UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Section de physique

UNIVERSITÄT BERN

STREAM

TCT measurements of the H35DEMO HV-CMOS detector

Ettore Zaffaroni, J. Anders, M. Benoit, A. Fehr,
S. Gonzalez-Sevilla, C. Merlassino, A. Miucci, DMS Sultan

34th RD50 workshop
12-14/06/2019

Smart Sensor Technologies and Training for Radiation Enhanced Applications and Measurements (STREAM) is a project funded by the European Commission under the Horizon2020 Framework Program under the Grant Agreement no 675587. STREAM began in January 2016 and will run for 4 years.

Outline

- H35DEMO test structures
- Transient Current Technique setup
- TCT measurements and results
  - Protons and neutrons irradiation + annealing
  - Depletion depth and N_{eff}
  - Timing characteristics

H35DEMO chip

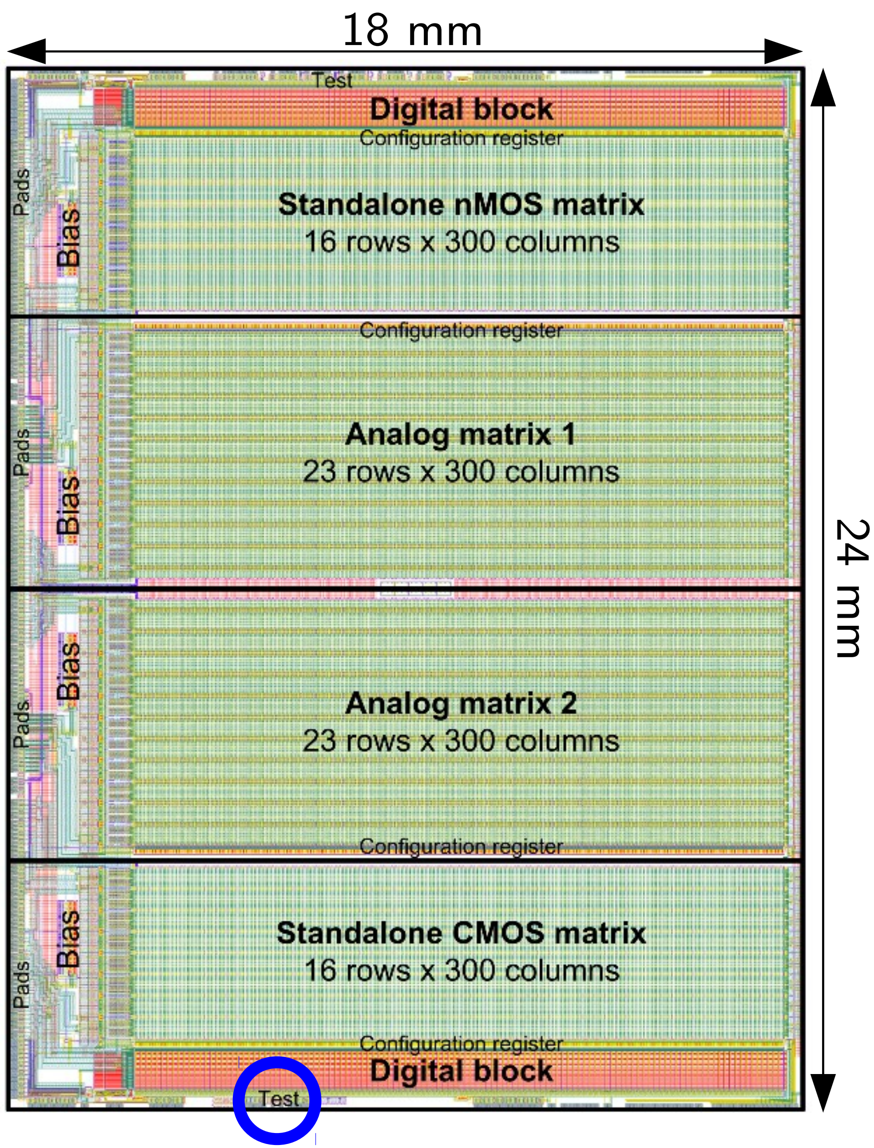
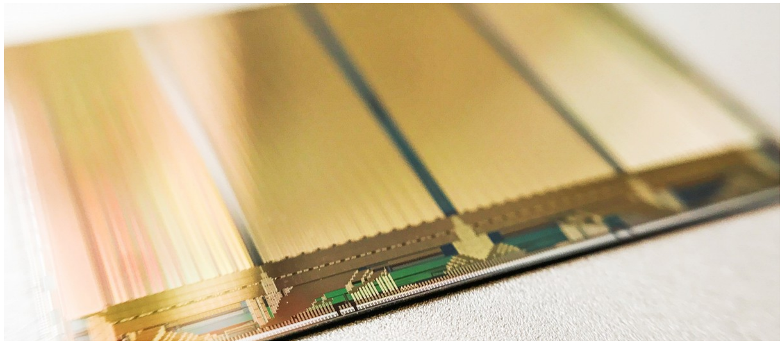
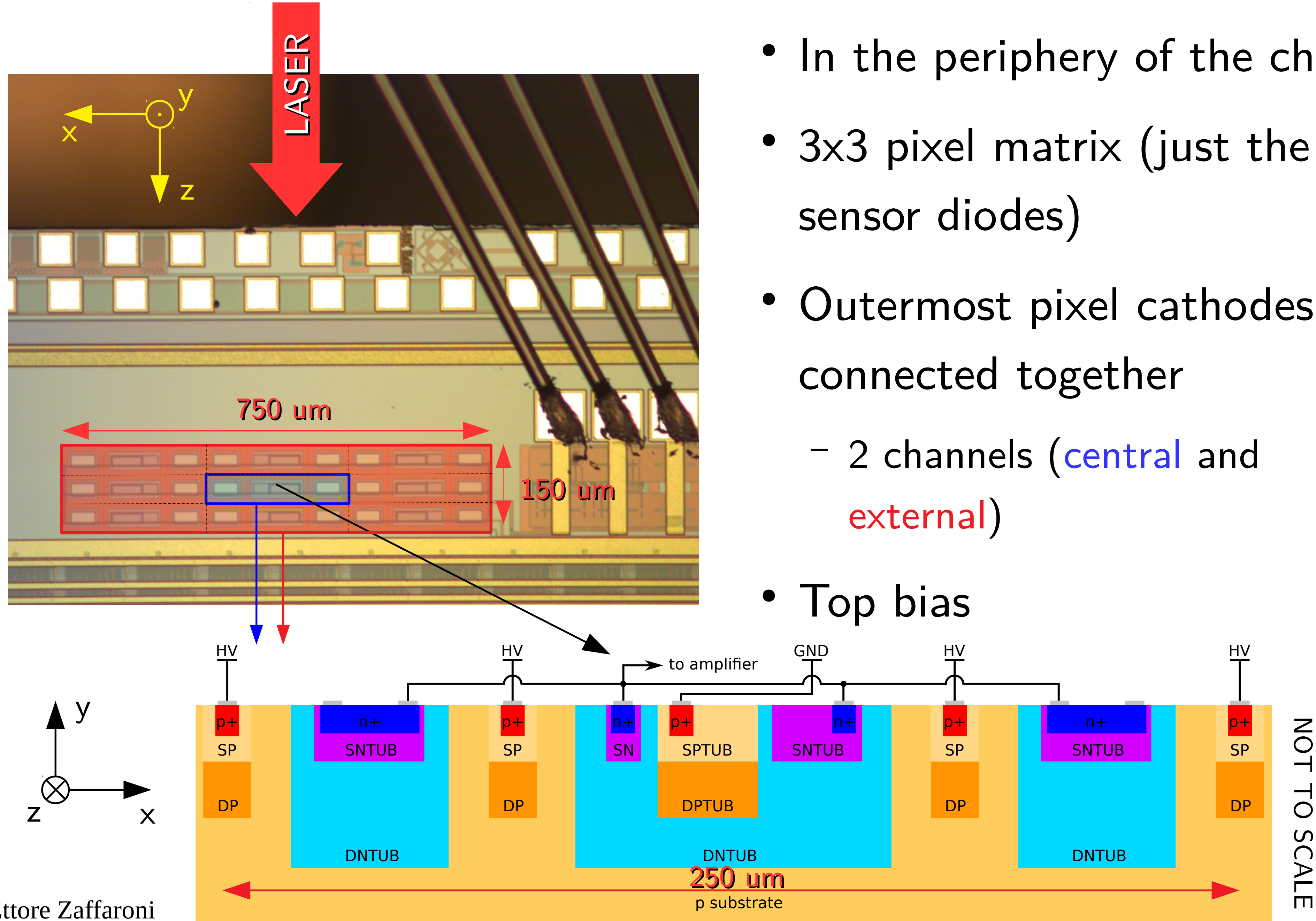


Image from: http://dx.doi.org/10.1088/1748-0221/11/01/C01012

- Designed for ATLAS ITk HV-CMOS project
  - KIT, Liverpool, IFAE, Geneva
- H35 technology by ams
  - 350 nm HV-CMOS, 700 µm thick
- 4 pixel matrices and **test structures**
- 250x50 μm^2 pixels
  - Large fill factor
- 4 different resistivities
  - 20, 80, 200, 1000 $\Omega \cdot$ cm



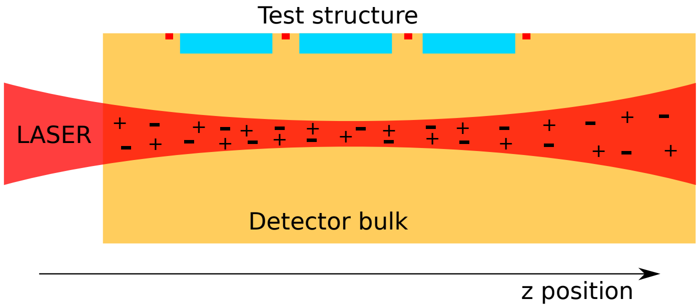
H35DEMO test structures

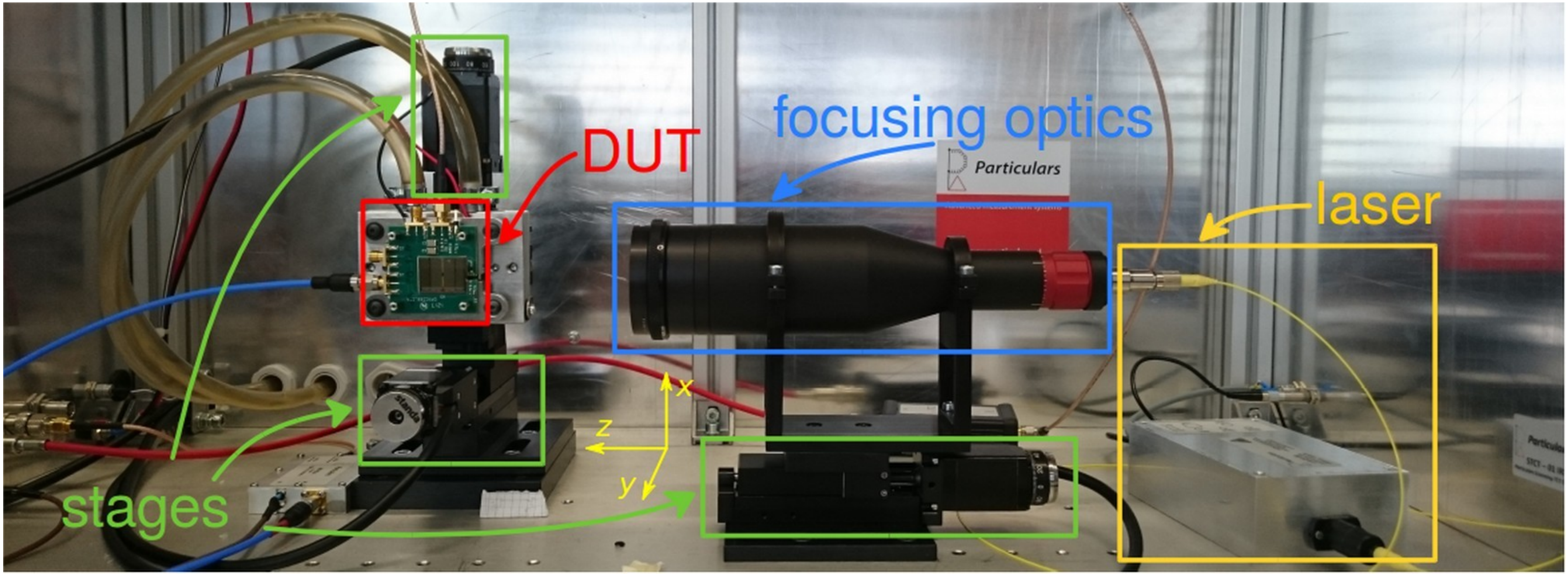


- In the periphery of the chip
- 3x3 pixel matrix (just the sensor diodes)
- Outermost pixel cathodes are connected together
  - 2 channels (central and external)
- Top bias

TCT (Transient Current Technique)

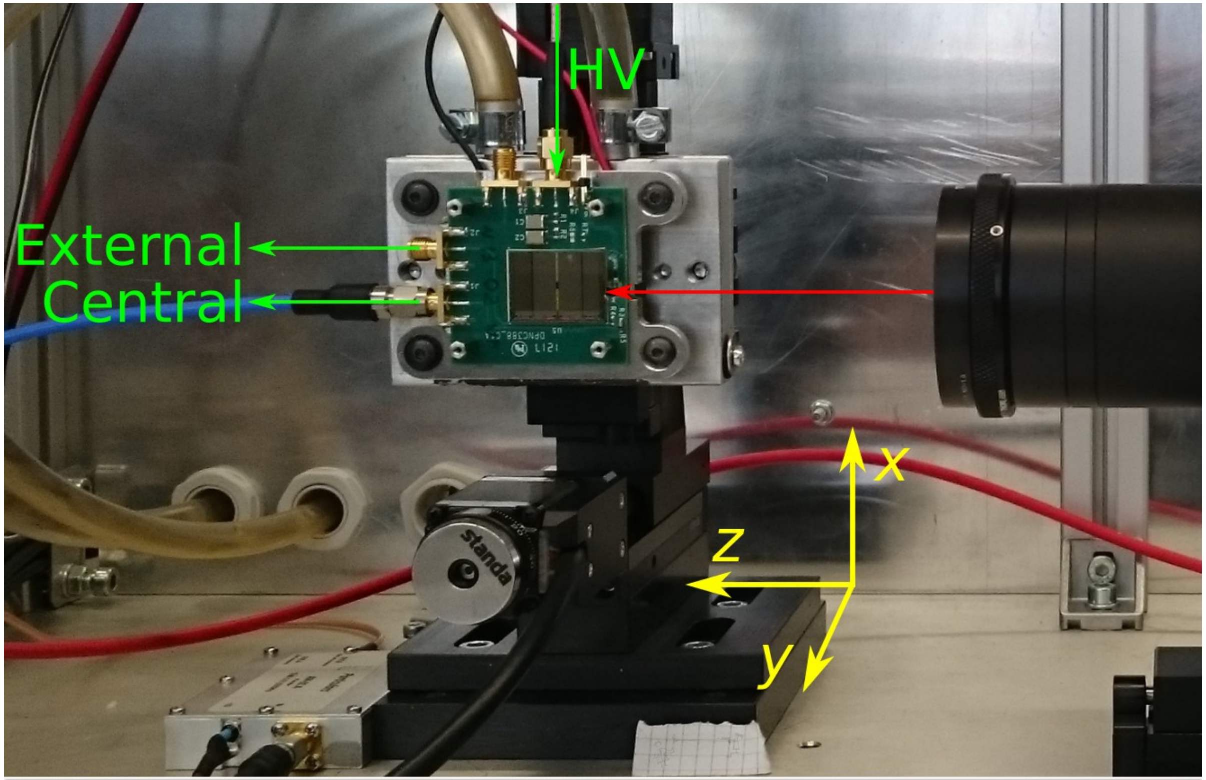
- Pulsed IR laser (1064 nm) with FWHM of 12 µm
- Detector at –27 °C using Peltier
- 1 µm step size in all axes



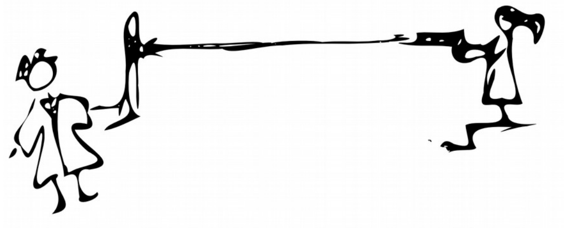


TCT (Transient Current Technique)

- DUT mounted vertically to reduce effects of swinging stages
- PCB with controlled impedance traces and correct termination to remove signal reflections



Irradiation campaigns



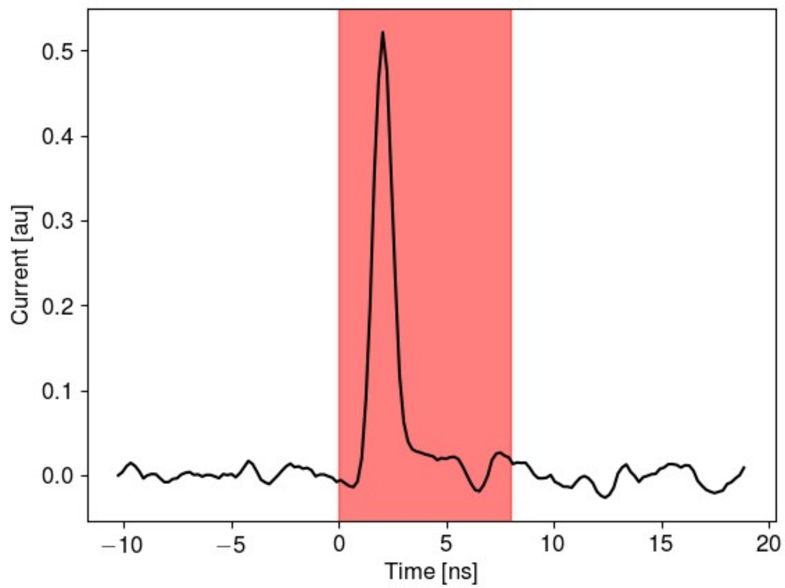
- Protons (measurements at Uni. Bern and Uni. Geneva)
  - BERN Inselspital cyclotron (16.7 MeV)
    - Multiple irradiation steps per sample
  - PS IRRAD (24 GeV)
    - One irradiation step per sample
- Neutrons
  - TRIGA reactor in Ljubljana
    - One irradiation step per sample
  - Annealing 80' at 60 °C

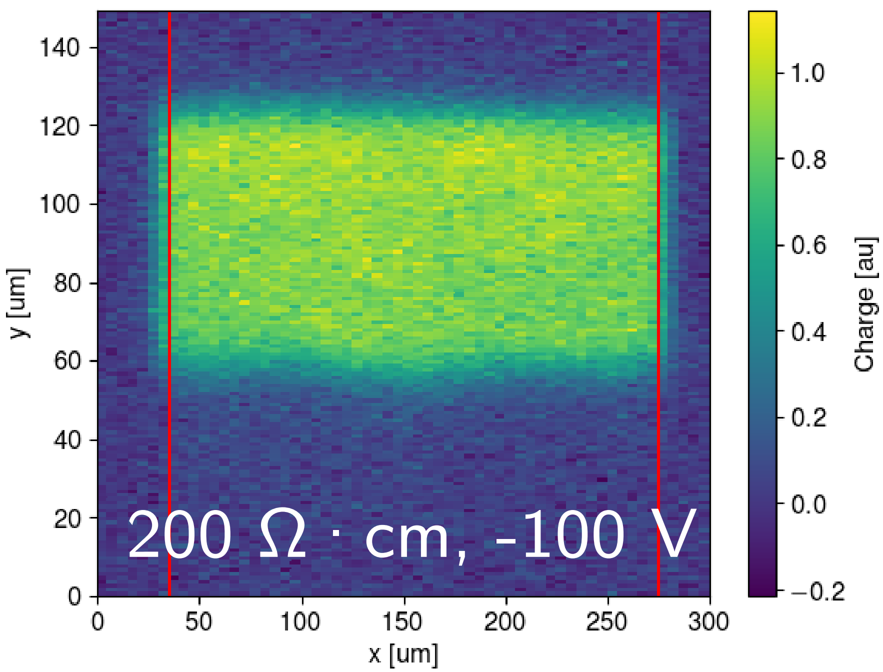
eTCT scans

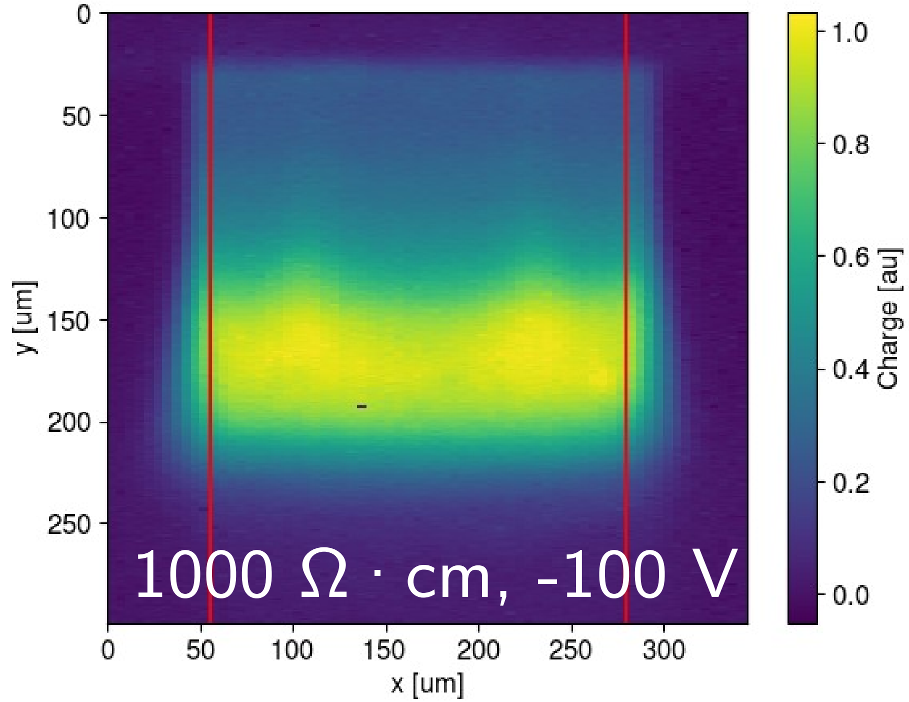
- Edge TCT scans perfomed
- 1 µm steps in y, 5 µm steps in x
- Several voltage steps (10 to 12 normally)
  - From 0 V to -100 or -165 V
- At each step the signal is averaged 40 times
- All results shown for central pixel

Data analysis - depletion

- Integration of current signal to get the charge
- Selection of the region

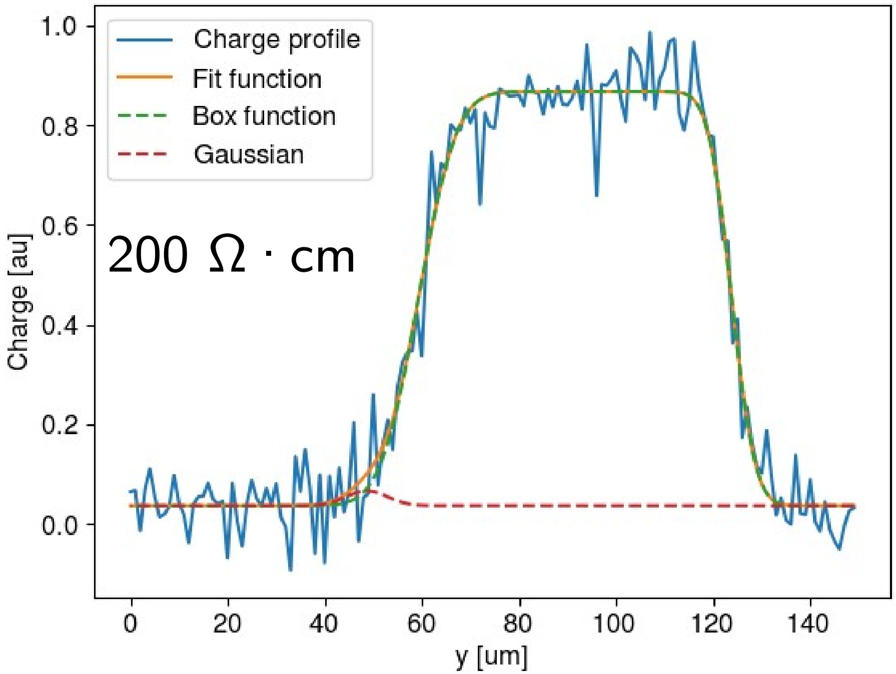


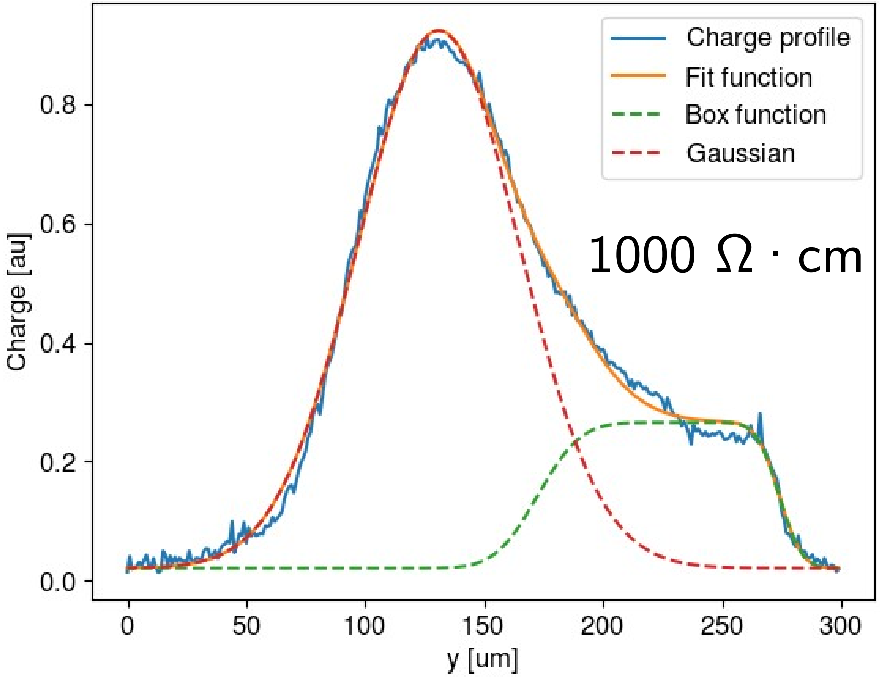




Data analysis - depletion

- Fit of the charge profiles
  - One fit per profile in the ROI
- Two contributions:
  - Smeared box function
  - Gaussian, to model the charge sharing
- Calculation of the FWHM
  - Max of the box function considered





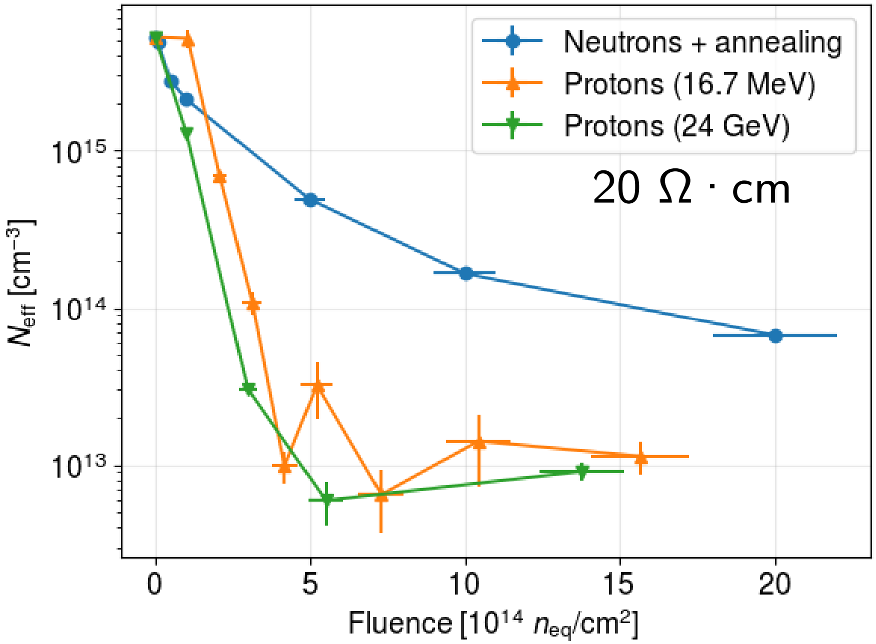
Data analysis - N_{eff}

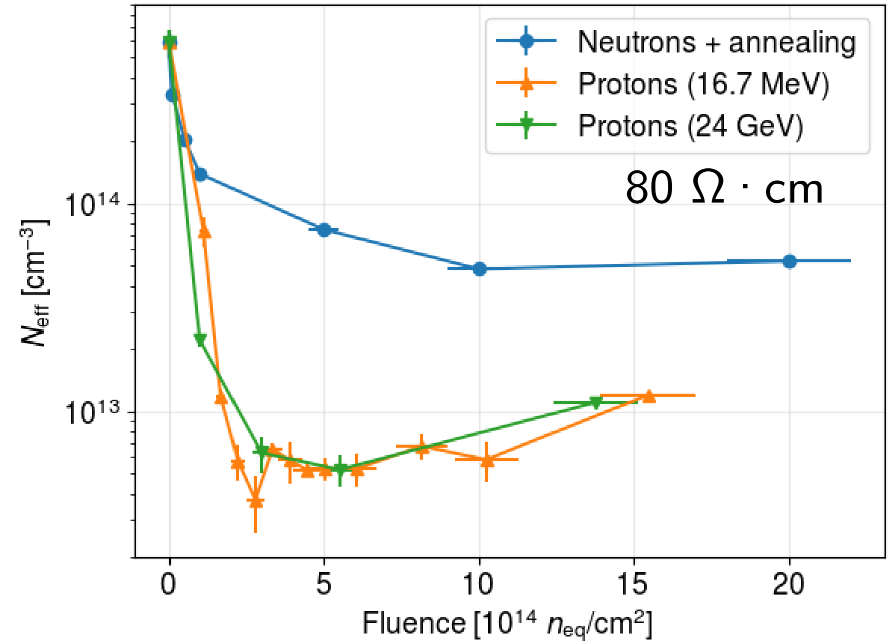
- N_{eff} is calculated by fitting the depletion vs voltage data with:

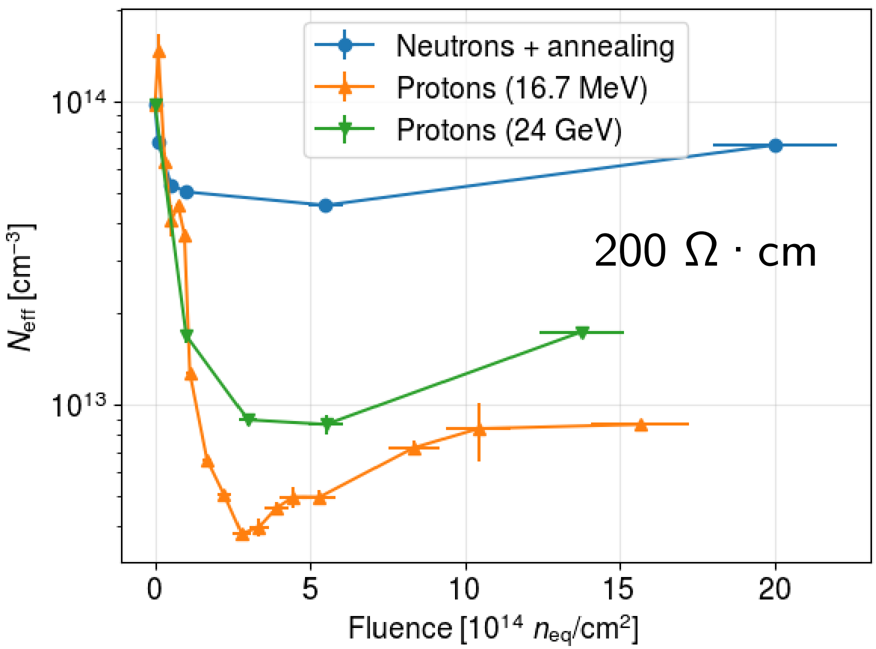
$$d = d_0 + \sqrt{\frac{2\epsilon}{e N_{eff}} V}$$

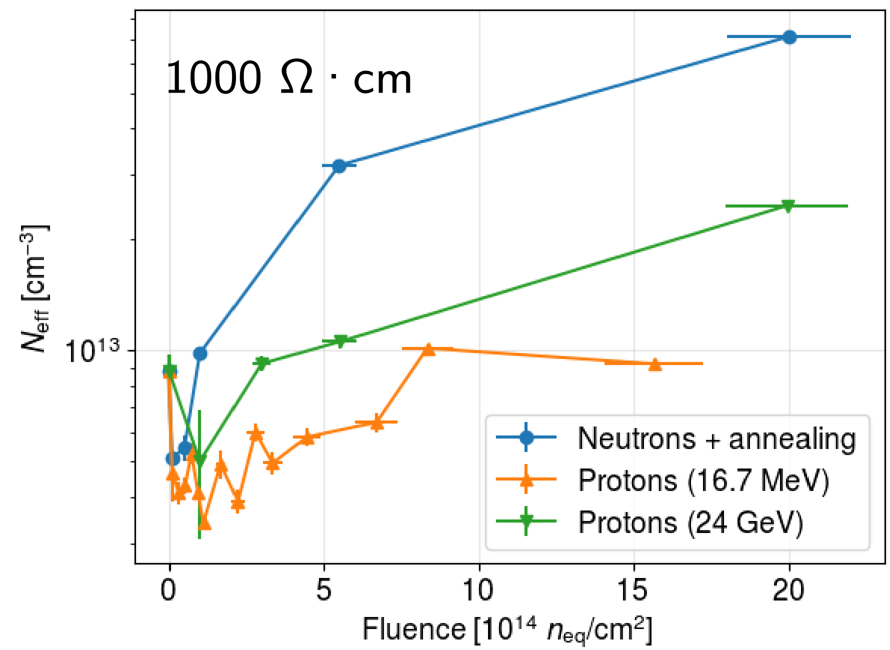
- d_0 and N_{eff} free parameters
  - e electron charge
  - ε silicon dielectric constant

Results - N_{eff}

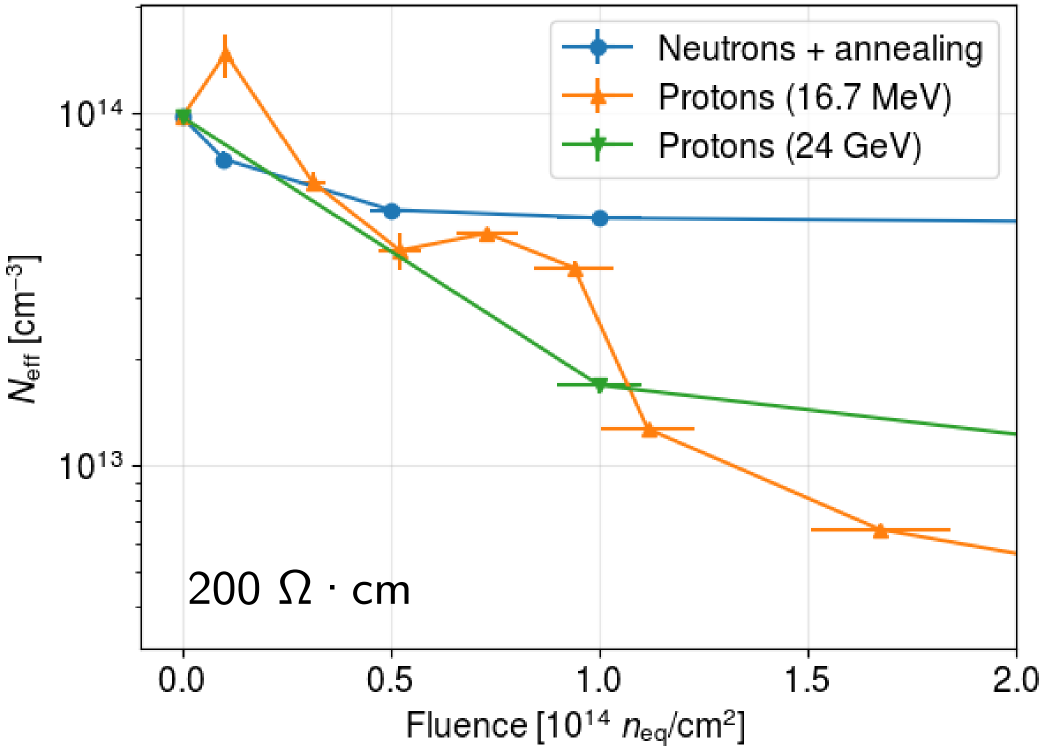


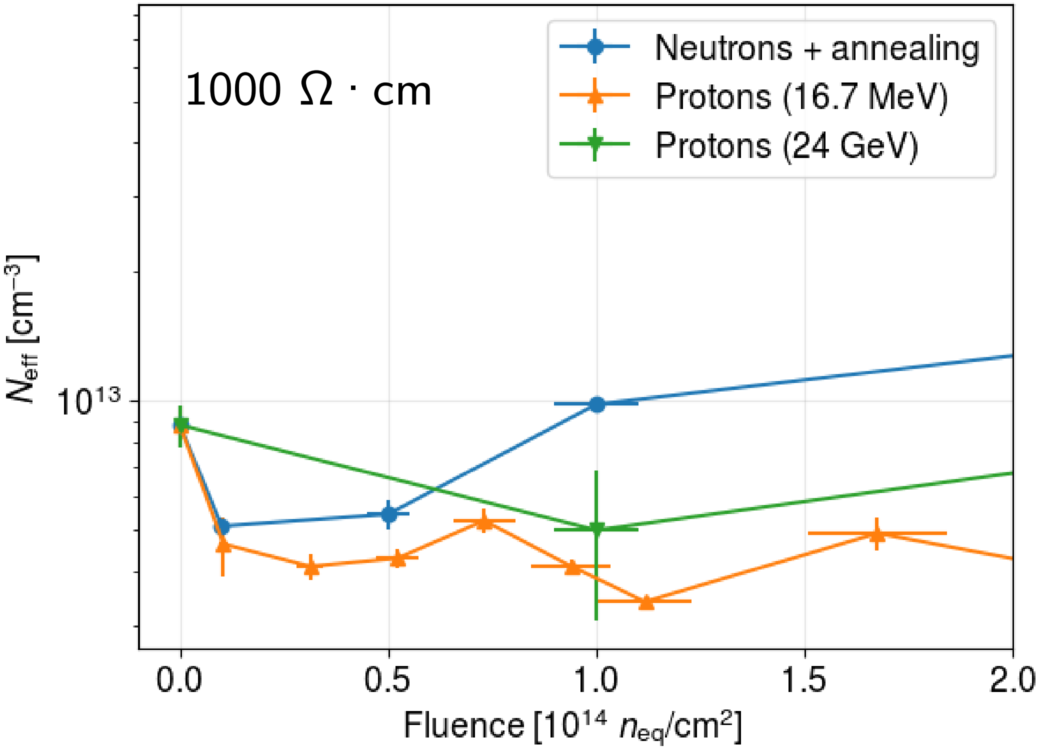






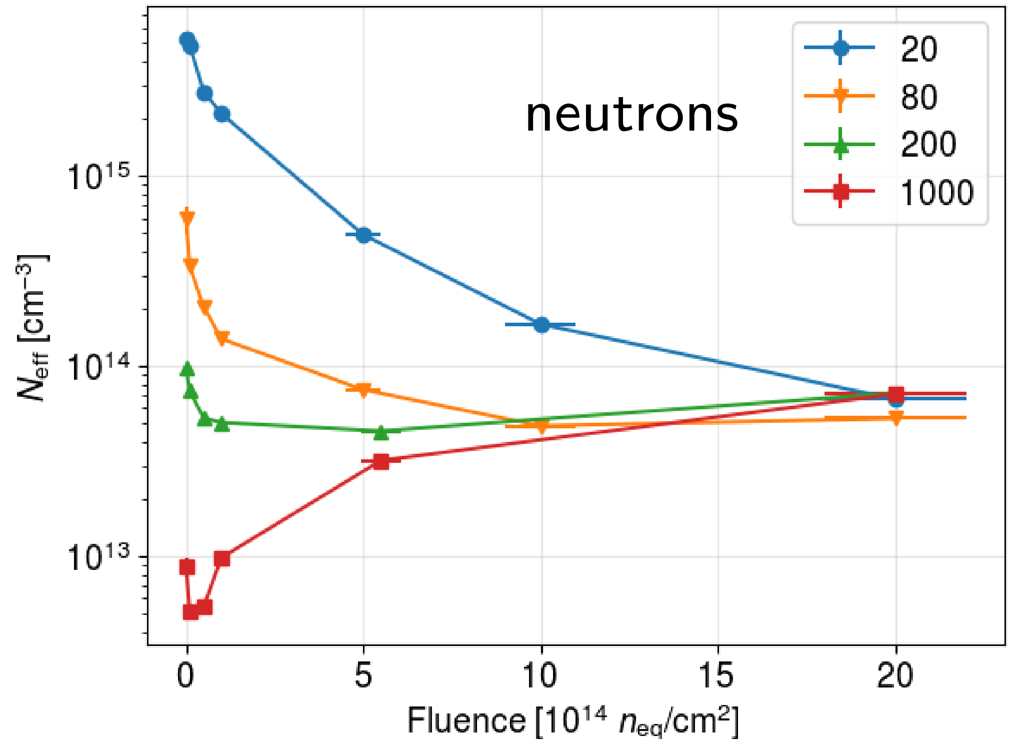
Results – N_{eff} (low fluences)

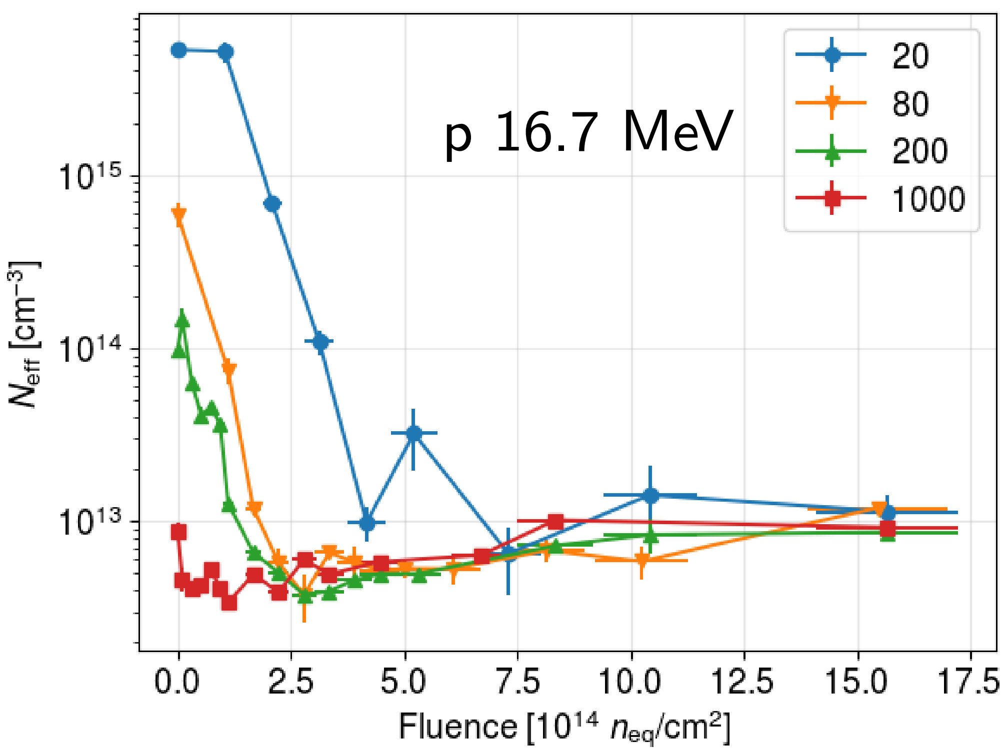


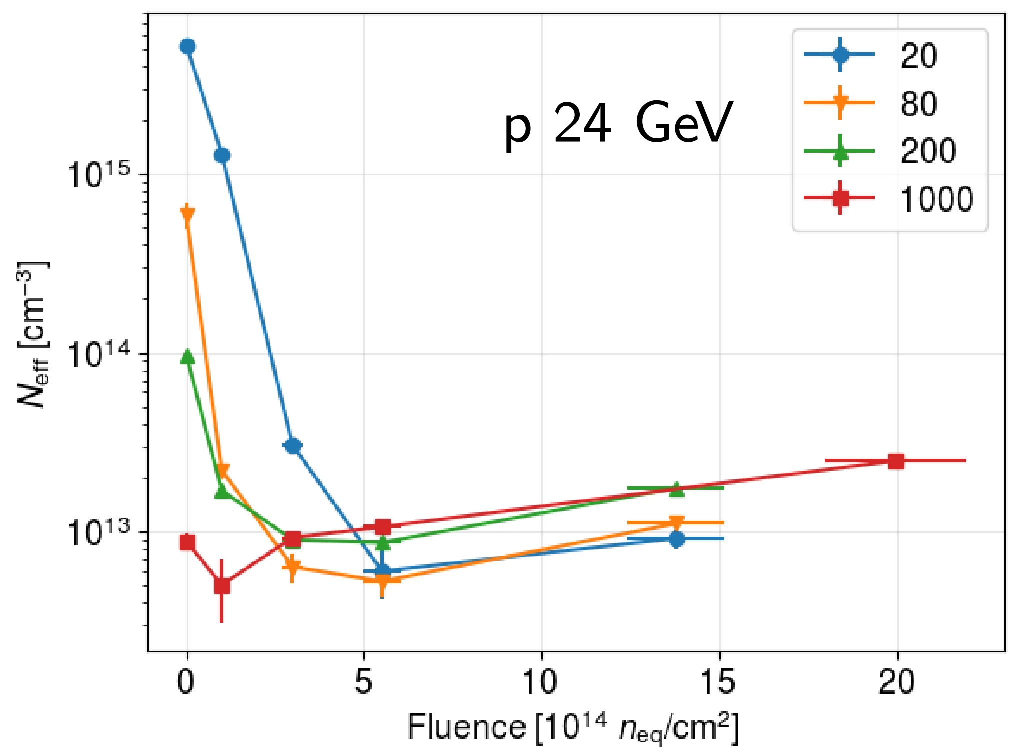


Results – N_{eff}

- Plots combined by particle type, for different initial resisitivities





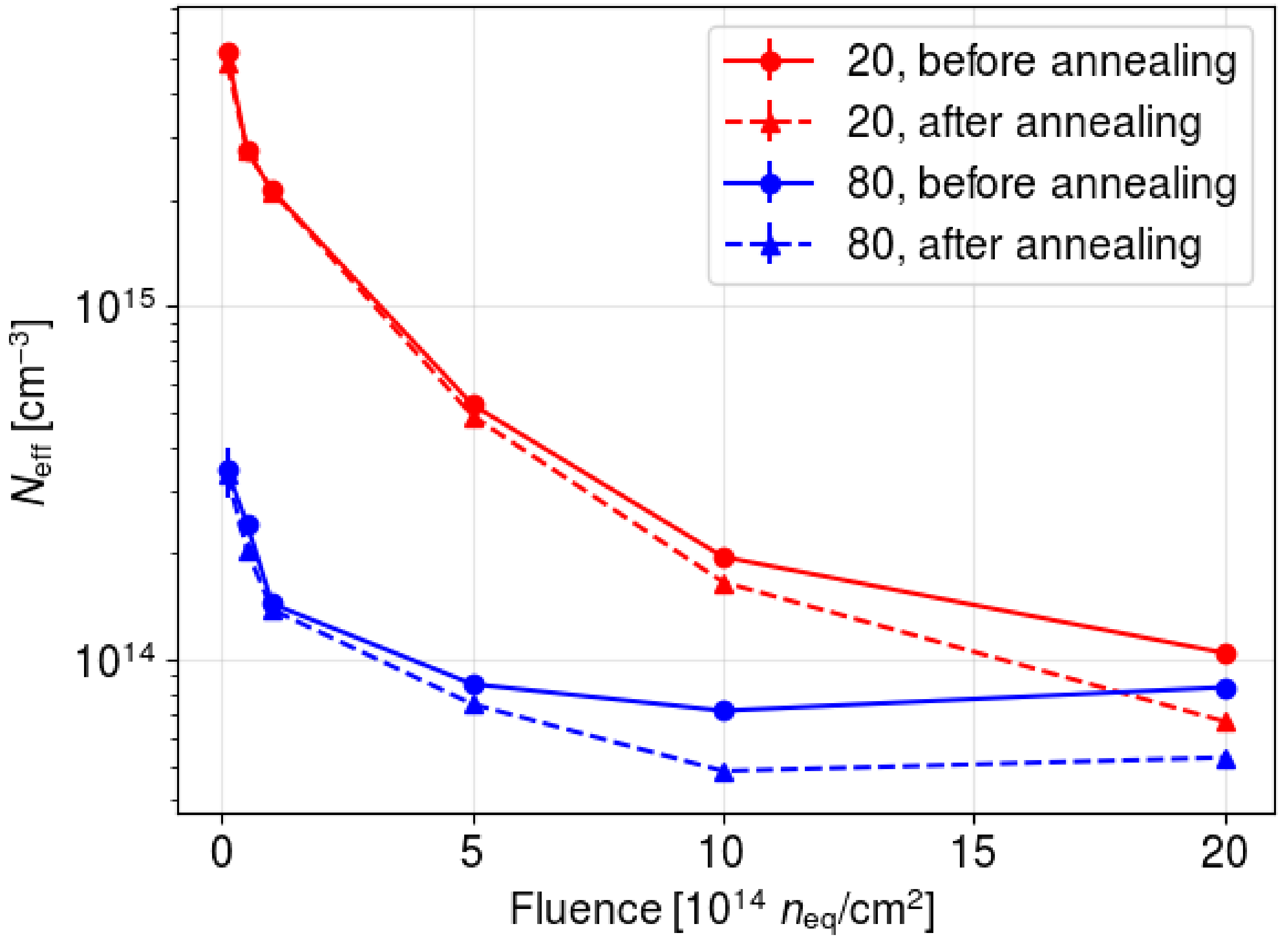


Comments

- Significant differences between protons and neutrons and between resistivities
- Initial increase of N_{eff} at very low fluences ($<$1e14 n_{eq}/cm^2, protons) for the 200 $\Omega \cdot$ cm sample
  - Effect competing with initial acceptor removal?
  - Not observed in 1000 $\Omega \cdot$ cm, data not available for 20 and 80 $\Omega \cdot$ cm
- Different initial resistivities tend to the same N_{eff} value at high fluence, for a given particle type

Results – annealing (neutrons)

- Annealing performed for 80’ at 60 °C (equivalent to 3 weeks at room temperature)

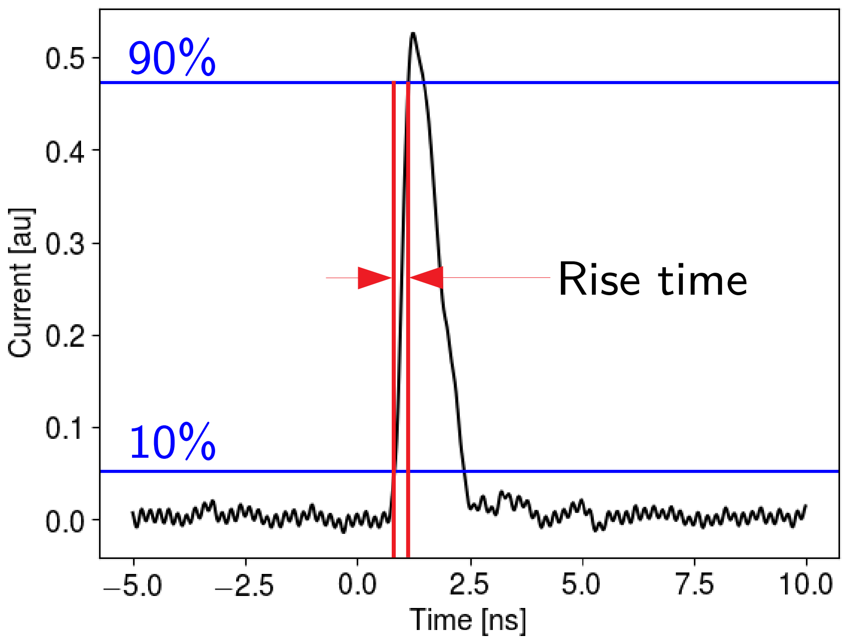


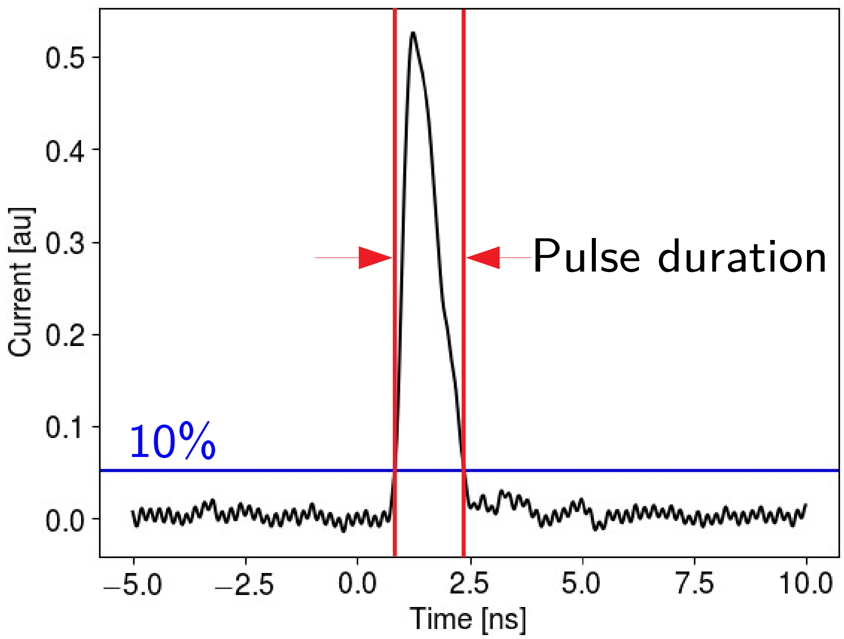
Comments – annealing (neutrons)

- Annealing starts to have an effect on N_{eff} after 5e14 n_{eq}/cm^2
- Consistent annealing study for protons not available
  - Small effects at low fluences (3e14 n_{eq}/cm^2)
- We will measure annealing after proton irradiation at higher fluence (1e15 n_{eq}/cm^2)

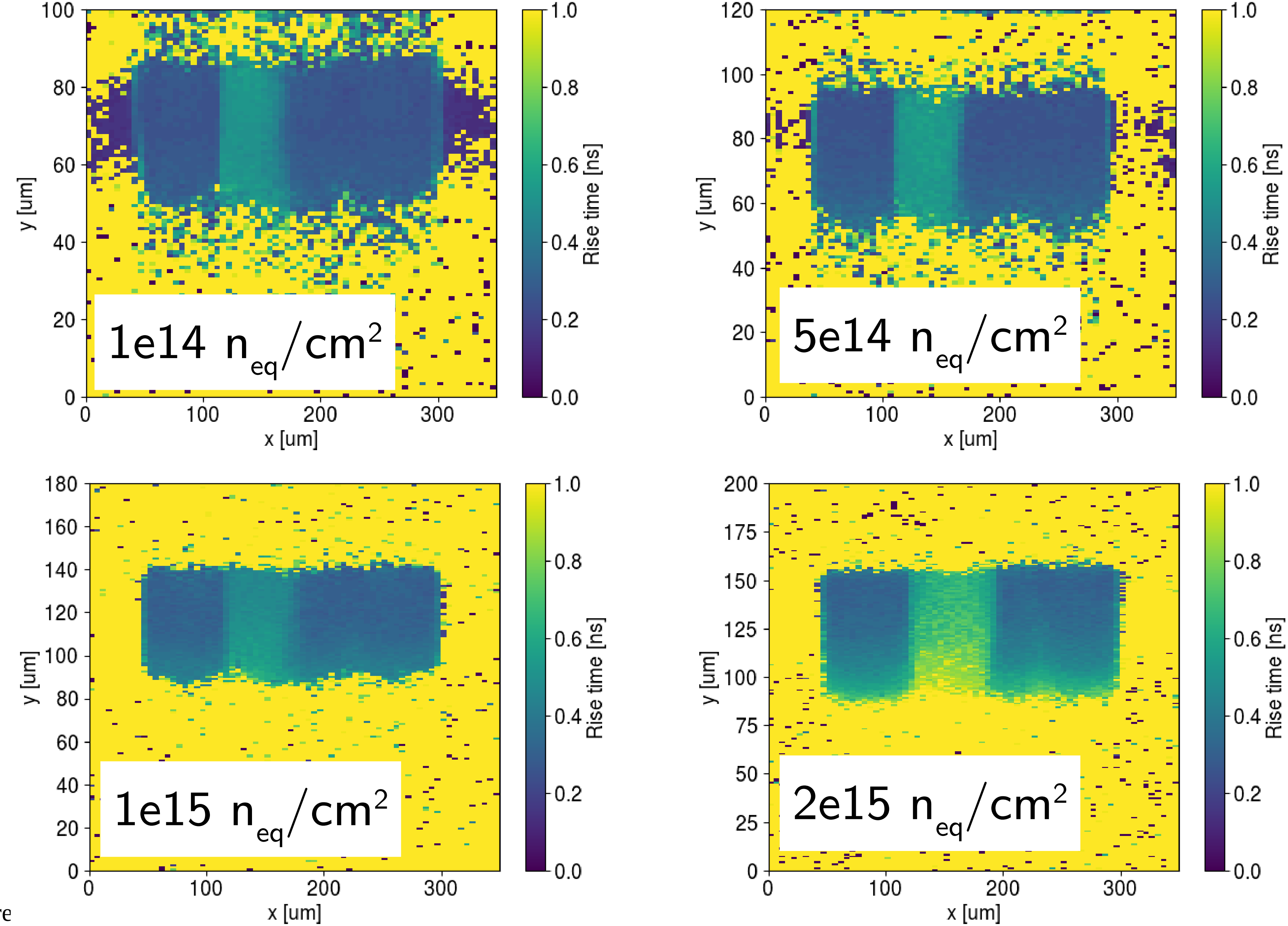
Data analysis - timing characteristics

- For each waveform
  - Rise time (10%-90%)
  - Pulse duration
- Dominated by amplifier bandwidth (2 GHz)

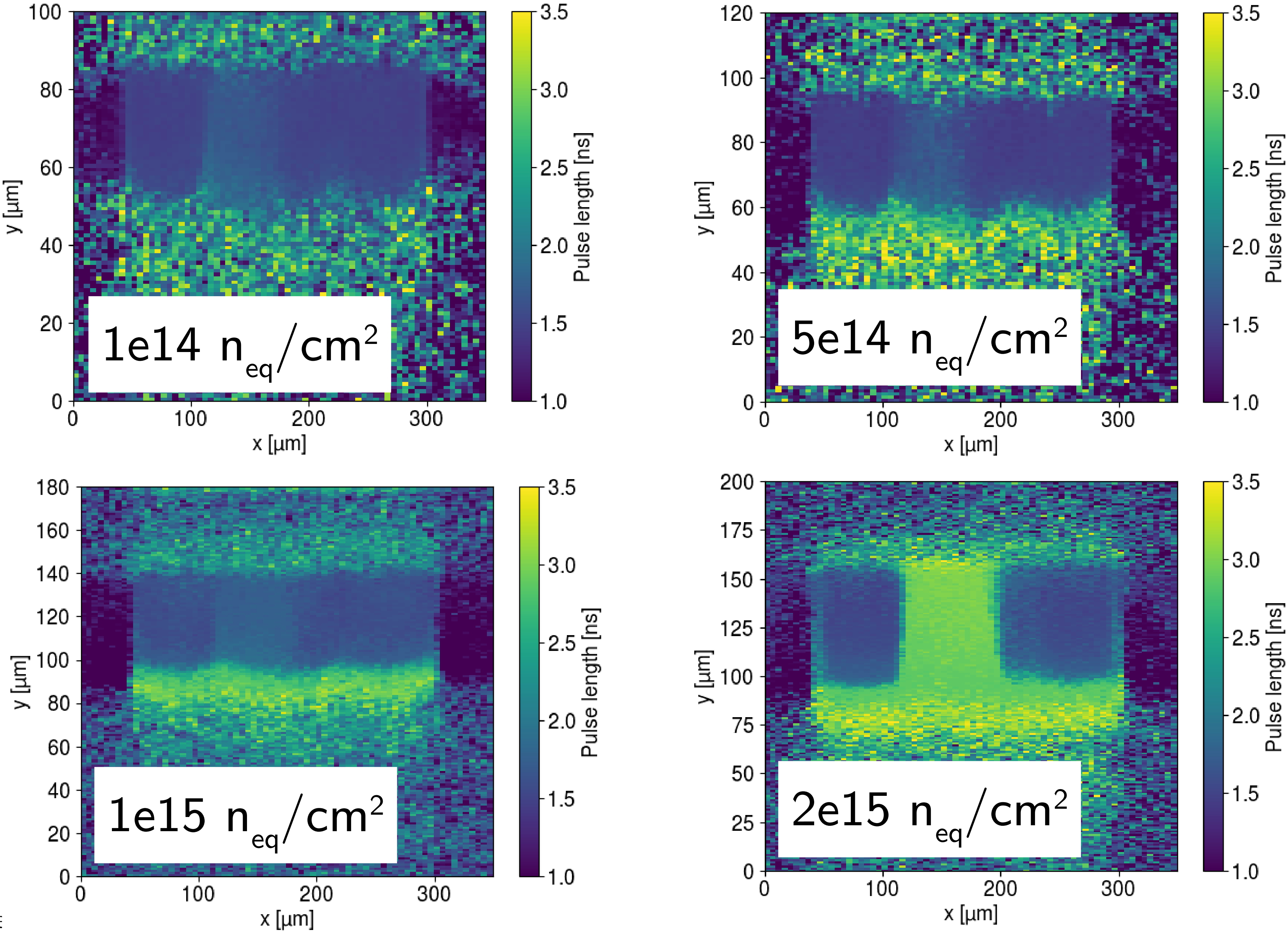




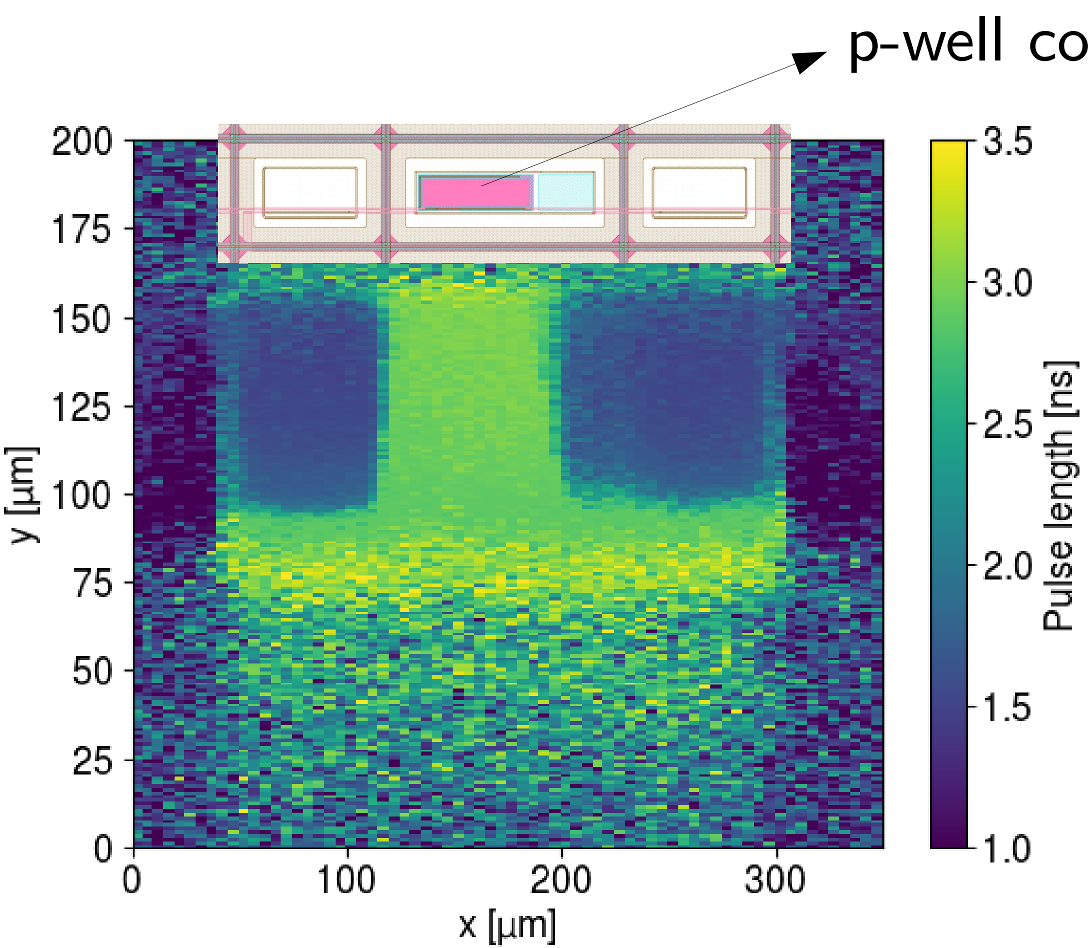
Results – rise time (20 Ω · cm, n)



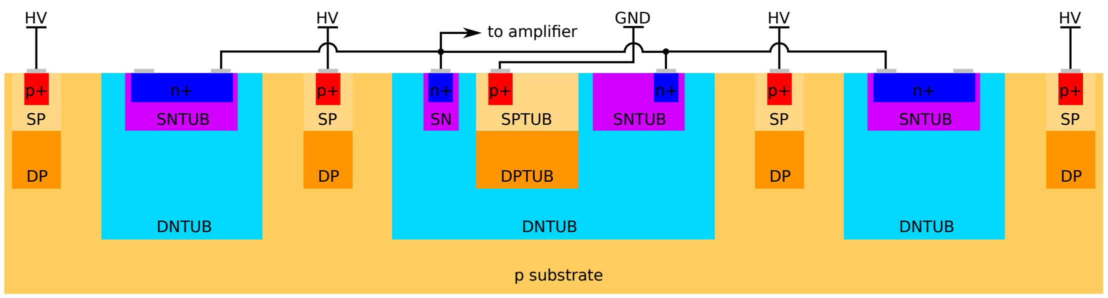
Results – pulse length $(20\ \Omega \cdot \text{cm, n})$

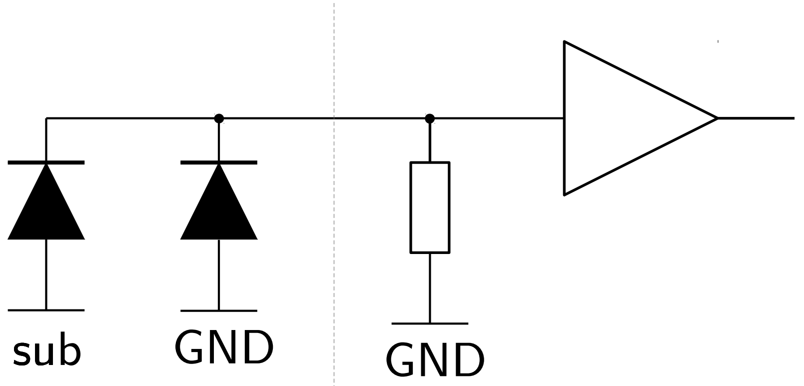


“Slower band” (possible) explanation



- p-well over deep n-well
  - Connected to GND
- Forms a diode in parallel with the sensor





Comments

- Rise time and pulse length become slightly longer with irradiation
- At higher fluences a slower signal zone appears at the bottom of the depletion region
  - Visible for the 80 $\Omega \cdot$ cm samples as well
  - Very little charge collected there
- Signals in the region below the p-well are slower
  - This effects is enhanced with irradiation

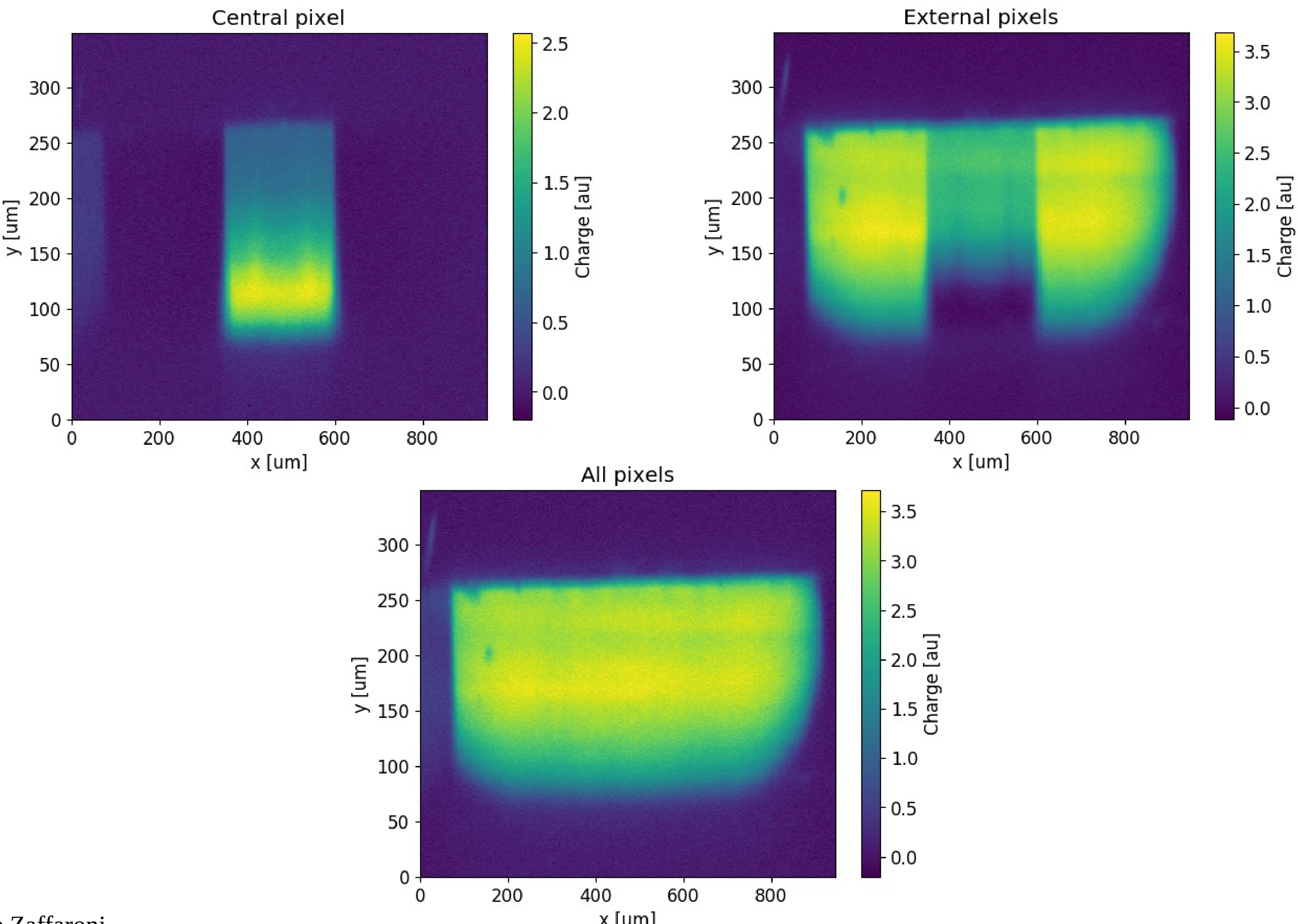
Conclusions

- H35DEMO characterized with TCT
- N_{eff} evolution varies a lot with resistivity and particle type
- Annealing effects (from neutron irradiation) visible after 5e14 n_{eq}/cm^2
- Timing characteristics of pulses vary with irradiation

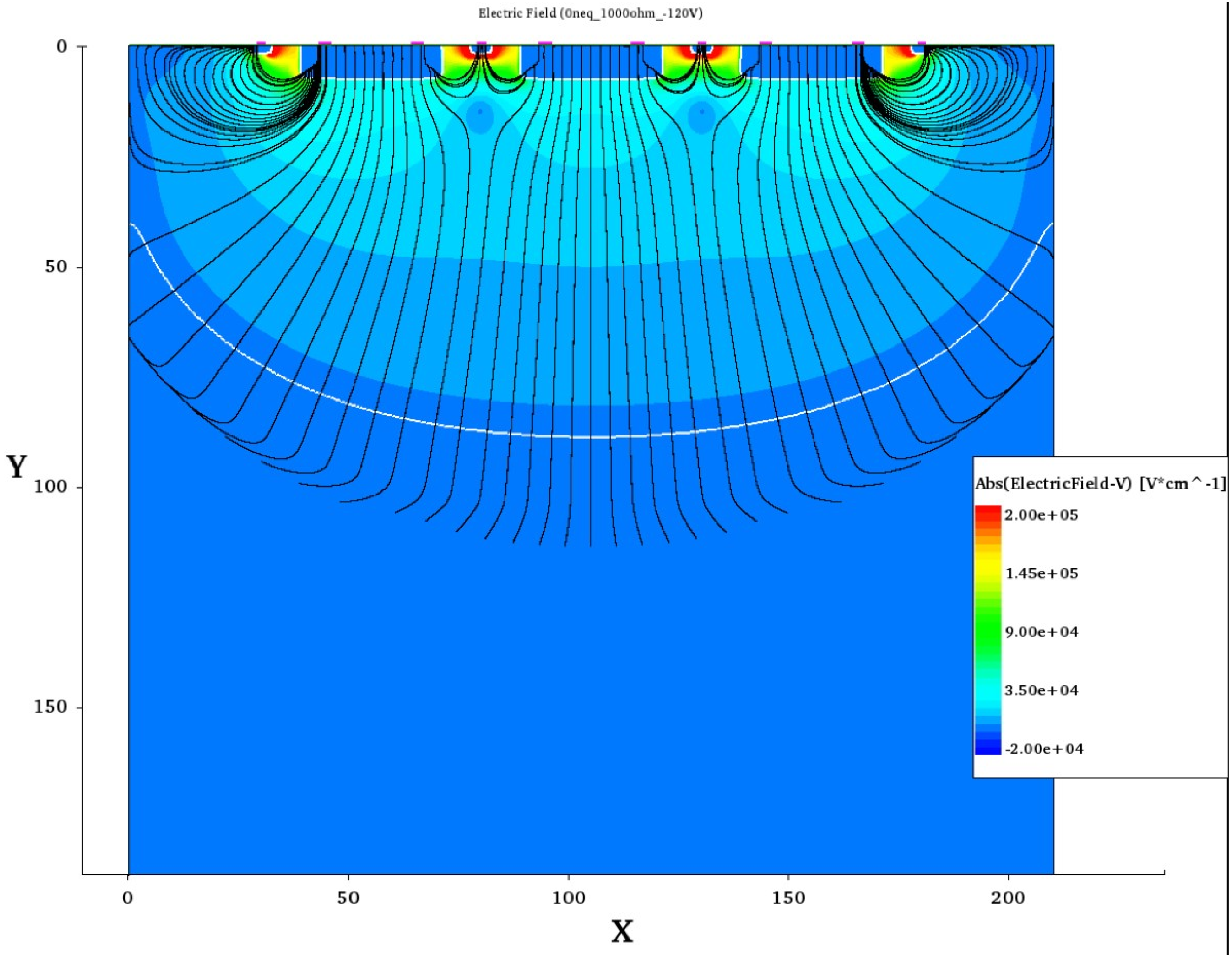
Thank you!

Backup

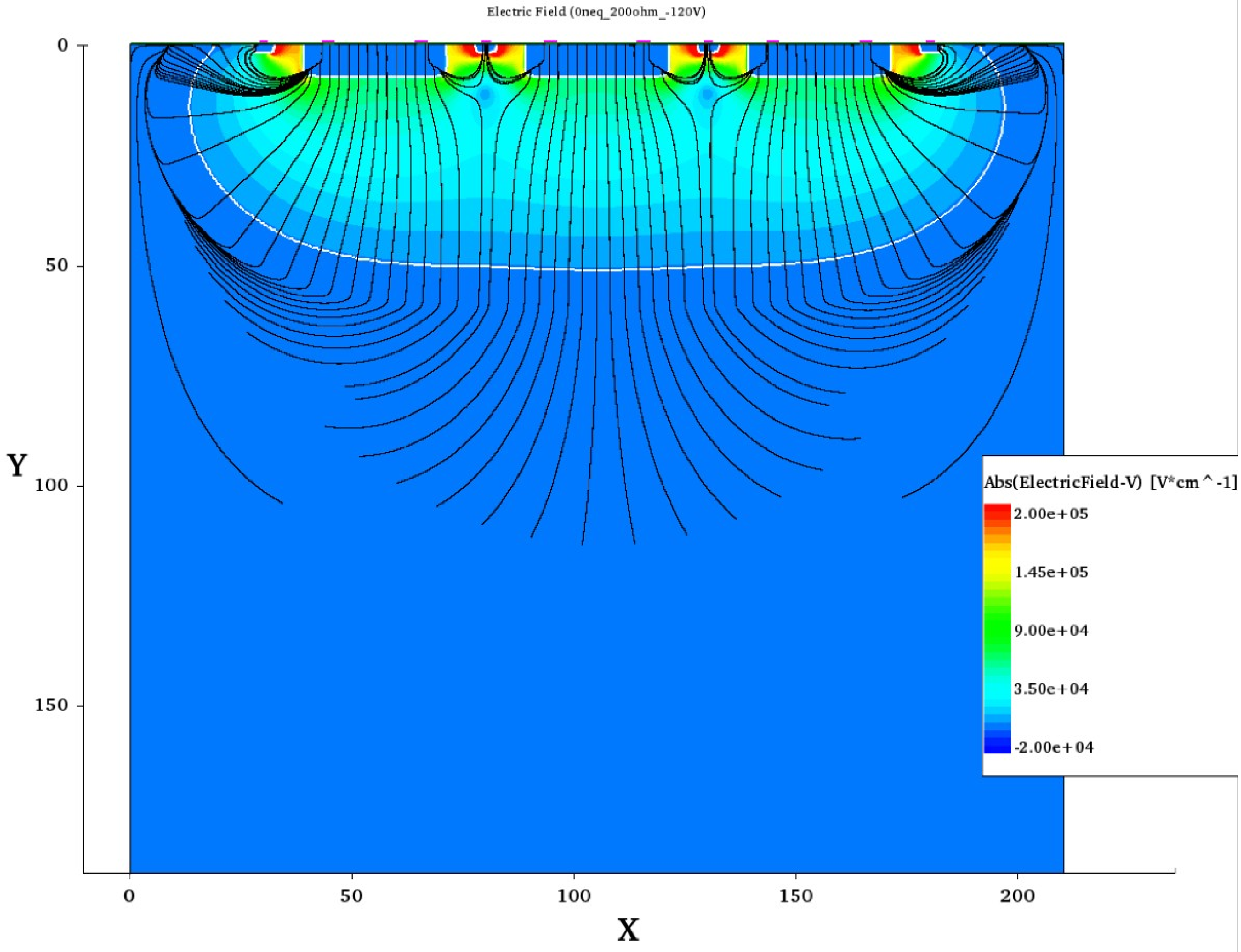
Charge sharing ($1000\ \Omega \cdot cm$ @ 5e13 n_{eq})



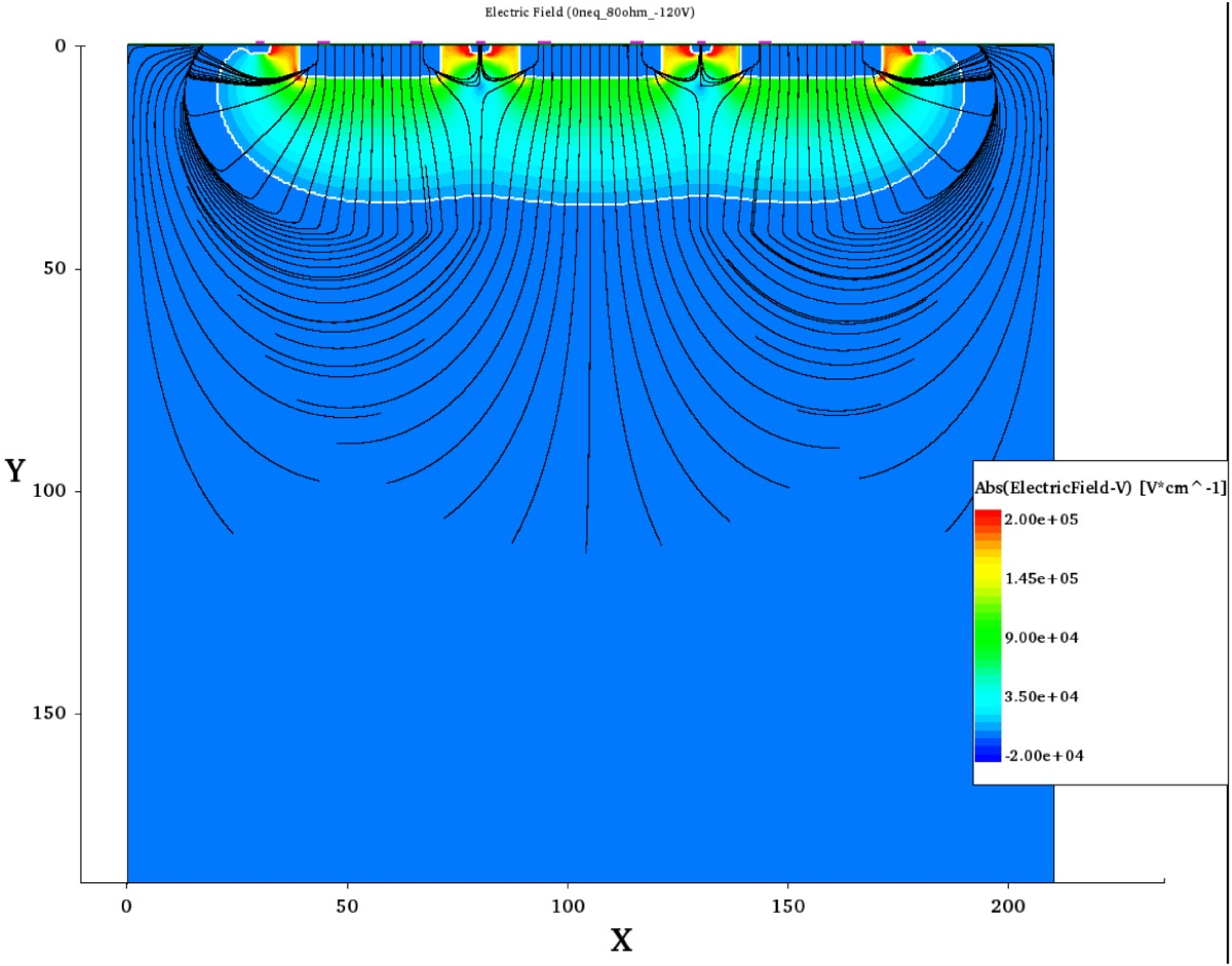
Electric field (1000 $\Omega \cdot$ cm)



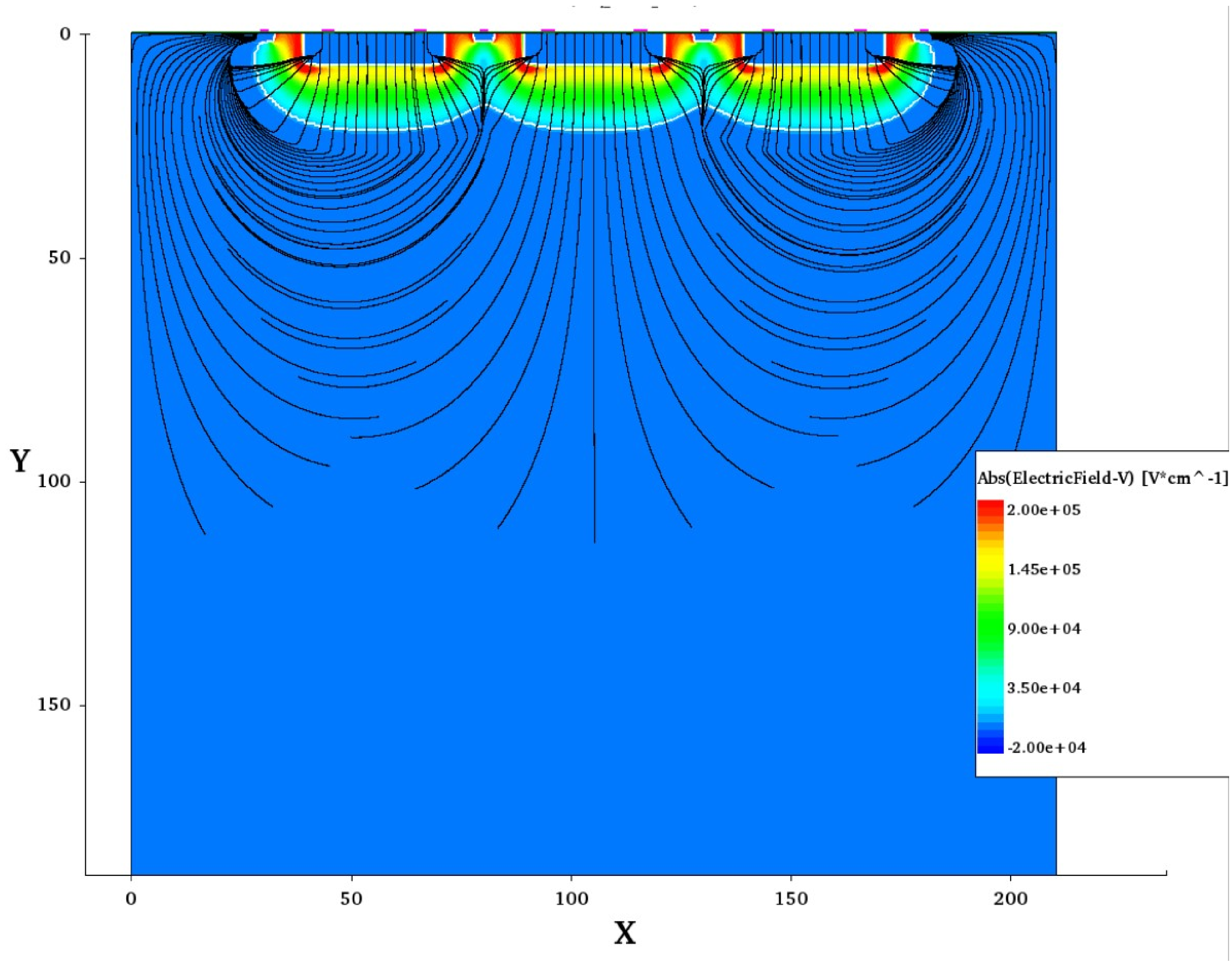
Electric field (200 $\Omega \cdot$ cm)



Electric field (80 Ω · cm)



Electric field (20 $\Omega \cdot$ cm)



Samples – protons 16.7 MeV

sample	resistivity	particle	irr. steps
pb-20-t01	20	p (16.7 MeV)	5
pb-20-t04	20	p (16.7 MeV)	9
pb-80-t03	80	p (16.7 MeV)	13
pb-200-t03	200	p (16.7 MeV)	13
pb-200-t04	200	p (16.7 MeV)	6
pb-1000-t03	1000	p (16.7 MeV)	12
pb-1000-t04	1000	p (16.7 MeV)	6

Samples – protons 24 GeV

sample	resistivity	particle	irr. steps
pp-20-4.45	20	p (24 GeV)	1
pp-20-13.33	20	p (24 GeV)	1
pp-20-24.53	20	p (24 GeV)	1
pp-20-61.32	20	p (24 GeV)	1
pp-80-4.45	80	p (24 GeV)	1
pp-80-13.33	80	p (24 GeV)	1
pp-80-24.53	80	p (24 GeV)	1
pp-80-61.32	80	p (24 GeV)	1
pp-200-4.45	200	p (24 GeV)	1
pp-200-13.33	200	p (24 GeV)	1
pp-200-24.53	200	p (24 GeV)	1
pp-200-61.32	200	p (24 GeV)	1
pp-1000-4.45	1000	p (24 GeV)	1
pp-1000-13.33	1000	p (24 GeV)	1
pp-1000-24.53	1000	p (24 GeV)	1
pp-1000-88.77	1000	p (24 GeV)	1

Samples - neutrons

sample	res.	particle	irr. steps
n-20-1e13-b1	20	n	1
n-20-5e13-b1	20	n	1
n-20-1e14-b1	20	n	1
n-20-1e14-b2	20	n	1
n-20-5e14-b2	20	n	1
n-20-5.5e14-b1	20	n	1
n-20-1e15-b2	20	n	1
n-20-2e15-b1	20	n	1
n-20-2e15-b2	20	n	1
n-80-1e13-b1	80	n	1
n-80-5e13-b1	80	n	1
n-80-1e14-b1	80	n	1
n-80-1e14-b2	80	n	1
n-80-5e14-b2	80	n	1

sample	res	particle	irr. steps
n-80-5.5e14-b1	80	n	1
n-80-1e15-b2	80	n	1
n-80-2e15-b1	80	n	1
n-80-2e15-b2	80	n	1
n-200-1e13-b1	200	n	1
n-200-5e13-b1	200	n	1
n-200-1e14-b1	200	n	1
n-200-5.5e14-b1	200	n	1
n-200-2e15-b1	200	n	1
n-1000-1e13-b1	1000	n	1
n-1000-5e13-b1	1000	n	1
n-1000-1e14-b1	1000	n	1
n-1000-5.5e14-b1	1000	n	1
n-1000-2e15-b1	1000	n	1