Silicon detector quality control demonstrator at LPI Moscow: Status and updates

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Hybrid pixel modules

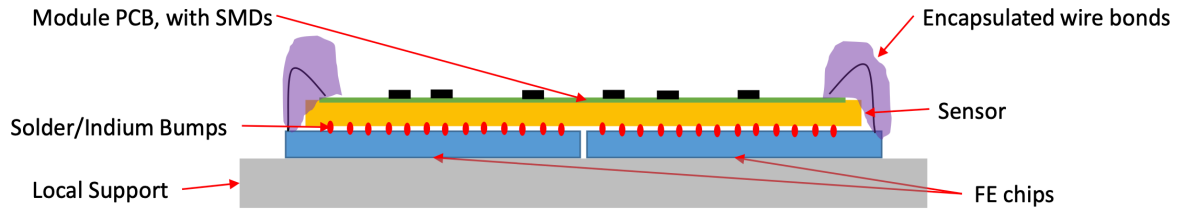
The hybrid pixel module is the basic detection unit of the pixel sub-detector. It consists of

- a silicon sensor,
- front-end chips flip-chip bump-bonded to the sensor pixel by pixel
- a flexible printed circuit board (PCB) for the data transmission to the readout system.

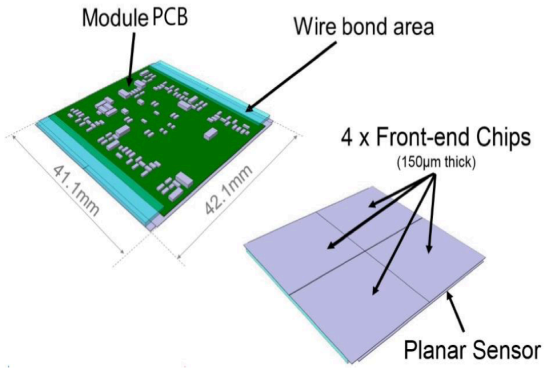
The pixel size is usually a few hundreds of um^2,

the module size is a few square centimeters,

containing several hundreds of channels

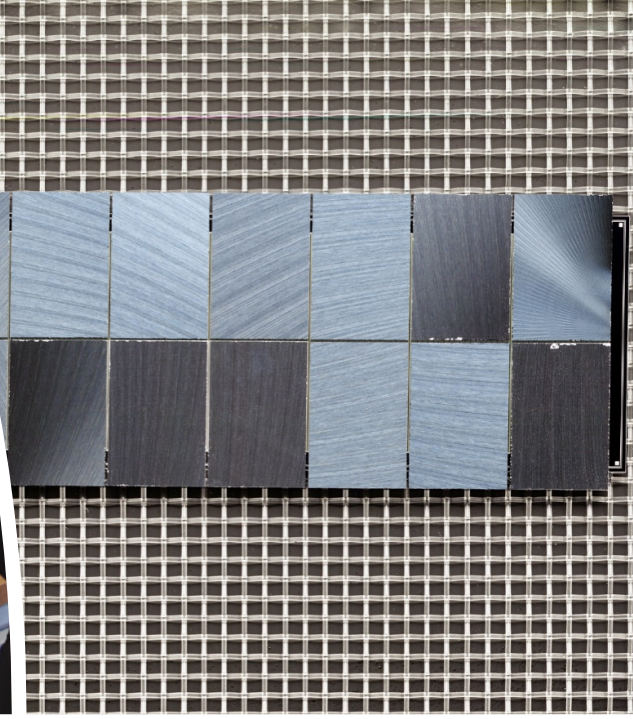


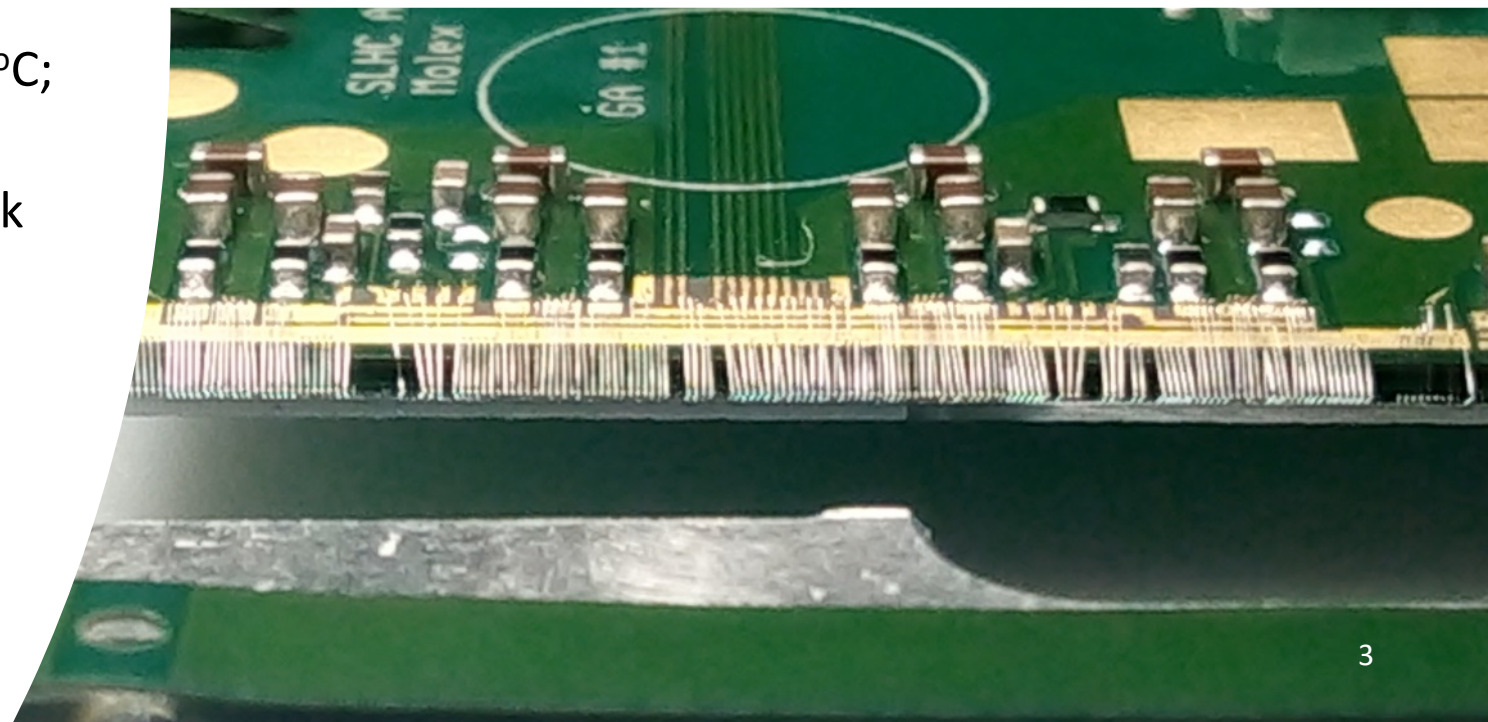
Bare module with PCB glued to back of sensor, wire bonded & encapsulated



Pixel module testing algorithm

- Visual inspection (under microscope) to be sure there is no damage due to the module transportation.
- Electrical tests and pixel scanning at room temperature;
- Calibration of the threshold values for each pixel to set the uniform threshold value along the module close to 1000 electrons.;
- Pixel scanning after calibration at room temperature and operating temperature -20 ^{o}C;
- Scanning the noise value for each pixel, mask the extremely noisy pixels, recording the mask matrix;
- Testing with sources of ionizing radiation;
- Monitoring the temperature dynamics of the detector during all pixel tests;
- Sending results to the cloud storage

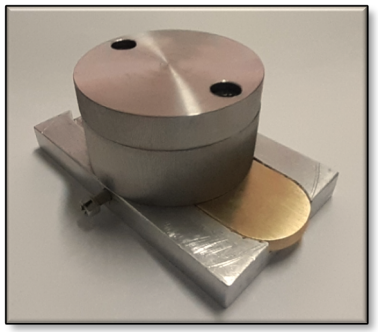


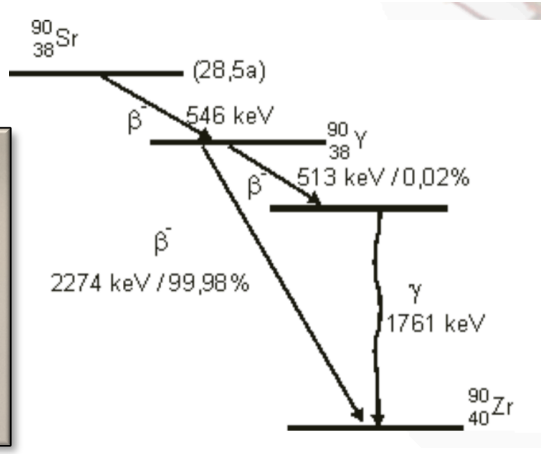


LPI laboratory equipment

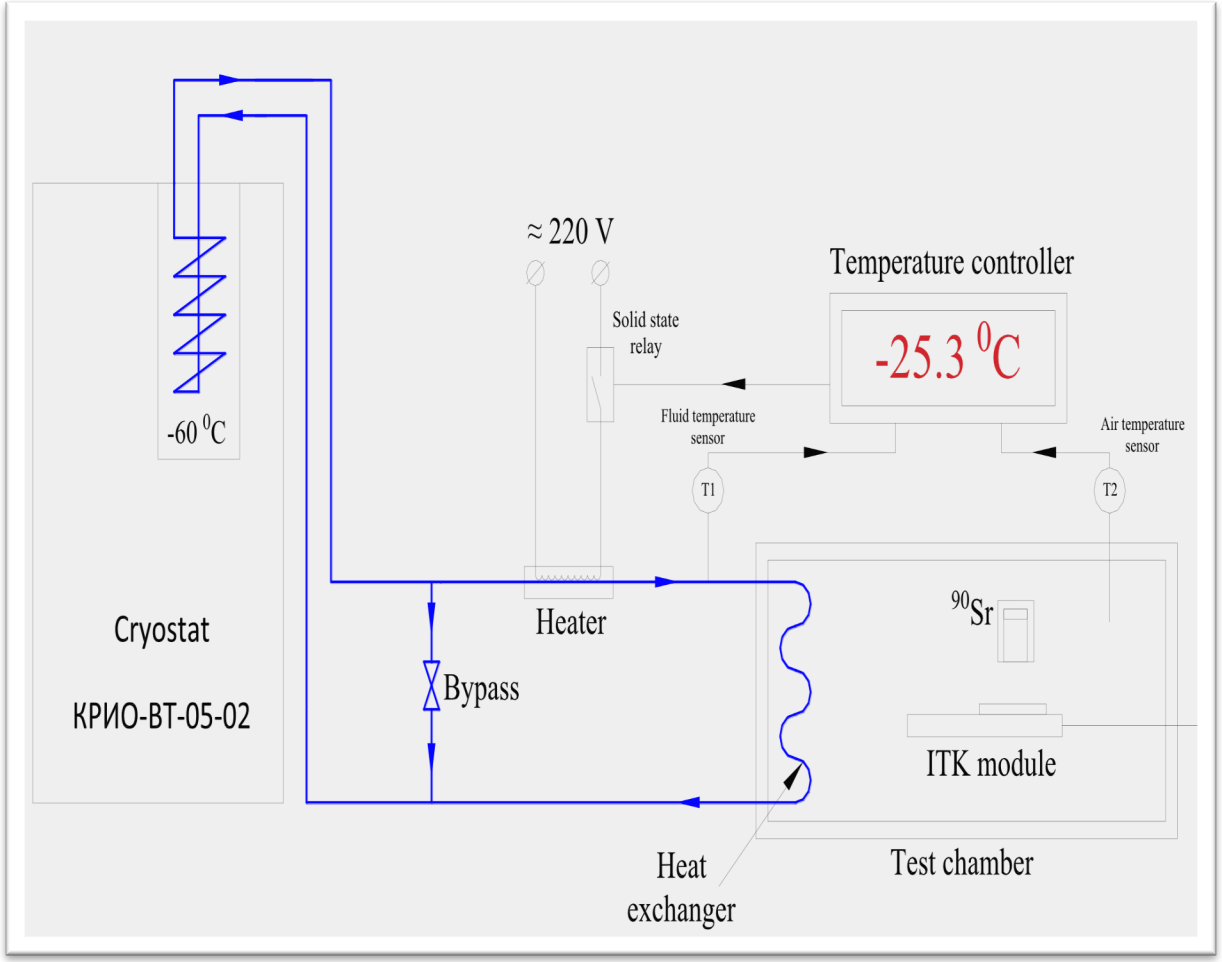
- Clean room ISO8 detailed project is prepared, the room will be put in operation in 2021
- PC with GPIB interface and software for ITk ATLAS pixel modules testing is installed
- Programmable high-voltage (up to 1000 V) GPIB power supply Keithley 2410 for automatic module scanning
- Two low-voltage (up to 20 V) GPIB power supplies Agilent E3633A;
- Adapter board for ITK ATLAS pixel modules;
- Cold box;
- Ionizing radioactive source $^{90}_{38}Sr$ 200 MBq;
- Direct inspection microscope

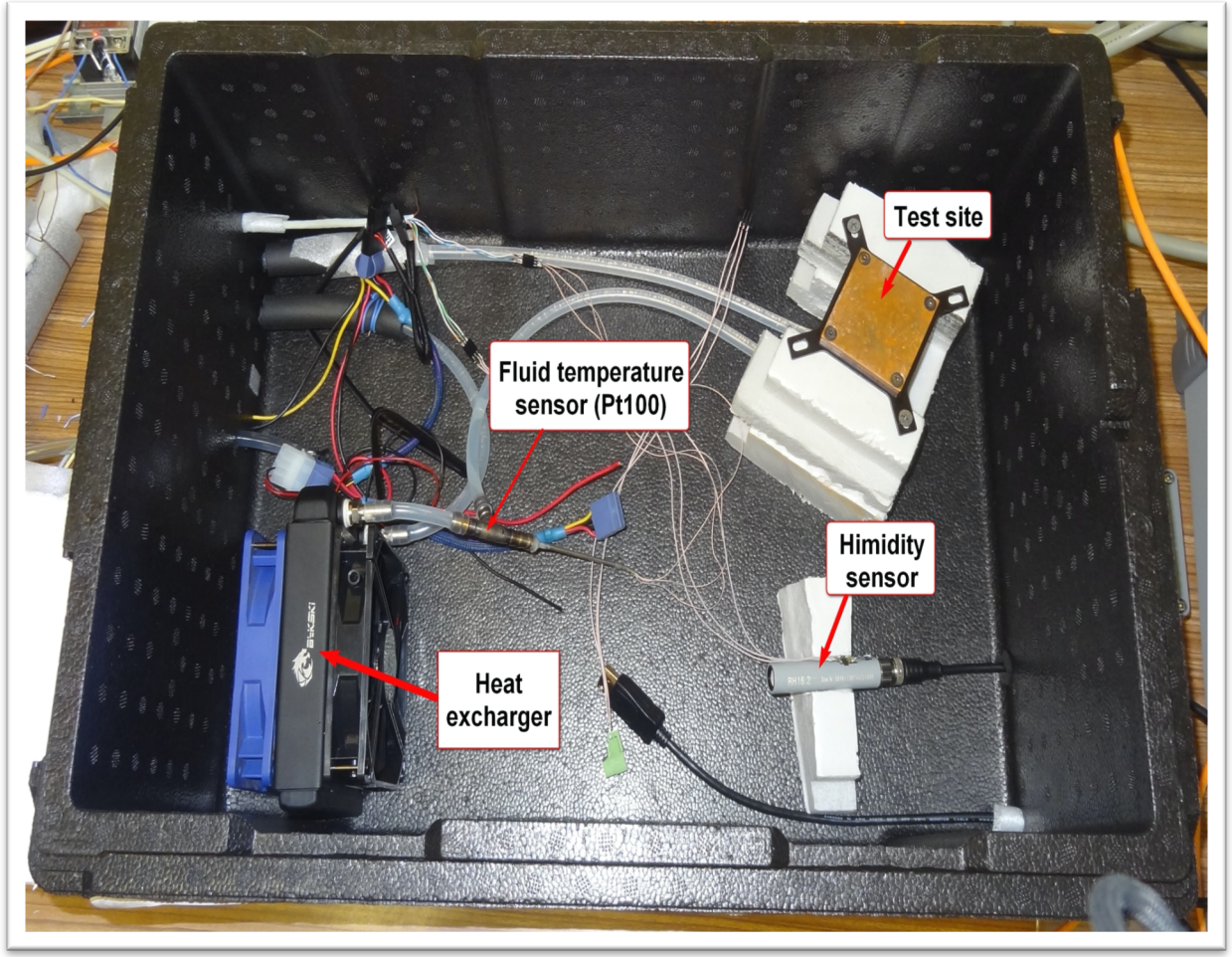
  Nikon Eclipse L200N.



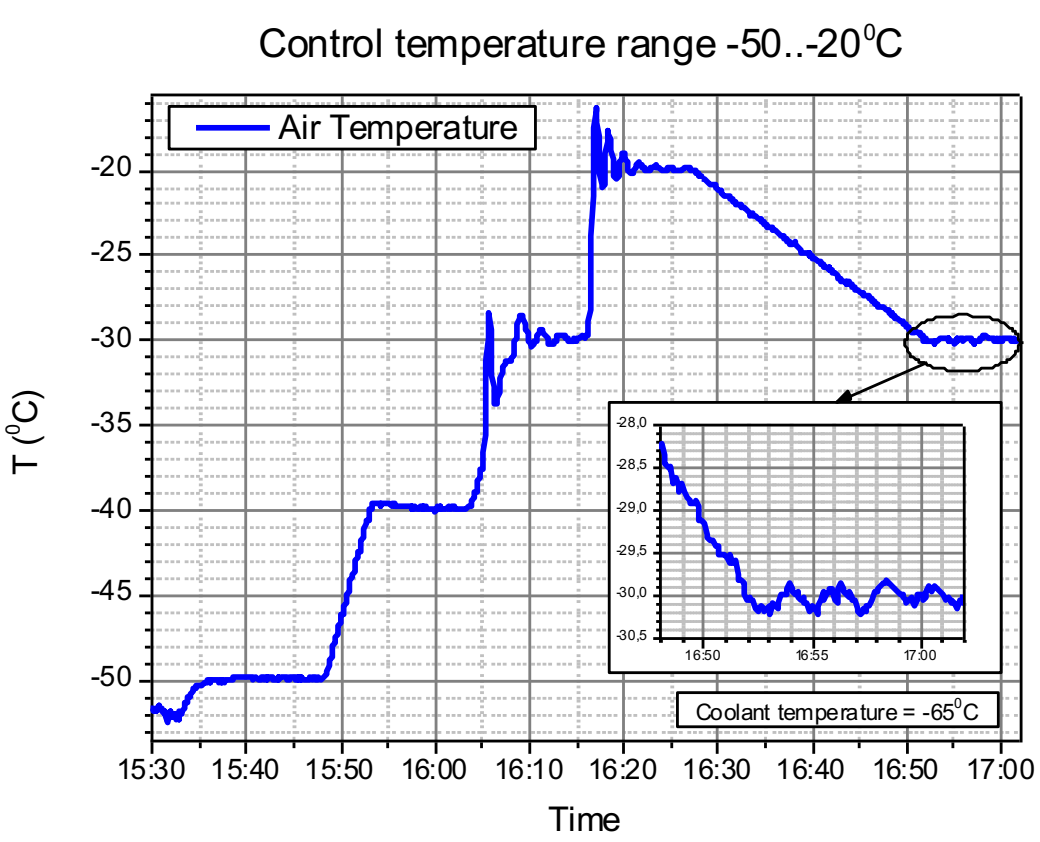


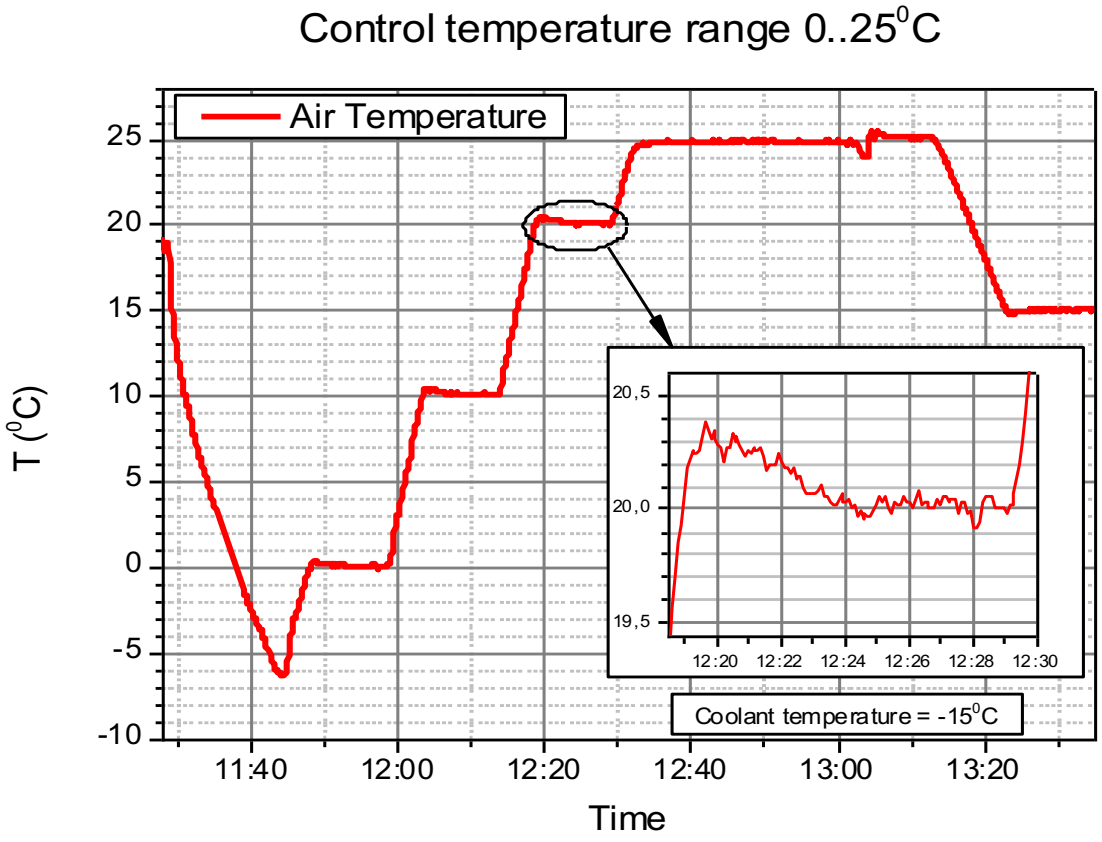
Cooling system





Thermal stability of cooling system



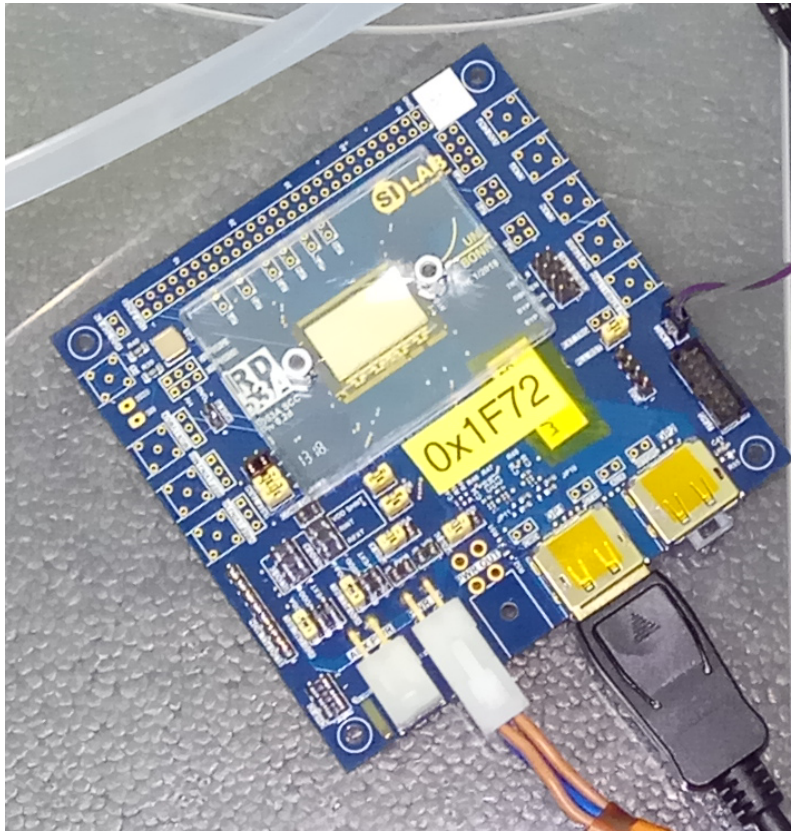


After the stabilization temperature deviation does not exceed 0.2 ^{0}C

After the stabilization temperature deviation does not exceed 0.1 ^{0}C

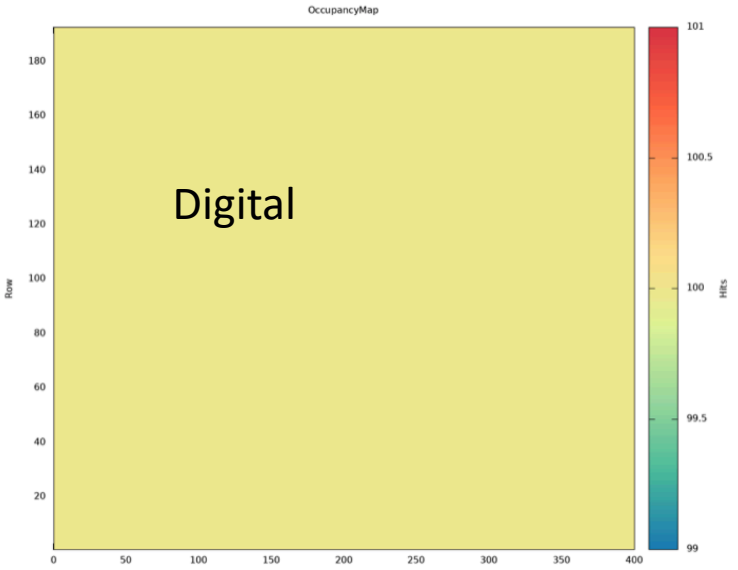
Pixel module prototype under test in LPI

- LPI group has beed involved in the creation of the pixel detector of ITk ATLAS collaboration since 2015, in particular, it is engaged in the assembly and testing of new pixel modules of ATLAS detector
- The ITk ATLAS pixel module consists of a silicon sensor, 4 front-end chips flip-chip bump-bonded together and a flexible printed circuit board (PCB) for transmitting data to the readout system.
- The pixel size is 50 x 50 mm^2, the module size is 41.1 x 42.1 mm^2, it has more than 600k channels (400 x 384 x 4).
- ¼ of standard ITk ATLAS pixel module and without sensor attached, only with electronics front end chip (RD53A single chip)
- 3 modules were tested in all the laboratories ITk ATLAS which are going to be involved in testing and the test results were presented on the collaboration meeting at CERN
- The LPI module test results are recognized satisfactory by collaboration, and LPI laboratory is considered as ITk Pixel module testing point.

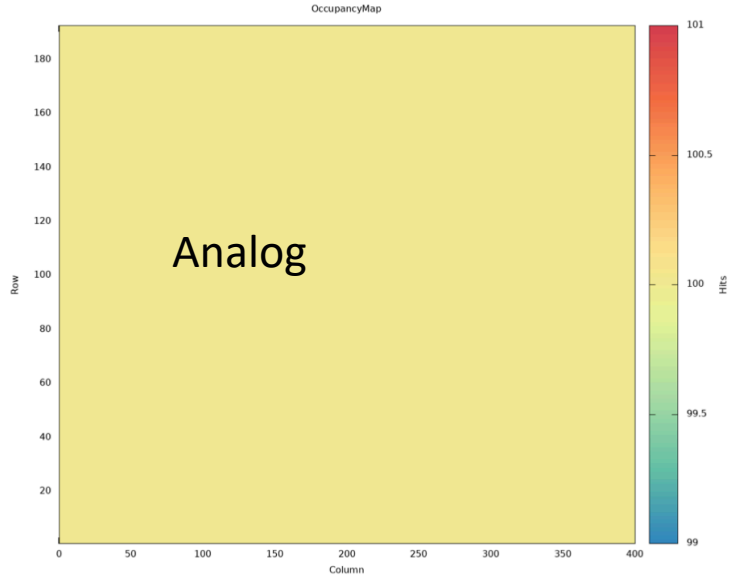


Digital and analog scans

A digital signal is injected into every enabled pixel to test the digital part of the chip. Only a few pixels are injected at once and the injection mask is shifted until all enabled pixels have been injected. If 100 injections are performed, after a successful digital scan, the occupancy map shows an occupancy of 100 hits for every pixel.



An analog pulse is injected into every enabled pixel. Again, only a few pixels are injected at once and the injection mask is shifted until all enabled pixels have been injected. Also in this case, by default the scan performs 100 injections, and after a successful analog scan, the occupancy map should look rather homogeneous with possible exception of some pixels that will be masked

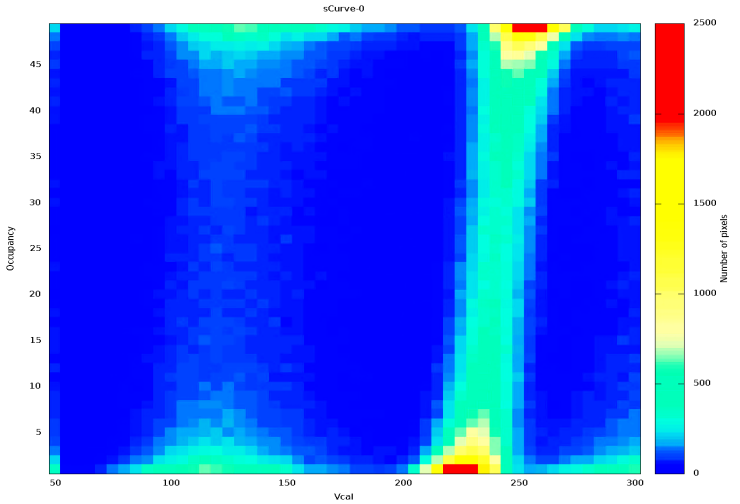


S-curves and module tuning

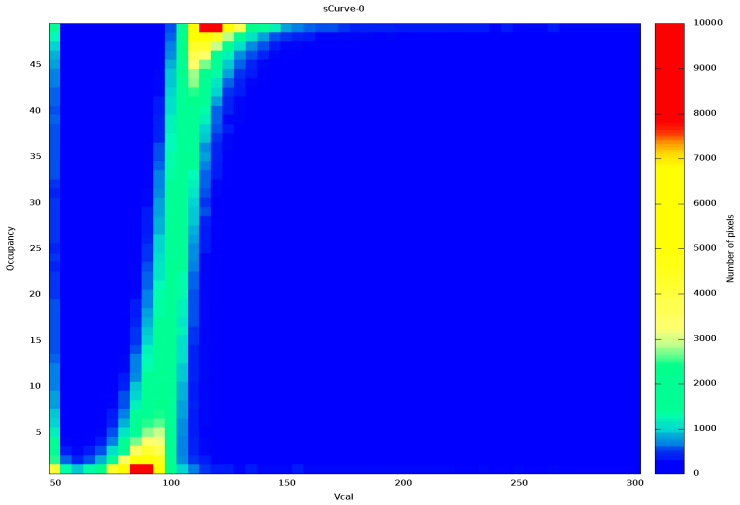
A voltage pulse *V* is injected on the calibration capacitance C_{inj} of each pixel. That will generate a signal at the input of the preamplifier equivalent to the one generated by a charge $V \times C_{inj}$.
A set of pulses is generated for different values of the injected charge (from 0 to ~5000 e, in ~10 e steps).
The number of collected hits for each injected charge is recorded and at the end of the scan an S curve is fitted.
The 50% efficiency on the S-curve defines the threshold value. The steepness of the transition from no detected hits to full efficiency is inversely proportional to the noise, which can be so calculated.

A fixed charge, corresponding to the desired threshold is injected several times into each pixel and the occupancy is measured for each pixel. The tuning algorithm then searches binary for the TDAC value closest to an occupancy of 50 %.
The second method consists in the measurement of the threshold of all pixels, as described for the Threshold Scan. Again a binary search algorithm searches for each pixel for the TDAC setting closest to the target threshold.

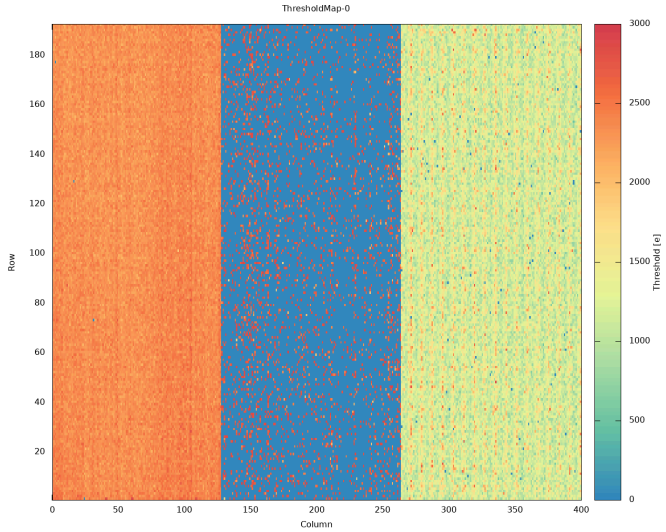
S-curves before module tuning:

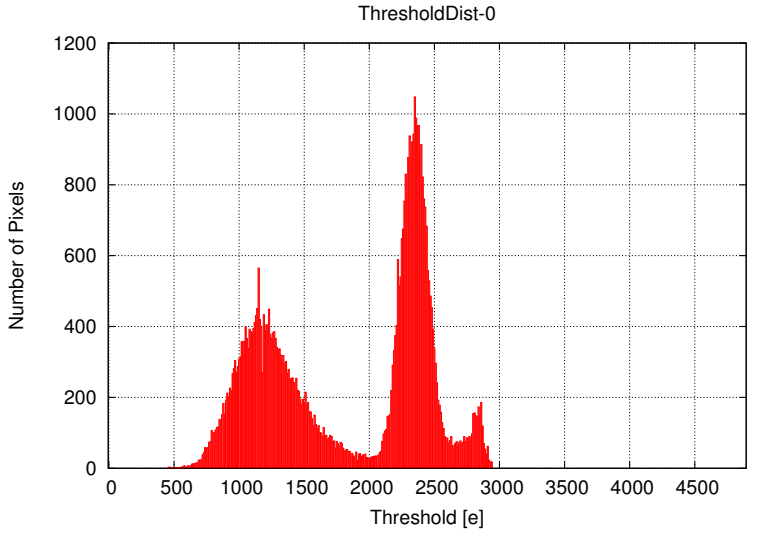


S-curves after module tuning:

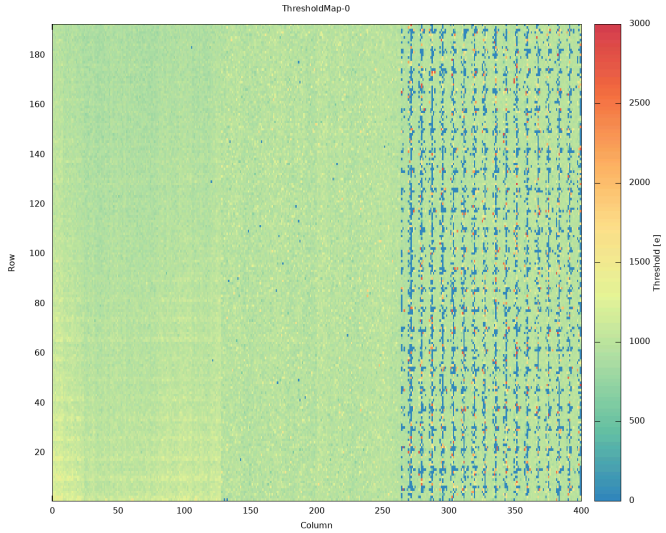


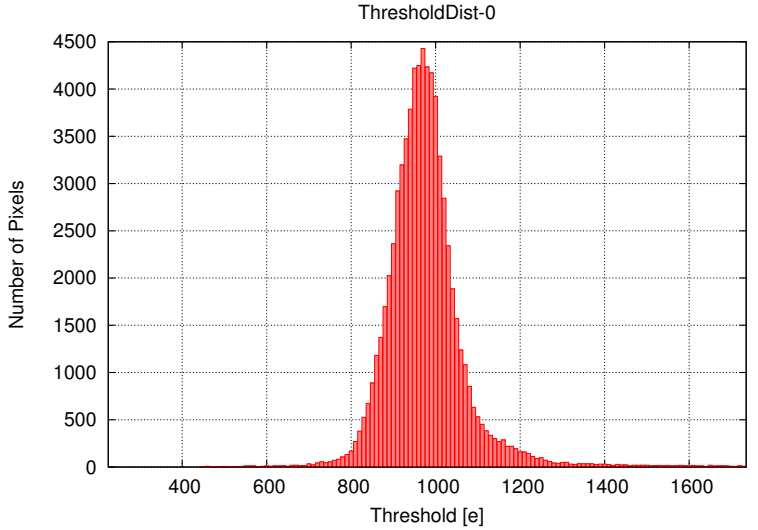
Threshold distributions





Before module tuning





After module tuning

Conclusions and plans

- The LPI pixel module quality control setup is assembled and tested on the module prototype, the measured characteristics coincided with the results obtained in other laboratories which were testing the same module prototype

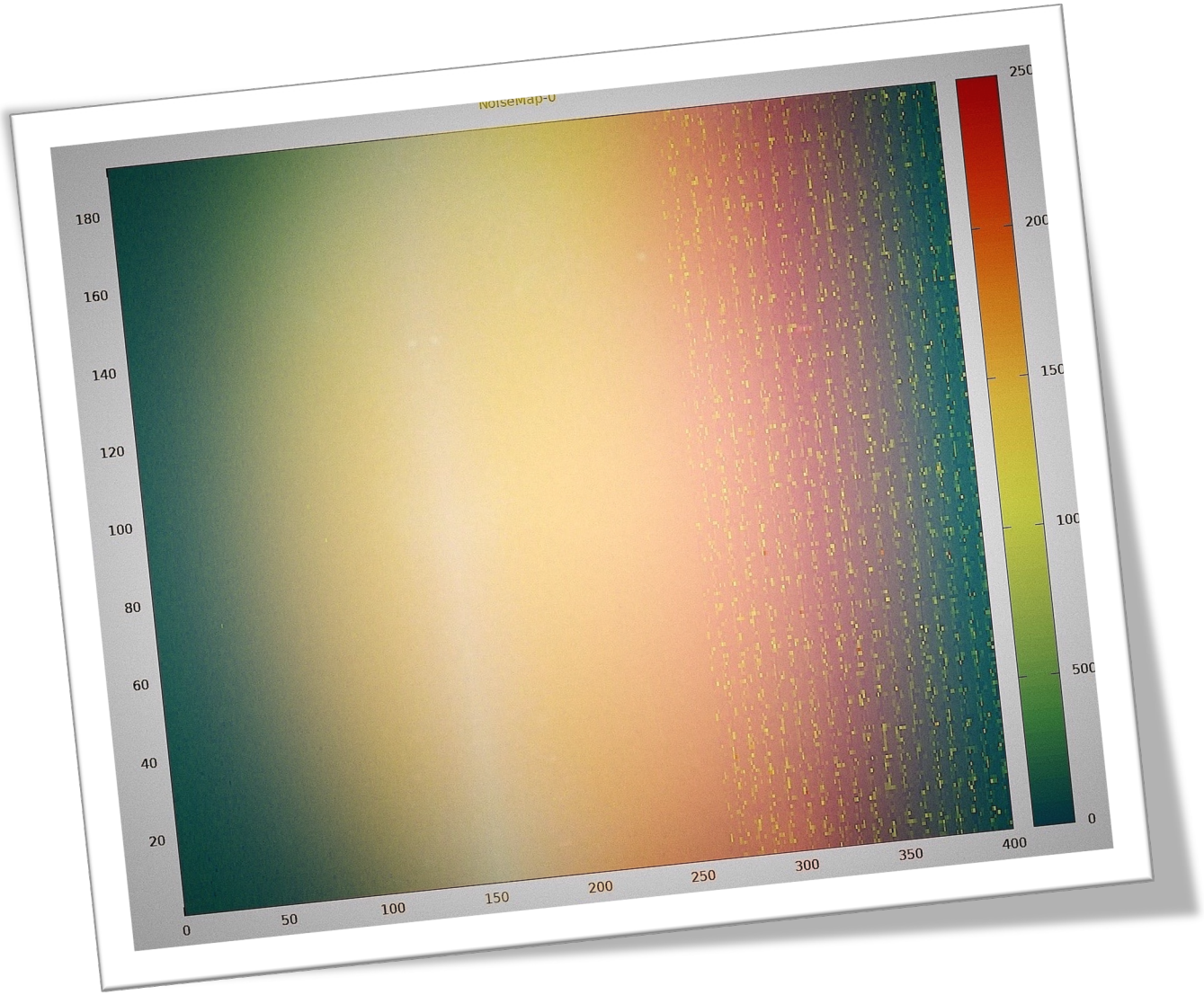
In 2021 we plan:

- Commissioning of clean room ISO8
- Module storage system installation

Laboratory applicabilities:

- LPI laboratory equipment allows to test any similar pixel or even microsrip silicon modules substituting the adapter board which is individual for every kind of module
- Existing software can be used as a starting point for any module testing after the necessary modifications depending on the particular module configuration

Extra slides



Source scan sketch, or what we could see if the module prototype under test would have a sensor attached

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FE Pixel cell block diagram

Each pixel has several parameters that can be tuned through a 14-bit control register. These bits are:

- ***FDAC 0-2****:* 3-bits to trim the feedback (*If*) current for tuning the ToT response.
- ***TDAC 0-6****:* 7-bits to trim the threshold in each pixel