Non Linear DEPFETs for E det 80k : simulations, design, status of the production

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We want to see something …

50 (better 100) primary electrons
per pixel provide enough contrast

100 primary e- (300keV, 50µm Si)

-> 800 000 signal electrons
to be stored per pixel

Dynamic range problem !

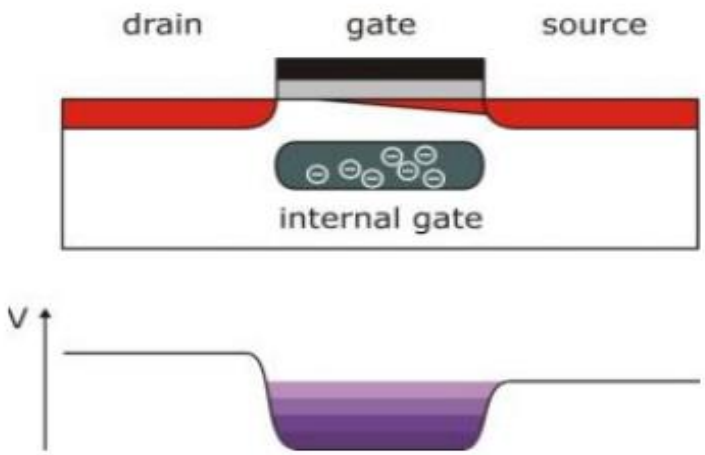
For example:

Charge handling capacity of
a Belle2-PXD DEPFET: 50 000 e-

☹

What happens if the Internal Gate is full?

DEPFET technology offers a simple natural solution



Internal amplification

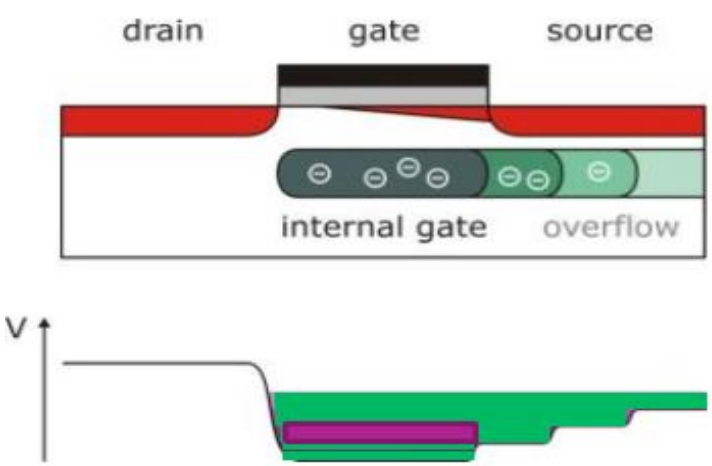
gq = dI/dQsig

for a given transistor :

gq ~ channel carrier velocity

gq ~ fraction of mirror charge

influenced in the channel by Qsig < 1



Multiple n-implants to create
an electric field towards the Internal Gate
and to tailor the response

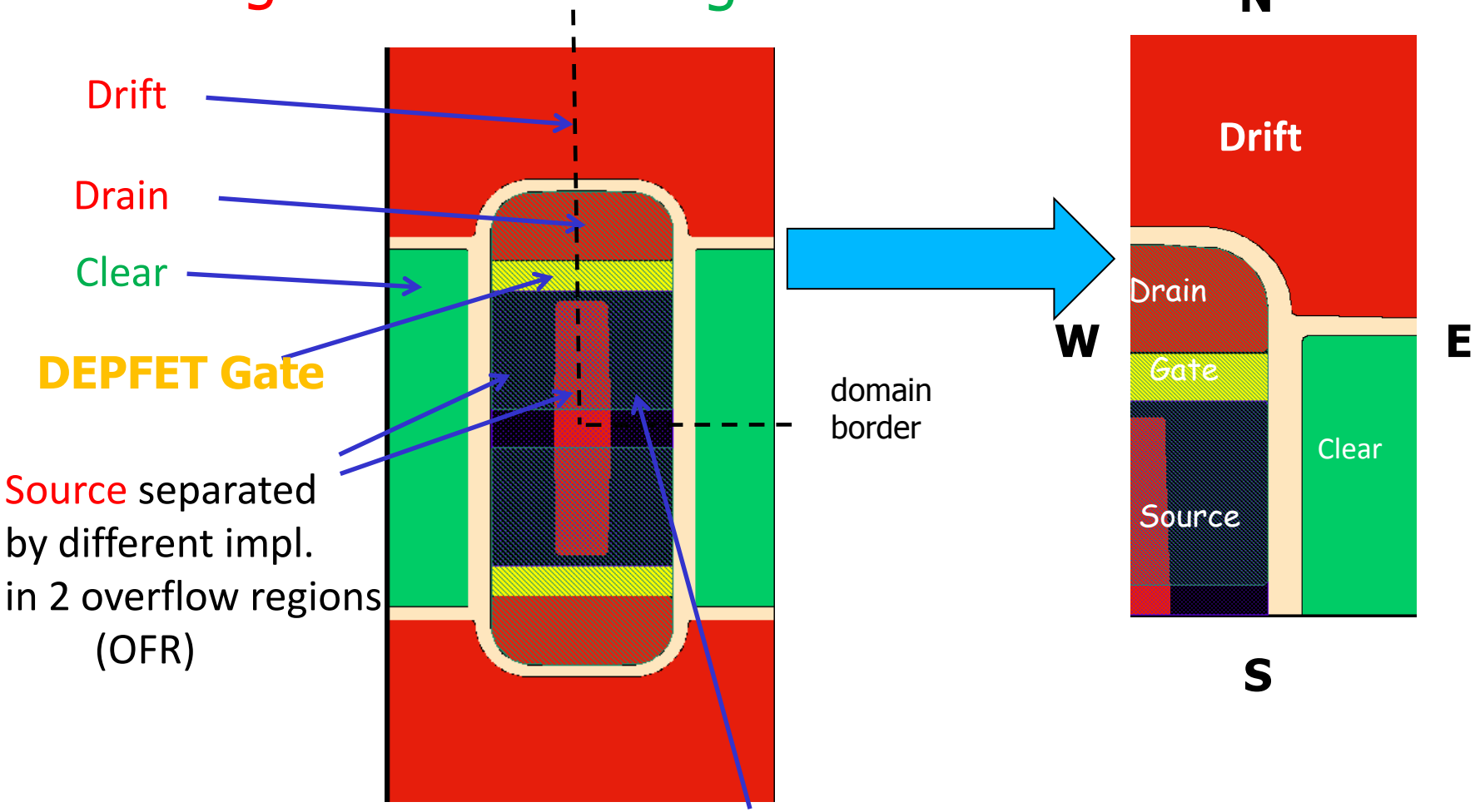
With courtesy:
P. Lechner et al
DEPFET Active Pixel Sensor
with Non-Linear Amplification
IEEE NSS, Valencia 2011

Circular Device
needs space

☹

Double cell -> Simulation domain (half cell)

P regions: Red N regions: Green

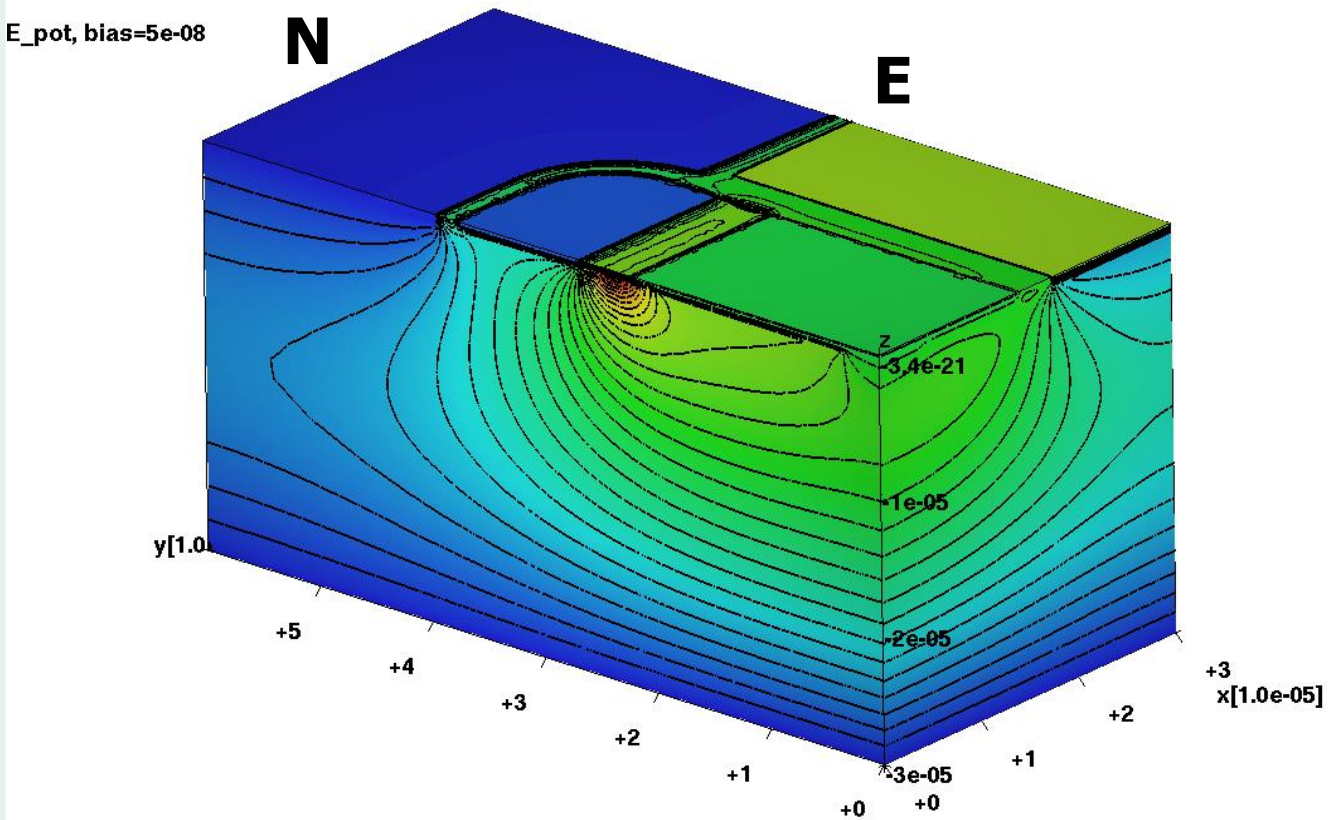


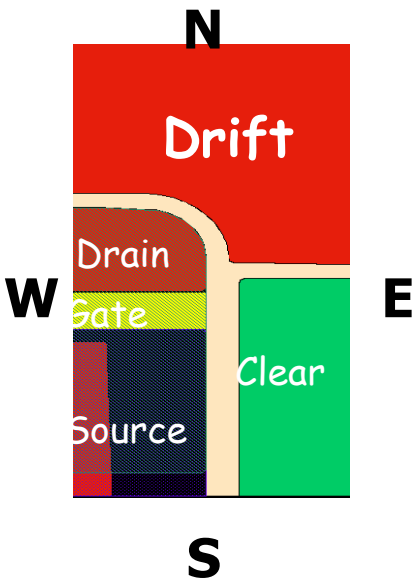
No need of multiple deep n-implantations

-> Drift field towards the Internal Gate by wedge shape of 2. OFR

3d Pixel Simulation

Potential distribution during charge collection

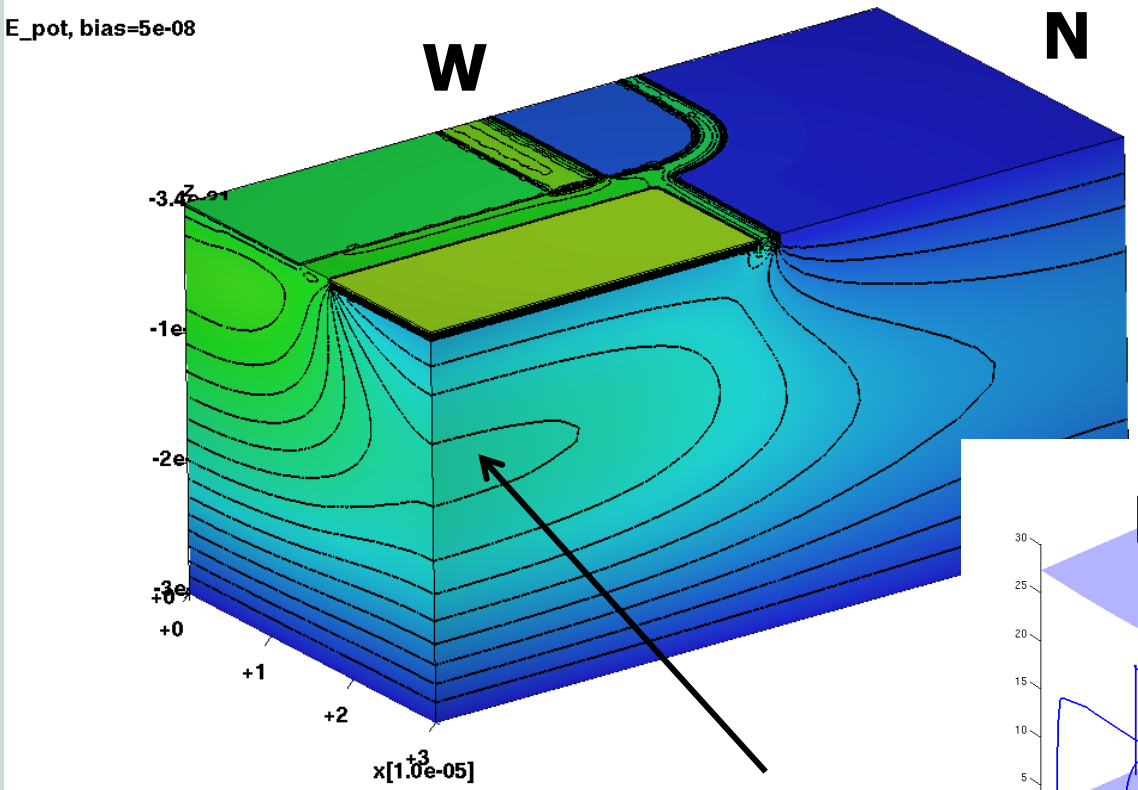


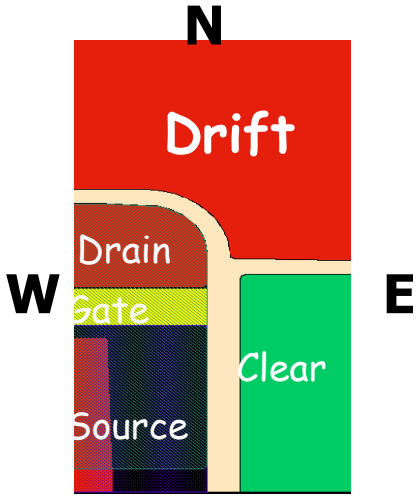


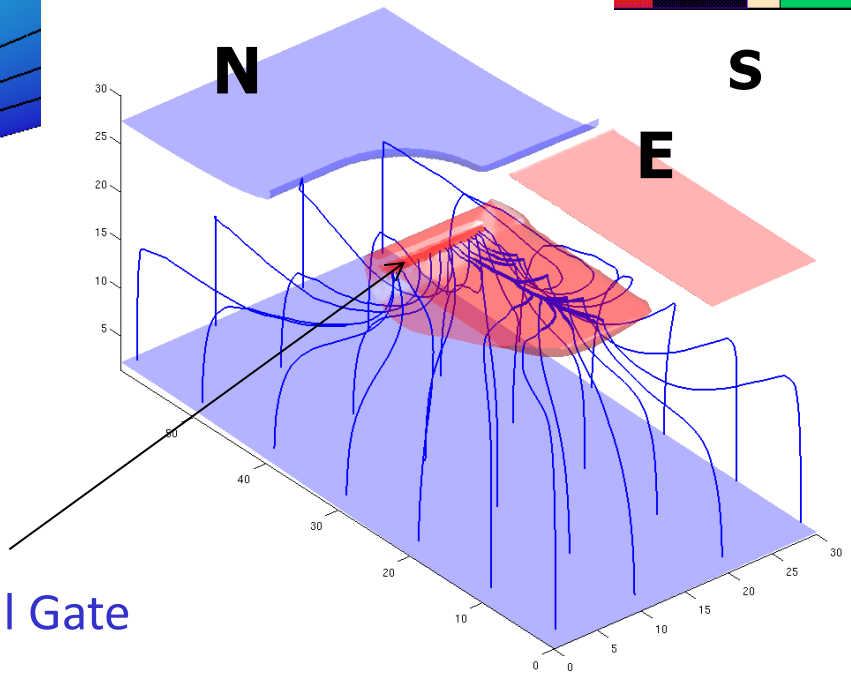
30µm detector thickness (charge collection more ambitious)

Simulated with Oskar3 (K. Gärtner)

View from SE (Clear Side)



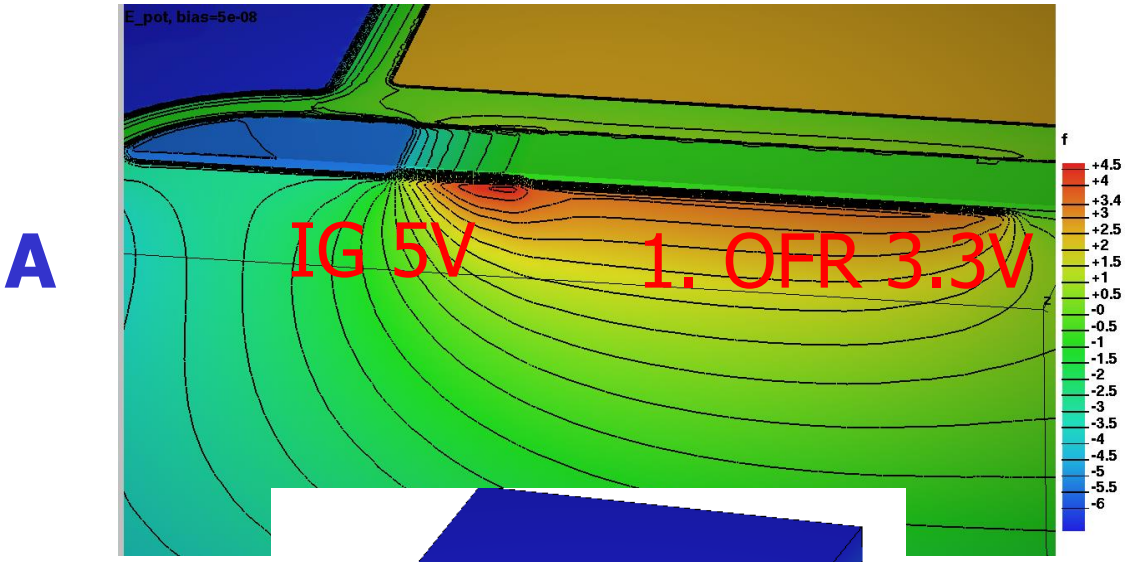


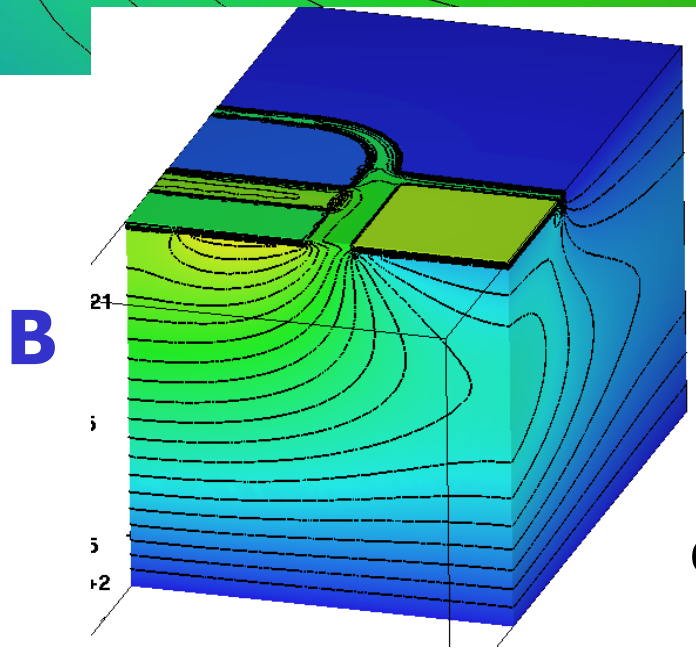


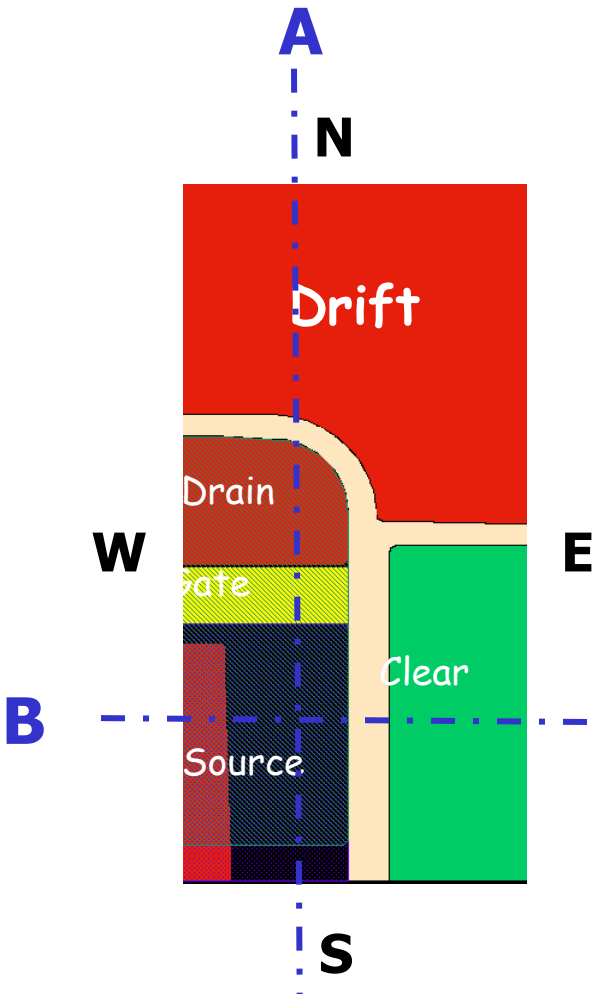
Does charge drift
to the pixel border ?

No, all paths end in the Internal Gate

Charge overflow regions (OFR)

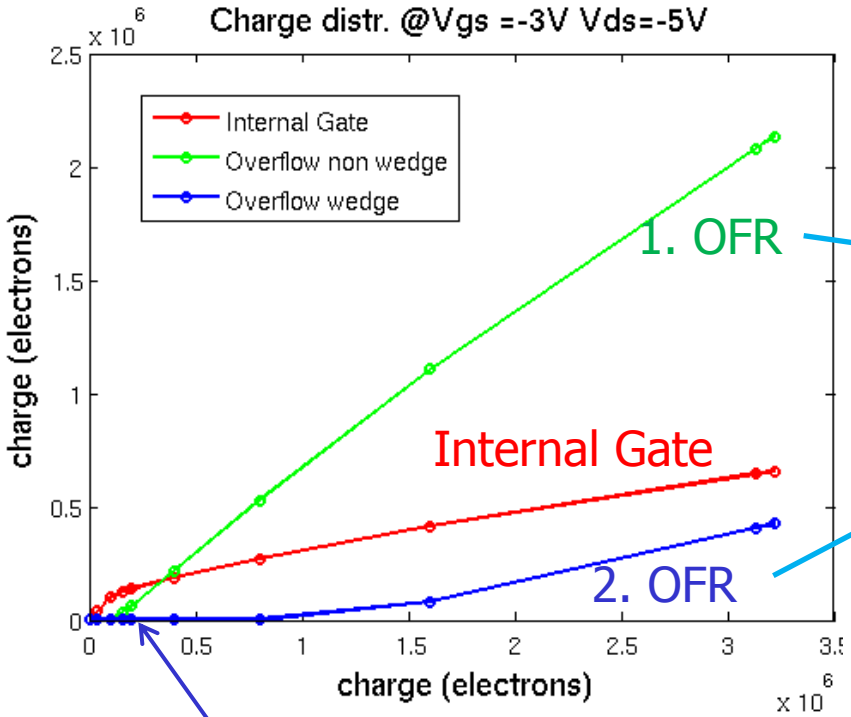


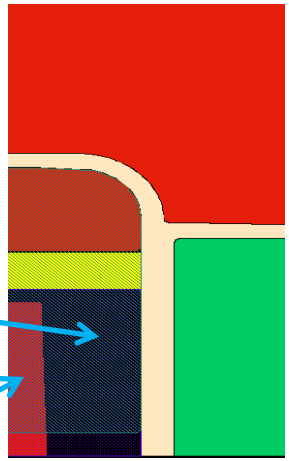


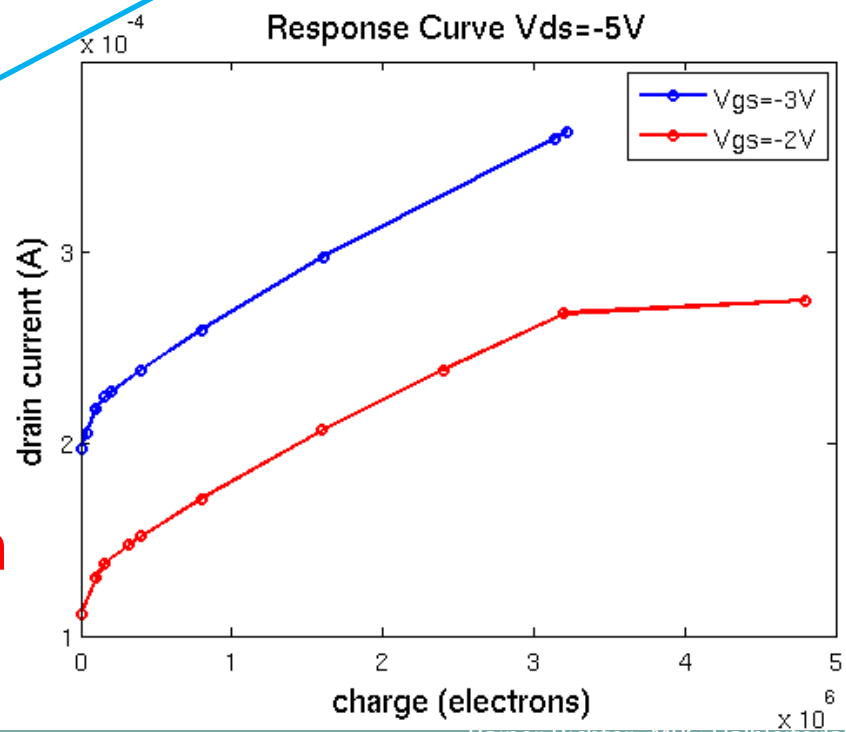


Cut through 1. and 2. OFR region

Charge distribution in storage regions and current response

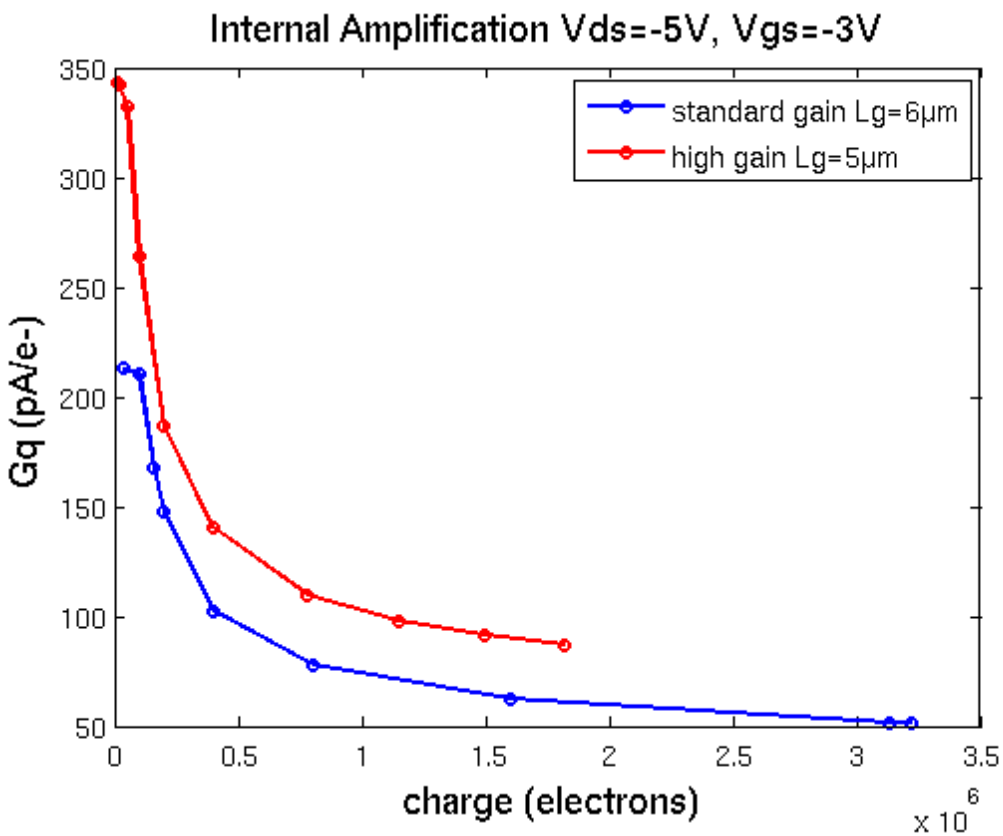






Onset of overflow
= onset of signal compression

Tailoring the amplification by design and implantation parameters

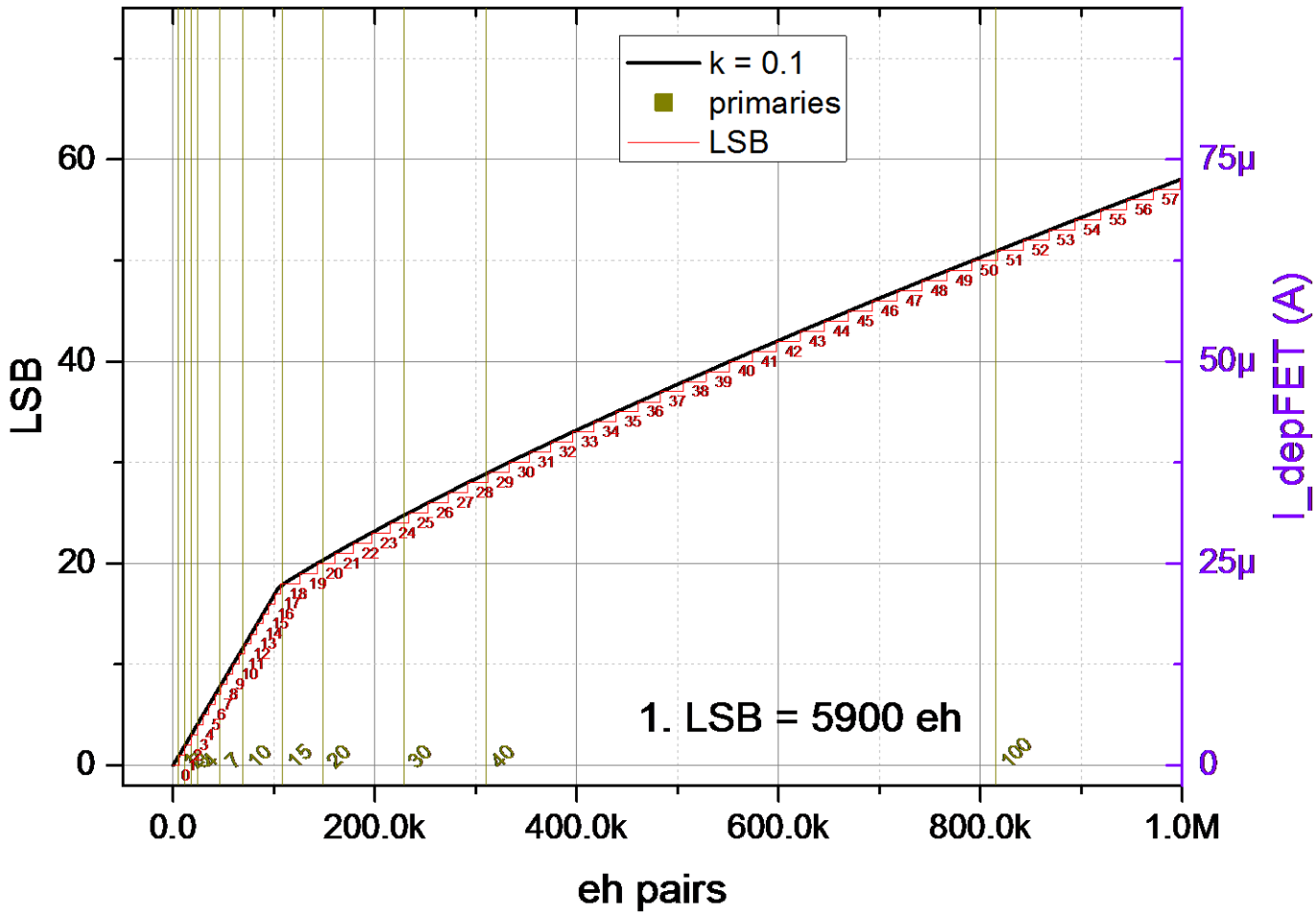


By signal compression we get single electron resolution as well as a high dynamic range

DCDE has 4 different gain settings to cope with various design options

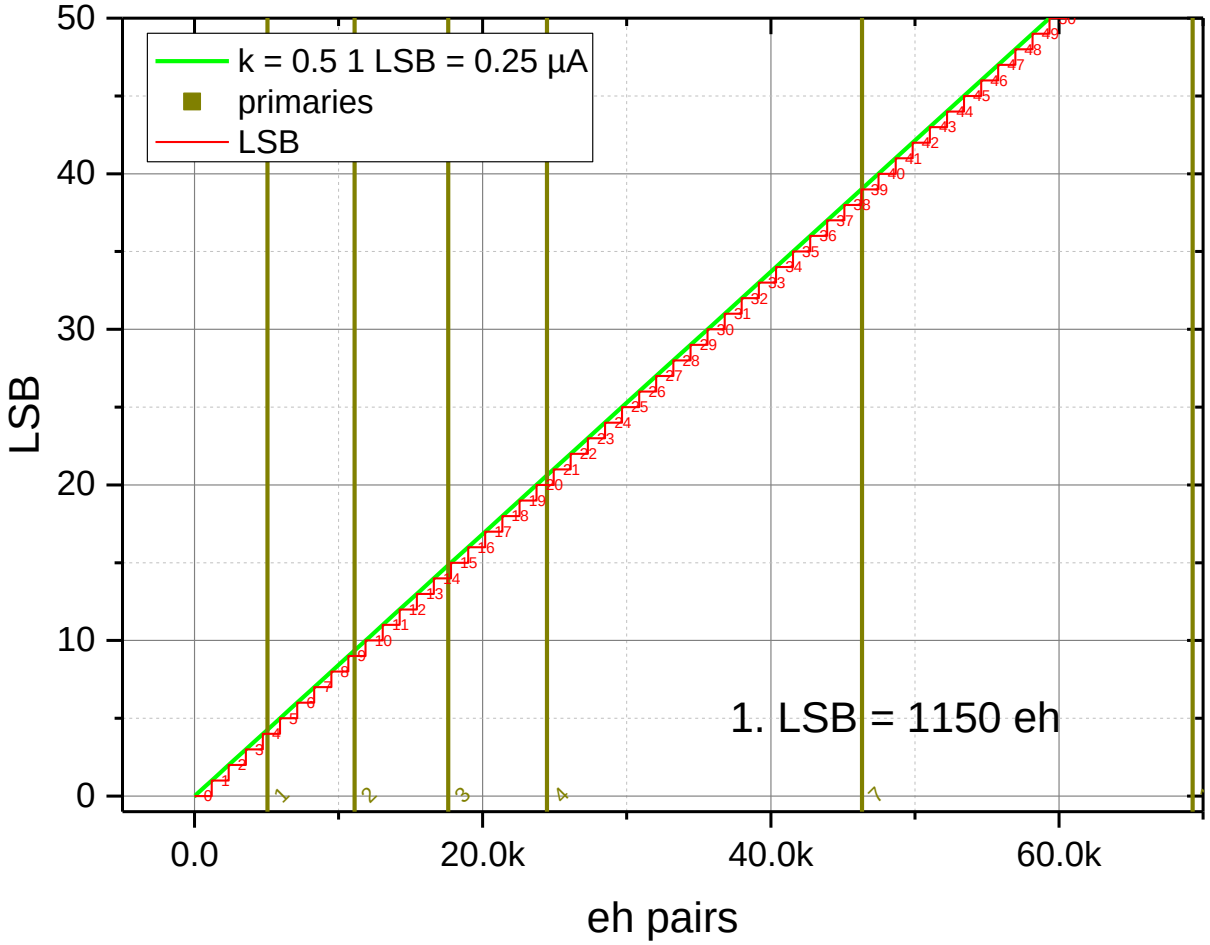
Matching of DEPFET response to DCDE gain (i)

Low DCDE gain = 0.1 -> high dynamic range



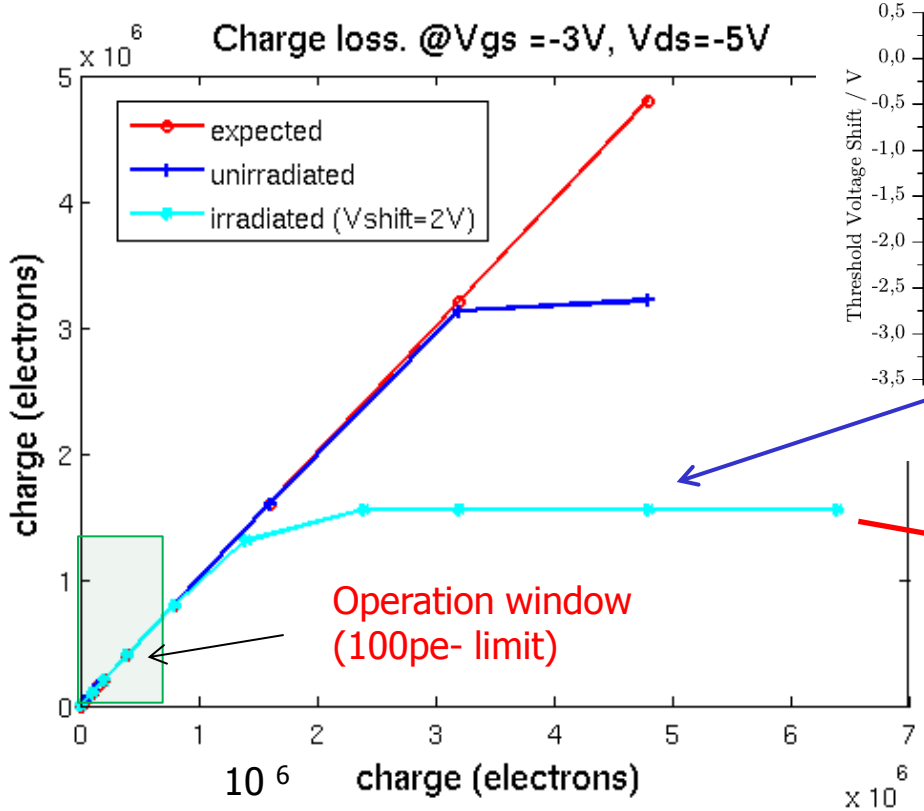
Matching of DEPFET response to DCDE gain (ii)

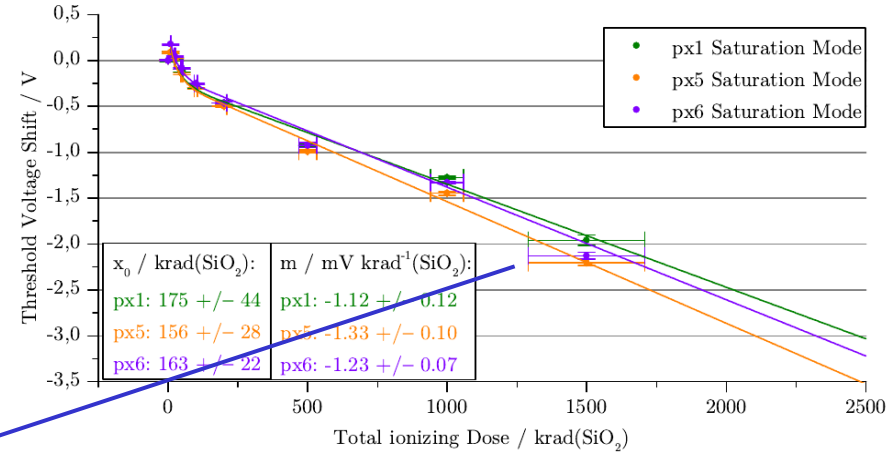
Higher DCDE gain = 0.5 -> single primary electron resolution



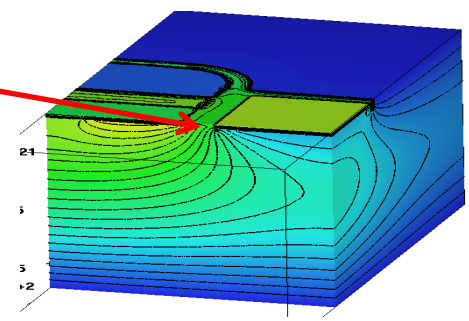
Reasonable single electron capabilities

Challenge: Radiation Hardness





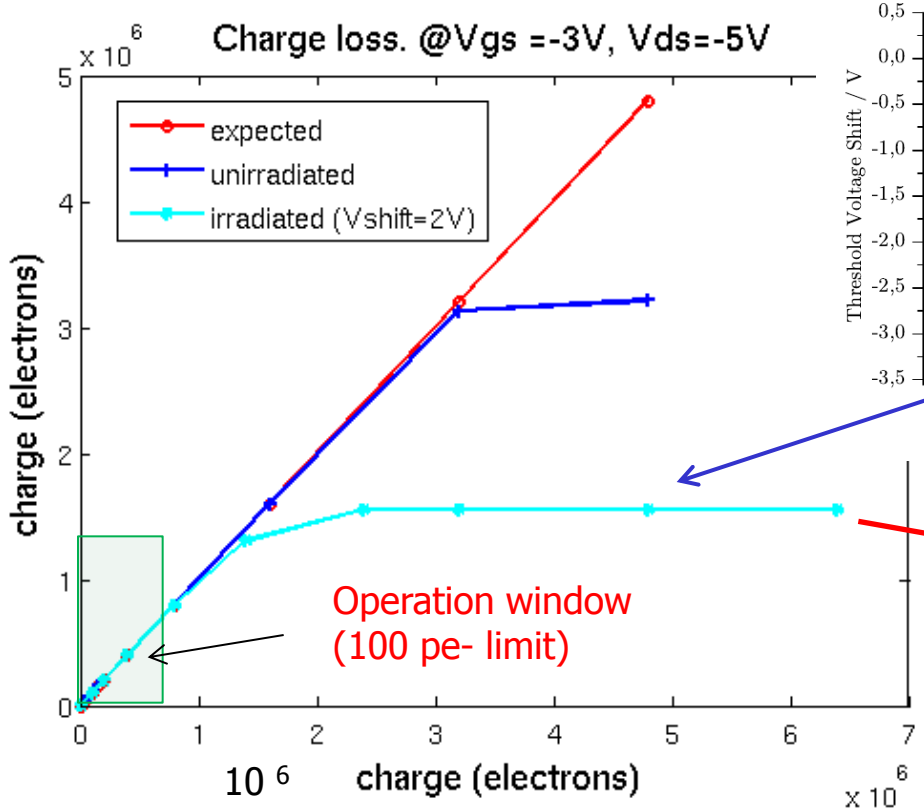
MOS

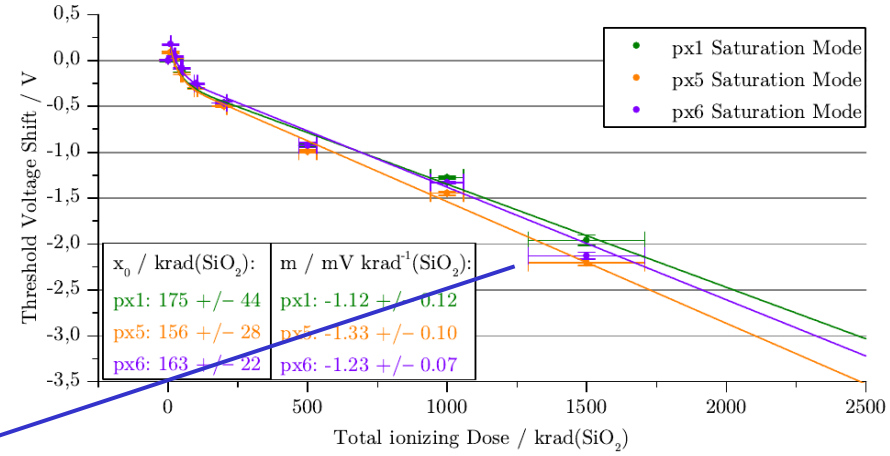


We will get enough data to validate the concept and to do research.

Real space detector sees a rather homogeneous radiation level
Hom. oxide charge build-up
-> compensated by Gate voltages
Concern: inhomogeneous rad.

Challenge: Radiation Hardness





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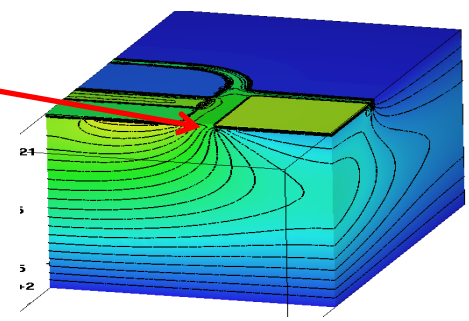


We are working on different approaches to prolonge the detector lifetime:

- Module can be heated up to 200°C to anneal radiation damage
- Technological work on the dielectrics to get an intrinsically better radiation hardness

Concept and System

4 modules closely placed (gap 2mm)

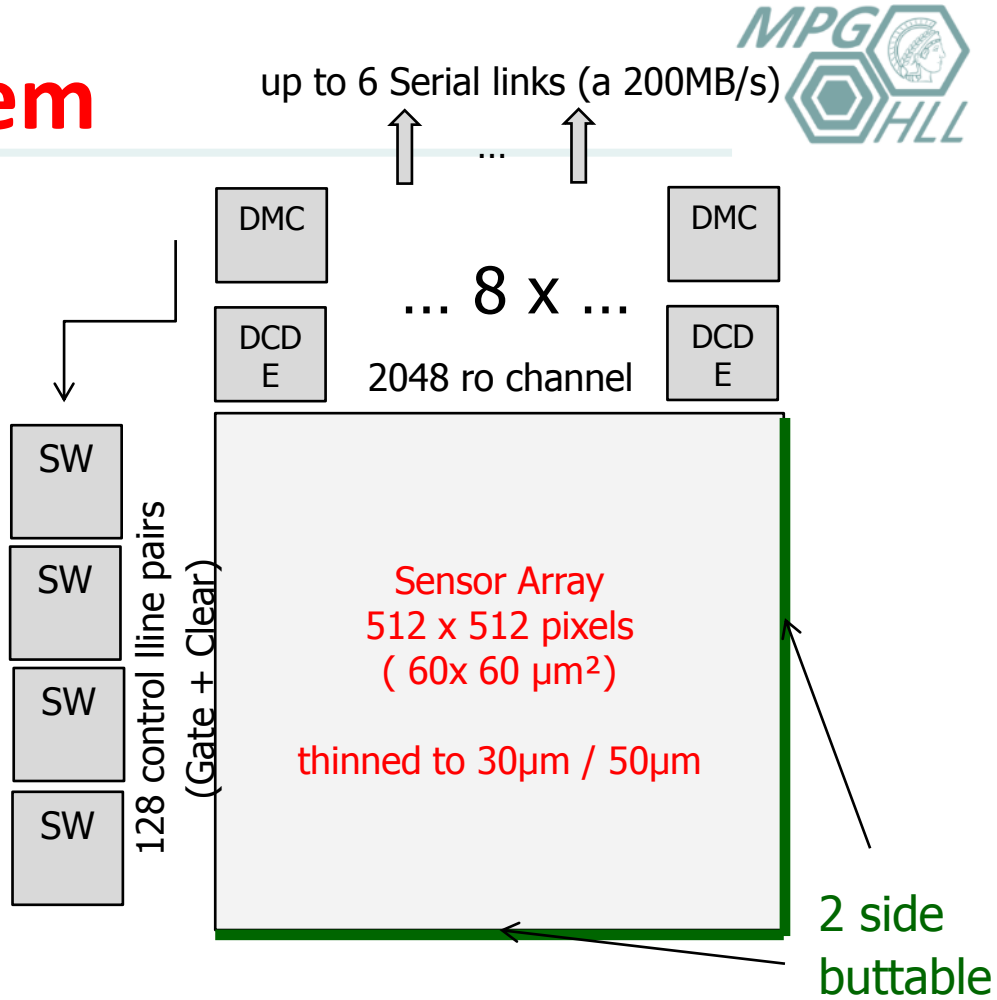
1M pixel

Sensor area: 36 cm²

Pixel size: 60x60µm²

4-fold ´rolling shutter' readout

(Belle proven ☺)

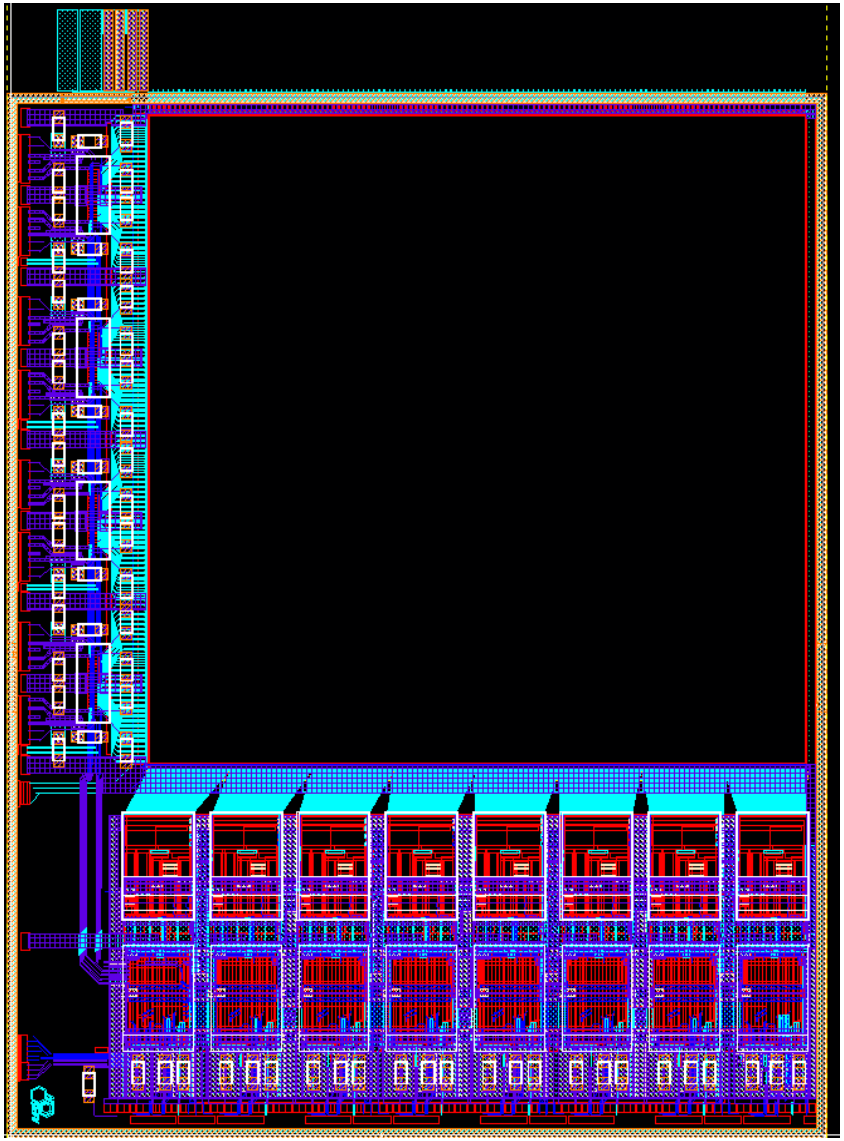


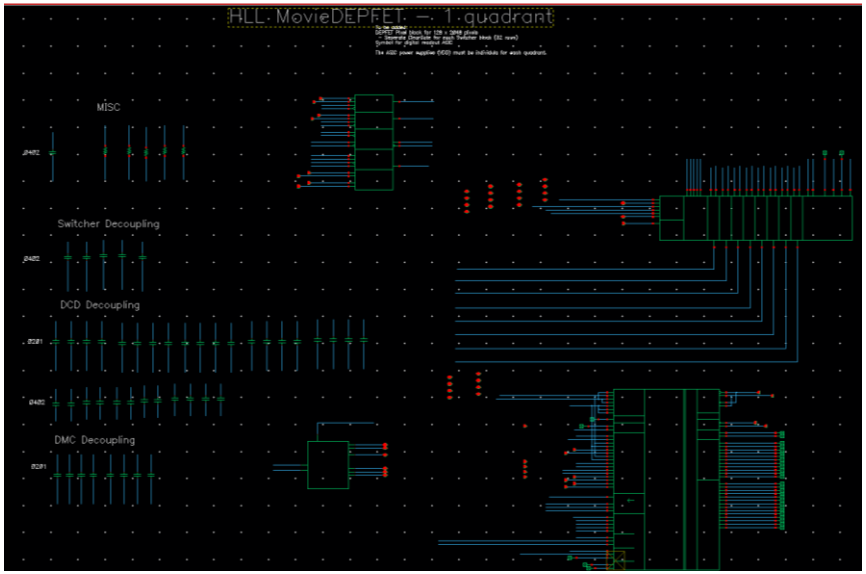
From Belle2-PXD: 100ns/row x 128 -> 80kHz frame rate !!

100 frames form one sequence (movie of 1.28 ms)

Duty cycle : < 1:10 (data transmission and sample changing)

EDET 80k 512 x 512 Module : Layout and Schematic



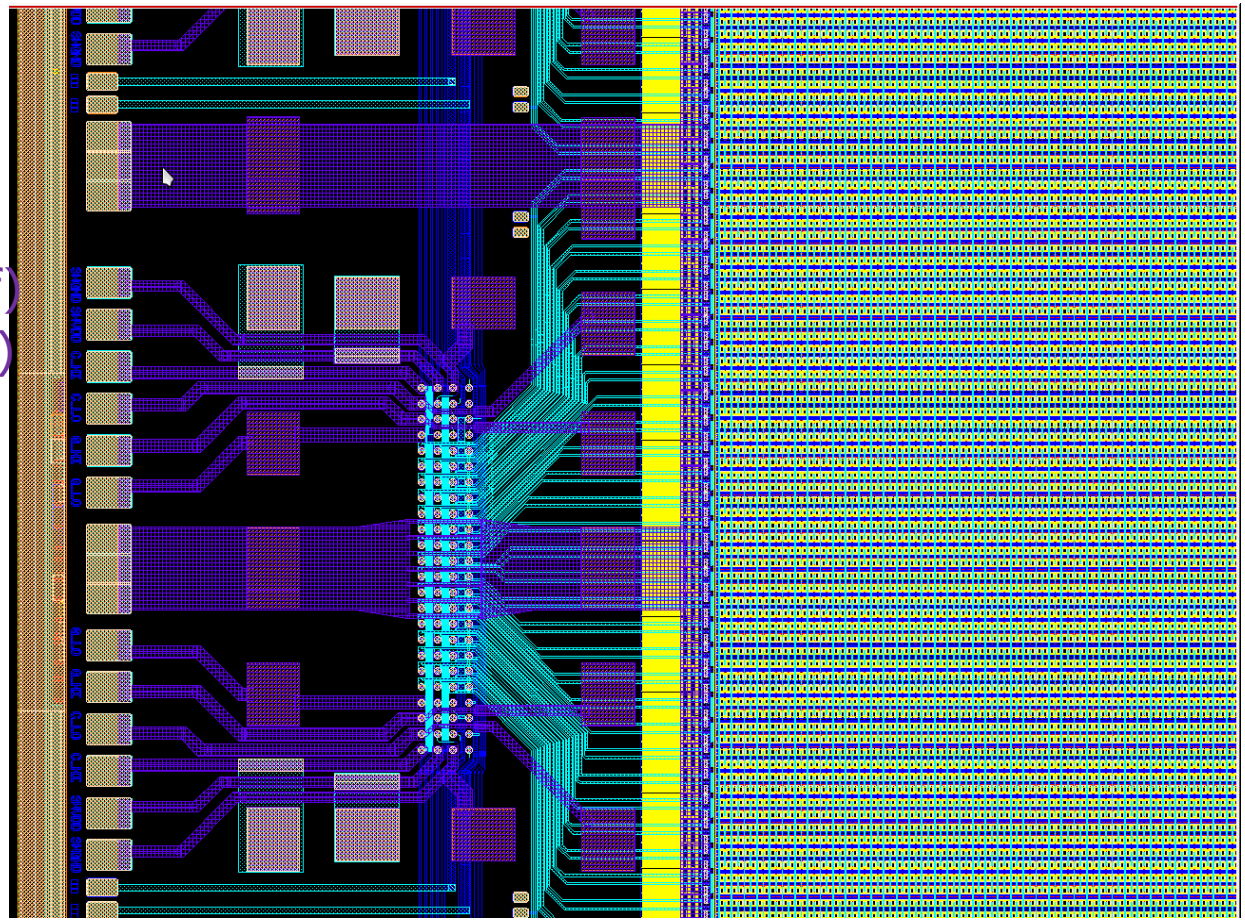


Based on Belle2 module:
Technology very similar
(2 poly, 3 metal, thinned)

2 side buttable -> accessible from the other 2 sides
helps a lot !

EDET 80k 512 x 512 Module : view on Switcher balcony

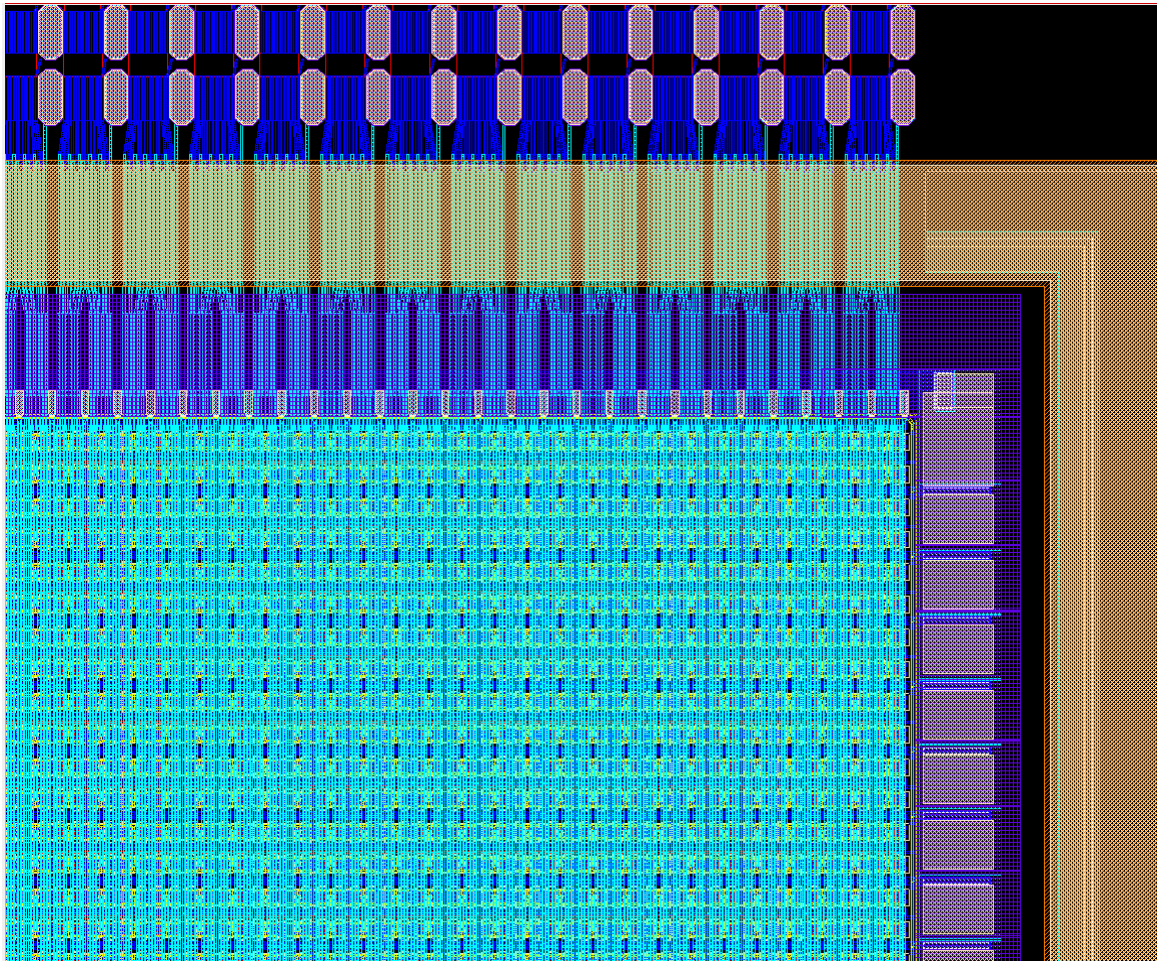
Low ohmic
copper lines
Vgate (on,off)
Vclear(on,off)
Vsource
VDDD (SW)
GND



Direct bond wire connection to each switcher

2-side buttable

Test fanout (to be removed)



Clear gate biasing
(poly resistors)

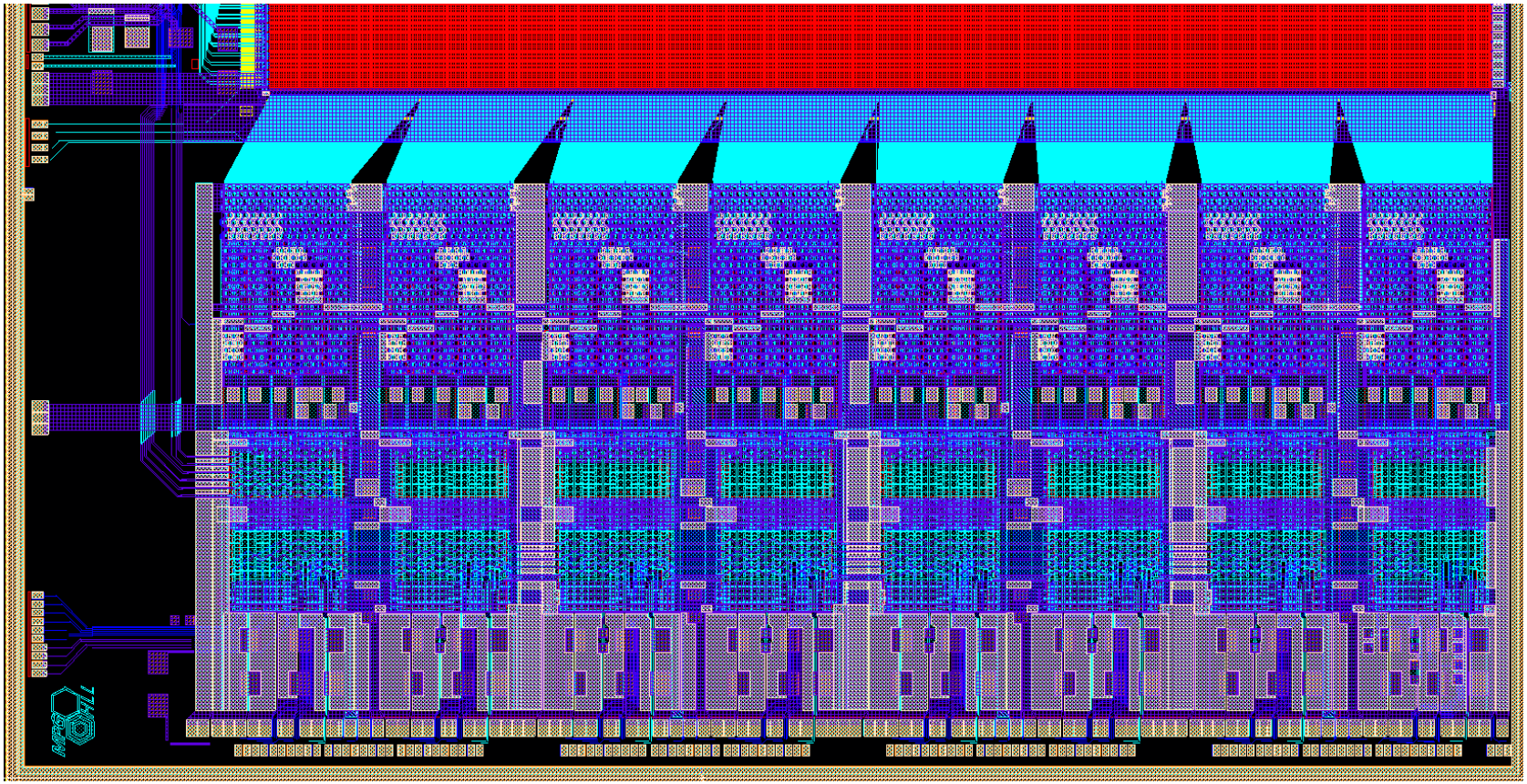
Need Source frame
for the matrix

Thick silicon for mechan. stability
and cooling

dead space: 800 µm

meet the 2mm requirement

EDET 80k 512 x 512 Module : view on ro-electronics



Similar to Belle2 – lateral Cu lines, vertical Al lines -> power sensing
DHP is replaced by DMC (footprint very similar)
Direct bonding to PCB panel (no copper soldering) – saves space
50um pixel -> 60µm pixel wider matrix - larger gaps inbetween RO chips, better power connection

Production Status

Split the production into 2 batches (for safety)

1. Batch: test of response behavior
   (small test matrices)
   Module function
   First metal layer written
   finished in September

2. Batch stopped bevor 2nd Poly
   adapt the gain, tailor the response curve
   includes technology variants (rad hard)

Summary

- A direct electron detector for real space observations in TEMs is proposed

- Making use of the all-silicon-module concept

very thin low mass DEPFET arrays (50µm or 30µm) provide:
good position resolution
very high readout frame rate: **80kHz**
(extrapolated from Belle2 PXD detector)

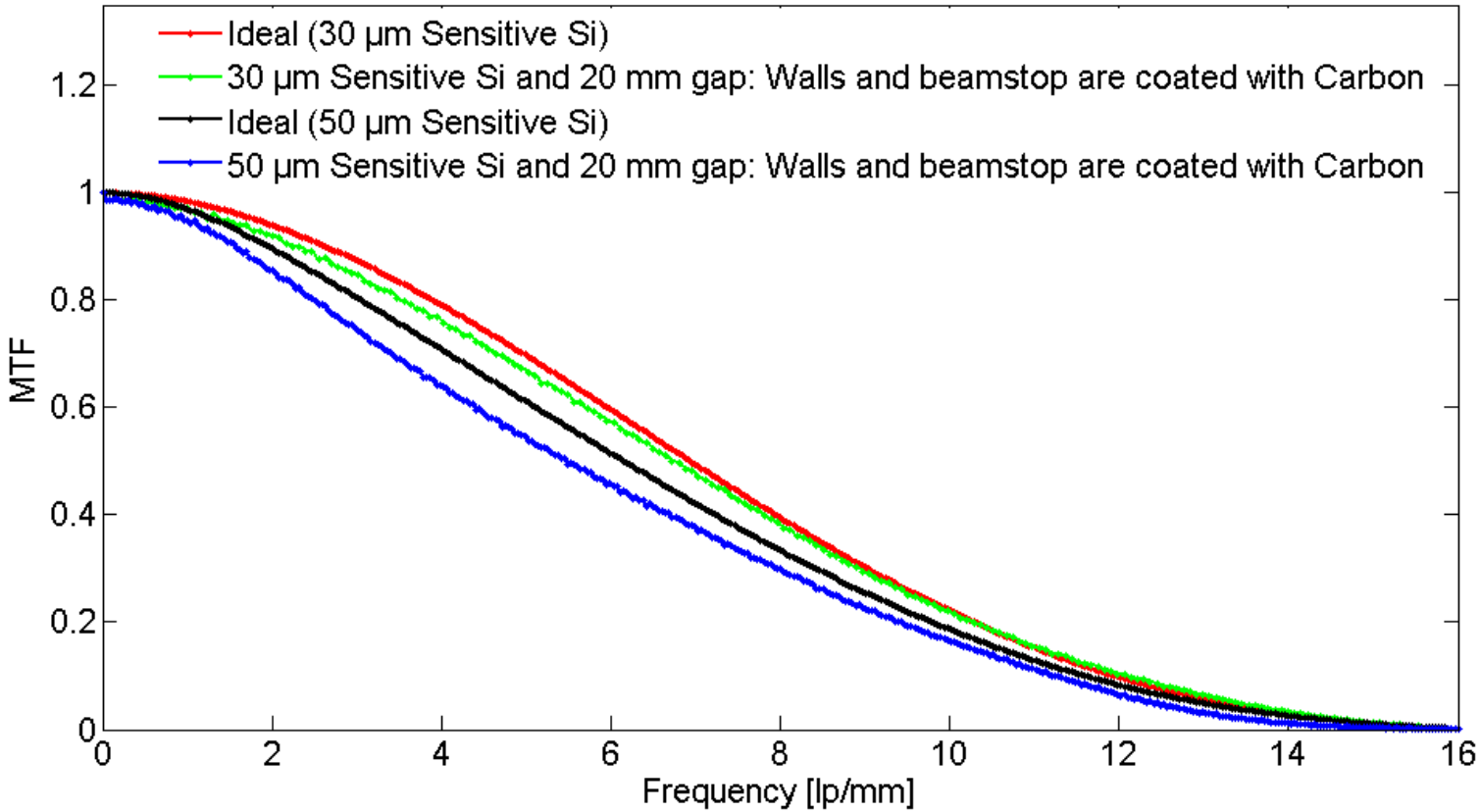
- Rectangular DEPFET pixels (60µm x 60µm) with signal compression have a charge handling capability of > 1Mio. electrons
(> 100 primary electrons of 300keV)

- Sensors are currently in fabrication at MPG Semiconductor Lab.

Thanks for your attention

Modulation transfer function

Provides a quantitative description for the contrast behavior



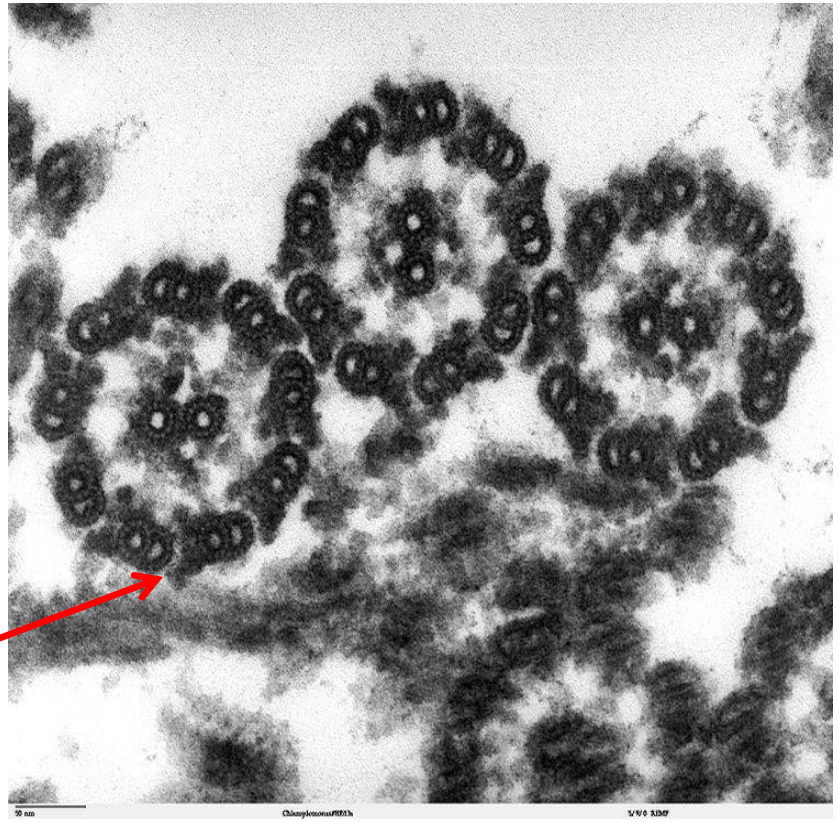
Direct Electron detector used for TEM

Direct electron have much better performance than films or even semiconductor coupled to scintillators

The talk is related to a

'real space imaging' detector .

Picture is generated by the absorption of electrons (shadow image). Does not rely on a crystallite structure of the biological samples



Concept and design is developed in close collaboration with the future users from MPSD

with a strong focus on speed !!

Main Requirements on a Direct Electron Detector

- Position resolution and contrast
- Speed

  (important for the special applications)
- High dynamic range

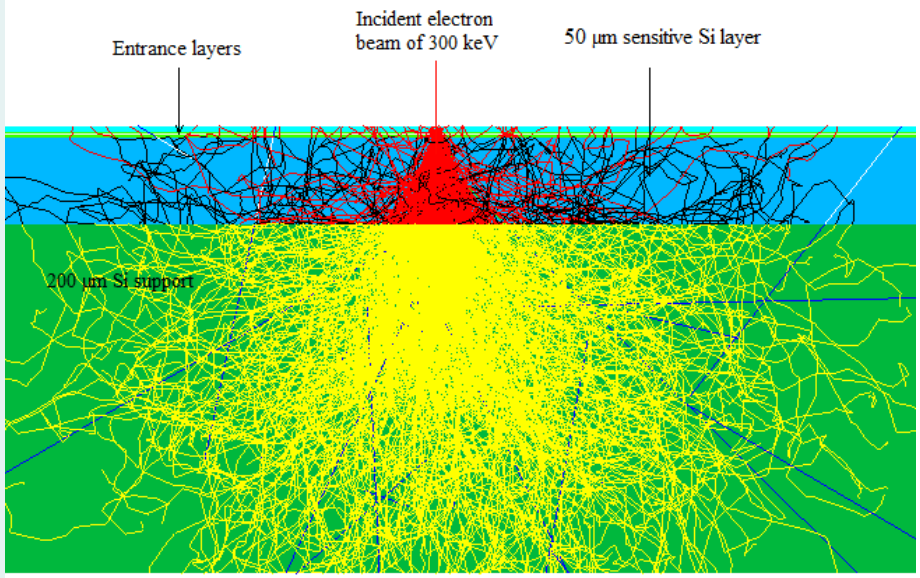
  (Charge handling capability)
- Radiation hardness

How can a DEPFET based detector system cope with this requirements ?

Position Resolution and Contrast

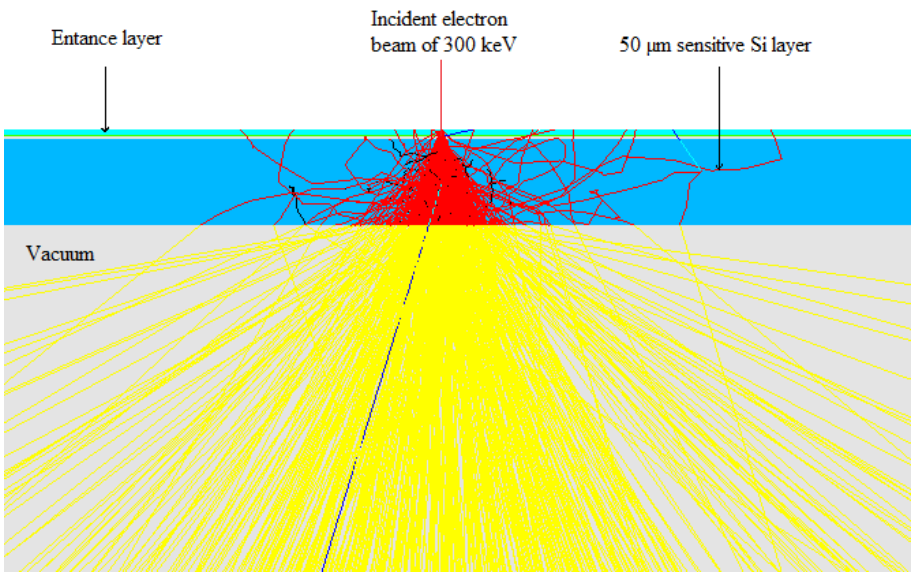
What do we need?

50μm thick detector
with 200μm passive Si support structure



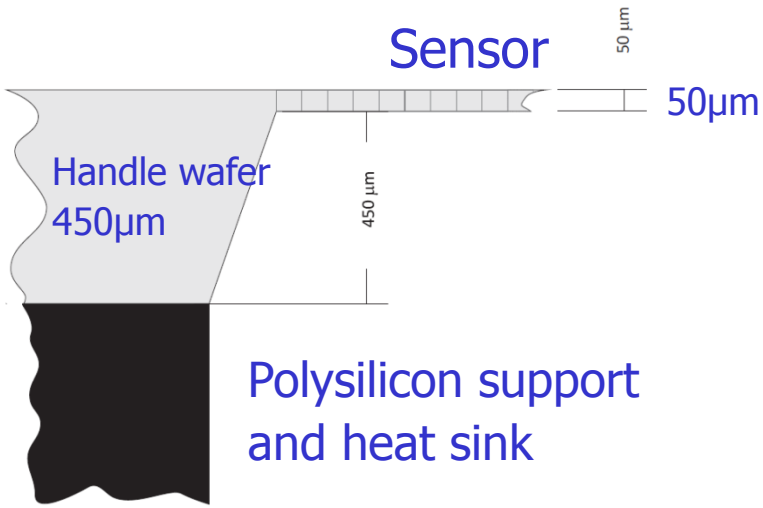
thin detector

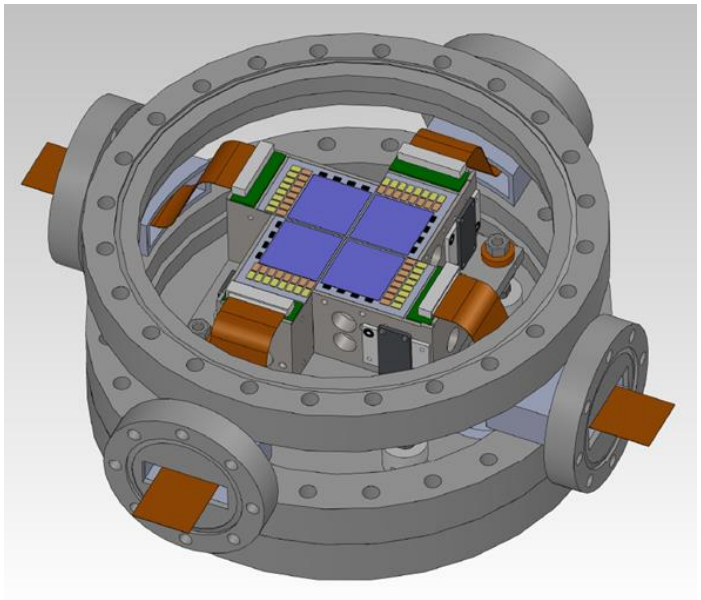
50μm thick detector without support structure
beam stop 20mm beneath



works only at very low power consumption for thermal reasons !

- The thinner the better. We do ….
  All-Silicon Module (50µm and 75µm thick see next talk by L. Andricek)





Sensor production on SOI wafer with 50µm and 30µm top wafers on the way

DEPFET operation principle

DEPFET integrated amplifier

p-FET on depleted n-bulk

signal charge collected in
potential minimum below FET channel

“Internal Gate"

FET current modulation ≥ 300 pA/el.

reset via n-FET (called Clear)
low capacitance & noise

charge storage, readout on demand
(rolling shutter mode)