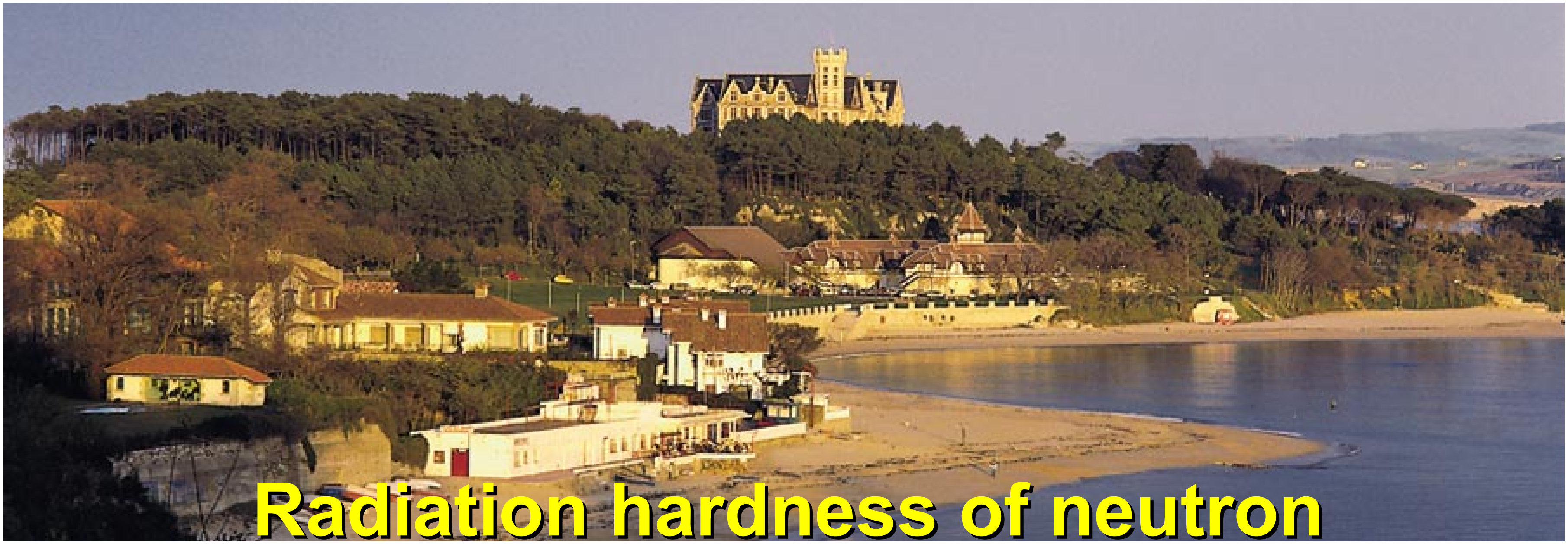

Radiation hardness of neutron irradiated HVCMOSv3

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CERN PH-DT-SSD

Marcos Fernandez Garcia
IFCA-Universidad de Cantabria (visiting scientist at CERN PH-DT-SSD)

Daniel Muenstermann
University of Geneva

26th RD50 workshop – June 22-24, Santander (Spain)

Outline

Introduction to eTCT and HVCMOS detectors

Measurement campaign

Raw data: depletion width and Collected Charge

Some thoughts on limits of eTCT for HVCMOS

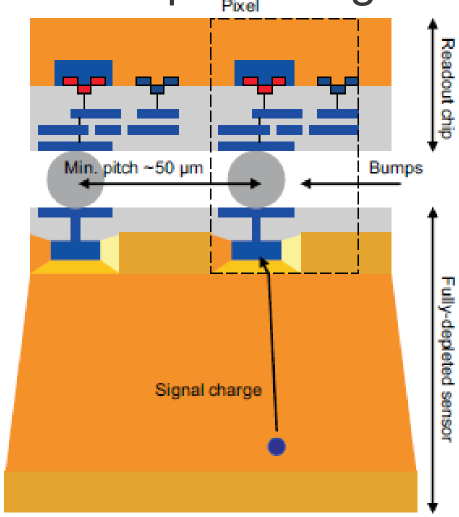
Interpretation of depletion width

Conclusions

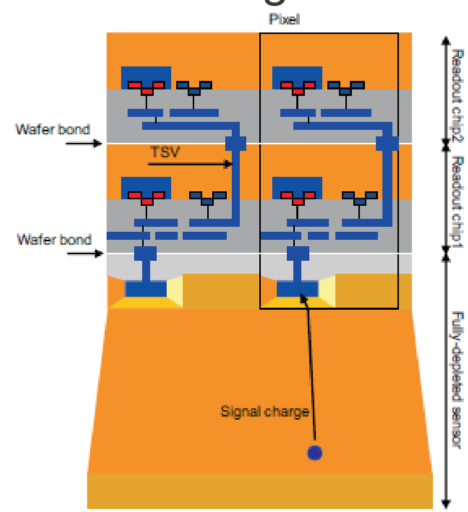
Introduction to HVCMOS

Hybrid pixels

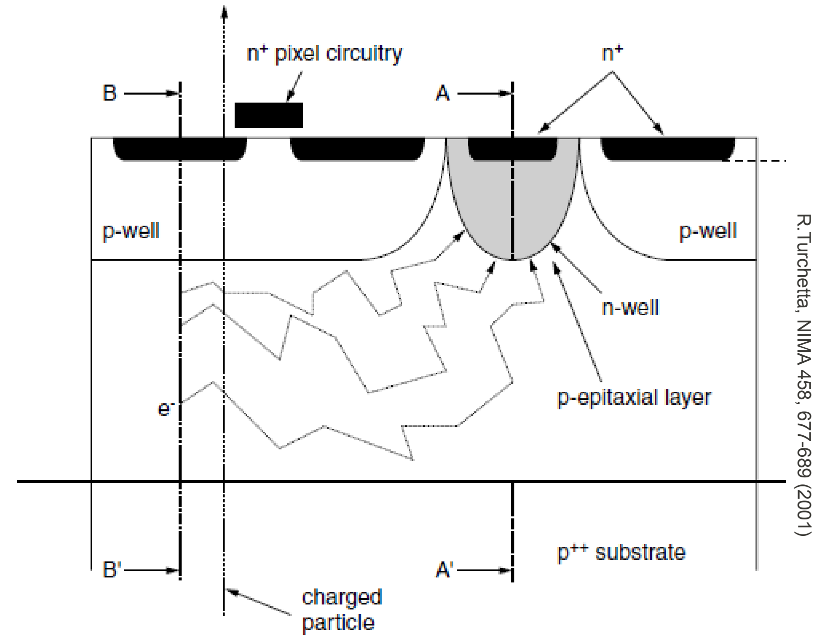
Bump bonding

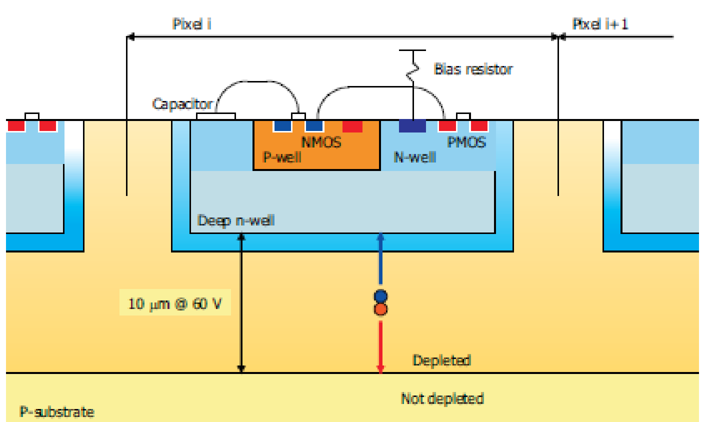


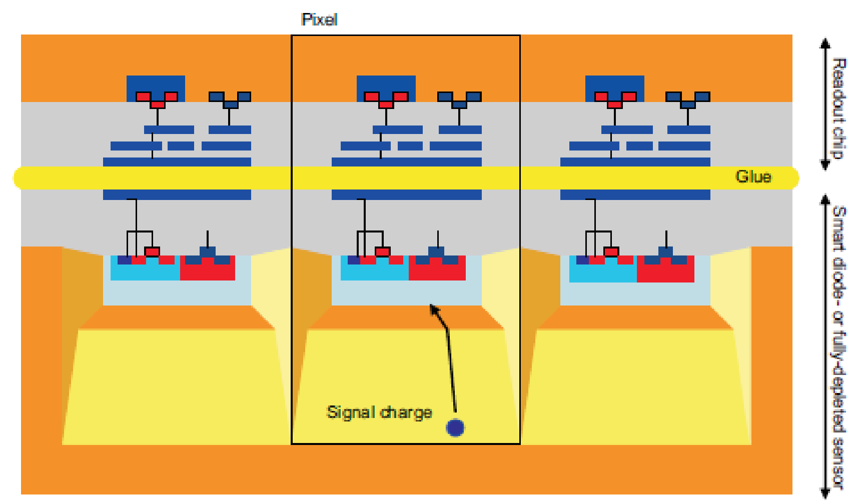
3D integration



Monolithic CMOS





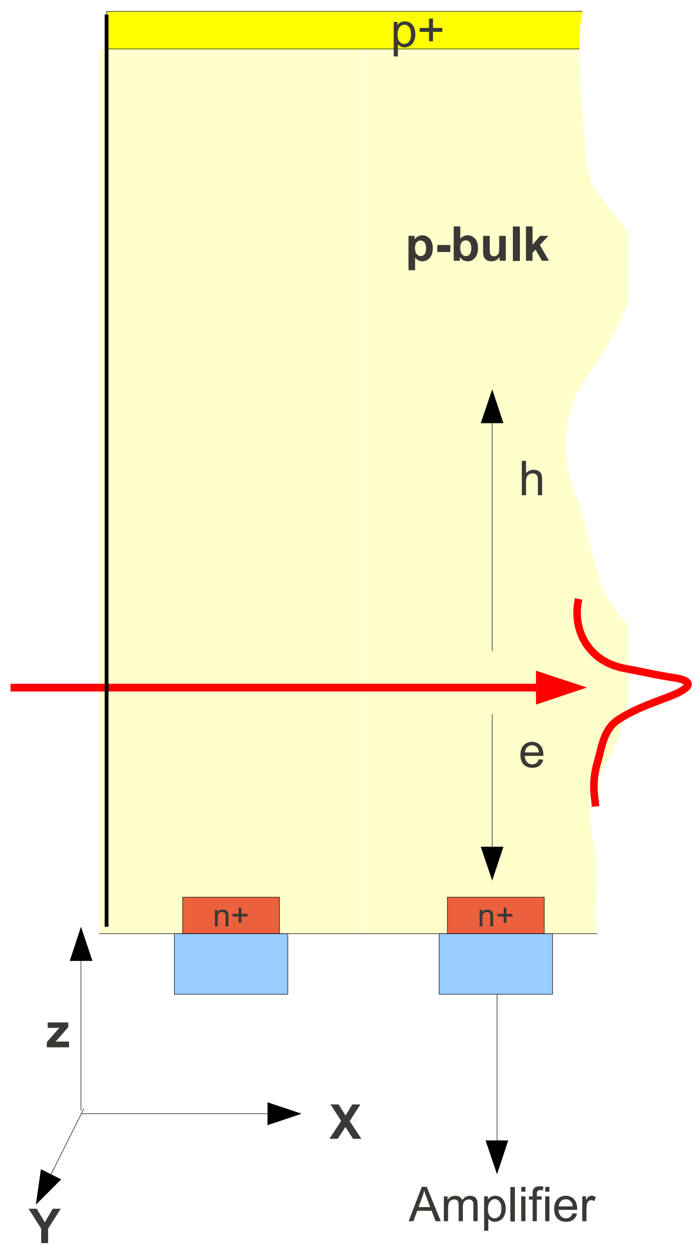


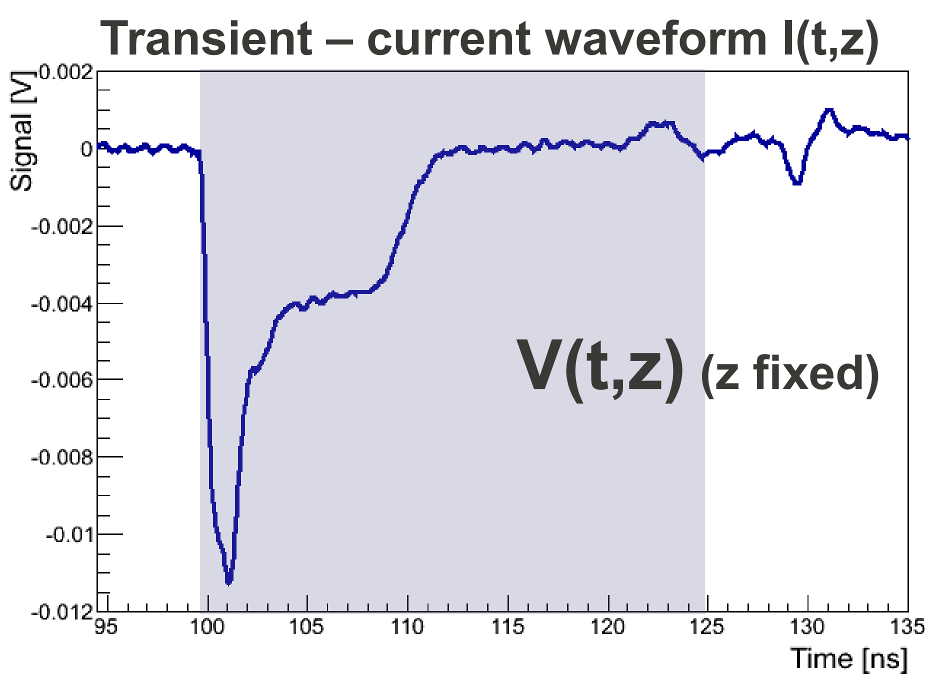
Unconfirmed guesses:
DNwell~1×10^{20} cm^{-3} ? , 5 µm depth (n-type)
Bulk 10 Ω.cm=1.4×10^{15} cm^{-3} (p-type)

HVCMOS sketches from I. Peric

ETCT summary

G. Kramberger et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 57, NO. 4, AUGUST 2010





Signal maps:
2D scan

I(t ; z) z variable

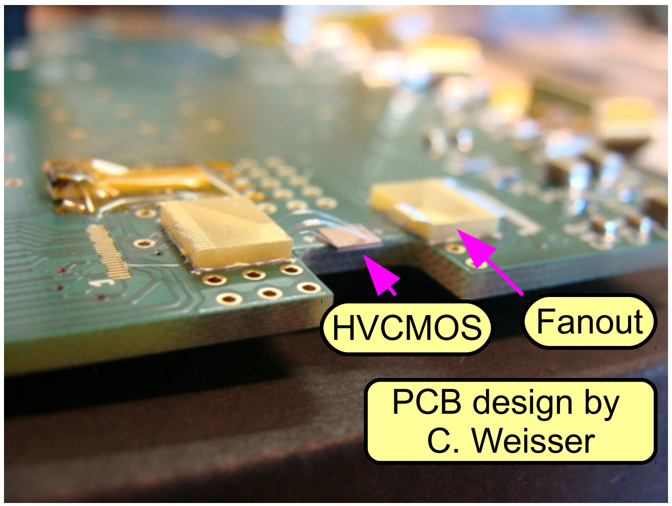
Charge profile
1D scan

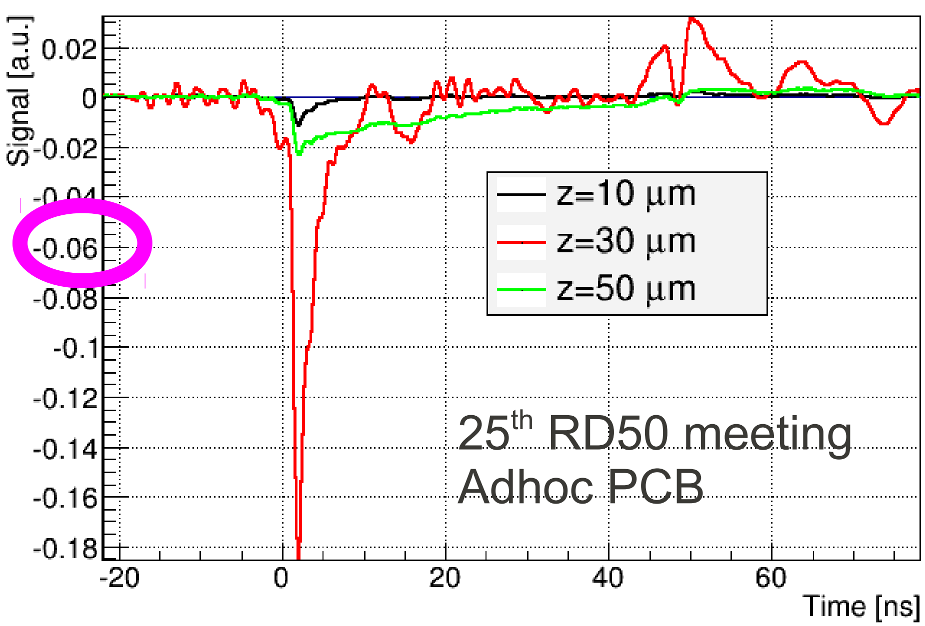
$$Q(z) = \int_0^{25\,ns} I(t,z)\,dt$$

Charge maps:
2D scan

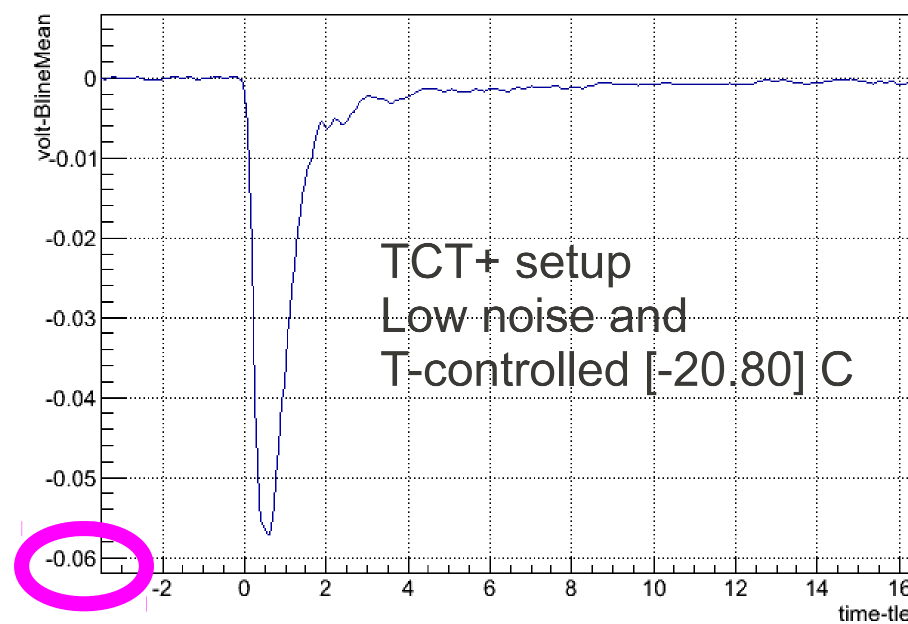
$$Q(x,z) = \int_0^{25\,ns} I(t;x,z)\,dt$$

- **25th RD meeting**: measurement of n-irradited (**0, 1e15, 7e15, 2e16 n_{eq}/cm^2**) in eTCT configuration.
- Detectors mounted on custom designed PCB. **Many reflections observed**.
- Only readout of a passive diode is needed → Overkilled solution





- **26th RD50 meeting**: measurements repeated on fresh samples using **CERN SSD TCT+ setup.** Measurement campaign by *C. Gallrapp.*
- Detectors mounted on a **passive PCB**, **diode connected to fast current amplifier** .
- T-controlled setup



Analysis of raw data

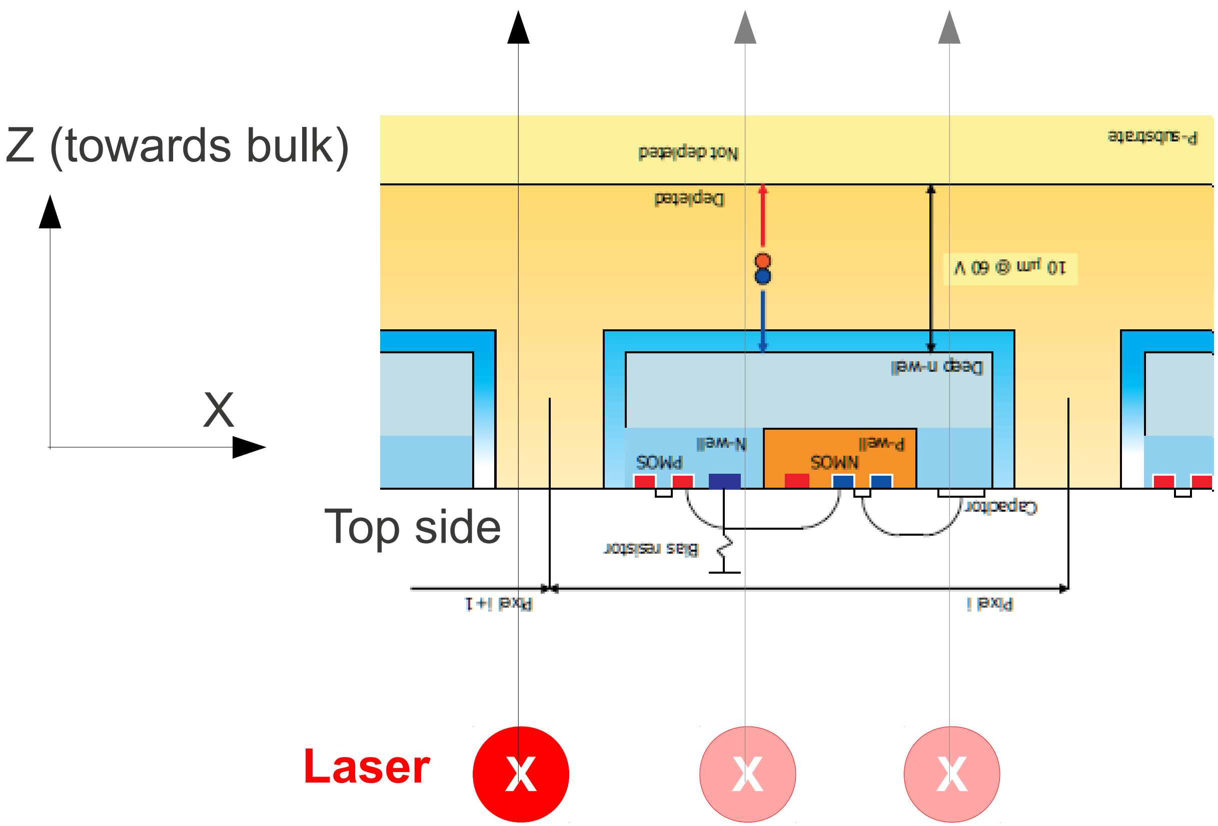
Neutron irrad: 0, 1e15, 7e15, 2e16 n_{eq}/cm^2

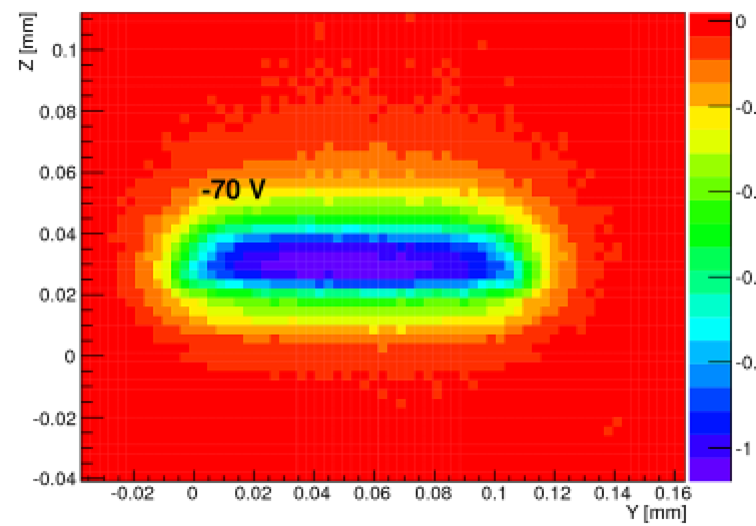
Detector edge 2D scan at 3 voltages and 3 Temperatures:

1) Good to measure lateral X dimension
2) depletion thickness (along Z)

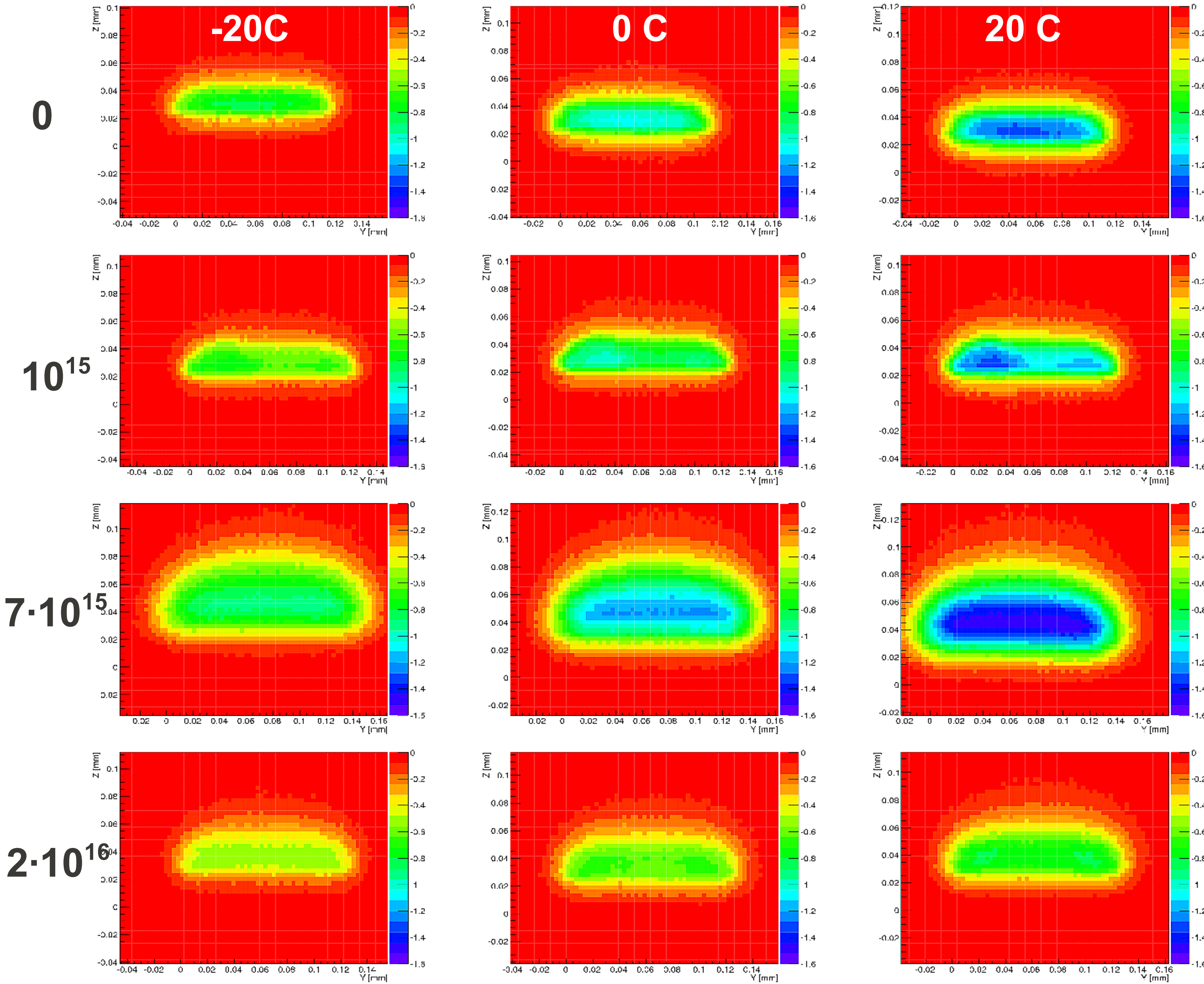
Q(x,z)=Charge maps [5ns]

$$Q(x,z;5\,ns)=\int_0^5 I(t;x,z)\,dt$$





Note: detector breakdown~90V. Detectors biased up to 80V only.

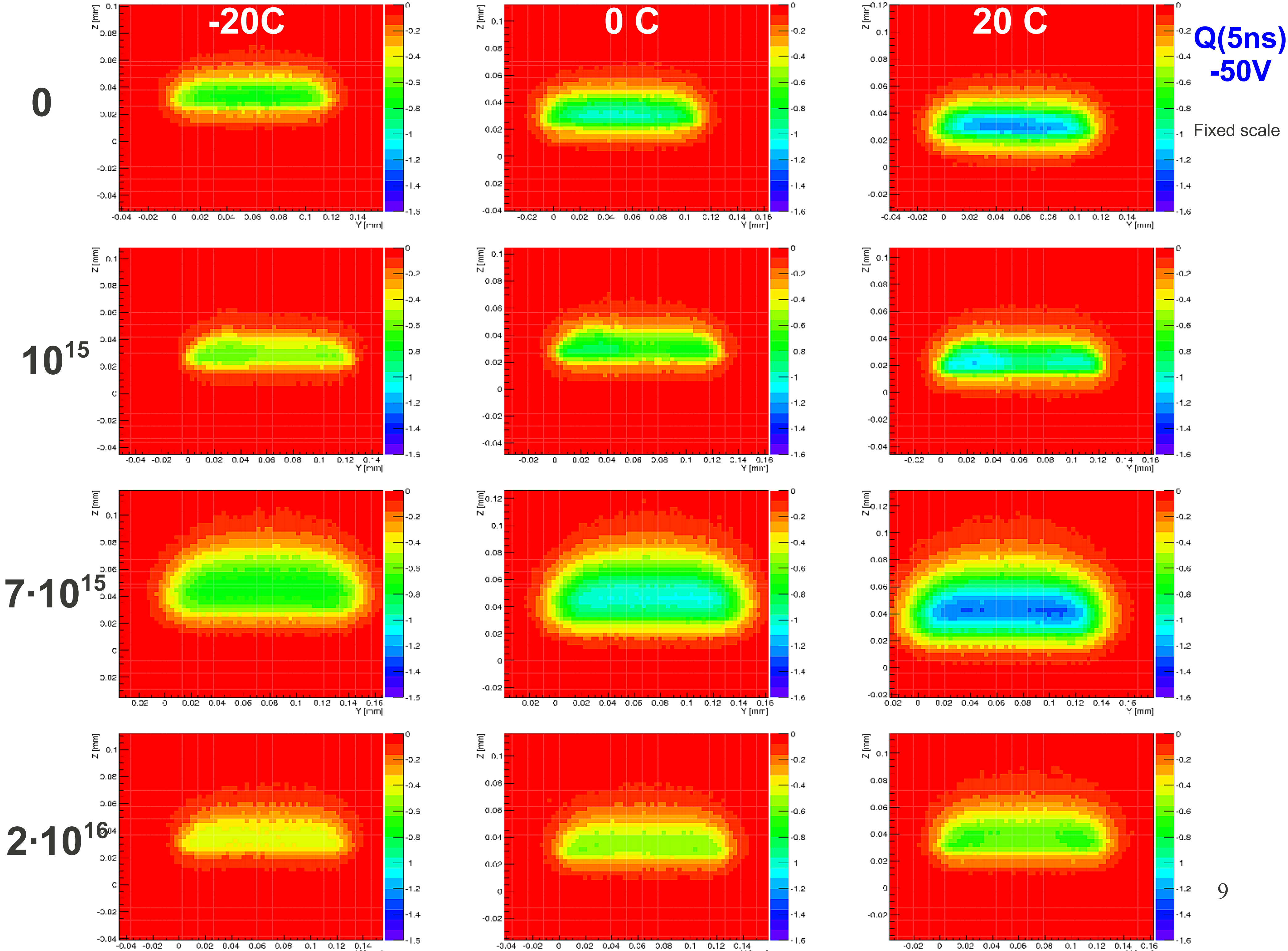


Q(5ns) -70V

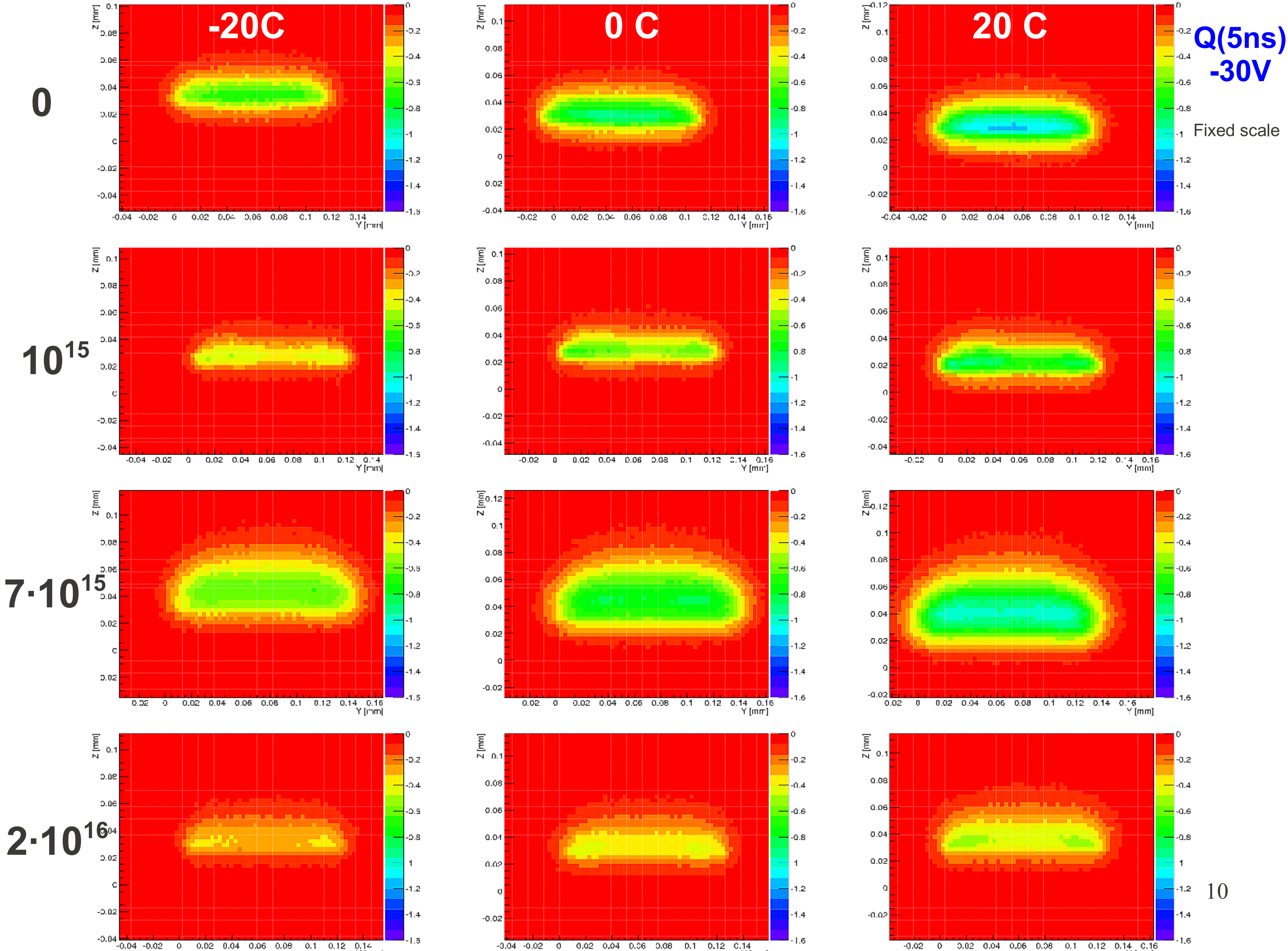
Fixed scale

X axis length and Y axis length is the same in all plots, even if the absolute coordinates are not the same.

Therefore the plots show windows of the same area including the detector.

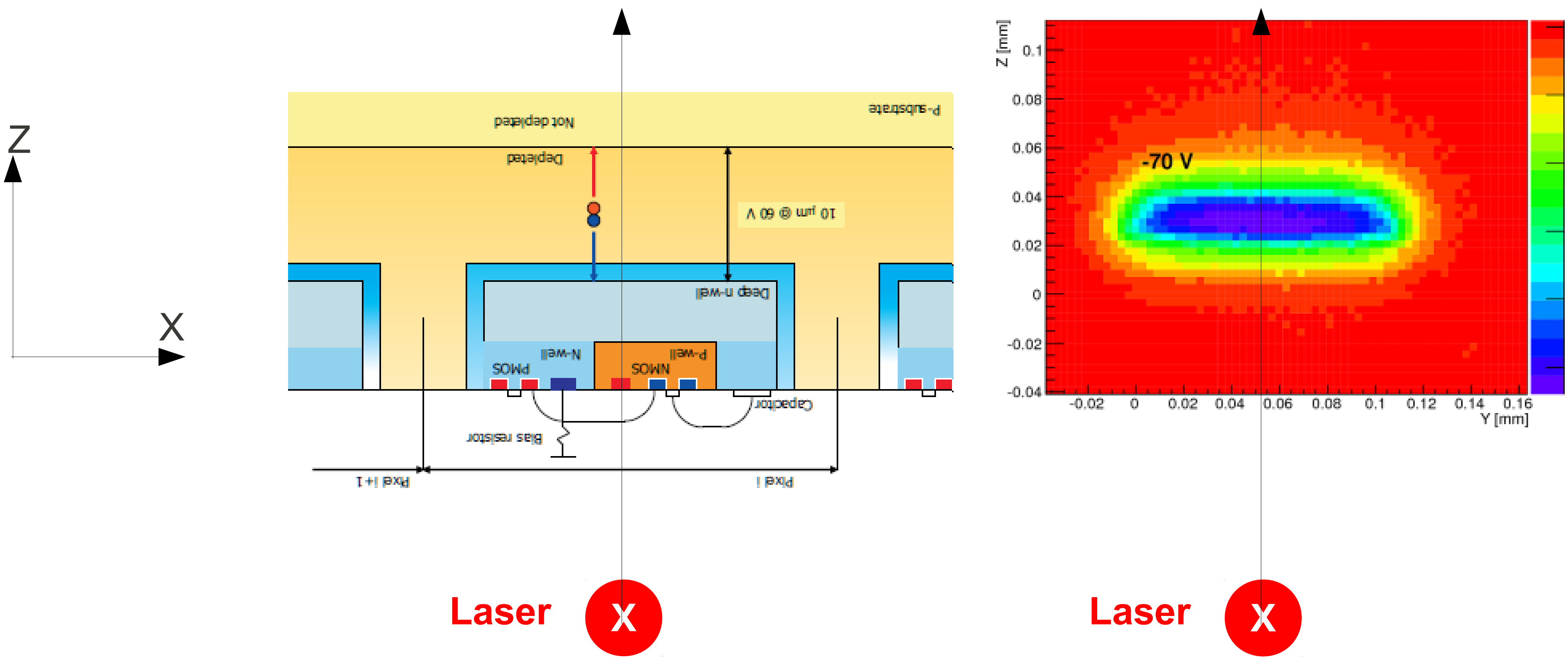


-20C
0 C
20 C
Q(5ns)
-50V
Fixed scale
0
10^15
7·10^15
2·10^16
Z [mm]
Y [mm]


-20C
0 C
20 C
Q(5ns)
-30V
Fixed scale
0
10^15
7·10^15
2·10^16
Z [mm]
Y [mm]

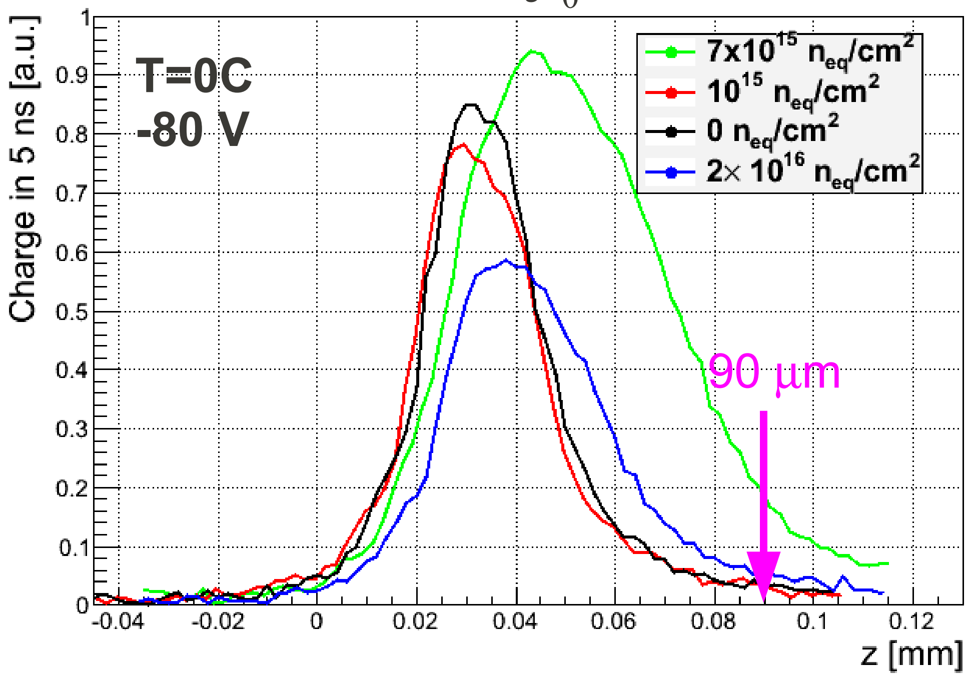
Detector edge 1D Zscan in steps of 10V, 3 temperatures:

1) Good to measure lateral X dimension
2) and depletion thickness, as a function of V, along Z.



Charge profiles:

$$Q(z,5ns)=\int_0^5 I(t,z)\,dt$$



Φ [neq/cm2]	Q(z) FWHM [mm]
0	0.022
10^{15}	0.028
7×10^{15}	0.048
2×10^{16}	0.034

- **Absolute Charge Collection CC** is the depth integrated charge profile

$$CC=\int_0^{90\,\mu m} Q(z,5ns)\,dz \quad \text{[a.u.] with:} \quad Q(z,5ns)=\int_0^5 I(t,z)\,dt$$

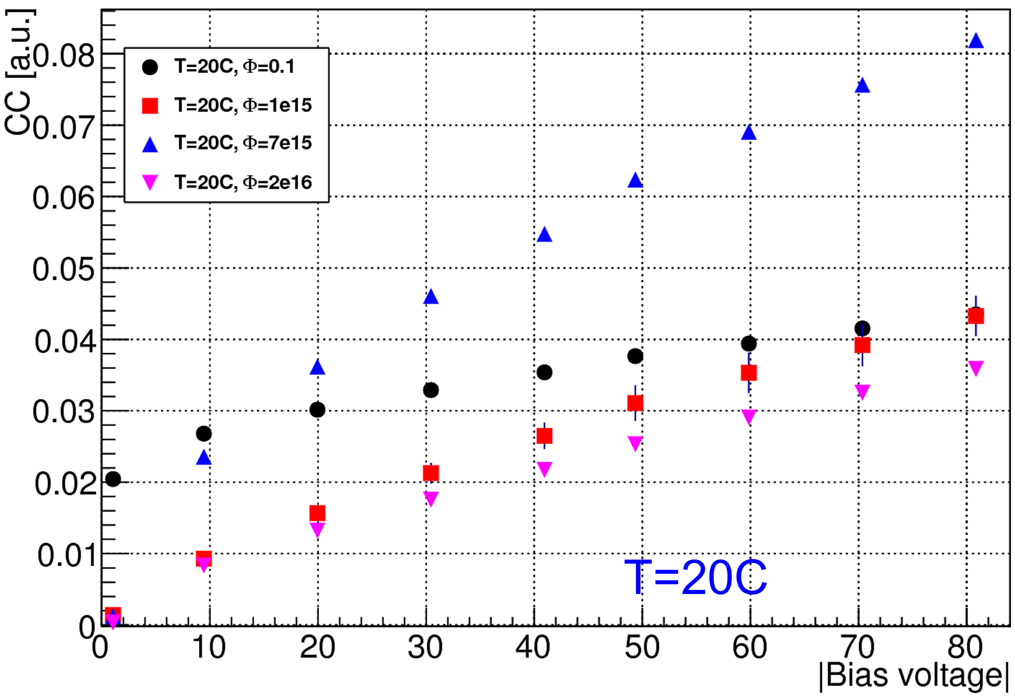
- **Relative CC** is the absolute CC of an irradiated detector divided by the absolute CC of the unirradiated detector.

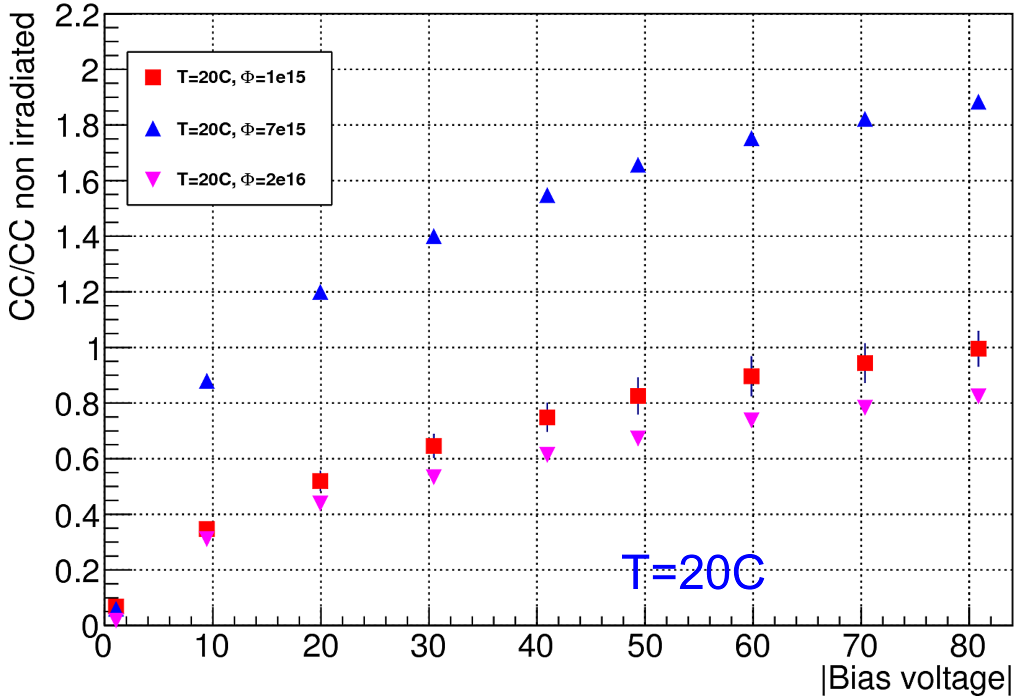
$$rCC=\frac{\int_0^{90\,\mu m} Q_{irr}(z,5ns)\,dz}{\int_0^{90\,\mu m} Q_{unirr}(z,5ns)\,dz}$$

Collected Charge (20 C)

$$CC=\int_0^{90\,\mu m} Q(z,5\,ns)\,dz$$

$$rCC=\frac{\int_0^{90\,\mu m} Q_{irr}(z,5\,ns)\,dz}{\int_0^{90\,\mu m} Q_{unirr}(z,5\,ns)\,dz}$$





Highest absolute CC for 7e15 n_{eq}/cm^2:

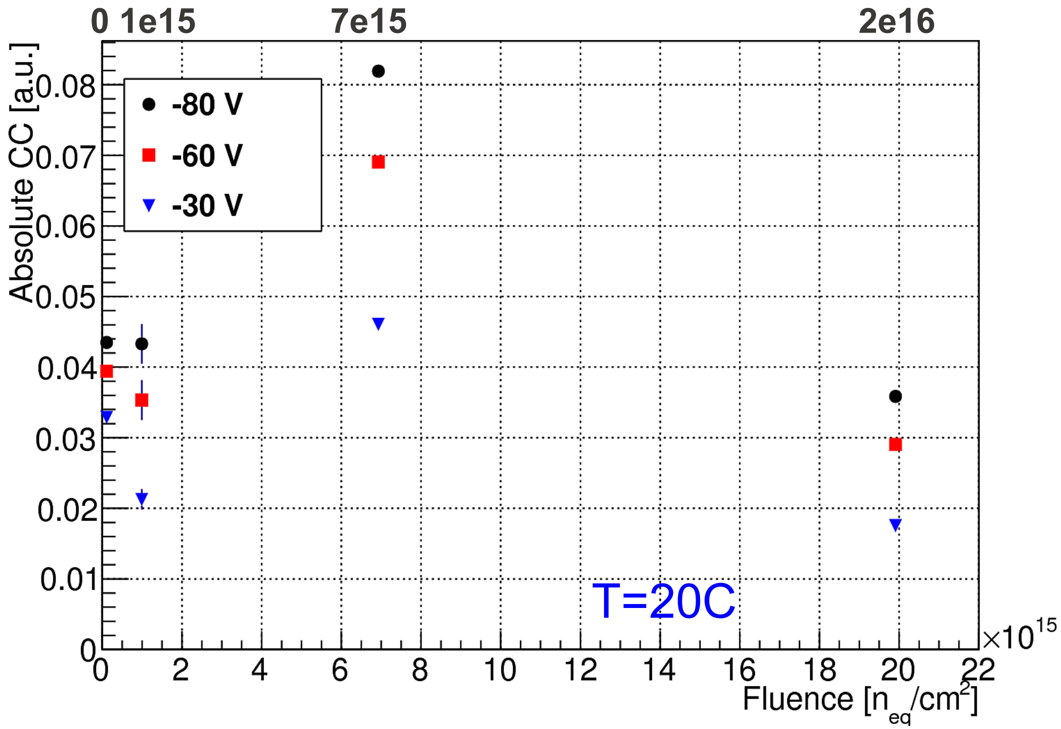
- for bias>20V, CC at 7e15 is higher than unirradiated
- At 80V charge is 80% bigger (~40% geometrical effect: wider depleted region → more beam integrated)

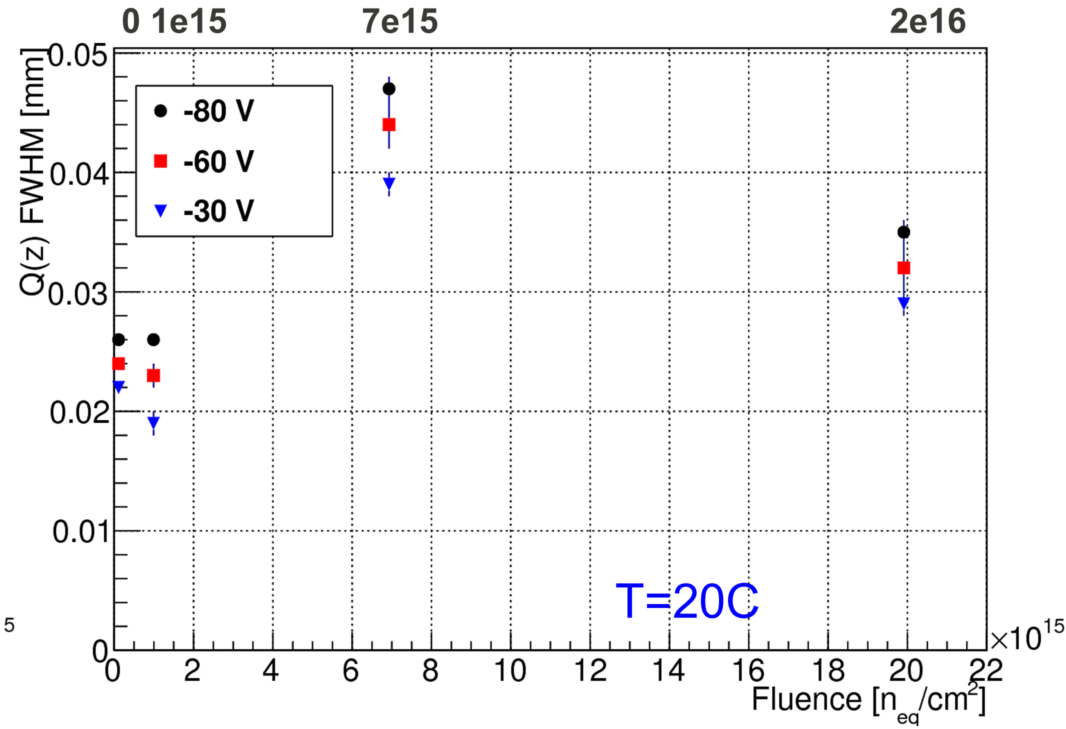
CC for 2e16 is 20% of unirradiated.

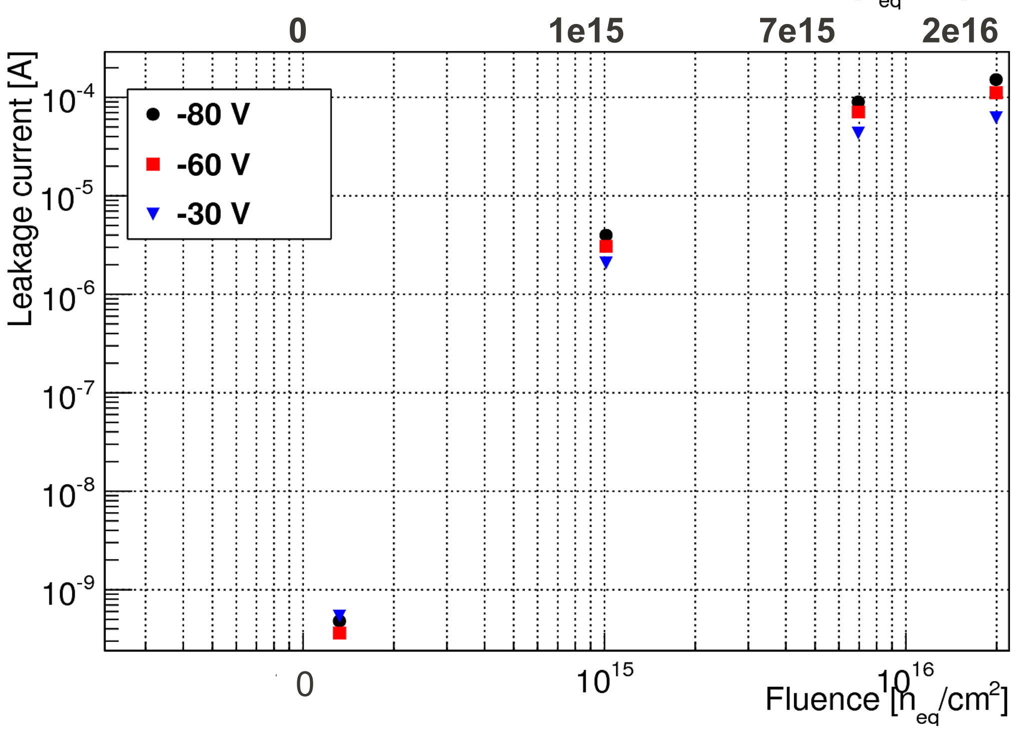
Trend is the same for -20, 0, 20 C (see backup slides).

Note: Error bars are spread in the mean (average over several measurements)

HVCMOSv3 performance vs fluence







CCE is maximum at 7e15.

FWHM is folded with laser beam width

At 2e16 depletion region is wider than unirradiated, but collected charge is smaller (→ trapping)

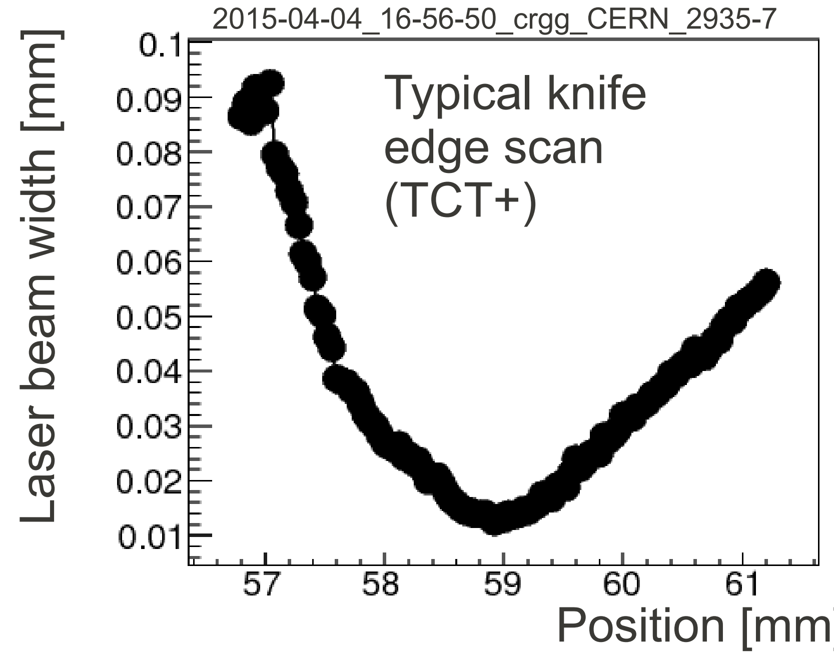
FWHM of charge plots clearly points to Neff decrease.

Calculation of:

1) depletion width
2) resistivity

Questions:

For 10 Ω.cm, 8 μm depletion width expected at 80V. Our beam width is 10 μm (FWHM=24 μm)



1) what is the **minimum bulk thickness** eTCT can resolve with a σ_{laser}=10 μm beam width?

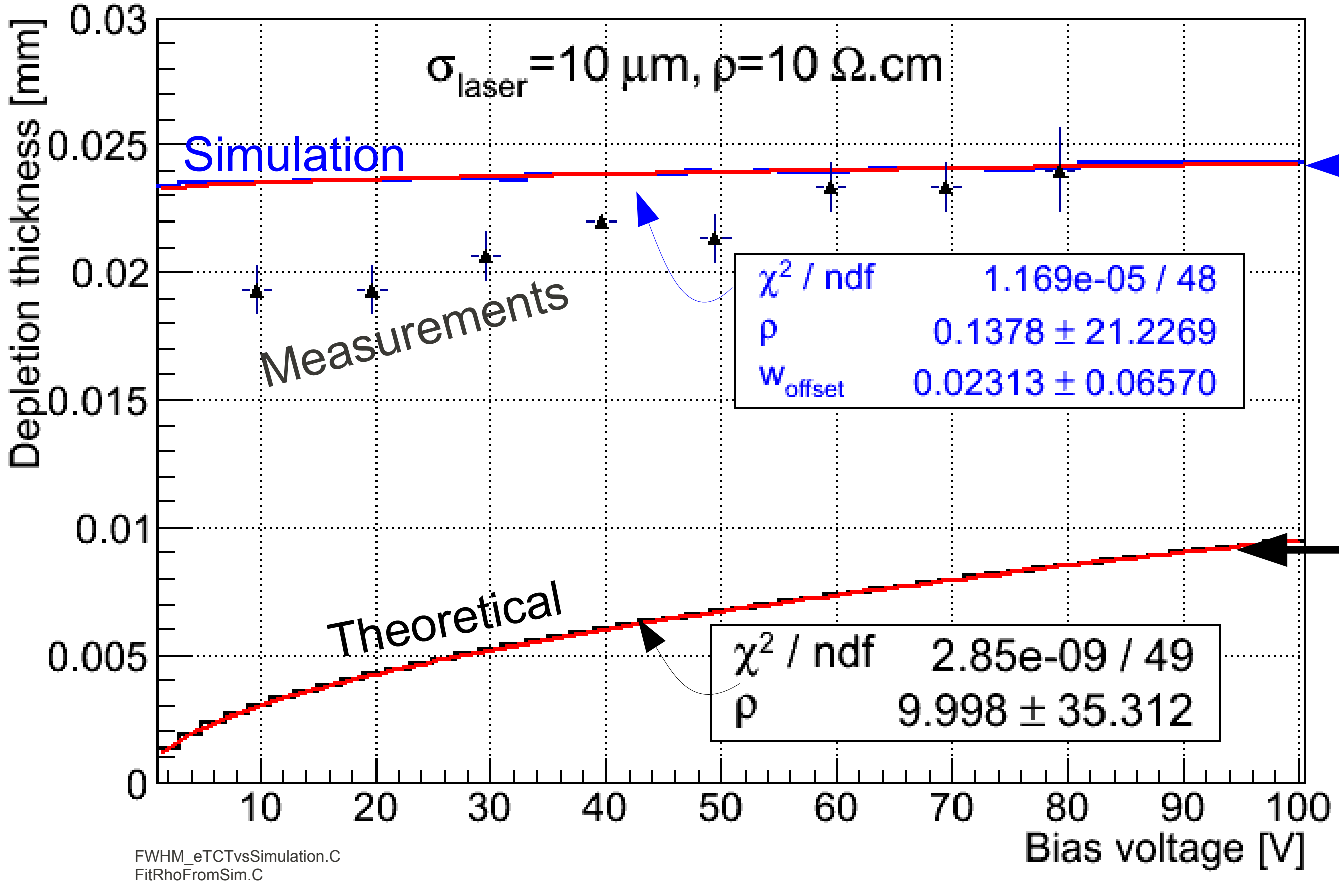
2) Since resistivity ρ (conversely Neff) can be calculated from:

$$w(V) = \sqrt{2\epsilon\epsilon_0\mu\rho V}$$

What's the maximum thickness (FWHM) uncertainty $\boldsymbol{\sigma_w}$ we can afford in low resistivity materials to obtain accurate ρ?

Simulation of charge profiles Q(z)

- Convolute a Gaussian (=laser) with a squared box (=active zone, efficient for charge collection). Shown FWHM of convoluted response.



Simulated eTCT FWHM (σ_{laser}=10 µm, ρ= 10 Ω.cm). This represents the measurement.

Expected depletion width from theory (abrupt junction).

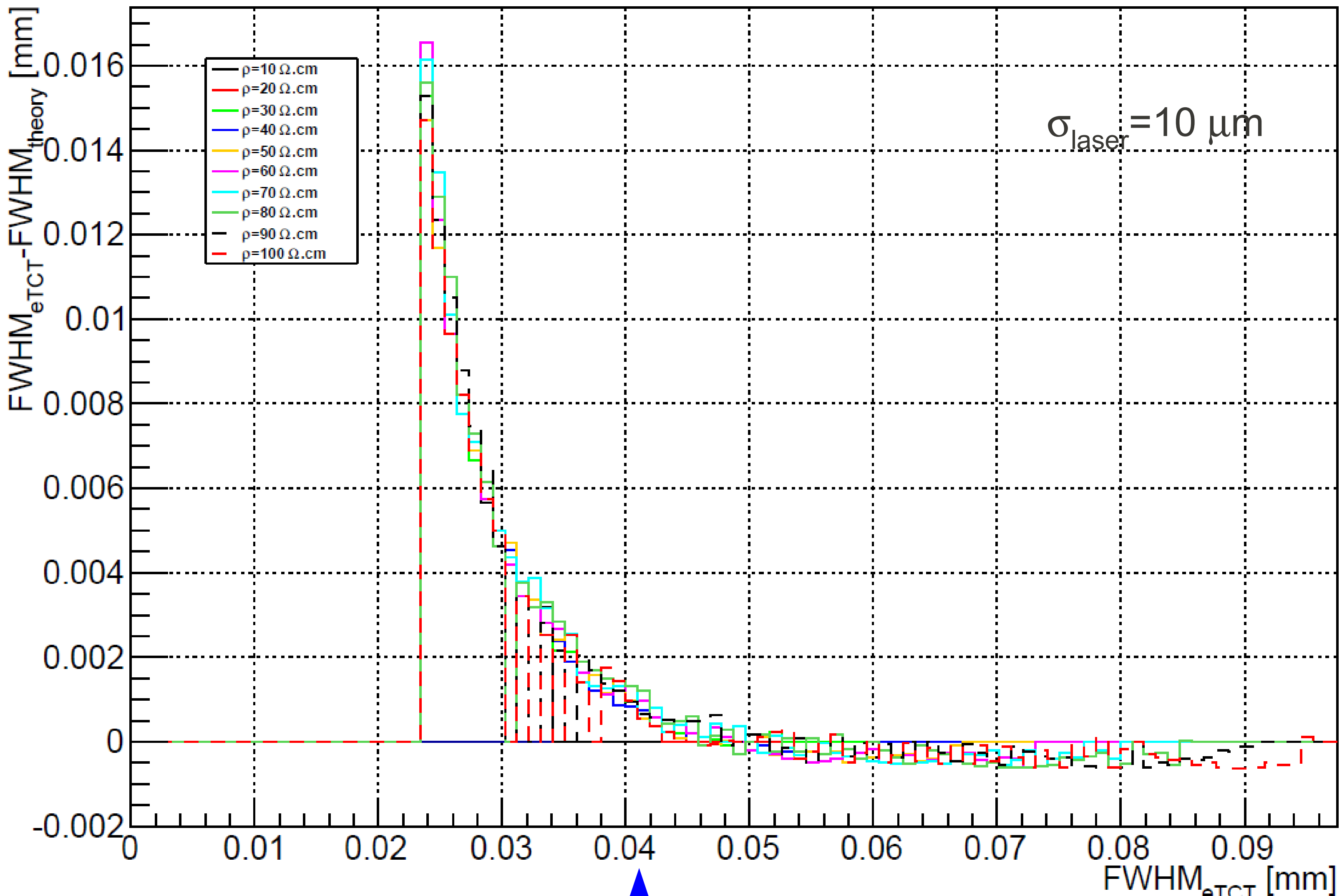
Simulation "slope" flatter than **theoretical**. **Calculated resistivity from FWHM measurement smaller than actual value.**

$$w_p[\mu m] \approx w_{offset} + 0.3\sqrt{\rho[\Omega \cdot cm]V}$$ ← Sim

$$w_p[\mu m] = 0.3\sqrt{\rho[\Omega \cdot cm]V}$$ ← Theory

eTCT resolution: $4\sigma_{laser}$

Difference between simulated and real depleted width, for different resistivities, as a function of the measured FWHM



For measured eTCT FWHM values≥40 μm the difference between measured and real FWHM is <1 μm for all resistivities.

2) Estimation of Neff from eTCT FWHM

$$w_p[\mu m] \approx 0.3\sqrt{\rho[\Omega \cdot cm](V+V_{bi})} \quad \Rightarrow \quad \sigma_\rho = \frac{2}{0.3}\sqrt{\frac{\rho}{V}}\sigma_w$$

$$w(V) = \sqrt{\frac{2\epsilon\epsilon_0}{q|N_{eff}|}V} \quad \Rightarrow \quad \sigma_{Neff} = \frac{4\epsilon\epsilon_0}{q}\frac{V}{w^3}\sigma_W$$

10 Ω.cm=1.4×10^{15} cm^{-3} (p-type)

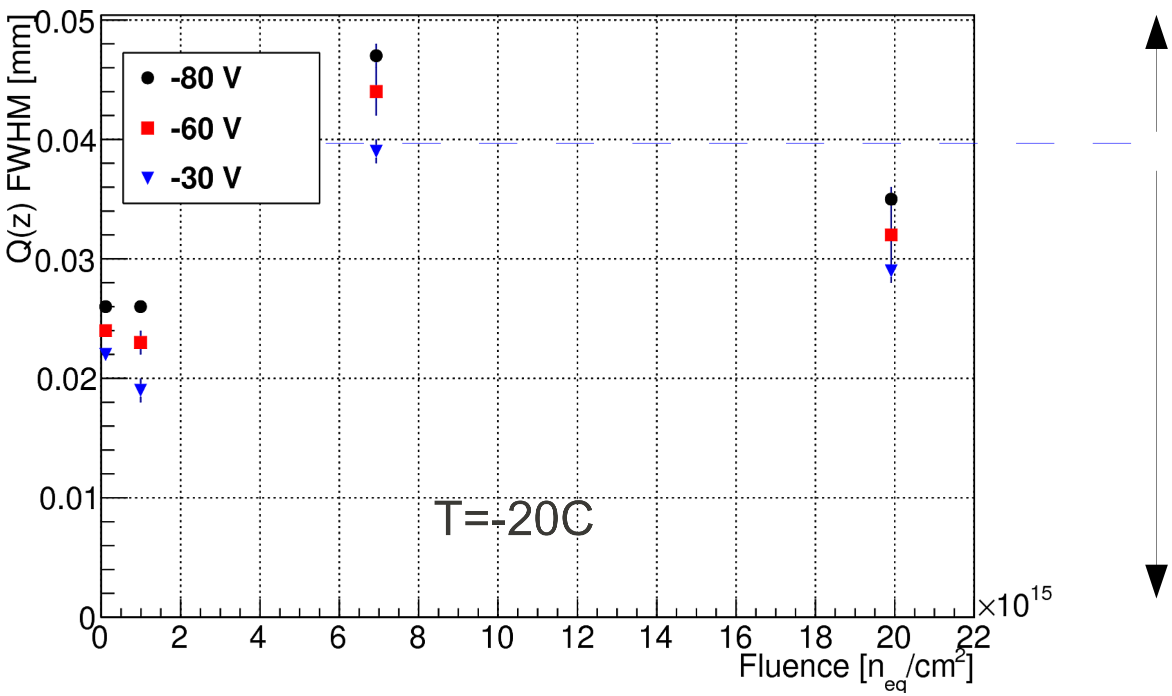
@V=80, w=8 μm

σ_W [μm]	σ_ρ [Ω.cm]	σ_{Neff} [cm^{-3}]
1	2.4	4 ×10^{-14}

Neff: 30% error

Therefore we need:

1) measured FWHM bigger than 40 μm (⇒ $FWHM_{eTCT}$=depletion width)
2) Step width ≤1-2 μm (bigger step allowed if ρ>10 Ω.cm)



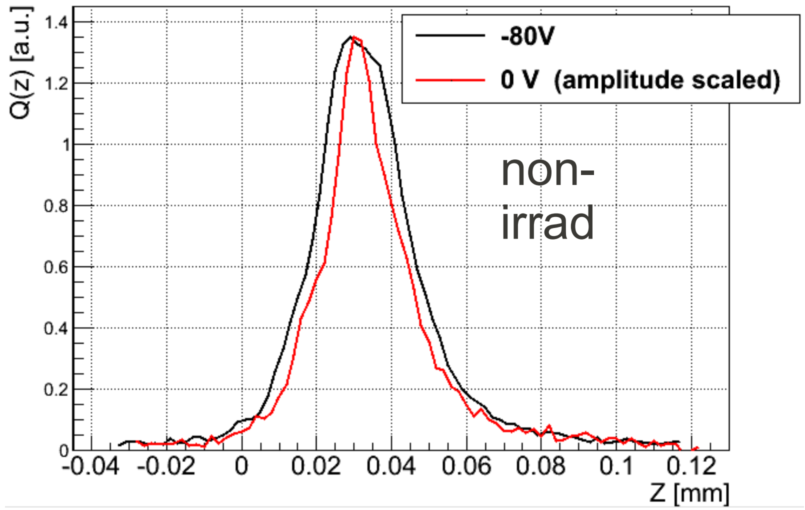
Reliable estimation of Neff

Measured FWHM does not coincide with real depleted thickness

… or we need to unfold the laser beam width from the measured FWHM

Deconvolution of laser width

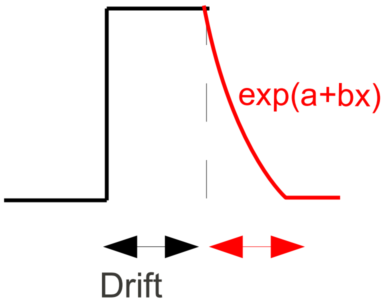
1) Difficult task for low resistivity, when depletion width << 4$\sigma_{laser.}$ For instance, charge profiles at 0 and 80V are very similar



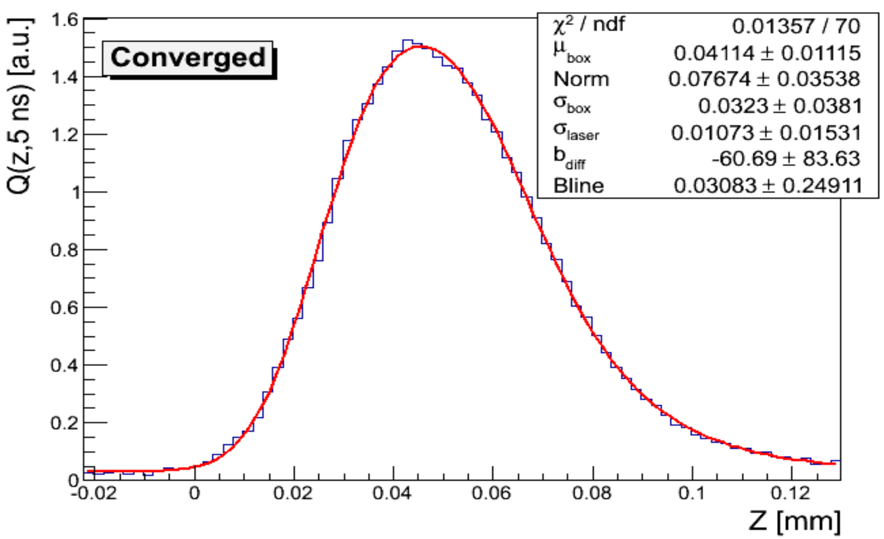
2) Work in progress. Fits are always very good, but we need to interpret results for small FWHM.

Best results obtained for 7e15, where depletion width is biggest. Example shown:

2) We have to assume a model for the shape of the active region. Waiting to have input from TCAD simulation of HVCMOS. First attempt done by guess/error



Model is used to fit measured curves and extract parameters



Conclusions

- Revisiting radiation hardness of neutron irradiated LGAD devices under improved measuring conditions: low noise, simplified PCB, T-controlled setup.

- Collected charge for 1e15 and 2e16 is very similar. Boosted for 7e15.

  2e16: 20% drop wrt non irradiated
  7e15: 80% increase wrt non irradiated

- Low resistivity of HVCMOS challenges e-TCT resolution with 8-10 μm laser gaussian σ. It would be a good case to proof Twp Photon Absorption TCT power..

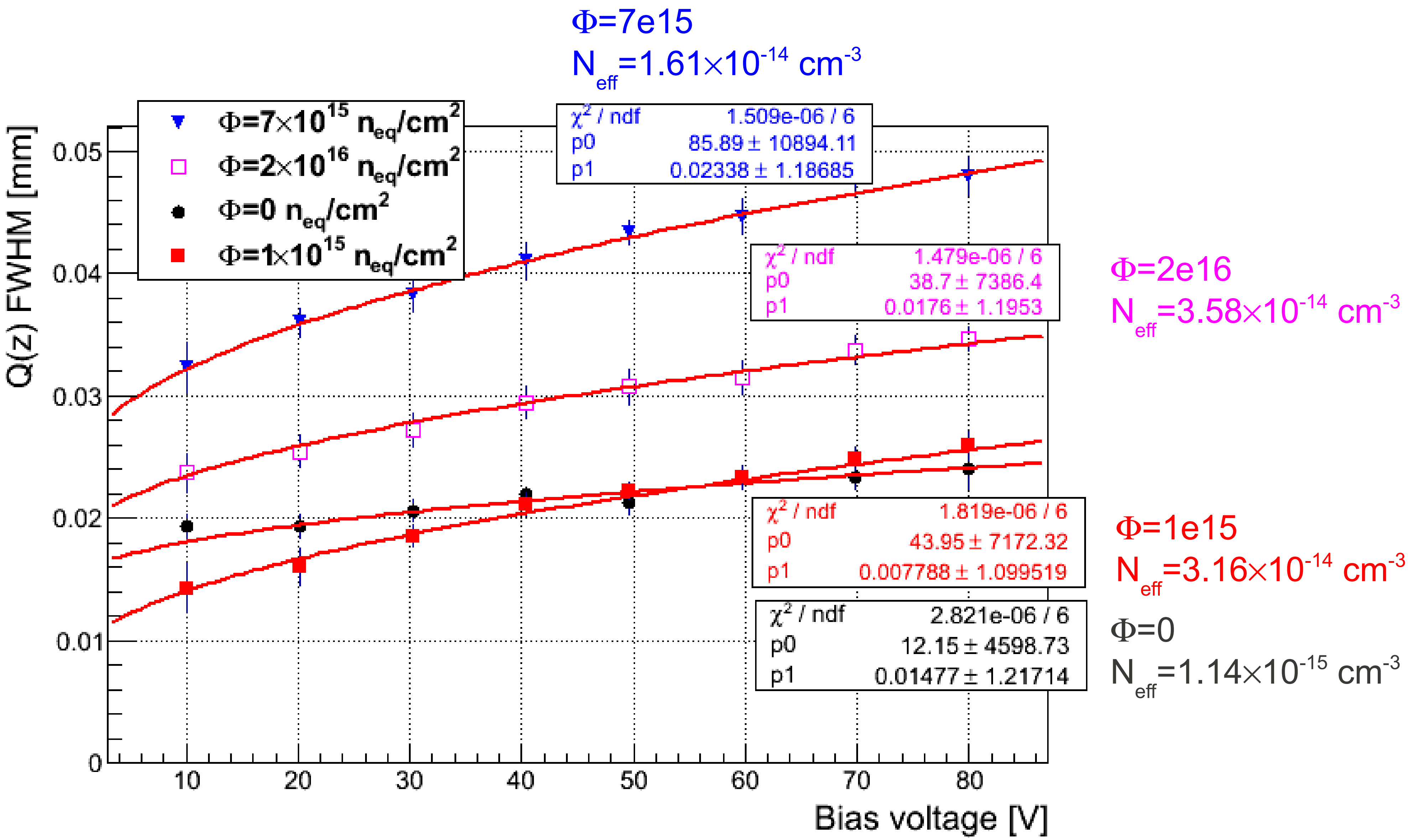
  In our setup (CERN-SSD), measured FWHM should be > 40 μm to draw accurate conclusions on Neff.

  Trying to unfold the actual depleted width from the measured FWHM
  We are testing different models for active region shape ← not finished in time for this meeting

- First measurements for p-irradiated samples... next talk

Thanks to: CERN PH-DT bonding lab

HVCMOSv3 FWHM description...



$$w_p[\mu m] \approx w_{offset} + 0.3\sqrt{\rho[\Omega \cdot cm]V}$$

p1 p0

(Very) first look at proton irradiated HVCMOSv3

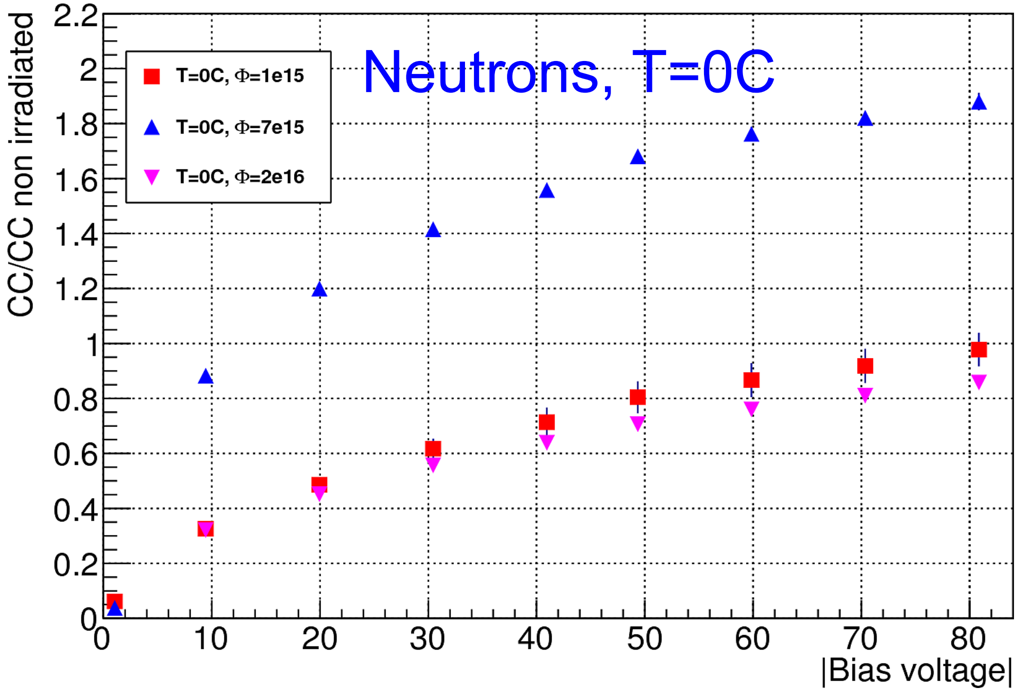
Sample irradiation at CERN PS with protons:

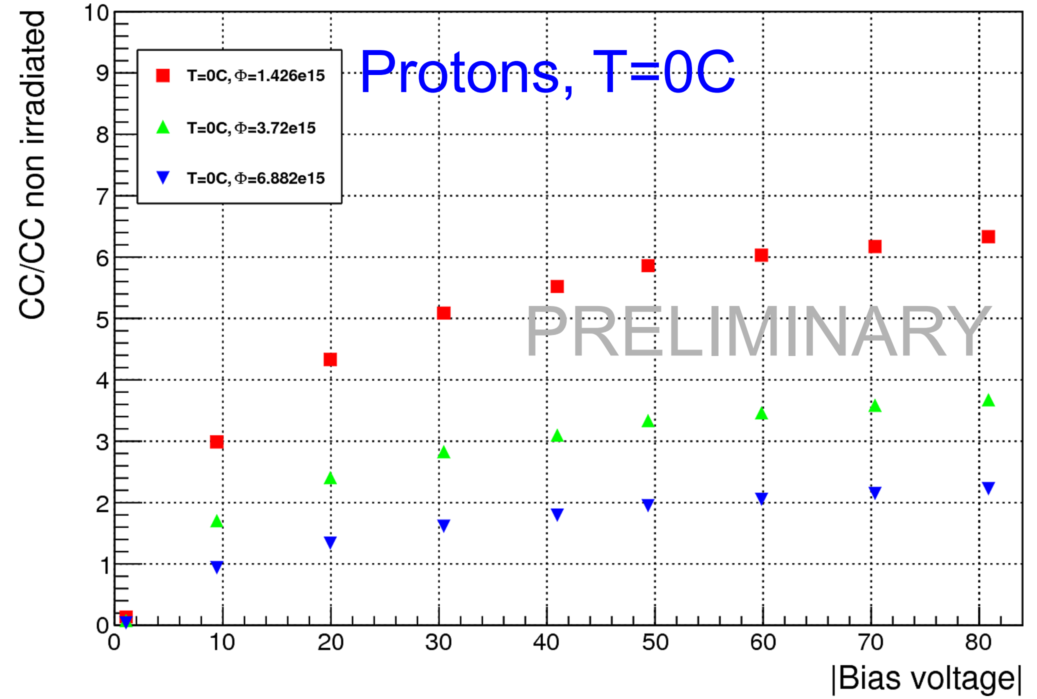
1.43e15, 3.72e15, 6.88e15 n_{eq}/cm^2

On-going measurement campaign by C. Gallrapp

T=-20 C, 0 C, (20 C ← missing)

Proton irradiation collected charge (T = 0C)





Mind the different vertical scales!!!

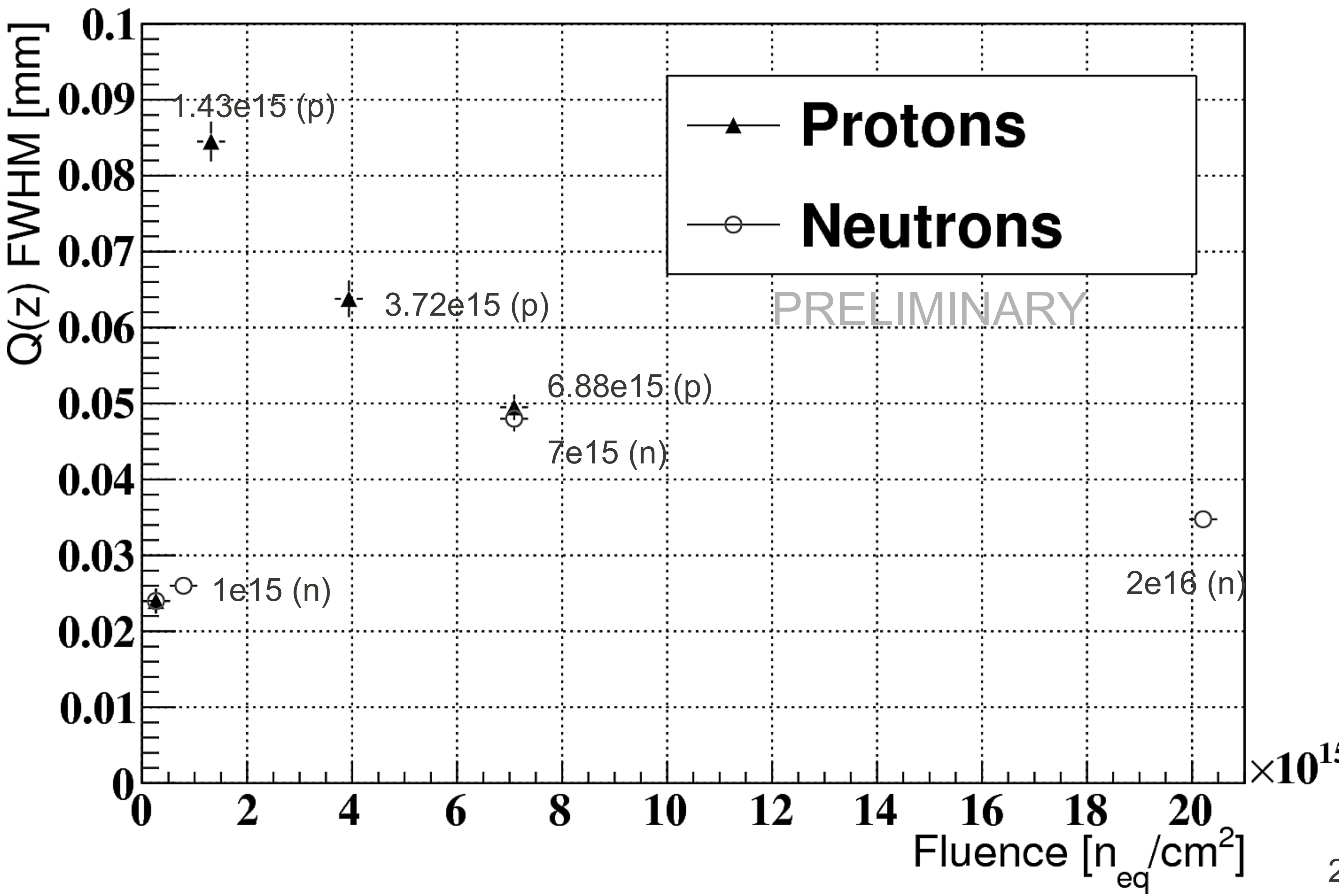
7e15 neq/cm2: same relative CC as with neutrons

For lower fluences:

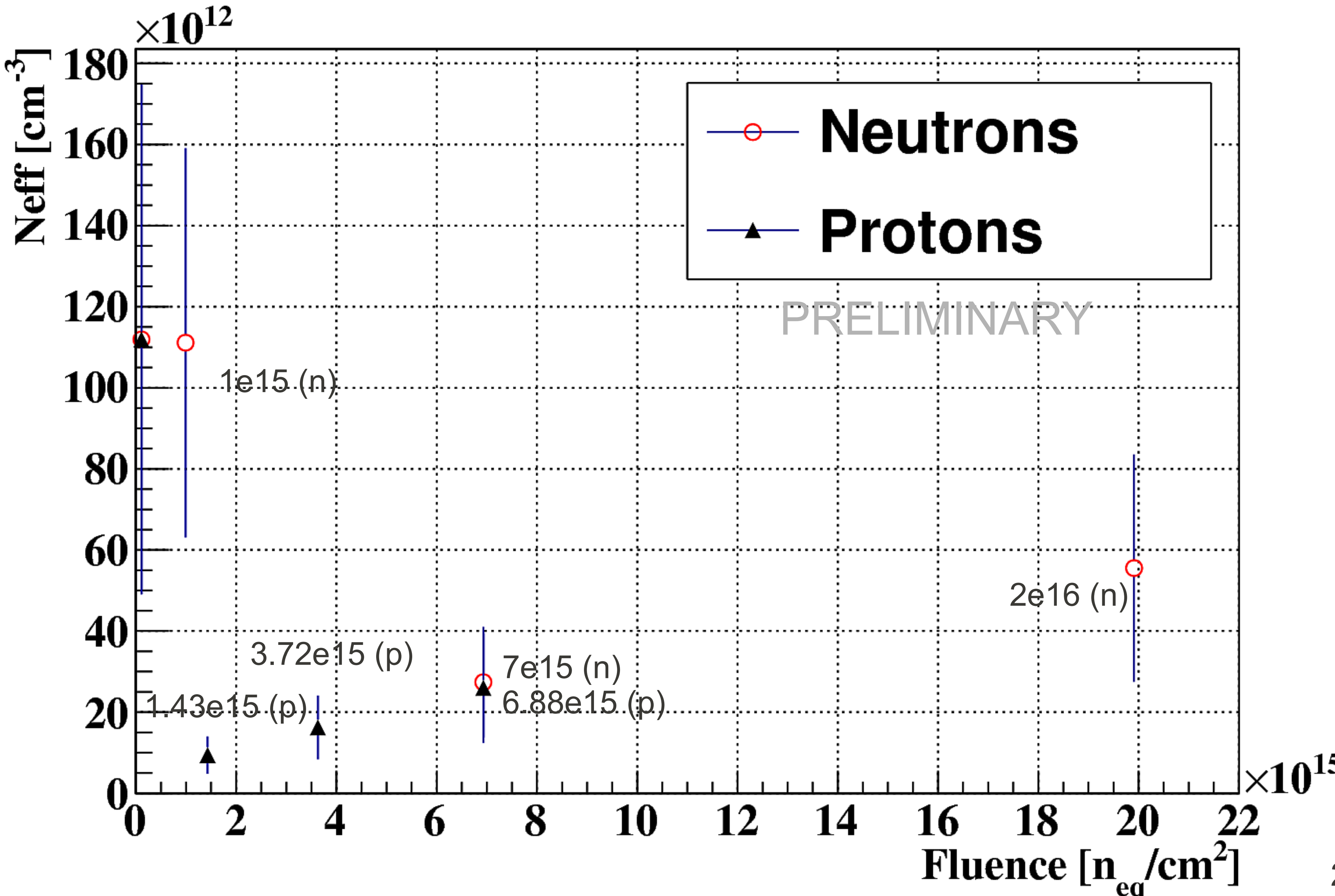
1e15 neutrons: rCC ×1 (rCC=relative to non-irrad)

1.4e15 protons: rCC ×6

Depletion width (FWHM) vs Fluence (n+p)



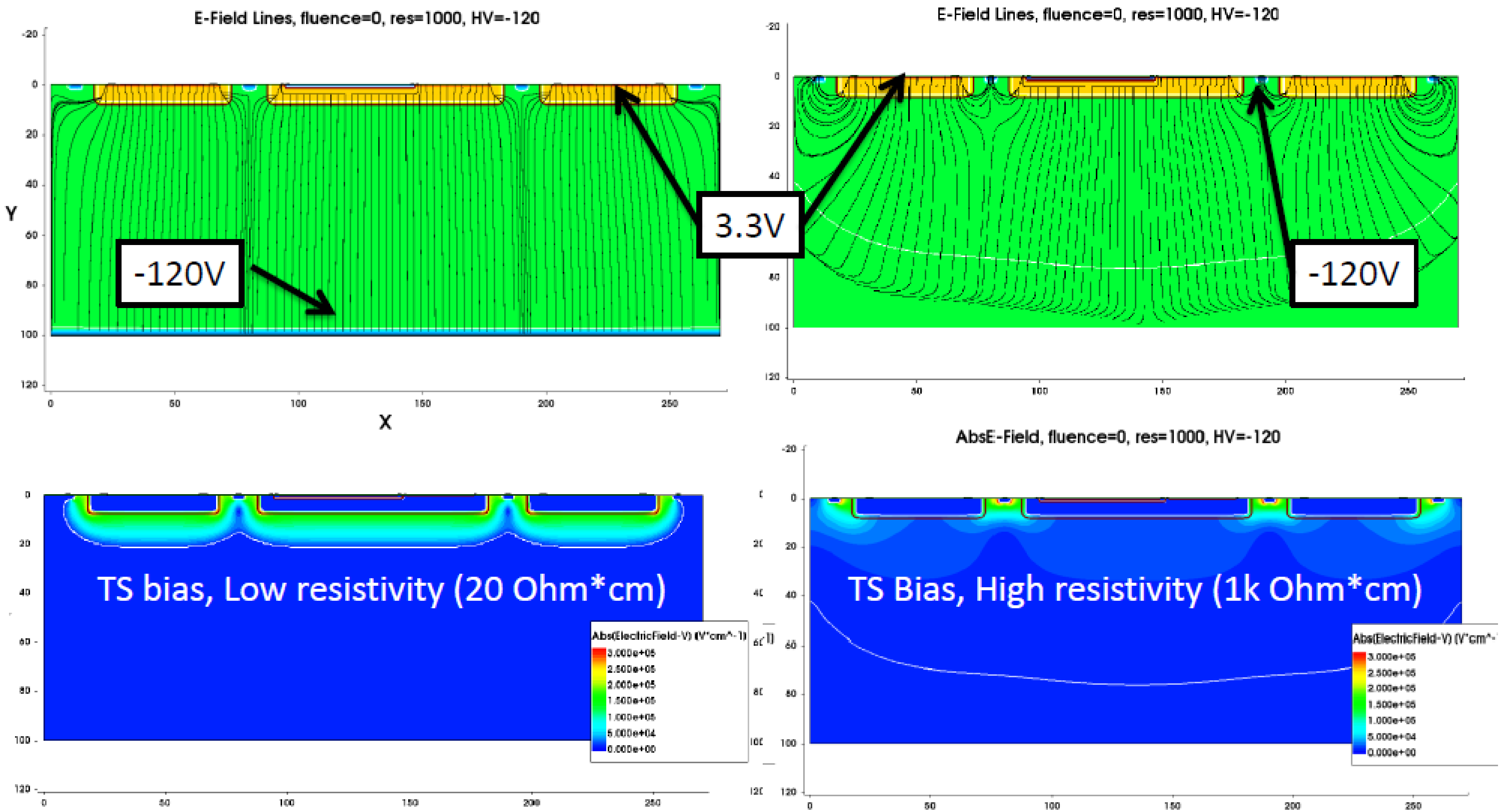
Neff vs Fluence (n+p)



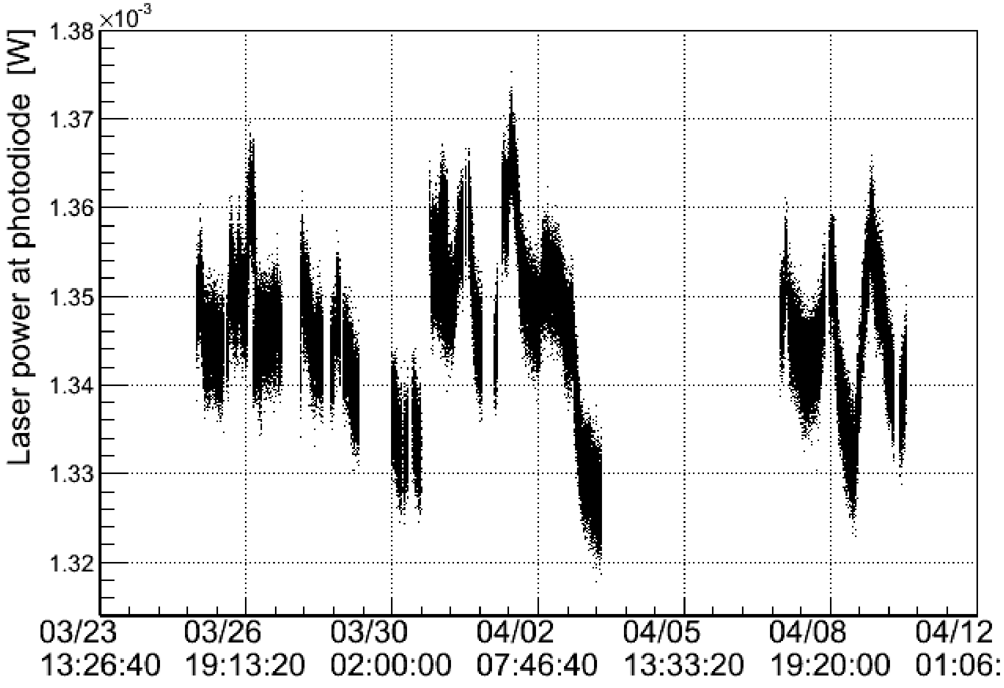
Error bars= spread on the mean, not σ_{Neff}

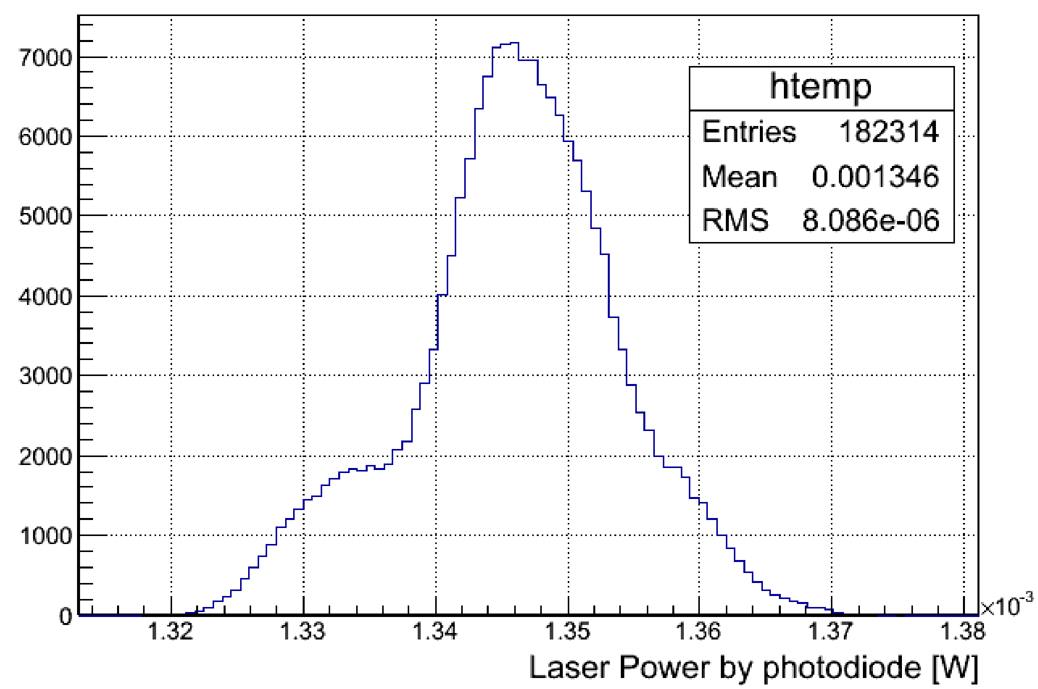
Extra info

Back-side versus top biasing



Laser power over 2 weeks





IR laser stability better than 1% over 2 weeks (measured on InGaAs monitoring diode) → Negligible.

We can discard laser as source of any variations in the data shown later on .

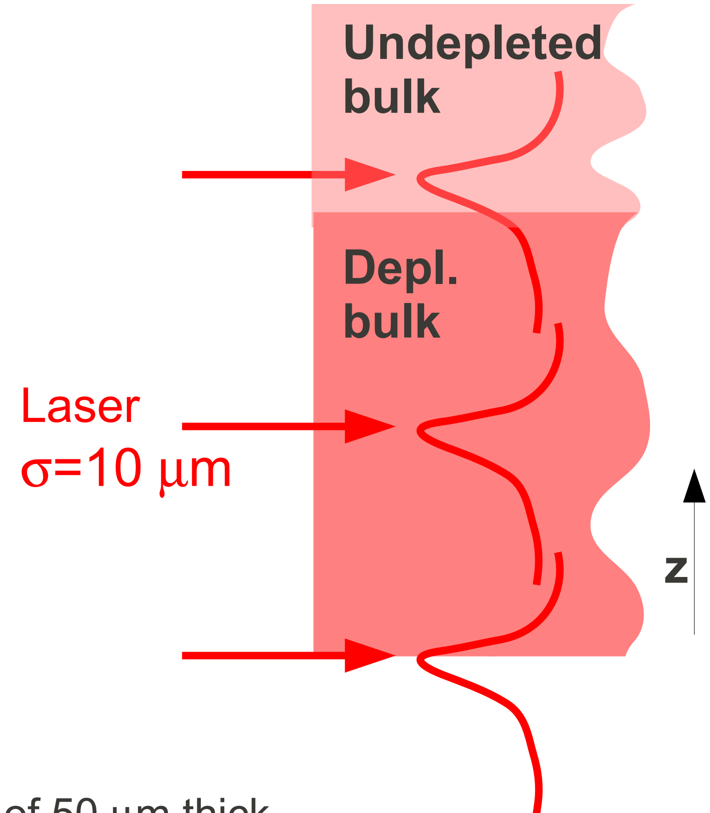
Power variations slightly not gaussian

Simulation of charge profiles Q(z)

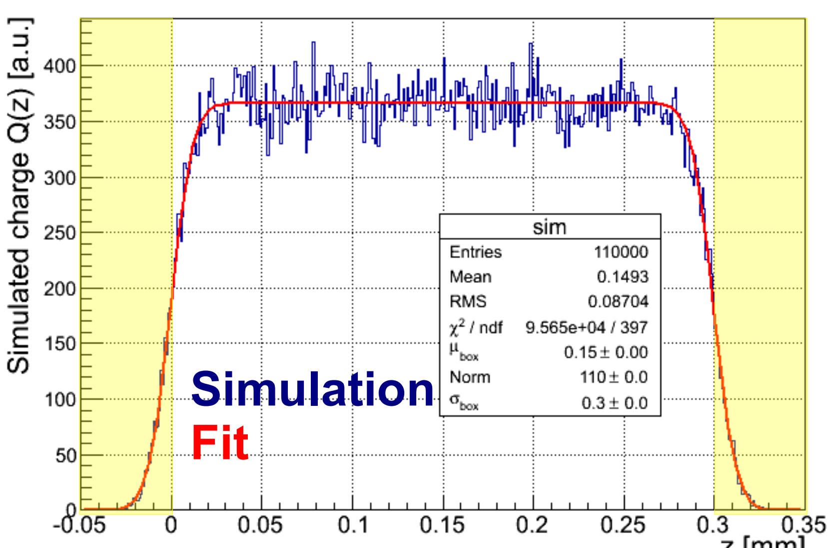
- **Depleted zone** interpreted as **fully efficient** to create e-h pairs. Simplest case first: discarding contribution due to diffusion. A **gaussian** laser beam is swept across the depth of the detector. Simulated eTCT response is calculated as the convolution of the gaussian beam G with a square (depletion) box B. Toy simulation=**random numbers** distributed according to:

$$Q(z) = N \cdot \int_{-\infty}^{\infty} G(z - z', \mu, \sigma) B(z') dz'$$

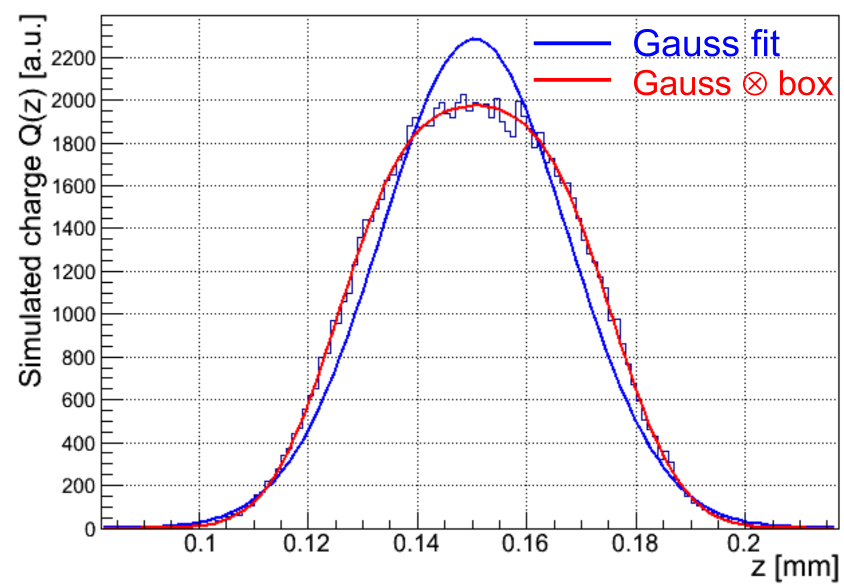
$$B(z) = \begin{cases} 1 & \text{if } (-d/2 < z < d/2) \\ 0 & \text{otherwise} \end{cases}$$

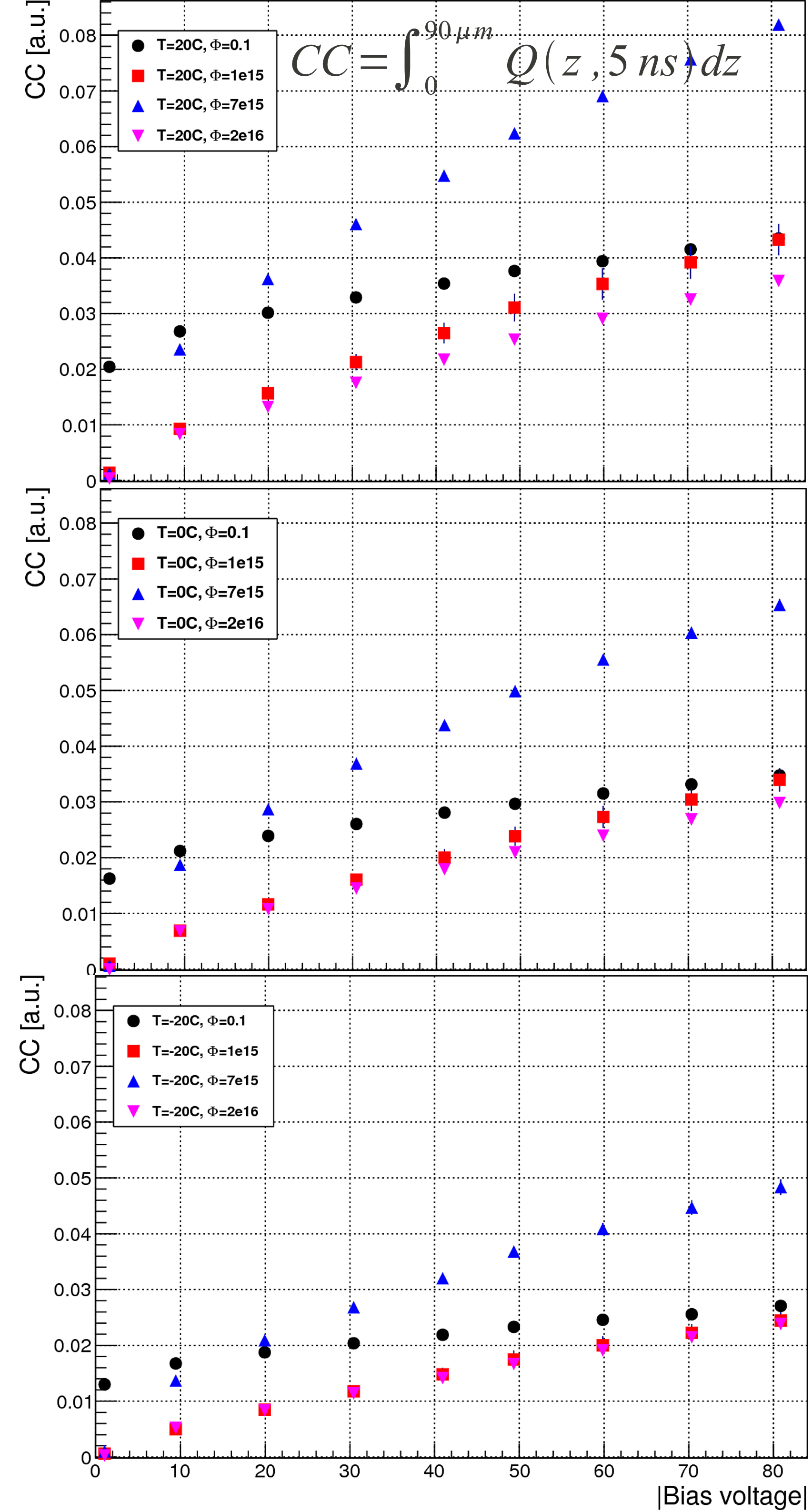


- Case of 300 μm thick sensor measured with σ_{laser}=10 μm. Due to the **non-zero beam width** signal is collected before (after) the center of the beam enters (leaves) the detector



- Case of 50 μm thick sensor measured with σ=10 μm.



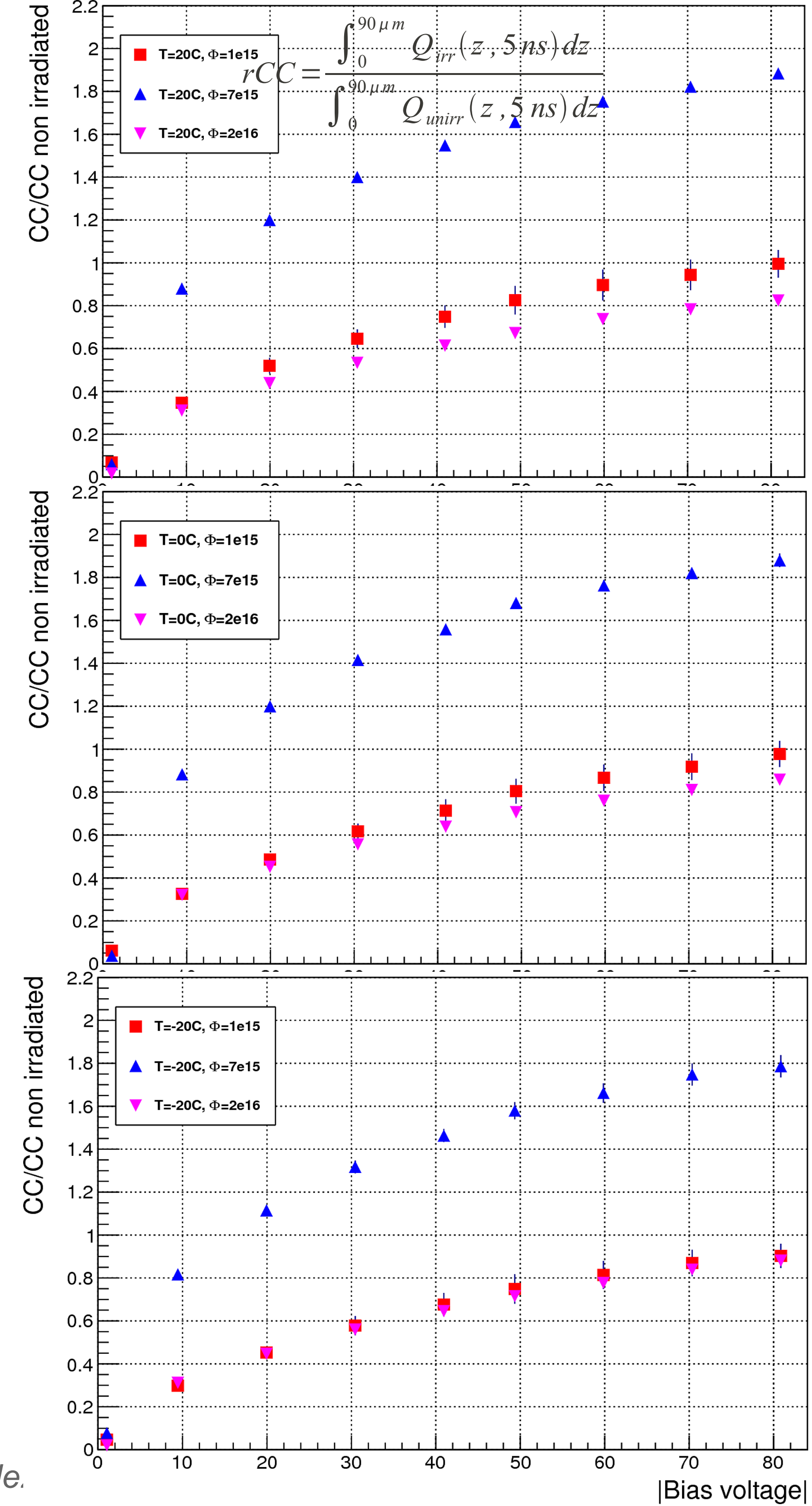


Highest absolute CC for 7e15

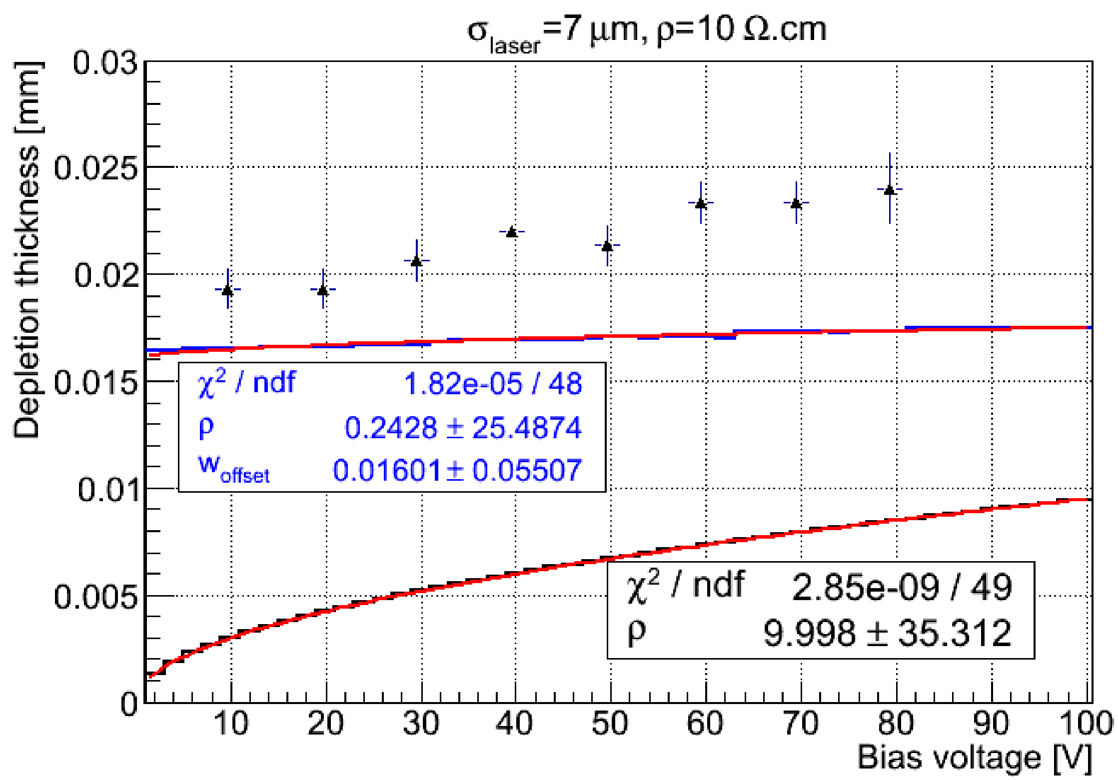
For bias>20V, CC at 7e15 is higher than unirradiated

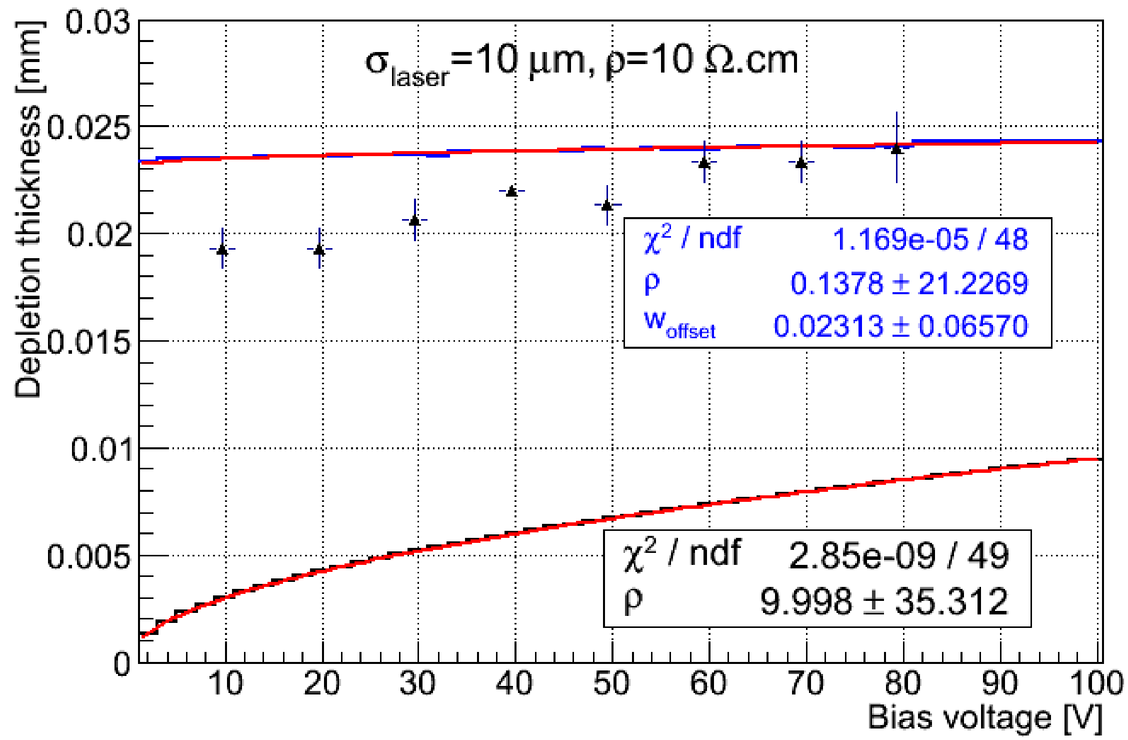
CC smallest for 2e16.

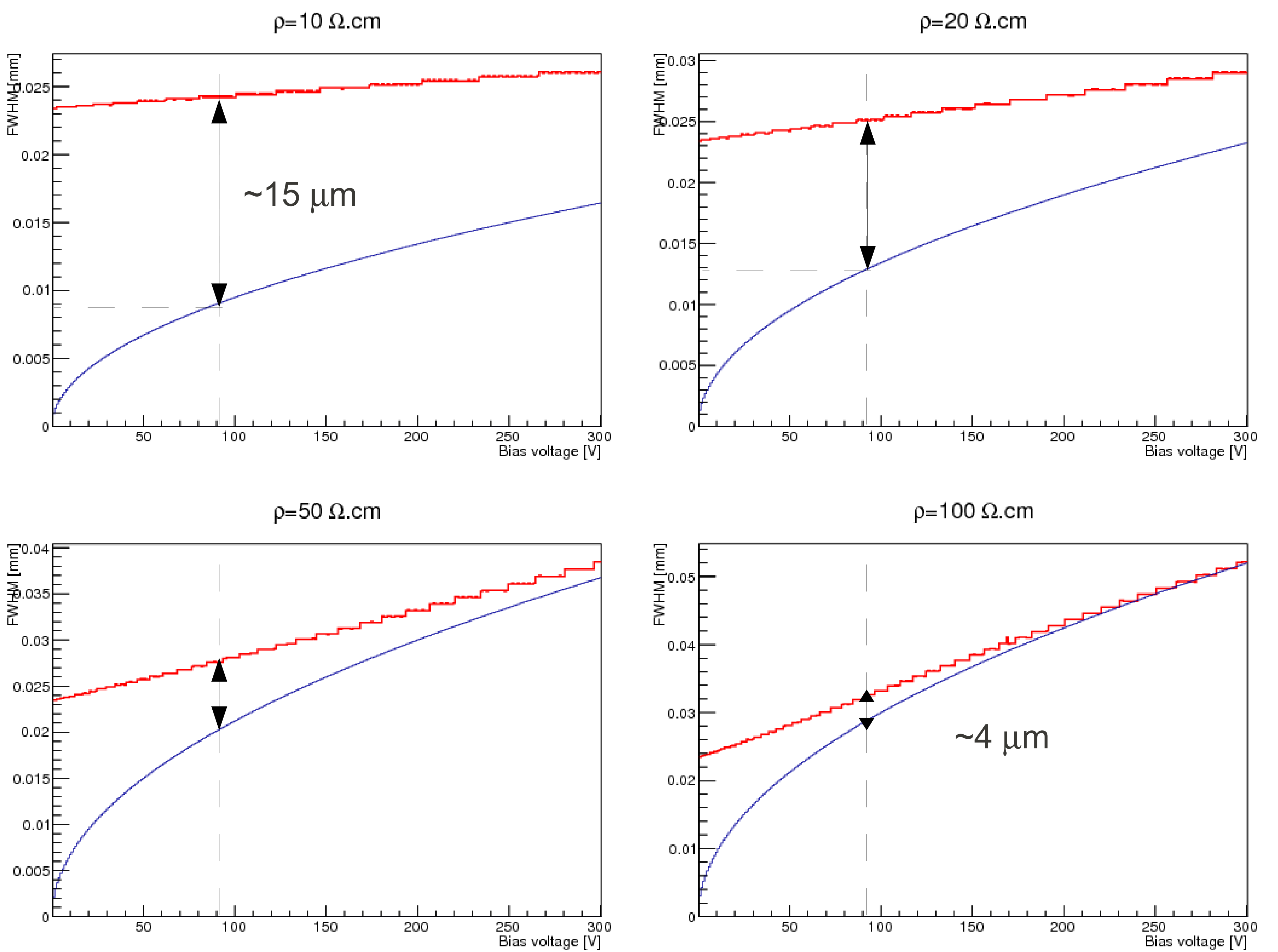
Trend is the same for -20, 0, 20 C. Higher CC at higher T (because of higher absorption)



M. Fernande.

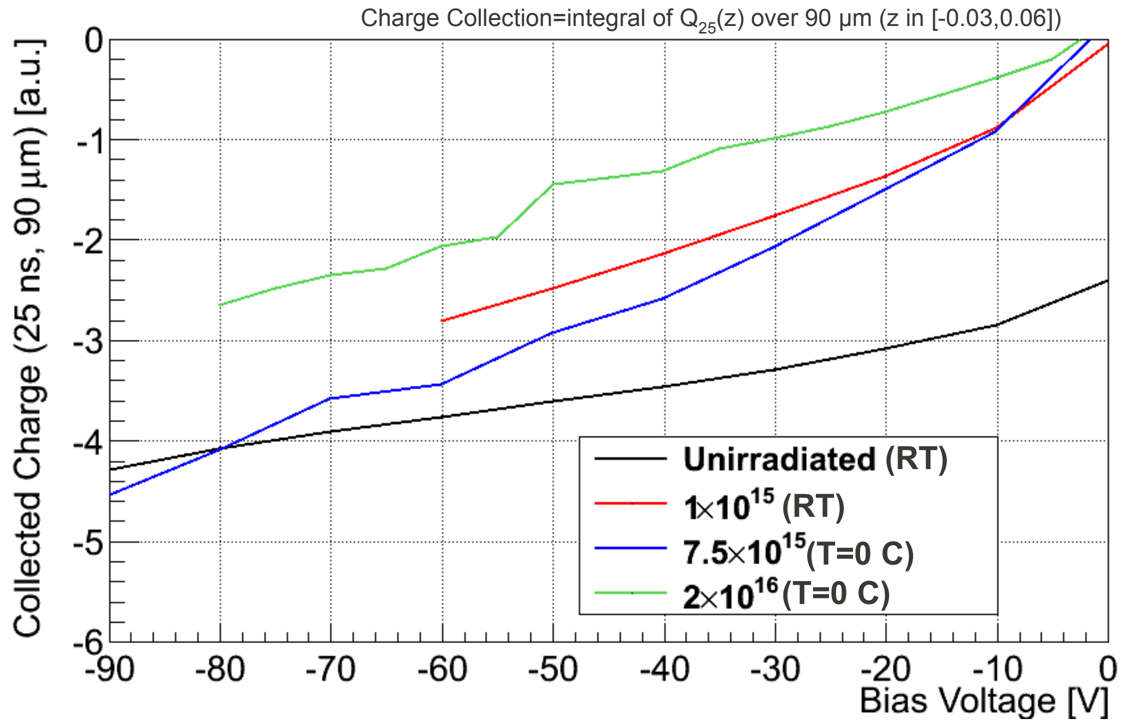

σlaser=7 μm, ρ=10 Ω.cm
Depletion thickness [mm]
Bias voltage [V]
χ2 / ndf 1.82e-05 / 48
ρ 0.2428 ± 25.4874
woffset 0.01601± 0.05507
χ2 / ndf 2.85e-09 / 49
ρ 9.998 ± 35.312


σlaser=10 μm, ρ=10 Ω.cm
Depletion thickness [mm]
Bias voltage [V]
χ2 / ndf 1.169e-05 / 48
ρ 0.1378 ± 21.2269
woffset 0.02313 ± 0.06570
χ2 / ndf 2.85e-09 / 49
ρ 9.998 ± 35.312

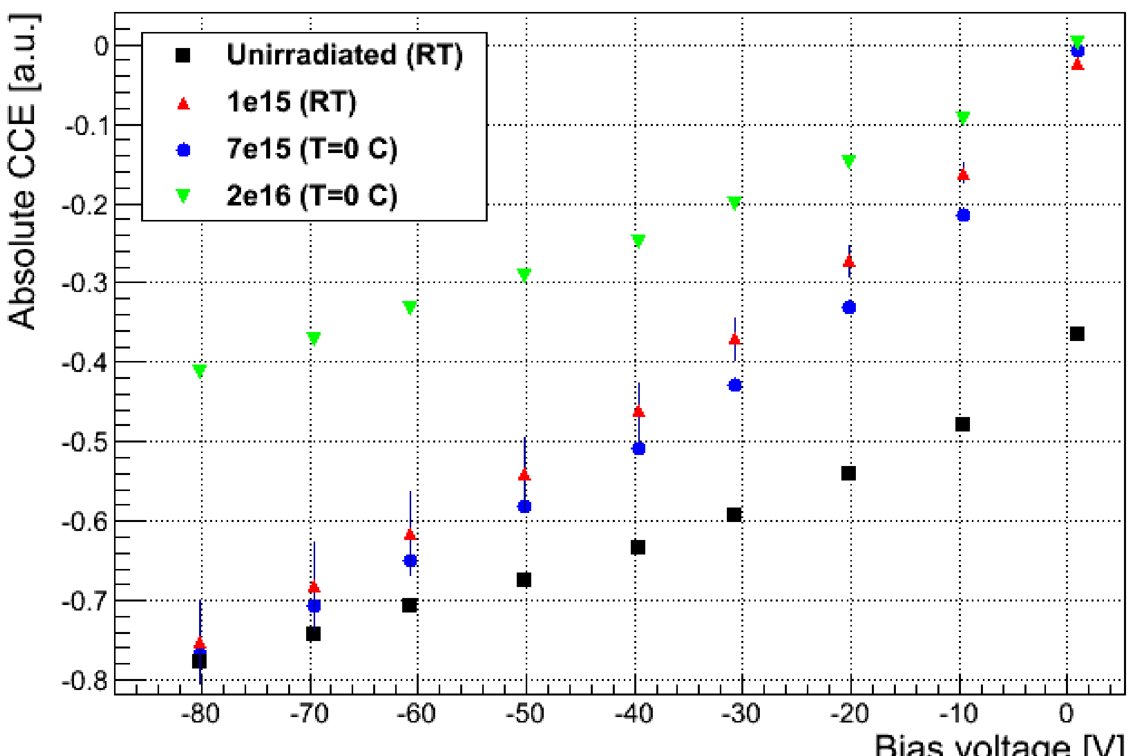


Depleted thickness grows with resistivity. Difference decreases with resistivity
Difference also depends on voltage

Comparison of measurement campaings

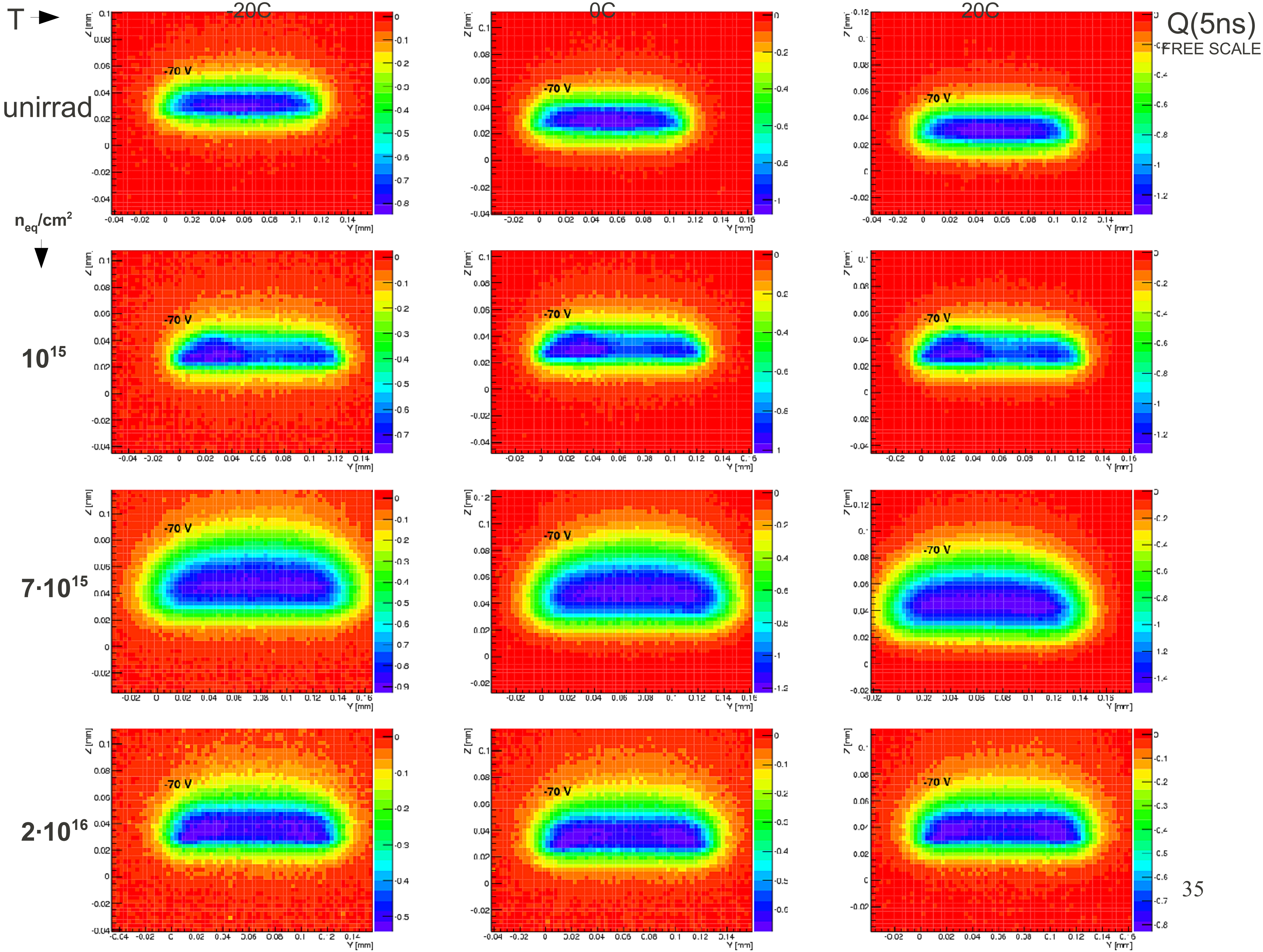


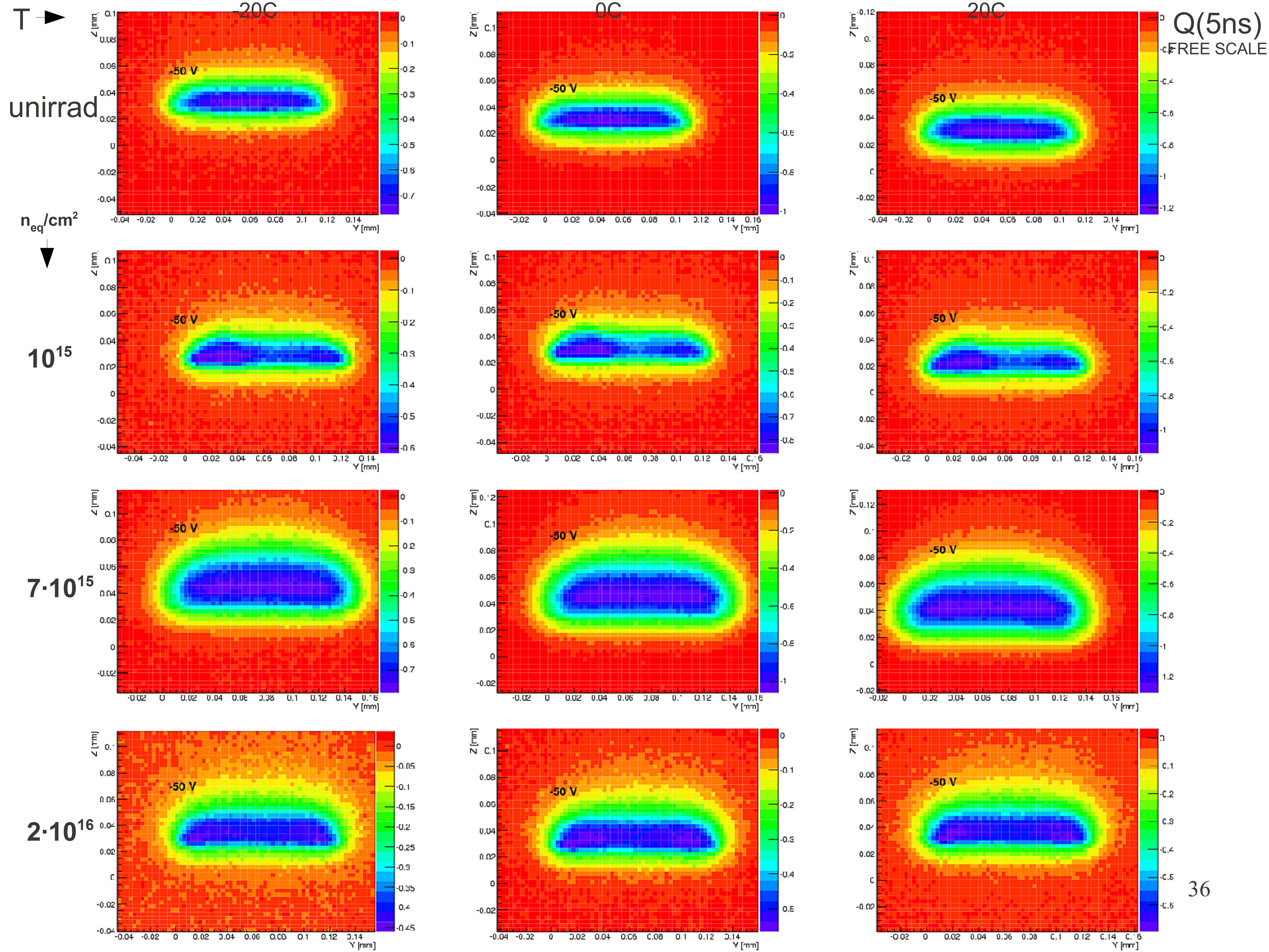
25th RD50 meeting

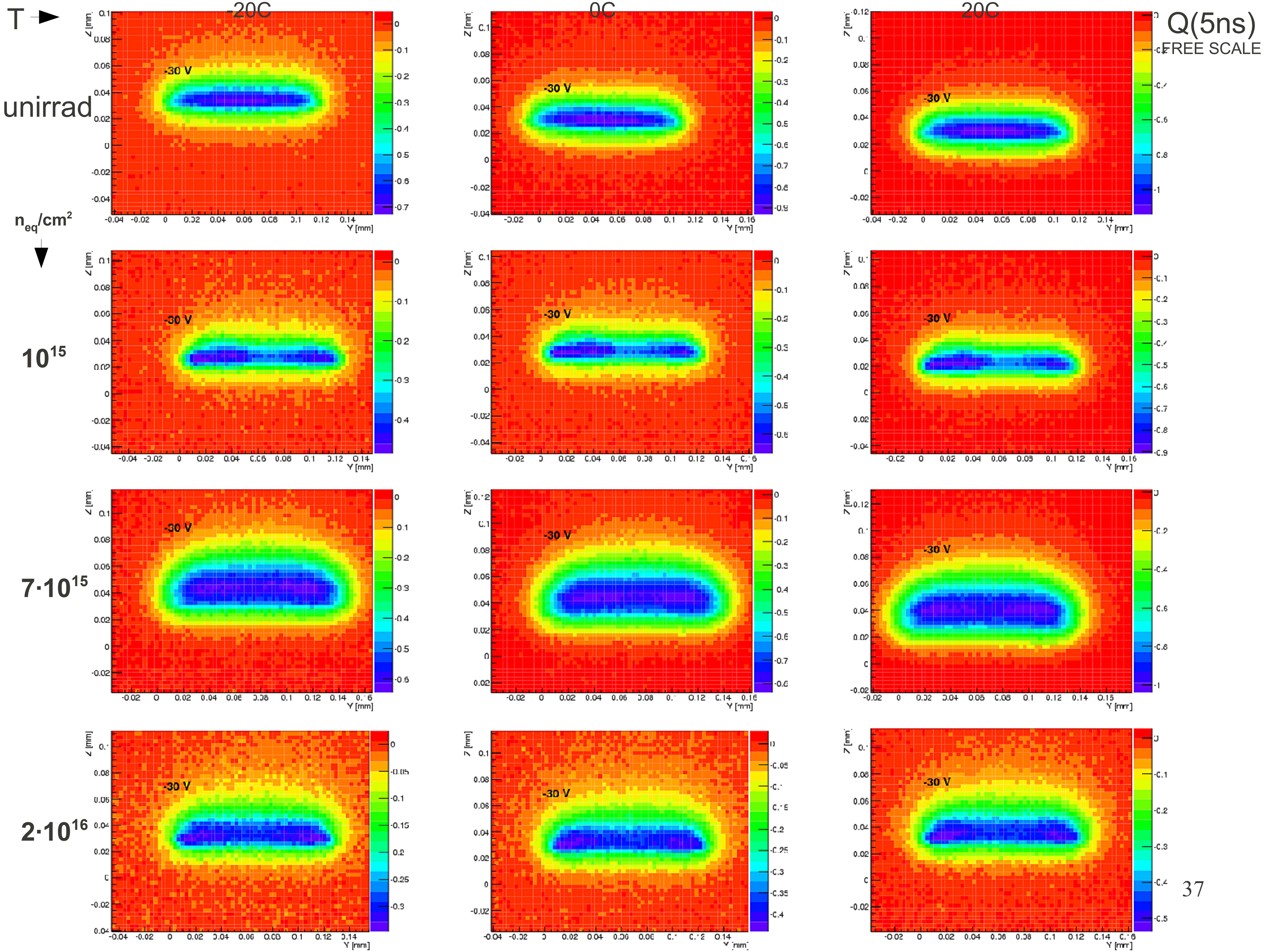


TCT+

Here considering different thickness depending on the fluence


T
-20C
0C
20C
Q(5ns)
FREE SCALE
unirrad
n_eq/cm^2
10^15
7·10^15
2·10^16
-70 V
Z [mm]
Y [mm]


T
-20C
0C
20C
Q(5ns)
FREE SCALE
unirrad
n_eq/cm^2
10^15
7·10^15
2·10^16
-50 V
Z [mm]
Y [mm]



T
-20C
0C
20C
Q(5ns)
FREE SCALE
unirrad
n_{eq}/cm^2
10^{15}
$7\cdot10^{15}$
$2\cdot10^{16}$
-30 V
Z [mm]
Y [mm]