Thermal Test and Monitoring of the Belle II Vertex Detector

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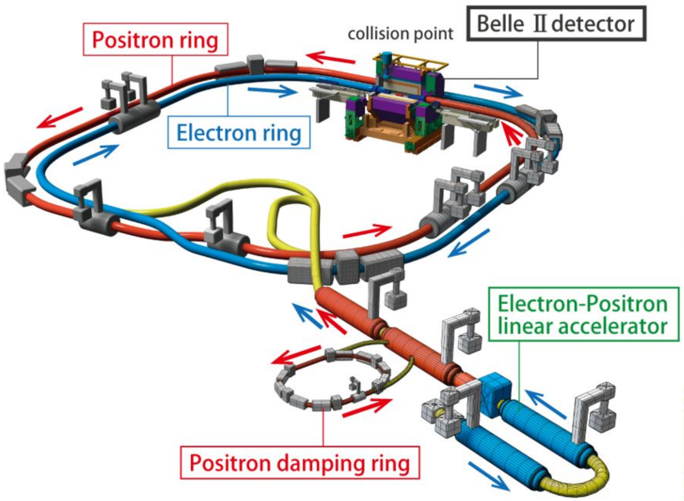
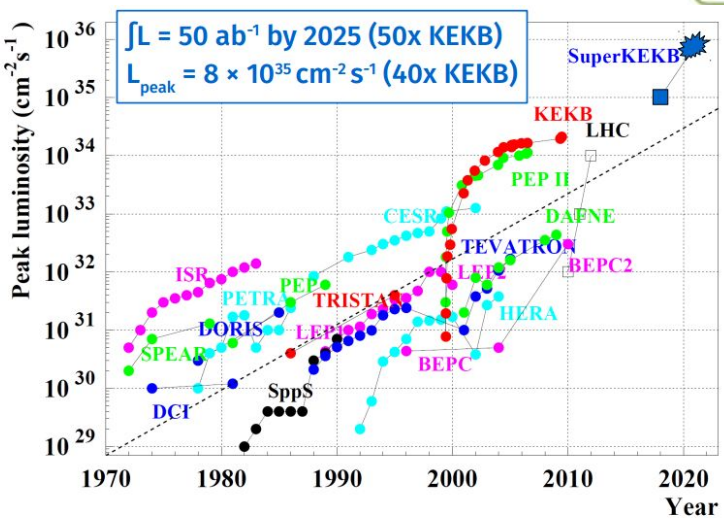
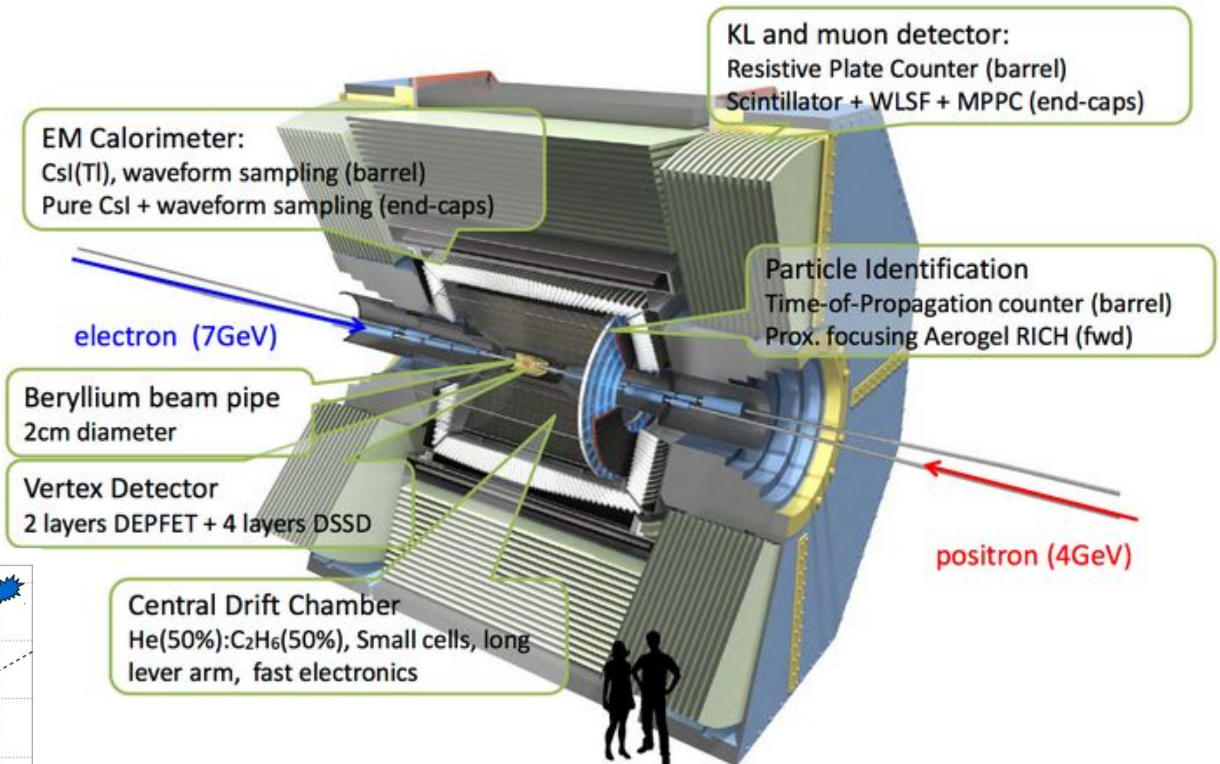
Forum on Tracking Detector Mechanics 2016
Bonn, 23-25 May

SuperKEKB/Belle II Upgrade





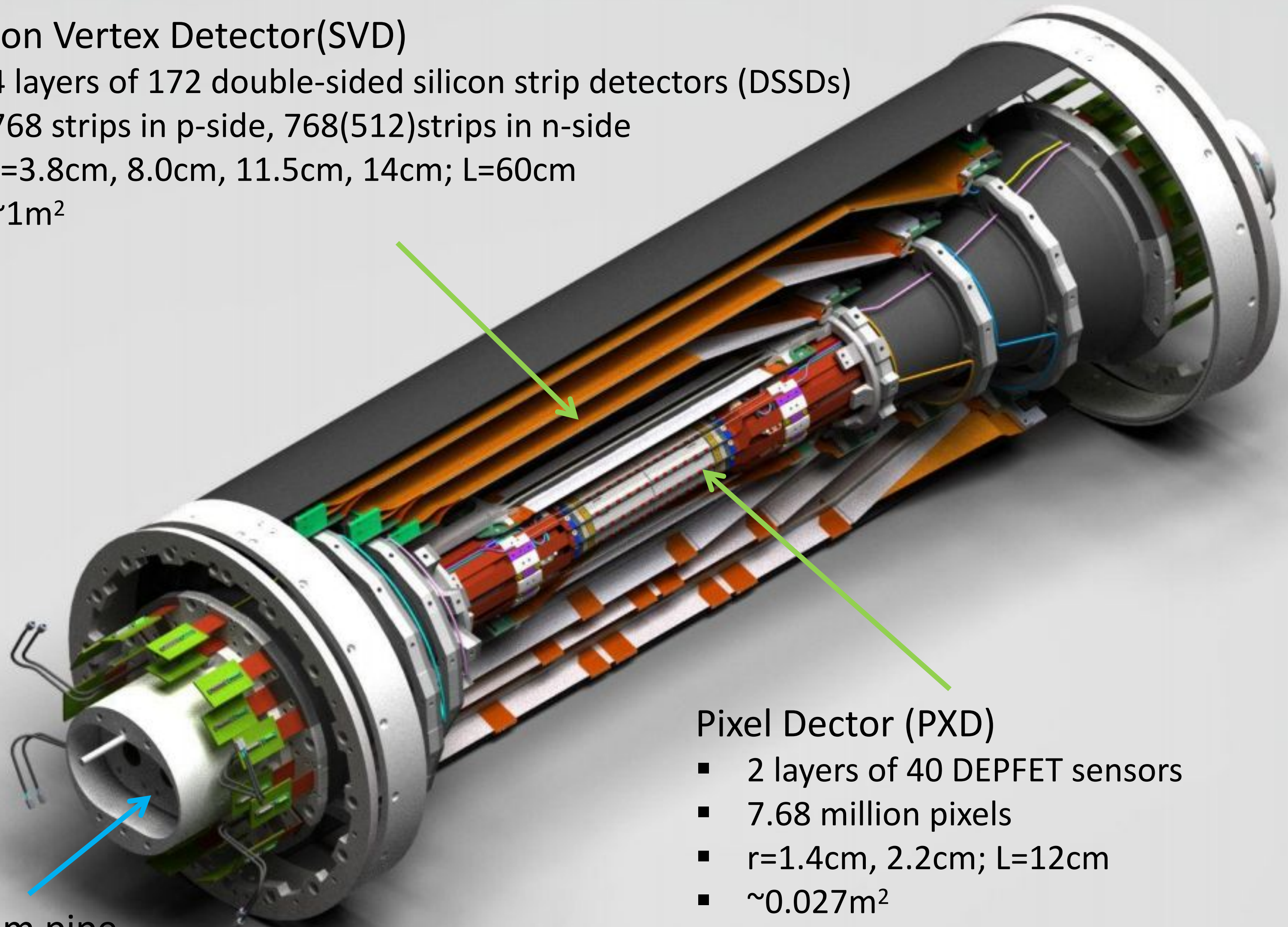


Belle II detector commissioning will start in 2017;
Physics run will start in 2018.

Belle II Vertex Detector (VXD)

Silicon Vertex Detector(SVD)

- 4 layers of 172 double-sided silicon strip detectors (DSSDs)
- 768 strips in p-side, 768(512)strips in n-side
- r=3.8cm, 8.0cm, 11.5cm, 14cm; L=60cm
- ~1m^2

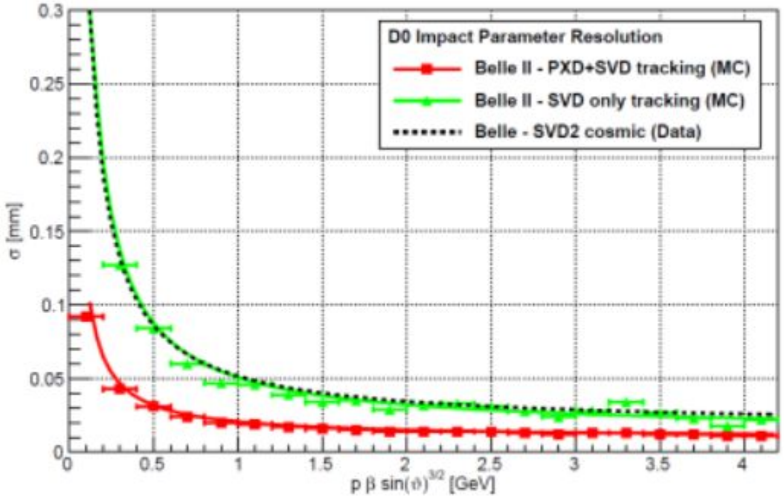


Pixel Dector (PXD)

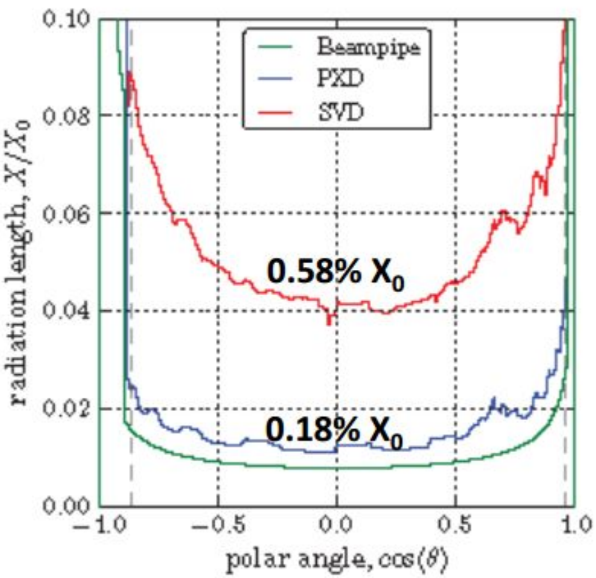
- 2 layers of 40 DEPFET sensors
- 7.68 million pixels
- r=1.4cm, 2.2cm; L=12cm
- ~0.027m^2

Belle II PXD Requirements

	Belle II PXD
Occupancy	<3%
Radiation	2 Mrad/year (TID)
	$2X10^{12}$ 1MeV n_{eq}/cm^2/year (NIEL)
Readout time	20 µs
Momentum range	80MeV to a few GeV
Acceptance	17^o - 155^o



- Spatial resolution (15 µm)
  → Moderate pixel size of ~ 50 X 50 µm²
- Lowest possible material budget (< 0.2% X_0 per layer)
- Avoid active cooling in sensitive area.

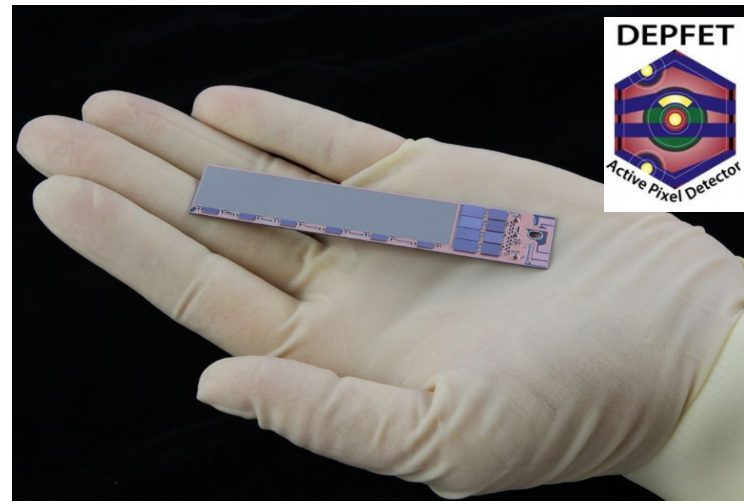


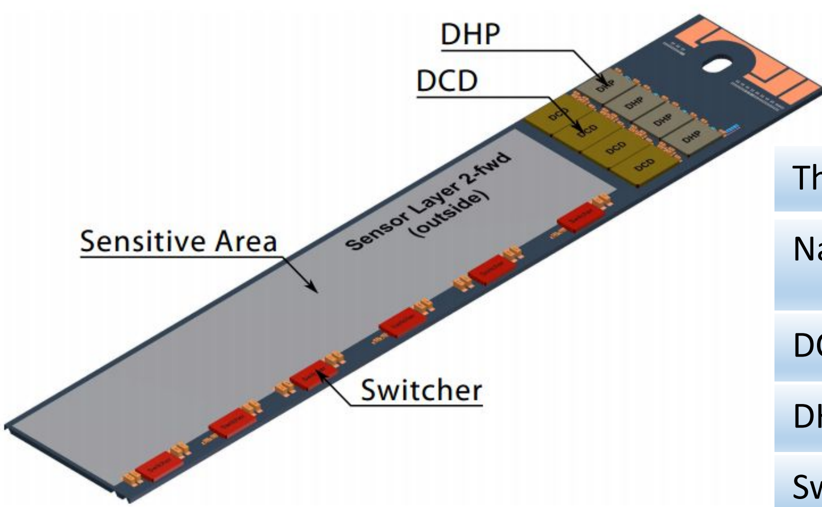
The DEPFET technology can cope with this challenging requirements.

Belle II PXD

Innermost part of the detector: 2 layer pixel detector with 40 DEPFET sensors

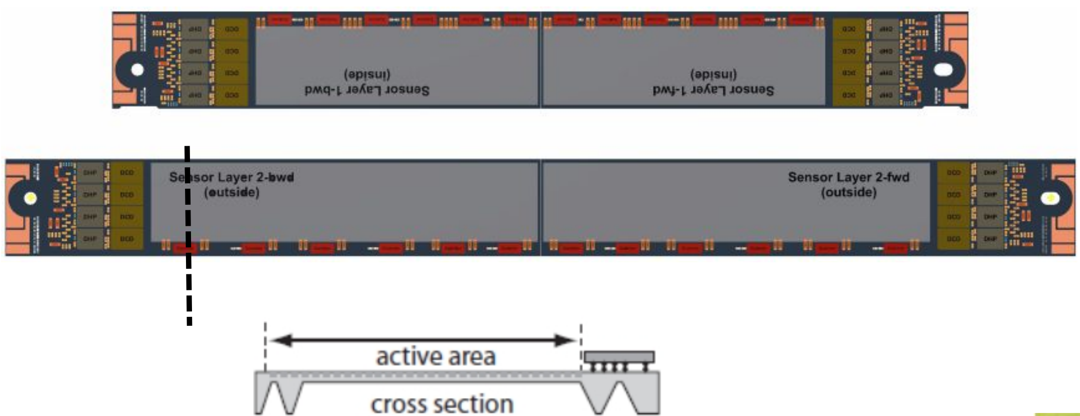
- 250 X 768 pixels with the size of 50 X 50(75) μm²
- sensitive area size:
  12.50 X 44.80 mm² (layer.1)
  12.50 X 61.44 mm² (layer.2)
  will be thinned down to 75 μm.
- sensitive area has power consumption of 0.5 W
- power consumption dominated by the ASICs at the end of sensor (8 W)

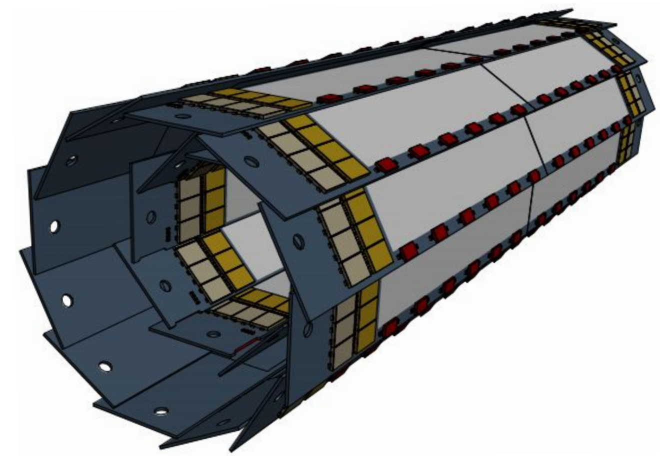


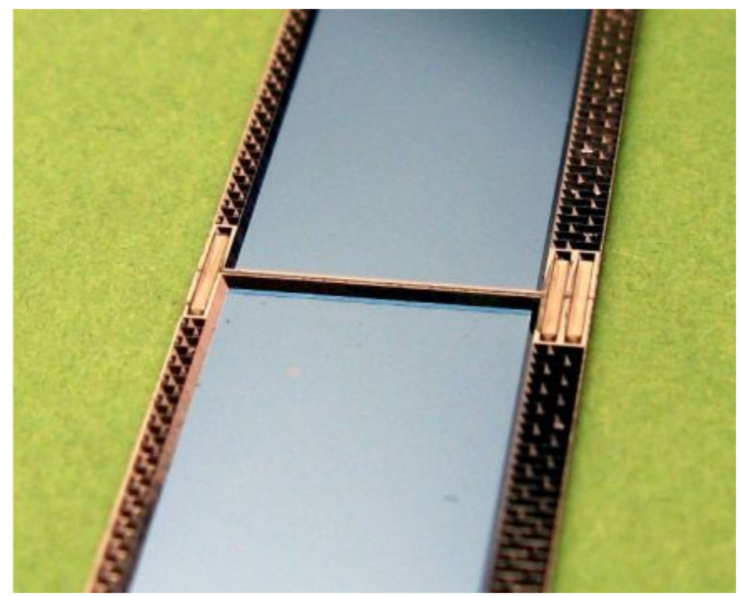


Three different ASICs on the sensor			
Name	Purpose	Position	Power consumption
DCD	Signal digitization	end of sensor	4 W
DHP	Digital signal processing	end of sensor	4 W
Switcher	Row addressing	along the sensor	0.5W

PXD Ladder Design







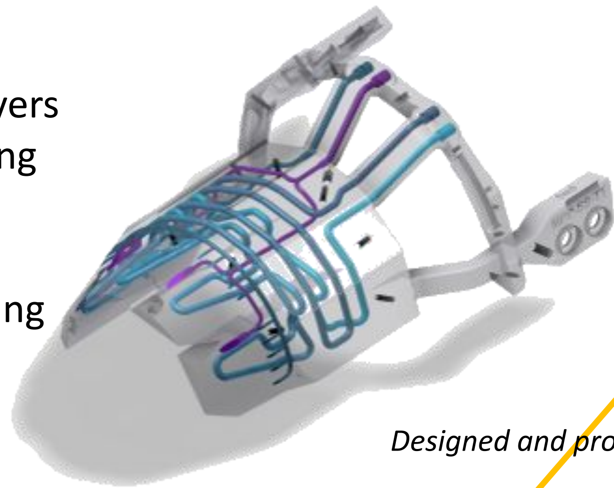
Ladder formed from 2 sensors

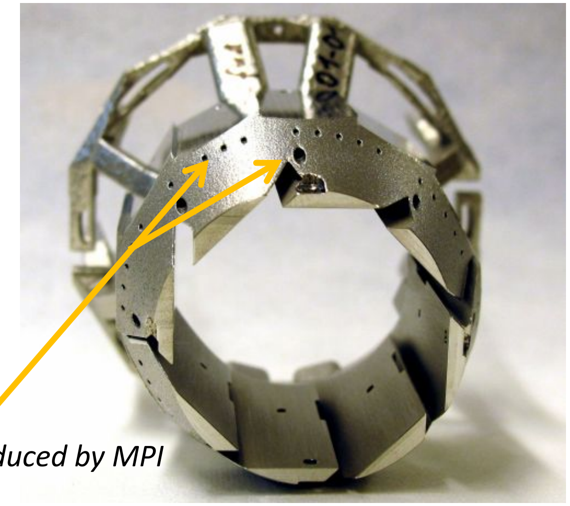
- self supporting
- 4 type of different sensors
- butt-face joint glueing
- ceramic mini-rods embedded in the thick rim of sensor

PXD Ladder Support

One common support for both layers

- 4 combined support and cooling blocks (SCBs)
- connected by silver coated carbon fiber tubes for air cooling and grounding



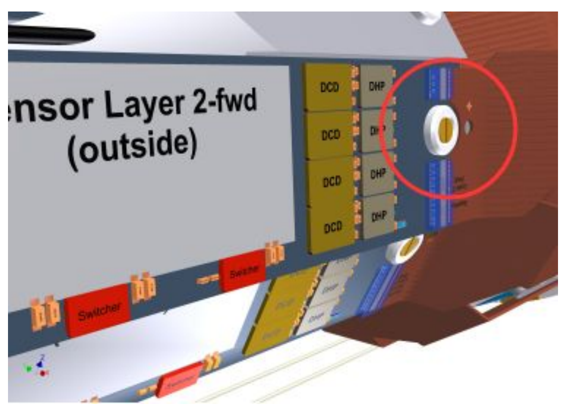


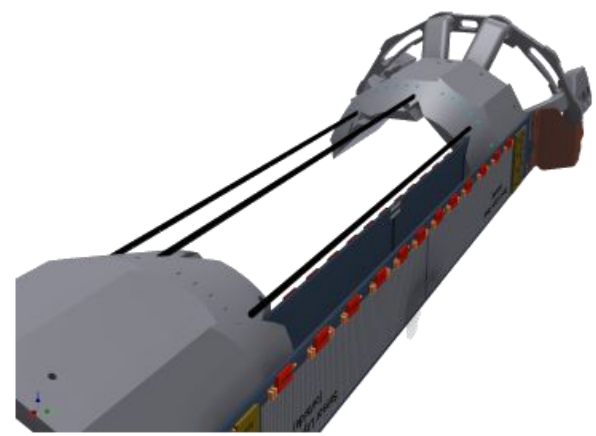
Designed and produced by MPI

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.

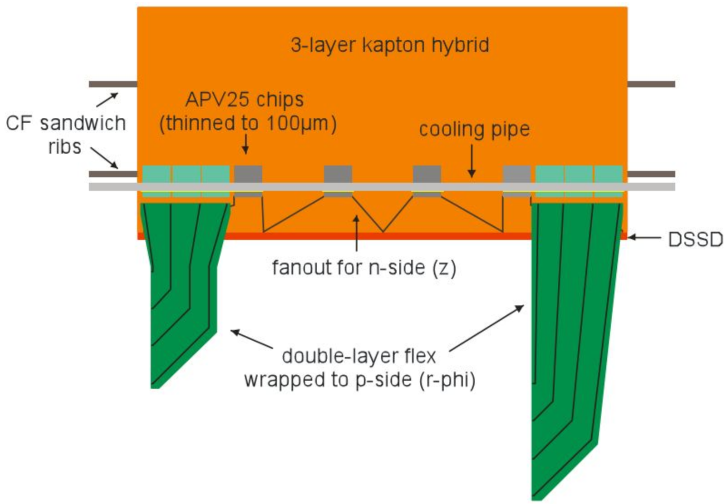


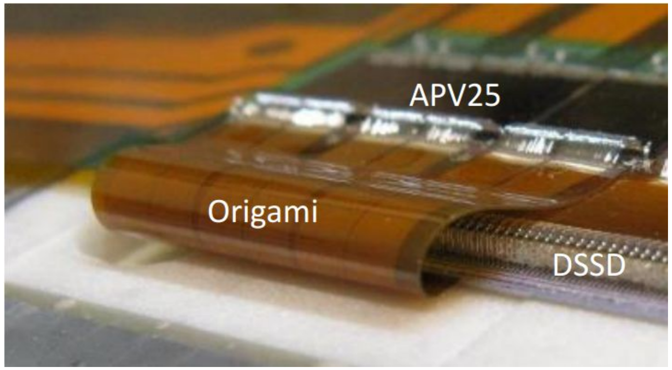


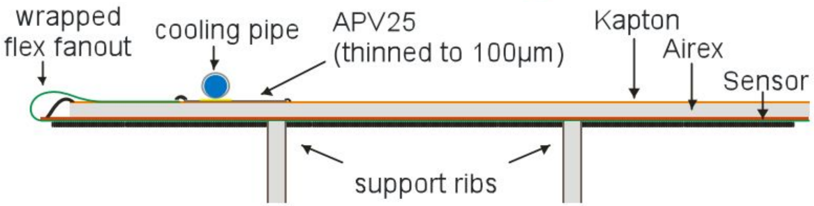
Belle II SVD

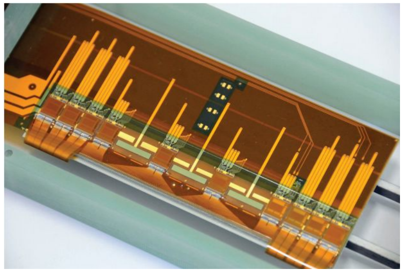
Silicon Vertex Detector

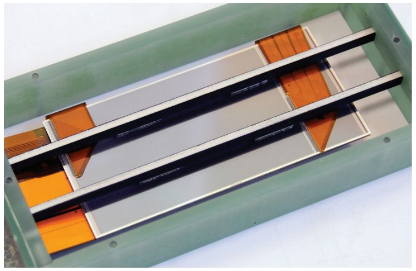
- Four layers from ladders with up to five DSSD sensors in a row.
- Supported by two ribs and Airex foam core sandwich.
- readout chip: APV25 (thinned down to 100 µm thickness)
- the Origami concept, all APV25 are aligned in a row and cooled by a single cooling pipe per ladder.
- Fwd/Bwd sensors are cooled by end rings







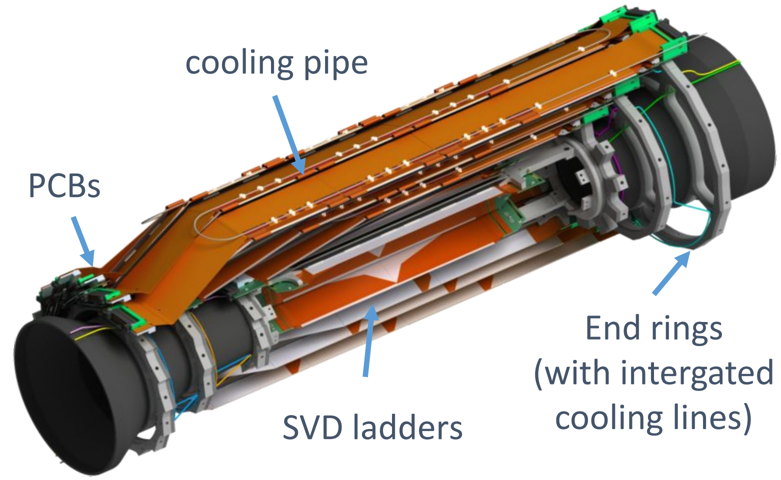


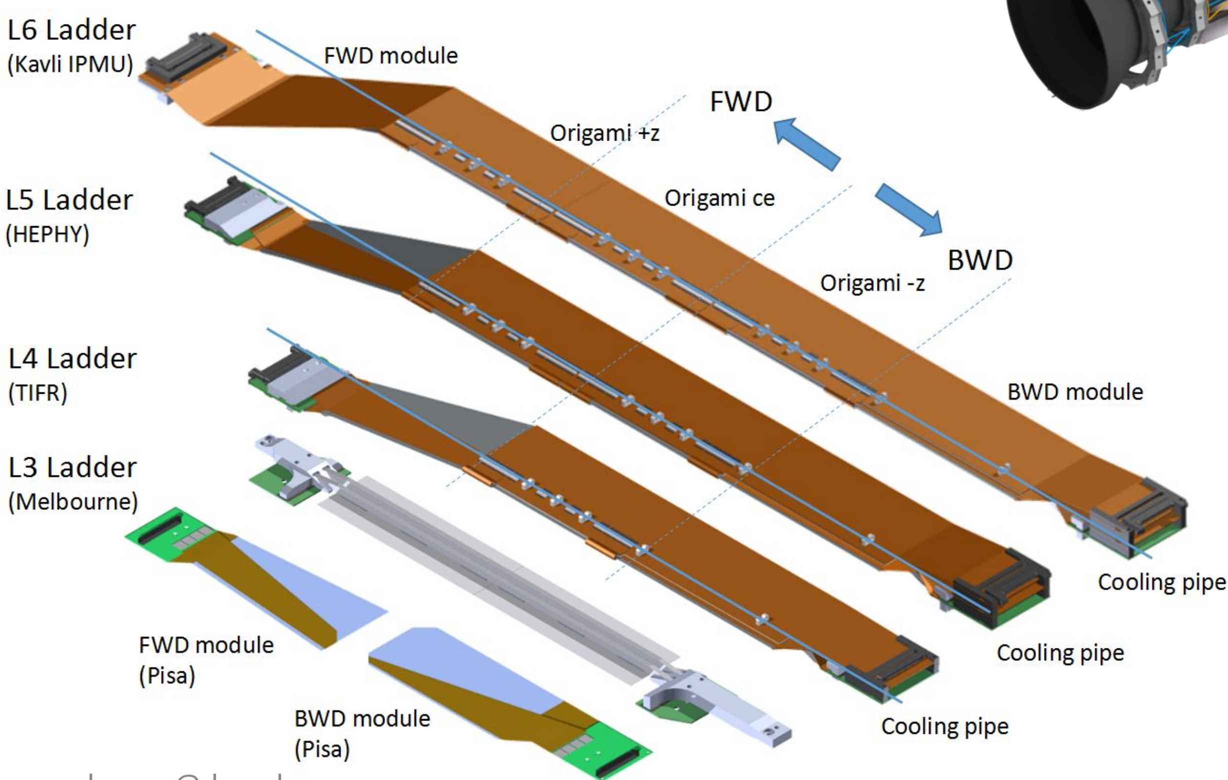


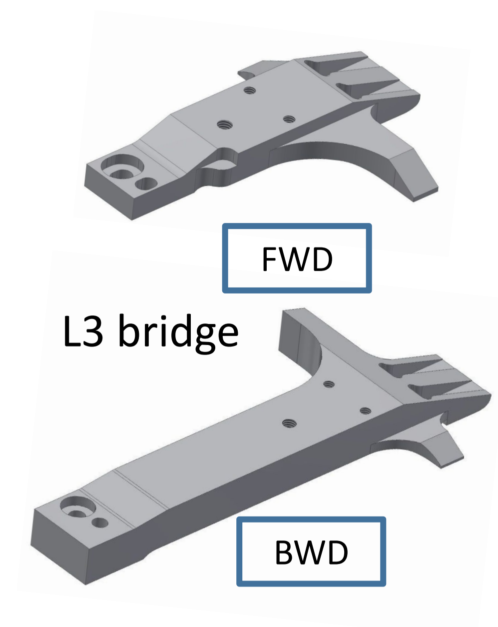
SVD Layout

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

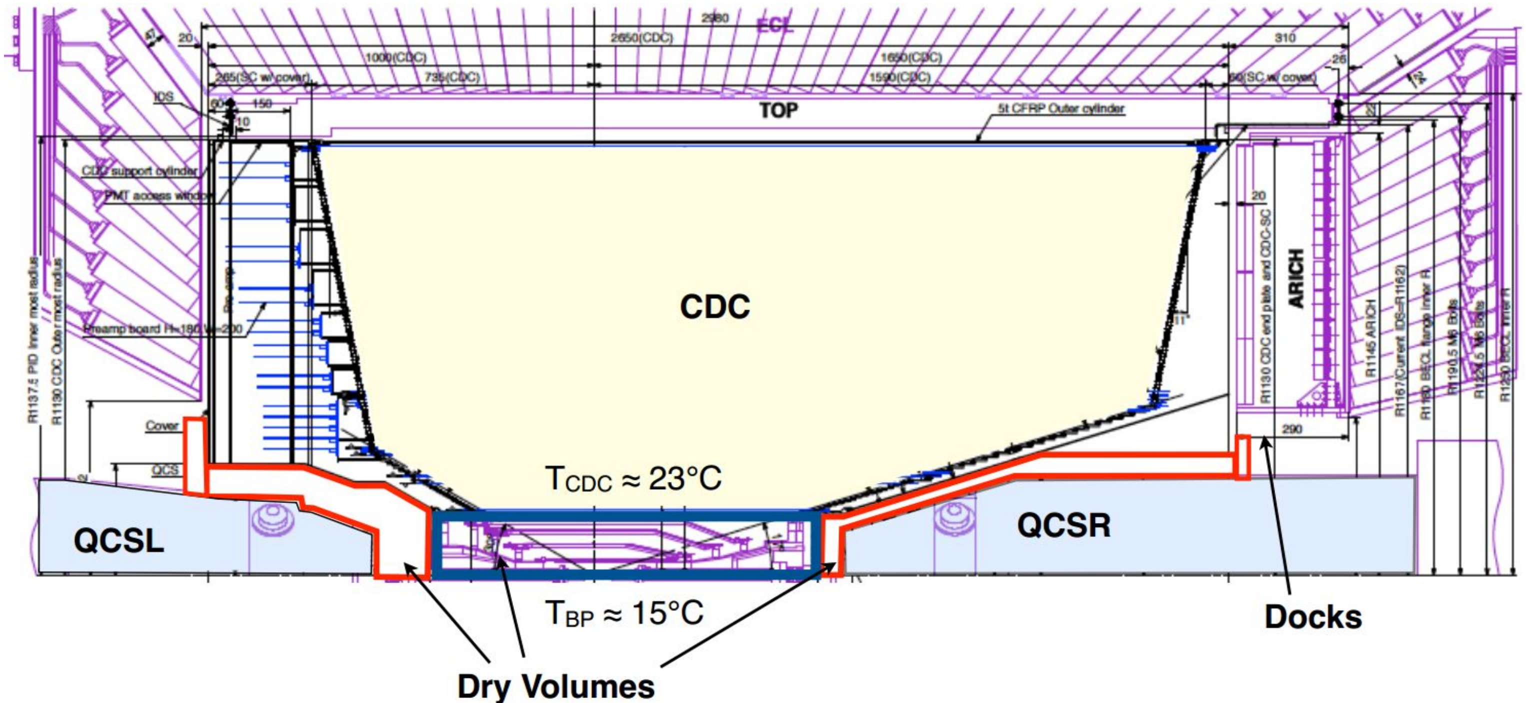
Type	Power(W)
endring	4 X 93
L4&5 origami	2 X 68
L6 origami	2 X 96







VXD Cooling System



Requirements

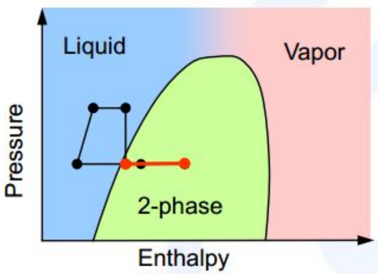
- PXD: Sensor < 25°C to minimize shot noise due to leakage current; ASICs < 50°C to avoid risk of electro-migration.
- SVD: APV25 readout chips surface@~0°C for SNR improvement.
- Power consumption: PXD 360W; SVD 700W, together with the heat load through 9m of vacuum isolated flex lines; required cooling 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

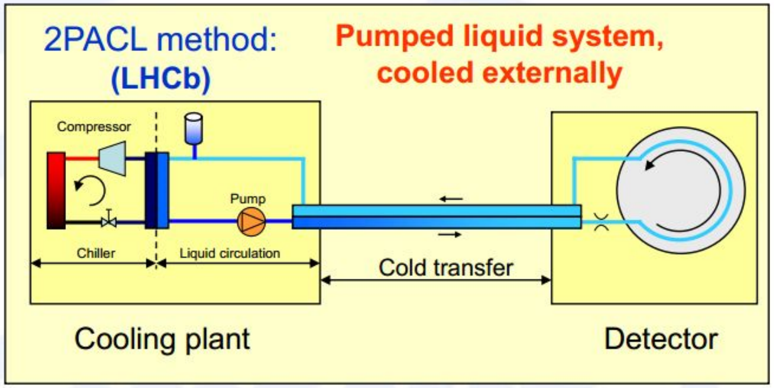
2-Phase CO_2 Cooling

NIKHEF bverlaat@nikhef.nl CERN

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

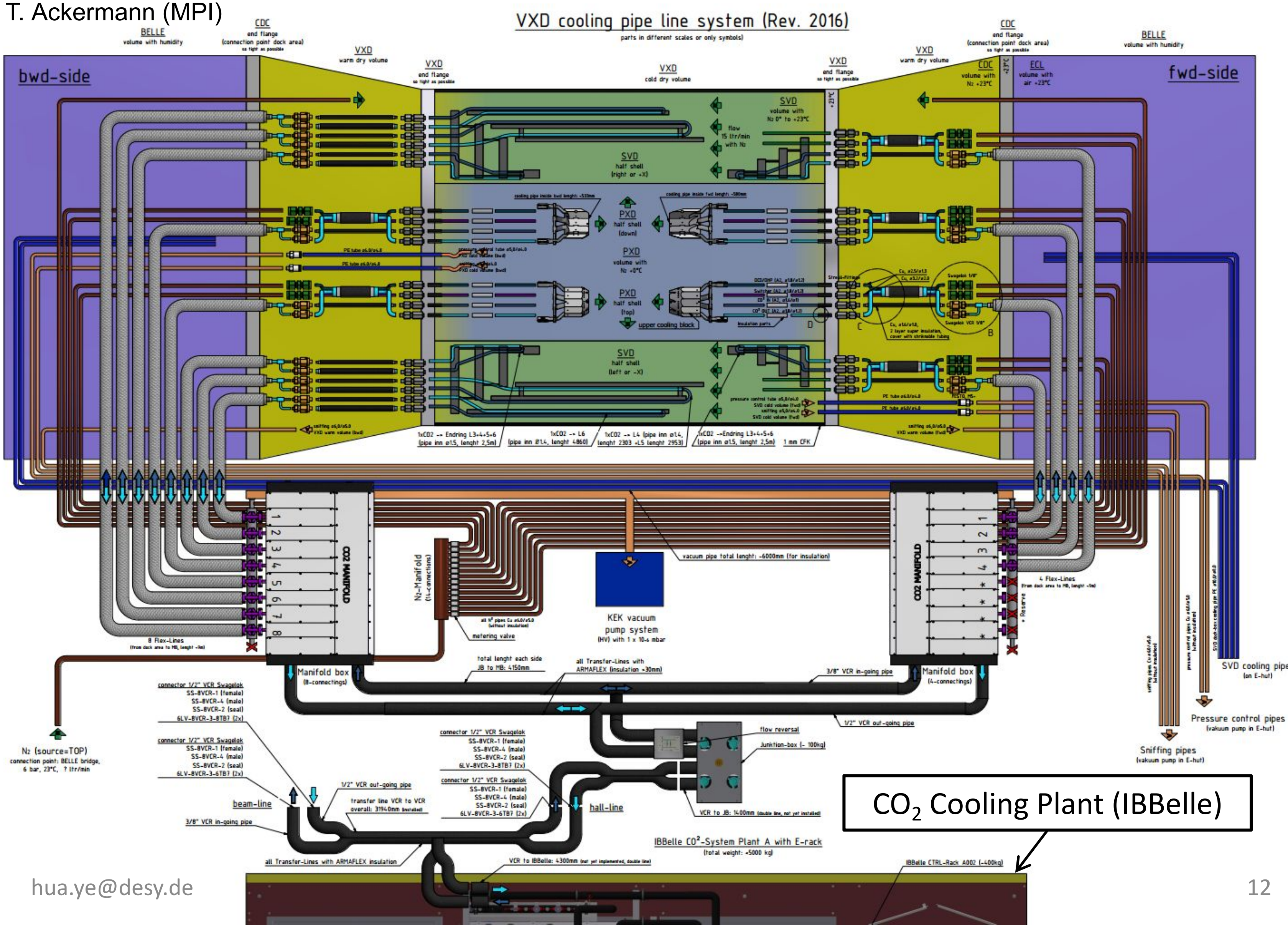
MARCO : ***M***ultipurpose ***A***pparatus for ***R***esearch on ***CO_2***

The 2-phase CO2 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”.

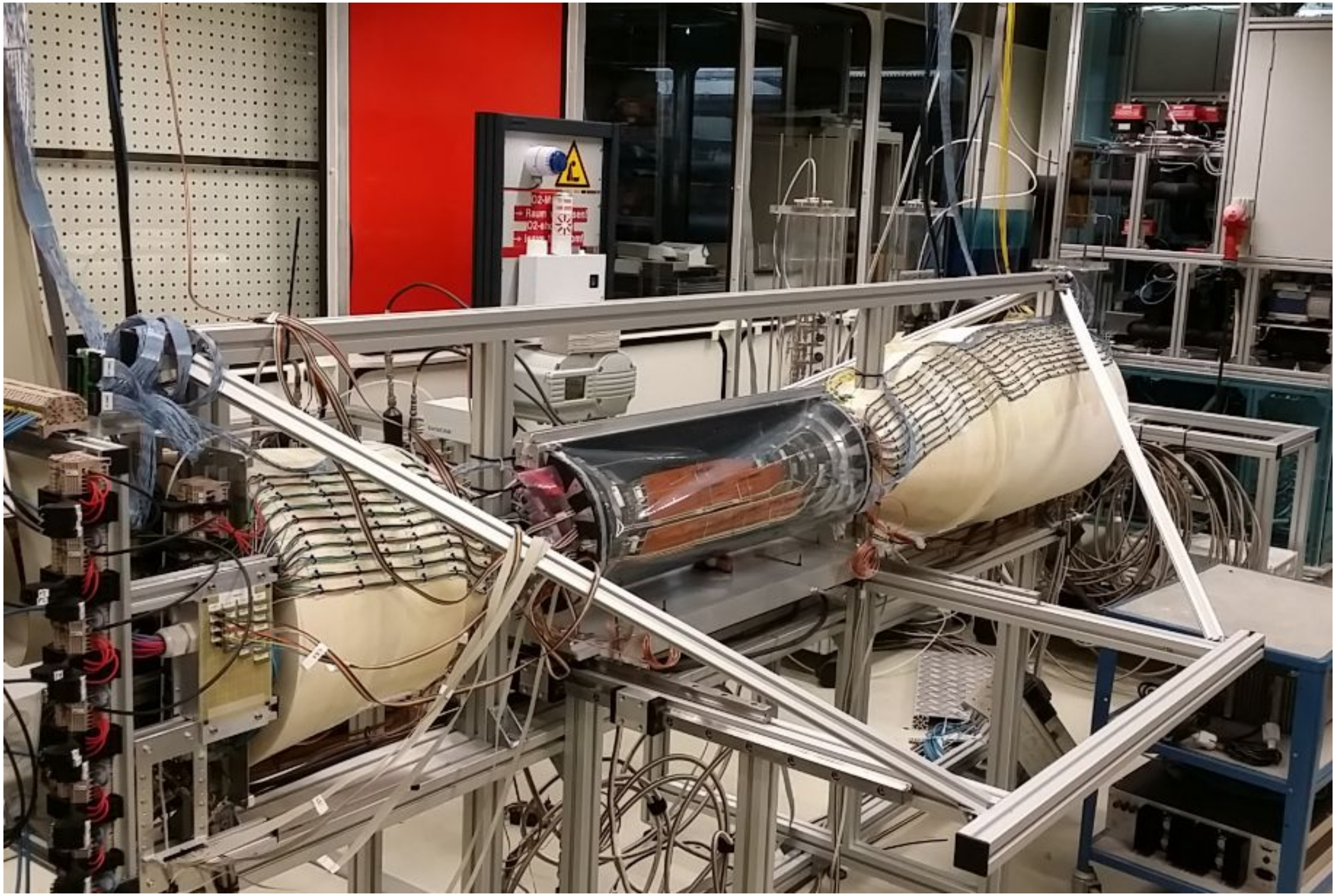
Belle II VXD Cooling Pipe Line System

From T. Ackermann (MPI)



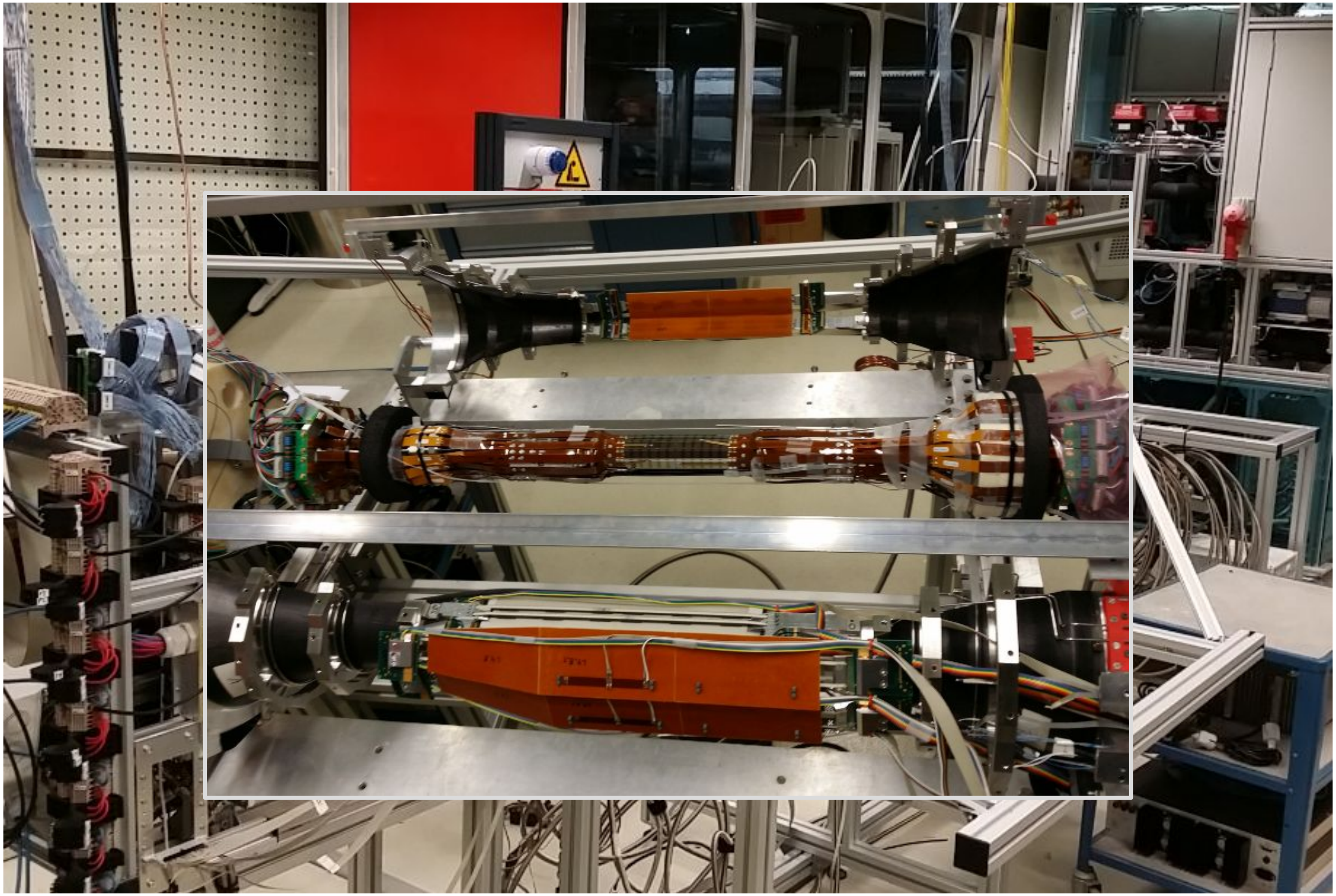
CO$_2$ Cooling Plant (IBBelle)

VXD Thermal Mockup @DESY



In Mar.2016

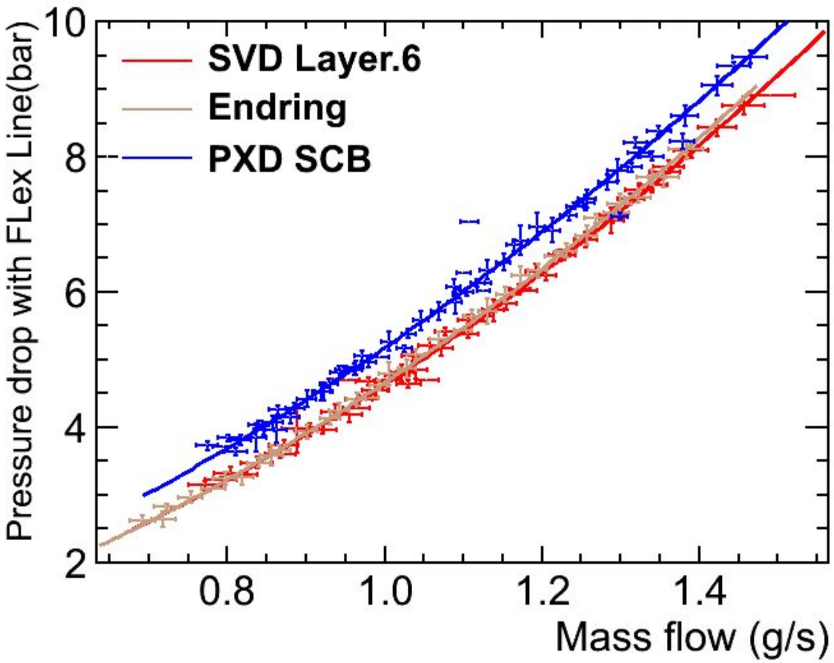
VXD Thermal Mockup @DESY

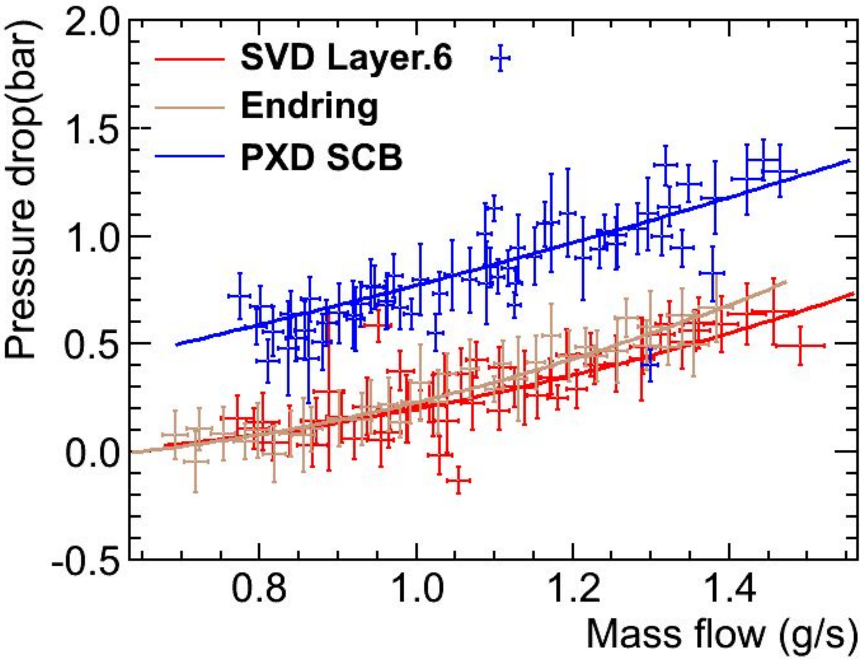


We build up structure layer wise from inside to outside.

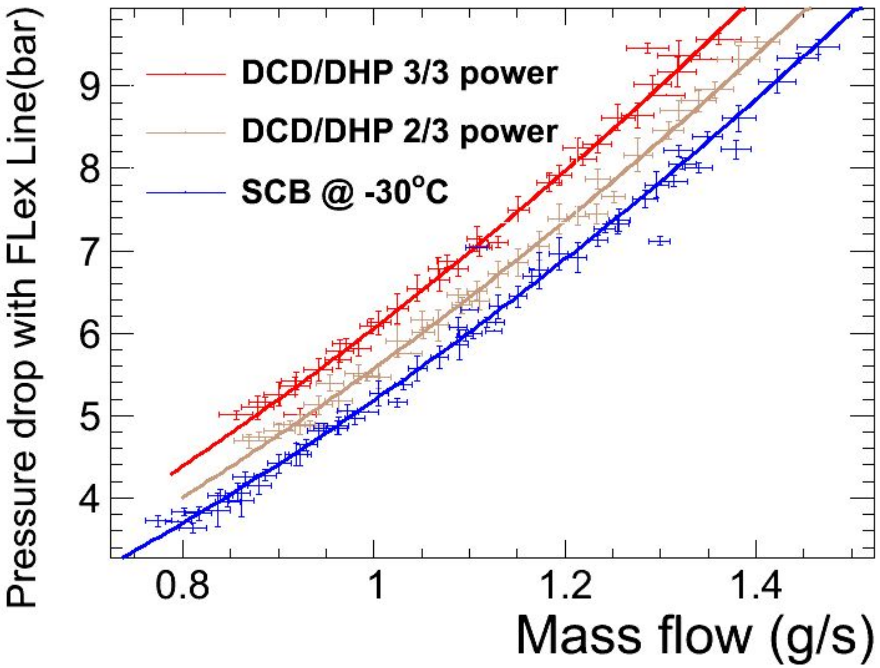
Pressure drop in Cooling Circuit

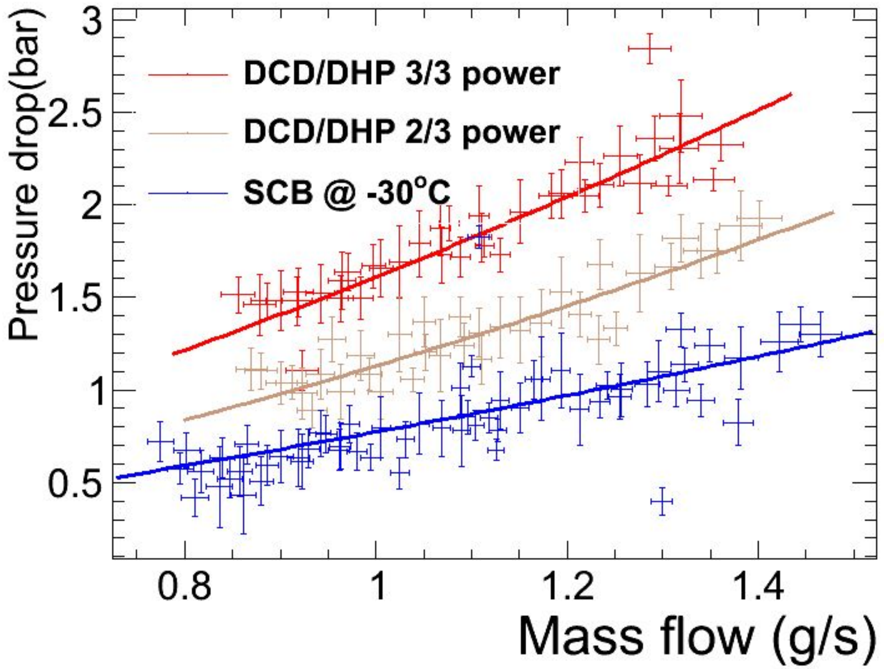
- The long and thin cooling lines cause relative high pressure drops, which cause temperature gradients.
- Relatively big contribution of pressure drop in transfer flex line, to ensure balanced CO_2 mass flow in each circuit.





Pressure drop in Cooling Circuit





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

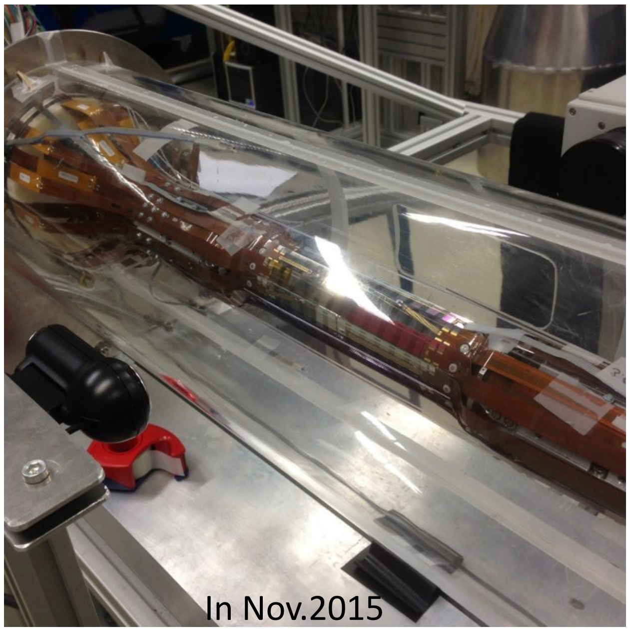
PXD dummy sensors

- The 75µm thick fragile dummy sensors are made of silicon in the same way as the real detector to study the thermal performance.
- Resistive dummy loads are integrated to simulate the power distribution in the functioning ladder.
- An extra power of 25 W is given on the kapton cables to simulate their power dissipation.

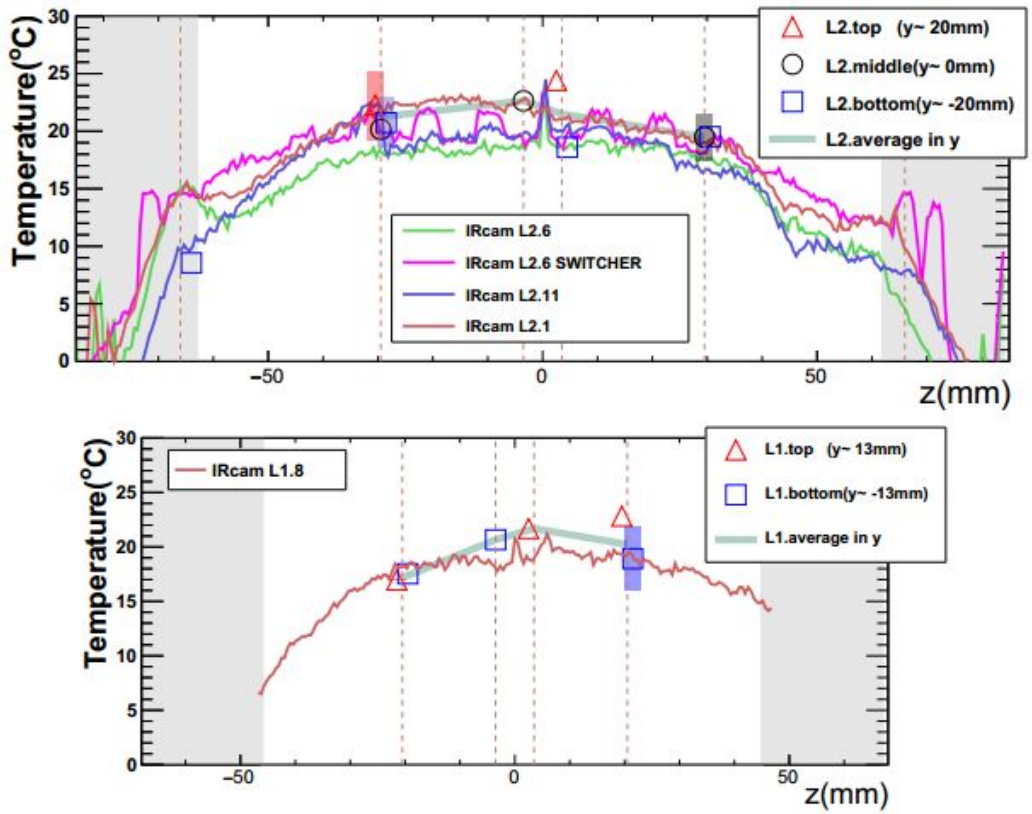
dummy ladders from MPG HLL

Thermal Mock-up Studies@DESY: Temperature on PXD

In the absence of SVD, a plastic cylinder (ID 18cm, length 70cm) act as dry volume.



CO_2@-30°C; N_2 23L/min



Temperature is monitored by resistance thermometers, Pt100s and infrared camera

Figure 5: The temperature distribution of PXD ladders along the z-direction. BW(FW) is on the left(right) side. The gray areas indicate the regions of DCD/DHP, while the 75μm thick sensitive area is shown in the center. The thick solid line indicates the averaged temperature along z-direction measured from the Pt100s. Different markers show the average temperature in y-direction at certain position along z-axis, the error bar on the marker represents the temperature range in x-direction. Thin solid lines show the temperature distribution measured by the IR camera on selected ladders.

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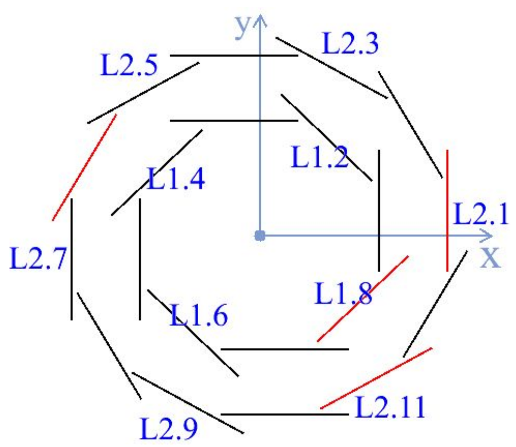
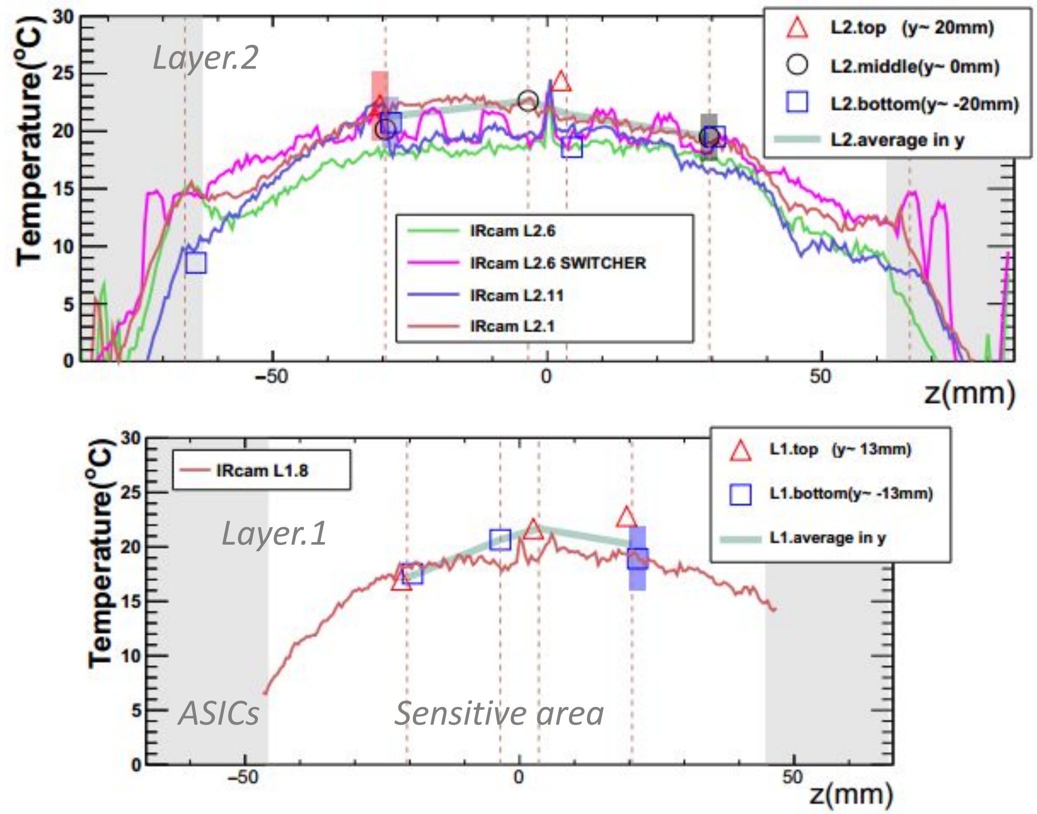


$\Delta T_Y \sim 5^oC$
due to higher density of cold N_2 .
$\Delta T_Z \sim 7^oC$

CO_2@-30°C; N_2 23L/min



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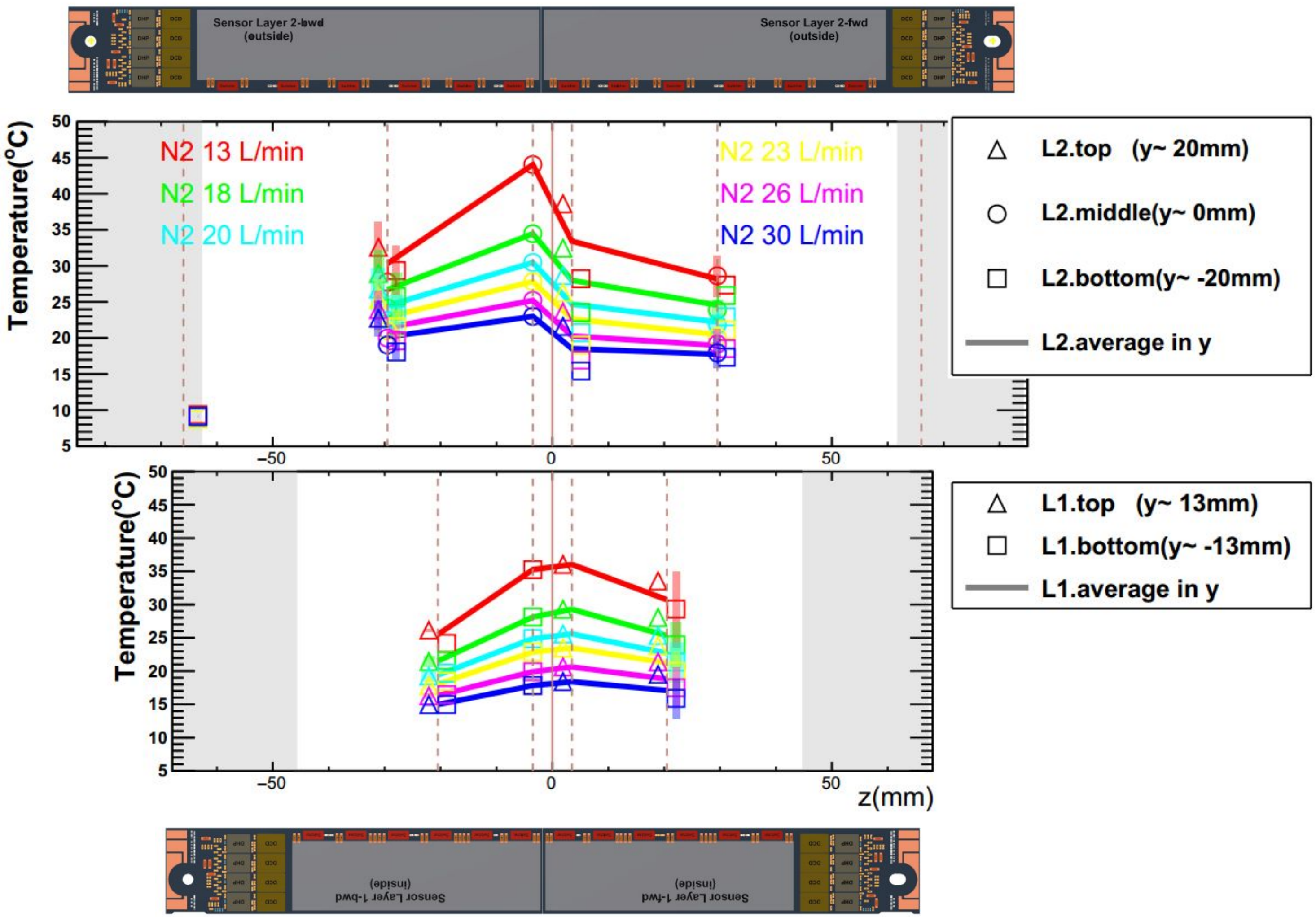
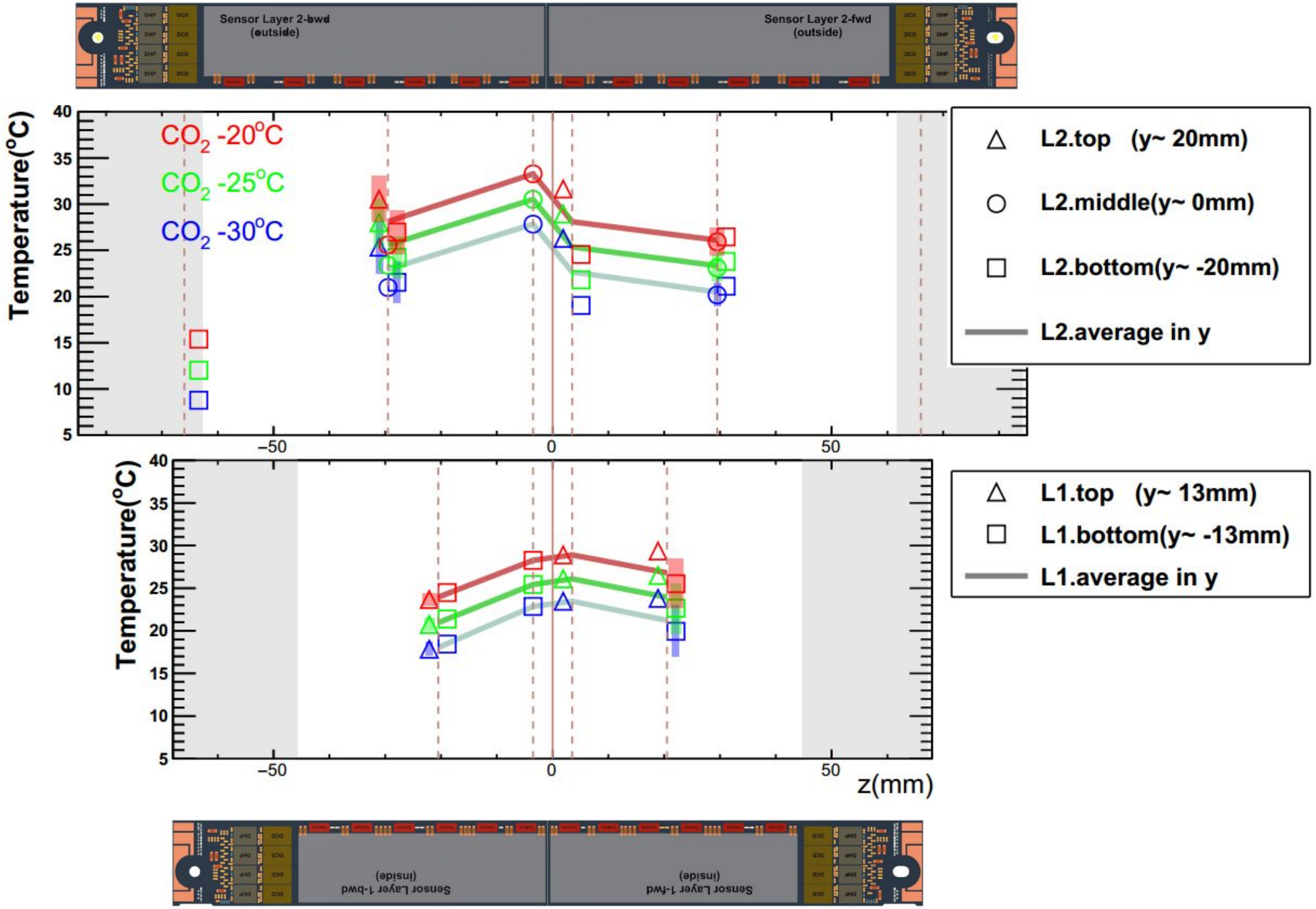
Comparison between different N_2 flow

CO_2@-30°C, full heat load to PXD.

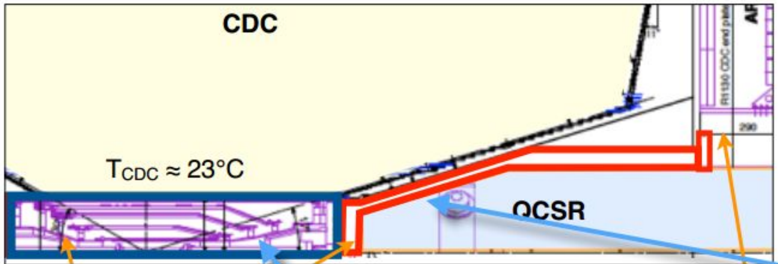


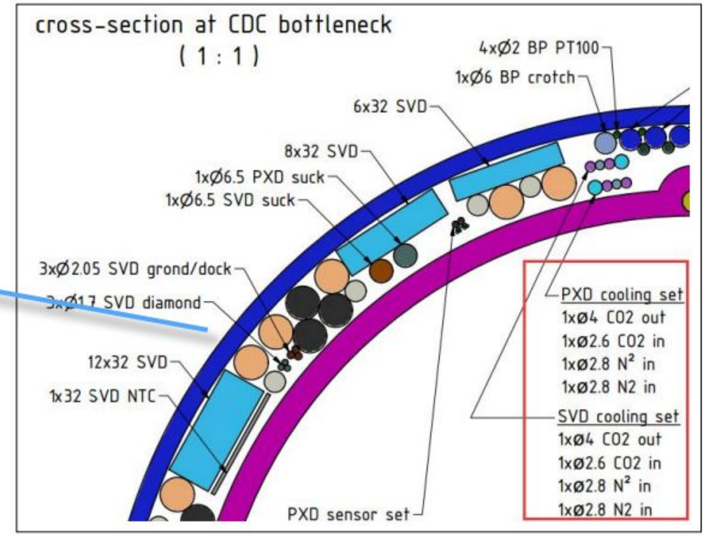
Comparison between different CO_2 temperature

N_2 flow 23L/min; full heat load to PXD.

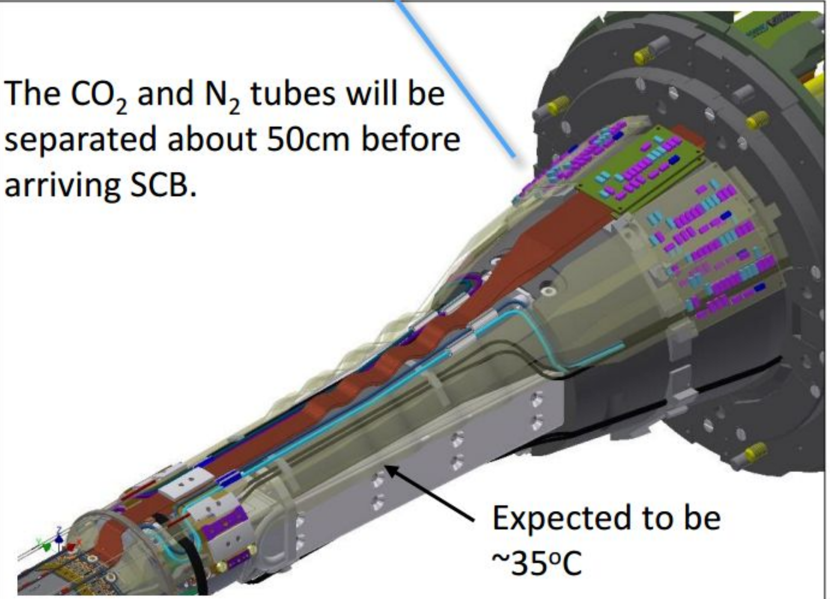


Impact of N_2 temperature and flow rate

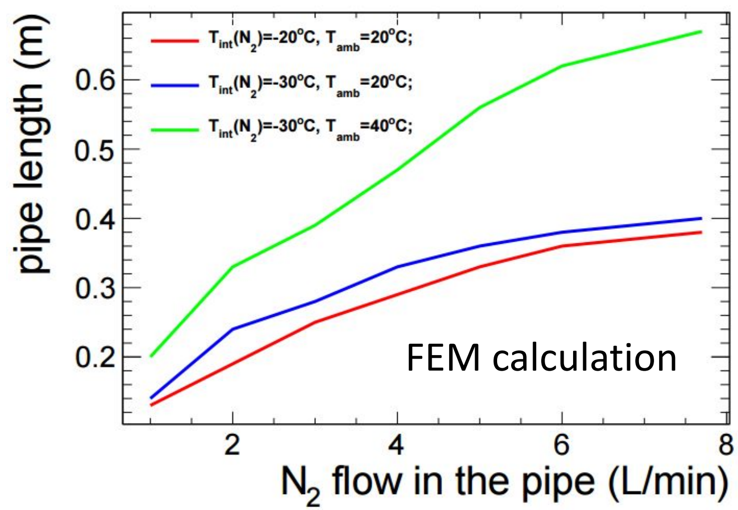




The CO_2 and N_2 tubes will be separated about 50cm before arriving SCB.



In unprotected lines N_2 rapidly assumes ambient temperature.



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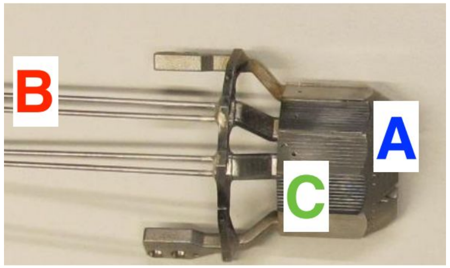
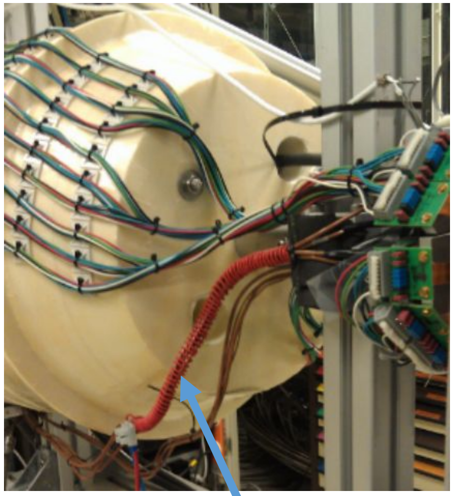
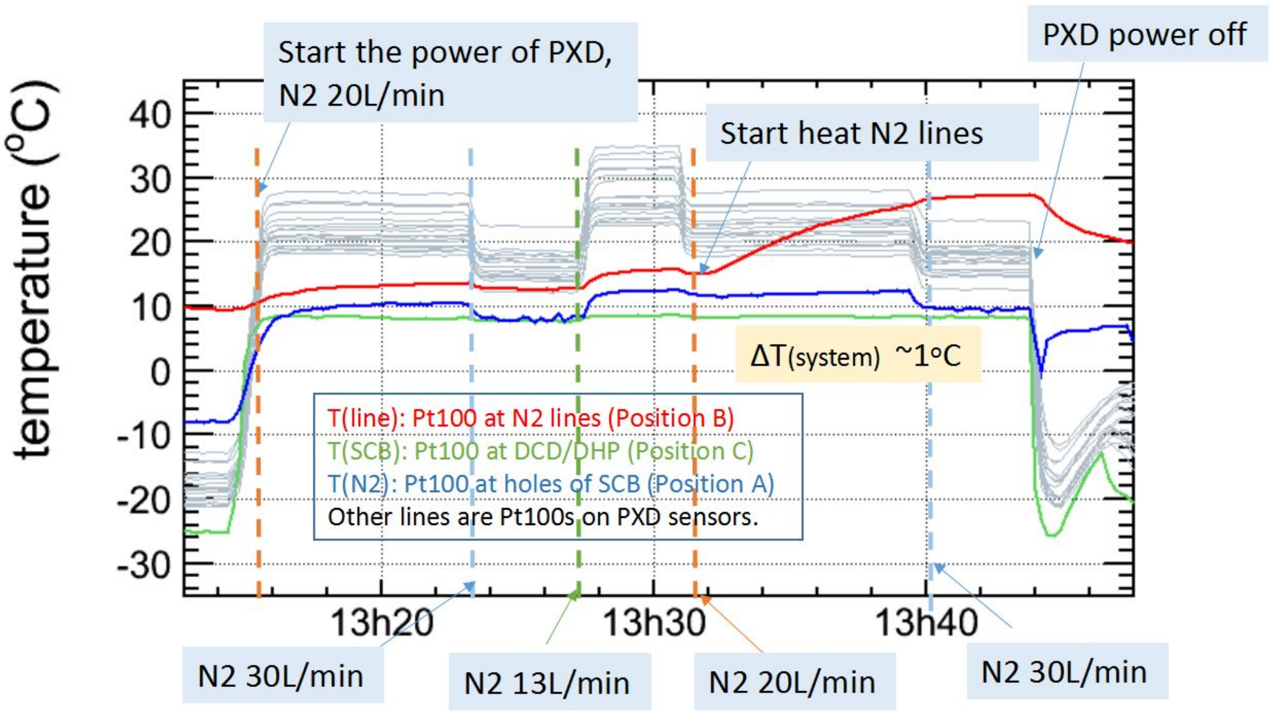




External heat to N2 lines, local temperature will be >40°C

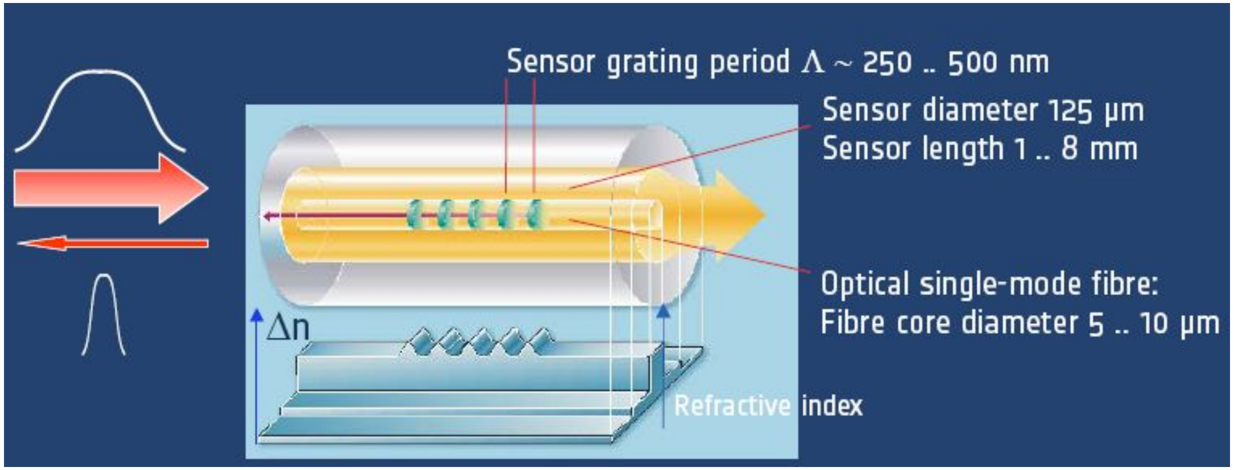


PXD temperature largely independent of N_2 input temperature at SCB

- SCB cooling of N_2 is quite efficient

N_2 flow rate plays the dominant role

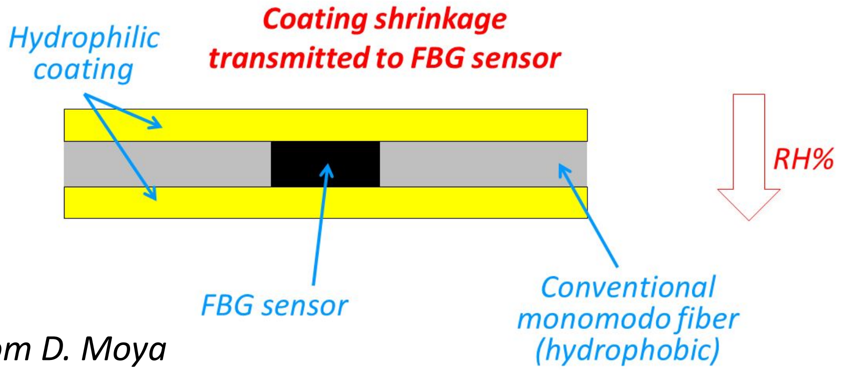
Humidity monitor: Sensitivity mechanism



4 Fiber Optical Sensors (FOSs) are mounted to monitor temperature and humidity in the dry volume

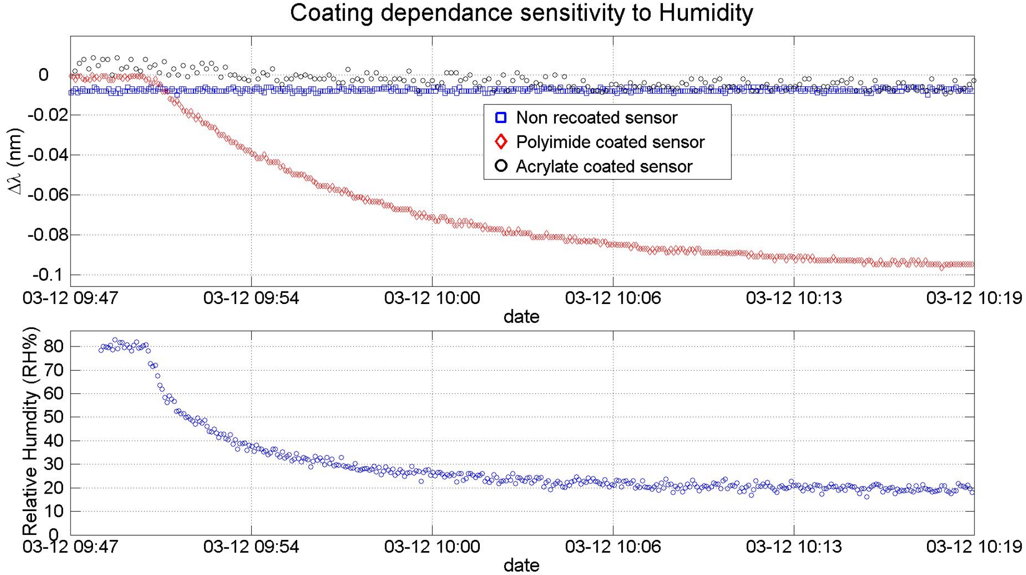
- The Sensitivity of the FBG sensors is a mechanical effect induced by the coating. FO is hydrophobic, but becomes sensitive to humidity when is protected with a hydrophilic coating. The coating swell under high relative humidity environment (due to water molecules absorption) and shrinkage with lower relative humidity. This deformation is transmitted to the fiber.

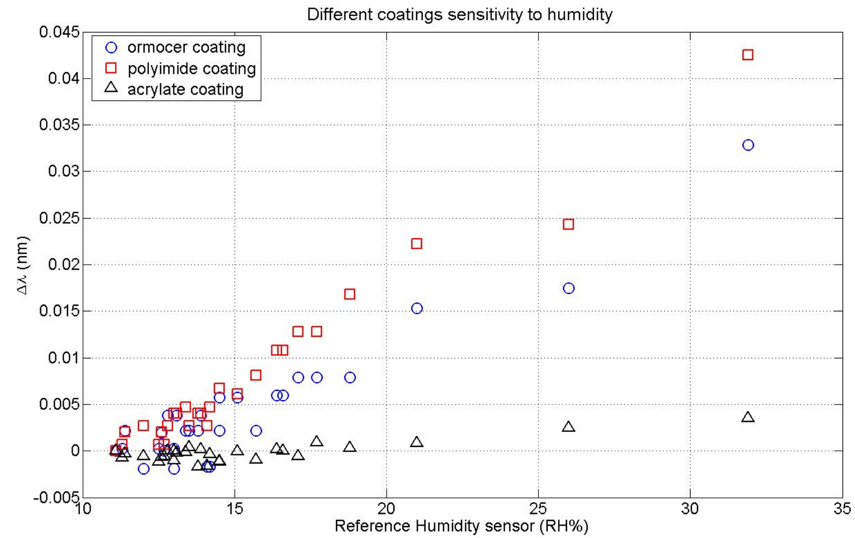
Advantages
- very low material budget
- radiation hardness
- all active electronics accessible



From D. Moya

Humidity monitor: Coating dependence





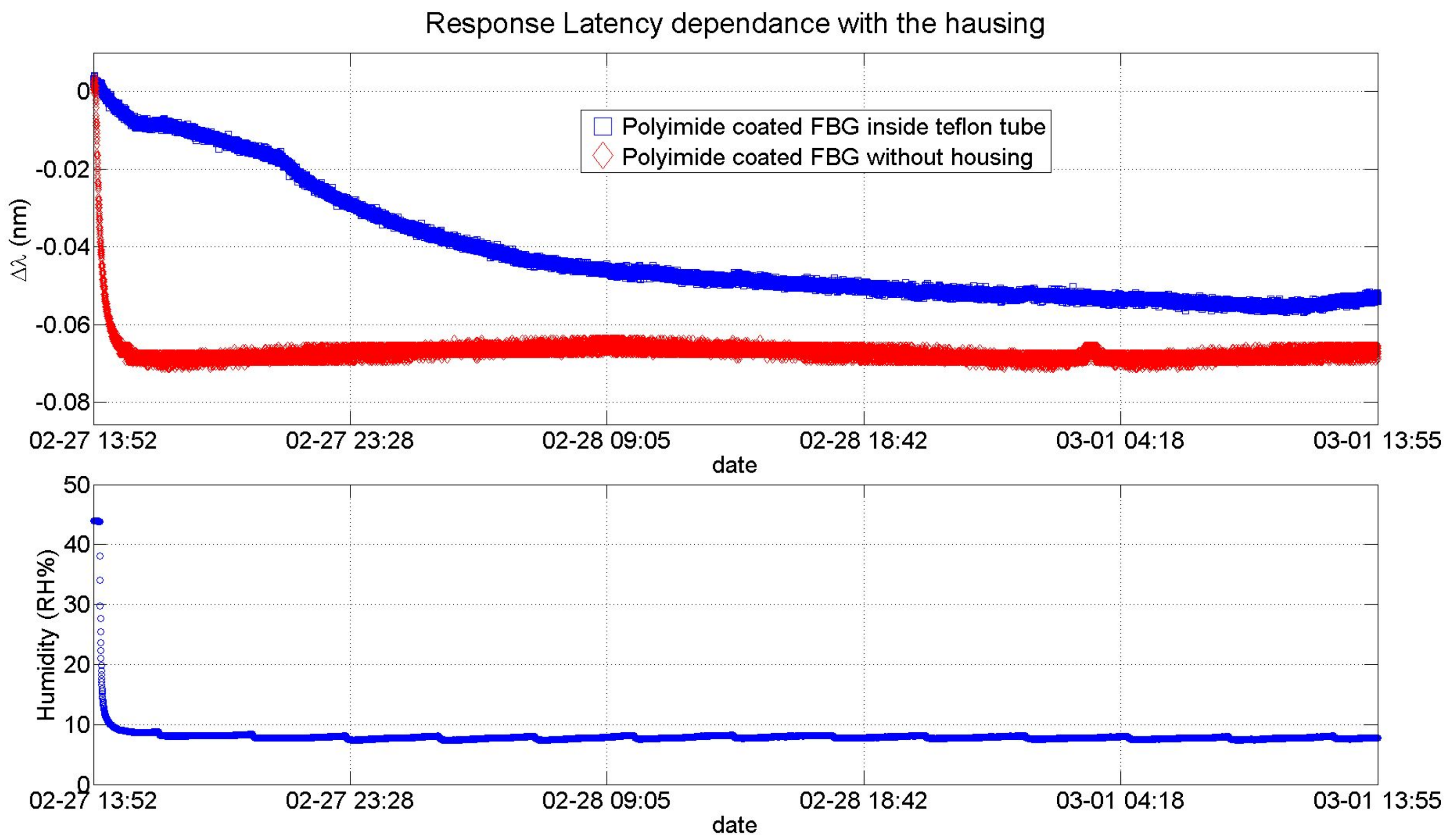
Humidity calibration under stable Temperature

Sensitivity to humidity depends on coating type and thickness.

- No coated (bare) FBG sensors are not sensitive to humidity
- Acrylate coated fibers have very low sensitivity (0.2pm /RH%)
- Polyimide coated fibers are very sensitive to humidity

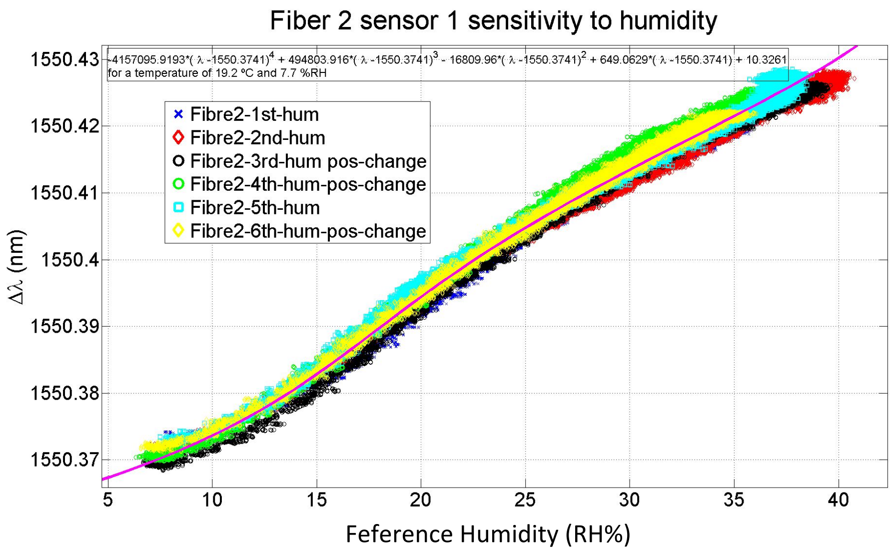
Latency to humidity

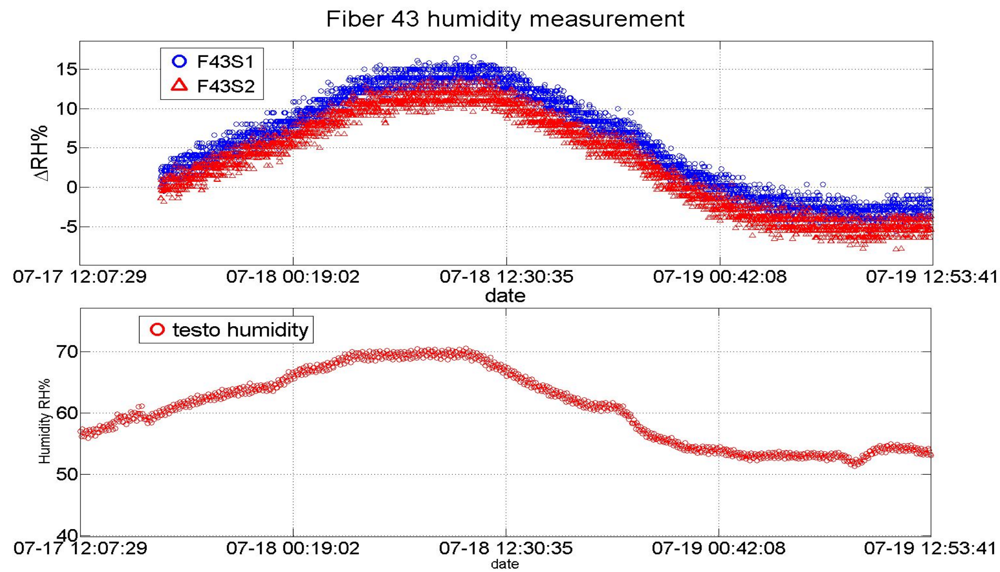
- Depending on the coating type, thickness and sensor housing (free or protected inside tube) the response time to humidity can change from some seconds to days.



From D. Moya

Humidity monitoring Challenges



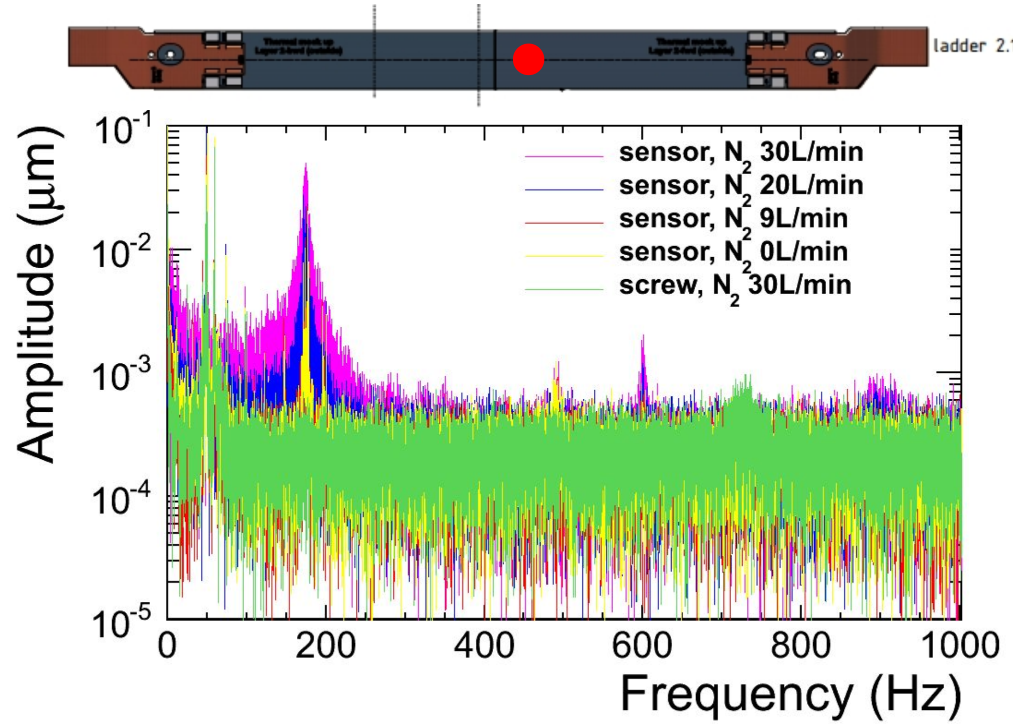


- For polyimide coated fibers with a thickness of 20 um the sensitivity to humidity is not linear, and it is reduced at low humidity (tests to be done < 7%RH).
- The sensitivity to humidity depends on the coating type and thickness . Problem of sensitivity reproducibility even in the same fiber.
- The temperature effect compensation on FBGs under non-stable environment is challenging. (1^{o}C of difference represents a changes of 5- 10% Relative humidity)

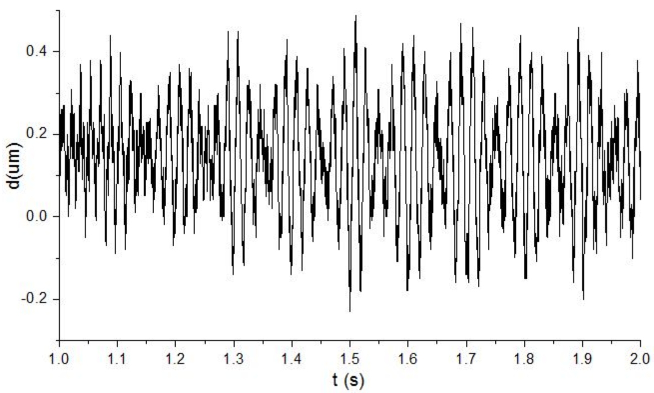
➢ Good results of humidity monitoring under stable environmental conditions in PXD mock-up.

Vibration v.s. N_2 flow rate

Using non-contact laser displacement sensor

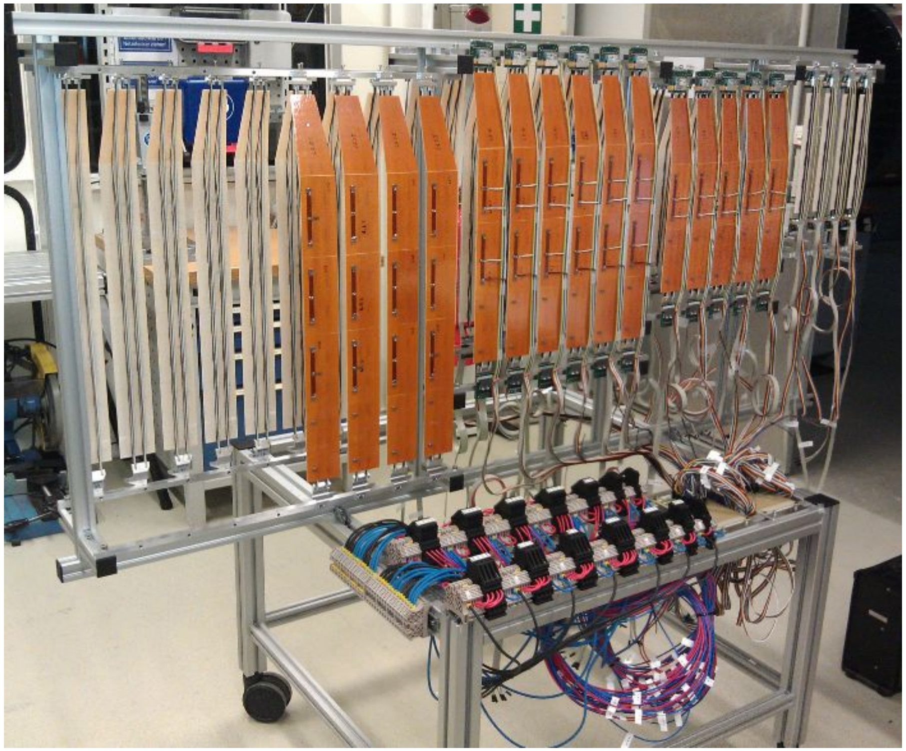


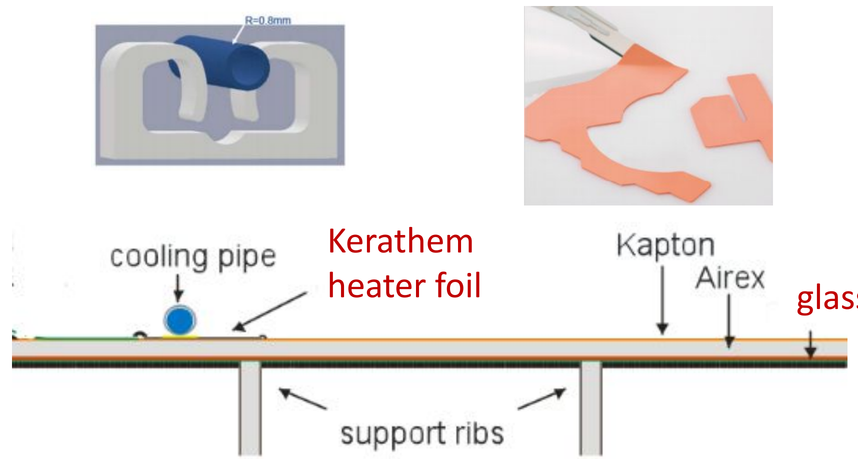
Vibration with RMS amplitude about 0.2um.



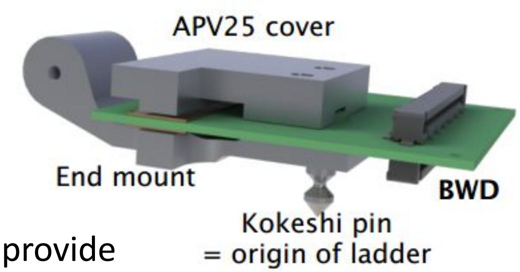
- A peak at about 175 Hz is observed, amplitude increases with the flow rate reaching about 0.02µm when 20L/min of N2 is injected.
- Flat background indicated by the measurements at the fixation screws on the SCB.

Thermal Mock-up: SVD part

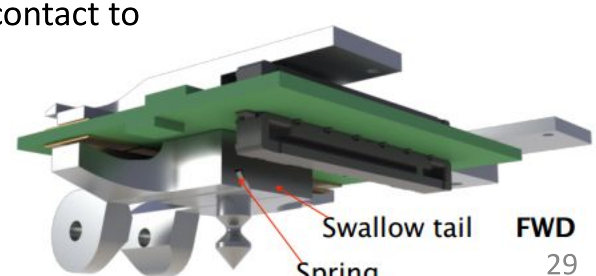




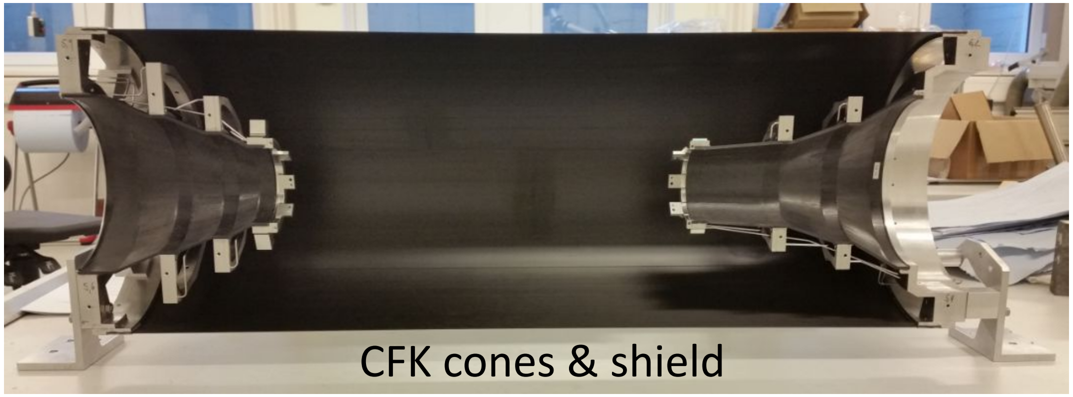
NTC temperature sensors are glued on the heater foils.



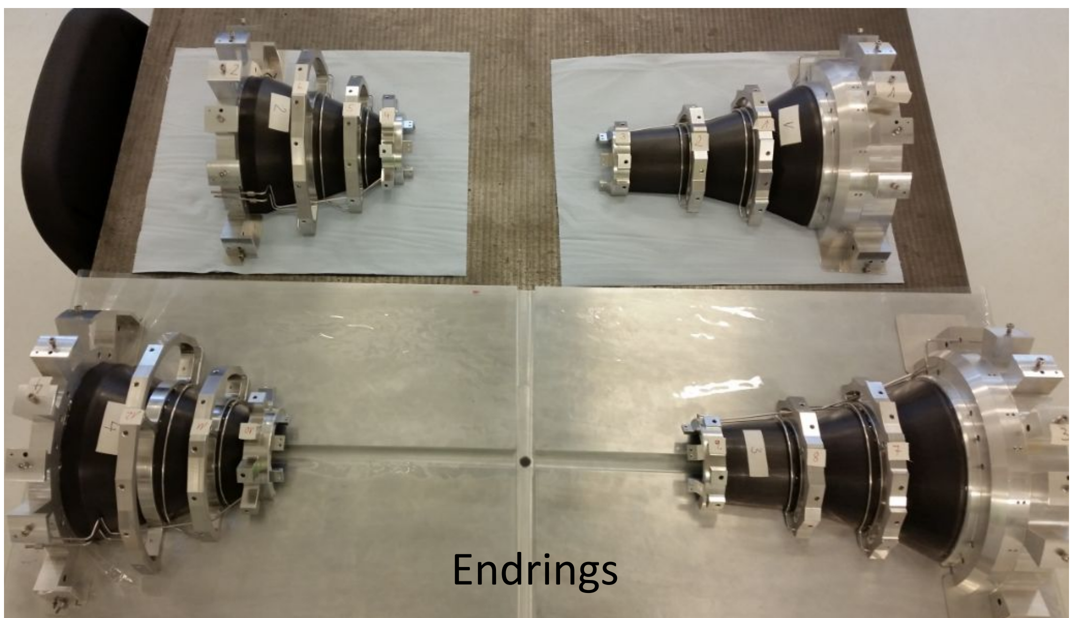
End mounts provide thermal contact to end rings



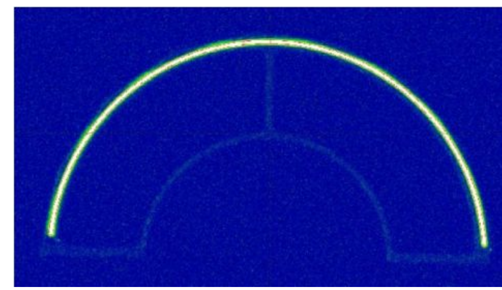
Thermal Mock-up: SVD part



CFK cones & shield



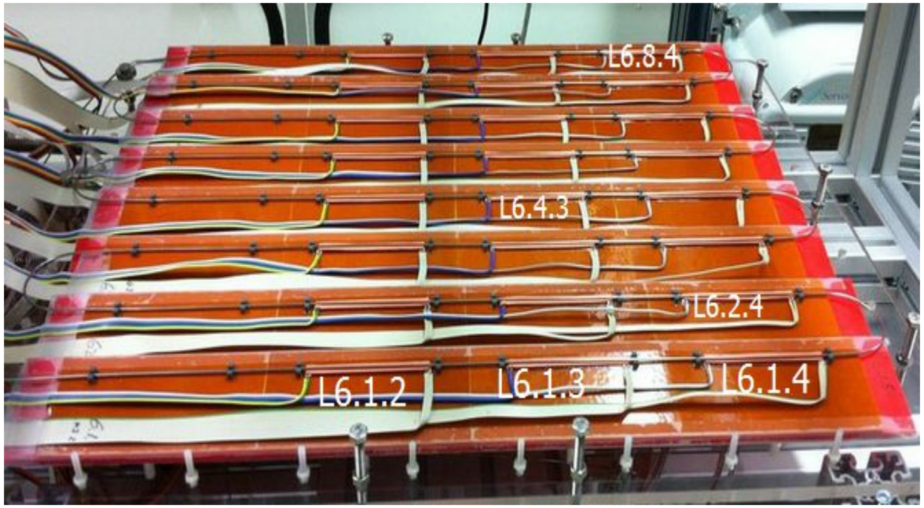
Endrings

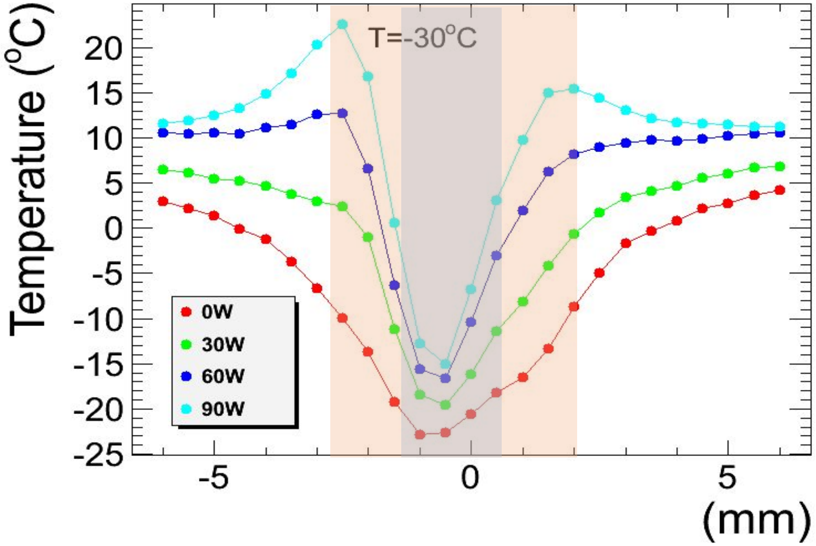


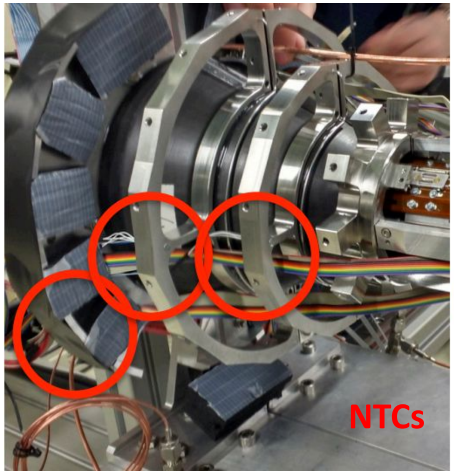
- End rings diffusion welded
- Pipes brazed to end rings
- End rings and flange glued to cone
- Outer shell on SVD halves providing outer envelope of dry volume and mechanical stability(0.5 mm CFRP)

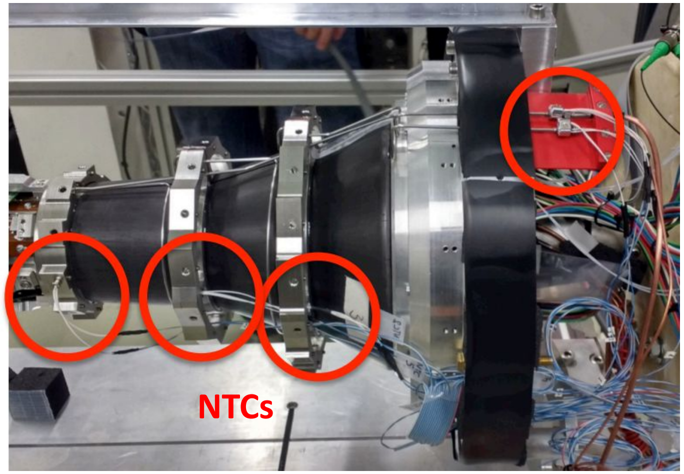
First Thermal Test with simplified SVD Set-up

SVD Layer.6 in flat arrangement







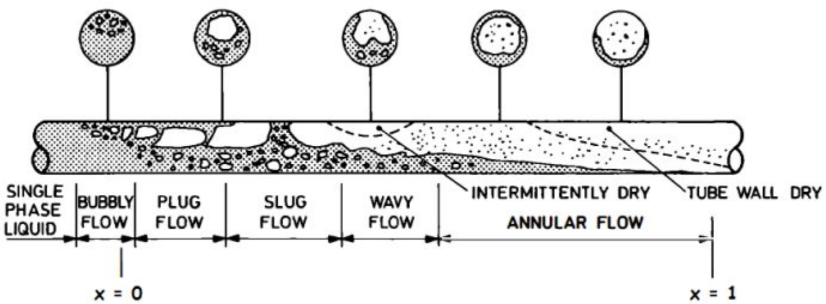


CO_2@-30°C

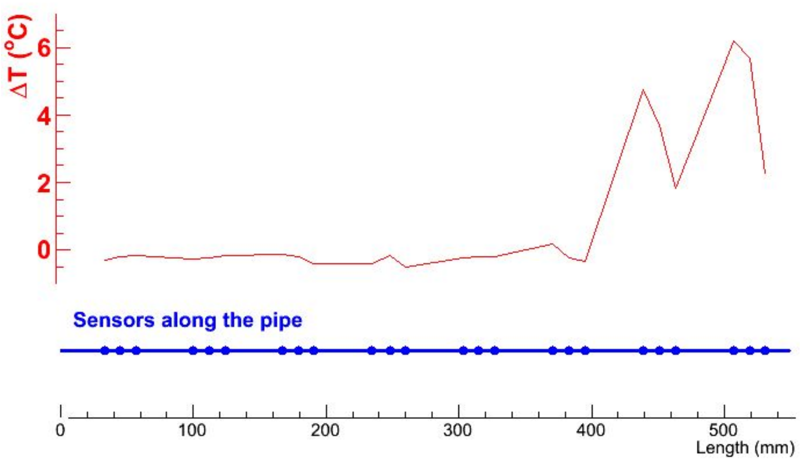
- Endrings temperature ~ -20°C
- CO_2 in/outlet cooling pipe temperature ~ -20°C

Study Onset of Dry-out

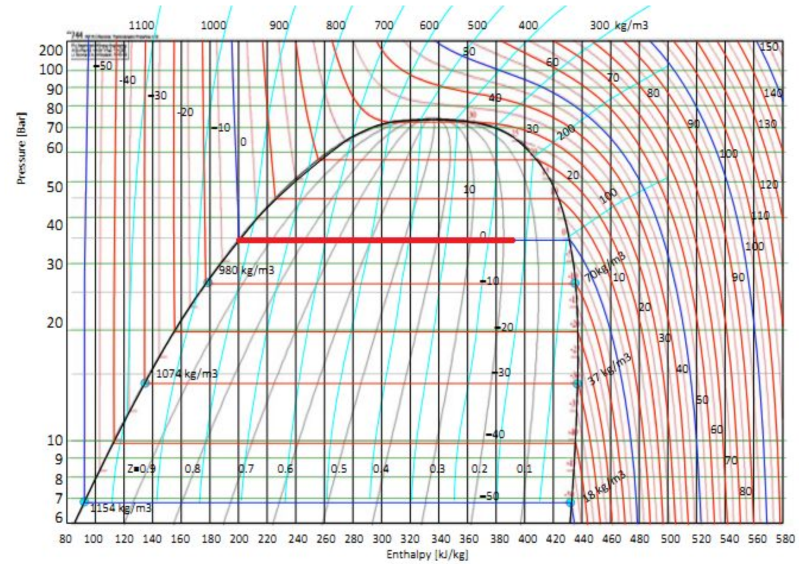
When the vapor quality gets too high, there will be no liquid film on the capillary walls, then result in a shape increase of the cooling block temperature.



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.

Summary

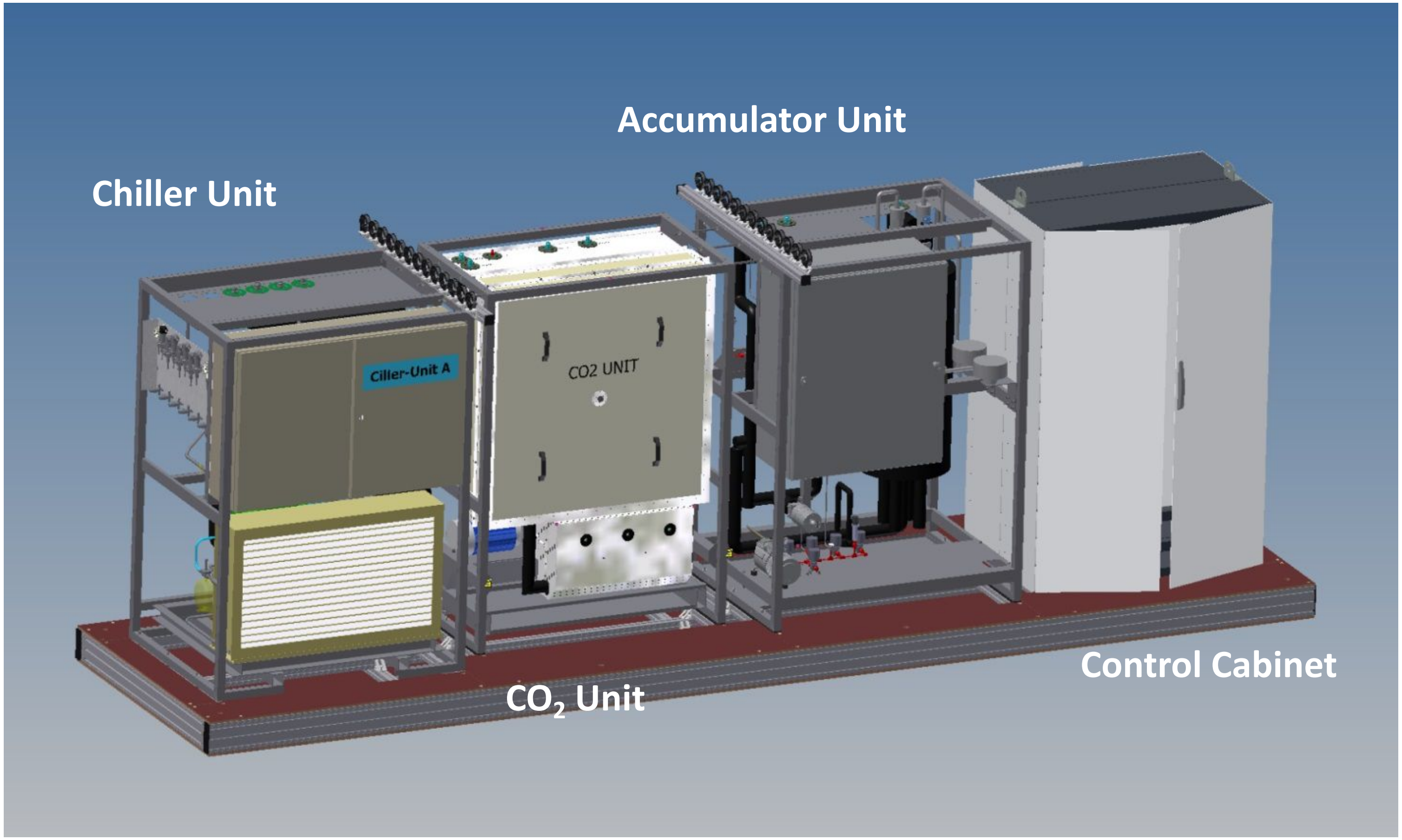
- Operating environment of Belle II PXD and SVD are strongly coupled, meanwhile, it will infulence the surrounding drift-chamber (CDC).
- A full-size thermal mock-up is built at DESY, to verify and optimize the cooling concept of Belle II VXD.
- Evaporative 2-phase CO_2 and airflow injection perform cooling to DEPFET PXD, thermal and mechanical measurements are presented.
- Polyimide coated FOSs are mounted to monitor humidity.
- Measurements to SVD and are ongoing.

Acknowledgement

The Belle II VXD cooling framework has been developed on the basis of the experience gained with the ATLAS-IBL cooling system. We would like to acknowledge the support from CERN experts.

Backup

VXD Cooling Plant: IBBelle



Beam Test @DESY