Recent status of FPCCD vertex detector R&D

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FPCCD Vertex Detector

- Fine-Pixel CCD (FPCCD) feature

Minimum pixel size		$(5\mu m)^2$	high impact parameter resolution
Number of pixels		$\sim 4 \times 10^9$	Low pixel occupancy ~1%
Thickness	Si	$50\mu m$	Low multiple coulomb scattering and low pixel occupancy
	Epitaxial layer	$15\mu m$	
Read out		In the train gap ~200msec	No ElectroMagnetic Interference
Temperature		-40℃	Suppression of CTI and dark current

Contents

- $(6\mu m)^2$ FPCCD prototype
  - Neutron irradiation test
- Ladder R&D
  - Ladder design
  - Assembly
- 2phase CO2 cooling system
  - Circulation using gas compressor

Neutron irradiation test

Neutron Irradiation Test

- Date: 15-17th Oct. 2014
- Place: CYRIC in Tohoku Univ.
- Fluence: $1.78 \times 10^{10} n_{eq}/cm^2$
  - It corresponds to 19 years at ILC beam time shared by ILD/SiD.

- FPCCD prototype whose pixels size is $(6\mu m)^2$, $(8\mu m)^2$, $(9.6\mu m)^2$ and $(12\mu m)^2$ are irradiated.
- We checked performance of the FPCCD and a R&D status was presented at ALCW2015 and IEEE.
  - I will focus on pixel size $(6\mu m)^2$ in this talk.

Performance of FPCCD

- 3 Parameters to measure radiation tolerance
  - Average dark current of all pixels
  - Hot pixel fraction
  - Charge transfer inefficiency

- We measured 3 parameters 3, 9, 23 and 199days after irradiation to see the annealing effect.
  - FPCCD chip is kept at room temperature (~23℃).

Performance of FPCCD

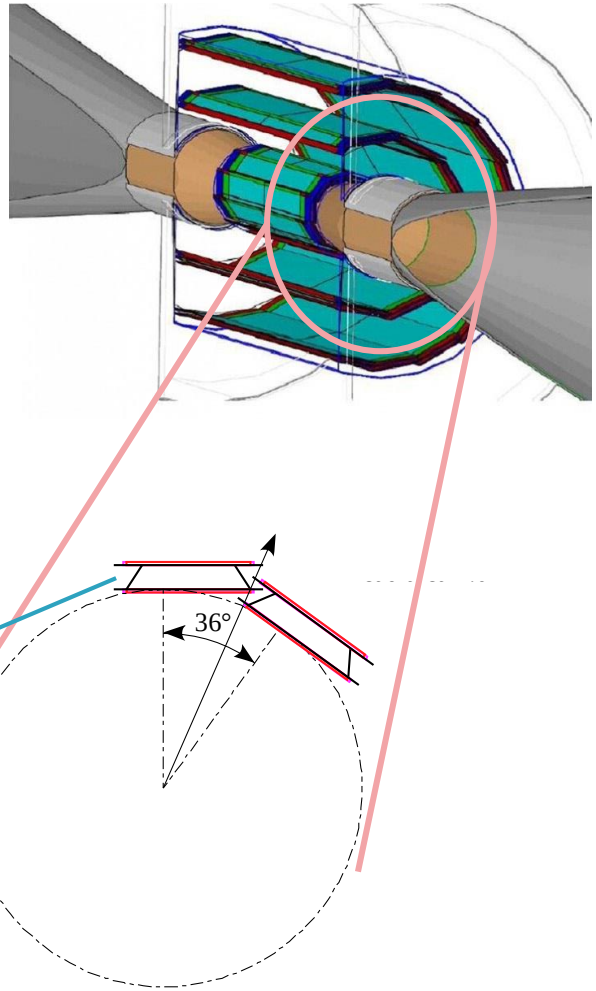
		Performance	Annealing effect
Dark current of all pixels	Mean	$(5.4 \pm 0.005) \times 10^{-2}$ [LSB]	Yes
	Mode	$(1.5 \pm 0.002) \times 10^{-2}$ [LSB]	No
Hot pixel fraction		2.76×10^{-5}	Yes
CTI		Maximum charge loss is 63%	No

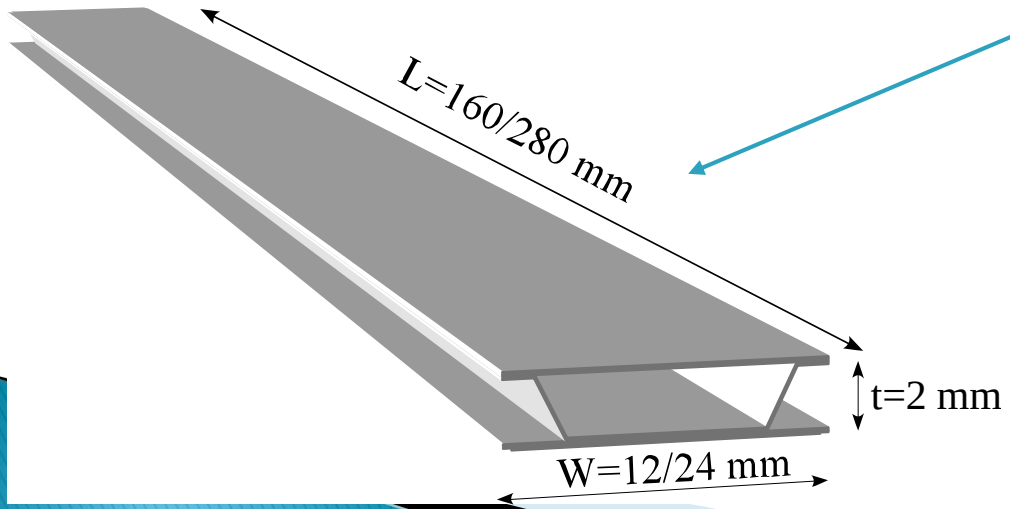
- Dark current and hot pixel fraction are OK.
- CTI is acceptable level.
  - There is unknown source of charge loss.

Ladder R&D

Ladder for FPCCD VTX

- Ladder design idea
  - Double-sided ladder ~2mm apart
  - 2 CCD chips / side
  - Readout ASICs on both ends
  - CFRP-FPC(Kapton/Cu)-Si structure





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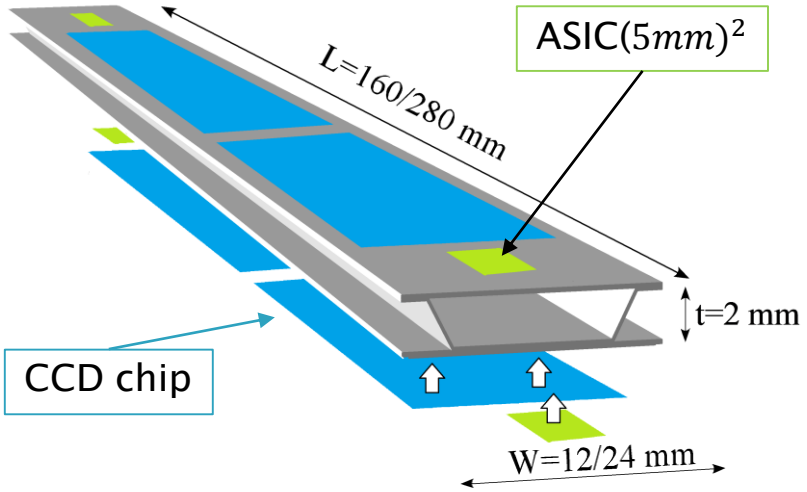
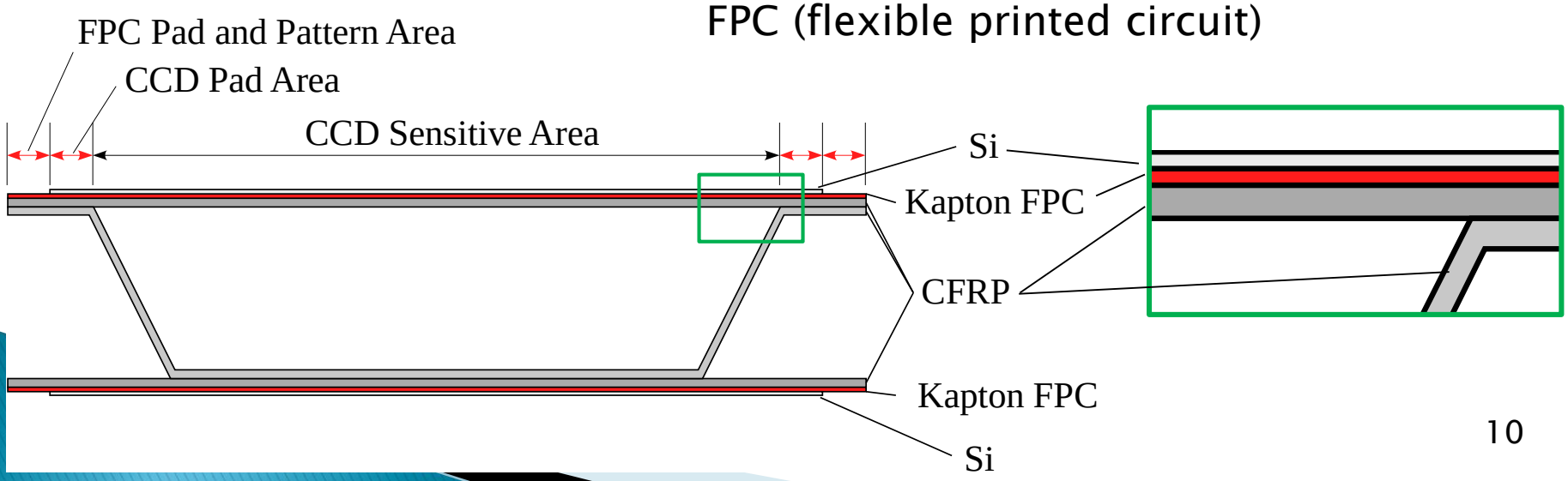
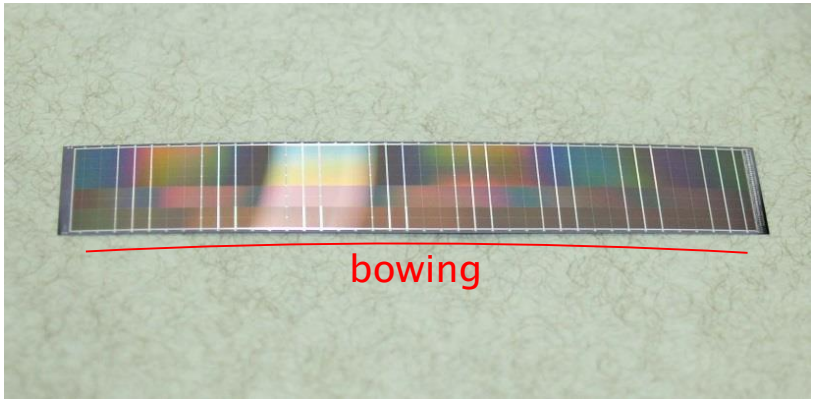


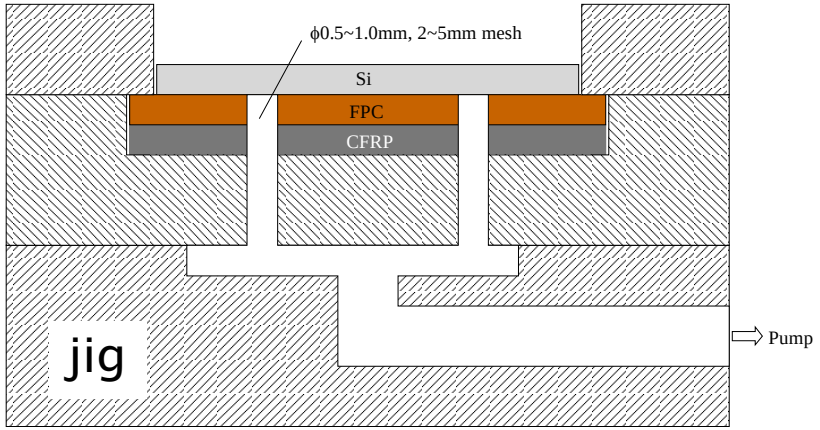
CFRP (carbon fiber reinforced plastic)
FPC (flexible printed circuit)



Ladder R&D

- Ladder assembly
  - 50μm thick wafer is found bending
  - We need vacuum suction during fabrication (for gluing)
- Thermal issue
  - FPCCD will be operated at low temperature (−40℃)
  - Difference of coefficients of thermal expansion between Si and CFRP is an issue
  - Stress has to be absorbed by soft glue
- ➔ R&D has just begun





assembly

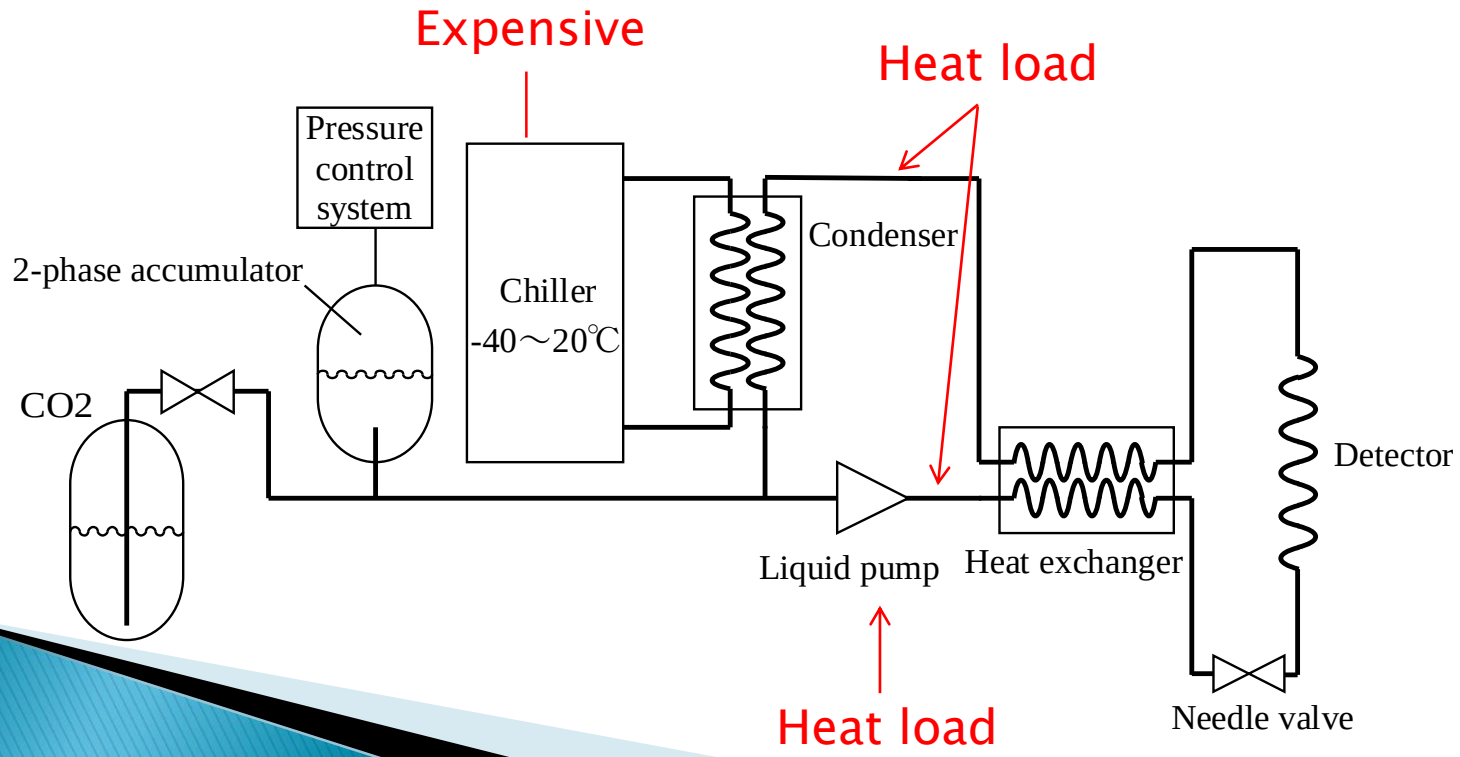
2 phase CO2 cooling system

2-phase CO2 cooling for FPCCD

- Requirement for cooling
  - FPCCD will be operated at low temperature (-40℃) to improve radiation tolerance (CTI and dark current)
  - Space for cooling pipe (and thermal insulator) inside ILD is very limited
  - ➔ 2-phase CO2 cooling is the most suitable choice
- Options of CO2 cooling
  - Circulation by liquid pump
  - Circulation by gas compressor ➔ Our R&D choice

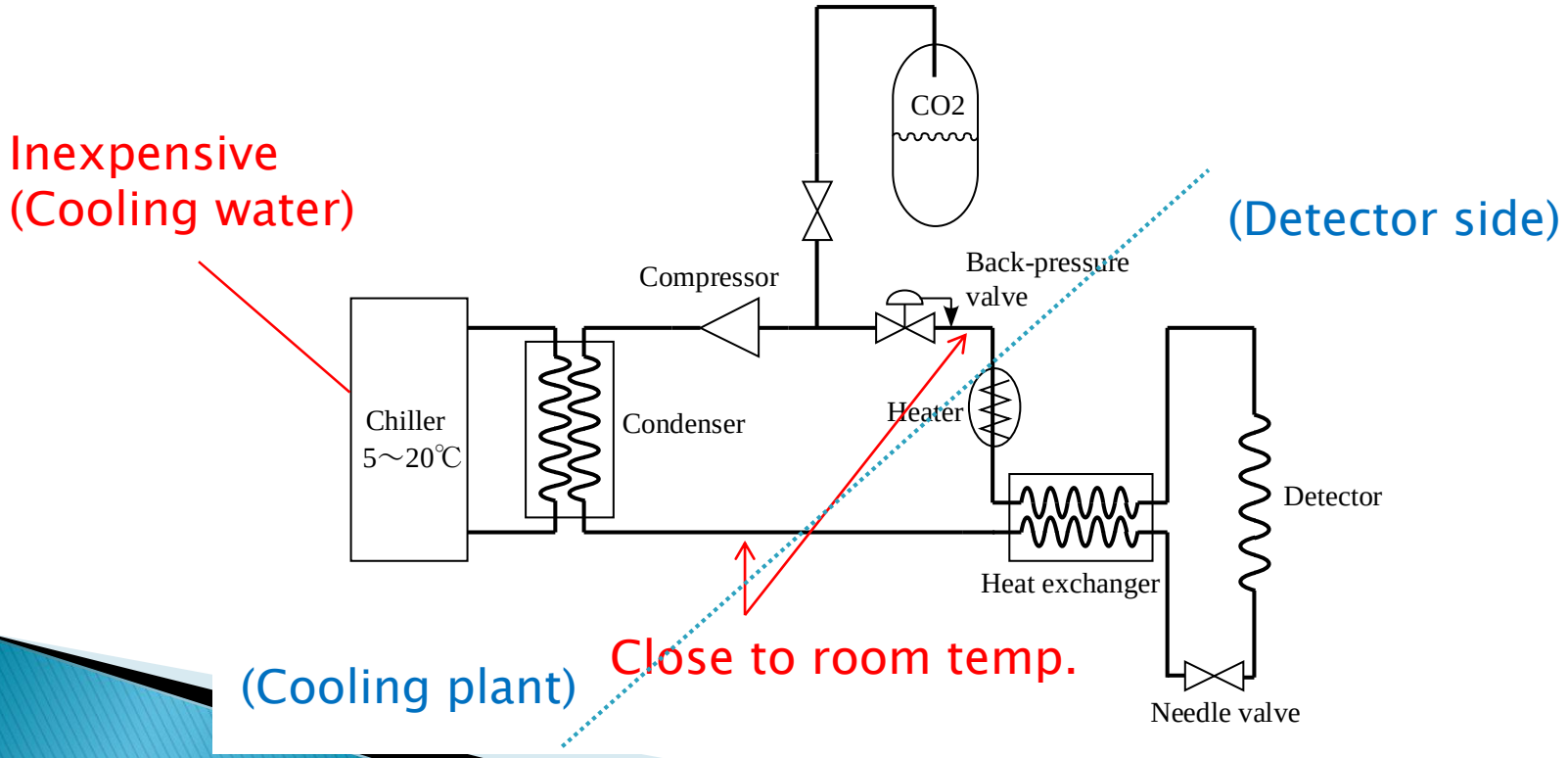
Circulating system option

- Circulating system using a liquid pump
  - Getting popular in HE physics experiments
  - Disadvantages: many low temperature parts/equipment



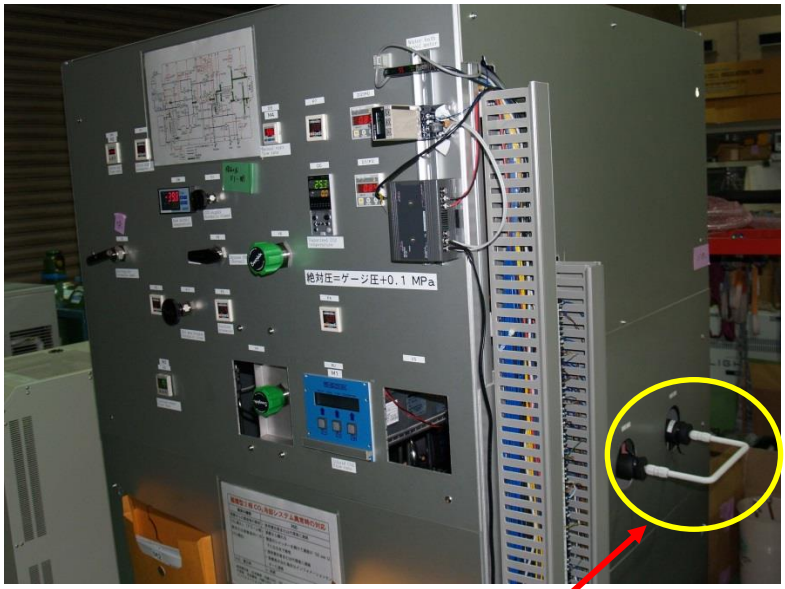
Circulating system option

- Circulating system using a gas compressor
  - For low temperature application, less heat load & less expensive



R&D status of CO2 cooling

- Cooling between −40℃ and +15℃ has been demonstrated with a prototype cooling system using gas compressor
- Next step
  - Stabilization of cooling temperature (pressure)
    - Manual back-pressure valve → Pressure controller
  - Low-mass heat exchanger near (inside) the detector
  - Study of durable O-ring
  - Small size prototype



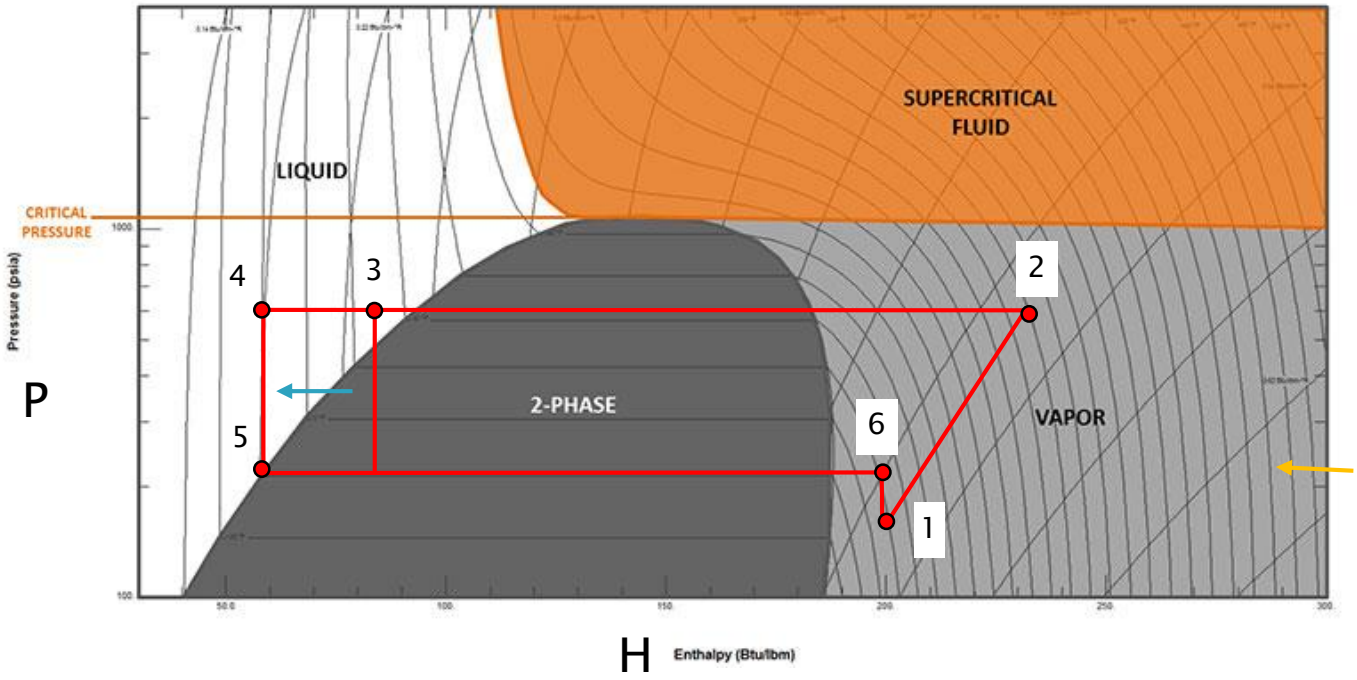
Cooling pipe for detector.
Frost due to −40℃ cooling can be seen.

Summary

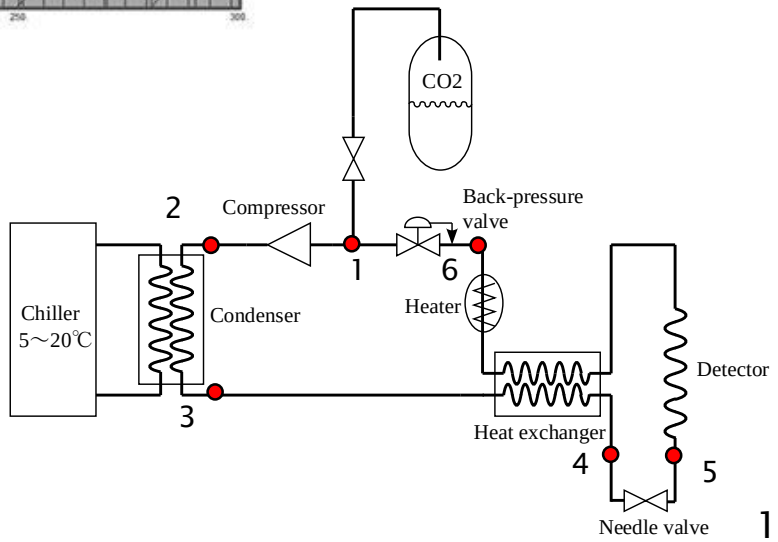
- $6\mu m^2$ FPCCD prototype is developed.
  - Neutron irradiation damage has been studied.
    - Dark current and hot pixel are OK.
    - Charge transfer inefficiency (CTI) is acceptable level
- Ladder R&D has just begun
- A prototype 2-phase CO2 cooling system using gas compressor for FPCCD at -40℃ has been developed.

Back up

Circulation system using gas compressor



Phase diagram



Comparison of two options

- Merit of gas compressor type
  - Near room temperature condensation and transfer ➔
    - No need for expensive low temperature chiller (Cooling water supplied to ILC detector hall can be used)
    - No need for thermal insulation for long transfer tube → Flexible tube off the shelf can be used → Merit for push-pull operation of ILC detectors
- Demerit of gas compressor type
  - Heater is needed to completely vaporize CO2 returning to gas compressor

	Liquid pump	Gas compressor
Temperature of pump/compressor	Low ($<T_{detector}$)	High
Temperature of condenser	Low ($<T_{detector}$)	~ Room temperature
Temperature of transfer tube: plant →detector	Low ($<T_{detector}$)	~ Room temperature
Temperature of transfer tube: detector → plant	Low ($<T_{detector}$) (2-phase)	~ Room temperature (Gas)