can be calculated using the following equation with table 1. [1]

$$\text{Gain} = \frac{N_t}{N_{pair}^{cell}}, \qquad N_{pair}^{cell} = N_{pair}\frac{dE^{cell}}{dE/dx}$$

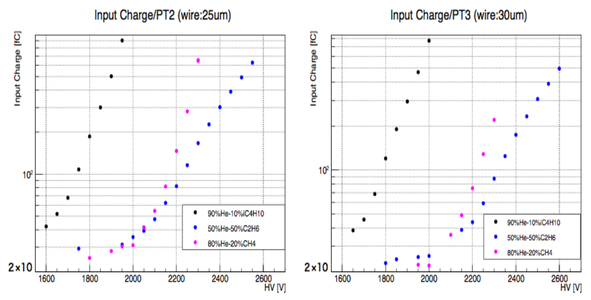


Fig. 17 Gas gain curve of prototype II & III for each gas

Mixture	dE^{cell} (keV/cell)	N_{pair}^{cell} (1/cell)
He:iC_4H_{10}(90:10)	0.938	32.39
He:C_2H_6(50:50)	1.180	43.44
He:CH_4(80:20)	0.389	4.50

Table. 1 Parameters used in gas gain calculation [1]

Analysis Result

- Range of high voltage and resolution that the hit efficiency is maximum for each type of gas mixture.

CDC Prototype II ($\varphi 25\mu m$)

Gas type	Ratio	Wire (um)	High Voltage	Efficiency % (<0.6mm)	Spatial resolution(um)
He :iC_4H_{10}	90:10	25	1850-1900V	94-96%	170-170
He : CH_4	80:20	25	2250-2300V	93-92%	169-174
He : C_2H_6	50:50	25	2300-2600V	95%-96%	176-17

Table. 3 Results of spatial resolution and hit efficiency of CDC prototype II for each gas mixtures where hit efficiency is maximum

CDC Prototype III ($\varphi 30\mu m$)

Gas type	Ratio	Wire (um)	High Voltage	Efficiency % (<0.6mm)	Spatial resolution(um)
He :iC_4H_{10}	90:10	30	1850-1950V	95-95%	170-166
He : CH_4	80:20	30	2300-2350V	92-92%	167-169
He : C_2H_6	50:50	30	2350-2600V	95%-96%	183-180

Table. 2 Results of spatial resolution and hit efficiency of CDC prototype III for each gas mixtures where hit efficiency is maximum

Note : The spatial resolution includes the tracker uncertainty.

Discussion

Crosstalk

Two types of crosstalk are observed when there is a signal.
- Within, the same ASD in RECBE readout board, the crosstalk-to-signal is bipolar and the ratio is -1.0%.
- Neighbour cells, the crosstalk-to-signal ratio is -3.0% due the positive ions movement.[2]

Beam test

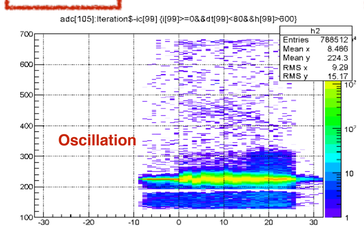


Fig.18 Accumulative Waveform

Bench test

Fig. 19 Crosstalk without shielding the sense cable

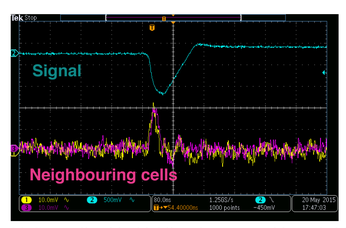


Fig. 20 Crosstalk with shielding the sense cable probably

Oscillation
- Grounding and shielding are very important issue for subsequent analysis.

Subsequent Analysis
- In beam test, oscillation of noise and crosstalk made lots of false events (TDC hit detection) in Belle II RECBE board.

Neighbour cell

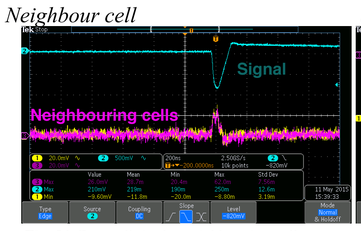


Fig. 21 Crosstalk in the neighbouring cells

Same ASD

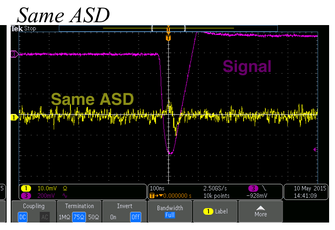


Fig. 22 Crosstalk within the same ASD

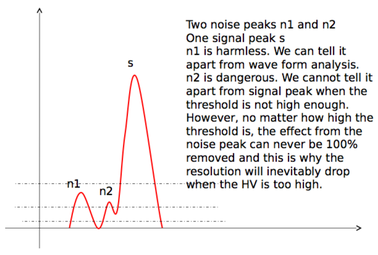


Fig. 23 False event is detected when crosstalk exist

Conclusion

- CDC prototype II and III are confirmed with, for some high voltage,
  (i) Hit efficiency 95% for all gas mixtures except methane.
  (ii) Spatial resolution less than 200μm for all gas mixtures.
- Both $\varphi 25\mu m$ $\varphi 30\mu m$ wires show high efficiency and low spatial resolution. To reduce the materials in the CDC, thinner wire $\varphi 25\mu m$ will be selected,
- Gas mixtures will be further studied by prototype IV.

Reference

[1] Y. Nakazawa *et al*., COMET Phase-I CDC Prototype Beamtest1, *70th JPS meeting at Waseda*, Mar, 2015

[2] S. Uno *et al*., Study of a Drift Chamber Filled with a Helium-Ethane Mixture, *Nucl. Instr. Meth*. **A330** (1993) 55-63