

The Timepix3 readout chip for hybrid pixel detectors: design and first measurements



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Outline

- Introduction to Timepix3
- Front-end architecture
- Tests on bare chips
- Measurements with sensor
- Summary

Timepix → Timepix3

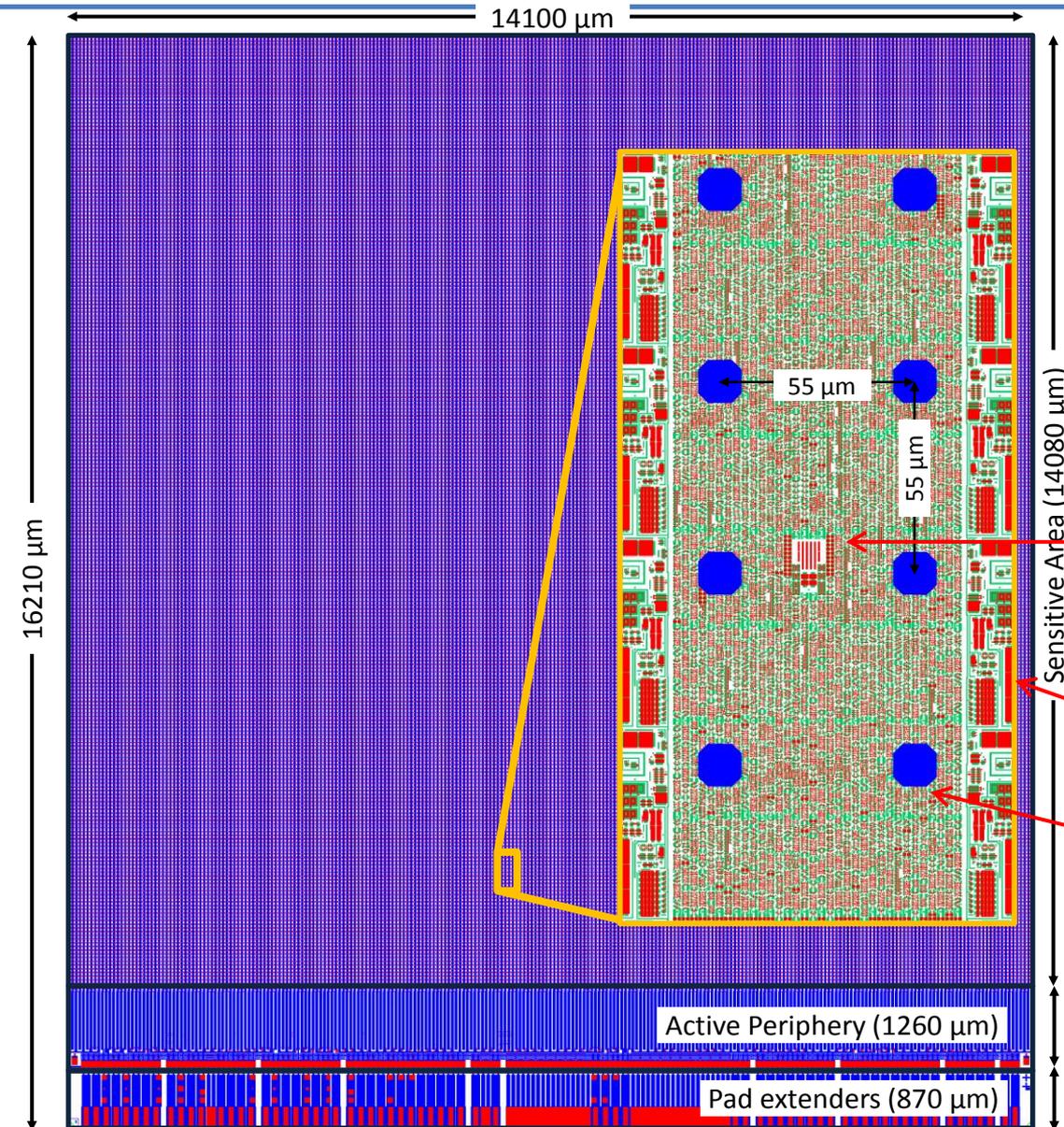
	Timepix	Timepix3
Year	2006	2013
# pixels	256 x 256	
Pixel size	55 x 55 μm	
Technology	CMOS 250nm	CMOS 130nm
Measurement modes	- Time-Over-Threshold (TOT) - Time Of Arrival (TOA) - Event counting (PC)	- Simultaneous 10bit TOT and 18bitTOA - 18bit TOA only - 10bit PC and 14bit integral TOT (itot)
Readout type	Sequential (frame-based)	- Frame-based - Data Driven (zero suppressed)
Dead time	>300 μs full frame readout	> 375ns packet transfer, maximum hit rate 40Mhits/s/cm ²
Time resolution	10ns	1.56ns
TOT monotonicity (h ⁺)	No	Yes
Power pulsing	No	Yes
Minimum threshold	~750e ⁻	>500e ⁻

Timepix3 is a joint design effort by **CERN**, **NIKHEF** and the **University of Bonn**

Main applications are:

- Fast readout of solid-state pixelated sensors
- Readout of gaseous detectors (TPC)
- Vertex Locator for LHCb (future VELOpix)
- Power pulsing tests for the Linear Collider
- Dosimetry

Timepix3



128 double columns:
2x256 pixels (64 SuperPixels)
each

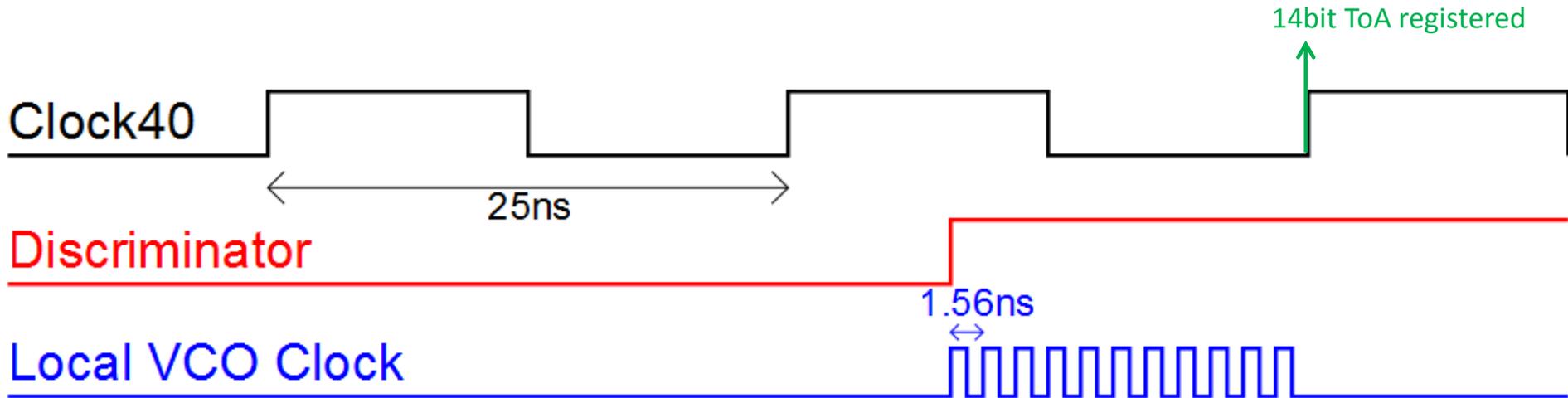
SuperPixel: 2 x 4 pixels

1 per SuperPixel:
VCO@640MHz
for the fast TOA

Analog Front-End 13 x 55 μm^2

Input pad on top of the digital
area

Fast ToA measurement

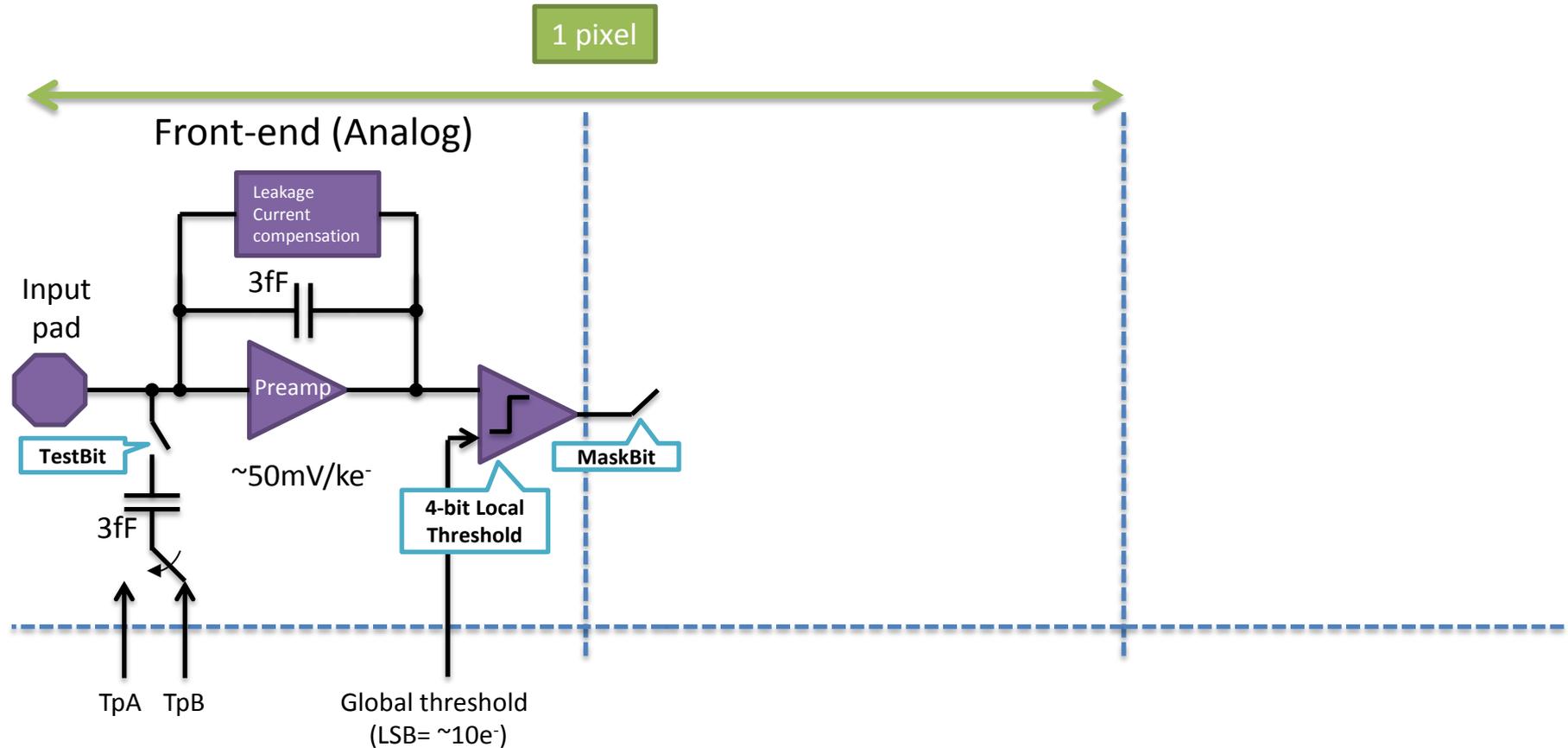


40MHz global clock always running (14bit ToA)

One 640MHz Voltage-Controlled Oscillator per SuperPixel (2x4 pixels) activated only when a discriminator fires (4bit fast ToA)

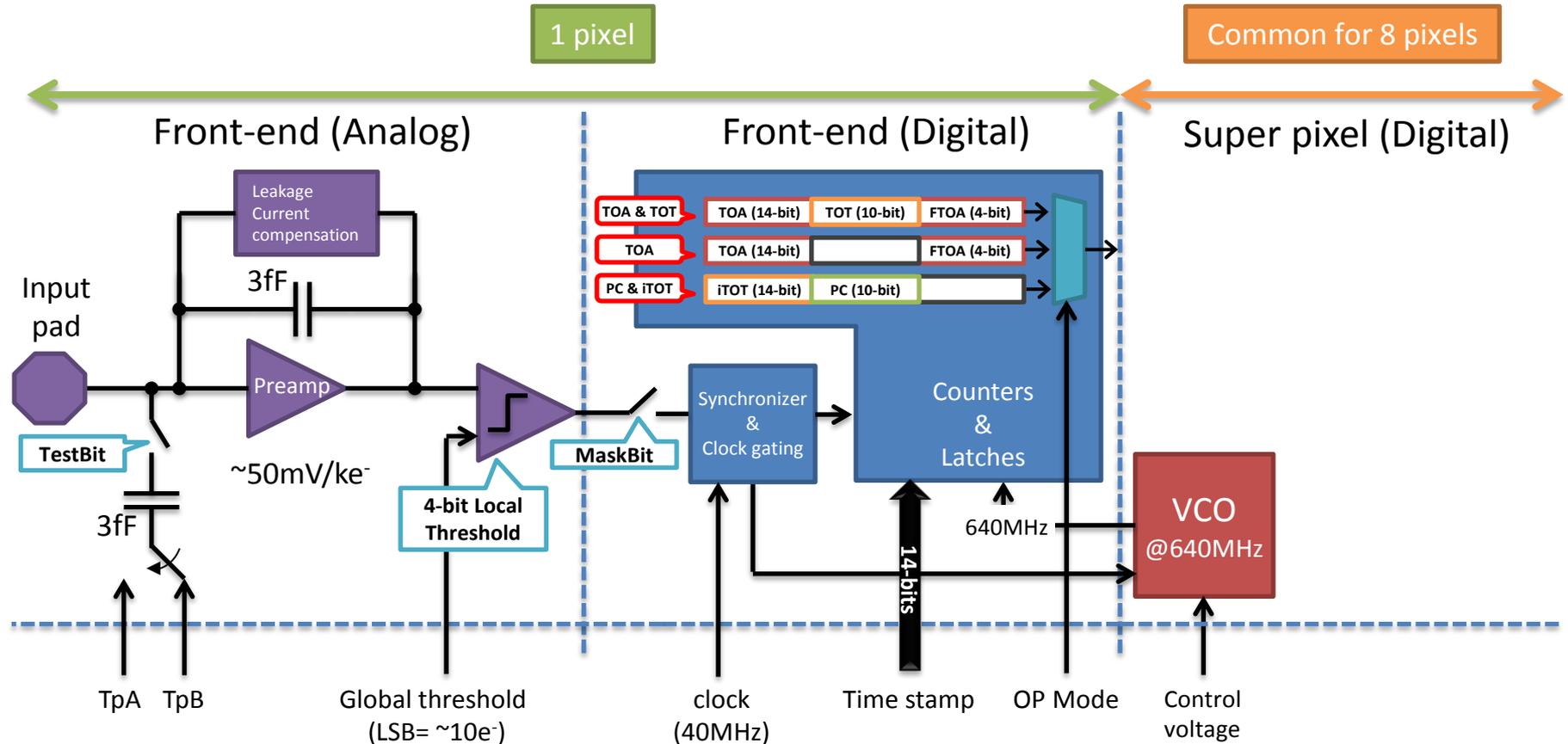
Pixel/SuperPixel diagram

T. Poikela



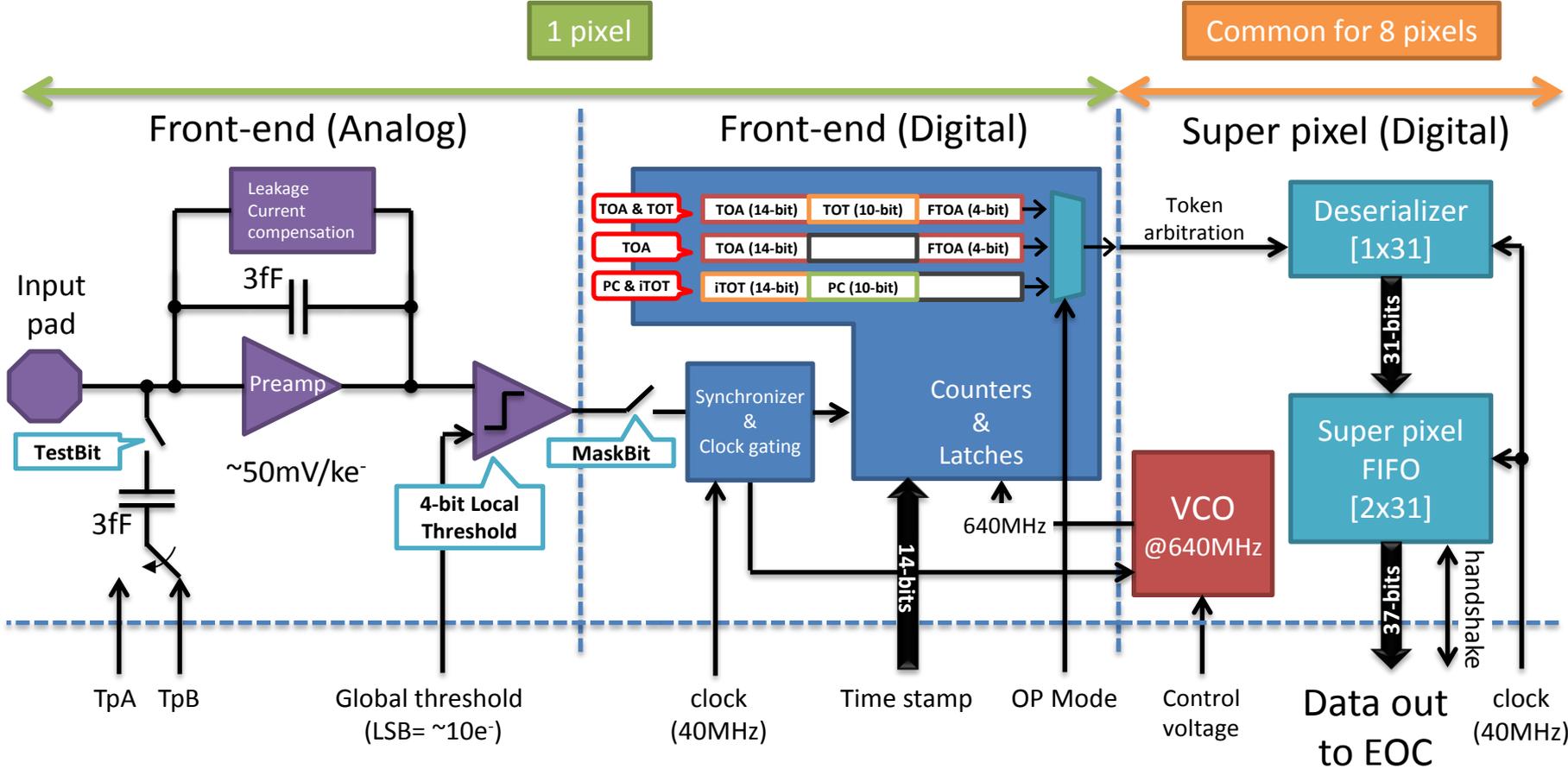
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Pixel/SuperPixel diagram

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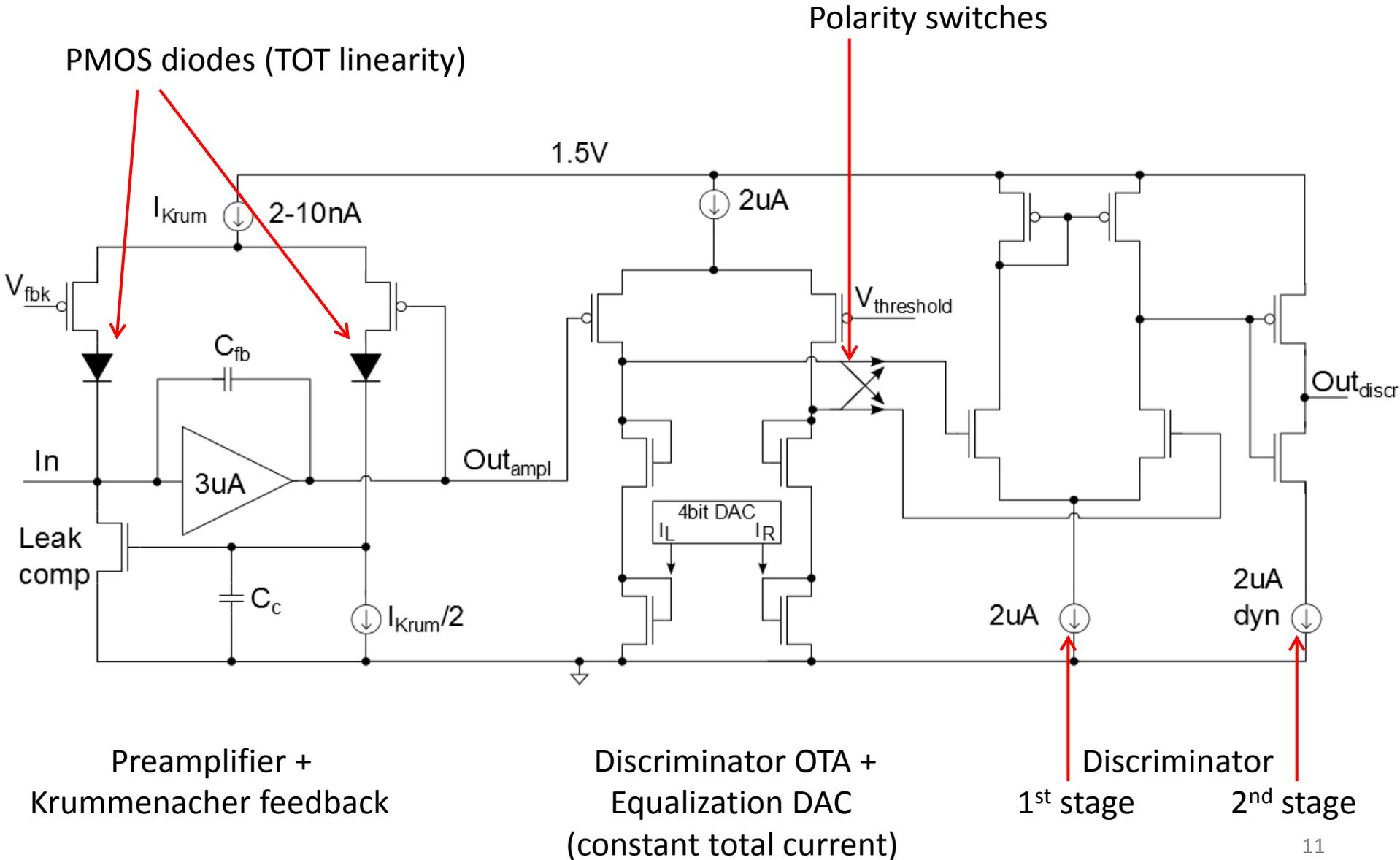
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Front-end specifications

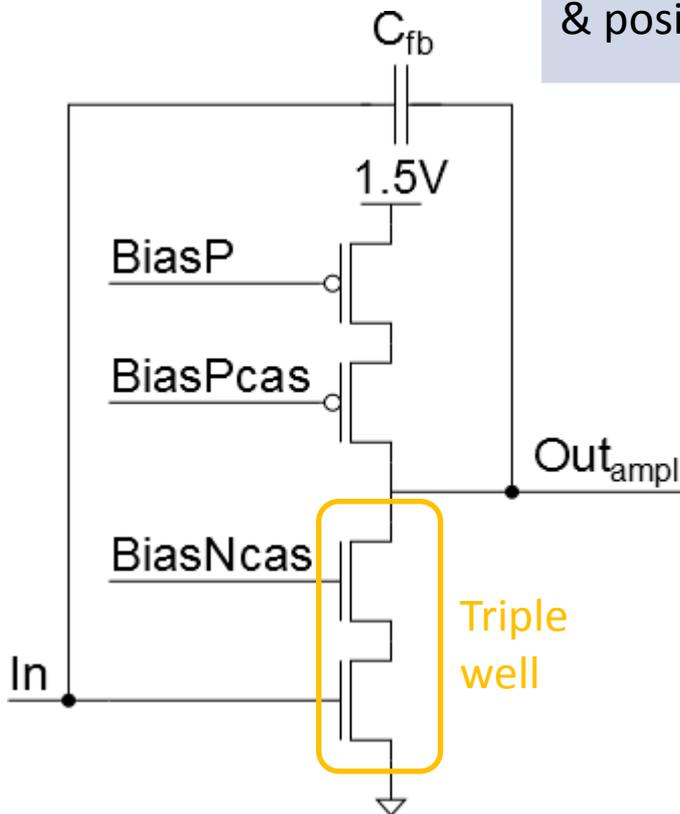
Parameter	Value	Notes
Area	55 μ m \times 13.5 μ m	
Signal polarity	Positive and negative	
Detector capacitance	\sim 50fF	25fF to 100fF
Leakage current	-5nA to +20nA	
Amplitude linearity	Not required	Time measurement
TOT monotonicity	Yes, up to 300kh ⁺	
ToA jitter and mismatch	Compatible with 1.56ns resolution	Gas detector applications
Time-to-peak	Target 25ns	In view of VELOpix
Noise + threshold mismatch	\sim 90e ⁻	for a minimum threshold \sim 500e ⁻
Equalization DACs	4bit	Compensate pixel-to-pixel threshold mismatch
Power consumption	12 μ W/pixel	

Front-end architecture



Timepix/Timepix3: preamplifier

	Timepix	Timepix3	Notes
Preamplifier	Differential	Single-ended	More efficient power usage
C_{fb}	8fF	3fF	Larger gain
Input pad size & positioning	20x20 μm , over analog domain	12x12 μm , over digital domain	Minimize parasitics, shielding to analog ground

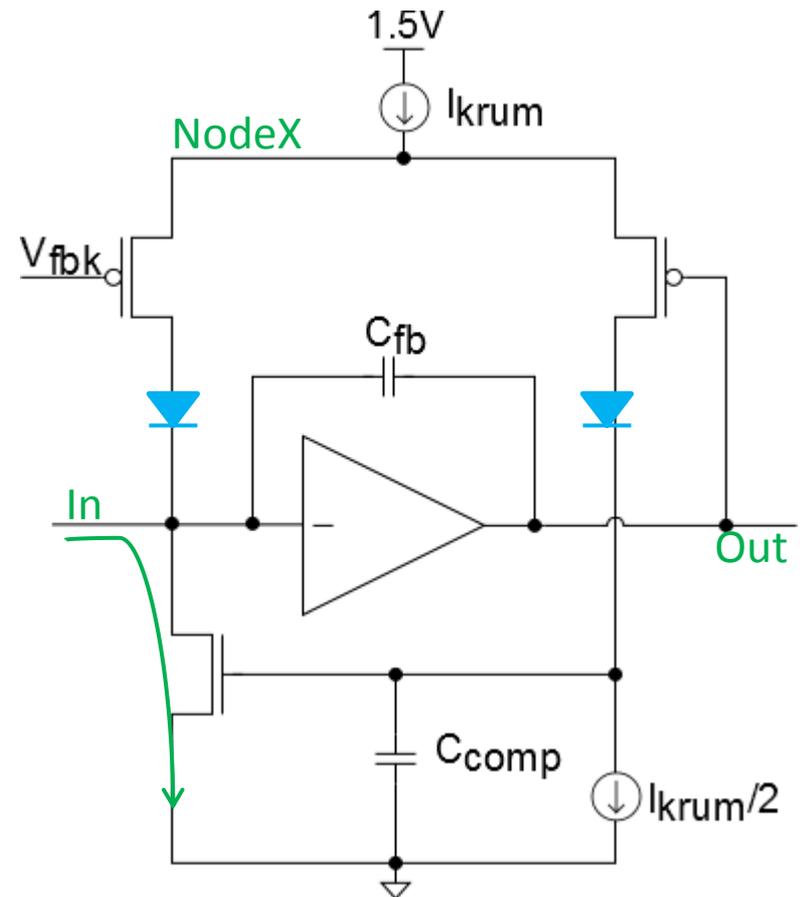
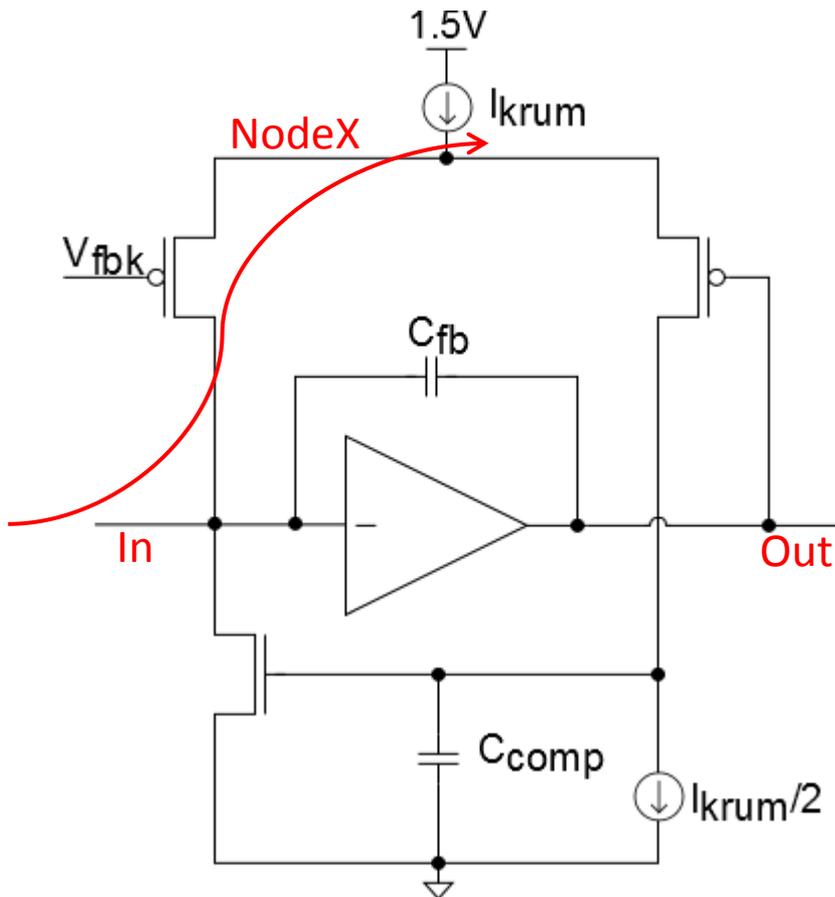


TOT monotonicity

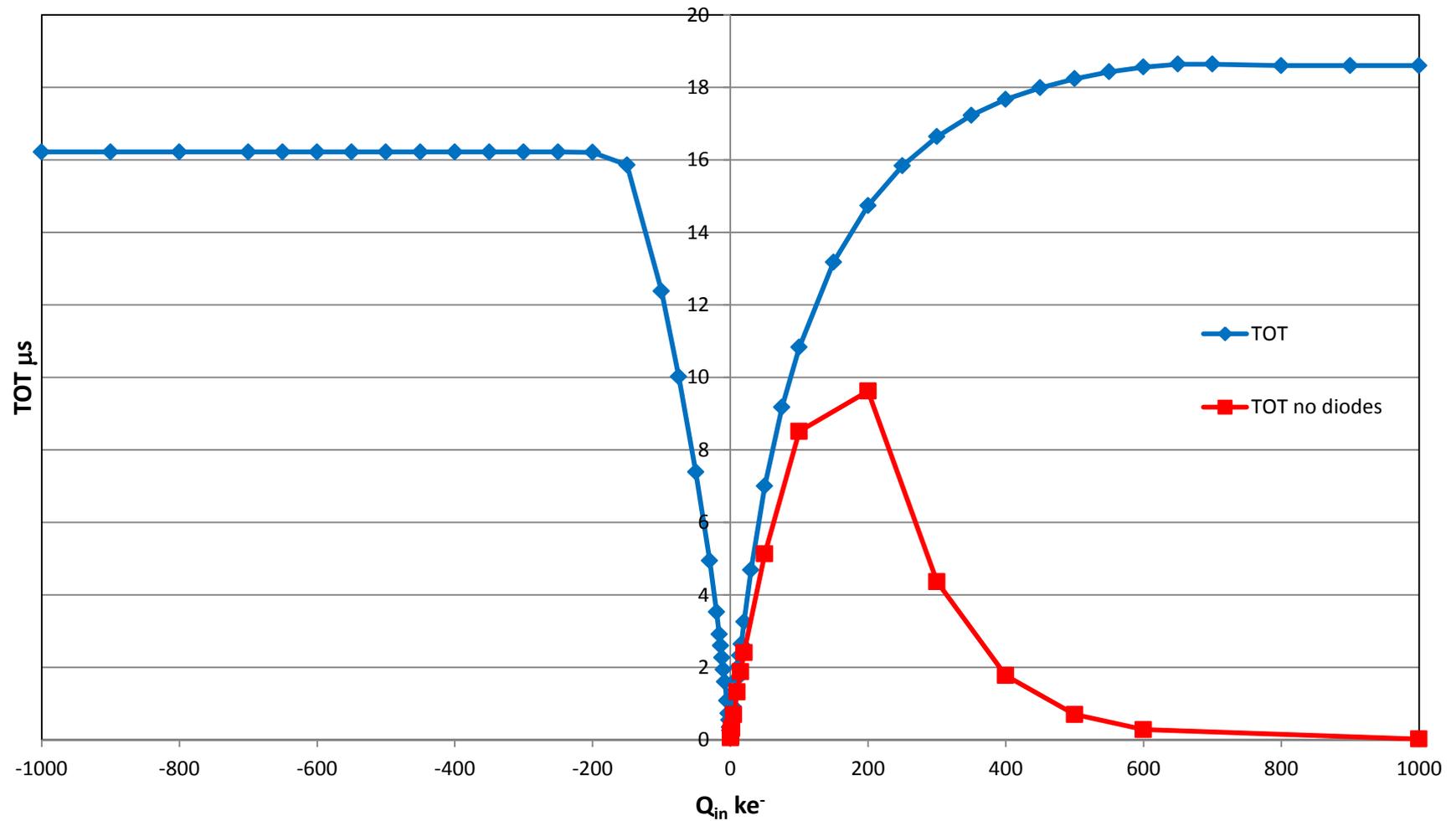
TOT monotonicity issue for large positive input charges:

$Q_{in} > 100kh^+ \rightarrow V(In) > V(NodeX) \rightarrow$ current through the **wrong path**

Added diode-connected PMOS transistors \rightarrow **good current path**



TOT monotonicity

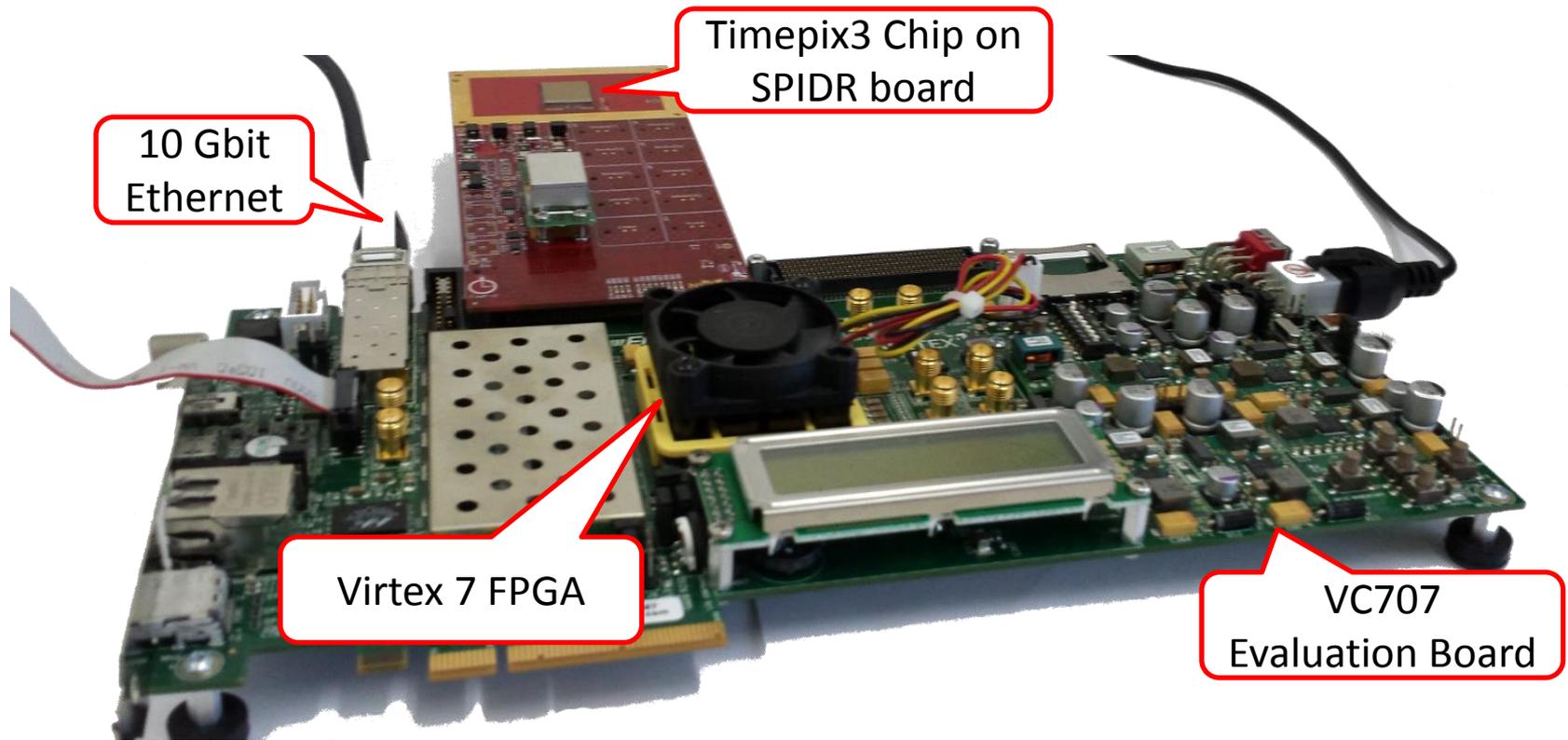


Comparison between TOT with and without monotonicity PMOS diodes.

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Test setup



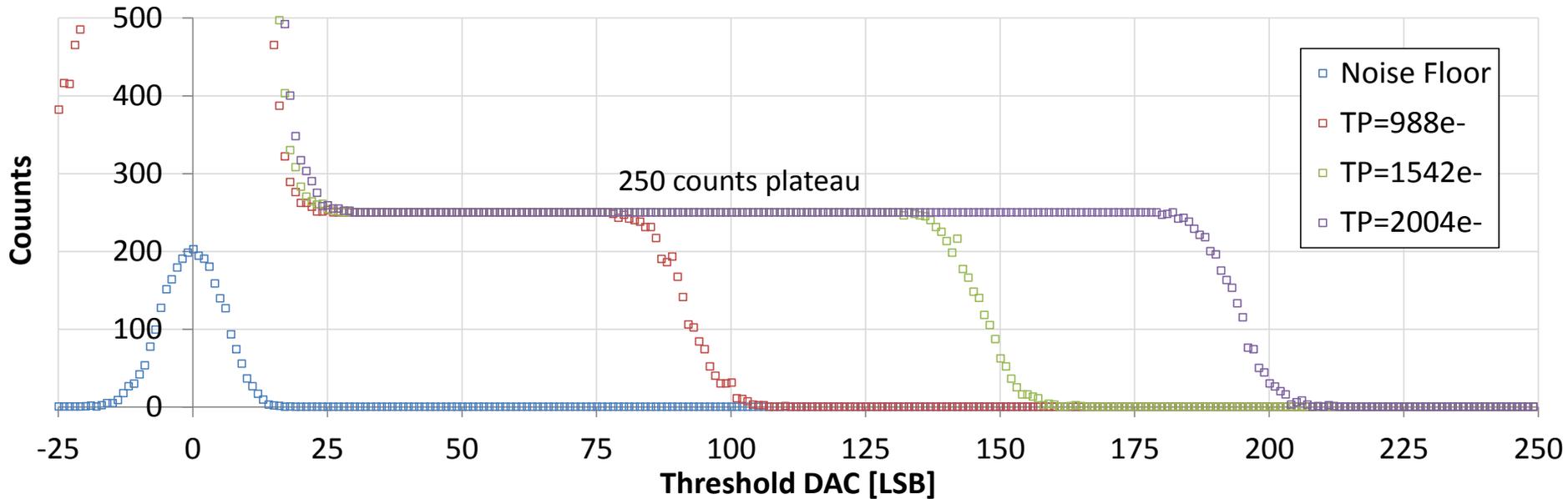
SPIDR: Speedy Pixel Detector Readout
Developed for Timepix3 (from single chips up to quads)
1 x 10Gbps Ethernet link IO

Credits:

Bas van der Heijden, Frans Schreuder, Henk Boterenbrood (NIKHEF)
Szymon Kulis (CERN)

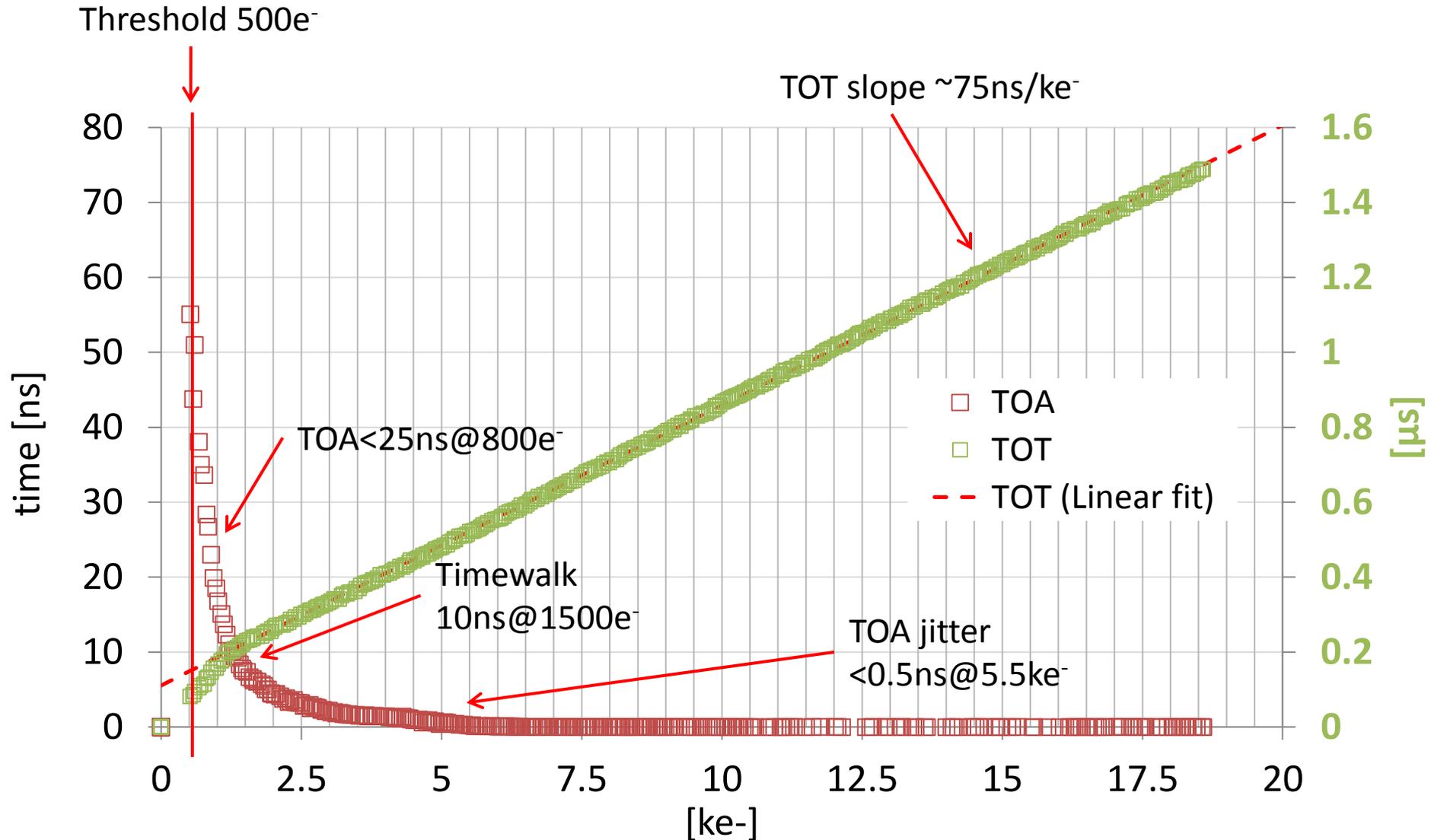
S-curves

X. Llopart



250 test pulses injected and counted in Photon Counting mode
ENC extracted from the S-width: $5.7\text{LSB} = 64e^- \text{ rms}$

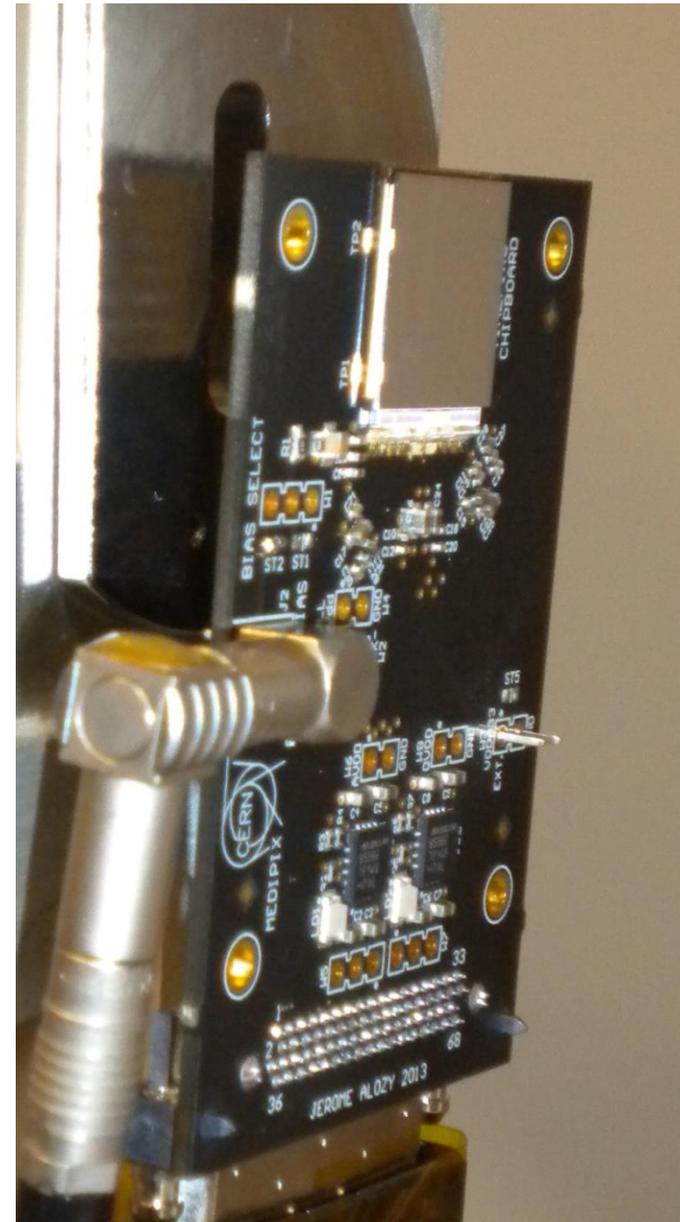
Timewalk and TOT linearity



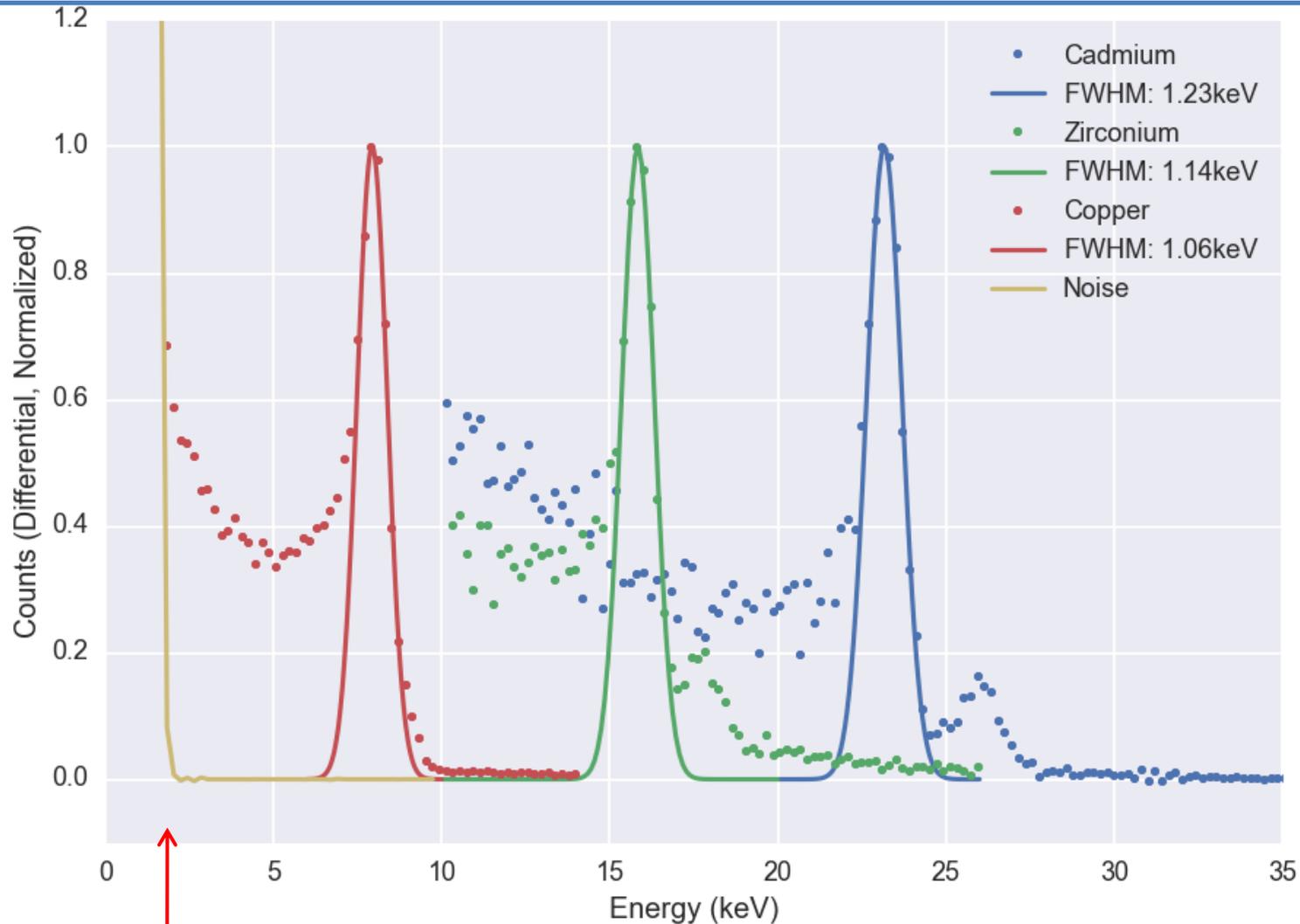
Measurements using test pulses, averaged over 64 acquisitions

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300 μ m Silicon P-on-N available since last week
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Fluorescence measurements (65k pixels)

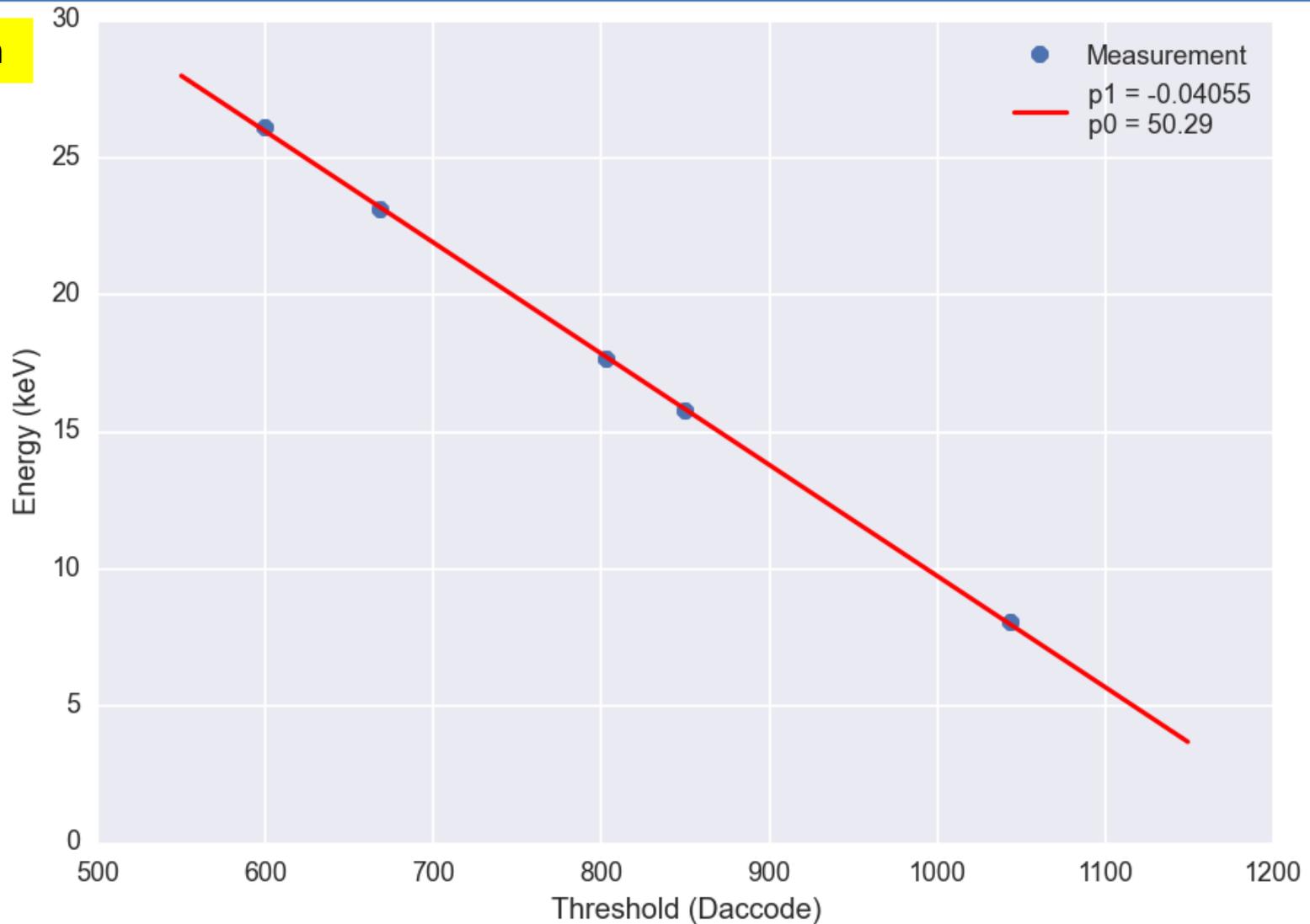


Noise hits start at 2keV=550e⁻

FWHM → energy resolution $\sigma=124e^-$ (Cu)
Equalization using noise floor
Charge measured over full matrix

Gain calibration using fluorescence (65k pixels)

E. Fröjdh

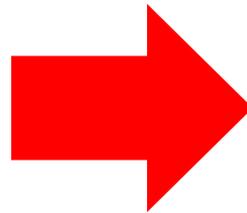
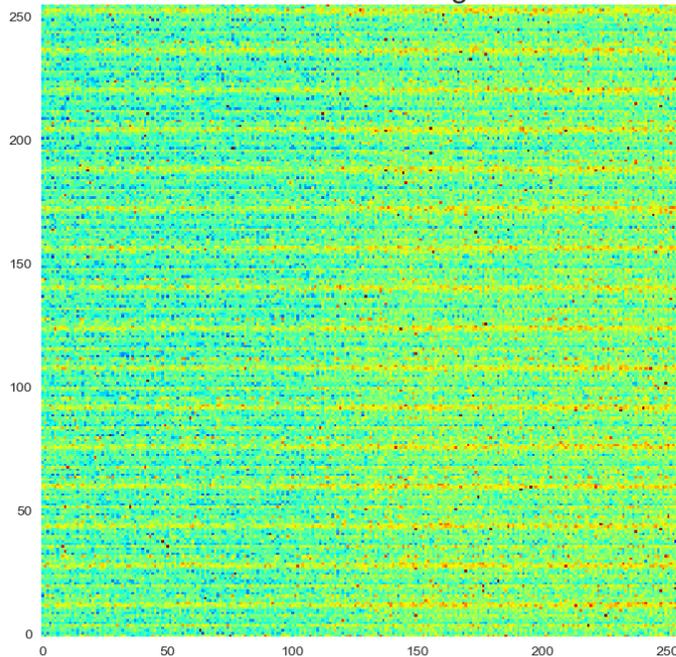


$$40.5\text{eV/LSB} = 11.2\text{e}^-/\text{LSB} = 44.6\text{mV/ke}^-$$

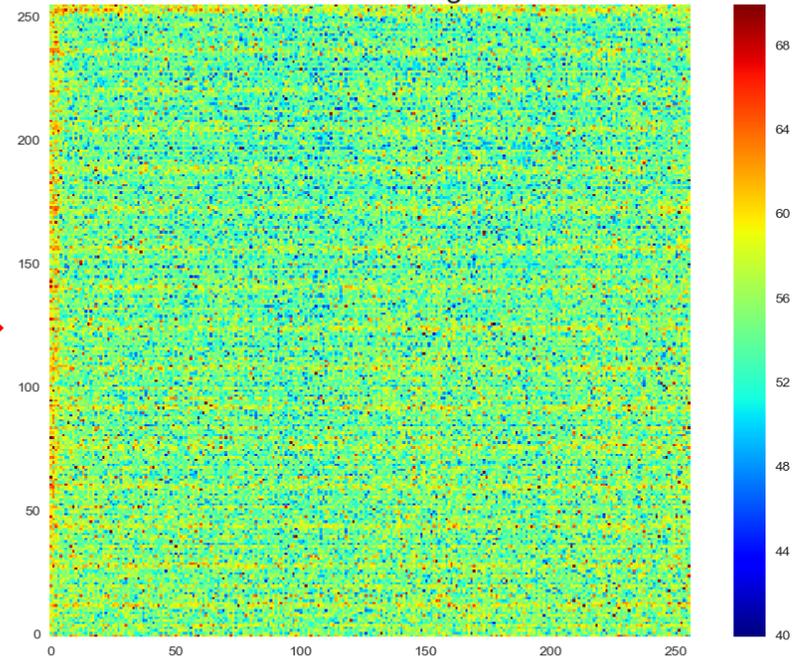
Noise map before/after bonding

Same chip measured at wafer level and after sensor bonding:

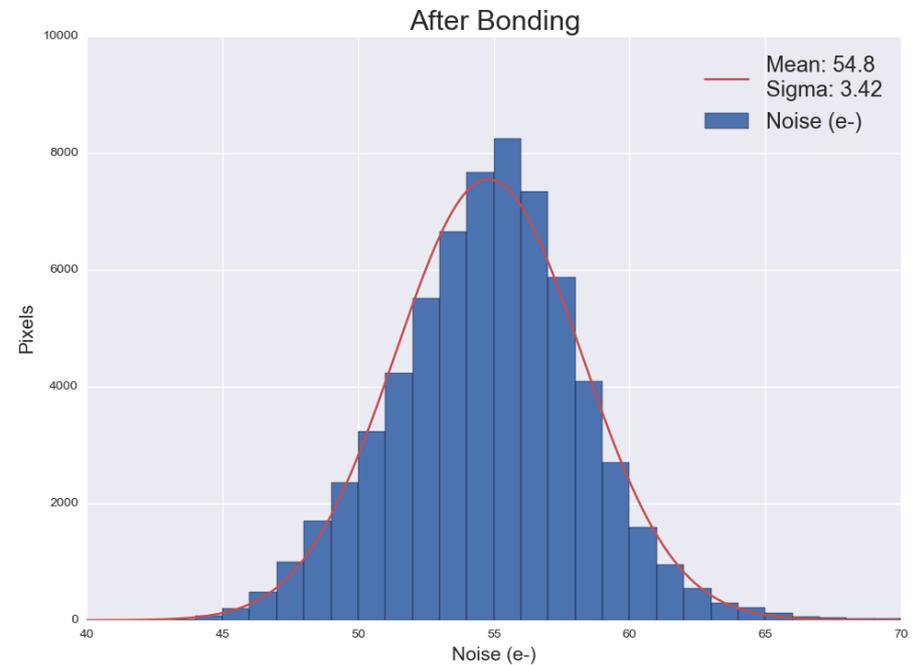
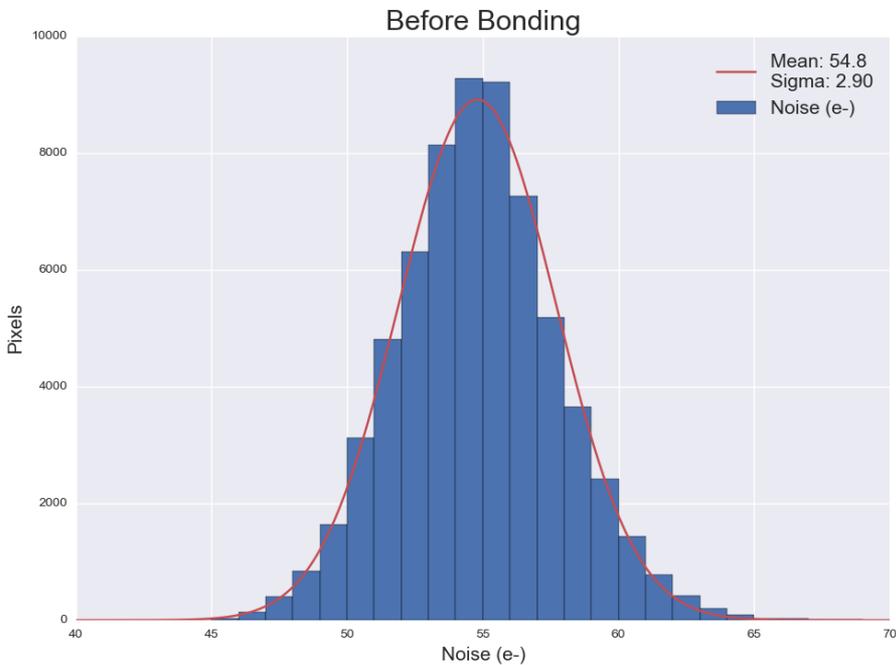
Before Bonding



After Bonding



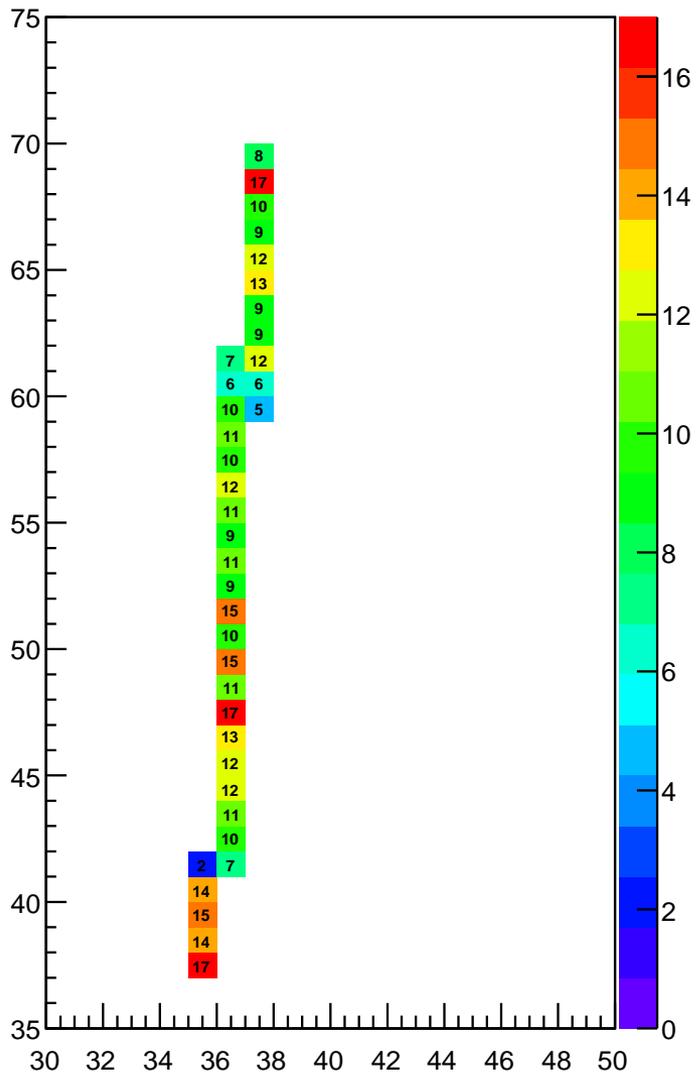
Noise distribution



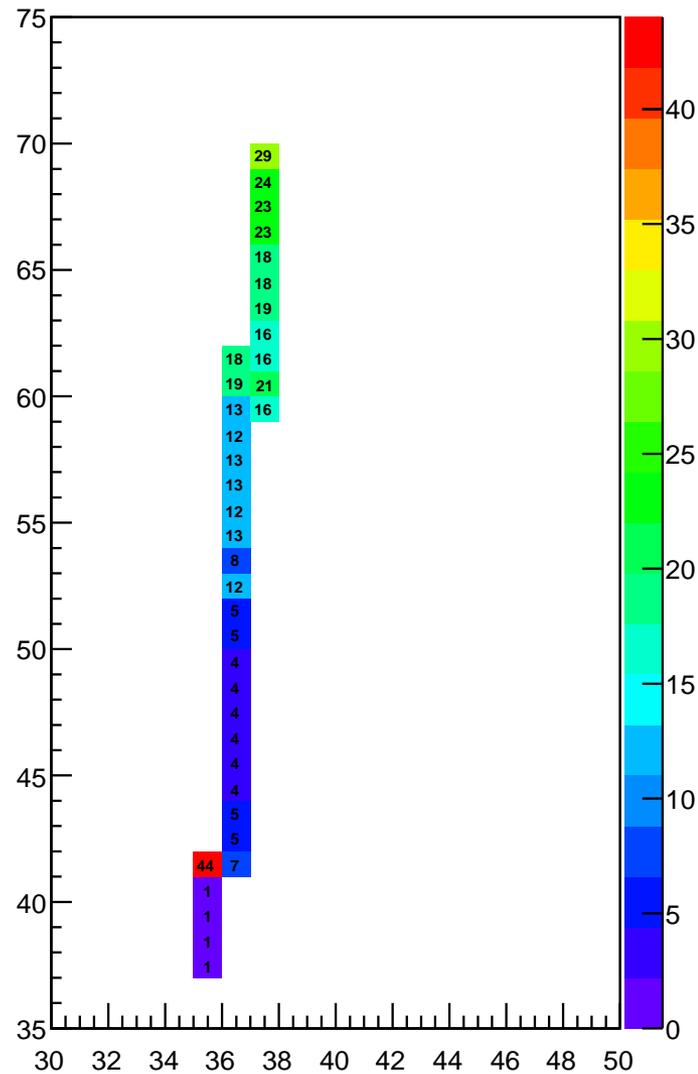
Average noise over the full matrix stays the same. Its distribution widens a little bit.

MIP (cosmic)

ToT

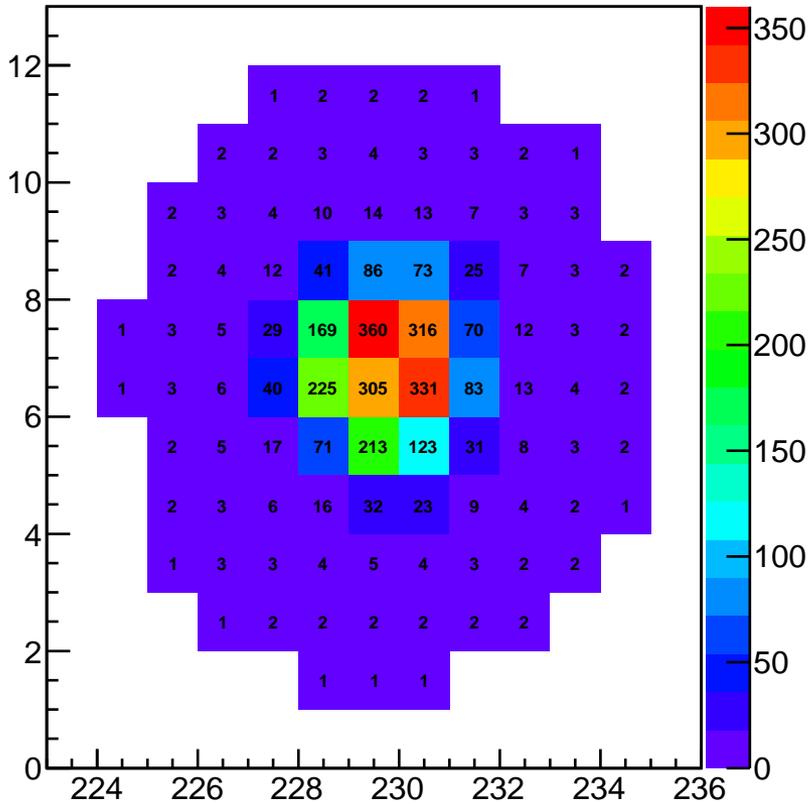


Time (ns)

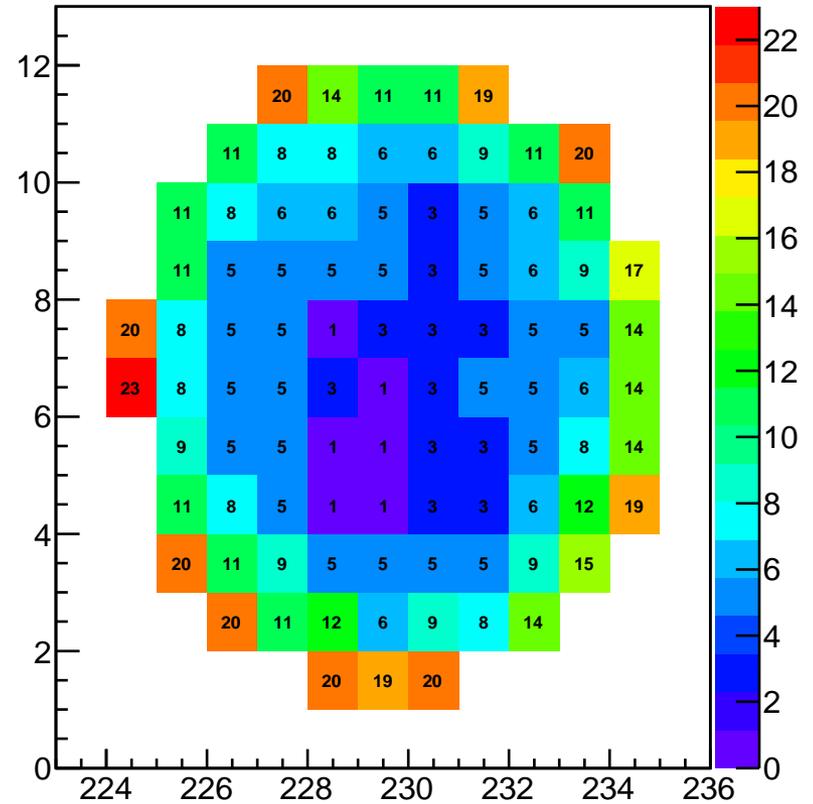


Alpha particle

Tot



Time (ns)



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Summary

- Timepix3 designed and fabricated in 2013
- Tests on bare chips and on wafers give good results
- First measurements with 300 μ m Silicon sensors look promising

	Bare chip	With 300 μ m Silicon sensor
Noise	55 \pm 2.9 e ⁻ rms	55 \pm 3.4 e ⁻ rms
Threshold mismatch (equalized)	35e ⁻ rms	35e ⁻ rms
Minimum threshold	500e ⁻	550e ⁻
TOT mismatch	6.5% rms	
Timewalk (1ke ⁻ above threshold)	10ns	
TOA < 25ns	Charge > 0.8ke ⁻	
TOA jitter < 0.5ns	Charge > 5.5ke ⁻	
Energy resolution		124e ⁻ (Cu) with equalization on noise floor

Thanks for your time and attention!

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Massimiliano De Gaspari for the CERN Medipix team (J Alozy, R Ballabriga, M Campbell, E Fröjdh, J Idarraga, S Kulis, X Llopart, T Poikela, P Valerio, W Wong), in collaboration with NIKHEF and the University of Bonn.

Thanks for your time and attention!

References:

- M. De Gaspari *et al.*

“Design of the analog front-end for the Timepix3 and Smallpix hybrid pixel detectors in 130 nm CMOS technology,” 2014 *JINST* 9 C01037

- T. Poikela *et al.*

“Digital column readout architectures for hybrid pixel detector readout chips,” 2014 *JINST* 9 C01007

- Y. Fu *et al.*

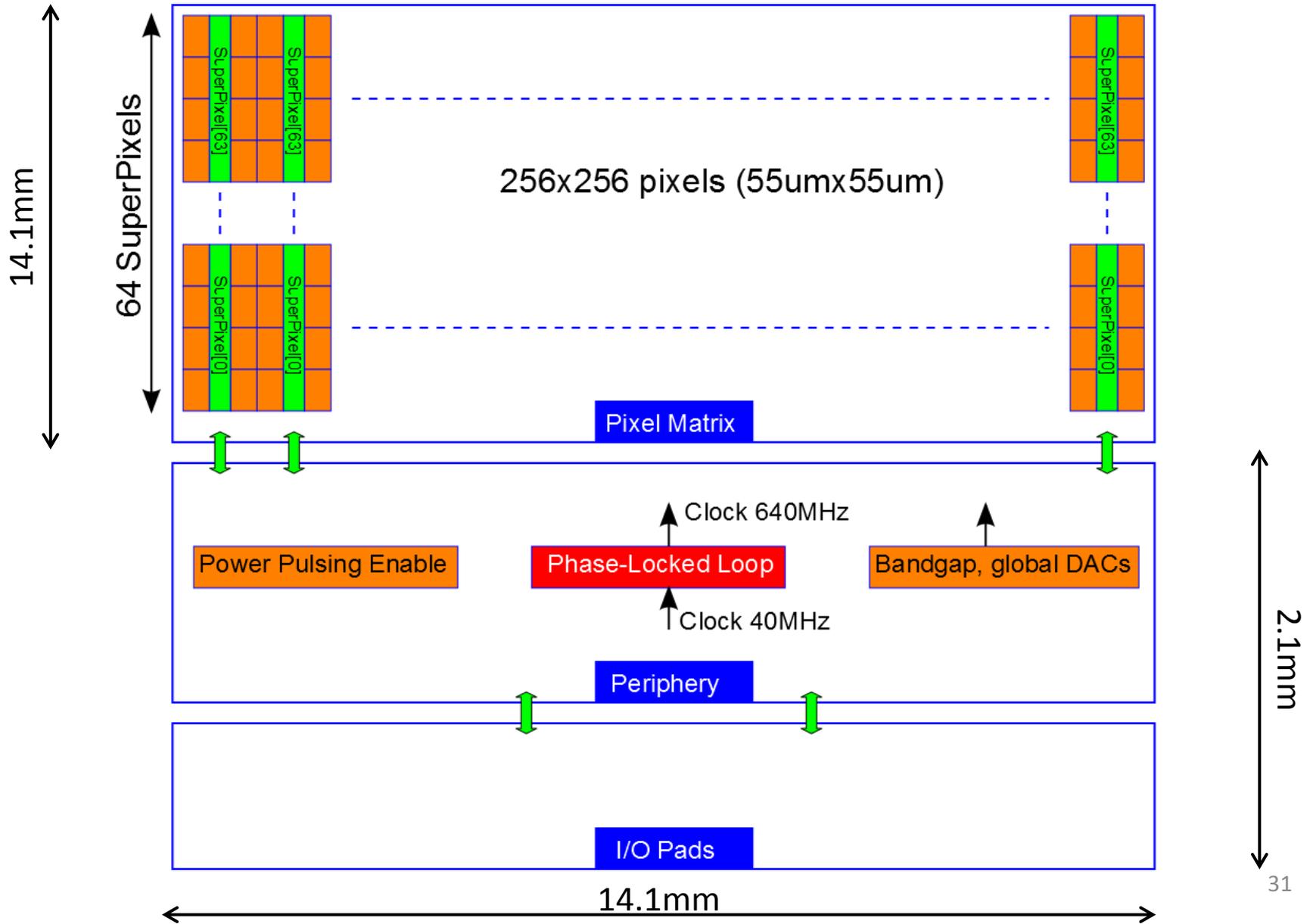
“The charge pump PLL clock generator designed for the 1.56 ns bin size time-to-digital converter pixel array of the Timepix3 readout ASIC,” 2014 *JINST* 9 C01052

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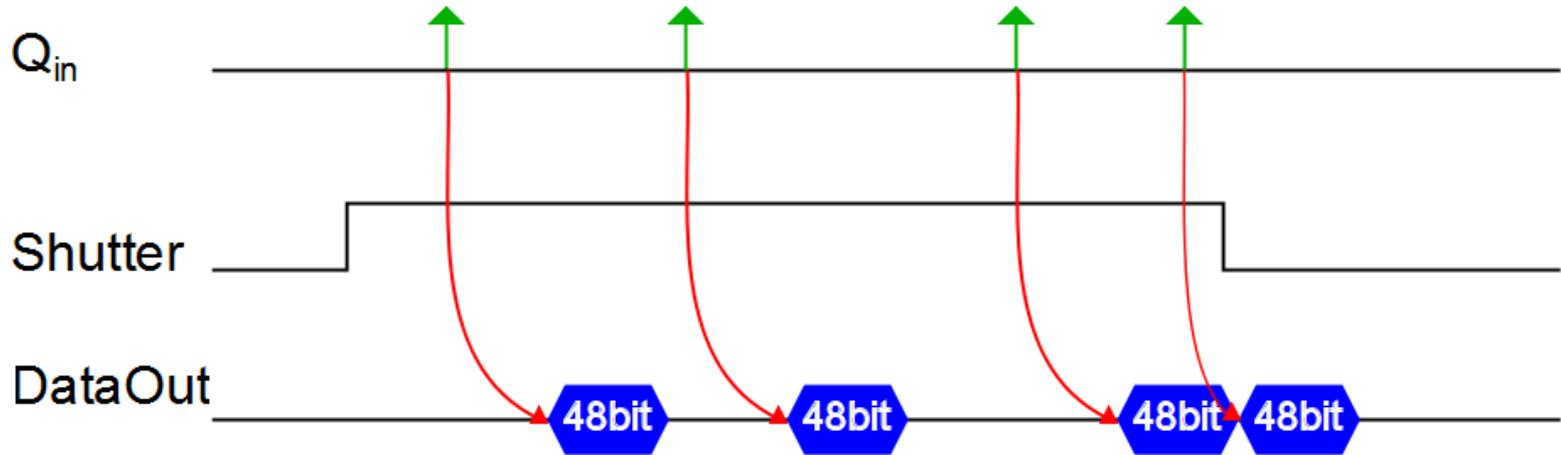
Outline

- Back up slides

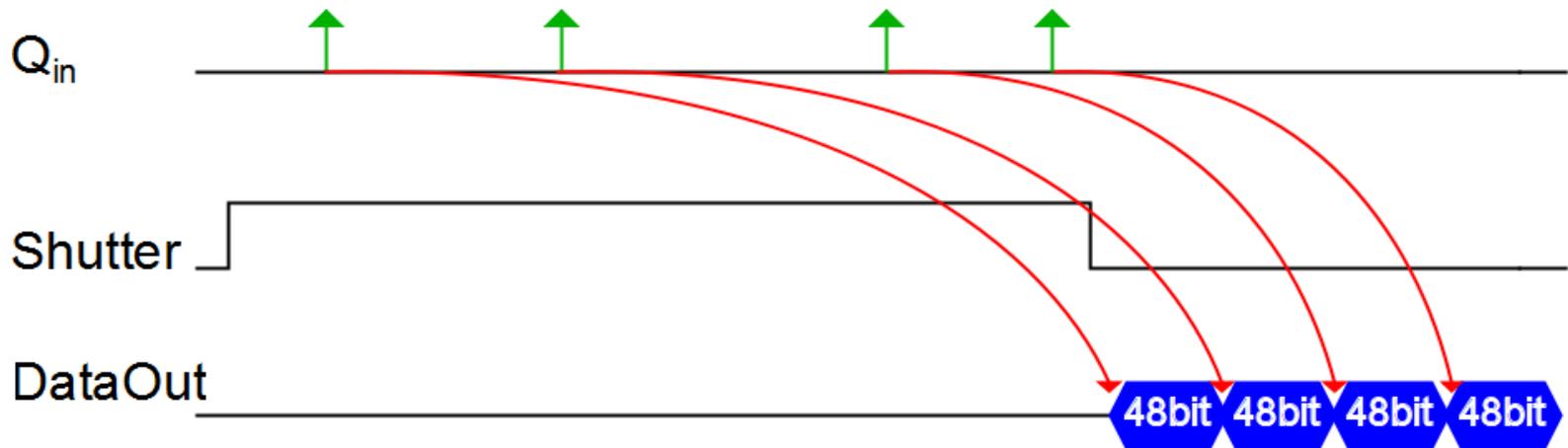
Timepix3 floorplan



Readout modes

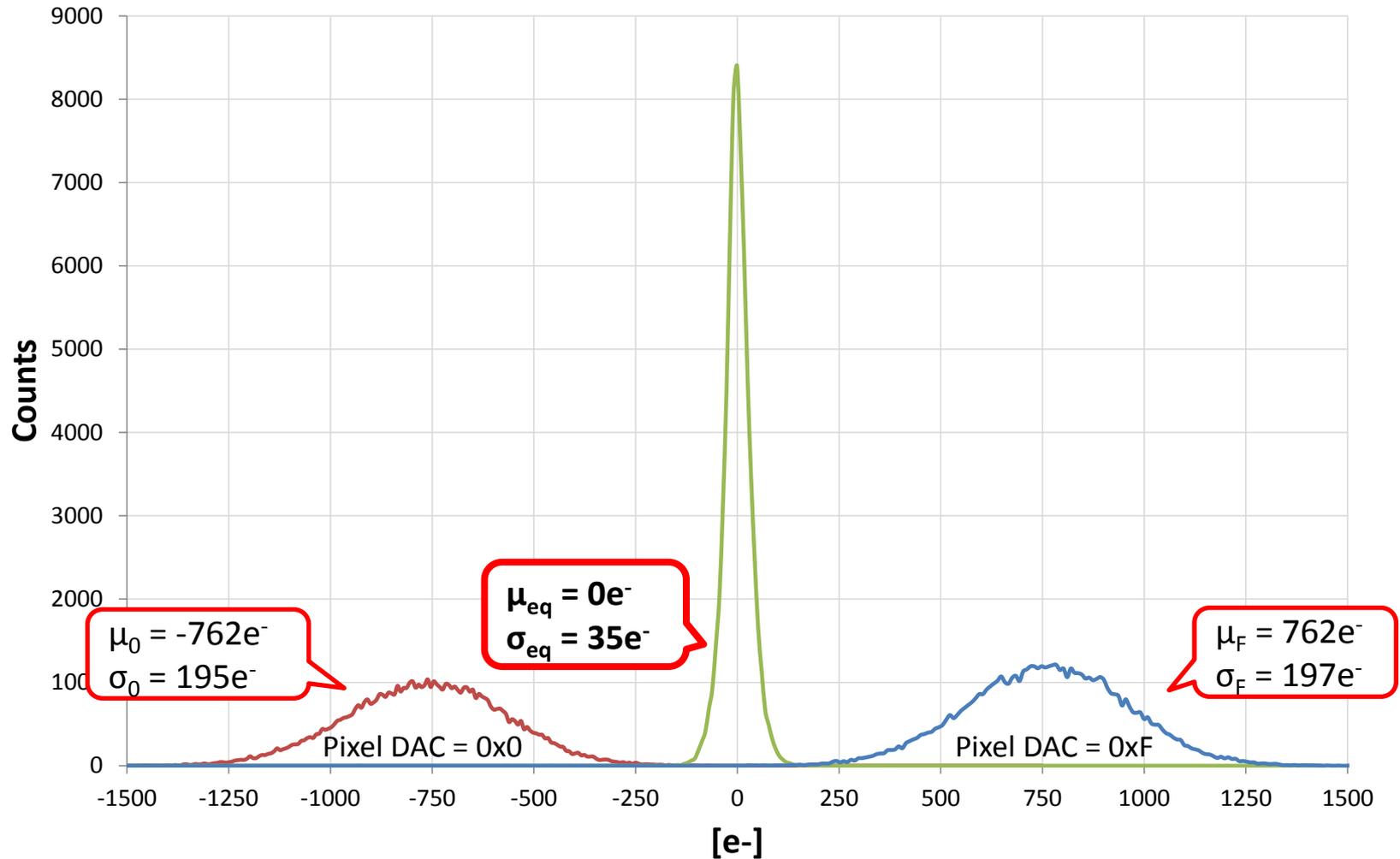


Data-driven readout mode.

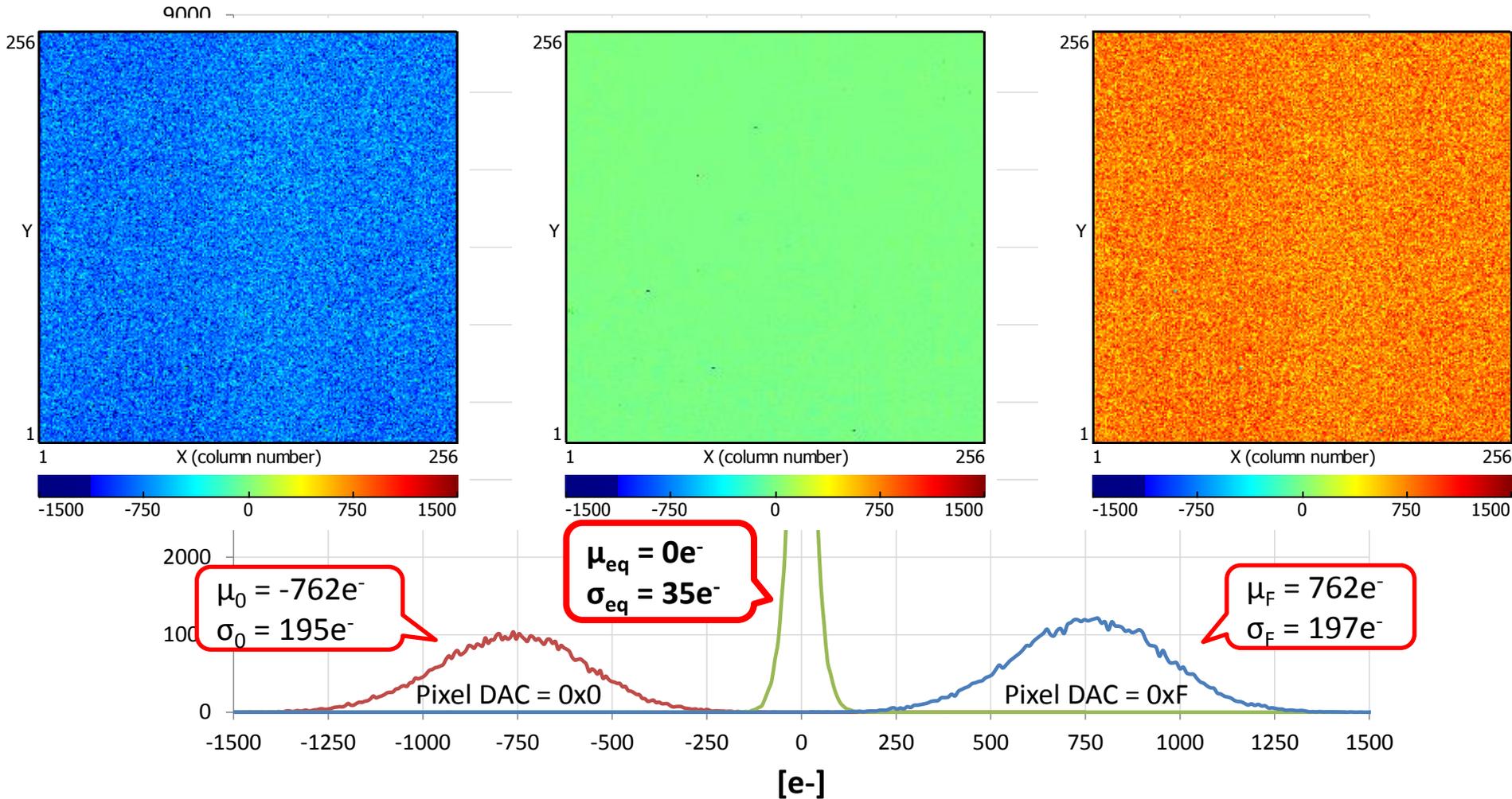


Sequential frame-based mode.

Threshold equalization



Threshold equalization



Fluorescence measurements

