THM$\overline{\text{P}}$ Calibration

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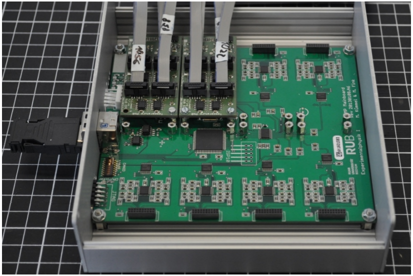
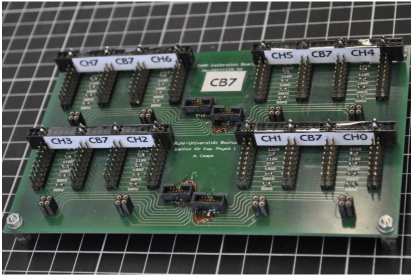
Latest Design of the THM$\overline{\text{P}}$



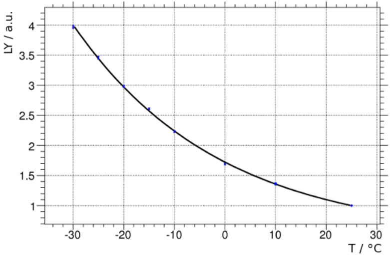


- Using type A USB connectors, still using the CAN-bus protocol!
- Temperature sensor integrated on mainboard
- Change of plugs and cables, which connect the THM$\overline{\text{P}}$ with the sensors, in order to match patch panel PCB

$\longrightarrow$ Modified the calibration boards

Why and How Do We Measure Temperatures?

PWO-II: LY depends on T with $\frac{d(LY)}{dT} = 3\,\%/^\circ\mathrm{C}$ at -25 °C



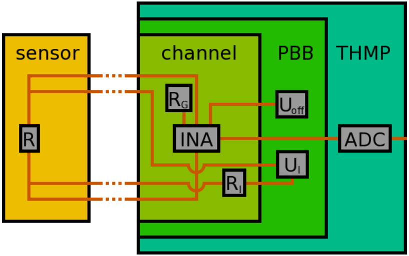
- Goal for $\overline{\mathrm{P}}$ANDA: $\Delta T < 0.1\,^\circ\mathrm{C} \longrightarrow$ sensors with $\sigma_T < 0.02\,^\circ\mathrm{C}$
- R vs T relation of platinum quite linear

$$R(T) \approx R(0\,^\circ\mathrm{C})(1 + \alpha_{\mathrm{Pt}} \cdot T), \quad \alpha_{\mathrm{Pt}} = 3.89 \cdot 10^{-3}\mathrm{K}^{-1}$$

- Accuracy for temperature sensors translates to accuracy for the THM$\overline{\mathrm{P}}$: $\sigma_R \approx \frac{\partial R(T)}{\partial T} \cdot \sigma_T \approx 7.8\,\mathrm{m}\Omega$

How Do We Measure Resistances?

- 4-wire measurement
- constant current $I = \frac{U_I}{R_I}$
- gain $G = 5 + \frac{200\,\mathrm{k}\Omega}{R_G}$
- offset voltage U_{off}
- ADC conversion factor C



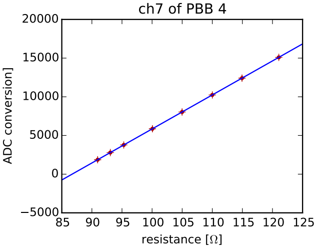
$$(R \cdot I \cdot G + U_{\mathrm{off}}) \cdot C = R \cdot \underbrace{I \cdot G \cdot C}_{m} + \underbrace{U_{\mathrm{off}} \cdot C}_{n} = N$$

$\longrightarrow$ σ_R corresponds to 3.5 ADC channels for optimized values of U_I, R_I, R_G and U_{off}

How Do We Measure Resistances Accurately?

! Electronic components vary within their production accuracy
all readout channels k on a PBB are different!

- constant current $I_k = \frac{U_I}{R_{I,k}}$
- gain $G_k = 5 + \frac{200\,\mathrm{k}\Omega}{R_{G,k}}$
- offset voltage U_{off}
- ADC conversion factor C



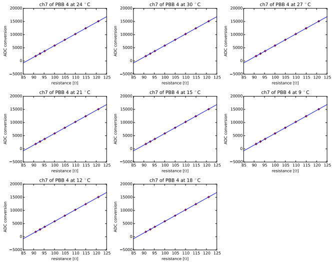
$$R_k \cdot \underbrace{I_k \cdot G_k \cdot C}_{m_k} + \underbrace{U_{\text{off}} \cdot C}_{n} = N_k$$

→ Calibrate each channel by fitting a 1^{st} order polynomial
to pairs of known resistors and ADC conversions!

How Do We Measure Resistances with Respect to the T?

! behaviour of diodes and resistors depends on T
for $R_{I,k}$, $R_{G,k}$ is $(\Delta R/R)/\Delta T = 10\,\text{ppm/K}$ the best available

- constant current $I_k(T) = \frac{U_I(T)}{R_{I,k}(T)}$
- gain $G_k(T) = 5 + \frac{200\,\text{k}\Omega}{R_{G,k}(T)}$
- offset voltage $U_{\text{off}}(T)$
- ADC conversion factor C

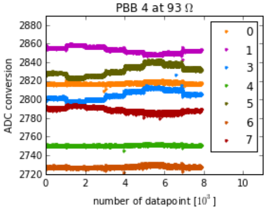


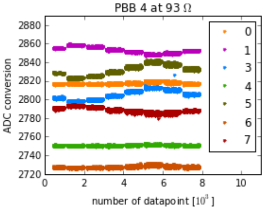
$$R_k \cdot \underbrace{I_k(T) \cdot G_k(T) \cdot C}_{m_k(T)} + \underbrace{U_{\text{off}}(T) \cdot C}_{n(T)} = N_k$$

→ Perform fits (prior slide) at different temperatures,
describe dependency on T & monitor THM$\overline{\text{P}}$ temperature!

How Do We Measure Resistances with Respect to the T?

- Measure with varying temperature for each resistance value
- Analyse the data from periods with stable temperature





- The temperature dependency is fairly linear

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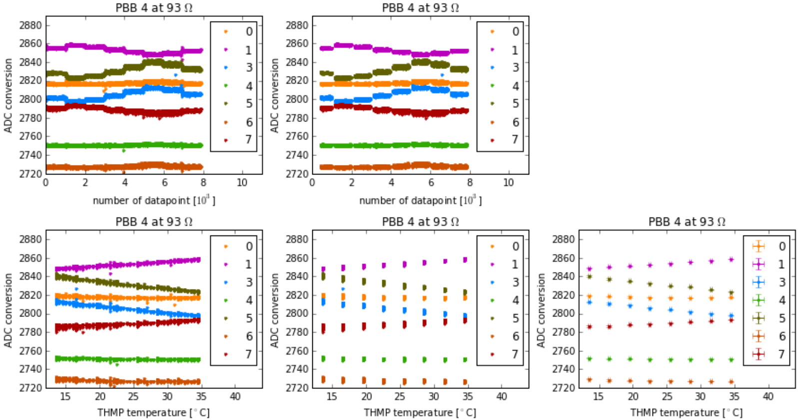

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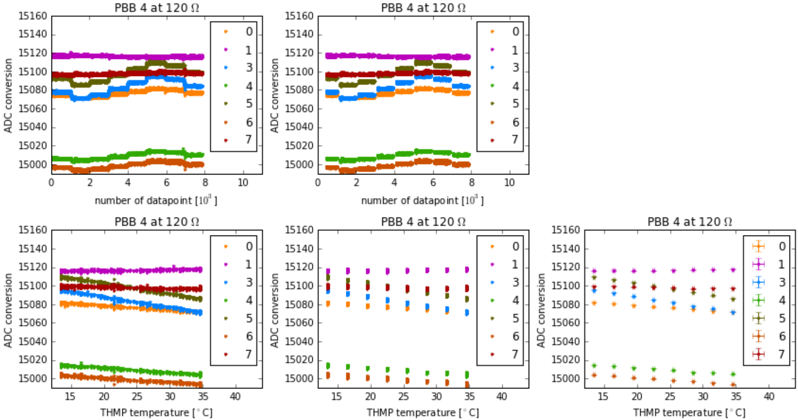
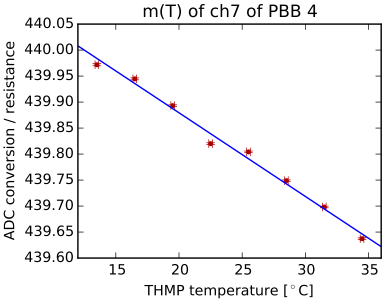
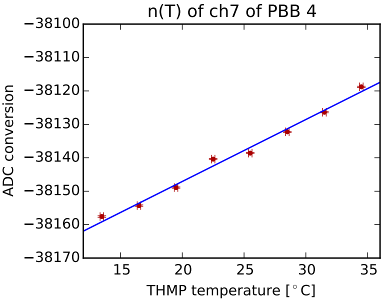


- The temperature dependency is fairly linear
  but differ for individual channels and different resistances

How Do We Measure Resistances with Respect to the T?

- Consequently $m_k(T)$ and $n(T)$ depend linearly on T

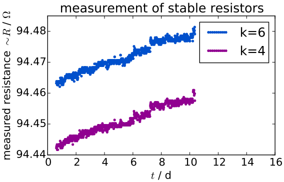




How Do We Measure Resistances Reliably?

! There is an additional PBB-wide drift of unknown origin (t)!

- constant current $I_k(T, t) = \frac{U_I(T,t)}{R_{I,k}(T)}$
- gain $G_k(T) = 5 + \frac{200\,\mathrm{k}\Omega}{R_{G,k}(T)}$
- offset voltage $U_{\mathrm{off}}(T, t)$
- ADC conversion factor C

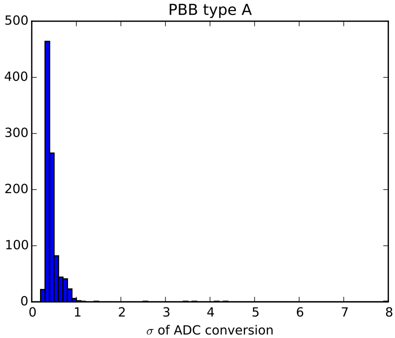


$$R_k \cdot \underbrace{I_k(T, t) \cdot G_k(T) \cdot C}_{m_k(T,t)} + \underbrace{U_{\mathrm{off}}(T, t) \cdot C}_{n(T,t)} = N_k(T, t)$$

→ Use a reference resistor on each PBB!
The 10 THM$\overline{\text{P}}$s foreseen for the fwd. endcap are still sufficient.

Choosing Best Configuration

- Two similiar options for R_G and diodes which generate the offset voltage U_{off} have been considered and were tested.



- The temperature dependency has to be dealt with anyway.
- The second option seems to be electronically more stable.

Summary and Outlook

- ! The resistance of resistors depends on T.
  The effect has already been minimized,
  but has still to be compensated.
- ✓ A temperature dependent calibration is done.
- ✓ The THM$\overline{\text{P}}$ temperature is monitored by a temperature sensor
  which is included in the final THM$\overline{\text{P}}$ design.
  The temperature dependency is quite linear.
- ! Additionally, a slow drift has been observed.
- → The source of the drift will be determined
  by a long-term measurement.
- ✓ The drift can be compensated by using a reference resistor.
- ! If you want a well calibrated THM$\overline{\text{P}}$,
  you will have to adjust the cabling.
- ✓ The setup for the temperature sensor calibration is updated,
  mimicking the endcap instead of the prototype design.

Questions? Comments?

How to Take the Reference Resistor Into Consideration?

- Two possible sources have been identified: U_I and U_{off}

→ Determine the impact of each source

$$m_k(T,t) = \frac{U_I(t)}{R_{I,k}(T)} \cdot G_k(T) \cdot C = m_k(T)\alpha(t)$$

$$\Rightarrow R_k \cdot m_k(T) \cdot \alpha(t) + n(t) = N_k(T,t)$$

$$\Rightarrow \frac{N_k(T,t) - N_j(T,t)}{R_k m_k(T) - R_j m_j(T)} = \alpha(t)$$

→ Long-term measurement with known resistors of different resistances for each channel

case 1 U_I stable: $n(t) = N_{\text{ref}}(T,t) - R_{\text{ref}} \cdot m_k(T)$

case 2 U_{off} stable: $R_k = \frac{N_k(T,t)-n}{N_{\text{ref}}(T,t)-n} \frac{m_{\text{ref}}(T)}{m_k(T)} R_{\text{ref}}$

case 3 Both unstable: Best ansatz with only one reference sensor:

$$\frac{N_k(T,t)-n(0)}{N_{\text{ref}}(T,t)-n(0)} \frac{m_{\text{ref}}(T)}{m_k(T)} R_{\text{ref}} = R_k \left(1 - \frac{n(t)-n(0)}{N_{\text{ref}}(T,t)} \left(1 - \frac{R_{\text{ref}} m_{\text{ref}}(T)}{R_k m_k(T)}\right)\right)$$