SSD – Solid State Detectors

- **R&D**: Development of radiation tolerant silicon detectors in the framework of **RD50** and **CMS**
- **Service**: Characterization of semiconductor devices

SSD Team:

- **CERN Staff**
  Michael Moll (0.6 FTE)
- **Fellows**
  Julio Calvo Pinto
  Matteo Centis Vignali
- **PhD student**
  Sofia Otero Ugobono
- **Trainees**
  Joaquin Gonzalez (SSD/CMS)
  Isidro Mateu Suau (RD50/IRRAD)
  Pedro Almeida (RD50)
- **Summer Students**
  Pablo, Jared, David, Matthias, Ana
- **Visiting Scientist** (>2m at CERN):
  Marcos Fernandez (Santander)
  Esteban Curras Rivera (Santander)
  Laura Franconi (Oslo)
  Sebastian White , Geetika Jain (Delhi), Rogelio Palomo Pinto (Sevilla), …

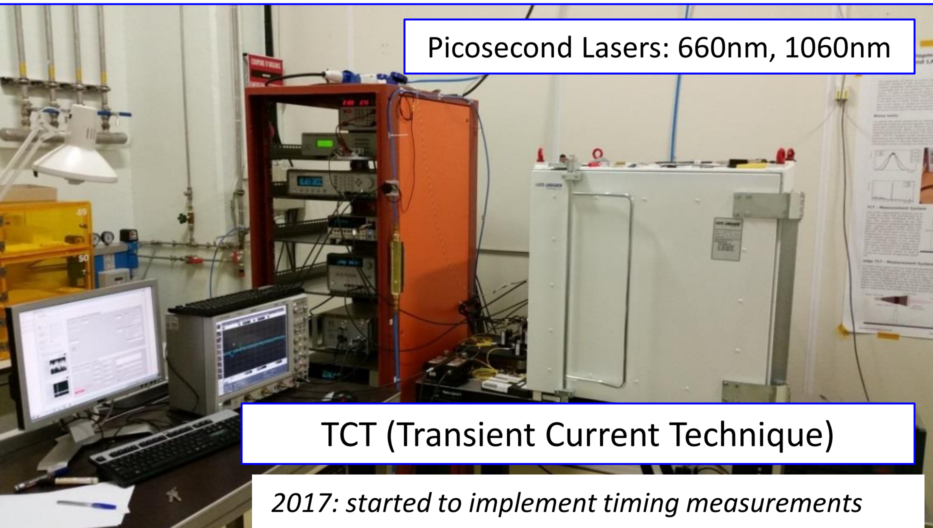
RD50 support:
Veronique Wedlake, Maurice Glaser

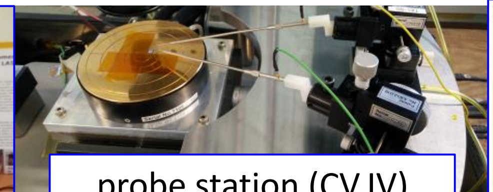
EP-DT
Detector Technologies

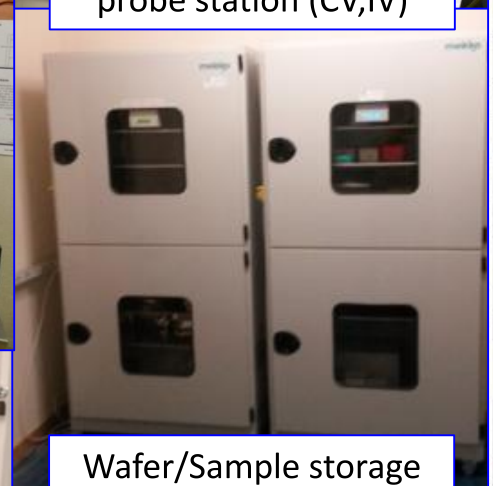
Instituto de Física de Cantabria

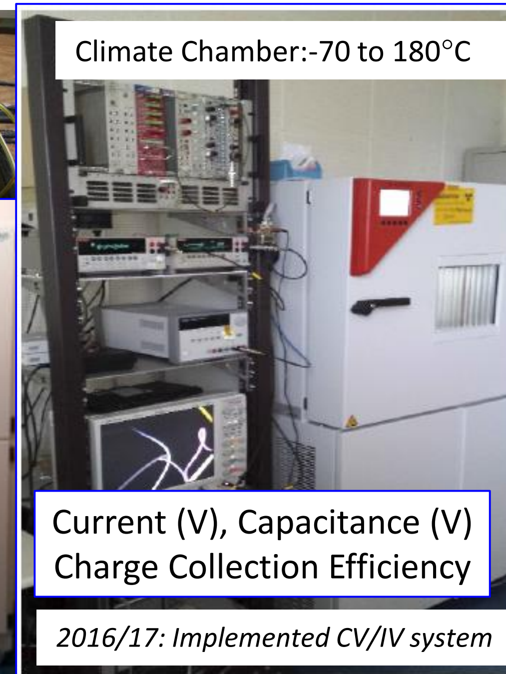
Solid State Detectors (SSD) lab

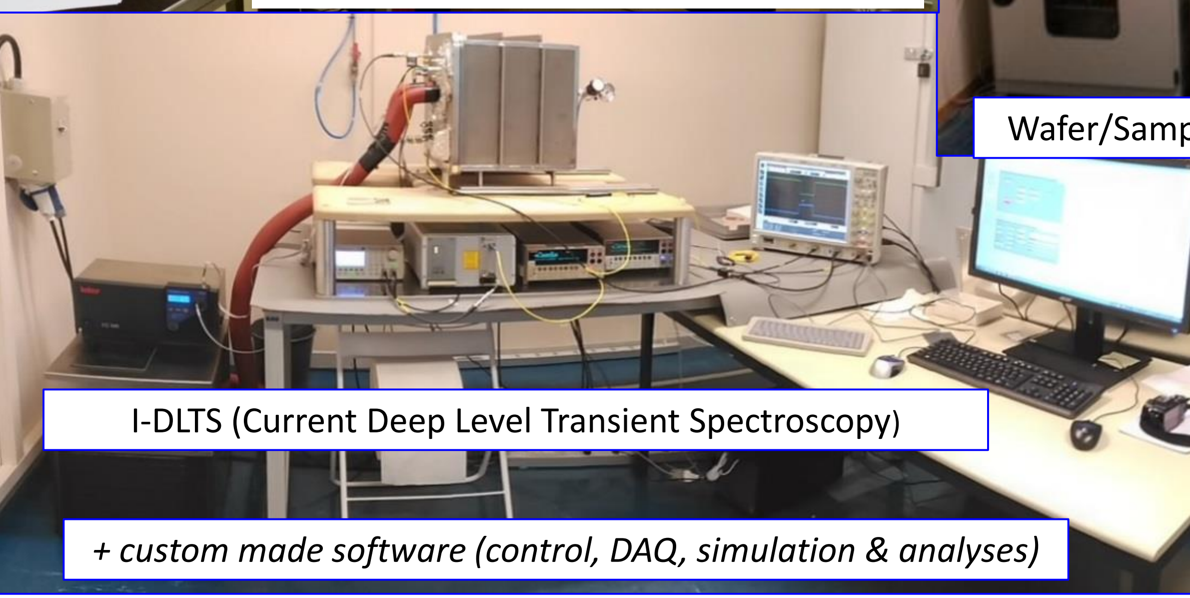
- Several bench tests in bldgs.28 and 186 (4 labs)
- Characterization of (electrical) sensor properties before and after irradiation









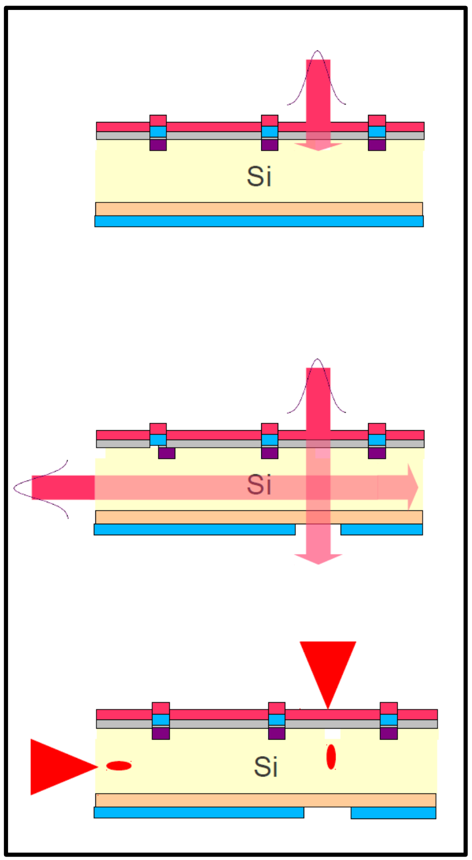


Development of Characterization Tools

TCT - Transient Current Technique

- Pulsed laser induced generation of charge carriers in the detector
  - Study of: electric field in sensor, charge collection efficiency, homogeneity,..
  - Benchmarking of simulation tools, measure physics parameters from mobility to impact ionization

- **New**: **Two Photon Absorption TCT** (TPA-TCT) developed by SSD & IFCA, UPV, Seville

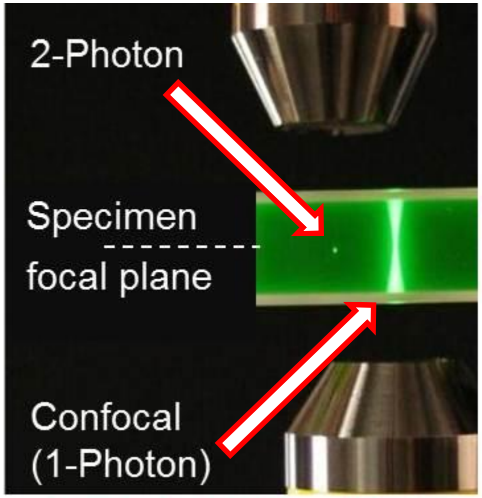


- **TCT (red)**
  - short penetration length (660nm = 1.9eV)
  - **carriers deposited in a few μm from surface**
  - front and back TCT
  - study electron and hole drift separately
  - 2D spatial resolution (5-10μm)

- **TCT (infrared)**
  - long penetration (1064nm = 1.17 eV)
  - **similar to MIPs (though different dE/dx)**
  - top and edge-TCT
  - 2D spatial resolution (5-10μm)

- **TPA-TCT (far infrared)**
  - No single photon absorption in silicon
  - 2 photons produce one electron-hole pair
  - **Point-like energy deposition in focal point**
  - **3D spatial resolution (1 x 1 x 10 μm³)**

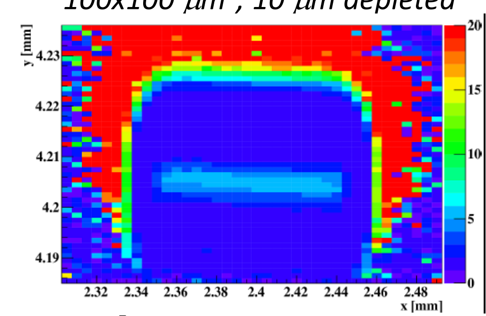
Concept: TPA TCT



Photography: Ciceron Yanez, University of Central Florida

Example: HV-CMOS

100x100 μm^2, 10 μm depleted

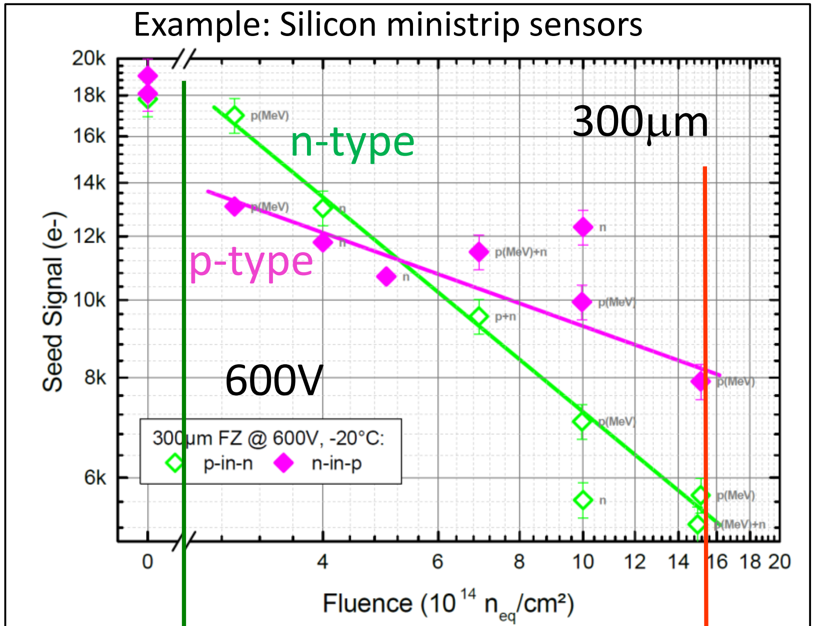


TPA-TCT [M.Fernandez et al., NIMA **2016**]

[since 2017: KT funded project to build TPA-TCT at CERN]

Motivation: Radiation Damage!

- **Detectors fail from radiation**: Need for radhard technologies and understanding of damage (physics, modelling, design,…)



[CMS – Proposal for Phase II upgrade]

LHC
highest fluence for strip detectors in LHC: p-in-n technology is sufficient
(pixel up to ~2×10^{15} cm^{2})

HL-LHC
n-in-p technology needed at radii presently (LHC) occupied by strip sensors
(pixel up to ~2×10^{16} cm^{2})

- **RD50: Radiation Hard Semiconductor Devices for High Luminosity Colliders**
  (55 Institutions, 300 members)

– Introduced **p-type silicon** i.e. n-in-p sensors
  (Used for ATLAS, CMS tracker upgrades)
– First commercialization of **3D sensors**
  (Used for ATLAS-IBL; ATLAS, CMS pixel upgrades)
– Reliable models for damage prediction
– Fundamental understanding of radiation damage

Hot topics in RD50 today:
– **Precision timing detectors**
– **MAPS** – Monolithic Active Pixel Sensors (with drift fields)

- **Our role (SSD team): RD50 base at CERN**

– Co-spokesperson, strategy, management
– Administration and technical service to collaboration
– Active contribution to R&D program

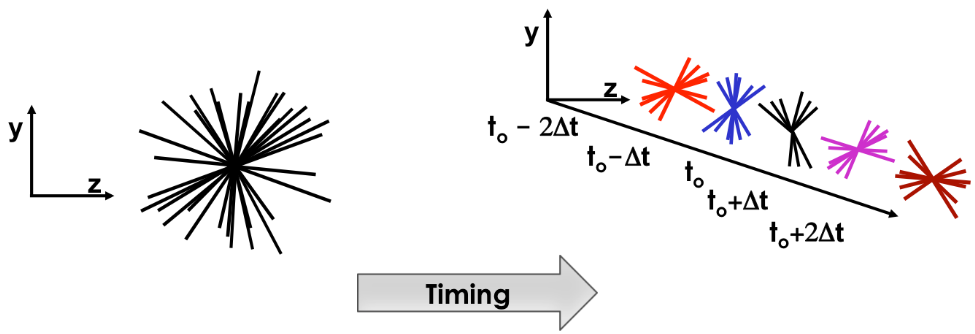
FCC (Future Circular Collider)
up to 7×10^{17}cm^{-2} and 300 MGy (30 ab^{-1})
<u>no technology available</u> for inner layers
..even testing for these radiation levels is a challenge by itself (see IRRAD facility talk)

SSD: Project Oriented R&D

- **R&D with LHC Experiments for specific detectors and with fixed timeline**
  - [2010-16] CMS Tracker — HPK Sensor Campaign (qualification of n-in-p-sensors)
  - [2014-17] CMS HGCAL — High Granularity Calorimeter ...continued by LCD/DT group (Eva Sicking et al.)
    Evaluation of radiation hardness to neutrons of sensors for the HGC
  - since 2017: CMS Endcap MIP Timing Layer, ATLAS HGT (High Granularity Timing) & AFP, ...

- **Precision timing detectors**
  - Aim for **4D tracking**: **10 ps** time and **10 μm** position resolution

Why? Counteract HL-LHC pile-up (PU≈140)
FCC (PU ≈ 1000) will not work without!



[H.Sadrozinski arXiv:1704.08666]

How?

Technology: Sensors with intrinsic gain
LGAD (Low Gain Avalanche Detectors)
DD-APD (Deep Diffused Avalanche Particle Detector)

RD50 status (after only ~ 5 years development)
Demonstrated 30ps (one layer) and 18 ps (3 layers) resolution;
first LGAD operating in LHC (CTPPS), ATLAS and CMS counting on LGADs (HGT, MTL, AFP,...)

Impressive!

...but devices suffer from **RADIATION DAMAGE**

SSD: Generic R&D

Example: Acceptor removal

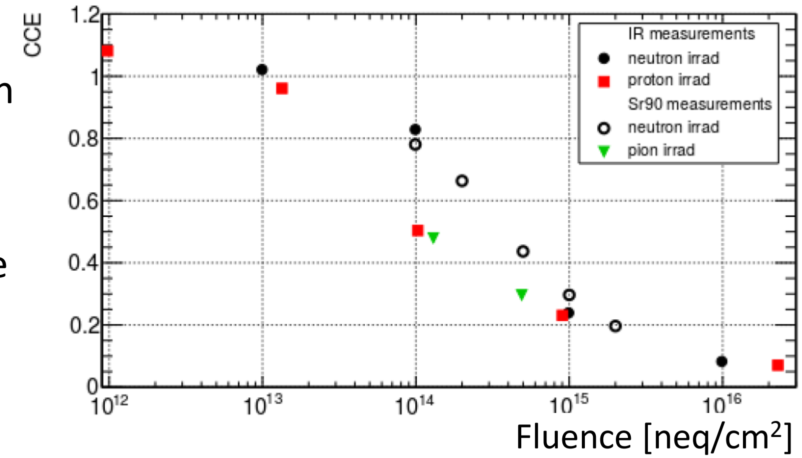
- **LGAD** Low Gain Avalanche Detector

  A gain layer produced by Boron doping provides a high electric field that leads to charge multiplication
  (i.e. increased signal → improved timing)

- **Problem**:
  Loss of gain in LGAD sensors due to radiation damage

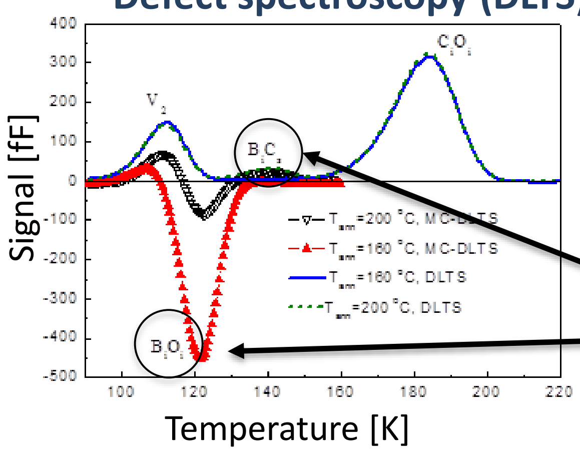
- **Reason** (most likely, ongoing R&D effort):
  Boron doping is de-activated by radiation damage

Damage: We are loosing the gain!



[SSD: submitted for publication]

Defect spectroscopy (DLTS)



[SSD & L.Makarenko (Minsk)]

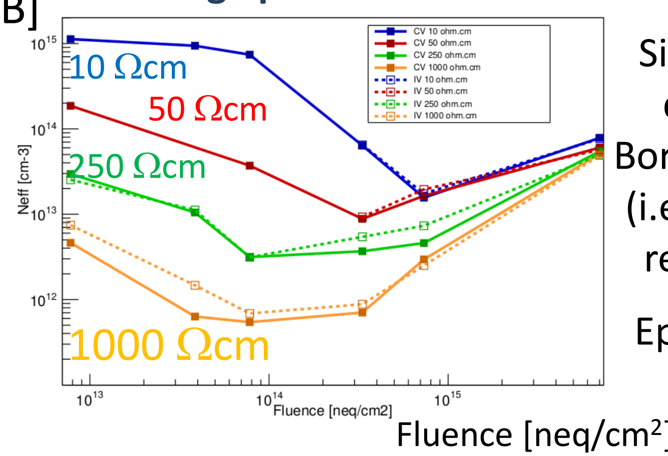
After irradiation: Boron bound in defects; visible as defect levels

B_iC_s

B_iO_i

Damage parameterization

[B]



Silicon with different Boron content (i.e. different resisitivity)

Epi-p, 50μm

[SSD: presented on RD50 Workshop in June 2017]

- **Mitigation approach** (under study)
  – Replace Boron by Gallium (another acceptor type)
  – Enrich silicon with Carbon (acts as defect getter)

Solid State Detector Lab

Summary & Outlook

- Solid State Detector Lab team working on radhard silicon sensor development and testing with very visible contributions to RD50 and some CMS projects in generic and applied R&D projects.

- Well equipped sensor characterization laboratory (come and visit us!)
  - Service: equipment and expertise is made available to clients
  - Strong expertise in laser based characterization techniques (TCT techniques)

- RD50: Good example that international R&D projects (with moderate CERN resources) have a very fruitful impact on detector developments *[p-type sensors saved the HL-LHC trackers]*

- **SSD Outlook**: Precision timing detectors and CMOS MAPS will dominate future work

- **General outlook**(RD50 and beyond): R&D for HL-LHC and FCC
  - Expertise on radiation damage, damage prediction and damage mitigation will be needed.
  - Timing detectors are not yet sufficiently radiation hard (HL-LHC)
  - There is no technology available for FCC inner tracking layers
  - Fluence range expected for FCC has not even been explored

Strong need to define R&D roadmap reaching beyond 2020!

- ***SSD activities not shown:*** *DD-APD development with RMD & US CMS groups, 3D sensor development for CMS, defect characterization within RD50, TRACS signal simulator (licensed with help of KT), TCAD modelling, study of Nitrogen enriched silicon within RD50, SiPM testing with CMS HCAL group; TCT-TPA testing at Bilbao laser facility, RD50 test beam support, …. (sorry to the colleagues working on this)*