Characterization of micro-strip detectors made with high resistivity n- and p-type Czochralski silicon

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on behalf of the SMART Collaboration*

** A Collaboration of the INFN sections of Bari, Firenze, Padova, Perugia, Pisa and ITC-IRST*

- Motivations
- Layout and materials used in the production of the SMART mini-sensors
- Pre-irradiation measurements and irradiation campaigns
- Results of the post-irradiation measurements
- Conclusions and outlook

Motivations

- A foreseen LHC upgrade … later than 2010

	LHC	SLHC
Beam energy	7 Tev	12.5 TeV
Luminosity	10^{34} cm$^{-2}\times$s^{-1}	10^{35} cm$^{-2}\times$s^{-1}

✓The R&D activity of the SMART Collaboration on MCz µstrip sensors aims to find a solution for the tracker of the SLHC experiments at intermediate radii, where the fast-hadrons fluences will be around 10^{15}cm^{-2}.

	Radial distances of the 'present' CMS Tracker		Fluences foreseen at S-LHC
Pixel:	4 cm	=>	1.6×10^{16} cm^{-2}
	11 cm	=>	2.3×10^{15} cm^{-2}
Microstrip:	22 cm	=>	8×10^{14} cm^{-2}
	115 cm	=>	1×10^{14} cm^{-2}

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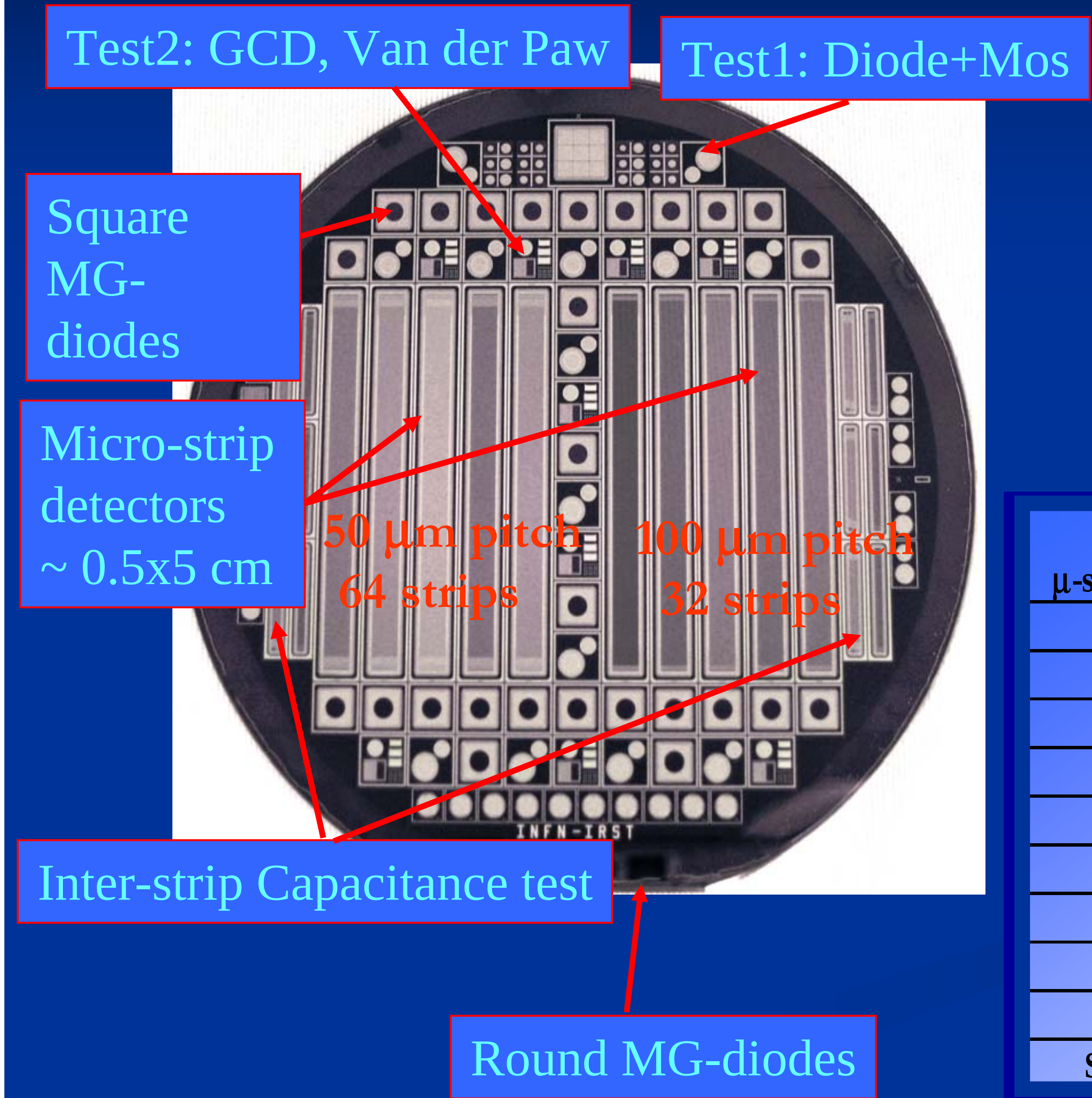
Wafer layout



- ✓ RD50 common wafer procurement
- ✓ Wafer Layout designed by the SMART Collaboration
- ✓ Masks and process by ITC-IRST
- ✓ 10 different strip geometries to explore their influence on the detector performances

µ-strip #	pitch (µm)	p+ width (µm)	Metal width (µm)
S1	50	15	23
S2	50	20	28
S3	50	25	33
S4	50	15	19
S5	50	15	27
S6	100	15	23
S7	100	25	33
S8	100	35	43
S9	100	25	37
S10	100	25	41

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Why Czochralski Silicon?

Materials	Symbol	ρ (Ωcm)	$[O_i]$ cm^{-3}
n- and p-type Standard Fz	FZ	1 – 7 10^3	< 5 10^{16}
Diffusion oxygenated Fz, n and p-type	DOFZ	1 – 7 10^3	~ 1 -2 10^{17}
Magnetic Czochralski, n and p-type	MCZ	1 - 2 10^3	~ 5 -9 10^{17}

- ✓It has intrinsically a high oxygen concentration thanks to its growth process and this improves the radiation-hardness
- ✓It is cheap (used routinely by the IC industry)
- ✓Recent developments (two years) made Cz available in sufficiently high purity (resistivity) to allow for use as a particle detector.

SMART — *Materials and processes*

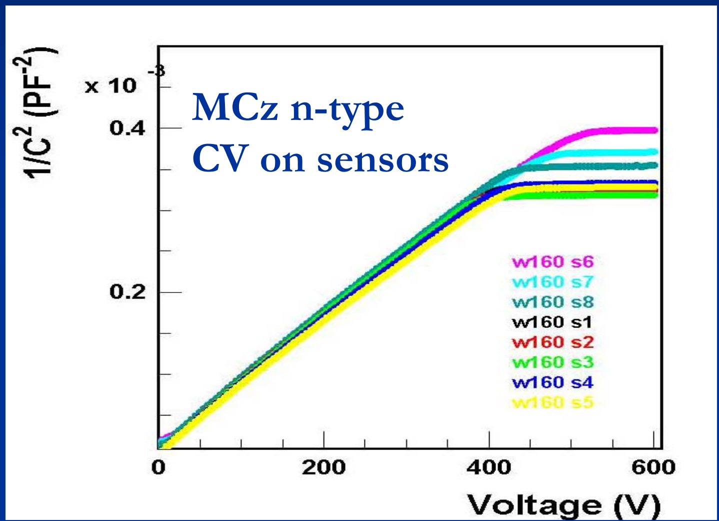
See accompanying poster by G. Segneri et al.

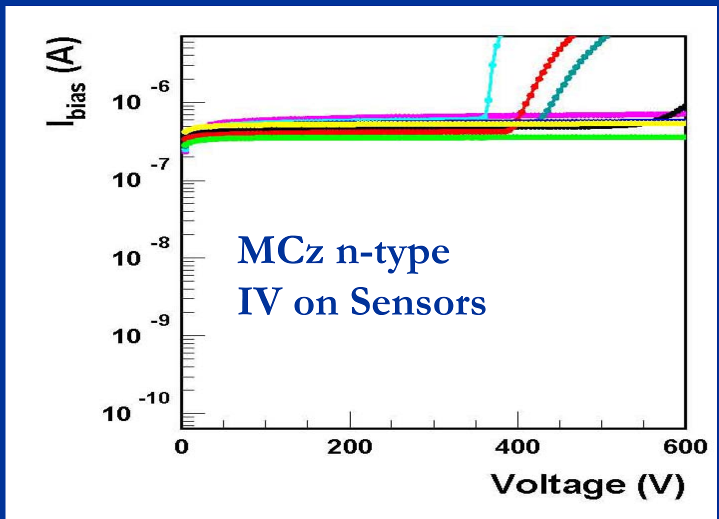
"Radiation hardness of high resistivity n- and p-type magnetic Czochralski silicon"
for the studies on the pre- and post-irradiated materials performed on the diodes of these production runs.

	MCz Samples	Fz Samples
RUN I **p-on-n** **22 wafers**	p-on-n **MCz** <100>, ρ>500 Ω cm ✓Standard: LTO, sintering @ 420C ✓no LTO, sintering @ 380C ✓no LTO, sintering @ 350C ✓no LTO, sintering @ 380C + TDK	p-on-n **Fz** <111>, ρ>6KΩ cm ✓Standard Process ✓sintering @ 380C
RUN II **n-on-p** **24 wafers**	n-on-p **MCz** <100>, ρ>1.8 KΩ cm ✓No LTO ✓Low dose p-spray (3.0E12 cm^{-2}) ✓High dose p-spray(5.0E12 cm^{-2})	n-on-p **Fz** , 200 μm, ρ>5KΩ cm ✓Low dose p-spray (3.0E12 cm^{-2}) ✓High dose p-spray(5.0E12 cm^{-2})

SMART — *Pre-irradiation Characterization*

✓Good performances of the n-type detectors in terms of breakdown voltages and current uniformity



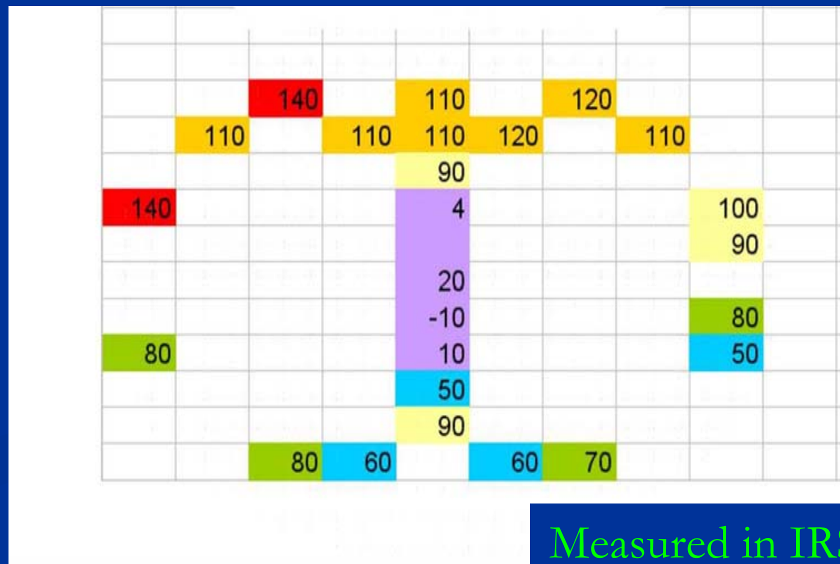


✓ Problems for the p-type detectors:

❖ low breakdown voltages for the 100 μm pitch detectors, probably due to the present implementation of the p-spray technique

❖ Disuniformity of the wafer resistivity, explained with a different oxygen concentration leading to a spread in the thermal donor activation.

Map of the diodes Vdepl in a p-type MCz wafer



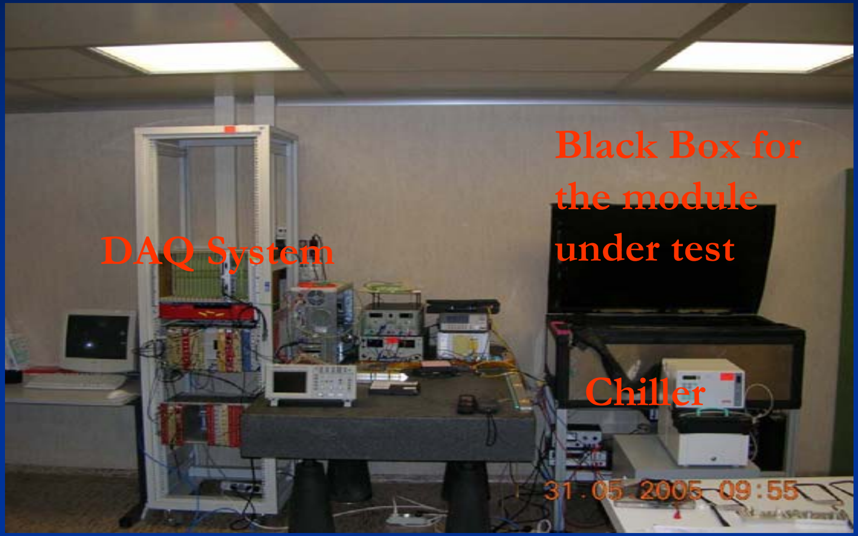
Measured in IRST

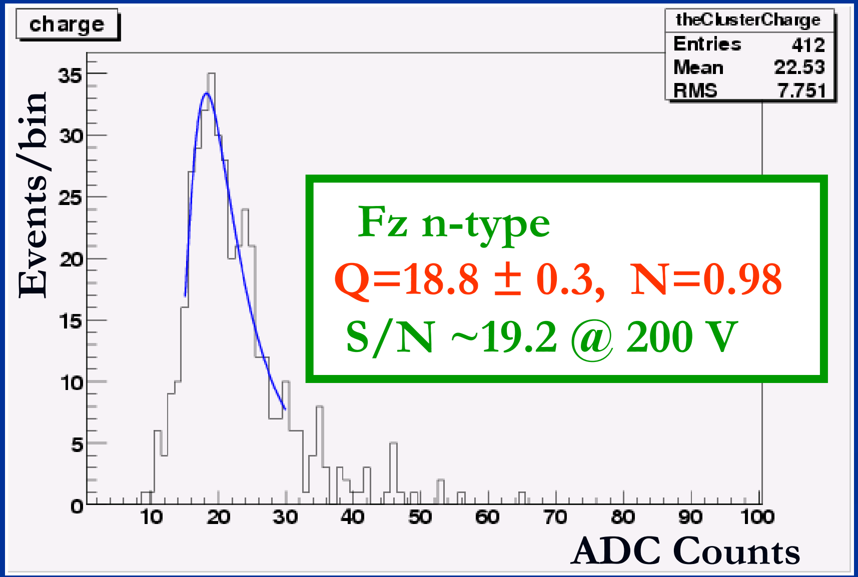
SMART — Measurement with a β source

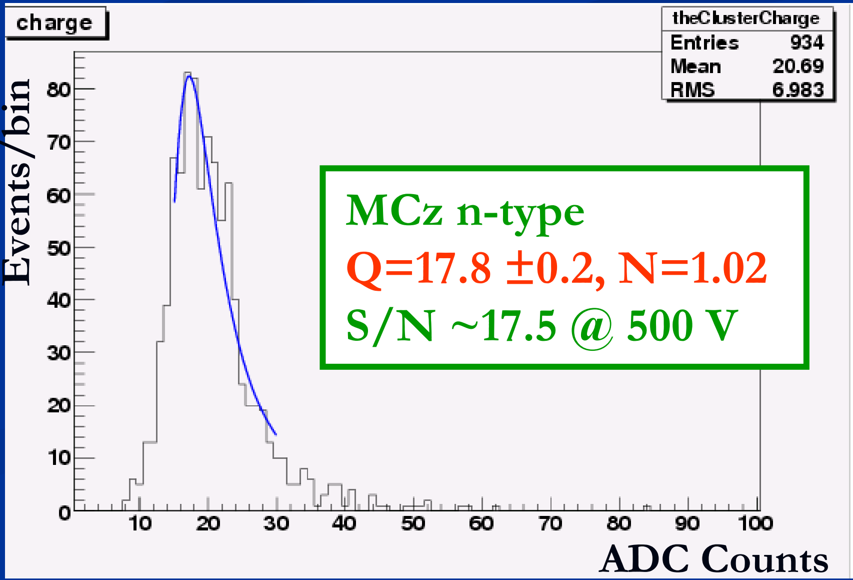
A few mini-sensors have been assembled in a detector unit and tested with a LHC-like DAQ system

Measurement with a β source:

- DAQ system configured in ***peak mode***
- Measurement performed at over-depletion for not-irradiated sensors







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Irradiation Campaigns

October 2004

Irradiation with 24 Gev protons at CERN SPS

3 fluences: 6.0×10^{13} 3.0×10^{14} 3.4×10^{15} 1-MeV n/cm^2

27 mini-sensors, 90 diodes

75 % n-type, 25 % p-type

Thanks to M. Glaser

May 2005

Irradiation with 26 MeV protons at the Cyclotron of the Forschungszentrum Karlsruhe

11 fluences: 1.4×10^{13} - 2.0×10^{15} 1-MeV n/cm^2

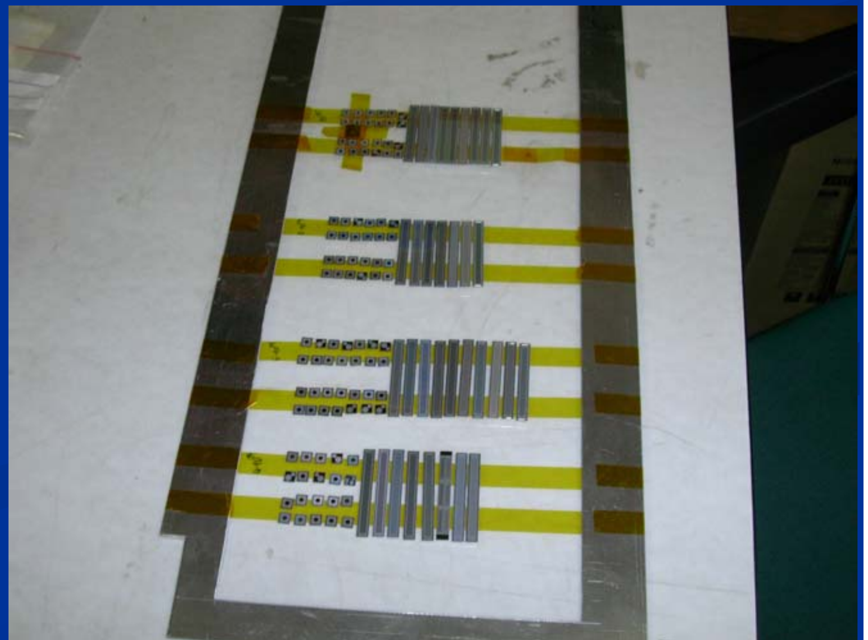
62 mini-sensors, 100 diodes

38 % n-type, 62 % p-type

Thanks to A. Furgeri

Structures of the CERN Irradiation

Structures of the Karlsruhe Irradiation



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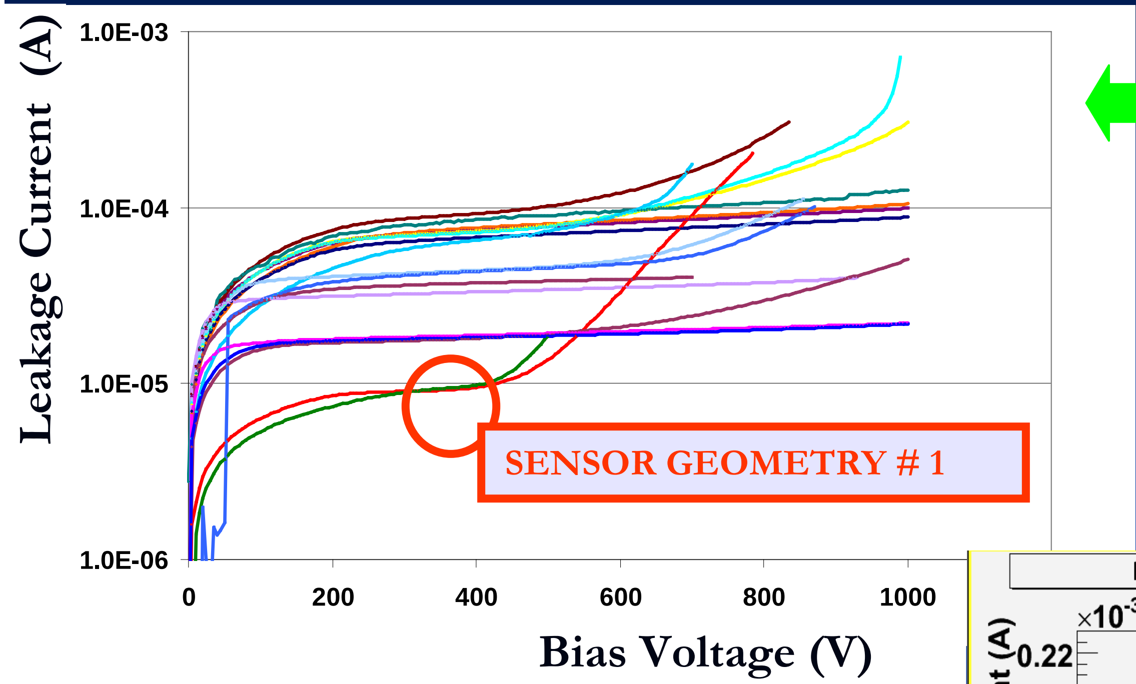
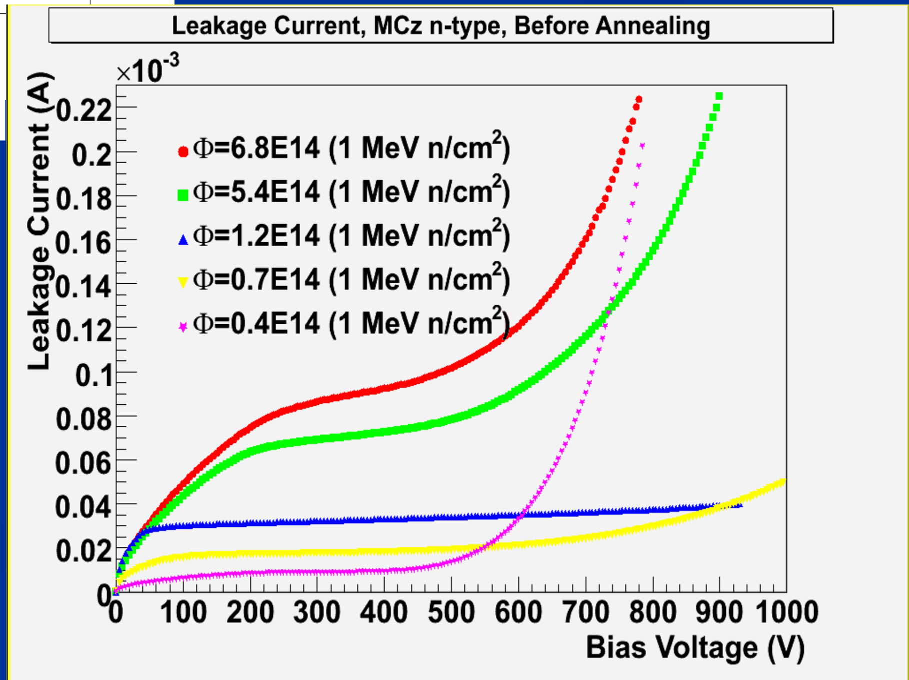
Preliminary Results of Post-Irradiation Measurements

SMART IV Characteristics after irradiation



- IV curves of n- and p-type detectors (low p-spray) in the full fluence range before annealing (measured at 0°C):
- Sensor geometry #1 shows a lower breakdown voltage



<u>In agreement with the NIEL hypothesis:</u>

✓ Current levels in n and p-type MCz detectors are comparable with Fz at a given fluence

✓ Leakage currents measured at Vdepl scale as the received fluences

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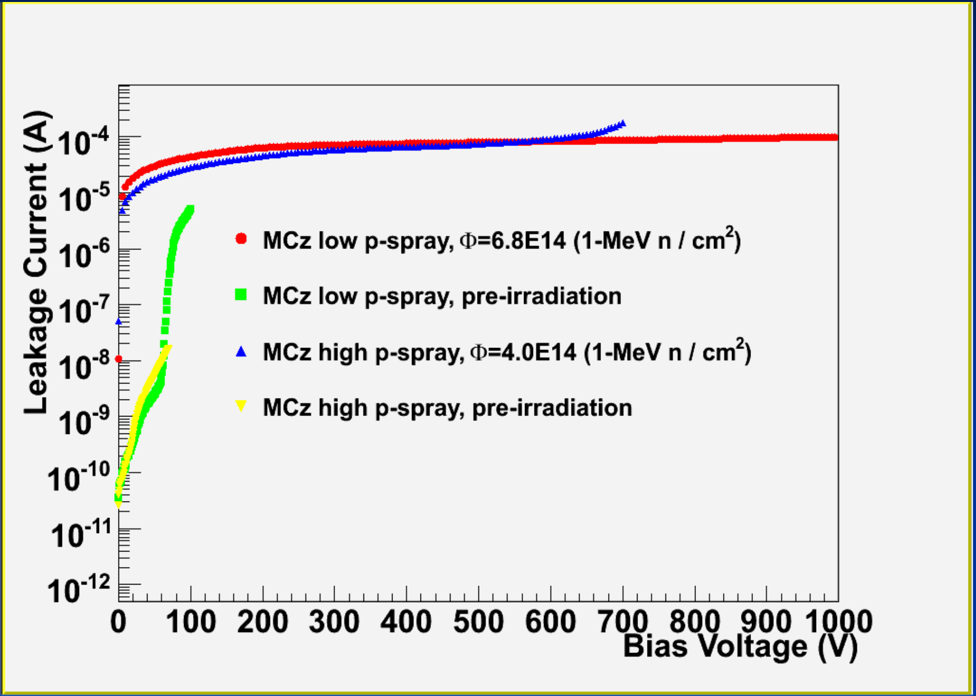
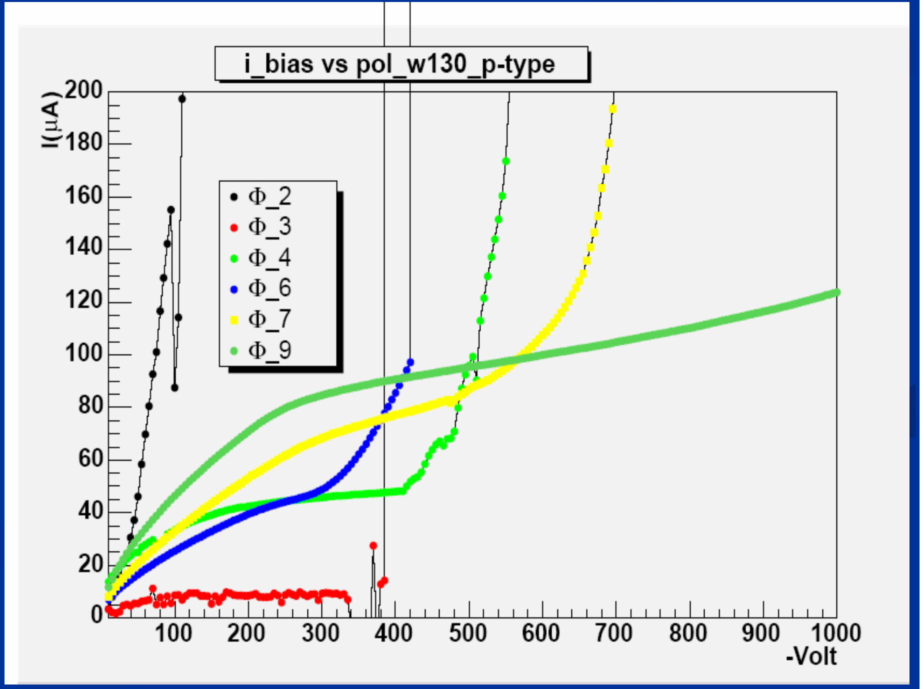
Performances of p-type detectors



The performances of Fz and MCz p-type detectors, comprising sensors with 100 μm pitch, are much improved after irradiation.

Sensors with low p-spray have breakdown voltages comparable with n-type detectors in all the fluence range.



Detectors with a high p-spray dose:

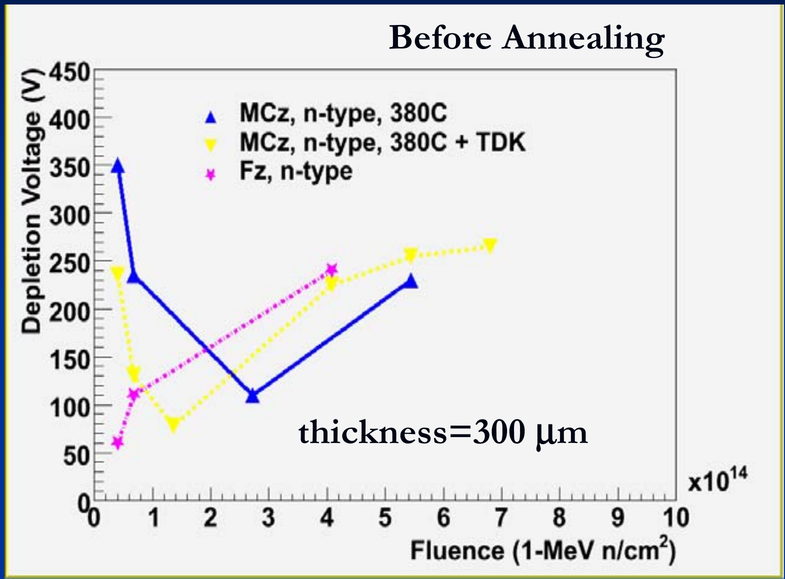
- breakdown problems at lower fluences ($< 4.0 \times 10^{14}$ 1-MeV n/cm^2)
- very good performances at the highest fluences.

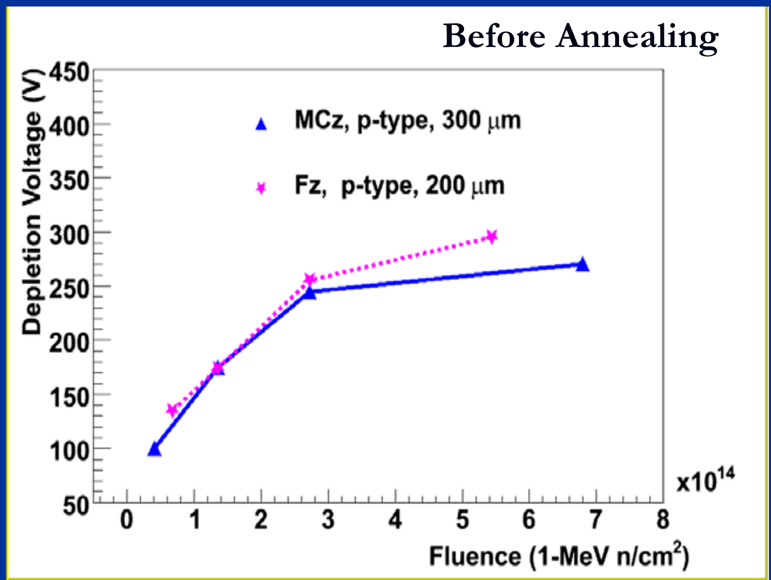
SMART *Depletion Voltages after Irradiation*

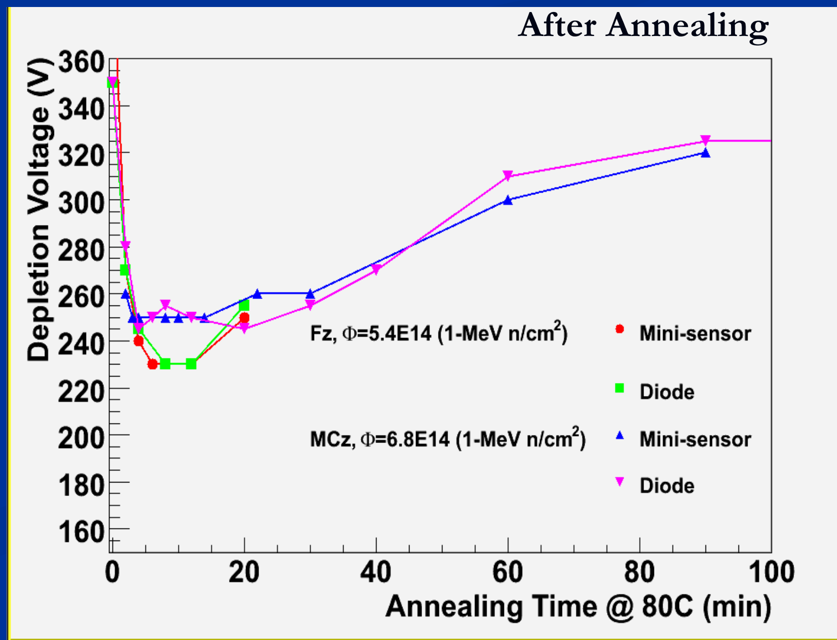
The depletion voltages of the mini-sensors follow the trends expected from the studies on the corresponding diodes.

<u>MCz have better performances than FZ:</u>

- ✓ lower β values both for p- and n-type (especially the samples with TDK)
- ✓ Type-inversion for n-type occurs at higher fluences
- ✓ Improved reverse annealing







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Inter-strip Capacitance after Irradiation

❖ One of the most important sensor parameters contributing to the determination of the S/N ratio.

❖ Depends on the width/pitch ratio of the strips and on the strip isolation technique

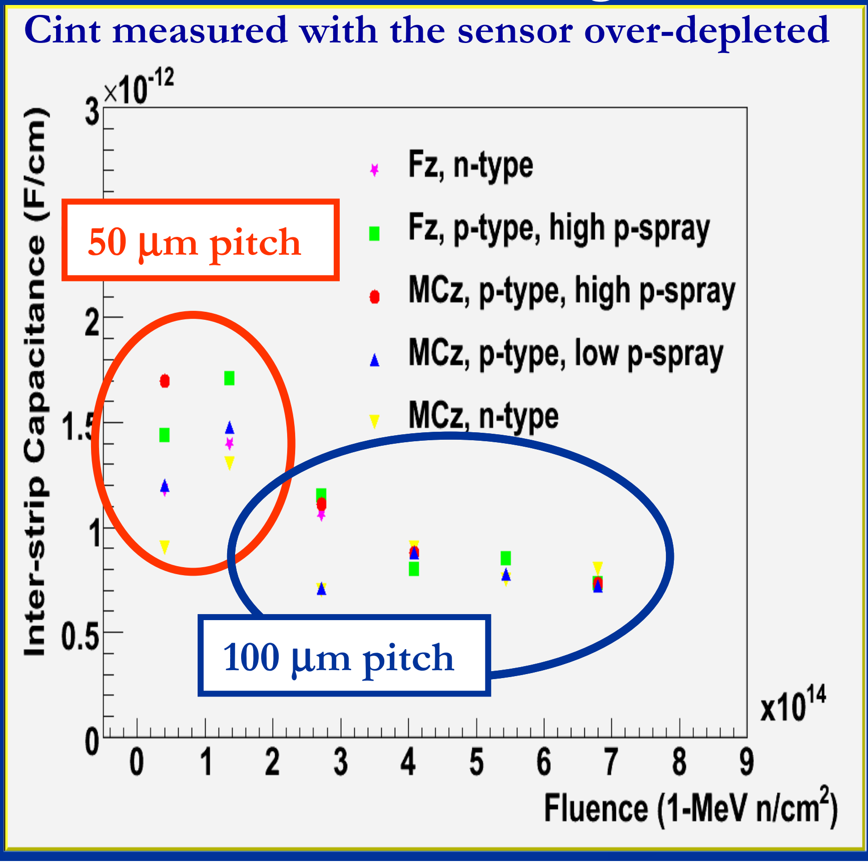
Post-Irradiation Results:

✓Mcz and Fz have comparable C_{int} values

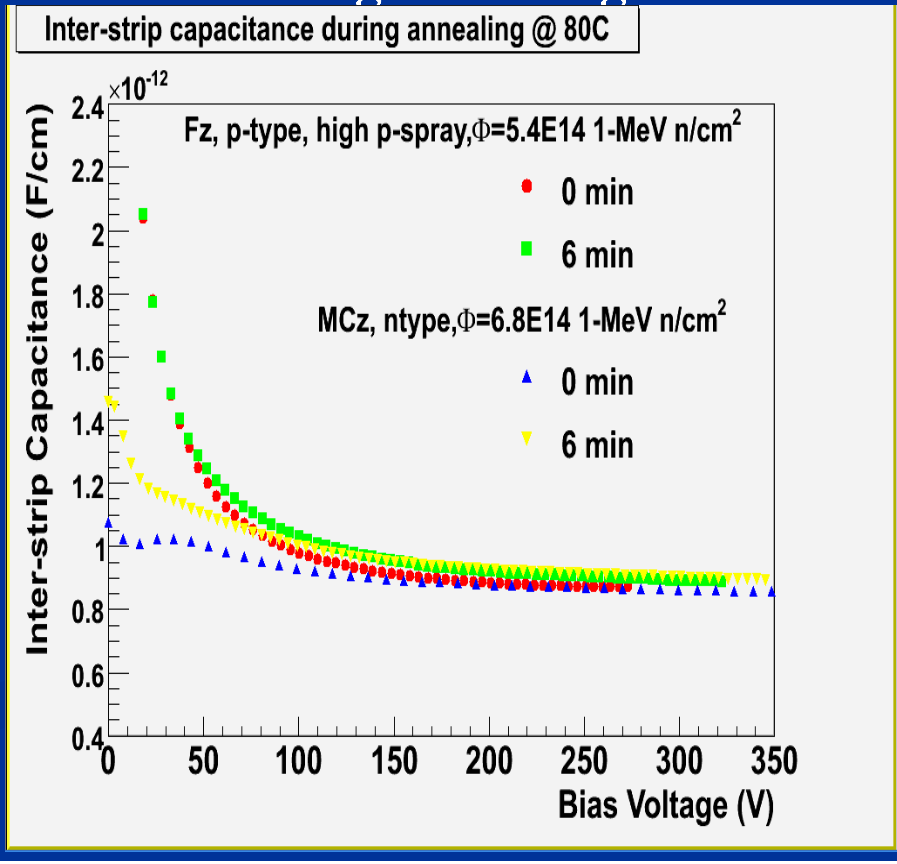
✓ C_{int} in p-type sensors decreases with fluence down to the n-type value.

✓ C_{int} stable during annealing

Before Annealing



During Annealing



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Summary and Outlook

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✓ The MCz micro-strip detectors are promising as a radiation-hard solution for the outer layer of the trackers at SLHC (fluences up to 10^{15}) :

- ✓ After irradiation they are comparable with Fz in the leakage current values, breakdown voltages, inter-strip capacitance.
- ✓ They have a better performance in terms of the depletion voltage.

✓ P-type detectors are more problematic than n-type, before and after irradiation. We need the CCE measurements after irradiation to complete the comparison.

✓A new production run is foreseen to study an improved strip isolation technique for the p-type detectors.