Signal detection temporal resolution with various filters

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Summary

1. Make a signal template from LNGS LN.

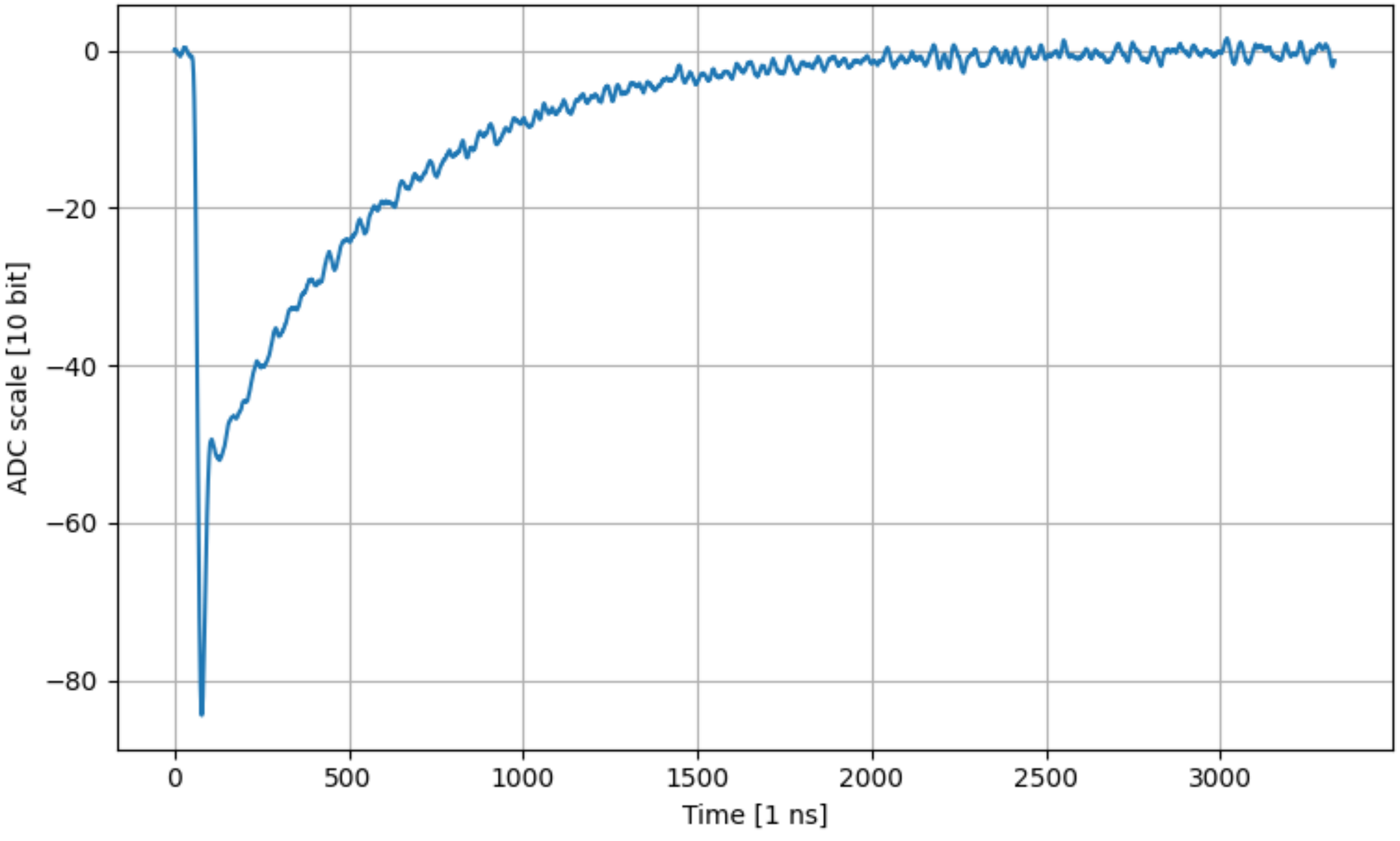
2. Generate one 1 p.e. signal per separate event with proto0 noise. The signal amplitude varies as it does in data, and the signal temporal position varies more finely than the sampling (125 MSa/s).

3. Filter and find the minimum value in the event, interpolate the minimum with a parabola (instead of e.g. upsampling).

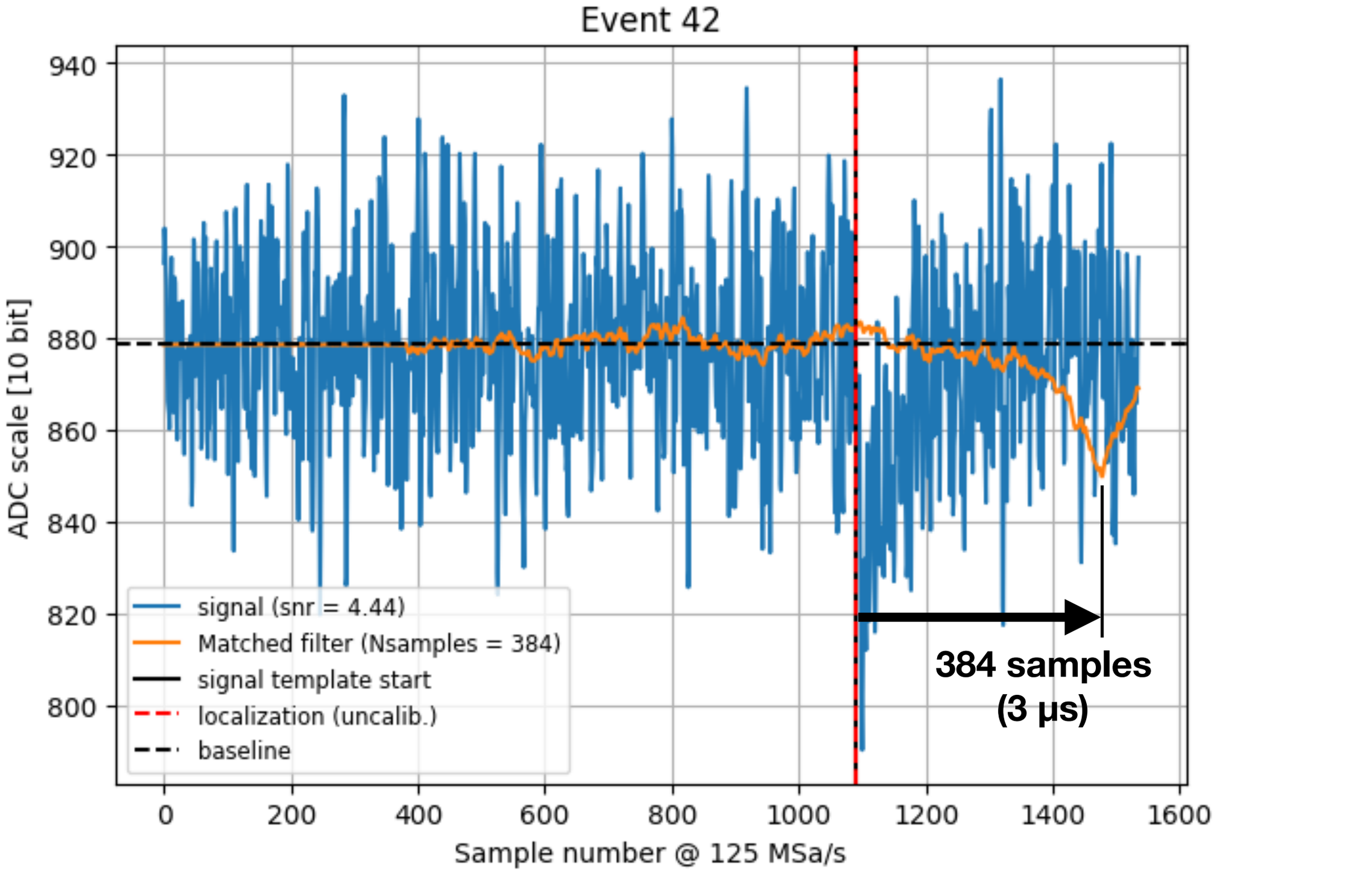
4. Repeat for various SNR and filters, compare Monte Carlo truth with temporal localization.

5. (Defects: no digitalization, no pile-up, fixed template shape.)

Signal template



Example event



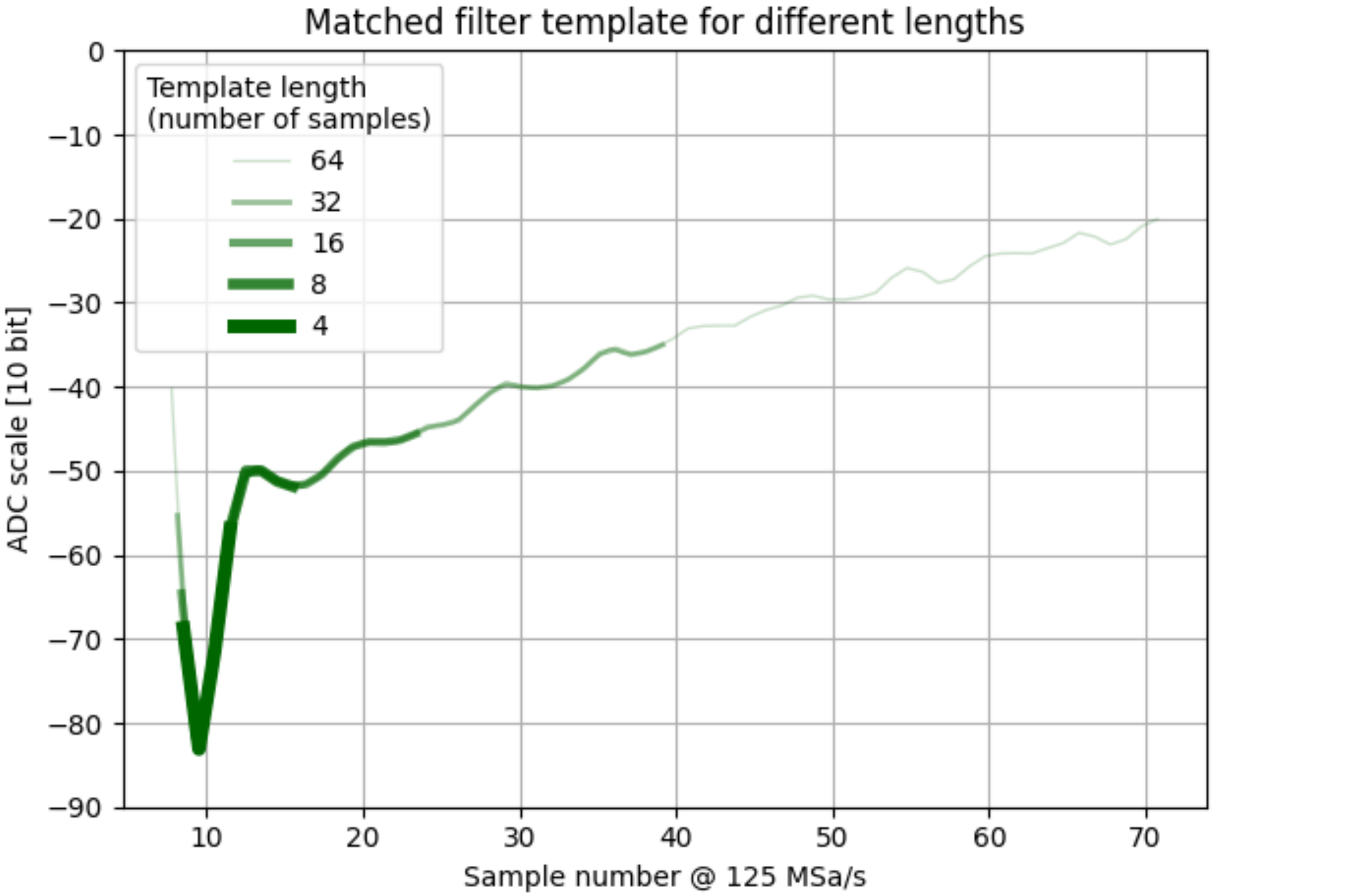
Matched filter (1/2)

- I'm computing the cross-correlation between the waveform and the signal template, so it is properly a matched filter in the case of white noise.

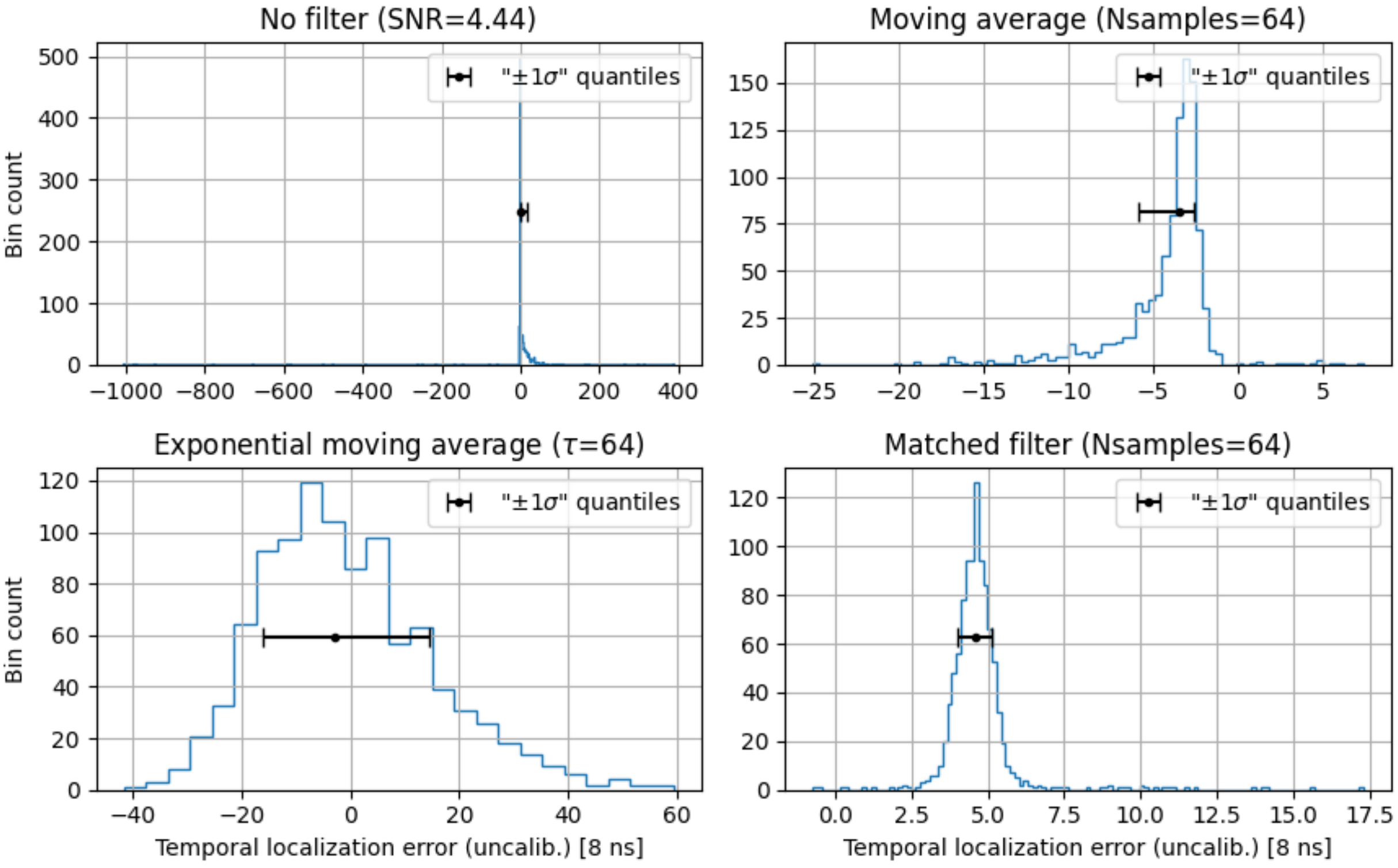
- The **downsampling** from the 1 GSa/s LNGS template to 125 MSa/s is done by **averaging in groups of 8 samples** (both for the filter and the simulated data).

- I try various lengths of the filter template. The **truncation** is done by keeping the part of the 1 GSa/s template that has **maximum vector norm** before downsampling (see figure next slide).

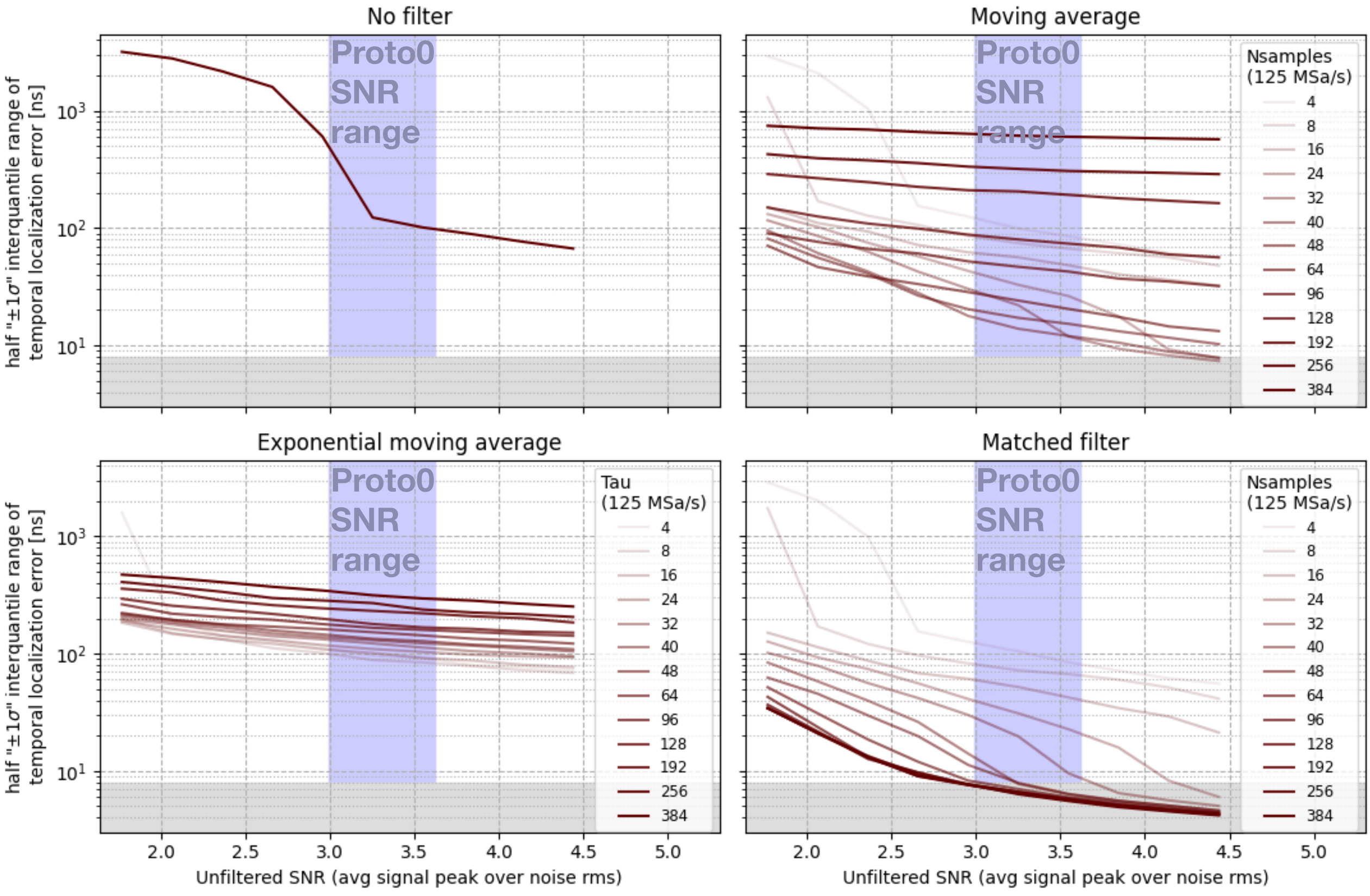
Matched filter (2/2)



Example temporal localization



Results (1/2)


No filter
Moving average
Exponential moving average
Matched filter
Proto0 SNR range
half "±1σ" interquantile range of temporal localization error [ns]
10^3
10^2
10^1
Nsamples (125 MSa/s)
Tau (125 MSa/s)
4
8
16
24
32
40
48
64
96
128
192
256
384
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Unfiltered SNR (avg signal peak over noise rms)

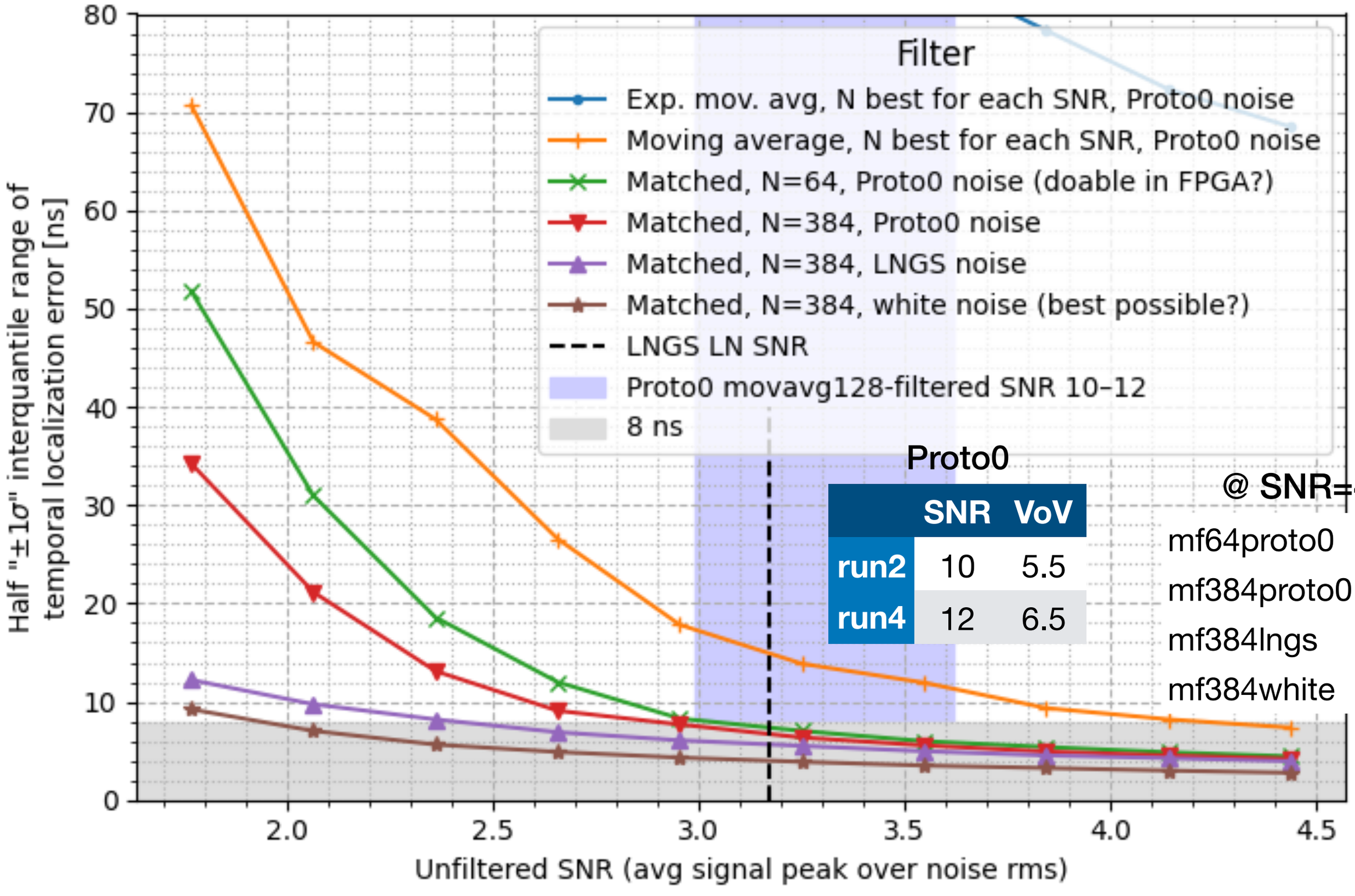
Results (2/2)

- On the vertical axis there's the half interquantile range 16%–84% (equivalent to 1 sigma for gaussians).

- The unfiltered SNR (x-axis) is the average signal peak height before downsampling over the noise standard deviation.

- The moving average does not go below one sample (8 ns) resolution. The expon. does not go below 10 samples but is stable. The matched filter goes down to 1/2 sample (4 ns), and is almost optimal from a template length of 96 onwards.

Comparison (1/2)



Proto0

	SNR	VoV
run2	10	5.5
run4	12	6.5

@ SNR=4.44

mf64proto0	4.4 ns
mf384proto0	4.2 ns
mf384lngs	3.9 ns
mf384white	2.8 ns

Comparison (2/2)

- The simulated signal is always done with the same template, which is used also for the filter. This is very optimistic.
- Resources on FPGA could be sufficient for the matched filter truncated to 64 samples.

Conclusions

- Best temporal resolution with LNGS SNR is 4.0–6.7 ns depending on noise model (roughly consistent with Luca Doria's results).

- The matched filter is already optimal with only 96 samples.

- Keeping 10 us of waveform is very conservative (will be checked thoroughly).

- Data: http://ds50tb.lngs.infn.it:2180/SiPM/Tiles/FBK/NUV/MB2-LF-3x/NUV-LF_3x_57/nuvhd_lf_3x_tile57_77K_64V_6VoV_1.wav
- Code: https://bitbucket.org/Gattocrucco/sipmfilter/src/master/

PDM 1		PDM 2		PDM 3		PDM 4		PDM 5	
	31		32		39		64		55
126	57	132	44	136	42	142	52	149	53
0	0	0	2	0	4	0	6	0	8
PDM 6		PDM 7		PDM 8		PDM 9		PDM 10	
	30		59		57		37		29
127	33	133	41	138	37	144	31	150	43
0	10	0	12	1	0	1	2	1	4
PDM 11		PDM 12		PDM 13		PDM 14		PDM 15	
	38		36		58		62		60
129	46	134	48	139	60	145	59	151	50
1	6	1	8	1	10	2	0	2	2
PDM 16		PDM 17		PDM 18		PDM 19		PDM 20	
	41		61		66		63		52
130	47	135	32	140	40	146	56	152	35
2	4	2	6	2	8	2	10	3	0
PDM 21		PDM 22		PDM 23		PDM 24		PDM 25	
	34		53		54		65		42
131	38	137	58	141	34	148	51	153	45
3	2	3	4	3	6	3	8	3	10

PDM slot	
	tile (run2)
PDM	feb
V1725[0..3]	Ch[0..15] (top)