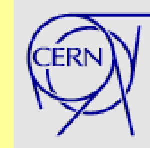

Progress in R&D on silicon edgeless strip detectors with Current Terminating Structure

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G. Pellegrini[4], G. Ruggiero[5], T. Tuuva[6]

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[5]CERN, Switzerland
[6]Lappeenranta University of Technology, Finland

13 RD50 Woskshop
CERN, Geneva, Nov 10-12, 2008

Outline

- ♦ **Overview of the approaches for rad-hard edgeless detectors**
- ♦ **Edgeless detector with CTS: design**
- ♦ **Models for potential and electric field distribution in p-on-n edgeless detector and experimental results**
- ♦ **Simulation of irradiated detectors**
- ♦ **Experimental results on CCE (test beam)**
- ♦ **Development of n-on-p edgeless detectors**

Conclusions

Requirements

Requirement: diminished dead area adjacent to detector sensitive area ➔

Close-to-beam applications (CERN, TOTEM, Roman pot) - maximal dead area width less than 50 µm

Other applications: imaging tileable arrays for diagnostics (medicine, biology etc.)

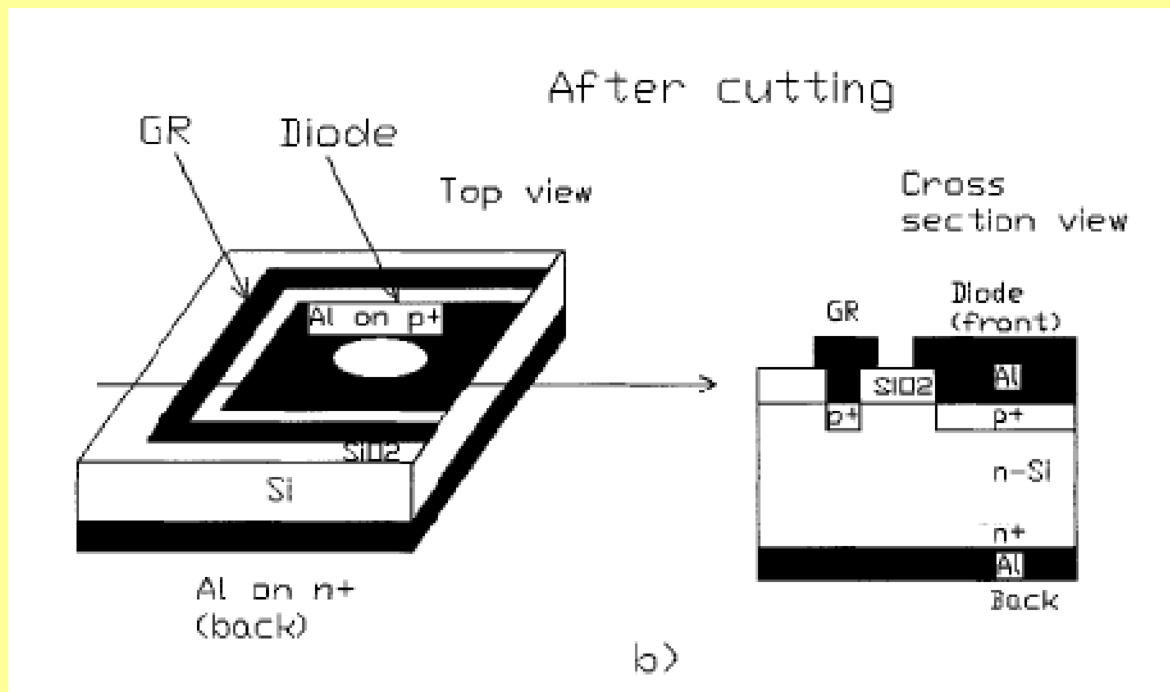
Solution: edgeless detectors (diced or cut)

Problem: elimination of the influence of high current from damaged cut on the properties of detector sensitive bulk

Prehistory

Z. Li et al., IEEE Trans. Nucl. Sci. NS-49 (2002) 1040-1046

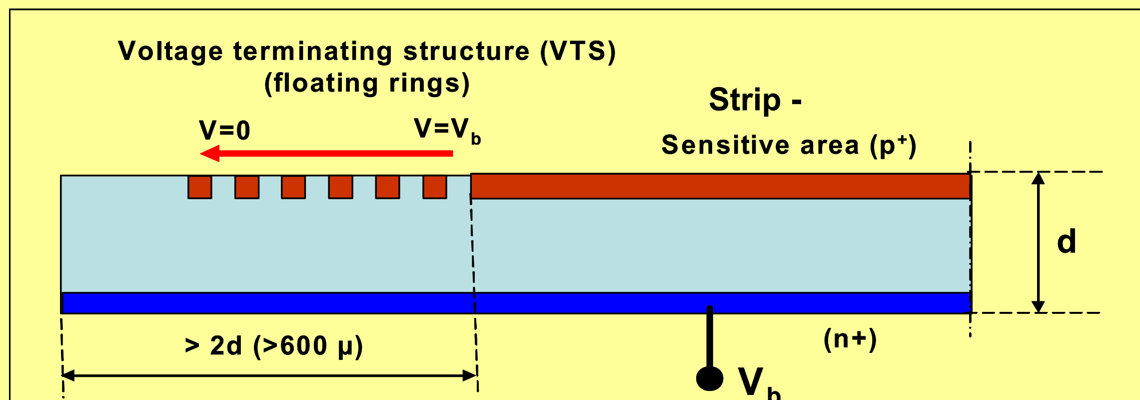
Pad detectors diced across p-n junction



I-V improvement:

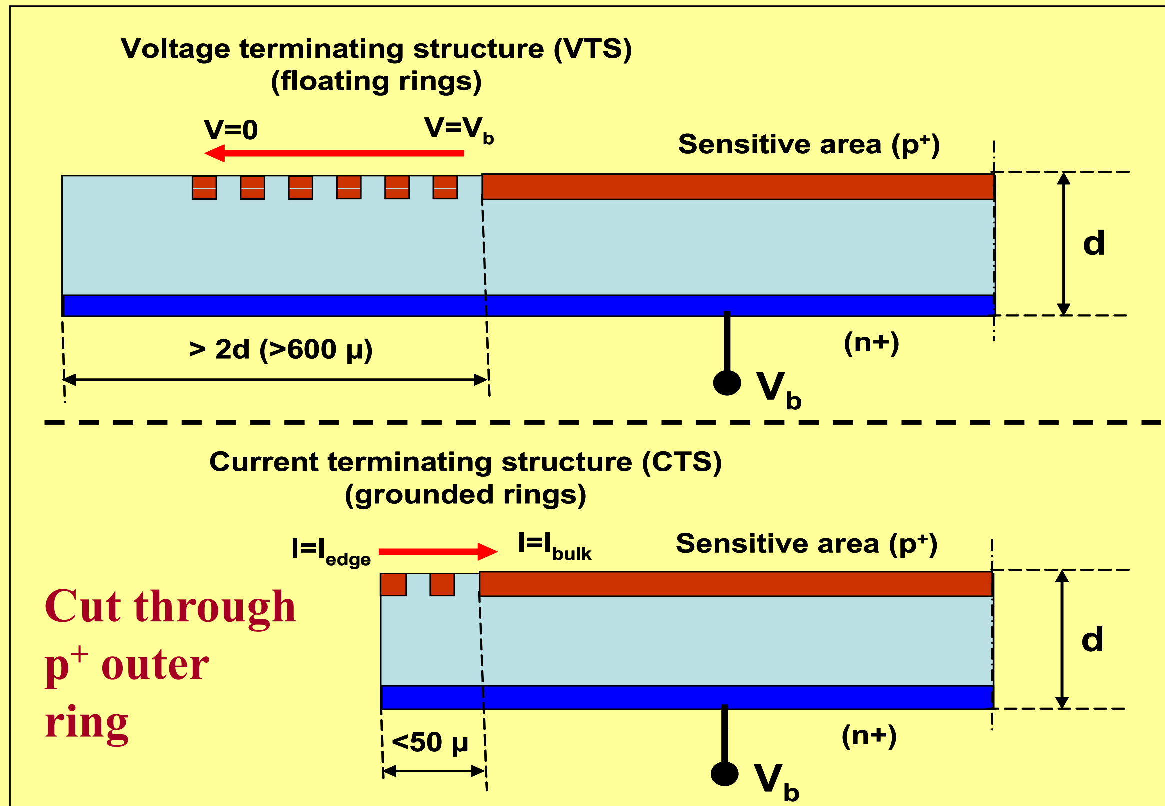
- Dicing from the back side
- Aging at RT

Overview of the approaches for edgeless detectors



Regular planar strip detector with Voltage Terminating Structure (VTS)

Approach: Edgeless strip detector with Current Terminating Structure (CTS)



Regular p^+-n-n^+ strip detector with Voltage Terminating Structure (VTS)

TOTEM: Edgeless p^+-n-n^+ strip detector with CTS

1. G. Ruggiero et al. IEEE Trans. Nucl. Sci. 52 (2005) 1899.
2. E. Noschis et al. Nucl. Instr. and Meth. A 563 (2006) 41.

Alternative approach: full 3D active edge detectors

C. Da Via et al., NIM A587 (2008) 243-249

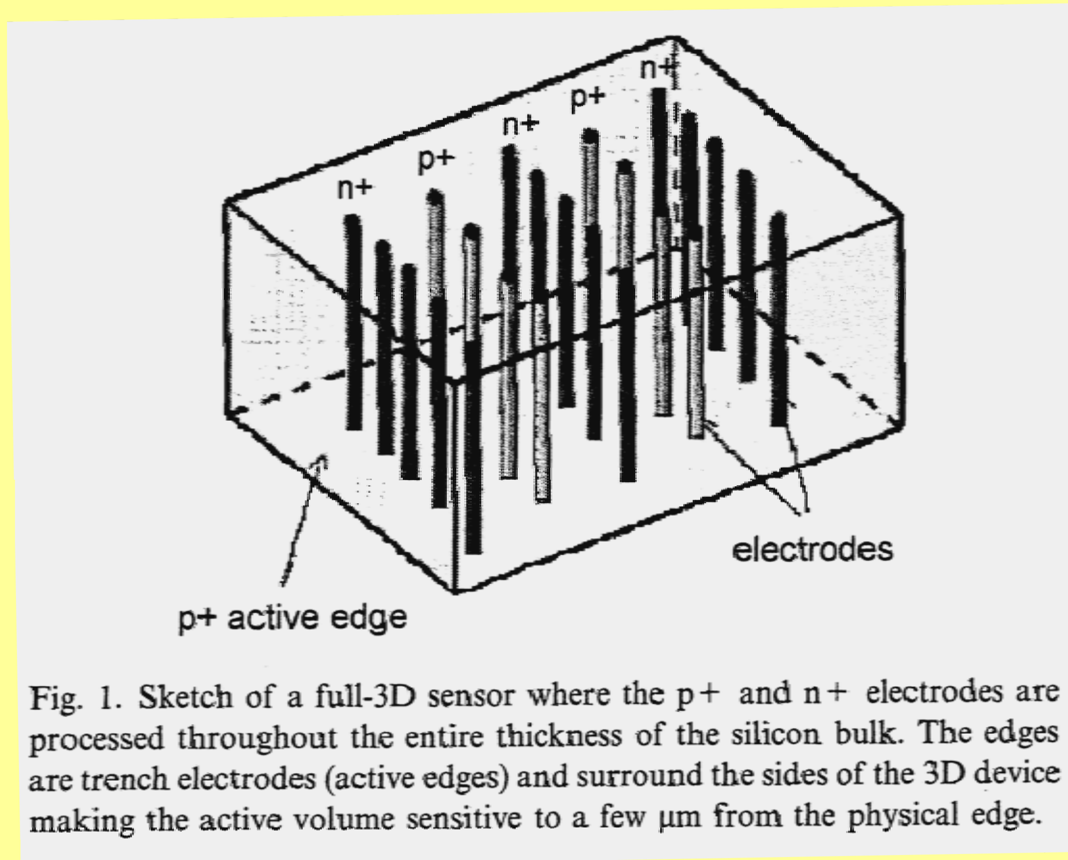


Fig. 1. Sketch of a full-3D sensor where the p+ and n+ electrodes are processed throughout the entire thickness of the silicon bulk. The edges are trench electrodes (active edges) and surround the sides of the 3D device making the active volume sensitive to a few μm from the physical edge.

Main features of design:

- p^+ and n^+ through entire bulk
- p^+ active edge

✓collection distance ≤ 50 μm
✓ fast response
✓ higher electric field due to cylindrical geometry
✓radiation hardness

but

✓Complicated technology

Further development of edgeless detectors with CTS: INTAS-CERN project TOSTER: TOtem STrip Edgeless Radiation hard detectors

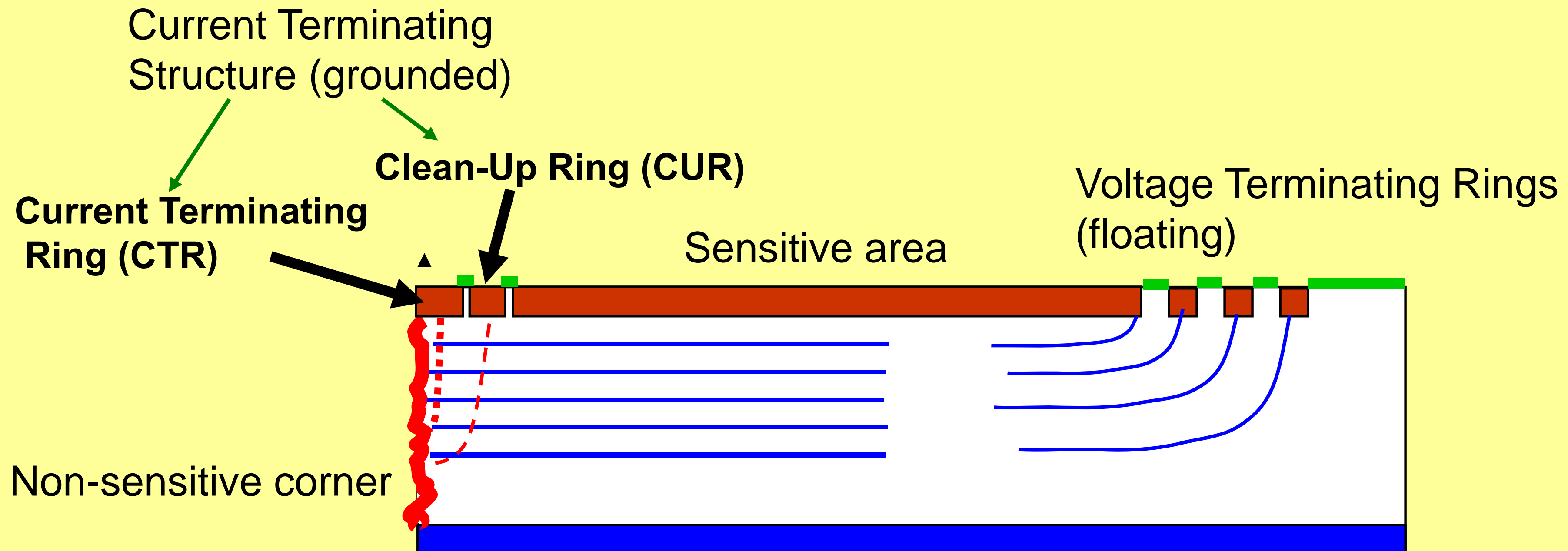
 # 05-103-7533 Started: July 2006

CONSORTIUM

CERN - Switzerland
Ioffe Physico-Technical Institute RAS - Russia
Research Institute of Material Science and Technology - Russia
Centro Nacional de Microelectronica - CSIC – Barcelona, Spain
University of Bologna - Italy
Lappeenranta University of Technology – Finland

Head of the project: Gennaro Ruggiero (CERN)

Conceptual design of edgeless detector with CTS

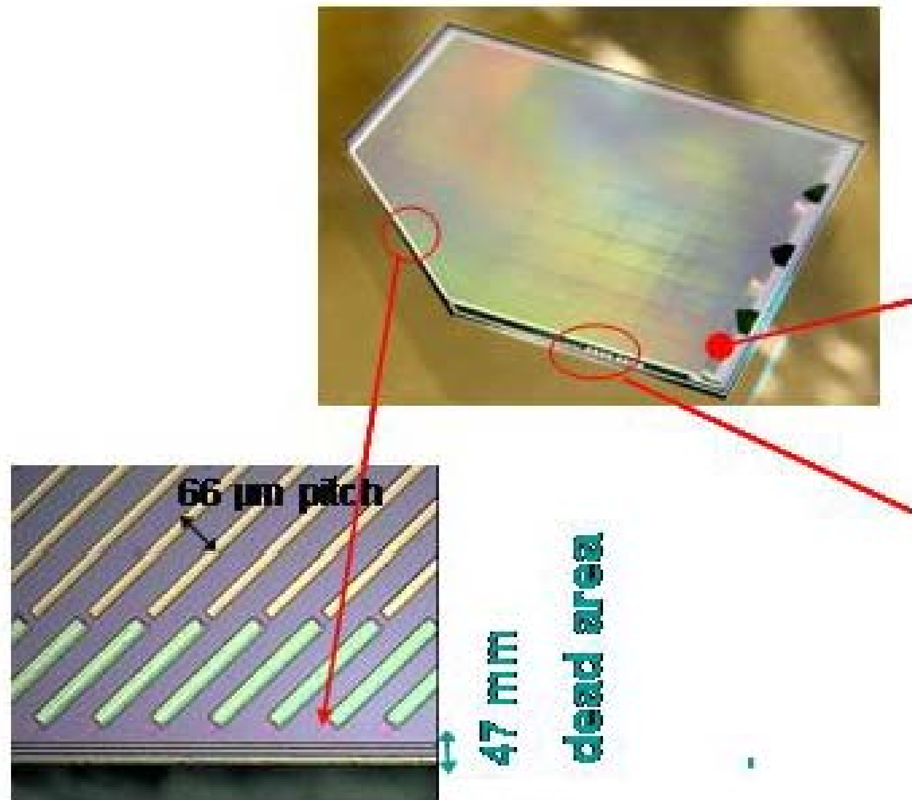


The current of CTR: ohmic current along the damaged cut

The current of CUR: diffusion current from the cut to the bulk

The current of sensitive area: bulk generated current

Performance of edgeless detector with CTS



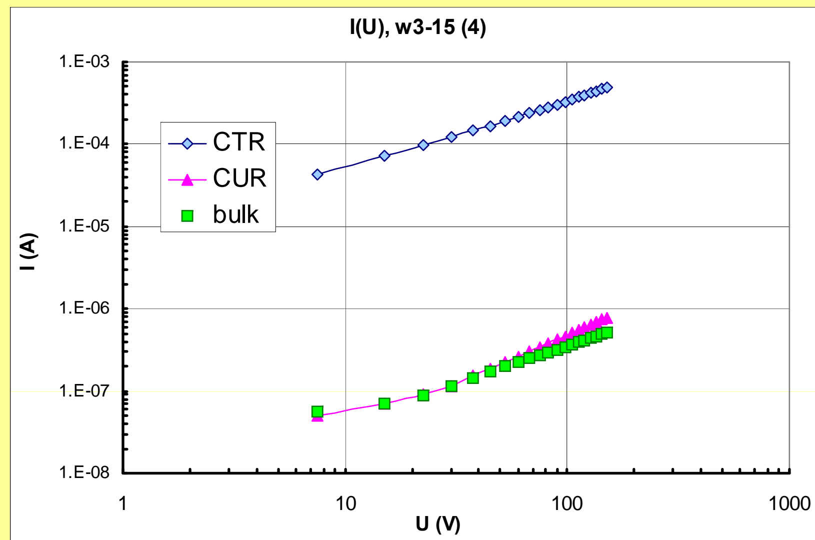
Dead area 47 µm

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

Electrical characteristics of p-on-n edgeless detectors

Processed by Ioffe&RIMST

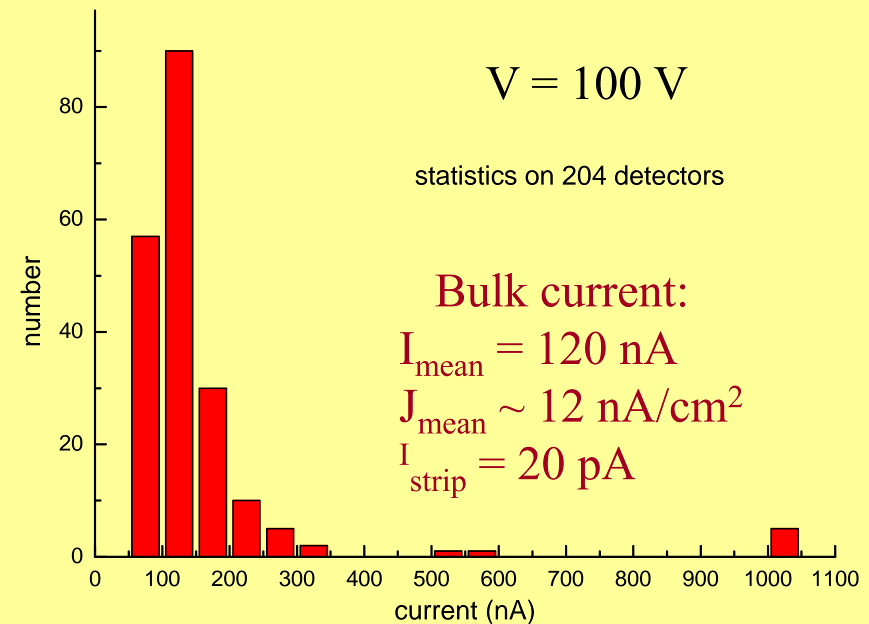
I-V characteristics



Statistics of reverse current

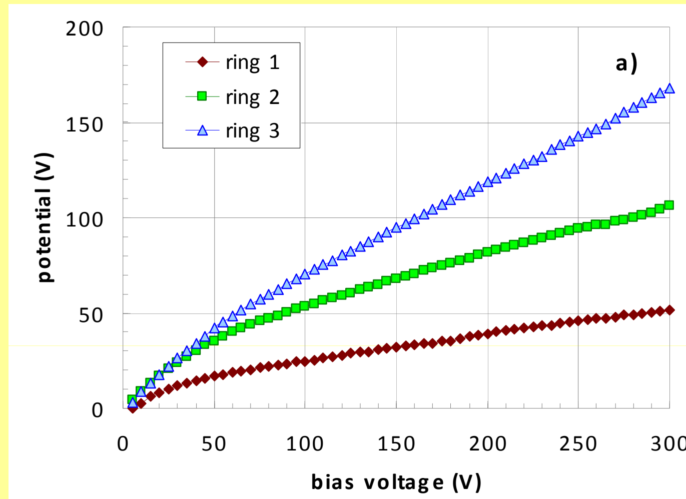
n-Si, $\rho \sim 20\ \text{k}\Omega\cdot\text{cm}$ V_{fd}: ~20 V; **S = 8 cm²**

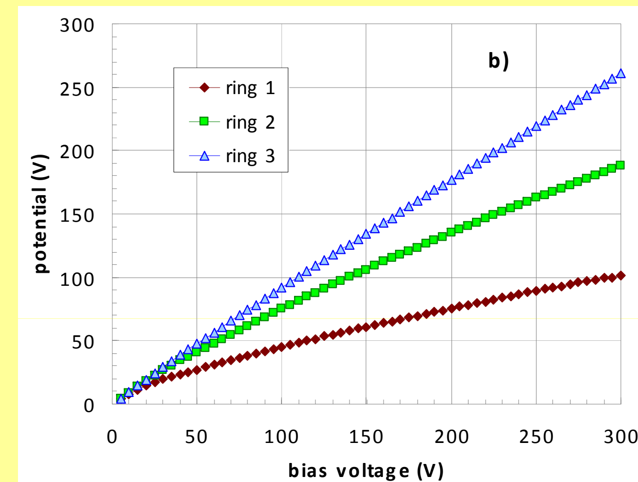
512 strips with a pitch of 66 μm



Potential distribution on VTS rings in p-on-n detector before and after scribing

Before cut **Test detectors** **After cut**





Before the cut: potential distribution occurs via punch-though effect, and potentials between the rings are distributed linearly.

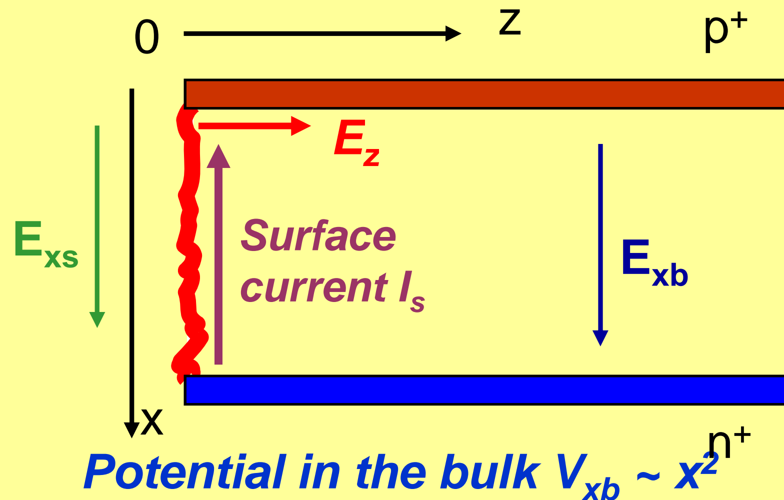
After cut: potential distribution is controlled by the increased current across the damage surface (~mA).

VTS operates and distributes potential outside the detector active area and eventually prevents the electric field focusing at the border of the detector active area.

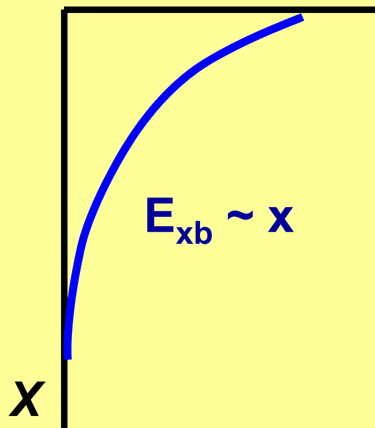
E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

Models of potential and electric field distribution at the sensitive cut

Components of potential and electric field



Potential in the bulk $V_{xb} \sim x^2$



In x direction:

V_{xs}, E_{xs} } at the cut (s)
V_{xb}, E_{xb} } and inside the bulk (b)

In z direction:

E_z – normal to the cut

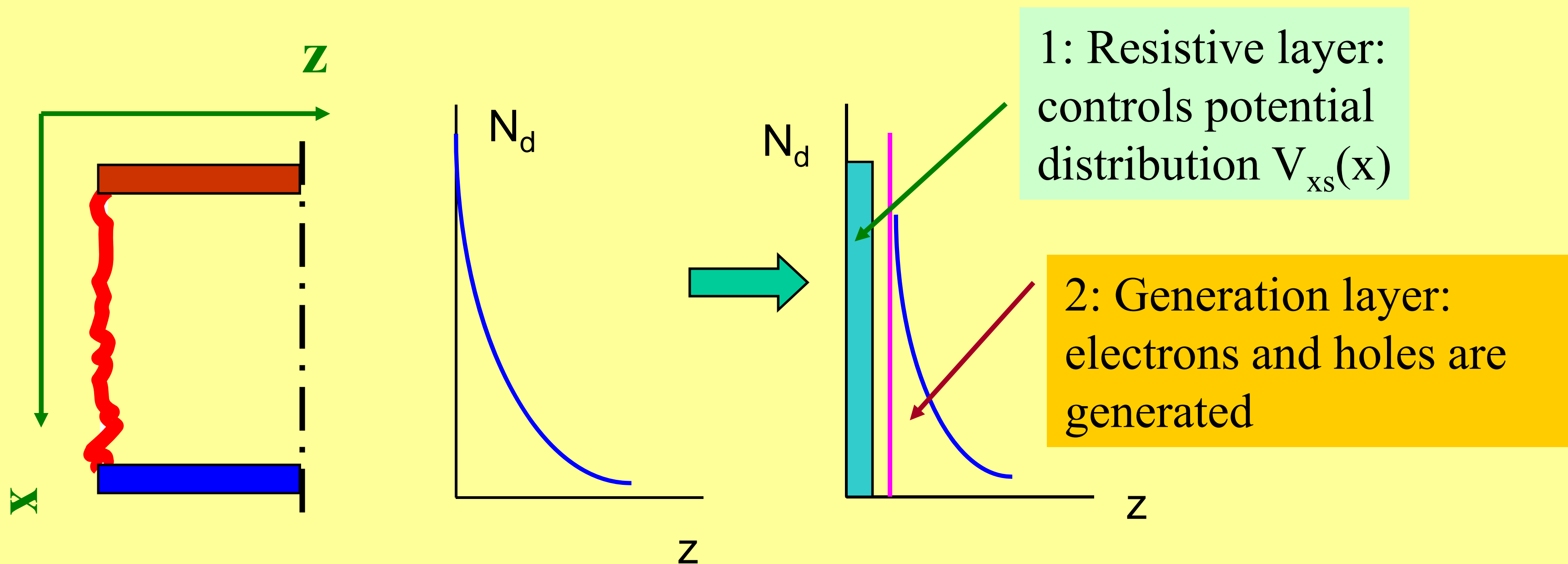
$$E_z \approx (V_{surf} - V_{bulk})/W_z$$

W_z – distance at which V_{xs} dissipates to V_{xb}

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

1. Model of resistive edge layer

Damaged edge with high concentration of defect levels

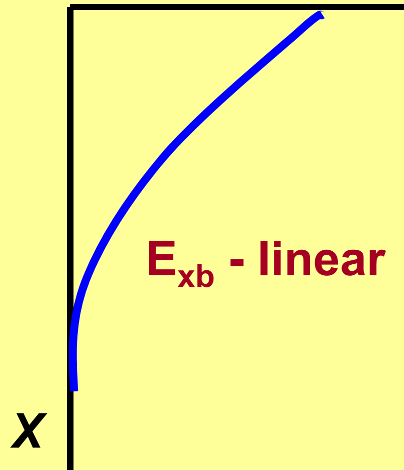


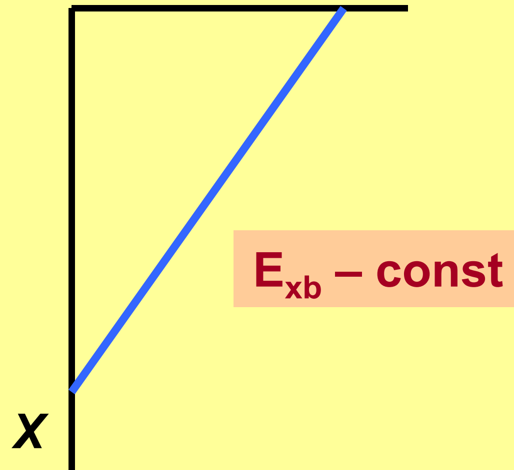
Free carriers in the generation layer do not disturb I_s and V_{xs}

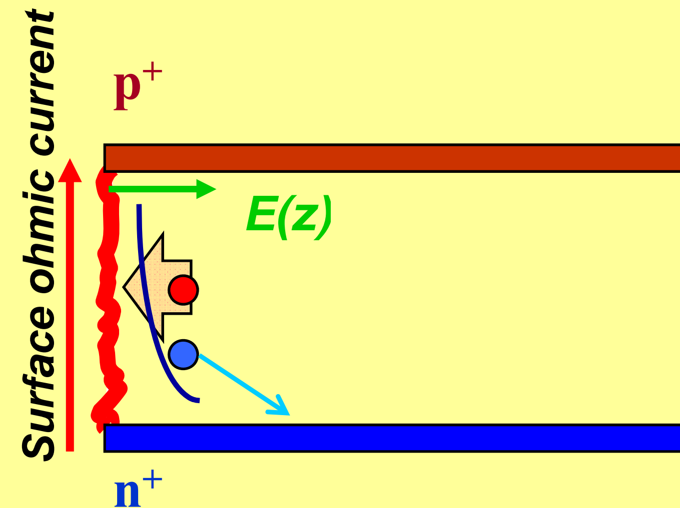
Model of resistive edge layer

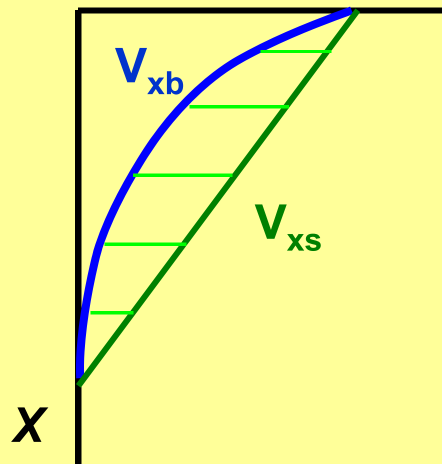
Potential in the bulk V_{xb}

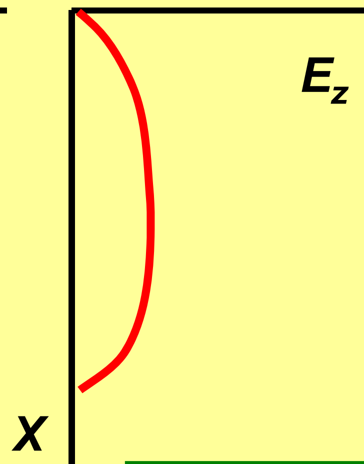
Potential at the cut V_{xs}











Generated carriers:
holes move to CTS;
electrons may partially flow inside the bulk

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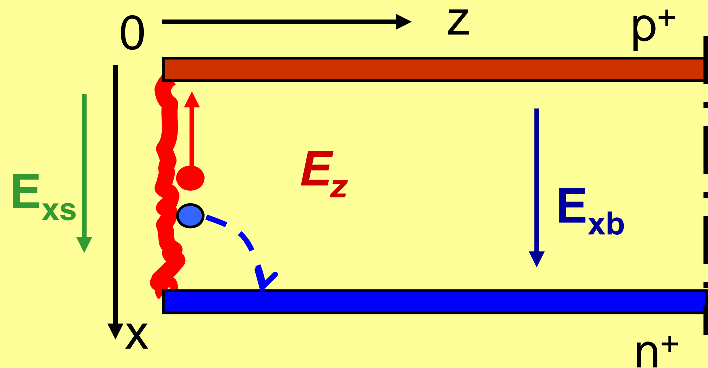
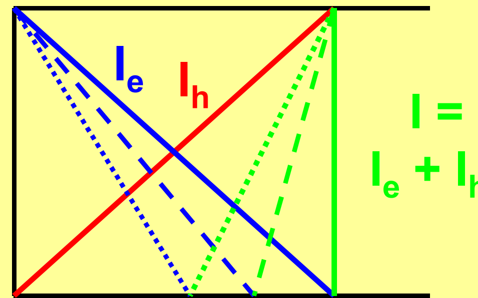
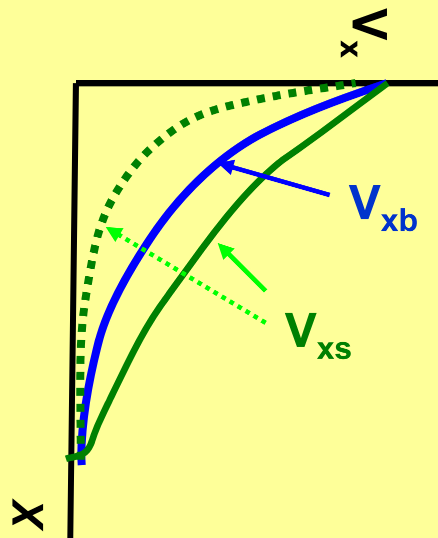
2. Model of amorphous edge layer



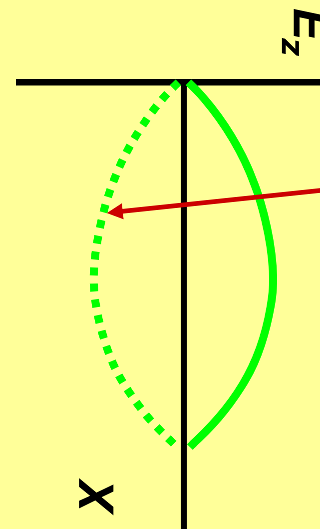


$$j_h = g_h(d - x)$$
$$j_e = (g_e - \eta_e)x$$

g – generation rate



$\eta_e \uparrow$



Inversion of E_z sign! – forces holes to move towards the bulk

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

Tools for study
of potential and electric field distribution

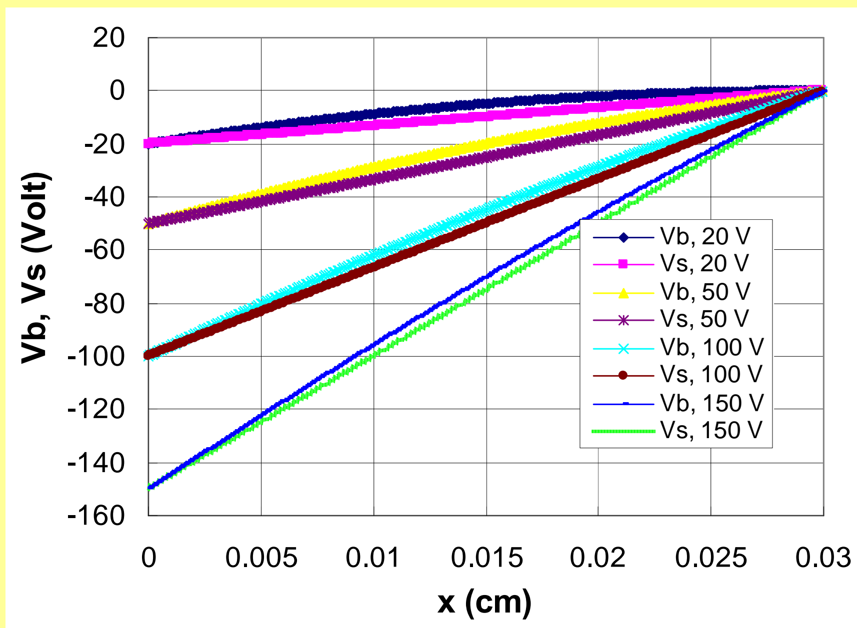
- Simulation of potential, electric field and hole trajectories (Ioffe Institute)
- Conductive MicroProbe Technique (Bologna University)
- Scanning Transient Current Technique (Ioffe Institute)
- E(x) simulation using ISE-TCAD with implemented Poisson and continuity equations (CNM Barcelona)

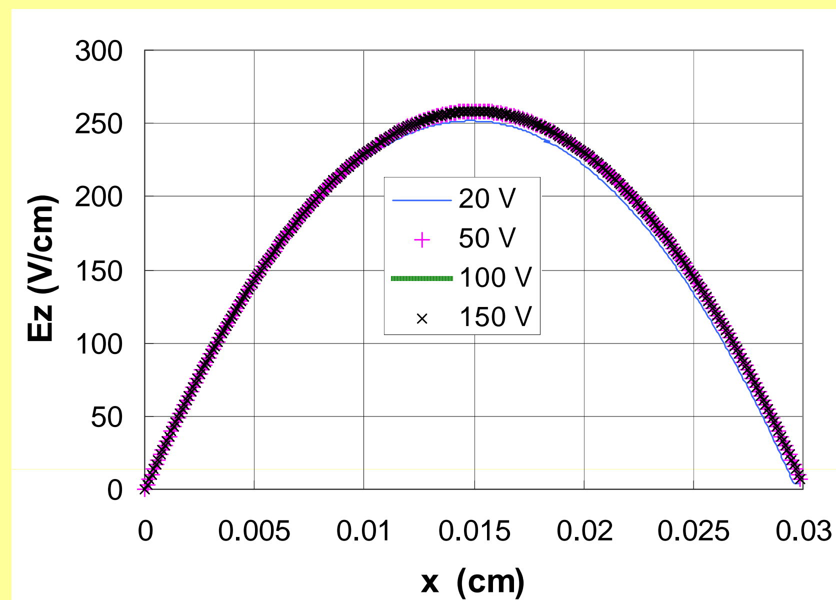
Additionally:

- ✓ Optical Beam Induced Current (Bologna Univ.)
- ✓ Scanning Electron Microscope (LUT)

Simulations: potential and electric field distribution, resistive edge

$N_{eff} = 3{\cdot}10^{11}$ cm^{-3}; $V_{fd} = 15$ V





$E_z \approx (V_{surf} - V_{bulk})/W_z$

$W_z = 300\ \mu m$

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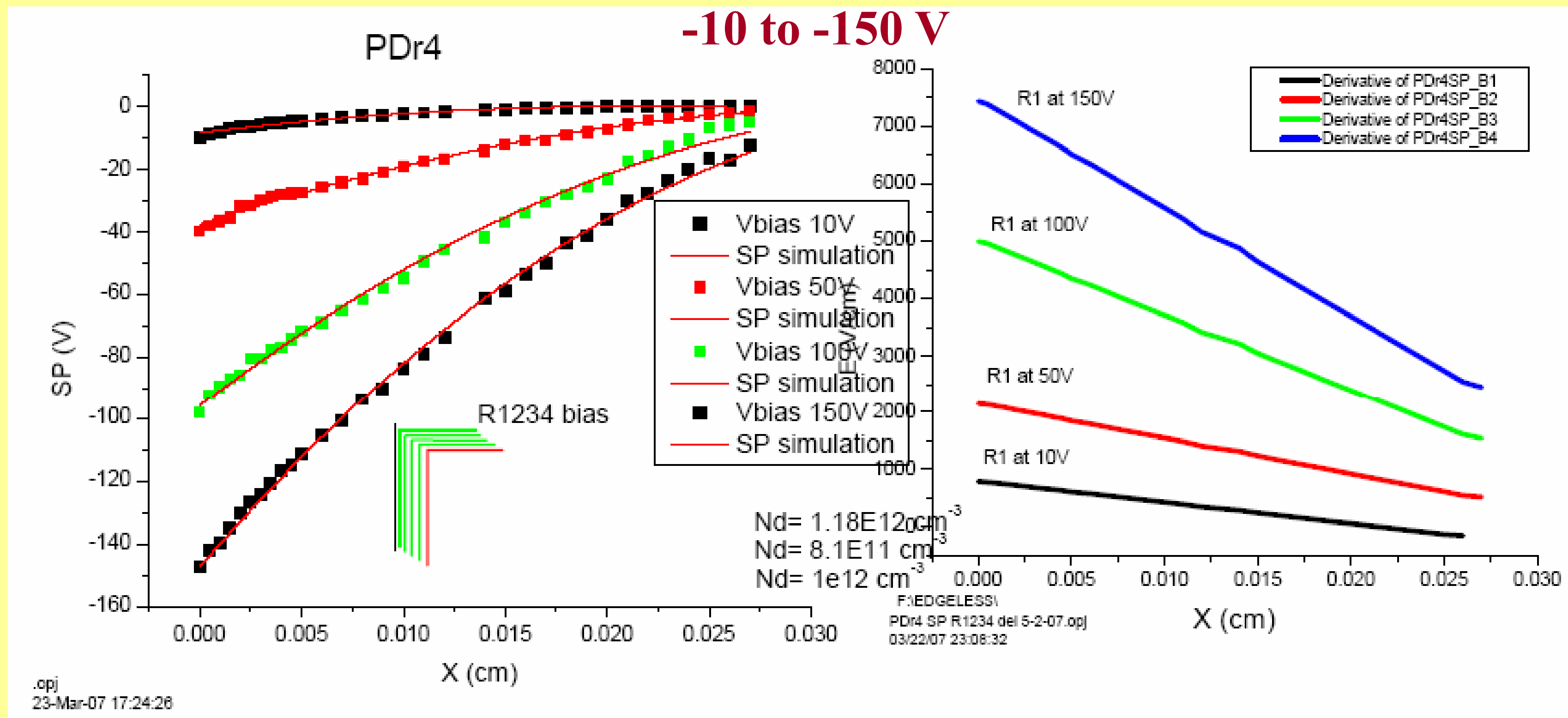
Experimental results on MicroProbe Technique: *surface potential SP(x), and E(x) at the cut edge*



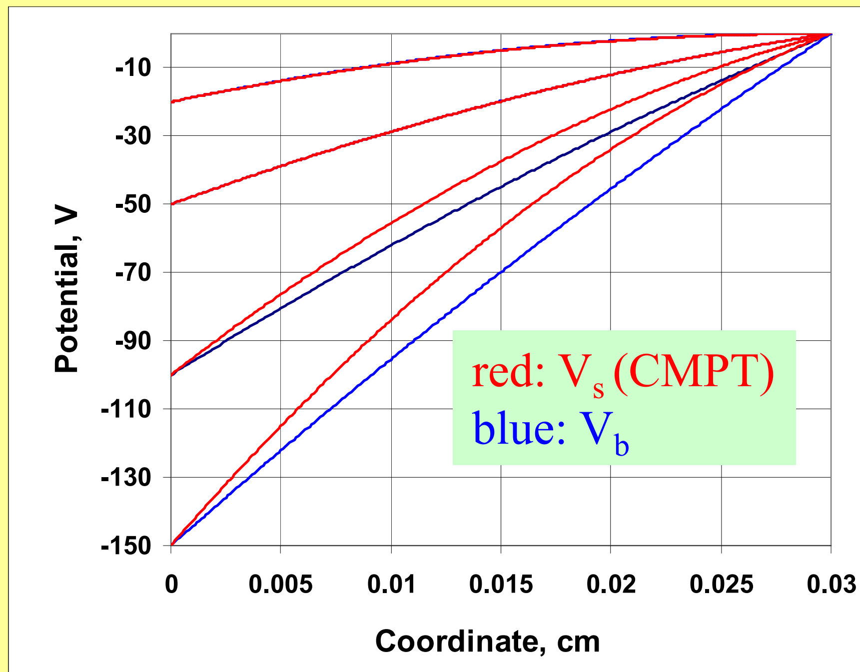
Main features:

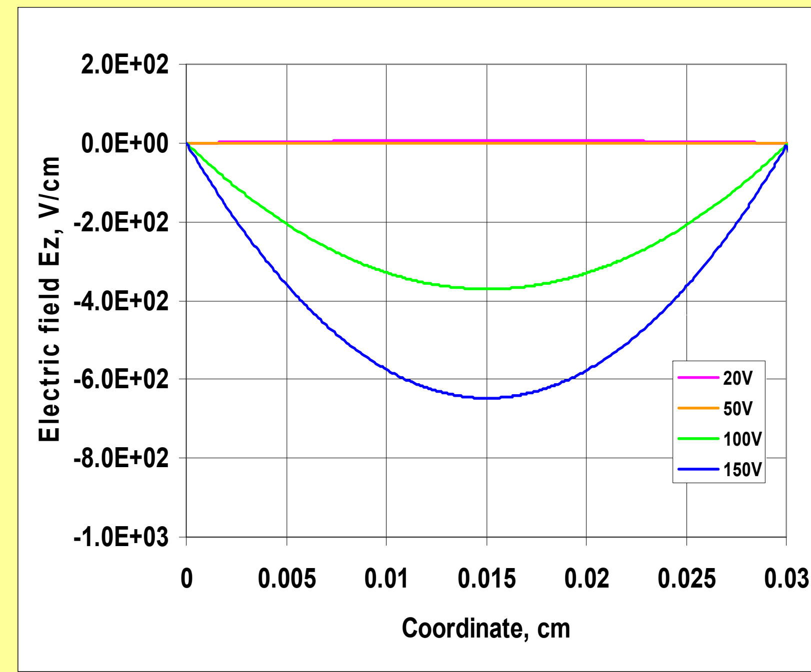
- ✓ **Potential is nonlinear**
- ✓ **E(x) is not constant**
- ✓ Slope of E(x) grows with voltage

disagreement with resistive edge model

Potential and E_z distributions based on CMPT data

E_z sign inversion





Experimental results on surface potential are in agreement to the amorphous edge model

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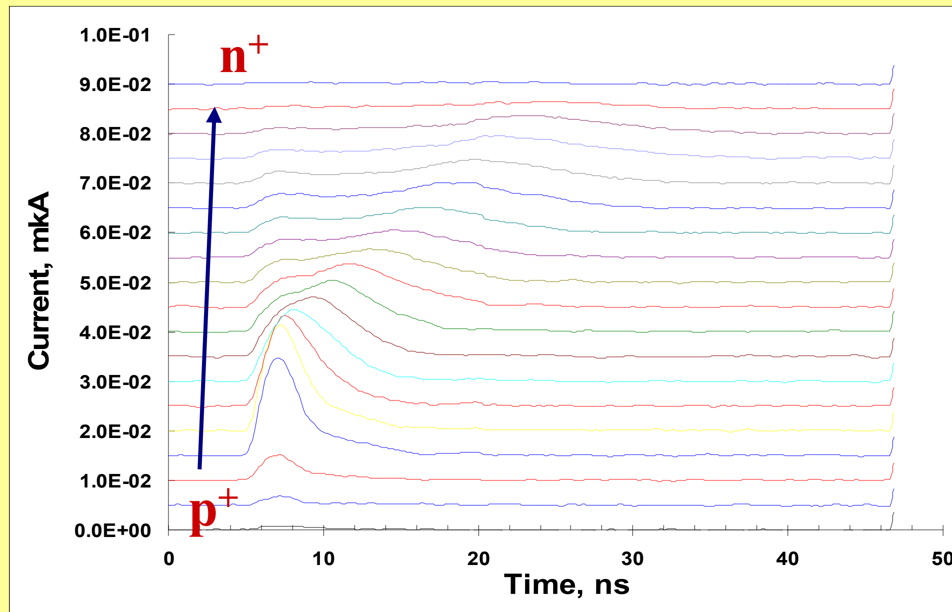
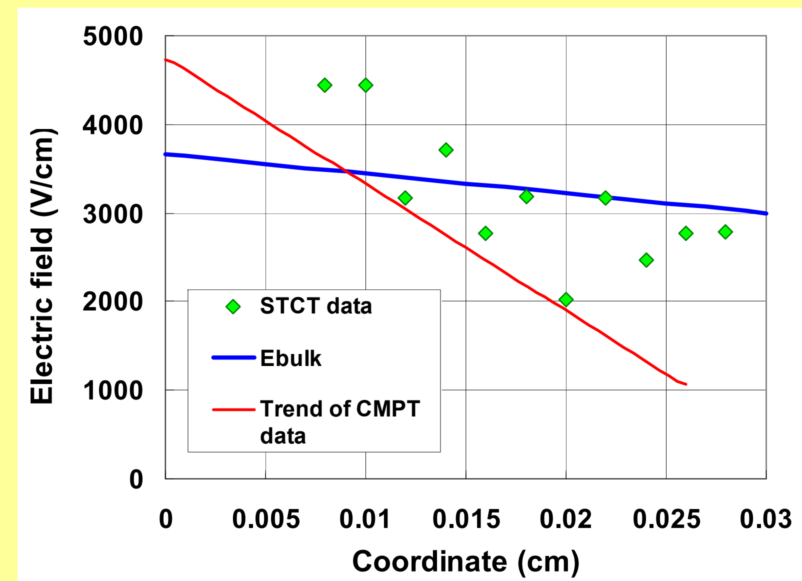
E_{xs} derived from STCT

V = 100 V, V_{fd} = 20 V, d = 300 μm

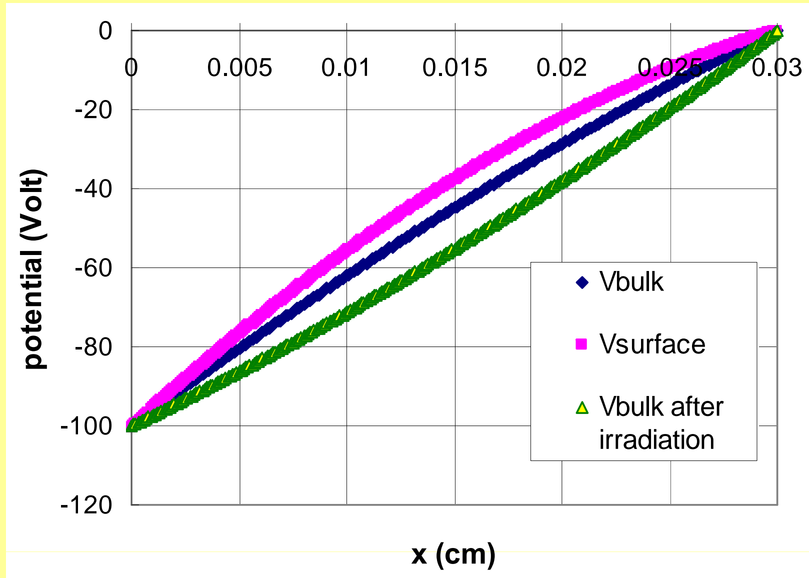


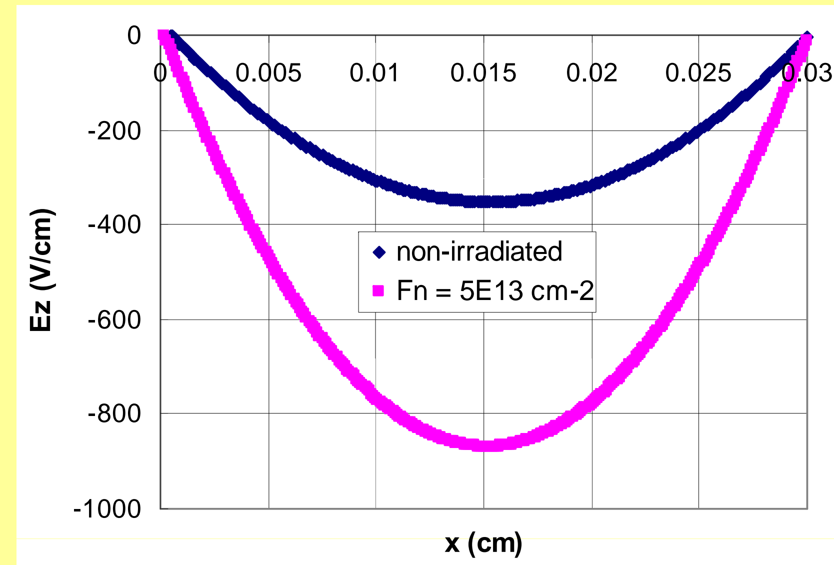


At $V > V_{fd}$ $\quad E(x) = \frac{2V_{fd}}{d}\left(1 - \frac{x}{d}\right) + \frac{V - V_{fd}}{d}$

Results on $E_x(x)$ derived from CMPT and STCT show the same tendency of E_s reduction

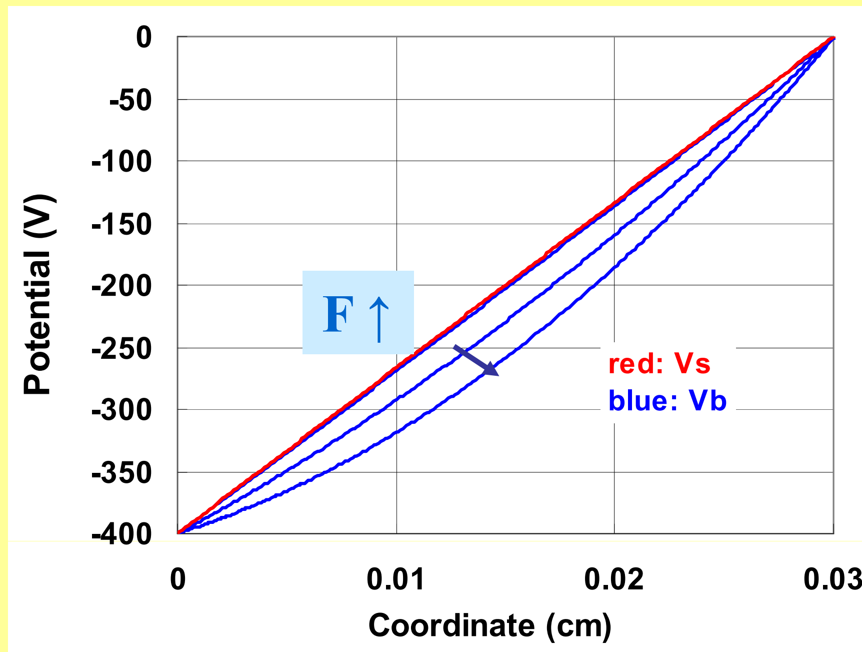
E_z simulation in irradiated p-on-n edgeless detectors

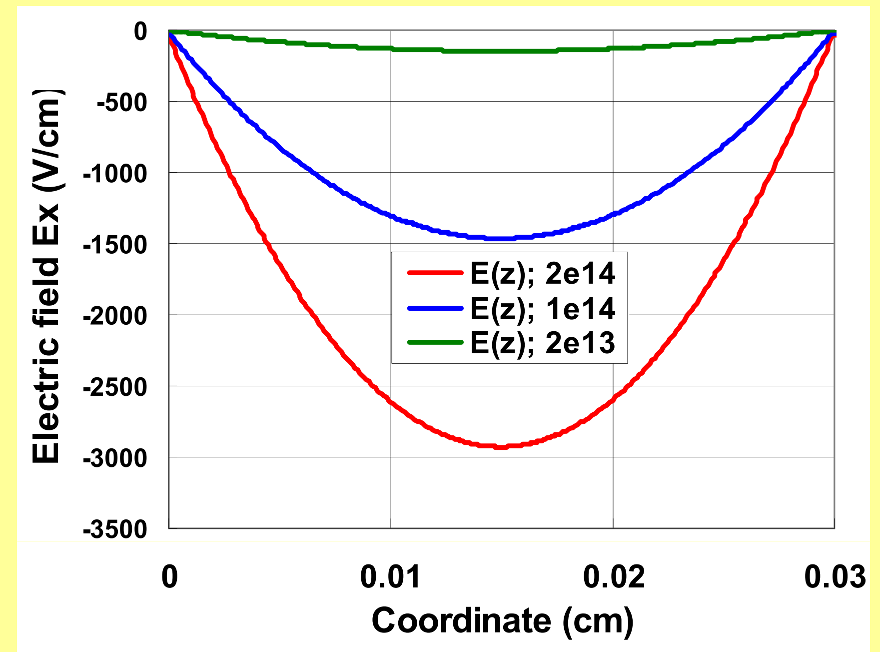




E_z simulation in irradiated p-on-n detectors

V = 400 V





E_z is ~kV/cm and increases with fluence ➔
predicts the increase of the hole current flow into the bulk and corresponding increase of the bulk current.

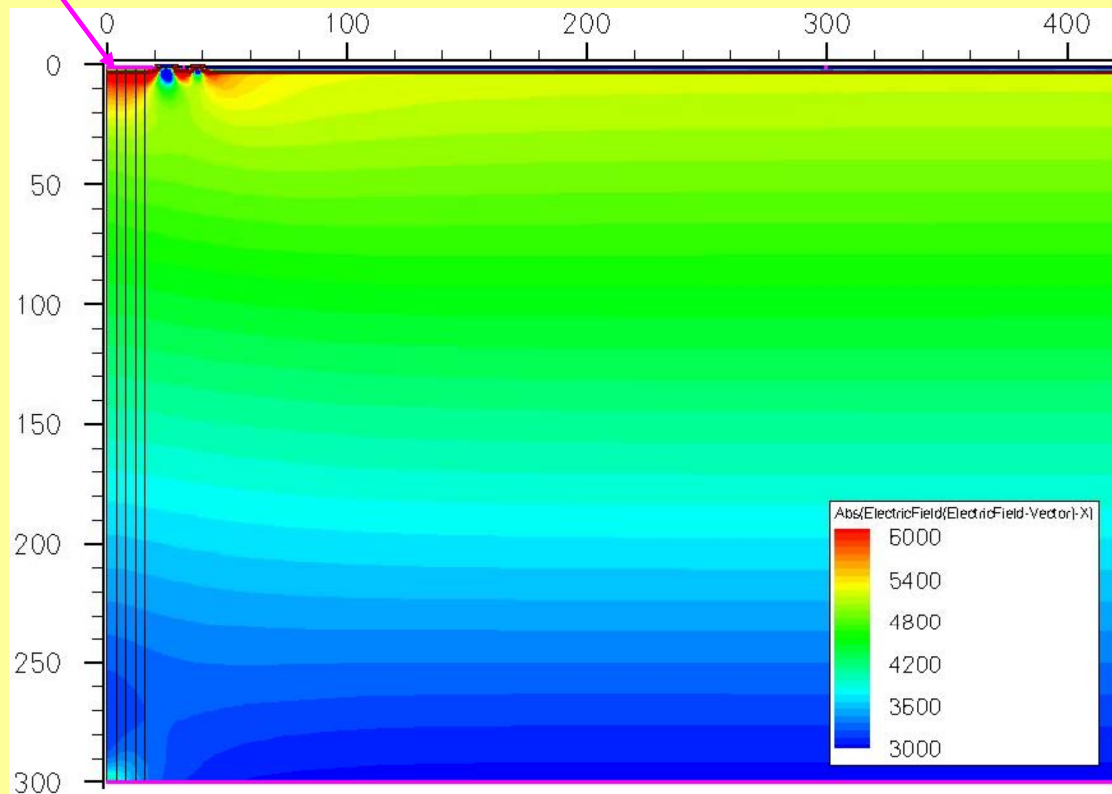
E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

E(x) simulation using ISE-TCAD

J.P. Balbuena et al., CNM, Barcelona, presented at NSS-2008 **and are in progress**

CTR

p-on-n detector, saw cut edge

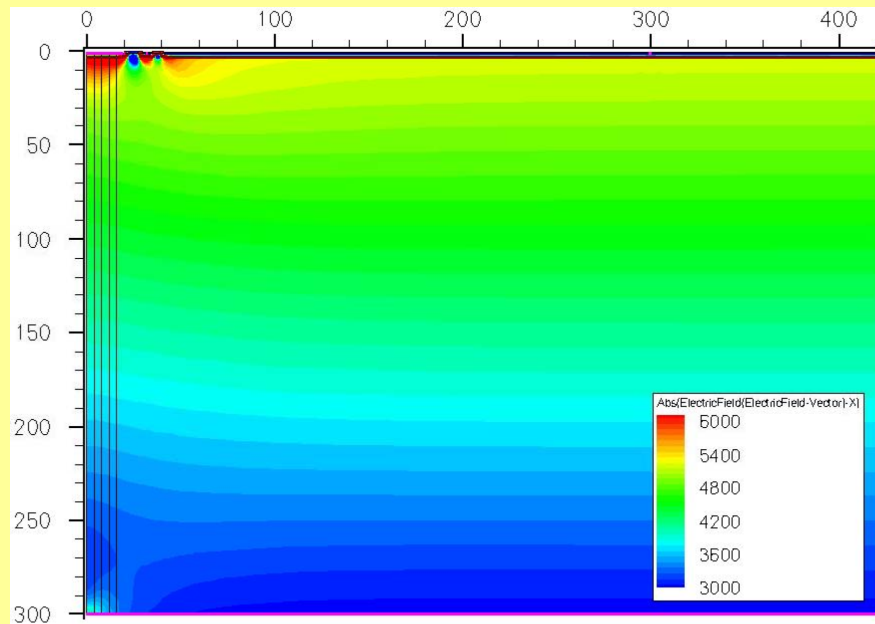


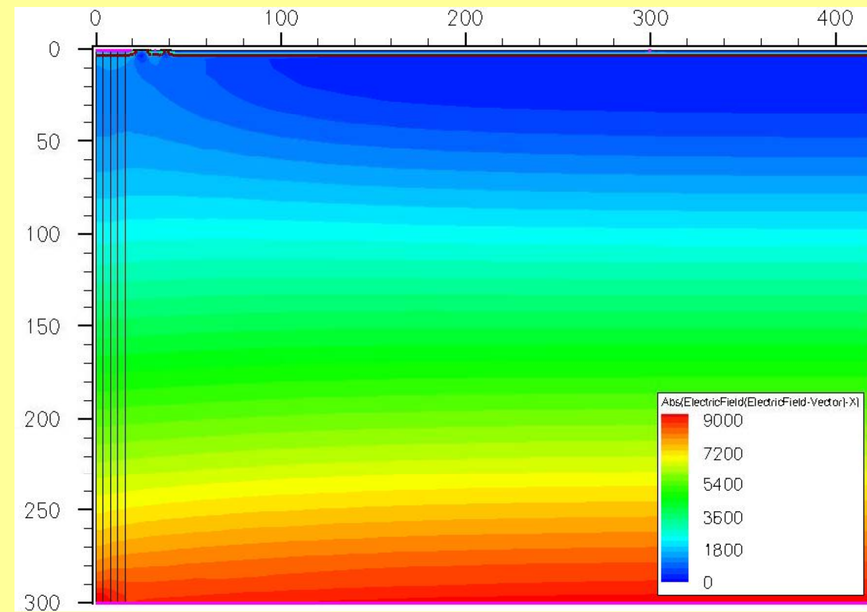
Electric field at the front contact is maximal at CTR (10 to 50 μm from the edge) and becomes lower under the strips

E_z simulation in irradiated p-on-n detectors (preliminary)

Non-irradiated

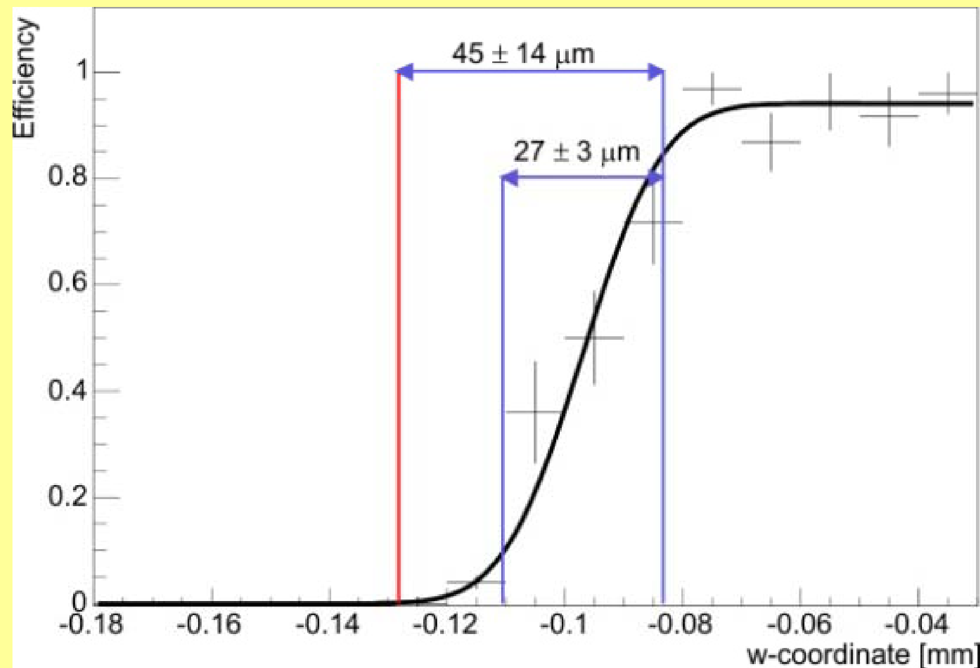
$F_n = 4 \cdot 10^{14}$ cm^{-2}





Recent experimental results on CCE in p-on-n edgeless detectors with CTS

Efficiency of CTS detector at the sensitive edge

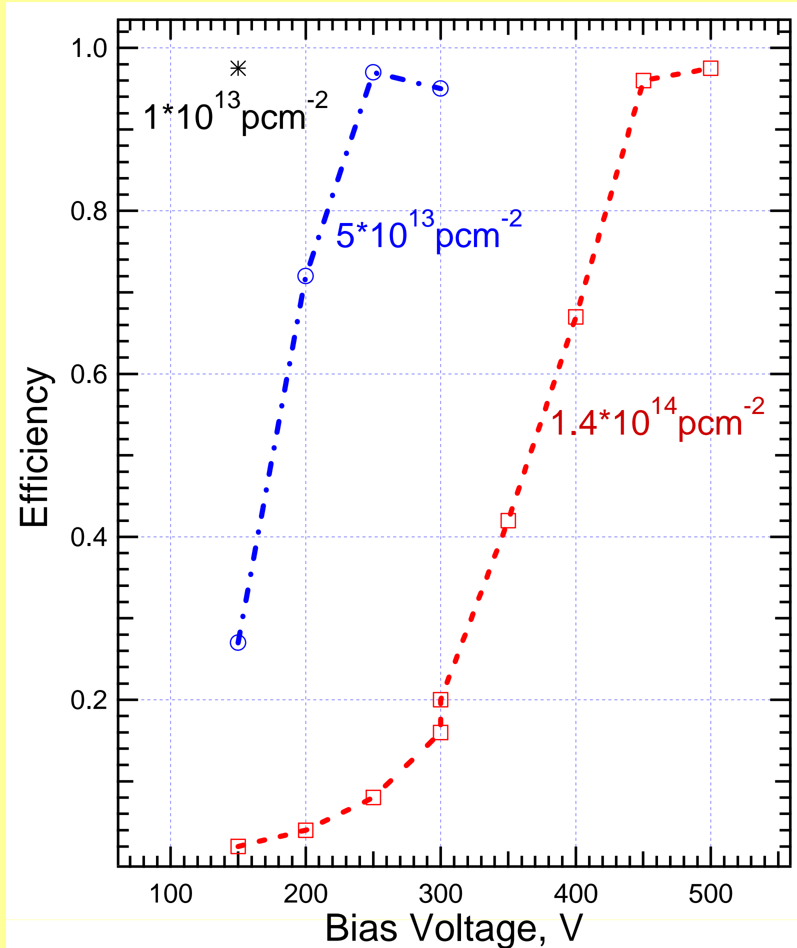


The left-most vertical line indicates the reconstructed position of the physical edge, the other two vertical lines indicate the 10%-90% efficiency rise interval.

Diminished non-sensitive width of 47 µm is achieved!

G. Ruggiero et al. Planar Edgeless Silicon Detectors for the TOTEM Experiment. Pres. 8th Intern.Conf. on Position Sensitive Detectors (PSD8), Glasgow, Sept 1-5, 2008, Nucl. Instr. and Meth. A (in press).

CCE in irradiated p-on-n edgeless detectors with CTS

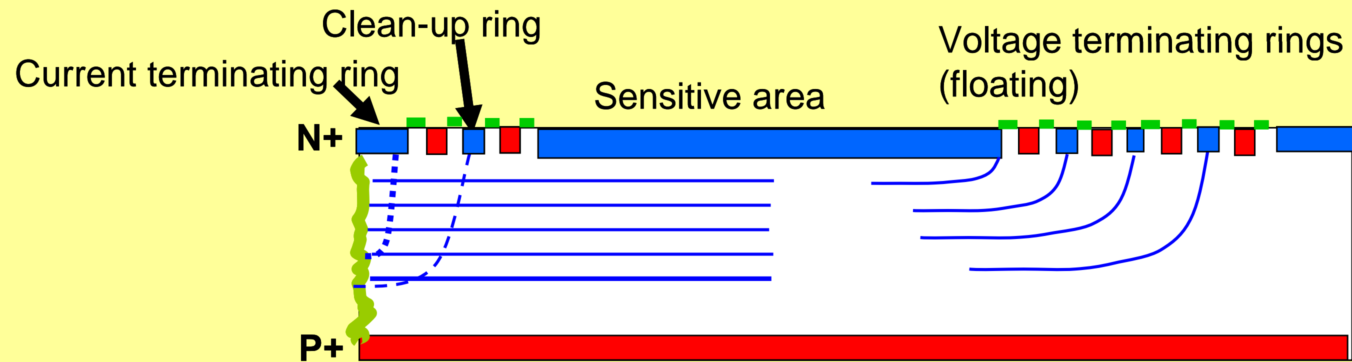


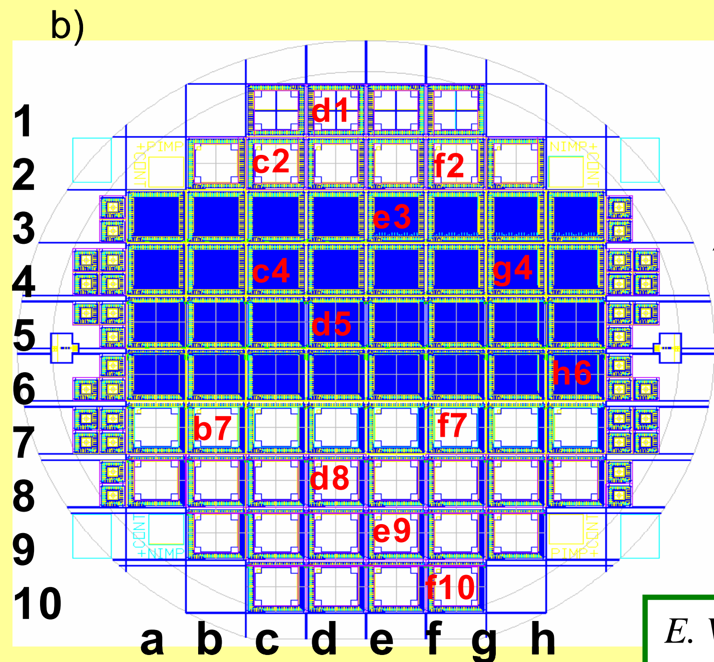
24 GeV/c protons
T = -18C

The efficiency has been calculated by comparing the hits in the irradiated detector with the hits in a non-irradiated detector placed in front, along the beam axis.

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

Development of n-on-p edgeless detectors with CTS





Layout: 10 different designs

MCZ p-type Si

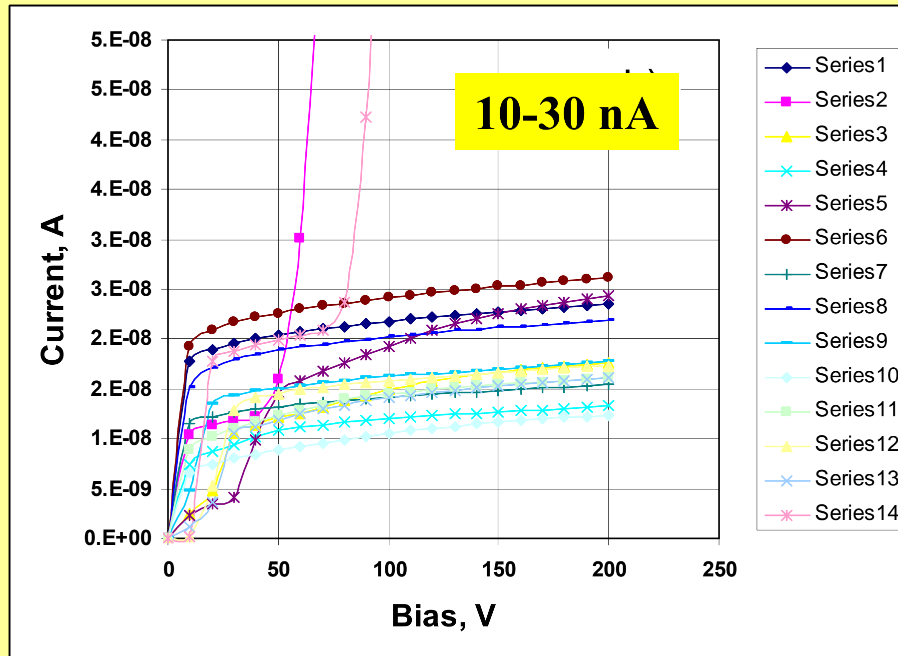
Processed by Ioffe&RIMST

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

I-V characteristics of n-on-p edgeless detectors

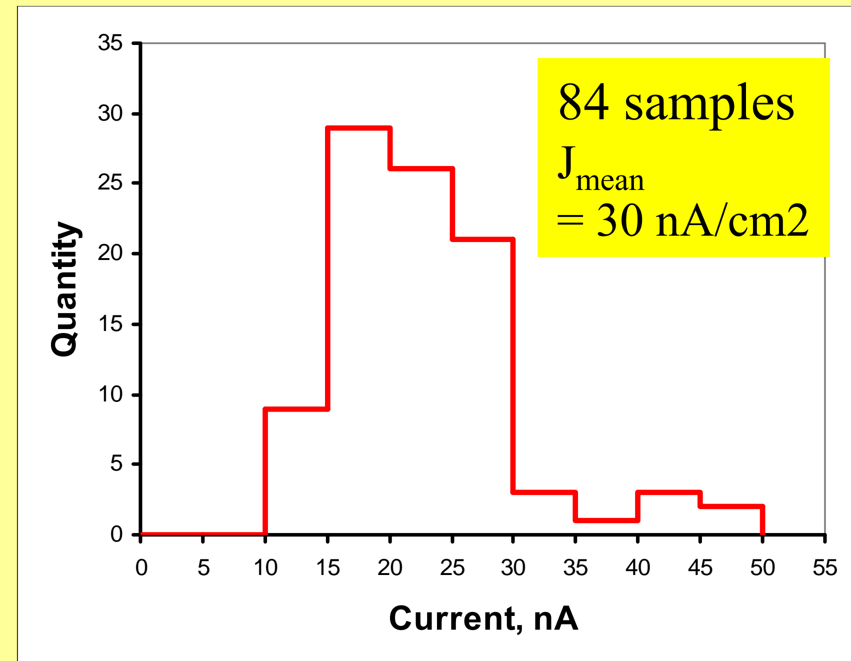
I-V characteristics

14 randomly selected detectors with different design



Statistics of reverse current

V = 200 V; S = 8x8 mm^2



MPT and TCT measurements are in progress!

E. Verbitskaya et al., 13 RD50 Workshop, CERN, Nov 10-12, 2008

Conclusions

- **Performance of edgeless detectors with CTS allows realization of edgeless detectors which characteristics are controlled by the bulk properties**

- **The model of amorphous edge is adequate to the experimental results on n-on-p edgeless detectors**

- **In detectors with CTS diminished non-sensitive width of 47 µm is achieved**

- **N-on-P edgeless strip detector seems to be radiation hard that needs experimental testing**

Acknowledgements

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and supported in part by:

- RF President Grant # 2951.2008.2,
- contract of Russian Agency on Science and Innovation # 2.516.11.6098

Thank you for your attention!