TCT measurements of n-type MCz diodes after irradiation with 70 MeV protons and 300 MeV pions

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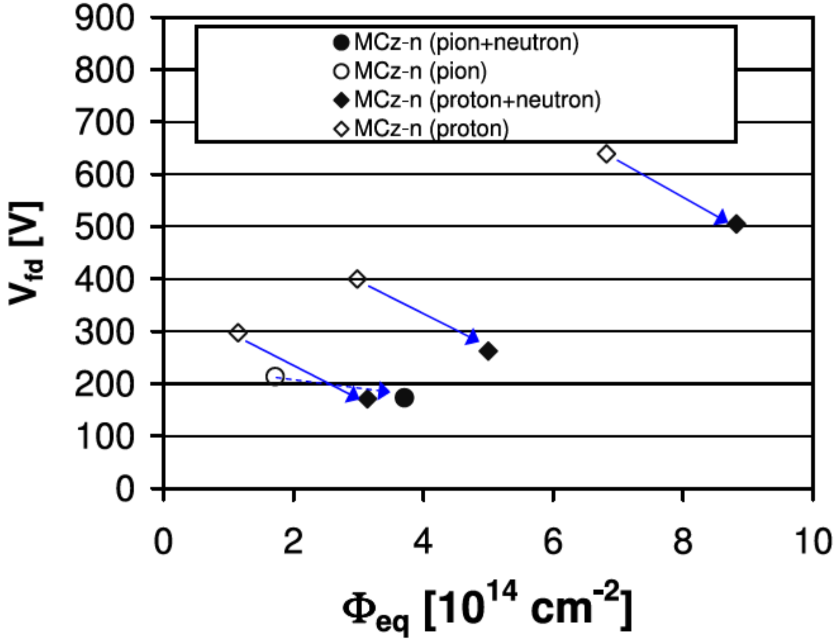
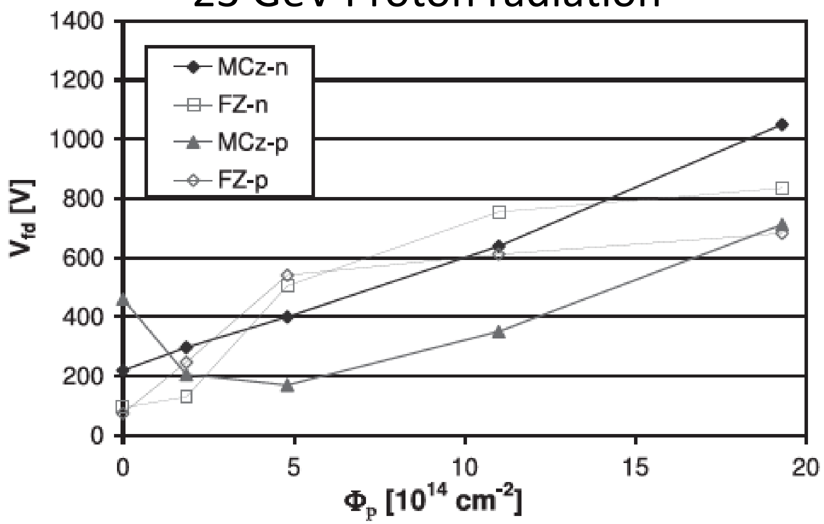
Background and motivation

N-in-N MCz detectors show peculiar properties:

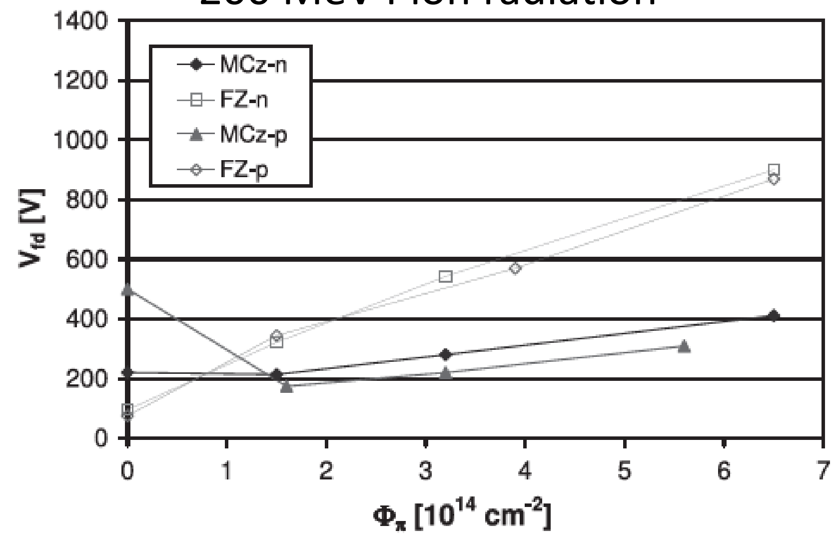
- No space charge sign inversion for 23 GeV protons
- Relatively stable V_{fd} for 200 MeV pions
- Additive space charge characteristics might enable the usage of cancelling effects to keep V_{fd} low/stable
  - Optimal N_{eff} stability at 2 parts proton and 1 part neutron radiation. Potential compensation of Neff 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



23 GeV Proton radiation

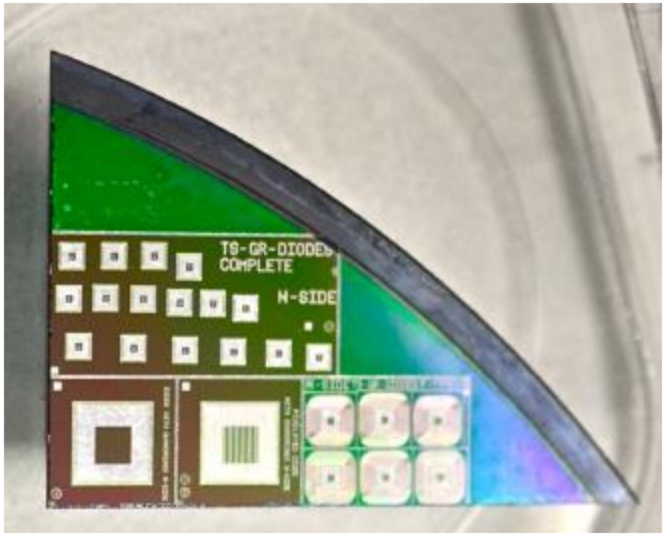


200 MeV Pion radiation

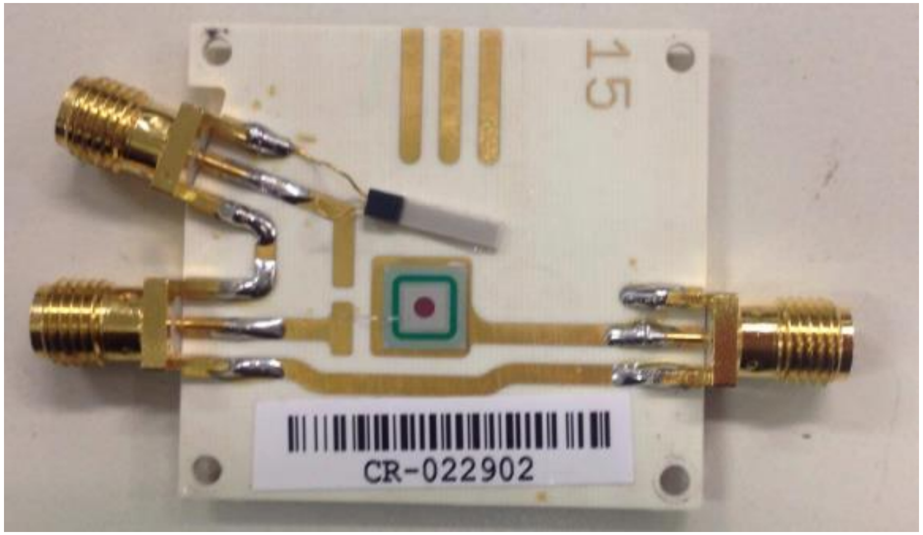


Background and motivation II

- 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



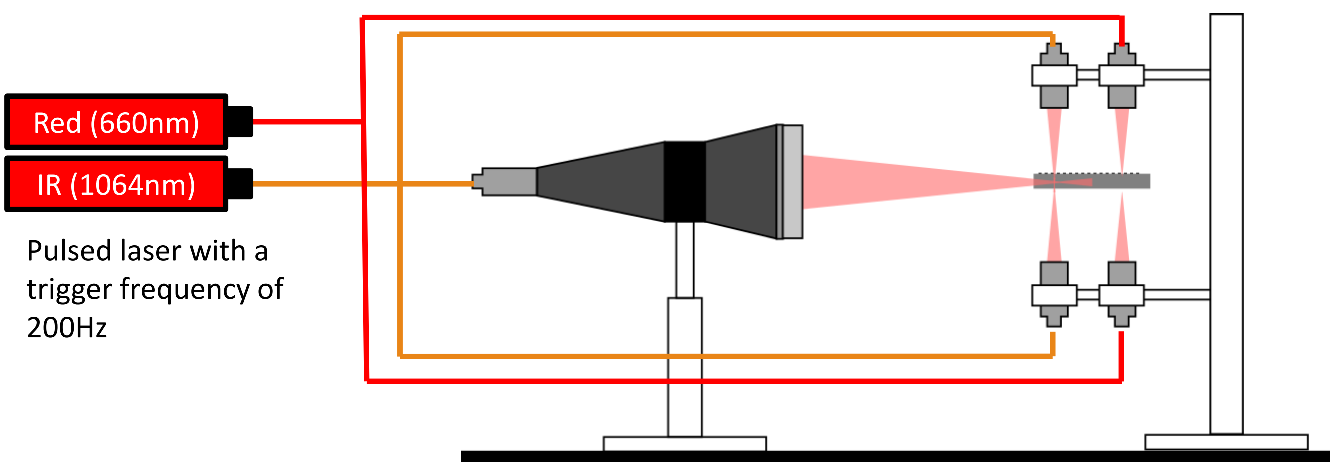
70 MeV proton samples



300 MeV pion samples

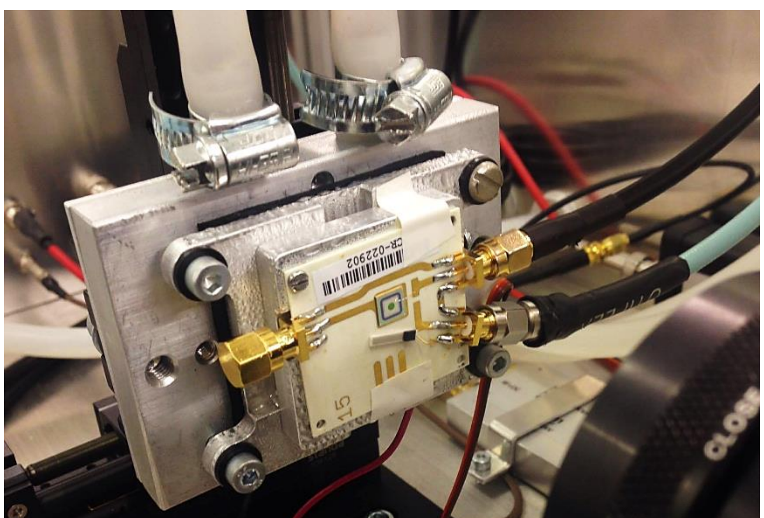
TCT+ setup at CERN

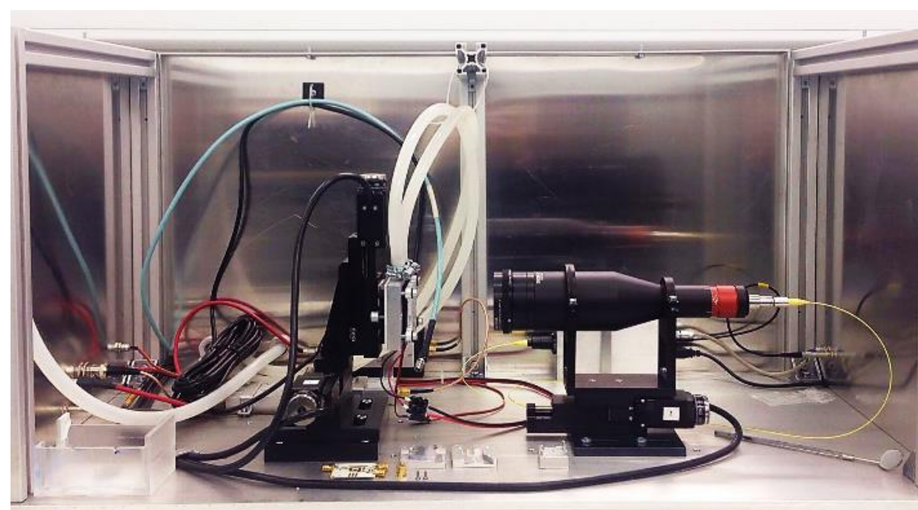
- Red Laser illumination possible from top and bottom side of DUT
- 2.5 GHz Agilent Scope
- Flushing with dry air
- Computer controlled peltier cooling down to -20° C
- Bias voltage up to 1000V



Particulars TCT setup at Lancaster University

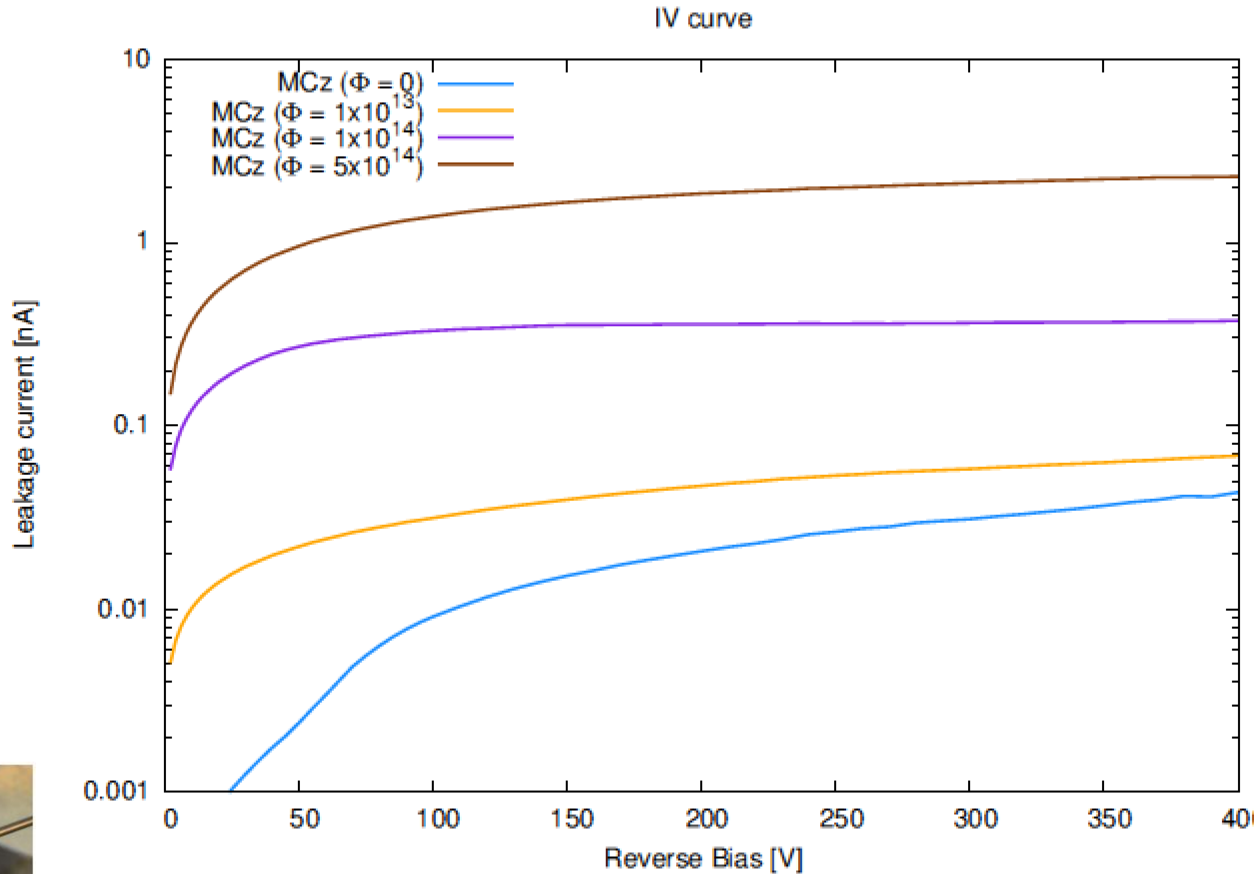
- IR pulsed laser
  - 20 kHz
  - ≤ ns pulse length
- Adjusted to CERN's PCB
- 2.5 GHz Tektronix DPO
- Nitrogen for flushing
- Peltier for cooling down to -20^{o} C
- Keithely 2410 for bias voltage up to 1100V

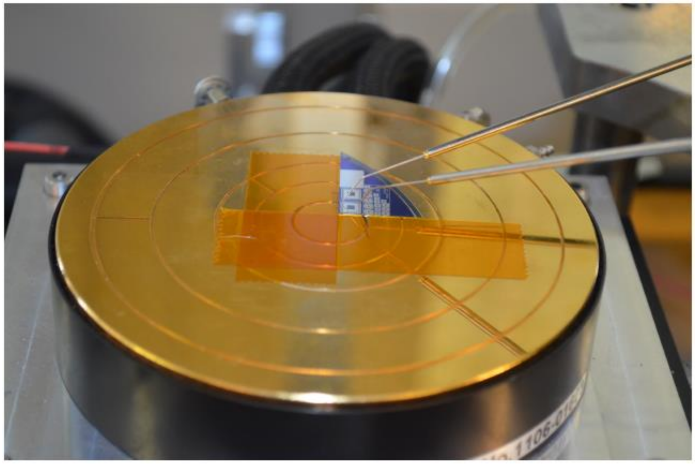




70 MeV Proton samples IV curve

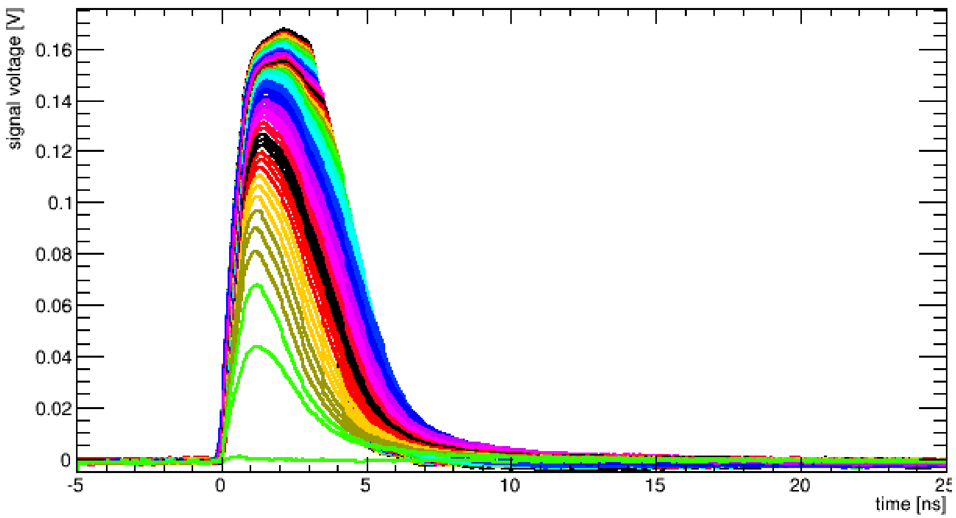
- IV measurements taken by Rebecca Carney with IV/CV measurement setup at CERN
- Clearly increasing leakage current with fluence, as to be expected



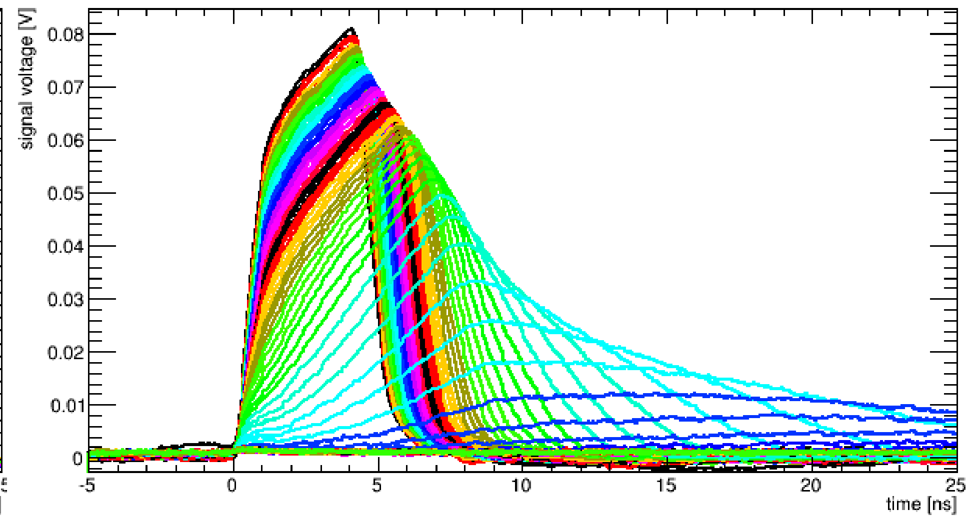


70 MeV Proton samples Waveforms

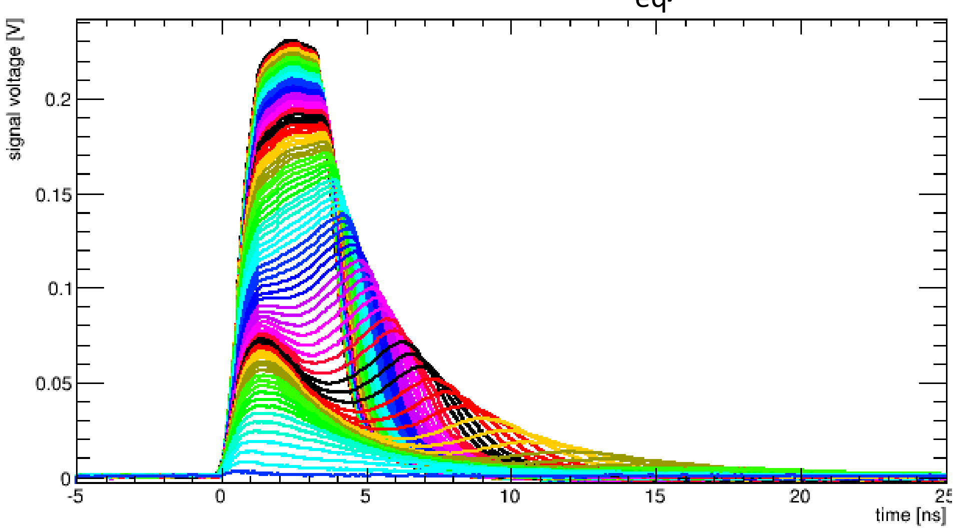
Electrons – 1e13 n_{eq}/cm^2



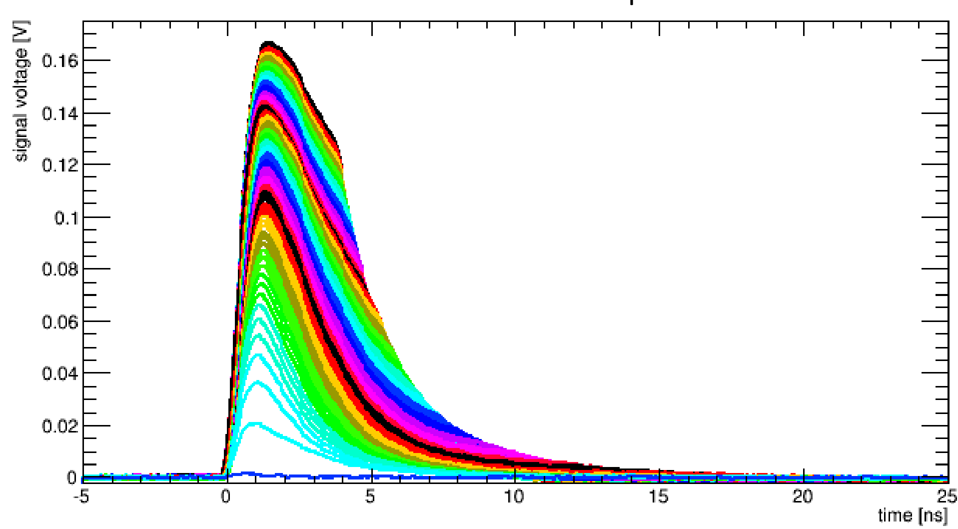
Holes– 1e13 n_{eq}/cm^2



Electrons – 5e14 n_{eq}/cm^2

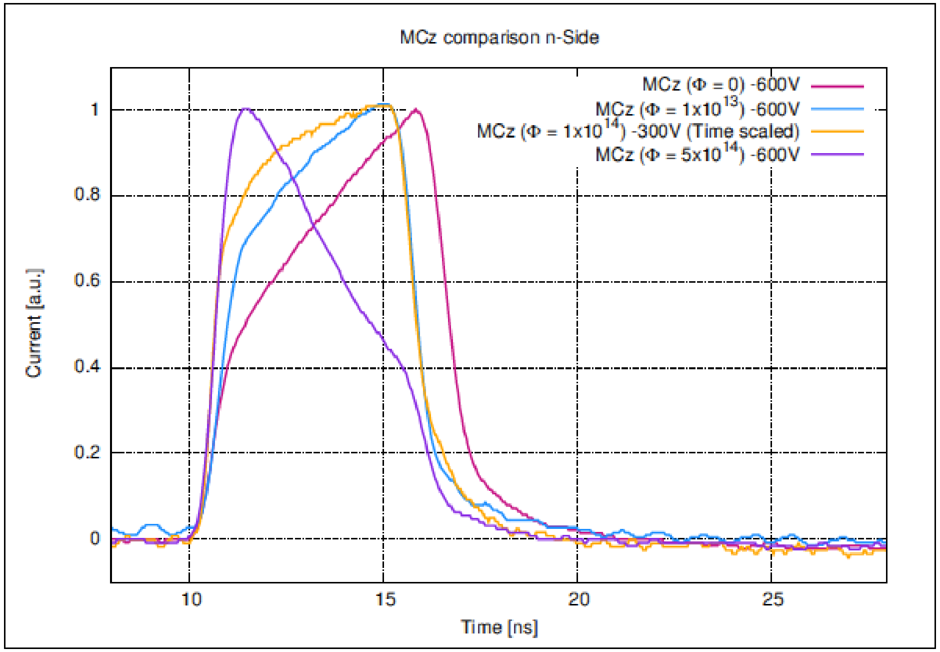


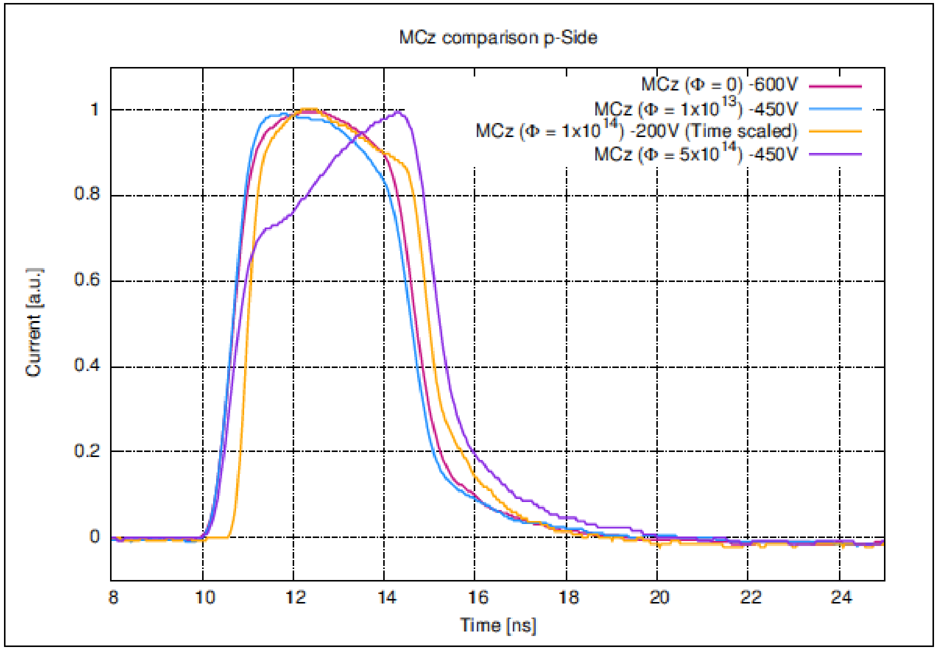
Holes– 5e14 n_{eq}/cm^2



70 MeV Proton samples Waveforms

- Waveforms highlight summarized below
- Both n-side and p-side show clearly shows a gradient sign change for the 5e14 n_{eq}/cm2 sample.
- Most likely suggests SCSI

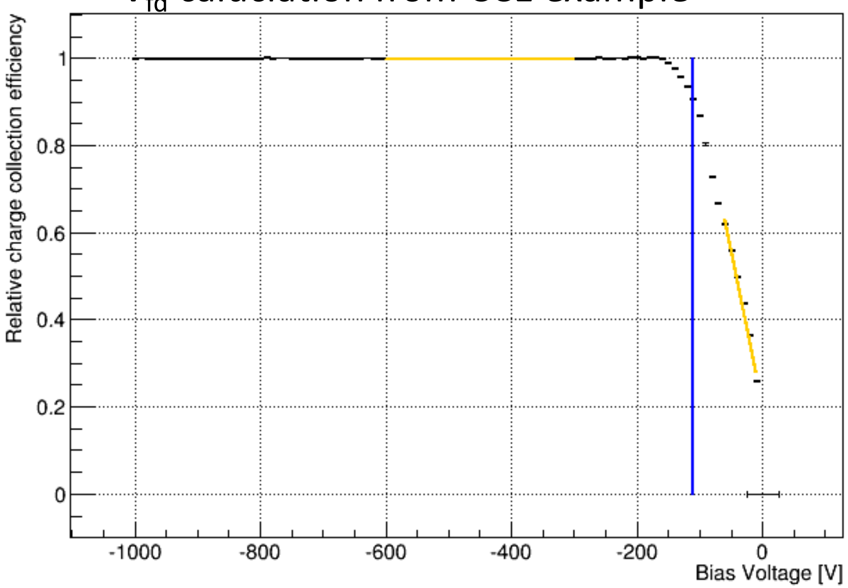


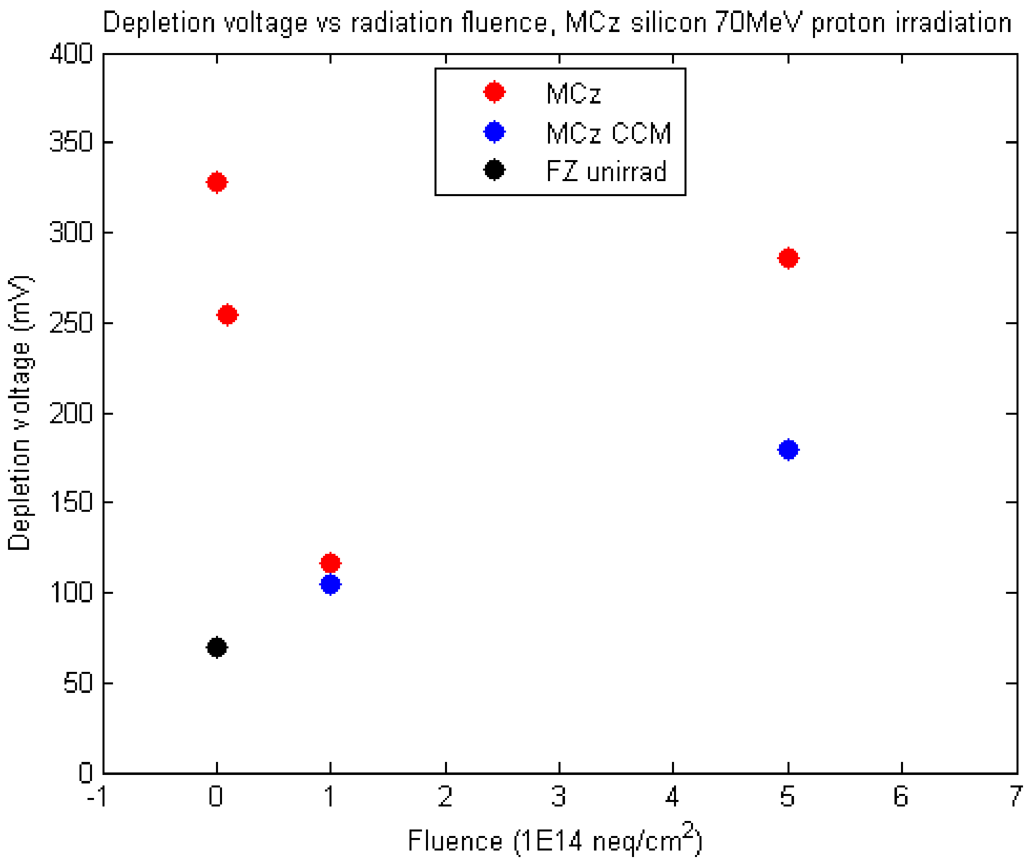


70 MeV Proton samples Depletion voltage

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

V_{fd} caluclation from CCE example

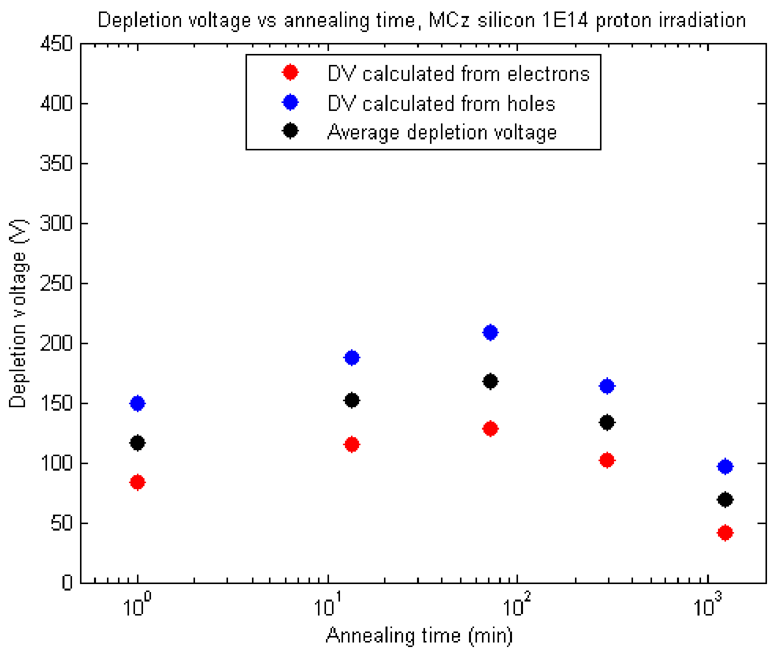


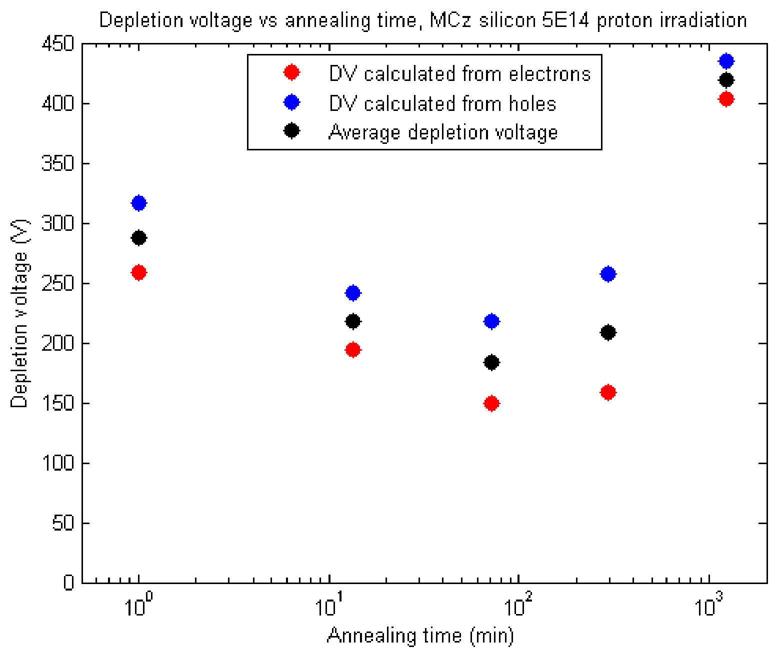


70 MeV Proton samples Annealing study

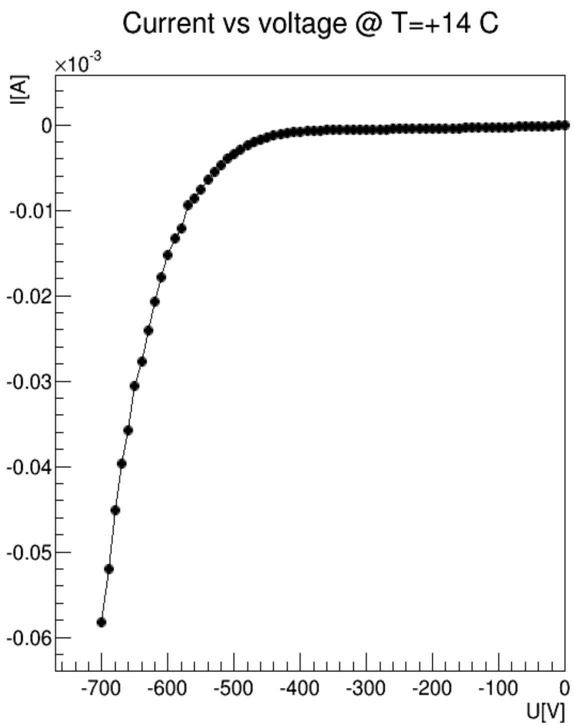
- Annealing done at 60° C
- After 1e14:
  - Initially reverse followed by beneficial annealing
- After 5e14:
  - Initially beneficial annealing
  - After approx. 70 min at 60° C reverse annealing is dominating
- <u>Analogous to DOFZ -> no compensation</u>

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

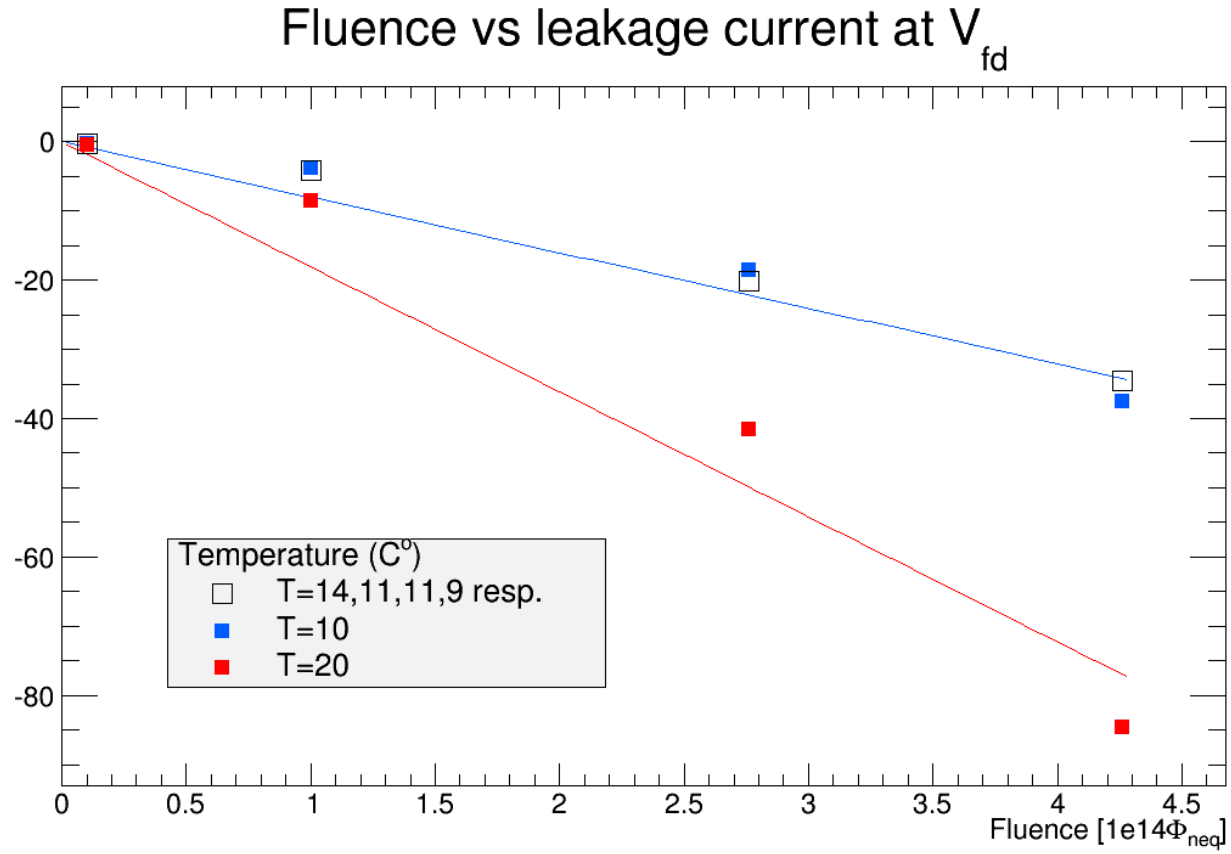




300 MeV pion samples
IV curves



1e13 MeV sample

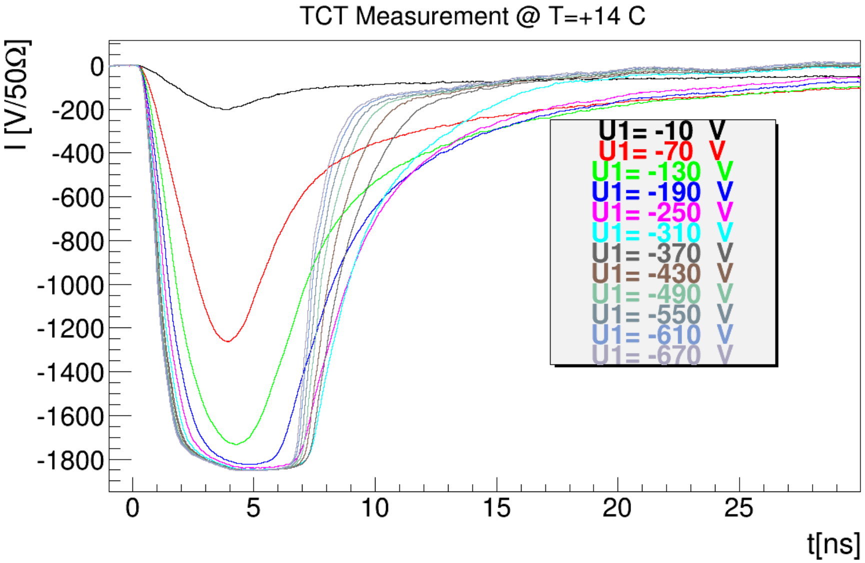


- V_{fd} values used from results with IR laser

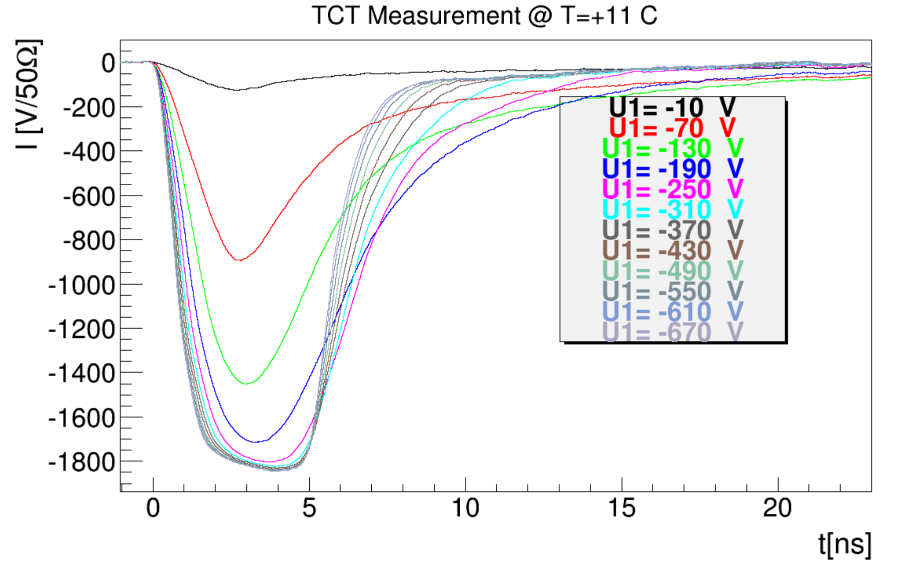
- $\frac{I_{L2}}{I_{L1}} \cong exp\left[\left(\frac{3}{\eta T} + \frac{E_G}{\eta T E_T}\right)\Delta T\right]$, ($\eta$=2, E_G=1.12eV, E_T=0.0259eV)
- I_{L1} is I_{leak} at temperature T.
- I_{L2} is I_{leak} at temperature T + ΔT.
- Used to calculate I_{leak} at different T

300 MeV pion samples Waveforms (IR)

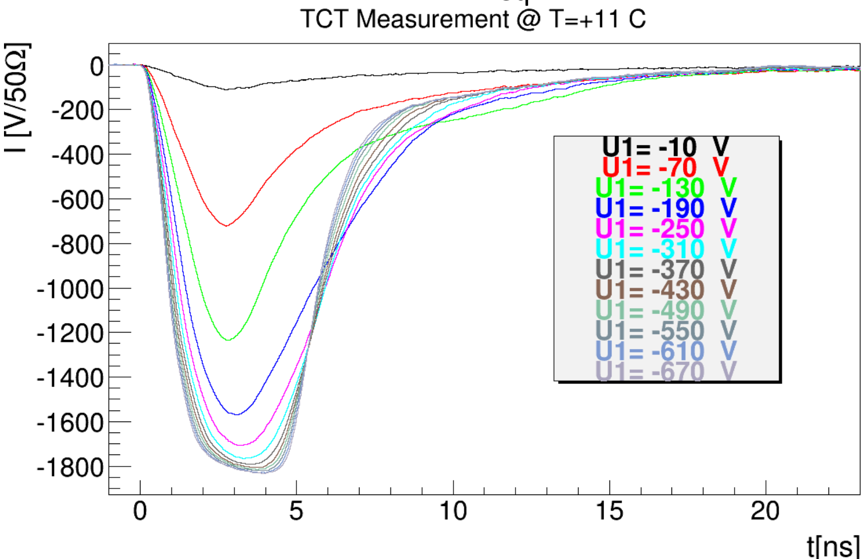
1e13 n_{eq}/cm^2



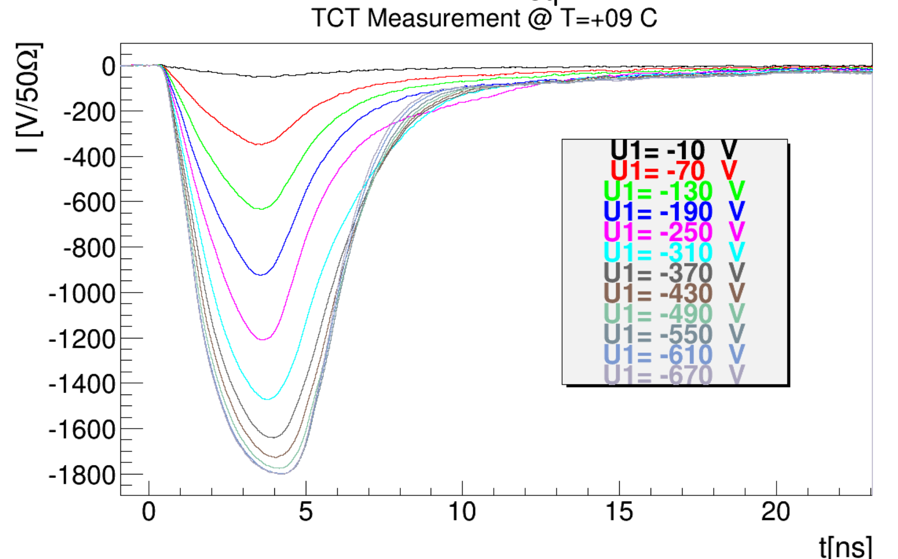
1e14 n_{eq}/cm^2



2.76e14 n_{eq}/cm^2

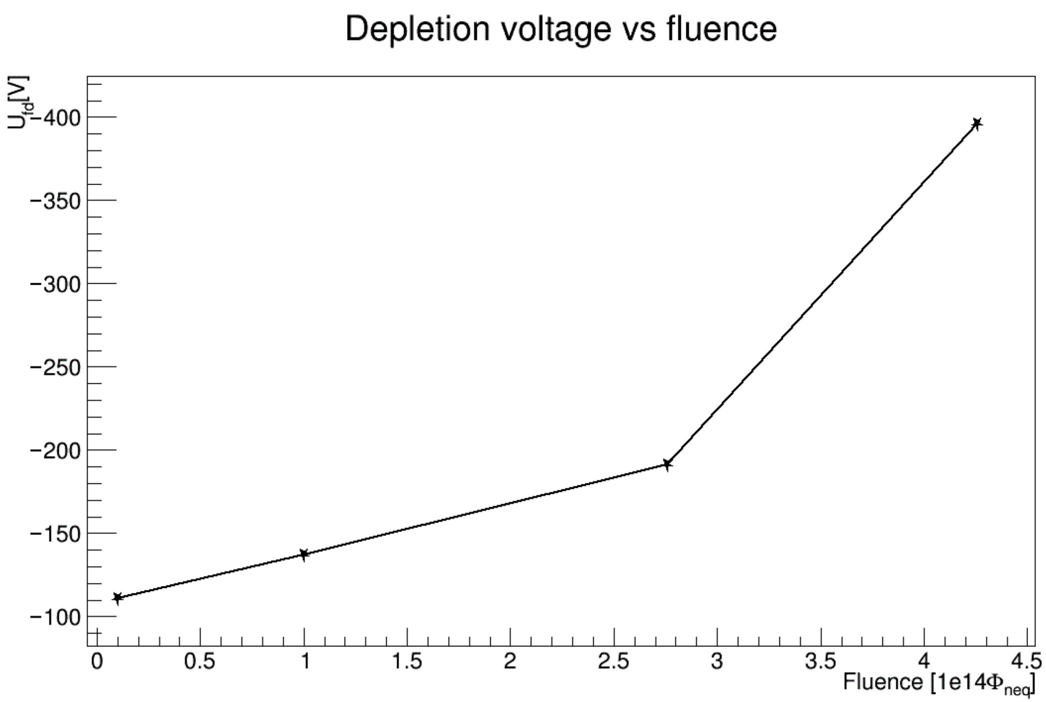


4.26e14 n_{eq}/cm^2

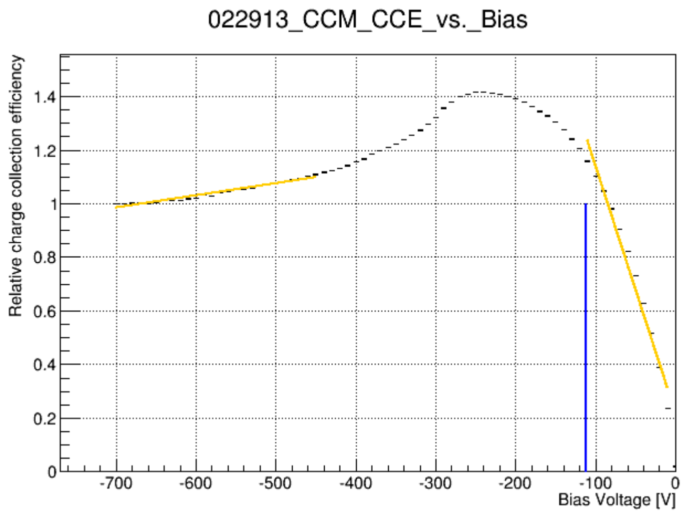


300 MeV pion samples CCE and V_{fd}

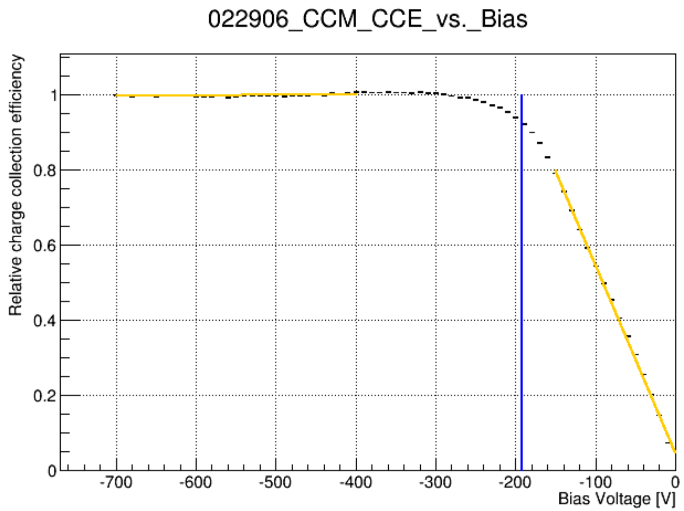
- Results hint at increasing N_{eff} with increasing fluence
- Systematically too low V_{fd} for two lowest fluences, due to overshoot.
- Unsure of overshoot origin (only seen in low fluences and unirradiated MCz)
  - Any ideas?



1e13 n_{eq}/cm^2



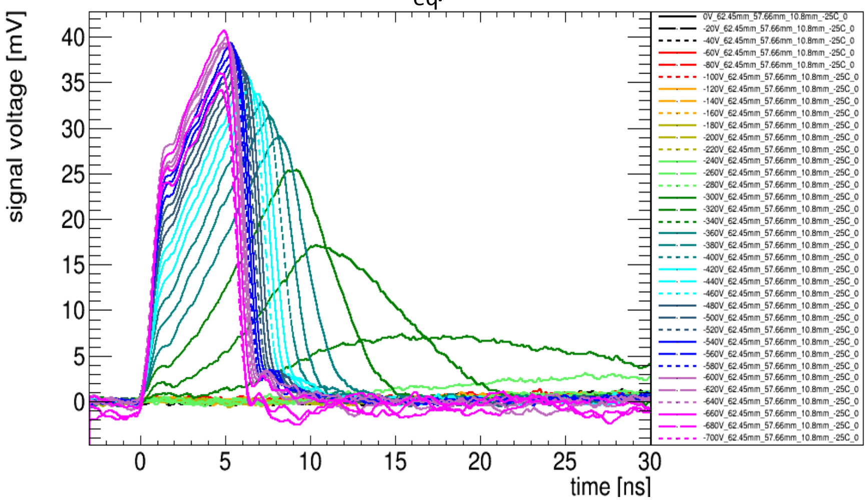
2.76e14 n_{eq}/cm^2



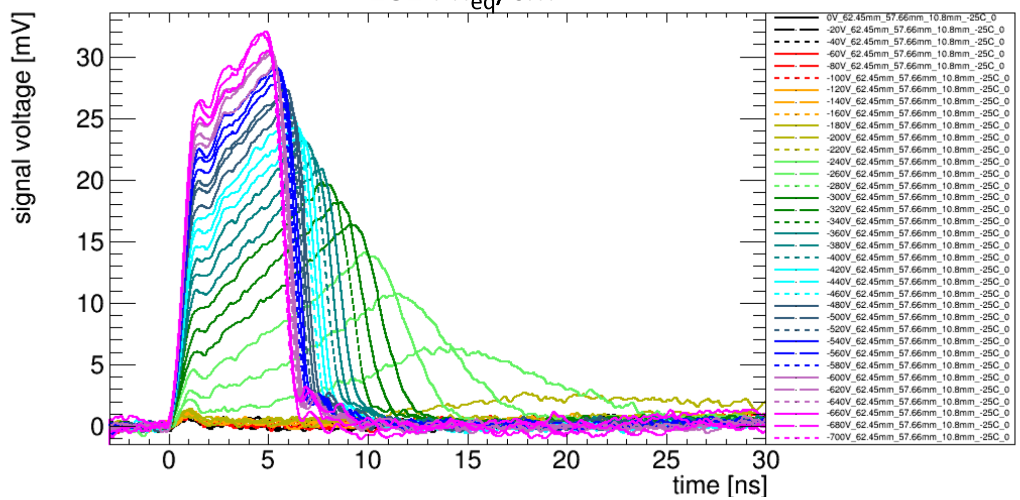
300 MeV Pion samples
Red Laser comparison (holes)

- Hints at possible SCSI or strong double junction forming between 1e14 n_{eq}/cm^2 and 2.76e14 n_{eq}/cm^2

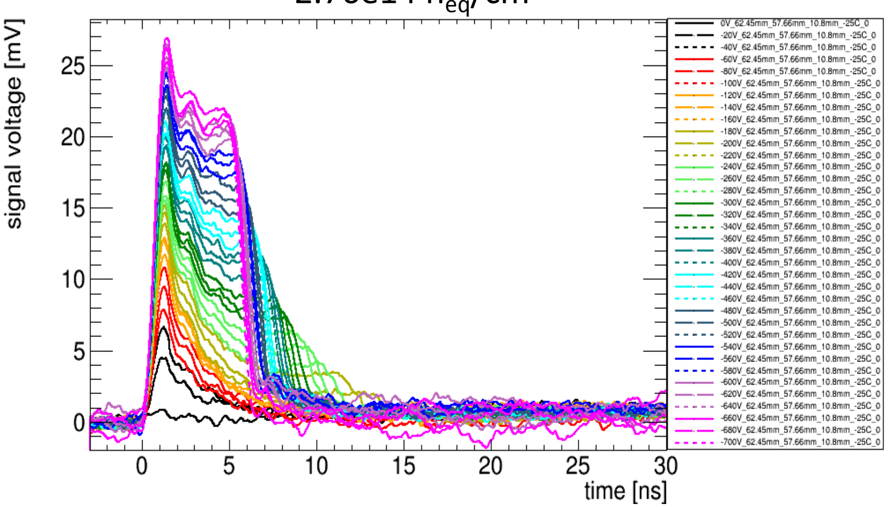
1e13 n_{eq}/cm^2



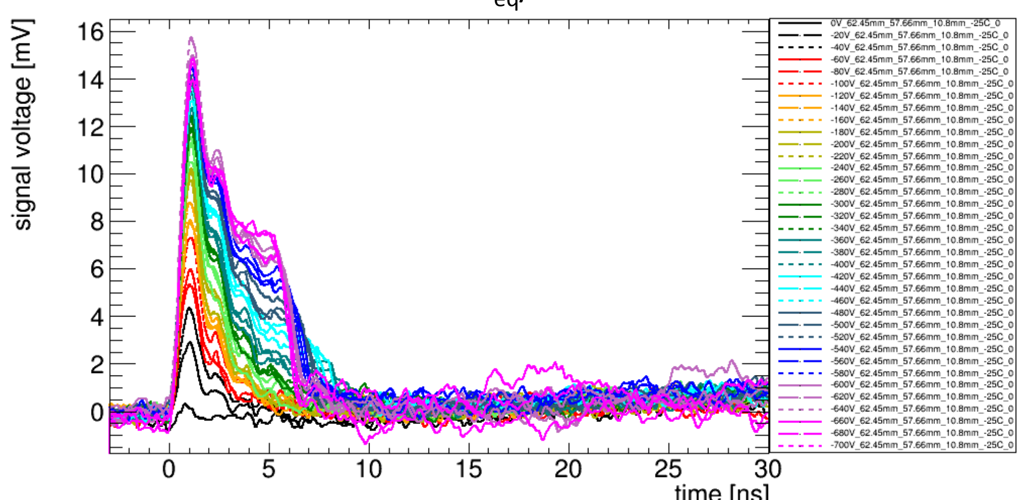
1e14 n_{eq}/cm^2



2.76e14 n_{eq}/cm^2



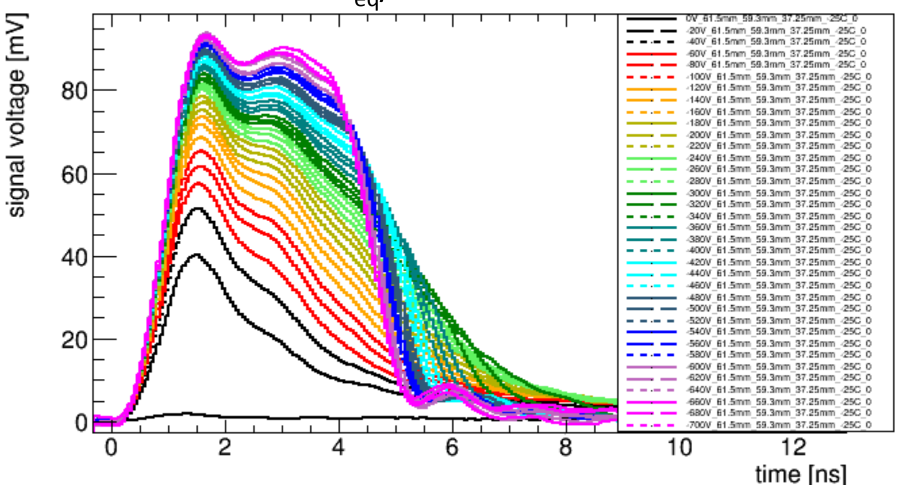
4.26e14 n_{eq}/cm^2



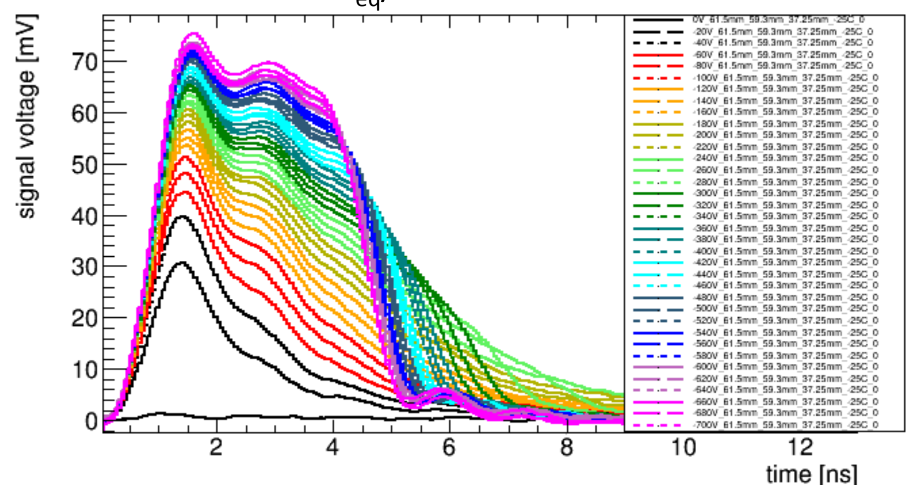
300 MeV Pion samples
Red Laser comparison (electrons)

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

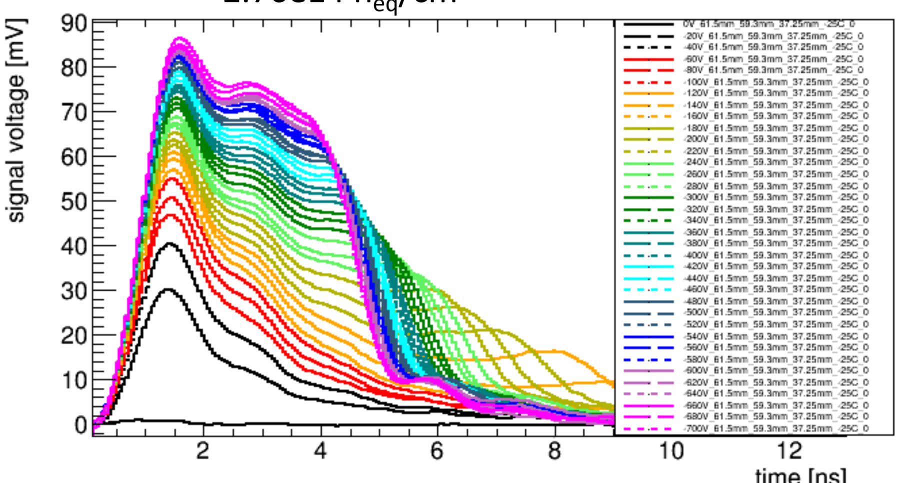
1e13 n_{eq}/cm^2



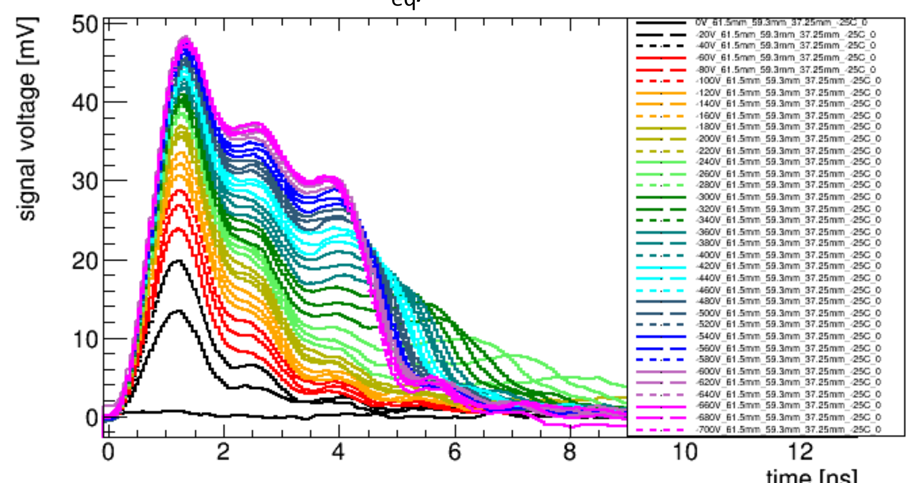
1e14 n_{eq}/cm^2



2.76e14 n_{eq}/cm^2



4.26e14 n_{eq}/cm^2



Data taken by Isidre Mateu at CERN

Conclusion

- n-in-n MCz still puzzling
- 70 MeV protons cause SCSI (like DOFZ, like reactor neutrons and 24 MeV protons in n-in-n MCz)
- 200 MeV pions looked somewhat ambigous in literature
- 300 MeV pions looked even more ambigous in our measurements:
  - red laser TCT data indicate SCSI or at least formation of a strong double junction
  - IR laser TCT data suffers from overshoot of slow moving charge (where from?) for low fluences, indicates rather no SCSI
- 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?