CMS Inner Tracker DAQ and System Tests

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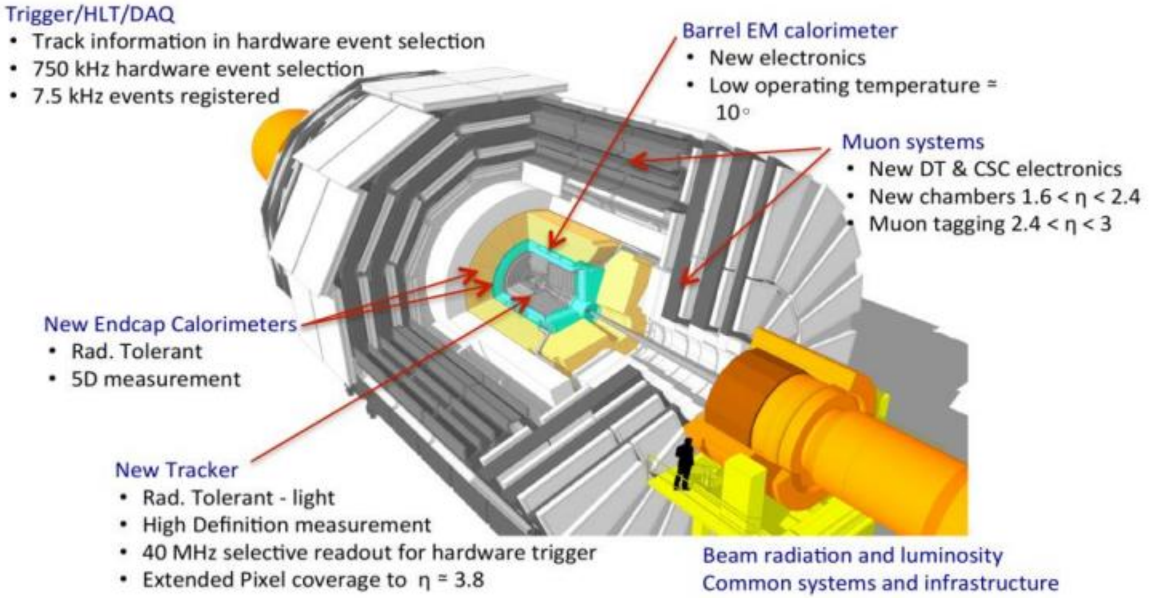
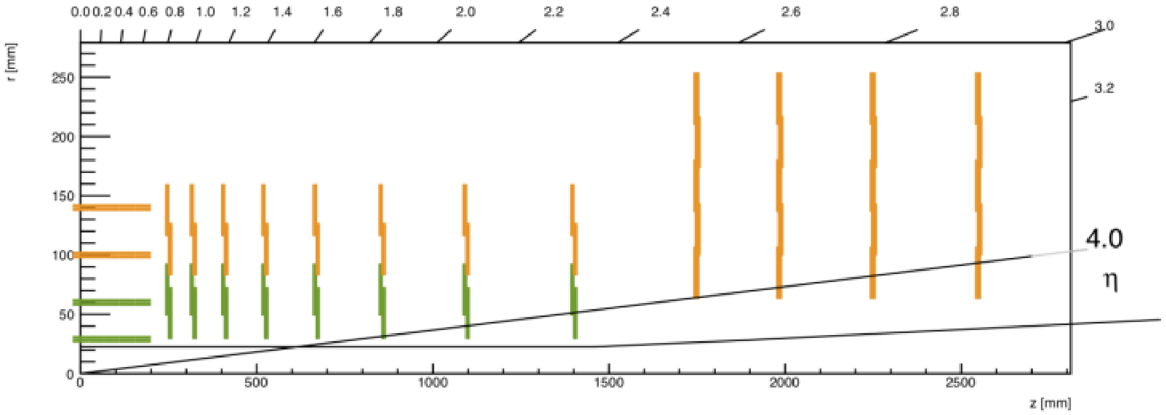
CMS Phase-II Upgrade

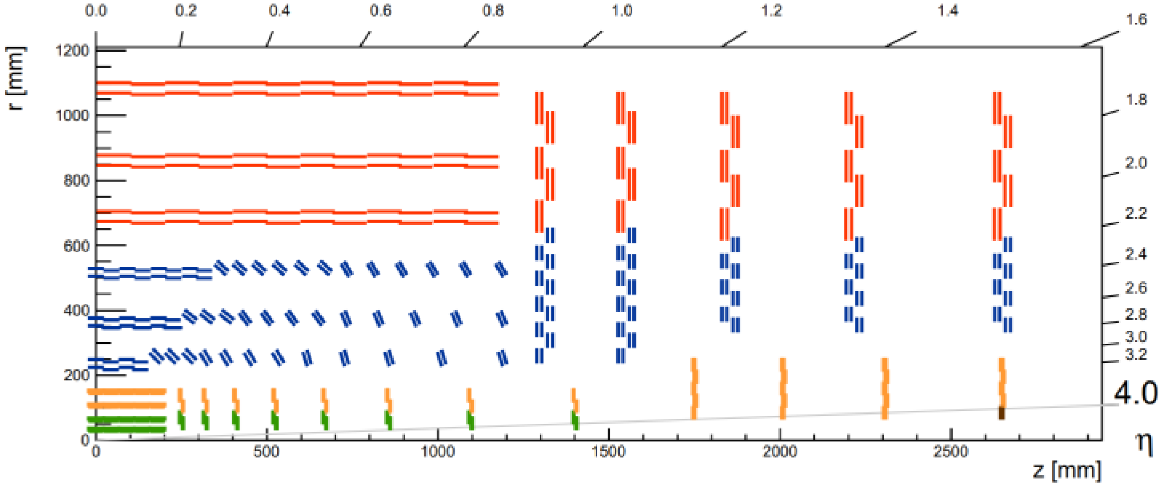
- High Luminosity LHC (HL-LHC):
  - LHC upgrade that will increase the rate of collisions
  - Detector upgrades are needed to support the increased hit rate and radiation
- CMS Phase-II upgrade:
  - Major upgrade of CMS planned for HL-LHC
  - New tracker design:
    - Increased radiation tolerance
    - Higher granularity (more channels, smaller pixels, etc.)
    - Lower mass
    - Contribution to Level-1 Trigger (Outer Tracker only)
    - Extended coverage ($0 < \eta < 4$)



CMS Phase II – Tracker Upgrade

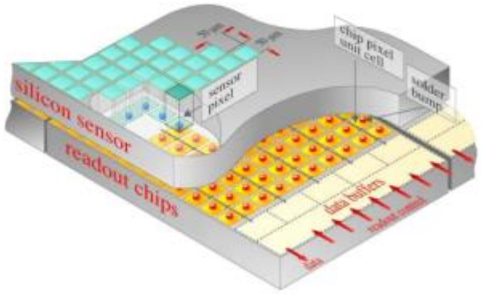
- Inner Tracker:
  - Innermost layer of CMS, right off the beam pipe
  - Silicon pixel detectors, 50 μm pitch
  - 10000 readout chips, 3900 hybrid modules
  - ~2 billion channels, 1342 links @ 10 Gbps
  - Modules consist of 1x2 or 2x2 chips
- Outer Tracker:
  - Largest part of the tracker
  - Double sided hybrid modules:
    - 7608 **Strip-Strip** (2S) and 5592 **Pixel-Strip** (PS) modules
  - Each module detects and transmits high p_T track segments (stubs) in real time

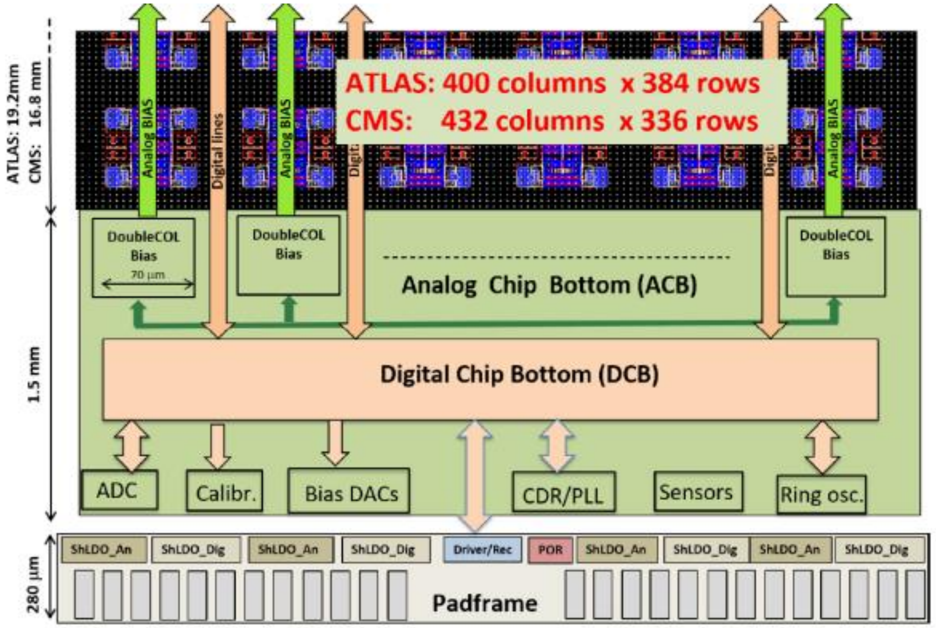


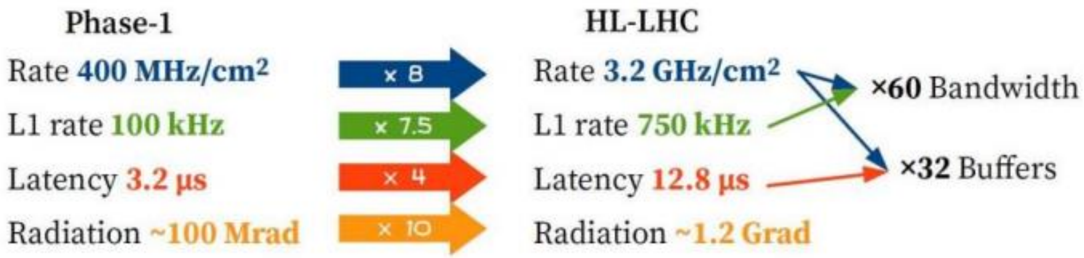


Inner Tracker ASIC

- Hybrid module design:
  - Separate sensor and readout chips
  - Flip chip assembly with bump bonding
- Readout chips developed by the RD53 Collaboration (CMS + ATLAS):
  - 65 nm process (TSMC)
  - **RD53A**: Half-sized demo version, extensively tested
  - **CROCv1**: Full-sized (336 x 432 pixels) pre-production prototype, received Sep `21
  - Final version to be submitted this year







Introduction to µDTC DAQ System

- The readout and control of the future front-end modules of the CMS Tracker, will be performed by the DAQ, Trigger and Control (DTC) System.

- The µDTC project was established to perform these tasks in the prototyping and production phases.

- Common framework for Outer Tracker (OT) and Inner Tracker (IT) based on FC7 board and IPBus* - this presentation focuses mostly on Inner Tracker implementation (IT-µDTC).

Software Suite
OT: INFL + DESY
IT: Milano + CERN + Demokritos

+

Firmware Suite
OT: DESY
IT: Demokritos

+

Hardware

FC7 Board, Developed by CERN

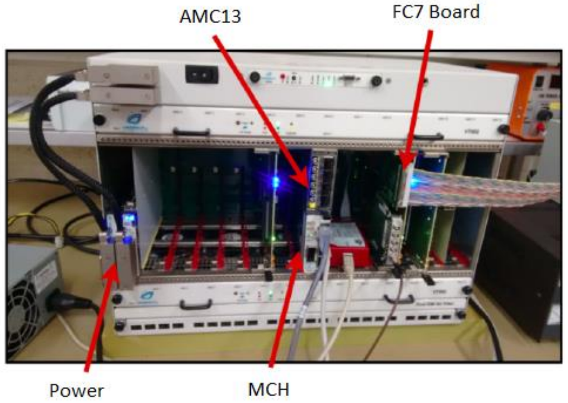
- **Demokritos has undertaken the responsibility to develop and maintain the DAQ for the Inner Tracker System Tests**
  - *Software in C++ and Python*
  - *Firmware in VHDL*

**IPBus: Ethernet-based communication protocol, developed by CERN.*

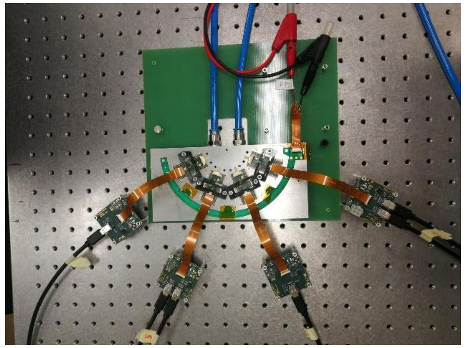
Introduction to µDTC DAQ System

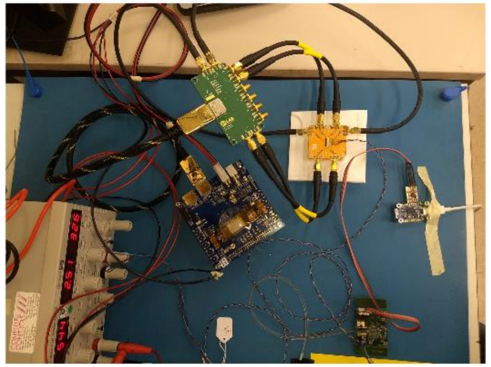
IT-µDTC will form the basis for the final DAQ System of the Tracker and provides support for various systems:

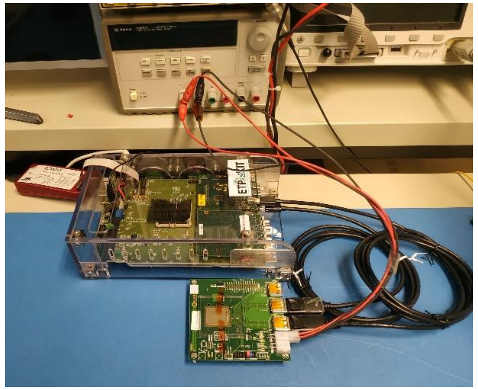
- Chip testing and characterization
- Hardware characterization
- Beam Tests
- Wafer Probing
- Multiple design flavors to support
  - Crate or Desktop operation, Optical or Electrical link, Single Chips or Modules, RD53A or CROCv1 chip



uDTC setup in Crate-mode operation


Setup with Quad-modules


Setup with optical link


INPP DIL setup with SCC and RD53B on electrical link (Desktop-mode)

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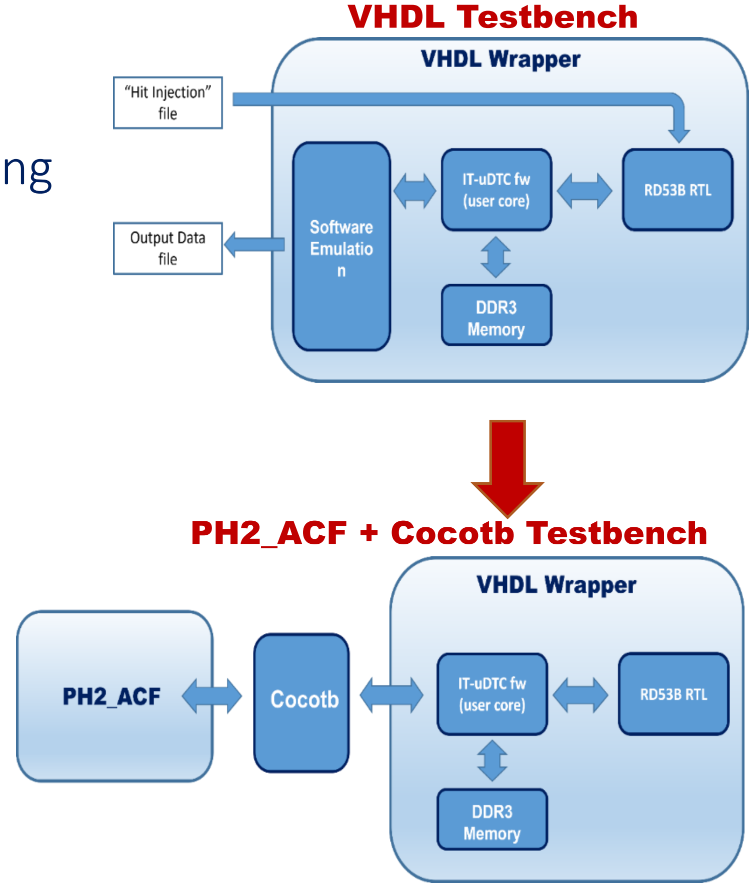
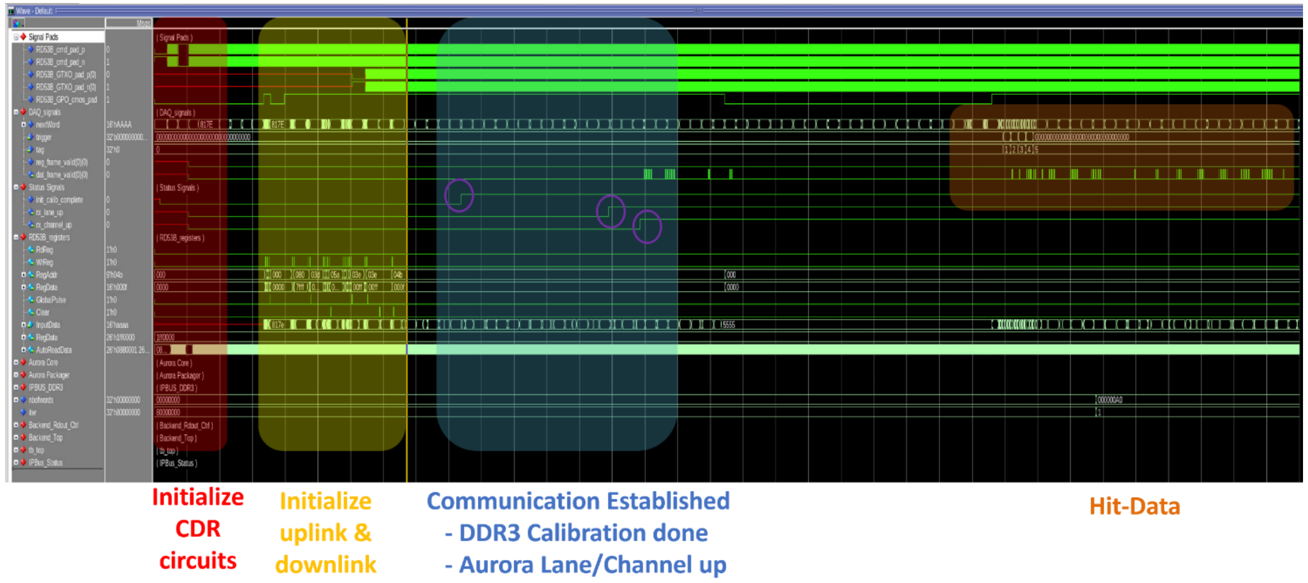
DAQ + ASIC co-simulation framework

In order to facilitate the development of the DAQ, a framework for co-simulation of DAQ + RTL of the chip in Questa simulator for past and future chips has been established

- Testbench originally implemented in VHDL
- Migrating to Cocotb to allow more advanced verification including the software in the simulation chain
  - Cocotb is a python-based simulation framework

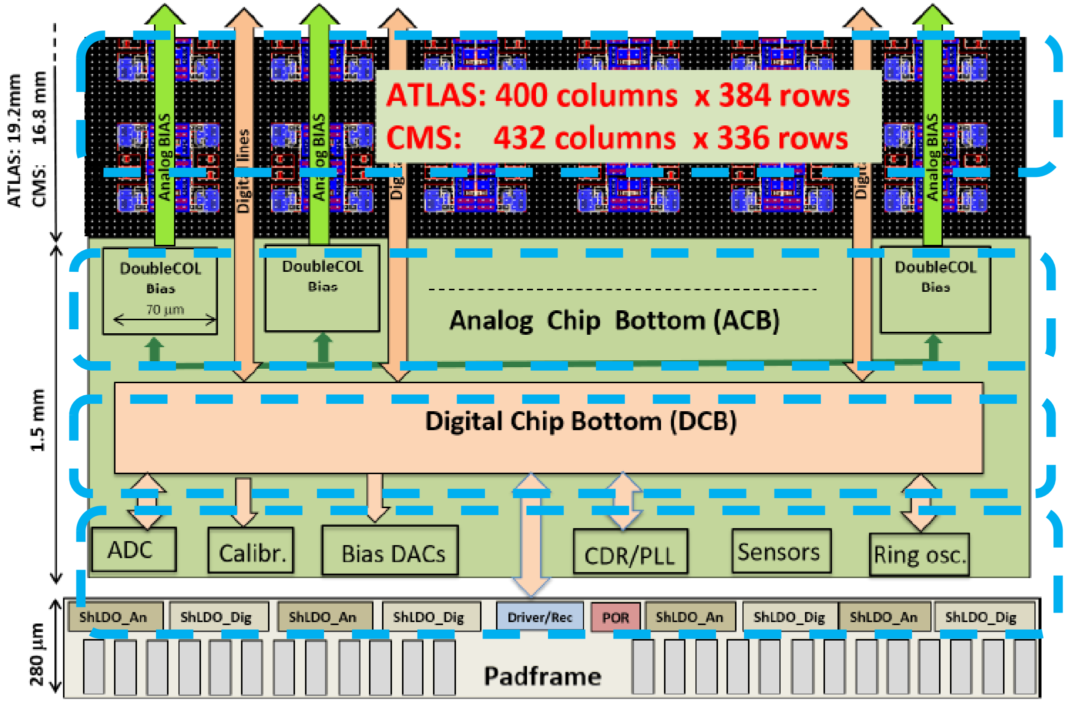




CROC_v1 Testing and Characterization

For the new version of the CMS readout chip, Demokritos is leading the team for the characterization of the ASIC.

- CROCv1 is a versatile ASIC:
  - Hundreds of global configuration parameters, various monitoring and calibration features
- Comprehensive suite of tests has been developed to characterize it



Pixel Matrix & Analog Front End:
CERN + Demokritos

Analog Chip Bottom:
University of Zurich

Digital Chip Bottom:
Demokritos

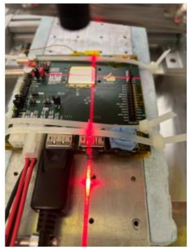
Power Supply Circuits:
Universita e INFN, Firenze

Coordinating the team:
Demokritos

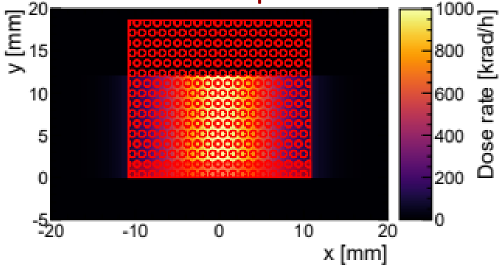
Lab Tests

During Lab-tests, the performance of the ASIC is evaluated under different conditions, mostly in bare-chip configurations (i.e., without a sensor).

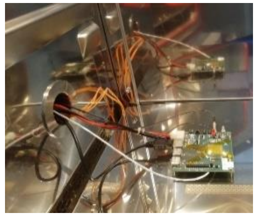
- X-Ray Irradiation Campaigns
  - Radiation tolerance is one of the most important aspects of the chip
  - CROC needs to survive after a TID of at least 1 Grad
  - Various tests performed before, during and after irradiation to verify that the performance is still acceptable


X-Ray setup

Dose-rate map at ETH

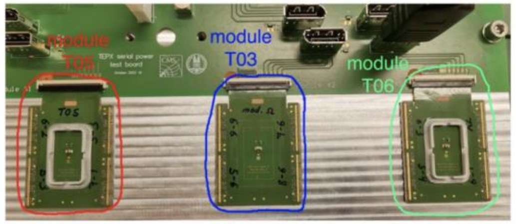


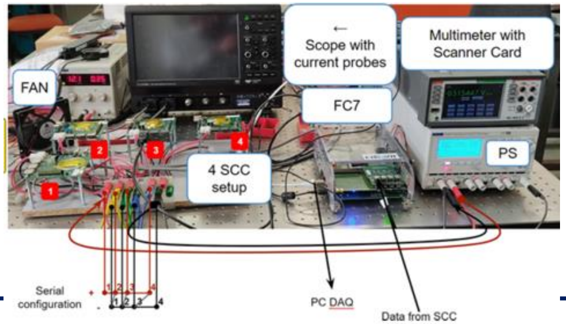
- Climatic Chamber Campaigns
  - Various parameters of the chip are affected by temperature
  - Dedicated studies with Climatic Chamber in Demokritos facilities
  - Controlled environmental conditions with temperature ranging between -40C to +40C


CROC SCC


Climatic Chamber

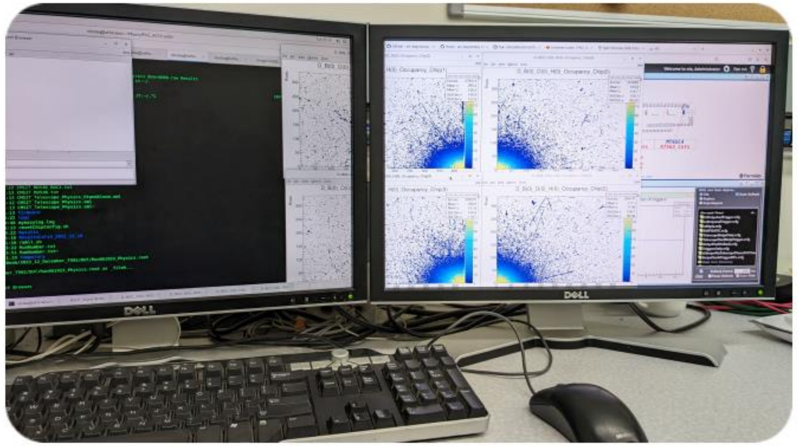
- Multi-chip module system tests
  - Detector-like configurations with chips assembled in 1x2 or 2x2 modules
  - Serial Powering tests

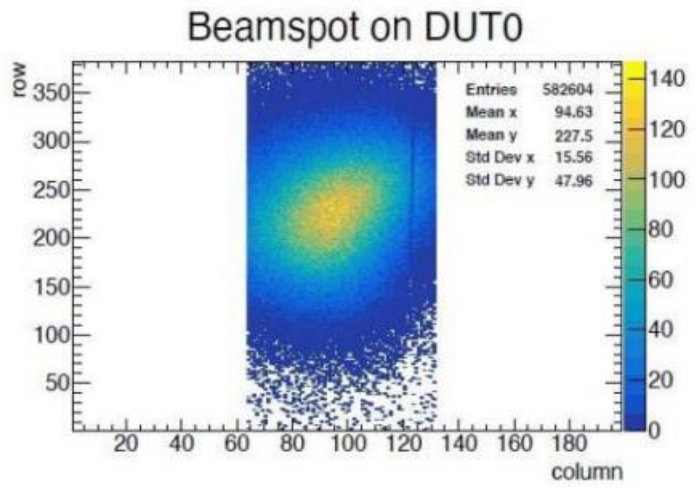




Beam Tests

- Test beams provide an opportunity to demonstrate the ability of the modules to detect particles efficiently
- CROC modules have been tested under particle beams at various accelerator facilities:
  - CERN North Area
  - DESY
  - Fermilab
- Various configurations have been tested:
  - Different sensors
  - Different telescope setups
  - Different angles of incidence





Summary and Outlook

"DEMOKRITOS" is involved in the following activities regarding CMS Inner Tracker Upgrade

- **Development of the DAQ for the prototyping and production stages**
  - Hardware validation and extensive tool-set for signal integrity studies
  - Wafer Probing for production testing of ASIC
  - Framework for co-simulation of DAQ + RTL of past and future chips

- **Testing and characterization of CMS Readout chip (CROC)**
  - Lab-tests (X-ray campaigns, temperature studies, performance evaluation)
  - Beam tests

- **Required skills to contribute:**
  - At least one of the following
    - Good knowledge of C++ and/or Python
    - FPGA design using VHDL

Backup