RD39 Status Report 2008

Zheng Li and Jaakko Härkönen

Full author list available at

http://rd39.web.cern.ch/RD39/

Outline

1. Trapping effect on Charge Collection Efficiency (CCE) in Super-LHC
2. Operation of current-injected-detectors (CID)
3. CCE measurements on CID
4. Beam test results of CID strip detectors
5. Summary

Trapping effect on CCE in S-LHC

$$CCE = \frac{Q}{Q_0} = CCE_{GF} \times CCE_t = \frac{w}{d} \times [\frac{\tau_t}{t_{dr}} \cdot (1 - e^{-t_{dr}/\tau_t})]$$

Depletion term

Trapping term

Overall CCE is product of

- CCE_t is trapping factor
- CCE_{GF} is geometrical factor

$$w = \sqrt{\frac{2\varepsilon\varepsilon_0 V}{eN_{eff}}} \text{ and } \frac{w}{d} = \sqrt{\frac{V}{V_{fd}}}$$

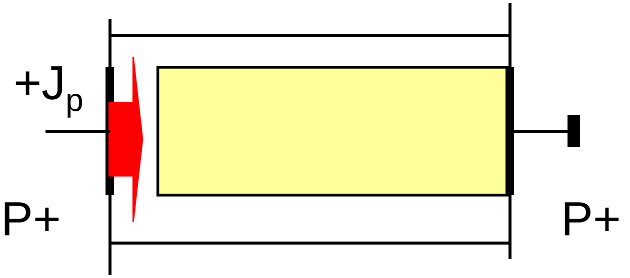
For fluence less than 10^{15} n_{eq}/cm^2, the trapping term CCE_t is not significant

For fluence 10^{16} n_{eq}/cm^2, $\frac{\tau_t}{t_{dr}} << 1$ the trapping term CCE_t is a limiting factor of detector operation !

$$Q = Q_0 \cdot CCE \cong Q_0 \cdot \frac{w}{d} \cdot \frac{\tau_t}{t_{dr}} = q_{MIP} \cdot d \cdot \frac{w}{d} \cdot \frac{v_{dr} \cdot \tau_t}{v_{dr} \cdot t_{dr}} = q_{MIP} \cdot v_{dr} \cdot \tau_t = q_{MIP} \cdot d_t$$

- d_t is trapping distance, and it is about 20 μm at 10^{16} n_{eq}/cm^2 for non-CID detectors
- q_{MIP} is unit charge/ μm for MIP in Si = 80 e's/ μm

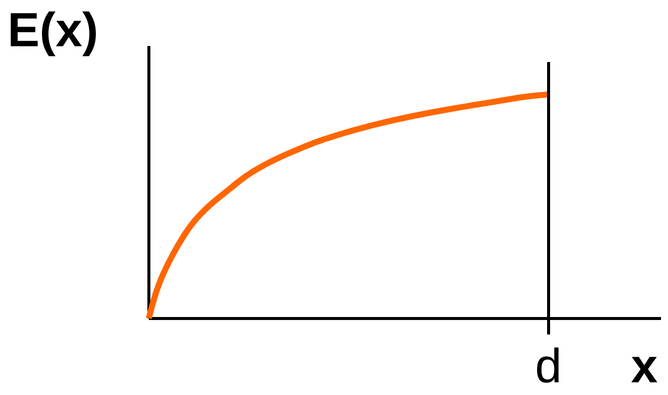
Current injected detector
(principle of operation)



$J_p = ep\mu E$
$divJ=0$
$divE=p_{tr}$
$E(x=0) = 0$ (SCLC mode)

$$j = \theta\varepsilon\varepsilon_0\mu\frac{V^2}{d^3}$$

$$E = \sqrt{\frac{2j}{\varepsilon\varepsilon_0\mu}}x^{1/2}$$

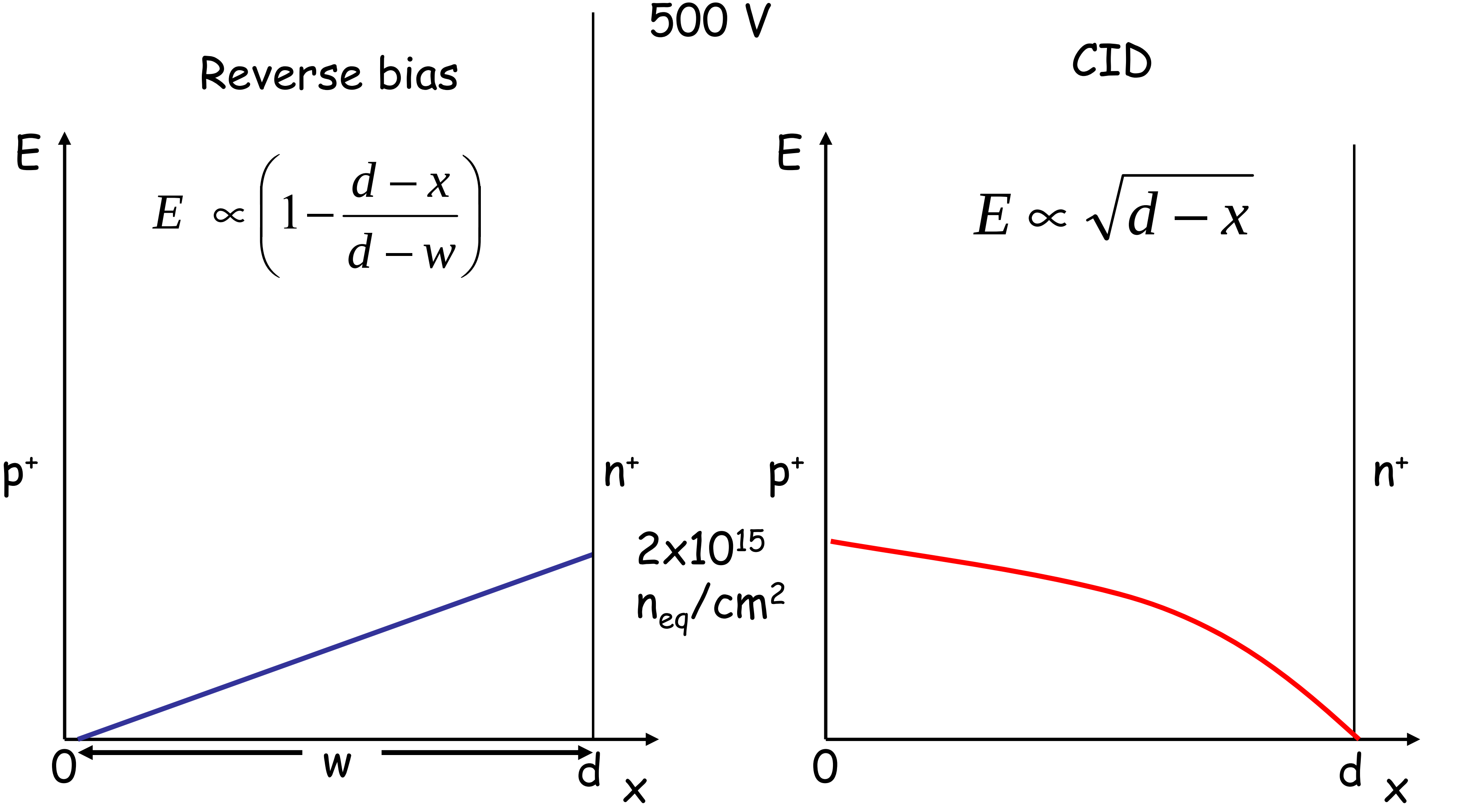


The key advantage:

The shape of ***E(x)*** is ***not affected*** by ***N$_{mgl}$***, and ***stable*** at any fluence

Charge Injected Detector (CID) –Operational Principle

Evolution of E(x) with fluences



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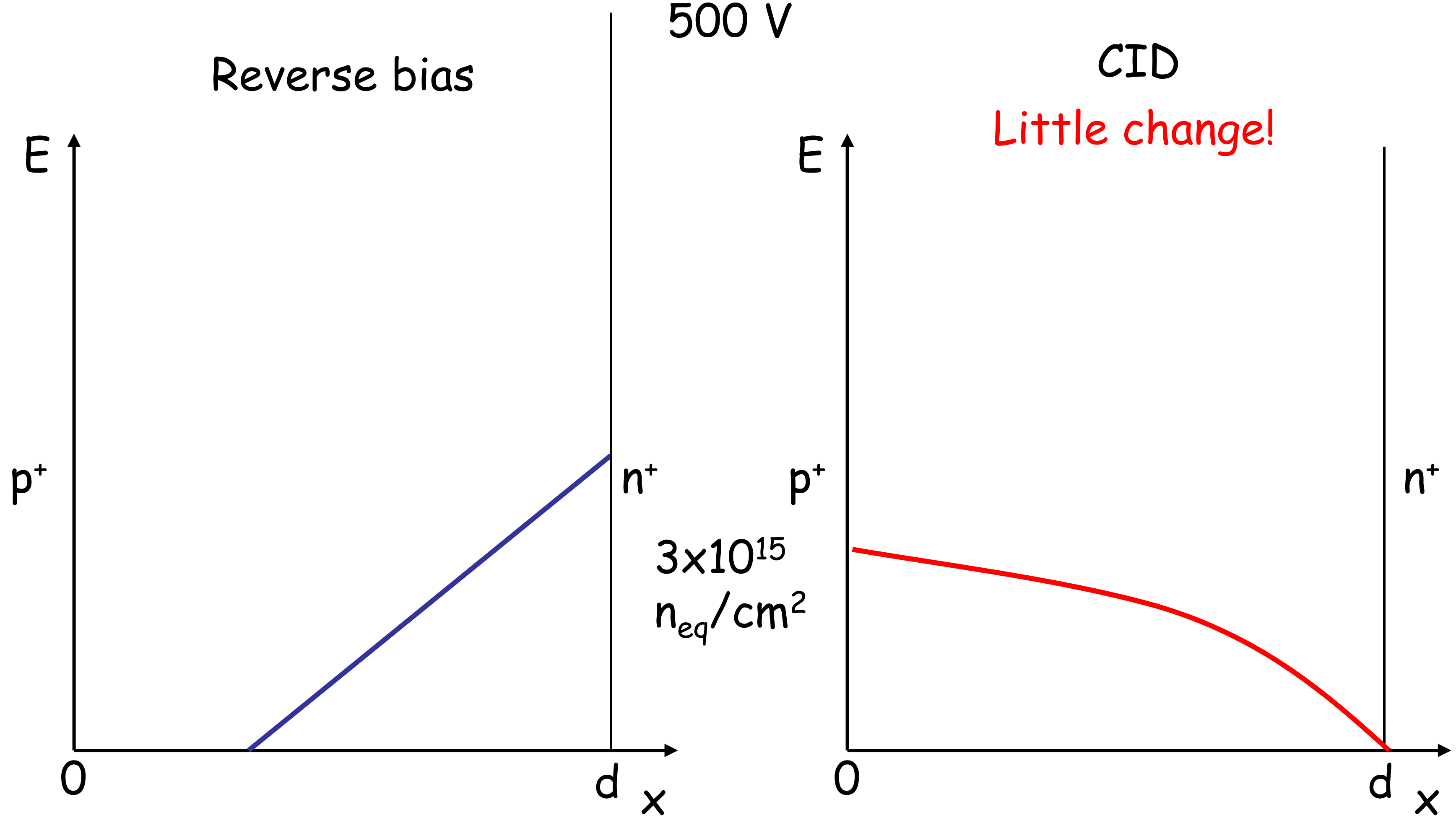

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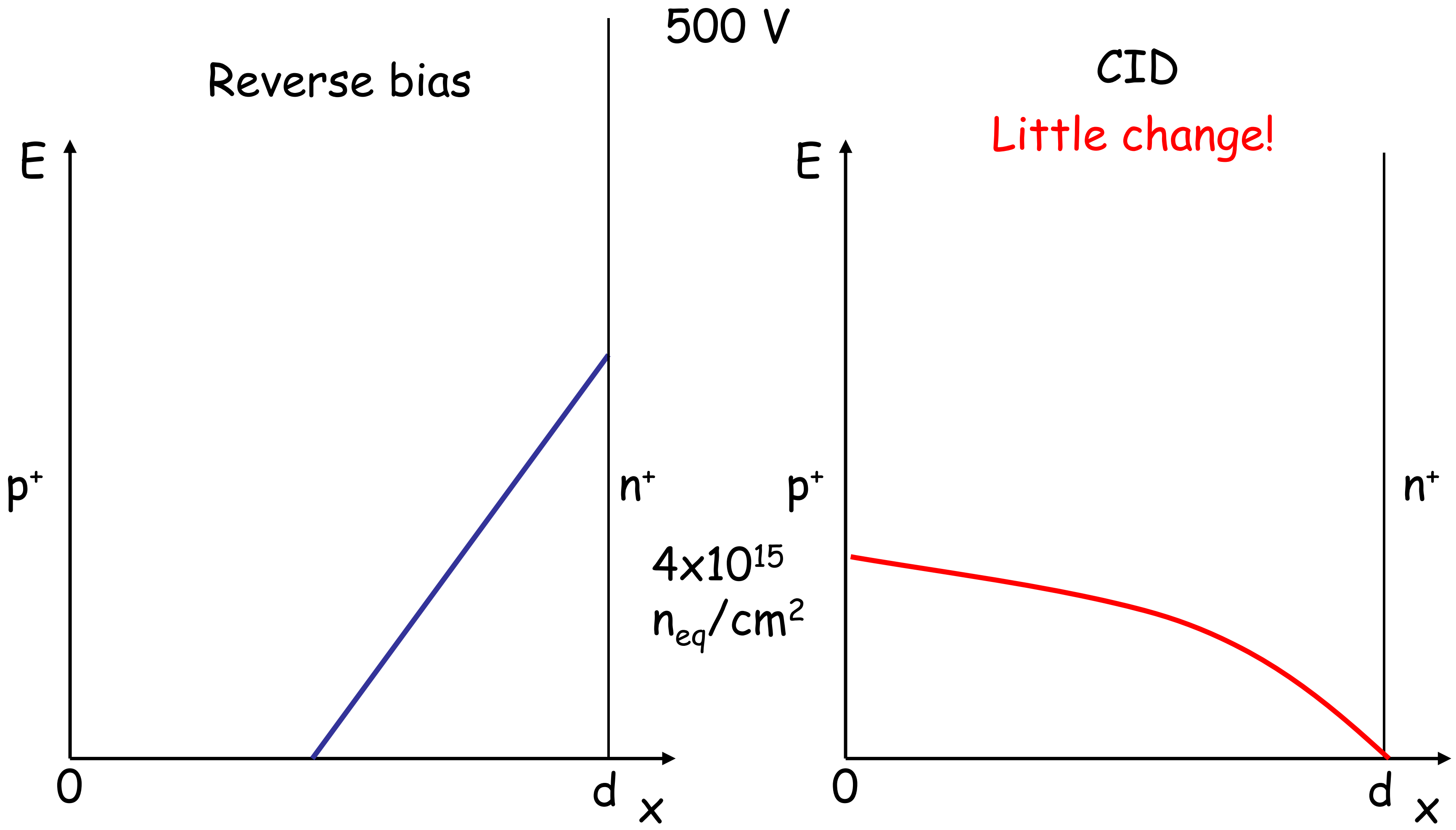

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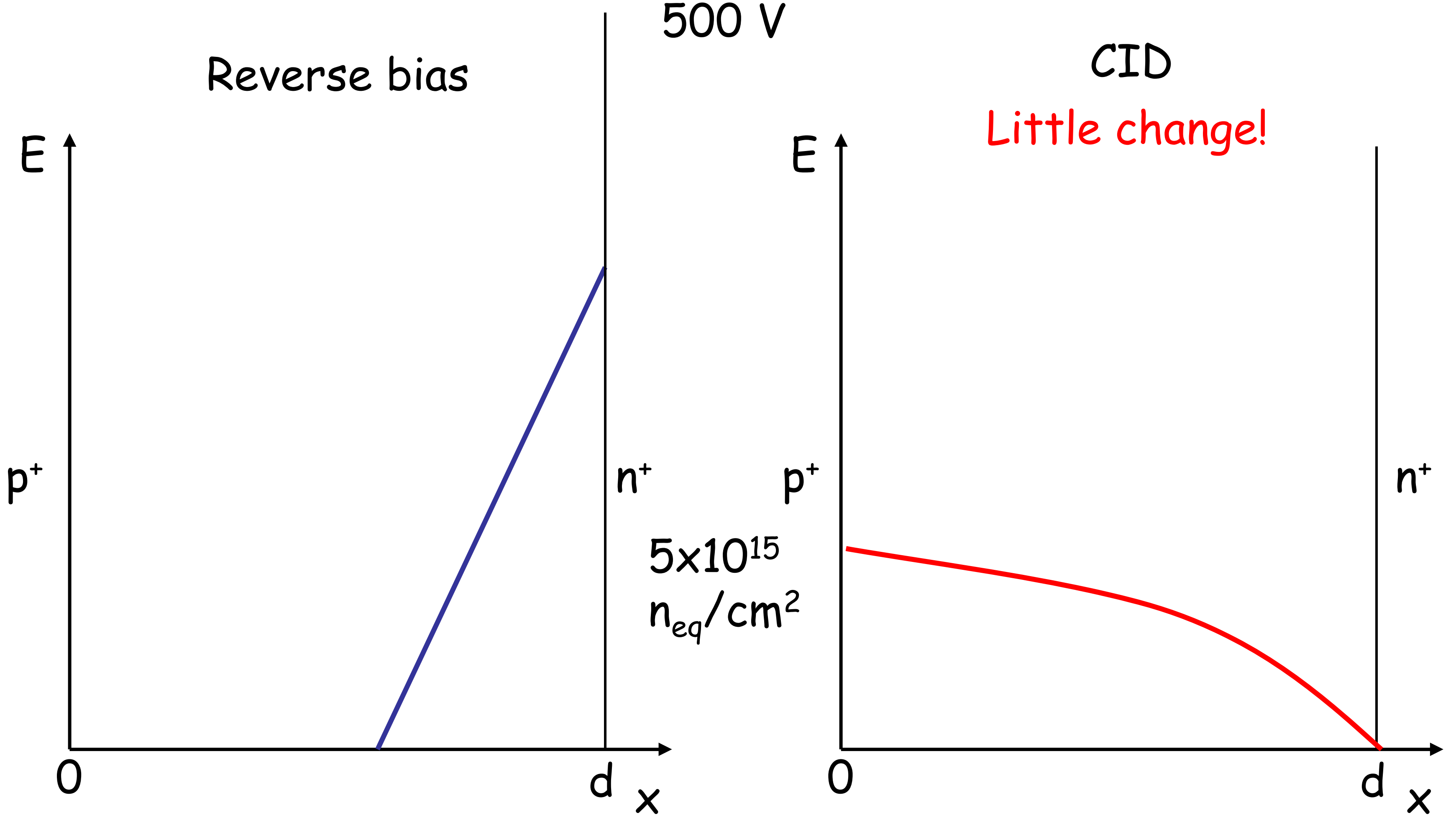

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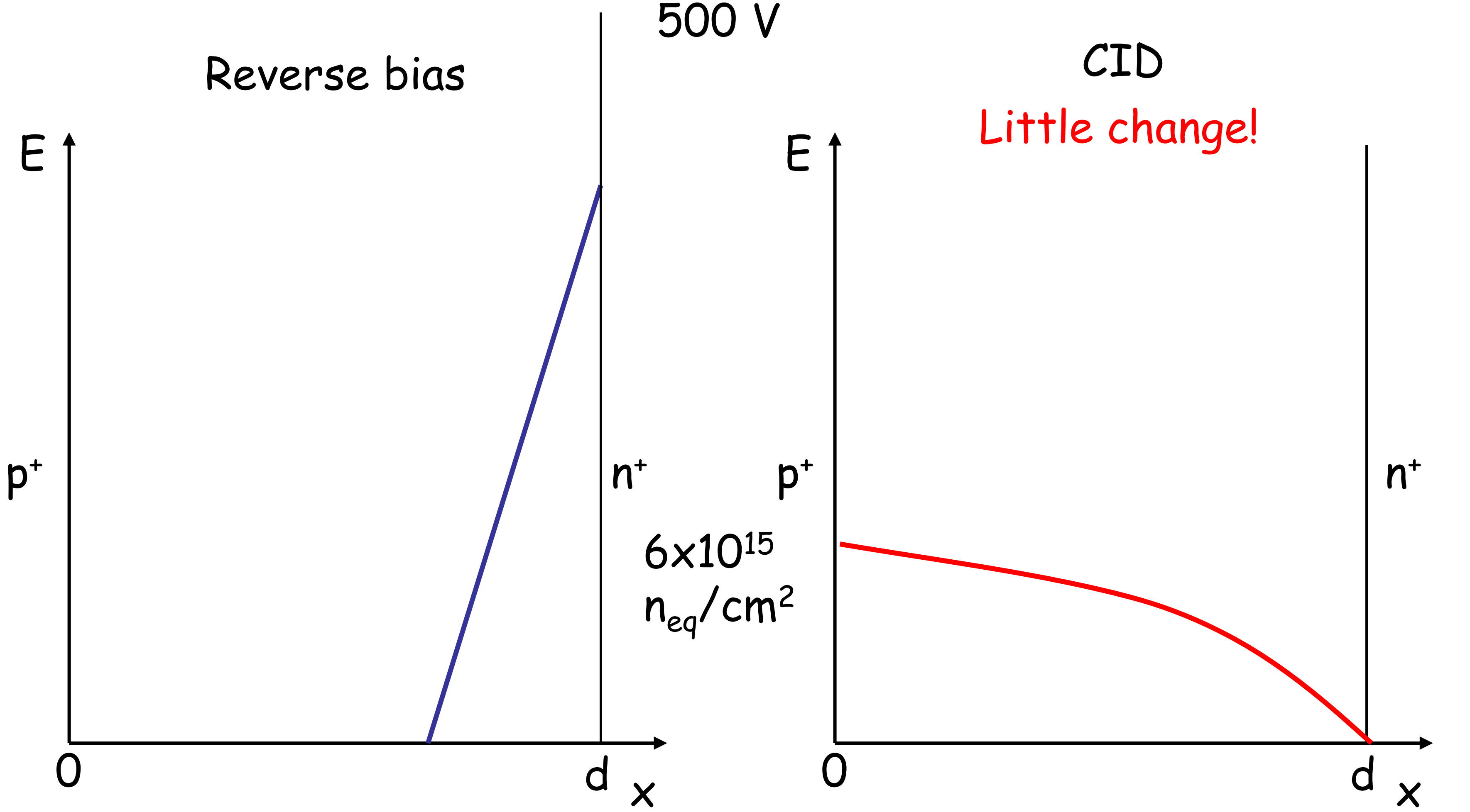

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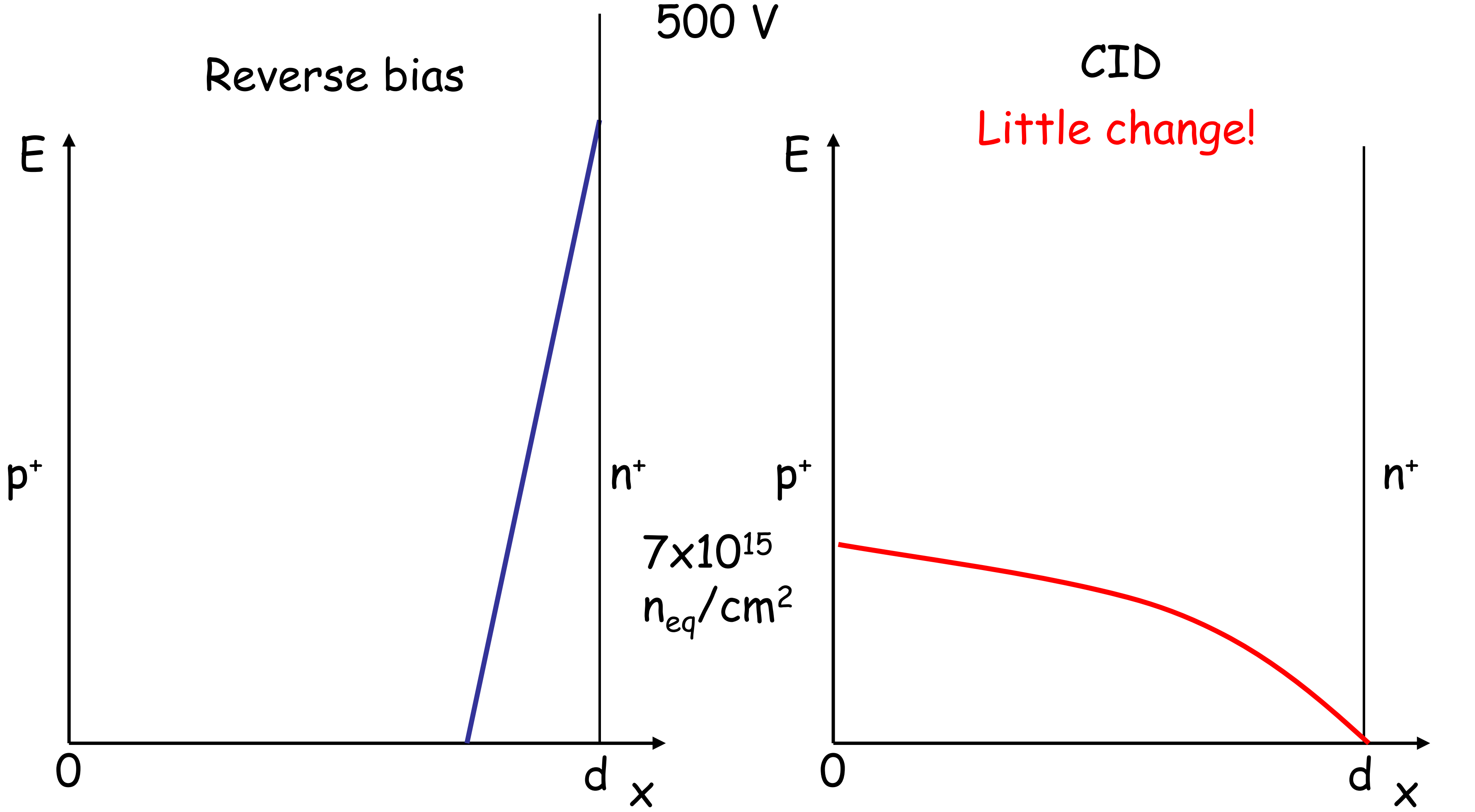

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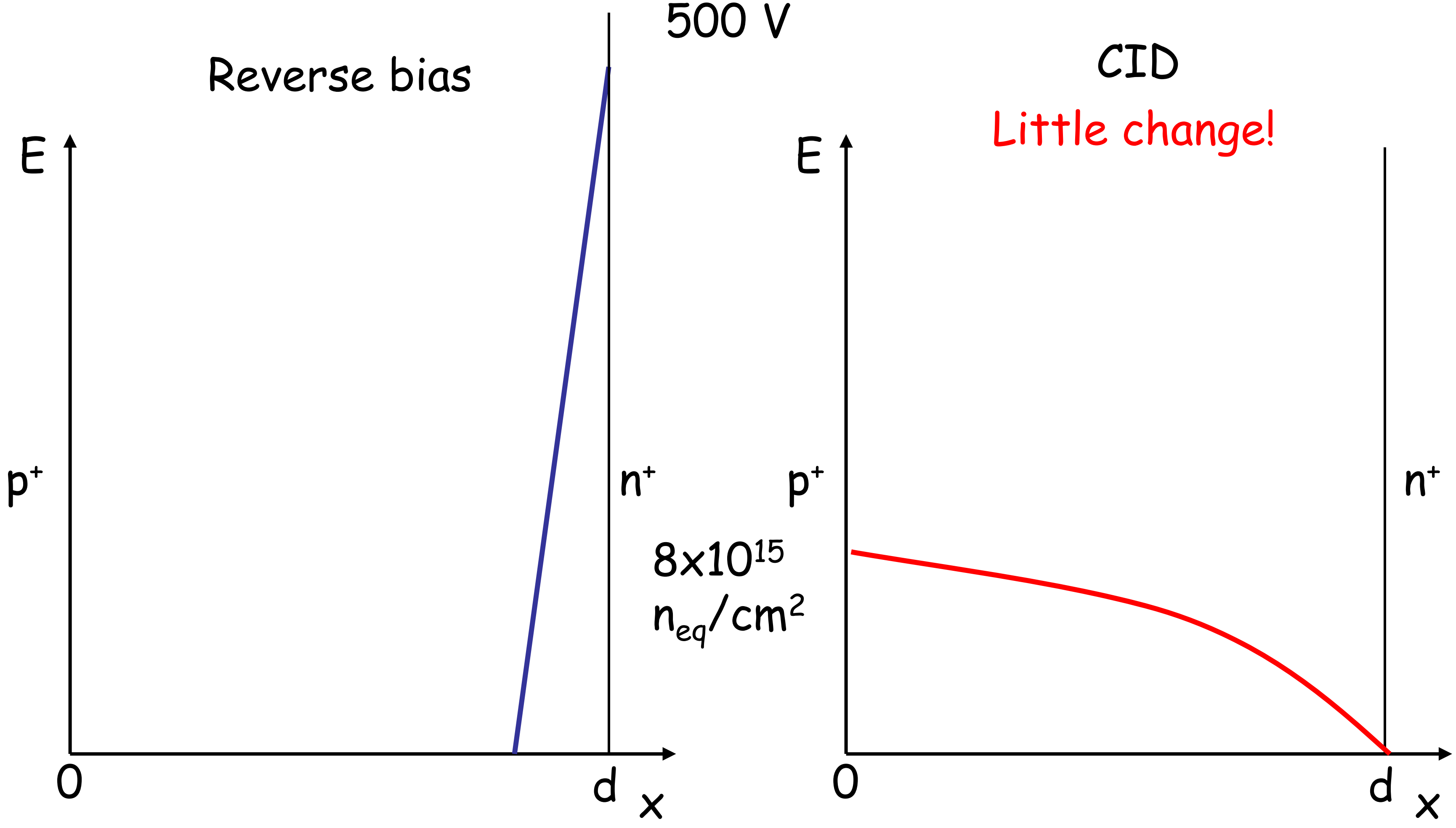

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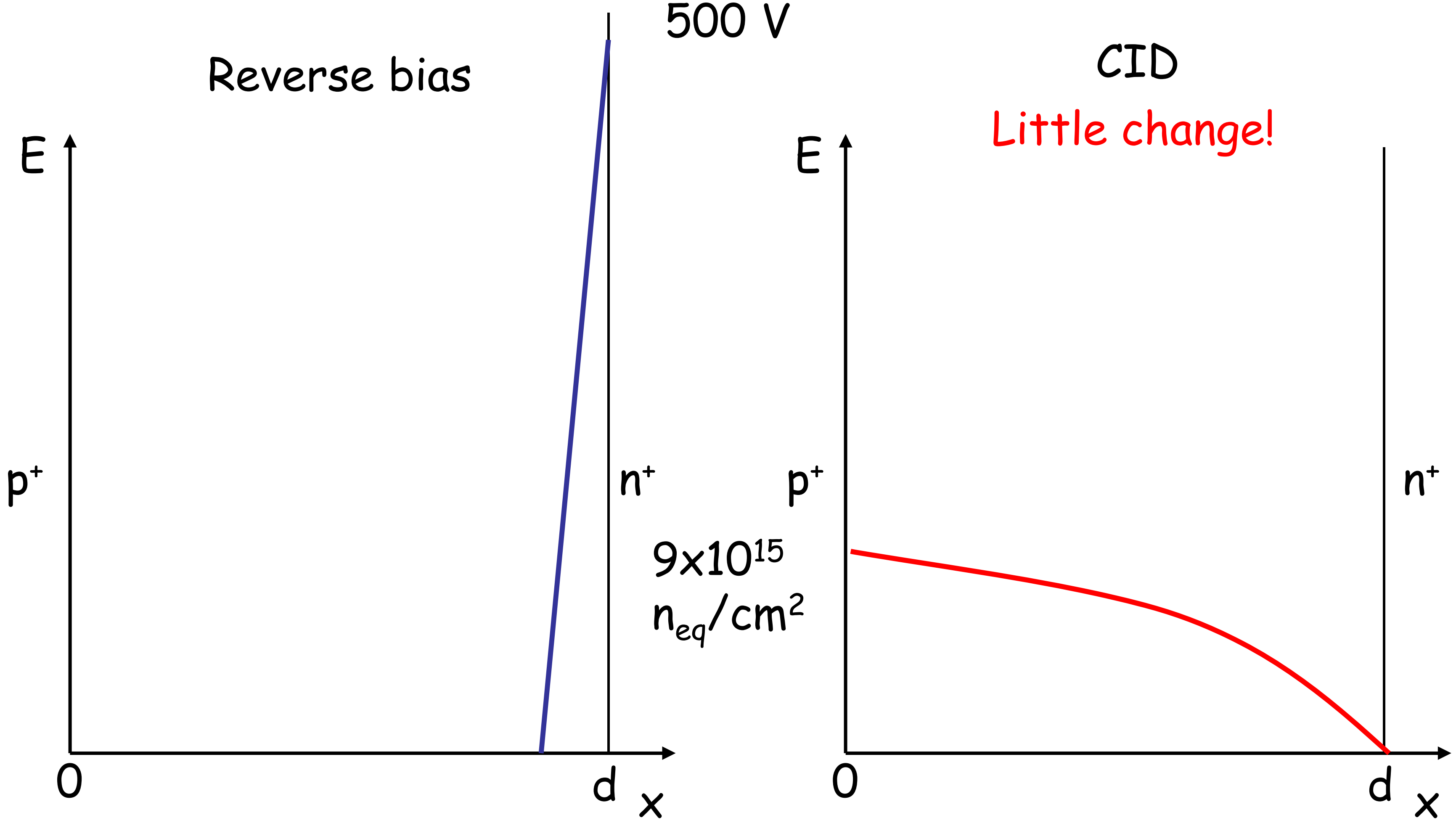

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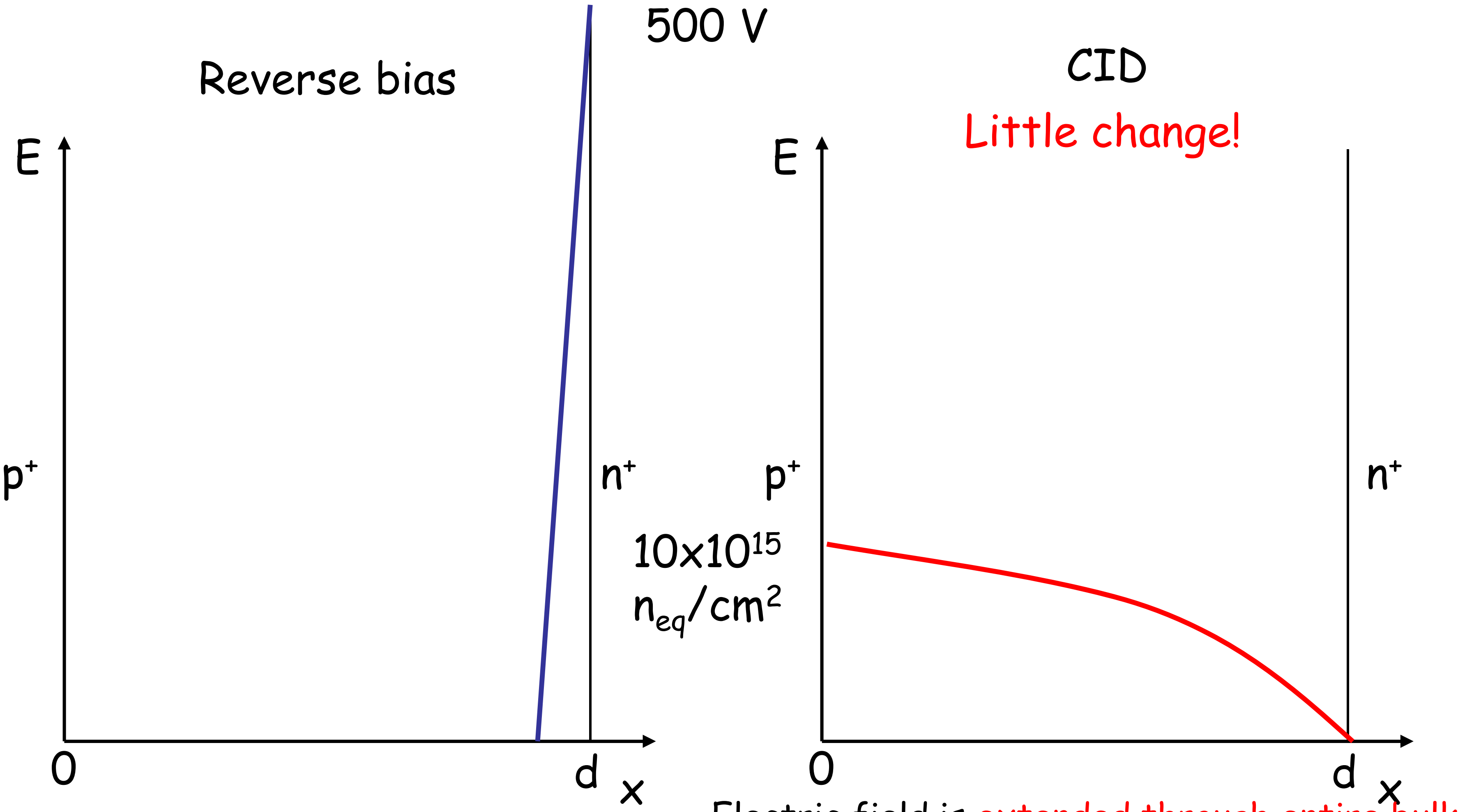
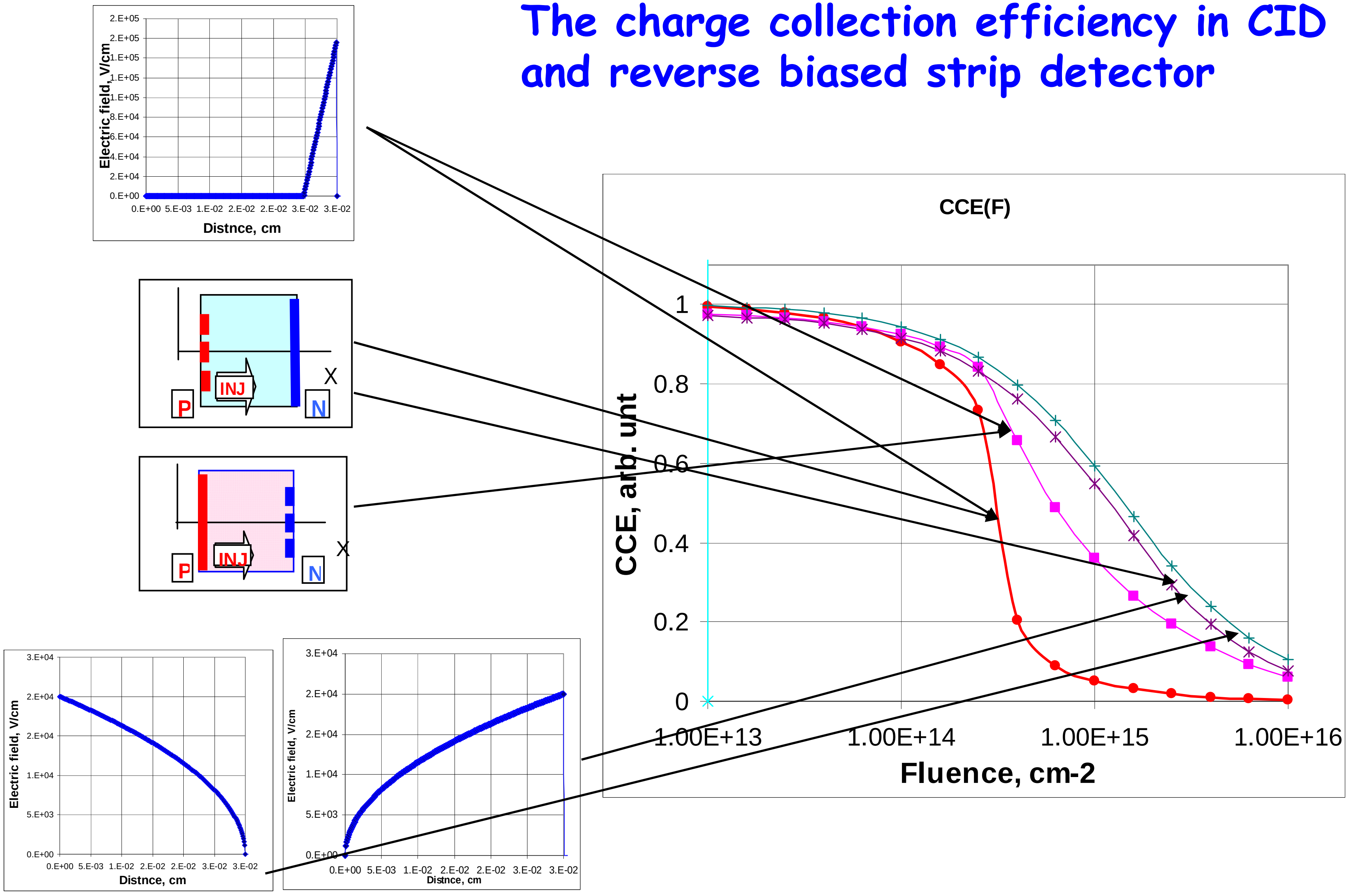


Electric field is extended through entire bulk regardless of irradiation fluence: **virtue full depletion**

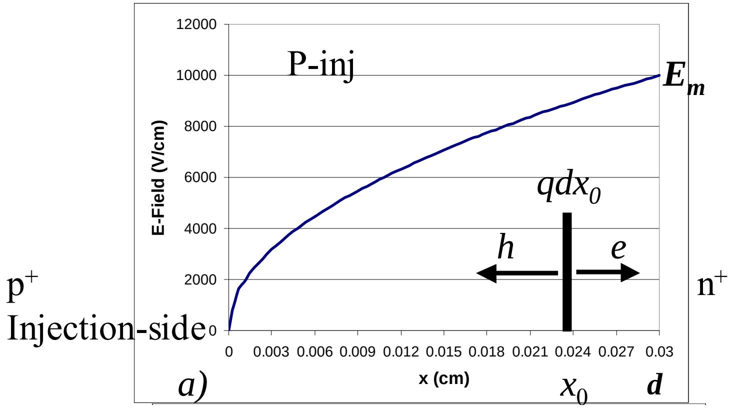
The charge collection efficiency in CID and reverse biased strip detector



Charge Collection Efficiency of CID detector

$$v_{dr}(x(t)) = \frac{dx(t)}{dt} = \frac{\mu E(x(t)}{1+\mu E(x(t)/v_s}$$

$$E(x) = E_m \cdot \sqrt{\frac{x}{d}} \quad ; \; E_m = \frac{3}{2}\cdot\frac{V}{d}$$



the total induced charge by electron sheet $q_{MIP}dx_0$ at x_0 is:

$$\Delta Q_e = q_{MIP}\Delta x_0 \int_0^{t_{edr}-t_{edr}(x_0)} v_{e\,dr}(t)\cdot E_W(x(t))\cdot e^{-t/\tau_{et}}\Delta t$$

Total charge collected is the sum of both e's and h's integrated over the detector thickness (for MIP)

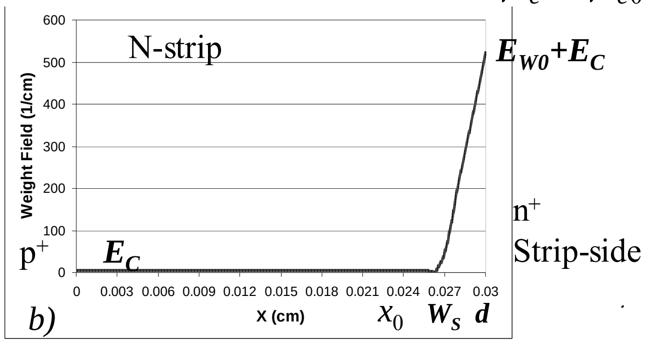
One has to take into account

1) Temperature dependence of e/h mobility

$$\mu_h = \mu_{h0}\left(\frac{T}{300}\right)^{-2.21} \qquad \mu_{h0} = 507cm^2/s/V$$

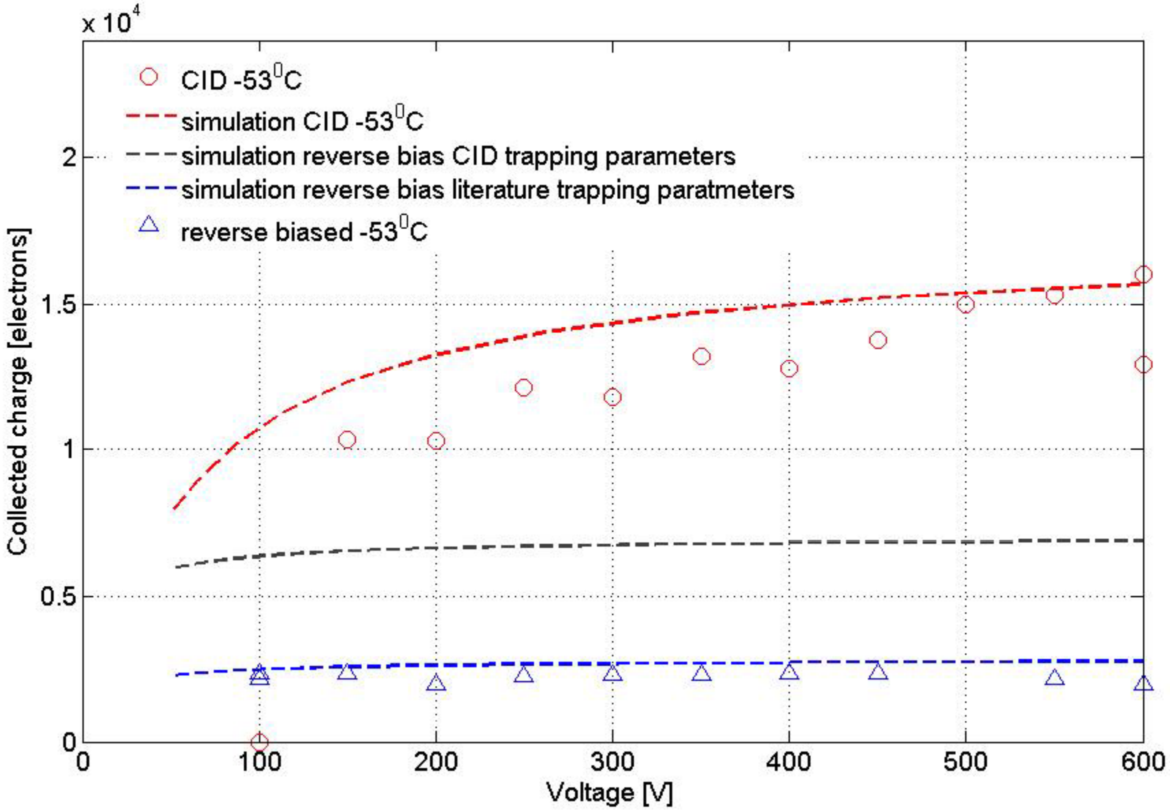
$$\mu_e = \mu_{e0}\left(\frac{T}{300}\right)^{-2.26} \qquad \mu_{e0} = 1590cm^2/s/V$$

2) Modification of *E(x)* due to segmentation of detector, i.e. so called weighting field E_W



CCE vs V simulation –CID vs reverse bias

$3X10^{15}\ n_{eq}/cm^2$

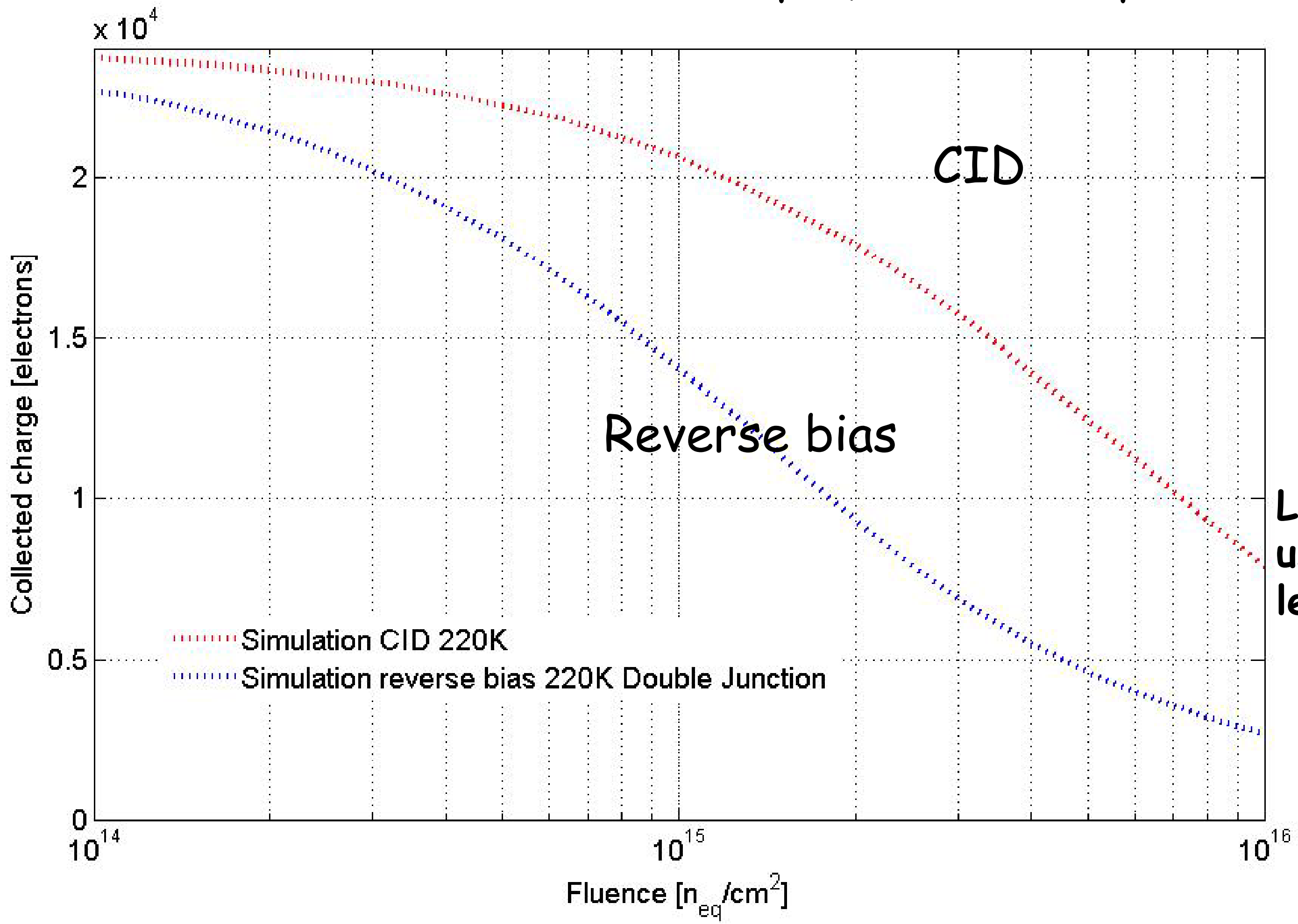


Larger τ_t
used to fit CID data
less trapping in CID

- Trapping of holes and electrons less in CID ?

CCE of strip detectors as a function of fluence

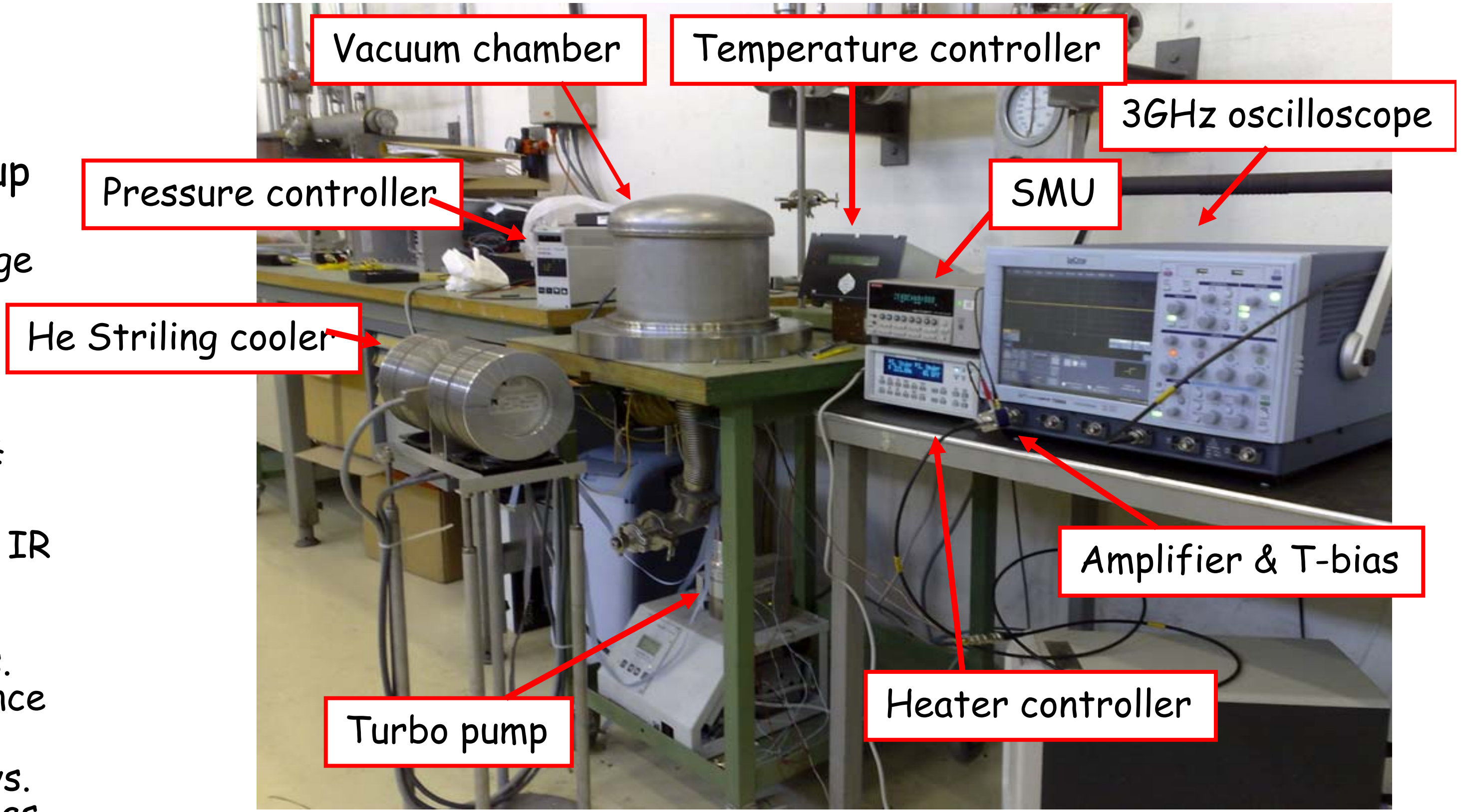
Pitch =80 μm, width =20 μm



Larger τ_t used to fit CID data less trapping in CID

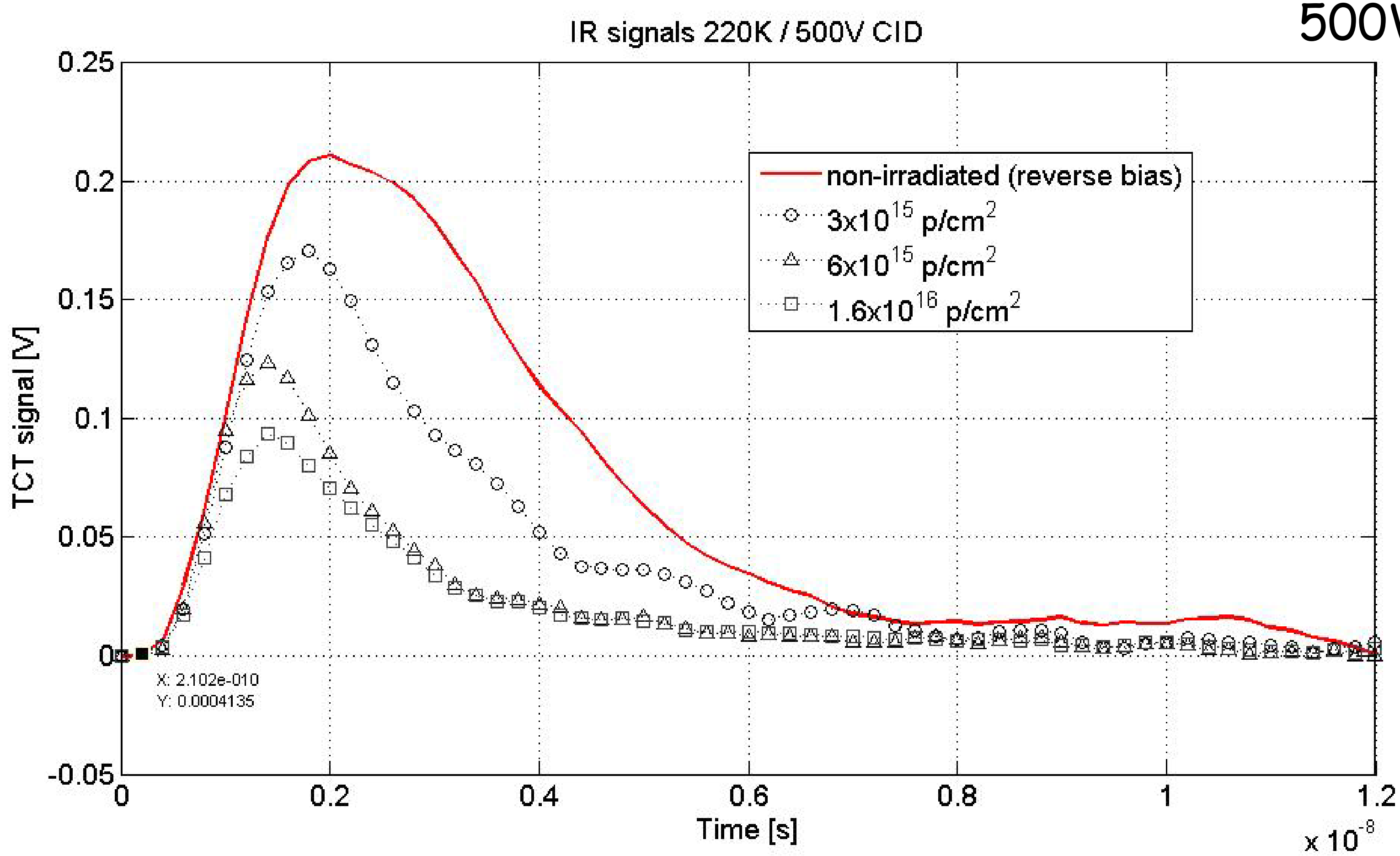
Characterization of CID detectors -Diodes

- CCE and TCT measurements with Cryogenic-TCT setup of RD39
  - Temperature range 40-300K
  - Measurements on diodes: i.e. no WF seen.
  - CCE with 1060nm IR laser.
  - Comparison of irradiated CID vs. non-irrad reference device.
  - Comparison CID vs. normal reverse bias under *exactly* same conditions.



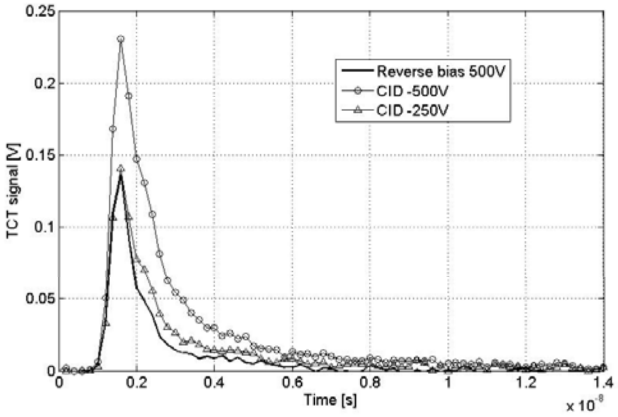
IR signals of 24 GeV/c irradiated pad detectors CID

500V / 220K

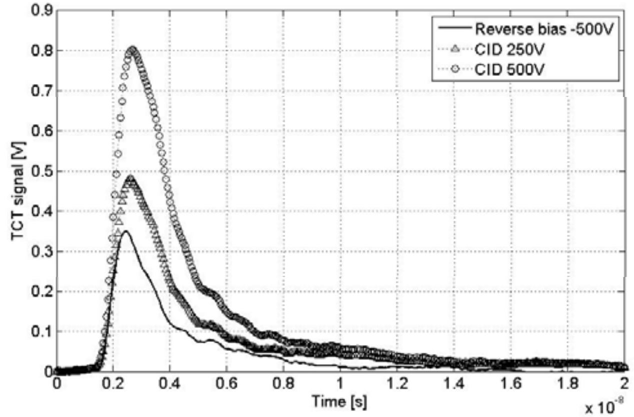


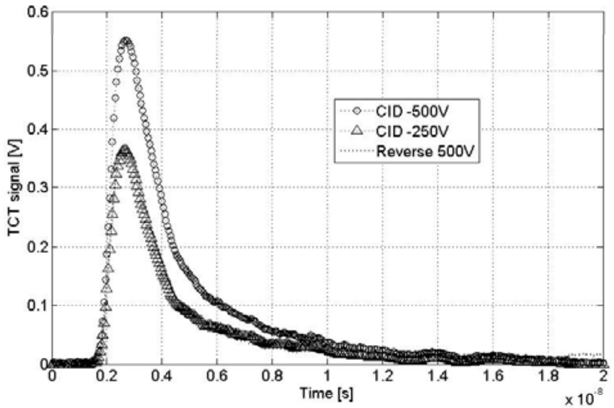
IR signals of heavily irradiated CID vs. reverse biased detectors

N-type P-type

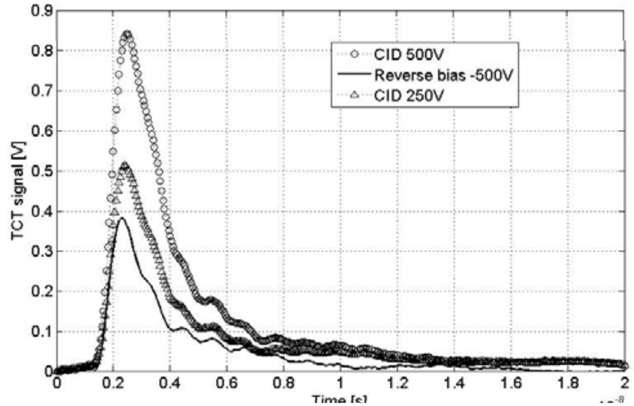


$1.0\times10^{16}n_{eq}/cm^2$

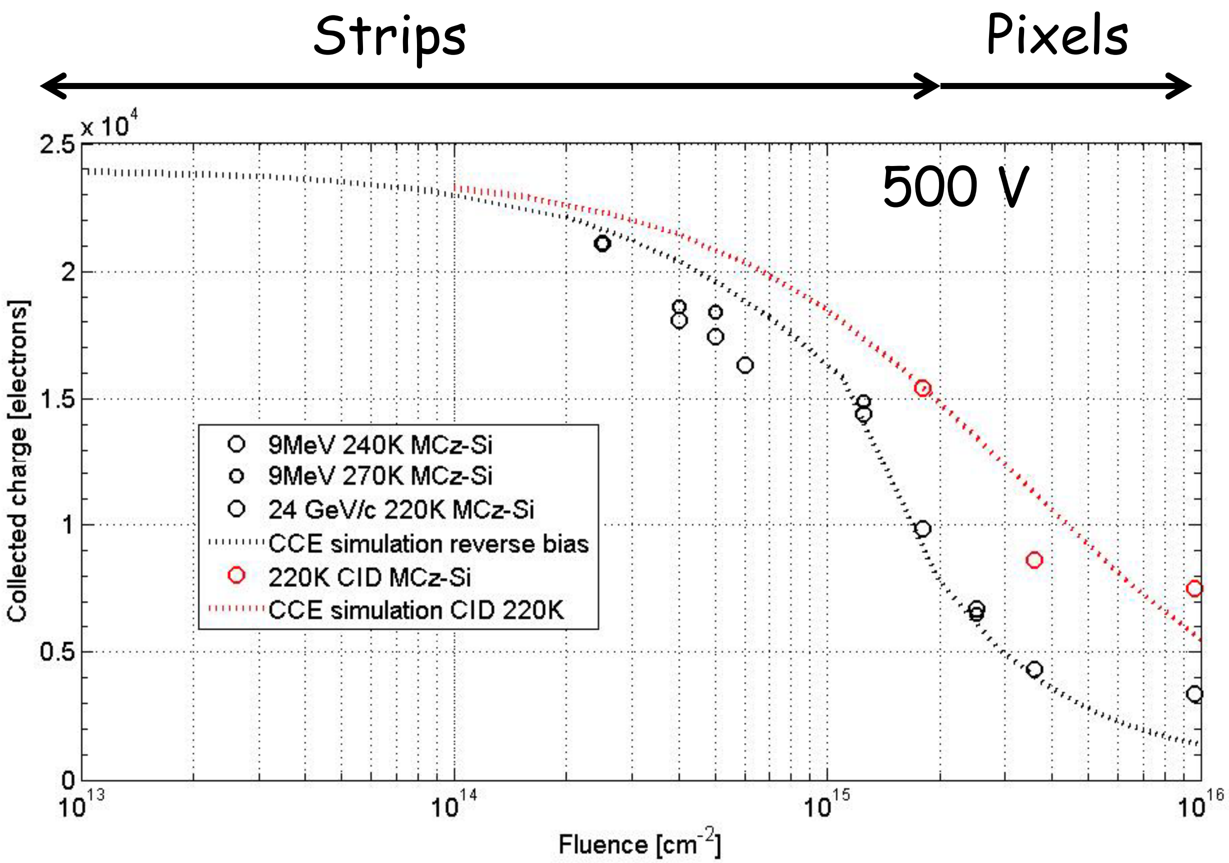




$3.0\times10^{15}n_{eq}/cm^2$



Expected CCE of CID at -50°C

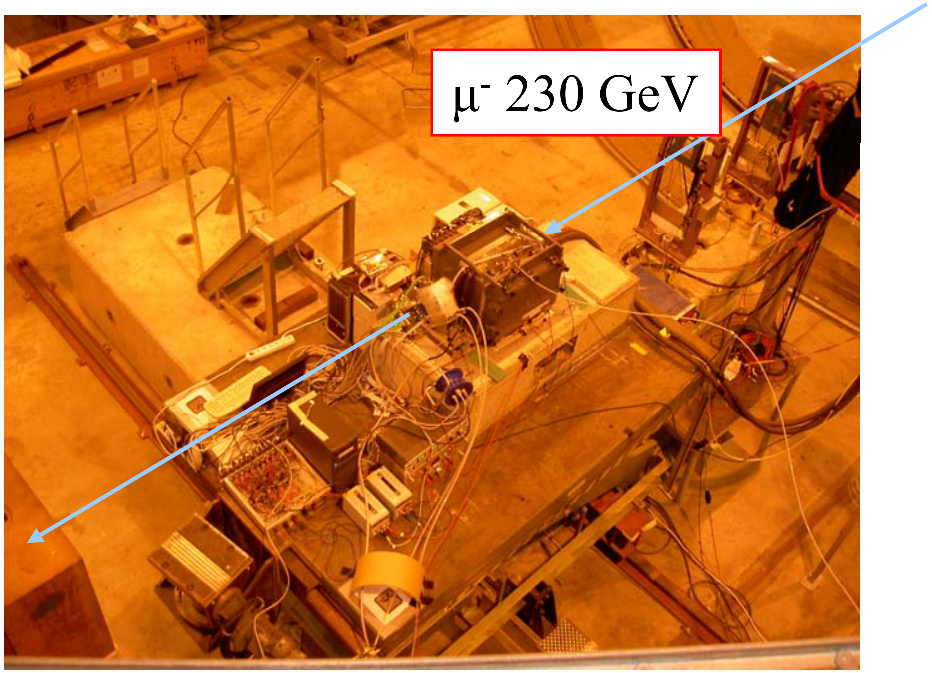


- Simulation takes into account linear dependence of trapping probability on fluence
- β=0.01 cm^{-1}
- $\sqrt{x}$ E-field distribution is assumed

$$E_{pin} \propto \left(1 - \frac{x}{w}\right)$$

$$E_{CID} \propto \sqrt{x}$$

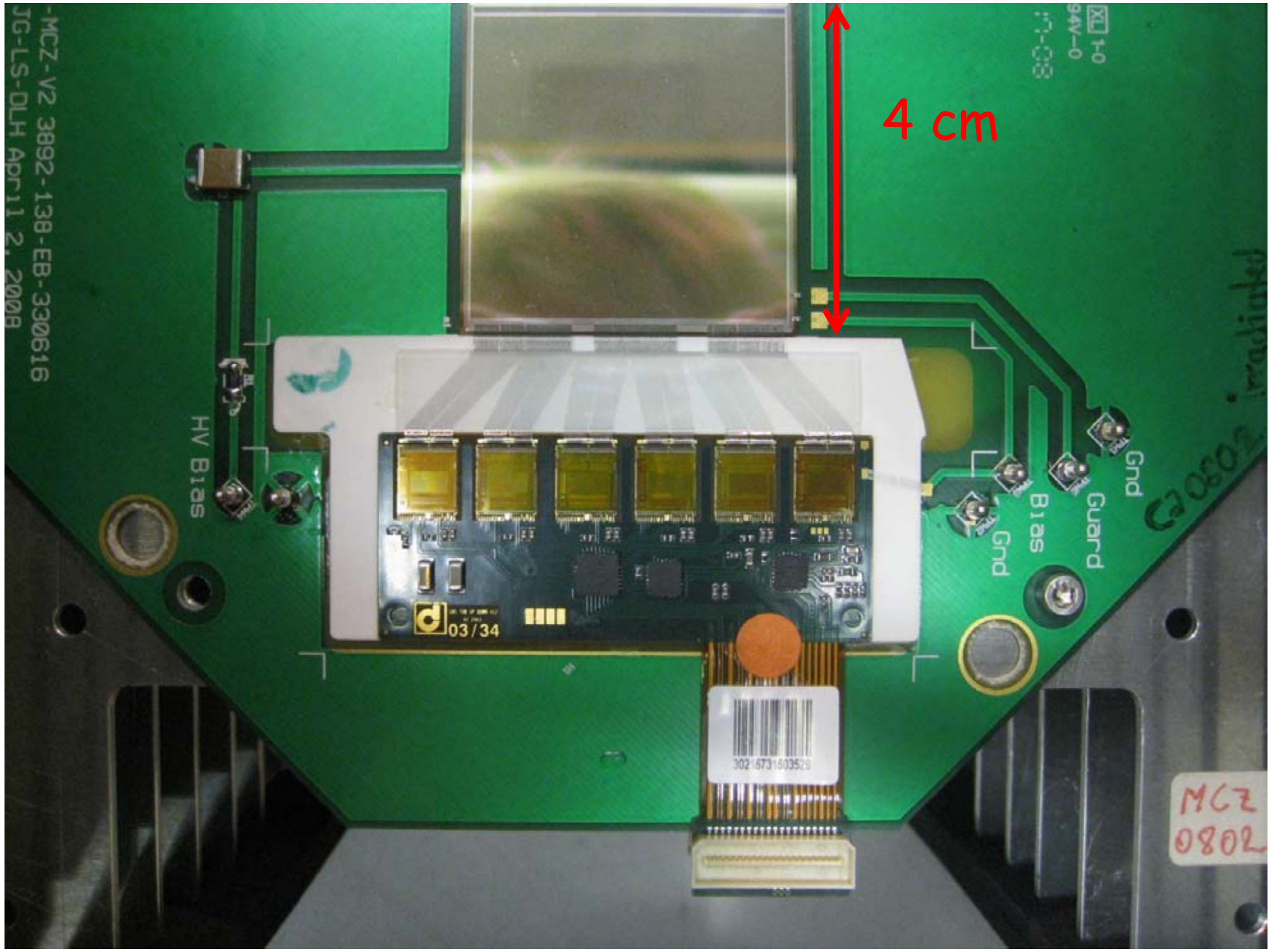
Characterization of CID strip detectors –Segmented detectors



- Test beam with 225 GeV/c muon beam at CERN H2.
- MCz-Si strip detector irradiated $3\times10^{15}n_{eq}/cm^2$.
- 768 channels attached to APV25 read-out
- CID detector placed in external cold box capable to cool down to -54°C while module is operational.
- Data acquisition with modified XDAQ. Analysis with CMSSW.

- 8 reference planes.
- Resolution ~4μm.
- About 25000 events in 20min.

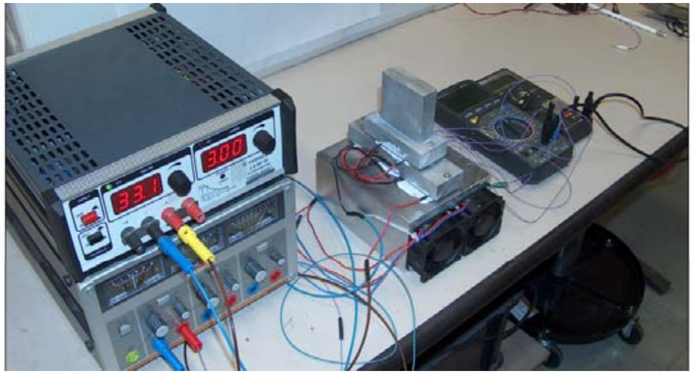
CID, irradiated up to $3\times10^{15}\ n_{eq}/cm^2$

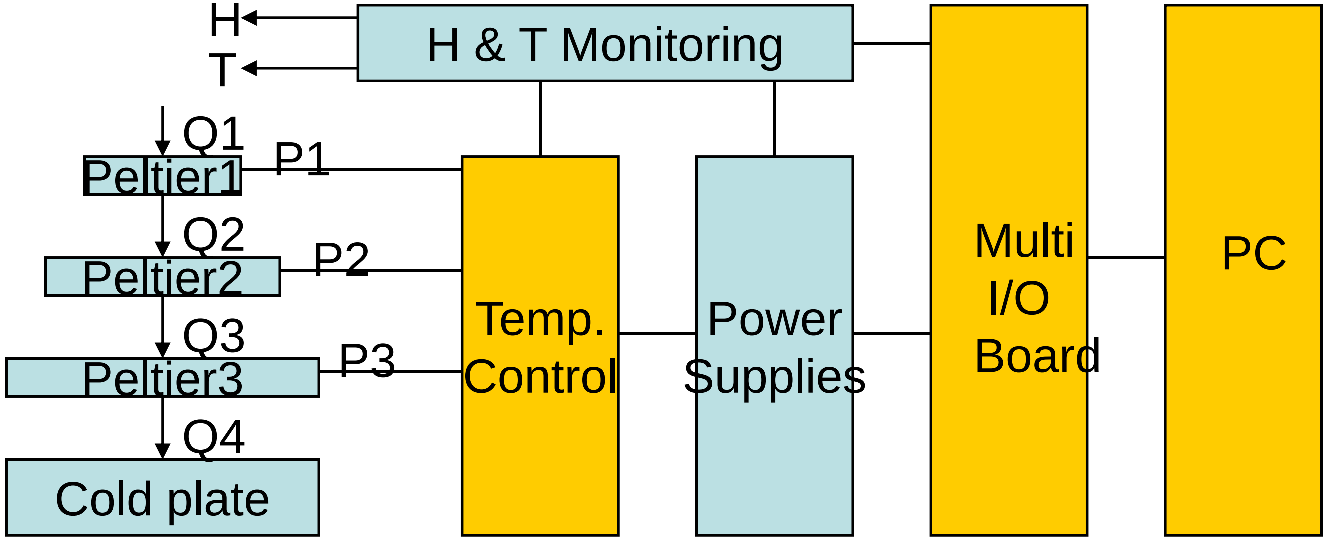


- MCz-Si AC-coupled strip detector with 768 channels
- APV25 readout
- Fabrication of detector and pitch adapter by HIP @ Helsinki University of Technology, Micronova
- Irradiation with 26 MeV protons @ University of Karlsruhe
- Bonding @ University of Karlsruhe

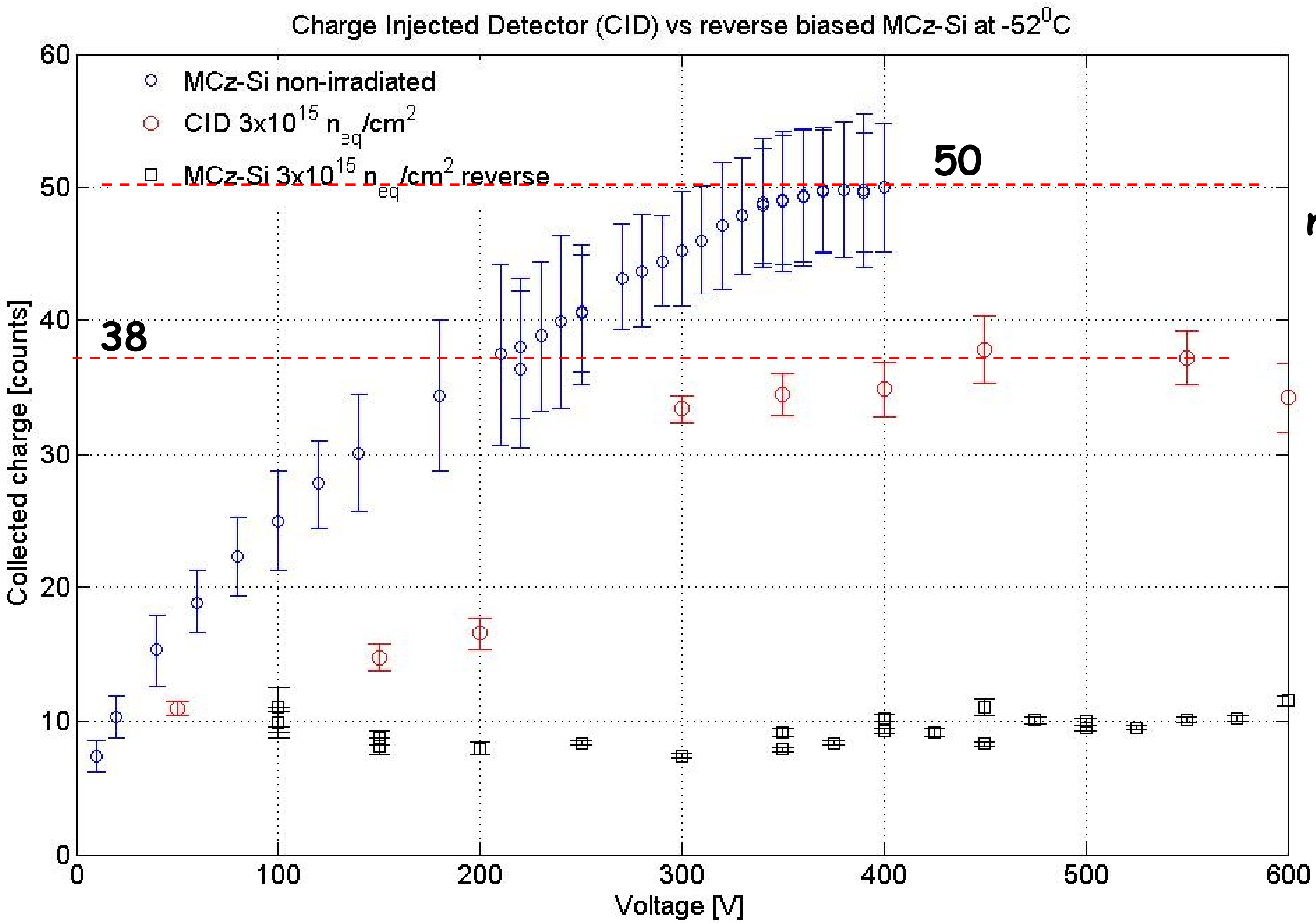
Cooling the CID down to -50^{0}C

- In order to measure the CID in a test beam, the SiBT telescope was used as a reference telescope.
- The CID was placed in front of SiBT inside an external cold finger, which was cooled down to -50 °C.
- *More about SiBT in Panja Luukka's talks at RD50 Workshops and CMS Upgrade meetings.*





CID strip detector test beam results –CCE at -52^{0}C



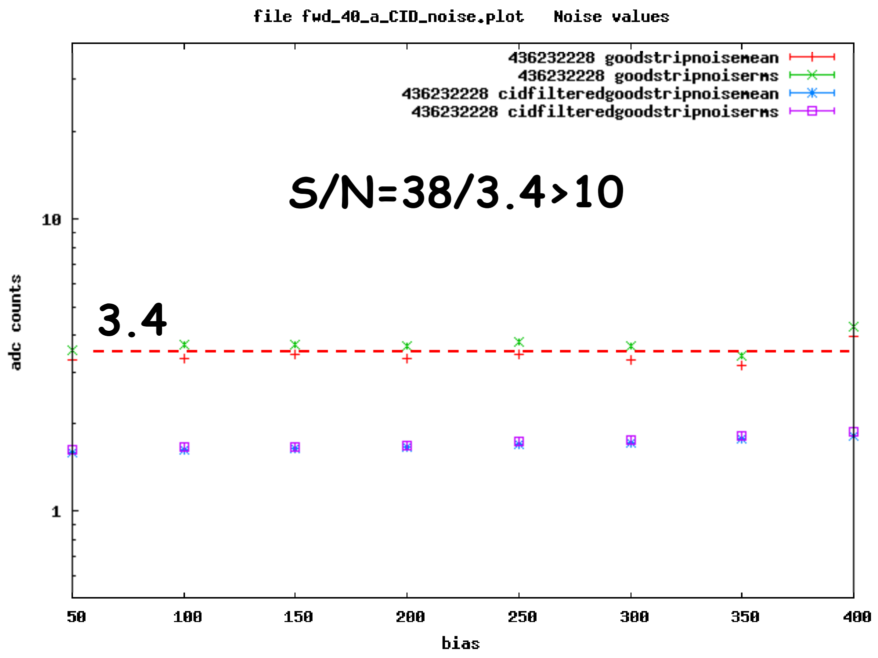
n fluence (n_{eq}/cm^2)

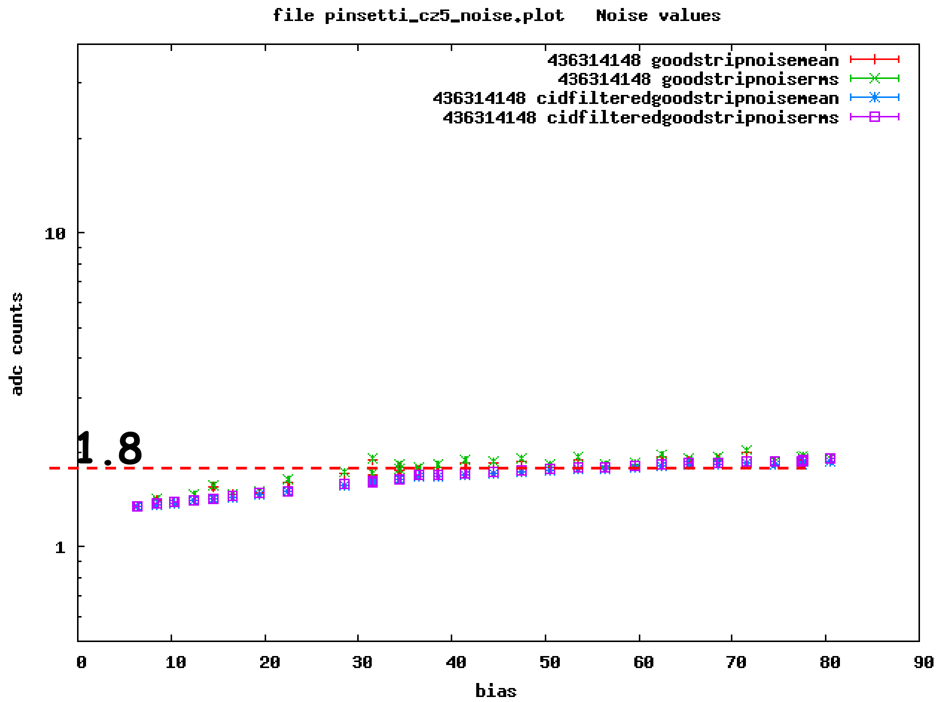
3×10^{15} → 1×10^{16}

75% → 22.5% (5400 e's)

20% → 6% (1440 e's)

Noise of CID and non-irradiated detector



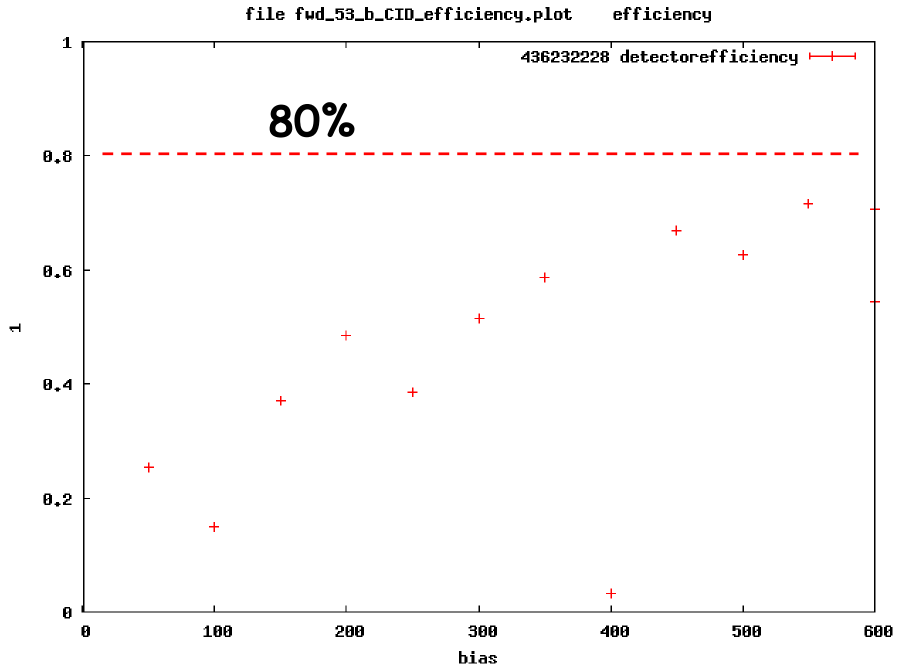


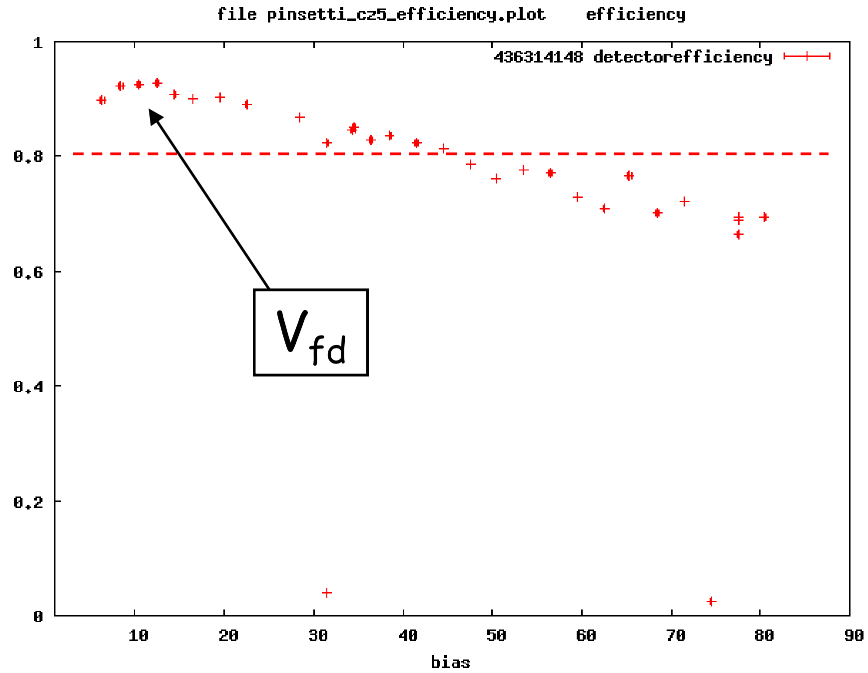
CID noise at -40 °C
Little change with T (-53 to -40 ° C)

Reference detector noise at -20°C

Fz-Si $p^+/n^-/n^+$, same design, same processing, V_{fd}~10V

Tracking efficiency of CID vs reference



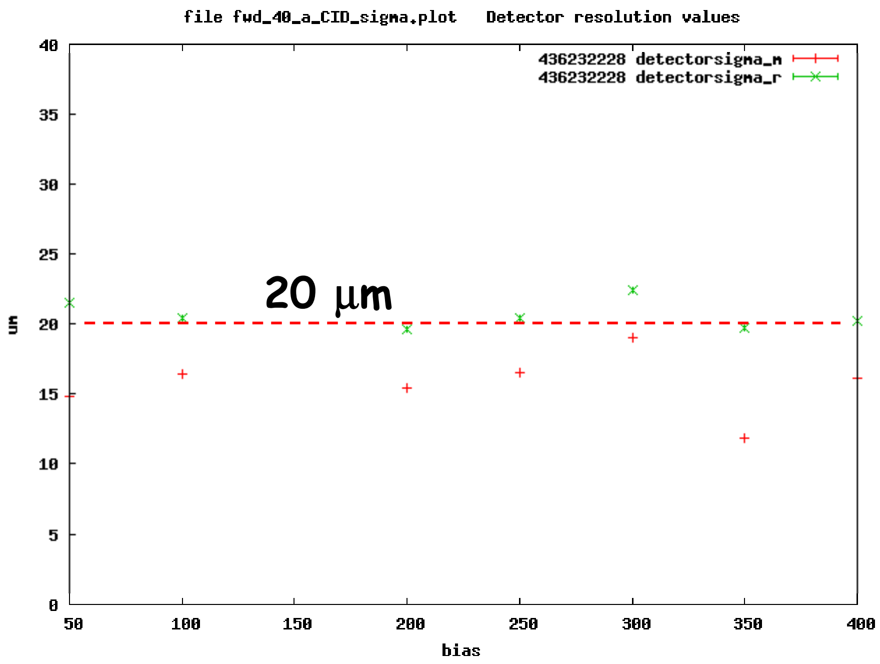


CID at -53°C

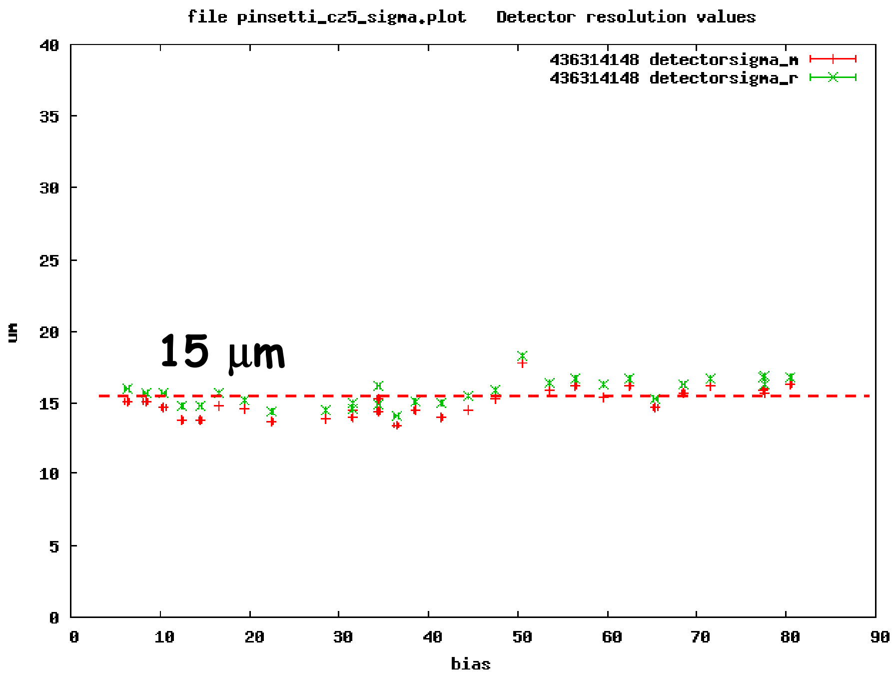
Reference Fz-Si at -20°C

Tracking efficiency in this content = probability that DUT measures the same track as 8 reference planes

Resolution of CID 3×10^{15} n_{eq}/cm^2 vs. non-irradiated reference



CID 3×10^{15} n_{eq}/cm^2 -40°C



Reference Fz-Si -20°C

Conclusions

- CID offers virtue full dpeltion and less trapping
- At least two times greater CCE is expected from CID than in reverse biased detectors according to C-TCT (IR laser) measurements and simulations.
- Normal detector operation possible by 300μm MCz-Si up to 2×10^{15} n_{eq}/cm^2 fluence, i.e. strip layers in Super-LHC trackers.
- CID was measured at -40°C, -45°C and -53°C for 768 channels AC-coupled MCz-Si strip detector in test beam.
- Test beam results reveal >70%, and S/N >10 after 3×10^{15} n_{eq}/cm^2 irradiation.
- Test beam was performed with recycled CMS electronics and DAQ.
- CID operation possible up to 1×10^{16} n_{eq}/cm^2 fluence.
- Collected charge equals ≈7000e$^-$ and 30%.

Work plan 2009

Goal: Be closer to the LHC experiments

- Test beam on heavily irradiated CID strip detectors available now in summer 2009.
- New micro strip sensor processing (ATLAS and CMS specifications).
  - Development (different thickness)
  - Irradiation 1.0-10×10^{15} n_{eq}/cm^2.
  - Module assembly and bonding.
  - Test beam in 2010

•Study of CID suitability for higher temperature operation.
- Target is -25°C i.e. operational temperature of current LHC trackers.
- Detector thickness study: the thicker, the higher operational T
- Temperature dependent simulations of CCE and S/N.
- Measurements on diodes with C-TCT.
- Trapping time constant measurement of CID
- Test beam results analysis.
- Optima detector configurations (n on p, symmetrical, p on p, n on n)

RD39 Conference participation in 2008

- 10th International Workshop on Radiation Imaging Detectors in Helsinki, Finland, June 29 - July 3, 2008.
- 6th IFAMST The International Forum on Advanced Material Science and Technology, Hong Kong, June 12-14, 2008.
- 7th International Conference on Radiation Effects on Semiconductor Materials Detectors and Devices, Florence,15-17 October 2008.
- Pixel2008, FNAL, Batavia, IL, USA, **23–26 September, 2008**
- CMS Upgrade workshop, FNAL, Batavia, IL, USA, November 18-20, 2008.

RD39 Workshops at Ljubljana, Slovenia and at CERN (June and November, 2008)