Air cooling for Vertex Detectors

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• Introduction
• PXD Mock-up for Belle-II
• Air flow cooling
• Conclusions
• Prospects
• Vertex Detector requirements for Future Linear Colliders:

→ High point resolution (< 5 µm)
→ Low material budget ($X_0 \sim 0.3\%$)
→ High radiation tolerance (~kRad/year)
→ Fast integration time (25-100 µs)
→ Low occupancy (<1%)
→ Low power consumption (~mW/cm²)

→ Proper mechanical design, support and cooling is key for achieving low material budget and due power dissipation
• **Purpose:**
  Test the mechanical design and cooling for the PXD detector at Belle-II (DEPFET sensors, remind Laci’s talk on Tu. R&D7)

  **BELLE-II:** 2 layers with 8 (inner) + 12 (outer) ladders (r=14,22mm)

  **ILC:** 5 layers with 10/11/12/16/20 ladders (r=15 - 60mm)

• **PXD @ Belle-II vs ILC:**

|                     | Belle-II        | ILC              |
|---------------------|-----------------|------------------|
| Point resolution    | 10 µm           | 5 µm             |
| Material budget     | ~ 0.1% X₀       | ~ 0.1% X₀       |
| Radiation tolerance | >1 MRad/year    | <100 kRad/year   |
| Frame time          | 10 µs           | 25-100 µs        |
| Occupancy           | 0.4 hits/µm²/s  | 0.13 hits/µm²/s  |
| Power consumption   | 18 W/ladder     | 5W entire detector (duty cycle 1:200) |

Prototype DEPFET pixel sensor and readout
Support and cooling block structures made by 3D sintering process (testing several materials)

Blue: CO$_2$ capillaries
Yellow: Air channels

Cooling Block (Stainless Steel)

DEPFET resistor samples
Mock-up setup:
- Cooling blocks, cooled down with CO$_2$ (~12 bar $\rightarrow$ T $\sim$ -30°C)
- Dry air/N$_2$ gas flow ($v$ = 2 m/s, T = -15 – 25°C *) (cooled down with N$_2$ liquid atmosphere)
- Dummy ladders: → Cu and Al ladders with heaters (inner and outer ladders).
  - Power dissipated along ladder: 1-4 W $\rightarrow$ T $\sim$ 30°C-60°C
  → Resistor Si samples
  - Power dissipation: Sensor: P $\sim$ 0.5 - 1 W
    Switchers: P $\sim$ 0.25 - 0.5 W
    DCDs/DHPs: P $\sim$ 2.5 - 8 W
CO$_2$ open system

Nitrogen liquid Dewar (cooled air)

Thermally isolated box with dry atmosphere

IR camera

Mock-up

chiller

Granada, September 2011
• Method:

- Measure temperature along inner and outer ladders and in the cooling blocks with an IR camera (properly calibrated) and PT’100 probes

• Studies:

**CO₂ cooling:**
→ Cooling Block temperature
→ Power dissipation (DCDs/DHPs)

**Air flow cooling:**
→ Air velocity
→ Power dissipation (sensor and switchers)
• Results:

- Effect of blowing dry air at room temperature (25°C):
  \( v_{\text{air (inlet)}} \sim 2 \text{ m/s} \)

Sensor: \( P \sim 1 \text{ W} \times 2 \)
Switchers: \( P \sim 0.25 \text{ W} \) (left switcher off)
DCDs/DHPs: \( P \sim 2.5 \text{ W} \times 2 \)

Air cooling

- The air flow (at room T) decreases and homogenizes the temperature along the detector.
  → Decreases \( T \sim 15^\circ \text{C} \)
  → Max \( \Delta T \) along the ladder 18°C → 8°C
• Results:
  - Cooling down the cooling blocks with CO$_2$ and blowing dry air/ N$_2$ gas at several temperatures

Sensor: $\rightarrow P \sim 0.5 \text{ W } \times 2$
Switchers: $\rightarrow P \sim 0.5 \text{ W}$
DCDs/DHPs: $\rightarrow P \sim 8 \text{ W } \times 2$

Sensor

Camera position

 Detector on
 Background (room T)
 End flanges cooled with CO$_2$
 Air flow at room T
 Air/N$_2$ flow cooled $[-8, -15]^\circ\text{C}$

(* $T$ measured before entering the pipes)
• Results:

- Sensor region (P≈0.5 W x 2):

  (corrected emissivity)

- Temperature for the sensor when switching on the detector: ~ 60 °C
- Cooling the endflanges (CO$_2$): $T_{sensor}$ < 25 °C (~ room T)
- Blowing air at room T → $T_{sensor}$ < 20 °C and homogeneous
- Blowing cooled air (-8,-15) °C → $T_{sensor}$ ~ 15 °C and homogeneous
- $\Delta T_{max}$ along the sensor ~ 10 °C
• Results:

- Switchers region (P~0.5 W):

(Only right switcher was operating)
- Temperature for the switchers when the detector is switched on ~ 40 °C
- Cooling the endflanges (CO₂): T switchers ~ 20-30 °C (~ room T)
- Blowing air at room T → T switchers < 25 °C and homogeneous
- Blowing cooled air (-8,-15) °C → T switchers < 25 °C and homogeneous
- Small ΔTₘₐₓ along the detector < 10 °C

(*) T measured before entering the pipes
• PXD Mock-up setup to study the cooling for Belle-II

• At present, all tests of air cooling show:
  • Significant effect of air cooling even at room T (ΔT=15°C for P ~2.5W)
  • Cooled air flow decreases the ladder temperature below ~20°C
  • $\Delta T_{\text{max}}$ along the ladder less or around 10°C (with cooled endflanges)

• Results may be suitable for ILC. Some issues:
  How is the air/N₂ delivered? (supporting disks?)
  How is the air/N₂ cooled (if needed)?
- Test air flow effect in the inner ladders (mainly for the switchers) through carbon fibers

- Test possible vibrations in the detectors due to the air flow (Capacitive Non-Contact Displacement detectors)
• Results:

**Effect of air velocity**

- It is enough to have a very low speed air flow (inlet) to achieve a proper heat dissipation in the ladder (1 W → ΔT ~ 6-7°C)

(Expected behaviour from C. Mariñas simulations, CERN-THESIS-2011-101)

**Power dissipation:**

ΔT = object T without air – object T when having a room T air flow (v ~ 2m/s).

- Power dissipation increases as power (i.e. heating) increases
Calibration tool for the IR camera: \( \varepsilon \) depends on the material

Al box filled with coolant: cooled down with chiller, heated with heaters. Study material \( \varepsilon \)

\[ \varepsilon \approx 0.65 \]

\[ \varepsilon \approx 0.35 \]

\[ \varepsilon \approx 0.18 \]
• Inner ladder:

![Diagram of inner ladder with heaters (3W)]

Heaters (3W)

Air flow T~0°C*

Air flow T~20°C*

CO2, No air flow

* entering in the box; T in the CB?
- Air flow cooling with the CO₂ return

Until now, air or N₂ gaseous cooled down by the atmosphere inside the liquid N₂ Dewar (-80°C). New CO₂ exchanged system to cool down the air flow in place (to test).

1.5m pipe coil at the CO₂ return to cool down the air:
Air flow temperature in the outlet ~ -5 - 0 °C
• Dummy ladders:

- Polycarbonate
- Al
- Cu

Heaters

Resistor samples