Status of the CERN RD50 collaboration

(new results carried out during 2007)

David Menichelli

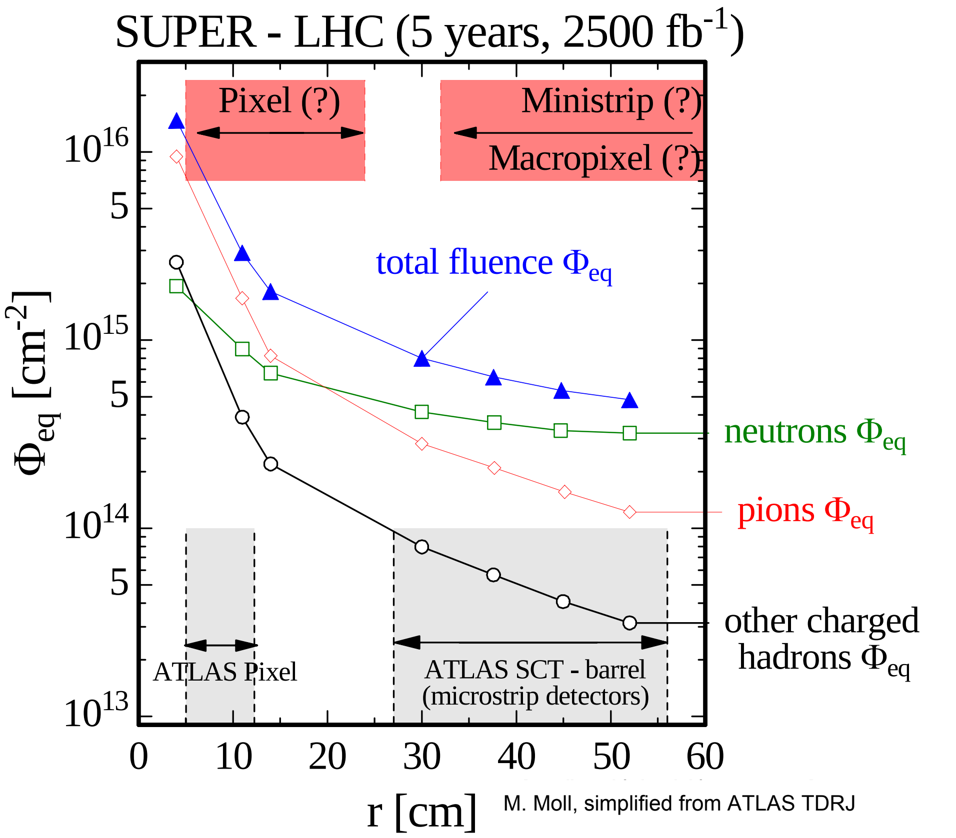
INFN and University of Florence

On Behalf of the RD50 collaboration

RD50: objective

development of radiation hard semiconductor detectors for very high luminosity colliders...

...particularly to face the requirements of a possible LHC upgrade to a luminosity of $10^{35}cm^{-2}s^{-1}$, corresponding to expected total fluences of fast hadrons $>10^{16}cm^{-2}$.



Spokespersons
Mara Bruzzi
INFN and University of Florence
Michael Moll
CERN

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Material Engineering

Defect / Material Characterization
Bengt Svensson
(Oslo University)

- Characterisation of the microscopic properties of standard, defect engineered and new materials, pre- and post-irradiation.
- Theory:
  Defect formation,
  defect annealing,
  energy states,…..

Defect Engineering
Eckhart Fretwurst
(Hamburg University)

- DOFZ/Oxygenation
- High resistivity CZ
- Epitaxial Silicon
- Dimerization
- Other impurities
  H, N, Ge, …
- Thermal donors
- Pre-irradiation treatments

Device Engineering

Pad Detector Characterization
Gregor Kramberger
(Ljubljana University)

- Characterisation of macroscopic properties of irradiated pads
- IV, CV, CCE
- NIEL
- Device modeling
- Operational conditions

New Structures
Richard Bates
(Glasgow University)

- 3D detectors
- Semi-3D
- Thin detectors
- Cost effective solutions

Full Detector Systems
Gianluigi Casse
(Liverpool University)

- Systematic characterisation of segmented LHC-like detectors.
- Links with LHC
- Links to electronic
Comparison:
pad-mini-full detectors

Aim of this talk:
to present most recent results carried out within RD50
(not to give an comprehensive overview of RD50 activities)

DEFECT CHARACTERIZATION : carriers trapping

Charge trapping is the ultimate limitation for detector applications.

Defects responsible trapping source: so far unknown!

Trapping is independent of:

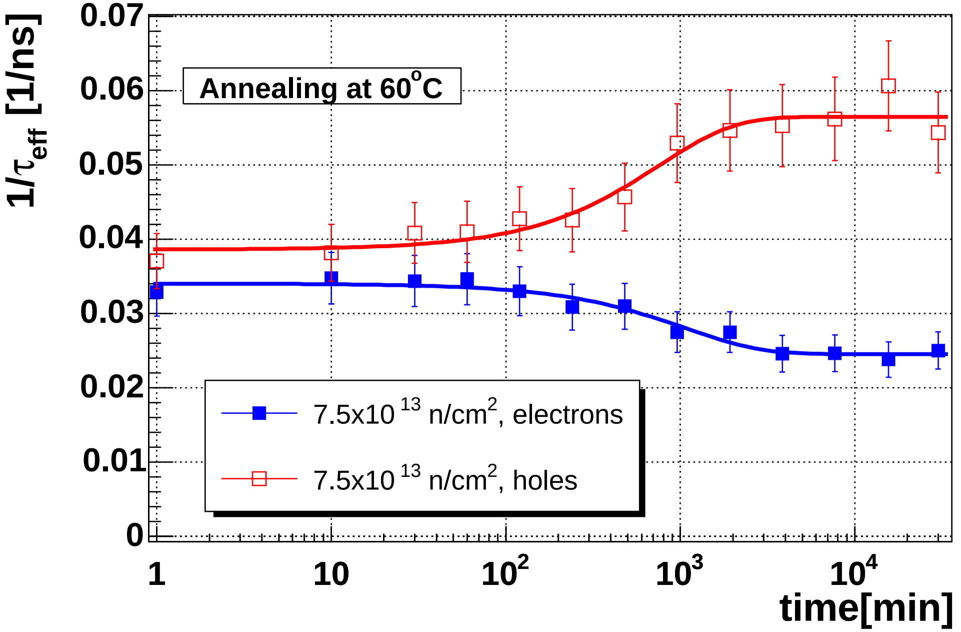
- material type (FZ, CZ, epi) and properties ([O],r, doping).
- irradiating particle type and energy (23 GeV protons, reactor neutrons).

Strategy:

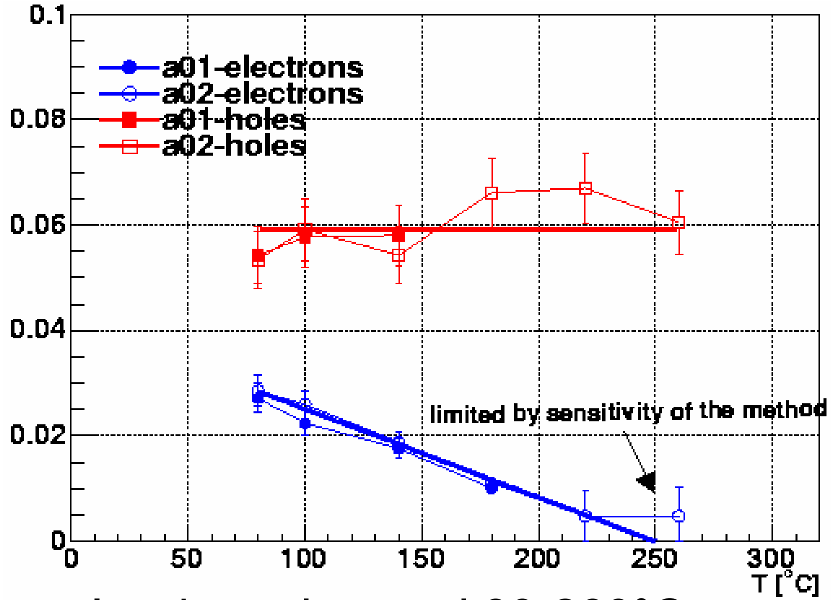
- use all available methods (DLTS, TSC, PITS, PL, τ, FTIR, PC, EPR, C/V, I/V, TCT).
- concentrate on MCz with FZ as reference.
- Use only the most readily available irradiation (TRIGA reactor at Ljubljana).

DEFECT CHARACTERIZATION : carriers trapping

p+-n STFZ pad detector, 15 kΩcm, 300 μm thick
Irradiated by neutrons to $7.5 \cdot 10^{13}$ cm^{-2}
Annealed 800 min at 80°C before isochronal annealing
TCT with red laser+Charge Correction Method to deterimine effective trapping times
Isochronal annealing steps of 40°C for 1h up to 260°C



Isothermal annealing at 60°C
e-trapping reduce by 30%.

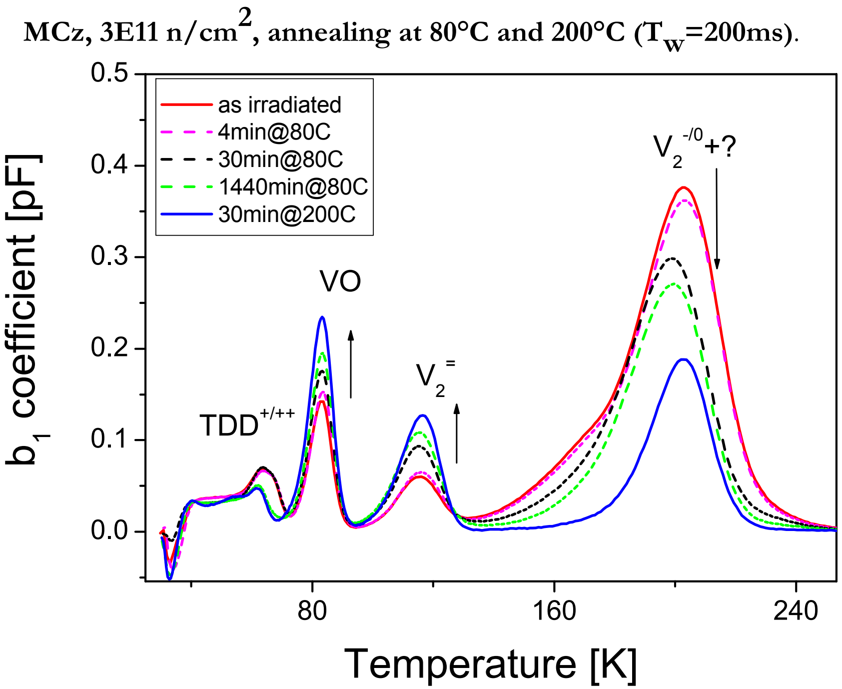


Isochronal anneal 80-260°C
stable h-trapping
e-trapping reduced by factor 5

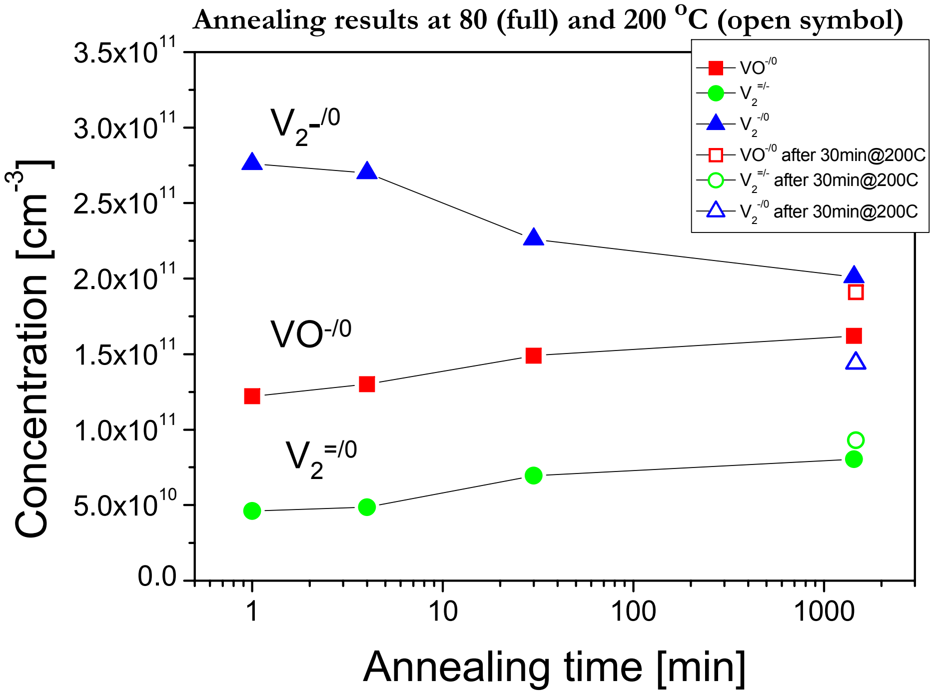
DEFECT CHARACTERIZATION : spectroscopy

Strong changes also observed after high temp. steps in DLTS, TSC, PL and FTIR

e.g. DLTS isothermal anneal at 80°C and 200°C



MCz, 3×10^{11} n/cm^2

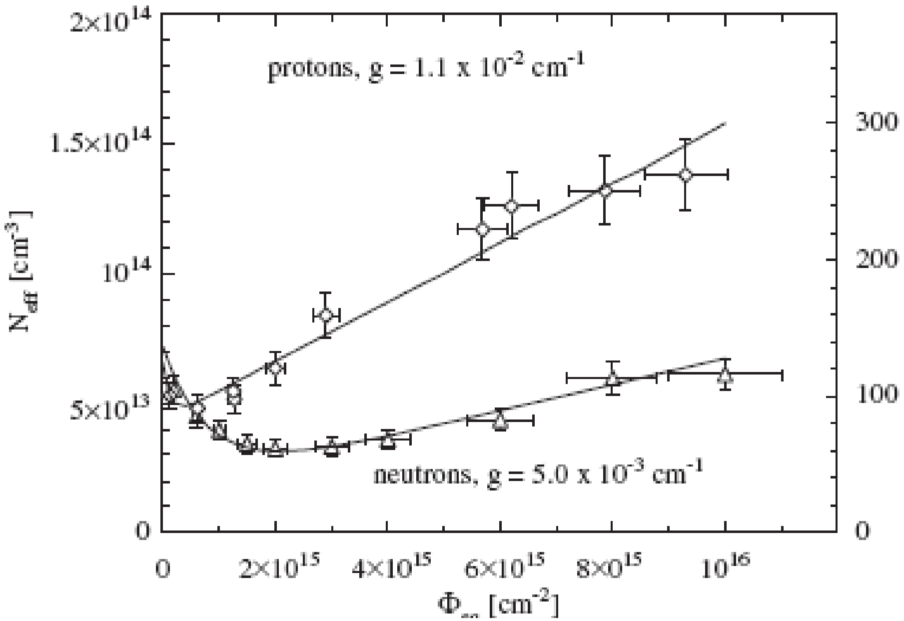


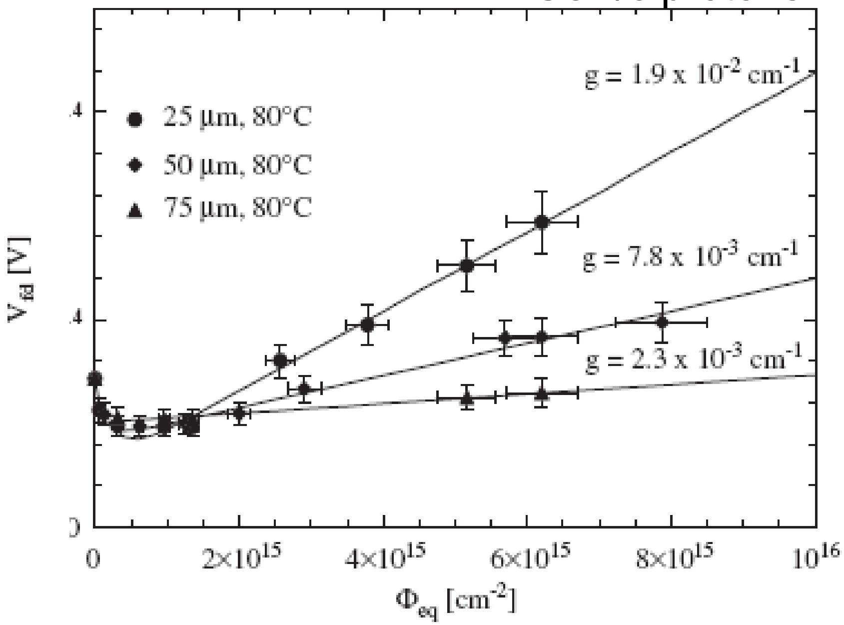
Annealing of vacancy cluster, increase of VO and signal for $V_2^{=/-}$

Indication that vacancy clusters might be responsible for e$^-$ trapping

DEFECT ENGINEERING : Epitaxial Silicon

Starting from 2005, RD50 had demonstrated that the space charge sign of n-type epi-layers with a thickness of 25, 50 and 75 µm and a resistivity of 50 Ω·cm stays positive after 24 GeV/c proton or neutron irradiation up to 10^{16} cm^{-2}.





G. Lindstroem et al., NIMA, 568 (2006) 66.

CCE in G. Kramberger et al., NIMA, 554 (2005) 212.

DEFECT ENGINEERING : Epitaxial Silicon (various manufacturers)

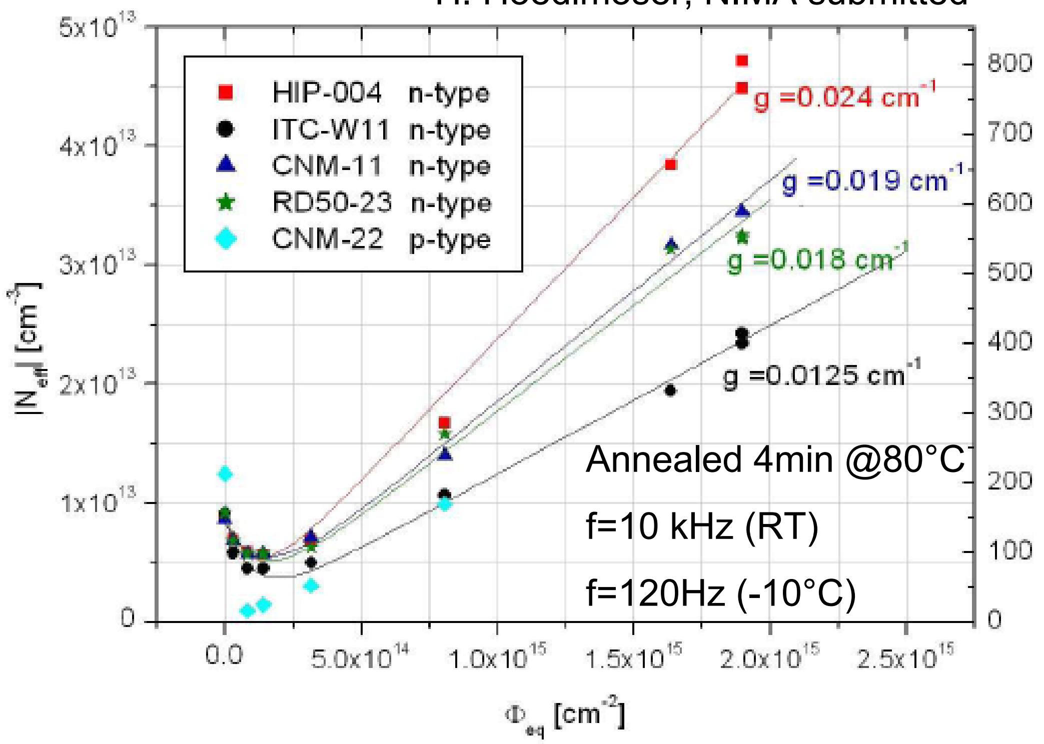
Aim of this research: to investigate the influence of the wafer processing on the material performance by comparing diodes from different manufacturers.

Material: 150 μm thick Si grown by ITME (Poland) on Cz highly-doped substrate.
Epi-layer: 150mm, <111>, substrate: 525mm, <111>
n-type silicon ~500 Ωcm
    Substrate: 525mm, <111>, Sb-doped, 0.015 Wcm
p-type silicon ~1000 Ωcm

Irradiation: 24 GeV/c protons up to $3 \cdot 10^{15}$ p/cm^2

DEFECT ENGINEERING : Epitaxial Silicon (various manufacturers, Neff)

H. Hoedlmoser, NIMA submitted



thickness	detector/processing	donor generation rate g
150μm	HIP-004-B	$2.4{\cdot}10^{-2}$/cm
150μm	CNM-11-E	$1.9{\cdot}10^{-2}$/cm
150μm	RD50-23-P	$1.8{\cdot}10^{-2}$/cm
150μm	ITC-W-11	$1.25{\cdot}10^{-2}$/cm
25μm	CiS [3]	$1.9{\cdot}10^{-2}$/cm
50μm	CiS [3]	$7.8{\cdot}10^{-3}$/cm
75μm	CiS [3]	$2.3{\cdot}10^{-3}$/cm

$$N(\Phi)=N_0 e^{-c\Phi}+g\Phi$$

Neff, TCT (red light) results:

1) p-type diodes undergo SCSI ($\Phi>10^{14}$ n/cm^2, n-type do not.

2) considerable spread of $g=1.3{\cdot}10^{-2}$ cm^{-1} (ITC) to $2.4{\cdot}10^{-2}$ cm^{-1} (HIP)

(ref.: MCzn~4, MCzp~3, STFZ~5, DOFZ~2×10^{-2} cm^{-1}).

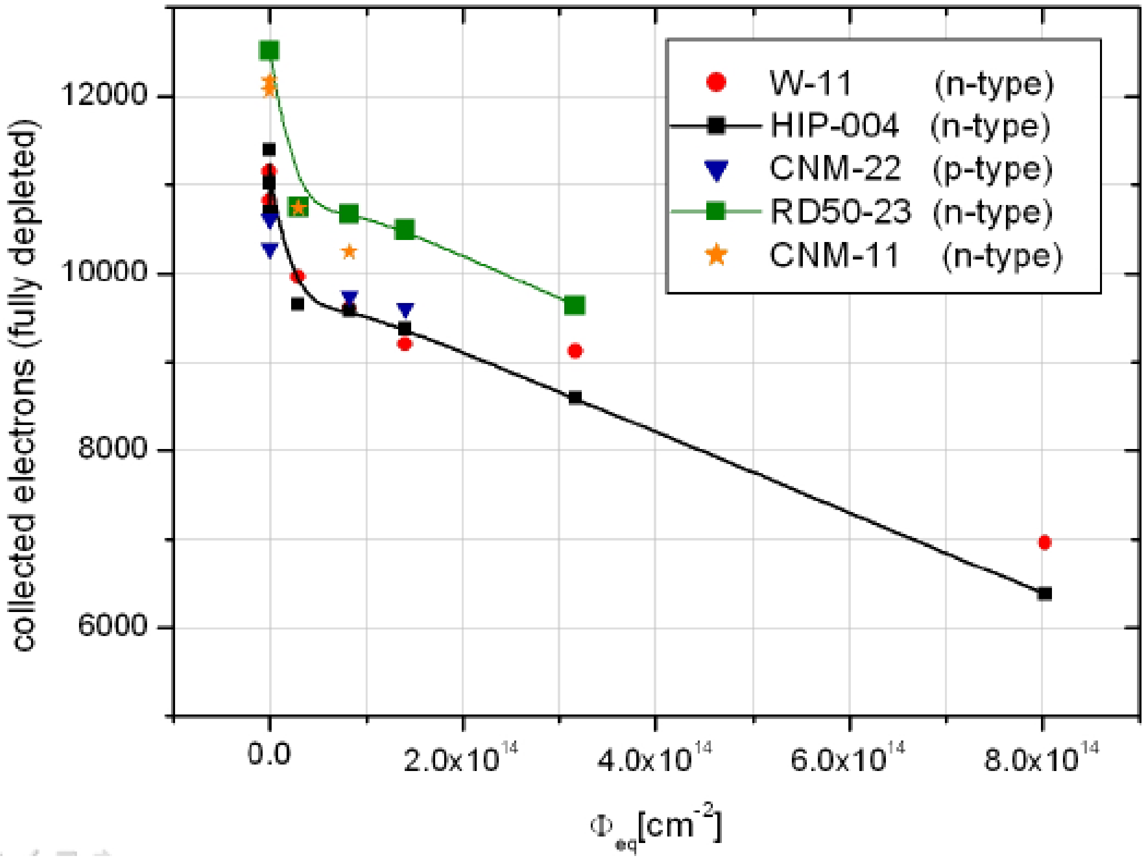
DEFECT ENGINEERING : Epitaxial Silicon (various manufacturer, CCE)

^{90}Sr source

2.5μs shaping time

T=-22°C

noise 567e$^-$ + 4.26e$^-$/pF



CCE, TCT (IR light) results: 15 % drop of CCE even for $\Phi=5\cdot10^{13}$ p/cm^2.

OPERATIONAL CONDITIONS: bias effect (samples)

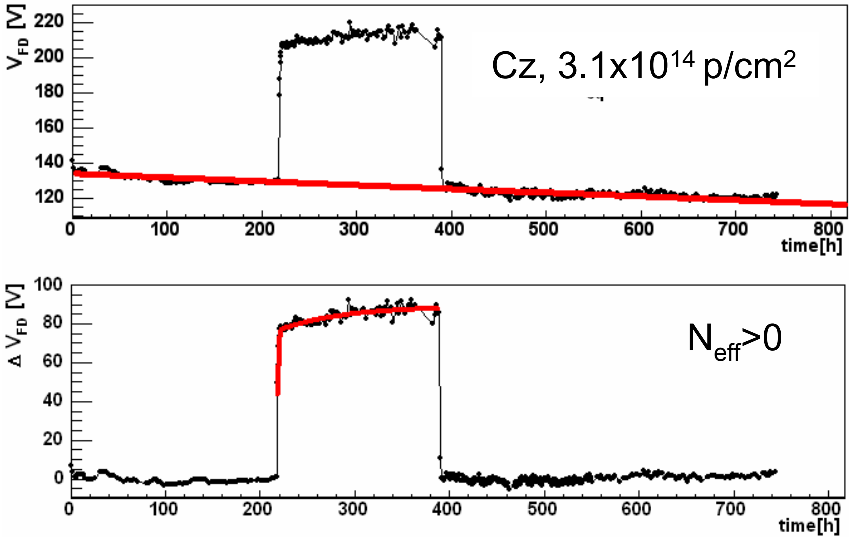
A significant change in the depletion voltage was found after the detector was set under bias and confirmed in CCE measurements as function of voltage. No influence on the leakage current was observed. (RD50 status report 2006)

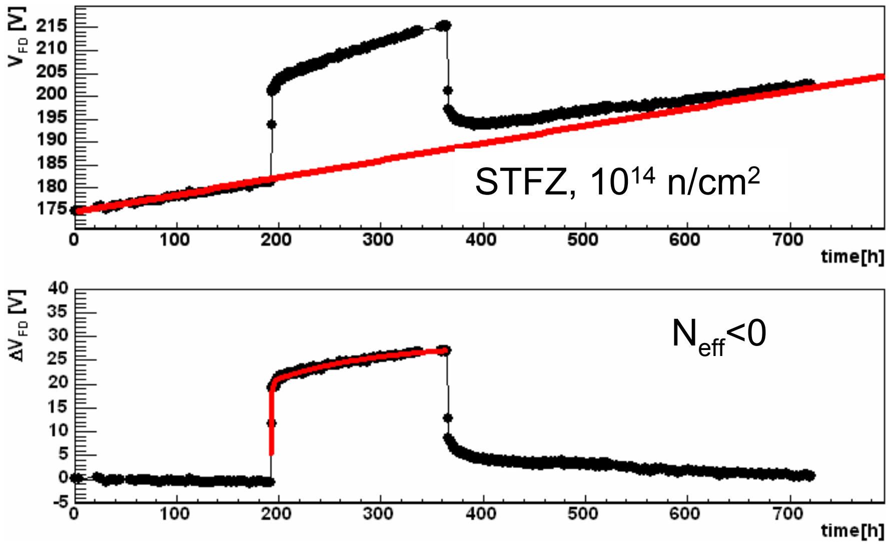
Group	Sample name	Material, thickness	Φ_{eq} [10^{14} cm^{-2}]	History
	W339	STFZ, n-bulk, 300 μm, 15 kΩcm	1 n	$\sim$ 2000 h at RT
[C]=1.8e16 cm^{-3} (SIMS)	P503n7	STFZ, n-bulk, 300 μm, 2 kΩcm	1 n	$\sim$ 1000 h at RT
High [O]	Cz36	MCz, n-bulk, 300 μm, 1 kΩcm	0.62, 3.1 p	$\sim$ 1000 h at RT
High [O]	5337_3	Cz-Sumitomo, n-bulk, 300 μm,	0.75 p	$\sim$ 500 h at RT
High [O_{2i}]	6378_07	Epi, n-bulk,50 Ωcm, 75 μm	13 p, 10 n	$\sim$ 20000 h at RT
High [O_{2i}]	5856_01	Epi, n-bulk,50 Ωcm, 50 μm	10,20 n	$\sim$ 20000 h at RT

- Large number of different samples:
  - -high [O], high [C], Cz, FZ, Epi-Si
  - -different resistivity,different thicknesses
  - -24 GeV proton and rector neutron up to 2 $\cdot 10^{15}$ cm^{-2}
- Different annealing history – could influence the results?

Samples connected to a switching matrix (T controlled).

OPERATIONAL CONDITIONS: bias effect (raw data)





$$\frac{\Delta|N_{eff}|}{\Phi_{eq}} = g_1(1-\exp(-\frac{t}{\tau_s})) + g_2(1-\exp(-\frac{t}{\tau_l}))$$

$$g_b = g_1 + g_2$$

$\tau_s \sim 1$ h ; $\tau_l \sim 100$ h

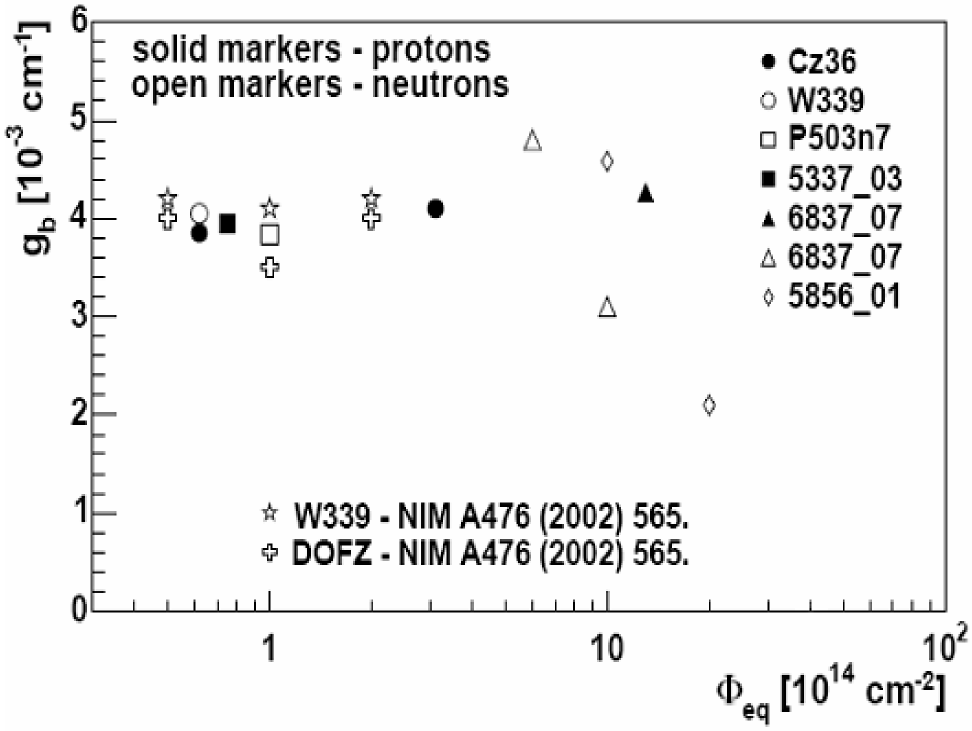
$g_1/g_b \sim 0.8$; $g_2/g_b \sim 0.2$

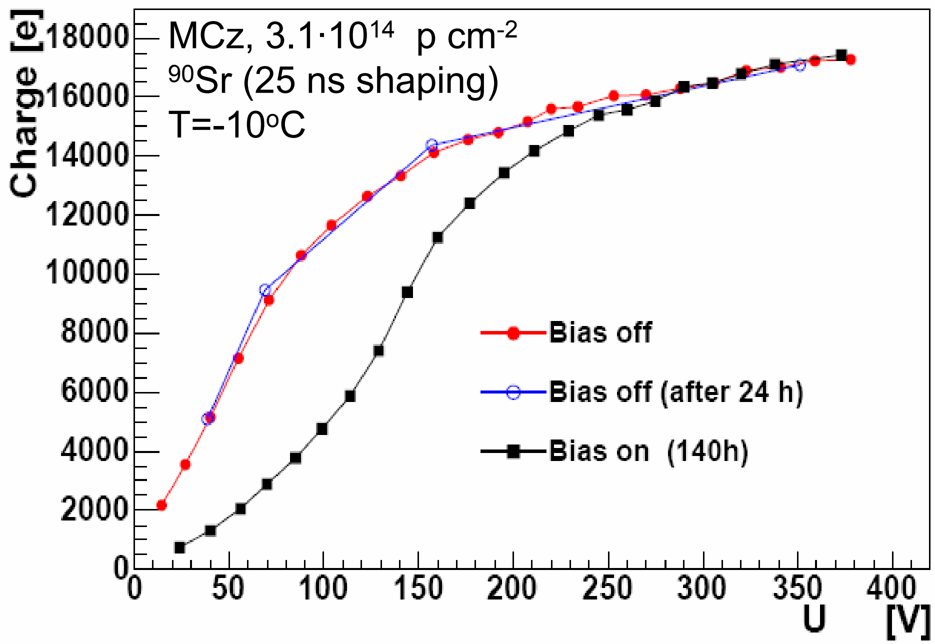
$g_b=g_1+g_2 \sim 0.004$ cm^{-1}

Additional contribution to the $|N_{eff}|=g_b \cdot \Phi_{eq}$, where g_b=0.004 cm^{-1}

OPERATIONAL CONDITIONS: bias effect (processed data)

- g_b=0.004 cm^{-1} for all investigated materials (except the highest fluences)
- the sign of g_bs is always such that the V_{fd} increases!
- The effect is present after proton and neutron irradiation with the same magnitude!
- Results confirmed by CCE measurements





CHARACTERIZATION OF P-TYPE DETECTOR

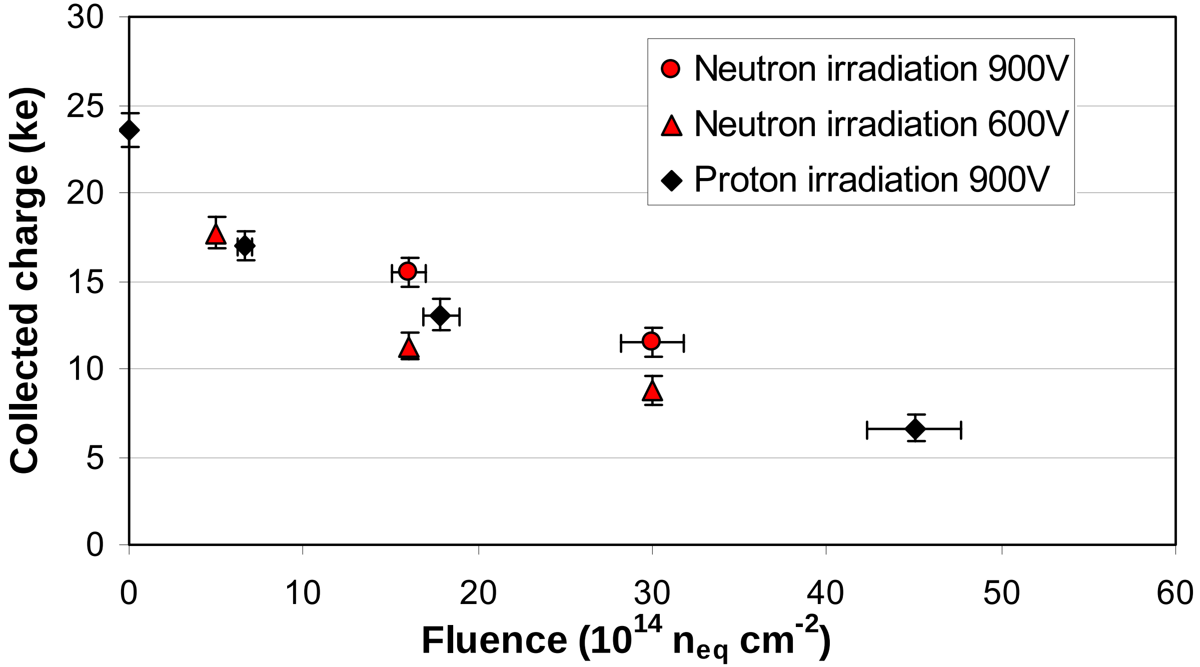
Reading-out finely segmented silicon detectors from the side were the high electric field is located after irradiation gives the major contribution to radiation hardness (charge trapping is the main cause of charge collection deficit). Traditional p-in-n detectors suffer from space charge type inversion, with the high electric field being located on the non-segmented side of the device.

RD50 status report 2006

n-side read-out can be implemented on a p-type substrate (it does not invert!). The p-type devices doe not required backplane processing (40-50% cheaper).

CHARACTERIZATION OF P-TYPE DETECTOR: new results

STFZ μ-strip (1X1 cm^2) made by Micron
140 and 300μm thick, high resistivity (ρ>10kΩ cm) p-type wafers



-neutron irr. at Ljubljana
-24GeV/c protons irr. at CERN/PS (thanks to M. Glaser)
-CCE measured with LHC speed analogue electronics (SCT128A).

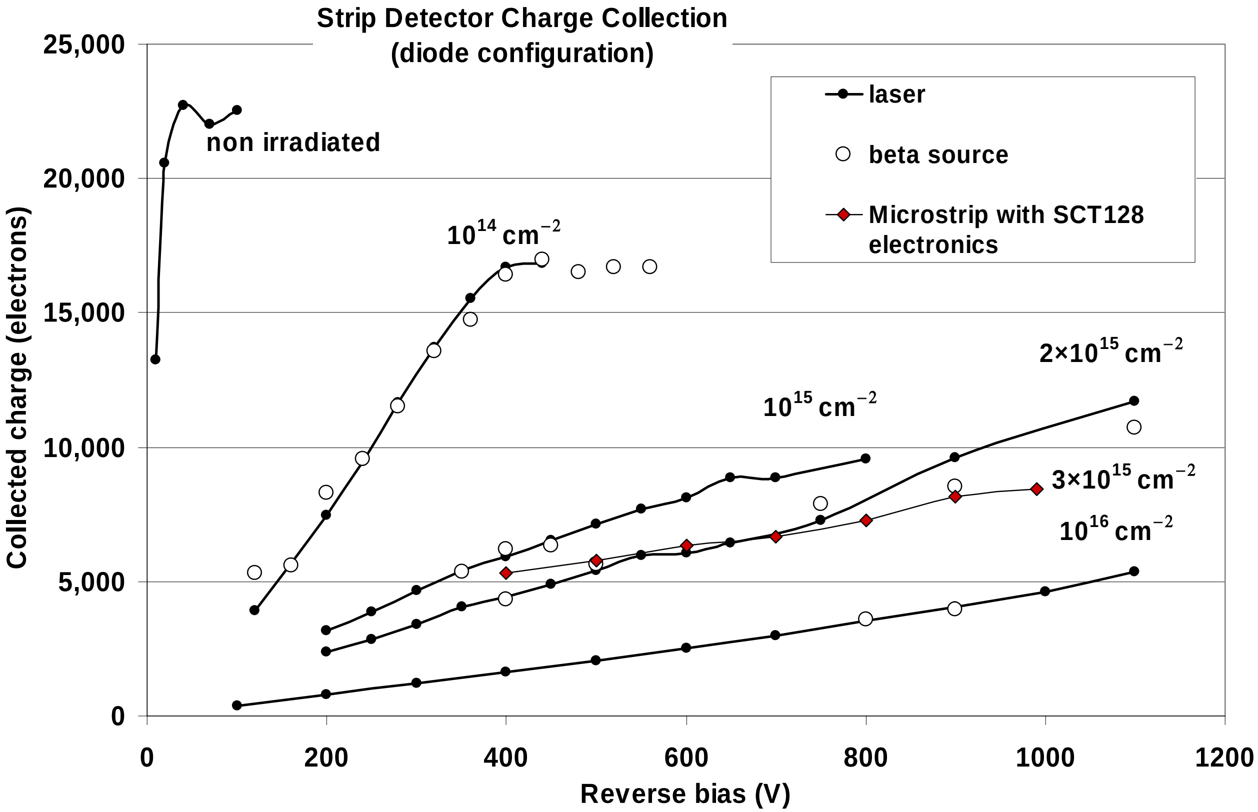
Even after the highest fluence (~10 years of sLHC operation) detectors are operational.

The CCE seems to scale with the NIEL function.

Long term annealing does not effect substantially the measured signal.

p-type detectors on MCZ and DOFZ are under irradiations.

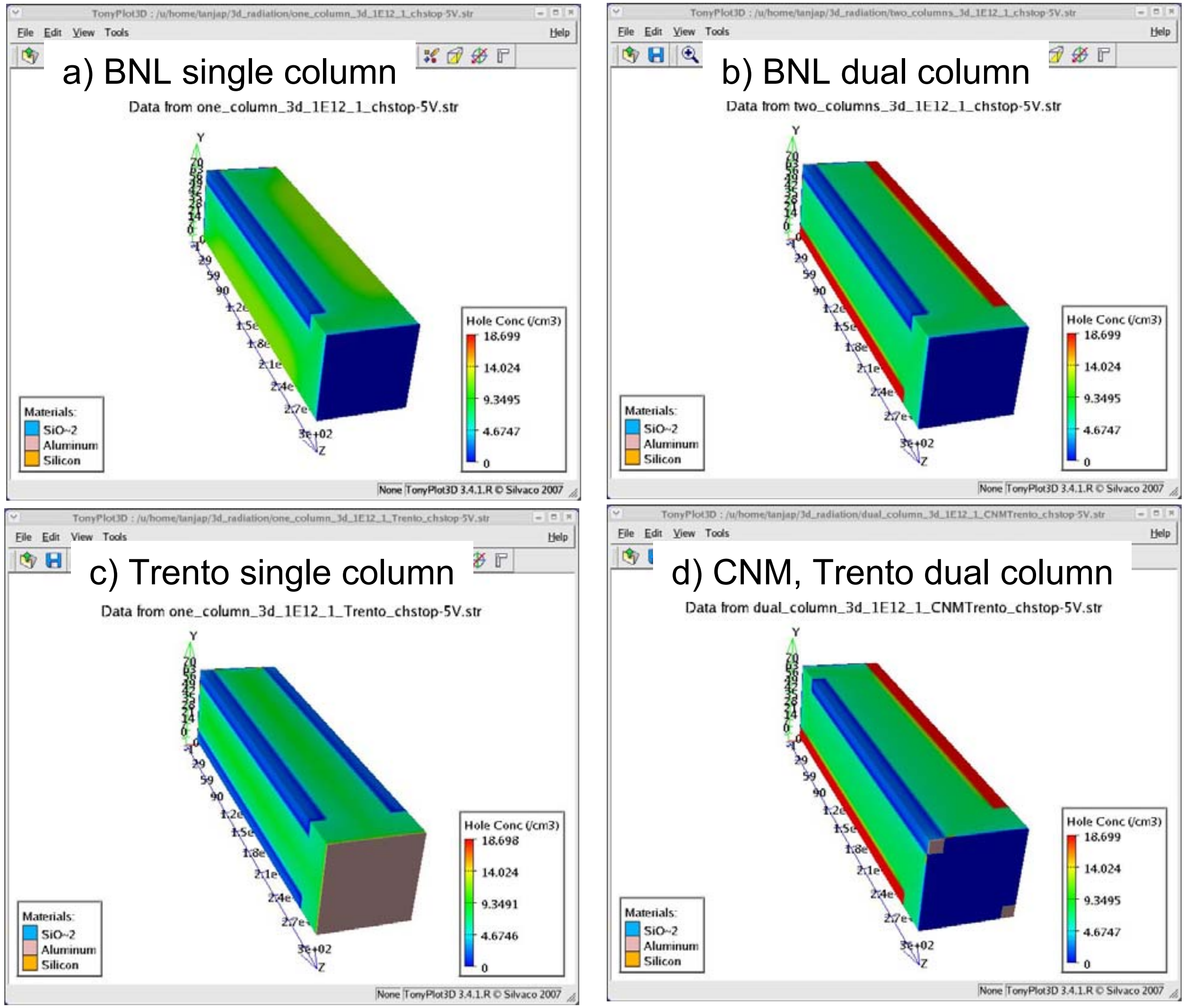
P-TYPE DETECTOR: comparison with elder results

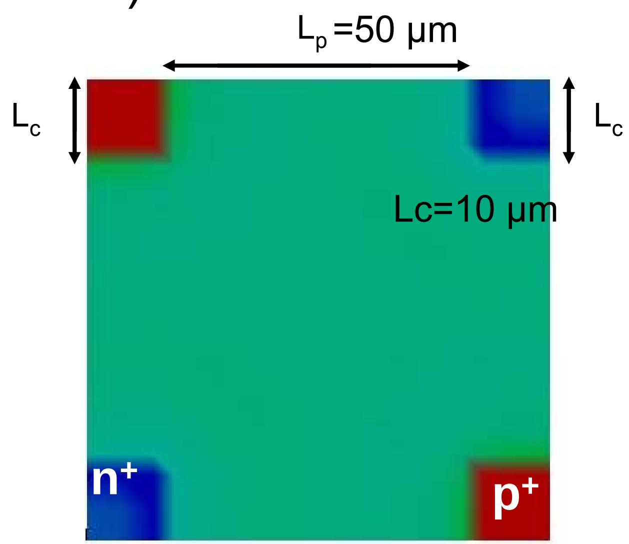


All strips shorted.
Single channel readout.
CCE at IFIC (Valencia).
Pulsed laser:
λ=1060 nm, 1.17 eV)
Beta source: ^{90}Sr.

- Wafers Siltronic, <100>, P type FZ,300µm, ρ = 20 kΩ·cm.
- N strips on P-type material Manufactured at CNM (Barcelona) with RD50 mask set
- 130 strips, 80 µm pitch, 1cm^{2}, AC coupled, poly resistor bias, P-spray isolation
- Neutron irradiation at TRIGA nuclear reactor Jozef Stefan Institute in Ljubljana.

NEW STRUCTURES: 3D (simulations at BNL, structures)





SilvacoDEVEDIT3D, DEVICE3D (ATLAS)

Neff(Φ) accounted.

$4x10^{11}/cm^2$ oxide charge accounted

4 p-type 3D structures

3D hole conc. & E-field profiles simulated

NEW STRUCTURES: 3D (simulations at BNL, results)

Structure	E-field profile	Rad-hard	Processing	Accessibility	Sensitivity under the column
Std 3d (UH)	Good	Super	Difficult	One-side	
BNL dct	Good	Super	One-sided	One-side	Some
IRST/CNM dct	Good	Super	Double-sided	Two-side	Some
BNL sct	Low E on back side	Good	One-sided	One-side	Some
IRST sct	Low E on front and center	Good	One-sided	One-side	Some

Double column detectosr:

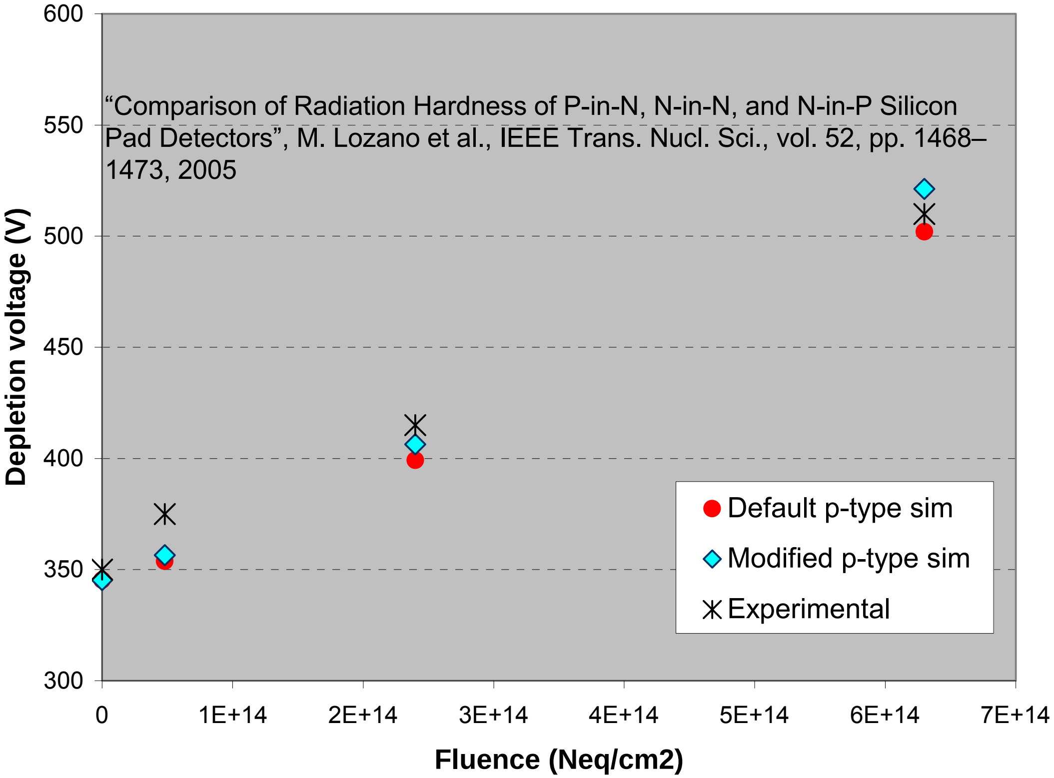
- V_{fd} for a dct 3D detector is about 1.4 time higher than a 2D pad with $d = L_p$
- Low E-field is between the two p^+ columns ;E minimum in the center of the cell
- In order to fully deplete a dual-column 3D detector at 1×10^{16} n_{eq}/cm^2 with a reasonable bias (<200 V), the column spacing L_p should be <50 μm
- The volume under the column can be depleted with modest biases (no dead area)

NEW STRUCTURES: 3D (simulations at Glasgow/CNM, calibration)

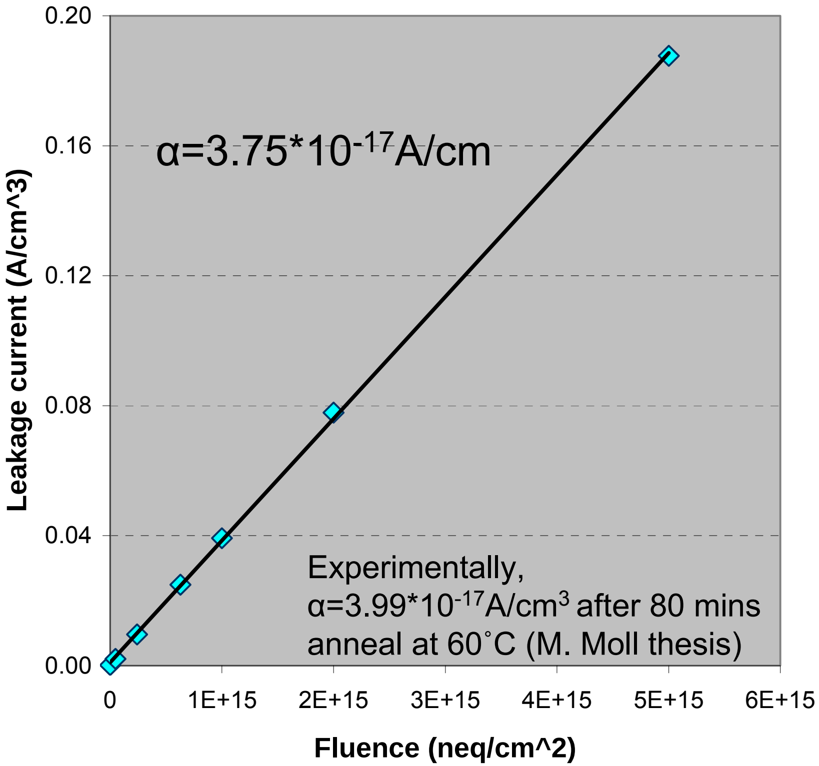
Modified "Perugia "P-type model and experimental data

Type	Energy (eV)	Trap	σ_e (cm^2)	σ_h (cm^2)	η (cm^{-1})
Acceptor	Ec-0.42	VV	$9.5*10^{-15}$	$9.5*10^{-14}$	1.613
Acceptor	Ec-0.46	VVV	$5.0*10^{-15}$	$5.0*10^{-14}$	0.9
Donor	Ec+0.36	CiOi	$3.23*10^{-13}$	$3.23*10^{-14}$	0.9

P-type trap models: Depletion voltages

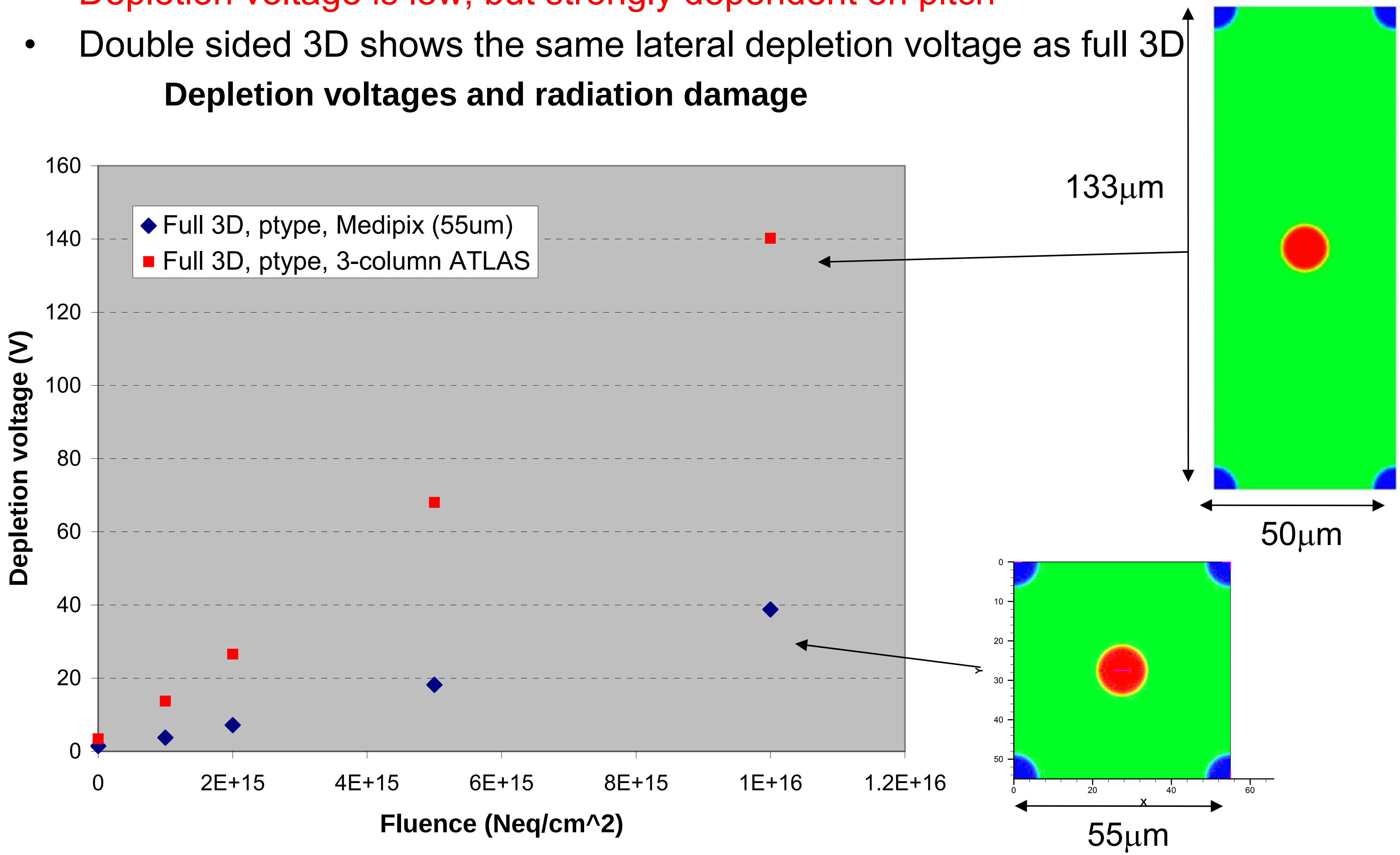


P-type trap model: Leakage Current



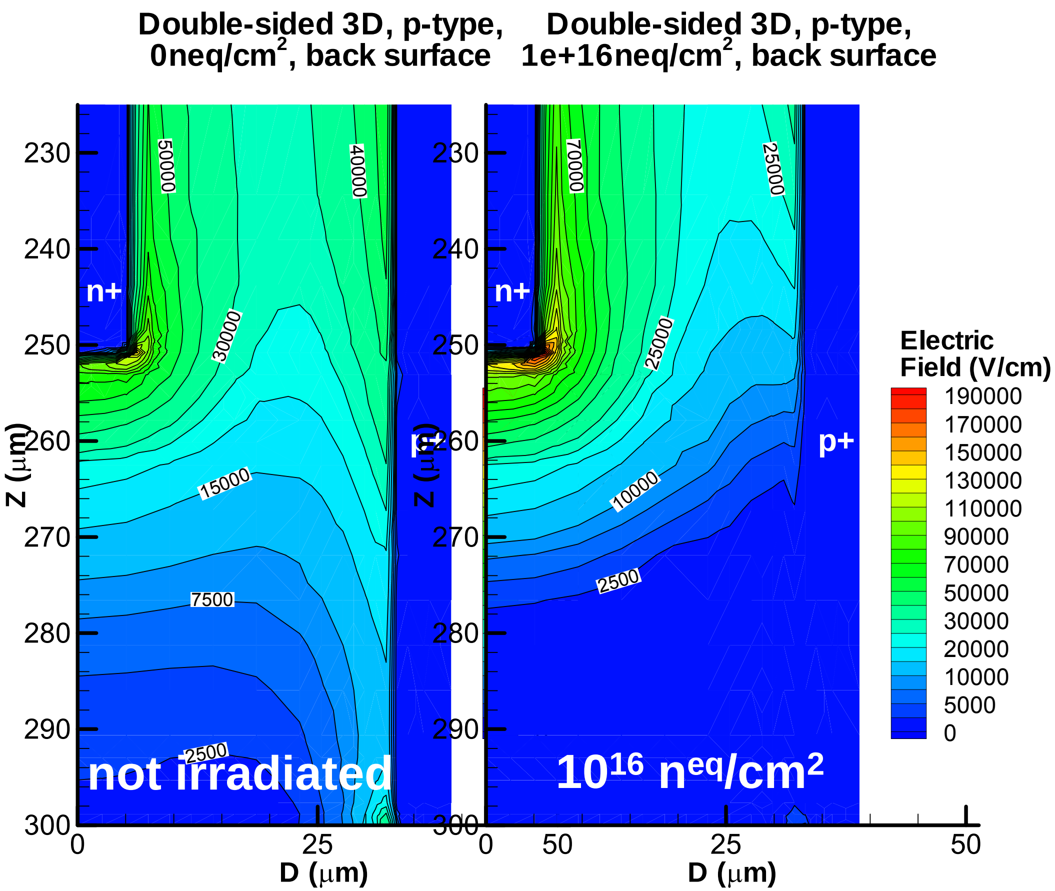
NEW STRUCTURES: 3D (simulations at Glasgow/CNM, V_{fd})

- Depletion voltage is low, but strongly dependent on pitch
- Double sided 3D shows the same lateral depletion voltage as full 3D



NEW STRUCTURES: 3D (simulations at Glasgow/CNM (E distribution in dct)

Region at back surface depletes more slowly – not fully depleted at 100V bias



Double-sided 3D detectors:

-Behaviour similar to standard 3D

-Depletion to back requires a higher bias

Preliminary tests of damage:

-Relatively low V_d, but electric field pattern is altered

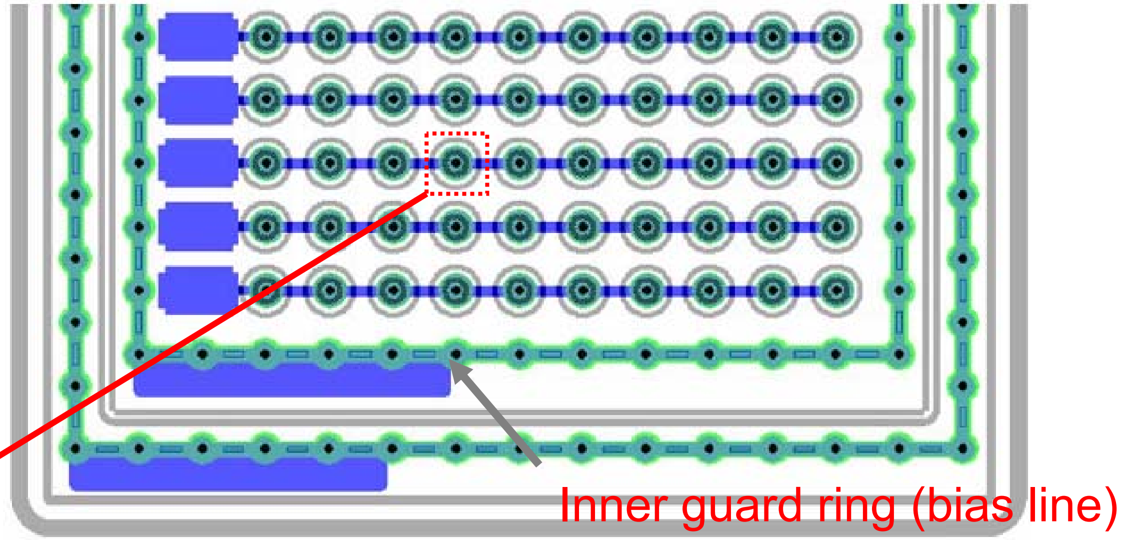
-Double-sided 3D shows undepleted region at back surface at high fluences

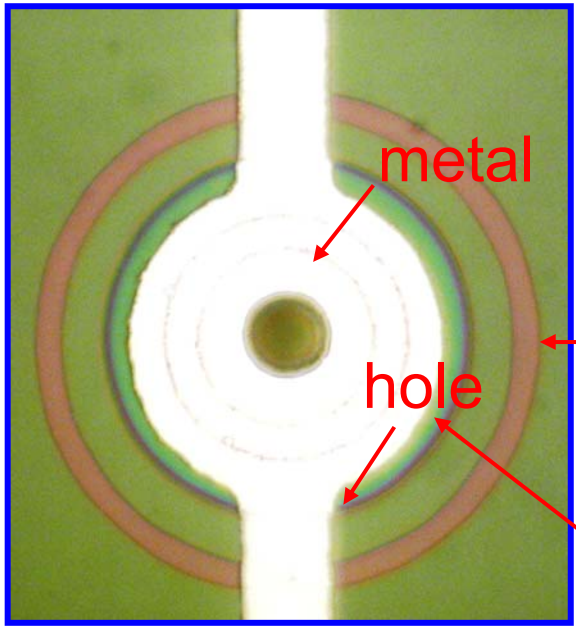
Further work: Simulate charge collection! Consider effects of different available pixel layouts CCE, depletion voltage, insensitive area, capacitance

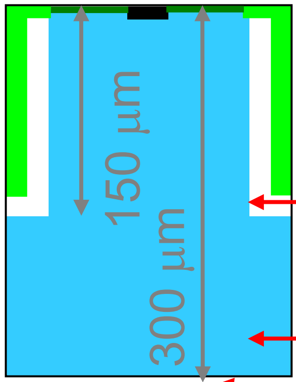
NEW STRUCTURES: 3D (sct TSC test, samples and setup)

- 3D-stc DC coupled detector
  (64 x 10 columns)
  80 μm pitch
  80 μm between holes
  10 μm hole diameter

- 3 adjacent channels bonded to electronics, other floating.





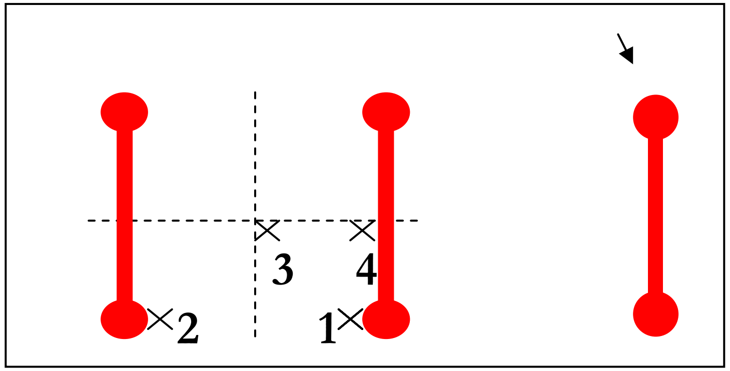


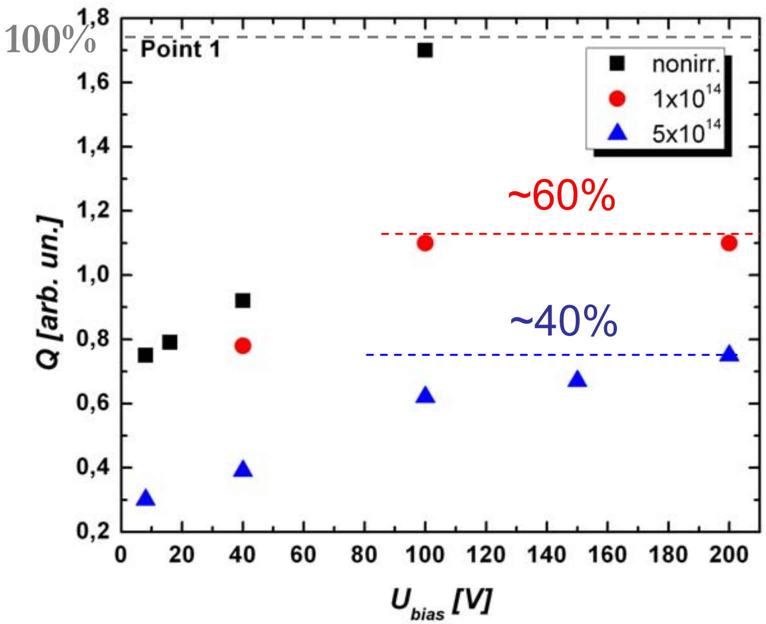
Setup at
Jožef Stefan Institute,
Ljubljana

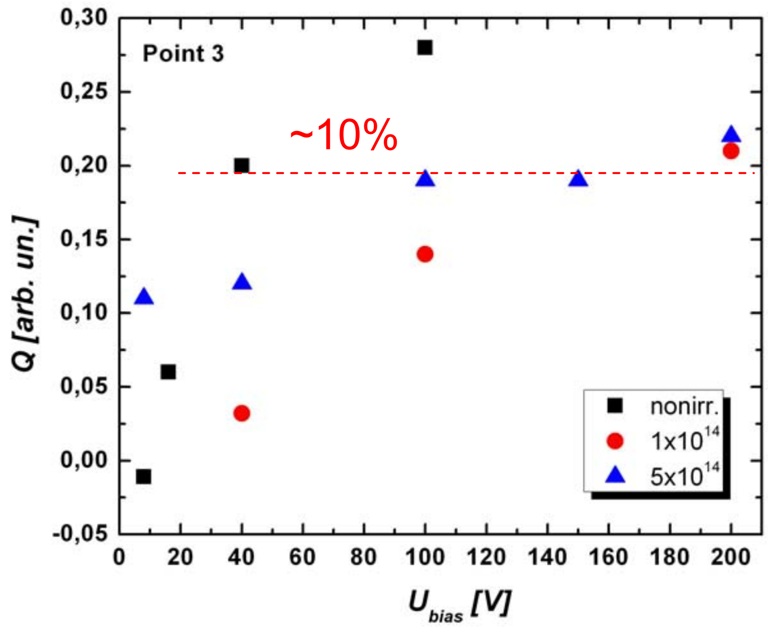
LASER:
Beam FWHM ~7 mm
Time width ~ 1ns
operation T=10°C
IR laser used

NEW STRUCTURES: 3D (sct TSC test, charge collection)

3D-sct do not seem suitable for fast charge collection (25 ns) of irradiated sensors:
- Ballistic deficit (slow hole drift)
- Trapping of holes
- Very non-homogenous response (E field saddle in the mid-region)







NEW STRUCTURES: 3D (double sided dct by CNM)

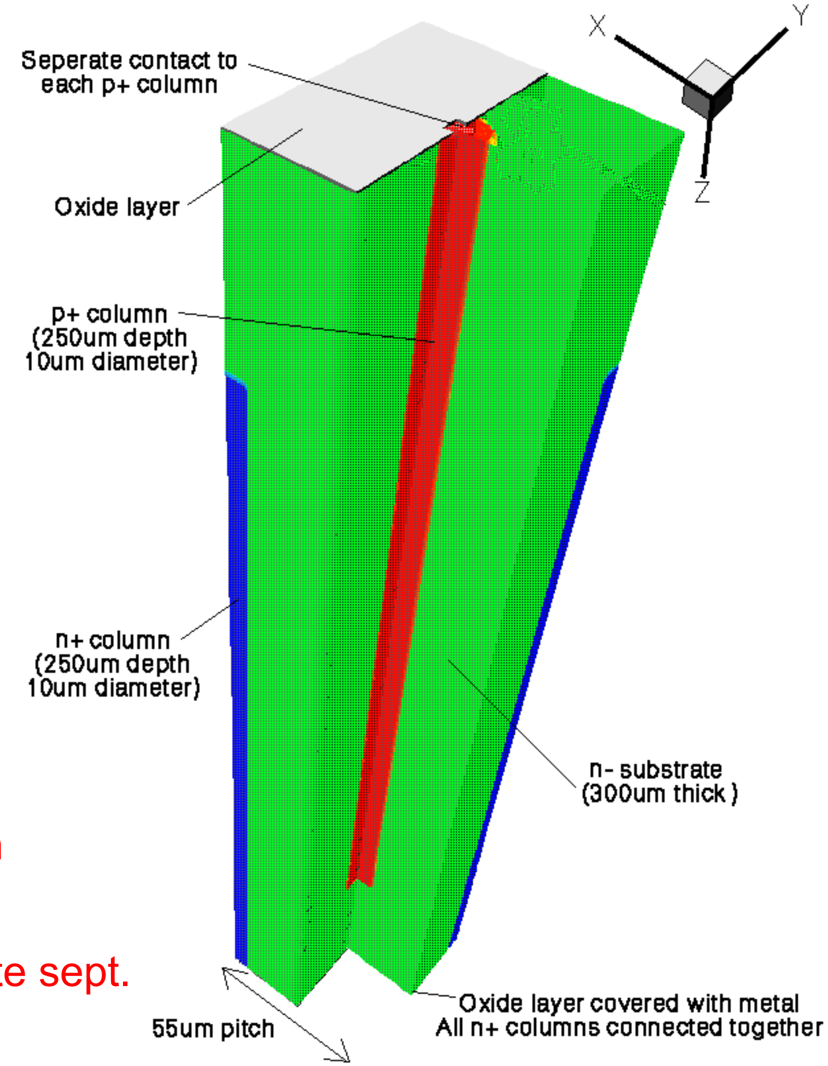
Double-sided design by CNM

4” masks by CNM and Glasgow,
funded by RD50 common fund

CNM 4” wafer design

6 Medipix2 pixels	Pitch 55µm, 256x256
6 ATLAS pixels	Pitch 50x400µm, 164x18
1 Pilatus pixel	Pitch 172µm, 97x60
4 short strip	Pitch 80µm, 50x50
1 long strip	Pitch 80µm, 50x180

+ pad detectors, test structures



p readout columns,n bulk:4 wafers in process~1 month

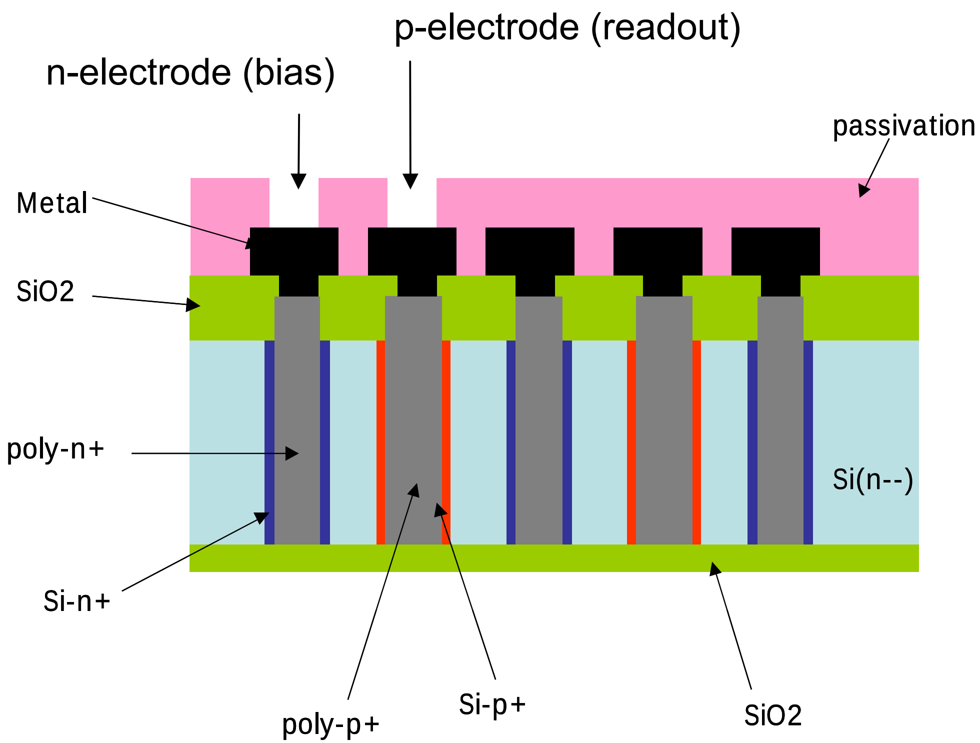
n readout columns, p bulk (with p-stops): begin estimate sept.

NEW STRUCTURES: 3D (full 3D at Glasgow)

Project: Glasgow/Diamond Light Source
Developing of 3D detectors for X-ray diffraction experiments at the DLS synchrotron

Full 3D detectors on n-type Si fabrication by IceMOS Technology Ltd. (Belfast).
Readout in p-columns only, no p-stops necessary (holes collection)
Bias in n-columns, contacts on the top, metal lines to connect n+ columns
1st run in progress.

Glasgow 4" wafer design
Pixel detectors:
4 Medipix2, Pitch 55 μm, 256x256
6 Pilatus, Pitch 172 μm, 97x60
1, 4 or 9 cells/pixel
Strip detectors
4 large ("Beetle") strips, pitch 80 μm, 128x100
22 small ("Hermes") strips, pitch 125 μm, 32x10
Square or hexagonal cell
+Pad detectors, test structures



CONCLUSIONS

Defect characterization: Isochronal anneal at 80-260°C, e-trapping reduced by 1/5. Strong changes after high T steps in DLTS, TSC, PL and FTIR. V Clusters are likely to be responsible for trapping-related CCE deficit.

Defect engineering: epitaxial Si.150 μm devices from various manufacturer compared. P type inverts, n-type does not. Wide spread of $g=1.3\text{-}2.4\cdot10^{-2}$ cm^{-1}: processing is critical to determine EPI Si performances.

Operational conditions: bias effect in Cz, FZ, Epi-Si.V_{fd} always increases regardless of space charge sign. Same effect for 24GeV protons and neutrons.

Characterization of irradiated p-type strips (LHC speed electronics).
Even at $4x10^{15}$ cm^{-2} detectors are still operational. The collected charge seems to scale with the NIEL function. Long term annealing doesn't effect substantially the measured signal.

New structures: 3D detectors. Low field regions (poor CCE) in sct predicted and measured. According to simulations, possible dead regions in duble-sided dct; small pitch required (<50μm). Double sided dct and full 3D under process.