Latest results from irradiation test-beam campaigns

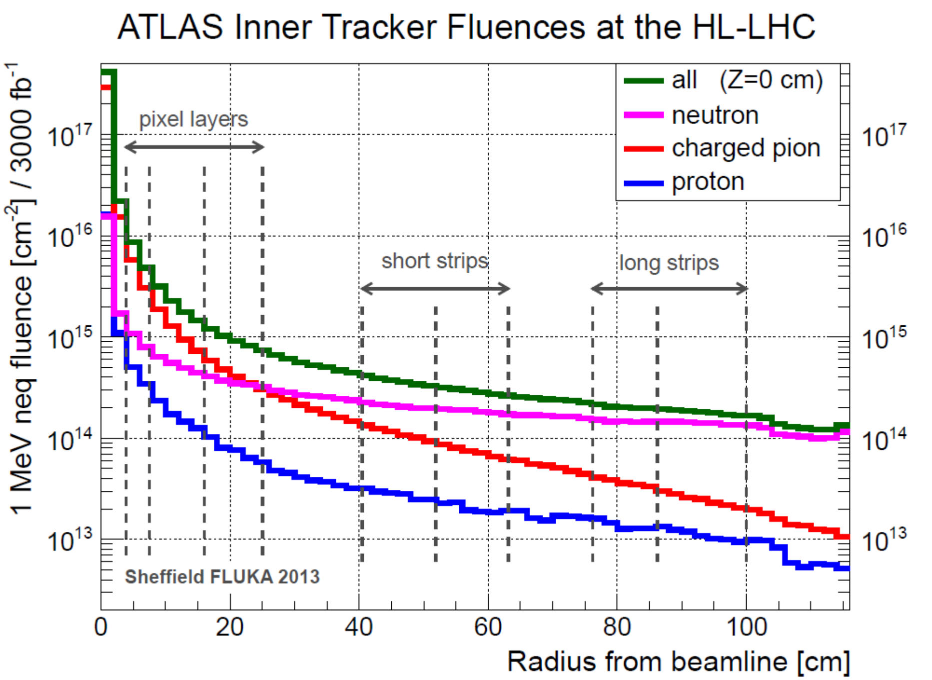
Alexandra Junkes
Helmholtz Allianz meeting
February 28th 2013 Mainz

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

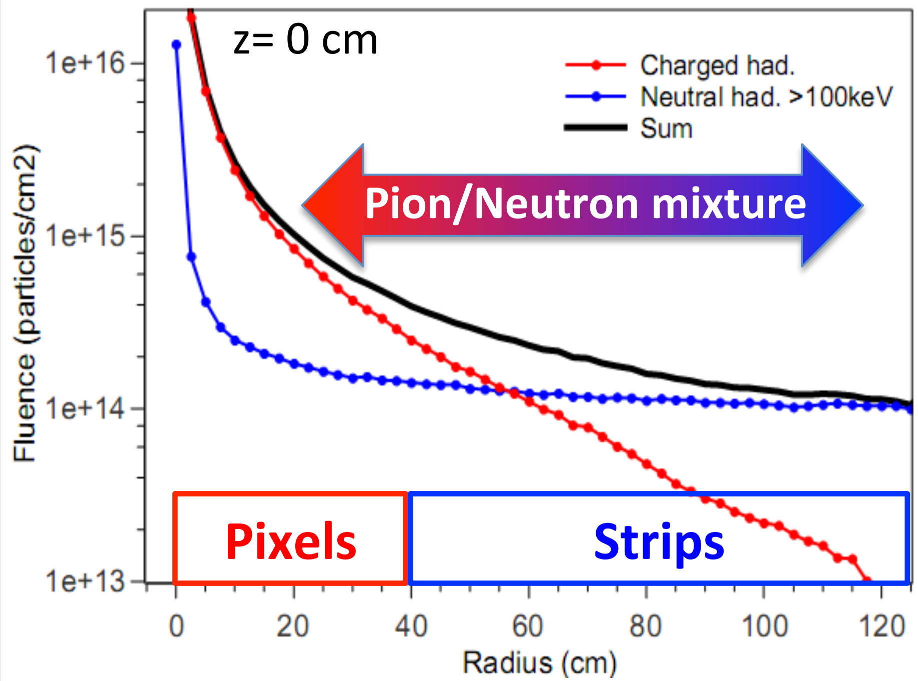
Expected radiation depending on position in detector for HL-LHC

ATLAS



[I. Dawson, P. S. Miyagawa , Atlas Upgrade radiation background simulations]

CMS



A. Mueller, KIT

Expected radiation damage very similar for ATLAS and CMS

Outline

- Introduction
- Planar sensors
- New structures

A future HL-LHC tracker should

- Have a better resolution
- Be more radiation hard
- Have less mass
- Save power
- Avoid dead regions
- Contribute to L1 trigger
- Be cost efficient
- …

Sensor Topics

Defect/material characterization

-General understanding of radiation damage
-Methods: DLTS, TSC…
-Investigate defects in the Si-bulk (and at the surface)

Detector characterization

-Testing of Si-materials and structured devices for response to radiation damage
-Methods: CV, IV, TCT, eTCT, source measurements, test-beam
-Investigate V_{dep}, I_{leak}, signal, noise, trapping

Simulations

-Optimize geometry
-Understand effects like trapping and charge multiplication
-Forecast radiation damage
- I_{leak}, V_{dep}, CCE…

New structures

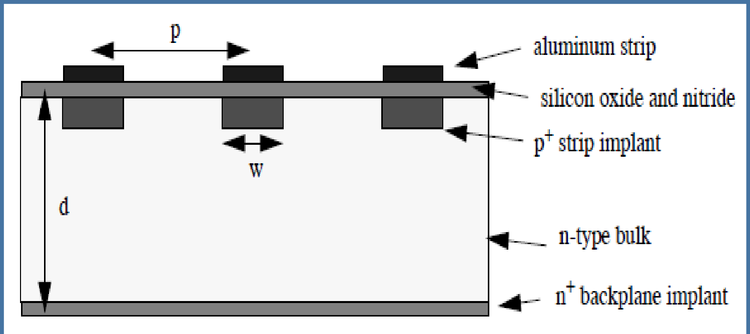
-3D
-Thin detectors
-Charge multiplication devices
-Active edges
-Cost effective solutions

Outline

- Introduction
- Planar sensors
- New structures

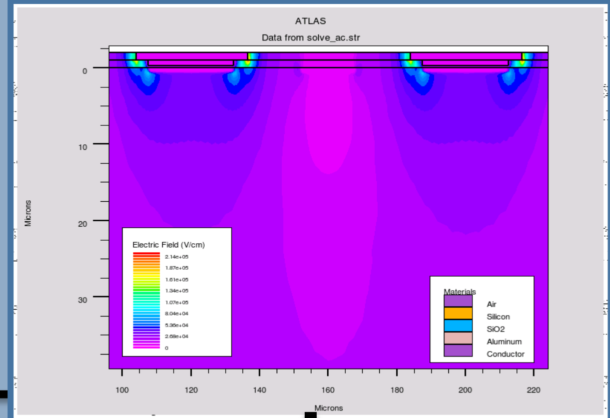
Simulation Efforts

Devices



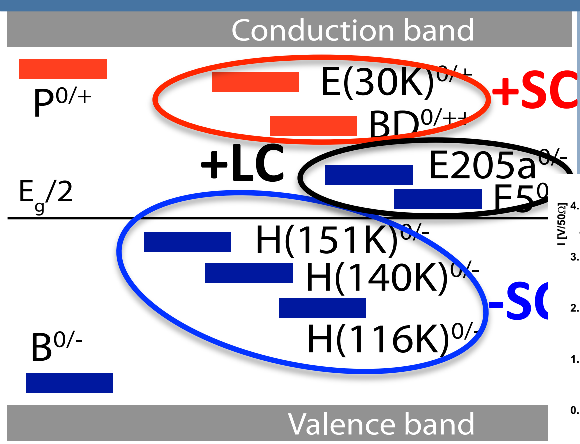
Simulate strip isolation, implant depth, strip width, metal overhang….

Optimize geometry

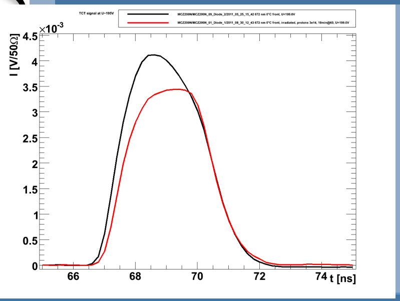


L. Altan, 20th RD50 meeting 2012, Bari

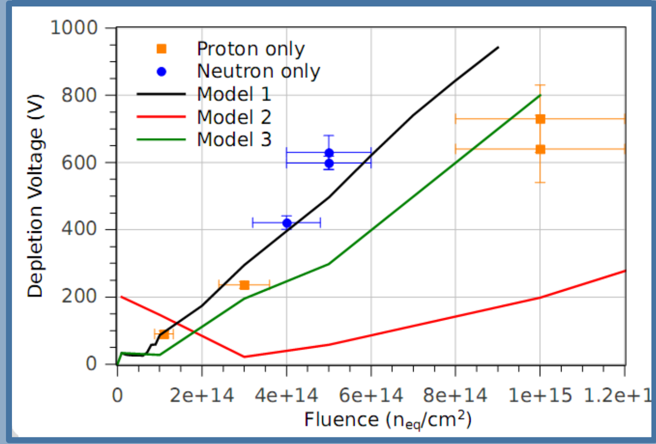
Simulation of rad. damage



Simulate E-Field, CCE, multiplication, current, voltage…



Radiation damage



R. Eber, 21st RD50 meeting, CERN

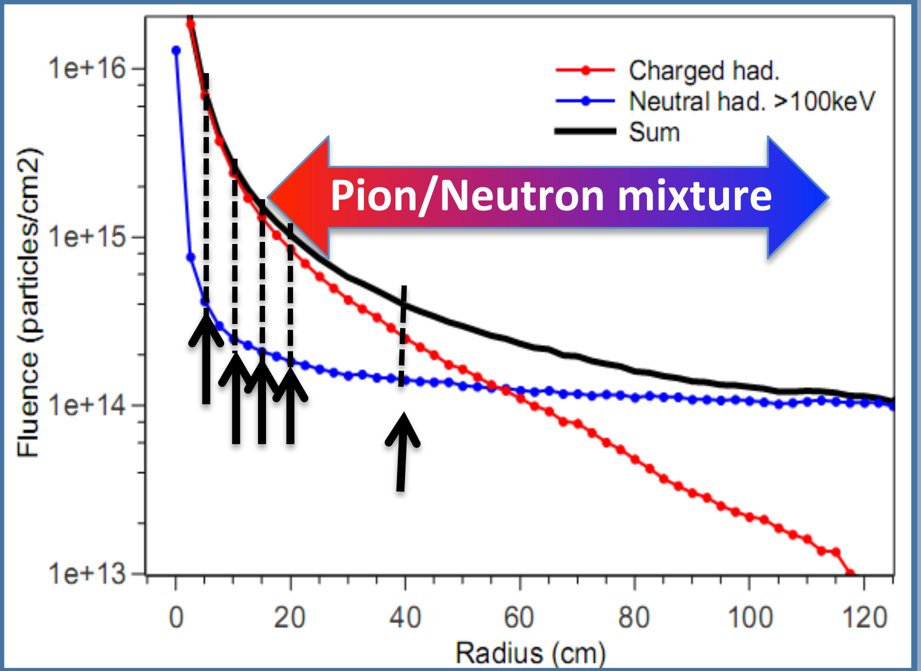
CMS tracker upgrade campaign

Radiation hardness of silicon defined by growth process

- Oxygen content (**MCz, FZ, dd-FZ, Epi**)
- Influence of doping and sensor thickness (100 μm – 320 μm)

→ Study diodes

→ Obtain: V_{dep}, I_{leak}, C_{end}, CC, defect parameters



Study best design parameters for structured devices

- Strip layout & and influence of sensor thickness
- Influence on n-type and p-type material

→ Strip and multi-geometry strip sensors

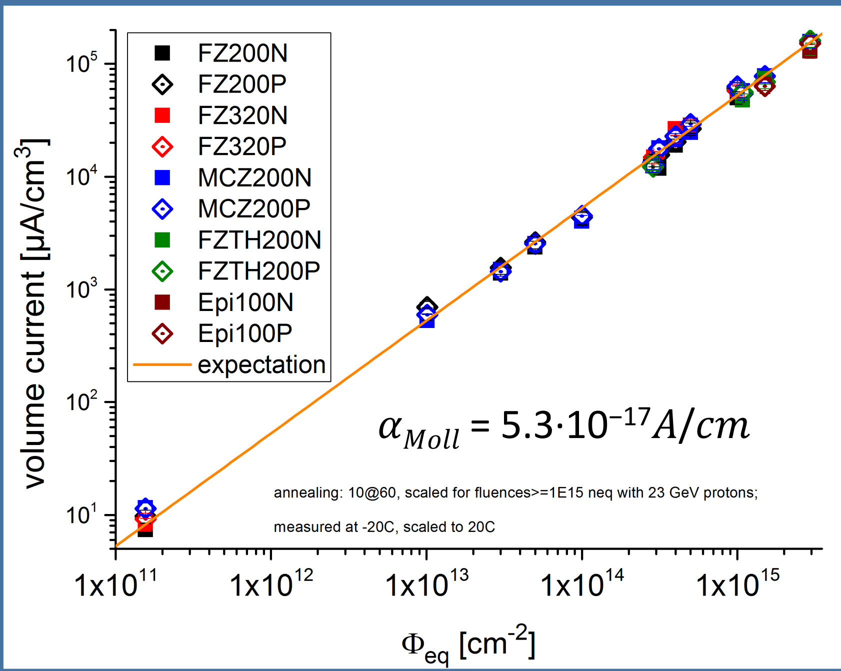
→ Obtain: V_{dep}, I_{leak}, CC, S/N, strip parameters

Available techniques:
CV/IV, TCT, e-TCT, source measurements, DLTS, TSC
Minimize differences in processing by using one vendor!

A. Junkes, VCI2013, Vienna

Current above full depletion

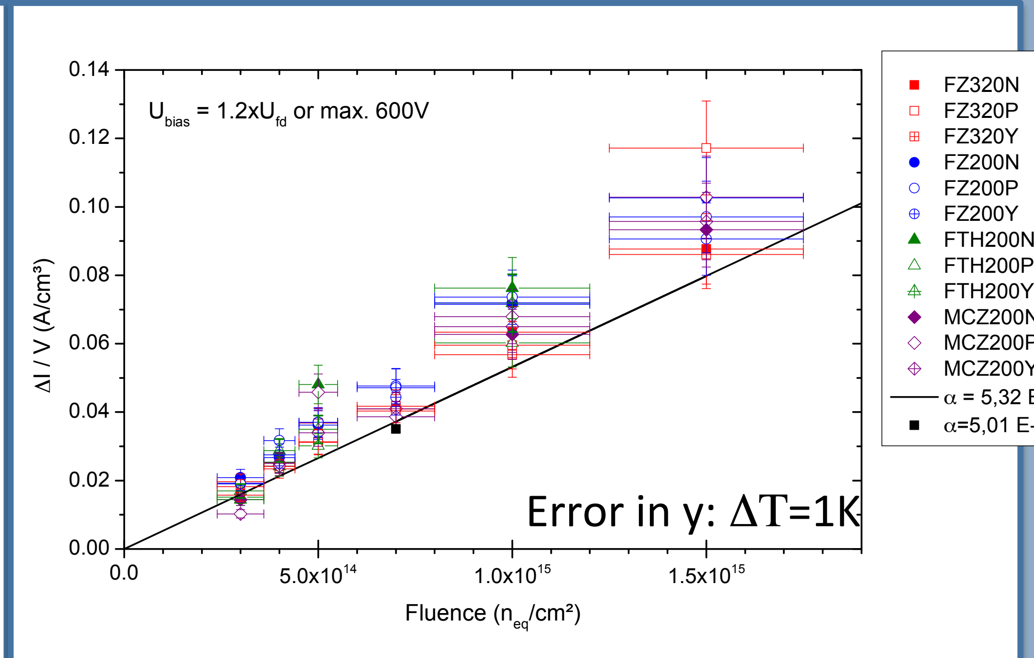
Diode measurement



Current taken at V_{dep} + 5%

- independent of material and irradiation type $I/V = \alpha \cdot \Phi_{eq}$

Strip measurements at max 600 V

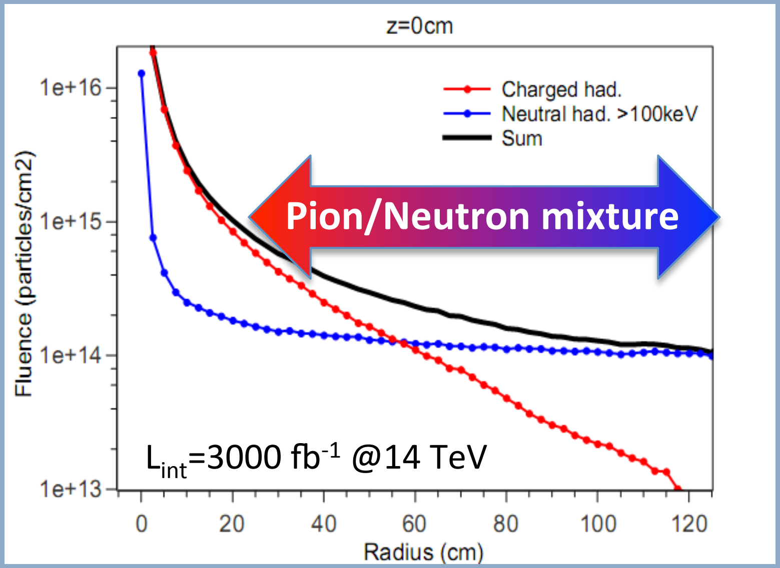


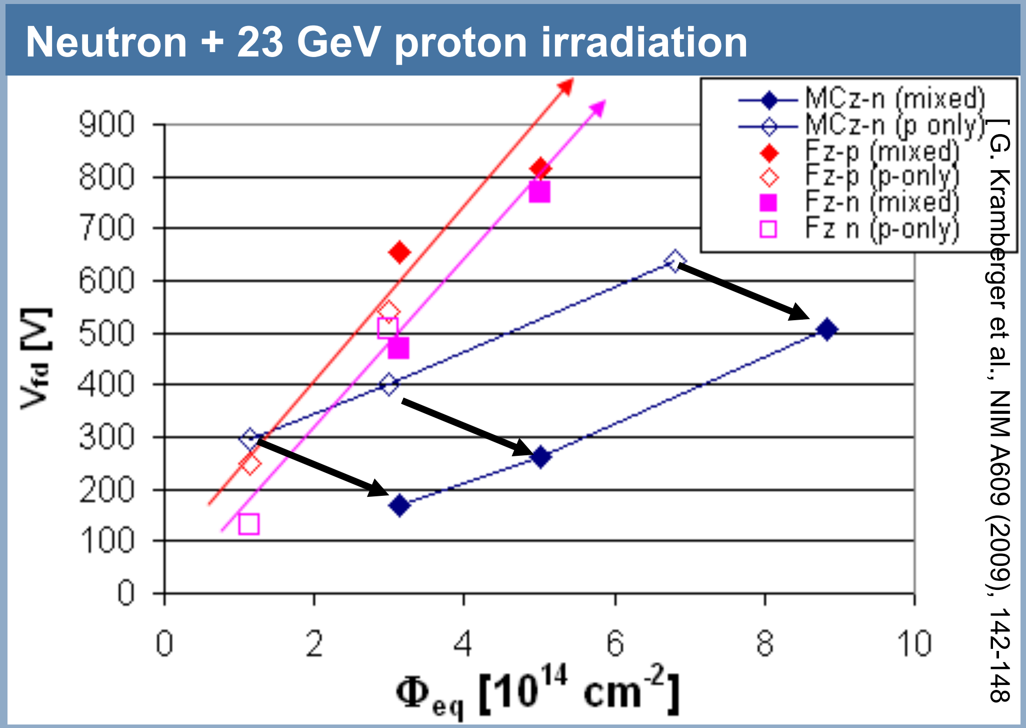
Thickness taken from CV measurements on diodes

- Some sensors not fully depleted at 600 V
- Leakage currents of strip sensors higher than expected from diodes

A. Junkes, VCI2013, Vienna

Expectation for mixed irradiations

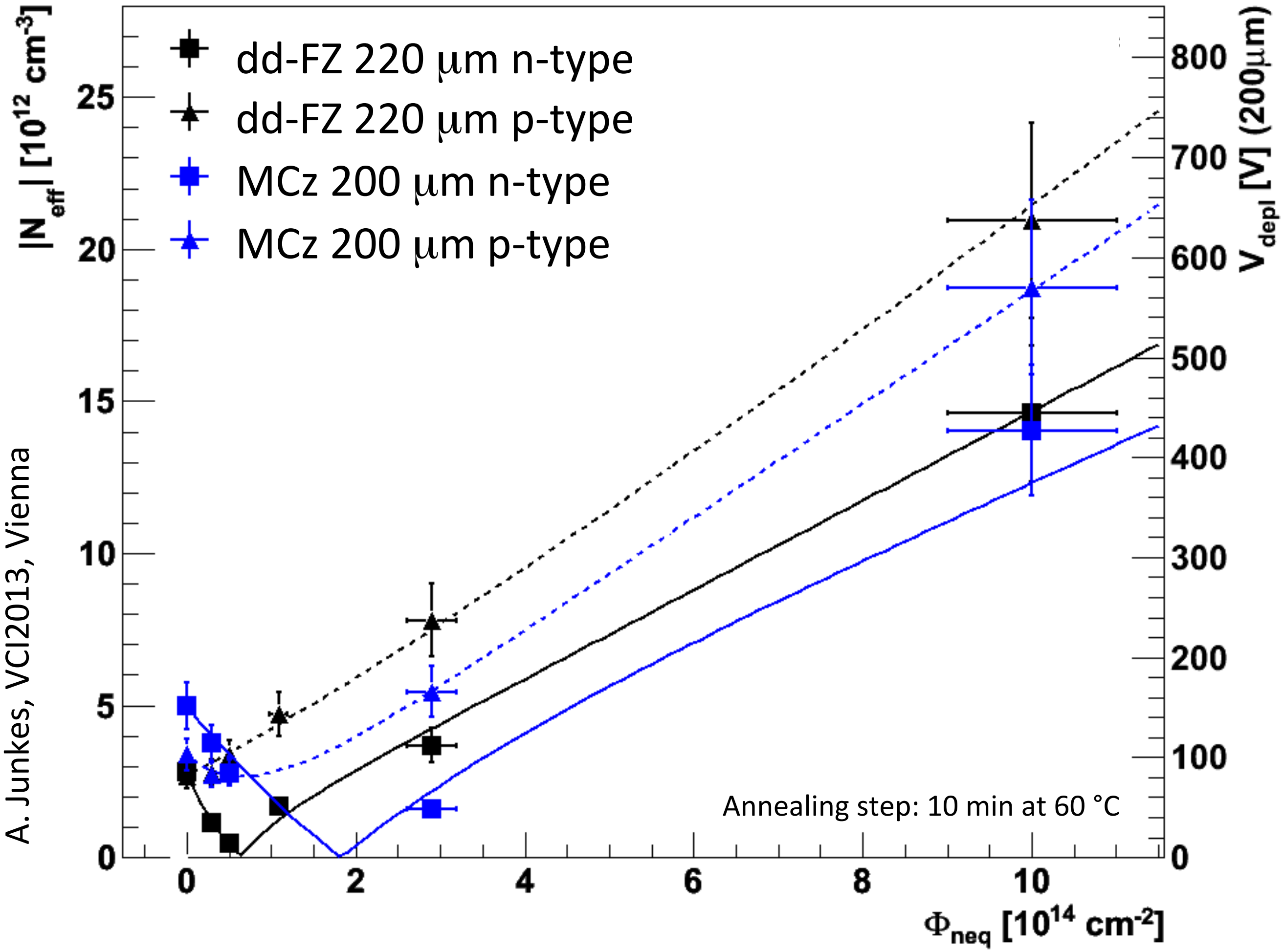




- Leakage current increases in accordance with received Φ_{eq}
- FZ: damage accumulated
- MCz-n: damage compensated

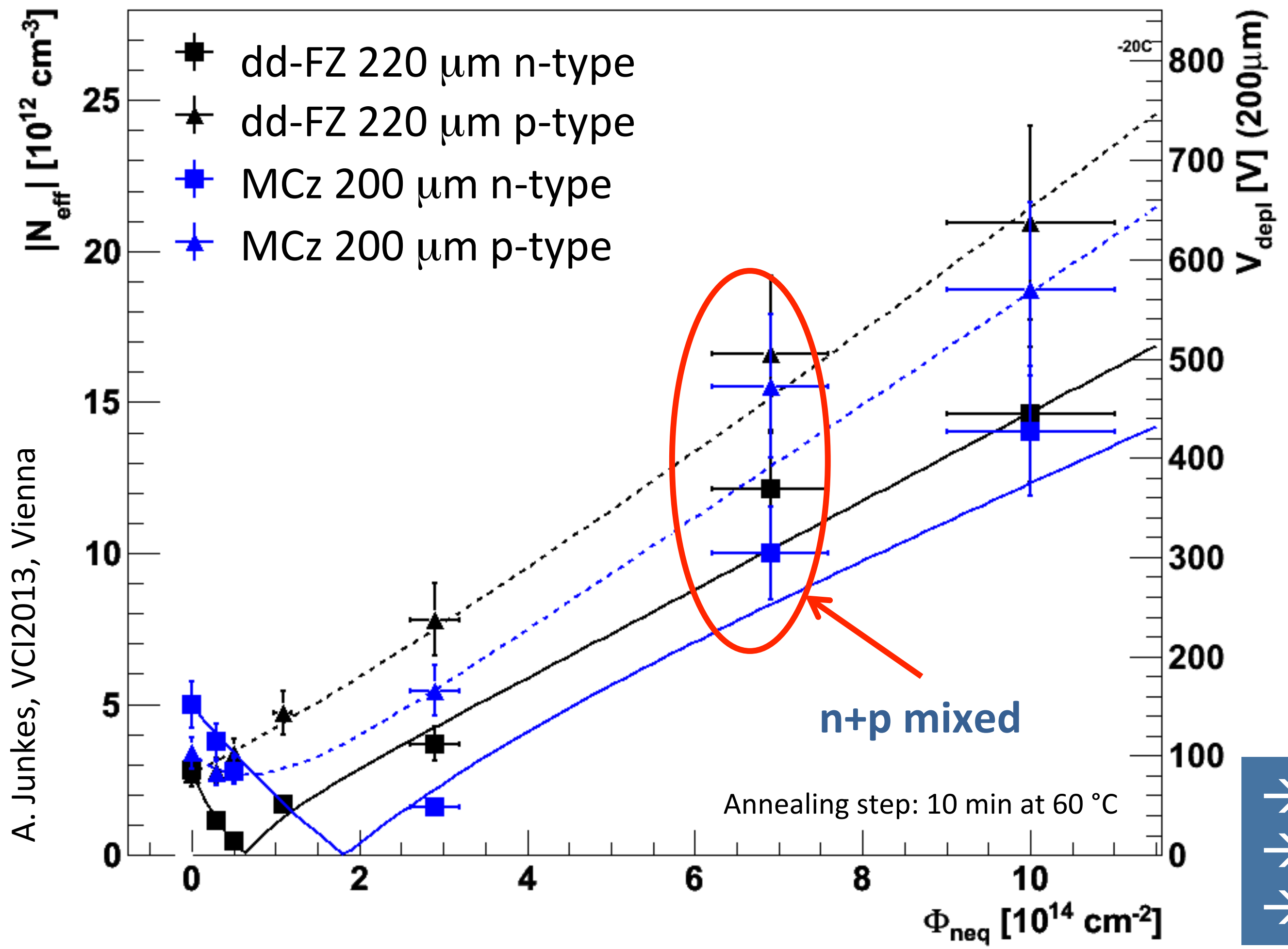
→ Donors introduced in p irradiation compensated by acceptors introduced in n-irradiation

Mixed irradiations: 23 MeV Protons



A. Junkes, VCI2013, Vienna

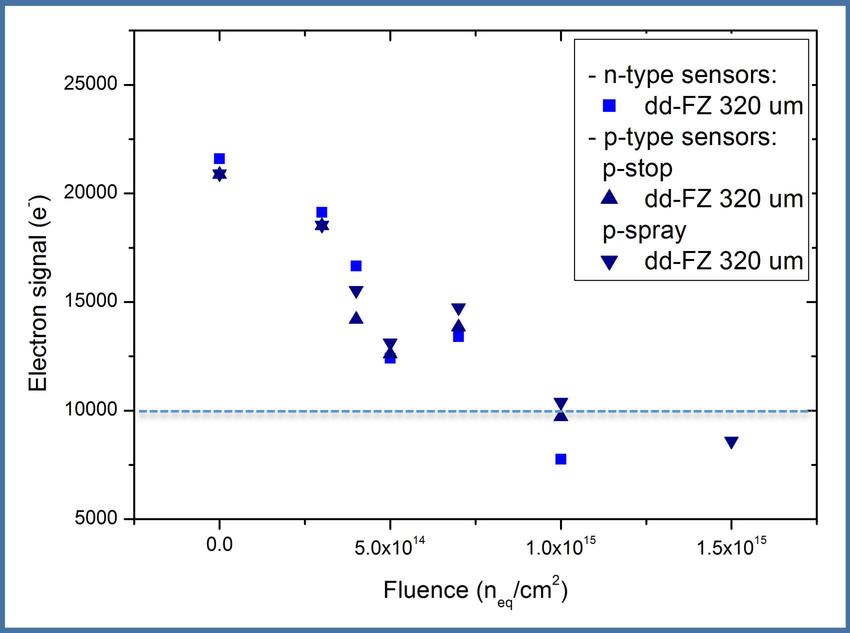
Mixed irradiations: 23 MeV Protons + Neutrons



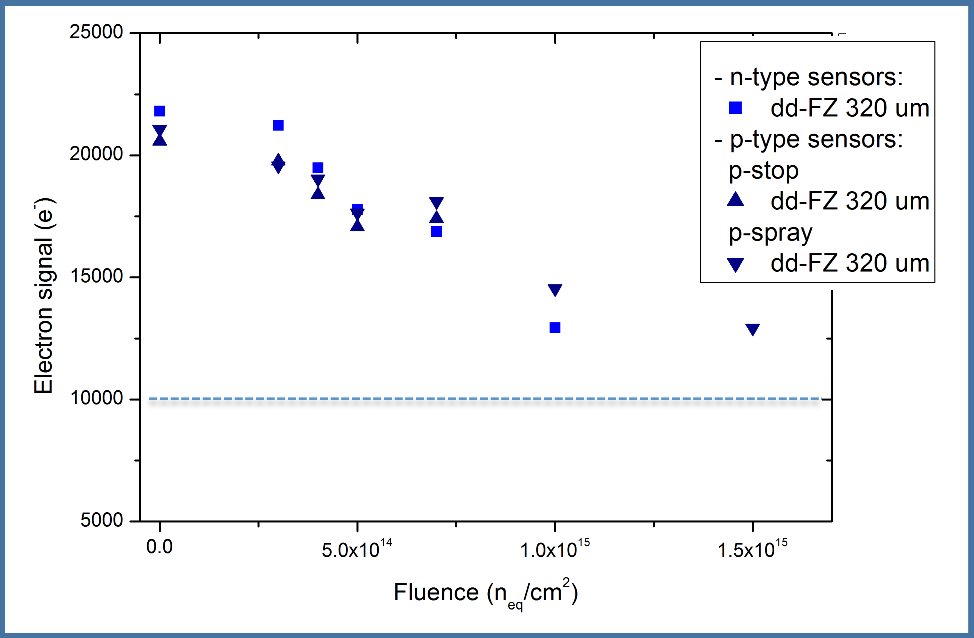
- → Fluences add up
- → No compensation effect
- → Test with 23 GeV p

Charge Collection from strip sensors

V_{bias} = 600 V



V_{bias} = 900 V



A. Junkes, VCI2013, Vienna

Measurement: β-setup with Alibava read-out

- FZ320 collects more charge up to $\Phi_{eq}=1\text{x}10^{15}$ cm^{-2}
- No significant difference between 200 µm and 300 µm above $\Phi_{eq}=1\text{x}10^{15}$ cm^{-2}

Charge Collection from strip sensors

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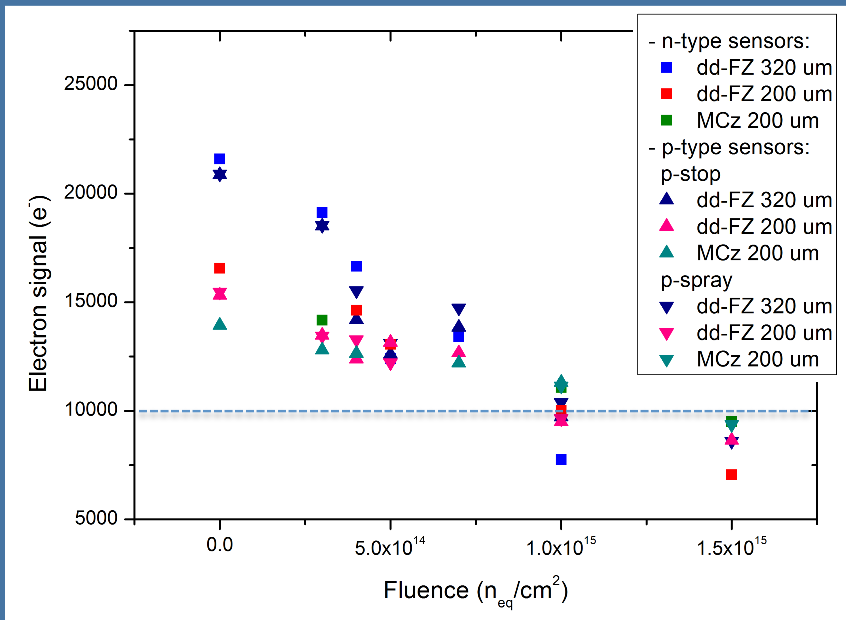

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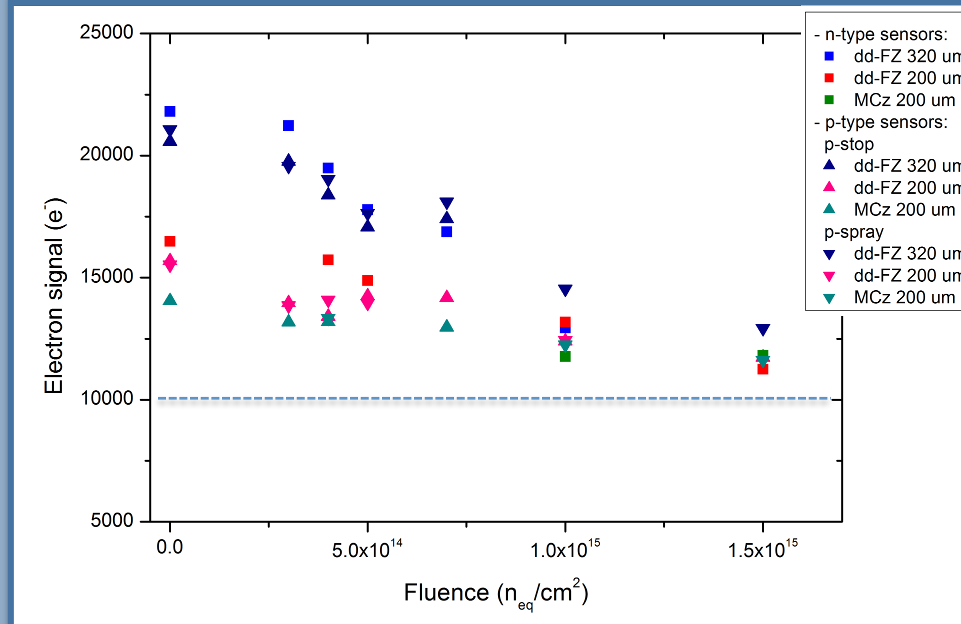

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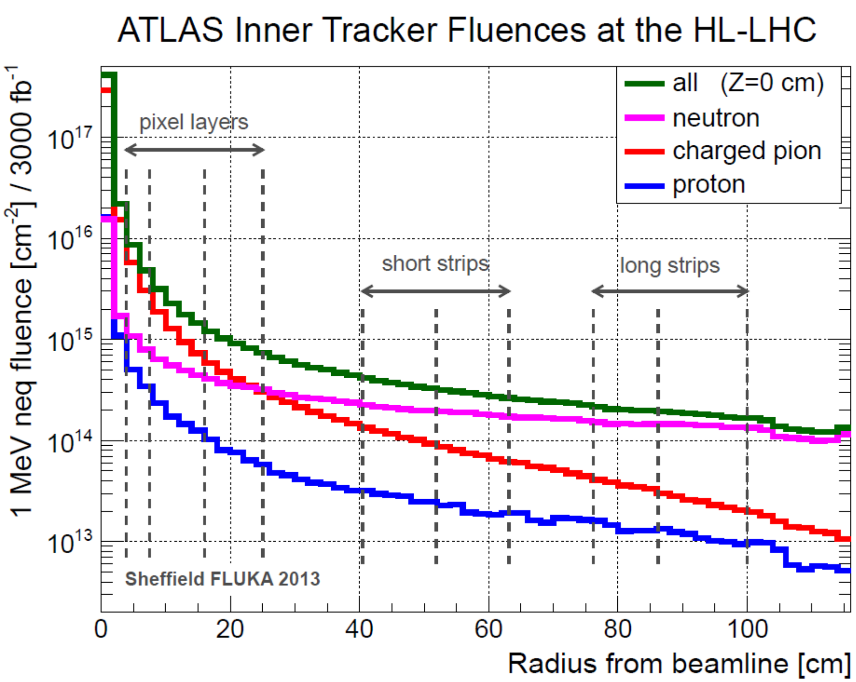
ATLAS planar n-in-p strip sensors



[I. Dawson, P. S. Miyagawa , Atlas Upgrade radiation background simulations]

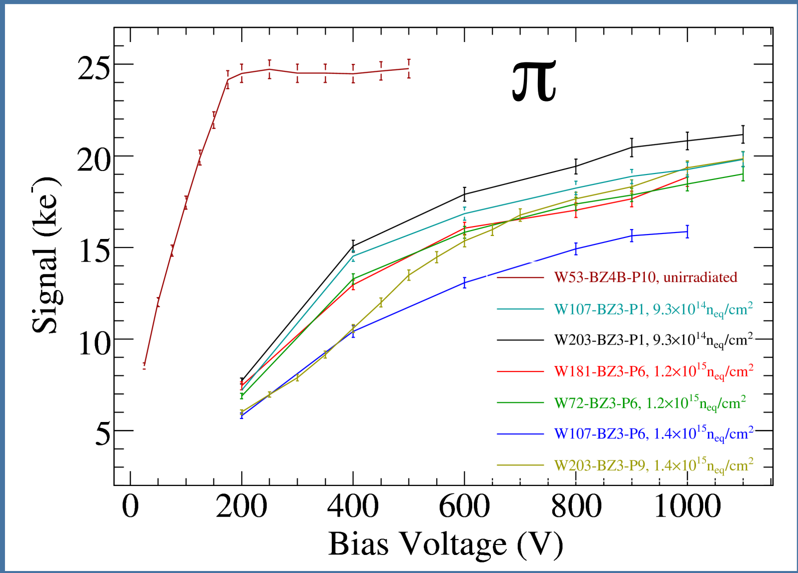
Mixed irradiation:
Irradiations corresponding to 3 specific radii in ATLAS ("strawman" layout v14-2009)

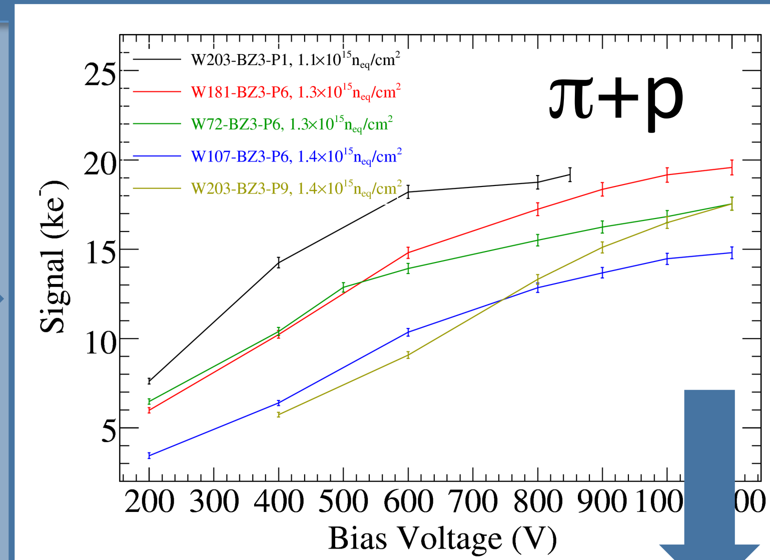
	fluence in n_{eq}/cm^2			
radius	pions	protons	neutrons	sum
19.0 cm	9.3×10^{14}	1.9×10^{14}	9.5×10^{14}	2.1×10^{15}
17.6 cm	1.2×10^{15}	1.9×10^{14}	1.0×10^{15}	2.4×10^{15}
14.2 cm	1.4×10^{15}	2.6×10^{14}	1.1×10^{15}	2.8×10^{15}

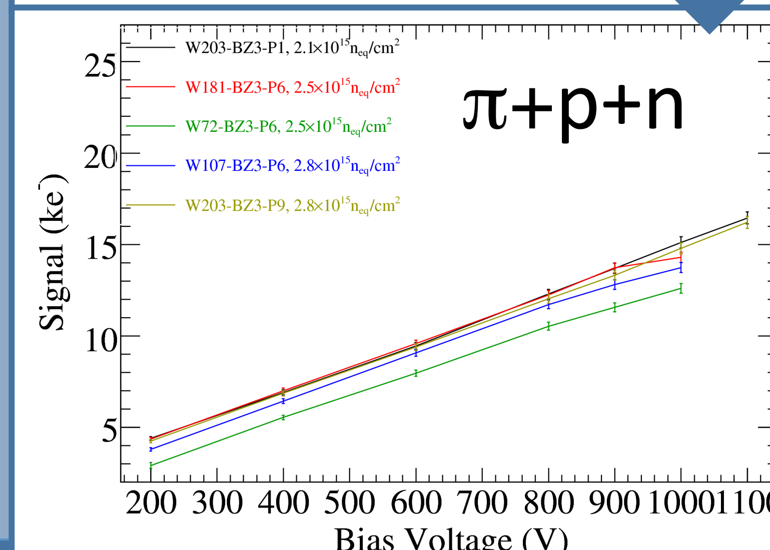
- Small n-in-p strip sensors from Hamamatsu, part of "ATLAS 07" production
- p-stop strip isolation, FZ silicon
- 320 µm thick, 74.5 µm strip pitch
- Size 1 cm x 1 cm (strip length 0.8 cm)
- AC coupling, 6.7 kΩcm resistivity

S. Kuehn, 21st RD50 meeting, 2012, CERN

Charge collection for n-in-p strip sensors







Collected charge increases with V_{bias}

- Max. signal after 2.8×10^{15} cm^{-2}: 11-16 ke (1000V)

Ileak at -21 °C similar values for all fluences:

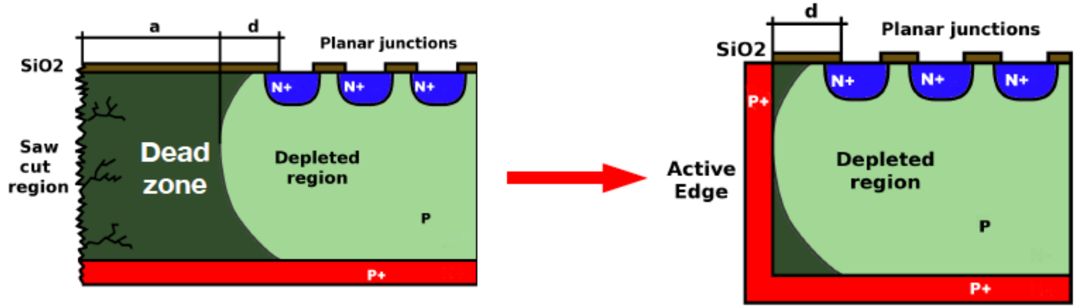
- At 400V: I_{leak}= 40 μA
- At 800V: I_{leak}= 64 μA

S. Kuehn, 21st RD50 meeting, 2012, CERN

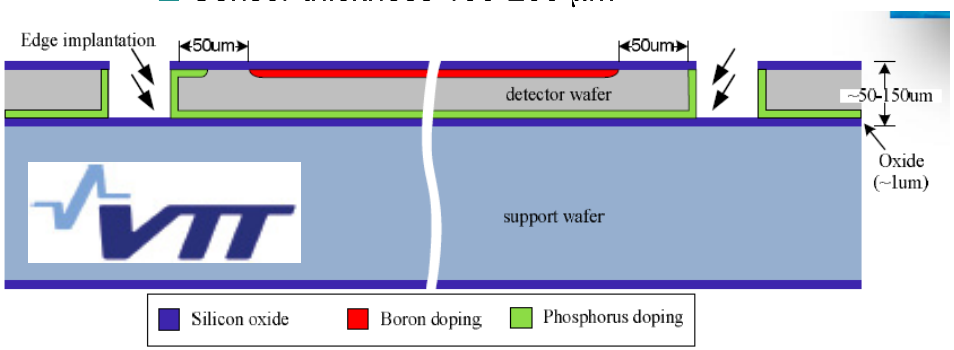
Active edges

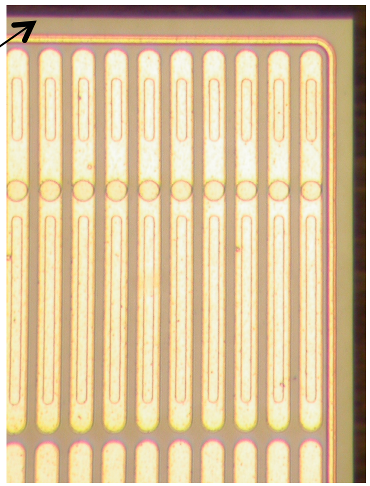
Reduce dead areas in sensors

- Active edges: Deep Reactive Ion Etching + Side implantation



- Trench doped by four-quadrant implantation
- Sensor thickness 100-200 μm
- Pixel-to-trench distance as low as 50 μm

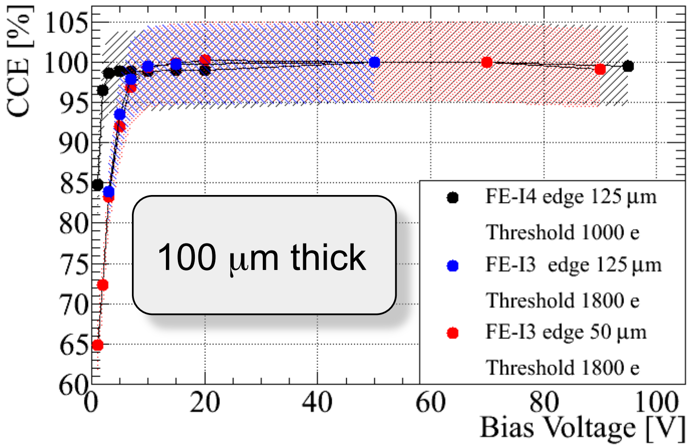




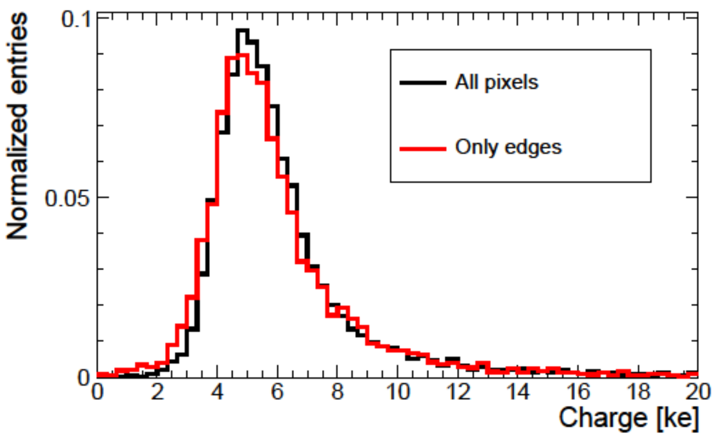
A. Macchiolo, VCI2013, Vienna

Characterization of active edge n-in-p sensors

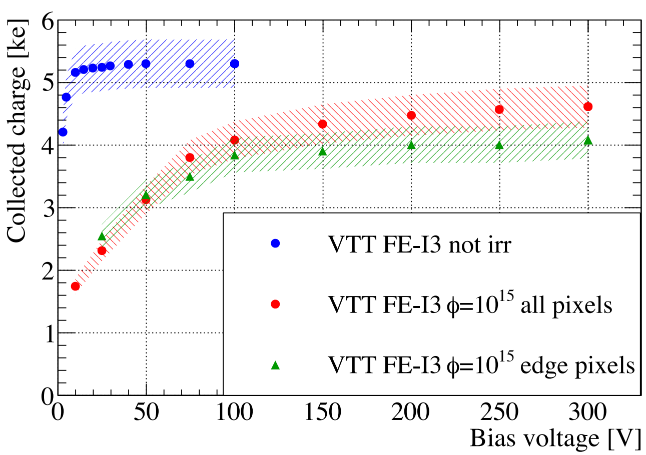
- CCE with ^{90}Sr scans before irradiation

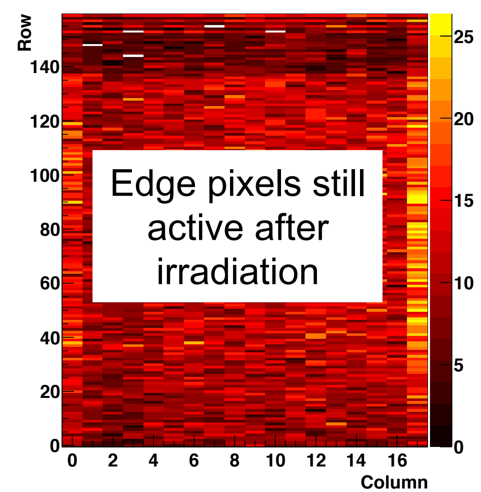


- Edge pixels show the same charge collection properties as the central ones



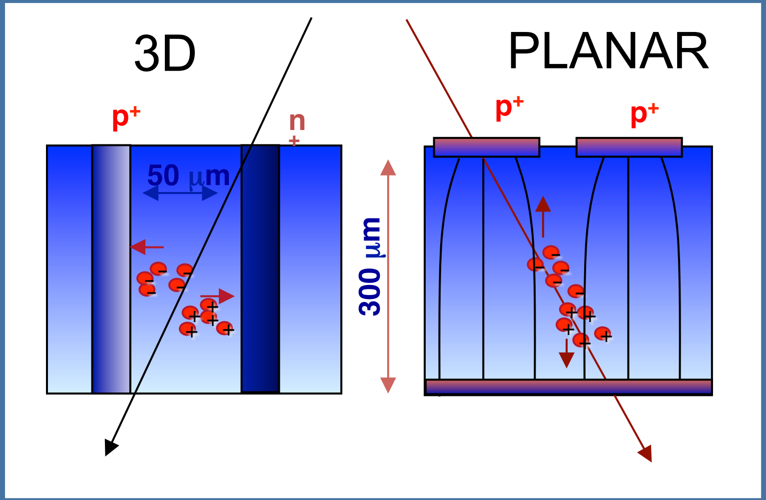
After irradiation: $\Phi=10^{15}$ n_{eq} cm^{-2}





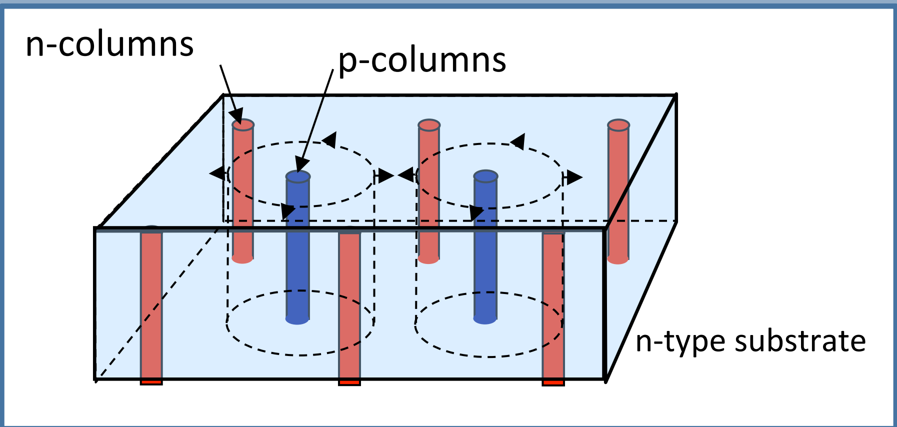
A. Macchiolo, VCI2013,Vienna

3D Detectors

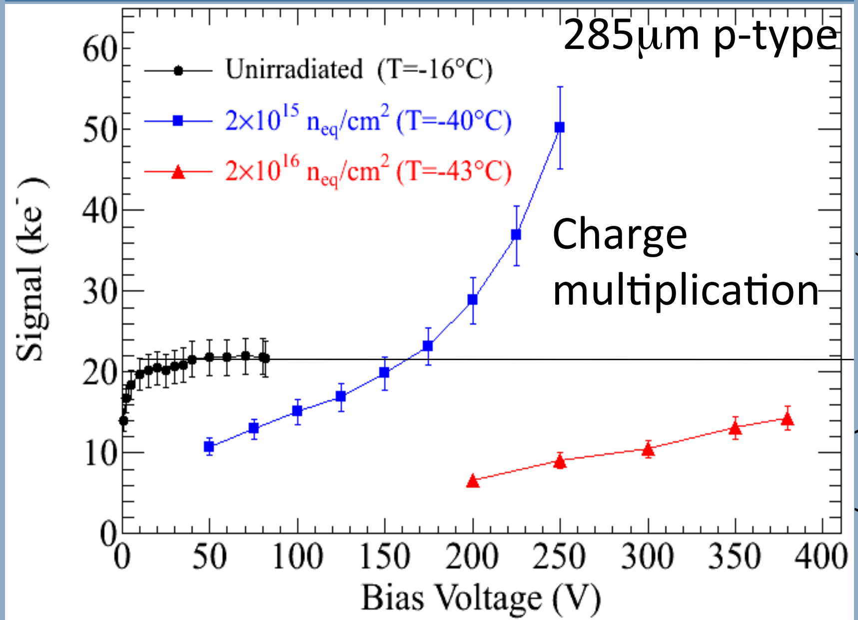


- **"3D" electrodes:** - Narrow columns along detector thickness
  - Diameter: 10 µm, distance: 50 – 100 µm
- **Lateral depletion:** - Lower depletion voltage needed
  - Thicker detectors possible
  - Fast signal

3D proposed by Parker and Kenney. See NIM A 395 (1997) 328

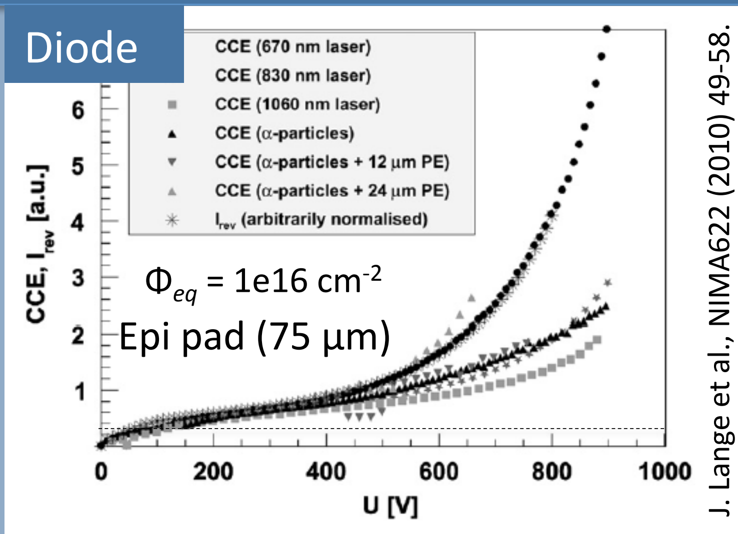


Charge collection with ^{90}SR-source

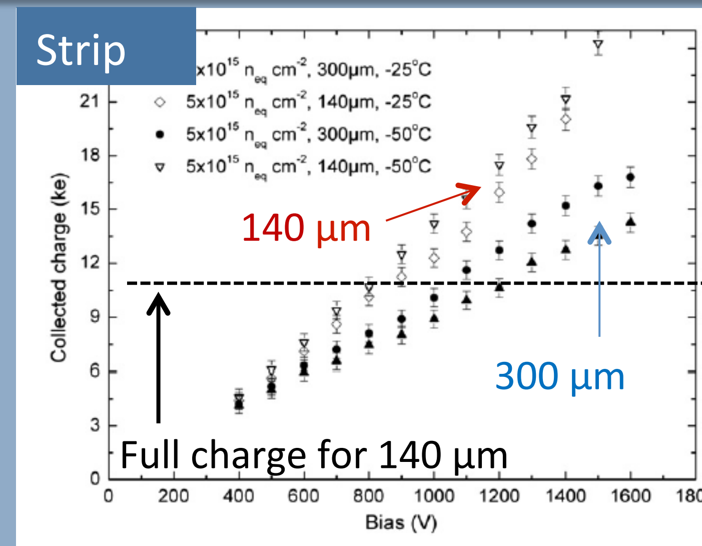


M. Köhler et al., NIM A 659 (2011) 272

Charge multiplication



J. Lange et al., NIMA622 (2010) 49-58.

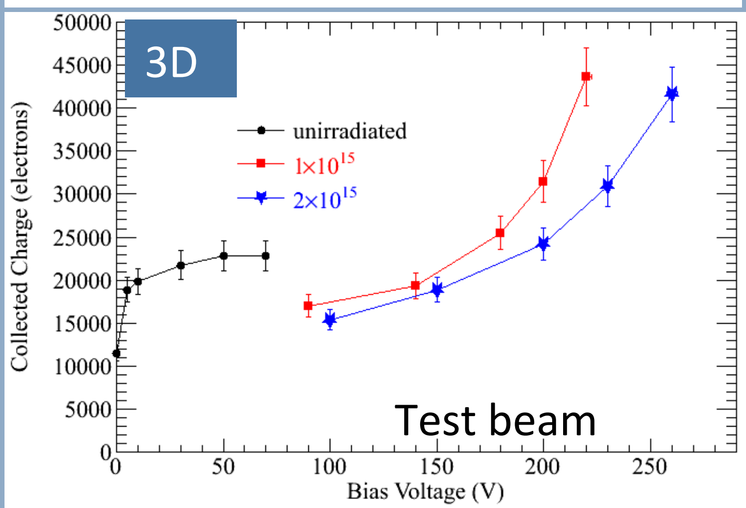


G. Casse et al., NIMA 624, 2010, 401-404

Φ_{eq} = 5e15 cm^{-2}, ^{90}Sr- alibava readout

M. Koehler et al., (2011) NIMA659 272-281

A. Affolder et al., (2011) NIMA658 11-16



Impact ionization in silicon begins when the electric field reaches 10-15 V/µm

Charge Multiplication measured after high levels of irradiation with different techniques and in several different types of devices

Charge multiplication studies

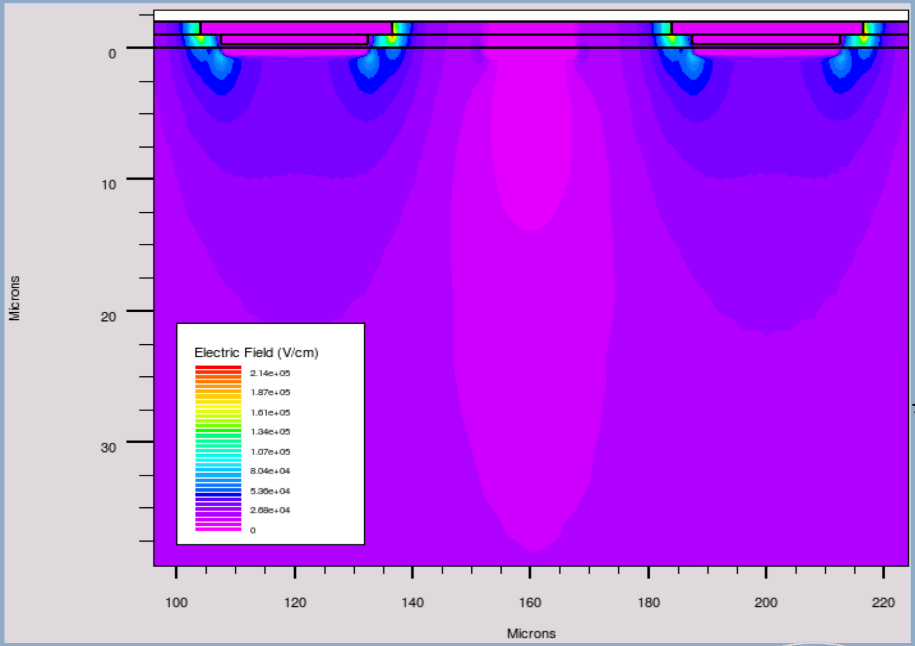
Dedicated RD50 sensors:

Geometry

- Depth (d = 150 µm, 305 µm, 675 µm)
- Width/pitch (0.075 < w/p < 0.75)
- Interstrip
- Active area: 10.18 mm x 11.76 mm

Processing

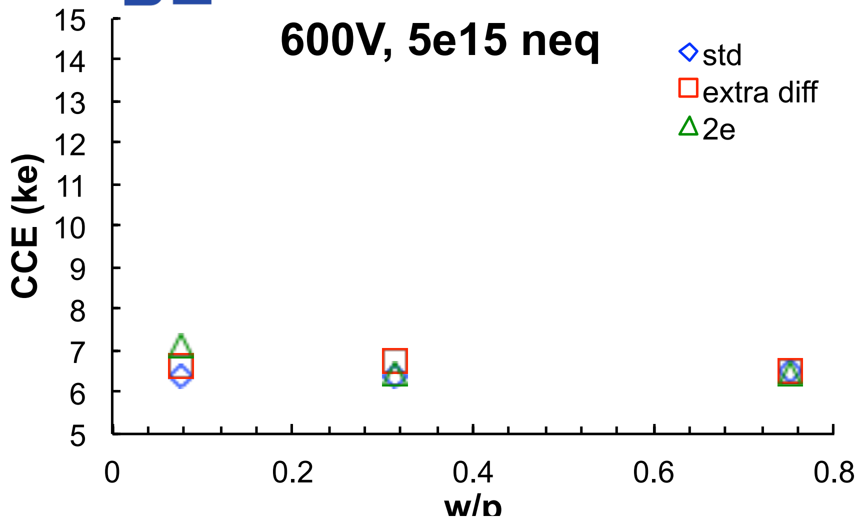
- Diffusion time
- Implantation energy

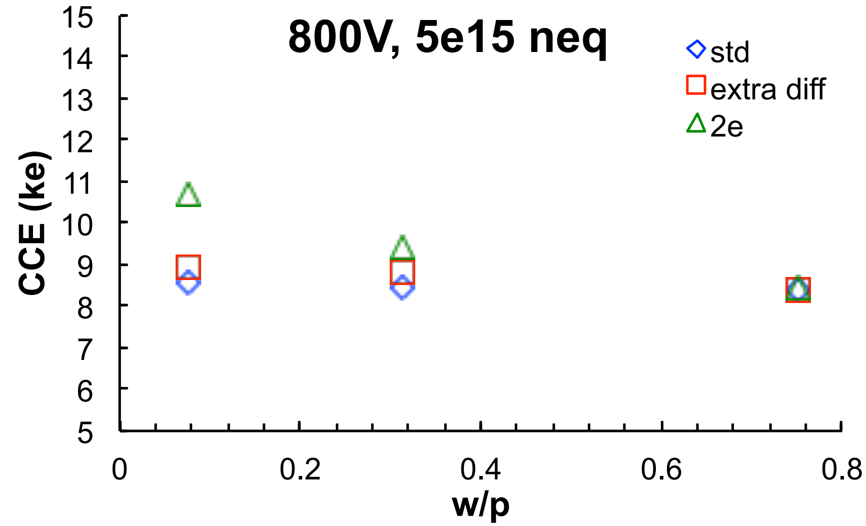


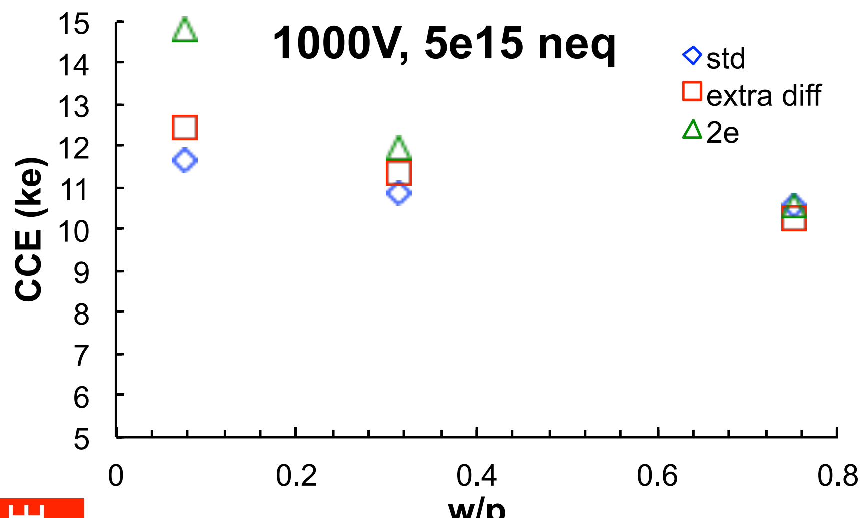
L. Altan, 20th RD50 meeting 2012, Bari

MICRON strip detectors of various geometries
1 cm x 1 cm, n-in-p FZ strip detectors developed by MICRON
5 type of wafers were produced: standard, double diff. time, double implant energy, thick and thin

Multiplication effects







- CM only seen at V_{bias} > 600V
- Both Extr. Diff. and 2E imp. Show signs of CM with respect to standard wafer
- Lower w/p ratio leads to more pronounced multiplication (as expected)

C. Betancourt, 21st RD50 meeting, 2012 CERN

Summary

Mixed irradiations important for accurate analysis of expected damage in sensors

Planar sensors perform pretty well for the strip region

3D detectors, active edge design, charge multiplication under development

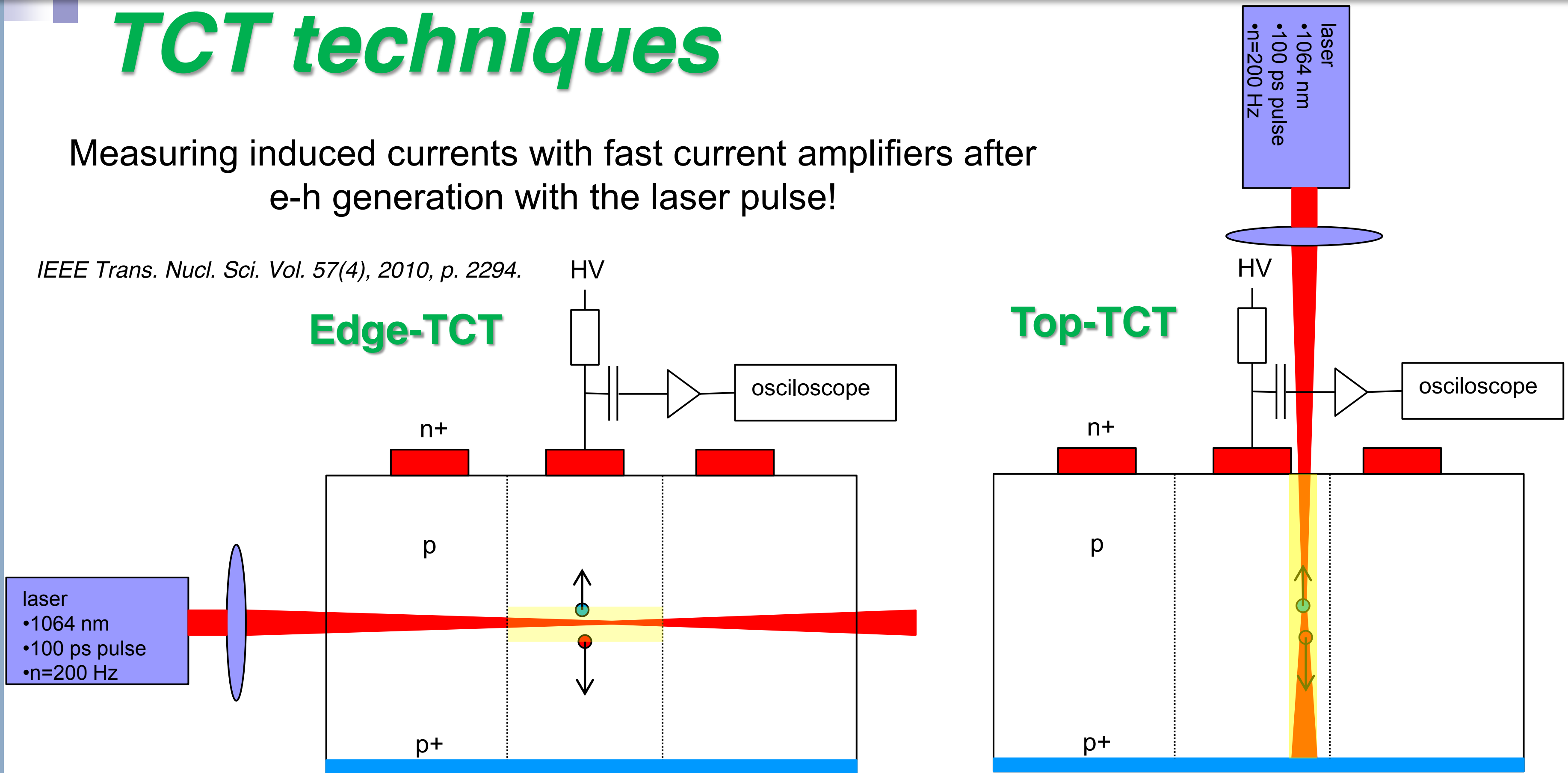
Back up

TCT techniques

TCT techniques

Measuring induced currents with fast current amplifiers after e-h generation with the laser pulse!

IEEE Trans. Nucl. Sci. Vol. 57(4), 2010, p. 2294.

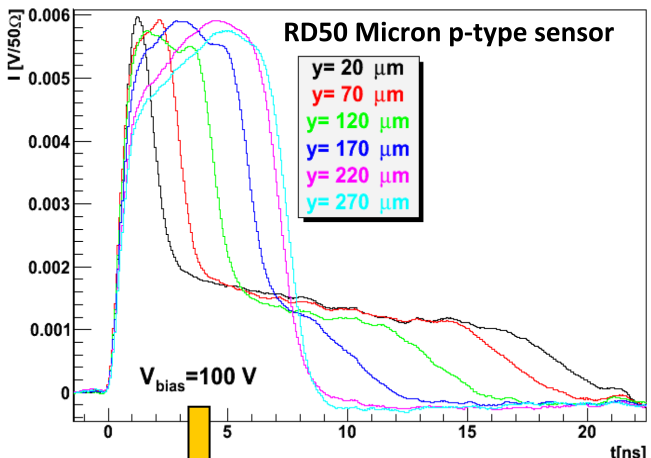


- Probing the field in depth (average)
  - Charge collection profile: $Q(y) = \int_0^{20ns} I(y,t)dt$
  - Velocity profile : $I(y,t\sim 0) \propto (v_e + v_h)(y)$
- Probing the lateral field (average)
  - Properties of the mid-strip region
  - Multiplication profiles
  - Trapping induced charge sharing

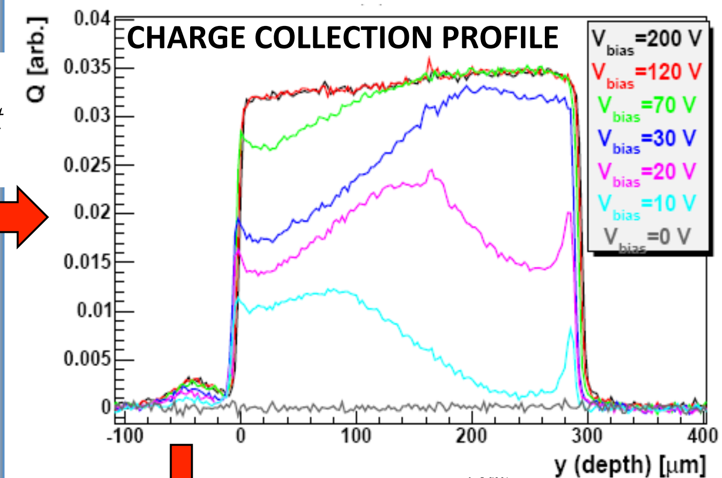
G. Kramberger, Vertex 2012

Charge and velocity profiles from e-TCT

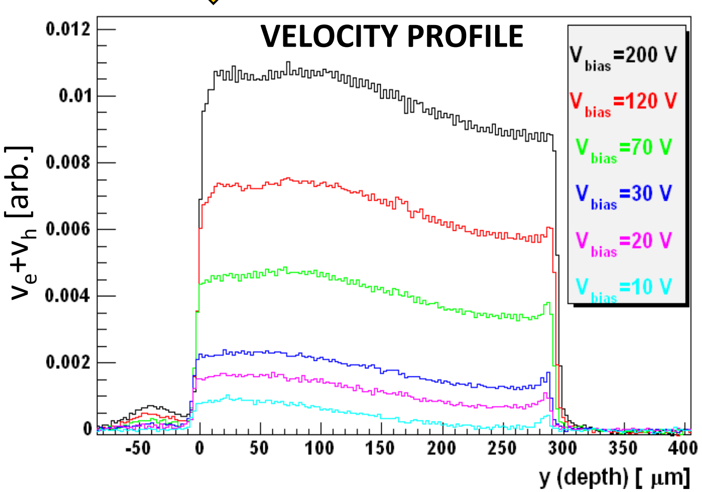
G. Kramberger, 17th RD50 Workshop (2010)



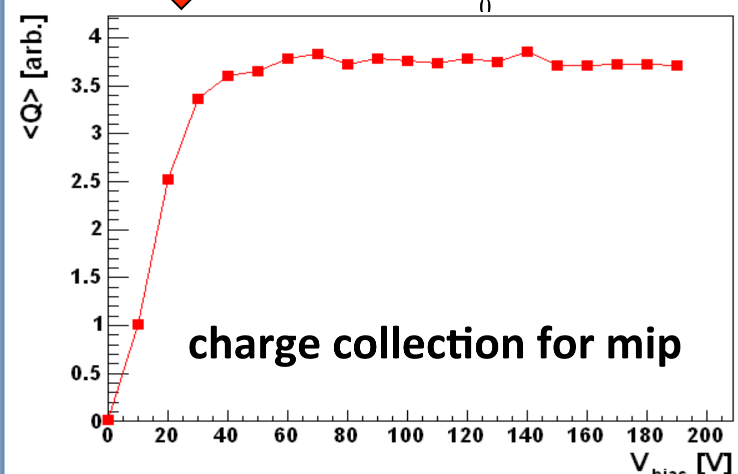
$$Q(y) = \int_0^{25ns} I(y,t)\,dt$$



$$I(y,t \sim 0) \propto v_e + v_h$$



$$Q_{mip} \propto \langle Q \rangle = \int_0^{25ns} I(y,t)\,dt$$



Beta Source Measurements

- MIPs from a ^{90}Sr source are used to perform charge collection measurements
- Time between trigger signal and edge of a 10 MHz clock is measured by the ALIBAVA TDC
- For each event, channel with largest SNR is chosen, and mean is calculated for each 1 ns time bin
- Only events in 10 ns window around max are considered
- Resulting spectrum is fitted with a convolution of a Gaussian and Landau distribution to determine MPV