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Update on tests with passive strucutres on CHESS 2 chip

ATLAS Strip CMOS meeting, 10.01.2017

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Samples

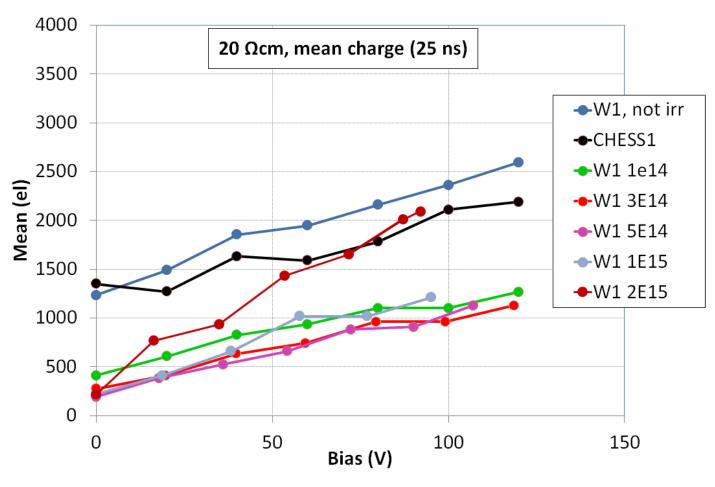| Resistivity [Ω-cm]	Wafer numbers	Wafers cut	Number of cut chips
std	1-6	1, 2	94
50-100	7-12	7, 8	97
200-300	13-18	13, 14	94
600-2000	19-24	19, 20	95

Neutron fluences 0e14, 1e14, 3e14, 5e14, 1e15, 2e15 neq/cm2

Test structures:
- 3 x 3 pixel array for E-TCT (pixel size 630 x 40 μm^2)
- Large array for Sr90 measurements (1.2 x 1.2 mm^2)

20 Ωcm, mean charge (25 ns)

Legend: W1, not irr; CHESS1; W1 1e14; W1 3E14; W1 5E14; W1 1E15; W1 2E15

Collected charge is less than expected from E-TCT measurements
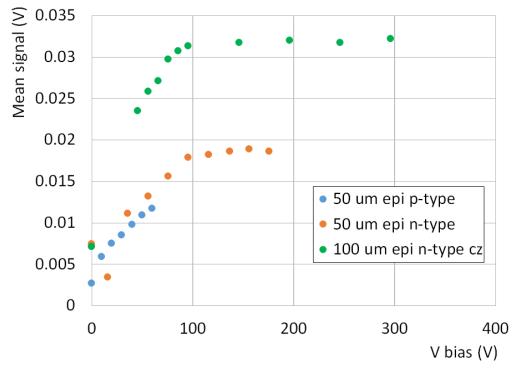
But is that really the case ?

Calibration of the Q-TCT setup was carried out, discussion on next slides

Q-TCT calibration 1

Sr90 calibration procedure
- using epitaxial diodes with known thickness (d = 50 and 100 μm)
- after epi-layer is fully depleted extract scaling factor $A = d \times 100$ pairs/μm / V_{sig}

Only n-type diodes could be biased highly enough for calibration
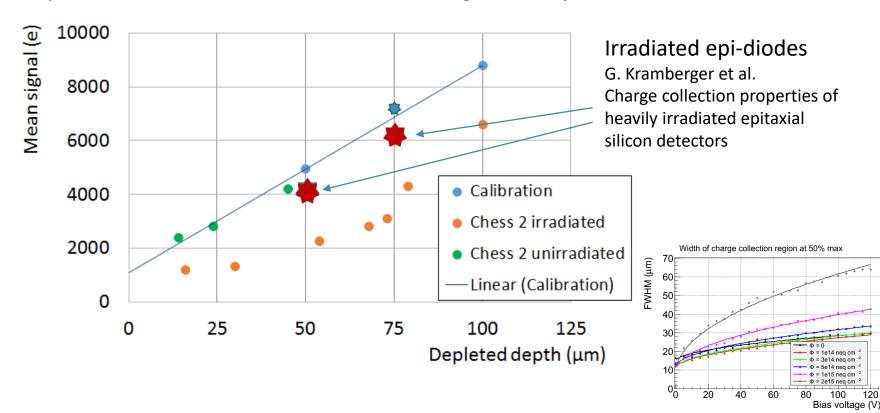p-type breaks down at 60 V, before full depletion

Q-TCT calibration 2

Results:

calibration factor in the same range as used up to now A = 275 000 pairs / V, but

the signals for unirradiated CHESS 2 devices are actually what we would expect only irradiated CHESS 2 devices have less charge than expected:
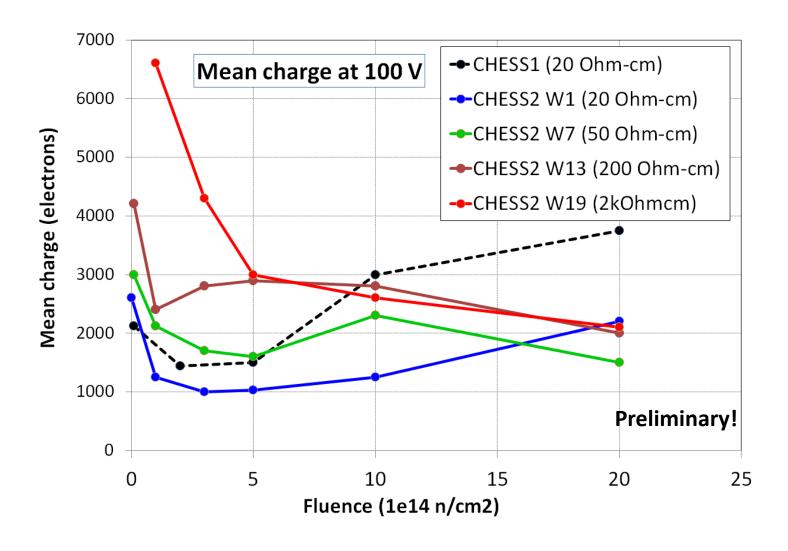

Irradiated epi-diodes
G. Kramberger et al.
Charge collection properties of heavily irradiated epitaxial silicon detectors

Depleted depth for CHESS 2 is determined from the formula:
(N_eff from E-TCT)

$$d = \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$$

Sr90 Comparison for different substrates

Mean charge at 100 V

- ━●━ CHESS1 (20 Ohm-cm)
- ━●━ CHESS2 W1 (20 Ohm-cm)
- ━●━ CHESS2 W7 (50 Ohm-cm)
- ━●━ CHESS2 W13 (200 Ohm-cm)
- ━●━ CHESS2 W19 (2kOhmcm)

Preliminary!

Y-axis: Mean charge (electrons)
X-axis: Fluence (1e14 n/cm2)
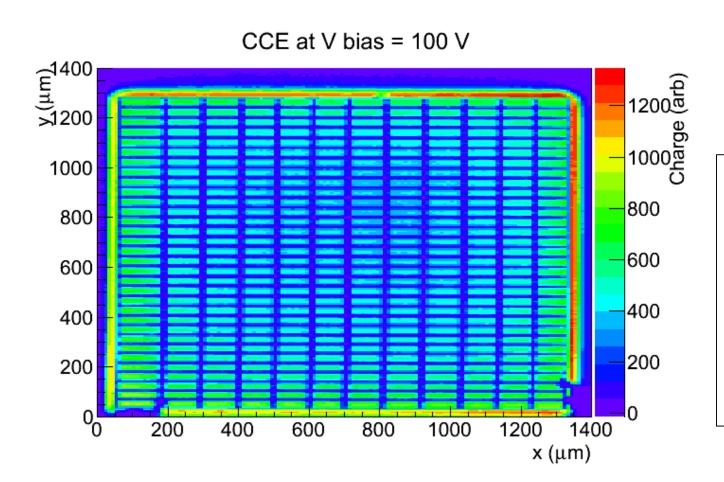
CHESS1 vs. CHESS2 (std. resistivity) : trend is similar, but mean charge differs
Could be due to a different wafer composition → different acceptor removal

- Charge from Sr90 measurements systematically only 60 % of that expected for the depletion depth measured by E-TCT
- Investigate with top TCT
  - IR light – 980 nm, abs. depth 100 µm → no reflections from back plane

CCE at V bias = 100 V

W19 5e14
Big array for Sr90
(1.2 mm x 1.2 mm)

Gaps between pixels due to metalization on top of the chip
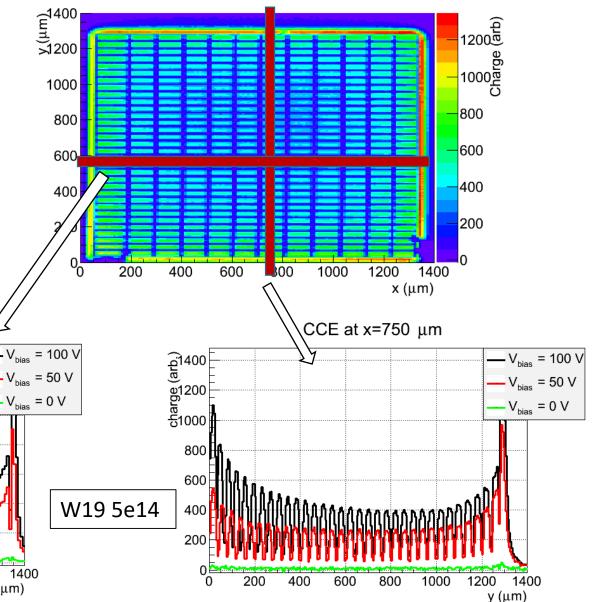
But on the large scale **intensity in central pixels less than on edges !**

Difference in the collected charge indicates a larger depletion depth on the edges of the Sr 90 array.
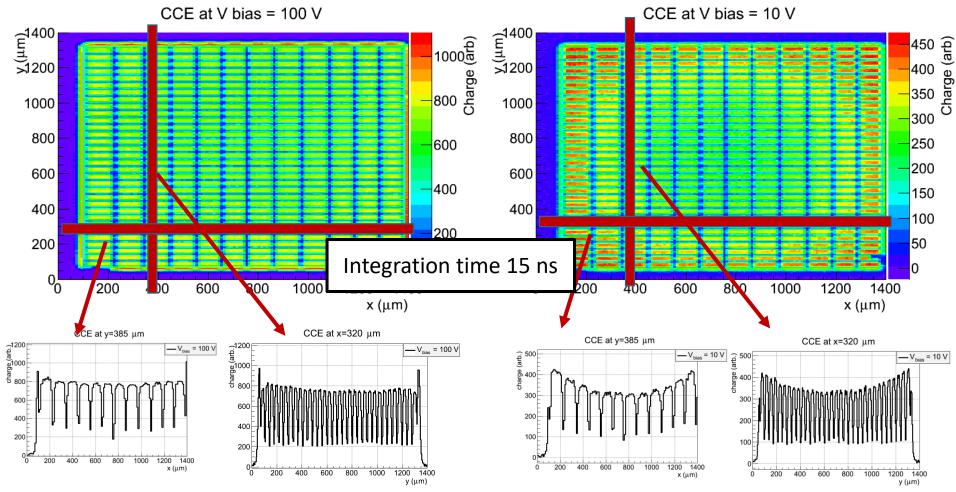
Edge-like pixels also measured in Edge-TCT. This may be a reason for discrepancy between the measurements.

W19 5e14

W13 unirradiated (200 Ohm-cm), λ=980 nm

Integration time 15 ns
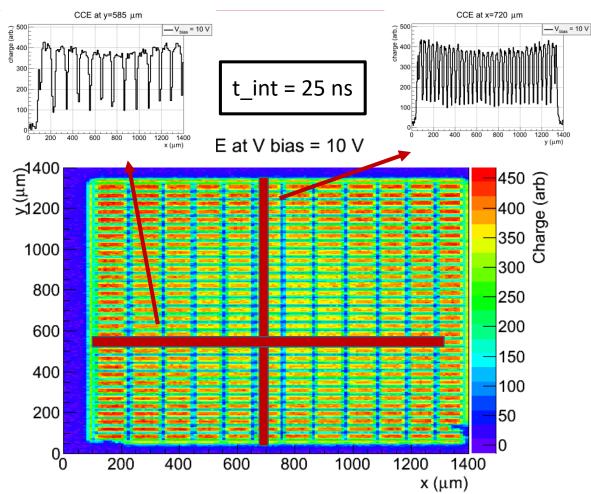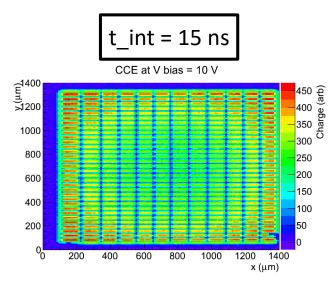
Unirradiated sample:

For 100 V bias charge is uniform across the structure, while for 10 V bias there is a distinctive gap in the centre. However the gap can be recovered by increasing integration time (next slide)

t_int = 25 ns

E at V bias = 10 V

t_int = 15 ns

CCE at V bias = 10 V

CCE at V bias = 10 V

t_int = 50 ns

In unirradiated samples the non-uniformity is recovered by increased integration time (.

What about irradiated samples?

Ch. 1:x=-7.000e+002,y=-3.900e+003,z=-4.800e+003,U1=10.00, U2=0.00

High charge (edges)
Low charge (centre)

Entries	2047
Mean	46.2
RMS	57.9
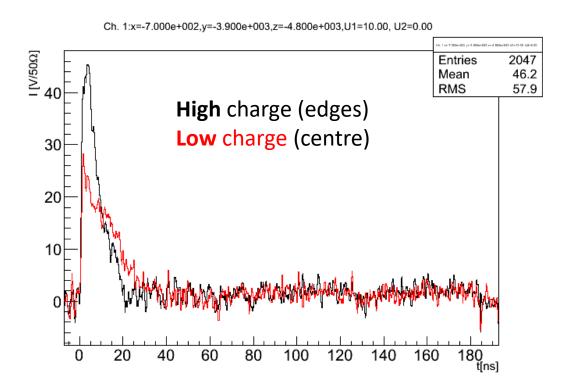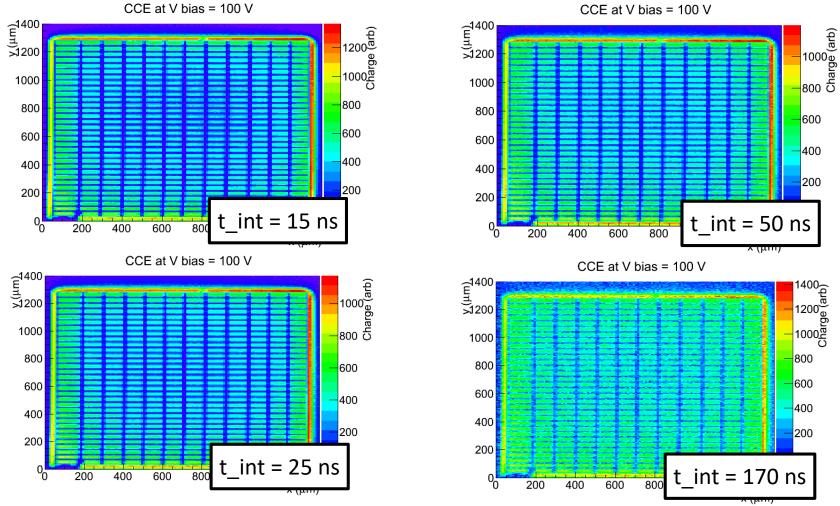
W19 5e14 n/cm2 (2 kOhm-cm), λ=980 nm
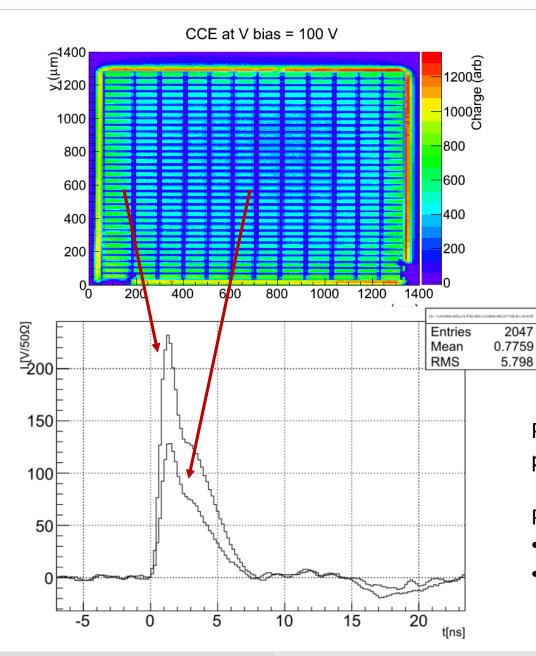
Neutron irradiation 5e14 n/cm2, wafer 19 (other than unirradiated sample)

Hole in the center remains for all integration times

Pulse shape irradiated sample

CCE at V bias = 100 V

Pulse shape does not change with position, only the scaling changes

Possible explanations:
- Different depleted depth
- Different light absorption (why ?)

	Entries	2047
	Mean	0.7759
	RMS	5.798

Summary
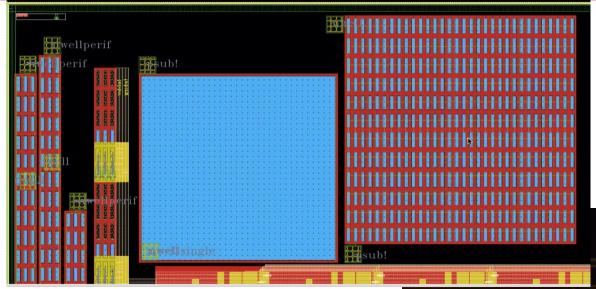
- Missing charge in Sr90 measurement
  - Before irradiation the collected charge is compatible with other measurements
  - After irradiation less charge is collected than expected / in other measurements

- Investigation with top TCT:
  - The centre of the Sr array collects less charge than the edges
  - Before irradiation: difference depends on integration time
  - After irradiation: difference depends much less on integration time

- Conclusions at present:
  - Charge collection within the Sr90 array is not uniform
  - Possible reasons:
    - Different depletion depth
    - Different light absorption
    - Electrical bugs ?
    - Any ideas ?

- Further investigations TBD

BACKUP

Passive structures on CHESS2
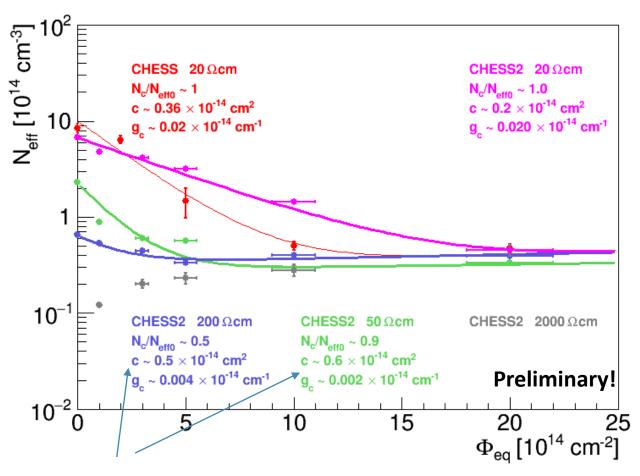
Red traces - metalization

$$N_{\text{eff}} = N_{\text{eff0}} - N_c \cdot (1 - \exp(-c \cdot \Phi_{\text{eq}})) + g_c \cdot \Phi_{\text{eq}}$$

CHESS   20 Ω cm
$N_c/N_{\text{eff0}} \sim 1$
$c \sim 0.36 \times 10^{-14}$ cm²
$g_c \sim 0.02 \times 10^{-14}$ cm⁻¹

CHESS2   20 Ω cm
$N_c/N_{\text{eff0}} \sim 1.0$
$c \sim 0.2 \times 10^{-14}$ cm²
$g_c \sim 0.020 \times 10^{-14}$ cm⁻¹

CHESS2   200 Ω cm
$N_c/N_{\text{eff0}} \sim 0.5$
$c \sim 0.5 \times 10^{-14}$ cm²
$g_c \sim 0.004 \times 10^{-14}$ cm⁻¹

CHESS2   50 Ω cm
$N_c/N_{\text{eff0}} \sim 0.9$
$c \sim 0.6 \times 10^{-14}$ cm²
$g_c \sim 0.002 \times 10^{-14}$ cm⁻¹

CHESS2   2000 Ω cm

Preliminary!
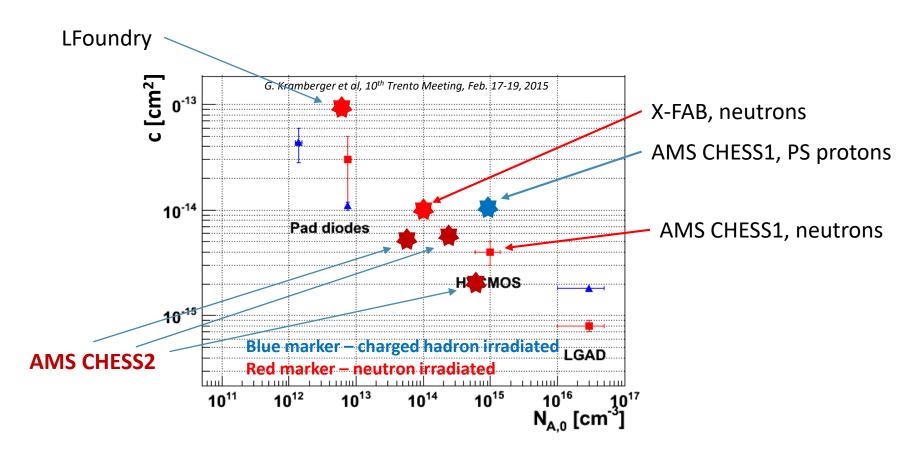
Removal at the highest resistivity substrate is completed below 1e14 neq/cm2 and was not observed in this study

should verify again

LFoundry

G. Kramberger et al, 10th Trento Meeting, Feb. 17-19, 2015

c [cm^2]

0^{-13}

10^{-14}

10^{-15}

Pad diodes

H CMOS

X-FAB, neutrons

AMS CHESS1, PS protons

AMS CHESS1, neutrons

AMS CHESS2

Blue marker – charged hadron irradiated
Red marker – neutron irradiated

LGAD

10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17}

$N_{A,0}$ [cm^{-3}]

IV w1
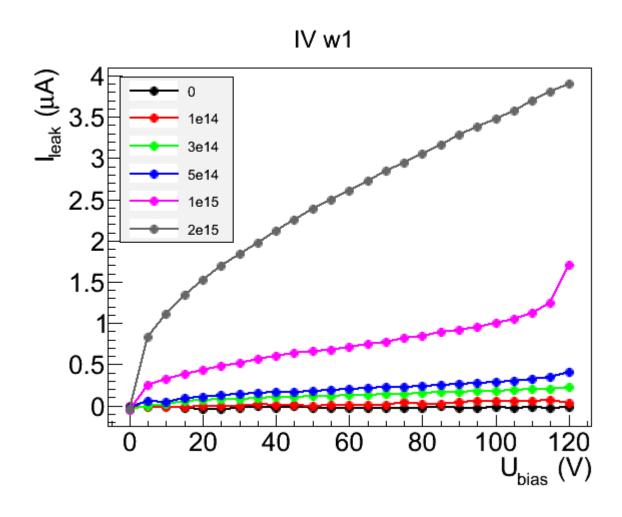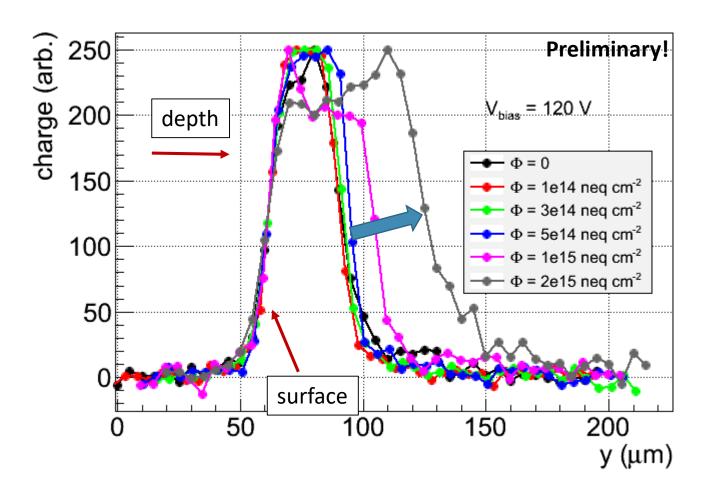
I-V measured on a TCT array
(3 x 3 pixels, pixel size 630 x 40 μm^2)
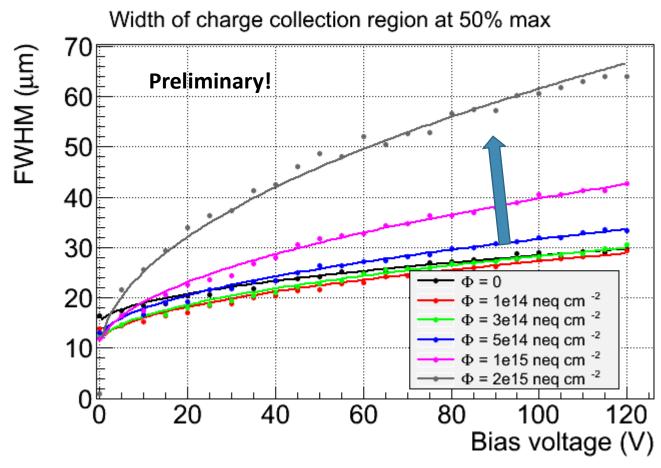
- Moderate charge collection width, but increases with irradiation
- Low resistivity → late acceptor removal

Width of charge collection region at 50% max

Preliminary!

FWHM (μm) vs Bias voltage (V)

Legend:
- $\Phi = 0$
- $\Phi = 1e14$ neq cm^{-2}
- $\Phi = 3e14$ neq cm^{-2}
- $\Phi = 5e14$ neq cm^{-2}
- $\Phi = 1e15$ neq cm^{-2}
- $\Phi = 2e15$ neq cm^{-2}

20 Ohm-cm :
late acceptor removal, largest charge
collection region at highest
measured fluences

$$Width(V_{bias}) = w_0 + \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$$
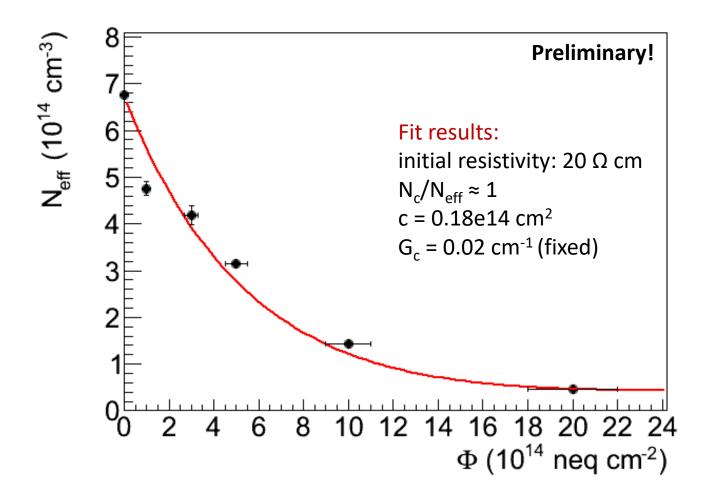
Extract value from fit

N$_{eff}$ vs. fluence
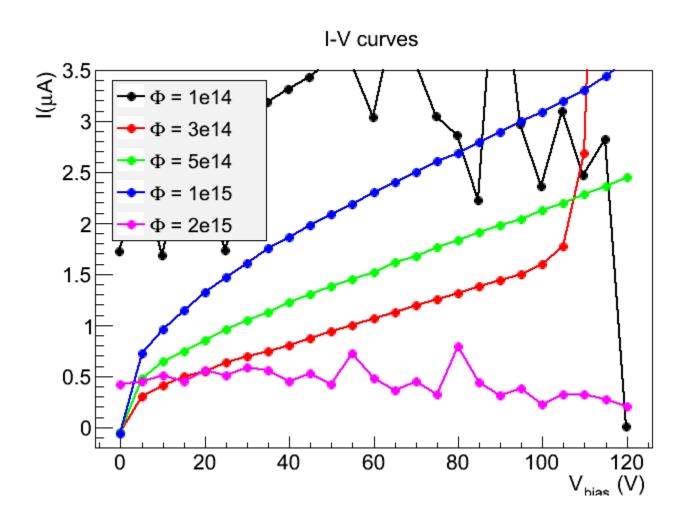
Fit:
$$N_{\mathrm{eff}} = N_{\mathrm{eff0}} - N_{\mathrm{c}} \cdot (1 - \exp(-c \cdot \Phi_{\mathrm{eq}})) + g_c \cdot \Phi_{\mathrm{eq}}$$

acceptor removal

Radiation introduced deep acceptors

Preliminary!

Fit results:
initial resistivity: 20 Ω cm
$N_c/N_{eff} \approx 1$
c = 0.18e14 cm^2
G_c = 0.02 cm^{-1} (fixed)

I-V curves

Width of charge collection region at 30% max

Preliminary!

FW at 30 % max (μm) vs Bias voltage (V)

Legend:
- Φ = 1e14
- Φ = 3e14 neq cm^{-2}
- Φ = 5e14 neq cm^{-2}
- Φ = 1e15 neq cm^{-2}
- Φ = 2e15 neq cm^{-2}
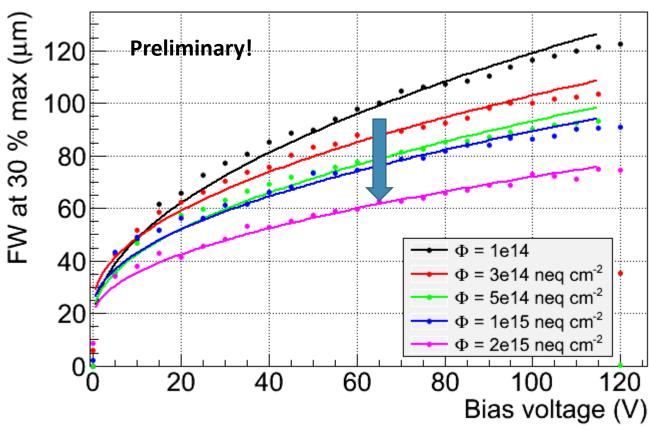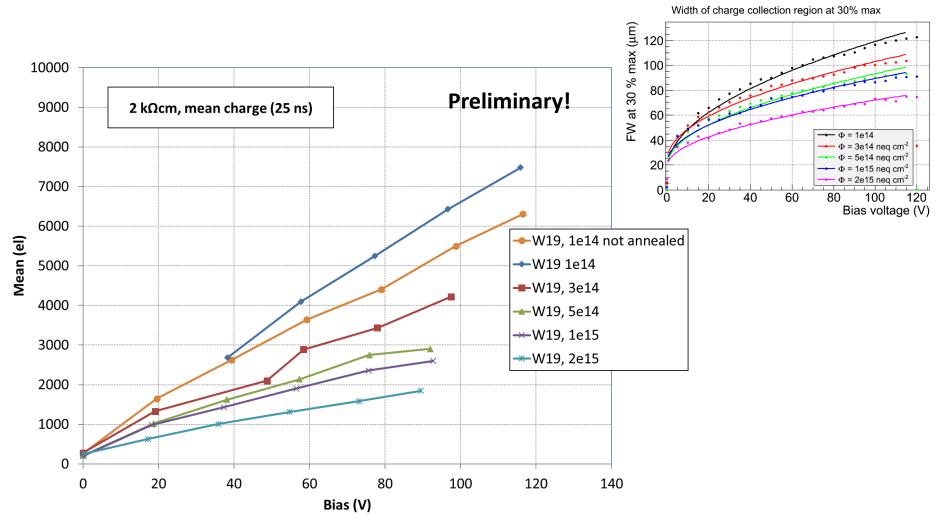
$$Width(V_{bias}) = w_0 + \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$$

- Sqrt functions falling monotonously with fluence

Sr90 charge

Width of charge collection region at 30% max

2 kΩcm, mean charge (25 ns)

Preliminary!

Legend:
- W19, 1e14 not annealed
- W19 1e14
- W19, 3e14
- W19, 5e14
- W19, 1e15
- W19, 2e15

FW at 30 % max (μm) vs Bias voltage (V):
- Φ = 1e14
- Φ = 3e14 neq cm⁻²
- Φ = 5e14 neq cm⁻²
- Φ = 1e15 neq cm⁻²
- Φ = 2e15 neq cm⁻²
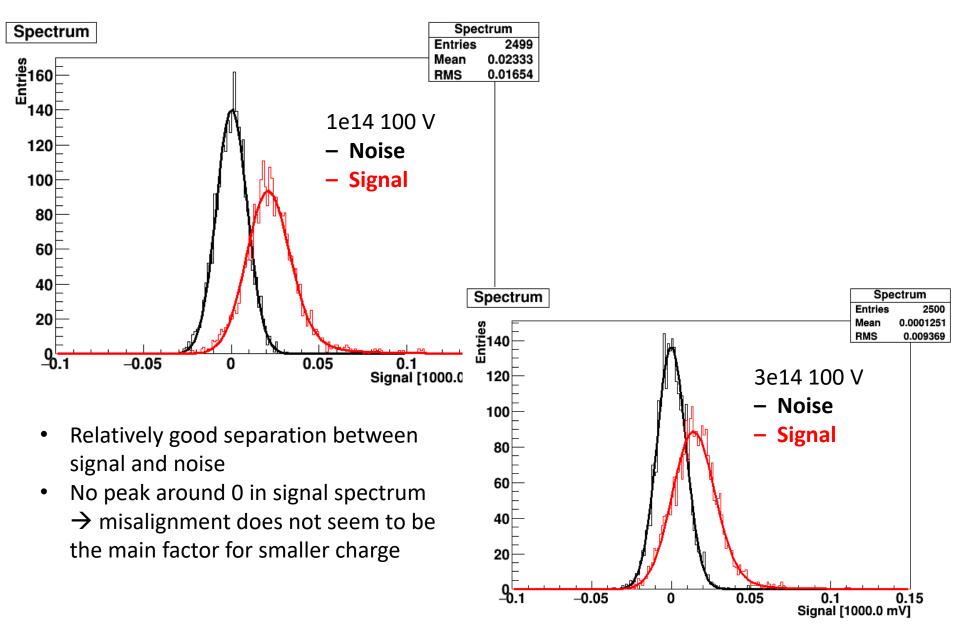
- TCT 1e14: depletion zone 120 um at 100 V
- We still collect less charge than expected (f.e. meas. 7000 e vs. 12000 e expected)
- Investigate with top TCT ?

Spectrum

Spectrum	
Entries	2499
Mean	0.02333
RMS	0.01654

1e14 100 V
- **Noise**
- **Signal**

Spectrum

Spectrum	
Entries	2500
Mean	0.0001251
RMS	0.009369

3e14 100 V
- **Noise**
- **Signal**

- Relatively good separation between signal and noise
- No peak around 0 in signal spectrum → misalignment does not seem to be the main factor for smaller charge
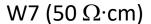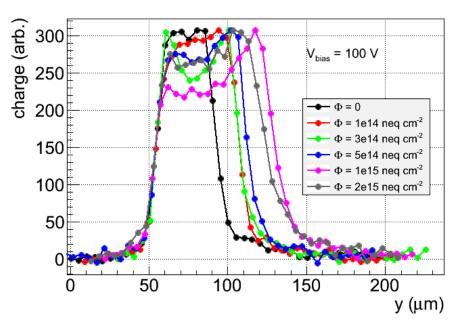
Charge profiles W7, W13
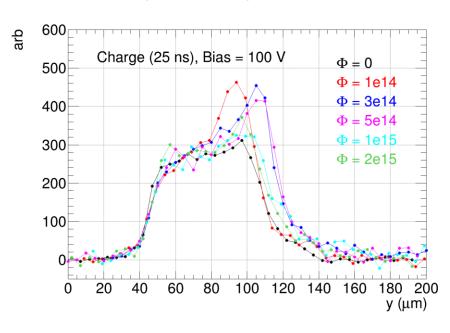
- Edge-TCT charge collection profile across central pixel

W7 (50 $\Omega\cdot$cm)

W13 (200 $\Omega\cdot$cm)

- increase of width with fluence up to 1e15
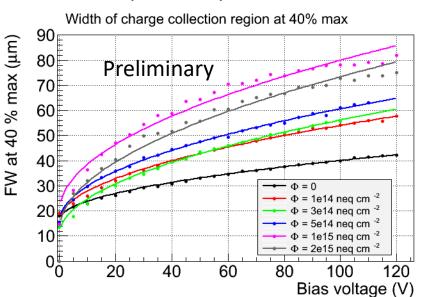
- not much change of profile width with fluence
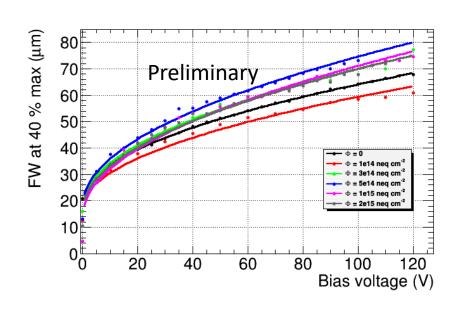
- width of charge collection profile vs. bias

W7 (50 $\Omega \cdot$cm)

W13 (200 $\Omega \cdot$cm)

Width of charge collection region at 40% max

Preliminary

Preliminary

Fit: $Width(V_{bias}) = w_0 + \sqrt{\dfrac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$

At Φ = 0

- W7: N_{eff} = 2.3e14 cm^{-3} → 56 $\Omega \cdot$cm
- W13: N_{eff} = 6.6e13 cm^{-3} → 200 $\Omega \cdot$cm
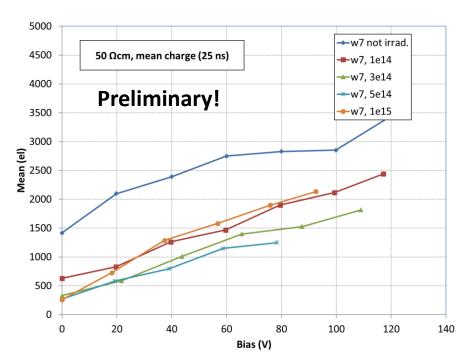
→ Good fit, good agreement with nominal resistivity

W7 (50 $\Omega \cdot$ cm)
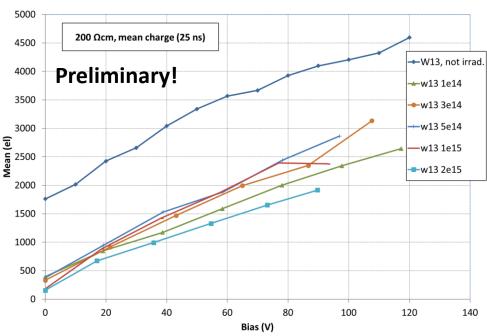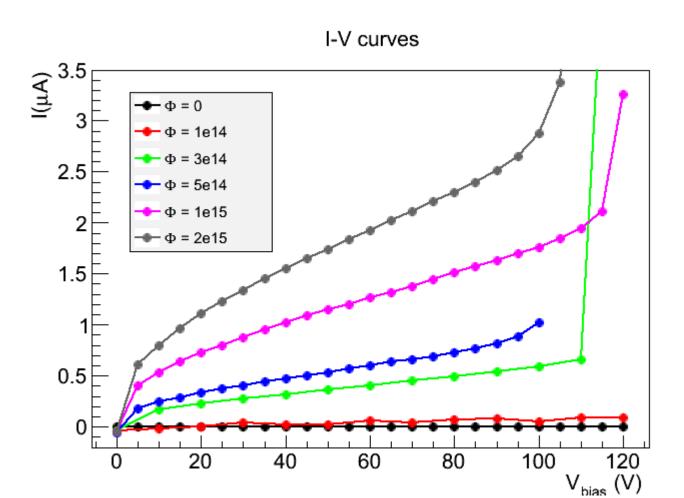
W13 (200 $\Omega \cdot$ cm)

- large drop of collected charge (delta ≈ 1300 el) after first irradiation step to 1e14 n/cm2
  - ➔ reduced contribution from diffusion
- TCT measurements indicate depleted region > 50 μm
  - Expect > 5000 el. from drift
  - Measure 2000 el.

No IV curves for wafer 7 due to a bug, but 0e14, 1e14, 1e15, 2e15 OK up to 120 V
5e14 up to 110 V, 3e14 at least up to 90 V
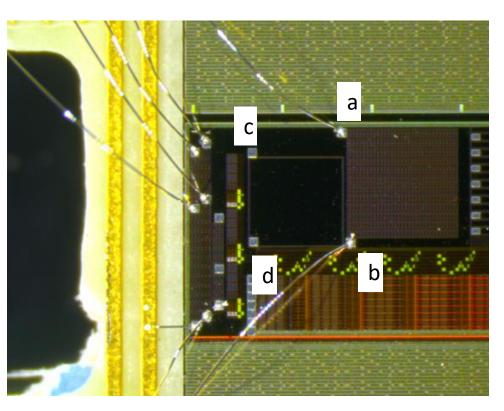
High resistivity wafers

- After suggestion from Santa Cruz tried biasing the substrate from other pads:
  - a & d → breakdown at 18 V
  - a & b → breakdown at 18 V
  - c & d → breakdown at 1 V
  - c & b → breakdown at 1 V

Planning also to measure IV of irradiated devices on probe station to see if there is improvement after irradiation
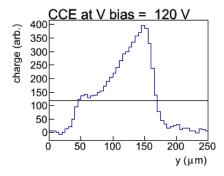
a – LPA nwells
b – LPA substrate
c – Large Pad nwells
d – Large Pad substrate