The ATLAS silicon tracker detectors are designed to sustain high dose integrated over several years of operation. The radiation hardness should also favour the survival of the detector in case of accidental beam losses. In 2006, measurements [NIM A, 565 (2006) 50-54] were published for the ATLAS Pixel detector modules (silicon planar hybrids coupled with FE-I3 electronics), confirming that they could survive to beam losses (1.5×10^16 protons/cm² in a single bunch) with minimal or no deterioration of performance. In this paper, preliminary results are shown, reporting the effect of a very intensive proton beam releasing a high instantaneous dose in two insertable B-Layer (IBL) pixel and one Inner Tracker (ITk) strip module detectors at High-Radiation to Materials (HiRadMat) Facility of CERN Super Proton Synchrotron (SPS).

**Devices Under Test**

For this test a new generation of ATLAS pixel modules have been used. The new modules were developed for the new layer IBL and inserted inside the pixel detector in 2014. They are at least a factor 5 more radiation-hard than the modules used in the previous test. The two modules have FE-I4 front-end electronics (total area ~2 x 2 cm²) coupled with a 3D silicon sensor. A module has 26680 pixels (50x250µm²/pixel).

- Produced by IBM 130 nm technology to cope with higher radiation levels (750 Mrad) and larger occupancies.
- 70 Million transistors
- 89% active area
- Lower noise than FE-I3 (~150 e+ with sensor)
- Local hit storage (four pixel region) supports higher occupancies without saturation

**ITk Strip Module for HL-LHC**

It consists of 2 x 1 cm² silicon strip sensor (ATLAS12) wire-bonded to a readout chip (ABC130)

- Front-End: ABC130
  - Fabricated in the 8RF IBM 130 nm CMOS
  - Data readout at a rate of 80 MHz
- Sensor: ATLAS12
  - Composed of 104 strips (74.5 µm pitch in 2 rows) with punch through protection (PTP) structures
  - All data were multiplexed through the hybrid control chip (HCC), and routed via a custom designed PCB along with HV and LV connections.
  - The HCC interfaces the ABC130 ASICs on the hybrid to end of structure electronics.

**3D Module**

The tests on IBL modules were performed during beam inter-fill to avoid loosing the FE configuration during the shots.

- Digital and Analog: Check the FE analog and digital part functionality
- Threshold: It measures the occupancy at different injected charges for a fixed threshold (2500 e⁻). In the pixels the response curve may be fitted with a sigmoidal curve, where the slope is a characteristic of the noise. In the irradiated modules it corresponds to about 50 electrons equivalent from leakage current and sensor capacitance and about 100 electron equivalents from the electronic (FE) noise.
- Self-triggering: In this modality the outputs of the individual pixel comparators are ORed together to form a hitbus that is used as a trigger signal.

Unfortunately the communication with the ITk readout chip was not possible, for this reason only the leakage current of the strip sensor was continuously monitored.

Two IBL modules configurations were used in 2 different configurations:
- ATLAS in Stable: sensor bias and FE preamplifiers off, this configuration is unstable with beam conditions to avoid local shorts in the sensors, or damages in FE electronics due to heavily ionizing particles (e.g. gate rupture in CMOS transistors)
- ATLAS in Stable beam operation: sensor bias and FE amplifiers on

On the left the effect of the 2 mm and 0.2 mm optics are visible after the shot using the self-trigger scan of the FE-I4 due to material activation.

**HiRadMat Facility at CERN**

HiRadMat is a users facility at CERN, designed to provide high-intensity pulsed beams to an irradiation area where material samples can be tested.

**Installation and Performed Tests**

The test box can host up to 8 modules on dedicated frames.

Due to the high radiation environment the box is equipped with only a cooling system which consists in four fans, but it allows to keep the temperature at ~40 °C.

**Preliminary Results**

In the inter-fill, Threshold scans have been performed with HV on. Results are shown on the left (top and bottom for the two modules). On the left panel the noise maps, where it is shown that the noise increases in correspondence of the beam spot.

On the right the correlation between the noise and the proton flux of one shot is shown.

**Conclusion**

The ITK sensors are able to drain the charge density generated in the bulk without evident radiation damages. The test has to be repeated with a system to monitor readout signals.

After the last shot the FE-I4 was damaged irreversibly. The problem seems to be a short between ground and analog voltage in the incident beam region at pixel level.

The lower limit for IBL modules on radiation damage has been evaluated at 10^16 protons/cm² for 288 bunches case at large beam spot.

Further investigations are currently ongoing and new tests are planned for 2018.