Semiconductor sensors development and applications WG-5.2

Status Report

FAPESP Thematic 2020/04867-2

May 25th 2023

WG-5.2.1 & WG-5.2.2 : Recap

- WG-5.2.1 : ATLAS High Granularity Timing Detector (HGTD)
- WG-5.2.2 : Low Gain Avalanche Detectors (LGADs) for low energy applications

Details on August kick-off meeting
and More details on March WG 5.2 Workshop

WG 5.2.1: People and Action Items (Recap)

1. Current Team
   - 1.1. M. Leite (Physicist)
   - 1.2. G. Saito (MS,PhD)
   - 1.3. R. Menegasso (TS)
   - 1.4. M. Kuriyama (TS)
   - 1.5. DD (Dedicated)
   - 1.6. DD (Sharing with PA)
   - 1.7. PD (Sharing with PA)
   - 1.8. IC (TT-2 ?)
   - 1.9. TT-4

DD–4: *Ultra-fast semiconductor sensors and associated instrumentation for radiation detection*

1. Deliverables
   - 1.1. LGAD Characterization Lab.
   - 1.2. Characterization of LGAD sensors (on-going)
   - 1.3. Performance studies on irradiated arrays (on-going)
   - 1.4. PEB test stand system
   - 1.5. Participation in HGTD assembly facility construction @ CERN (on-going)
   - 1.6. Demonstrator construction @ CERN (on-going)
   - 1.7. HGTD installation
   - 1.8. HGTD commissioning

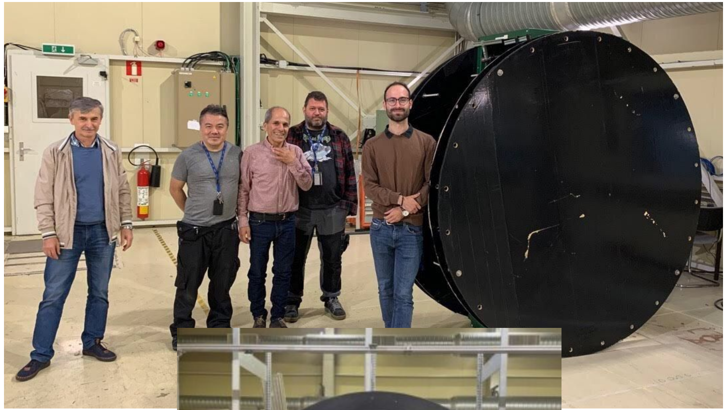
1. Action items
   - 1.1. Equipment availability (importation)
   - 1.2. Preparing civil infrastructure for Lab
   - 1.3. Lab installation
   - 1.4. PD, DD, TT hiring
   - 1.5. Start testing sensors
   - **1.6. Significant work to commission local infrastructure (EMU FAPESP)**
   - **1.7. Significant commitment of people on @CERN activities**

Almost zero float on these items !

WG 5.2.1 : ATLAS HGTD - Infrastructure @CERN

On track (2023)

- **R. Menegasso & M. Kuriyama** @ CERN (3 Months)
  - Clean room and metrology setup for HGTD assembly @ B180
  - Demonstrator construction and thermal test system support
  -
- Next campaign July-October 2023

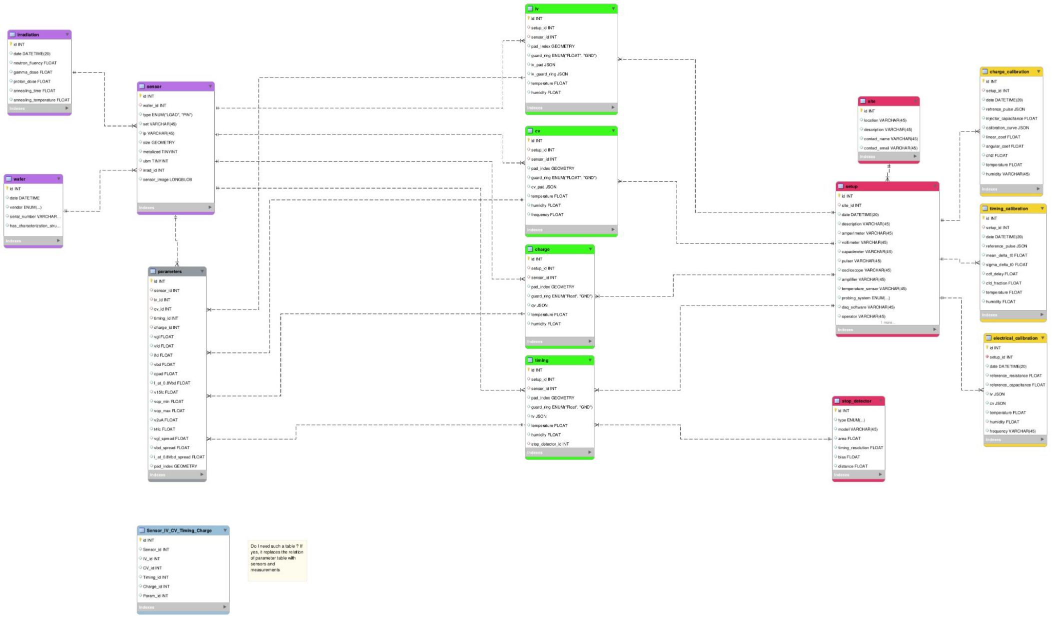


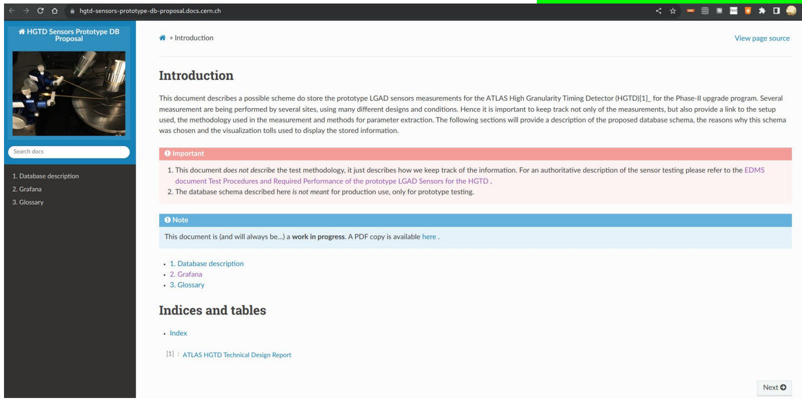
WG 5.2.1 : ATLAS HGTD - Sensor test and Database

On Track

- **M. Leite, G. Saito - collaboration in HGTD DB group**
  - Documentation (Sphinx, gitlab pages)
  - Sensor database (MySQL)
  - Plot (Grafana)
- Concludes in 2023, updates after that

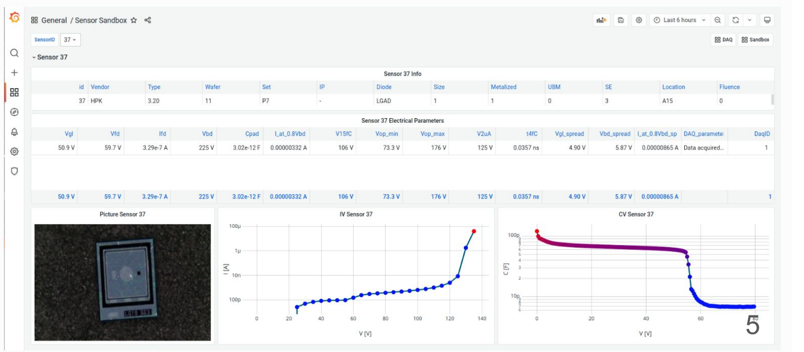
DB Schema





DB Query and plot in Grafana

2.2. Sensors

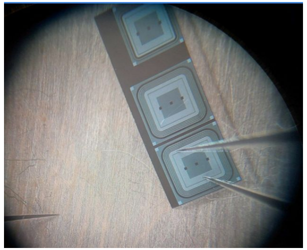


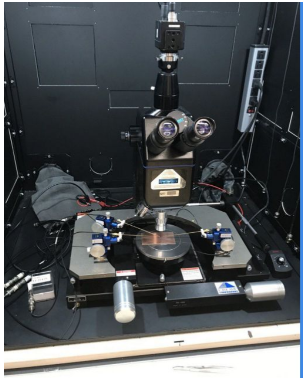
Example of a grafana dashboard showing information about sensors.

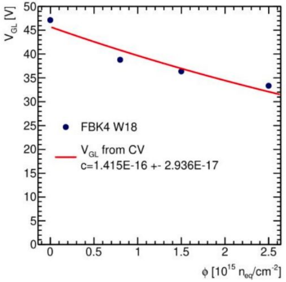
WG 5.2.1 : ATLAS HGTD - Sensor tests and Database

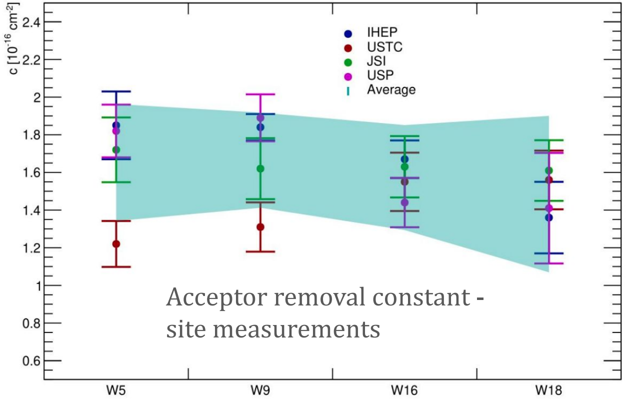
On Track

- **M. Leite, G. Saito - ongoing sensor testing**
  - Sensor tests at USP and FEI (M. Pavanello)
  - New laser system in 2023 …
- Part of the commitments for HGTD (forever …)

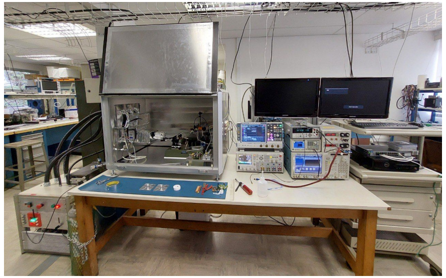


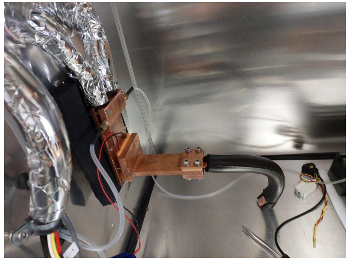






Acceptor removal constant - site measurements

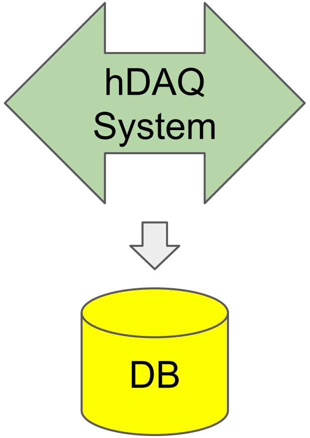




WG 5.2.1 : ATLAS HGTD - Infrastrucutre @USP

Watch ➡ **On Track**

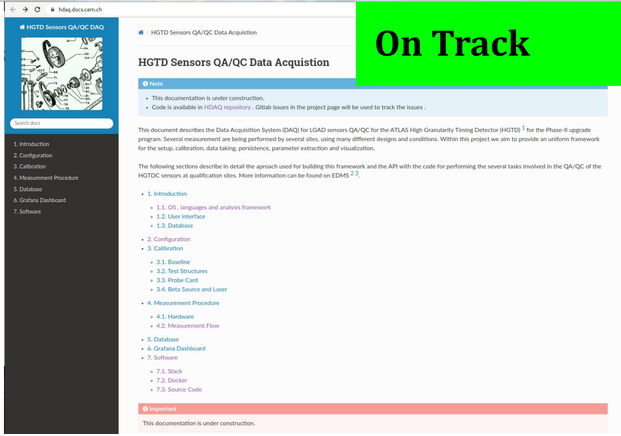
- We need to be ready by ~~March 2023~~ as soon as possible
- Importation in several advanced stages by FAPESP and/or acquired in local distrib. (but support for other equip. across institutes)
- Bias tee, low noise conexion boxes and matrix switch being assembled



WG 5.2.1 : ATLAS HGTD - hDAQ

- Integrated DAQ System for Sensor QC
- Unique system developed for CERN/IJS/IHEP/USP
- Sensor and control structures
- MySQL DB integration
- Part of the commitments for HGTD (forever …)
- https://hdaq.docs.cern.ch
- https://gitlab.cern.ch/ATLAS_USP/HGTD/Sensors/QAQC/HDAQ

On Track


hdaq.docs.cern.ch

HGTD Sensors QA/QC DAQ

Search docs

1. Introduction
2. Configuration
3. Calibration
4. Measurement Procedure
5. Database
6. Grafana Dashboard
7. Software

HGTD Sensors QA/QC Data Acquistion

HGTD Sensors QA/QC Data Acquistion

Note

- This documentation is under construction.
- Code is available in HDAQ repository . Gitlab issues in the project page will be used to track the issues .

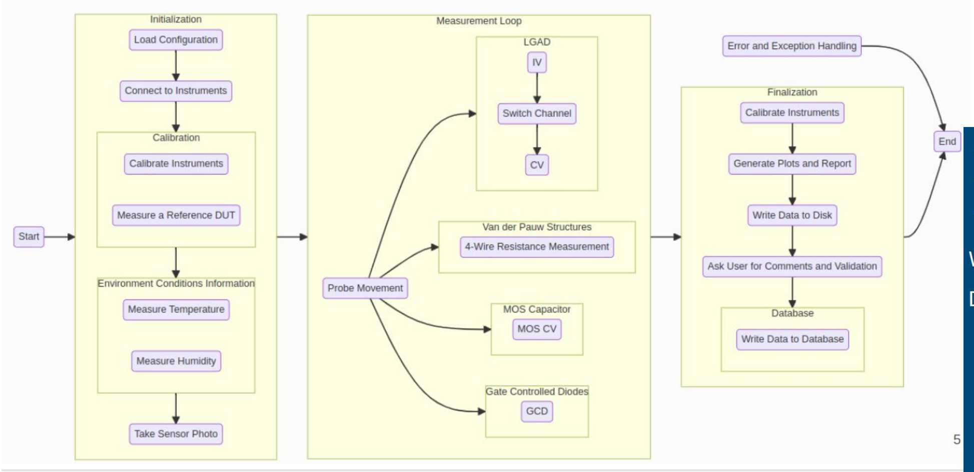
This document describes the Data Acquisition System (DAQ) for LGAD sensors QA/QC for the ATLAS High Granularity Timing Detector (HGTD) [1] for the Phase-II upgrade program. Several measurement are being performed by several sites, using many different designs and conditions. Within this project we aim to provide an uniform framework for the setup, calibration, data taking, persistence, parameter extraction and visualization.

The following sections describe in detail the aproach used for building this framework and the API with the code for performing the several tasks involved in the QA/QC of the HGTDC sensors at qualification sites. More information can be found on EDMS [2] [3].

- 1. Introduction
  - 1.1. OS , languages and analysis framework
  - 1.2. User interface
  - 1.3. Database
- 2. Configuration
- 3. Calibration
  - 3.1. Baseline
  - 3.2. Test Structures
  - 3.3. Probe Card
  - 3.4. Beta Source and Laser
- 4. Measurement Procedure
  - 4.1. Hardware
  - 4.2. Measurement Flow
- 5. Database
- 6. Grafana Dashboard
- 7. Software
  - 7.1. Stack
  - 7.2. Docker
  - 7.3. Source Code

Important

This documentation is under construction.



Development at São Paulo

Writing driver for our instruments

Done :

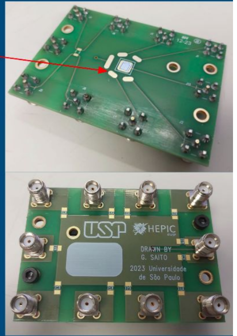
- Keithley Electrometer 6514
- Keithley Electrometer 6517B
- Keysight DMM 34461A
- R&S LCR HM8118

To do :

- Keithley SMU 2450
- R&S LCR LCX200
- Keysight Electrometer B2985B
- JSI switching matrix driver

Reference Board:

HPK LGAD



Reference Board

- PCB to wire bond a sensor or test structure die and SMD resistor/capacitor for calibration
- Handy to develop DAQ software
- Good to debug noise & connection (without Probe Station)

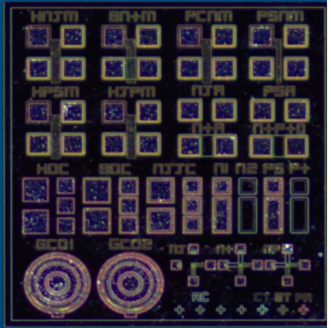
WG 5.2.1 : ATLAS HGTD - Test structures

- First tests done at USP
- Done @FEI with M. Pavanello

Test Structures

IHEP test structures:

- 3 Sheet Resistors
- 3 Contact Resistors
- 7 Capacitors
- 1 Diode
- 2 Gated Diodes
- ~~6 MOSFET~~



Not the production design

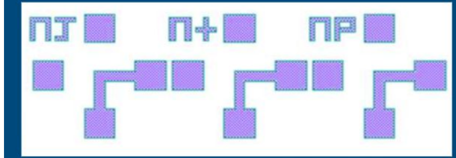
To get hands-on experience for the Sensors QC

Contact Resistance

- NJ
  - NJTE contact resistor
- N+
  - N++ contact resistor
- NP
  - N++/P+ layer contact resistor

> First tried with B1500, but no reliable measurement

> Then used a DMM and LCR 4-wire Resistance



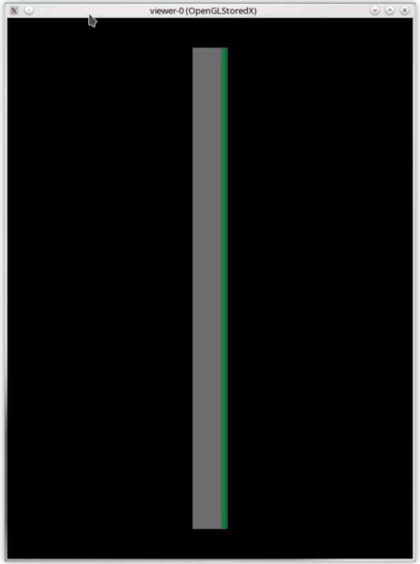
		NJ	N+	NP
DMM 34461	Die 1	378 kΩ	13.0 Ω	11.5 Ω
	Die 2	386 kΩ	13.6 Ω	11.6 Ω
	Die 3	374 kΩ	12.9 Ω	10.9 Ω
LCR HM8118	Die 1	65 kΩ	14.3 Ω	12.8 Ω
	Die 2	550 kΩ	14.0 Ω	12.6 Ω
	Die 3	549 kΩ	13.3 Ω	11.5 Ω

DMM 34461 Current Source: 1mA for 1kΩ; 5μA for 1MΩ
LCR HM8118: 0.5V 20Hz

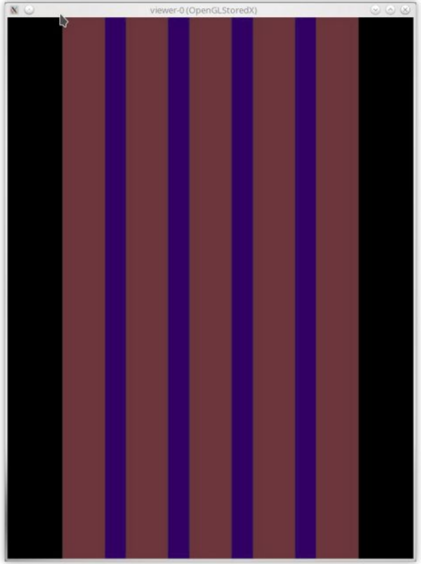
WG 5.2.2 : Low Energy Applications - G4 Simulations

- First G4 simulation framework from M. Moralles for AC-LGADs
- More info on March WG 5.2 Workshop (https://indico.cern.ch/event/1251642/contributions/)

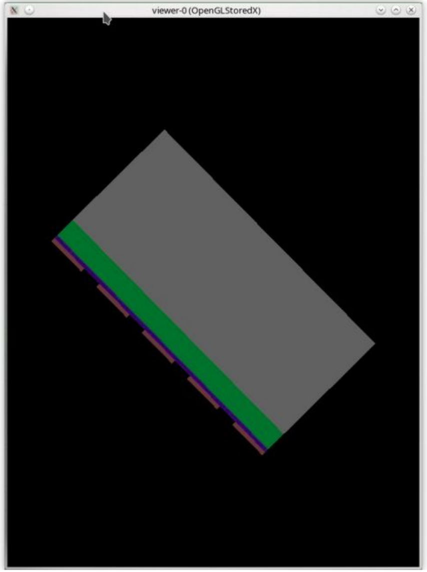
Detector – thickness view



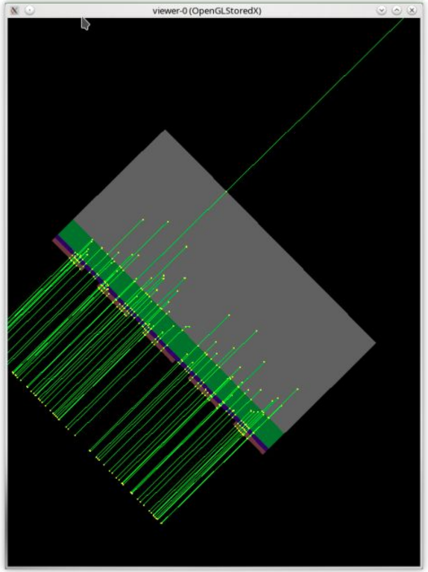
Detector – strips view



Detector – top view

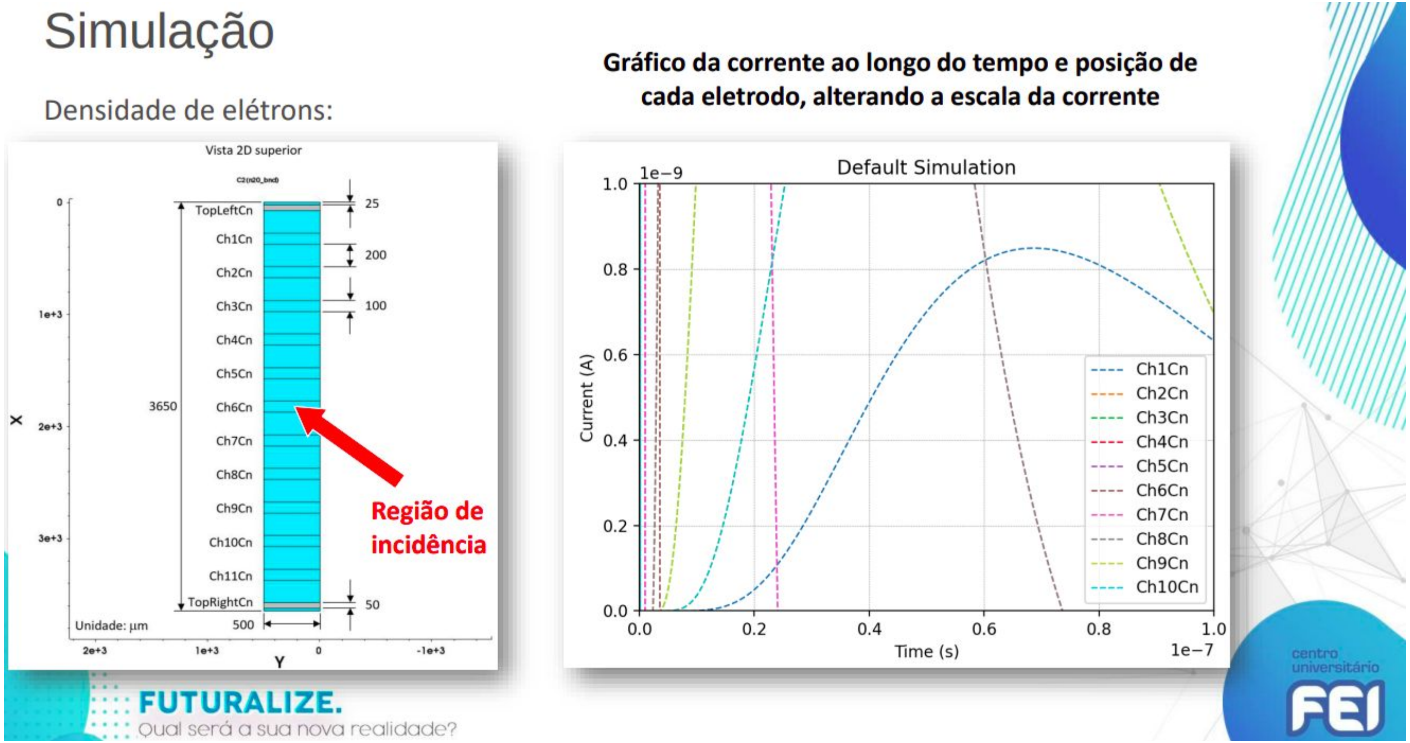


Detector – top view with X-rays (8 keV)



WG 5.2.2 : Low Energy Applications - TCAD Simulations

- TCAD AC-LGAD example from UCSC run by R. Buhler & R. Giacomini
- More info on March WG 5.2 Workshop   (https://indico.cern.ch/event/1251642/contributions/)



WG 5.2.2 : Low Energy Applications - TCAD Simulations

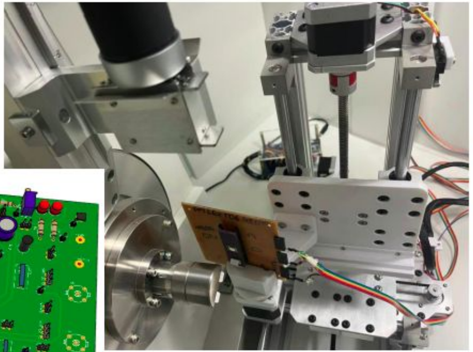
- LGAD TID tests (X-ray) @ FEI (M. Guazelli) bard with HPK 3.1 & 3.2 wire bonded
- More info on March WG 5.2 Workshop   (https://indico.cern.ch/event/1251642/contributions/)

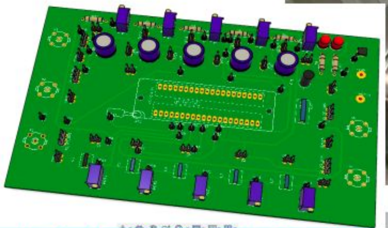
EXEMPLO DE TESTE QUE ACABA DE SER PLANEJADO E PREPARADO NA FEI

CI com 3 retangulares e 2 ELT

TID

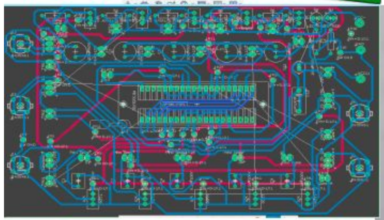
Irradiado até 300 keV. Analisado antes, durante e após irradiação

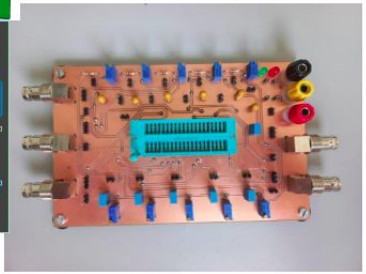


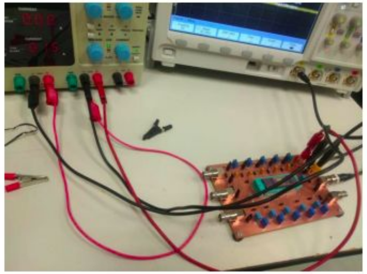


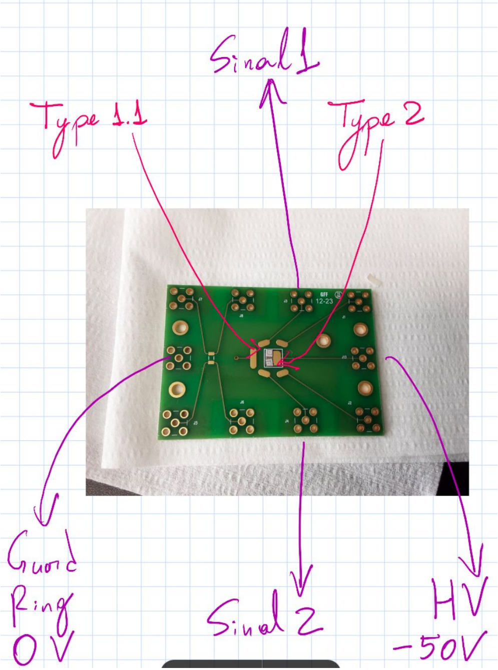
SEE

Verificar sinal analógico do pico de corrente (SEE) em função do tempo. Número de SEE em função do tempo, para um determinado LET. Serão monitorados 1 Ret e 1 ELT ao mesmo tempo.









centro universitário FEI

WG 5.2.2 : SSRL LGAD and AC-LGAD Tests

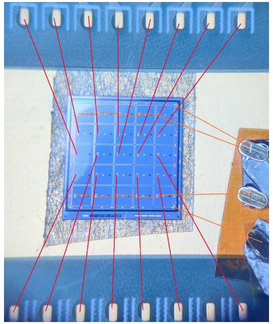
LGADs/AC-LGADS for picosecond time-resolved X-ray testing

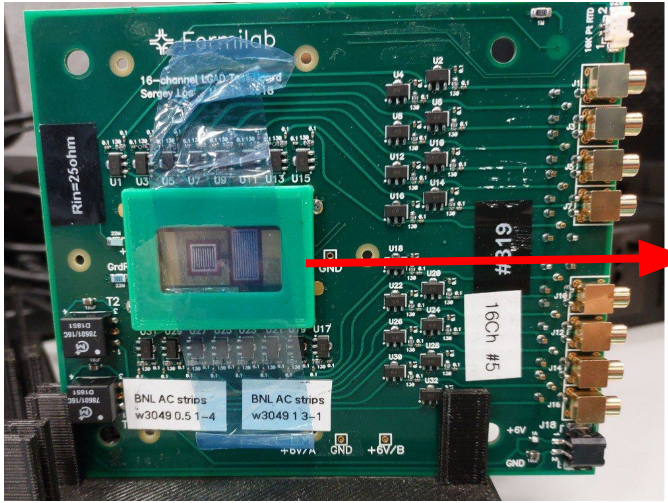
On Track

4. Radiation testing of *available* LGAD, AC-LGAD
   4.1. X-Ray testing
   4.2. Charged particle testing (electrons, protons, ions)
   4.3. Time Resolved X-Ray testing (**M. Leite & UCSC**)

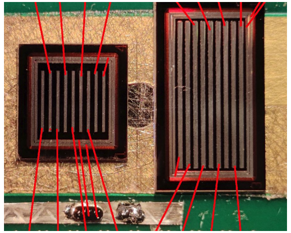
Tested at Stanford SLAC SSRL test beam with UC Santa Cruz in November 2022

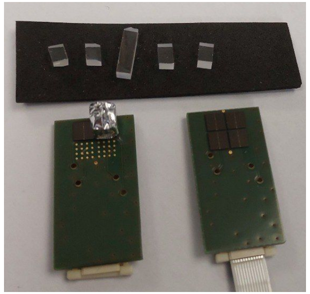
- Energies from 5keV to 53 keV (70 keV with harmonics)
- “Flat” beam (BL 11.2) : 12.6mm x 2.14mm
- Several intensities and bias voltages
- LGADs :
  - HPK 3.1 Single (1.3mm)
  - HPK 3.2 single (1.3mm)
  - HPK 3.2 5x5 (1.3mm)
  - BNL 20μm Single (1mm)
- AC-LGADs :
  - BNL strips

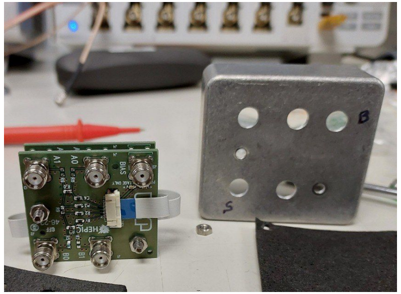




Strips
AC-LGAD







Compton Box
(SiPM + LYSO)

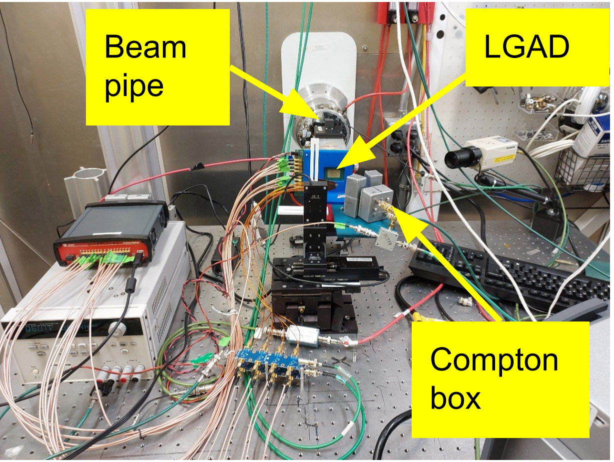
Long range and continuous effort - also discussion with Sirius detector group

WG 5.2.2 : WBS and Deliverables

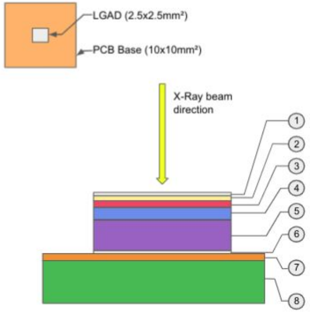
Part-I - LGADS for picosecond time resolved X-ray testing

On Track

SSRL BL 11-2



- Significant amount of work since Dec. 2022
- Analysis almost completed, paper in preparation (JINST) to be submitted next month or so



	LGAD layer	Thickness (μm)
1	Al cathode Contact	0.3
2	n++	1.0
3	gain (p+)	1.0
4	bulk active	45.0
5	p++ substrate	150.0
6	Al anode contact	0.3
	PCB Base layer	**Thickness (μm)**
7	Copper Laminate	100
8	FR4	1600

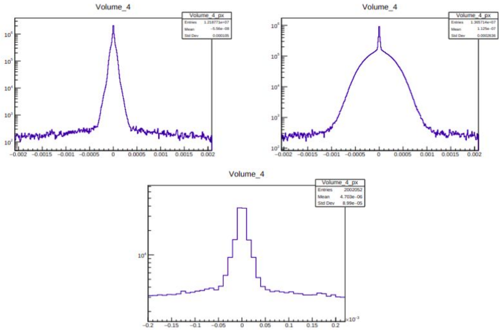
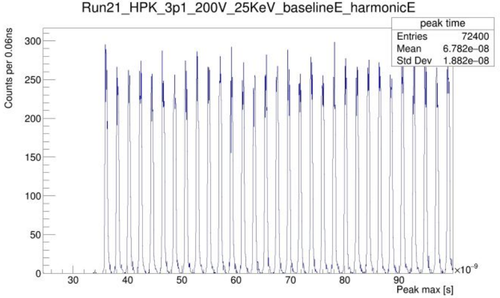


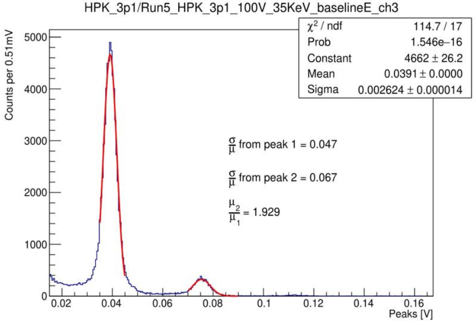
Figure 11: Simulation of primary charge transverse distribution (considering a point-like beam) in the LGAD BULK region for photons of 5(a), 10(b) and 30(c) keV

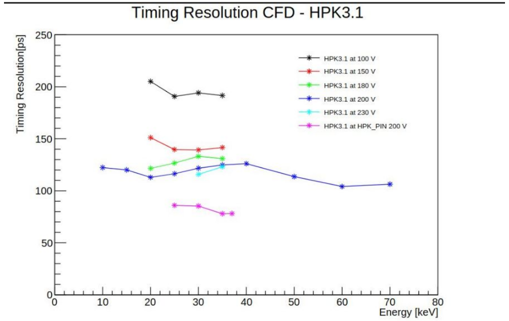
Energy resolution

Timing resolution



Bunch structure





WG 5.2.x : Deliverables

Three papers about to be submitted

Performance of a front-end prototype ASIC for the ATLAS High Granularity Timing Detector

E-mail: makovec@cern.ch

Abstract: This paper presents the design and characterisation of a front-end prototype ASIC for the ATLAS High Granularity Timing Detector, which is planned for the High-Luminosity phase of the LHC. This prototype, called ALTIROC1, consists of a 5×5-pad matrix and contains the analog part of the single-channel readout (preamplifier, discriminator, two TDCs and SRAM). Two preamplifier architectures (transimpedance and voltage) were implemented and tested. The ASIC was characterised both alone and when connected to a 5×5-pad array of LGAD sensors. In calibration measurements, the ASIC operating alone was found to satisfy the technical requirements for the project, with similar performances for both preamplifier types. In particular, the jitter was found to be 15±1 ps (resp. 35±1 ps) for an injected charge of 10 fC (resp. 4 fC). A degradation in performance was observed when the ASIC was connected to the LGAD array. This is attributed to digital couplings at the entrance of the preamplifiers. When the ASIC is connected to the LGAD array, the lowest detectable charge increased from 1.5 fC to 3.4 fC. As a consequence, the jitter increased for an injected charge of 4 fC. Despite this increase, ALTIROC1 still satisfies the maximum jitter specification (below 65 ps) for the HGTD project. This coupling issue also affects the time-over-threshold measurements and the time-walk correction can only be performed with transimpedance preamplifiers. Beam test measurements with a pion beam at CERN were also undertaken to evaluate the performance of the module with LGAD pulses. The best time resolution obtained using only ALTIROC information was 46.3±0.7 ps for a restricted time-of-arrival range where the coupling issue is minimized. The residual time-walk contribution is equal to 23 ps and is the dominant electronic noise contribution to the time resolution at 15 fC.

Destructive breakdown studies of irradiated LGADs at beam tests for the ATLAS HGTD

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X-ray detection with Low-Gain Avalanche Diodes

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Abstract: The response of Low Gain Avalanche Diodes (LGADs), which are a type of thin silicon detector with internal gain, to X-rays of energies between 6-70 KeV was characterized at the SLAC light source (SSRL). The utilized beamline at SSRL was 11-2, with a nominal beam size of 3 cm x 0.5 cm, repetition rate of 500 MHz, and exceptionally monochromatic. LGADs of different thicknesses and gain layer configurations were read out using fast amplification boards and digitized with a fast oscilloscope. Standard PiN devices were characterized as well. The devices' energy resolution and time resolution as a function of X-ray energy were measured. The charge collection and multiplication mechanism were simulated using TCAD Sentaurus, and the results were compared with the collected data.

Keywords: fast silicon sensors; charge multiplication; thin tracking sensors; X-rays; time resolution

WG 5.2.1 & WG 5.2.2 : **ACTION ITEMS FOR NEXT MONTHS**

on track
critical
new

ATLAS HGTD

- Move ahead with USP infrastructure
  - Most critical item
  - Involves space, import and equipment purchase
  - Needs to prepare lab infrastructure while space discussion is on-going
- DAQ development and DB integration @ USP (in sync with CERN/IHEP/USTC/JSI)
- Infrastructure (baby demo and mockup) @ CERN
- Build the laser system with motorized stages + position measurement

New applications

- Validate first functional TCAD and Geant4 simulation
- Add Ad-hoc simulation code for multiplication mechanism
- Analyze data from TB @SLAC, resume discussion with Sirius (more people involved…)
- Understand irradiation needs and prepare infrastructure/tests at local facilities
- Explore/Converge designs for fabrication (WG 5.2.3 - see next presentation)

New involvements

- **G. Saito →DD** (qualification tomorrow, "Ultra-Fast Silicon Detectors for Radiation Sensing") ;
  R. Mansano (Poli) + M. Leite (IFUSP)

- **R. Estevam →DD** (Start next month : "*Métodos de aprendizado profundo e processamento de sinais aplicados à reconstrução de trajetórias em 4 dimensões para o HL-LHC*" ;
  V.H. Nascimento (Poli) + M.Leite (IFUSP)

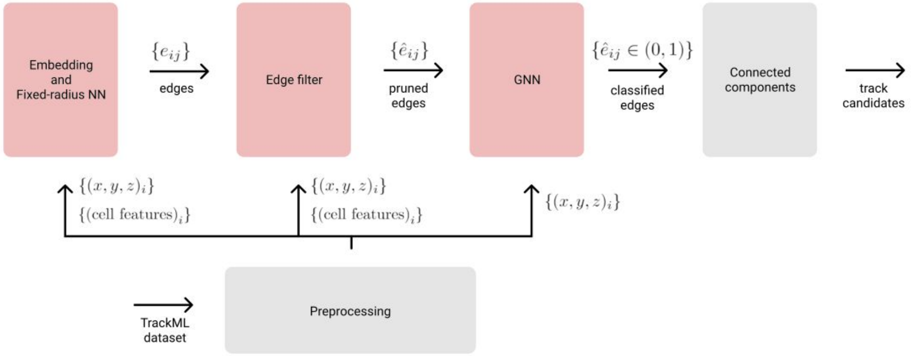
- ECFA Detector Roadmap : DRD3 R&D on Solid State Detectors (on-going)

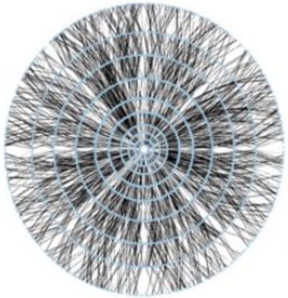
WG 5.2.1 & WG 5.2.2 : **ACTION ITEMS FOR NEXT MONTHS**

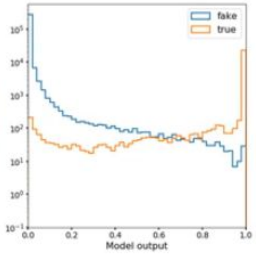
new

Graph based Neural Network approach for ATLAS HL-LHC (iTK+HGTD)

- Exa.trk: HEP advanced tracking algorithms at the Exascale

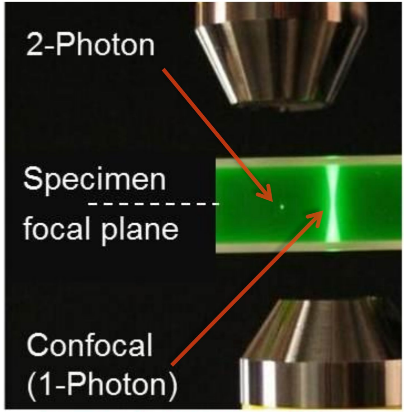






Characterization of Semiconductor sensor using TCT and TPA Laser techniques

- Conventional TCT:
  - Localized generation of e-h pairs on X-Y
- Two-photon absorption TCT:
  - Localized generation of e-h pairs on X-Y-Z



Photography: Ciceron Yanez, University of Central Florida

DRD-3 R&D on semiconductor sensors

- We are covering all ECFA DRDTs
- Additional WGs were added to cover simulations, facilities and dissemination corresponding to **General Strategic Recommendations (GSRs)** in the ECFA roadmap