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Irradiation test of Silicon detectors with 7-10 MeV protons

- First results -

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RD48/ROSE Collaboration

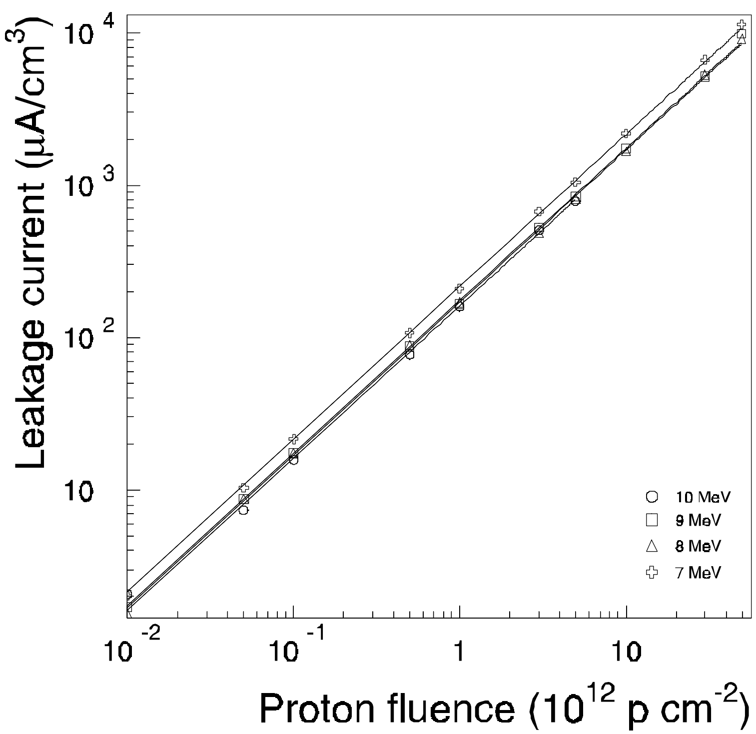
Most measurements performed by **Patrick Roy**, who can not be here because he is having the Defense of his thesis today (Good luck !)

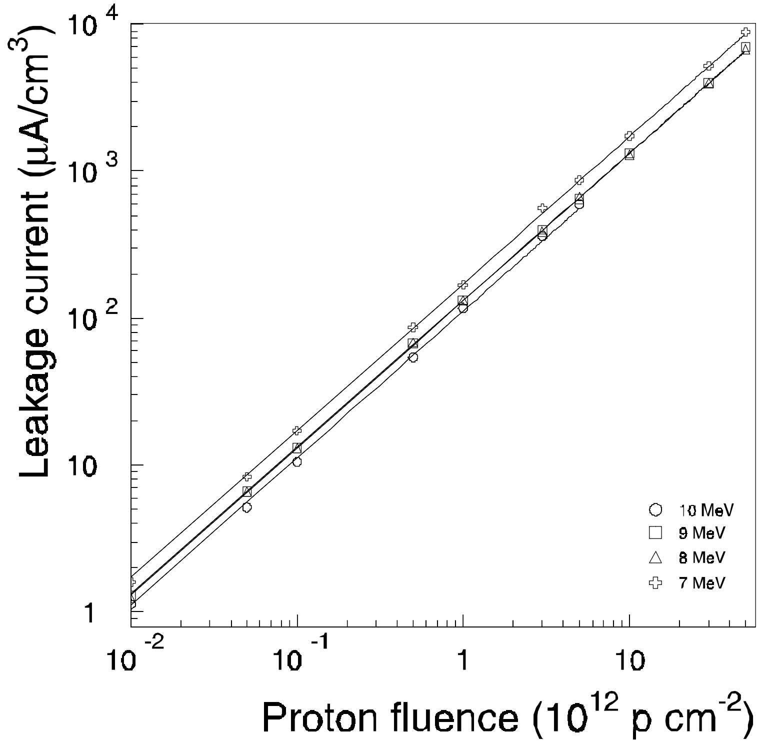
Material / Diodes / Irradiation

- Wacker silicon
- Orientation: <100>
- Resistivity: 2 KΩcm
- Diode producer: ST Microelectronics - ROSE mask
- No oxygen enrichment
  SIMS (150μm) $\Rightarrow$ $[O] = 9 \times 10^{15}\,cm^{-3}$, $[C] < 3 \times 10^{15}\,cm^{-3}$
- Irradiation with 7, 8, 9, 10 MeV protons
- Fluence range: 1×10^{10} p/cm^2 to 5×10^{13} p/cm^2
  (all given fluences not normalized to NIEL)
- Measurements: IV,CV, annealing at 80ºC
  DLTS (see talk of Martin Kuhnke)
- Goal: Does NIEL work for low energy protons ?
  - "Very high ratio of point defects to clusters" -

Increase of Leakage Current

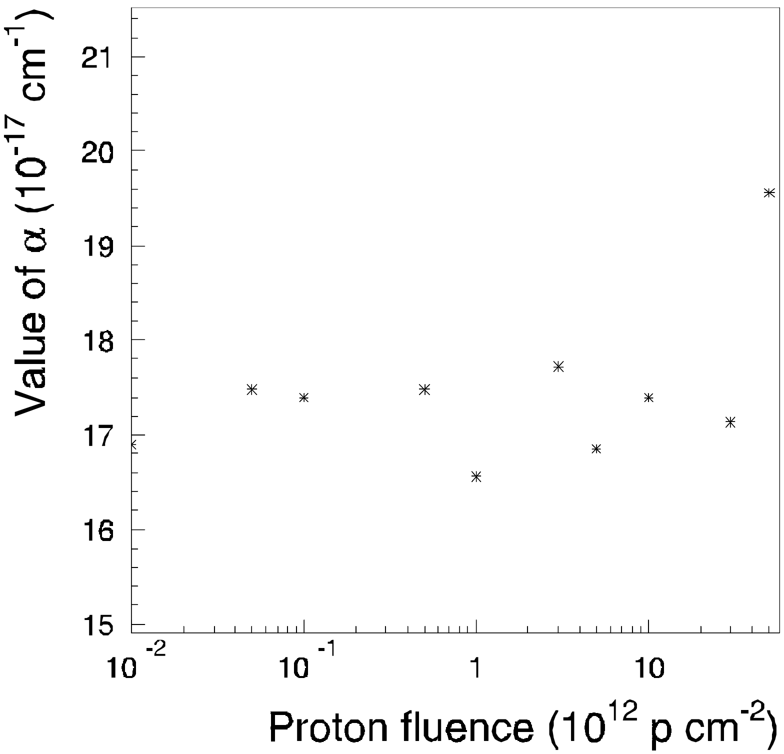
- Leakage Current measured at full depletion directly after irradiation (left) and after annealing of 4min at 80ºC (right)

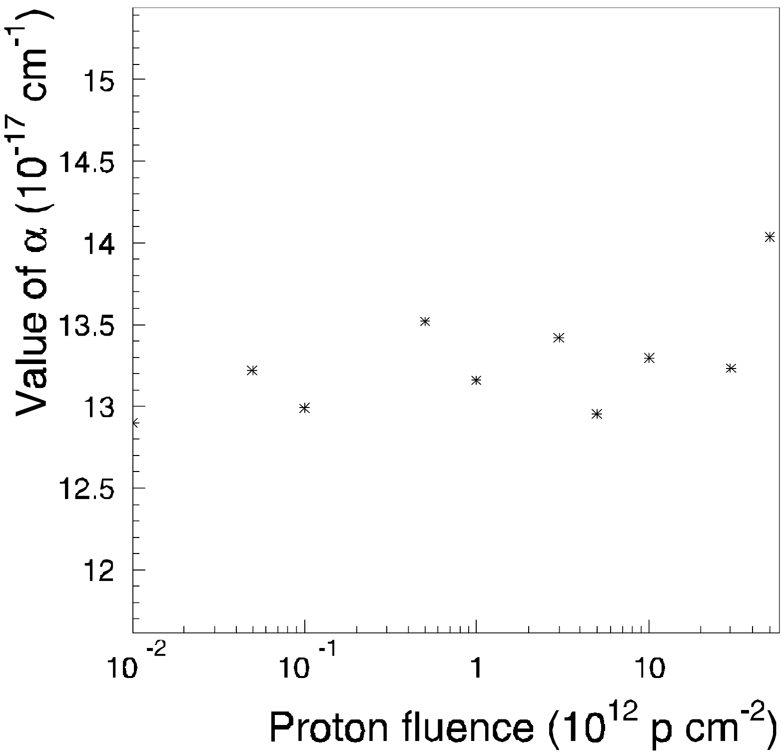




α-value

- α-value for 9 MeV protons measured directly after irradiation (left) and after annealing of 4min at 80ºC (right)





α-value - Hardness factor

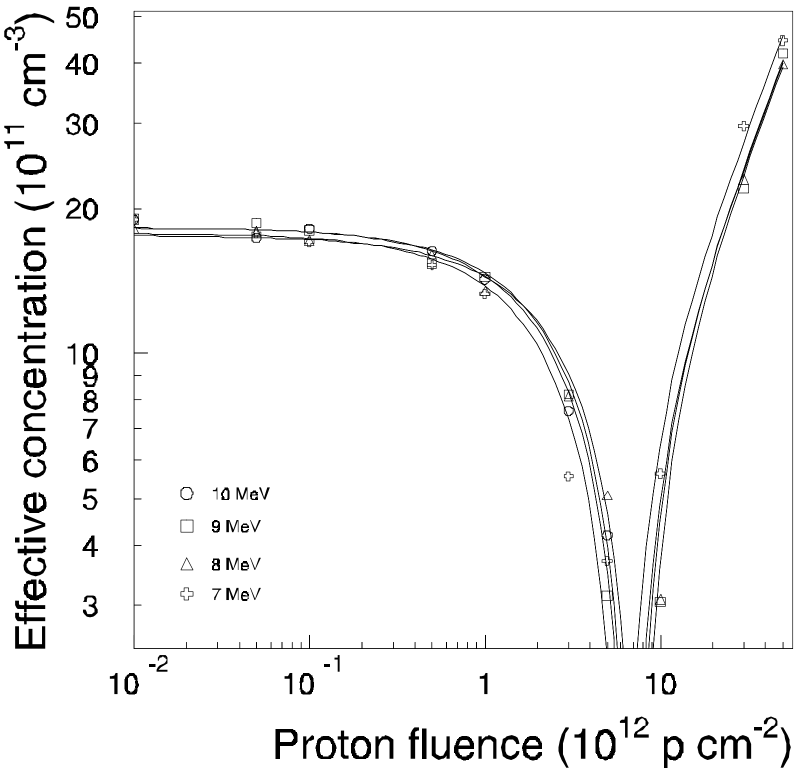
- Leakage Current measured at full depletion (preliminary data)

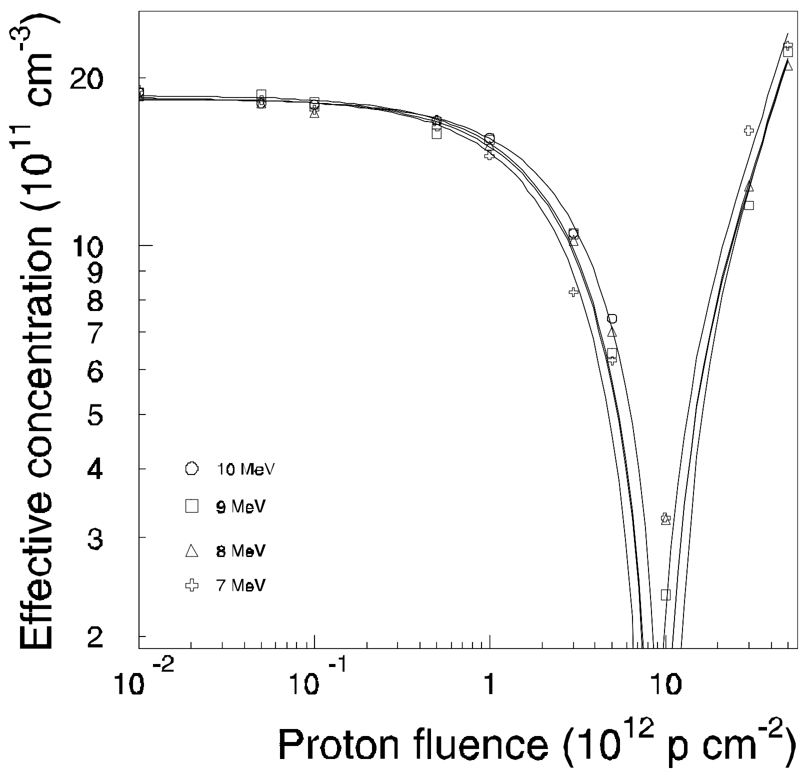
Energy / Particle	α (after irrad.) $[10^{-17}$A/cm]	α (4 min 80°C) $[10^{-17}$A/cm]	hardness factor (leakage current)	hardness factor (damage function) D(E)/95 MeVmb
7 MeV proton	21.4	17.2	3.8	5.3
8 MeV proton	16.9	13.2	2.9	4.8
9 MeV proton	17.4	13.3	2.9	4.3
10 MeV proton	16.1	11.2	2.5	4.0
23 GeV proton		2.68	0.6	≈ 0.5
1 MeV neutron (used as reference)		4.56 (reference)	1 (reference)	1 (95 MeVmb)

- α-value does not scale with NIEL for low energy protons
  (α-value measured for 1MeV neutrons was taken as reference)
- α-value 30 to 40% smaller than expected from NIEL

Change of effective doping concentration

- Effective doping concentration measured directly after irradiation (left) and after annealing of 4min at 80ºC (right)





Damage parameters for ΔN_{eff}

- Parameters extracted from fit to data

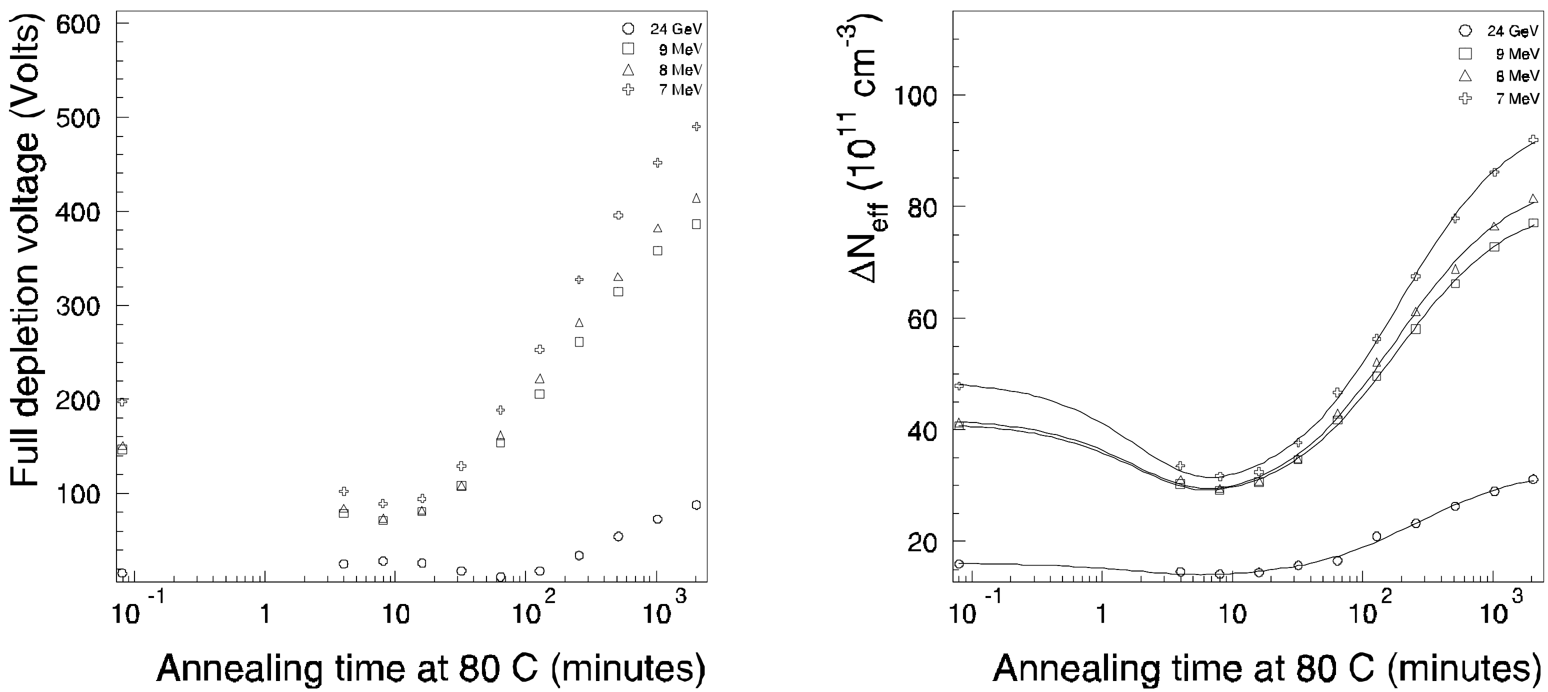
Energy / Particle	N_d $[10^{11}cm^{-3}]$	β $[10^{-2}cm^{-1}]$	c $[10^{-14}cm^2]$	hardness factor κ determined from β	hardness factor (damage function) D(E)/95 MeVmb	hardness factor (leakage current)
7 MeV proton	18.4	4.80	19.3	5.2	5.3	3.8
8 MeV proton	18.4	4.27	17.2	4.7	4.8	2.9
9 MeV proton	18.6	4.35	17.0	4.7	4.3	2.9
10 MeV proton	18.3	(4.3)	(13.6)	4.7	4.0	2.5
1 MeV neutron (used as reference)		0.55		reference with $\kappa = 0.6$		0.6

- β-value scales with NIEL for low energy protons

  (β-value measured for 24GeV/c protons was taken as reference)

Change of effective doping concentration

- Annealing of depletion voltage / effective doping concentration



- Fluence: 3.0×10^{13} p/cm^2 for 7,8,9,10 MeV protons
  4.9×10^{13} p/cm^2 for 24 GeV/c protons

Damage parameter g_y (reverse annealing)

- Parameter extracted from fit to data

Energy / Particle	g_y [cm^{-1}]	hardness factor κ determined from g_y	hardness factor (damage function) D(E)/95 MeVmb	hardness factor κ determined from β	hardness factor (leakage current)
7 MeV proton	0.23	5.7	5.3	5.2	3.8
8 MeV proton	0.20	4.9	4.8	4.7	2.9
9 MeV proton	0.18	4.5	4.3	4.7	2.9
23 GeV protons (used as reference)	0.04	reference with κ = 0.6			

- g_y scales with NIEL for low energy protons
(g_y measured for 24GeV/c protons was taken as reference)

Conclusions

- Extraction of damage parameters for standard material irradiated with low energy protons

- α-value does not scale with NIEL for low energy protons (7-10 MeV)
  (if α-value for 1MeV neutrons is taken as reference)
  measured values too low by about 30-40 %

- Damage parameters β and g_y do scale with the NIEL for low energy protons (7-10 MeV)