Thermal Mockup Studies of Belle II Vertex Detector

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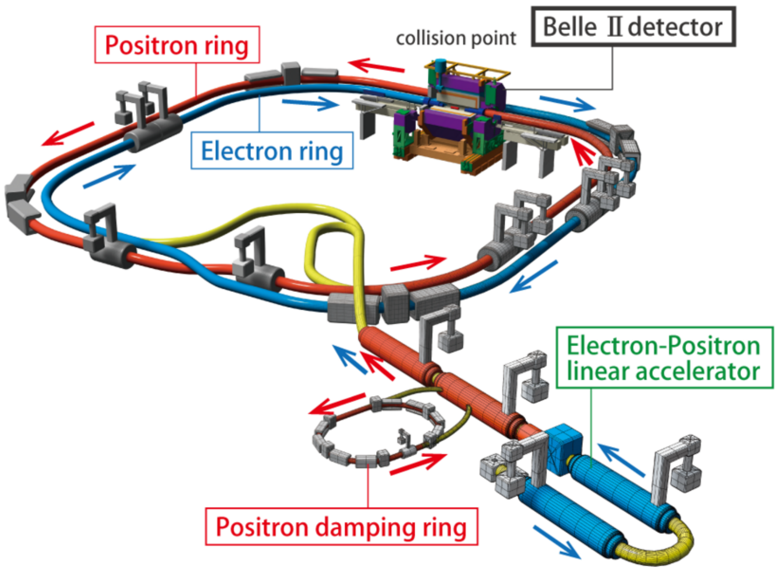
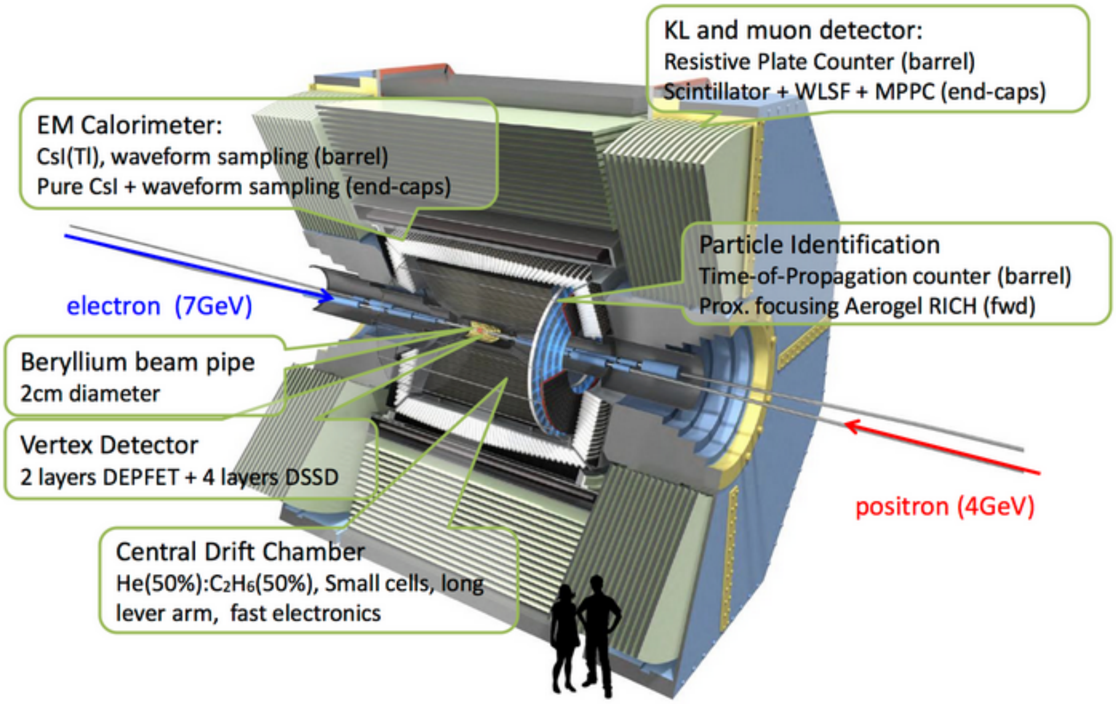
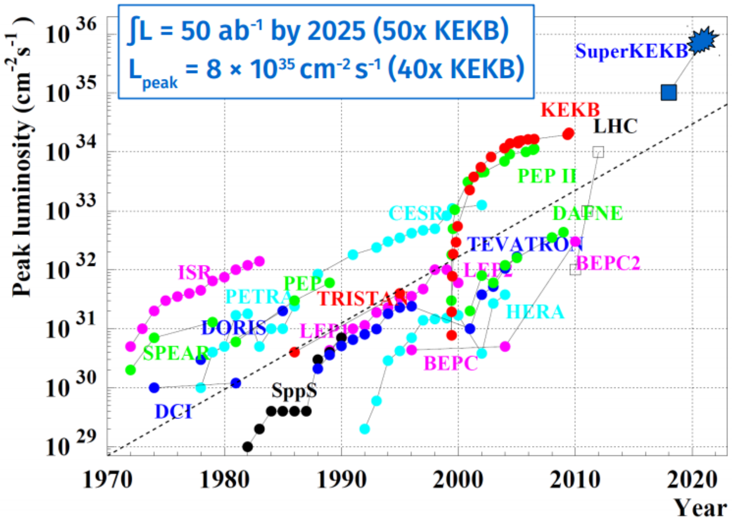
SuperKEKB/Belle II Upgrade





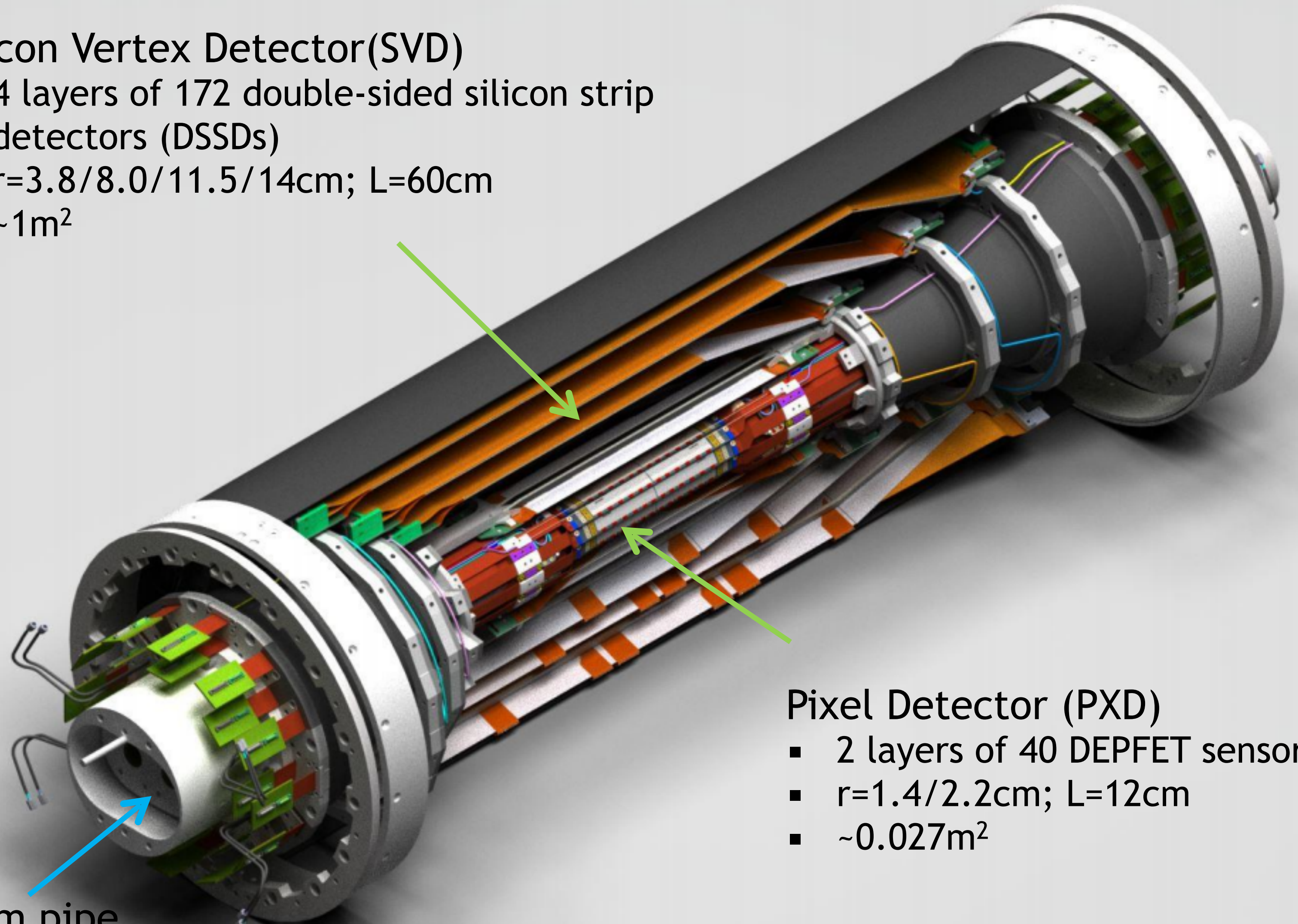


- SuperKEKB aims to increase the peaking luminosity to $8X10^{35}cm^{-2}s^{-1}$.
- Belle II experiment is expected to accumulate 50 ab^{-1} integrated luminosity by 2025, to search for new physics beyond Standard Model.
- The Belle II detector was rolled in in April 2017.

Belle II Vertex Detector (VXD)

Silicon Vertex Detector(SVD)

- 4 layers of 172 double-sided silicon strip detectors (DSSDs)
- r=3.8/8.0/11.5/14cm; L=60cm
- ~1m^2



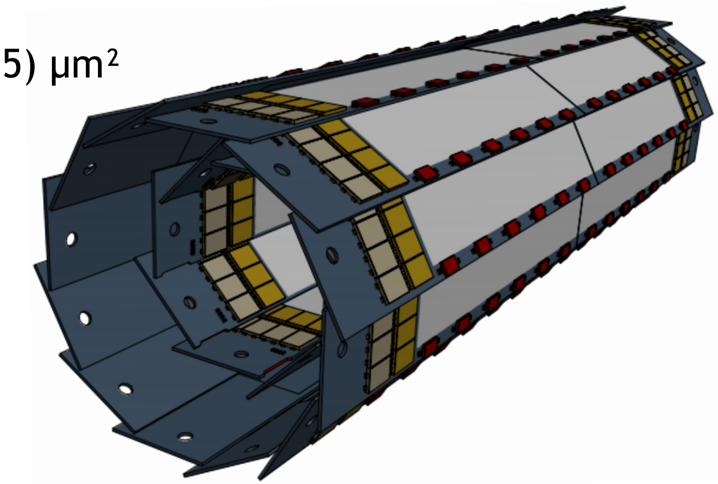
Pixel Detector (PXD)

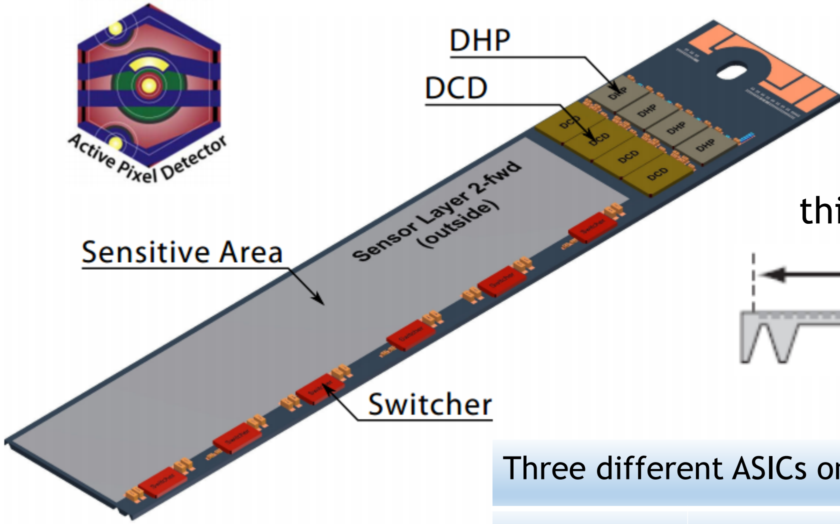
- 2 layers of 40 DEPFET sensors
- r=1.4/2.2cm; L=12cm
- ~0.027m^2

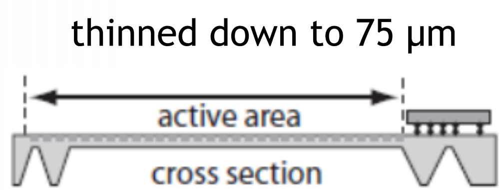
Beam pipe

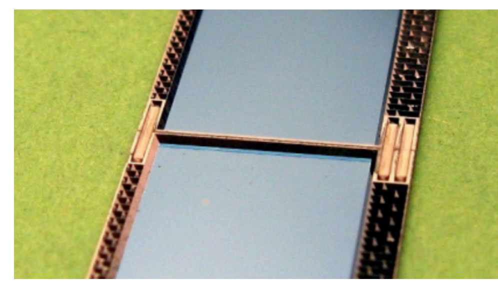
Belle II PXD: Ladder Design

- 2 layers pixel detector with 40 DEPFET sensors
- 7.68 million pixels with the pitch size: 50x(55/60/70/85) μm^2
- sensitive area size:
  12.50 X 44.80 mm^2 (layer.1)
  12.50 X 61.44 mm^2 (layer.2)
  will be thinned down to 75 µm.
- Operated by 3 types of ASICs. Power consumption dominated by the ASICs at the end of sensor









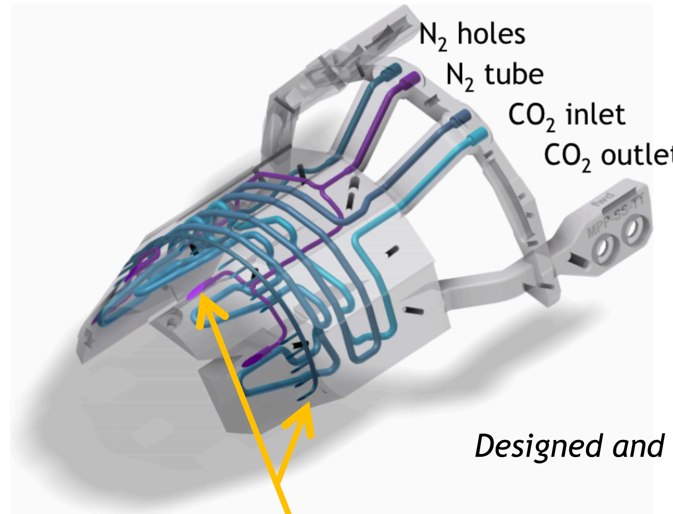
Ladder formed from 2 sensors
- ❑ butt-face joint glueing
- ❑ ceramic mini-rods embedded in the thick rim of sensor

Three different ASICs on the sensor	
DCD	Drain Current Digitizer
DHP	Data Handling Processor
Switcher	to do row control

PXD Ladder Support

Both layers are mounted on the combined support and cooling blocks (SCBs)

- connected by silver coated carbon fiber tubes for air cooling and grounding

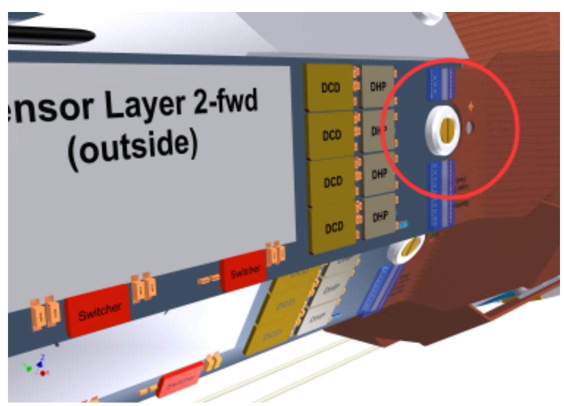


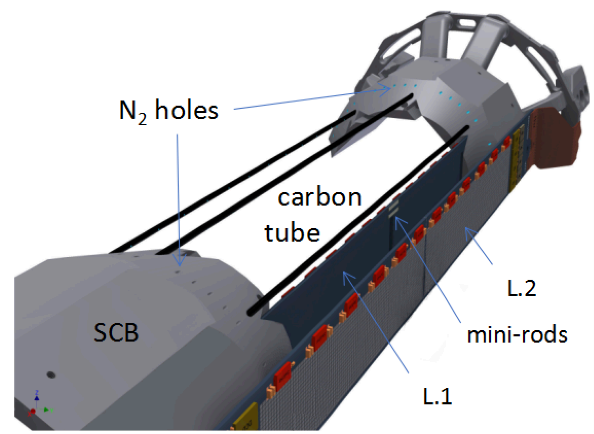
Designed and produced by MPI

SCB, manufactured using 3D printing technology, with enclosed CO_2 and open N2 channels inside.

Ladders screwed on support

- elongated hole on the FWD side
- M1.2 screw with plastic washer o-ring to prevent electrical contact between screw and silicon.
- torque of 7mNm allows for compensating of thermal expansions.



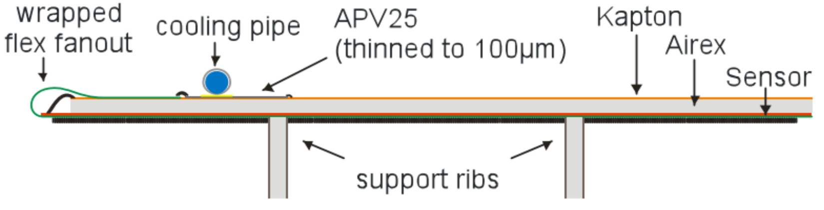


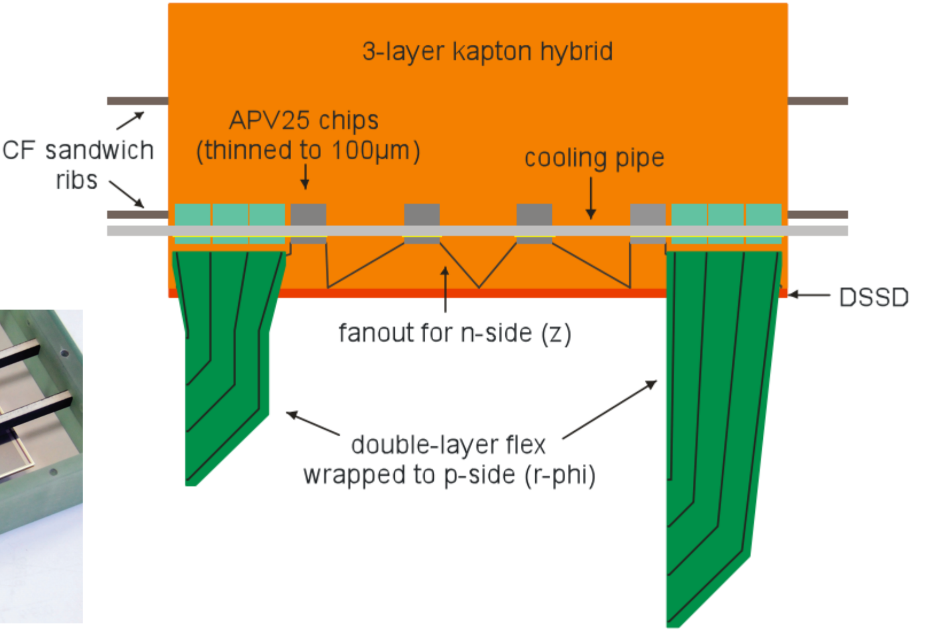
Belle II SVD Module

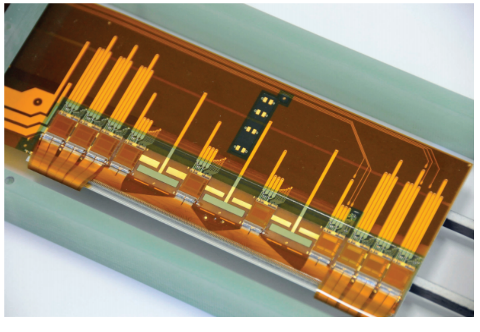
Silicon Vertex Detector

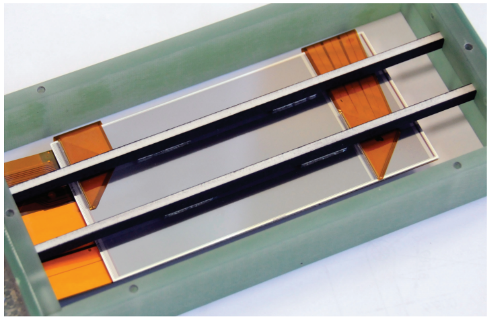
- Four layers (numbered from 3 to 6) from ladders with up to 5 DSSD modules in a row.
- p-strip pitch: 50(75)μm, n-strip pitch: 160(240)μm
- Supported by two ribs and Airex foam core sandwich.
- readout chip: APV25 (thinned down to 100 μm thickness)
- the Origami concept, all APV25 are aligned in a row and cooled by a single cooling pipe per ladder.

Modules in the barrel



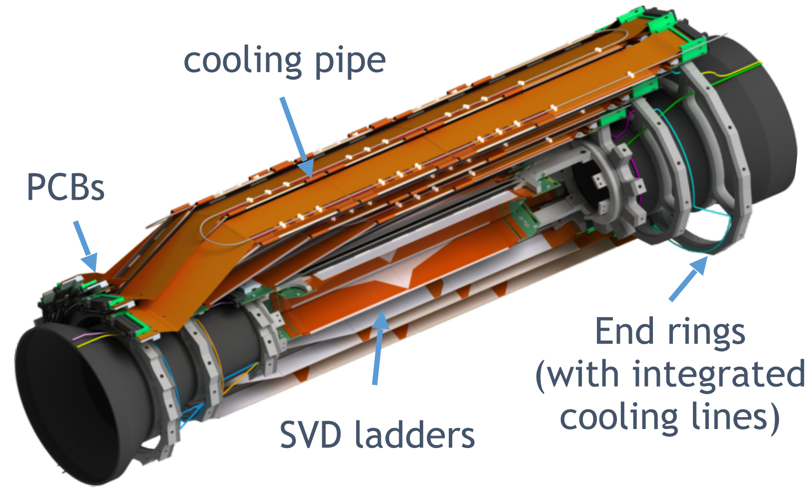


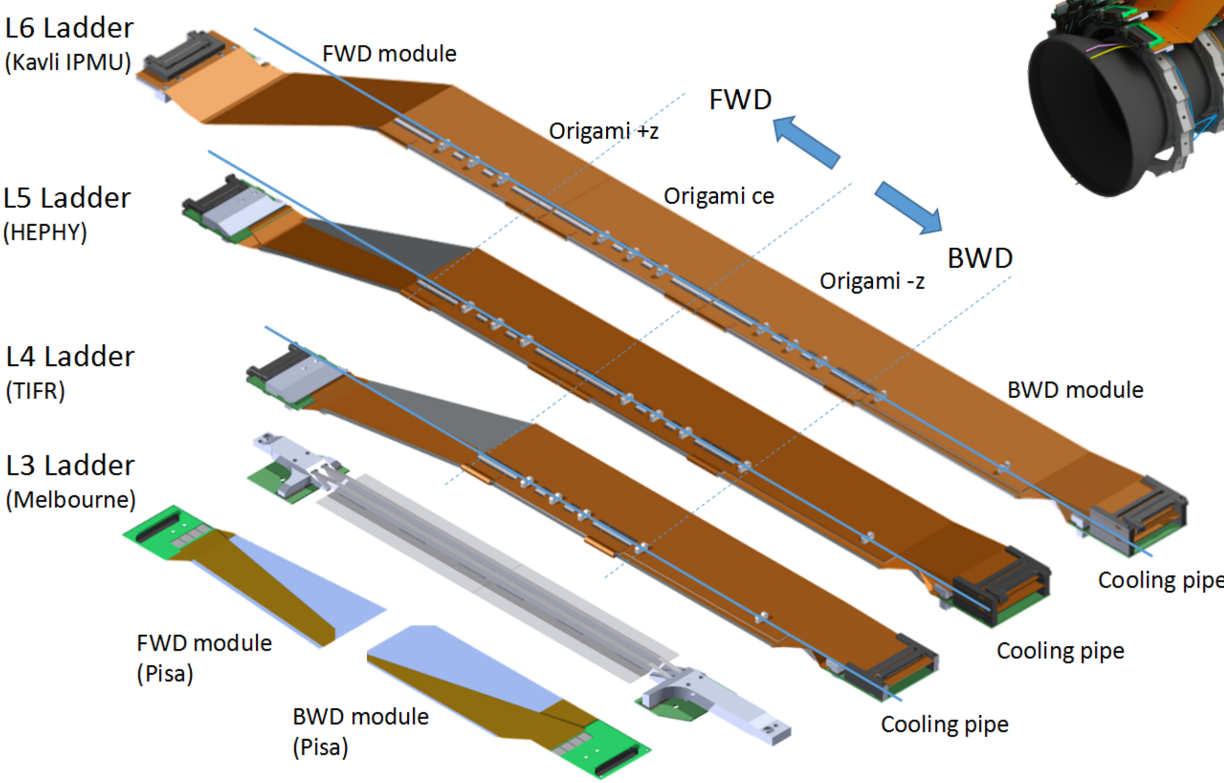




SVD Layout

- For layers.4-6, a slant angle with trapezoidal sensors is implemented in the forward part.
- For Lay.3 and forward/backward DSSDs of Layers.4-6, the APV25s are mounted in the end of the ladder and get support and cooling with the endrings.
- The barrel DSSDs of Layers.4-6 are cooled by pipes.





Layer	Ladders(DSSDs)
6	16 (5)
5	12 (4)
4	10 (3)
3	7 (2)

VXD Cooling Requirement

Powder Consumption

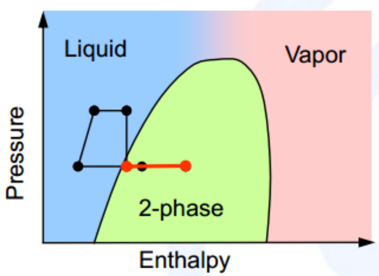
CO_2 Circuit	Detector	Half	Layer	Type	Side	Power [W]
1	PXD	up	1&2	endring	bwd	90
2			1&2	endring	fwd	90
3		down	1&2	endring	bwd	90
4			1&2	endring	fwd	90
					sum PXD	360
5	SVD	left	3-6	endring	bwd	93
6		right	3-6	endring	bwd	93
7		left	3-6	endring	fwd	93
8		right	3-6	endring	fwd	93
9		left	4&5	origami	bwd	68
10		right	4&5	origami	bwd	68
11		left	6	origami	bwd	96
12		right	6	origami	bwd	96
					sum SVD	700
					sum VXD	1060

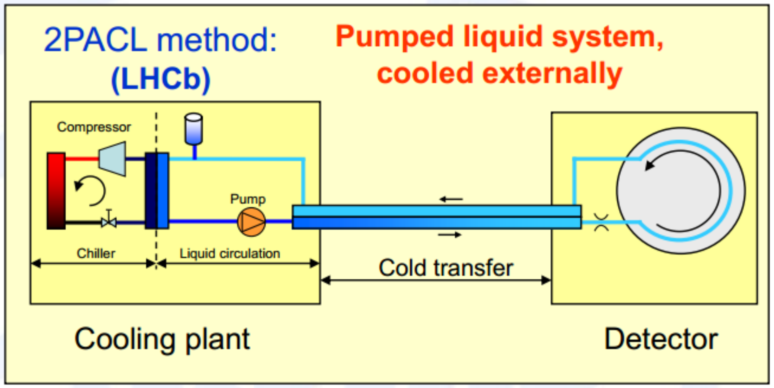
Requirements

- PXD: Sensor < 25ºC to minimize shot noise due to leakage current; ASICs < 50ºC to avoid risk of electro-migration.
- SVD: APV25 readout chips surface@~0ºC for SNR improvement.
- Power consumption: PXD 360W; SVD 700W, together with the heat load through 9m of vacuum isolated flex lines; required cooling capacity of 2-3kW.
- VXD needs to be thermally isolated against CDC and beam pipe. Room temperature at the inner surface of CDC is required for stable calibration and dE/dx performance

2-phase CO_2 cooling

New cycle for particle detectors: 2PACL
(The 2-Phase Accumulator Controlled Loop)





- The 2PACL has the following advantages:
  - Cycle stays on the liquid side, no heat required (experiment can be cooled unpowered and no control heaters required)
  - Evaporator pressure=(temperature) controlled with a 2-phase vessel away from the experiment. No local control nor sensing needed!
  - All control hardware in a distant accessible cooling plant
  - Primary cooling can be anything, no accurate temperature control needed as long as it is colder than the 2PACL 2-phase temperature.
  - Inlet fluid state defined by physics => saturated liquid.
  - Large temperature range (typical from room temperature down to -40°C)

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From B. Verlaat, SLAC Advanced Instrumentation Seminars in March 2012

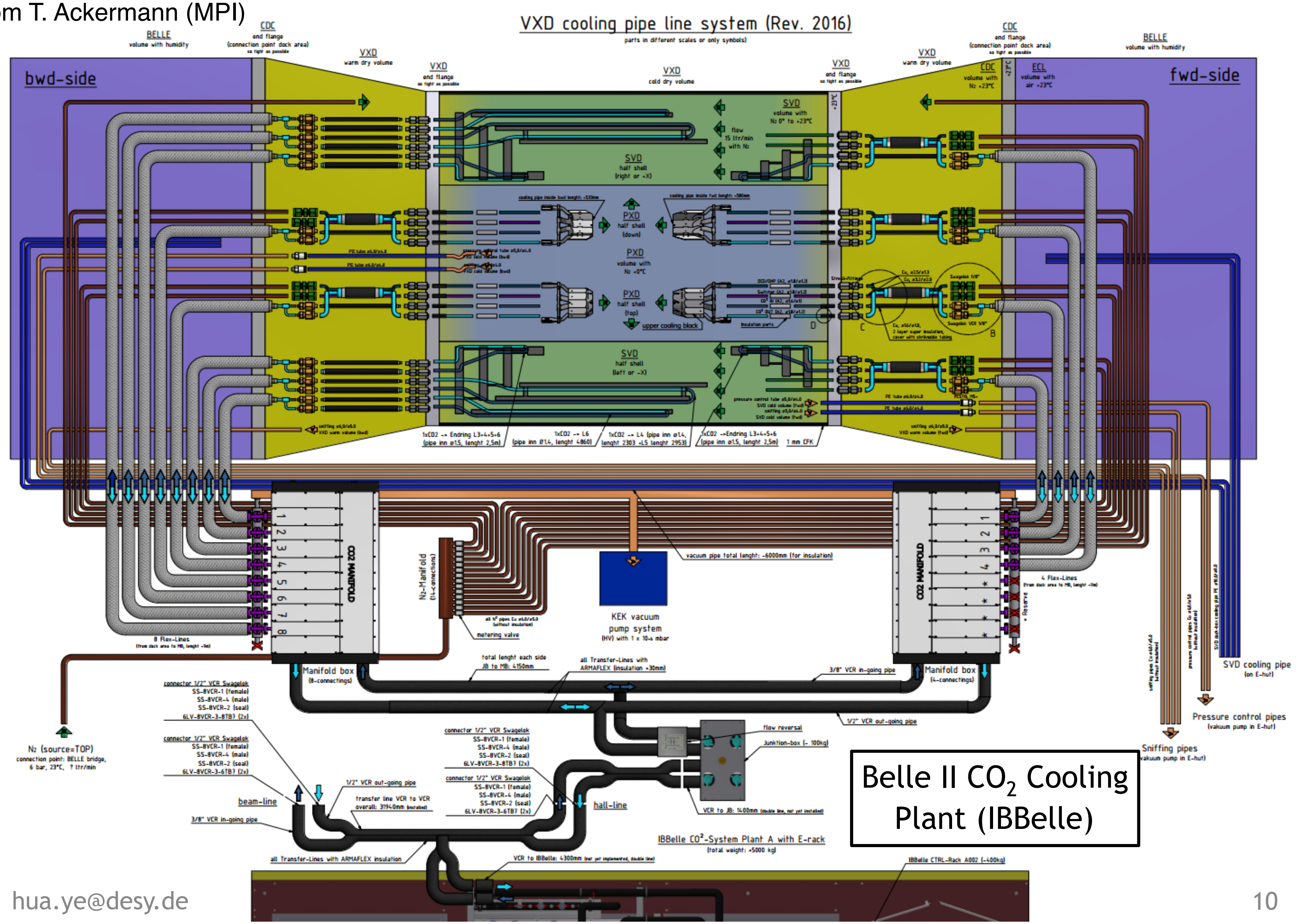
MARCO : ***M***ultipurpose ***A***pparatus for ***R***esearch on ***CO_2***

The 2-phase CO_2 cooling is an efficient concept for low-mass detector.

- ➢ Heat removal by evaporating liquid CO_2 at the constant temperature and pressure.
- ➢ The temperature can be controlled and monitored by the pressure.
- ➢ Challenges: need to guarantee the 2-phase state, otherwise “dry-out”.

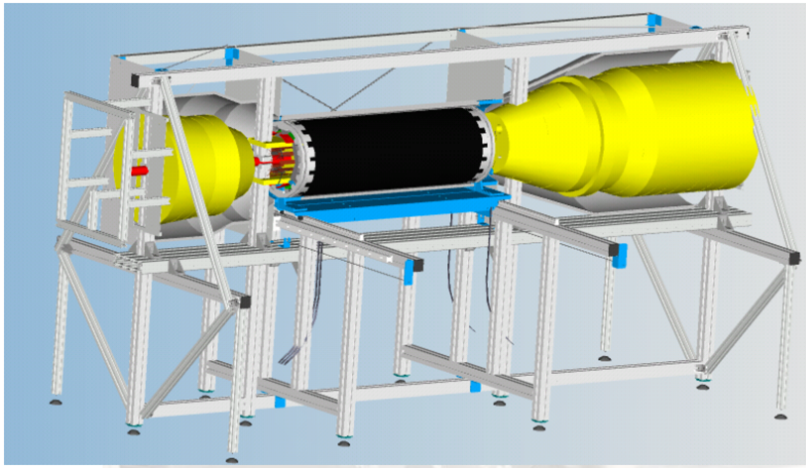
VXD Cooling System

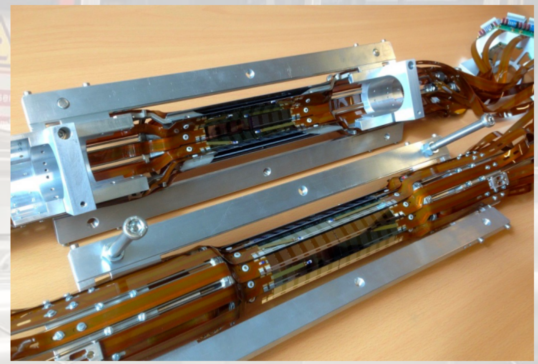
From T. Ackermann (MPI)

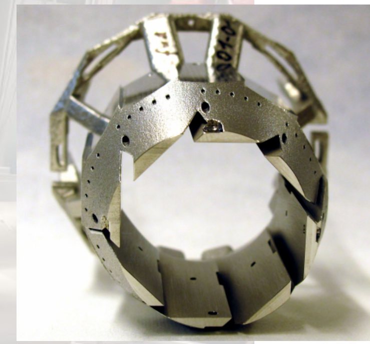


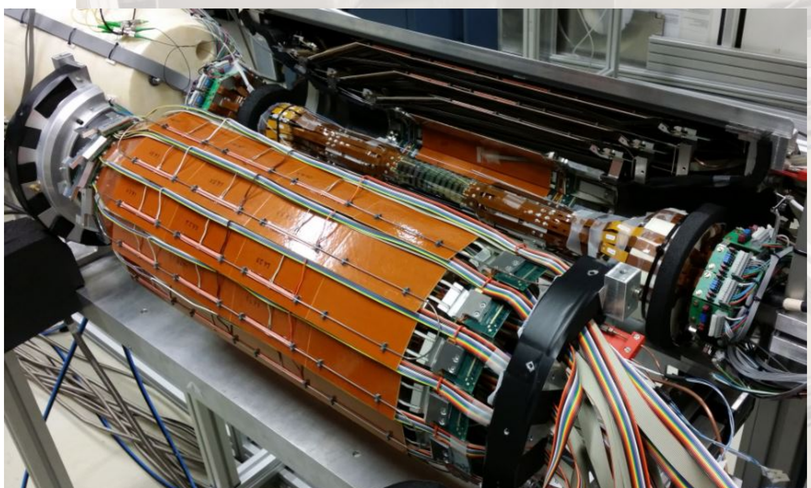
VXD Thermal Mockup@DESY

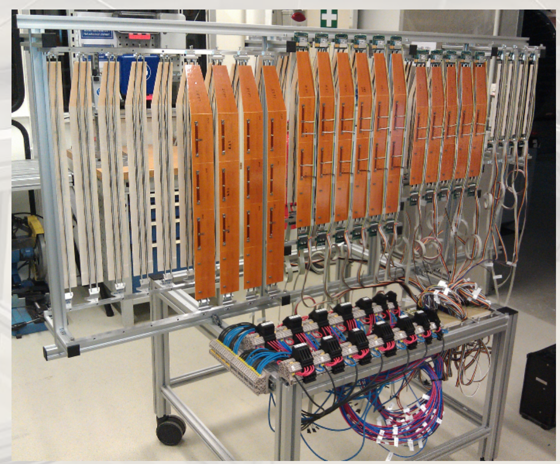
VXD Thermal Mockup@DESY

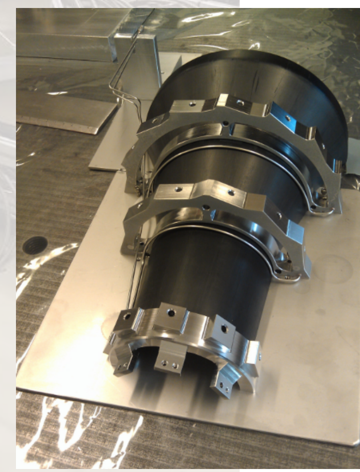






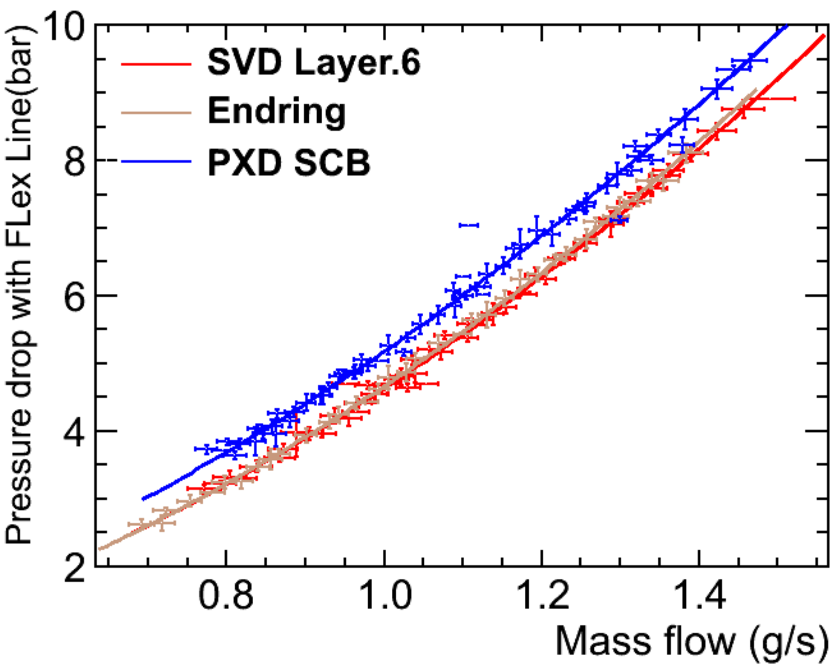


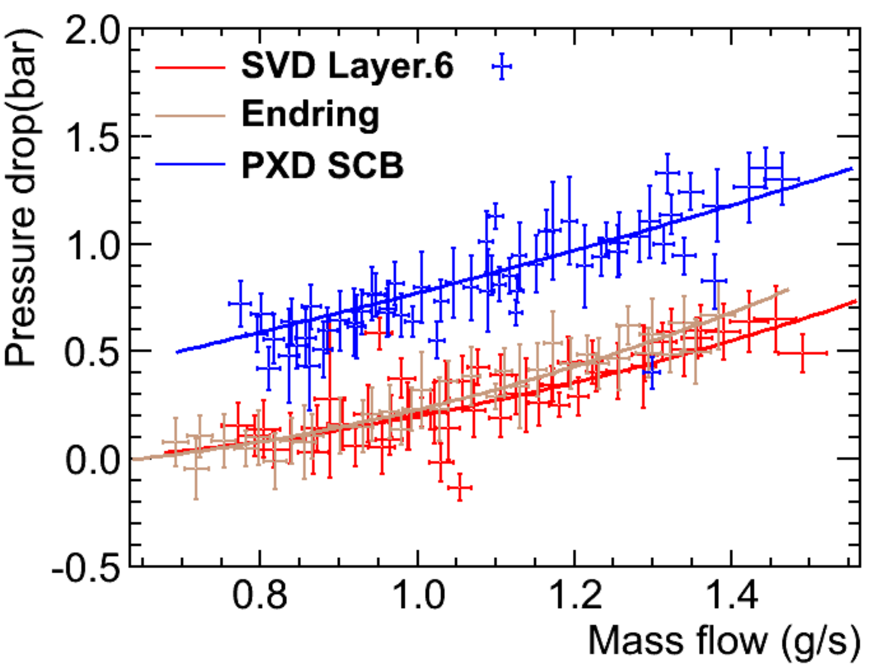




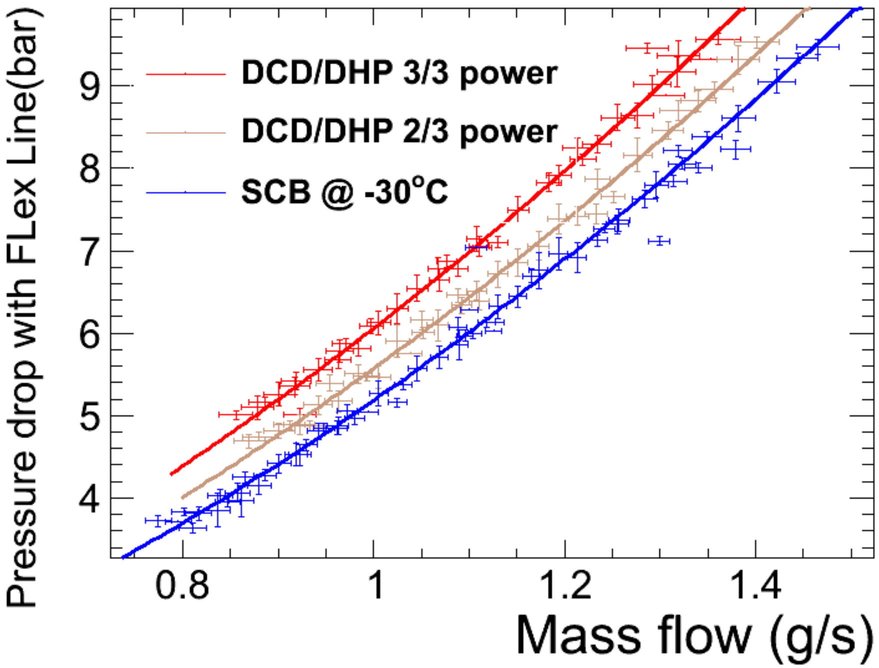
Pressure drop in Cooling Circuit

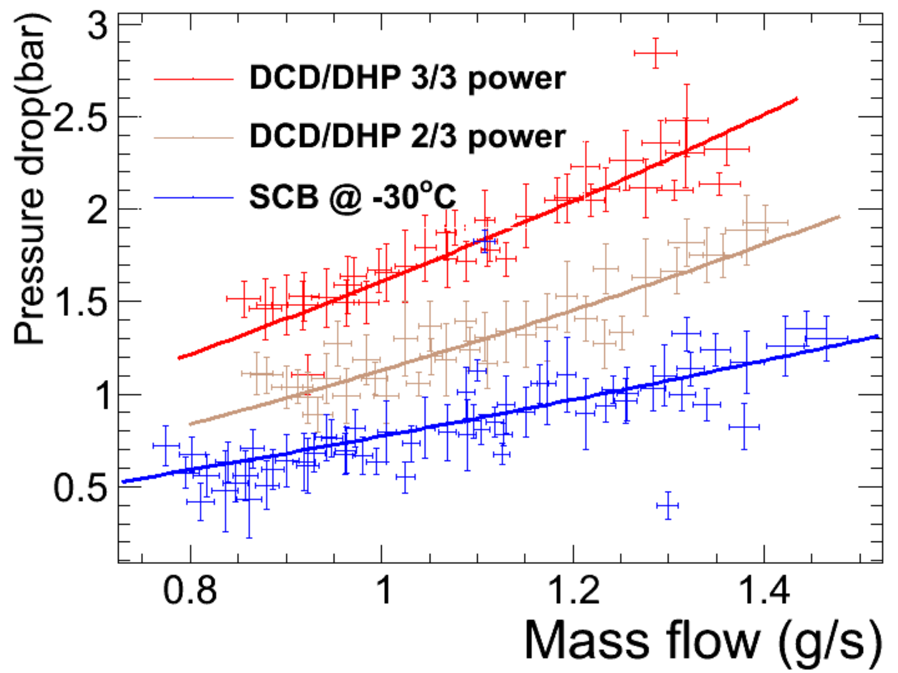
- The long and thin cooling lines cause pressure drops, which result in temperature gradients.
- Relatively big contribution of pressure drop in transfer flex line, to ensure balanced CO_2 mass flow in each circuit.





Pressure drop in Cooling Circuit

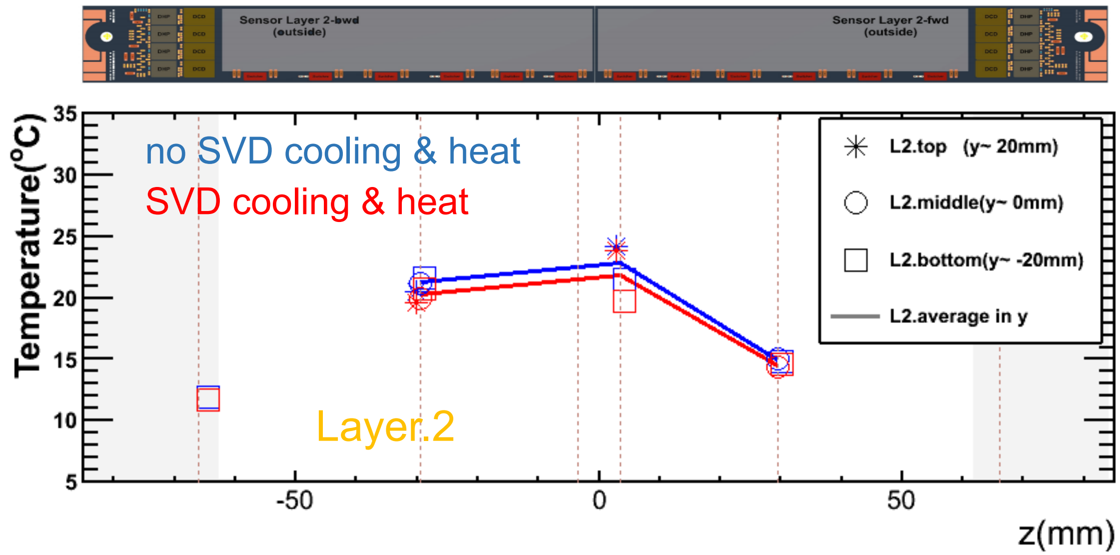


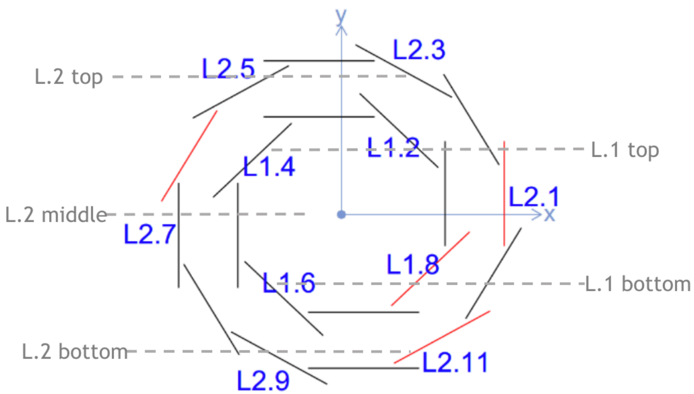


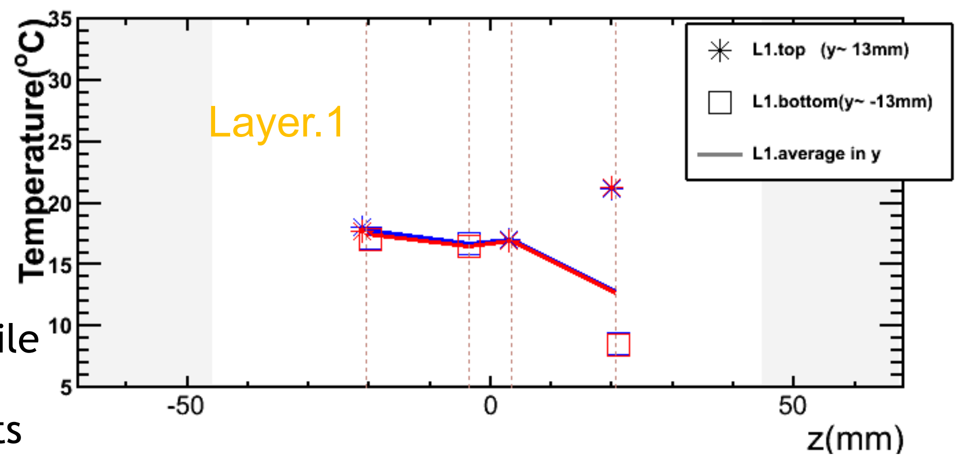
- Additional pressure drop of about 1 bar results from the heat load in PXD ASICs.

Temperature Distribution on PXD

- CO_2@-25°C; N_2 20L/min
- Power consumption*:
  - DCD/DHP 8W, Switcher 0.5W,
  - matrix 0.5W
- Temperature is monitored by resistance thermometers.
- With SVD cooling and power on, temperature on PXD changes ~2°C.





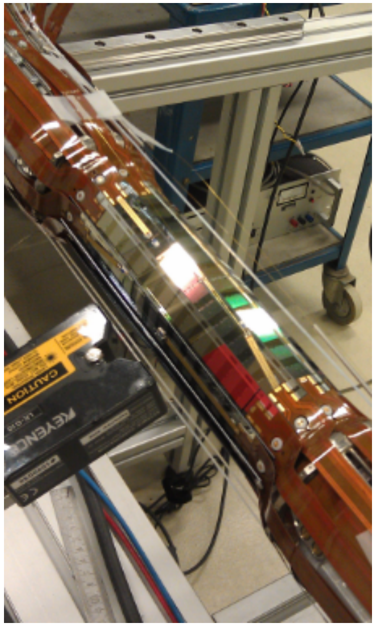


ΔT_Y ~ 5°C, ΔT_Z ~ 7°C

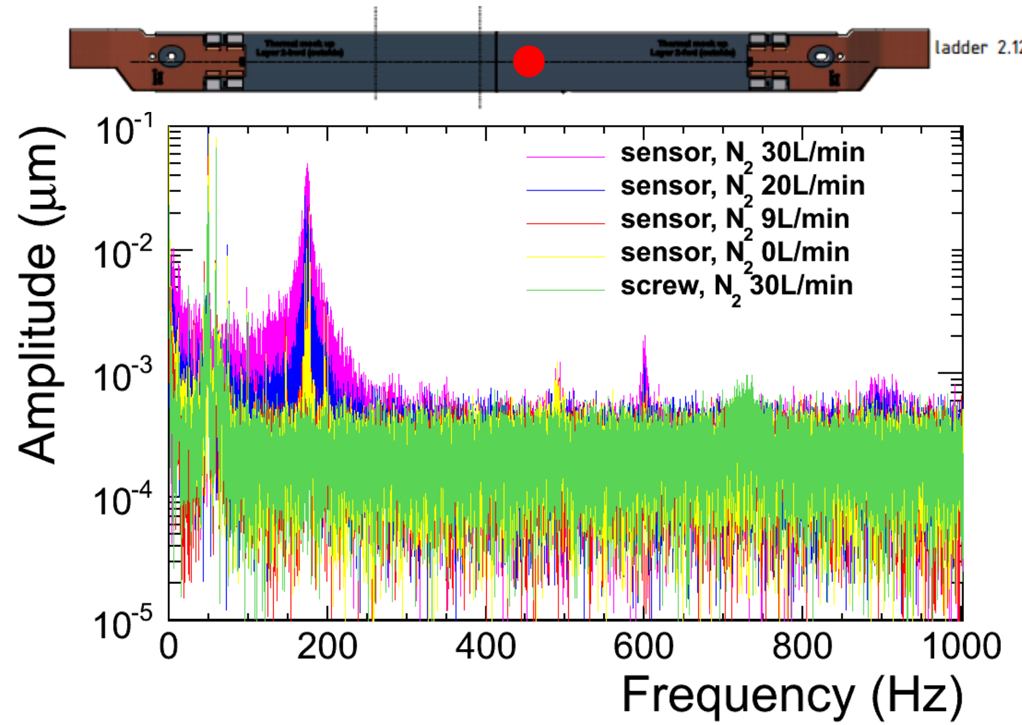
- By changing the CO_2 set point, the temperature distribution gets shifted, while the gradients stay.
- By increasing the N_2 flow, the gradient gets improved.

** Based on the initial numbers for the first versions of chips for DEPFET, the final numbers need to be confirmed in future.*

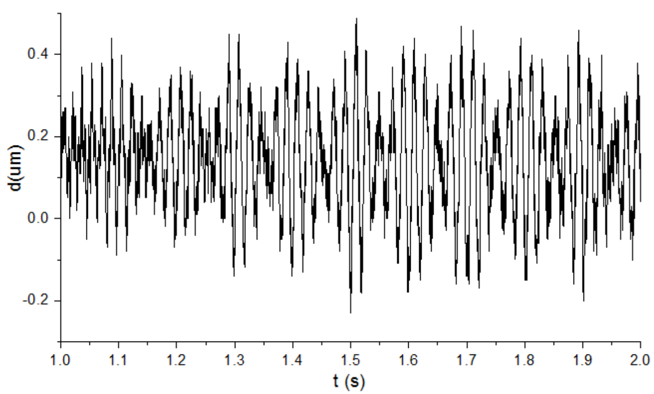
Vibration v.s. N_2 flow



Using non-contact laser displacement sensor

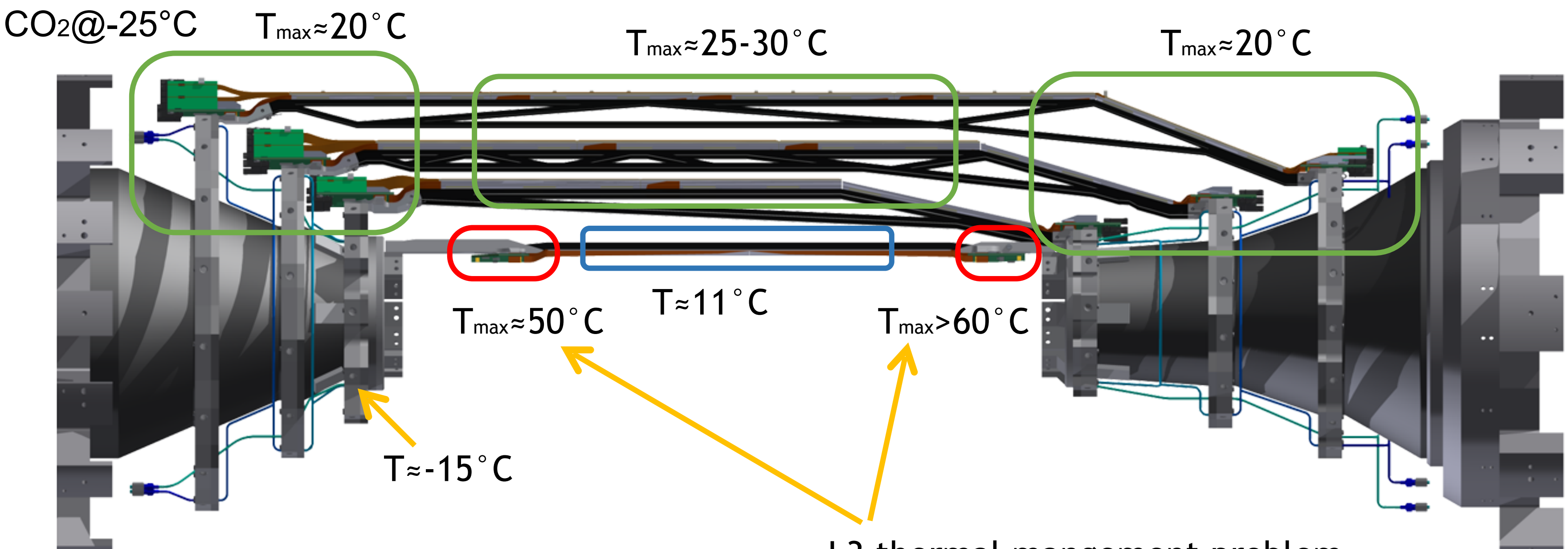


Vibration with RMS amplitude about 0.2um.



- A peak at about 175 Hz is observed, amplitude increases with the flow rate reaching about 0.02µm when 20L/min of N2 is injected.
- Flat background indicated by the measurements at the fixation screws on the SCB.

Temperature in SVD

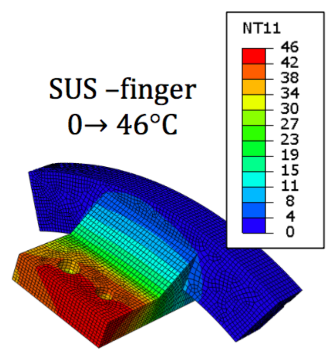


L3 thermal mangement problem

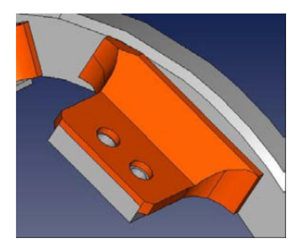
- Finite Element (FE) Simulation indicates most of the gradient (~45°C in FW) is in the endring finger, made of stainless steel.

- Temperature in the middle of L.3 sensors is strongly influenced by PXD, therefore relies on the injected N2 flow.

- For L4/5/6, with nominal load, the maximum temperature on FW/BW edges reaches about 20°C, and module ASICs reach about 25-30°C.



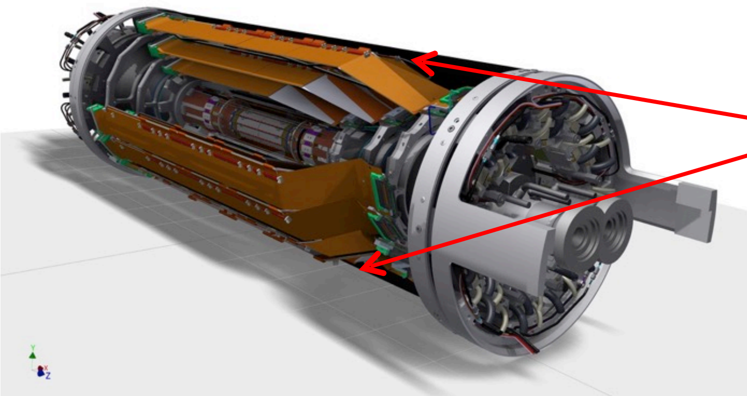
Update with copper insert, under testing in Melbourne.



Temperature in VXD Volume

Temperature on the top/bottom of inner side of VXD CFRP shield and CDC inner surface (Al shield).

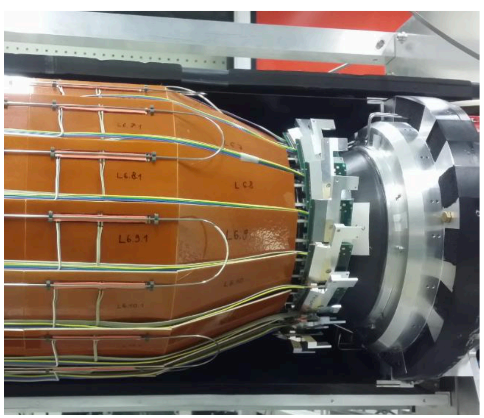
CO_2@-25°C

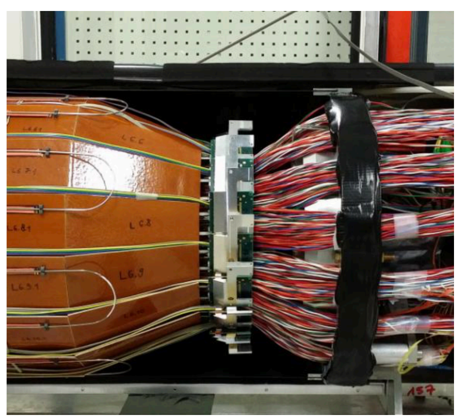


	VXD shield inner surface	CDC inner cover
top	10	15
bottom	4	8

About 6°C's gradient.

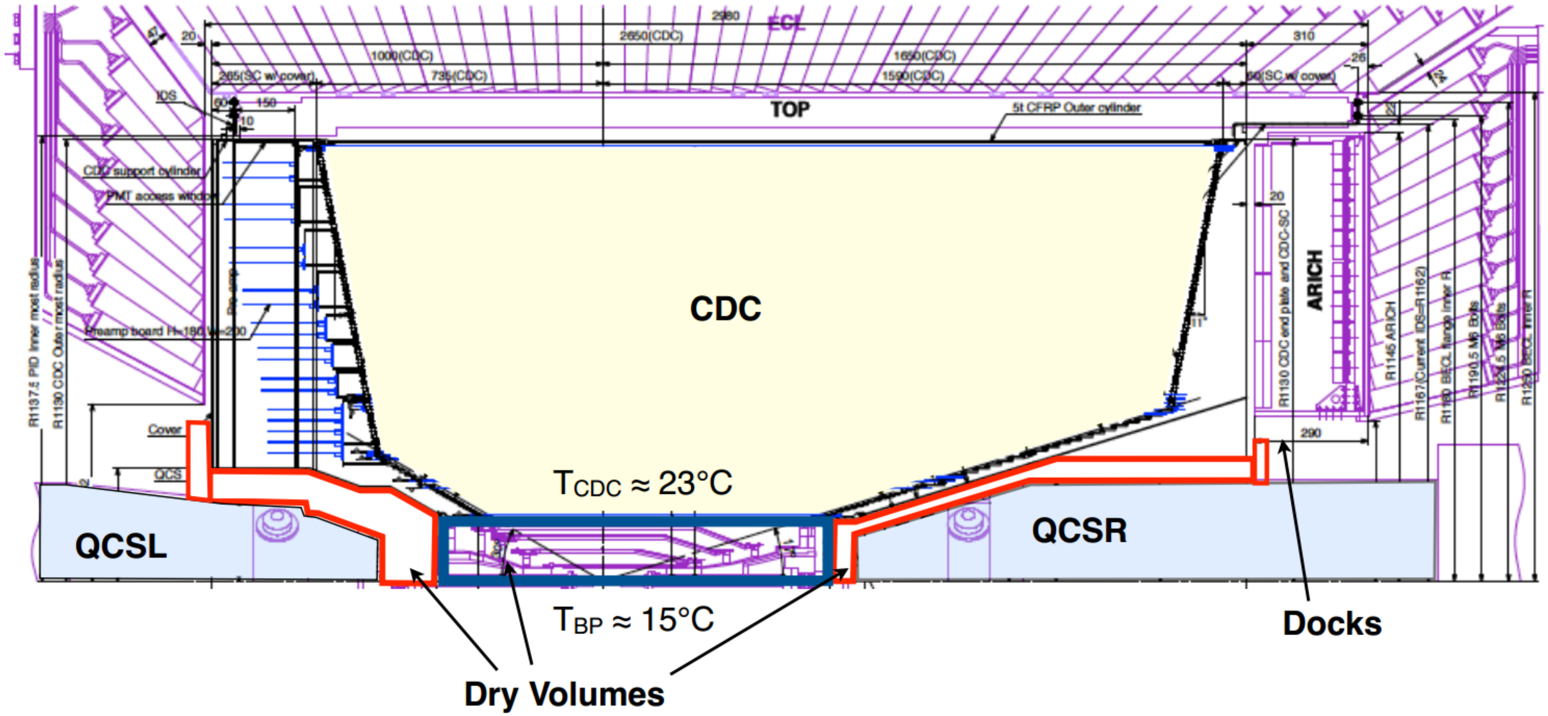
Thermal transfer through cables

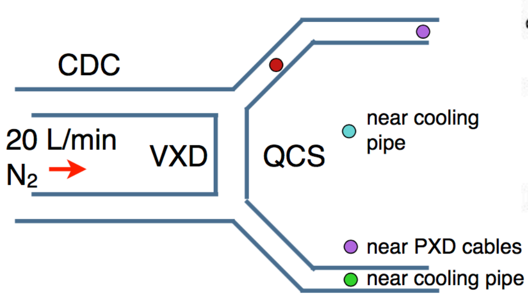


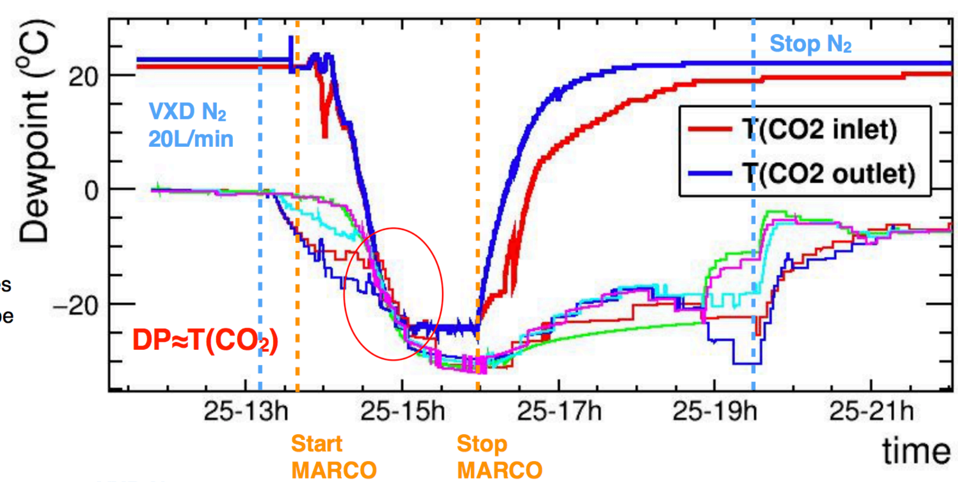


- Electronic cables are insert to FW +x half endring, contacting L5&6.
- Little influence from cables' thermal conductivity.

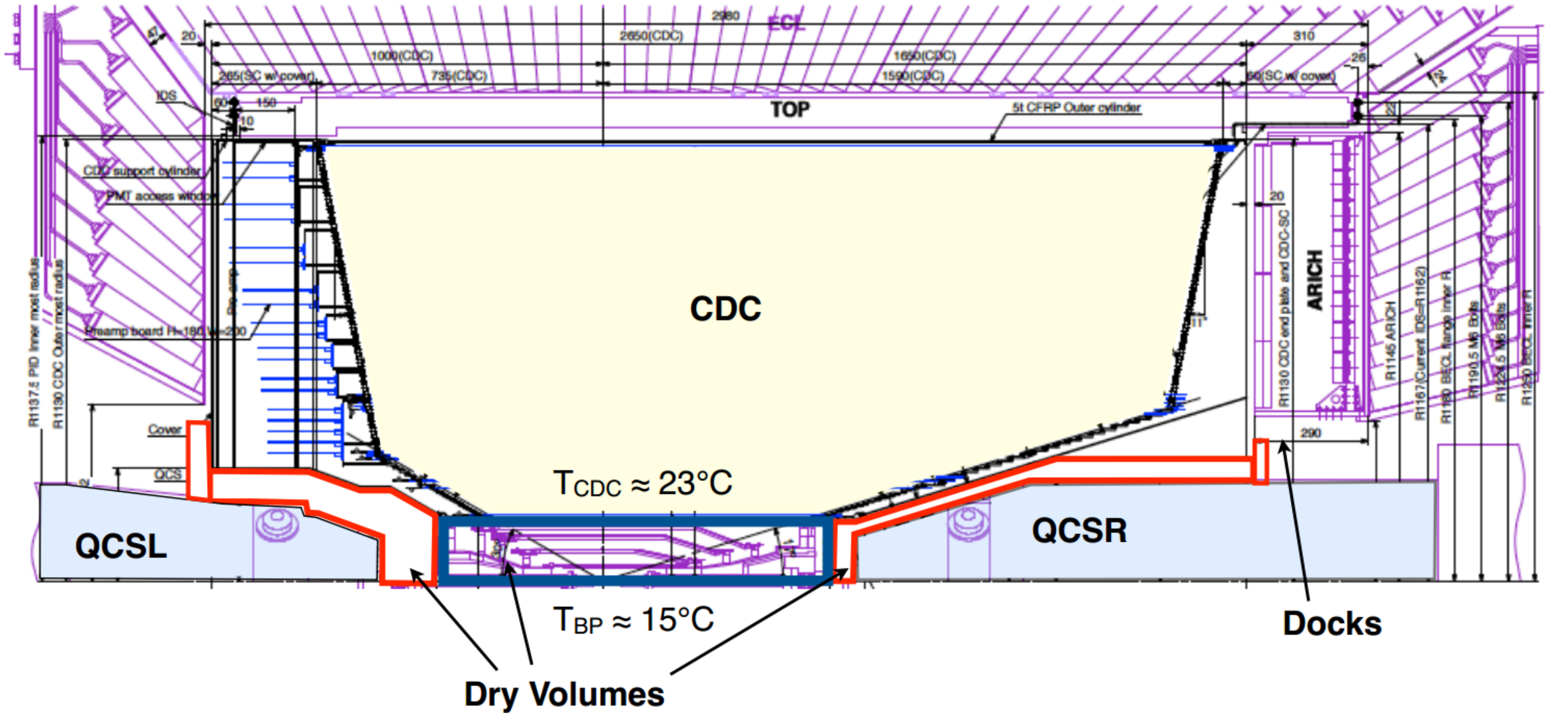
Dew Point in Dry Volume v.s. N_2 flow

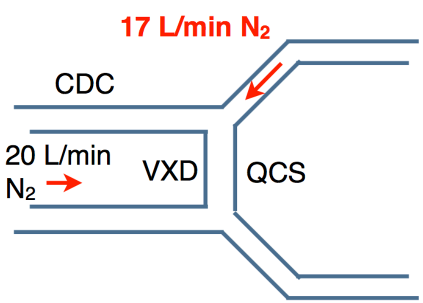


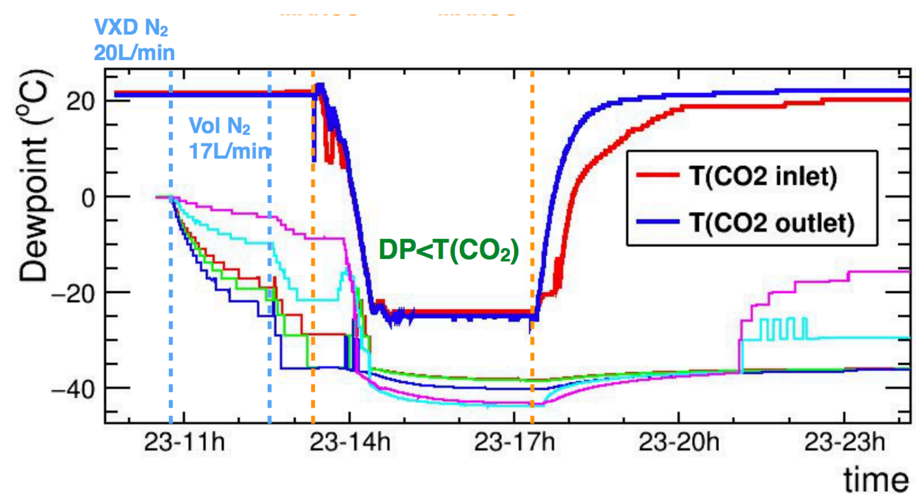




Dew Point in Dry Volume v.s. N_2 flow







Summary

- Operating environment of Belle II PXD and SVD are strongly coupled, meanwhile, it will influence the surrounding drift-chamber (CDC). Evaporative 2-phase CO_2 and airflow injection perform VXD cooling.
- A full-size thermal mock-up is built at DESY, to verify and optimize the cooling concept of Belle II VXD.

PXD

- With CO2 set at -25°C and N2 flow of 20L/min, temperature on PXD ladders is determined as <25°C.
- Temperature gradient along the sensitive area is ΔT_z ~7°C, top-bottom gradient ΔT_y ~5°C.
- N2 flow of 20L/min induces negligible vibrations on PXD sensors.

SVD

- ASICs on L3 suffer from high temperature, modifications are underway.
- Other ASICs temperature is <30°C.
- Heat transport through SVD electronic cables has minor effect to temperature distribution.

Dry Volume

- N2 injection >20L/min into the dry volume is required to avoid condensation.

CDC

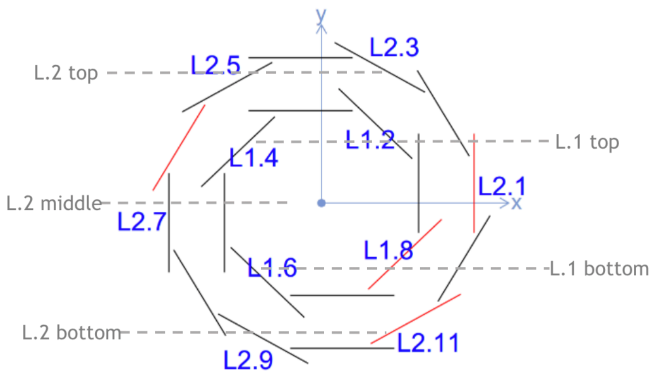
- Temperature on the inner surface of CDC cylinder range from 15°C(top) to 8°C(bottom).

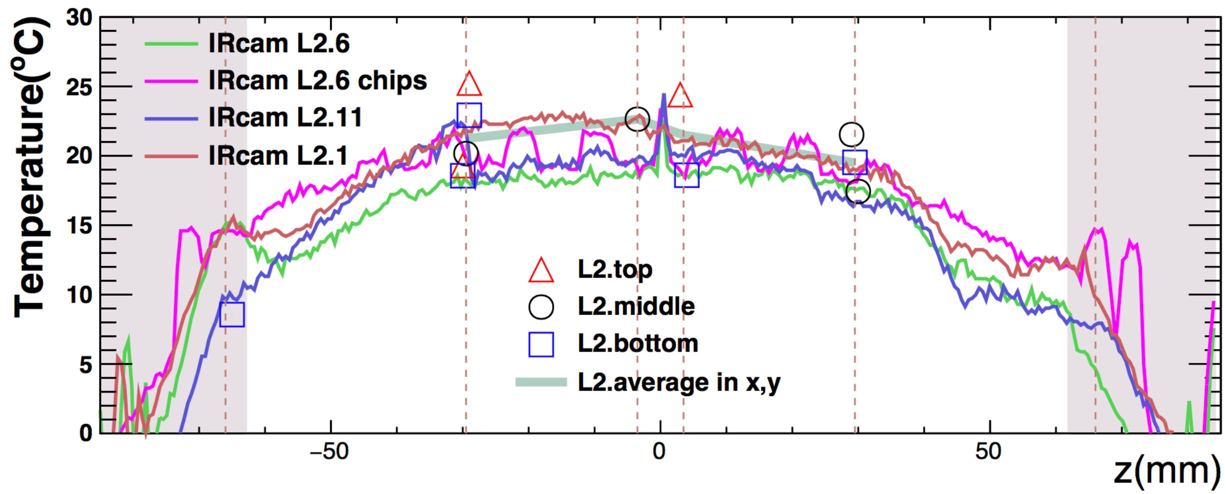
Acknowledgements:
We wish to thank MPI für Physok, München group for preparing the SCBs, MPG-Halbleiterlabor(HLL) group for producing PXD dummy sensors. The Belle II VXD cooling frame is developed based on the experience of ATLAS-IBL, we would like to acknowledge the support form CERN experts.

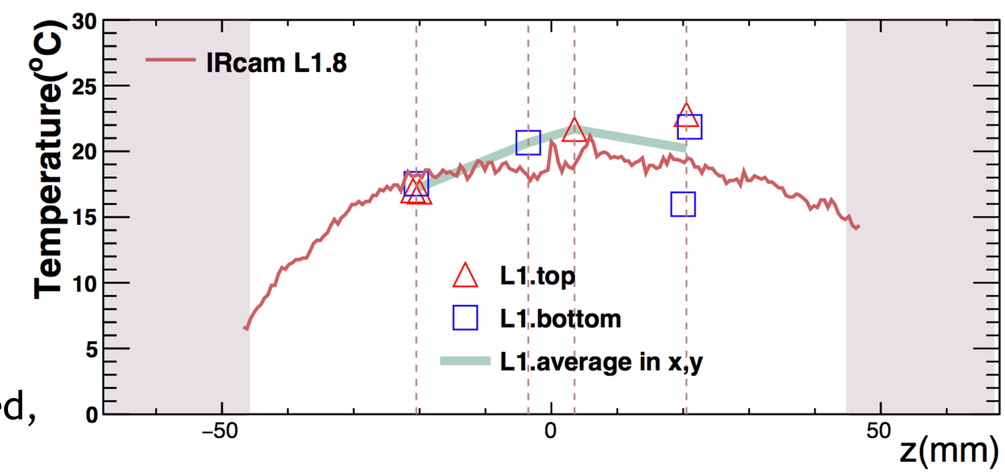
Backup

Temperature Distribution on PXD

- CO_2@-30ºC; N_2 23L/min
- A plastic cylinder (ID 18cm, length 70cm) act as dry volume.
- Temperature is monitored by resistance thermometers, Pt100s and infrared camera





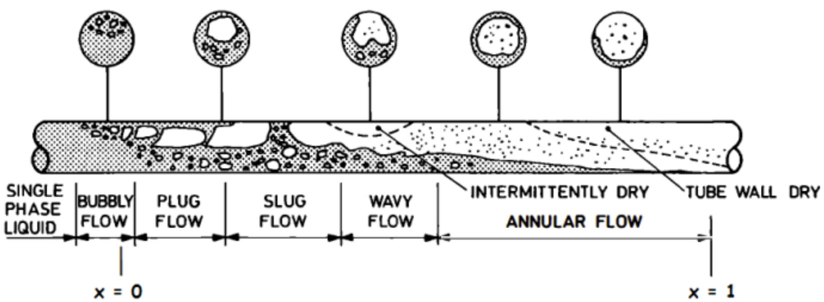


- By changing the CO_2 set point, the temperature distribution gets shifted, while the gradients stay.
- By increasing the N_2 flow, the gradient gets improved.

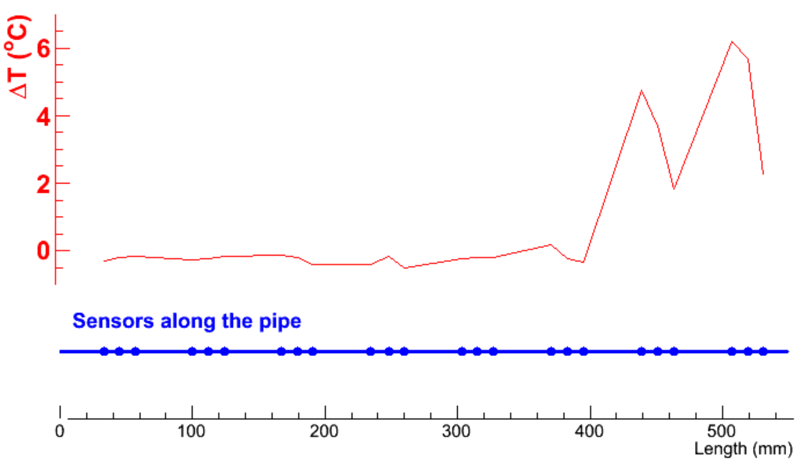
$\Delta T_Y \sim 5^oC$, $\Delta T_Z \sim 7^oC$

Study Onset of Dry-out

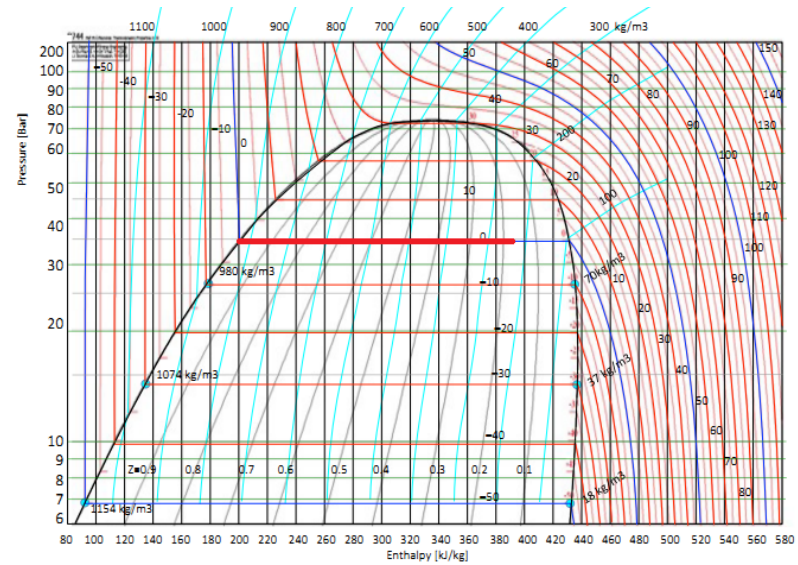
When the vapor quality gets too high, there will be no liquid film on the capillary walls, then result in a shape increase of the cooling block temperature.



Dry out



The dry out happens in the last 6 sensors



Estimated mass flow to get rid of 'dry out'

- ➢ CO_2@-30°C, mass flow in the mockup should not be lower than 5.4 g/s, giving the pressure drop of about 1.7 bar in the cooling circuit.