Detector Physics Meeting

Edge – TCT – A new approach to study radiation damage in silicon sensors

11. October, 2011
Nicola Pacifico

PH-DT/TP group
(Markus Gabrysch, Irena Dolenc Kittelmann, Michael Moll, Nicola Pacifico)

Outline

- Field determination in silicon detectors
- Transient current technique in silicon detectors
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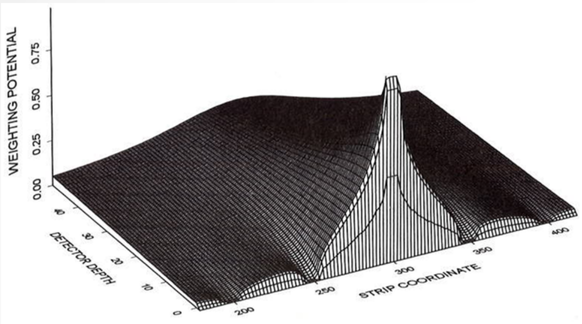
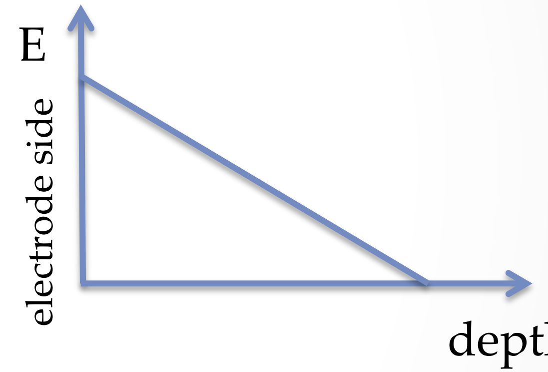
  - Drawbacks
- Edge-TCT technique
  - Concept
  - Implementation
  - Analysis techniques
- Results
  - FZ p-on-n detectors
  - FZ-n-on-p detectors after pion irradiation
  - FZ n-on-p detectors after 24 GeV/c proton irradiation
    - Investigation of anomalous CCE In heavily irradiated p-type detectors
- Overview and conclusions

Field in silicon detectors

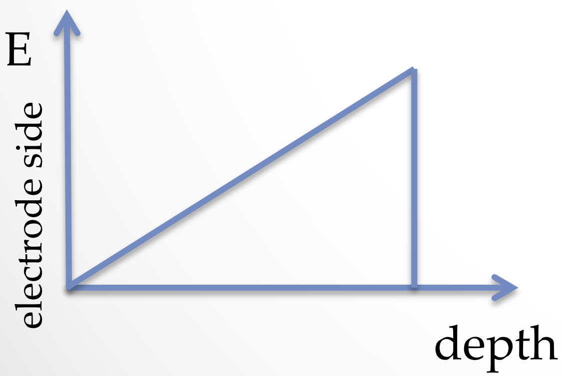


Signal development in silicon sensors with segmented readout is determined by the weighting field of the electrode (E_w)

$$i_K(t(x)) = -q \cdot \mu(\vec{E})\vec{E}(x) \cdot \vec{E}_w(x)$$



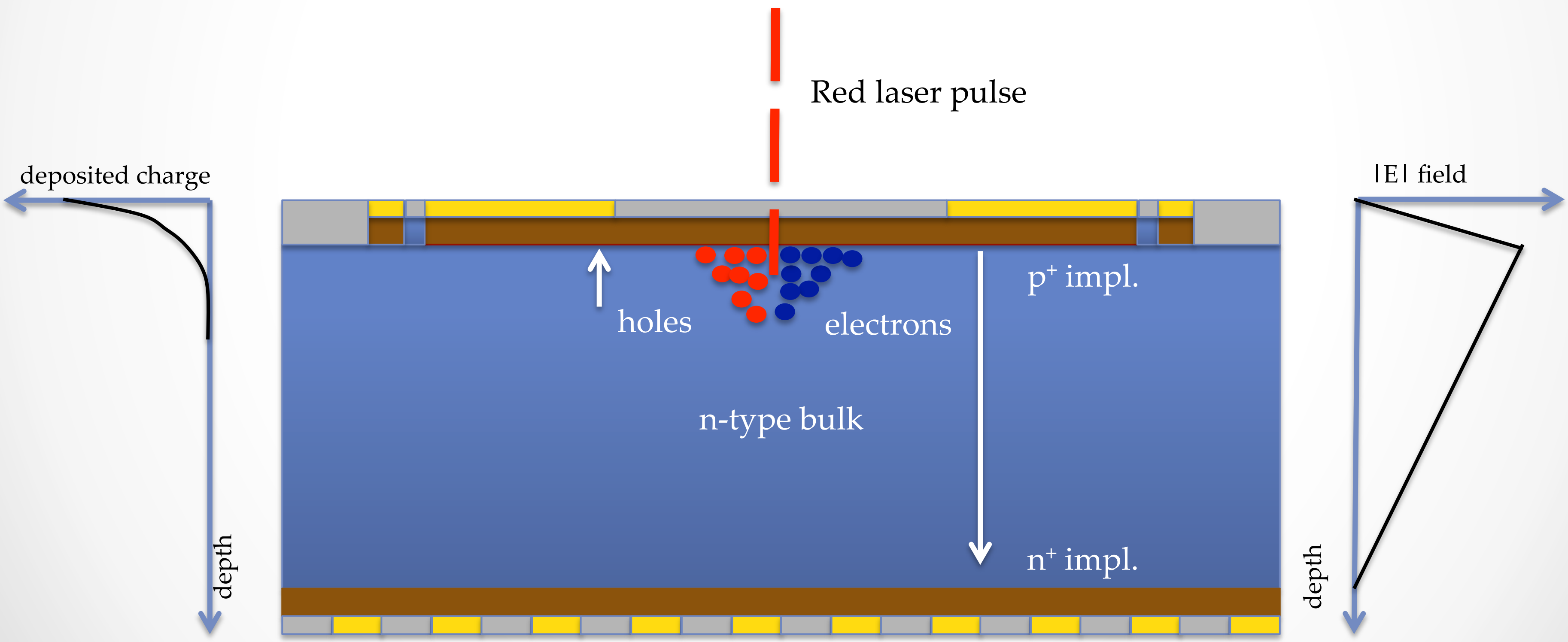
Since the weighting field in silicon detectors is depending (almost exclusively) from the geometry of the detector, the electric field should be maximum close to the electrode region, which is true by design for unirradiated detectors (apart from the special case of n-on-n detectors)…



… however it is renown that irradiation changes the field configuration in the detector and can bring the high field region towards the back of the detector itself (space charge sign inversion)

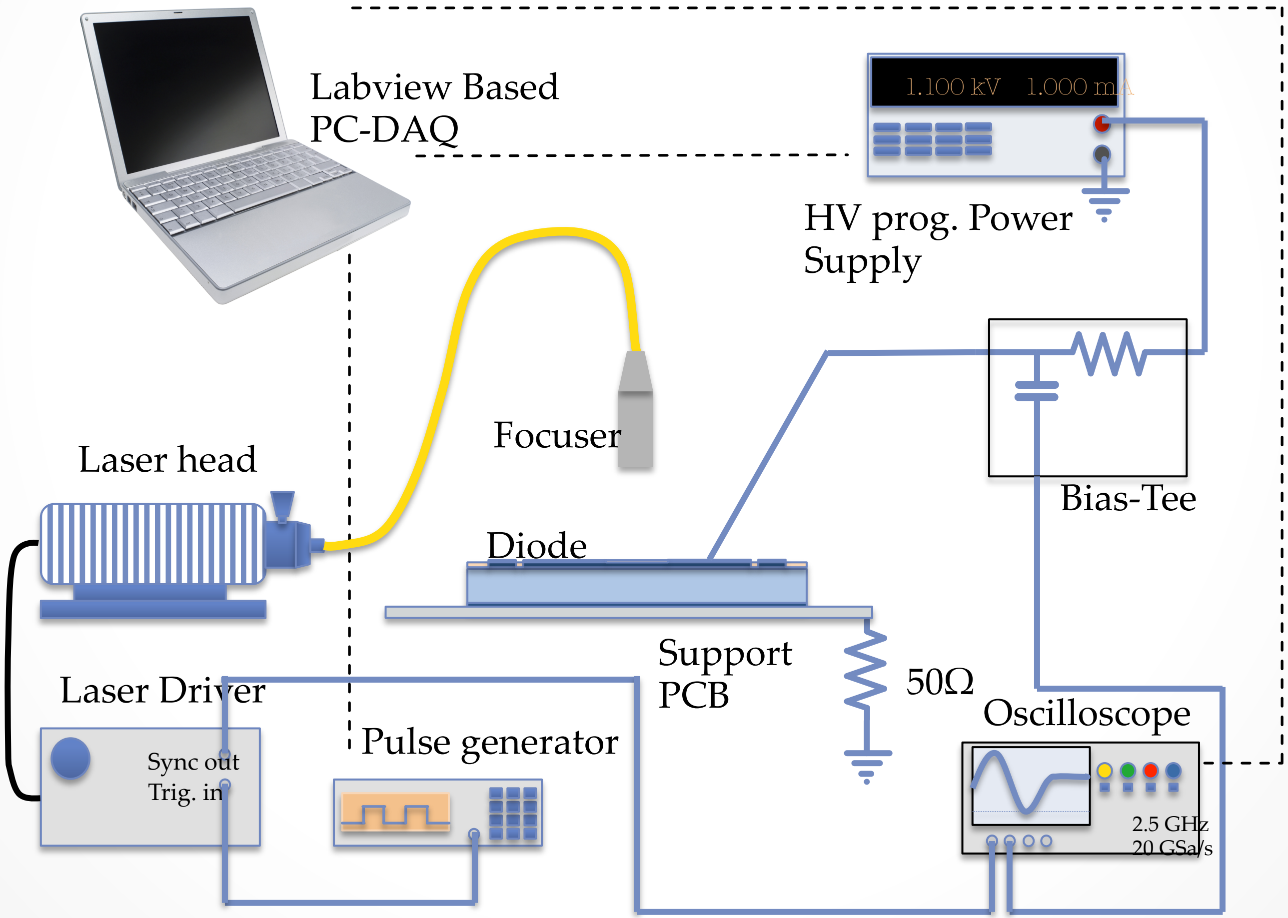
Transient Current Technique

Concept: Charge is injected close to the surface with a short (80 ps) laser pulse with wavelength of 660 nm (absorption length ~3 μm). One of the two type of carriers is immediately collected by the nearby electrode, while the other travels throughout the volume inducing on the two electrodes the major part of the signal.



Transient Current Technique

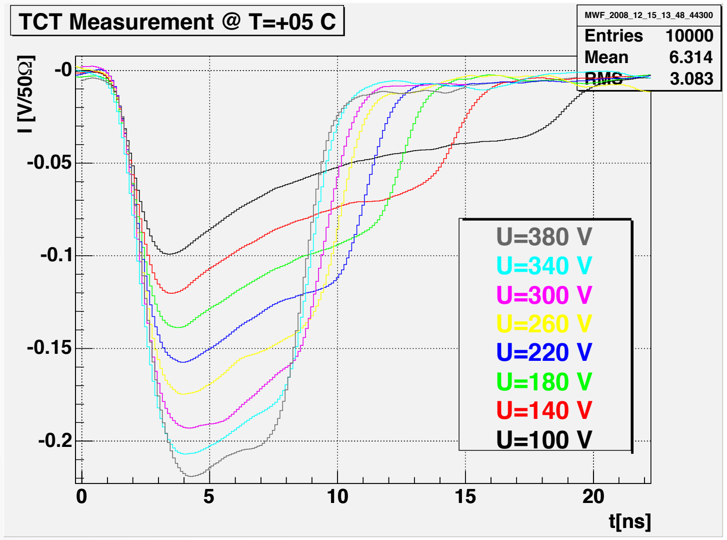
It's a first approach to the study of the field by analyzing the transient pulse resulting from the injection of carriers in a region neighboring one of the two electrical implants in a diode ($|E_W|=1/d=\text{constant}$).



Transient Current Technique

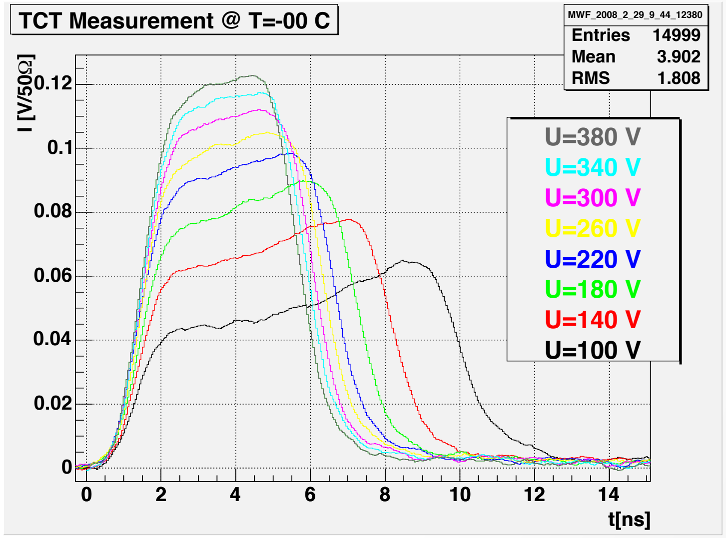
Analyzing the transient pulse as it develops with time, we gather information on the location of the high field.

High field on the front side



$1.7 \cdot 10^{14}$ p – MCz n-on-p
with no annealing (front)

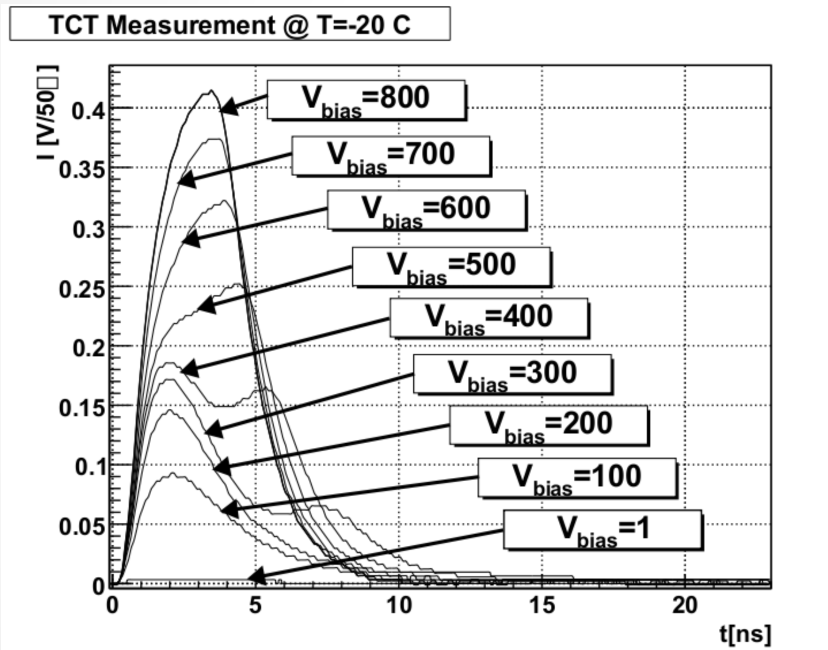
High field on the back side



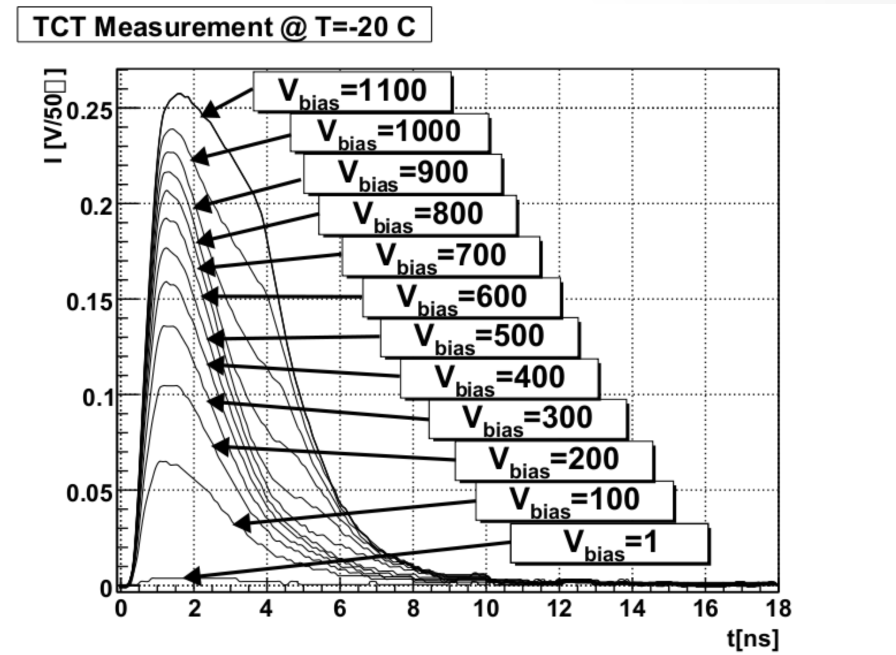
$1.7 \cdot 10^{14}$ p – MCz p-on-n
after 1000 mins@80°C (front)

Transient Current Technique

There are however limitations in the usage of the transient current technique: The technique can give clear results only up to low fluences (~3•10^{14} part/cm^2) which was fine for standard LHC for outer strip trackers…



1•10^{15} n – MCz p-on-n



3•10^{15} n – MCz p-on-n

So… this one type inverted…

… and this not??

Transient Current Technique

Charge trapping plays a consistent role at high fluences.
First we relied on the proportionality between current and field…

$$\vec{j}_{e,h} = n_{e,h} \cdot q_0 \cdot \mu_{e,h}(\vec{E}) \cdot \vec{E}$$

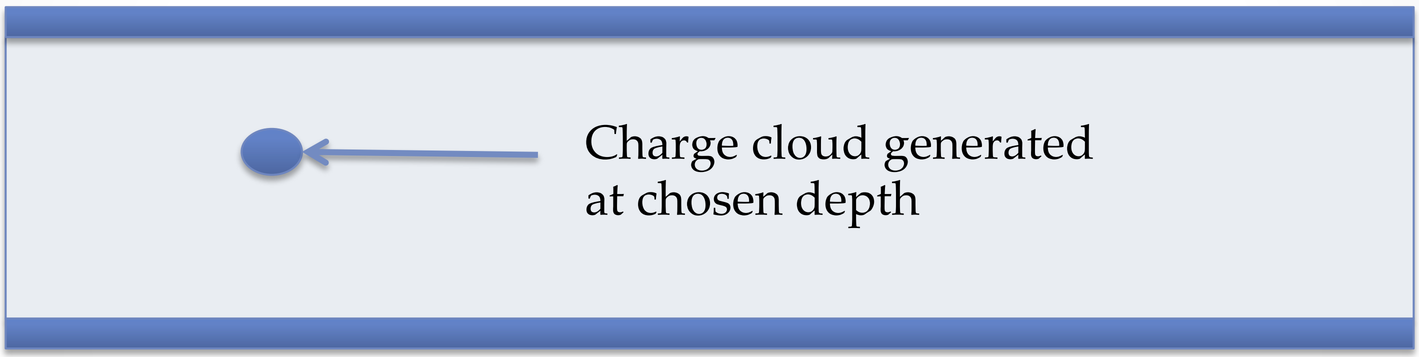
… but for irradiated detectors, *n*, which is the number of drifting carriers, cannot be assumed anymore constant, since radiation introduces trapping centers that eat away a good deal of the signal (at $1 \cdot 10^{15}$ $\tau \sim 2\text{-}3$ ns), so the *n* term should be replaced with something obtained by solving this equation…

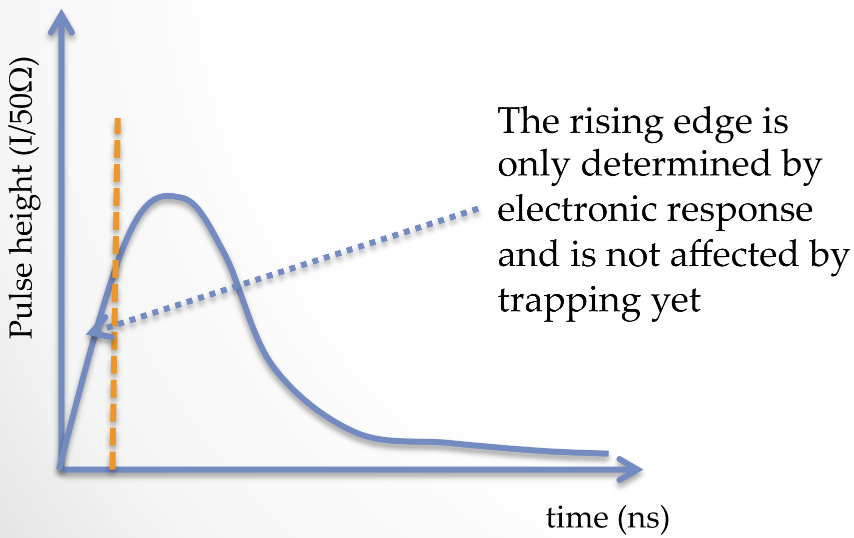
$$dn_{e,h} = -n_{e,h}(t) \frac{dt}{\tau_{e,h}(E)}$$

Unfortunately, the **τ(E) functional dependence is not known** (yet). With **low fluences** (up to $\sim 3 \cdot 10^{14}$) it's still possible to assume the **trapping to be a constant independent from the field**, but it's not an option for the upgrade of tracking detectors for the phase II upgrade of the various LHC experiments.

Edge-TCT

It would be nice to be able to create the charge cloud at a given depth of the detector:



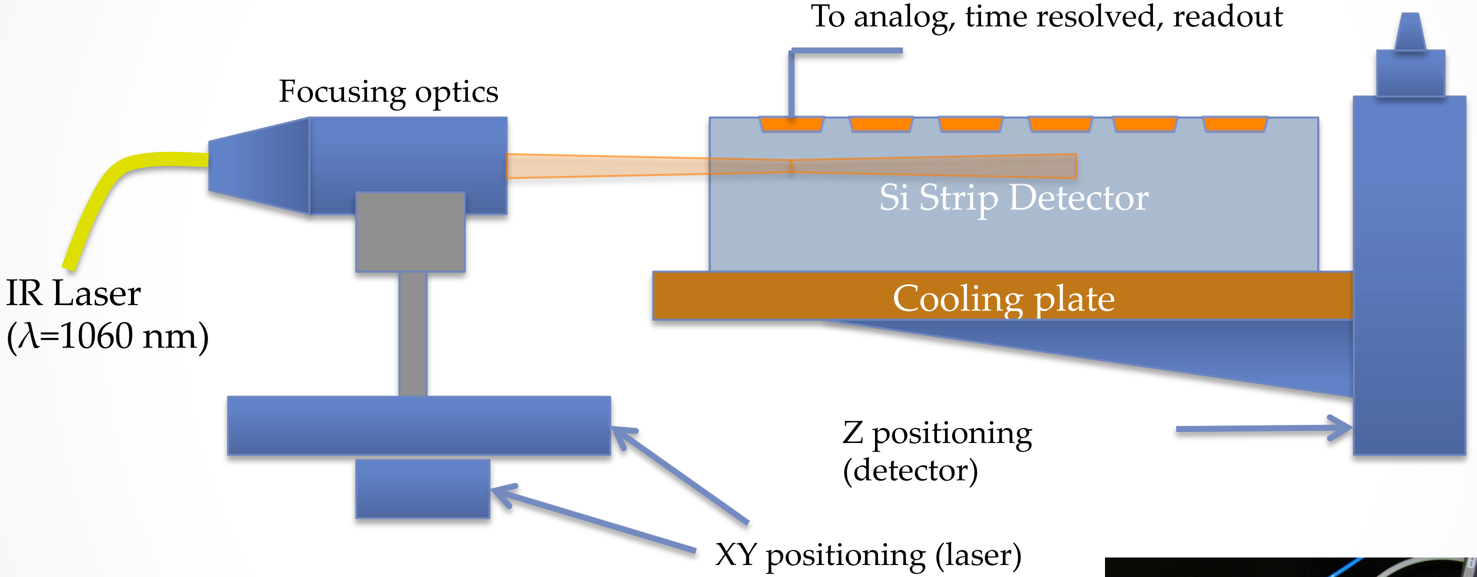


Even though the overall signal would still be affected by trapping, we could use the peaking region to extract local information about the injection site…

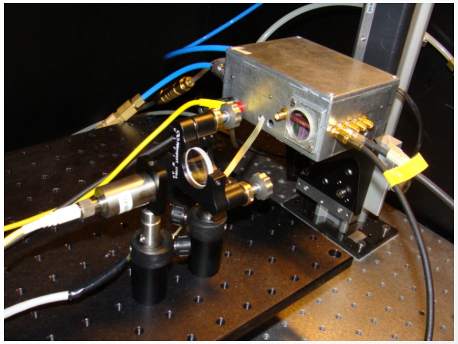
Edge-TCT setup

Edge-TCT is a laser scanning technique, exploiting ps light-induced transients to explore microscopic parameters (*efficiency*, *field profile*, *trapping*) in unirradiated and irradiated silicon strip and pixel detectors.

Including the one developed at CERN there are only two such setups in the world.



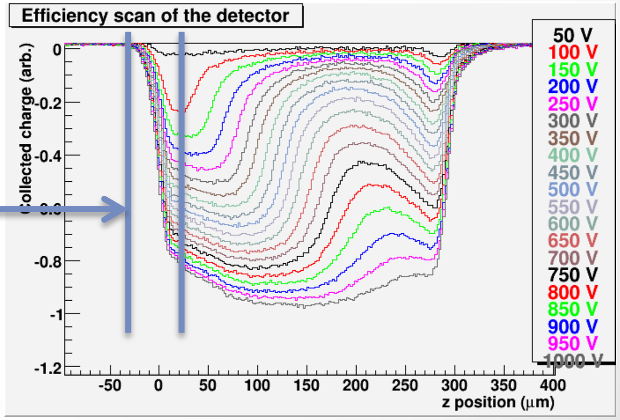
The setup at CERN was fully developed (mechanics, electronics, controls, DAQ, data analysis, cooling), in the timeframe 07.2009-07.2011



Edge-TCT

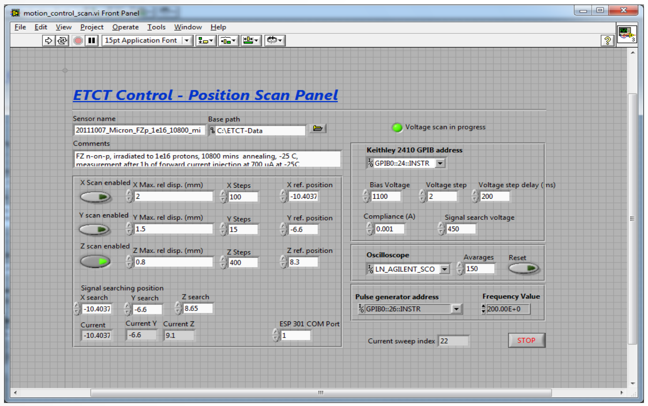
Detector requirements for Edge-TCT

- Since it's not possible to keep a laser focused throughout the whole width of the detector, a segmented (strip) detector should be used
  - Still, since the charge will be induced from a "tunnel" perpendicular to the strip, the weighting field will appear to be diode-like
- Detector should be prepared by polishing its sides to sub-micron level ➔ Polishing by 3M fiber cleaner diamond paper and 0.1 um grade diamond compound.
- The edge of the detector has to be floating to avoid reflection of laser from support structures.
- The laser has to be set to the proper focusing distance. This is done empirically by scanning the thickness at different depths and ensuring to have the minimum **<u>rising edge</u>** of signal height when entering and exiting the detector volume…

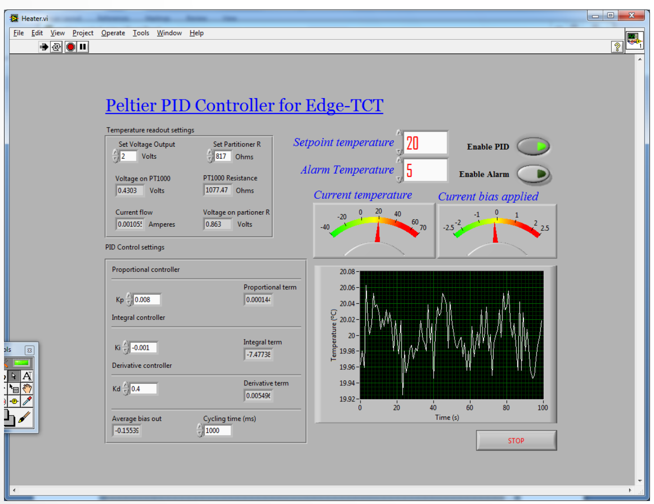


Edge-TCT – DAQ

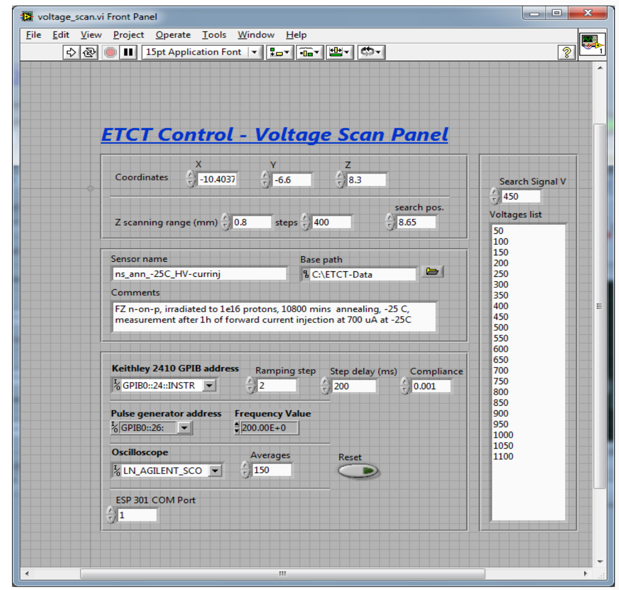
DAQ of the system is written in LabView allowing:



Position scan



Temperature control (-35°C to +65°C)

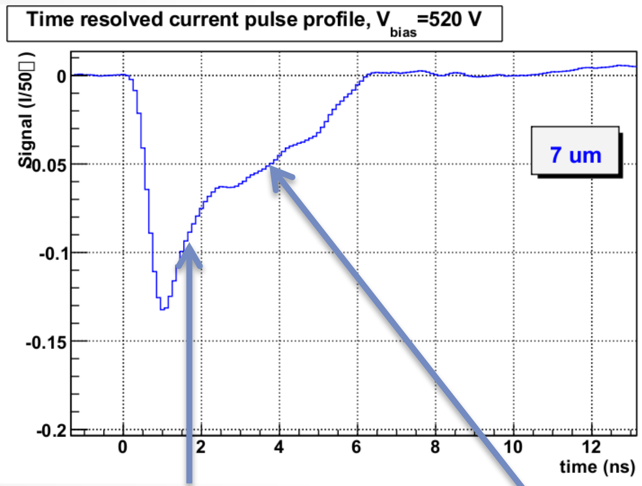


Voltage (position) scan

Edge-TCT – Analysis

Due to the large amount of data to process for one measurement (up to 300 MB), analysis routines are packaged in a ROOT library.
Pulses samples for low irradiated pion FZ n-on-p detector

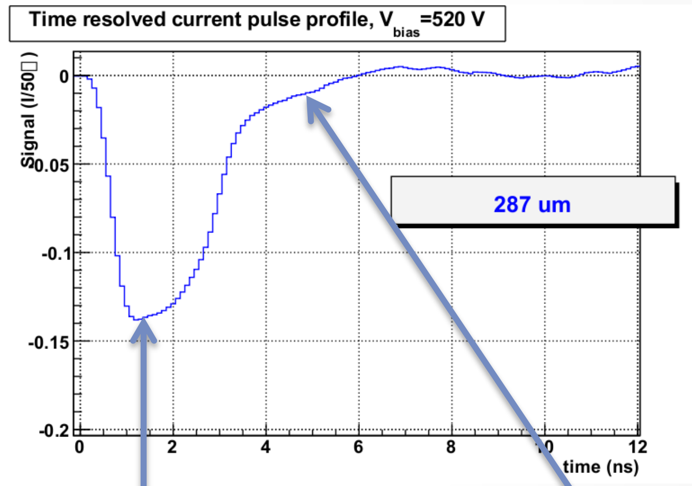
Front Injection



immediate electron collection

long tail due to holes travelling towards low field

Back injection



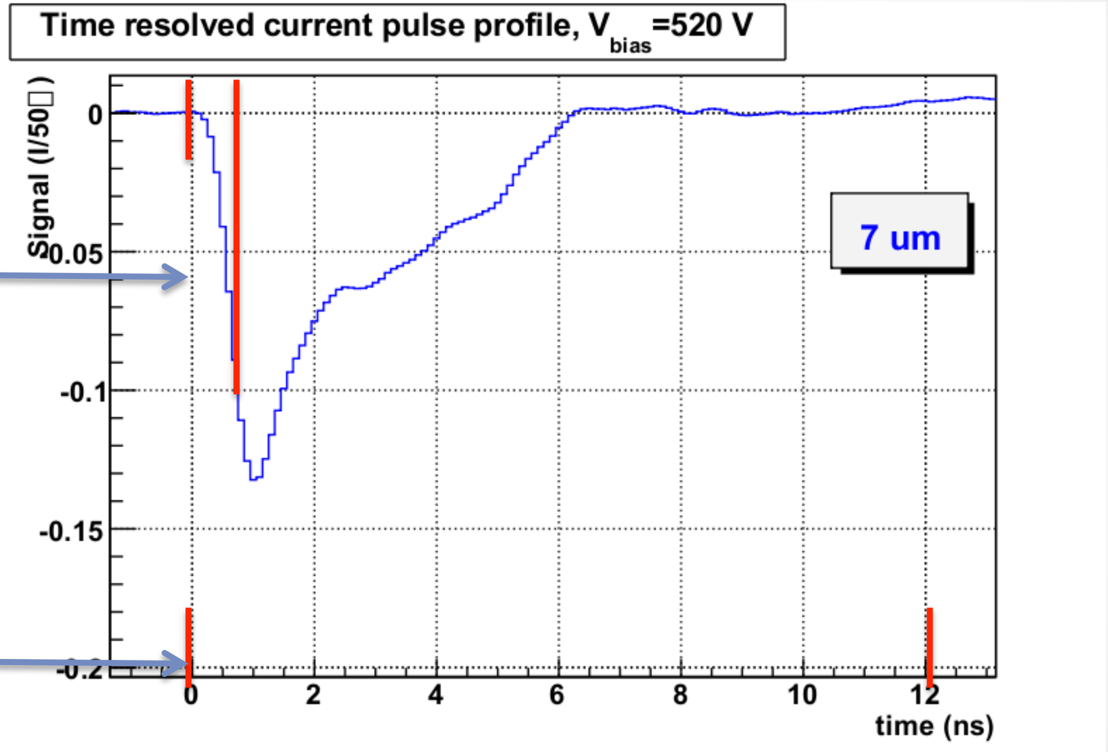
holes collected + electrons going into high-field (signal dumped by trapping)

fast collection of fast travelling electrons

Edge-TCT – Analysis

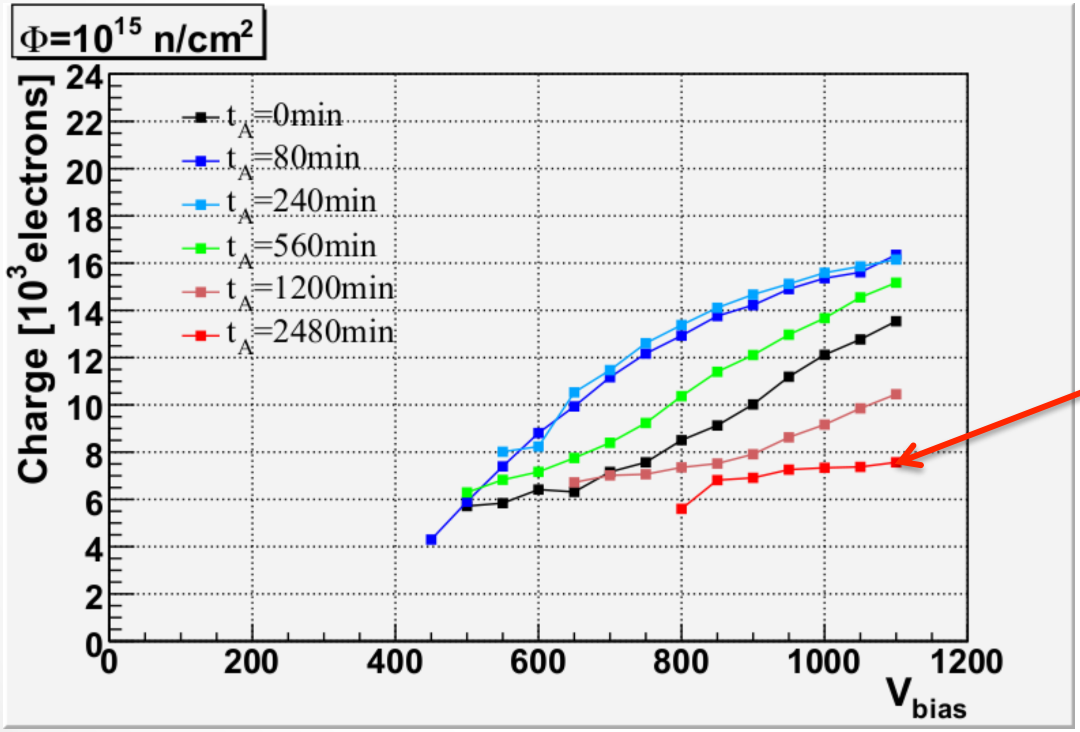
Prompt Current Method:
Integration over rising edge gives information about drift velocity (weighted average of holes and electrons drift velocity) at injection depth.

Efficiency scan
Integration over whole pulse gives information about how much the scanned depth contributes to the overall signal of the detector.



Edge-TCT – Results

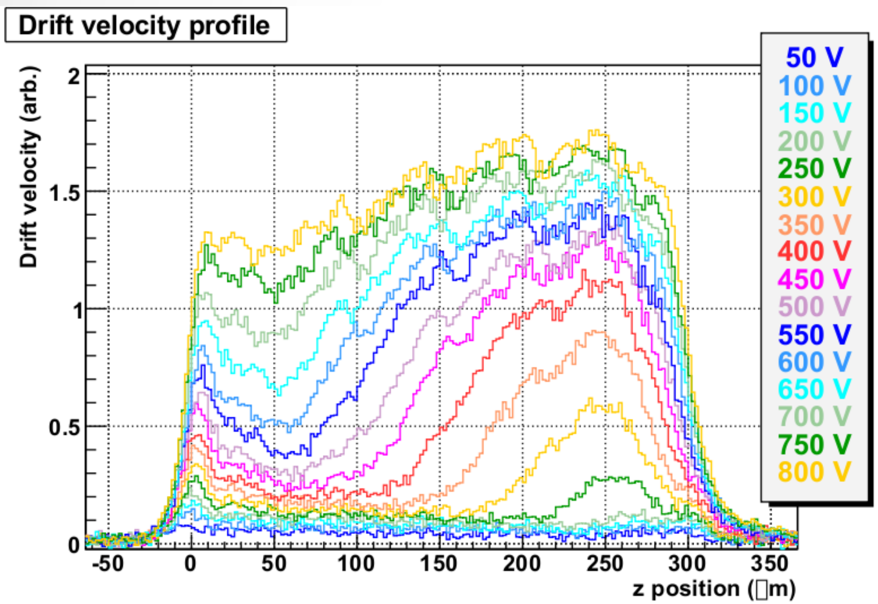
Preface: A β source CCE study was performed on the current strip sensors (FZ p-on-n) used in the CMS tracker. They were irradiated up to a fluence of $1 \bullet 10^{15}$ n/cm^2 and then annealed at 60°C to simulate long maintenance shutdown periods

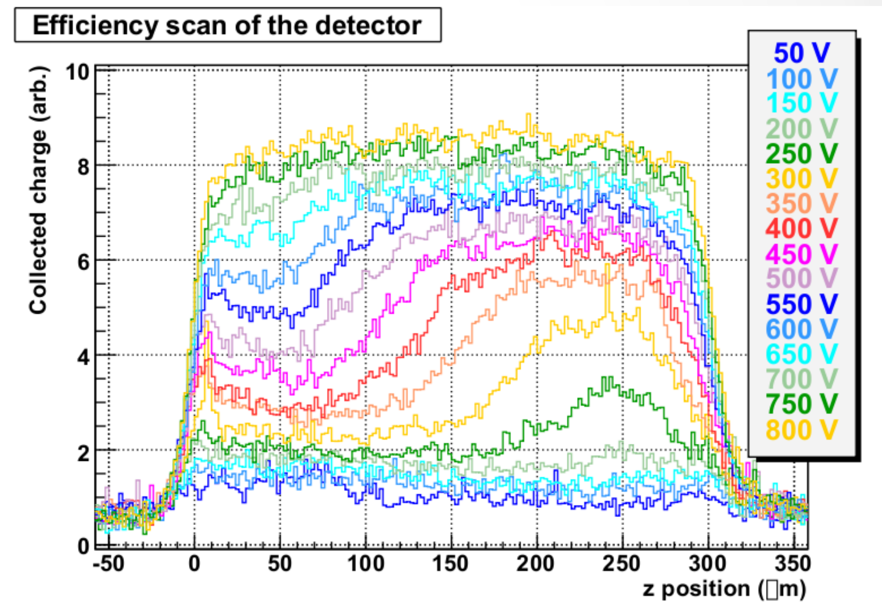


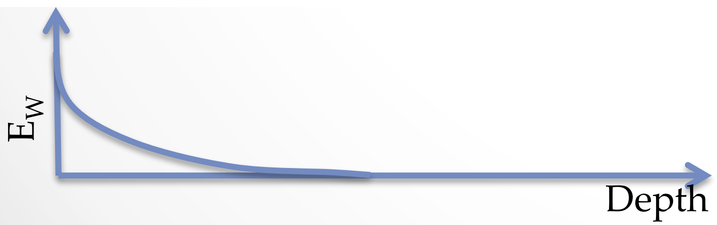
SNR < 4 after 2480 minutes… and we wanted to know why…

Edge-TCT – Results

We mounted the first irradiated detector on the Edge-TCT setup. Detector was received already irradiated, so proper polishing was not possible, but the measurement still gave good results.



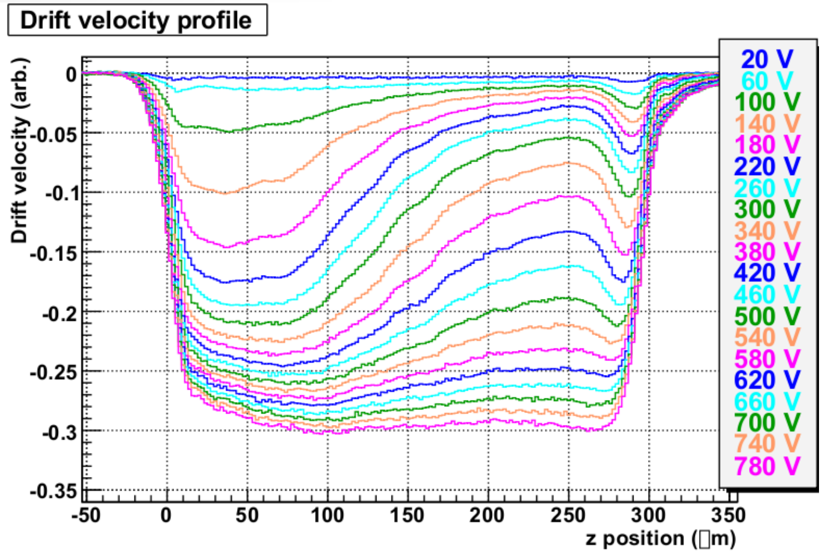


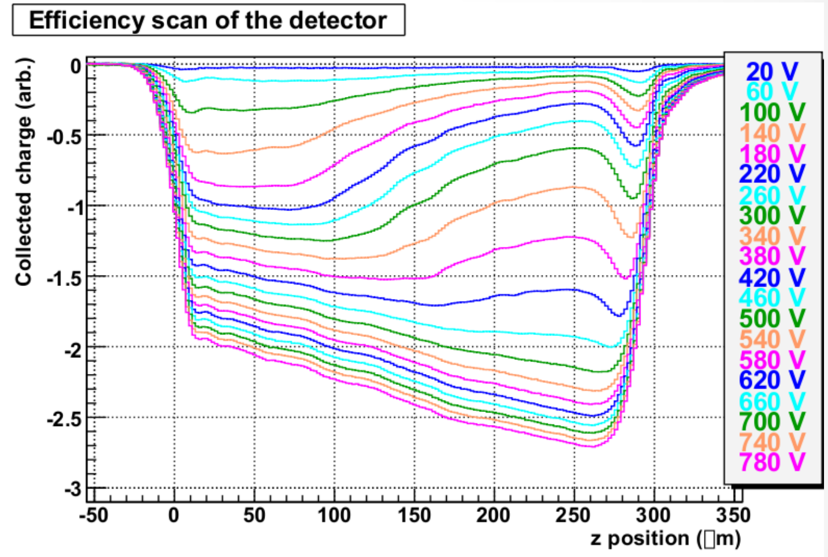


Field develops from the back region:
Minor overlapping with the strip's weighting field.
(Remember that in E-TCT observed weighting field is diode-like)

Edge-TCT – Results

Next example: pion irradiated ($1 \bullet 10^{15}$ n_{eq}/cm^2) Float Zone n-on-p sample.





Though the field develops from the front side, the more efficient region at high voltages is located close to the backside:

- Electrons travelling from the back to the front are travelling faster than holes from the front to the back, thus having less chance of being trapped.

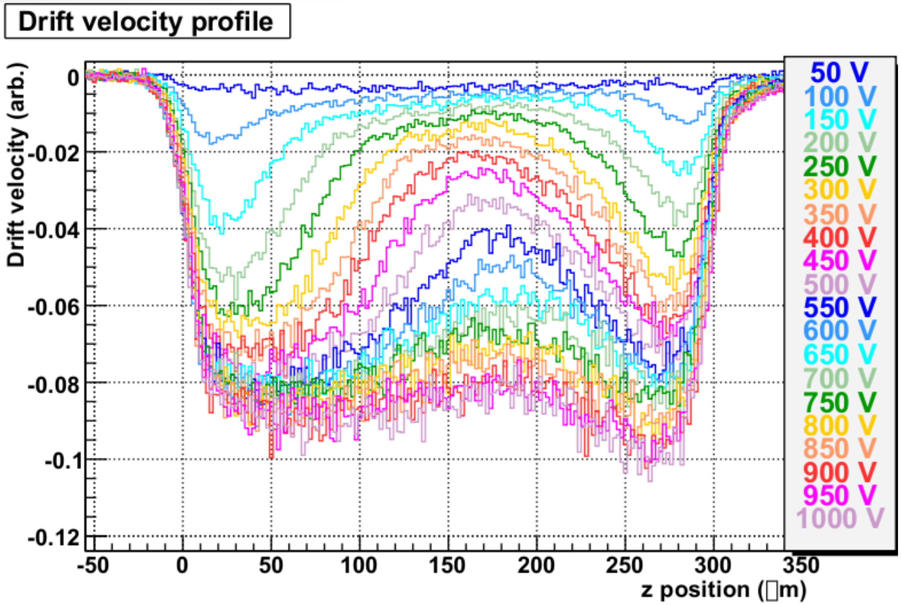
And now some preliminary and unpublished results on the most probable candidate for the LHC upgrade…

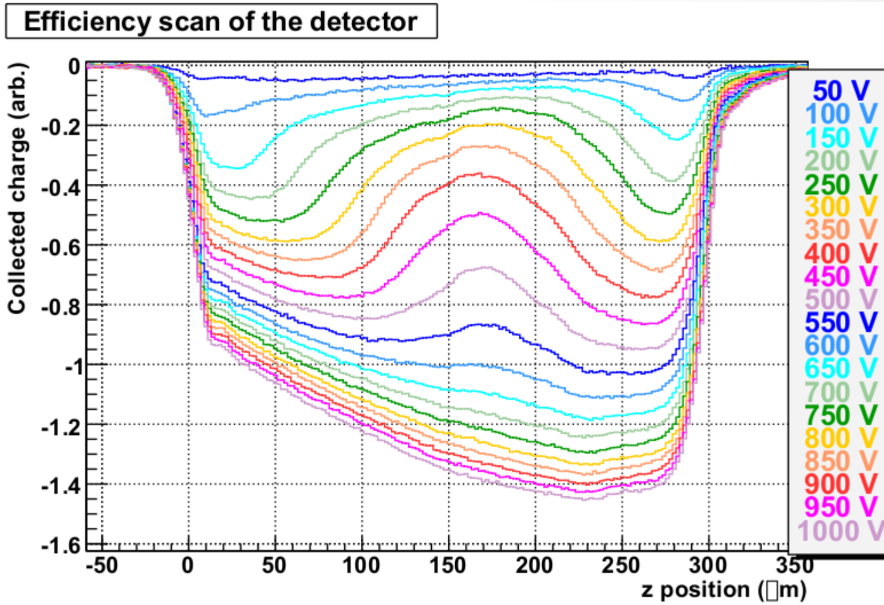
Edge-TCT – Results

Most experiments are focusing their efforts towards Float Zone n-on-p detectors.

One of the observed features in recent literature is that the collected charge doesn't seem to degrade significantly with annealing but even increase…

Example for a heavily irradiated ($1 \cdot 10^{16}$ 24 GeV/c protons/cm^2) detector with no annealing:

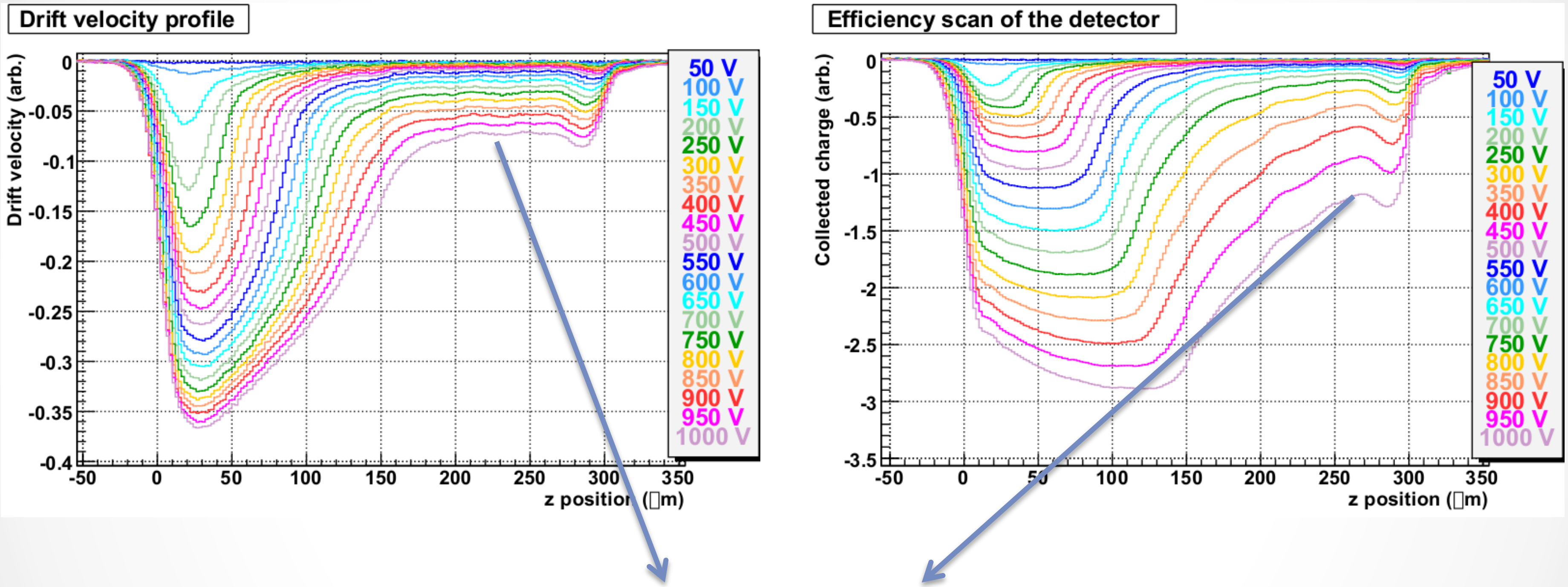




Heavy positive space charge introduction on the backside of the detector. This is a known characteristic of cluster formation after 24 GeV/c proton irradiation.

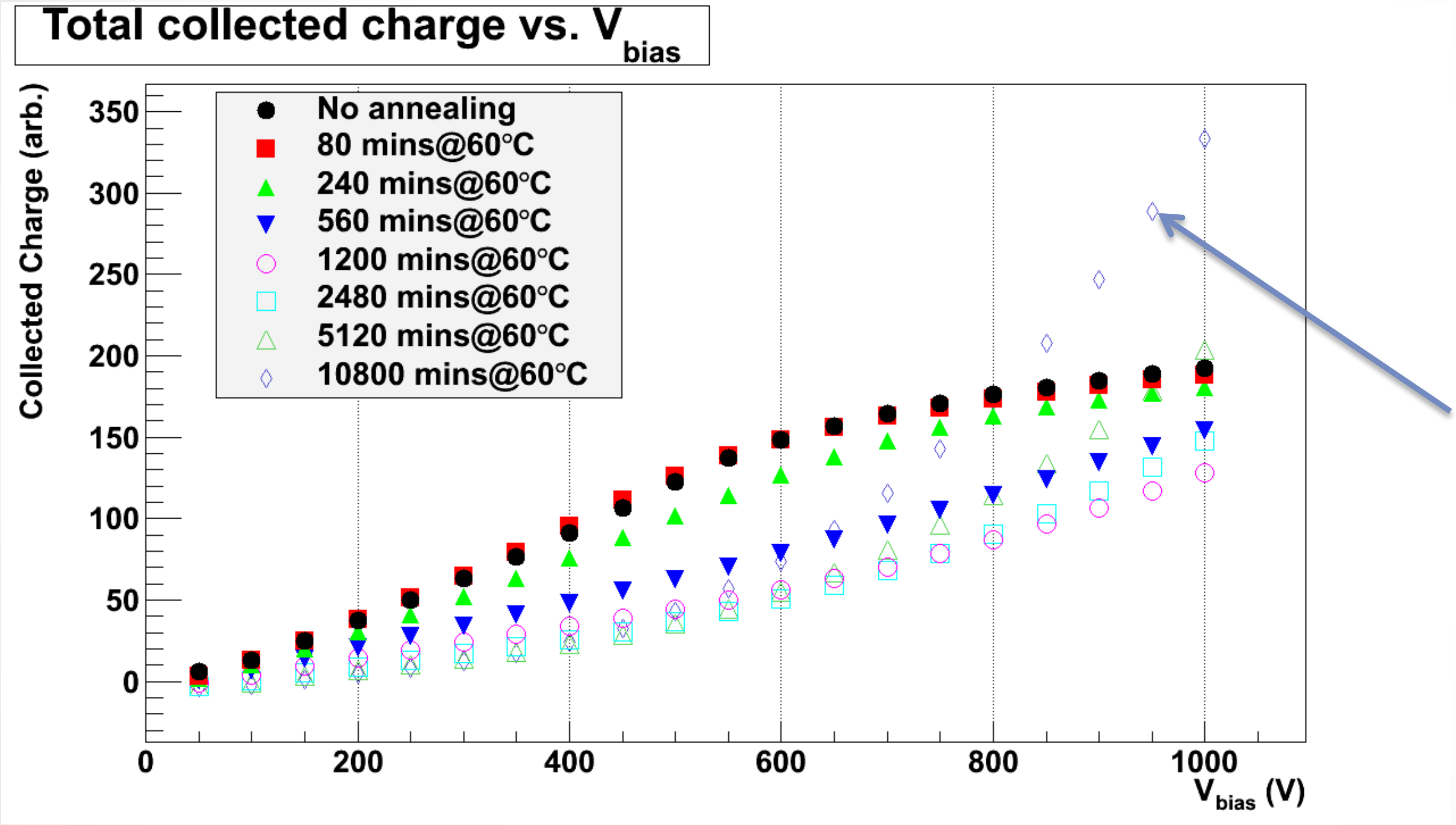
Edge-TCT – Results

After 10,000 mins annealing at 60°C:



Even in this undepleted region (a small constant field is related to the resistive drop of the leakage current) the efficiency on the backside region is very high. Let's compare at different annealing steps the total collected charge, obtained by integrating the efficiencies plots over the whole thickness…

Edge-TCT – Results



The increase of the efficiency on the backside is related to impact ionization multiplication, triggered by the high voltages now present at the front side of the detector…

Conclusions

- Edge-TCT proves to be a powerful replacement for standard TCT at upgrade fluences.
- Still, it lacks the ease of use and mass-measurements ability of standard-TCT, but this is by far compensated by the amount of information that can be extracted.
- The setup at CERN is fully operational under every aspect.
- More work is in progress on the analysis front. It would be nice now to extract trapping times, absolute field profiles. Deconvolution techniques have to be widely used here to get good results.
- A final note on avalanche formation in FZ n-on-p silicon:
  It could answer to the problem of SNR degradation in silicon detectors. However the process has to be fully understood and parametrized, and the need for having very high voltages (up to 1000 V or more) could be the major drawback.

Thank you…