RD50

CCE measurements and annealing studies on proton irradiated p-type MCz diodes

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Contents

- CCE setup
- CCE Measurements on irradiated p-type MCz
- CV/IV characterization of irradiated p-type MCz
- Differences in reverse-annealing due to thermal donors

Investigated material

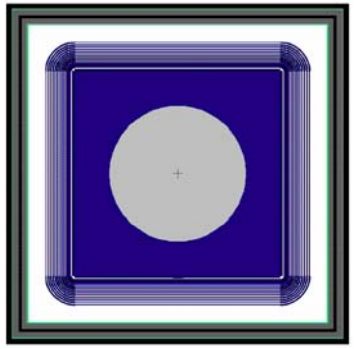
300 µm MCz by Okmetic
Processing: ITC-IRST square MG diodes n^+/p (batch SMART2)

W066 – series: p-spray dose = 3 x 10^{12} cm^{-2} — 8 diodes with V_{DEP} = 8 to 17 V
W182 – series: p-spray dose = 5 x 10^{12} cm^{-2} — 8 diodes with V_{DEP} = 97 to 110 V

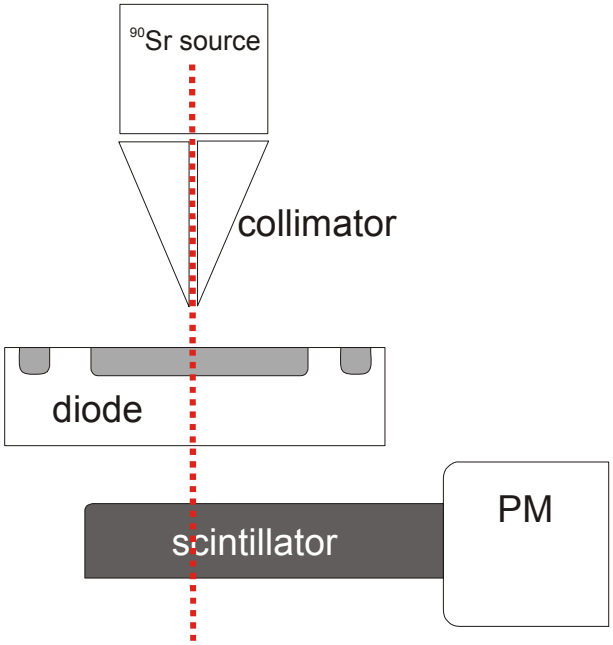
After being processed together the two wavers were inhomogeneous:
Differences in V_{DEP} between the wavers and between different locations on the waver due to inhomogeneous TD generation
according to talk by D. Menichelli, at the Hamburg-Workshop;

Irradiation: 24 GeV/c protons @ CERN/PS up to Φ = 10^{16} cm^{-2}

Die dimension: $(5920\ \mu m)^2$
Diode area (p+ implant): 13.688 mm^2
Metal hole area: 4.524 mm^2 (Φ 2.4 mm)
1 Large guard (~90 µm) + 10 float rings



CCE system



bias: up to 1000 V
guard ring: connected to ground

noise: 567e- + 4.26 e- /pF

trigger rate with ^{90}Sr source: ≈ 50-60 Hz

control software: labview

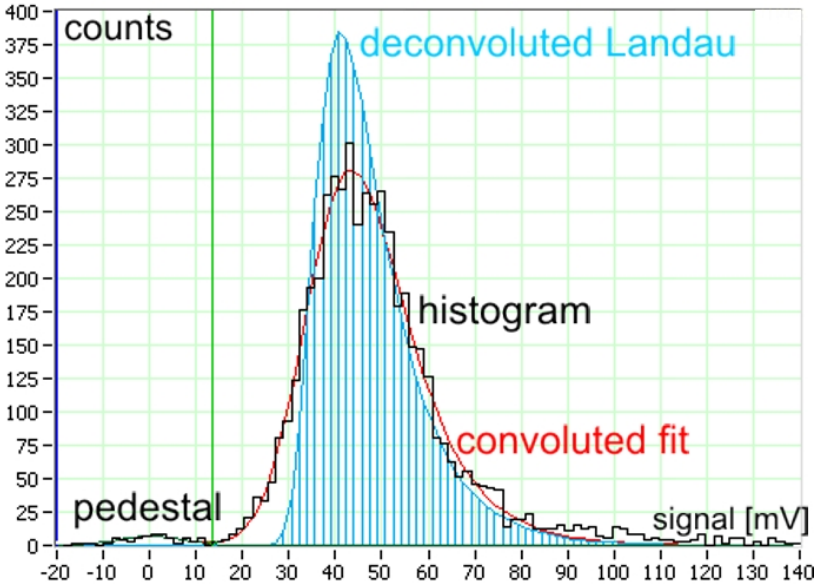
NIKHEF CCE system © Fred Hartjes

signal shaping time: 2.5 µs

gain calibration factor: 245 e^-/mV

temperature:
down to -30 °C with fridge + peltier

CCE: measurement & analysis

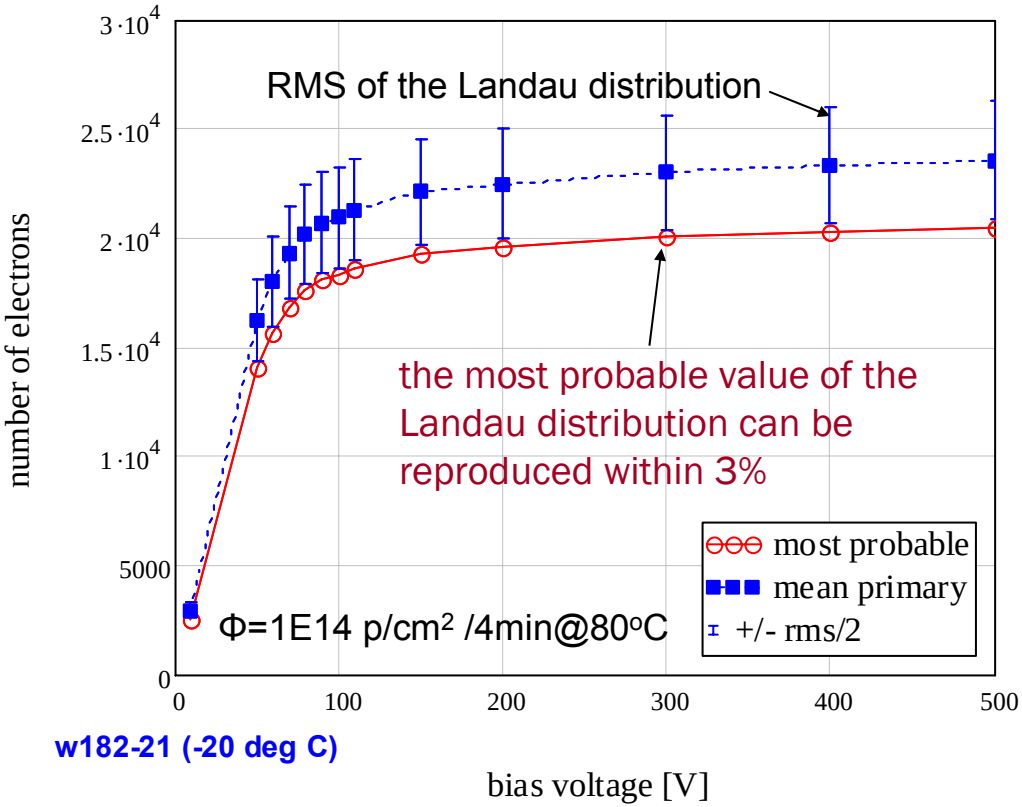


pedestal events: < 2%

separate pedestal measurement to deconvolute gaussian noise fror signal

NIKHEF CCE analysis software

automatic Landau fit and noise deconvolution



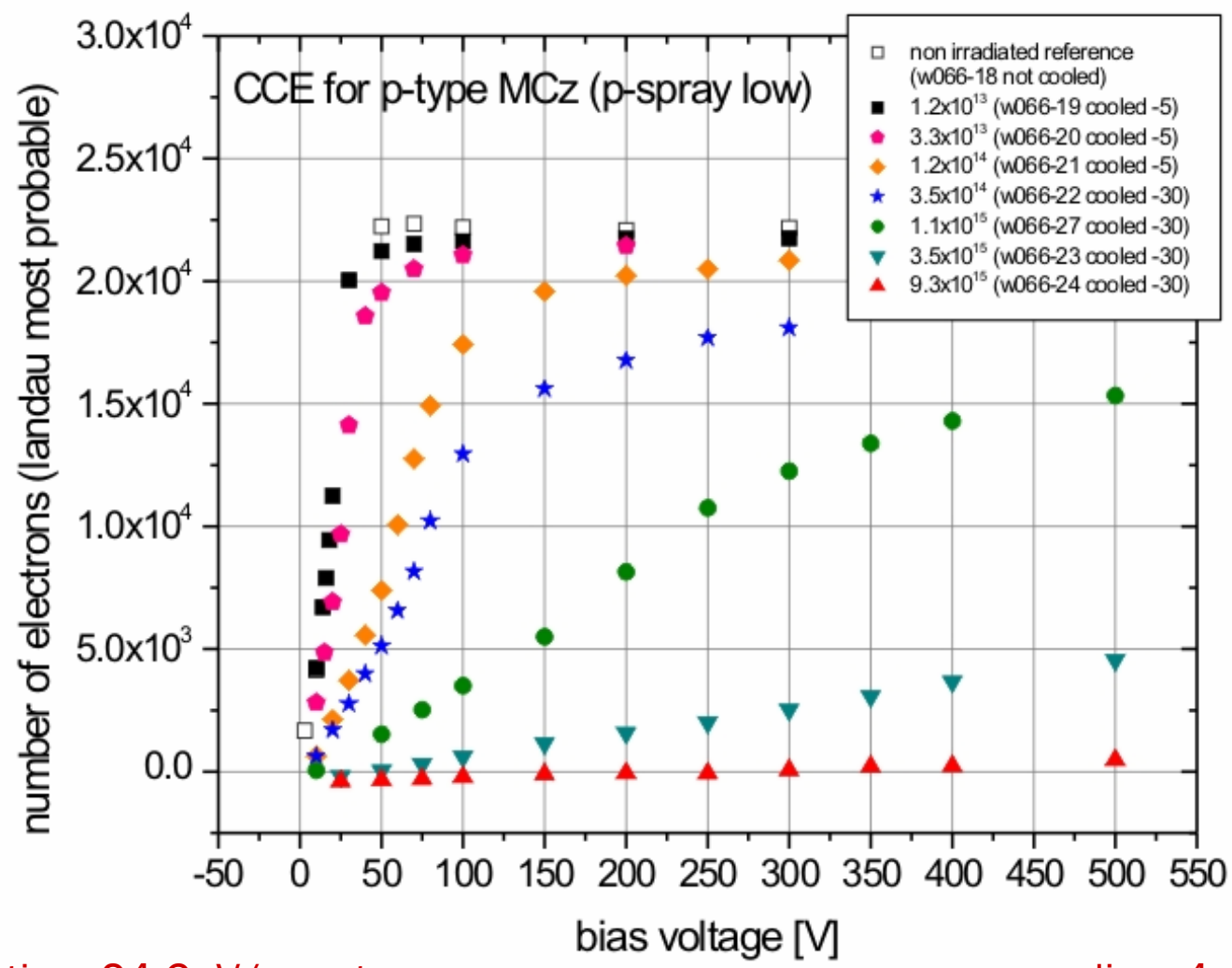
Measurements & Parameters

Measurements performed for the investigations

- CCE: measured at -10^{o}C (-25^{o}C for highly irradiated diodes)
- CV: measured at -10^{o}C and at room temperature (RT)
- IV: measured at -10^{o}C and at room temperature (RT)
- Annealing: at 80^{o}C

T-dependence of measurements!

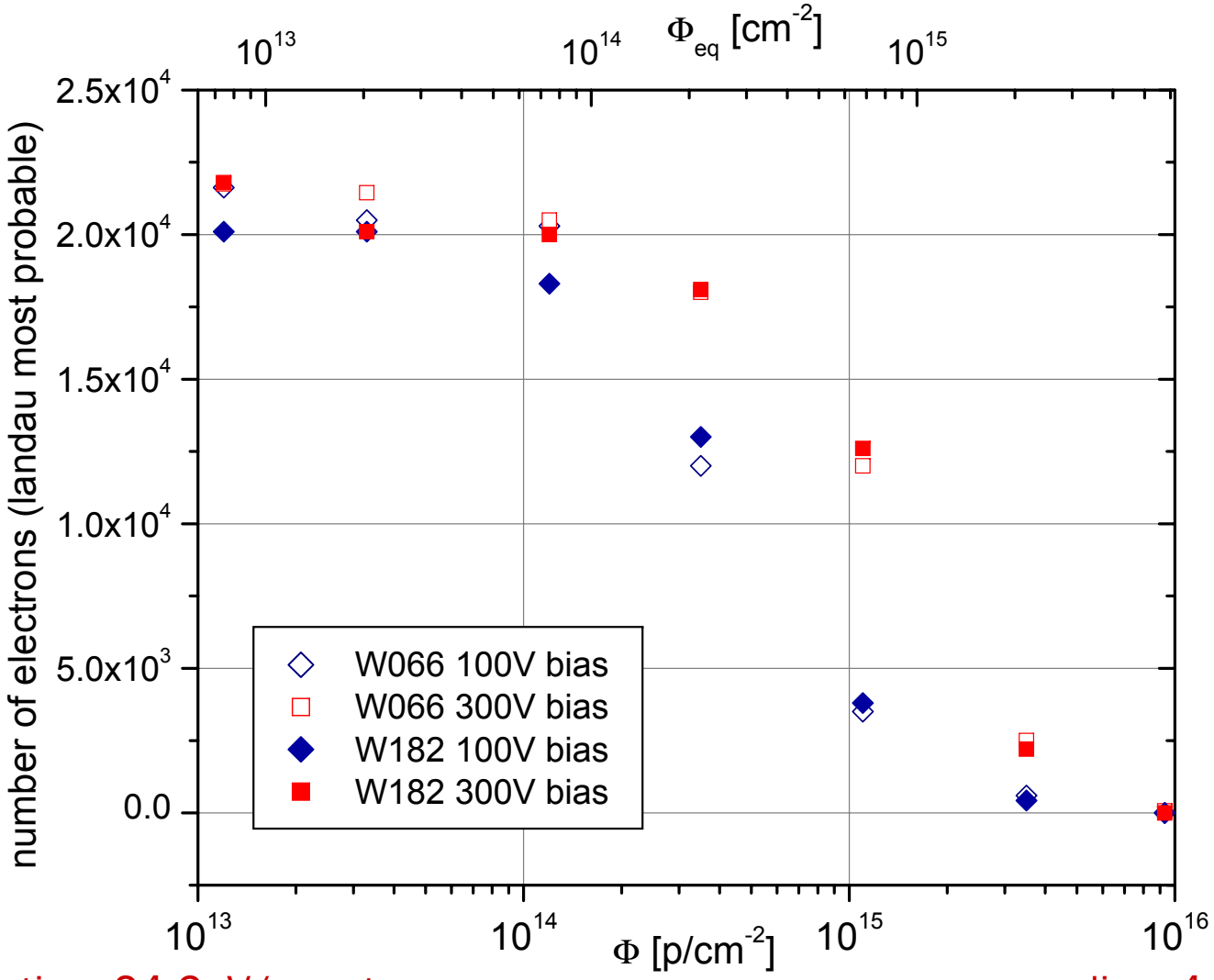
CCE for irradiated detectors



irradiation: 24 GeV/c protons

annealing: 4 min @ 80 °C

CCE as a function of fluence

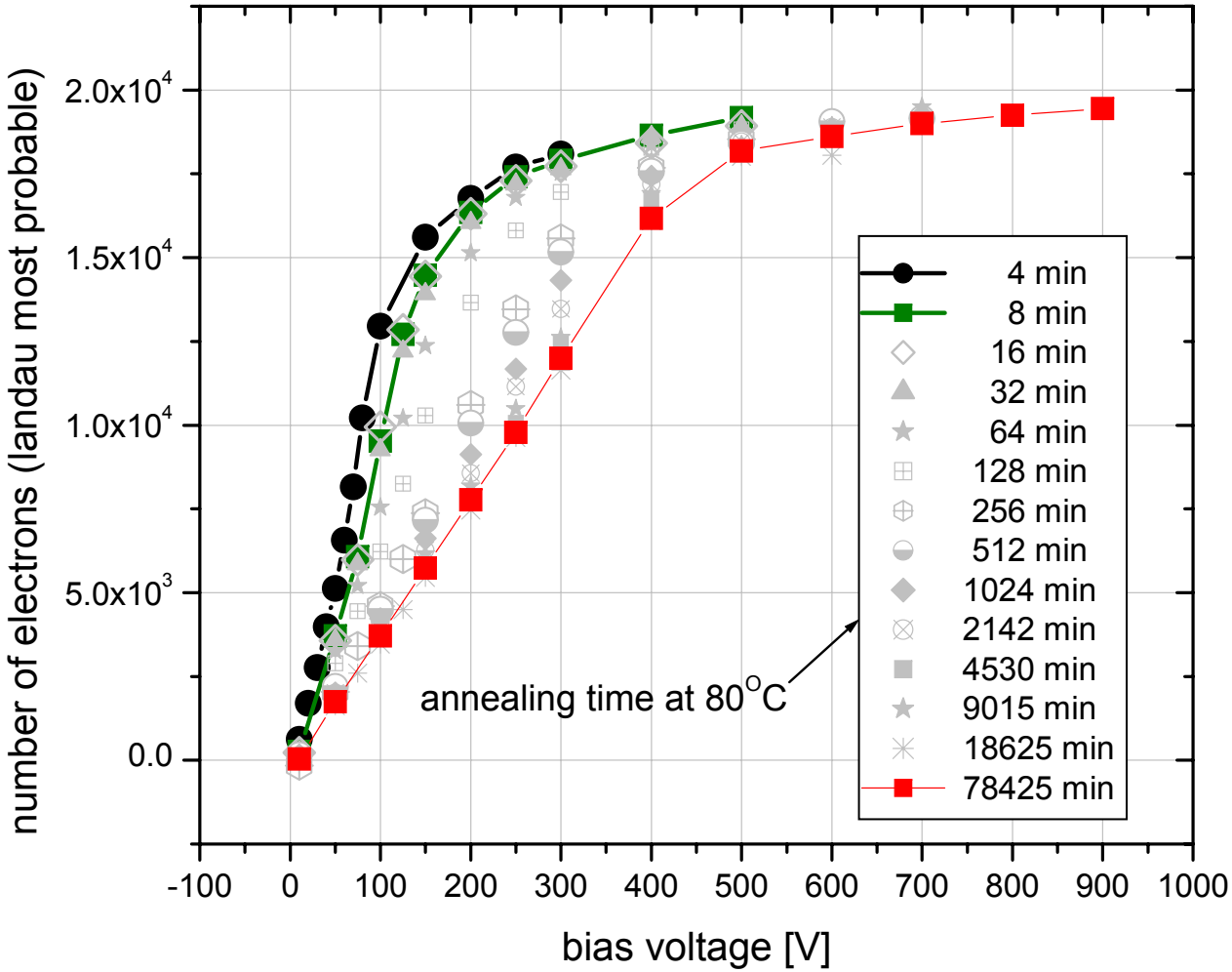


irradiation: 24 GeV/c protons

annealing: 4 min @ 80 °C

Annealing: CCE

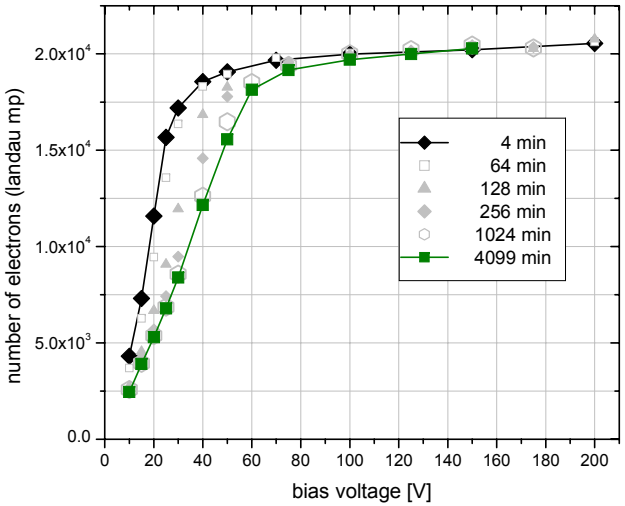
IRST-W066-22 irradiation: $\Phi = 3.5\times10^{14}$ p/cm^2 CCE@-10^{o}C



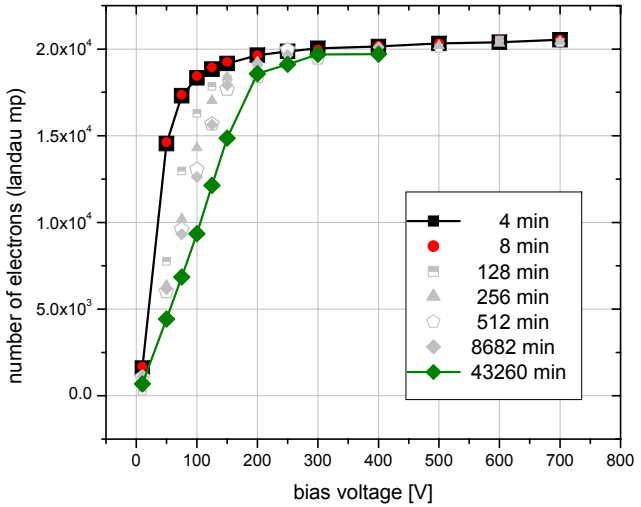
only depletion voltage changes, maximum CCE remains at 82%

Annealing: CCE

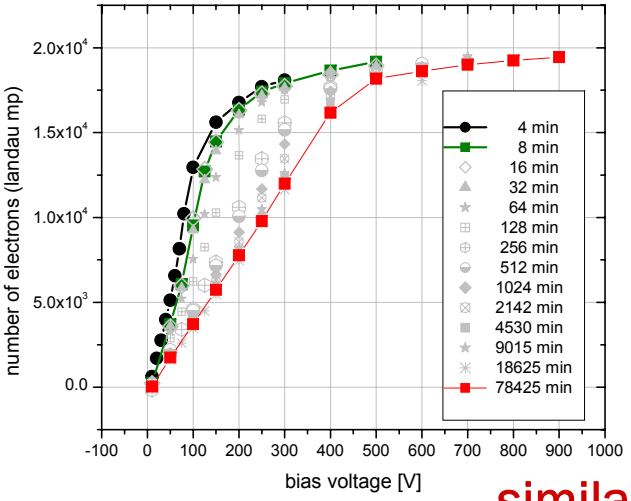
IRST-W066-20 irradiation: $\Phi = 3.3\times10^{13}$ p/cm^2



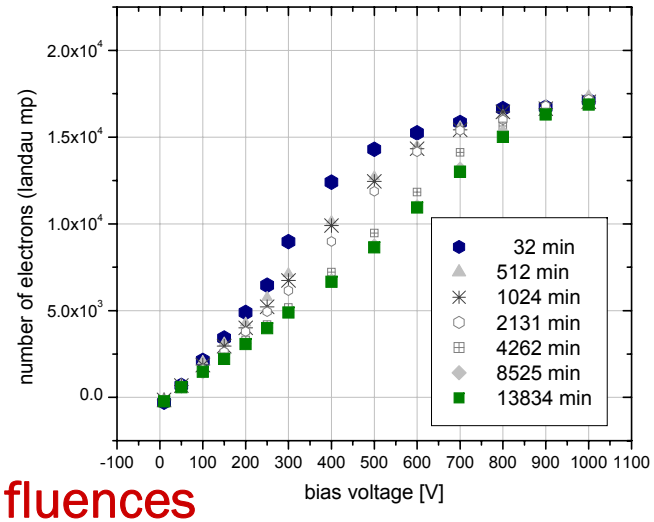
IRST-W066-21 irradiation: $\Phi = 1.1\times10^{14}$ p/cm^2



IRST-W066-22 irradiation: $\Phi = 3.5\times10^{14}$ p/cm^2



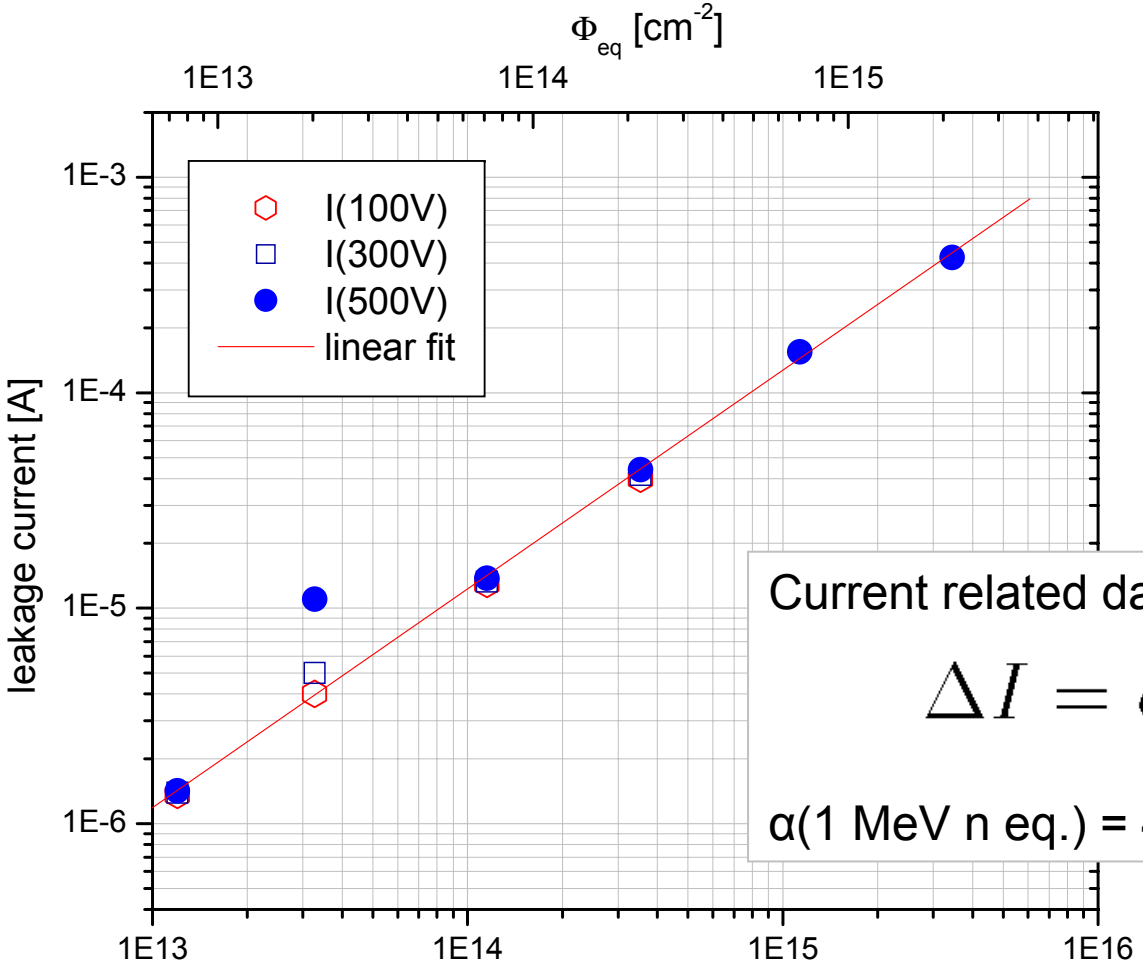
IRST-W066-27 irradiation: $\Phi = 1.1\times10^{15}$ p/cm^2



similar results for all fluences

Leakage current

IV measurements @ room temperature



Current related damage rate:

$$\Delta I = \alpha \, \Phi_{eq} \, V$$

α(1 MeV n eq.) = 4.9 x 10^{-17} [A cm^{-1}]

irradiation: 24 GeV/c protons

annealing: 4 min @ 80 °C

Annealing: leakage current

Annealing @ 80°C; measurements at room temperature

Measurement of the current related damage rate α as a function of annealing time:

$$\Delta I = \alpha \, \Phi_{eq} \, V$$

Comparison with parametrization of α:

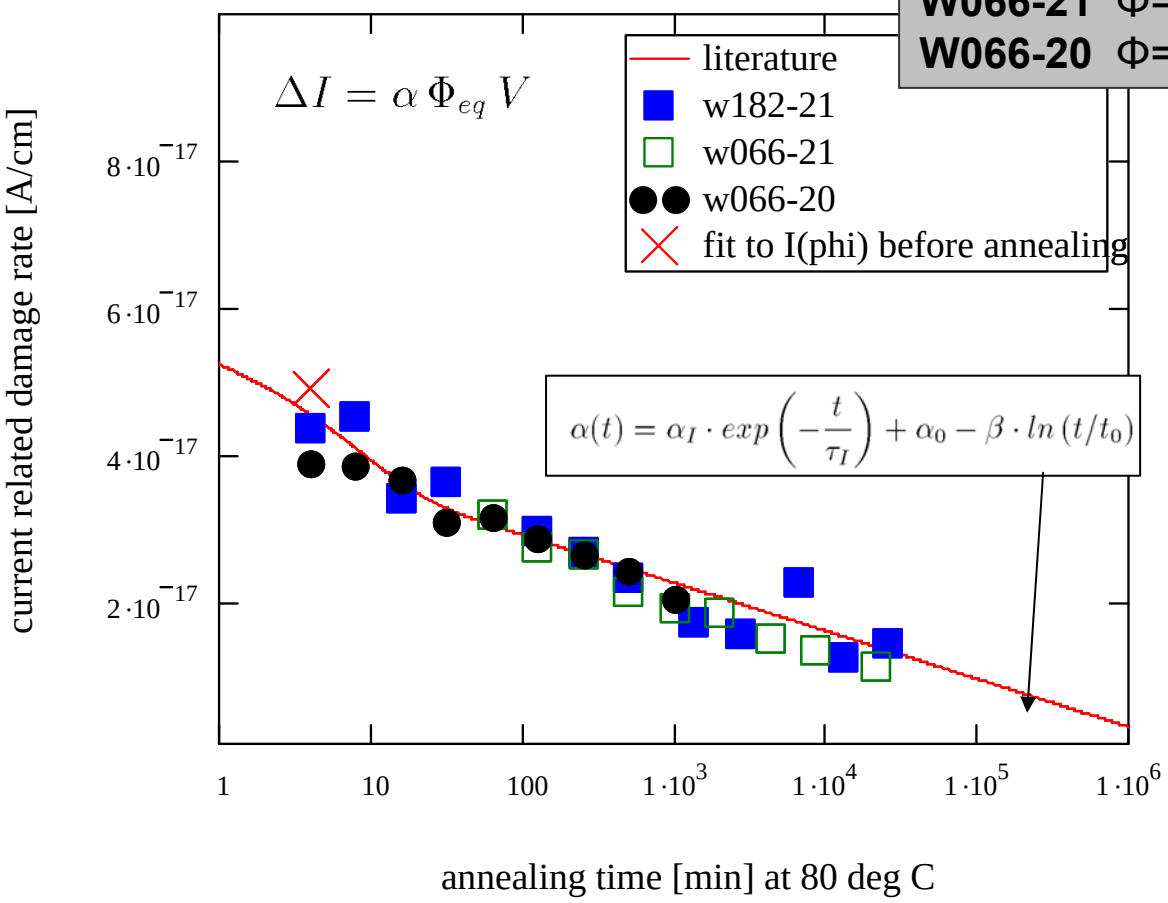
$$\alpha(t) = \alpha_I \cdot exp\left(-\frac{t}{\tau_I}\right) + \alpha_0 - \beta \cdot ln\,(t/t_0)$$

T_a [°C]	α_I 10^{-17} A/cm	τ_I [min]	α_0 10^{-17} A/cm	β 10^{-18} A/cm	t_0 [min]
21	1.23	1.4×10^4	7.07	3.29	1
49	1.28	260	5.36	3.11	1
60	1.26	94	4.87	3.16	1
80	1.13	9	4.23	2.83	1
106	–	–	3.38	2.97	1

Annealing: leakage current

Results for annealing of 3 different diodes:

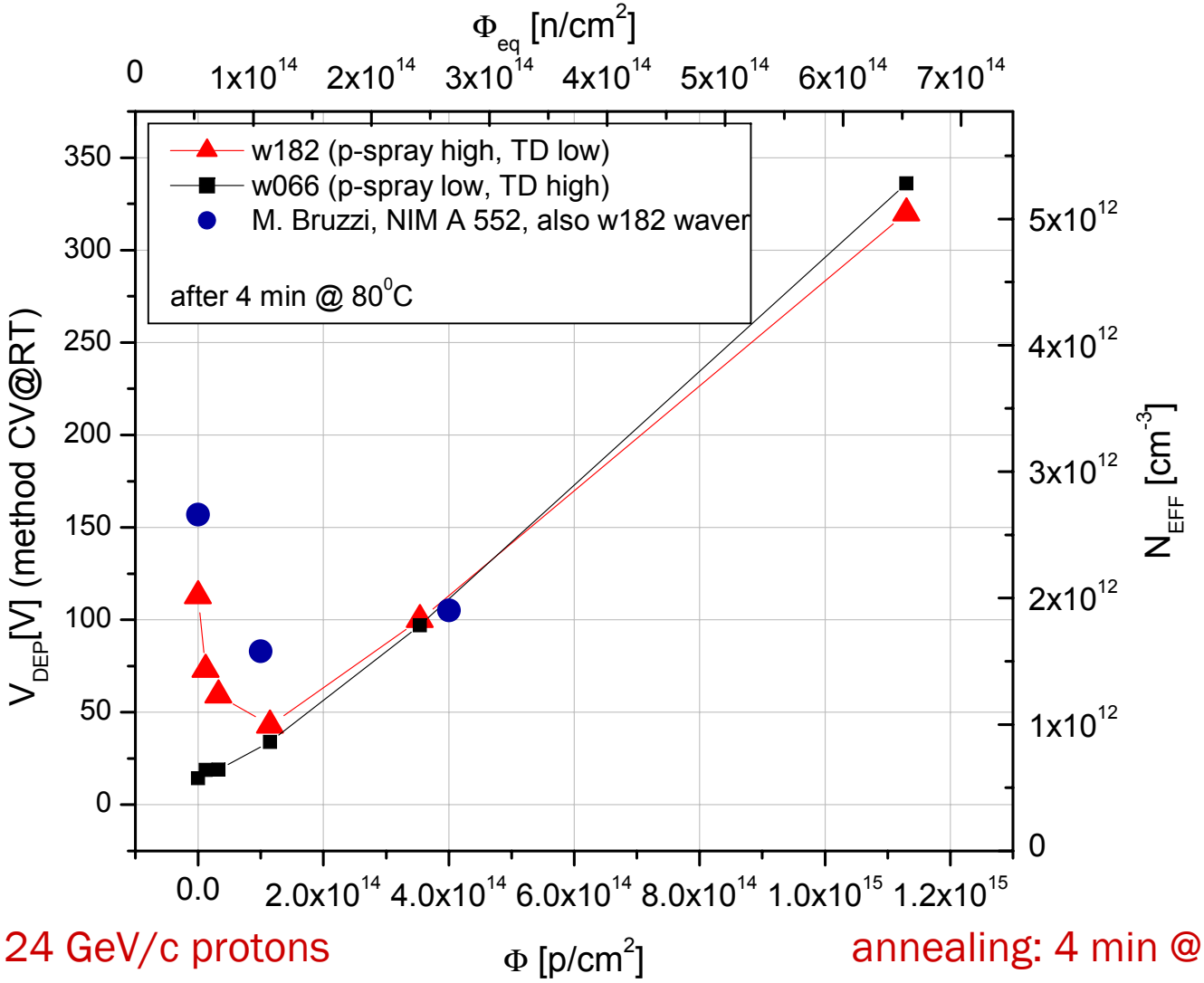
W182-21 Φ= 1.1×10^{14} p/cm^2
W066-21 Φ= 1.1×10^{14} p/cm^2
W066-20 Φ= 3.3×10^{13} p/cm^2



Currents corrected to reference temperature!

V_{DEP} as a function of fluence

CV measurements @ room temperature

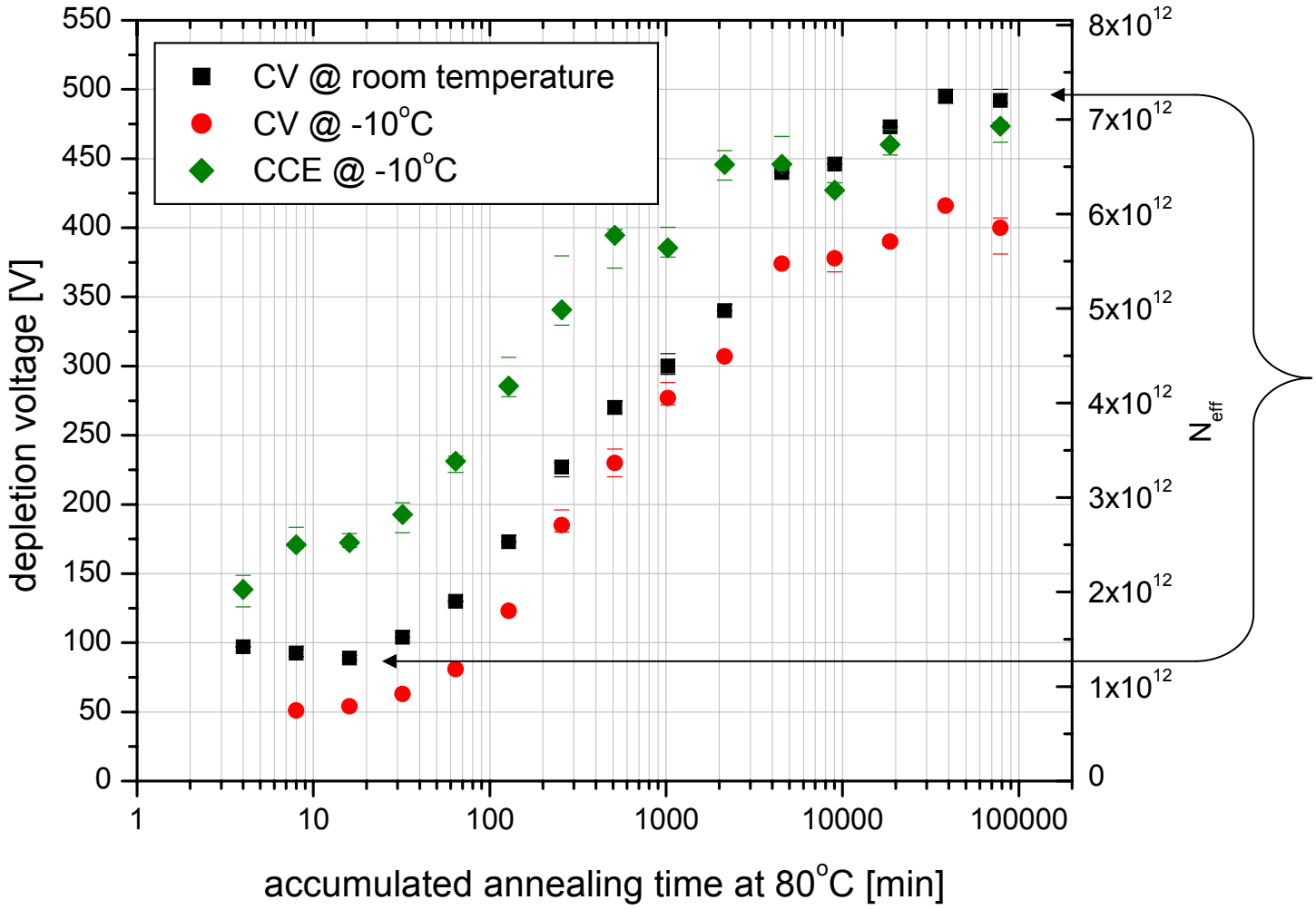


irradiation: 24 GeV/c protons

annealing: 4 min @ 80 °C

Annealing: V_{DEP}

IRST-W066-22 irradiation: $\Phi = 3.5 \times 10^{14}$ p/cm^2



Evaluation of:

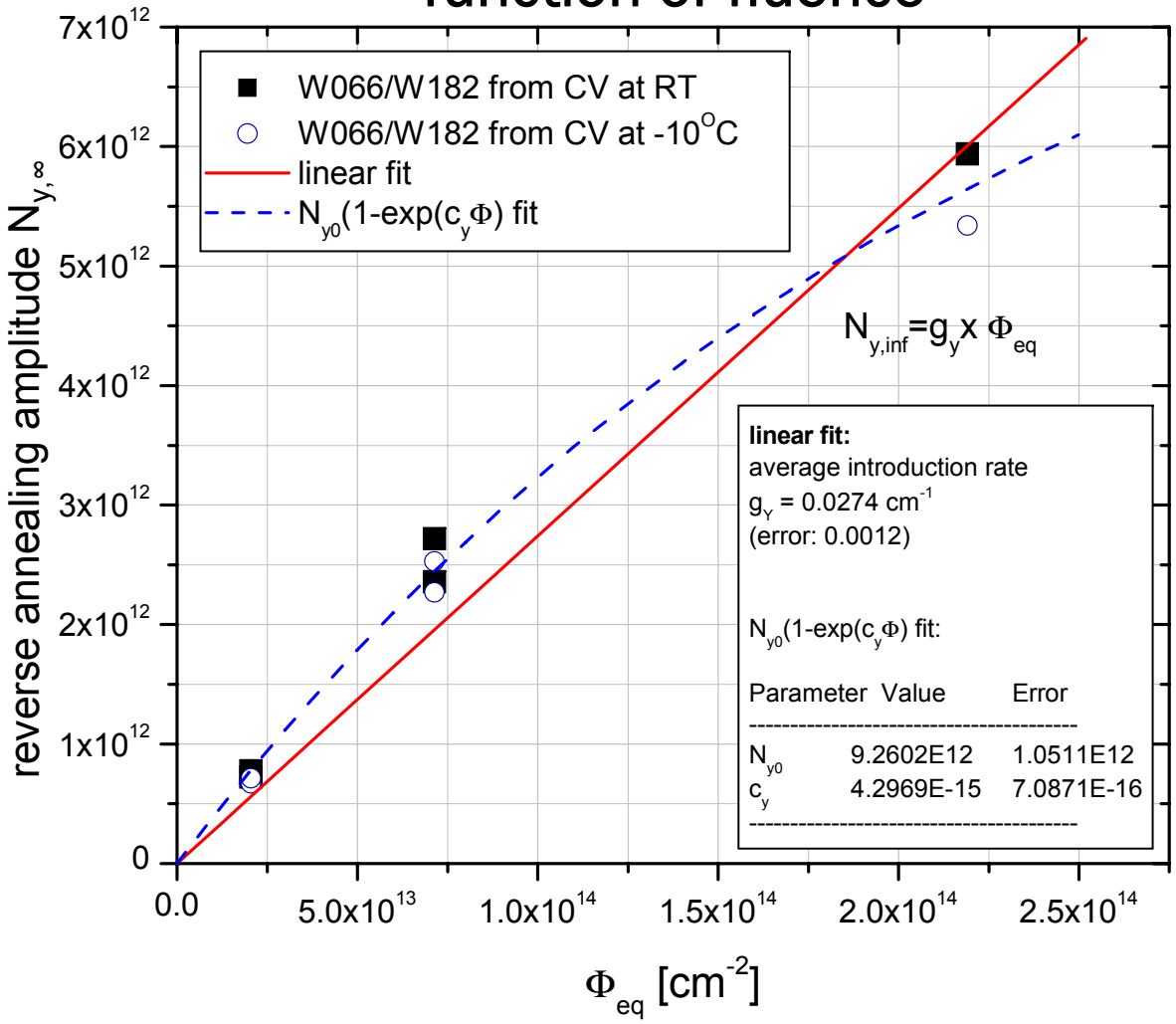
$\Delta N_{eff} \approx 6E12$ cm^{-3}

$\equiv N_{y,\infty}$

reverse annealing amplitude

Annealing: V_{DEP}

Evaluation of change in effective doping concentration as a function of fluence



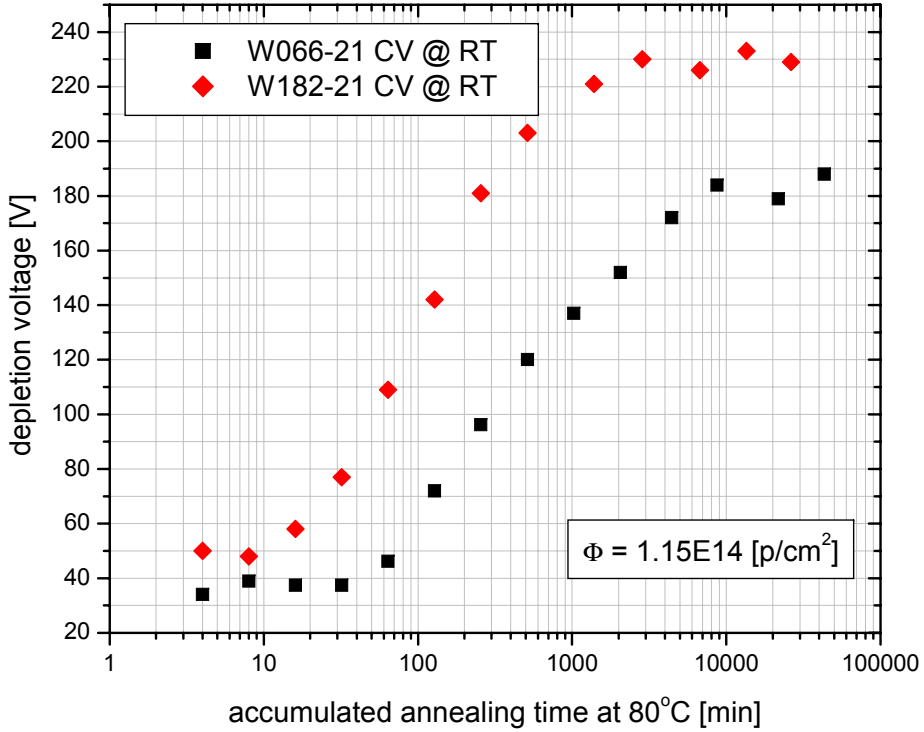
Difference in annealing behavior due to TDs?

Difference between w066 and w182 series presumably due to TDs:
Depletion voltage before irradiation ≈ 10 x higher for w182!

Depletion voltage before irradiation			
w066-20	12	w182-20	107.6
w066-21	11.3	w182-21	108.2
w066-22	9.3	w182-22	105.2
w066-27	7.8	w182-27	96.4

Higher TD concentration

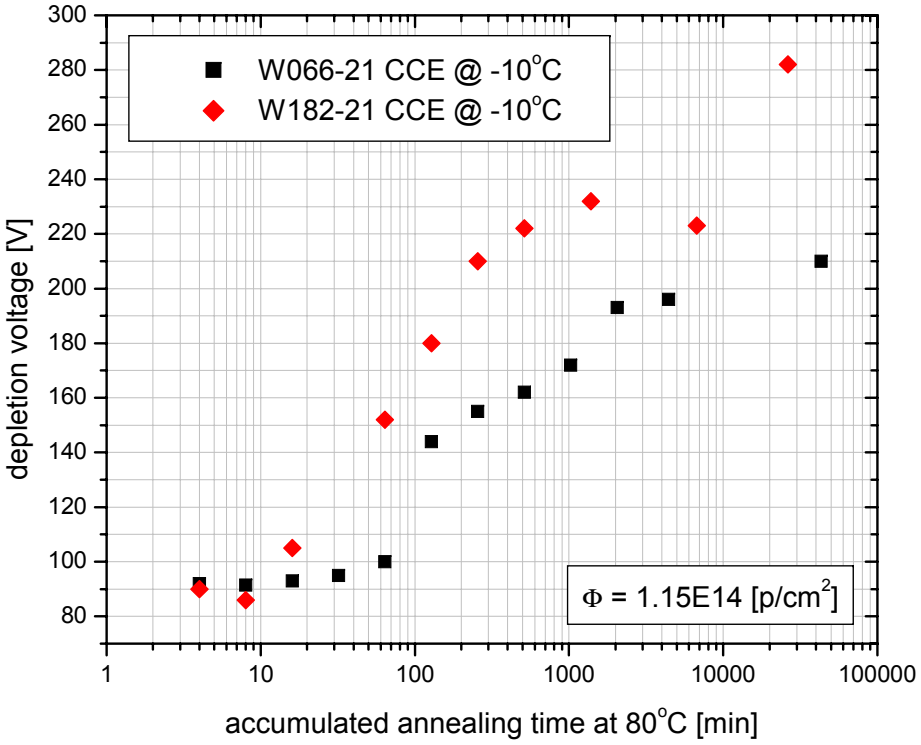
Reverse annealing of W066 series (higher TD concentration) is delayed:



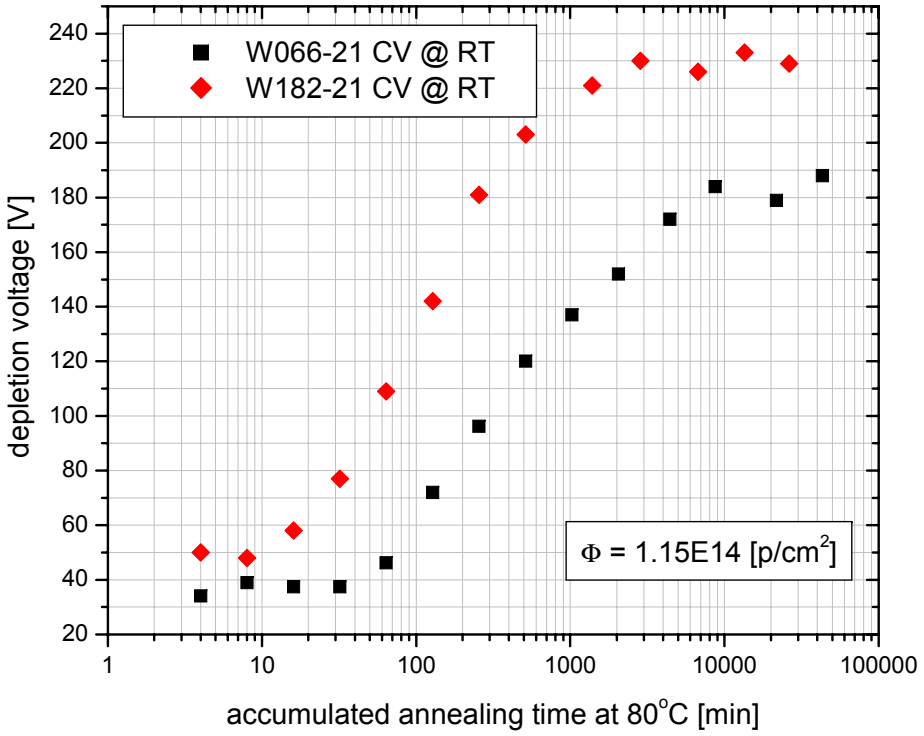
Difference in annealing behavior due to TDs?

Effect confirmed with independent evaluation of V_{DEP} by CV and CCE

V_{DEP} by CCE

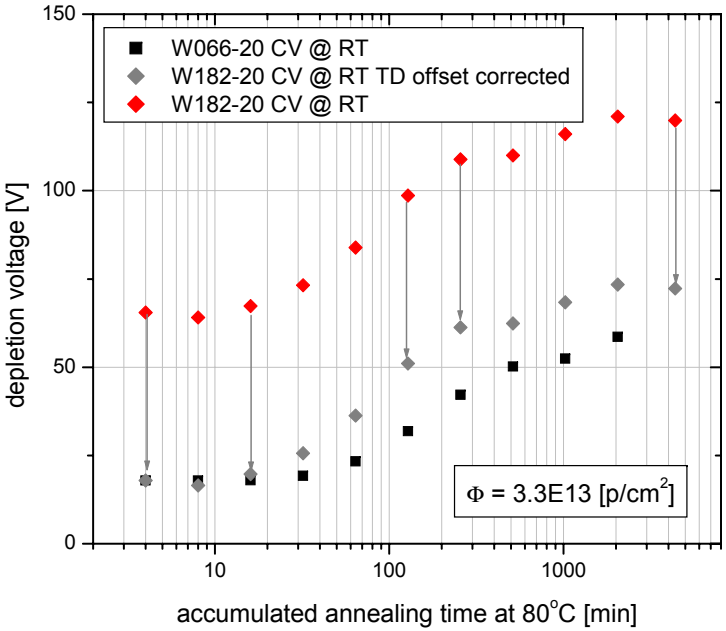


V_{DEP} by CV

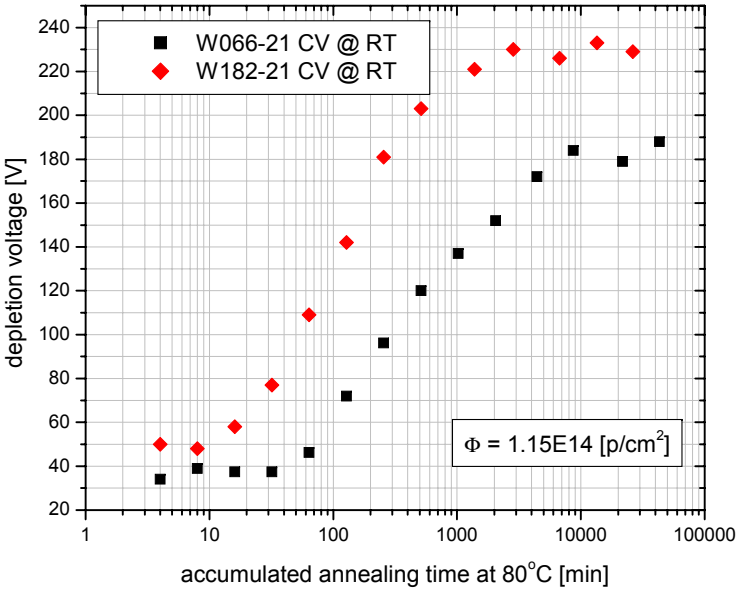


Reverse annealing of W066 series is delayed

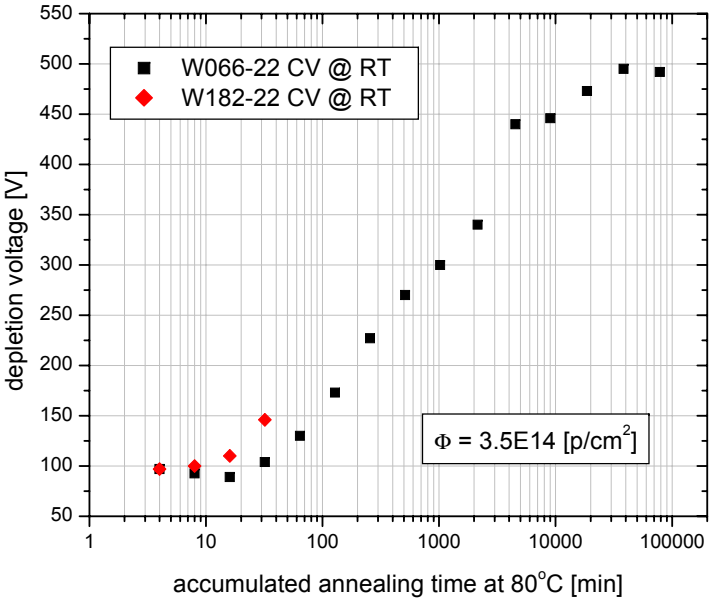
RD50 *Difference in annealing behavior due to TDs?*

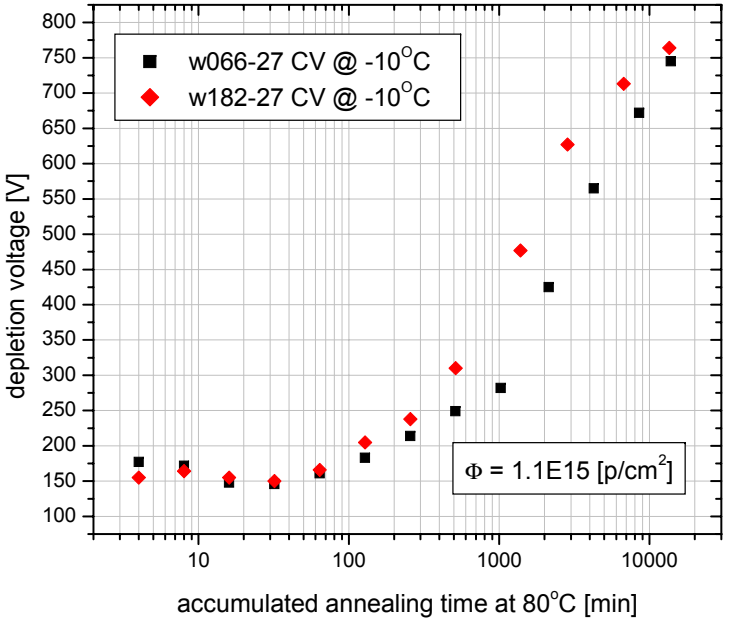


Effect confirmed for different fluences:



reverse annealing of W066 series (higher TD conc.) is delayed

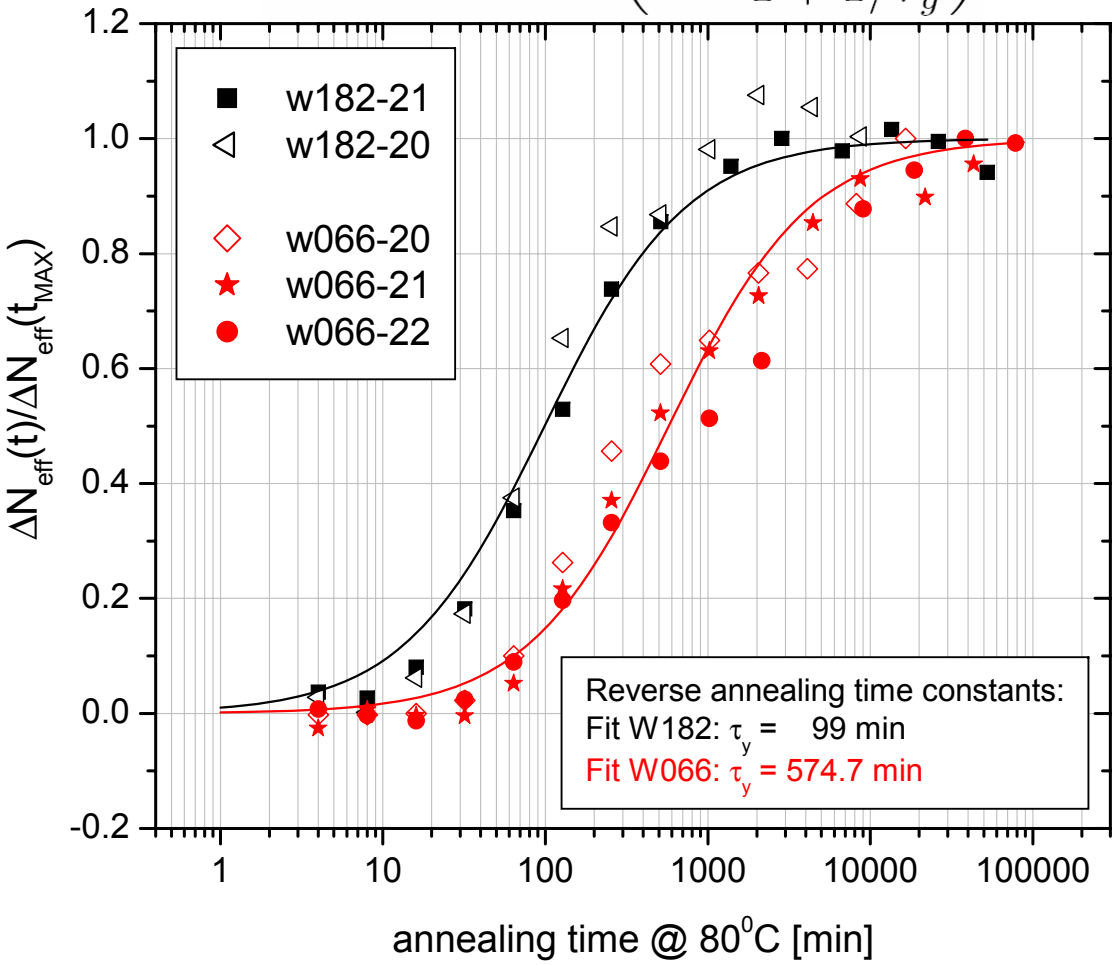




Difference in annealing behavior due to TDs?

Comparison of reverse-annealing time constants

$$N_y(t) = N_{y,\infty}\left(1 - \frac{1}{1 + 1/\tau_y}\right)$$



Summary

- CCE/CV/IV measured for p-type MCz diodes irradiated up to fluences of 10^{16} 24 GeV/c p/cm^{-2}

  CCE(300V): 93% @ 1.2E14 p/cm^2 (7.4E13 1MeV/c n/cm^2)
  55% @ 1.1E15 p/cm^2 (6.8E14 1MeV/c n/cm^2)

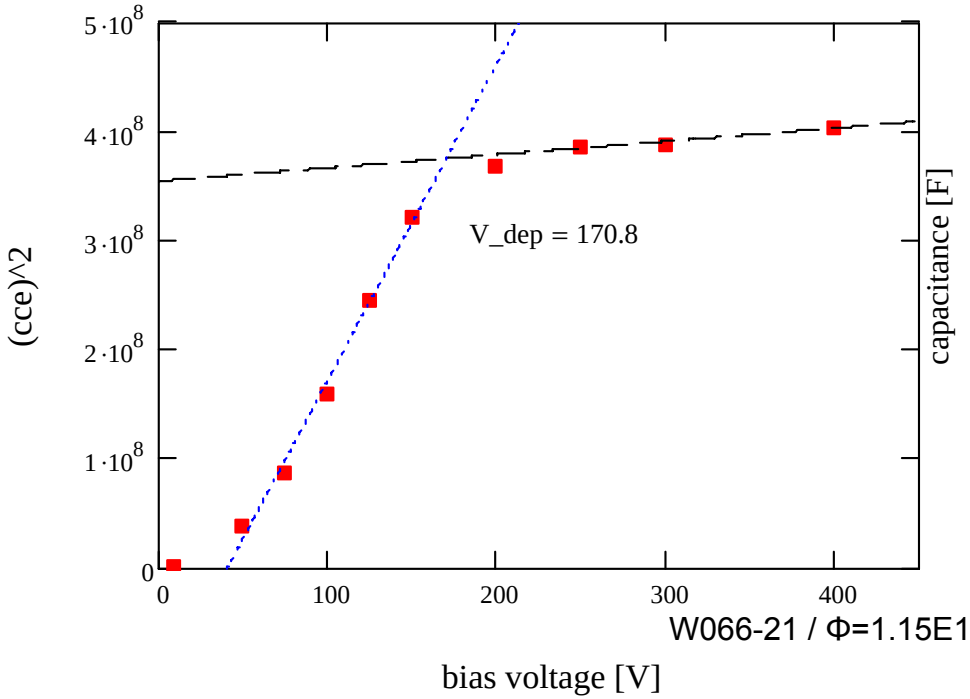
- Annealing of an irradiated diode changes depletion voltage and leakage current but not CCE

- TDs seem to influence reverse-annealing:
  higher TD concentration → delayed reverse-annealing?

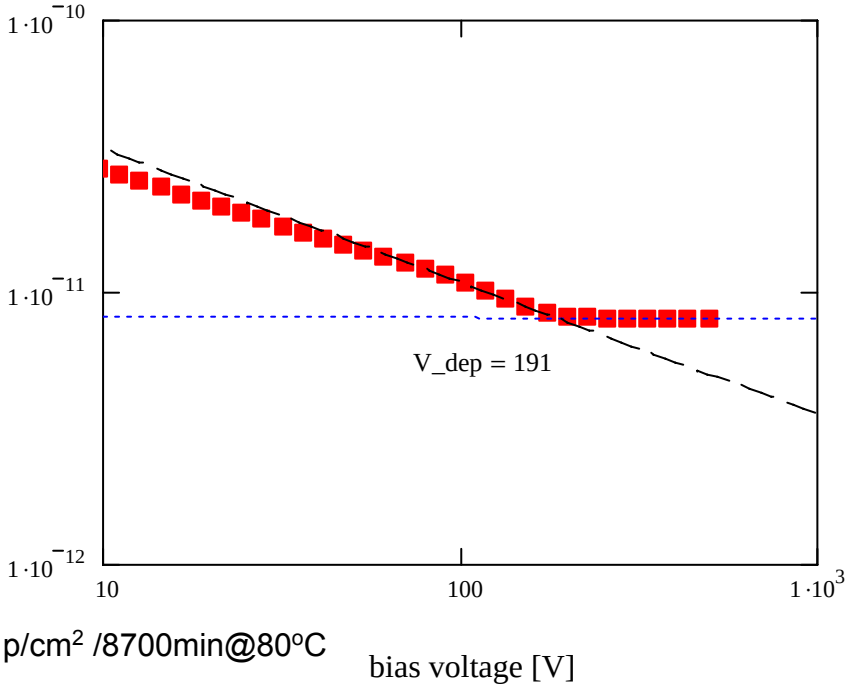
- Plan: systematic study of this effect by deliberate activation of TDs in p-type MCz.

backup slide Evaluation V_{DEP}

V_{DEP} by CCE @ -10°C



V_{DEP} by CV @ RT



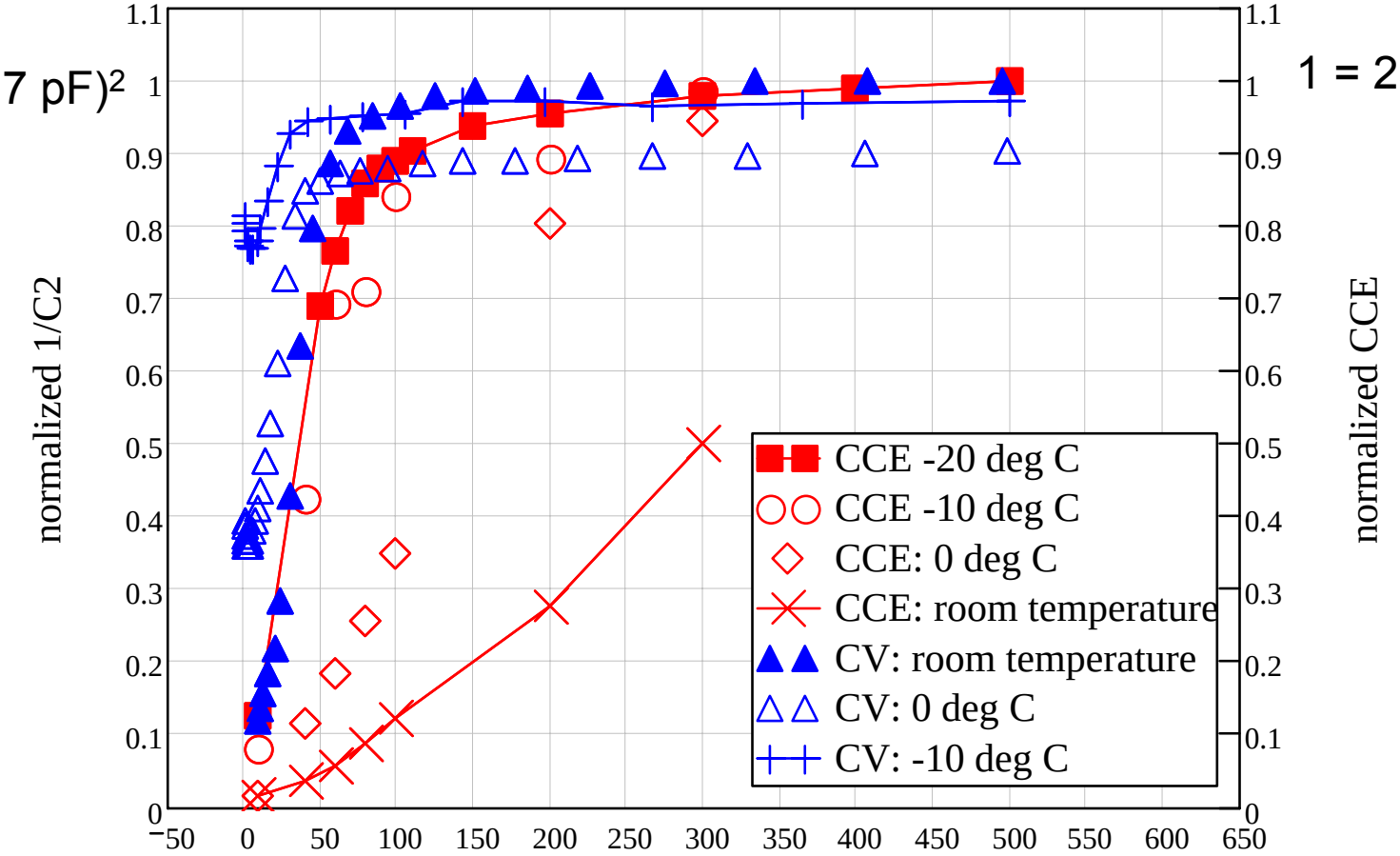
W066-21 / Φ=1.15E14 p/cm² /8700min@80°C

evaluation by CCE usually leads to higher values of VDEP than CV: differences tue to T dependencies and slow CCE measurement

backup slide CCE: comparison to CV

1 = 1/(6.7 pF)^2

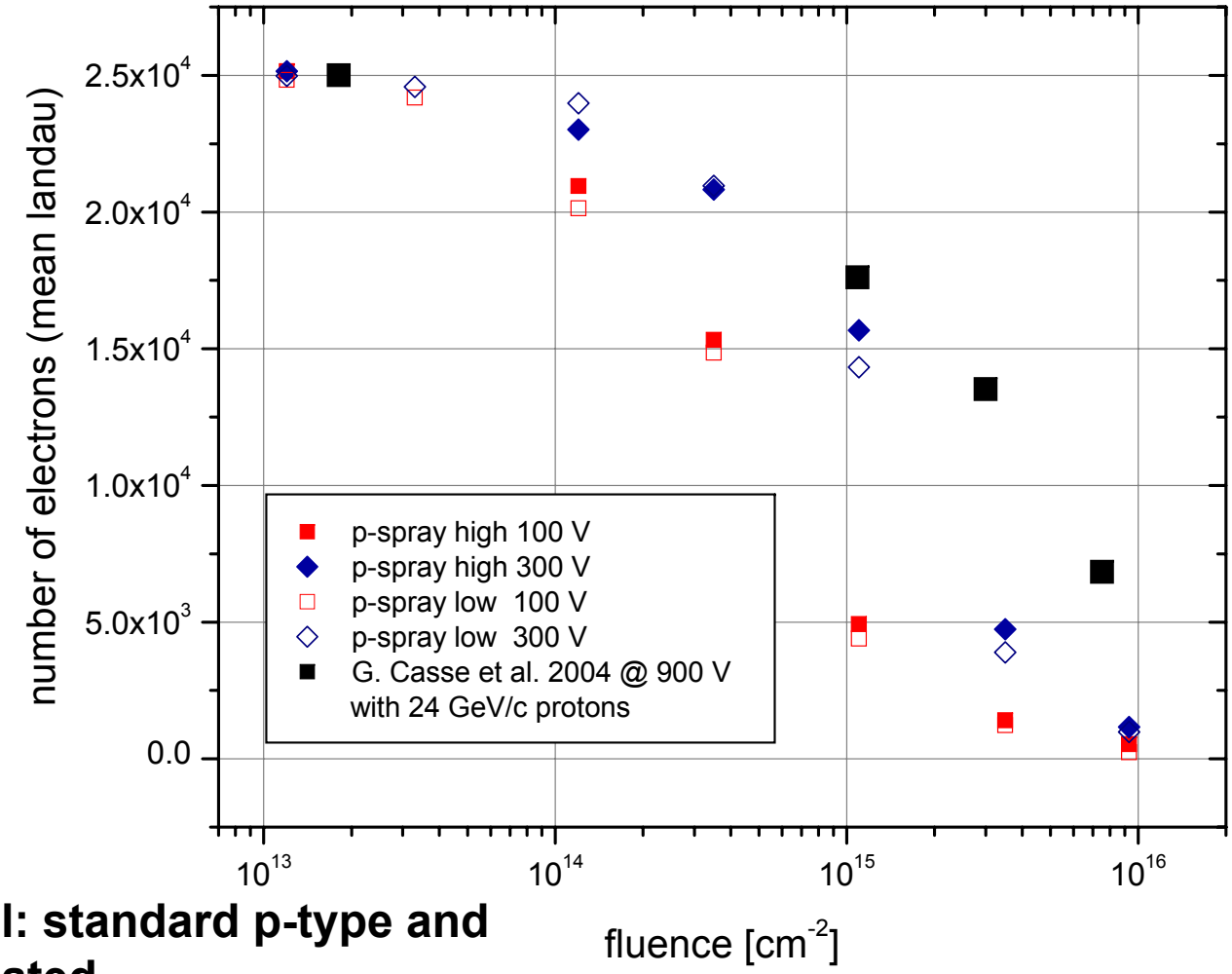
1 = 23000 e$^-$



W182-21 / Φ=1E14 p/cm^2 /4min@80^{o}C

....considering the T-dependencies in the measurements of irradiated detectors!

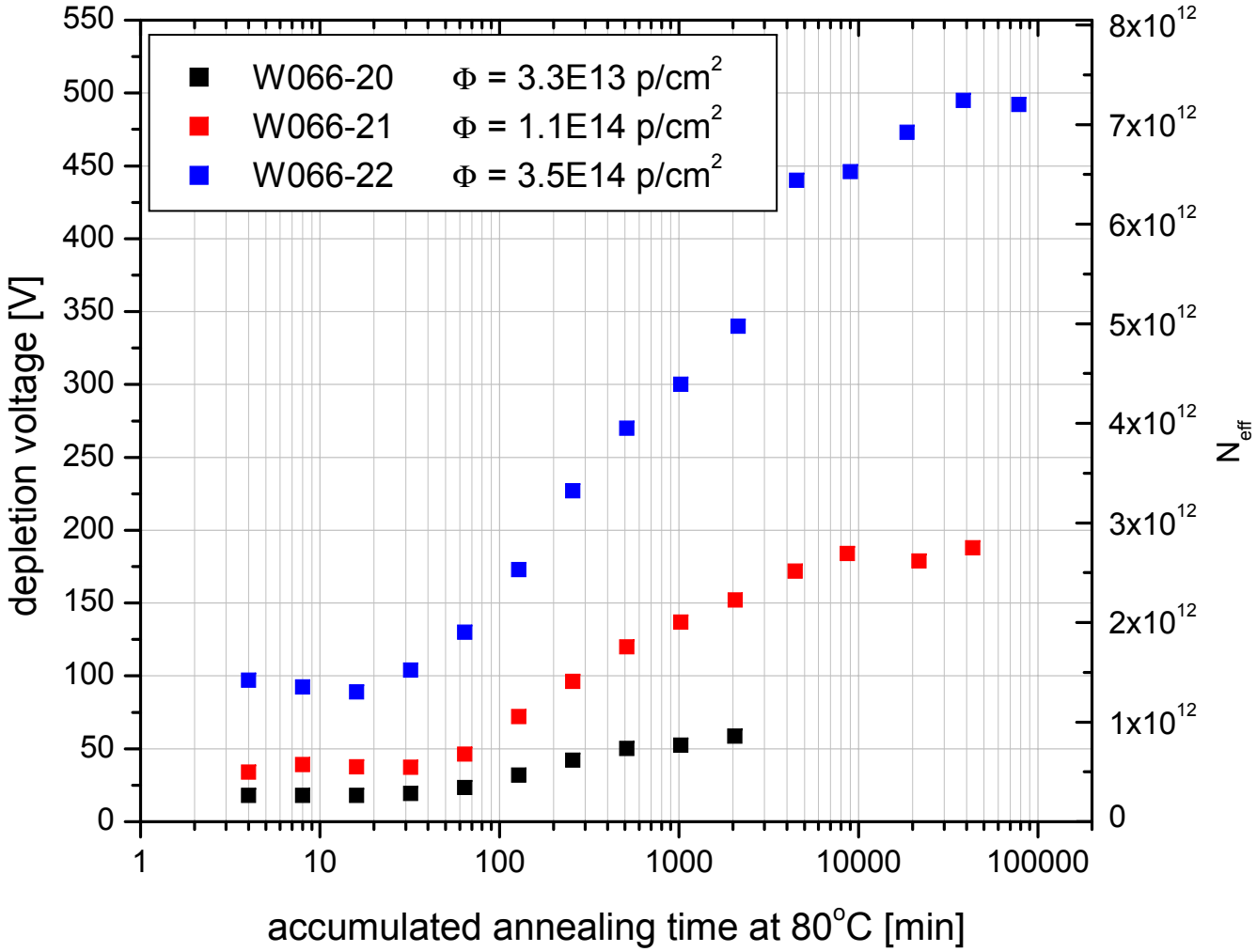
backup slide CCE(fluence)



Material: standard p-type and oxygenated (DOFZ) p-type

backup slide Annealing: V_{DEP}

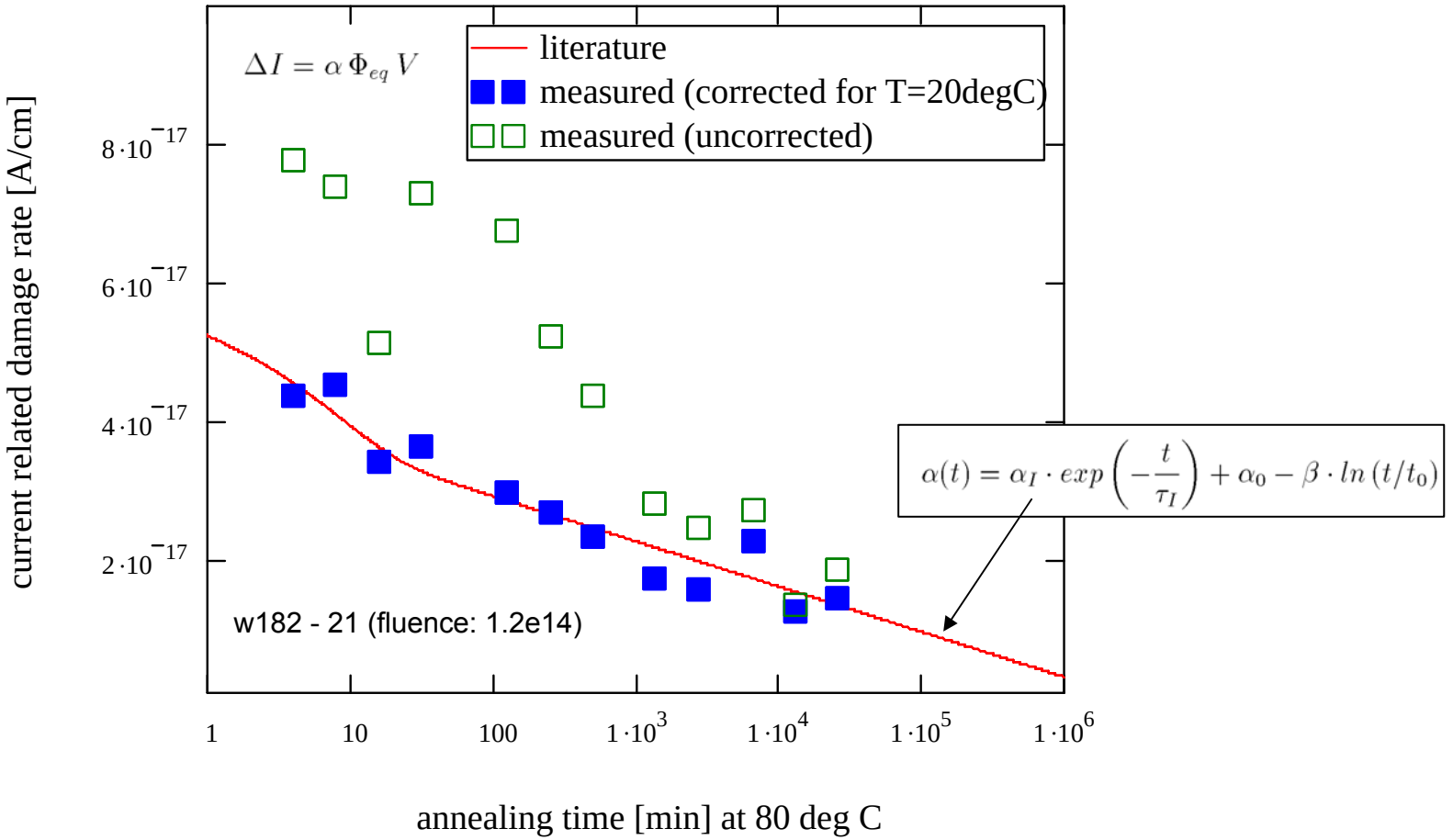
Reverse annealing for different fluences:



Annealing: leakage current

Correction of the measured currents for T-dependency:

$$I(T_R) = I(T) \cdot R(T) \quad \text{mit} \quad R(T) = \left(\frac{T_R}{T}\right)^2 \exp\left(-\frac{E_g}{2\,k_B}\left[\frac{1}{T_R} - \frac{1}{T}\right]\right).$$

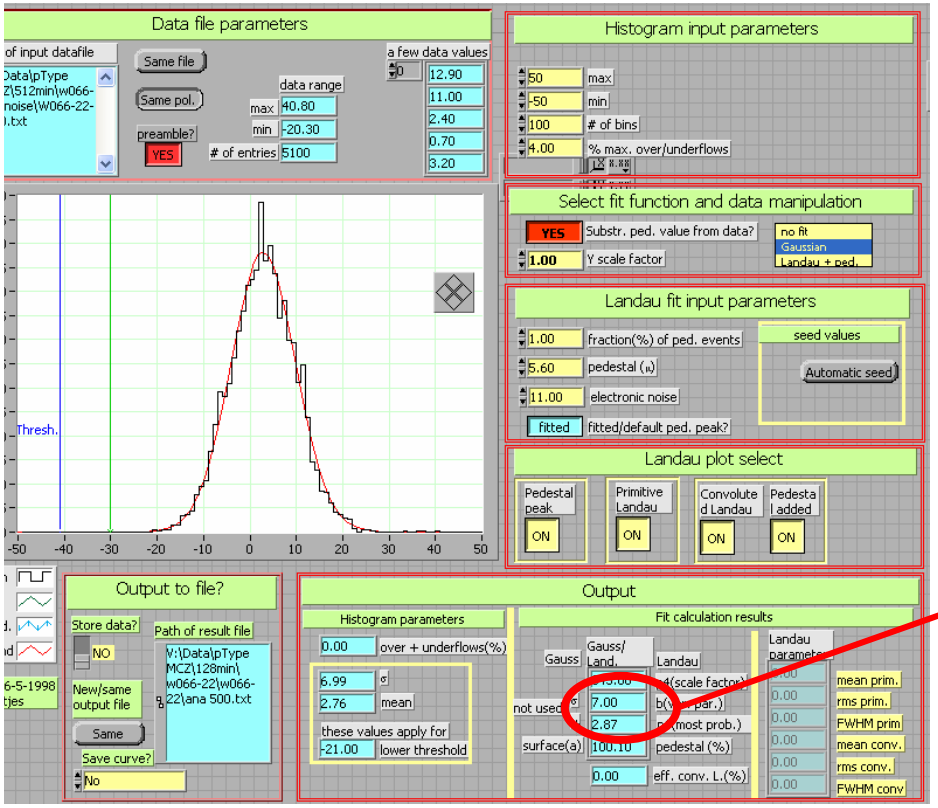


CCE: measurement & analysis

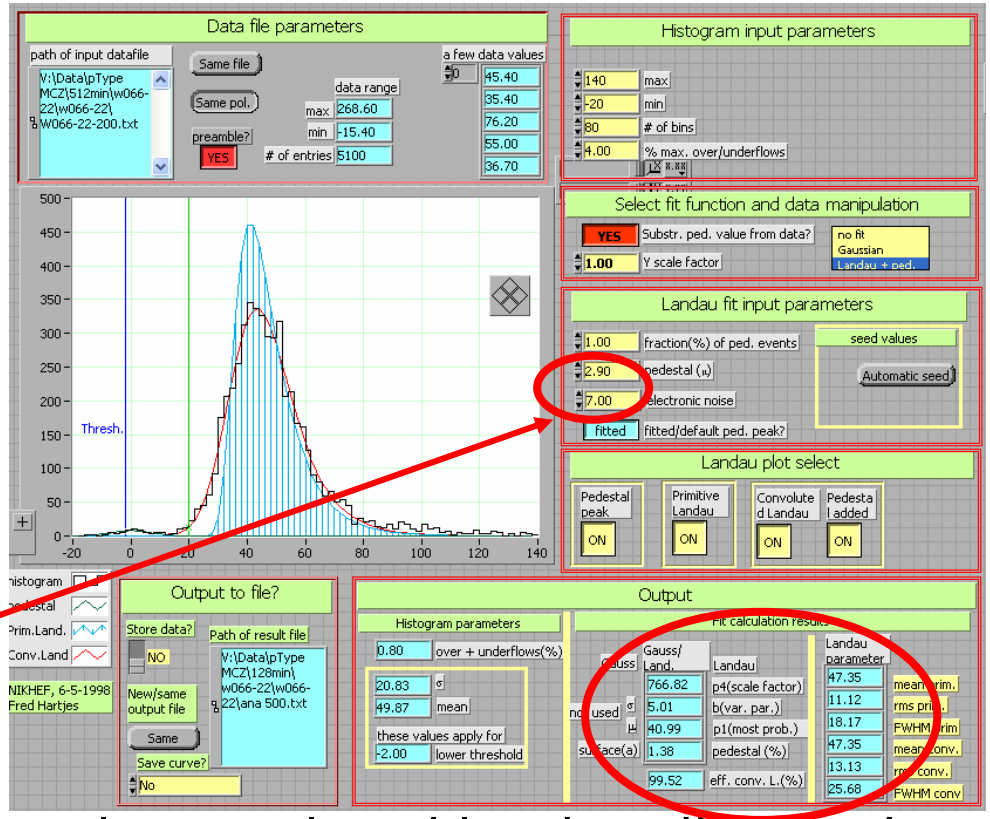
Example: p-type MCz IRST-W066-22

irradiation: $\Phi = 3.5 \times 10^{14}$ p/cm^2 temperature: -10 °C

annealing: 512 min @ 80 °C bias: 200 V



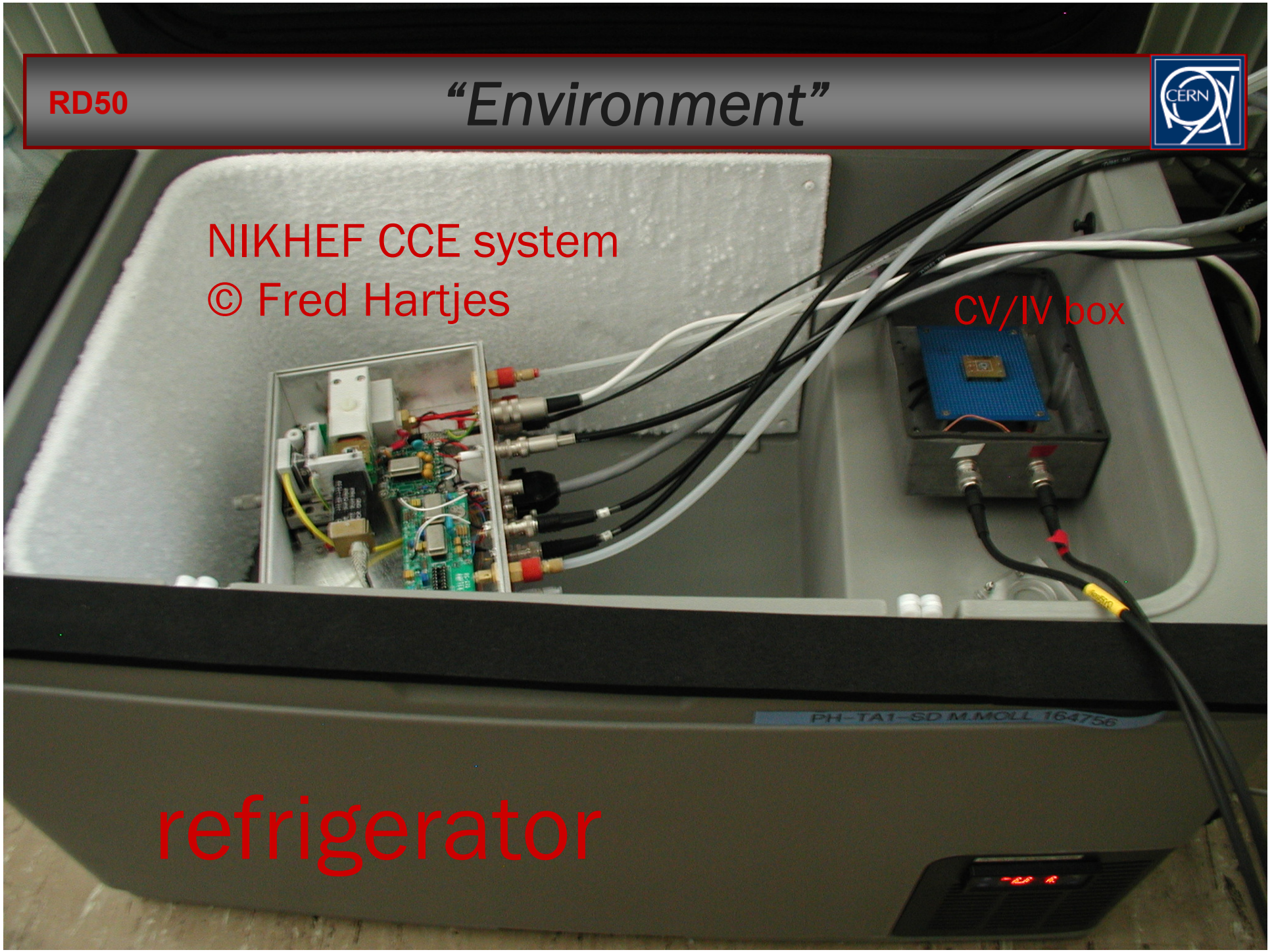
pedestal measurement



deconvoluted landau distribution

Setup: *NIKHEF CCE system © Fred Hartjes*

"Environment"



Setup: detector mounting