Charge collection and annealing studies on 800 MeV proton irradiated AMS H18 HV-CMOS sensors

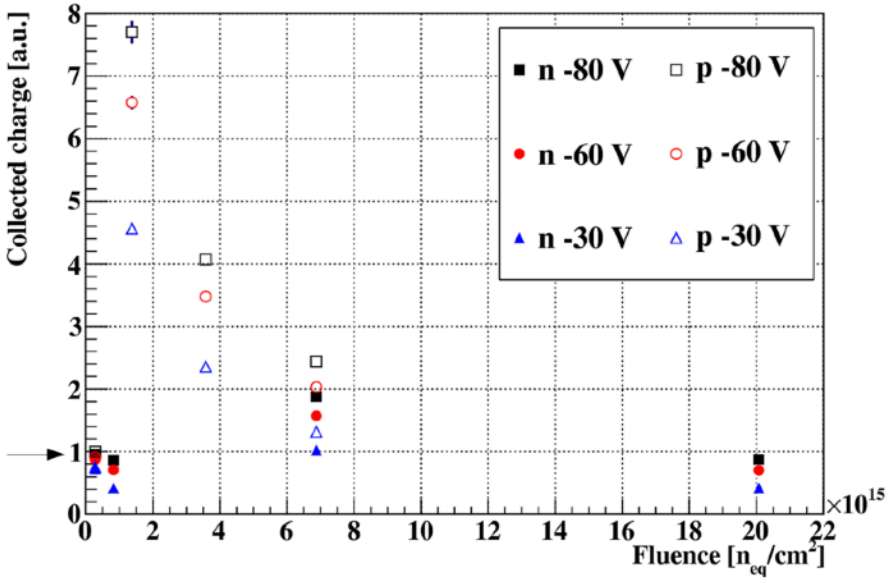
William Holmkvist[1,2], Daniel Muenstermann[1],
Marcos Fernandez Garcia[2,3], Michael Moll[2]

[1]*Lancaster University,* [2]*CERN,* [3]*Universidad de Cantabria*

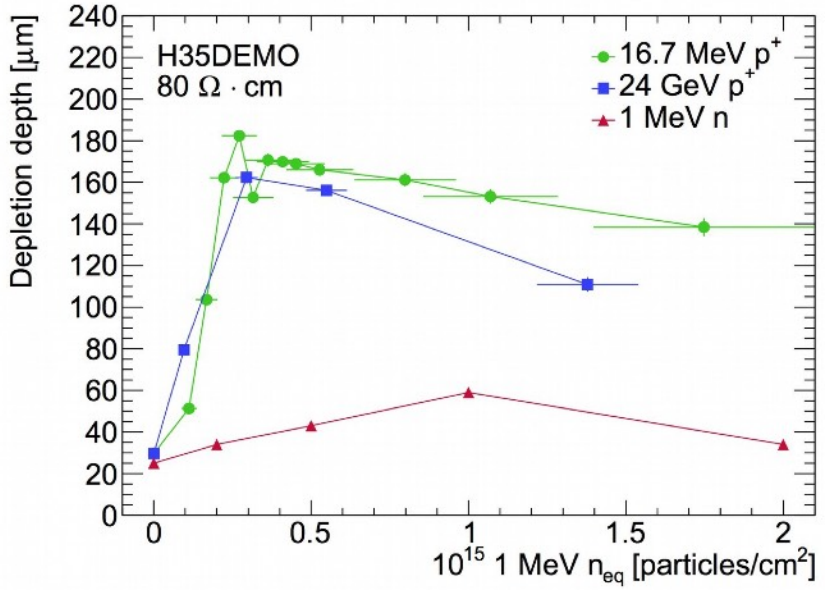
32nd RD50 Workshop, Hamburg, 5th June 2018

Motivation

- (Monolithic) HV-CMOS proposed for the 5th layer in HL-LHC ATLAS pixel detector
- CMOS foundry standard substrate uses 10 - 20 Ωcm silicon
  - Initial small depletion volume, low charge collection -> challenge
  - Mitigated through medium/high resistivity substrates (not always accepted, potentially expensive)
  - Standard substrate available for prototyping at an affordable price through MPWs
  - Differing irradiation behaviour from high resistivity samples
- Previous reactor neutron and 24 GeV/c proton results good, but few fluences
- 800 MeV protons closer to simulated background radiation in HL-LHC (pixel)



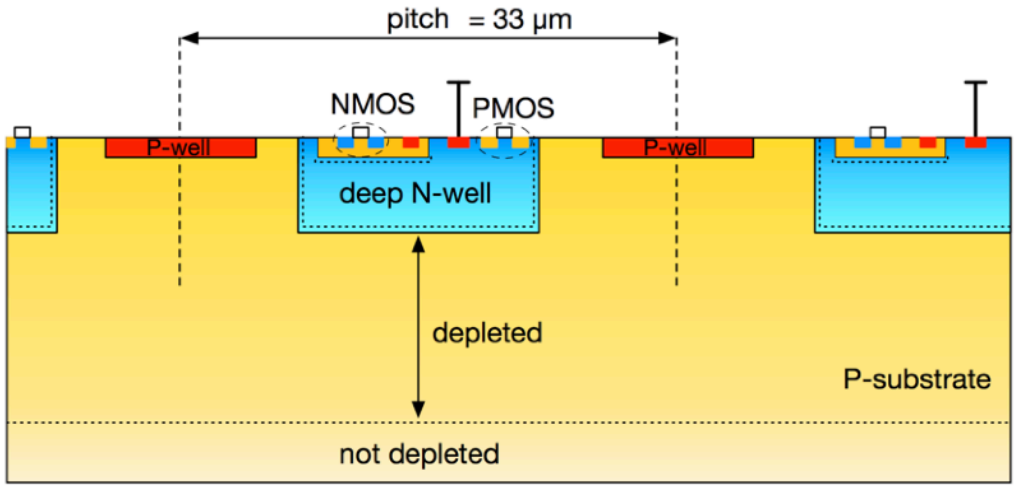
M. Fernandez Garcia, 26th RD50 workshop

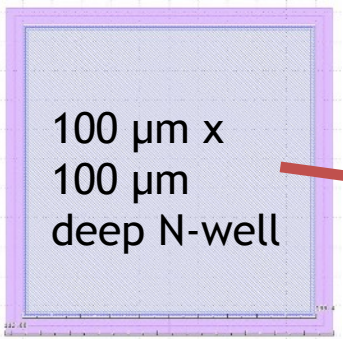


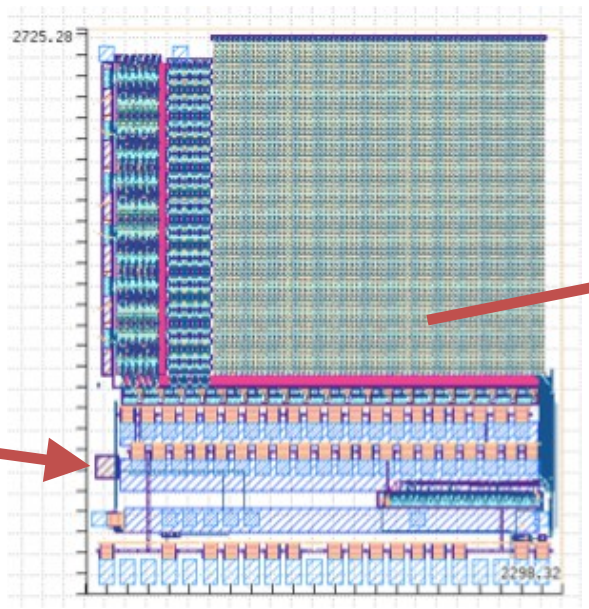
A. Fehr, 13th Trento workshop

Samples

- CCPDv3 chip (AMS H18 HV-CMOS) from an MPW (I. Peric)
- 10 Ωcm substrate, 250 µm thickness
- All tests done on passive diode
  - 100 x 100 µm^2 n-well without active circuit
- Irradiated with 800 MeV protons at LANSCE (thanks to S. Seidel and M. Hoeferkamp)
- Attached to PCB with Wolbring LS200N
- Wire bonded at Lancaster, digital and analog ground connected and shorted to common ground.



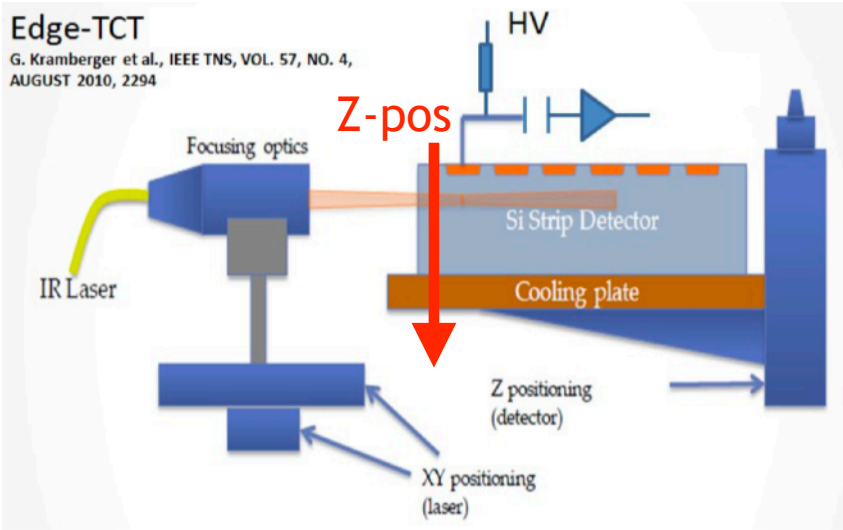




TCT+ setup at CERN

- Edge-TCT performed with TCT+ at CERN
- 200 Hz pulsed IR laser
- Ref. diode used for normalising all signals
- All measurements at -15 ± 0.6 °C
- Position scan and focus scan done for each measurement

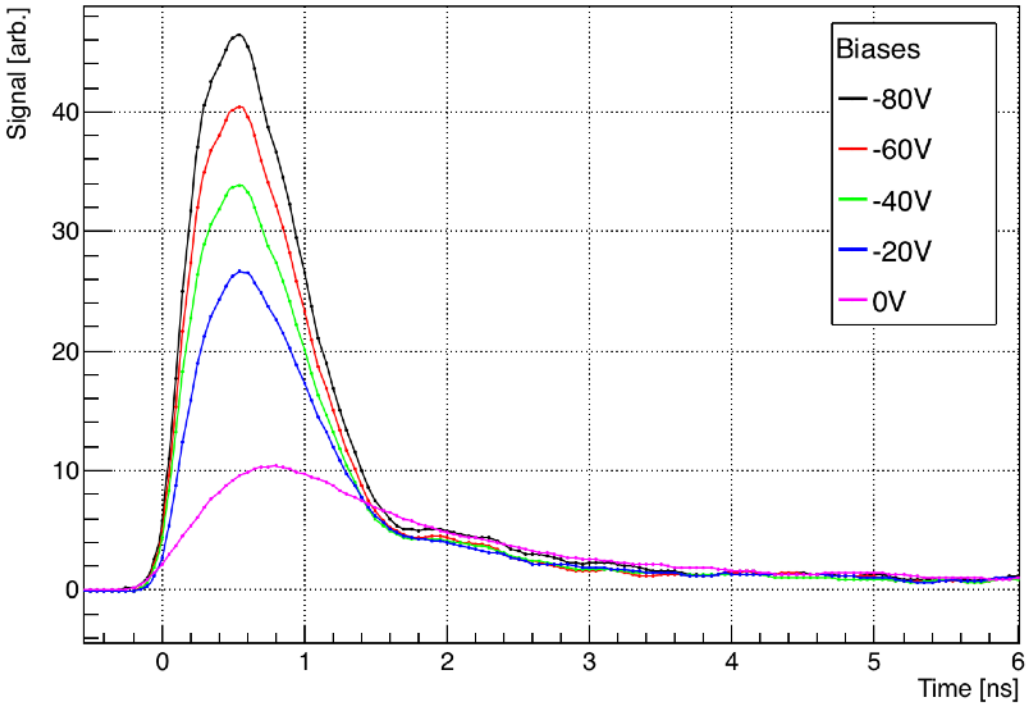
- First annealing step done at 22 °C to bring all samples to equal conditions
- Subsequent annealing done at 60 °C
- Temperature logged with Pt1000 on separate bare PCB



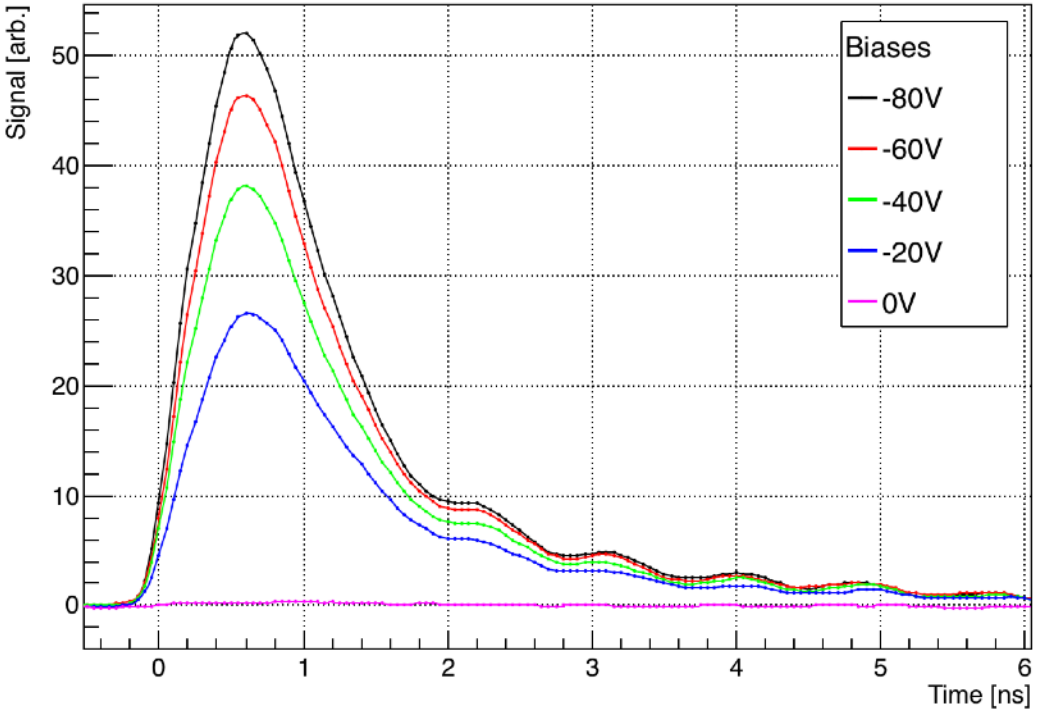
Waveforms

- Waveforms taken at peak CC
- Signal at V=0 vanishes after 3e14 n_{eq}/cm^2
- Fast (<2 ns) charge collection at all fluences
- Rise time negligibly reduced

Waveform of unirradiated HV-CMOS (CCPDv3)



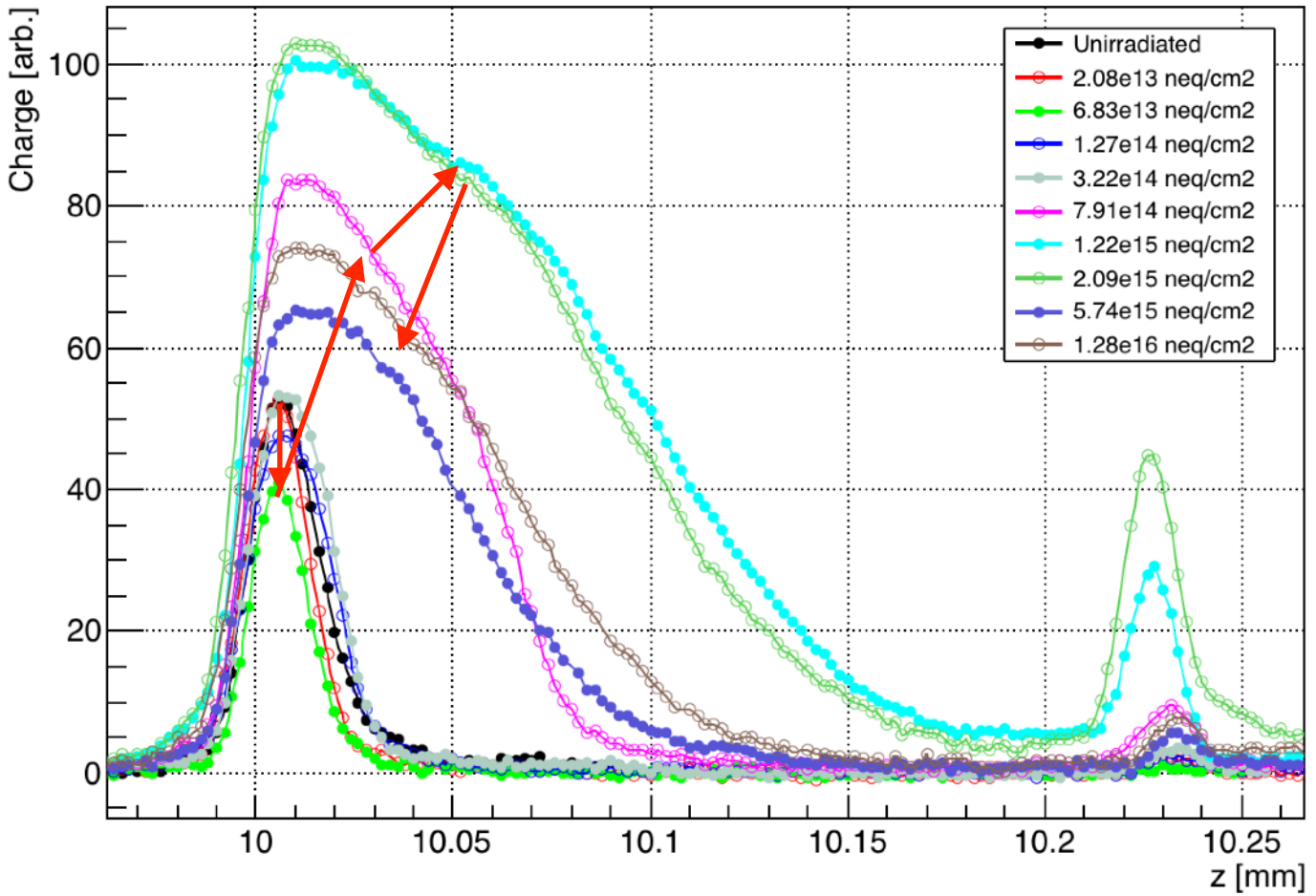
Waveform of 1.28e16 n_{eq}/cm^2 p-irrad CCPDv3



Charge collection

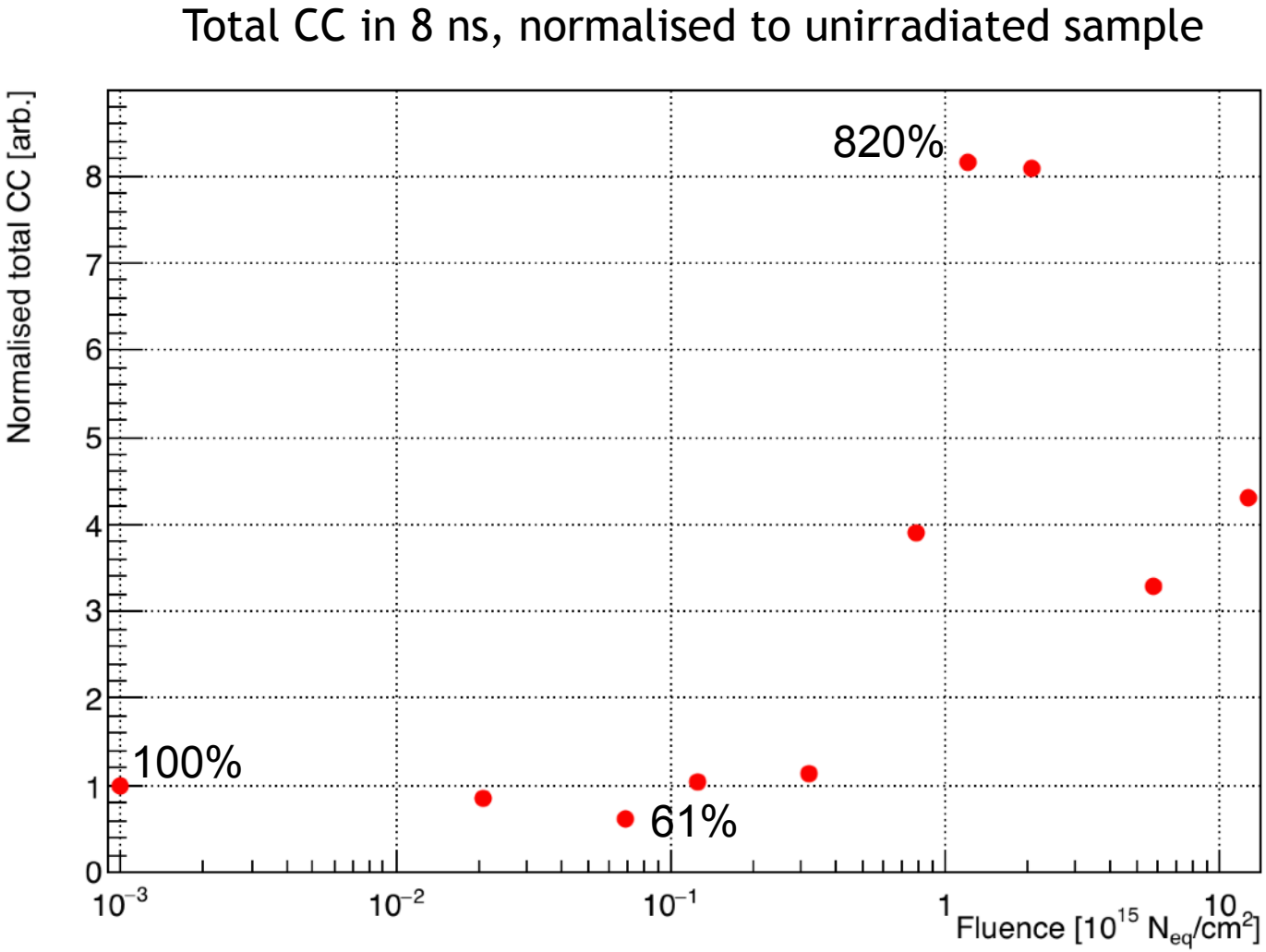
- Charge collection peaking at around 1 - 2e15 n_{eq}/cm^2
- Slight decrease for low fluences
- Note: sides unpolished
- Electric field visible on the backside
- CC profile unchanged with temp.
- Backside collection possibly due to light diffraction or Schottky junction

CC in 8 ns in 800 MeV p-irrad CCPDv3 at -80 V



Total collected charge

- Calculated through integration over the charge collection
- Charge collection at backside not included
- Lowest fluence represents unirradiated sample
- Increase up to over 800% of initial value
- Slight decrease at lower fluences can pose a challenge

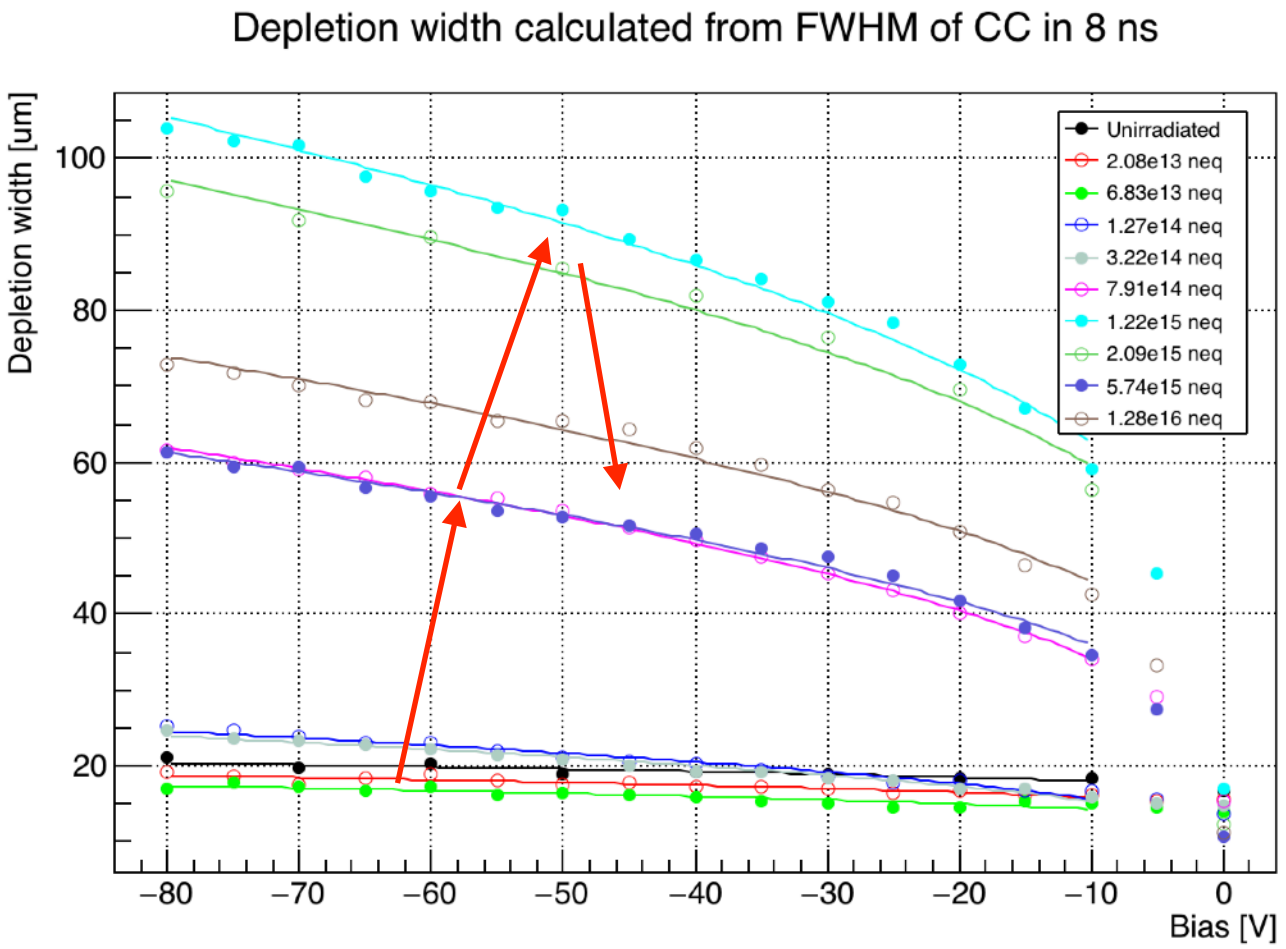


Depletion depth

- Depletion depth defined as FWHM of charge collection curve
- Fit eq.:

$$d = d_0 + \sqrt{\frac{2\,\varepsilon_{Si}}{e_0\,N_{eff}}\,V_{sub}}$$

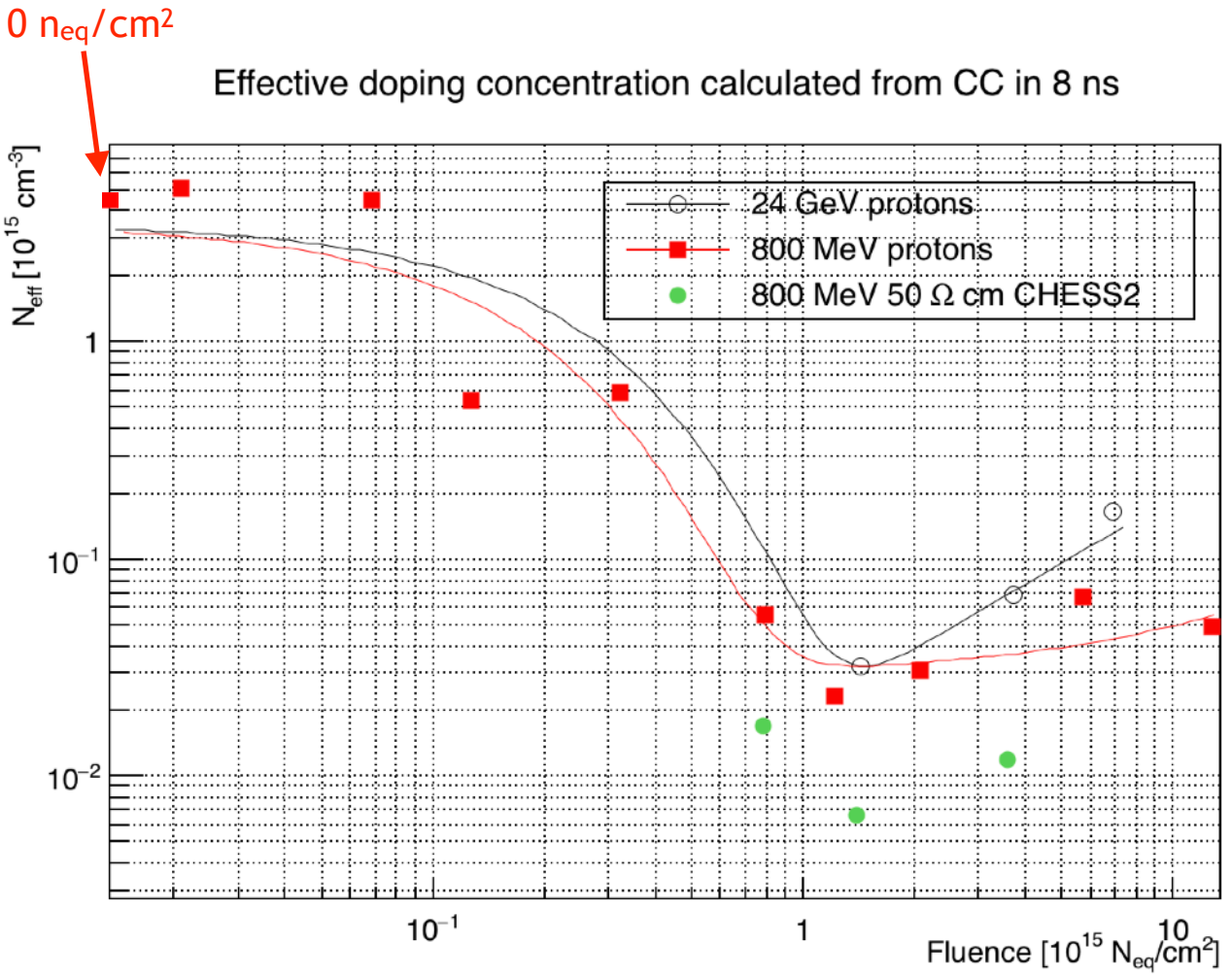
- d_0 and N_{eff} are fitting parameters.
- Low voltages not included in the fit due to large uncertainty of FWHM



Effective doping concentration

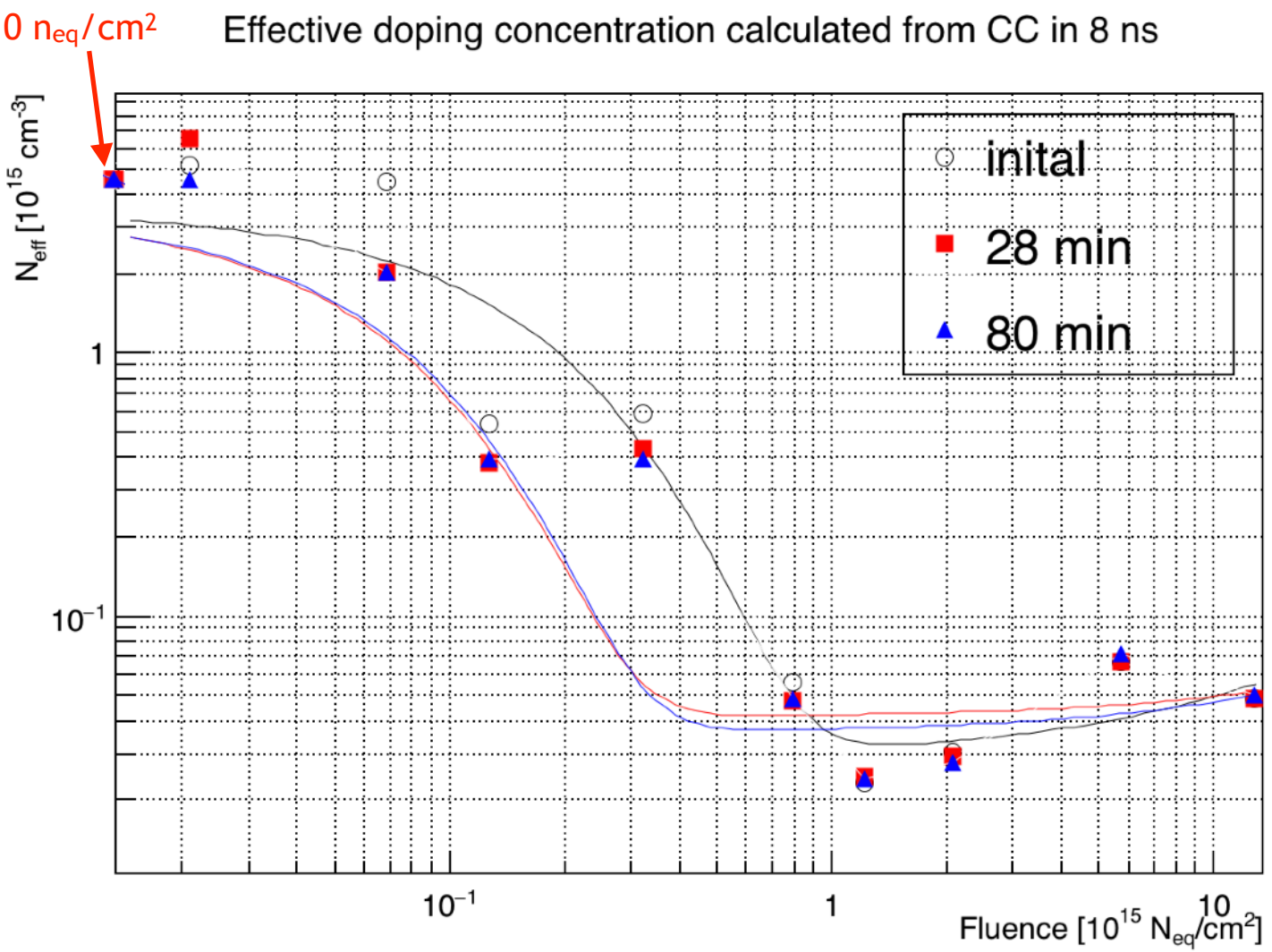
- N_{eff} acquired from fitting parameter on previous slide.
- Nominal N_{eff} is 1.32e15/cm^3 for 10 Ωcm, measured 3.51e15/cm^3 (~4 Ωcm)in unirradiated sample.
- Incomplete acceptor removal formula fit to N_{eff}, $N_{eff,0}$ fixed to 3.51e15
- N_A = 3.48e15, c = 6.62e-15, g_c = 2e-3
- 24 GeV data for comparison, CCPDv3 10 Ωcm, M. Fernandez Garcia, 27th RD workshop
- Green data points for comparison, 50 Ωcm. B. Hiti, 31st RD50 workshop, 12/2017

$$N_{eff} = N_{eff,0} - N_A\,(1 - exp(-c \cdot \Phi_{eq})) + g_C \Phi_{eq}$$



N_{eff} after annealing

- Samples with two highest fluences had initially 6300 min at RT
- First annealing step at RT to 6300 min for all samples. (eq. 28 min at 60 °C, Hamburg model)
- Small increase for lower fluences
- Negligible change for higher fluences

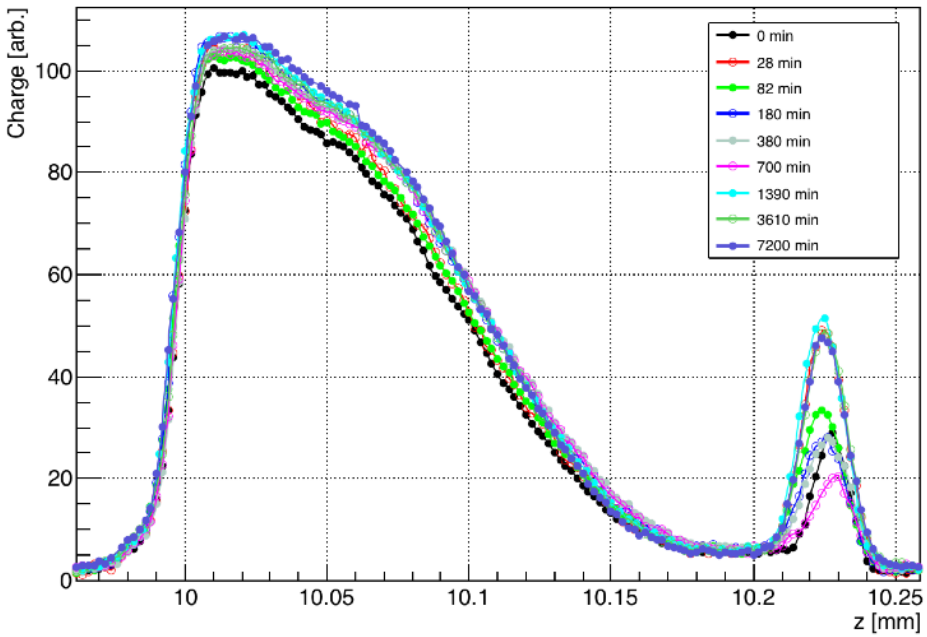


N_{eff} after annealing

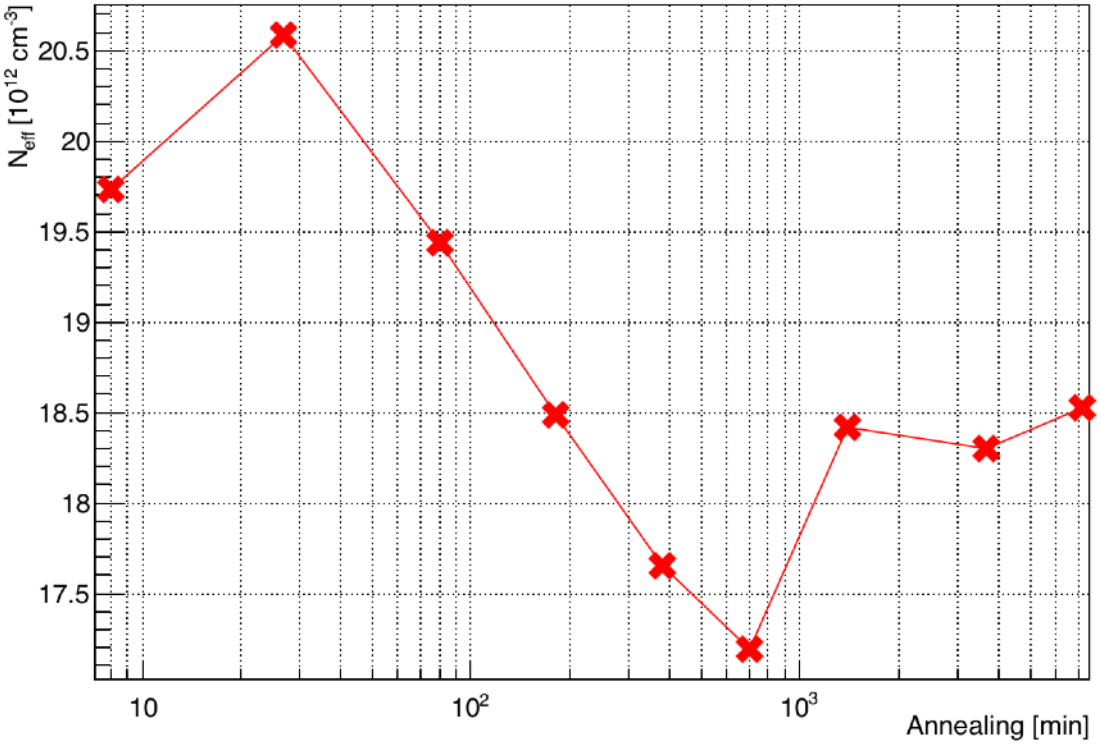
- 10~15% Increase in CC after ~ 700 min at 60 ºC
- No reverse annealing observed
- Change in CC at backside possibly due to slight change in laser focus

- Similar to epitaxial 10 Ωcm p-type pad diode results. P. Almeida, 31st RD50 workshop

CC in 8 ns for annealed 1.22e15 n_{eq}/cm^2 sample at -80V



N_{eff} calculated from CC in 8 ns for annealed 1.22e15 n_{eq}/cm^2 sample



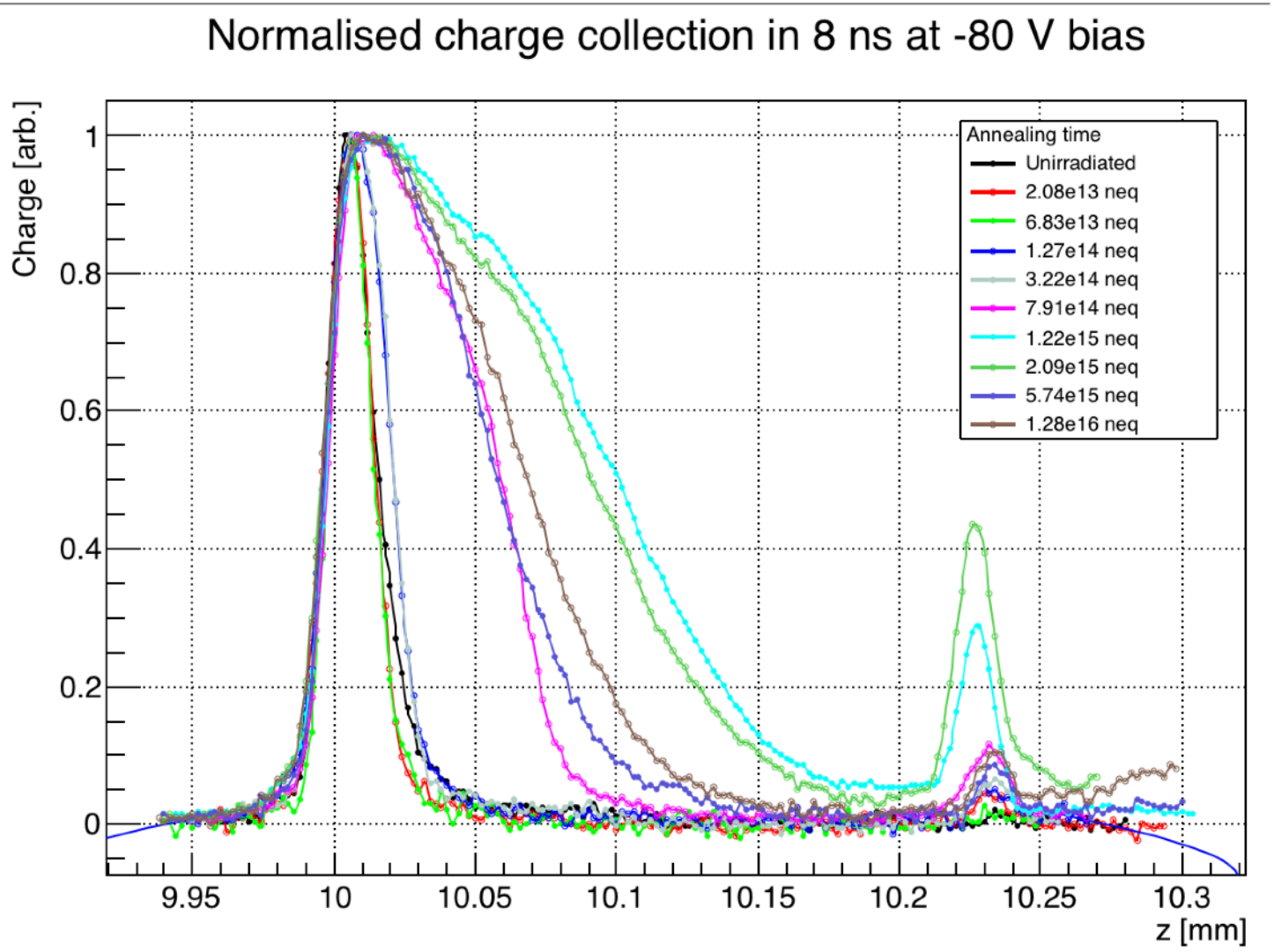
Outlook

- Results in agreement with 24 GeV and 16.7 MeV proton irradiated. Charged hadrons show much stronger acceptor removal.
- Decrease in charge collection at low fluences (~7e13 n_{eq}/cm^2) for low resistivity a challenge.

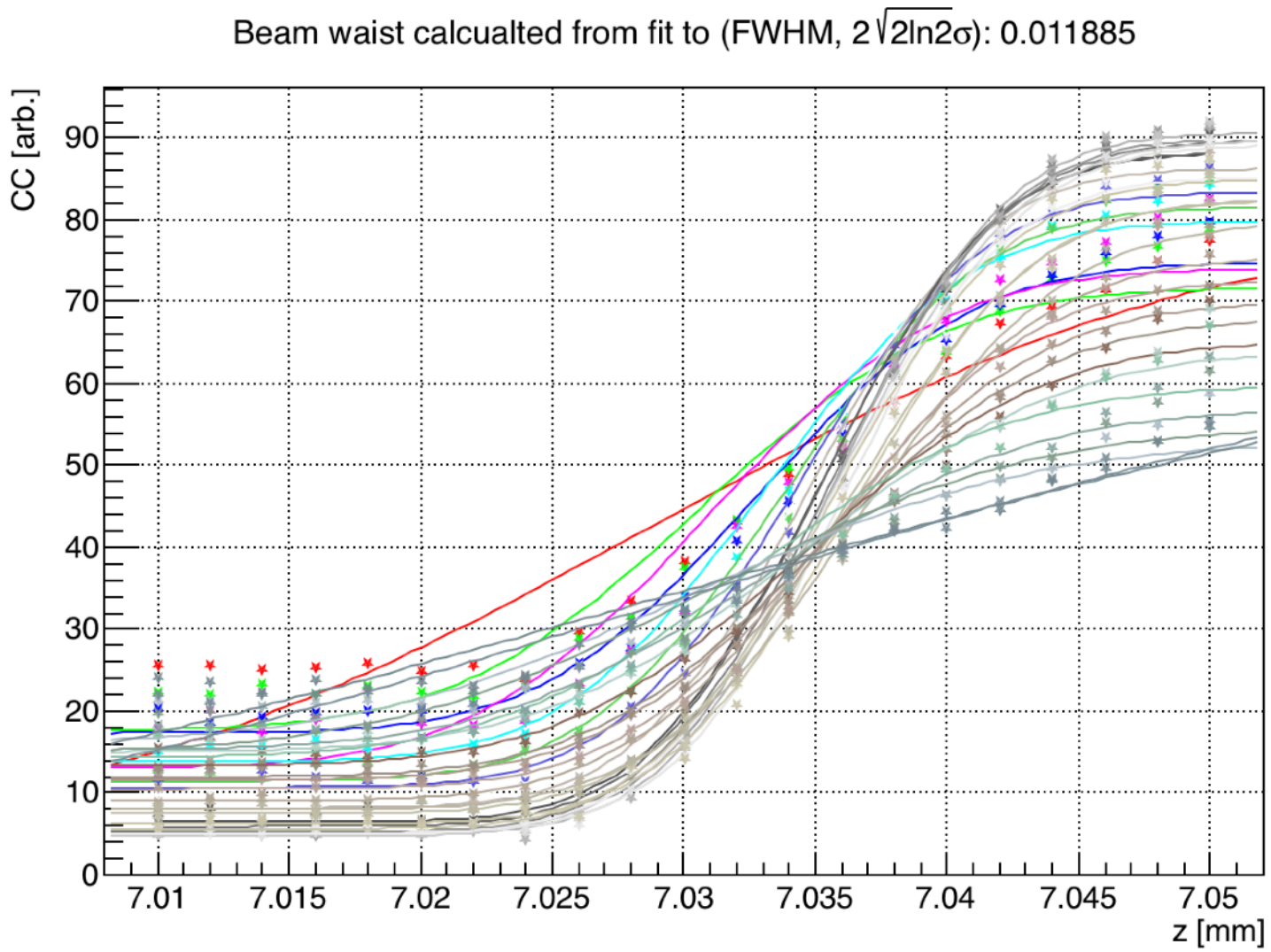
- 800 MeV irradiated 10 Ωcm HV-CMOS:
  - Depletion region grows after ~5e14 n_{eq}/cm^2
  - Maximum reached around ~1-2e15 n_{eq}/cm^2
  - Still substantial signal and large depletion region after 1.3e16 n_{eq}/cm^2
  - Slight increase in charge collection after annealing
  - No reverse annealing visible up until ~7000 min at 60 °C

- Mixed irradiations similar to simulated HL-LHC background radiation to follow

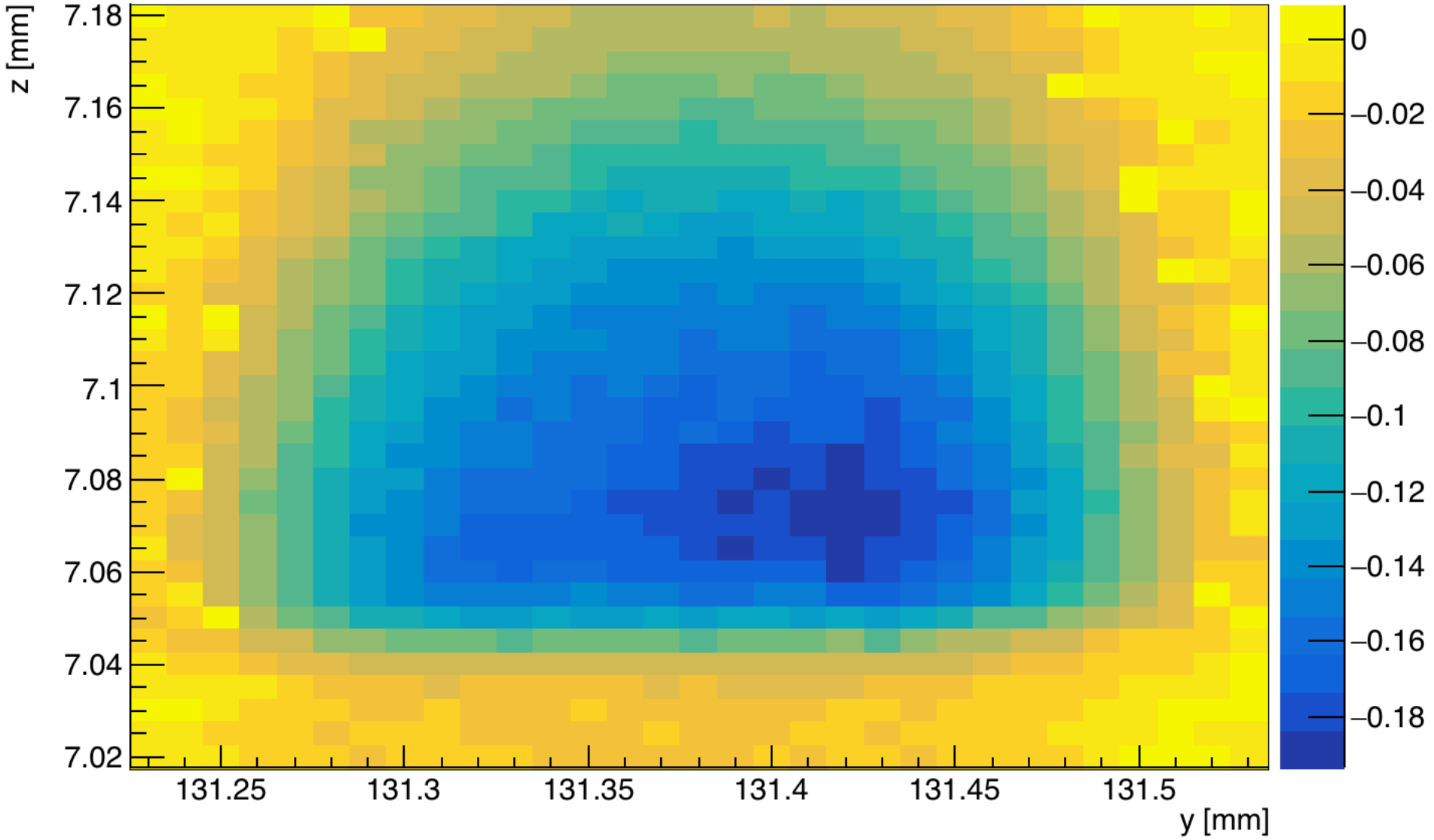
Backup


Normalised charge collection in 8 ns at -80 V bias
Charge [arb.]
1
0.8
0.6
0.4
0.2
0
9.95
10
10.05
10.1
10.15
10.2
10.25
10.3
z [mm]
Annealing time
Unirradiated
2.08e13 neq
6.83e13 neq
1.27e14 neq
3.22e14 neq
7.91e14 neq
1.22e15 neq
2.09e15 neq
5.74e15 neq
1.28e16 neq

Calculation of beam waist



YZ plot of 2.09e15 neq/cm2



Waveform for all fluences