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Dottoranto in Fisica e Nanoscienze - Ciclo XXXVIII - Second Year Report

Tutors

Claudia Gemme: Researcher at *Istituto Nazionale Fisica Nucleare* division of Genova
Fabrizio Parodi: Professor at *University of Genova* - Physics Department

Research activity

My research activity fits in the context of the ATLAS experiment, that is one of the four large experiments operating at the Large Hadron Collider (LHC). During my second year I was mainly involved in the operation and calibration of the ATLAS Pixel detector and in the Phase-II upgrades that are foreseen to cope with the high luminosity phase of the machine, where the luminosity will grow up to a factor seven compare to the LHC working point. To cope with these harsher conditions in terms of radiation hardness and electronic performance the ATLAS experiment will be equipped with a completely new all-silicon tracker, the so-called Inner Tracker (ITk). I carried out all my activities with the ATLAS Genova group.

Calibration and Operation of the ATLAS Pixel detector

The ATLAS Inner Detector (ID) has been designed to provide robust pattern recognition, excellent momentum resolution and both primary and secondary vertex measurements for charged tracks up to $\eta = 2.5$. It is immersed in the 2 T magnetic field delivered by the surrounding solenoid. The ID consists of a high-granularity Pixel detector in the region closest to the beam pipe and a Semi-Conductor Tracker (SCT) in the outer parts. These silicon detectors are complemented by the Transition Radiation Tracker (TRT), which enables radially extended track reconstruction up to $|\eta|$=2. During the summer 2024 (June-September) I was deeply involved in the operation of the ATLAS Pixel detector, taking on-call shifts to guaranteed the operation of the detector 24/24 hours, every day. Moreover, I was involved in the weekly calibration of the pixel detector that is done to cope with the radiation damage that can affect the modules' performance.

The ATLAS Inner-Tracker Phase-II upgrade

The ITk will consist of a Pixel detector at smaller radius, close to the beam pipe, and a large area Strip detector surrounding it. The ITk Pixel detector will be instrumented with 5 layers of hybrid pixel modules, consisting of a pixel sensor for signal detection, Front-End electronics (FE) for readout and discrimination and an electrical flex to distribute power and collect data. Each pixel of the sensor is connected to a readout channel of the FE through a process called bump-bonding. This process consists in depositing solder (SnAg, SnPb) or Indium bumps on the sensor (or both on the sensor and on the FE) and then connecting the layers through a thermal compression cycle (flip-chip). A flex module is then glued to the back of the sensor. Two technologies are used for the ITk Pixel detector modules: triplet modules in the innermost layer, consisting of three single FE-sensor assemblies sharing the same flex, and quad modules in all other layers, consisting of four FE chips on a single sensor tile sharing one flex.
Planar pixel sensors has been chosen as the baseline for the ITK Pixel outermost layers, however, due to the extremely high radiation level in the innermost layer, planar sensors can not be efficiently operated in the innermost layer. Therefore, pixel sensors implemented with the 3D technology will instrument it. The 3D technology consists of direct drilling of the electrodes in the silicon substrate, which allows the sensor thickness to be decoupled from the inter-electrode distance and makes it possible to realize extremely radiation-hard pixel detectors. Two pixel pitches has been chosen for the project: a pixel cell of 25x100 μm^2 is used for the barrel and a 50x50 μm^2 layout in the end-caps. The choice of the two pitches is mainly driven by the tracking performance to improve the performance of the high-level objects, such as b-tagging and pile-up jet rejection.

During my second year within the group, the main goal of my activities was the assembly and qualification of the first 5 pre-production triplet modules for the ITk innermost layer. Before starting the construction of the modules, I worked on the qualification of the first pre-production 25x100 μm^2-pitch sensors that will be used for the modules. I personally joined the installation of several modules at the IRRAD facility at CERN, where the sensors have been irradiated up to a fluence of $2 \cdot 10^{16}$ n_{eq}/cm^2, which is the expected sensors' end-of-life fluence at the end of the HL-LHC program. After the irradiation, I joined the beam test activities at the CERN Super Proton Synchrotron beamlines, participating in the installation of modules and in the data taking. At the end of the campaigns I took care of the data analysis, studying the efficiency and the performance of the sensor as a function of the bias voltage. Thanks to the analysis result we proved that these 3D sensors meet the ITk requirements, passing the Production Readiness Review (PRR) and receiving green light from the ITk reviewers to start the production of the sensors.
After the sensor PRR I started my work towards the triplet modules pre-production. The assembly strategy used at the INFN Genova laboratory is based on a pick&place machine. The machine allows X/Y/Z and θ movement, with a precision and repeatability of about 3 μm. It has been equipped with suction cups that allow placing the bare modules, and a high-resolution camera used for pattern recognition. The pattern recognition algorithm is based on the Yolo V5 model (You Only Look Once version 5) which is an advanced object detection model developed by Ultralytics. The model has been adopted to recognise fiducial markers on the bare modules and on the flexible PCB of the ITk triplet modules. The goal of the machine is to align the bare modules with respect to each other. Once the bare modules have been placed, the flexible PCB is then glued on top of them using a dedicated jig able to ensure the correct alignment with an accuracy of about 100 um, sufficient to guarantee the hermeticity of the detector and the feasibility of the wire bonding connection between the front-end electronics and the flexible PCB. I personally contributed in developing the hardware for the pick&place machine and optimizing a dedicated measurement software that has been designed and implemented in the machine. Thanks to the work that we have carried out on the machine the INFN Genova group was able to built the first five pre-production modules matching the mechanical and electrical specification of the project during the spring-summer 2024. Thank to these results the assembly of the triplet modules will move into the production phase soon, nominally by the end of 2024.

PHD SCHOOLS

ISOTDAQ 2024 The the 14th International School on Trigger and Data AcQuisition, June 2024, Hefei (Cina).

COURSES TAKEN

Advanced Statistics for Data Analysis: *F. Badaracco, F.A. Di Bello, F. Parodi*

PUBBLICATIONS

Ø. Bergsagel, G. Calderini, T. I. Carcone, J. I. Carlotto, P. Chabrillat, O. Dorholt, C. Gemme, A. Grigorev, T. Heim and S. Hassan, *et al.* **Test Beam Results of SINTEF 3D Pixel Silicon Sensors**, PoS **VERTEX2023** (2024), 076 doi:10.22323/1.448.0076

M. A. A. Samy, G. Calderini, T. I. Carcone, J. I. Carlotto, P. Chabrillat, G. F. Dalla Betta, C. Gemme, A. Grigorev, T. Heim and L. Meng, *et al.* **Qualification of irradiated 3D pixel sensors produced by FBK for the pre-production of the ATLAS ITk detector**, PoS **VERTEX2023** (2024), 072 doi:10.22323/1.448.0072

S. Ravera [ATLAS], **Results of multi-module system test for the ATLAS ITk Endcap detector**, Nuovo Cim. C47 (2024) no.3, 134 doi:10.1393/ncc/i2024-24134-8

G. Calderini, F. Crescioli, G. F. D. Betta, G. Gariano, C. Gemme, F. Guescini, S. Hadzic, T. Heim, A. Lapertosa and S. Ravera, *et al.* **Qualification of the first pre-production 3D FBK sensors with ITkPixV1 readout chip**, PoS **Pixel2022** (2023), 025 doi:10.22323/1.420.0025

TEACHING

Tutor Fisica Generale 1 - Classe L-30, Corso di laurea triennale in Fisica (30h).

Tutor Fisica Generale - Classe L-11, Corso di laurea magistrale in conservazione e restauro dei beni culturali (20h)

CONFERENCES

VERTEX23. The 32nd International Workshop on Vertex Detectors, Sestri Levante, October 2023. Poster: Qualification of irradiated 3D pixel sensors produced by FBK for the pre-production of the ATLAS ITk detector.

IFAE 2024. The 20th Incontri di Fisica delle Alte Energie, Firenze, Aprile 2024. Poster: Costruzione e test di moduli a pixel con tecnologia 3D per il rivelatore ATLAS ITk Pixel.