Influence of trapping on silicon microstrip detector design and performance

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Outline:

- Motivation
- Detector Simulation
- Results
  - choice of strip type, width
  - detector thickness
  - charge induced on neighboring strips
  - influence of magnetic field
- Conclusions

Motivation

Recent measurements of $\tau_{eff,e,h}$

- differ substantially from old ones
- systematically measured (irradiation particle type, material, T, Φ_{eq}, annealing)

Segmented detector geometry results in:

- charge drift time depends on position of creation
- charge sharing between electrodes depends on drift duration and creation point
- electrons and holes contribute unequally to the induced charge

What is the impact of trapping on charge collection in segmented devices and diodes ?

An emphesis is given on operation of strip detectors, particularly on ATLAS strip detector design (80-18-280 μm)

Detector simulation

$$\vec{F} = \vec{E} + \mu_{H\,e,h}\ \vec{E} \times \vec{B}$$

point charge "bucket":

$$I_{e,h}(t) = q \exp(-\frac{t}{\tau_{eff,e,h}})\ \vec{E}_w(\vec{r}_{e,h}(t))\ \mu_{e,h}\ \vec{F}(\vec{r}_{e,h}(t))$$

trapping

weighting field

electric and magnetic field

$$\frac{1}{\tau_{eff,e,h}} = \beta_{e,h}\ \Phi_{eq}$$

	β_e (10^{-16} cm^2/ns)	β_h (10^{-16} cm^2/ns)
reactor neutrons	**4.1** **~ 6-7**	**6.0** **~2-3**
p+ (24 GeV) **π+ (200 MeV)**	**5.7** -	**7.7** -

constant *1/D* if pad or strip dimension>>D

complex otherwise highest close to the strips or pads

$\vec{B}$ parallel with strips

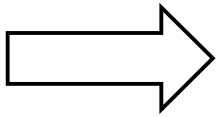
Irradiation: $N_{eff} = -g \cdot \Phi_{eq}$

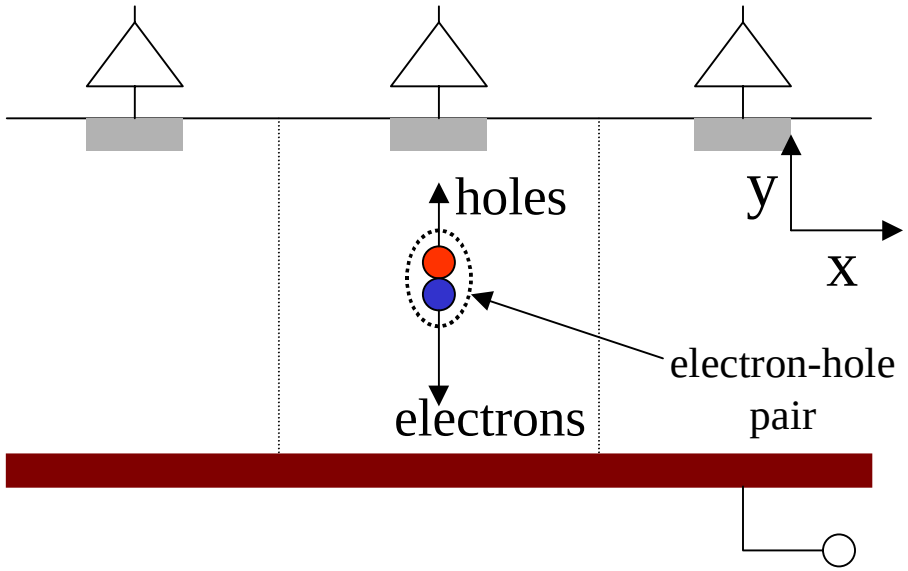
$$\nabla^2 U = -\frac{e_0\ N_{eff}}{\varepsilon\varepsilon_0}$$

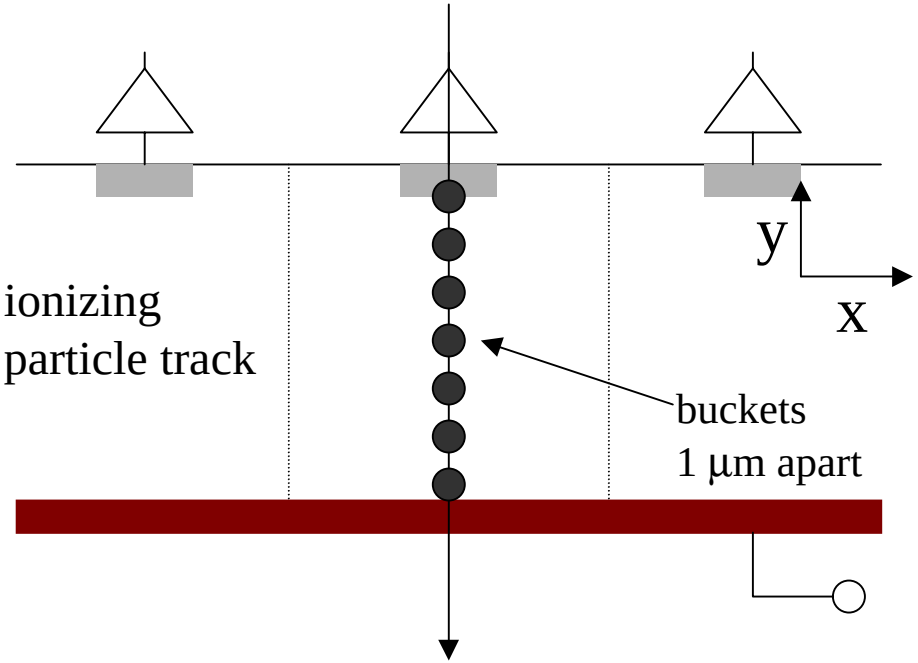
$$\Downarrow$$

$$\nabla U = -\vec{E}$$

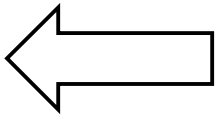
Point charge





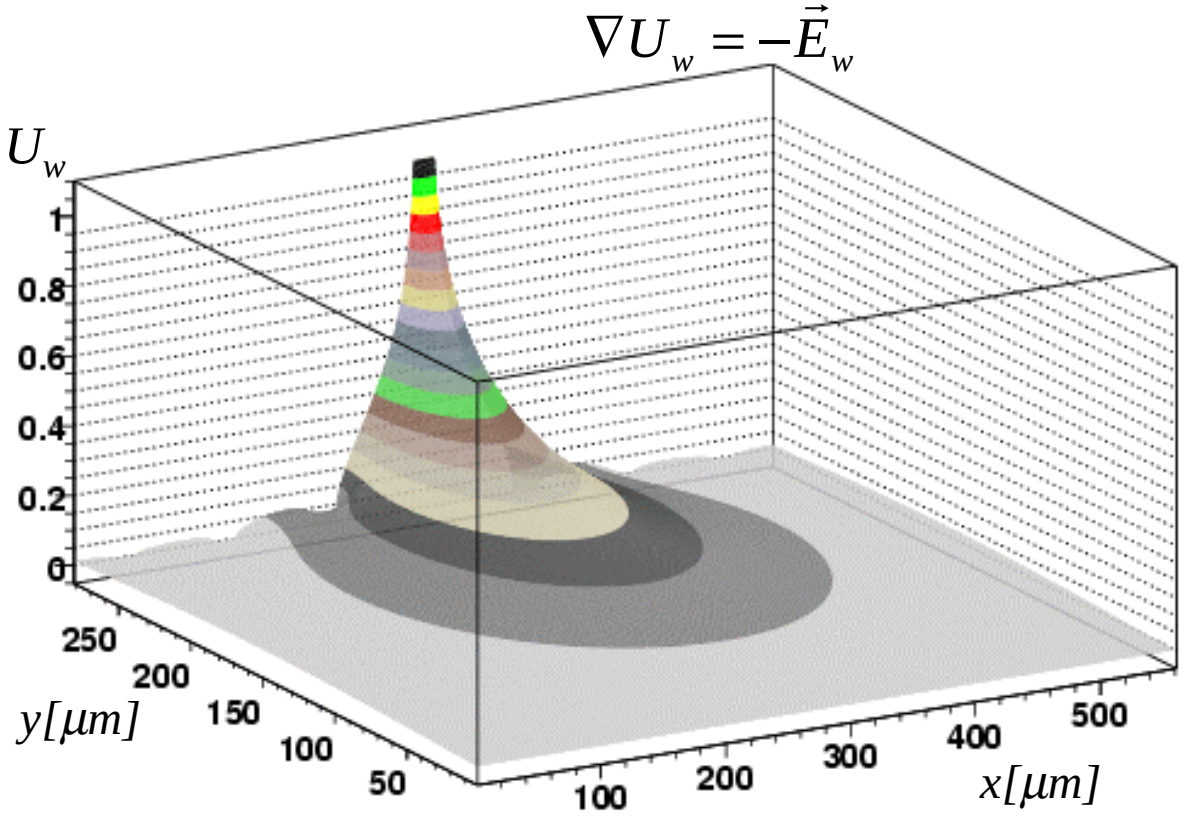


track



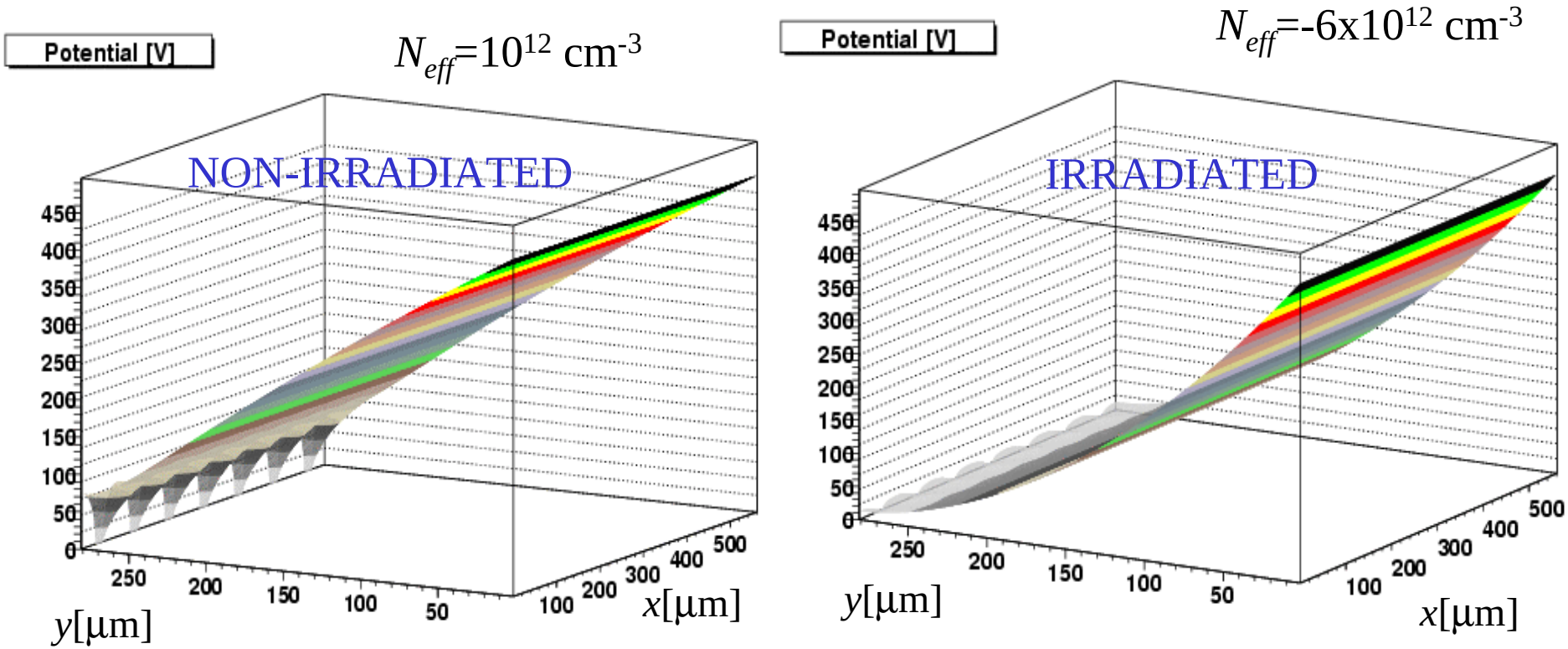
$$I(t) = \sum_{buckets} I_e(t) + I_h(t)$$

Weighting potential
in strip detector:
thickness=280 μm
strip pitch=80 μm
strip width=18 μm

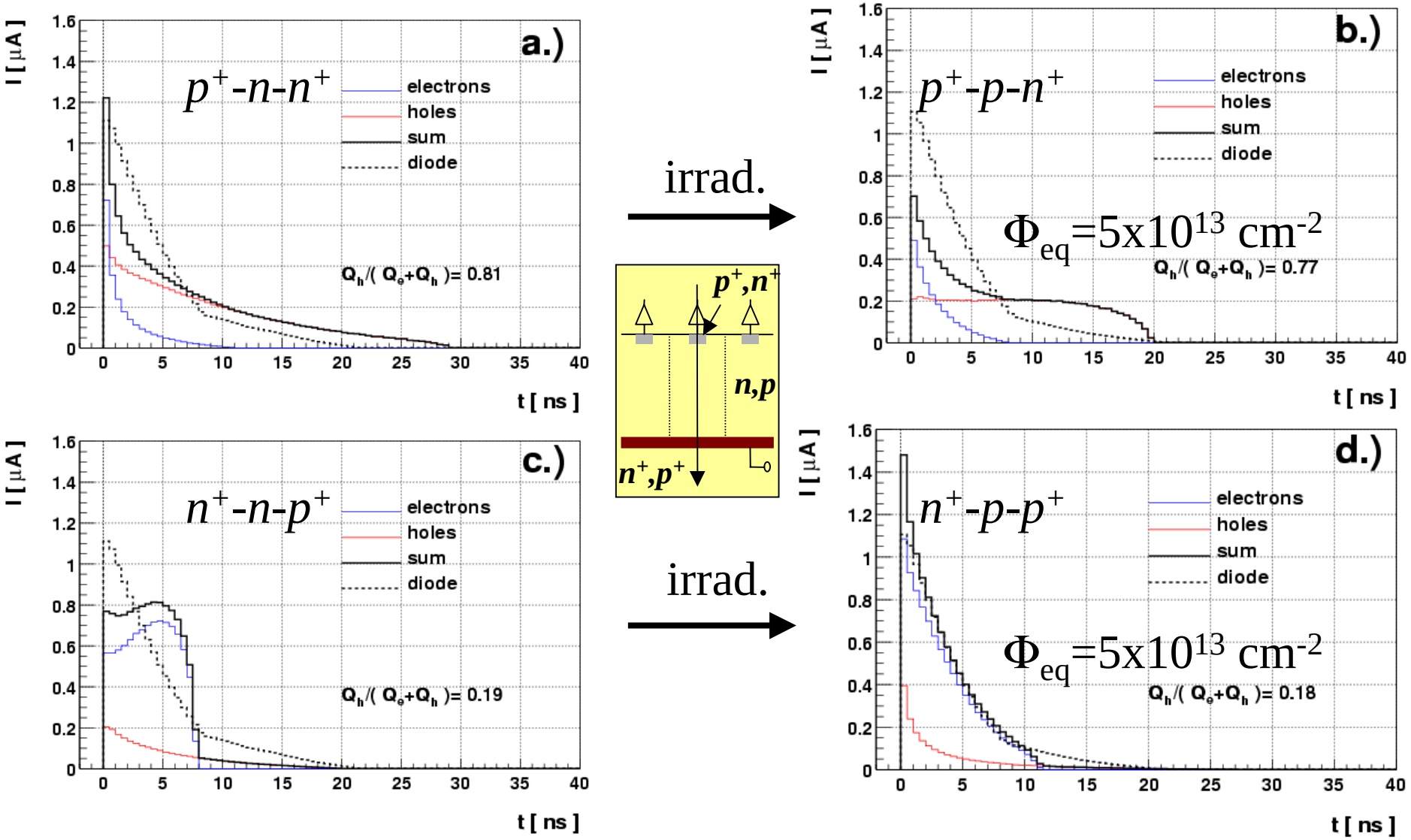


far from constant
as it is in a diode → carries drifting to strips contribute larger part to the induced charge

Example of calculated electric field

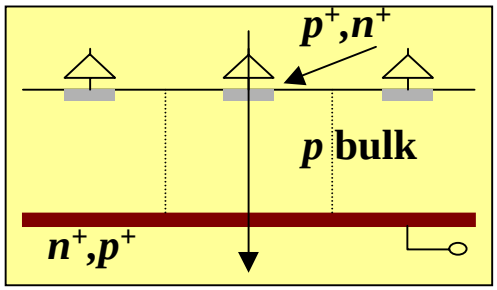


Choice of strip type



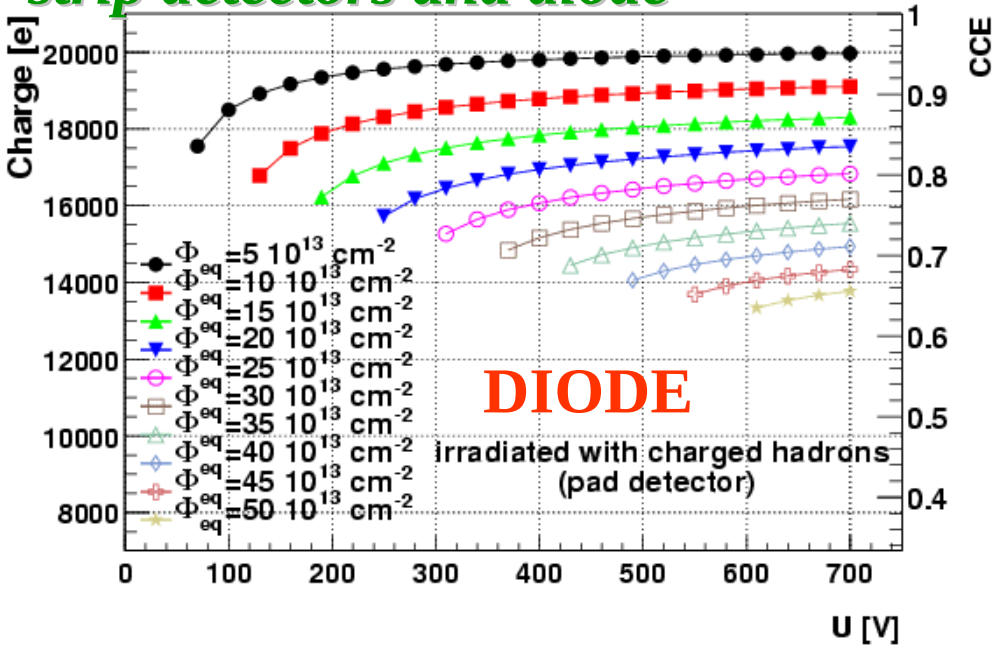
NOTE THAT DIODE SIGNAL HAS THE SAME SHAPE!

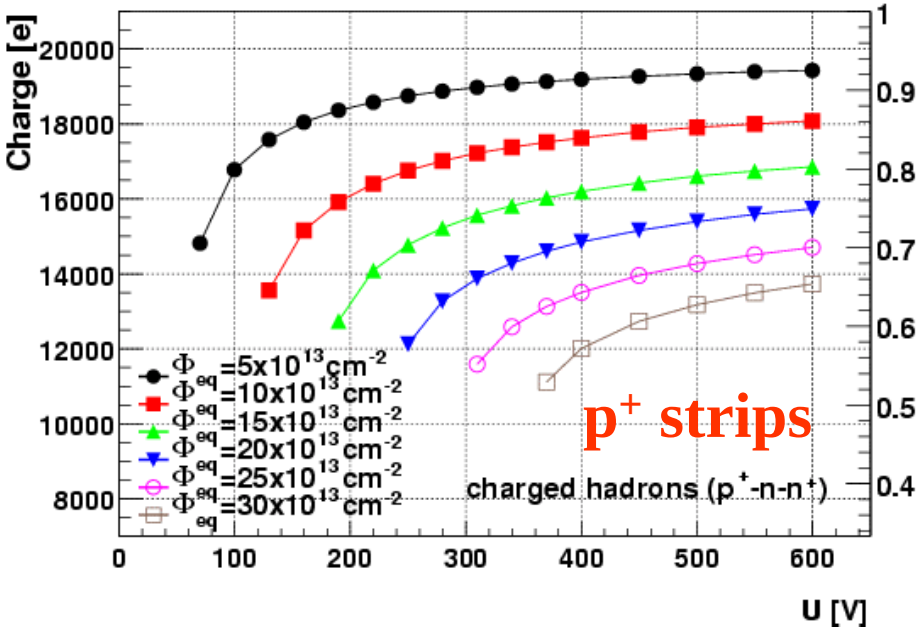
I. CCE of irradiated p⁺, n⁺ strip detectors and diode

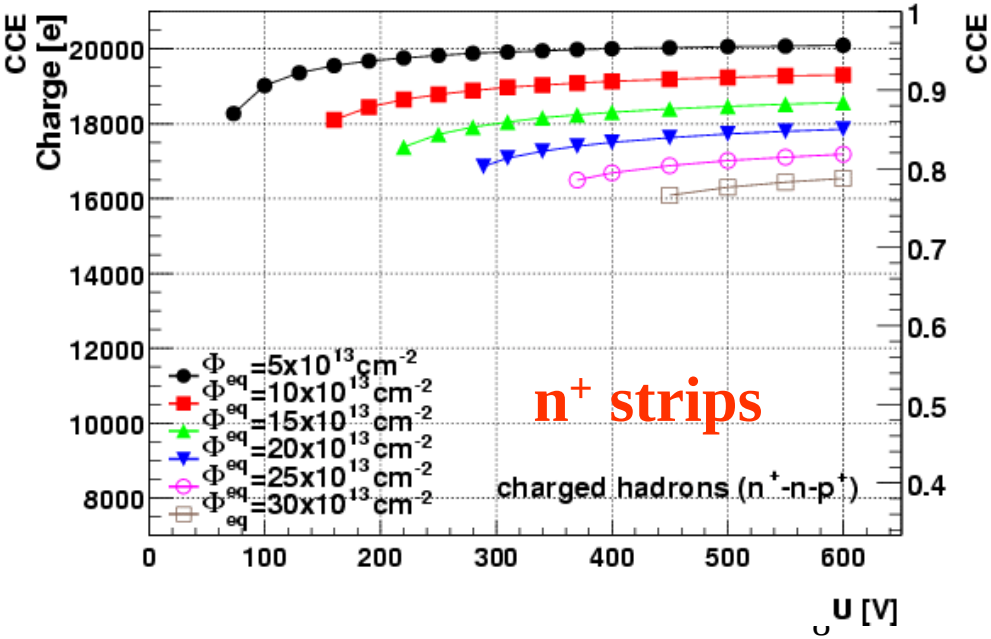


Double trouble for ***p⁺-n-n⁺*** detectors:

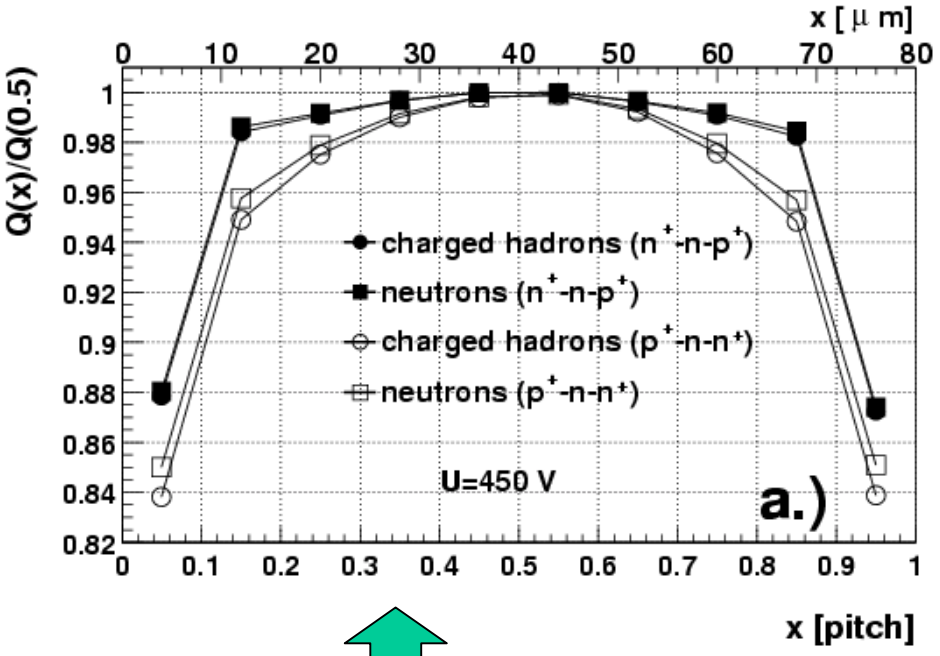
- longer drift time of holes
- larger effective trapping probability

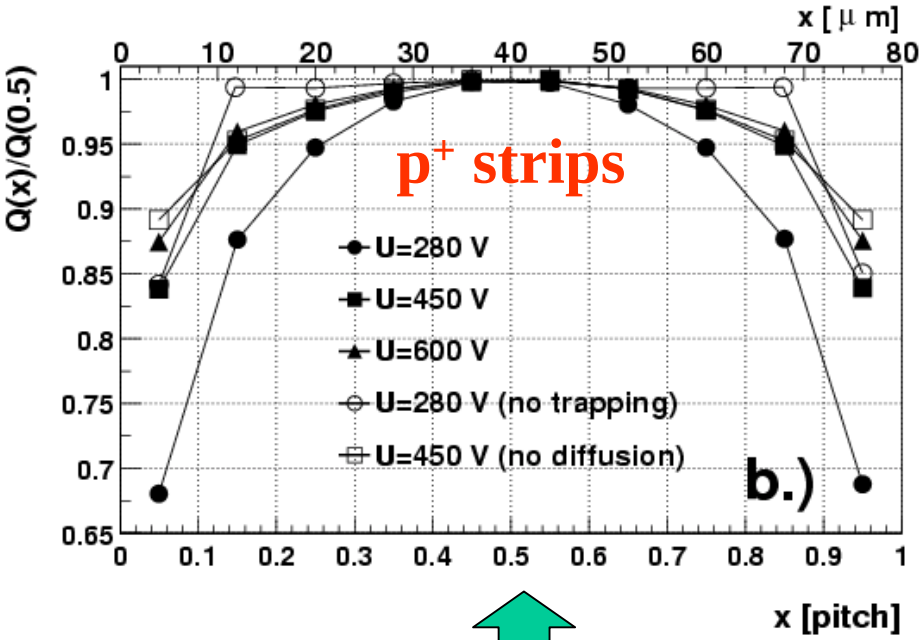




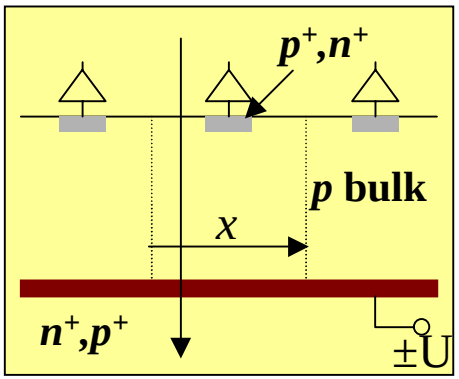


II. CCE of irradiated detectors with p^+ and n^+ strip after $\Phi_{eq}=2x10^{14}$ p cm^{-2} for tracks off the strip centre



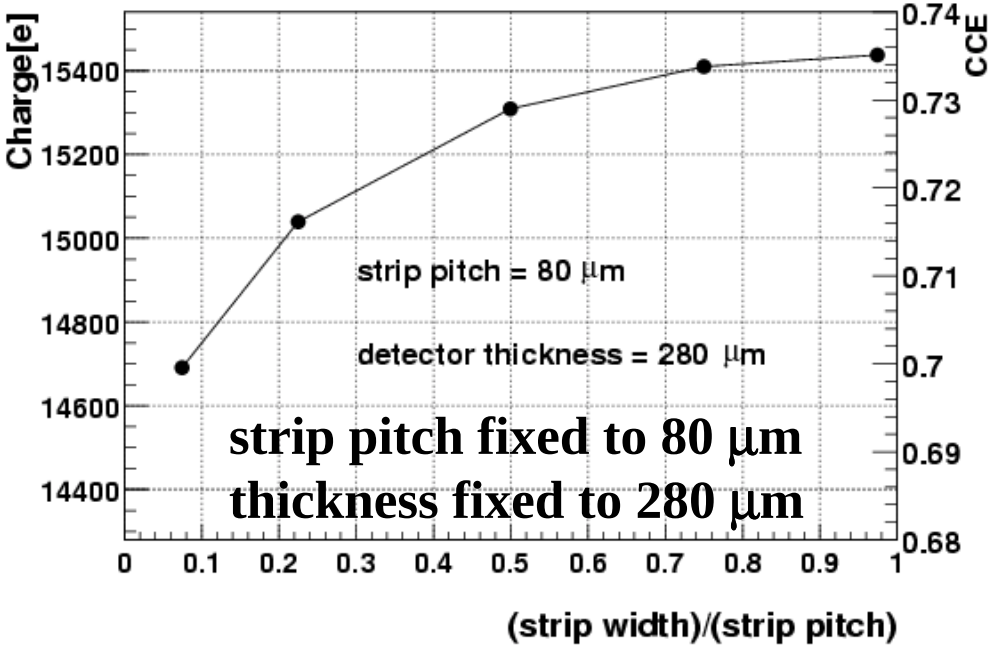


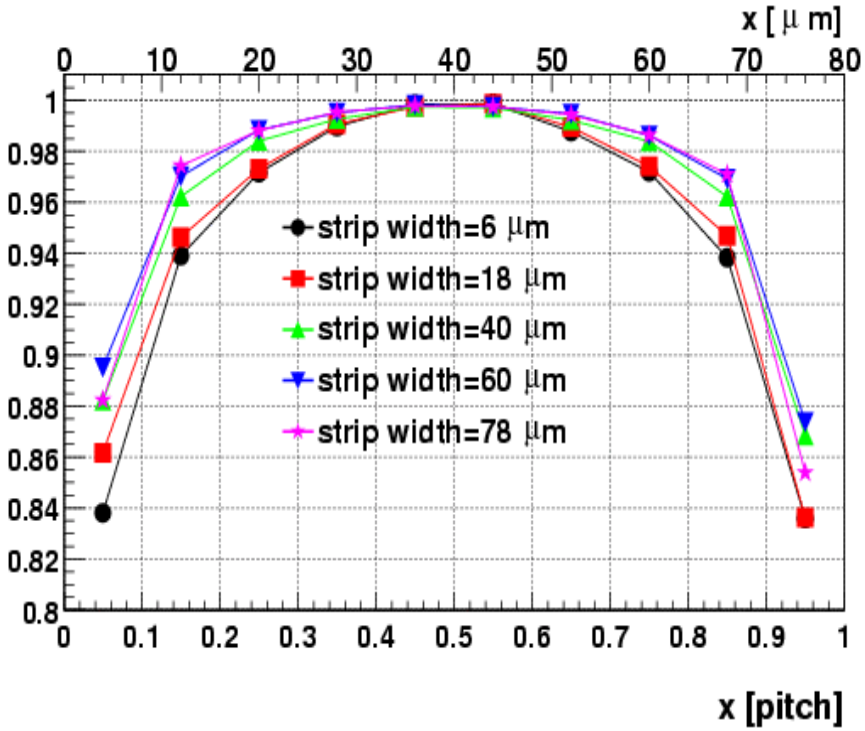
Higher CCE for detector with n^+ strips!



Loss of charge
high U: trapping
low U : diffusion

Influence strip width to CCE for detector with p^+ strips after $\Phi_{eq}=2x10^{14}$ p cm^{-2}





wide strip → E similar to diode → shorter drift paths → less trapping??

⇕

wide strip → for tracks close to border diffusion more important

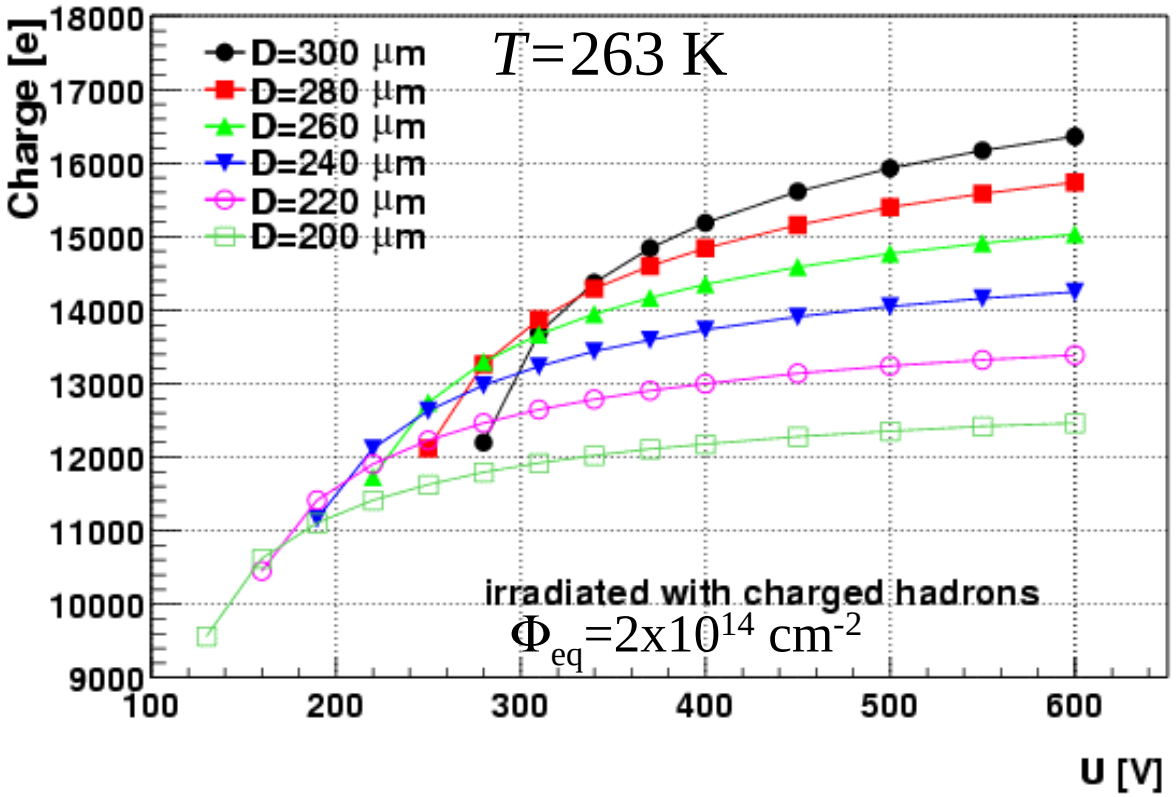
Influence of detector thickness to CCE for p^+-n-n^+ detector

$$V_{FD} \propto D^2 \, N_{eff}$$

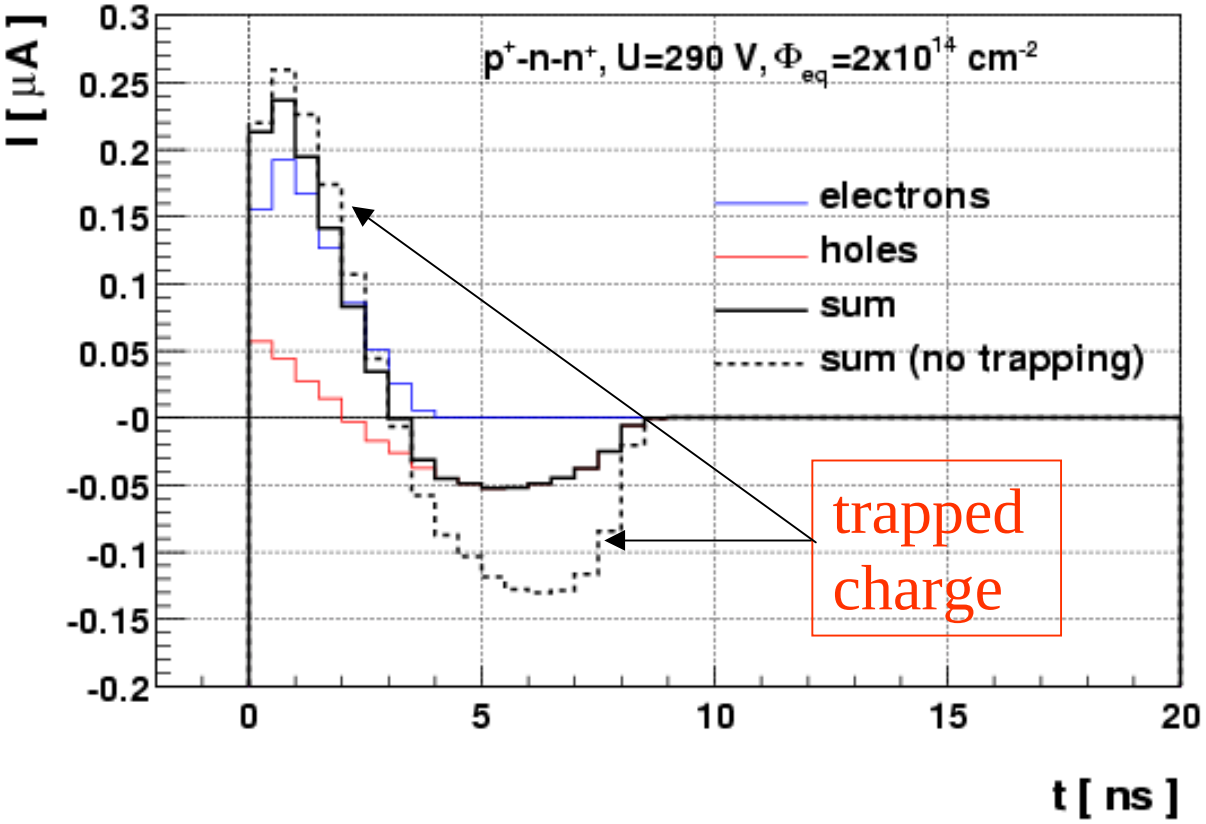
What is ideal detector thickness at fixed voltage and fluence?

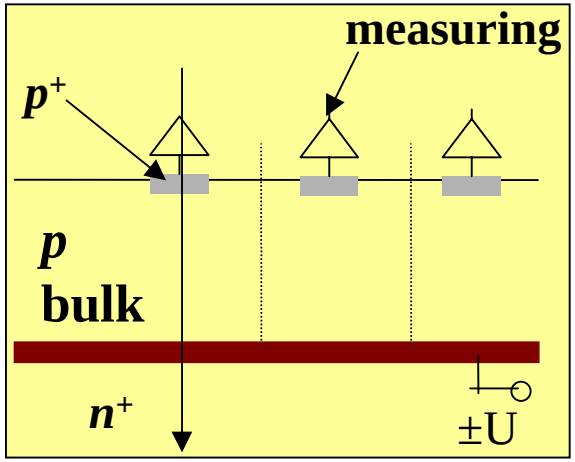
thinner detector → higher field → less charge trapped

Compensation for less charge deposited by ionizing particle?



Charge induced on neighbouring strips

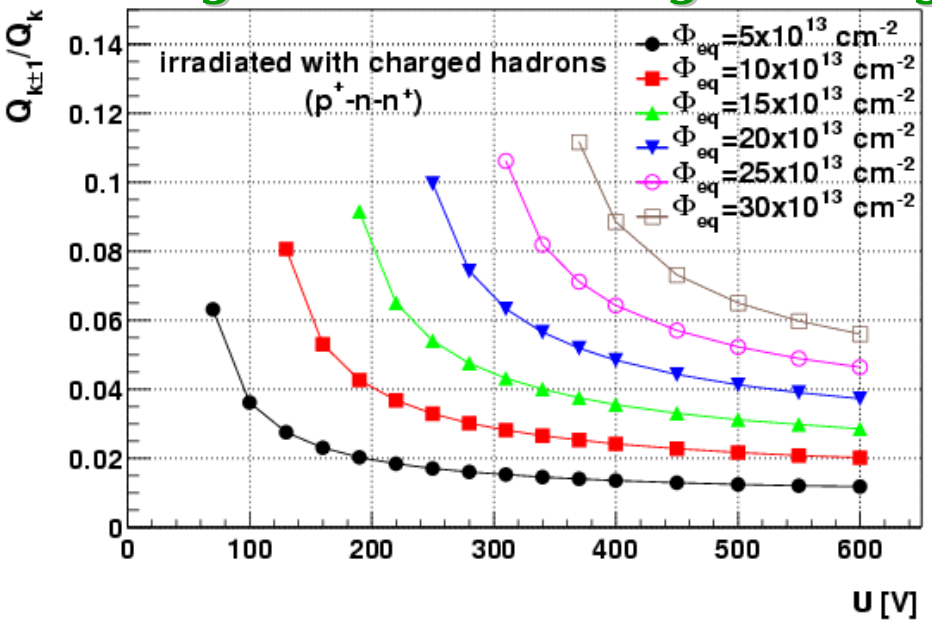


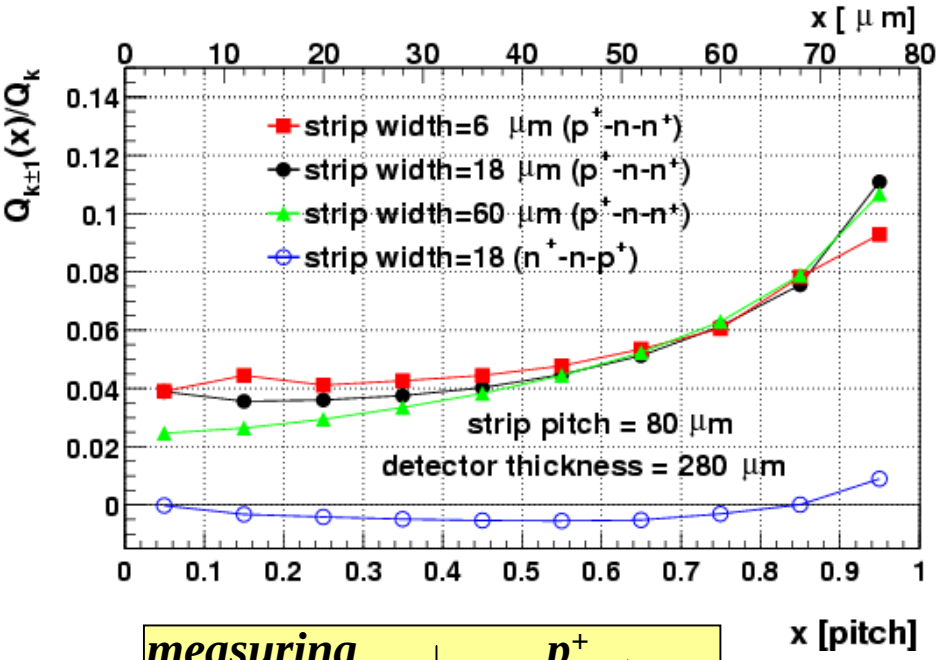


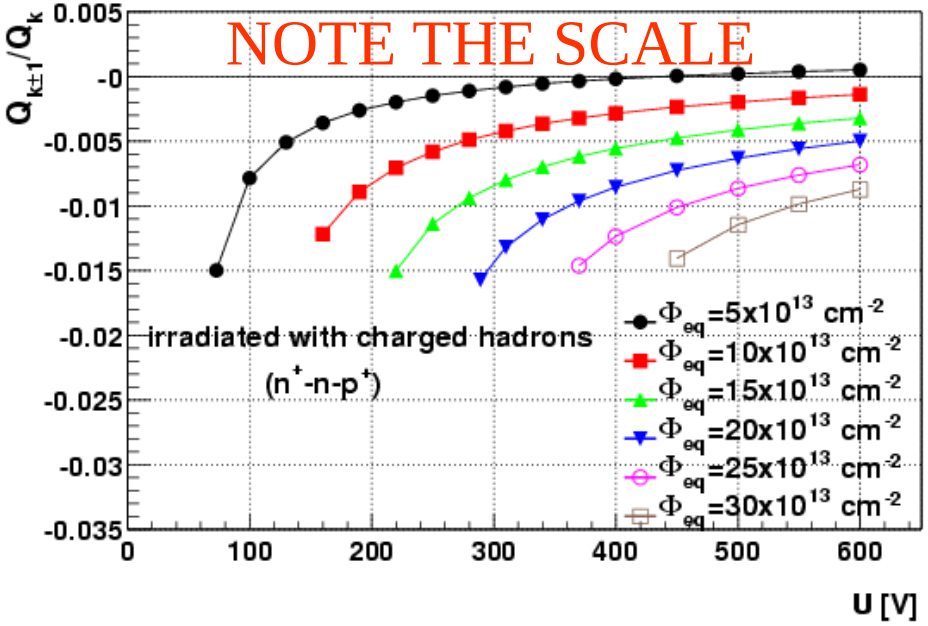
absence of trapping $\int I(t)\,dt = 0$ —trapping→ $\int I(t)\,dt \neq 0$

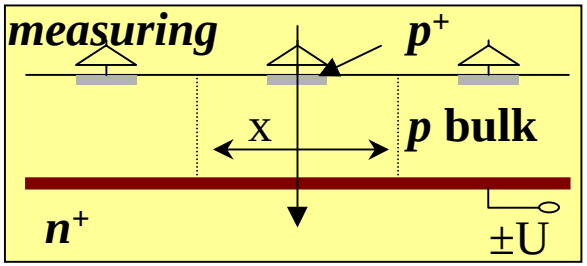
- this effect is far more important in irradiated detector with p^+ strips
- charge sharing mechanism also in other devices e.g. CVD diamond ??
- the amount of charge induced depends also on strip geometry

Charge induced on neighbouring strips after Φ_{eq}=2x10^{14} p cm^{-2}





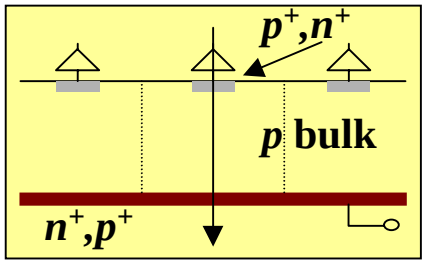




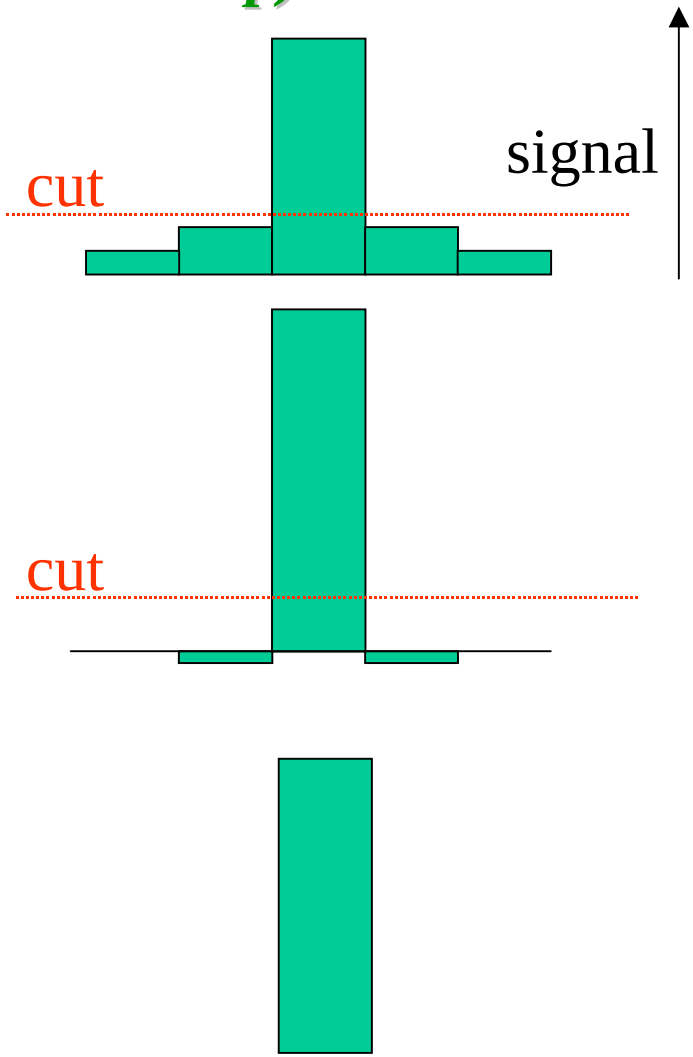
sum of charge on all strips approaches to charge induced in the diode

Consequences of charge sharing in heavily irradiated silicon detector (pixel? or strip)

p$^+$ strip detector

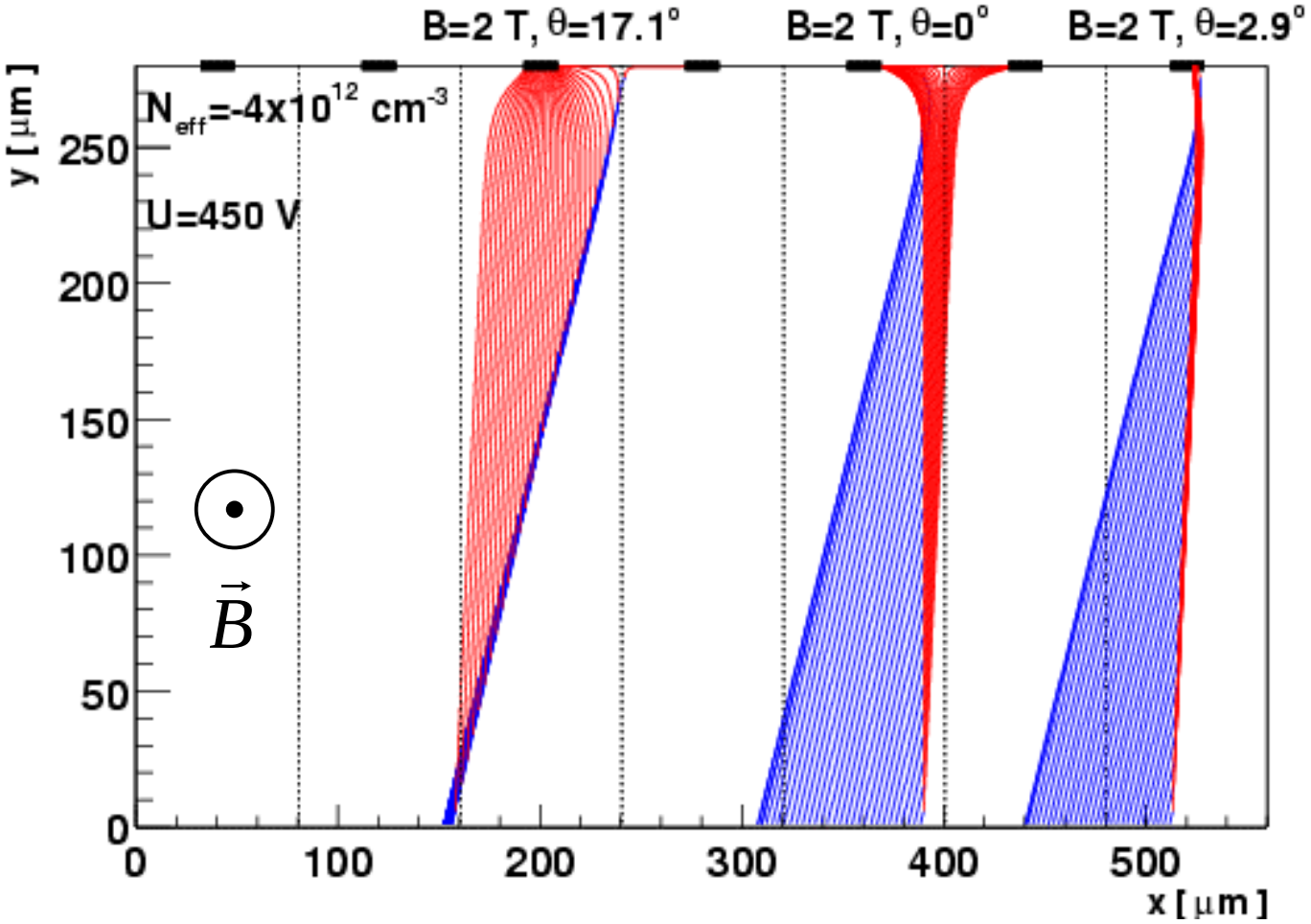


n$^+$ strip detector



pad detector - diode

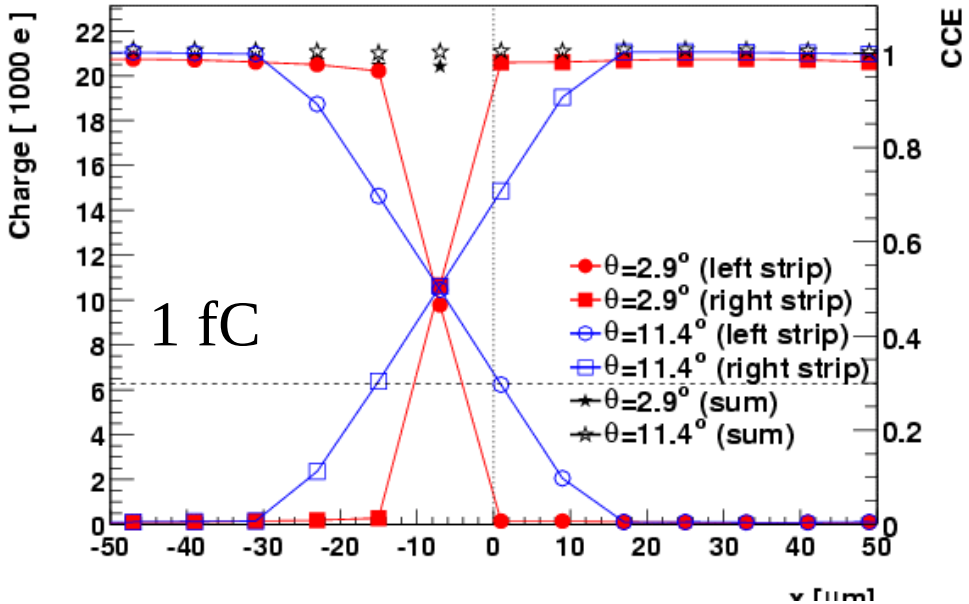
Operation in magnetic field

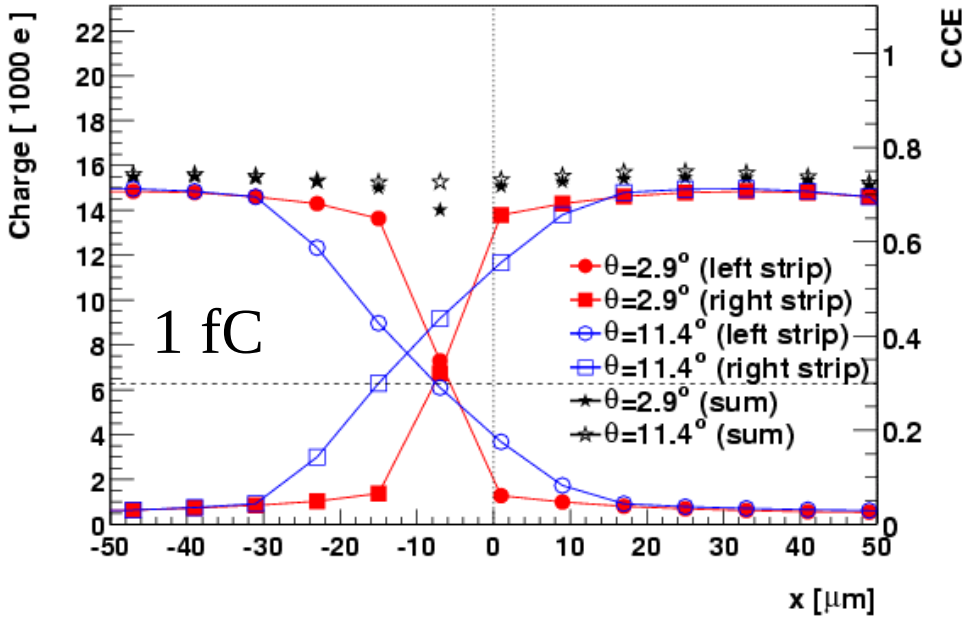


magnetic field perpendicular to the *xy* plane

detector irradiated to $2x10^{14}$ cm^{-2}

Operation in magnetic field





tilting detector under appropriate angle minimizes charge sharing

irradiated detector

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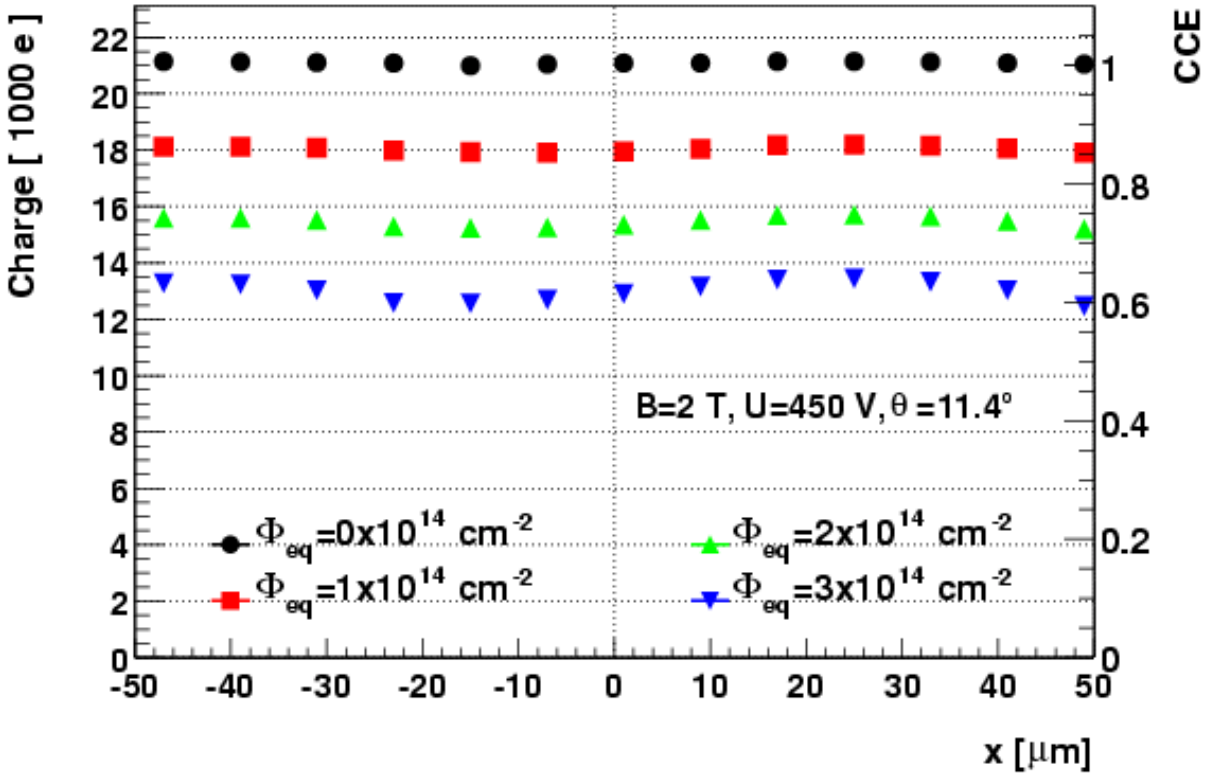
effective border between strips depends on tilt angle

Operation in magnetic field



sum of the charge on two adjacent strips
longer drift paths ⟶ larger amount of charge trapped
compensated by more charge deposited

Conclusions

Effective trapping times influence significantly strip detector performance:

- CCE for detectors with n^+ strips is higher than for p^+ strips (LHC~10%)
- strip width has a minor influence on CCE for both detector types
- if voltage is limited, operation of thinner detectors can be beneficial
- charge can be induced on neighbors due to trapping
  - much larger effect in detectors with p^+ strips
  - tracks closer to the strip border induce more charge on neighbors
- trapping influences performance of detectors in magnetic field

Future work: simulation of pixel detectors, non-linear electric field