Non-BELLE applications

Multigate DEPFETs – future trends and possible applications

19th international workshop on DEPFET Detectors

Seeon monastery

11.5.20

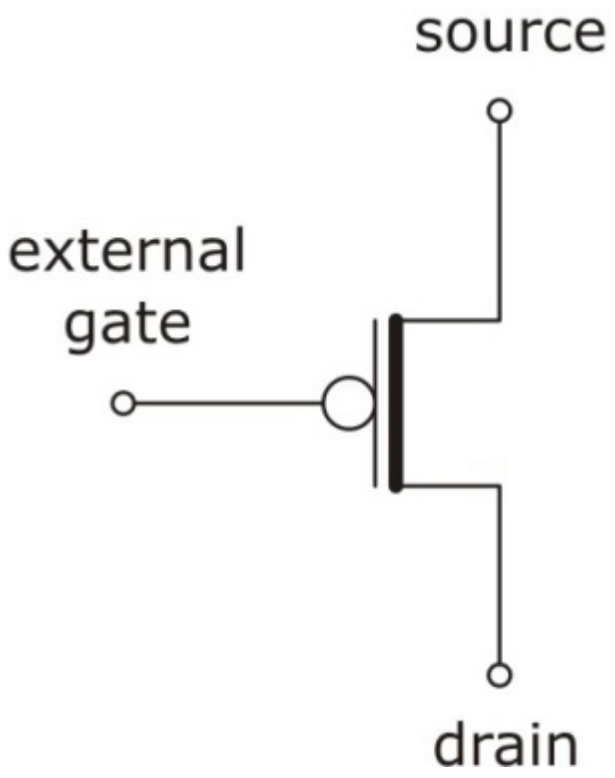
Co nts:

- Standard DEP
- GPIX:
  - GPIX Ba ierg e
  - PIX Bl dgate
- Infinipix variants:
  - Infinipix
  - Infinipix Quad (IQ)
  - Central Anode (IQCA)
- EPFET RNDR
- RNDR GPix
- RNDR INFINIPIX
- Application prospects

BORING!

Welcome to…

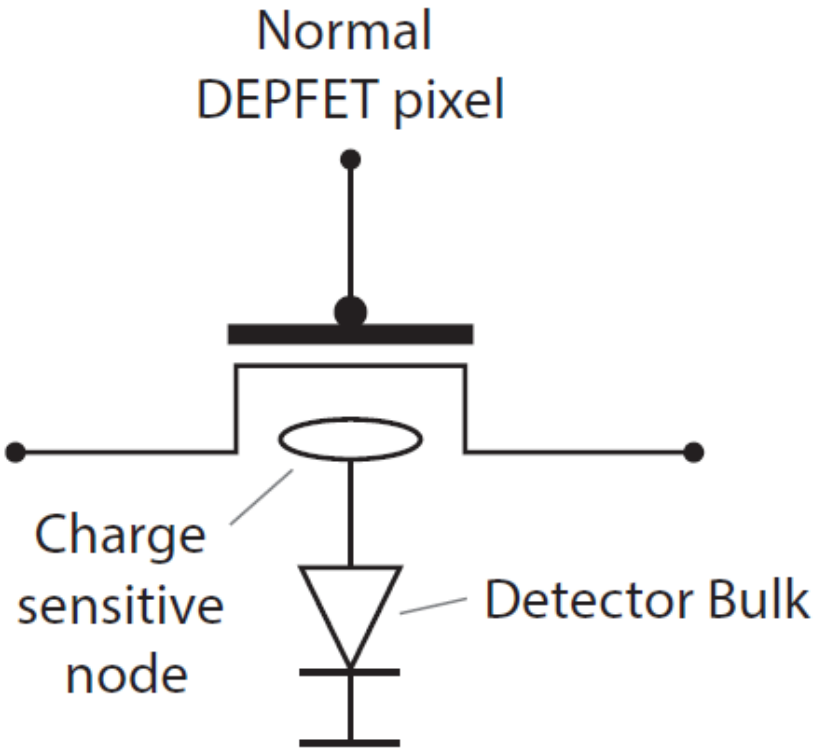
DEPFET



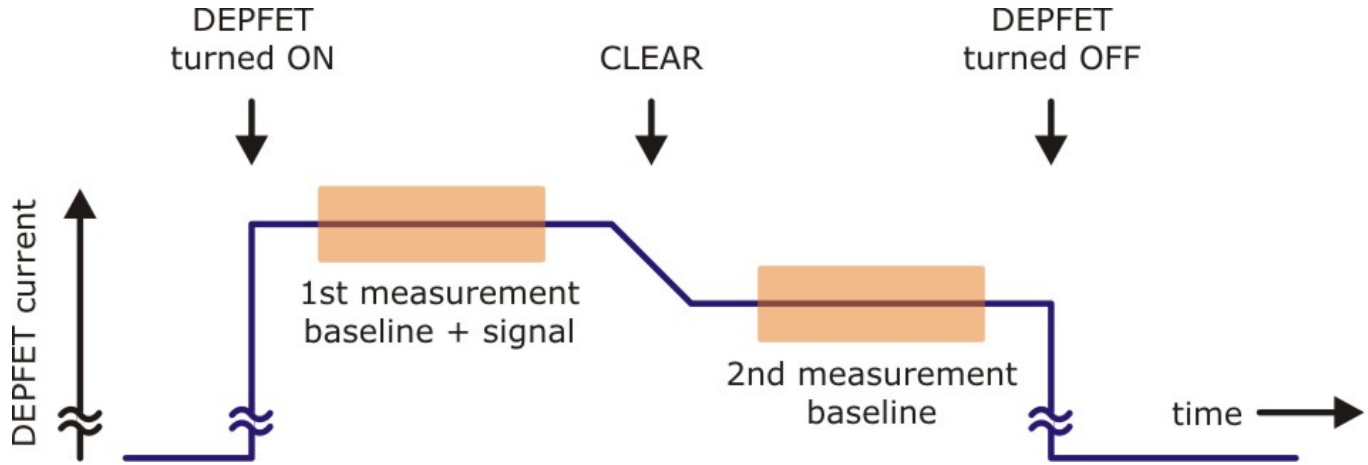
Multigate DEPFET

Introduction of additional gate electrodes to implement more functionality into one DEPFET (super-)pixels

DEPFET

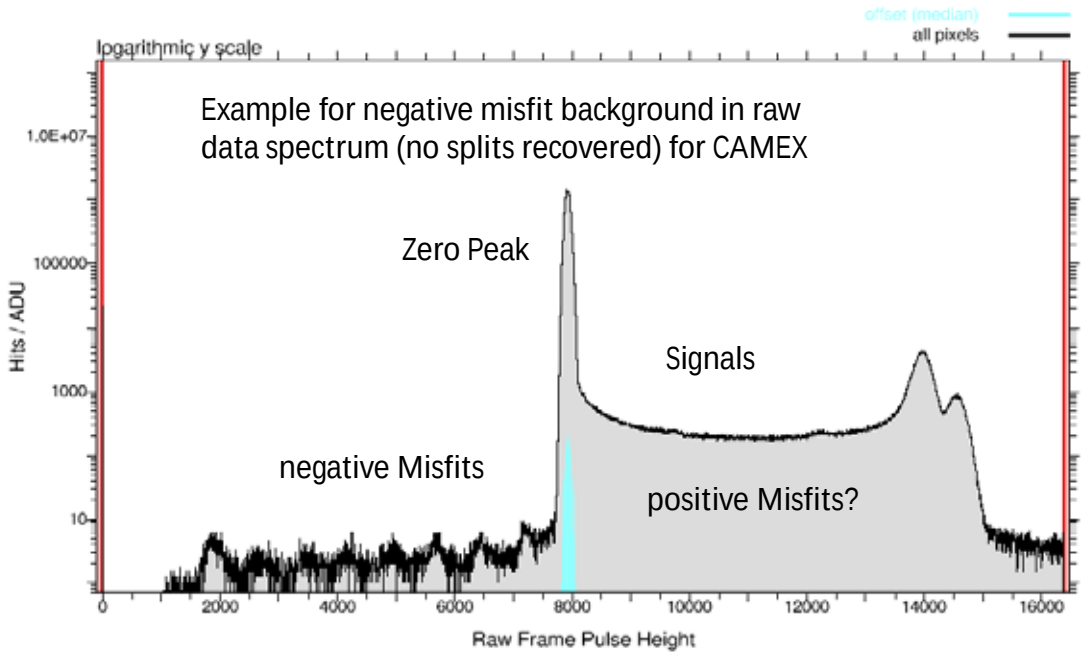


Problem I: Misfits

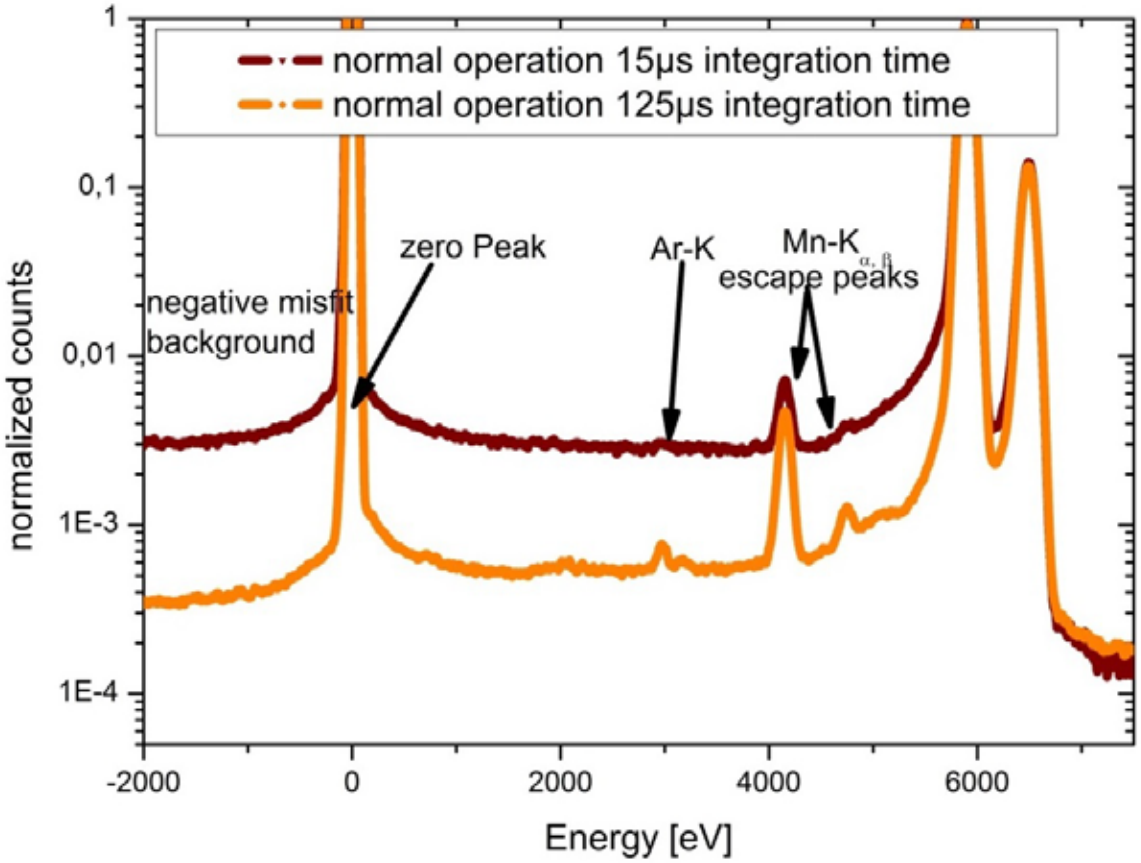


Measurement of signal:

- Measure signal levels
- Measure „mean values“ both before and after clear
- Calculate the difference of mean values = „Charge Signal“
- Hit during integration phase distorts signal



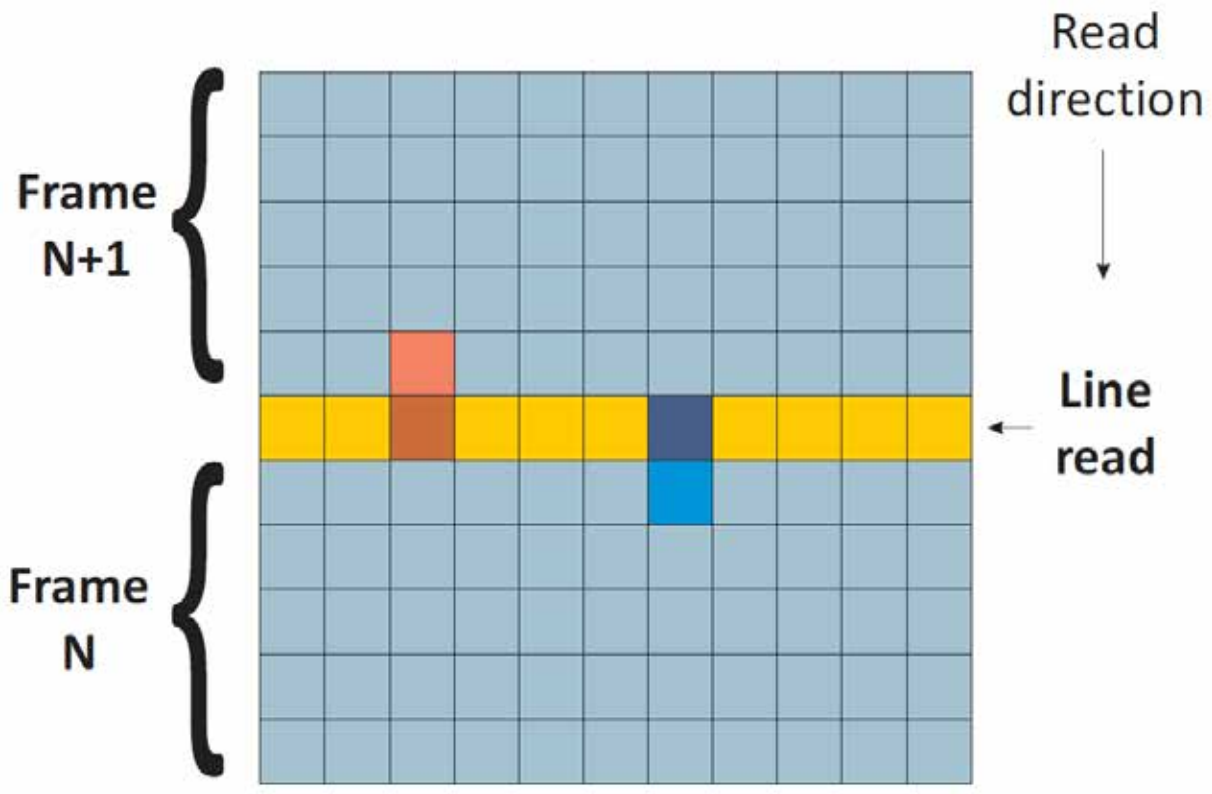
Problem I: Misfits



Signal processing of 4.2µs:

- P/B=280, FWHM=129eV @15µs signal integration
- P/B=1600, FWHM=133eV @125µs signal integration

Problem II: Broken patterns



- **Broken patterns** due to rolling shutter effect
- "Lost" split partners / allocated to different frames
- **Red case:** Positive misfit causes broken pattern
- **Blue case:** Negative misfit causes broken pattern

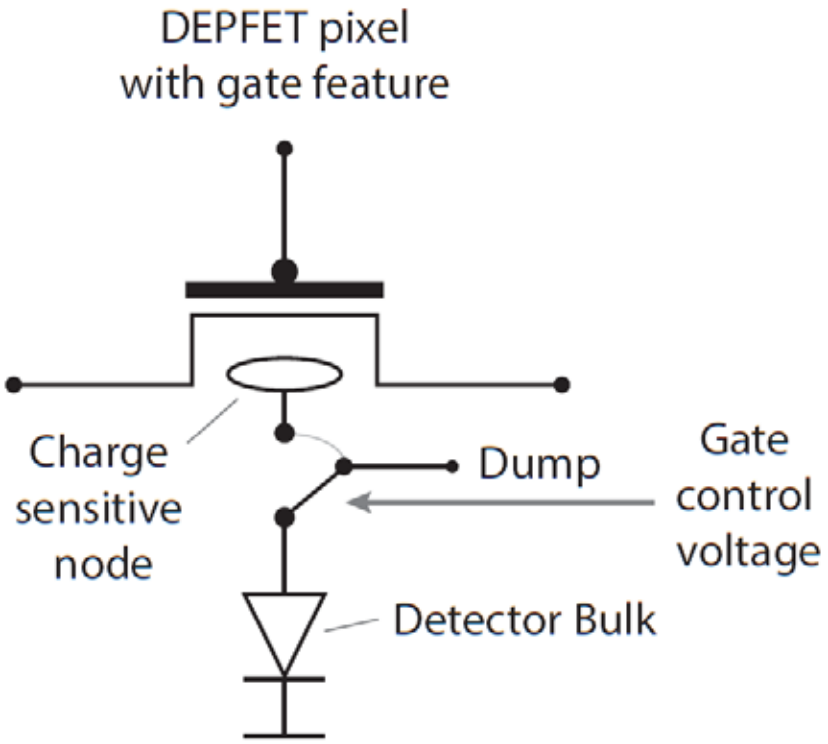
Multigate DEPFET

Turn off sensitivity of DEPFET during readout

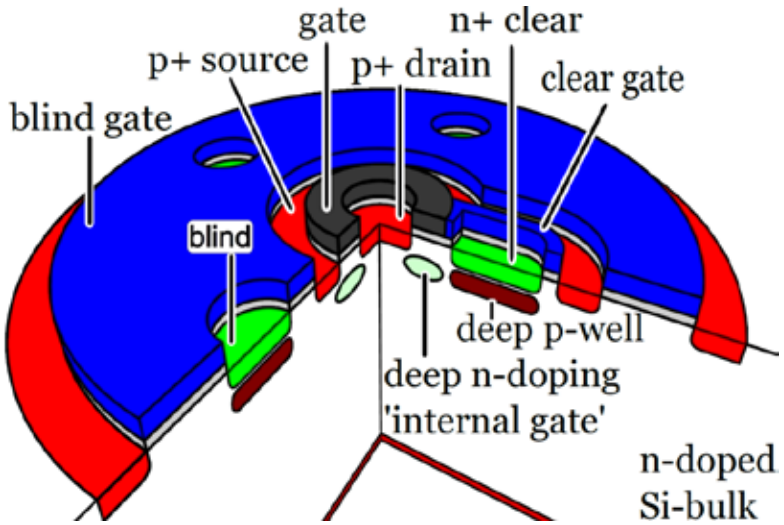
Dump unwanted bulk generated charge to dedicated electrode

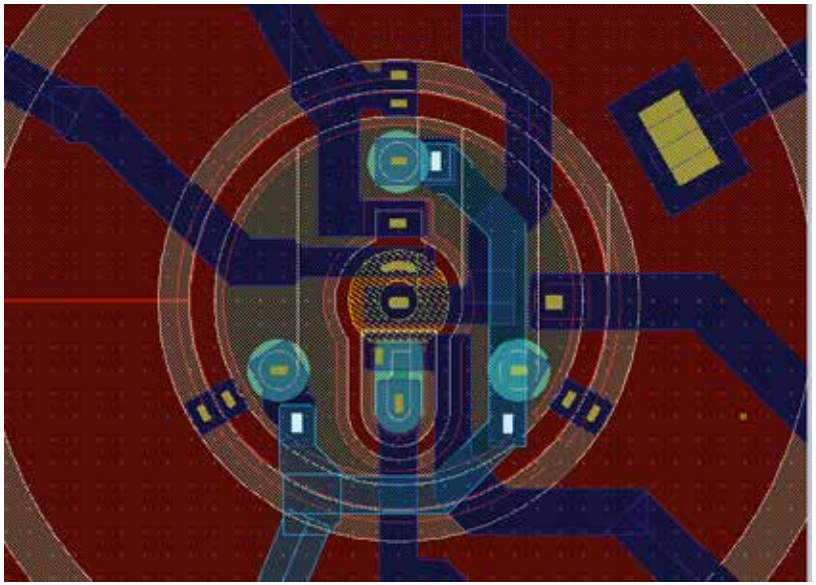
"Global shutter" functionality with precise timing

GPIX device


DEPFET pixel
with gate feature
Charge
sensitive
node
Dump
Gate
control
voltage
Detector Bulk

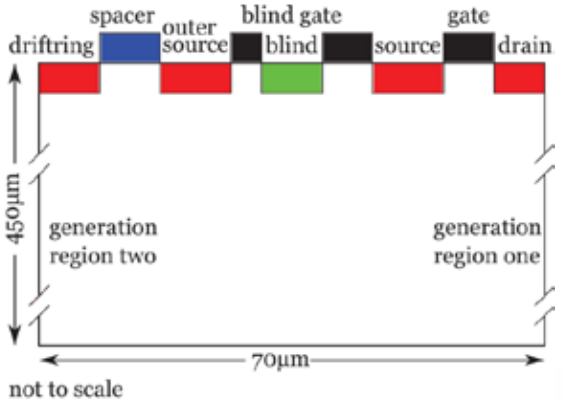
GPIX





- **Critical parameters:**
  - Charge retention (similar to CHC)
  - Charge suppression > 5 x10^{-4}
  - Shutter speed < 100 ns

Simulations

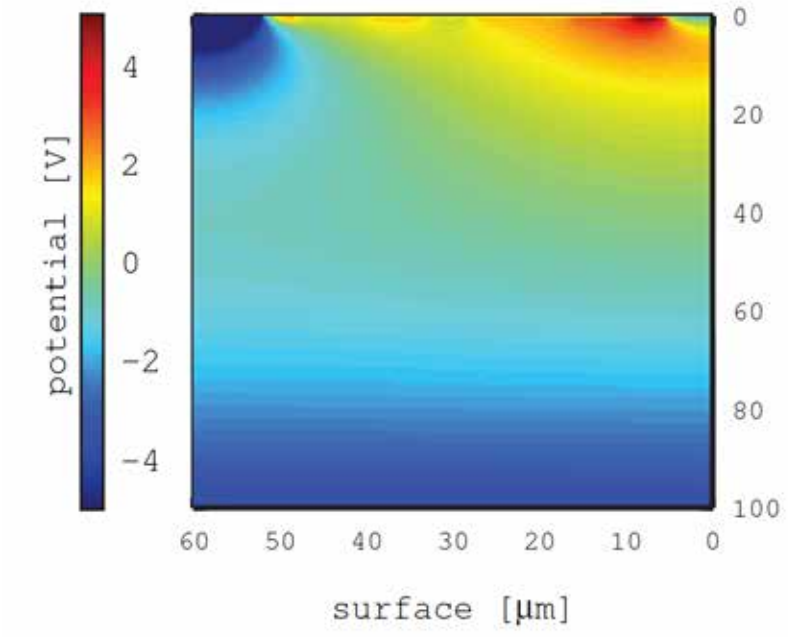


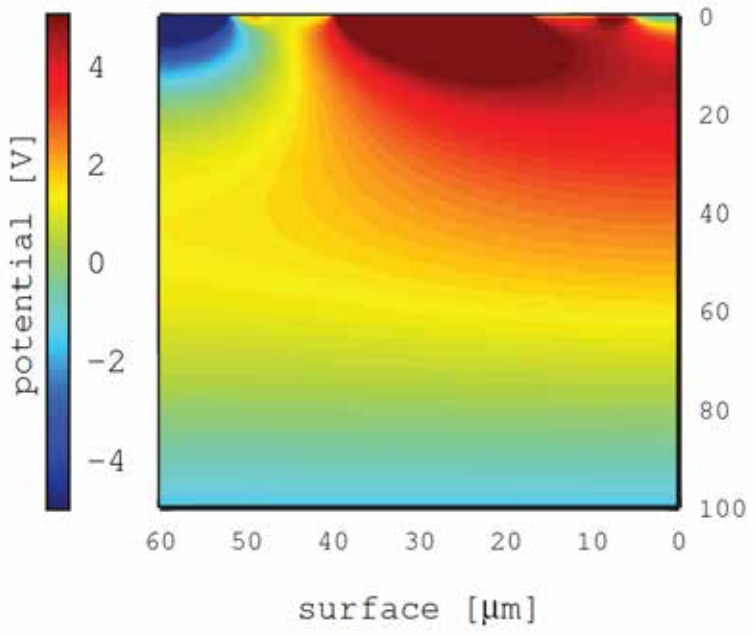
Collection mode:

- Blind and blindgate low

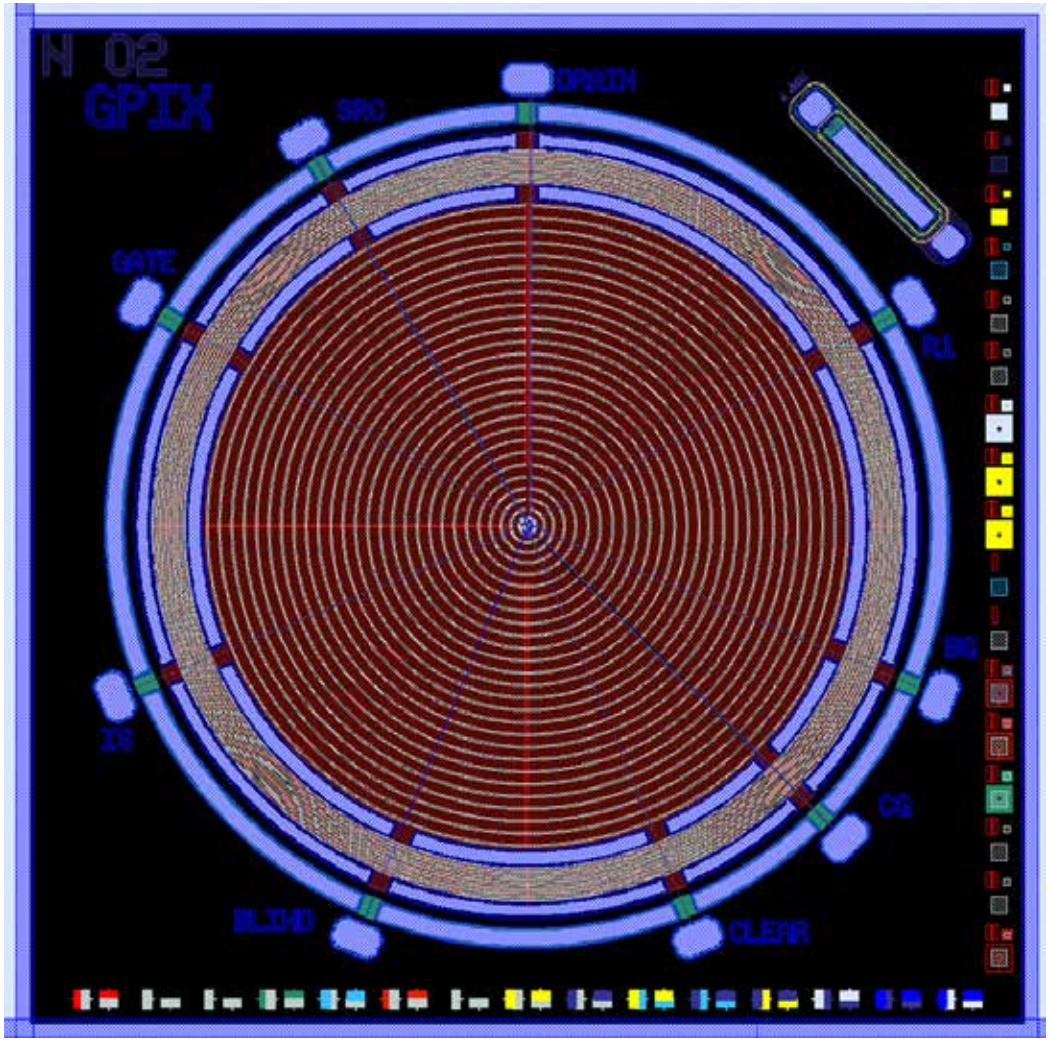
Blinded mode:

- Blind and blindgate high

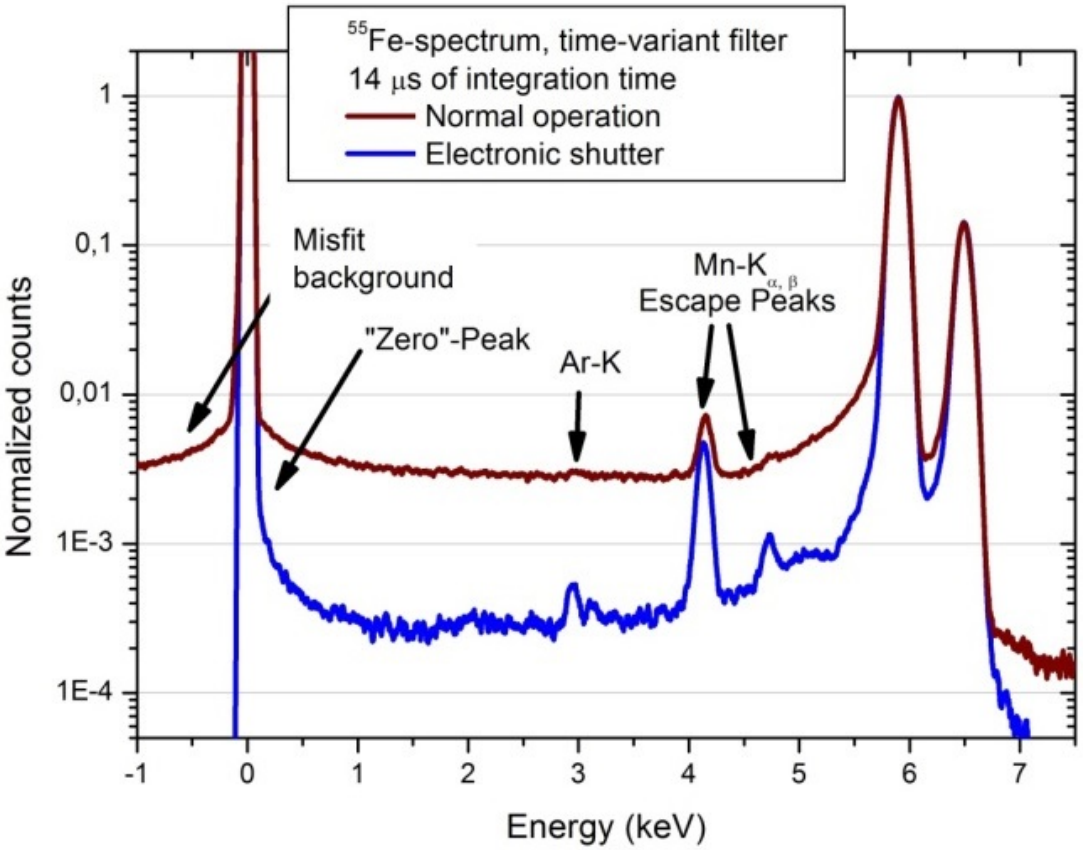




Prototype device



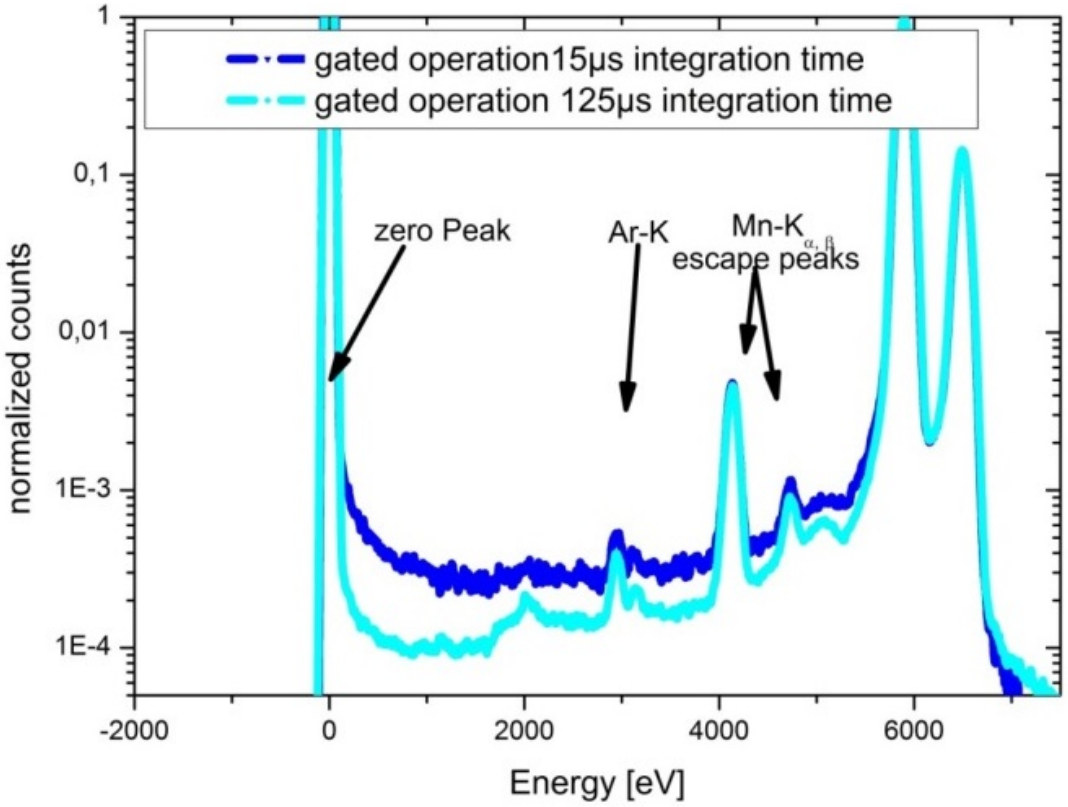
Results



Signal processing of 4.2µs:

- P/B=280, FWHM=129eV @15µs signal integration
- P/B=3100, FWHM=129eV @125µs signal integration

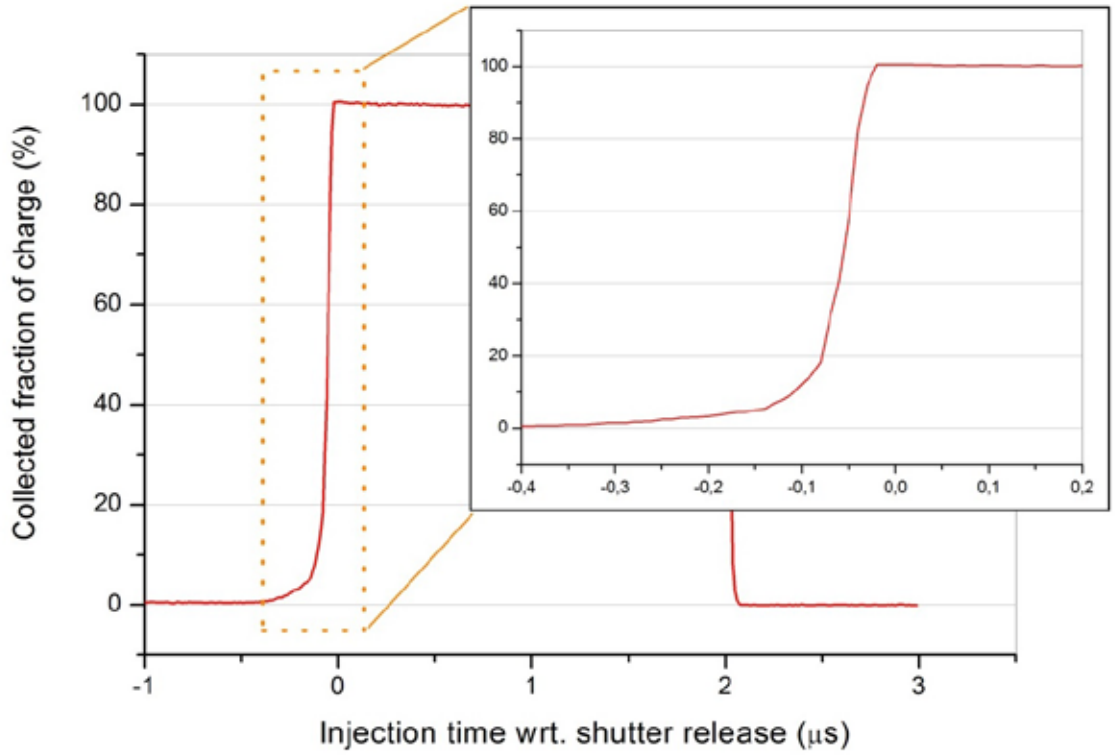
Results



Signal processing of 4.2µs:

- P/B=3100, FWHM=129eV @15µs signal integration
- P/B=1100, FWHM=133eV @125µs signal integration

Results



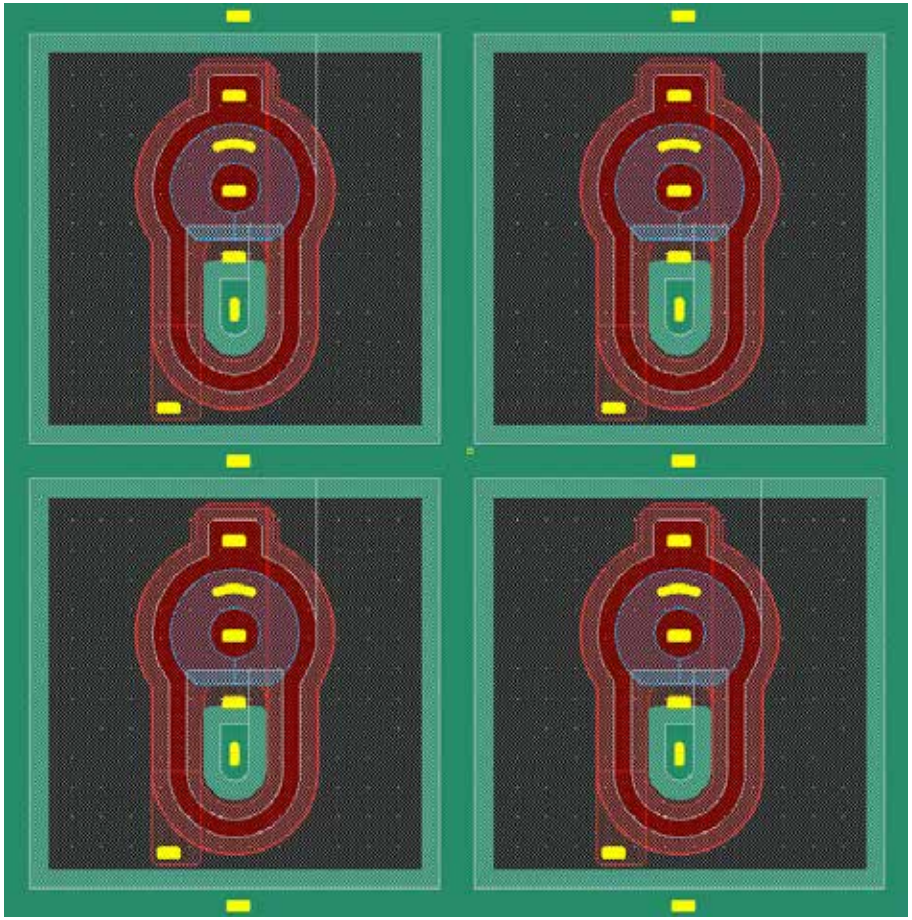
Timing:

- Rise time 10% - 90 % < 100 ns

Matrix device

Prototype matrix:

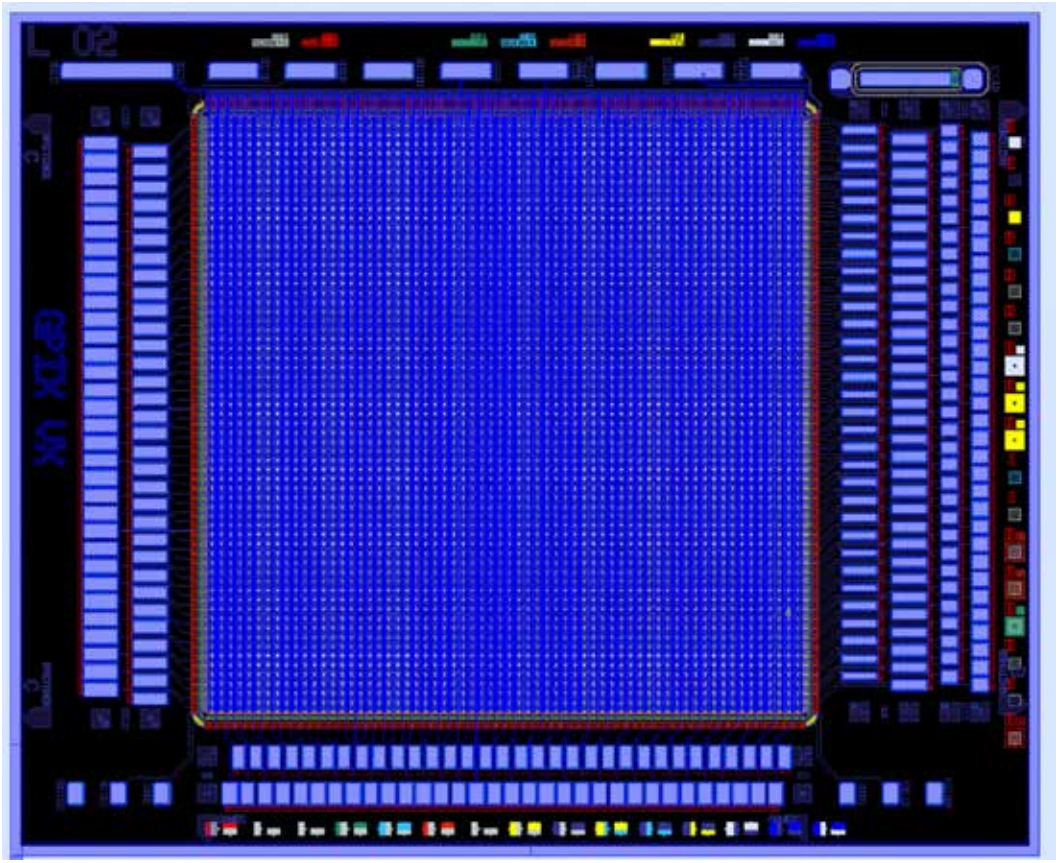
- Global shutter:
  - Global Blind
  - Global Blindgate
- Blind and collection mode can alternate with arbitrary timing
- Matrix can be read during blind mode
- Source follower readout
- Normal "rolling shutter" r/o
- No misfit or broken pattern issues
- Source width issue



Matrix device

Prototype matrix devices:

- 64 x 64 pixels
- 75 x 75 mm^2 size
- Sensitive area: 4.8 x 4.8 mm^2
- Backside illuminated
- "Optical" entrance window
- Chip size: 8.5 x 7 mm^2
- PXD 7 technology (spectroscopy grade)
- Available for evaluation!



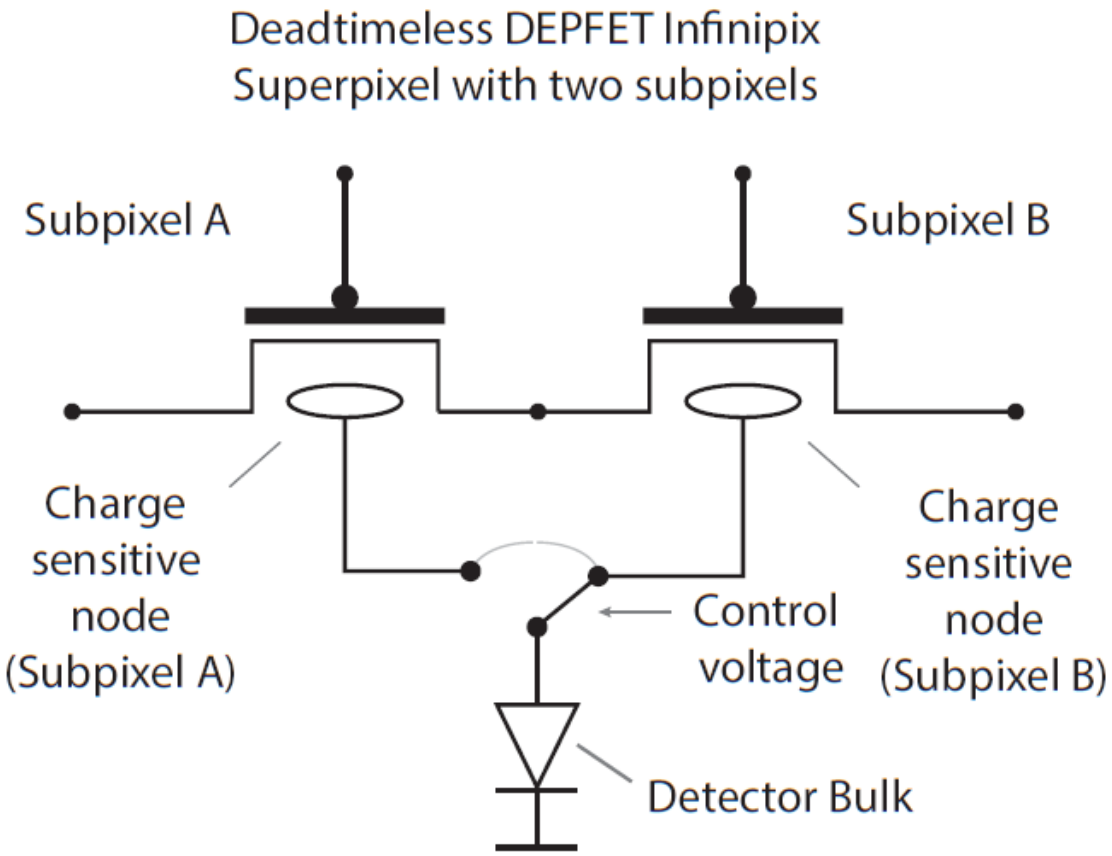
Problem: Dead time

Multigate DEPFET

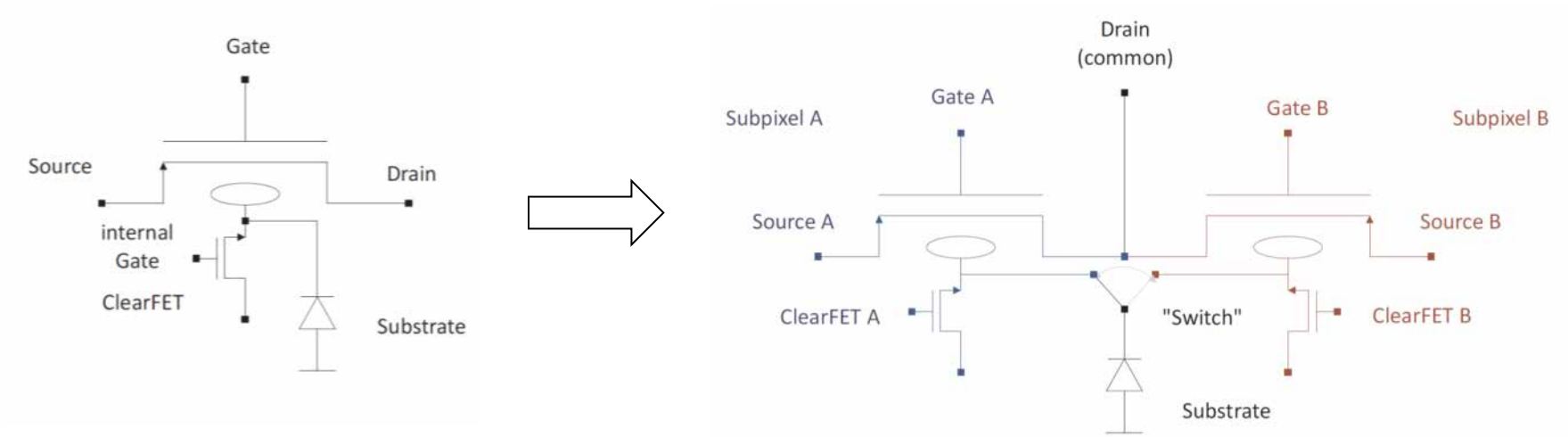
Turn off sensitivity of DEPFET during readout

Do not dump charge, but deviate charge to neigboring pixel

Infinipix

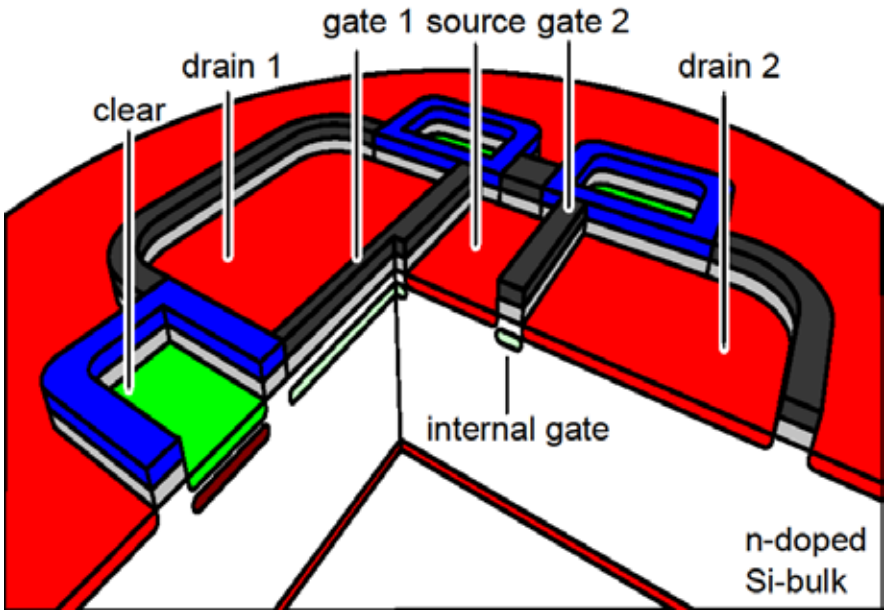

Deadtimeless DEPFET Infinipix
Superpixel with two subpixels
Subpixel A
Subpixel B
Charge sensitive node (Subpixel A)
Control voltage
Charge sensitive node (Subpixel B)
Detector Bulk

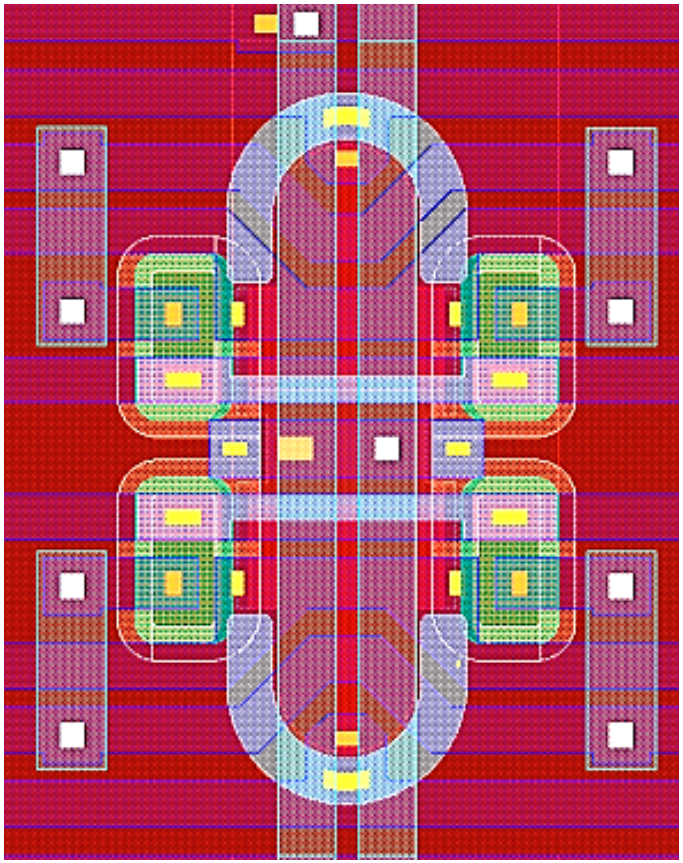
Infinipix



- Superpixel consist of two subpixels
- Charge is deviated to one of the subpixels by using the drain potential
- Only insensitive pixel can be read out
- Strong suppression of MISFIT induced background
- Elimination of broken pattern background due to Rolling Shutter effect
- Benefit larger in case of fast timing
- Optimum case corresponds to **fully parallel readout**

Infinipix



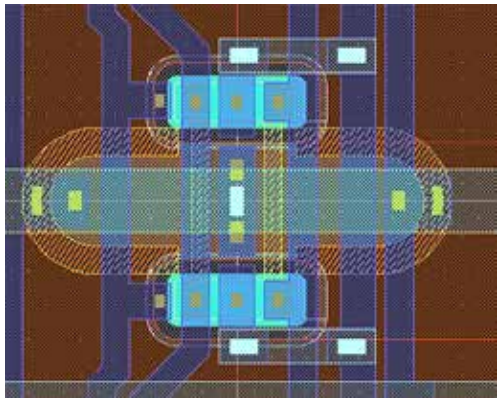


- **Critical parameters:**
  - Charge retention (similar to CHC)
  - Charge selectivity > 5 x10^{-4}
  - Switch speed < 100 ns

Infinipix

Matrix operation:

- Interconnection generates two independent subframes
- Interleaved storage of images in alternating subframes
- Charge integration in "sensitive" subframe
- Readout of insensitive subframe
- Only insensitive subframe can be read out

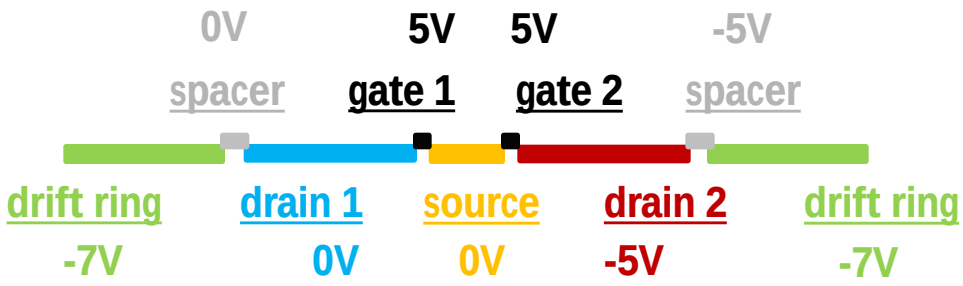


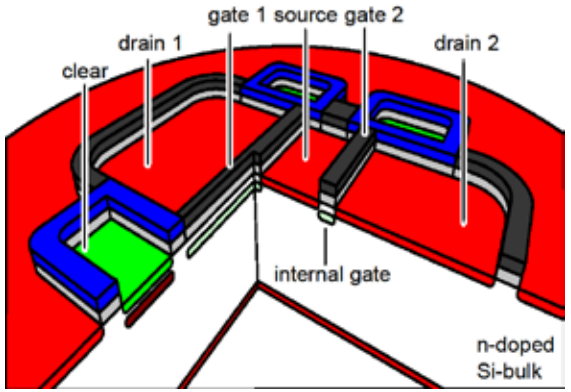
$$\lim_{n \to \infty} a_n = \infty$$

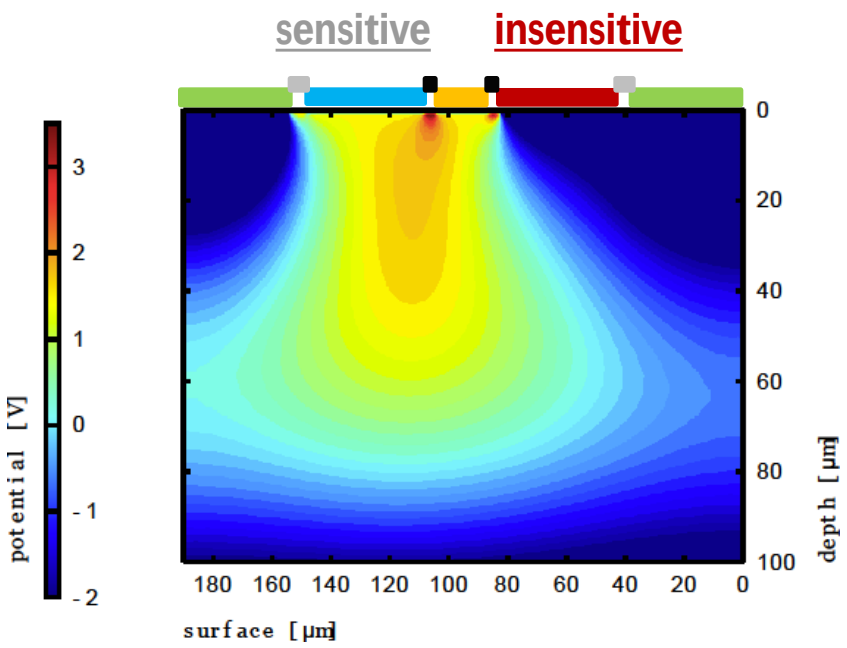
The working title “InfiniPix” was chosen because

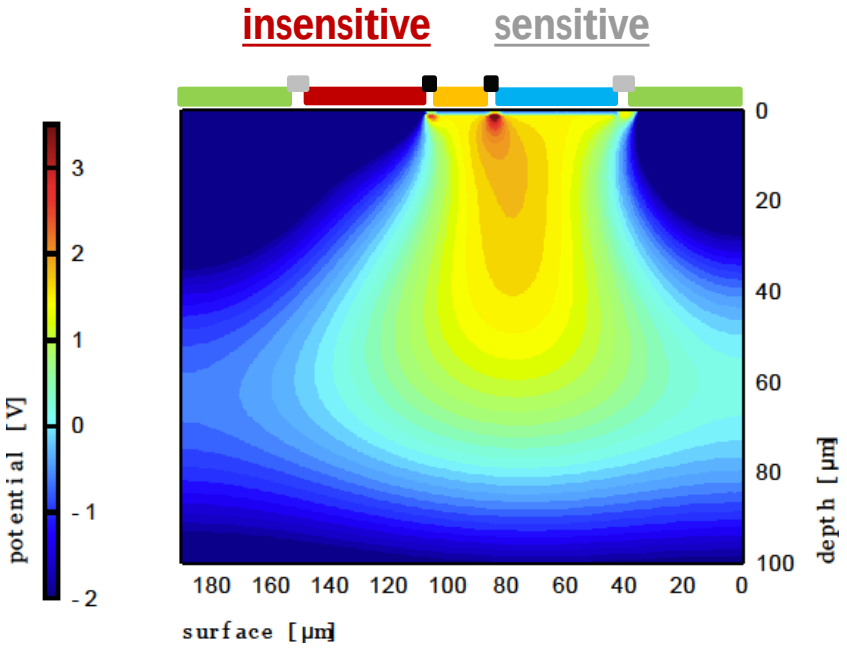
- Infinipix design resembles ‘infinity’ symbol and Moebius strip

Simulations

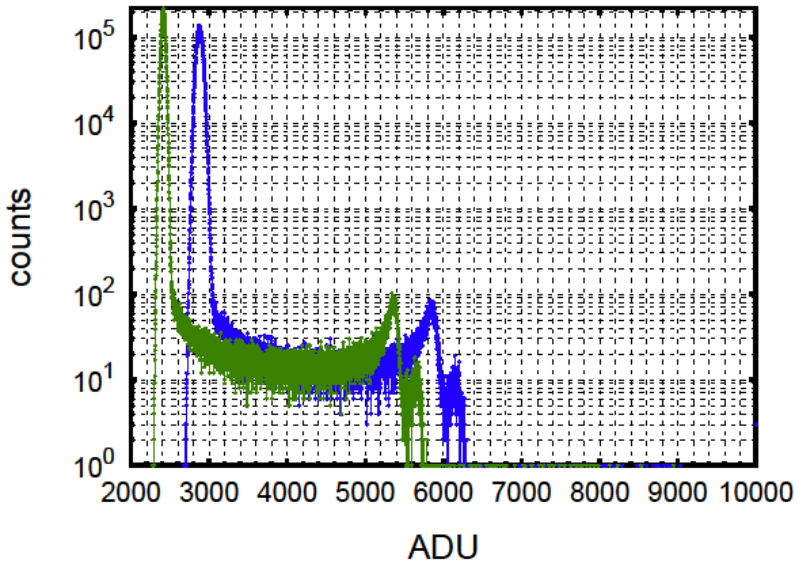


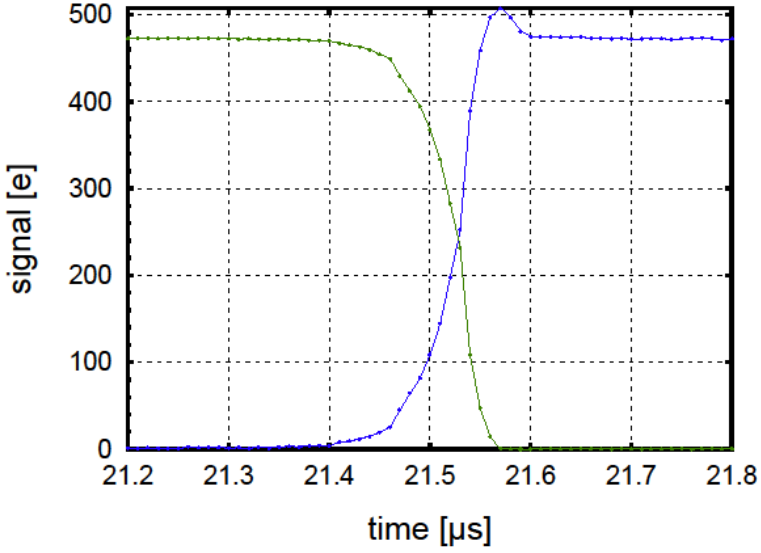


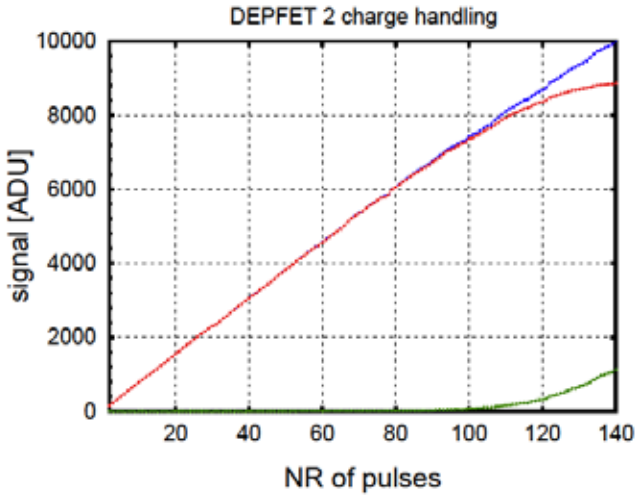


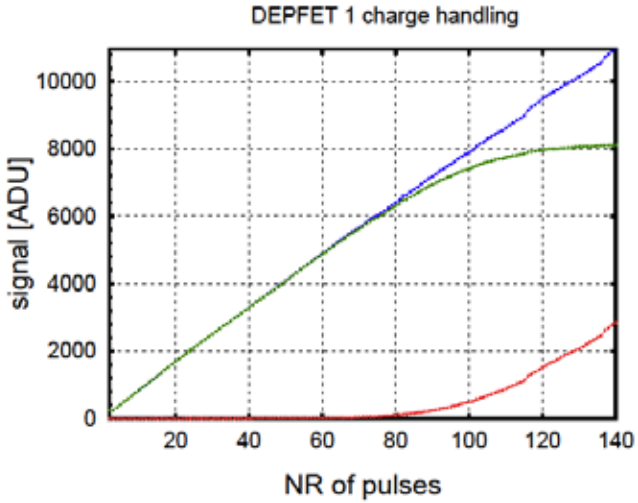


Measurements

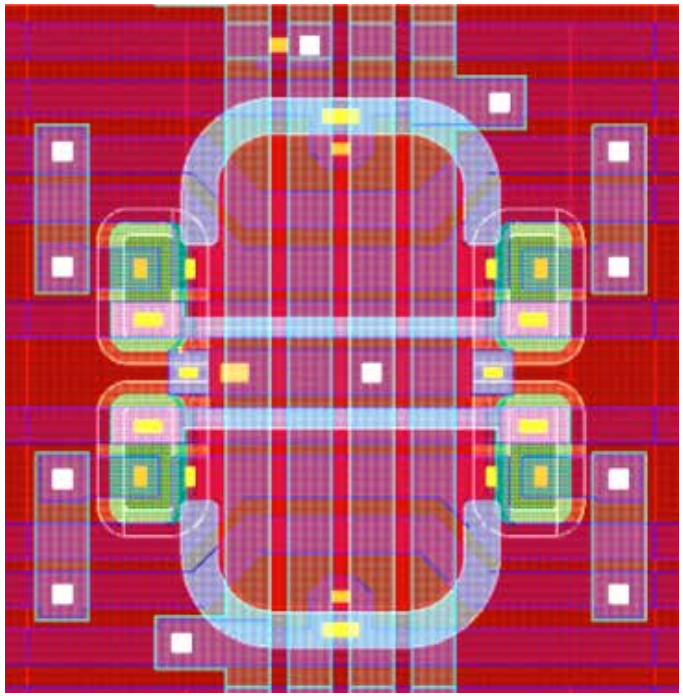


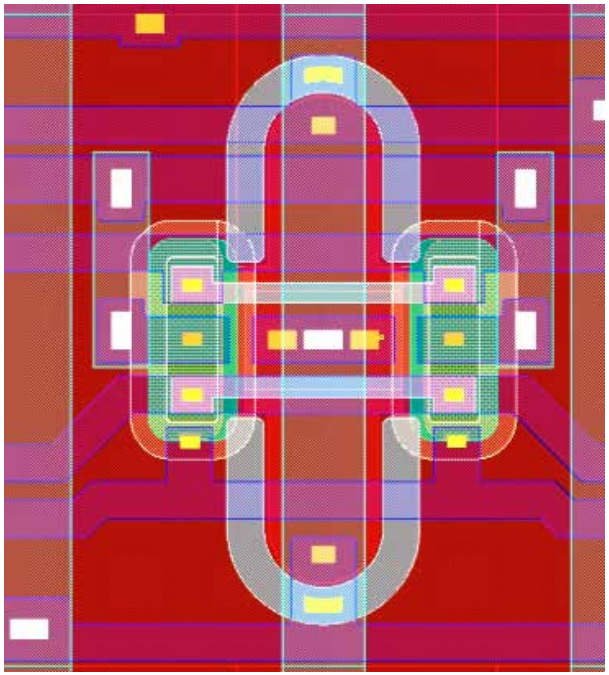






Matrix devices





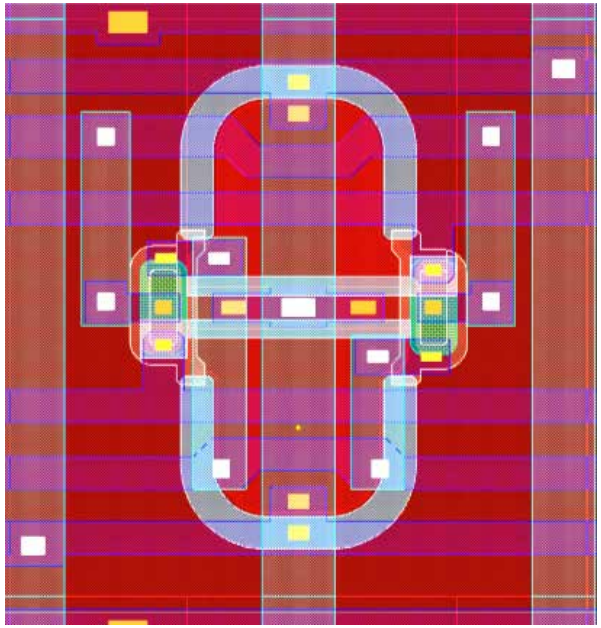
Infinipix 5 large:

- Dual Clear
- L(Source) = 16 mm, L(Drain) = 42 mm, L(gate) = 4.5 mm
- W = 30 mm (Infinipix 5), W = 60 mm (Infinipix 5 large)

Infinipix 6:

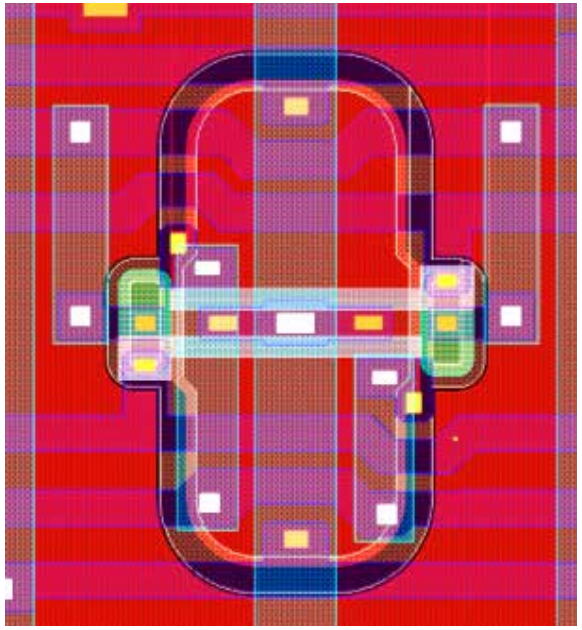
- Single Clear
- L(Source) = 16 mm, L(Drain) = 42 mm, L(gate) = 4.5 mm
- W = 30 mm

Matrix devices



Infinipix 7:

- New design with optimized dimensions according to simulations
- Single Clear
- L(Source) = 8 mm, L(Drain) = 44 mm, L(gate) = 4.5 mm
- W = 42 mm



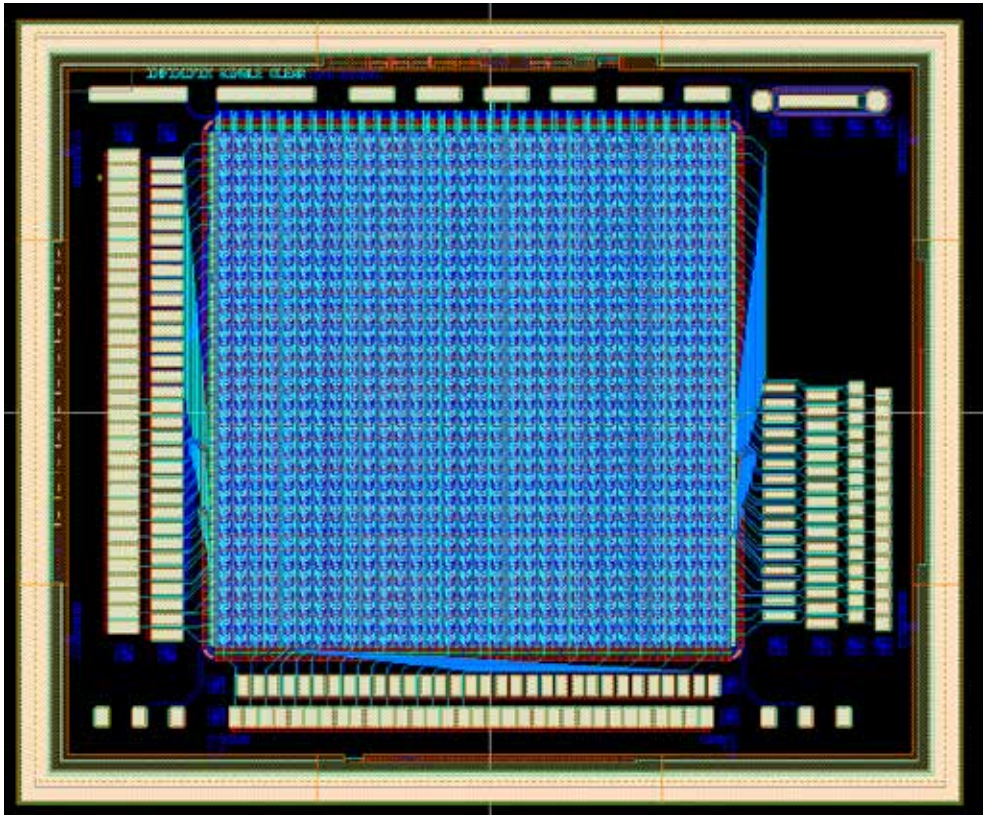
Infinipix Omega:

- New design with optimized dimensions according to simulations
- Single Clear / Cleagate separator
- L(Source) = 8 mm, L(Drain) = 44 mm, L(gate) = 4.5 mm
- W = 42 mm

Matrix devices

Prototype matrix:

- 32 x 32 pixels
- 150 x 150 mm^2 size
- Sensitive area: 4.8 x 4.8 mm^2
- Backside illuminated
- "Optical" entrance window
- Chip size: 8.5 x 7 mm^2
- PXD 8 / PXD 11 technology (spectroscopy grade)
- PXD 8 devices under investigation
- PXD 11 devices in fabrication
- Soon: New production dedicated to Infinipix devices



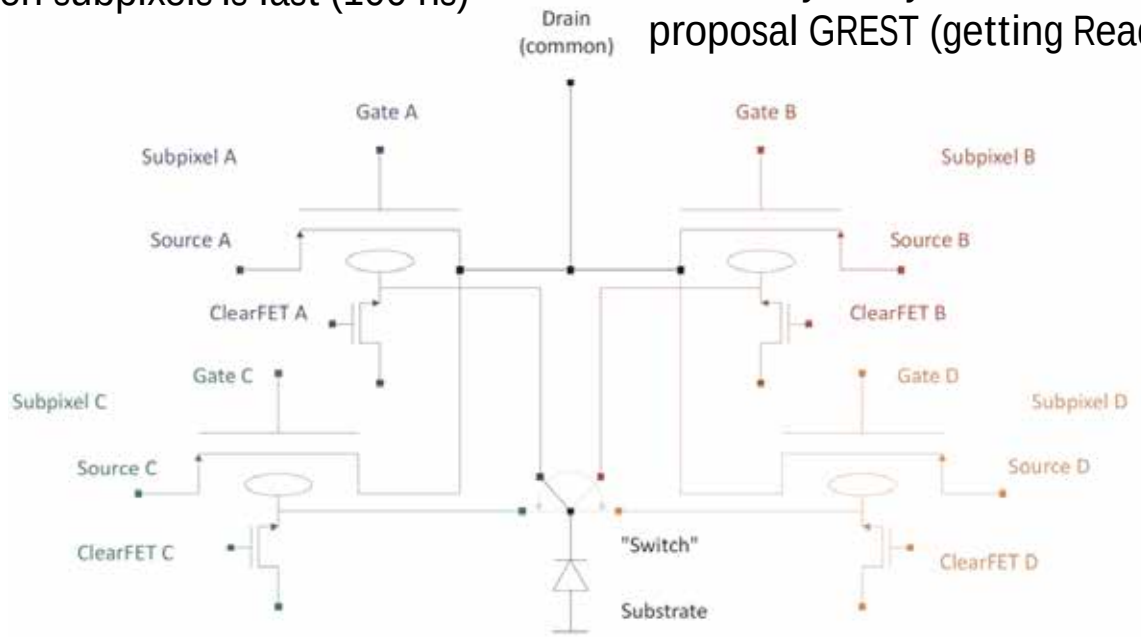
Idea

Why only two subframes?

Infinipix Quad (IQ) structures

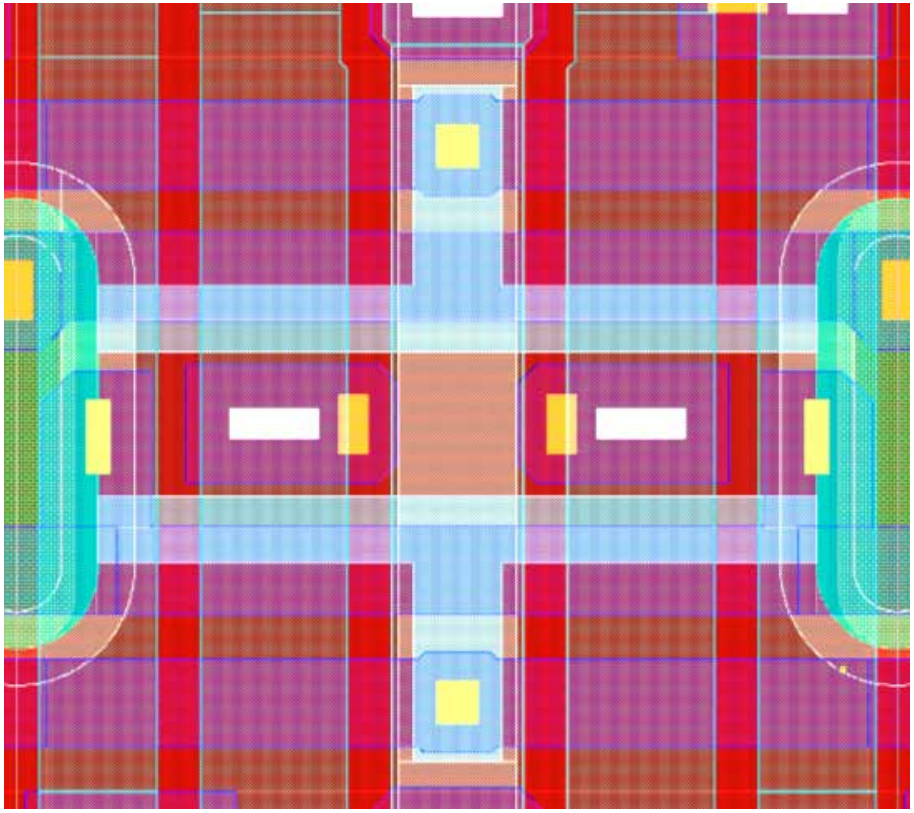
Application driven:

- Infinipix subframe / subpixel counts higher than 2
- Infinipix superpixels with 4 subpixels suitable for future (solar) polarimeter (See talk by A. Feller)
- Integrated charge for one of four polarization states (Stokes vector components) is stored in one associated subpixel
- Switching between subpixels is fast (100 ns)
- Due to large charge handling capacitance, large numbers of images can be integrated
- Readout noise is accounted only once
- Very high duty cycle
- Very high modulation rate
- Very low noise
- Feasibility study within the scope of H2020 proposal GREST (getting Ready for EST)



IQ Structures

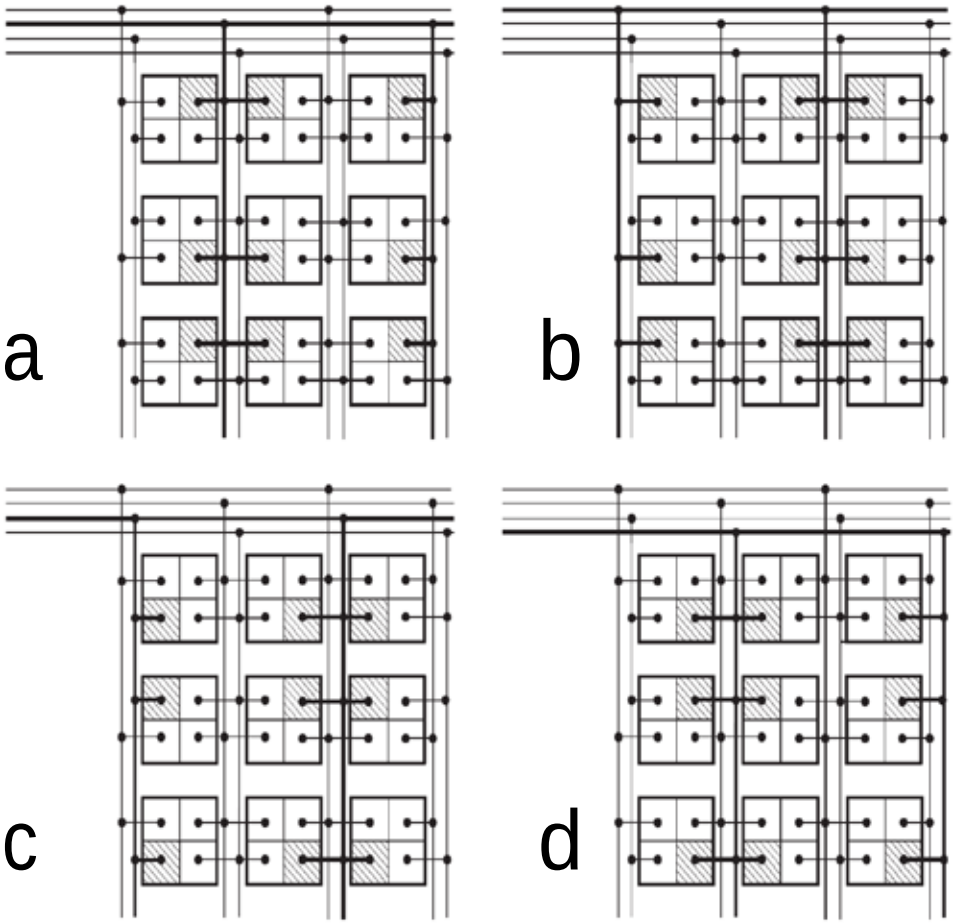
- **Simplified structure:**
  - Common clear
  - Two gates instead of 4
  - Two sources
  - Source follower
  - Device can be sensitive with Gate off
  - Shutter speed < 100 ns
- **Critical parameters:**
  - Charge retention (similar to CHC)
  - Charge selectivity > 5 x10^{-4} ?
  - Switch speed < 100 ns
  - **New: Spatial conformity!**



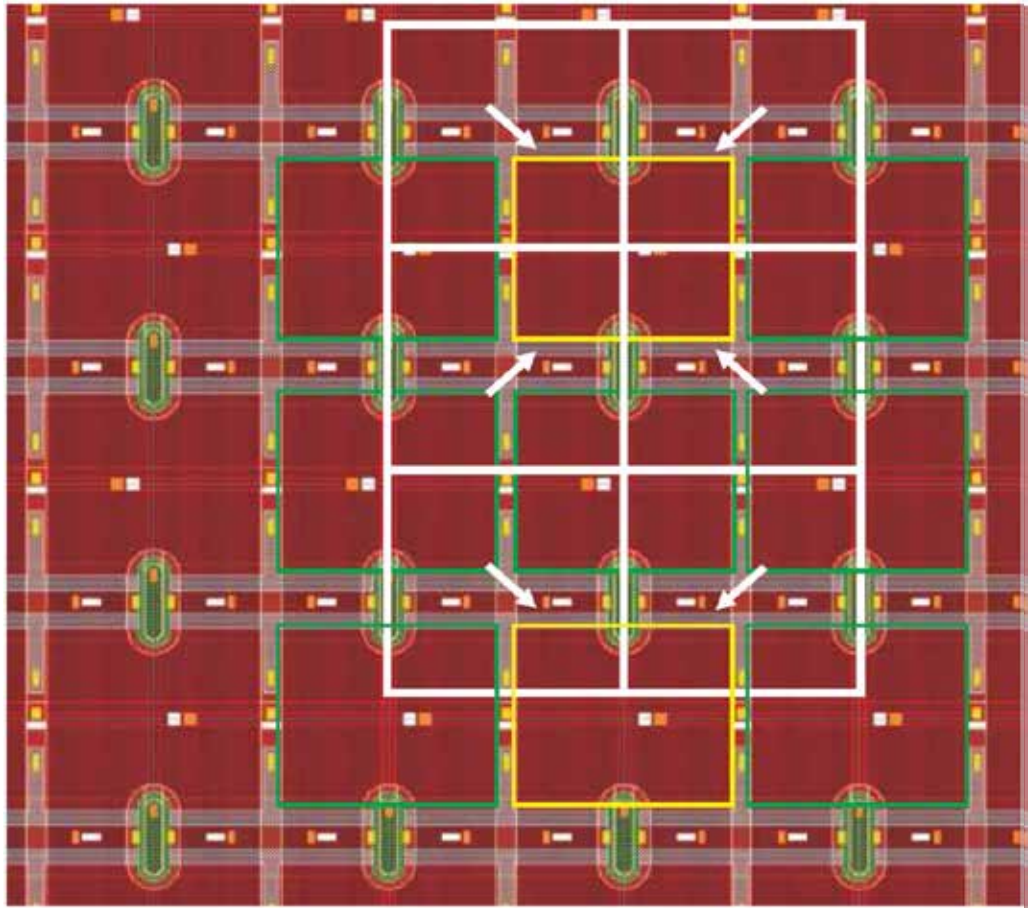
"Standard" IQ (Infinipix Quad) structure

Infinipix device

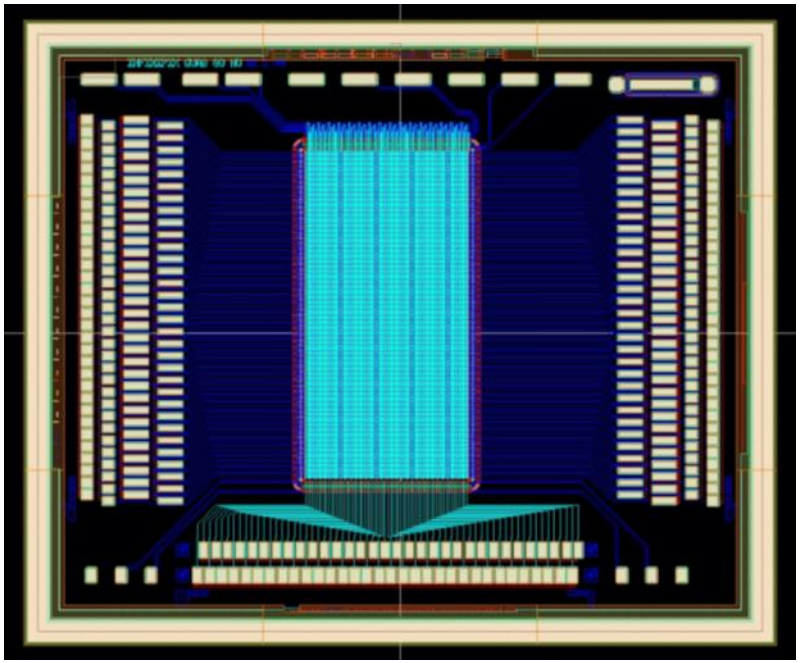
- Interlaced connection of subframes
- Contiguous large drain areas, area efficient approach
- Rotating sensitivity allows for sampling of 4 phases of polarimetry measurement
- Test layouts done and in fabrication

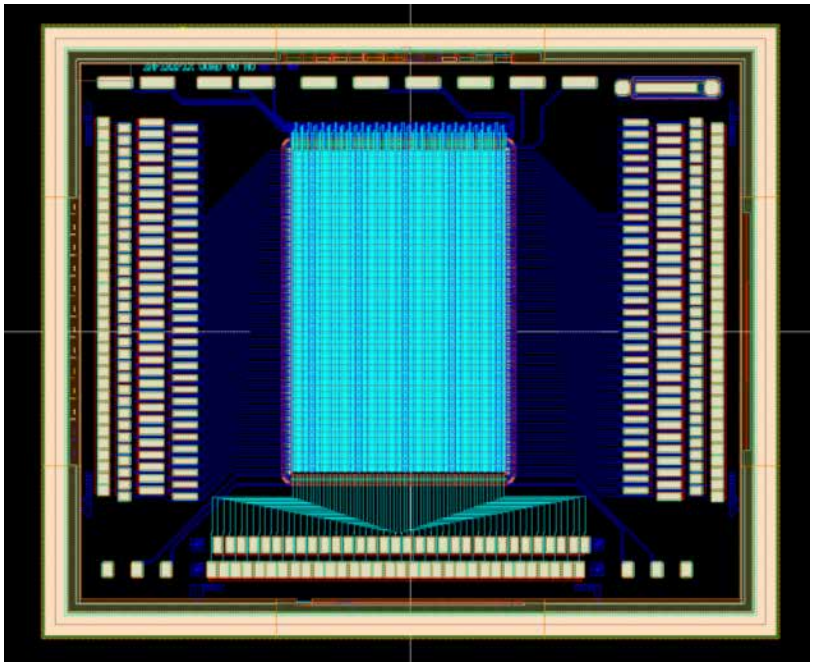


Device layout



IQ Structures

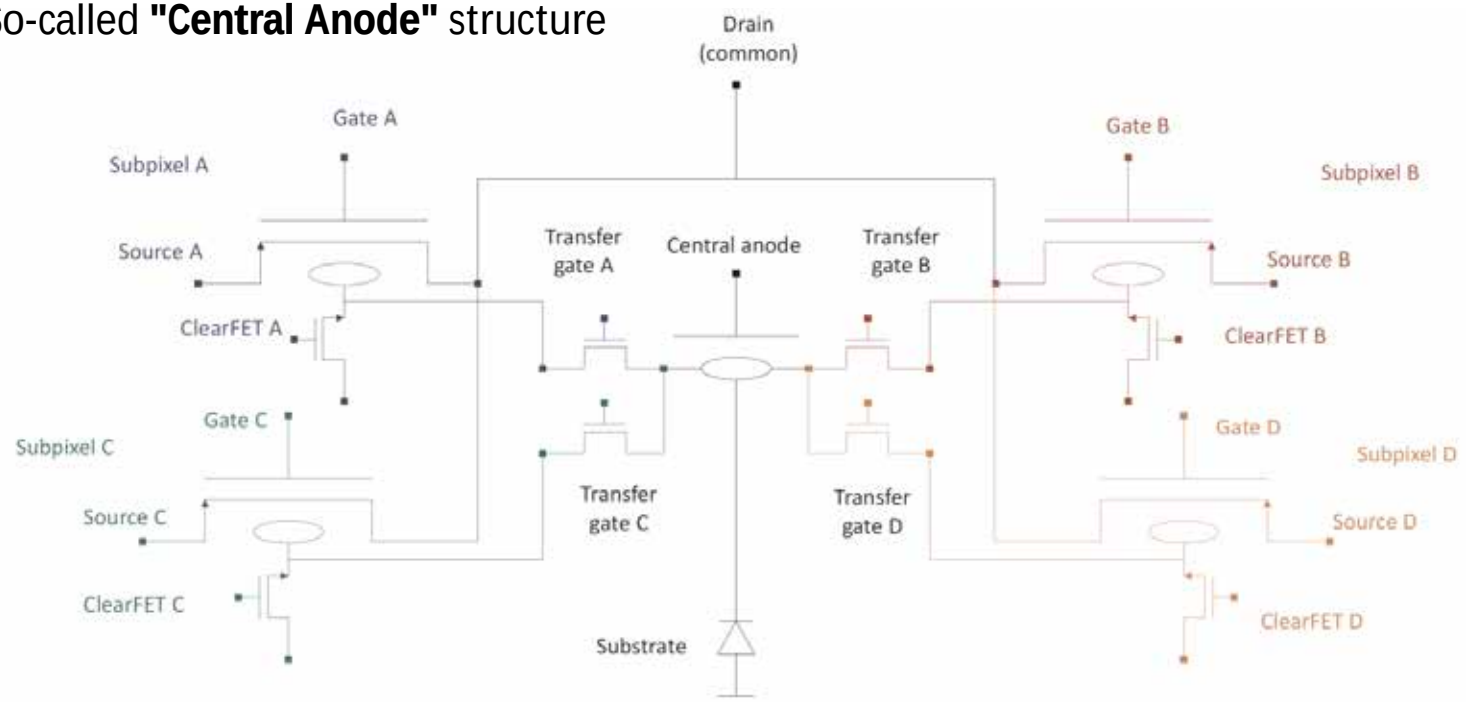




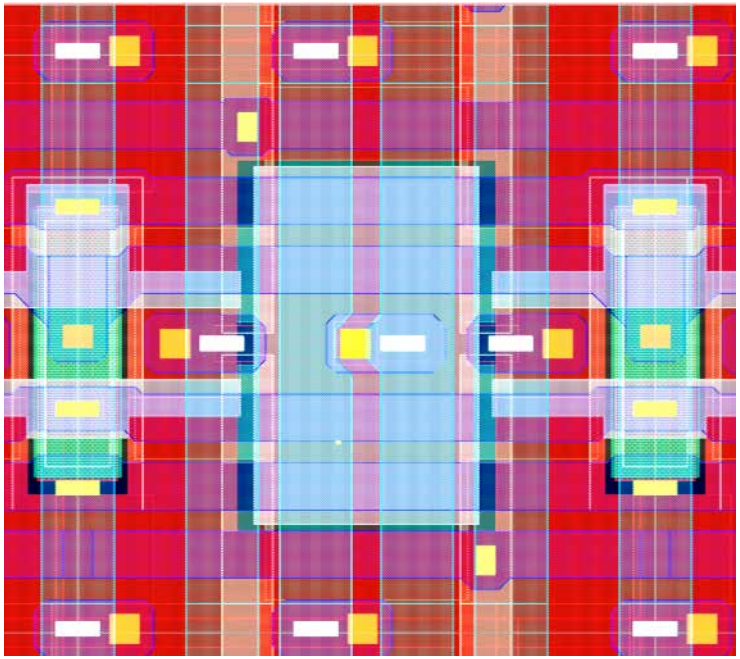
- 60 x 60 mm^2 and 80 x 80 mm^2 pixel prototypes
- Single clear
- Clocked Cleargate
- Source follower readout
- Prototype matrices of 32 x 64 (60 x 60 mm^2) and 32 x 48 (80 x 80 mm^2) pixels on standard matrix scaffold

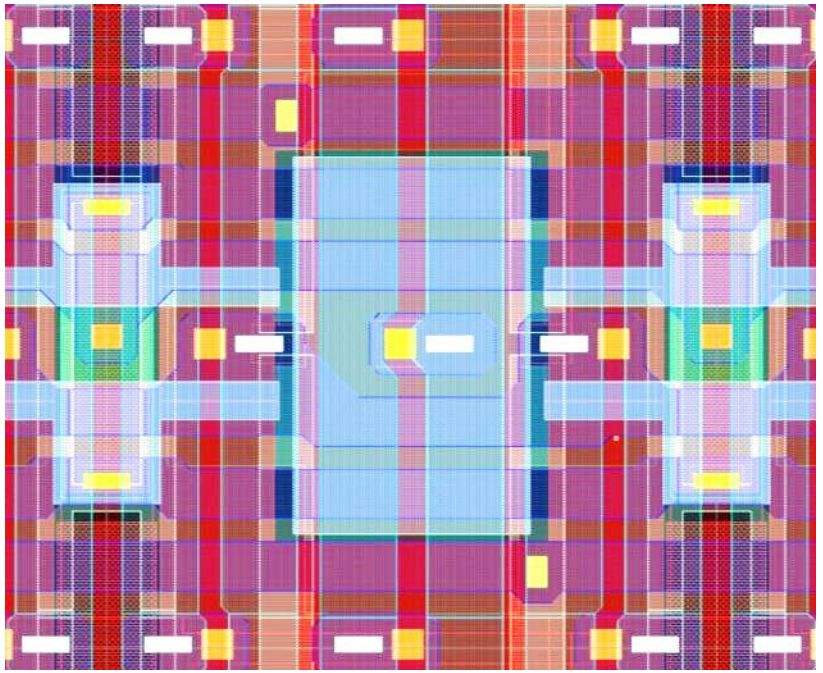
IQCA Structures

- In case very high polarimetric efficiencies are to be achieved, spatial shift of images due to the varying control potentials ("switch") could interfere with the measurements and affect the
- Effect can be eliminated in sensor, if pixel structure robust against this effect
- Have structure with **common central storage node** and transfer the charge collected during integration on-demand to respective storage DEPFET
- So-called **"Central Anode"** structure



IQCA Structures



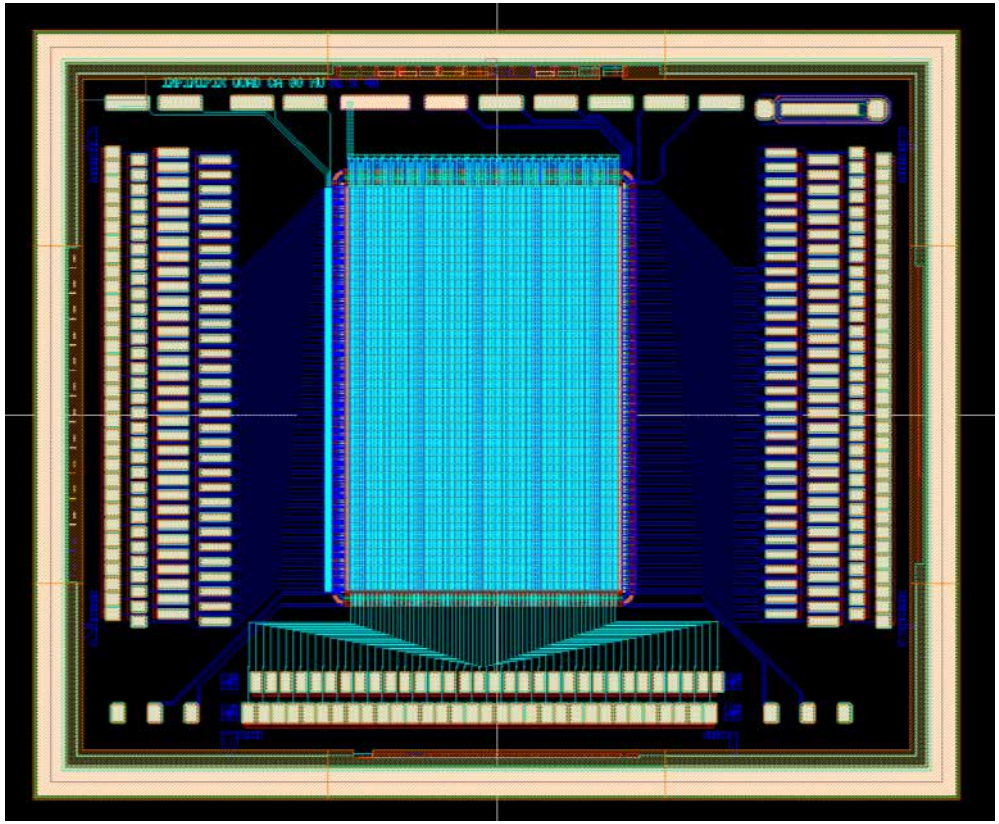


- Clocking of Drain not required
- Transfergate and Anode potential are clocked globally
- Sequential readout of two transistors per row

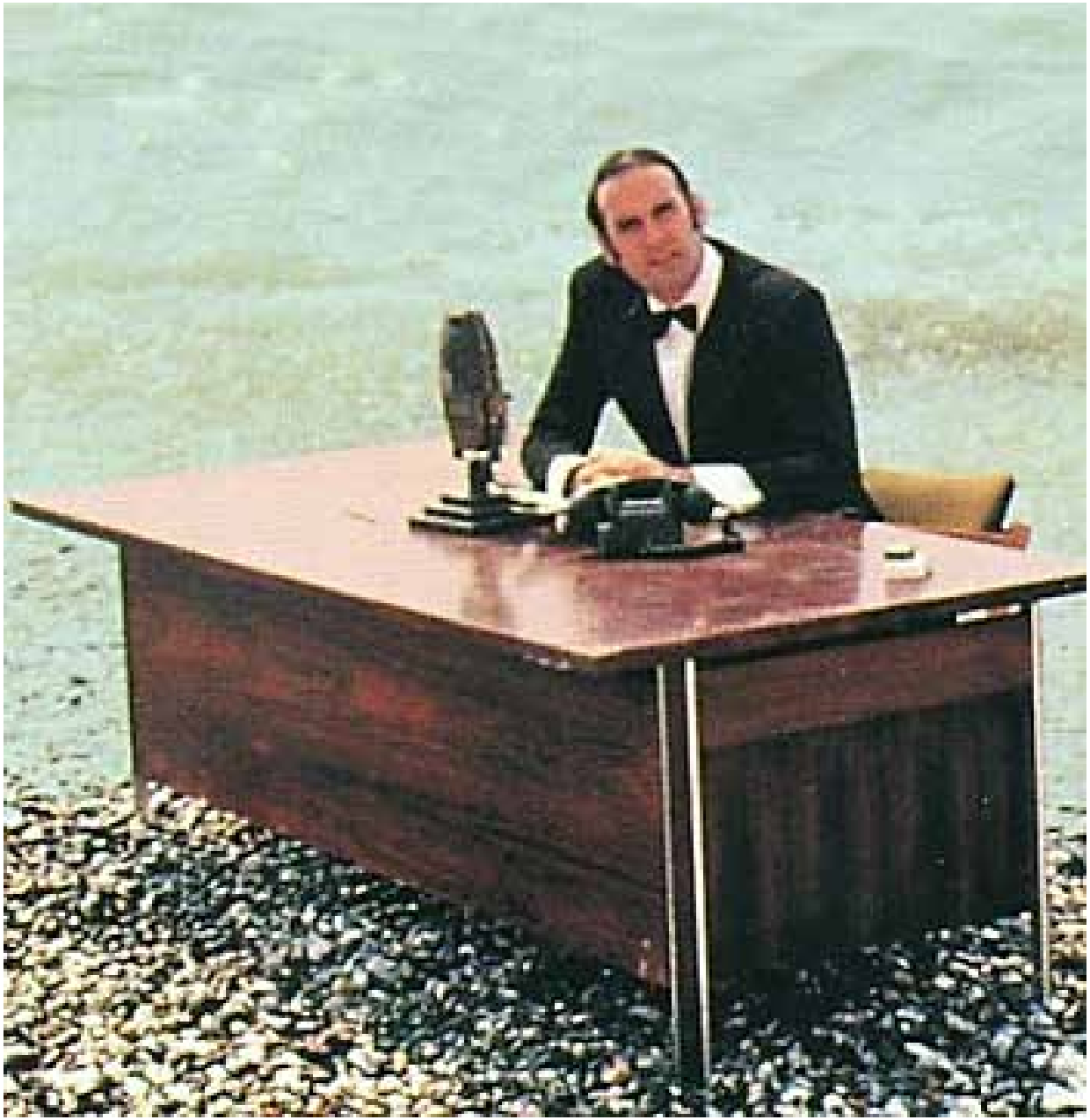
- 80 x 80 mm^2 pixel prototypes
- Single clear
- Clocked and Static cleargate
- Source follower and drain readout

IQCA Structures

- 32 x 48 pixel prototypes
- Integrated on standard matrix scaffold



- **Critical parameters:**
  - Charge retention (similar to CHC)
  - Charge selectivity
  - Switch speed < 100 ns
  - **New: Spatial conformity!**
  - **New: Charge transfer efficiency!**

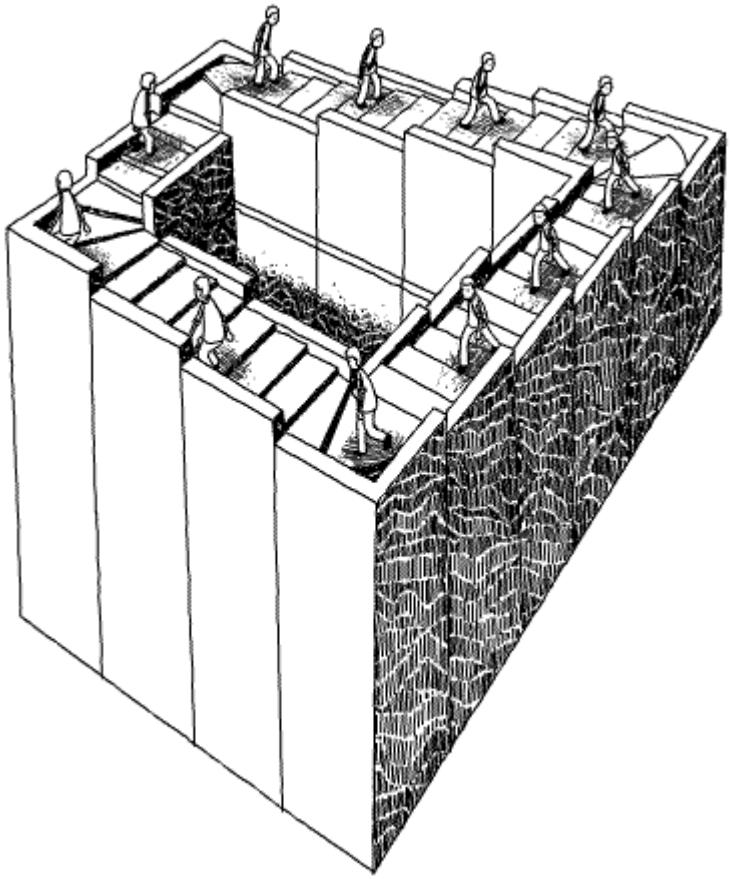


Repetitive-non-destructive readout

Beat noise limit using the central limit theorem!

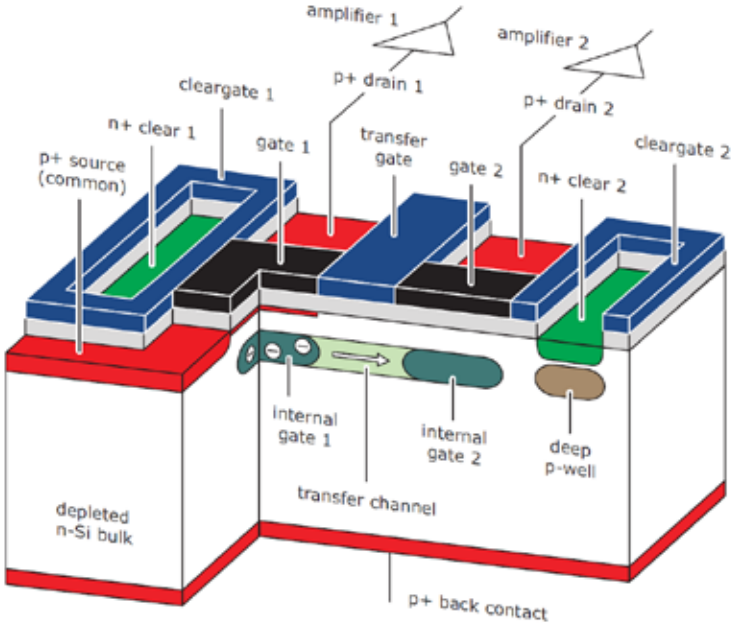
Lower initial noise!

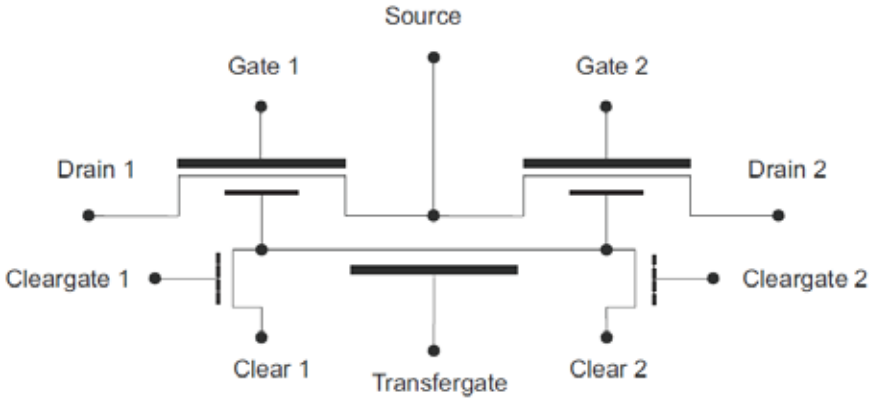
Achieve single electron photon sensitivity!



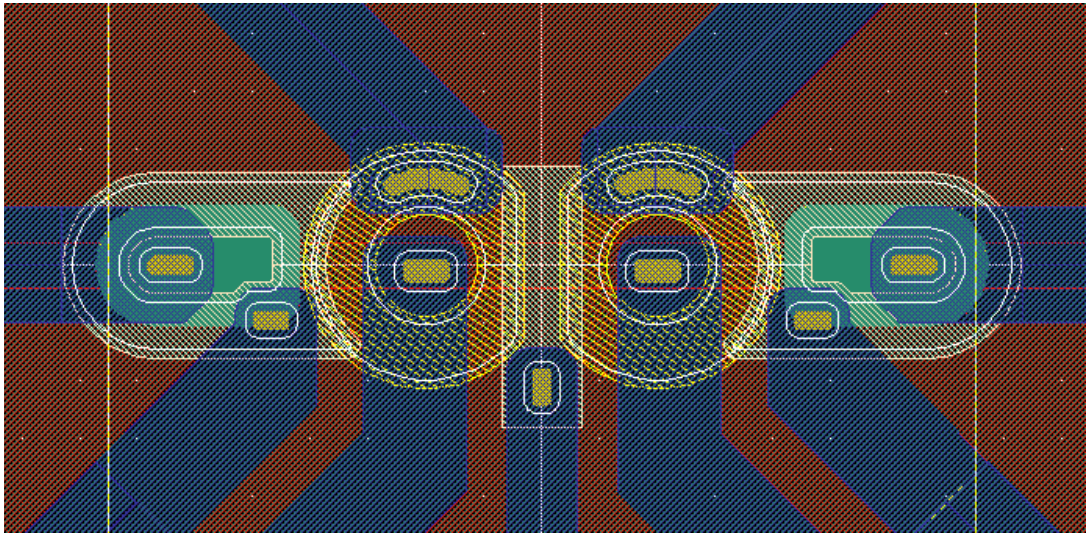
RNDR devices

- DEPFET repetitive non-destructive readout (RNDR)
  - practical application of the central limit theorem
  - 2 DEPFET “sub”pixels in “super”1 pixel
  - intra-pixel charge transfer via transfer gate
  - allows for statistically independent measurements
  - elimination of 1/f-noise limit
  - noise reduction by $N^{1/2}$ @ N readings
  - sub-electron noise: 0.18 el. ENC
  - single electron distinction

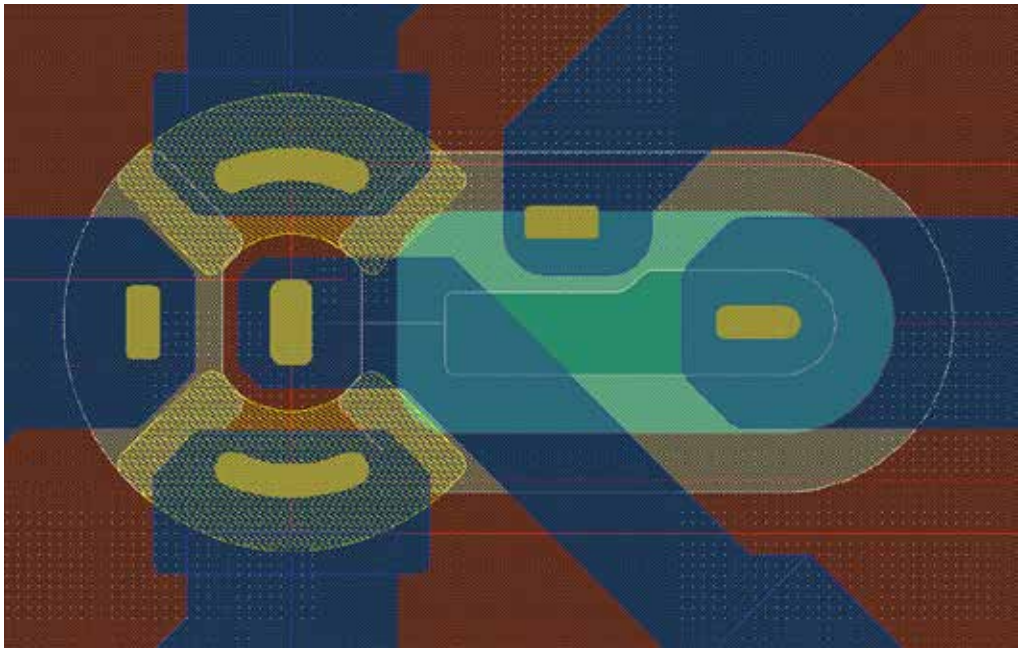




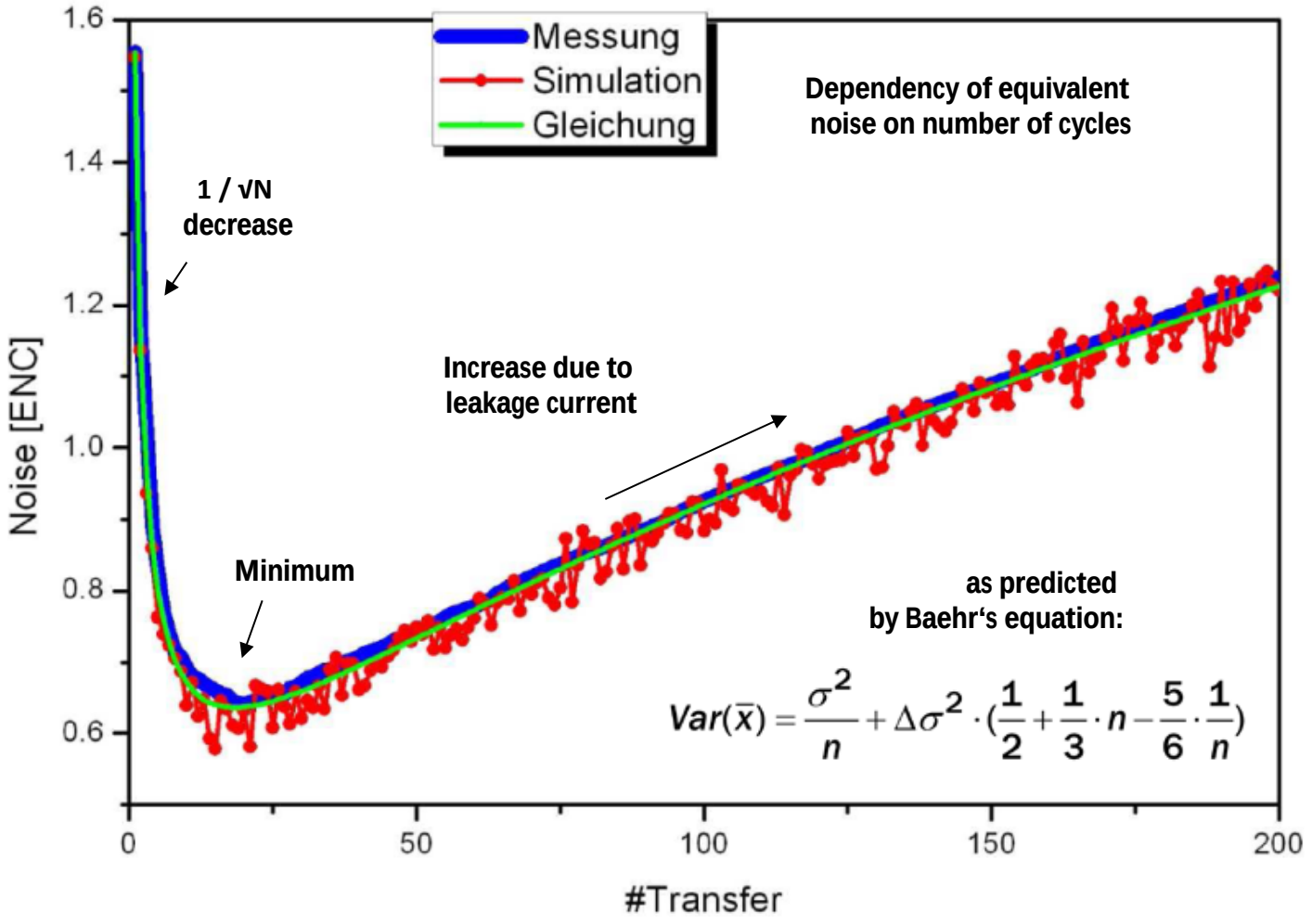
RNDR devices



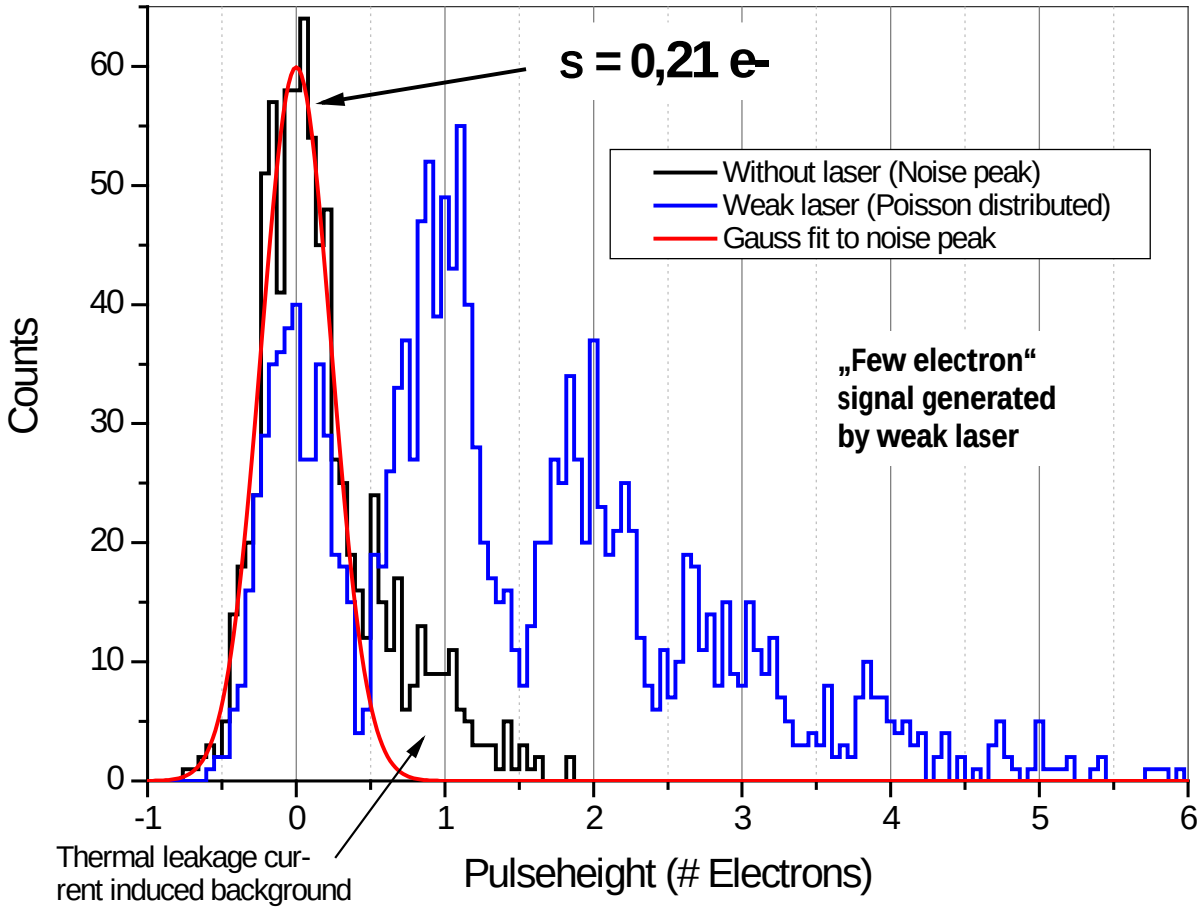
RNDR devices



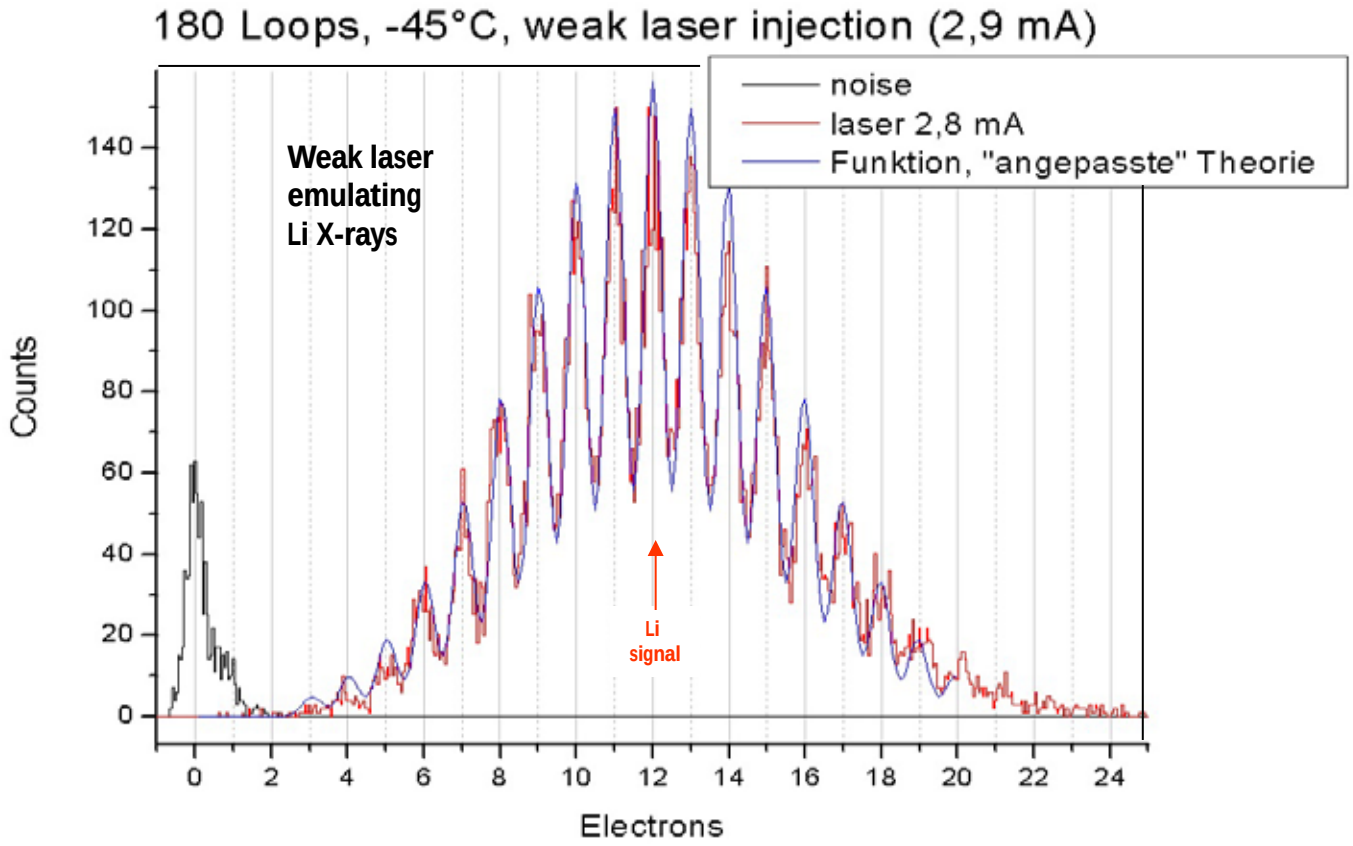
RNDR


Messung
Simulation
Gleichung
Dependency of equivalent noise on number of cycles
1 / √N decrease
Increase due to leakage current
Minimum
as predicted by Baehr's equation:
$Var(\bar{x}) = \frac{\sigma^2}{n} + \Delta\sigma^2 \cdot (\frac{1}{2} + \frac{1}{3} \cdot n - \frac{5}{6} \cdot \frac{1}{n})$
Noise [ENC]
#Transfer
1.6
1.4
1.2
1.0
0.8
0.6
0
50
100
150
200

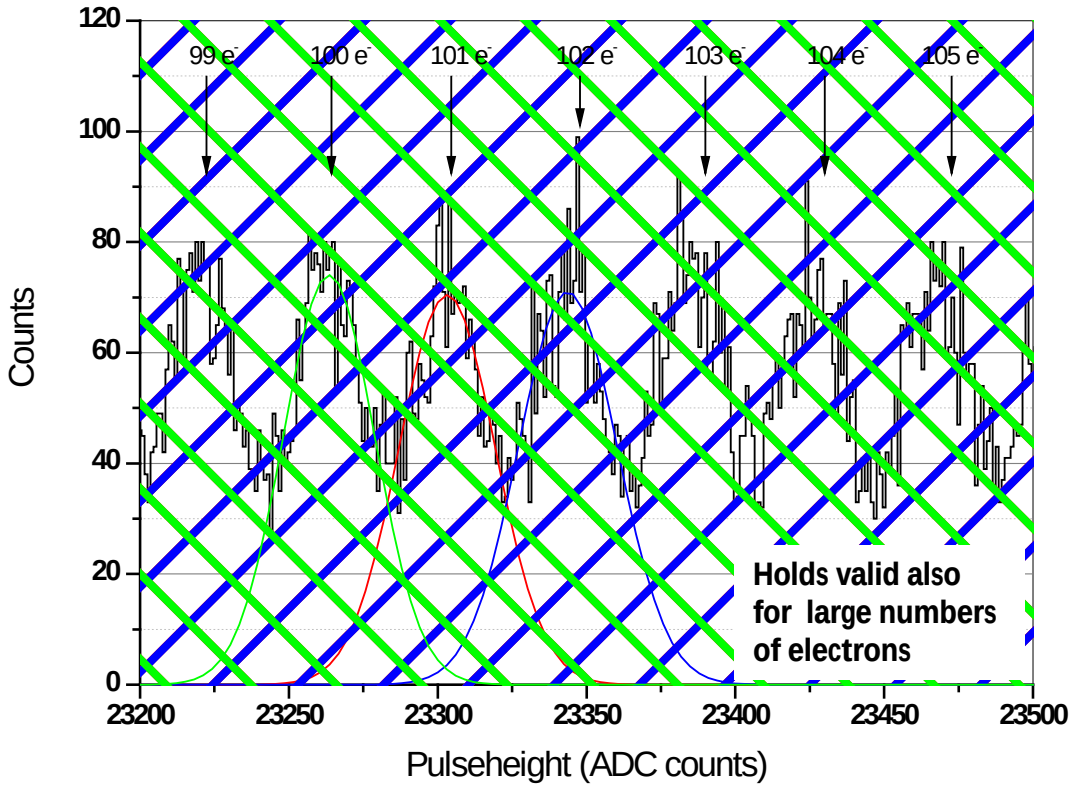
RNDR


s = 0,21 e-
Without laser (Noise peak)
Weak laser (Poisson distributed)
Gauss fit to noise peak
„Few electron“
signal generated
by weak laser
Counts
Pulseheight (# Electrons)
Thermal leakage cur-
rent induced background
0
10
20
30
40
50
60
-1
0
1
2
3
4
5
6

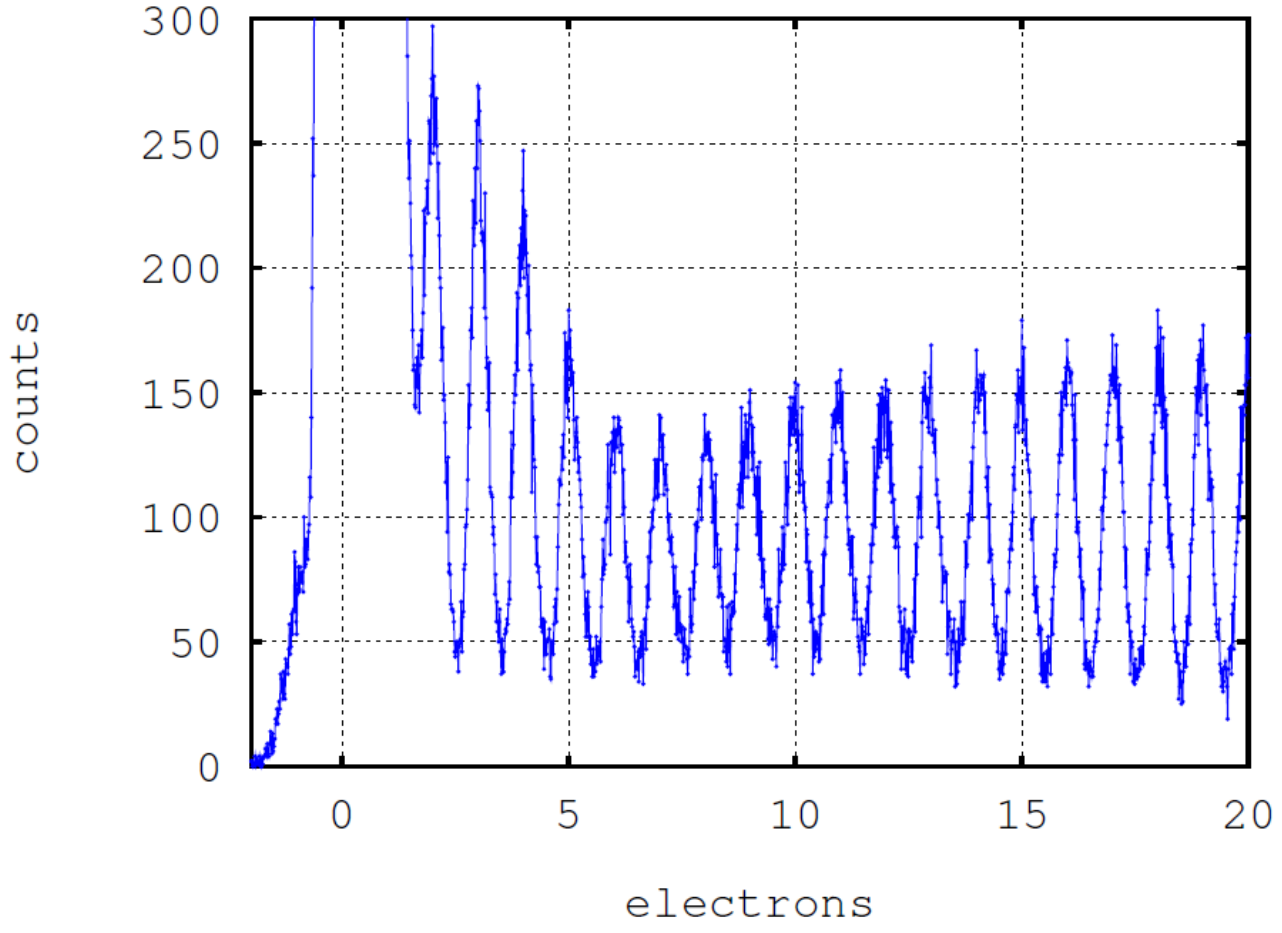
RNDR


180 Loops, -45°C, weak laser injection (2,9 mA)
noise
laser 2,8 mA
Funktion, "angepasste" Theorie
Weak laser emulating Li X-rays
Li signal
Counts
Electrons
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
18
20
22
24

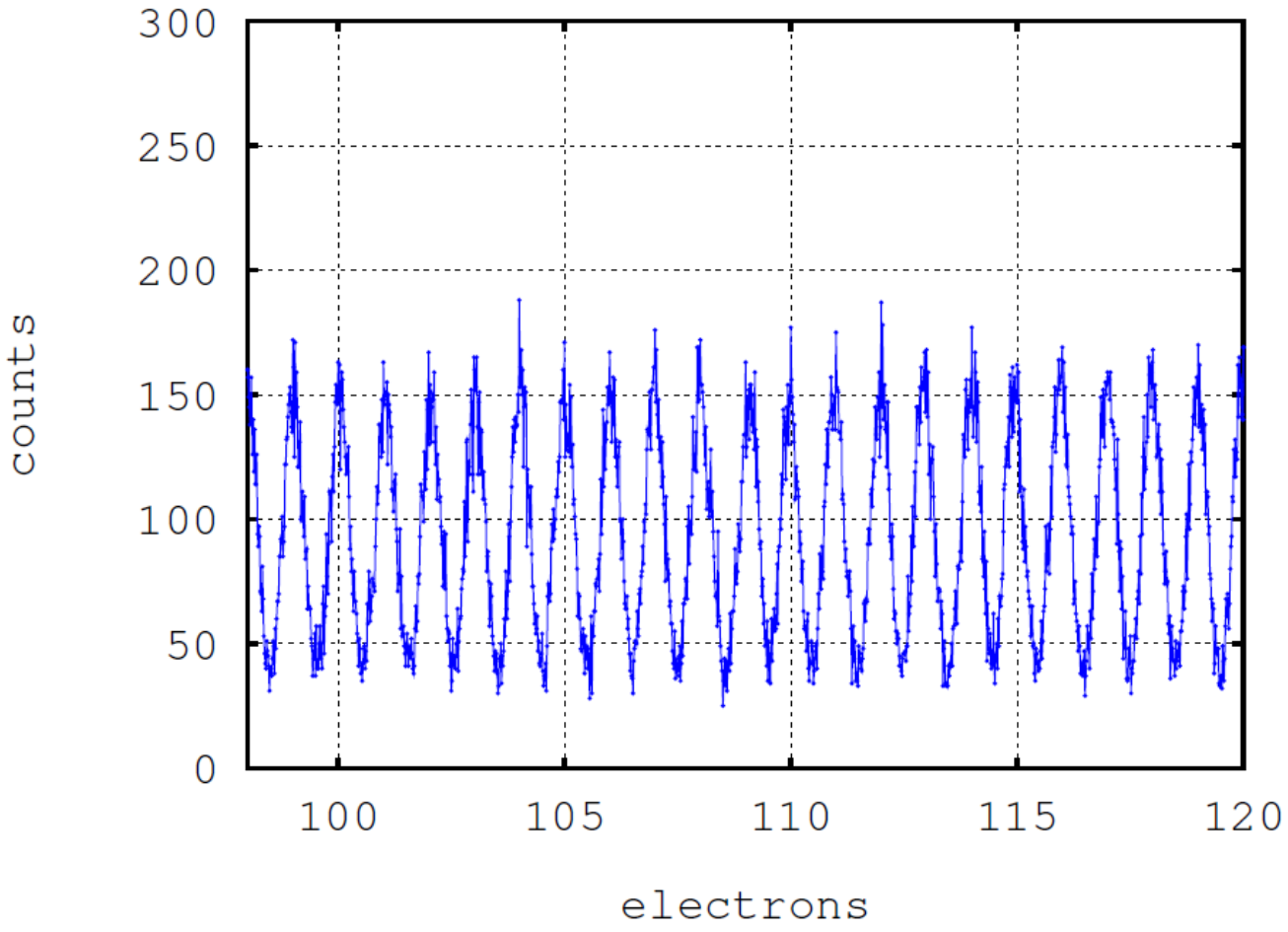
RNDR devices



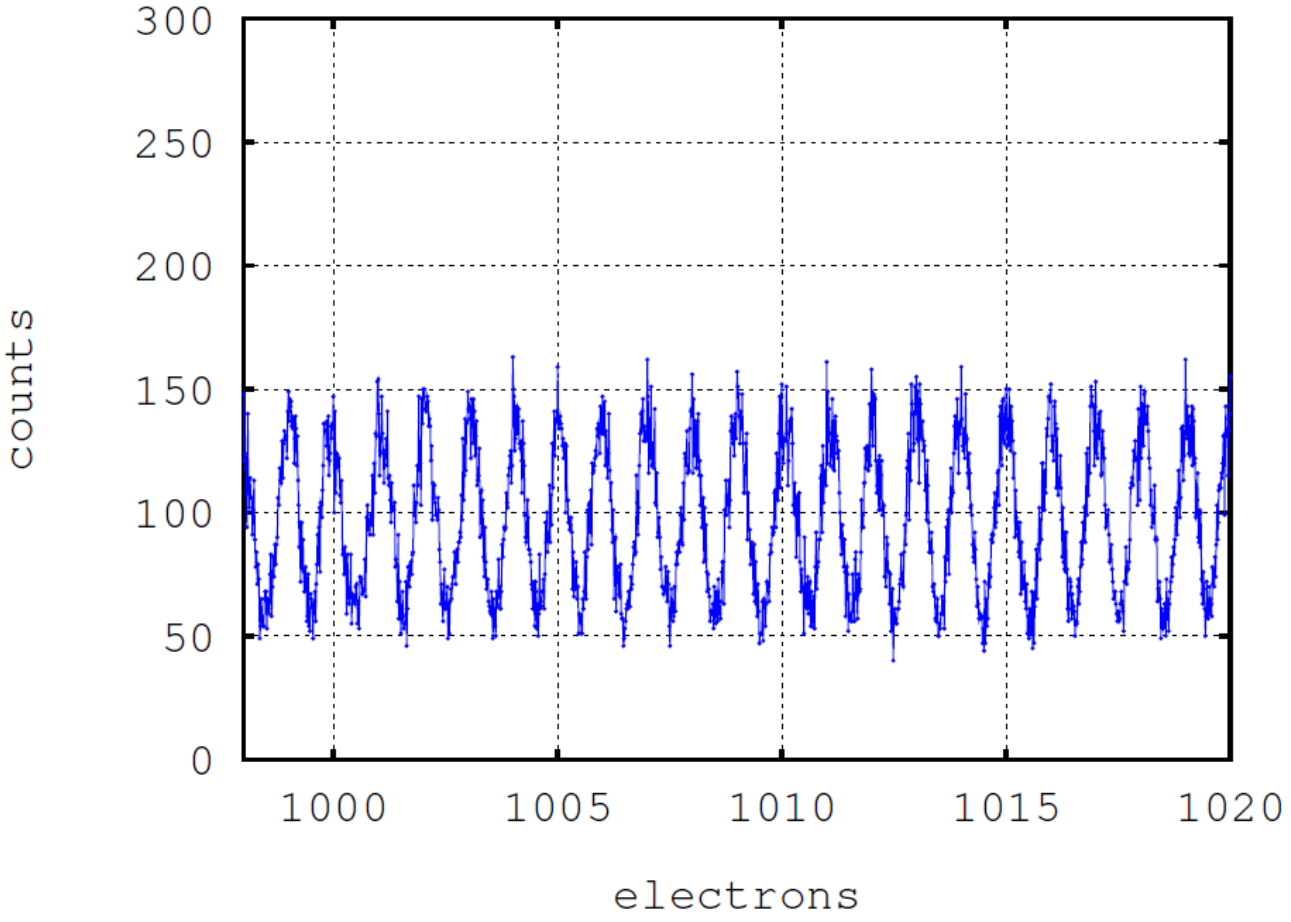
Series: 0 to 20 e^-



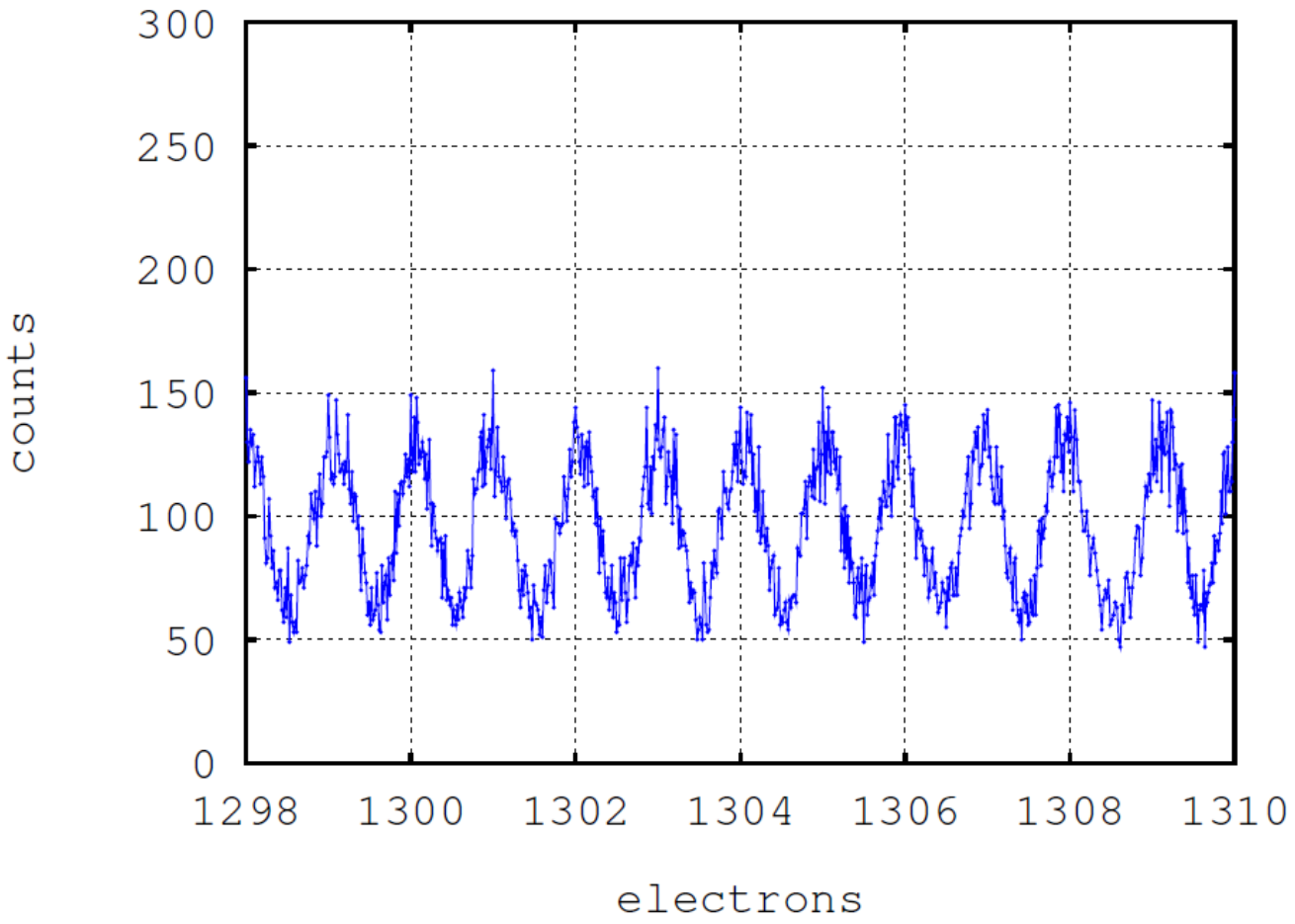
Series: 98 to 120 e^-



Series: 998 to 1020 e^-

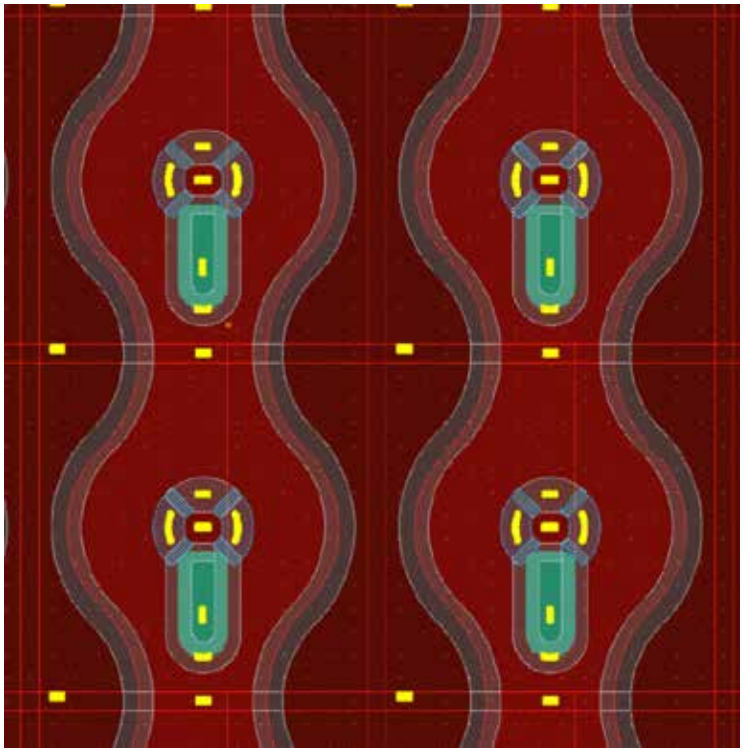


Series: 1298 to 1310 e^-



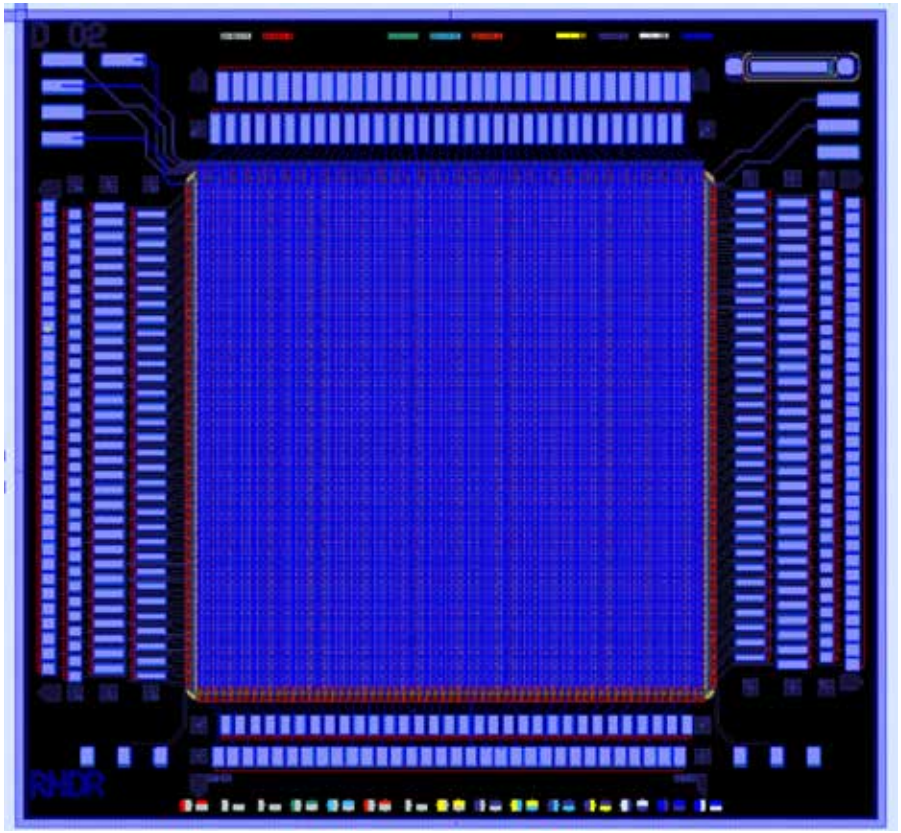
Matrix devices

- 64 x 64 pixel prototypes
- compact pixel topology
- source follower readout
- row-individual transfergate



Matrix devices

- 64 x 64 pixel prototypes
- Integrated on standard matrix scaffold
- third switcher device required (for transfergate clocking)
- Devices available for evaluation

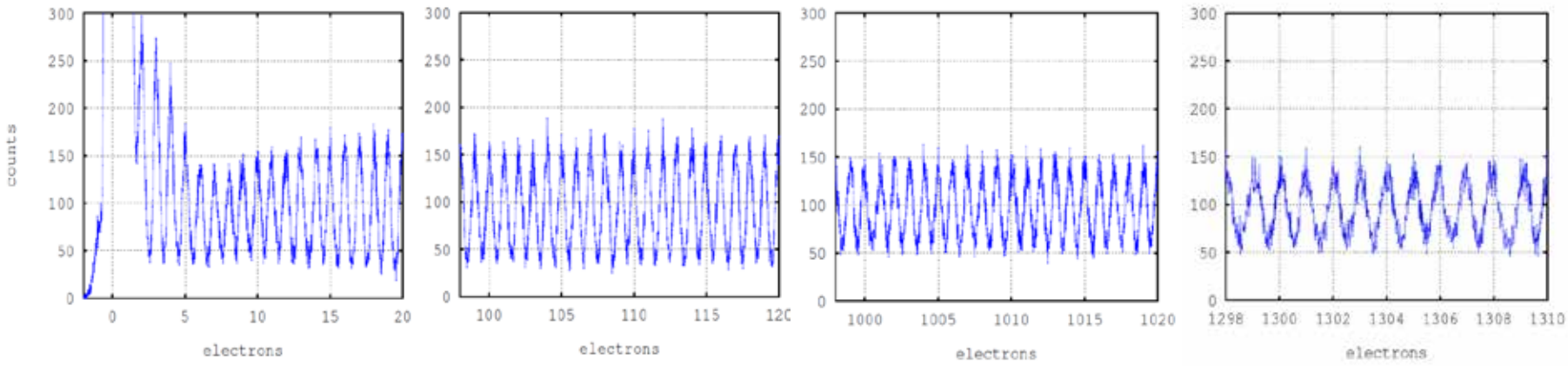


- **Critical parameters:**
  - Charge transfer efficiency
  - Transfer speed speed < 100 ns
  - Initial noise
  - Leakage current

RNDR

RNDR principle works in reality, but totally impractical for use in experiment (except for shuttered solutions)

But what if...?



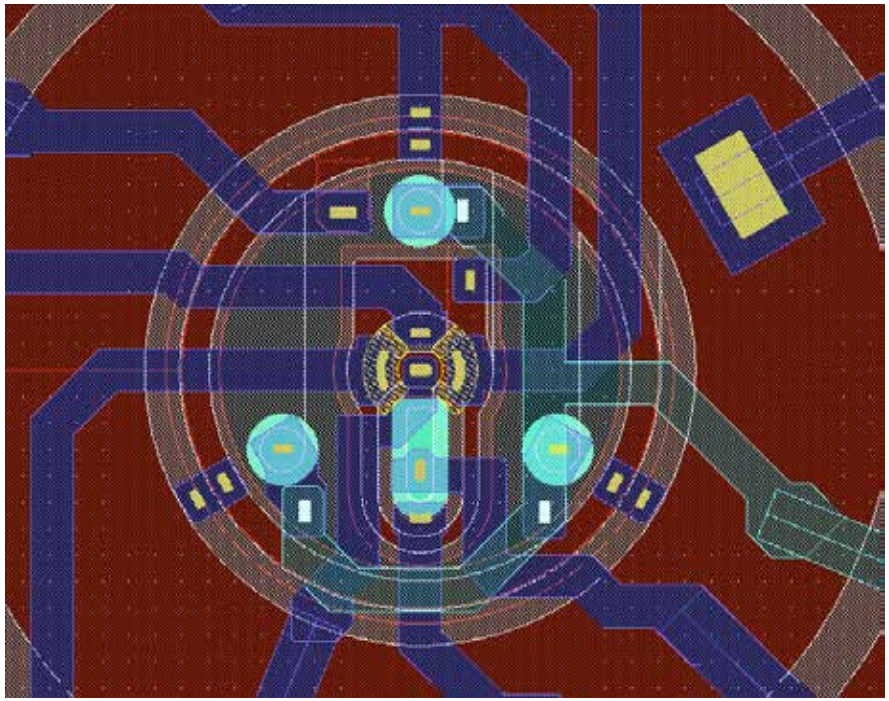
Composite multigate DEPFETs

Combine different conceptual features

Create devices with multiple capabilities

GPIX RNDR

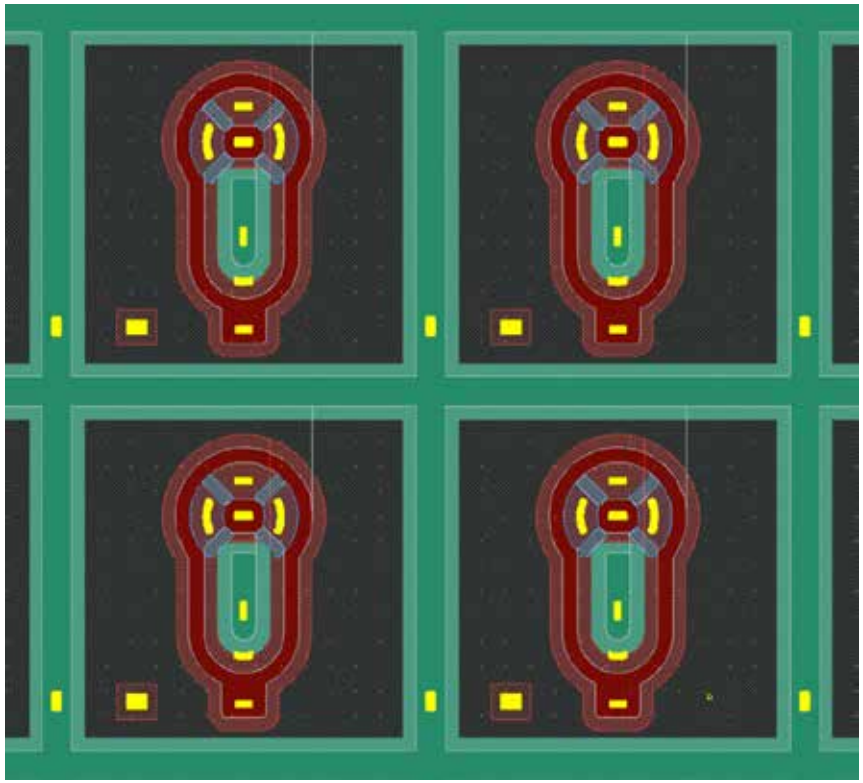
- RNDR pixel embedded in blindgate structure
- Global shutter
- Suppression of bulk leakage current
- RNDR process can take arbitrary time



- **Critical parameters:**
  - Charge transfer efficiency
  - Charge retention (also during transfer)
  - Charge selectivity
  - Transfer speed
  - Initial noise

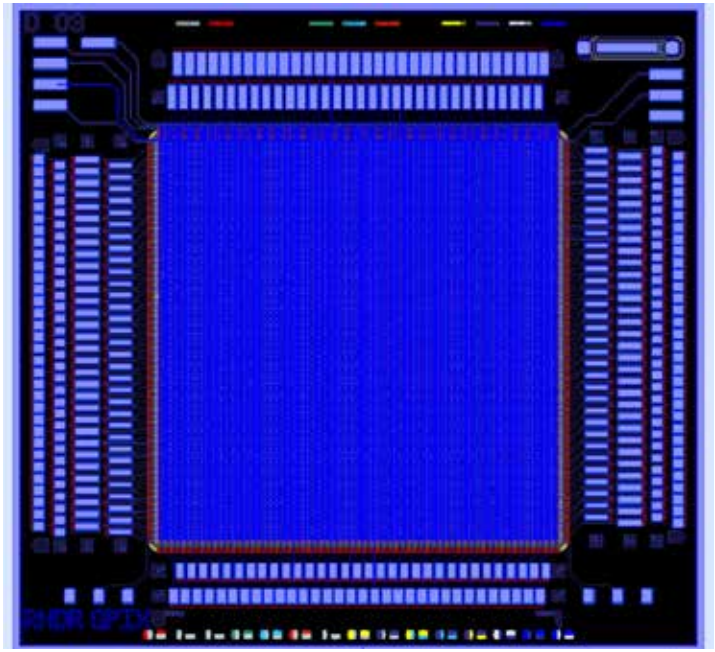
Matrix device

- Matrix variant available
- 75 x 75 mm^2 size
- Row-individual transfergate
- Global blind and blindgate
- Sourec follower readout



Matrix device

- 64 x 64 pixel prototypes
- Integrated on standard matrix scaffold
- third switcher device required (for transfergate clocking)
- Devices available for evaluation



Does it also work with Infinipix?

In theory, yes.

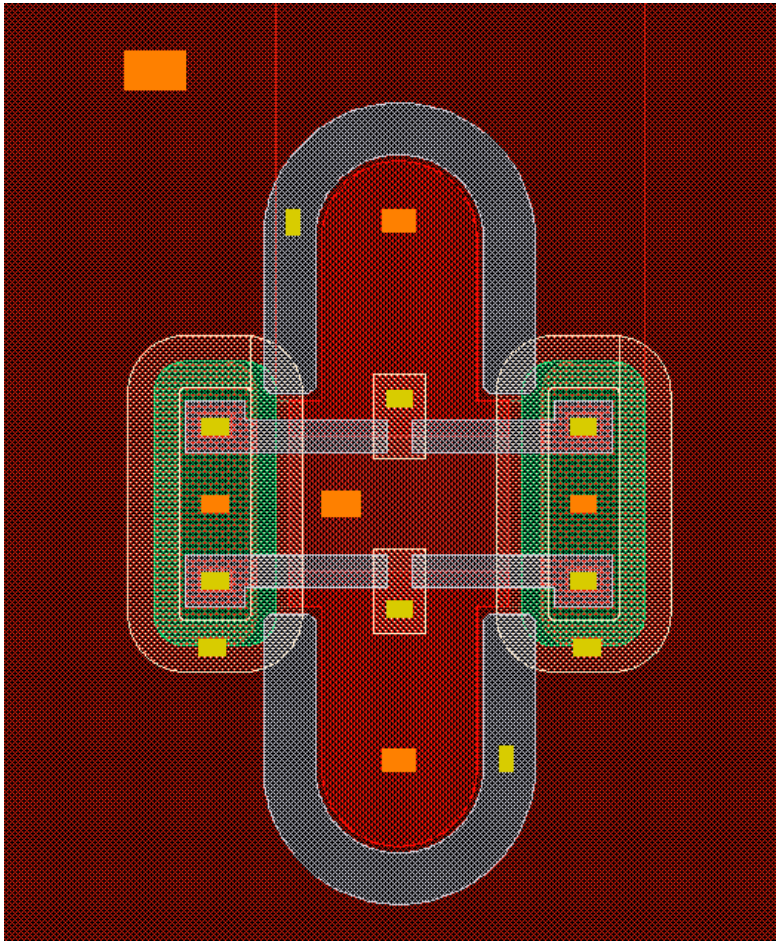
We'll see.

Infinipix RNDR

Prototype structure:

- RNDR feature can easily be implemented
- Global transfergate
- Common clear

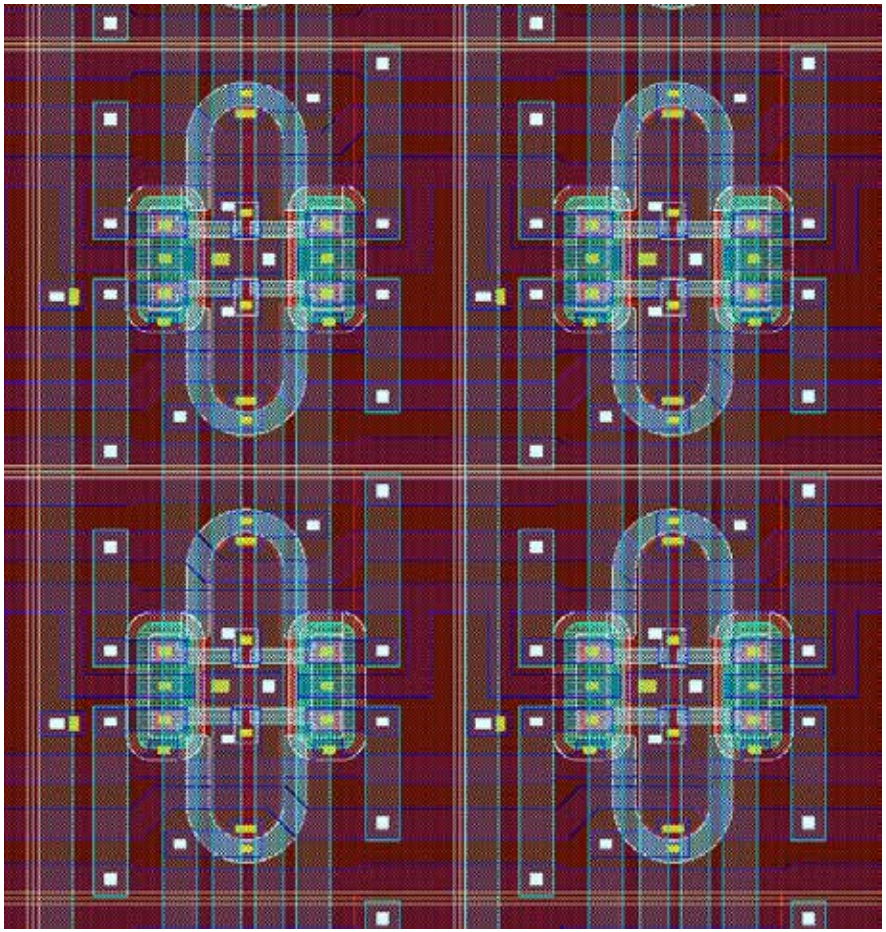
- **Critical parameters:**
  - Charge transfer efficiency
  - Charge retention (also during transfer)
  - Charge selectivity
  - Transfer speed
  - Initial noise



Matrix device

Prototype matrix:

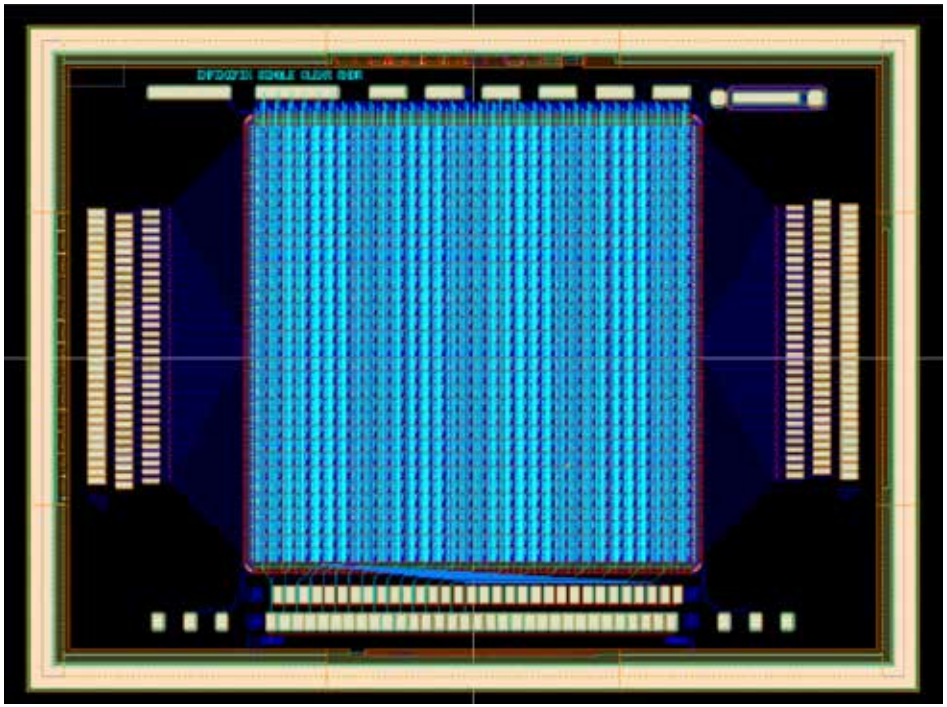
- 150 x 150 mm^2 size
- Two Subpixels per Superpixel
- Common source
- Source follower readout



Matrix device

Prototype matrix:

- 32 x 32 pixels
- 150 x 150 mm^2 size
- Sensitive area: 4.8 x 4.8 mm^2
- Backside illuminated
- "Optical" entrance window
- Chip size: 9.5 x 7 mm^2
- PXD 11 technology (spectroscopy grade)
- PXD 11 devices in fabrication
- Soon: New production dedicated to Infinipix devices



Overview

Device	# Gates / pixel	Single pixels	Drift detectors	Matrices
Standard DEPFET	3	available	available	available
GPIX	4	available	available	available
Infinipix	6 (5)[a)]	available	available	available[b)]
IQ	12 (10) [a)]	in production	not available	in production
IQCA	17 (15) [a)]	in production	not available	in production
RNDR	7 (6) [a)]	available	available	available
GPIX RNDR	8 (7) [a)]	available	available[c)]	available
Infinipix RNDR	12 (10) [a)]	in production	in prodcution	in production

[a)] number in brackets is for devices w/ shared clear

[b)] evaluation by MPE

[c)] few devices left

Summary

DEPFET devices are an ideal platform for the implementation of functional concepts manipulating directly the signal charge

Many different conceps have been tested and verified

We need to find better problems for our solutions!