



# TCT measurements of n-type MCz diodes

18-10-2016, 2<sup>nd</sup> TCT workshop, Jožef stefan institute, Ljubljana

William Holmkvist

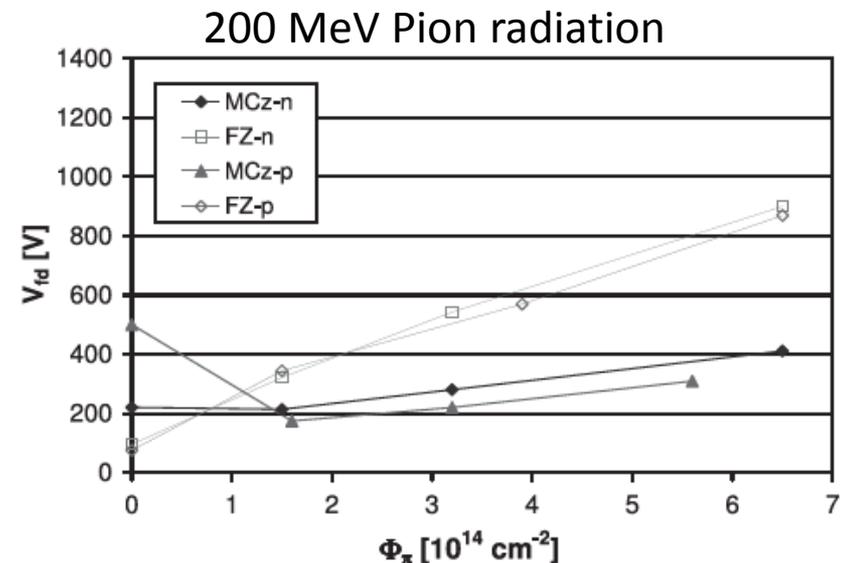
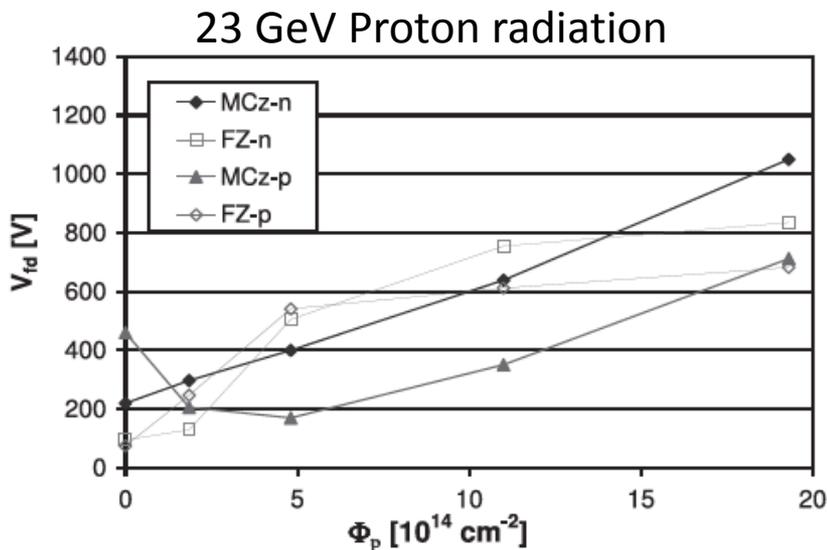
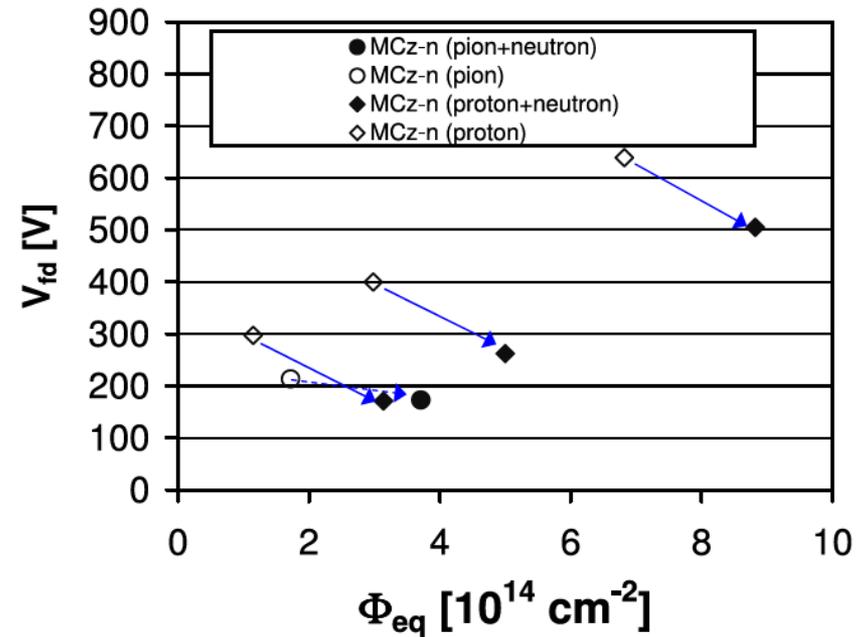
Co-Authors: Daniel Muenstermann, Rebecca Carney, Christian Gallrapp and Karola Dette

# Background and motivation



N-in-N MCz detectors show peculiar properties:

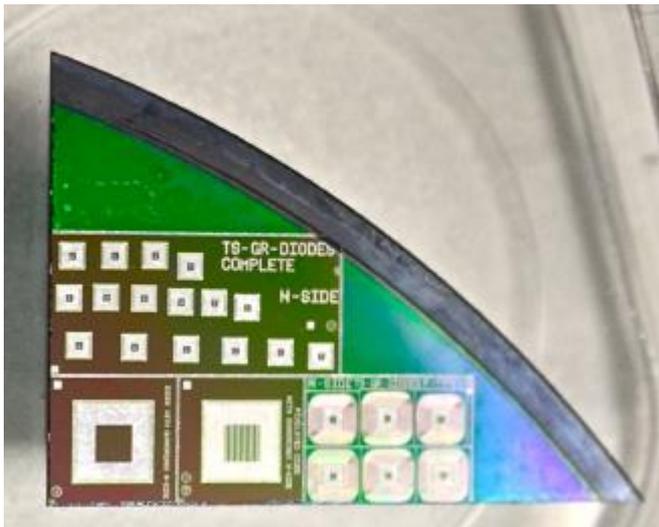
- No space charge sign inversion for 23 GeV protons
- Relatively stable  $V_{fd}$  for 200 MeV pions
- Additive space charge characteristics might enable the usage of cancelling effects to keep  $V_{fd}$  low/stable
  - Optimal  $N_{eff}$  stability at 2 parts proton and 1 part neutron radiation. Potential compensation of  $N_{eff}$  for intermediate radii in ATLAS/CMS for n-in-n MCz.
- Results from: Kramberger et al., NIM A **612** (2010) 288 and NIMA A 609 (2009) 142



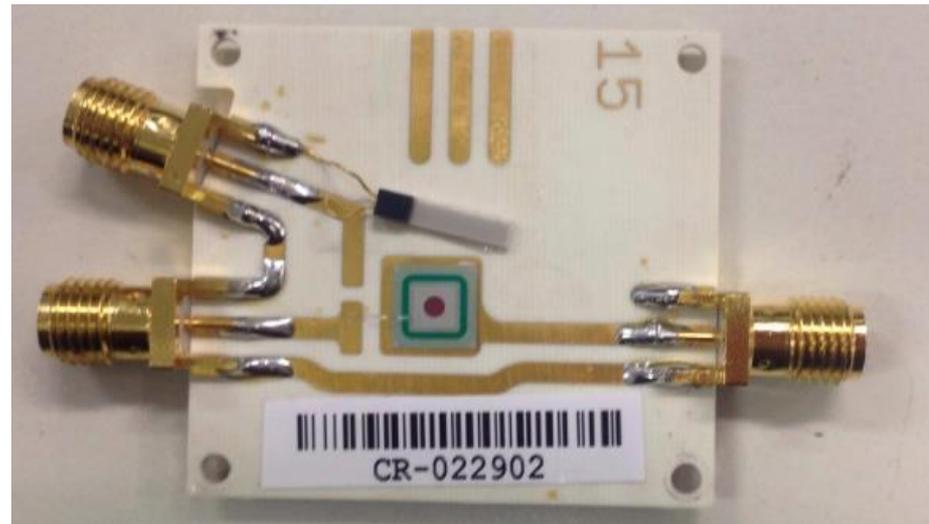
# Background and motivation II



- From previous results we know that 24 MeV proton irradiated n-in-n MCz behave like FZ silicon, while 23 GeV proton irradiation do not.
  - LHC background energy spectrum peaks around 100-200 MeV
- 70 MeV proton irradiated samples acquired to investigate their behavior.
  - $1e13 n_{eq}/cm^2$ ,  $1e14 n_{eq}/cm^2$ ,  $5e14 n_{eq}/cm^2$
- 200 MeV pion literature results showing ambiguous behavior.
- 300 MeV pion irradiated samples acquired to see if the results can be clarified
  - $1e13 n_{eq}/cm^2$ ,  $1e14 n_{eq}/cm^2$ ,  $2.76e14 n_{eq}/cm^2$ ,  $4.26e14 n_{eq}/cm^2$



70 MeV proton samples



300 MeV pion samples

# TCT+ setup at CERN

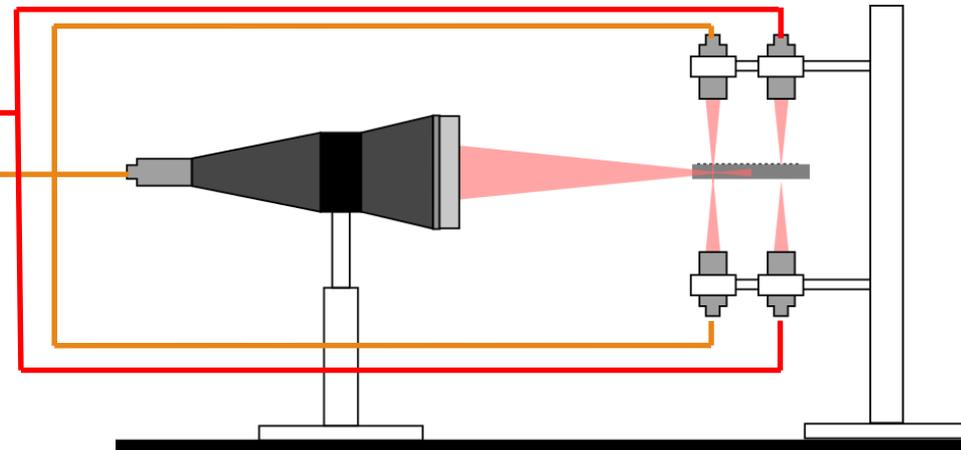


- Red Laser illumination possible from top and bottom side of DUT
- 2.5 GHz Agilent Scope
- Flushing with dry air
- Computer controlled peltier cooling down to  $-20^{\circ}\text{C}$
- Bias voltage up to 1000V



Red (660nm)  
IR (1064nm)

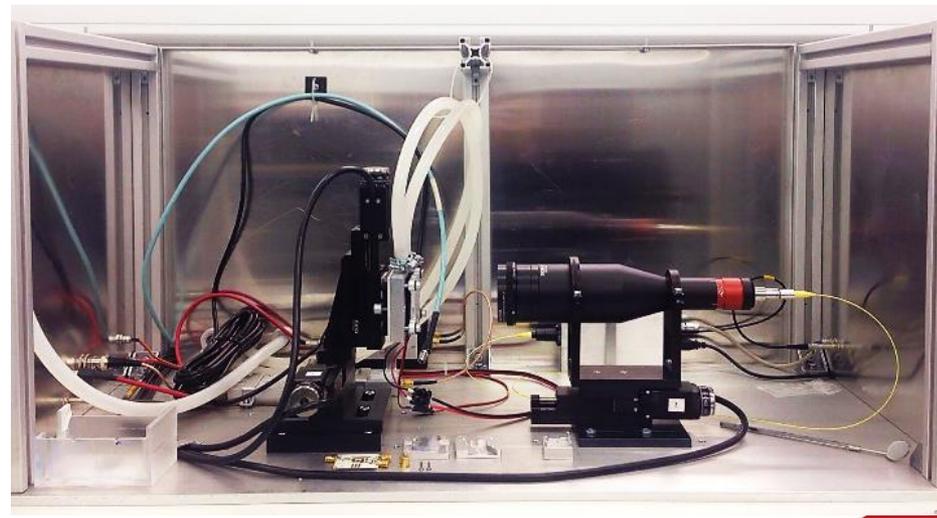
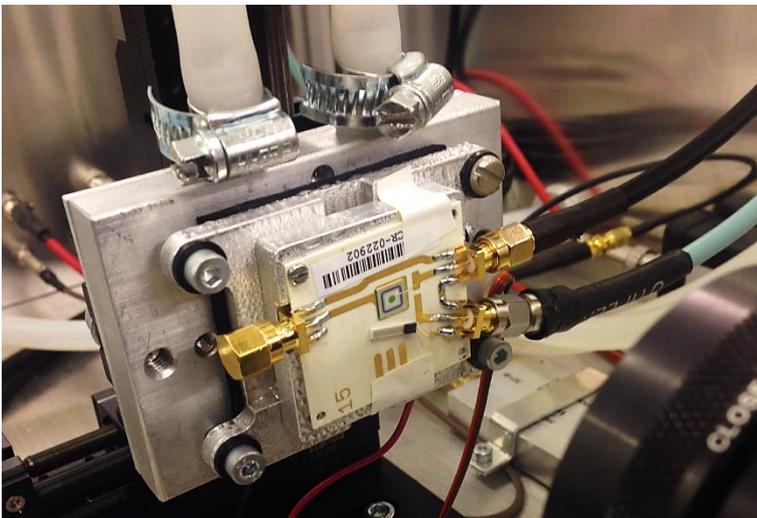
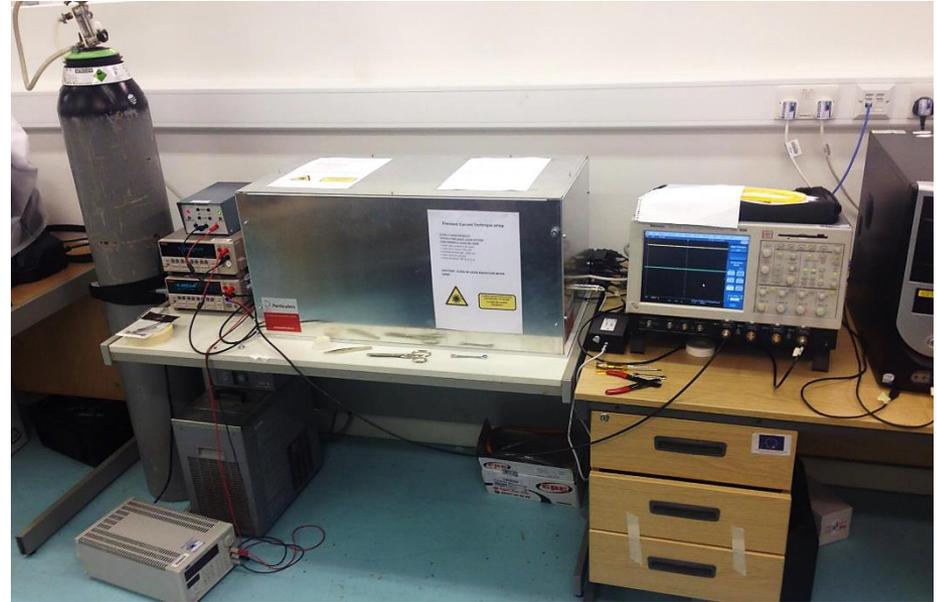
Pulsed laser with a trigger frequency of 200Hz



# Particulars TCT setup at Lancaster University



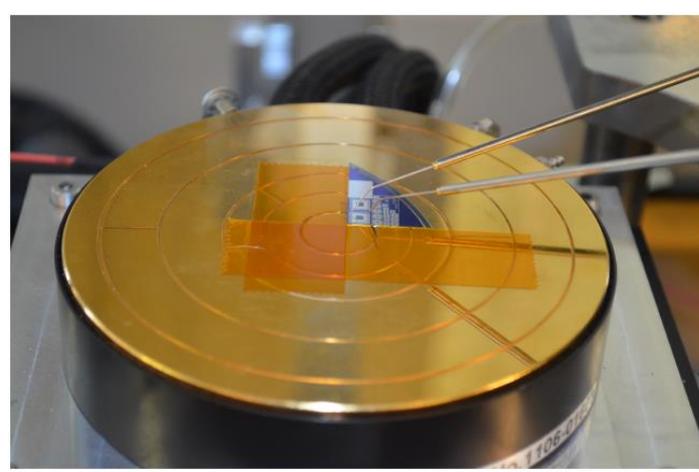
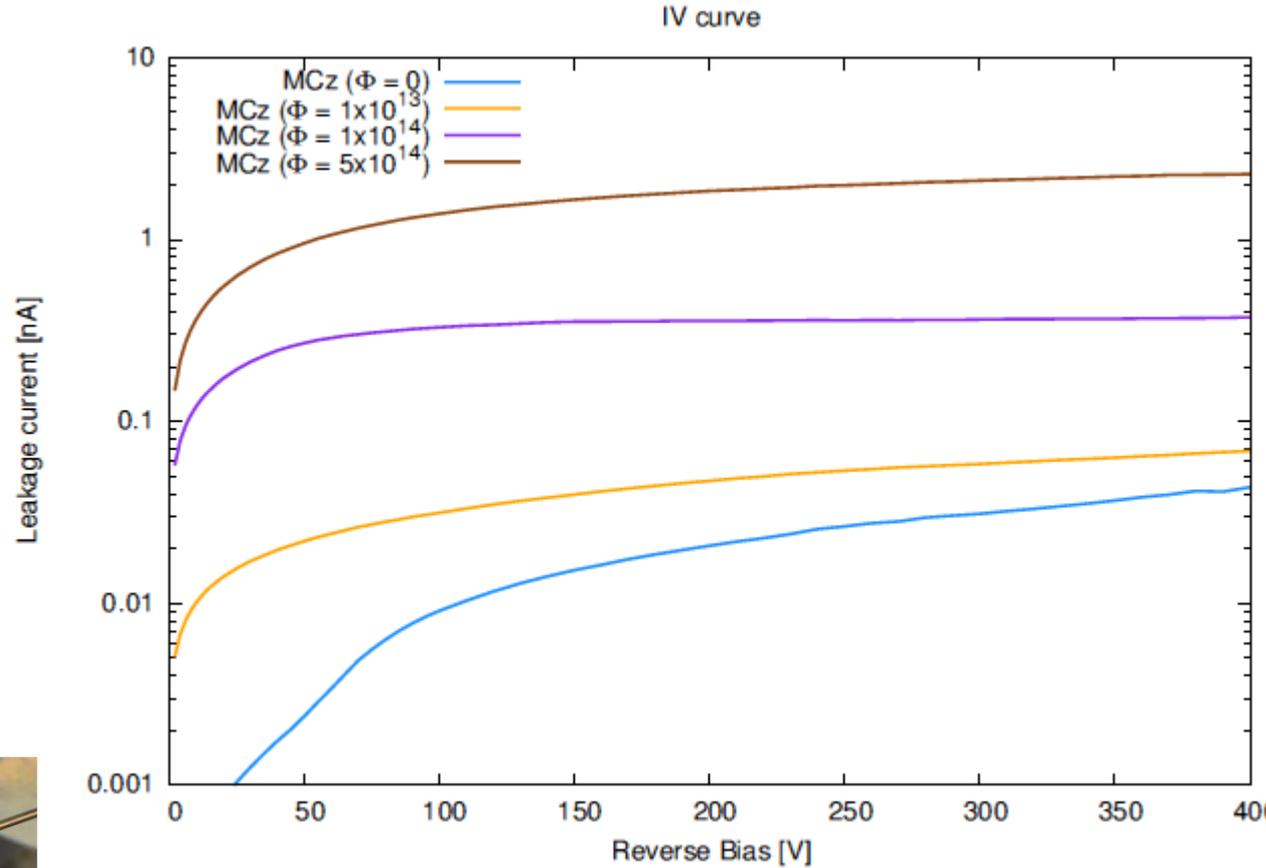
- IR pulsed laser
  - 20 kHz
  - $\leq$  ns pulse length
- Adjusted to CERN's PCB
- 2.5 GHz Tektronix DPO
- Nitrogen for flushing
- Peltier for cooling down to  $-20^{\circ}$  C
- Keithley 2410 for bias voltage up to 1100V



# 70 MeV Proton samples IV curve



- IV measurements taken by Rebecca Carney with IV/CV measurement setup at CERN
- Clearly increasing leakage current with fluence, as to be expected

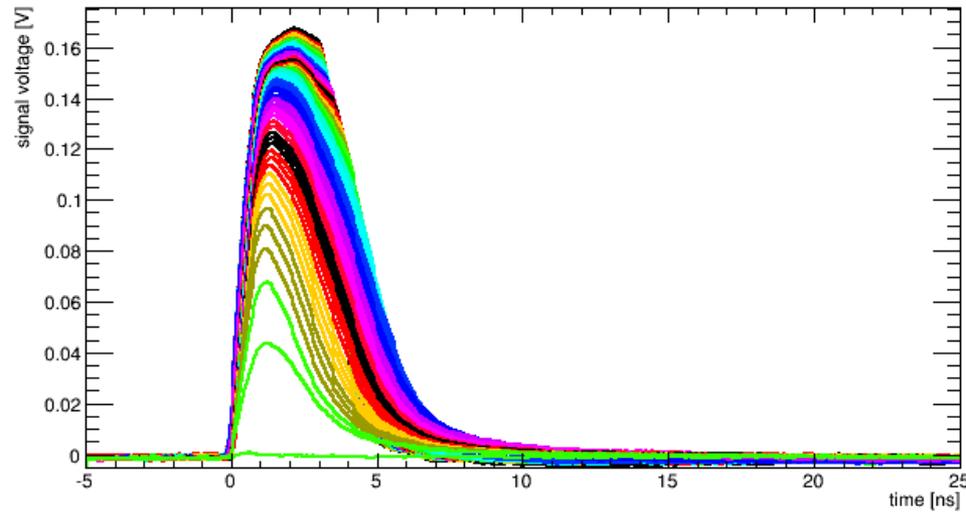


# 70 MeV Proton samples

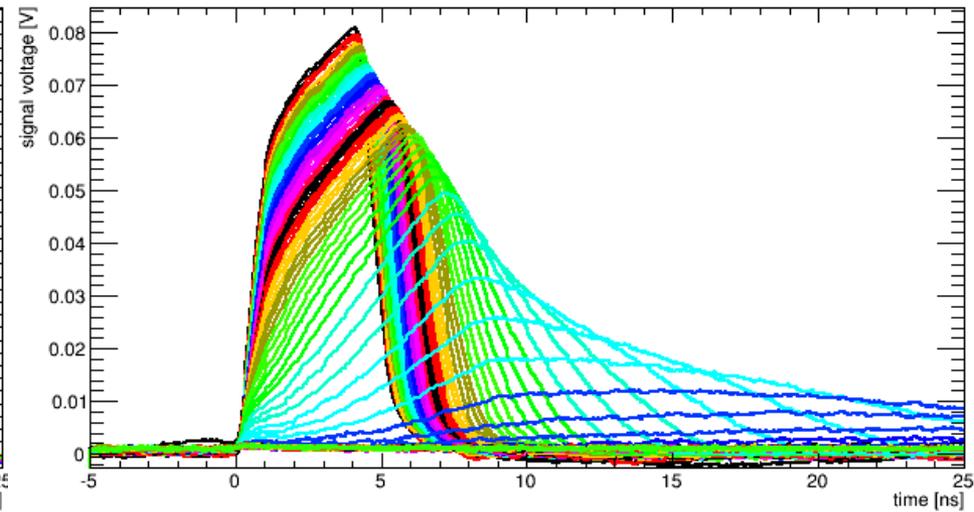
## Waveforms



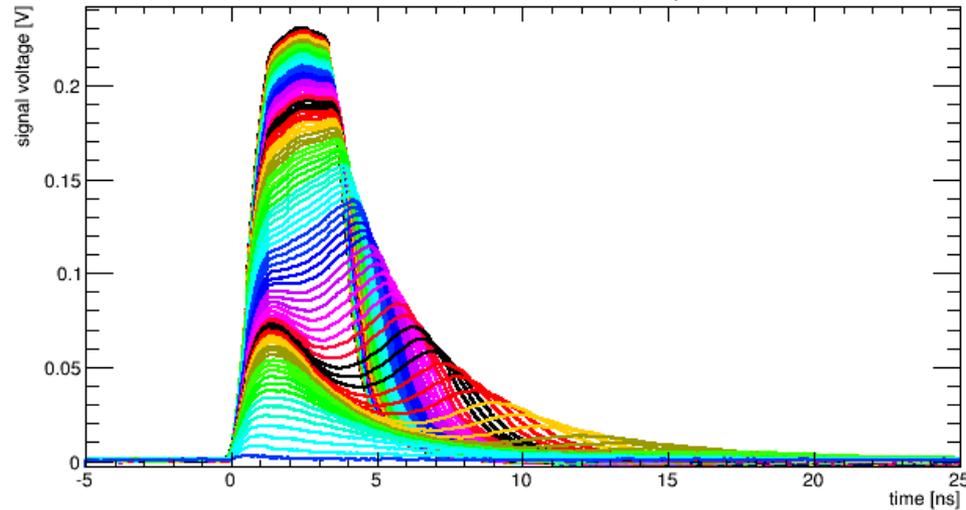
Electrons –  $1e13 n_{eq}/cm^2$



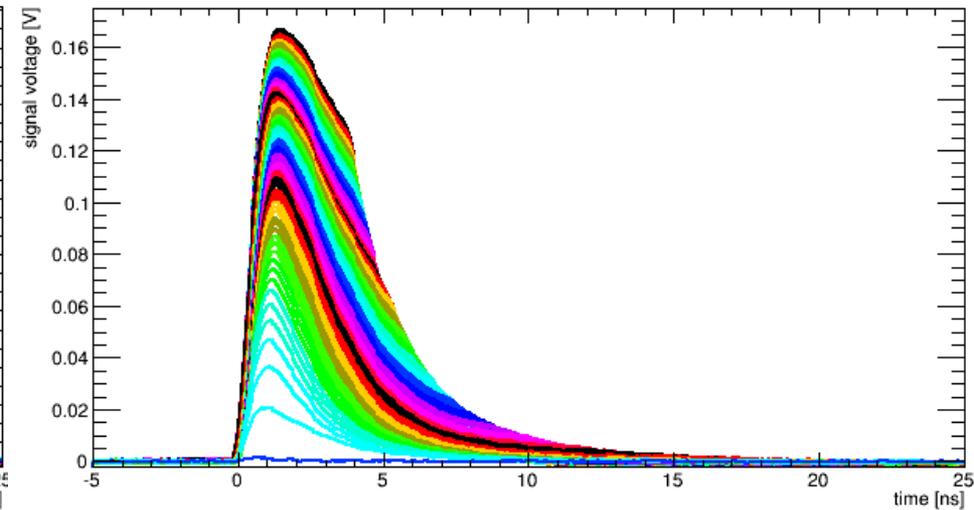
Holes –  $1e13 n_{eq}/cm^2$



Electrons –  $5e14 n_{eq}/cm^2$



Holes –  $5e14 n_{eq}/cm^2$

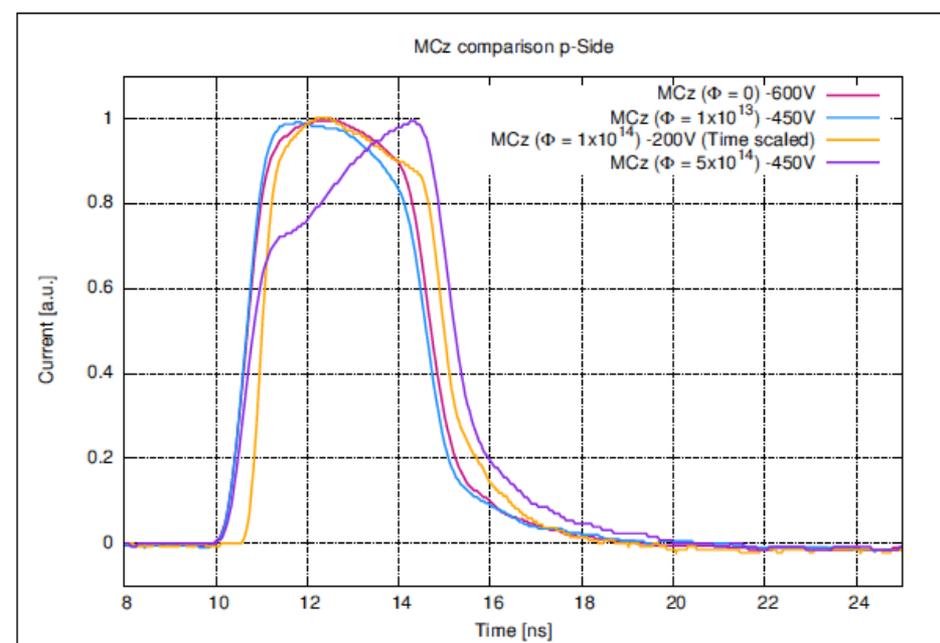
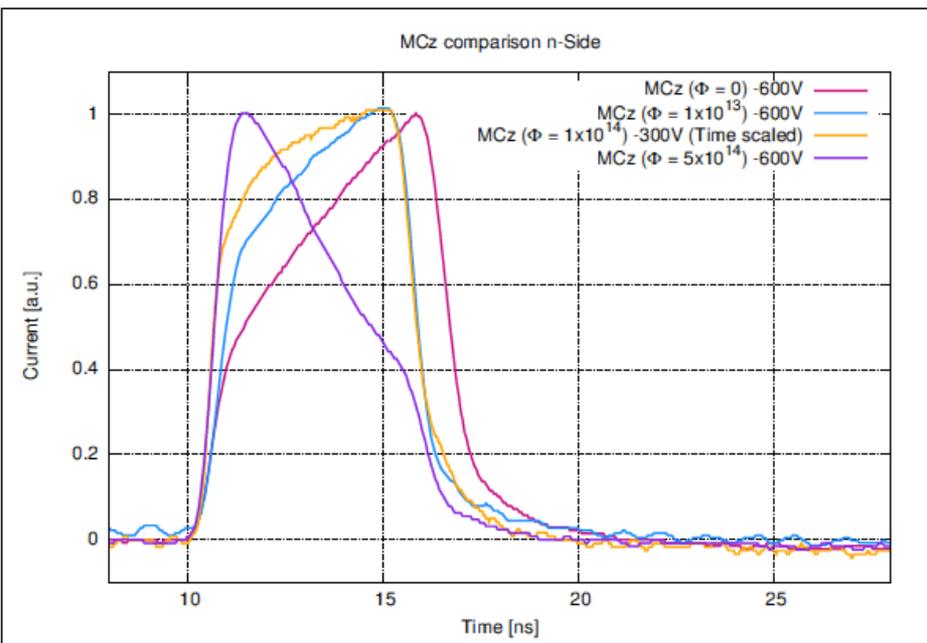


# 70 MeV Proton samples

## Waveforms



- Waveforms highlighted summarized below
- Both n-side and p-side show clearly shows a gradient sign change for the  $5 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$  sample.
- Most likely suggests SCSI



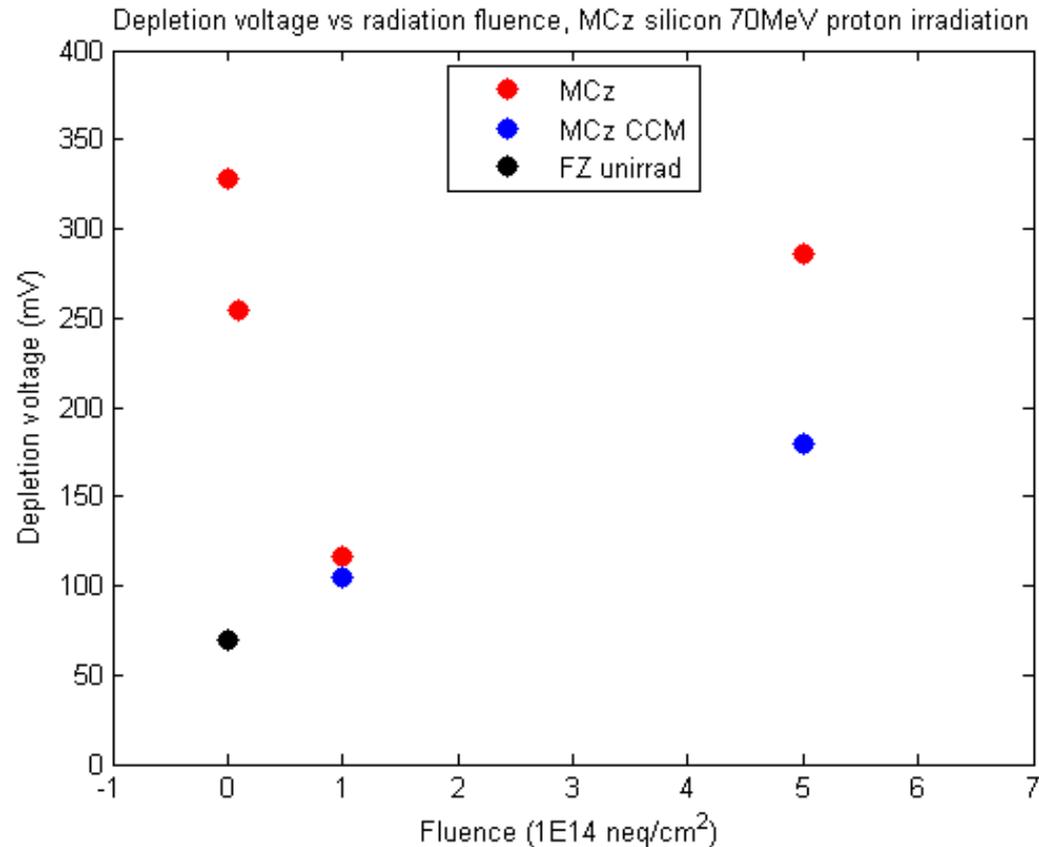
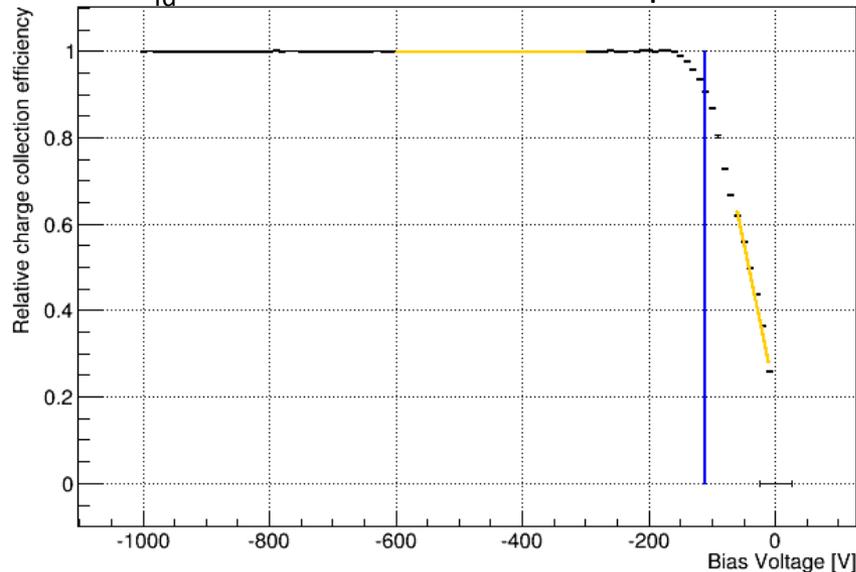
# 70 MeV Proton samples

## Depletion voltage

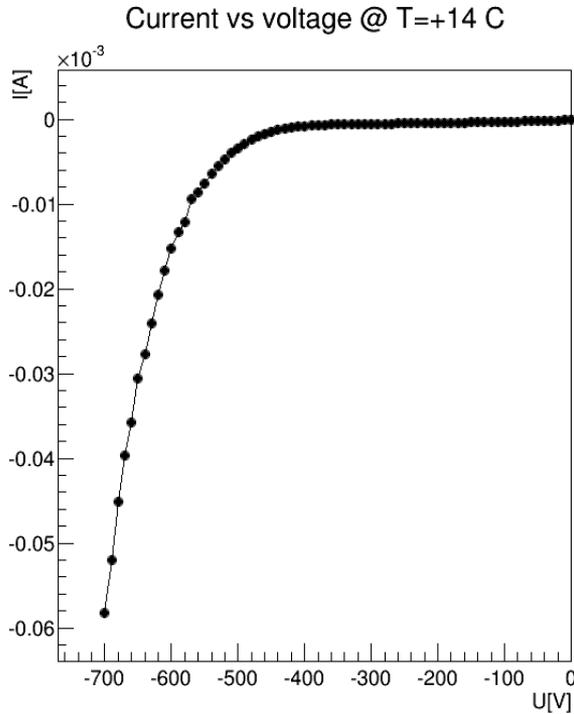


- $V_{fd}$  calculated with TCTana analysis, same method as 300 MeV pion samples
- Together with waveforms, most likely SCSI occurs slightly above  $1e14$   $n_{eq}/cm^2$

$V_{fd}$  calculation from CCE example

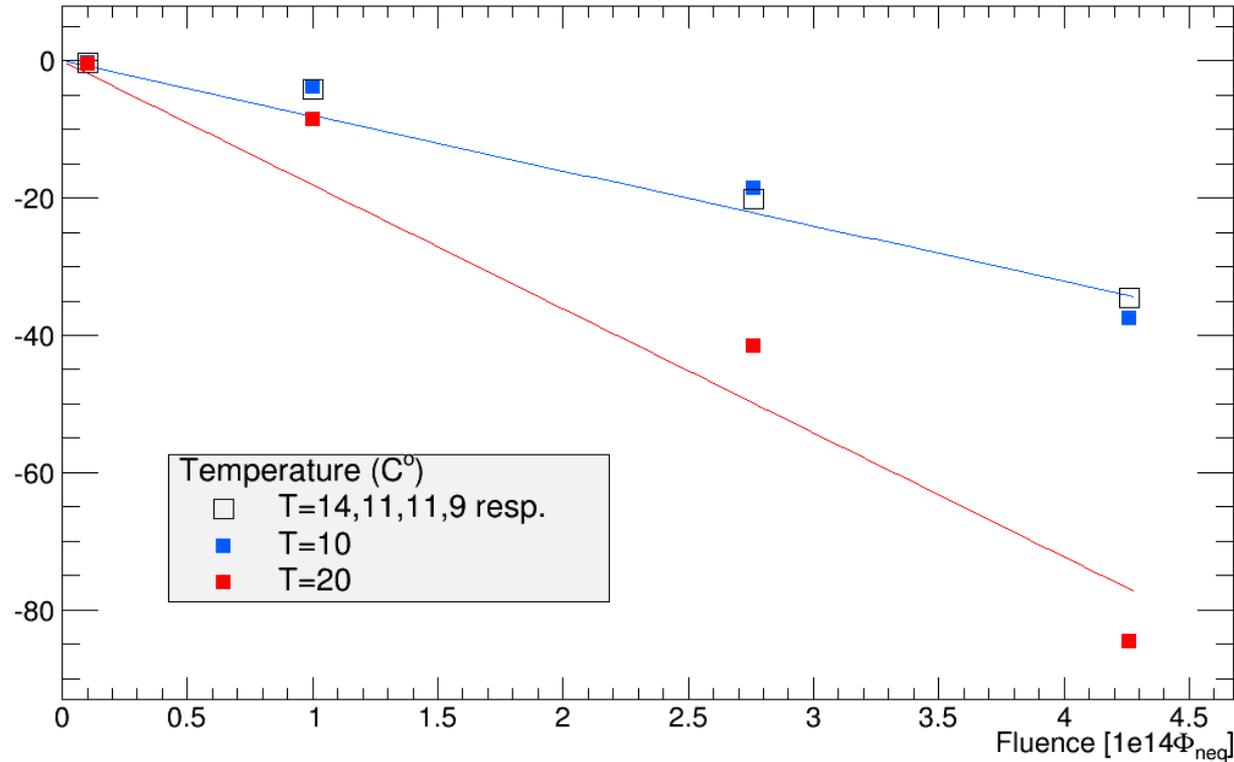


# 300 MeV pion samples IV curves



1e13 MeV sample

## Fluence vs leakage current at $V_{fd}$



- $V_{fd}$  values used from results with IR laser

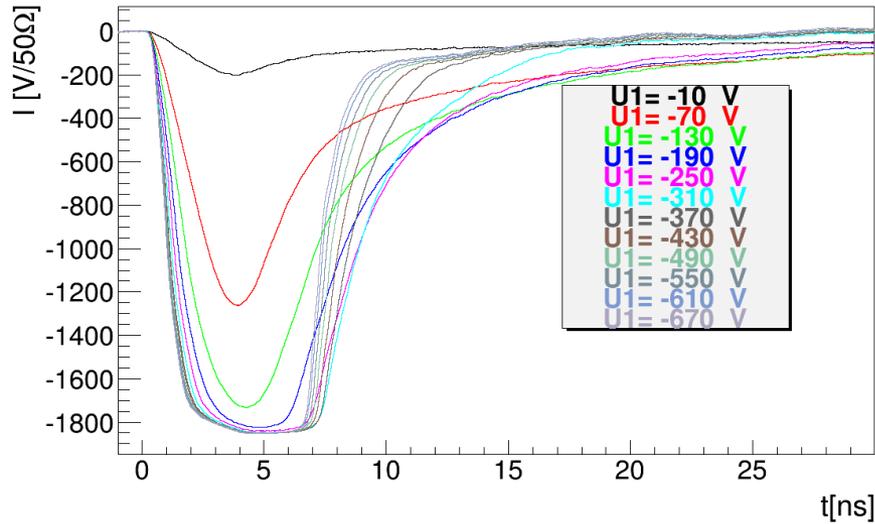
- $\frac{I_{L2}}{I_{L1}} \cong \exp \left[ \left( \frac{3}{\eta T} + \frac{E_G}{\eta T E_T} \right) \Delta T \right]$ , ( $\eta=2$ ,  $E_G=1.12\text{eV}$ ,  $E_T=0.0259\text{eV}$ )
- $I_{L1}$  is  $I_{leak}$  at temperature  $T$ .
- $I_{L2}$  is  $I_{leak}$  at temperature  $T + \Delta T$ .
- Used to calculate  $I_{leak}$  at different  $T$

# 300 MeV pion samples Waveforms (IR)

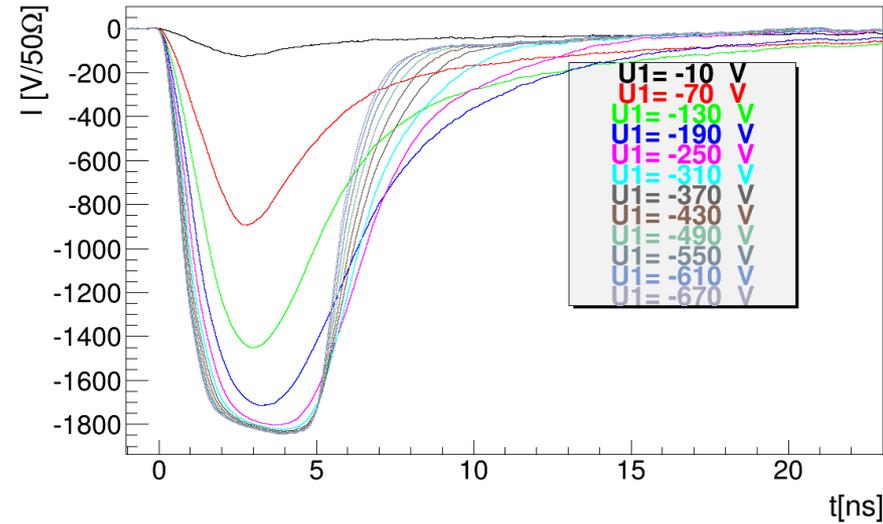


$1e13 n_{eq}/cm^2$

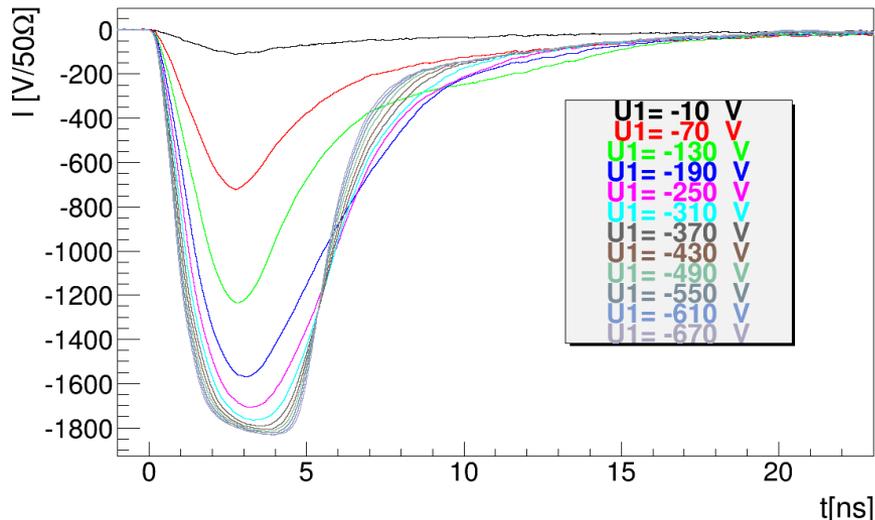
TCT Measurement @ T=+14 C



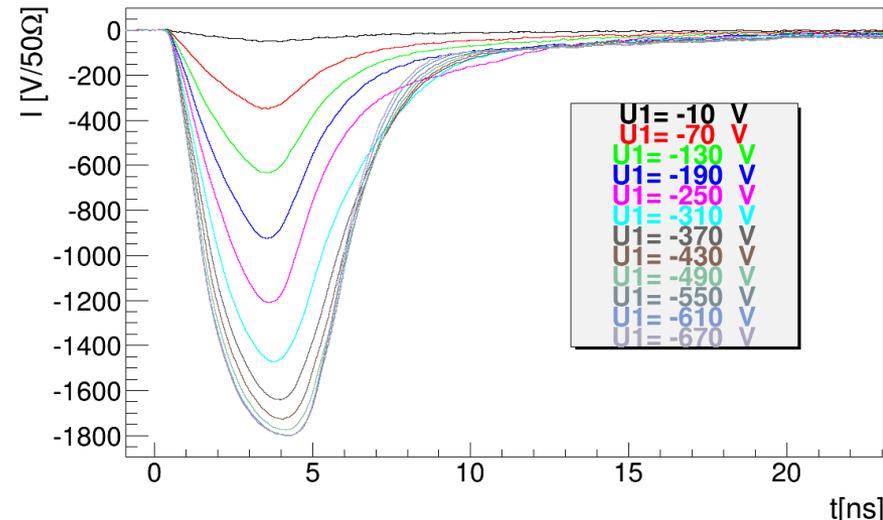
$1e14 n_{eq}/cm^2$   
TCT Measurement @ T=+11 C



$2.76e14 n_{eq}/cm^2$   
TCT Measurement @ T=+11 C



$4.26e14 n_{eq}/cm^2$   
TCT Measurement @ T=+09 C



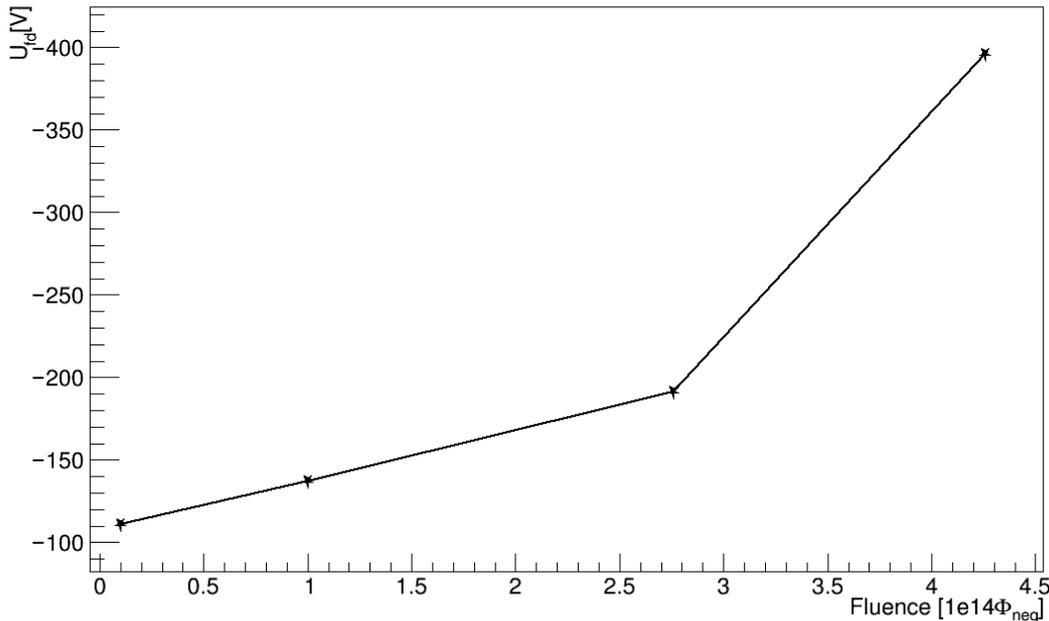
# 300 MeV pion samples

## CCE and $V_{fd}$



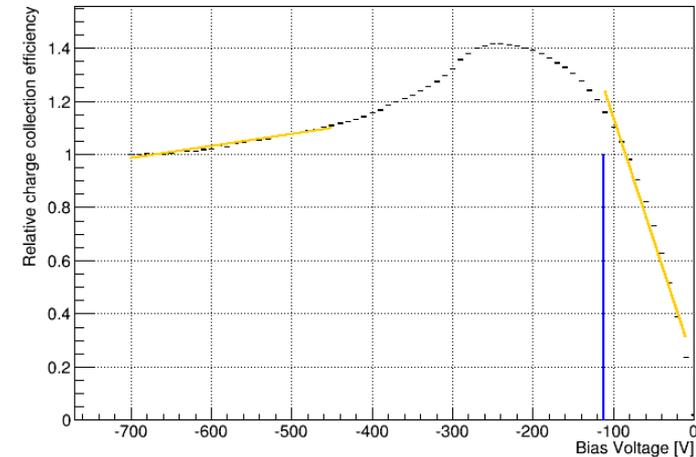
- Results hint at increasing  $N_{eff}$  with increasing fluence
- Overshoot for low voltages due to amplifier saturation
- Systematically too low  $V_{fd}$  for two lowest fluences, due to overshoot.

Depletion voltage vs fluence



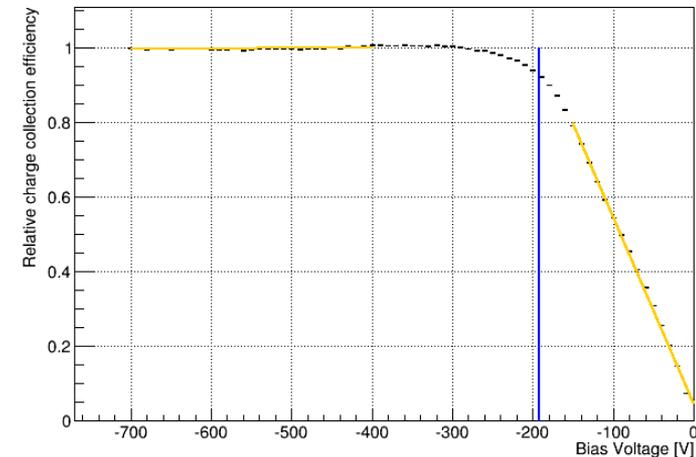
$1e13 n_{eq}/cm^2$

022913\_CCM\_CCE\_vs.\_Bias



$2.76e14 n_{eq}/cm^2$

022906\_CCM\_CCE\_vs.\_Bias

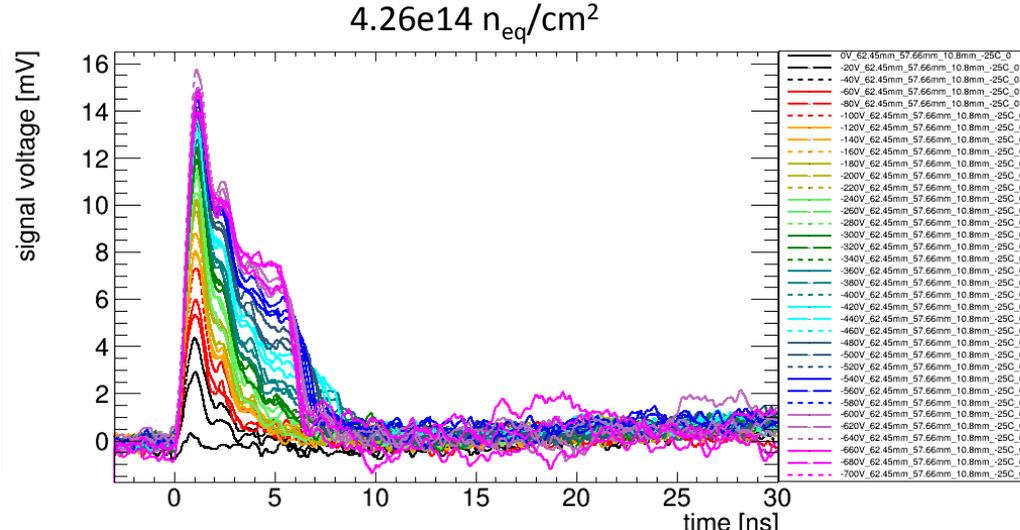
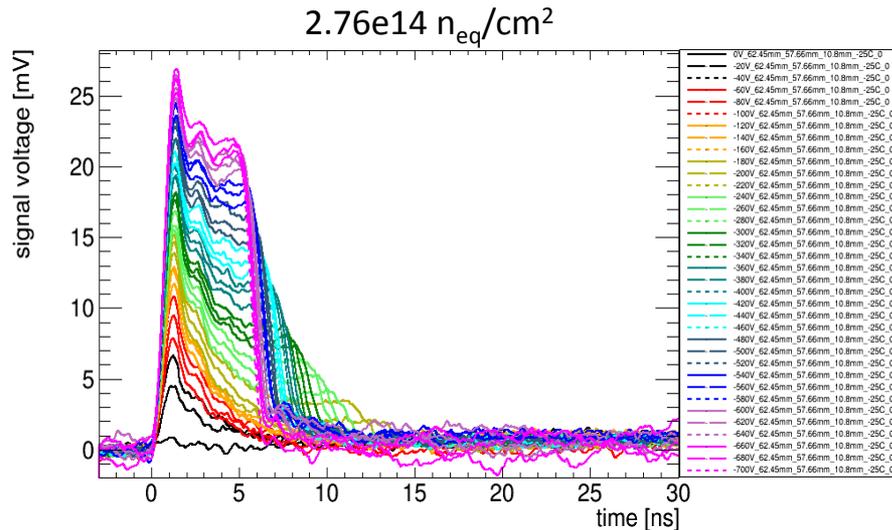
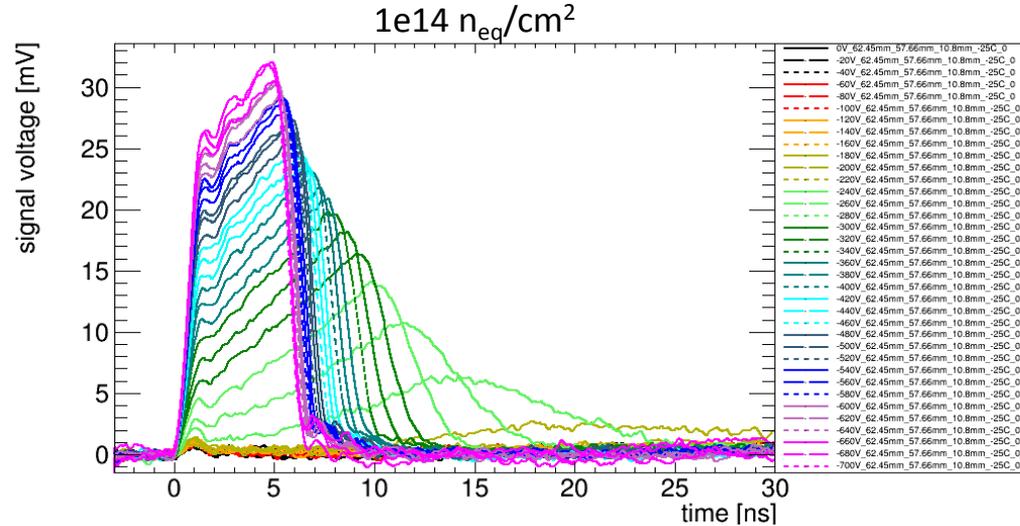
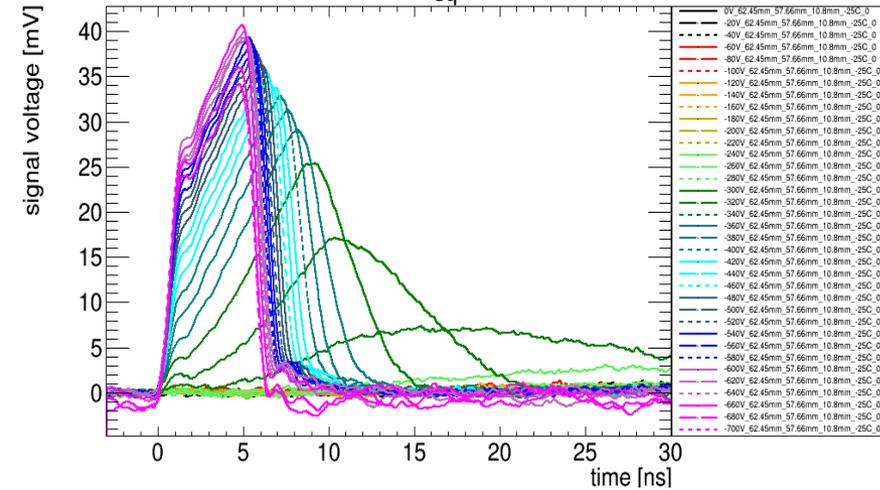


# 300 MeV Pion samples

## Red Laser comparison (holes)



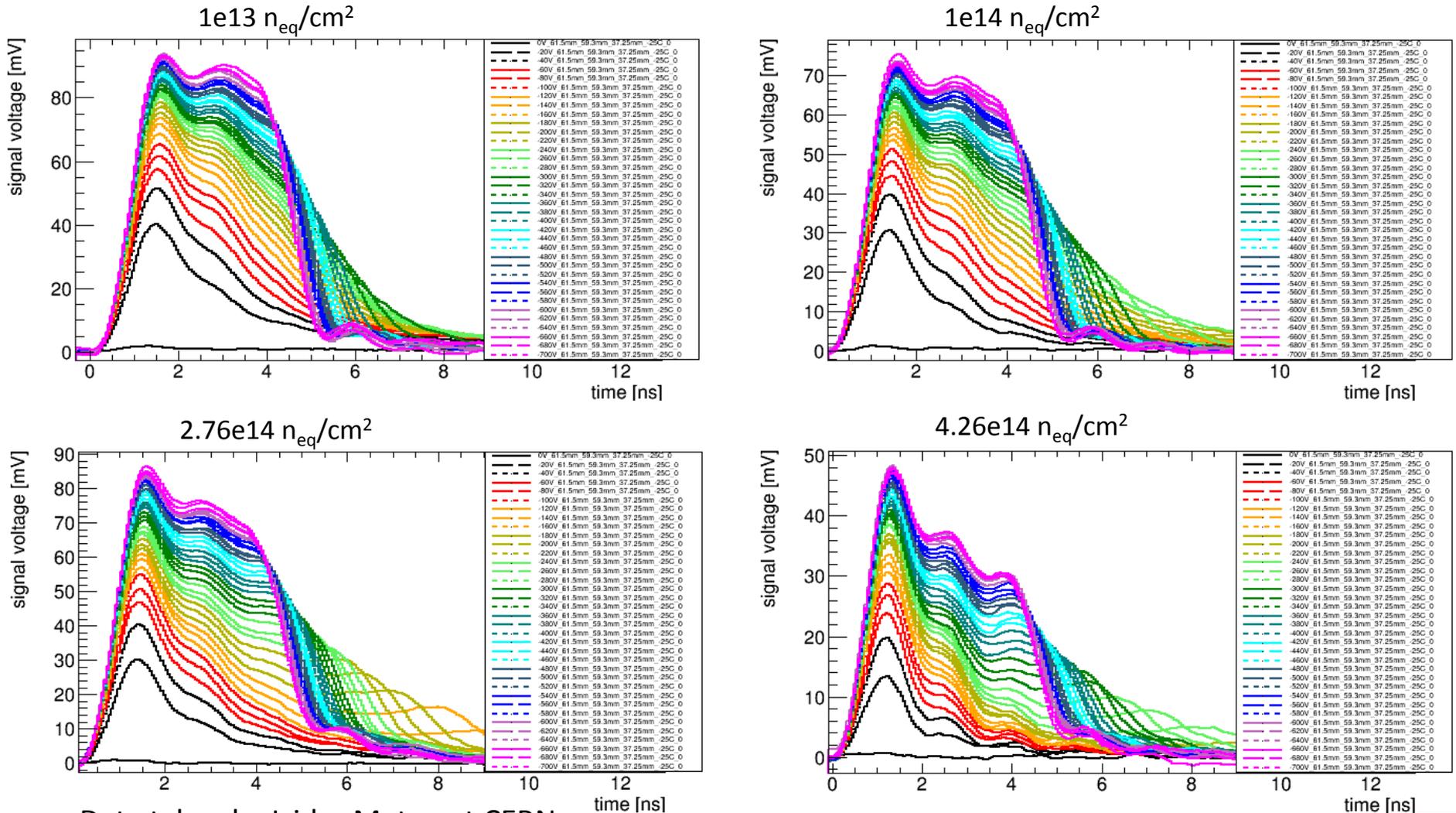
- Hints at possible SCSJ or strong double junction forming between  $1e14 \text{ n}_{eq}/\text{cm}^2$  and  $2.76e14 \text{ n}_{eq}/\text{cm}^2$



# 300 MeV Pion samples Red Laser comparison (electrons)



- No suggestion at SCSI from electron drift, rather seems to hint at a double junction



Data taken by Isidre Mateu at CERN

# Conclusion



- n-in-n MCz still puzzling
- 70 MeV protons cause SCSJ (like DOFZ, like reactor neutrons and 24 MeV protons in n-in-n MCz)
- 200 MeV pions looked somewhat ambiguous in literature
- 300 MeV pions looked even more ambiguous in our measurements:
  - red laser TCT data indicate SCSJ or at least formation of a strong double junction
  - IR laser TCT data suffers from amplifier saturation, but indicates rather no SCSJ
- Outlook:
  - CV measurements on 300 MeV pion-irradiated diodes
  - annealing study
  - add more irradiations in relevant energy region:
    - slow down 800 MeV protons at LANCSE or pions at PSI?
    - more additive studies?

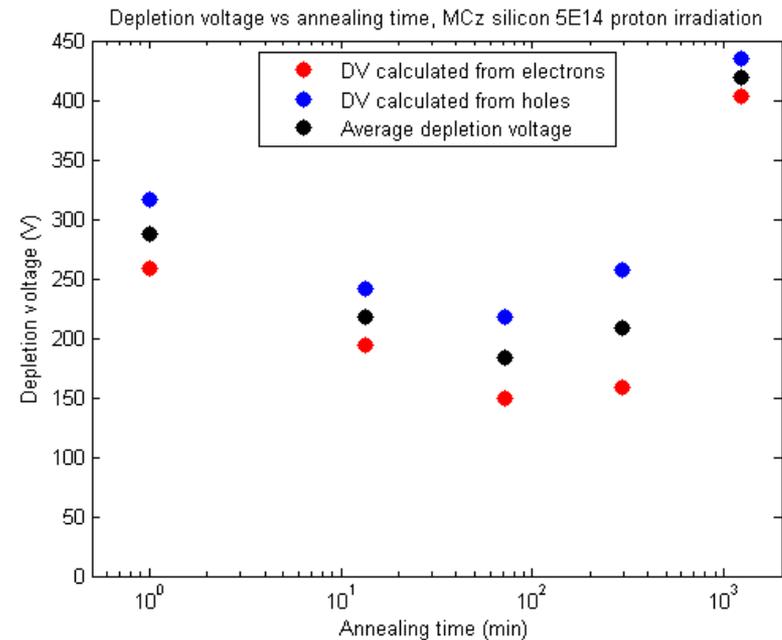
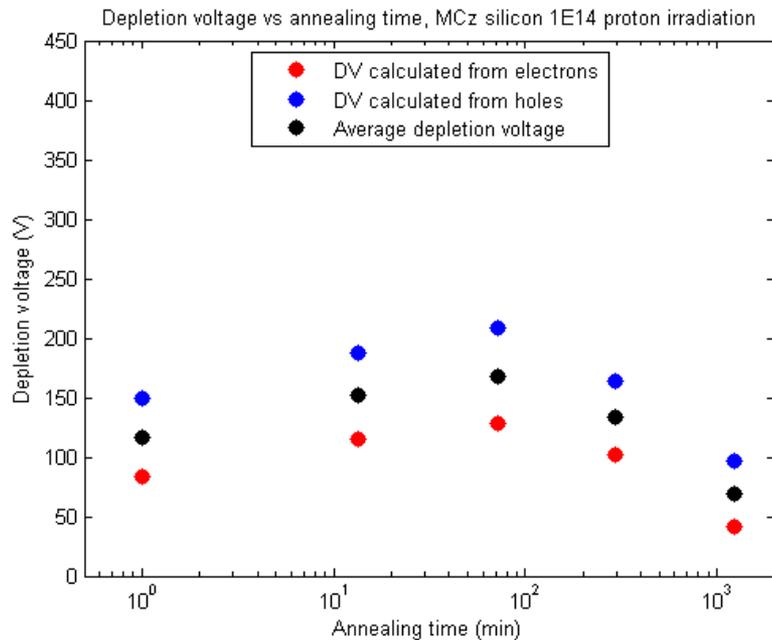
# Backup - 70 MeV Proton samples

## Annealing study



- Annealing done at 60° C
- After 1e14:
  - Initially reverse followed by beneficial annealing
- After 5e14:
  - Initially beneficial annealing
  - After approx. 70 min at 60° C reverse annealing is dominating
- Analogous to DOFZ -> no compensation

Annealing step	Time in oven (min)	Compensated time (min)	Total annealing time (min)
1	20	13.5	13.5
2	70	58	71.5
3	250	222	293.5
4	988	931.5	1225

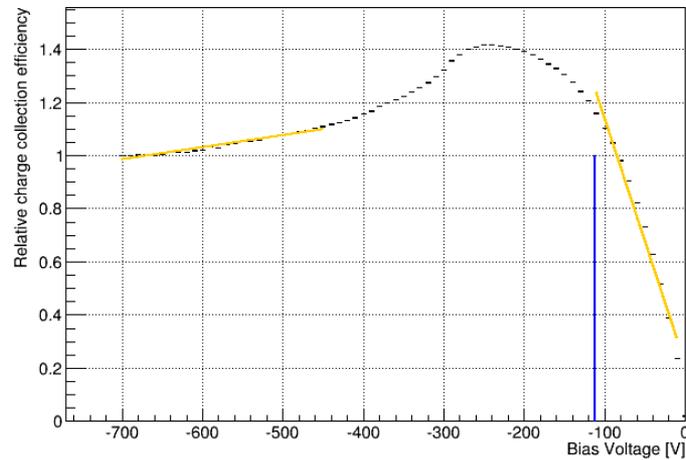


# Backup - 300 MeV pion samples CCE plots



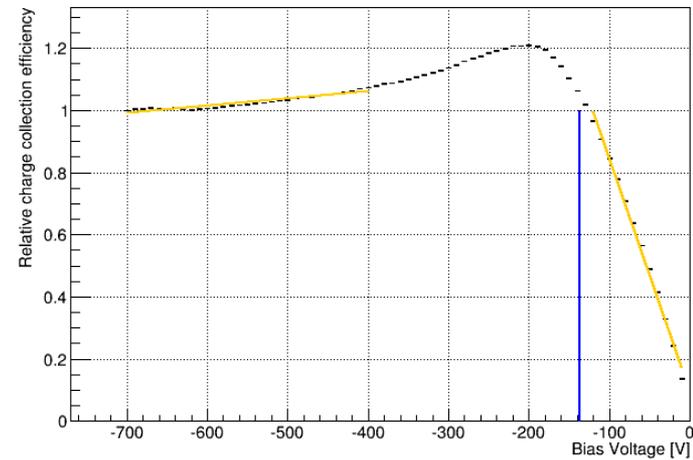
$1e13 \text{ n}_{\text{eq}}/\text{cm}^2$

022913\_CCM\_CCE\_vs.\_Bias



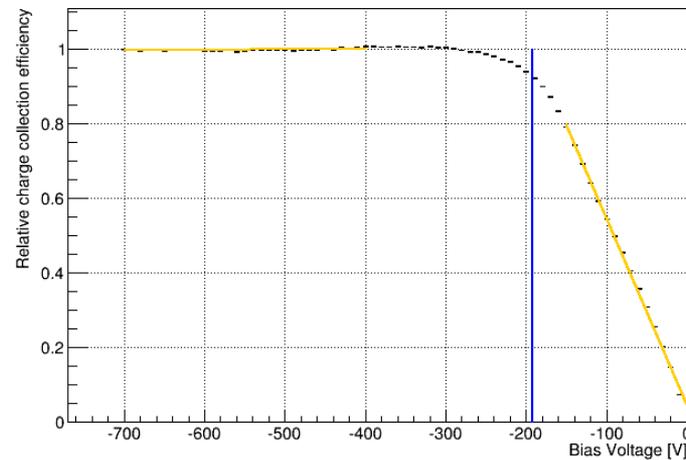
$1e14 \text{ n}_{\text{eq}}/\text{cm}^2$

022908\_CCM\_CCE\_vs.\_Bias



$2.76e14 \text{ n}_{\text{eq}}/\text{cm}^2$

022906\_CCM\_CCE\_vs.\_Bias



$4.26e14 \text{ n}_{\text{eq}}/\text{cm}^2$

022902\_CCE\_vs.\_Bias

