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Sub-electron noise measurements on Ping-Pong devices

Stefan Wölfel

Ringberg Workshop

Schloss Ringberg, Tegernsee

im sonnigen April 2007

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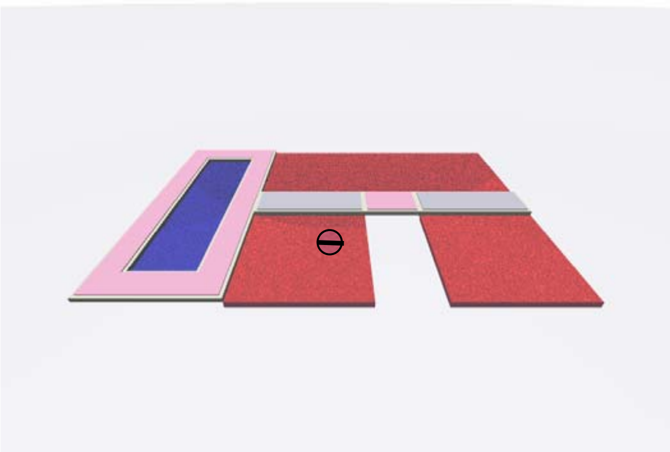
Sub-electron noise measurements on RNDR devices



Stefan Wölfel

HLL Ringbergmeeting

Schloss Ringberg, Tegernsee

im sonnigen April 2007

Outline

- The basic idea of a RNDR device
- The DEPFET concept
- Realisation of a RNDR device
- Measurements
  - Charge loss in non HE devices
  - resolution
  - laserspectra
- discussion of readout speed and optimum measurement time
- New devices in production

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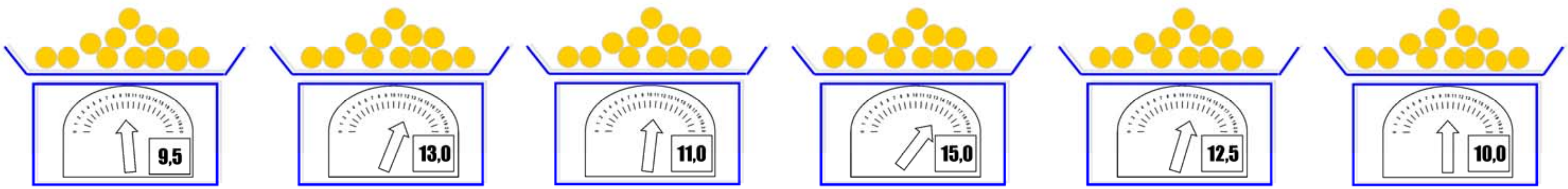
The basic idea of a RNDR device



First … second … third … fourth … fifth … sixth measurement

- In each measurement are errors, no measurement is exact!
- Measuring the number of yellow balls six times, you get six different results!

F1 50:50

F2

F3

STOP

Why is it better to measure the balls multiple times ?

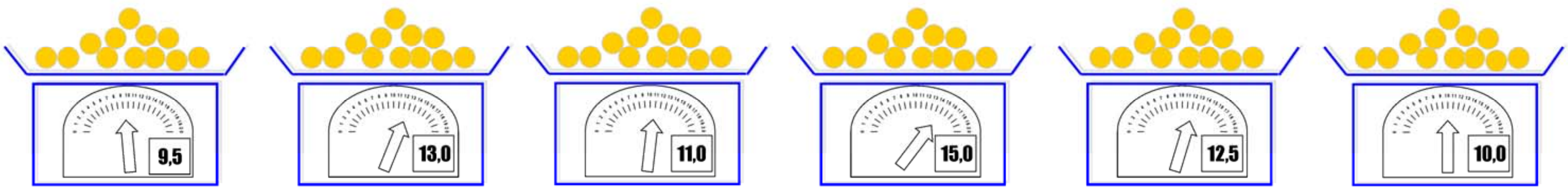
A: The scale becomes more precise (warm up effect).

B: You can choose the value, which fits best to your theory.

C: Calculating the mean of all meas. results in a more precise value.

D: It is not better.

Answer C:



First … second … third … fourth … fifth … sixth measurement

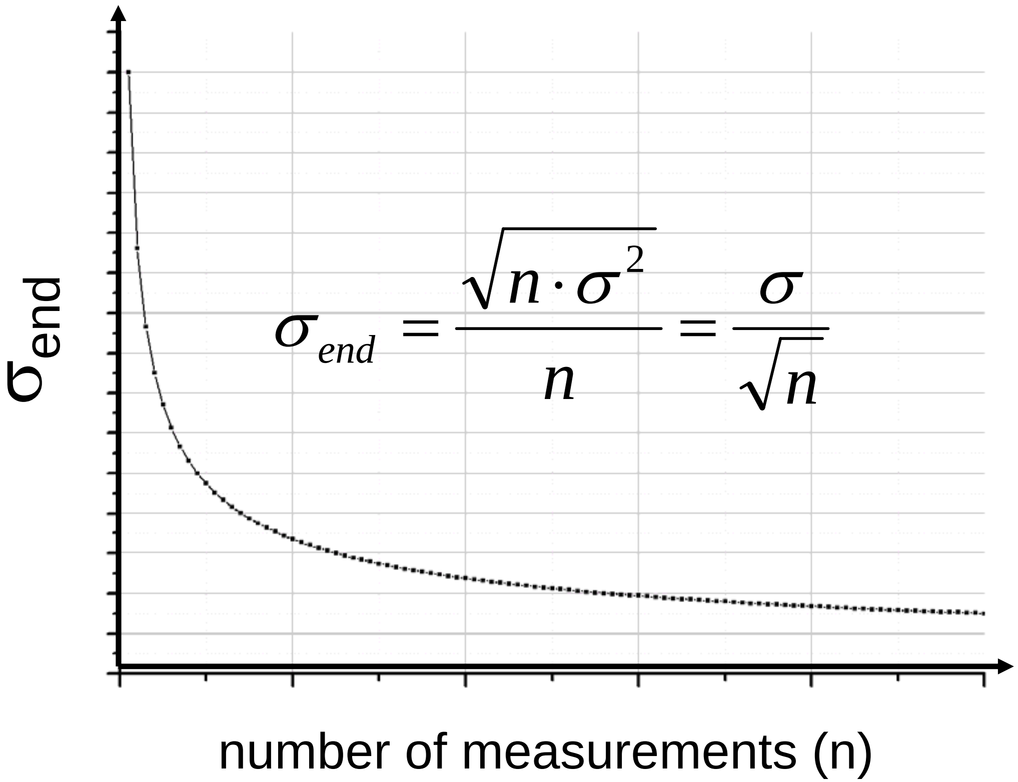
$$\frac{9{,}5 + 13{,}0 + 11{,}0 + 15{,}0 + 12{,}5 + 10{,}0}{6} = \mathbf{11{,}83}$$

Real number of yellow balls = **12**

Stefan Wölfel
Ringberg Meeting,
April 2007

The basic idea of a RNDR device

- By measuring the charge multiple (n) times the noise (σ) can be reduced by $1/\sqrt{n}$.
- Because the collected charge is stored during readout in the DEPFET-RNDR, the very same charge can be measured multiple times.
- => name: repetitive non destructive readout -> RNDR



$$\sigma_{end} = \frac{\sqrt{n \cdot \sigma^2}}{n} = \frac{\sigma}{\sqrt{n}}$$

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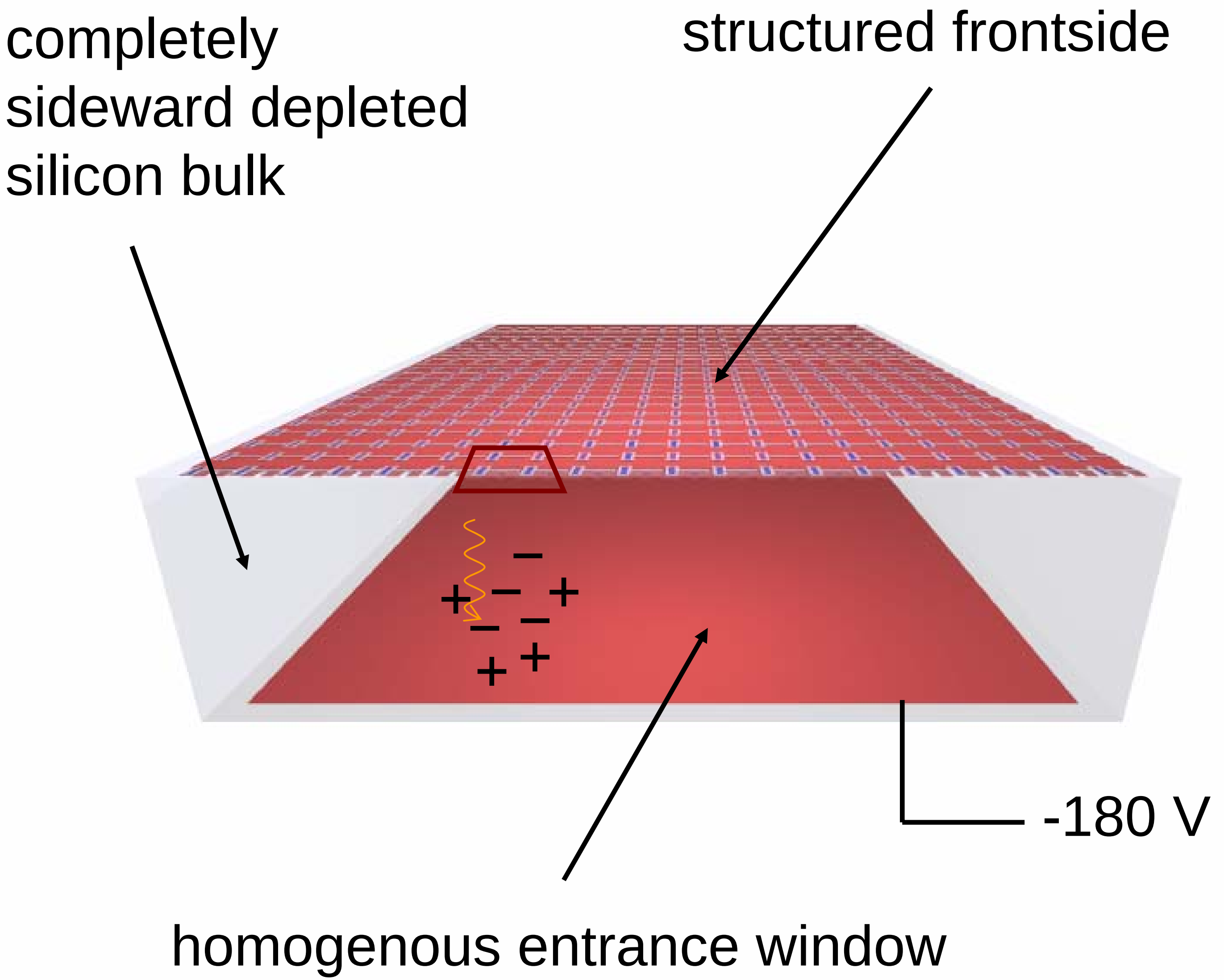
Realisation of a RNDR Detector



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Realisation of a RNDR Detector

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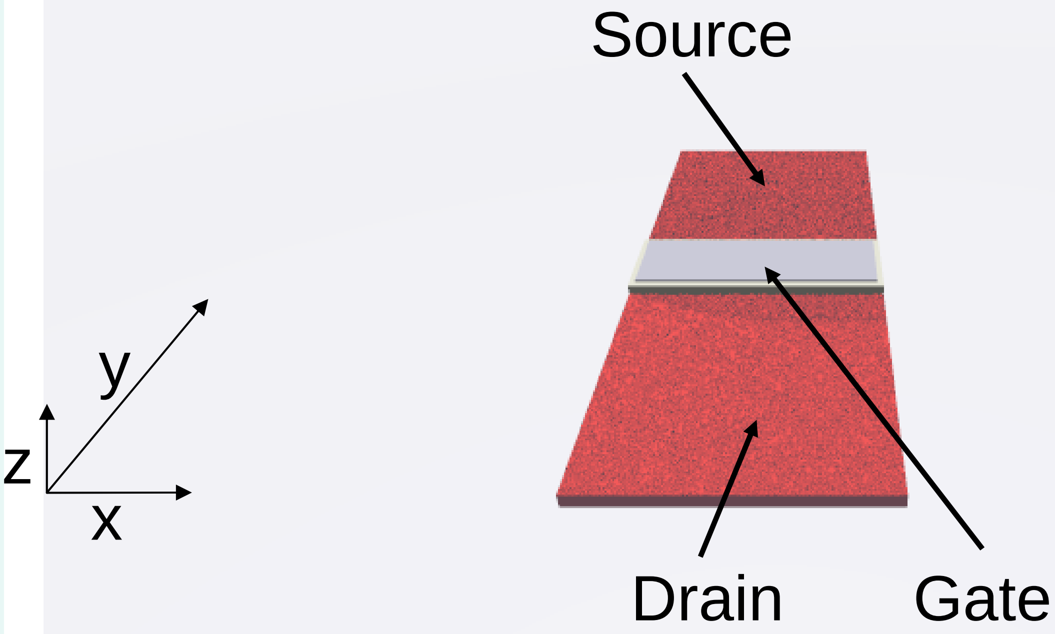

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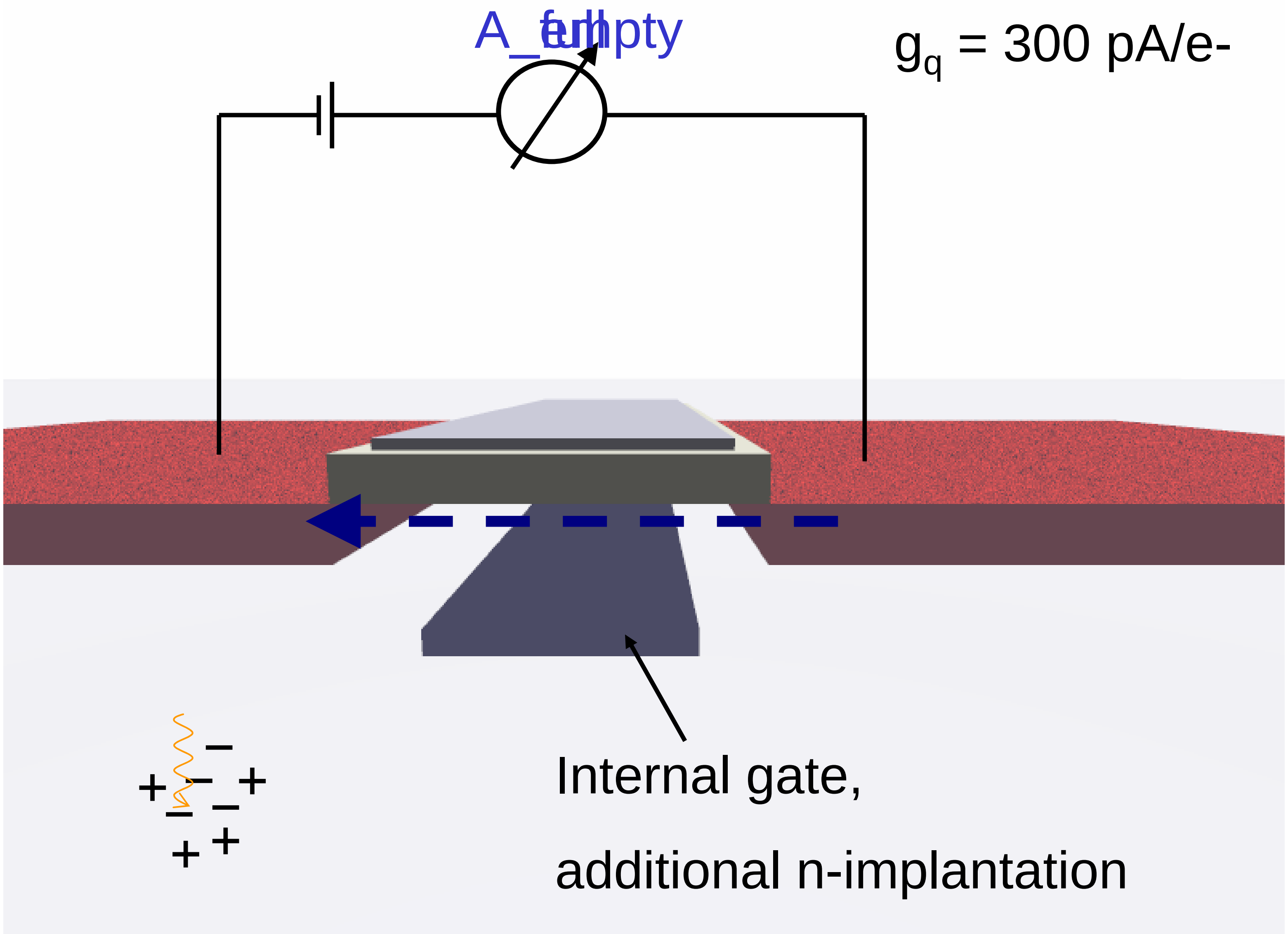
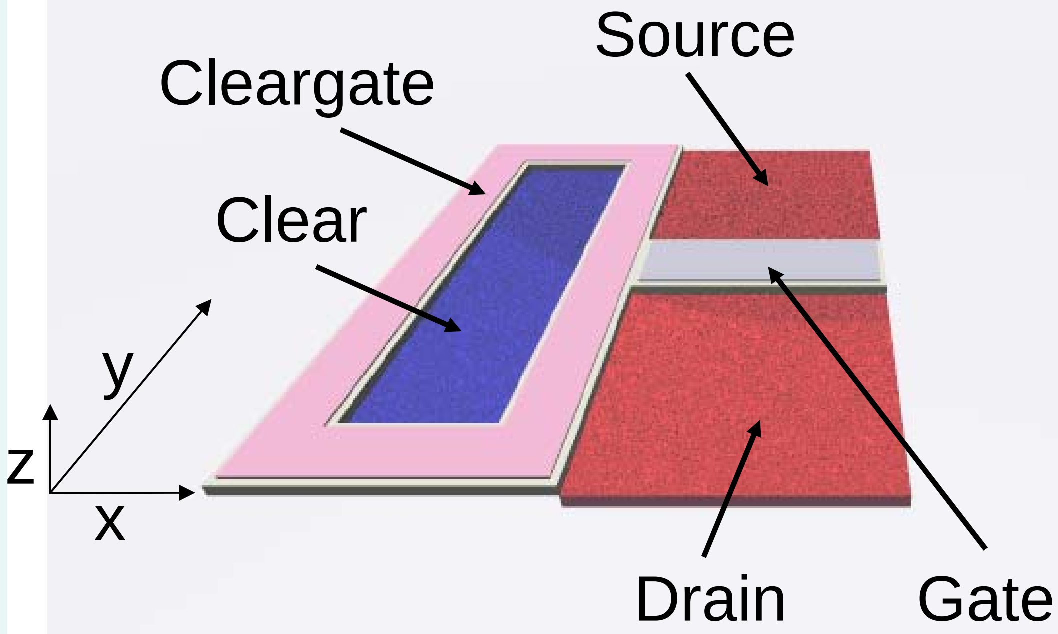
Charge measurement



The Clearcontact



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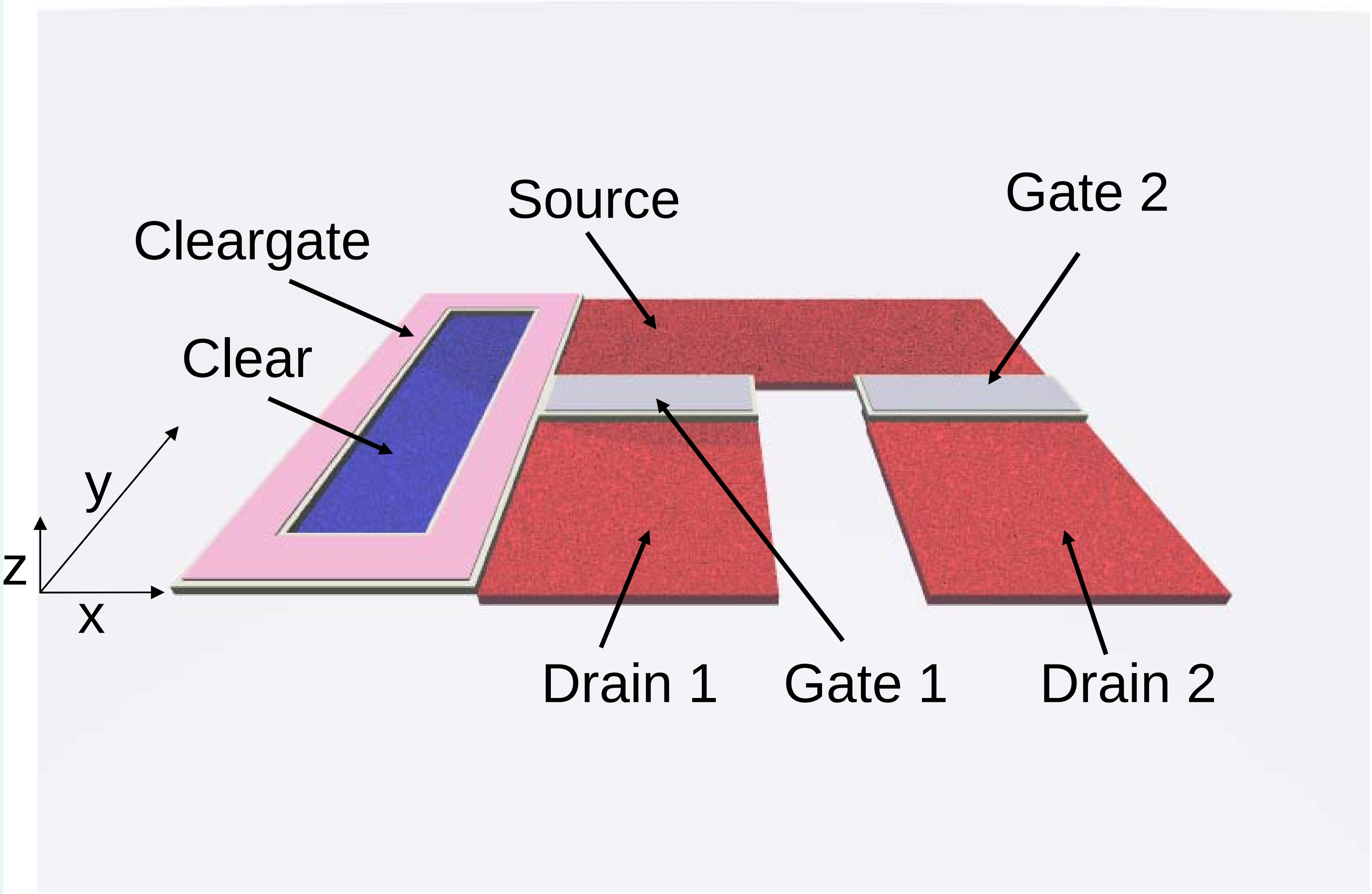
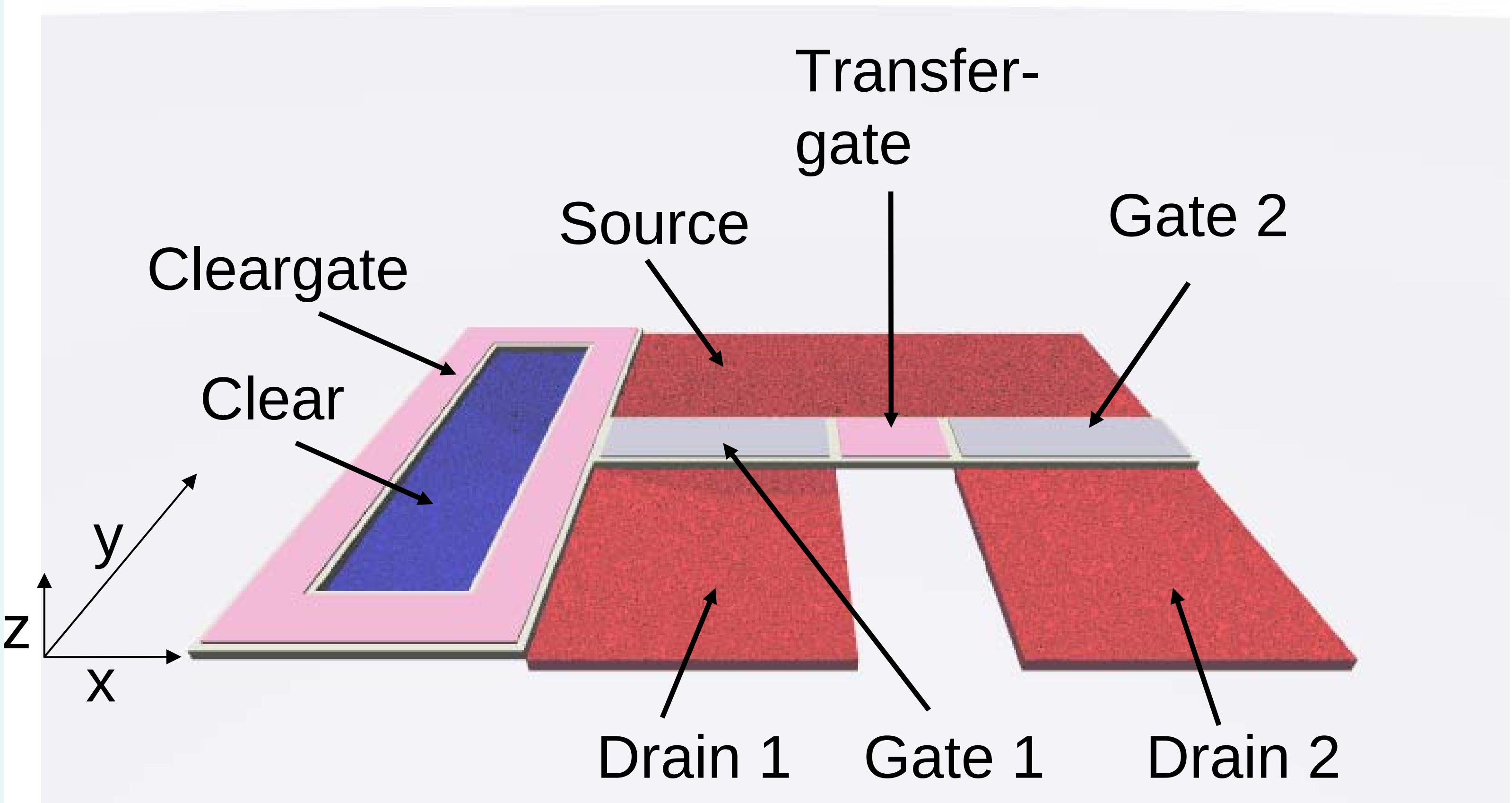
The RNDR concept



The RNDR concept



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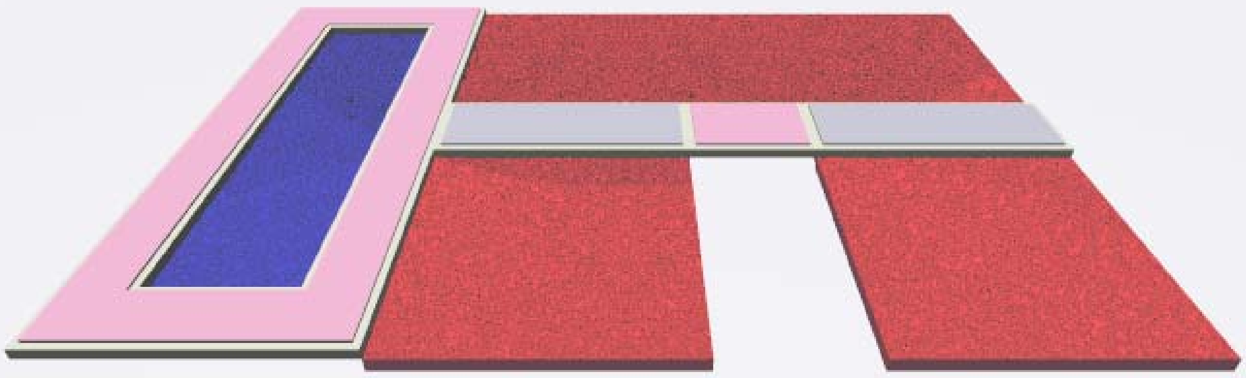
The RNDR concept



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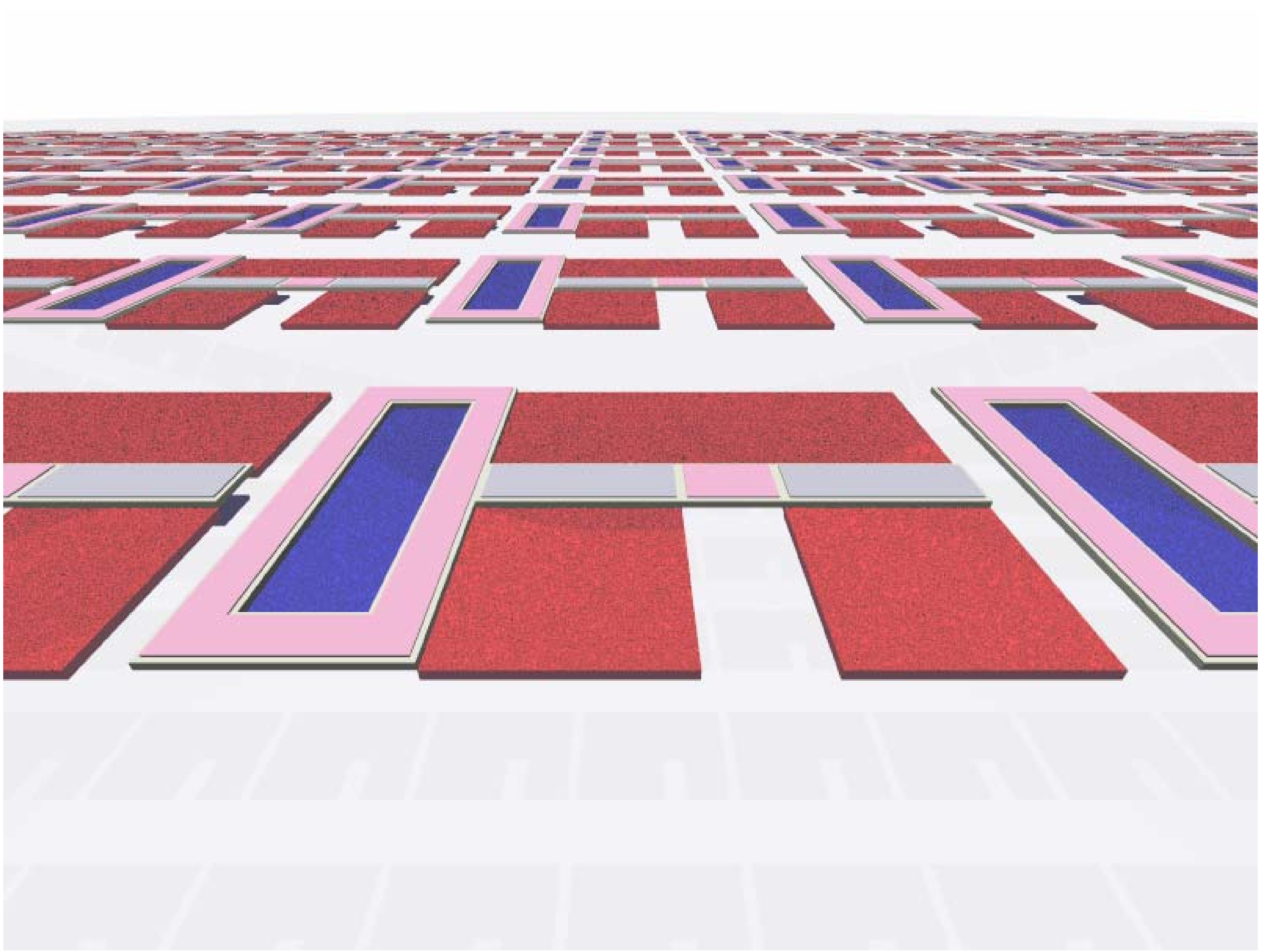
Matrix operation



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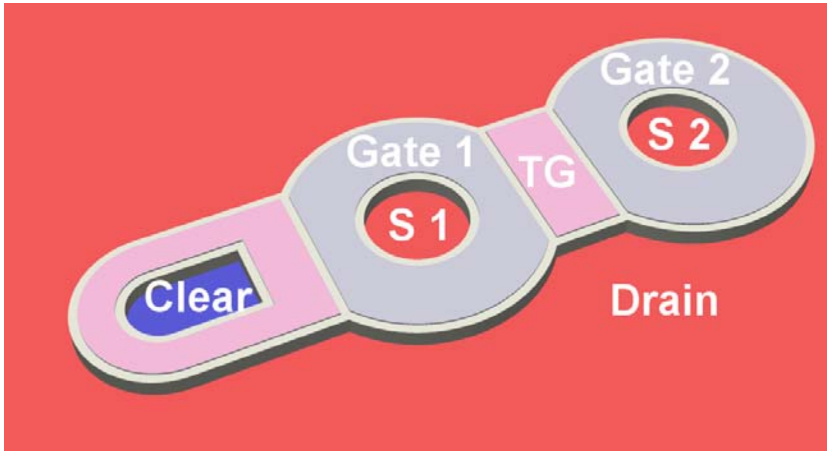
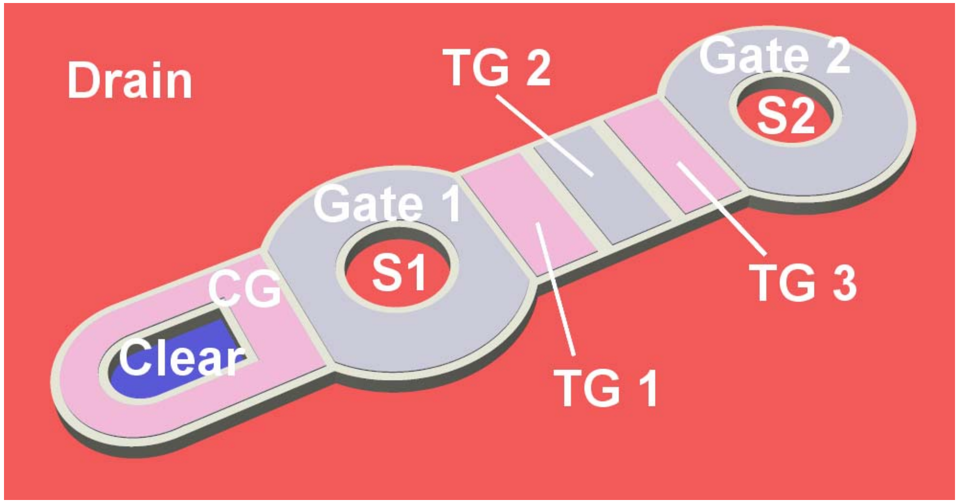
Circular variants



Two circular DEPFETs with <u>one</u> transfergate

Two circular DEPFETs with <u>three</u> transfergates



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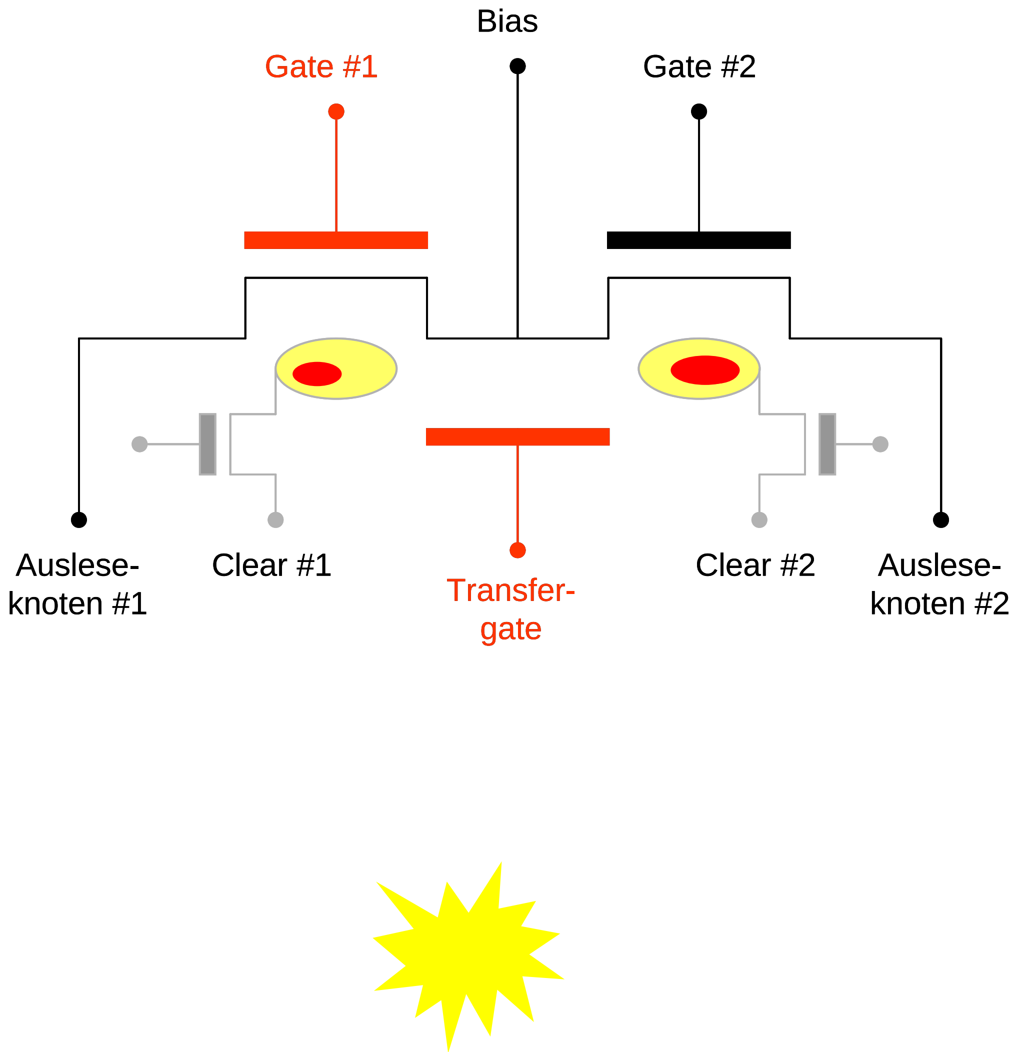
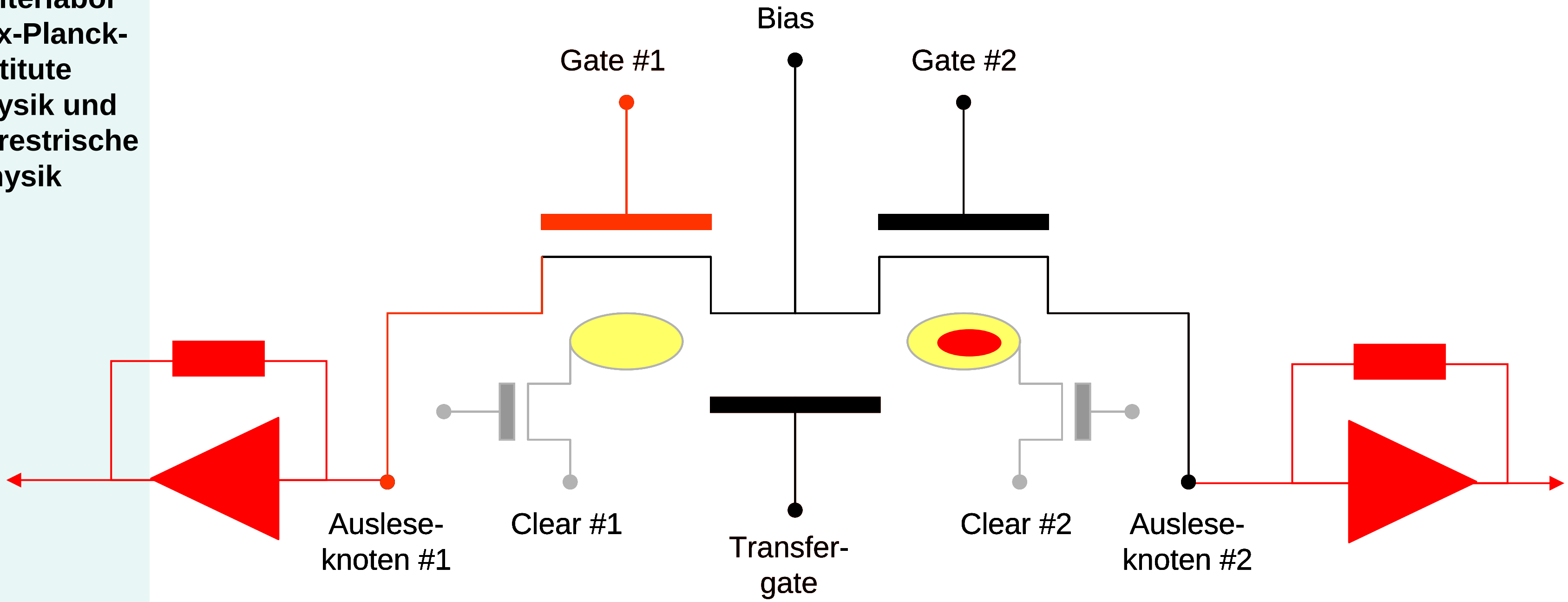
The RNDR principle



RNDR principle



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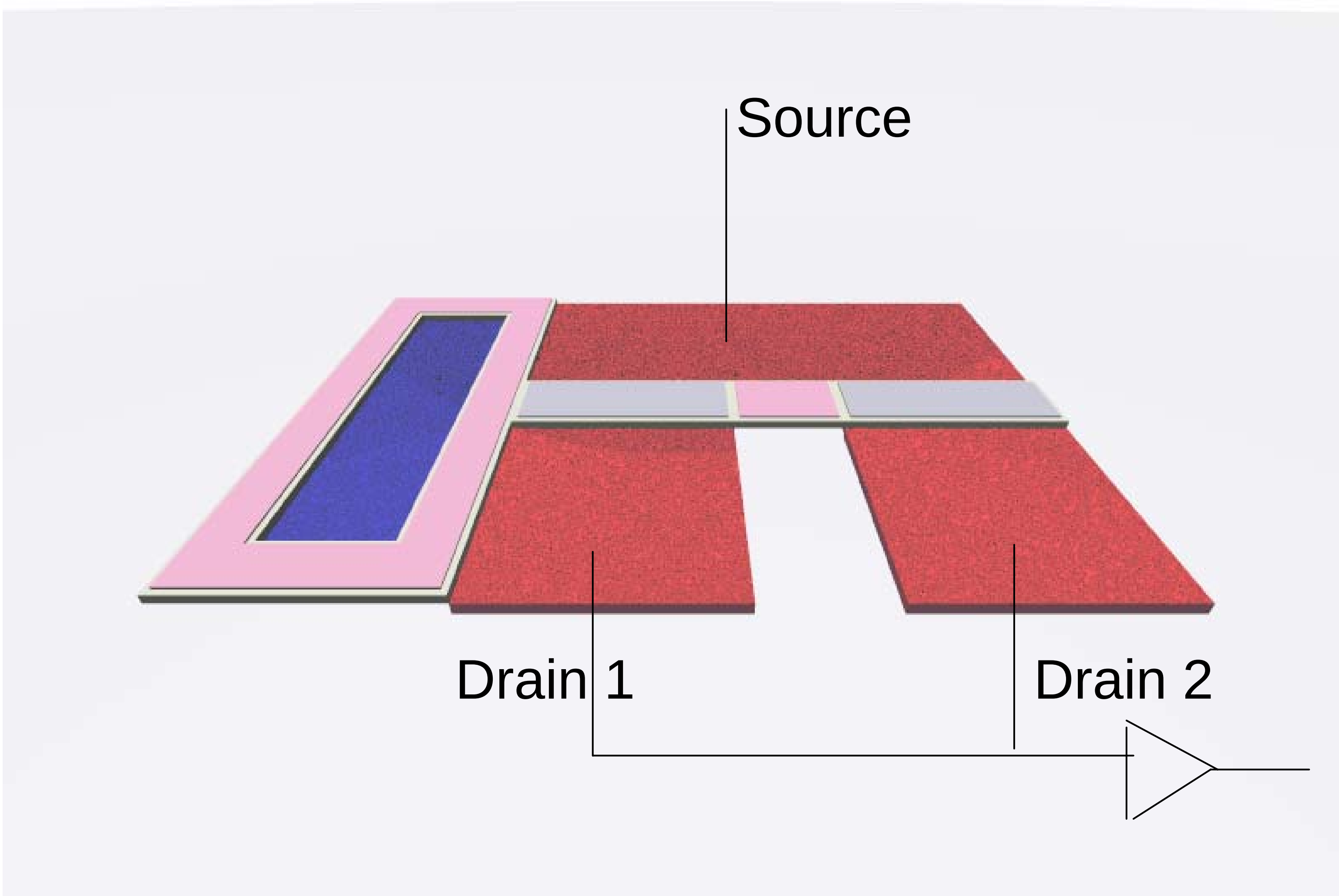
The RNDR concept



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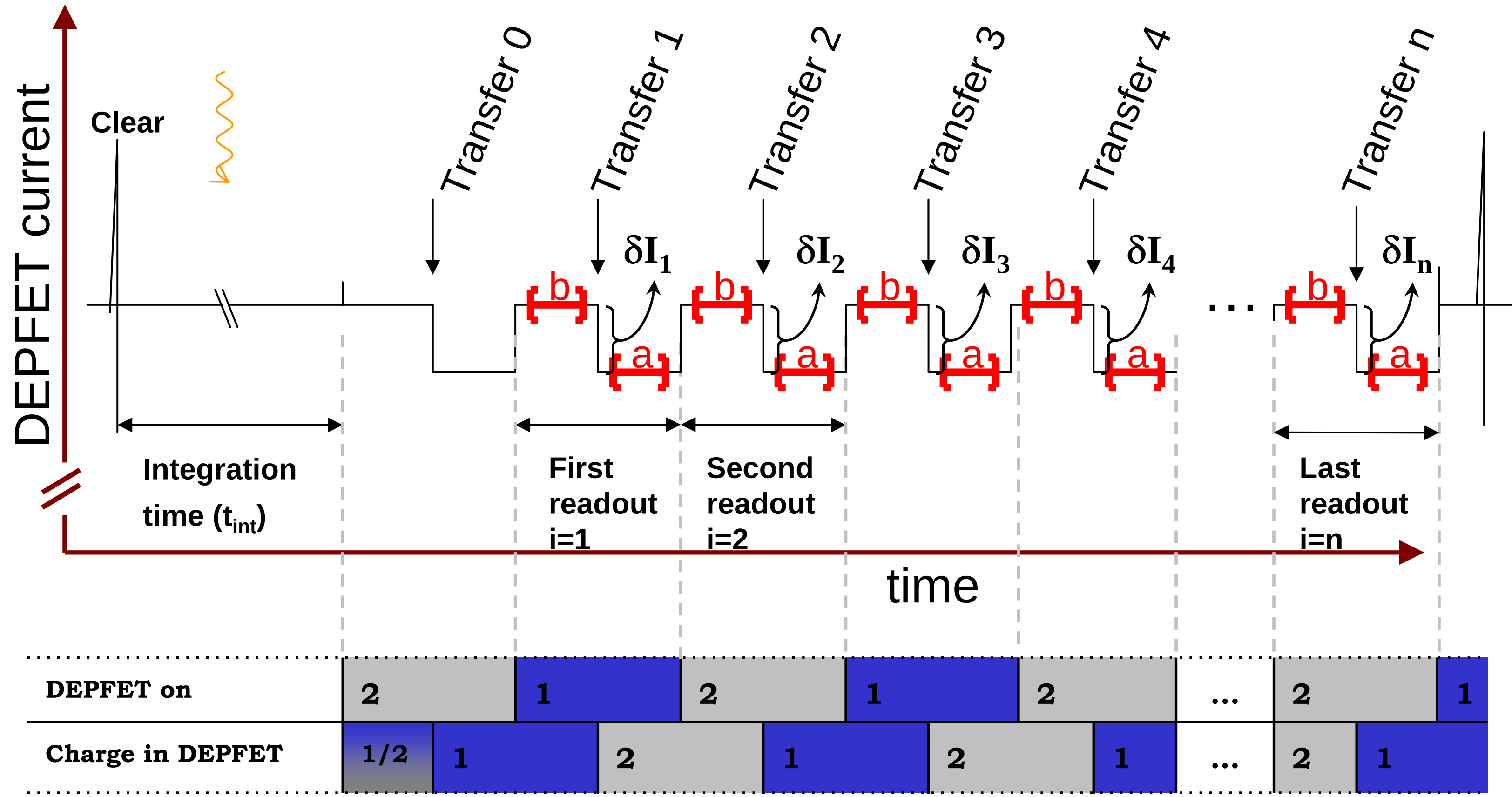
The readout sequence



Depfet 1

Depfet 2

measurement before transfer b

measurement after transfer a

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First Summary

- With the DEPFET detector, the collected charge can be **measured**
- Collected charge is **stored** during readout

→ charge can be **measured arbitrarily often**

All other good detector properties remain untouched:

- high quantum efficiency
- low leakage current
- fast signal charge collection
- homogenous entrance window

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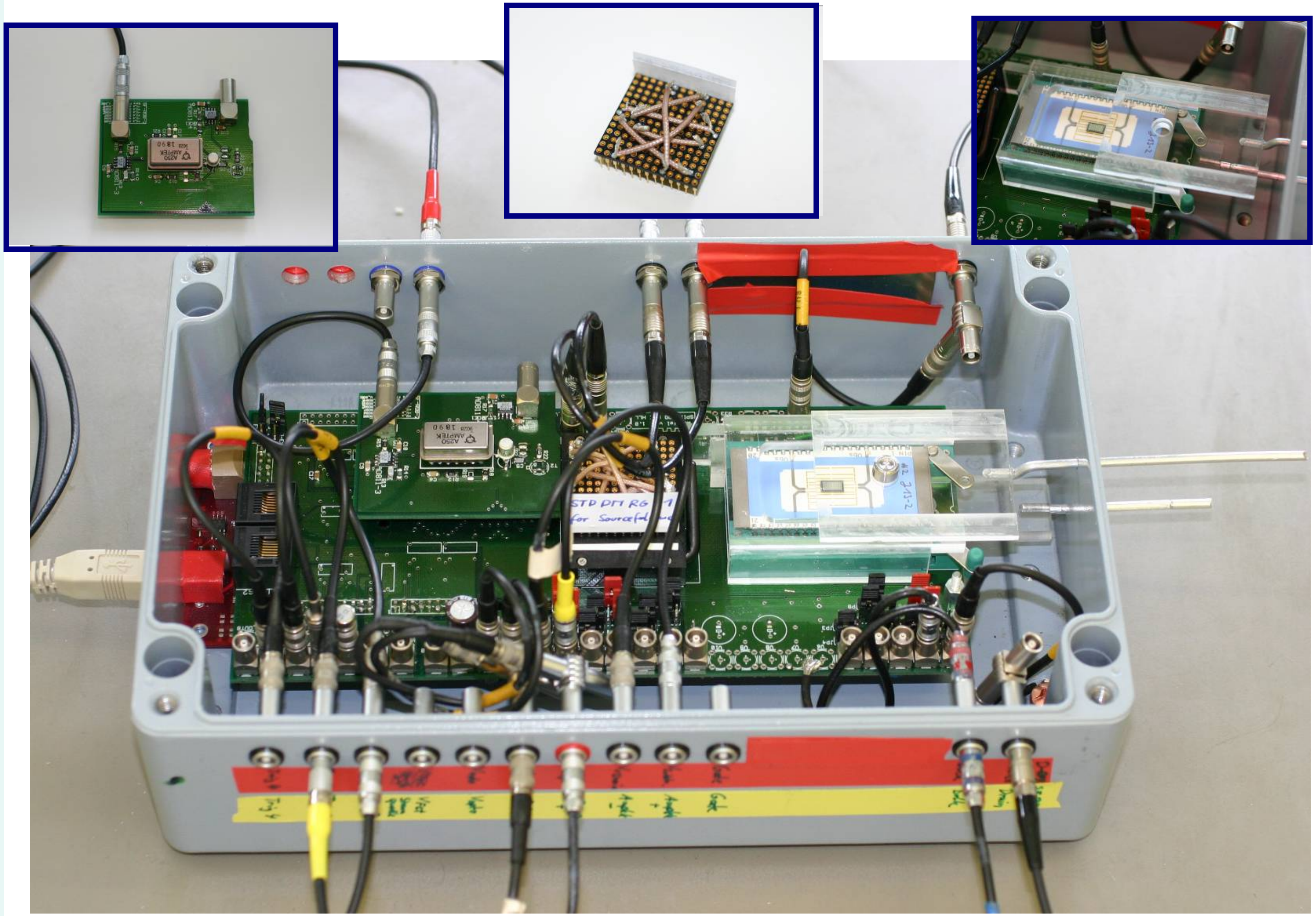
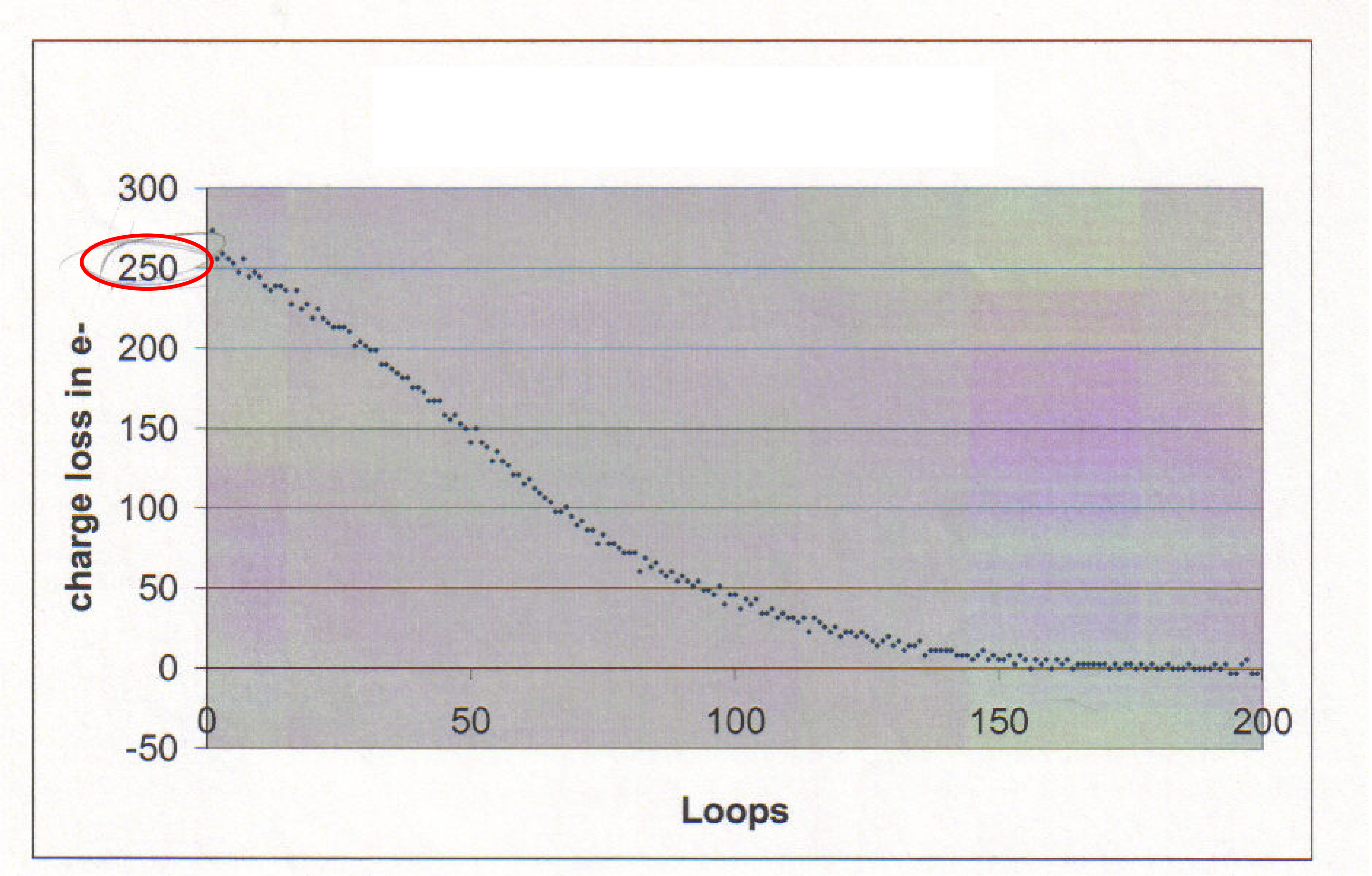
The measurement setup



Charge loss with non-HE devices



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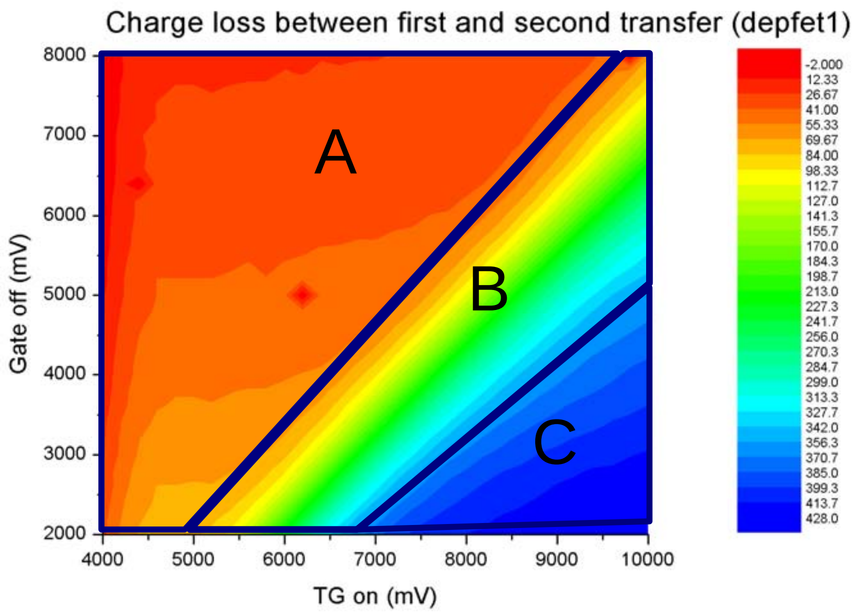
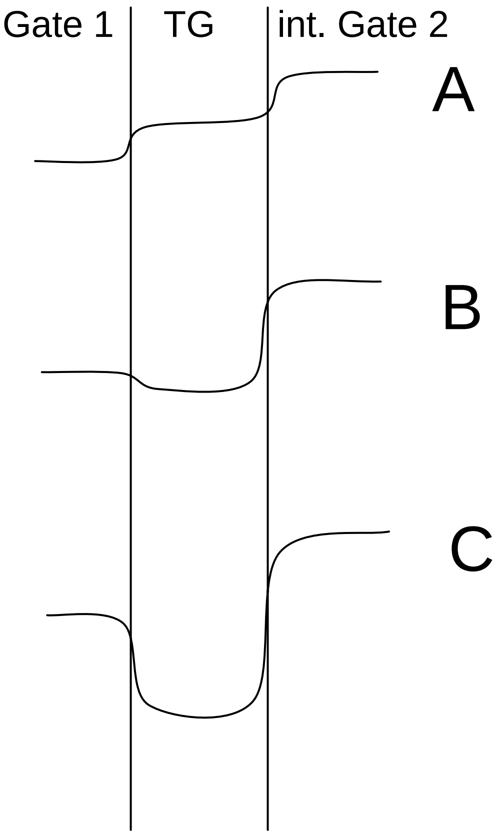
The first devices: Charge loss in non-HE Ping-Pong





A) little chargeloss

B) some chargeloss

C) high chargeloss

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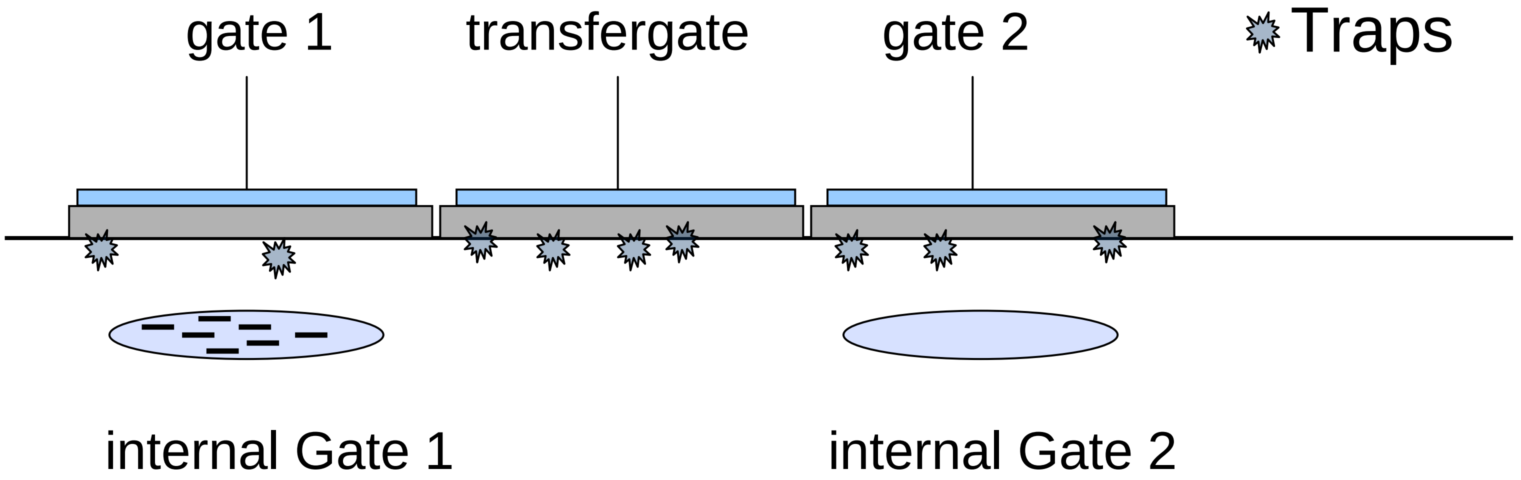
Telefone Joker: Rainer

Where does the charge loss come from?

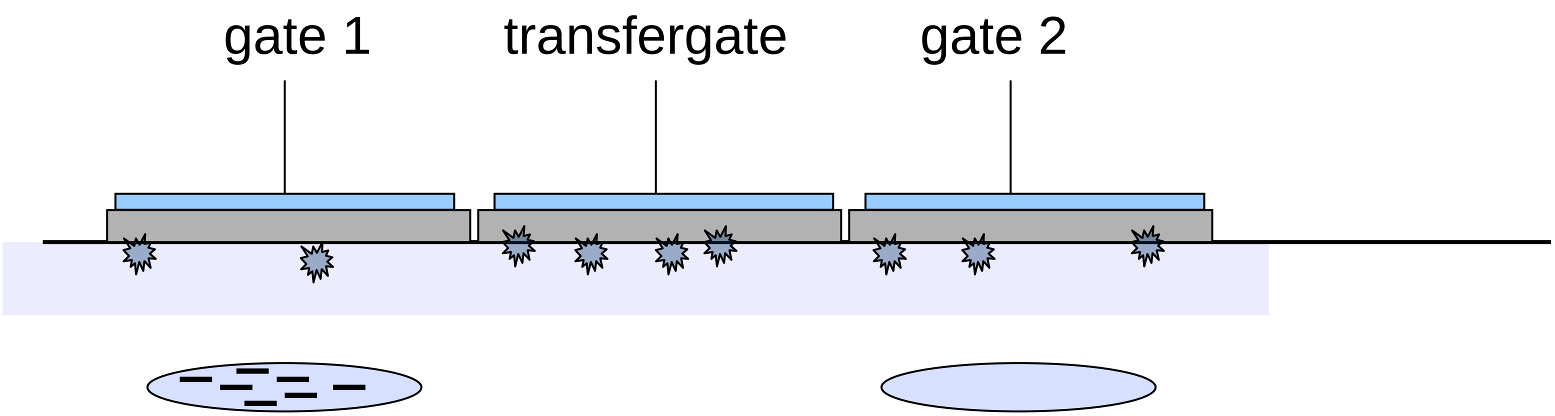
- A: Special decay of the electron
- B: Electrons are repulsed into the bulk
- C: Interface traps under the transfergate
- D: New physics

Answer C) Charge loss due to traps

non HE:



HE:



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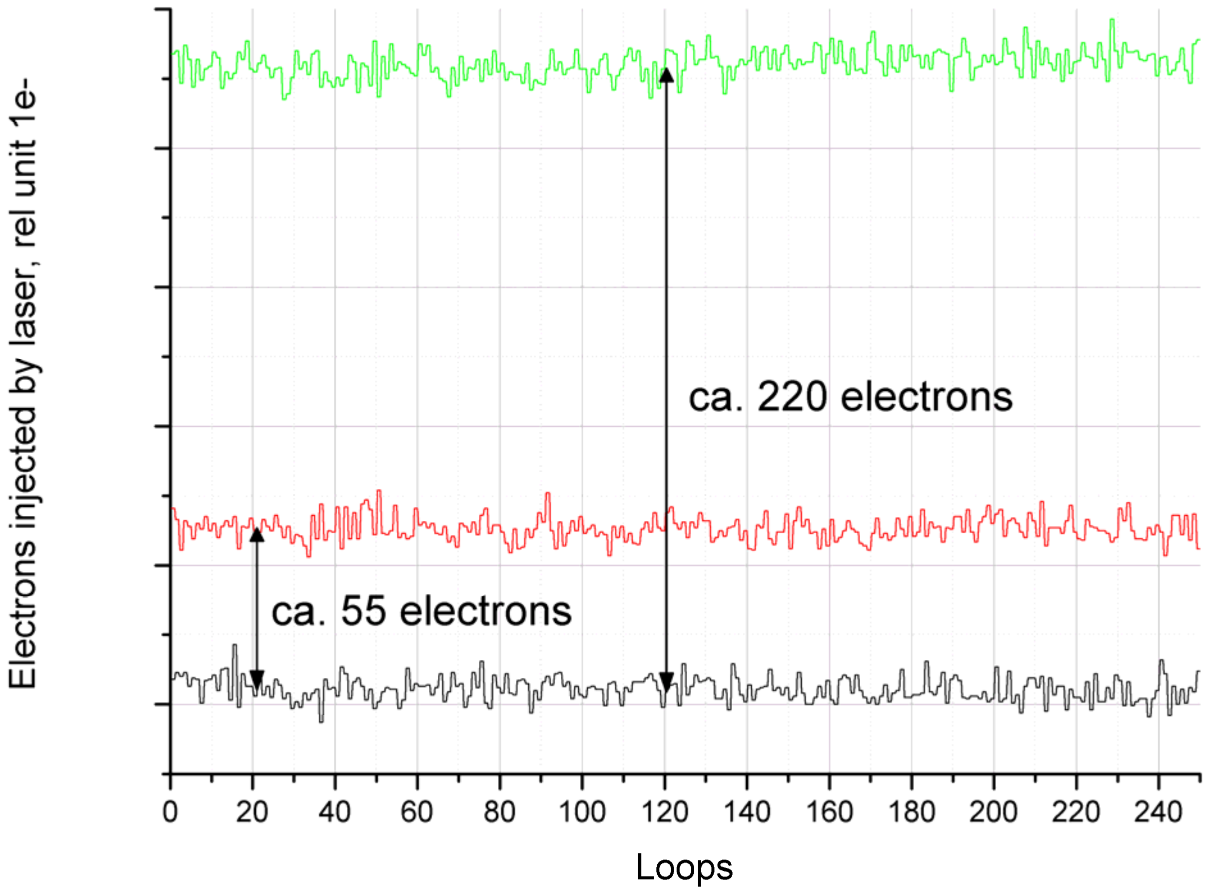
No charge loss with HE-RNDRs

weak charge injection by laser -> no visible chargeloss



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Noise measurements with HE-devices

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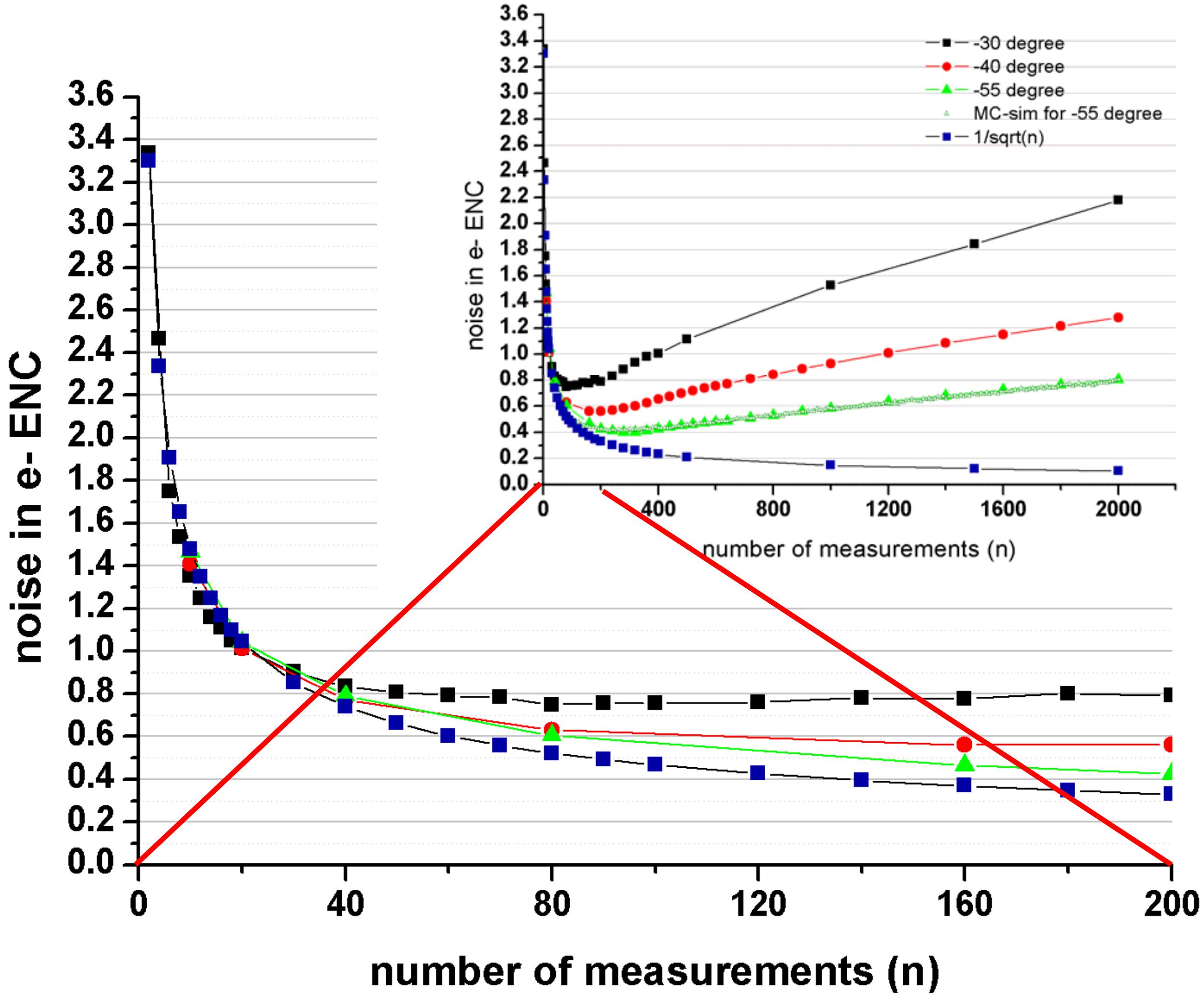

F1 50:50

F2

F3

STOP

Why does the noise first decrease and then increase again with a higher number of readouts?

A: White noise

B: Green noise

C: Red noise

D: Leakage current electrons

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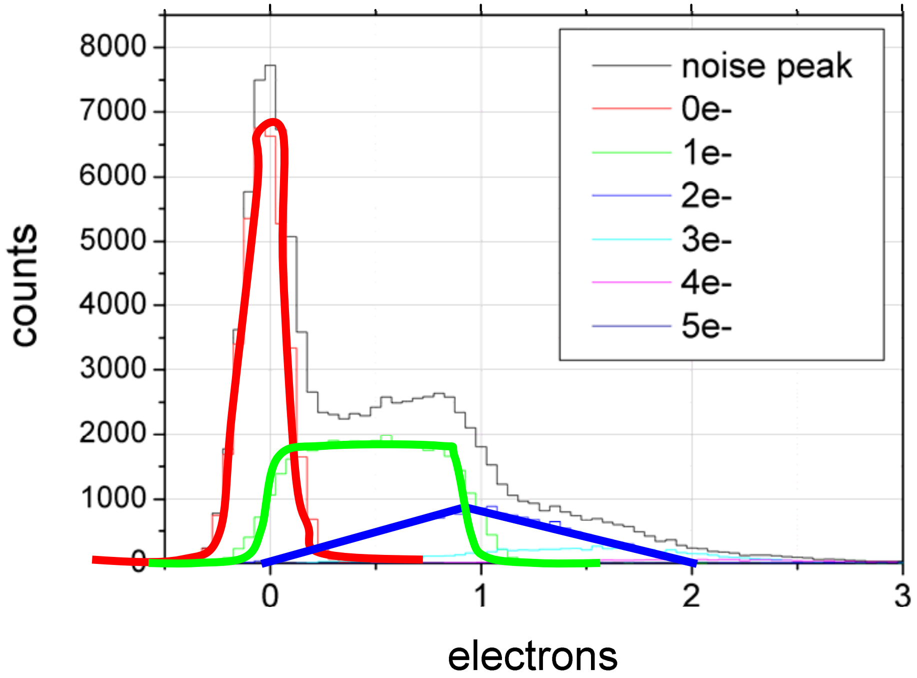
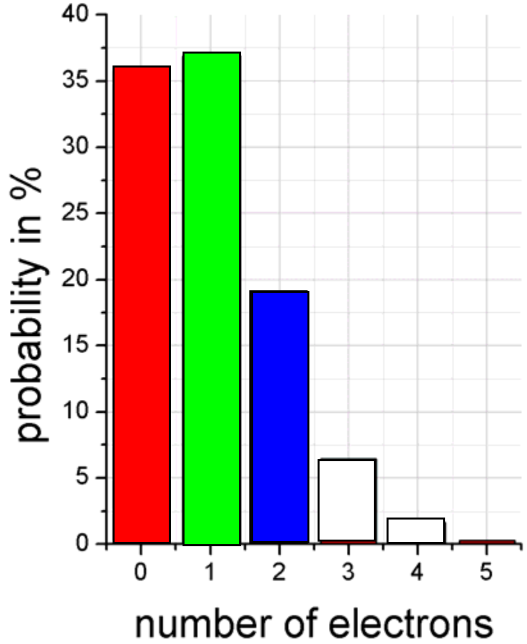
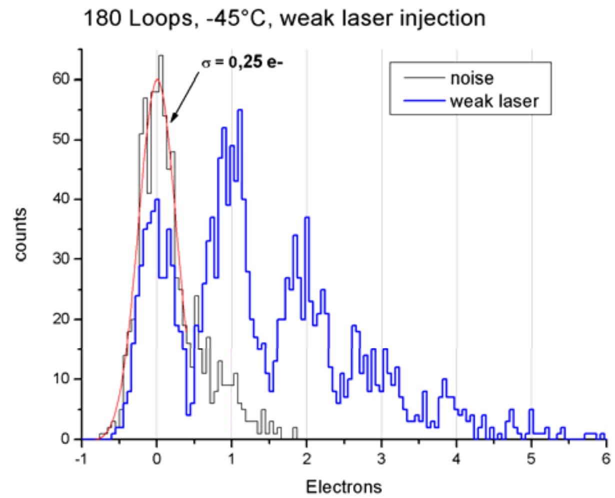
Answer D) Noise peak of a RNDR-Device

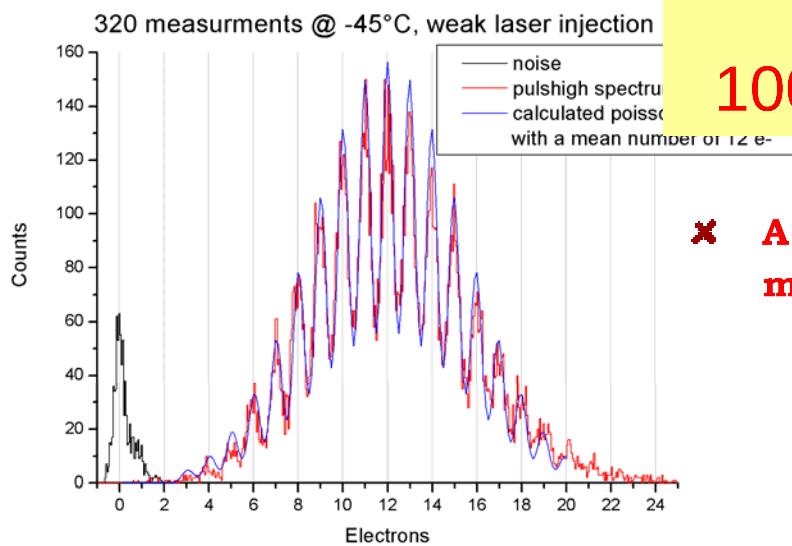




- For higher loop numbers the noise peak becomes more and more asymmetric.
- Asymmetry to higher energies (electrons) due to arriving electrons during readouts.

What is the achievable resolution?





- Photon injection by laser during integration time
- 360 measurements (9,18 ms)
- Temperature: -45 degree

Single optical photon counting,

in terms of a real linear amplifier, e.g. it is possible to separate

100 photoelectrons from 101!

- **A readout noise of 0.18 e^- was measured. This is a new world record !**

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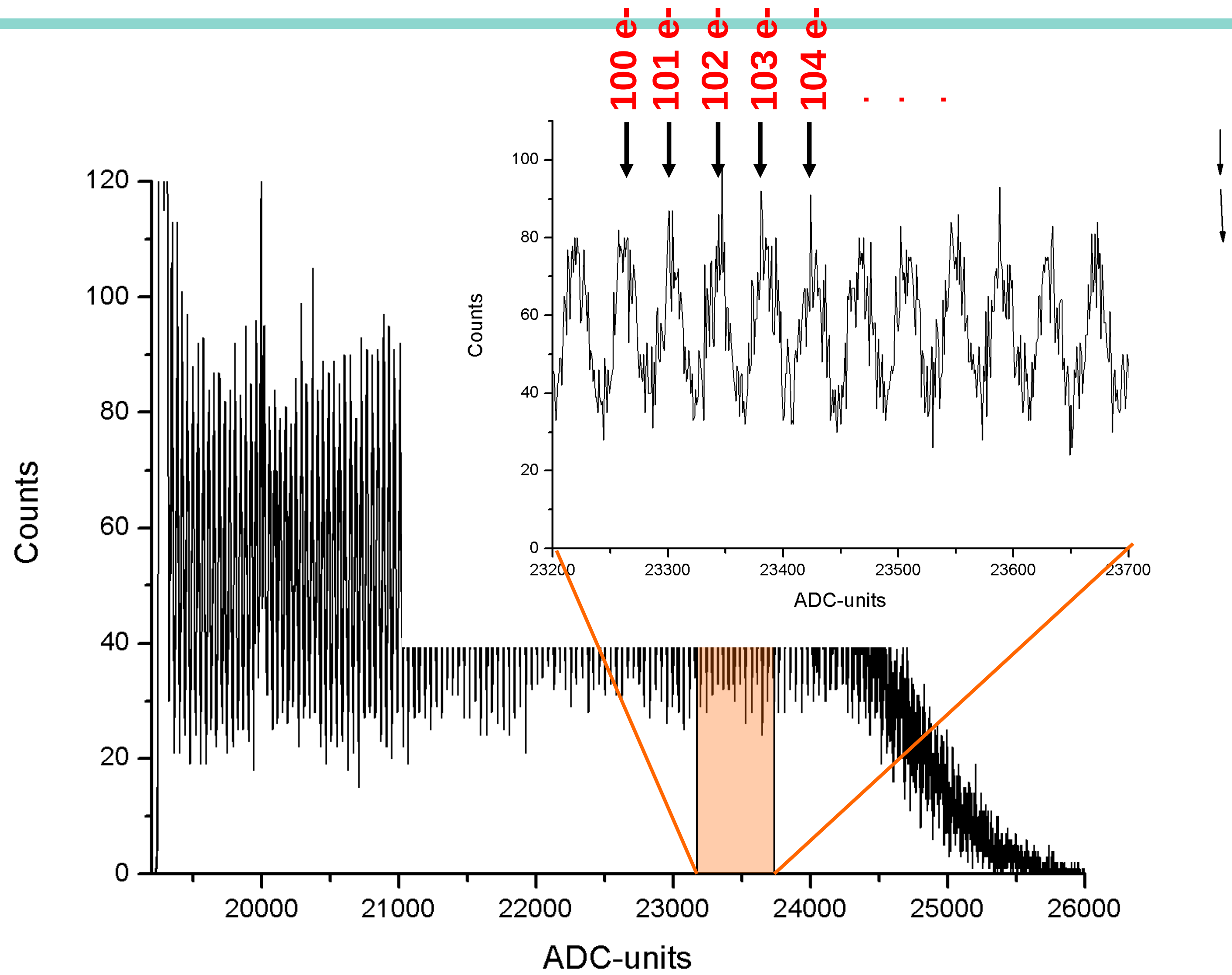
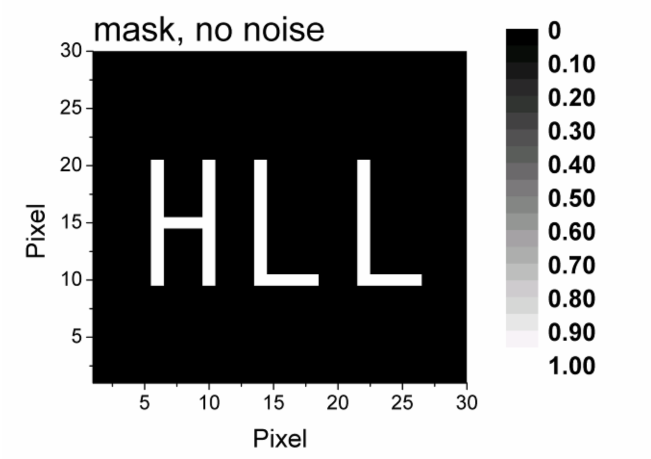
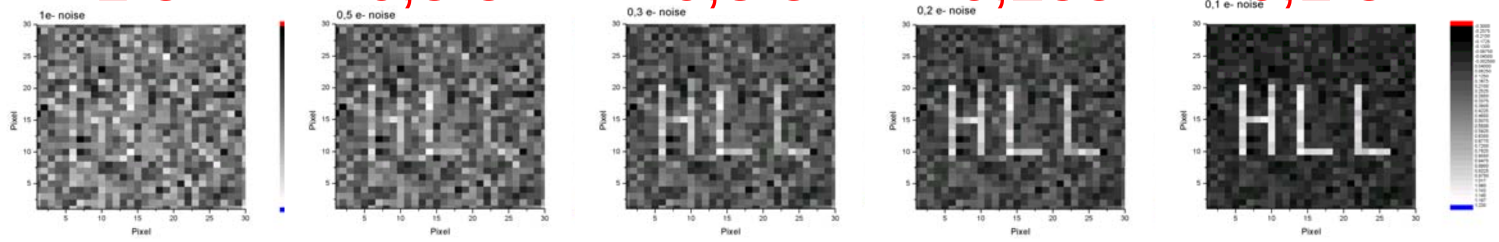
How to distinguish 100 electrons from 101?



What does a certain resolution mean in terms of contrast?



σ = 1 e- 0,5 e- 0,3 e- 0,25e- 0,1 e-



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F1 50:50

F2

F3

STOP

What is the optimum measurement time for one readout?

A: As long as possible

B: 1 μs

C: Short measurement, but many loops

D: It depends …

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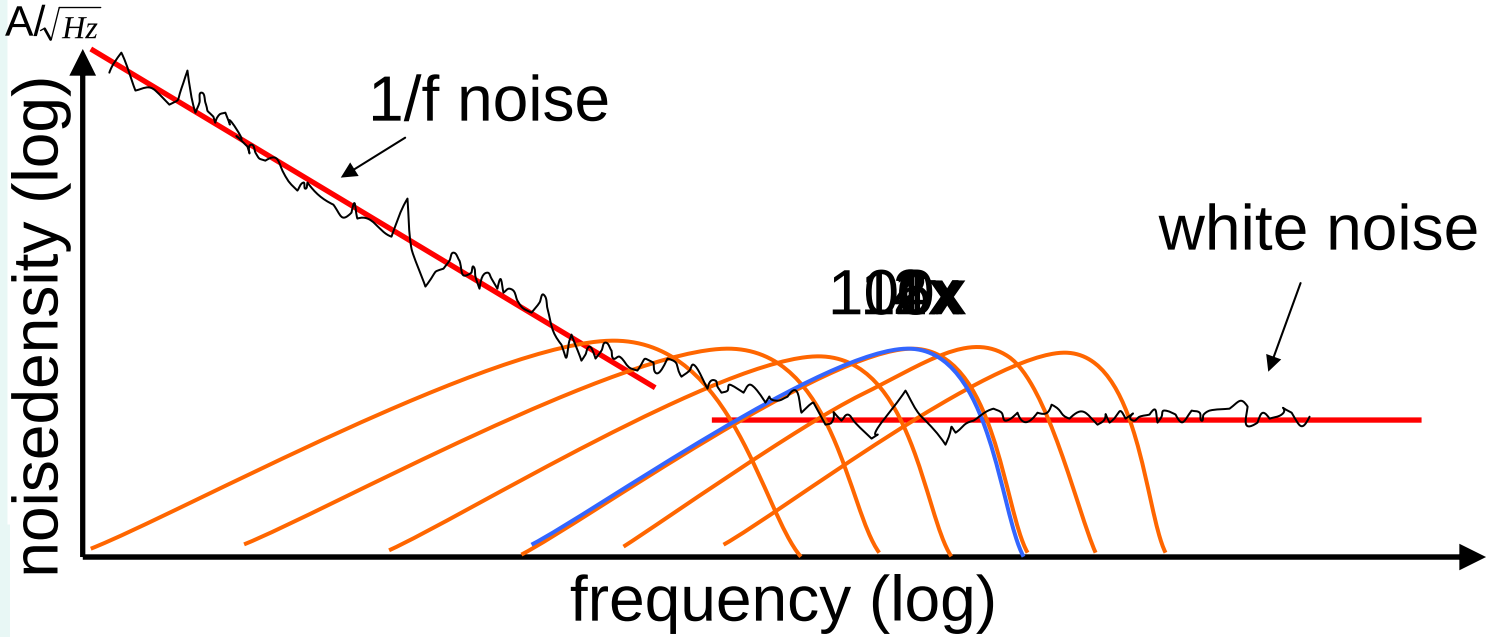
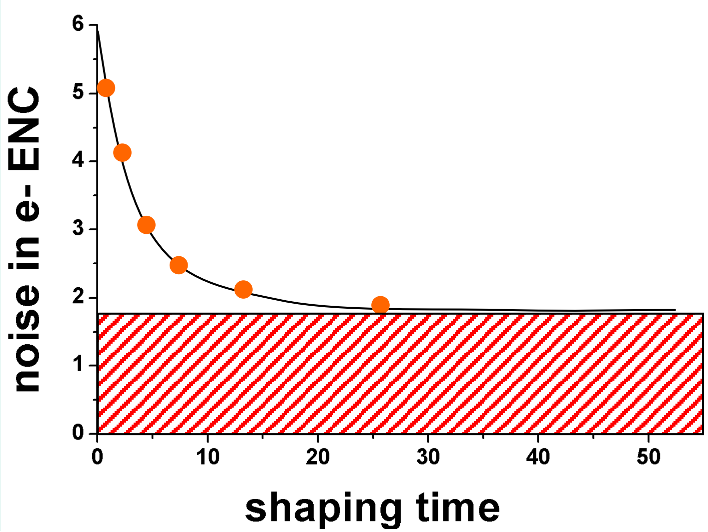
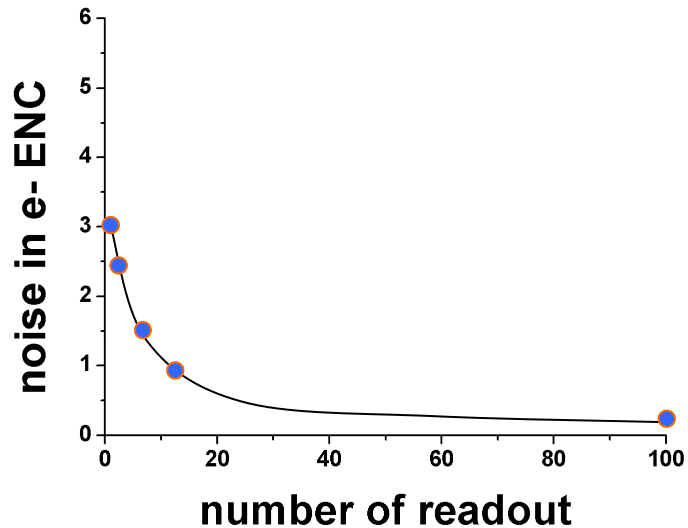
Answer D) It depends on the 1/f noise







The shortest time to achieve a certain noise

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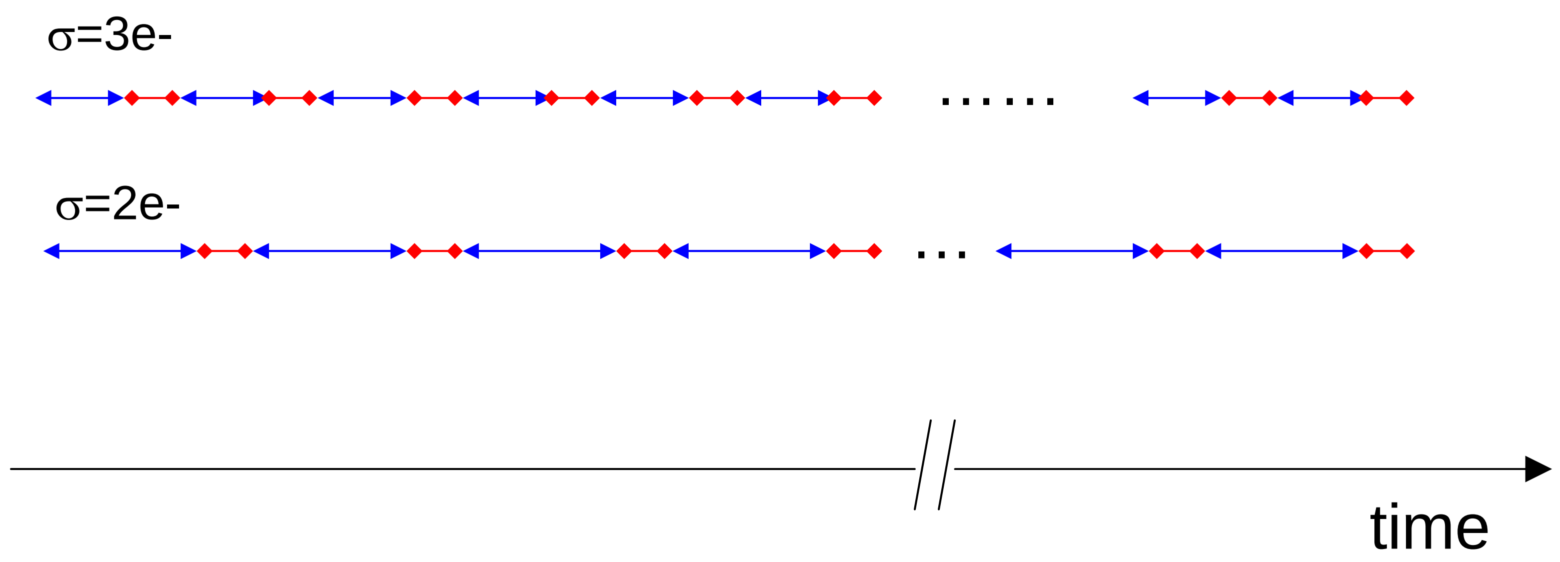

$$\tau_{opt} = \frac{1}{\sigma_{1/f}} \cdot \sqrt{a \cdot C^2 \cdot A_1 \cdot t_{no\_measurement}}$$

detector electronics and detector


F1
50:50
50:50 Joker
STOP
F2
F3
Is that an important result?
A: Yes
B: No
C: No
D: Yes

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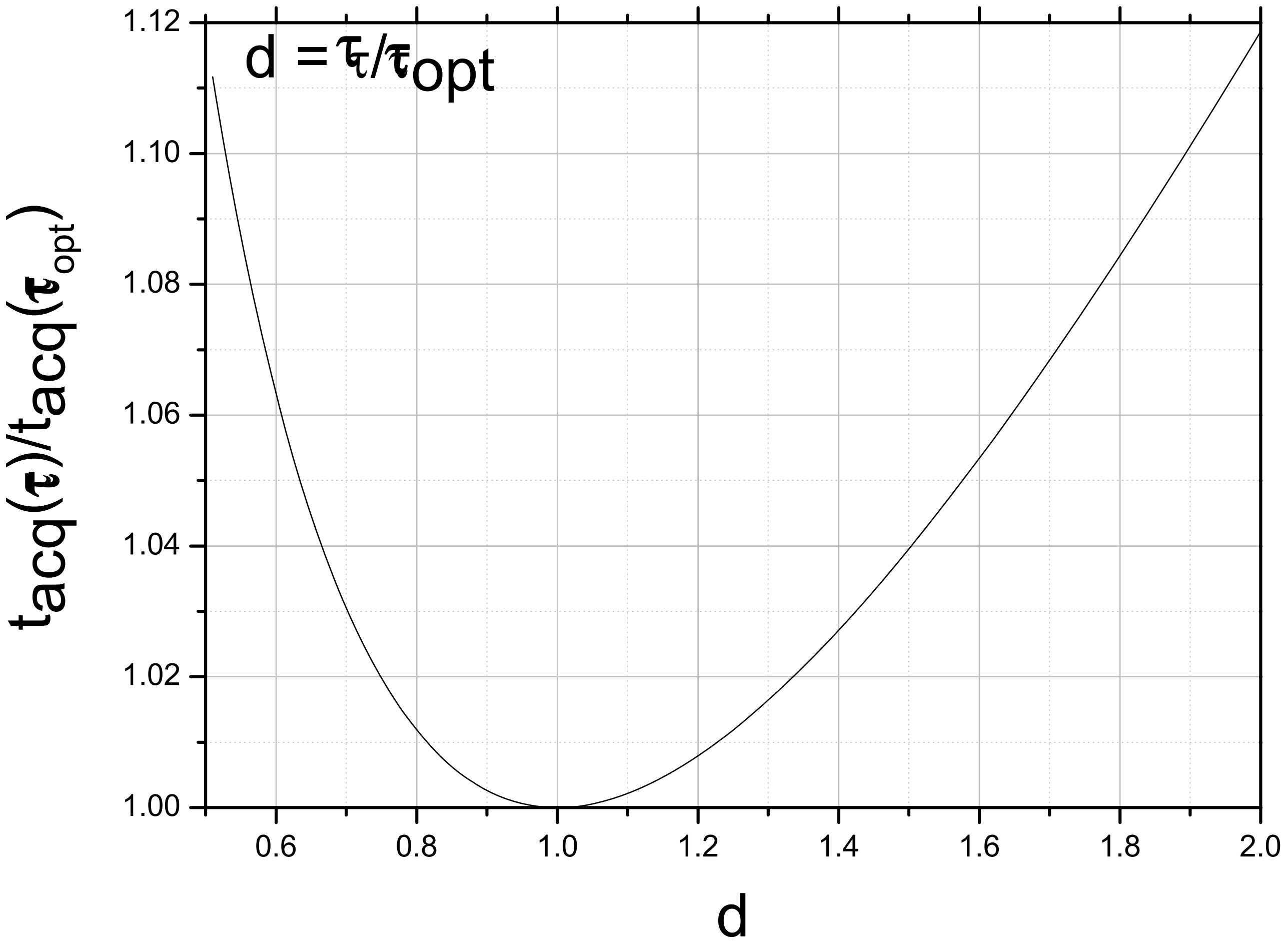
Answer B and D) Impact on the overall readout time



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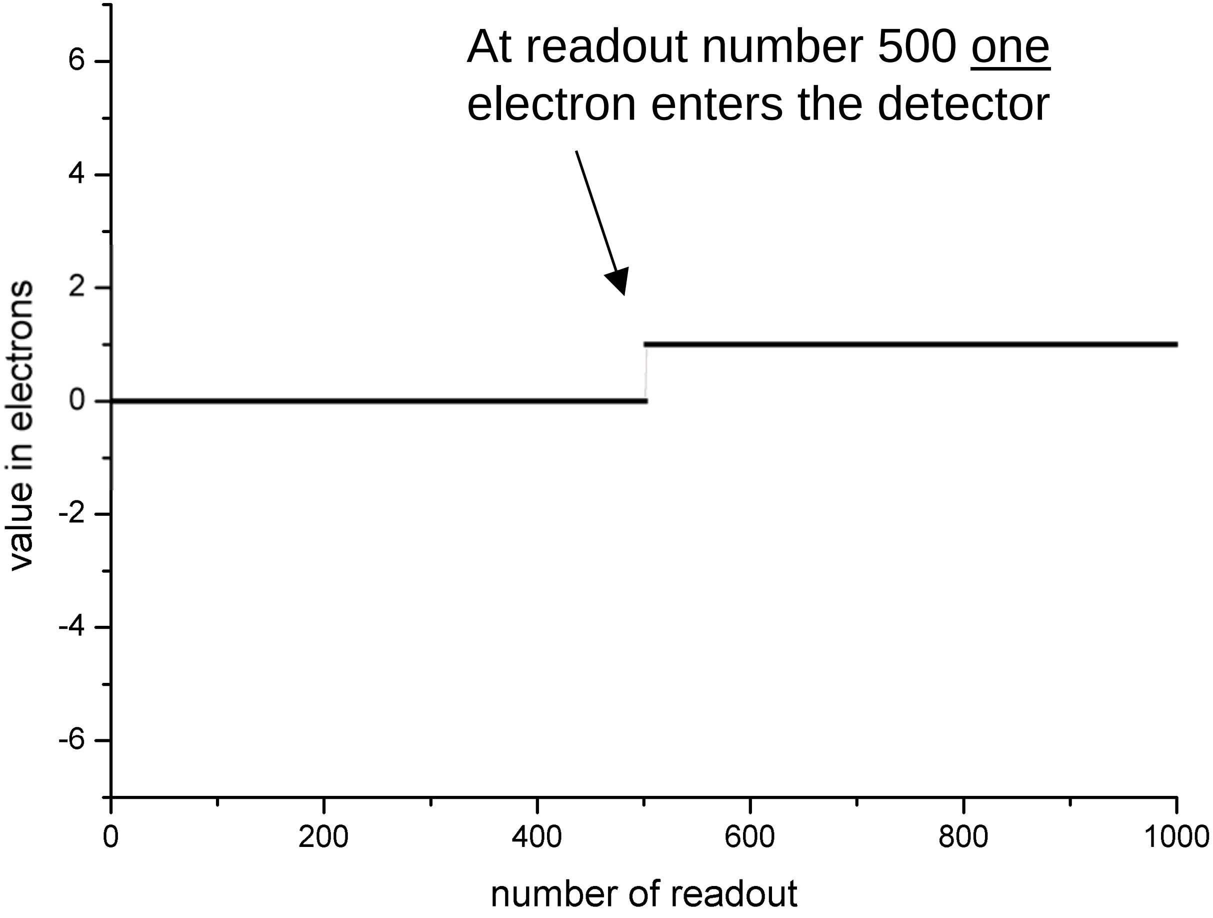
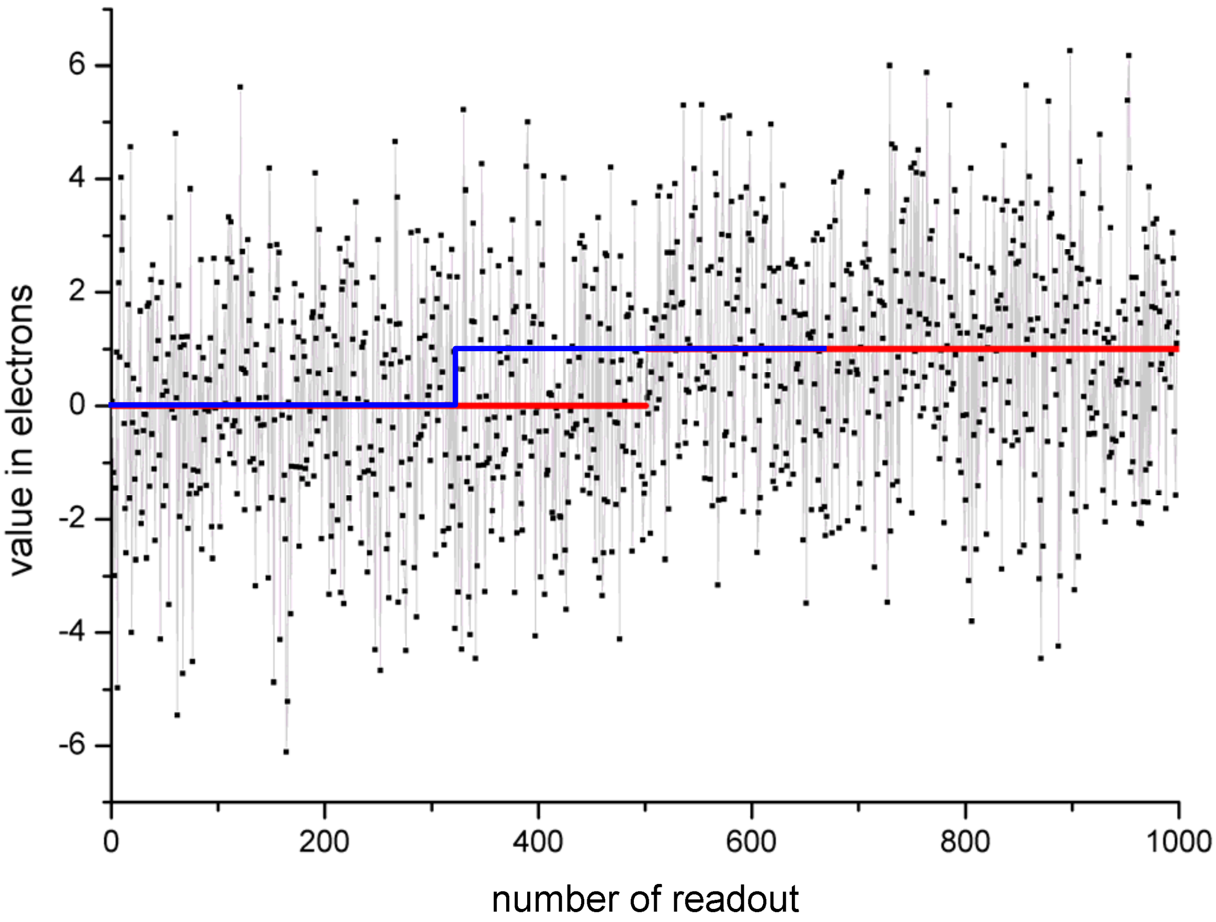
Continuous running readout



Continuous running readout



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Timing resolution of a RNDR device

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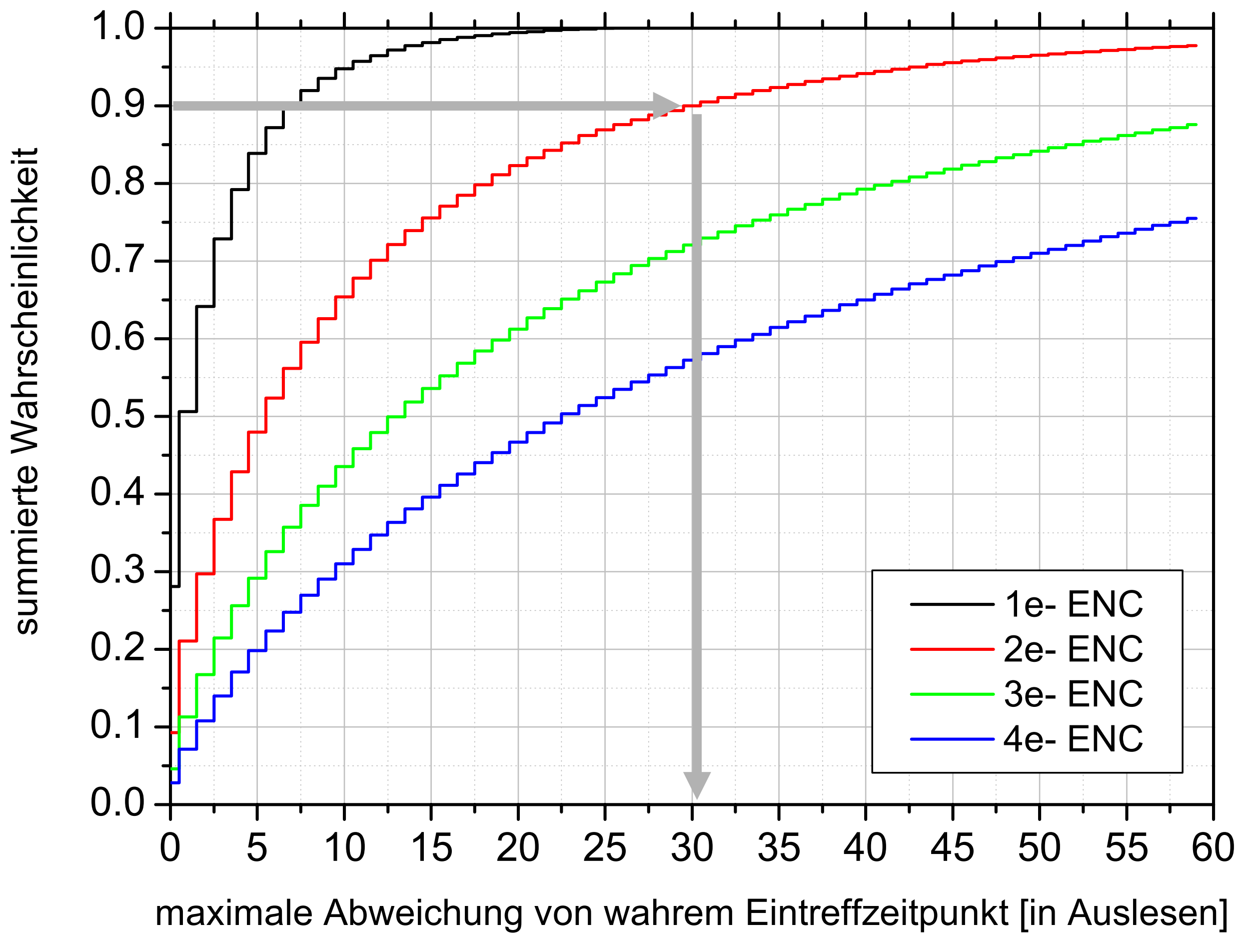

Next devices under production

- RNDR-Matrizes
- CCDs with DEPFET-RNDRs as readout nodes

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Summary and Conclusion

- **RNDR devices** where fabricated by connecting the internal gates of **two DEPFETs** via an additional transfergate
- The number of collected electrons could be measured with a resolution of only **0,18 electrons**
- **Single optical photon** detection was achieved
- **Matrix** operation is possible
- **Readout** anode for **CCDs**
- Only **moderate cooling** (-50 °C) needed
- Possible applications:
  - Ultra low noise x-ray detector
  - Single optical photon detector
  - New detector concept: timing measurement with continuous readout