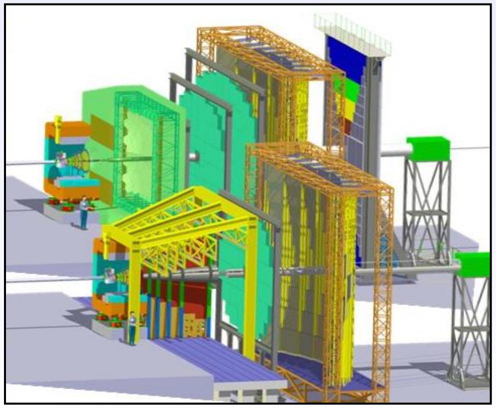
Radiation tolerance of MAPS manufactured in the TowerJazz 0.18µm process

M. Deveaux, Goethe University Frankfurt and CBM
on behalf of the CBM-MVD collaboration.



Outline

0. ~~Introduction~~ Not needed today
1. Tolerance to ionizing radiation
2. Tolerance to non-ionizing radiation
3. What else to keep in mind…
4. Summary and conclusion

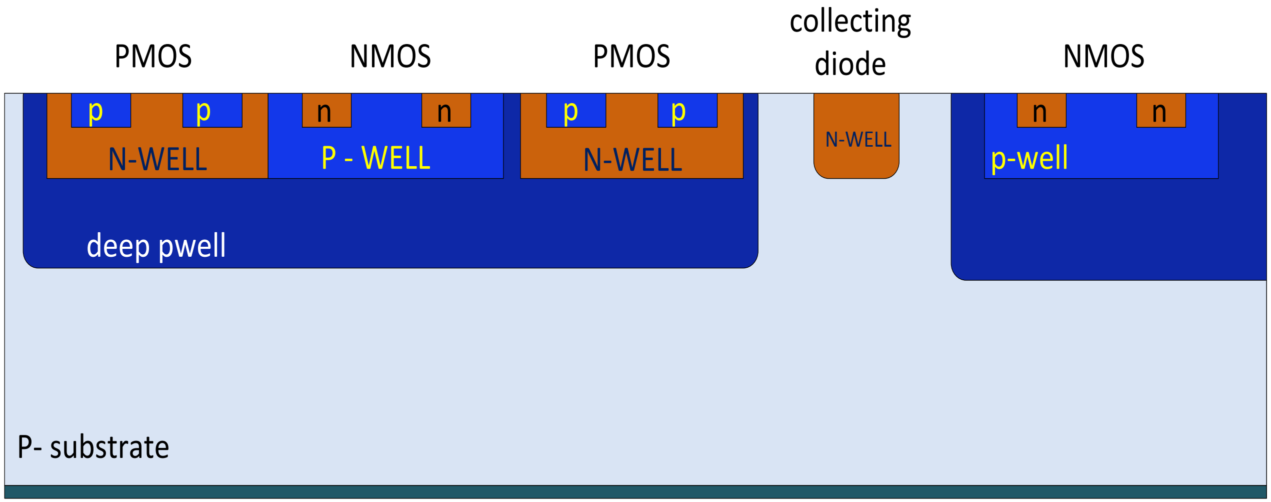
Sensors in 0.18µm reported about:

- MIMOSA-32 (IPHC)
- MIMOSA-34 (IPHC)
- TID_TJ180 (CERN)
- Explorer-0/1 (CERN)

Designed for the ALICE-ITS upgrade and the CBM-MVD

Design goal: ~$10^{13} n_{eq}/cm^2$, few Mrad

TOWER (0.18µm)

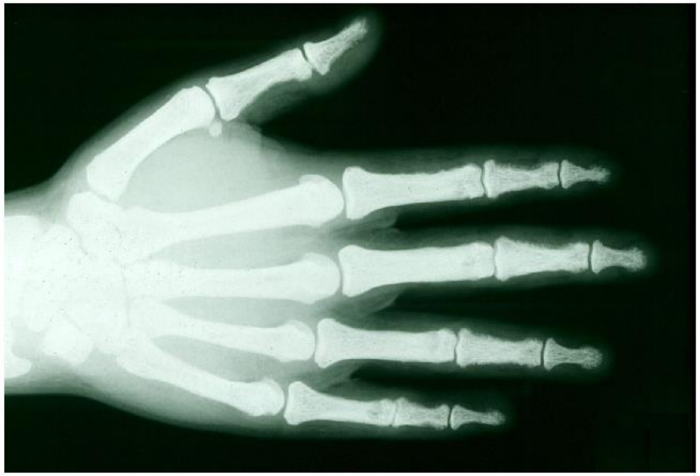


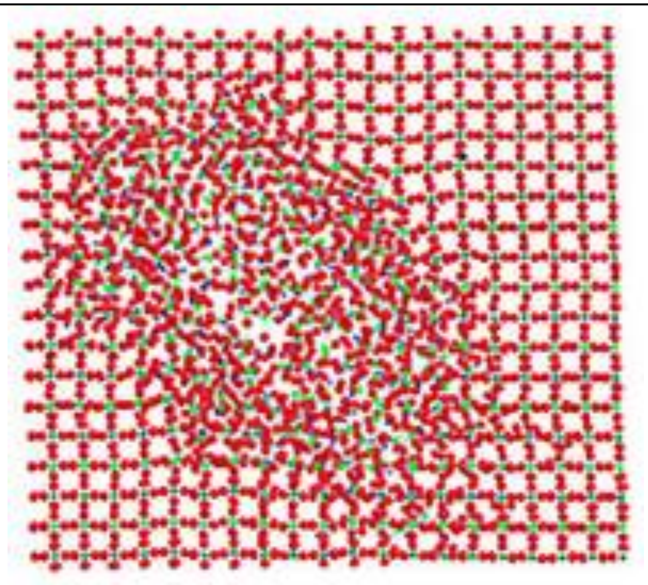
- Tower 0.18µm
- Quad-well technology
- Available with various epi layers 1-8 kΩ cm, 18-40µm thickness
- R&D carried out for ALICE-ITS upgrade and the CBM-MVD

Types of radiation damage?

Ionising radiation:

- Energy deposited into the electron cloud
- May ionise atoms and destroy molecules
- Caused by charged particles and photons



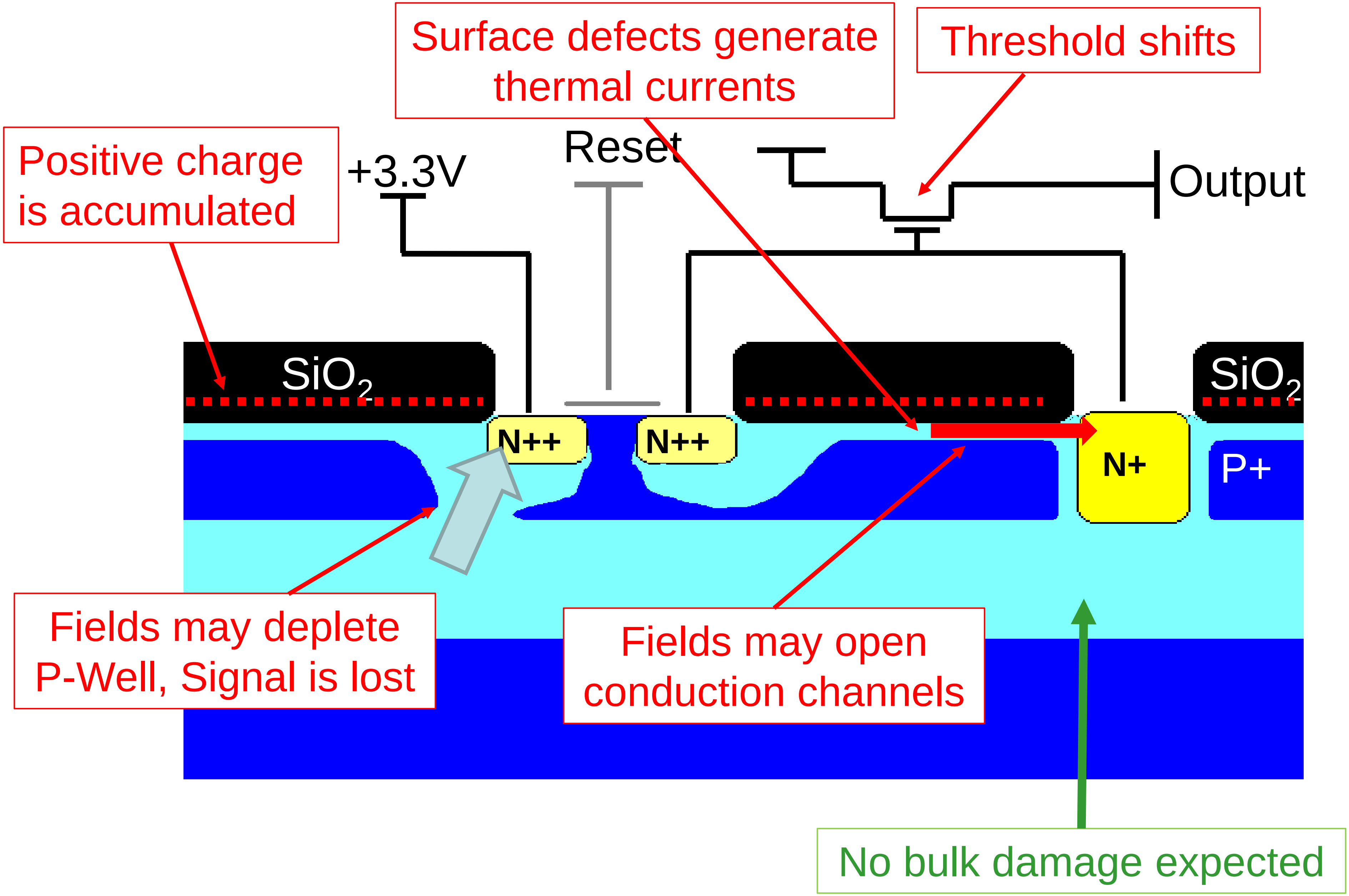


Non-ionising radiation:

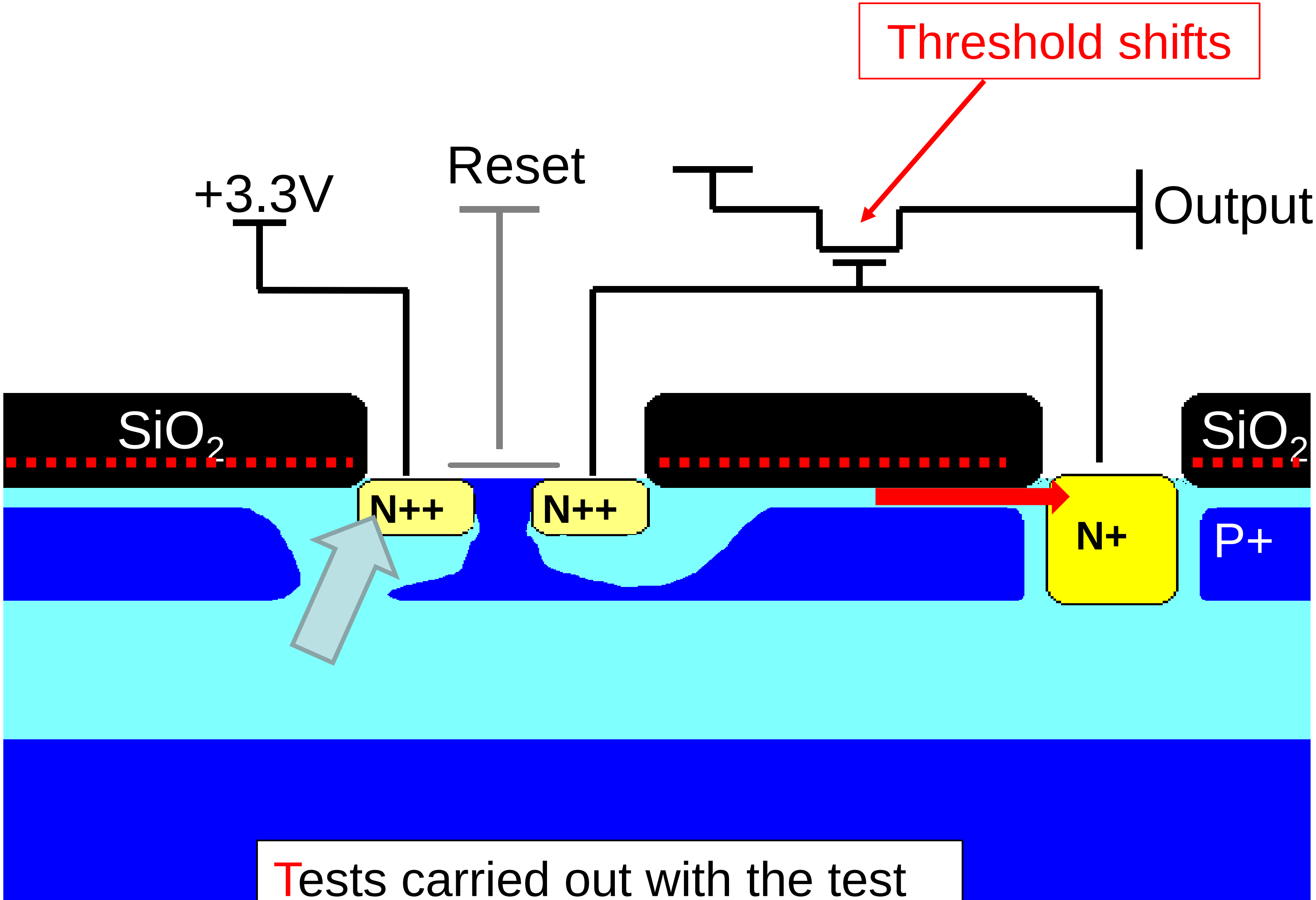
- Energy deposited into the crystal lattice
- Atoms get displaced
- Caused by heavy (fast leptons, hadrons) charged and neutral particles

Farnan I, HM Cho, WJ Weber, 2007. "Quantification of Actinide α-Radiation Damage in Minerals and Ceramics." *Nature* 445(7124):190-193.

Known ionizing radiation damage effects

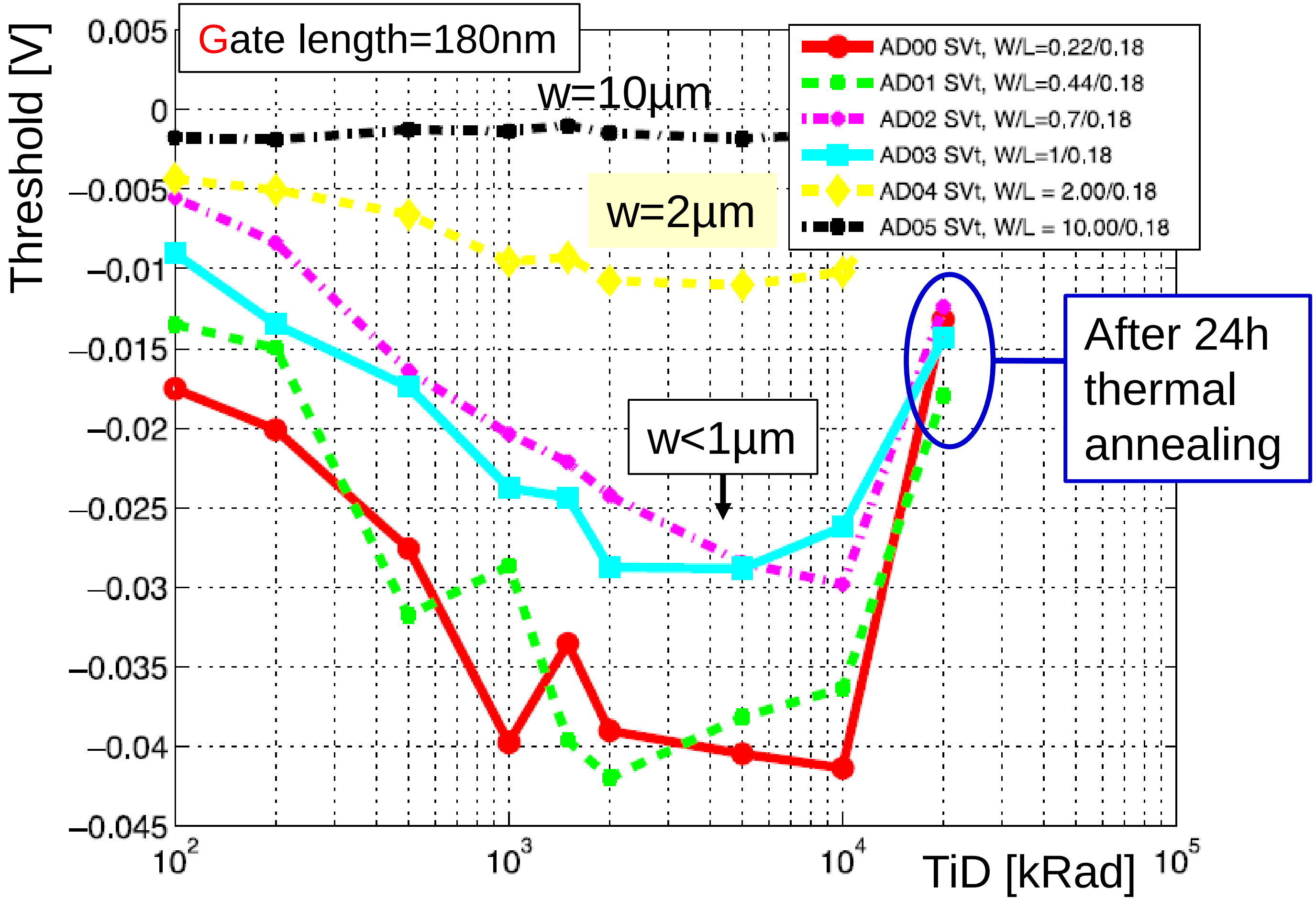


Known ionizing radiation damage effects



Tests carried out with the test structure TID_TJ180 (CERN)

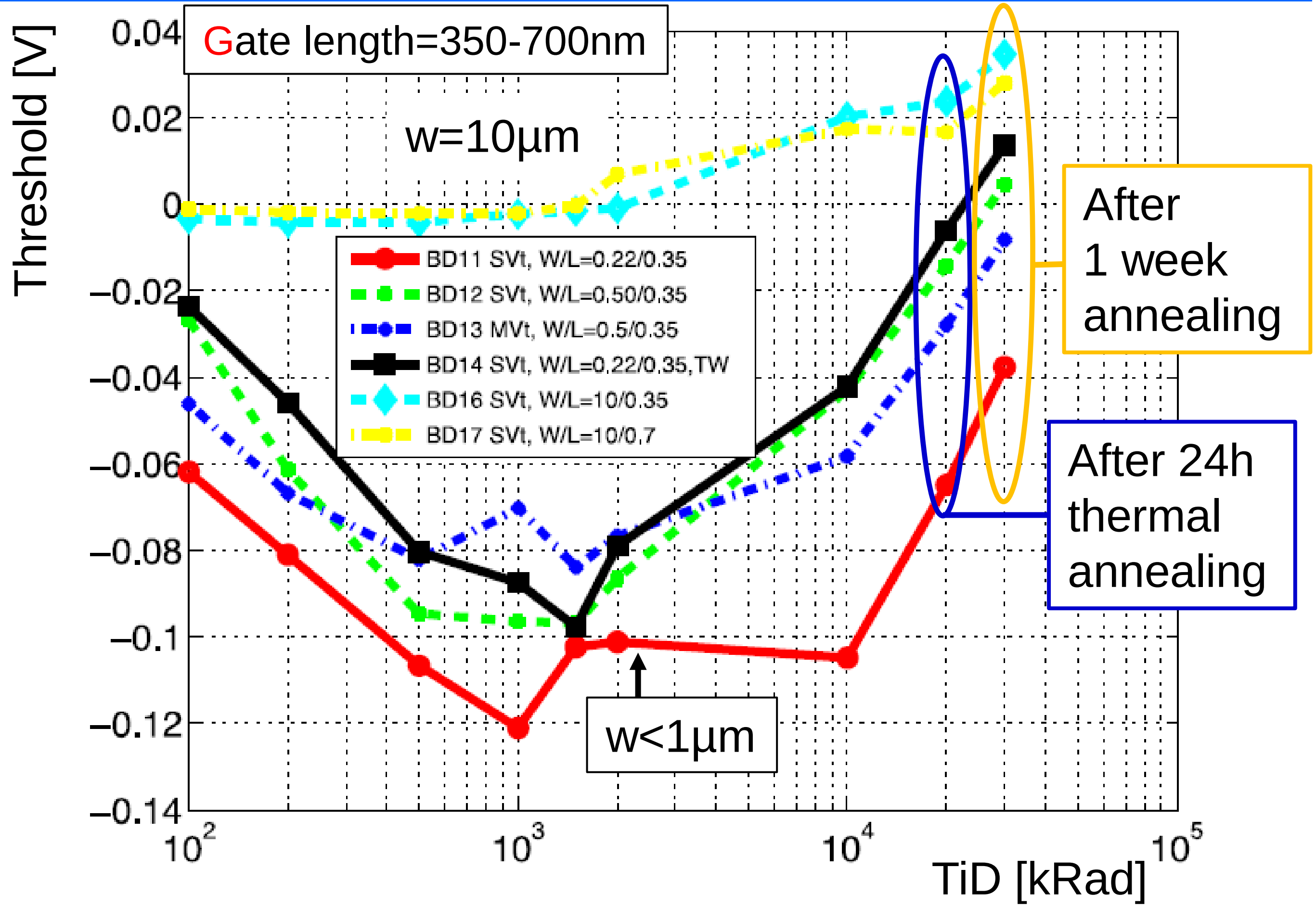
Threshold Shifts (1.8V NMOS)



H. Hillemanns et al., proceedings of the NSS/MIC, 2013 IEEE

Threshold shifts
- remain small if w>2µm
- are recovered by thermal annealing

Threshold Shifts (3.3V NMOS)

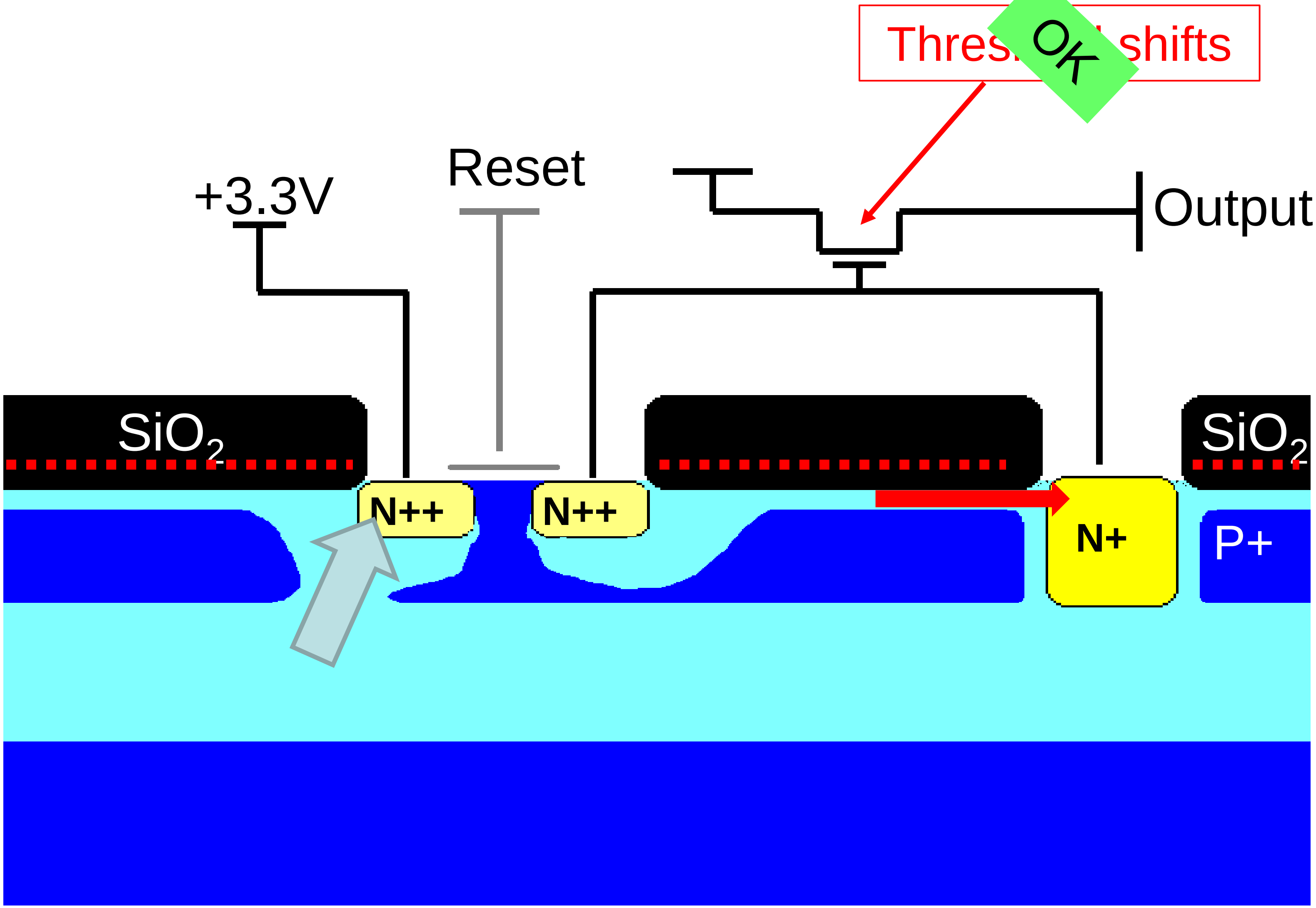


H. Hillemanns et al., proceedings of the NSS/MIC, 2013 IEEE

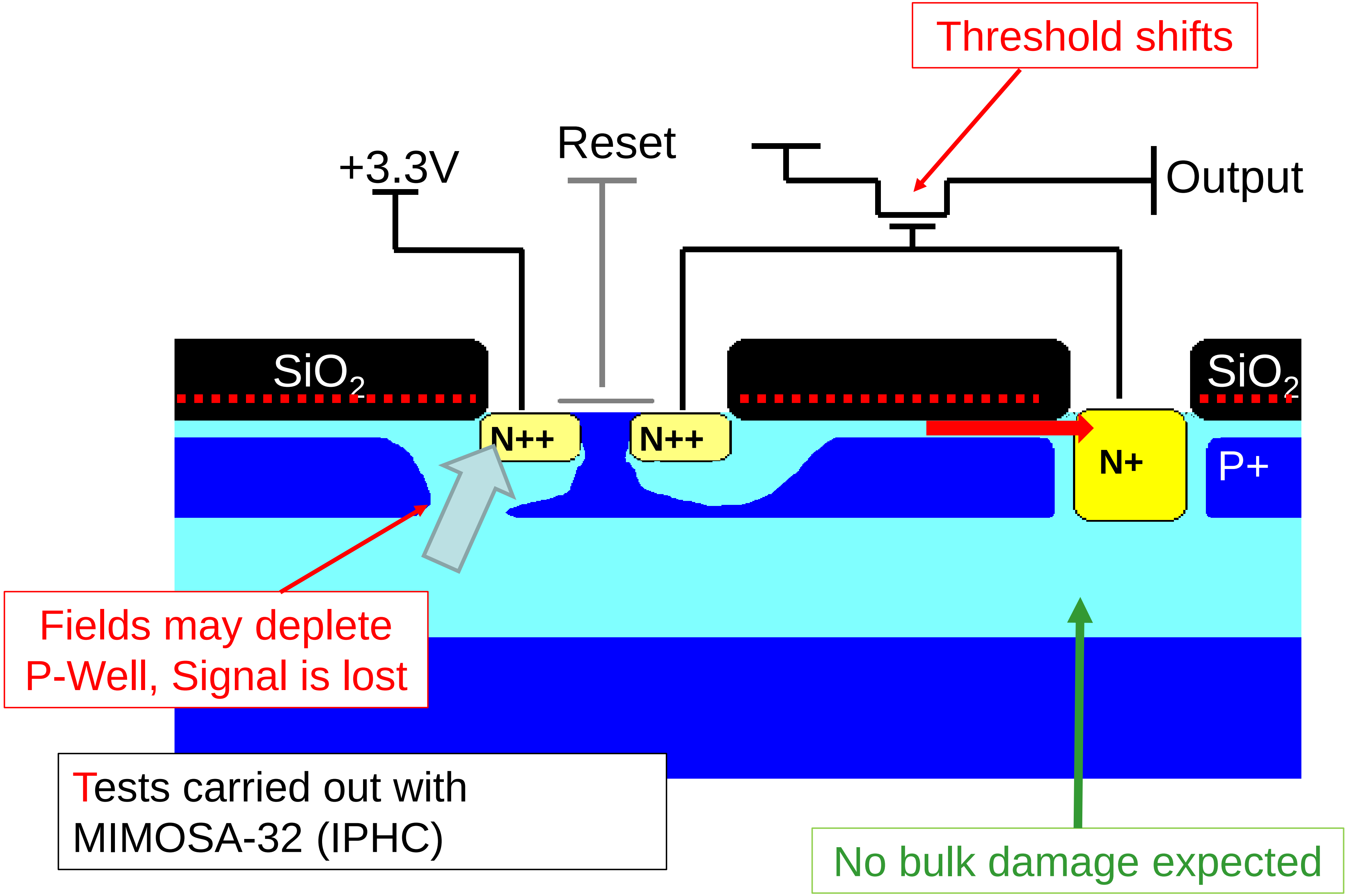
Threshold shifts

- remain small if w=10µm
- are recovered by thermal annealing
- „negative states“ observed at > 1 Mrad

Known ionizing radiation damage effects

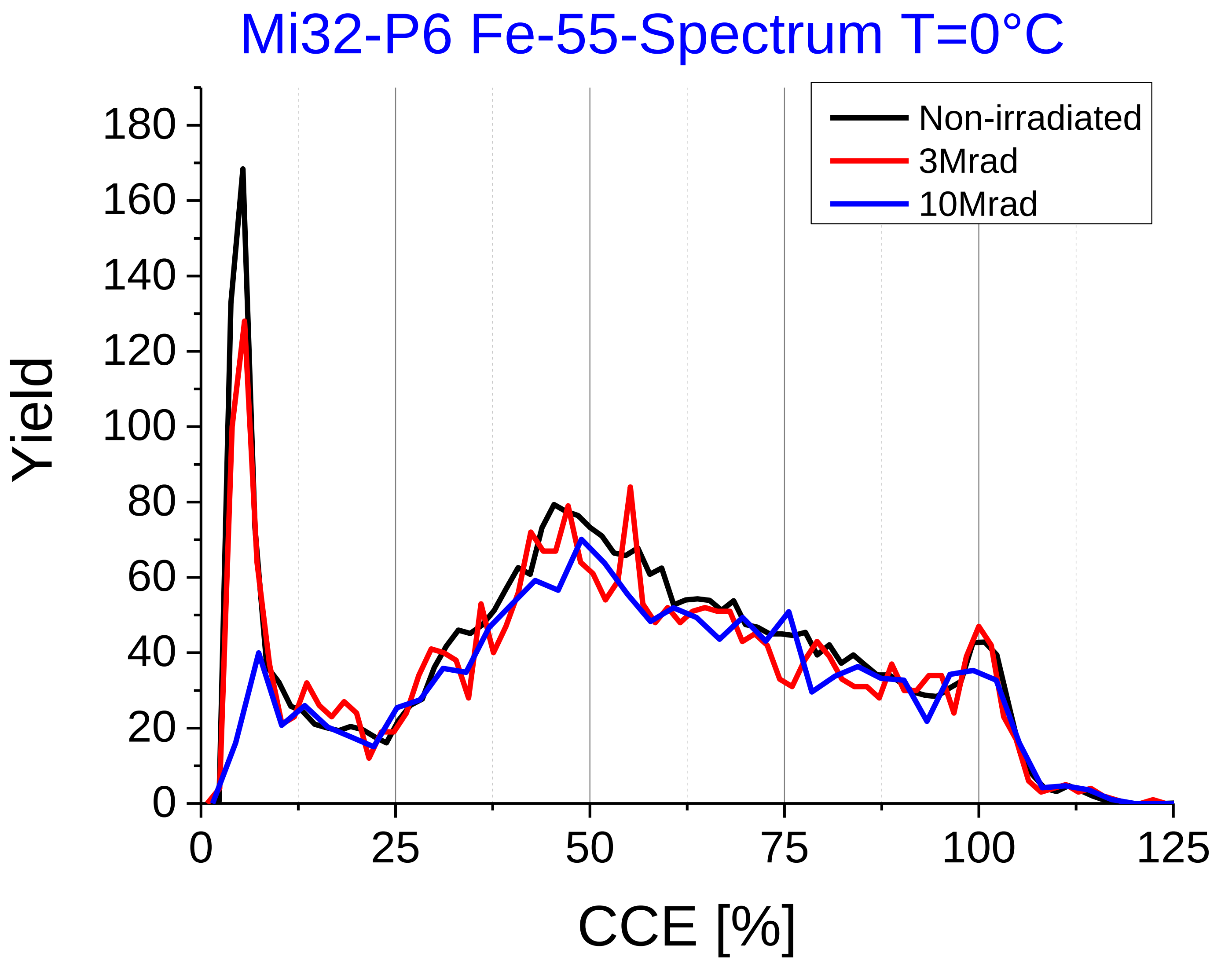


Known ionizing radiation damage effects



Tests carried out with MIMOSA-32 (IPHC)

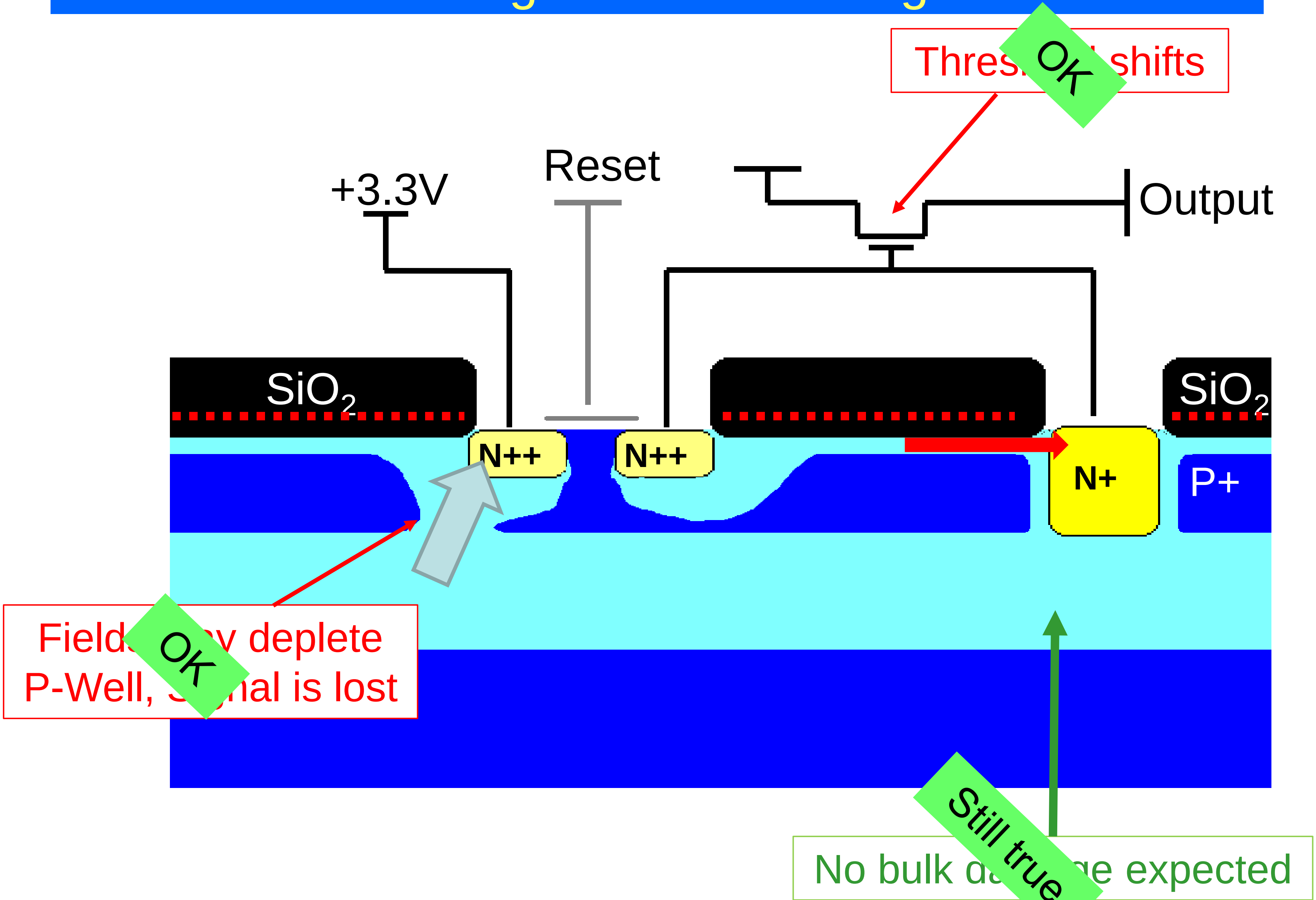
Separation of electronics and sensitive volume



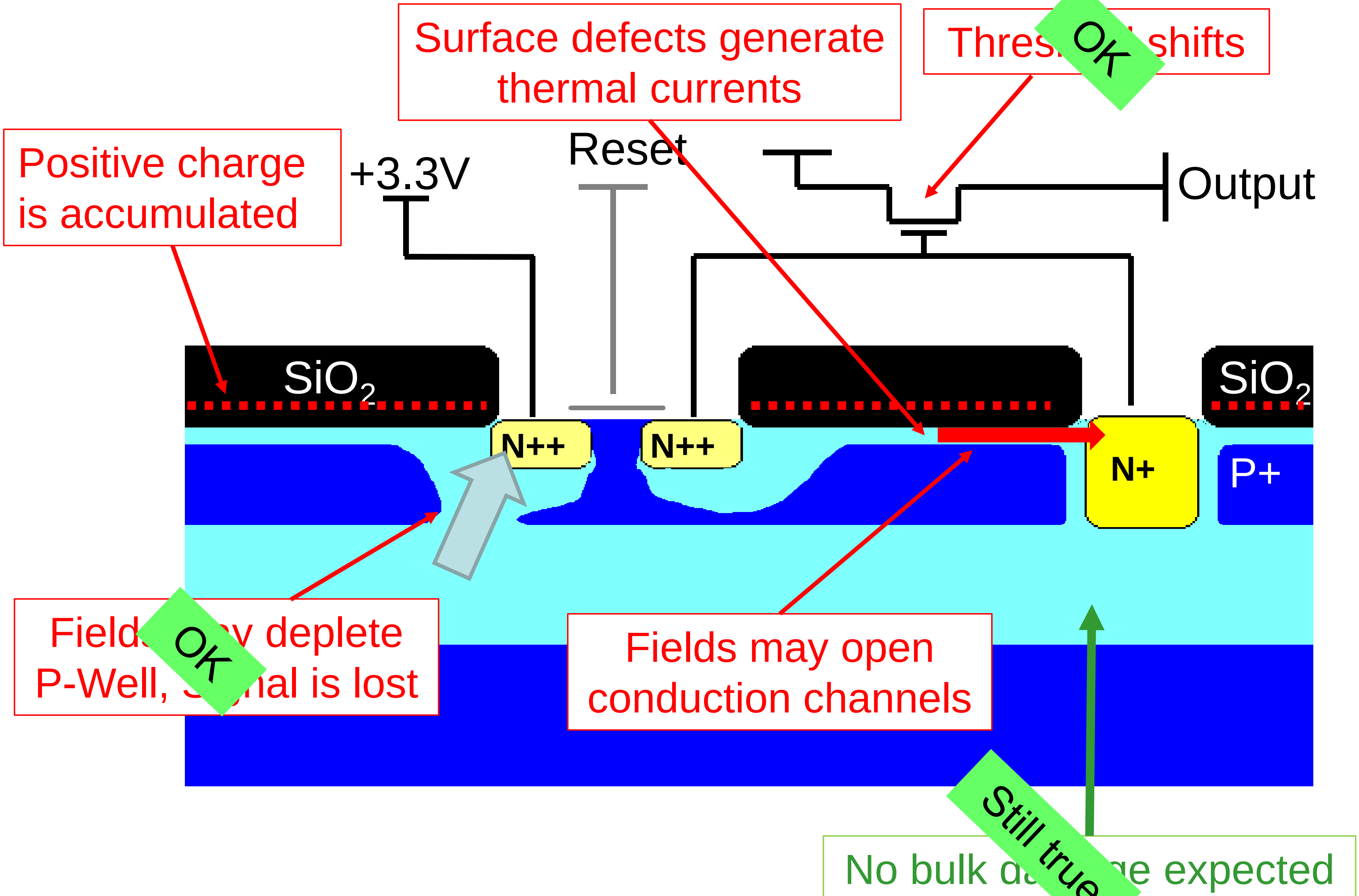
D. Doering, CBM/IKF Frankfurt

No evidence for signal loss

Known ionizing radiation damage effects

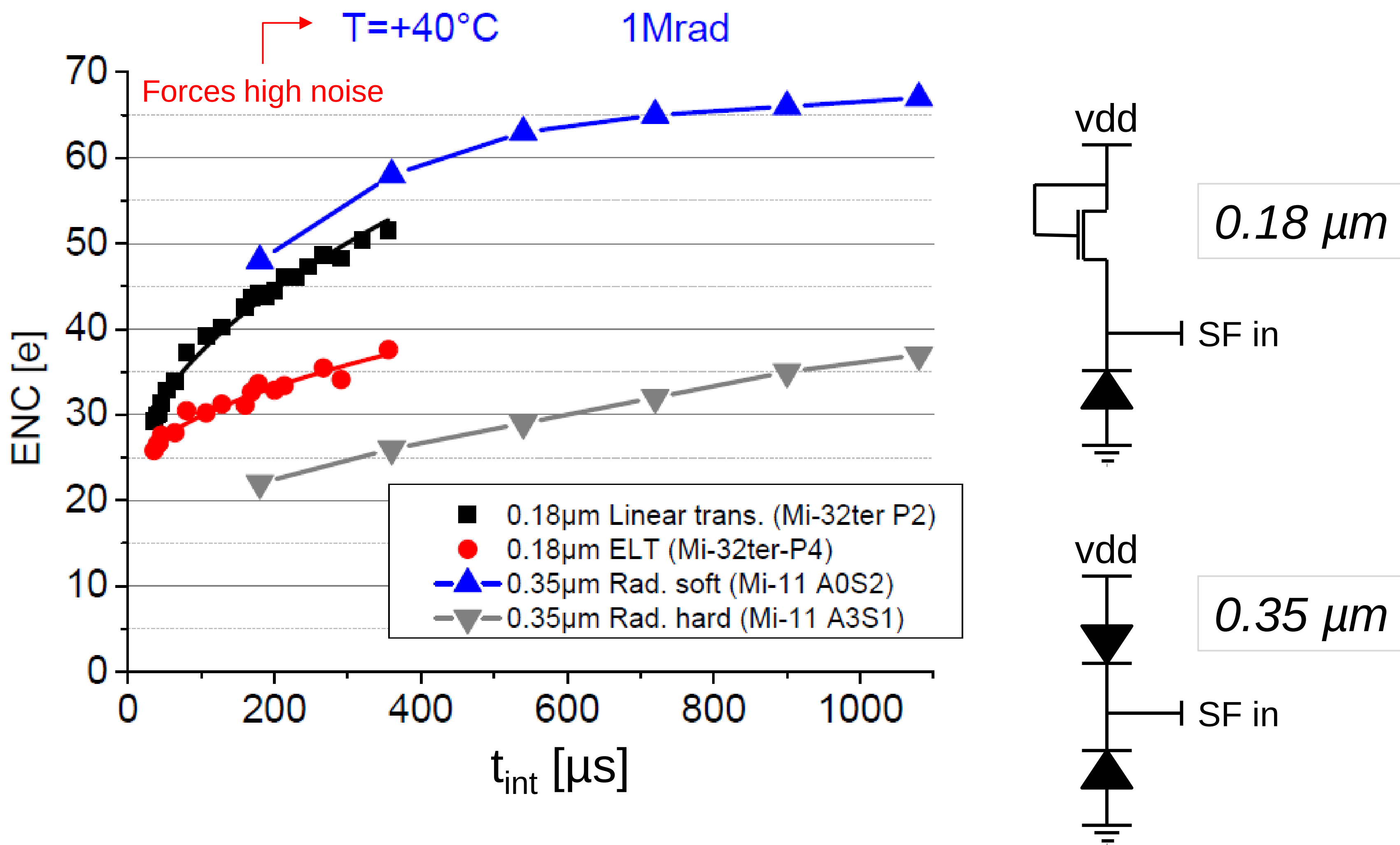


Known ionizing radiation damage effects



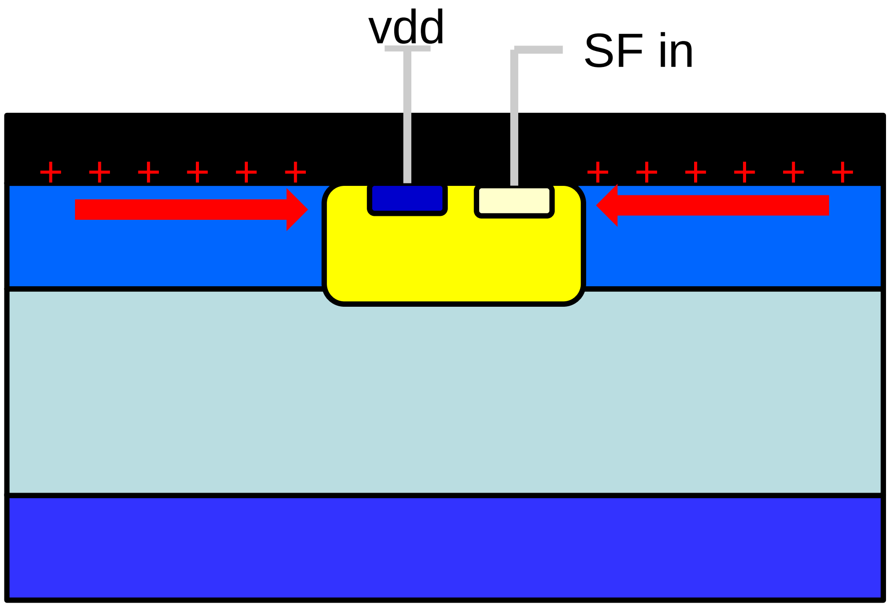
Noise of different sensors

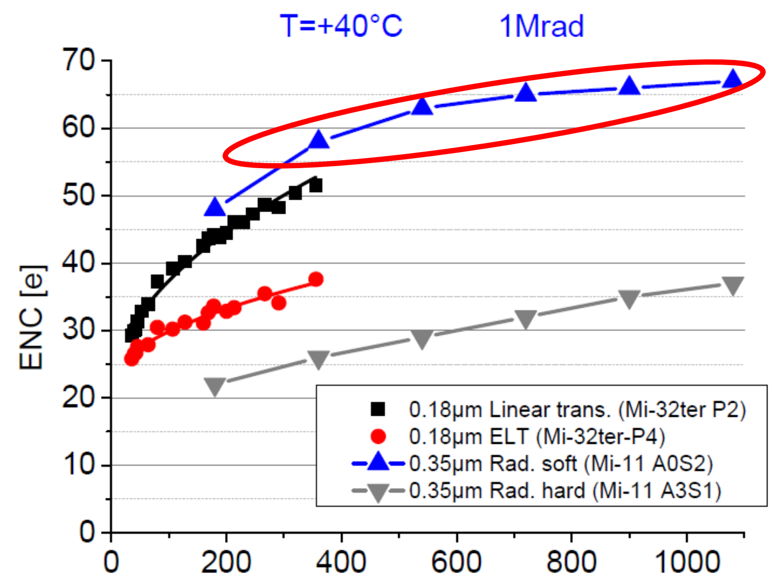
D. Doering, B. Linnik, CBM / IKF Frankfurt



Reducing shot noise (diode, 0.35µm)

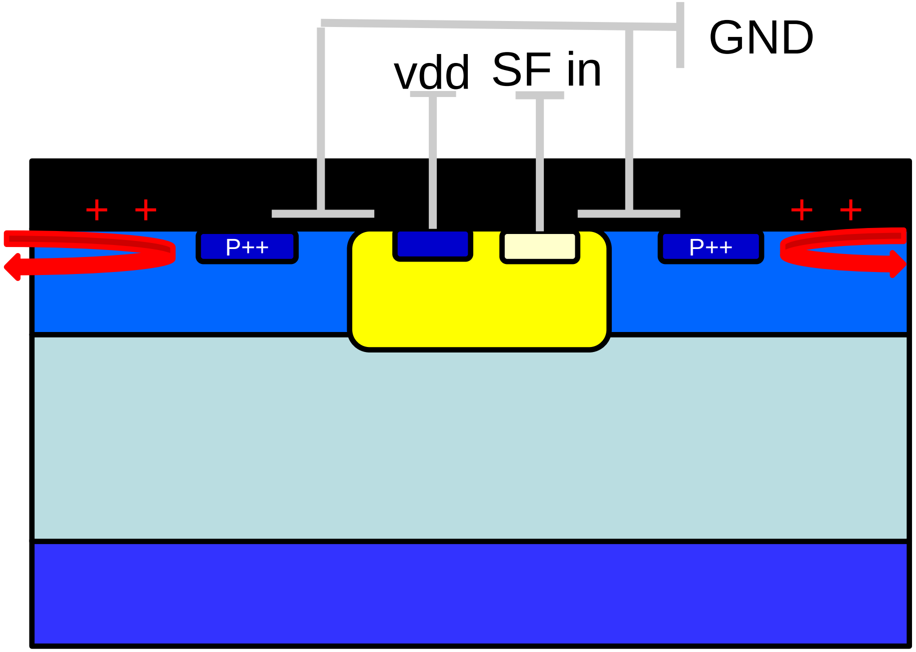
D. Doering, B. Linnik, CBM / IKF Frankfurt

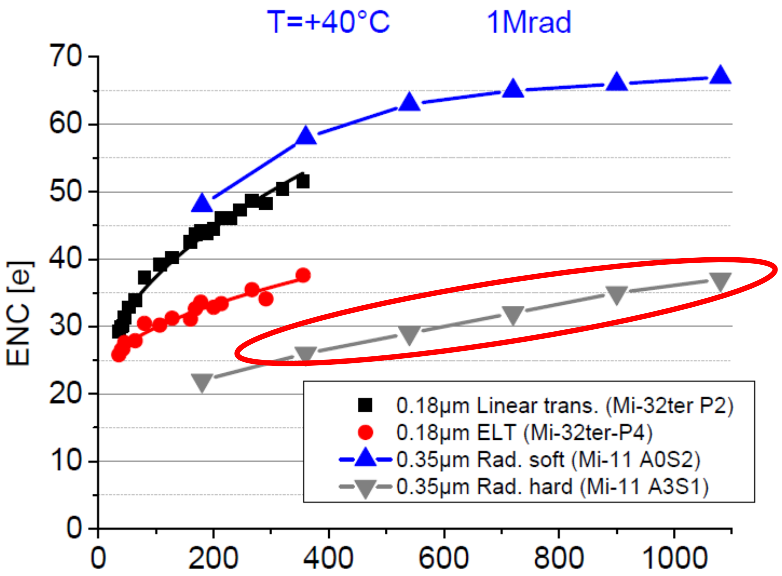




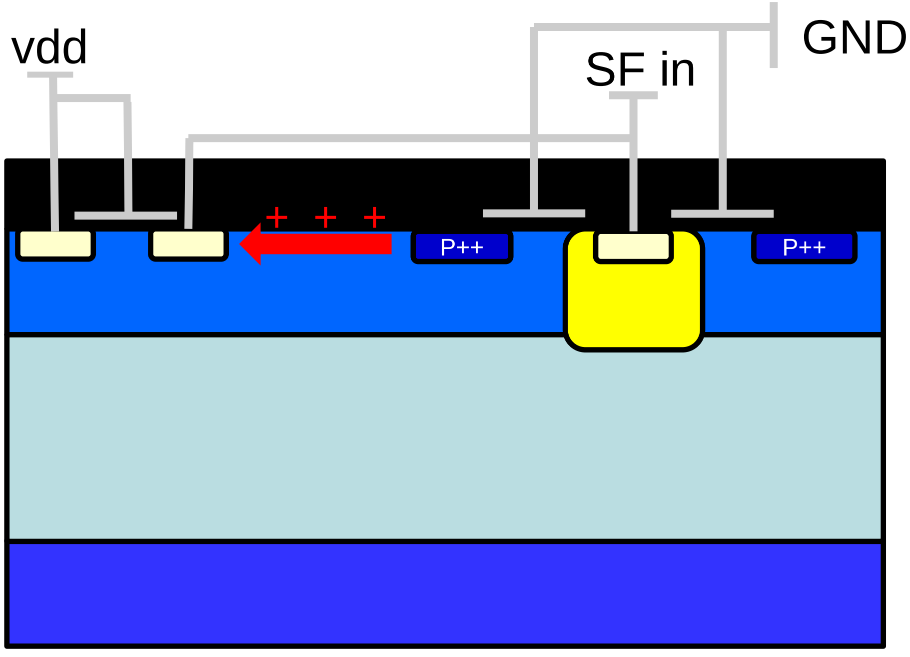
Reducing shot noise (diode, 0.35µm)

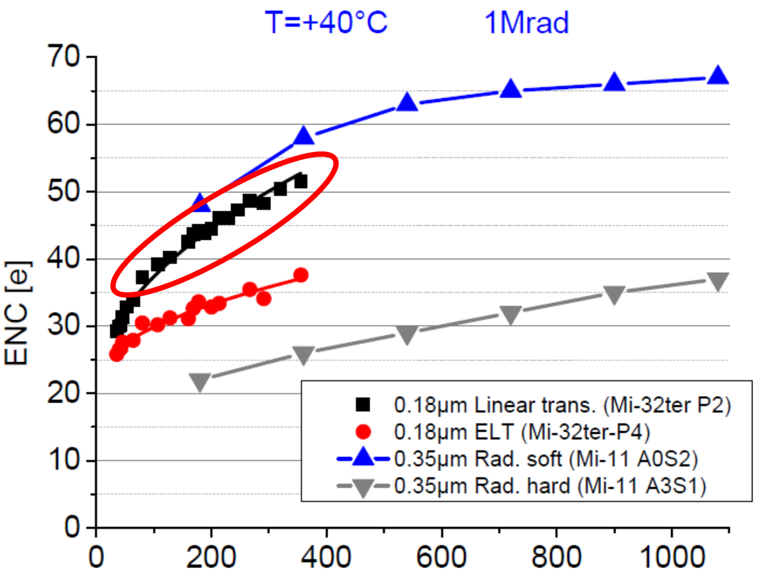
D. Doering, B. Linnik, CBM / IKF Frankfurt





Reducing shot noise





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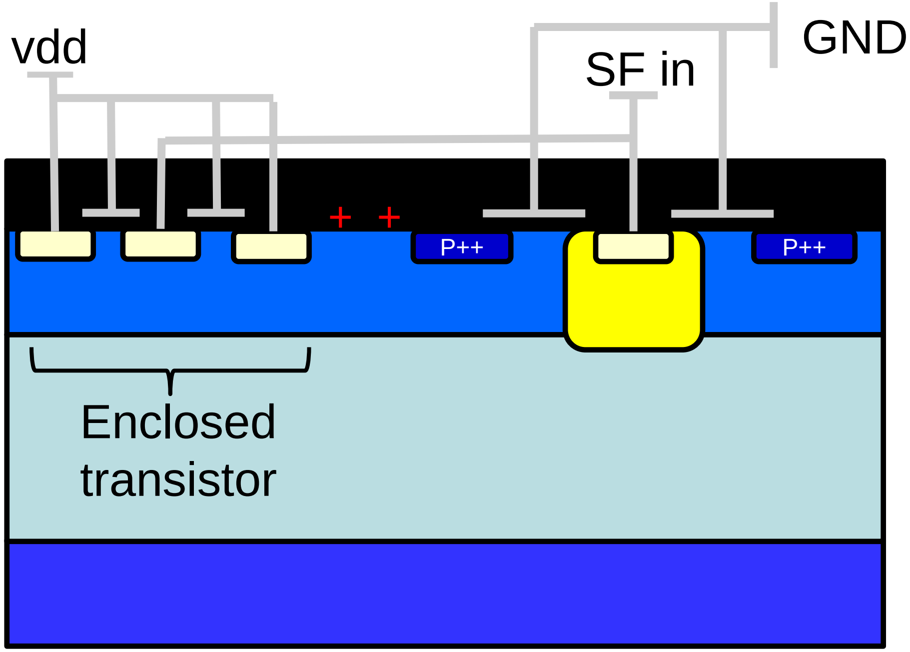
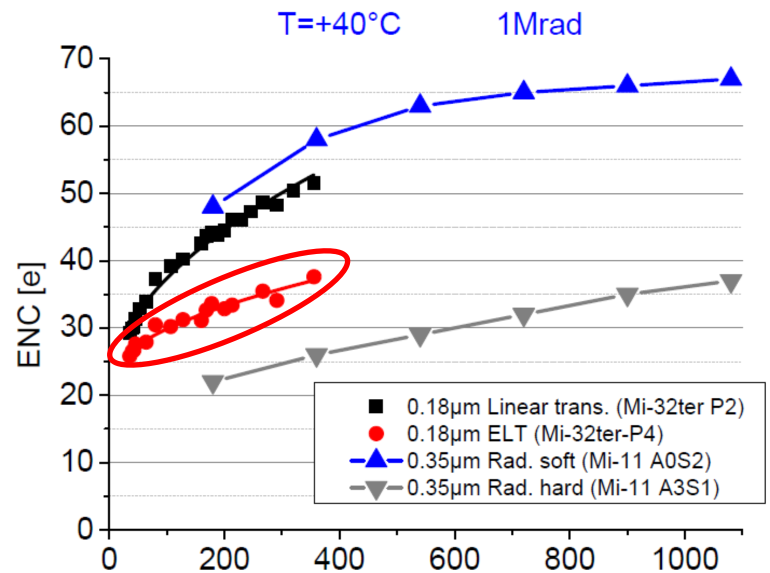
Reducing shot noise

D. Doering, B. Linnik, CBM / IKF Frankfurt



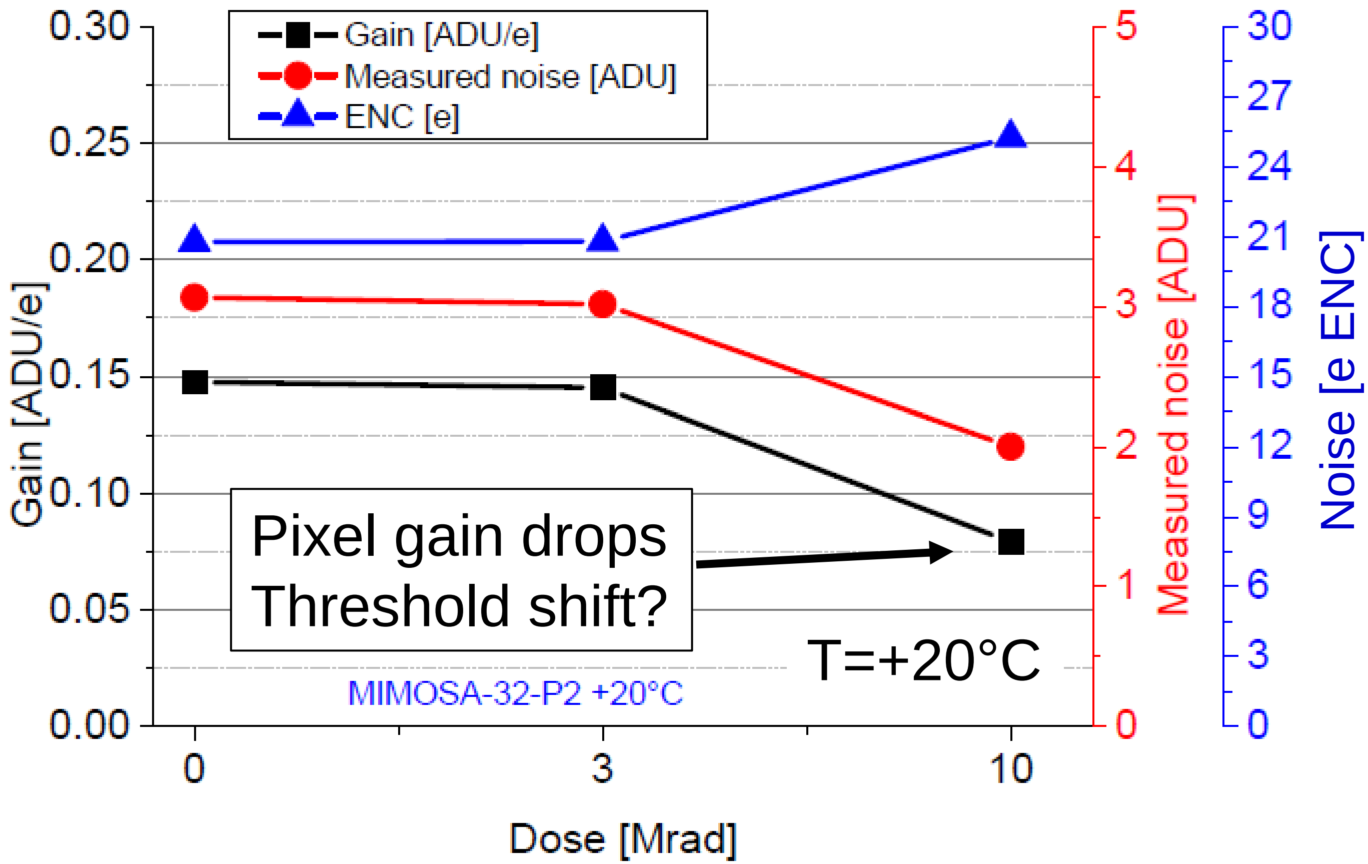


(Besides RTS) Noise increase is dominated by shot noise

- Intrinsic radiation tolerance of 0.18µm does not help much
- Short integration time helps
- Cooling helps
- ELT transistors and guard rings help

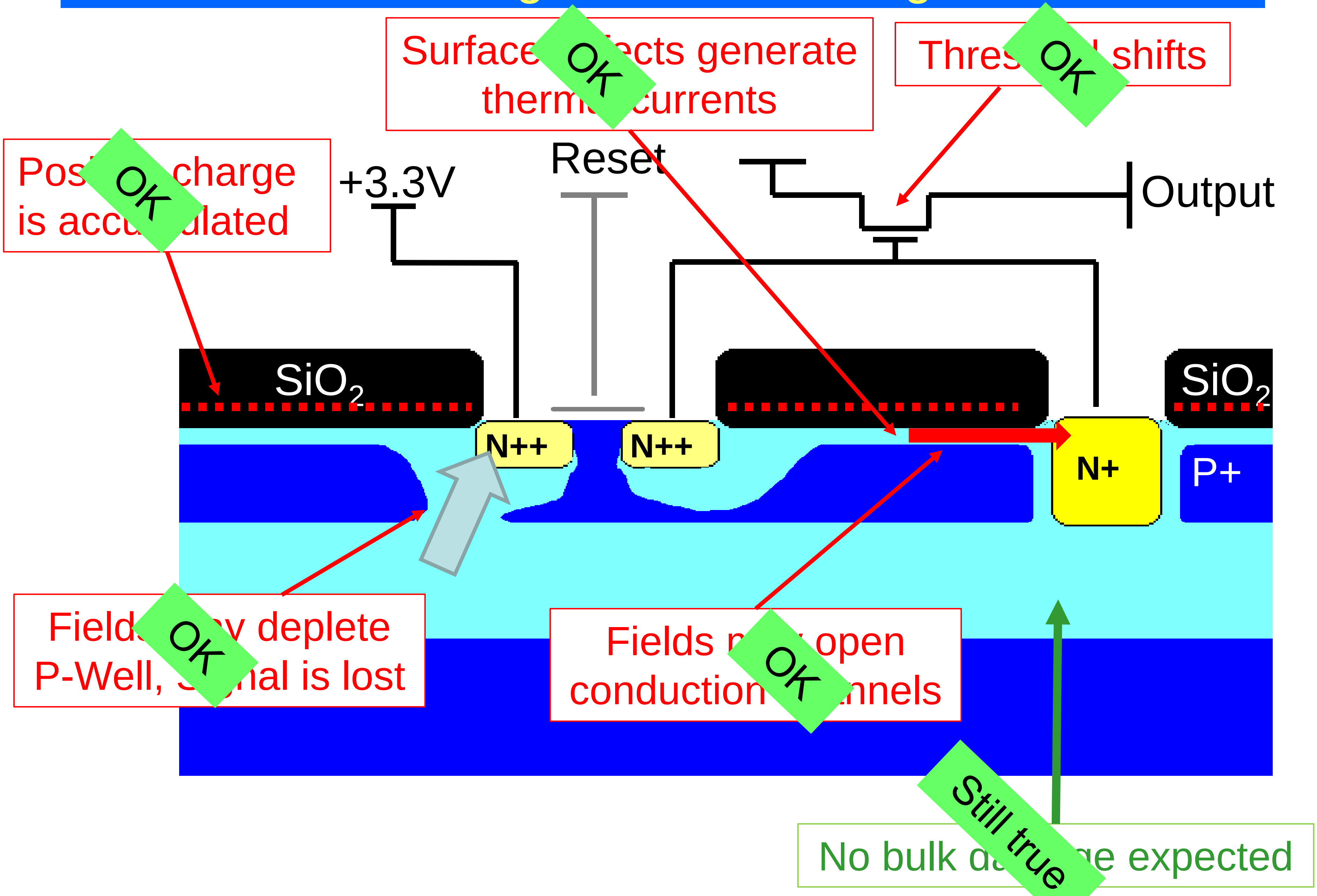
Going to 10 MRad

D. Doering, CBM / IKF Frankfurt



For fast integration time (32µs) and +20°C
Few effects at 3 Mrad, gain drops at 10 Mrad.
S/N acceptable after 10 Mrad

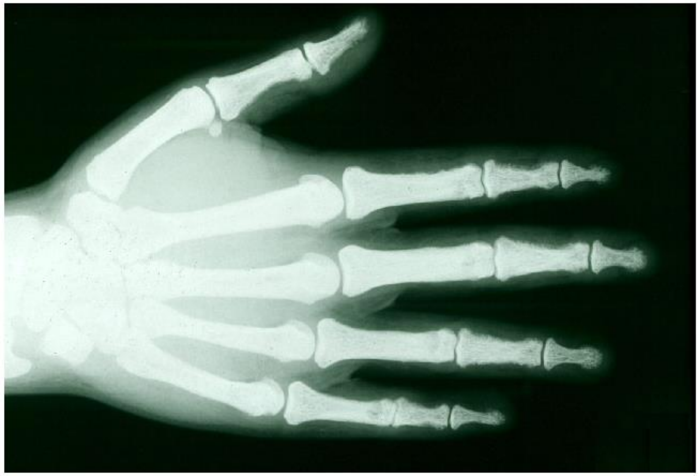
Known ionizing radiation damage effects

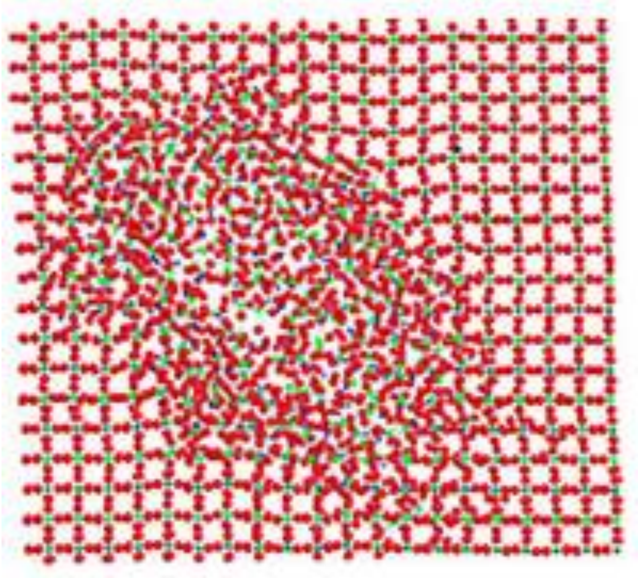


What about radiation hardness?

Ionising radiation:

- Energy deposited into the electron cloud
- May ionise atoms and destroy molecules
- Caused by charged particles and photons





Non-ionising radiation:

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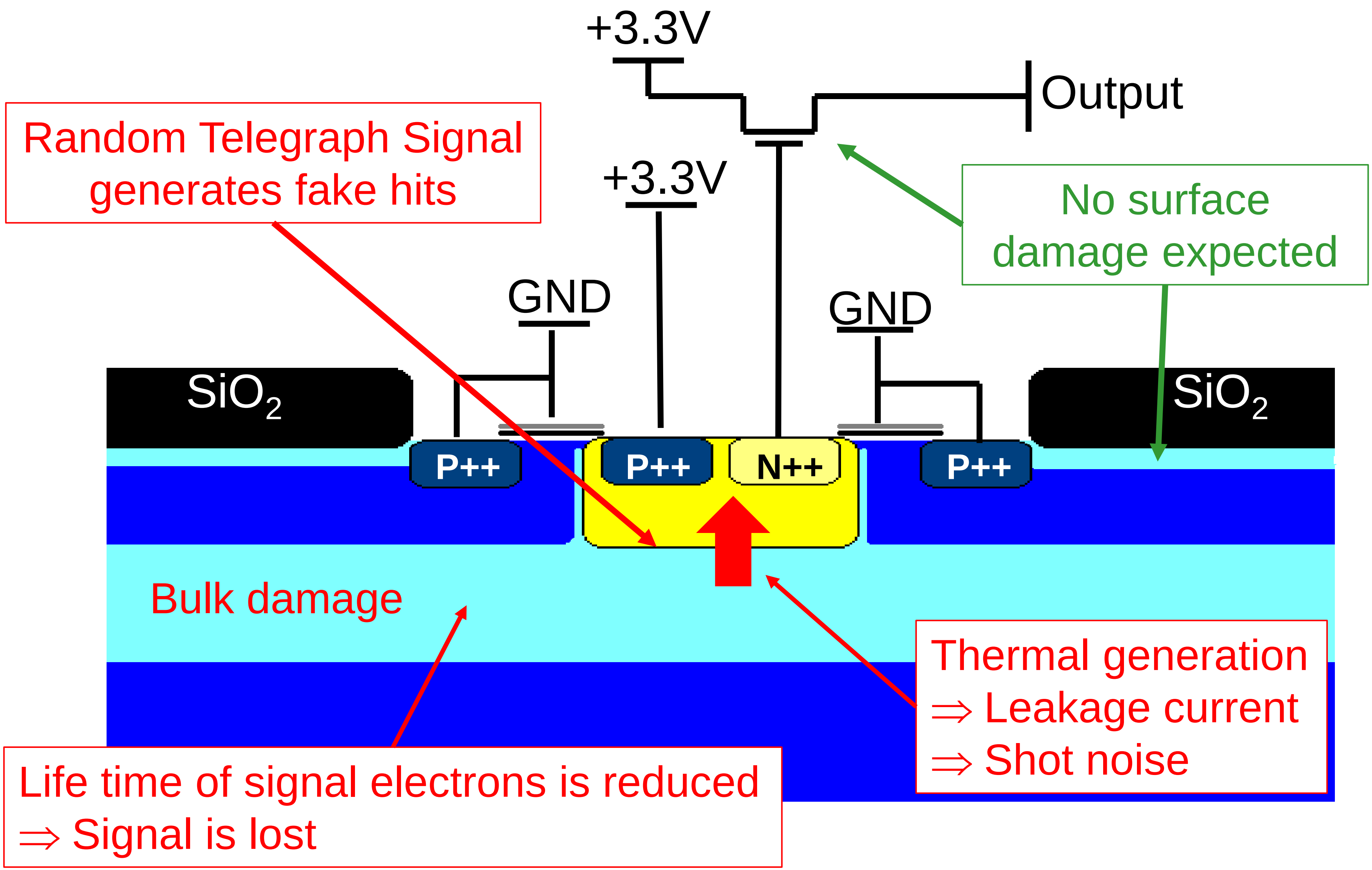
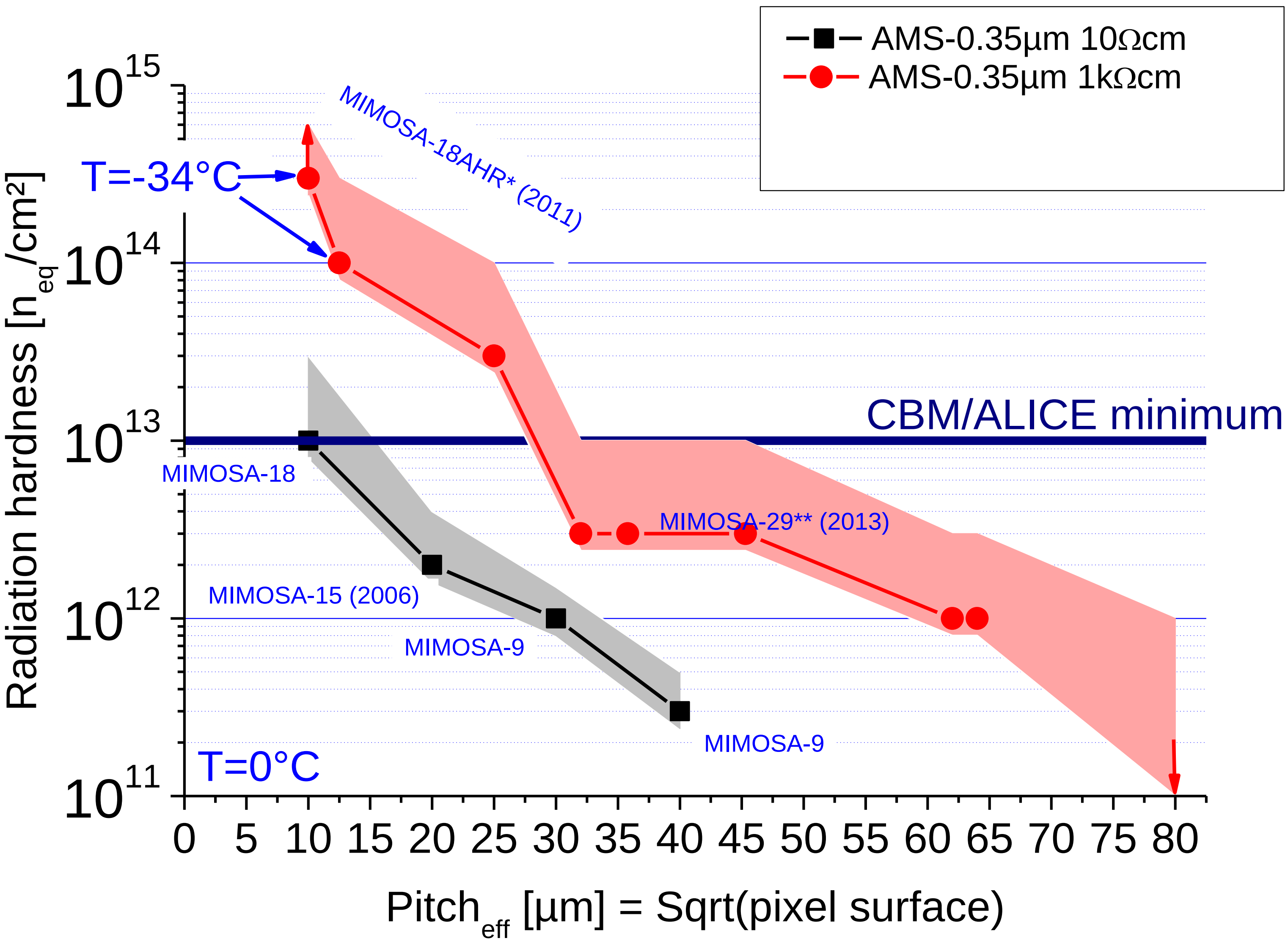
Farnan I, HM Cho, WJ Weber, 2007. "Quantification of Actinide α-Radiation Damage in Minerals and Ceramics." *Nature* 445(7124):190-193.

Known effects of non-ionizing radiation



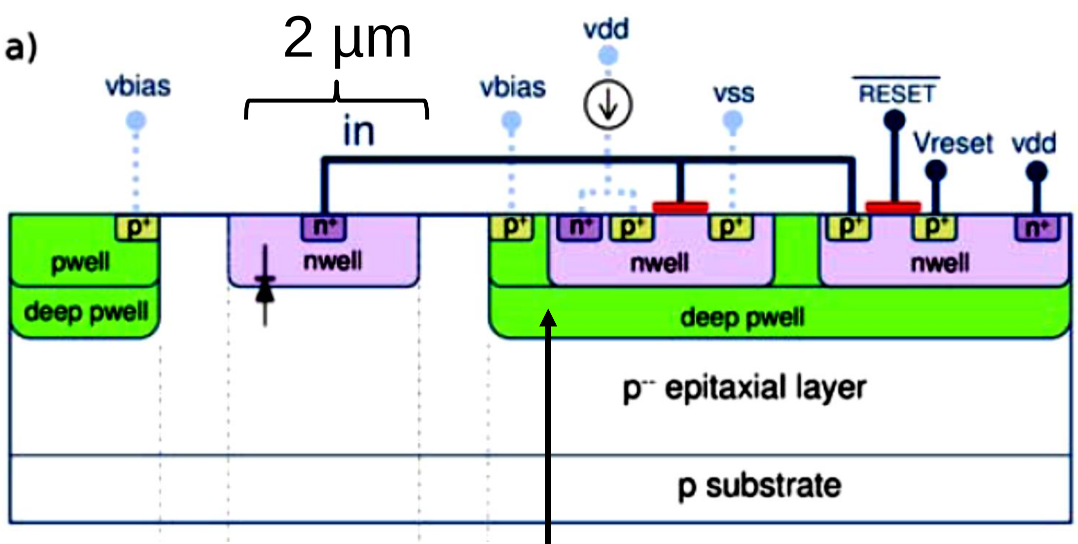
Established knowledge on radiation tolerance

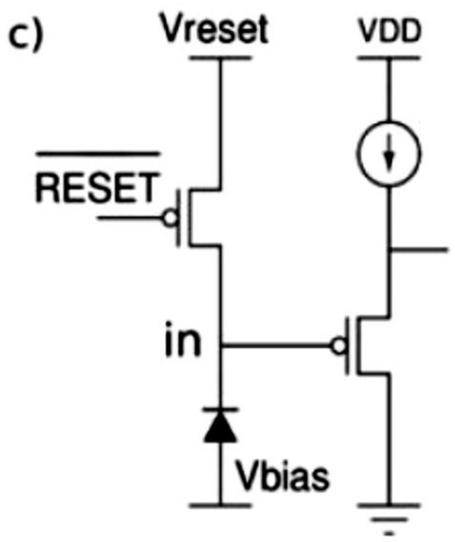


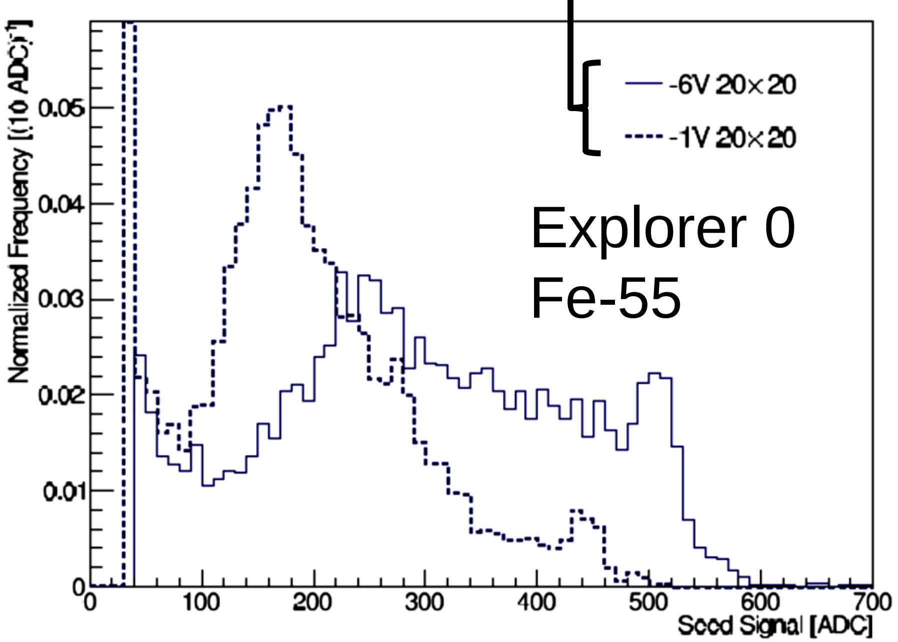
Sensors: IPHC Strasbourg

M. Deveaux, D. Doering, S. Strohauer, CBM/IKF Frankfurt

The Explorer – prototypes



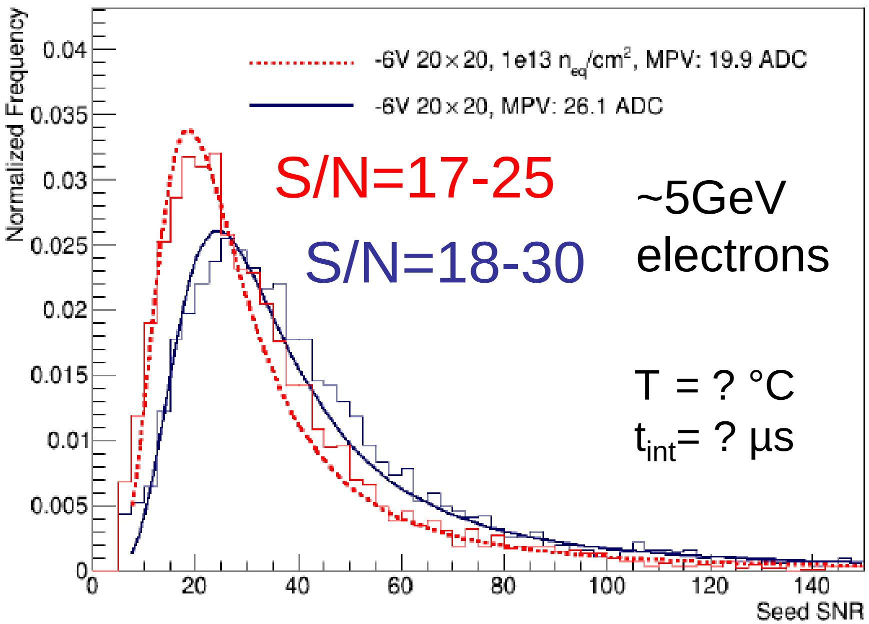


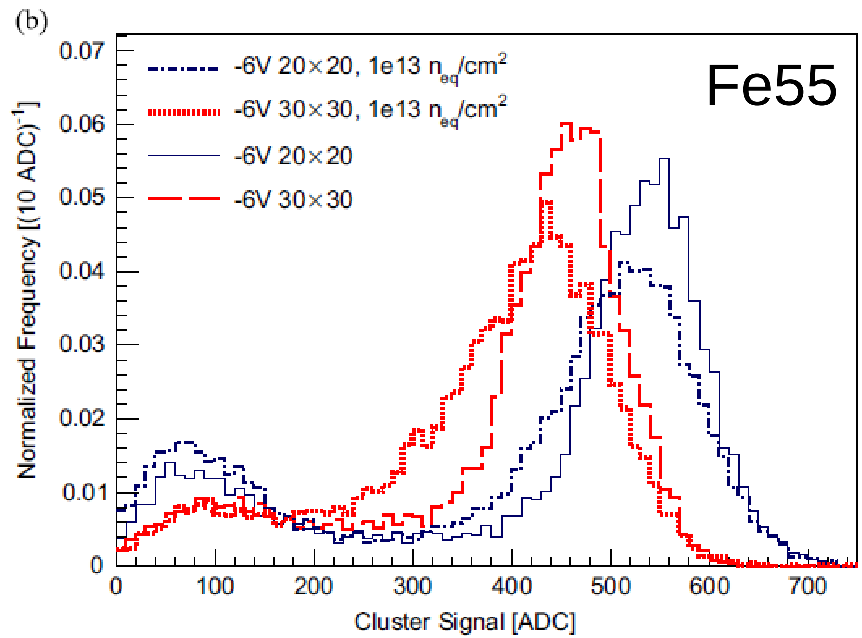


T. Kugathasan et al., Proc. NSS/MIC, IEEE (2013)

Radiation tolerance of Explorer 0

Process details: 18µm epi, 1-5kΩ cm



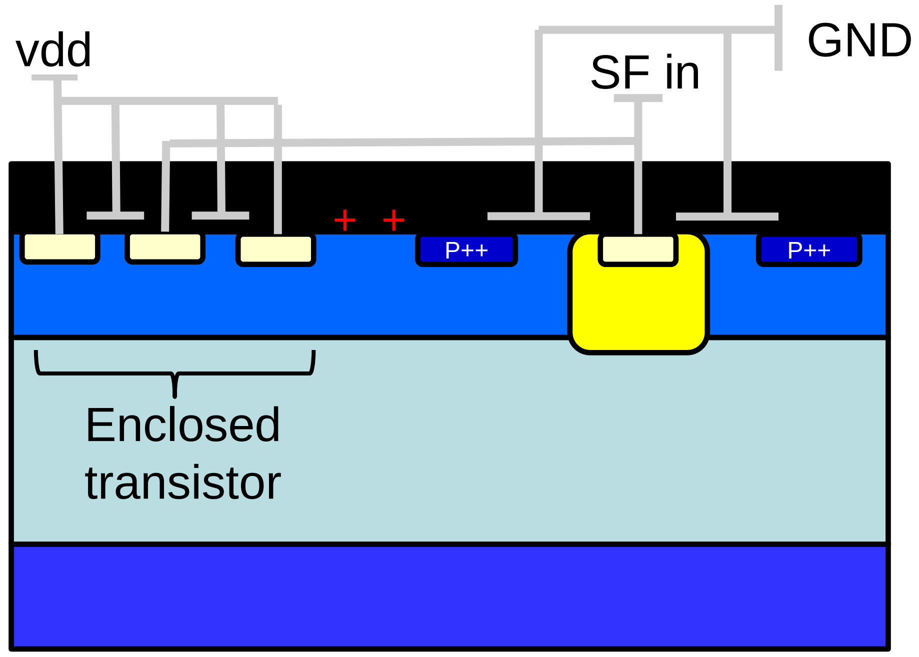


H. Hillemanns et al., proceedings of the NSS/MIC, 2013 IEEE

Concept works:

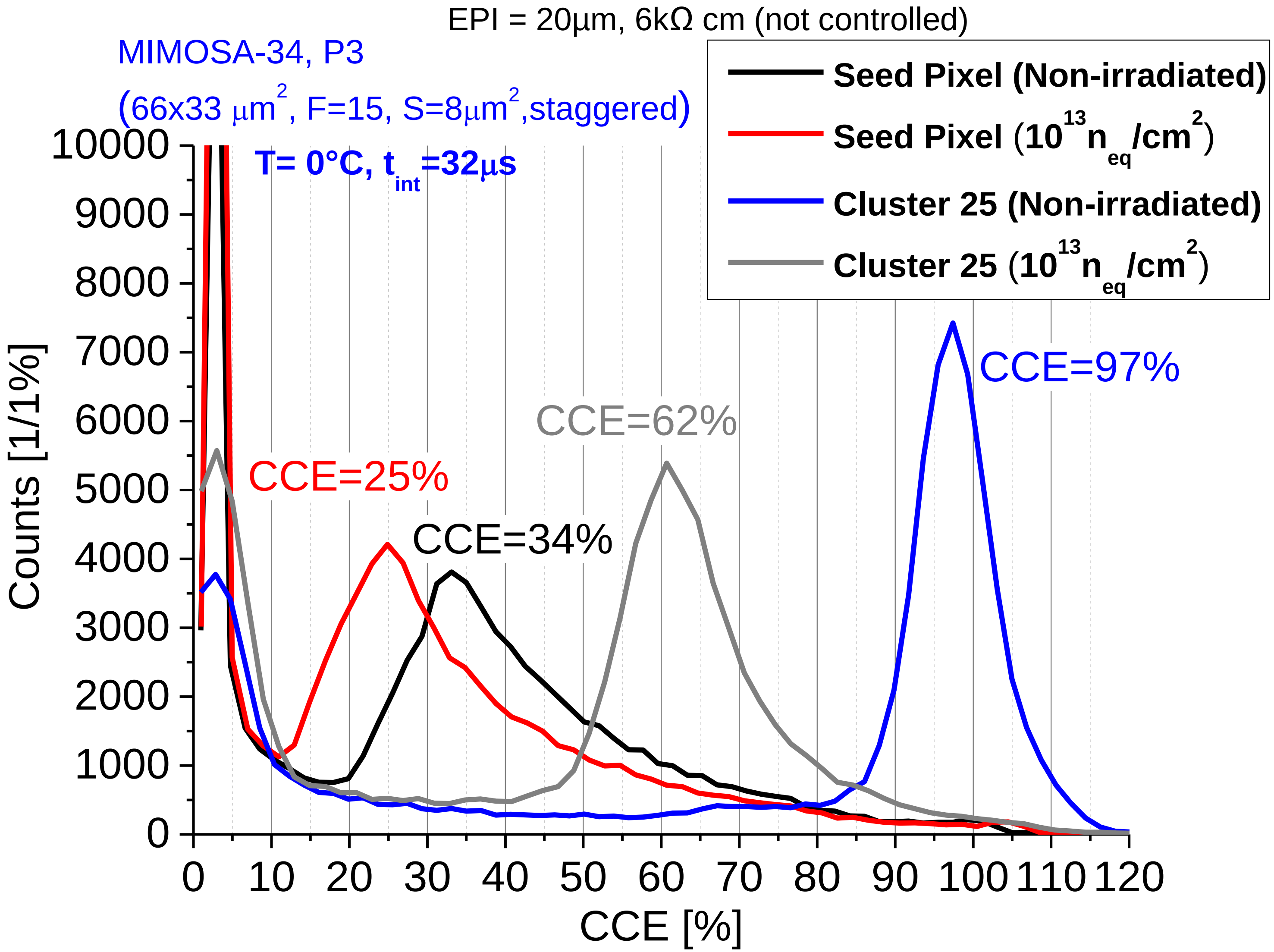
- Good MIPs detection performance
- Tolerant to $10^{13} n_{eq}/cm^2$
- Relatively high noise (19-34e -> 21-39e)

MIMOSA-34



„Standard MAPS“ on 20µm HR-epi layer
No active depletion, more sizable diode than Explorer

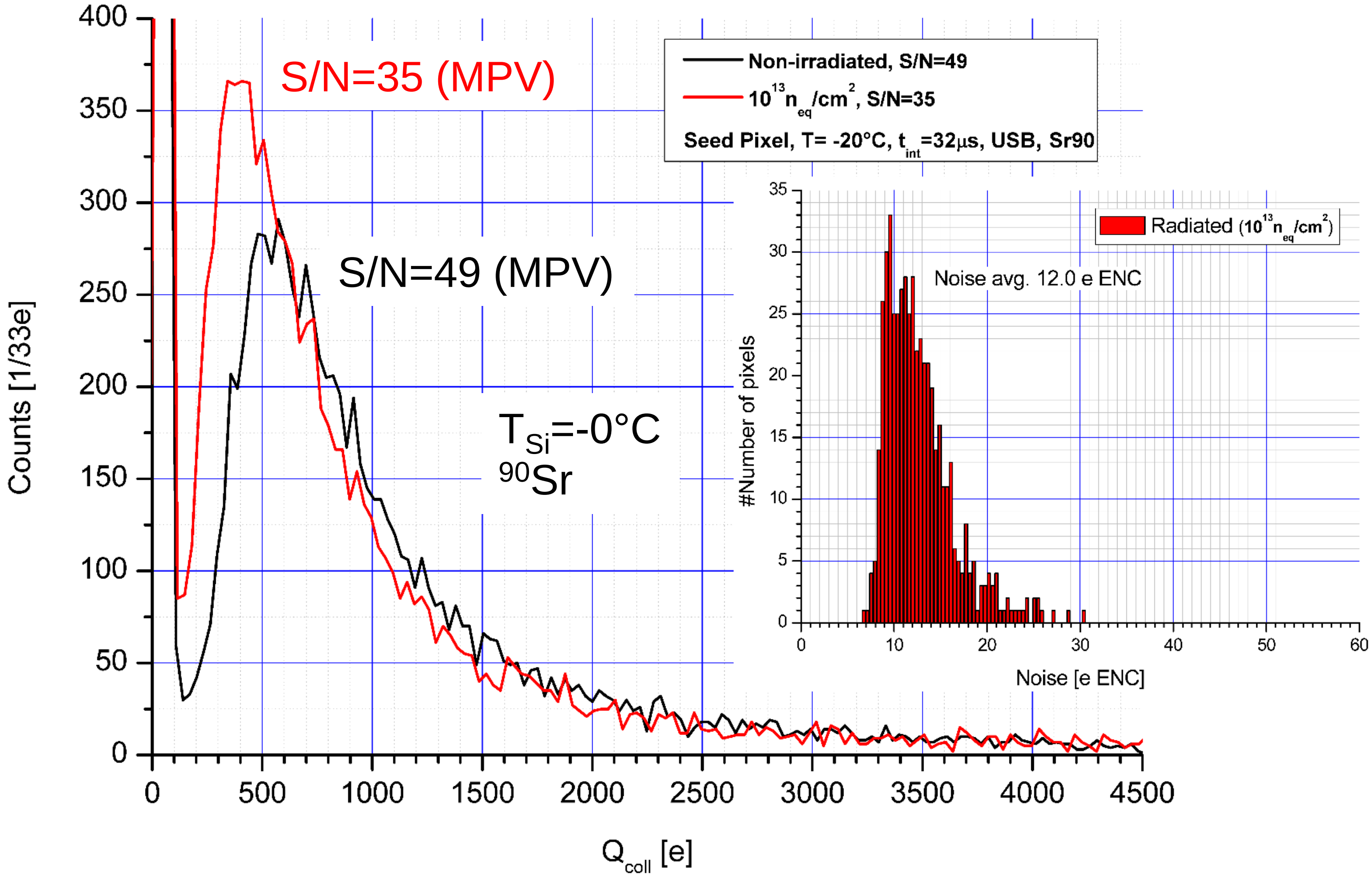
Results on radiation tolerance



Looks surprisingly radiation tolerant

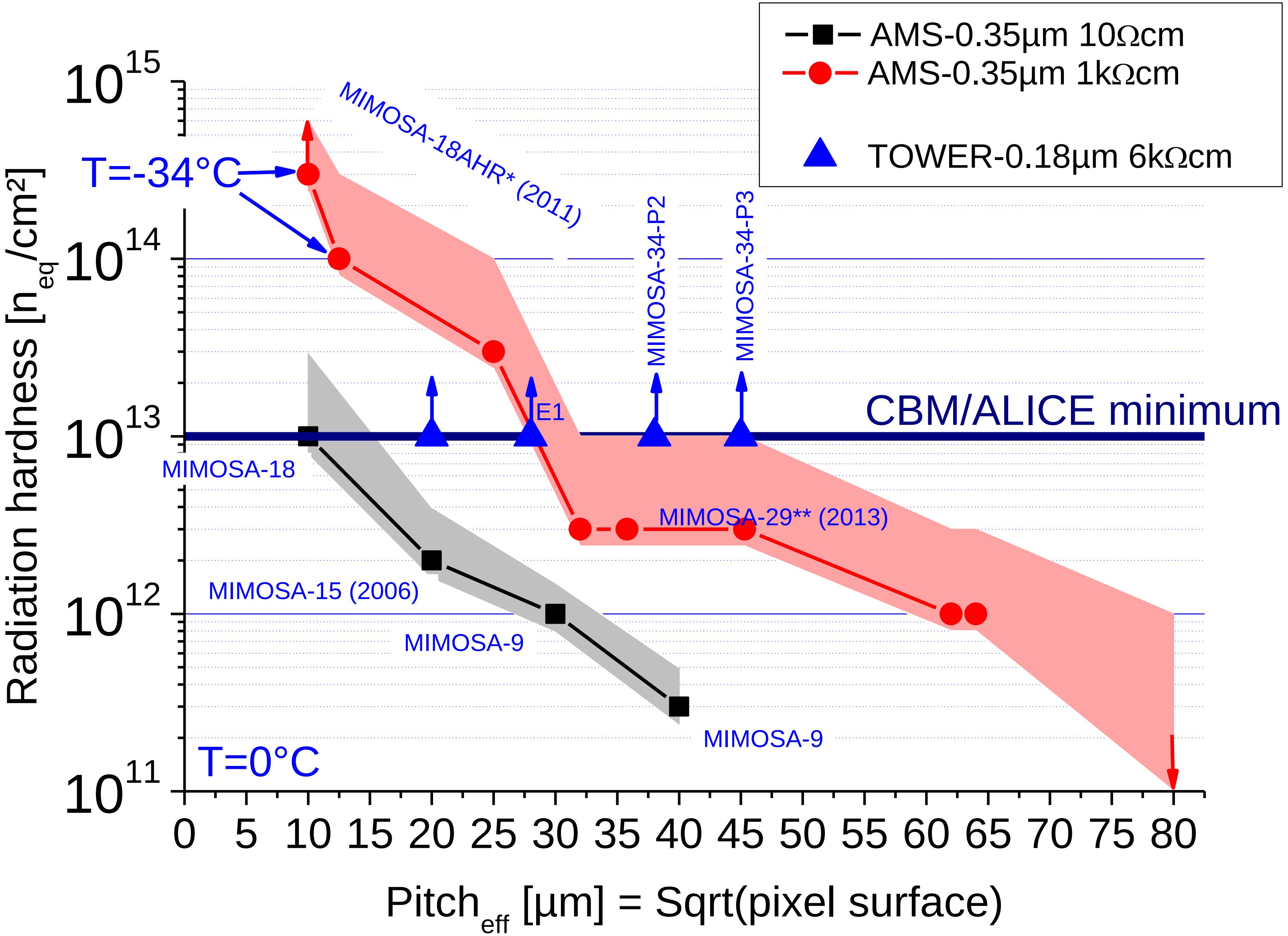
Results on radiation tolerance

MIMOSA-34, P3 (66x33 μm², F=15 μm², S=8 μm²,staggered)



Looks excellent, beam test pending

Established knowledge on radiation tolerance



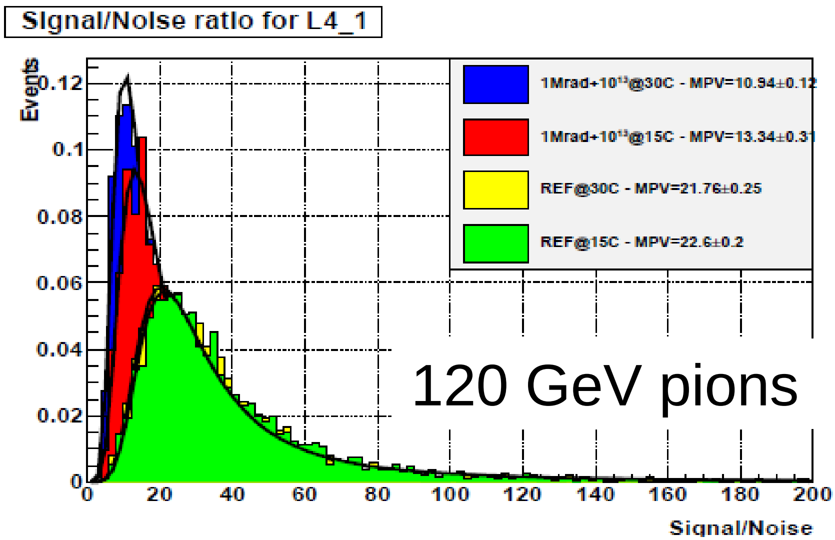
Sensors: IPHC Strasbourg
M. Deveaux, D. Doering, S. Strohauer, CBM/IKF Frankfurt

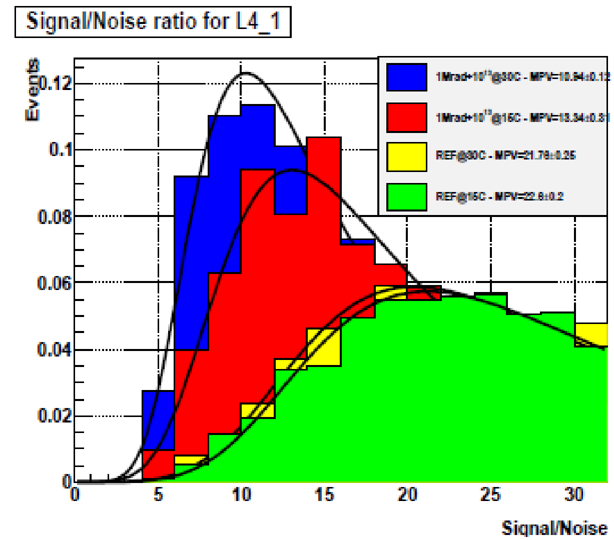
Beam test results (MIMOSA-32)

L4-1: 20x40 μm^2 (1 Sensing Diode)

- **Coolant temperature and radiation dose dependence:**

  ⁎ T = 15°C & 30°C ⁎ Doses: 1 MRad$\oplus$1$\times$10^{13}n$_{eq}$/cm^2





- **SNR (MPV) and detection efficiency** *(stat. uncertainty only)*:

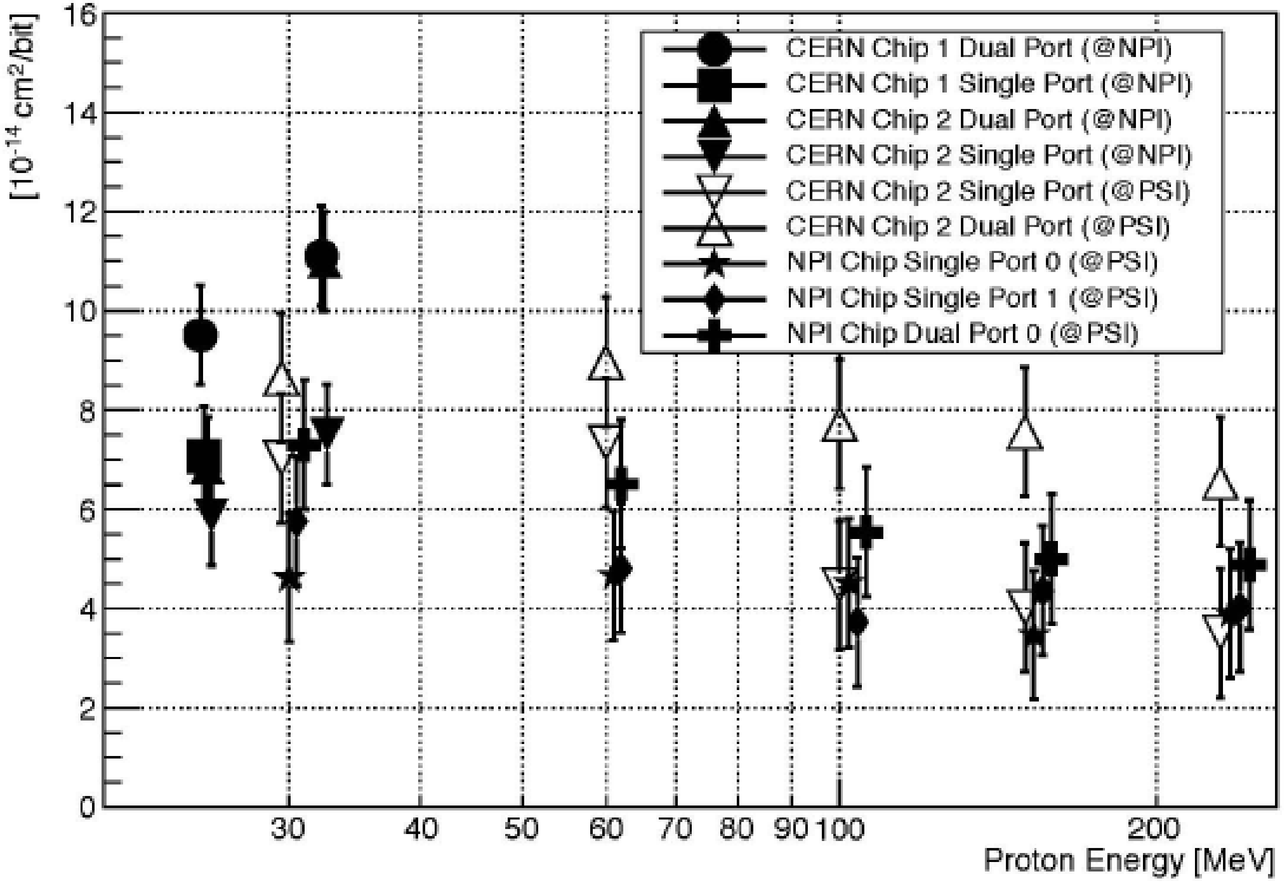
Irradiation Dose	SNR (MPV) 15°C	SNR (MPV) 30°C	Detection efficiency [%] 15°C	Detection efficiency [%] 30°C
0	*22.6 ± 0.2*	*21.8 ± 0.3*	*99.86 ± 0.06*	*99.78 ± 0.08*
1 MRad & 1$\times$10^{13}n$_{eq}$/cm^2	*13.9 ± 0.3*	*10.9 ± 0.1*	*99.51 ± 0.25*	*97.99 ± 0.25*

Good performance after irradiation
Note: Device not optimized for radiation tolerance

Learn more: S. Senyukov, NIM A730 (2013) 115-118

What else: SEE

RAM on TOWER 0.18µm exposed to proton beam

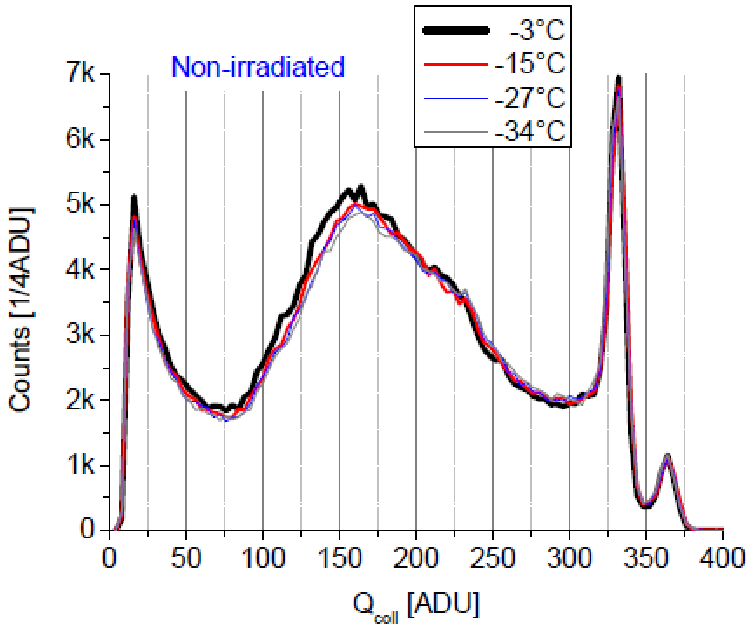


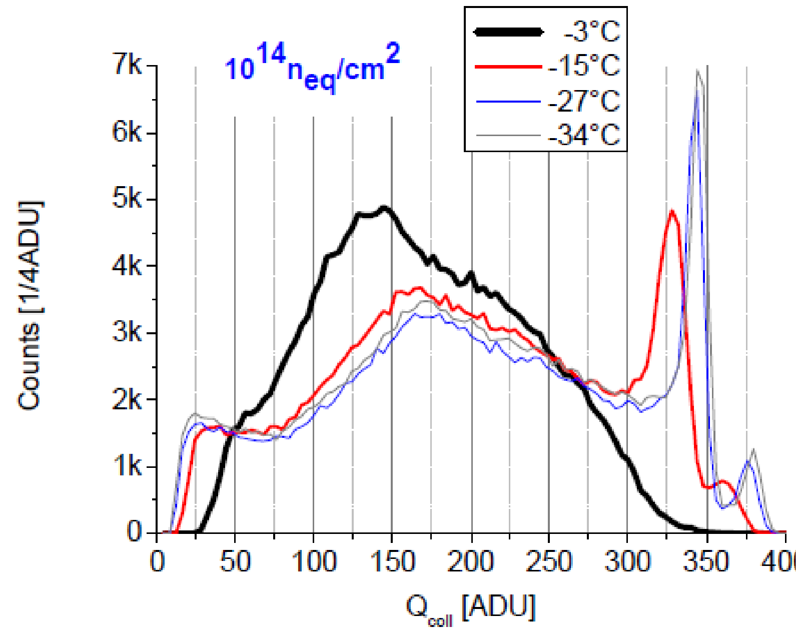
H. Hillemanns et al., proceedings of the NSS/MIC, 2013 IEEE

„ … A protection of the configuration logic might be neccessary…“

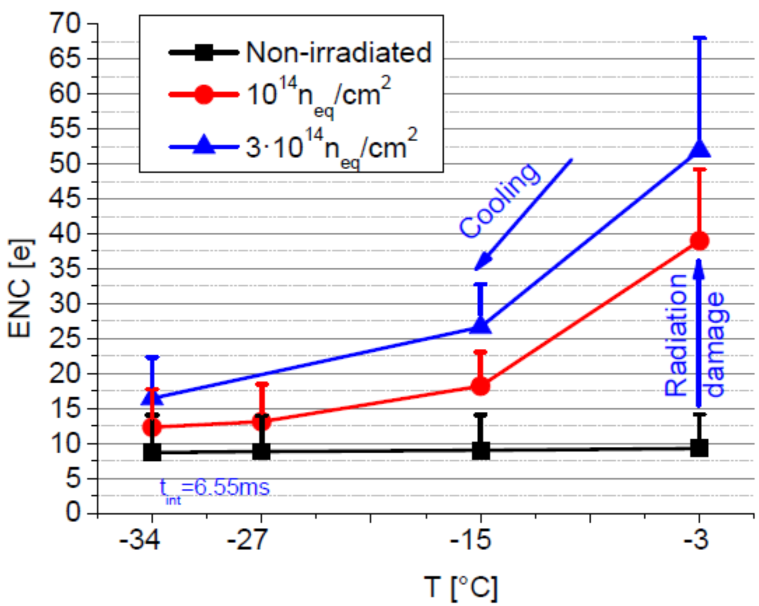
A final warning: Mind the shot noise!

AMS 0.35µm, 10µm pitch, Mi18AHR





D. Doering



MIMOSA-18AHR

AMS 0.35µm, t_{int}=4ms, faster readout helps

Radiation tolerance limited by leakage current, shot noise

100 fA = high current

Summary and Conclusion

First experiences with radiation tolerance of 0.18µm sensors:

Threshold shifts small after:

- Transistors with w>2µm (1.8V)
- Transistors with w some µm (3.3V)

Integrated radiation damage (Ionizing):

- Few radiation damage effect until 3 MRad, tolerable to 10 MRad
- Leakage current control (guard rings) is important

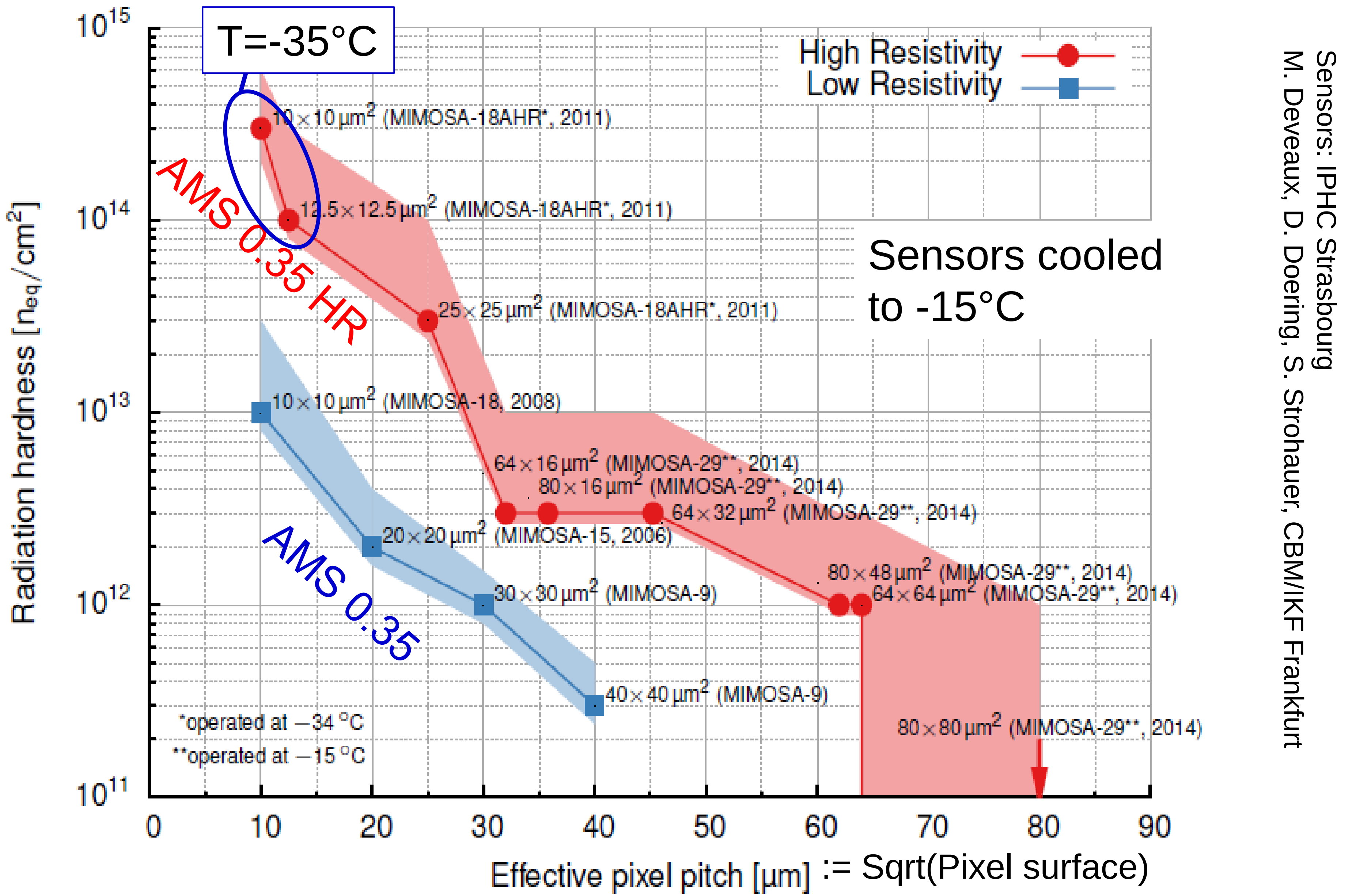
Integrated radiation damage (Non Ionizing):

- Tolerance to $10^{13} n_{eq}/cm^2$ even for big pixels (66x33µm²)
- Expect substantially higher rad. tolerance for smaller pixels

- Managing leakage current / shot noise is important.
- SEE (bit flips) might be an issue

There is more to come, stay tuned

Established knowledge on radiation tolerance



Random Telegraph Signal (Amplifier)

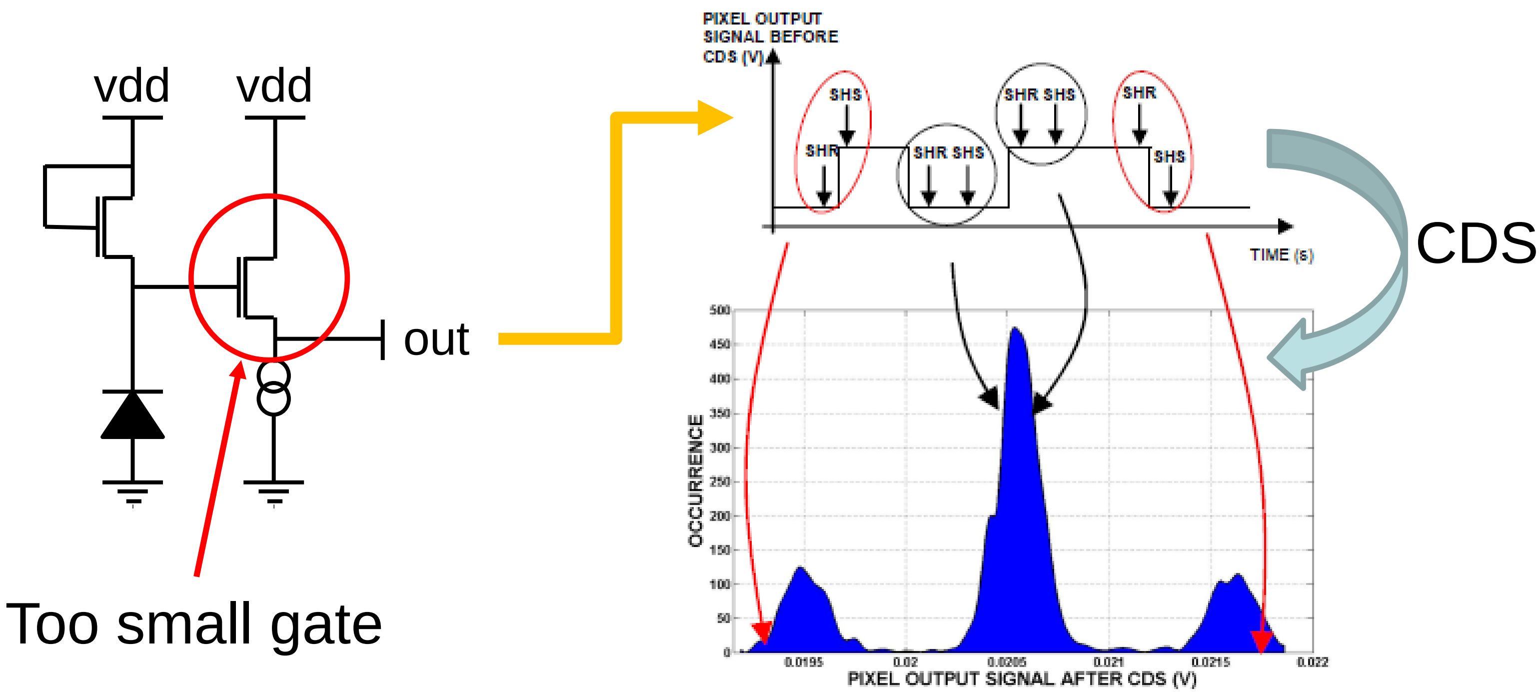


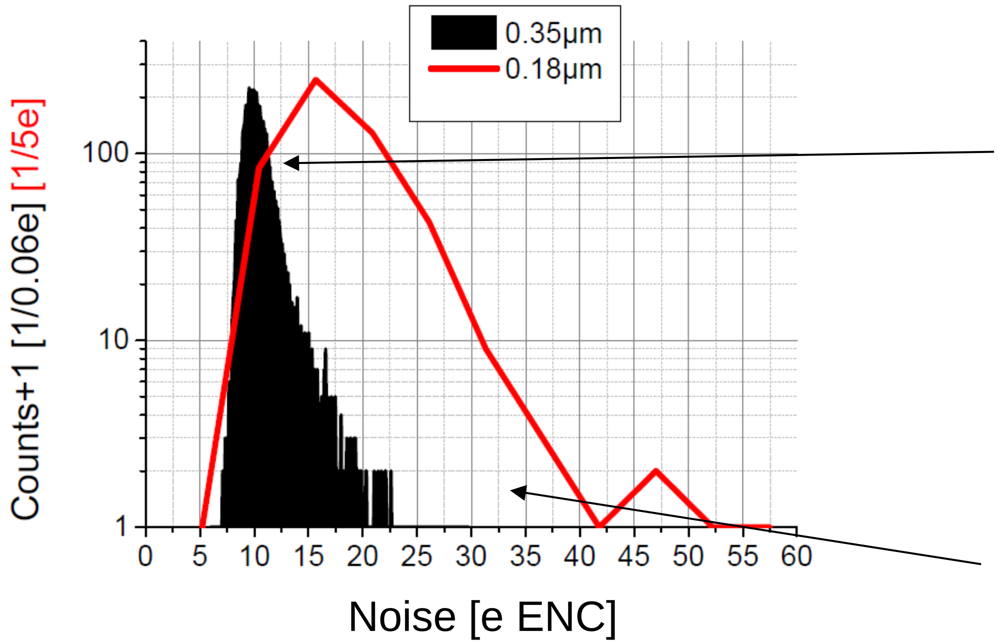
Fig. 4: Image sensor output noise response subject to significant RTS noise of in-pixel source follower transistor

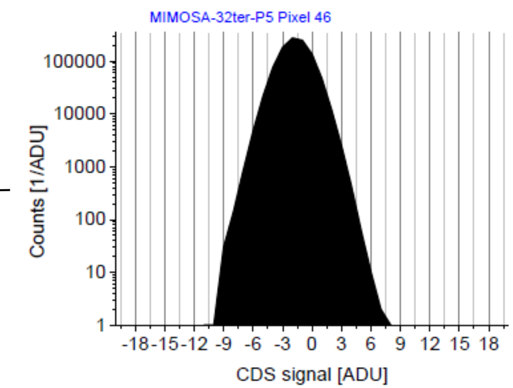
Martin-Gonthier, Philippe, Magnan, Pierre. *RTS Noise Impact in CMOS Image Sensors Readout Circuit, 16th IEEE International Conference on Electronics, Circuits, and Systems*, IEEE, , 928-931 (2010) ISBN 978-1-4244-5090-9

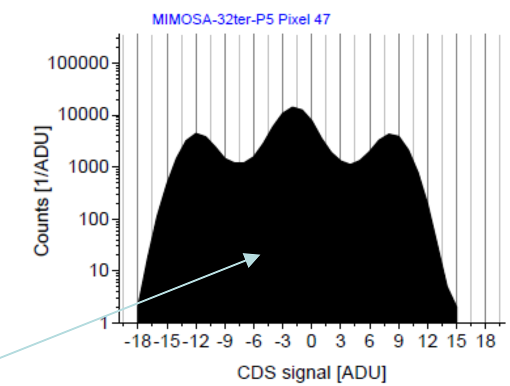
Xinyang Wang et al. *Random Telegraph Signal in CMOS Image Sensor Pixels, Electron Devices Meeting*, IEDM '06. International 1,4, 11-13 Dec. (2006)

Transistors with small gate show 1/f or RTS-noise
May be cured by extending the gate

Random Telegraph Signal (Amplifier)







Reminder: This is a Gauss-distribution… ;-)

Sensors tested show RTS-noise in the SF-transistor

- Exected radiation damage = Shot noise
- Dominated by RTS-Noise => Systematic uncertainty