Charge collection studies on heavily diodes from RD50 multiplication run (update)

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Motivation

RD50 had/has a “multiplication wafer” run with Micron, which included special devices/diodes for studying impact of various parameters on charge collection:

- Does implant diffusion time matter?
- Does energy of implantation ions matter?
- How much does thickness matter?

In addition:

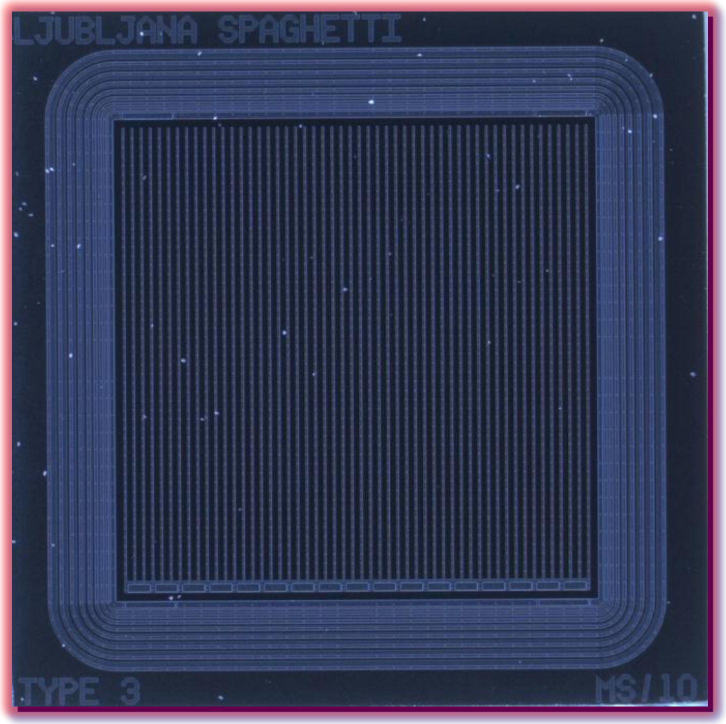
- What is the wafer-to-wafer reproducibility?
- How big is the is the difference between a pad diode and spaghetti diode?
- Does long term annealing depend on material?
- Are detector still alive at Φ_{eq}~10^{17} cm^{-2}?

Additional information are in the talk at 20th RD50 Workshop:
https://indico.cern.ch/getFile.py/access?contribId=15&sessionId=4&resId=1&materialId=slides&confId=175330

Samples

Special diodes-pad detectors were designed on that wafers which are particularly suitable for studies of charge collection:

- DC coupled, guard ring structure – high breakdown voltage
- 80 μm pitch, 20 μm implant width (ATLAS geometry)
- 4x4 mm^2 , 300 and 150 μm thick
- All strips connected together at one side:
  - almost the same electric field as in strip detector
  - much simpler handling (CCE, CV-IV etc. measurements)
  - weighting field has same shape as the electric field



Type 3 (used in this work)
Metalized implant

Irradiations and measurements

Type 3: samples from different wafers:

2935-2 – standard
2935-3 - standard
2935-4 – standard
2935-5 - standard
2935-6 - standard
2935-7 – standard
2935-8 - standard
2935-9 – standard
2884-7 – standard

(2e15 cm^{-2}, 150 keV P; 5e15 cm^{-2}, 80 keV B; 220 nm thermal oxide)

2935-10 - double diffusion (1000ºC for 3h)

2912-2 - double energy
2912-3 - double energy

(300 keV of P ions doubly charged !)

2885-5 – thin

Sample treatment:

✓Neutron irradiations: in steps up to 8·10^{16} cm^{-2},80 min annealing at 60ºC in between

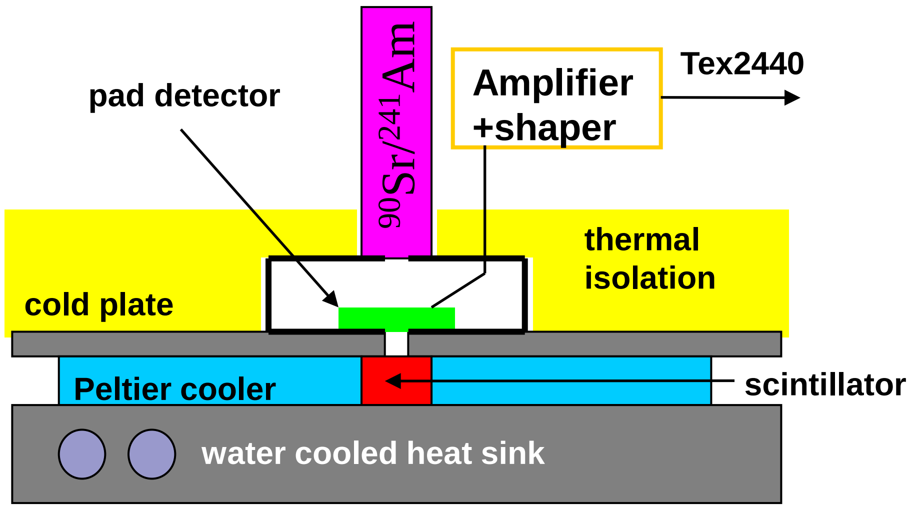
✓Measurements done in the range [-20ºC, -25ºC]

✓some samples irradiated to a fix fluence (single step) to check for consistency

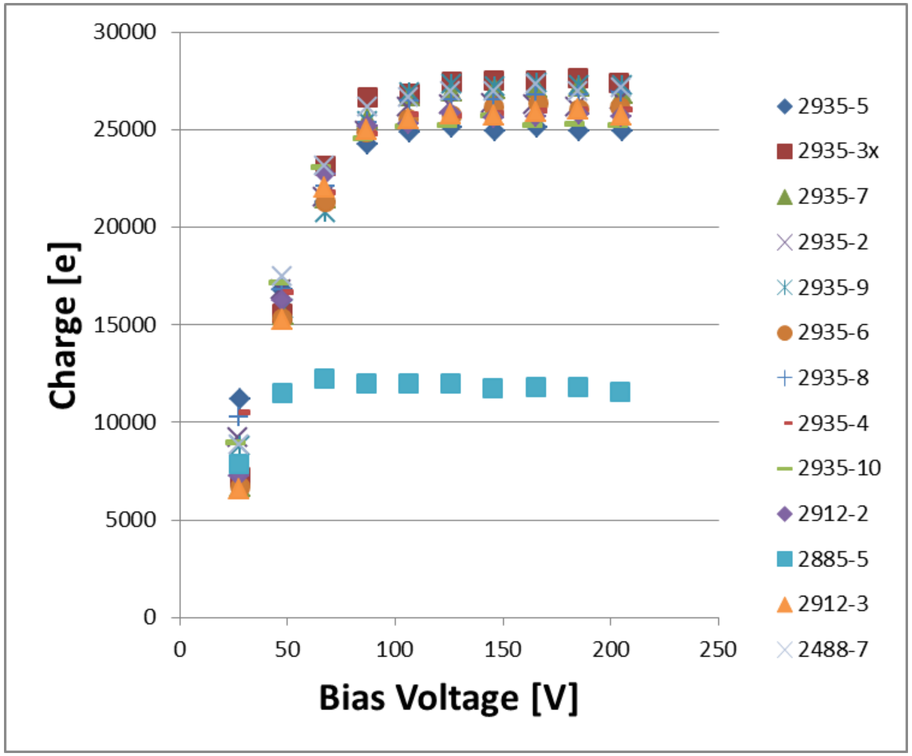
✓some standard p-type diodes were also irradiated for comparison

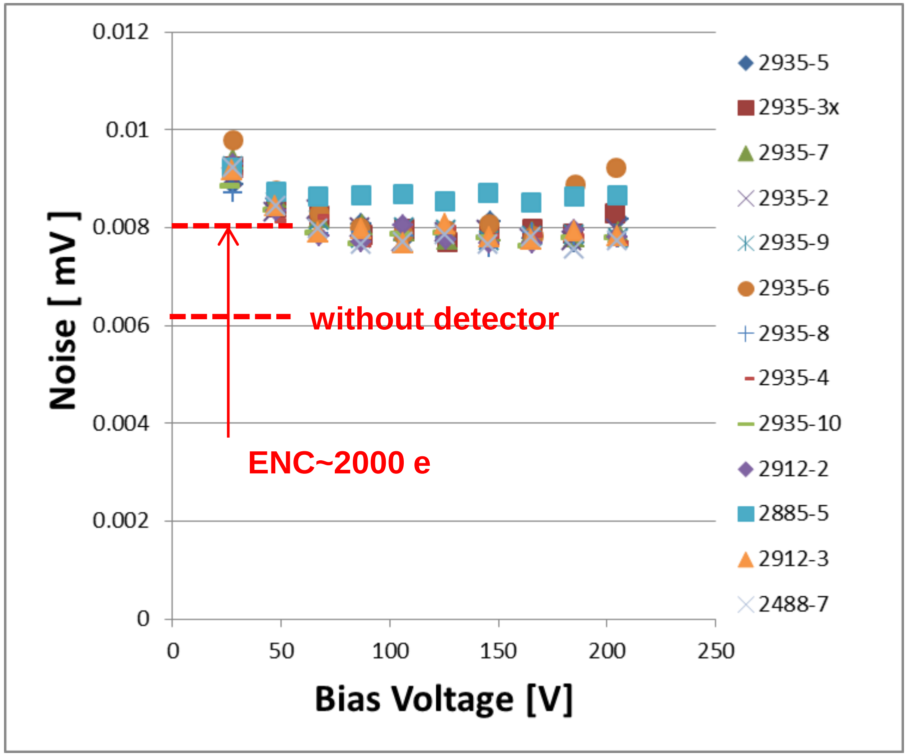
Measurements:

- CCE measurements with ^{90}Sr setup
  - 25 ns shaping
  - 97% trigger purity
  - Calibrated for non-irradiated detector with 59.5 keV line from ^{241}Am
  - I-V measured



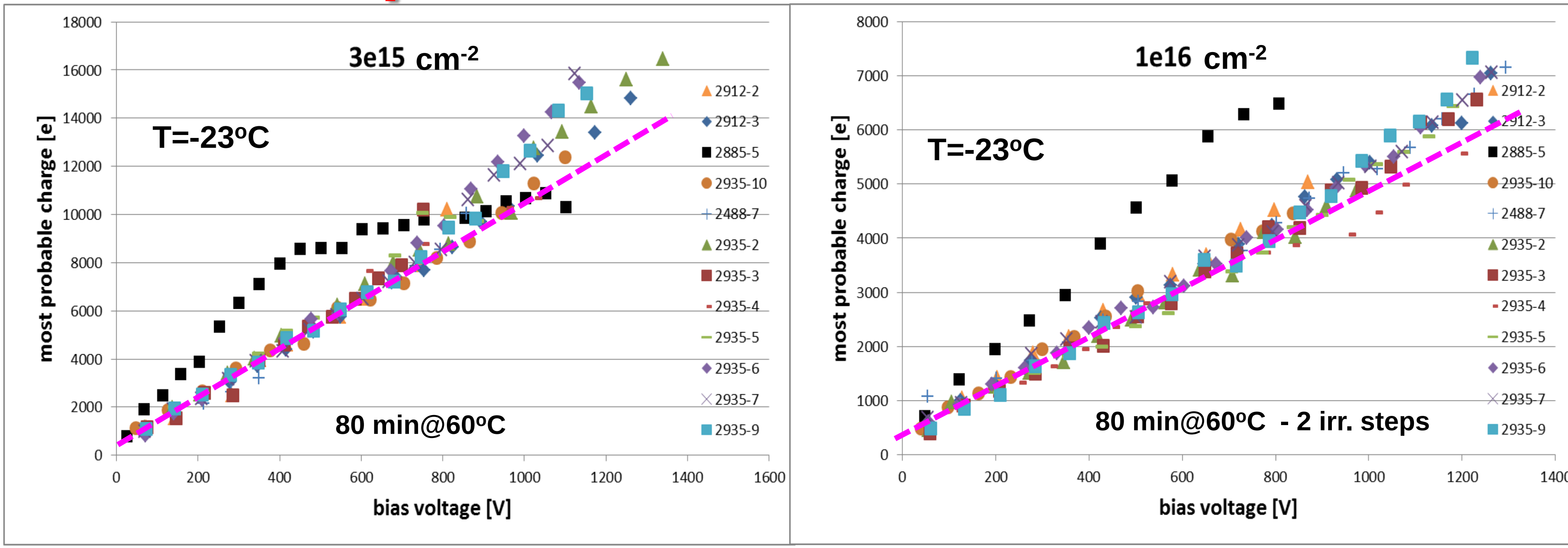
CCE and noise for non-irradiated samples





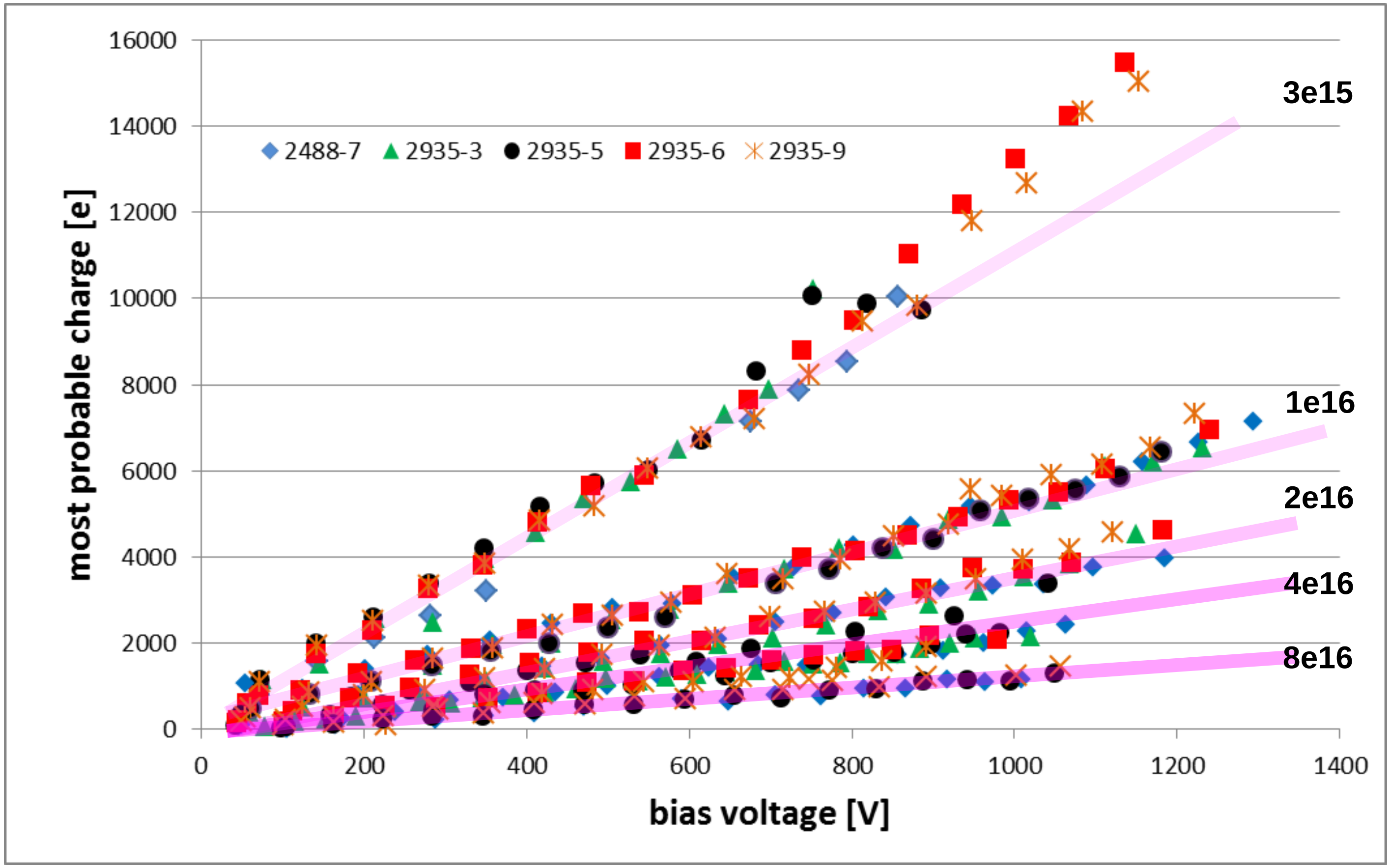
- variation of ~10% for charge at $V>V_{fd}$ – several samples were re-measured and reproducibility was found to be better than that
- good agreement of V_{fd} determined from *Q-V* with that of *C-V*
- Noise performance in accordance with expectations

CCE comparison for all wafers



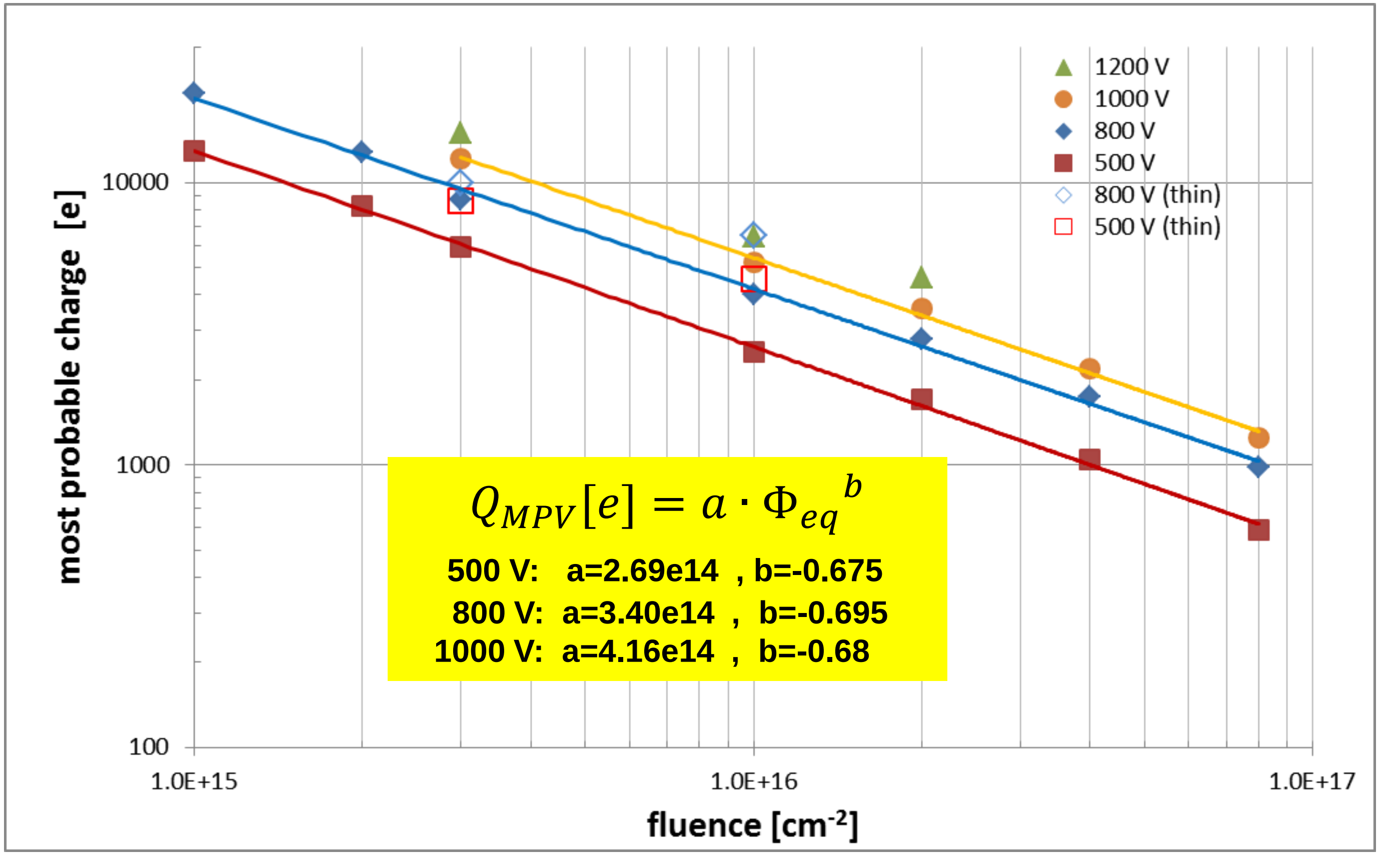
- almost no difference in charge collection efficiency for different implants (but only limited parameter region of investigation)
- superior performance of thin detectors (black squares) at lower voltages
  - very high CCE for thin detector (~10-11 ke for $3\cdot10^{15}$ cm^{-2}).
  - up to 1000 V thin are at least as good as thick
  - only moderate increase of charge collection with high bias voltages for thin device – **why don't we see larger increase of multiplication?**

CCE of "standard" wafers for all fluences



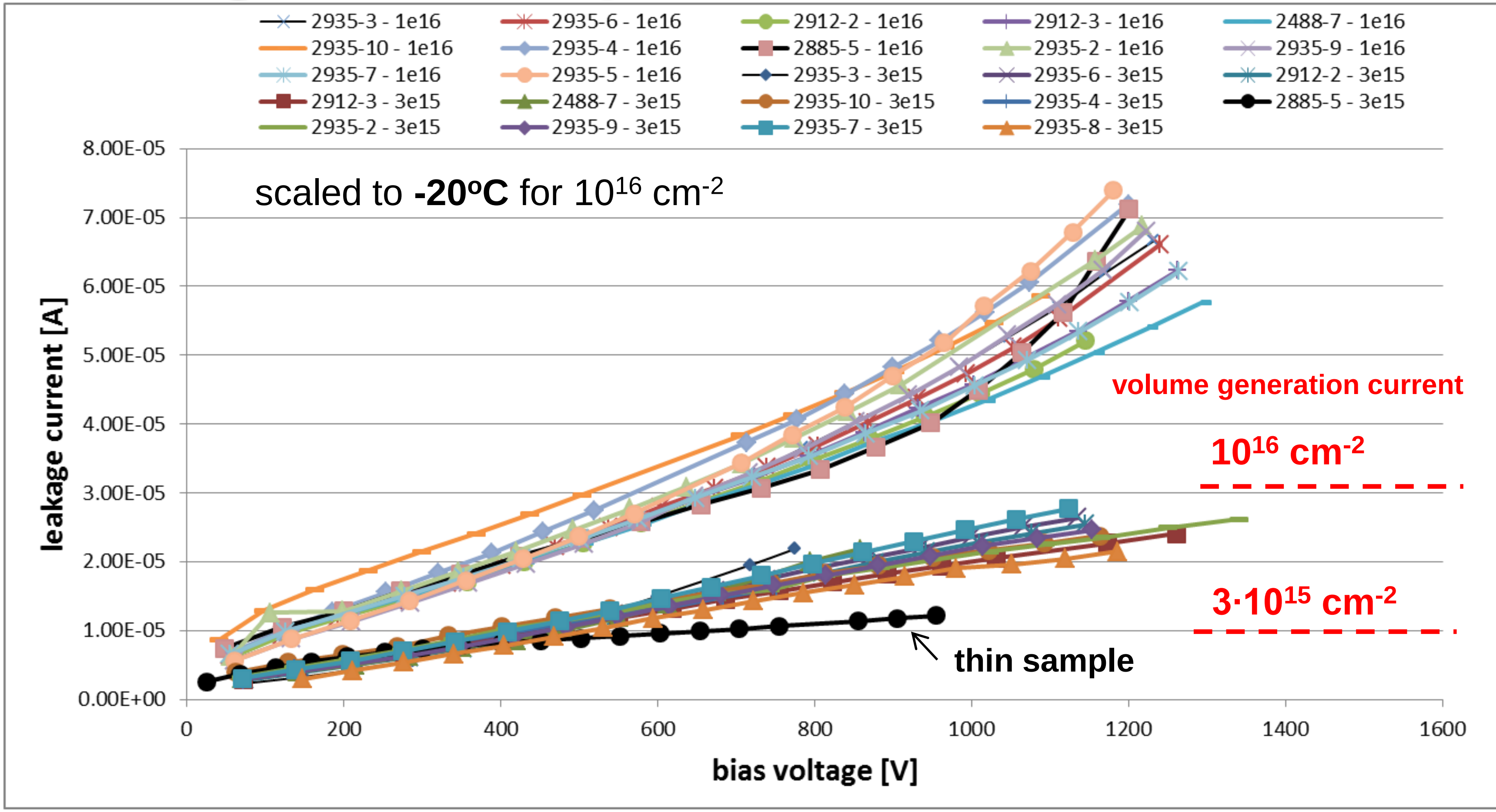
- Even at $8 \cdot 10^{16}$ cm^{-2} a signal of ~1200 e can be expected i.e. few mip sensitivity with present electronics
- An interesting observation – at very high fluences ($2,4,8 \cdot 10^{16}$ cm^{-2}) no problems with micro discharges – very stable operation!

Dependence of CCE on voltage



- power law dependence of Q_{MVP} on fluence ("an empirical formula") surprisingly works over two orders of magnitude!
- almost constant in collected charge for different voltages at given fluence

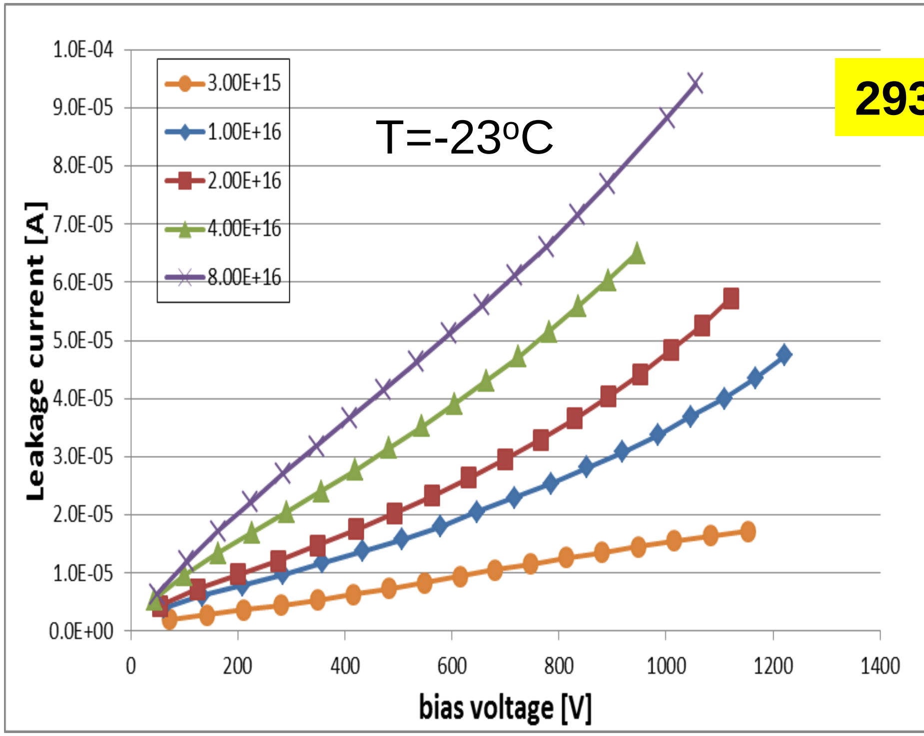
Leakage current performance

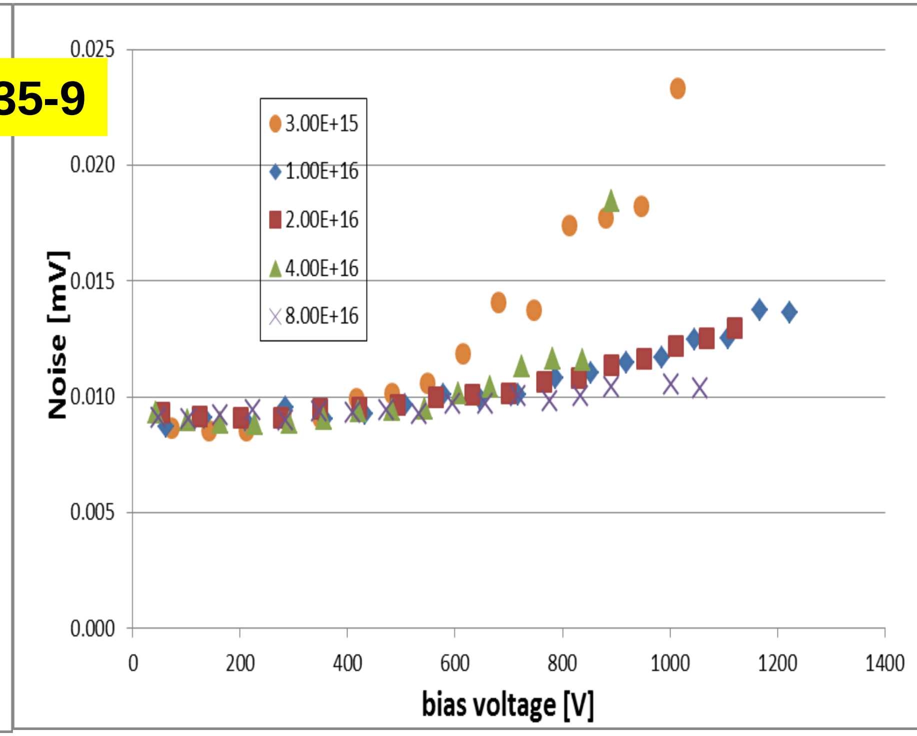


- Leakage current larger than given by volume bulk
- does not scale precisely with fluence (factor ~3) – difference in M_I ?

…, but the I_{leak} is a sum of guard and bulk currents

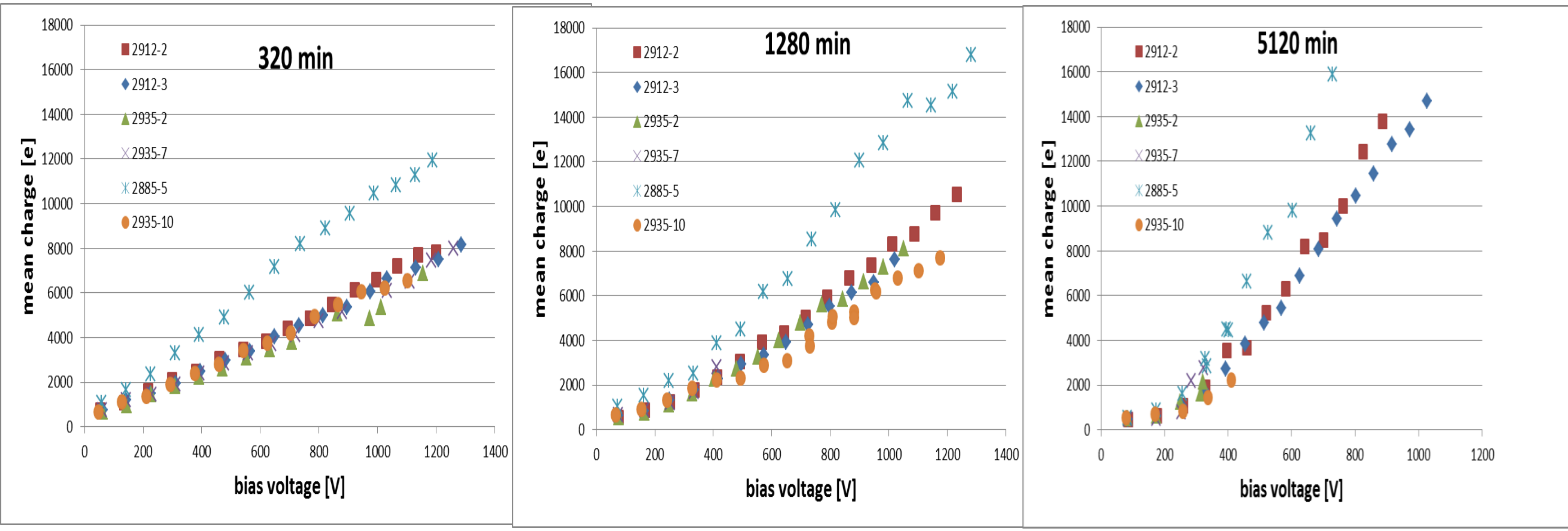
Leakage current and noise at high fluences





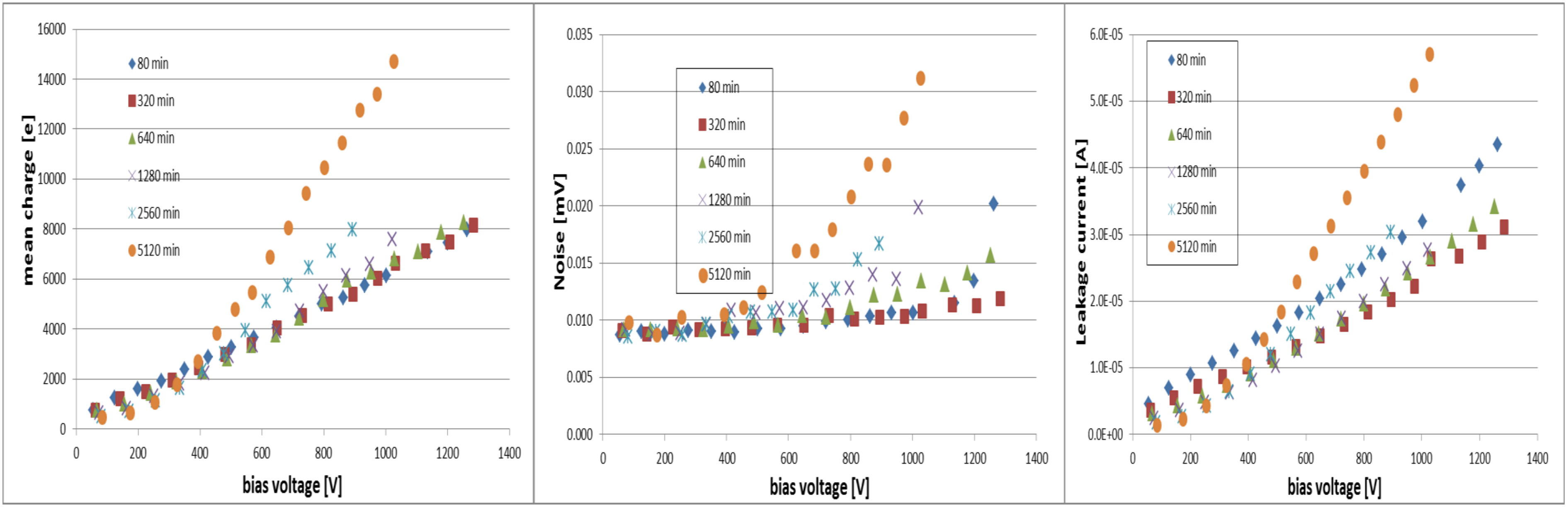
- Leakage current at given voltage doesn't scale with fluence (even at voltages below "expected V_{fd}") and shows a tendency to saturate. Reasons:
  - reduced multiplication at very high fluence ?
  - saturation of responsible generation centers?
- Low noise for higher irradiated devices in spite of large leakage current?
- At lowest fluence the onset of micro discharges can be seen in the noise.

Annealing of wafers with different implants



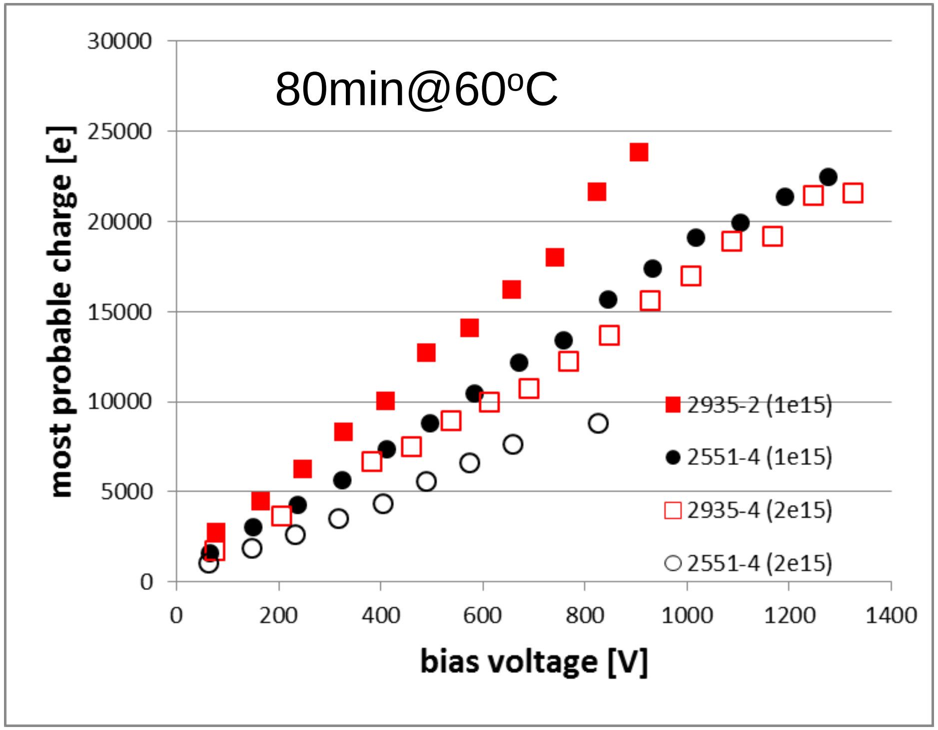
- There is no systematic difference between different implants in terms of CCE during long term annealing
- Thin detector performs best also during long term annealing
- The slope of the charge rise with voltage increases with annealing – seen already several times before (CERN, JSI, Glasgow…)
- CCE>1 for the thin device already at 600 V after 5120 min @ 60^{o}C

Annealing of wafers with different implants

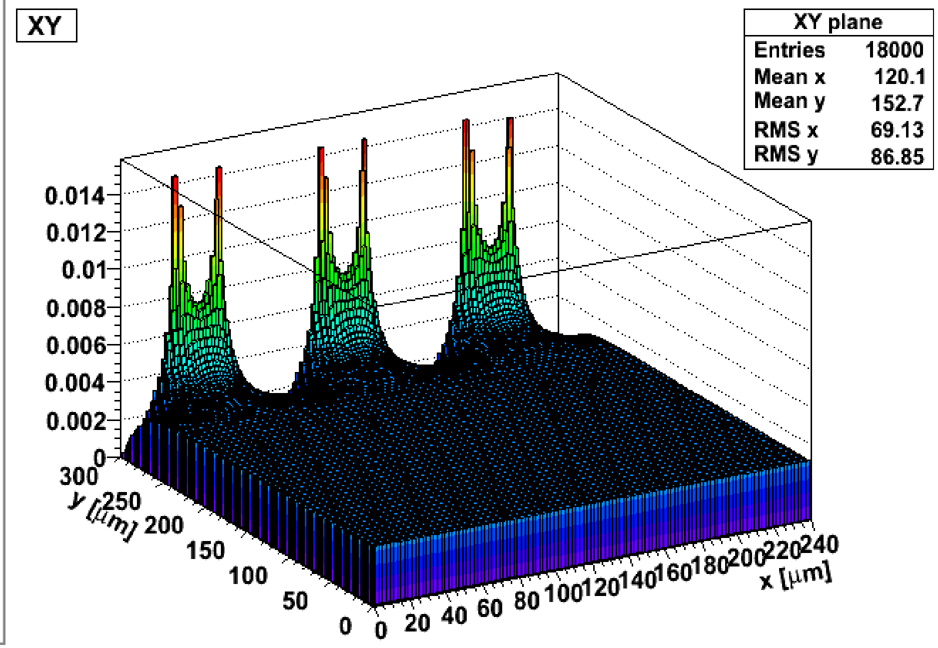


- The Q-V plot shows rapid rise of charge after 1280 min annealing
- At low bias voltages the charge is smaller for longer annealing times (<400 V)
- Increase of noise is related to increase of charge, but a detector with smaller electrodes would have larger S/N (series noise should dominate over shot noise)
- I-V has a similar shape as Q-V with a difference because of generation current annealing (initial drop of current)
- Similar behavior seen for all investigated materials.

Difference between pads and strips



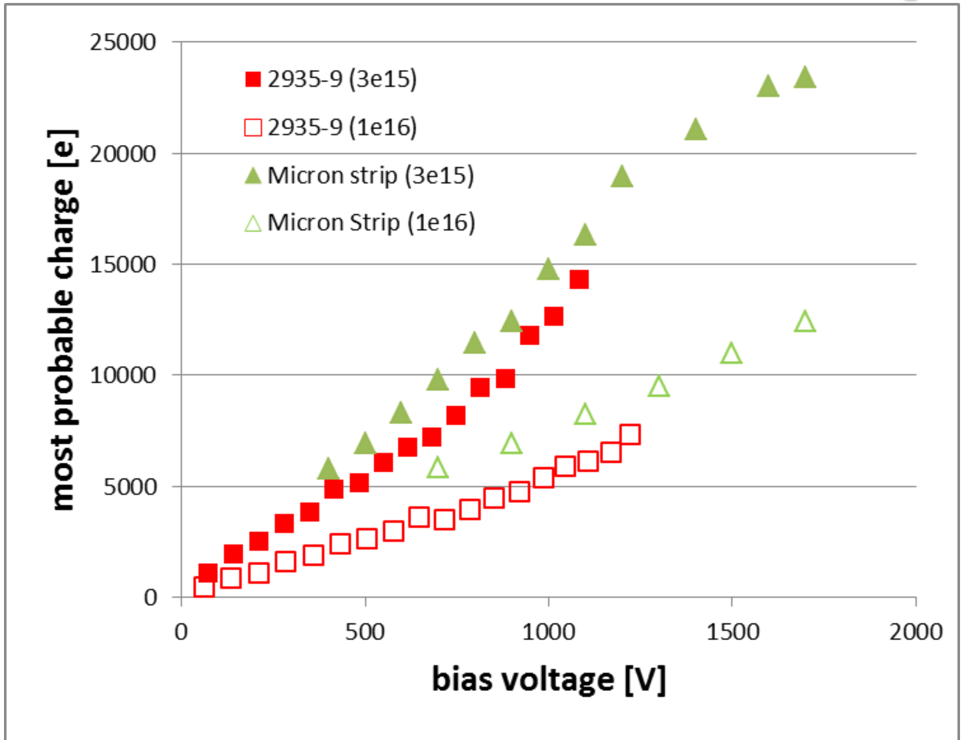
weighting field for spaghetti diode (3 strips)



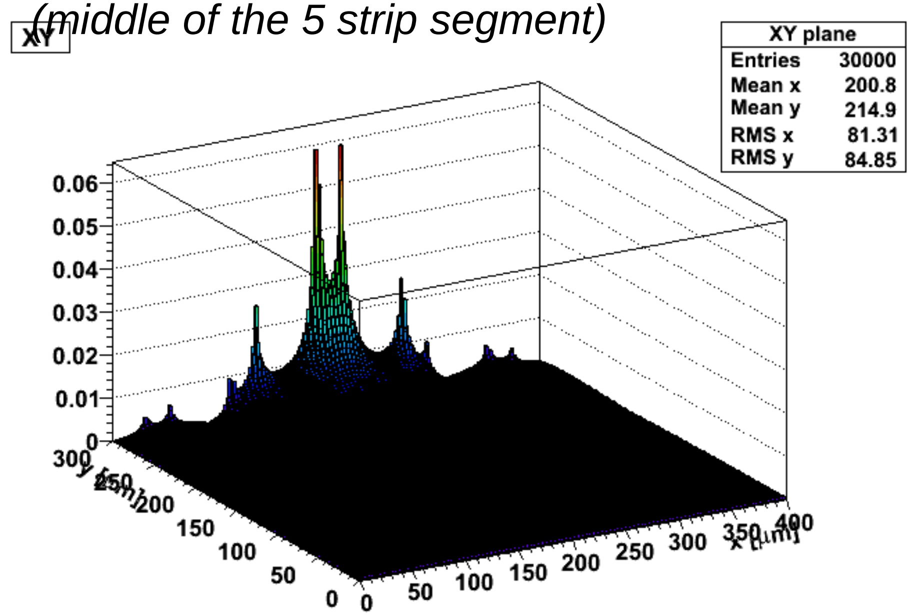
Two standard FZ-p pad detectors from Micron were used for comparison (2551-4 wafer) irradiated to the same fluence:

- the difference between pad and spaghetti is large
  - can not the due to weighting field $Q_e/(Q_e+Q_h)=0.53$, diode~0.5
  - can be due to multiplication, but the difference is there also at low voltages
- Relative difference is somewhat larger at larger fluence (not conclusive)

Difference between pads and strips

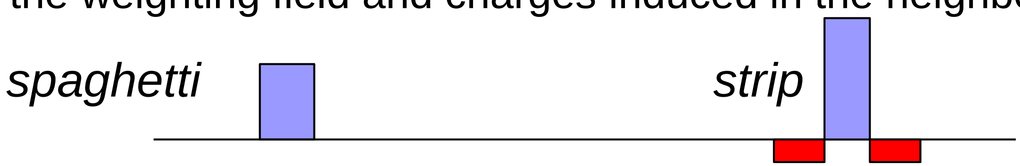


weighting field for strip detector (middle of the 5 strip segment)



Two standard FZ-p strip detectors of the same strip geometry from Micron were used for comparison irradiated to the same fluence:

- the difference between strip and spaghetti is **relatively small,** very likely due to multiplication (note larger fluences as for pads)
- The difference comes from the weighting field and charges induced in the neighbors (see I. Mandic's talk)



Conclusions & future work

- New "spaghetti" diodes perform well
- Within the parameter space investigated in RD50 Micron Multiplication run:
  - the **"double energy"** of implantation ions and
  - the **"double diffusion time"**

  processed diodes perform equally after irradiation and also during long annealing to spaghetti diodes processed in a standard way
- Thin diodes perform better than standard ones for both fluences for bias <=1000 V
- Strong increase of charge during long term annealing, but also noise and leakage current
- As expected the spaghetti diodes perform better than standard pad diodes (multiplication?) and worse than strip detectors (trapping induced charge sharing) at given fluence.
- Spaghetti diodes are still "alive" **at $8 \cdot 10^{16}$ cm^{-2}** – the charge of 1250 e can be expected (probably more for strip detectors) at 1000 V .

Further studies are underway with TCT (see Igor's talk)!