CO2 cooling for FPCCD Vertex Detector

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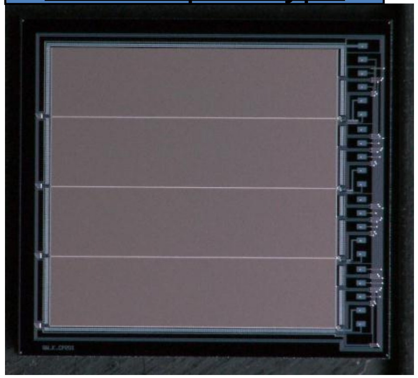
FPCCD vertex detector

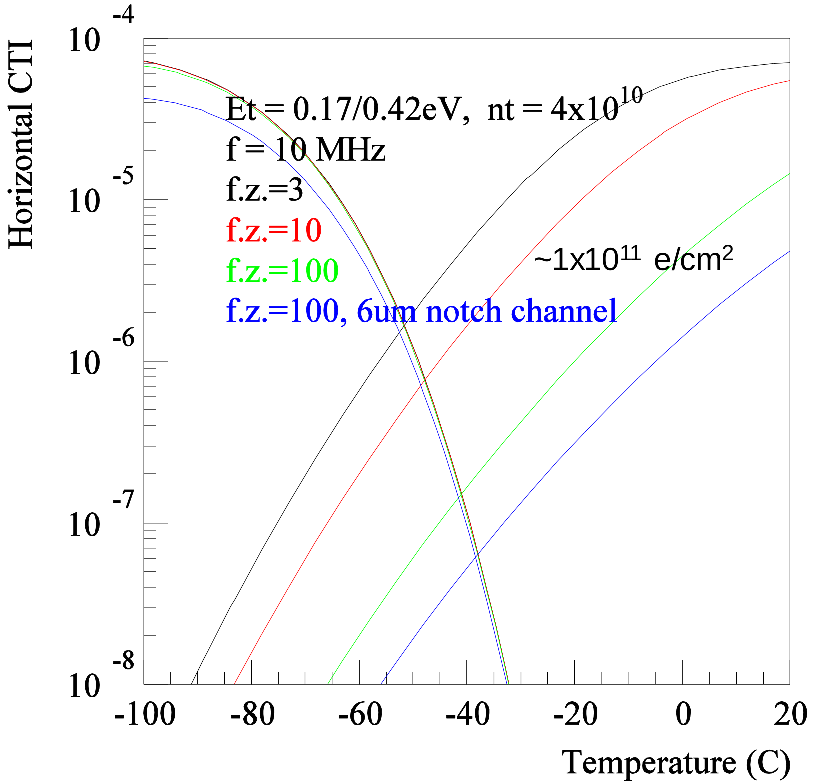
- Fine Pixel CCD
  - Pixel size ~ 5μm
  - Fully depleted epitaxial layer
  - Multi-port readout
  - Read out between trains (No power pulsing)
- FPCCD vertex detector
  - Double-sided ladder
  - Sensors and front-end ASICs inside a cryostat
  - Power consumption > 50W inside the cryostat

FPCCD prototype



Operation temperature

- Optimization for radiation tolerance
  - Charge transfer inefficiency (CTI) due to radiation damage is a function of temperature
  - A simple simulation of CTI based on Shockley-Read-Hall theory shows around -40℃ is optimal



Cooling options

- Cold nitrogen gas
  - Flow rate of ~1 L/s is necessary to extract 50W power with $\Delta T=40K$
  - Thick cooling tube would be necessary
- Two-phase CO_2
  - Flow rate of ~0.15 g/s is necessary to extract 50W power with $\Delta T \sim 0K$ (latent heat)
  - Thin tube is OK →
    - Less material budget
    - Less space between forward Si disks and beam pipe

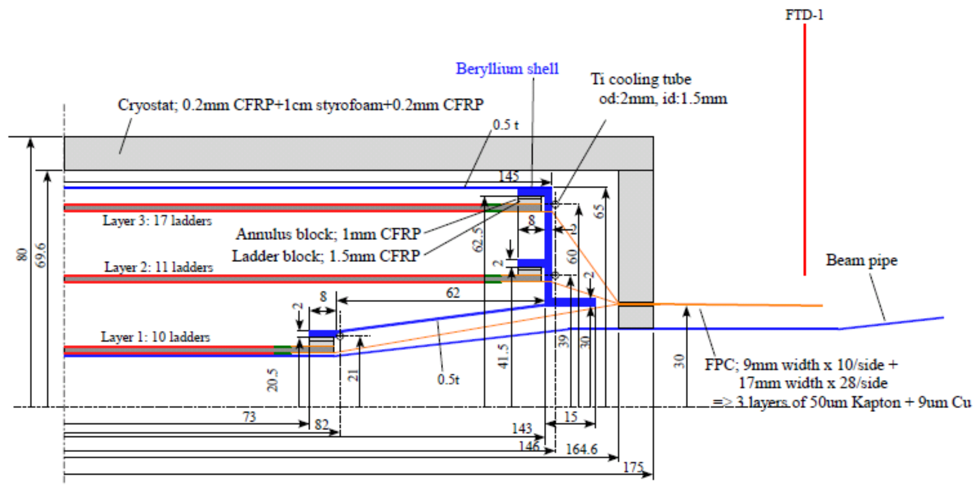
Advantages of CO_2 cooling

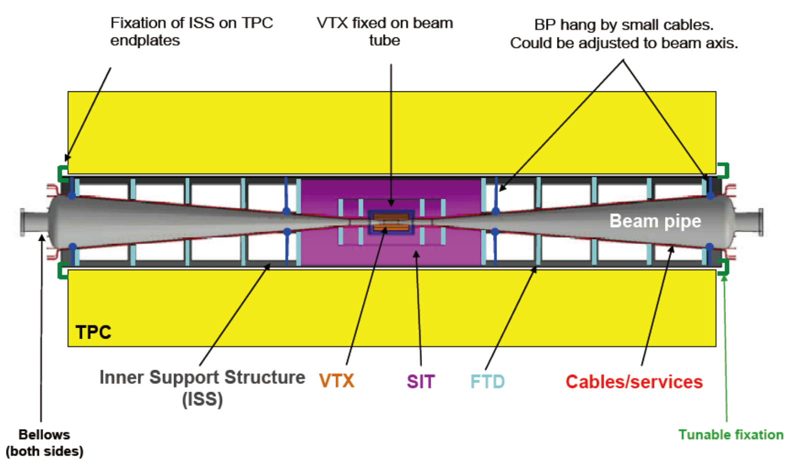
- Large latent heat ~300 J/g (x3 of PFC)
- High pressure ~1 MPa @-40℃
  - Less evaporated gas volume
  - Less temperature drop due to pressure drop
- Much less Global Warming Potential

	CO_2	C_2F_6	C_3F_8
Latent heat @-40C	321 J/g	~100 J/g	~110 J/g
Critical point	31.1℃	19.7℃	71.9℃
Pressure @-40C	1 MPa	~0.5 MPa	~0.1 MPa
GWP	1	9200	7000

CO2 cooling for FPCCD VTX

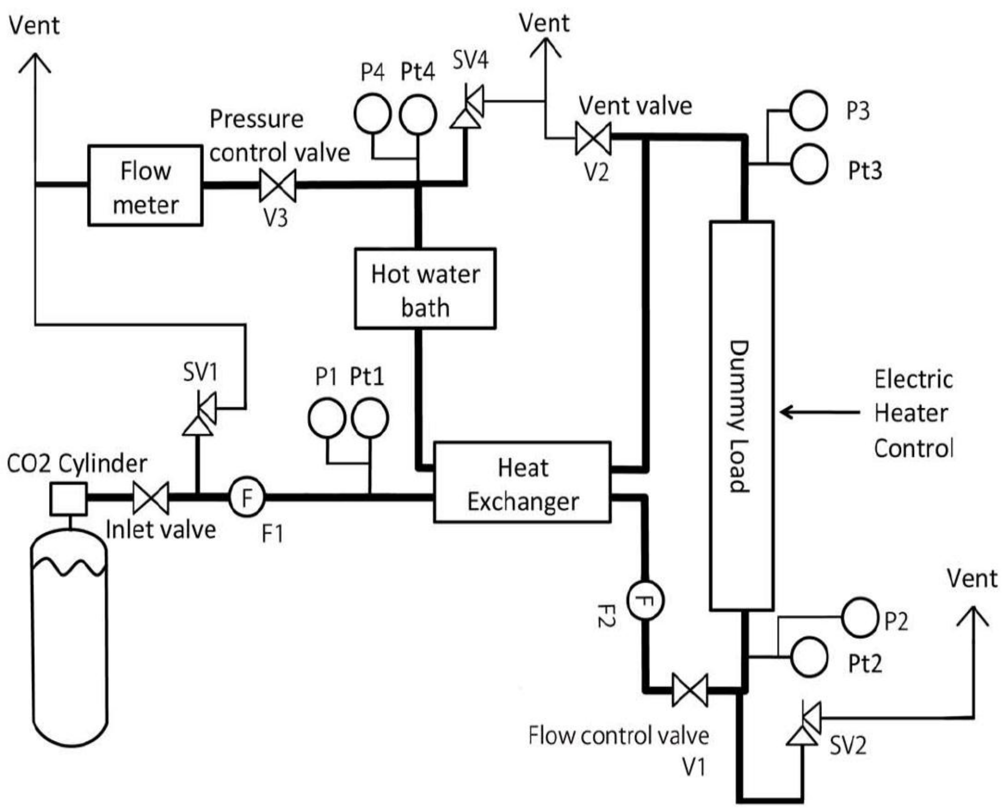
- Cooling tube is attached to VTX end-plate and heat produced by CCD output amp and ASIC is removed by conduction through CFRP ladder (simulation study for thermal design is necessary)
- Return line of CO_2 will be used to cool the electronics outside the cryostat (~200W/side)
- Inner support tube should be air-tight and filled with dry air/nitrogen in order to prevent condensation on the CO_2 tube





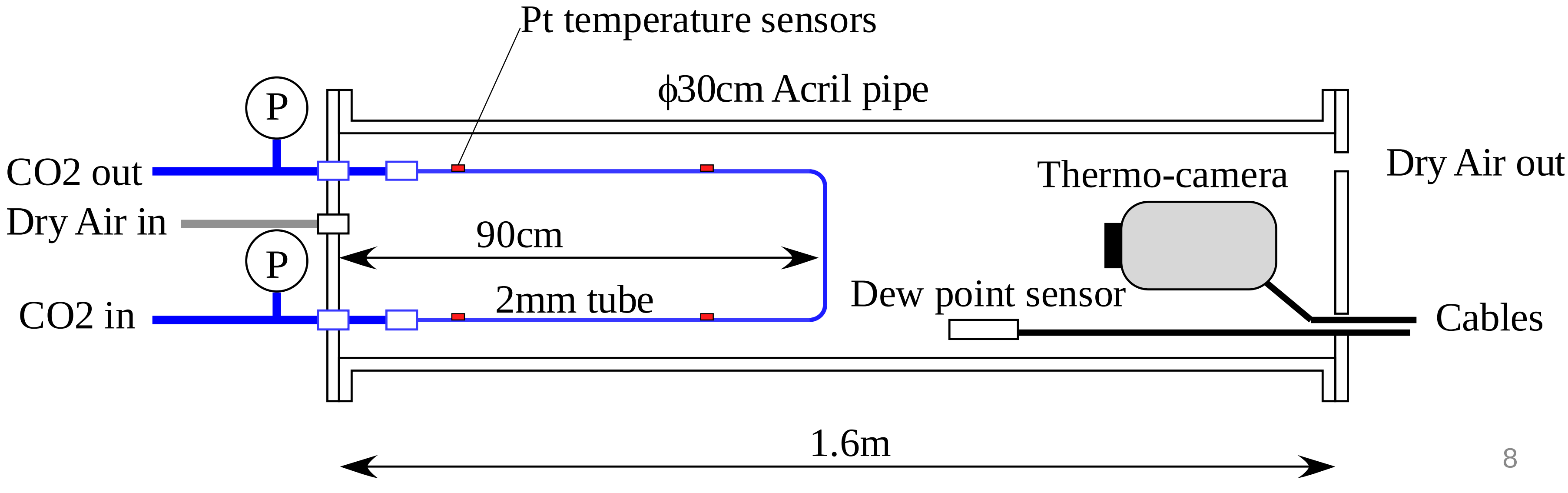
CO2 blow system

- CO2 collaboration in Japan
  - ILC VTX, ILC TPC, Belle-II VTX, and KEK cryogenic group
  - We constructed "blow system" and temperature was successfully controlled between -40℃ and +15℃

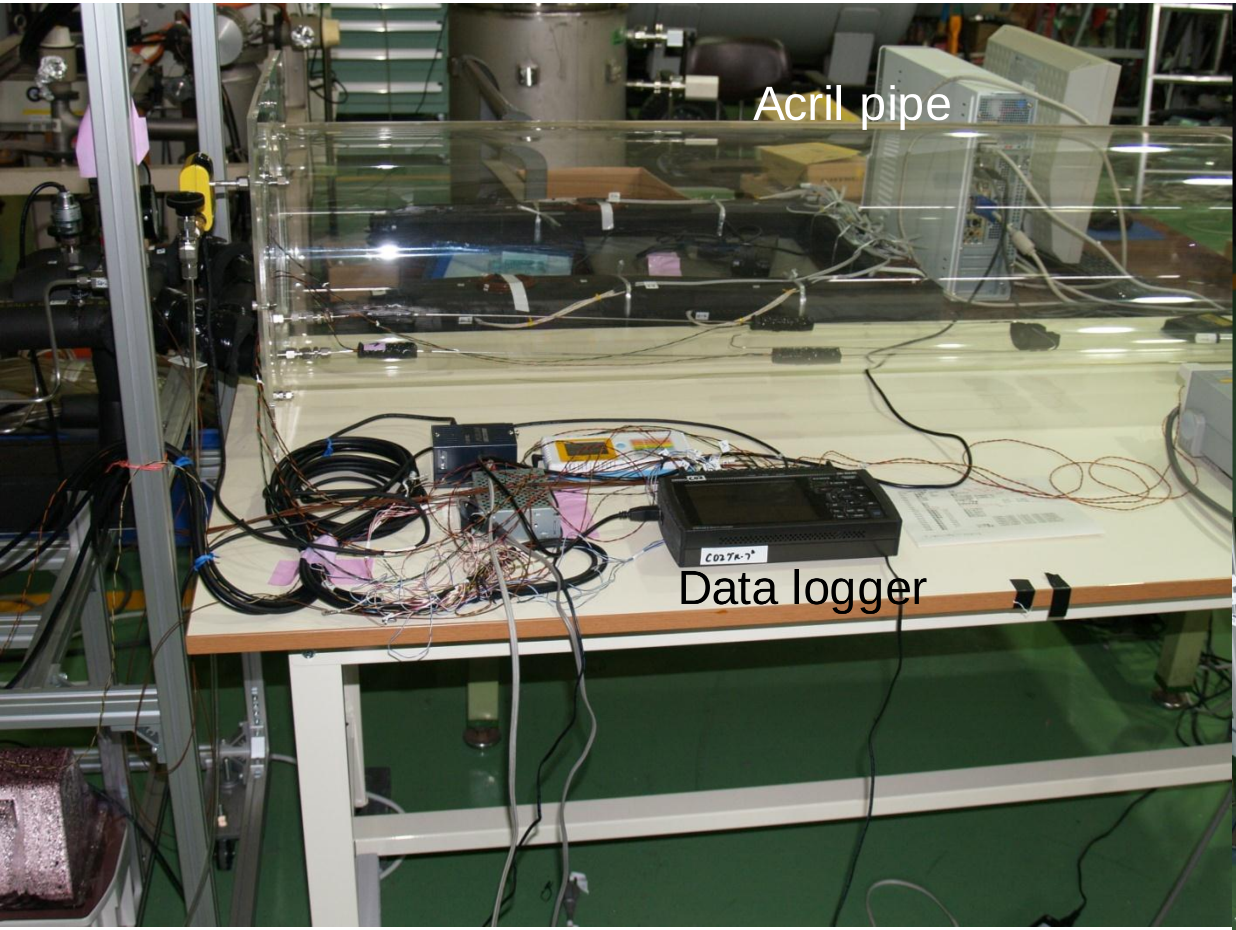


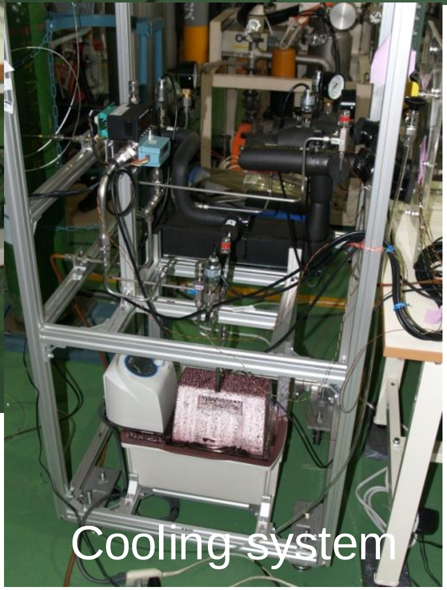
CO2 cooling test mockup

- Acril pipe filled with dry air, which mimics ILD inner support tube
- Purpose
  - Demonstrate that a bare cooling tube can be used in the dry air: No condensation, small heat penetration
  - Measure pressure drop (temperature drop) through a thin tube



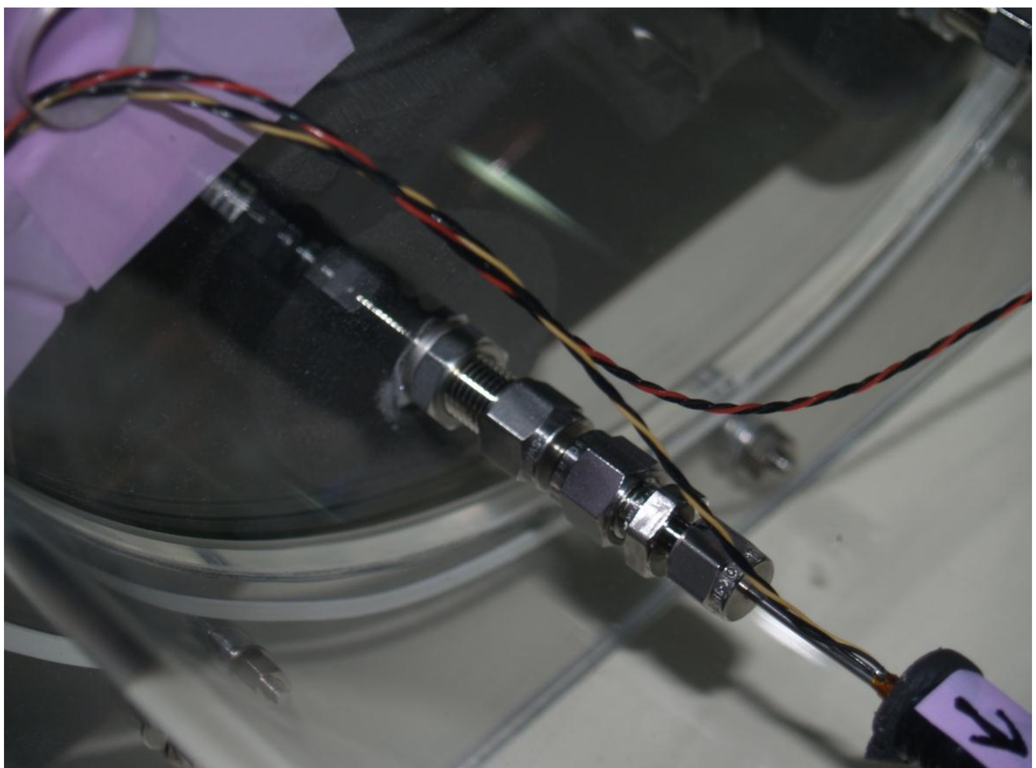
CO2 cooling test mockup





Test results (1)

- Dew point of <-45℃ can be easily achieved within 5 hours with the dry air flow rate of 5 L/min
- No condensation was observed on the 2 mm tube with -40℃ 2-phase CO2



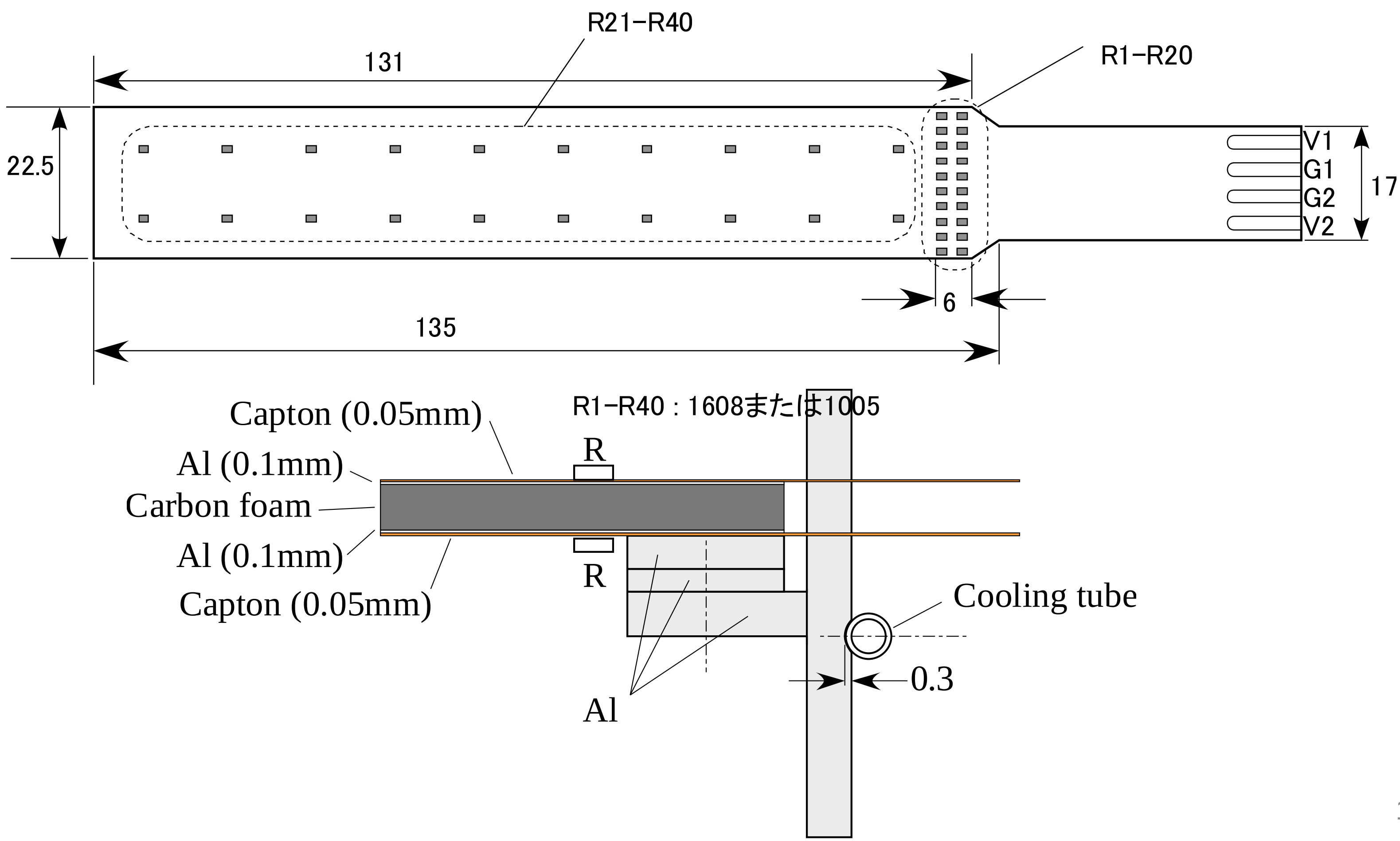
Test results (2)

- Heat penetration
  - Heat penetration was obtained from the difference of flow rates when “dry-out” occurs at different points
  - Dry out can be observed as a sudden rise of temperature
  - Flow rate difference of 0.03g/s caused dry-out point difference of 50cm

    → heat penetration ~ 20 W/m

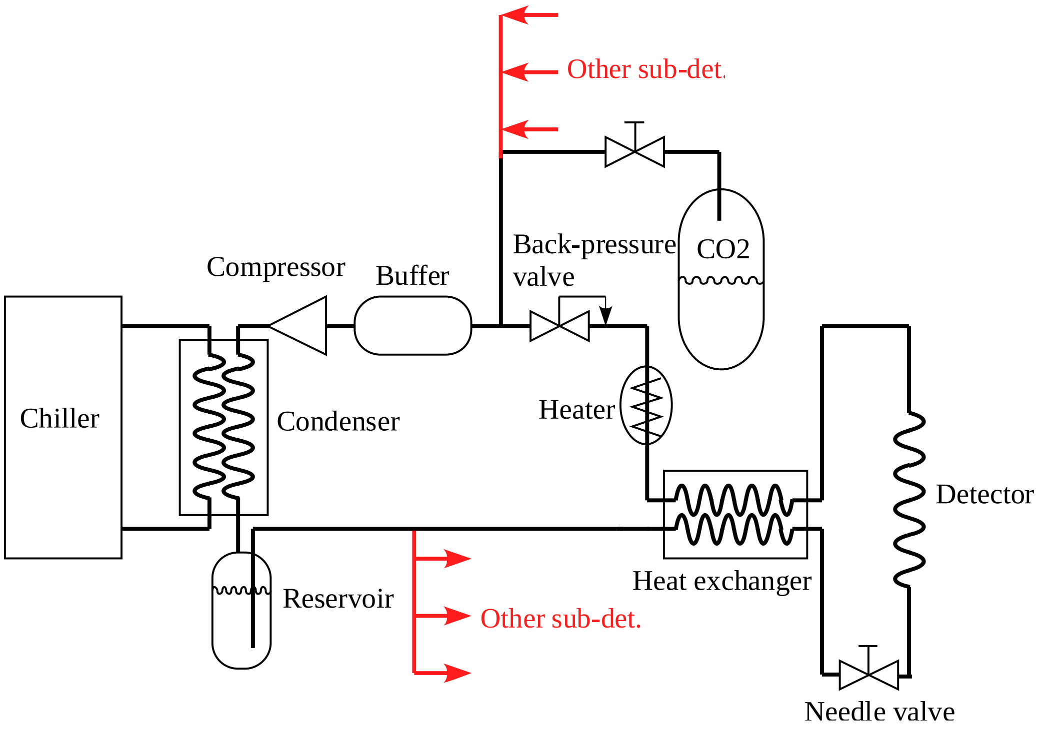
Future plan (1)

- Cooling test of dummy ladder/end-plate



Future plan (2)

- Blow system → Circulating system
  - We will conduct R&D on a 2-phase CO_2 cooling system which circulates CO_2 using a compressor
  - One compressor may be used for different sub-detectors (different temperature)



Summary

- Two-phase CO_2 cooling is a very attractive option for the cooling system of FPCCD vertex detector
- It has been demonstrated that 2mm cooling tube can be used in dry-air atmosphere without condensation and with reasonably small heat penetration of 20 W/m @-40℃
- We will conduct R&D on the circulating CO_2 cooling system using a compressor