New results on standard diodes irradiated with 34 MeV proton beam.

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Outline

- Structures description;
- irradiation conditions;
- measurements of diode leakage current → k factor estimation;
- measurements of depletion voltage as a function of fluence and annealing time → annealing parameters;
- k factor estimation from bias leakage current of a microstrip detector;
- conclusions

Structures description

Characterisation before and after irradiation of:

- Diodes: p+/n
  0.24*0.24 cm^2

- Baby detectors: 300 µm thick (n)
  128 strips p+
  3.22 cm long
  14 µm wide
  61 µm pitch

Built on two different kind of standard substrates:

- Low resistivity: 1.5 -2 KOcm
  Crystal orientation <100>

LR <100>

- High resistivity : 6 -10 KOcm
  Crystal orientation <111>

HR <111>

Irradiation conditions

The irradiation with **34 MeV protons**, up to 10^{14} pcm^{-2}, was performed at the Cyclotron of the Research Centre of Karlsruhe **FZK** (Germany)

Diodes were also irradiated with **protons of p = 24 GeV/c** at CERN.

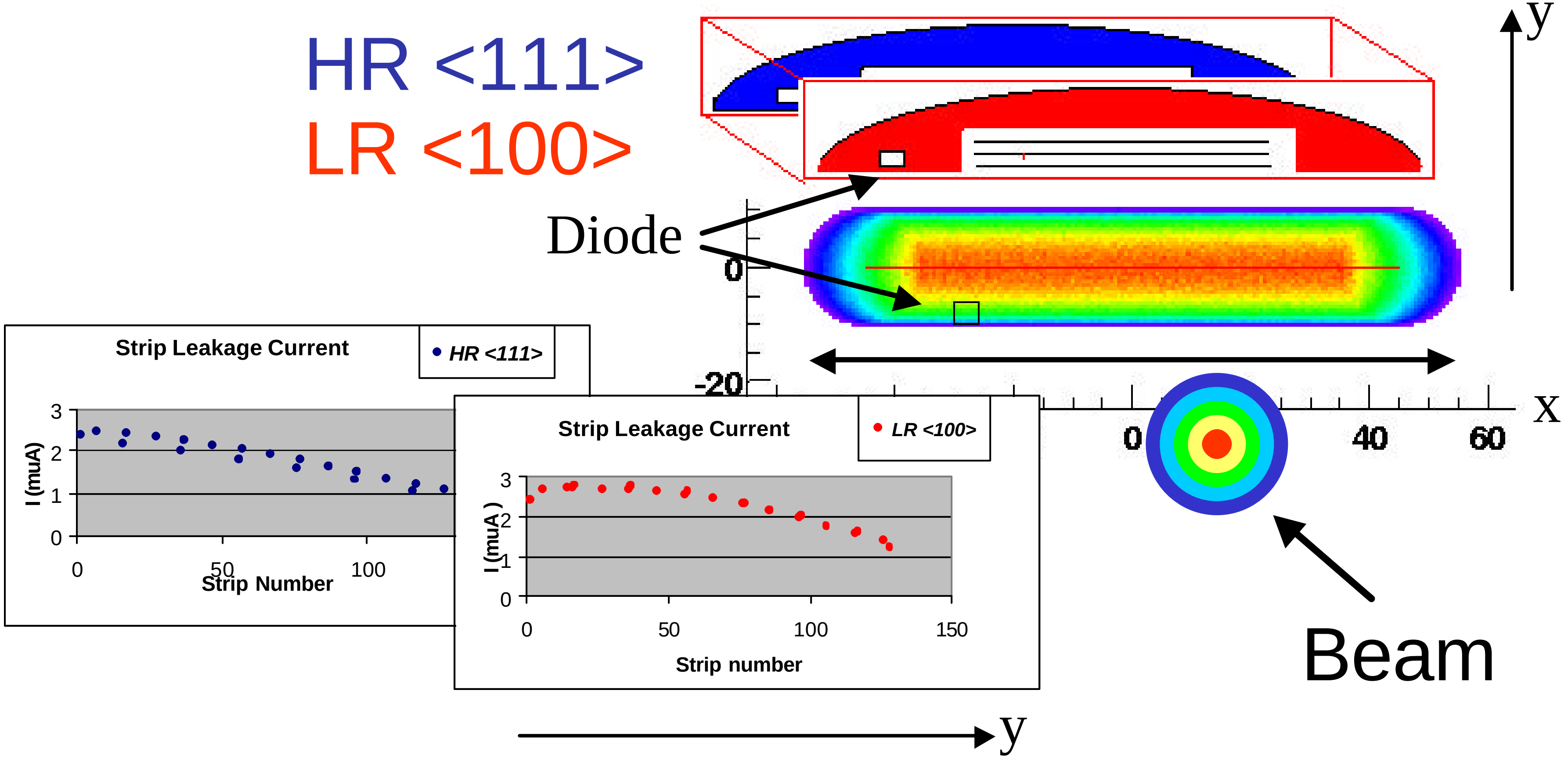
$F^{\mathbf{max}} = 5*10^{14}\ pcm^{-2}$

The **neutrons (1-10^6 eV)** irradiation was performed at nuclear reactor at ENEA, Rome.

$F^{\mathbf{max}} = 10^{14}\ ncm^{-2}$

?
Nominal
fluences

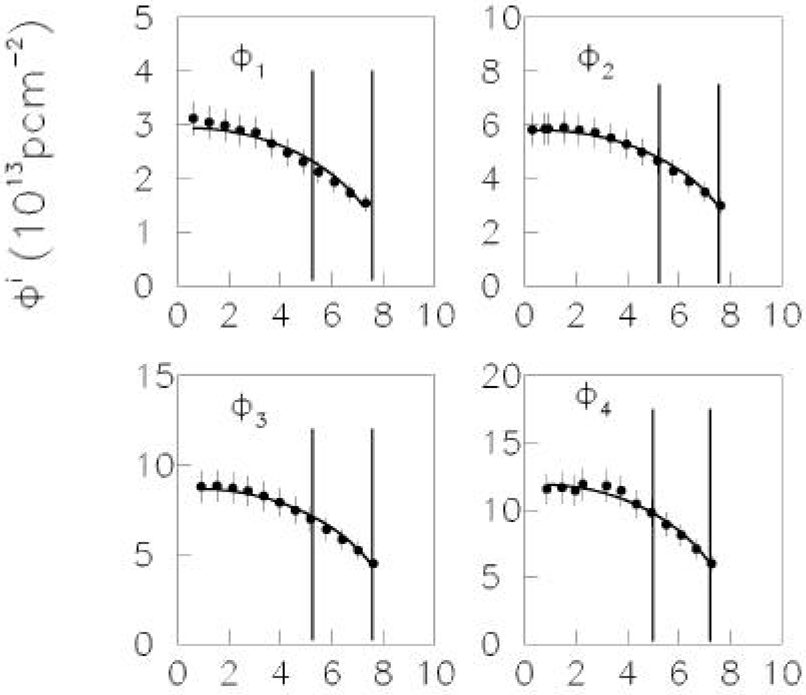
Irradiation conditions at FZK



The circular beam spot of $r = 8 \div 10mm$ was scanned over the length (x axis) of the half-moon producing a non uniform irradiation along the y direction, the diodes received only **75-80 %** of the maximum flux.

How we have determined the diode F ^{P}

Beam profile: $N(r) = N_0 \cdot \cos(arcsen(r/r_0))$



y (mm)

Diode position

$$\boxed{\Phi^i = \frac{I^i}{\bar{I}} \cdot \bar{\Phi}} \longrightarrow$$ Experimental point of F ^{i}

were fitted with the function:

$$\Phi^i(r) = \Phi^{MAX} \cdot \cos(arcsen(y/r_0))$$

where y is the strip position with respect to the centre of the beam

↓

We can estimate the diode mean fluence

Measurements

After irradiation the structures were kept at 0^{0}C;

Neutron irr. → ***after*** 12 days of annealing at T_a=22±1 ^{0}C

34 MeV **proton irr.** → ***during*** 10 days of annealing at T_a=22±1^{0}C

24 GeV/c **proton irr.** → { ***during*** 7 days of annealing at T_a=22±1 ^{0}C
+ 7 days of annealing at T_a= 80 ^{0}C

All the measurements were performed at T_m = 22±1 ^{0}C → T=21^{0}C

$$I(T) = I(T_m)\cdot\left(\frac{T}{T_m}\right)^2\cdot e^{-\frac{E_g}{2k_B}\left(\frac{1}{T}-\frac{1}{T_m}\right)}$$

$$V_{dep}(T) = V_{dep}(T_m)\cdot\frac{1.0526}{1+0.00936\,e^{T_m/11.58}}$$

Measurements

34 MeV
proton irradiation

Diodes → diode leakage current → F^{N} → k

diode depletion voltage vs. F^{N}

Baby → strip and bias leakage current → k

24 GeV/c
proton irradiation

Diodes → diode leakage current → F^{N} → k

diode depletion voltage vs. F^{N}

$|?\ N_{eff}|$ vs. annealing time

neutron irradiation

Diodes → diode leakage current → F^{N}
diode depletion voltage vs. F^{N}

Leakage current

$$\boxed{\Delta I = a(t, T_a) \cdot \Phi^{N} \cdot V}$$

$$\boxed{a^{short}(t, T_a) = a_{\infty} \sum_{i} \frac{b_i}{b_{\infty}} \cdot e^{\left(-\frac{t}{t_i(T_a)}\right)}} \; (*)$$

$$\boxed{a^{long}(t) = a_I \cdot e^{-\frac{t}{t_I}} + a_0 - b \cdot \ln\left(\frac{t}{t_0}\right)} \; (*)$$

We can determine the hardness factor → $k = \Phi^{N} / \Phi^{P}$

(*) Standard parameterisation for a(t,F) and parameters value from M. Moll PhD thesis

The effective doping concentration $\mathrm{N}_{\mathrm{eff}}$

$$\boxed{N_{eff}^{\ \Phi} = N_{eff}^{\ 0} - N_A(\Phi, t(T_a)) - N_C(\Phi) - N_Y(\Phi, t(T_a))}$$

Short term annealing:

$$N_A = g_A \Phi \cdot e^{-t/t_A}$$

Stable damage component:

$$N_C = N_{C0}\left(1 - e^{-C\Phi}\right) + g_C \cdot \Phi$$

Long term annealing:

$$N_Y = g_Y \Phi \cdot \left(1 - e^{-t/t_Y}\right)$$

first order process

$$N_Y = g_Y \Phi \cdot \left(1 - \frac{1}{1 + k_2 g_Y \Phi t}\right)$$

second order process:
with $t_Y \propto 1/\Phi$

N_{eff} vs. F :

For a fixed annealing time t, $t_A \ll t \ll t_Y$:

$$N_{eff}^{\ \Phi} = N_{eff}^{\ 0} - N_{C0}\left(1 - e^{-C\Phi}\right) - b\cdot\Phi$$

REMOVABLE DONOR CONCENTRATION

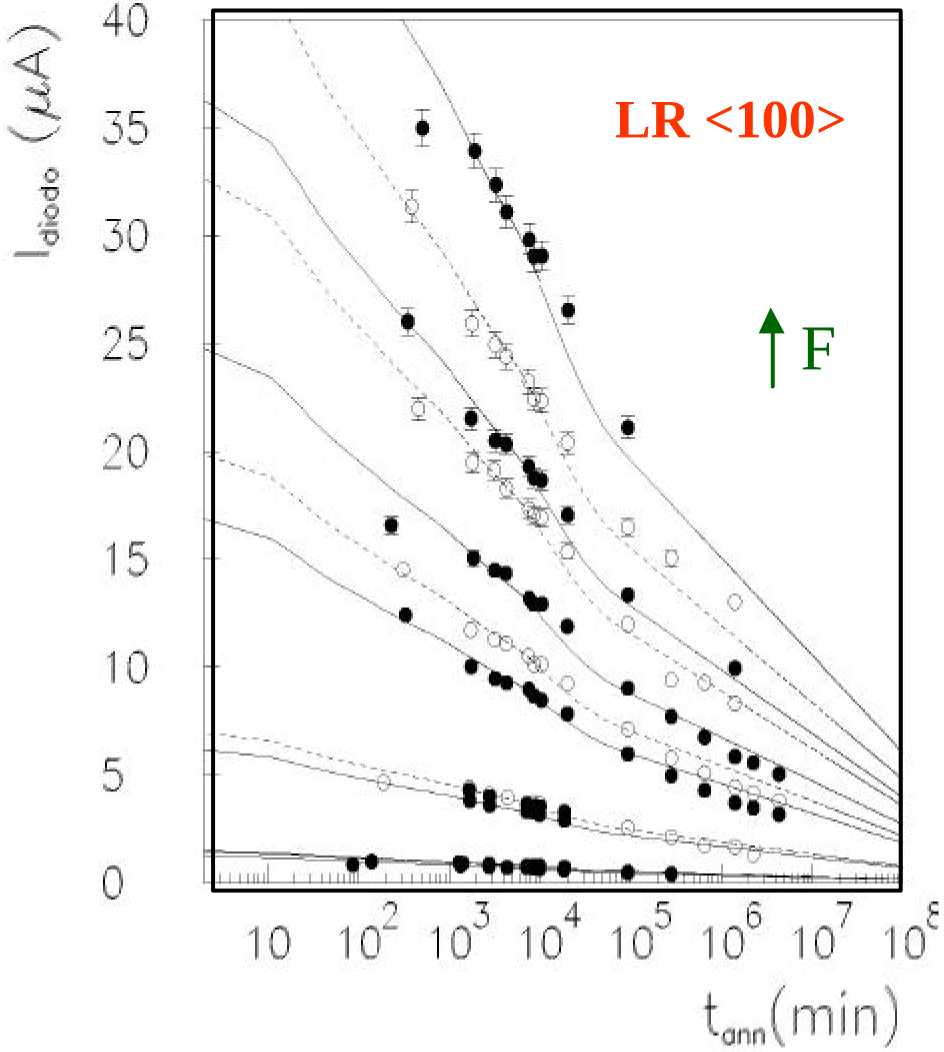
- **Neutron** irradiation: $N_{eff}^{\ 0}\cdot C = 10.9\cdot 10^{-2}\,cm^{-1};\quad N_{C0} = 0.69\cdot N_{eff}^{\ 0}$

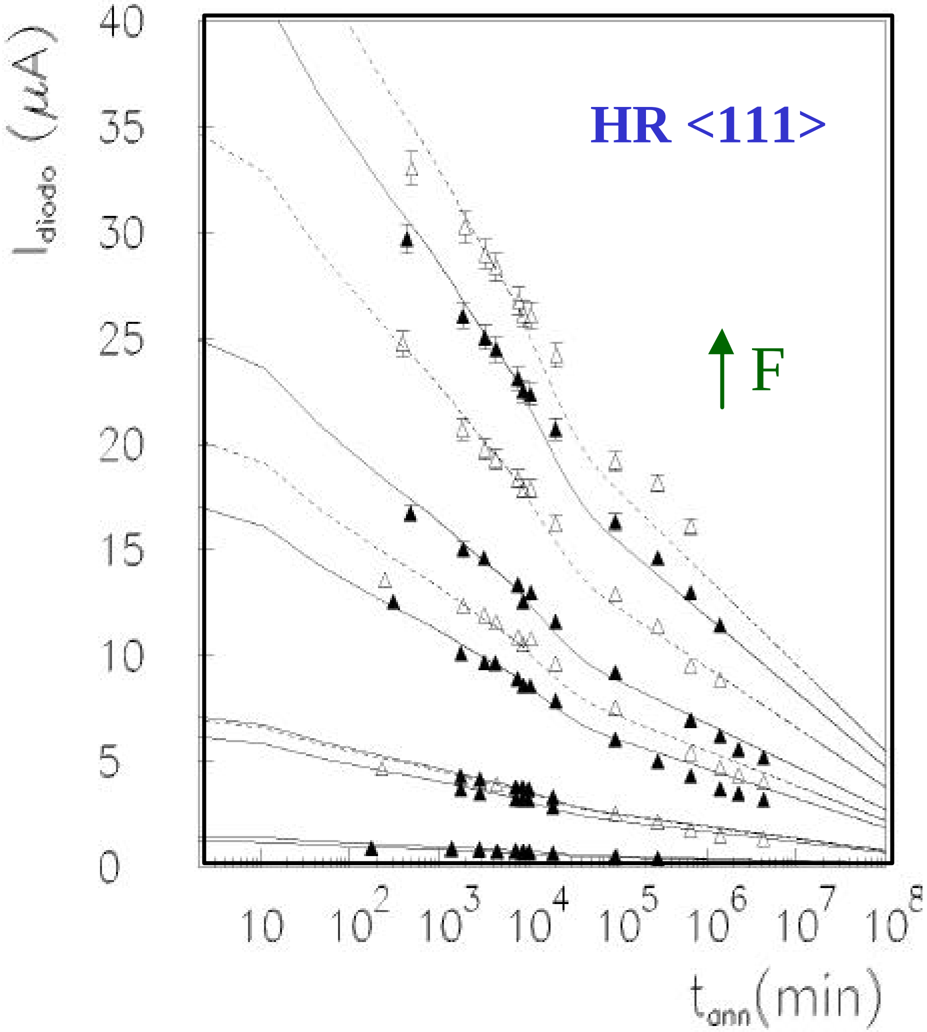
$$\boxed{N_{eff}^{\ \Phi} = 0.69\cdot N_{eff}^{\ 0}\left(1 - e^{-(0.109/N_{eff}^{\ 0})\Phi}\right) - b\cdot\Phi}$$

- **Proton** irradiation: $N_{C0} \cong N_{eff}^{\ 0}$ ← ***Complete donor removal***

$$\boxed{N_{eff}^{\ \Phi} = N_{eff}^{\ 0} e^{-C\Phi} - b\cdot\Phi \xrightarrow{High\Phi} -b\cdot\Phi}$$

24 GeV/c proton irradiation

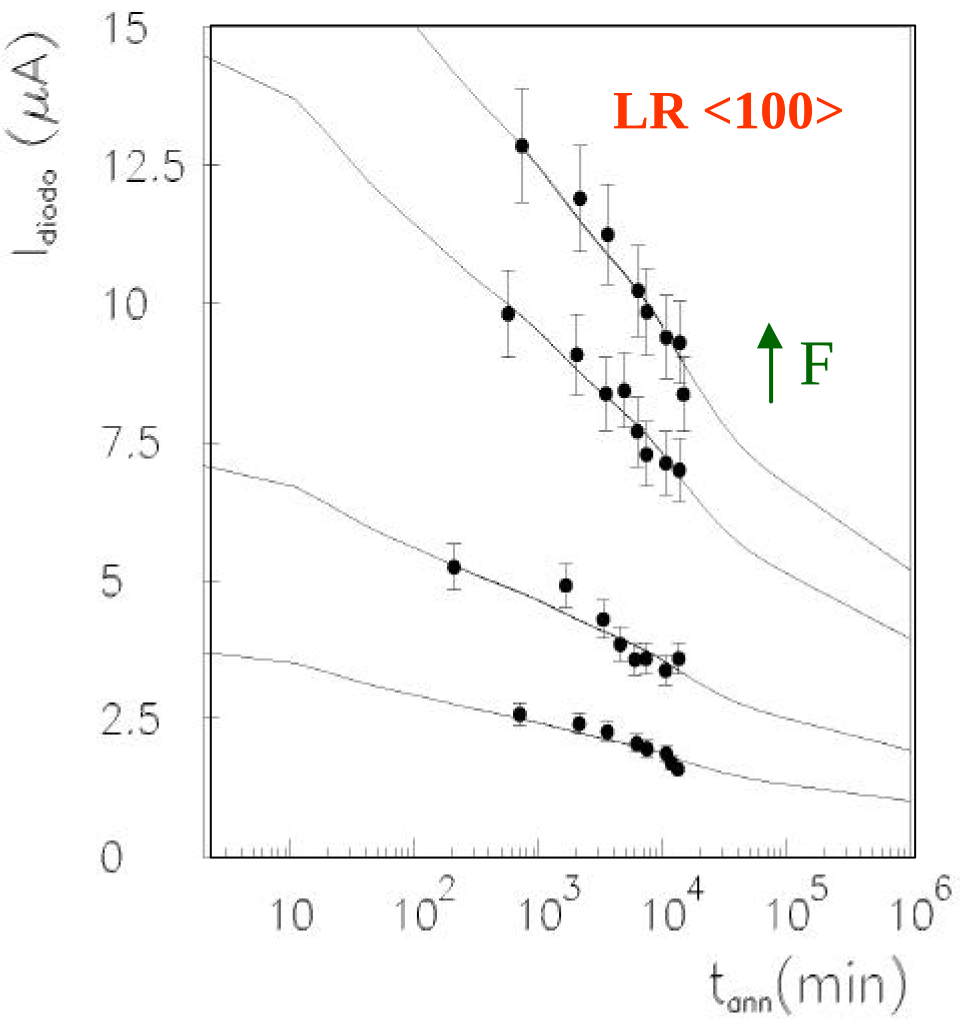


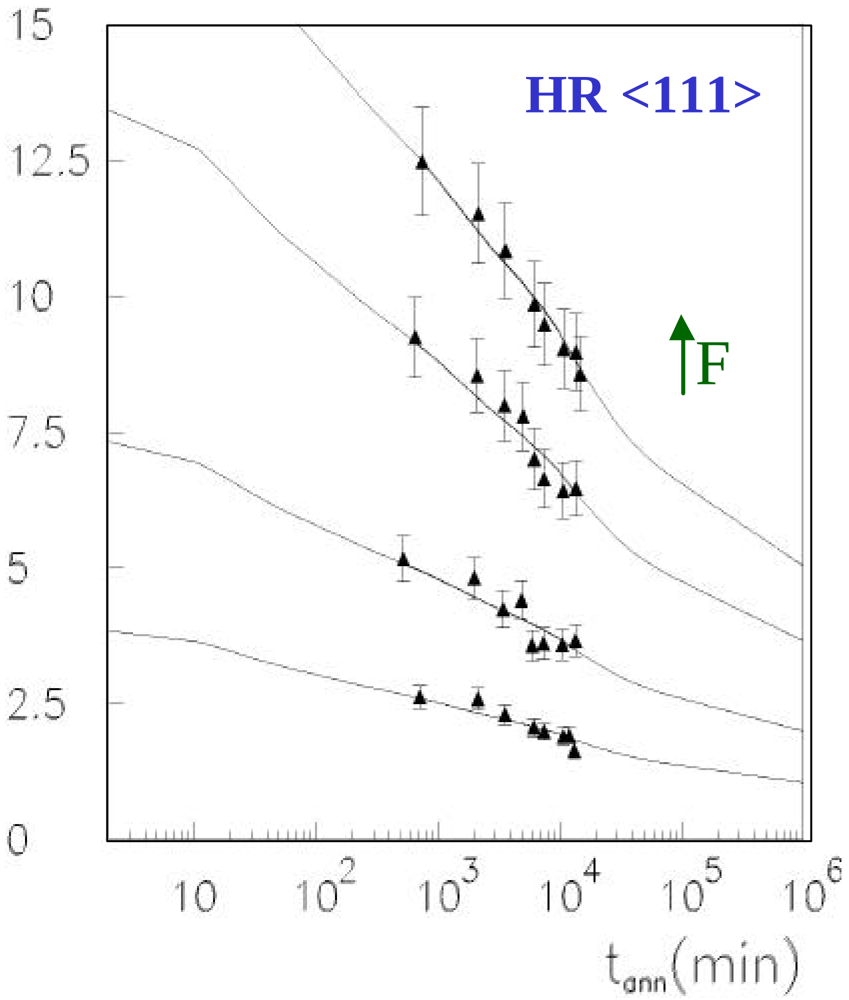


$$\overline{k} = 0.63 \pm 0.07$$

$$k^{ex} = 0.62; \; k^{th} = 0.5$$

34 MeV proton irradiation

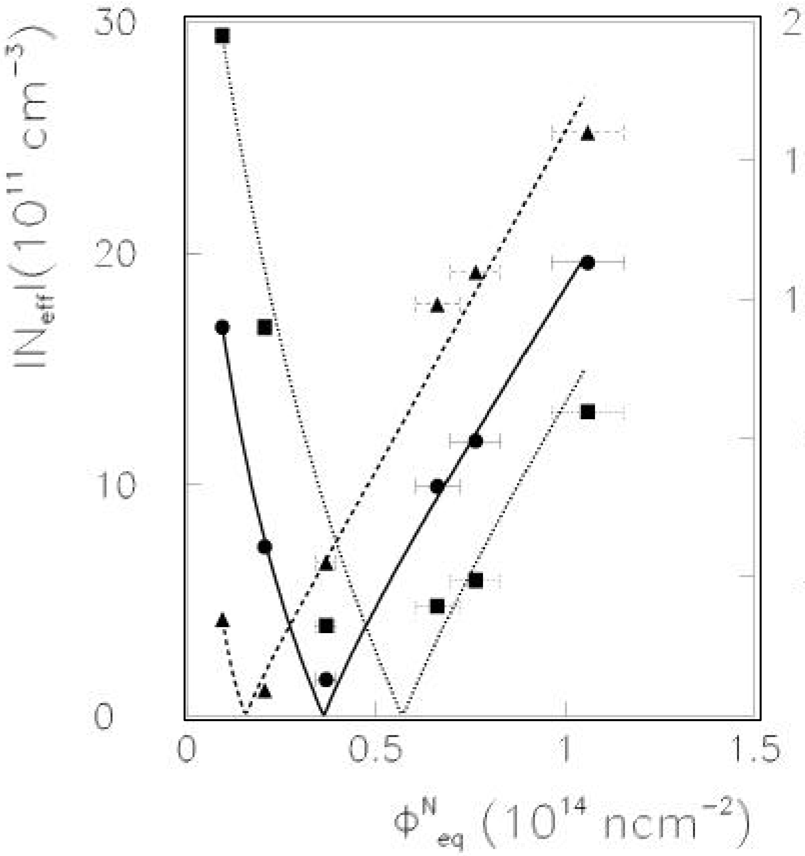




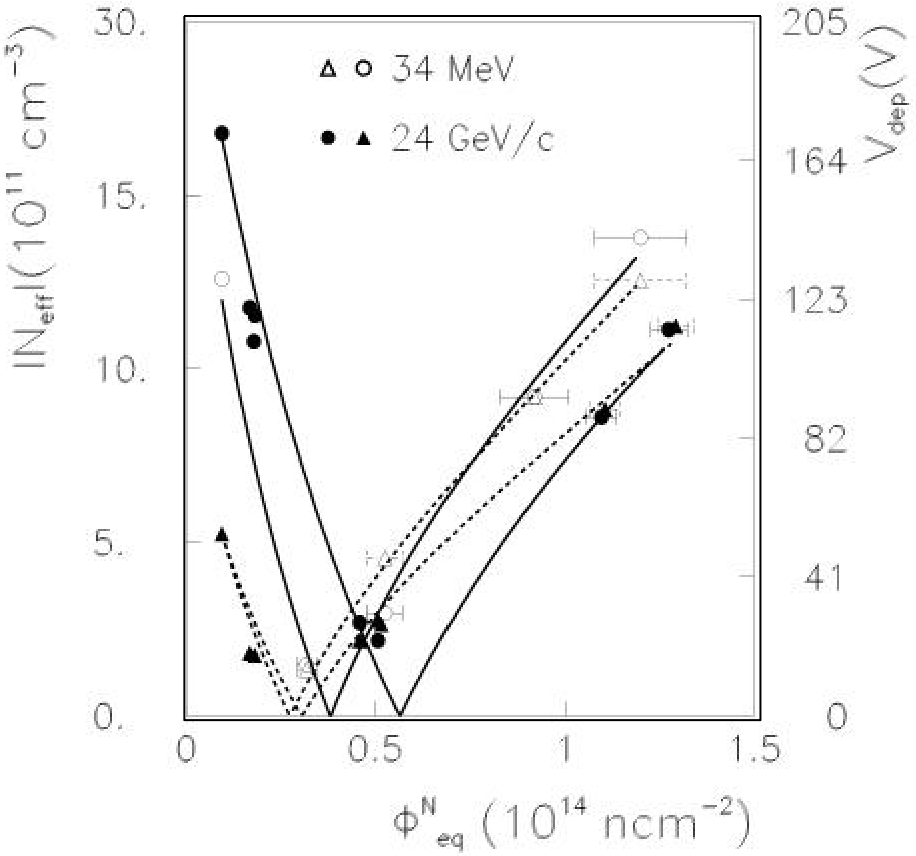
$$\bar{k} = 1.3 \pm 0.3$$

$$k^{th} = 2$$

Neutron irr.



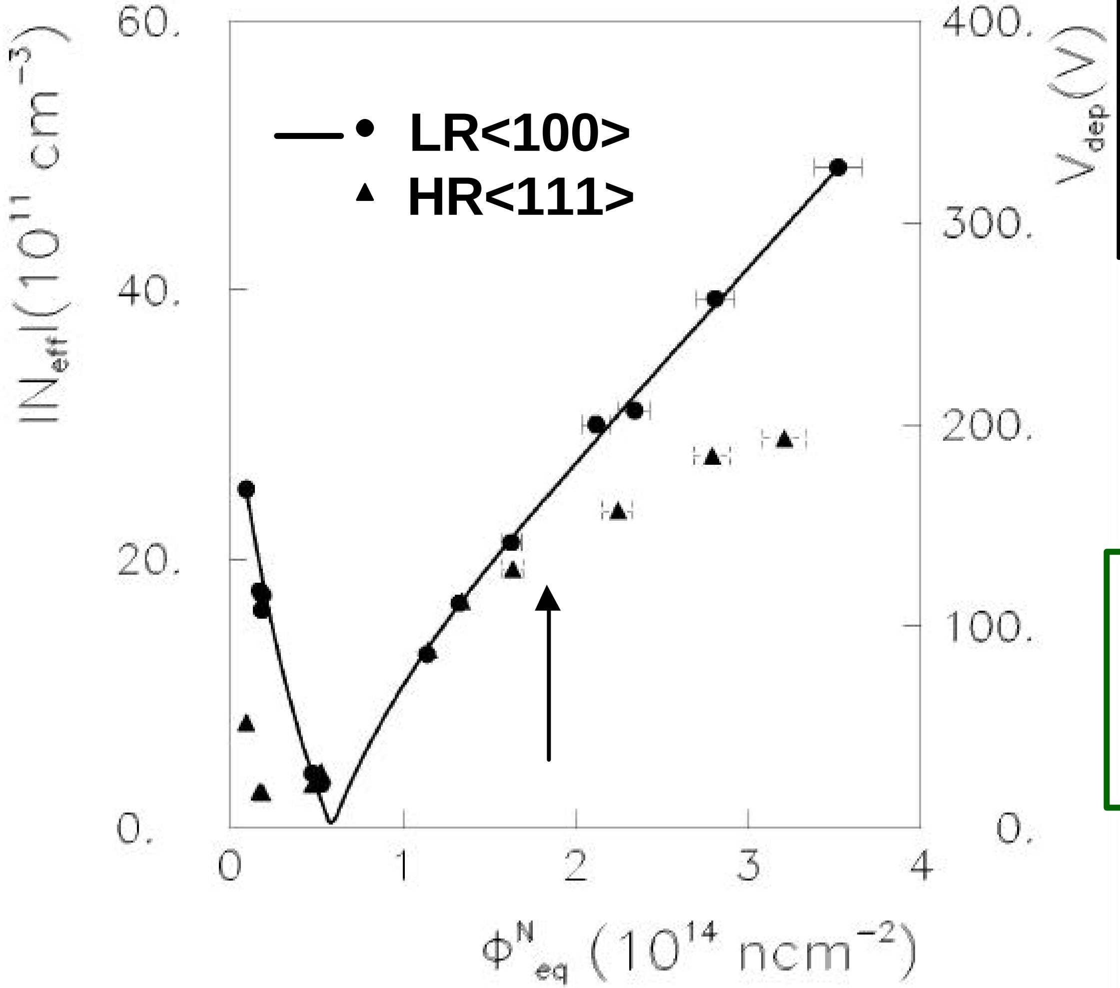
Proton irr.



ß = { 2.5 cm^{-2} ■ LR<111>
2.5 cm^{-2} ● LR<100>
2.6 cm^{-2} ▲ HR<111>

Diode	Energy	ß (cm^{-1})	C (cm^{-2})
● LR<100>	24 GeV/c	$1.4*10^{-2}$	$2.3*10^{-14}$
▲ HR<111>	24 GeV/c	$1.3*10^{-2}$	$4.5*10^{-14}$
○ LR<100>	34 MeV	$1.7 *10^{-2}$	$3.9*10^{-14}$
△ HR<111>	34 MeV	$1.6 *10^{-2}$	$4.9*10^{-14}$

24 GeV/c proton irradiation



The depletion voltage values of ▲ HR<111> diodes show a saturation effect with the fluence.

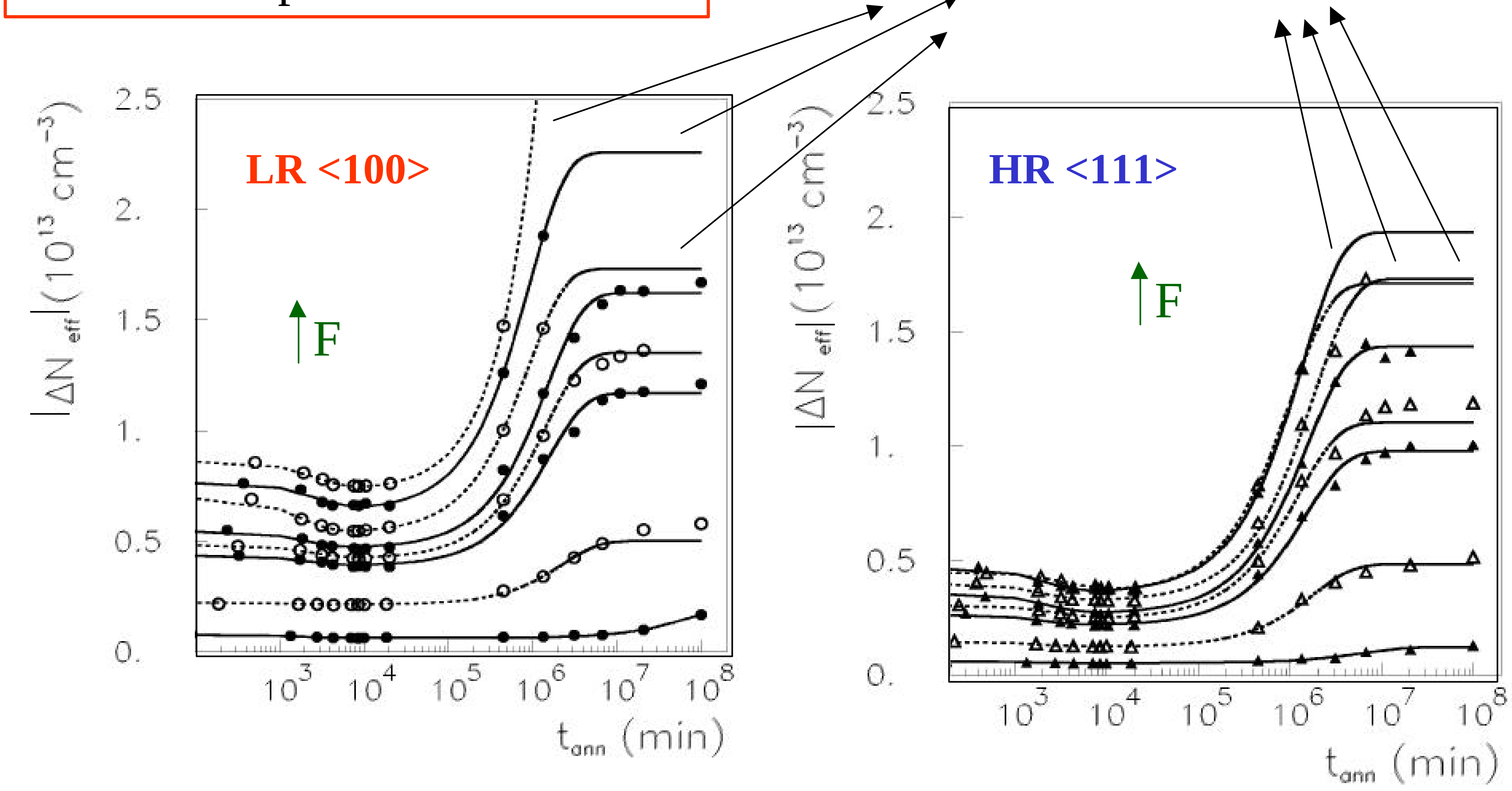
Are they oxygenated ?

We plan to measure the oxygen concentration with *SIMS* measurements

Annealing behaviour of |? N_{eff}|

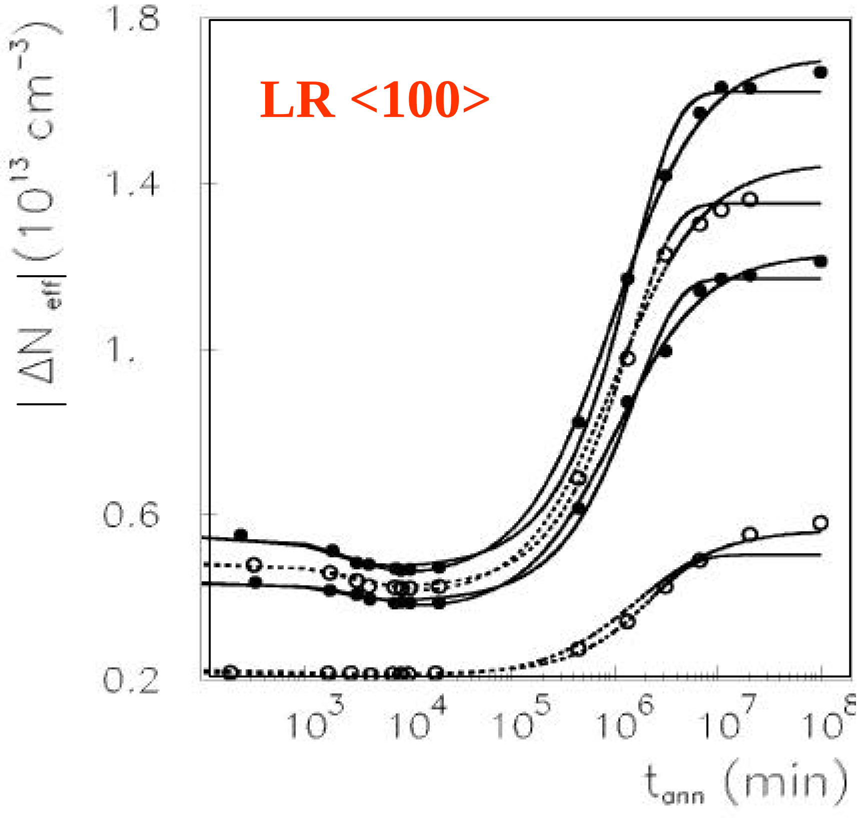
- |? N_{eff}| =| N_{eff}^{0} - N_{eff}^{F} |
- Proton irradiation of 24 GeV/c.
- First order parameterisation

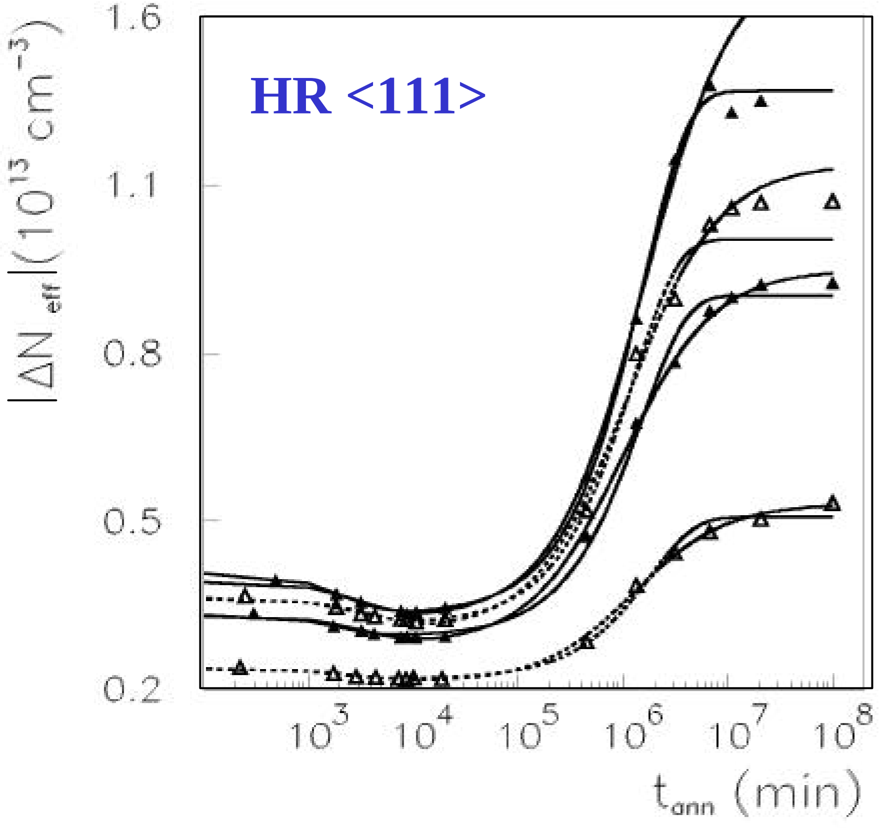
The annealing curves of the last 3 fluences are not **complete**, because for $t_{ann}>10^6$ min the V_{dep} is higher than 1000 V.



I and II order parameterisation

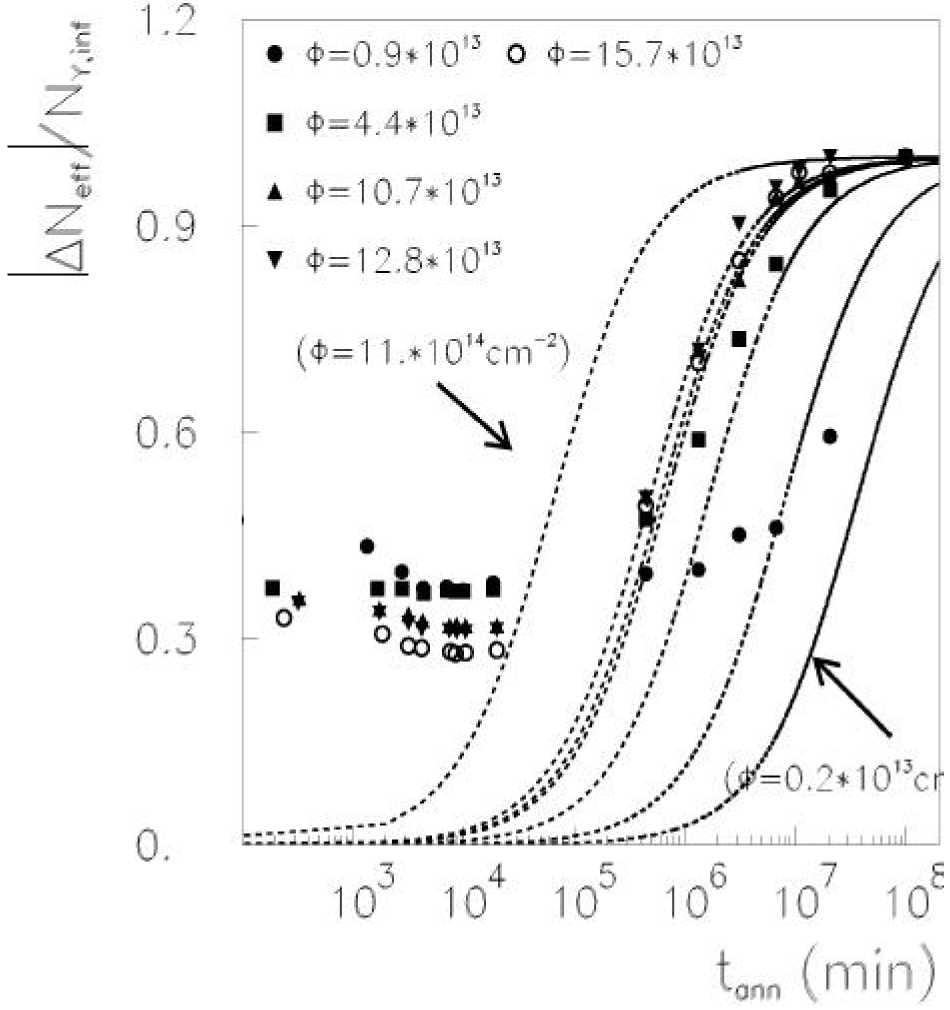
Experimental points are fitted with a first and second order parameterisation.



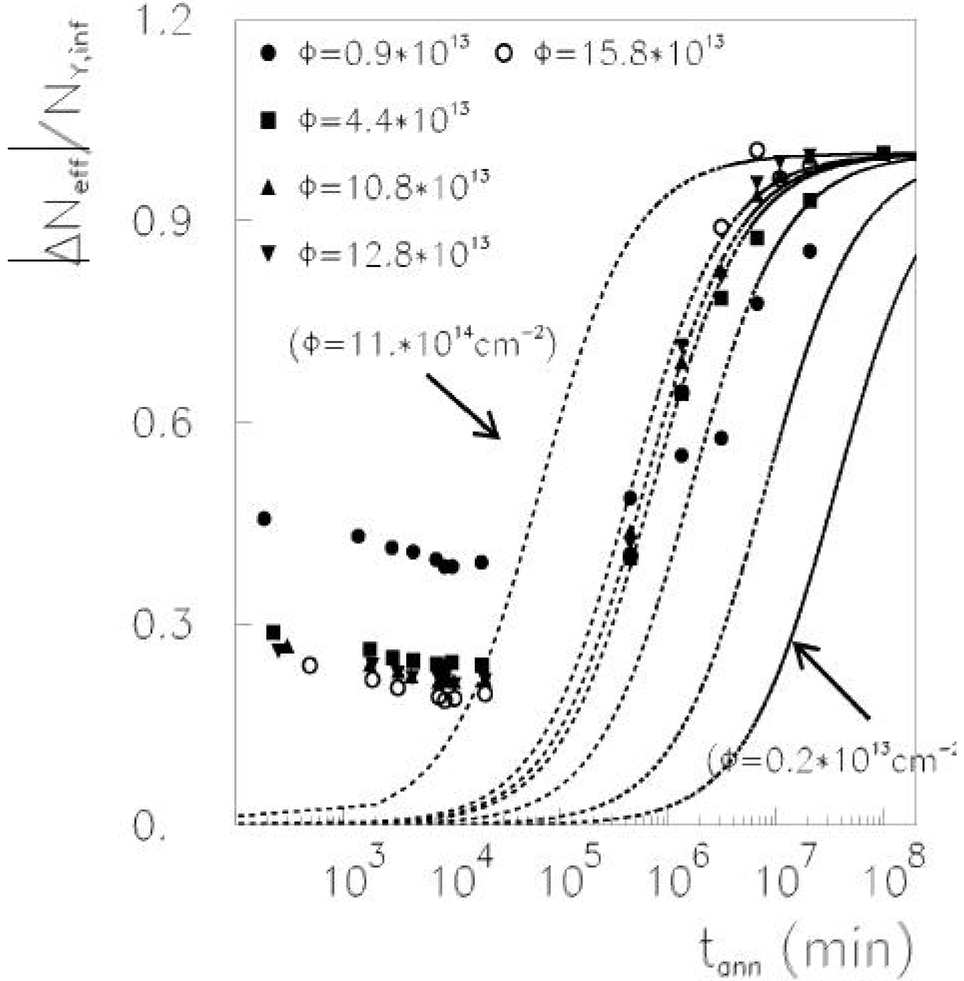


|? N$_{eff}$|/N$_{Yinf}$ vs. annealing time

LR <100>

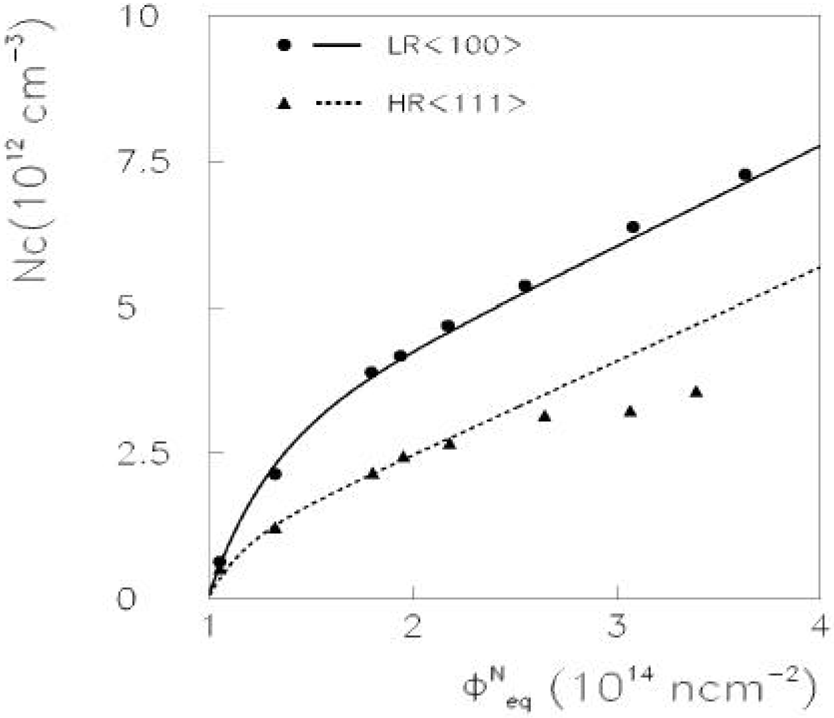


HR <111>

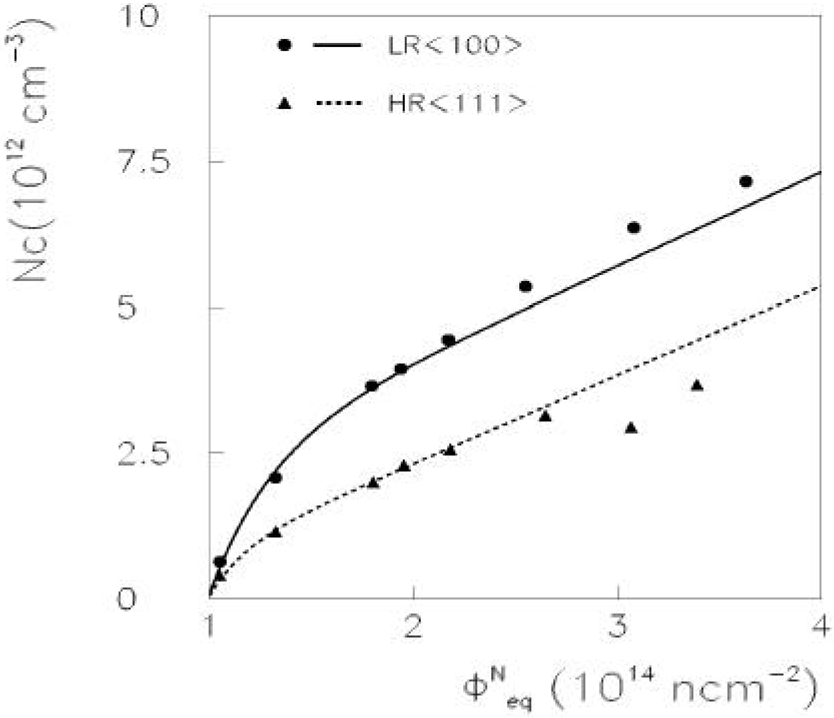


N_C vs. F^N

I order



II order



	N_{eff0} (10^{12} cm^{-3})	N_{C0} (10^{12} cm^{-3})	g_C (10^{-2} cm^{-1})	N_{C0}/N_{eff0}
LR I	2.34	2.58±0.06	1.29±0.05	1.1
HR I	0.73	0.84±0.01	1.21±0.01	1.1
LR II	2.34	2.48±0.06	1.21±0.06	1.1
HR II	0.73	0.8±0.1	1.1±0.1	1.1

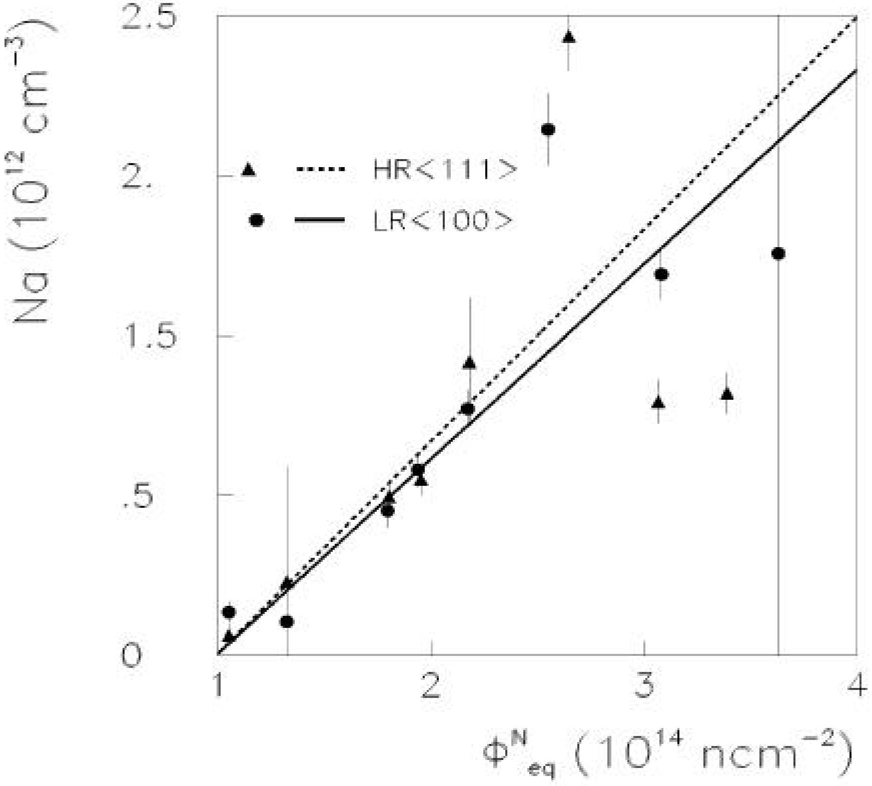
—● **LR<100>**

----▲ **HR<111>**

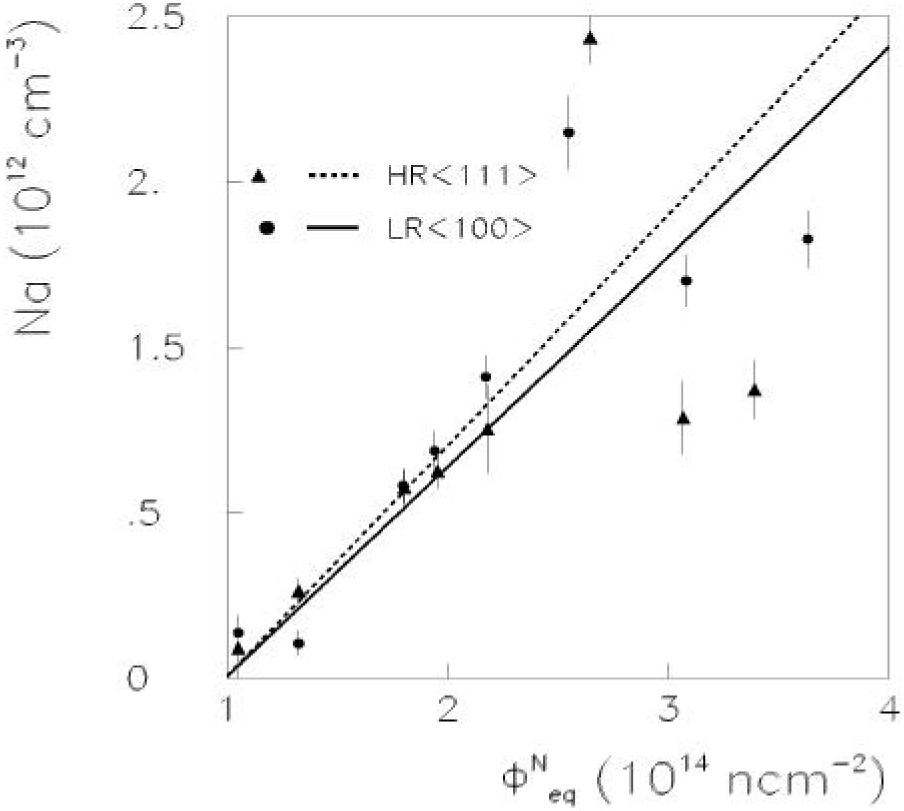
Complete donor removal

N_A vs. F^N

I order



II order

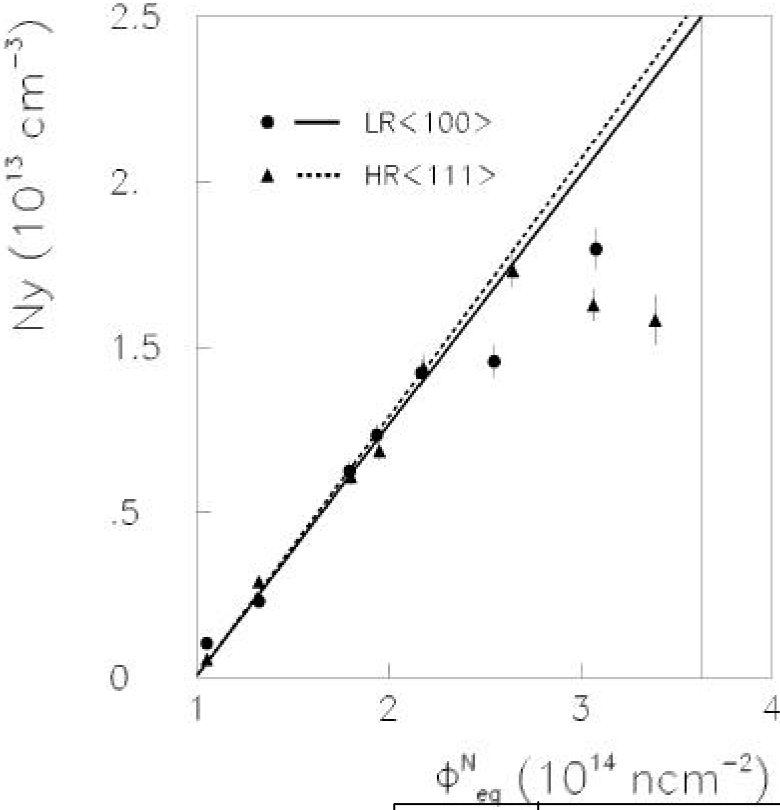


	N_{eff0} (10^{12} cm^{-3})	g_A (10^{-2} cm^{-1})	t_A (10^3 min)
LR I	2.34	0.57±0.03	2.1±0.2
HR I	0.73	0.6±0.7	2.1±0.4
LR II	2.34	0.60±0.07	3.5±0.4
HR II	0.73	0.65±0.05	3.8±0.9

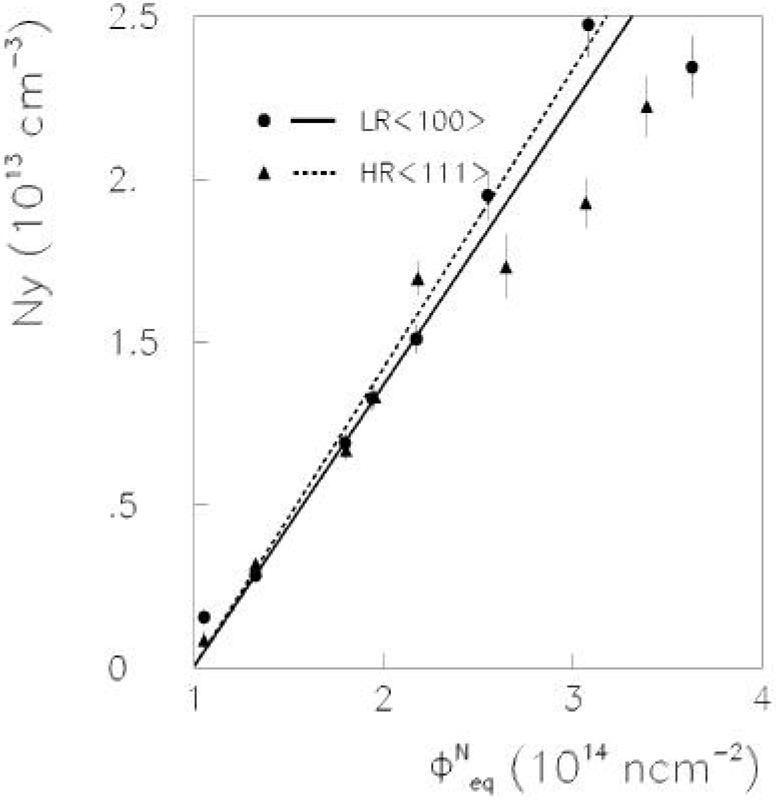
—— ● LR<100>
------ ▲ HR<111>

N_Y vs. F^N

I order



II order



	N_{eff0} (10^{12} cm^{-3})	g_y (10^{-2} cm^{-1})	t_y (10^6 min)
LR I	2.34	7.11±0.03	1.67±0.03
HR I	0.73	7.34±0.04	1.52±0.02
LR II	2.34	8.10±0.03	1.13±0.01
HR II	0.73	8.60±0.04	1.23±0.02

—● LR<100>
----▲ HR<111>

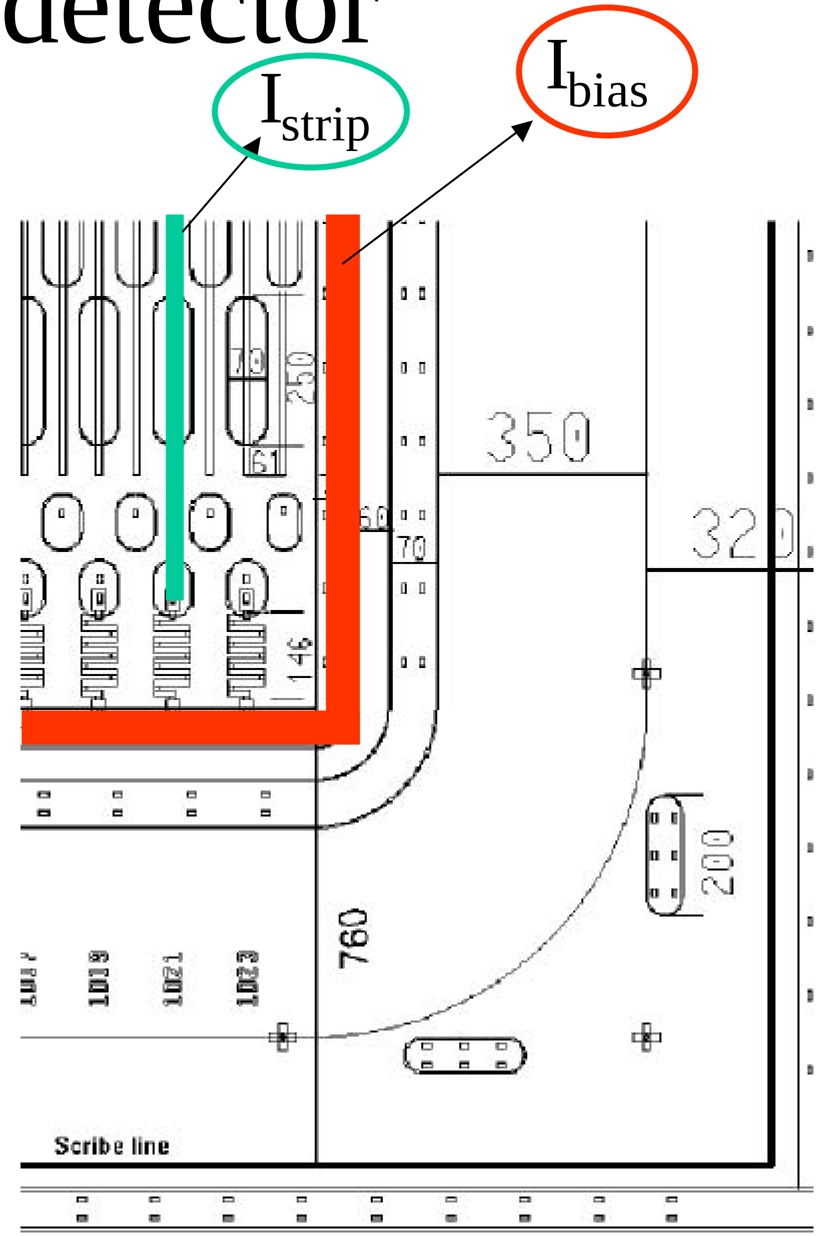
The microstrip detector

p^+ on n single sided

Active region 6.2*6.2 cm^2
with 300 µm

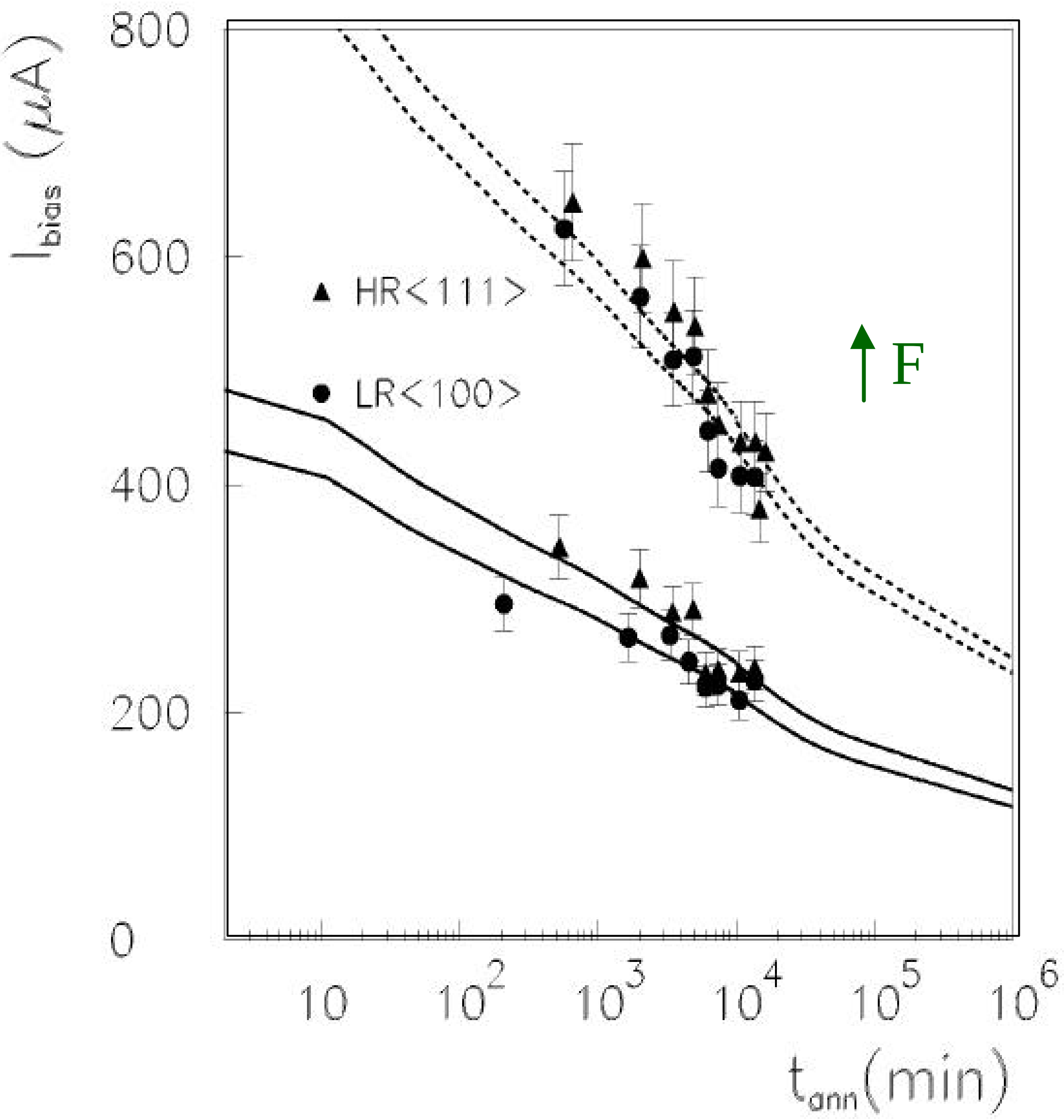
Crystal orientation <100>/<111>
resistivity 1- 3 KOcm (low)
6 -10 KOcm (high)

128 strips
61 µm pitch
14 µm with



34 MeV proton irradiation

I_{bias}



$$\overline{k}^{bias} = 1.4 \pm 0.3$$

Conclusions

- Leakage current doesn’t depend on the substrate resistivity and orientation.

- The measurement of I_{leak} vs. annealing time allows a good estimation of F^{N} and a determination of the k factors both for 34 MeV and for 24 GeV/c protons. We have extracted:

k=0.63±0.07 for **24 GeV/c** proton irradiation
k=1.3±0.3 for **34 MeV** proton irradiation → less than the theoretical value of $k^{th} = 2$ obtained from displacement damage function (NIEL hypothesis).

- Low and high energy **proton irradiation** is characterized of a **complete donor removal** while in **neutron irradiation** the depletion voltage after inversion still **depends** on the initial resistivity.

- The **annealing parameters** were extracted for 24 GeV/c proton irradiation both for I and II order process.

- The experimental points don’t show a clear indication of the fact that the reverse annealing should be described as a **first or a second** order process.