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edge-TCT results from AMS H18 HV-CMOS test chips irradiated with 800 MeV protons

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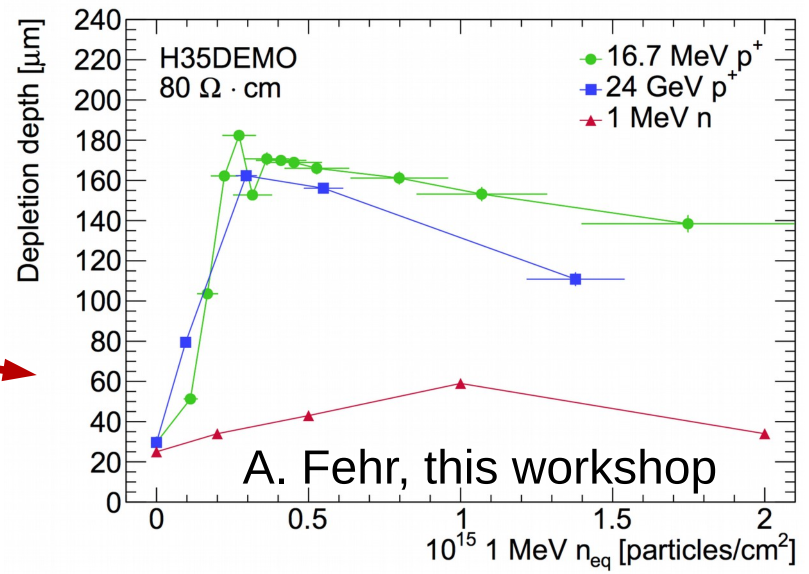
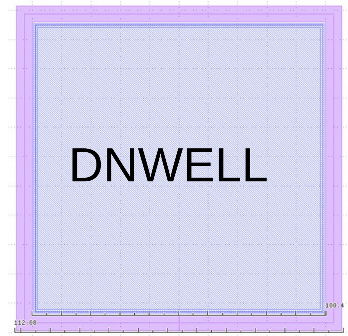
What is this presentation about?

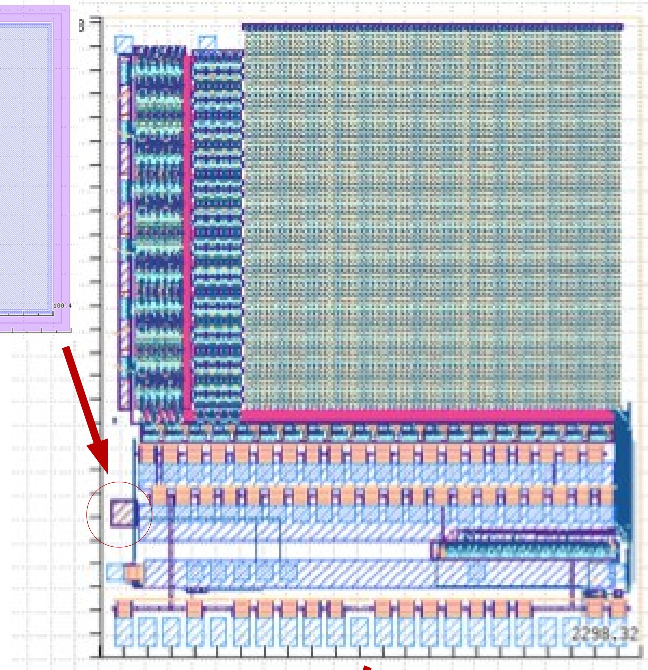
- Irradiation "habits": neutrons
  - In our community, we often irradiate with reactor neutrons as it is (thanks to our Ljubljana colleagues) convenient, fast and reliable
  - In the HL-LHC (pixel), however, we are expecting mainly charged hadrons of o(100 MeV) – even at the outermost pixel layer they are still dominating (>50%)
- CMOS foundry default substrates: 10-20 Ωcm
  - In recent years, it has been shown with several foundries that CMOS processes can be used to create radiation-tolerant drift-based monolithic sensors (DMAPS/HV-MAPS)
  - The standard substrates, which are accessible for prototyping at a very affordable price (~10 kEUR) via Multi-Project Wafer submissions (MPWs), are often low(er) resistive than we are used to – typically 10-20 Ωcm
  - These substrates have been found to behave different from the high-resistive FZ substrates we are used to – strong acceptor removal has been observed, leading to an increasing depletion depth
  - Neutrons and protons have quite different behaviour!

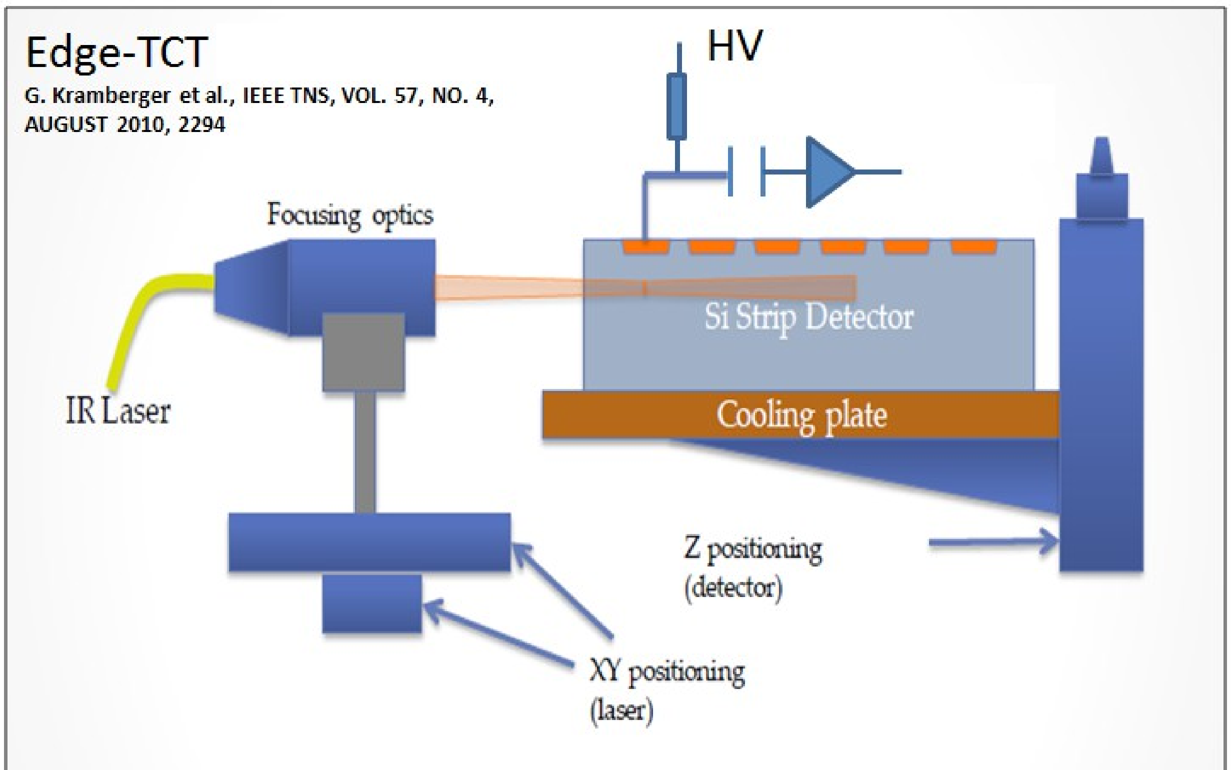


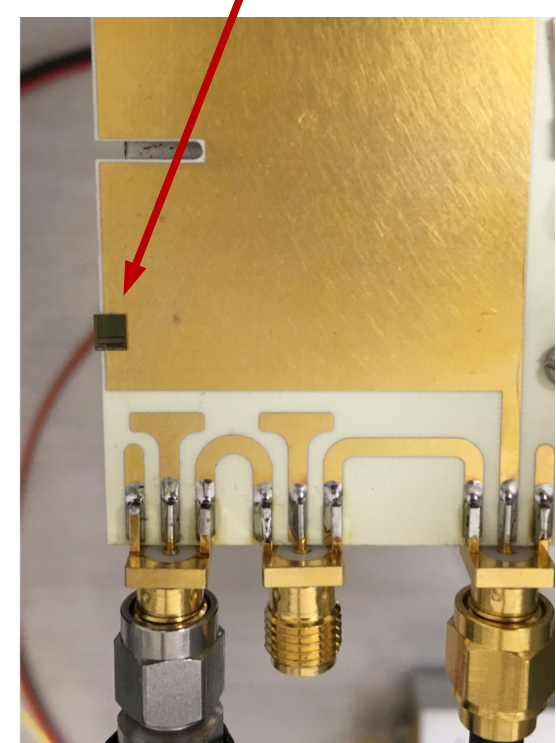
What did we do?

- Used ams H18 CCPDv3 HV-CMOS test chips from an MPW (I. Peric)
  - contains 100 µm x 100 µm passive diode, 10 Ωcm substrate
- Irradiated with 800 MeV protons at LANSCE (thanks to S. Seidel and M. Hoeferkamp!)
- Performed edge-TCT measurements to characterise depletion depth and signal



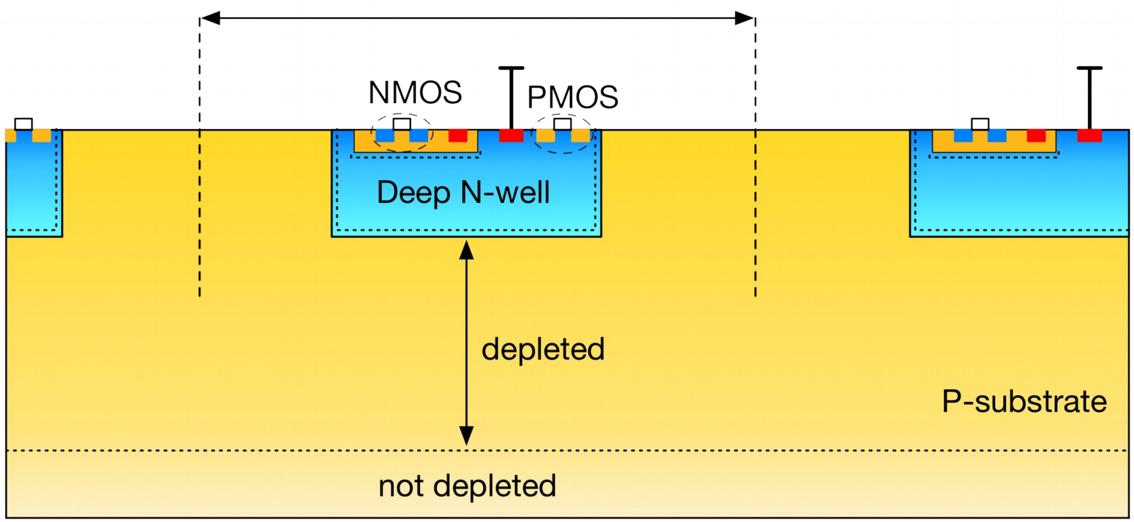






What did we do?

- Some more details:
  - the diode only utilises a deep N-well, but contains no logic
    - was placed close to the edge for eTCT and bulk characterisation



- 9 fluences from 2.1e13 to 1.3e16 n_{eq}/cm^3
- chip is thinned by the foundry to ~250 µm, but not backside processed
- chip backside is connected to the HV plane using conductive glue
  - this indeed establishes a contact – in spite of no processing, implant or metal
    - but low-resistive silicon bulk!
  - minor differences with/without top side biasing
  - might be an option for contacting, but beware of issues when approaching “full depletion”!

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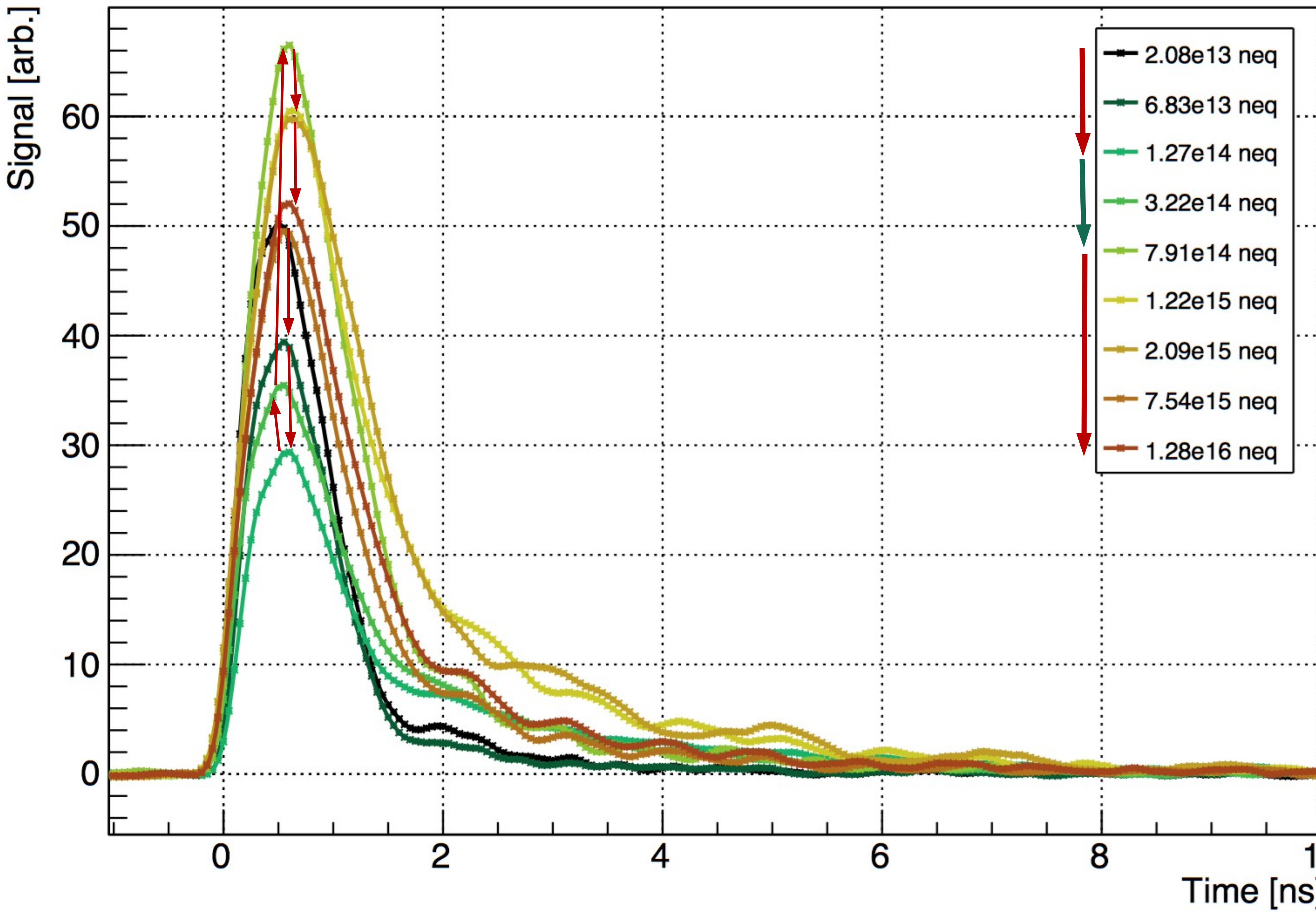
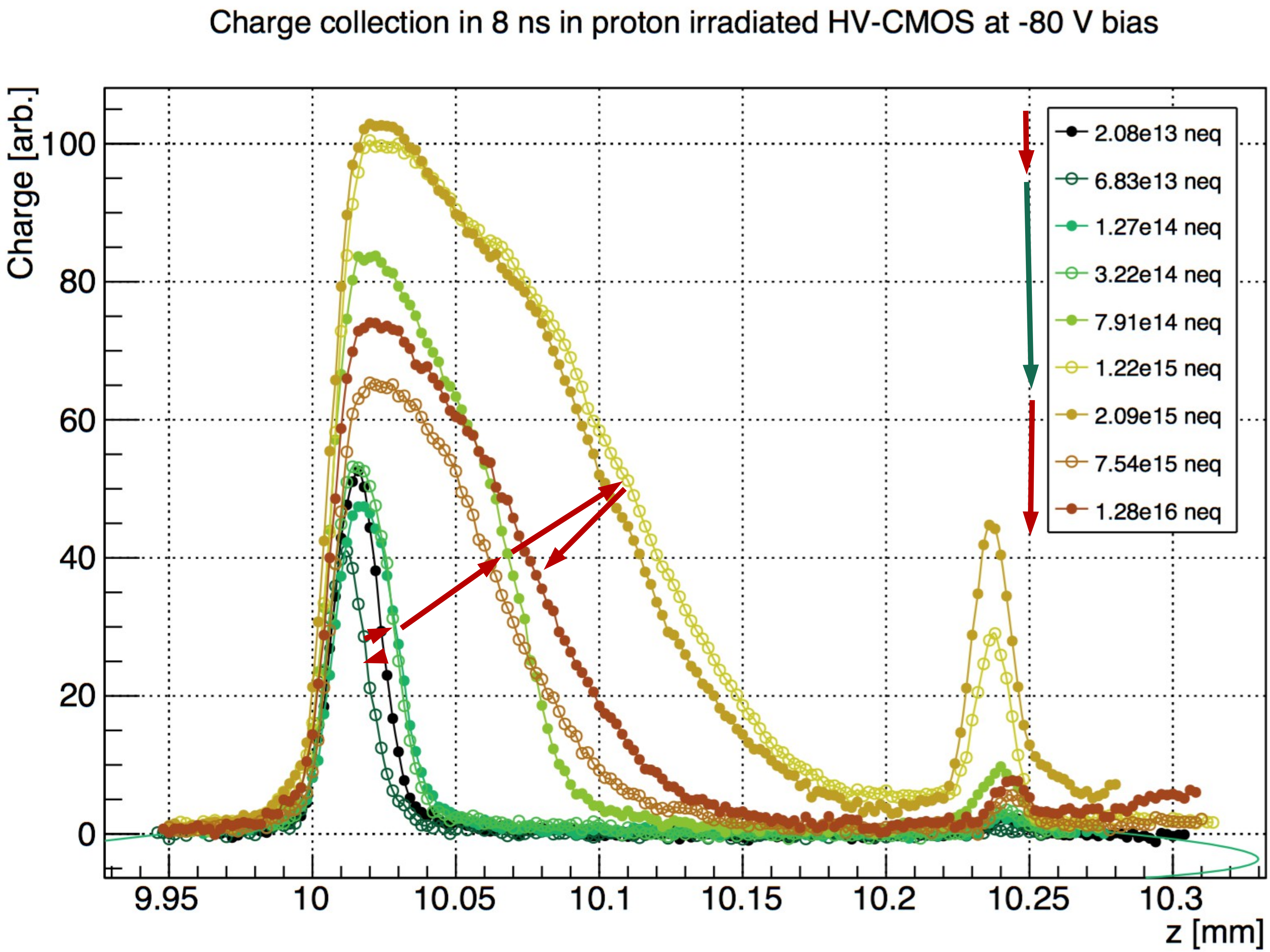
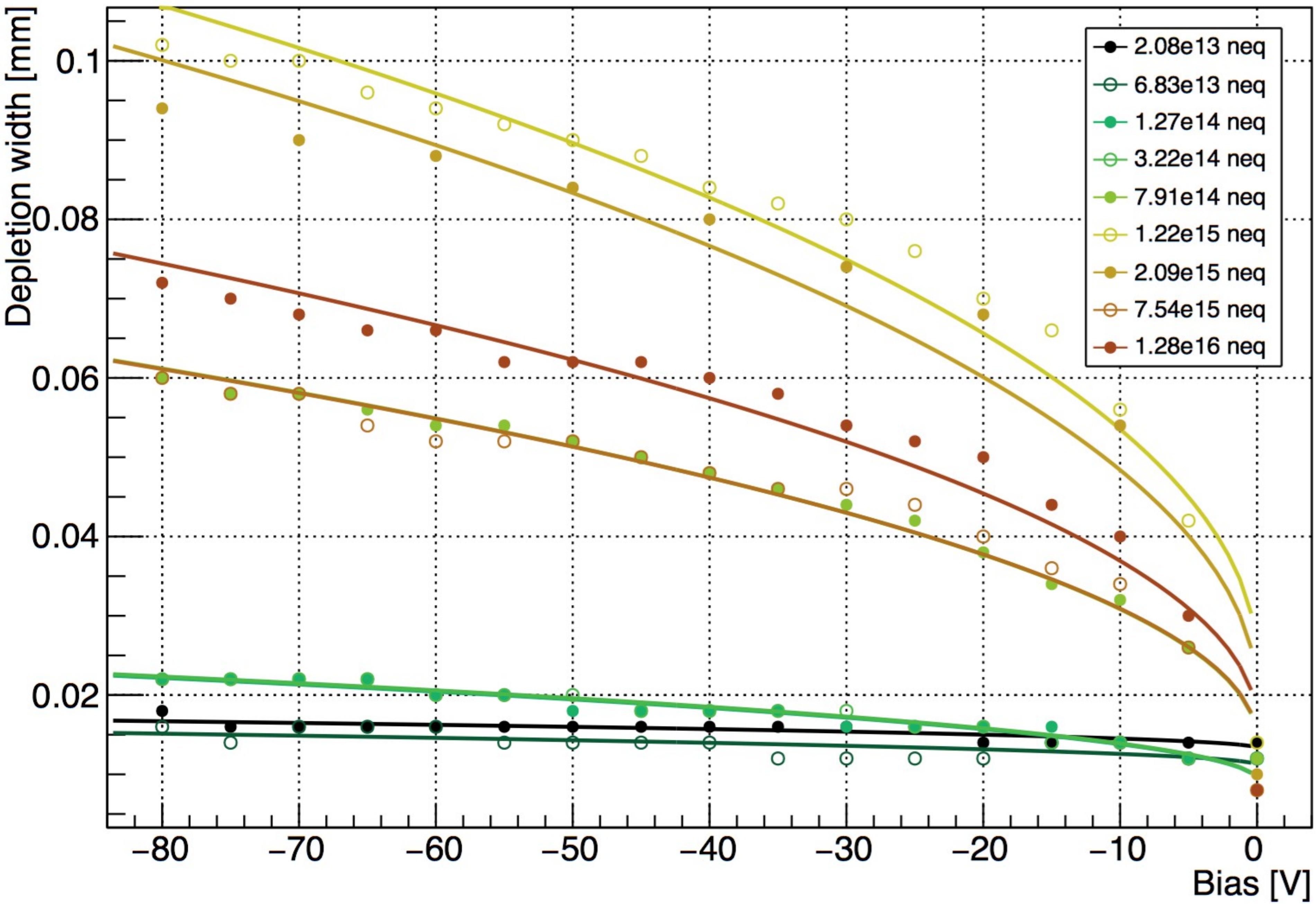
Waveforms – sidewall not polished!



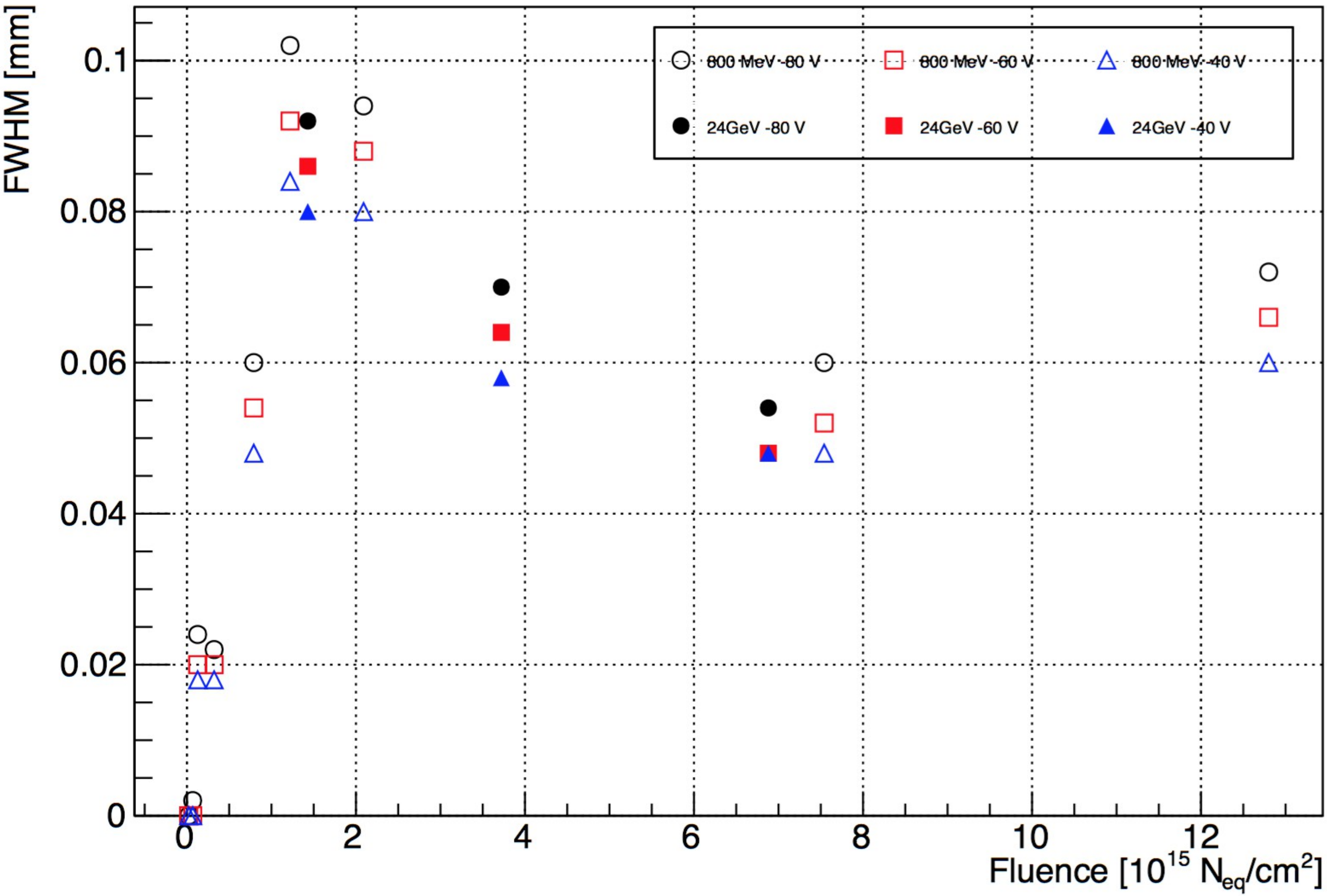
z-profiles


Charge collection in 8 ns in proton irradiated HV-CMOS at -80 V bias
Charge [arb.]
100
80
60
40
20
0
9.95
10
10.05
10.1
10.15
10.2
10.25
10.3
z [mm]
2.08e13 neq
6.83e13 neq
1.27e14 neq
3.22e14 neq
7.91e14 neq
1.22e15 neq
2.09e15 neq
7.54e15 neq
1.28e16 neq

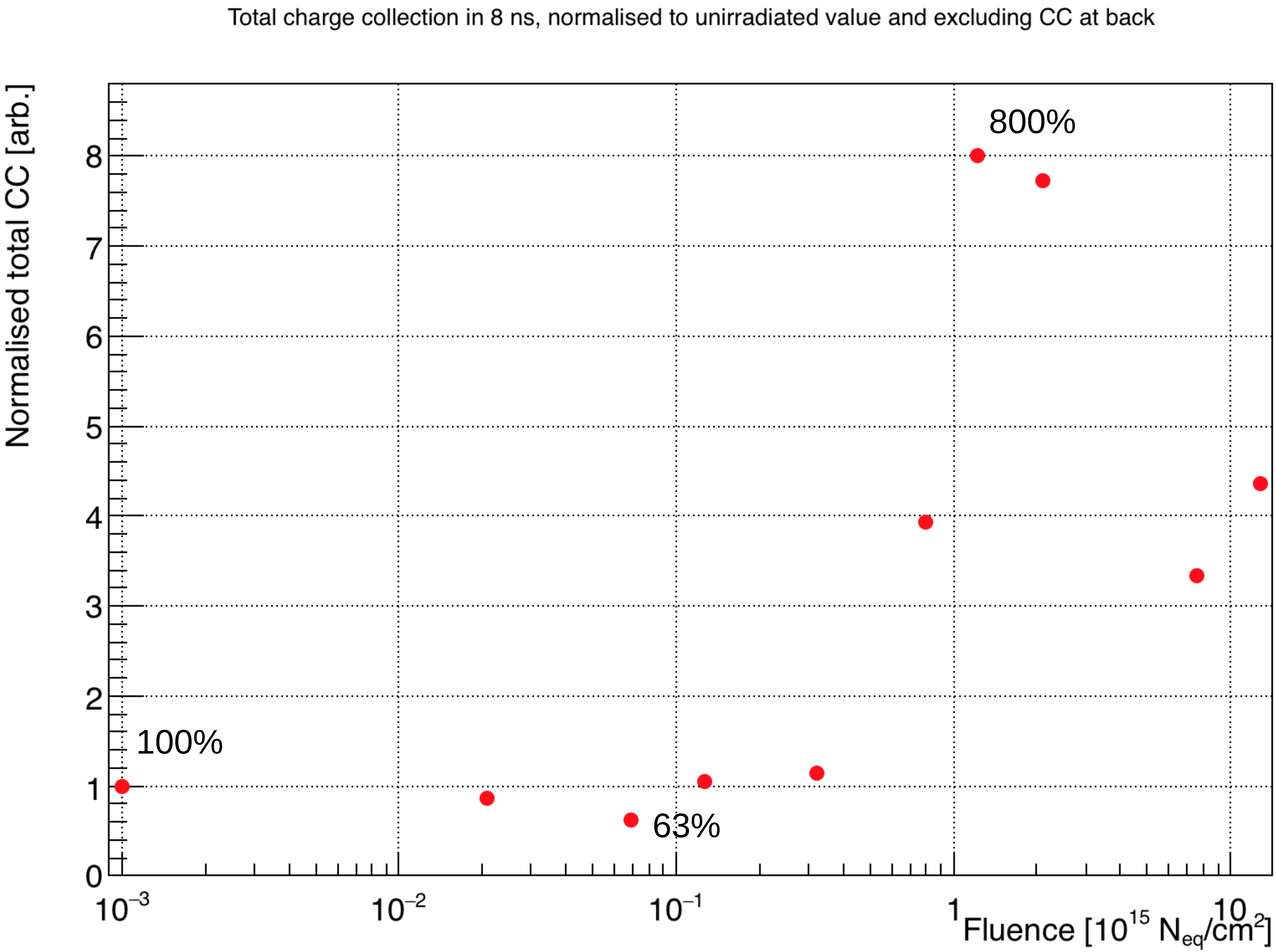
Depletion depth



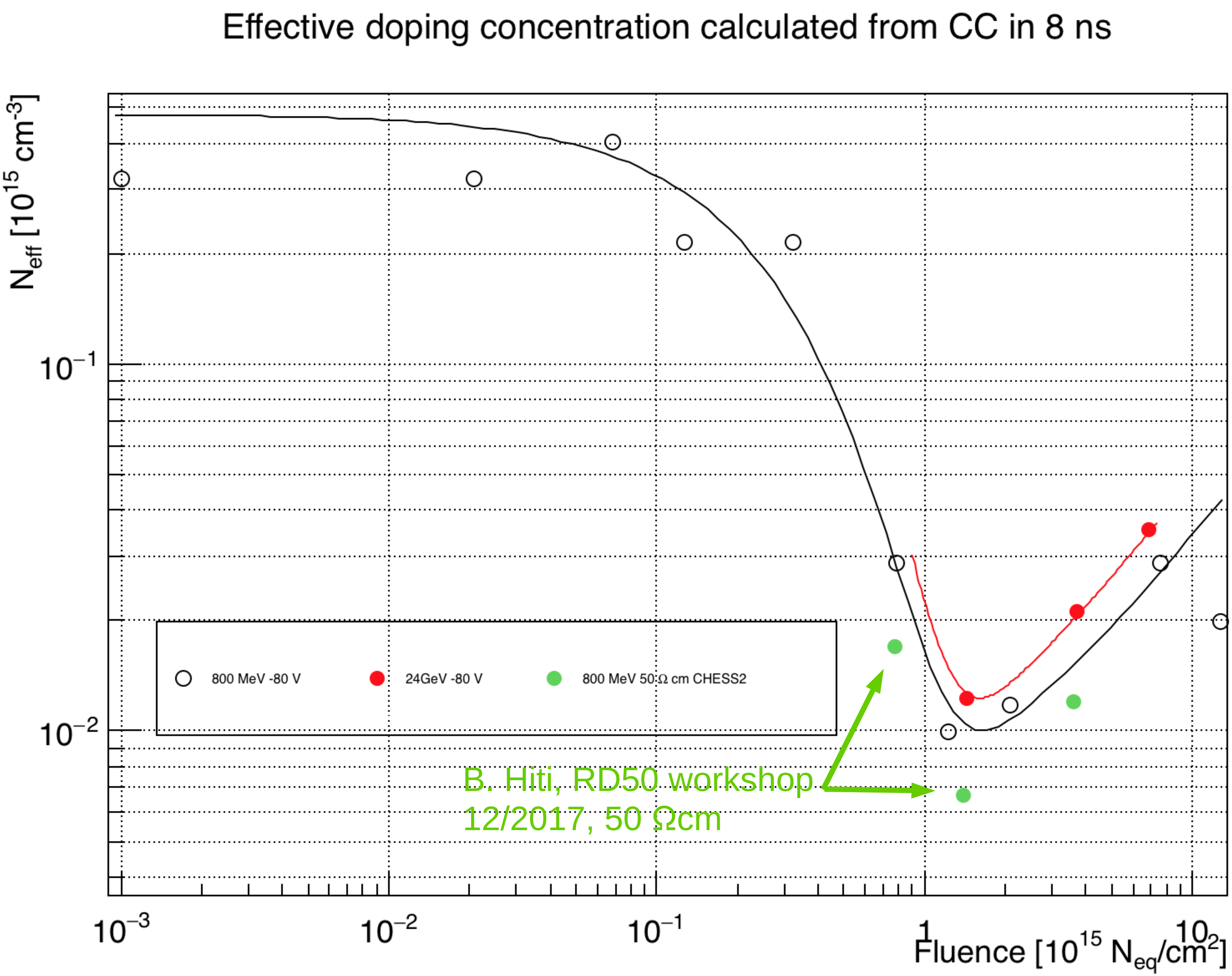
Depletion depth



Total collected charge (integral over z) vs. fluence

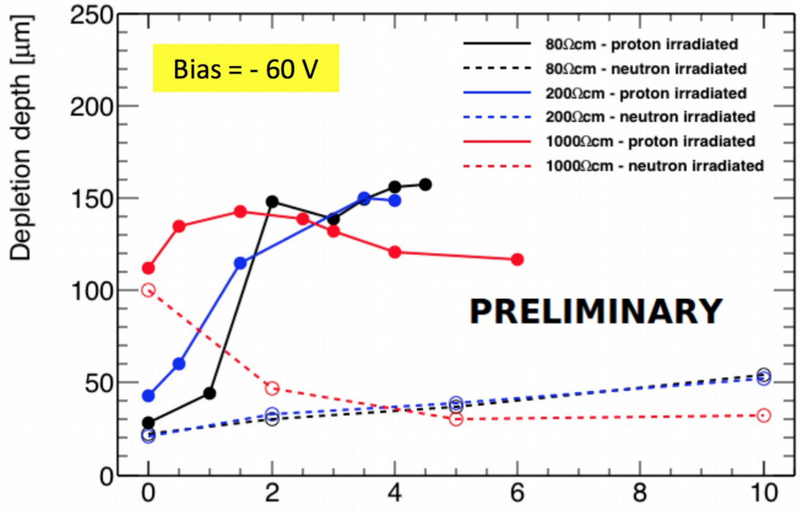


N_{eff} evolution



Conclusions and outlook

- Acceptor removal is much stronger with charged hadron irradiation
  - 800 MeV protons are closer to HL-LHC case than 24 GeV or 18 MeV, but results are (luckily!) similar
  - “valley of tears” around ~7e13 n_{eq}/cm^2 for 10 Ωcm substrate
    - if this can be survived with good efficiency, then collected charge should be much larger until >1e16 n_{eq}/cm^2 (!)



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- For default substrate resistivities of 10 Ωcm
  - depletion zone starts to grow after ~ 5e14 n_{eq}/cm^2
  - maximum reached at 1-2e15 n_{eq}/cm^2
  - still ~70 μm width after 1.3e16 n_{eq}/cm^2
  - not really unsuitable for HL-LHC – if your sensor survives the “valley of tears”, it will survive until the end-of-life
- Samples without backside processing can be contacted via conductive glue, provided the depletion zone does not reach the surface
- Mixed irradiations to mimic realistic environment to follow