TIPP '14

International Conference on Technology and Instrumentation in Particle Physics

2 – 6 June 2014 / Amsterdam, The Netherlands

"Instrumentation as enabler of Science"

Silicon Sensors for High Luminosity Trackers
RD50 Status Report

TIPP '14

03.06.2014

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Susanne Kuehn, Albert-Ludwigs-University Freiburg

On behalf of the RD50 Collaboration

RD50 - Radiation hard semiconductor devices for very high luminosity colliders

Outline

- Introduction
- Results from (selected) Research Fields of the RD50 Collaboration
- Achievements and Findings for LHC Experiments
- Summary

Only a selection on interesting topics, the full variety of RD50 can be found on:
http://rd50.web.cern.ch/rd50/

Structure and Research Fields of RD50

Co-Spokespersons

Gianluigi Casse **and** ***Michael Moll***

(Liverpool University) (CERN PH-DT)

Defect / Material Characterization

Mara Bruzzi
(INFN & Uni Florence)

- **Characterization of microscopic properties of standard-, defect engineered and new materials pre- and post-irradiation**
- **DLTS, TSC, …**
- **SIMS, SR, …**
- **NIEL (calculations)**
- WODEAN: Workshop on Defect Analysis in Silicon Detectors (G.Lindstroem & M.Bruzzi)

Detector Characterization

Eckhart Fretwurst
(Hamburg University)

- **Characterization of test structures (IV, CV, CCE, TCT)**
- **Development and testing of defect engineered silicon devices**
- **EPI, MCZ and other materials**
- **NIEL (experimental)**
- **Device modeling**
- **Operational conditions**
- **Common irradiations**
- Devices Simulations (V. Eremin)
- Wafer procurement (M.Moll)

New Structures

Giulio Pellegrini (CNM Barcelona)

- **3D detectors**
- **Thin detectors**
- **Cost effective solutions**
- **Detectors with internal gain (avalanche detectors)**
- **Slim edges**
- **Other new structures**

- 3D (R.Bates)
- LGAD (V. Greco)
- Thinned detectors
- Slim Edges (H.Sadrozinski)

Full Detector Systems

Gregor Kramberger
(Ljubljana University)

- **LHC-like tests**
- **Links to HEP**
- **Links electronics R&D**
- **Low rho strips**
- **Sensor readout (Alibava)**
- **Comparison:**
  - pad-mini-full detectors
  - different producers
- **Radiation Damage in HEP detectors**

- Test beams (G.Casse)

Collaboration Board Chair & Deputy: G.Kramberger (Ljubljana) & J.Vaitkus (Vilnius), Conference committee: U.Parzefall (Freiburg)
CERN contact: M.Moll (PH-DT), Secretary: V.Wedlake (PH-DT), Budget holder & GLIMOS: M.Glaser (PH-DT)

M.Moll 09/2013 + Update

The RD50 Collaboration

41 European institutes

Belarus (Minsk), Belgium (Louvain), Czech Republic (Prague (3x)), Finland (Helsinki, Lappeenranta), France (Paris), Germany (DESY, Dortmund, Erfurt, Freiburg, Hamburg, Karlsruhe, Munich(2x)), Greece (Demokritos), Italy (Bari, Florence, Perugia, Pisa, Torino), Lithuania (Vilnius), Netherlands (NIKHEF), Poland (Krakow, Warsaw(2x)), Romania (Bucharest (2x)), Russia (Moscow, St.Petersburg), Slovenia (Ljubljana), Spain (Barcelona(2x), Santander, Valencia), Switzerland (CERN, PSI), Ukraine (Kiev), United Kingdom (Glasgow, Liverpool)

Collaborators from several experiments at the LHC: ATLAS, CMS and LHCb and also from ILC
→ Cross-experiment discussions

6 North-American institutes

Canada (Montreal), USA (BNL, Fermilab, New Mexico, Santa Cruz, Syracuse)

1 Middle East institute Israel (Tel Aviv)

1 Asian institute India (Delhi)

14th Workshop in Freiburg, 2009

→ **49 institutes and 275 members**

+ 21 observers

→ **Workshops**

→ **Irradiation facilities**

More details on: http://rd50.web.cern.ch/rd50/

Challenge: Radiation Damage in the upgrade of LHC

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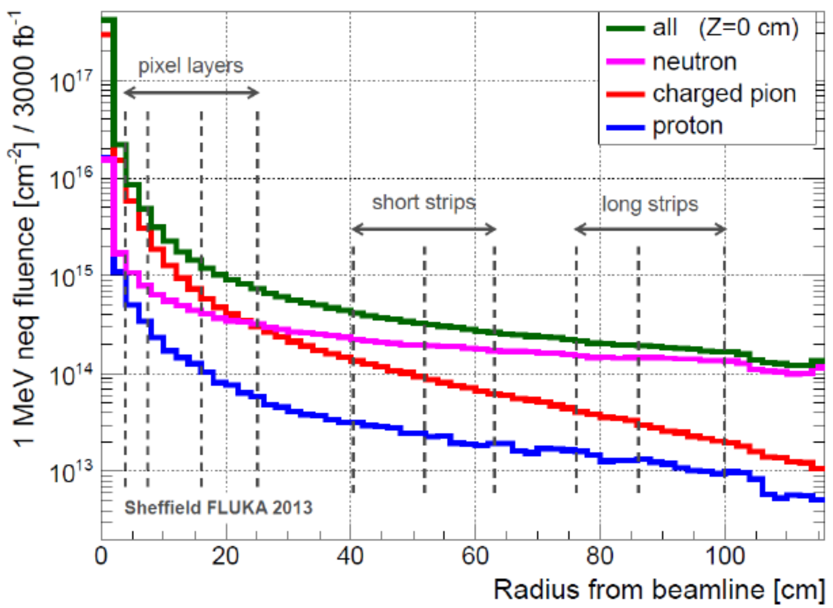
Planned upgrade of the LHC to HL-LHC (and beyond HE-LHC, VHE-LHC)
For HL-LHC in ~2023: 3000 fb^{-1} expected integrated luminosity

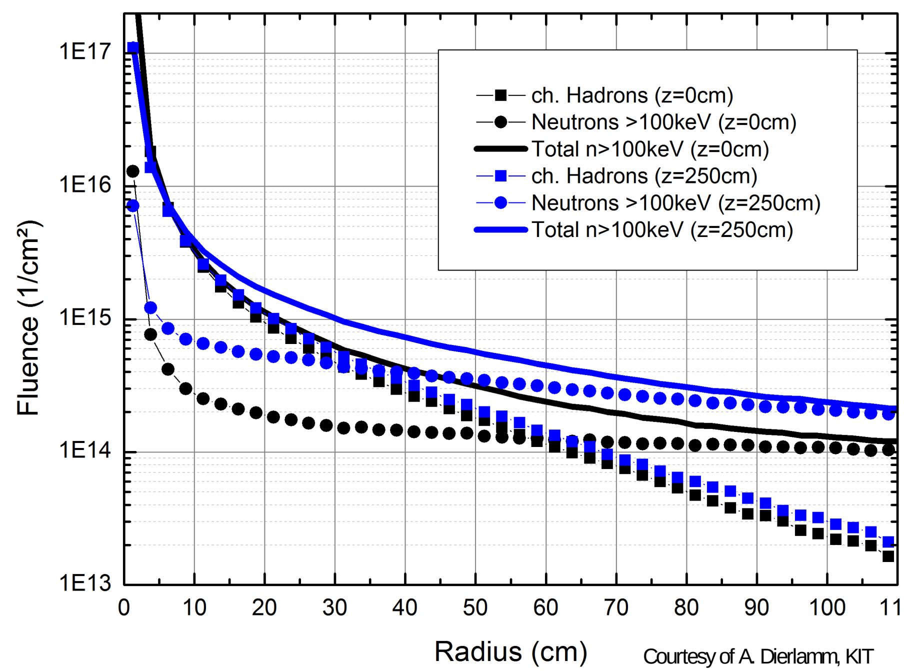
Expected particle fluences for

the ATLAS Inner tracker:



I. Dawson, P. S. Miyagawa, Sheffield University, Atlas Upgrade radiation background simulations

the CMS tracker:



Courtesy of A. Dierlamm, KIT

→ Pixel damage due to neutrons and pions, strips mainly due to neutrons
→ Exposure up to $1*10^{16}$ neq/cm^2
→ **Investigation and understanding of radiation damage of sensors needed**

Defect Characterization

Albert-Ludwigs-Universität Freiburg

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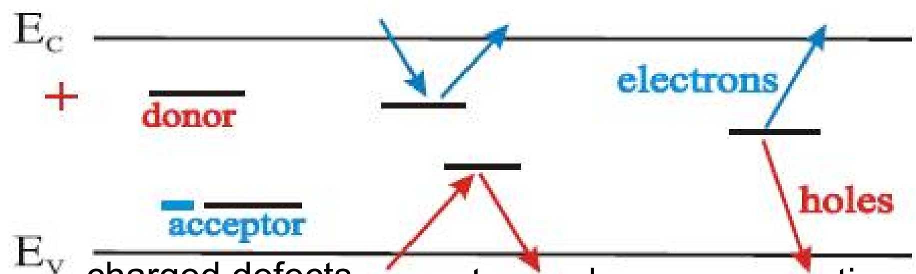
- Generation of defects depending on incident particle type and energy
- Goal: Identify defects causing change of detector properties, namely trapping, leakage current and N_{eff} (V_{dep})

  → use knowledge for device engineering and input to simulations



charged defects, V_{dep}, N_{eff}

capture e, h → trapping

generation e,h → leakage current

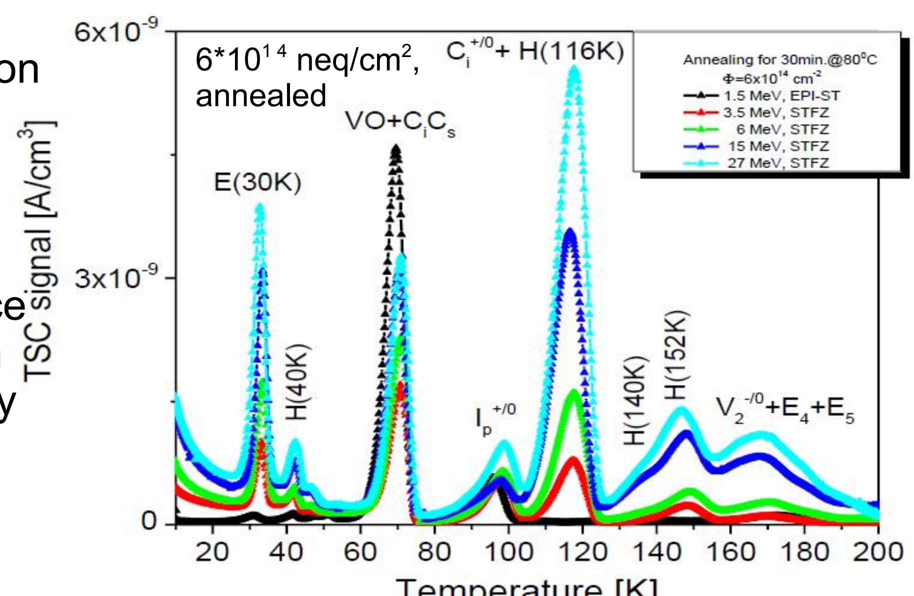
Defect parameters: cross section, ionization energy, concentration, type

- Work: Defect Analysis on many identical samples performed with the various tools in RD 50 Collaboration
  - C-DLTS (Capacitance Deep Level Transient Spectroscopy)
  - I-DLTS (Current Deep Level Transient Spectroscopy)
  - TCT (Transient Charge Technique)
  - TSC (Thermally Stimulated Current)
  - CV/IV (Capacity/Voltage vs. Current) ..
- Tests after irradiation with protons, neutrons, electrons and ^{60}Co-gammas

TSC measurement on defects after electron irradiation

↓

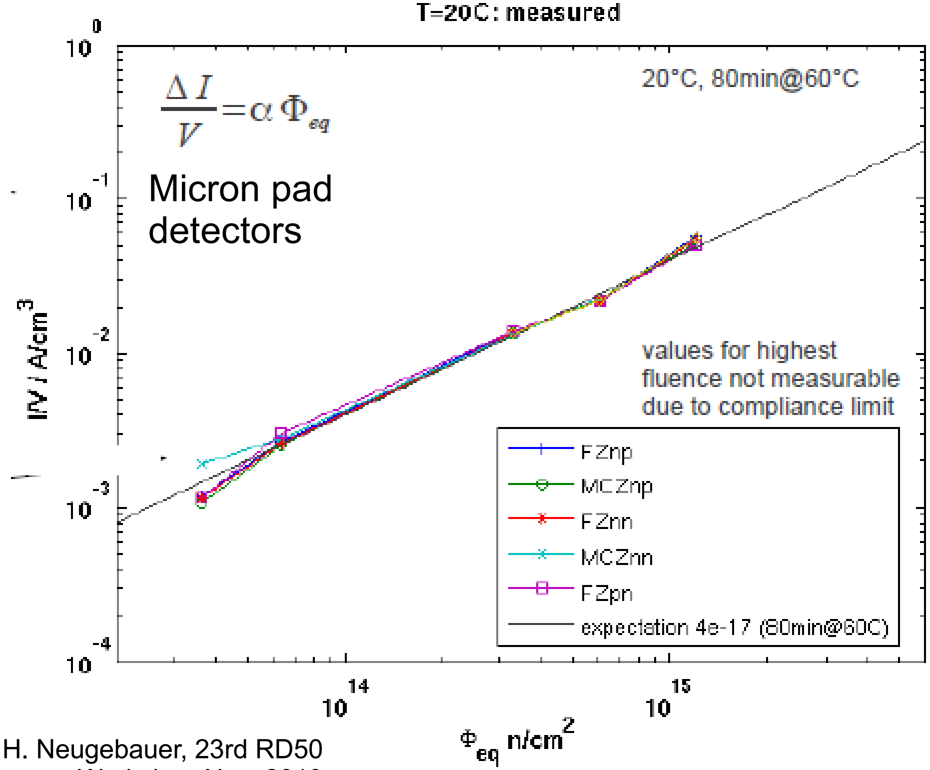
dependence on electron energy



I. Pintilie, 23rd RD50 Workshop, Nov. 2013

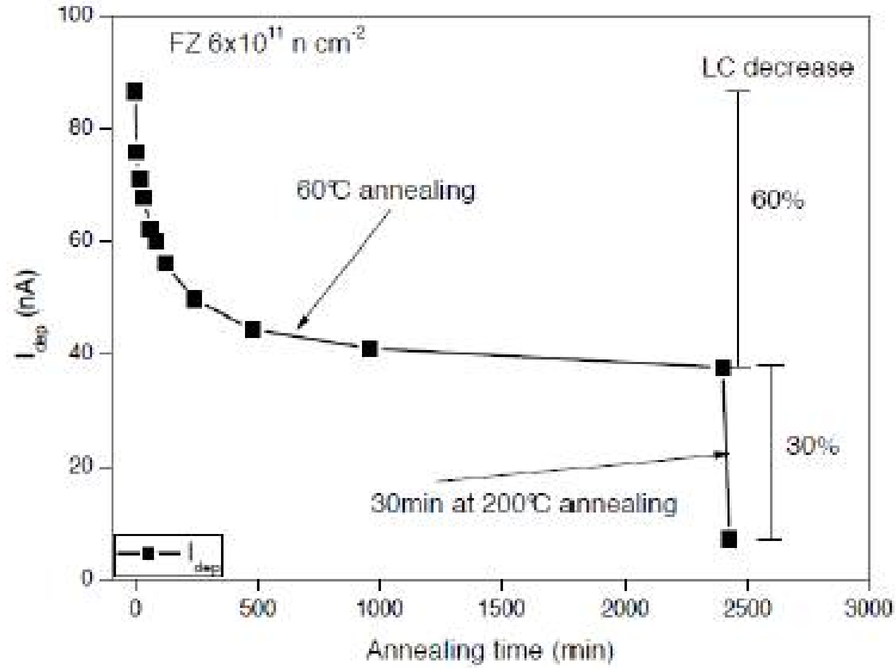
Impact of Defects: Change of I_{leak}

- Dependence of leakage current on material



H. Neugebauer, 23rd RD50 Workshop Nov. 2013

- Dependence on annealing



A. Junkes PoS(Vertex2011)035

- Leakage current independent of material
  - Scales with fluence α = $4.38 \cdot 10^{-17}$ A/cm² up to $2 \cdot 10^{15}$ Neq/cm²
- Leakage current decreases after annealing, temperature dependent
- DLTS result due to defects E4/E5 and E205a

Defect Characterization Overview

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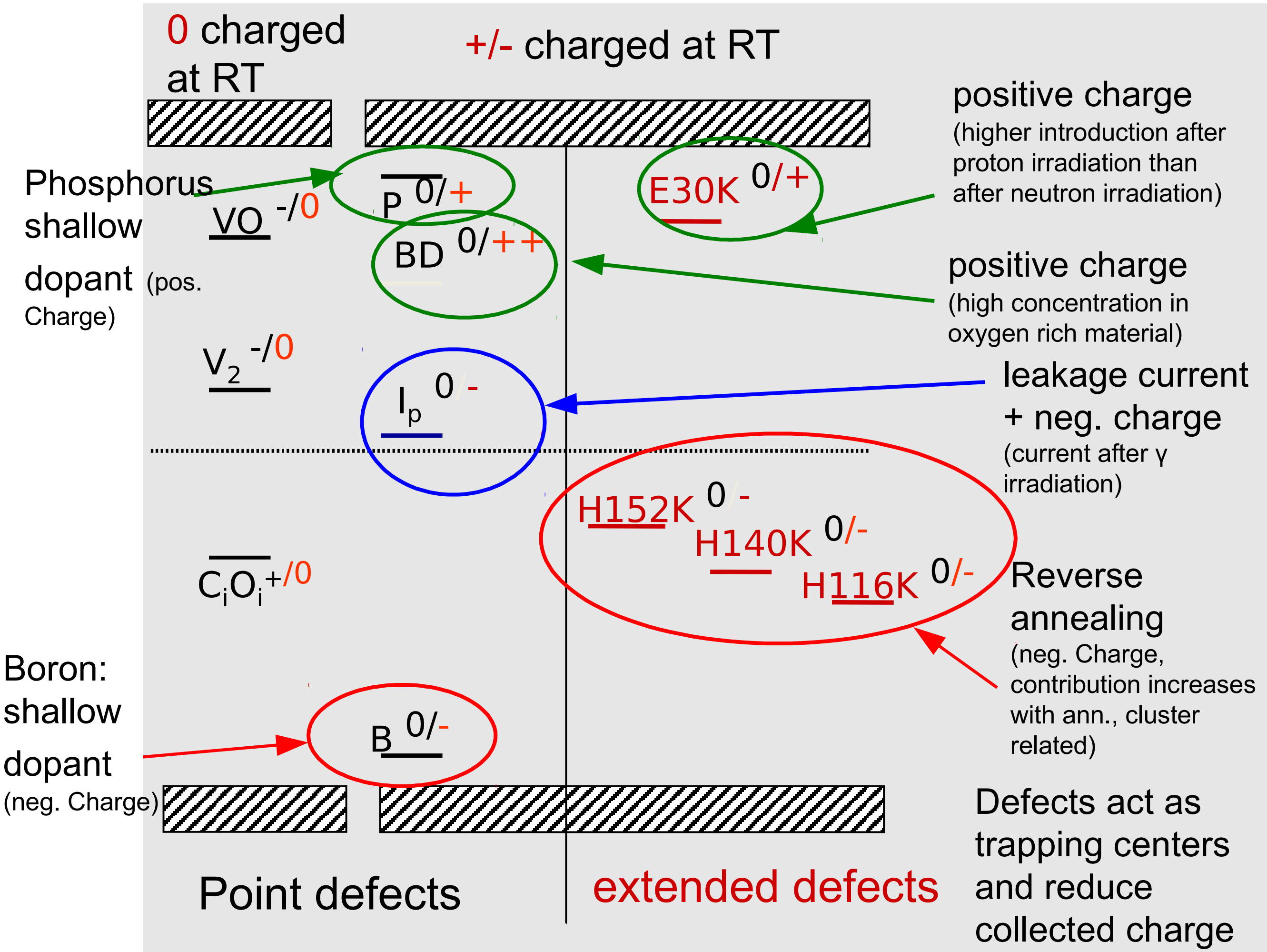
- WODEAN (Workshop on Defect Analysis in Silicon Detectors) since 2005



G. Casse, M.Moll, LHCC report 2012

I.Pintilie et al., Appl. Phys. Lett.92 02410, 2008

Achievements:
- Consistent set of defects after different irradiations
- Defect introduction rates depend on particle type and energy
- H152K indicated to trigger trapping

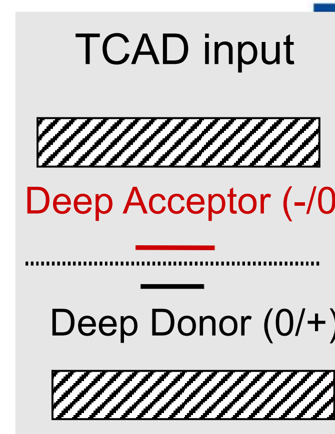
→ More measurements and understand effects by using simulation

Simulation group in RD50

Albert-Ludwigs-Universität Freiburg

- **Goal: development of approach for simulation of performance of irradiated silicon detectors using professional software**

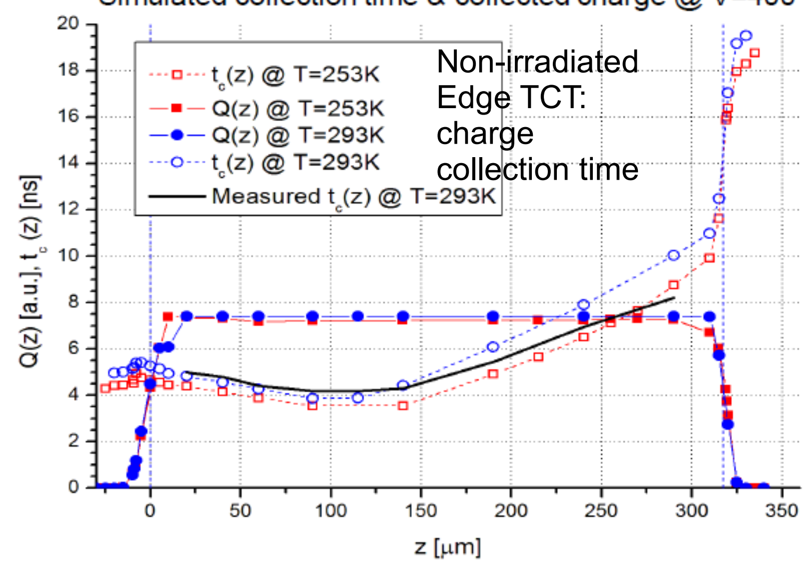
- Simulations needed to predict electric fields (double junction), trapping
- Several institutes involved
- Using effective mid gap levels in simulation
- Large parameter space needs tuning to experimental TCT results (introduction rates, cross sections of defects)



→ **Start to have predictive power**
→ **Leakage current, depletion voltage, partially trapping of irradiated sensor can be modelled**

- Aim to prepare **common database** with cross sections, concentrations
- **More tuning** needed and ongoing e.g.using Edge-TCT results to compare E-field profile

Simulated collection time & collected charge @ V=400 V



P-in-n, 320 μm, strip w=14 μm, implant w=10 μm, pitch=80 μm   T. Peltola, 23rd RD50 Workshop Nov. 2013

See Poster: Development of Radiation Damage Model using TCAD tools for Irradiated Silicon Sensors

Full detector systems: Planar Detectors FZ

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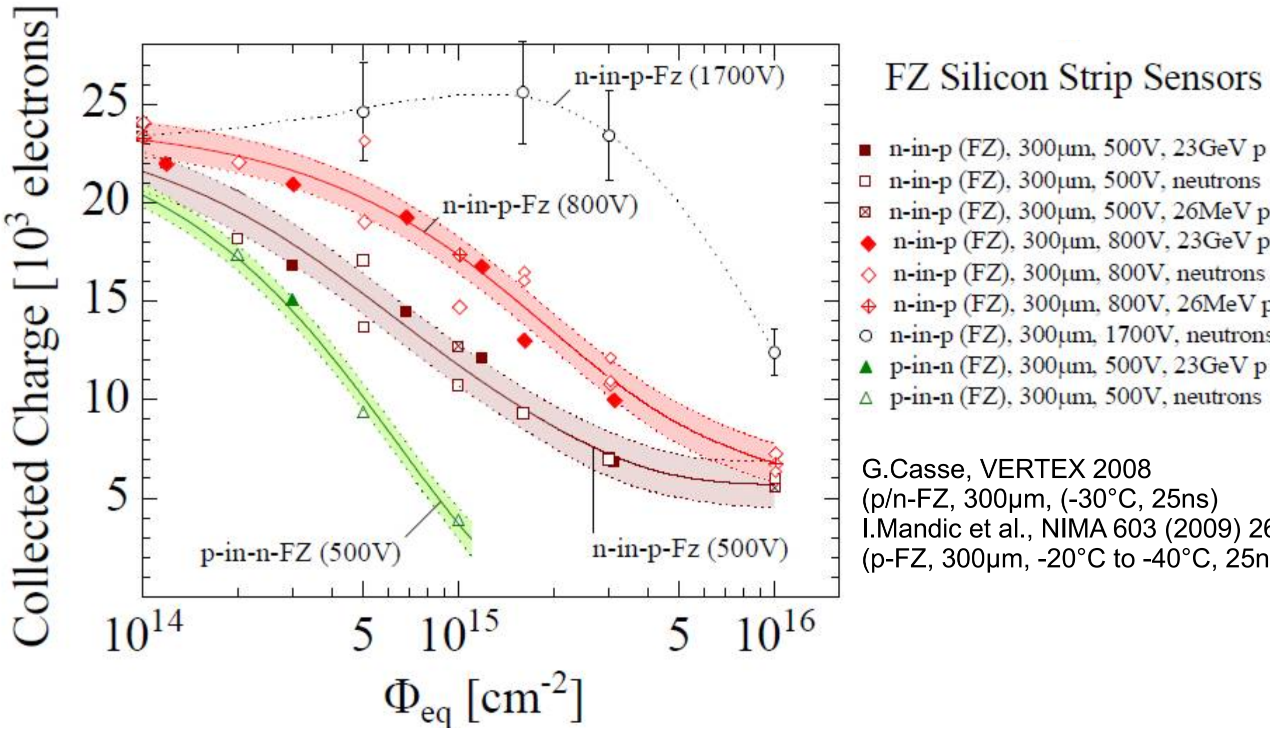
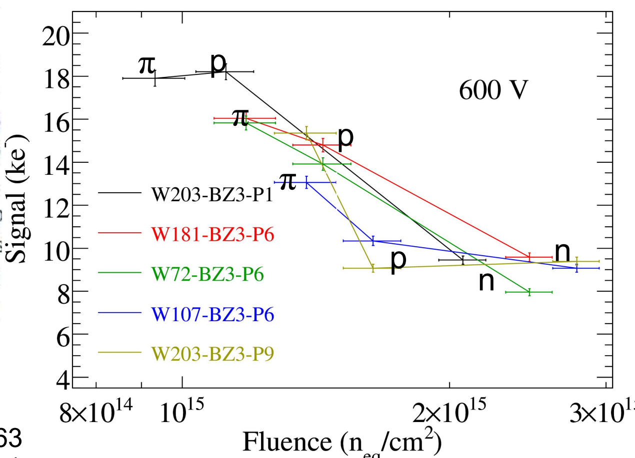
Task: Systematic evaluation of strip and pixel sensors connected to fast electronics before and after irradiation with protons, neutrons, pions



G.Casse, VERTEX 2008
(p/n-FZ, 300µm, (-30°C, 25ns)
I.Mandic et al., NIMA 603 (2009) 263
(p-FZ, 300µm, -20°C to -40°C, 25ns)

N-in-p FZ after pion, proton and neutron irradiation, beta source tests



S. Kuehn, 21rd RD50 Workshop Nov. 2012

After 2.8*10^{15} neq/cm^2:
Collected charge 600 V 9.0±0.7 ke
Signal-to-noise ratio 12.3±0.1

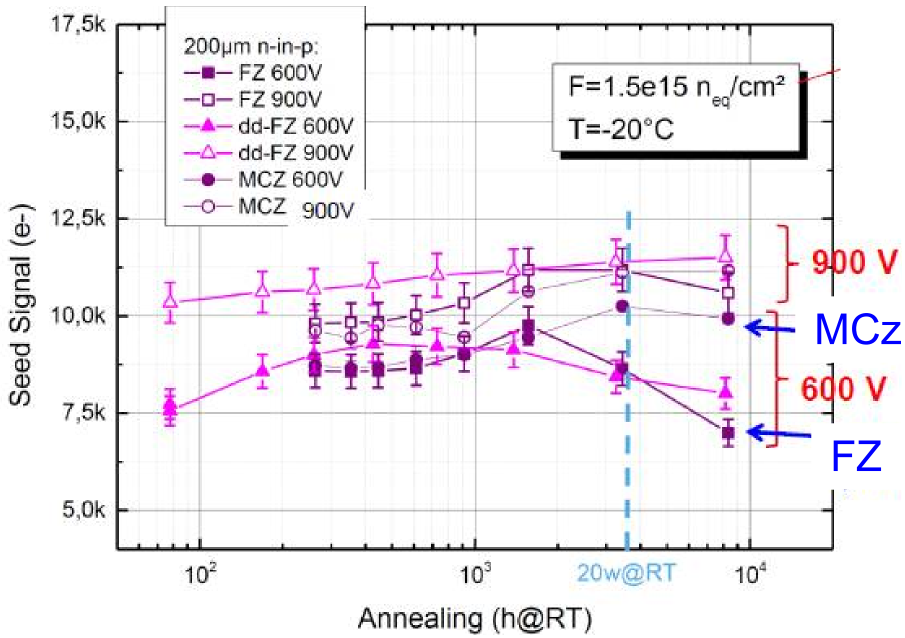
→ n-in-p performs best:
- No space charge inversion
- Favourable combination of weighting and electric field after irradiation
- Readout at n-type electrodes: collection of electrons (fast), shorter trapping times, enhance amount of charge

Baseline for upgrade of ATLAS and CMS silicon strip tracking detectors
(in current detectors p-in-n)

Full detector systems: FZ vs. MCz and Thin detectors

MCz with [O] ~ $5 \cdot 10^{17}$ cm^{-3} (introduced by RD50)

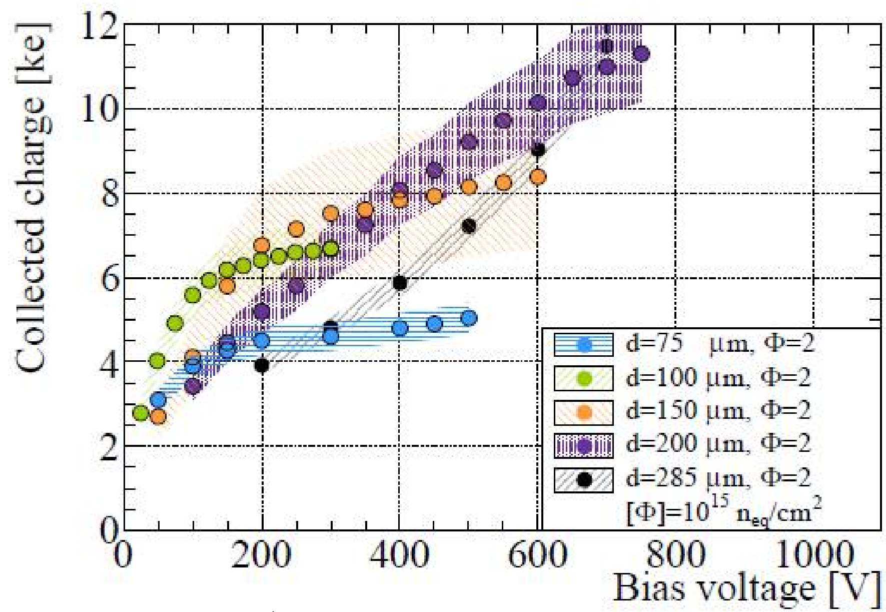
- Sensors 200 µm thick, $1.5 \cdot 10^{15}$ neq/cm^2 protons



G. Steinbrück, 23rd RD50 Workshop Nov. 2013

Thin detectors

- CIS FZ sensors of different thickness, ATLAS FEI4, 25 MeV protons, beta source



S. Terzo, 23rd RD50 Workshop Nov. 2013

- MCz performs better than FZ
- MCz less affected by annealing, stable annealing behaviour
- Improved performance in mixed fields due to compensation of neutron and charged particle damage in oxygen rich MCz

- 100-150 µm thick sensors show the highest collected charge at moderate voltages (200-300 V) for fluences above $1 \cdot 10^{15}$ neq/cm^2
- Beam tests show 98.1% hit efficiency (100 µm active edge sensor, 300V, $5 \cdot 10^{15}$ neq/cm^2)
- Less material

See also Talks of A. Macchiolo today and A. Junkes on Friday

New Structures: 3D sensors

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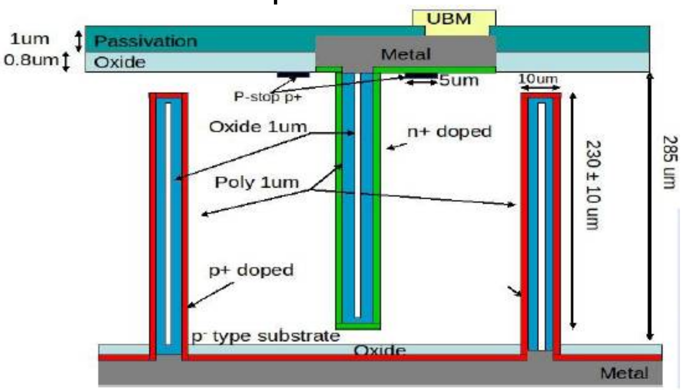
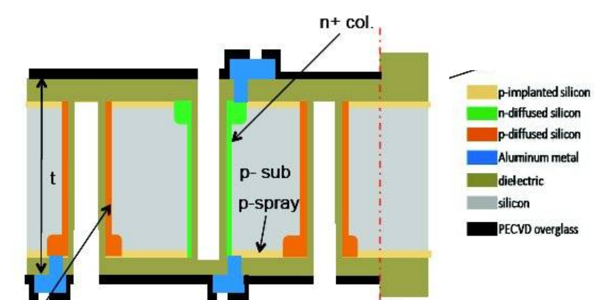
3D sensors: doped columns vertical to surface
- Decoupling of depletion voltage and detector thickness (collected charge) but have low-field region

CNM: columns part. filled

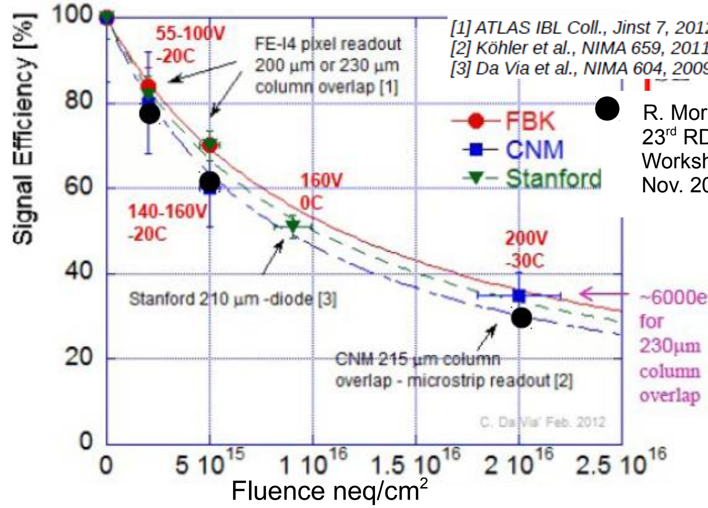


G. Pellegrini, NIM A 592 (2008) 38-43

FBK 3D double side double type sensor: columns through wafer, empty



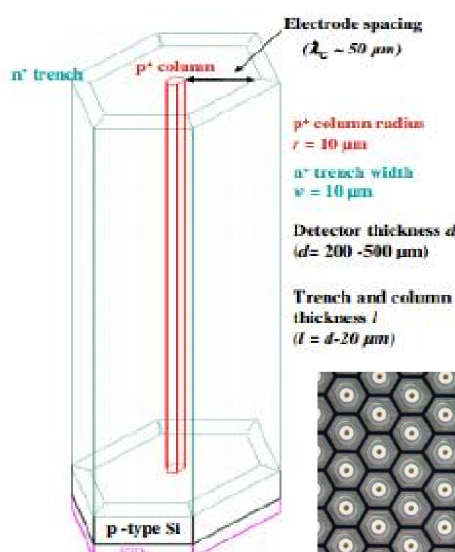
E. Vianello, 6th Trento Workshop, 2011

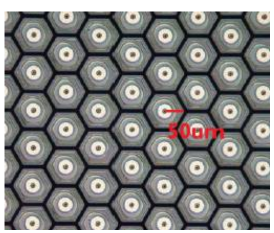


R. Mori, 23rd RD50 Workshop Nov. 2013

→ Well performing and installed in ATLAS IBL
→ decent signal after $2 \cdot 10^{16}$ neq/cm^2

New development: 3D-Trench Electrode Detector (BNL&CNM)





- Overcomes low-field region in 3D detectors
- First sample V_{FD} ~95 V after $1 \cdot 10^{16}$ neq/cm^2
- Uniform electric field
- Full charge collected by ^{241}Am source test

Next: position-resolved laser tests

A. Montalbano et al., http://dx.doi.org/10.1016/j.nima.2014.03.066

New Structures: Active/slim edge sensors

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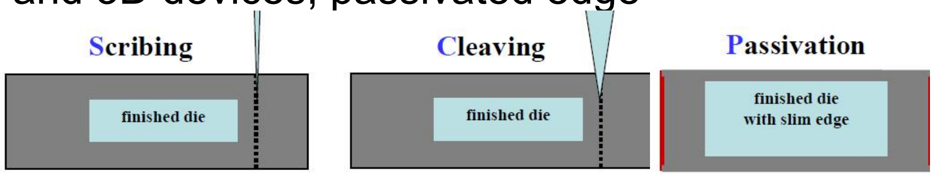
Minimize "dead" area of sensors: several techniques

SCP slim edges

- Exploits scribe and cleave technique on planar and 3D devices, passivated edge



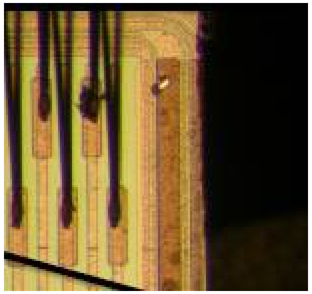
Laser, XeF_2 etch, DRIE etch, saw cut

Tweezers, new: Dynatex machine

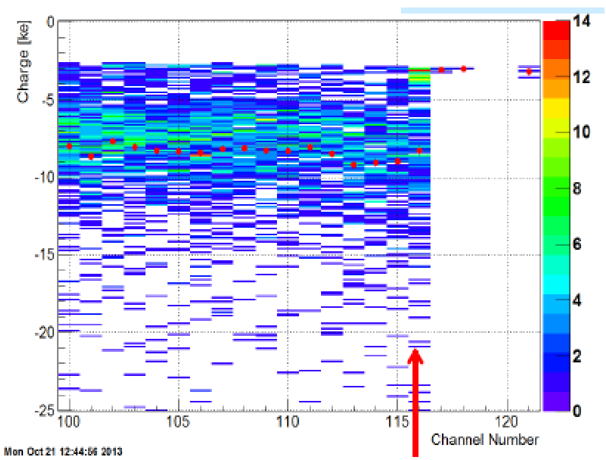
Native Oxide + Radiation or PECVD (n-type), ALD (p-type)

V. Fadeyev et al, NIM A 731 (2013) 260
V. Fadeyev, 23rd RD50 Workshop Nov. 2013

CIS n-in-p, 285 µm thick, 150 µm slim edge, 800 V bias, $4*10^{15}$ neq/cm^2



Sr90, Alibava, single cluster plot

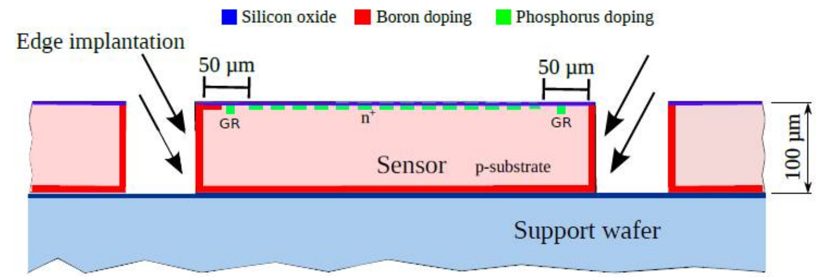


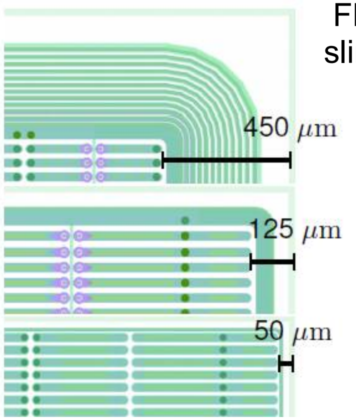
Similar median charge as for other strips

Also under development at HPK

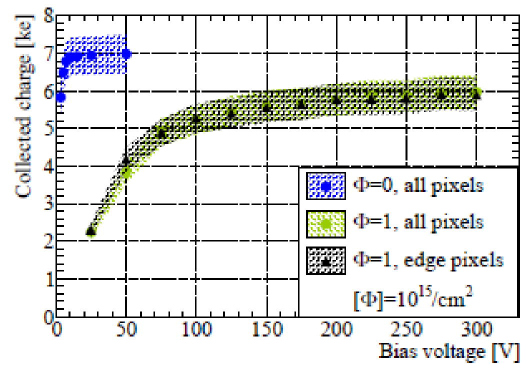
VTT/MPI active edges project

- Pixel sensors with slim edges, trenches doped by four-quadrant implantation





FE-I3 FZ silicon, 100 µm thick, 125 µm slim edge, threshold: 1500 e$^-$



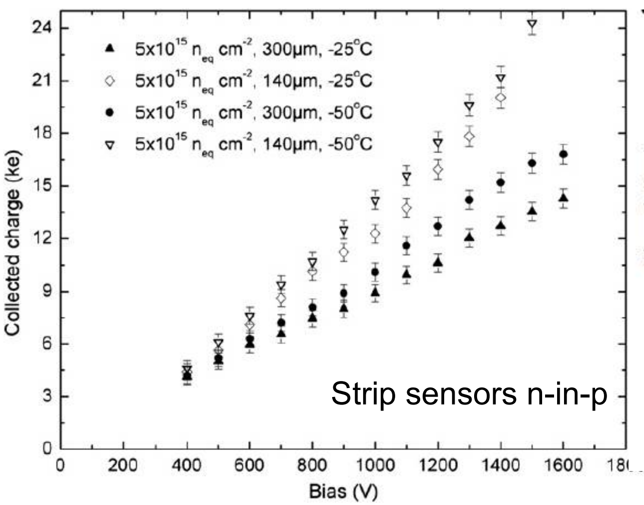
Hit efficiency (98.9+-3)% at 300 V after $5*10^{15}$ neq/cm^2

S. Terzo, 23rd RD50 Workshop Nov. 2013

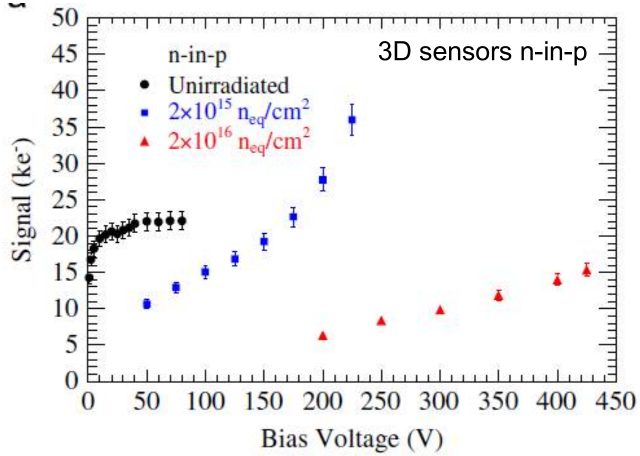
Overall efficiency, I_{leak} and noise unaffected by edge-cutting

Full detector systems: Charge Multiplication

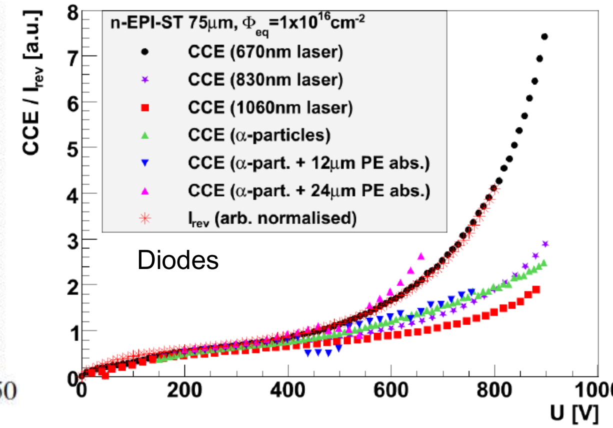
Charge multiplication observed after irradiation to 2-5*10^{15} neq/cm^2
Characterized with different techniques and in different type of devices



G. Casse, NIM A, 624(2011), 401–404



M. Köhler, NIM A, 659 (2011), 272–281,
16th RD50 Workshop, June 2010



J. Lange, 16th RD50 Workshop, June 2010

Charge Collection (Beta source, Alibava readout)

Origin: Irradiation leads to high negative space charge concentration in detector bulk
→ increase of the electric field close to n-type strips
→ impact ionization

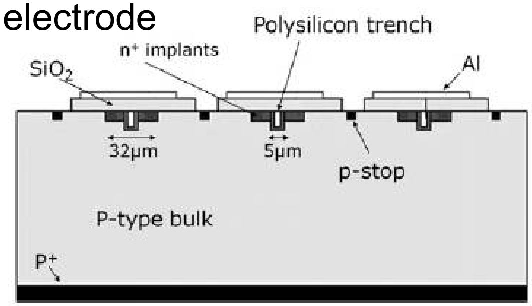
Goals:
- Simulation and prediction of charge multiplication
- Long term, S/N behaviour
- Is exploitation of charge multiplication possible?

- Dedicated R&D in RD50 to understand and optimize multiplication mechanism
- Evaluating possibility to produce fast segmented sensors

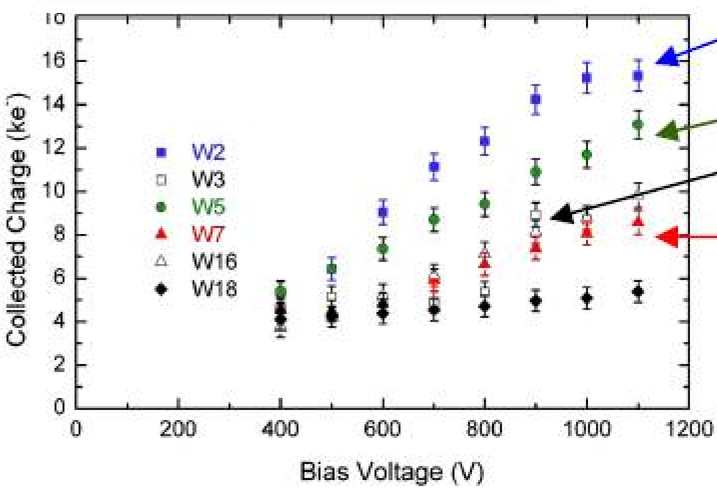
Full detector systems: Enhancing Charge Multiplication

Production of sensors with trenches:

- 5, 10, 50 µm deep, 5 µm wide in center on n+ electrode

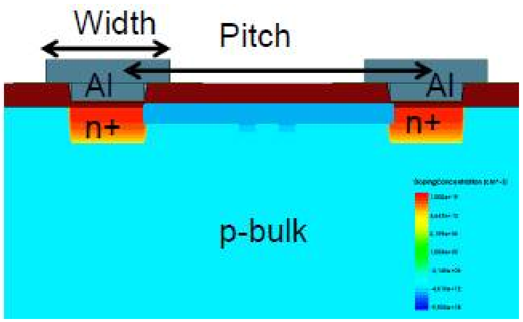


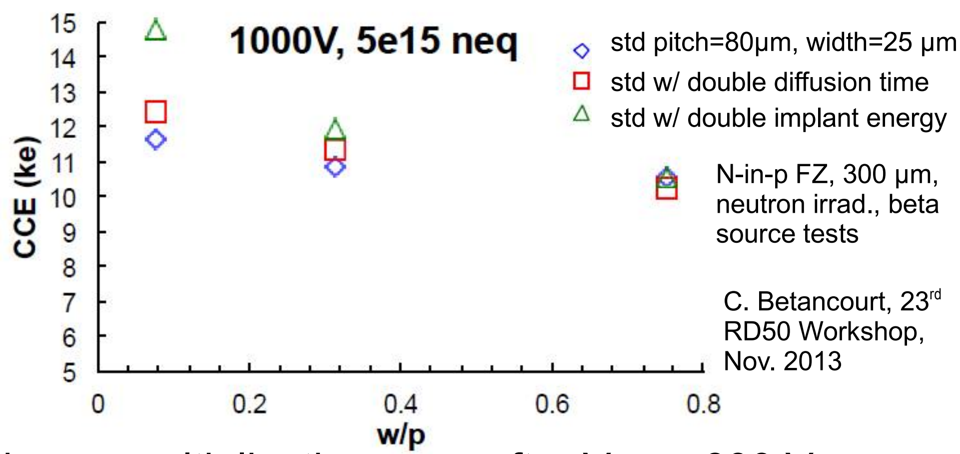
G. Casse, NIM A 669 (2013) 9-13,
P. Fernández-Martínez, NIM A 658 (2011) 98-102



After $5*10^{15}$ neq/cm^2 neutrons, n-in-p sensor 300 µm thick
→ CCE higher for sensors 5 and 50 µm trenches compared to standard sensors

N-in-p sensors with different strip widths and pitches:





N-in-p FZ, 300 µm, neutron irrad., beta source tests

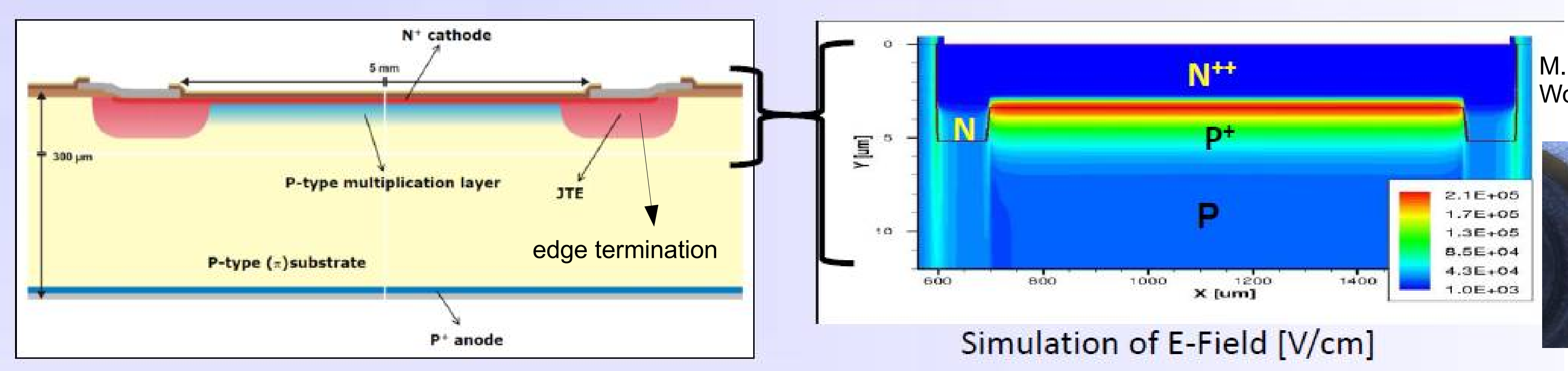
C. Betancourt, 23rd RD50 Workshop, Nov. 2013

- Charge multiplication seen after V_{Bias} > 600 V
- Both Extr. Diff. and 2E imp. show signs of CM with respect to standard wafer
- Lower w/p ratio leads to more pronounced multiplication
- Long term behaviour under test, first indications for degradation after few days

see also talk of R. Klanner on Friday

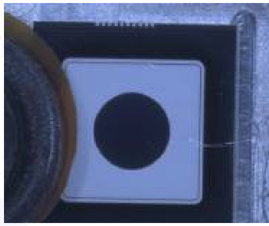
New Structures: Low Gain Avalanche Diodes - LGAD

Diodes with implemented multiplication layer (deep p+ implant): n^{++}-p^{+}-p-p^{+}

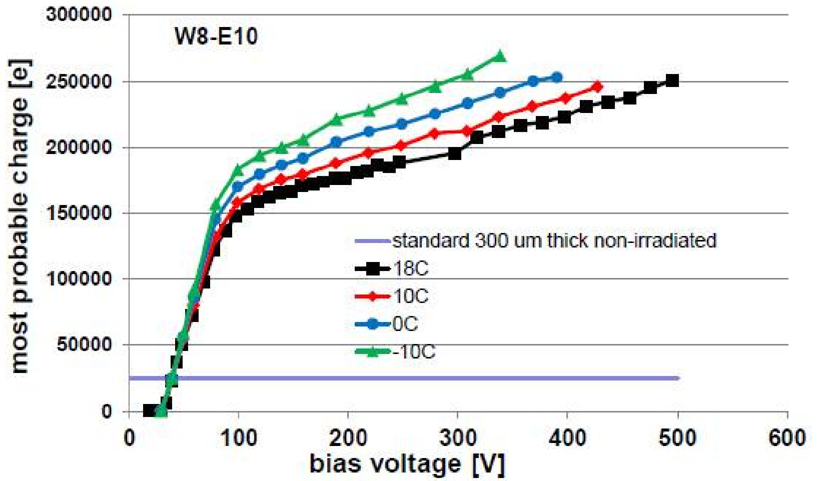


Simulation of E-Field [V/cm]

M. Baselga, 8th Trento Workshop, 2013

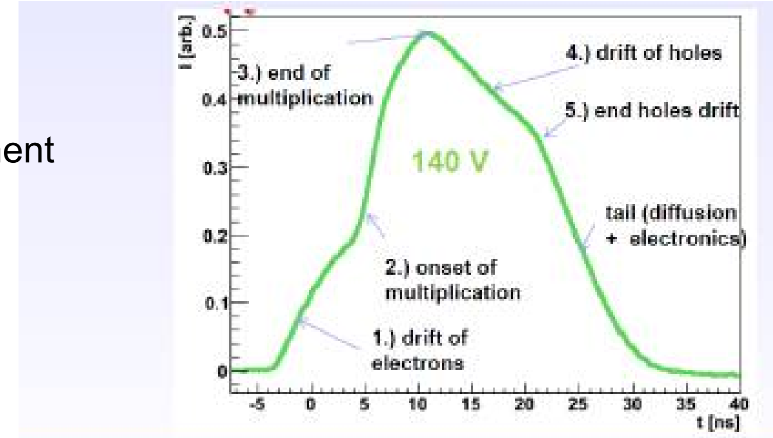


- P-doped diffusion under cathode → multiplication layer
- Edge termination needed: low doping n-well
- First samples under test
- Gain of ~10 before irradiation (Landau spectra Sr90)
  - Current and noise independent of gain



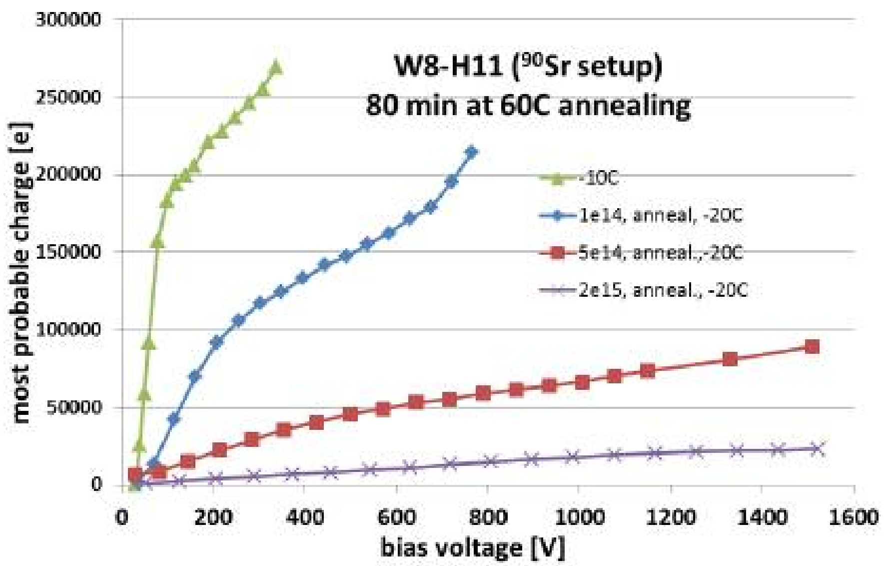
G. Kramberger, 22nd RD50 workshop, June 2013

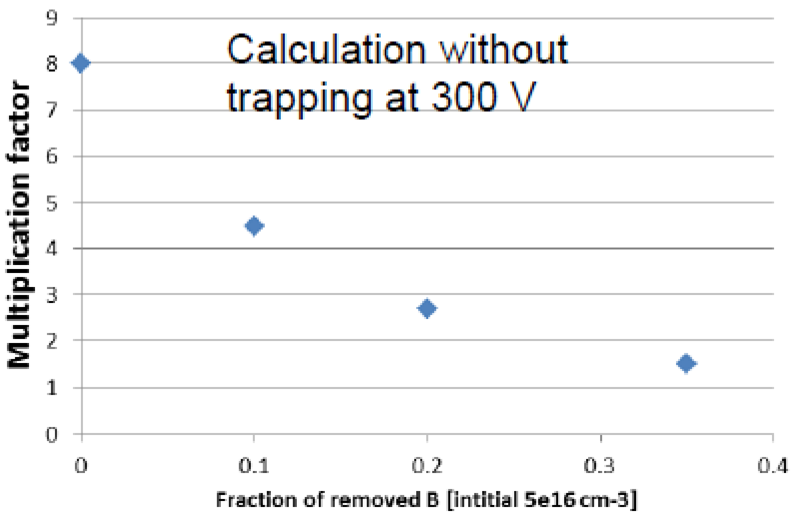
TCT measurement matches simulation



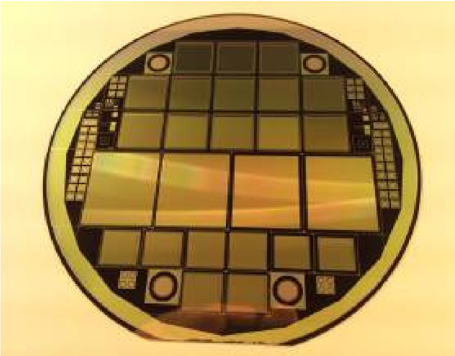
New Structures: Low Gain Avalanche Detectors – LGAD irradiated

- After irradiation: Degradation in multiplication, gain reduces to about 1.5
- Reasons (under investigation):
  - Boron removal in p-type layer, not due to electron trapping
  - Reduction in electric field
    → Removal of initial acceptors,
    more removal than in normal diodes
  - Noise scales with multiplication
  - 6000 e- after $1*10^{16}$ neq/cm^2
- Gain depending on temperature (high T, low gain)





- More wafers for detailed tests in production
- Irradiation programme with protons, gammas and neutrons



G. Kramberger, 23rd RD50 workshop, Nov 2013,

Achievements of RD50 in light of LHC experiments

- Observed radiation damage in LHC experiments agrees with predictions developed by RD50
  - Leakage current increase in ATLAS, depletion voltage evolution in LHCb

- Recommendations for silicon tracking detectors at HL-LHC

  - Inner layers with fluences of about $1*10^{16}$ neq/cm^2
    → planar sensors collect decent amount of charge, hit efficiency 97%
    → n-in-p (or n-in-n) candidate material (important collection of electrons)
    → thin detectors overcome problem of requirement of high bias voltage, advantageous with doses > $1*10^{15}$ neq/cm^2
    → 3D detectors are alternative option and show good performance with lower bias voltage (used now in IBL of ATLAS experiment)

  - Outer layer with fluences of about $2*10^{15}$ neq/cm^2
    → planar FZ n-in-p sensors baseline for ATLAS and CMS upgrade strip tracker (FZ has reverse annealing after > 12 weeks at room temperature)
    → MCz also option, damage is compensated in mixed fluences, long-term beneficial annealing (50 weeks at room temperature)

Summary: Key results

- Recommendations for silicon tracking detectors at HL-LHC
- Progress in understanding microscopic defects, origin of positive space charge
- Simulation working group: simulations get predictive power, common database in preparation
- New structures under investigation: 3D-Trench detectors, thin detectors
- Consolidation of data on n-in-p-type, thin segmented and slim/active edge sensors
- Charge multiplication investigated systematically to allow its exploitation
  → Dedicated sensor productions: Trenches, Pitch/Width, Low Gain Avalanche Diodes

Other results of RD50

- RD50 collaboration works on radiation hard semiconductor devices for LHC experiments
  - Tested plenty of different devices (material, geometry, engineering)
  - Significantly improved understanding of radiation effects
  - Developed rich tooling for sensor characterization: Alibava, Edge-TCT, Beam telescope
  - Common sensor production
  - Inter-experiment working towards advise for selection for tracking detectors at HL-LHC and beyond: “LHC-wide” exchange of knowledge

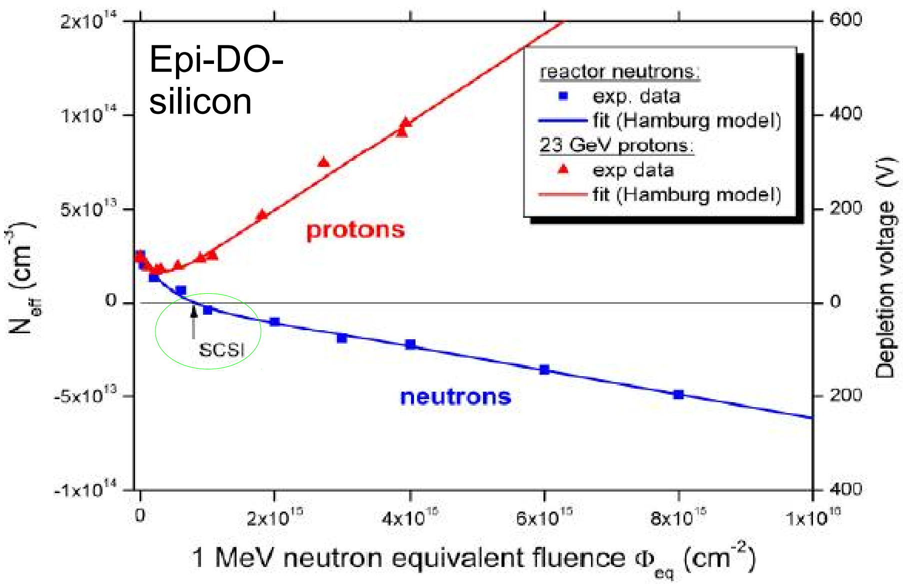
- Other projects:
  - Low-resistance strip sensor project
  - Annealing parametrisation, carrier de-trapping
  - Irradiation to extreme fluences

Very active community and many projects ongoing!
More on www.cern.ch/rd50
Thank you to all colleagues for material!

Backup

Impact of Defects: Change of N_{eff}

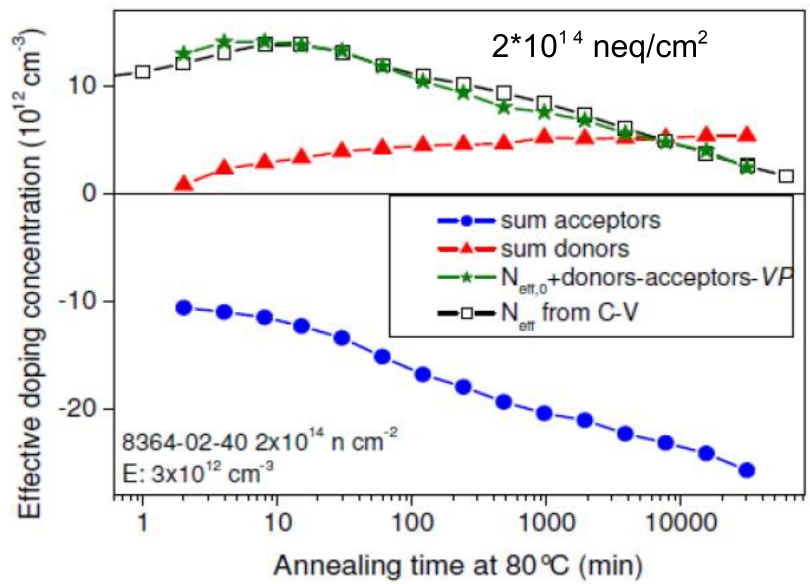
- Dependence on particle type: proton vs. neutron irradiation



I.Pintilie et al., NIM A 611 (2009) 52-68

- TSC result:
  - Donor E(30K) introduces positive space charge after proton irradiation
    Violates NIEL hypothesis!
  - Introduces more positive space charge in oxygen rich material

- Effect of reverse annealing after irradiation



A. Junkes PoS(Vertex2011)035, I. Pintilie et al., APL 92,024101 (2008)

- TSC result:
  - Acceptors H(116K), H(140K), H(152K) increase with reverse annealing
  - H(116K) might depend on oxygen concentration
    → increase of negative space charge

Defect Characterization

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Defects induced by irradiations in Si (forming and transforming at ambient temperatures)

Defects	$\sigma_{n,p}$ [cm²]	E_A [eV]	Assignment/References	Impact on electrical characteristics at RT
E(30K)	$\sigma_n = 2.3 \times 10^{-14}$	$E_C - 0.1$	Electron trap with a donor level in the upper half of the Si bandgap /[Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52]	On the N_{eff} by introducing positive space charge *-It makes the difference between proton and neutron irradiations* *-More generated in O rich material*
$BD_A^{0/++}$ $BD_B^{+/++}$	$\sigma_n = 2.3 \times 10^{-14}$ $\sigma_n = 2.7 \times 10^{-12}$	$E_C - 0.225$ $E_C - 0.15$	**Bistable Thermal double donor TDD2** (two configurations A and/or B) - Electron trap with a donor level in the upper half of the Si bandgap/ [Appl. Phys. Lett. 50 (21) (1987) 1500; Nucl. Instr. and Meth. in Phys. Res. A 514 (2003) 18; Nucl. Instr. and Meth. in Phys. Res. A 556 (2006) 197; Nucl. Instr. and Meth. in Phys. Res. A 583 (2007) 58]	On the N_{eff} by introducing positive space charge *-Strongly generated in O rich material*
$I_p^{+/0}$ $I_p^{0/-}$	$\sigma_p = (0.5\text{-}9) \times 10^{-15}$ $\sigma_n = 1.7 \times 10^{-15}$ $\sigma_p = 9 \times 10^{-14}$	$E_V + 0.23$ $E_C - 0.55$	Donor level of V_2O or of a still unkown C related defect / [Appl. Phys. Lett. 81 (2002) 165; Appl. Phys. Lett. 83, 3216 (2003); Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52] Acceptor level of V_2O or of a still unkown C related defect/[Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52, Appl. Phys. Lett. 81 (2002) 165]	On the N_{eff} by introducing negative space charge and on LC *-Strongly generated in O lean material*
E_4 E_5	$\sigma_n = 1 \times 10^{-15}$ $\sigma_n = 7.8 \times 10^{-15}$	$E_C - 0.38$ $E_C - 0.46$	Acceptor in the upper part of the gap associated with the double charged and single charged states of V_3, respectively ($V_3^{=/-}$ and $V_3^{-/0}$) / [J. Appl. Phys. 111 (2012) 023715.]	On LC
H(116K)	$\sigma_p = 4 \times 10^{-14}$	$E_V + 0.33$	Hole trap with an acceptor level in the lower part of the Si bandgap - Extended defect (cluster of vacancies and/or interstitials) / [Appl. Phys. Lett. 92 (2008) 024101, Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52-68]	On the N_{eff} by introducing negative space charge
H(140K)	$\sigma_p = 2.5 \times 10^{-15}$	$E_V + 0.36$	Hole trap with an acceptor level in the lower part of the Si bandgap - Extended defects (clusters of vacancies and/or interstitials)/[Appl. Phys. Lett. 92 (2008) 024101, Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52-68]	On the N_{eff} by introducing negative space charge
H(152K)	$\sigma_p = 2.3 \times 10^{-14}$	$E_V + 0.42$	Hole trap with an acceptor level in the lower part of the Si bandgap - Extended defects (clusters of vacancies and/or interstitials)/[Appl. Phys. Lett. 92 (2008) 024101, Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52-68]	On the N_{eff} by introducing negative space charge
$VO_i^{-/0}$	$\sigma_n = 1.44 \times 10^{-14}$	$E_C - 0.176$	$VO_i^{-/0}$ /[J. Appl.Phys.79(1996)3906 ; Mat. Sci. in Semic. Proc. 3 (2000) 227]	
$C_iC_s^{-/0}$	$\sigma_n = 1.4 \times 10^{-14}$	$E_C - 0.171$	$C_iC_s^{A\,-/0}$ /[Phys. Rev. Lett. 60 (1988) 460-463, Phys. Rev. B42 (1990) 5765]	
H(40K)	$\sigma_p = 1.7 \times 10^{-15}$	$E_V + 0.09$	Hole trap/ [Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52-68]	
$C_i^{+/0}$	$\sigma_p = 4.3 \times 10^{-15}$	$E_V + 0.284$	$C_i^{+/0}$/ [M. Moll, PhD Thesis, University of Hamburg, DESY-THESIS-1999-040, 1999]	
$C_iO_i^{+/0}$	$\sigma_p = 4.3 \times 10^{-15}$		[J.Appl.Phys.79(1996)3906]	
$V_2^{-/0}$	$\sigma_n = 2.1 \times 10^{-15}$	$E_C - 0.424$	$V_2^{-/0}$ / [J.Appl.Phys.79(1996)3906; M. Moll, PhD Thesis, DESY-THESIS-1999-040, 1999]	
H(87K)	$\sigma_p = 0.3 \times 10^{-15}$	$E_V + 0.193$	$V_3^{0/+}$ /[Phys. Status Solidi A 208 (2011) 568.]	

I. Pintilie/ R. Radu, 23rd RD50 Workhshop, Nov. 2013

Detector Characterization: Investigation of Electric Fields with Edge-TCT

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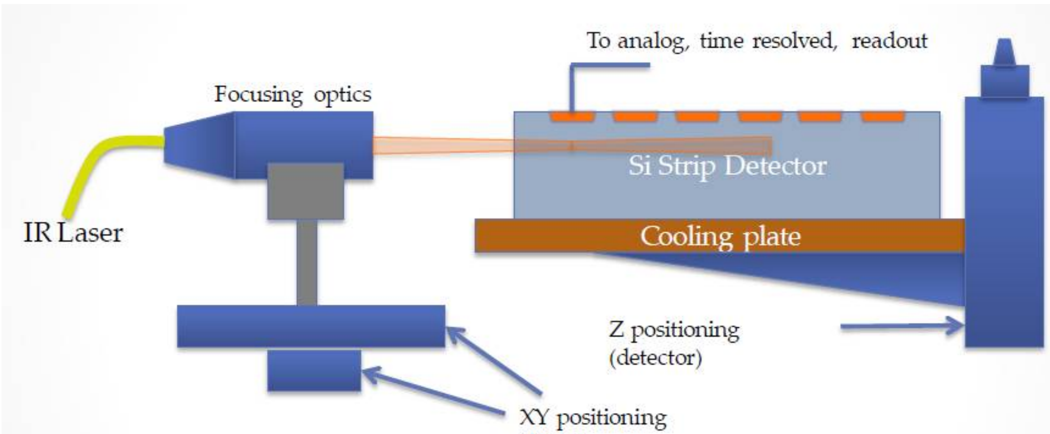
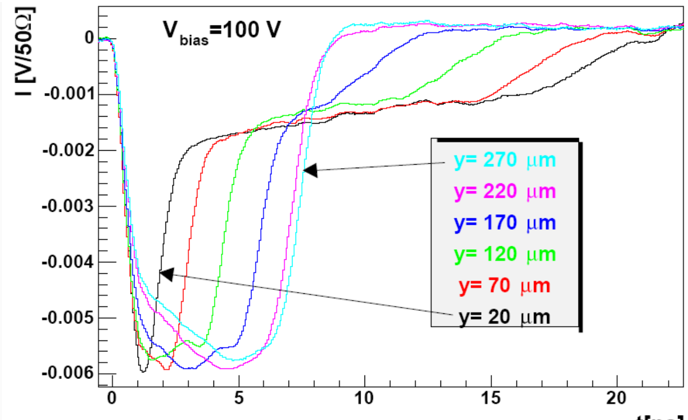
- Goal: Measurement of electric field in unirradiated and irradiated devices, usual TCT (Transient Charge Technique) not working due to trapping after irradiation

Edge-TCT, G. Kramberger, IEEE TNS, VOL. 57, NO. 4, AUGUST 2010, 2294



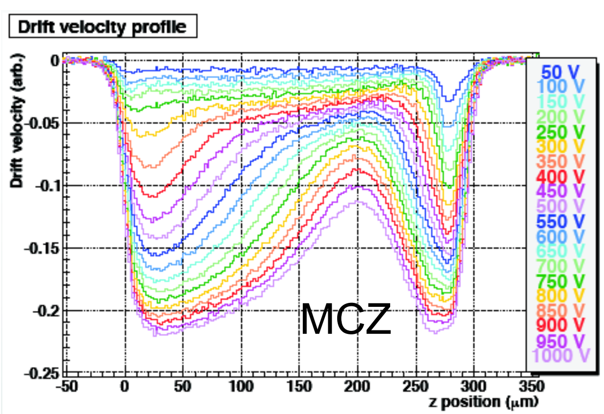
N.Pacifico, 20th RD50 Workshop, 2012

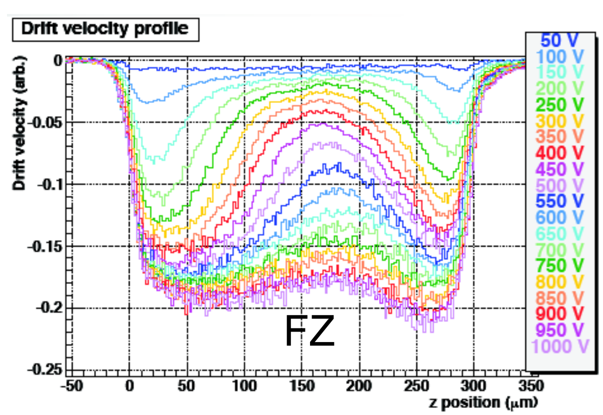


G. Kramberger, 5th Trento Workshop, 2010

- Example: n-on-p strip detector (pitch 80 µm), irradiated to $1*10^{16}$ neq/cm^2, with protons, no annealing

N.Pacifico, 20th RD50 Workshop, 2012





I(y,t~0) proport. v_e+v_h

Different drift velocity in FZ and MCZ silicon

Full detector systems: Goals and Tools

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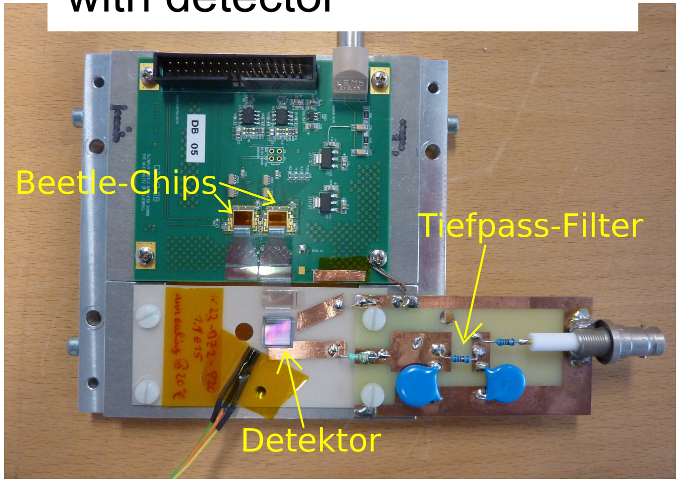
Systematic evaluation of strip and pixel sensors connected to fast electronics before and after irradiation with protons, neutrons, pions

- Use fast (40 MHz) analogue or binary readout electronics
- Determine parameters like collected charge, noise, signal-to-noise by using beta source set-ups, laser set-ups and test beams
- Design and realization of pixel/strip detectors in contact with manufacturers
  (CiS, CNM, HIP, HPK, Micron, Sintef)

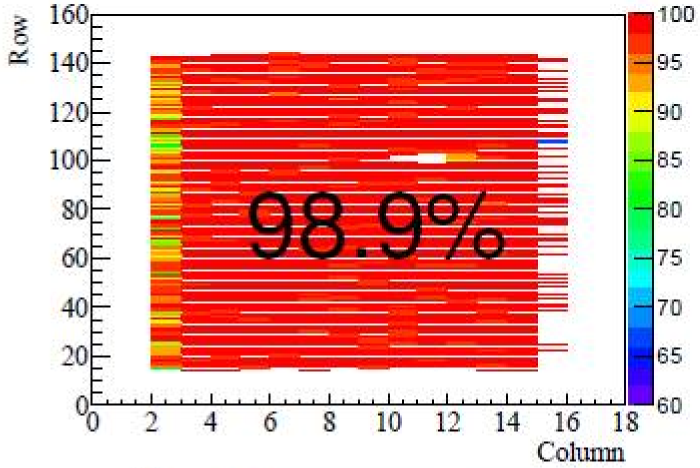
ALIBAVA daughter board with detector



- RD50 test beam setup (additional to other setups in the Collaboration (EUDET, CMS))
  - Based on ALIBAVA system with analogue fast readout
  - Device under test and sensors for track reconstruction run with same readout
  - Allows easy handling and high resolution measurements

Hit efficiency: VTT 100 μm FE-I3

- PPS test beam at DESY
  - 4 GeV electrons
  - EUDET telescope
  - perpendicular incidence tracks



- **VTT 100 μm FE-I3 Float Zone**
  - 125 μm slim edge
  - threshold: 1600 e^-
  - 20 ToT at 60 ke
  - Φ=5$\times 10^{15} n_{eq}/cm^2$
  - (98.9$\pm$0.3)% global hit efficiency at 300 V

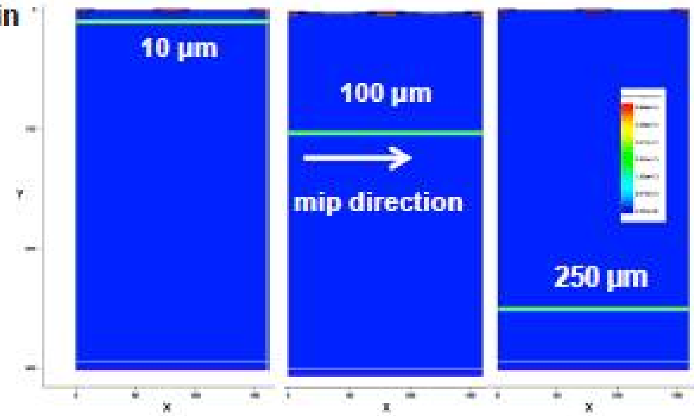
S. Terzo, 23rd RD50 Workshop Nov. 2013

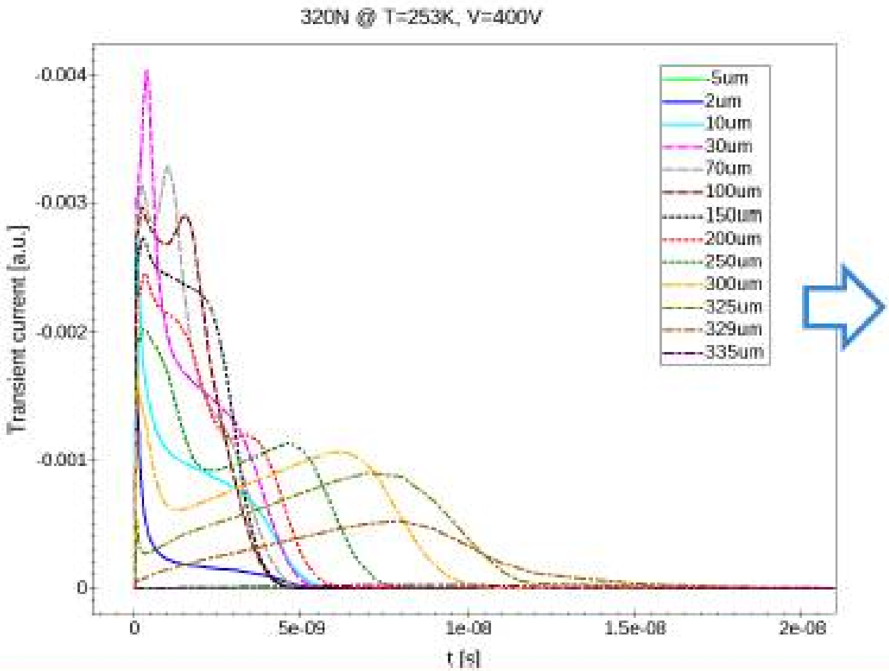
Edge-TCT: Lifetime of charges

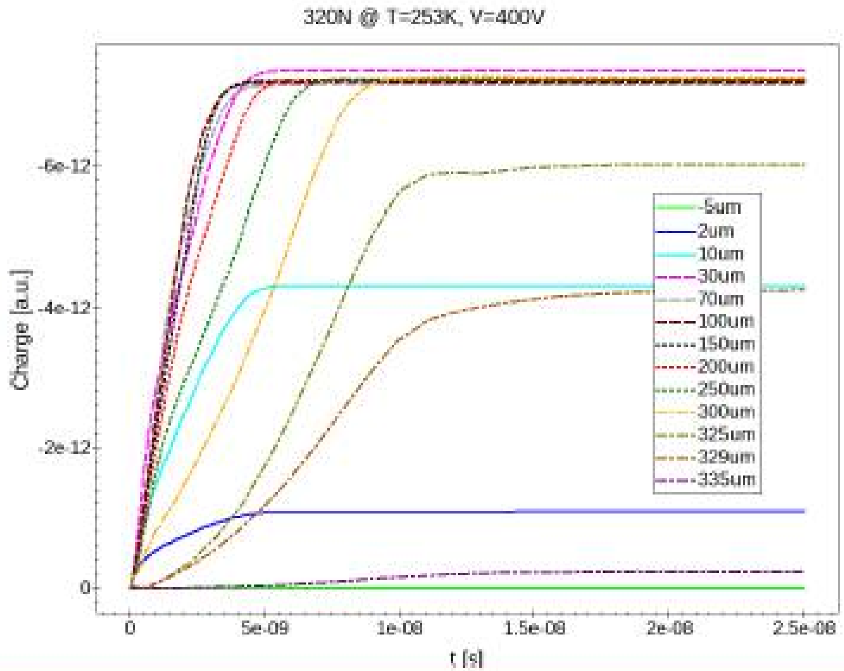
- **Goal:** extract electric field E from drift velocity v_{drift} using eTCT
- eTCT provides measurement of collection time t_c that is proportional to the v_{drift}
- v_{drift} is related to the E → possible to determine E out of drift velocity?

- Collected eTCT generated transient signals and charges as a function of injection distance:

MIP trajectories in 300N device:



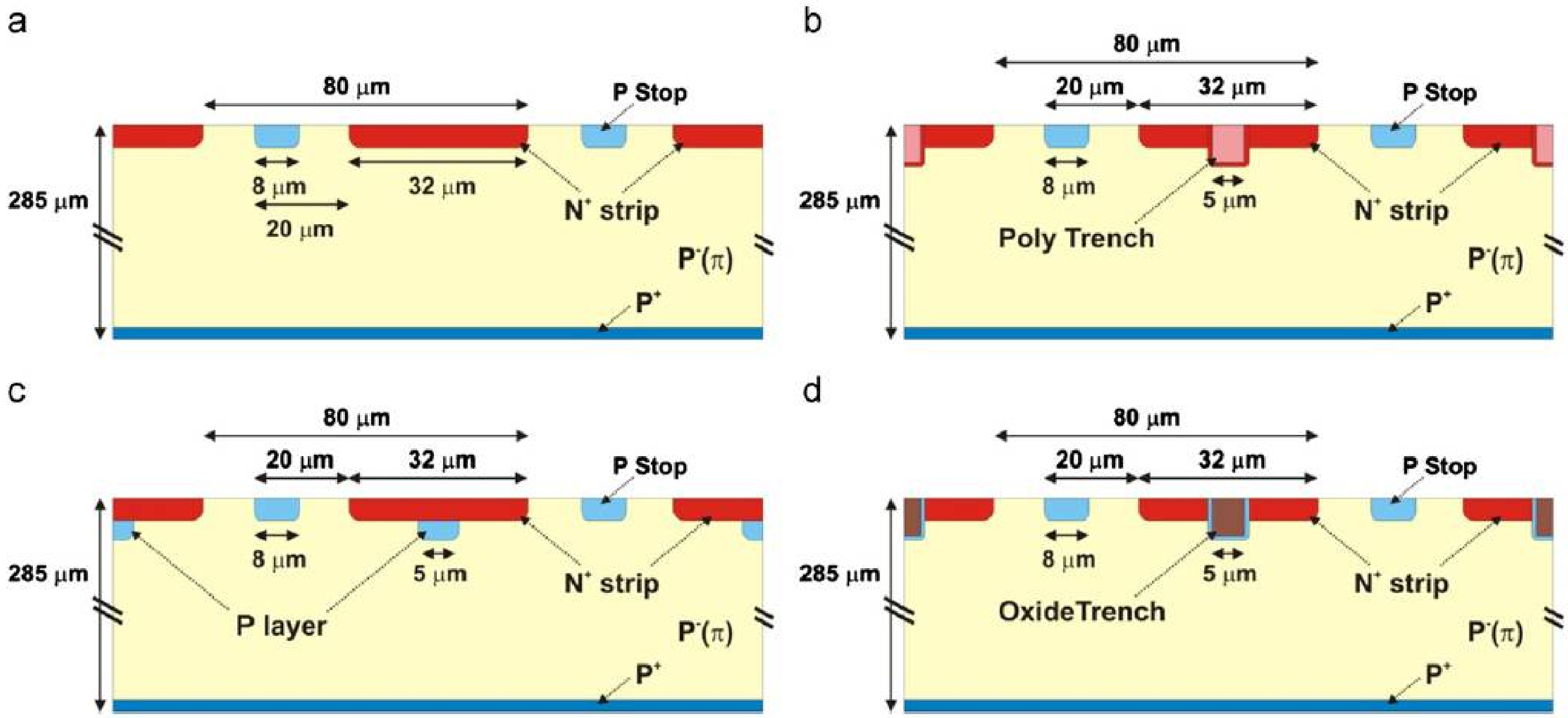




T. Peltola, 23rd RD50 Workshop Nov. 2013

Trenches

a standard, **b** poly trench including poly silicon doped with phosphorus, **c** p-layer with p-type diffusion, **d** oxide trench



P. Fernández-Martínez, NIM A 658 (2011) 98-102

Full detector systems: Enhancing Charge Multiplication

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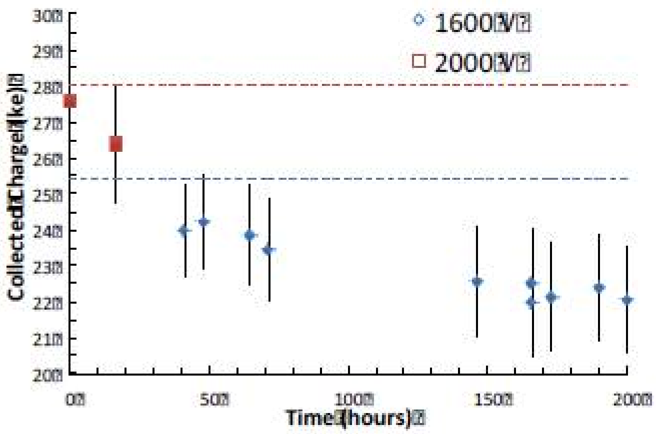
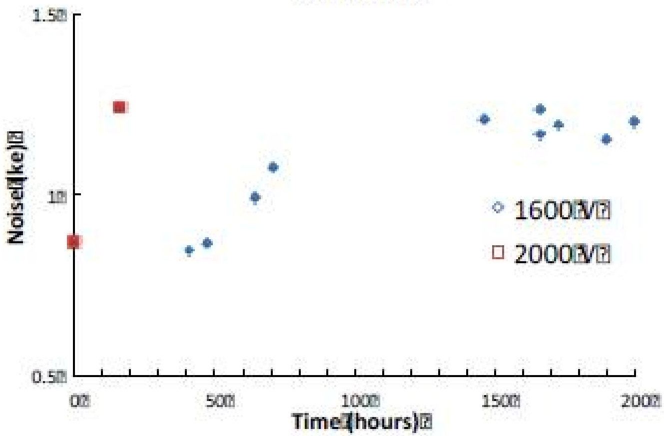
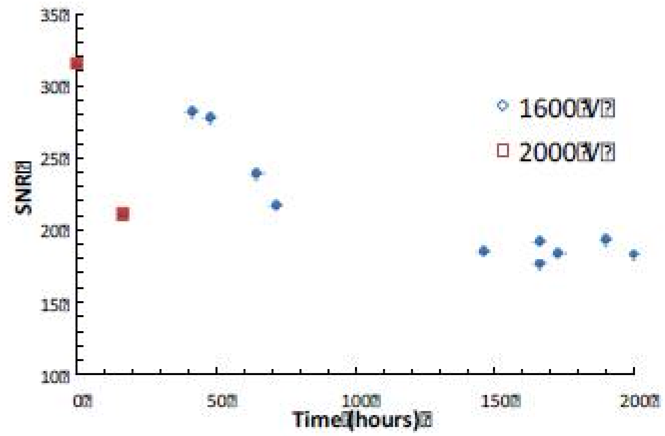
Long term behaviour of charge multiplication:

Long-term tests (std, p80,w60, 1e15)



- Real-world application requires sensors to be operated at high voltages for long time intervals
- Initial tests taken over many days indicates degradation of the CM effect
- While signal goes down with time, noise increases



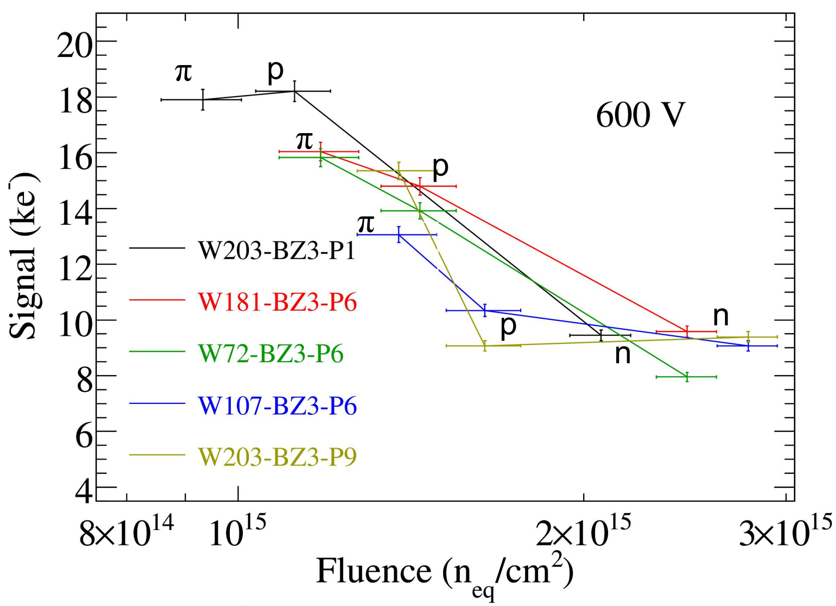


November 13, 2013 C. Betancourt, 23rd RD50 Workshop, CERN 14

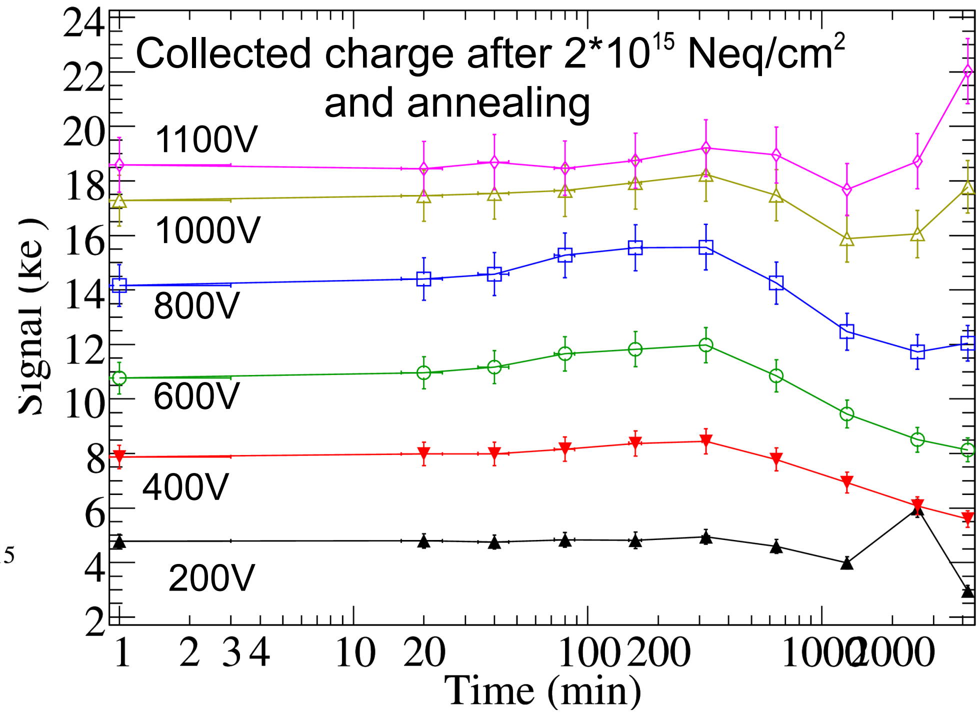
Full detector systems: p-type Detectors

Albert-Ludwigs-Universität Freiburg

Example: FZ n-in-p ministrip sensors (HPK 300 μm thick, 80 μm pitch), tested with beta source, readout with ALIBAVA system (40 MHz) and irradiated with pions, protons and neutrons



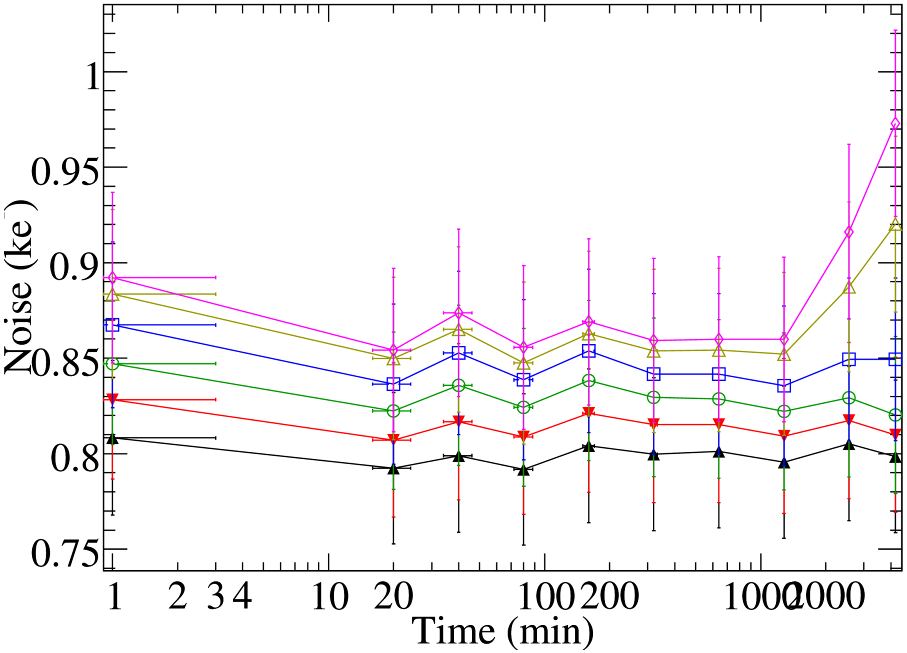
S. Kuehn, 21rd RD50 Workshop Nov. 2012



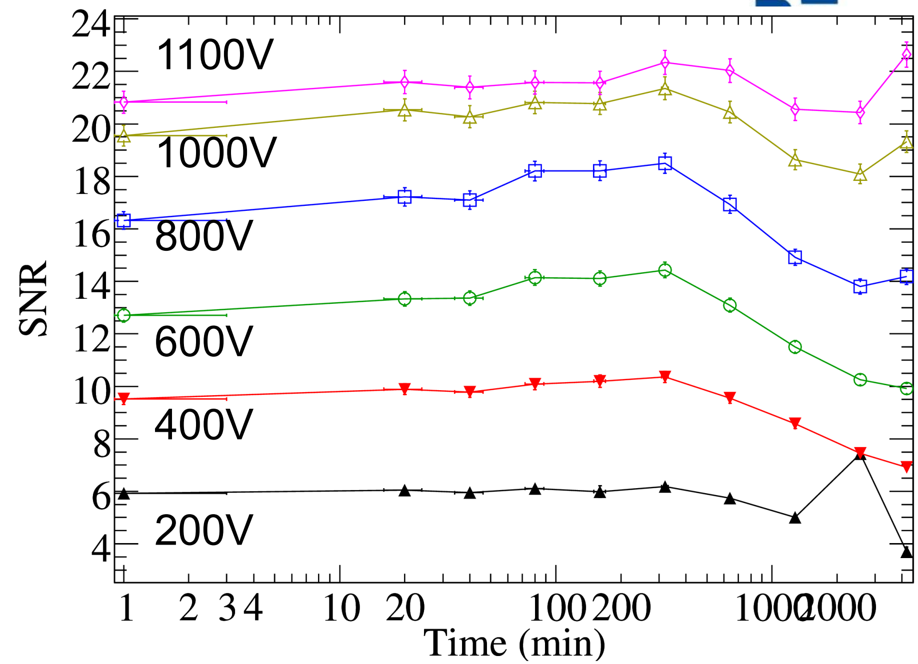
- Collected charge reduces at 600 V to 9.0±0.7 ke (~40%)
- After 2.8*10^{15} neq/cm^2: signal-to-noise ratio 12.3±0.1

- Different steps of annealing visible
- Collected charge stable until 320 min (~120 days at room temperature) – no reverse annealing
- Enhancement of charge multiplication after 2560 min for voltages above 800 V

Annealing studies after $2.1*10^{15}$ neq/cm^2



Noise



SNR

S. Kuehn, 21rd RD50 Workshop Nov. 2012