Characterization of n and p-type diodes processed on Fz and MCz silicon after irradiation with 24 GeV/c and 26 MeV protons and with reactor neutrons

The SMART collaboration:

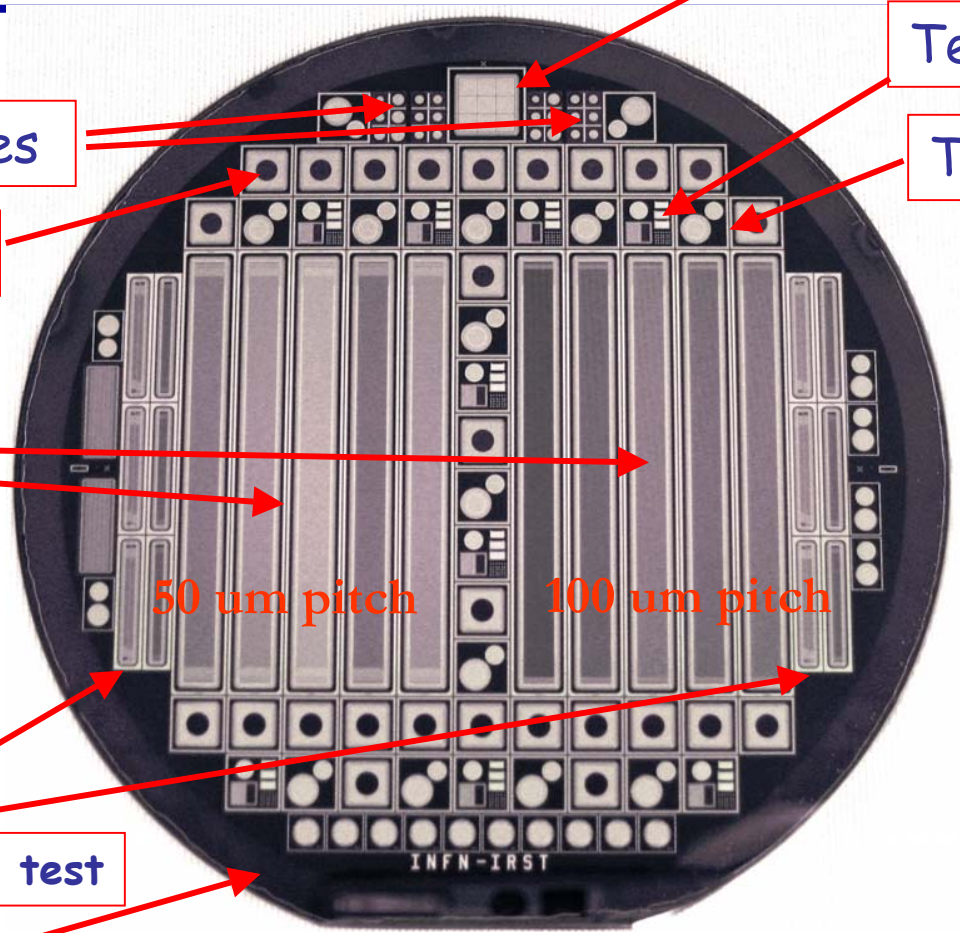
Bari, Firenze, Padova, Perugia, Pisa & Trieste INFN sections

ITC-IRST Trento

6th RD50 - Workshop on Radiation hard semiconductor devices for very high luminosity colliders

Helsinki, 2-4 June, 2005

Wafer layout - SMART



Pad detector

Test2

Test1

Edge structures

Square MG-diodes

Microstrip detectors

Inter strip Capacitance test

Round MG-diodes

RUN I p-on-n

22 wafers Fz, MCz, Cz, Epi

RUN II n-on-p

24 wafers Fz, MCz

Run I: p-on-n batch

Silicon substrates:

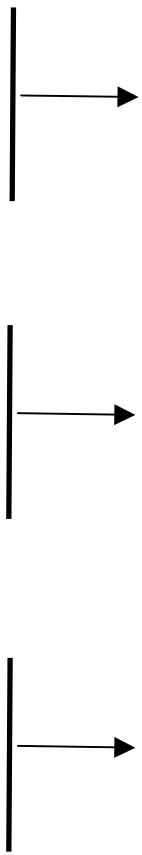
- **Fz** <111> n-type ~6 kW-cm
- **MCz** <100> n-type >500W-cm
- **Cz** <100> n-type >900W-cm
- **Epi** <100> n-type (50 and 75 μm, ITME)

Process splittings:

- STANDARD (LTO as passivation layer, sintering @ 420 °C)
- NO passivation, sintering @ 380°C or @ 350°C

Run II: n-on-p batch

#	sub-type	comments
3	FZ 525	p-spray 3E12
3	FZ 525	p-spray 5E12
3	FZ 200	p-spray 3E12
3	FZ 200	p-spray 5E12
6	MCz	no OG; p-spray 3E12
5	MCz	no OG; p-spray 5E12



FZ <100>
p-type
>5000Ωcm
525μm

FZ <100>
p-type
>5000Ωcm
200μm

MCz <100>
p-type
>1.8kΩcm
300μm

Irradiations

Thanks to Michael and Maurice

Thanks to Alexander and Andreas

24 GeV Protons @ CERN → up to $6*10^{15}$ n/cm^2
26 MeV Protons @ Karlsrhue → up to $3*10^{15}$ n/cm^2
Nuclear Reactor Neutrons @ Lubjana → up to $1*10^{15}$ n/cm^2

Irradiation at CERN:

fluences from $1*10^{14}$ to $5.6*10^{15}$ p cm^{-2}

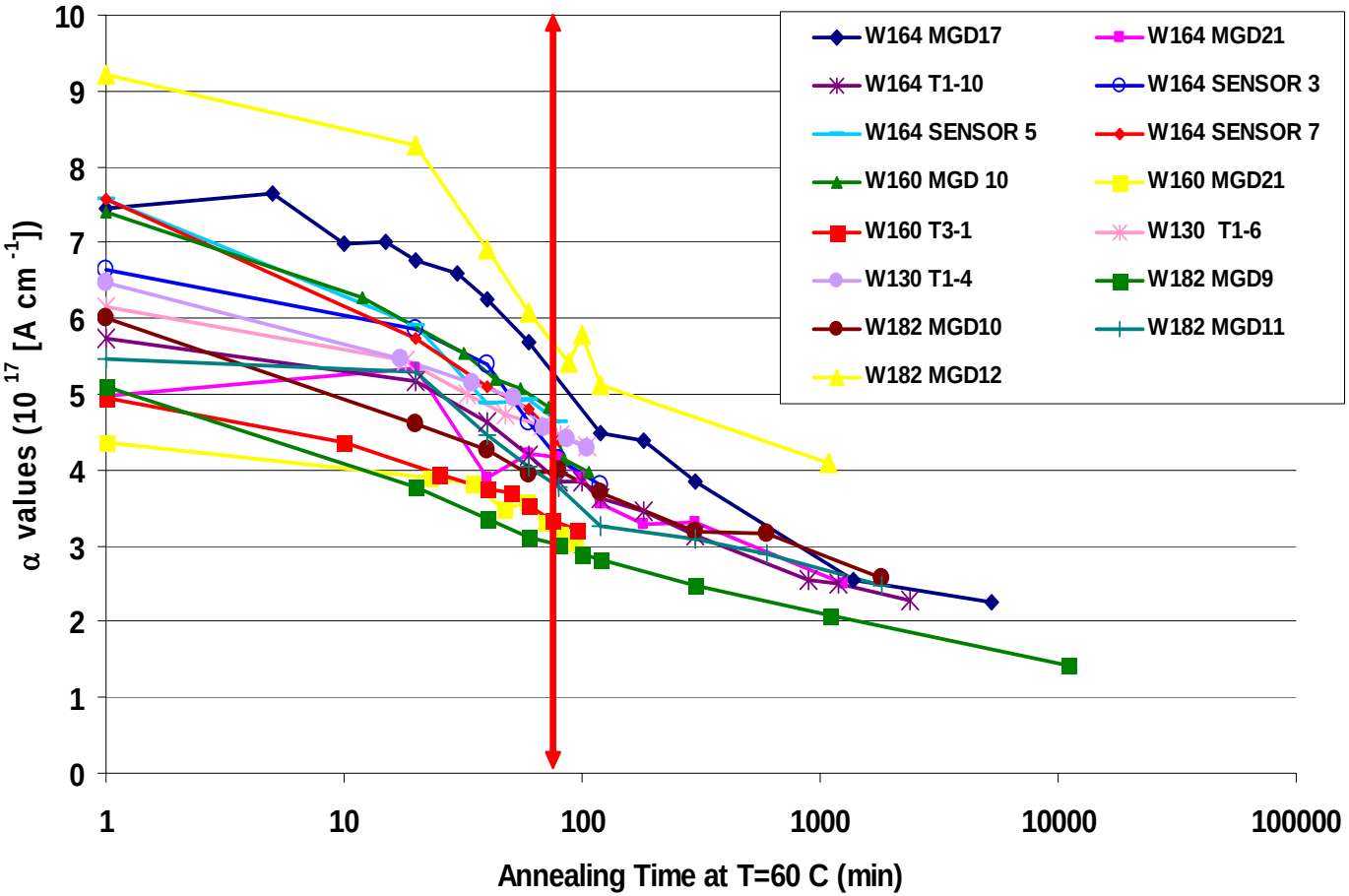
- After irradiation the structures have been kept in the fridge (T< -10 °C) whenever not in use
- A first measurement (IV and CV) has been performed before any annealing
- Two annealing temperatures have been used for these structures: **60°C and 80°C**
- After each annealing step the following measurements have been performed:

  I-V curves at T=20°C or at 0°C

  C-V curve at T=0°C and f=10 KHz

- Alpha parameter calculated with currents at depletion voltage + 50 V, at T = 20°C (or with currents at T = 0°C normalized to T = 20°C),after 8 minutes at $T_{annealing}$= 80°C or 80 minutes at $T_{annealing}$= 60°C
- Neff dependence on fluence calculated after full benefical annealing

Parameter α - MCz p and n-type



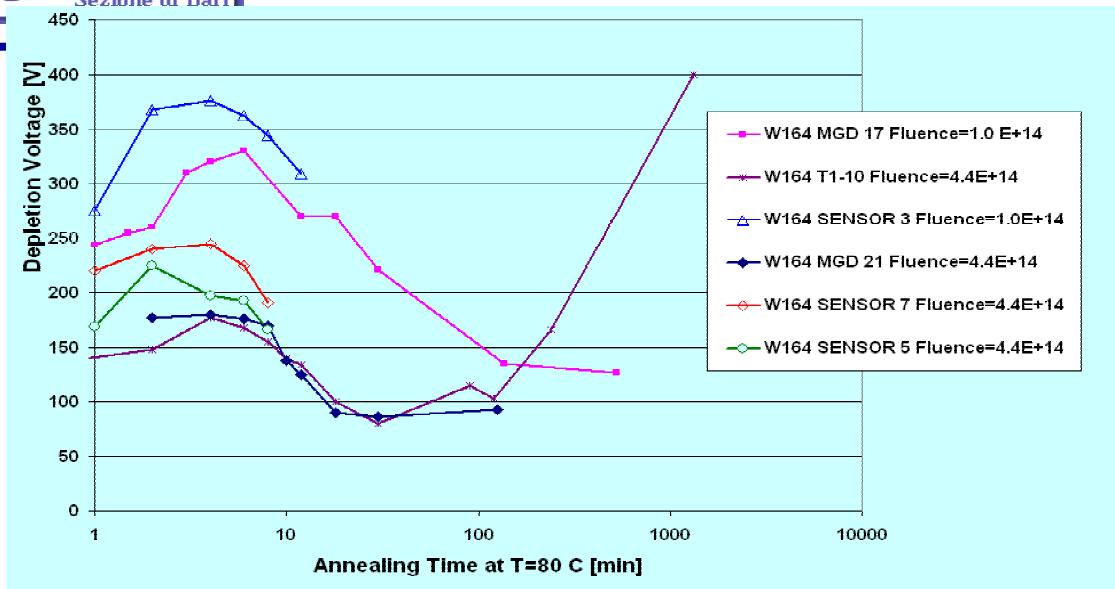
Average MCz p-on-n:

4.37E-17 A/cm

Average MCz n-on-p:

4.16E-17 A/cm

Annealing studies (Vdepl) MCz n-type



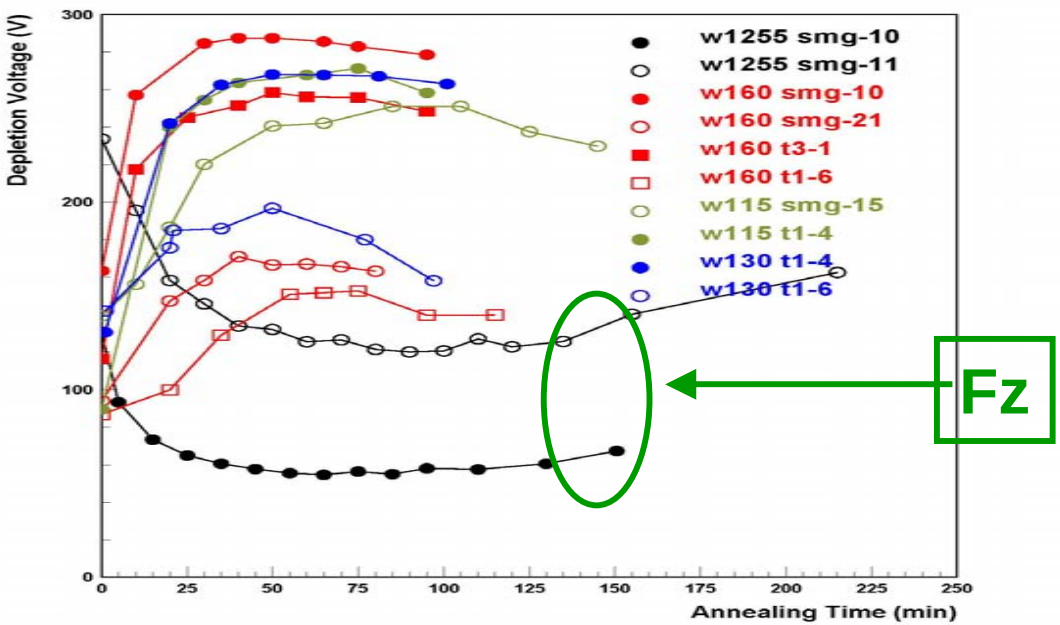
W164 MCz n-type

Annealing at T=80°C

No inversion up to

4.4 10^{+14} p cm^{-2}

(2.7 10^{+14} n cm^{-2})



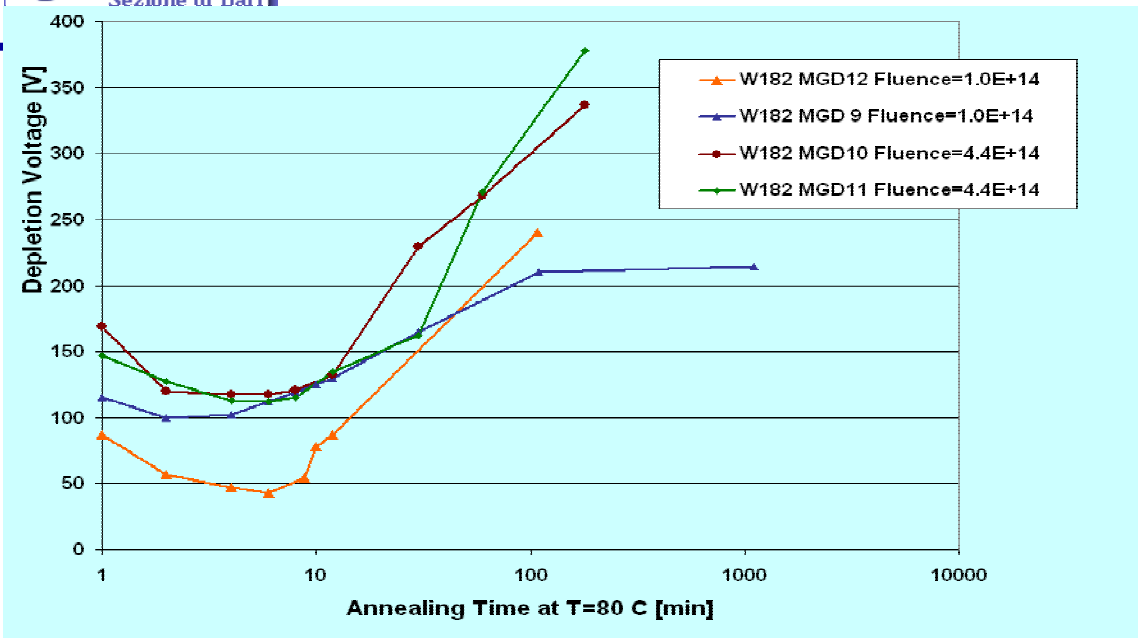
Fz and MCz n-type

Annealing at T= 60°C

● = 1.0 10^{+14} p cm^{-2}

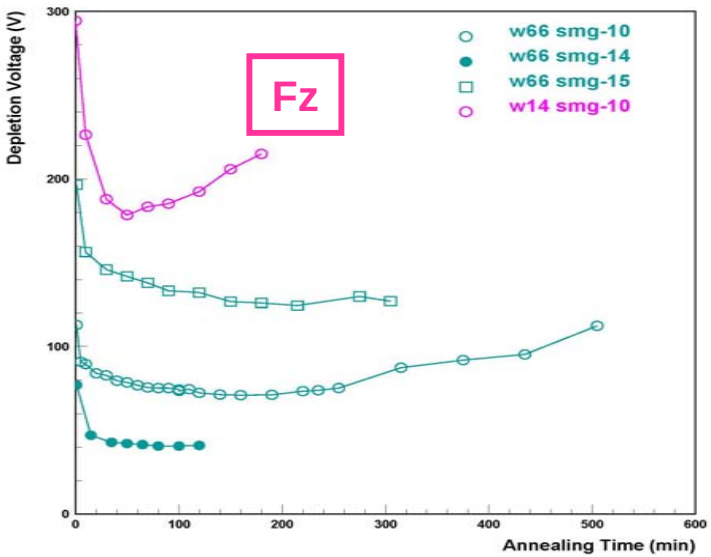
○ = 4.4 10^{+14} p cm^{-2}

Annealing studies (Vdepl) MCz and Fz p-type



W182 MCz p-type

Annealing at T=80°C



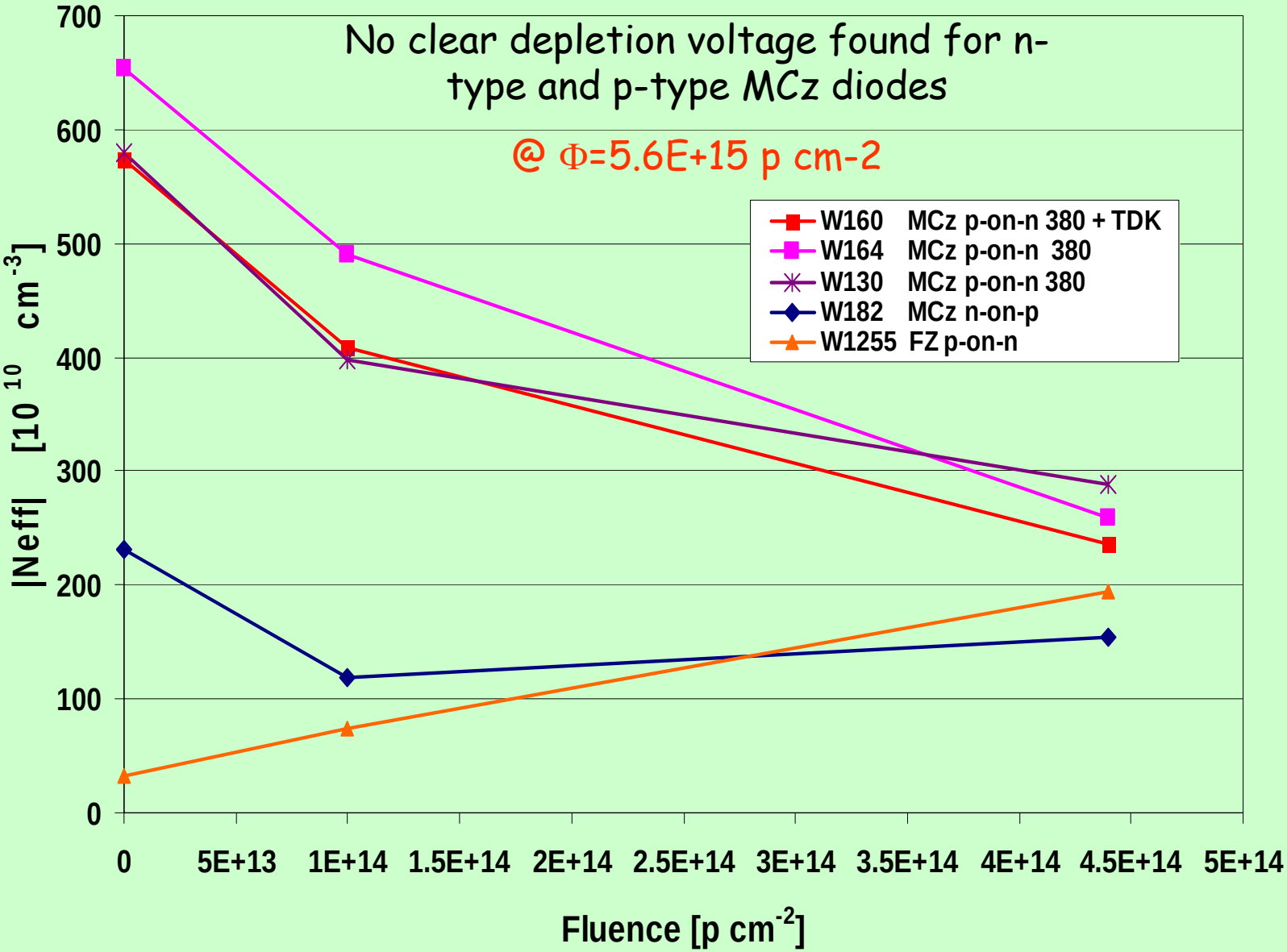
Fz and MCz p-type

Annealing at T= 60°C

● = 1.0 E+14 p cm^{-2}

○ = 4.4 E+14 p cm^{-2}

Neff variation with fluence



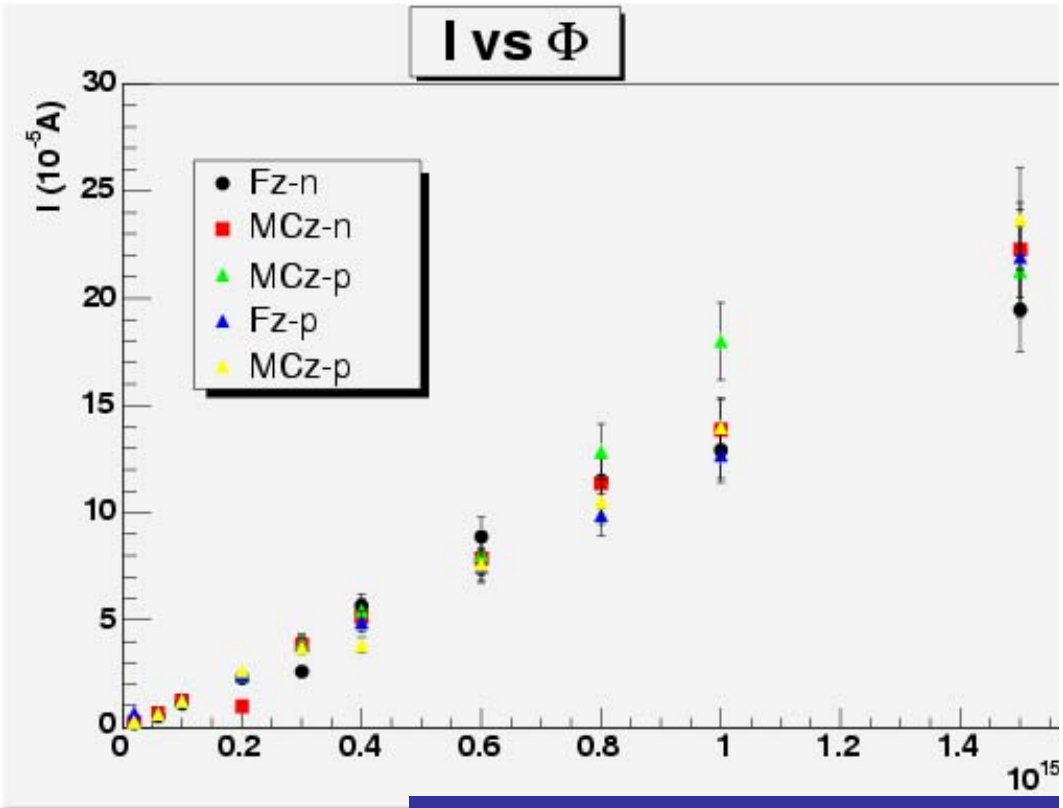
Irradiation at Karlsruhe:

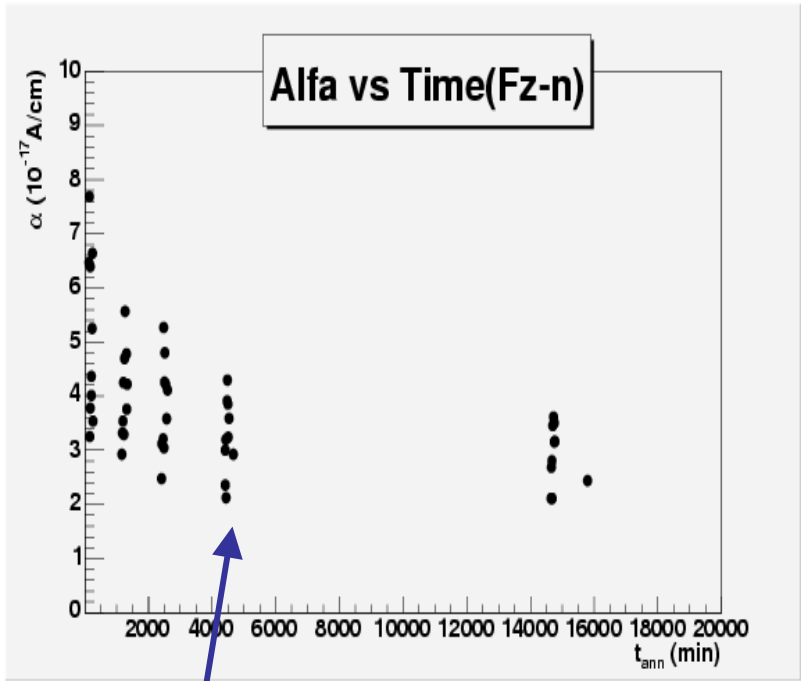
fluences from $2*10^{13}$ to $3*10^{15}$ 1MeV eq n cm^{-2}

- Karl-Suss Probe-Station instrumented
- LCR Meter HP4284A with a frequency range from 20 Hz to 1 MHz
- HP4241B Voltage Source up to 1000 V + Pico-amperometer

- The structures have been kept in the fridge whenever not in use
- A first measurement (IV and CV) has been performed before any annealing
- The annealing performed at room temperature
- After each annealing step the following measurements have been performed:
  - I-V curves @ T~22°C
  - CV curve @ T~22°C and f=10 KHz – 100 KHz
- Alpha parameter calculated with currents at depletion voltage, at T=21°C, during the annealing
- Neff (Vdep) dependence on fluence and annealing Time → study of SCSI

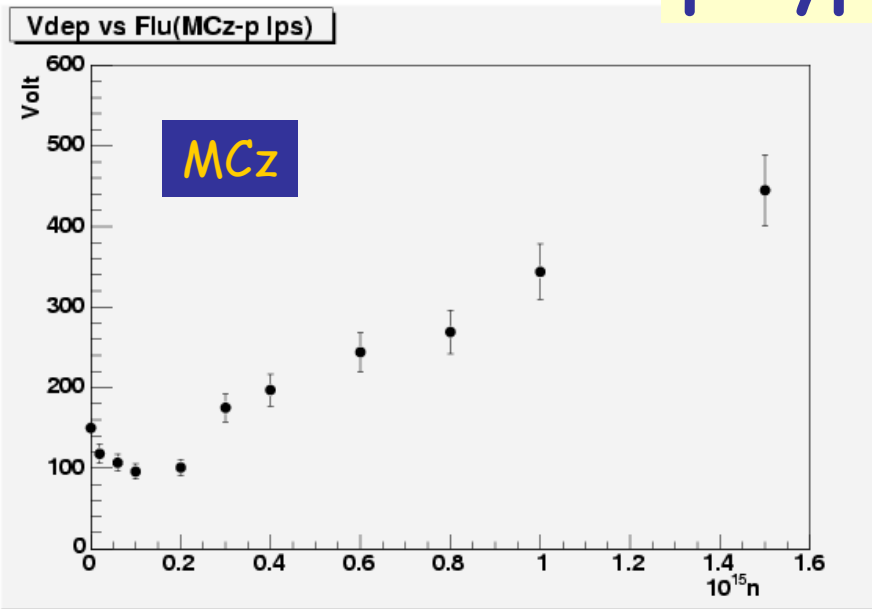
Current Variation with fluence -> α

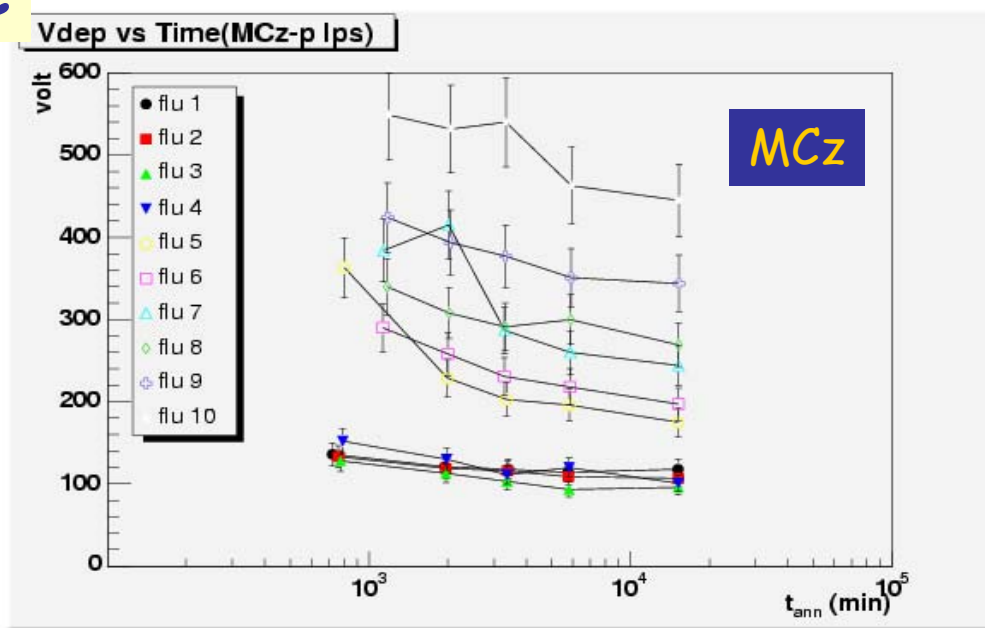


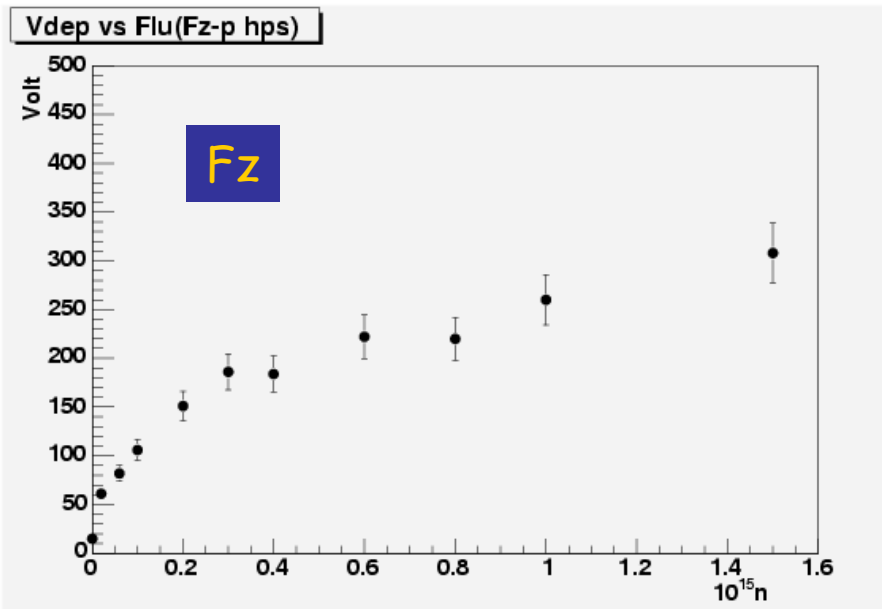


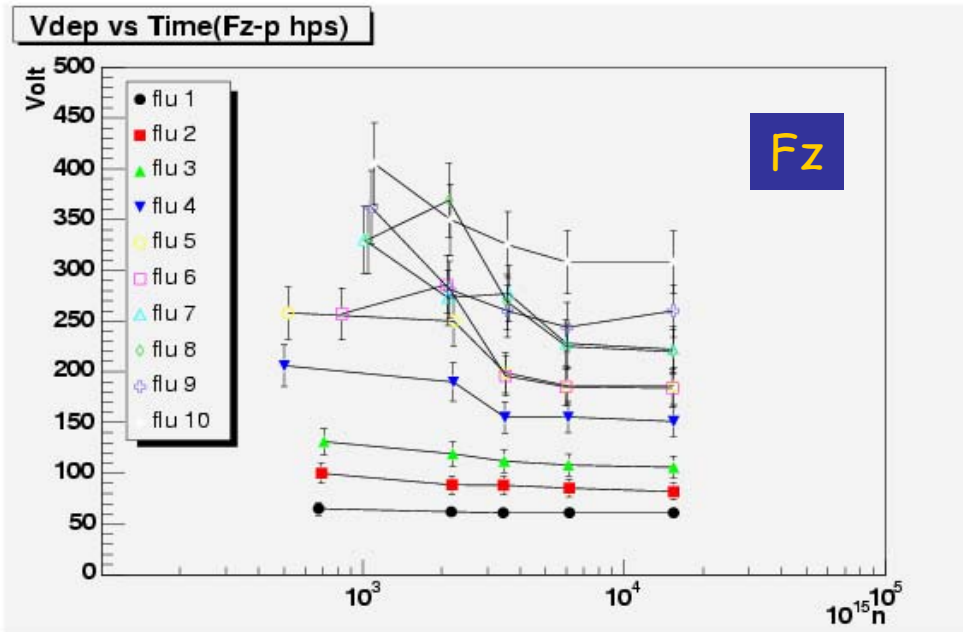
$\alpha \sim 3{,}6\ 10^{-17}\ Acm^{-1}$ @ t_{ann} = 4500 min at room temp.

p type

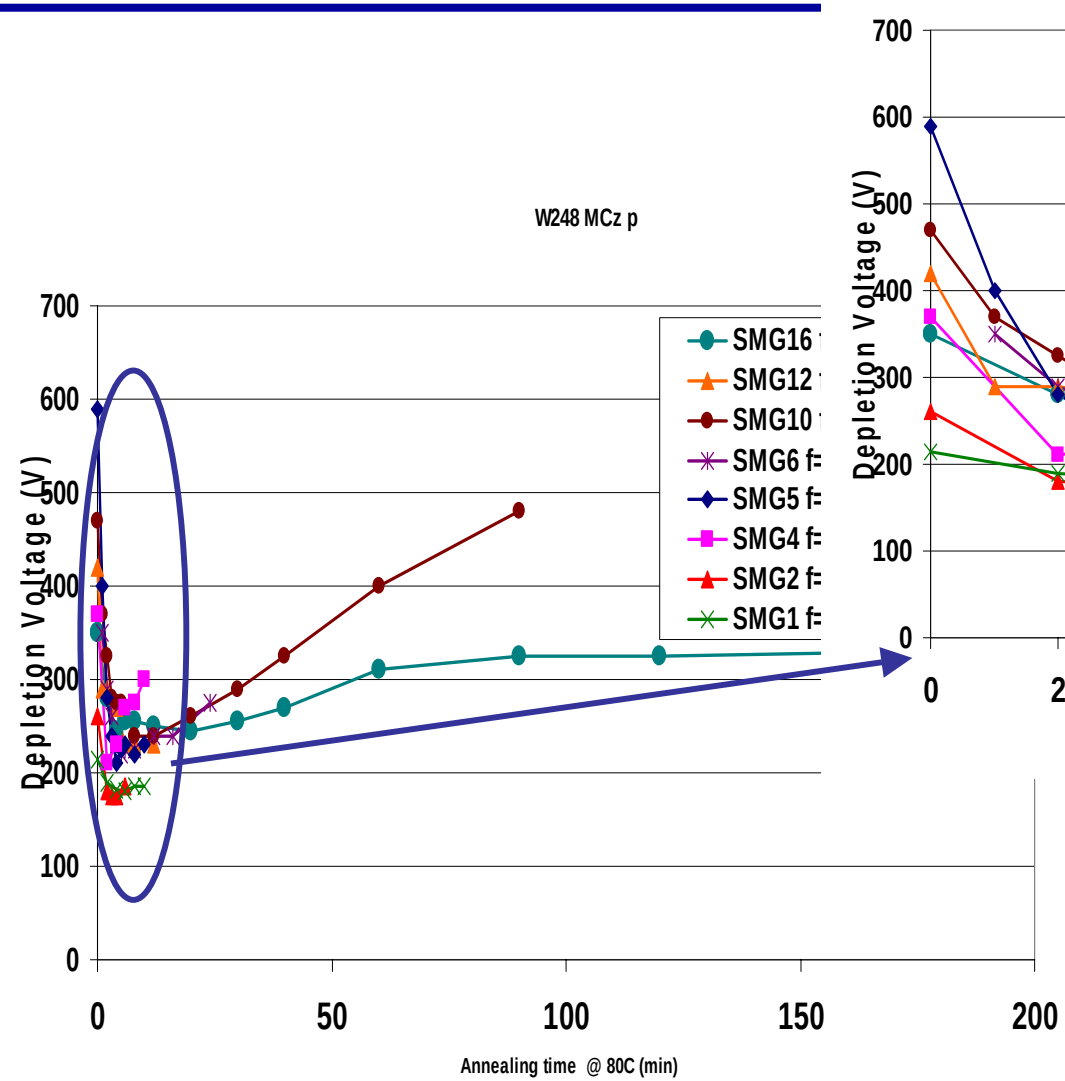

Vdep vs Flu(MCz-p Ips)
Volt
MCz
10^{15}n

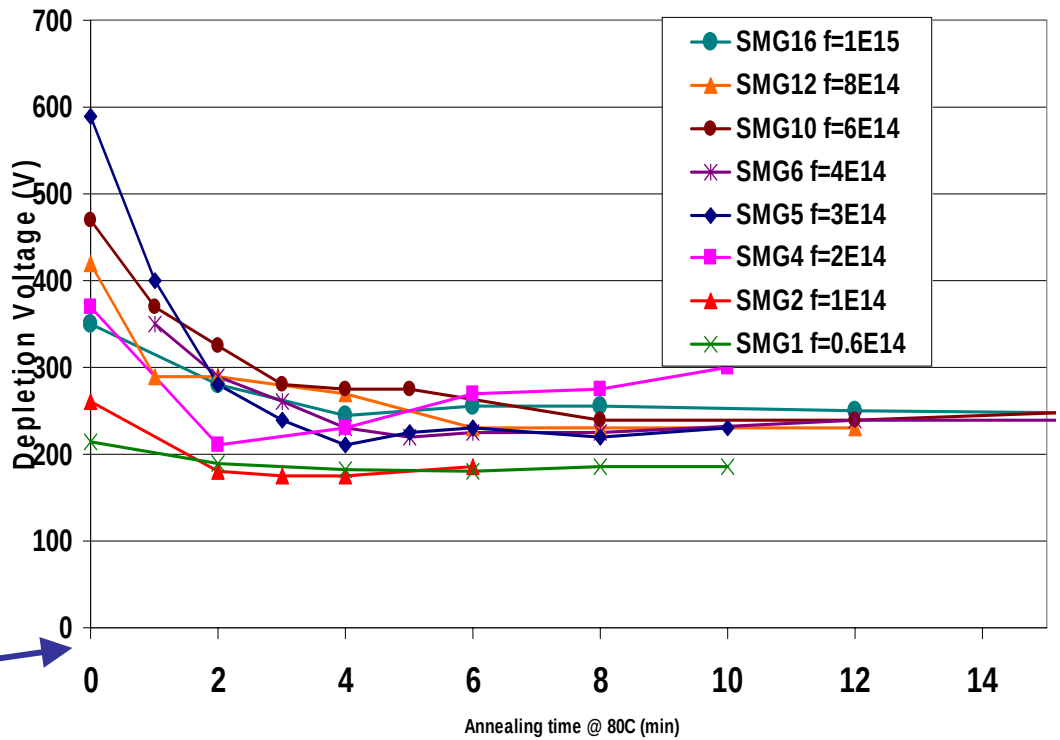

Vdep vs Time(MCz-p Ips)
volt
flu 1
flu 2
flu 3
flu 4
flu 5
flu 6
flu 7
flu 8
flu 9
flu 10
MCz
t_{ann} (min)


Vdep vs Flu(Fz-p hps)
Volt
Fz
10^{15}n

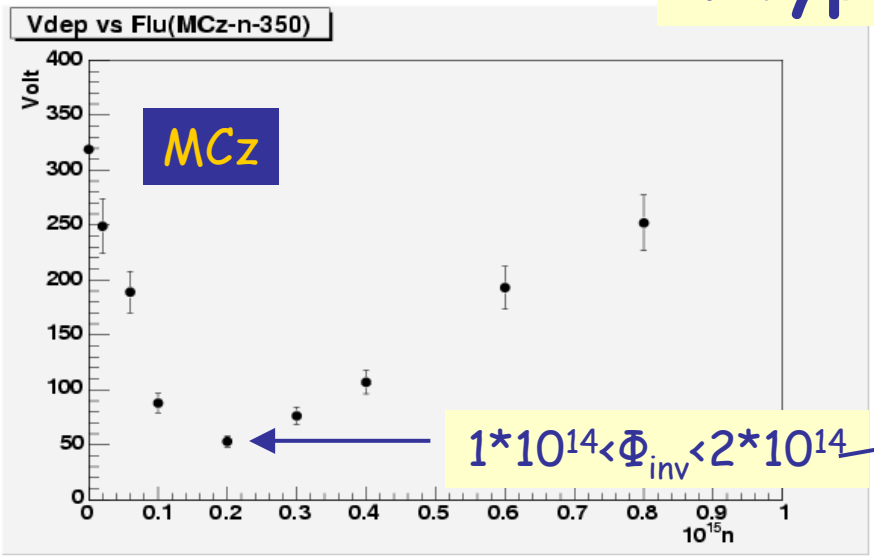

Vdep vs Time(Fz-p hps)
Volt
flu 1
flu 2
flu 3
flu 4
flu 5
flu 6
flu 7
flu 8
flu 9
flu 10
Fz
10^{15}n

MCz p type - annealing @ 80°C

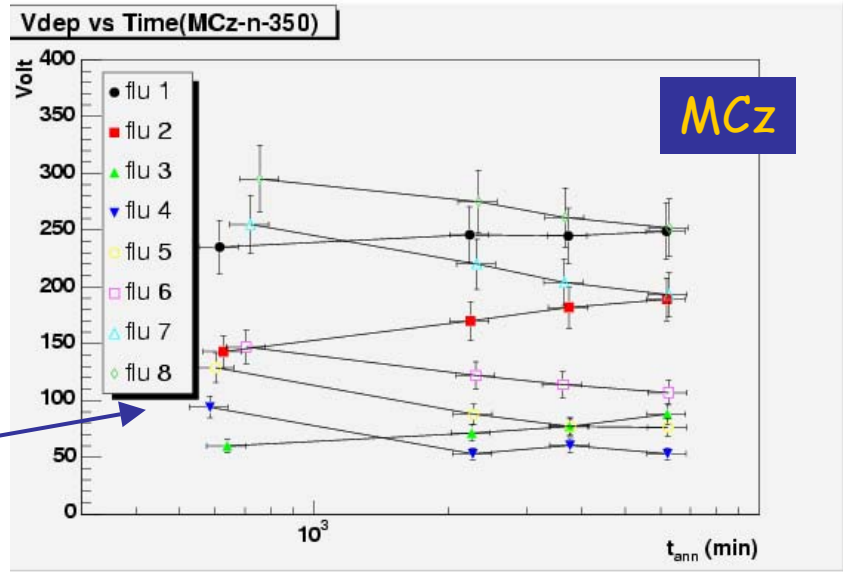


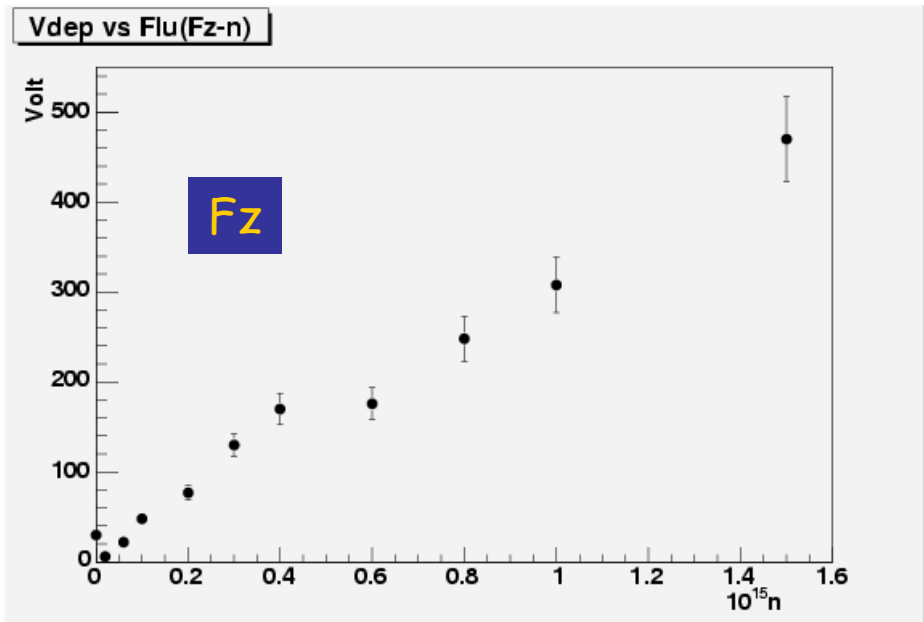


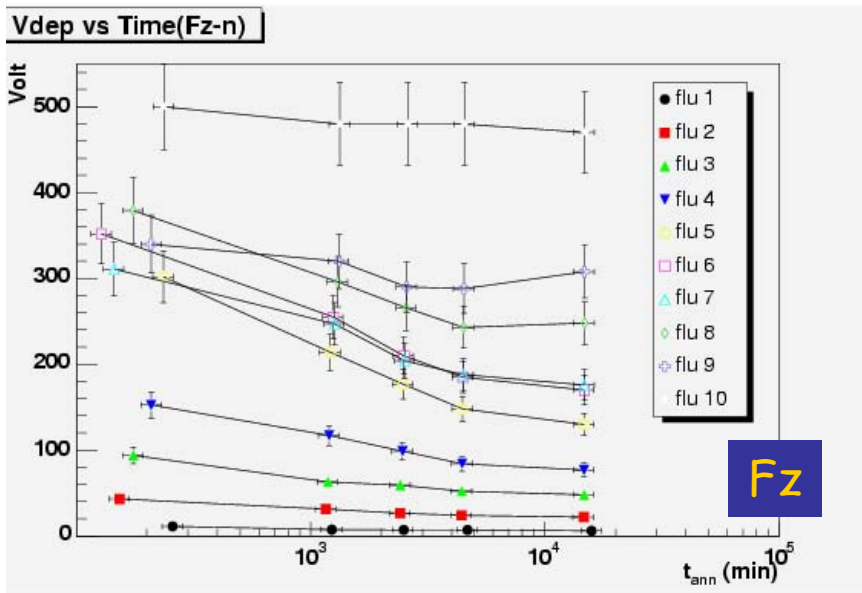
n type



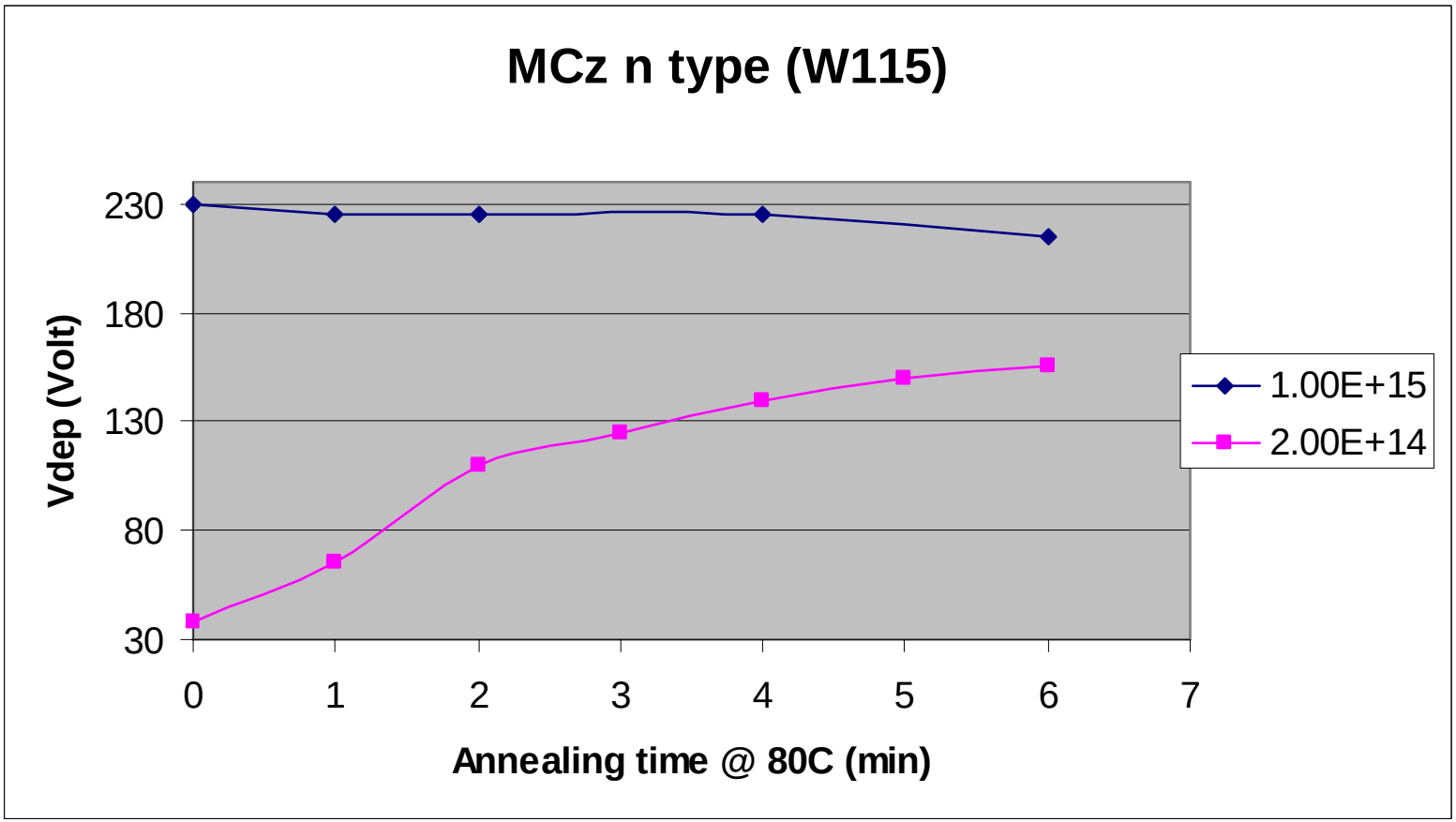
$1*10^{14}<\Phi_{inv}<2*10^{14}$







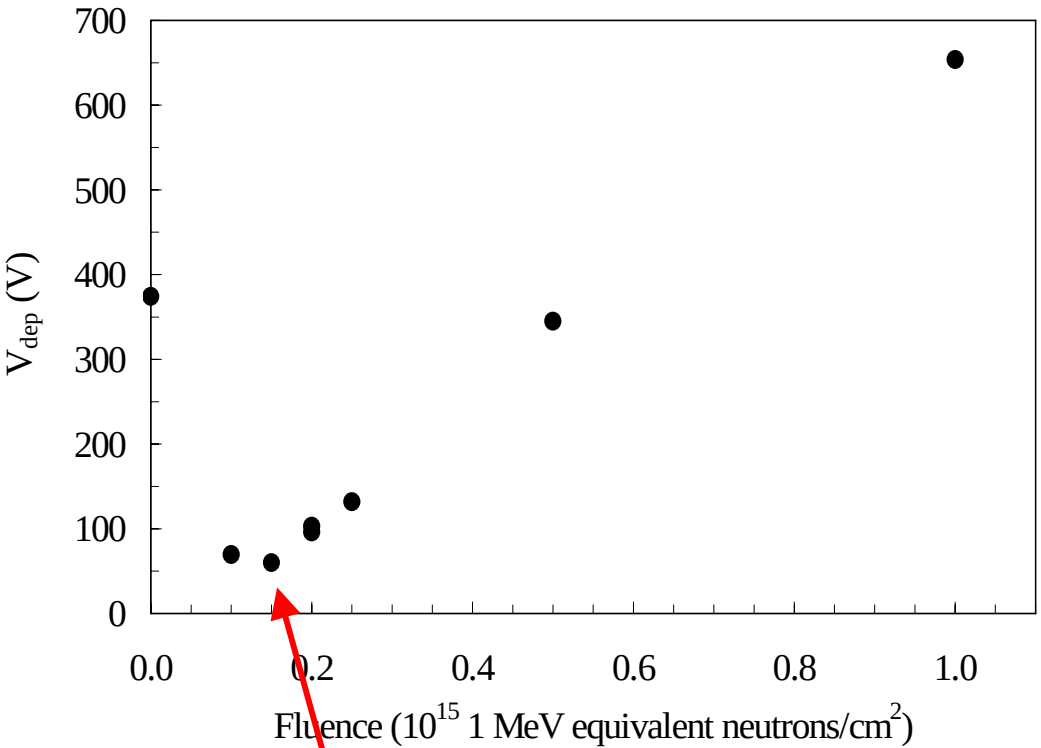
MCz n type – annealing @ 80°C



Still not inverted @ $2*10^{14}$ ncm^{-2}

Irradiation at Lubjana:

fluences up to 1*1015 1MeV eq n cm-2



MCZ n-type 300 μm thick

ρ= 0.6 kΩ×cm

neutron irradiation

"Inversion Fluence" < $2*10^{14}$ ncm^{-2}

β~$12*10^{-3}cm^{-1}$

to be checked with Annealing curves

MCz n: Conclusions (preliminary)

MCz n (Wafer #)	Vfd before irr (Volt)	Φinv (10^{14}ncm^{-2})
179	319	~ 2 (26 MeV p)
127	323	~ 2 (26 MeV p)
132	380	~ 1.5 (reactor n)(*)
91	520	~ 3 (26 MeV p)
115	540	>2 (26 MeV p) >2,6 (24 Gev p)

- 24 GeV p → no inversion up to $2.7*10^{14}$ ncm^{-2}
- 26 MeV p → inversion @ $2\div3*10^{14}$ ncm^{-2} depending on initial resistivity
- Neutrons → "inversion(*)" < $2*10^{14}$ ncm^{-2} (to be checked by means of the annealing studies)

Conclusions (preliminary)

MCz p

- Not very uniform dependence of Vdep with fluence
- 24 GeV p → milder annealing dependence with respect to Fz
- 26 MeV p → annealing studies are under way

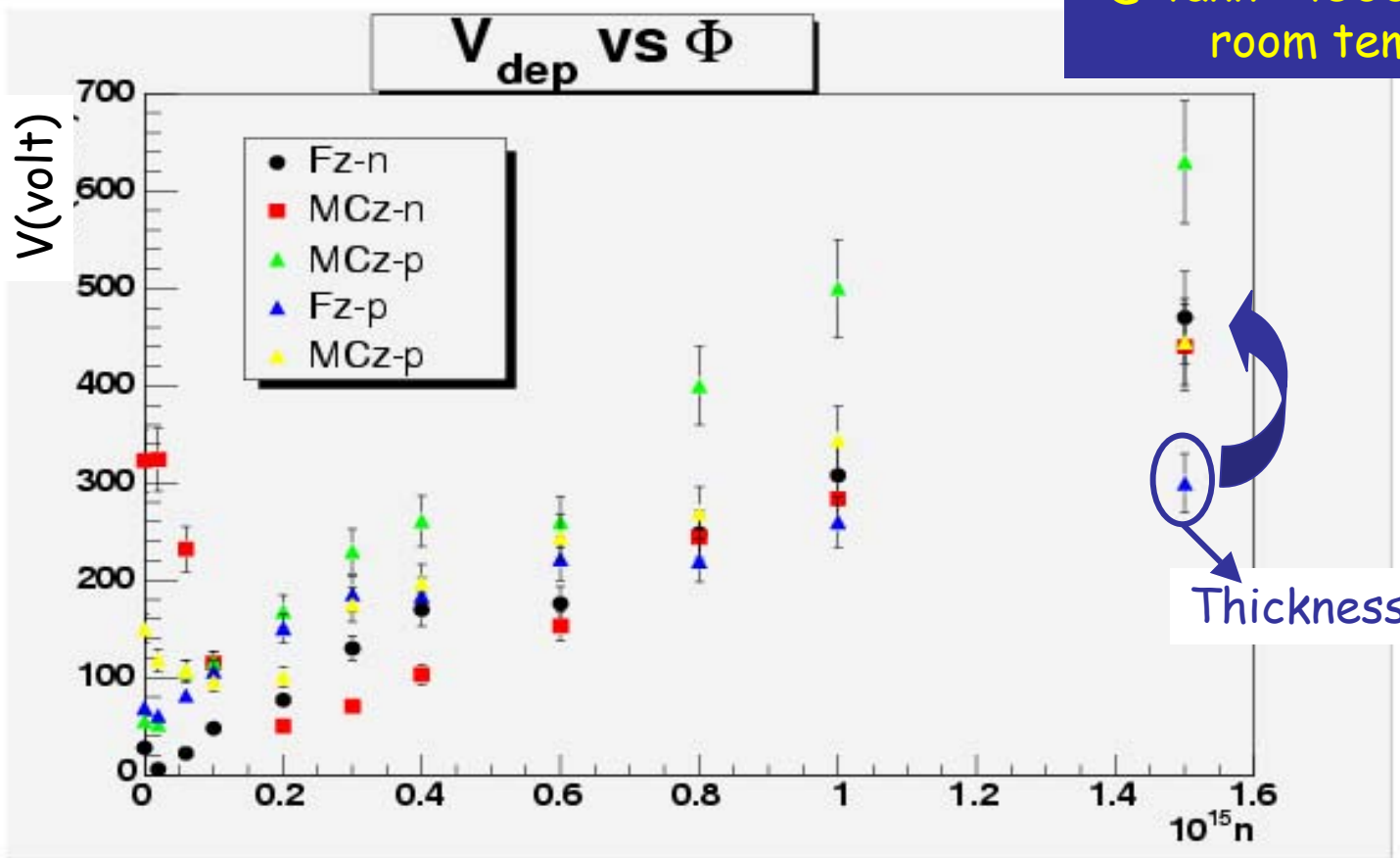
Hundreds of irradiated diodes and sensors presently under measurement: big amount of work still to be done!

More detailed analysis is needed !


SARDUS

Vdep VS Fluence

@ tann= 4500 min at room temp.



Thickness 200 μm !

Material under investigation

· W1253 FZ	Standard		p-on-n
· W127	MCz tdk		p-on-n
· W91	MCz	no LTO, sintering @ 380°C	p-on-n
· W179	MCz	no LTO, sintering @ 350°C	p-on-n

· W64	FZ200 Std	5E12 p spray dose	n-on-p
· W9	MCz sintering ?	3E12 p spray dose	n-on-p
· W130	MCz sintering ?	5E12 p spray dose	n-on-p

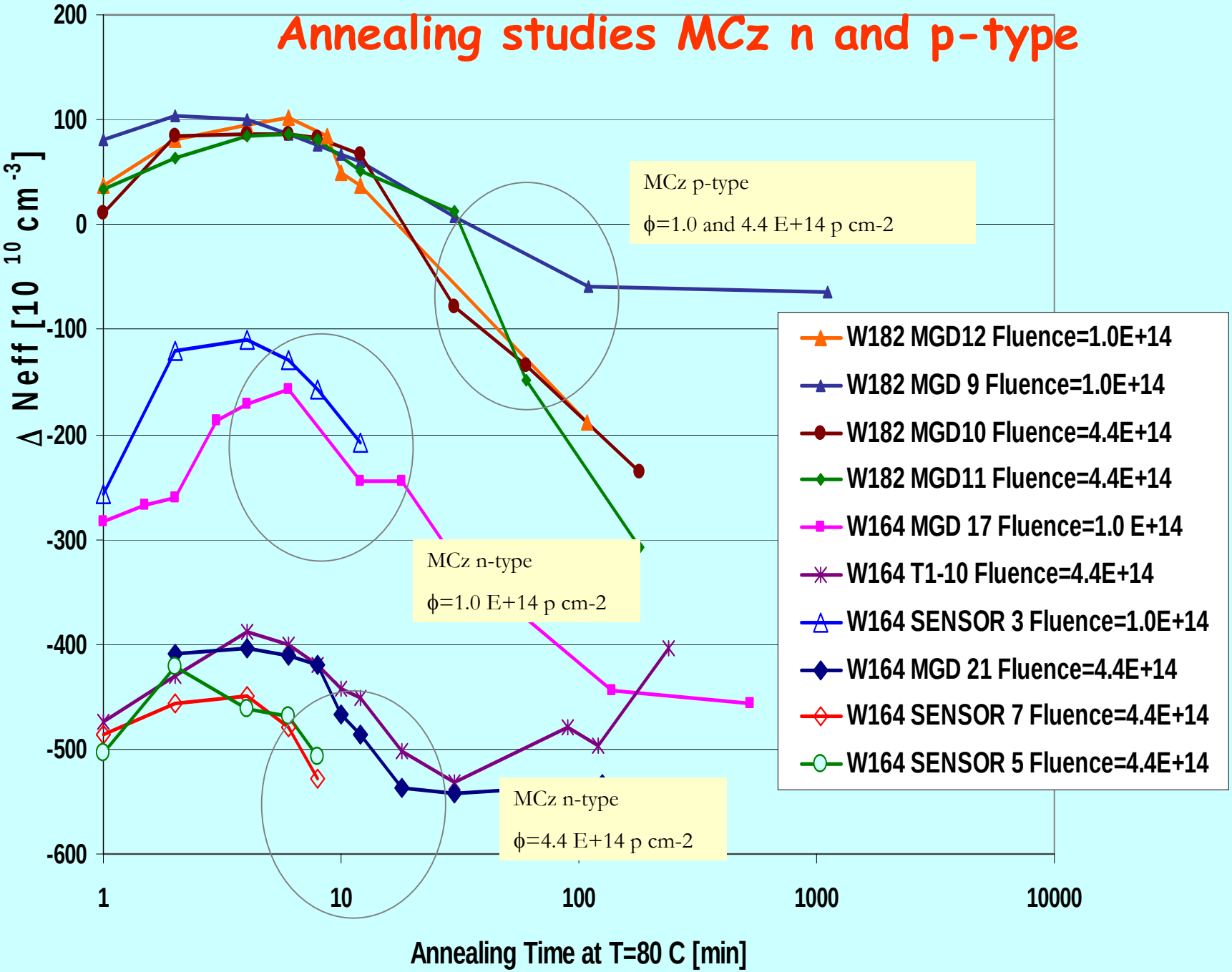
- Alta corr.
- Molti punt
- Studio piu dettagl. andamenti
- Experimental set-up

Overview irr at CERN:

fluences from 1.0 E+14 to 5.6 E+15 p cm^{-2}

- Pre-irradiation measurements
- Irradiation fluences and layout
- Experimental set-up
- Results on diodes for n and p-type MCz and Fz at ϕ = 1.0 and 4.4 E+14 p cm^{-2}
- Results at ϕ = 5.5 E+15 p cm^{-2}

Annealing studies MCz n and p-type



Material under investigation

- **p-on-n MCz <100> ρ > 500 Ω cm**

standard process	W364
no LTO, sintering @ 380 °C	W115,W130,W164
no LTO, sintering @ 380 °C + TD killing	W160

- **n-on-p MCz, no OG <100> ρ > 1.8 KΩ cm**

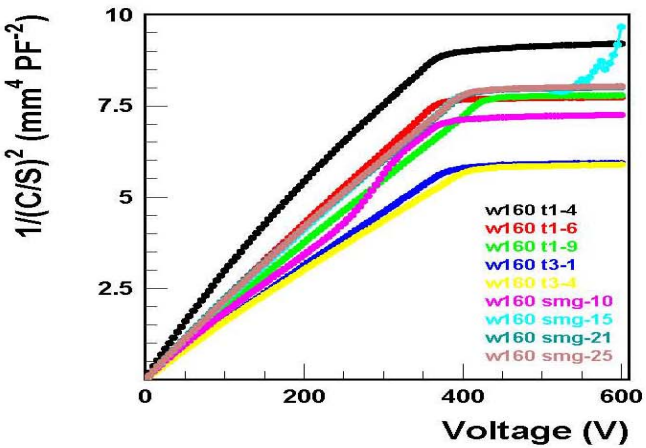
low dose p-spray 3E+12 cm^{-2}	W66
high-dose p-spray 5E+12 cm^{-2}	W182

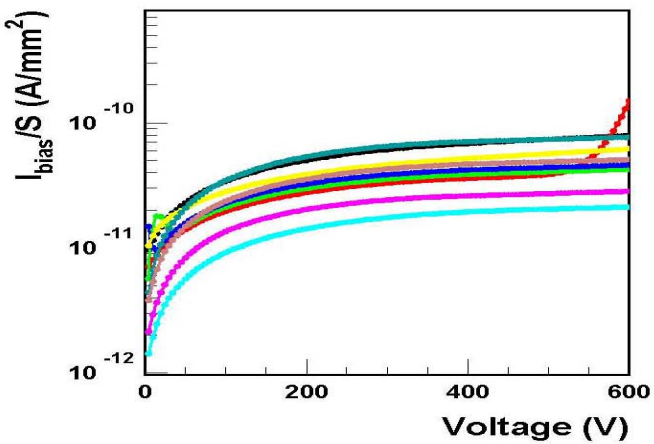
- **Fz reference samples**

n-type <111>	W1254 (std) , W1255 (T=380 C)
p-type (passivated)	W14 (low dose p-spray), W37 (high dose p-spray)

Pre-irradiation measurements

MCz *n-type* W160





MCz *p-type* W66