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CMS Performance Note

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10 February 2020

Expected Leakage Current Distribution in BPix based on Measurements in a Thermal Mock-Up

CMS Collaboration

Abstract

This Detector Performance Summary shows results from detailed temperature studies on a mock-up of a half-layer of the CMS Phase-1 pixel detector using realistic heat loads and identical CO_2 cooling circuits. From the measured temperature distribution the consequences on leakage currents have been evaluated.

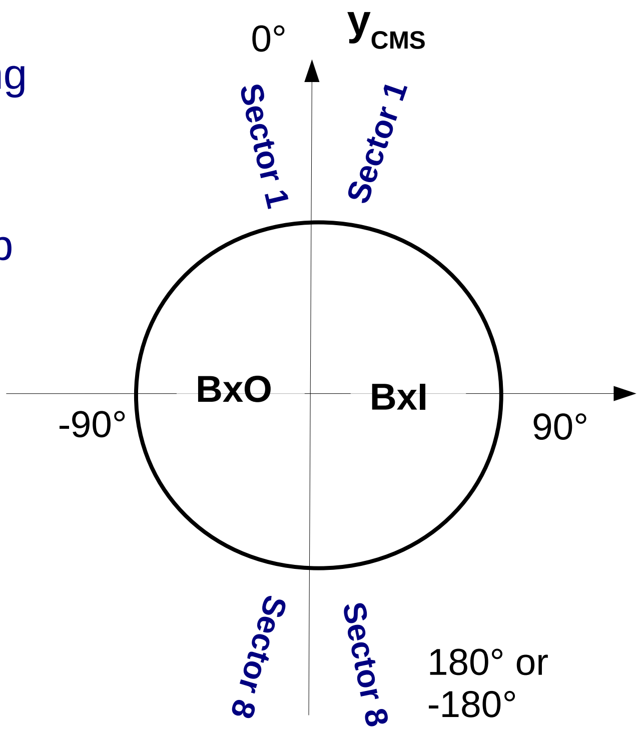
Leakage Current Distribution in BPIX Thermal Mock-Up Measurements

https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSPixelOperationPlots2018

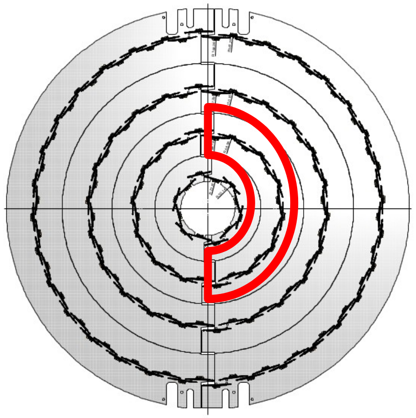
cms-tracker-runcoord@cern.ch
cms-dpg-conveners-tracker@cern.ch

Overview

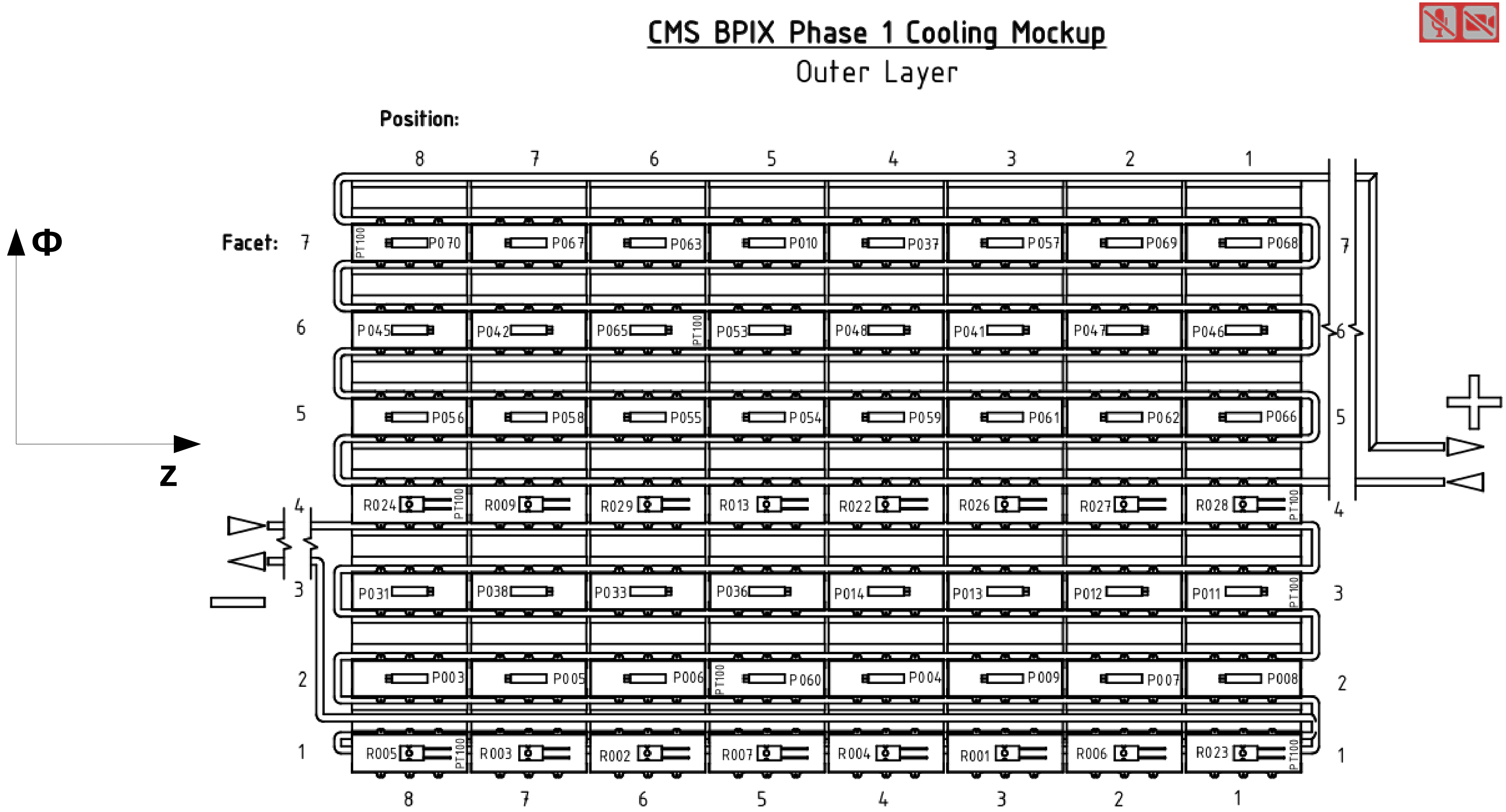
- Characterization of the high-voltage leakage currents and the thermal behavior in BPIX
  - In the two-phase CO_2 cooling system, a temperature drop in the order of 4K occurs along the cooling line (expected behavior)
  - Sensor leakage current is temperature dependent and thus varies along one cooling loop
    - ➔ Effect is seen in the real detector
    - ➔ Effect was confirmed with measurements in a BPIX thermal mock-up



- Leakage current distributions are visualized using 2d-maps in the z-phi plane
  - Coordinate system chosen here is not identical to the CMS coordinate system
  - Coordinate system chosen here is motivated by the numbering of the power sectors
- Measurements with a thermal mock-up were performed
  - Mechanics identical to one BPIX Layer 2 half-shell
  - 2-phase CO_2 cooling with the LUKASZ plant in the BPIX clean room



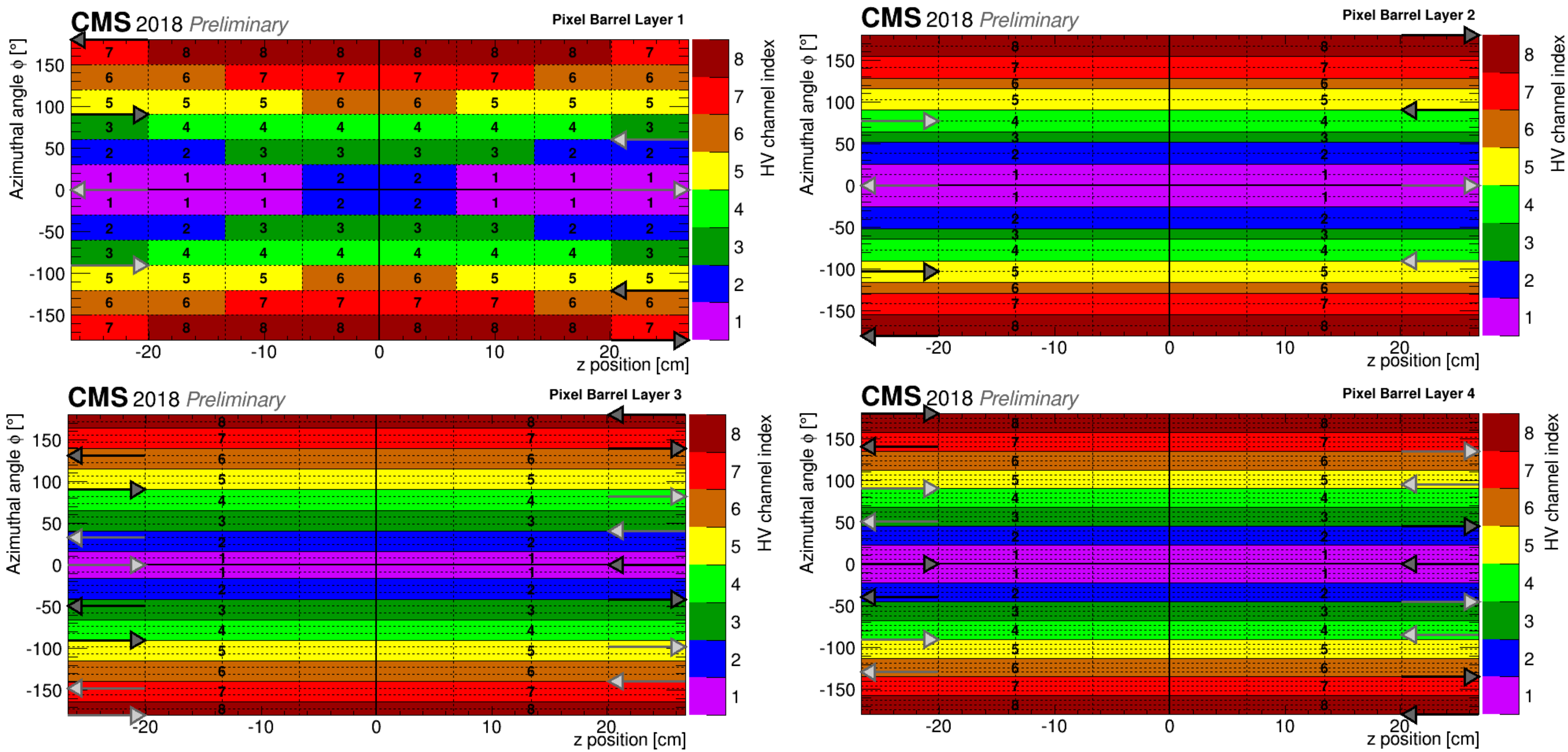
Reminder: Cooling Pipe Routing



- Cooling lines enter the BPIX detector either from the +z-end or from the -z-end
- One cooling line cools up to eight ladders (eight modules per ladder) and leave the detector at the same end where it came from

BPIX Power Sectors

- The maps show the BPIX power sectors in the phi-z-plane
  - Thick black lines indicate the four quadrants of BPIX (top-left: BmI, top-right: BpI, bottom-left: BmO, bottom-right, BpO)
  - Full lines indicate the power sectors (for Layer 2-4 only), dashed lines indicate individual modules
- Arrows indicate the inlet and outlet of the 2-phase CO_2 cooling lines



BPIX Leakage Currents

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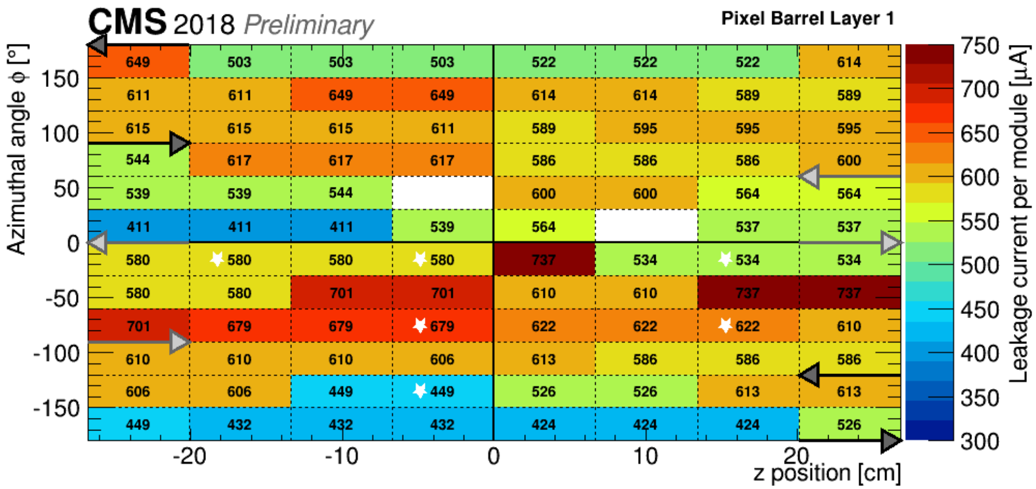
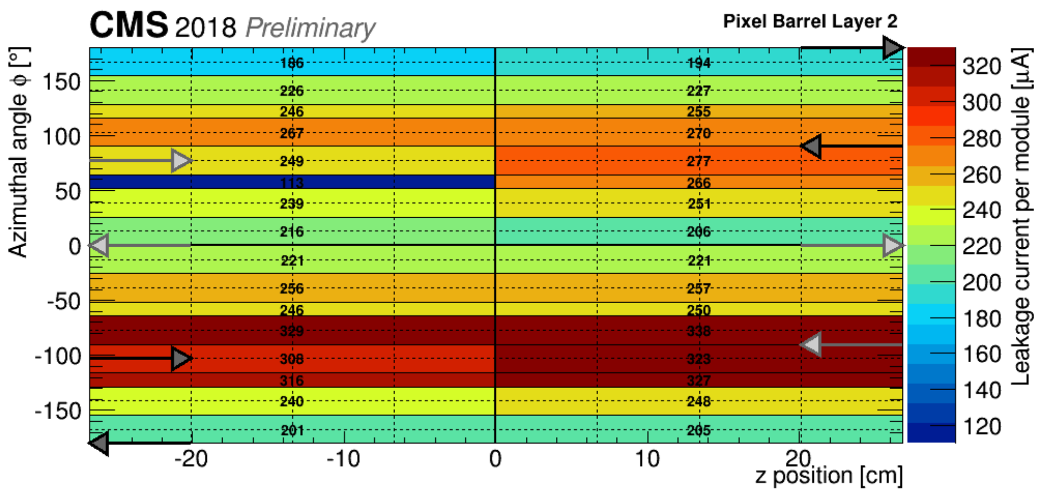
  - Normal lines indicate the power sectors
  - Dashed lines indicate individual modules
- The values in the map are: sector leakage current divided by the number of connected modules
  - For sectors (or modules) which are not powered, the corresponding bin is left blank
  - Modules in Layer 1 marked with a white asterisk have been exchanged during YETS 2017/18 → less integrated luminosity for these modules
- Arrows indicate the inlet and outlet of the 2-phase CO_2 cooling lines
- The plots show that the leakage current decreases along one cooling loop
  - ➔ Temperature drop in CO_2 cooling causes lower a leakage current towards the outlet





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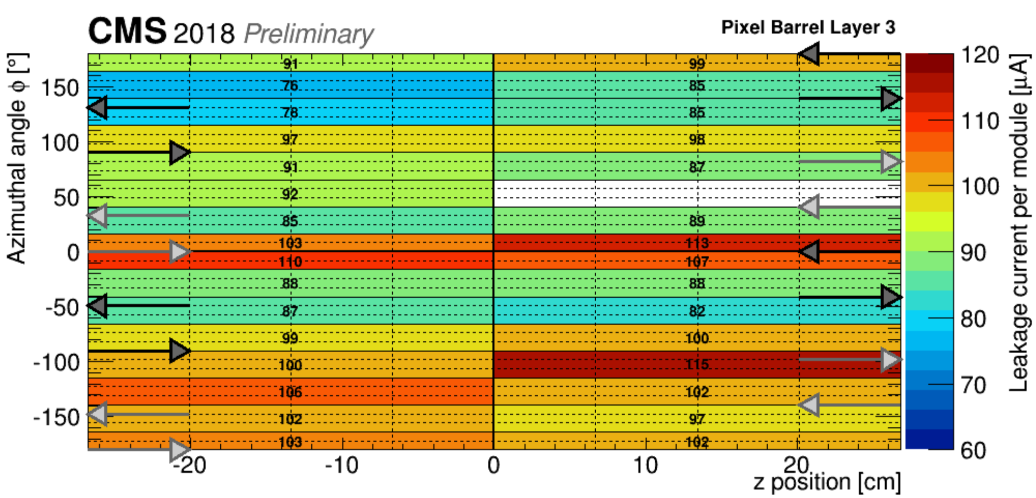
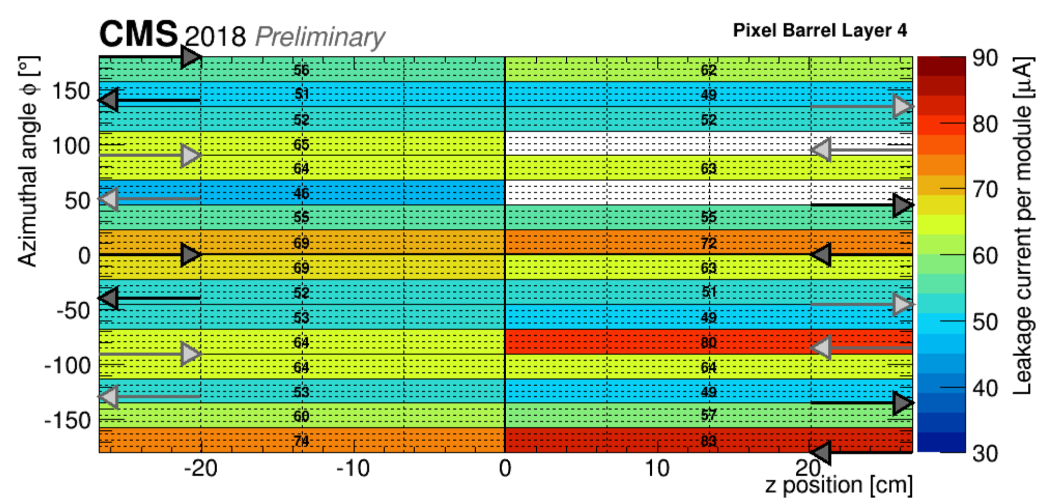
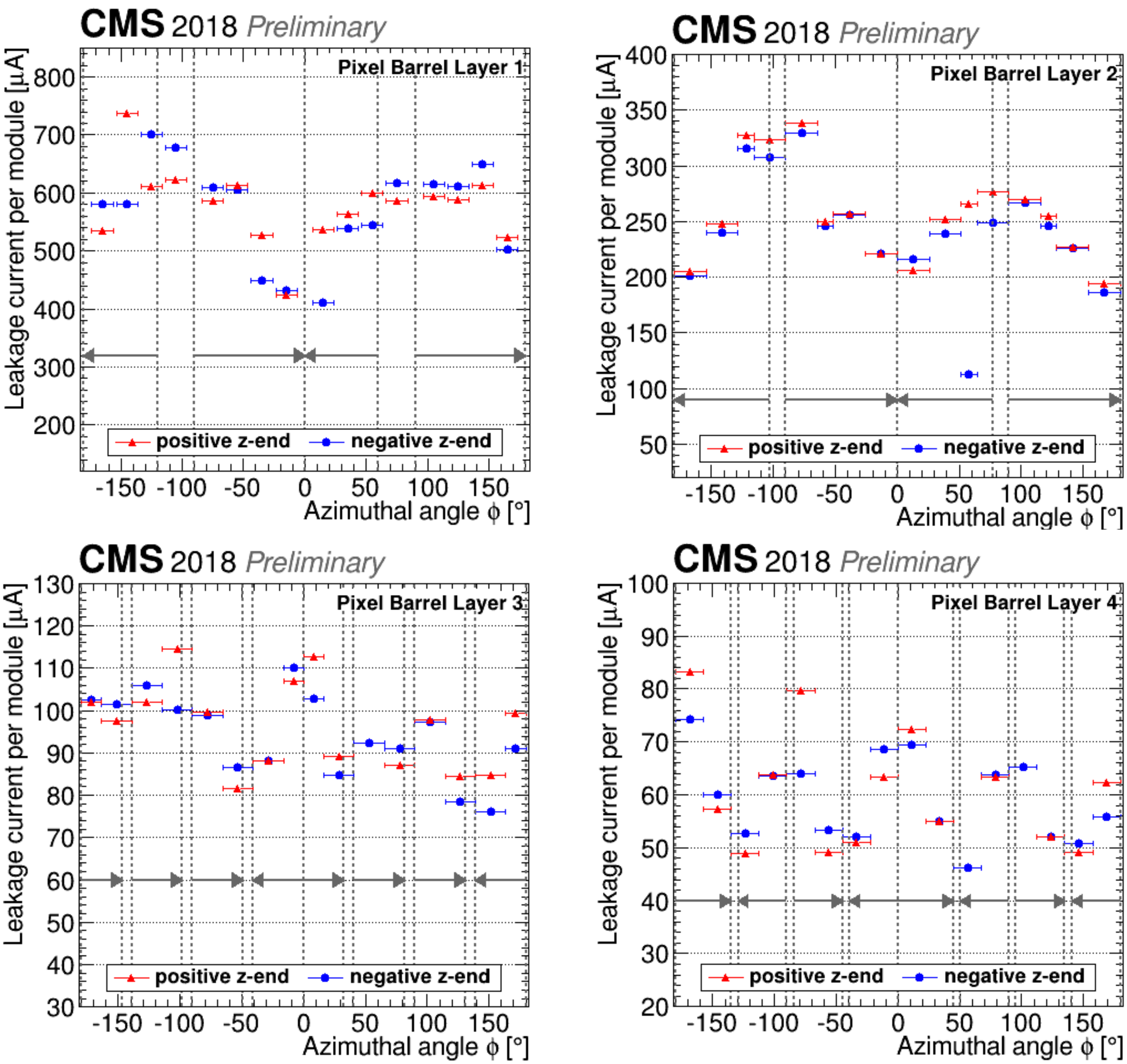


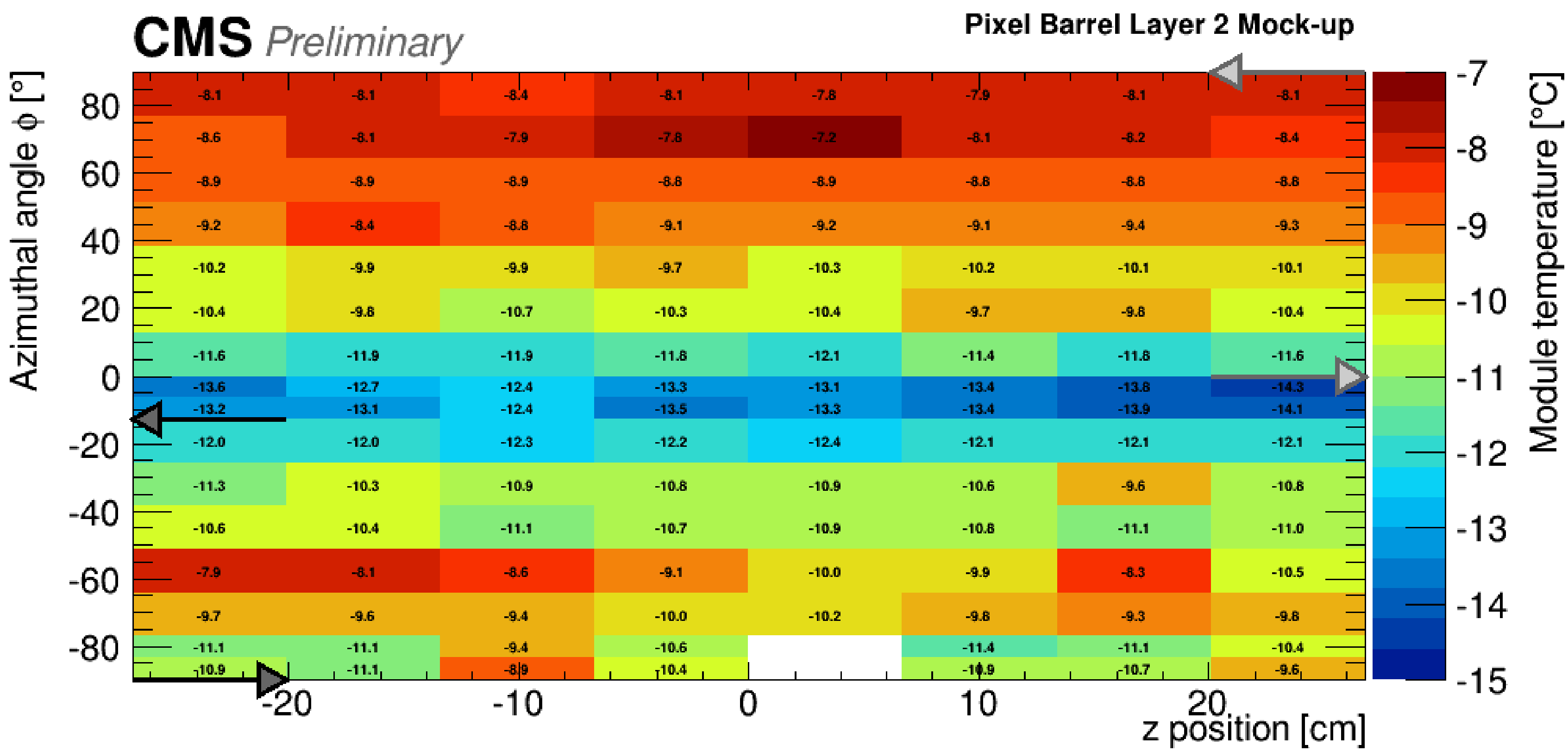


BPIX Leakage Currents



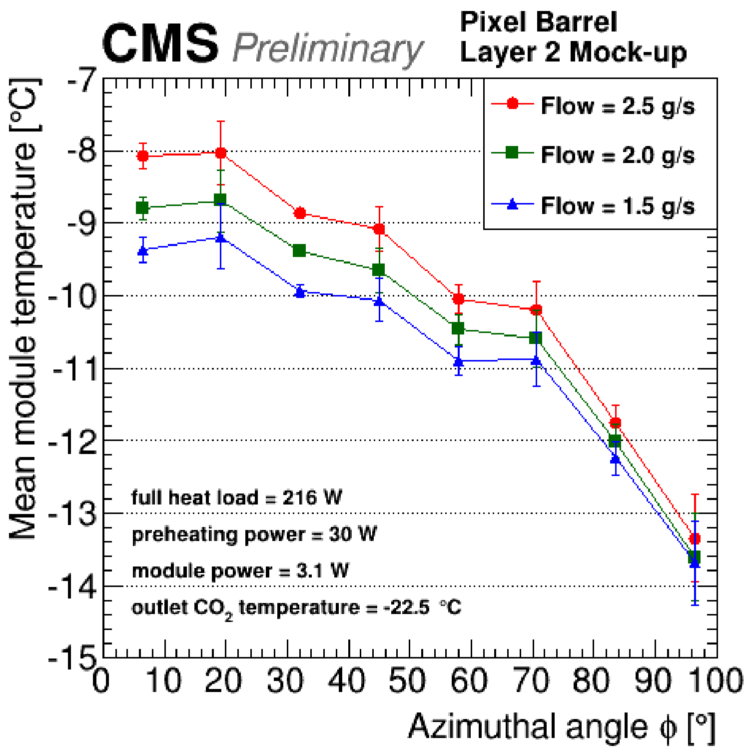
- Same data as shown on Slide 4 and 5.
  - Red markers: positive z-end-sectors
  - Blue markers: negative z-end-sectors
- Error bars in x indicate the phi-coverage of the sector.
- Dashed lines indicate the inlet or outlet of a cooling line.
- Gray arrows indicate the CO_2 flow direction.

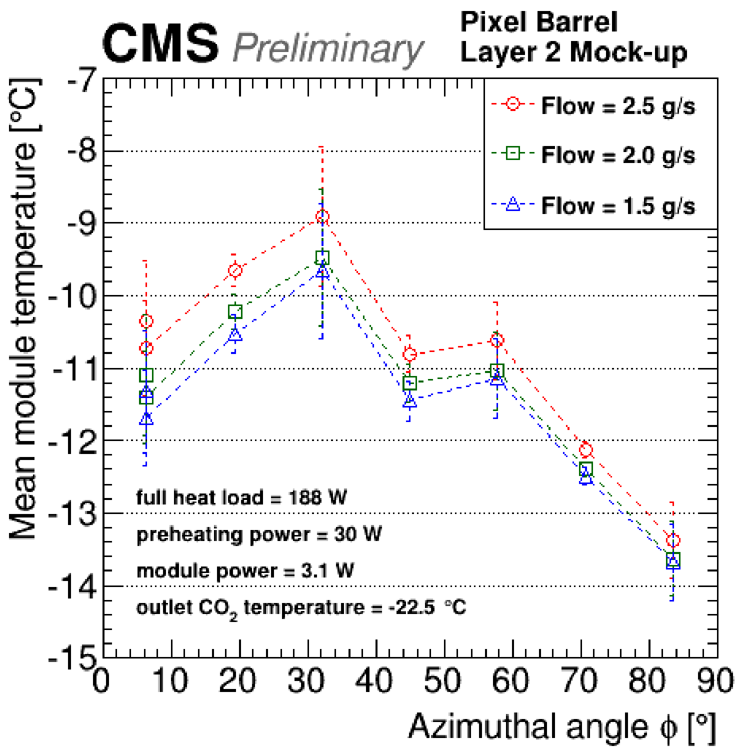
BPIX Thermal Mock-Up Temperatures



- The plot shows the temperature values measured with the BPIX Thermal Mock-up
- Measurement conditions:
    - module power 3.1W, nominal CO_2 temperature -22.5°C, ambient temperature -15°C, preheating power 30W
- Arrows indicate the inlet and outlet of the 2-phase CO_2 cooling lines
- Module temperatures decrease along one cooling loop → temperature drop in 2-phase CO_2 cooling
    - Some irregularities appear → cross-checked many times → still not clear
    - White bin: broken dummy module
- Conclusion of the plot: The modules have lower temperatures towards the return of the cooling loop. The module temperature in the detector is not uniformly distributed, but determined by the CO_2 flow and its 2-phase behavior.

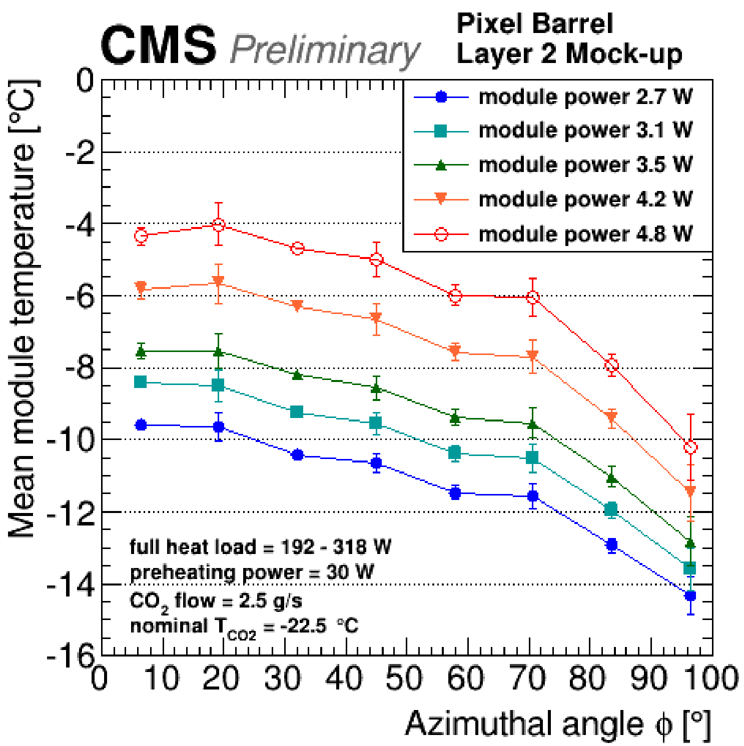
BPIX Thermal Mock-Up Temperatures

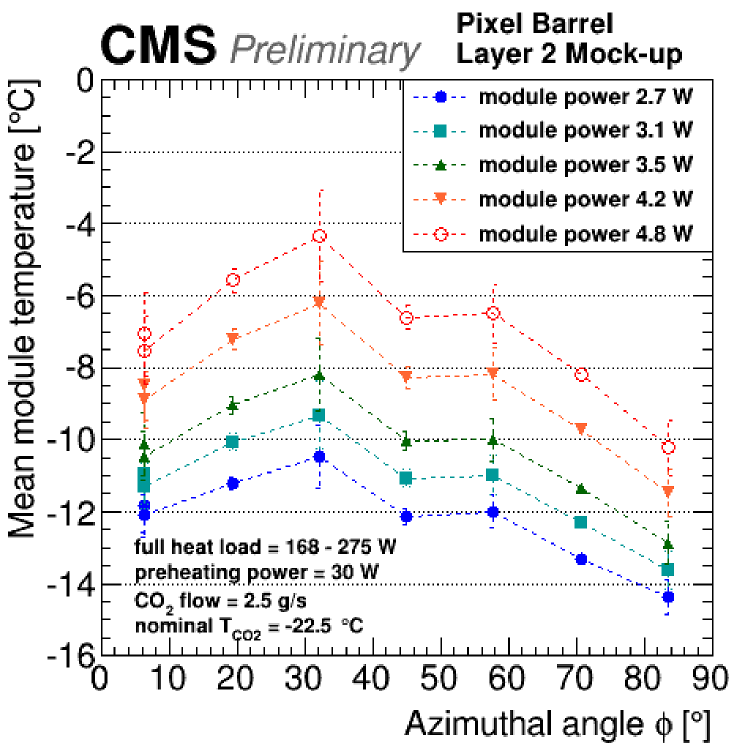




- The mean module temperature is plotted versus the average phi-position of the modules for different mass flows of 2-phase CO_2
- Measurement conditions:
  - module power 3.1W, nominal CO_2 temperature -22.5°C, ambient temperature -15°C, preheating power 30W
- The plot shows that the overall temperature difference in the mock-up half-shell is about 1.5K smaller if the CO_2 mass flow is lowered from 2.5 g/s to 1.5 g/s
- Conclusion of the plot: The effect observed is due to the properties of the CO_2 in two-phase state, e.g. the velocity of mass flow, friction, boiling behavior… While the module temperature at the return point (phi ~= 90°) stays nearly constant, it is lower for modules which are closer to the inlet of the cooling loop (phi ~= 0°). Reducing the CO_2 mass flow might thus reduce the module temperatures and leakage currents (and their spreads with respect to the whole BPIX).

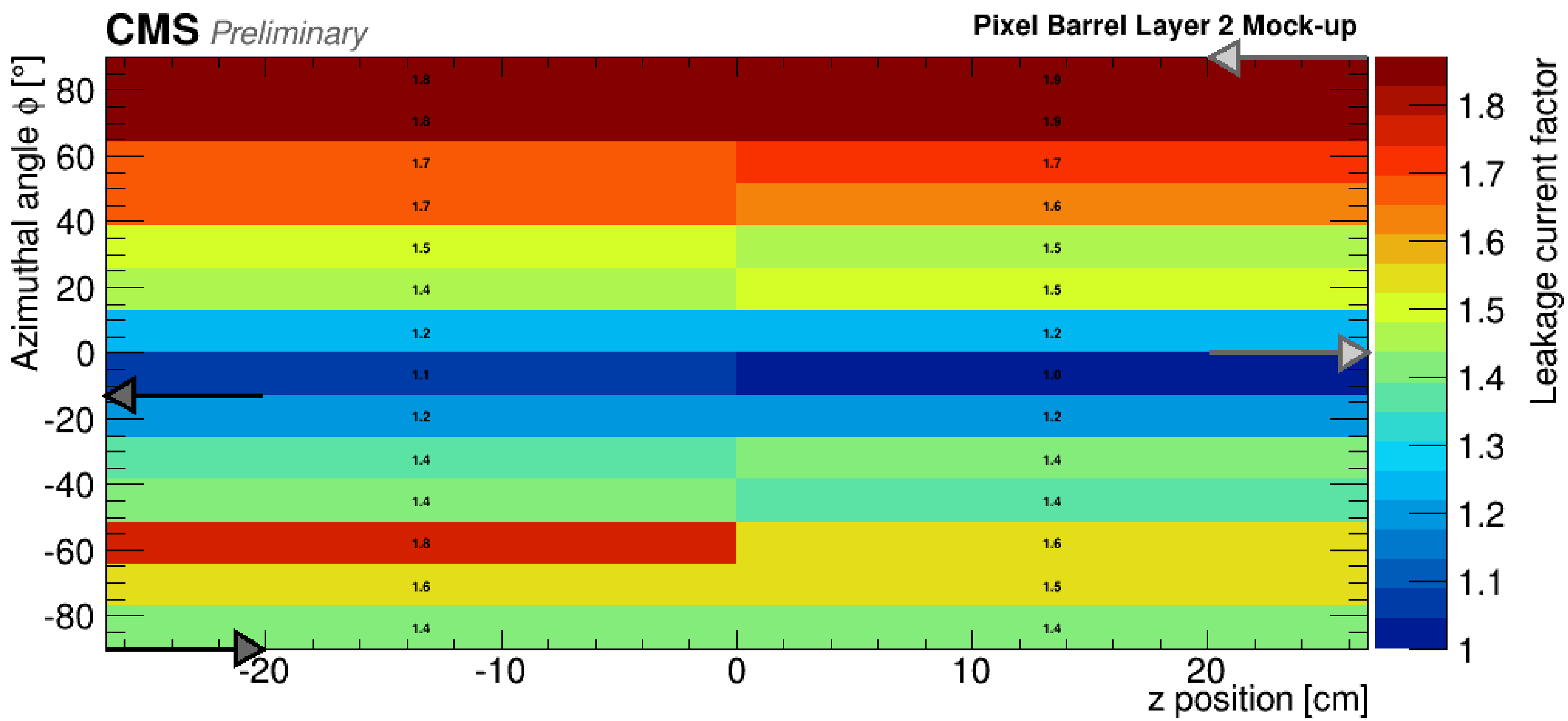
BPIX Thermal Mock-Up Temperatures





- The plot shows the temperature values measured with the BPIX Thermal Mock-up for different module powers.
  - It is estimated that the BPIX Layer 2 modules currently have a power of ~ 3W.
  - A module power of 4.8 W can be considered as an upper limit for the end-of-life-time power.
- The mean module temperature is plotted versus the average phi-position of the modules for different module powers at a CO_2 mass flow of 2.5g/s.
- Conclusion of the plot: A significant higher module power also affects the module temperatures (6K higher module temperatures at 2W higher power. The overall temperature difference in the mock-up half-shell is increased from 4K for a module power of 2.7W to 6K for a module power of 4.8W. The temperature differences in the detector do also depend on the full heat load.

BPIX Thermal Mock-Up Temperatures



- The modules are arranged into groups of four modules per ladder and z-end.
- The factor of HV leakage current per module is normalized to the lowest module temperature T_0 that is measured in the mock-up. Then the z-axis is normalized to the module group with the lowest leakage current.

$$\text{leakage current factor} = \frac{I}{I_0} = \frac{1}{N_{\text{modules}}} \sum_i \frac{T_i^2}{T_0^2} \exp\left[-\frac{\Delta E}{2\,k_B} \left(\frac{1}{T_i} - \frac{1}{T_0} \right) \right]$$

- Conclusion of the plot: The plot shows that a factor of 1.9 between leakage currents at different ladders is expected from the measurements with the thermal mock-up. These leakage current factors which are estimated from the mock-up measurements, were compared to the detector currents where the location of the cooling was taken into account. The results are in good agreement with the actually measured leakage currents in the BPIX detector.