Direct Electron Detectors with DEPFETs

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for the MPG Halbleiterlabor

Requirements on an electron detector and how they can be fulfilled

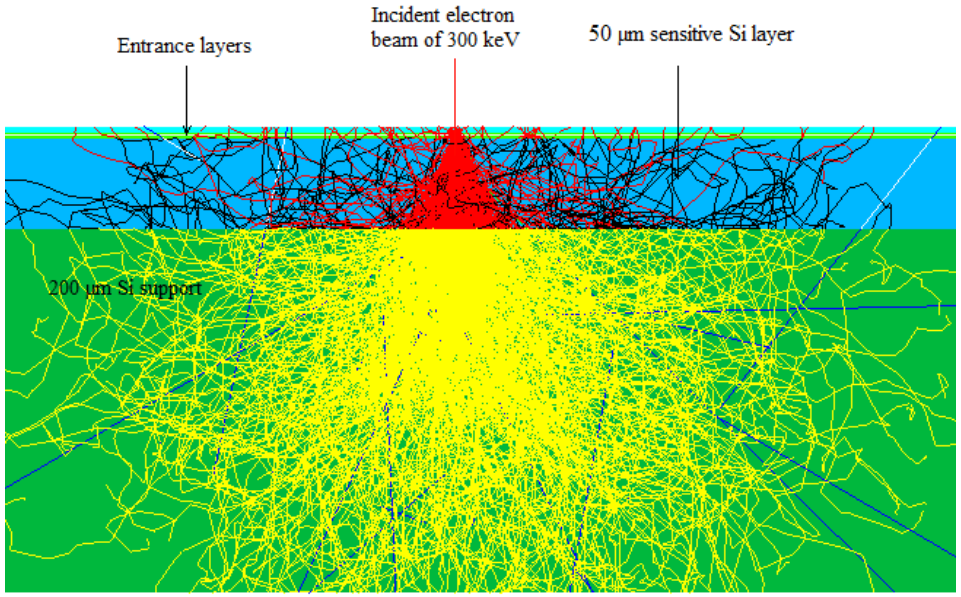
with DEPFETs

Focus on real space applications (80kHz detector)

Direct Electron Detectors with Depfets ?

What is needed? 1. thin detector

50µm thick detector
With 200µm pass. Si support structure

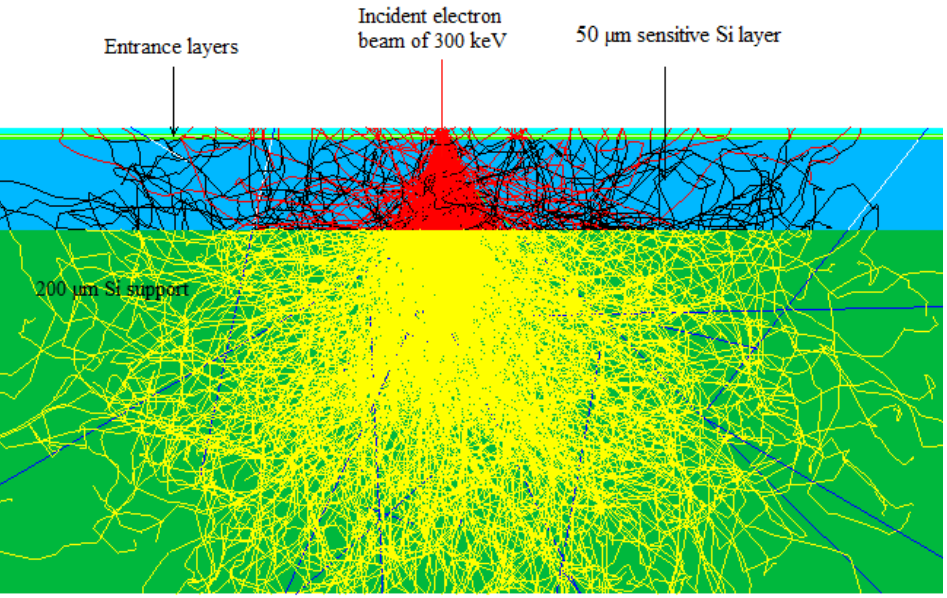


300keV electron beam, MC Geant4 by Ibrahym Dourki

Direct Electron Detectors with Depfets ?

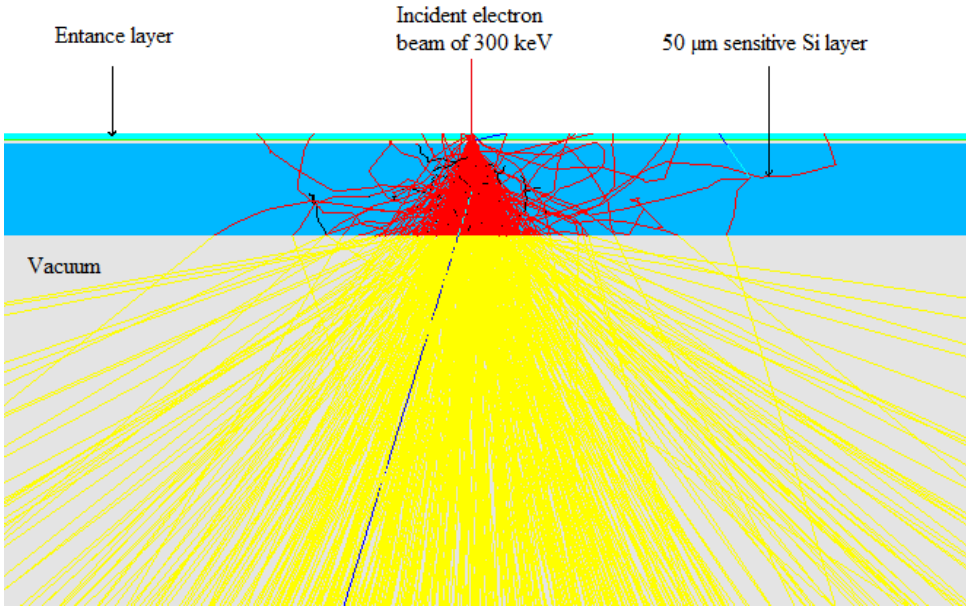
What is needed?

50µm thick detector
with 200µm pass. Si support structure



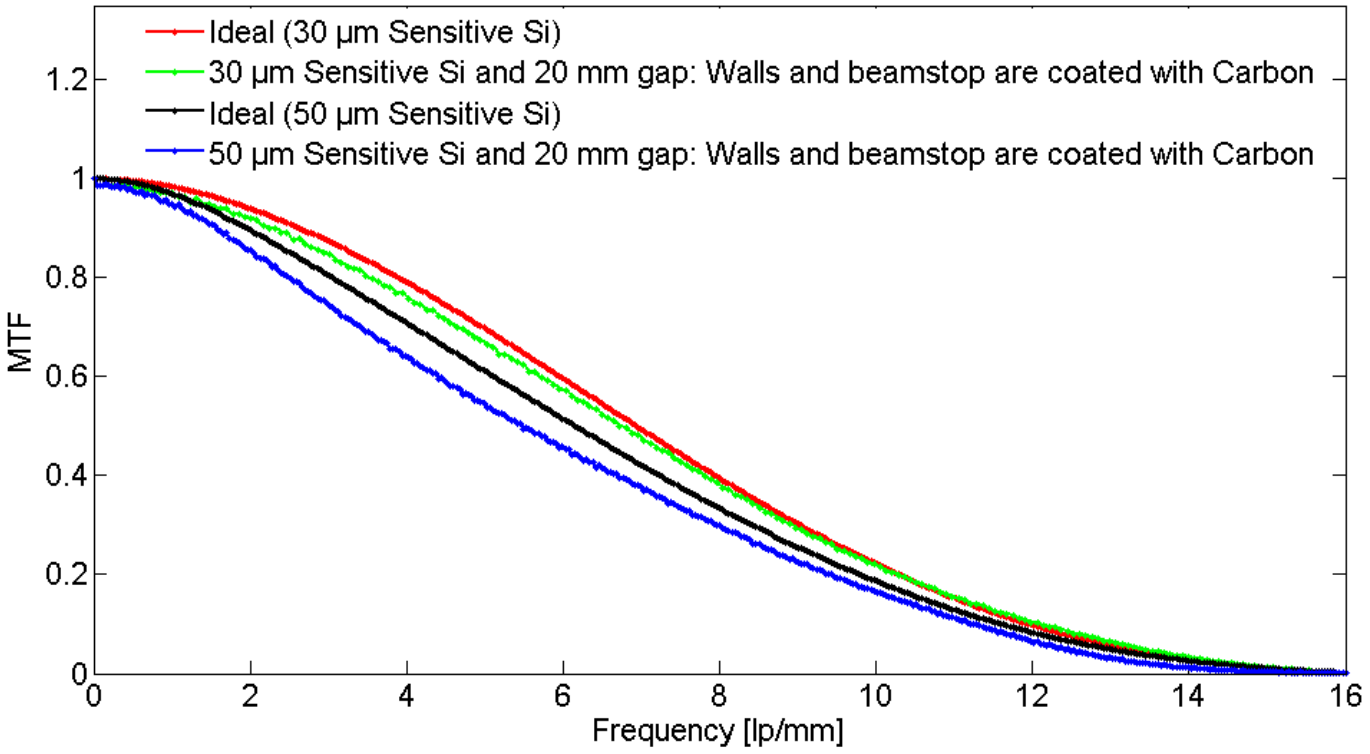
1. thin detector

50µm thick detector
without 200µm support structure
carbon beam stop 20mm beneath



works only at very low power consumption !

Modulation Transfer Function (MTF)



2. Low noise - single electron detection if possible

No problem

1 primary electron in 50um Si

-> about 5000 e/h

Well known from Belle2 pixel detector even at high speed ☺

Low noise of DEPFET – small Internal Gate capacitance !!

2. High speed

as in Belle …

- 100ns row processing time (DCD)

- 4-fold readout

512 x 512 sensor array (currently in production)

-> 12.5 µs (80kHz)

4. high dynamic range (i)

Sascha Epp:
50 better 100 primary electrons

►100 el/px Poisson only

- ► 100 keV
- ► pitch black = 1000 A sample
- ► very white = 0 A sample
- ► 0..1000A in 256 steps

4. High dynamic range (ii)

100 primary e- (300keV, 50um) -> 500 000 signal e- to be stored

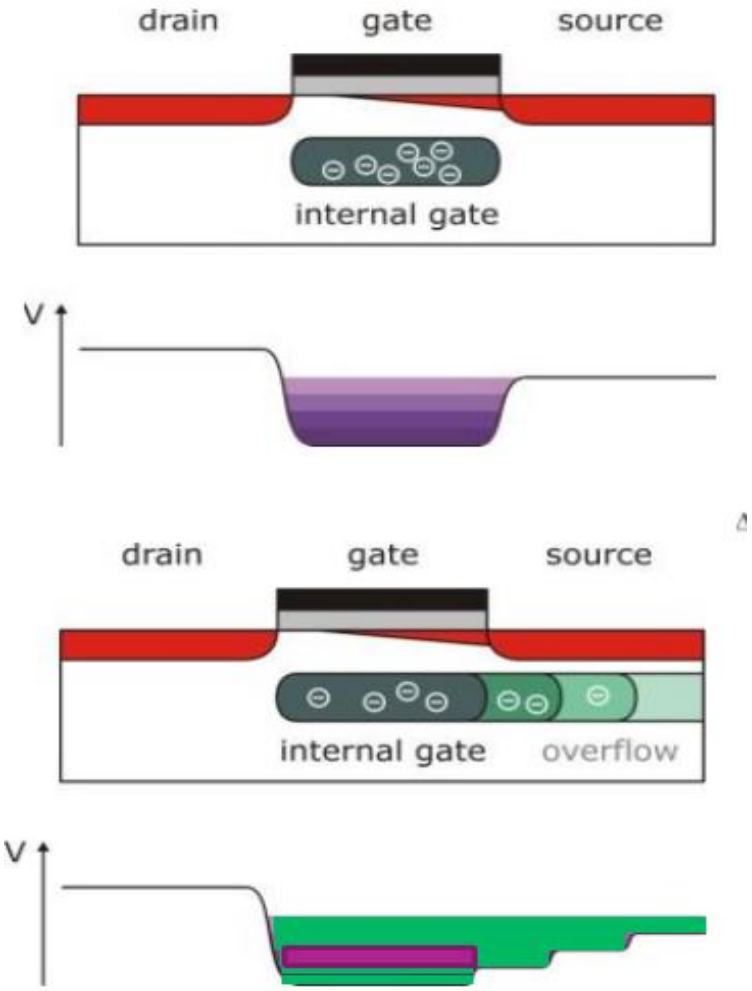
Charge handling capacity of a Belle DEPFET: 50 000 e- ☹

Very small Internal Gate capacitance …

DEPFET technology

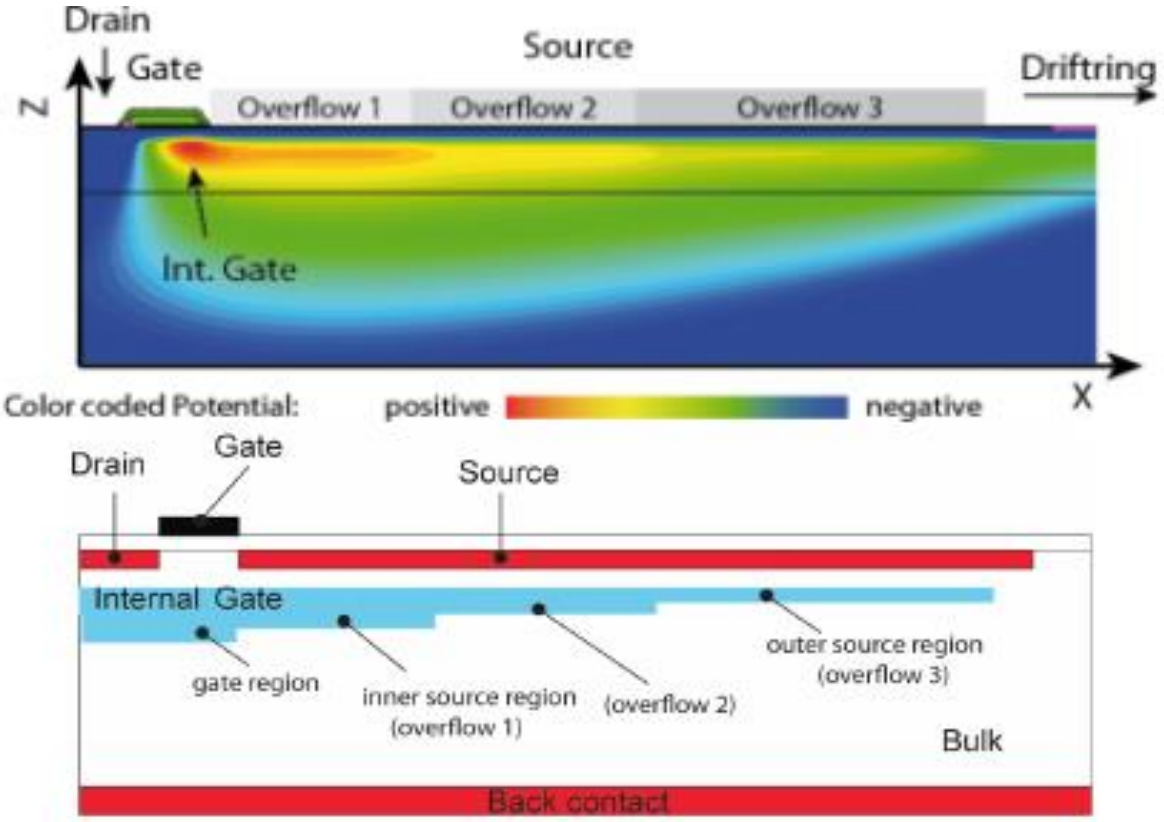
offers a simple natural solution

What happens if the Internal Gate is full?



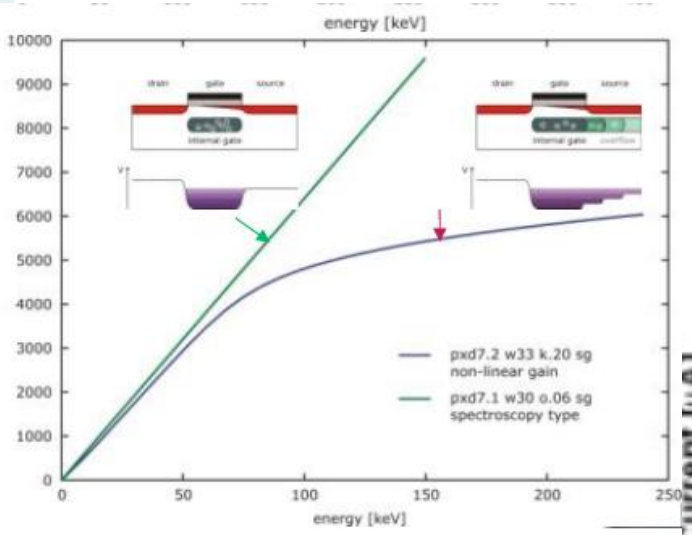
Pictures taken from DSSC-Project

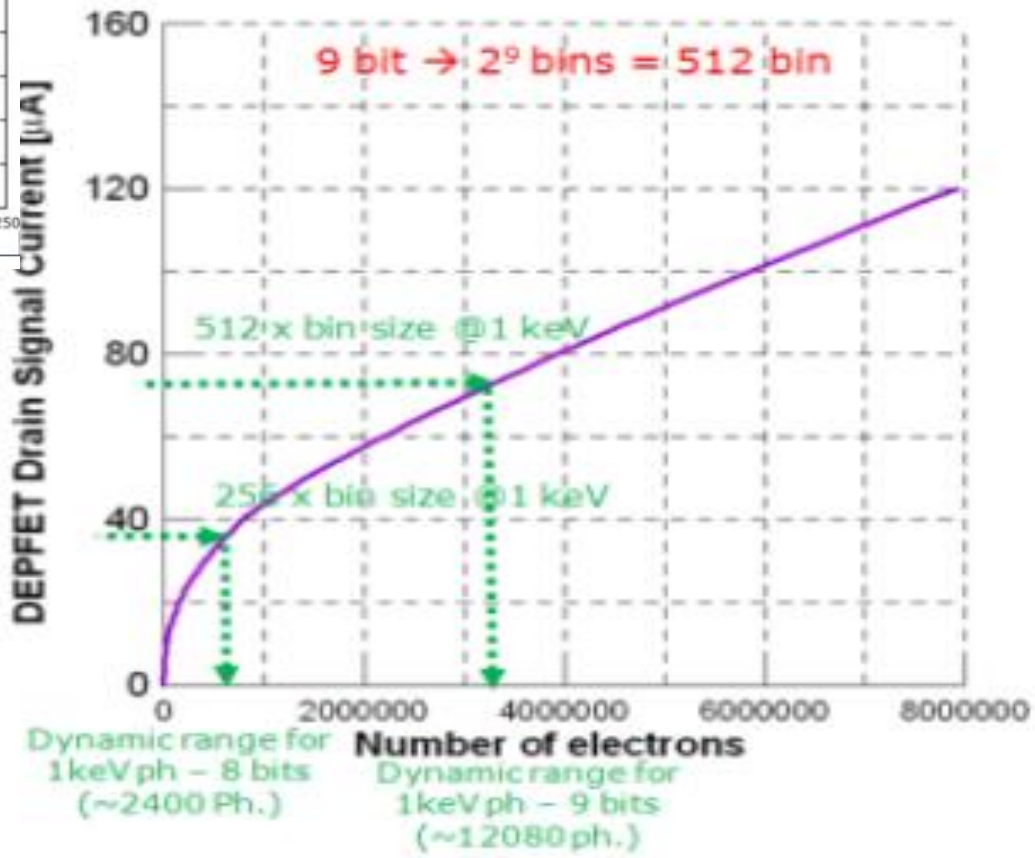
The DSSC-DEPFET for the XFEL Project



Input capacitance increases if charge spills over

DEPFET response: charge storage and signal compression at once



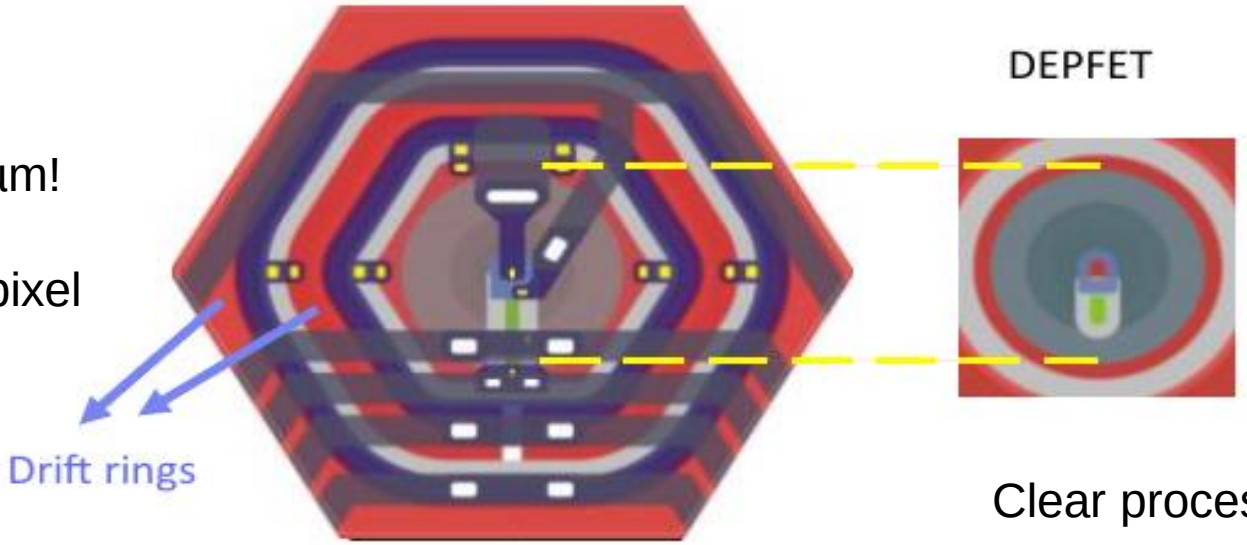


DSSC concept suitable for electron detection?

Pixel size 200µm!

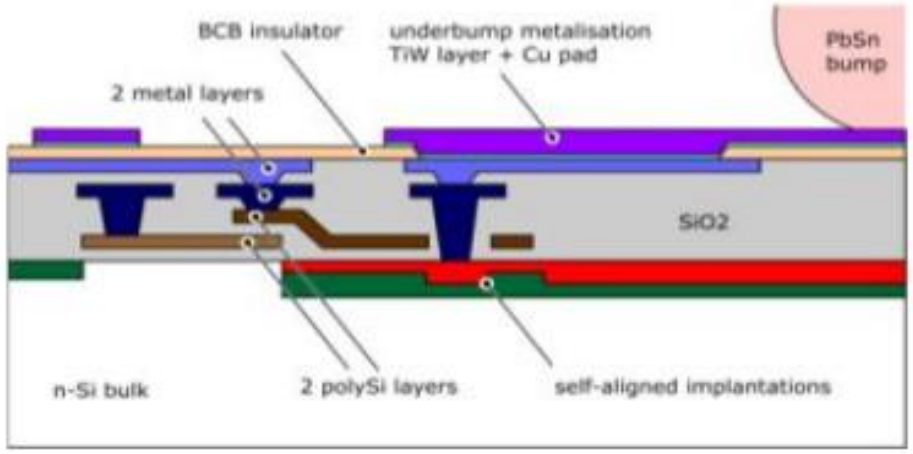
Much smaller pixel required

☹



Clear process slow

☹



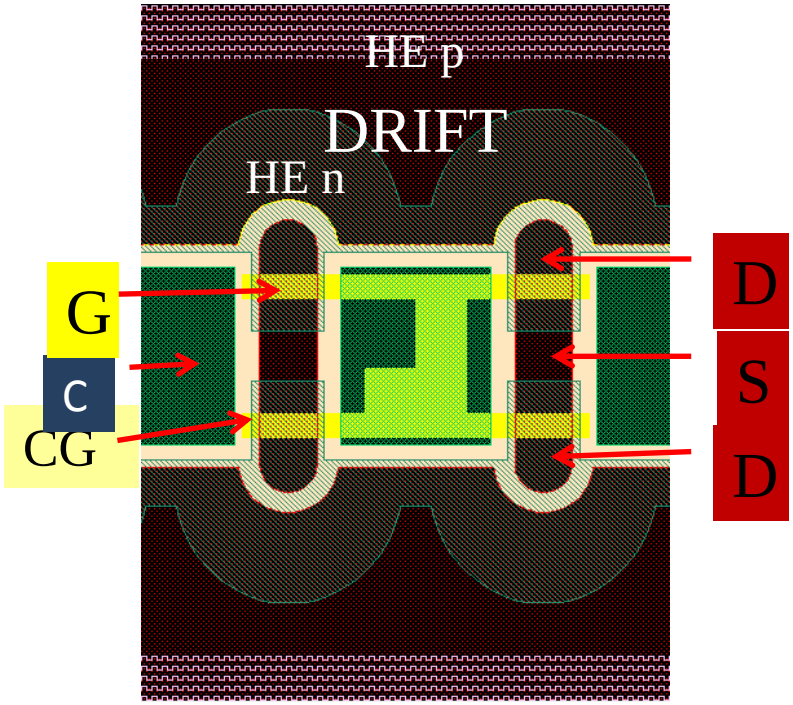
Very fast but
ro- electronics
Is bumpbonded
on top

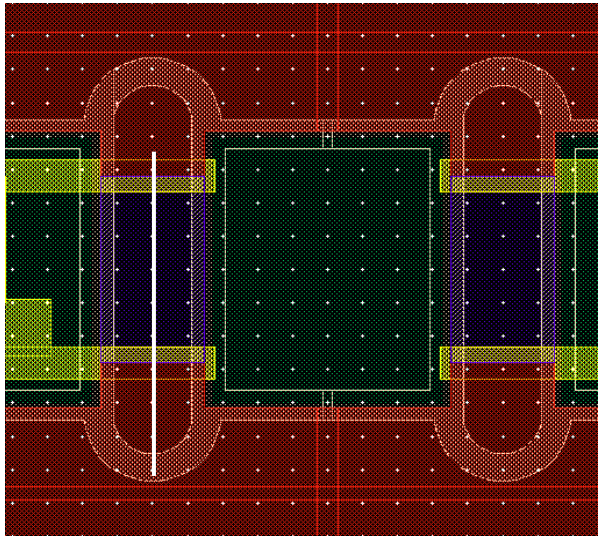
☹

What about the Belle design?

Thinned detector (50µm PXD6)	ok
Fast detector: row readout 4 fold row read out + DCD	100ns !!
Low power consumption: (passive cooling)	ok
Pixel size (linear transistor)	acceptable
Single electron detection	ok
Dynamic range	no

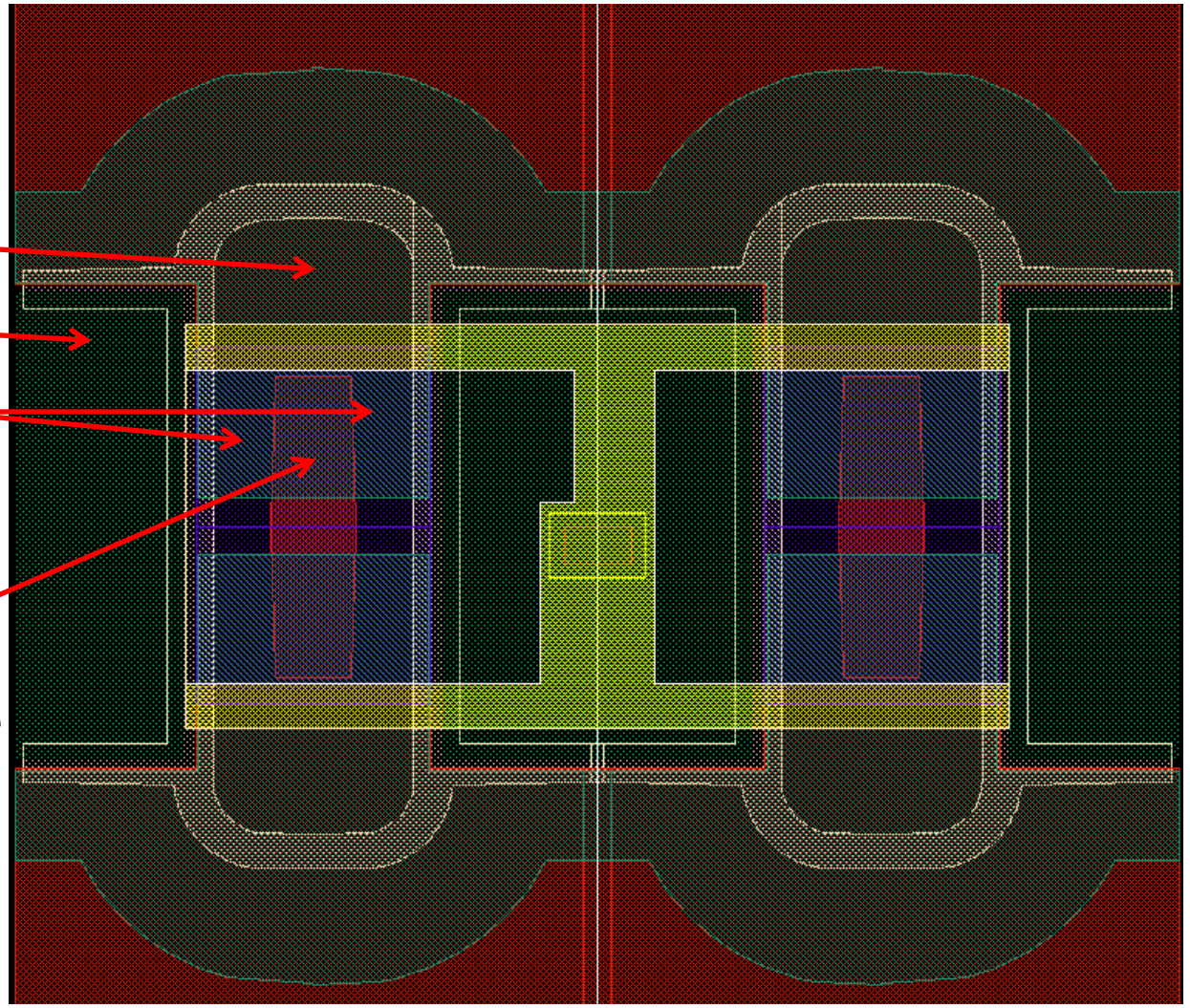
Depfet Design for Belle II



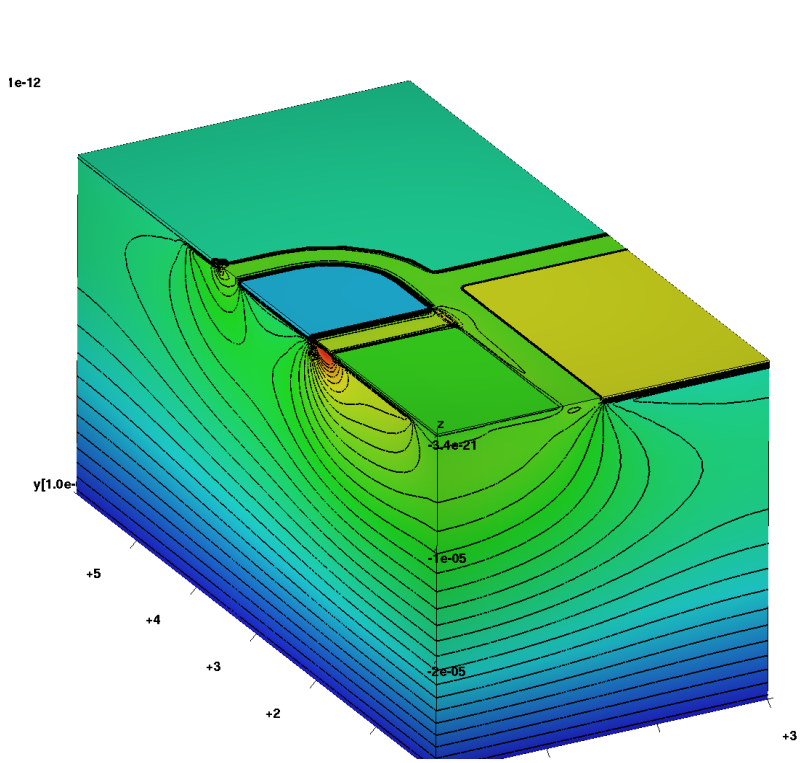


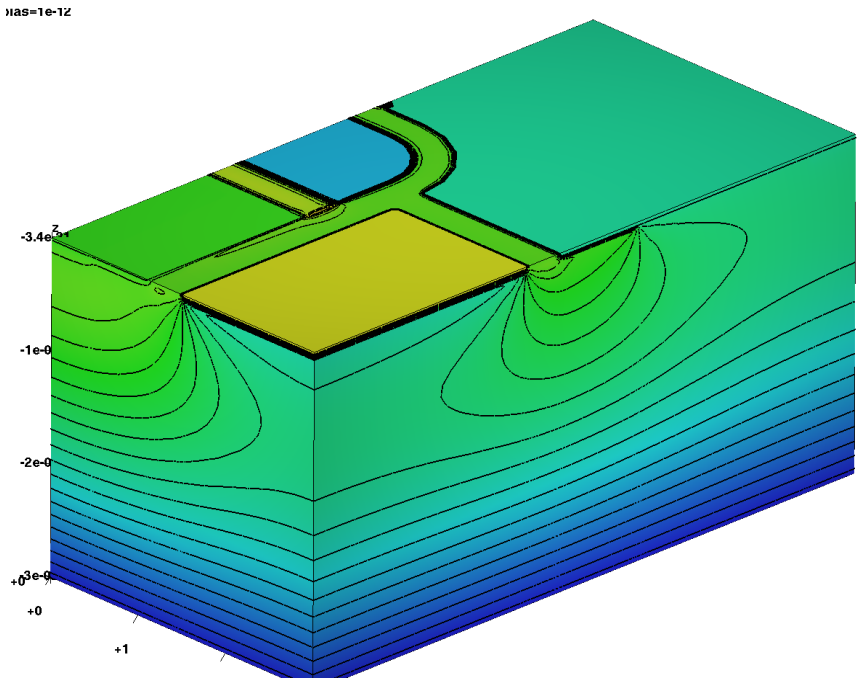
View on 4 pixel (60x60µm²)

Similar to Belle but larger Sources and different doping



Potential Distribution during Collection (empty Internal Gate)

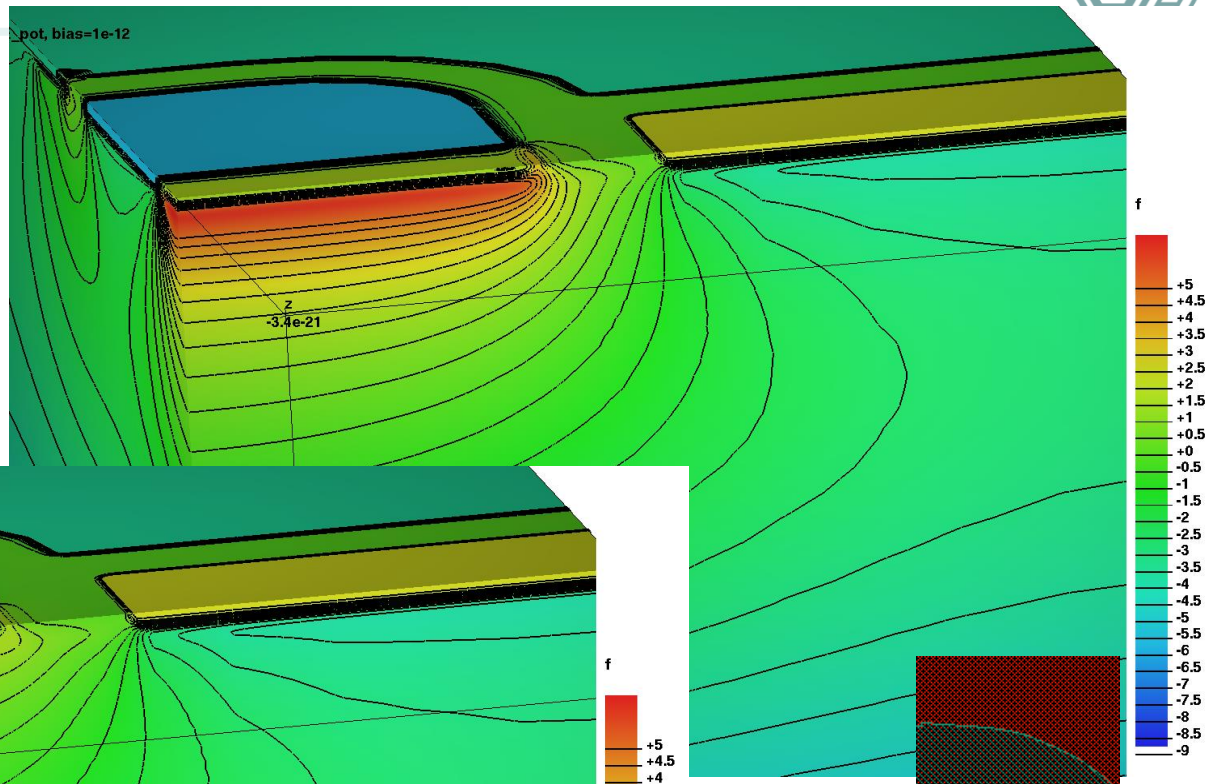


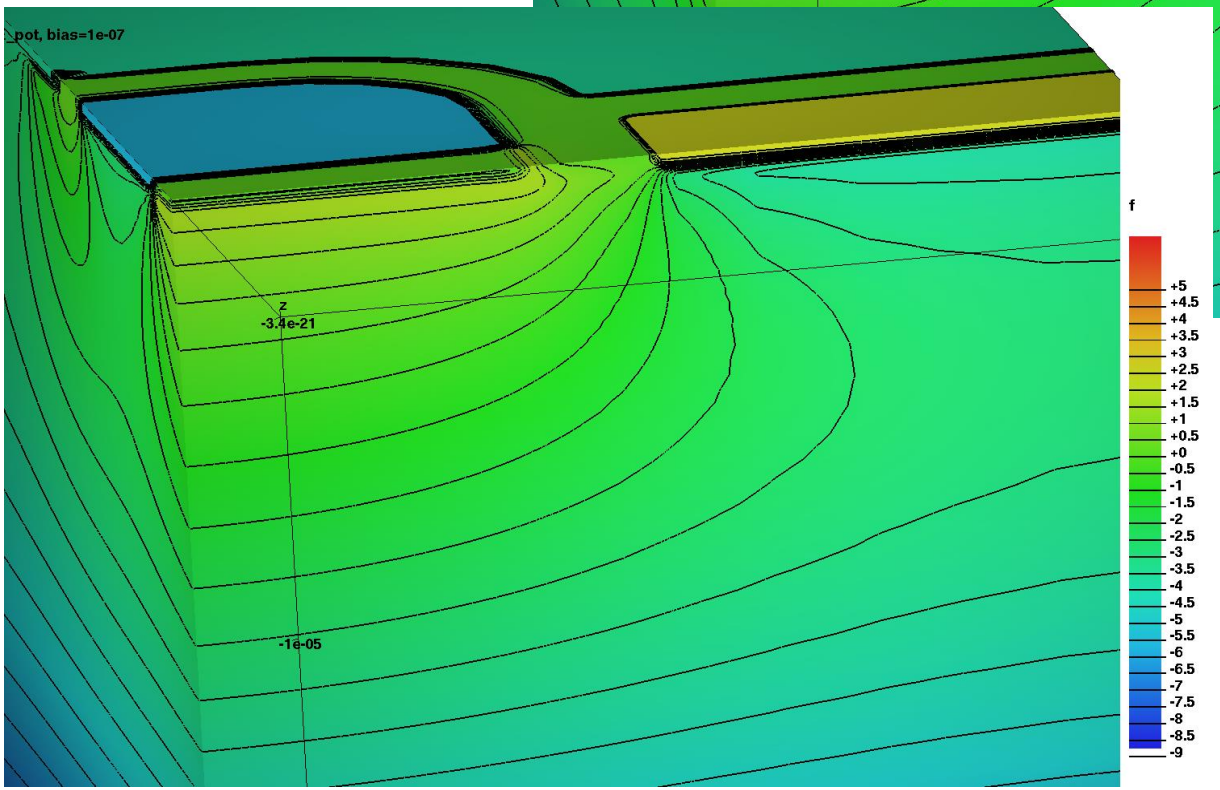


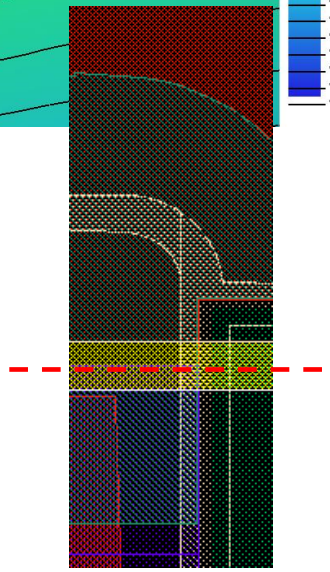
- Cut through Internal Gate

Empty

filled 400k e-



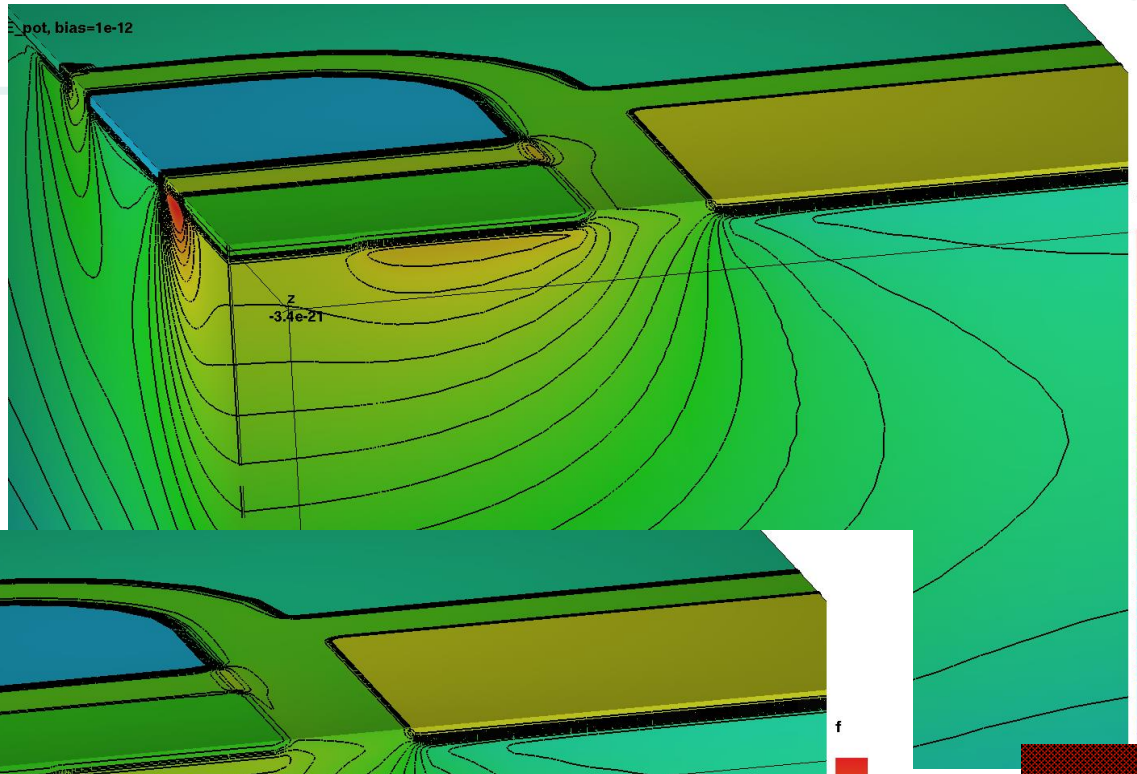


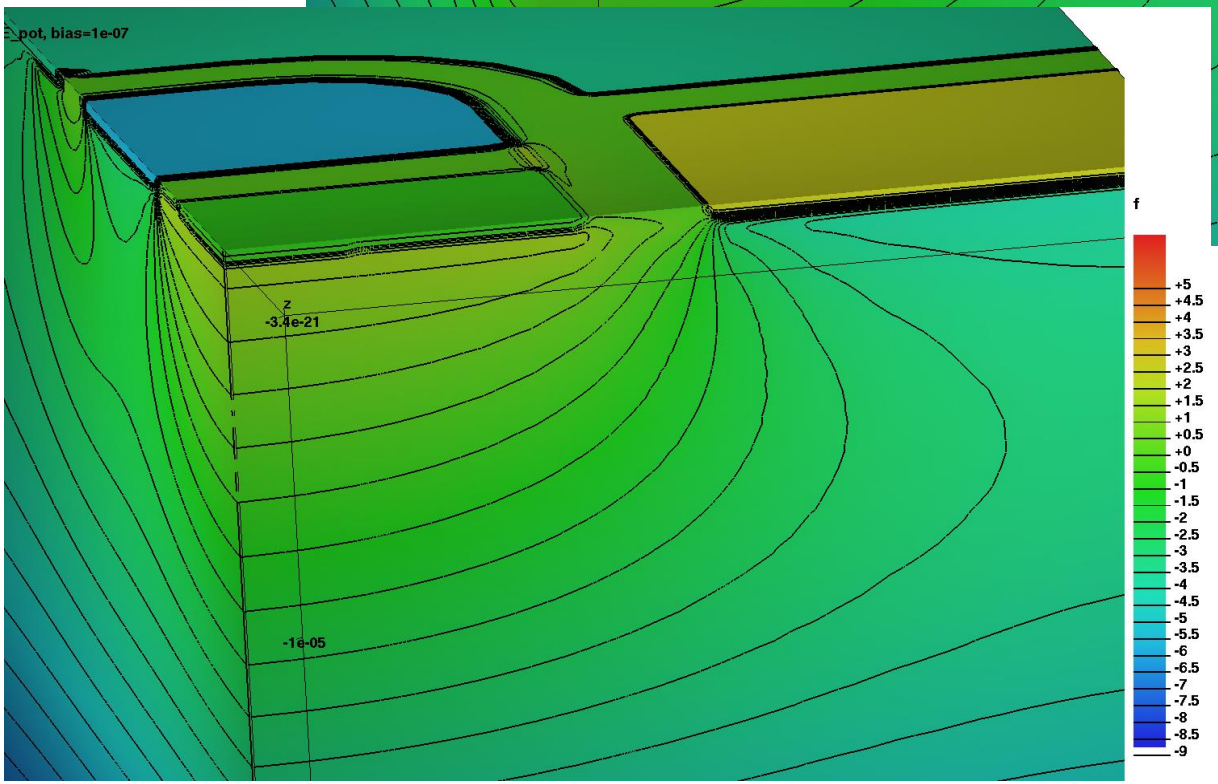


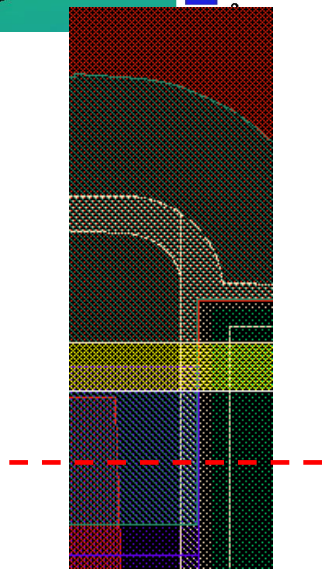
Cut through Source

Empty

filled



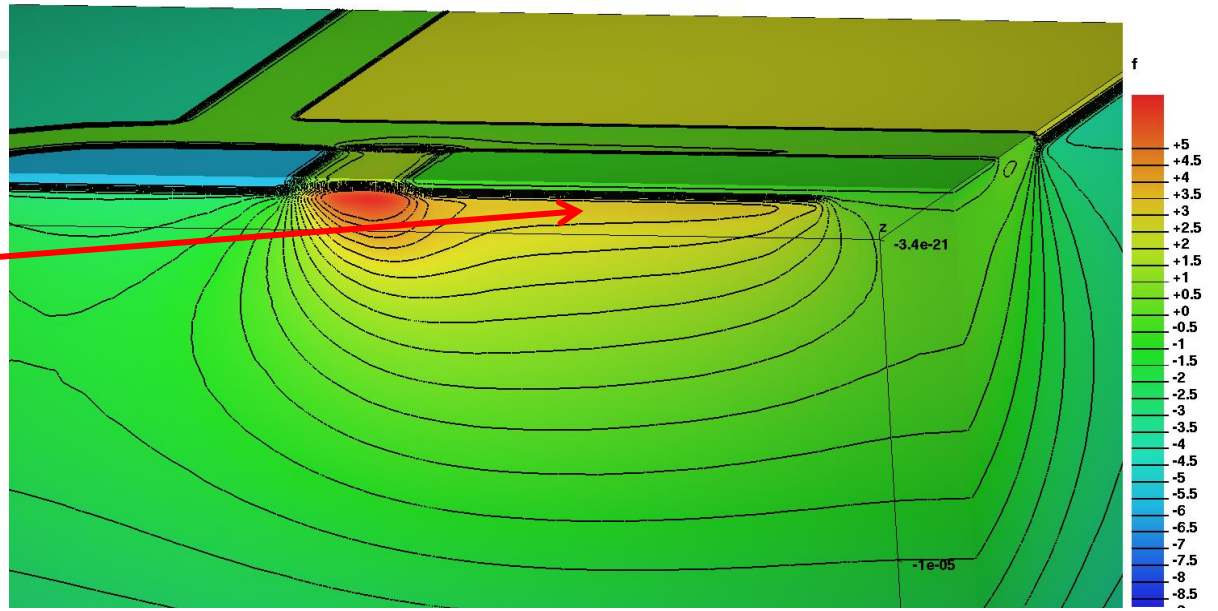


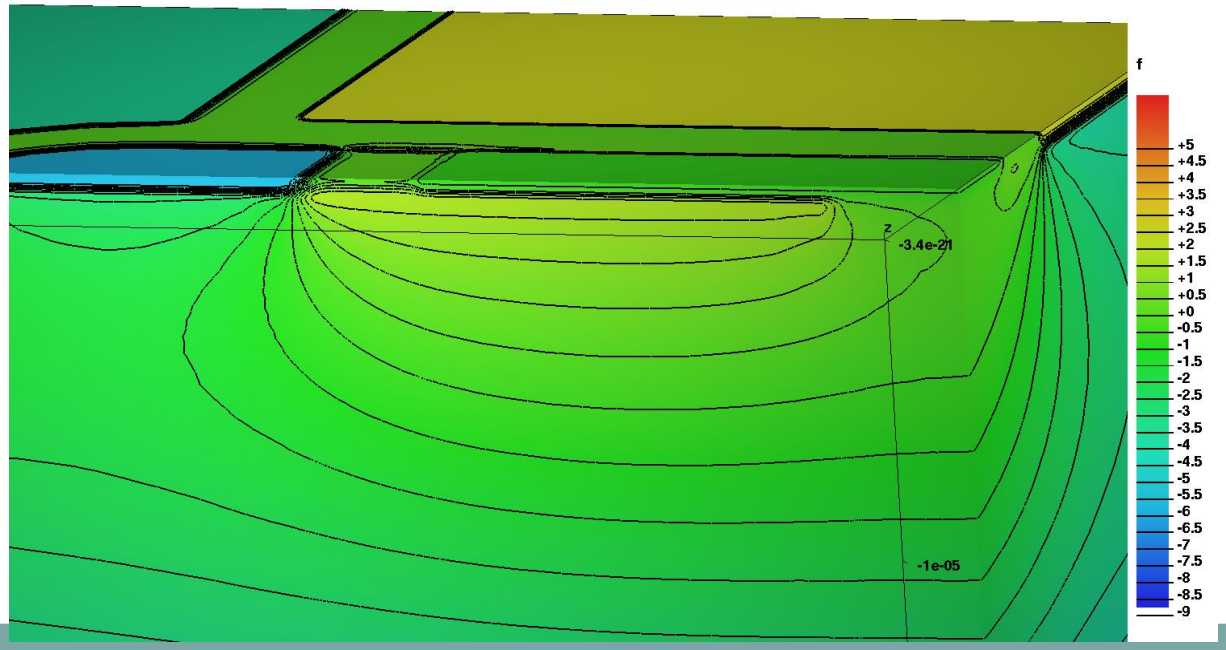


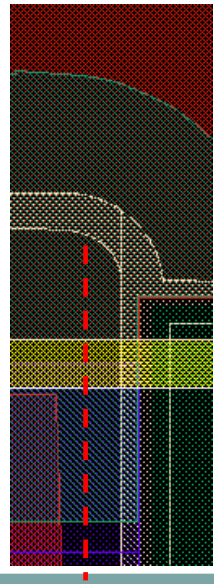
Modulation of potential by wedge

empty state

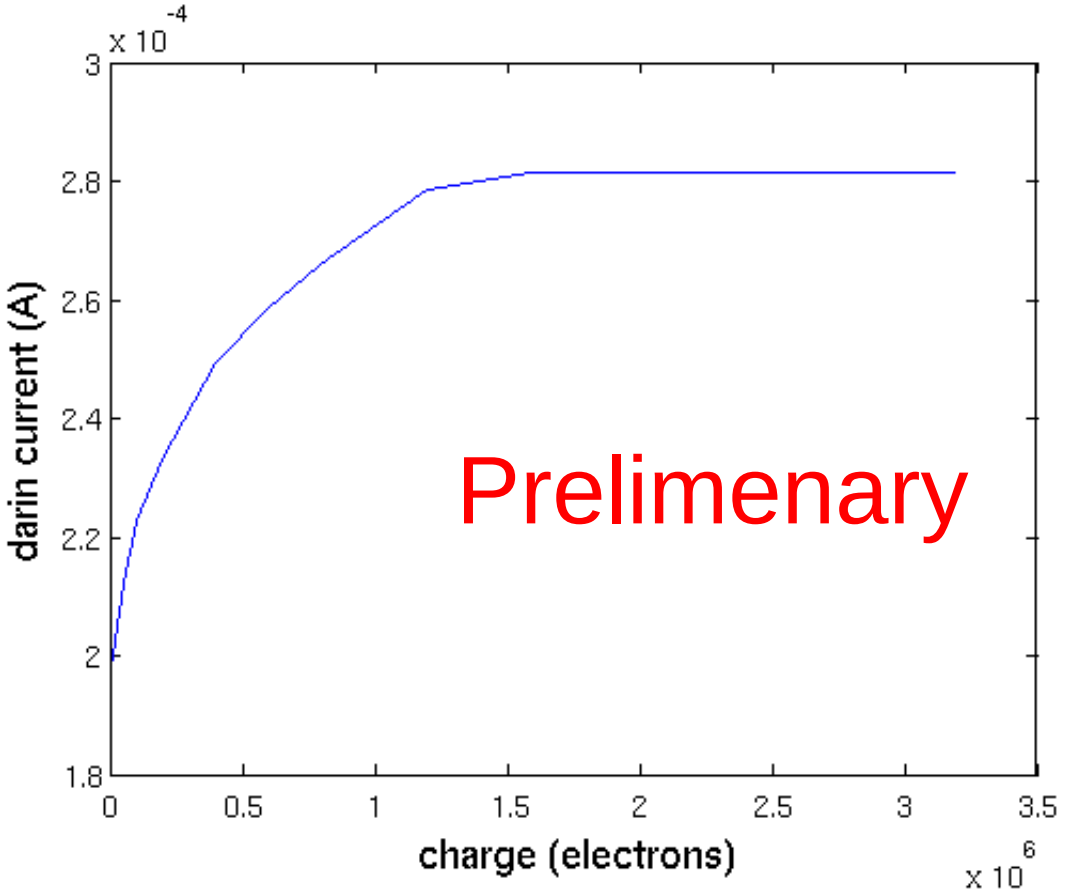
filled state
400k electrons







Simulated response curve



Saturation due to overflow in the Clear Regions

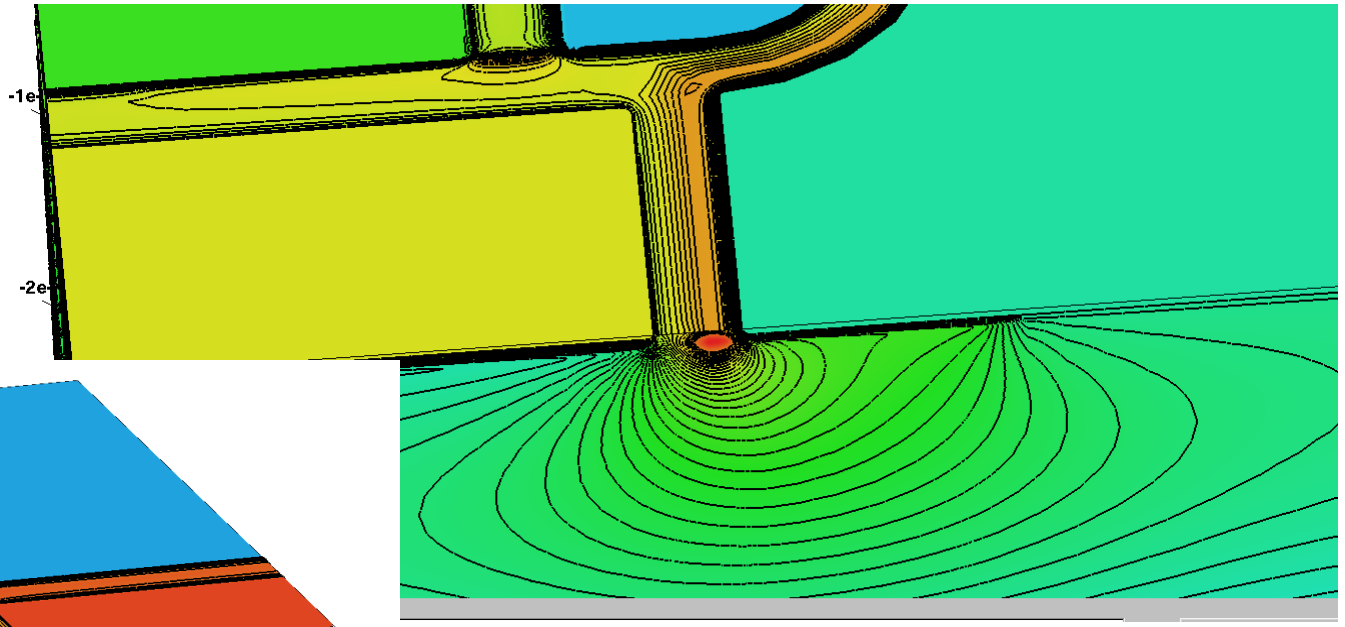
5. radiation tolerance

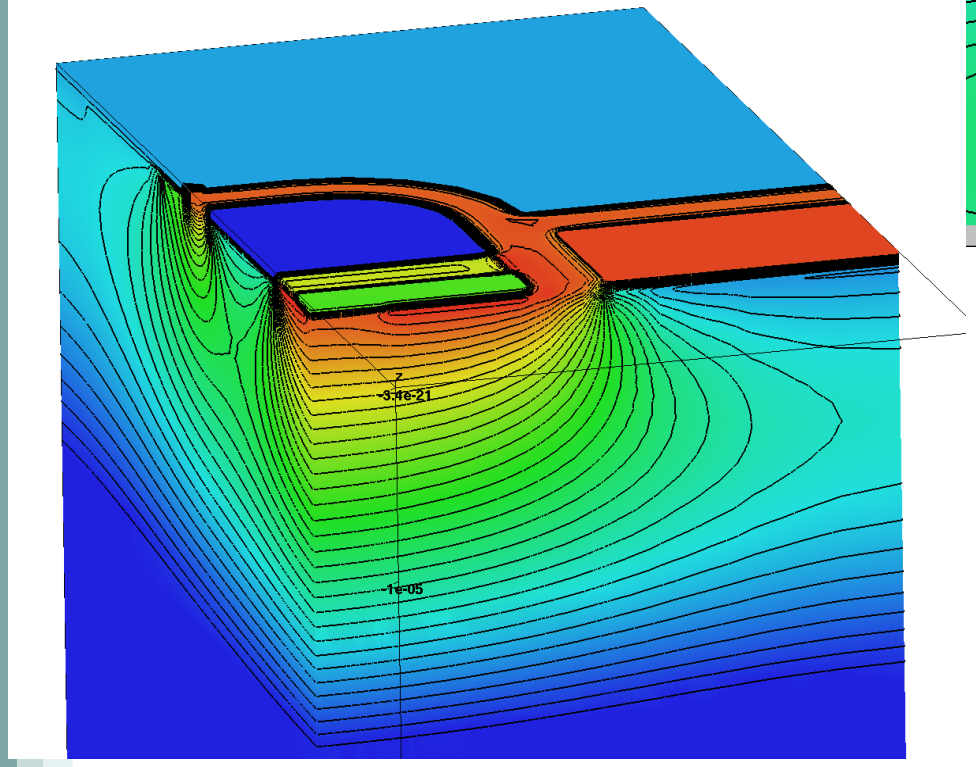
Real space detector sees a rather

homogeneous radiation level

(easier task)

What is crucial ? Surface damage of oxides

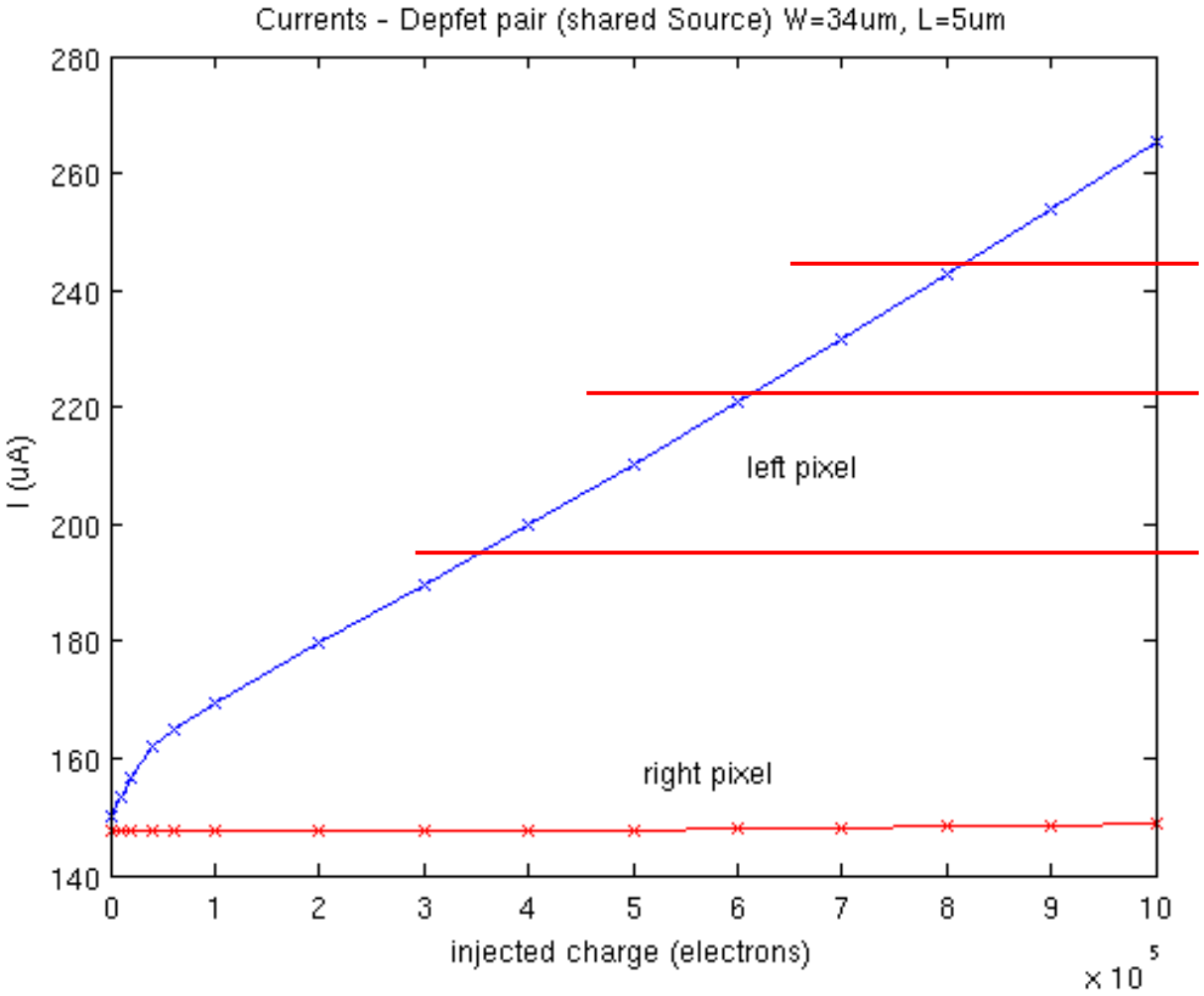




Irradiated state:

Vclgate = 2.5V

During irradiation - Charge handling capabilty



Overflow points to Clear Gate

Fluence 1

Fluence 2

Fluence 3

How to deal with radiation damage?

1. Oxide charge compensation by gate voltage adaption
   works only for homogeneous radiation

2. Annealing : Module should stands about 200°C
   significant annealing of surface damage possible
   (Master thesis: Martin Hensel)

3. Technology improvement

   thinner oxides- studies ongoing

Summary

DEPFET fulfills many requirements on a direct electron detector

Especially the ‘Belle design‘ provides

low material, high speed, low noise, low power, small pixel

Not intrinsically given:

Dynamic range increase should work

Radiation hardness: work ongoing