Charge collection studies on heavily diodes from RD50 multiplication run

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Motivation

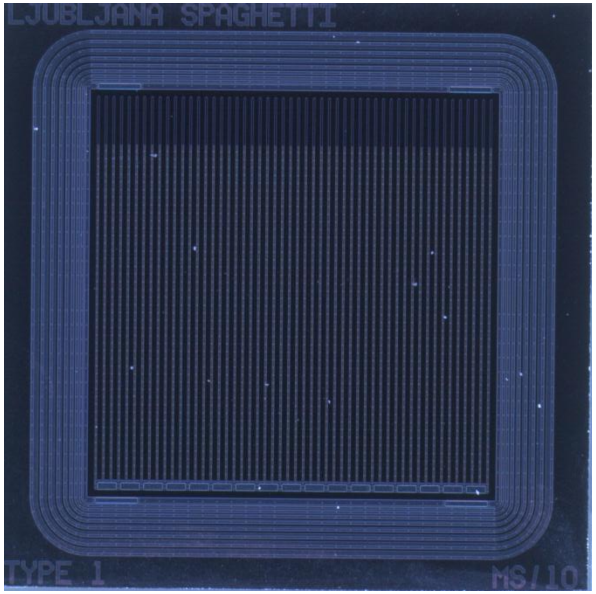
RD50 had/has a "multiplication wafer" run with Micron, which included special devices/diodes for studying:

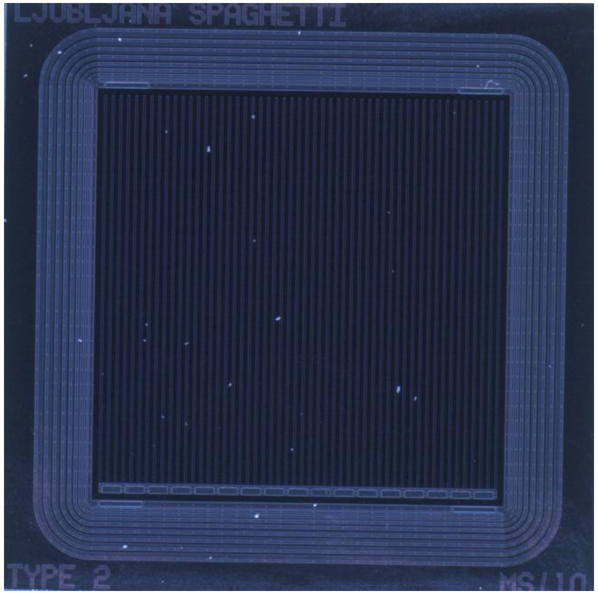
- Impact of various parameters on charge multiplication
  - Does implant diffusion time matter?
  - Does energy of implantation ions matter?
  - How much does thickness matter?
- What is the wafer-to-wafer reproducibility?

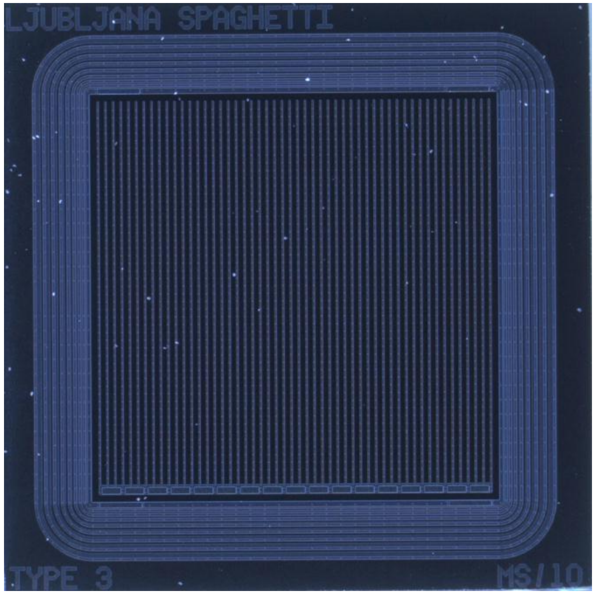
Samples

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
- 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 similar to that of a diode







Type 1:
Partially metalized implant

Type 2:
Not-metalized implant

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)

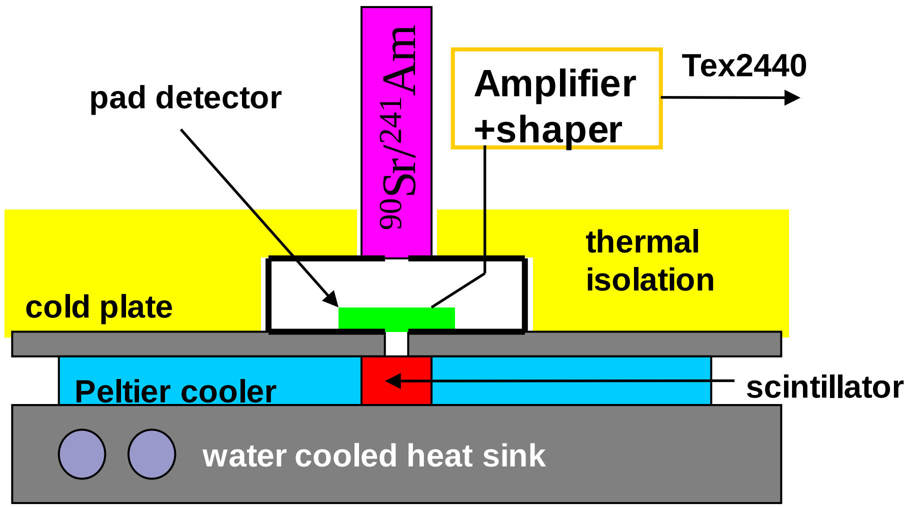
2935-10 - double diffusion (1000°C for 3h)
2912-2 - double energy
2912-3 - double energy
(**300 keV of P ions doubly charged !**)
2885-5 – thin

Sample treatment:

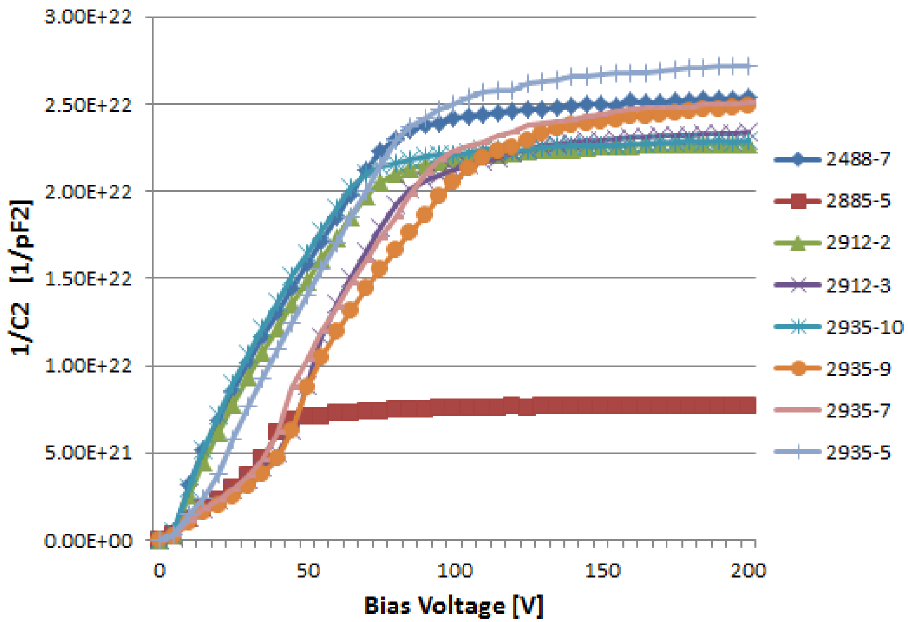
✓Neutron irradiations: $3\cdot10^{15}$ cm^{-2} and 10^{16} cm^{-2}
✓Measurements done at -20°C for $3\cdot10^{15}$ cm^{-2} and -23°C (10^{16} cm^{-2})
✓Irradiation performed in steps with 80 min annealing at 60°C in between
✓3 samples were irradiated in a single step also to 10^{15} cm^{-2}, $2\cdot10^{15}$ cm^{-2} and 10^{16} cm^{-2} to check the consistency

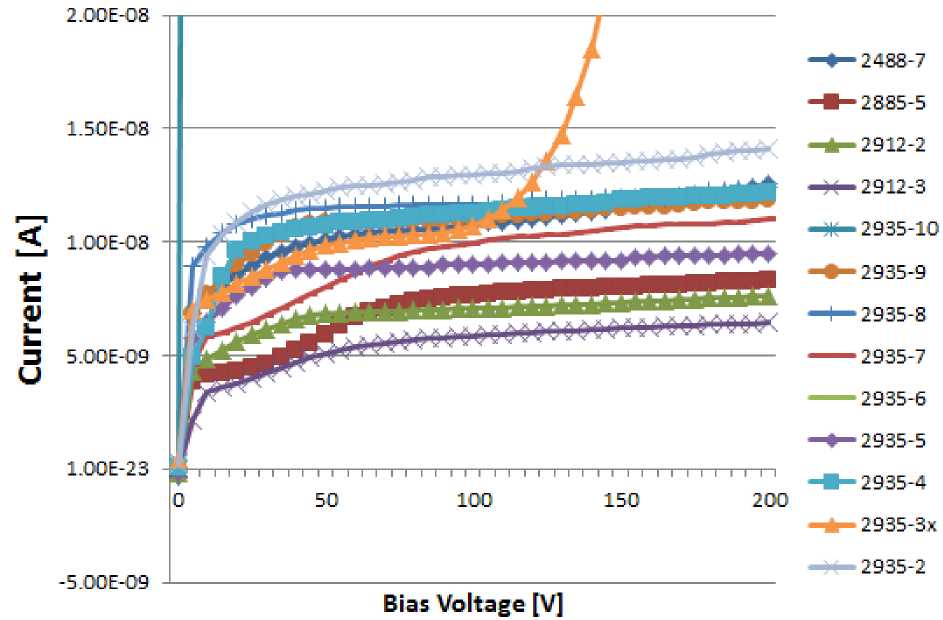
Measurements:

- CCE measurements with ^{90}Sr setup
  - 25 ns shaping
  - 98% trigger purity
  - Calibrated for non-irradiated detector with 59.5 keV line from ^{241}Am
- CV at RT for non-irradiated samples
- IV for cold and irradiated samples



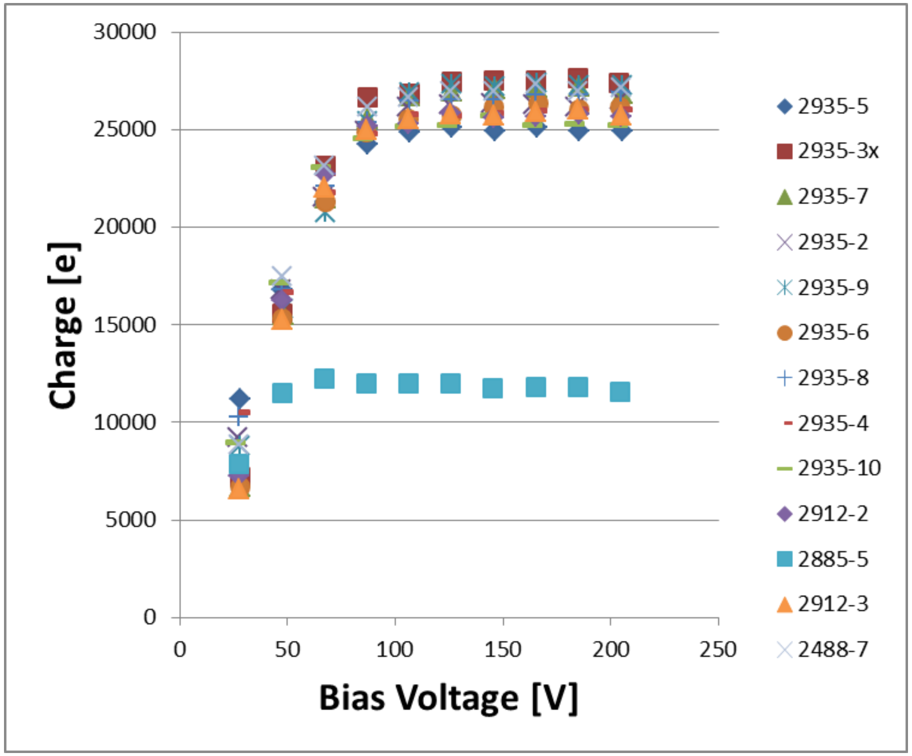
Capacitance and current characteristics

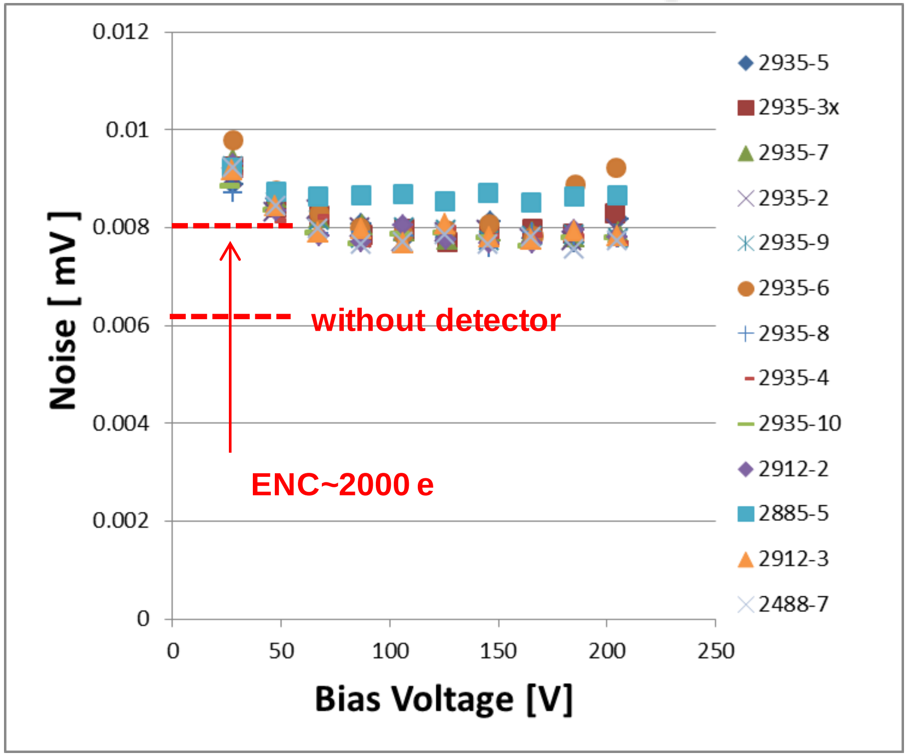




- Standard thickness: *C~6* pF (thick), *C~12* pF (thin), V_{fd}*~70* V (~40 V for thin).
- $1/C^2$ vs. V_{bias} deviates from straight line for some samples
- Current are around 10 nA at full depletion voltage. Only one sample showed a soft breakdown.

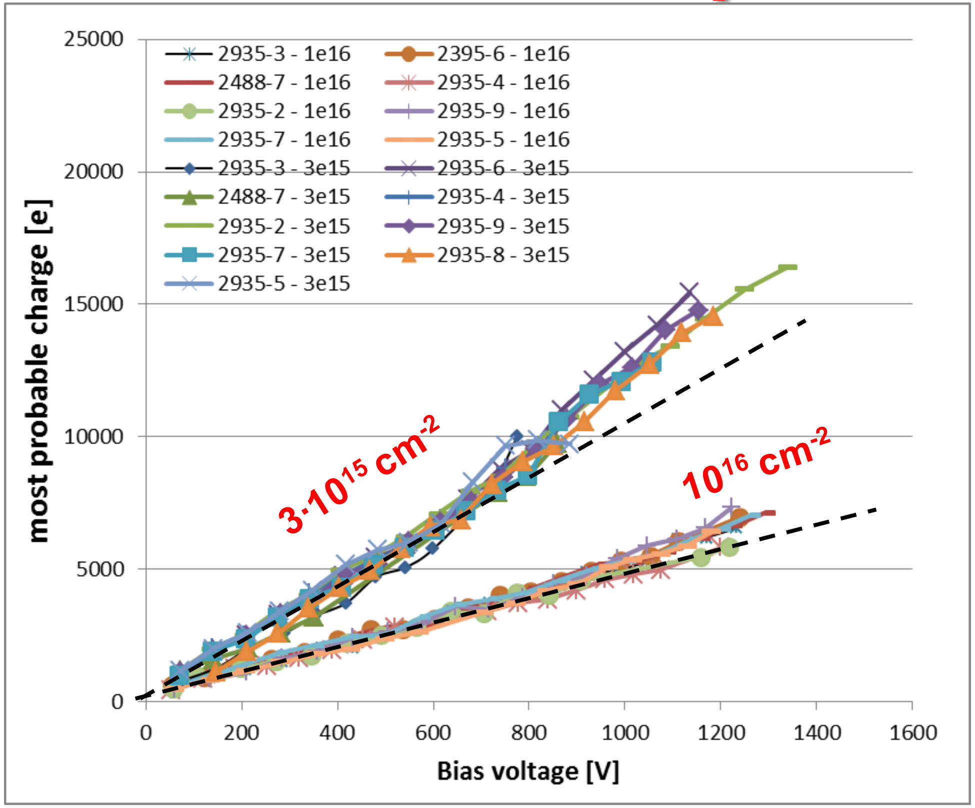
CCE and noise for non-irradiated samples





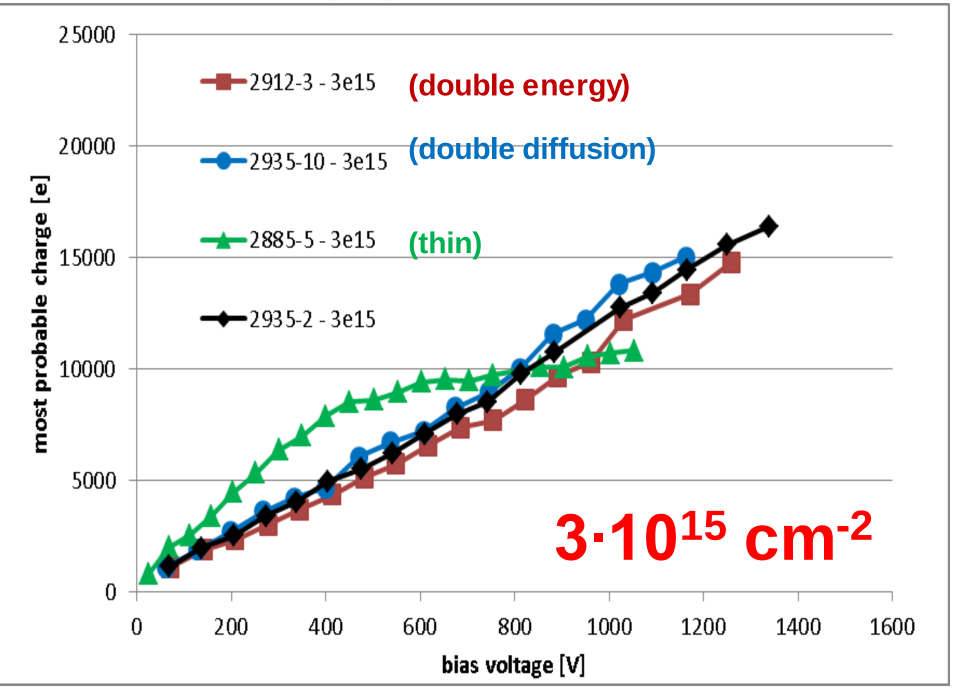
- variation of ~10% for charge at $V>V_{fd}$ – several samples were re-measured and reproducibility was found to be better than that
- good agreement of V_{fd} determined from *Q-V* with that of *C-V*
- Noise performance in accordance with expectations

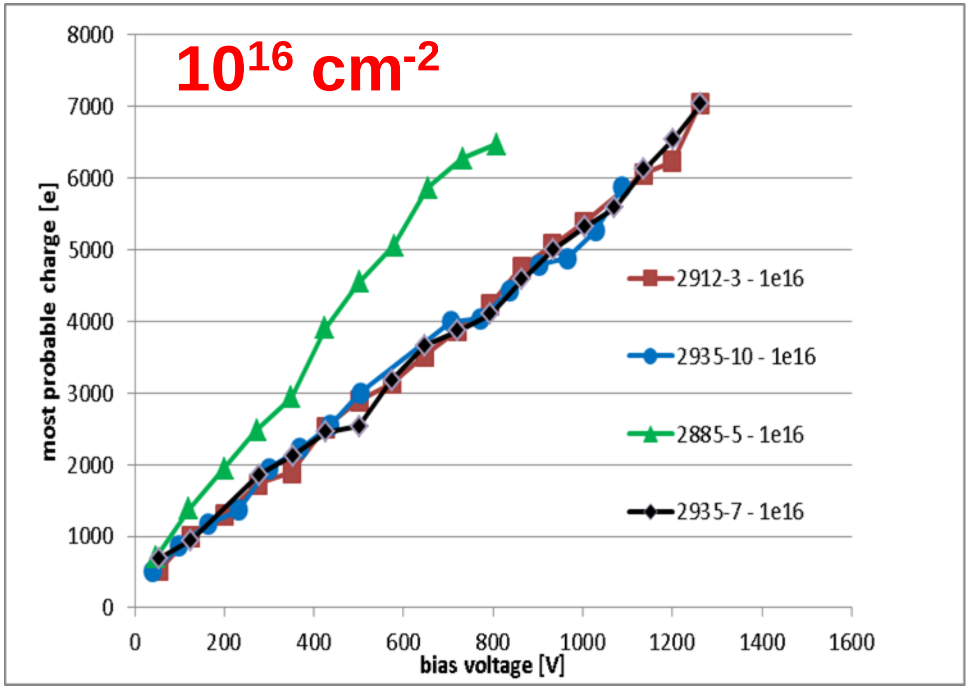
CCE (I) - wafer to wafer reproducibility



- Wafer-wafer (randomly chosen samples) variation of CCE is within 10% (peak-peak) – comparable or better than before the irradiation.
- Larger problem with micro discharges for lower fluence. Radiation improves HV stability significantly – no problem of operation all samples at >1000 V.
- Linear rise of MPC with voltage – deviation at larger bias – multiplication?
- Degradation of CCE as expected from previous measurements.

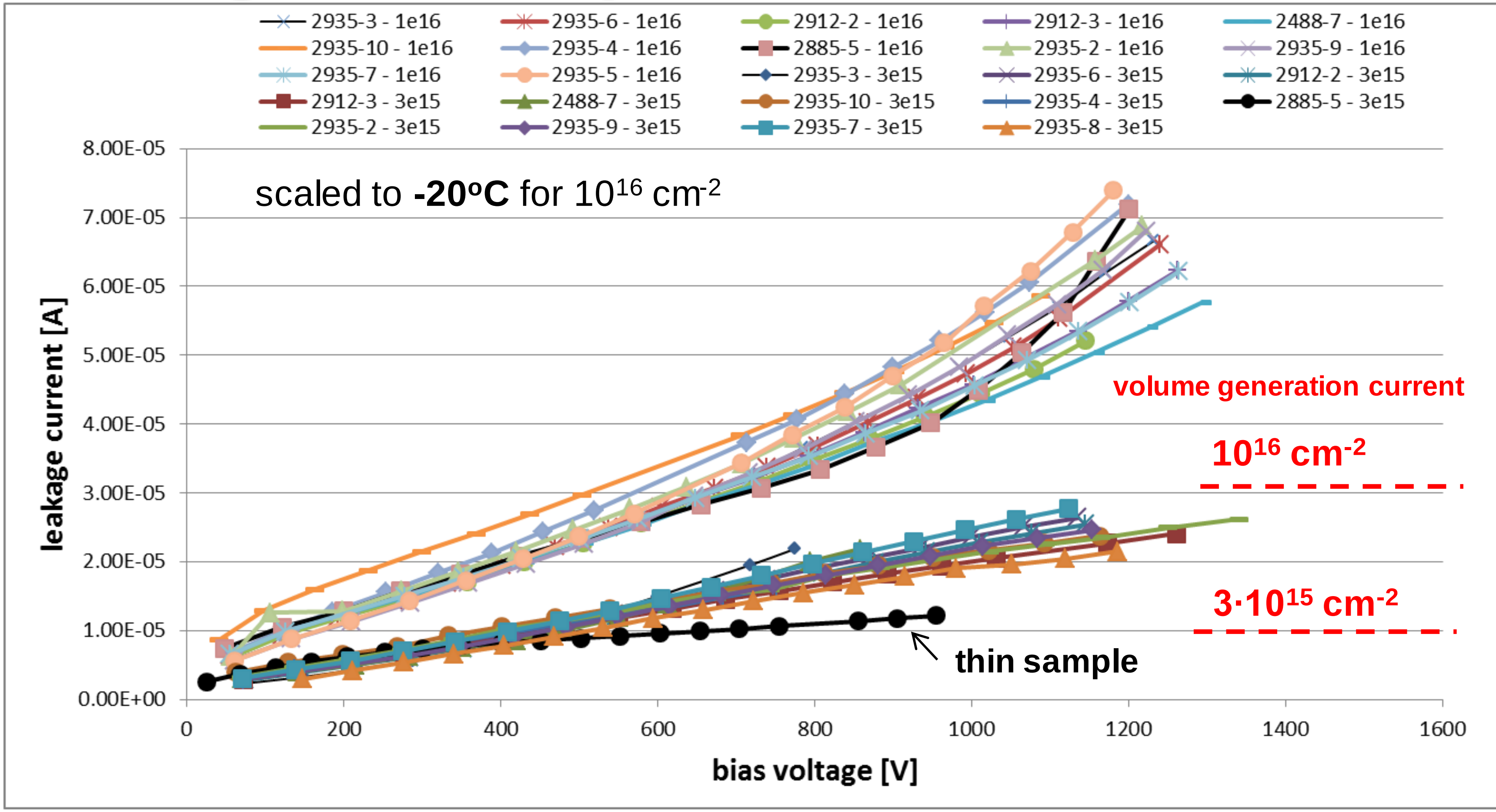
CCE (II) - implantation and thickness





- almost no difference in charge collection efficiency for different implants (… but only limited parameter region of investigation, *see I. Mandic talk where it is shown that implants should play a role*)
- dQ/dV(3e15)/dQ/dV(1e16)~2.5
- Large difference between thick and thin detectors:
  - very high CCE for thin detector (~10-11 ke for 3·1015 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?**

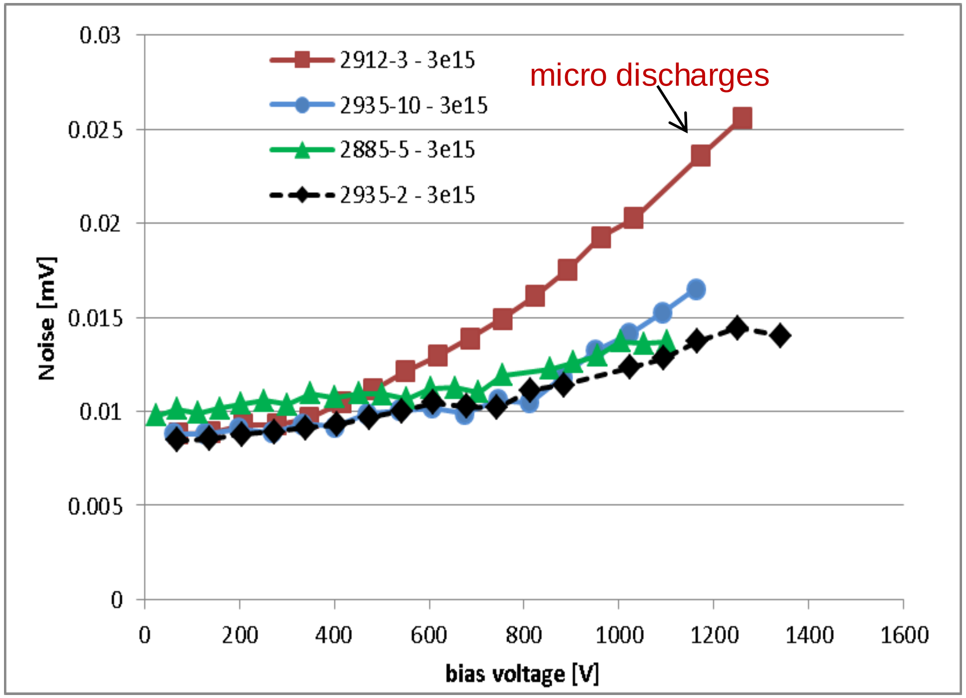
Leakage current performance

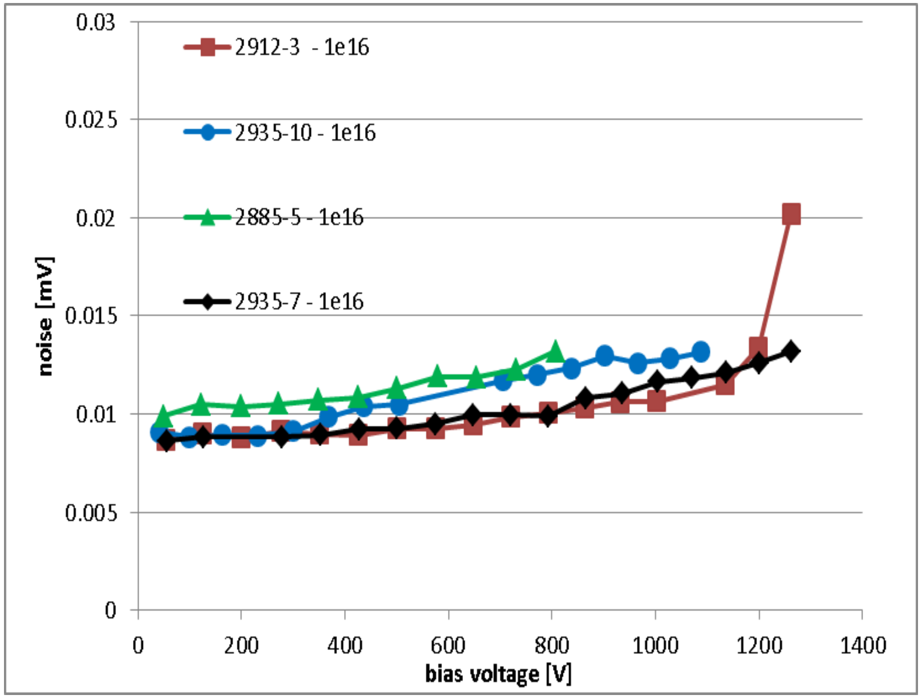


- Leakage current larger than given by volume bulk
- does not scale precisely with fluence (factor ~3) – difference in M_I ?

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

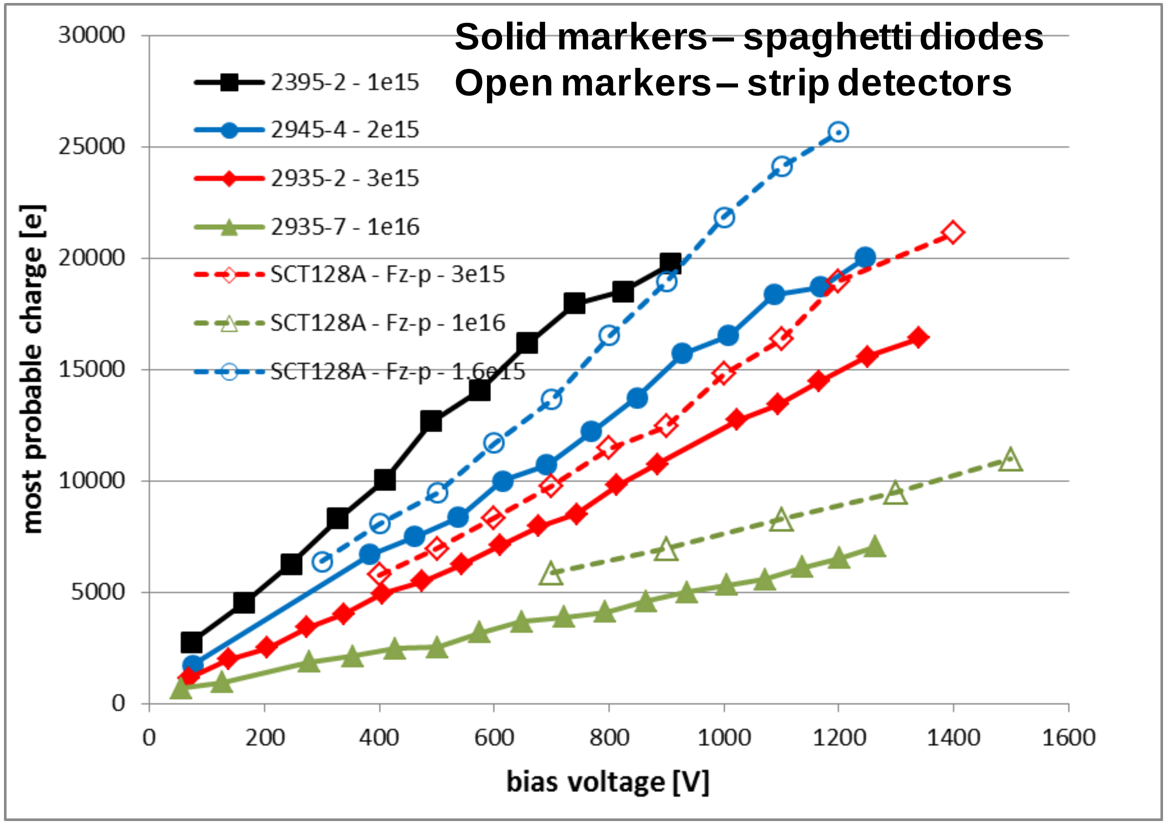
Noise performance



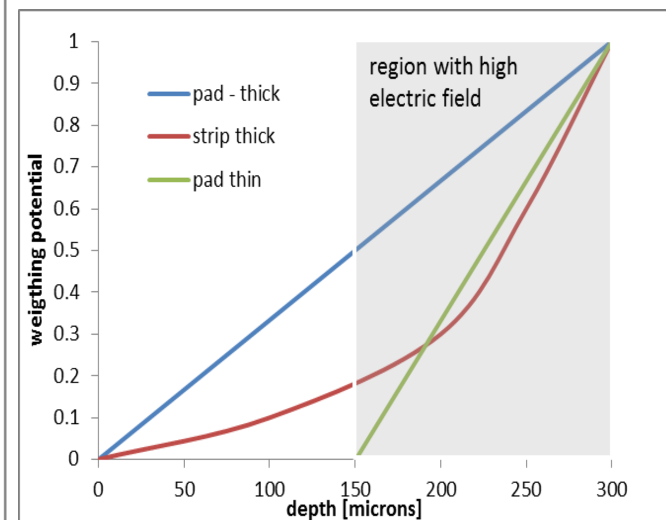


- increase of noise with bias is smaller than increase of signal with bias
- Thin detector has larger noise, but only marginally
- similar noise for low and high fluence measurements although leakage current differ by factor of 2 – ($ENC_{MI} \sim ENC_I \sqrt{F}\, M_I$)

Fluence dependence of CCE

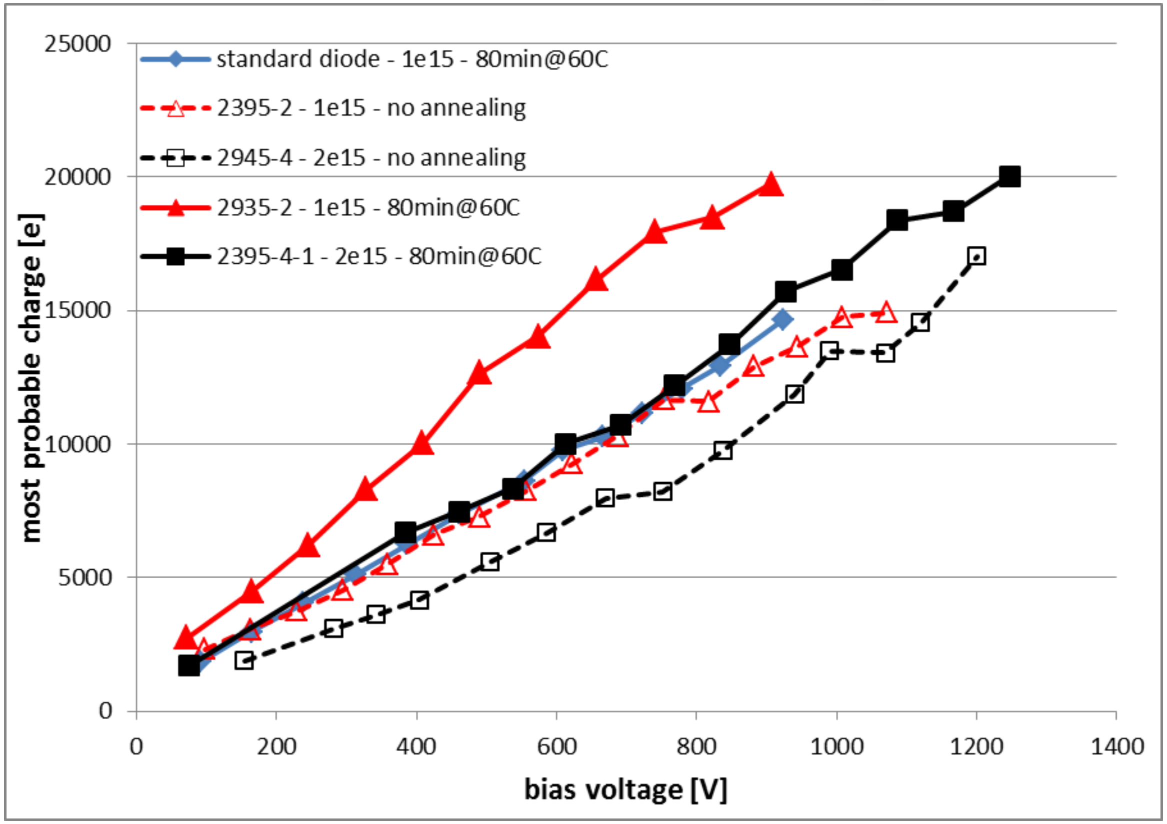


Samples irradiated to fixed fluences and annealed for 80 min @ 60^{o}C



- Larger charge collection for strip detectors can be attributed to more favorable weighting field profile and difference in absolute charge calibration
  - ~15% difference at 1100 V for $3\cdot10^{15}$ cm^{-2}, ~30% difference for 10^{16} cm^{-2}
  - Larger fraction of weighting potential is in the region with very high electric field

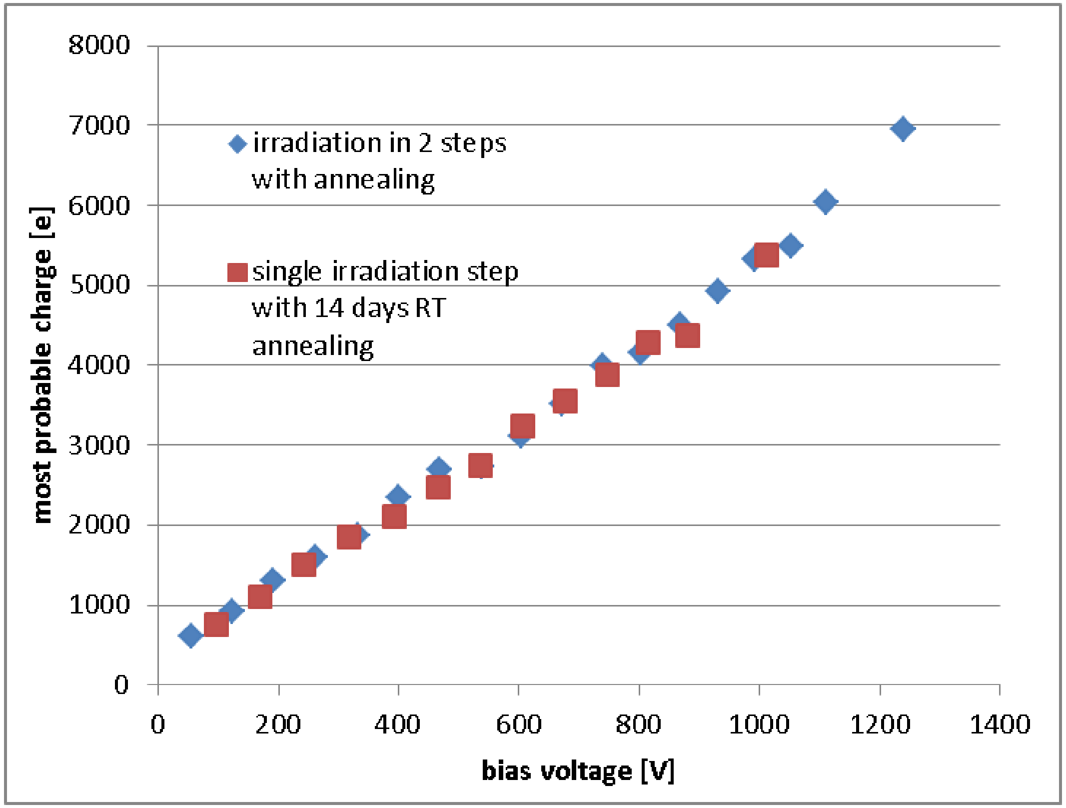
CCE – beneficial annealing



- Around 30% better charge collection efficiency as before annealing
- Much larger CCE for spaghetti diode than for standard RD50 diode from previous Micron run:
  - the effect of multiplication, due to strip geometry?
  - partially also weighting field? - although only a small difference in the between standard and spaghetti diode

CCE – irradiation in steps

How does the irradiation in steps with subsequent annealing compare to fixed fluence irradiation?



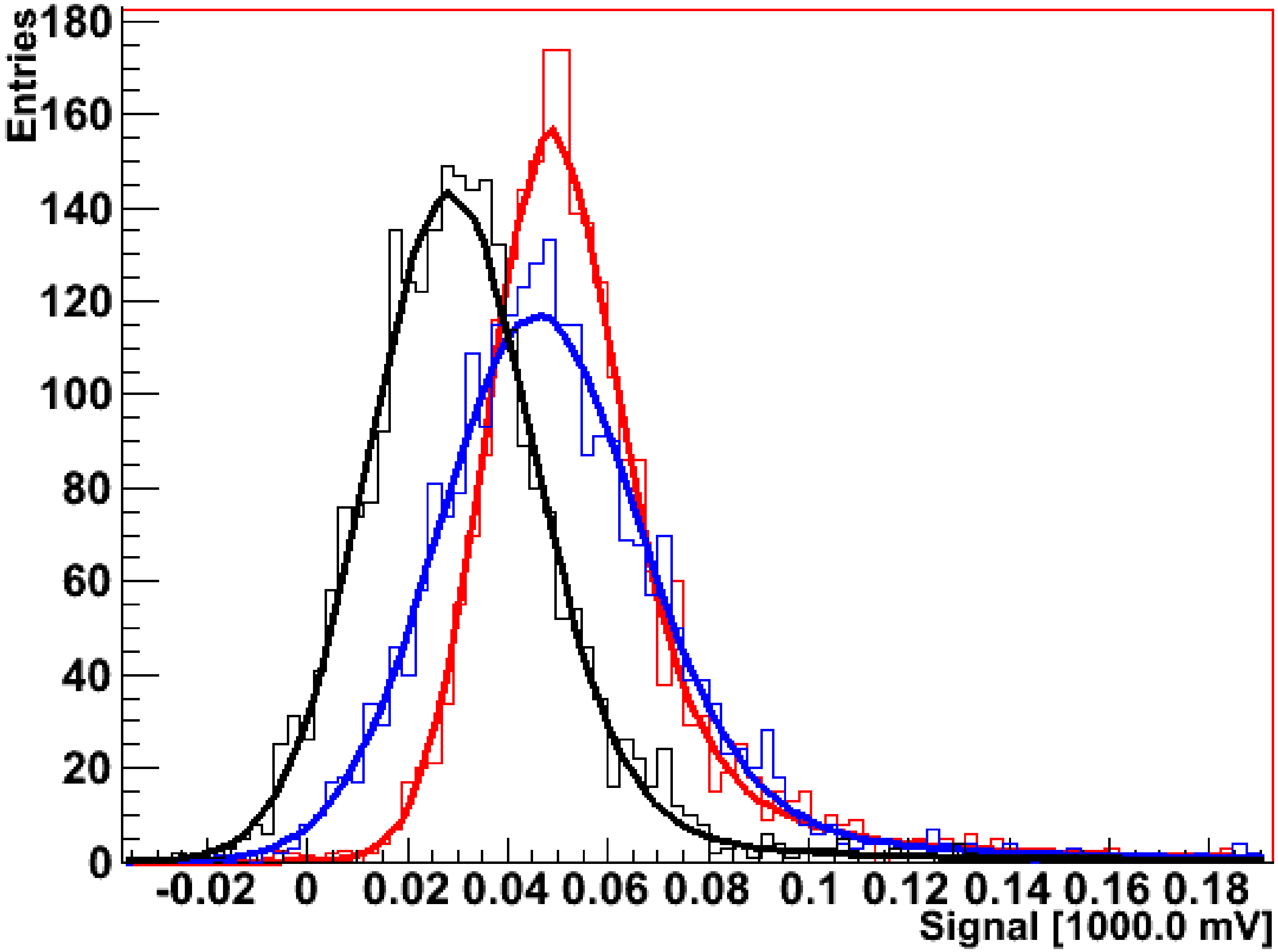
Almost identical most probable charge measured!

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 for charge collection measurements with ^{90}Sr electrons as standard diodes
- Thin diodes perform better than standard ones for both fluences up to 1000 V
- The “CERN scenario” irradiations give identical results as samples irradiated to fixed fluences and subsequently annealed at RT for 14 day
- As expected the spaghetti diodes perform “better” than standard diodes and worse than strip detectors at given fluence, annealing time and voltage due to difference in weighting field.

Further studies are underway with TCT for which these samples are ideal !



Entries
180
160
140
120
100
80
60
40
20
0
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
Signal [1000.0 mV]