Characterization of the IBEX ASIC for Electron Detection

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Motivation

1. ***The EIGER2 Silicon* hybrid photon counting (HPC) *detector is characterized for* Direct Electron Detection**

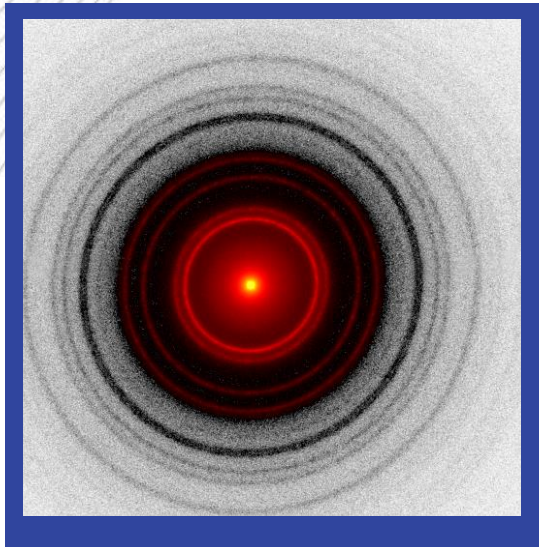
2. ***Important advantages vs traditional detectors***

   - noise free single-particle counting
   - high counting dynamic range
   - very high count rates
   - high MTF and DQE
   - high frame rate in kHz range

   → *optimal technology for Materials Science TEM experiments*

3. ***The detector QUADRO prototype***

   - produced electron diffraction patterns
   - achieved atomic resolution images



TedPella standard diffraction grating Al sample

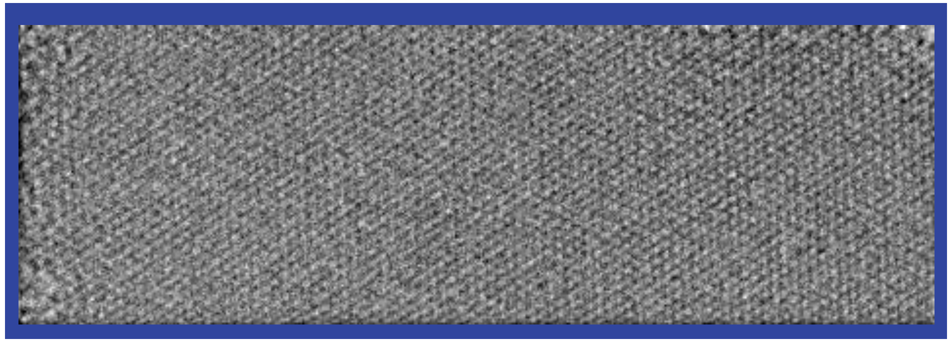


Image of Molybdenum Disulfide monolayer with atomic resolution

The EIGER2 Si Module (*)

Features	Value	Remarks
ASIC size / Pixel size	256x256 pixels / 75 x 75 μm^2	
Input signal polarity	hole/electron collection	
Energy Range	20 - 300 keV	
Threshold Range	5 - 120 keV	Noise-free electron counting
Counting Dynamic Range	16 / 32 bits	Continuous readout / high dynamic range No beam stop required for the un-scattered beam
Maximum Frame Rate	Up to 18000 Hz	In windowed mode
Detective Quantum Efficiency (0)	0.9 100keV; 0.99 200keV	Close to Ideal DQE
Count Rate Capability (CutOff)	28 Mcounts/pixel/second	Instant retrigger technology
Radiation Tolerance	yes	No damage observed (even after 10min of irradiation with 300keV electron beam @ flux ~ 250 Melectrons/pixel/s)

(*) Based on IBEX ASIC: Bochenek, M. et al. (2018), IBEX: Versatile Readout ASIC with Spectral Imaging Capability and High Count Rate Capability. IEEE Trans. Nucl. Sc., doi: 10.1109/TNS.2018.2832464.

Our Plan for Characterization

The IBEX ASICs bonded to Si sensor: 75µm pixel size/450µm thick

has been extensively characterized at TEM at DECTRIS (max energy 200keV)

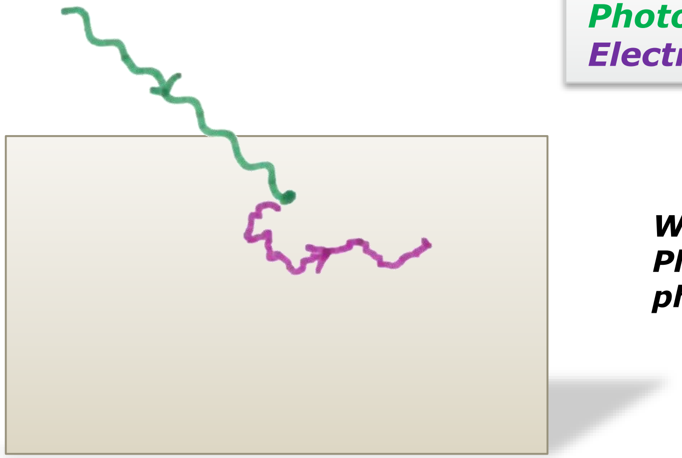
and up to 300keV at the Electron Microscopy Center at EMPA (Switzerland)

- Transmission Electron Microscope FEI Tecnai F20 @ DECTRIS Energy range up to 200keV

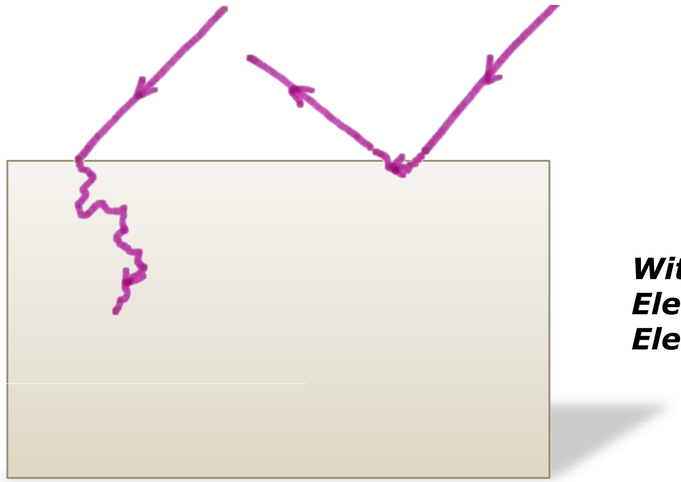
- Homogeneity
- Event Cluster size
- Spectral Properties
- Imaging Properties
- Rate and Stability
- Monte-Carlo Simulations with FLUKA Monte-Carlo package developed at CERN (http://www.fluka.org)

Simulation: Xray vs Electron Tracks in Si

Photons
Electrons



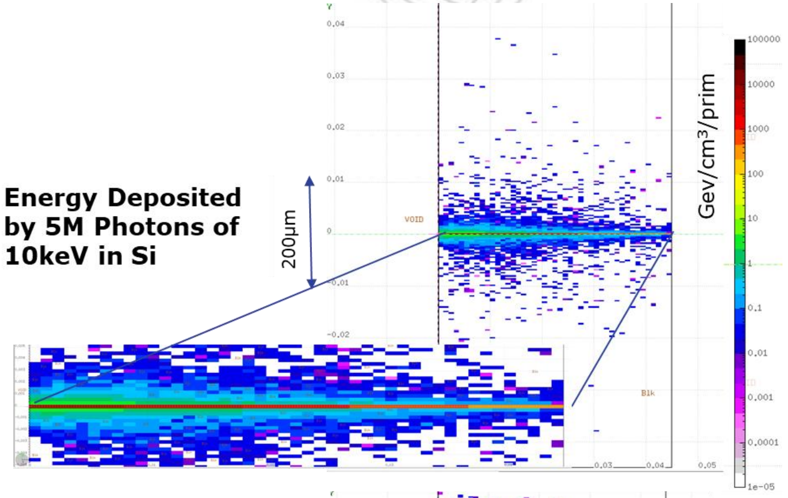
With X-rays:
Photon absorption by
photo-electric effect



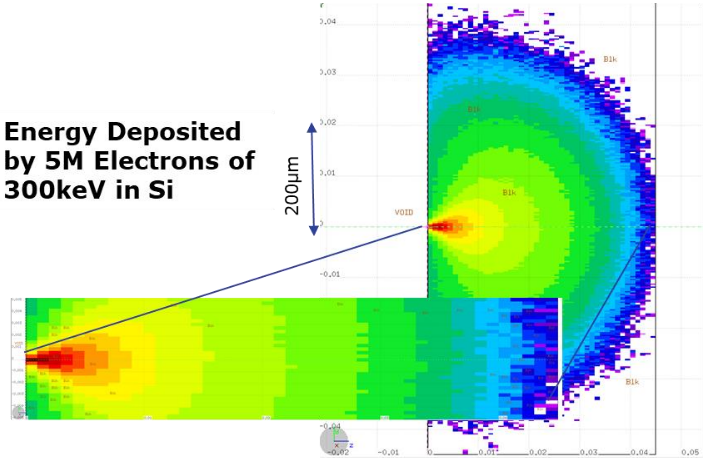
With electrons:
Electron-electron scattering
Electron-nuclei scattering

FLUKA Simulation

Energy Deposited by 5M Photons of 10keV in Si



Energy Deposited by 5M Electrons of 300keV in Si



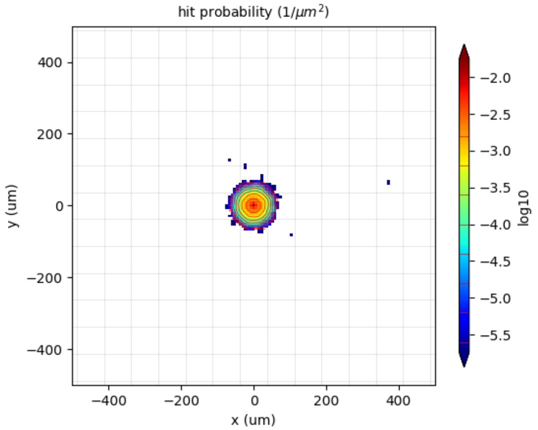
Simulation:

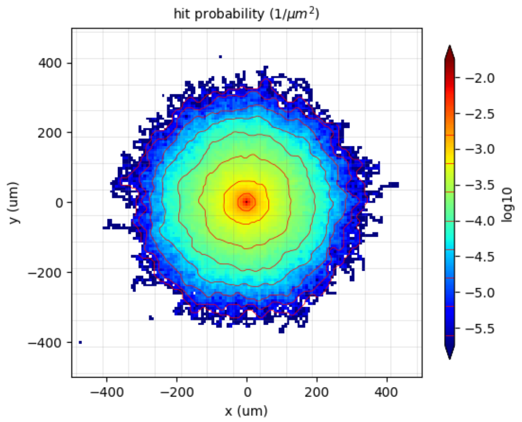
Probability for an electron to pass in Si box (7x7x10μm²)

Electron energy of 100keV

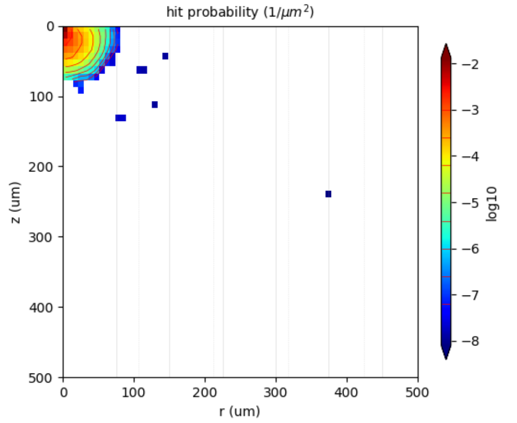
Electron energy of 300keV

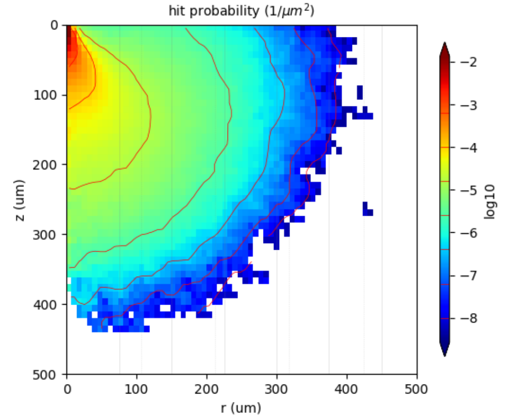
Top View

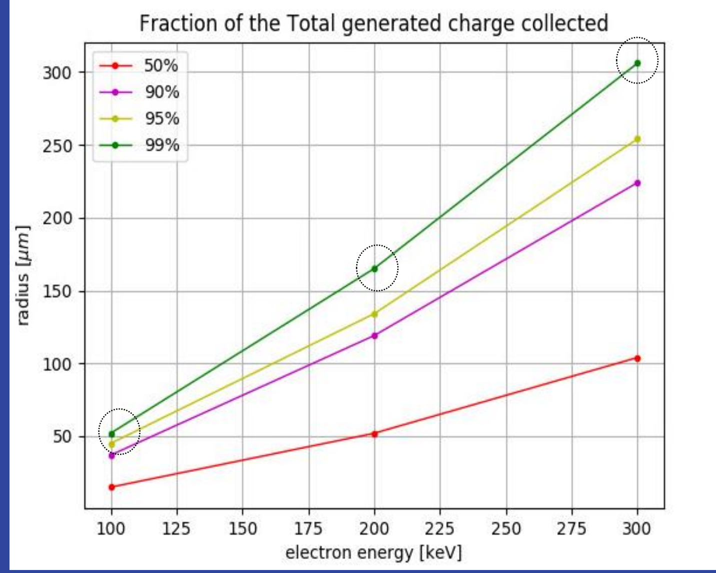




Side View



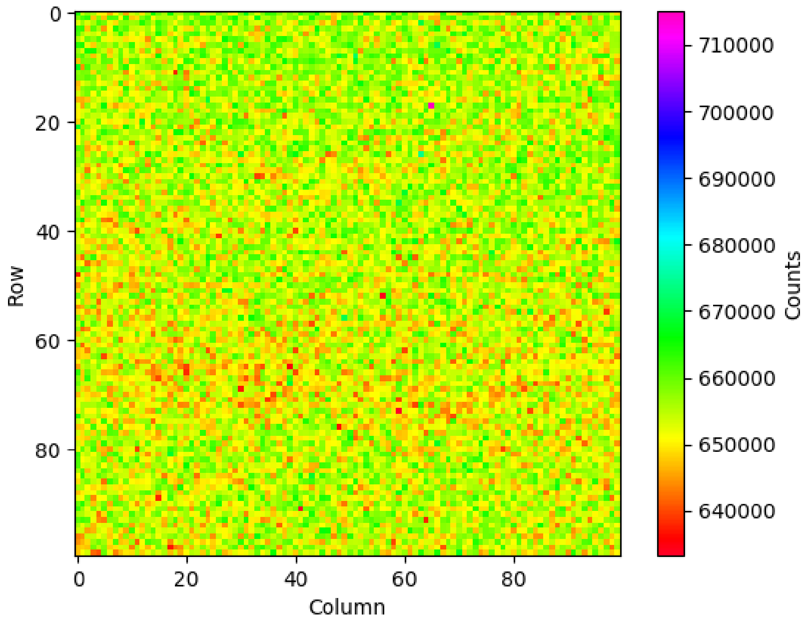




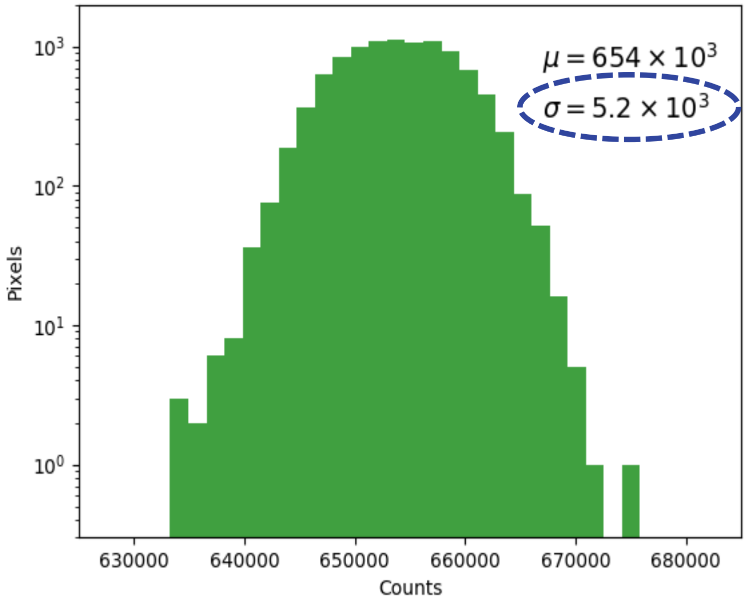
Detector Uniformity

1. **_Detector calibrated with X-rays fluorescence_**
   - global threshold, trimming and gain adjustment for different threshold settings from 5 to 120keV
2. **_Image with electron Energy=300keV, Ethr=30keV, no flat field applied_**
   - Small count dispersion after calibration with X-rays: σ/μ = 0.8%,

Not Flat Field corrected
Eng=300keV, Eth=30keV



Count Distribution
on 100x100 pixels
Eng= 300keV, Eth=30keV



Event Multiplicity / Cluster size

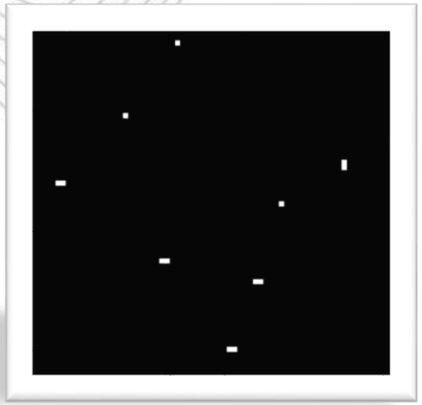
Defined as "the cluster size of a single electron event"

– depends on the track length in sensor → increases with electron energy

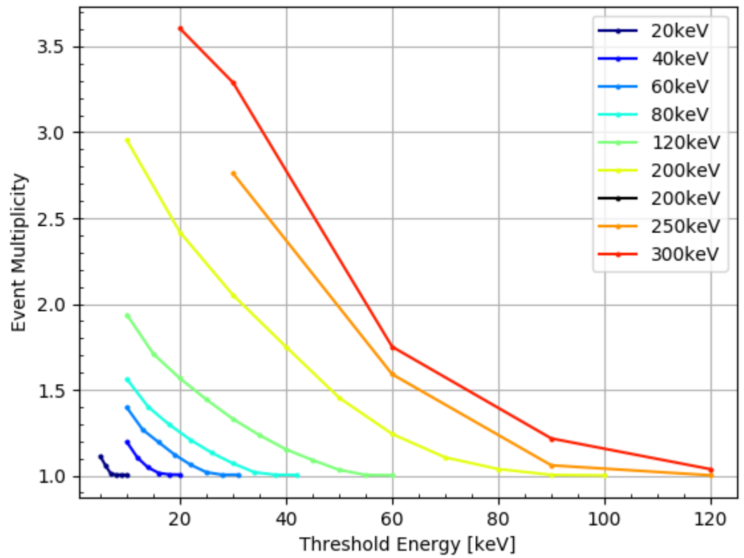
– depends on the shared charge → depends on the electric field in sensor

– depends on the threshold → from 3.5 to 1 @ half beam energy

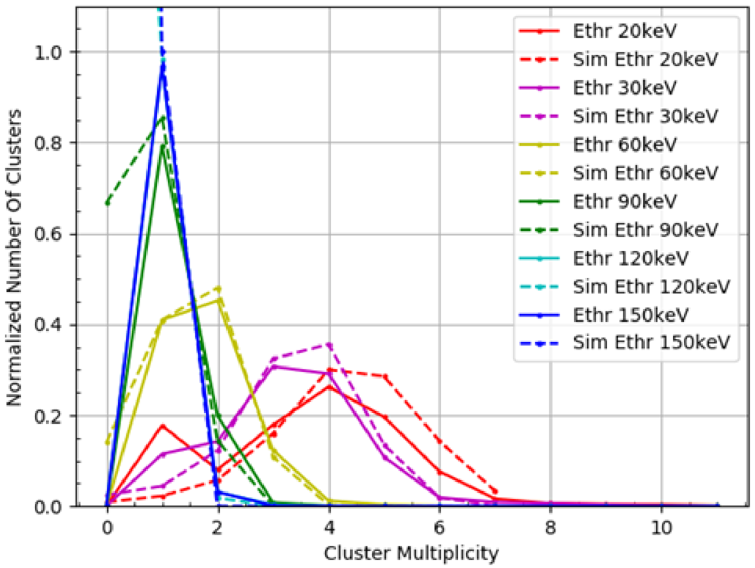
Low Statistic Image, Eng=120keV, Eth=30keV



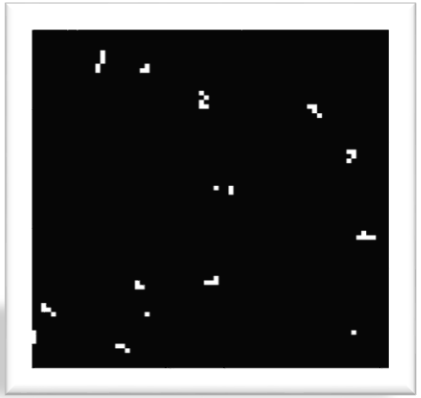
Average Multiplicity vs electron energy and Ethr



Normalized #clusters E=300keV, Simulation and Measurements



Low Statistic Image, Eng=300keV, Eth=30keV



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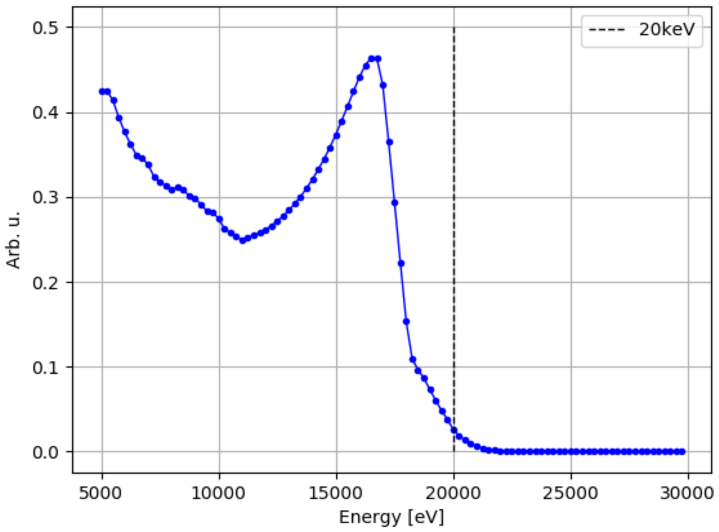
Electron energy spectra

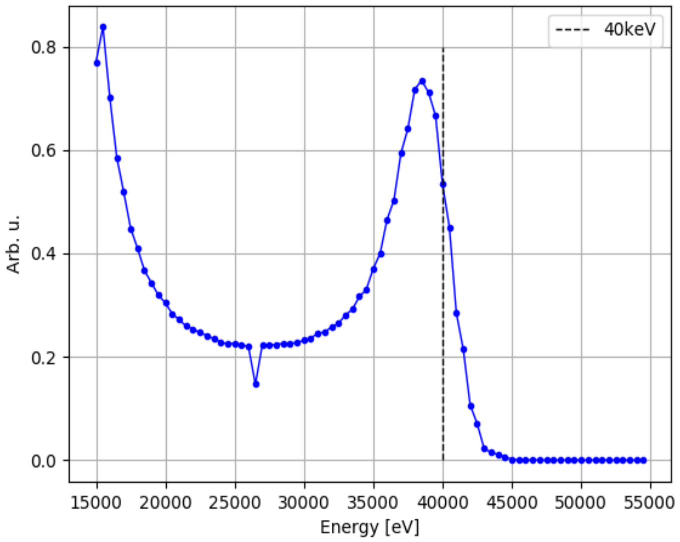
- peak shifts: mainly due to finite track length, charge sharing, insensitive layers on top of the sensor
- increase of the counts at energies <20keV: due to the backscattering and shared tracks

Electron energy of 20keV



Peak Pos = 16.59 keV
Peak Res rms= 0.87 keV

Electron energy of 40keV



Peak Pos = 38.73 keV
Peak Res rms= 1.44 keV

Imaging Properties

- Images with Al blade projection → ESF and LSF
- Fourier Transform of the LSF → MTF
- Fourier Transform of flat images → NPS
- the integral flux Q → measured with a Faraday Cup

$$DQE = \frac{SNR_{out}^2}{SNR_{in}^2} = \frac{MTF^2}{NNPS} * 1/Q$$

Single chip with Steel blade

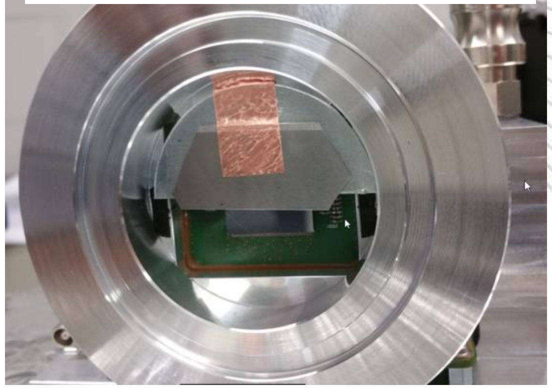
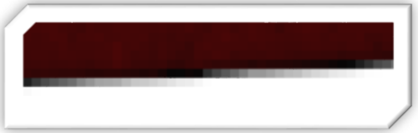
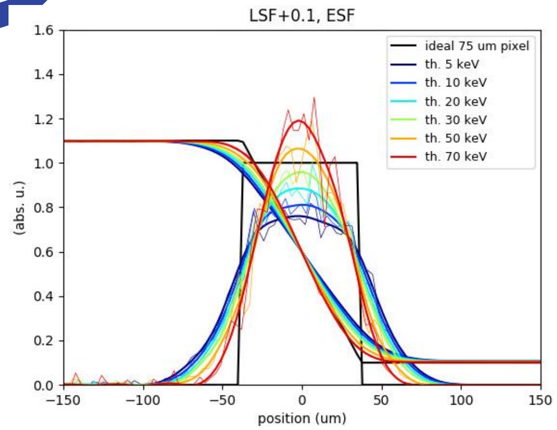


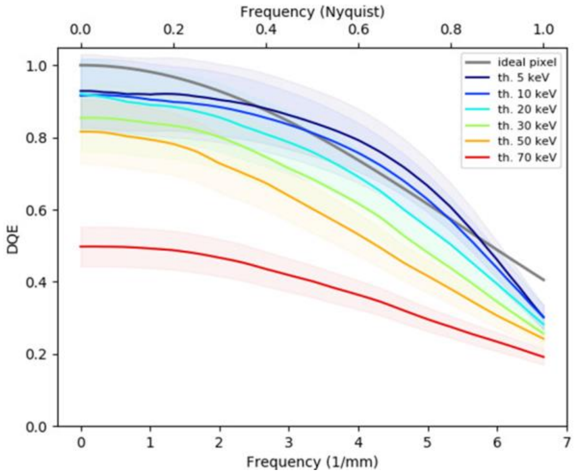
Image of the Edge
Electron energy of 100keV



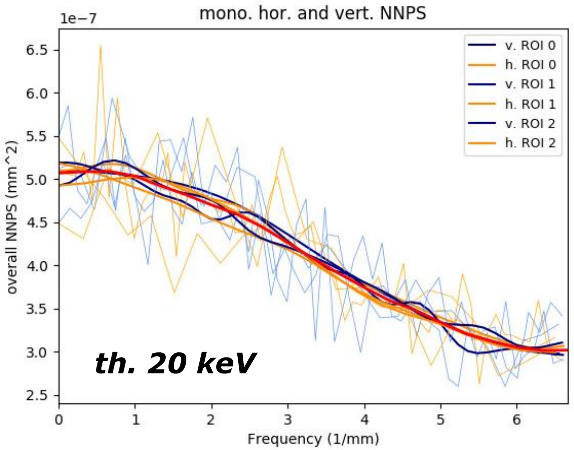
Edge/Line Spread Function



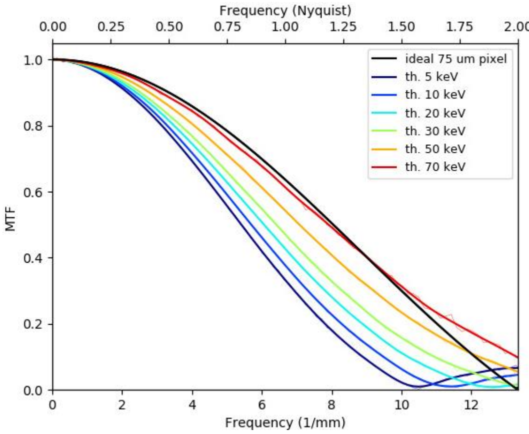
Detective Quantum Efficiency



Noise Power Spectrum



Modulation Transfer Function



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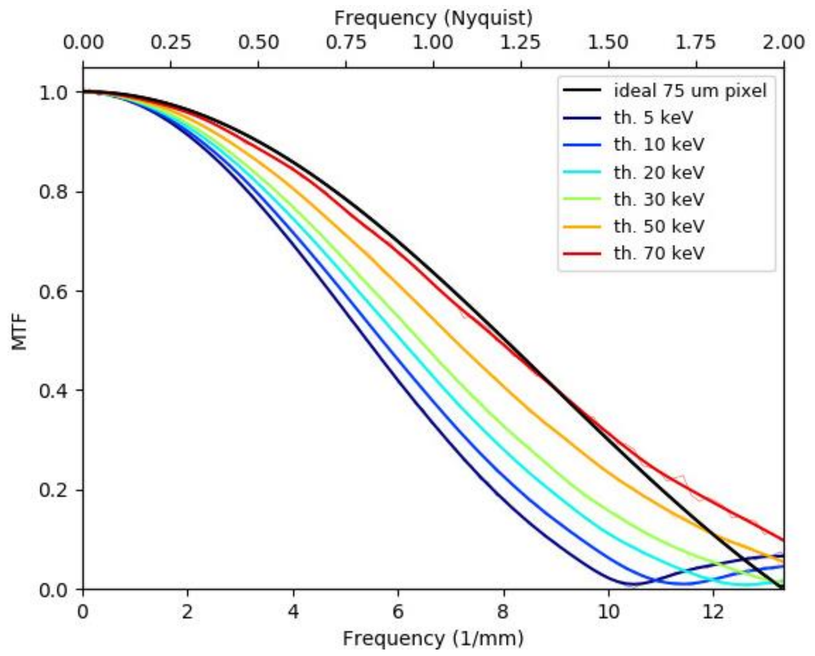
Modulation Transfer Function

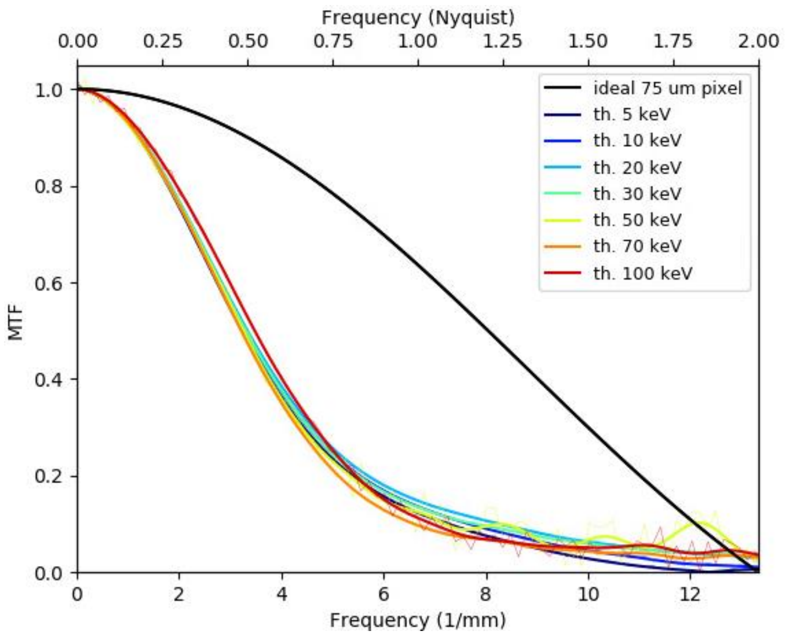
Higher MTF means better spatial resolution

- 100keV e-tracks ~55 µm → charge sharing at pixel borders → MTF depends on Ethr
- 200keV e-tracks ~170 µm → charge sharing does not matter BUT Long tracks degrade the MTF

Electron energy of 100keV



Electron energy of 200keV



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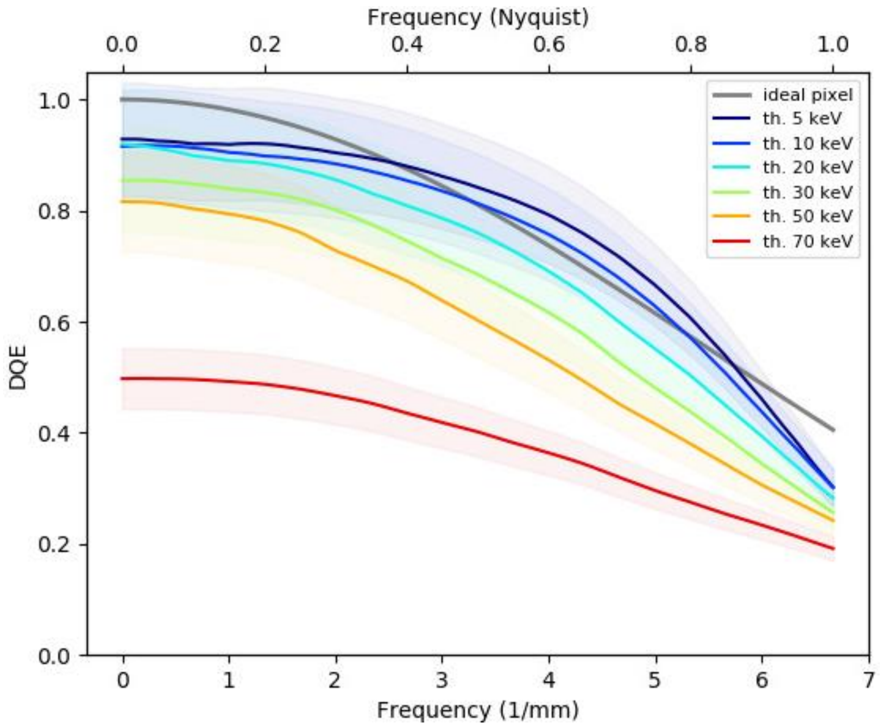
Detective Quantum Efficiency

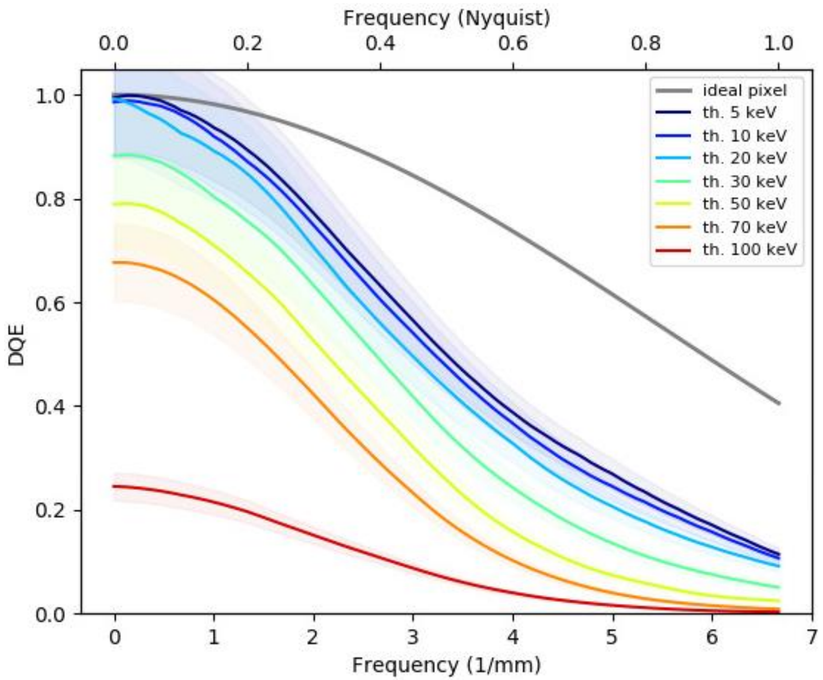
Higher DQE means better S/N

- DQE is better for lower energy thresholds
- 200keV the DQE is always lower than the ideal pixel due to the suppressed MTF by the long tracks

Electron energy of 100keV



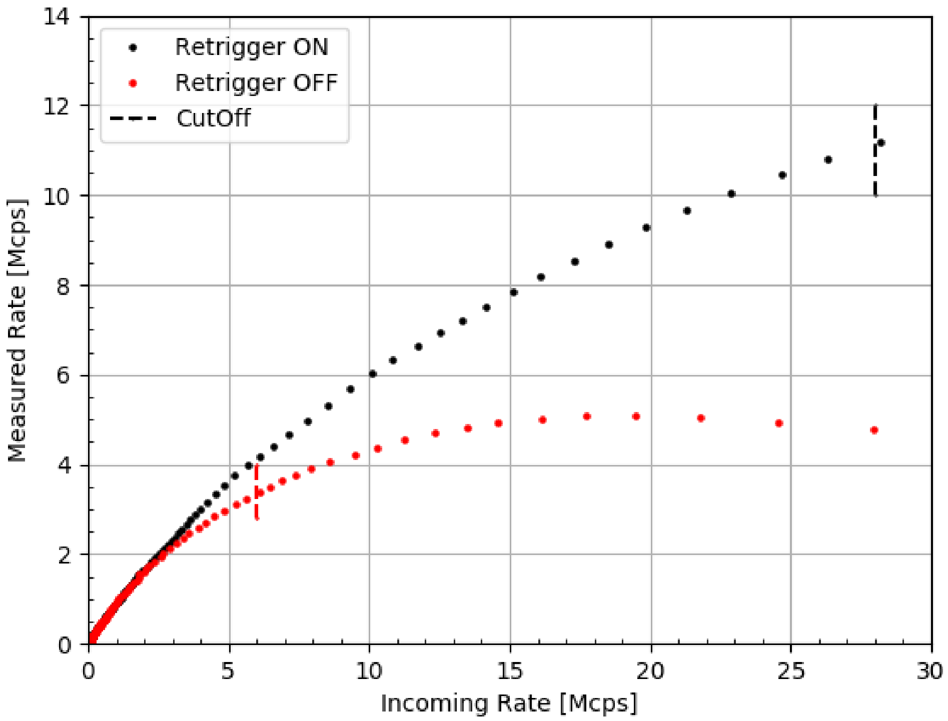
Electron energy of 200keV



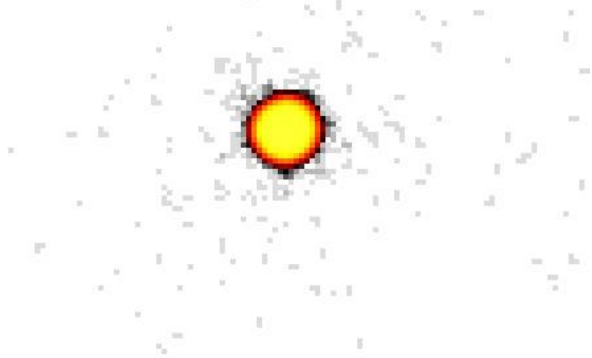
Count Rate Capability

- beam intensity is increased in small step
- background radiation at the spot border is used to normalize the incoming rate
- count rate depends on the ROC settings, the pixel size, E/Ethr, multiplicity *(Eng=80keV Ethr=30keV mult. 1.1)*

Electron energy of *80keV, Ethr 30keV*



Spot Size

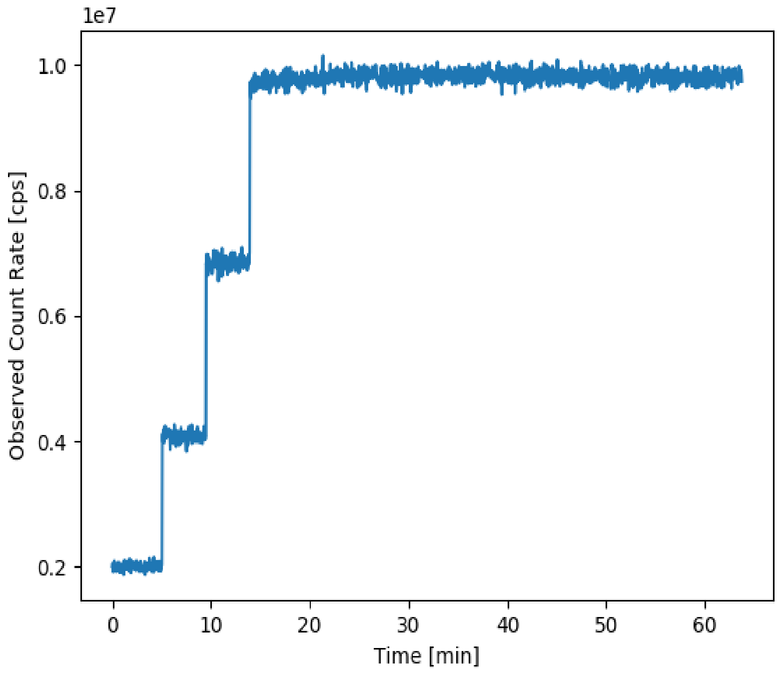


{*} CutOff is defined as the incoming rate @ the slope of the rate curve is 0.2/0.3 with Retrigger ON/OFF

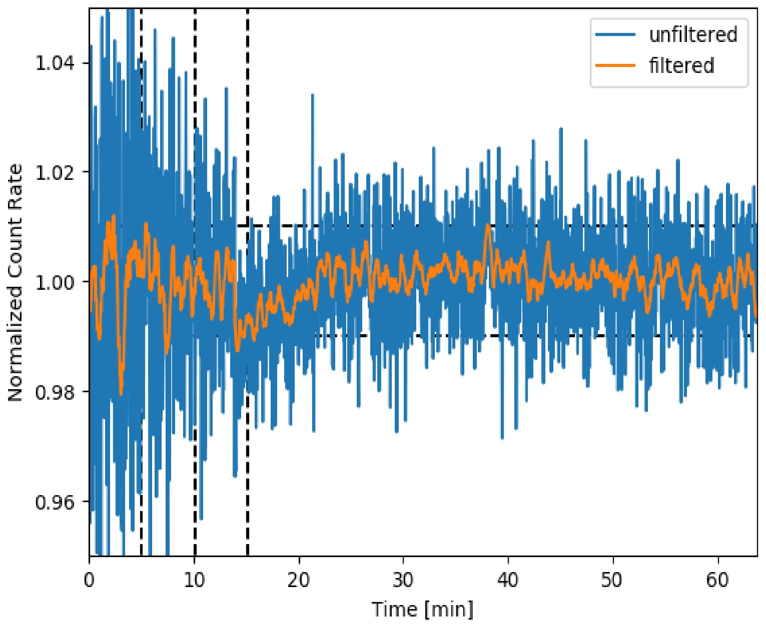
Count Stability

- beam intensity is increased in four steps up to 10Mcps/pixel kept for 50min
- background radiation to normalize to the beam variation
- the average intensity remains stable within one percent

Mean count stability
Electron energy of 300keV



Normalized intensity stability
Electron energy of 300keV



Summary

1. ***The IBEX ASIC bonded to Silicon sensor has been extensively characterized with electrons up to 300keV***

2. ***The full set of experimental results are compared with simulations***

3. ***Count homogeneity has dispersion less than 1%***

4. ***DQE* is excellent**

5. ***High rate capability thanks to the Instant Retrigger Technology***

6. ***Count rate is stable at high fluxes***

The very good performance is ideally suited for most advanced Material Science application at TEM

Dectris Team in Engelberg in 2018

Thank your for your attention!

BackUp Slides

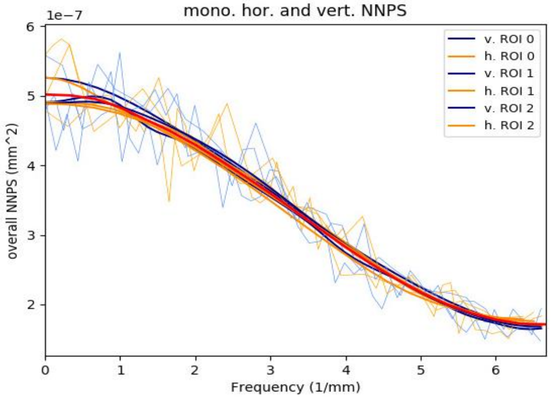
Noise Power Spectrum

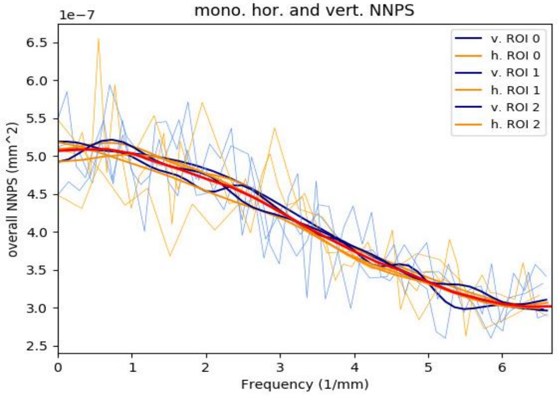
Lower NPS means less noise

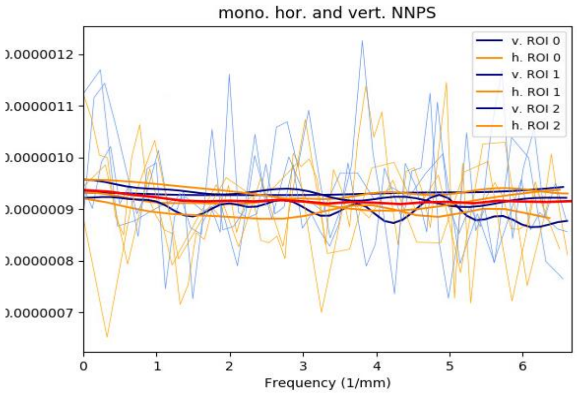
- Correlated to the event multiplicity, i.e. strongly depends on the threshold energy,

Ethr 5 keV ***th. 20 keV*** ***th. 70 keV***

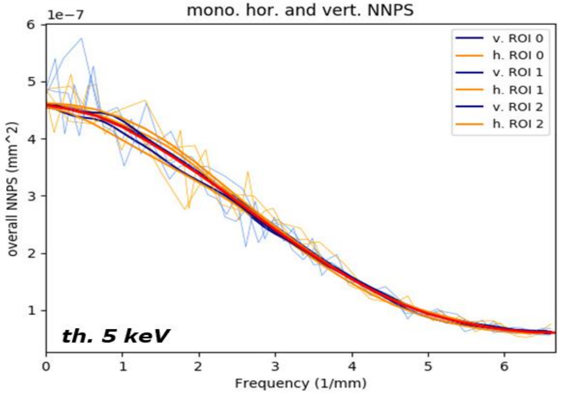
Electron energy 100keV

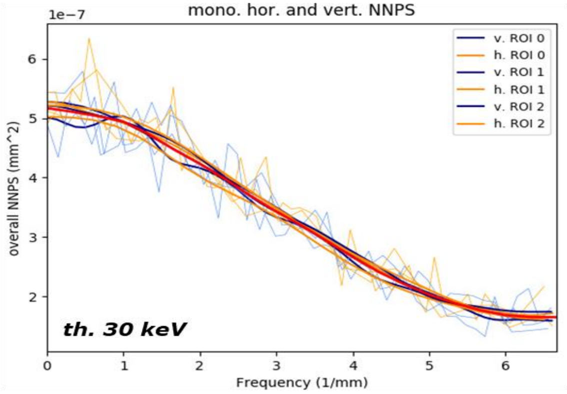


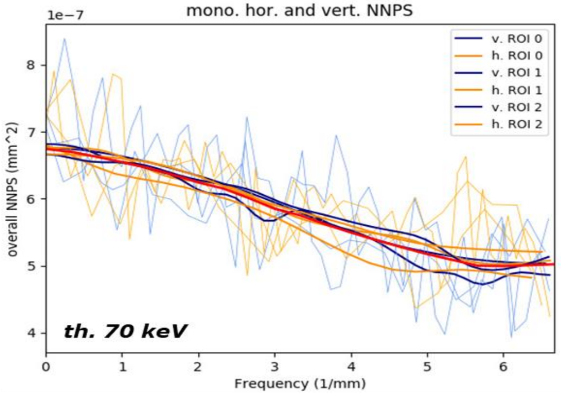




Electron energy 200keV







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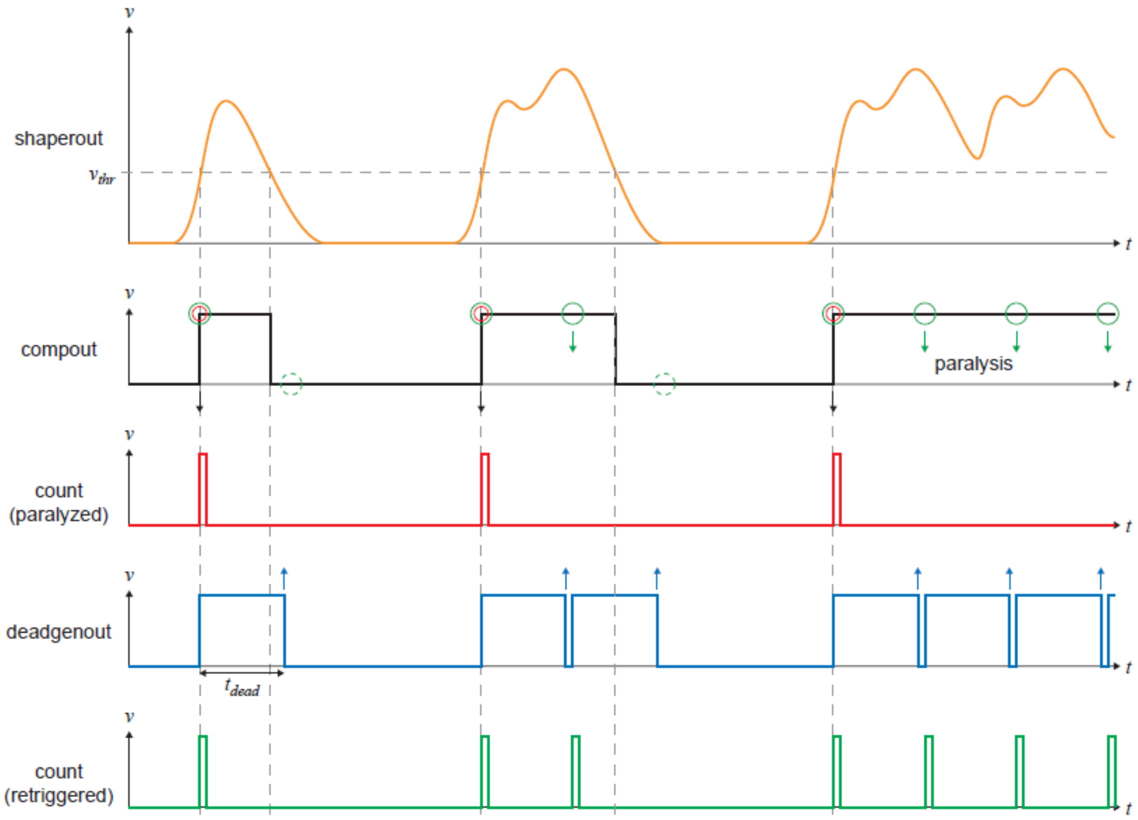
Instant Retrigger Technology



Dead time: the signal pulse is re-evaluated after a predetermined interval after each count
Count: the counting circuit is retriggered in case of pulse pile up → non-paralyzable counting

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