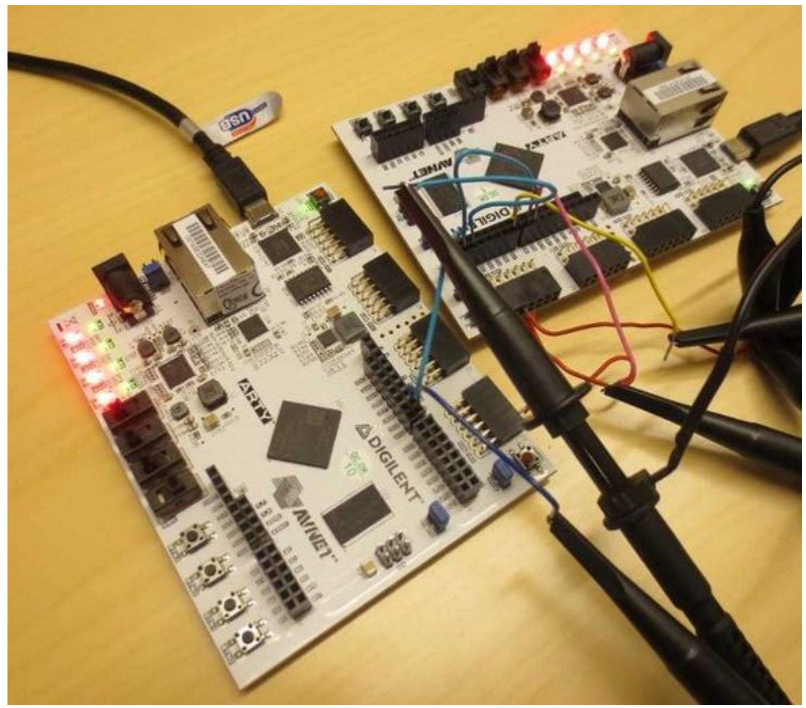
FPGAs for timing and compression

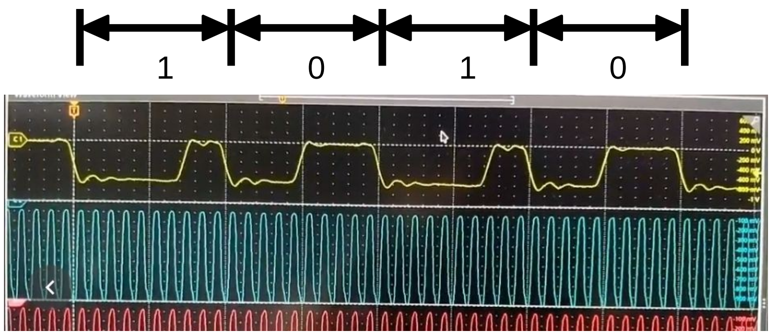


Håkan T. Johansson, Chalmers, Göteborg
SFAIR / SFS-KF XLI(I)[?], AlbaNova, Stockholm, Oct 2022

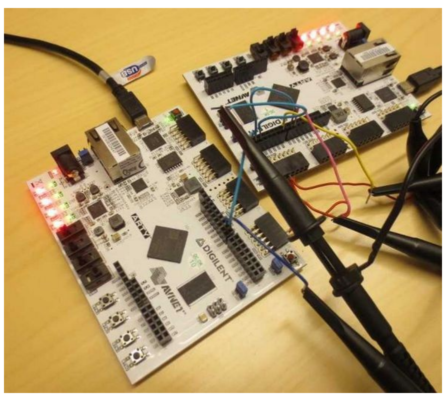
[?] Did we stop counting?

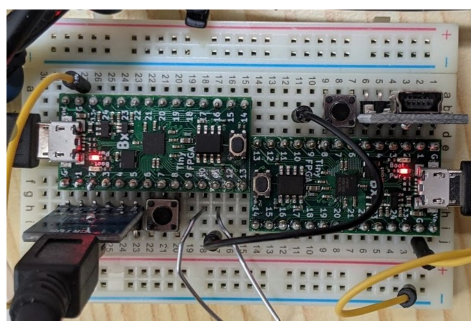
High-precision time and clock distribution - Rataclock

- Single-wire, DC-balanced serial clock + time signal
- PLL-friendly (-> clock)
- 64-bit timestamp, continuously



With Bastian Löher, GSI. ”sales”, HW & test.





- Used @ R3B in 2022 (FOOT, TPC)
- DTAS (DESPEC), 2022
- Several more prepared...

(Talk by Hans)

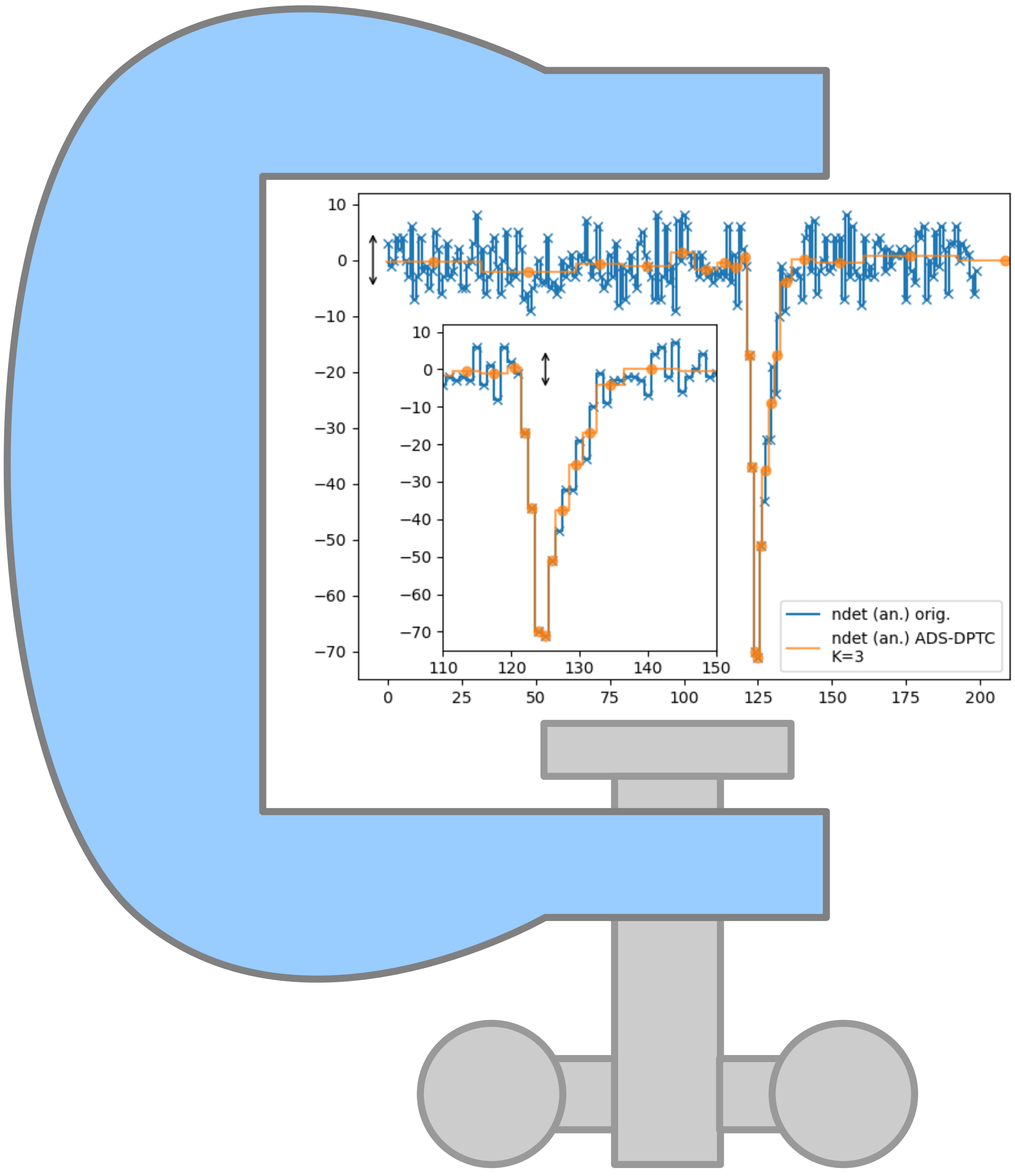
Developed with paper-clips...

- < 50 ps so far (with SIS3316)

& elsewhere!

http://fy.chalmers.se/~f96hajo/rataser/

Traces: size, value and cost

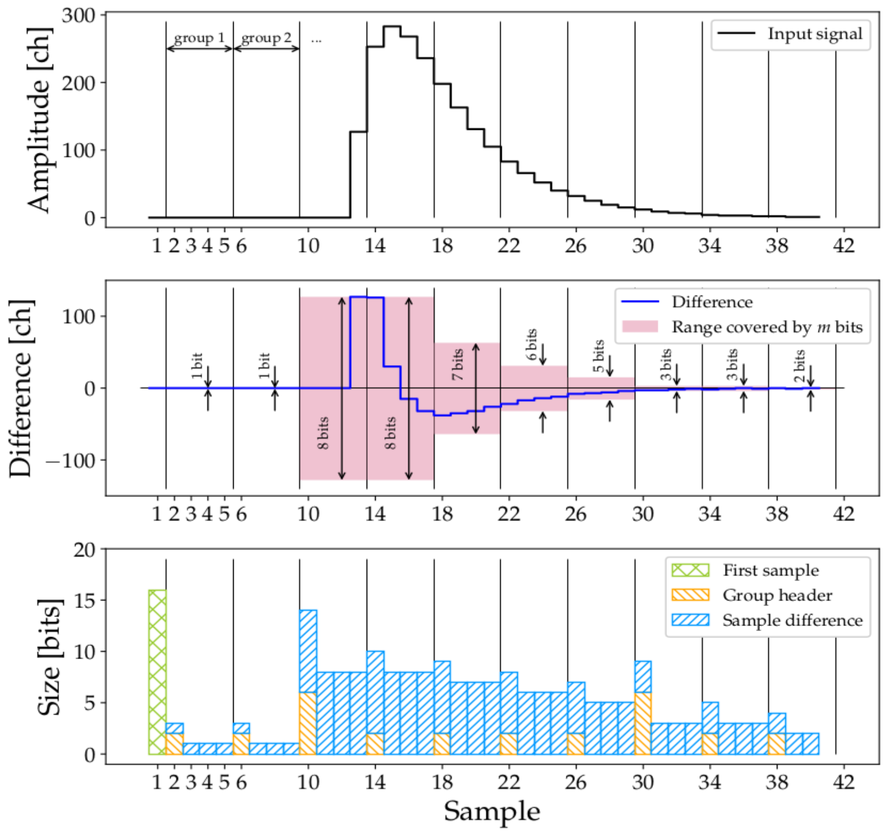


Adaptive downsampling:

- What is the gain?
- What is the damage?

Adaptive downsamping for DPTC:
Developed by (MSc theses):
Lukas Rahmn, Anton Fredriksson (2020)
Hezhe Xiao (2021)

In the previous episode… (DPTC)



Difference predicted trace compression

0. Get a trace.

Easiest: ask a friend!

1. Calculate differences.
2. Group (e.g. by 4).
3. Determine min. bits needed in group.
4. Store. Group headers give bits/sample.

Presented by Giovanni at SFS-KF XXXVII, 2017, AlbaNova

DPTC:
Giovanni Bruni and H T Johansson
IEEE Trans. on Circuits and Systems I, Vol 67 (1), Jan. 2020.

(Talk by Hans)

DPTC in use:
F. Hueso-González et al.,
A dead-time-free data acquisition system for prompt gamma-ray measurements during proton therapy treatments
NIM A, 1033, 2022.
Struck SIS1160/SFMC01 (FPGA)

At R^{3}B, for FOOT (Si) readout
Terasic DE10 nano boards (ARM CPU)

or Why experimentalists not are bored...

Non-ideal measurements

Geant4 (Monte Carlo)

Simulation realism...

Time-varying...

Calibration, Reconstruction

- Physical processes (statistical)
  (e.g. energy straggling)
- Material/detector imperfections
  (e.g. thickness variation)
- Noise
  (e.g. thermal; Ge cooling…, electronics)
- Drift
  (electronics, temperature...)
- Digitisation (integer quantisation)
  (often negligible)
- Compression (lossy)
  (traces)
- Data treatment / analysis

Today (exception): our ”accomplice”.

Today

Focus

DPTC storage cost is noise driven!

Difference predicted trace compression

COMPRESSION EFFICIENCY OF THE DPTC ALGORITHM FOR ACTUAL TRACES, CATEGORISED BY DETECTOR TYPE AND DETECTED RADIATION, AND COMPARED TO POPULAR GENERAL-PURPOSE COMPRESSION METHODS AND HUFFMAN ENCODING.

Label	Category	Details	Traces #	Samples #	$\langle A_\mathcal{P}\rangle_\mathrm{g.}$	$\sigma_\mathcal{N}$	$\langle c_\mathcal{S}\rangle$	DPTC	gzip	xz(LZMA)	Huff.
								— — — — Bits/sample	— — — —		
a		core signal	40	5000	78.3	2.16	4.06	**3.89**	5.54	4.04	3.58
b	γ in segmented BEGe	segment 1	40	5000	27.3	2.16	4.06	**3.86**	4.87	3.89	3.55
c		segment 5	40	5000	53.2	2.21	4.09	**3.91**	5.54	4.13	3.59
d		Ionisation chamber	200	200	907	71.2	9.10	**9.16**	11.37	9.78	8.75
e	n/γ discrimination	n-det. anode	200	200	226	4.88	5.24	**5.36**	6.63	5.32	5.12
f		n-det. cathode	200	200	220	6.20	5.58	**5.71**	7.00	5.62	5.46
g	position-sensitive	α-particles	50	1000	852	29.7	7.84	**7.81**	11.07	8.10	7.38
h	Si pin-diode	^{40}Ar	50	1000	638	6.36	5.62	**5.58**	9.37	6.23	5.24
i		no signal split	100	200	534	5.30	5.36	**5.55**	7.91	6.33	5.47
j	γ from ^{137}Cs	signal split 1:2	100	200	292	3.90	4.91	**5.08**	7.18	5.67	4.98
k	in $LaBr_3$	signal split 1:4	100	200	194	3.23	4.64	**4.81**	6.69	5.24	4.68
l		signal split 1:8	100	200	122	3.05	4.56	**4.65**	6.37	5.06	4.43
m		350V ^{a}	100	600	9.2	0.25	0.94	**1.67**	0.65	0.49	0.65
n	cosmic μ in $LaBr_3$, varying HV of PMT	400V ^{a}	100	600	19.4	0.25	0.94	**1.67**	0.84	0.63	0.78
o		450V	100	200	921	4.28	5.05	**5.55**	8.36	6.42	5.76
p	cosmic μ in $LaCl_3$,	CAEN DT5730	100	400	301	3.88	4.90	**5.00**	7.23	5.47	4.89
q	different digitizers	CAEN DT5751	100	400	40.6	0.86	2.73	**2.72**	3.94	2.82	2.64
r		all values 0	1	1000	0	0	-	**1.51**	0.28	0.67	0.26
s	Flat traces ^{b}	all values 10	1	1000	0	0	-	**1.51**	0.28	0.67	0.26
t		all values 100	1	1000	0	0	-	**1.51**	0.28	0.67	0.26

Based on the noise of the signal...

... the average storage size (bits/sample) is estimated...

...and matches actual!

DPTC storage cost is noise driven!

Difference predicted trace compression

COMPRESSION EFFICIENCY OF THE DPTC ALGORITHM FOR ACTUAL TRACES, CATEGORISED BY DETECTOR TYPE AND DETECTED RADIATION, AND COMPARED TO POPULAR GENERAL-PURPOSE COMPRESSION METHODS AND HUFFMAN ENCODING.

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								— — — —	Bits/sample	— — — —	
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	...EGe	segment 1	40	5000	27.3	2.16	4.06	**3.86**	4.87	3.89	3.55
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r			1	1000	0	0	-	**1.51**	0.28	0.67	0.26
s	Flat traces	all values 10	1	1000	0	0	-	**1.51**	0.28	0.67	0.26
t		all values 100	1	1000	0	0	-	**1.51**	0.28	0.67	0.26

Among friends...

Side remark:

Testing with **real data** critical.

DPTC developments were first done with *synthetic* traces. (i.e. we thought we know how traces and noise behave.)

We were … **not right**.

Major change to storage (i.e. compression) strategy...

Based on the noise of the signal...

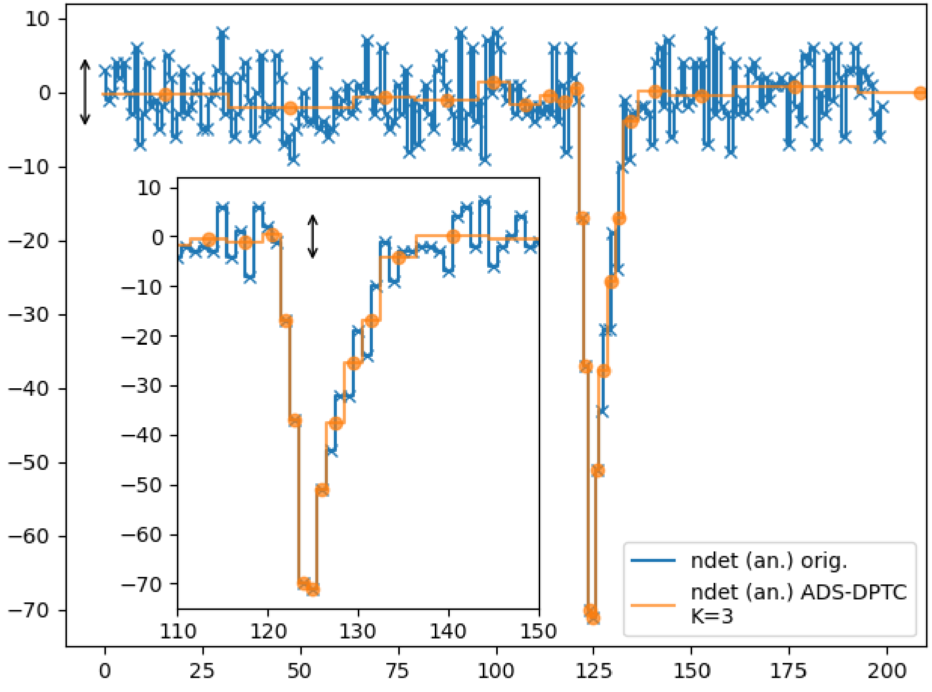
… the average storage size (bits/sample) is estimated...

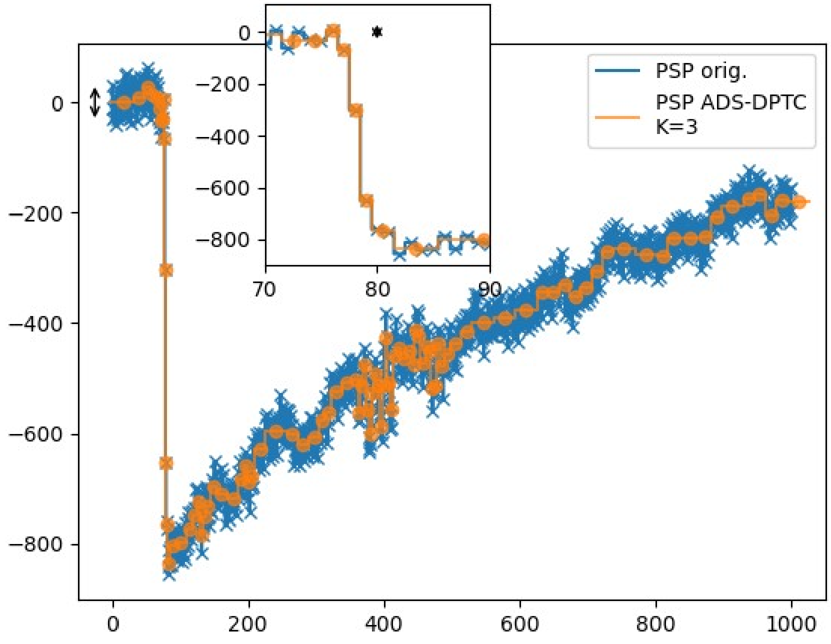
...and matches actual!

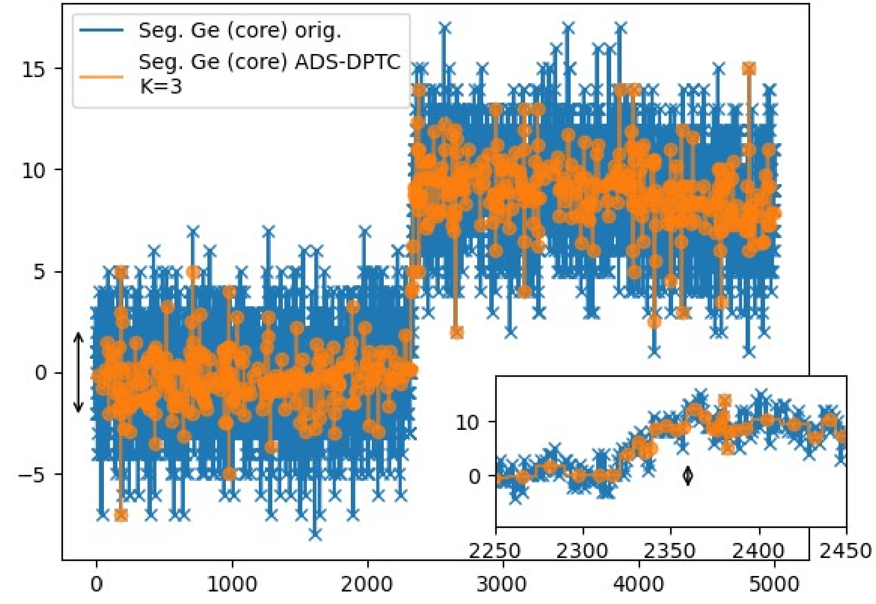
Adaptive downsampling

Reduce storage need by reducing number of **samples**:

- Combine as **average**.
- Where '**compatible**' with **noise**.
- **Lossy…** (but maintains integral)







Adaptive downsampling: method

Group samples into as **few averages** as 'possible'.

'Possible' when **deviations** are **within** expectations of **noise** (σ_{noise}).

Control parameter: *K*

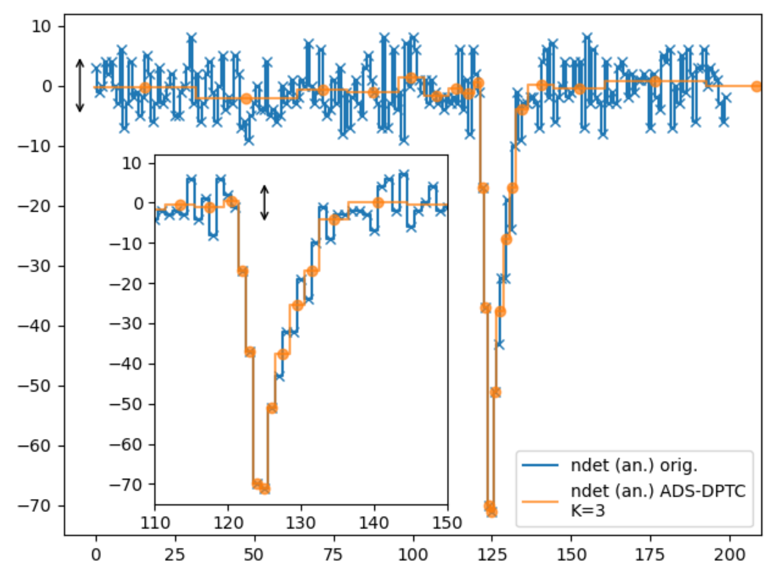
Averaging **lengths: 2*ⁿ***, only change **-1,0, or +1** each step.

Additional storage: **1 or 2 bits** per average. (1 for 0, 2 for ± 1).

For **all** $\boldsymbol{x_i}$ and **all** $\boldsymbol{n}$ < max level:

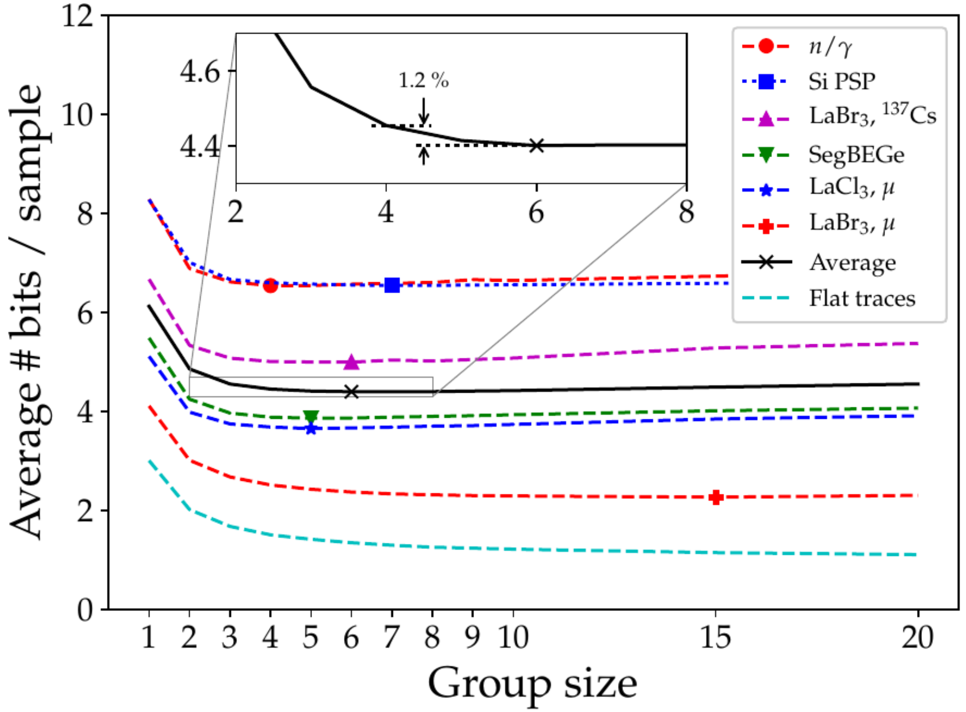
$$\sum_{j=1}^{2^n} x_{i+j-1} - \sum_{j=1}^{2^n} x_{i-j} < K\sqrt{2^{n+1}}\,\sigma$$

- Yes: no restriction.
- No: averaging **length ≤ $\boldsymbol{2^n}$** *for* x_{i-1}, x_i.

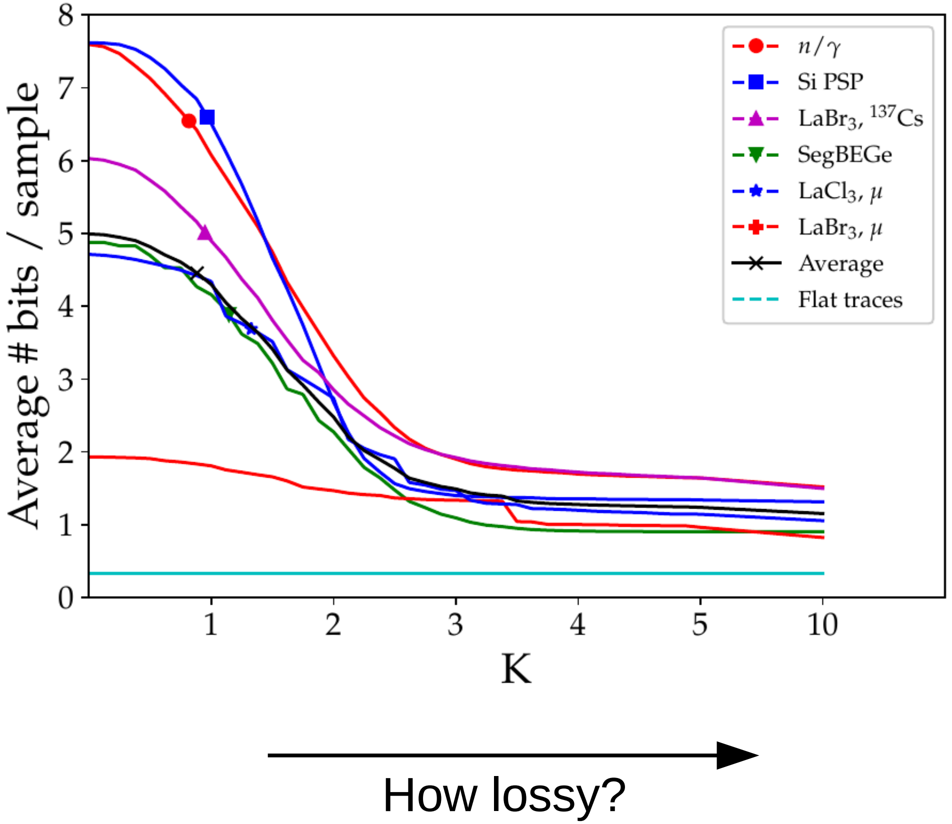


Real-world traces – costs (savings)

Lossless (DPTC)



Lossy (ADS-DPTC)



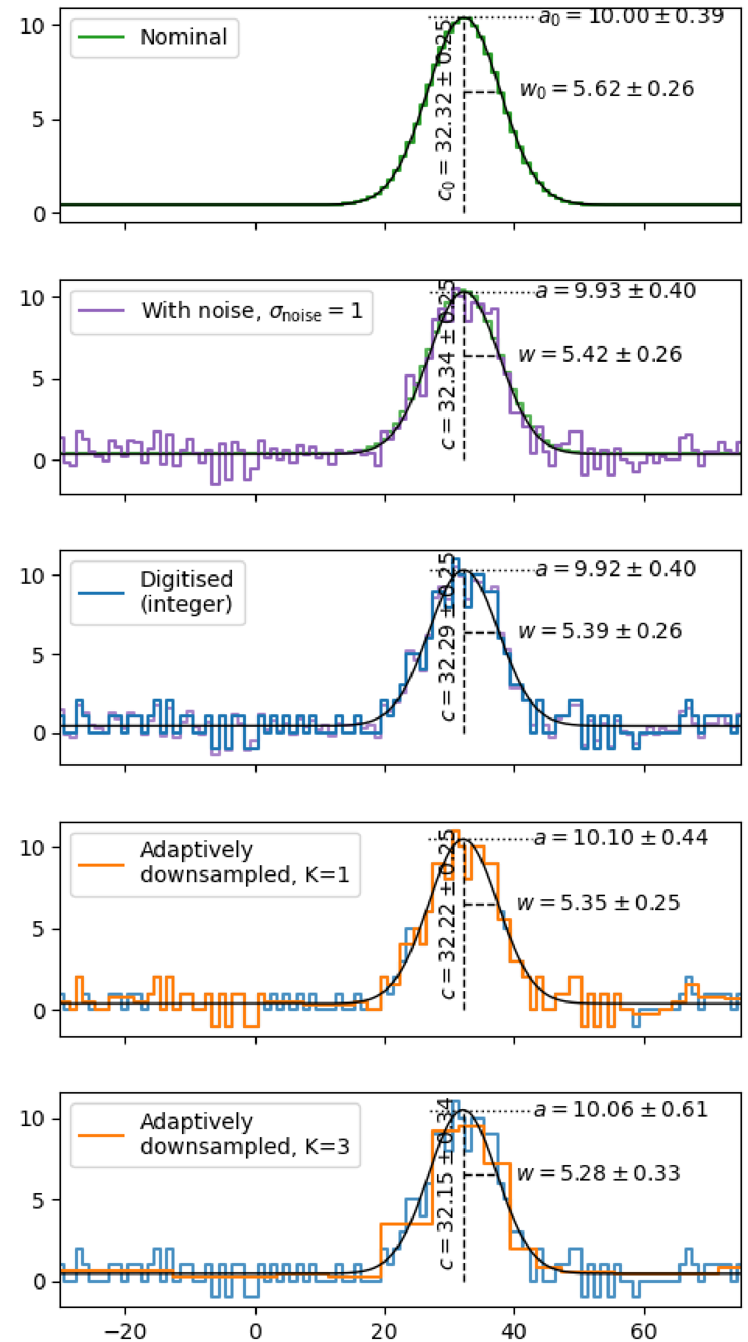
Typical non-compressed size:
16 bits / sample.
(12/10 bit flash-ADC)

„Damage report”

The fate of one particular Gaussian:

To assess the impact of the lossy compression:

Study fits of Gaussian pulses.

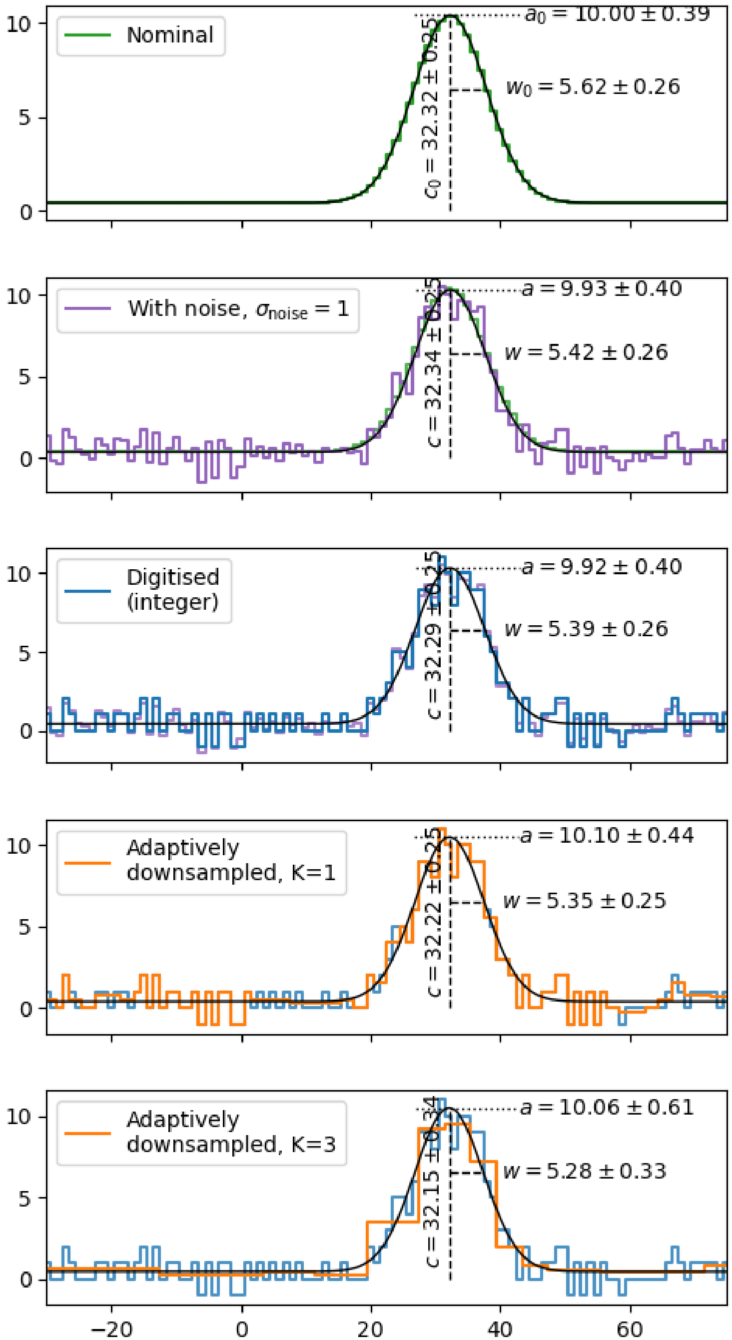


It can always get worse… ↓

Next page: Many Gaussians

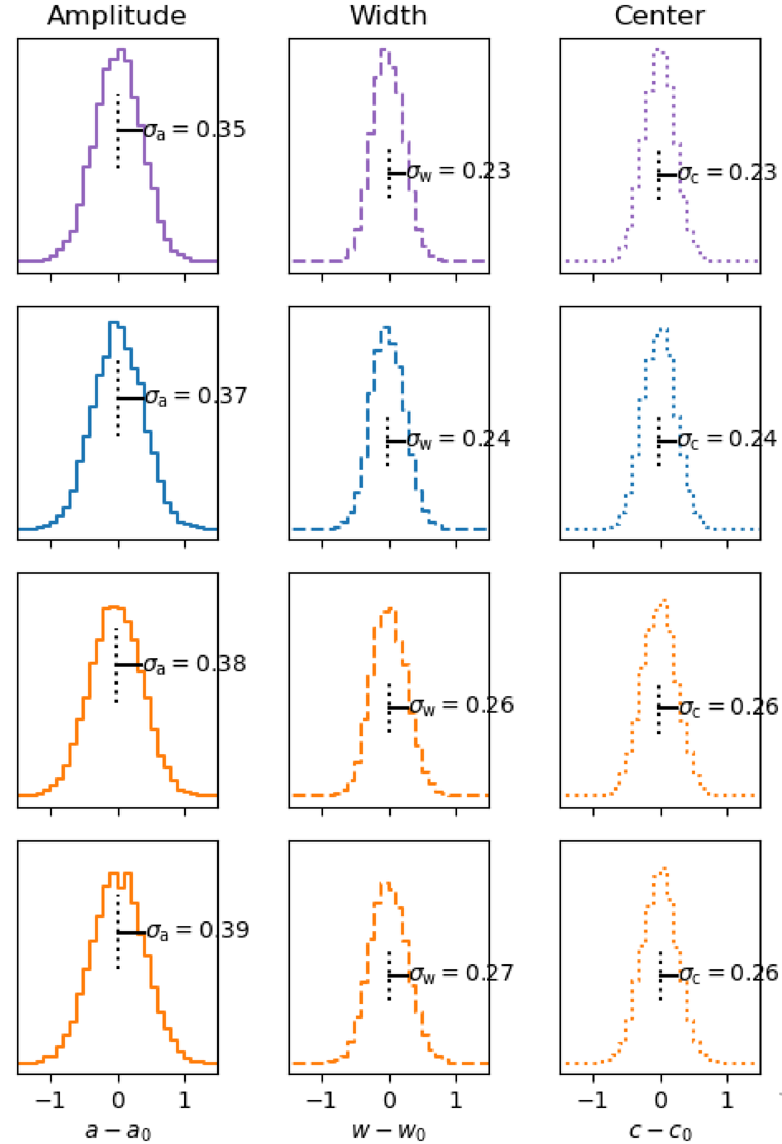
"Damage report"

The fate of one particular Gaussian:



All a_0 = 10.0, w_0 = 5.62, σ_{noise} = 1.0.

Reconstruction error of ensamble of Gaussians:



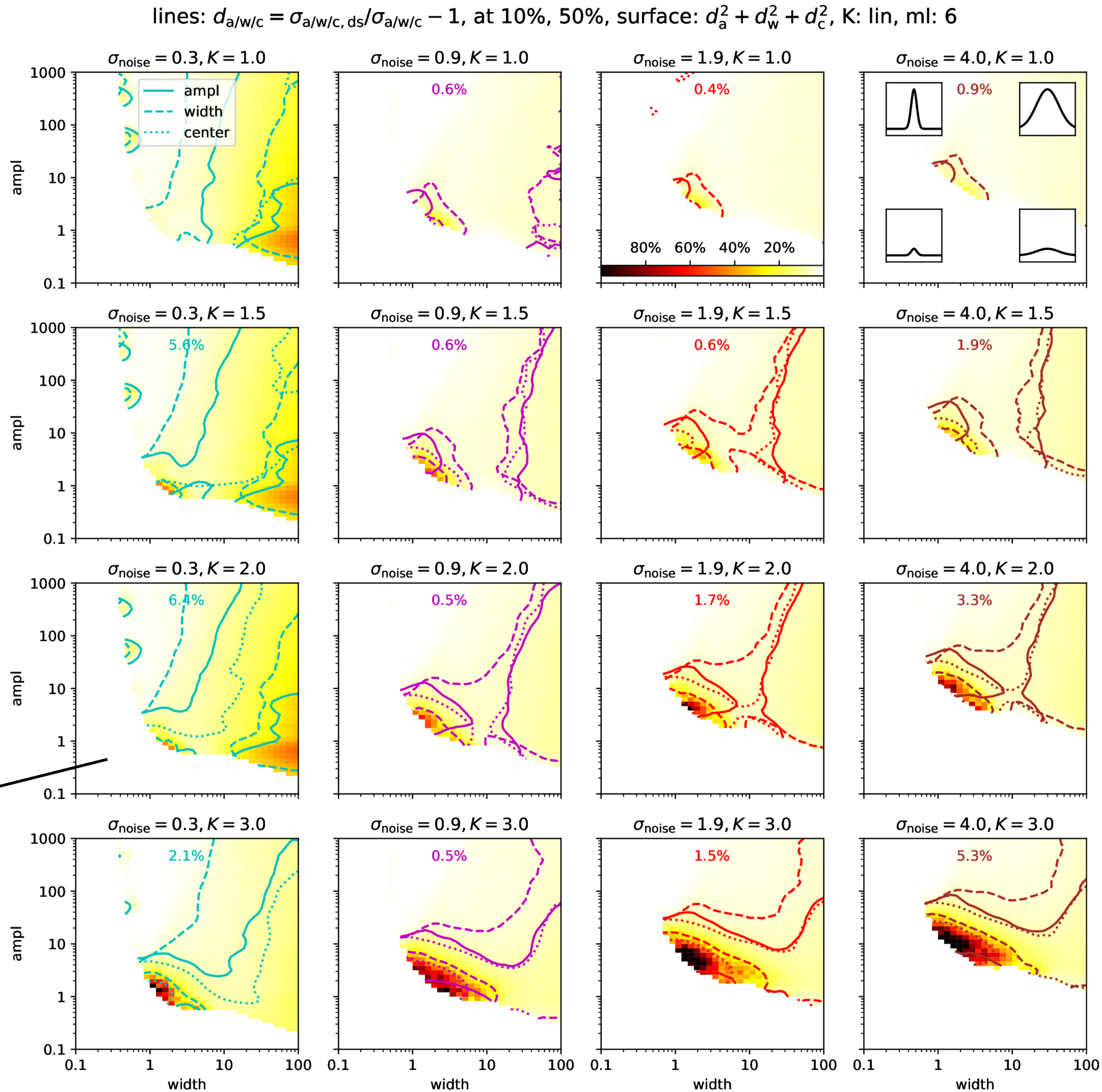
Quite some visual difference

'Small' fit difference

Next page: More Gaussians

Linear (triple) downsample conditon.

Loss map

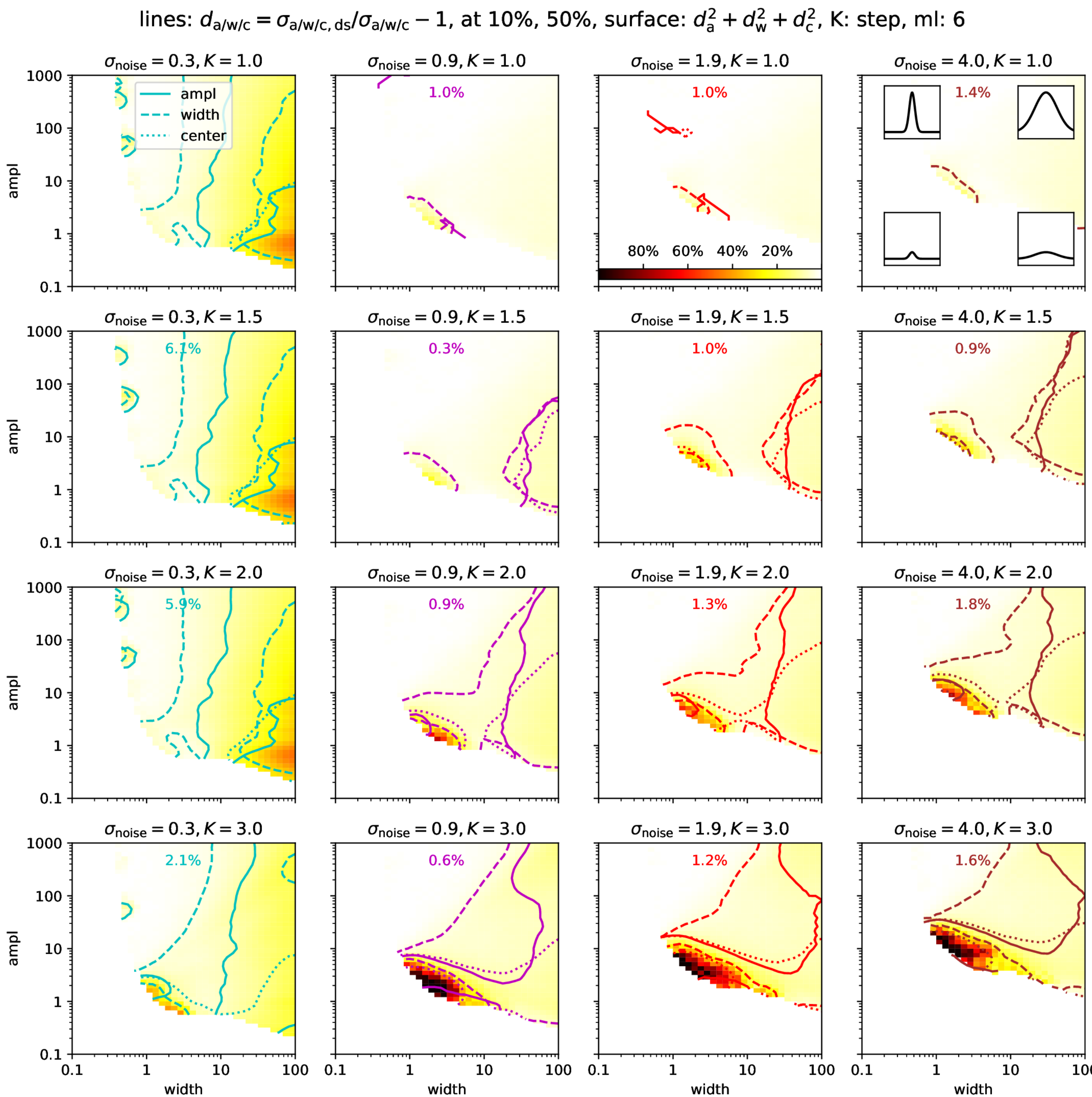


"Terra impraticabile"

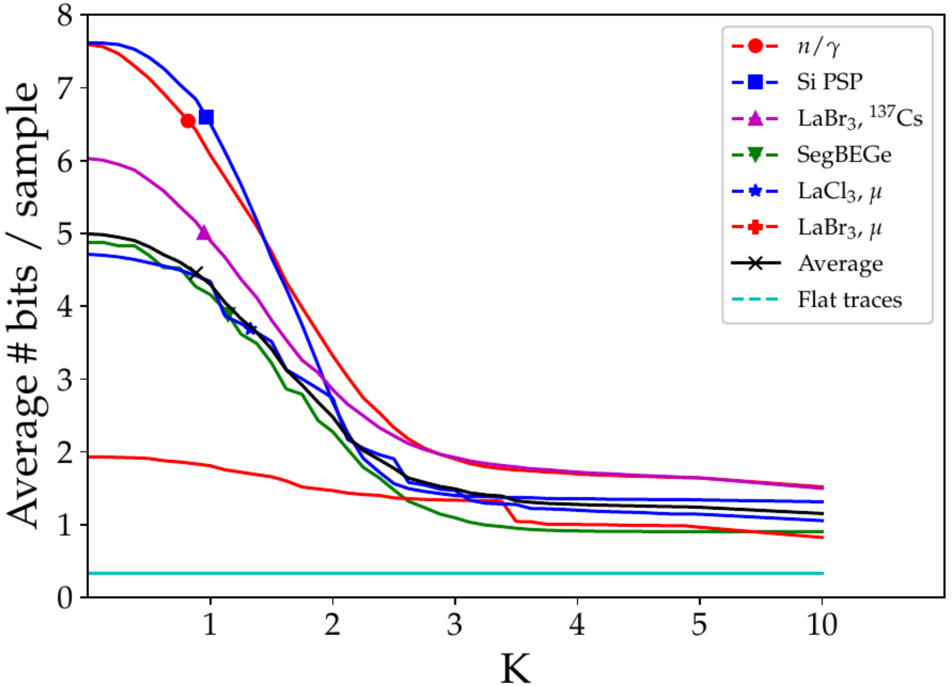
(No fit – too much noise.)

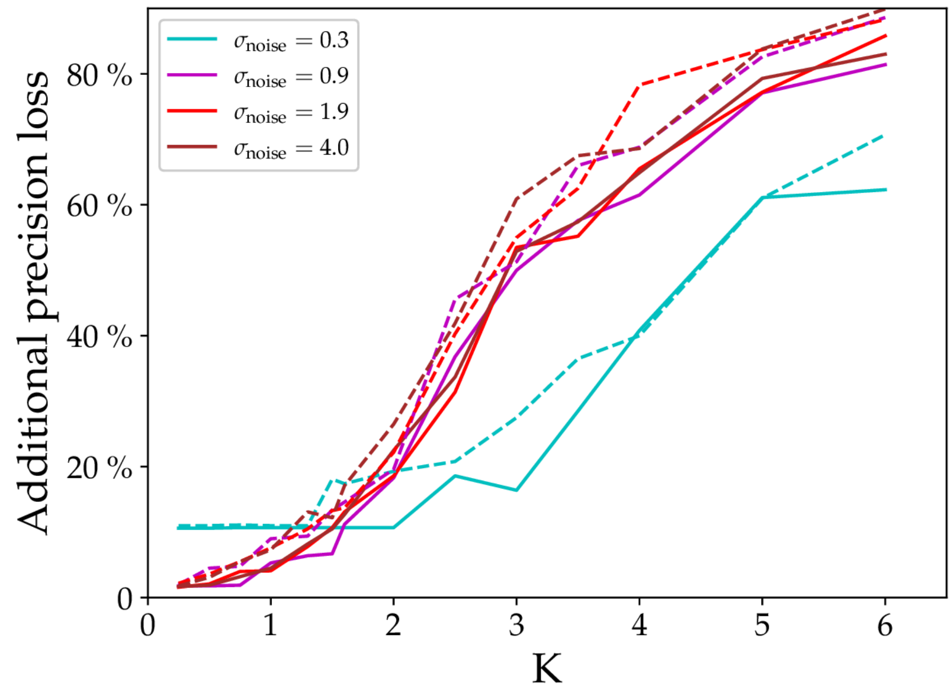
Step (pair)
downsample
conditon.

Loss map



Wrapping up: savings vs. loss





Note: **precision loss** compared to **noise loss** only.
Detection processes may induce much larger uncertainties, due to **statistical physical processes**, e.g. energy loss straggling.

Wanted!

Real-world examples of final-result effects...

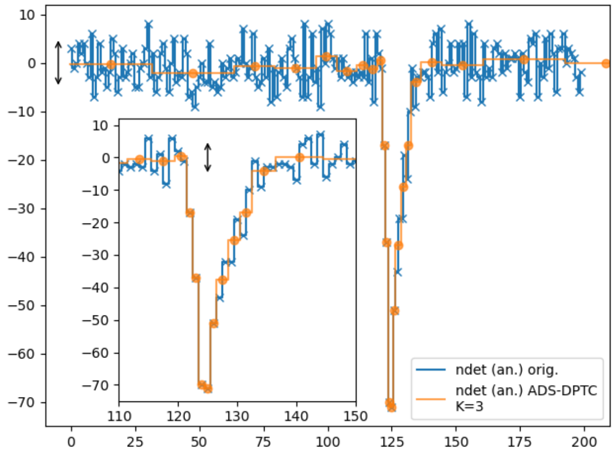
- Do **you** analyse pulse shapes?
- Does your analysis yield **FoM** values?

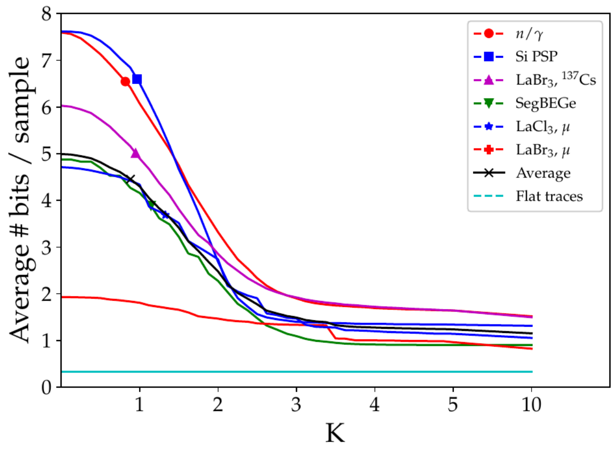
Figure-of-merit;
Signal separation…
=
Quantify quality?

- Want to **try** ADS-DPTC?

→ Please contact me.

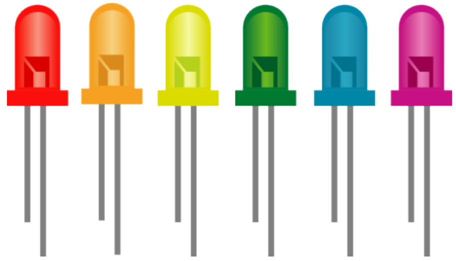
Finale!





Thank you!

Adaptive downsamping for DPTC:
Developed by (MSc theses):
Lukas Rahmn, Anton Fredriksson (2020)
Hezhe Xiao (2021)



Rataclock protocol

64-bit timestamp + 16 extra

4 time + 2 group + 5 signals

Hamming 11 data+5parity

24-slot word
2x8 data+6 mark+2x1 aux

2 mark + 3x2 duplication
(optional)

Fixed rising edge period;
Encode as long/short