RD50

LHCC – 4.June 2014, CERN

RD50 Status Report – June 2014

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OUTLINE:

- RD50 Collaboration
- Scientific results
  - Defect and Material Characterization
  - Detector Characterization
  - New Detector Structures
  - Full Detector Systems
- RD50 key results 2013/2014
- RD50 Work Program 2014/2015
- RD50 achievements

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The RD50 Collaboration

- **RD50: *49 institutes and 275 members***

41 European and Asian institutes

Belarus (Minsk), Belgium (Louvain), Czech Republic (Prague (3x)), Finland (Helsinki, Lappeenranta), France (Paris), Greece (Demokritos), Germany (Dortmund, Erfurt, Freiburg, Hamburg (2x), Karlsruhe, Munich(2x)), 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)

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)

Joined 2013

- Joined: MPG Munich (L.Andricek), Demokritos (D.Loukas), Torino (N.Cartiglia)
- Left: Padova, (D.Bisello), Trento (M.Boscardin)
- Request: Orsay, LAL (A.Lounis)

Detailed member list: http://cern.ch/rd50

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RD50 Organizational Structure

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**
- Wafer procurement (M.Moll)
- Device Simulations (V.Eremin)

New Structures

Giulio Pellegrini

(CNM Barcelona)

- **3D detectors**
- **Thin detectors**
- **Cost effective solutions**
- **Other new structures**
- **Detectors with internal gain (avalanche detectors)**
- **LGAD – Low Gain Avalance Det.**
- **Slim Edges**

New WG

- 3D (R.Bates)
- LGAD (V.Greco)
- 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 (M.Bomben & 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)

Defect & Material Characterization

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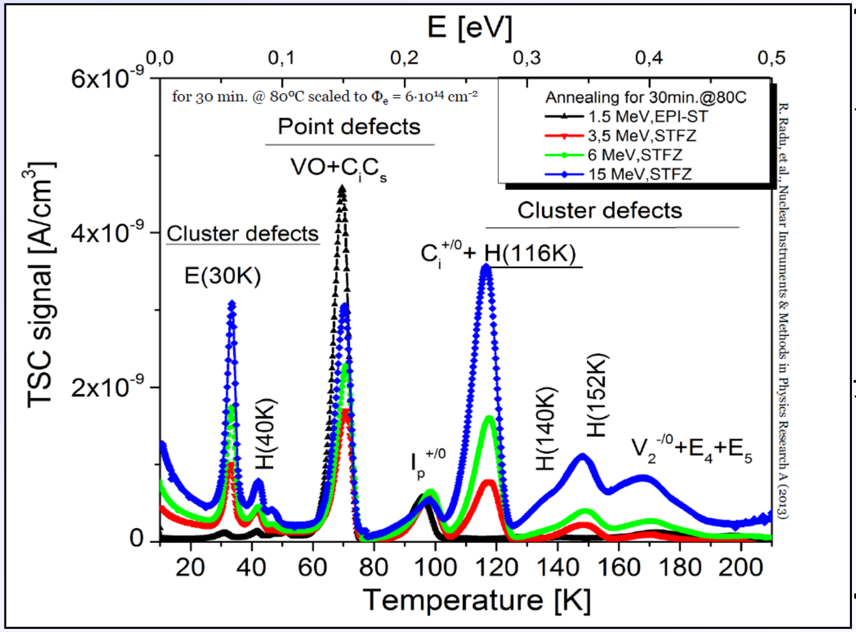
Defect Characterization

• Defect characterization

- **Aim:**
  - Identify defects responsible for Trapping, Leakage Current, Change of N_{eff}, Change of E-Field
  - Understand if this knowledge can be used to mitigate radiation damage (e.g. defect engineering)
  - Deliver input for device simulations to predict detector performance under various conditions

- **Method: Defect Analysis on identical samples performed with various tools inside RD50:**
  - **C-DLTS** (Capacitance Deep Level Transient Spectroscopy)
  - **I-DLTS** (Current Deep Level Transient Spectroscopy)
  - **TSC** (Thermally Stimulated Currents)
  - **PITS** (Photo Induced Transient Spectroscopy)
  - **FTIR** (Fourier Transform Infrared Spectroscopy)
  - **RL** (Recombination Lifetime Measurements)
  - **PC** (Photo Conductivity Measurements)
  - **EPR** (Electron Paramagnetic Resonance)
  - **TCT** (Transient Current Technique)
  - **CV/IV** (Capacitance/Current-Voltage Measurement)



[R.Radu, 22nd RD50 Workshop, 3-5 June 2013]

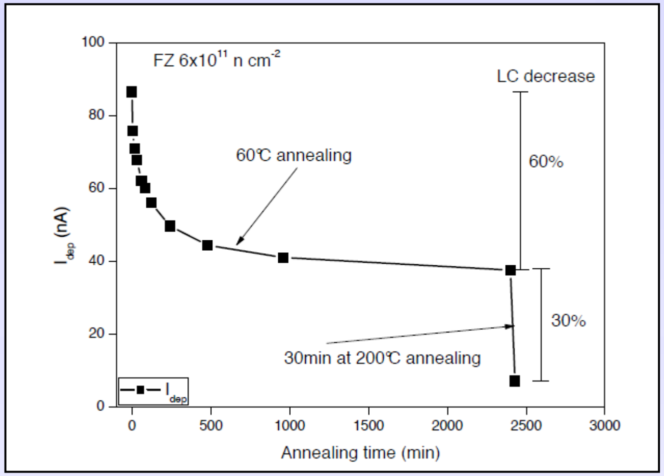
Example: TSC measurement on defects produced by electron irradiation (1.5 to 15 MeV)

- **RD50: several hundred samples irradiated with protons, neutrons, electrons and ^{60}Co-γ**

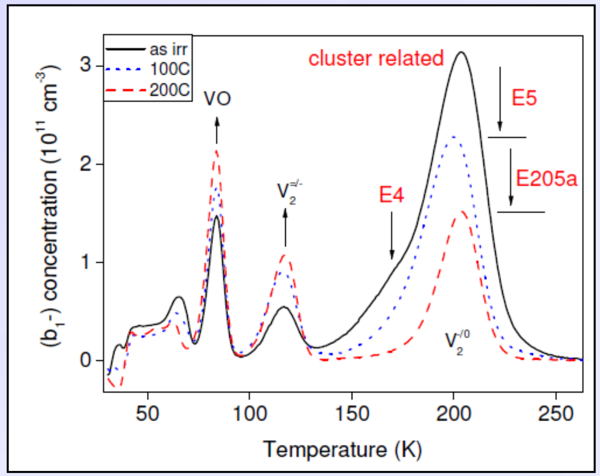
… significant progress on identifying defects responsible for sensor degradation over last 5 years!

Example: Defects with impact on leakage current

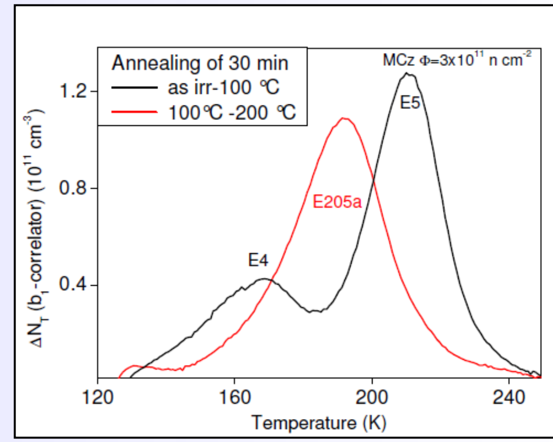
- **Macroscopic observation: Leakage current build-up following NIEL (for hadrons)**
  - *Leakage current scaling (almost) with NIEL and independent of silicon material (not for gammas!)*
  - *Leakage current is annealing in time and with temperature.*
- **Example:** Annealing study on a FZ sample ($6x10^{11}$ n/cm^2)



Leakage Current



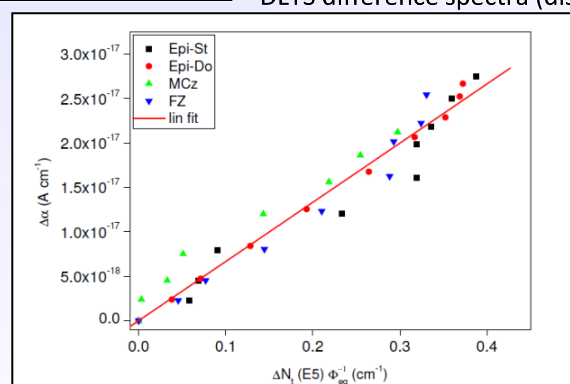
DLTS spectra



DLTS difference spectra (disappearing peaks)

- **Microscopic observation**
  - *The defects* ***E4/E5*** *(annealing at 60°C)and* ***E205a*** *(annealing at 200C) are contributing to the leakage current with 60% and 30 % respectively.*

Decrease in current



Decrease in defect concentration

ΔN_t(E5) vs. $\Delta\alpha$
Correlation found for many materials after neutron irradiation

[A.Junkes, PhD thesis 2011 & Vertex 2011 Proceedings]

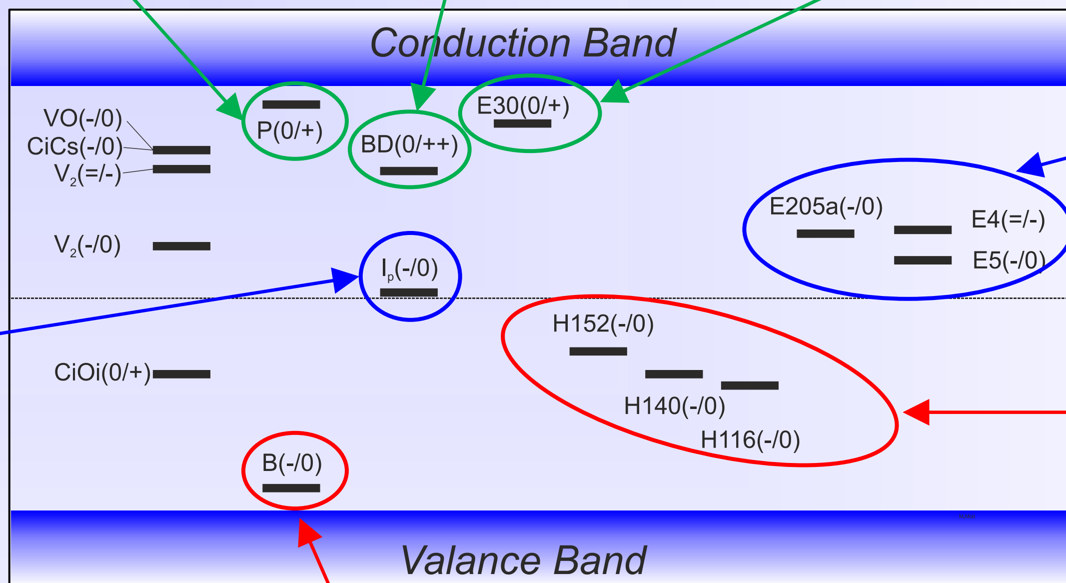
RD50 Summary on defects with strong impact on device performance after irradiation

- **Some identified defects**

Phosphorus: shallow dopant (positive charge)

positive charge (higher introduction after proton than after neutron irradiation, oxygen dependent)

positive charge (higher introduction after proton irradiation than after neutron irradiation)



Leakage current
E4/E5: V_3 (?)

leakage current & neg. charge
current after γ irrad, V_2O (?)

Reverse annealing (negative charge)

Boron: shallow dopant (negative charge)

A table with levels and cross sections is given in the next slide (spare slide).

- **Trapping: Indications that E205a and H152K are important** (further work needed)
- Converging on consistent set of defects observed after p, π, n, γ and e irradiation.
- Defect introduction rates are depending on particle type and particle energy and (for some) on material!

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Summary on defects with strong impact on device performance after irradiation

- **Some identified defects** *[Ioana Pintilie (Bucharest), RD50 Workshop, Nov.2013]*

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

Defects	$\sigma_{n,p}$ [cm^2]	E_A [eV]	Assignment/References	Impact on electrical characteristics at RT
E(30K)	σ_n= 2.3 x 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*
$BD_A^{0/++}$ $BD_B^{+/++}$	σ_n= 2.3 x 10^{-14} σ_n= 2.7 x 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*
$I_p^{+/0}$ $I_n^{0/-}$	σ_p= (0.5-9) x10^{-15} σ_n=1.7 x10^{-15} σ_p= 9 x 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	σ_n=1 x 10^{-15} σ_n=7.8 x 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)	σ_p=4 x 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)	σ_p=2.5 x 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)	σ_p=2.3 x 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
$VO_i^{-/0}$	σ_n= 1.44 x 10^{-14}	E_C -0.176	**$VO_i^{-/0}$** /[J. Appl.Phys.79(1996)3906 ; Mat. Sci. in Semic. Proc. 3 (2000) 227]	
$C_iC_s^{-/0}$	σ_n= 1.4 x 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)	σ_p= 1.7 x 10^{-15}	E_V + 0.09	Hole trap/ [Nucl. Instr. and Meth. in Phys. Res. A 611 (2009) 52-68]	
$C_i^{+/0}$	σ_p =4.3 x 10^{-15}	E_V + 0.284	**$C_i^{+/0}$**/ [M. Moll, PhD Thesis, University of Hamburg, DESY-THESIS-1999-040, 1999]	
$C_iO_i^{+/0}$	σ_p =4.3 x 10^{-15}		[J.Appl.Phys.79(1996)3906]	
$V_2^{-/0}$	σ_n=2.1 x 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)	σ_p=0.3 x 10^{-15}	E_V + 0.193	**$V_3^{0/+}$** /[Phys. Status Solidi A 208 (2011) 568.]	

Reminder: NIEL – Non Ionizing Energy Loss Displacement damage functions

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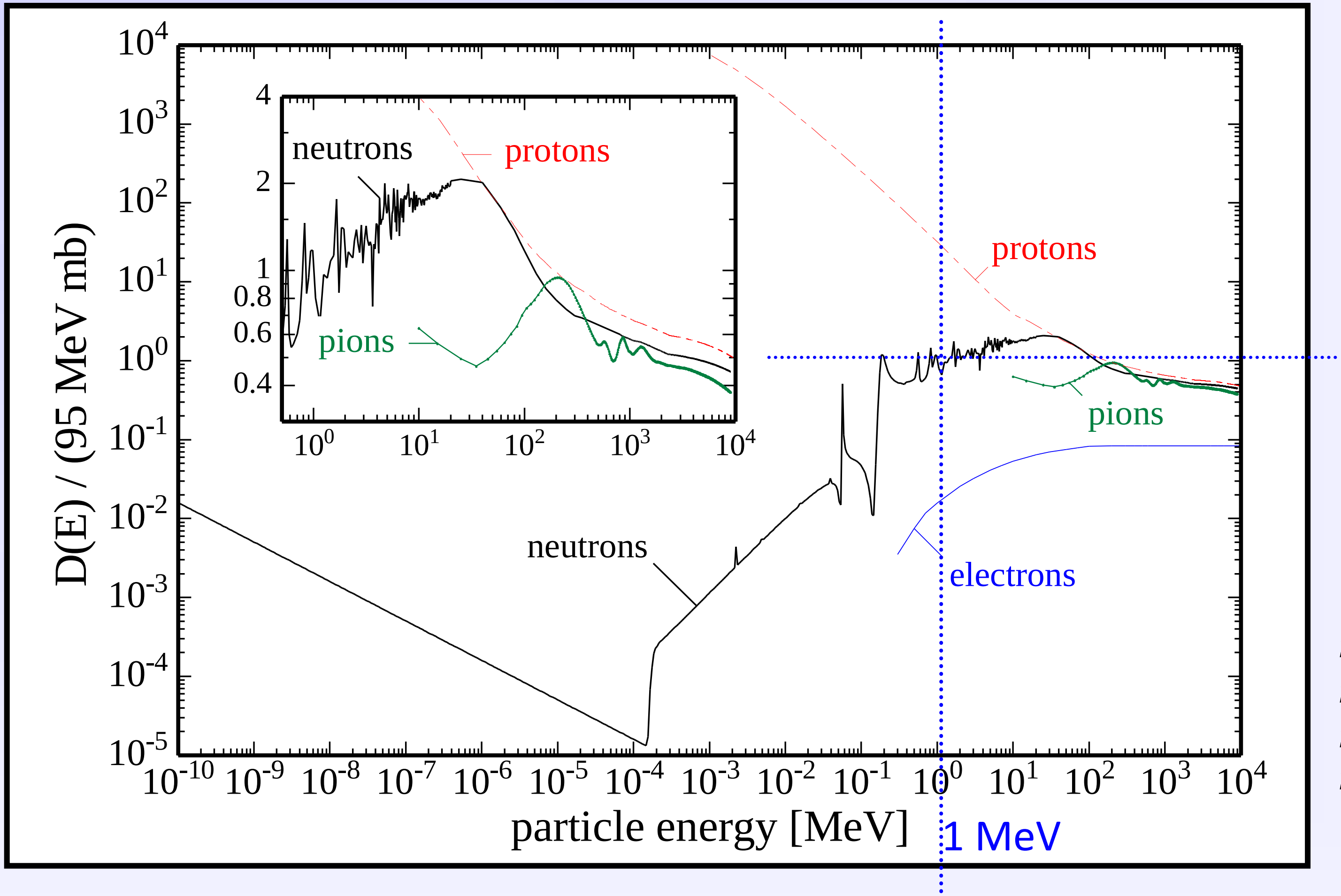


1 MeV neutron equivalent damage

$$\Phi_{eq} = \kappa_x \, \Phi_x$$

κ_p =0.62 (24 GeV/c protons)

κ_p = 1.85 (26 MeV protons)

κ_π = 1.14 (300 MeV pions)

κ_n = 0.92 (reactor neutrons >100 keV)

- **Hypothesis: Damage parameters scale with the NIEL**
  - **Be careful, does not hold for all particles & damage parameters (see later)**

Electron Damage: Defects & NIEL

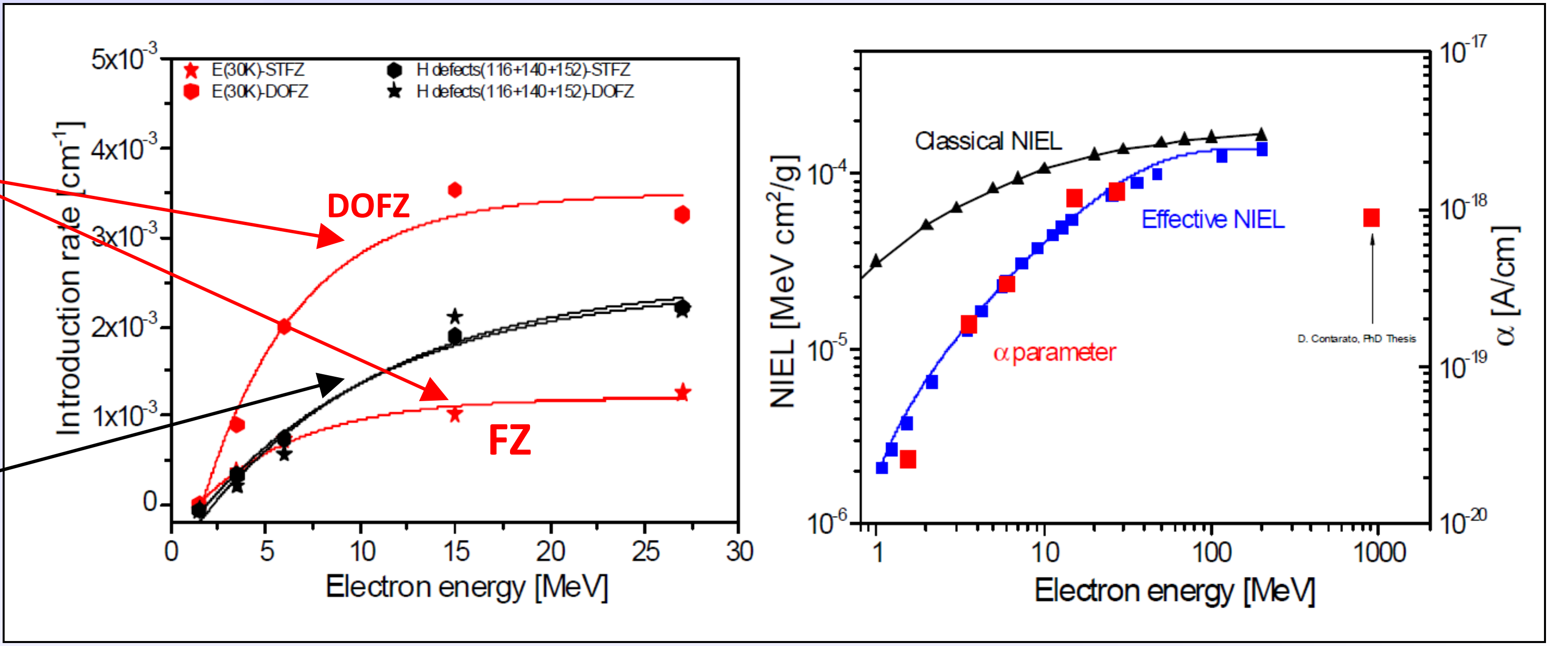
- **Defects concentrations after electron irradiation (1.5 to 15 MeV)**
  - **Do the defect concentrations scale with NIEL (Non Ionizing Energy Loss)?**
    - DOFZ – Diffusion Oxygenated Floating Zone Silicon (oxygen rich)
    - FZ – Floating Zone Silicon (oxygen lean)

Material dependence

E(30): Defect linked to “oxygen effect” (pos. space charge)

No Material dependence

H(116,140,152): Defects producing “reverse annealing”



[Effective NIEL: Inguimbert et al., IEEE TNS 57 (2010)1915]

- NIEL scaling of alpha parameter (leakage current) violated for electrons !
  - – Approach to use “effective NIEL” looks very promising
  - – Does this also improve damage scaling for hadrons? ….to be investigated.

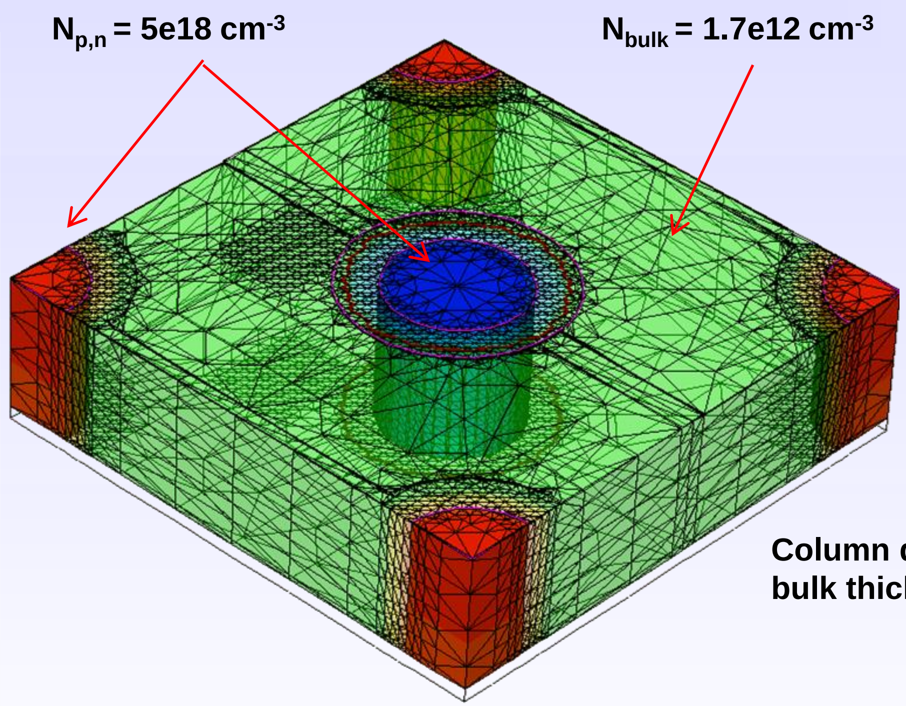
[I.Pintilie, 23rd RD50 Workshop, Nov. 2013]

Device Characterization & Simulation

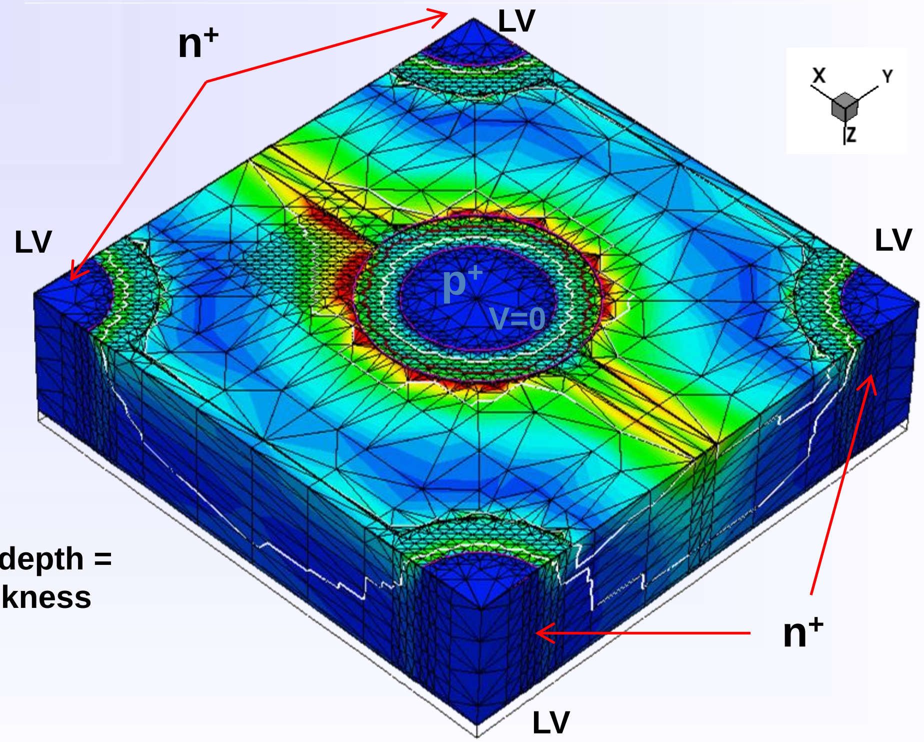
TCAD simulations

- **Why do we need TCAD simulations ?**
  - **Complexity of the problem**
    - Coupled differential equations (semiconductor equations)
    - Impact of defects depending on local charge densities, field-strength, … (“feedback loop”)
    - Complex device geometry and complex signal formation in segmented devices ….
    - Interplay of surface and bulk damage
    - *Example: 3D sensors*

Doping profiles



Electric field distribution in 3D detector (Al & oxide layer transparent for clarity)

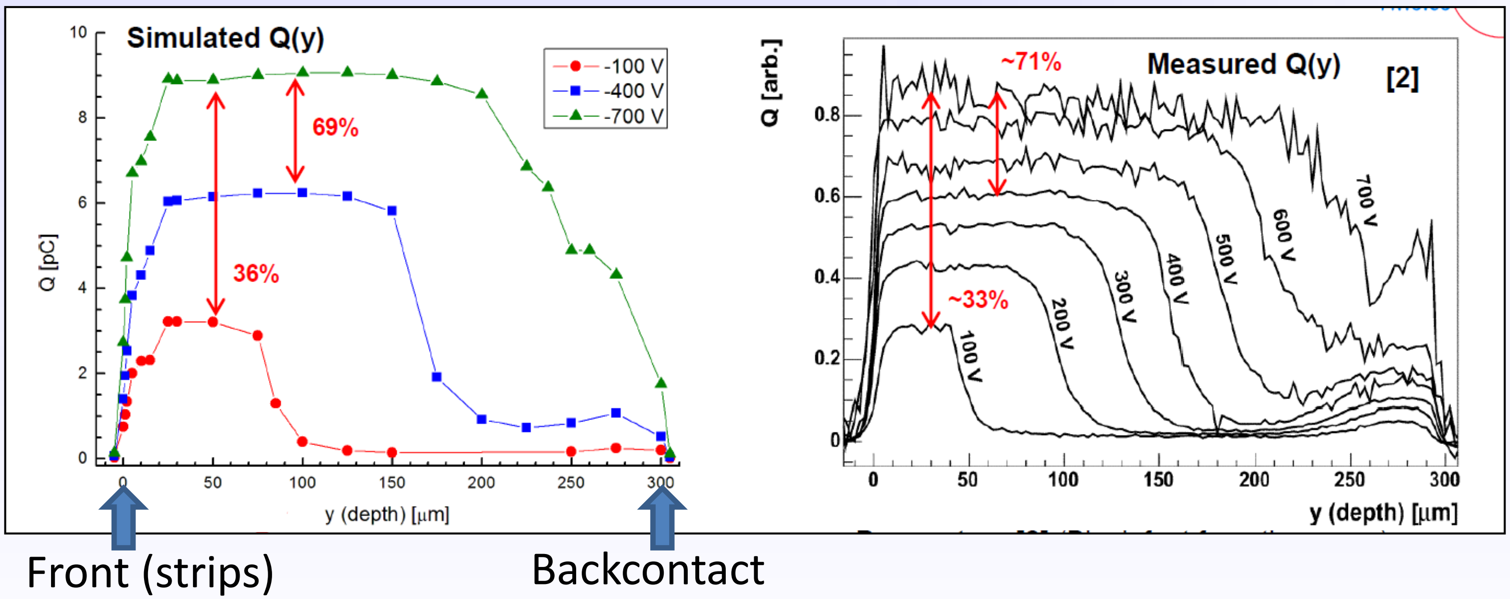


Column depth = bulk thickness

Example of 3D sensor: T.Peltola (HIP, Helsinki): CMS & RD50

RD50 Simulation working group

- **Device simulation working group formed in 2012** *(10 institutes guided by V.Eremin, Ioffe)*
  - **Aim:** Produce TCAD input parameters that allow to simulate the performance of irradiated silicon sensors and eventually allow for performance predictions under various conditions (sensor material, irradiation fluence and particle, annealing).
  - **Tools**: Commercial TCAD software (Synopsis & Silvaco) and custom made software
  - **Ongoing activity:** Inter-calibration of the used tools using a predefined set of defect levels and physics parameters & definition of defect levels & study surface effects
  - **Example of results (simulation vs. measurement):**
    - edge-TCT on a neutron irradiated p-type strip sensor (5e14n/cm^2); -20°C; simulation: 3 level model
    - Loss of efficiency at low voltages in region close to strips explained by simulations



[T.Peltola, RD50 Workshop – Nov. 2013]

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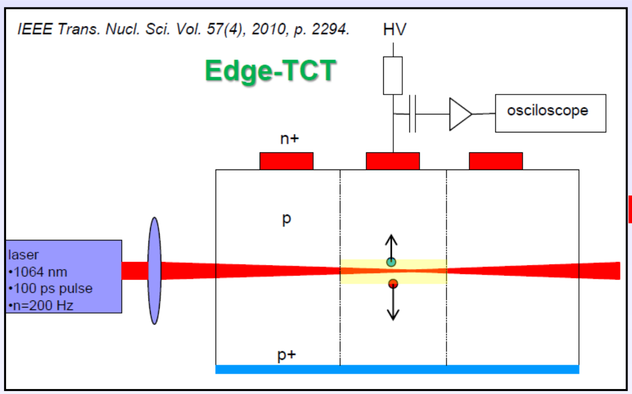
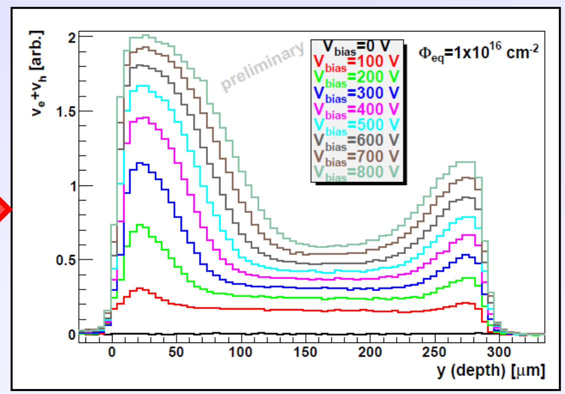
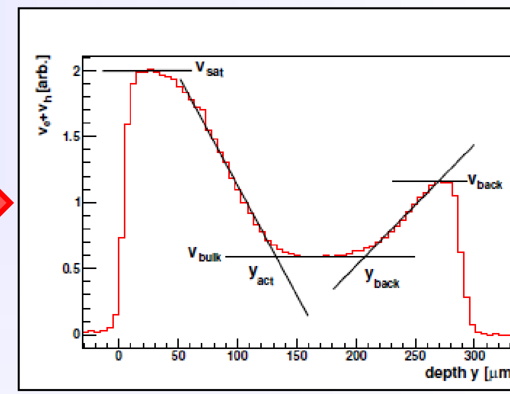
Simulation vs. Parameterization

- **Parameterization known as e.g. “Hamburg model”**
  - **Leakage current (from IV), Neff (from CV), Trapping times (from TCT)**
  - **Does not include the electric field respectively the double junction effect!**
- **TCAD simulations**
  - **Quite complex and no parameter set that is covering full phase space … reliable?**
    (silicon materials, different particles, full fluence range, annealing)
- **Parameterization of electric field instead?**
  - Edge-TCT: Extract E-field (more precisely the drift velocity) profile and parameterize it

[G.Kramberger et al., PoS (Vertex 2012) 022]







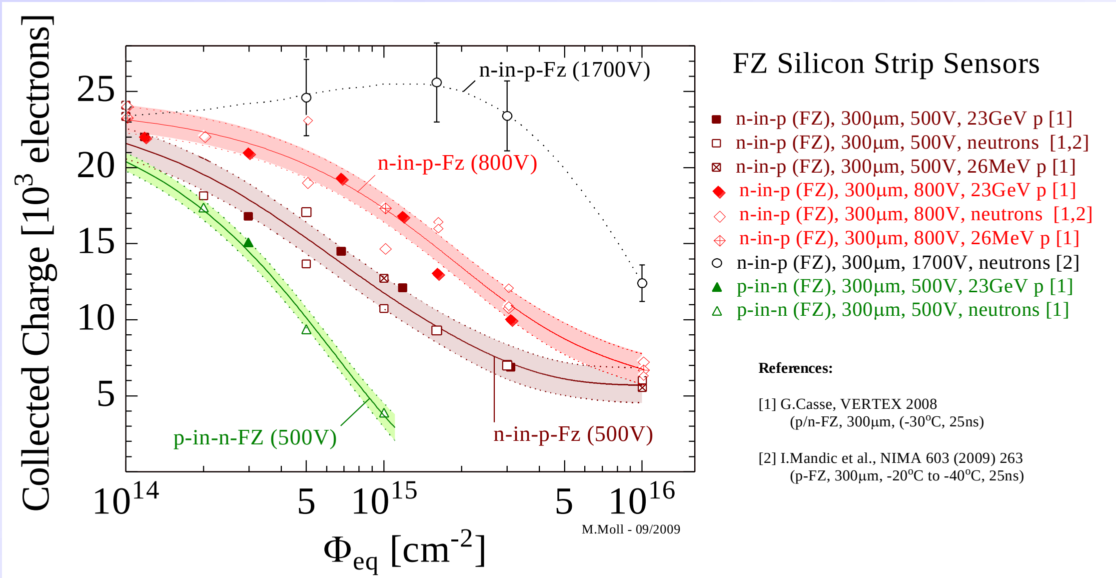
Edge-TCT → Drift velocity profile (v_e+v_h) → fit to extract parameters

Segmented Sensors with read-out at the n^+ contact

(n-in-p or n-in-n)

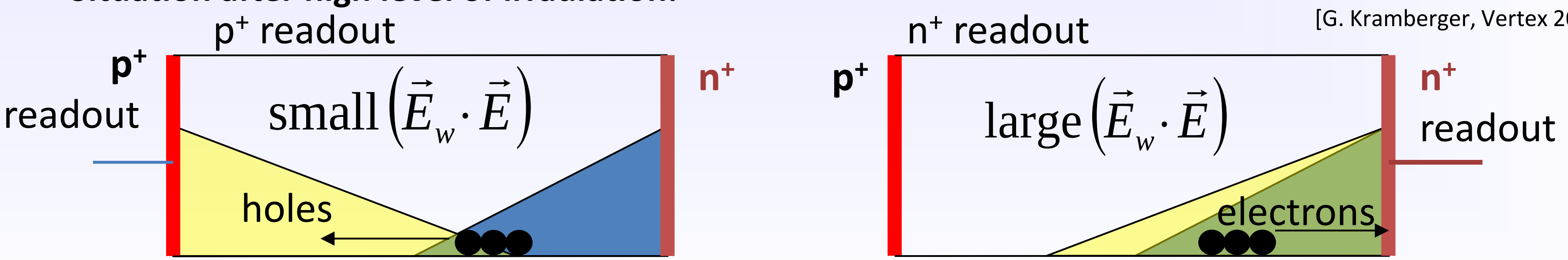
RD50 Reminder: Segmented sensors: n^+ vs. p^+ readout

- **p-type silicon** (brought forward by RD50) **Baseline for ATLAS and CMS Tracker upgrades**



- **n^+-electrode readout (“natural in p-type silicon”):**
  - favorable combination of weighting and electric field in heavily irradiated detector
  - electron collection, multiplication at segmented electrode
- **Situation after high level of irradiation:**

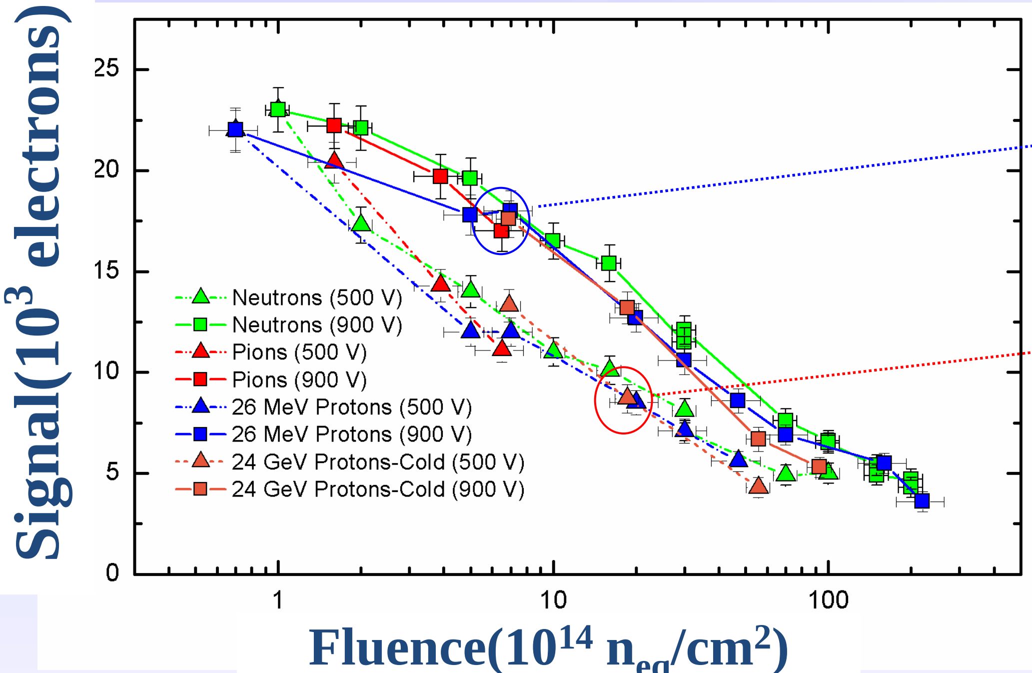
[G. Kramberger, Vertex 2012]

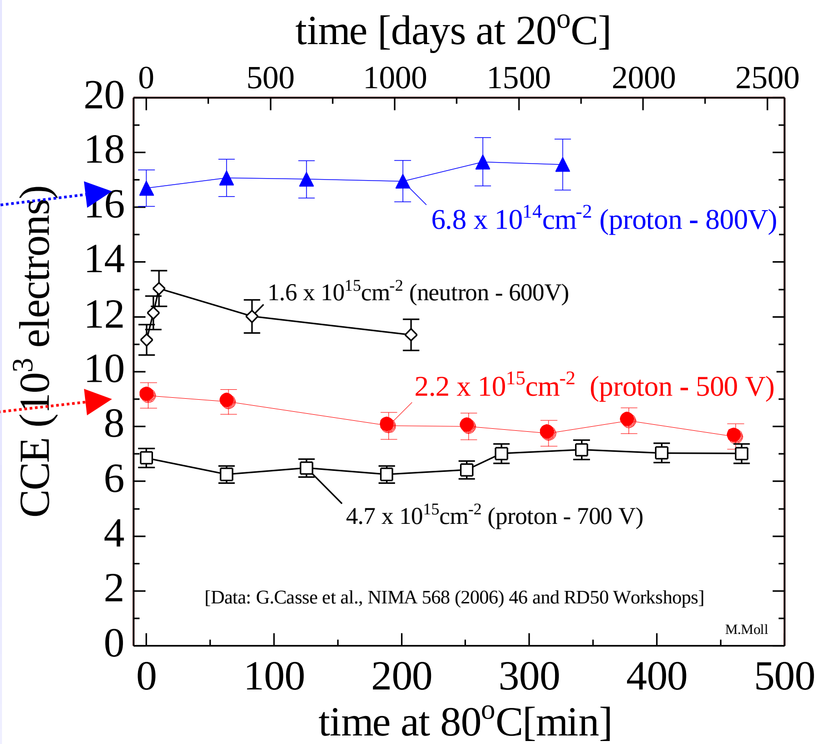


RD50 Reminder: FZ n-in-p microstrip detectors (n, p, π – irrad)

- **n-in-p microstrip p-type FZ detectors** (Micron, 280 or 300µm thick, 80µm pitch, 18µm implant)
- **Detectors read-out with 40MHz** (SCT 128A)

[A.Affolder, Liverpool, NIMA 623, 2010, 177–179]



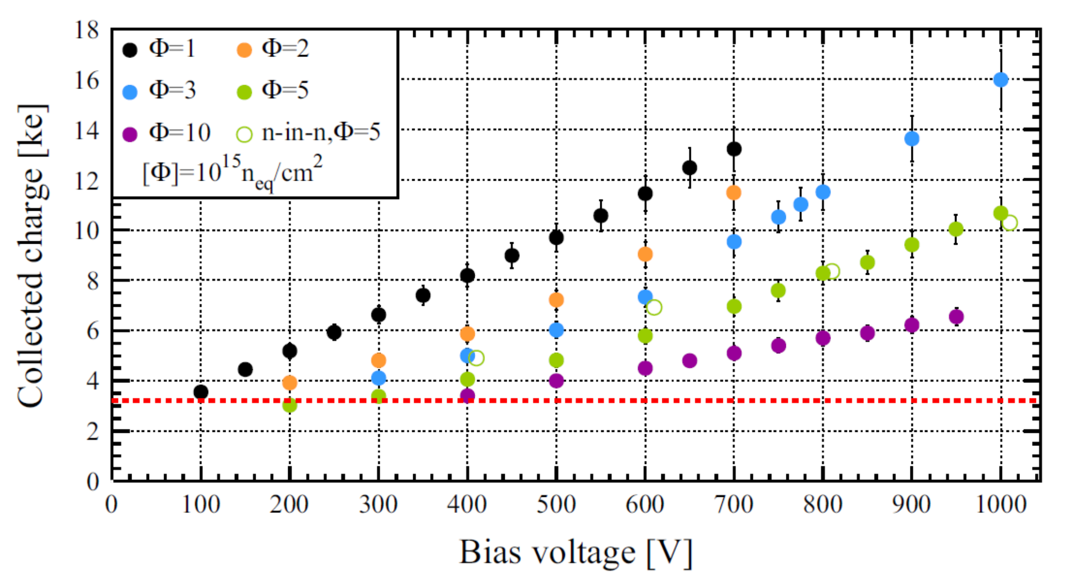


- **CCE: ~7300e (~30%)**
  after ~ 1×10^{16}cm^{-2} 800V
- **n-in-p sensors are baseline for ATLAS and CMS Tracker upgrades** (previously p-in-n used)

- **<u>no reverse annealing</u> in CCE measurements for neutron and proton irradiated detectors**

P-type pixel sensors

- **Planar segmented detectors n-in-p or n-in-n**
  - **results on highly irradiated planar segmented sensors have shown that these devices are a feasible option for the innermost layers of LHC upgrade**

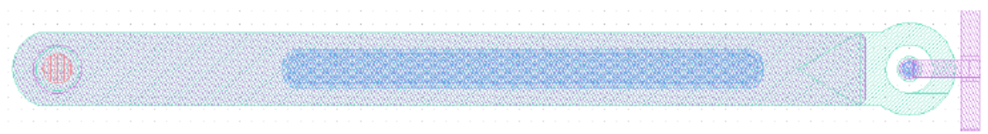


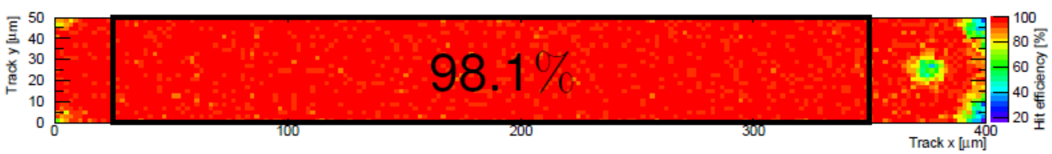
Example:

- 285 μm thick n-in-p FZ pixels
- FE-I3 readout
- sufficient charge also at $\Phi_{eq} = 1\cdot10^{16}$ n/cm²

$\Phi_{eq} = 1\cdot10^{16}$ n/cm²

- test beam, EUDET Telescope CERN SPS, 120 GeV pions:
- perpendicular beam incidence
- bias voltage: 600V
- threshold: 2000 el





[S. Terzo, 21th RD50 Workshop, CERN, 2012]
[D.Forshaw, NIMA 2013, to be published]

➔ 97.2% hit efficiency (98.1% in the central region)

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Thin p-type pixel sensors

From M.Moll VERTEX 2013 proceedings

- **Optimizing the sensor thickness**
- **Measurement of thin FZ p-type pixel sensors: 75, 100, 150 and 285 μm (MPI/CIS)**

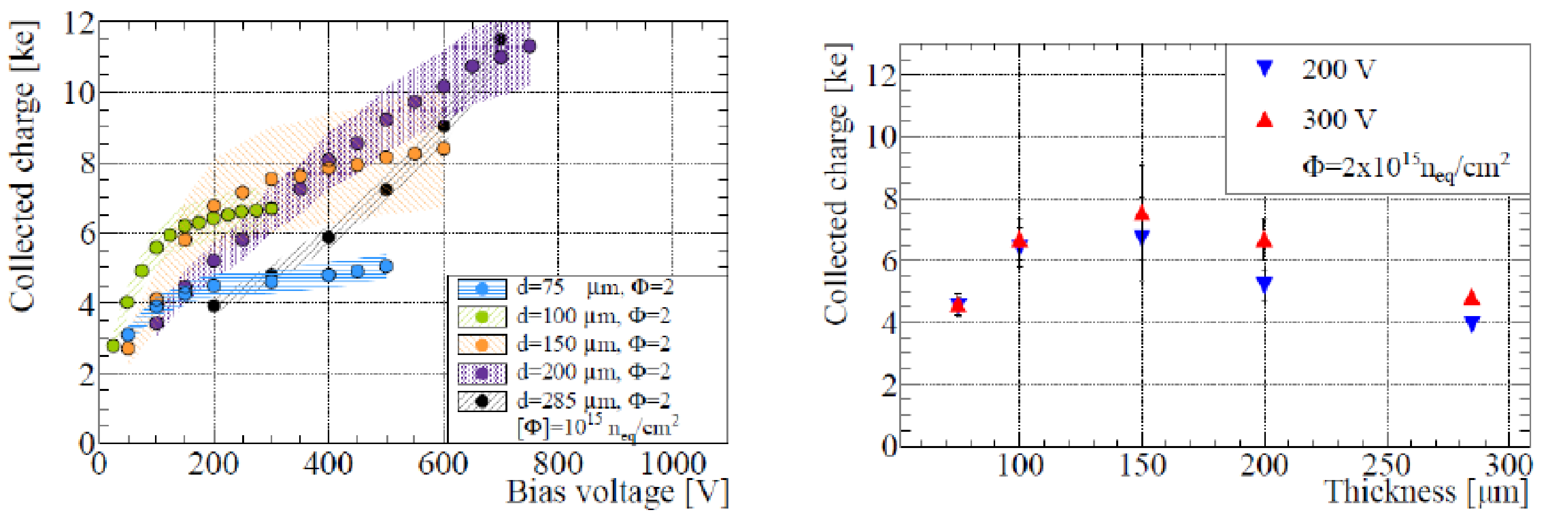


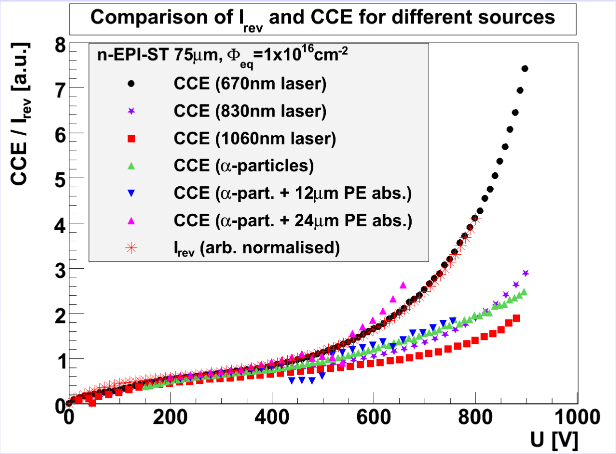
Figure 4: Comparison of collected charge as measured with a Sr^{90} source on irradiated ($\phi_{eq} = 2 \times 10^{15} n_{eq} cm^{-2}$) p-type pixel sensors with different thickness bump-bonded to ATLAS FEI4 readout chips [23]. Left: Collected charge as function of voltage. Right: Collected charge as function of device thickness for 200V and 300V.

[23] S.Terzo. Irradiated n-in-p planar pixel sensors with different thicknesses and active edge designs. *23rd RD50 Workshop, November 2013.*

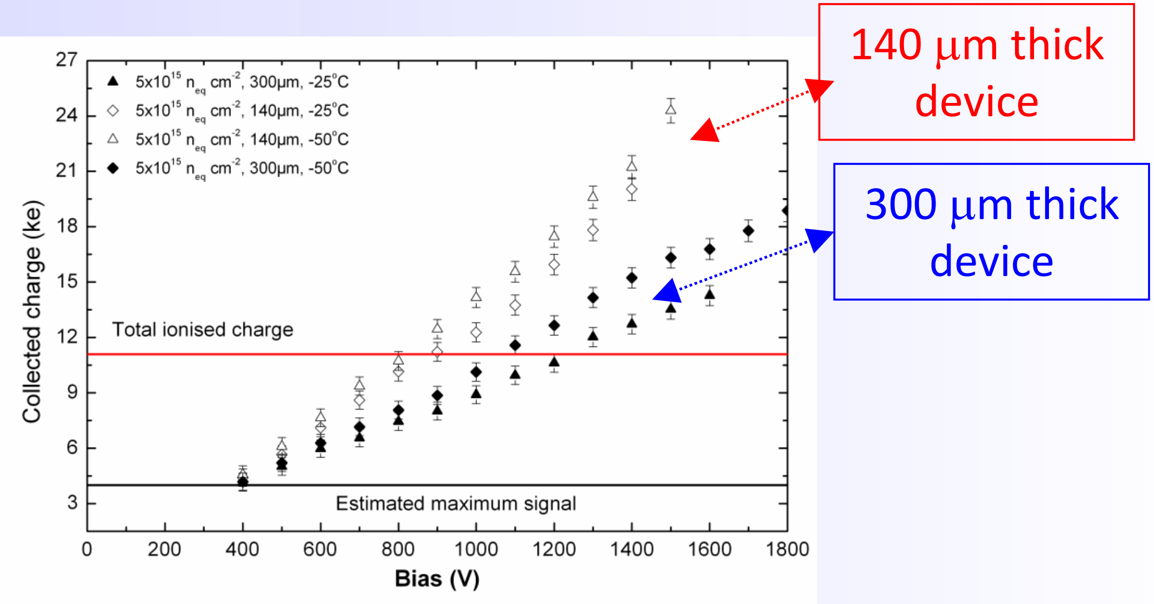
Charge Multiplication
(Sensors with intrinsic gain)

RD50 Reminder: Charge Multiplication

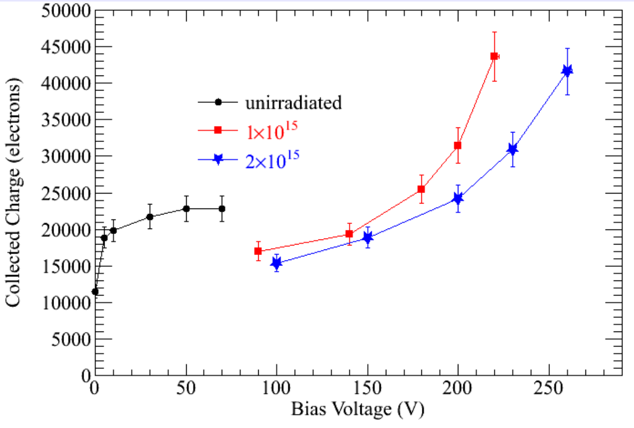
- <u>Charge Multiplication</u> observed and characterized after high levels of irradiation with different techniques and in several different types of devices



<u>Diodes</u> ($\Phi_{eq}=10^{16}$ cm^{-2})
Leakage Current & Charge Collection



<u>Strip sensors</u> ($\Phi_{eq}=5\times10^{15}$ cm^{-2}, 26 MeV p)
Charge Collection (Beta source, Alibava)



<u>3D sensors</u> ($\Phi_{eq}=1\text{-}2\times10^{15}$ cm^{-2})
Charge Collection (test beam)

<u>**Questions:**</u>

- **Can we simulate and predict charge multiplication ?**
- **Can we better exploit charge multiplication?**

Ref: Diode: J.Lange et al, 16th RD50 Workshop, Barcelona
Strip: G. Casse et al., NIMA 624, 2010, Pages 401-404
3D: M.Koehler et al., 16th RD50 Workshop, Barcelona

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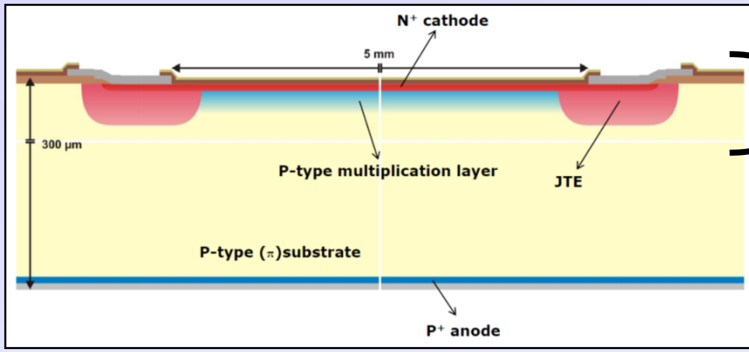
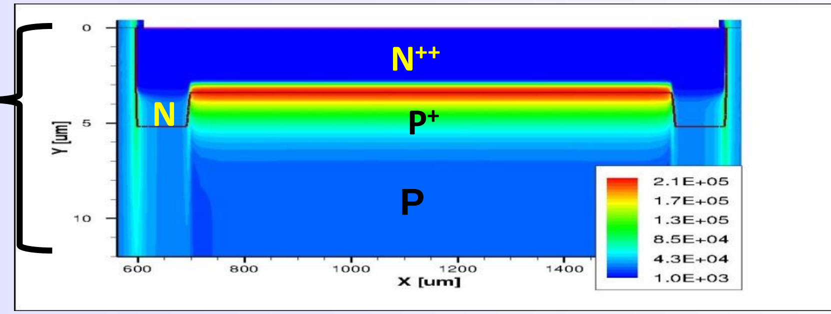
Low Gain Avalanche Detectors (LGAD)

[G.Pellegrini, 9th Hiroshima, 9/2013]

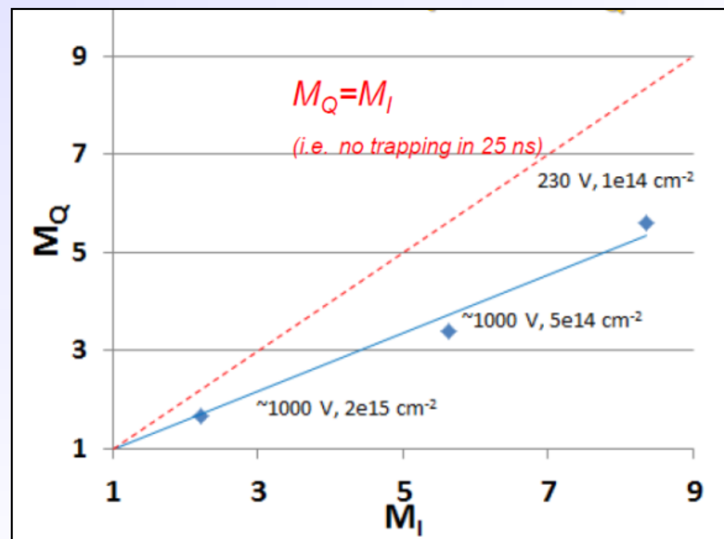
- **Diodes with implemented multiplication layer (deep p+ implant)**
  - **APD concept [n^{++}-p^{+}-p-p^{+} structure] with JET (Junction Edge Termination)**





Simulation of E-Field [V/cm]

  - **Gain of approx. 10 before irradiation : linear mode : spectra are Landau spectra (^{90}Sr)**
- **Gain reduces with irradiation**
  - **Dropping to about 1.5 after 2e15 n/cm²**
    - Why? Boron removal in p-type layer?
  - **Current and noise scale as expected with multiplication**
  - **Charge (Sr-90) Multiplication versus Current Multiplication (Sr-90)**



[G.Kramberger, RD50, June 2013]

- **Further work ongoing (strip, pixel, …)**

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Key results (in 2013/2014)

CERN

- **Progress in understanding microscopic defects**
  - Defects responsible for positive space charge in DOFZ, MCZ and EPI and defects provoking reverse annealing are characterized!
  - Consistent list of defects produced covering electron, gamma, neutron and proton/pion damage
- **TCAD simulations : Good progress on simulations** *[Note: RD50 profiting from strong CMS simulation group]*
  - Commercial TCAD packages well understood and proved to be well adopted to our needs (defect description)
  - Simulations can reproduce pulse shapes, depletion voltage, charge collection and leakage current. Getting predictive capabilities!
- **Systematic analysis of the Charge multiplication mechanism**
  - Noise issue particularly important for exploitation of this feature in Experiments
  - New dedicated sensors produced to test avalanche effects, sensors working after irradiation
- **Consolidation of data obtained on p-type and thin segmented sensors**
  - Further results on radiation tolerance and further results on long term annealing
  - Thin sensors seem to extend fluence reach of silicon detectors; Optimization: Optimum thickness depends on many parameters !
- **Slim and active edges**
  - Further progresses towards reduction of insensitive area (edges) of detectors
- **New structures based on mixed technologies**
  - Exploitation of DRIE etching: 3D-trench electrode, semi-3D sensors; planar strip with trenched electrodes, active edge planar pixel, ……..; Use of deep implantation for controlling avalanches.
- **Use of tools developed in framework of RD50: ALIBAVA & Edge-TCT & Beam telescope**
  - Edge-TCT and TCT systems are now produced centrally and can be procured by interested groups
  - Use of the ALIBAVA readout system in many RD50 institutions; Telescope commissioned

RD50

Workplan for 2014/2015 (1/2)

- **Defect and Material Characterization** *(Convener M.Bruzzi, INFN and University of Florence, Italy)*
  - Consolidate list of defects and their impact on sensor properties (Input to simulation group) including introduction rates & annealing for different type of irradiations and materials
  - **Extend work on p-type silicon**
    - Understand boron removal in lower resistivity p-type silicon
  - **Review NIEL approach; Modeling and understanding role of clusters;**
    - Study of electron damage

- **Detector Characterization** *(Convener: E.Fretwurst, University of Hamburg, Germany)*
  - **RD50 Simulation Working Group** (Leader: V.Eremin, Ioffe, St.Petersburg, Russia)
    - Cross-calibration of different simulation tools (ongoing)
    - Refine defect parameters used for modeling (from effective to measured defects)
    - Extend modeling on charge multiplication processes
  - **Extend experimental capacities on edge-TCT (implement set-up at more RD50 institutions)**
    - Parameterization of electric field (fluence, annealing time, etc.)
    - Studies on charge multiplication processes
  - **Continue study on "mixed" irradiations**
  - **Extend irradiation program using charged hadrons of different energy [Pion irradiation in 2014]**
  - **Explore fluence range to10^{17}cm^{-2} (to prepare for future needs in forward physics)**

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Workplan for 2014/2015 (2/2)

- **New structures** *(Convener: Giulio Pellegrini, CNM Barcelona, Spain)*
  - **Continue edge-TCT studies on 3D and thin sensors**
  - **Characterization of dedicated avalanche test structures** (devices have been produced)
    - Understand impact of implant shape and other geometrical parameters on avalanche processes
    - Combine results with edge-TCT data and simulations to get deeper understanding
  - **Evaluate 'low resistance strip' sensors**

- **Full detector systems** *(Convener: G.Kramberger, Ljubljana University, Slovenia)*
  - **Further studies of thin (low mass) segmented silicon devices**
  - **Study performance of thin and avalanche sensors in the time domain (Fast sensors!)**
  - **Long term annealing of segmented sensors** (parameterize temperature scaling)
  - **Continue RD50 test beam program and RD50 beam telescope [Test beam time in 2014]**
  - **Cold irradiations and irradiations under bias** (segmented detectors)
  - **Continue study on "mixed" irradiations** (segmented detectors)
  - **Continue RD50 program on slim edges, edge passivation and active edges**

- **Links with LHC experiments and their upgrade working groups**
  - **Continue collaboration on evaluation of radiation damage in LHC detectors**
  - **Continue common projects with LHC experiments on detector developments**

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RD50 main achievements & links to LHC Experiments

Some important contributions of RD50 towards the LHC upgrade detectors:

- **p-type silicon** (brought forward by RD50 community) is now considered to be the base line option for the ATLAS and CMS Strip Tracker upgrades
- n- MCZ (introduced by RD50 community) might improve performance in mixed fields due to compensation of neutron and proton damage: MCZ is under investigation in ATLAS, CMS and LHCb
- Double column 3D detectors developed within RD50 with CNM and FBK. Development was picked up by ATLAS and further developed for ATLAS IBL needs.
- RD50 results on very highly irradiated **planar segmented sensors** have shown that these devices are a **feasible option for the LHC upgrade**
- **RD50 data are essential input parameters** for planning the running scenarios for LHC experiments and their upgrades (evolution of leakage current, CCE, power consumption, noise,….).
- **Charge multiplication** effect observed for heavily irradiated sensors (diodes, 3D, pixels and strips). Dedicated R&D launched in RD50 to understand underlying multiplication mechanisms, simulate them and optimize the CCE performances. Evaluating possibility to produce fast segmented sensors?
- **Close links to the LHC Experiments:**
  - **Many RD50 groups are involved in ATLAS, CMS and LHCb upgrade activities (natural close contact).**
  - **Common projects with Experiments:**
    Irradiation campaigns, test beams, wafer procurement and common sensor projects.
  - **Close collaboration with LHC Experiments on radiation damage issues of present detectors.**

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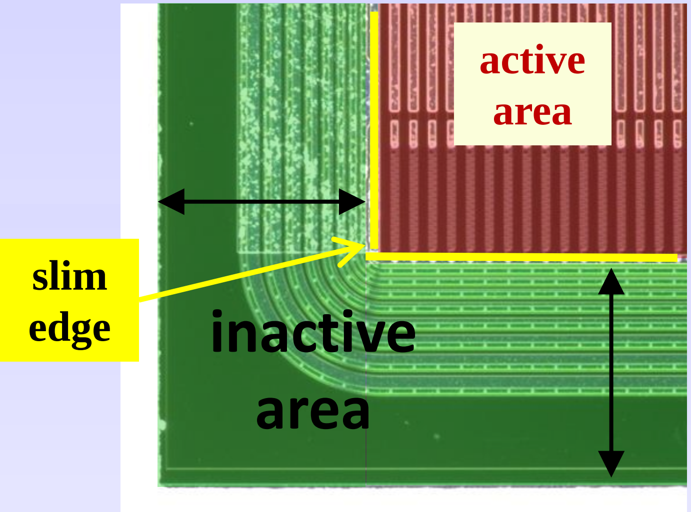
Spare Slides

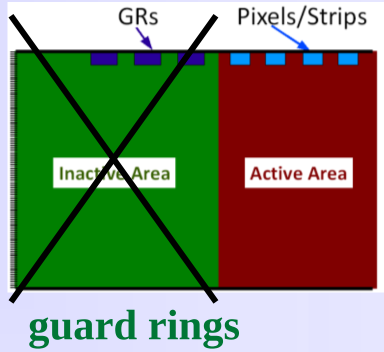
- Some spare slides
- More details on http://www.cern.ch/rd50/

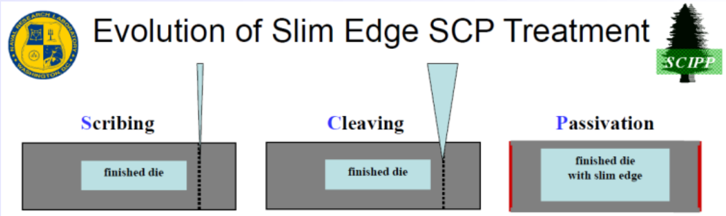
  - Most results presented here have been shown on the 22nd and 23rd RD50 Workshop

New structures: slim and active edges

- **RD50 slim edges project (reduce dead space around the active sensor)**







- **Scribe** XeF_2 etch, diamond scribe, DRIE
- **Cleave** automated, manual
- **Passivate** nitride, oxide (n-type) alumina ALD (p-type)

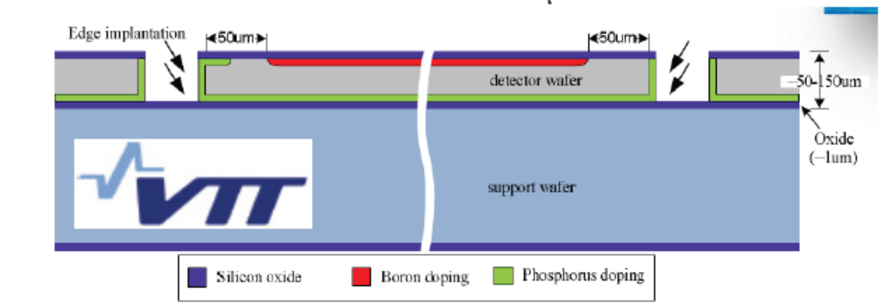
[V. Fadeyev, 22nd RD50 Workshop, Albuquerque, June 2013]

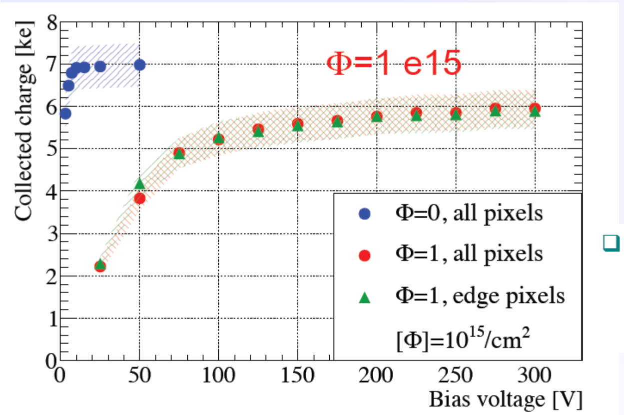
… development picked up by HPK (see Hiroshima Symposium 9/2013)

- **Active edges (VTT & MPI Munich)**
  - **Thin wafers with active edges produced at VTT** [A.Macchiolo, 22nd RD50, Albuquerque, June 2013]

❑ Trench doped by four-quadrant implantation

❑ Sensor thickness 100-200 µm





10^{15} p/cm^2

Testbeam: no difference between edge and other pixel!

❑ FE-I3 100 µm thick sensor with 125 µm slim edge, threshold 1500 e- → 87% CCE at 300 V for both all and edge pixels after irradiation at KIT

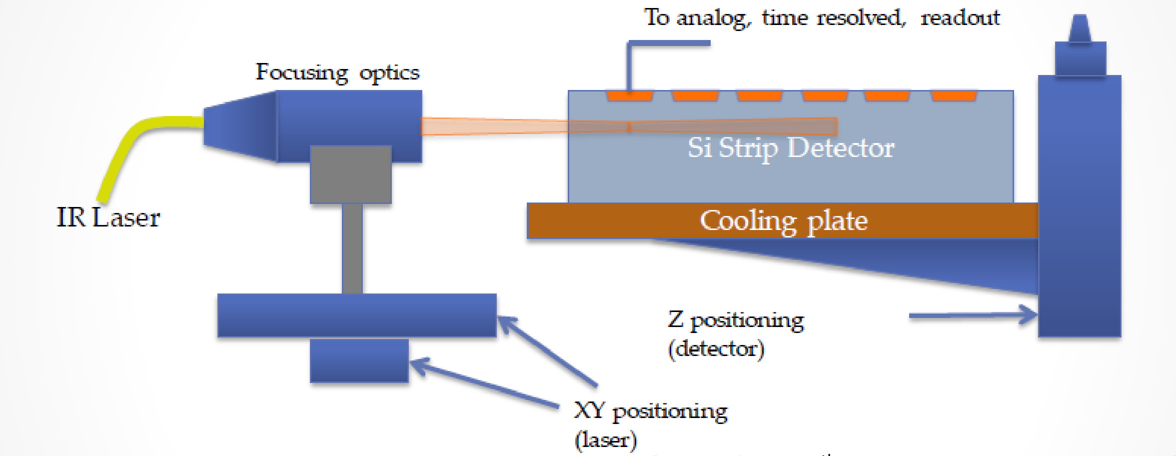
Edge-TCT to Study Fields

RD50

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

- **Study of Electric field inside silicon sensor very challenging problem**

- **New tool (2010): Edge-TCT (Transient Charge Technique)**
  - **Illuminate segmented sensor from the side with sub-ns infrared laser pulses**
  - **Scan across the detector thickness**
  - **Record current pulses as function of depth**
  - **Extract rise time and collected total charge**
  - **Reconstruct the electric field**



[N.Pacifico, 20th RD50 Workshop, Bari, 2012]

- **Expectations**
  - **Significant electric field only in depleted volume**
  - **Charge generated in 'undepleted' part of detector is lost**