WP1.4. Silicon Detectors Characterization and Simulation

Eric Buschmann, Justus Braach, Esteban Curras, Katharina Dort,
Dominik Dannheim, Marcos Fernandez Garcia, Anja Himmerlich,
Michael Moll, Sebastian Pape, Vendula Maulerova-Subert

on behalf of the WP1.4. team

WP 1.4. Simulation & Characterization

- The WP aims for enabling a fundamental understanding and optimization of the performance of particle detectors
- Increasingly complex sensors and readout ASICs require improved characterization, modelling and simulation, including radiation effects

Radiation-hardening

- Defect characterization
- Damage models & simulation
- Radiation hard devices
- LGAD and p-type silicon

Characterization Infrastructure Development

- Flexible readout systems
- Laser test stands (TPA-TCT)
- Defect characterization tools

Radiation monitoring techniques

- New radiation sensors
- Revision of NIEL scaling
- Dosimetry for ultra-high radiation levels

Advanced detector simulations

- Charge & damage creation
- Device physics, signal formation
- Front-end response
- Simulation of data stream

WP1.4. Team at CERN

- *Michael Moll & Dominik Dannheim (WP leaders)*
- *Marcos Fernandez-Garcia (IFCA, Spain, visiting scientist)*
- *Ruddy Costanzi (Technical Engineer EP-DT, support)*

- Esteban Curras *[until Feb.23]*
  - Fellow, EP-DT/**WP1.4.**
  - LGAD sensors & SSD lab


Esteban

- Anja Himmerlich *[until Jan.23]*
  - Fellow, PCB
  - Defect studies – DLTS, TSC


Anja

- Sebastian Pape *[until Feb.24]*
  - DOCT, Gentner Prg.
  - TPA-TCT measurements


Sebastian

- Vendula Subert *[until Oct.23]*
  - DOCT, **WP1.4.**
  - NIEL studies, Geant4


Vendula

- Eric Buschmann *[until July 23]*
  - Fellow, **WP1.2./1.4.**
  - Caribou, DAQ, MAPS


Eric

- Katarina Dort *[until June 22]*
  - DOCT, Gentner Prg.
  - Simulations (TCAD, AP2) MAPS


Katarina

- Justus Braach *[until Feb.24]*
  - DOCT, Gentner Prg.
  - Test-beam & lab hardware, MAPS


Justus

- many more collaborators ….

WP1.4. - Resources

- WP1.4. core resources (2022)
  - 1.5 FTE/year Fellow
  - 1 FTE PhD/year
  - 75 KCHF/year materials
- Resources through other funds/programs (essential!)
  - Close collaboration with other EP-RD silicon WPs
  - CERN PCB Fellow, Gentner Prg., EP/DT labs & services
  - AIDAinnova, EUROLABS, RD50, ..
- Participants
  - WP1.4.& WP1.x EP-RD teams at CERN
  - External collaborators
    (see slides about specific WP1.4. projects)
    + many more collaborators
    https://ep-rnd.web.cern.ch/topic/simulation-and-characterization

- AIDAinnova (2021-25)
  - WP1.4. members are leading tasks
  - CERN (WP1.4.) is beneficiary in:
    - **Task 3.5**. Development of common DAQ hardware [**Caribou project**]
    - **Task 4.3**. Common tools for irradiation facilities quality control [**NIEL project**]
    - **Task 4.4**. Design & development of a TPA-TCT characterisation system [**TPA-TCT project**]
    - **Task 6.3** Validation of common 3D and LGAD sensor productions [**LGAD project**]

- RD50
  - WP1.4. projects are part of RD50 work program
  - RD50 projects with RD50 financial contribution:
    - Caribou common board production
    - TPA-TCT beam time at laser facilities
    - Common production of test structures

- EUROLABS (from 9/22)
  - TNA to irradiation facilities

Work Plan and Deliverables

R&D work plan 2018
(initial plan)

- Commission a **TPA-TCT setup**
  (Two Photon Absorption-Transient Current Technique)
- Produce a high resolution (spatial, timing) **beam telescope**
- **Advanced simulation tools**
- **Radiation damage** measurements and validated **models incl. TCAD**
- **Radiation monitors** for $>10^{16} n_{eq}/cm^2$
- **Flexible readout system**
- Maintain & extend characterization lab

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(reduced budget allocated)

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- **Advanced simulation tools**
  (reduced scope: no WP1.4. funding)
- **Radiation damage** measurements and validation of **models**
  (reduced scope: no TCAD modelling)
- **Radiation monitors** for facility calibration including NIEL studies (reduced scope: no ultrahigh fluence,staged sensor production)
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Status 2022
(see following presentations)

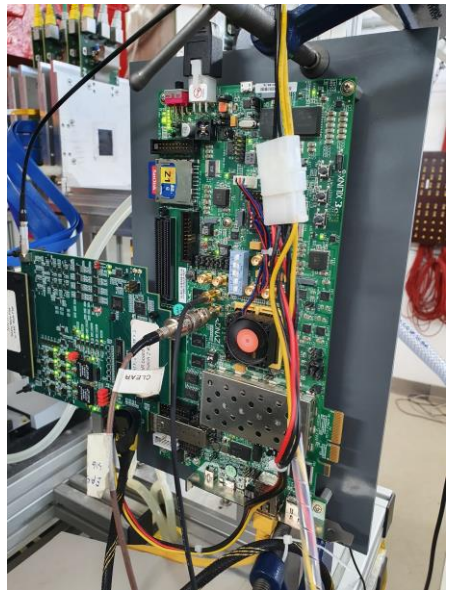
- **TPA-TCT setup existing at CERN**
- **Simulation tools validated**
  - TCAD and generic MC tools validated
- **Radiation damage models**
  - **LGAD** studies lead to new model for impact ionization (WP1.4.)
  - **Acceptor removal** project identifies the defect responsible for the LGAD degradation (Defect engineering!)
  - LGAD radiation hardness achieved with Carbon co-doping (RD50 collaboration)
- **NIEL model advancing**
- **Caribou readout system**
  - DAQ extended, systems distributed
- **Characterization lab**
  - New tools produced

Caribou

- Versatile open-source DAQ system adapted and used for various monolithic and hybrid EP R&D pixel-detector developments

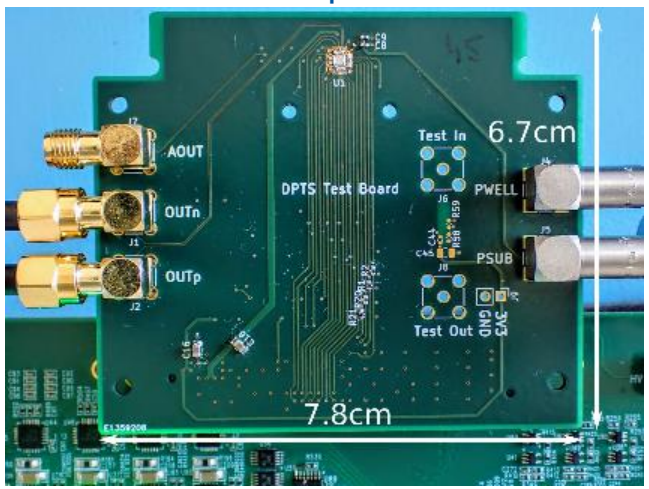
- Significant progress in 2021/22, thanks to external resources and large user community (RD50, AIDAinnova):
  - Implementation of several new 65-nm devices: DPTS, APTS, H2M (in progress)
  - full analog pixel readout with fast sampling ADCs
  - Integration in various beam-telescopes (AIDA, Timepix3, ALPIDE)

Caribou in DESY TB

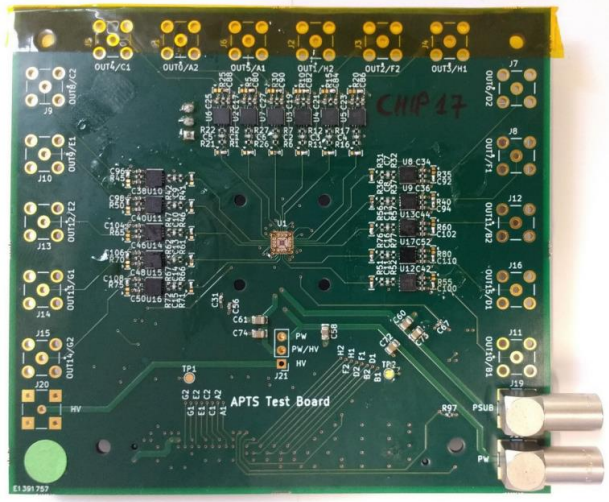


Caribou in CERN Timepix3 telescope

DPTS chip board



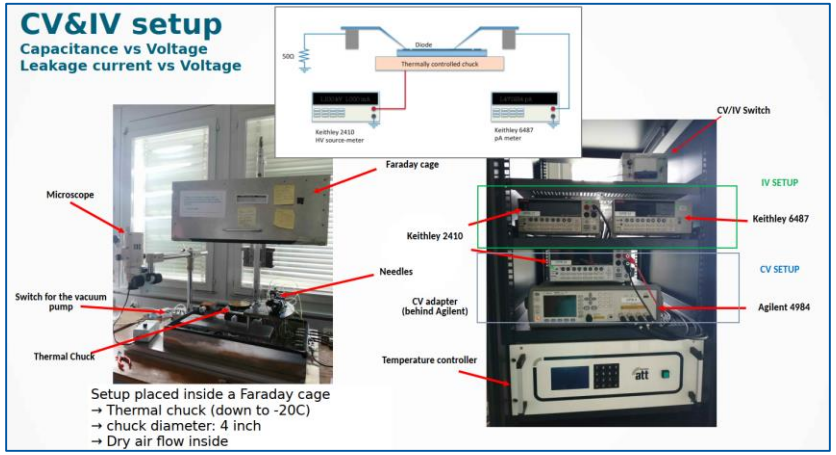
APTS chip board



SSD: Solid State Detectors lab & test beam activities

CV&IV setup

Capacitance vs Voltage
Leakage current vs Voltage

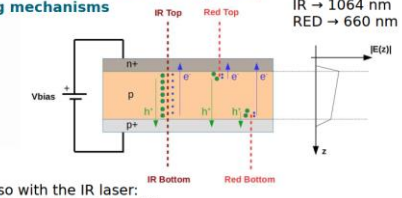


Setup placed inside a Faraday cage
→ Thermal chuck (down to -20C)
→ chuck diameter: 4 inch
→ Dry air flow inside

TCT setup (Transient Current Technique)

Signal formation, charge collection and trapping mechanisms
Timing capabilities

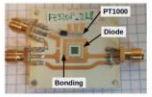
IR → 1064 nm
RED → 660 nm



Also with the IR laser:
→ Edge TCT with the IR laser.
→ Timing measurements.

Set up inside a Faraday cage.
Temperature down to -20C.
Dry air flow inside to control RH.

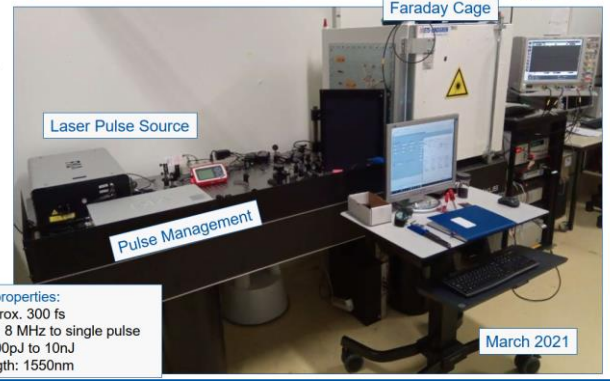
Specific pcb for the measurements



TPA-TCT system at CERN (SSD)

AIDA innova

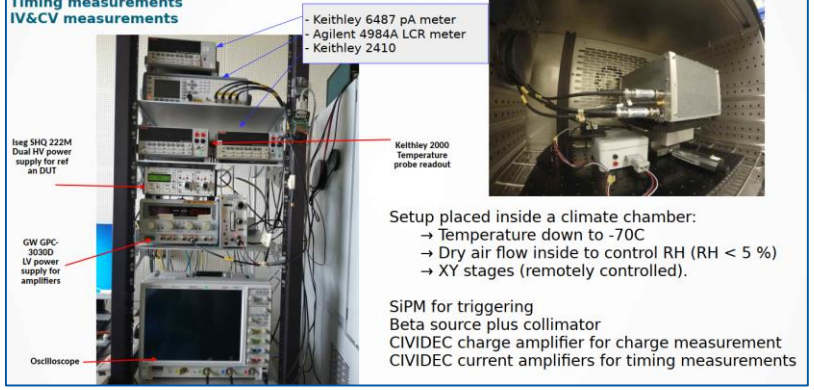
- Location at CERN
  - Solid State Detectors (SSD) lab of EP-DT group
  - dedicated laser room (186/RG25) with safety interlocks, access control and personal protection equipment



Laser output pulse properties:
- pulse width: approx. 300 fs
- pulse frequency: 8 MHz to single pulse
- pulse energy: 100pJ to 10nJ
- central wavelength: 1550nm

Beta setup (Sr-90 26MBq)

Charge deposition studies with MIPs
Timing measurements
IV&CV measurements

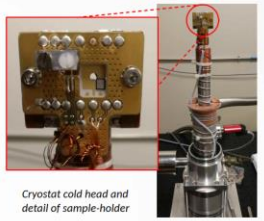


Setup placed inside a climate chamber:
→ Temperature down to -70C
→ Dry air flow inside to control RH (RH < 5 %)
→ XY stages (remotely controlled).

SiPM for triggering
Beta source plus collimator
CIVIDEC charge amplifier for charge measurement
CIVIDEC current amplifiers for timing measurements

Cryostat

For defect Spectroscopy on Silicon sensors



Cryostat cold head and detail of sample-holder

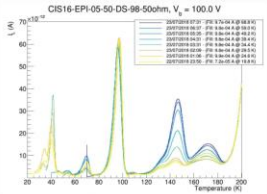
2 characterization techniques available:

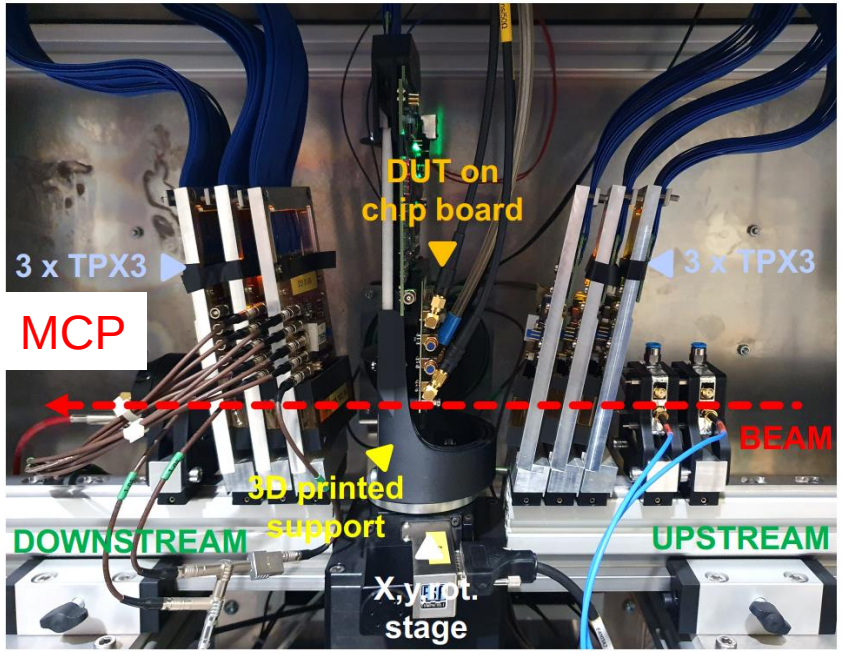
Thermally Stimulated Current (TSC) Spectroscopy
→ Keithley 6517A picoAmmeter + custom made DAQ)

Deep Level Transient Spectroscopy (DLTS)
→ Commercial system (Phystech HERA DLTS)

Closed cycle liquid helium cryocooler machine
Temperature range: 10 K to 400 K

Addition of light source in progress
Sensor front and back illumination
530, 625, 740 and 940 nm wavelengths





EP-DT
Detector Technologies

WP1.4. characterization tools for solid state detectors: also a service to the community!

WP1.4 Achievements & Outlook

- All present WP1.4. activities are **well aligned with the detector roadmap**
  - they are targeted in **DRDT 3.2. "4D-solid state detectors"** and **DRDT 3.3. "extreme fluences"**

- **WP1.4. major achievements:**
  - Two Photon Absorption TCT (**TPA-TCT**) fully commissioned: A major step forward in sensor characterization.
  - Significant progress in understanding **defect formation in p-type silicon** & impact on detector performance.
    - Defect engineering with **Carbon enrichment has enabled operation of LGADs for ATLAS/CMS phase II timing detectors**
  - **Caribou readout system** widely used in the community
  - **Advanced simulation tools** (Allpix Squared and Garfield++, combined with 3D TCAD) were further improved and validated against data and now allow for precise time-resolved modelling, which has been instrumental for a wide range of sensor optimisations.

- **Future plans** (assuming we manage to replace the leaving externally funded researchers):
  - **TPA-TCT:** upgrade towards a versatile fully fiber based system (within AIDAinnova/RD50)
  - **Defect studies:** solve the "acceptor removal riddle", i.e. go from qualitative to quantitative understanding
    - new sensor production (Carbon + Boron doping) + collaborate with Solar Cells for space community
  - **NIEL:** production of sensors for better NIEL measurements
  - **Caribou:** Implement prototype MAPS developed in WP1.2. + long term upgrade to System on Module platform
  - **SSD lab:** extend characterization lab with an optical cryostat
  - New study: Evaluate CCDs for Dark Matter search to understand if formation of defects can be used for DM searches