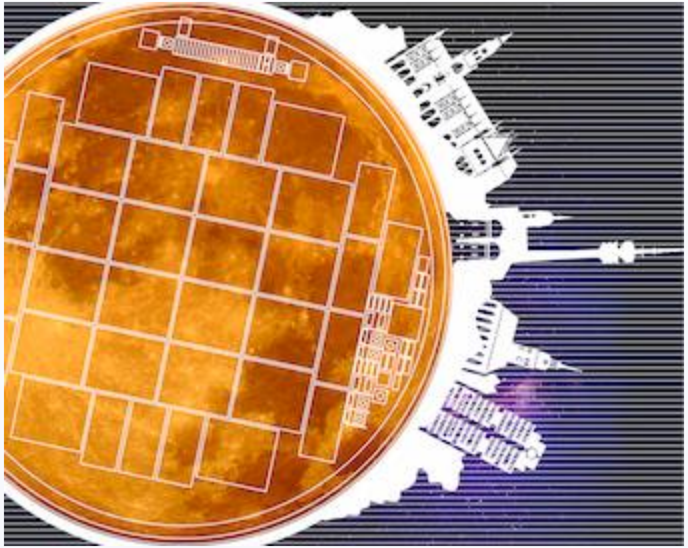
Compilation of the results on characterization of ADVACAM edgeless pixel sensors



D. Hohov[1,2], A. Lounis[1,2], D. Varouchas[1]
K. Lie[3,4] , K. Prokofiev[3,4], J. Iturbe[5]

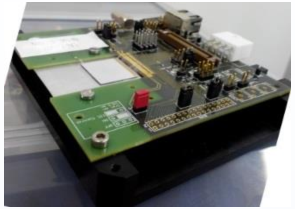
1. *Laboratoire de L'accélérateur Linéaire, Orsay, France*
2. *Université Paris-SUD XI*
3. *The Hong Kong University of Science and Technology*
4. *HKUST Institute for Advanced Study*
5. *The Chinese University of Hong Kong*

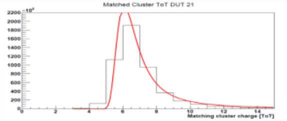
13th "Trento" Workshop on Advanced Silicon Radiation Detectors 2018

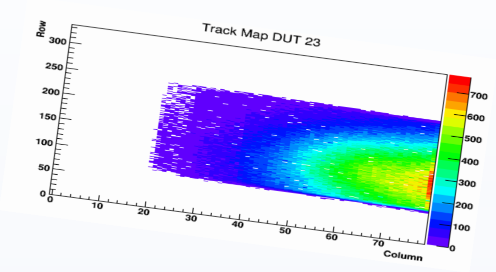
19 – 21 February, Munich

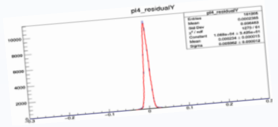
Outline

- Introduction
  - ATLAS ITk upgrade
  - Planar pixel sensors to test
  - Test beam telescope setup
- Results
  - Test beam results on active and slim edge ADVACAM sensors
- Clean room characterization
  - Infrared laser test bench setup
- Conclusions









Introduction

Motivation for ATLAS Inner Detector upgrade

Name of the upgrade	Date	Luminosity	Energy $\sqrt{s}$
LHC startup	2009	$6x10^{33}$ $cm^{-2}s^{-1}$	7-8 TeV
Phase- 0	2014	$1x10^{34}$ $cm^{-2}s^{-1}$	13 TeV
Phase- 1	2018	$2x10^{34}$ $cm^{-2}s^{-1}$	13-14 TeV
Phase- 2	2023	$7,5x10^{34}$ $cm^{-2}s^{-1}$	14 TeV

Very severe pile-up conditions expected:

Corresponding num. of inelastic **pp** collisions per beam-crossing (25 ns) will increase : **25 -> 200**

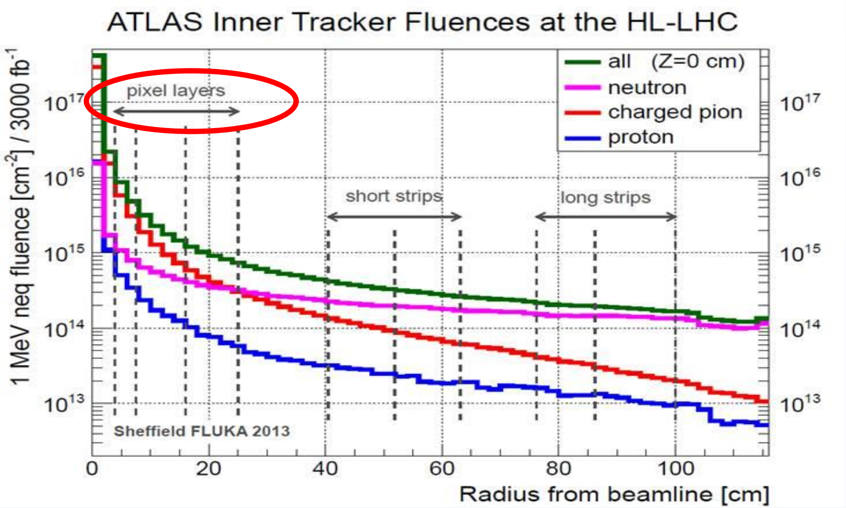
New Tracking detectors must fulfill the conditions:

- Fast (40MHz), high granularity & good pattern recognition capabilities (10^3 tracks/25 ns).

Introduction

Motivation for ATLAS Inner Detector upgrade

- Increased luminosity also leads to increasing of radiation load.



Aim is **3-4k fb^{-1}** integrated luminosity

ID (Inner Detector) has limited lifetime:

Expected: $1.6 \cdot 10^{16}\ n_{eq}\ cm^{-2}$ ➡ **1.7 GRad**

Designed : $10^{14}\ n_{eq}\ cm^{-2}$ → estimated to correspond to **400 fb^{-1}**

Radiation Effects:

- Creation of lattice defects (loss in the charge collection due to charge capture).
- Change of depletion voltage (due to type inversion).
- Rise of leakage current (additional energy levels are being formed in the band gap region)

Planar pixel sensors to test

Samples to study: FE-I4 compatible thin **n-in-p** planar pixel sensors with *the active and slim edge design* produced by ADVACAM.

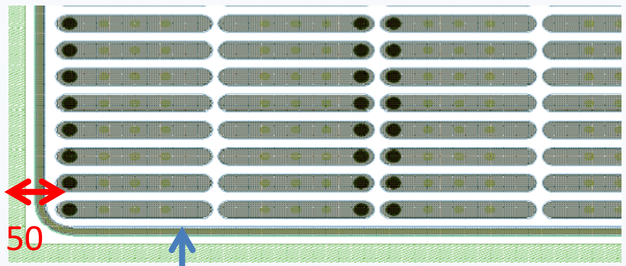
- Radiation hard (no type inversion, thin);
- Single side processing;
- Thickness : 50 um, 100um, 150um;
- Maximized active area (Deep Reactive Ion Etching (DRIE));

It is particularly interesting for the innermost layers where it is important to reduce geometrical inefficiencies.

Goal:

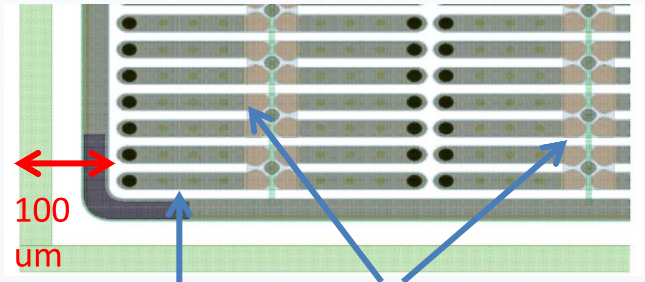
- Study the overall and edge hit efficiency with normal and inclined tracks before and after irradiation;

Active edge



ADV-50-3-1D , ADV-NP50-3-1A, ADV-NP150-6-1A

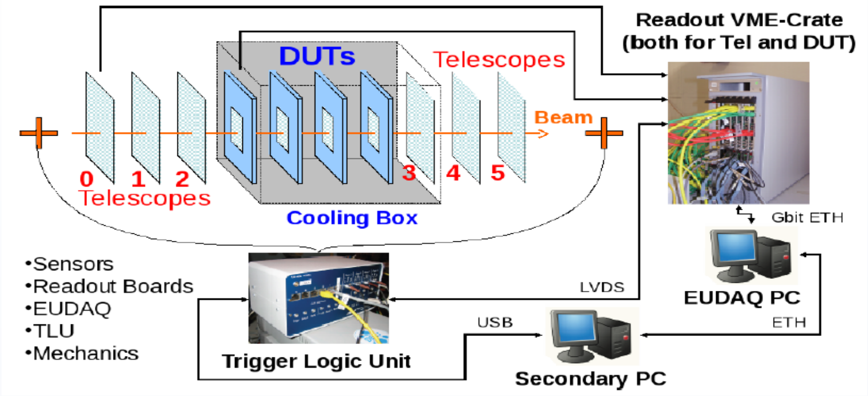
Slim edge



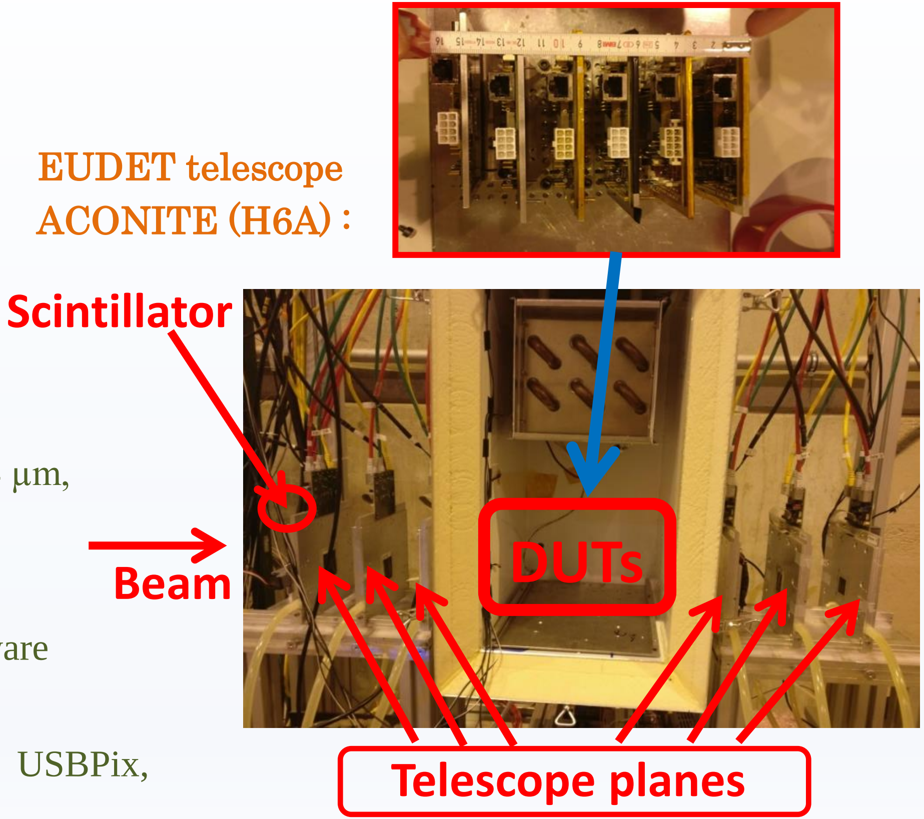
ADV-50-3-3A , ADV-NP50-3-3B, ADV-NP100-7-2A

Overview of the setup

Test Beam telescope setup:



EUDET telescope ACONITE (H6A) :



- Mimosa26 sensors (1152 x 576) with a pixel pitch of 18.4 µm,
- 50µm thick;
- Spatial resolution up to 2 um;
- Pixel read-out systems fully integrated into EUDAQ software framework;
- Multiple DAQ systems for lab tunings and measurements: USBPix, RCE, etc

Goals

- Efficiency for **50µm-thick ADVACAM samples** with **active edge** and **slim edge** design
  - with and without irradiation **$1x10^{15}$ n_{eq}/cm^2 ;**
  - on different side edges;
  - with **normal** and **inclined** incident (DUT tilted at 30˚, 45˚ (around y-axis));
- Efficiency for **100µm-thick ADVACAM sample** with **slim edge** design before and after irradiation **$2x10^{15}$ n_{eq}/cm^2 ;**
- Efficiency for **150µm-thick ADVACAM sample** with **active edge** design before and after irradiation **$2x10^{15}$ n_{eq}/cm^2 ;**

Beam: CERN SPS 120 GeV pions, DESY 4 GeV electrons;

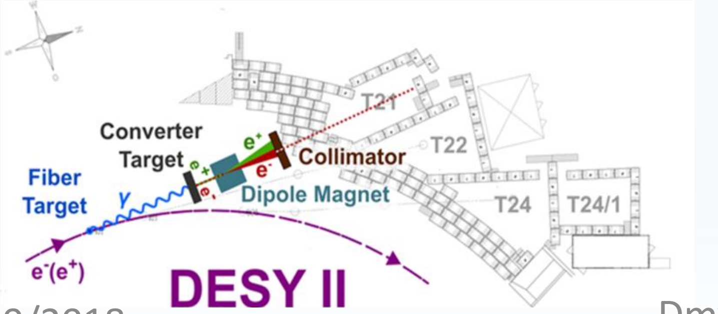
Telescopes: DURANTA (TB22) , ACONITE (H6A) and AIDA (H6B);

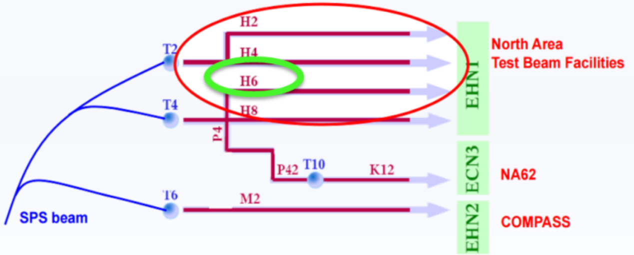
Cooling: Cooling box (-40ºC to -44ºC), Dry ice cooling (approx. -40 to -50 ˚C);

Bias voltage points:

from 50 V to 120 V (for 50um);

from 50V to 200V (100um,150um)





- Efficiency study for the **<u>50µm-thick</u>** ADVACAM edgeless sensors

  - **<u>ACTIVE EDGE</u>** design
    - with and without irradiation on different side edges;
    - Normal and Inclined tracks;

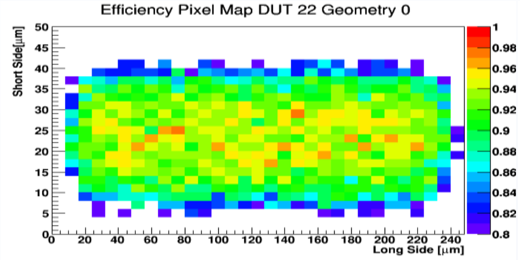
    (CERN-SPS during July and October TB period.)

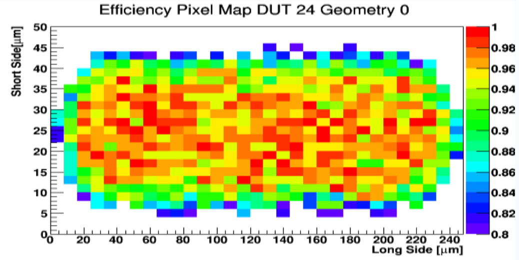
Results

Active Edge, non-irradiated and irradiated 1e15 n_{eq}/cm^2

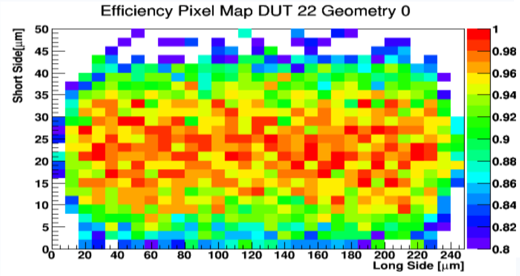
Left Edge (Col 0) Right Edge (Col 80)

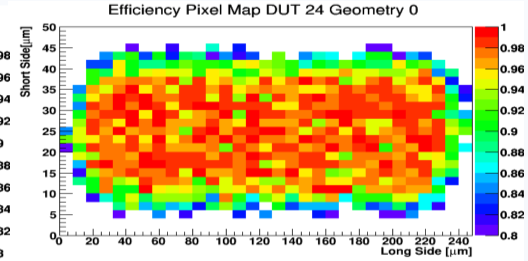
Before Irradiation: 94,86±0,04% 97,21±0,05%





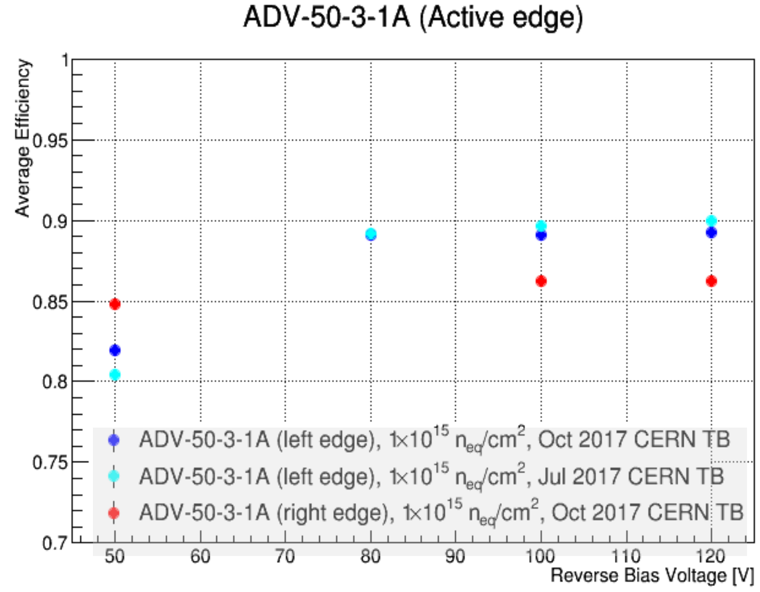
81,90±0,07% 50V 84,78±0,11% 50V





86,90±0,12% 120V 89,27±0,09% 120V

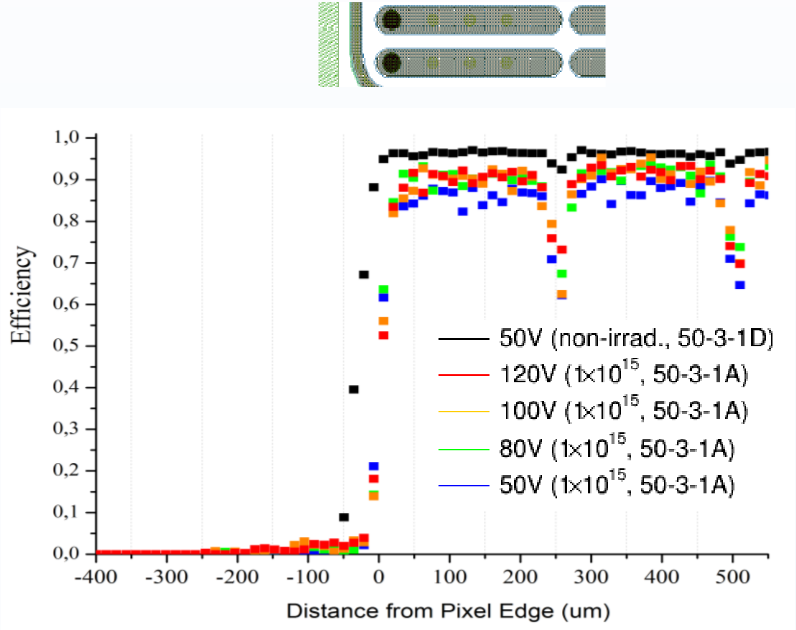
Global **efficiency vs bias voltage**

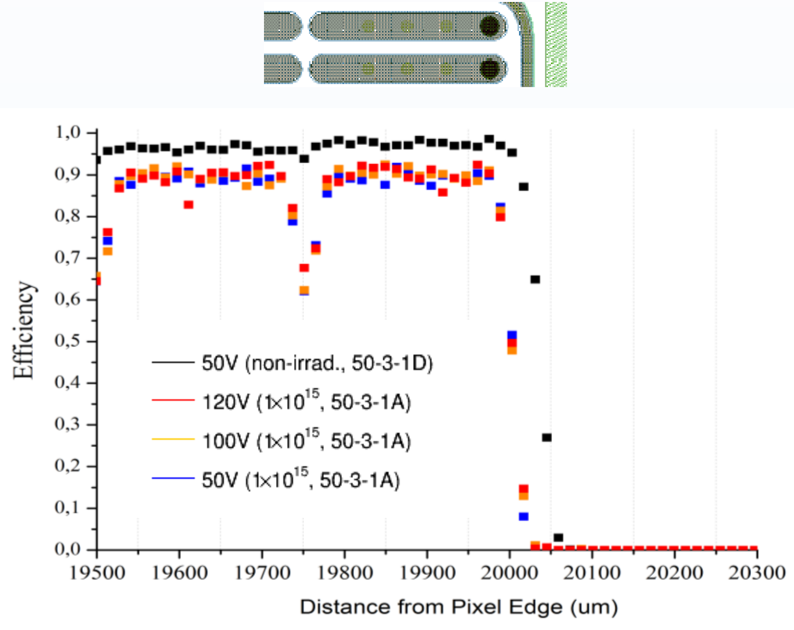


Results

Edge efficiency:

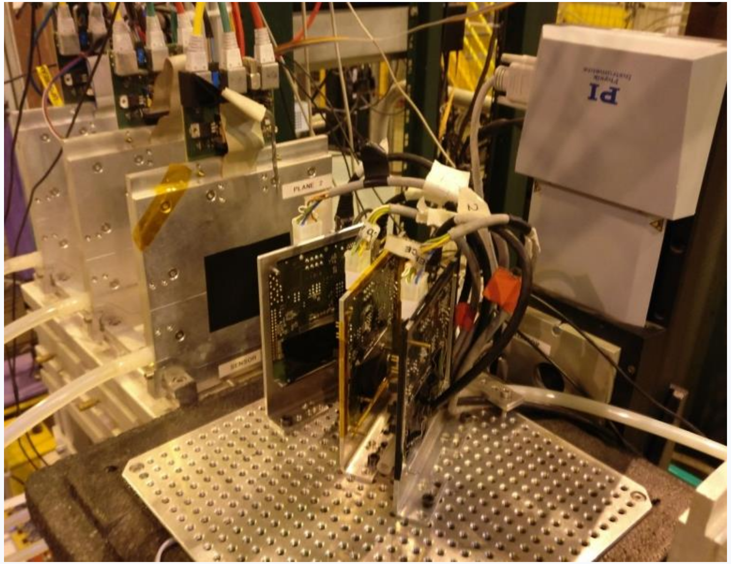
ADV-50-3-1D (non-irrad.) and ADV-50-3-1A (1e15 n_{eq}/cm^2)

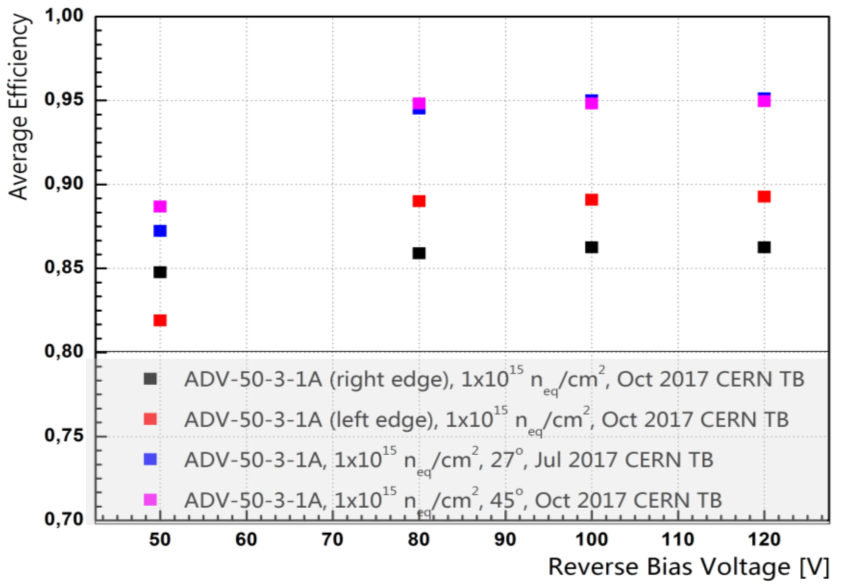




Results

- Efficiency vs bias voltage: irrad. **$1x10^{15}$ n_{eq}/cm^2**, and **tilted (45° and 27°)**





At a tilted angle of 45˚, the efficiency performance improved, reaching 95% at 80V bias voltage.

- Efficiency study for the **<u>50µm-thick</u>** ADVACAM edgeless sensors

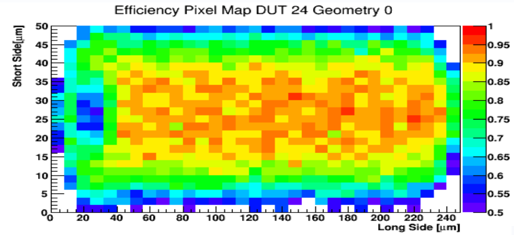
  - **SLIM EDGE** design
    - with and without irradiation on different side edges;

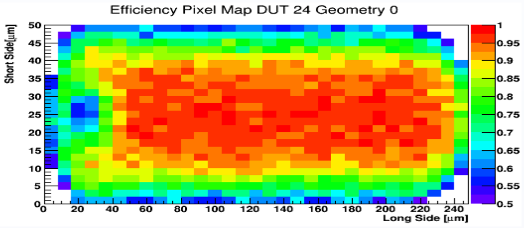
(CERN-SPS during July and October TB period.)

Results

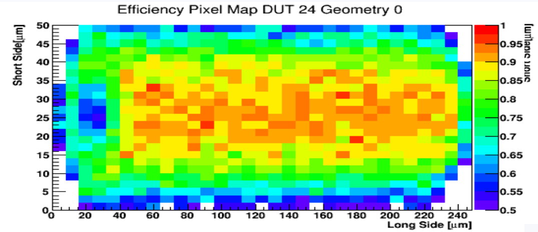
Slim Edge, non-irradiated and irradiated 1e15 n_{eq}/cm^2

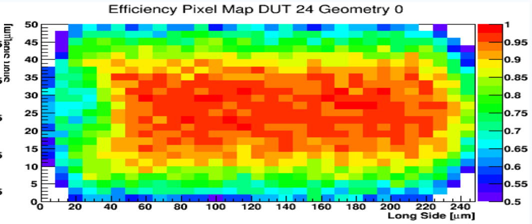
	Left Edge (Col 0)	Right Edge (Col 80)
Before Irradiation:	**92,71+0,05%**	**94,73+0,24%**





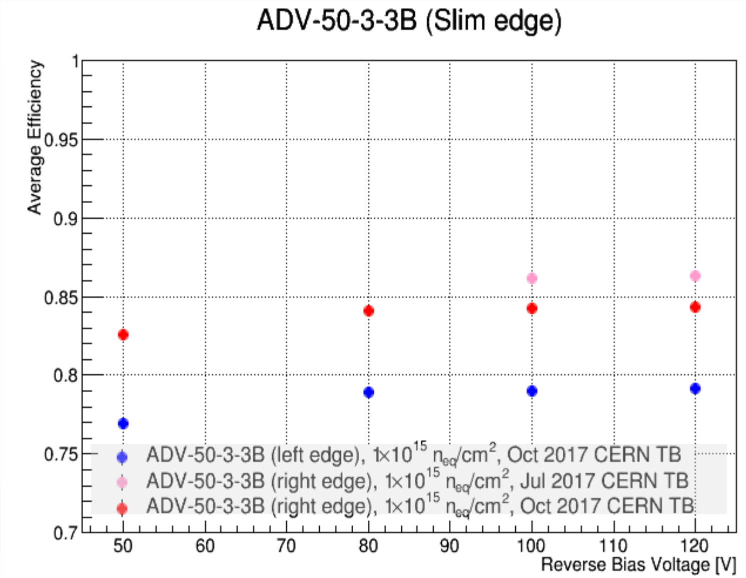
76,93±0,09% 50V **82,56±0,3% 50V**





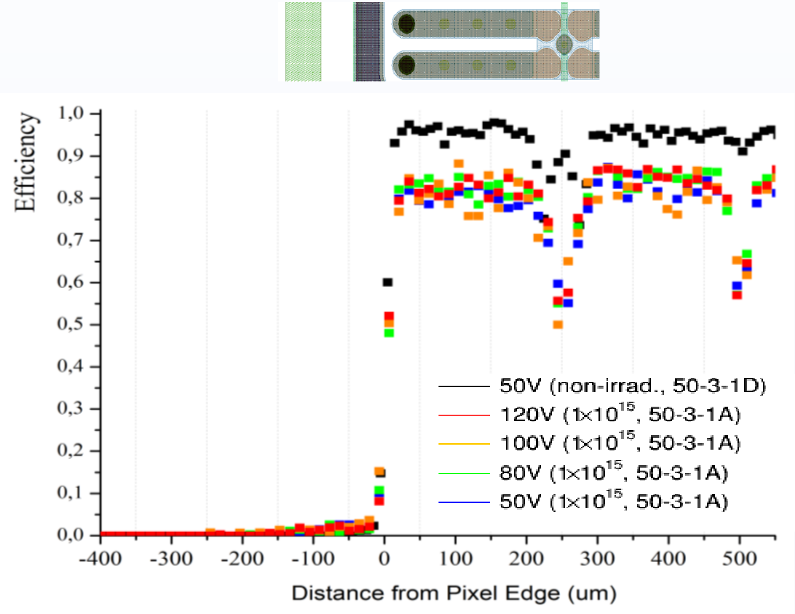
79,27±0,1% 120V **84,33±0,09% 120V**

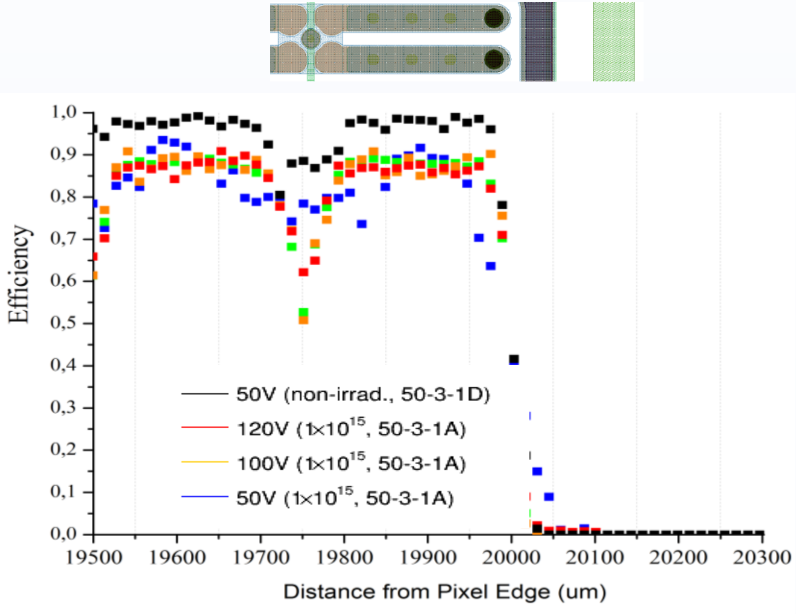
Global efficiency vs bias voltage



Results

Edge efficiency:
ADV-50-3-3A (non-irrad.) and **ADV-50-3-3B** (1e15 n_{eq}/cm^2)





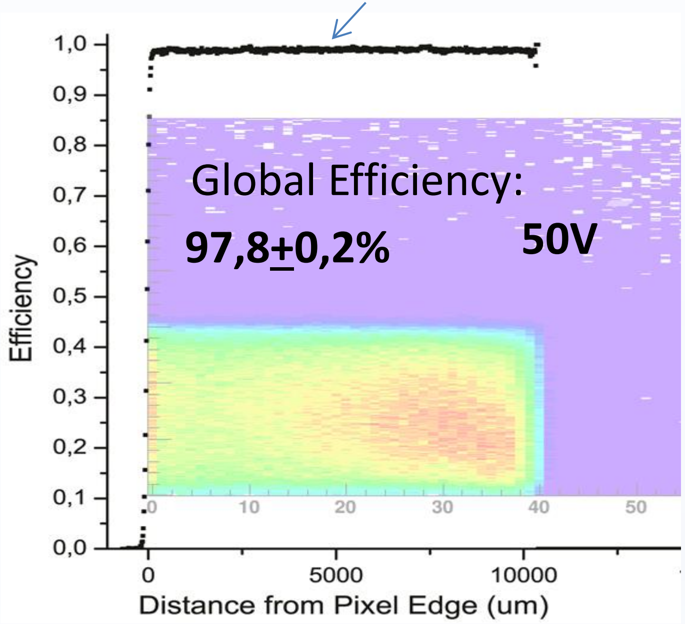
- Efficiency study for the **<u>150µm-thick</u> active edge and <u>100µm-thick</u> slim edge** ADVACAM sensors.

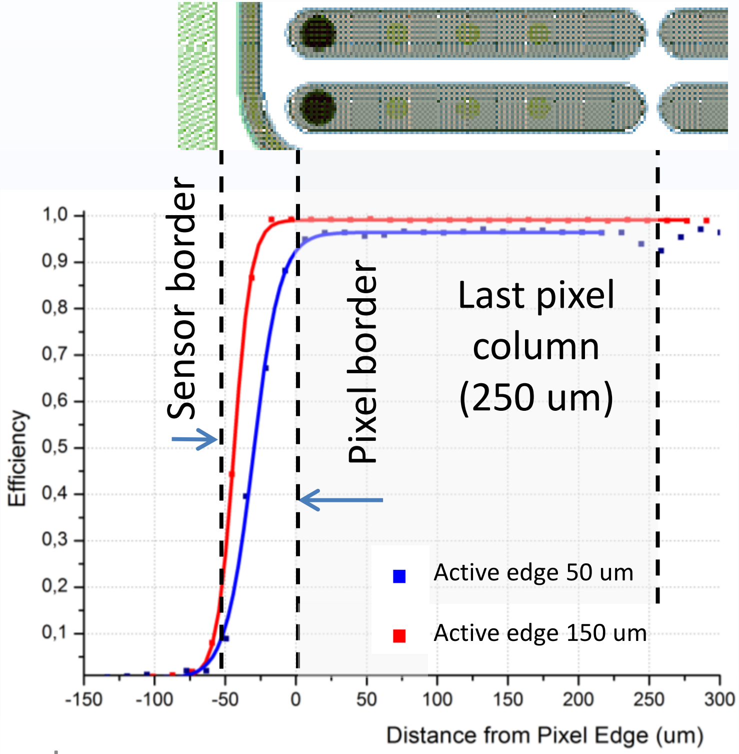
  - Non-irradiated (tested at CERN – Nov 2016 and DESY – March 2017)
  - Irradiated to $\mathbf{2x10^{15}\ n_{eq}/cm^2}$ (tested at DESY –Dec 2017)

Results

Edge efficiency performance for the <u>non-irradiated</u> **active edge** samples of **<u>150 um</u>** thickness and comparison with ***50um-thick*** sensor of the same design (*ADV-50-3-1D, ADV-NP150-6-1A*)

- *Efficiency vs track impact position*

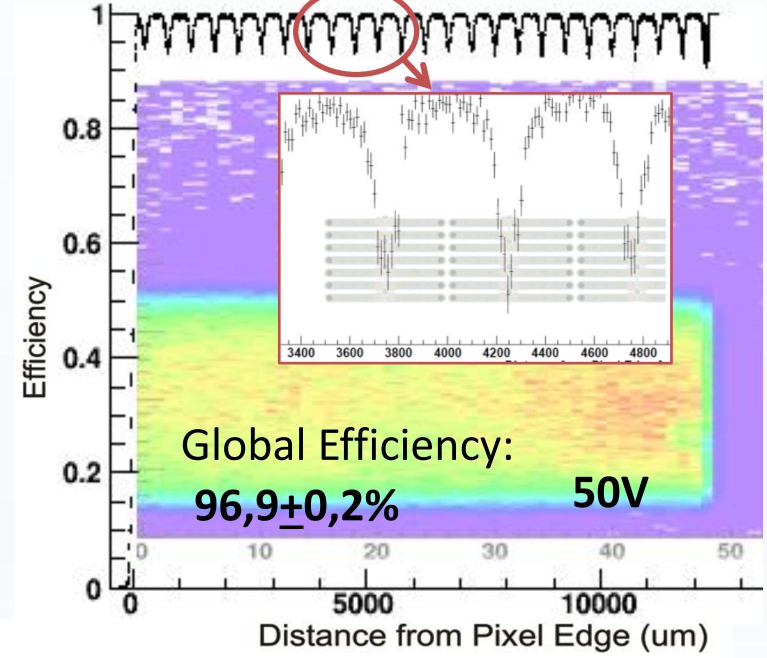


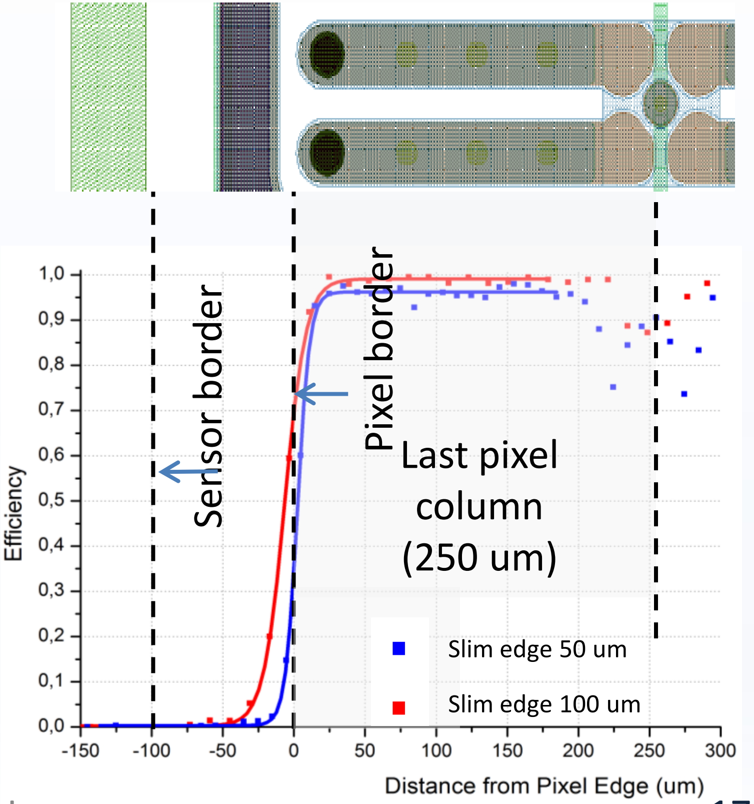


Results

Edge efficiency performance for the non-irradiated **slim edge** samples of **100 um** thickness and comparison with ***50um-thick*** sensor of the same design *(ADV-50-3-3A, ADV-NP100-7-2A)*

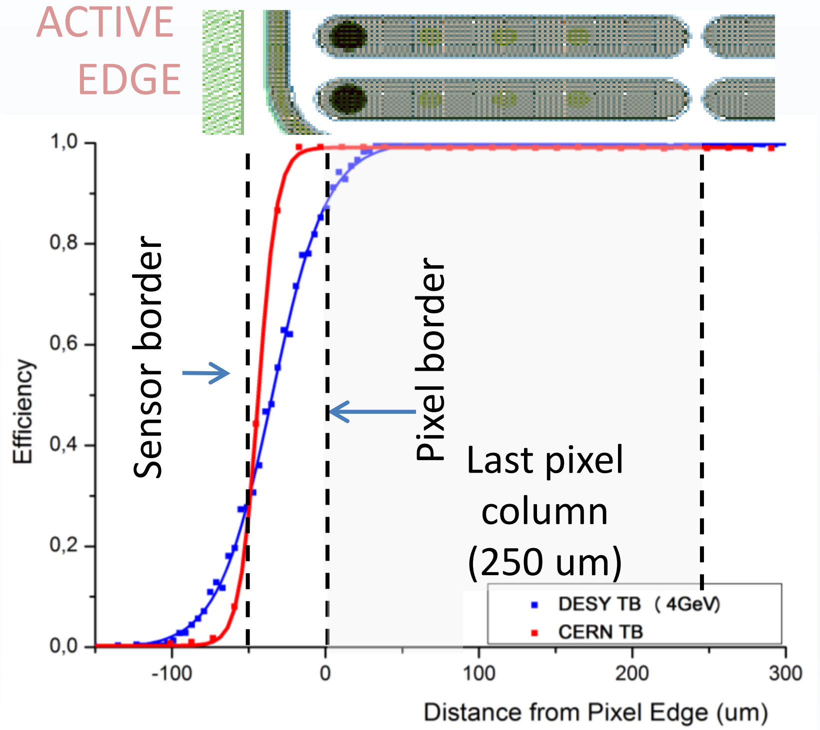
- *Efficiency vs track impact position*

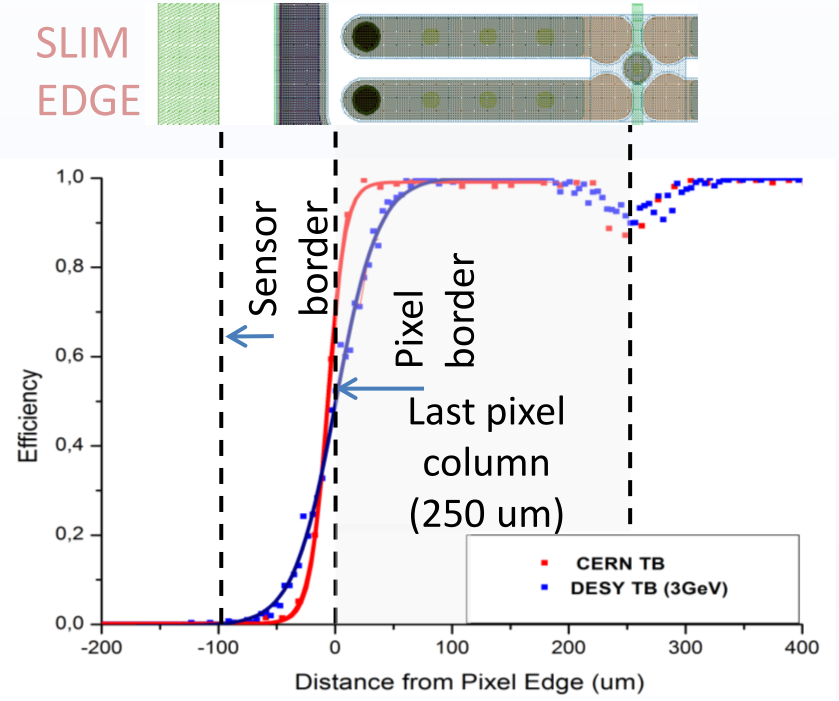




Results

Comparison of the **CERN** and **DESY** test beam results for the <u>non-irradiated</u> (*ADV-NP150-6-1A and ADV-NP100-7-2A*) samples.





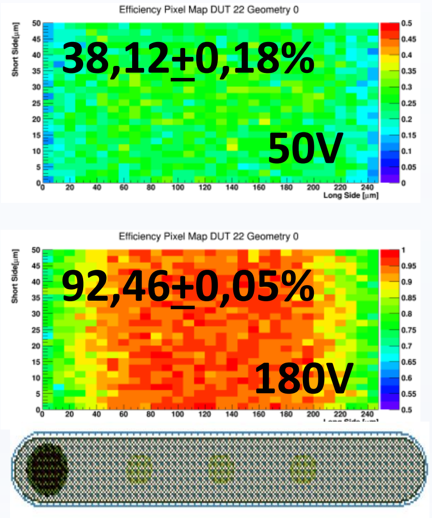
Results

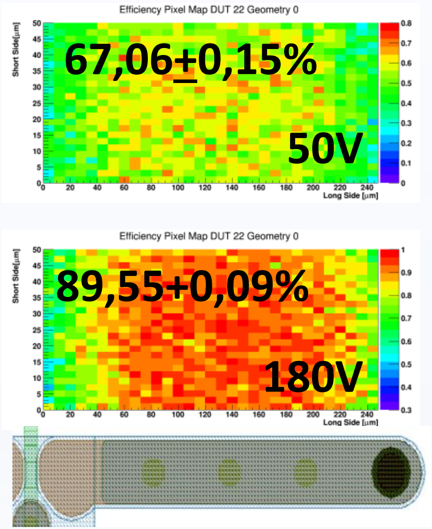
Efficiency performance for the **active edge (150 um)** and **slim edge (100 um)**
(*ADV-NP150-6-1A, ADV-NP100-7-2A*) after irradiation **$2x10^{15}$ n_{eq}/cm^2** at different bias voltages.

- In-pixel efficiency maps

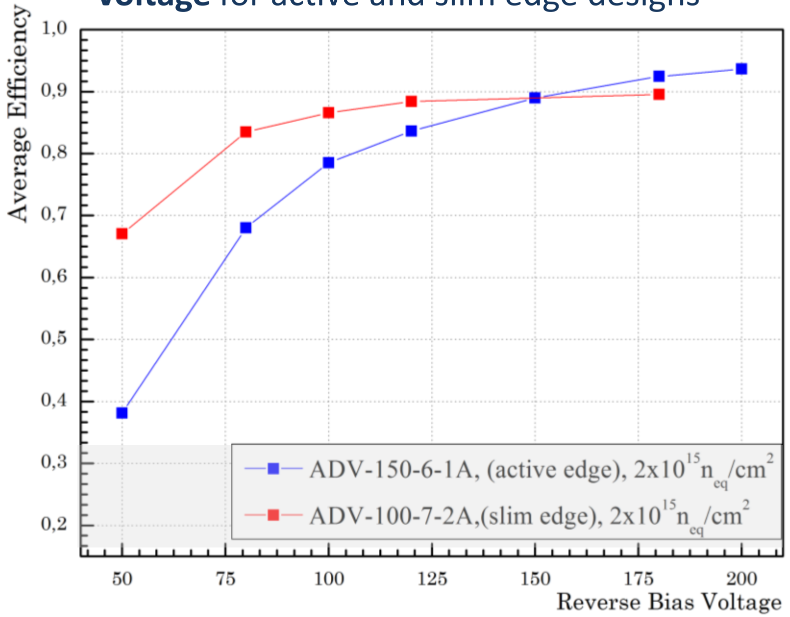
Active edge

Slim edge



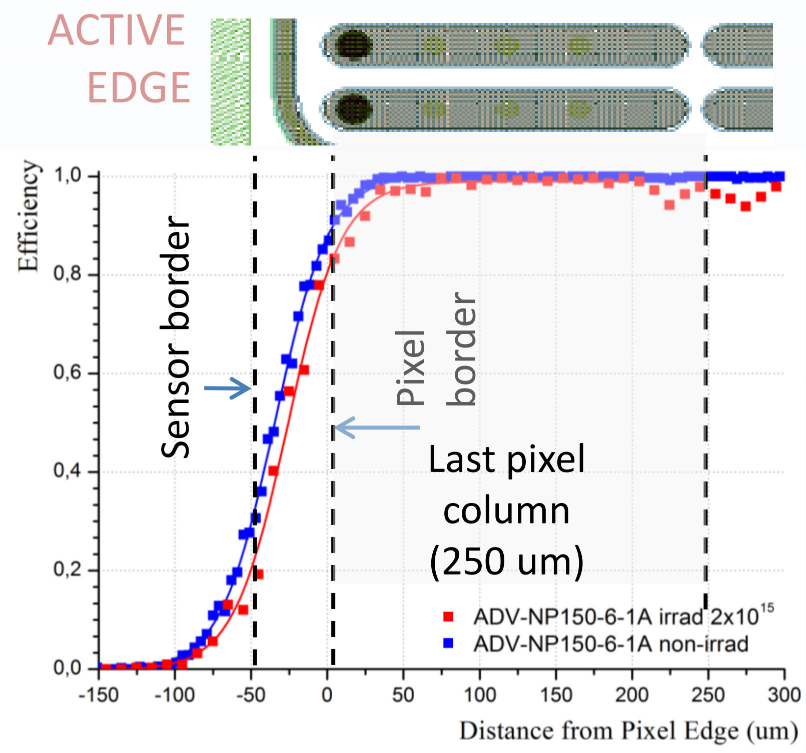


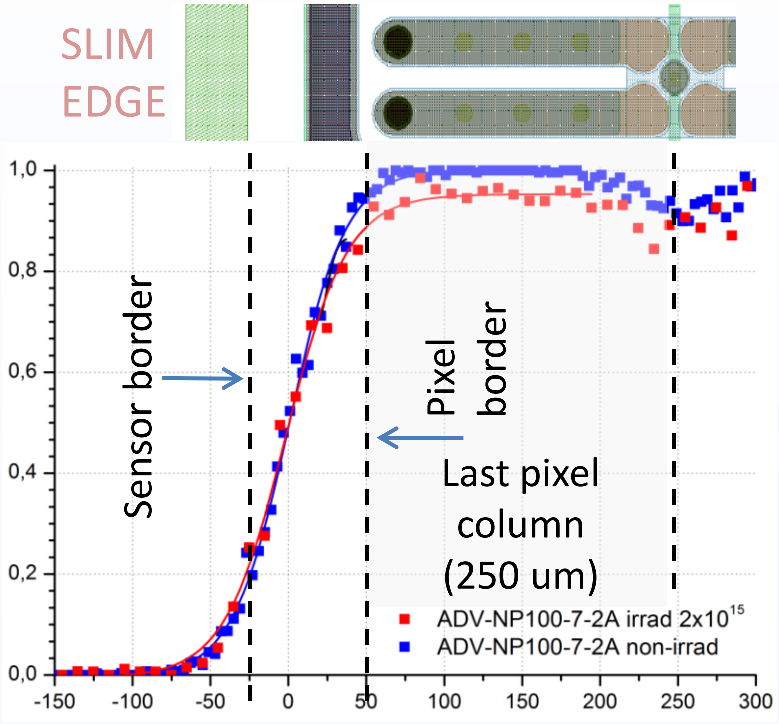
Comparison of the **Global efficiency vs bias voltage** for active and slim edge designs



Results

Efficiency performance for the **active edge (150 um)** and **slim edge (100 um)** before and after irradiation.





Results

Comparison of the performance of active and slim edge design sensors:

- 50 um – thick sensors:
  - Before irradiation **active edge** shows efficiency of 97,2% while **slim edge** has 94,7% (50V);
  - At $1e15\ n_{eq}/cm^2$, the efficiency of **active edge** is 86-89%, while **slim edge** is 79-84% at 120V.
- 100 um **slim edge** sensor :
  - Before irradiation provides 96,8% of hit efficiency (50V);
  - After irradiation at $2e15\ n_{eq}/cm^2$ the efficiency can recover 89.5% at 180V;
- 150 um **active edge** sensor:
  - Before irradiation provides 97,8% of hit efficiency (50V);
  - After irradiation at $2e15\ n_{eq}/cm^2$ the efficiency can recover 93.6% at 200V;

Both designs had an issue during TB with the achievement of high voltage (breakdown starts and sensor becomes noisy)

Clean room characterization

Infrared laser test bench setup

Laser test bench setup

Purpose: To have a compact set-up to characterize silicon pixel modules and test their functionality in clean room before beam tests.

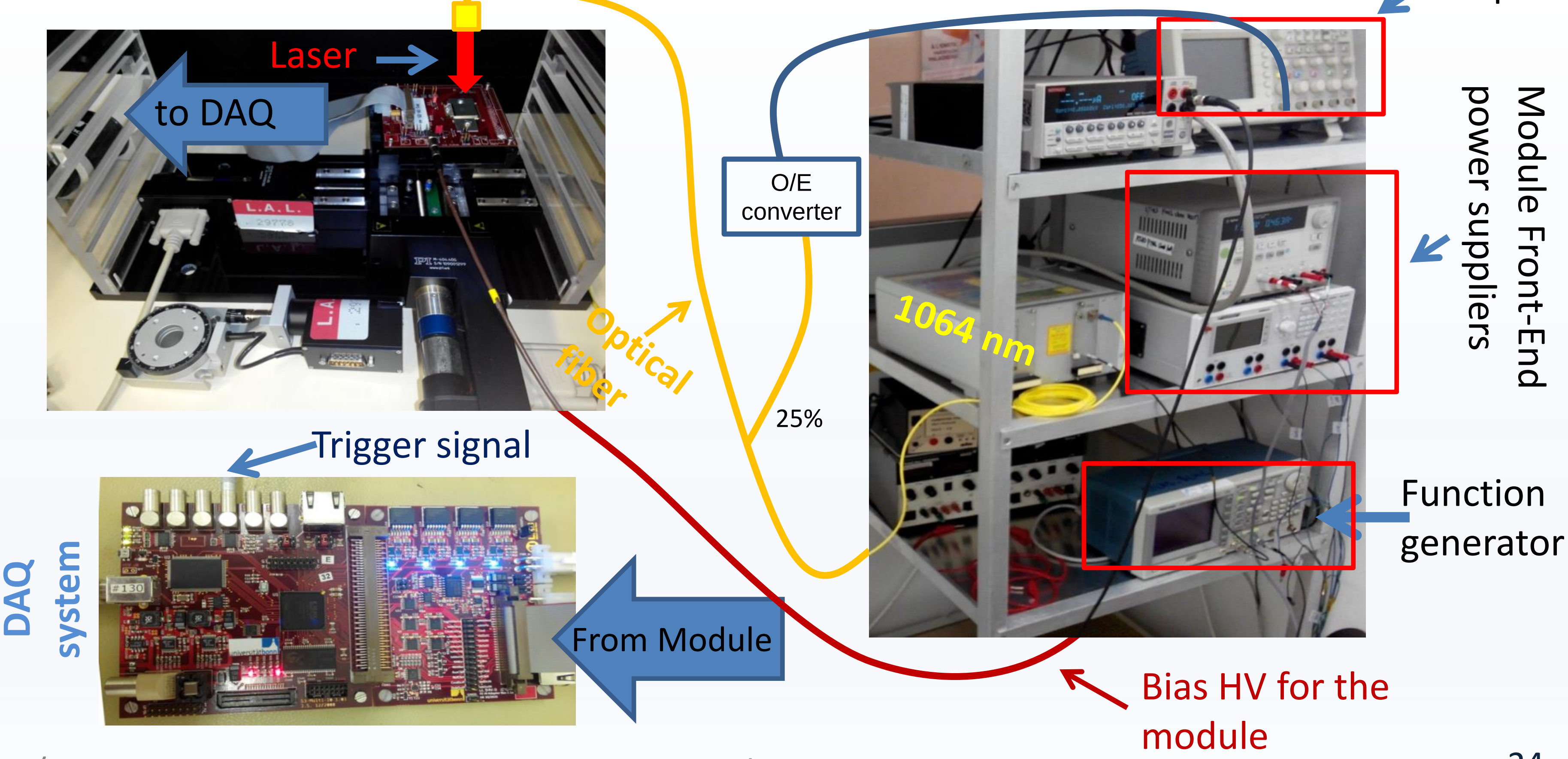
- charge collection efficiency (before and after irradiation, for the edges, scanning along an individual pixel);
- charge sharing between adjacent pixels;
- performance with inclined tracks;

Our goals for this development:

- to have a setup based on infrared laser to mimic a MIP like charge generation;
- to have a possibility for micrometric positioning of the DUT in X-Y direction (so the interaction point determination without reconstruction);
- to be able to rotate a DUT to perform studies with inclined tracks;
- to adapt to new quad sensors and RD53-A readout electronics;
- have high rates (kHz), for high statistics in measurements;

Laser test bench setup

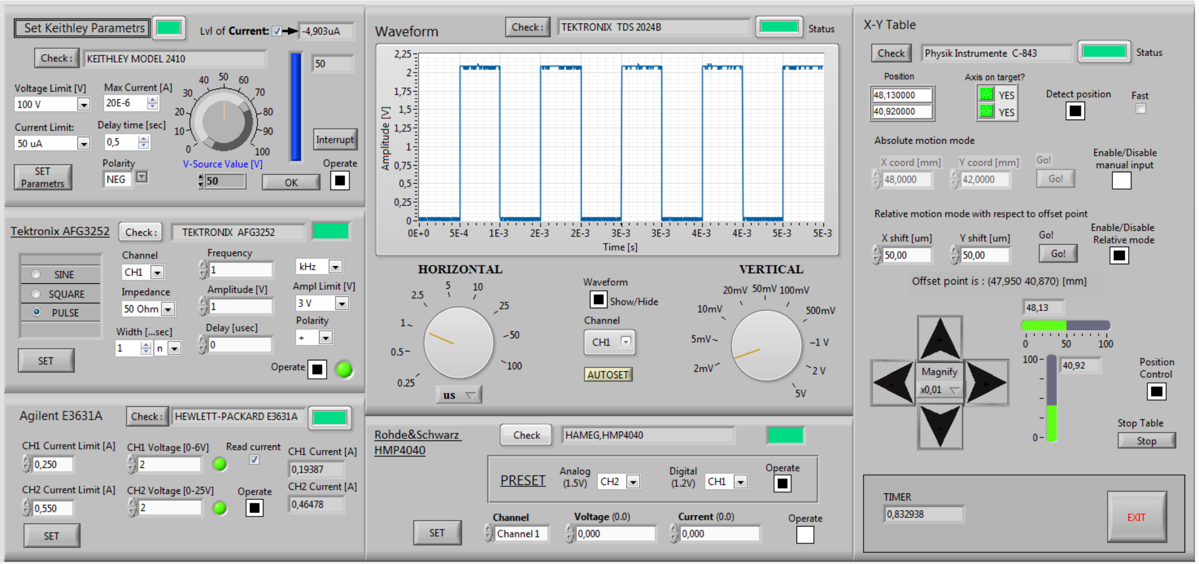
Schematics:

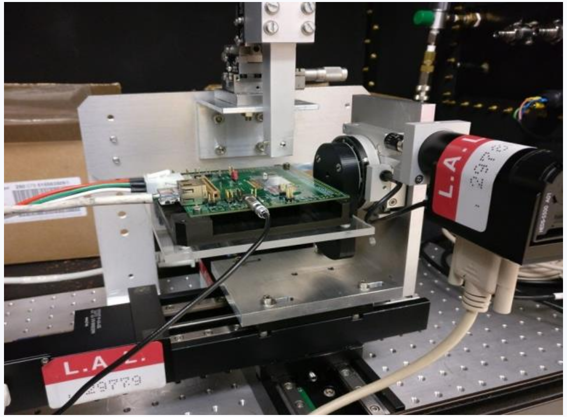


Laser test bench setup

LabVIEW software for the laser test bench controlling and parameters readout

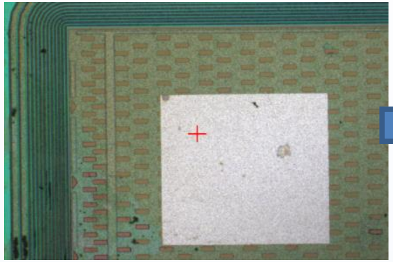
DUT support with rotating stage

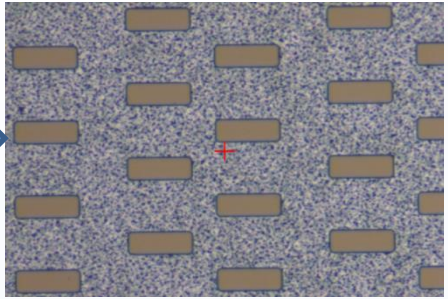


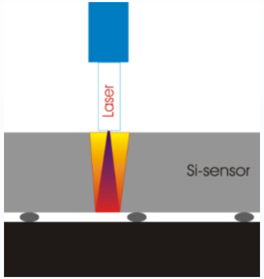


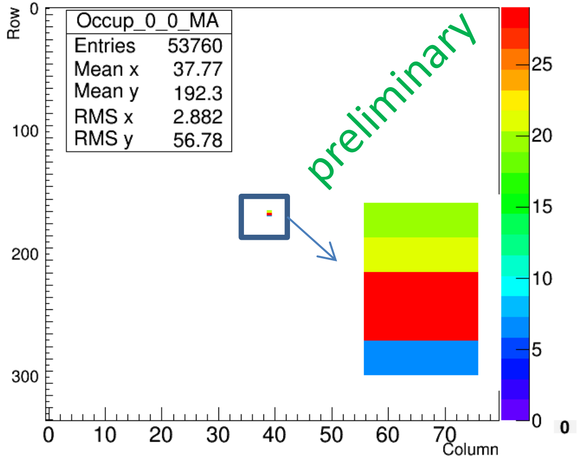
Laser test bench setup

Openings on a back side

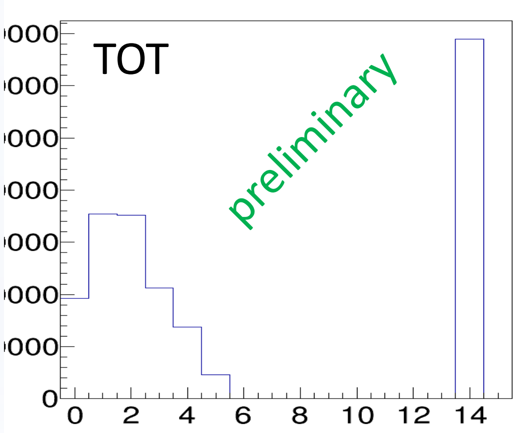


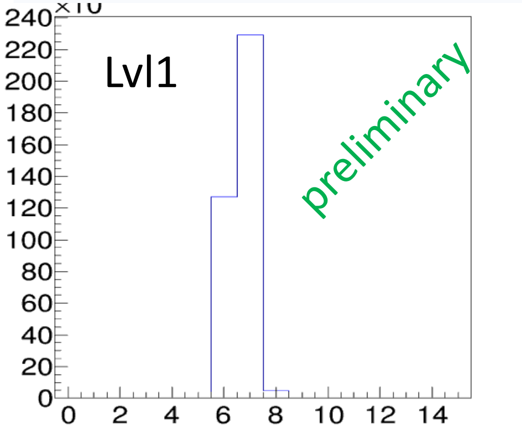






Hit map with the visible laser spot.





We wish to request the new n-in-p sensors production with openings on the Al backside for laser tests performing.

Summary and Conclusions

- 50 μm-thick samples (two are non-irradiated and two are at $1x10^{15}$ n_{eq}/cm^2 irradiation level) and 150 and 100 μm-thick samples (before and after irradiation $2x10^{15}$ n_{eq}/cm^2) of active and slim edge design have been measured at CERN (Oct-2017) and at DESY facilities (March, Dec-2017).
- The efficiencies (global, in-pixel, edge) were calculated for various sensor conditionals including: before and after irradiation case, the horizontal position of the sensor being illuminated, and tilted angle to the beam.
- The efficiency performance is generally better in sample with active edge design compared to the one with slim edge design. Thicker sensors show better performance.
- The laser test bench setup for SPD is being developed in the clean room at LAL .
  - **We will be very happy to have any assistance in developing (comments, ideas, experience)**

Thank you for your attention!