Binary Readout

Detector WS 2016
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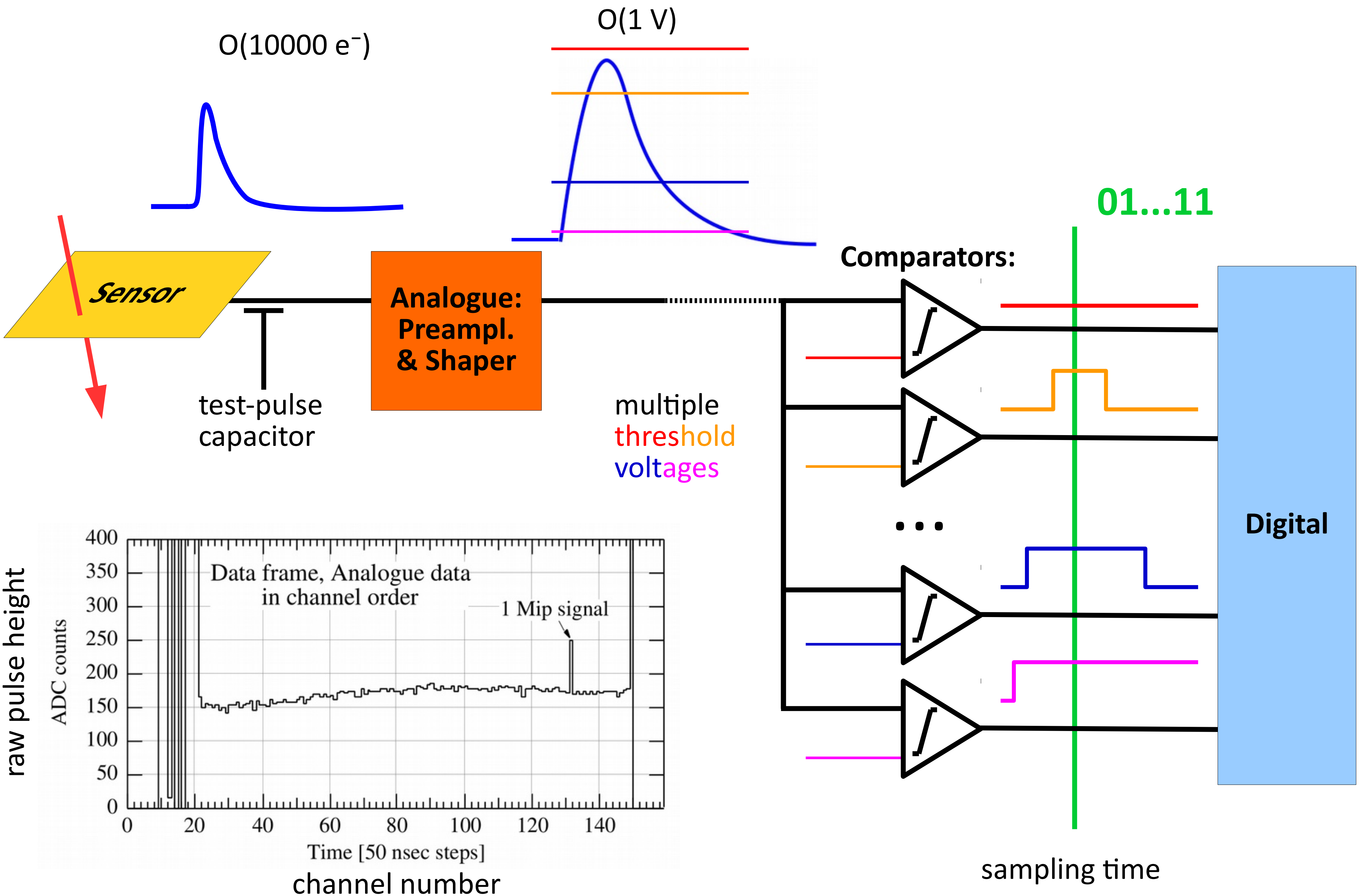
Overview

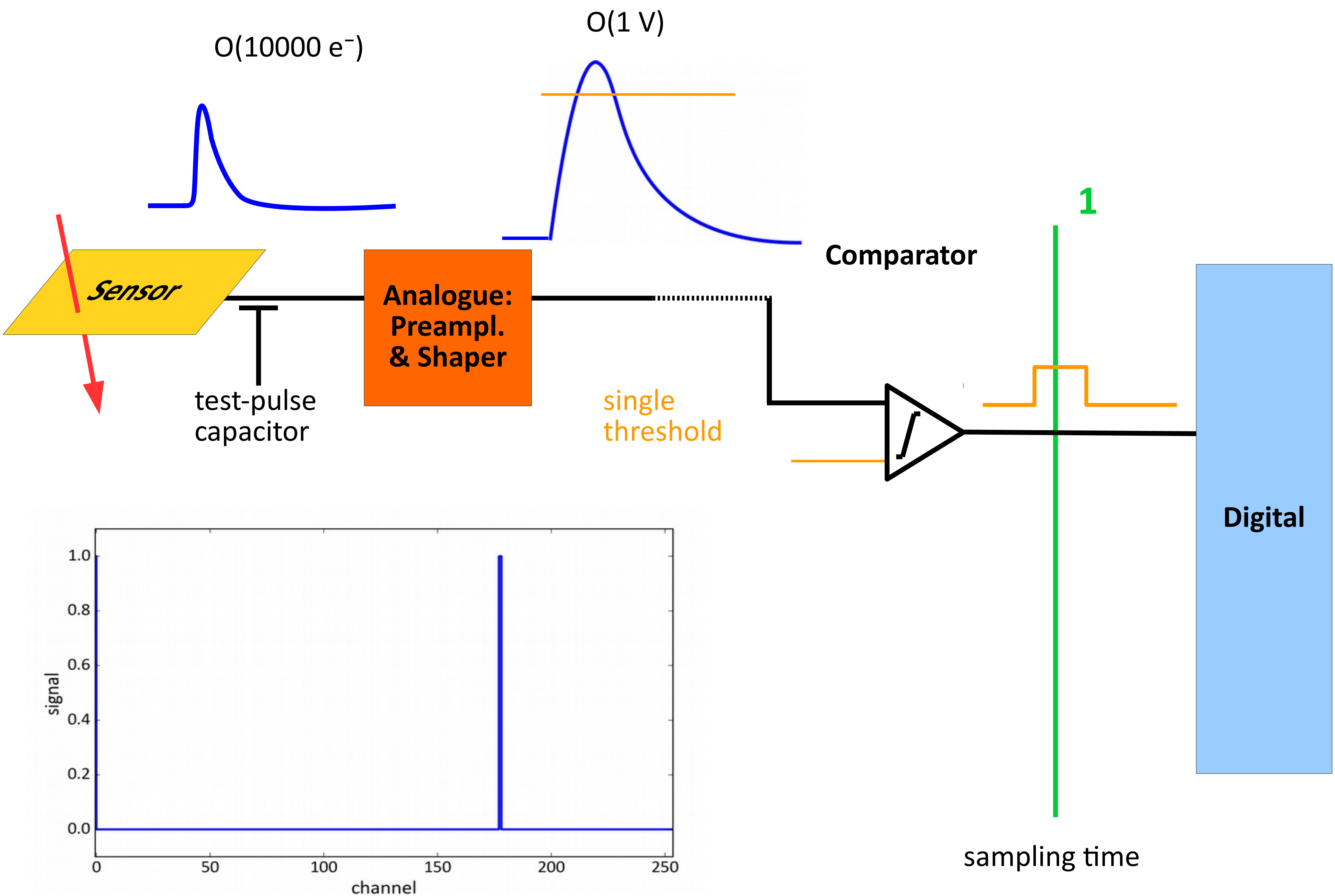
- introduction
  - micro-strip detector readout
  - motivation for binary readout

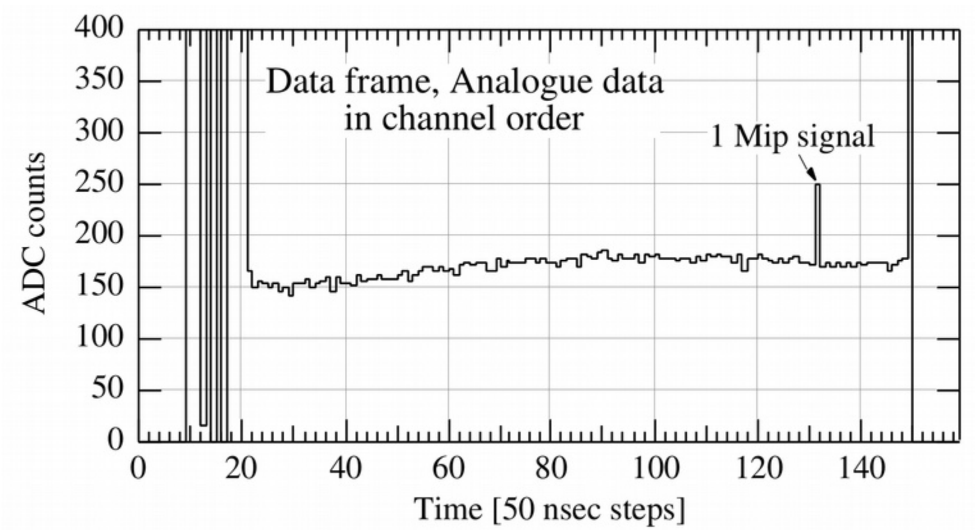
- noise
  - single channel noise
  - common mode noise

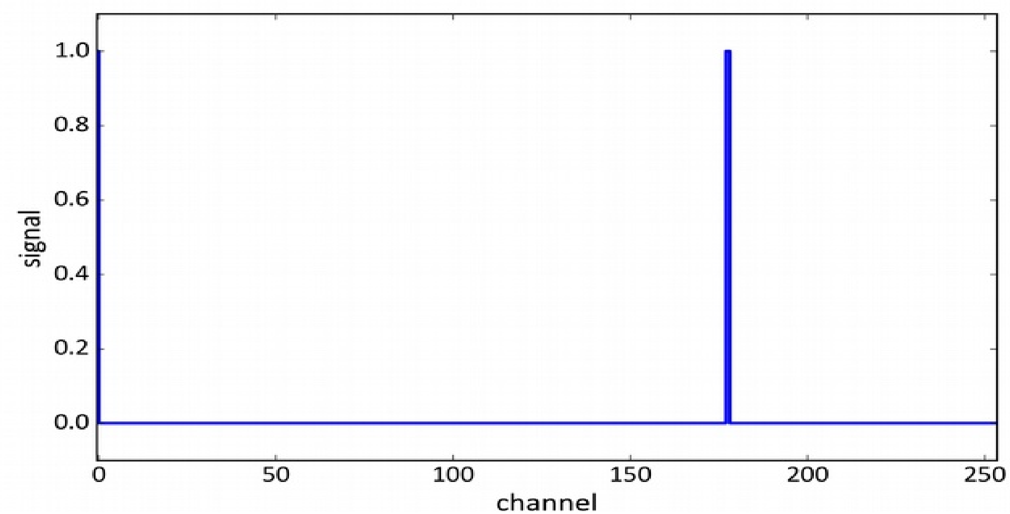
- signal
  - test-pulses
  - x-rays
  - mips (Sr90 betas)

Non-Binary Readout Chain

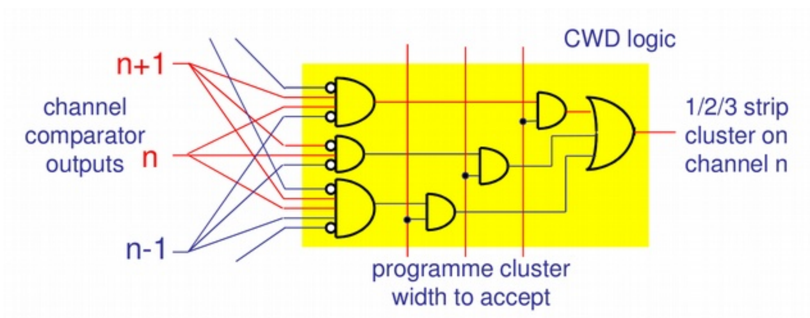



O(10000 e⁻)
O(1 V)
Sensor
test-pulse capacitor
Analogue: Preampl. & Shaper
single threshold
Comparator
1
Digital
sampling time
signal
channel
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250





- in binary readout system the only information you can extract is a lower bound on the signal height
- cons: during *normal* operation no measurement of the (common mode) noise, no dE/dx
- pros:
  - more efficient in terms of bandwidth & cache (~x10 without any zero suppression)
  - for CMS Phase2 Tracker: incorporate fast binary logic on read-out chip:
    - simple clustering, “stub” building
      … with handfull ORs / ANDs / NEGs
      (fast and power-efficient, *coarse*)

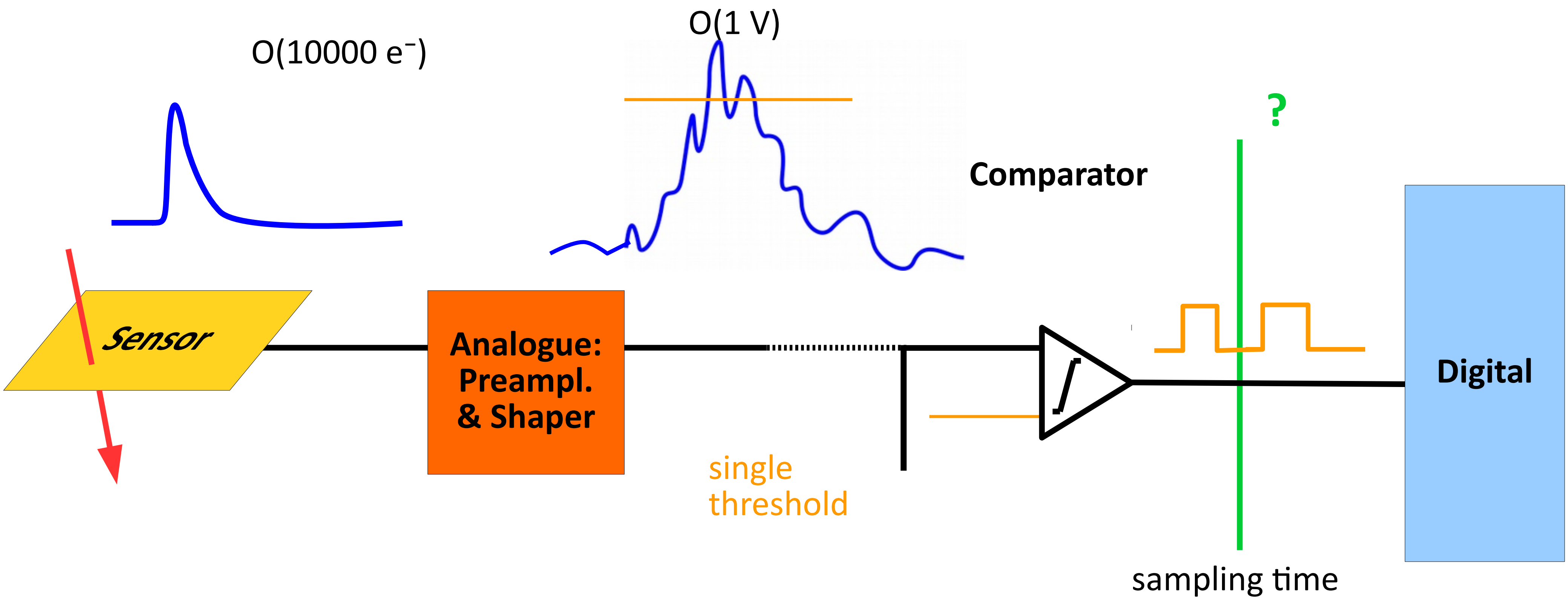


- identify and quantify noise & signals to distinguish them

Noise

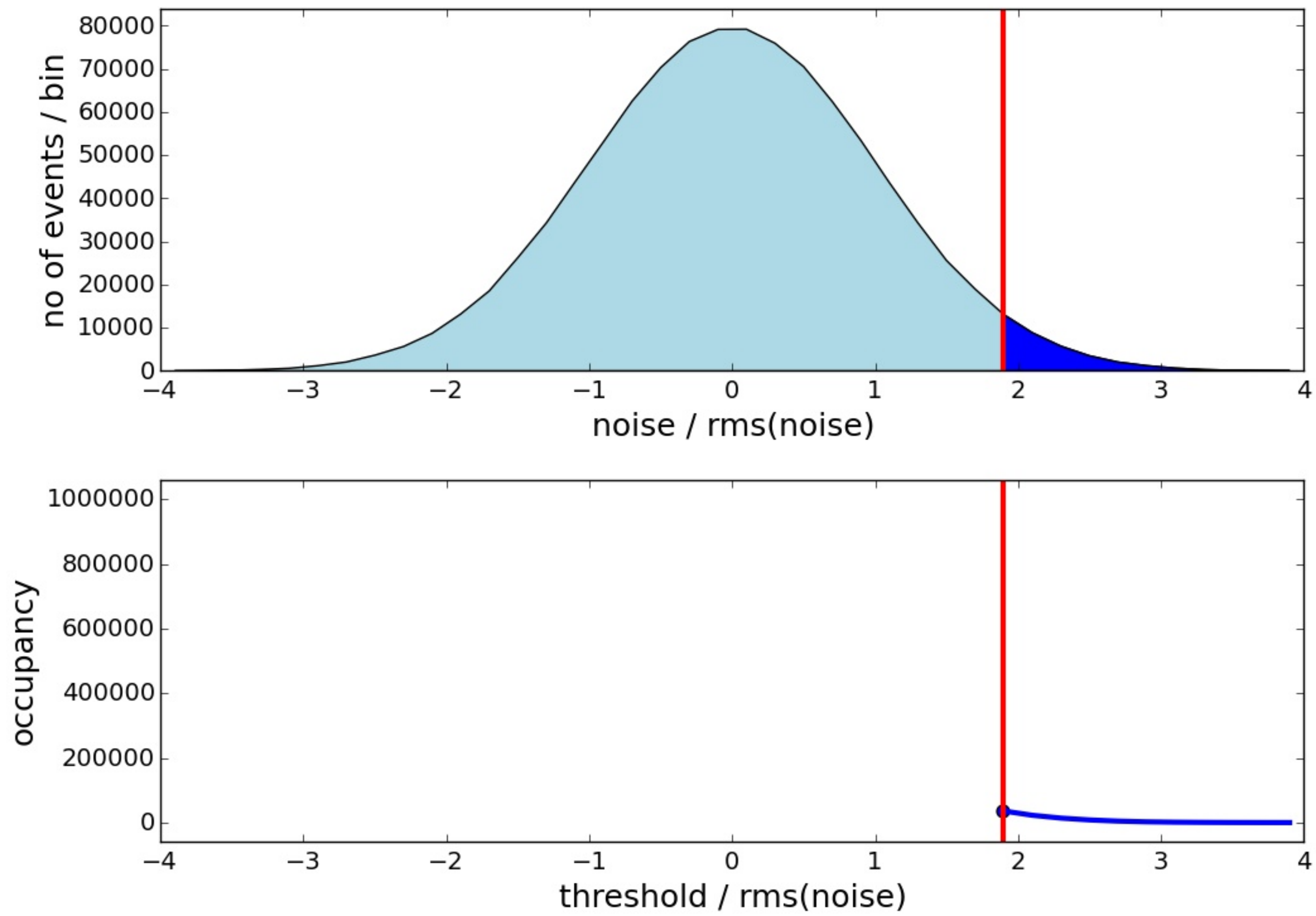
- single channel / intrinsic noise
- common mode noise

- definition: noise is a random fluctuation in an electrical signal



- if not (noise << signal): potential challenges / problem
- one needs to verify that in a complete system (modules, petal, …) the signal pulse height (S) is sufficiently large compared to the noise (N)
  - trackers: S/N > 10

Noise & S-Curves in Threshold Scan



- assume Gaussian distributed noise: → mean μ, width σ
- if signal exceeds threshold τ is converted into a hit

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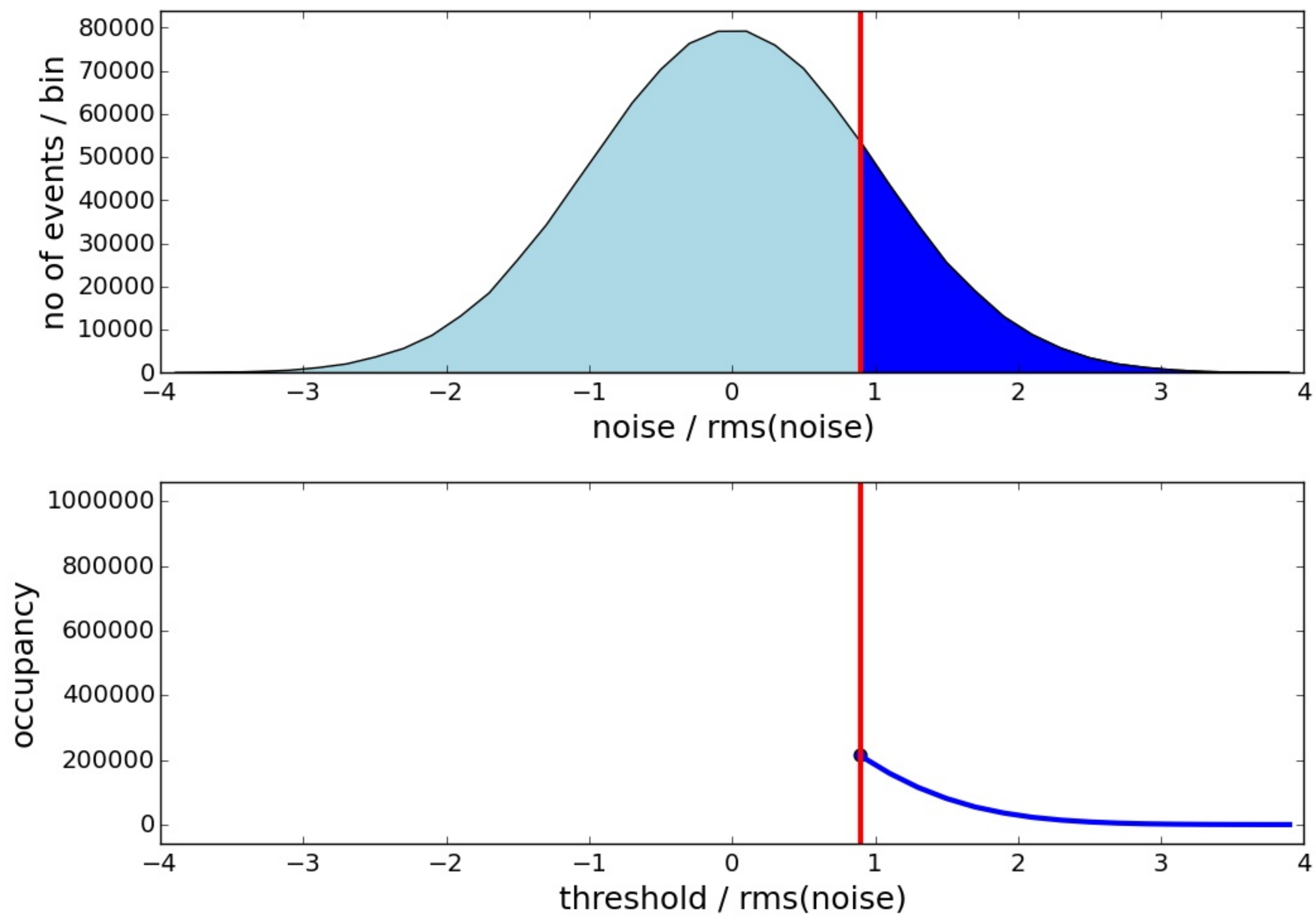

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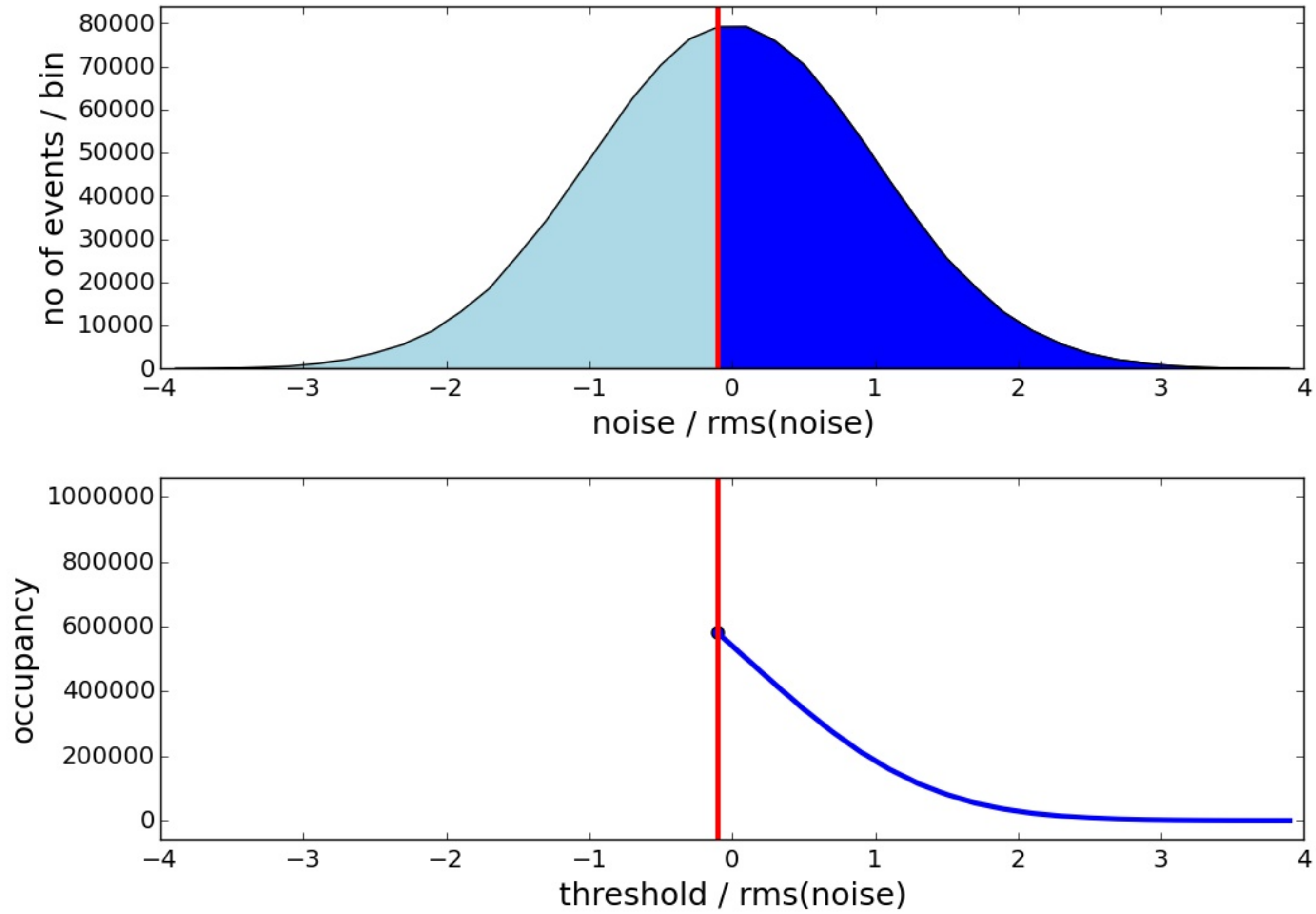

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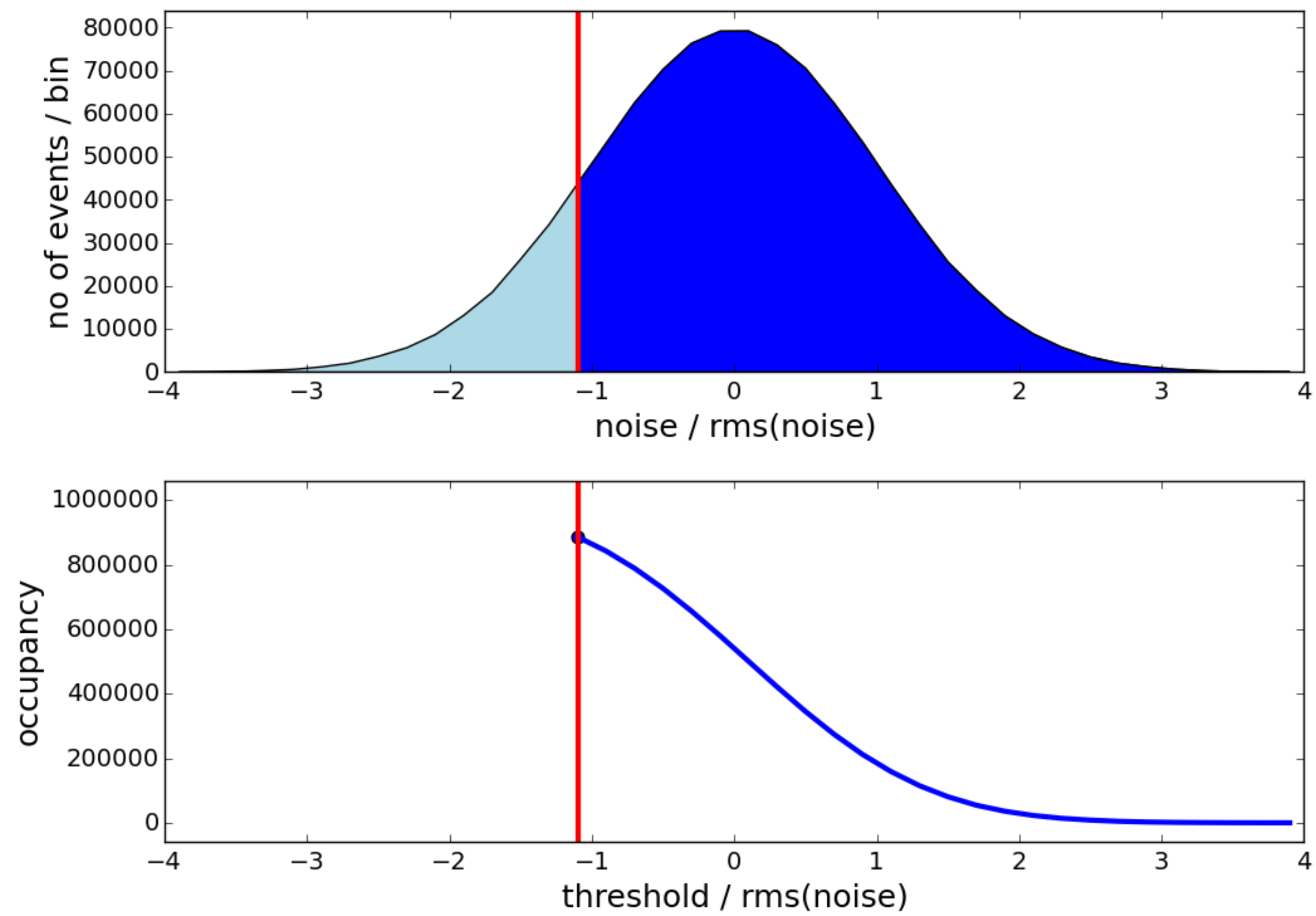

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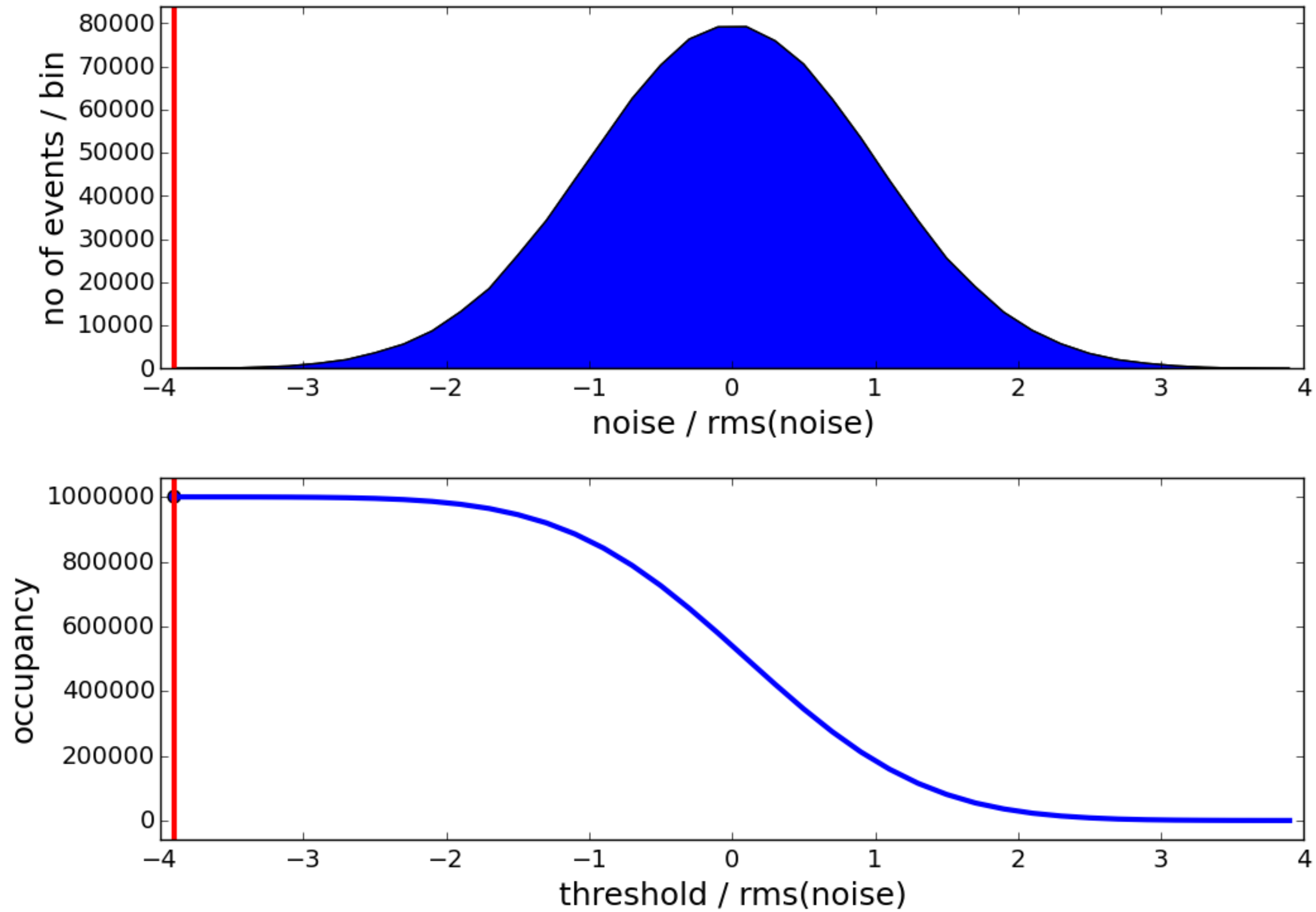
Noise & S-Curves in Threshold Scan

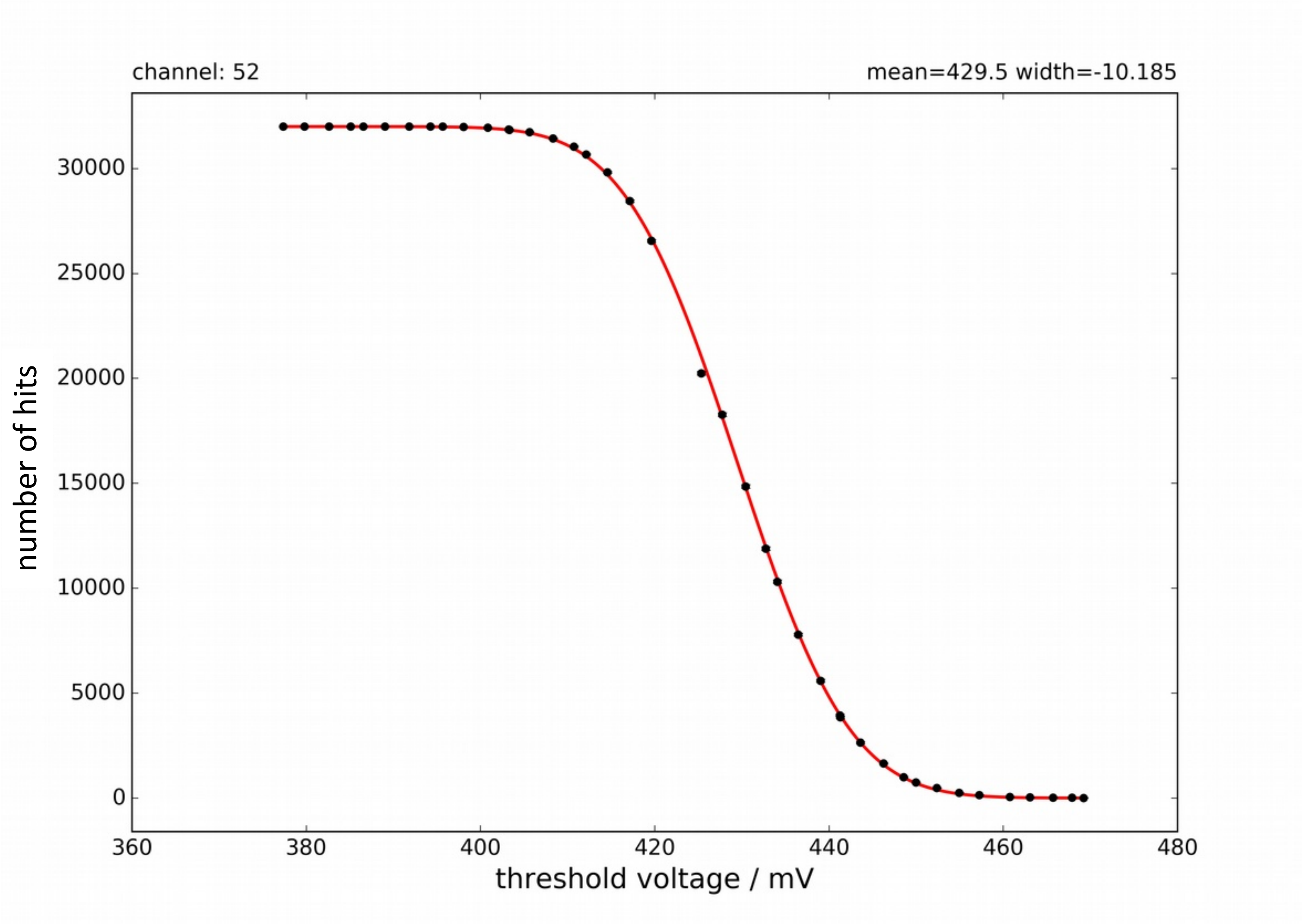


- assume Gaussian distributed noise: → mean μ, width σ
- if signal exceeds threshold τ is converted into a hit → results in **s-curve**
- probability of a noise hit:

$$p(\mu,\sigma,\tau)=\frac{1}{\sigma\sqrt{2\pi}}\int_{\tau}^{\infty}\exp\left(\frac{-1}{2}\left(\frac{\tau'-\mu}{\sigma}\right)^{2}\right)d\tau'=\frac{1}{2}\left(1+erf\left(\frac{\tau-\mu}{\sqrt{2}\sigma}\right)\right)$$

Example S-Curve Measurement

- extract the width and mean of the noise from a 'signal depleted' threshold scan
  - fitting number of hits vs. threshold with an error-function
  - in units of the threshold



single channel in CBC2 chip

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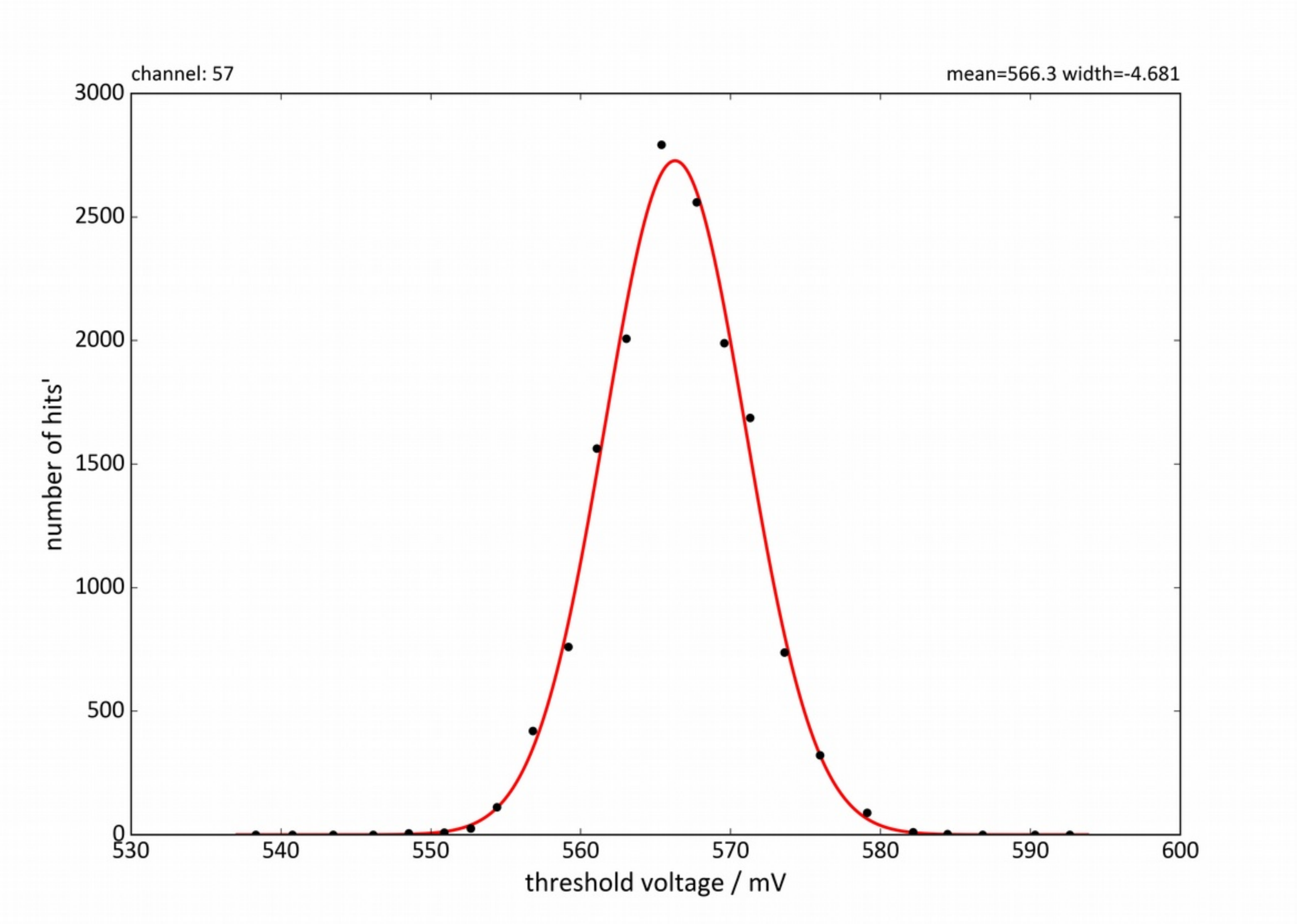

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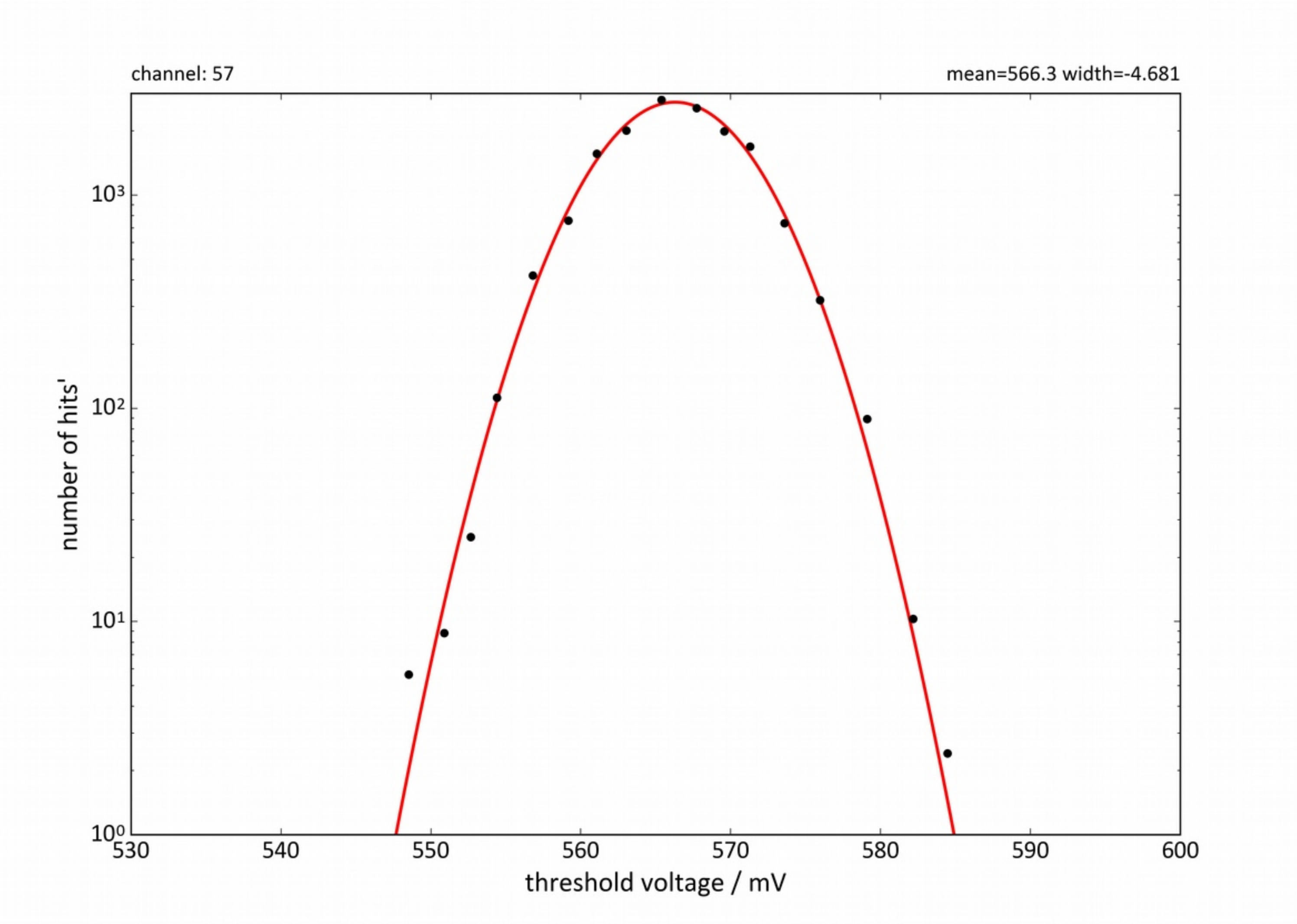
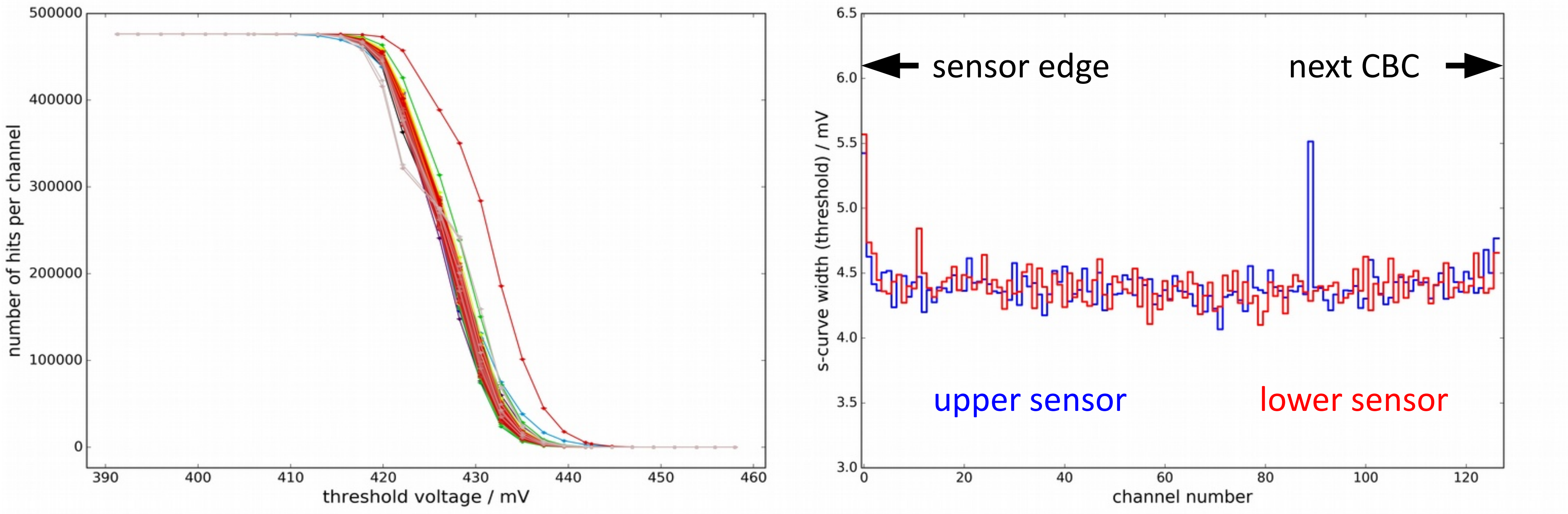


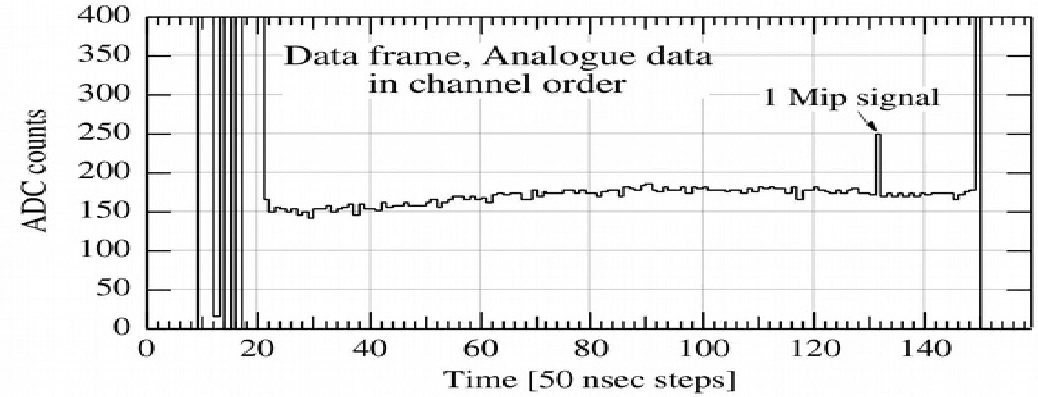
single channel in CBC2 chip

S-Curve Width / Noise Distributions

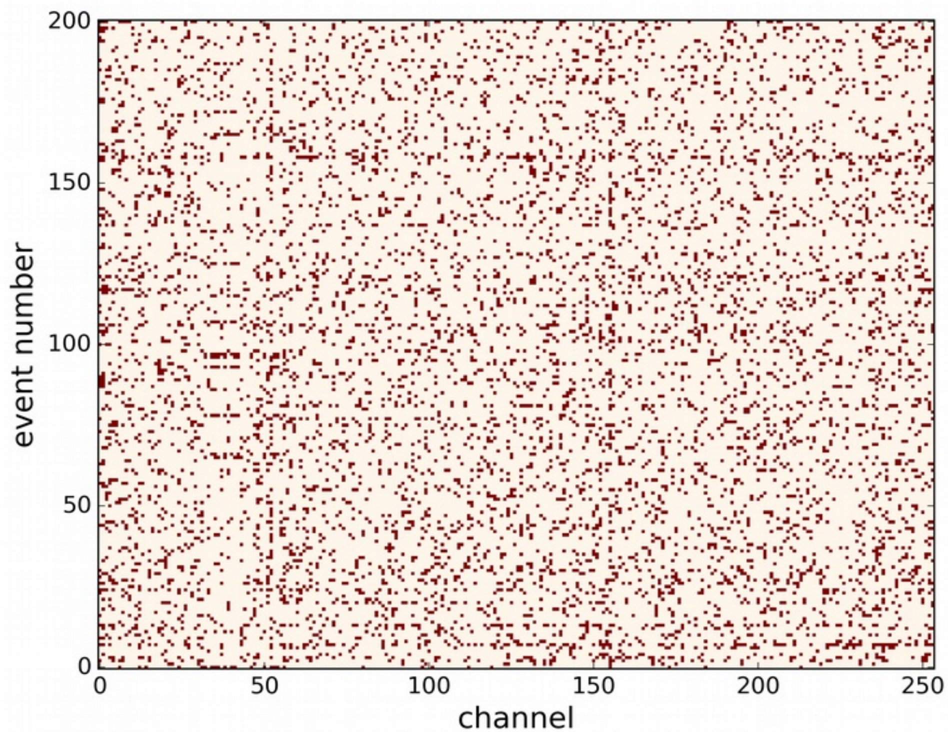


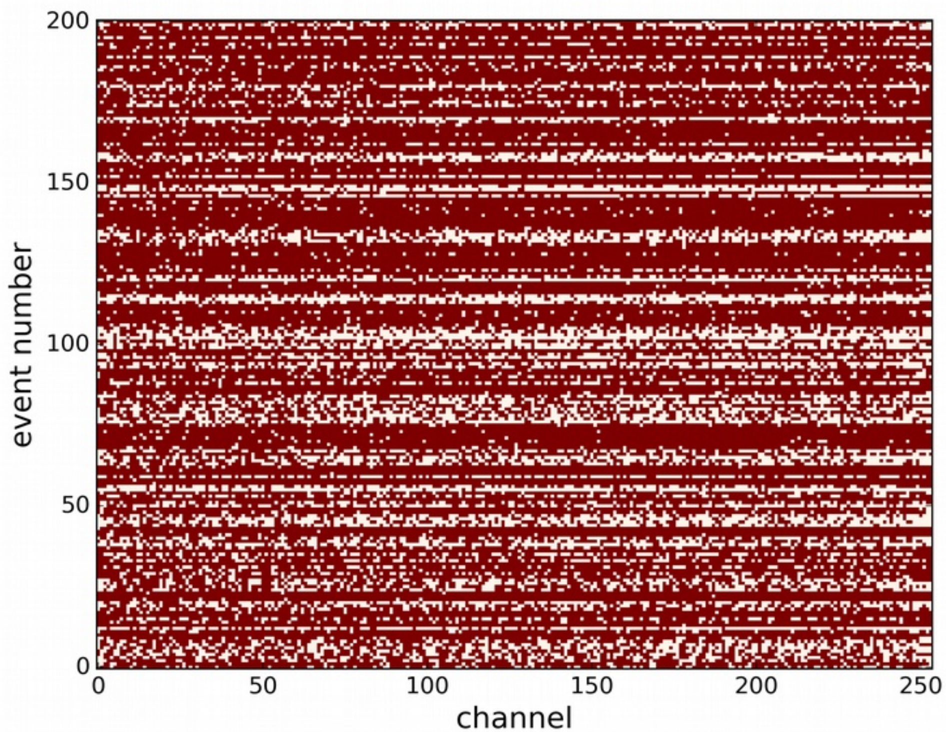
- channels have been tuned to the same 50% occupancy point
  - where nominally no charge is entering the analogue front-end

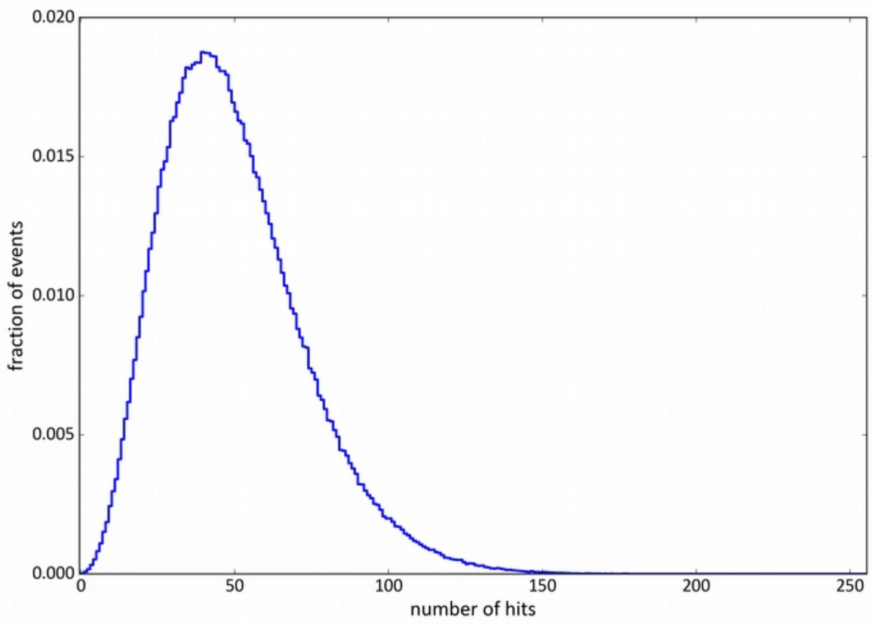
Common Mode Noise

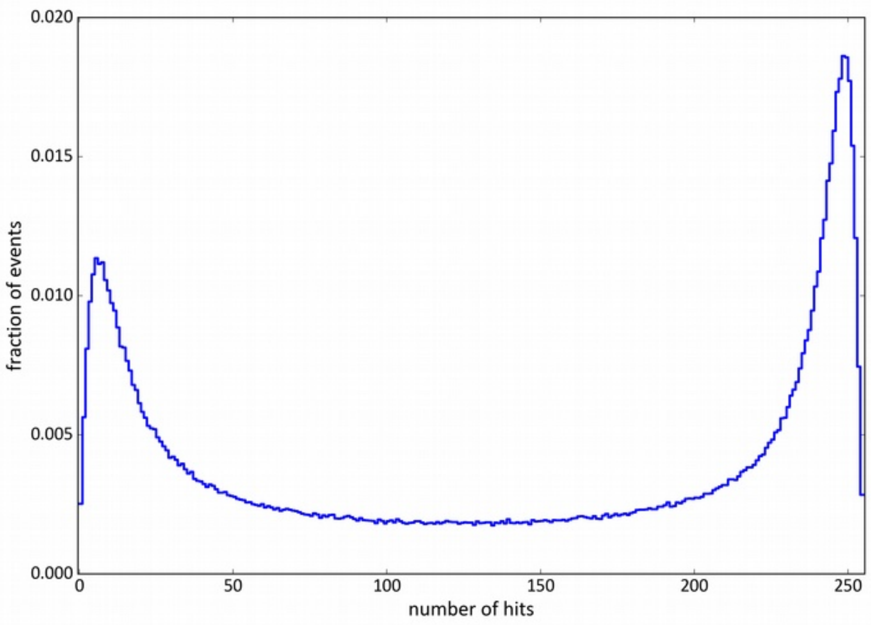


- channels are not isolated, coupled via:
  - inter-strip capacitance in sensor, ...
  - ground, power rails, threshold voltage
- common mode noise: coherent pulse-height variations in groups of multiple channels
- analogue / digital (non zero supressed) readout: monitor (common mode) noise during operation → suppression on per event basis
- binary readout scheme: measure noise in common mode between operation e.g.
  Measurement of common mode noise in binary read-out systems (L. Feld et. al) NIM A 487 (2002) 557–564



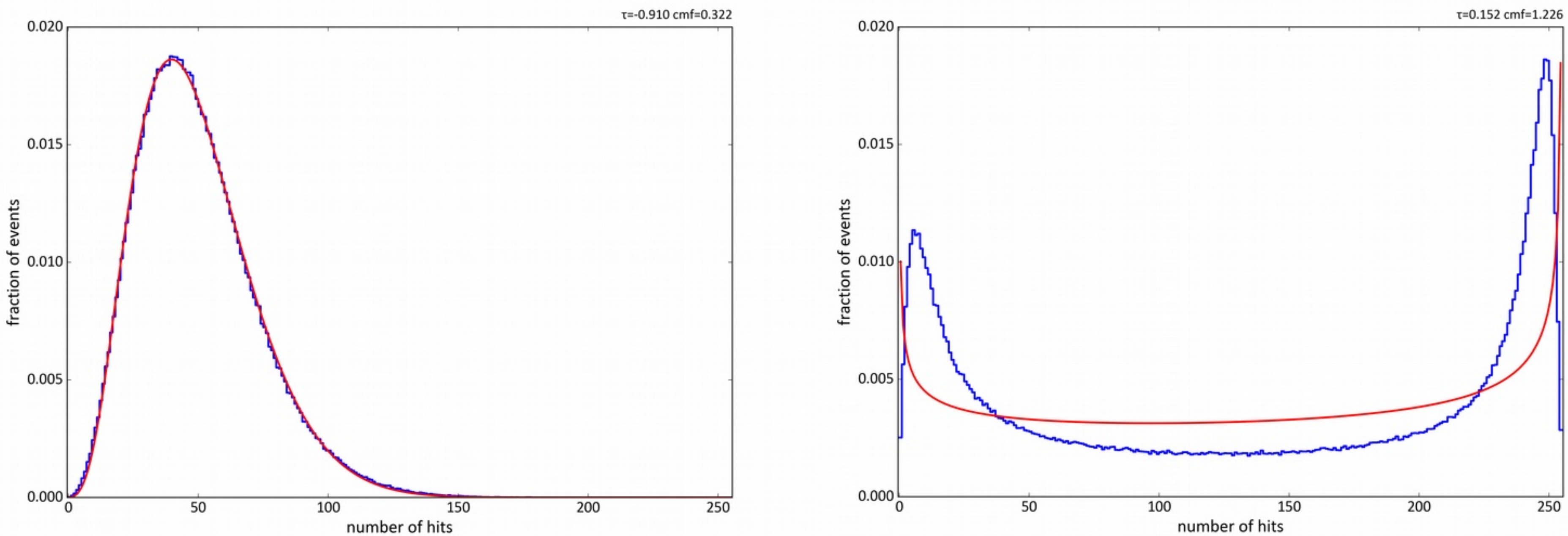






measurement

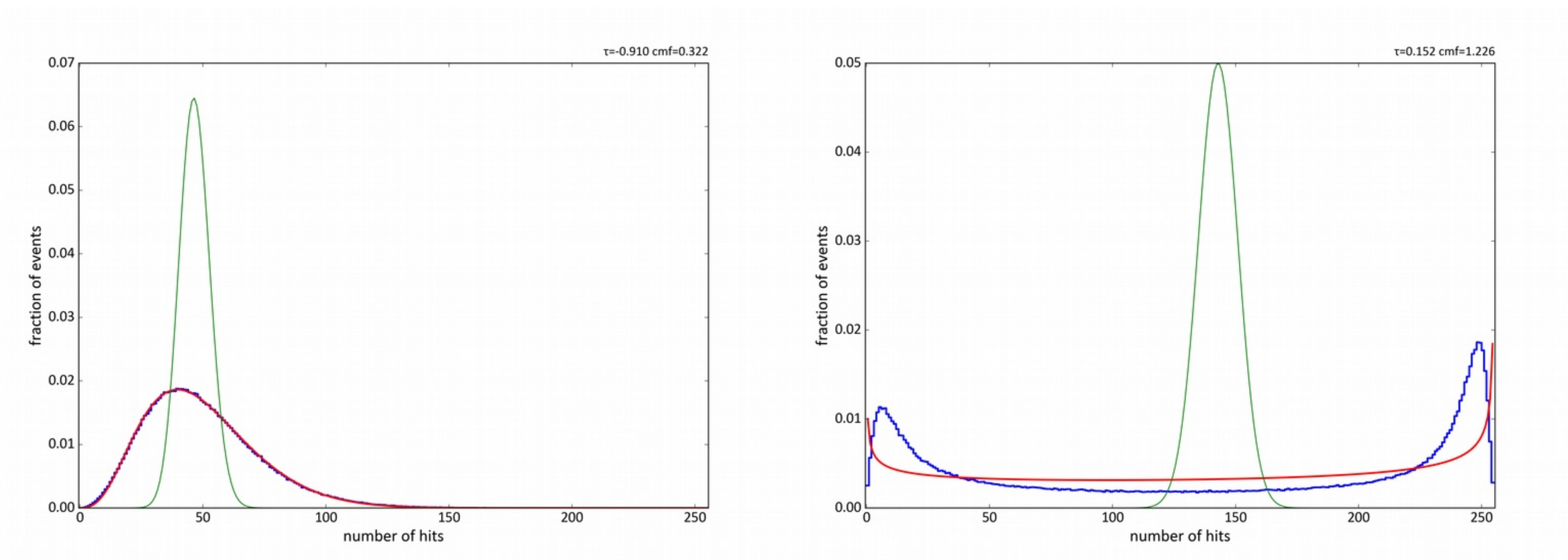
Number of Hits Histogram



measurement fit

- fit number of hits distribution → extract fraction of common mode in overall noise
  - single channel hit prop.: $p(\sigma, \mu, \tau) = \mathrm{norm}_{CDF}(\sigma, \mu, \tau)$
  - k out of N strips: $b(N, k, \sigma, \mu, \tau) = \mathrm{binom}_{PDF}(N, k, p(\sigma, \mu, \tau))$
  - express common mode as threshold variation: $a(\tau, \sigma_{CM}) = \mathrm{norm}_{PDF}(\tau, \sigma_{CM})$
- number of hits$(\mu, \tau, \mu_{CM}) = \mathrm{int}(\, b(N, k, \sigma, \mu, \tau_{CM}) \cdot a(\mu-\tau_{CM}, \sigma_{CM}),\ \ \tau_{CM}=-\infty\ldots\infty)$ for $k=0..N$
  - evaluate numerically
  - assumes identical $p(\sigma, \mu, \tau)$ for all channels

Number of Hits Histogram



measurement fit no common mode

- fit number of hits distribution → extract fraction of common mode in overall noise
  - single channel hit prop.: $p(\sigma, \mu, \tau) = \text{norm}_{CDF}(\sigma, \mu, \tau)$
  - k out of N strips: $b(N, k, \sigma, \mu, \tau) = \text{binom}_{PDF}(N, k, p(\sigma, \mu, \tau))$
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- number of hits(μ, τ, μ_{CM}) = int($b(N, k, \sigma, \mu, \tau_{CM}) \cdot a(\mu-\tau_{CM}, \sigma_{CM})$, $\tau_{CM}=-\infty\ldots\infty$) for k=0..N
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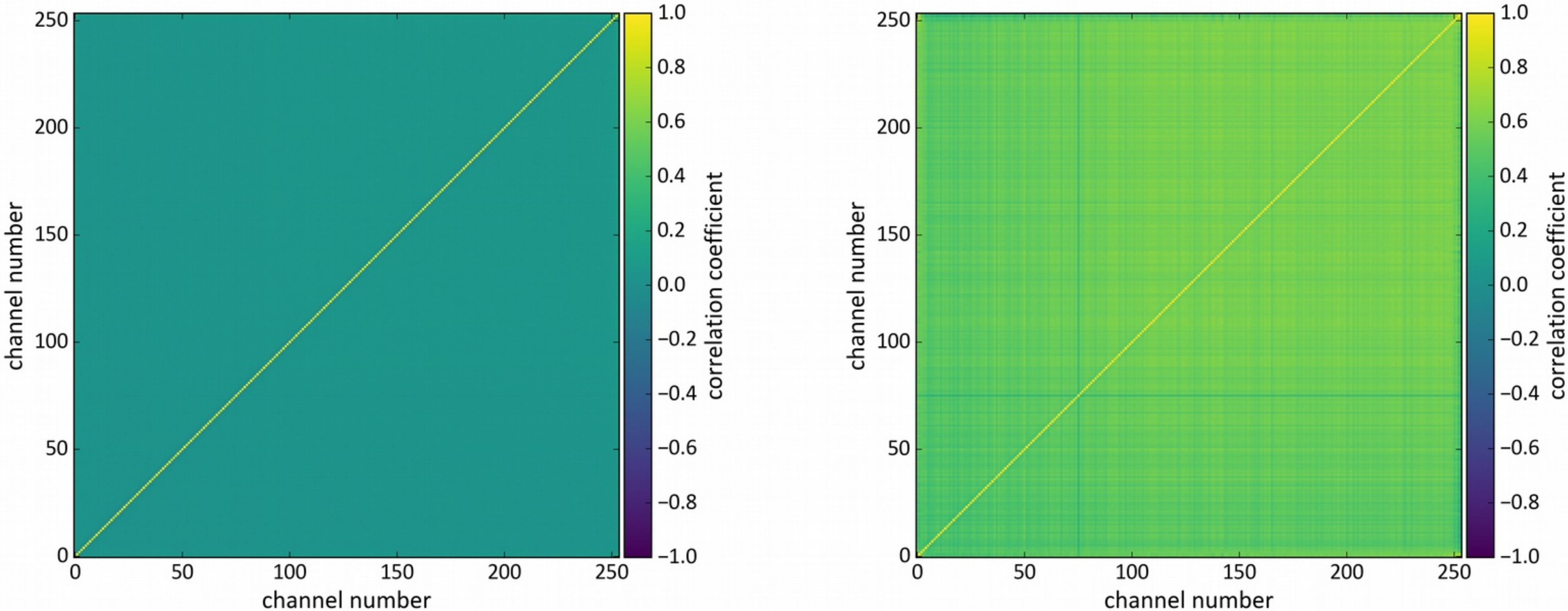
Correlation Coefficient



$$\mathrm{cor}_{xy} = \frac{\langle xy \rangle - \langle x \rangle \langle y \rangle}{\sigma_x \sigma_y}. \qquad = \frac{\Omega_{x \cdot y} - \Omega_x \Omega_y}{\sqrt{\Omega_x - (\Omega_x)^2}\sqrt{\Omega_y - (\Omega_y)^2}}$$

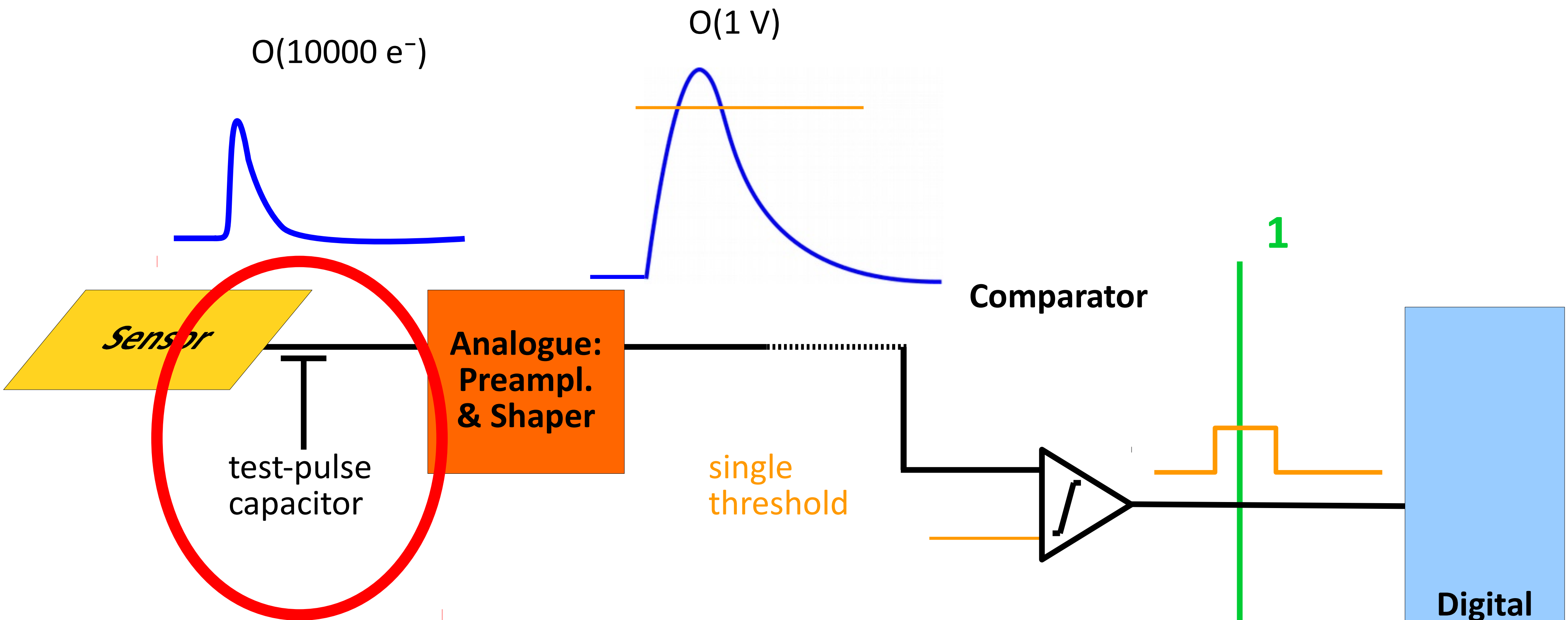
Ω_x = number of events with hit in channel x / number of total events

Ω_{xy} = number events with hit in channels x AND y / number of total events

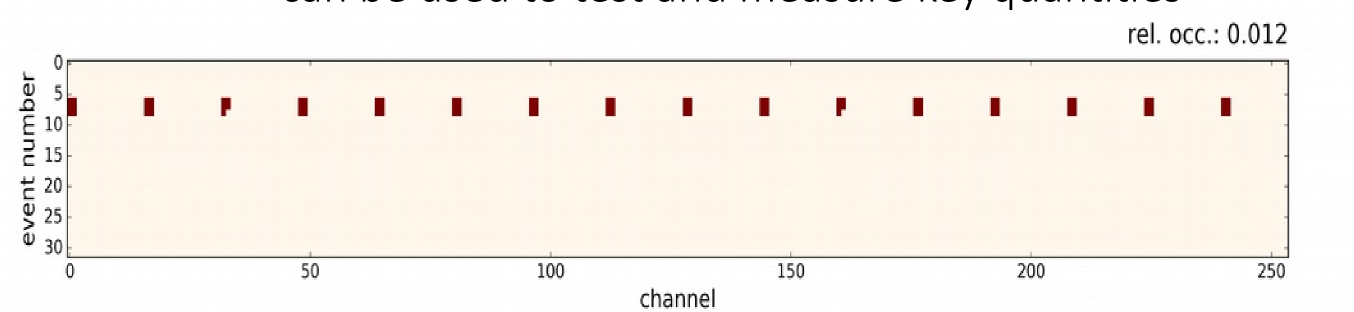
Signals

- test-pulses
- x-rays
- betas / mips

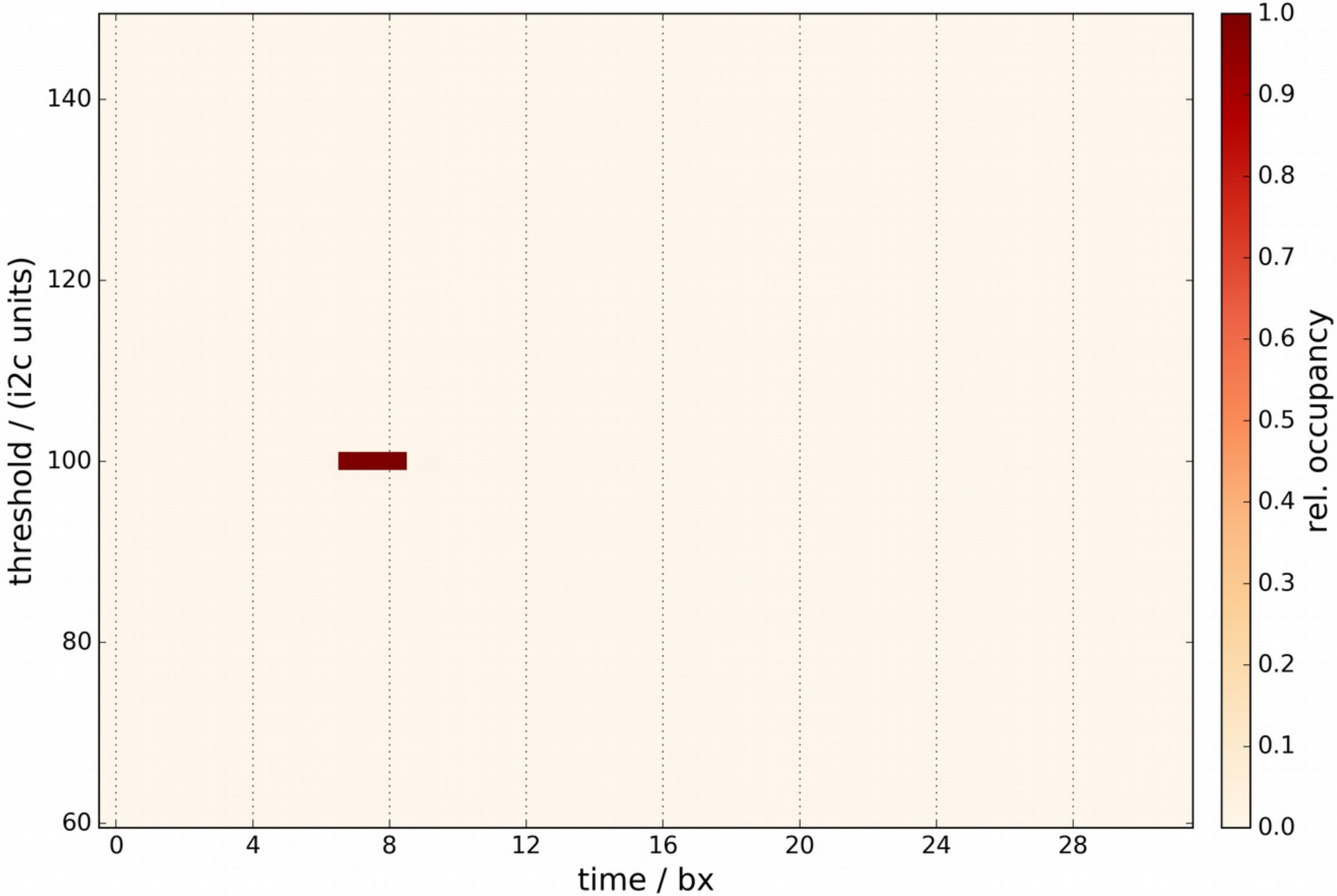
Test Pulse Injection



- “known” capacitance (e.g. 22fF) → Q = CU
- control on discharge time w.r.t. sampling time
- → inject configurable charge pulse into front-end
  - can be used to test and measure key quantities

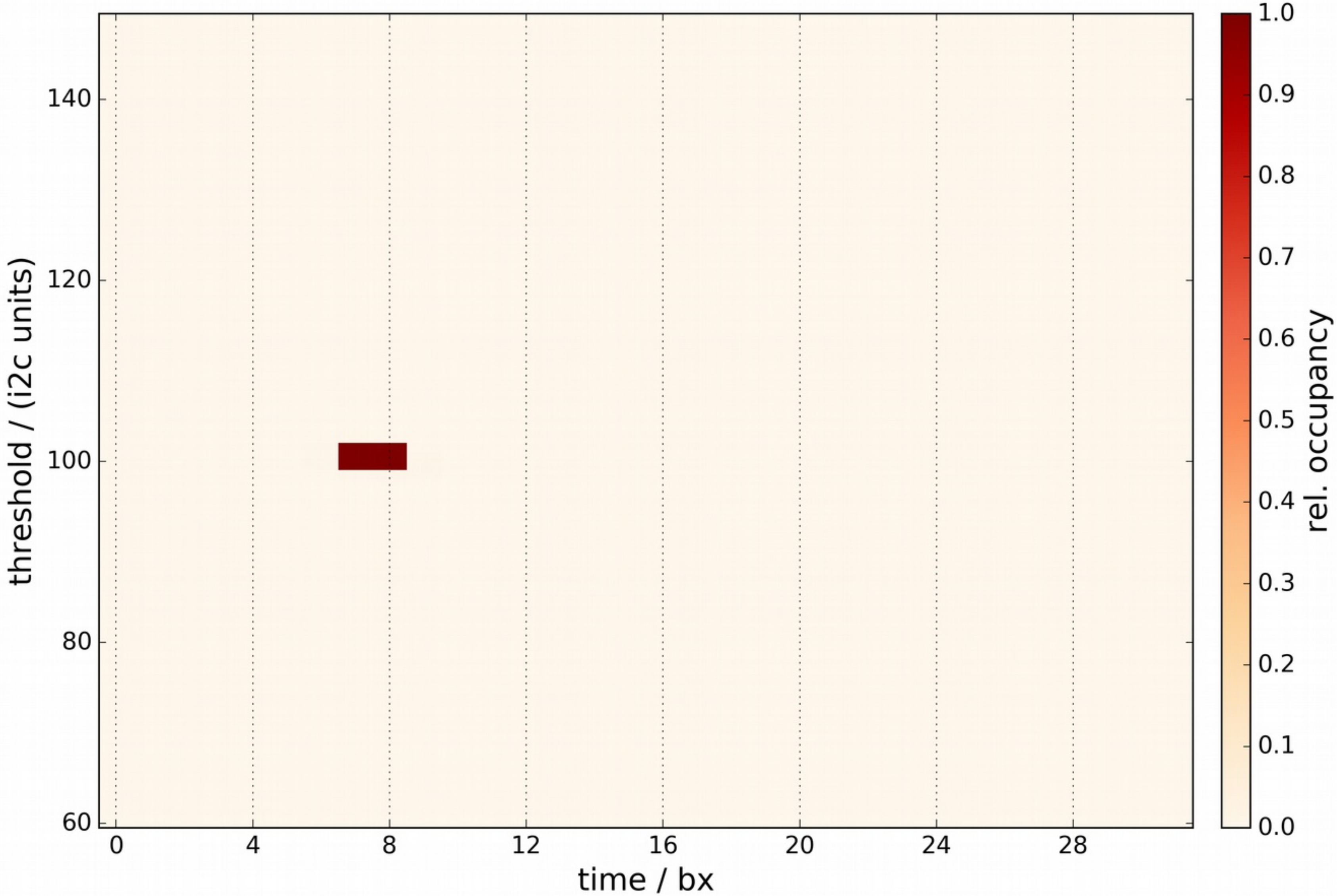


Test Pulse – Threshold Scan



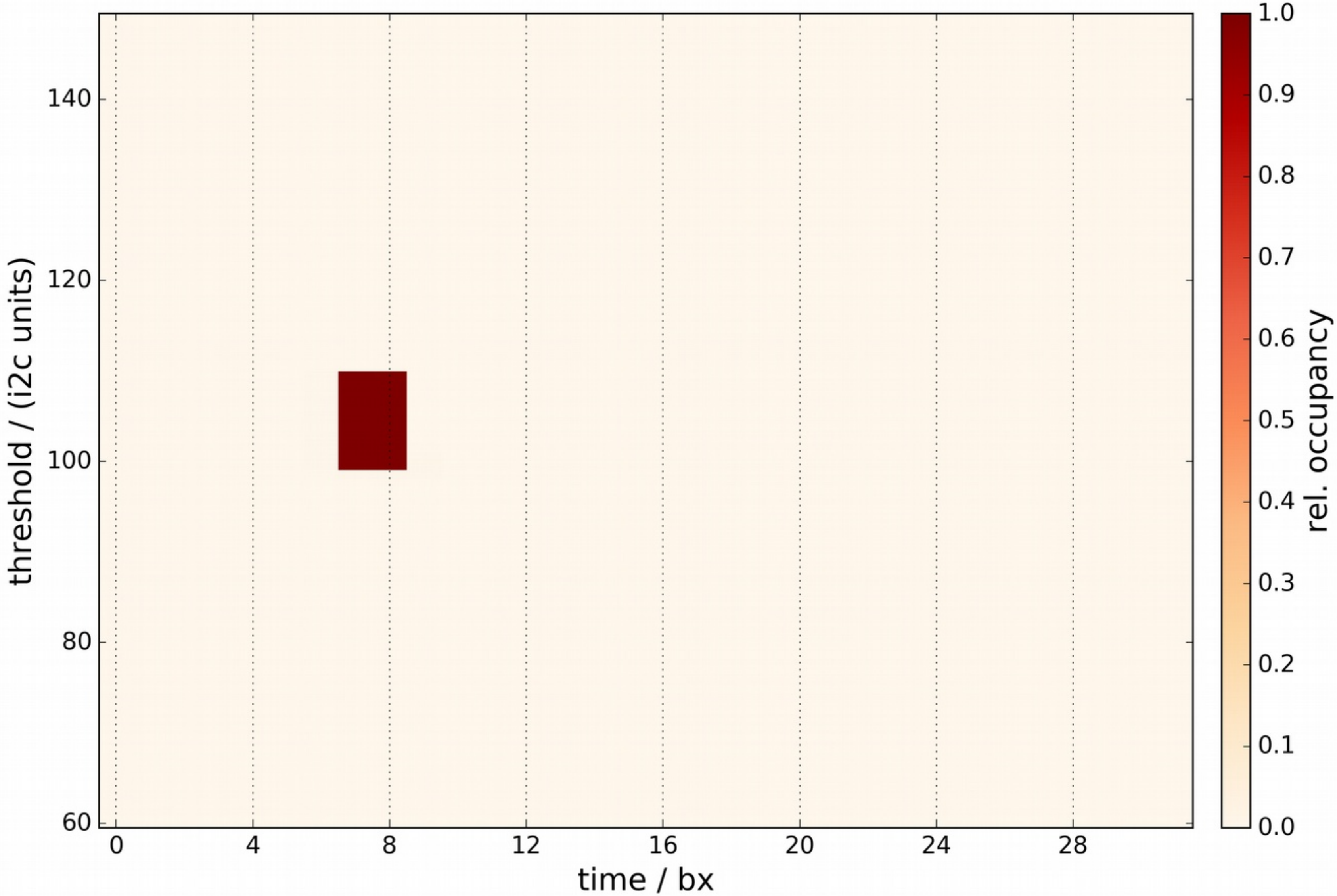
- inject many test-pulses and read frames of 32 consecutive events

Test Pulse – Threshold Scan



- inject many test-pulses and read frames of 32 consecutive events
- + threshold scan

Test Pulse – Threshold Scan



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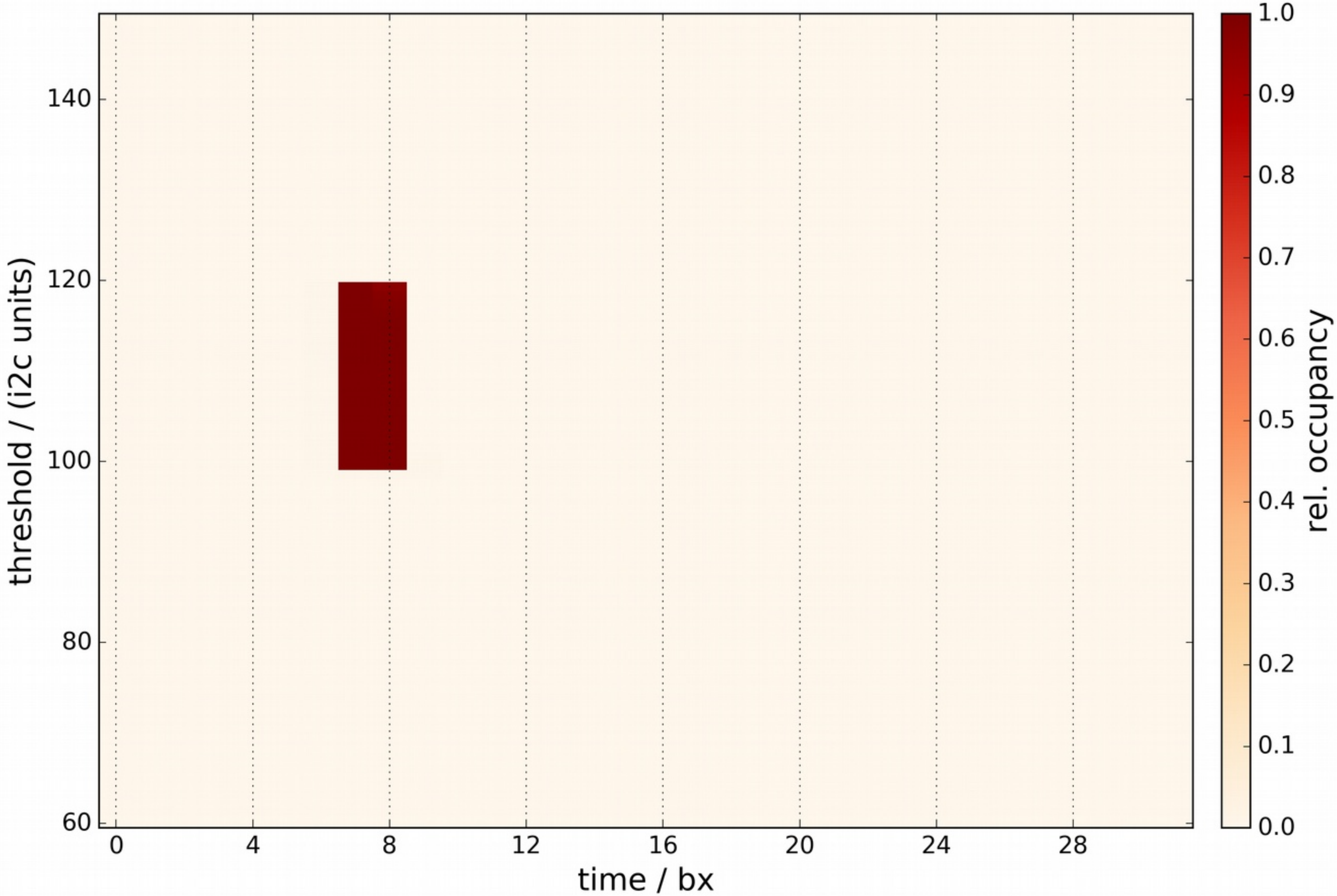

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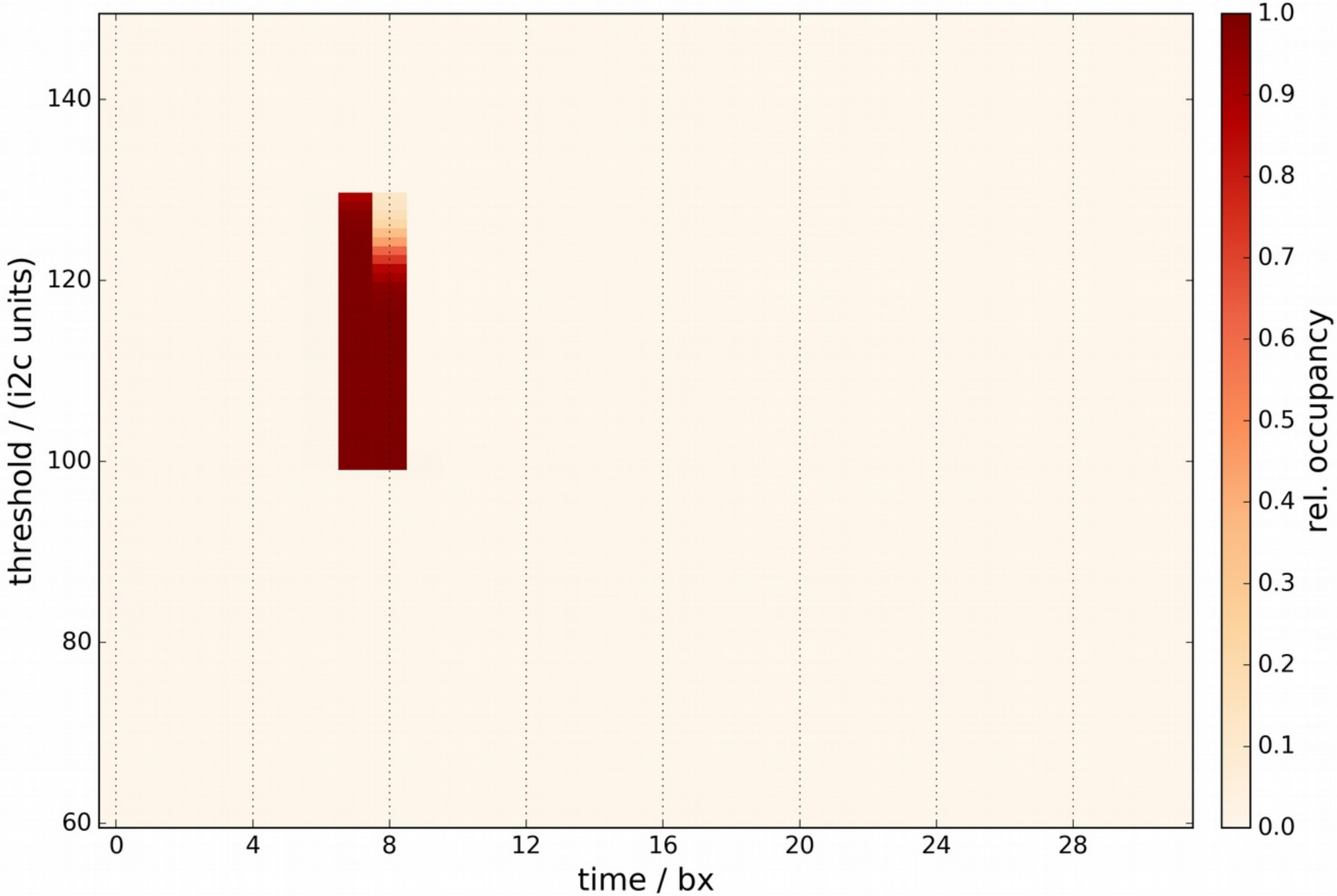

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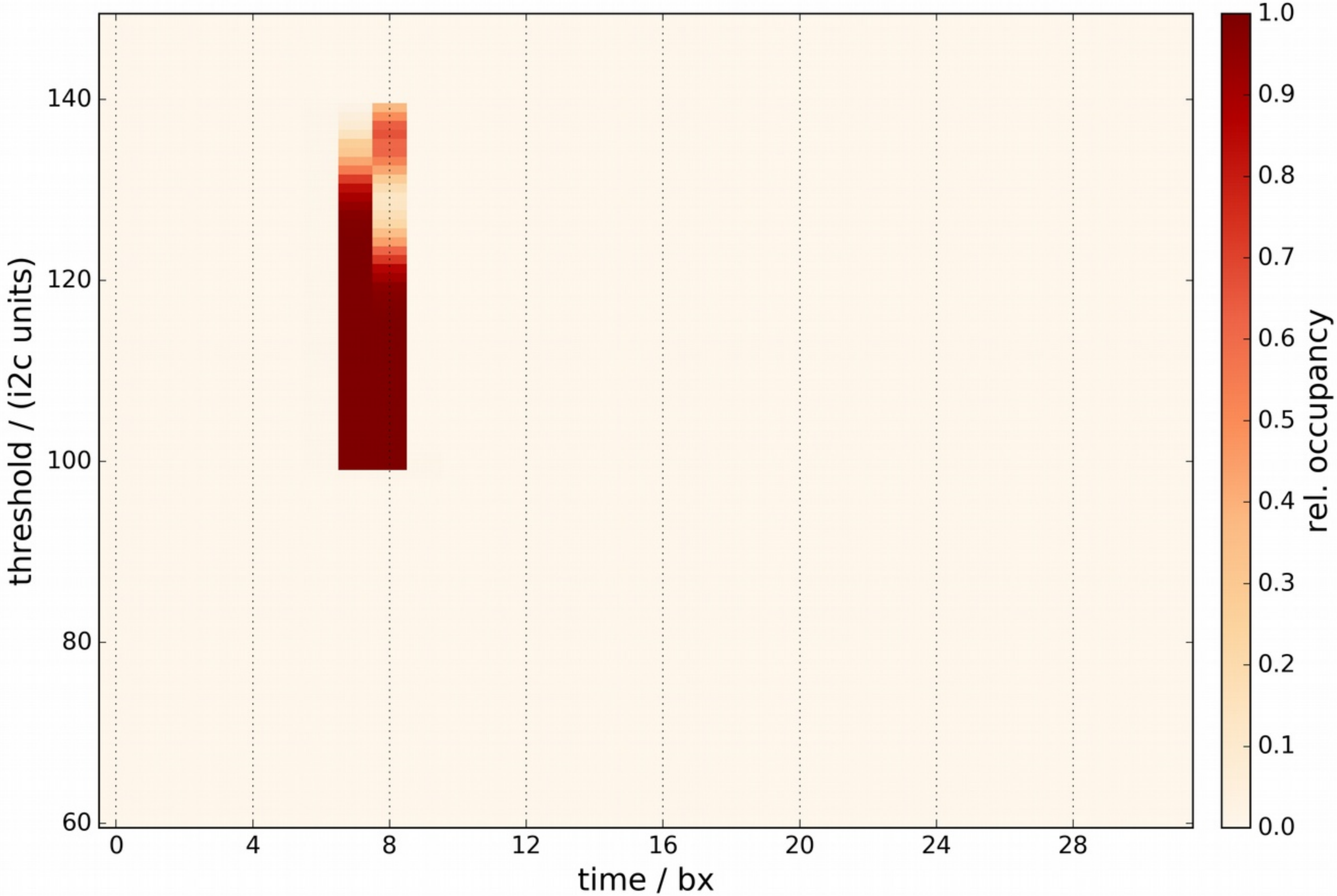

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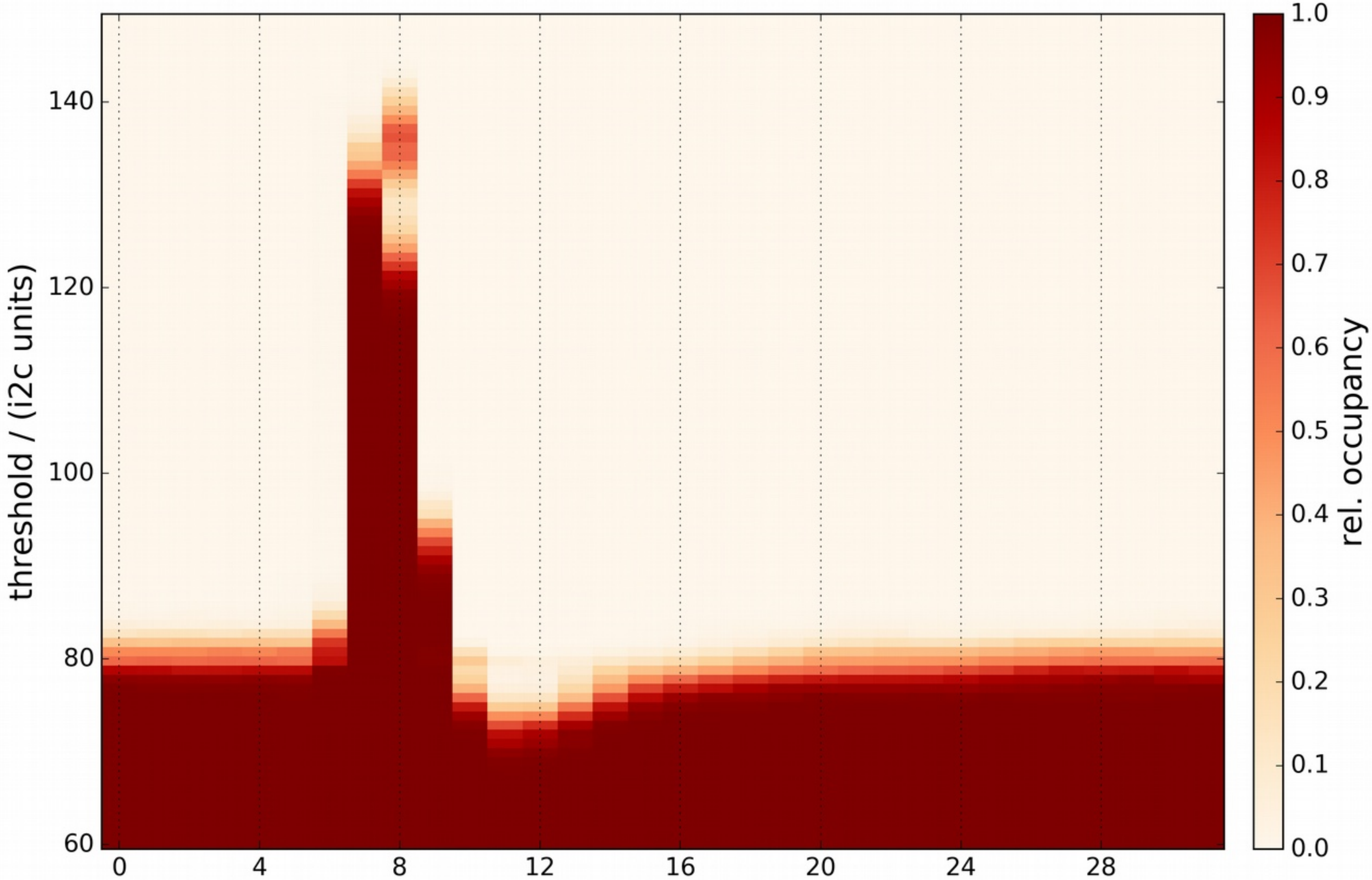

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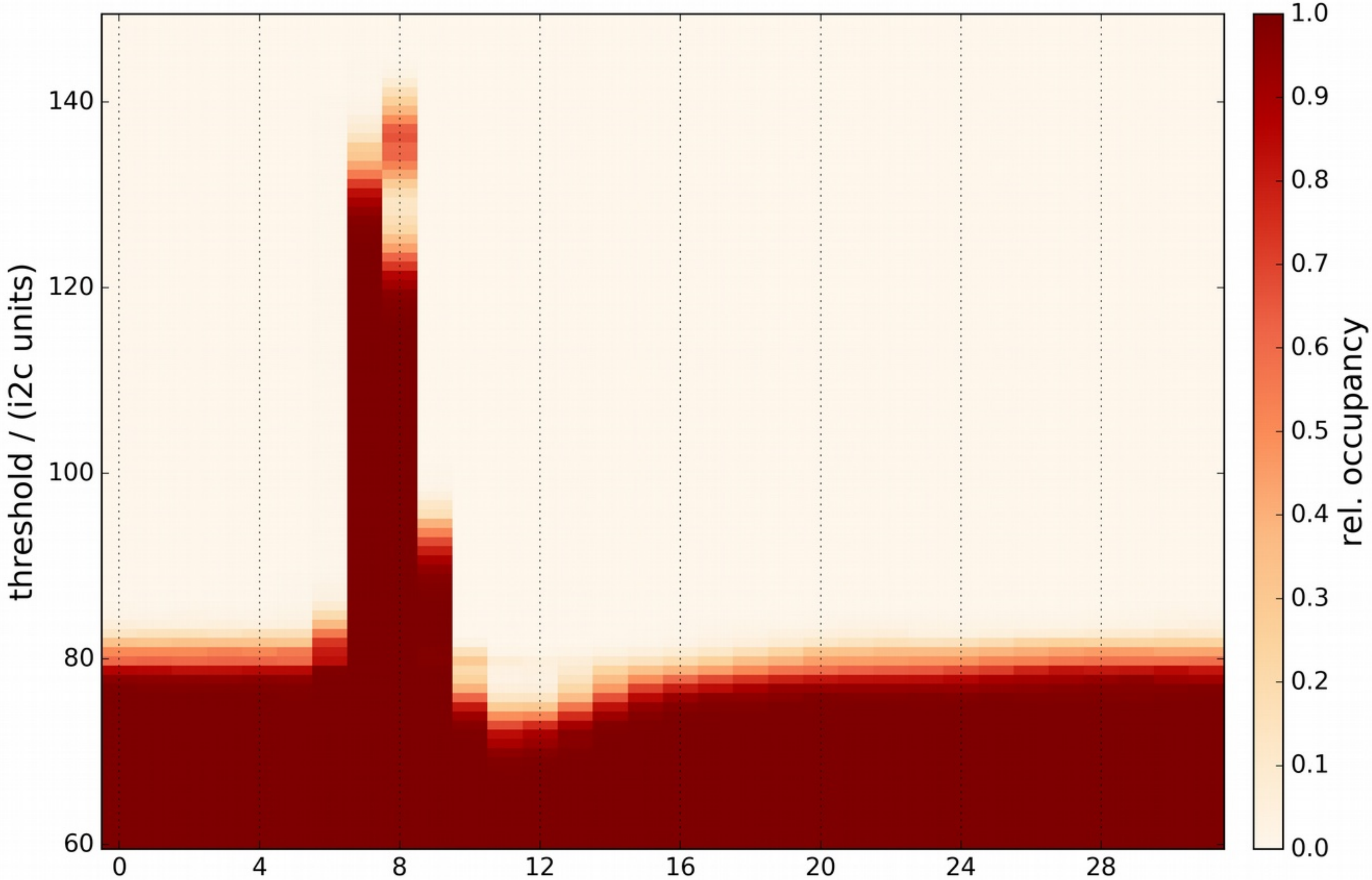

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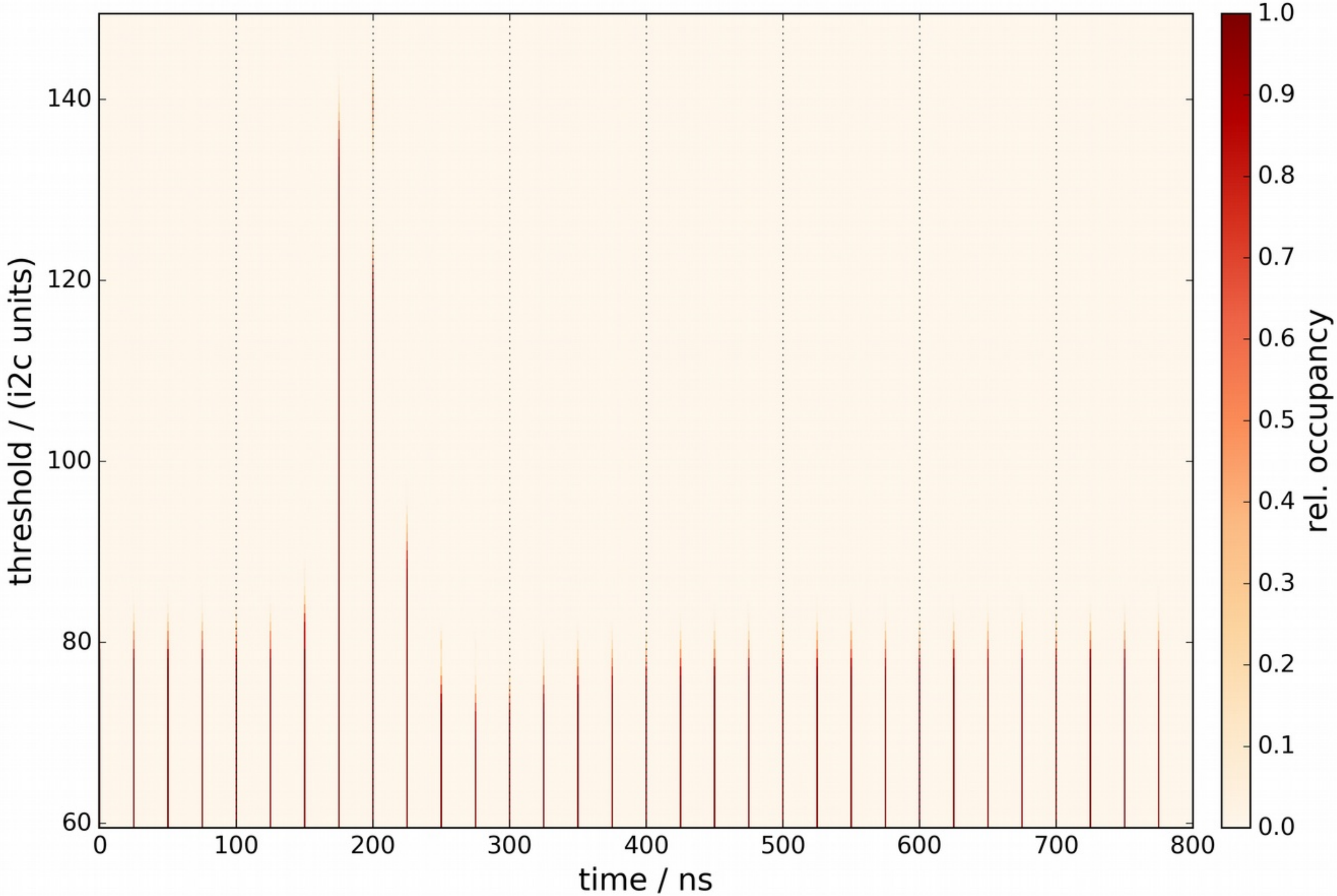
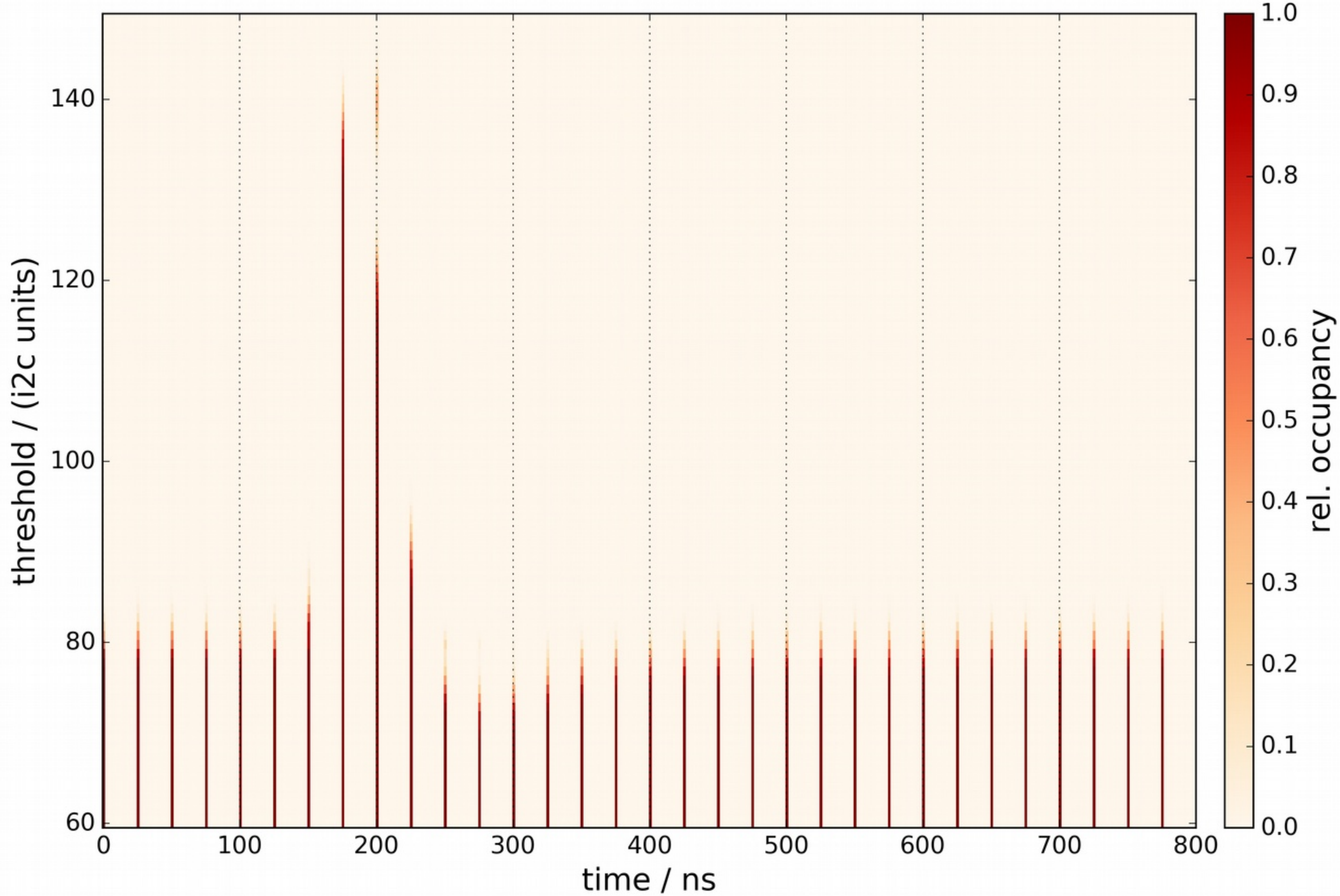
Test Pulse – Delay Scan



- inject many test-pulses and read frames of 32 consecutive events
- + threshold scan
- + variation of test-pulse release time (1ns steps)

Test Pulse – Delay Scan



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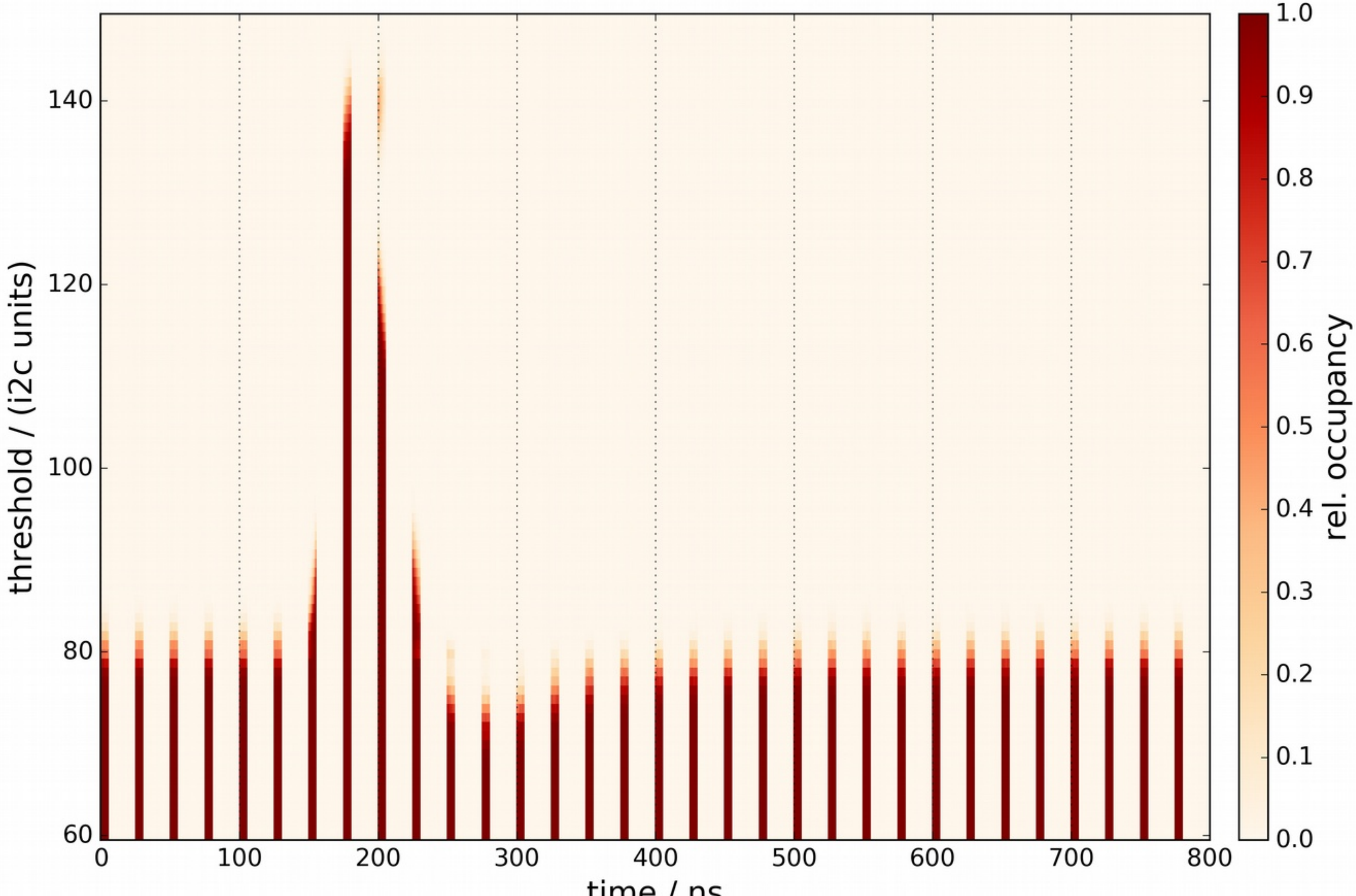

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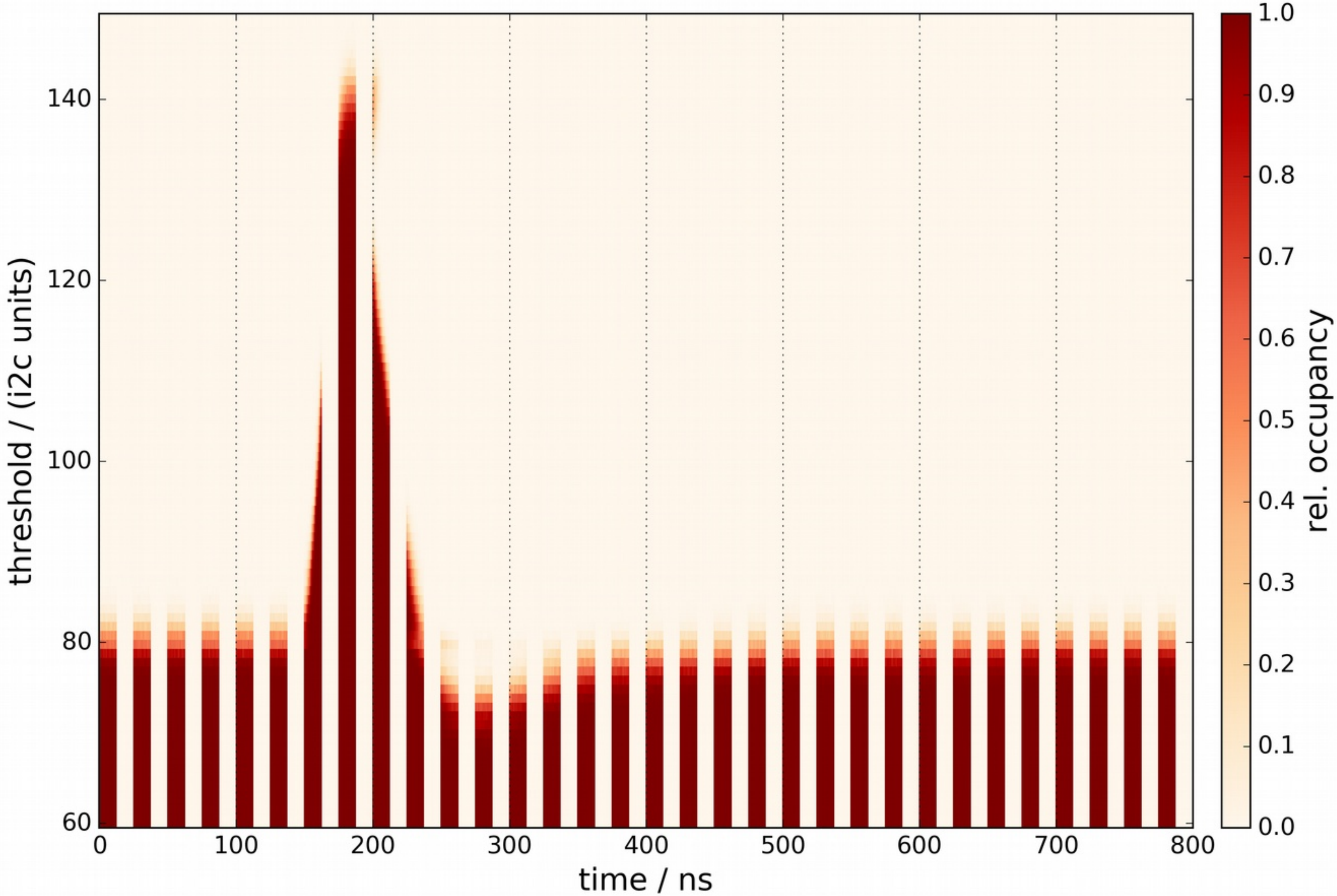

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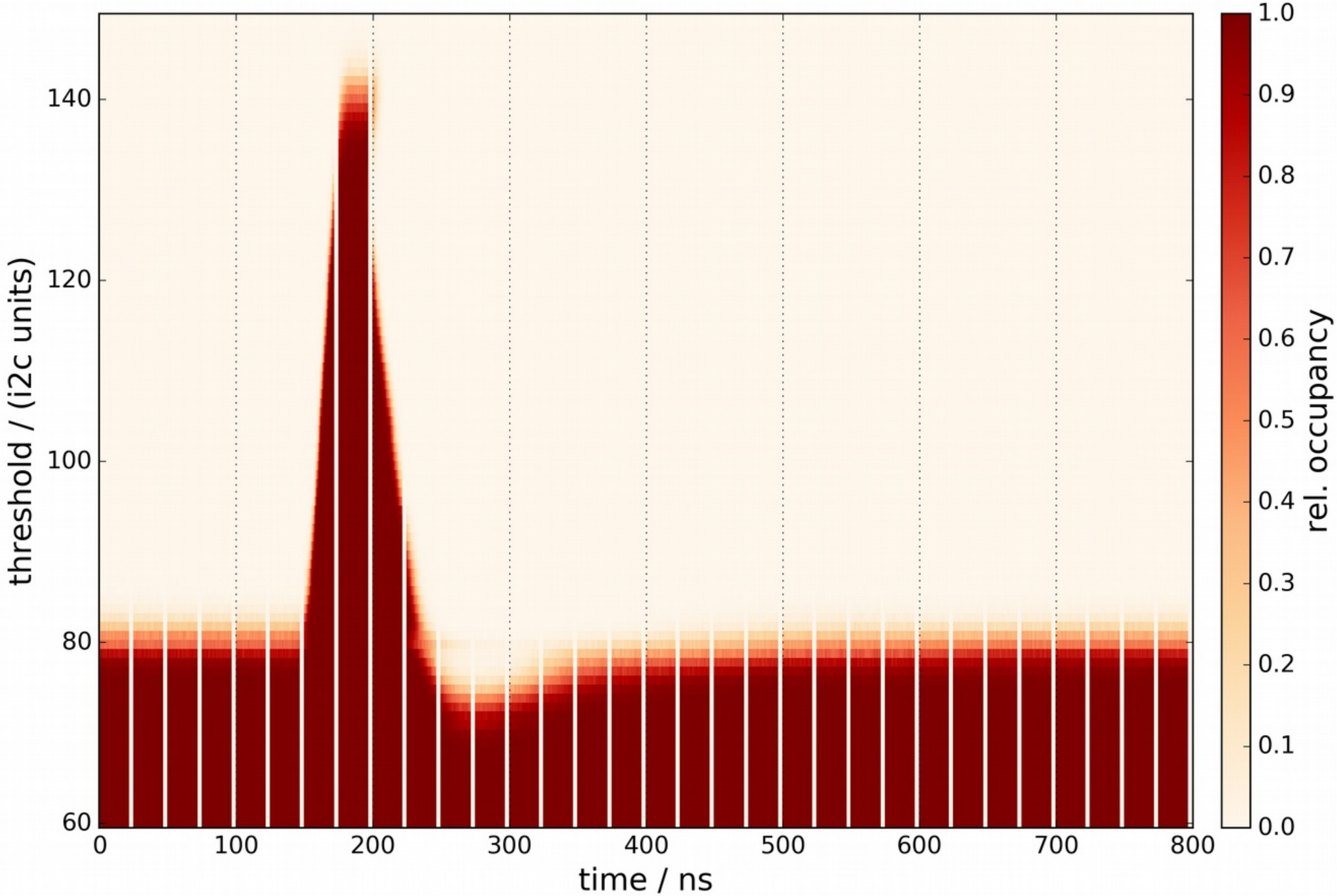

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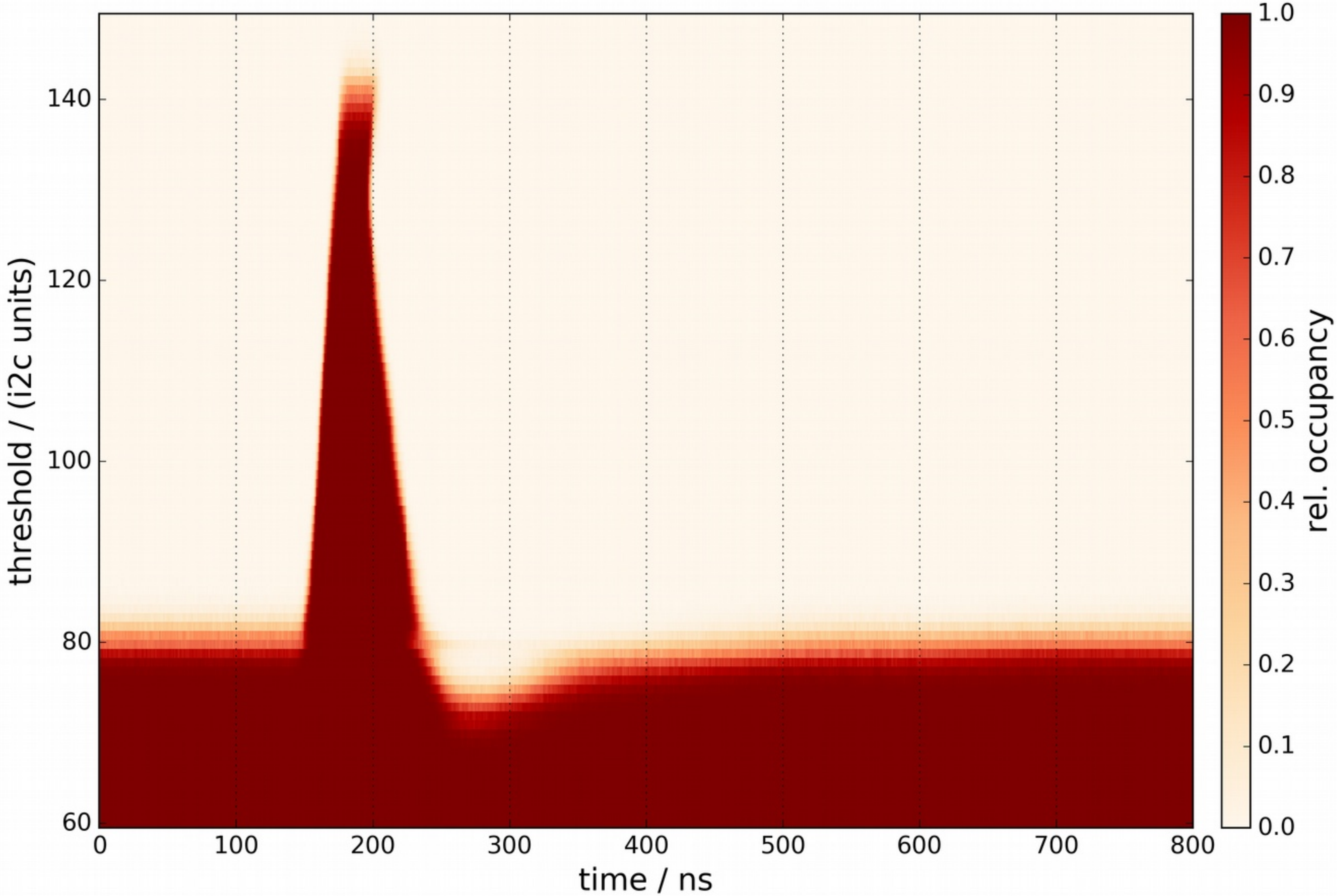
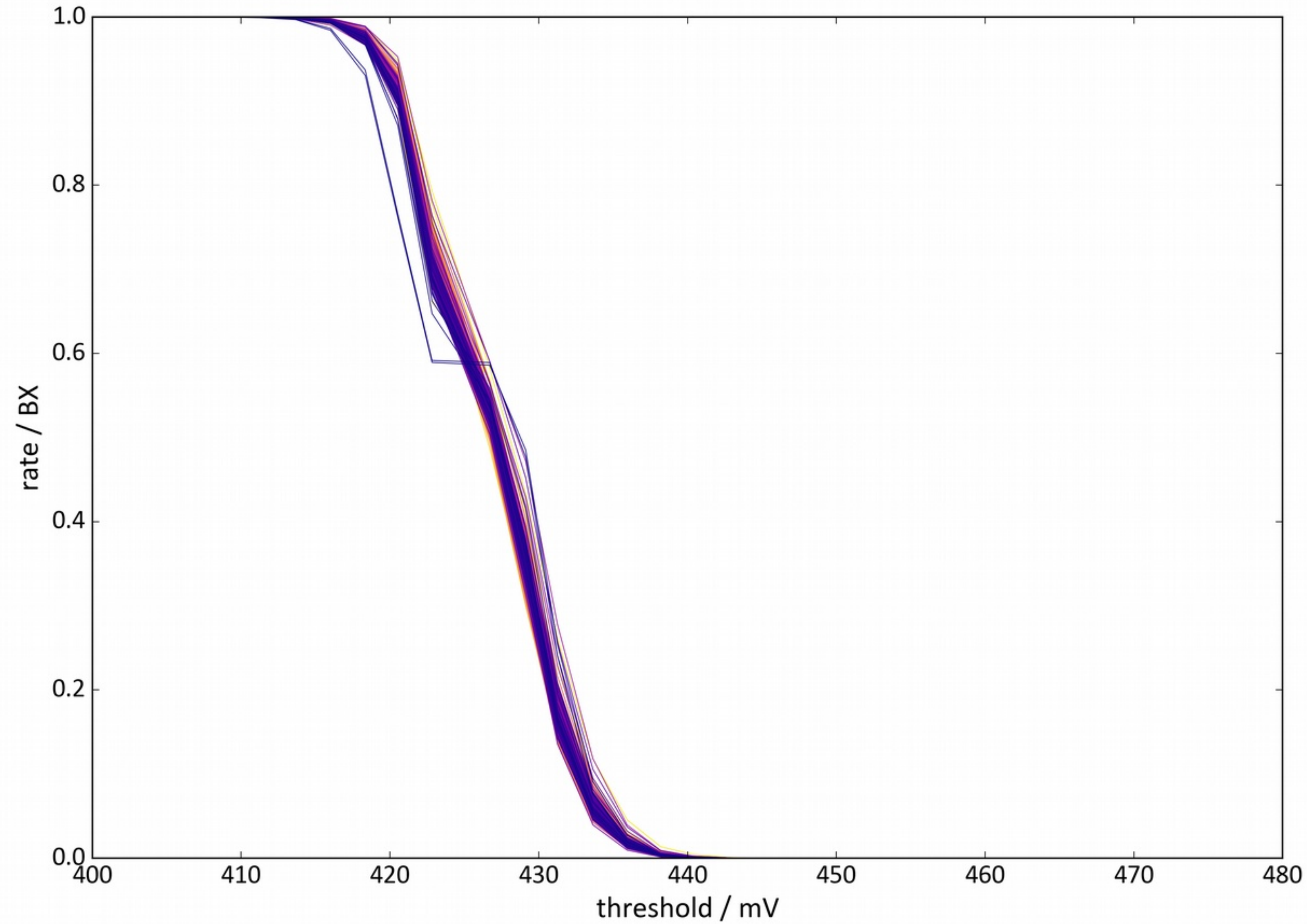


- inject many test-pulses and read frames of 32 consecutive events
- + threshold scan
- + variation of test-pulse release time (1ns steps)

→ reconstruction of the pulse shape

- until now no 'real' signal in the sensor (can do everything on a bare hybrid)
- x-rays in silicon: prop. of interaction of photon with silicon
  → full photon energy is deposited in the silicon sensor (keV x-rays) → Q = E / 3.65 V



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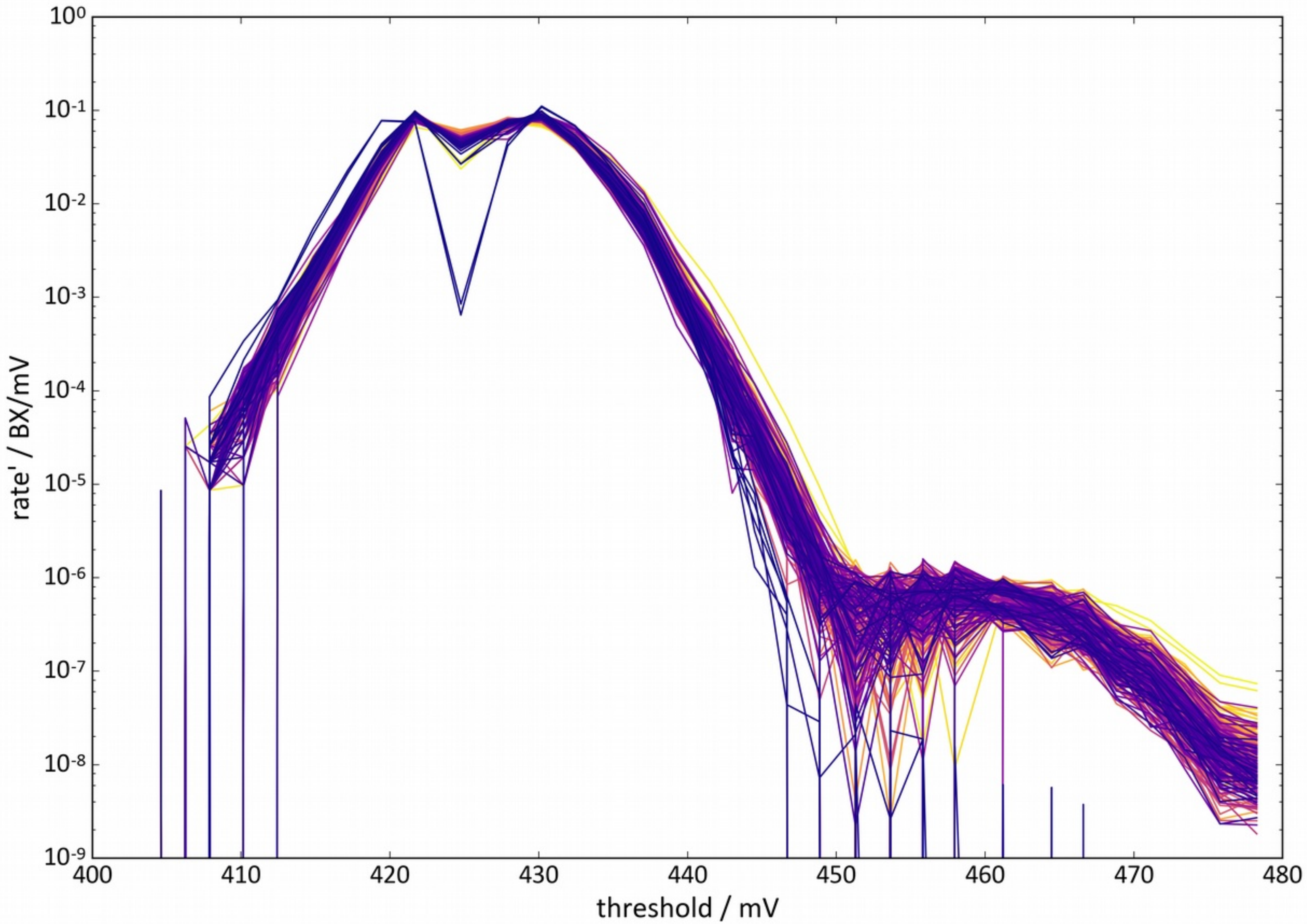

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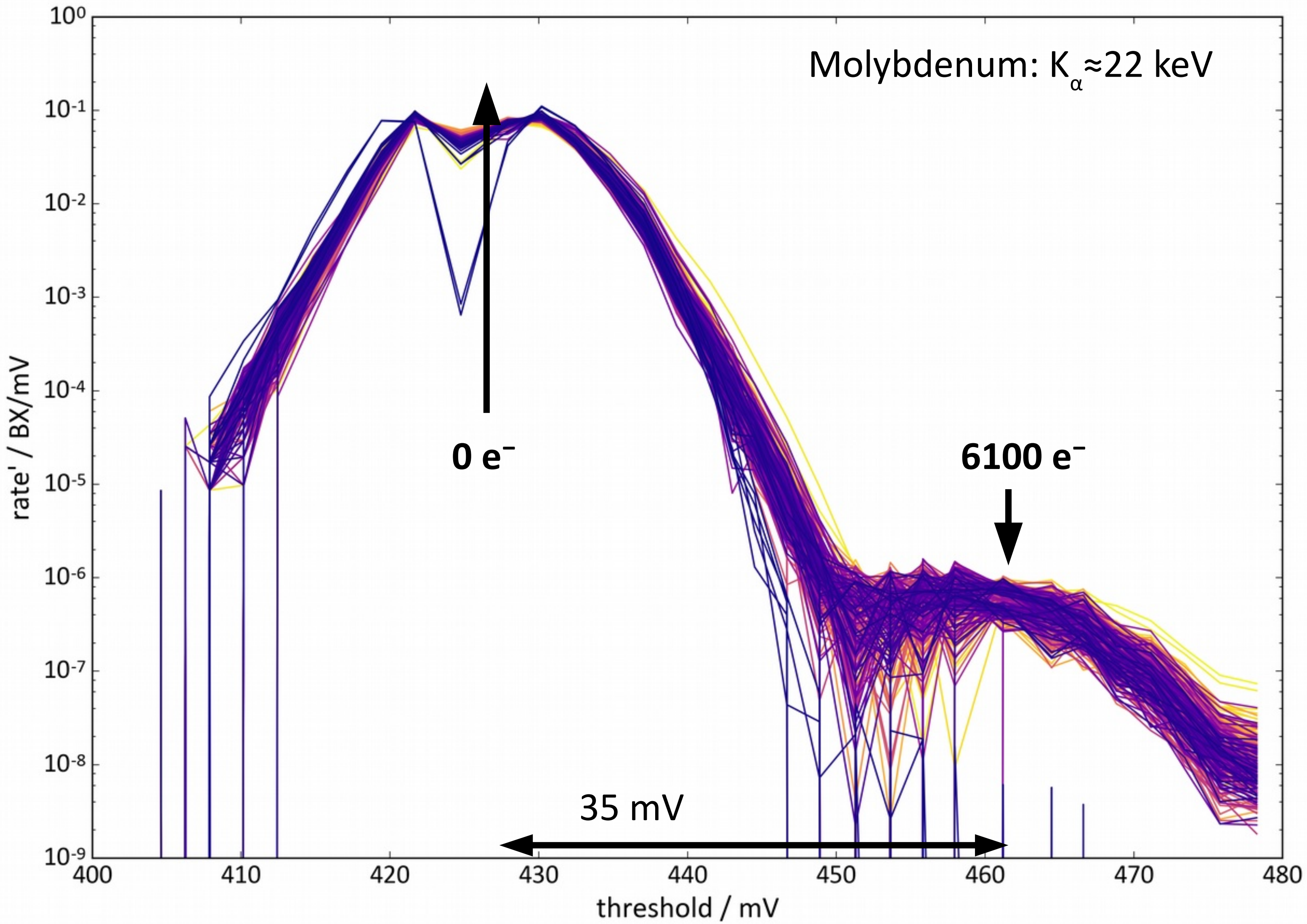
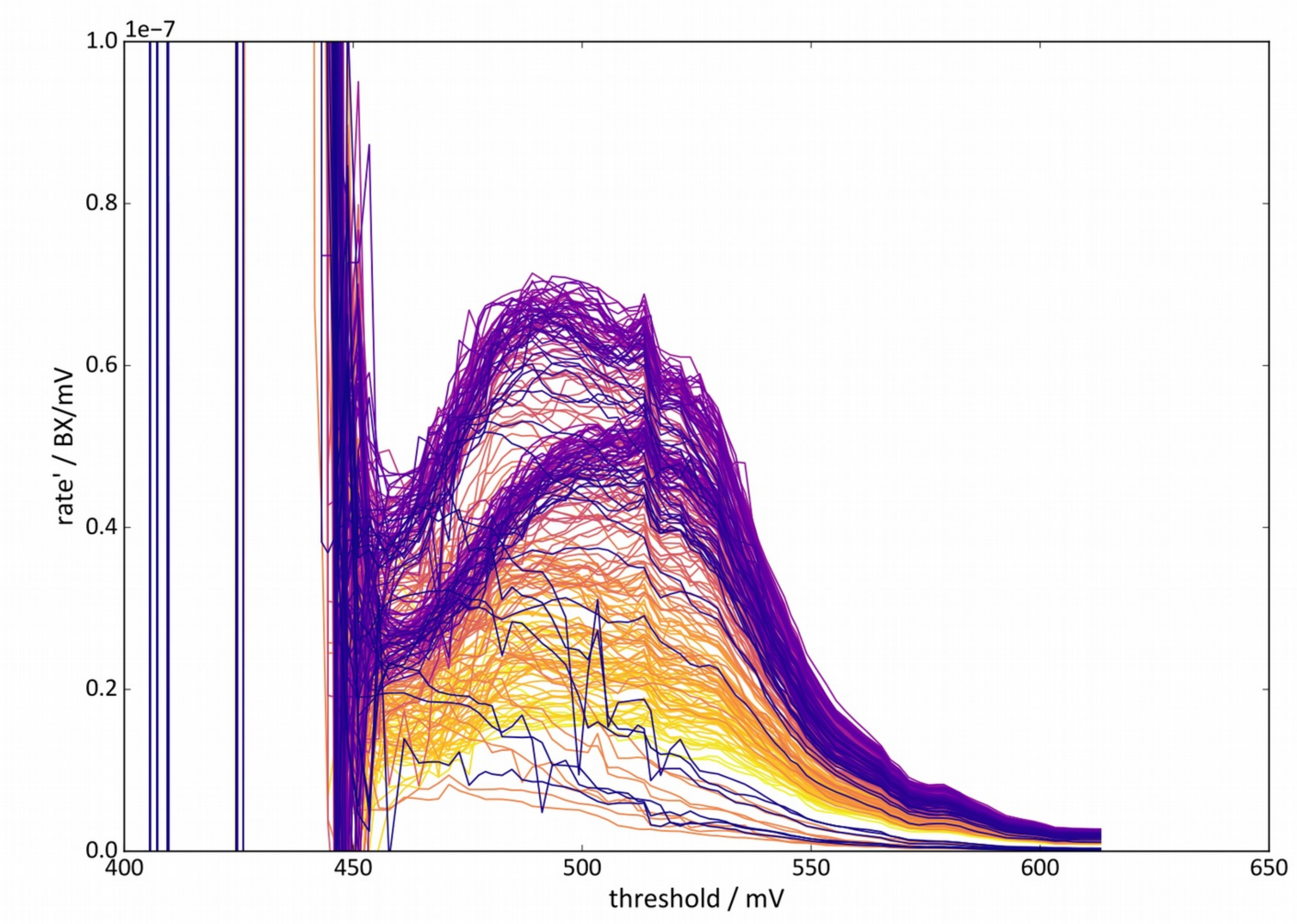
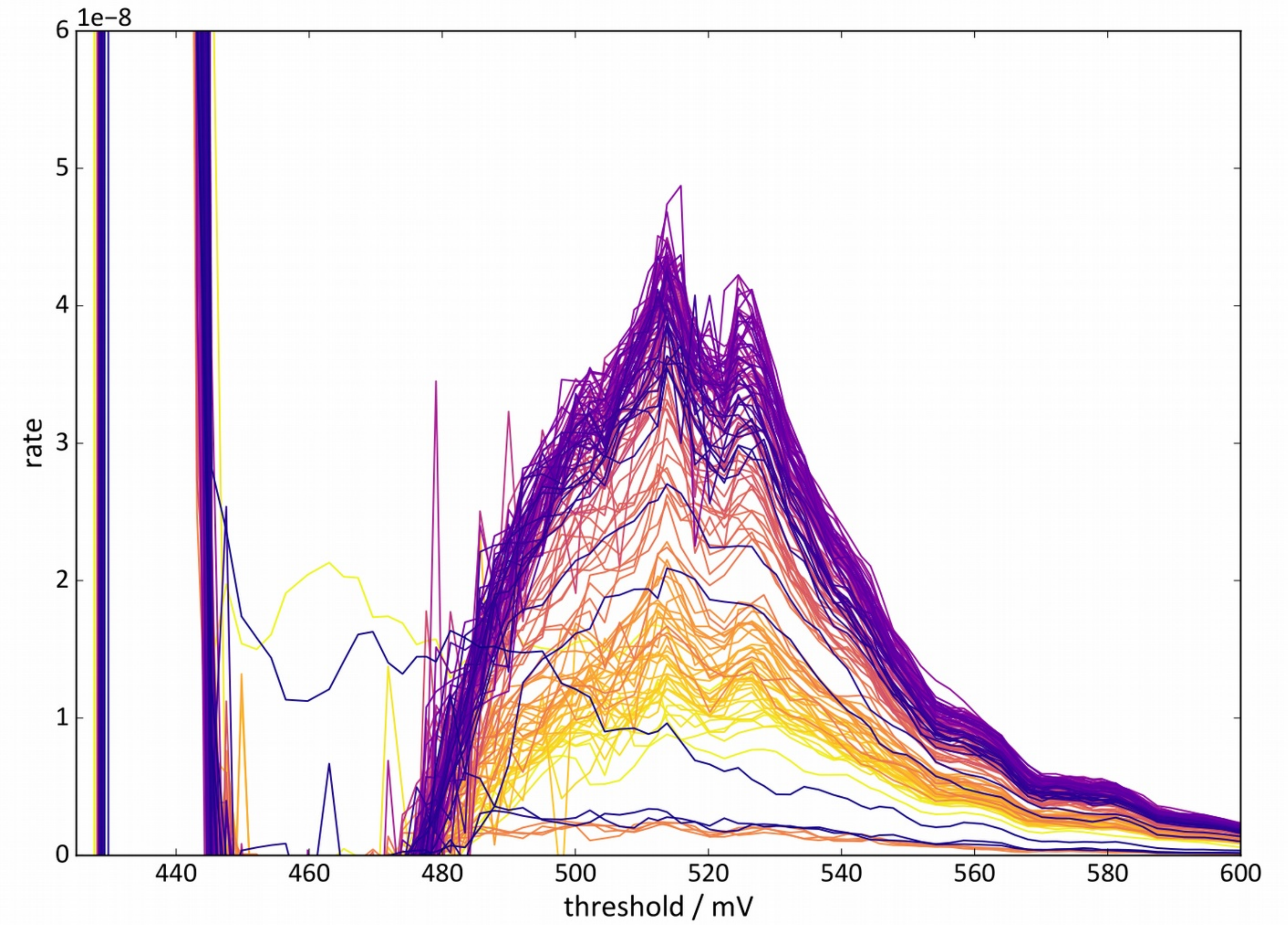


Gain ≈ 6 ke⁻ / 35 mV → Noise ≈ 4.5 mV * 6 ke⁻ / 35 mV ≈ 780 e⁻

Sr90: Hit Rate'



Sr90: Single Strip Clusters



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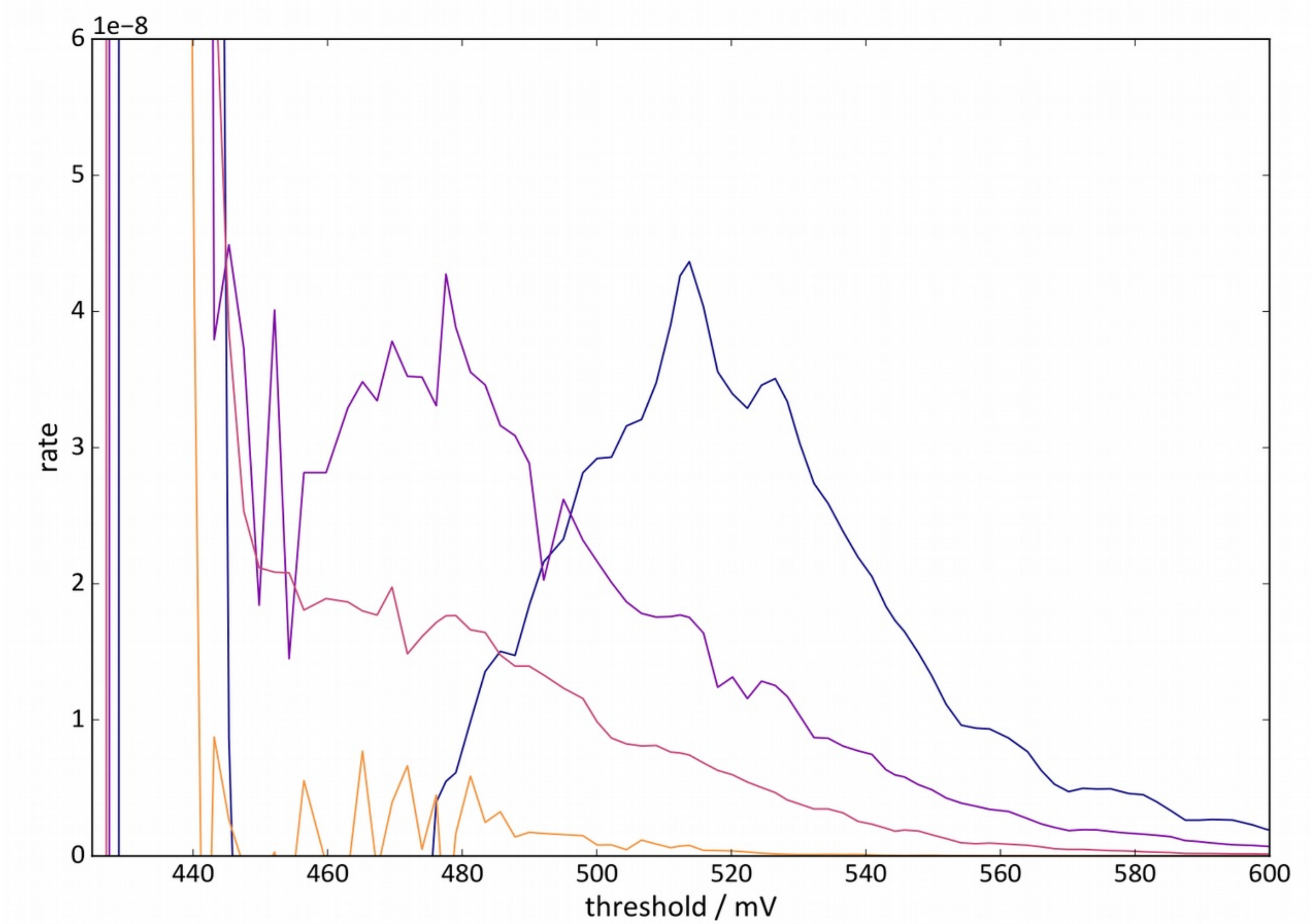
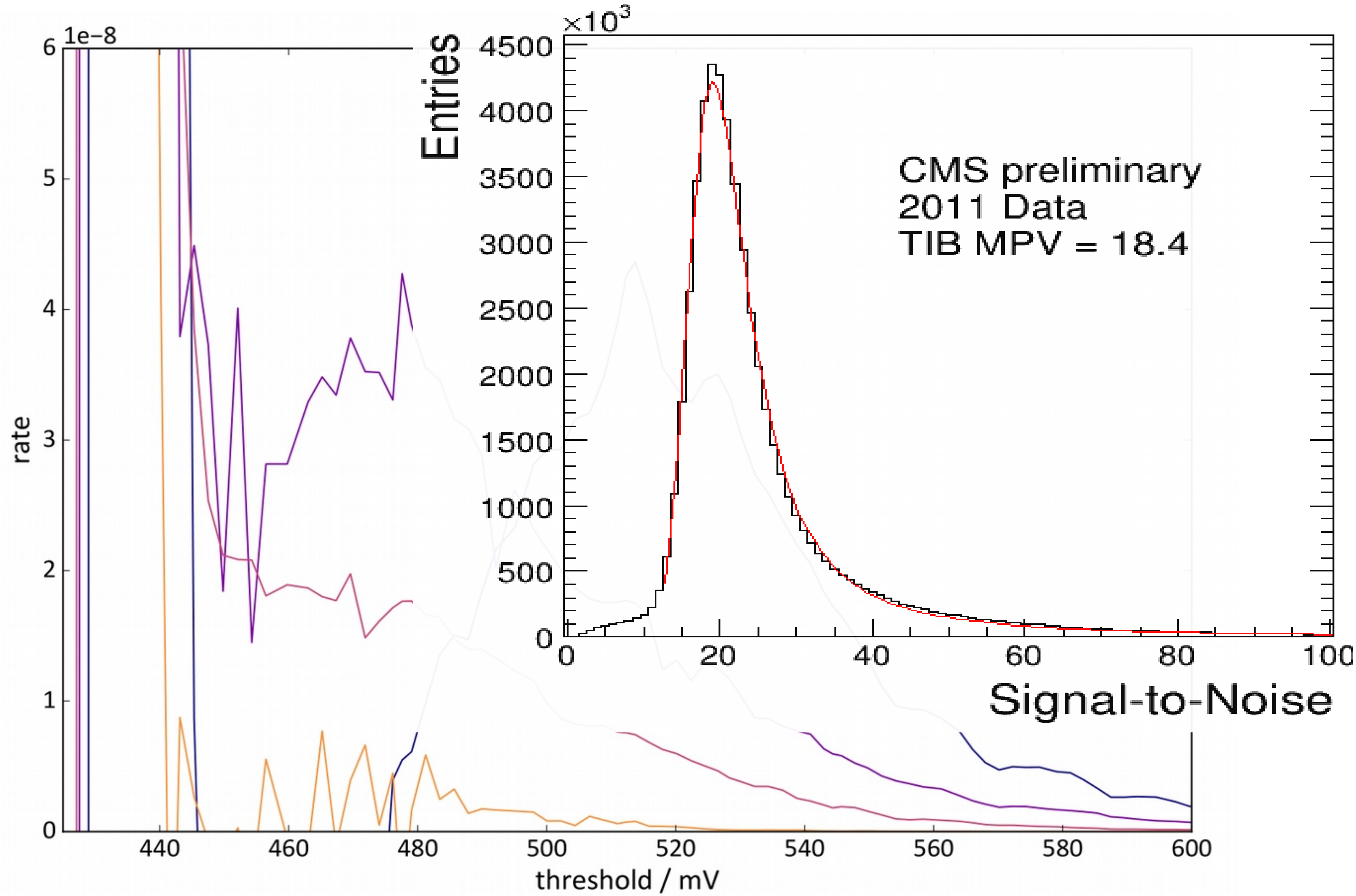


- signal height / MPV: 100mV * 6 ke^- / 35 mV ≈ 17 ke^- (MIP 300µm Si ~ 22ke^-)



- signal height / MPV: 100mV * 6 ke⁻ / 35 mV ≈ 17 ke⁻ (MIP 300µm Si ~ 22ke⁻)
- ideas / references how to fully reconstruct the expected landau-distribution are most welcome!

Summary

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  - micro-strip detector readout
  - motivation for binary readout

- noise
  - single channel noise
  - common mode noise

- signal
  - test-pulses
  - x-rays
  - mips (Sr90 betas)

Backup