Karlsruhe Institute of Technology

Qualification of a Temperature Stabilized Test Station for Silicon Sensor Modules for the CMS Experiment

T 68.9

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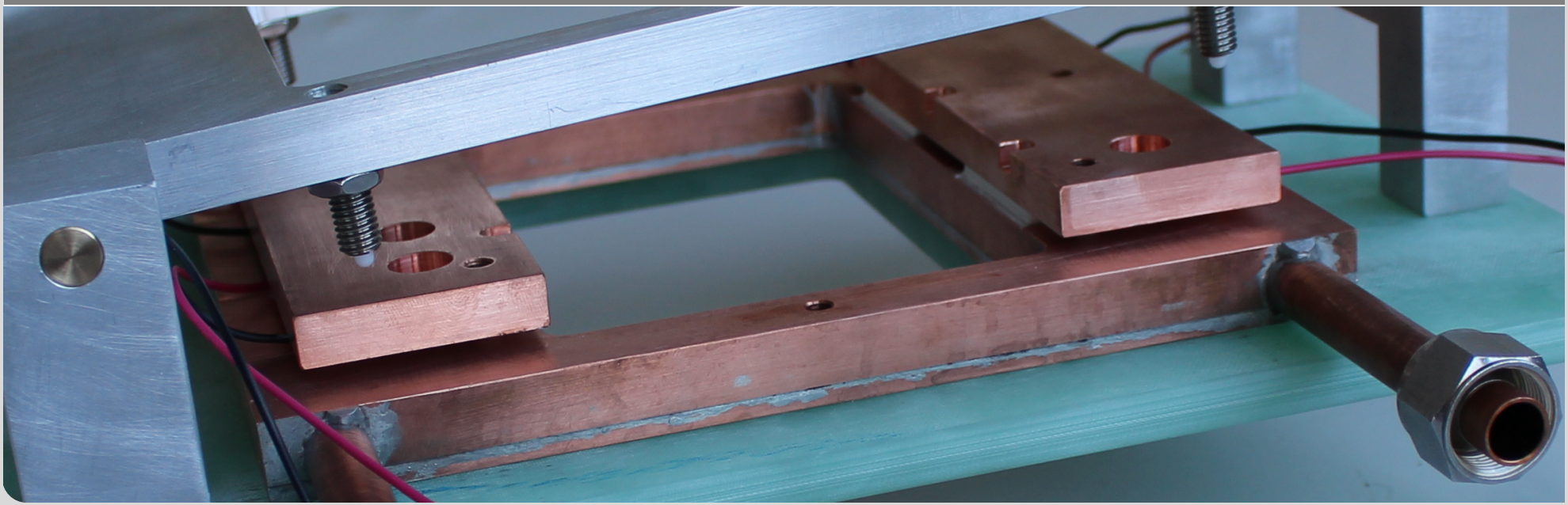
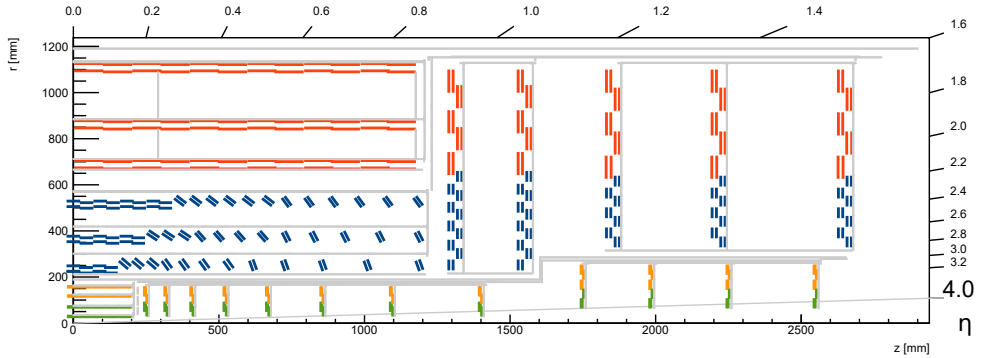
INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS

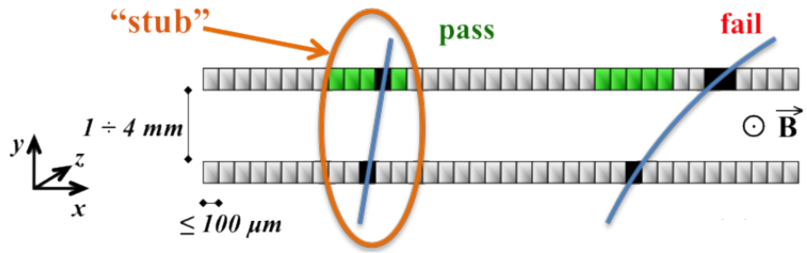


Phase-2 Upgrade of the CMS Outer Tracker

- New silicon tracker for the CMS experiment at the HL-LHC by 2026
- Requirements for the Outer Tracker upgrade:
  - Improved radiation tolerance up to $10^{15}\,\mathrm{n_{eq}cm^{-2}}$
  - Increased granularity
  - Improved two-track separation
  - Reduced material in tracking volume
  - Contribution to L1 trigger



2S modules and PS modules in the Phase-2 Outer Tracker



- Silicon sensors in tracker modules will be operated at about $-20\,^{\circ}\mathrm{C}$

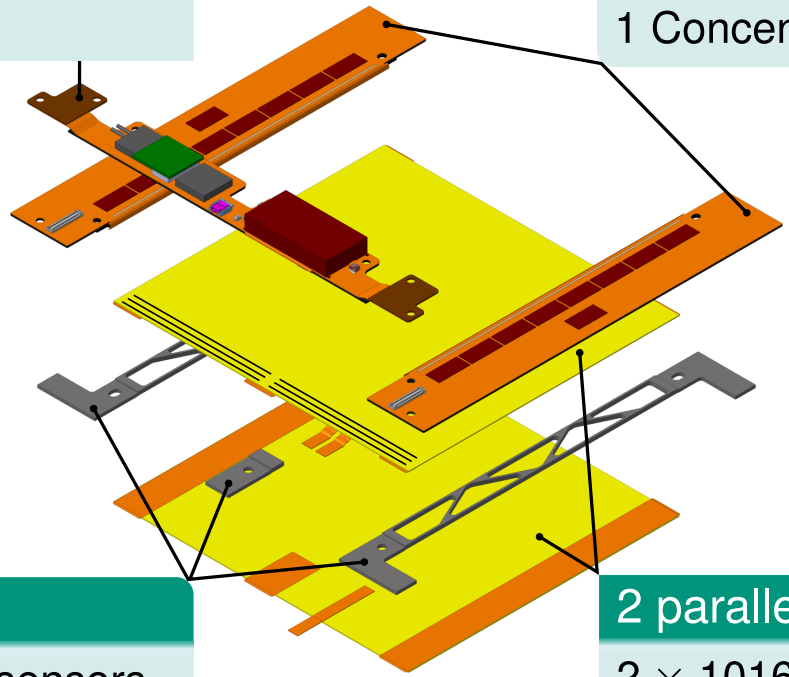
2S Module for the CMS Outer Tracker

Service Hybrid

Powering
Data transmission

2 Front-end Hybrids

8 CMS Binary Chips each
1 Concentrator Chip each



Al-CF Spacer[1]

Spacing between sensors
Main cooling path
Mechanical fixation

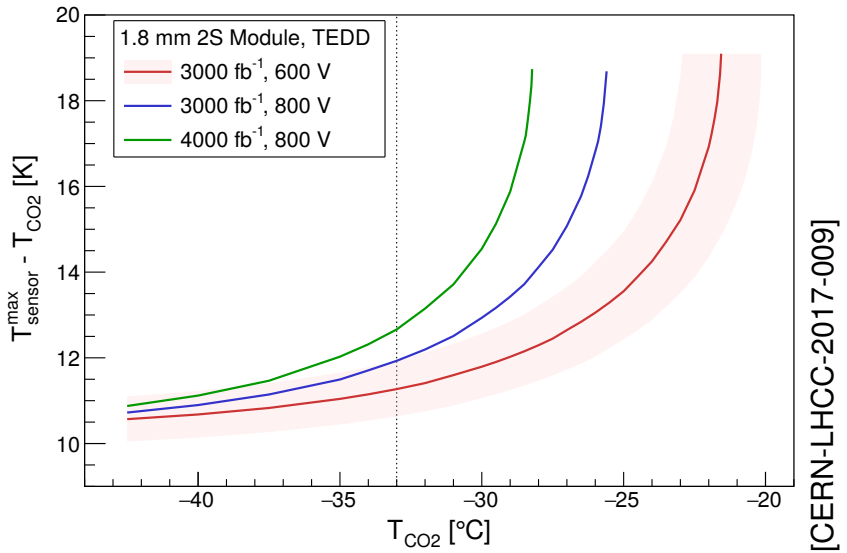
2 parallel silicon strip sensors

2×1016 strips each
5 cm long strips, 90 µm pitch
Active area $\approx 2 \times 90\,\mathrm{cm}^2$

[1] Aluminum / carbon fiber composite

Design Requirements for a 2S Module Test Station

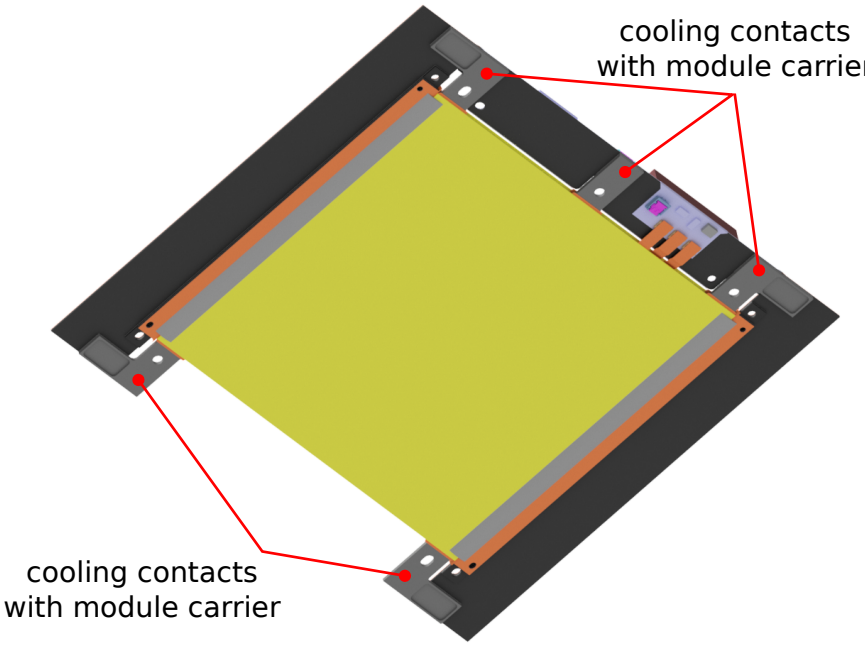
- Test modules during prototyping and production (electrical calibration, charge deposition, thermal cycles)
- Readout station appropriate for module production
  - Quick and safe mounting and removal of modules (no screws)
  - Automate processes as far as possible
  - Reach T_{Set} quickly
- $T_{\mathrm{Set}} \leq -33\,^{\circ}\mathrm{C}$ (cooling temperature in CMS)



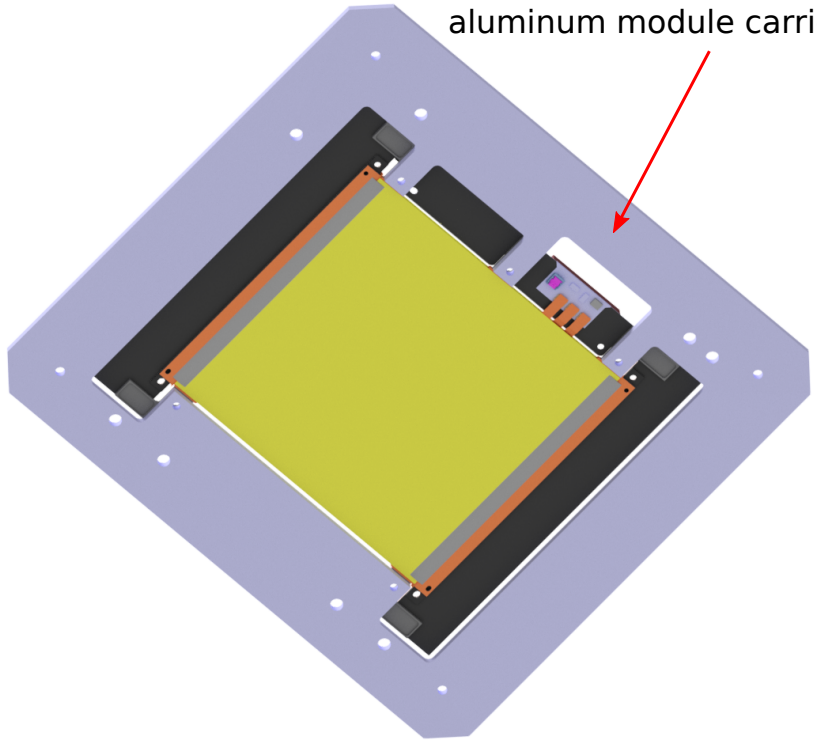
- Thermal runaway simulation performed with heat load of approx. 6 W

Design Requirements for a 2S Module Test Station

- After assembly procedure: module mounted on aluminum carrier
- 5 cooling points per module



Bottom view of 2S module

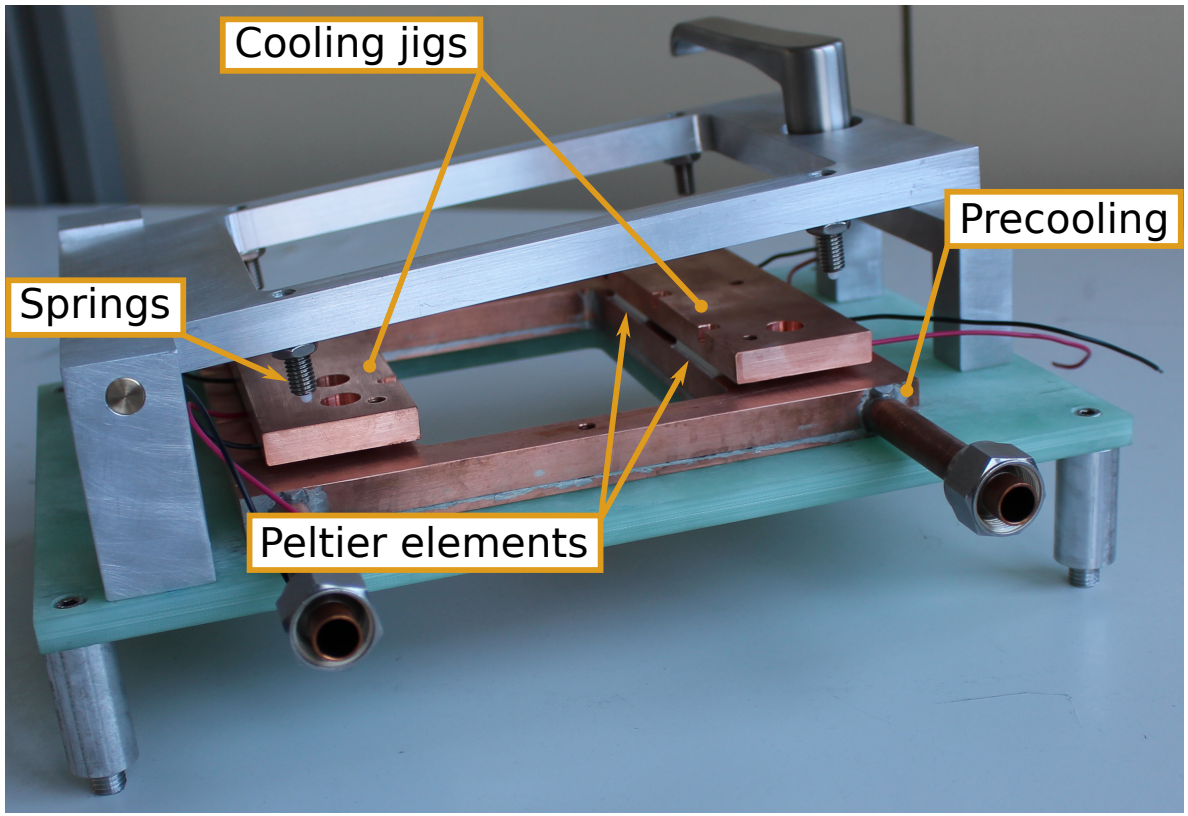


Bottom view of 2S module

mounted on module carrier

Experimental Setup

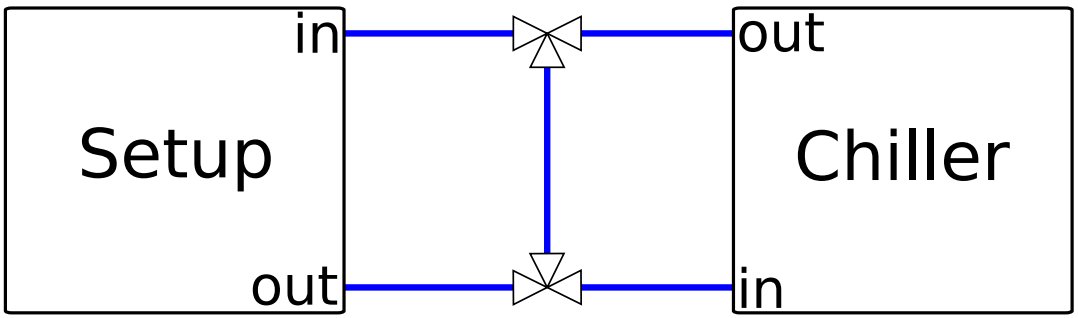
- Place module carrier on two copper jigs
- Jigs cooled with two-stage cooling system:
  Four Peltier elements and precooling at $-10\,^{\circ}\mathrm{C}$



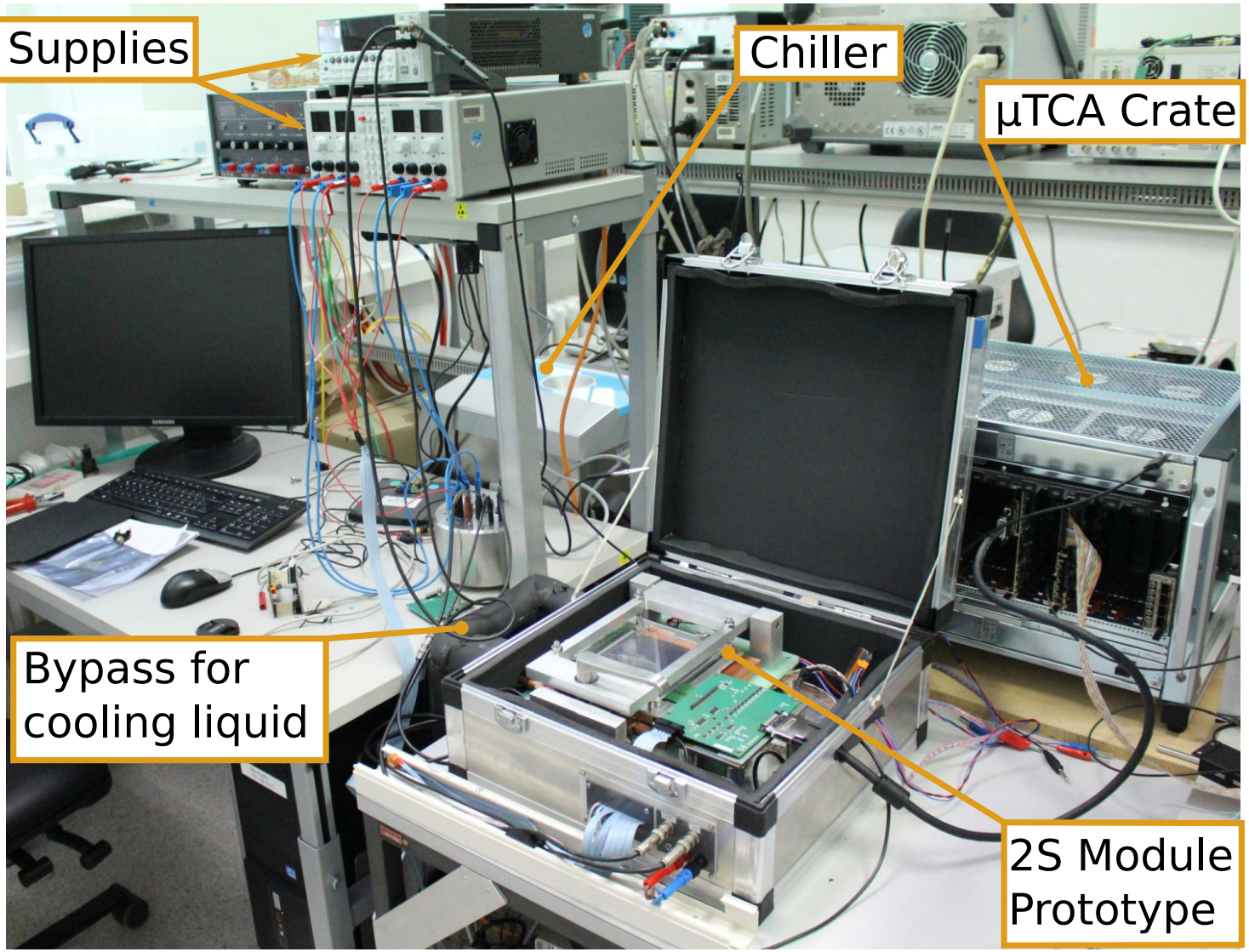
[Koppenhöfer18]: Master Thesis, ETP-KA/2018-17

Experimental Setup

- Setup placed in aluminum box:
  - Thermal insulation
  - Faraday cage
  - Shielding against light and radiation exposure
  - Stabilization of humidity level
- Bypass for cooling liquid outside box
  $\Rightarrow$ allows warming up of precooling blocks to open box quicker (dew point)

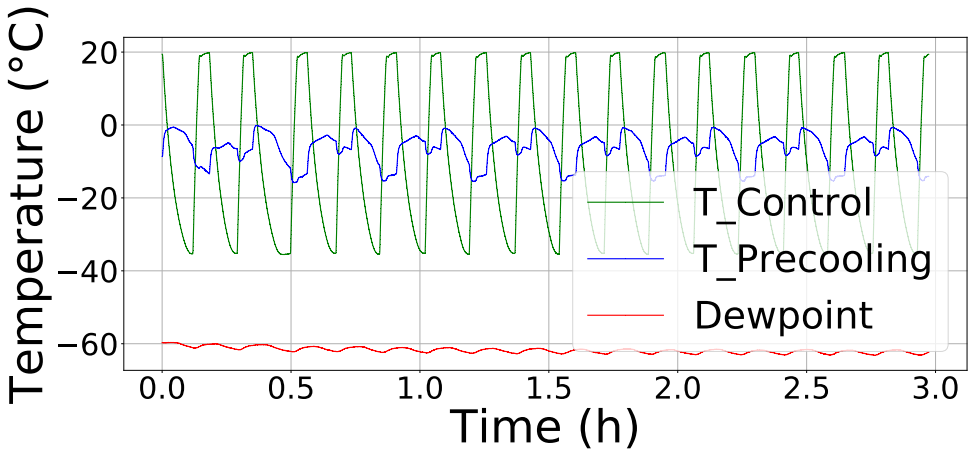


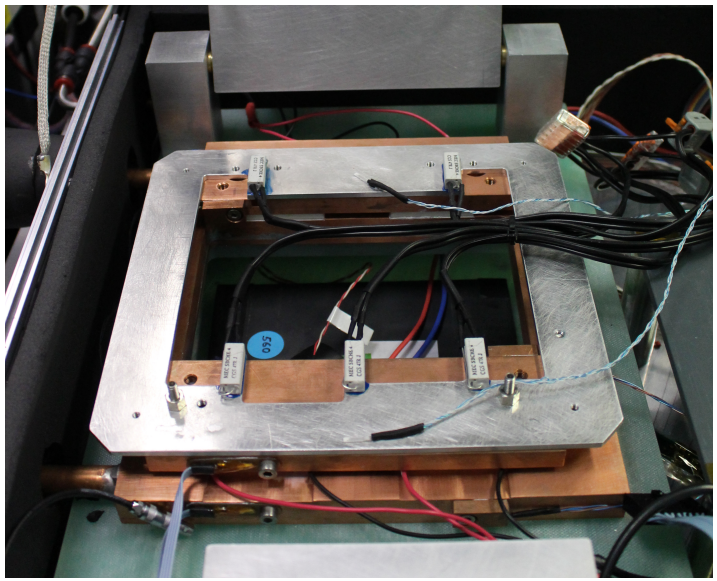
Experimental Setup



Thermal Performance

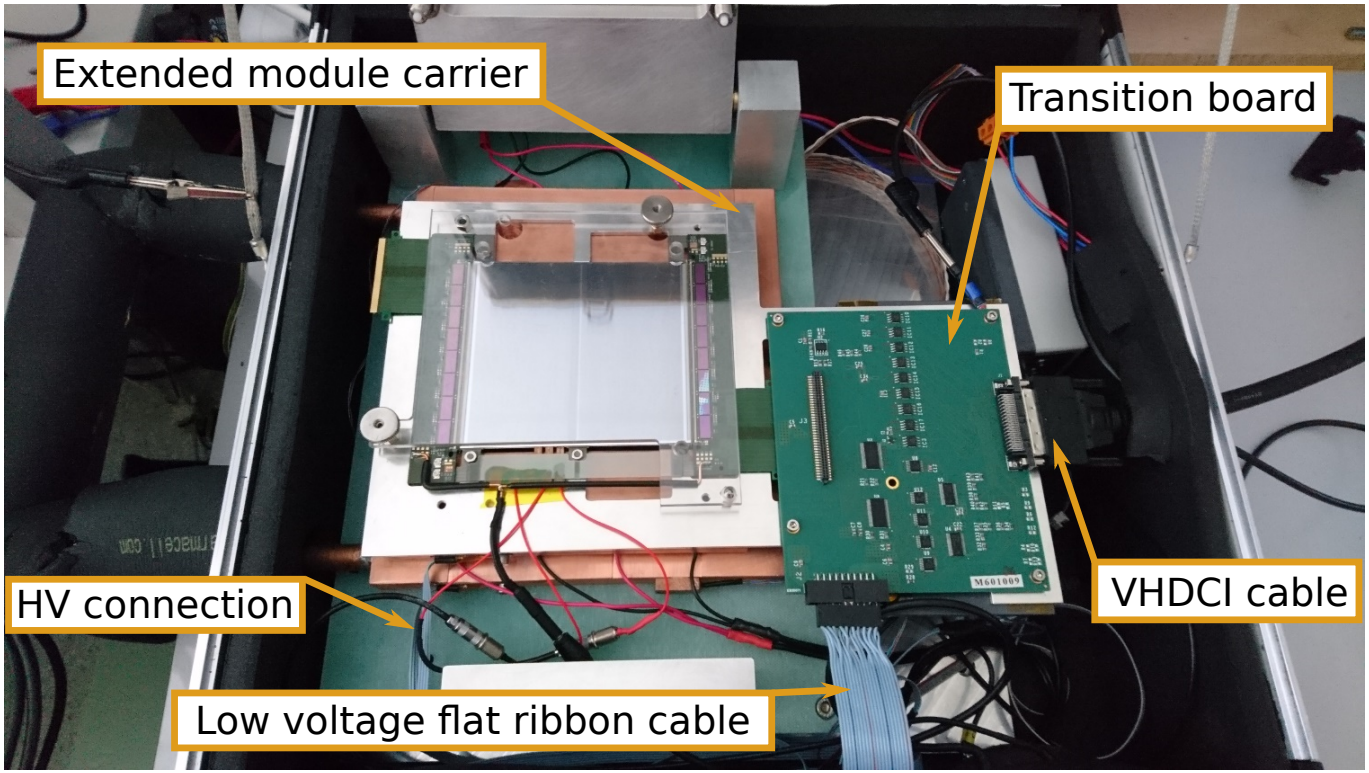
- Minimal temperature to reach: $-45\,^{\circ}\mathrm{C}$ on cooling jigs
  $\Leftrightarrow \approx -34\,^{\circ}\mathrm{C}$ on sensors for switched-off 2S module
- Thermal cycles between $20\,^{\circ}\mathrm{C}$ and $-35\,^{\circ}\mathrm{C}$:
  100 cycles in 24 hours possible
- Thermal heat load up to 7 W induced to module carrier on cooling jigs: no thermal runaway of temperatures in station





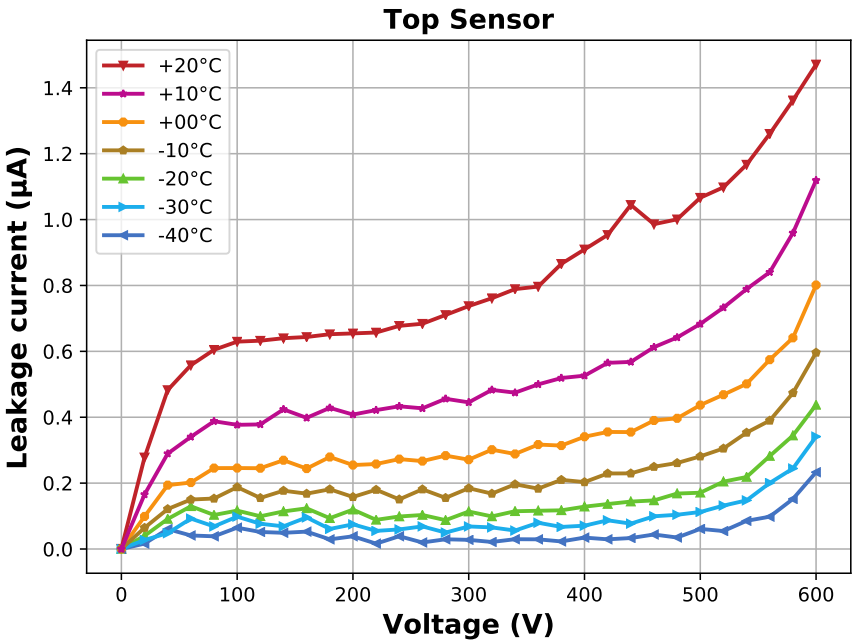
Functional Tests

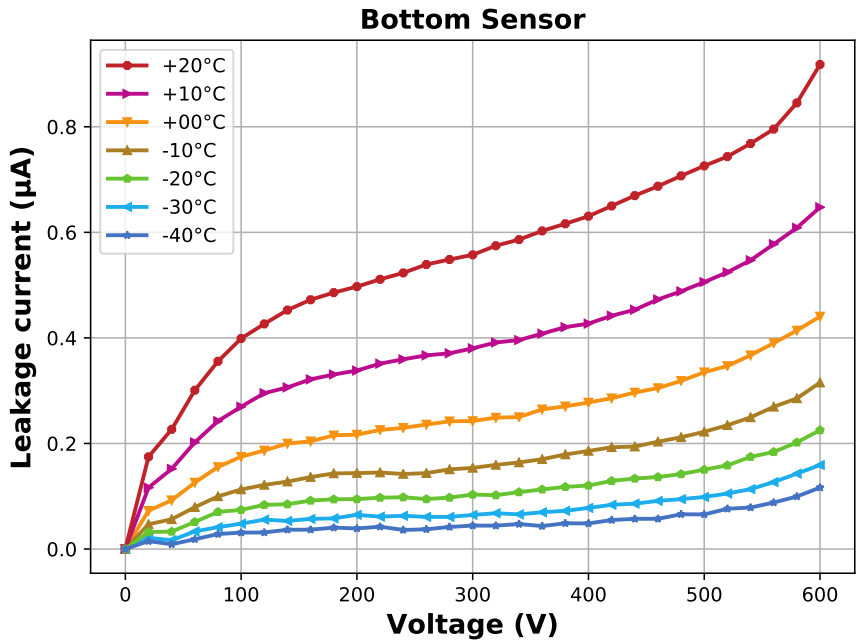
- Functional tests performed with 2S module prototype built at KIT



Functional Tests – Results

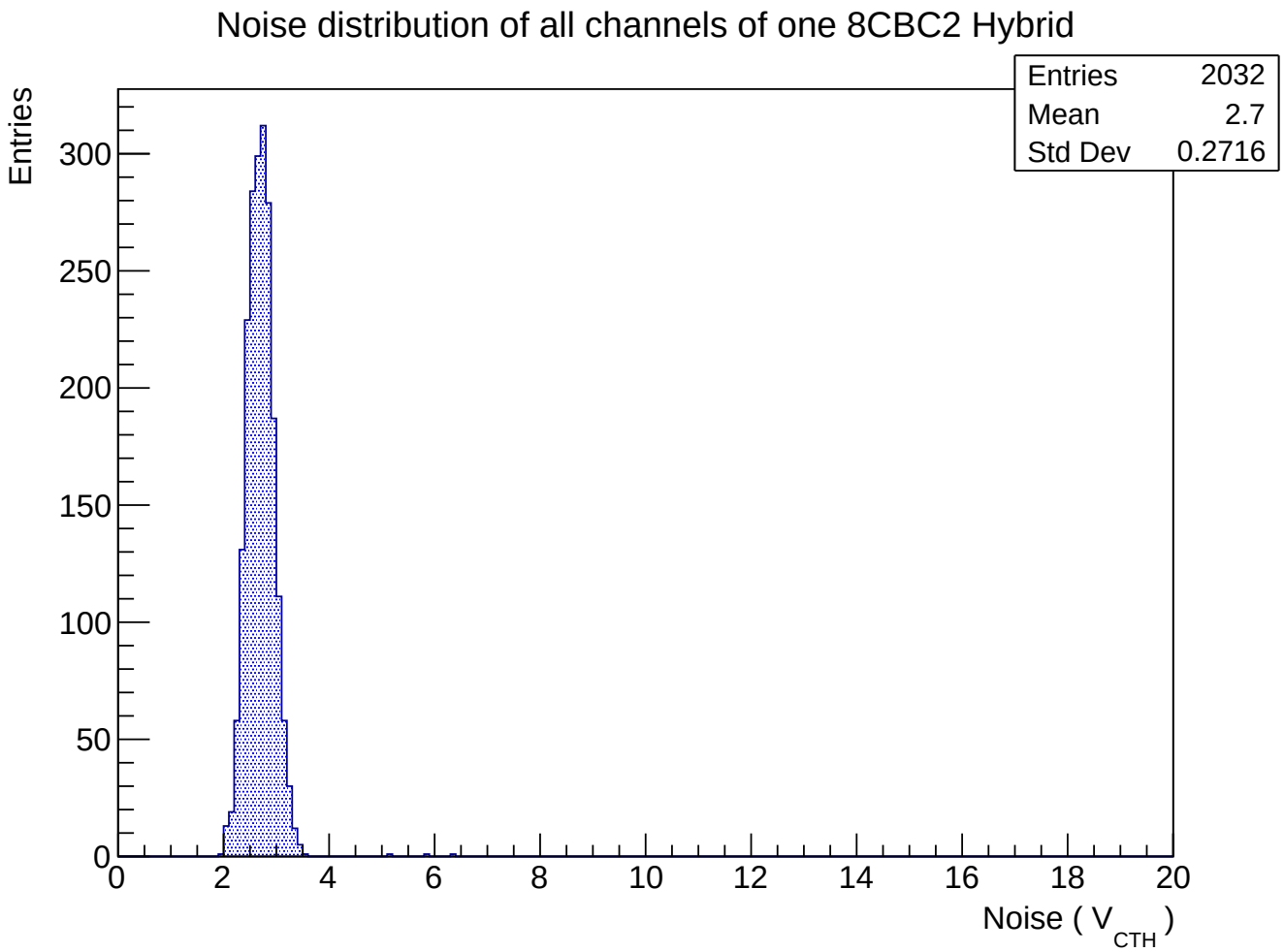
- IV-curves at several stable temperatures on the cooling jigs





Functional Tests - Results

- Noise measurement at room temperature (cooling deactivated)



CBC2:

$1\,\mathrm{V_{CTH}} \approx 350\,\mathrm{e^-}$

Measured noise with 5 pF attached:

$\approx 800\,\mathrm{e^-}$ [Braga+14]

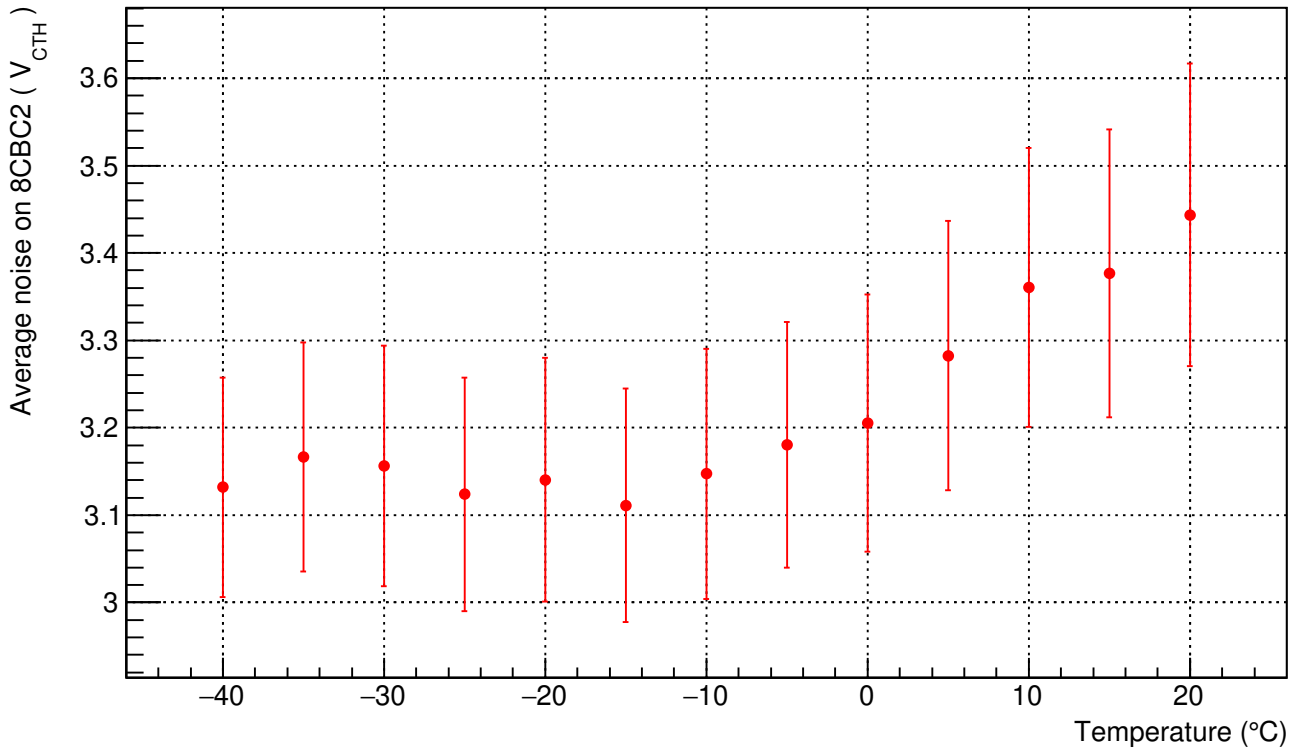
In station:

$2.7\,\mathrm{V_{CTH}} \approx 950\,\mathrm{e^-}$

(sensor attached)

Functional Tests – Results

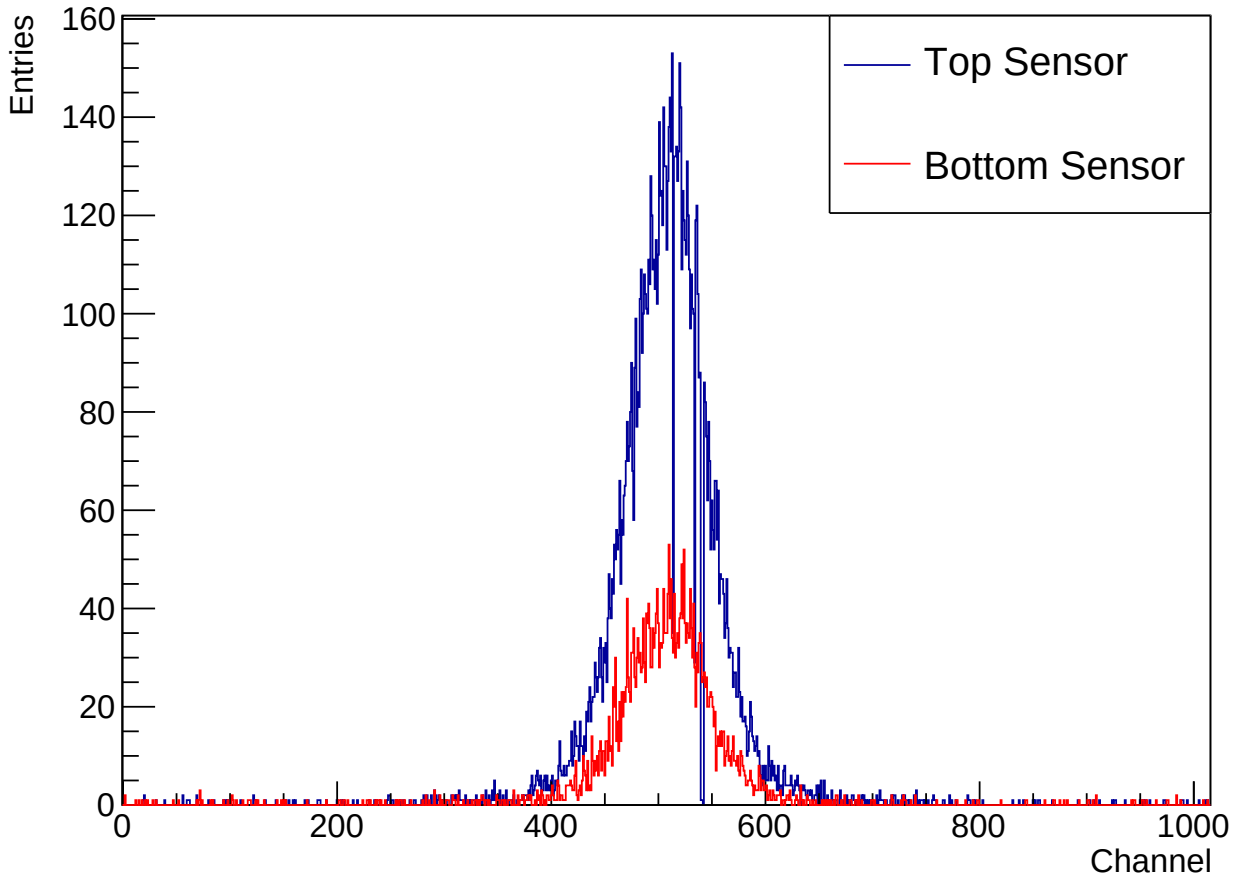
- Noise slightly increases if Peltier cooling is turned on
- No large temperature dependence of noise level observed



Error bars indicate standard deviation, temperatures measured on cooling jigs

Strip Readout with ^{90}Sr Source

- Crosscheck of functional test results with radioactive source possible
- Random trigger, $T = 20\,°\mathrm{C}$, $V_{\mathrm{bias}} = 300\,\mathrm{V}$



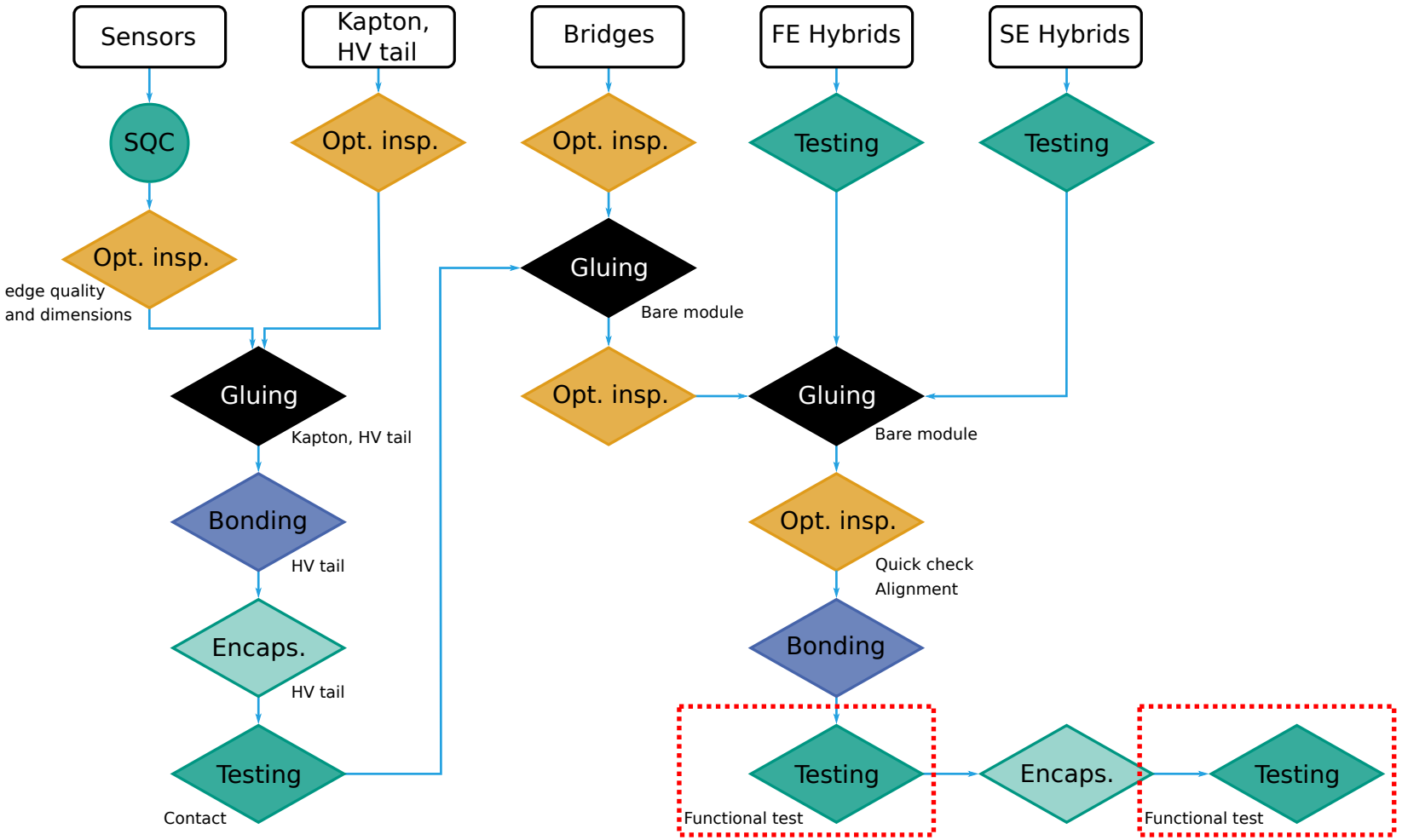
Conclusions

- New CMS Outer Tracker will be made of PS and 2S modules after Phase-2 upgrade
- Developed 2S module test station for module testing during prototyping and production
- Thermal power of cooling system validated
  $\rightarrow$ Testing of 2S modules under expected thermal conditions in the upgraded CMS experiment possible
- Functional tests with 2S module prototype successfully performed

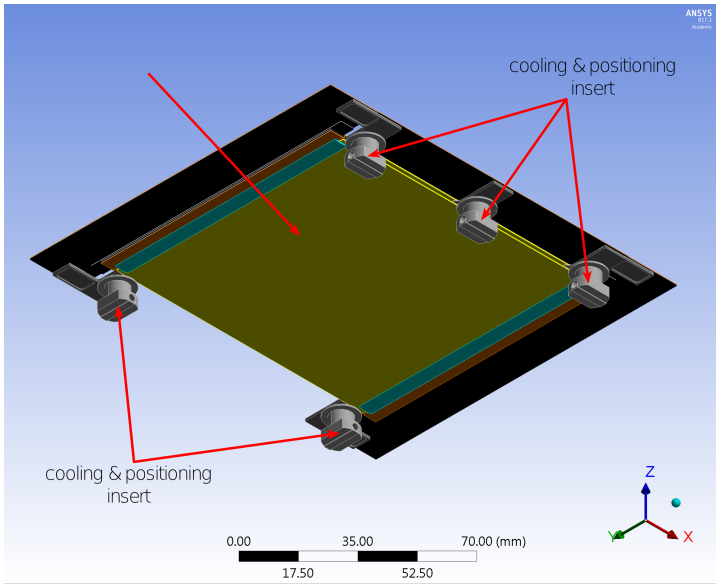
- Outlook: Further functional and thermal tests with upcoming module prototypes this year

Backup

2S Module Production at ETP

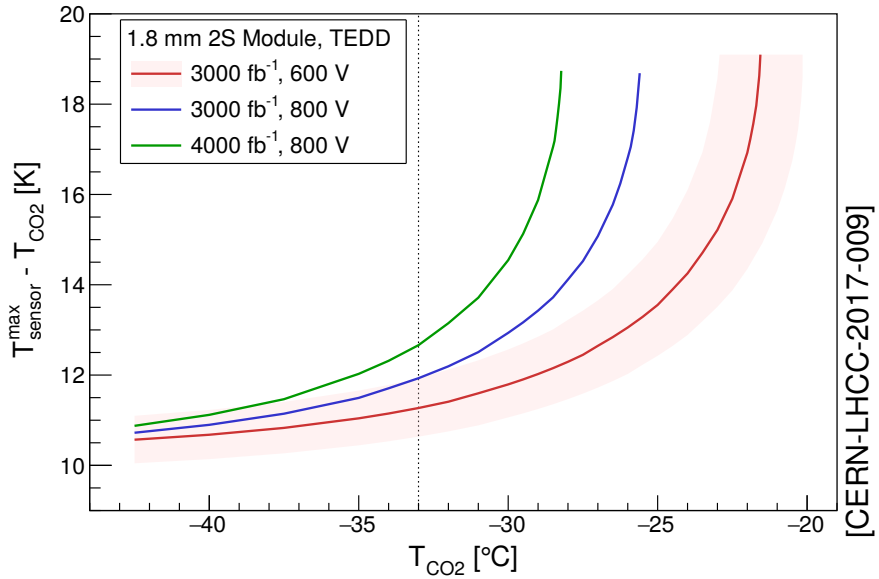


Thermal Performance of 2S Modules



Component	Power Consumption (mW)
2 × CBCs	2188
2 CICs	625
LpGBT	500
VTRx+	306
DC-DC converters	1770
Total	5389

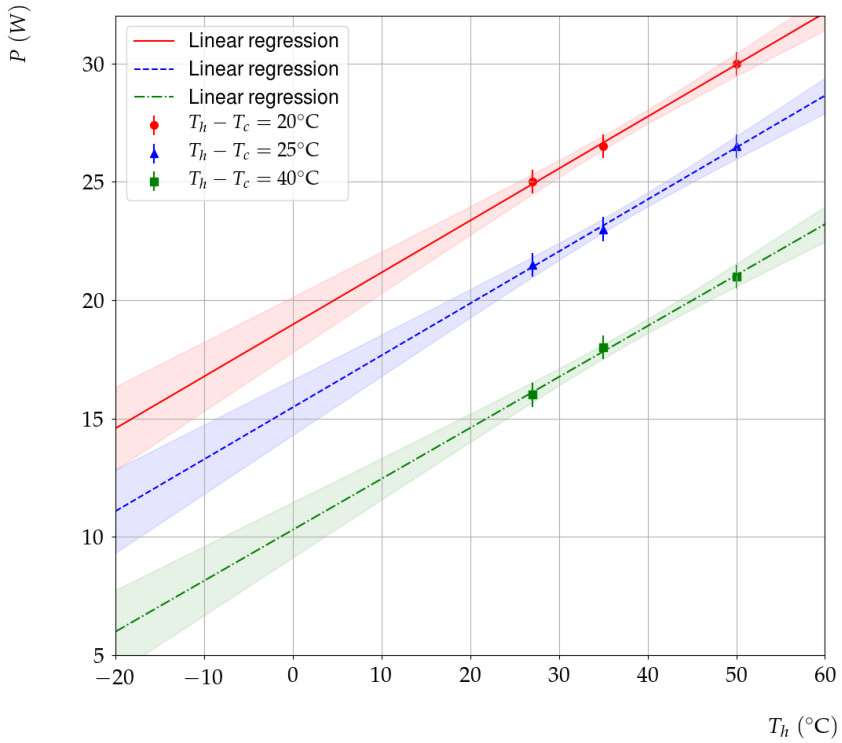
[CERN-LHCC-2017-009]

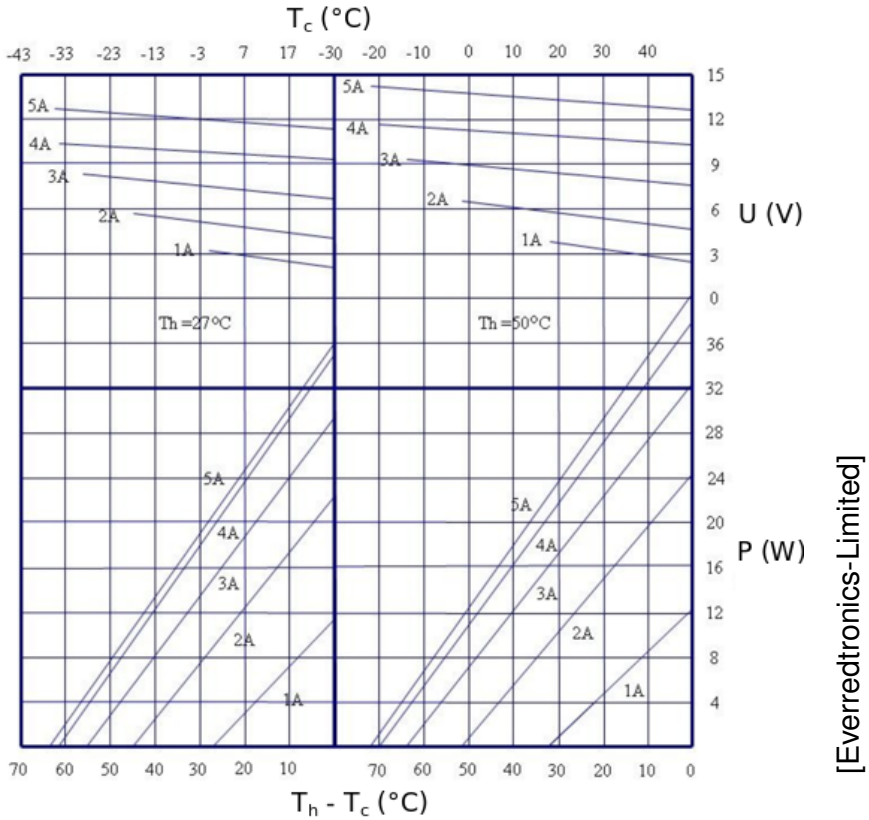


- Thermal runaway
  $T_{\mathrm{TR}}(3000\,\mathrm{fb}^{-1}) = -21.6\,^{\circ}\mathrm{C}$
- $T_{\mathrm{CO2}} \leq -33\,^{\circ}\mathrm{C}$

Cooling Power of Peltier element

TEC1-12705





- $P_{\text{therm}}^{\max}(\Delta T = 25\,°\text{C}) \approx 13\,\text{W} \Rightarrow T_{\text{Preecooling}} = -10\,°\text{C}$

Fryka ULK 2002 Datasheet

Model	ULK 1002	ULK 2002
Temperature range [min/max]	-10°C / +40°C	-10°C / +40°C
Control accuracy	+/- 0,5 K	+/- 0,5 K
Cooling capacity [at +20°C]	1200 W	2300 W
[at +10°C]	850 W	1600 W
[at -10°C]	400 W	750 W
Pump capacity flow rate	12 l/min	12 l/min
Pump capacity flow pressure	2,9 bar	2,9 bar
External dimensions WxDxH	35x44,5x66cm	35x44,5x94cm
Weight	41 kg	65 kg
Ambient temperature [min/max]	+12°C / +30°C	+12°C / +30°C
Electrical connection	230V / 50 Hz	230V / 50Hz
Current [max.]	3,5 A	8,0 A
Coolant tank	2,0 to 9,5 l	2,0 to 9,5 l

Characteristics:

modern generation of circulating coolers for professional applications

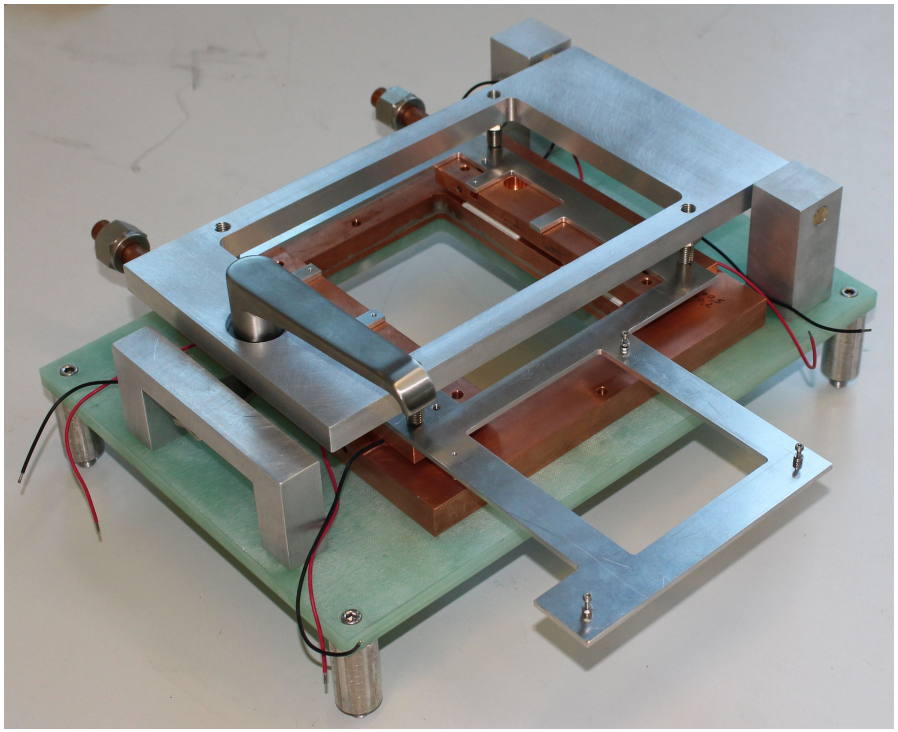
- **energy-efficient:**
  - fan with EC technology
- **low noise level:**
  - particularly quiet components
  - fan adjusts its speed to the required value
- **user-friendly:**
  - integrated funnel
  - self-sealing hose connector with quick coupling
  - drain cock
- **high-quality components:**
  - touchscreen controller with high-grade glass screen and integrated flow and digital fill level indicators
  - components from renowned manufacturers
  - refrigeration unit: fully hermetically sealed, air-cooled, low maintenance
- **high operational reliability:**
  - freeze-up and thermal overload protection
  - flow control with dry running protection
  - optical and acoustical alarm
  - error messages are displayed in plain text
- **proven standard:**
  - MOD bus interface

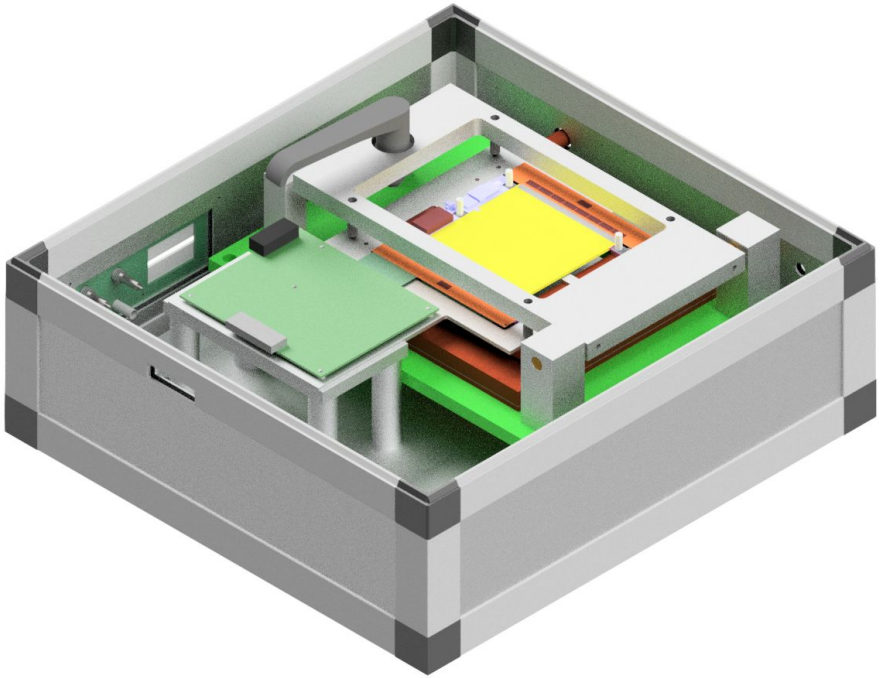
Options:

- Operation with natural coolants
- Heating for extended temperature range
- Portable version
- Potential-free alarm contact with connection to an external alarm system
- Voltage input for externally setting the set point
- Voltage output for reading the actual value
- Interface converter/gateway from RS485 to USB or Ethernet
- Optional direct measurement of the application's temperature with an external gauge; by subsequently setting the set point, greater temperature stability can be achieved than with a standard system

[Fryka-Kältetechnik]

Experimental Setup

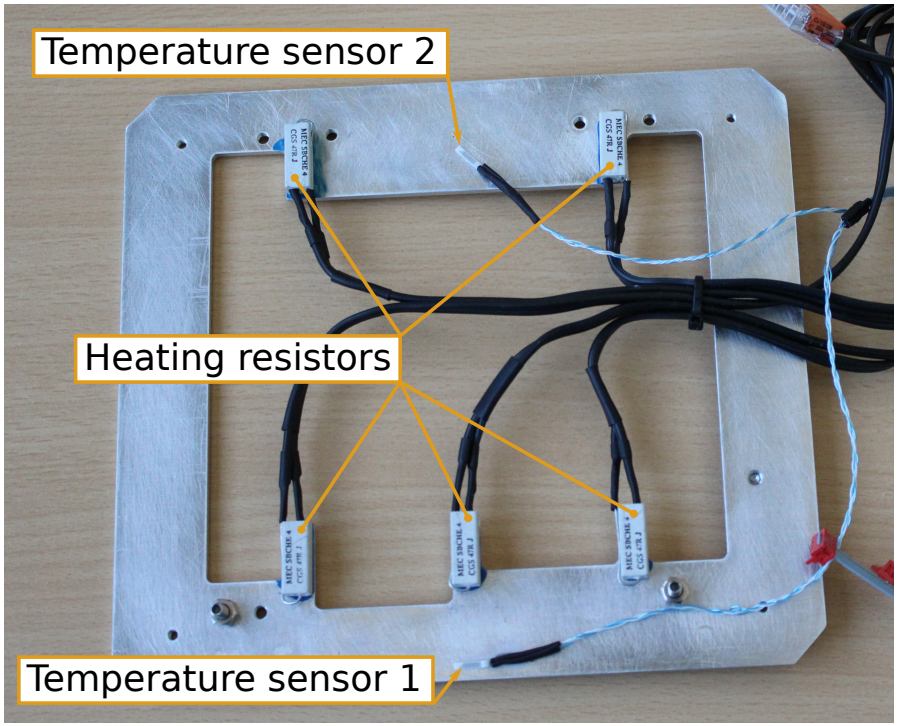




- 8CBC2 module readout via transition board possible at one hybrid side (turnable)
- Same procedure planned for 8CBC3 module with universal interface board

Thermal Performance

- Thermal study of cooling power using heating resistors
  $P_{\mathrm{therm}} \leq 5 \times 1.4\,\mathrm{W}$



P_{therm}	T_{PID}	T_{S1}	T_{S2}	ΔT
0 W	−35	−34.3	−33.6	0.7
7 W	−35	−33.3	−33.5	−0.2

✓

all temperatures in °C

Module Readout and Temperature Control Software

- 2S module readout using software developed by CMS community
- Combine module readout and temperature control with Graphical User Interface to simplify test procedure
  - GUI written in Qt 5.6.3
  - Temperature readout via PT-sensors
  - PID algorithm used for control of power of Peltier elements
  - Monitoring of power supplies (low and high voltage)
  - Monitoring of dew point (1-wire sensor)