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Cold Si microstrip detectors for very forward protons at the LHC

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Physics motivation:

For experiments at the Large Hadron Collider (LHC) at CERN, radiation-hard detectors, with good efficiencies and resolution, are a must. In particular, it is the case for some specific research topics, like photon-photon or photon-proton interactions, where usage of very forward tracking detectors (roman pots) is needed. In addition, such detectors require features like *edgelessness* – *i.e.* the detector response time and charge collection efficiency (CCE) should remain constant and uniform up to its physical edge. Such requirements exclude classical silicon sensor designs with many guard rings surrounding the sensitive area. This fairly naturally leads to a R&D program on silicon sensors used at low temperatures. First, several sensors with a classical design have then been cut with laser or plasma beams. Then, two detector modules have been assembled : one with a full size (not cut) sensor for studies in the cold of its response and radiation hardness ; and another one with 2 pairs of half-sensors, cut with a laser, for the evaluation of the detector edgelessness and the reliability of this cut technique.

Detector module design and components :

Both module prototypes are based on the same design, with only slight differences. The sensors are glued on a silicon plate, with a bias line bonded to RC filters for their power supply. The sensor microstrips are connected to the readout electronics through a pitch adapter. Some APV25 readout chips, mounted on silicon hybrids from the CMS tracker, readout and shape sensor signal, and then transfer the data from the modules to the external acquisition system. In addition, the full-size module features a 0.5mm outer diameter cooling tube, glued between the silicon support plate and the pitch adapter. A two-phase flow of nitrogen cools down the whole module, taking away the heat generated by the electronics (a few mW).

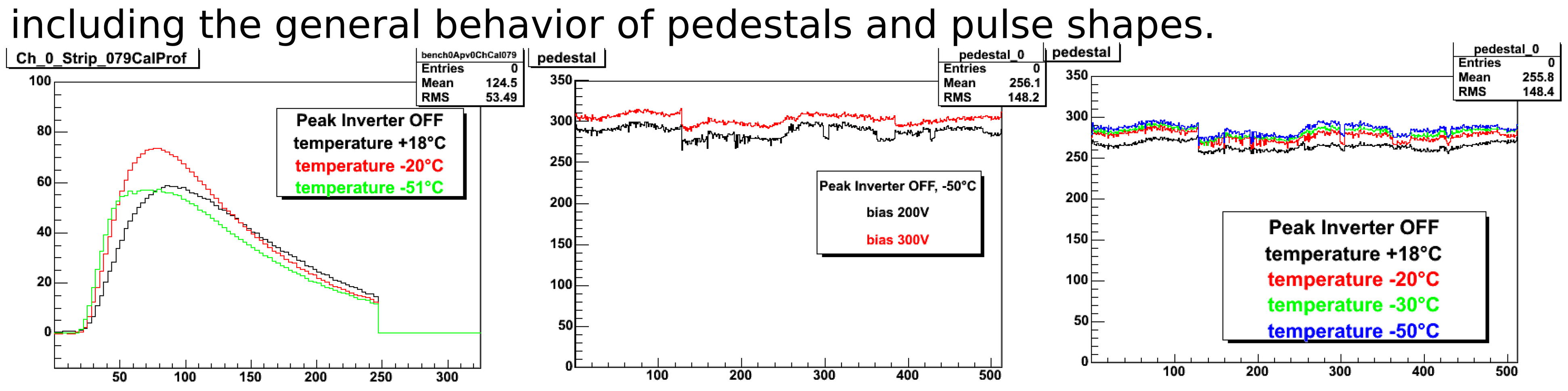
Prototype of a full-size cryogenic module (left), cooled down to very low temperatures via its 0.5mm cooling tube. The silicon sensor is 380µm thick, with 1024 strips and 50µm pitch. The strips are readout by 4 APV25 chips mounted on a full-ceramic CMS tracker front-end hybrid, clocked at 40MHz.

Prototype of an edgeless module (right), made of two pairs of half (laser cut) baby detectors, 320µm thick. The mother sensors, before the cut, had 192 strips with 120µm pitch. The readout chips are also 4 APV25 chips, mounted on a kapton-on-ceramic CMS tracker hybrid.
One sensor is cut along the strips, one is cut with a small angle with respect to the strip direction. The edgeless module prototype has no cooling tube.

Results

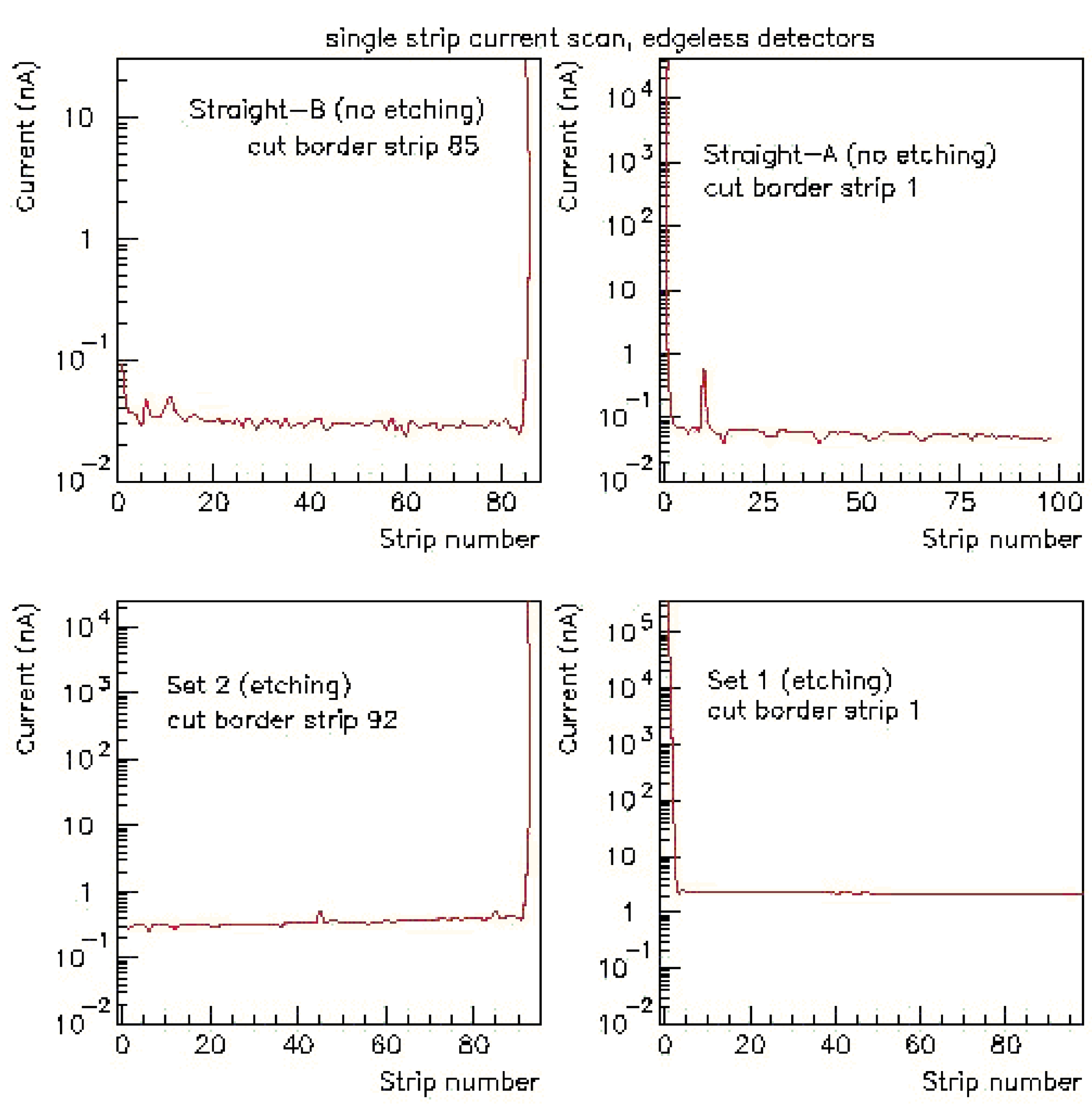
for the full-size module prototype:

Characterization of the electronics was obtained at different temperatures, including the general behavior of pedestals and pulse shapes.



Pulse shape evolution with temperature (left): one sees a shorter rise-time, as expected in the cold, and a rather stable gain. Pedestal evolution with temperature and sensor bias voltage (middle and right) : changes of pedestal are relatively small and will not affect the real particle signals.

for the edgeless module prototype:



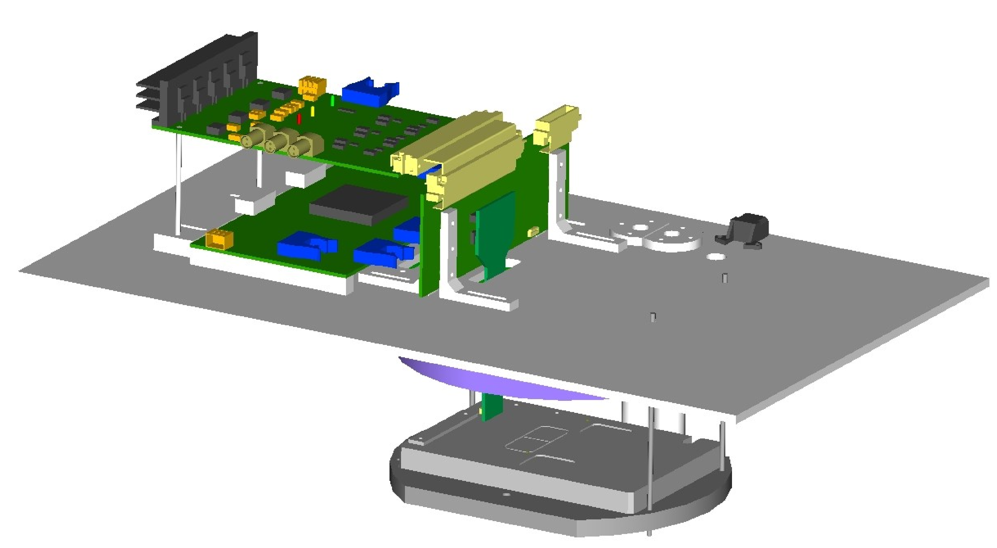
Single strip current scan for the strips of both pairs of half sensors of the edgeless module. The current stays flat almost all over the sensor strips, but explodes for the 2 strips close the each side of the edge. These strips thus practically drive all the total current of each sensor. This behavior is expected due to the damage of the silicon substrate during the cutting process. A chemical etching does not seems to change this. A new plasma cut technique is now under evaluation. It is expected that the sensor electrical properties should improve thanks to a sharper and cleaner cut.

Test setup:

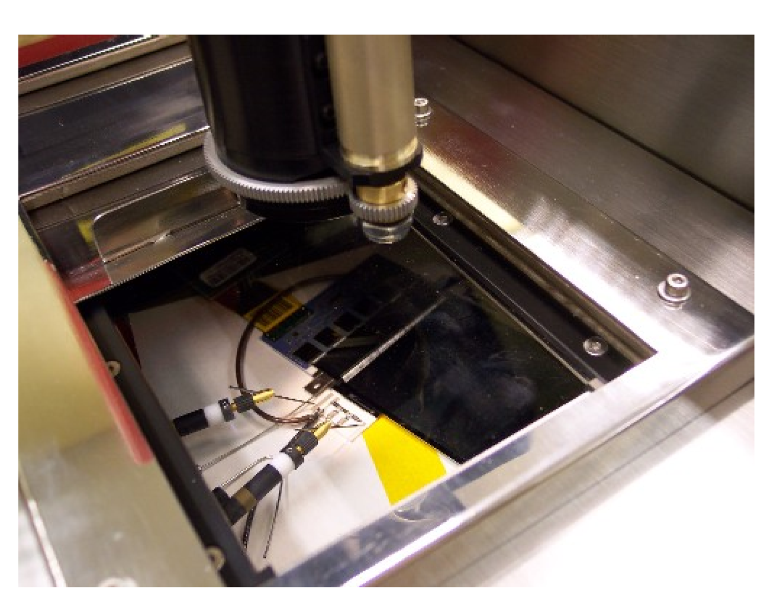
Different test setups are used in order to characterize our modules and test their behavior in the cold. The IV curves and the strip current are measured with a probe station, with needles that make an electrical contact directly on the strips or the bias ring. Small structures can be cooled down to –30°C.

An instrumented chuck is used to test the hybrids and the modules in the cold in a large dewar. The low temperatures are reached by direct contact of the module to a plate (equipped with heating resistors) which in turn is in direct contact with a liquid nitrogen bath. An external controller drives the current through the resistors to maintain stable environment, and humidity is controlled with an inlet of dry air. The effective temperature of the tested module can be as low as the nitrogen boiling point. The output data from the electronics is read using the dedicated on-board electronics, on top of the cap of the dewar.

Finally, a third setup is under preparation, with a movable laser beam which will excite a single strip and will allow detailed studies of the strip response uniformity.



Instrumented chuck for tests of electronics and modules in a dewar, from well above the room temperature (60°C) to around the nitrogen boiling point (-190°C). In practice, the structures are tested from 20°C to –70°C.



Picture of the probe station with 2 needles for the electrical characterization, like IV curves, of single or module-mounted sensors, from room temperature to –30°C.