Detectors and electronics for Super-LHC:
IRRADIATION RESULTS

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OUTLINE

The presented results are from experiments performed by:
-**SMART** Collaboration (Bari, Firenze, Pisa, Padova, Perugia, Trieste, Trento)
-Department of Information Engineering (**DEI**), University of Padova

Measurements are in progress …

1) Nuclear reactor irradiation in Lubiana:
-**MCZ** n-type detectors (**SMART**)
-**Epitaxial** n-type detectors (**SMART**)

2) 24 GeV proton irradiation at CERN:
-**Epitaxial** n-type detectors (**SMART**)
-**FZ thinned** n-type detectors (**SMART**)
- **0.13 μm CMOS** technology (**DEI**)

DETECTORS

-**MCZ** detectors

Substrate: MCZ, n-type, 300 μm thick, ρ= 0.6 kΩ×cm, from Okmetic
Detector processing: IRST

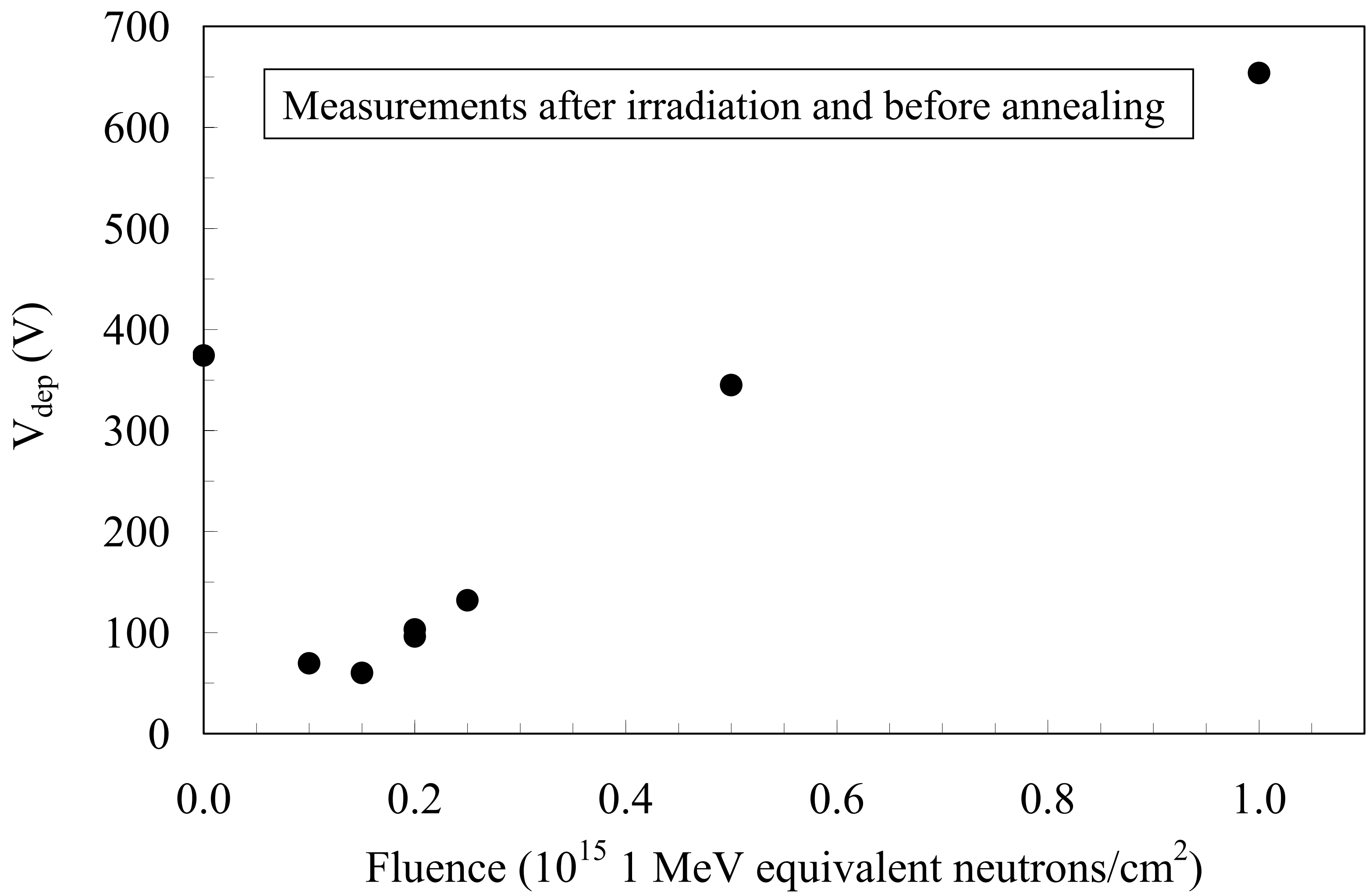
-**Epitaxial** detectors

Epitaxial layer: n-type, 50 μm thick, ρ= 50 Ω·cm,
grown by ITME on CZ substrate
Detector processing: IRST

-**FZ thinned** detectors

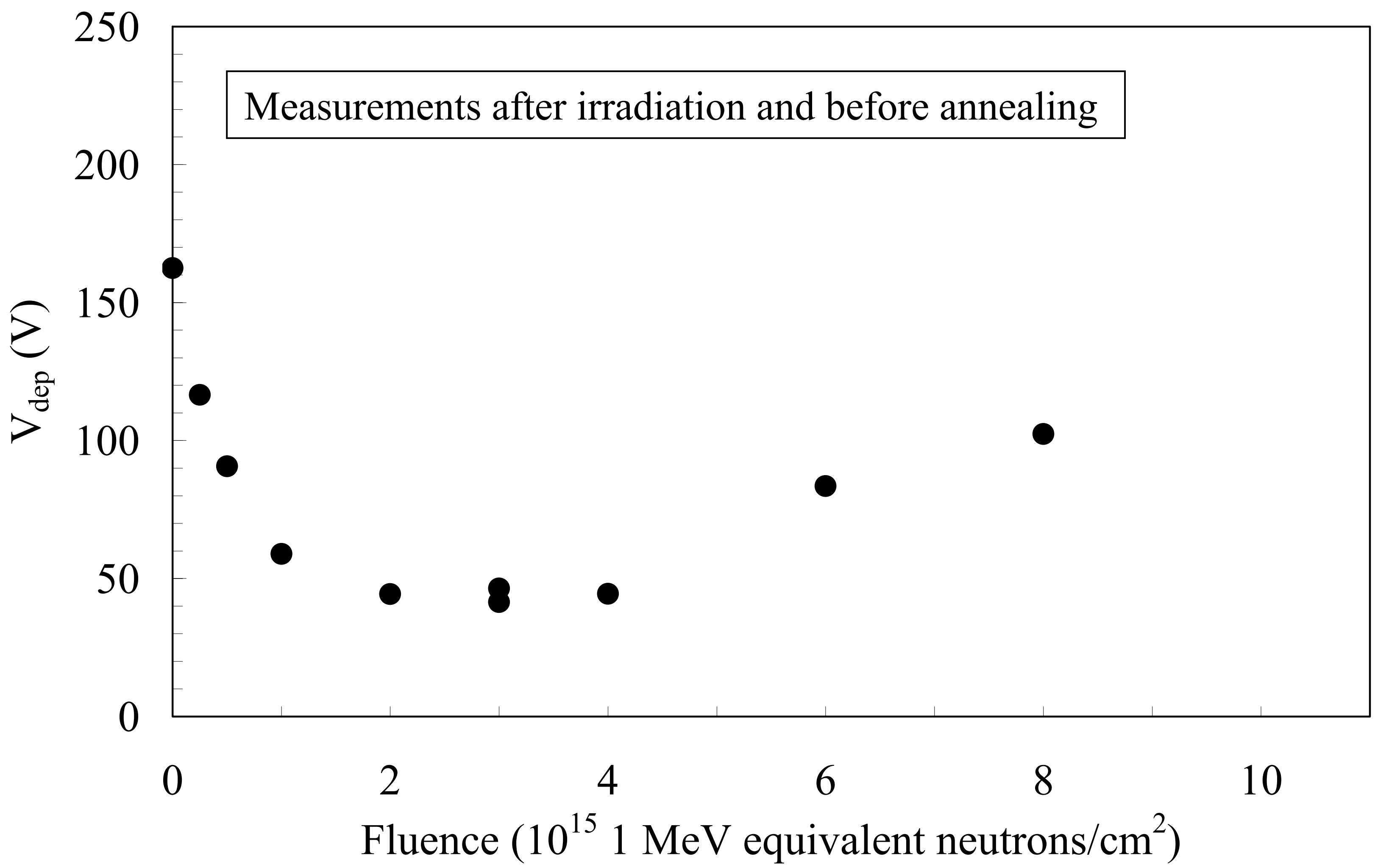
Substrate: FZ, n-type, 300 μm thick, ρ= 6 kΩ·cm
Thinning: down to 50-100 μm by Tetra Methyl Ammonium Hydroxide (TMAH) etching from backside: IRST
Detector processing: IRST

MCZ n-type 300 μm thick detectors: neutron irradiation



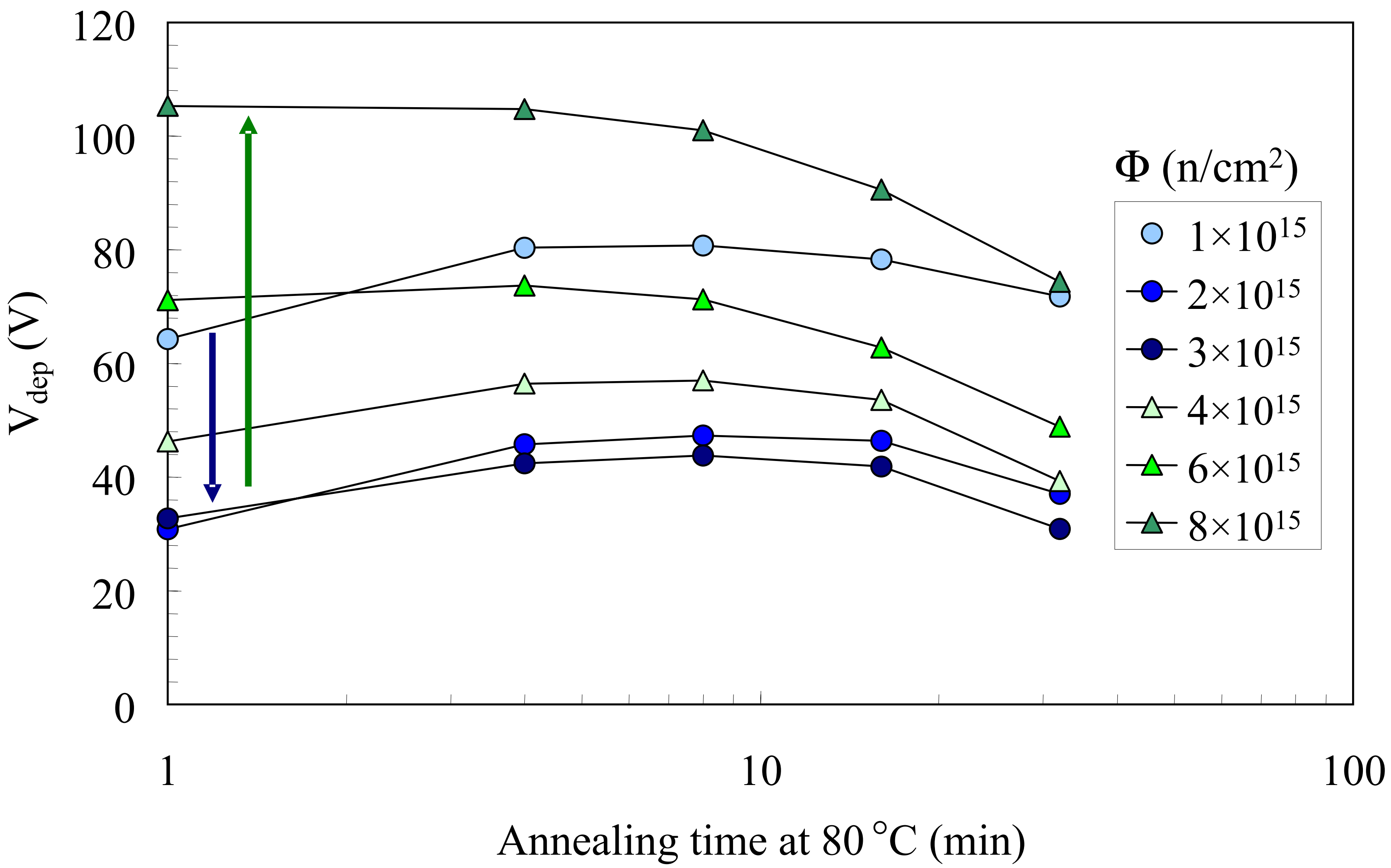
- The minimum of V_{dep} is reached at 1-1.5×10^{14} n/cm^2.
- V_{dep} is ≈650 at 10^{15} n/cm^2.

Epitaxial n-type 50 μm thick detectors: neutron irradiation



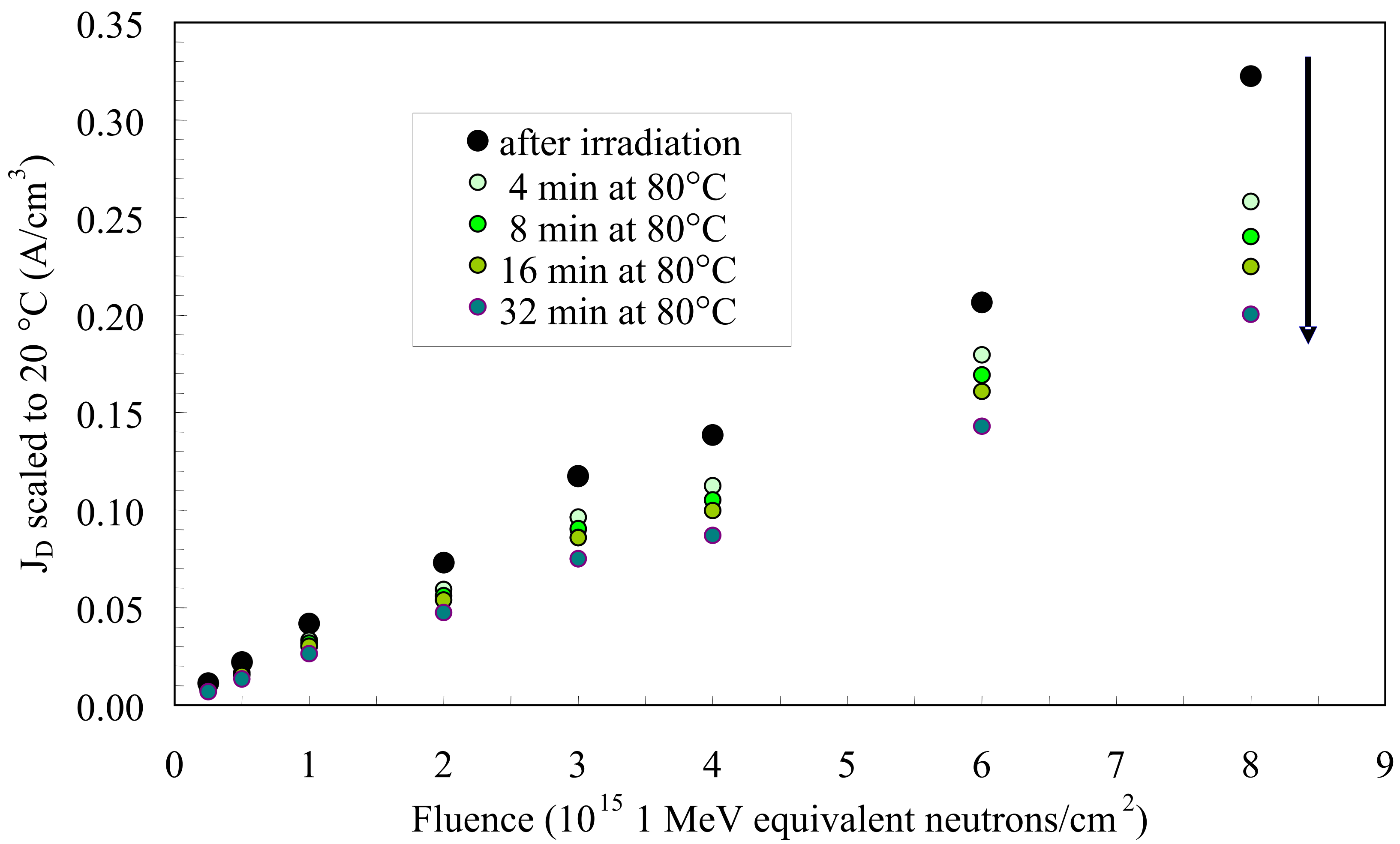
- The minimum of $V_{dep}\approx$40-50 V is reached at 2-4$\times10^{15}$ n/cm^2.
- $V_{dep}< V_{dep,0}$ at 8$\times10^{15}$ n/cm^2.

Epitaxial n-type 50 μm thick detectors: neutron irradiation



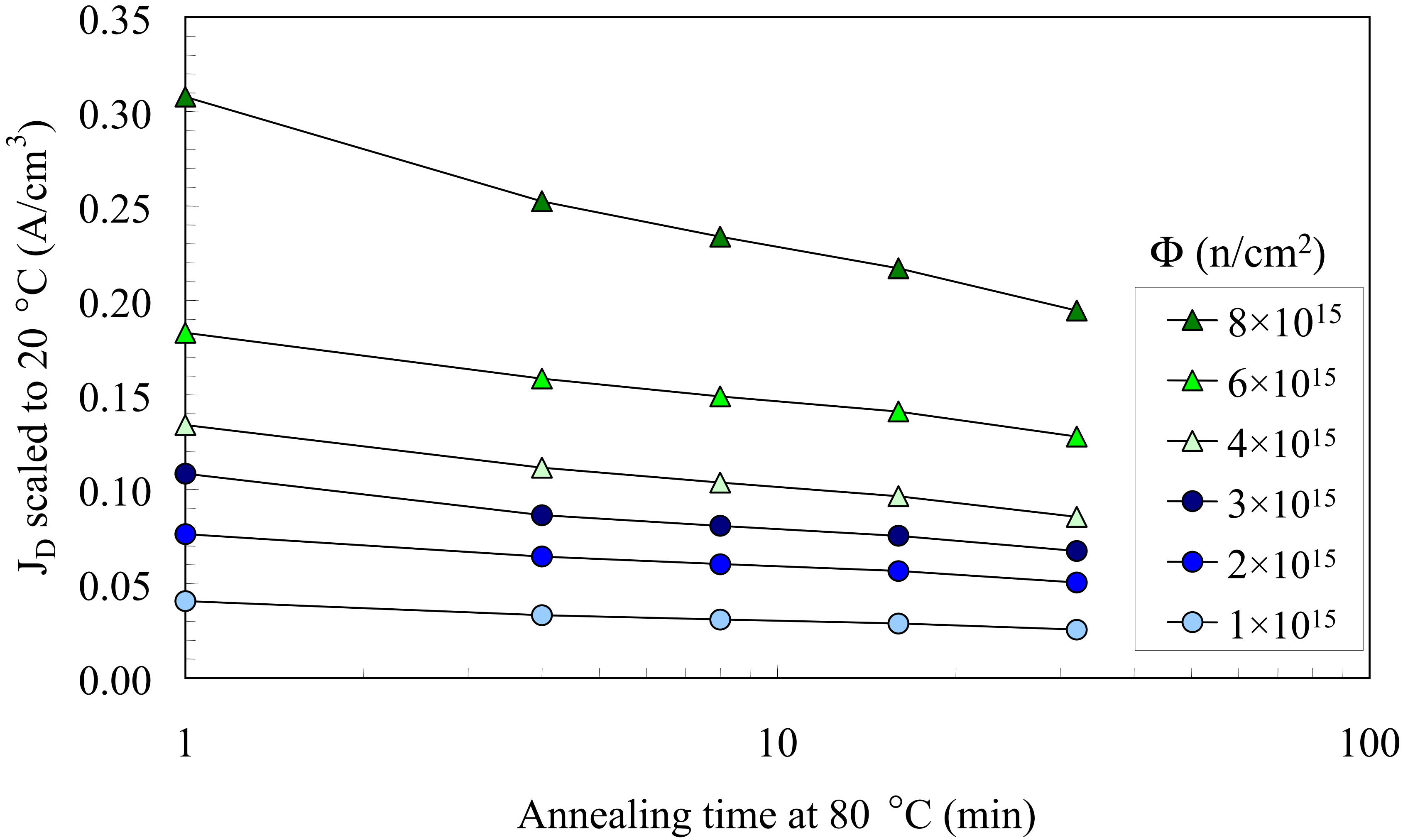
- V_{dep} decreases for annealing times at 80 °C higher than 8 minutes.
- If this effect is due to deep acceptor generation, devices are not type inverted.

Epitaxial n-type 50 μm thick detectors: neutron irradiation



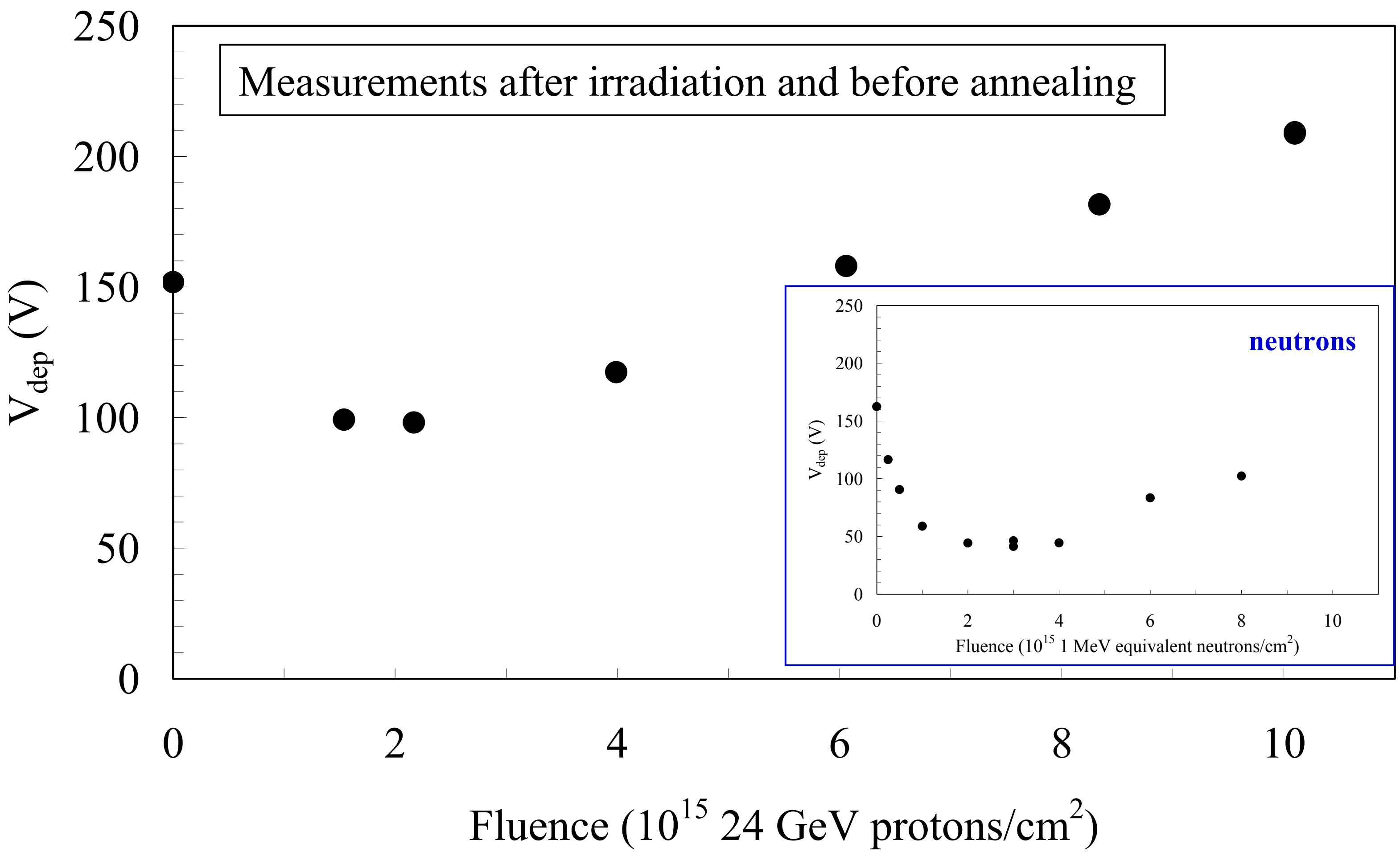
- J_D increases linearly with fluence.
- J_D decreases with annealing time at 80 °C.

Epitaxial n-type 50 μm thick detectors: neutron irradiation



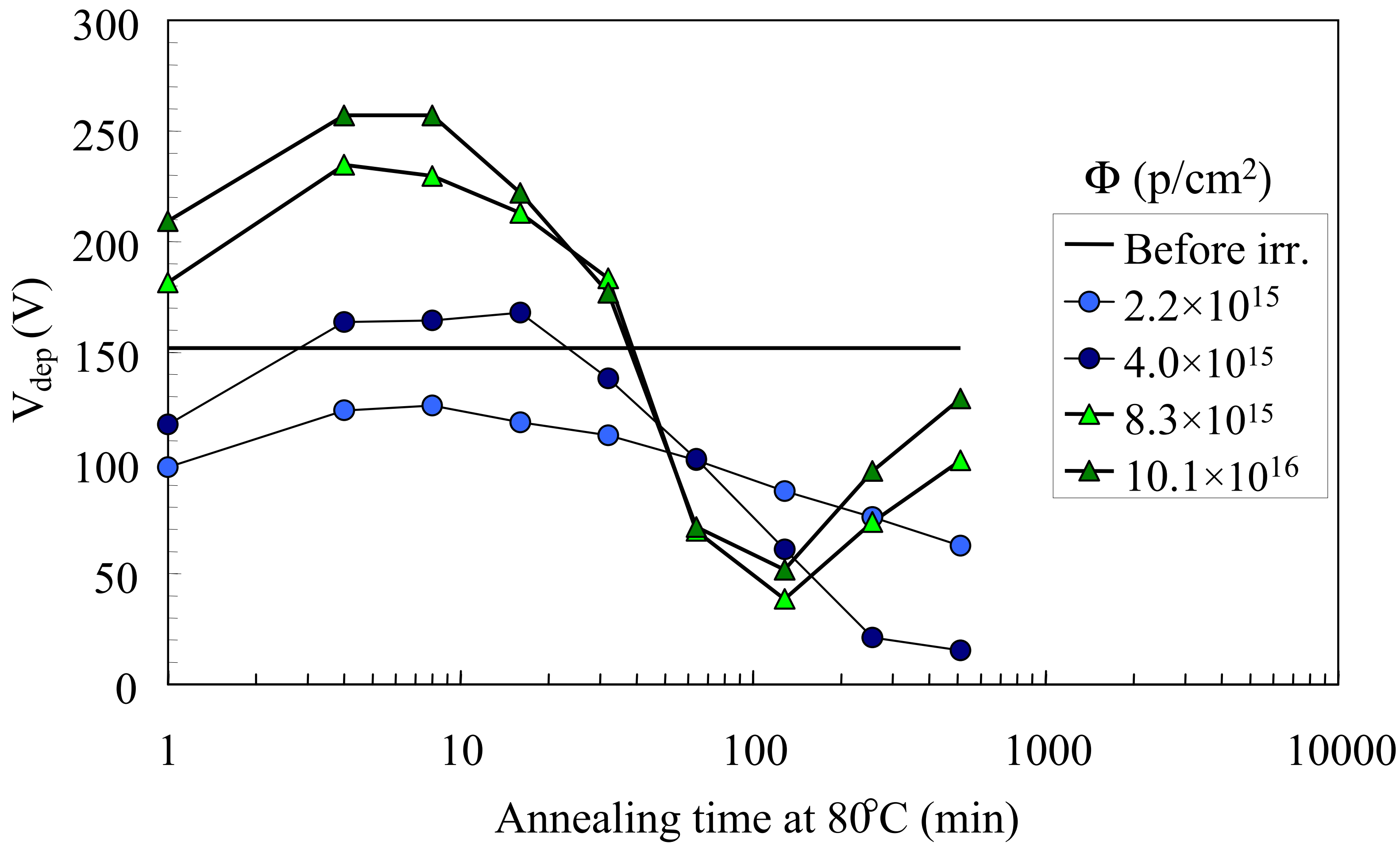
- J_D decreases with annealing time at 80 °C.

Epitaxial n-type 50 μm thick detectors: proton irradiation



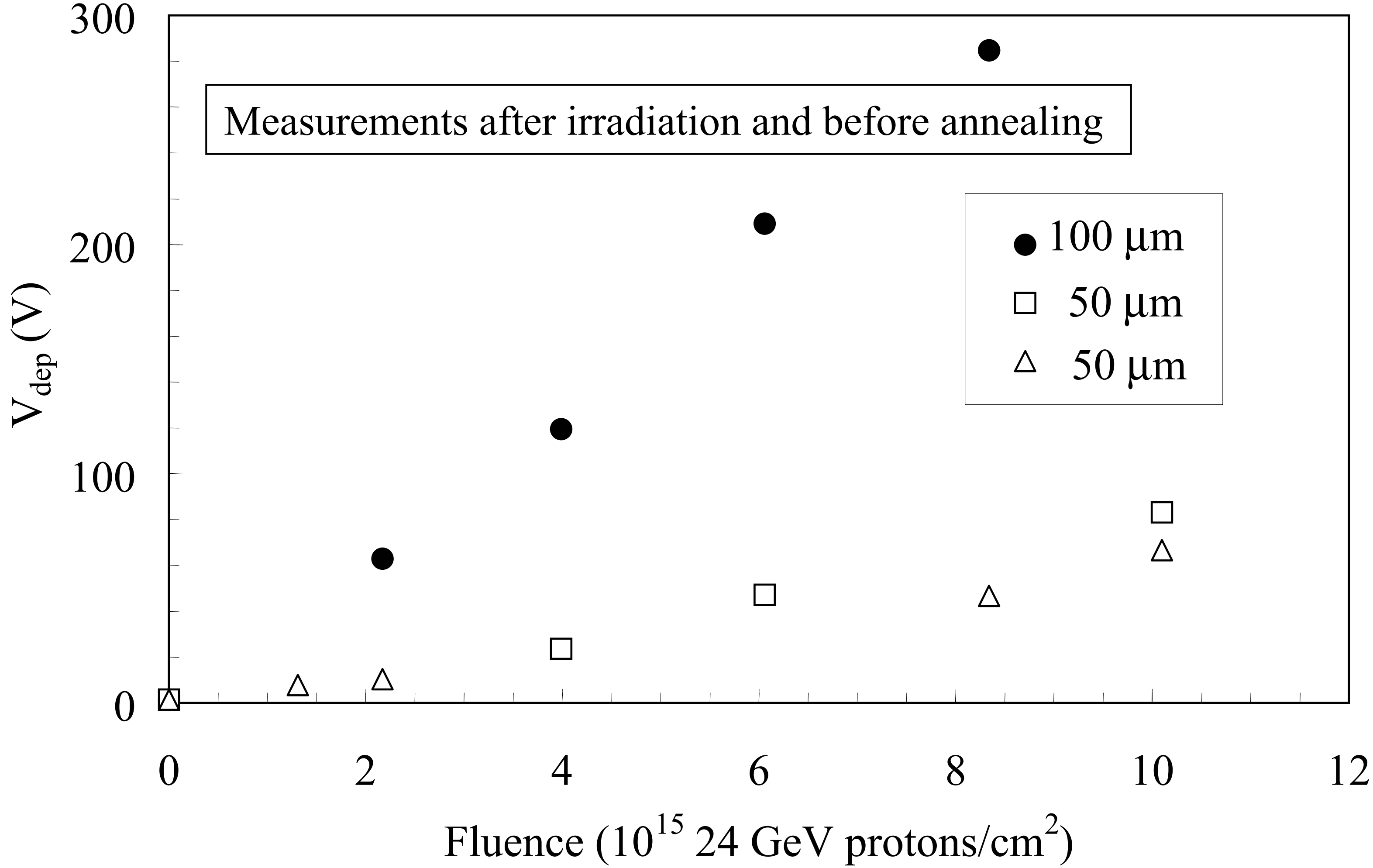
- The minimum of V_{dep} for protons (90-100 V) is higher than for neutrons (40-50 V).
- $V_{dep} > V_{dep,0}$ at 10^{16} p/cm^2.
- The radiation effects induced by neutrons and protons are different.

Epitaxial n-type 50 μm thick detectors: proton irradiation



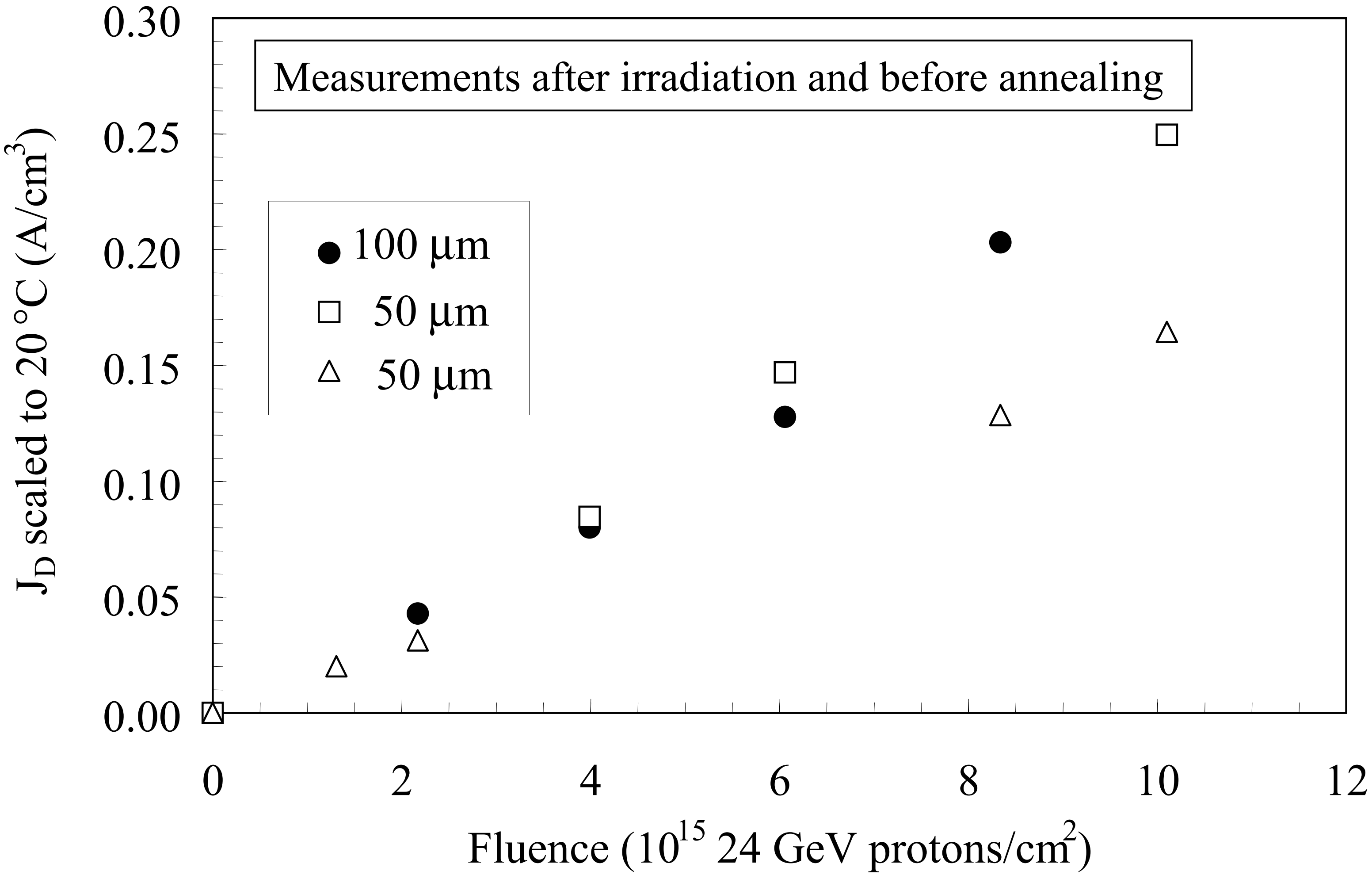
- V_{dep} decreases for annealing times at 80 °C higher than 8 minutes.
- If this effect is due to deep acceptor generation, devices are before SCSI after irradiation:
  for devices irradiated at low fluences V_{dep} ↑, ↓: no SCSI during long-term annealing;
  for devices irradiated at high fluences V_{dep} ↑, ↓, ↑: SCSI during long-term annealing.

FZ thinned n-type detectors: proton irradiation



Device thinning limits the V_{dep} increase after irradiation:
-$V_{dep} \approx 290$ V for 100 µm thick detectors at 8×10^{15} p/cm^2
-$V_{dep} \approx 70$ V for 50 µm thick detectors at 10^{16} p/cm^2

FZ thinned n-type detectors: proton irradiation



- J_D linearly increases with fluence, independently on the thickness. (some data dispersion is present)

DETECTORS: future activity

CERN, 24 GeV protons, May 2004 (n-type materials)

Fluence (24 GeV protons/cm^2)	CZ n-type 300 um	MCZ n-type 300 um	Epitaxial n-type 50 um	Thinned FZ n-type 50 um	Thinned FZ n-type 100 um
5.10E+14	1	1	---	---	---
1.31E+15	---	---	---	1	---
1.54E+15	1	1	1	---	---
2.17E+15	1	1	1	1	1
3.99E+15	1	1	1	1	1
6.06E+15	1	1	1	1	1
8.34E+15	---	---	1	1	1
1.01E+16	---	---	1	2	---
Total	5	5	7	7	4

Lubiana, nuclear reactor neutrons, December 2004 (n- and p-type materials)

Fluence (1 MeV equivalent neutrons/cm^2)	CZ n-type 300 um	MCZ n-type 300 um	Epitaxial n-type 50 um	FZ p-type 200 um	MCZ p-type 300 um
1.00E+14	2	1	---	0	0
1.50E+14	2	1	---	1	1
2.00E+14	2	2	---	2	2
2.50E+14	2	1	1	1	1
5.00E+14	2	1	1	2	2
1.00E+15	2	1	2	1	1
2.00E+15	---	---	2	2	2
3.00E+15	---	---	3	0	0
4.00E+15	---	---	2	---	---
6.00E+15	---	---	2	---	---
8.00E+15	---	---	2	---	---
Total	12	7	9	9	9

ELECTRONICS

-**Electronics for LHC** (10 Mrad(Si) and 10^{15} fast hadrons/cm^2):

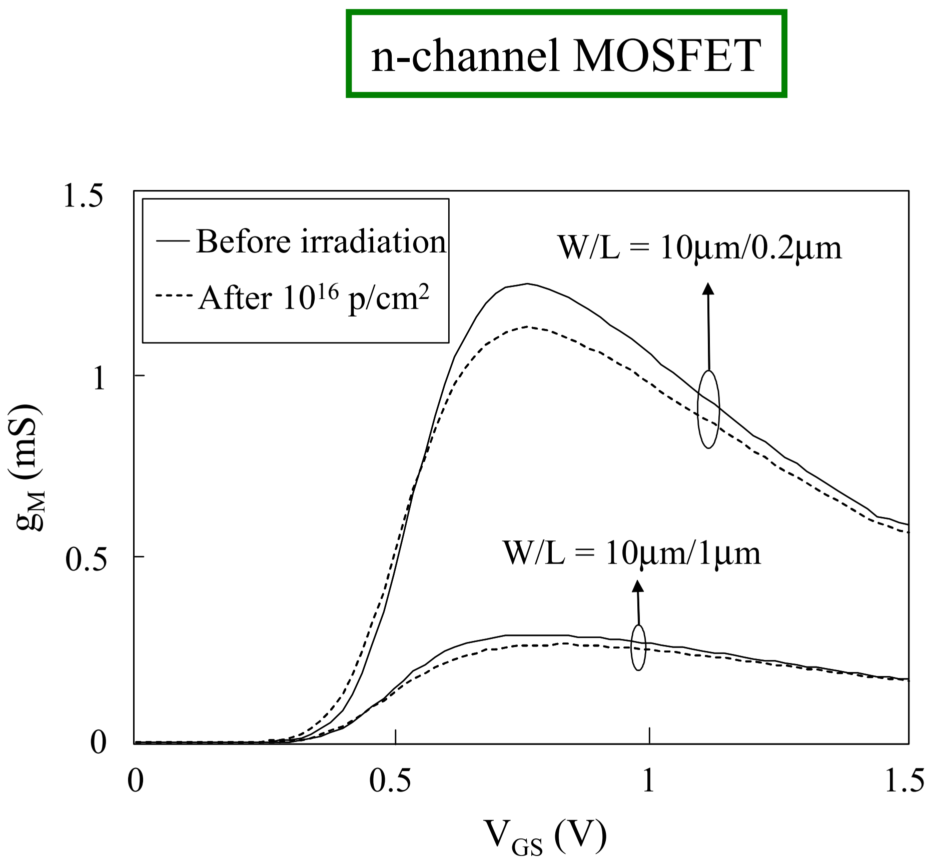
- **0.25 µm CMOS** technology from **IBM**;
- **5.5 nm** oxide thickness;
- radiation hardened by design: **enclosed geometry** transistors.

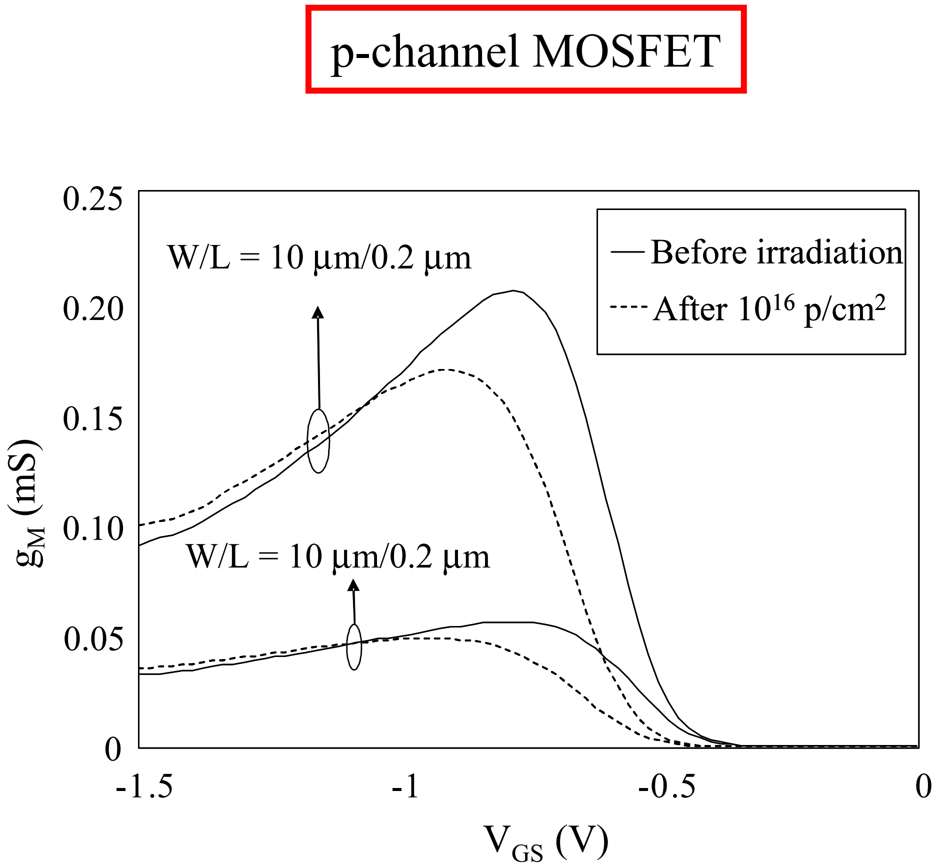
The 0.25 µm CMOS technology will not be any more available for Super-LHC

-**Electronics for Super-LHC** (100 Mrad(Si) and 10^{16} fast hadrons/cm^2): following the scaling down of the commercial CMOS technologies?

- **0.13 µm** minimum channel length;
- **2.5 nm** oxide thickness;
- no radiation hardened by process;
- no radiation hardened by design (i.e., no enclosed geometry).

0.13 µm CMOS technology: proton irradiation





- g_M peak decrease 15%
- g_M peak shift negligible

- g_M peak decrease higher than in n-MOSFET
- g_M peak shift of 200 mV