Comparison of Radiation Hardness of P-in-N, N-in-N and N-in-P Silicon Pad Detectors

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Outline

- Introduction
- Fabrication technology
- Preliminary results
- Conclusion and future work

Object of the investigation

To understand influence of the fabrication technology in the radiation-induced degradation:

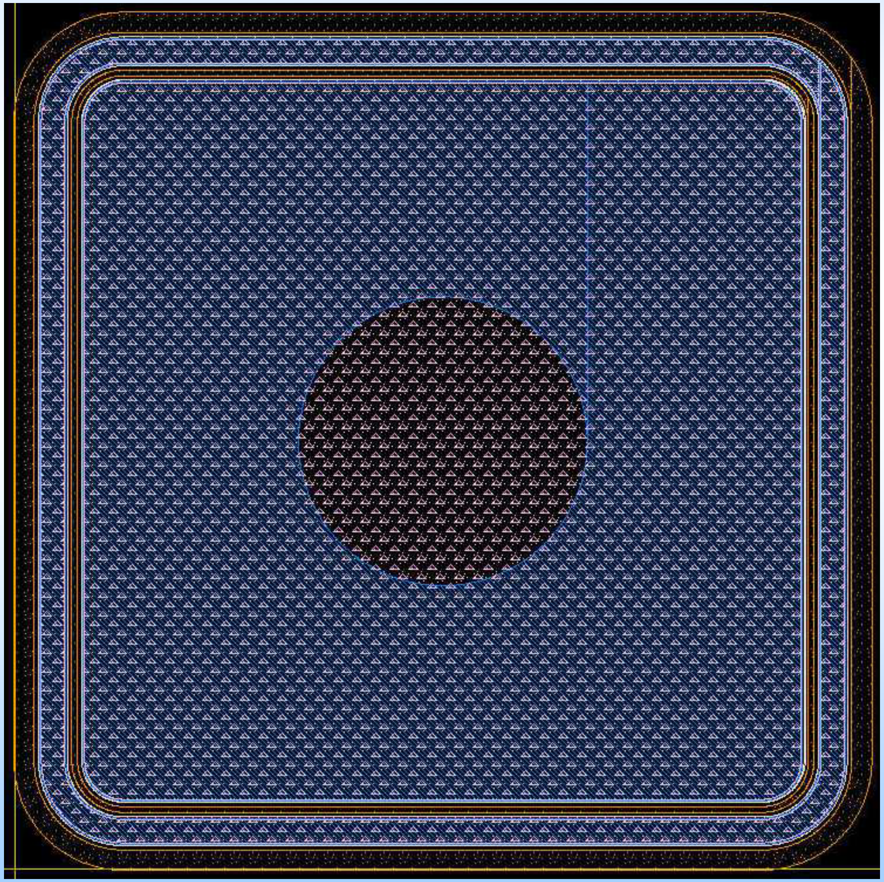
- Silicon diodes were fabricated simultaneously

  P-in-N N-in-P N-in-N

- Standard and oxygenated silicon

- Diodes were irradiated with 24GeV protons to fluences up to $1x10^{15}cm^{-2}$

Pad detectors

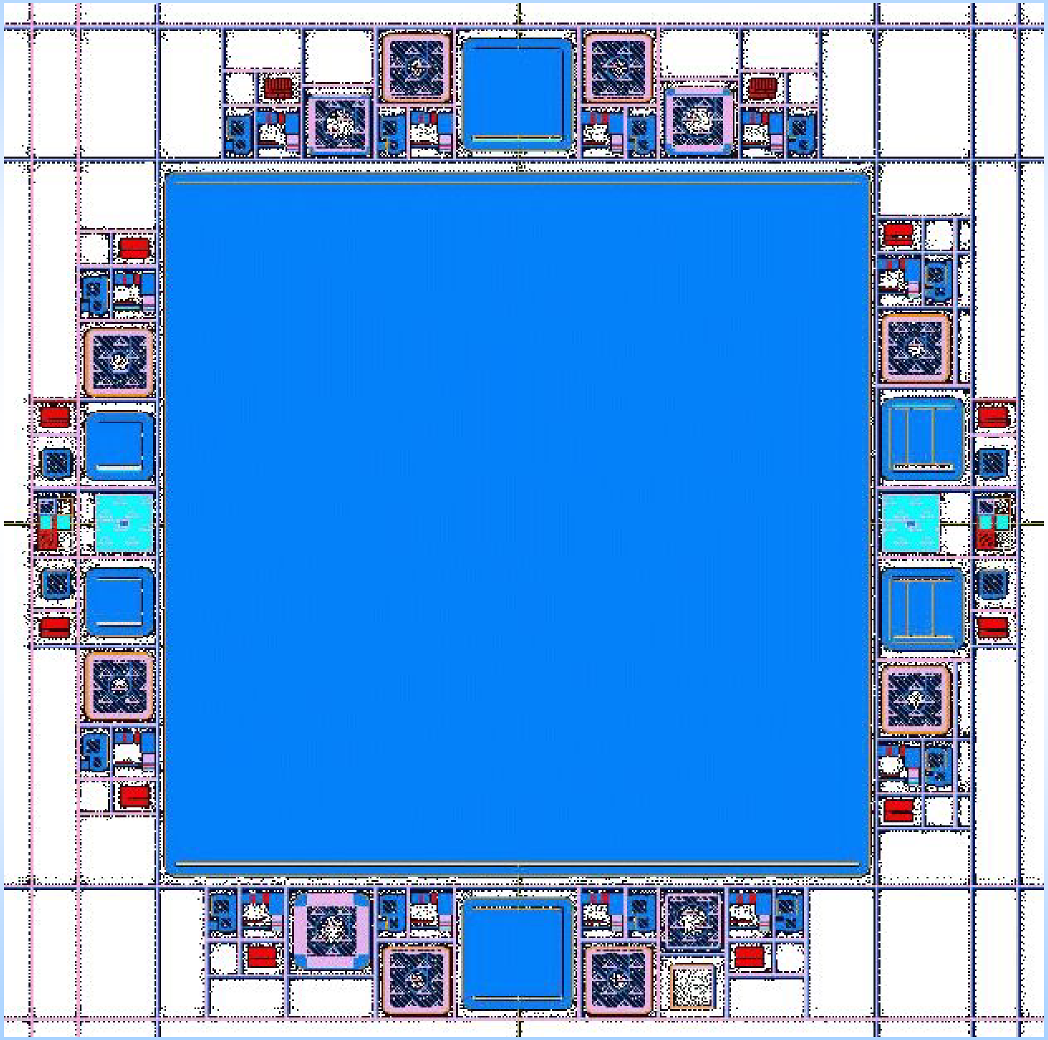


- Mask designed by Liverpool
- Area= $5x5mm^2$
- Guard ring=200µm
- Thickness=280±15µm

N-in-P and N-in-N p-stop			
10^{13} cm^{-3}		10^{14} cm^{-3}	
Std	Oxg	Std	Oxg

P-in-N	
Std	Oxg

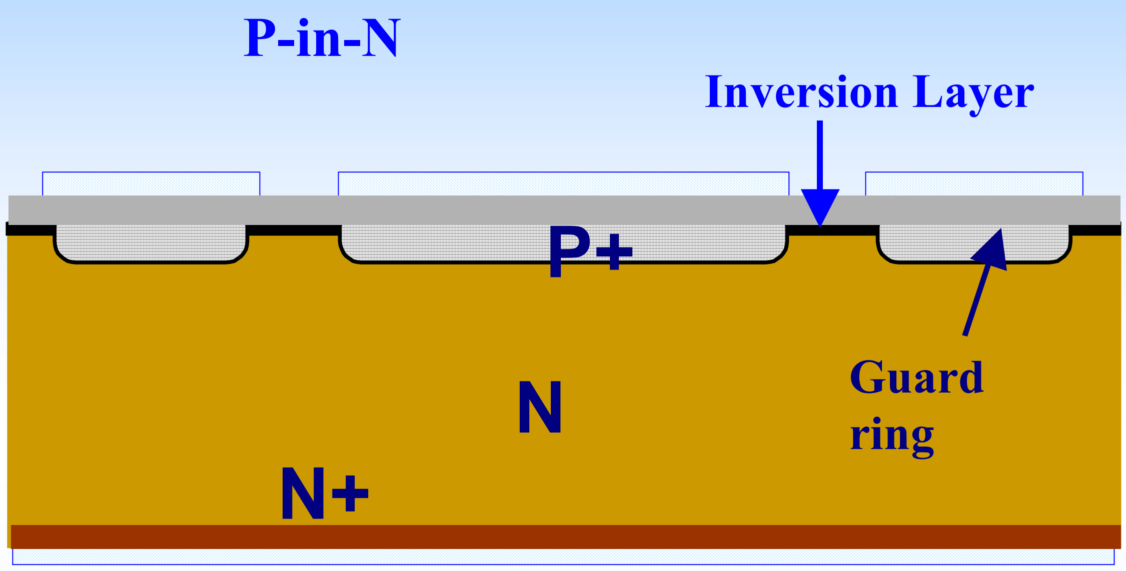
Silicon Microstrip Detectors



- 770 strips diodes
- 80 μm wide
- 61570 μm long
- polysilicon biasing resistors
- Strips capacitively coupled

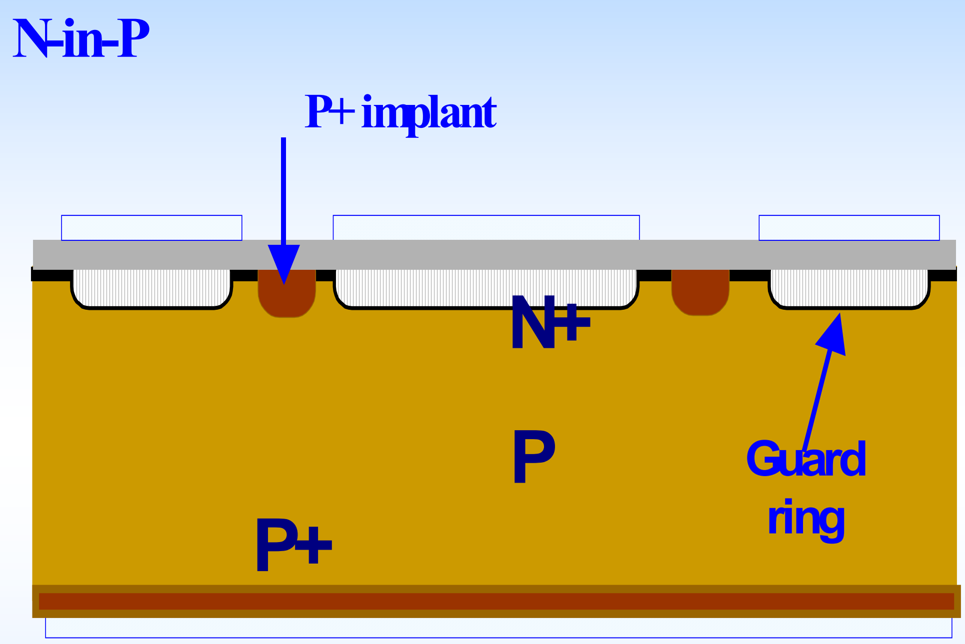
Mask set was designed between University of Liverpool and IMB-CNM

Technology: P-in-N



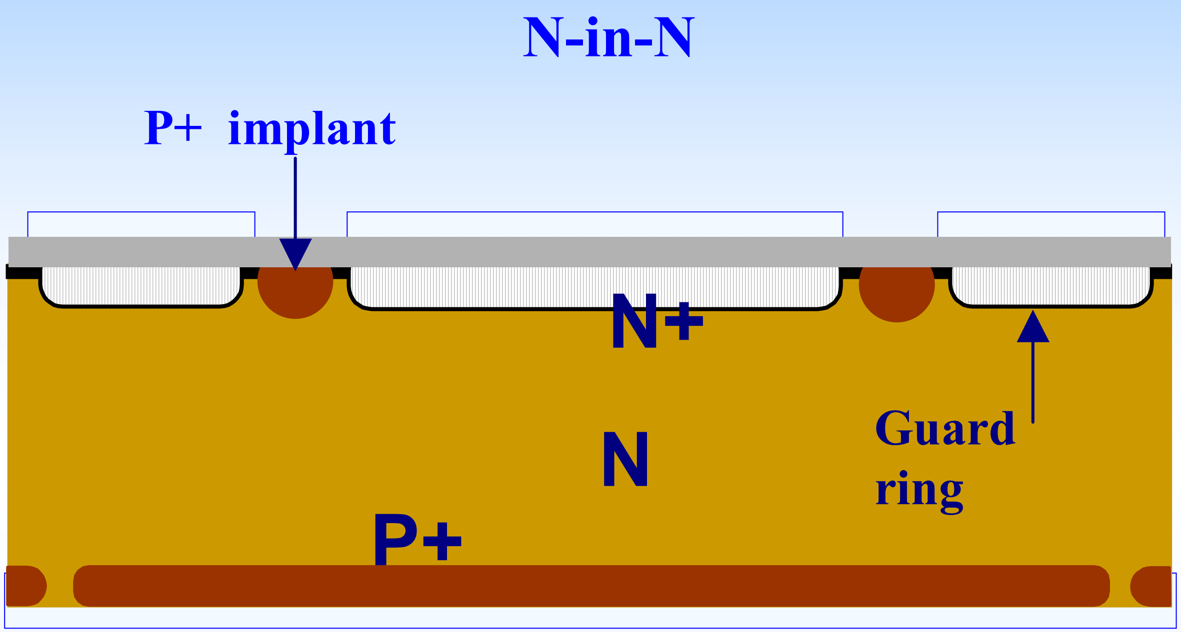
- Simple technology, only 5 mask levels.
- Bulk inversion to p-type at around 2×10^{13} 1 MeV n. equ.
- Collection of holes.

Technology: N-in-P



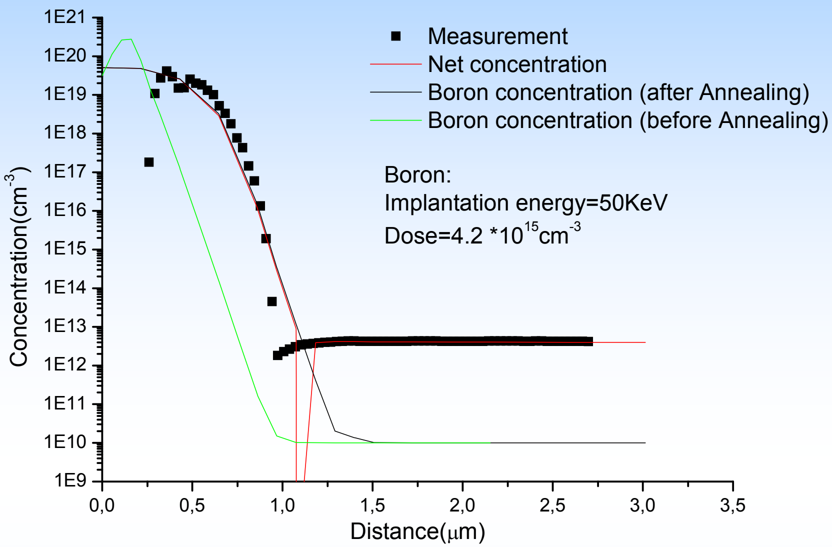
- More complex technology, 7 masks levels
- Extra surface insulation, p-stop or p-spray
- No type inversion expected
- Collection of electrons

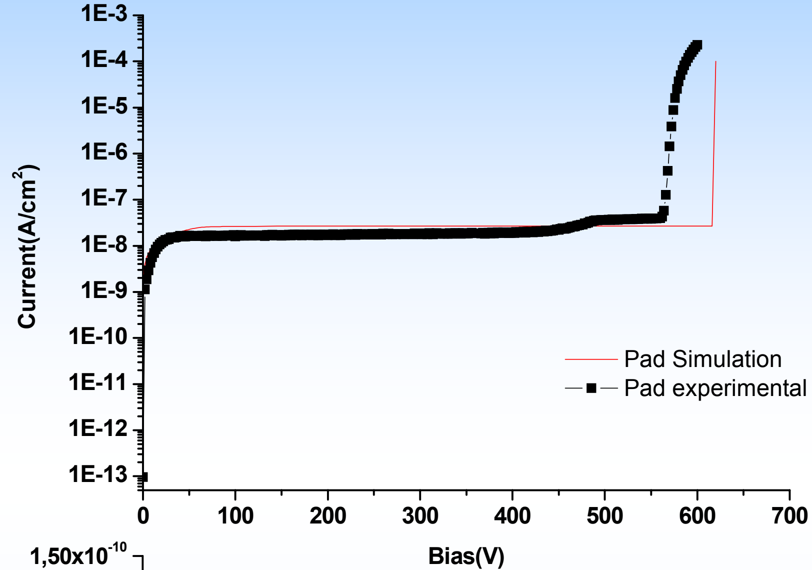
Technology: N-in-N

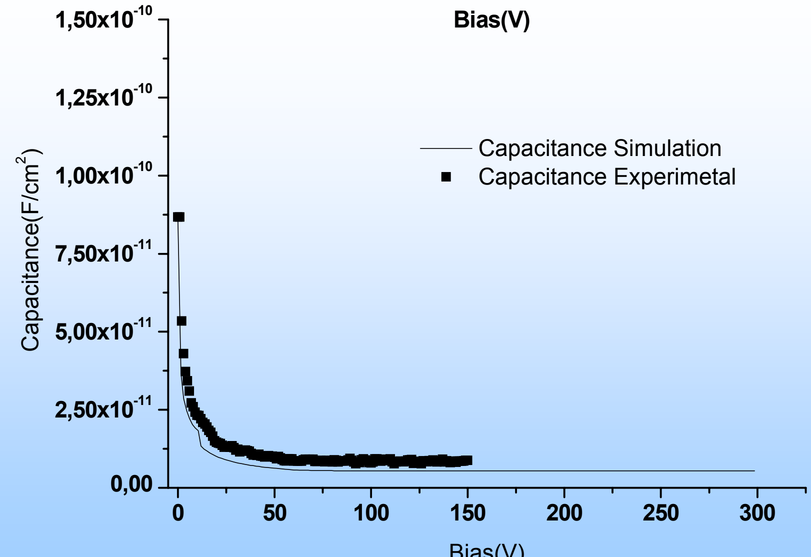


- Complex technology, 10 mask levels
- Both surfaces processing
- Type inversion but at high radiation fluences bulk silicon depletes from the N+ side
- Collection of electrons after type inversion

Simulation







- Spreading resistance
- Oxide charges 5×10^{11} cm^{-2}
- Cylindrical coordinates
- Irradiation studies.

Characterisation

1) I-V: Leakage current measurements:

Effect of the p-stop on N-in-P and N-in-N diodes

Breakdown voltage.

2) C-V: capacitance measurements

full depletion voltage

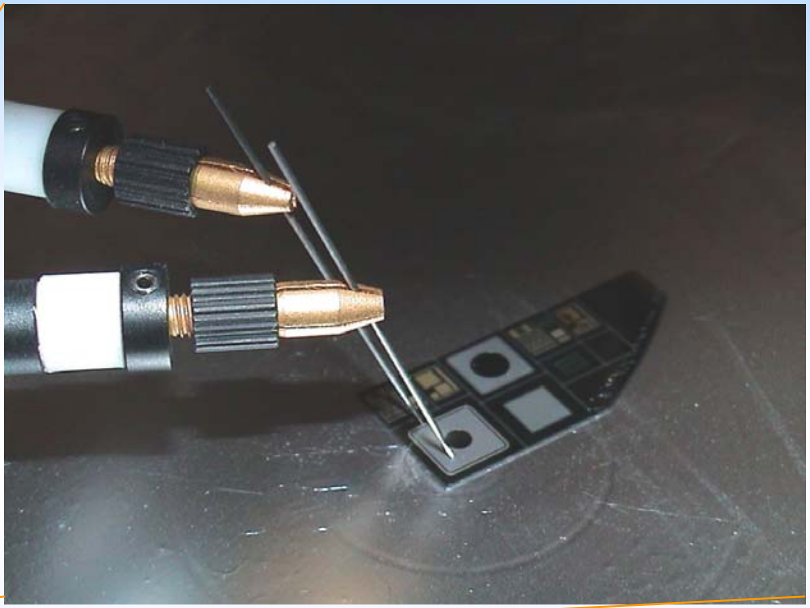
3) Radiation hardness: 2 parameters

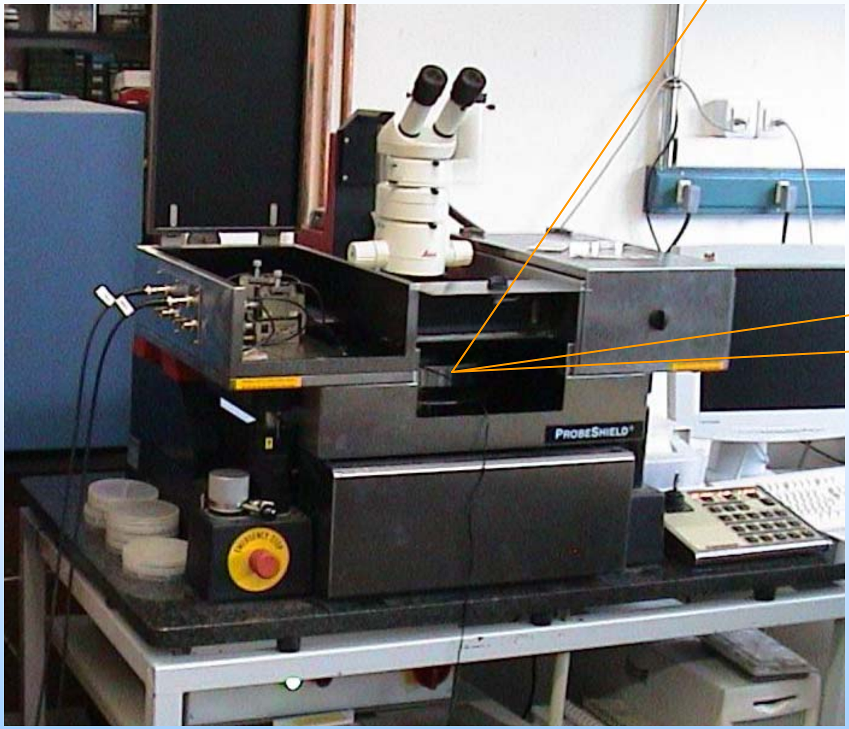
α: "damage" constant

β: the introduction rate of stable defects

Probe station IV and CV

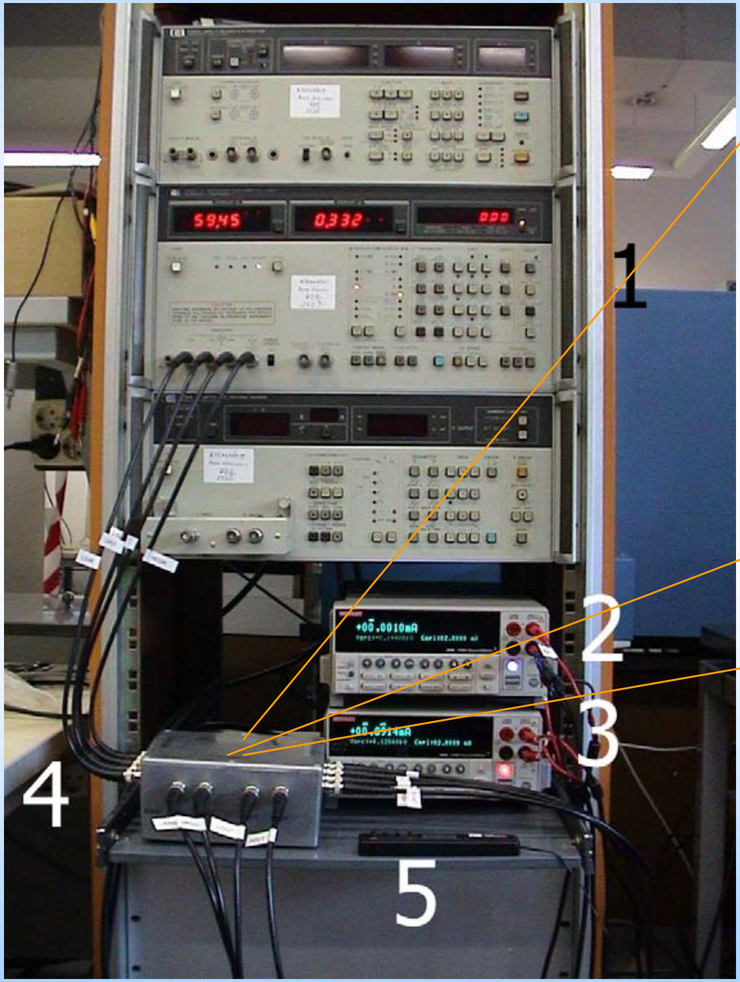
Karl Suss PA200

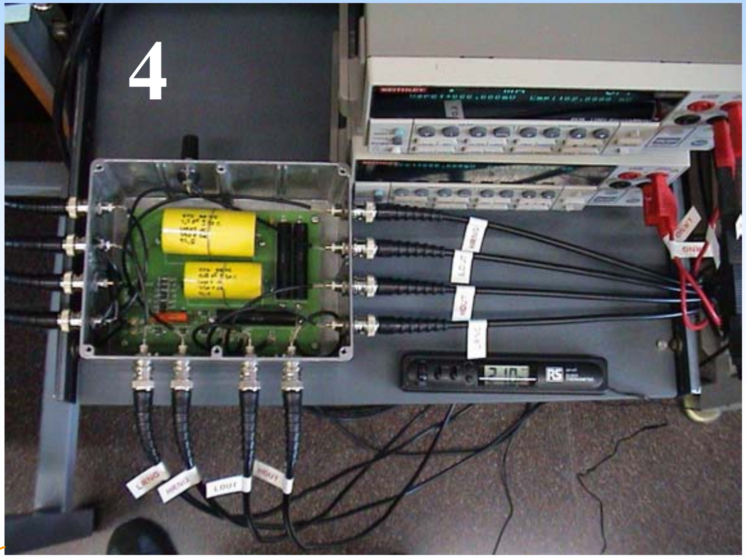




Low noise measurements

Measurements IV and CV





1: Impedance Analyzer HP 4192A
2, 3: Keithley 2410 SourceMeter
4: CERN Bench
5: RS Clock Thermometer
Capacitance measured in parallel
f=10kHz

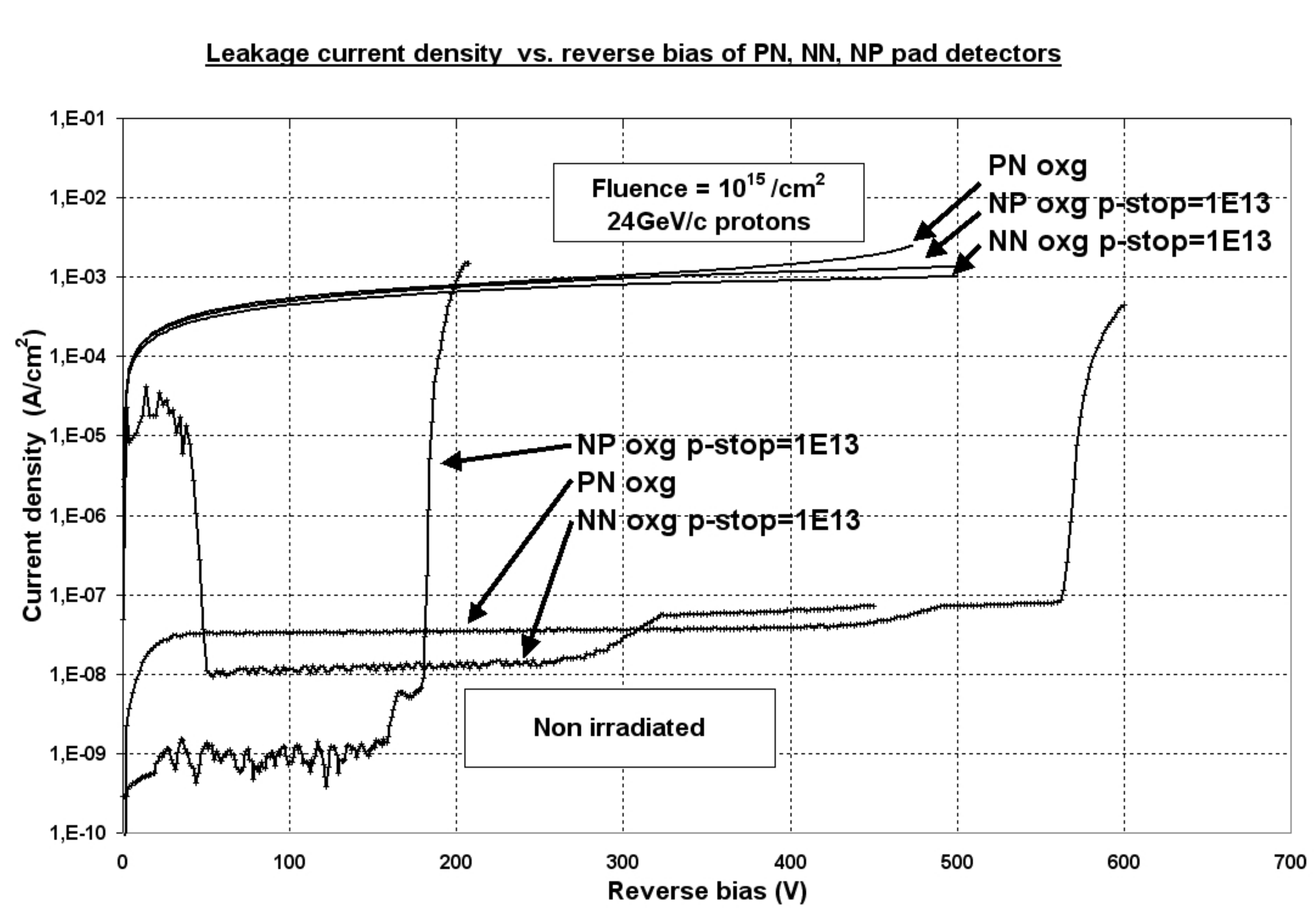
Irradiation at CERN

Fluences (protons/cm^2)

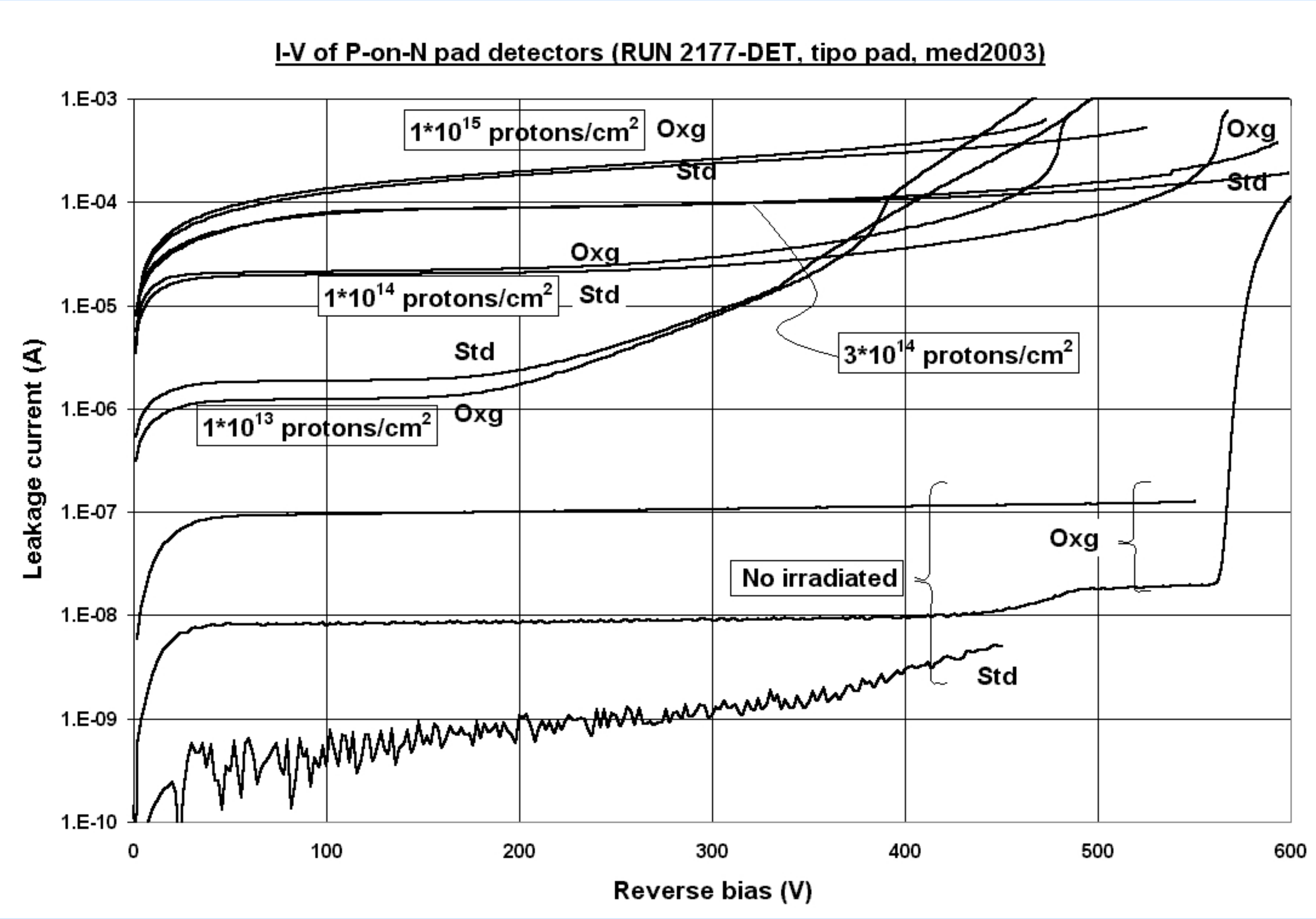
N-in-N	N-in-P	P-in-N
0.00E+00	0.00E+00	0.00E+00
7.73E+12	-	7.73E+12
7.87E+13	7.87E+13	7.87E+13
2.70E+14	2.70E+14	2.70E+14
1.02E+15	1.02E+15	1.02E+15

- Protons 24GeV
- Diodes measured before annealing.
- Diodes irradiated without bias.
- Diodes stored at –35C.
- NIEL factor= 0.62 keVcm^2/g

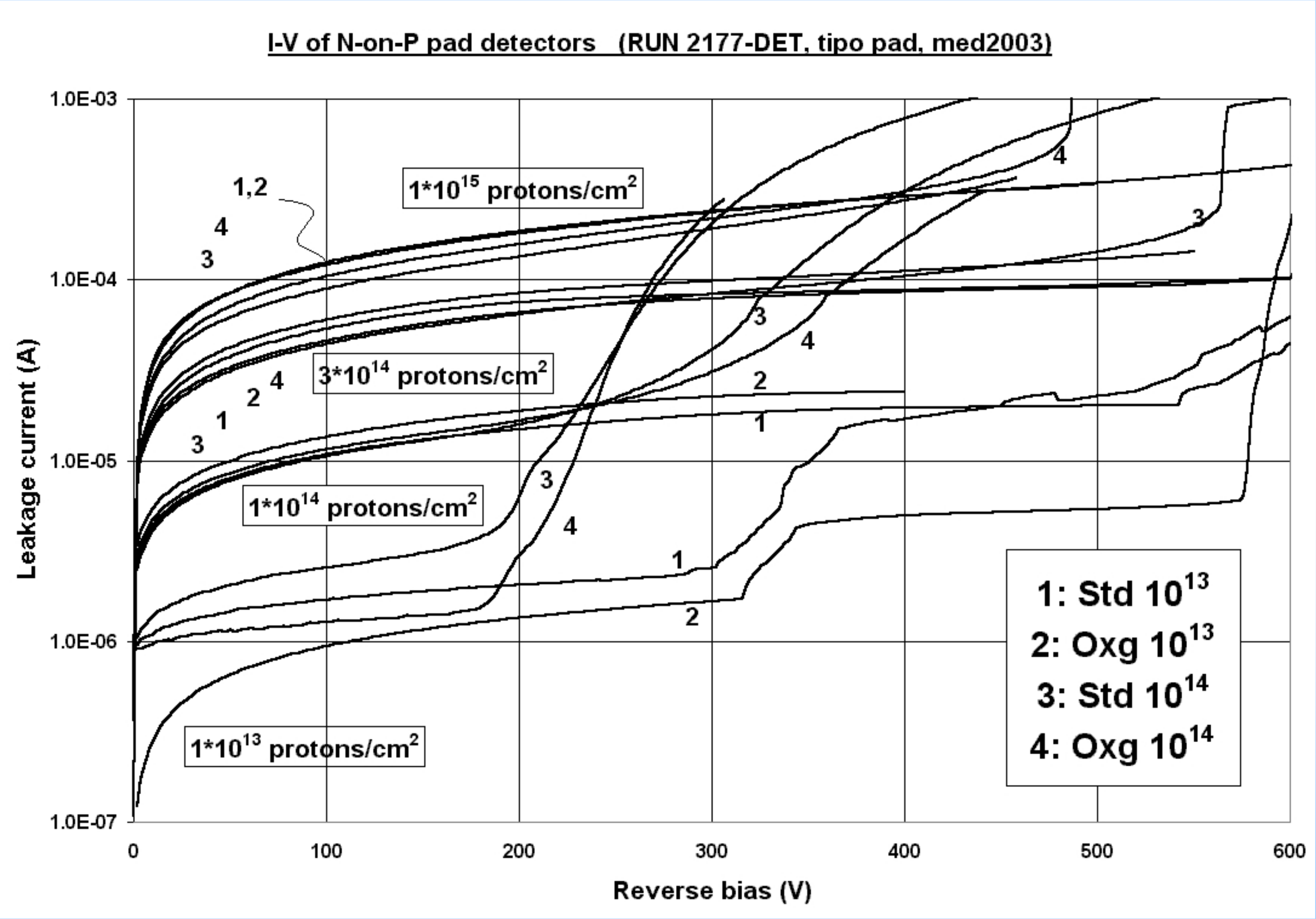
Leakage current measurements



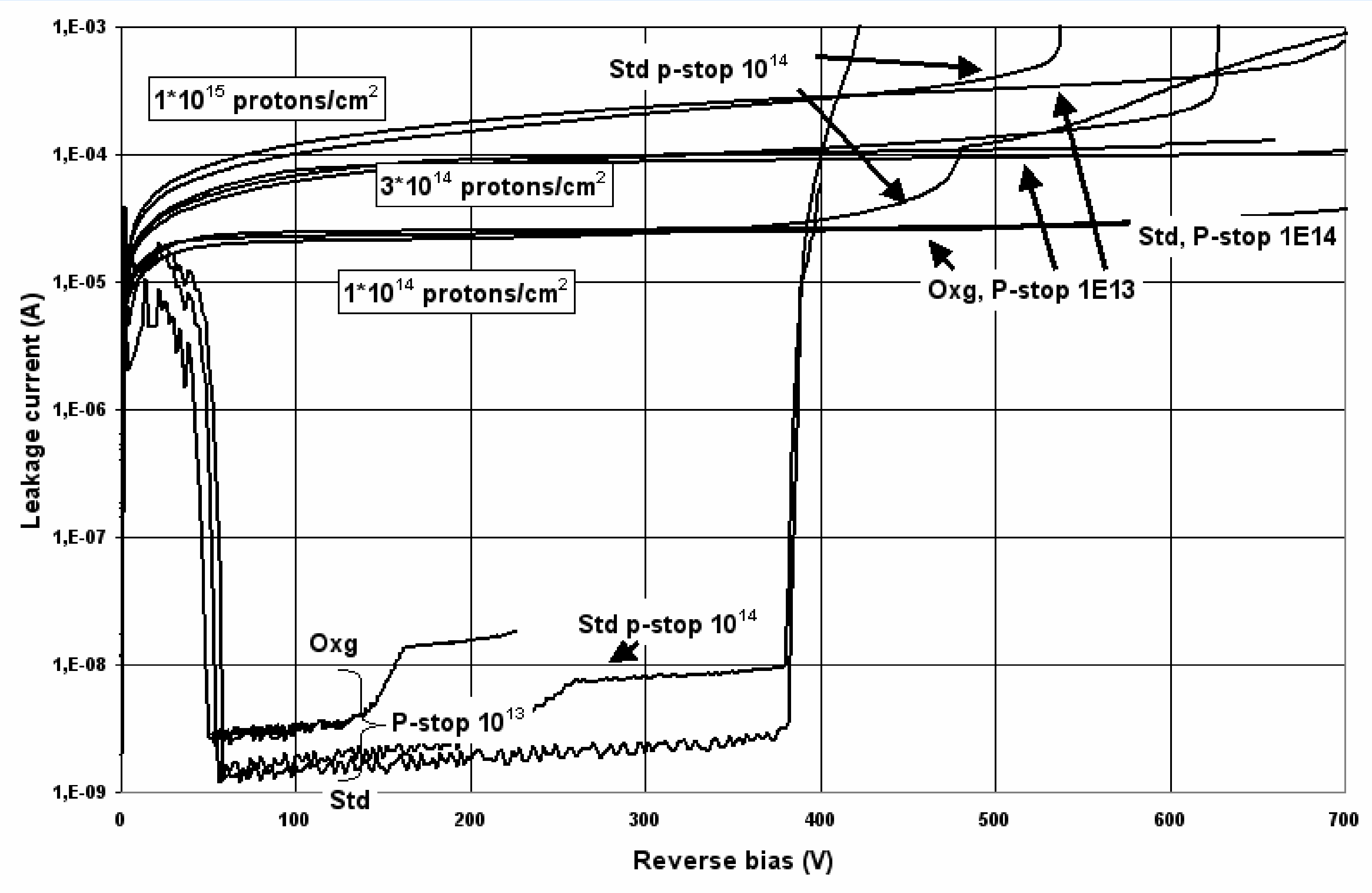
Leakage current for P-in-N diodes



Leakage current for N-in-P diodes



Leakage current for N-in-N diodes



Parameter α

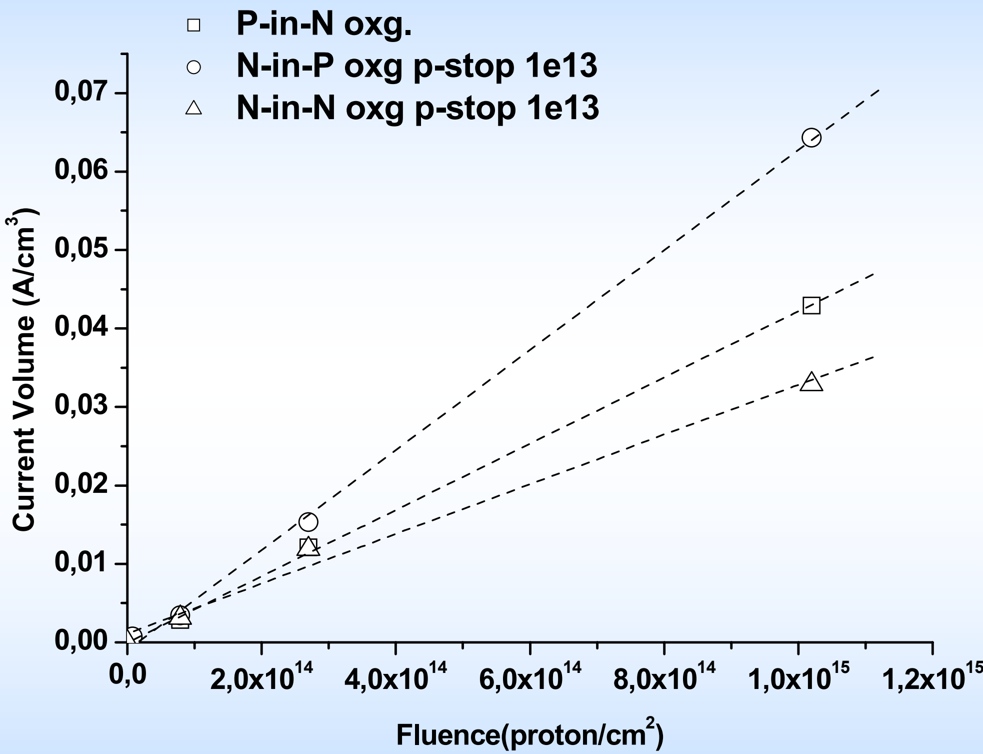


Table 6 Parameter α of N-in-P normalized at 20ºC

	N in P			
P-stop	1E+14		1E+13	
substrate	Std	Oxg	Std	Oxg
α (10^{-17}A/cm)	4.9±0,2	4.9±0,1	4.6±0,6	4.1±0,2
α_{eq} (10^{-17}A/cm)	7.9±0,4	7.9±0,2	7.4±1,2	6.6±0,4

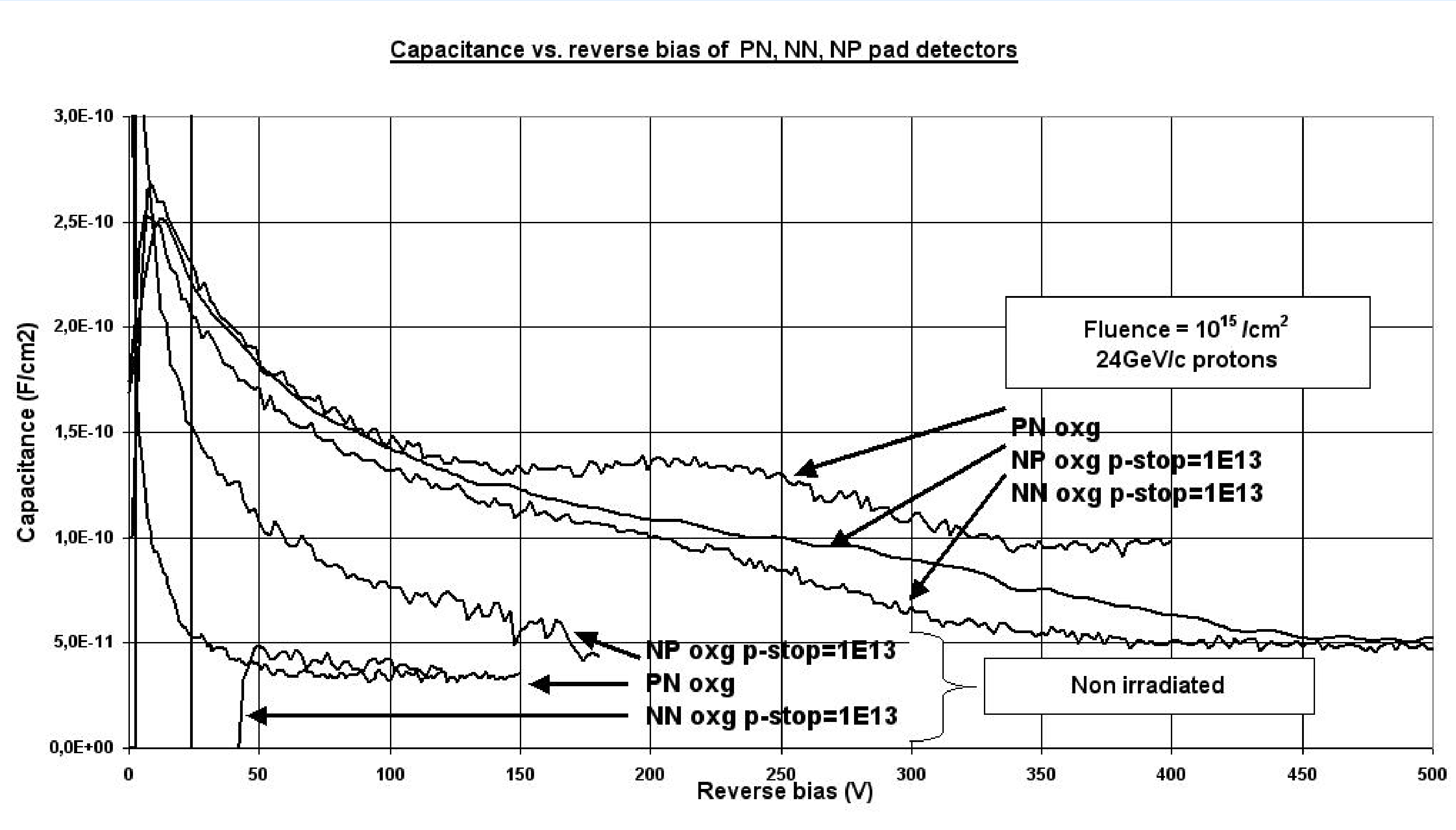
Table 7 Parameter α of N-in-N and P-in-N normalized to 20ºC

	N in N			P in N	
P-stop	1E+14	1E+13		-	-
substrate	Std	Std	Oxg	Std	Oxg
α (10^{-17}A/cm)	4.6±0,2	5.4±0,2	3.2±0,3	4.2±0,2	3.5±0,2
α_{eq} (10^{-17}A/cm)	7.4±0,4	8.7±0,4	5.2±0,5	6.8±0,4	5.6±0,4

$$\Delta I_{Vol} = \alpha\phi$$

Currents were normalized to 20ºC according to equation: $I \sim T^2 \exp(-E_0/2kT)$ with E_0=1.12 eV.

CV measurements



f = 10kHz

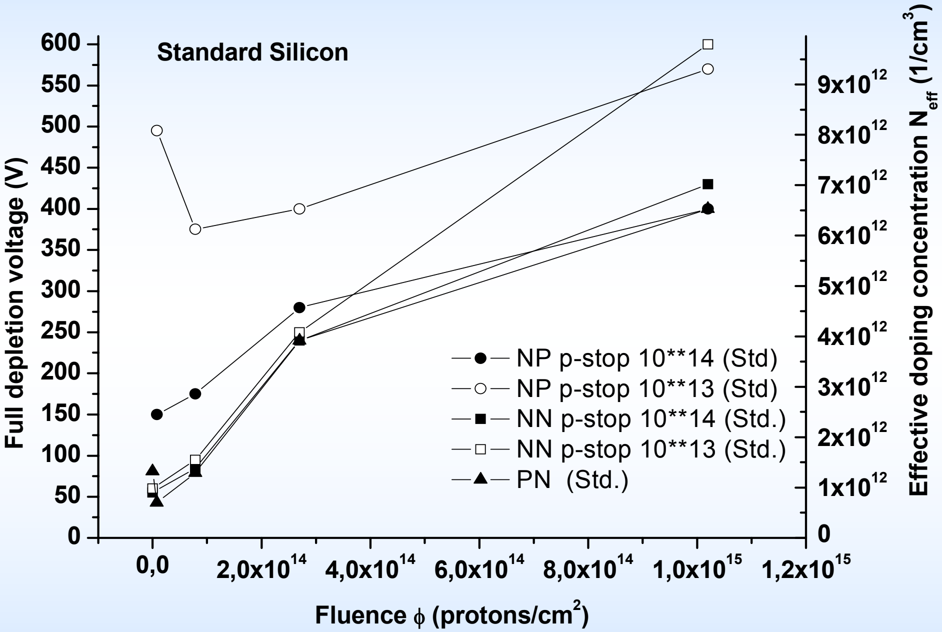
Full depletion

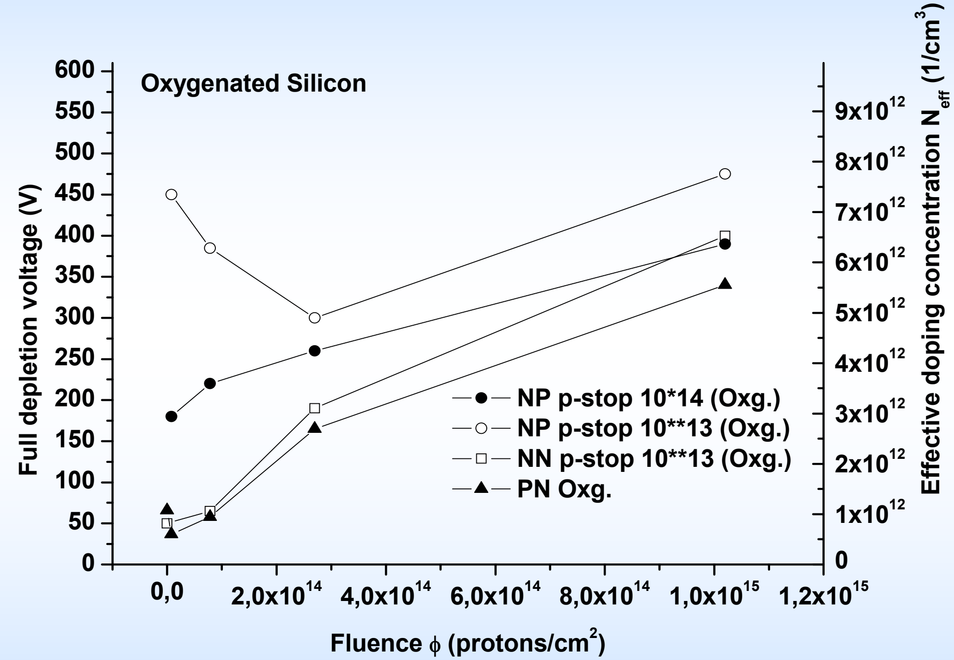
V_{FD} (V)	N in N			P in N	
P-stop	1E+14	1E+13		-	-
substrate	Std	Std	Oxg	Std	Oxg
non irr.	55±5	60±5	50±5	80±10	65±10
10^{15}p/cm^2	430±30	600±30	400±20	400±20	340±20

V_{FD} (V)	N in P			
P-stop	1E+14		1E+13	
substrate	Std	Oxg	Std	Oxg
non irr.	-	-	-	-
10^{15}p/cm^2	400±50	390±30	570±40	480±30

V_{FD} was extrapolated by crossing two straight lines in the logC-logV plot near the kink.

Full depletion vs. fluence





The last two points in these plots were used to calculated the value of β.

Parameter β

	N in P			
P-stop	1E+14		1E+13	
substrate	Std	Oxg	Std	Oxg
β (1/cm)	0.011	0.011	0.015	0.016
β_{eq} (1/cm)	0.017	0.018	0.024	0.025

	N in N			P in N	
P-stop	1E+14	1E+13		-	-
substrate	Std	Std	Oxg	Std	Oxg
β (1/cm)	0.031	0.019	0.017	0.014	0.016
β_{eq} (1/cm)	0.050	0.030	0.027	0.023	0.026

Conclusions and future work

Conclusions

- Oxygenated detectors have low full depletion voltage after irradiation.
- α is lower for N-in-N detectors
- Detectors with p-stop of 10^{14}cm^{-3} have breakdown voltages lower than detectors with p-stop of 10^{13} cm^{-3}.
- N-in-P oxygenated detectors show a bulk inversion at a fluence of $2.7x10^{14}$ p/cm^2

Future work:

- Annealing studies
- Charge collection efficiency
- Measurements of microstrip
- Simulation
- Irradiation up to 10^{16} protons/cm^2