ATLAS silicon strip tracker upgrade:
Anatomy of a petal

Dario Ariza, Soeren Ahrens, Yu-Heng Chen, **Claire David**, Sergio Dìez Cornell, Nils Flaschel, Carina Jacobi, Yi Liu, and the help of many others.

Tuesday, November 29, 2016 DESY FH Fellow Meeting

Introduction

Little bio

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2005-2010

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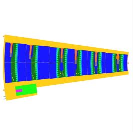
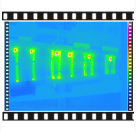
Content of this talk

1. ATLAS upgrade: why and what?
2. Presentation of the petal
3. Infrared anatomy
4. Optical metrology
5. Summary and videos!





The ATLAS detector at the High-Luminosity LHC (HL-LHC)

Goals of HL-LHC program: increase discovery potential and precision on measurements

⇒ increase of instantaneous luminosity and number of collisions / bunch crossing

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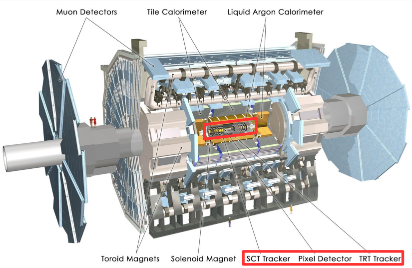

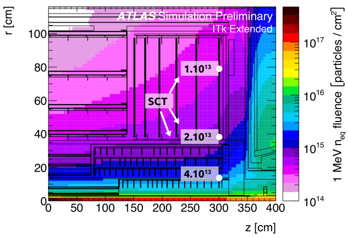

Fluence for the ITk layout (1 MeV neutron equivalent flux)

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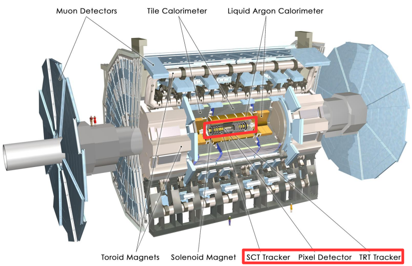

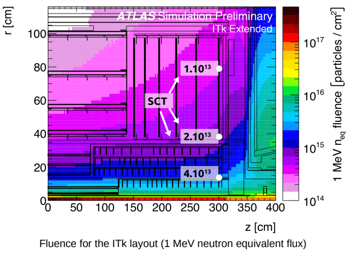

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Need new trackers for Run 4 onwards in 2026 with requirements:

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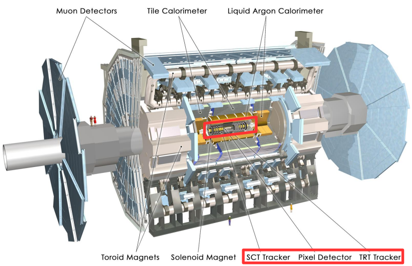

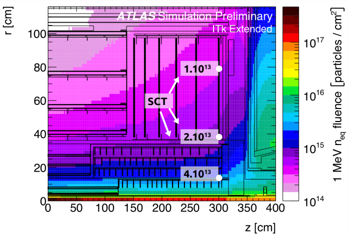

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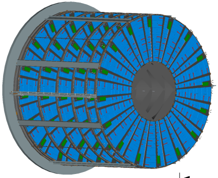
Need new trackers for Run 4 onwards in 2026 with requirements:

High performance	low p_T: reduce tracking volume material
	high p_T: reduce average pitch
High radiation hardness	radiation hard sensor material
	new readout electronics
High granularity	to resolve $\sim$ 200 collisions/bunch crossing
	maintain detector occupancy below % level

Introducing the thermo-mechanical petal

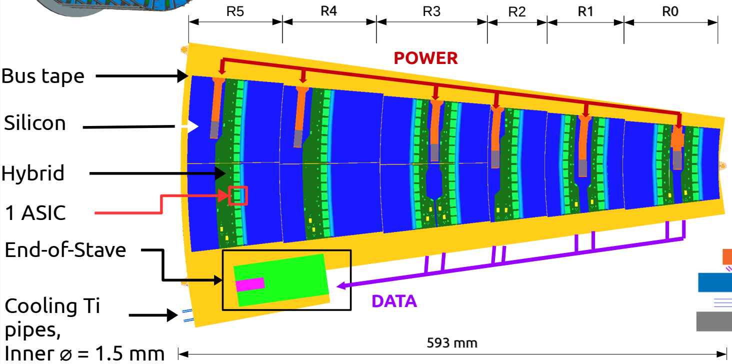


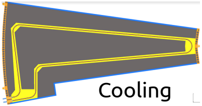
1 endcap = 6 disks

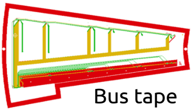
→ 32 petals

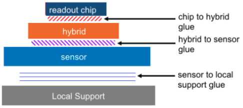
→ 9 modules x 2 sides

384 petals → 6912 endcap modules



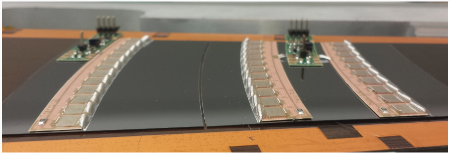


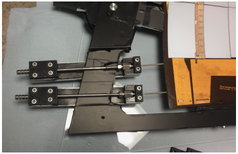


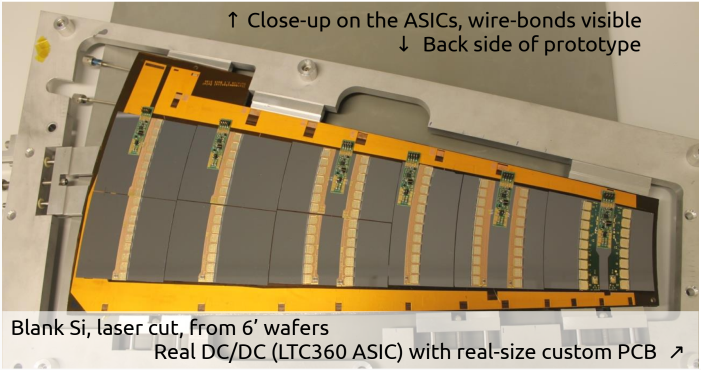


Layers of a module

Thermo-mechanical petal prototype: the real thing





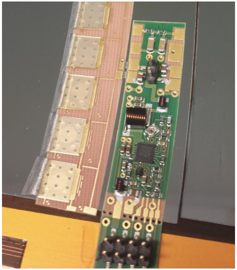


↑ Close-up on the ASICs, wire-bonds visible

↓ Back side of prototype

Blank Si, laser cut, from 6’ wafers

Real DC/DC (LTC360 ASIC) with real-size custom PCB ↗



Goals of petal characterization

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  - resistance to deformations
  - reaction to shearing
  - vibration tests

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- **Optical tests**
  - flatness measurements
  - glue thickness measurements
- **Infrared thermography**
  - temperature distribution on petal's surface
  - see temperature ranges in normal/abnormal conditions
  - estimate temperature when thermal runaway can occur

Basics of thermal imaging

There is no direct method to measure the temperature

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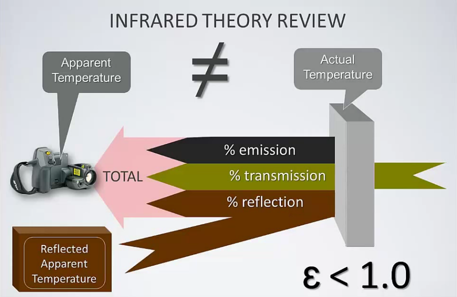


Source: Instrument FLIR Webinar

Infrared camera can't differentiate the different sources!

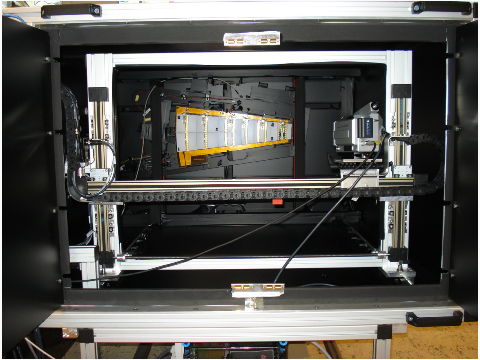
Emissivity

$$\epsilon = \frac{\text{Actual emission from a surface at temperature T}}{\text{Emission from a black body at temperature T}}$$

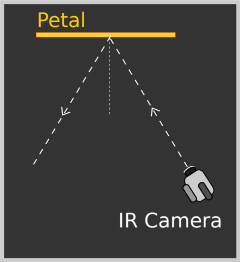
- describes how well the target emits infrared radiation

Custom thermal chamber at DESY

Front view



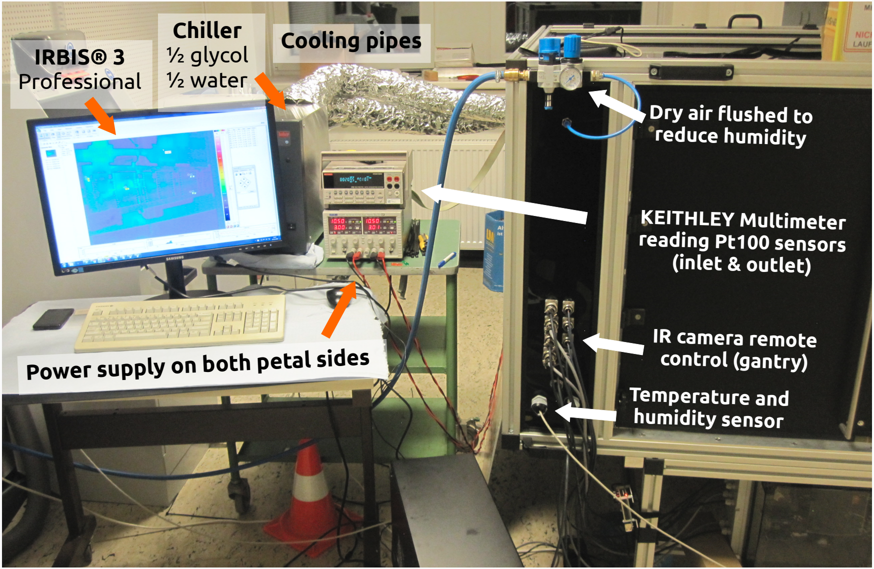
Top view



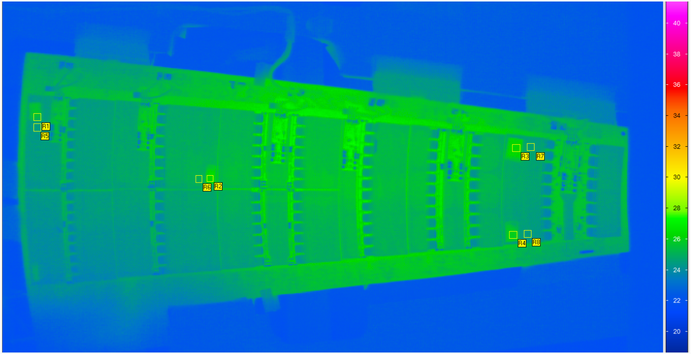
- Camera angled to avoid Narcissus effect

- Thermo-mechanical prototype maintained vertical
- IR Camera: Infrated VarioCam® HD Inspect 600 (640 × 480 pixels)
- Arduino-controlled lead screw gantry system (IGUS SAW-1040, NEMA 23) to move camera in XY direction

Instrumentation of chamber



Screenshot from IRBIS® software, full petal at ambiant (warmer)



Difficulty: emissivity of silicon not known + need a non-destructive method

The black tape trick: emissivity constant (0.9) and at therm. eq. $\rightarrow T_{\text{tape}} = T_{\text{Si}}$

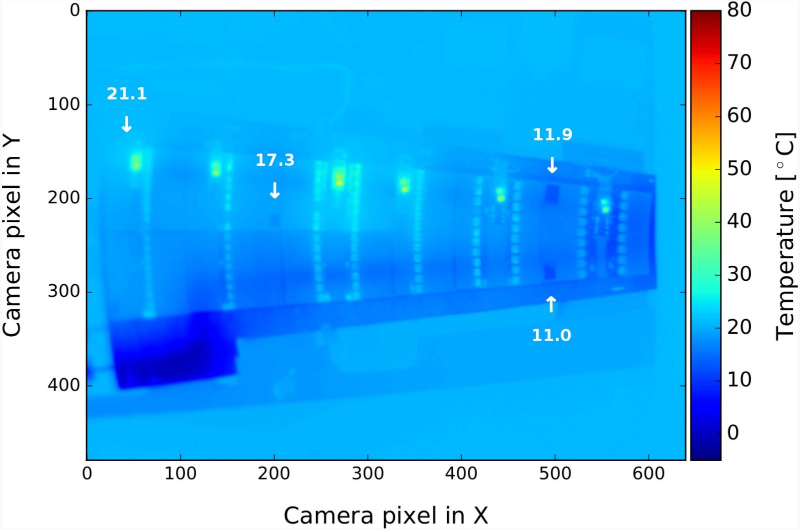
Steps:

1. take thermogram at $\epsilon = 0.9$
2. get emissivity next to black tape $\rightarrow$ compute average emissivities $\bar{\epsilon}$
3. take thermogram with $\bar{\epsilon} \Rightarrow$ temperature values corrected

Corrected thermogram, full petal, cooled, power on

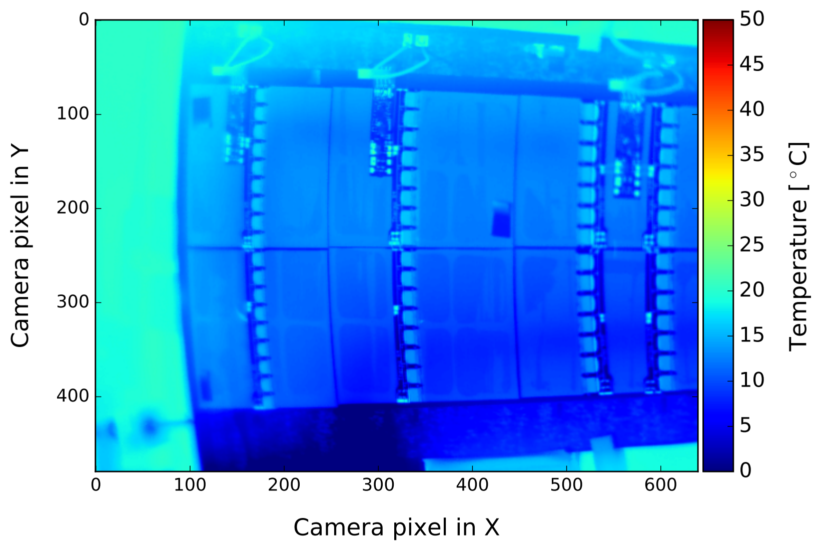
Petal cooled down at -20°C (chiller), inlet cooling pipe at -6°C, $\epsilon = 0.64$

Power on!: 10.5 V ; 2.40 A on both sides



Close-up on modules R5 and R4, cooled, no power

Modules R5 (left) and R4 (right) cooled at -20°C (chiller), no power , $\epsilon = 0.64$



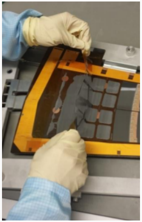
Inter(g)lude

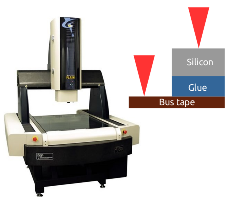
Metrology of module on-core gluing

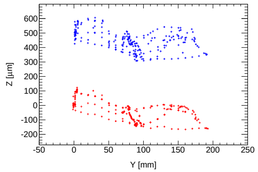
Manual assembly, SE4445 DC adhesive

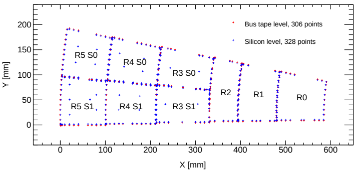
140 μm fishing lines to control glue height

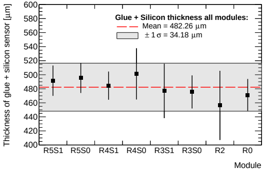
Glue thickness measured around Si sensors with CNC670 SmartScope optical table











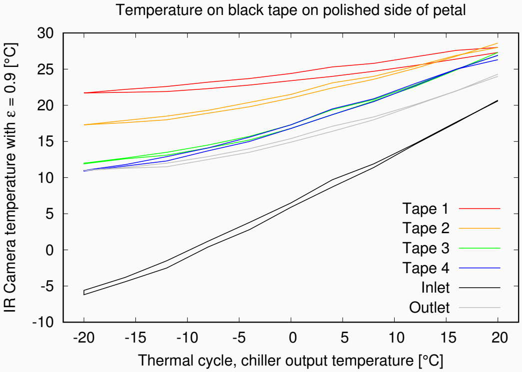
Average glue thickness of around 162 μm, narrow distribution (1 $\sigma = 34$ μm)

Also studied with SmartScope: Sensor bow estimated with 180 - 300 points. Calculated flatness around 150 - 200 μm.

Back to IR results

Thermal cycle

- Powered petal (10.5 V; 2.3 A) undergoing “thermal cycle”
- Start: chiller at 20°C, go to -20°C, back to 20°C with step $\Delta T = 4\ ^\circ$C
- Thermal equilibrium reached at each step (as much as possible)
- Recorded temperatures: inlet + outlet cooling pipes + 4 black tape on petal



- reduction of silicon surface temperature up to $\Delta T = 16\ ^\circ$C
- Upper curve ≡ cooling down
- System does not exhibits thermal memory for considered temperature range [-6°C ; 22°C].

Conclusions and outlook

A petal prototype for the future ATLAS ITk strip detector is beeing characterized at DESY:

Metrology

Optical inspection with SmartScope on glue thickness and sensor bow

⇒ Results are very satisfying given the fact the petal was manually assembled!

Thermograms

First tests of thermo-mechanical petal in DESY custom thermal chamber

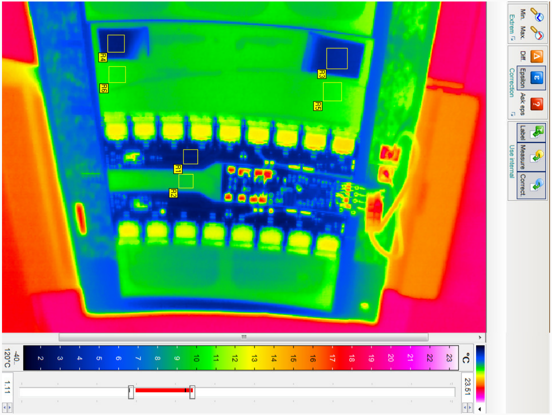
Non-destructive method to correct thermogram to the emissivity of silicon

First (pre)-thermal cycle showing no history from range -6 ; 22°C for Si sensors

What's next?

- Automation of optical measurements using SmartScope software
- Improving the infrared tests with
  - new camera
  - new chiller (CO_2 evaporative cooling)
  - new calibration ideas (using dummy modules with glued thermocouples)

Dr. Frank-Einstein Petal

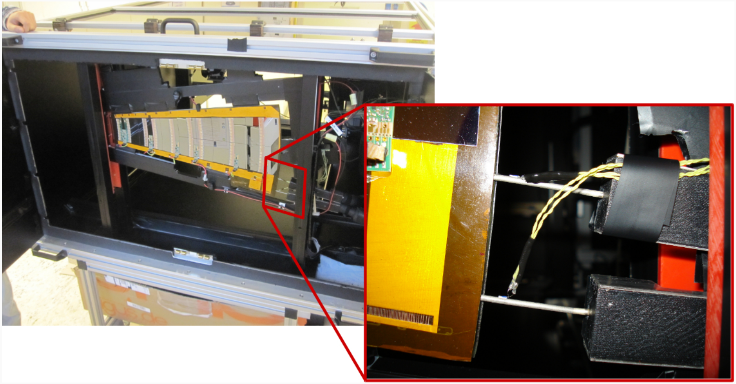


Claire don't forget the videos

Backups

Custom thermal chamber at DESY

Back side of chamber



- Two petal sides powered with 10.5 V & $\sim$2.35 A $\Rightarrow$ $\sim$24 W dissipated / side
- Pt100 4-wire sensors to measure inlet and outlet temperatures
  $\rightarrow$ glued to titanium cooling pire with WEICON Contact Cyanoacrylate

Method to correct for the emissivity

Difficulty

- Emissivity of silicon unknown
- Petal not to be touched

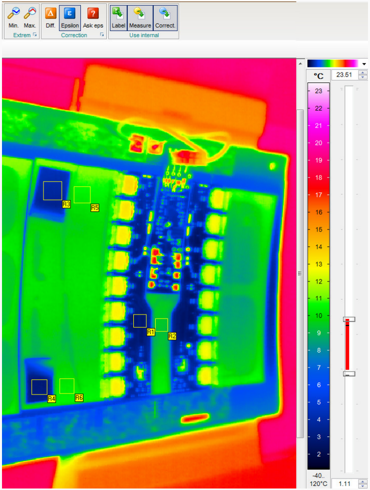
Trick of black tape:

- known and stable emissivity
- $T_{\text{tape}} = T_{\text{Si}}$ at therm. equil.

Pieces of black tape were put on petal.

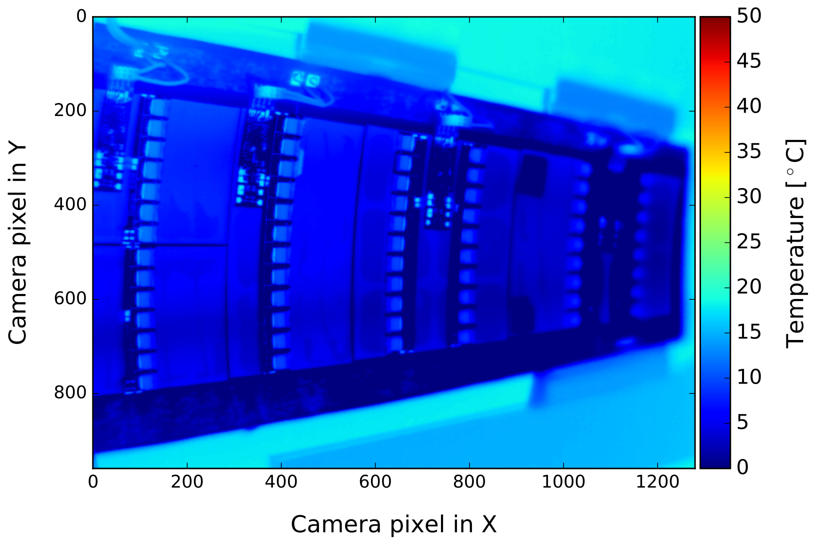
Correction

1. Set $\epsilon = 0.9$ and take thermogram
2. Measure T_i on black tape markers i
3. Get ϵ_i of Si point near each marker i
4. Get average emissivity $\bar{\epsilon}$
5. Take globally corrected thermogram with $\bar{\epsilon}$



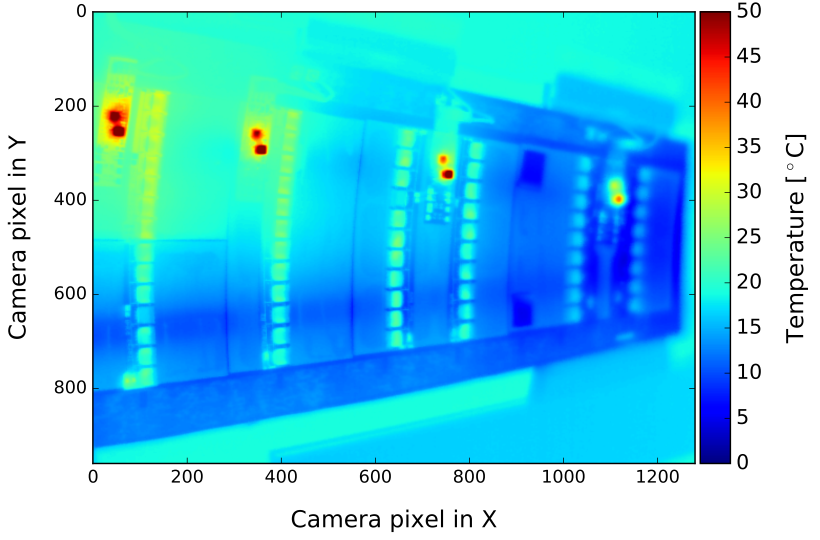
Close-up on module R2 and R1, cooled, power off

Modules R2 (left) and R1 (right) cooled (inlet pipe -6.3°C), no power, $\epsilon = 0.64$



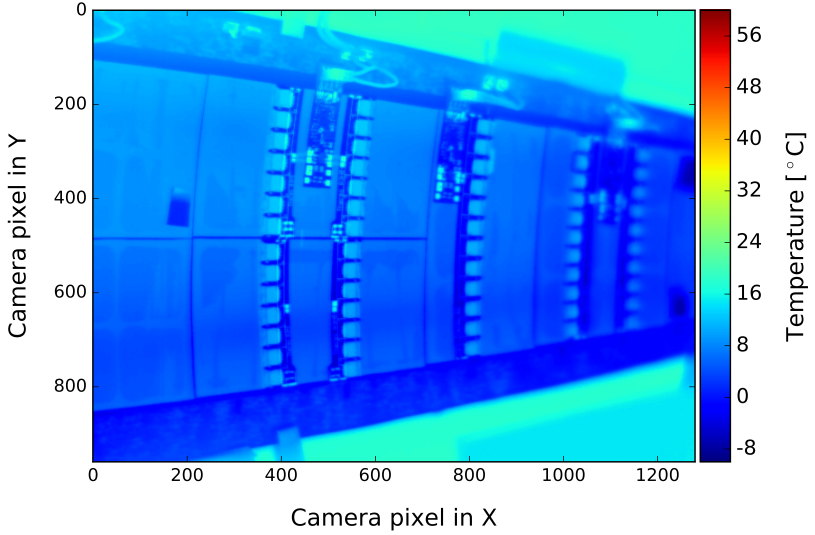
Close-up on module R2 and R1, cooled, power on

Modules R2 (left) and R1 (right) cooled (inlet pipe -6.3°C), power on, $\epsilon = 0.62$



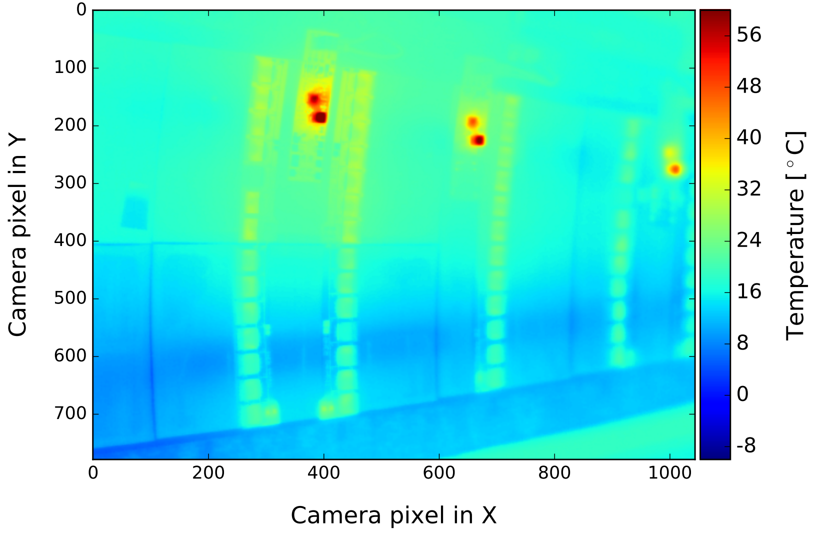
Close-up on module R3, cooled, power off

Module R3 (left) cooled at -20°C (chiller), -5.9°C (inlet pipe), no power, $\epsilon = 0.65$



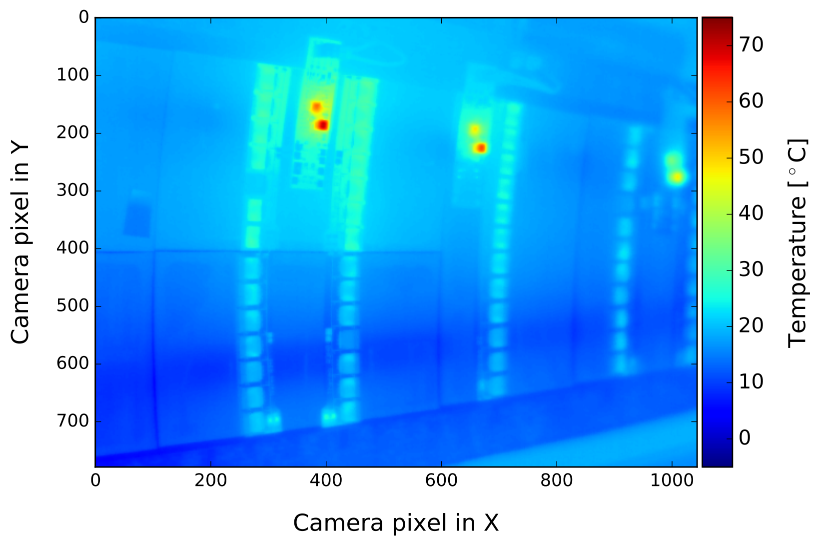
Close-up on module R3, cooled, power off

Module R3 (left) cooled at -20°C (chiller), -5.9°C (inlet pipe), no power, $\epsilon = 0.63$



Close-up on module R3, cooled, power off

Module R3 (left) cooled at -20°C (chiller), -5.9°C (inlet pipe), no power, $\epsilon = 0.63$

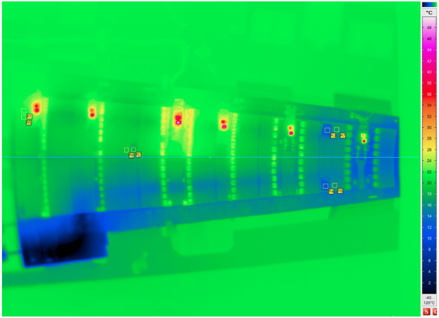


Alternative method to correct for the emissivity

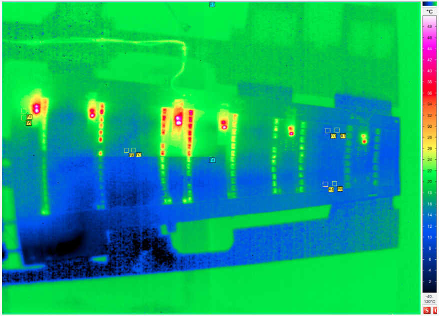
"Filter tool" from IR camera software IRBIS® to correct thermogram

- needs a reference image + ambiant & object temperatures
- supposes a strict uniform distribution of object temperature
- output emissivity map coherent with assumptions (black tape $\sim$ 1)

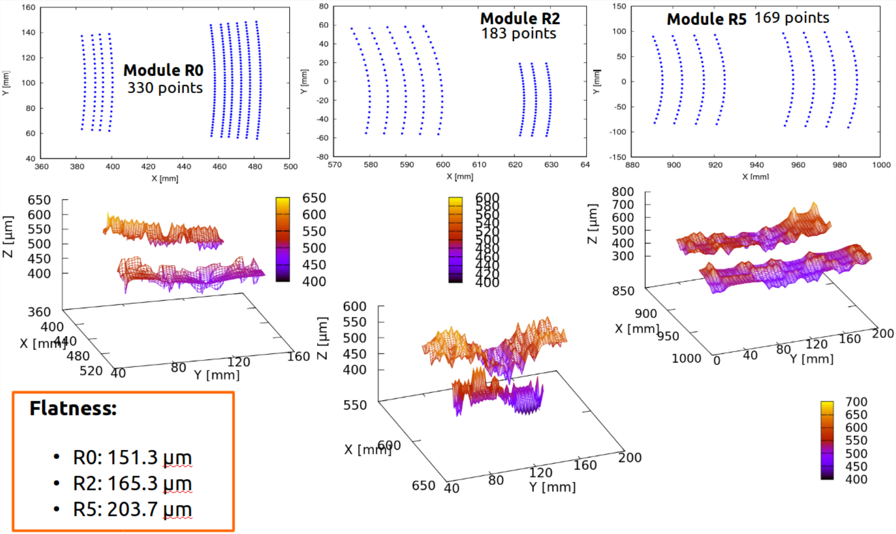
Uncorrected thermogram



Corrected using filter method



Metrology of module on-core gluing



Flatness:

- R0: 151.3 µm
- R2: 165.3 µm
- R5: 203.7 µm

Details in presentation at Strip Module Meeting 17 Nov 2016