XEC noise study

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Development of Researches in Lepton Flavor Physics with Muons

5 Apr. 2018

What we reported at the last meeting

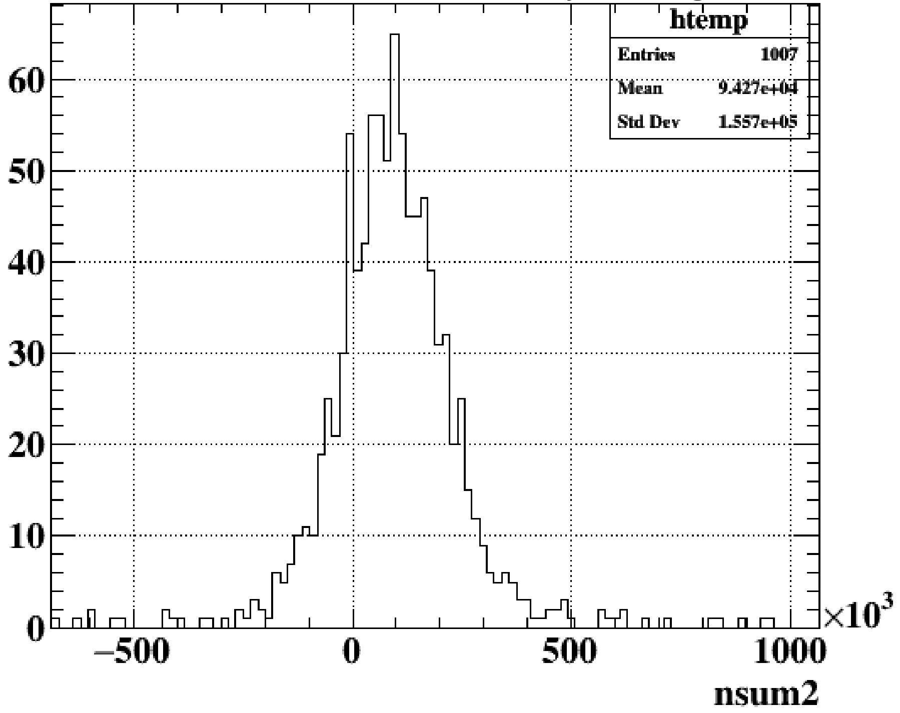
- Offline noise subtraction task was implemented.
  - Cell pedestal subtraction
  - Template noise subtraction (120MHz)
    → improved by Shinji

- After noise subtraction, RMS of total Nphoton (corrected by coverage) in pedestal run was ~1% of the Nphoton for 53 MeV γ.
  → It will increase when all cables are connected.

- Noise was coherent among channels in same WD board.

Total number of photons

(corrected by coverage)



Updates

We have a lot of additional information, but have not yet solved the problem.

- Hardware tests
  - Test of changing grounding scheme (by using noise cut power transformer etc.)
  - Cable removal test
  - Noise test at office
  - Ferrite core test

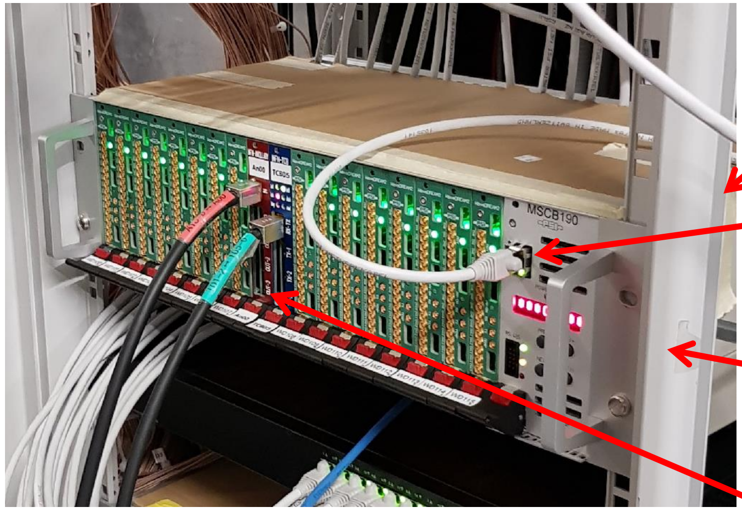
- Analysis updates
  - New noise map
  - Notch filter test
  - Hi-pass filter test
  - Quantification of noise by using correlation matrix and covariance matrix

Hardware tests

Ground connection change

Shared GND in piE5 area is connected to everywhere and maybe noisy.
WD crate is connected to the shared GND by many cables etc.

We tried to disconnect the crate from shared GND.



Power plug (backside) → Use noise cut transformer

LAN cable → Use plastic shield LAN cable

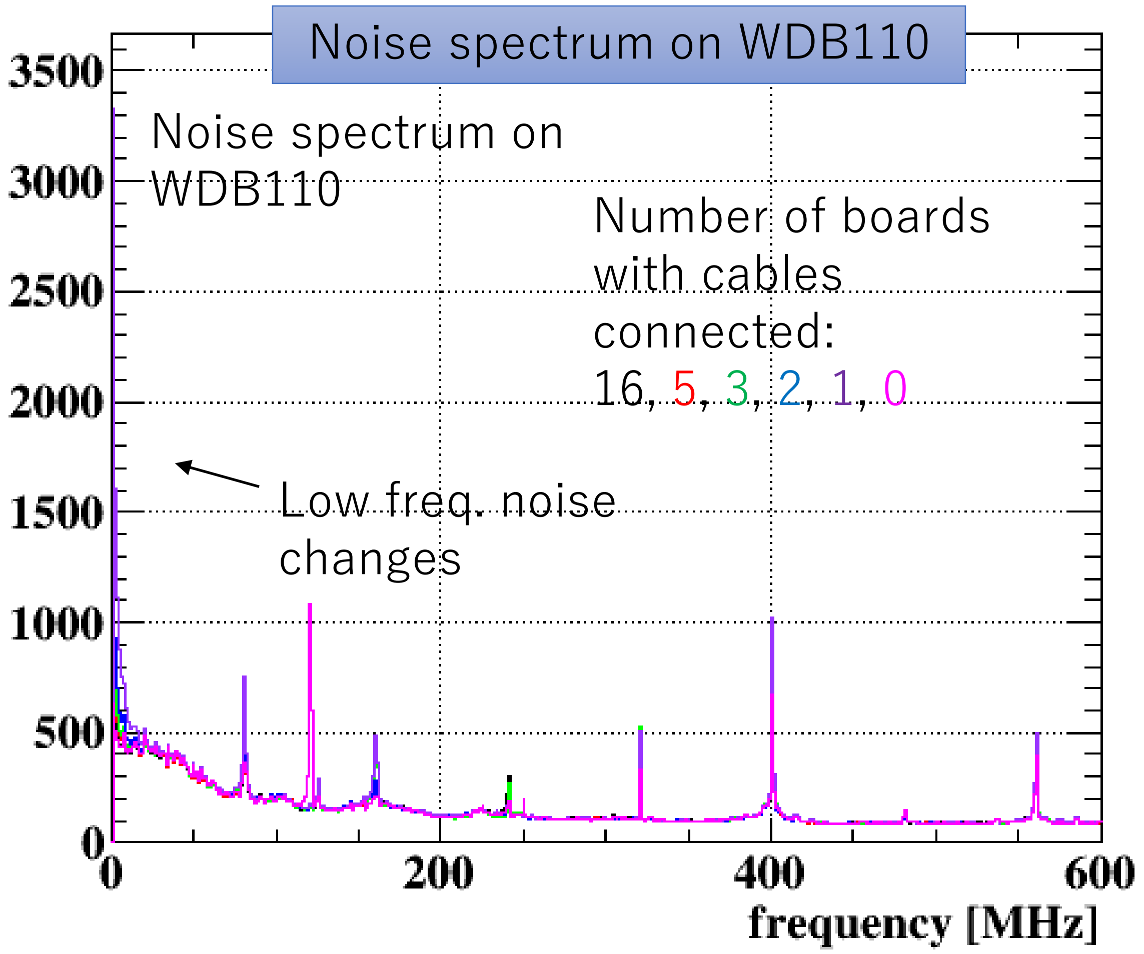
Rack → Insert Teflon sheet

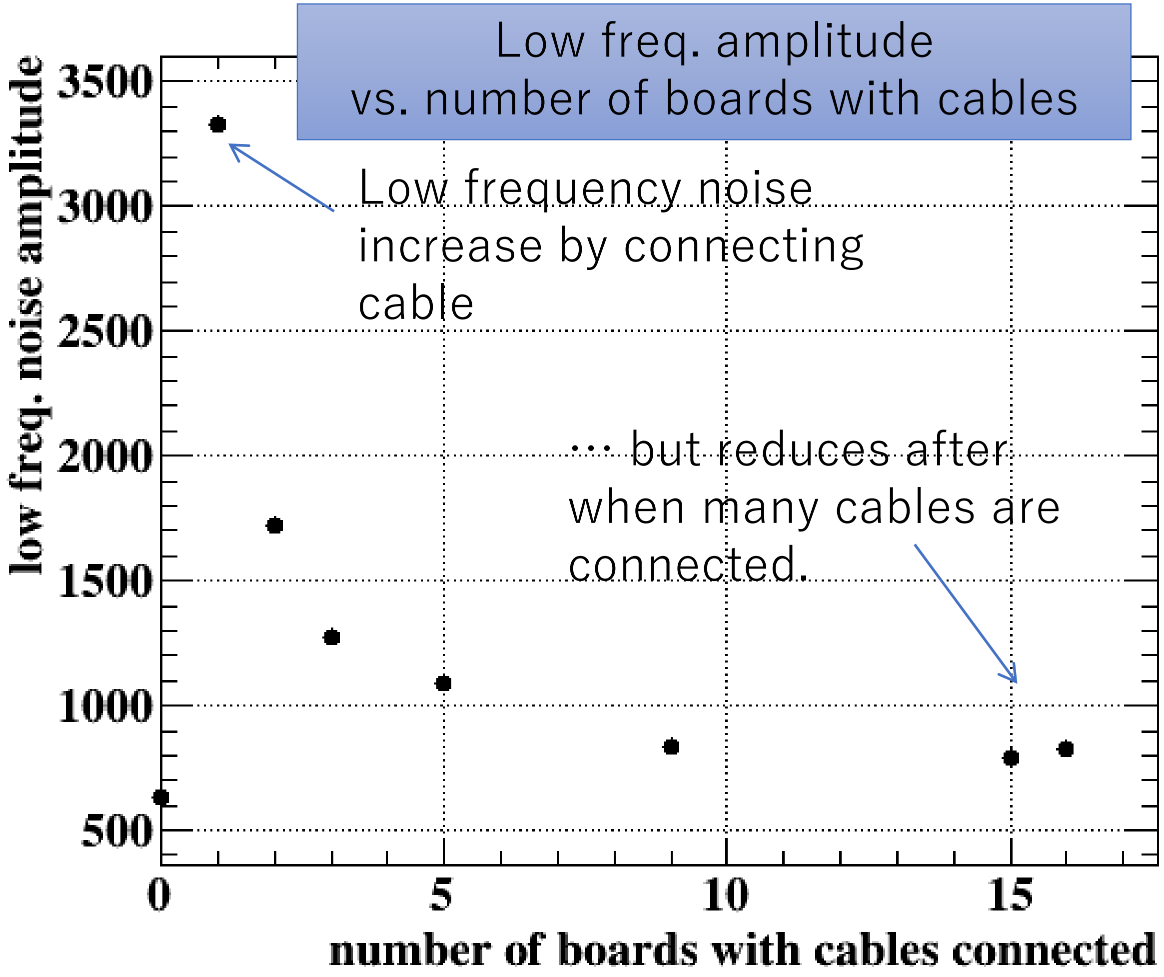
TRG cables → cannot be removed

However, FFT noise spectrum did not change.

Effect of removing cables

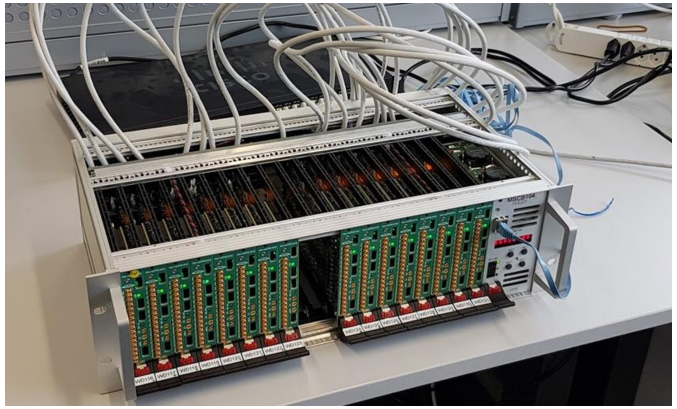
I checked the effect of disconnecting MPPC cables from WD crate #2.

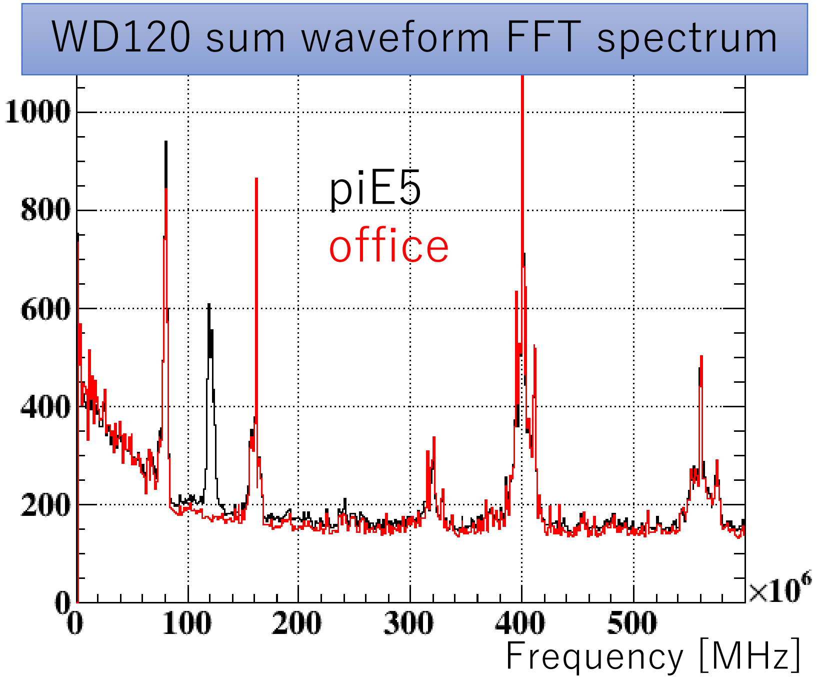


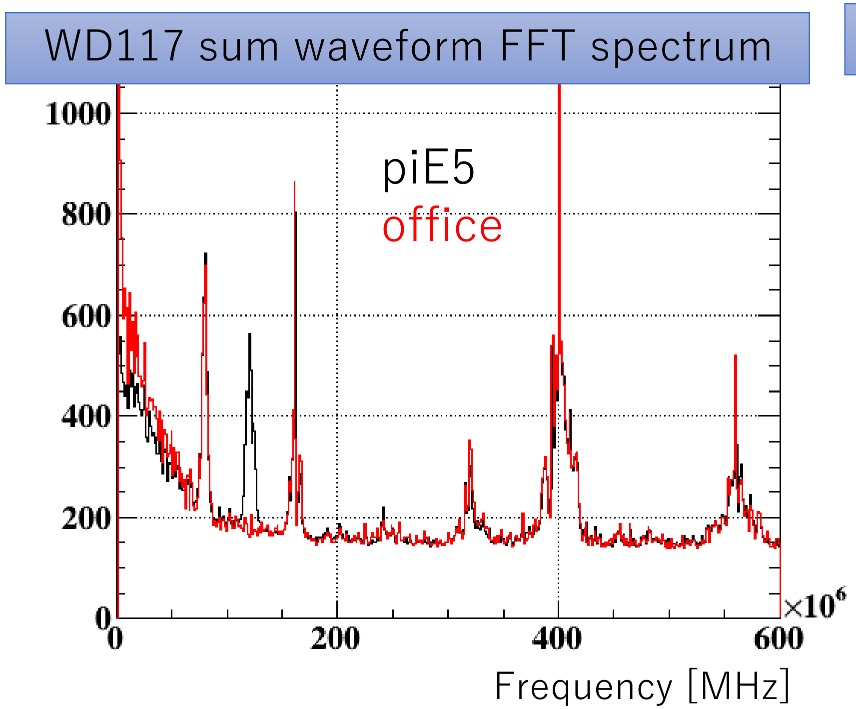


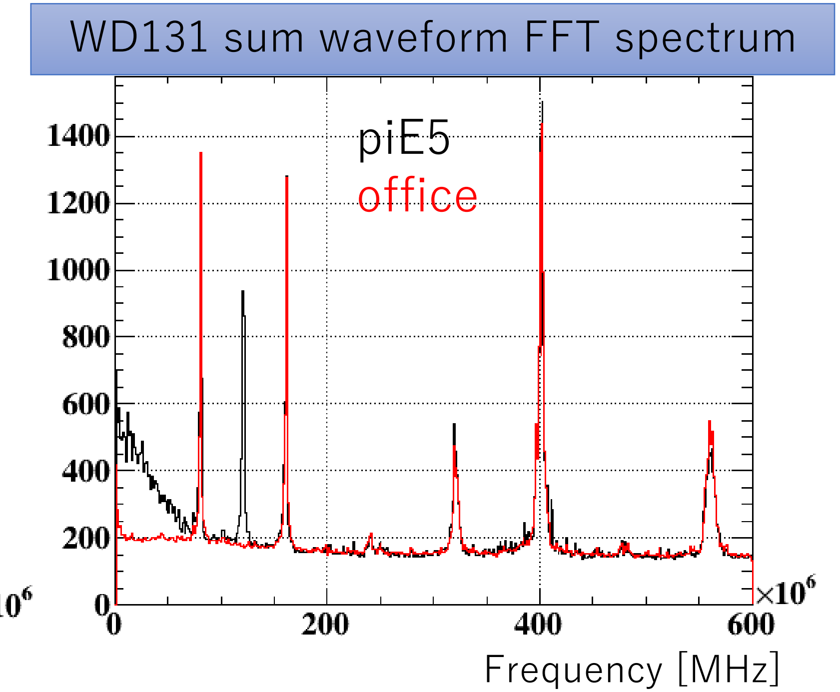
Noise test in the office

I measured the noise of crate #5 at office.
Because normal DAQ was not available, I used WD server (oscilloscope functionality) to record the waveforms.





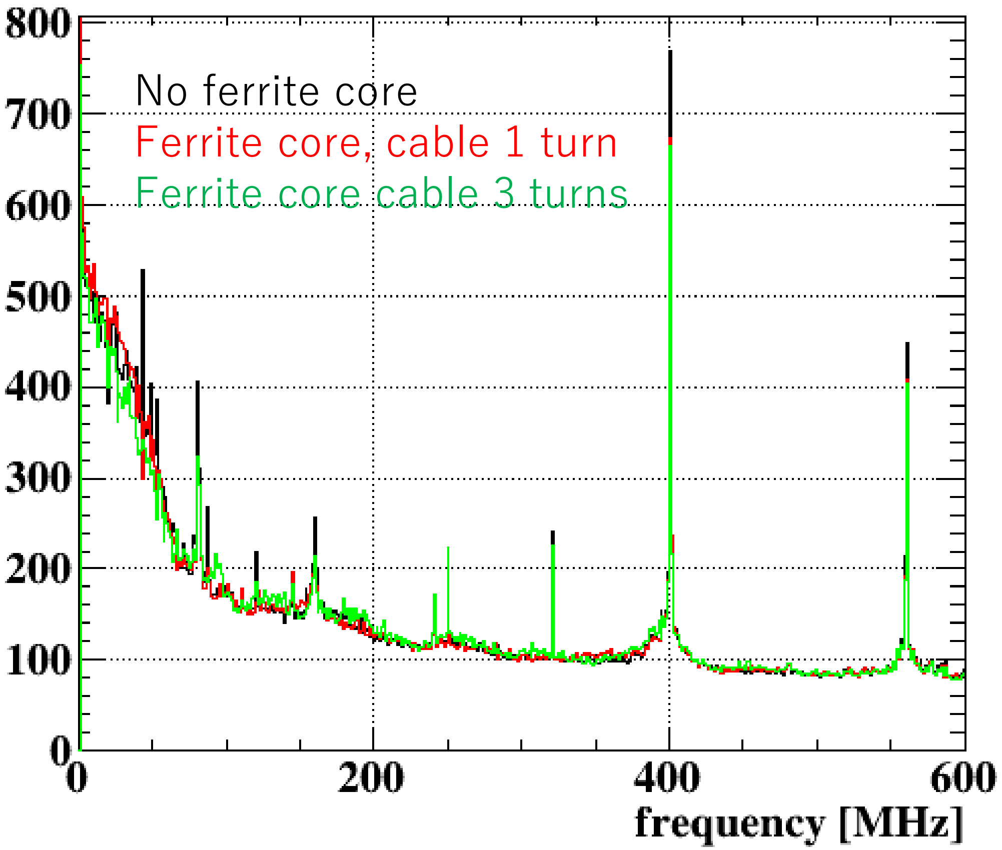




Different behavior was observed for different boards.
We do not understand this result yet (maybe just a bug in my analysis).

Ferrite core test

Stefan suggested to test Ferrite core.
I attached it to 16 channels on one WD board.



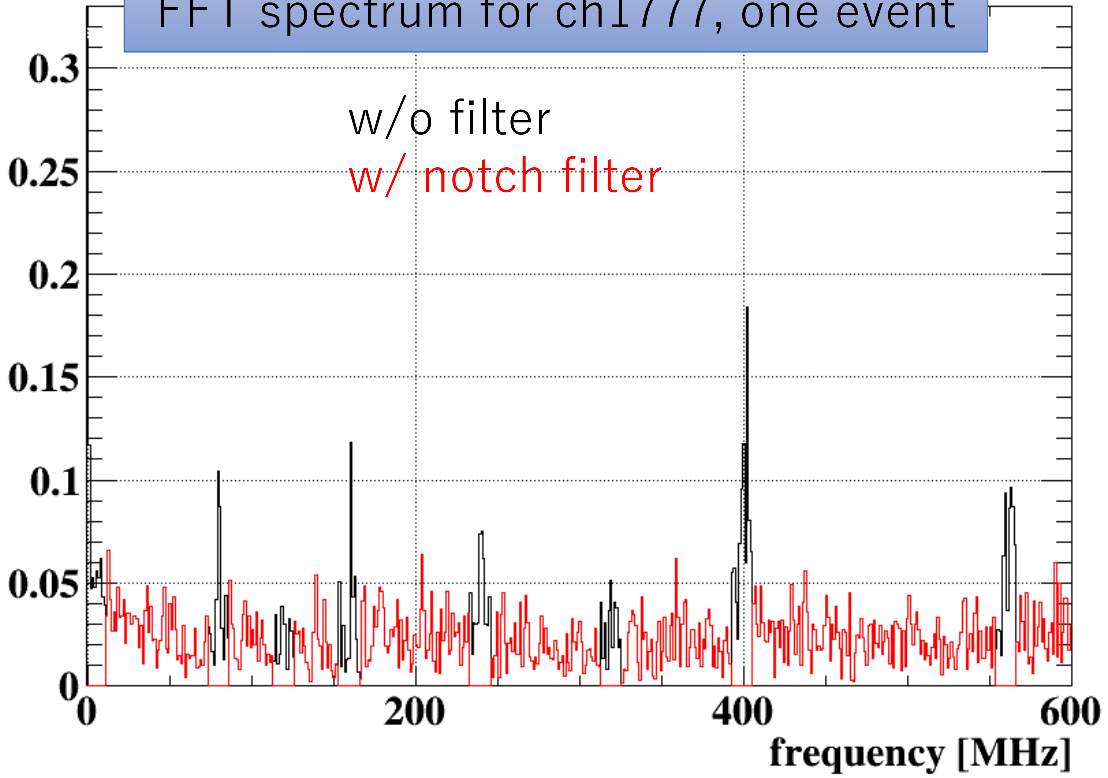
Low frequency noise did not reduce.

Analysis updates

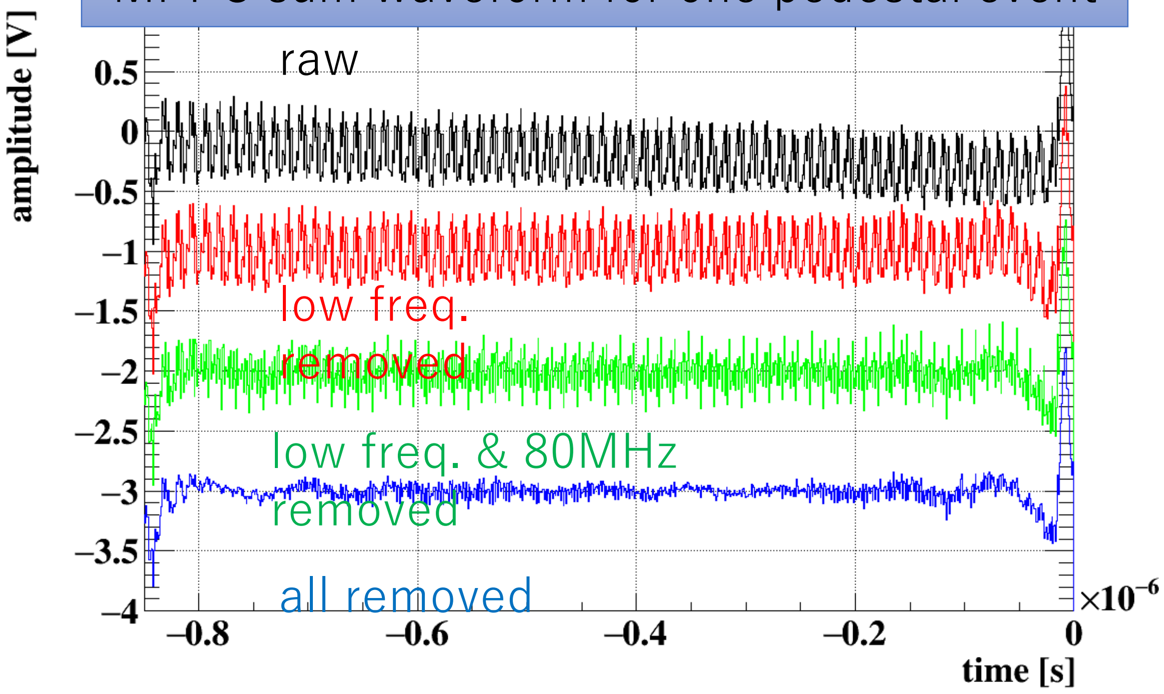
Notch filter

In order to see which noise frequency component affect the XEC energy resolution, I implemented “notch filter”.

FFT spectrum for ch1777, one event



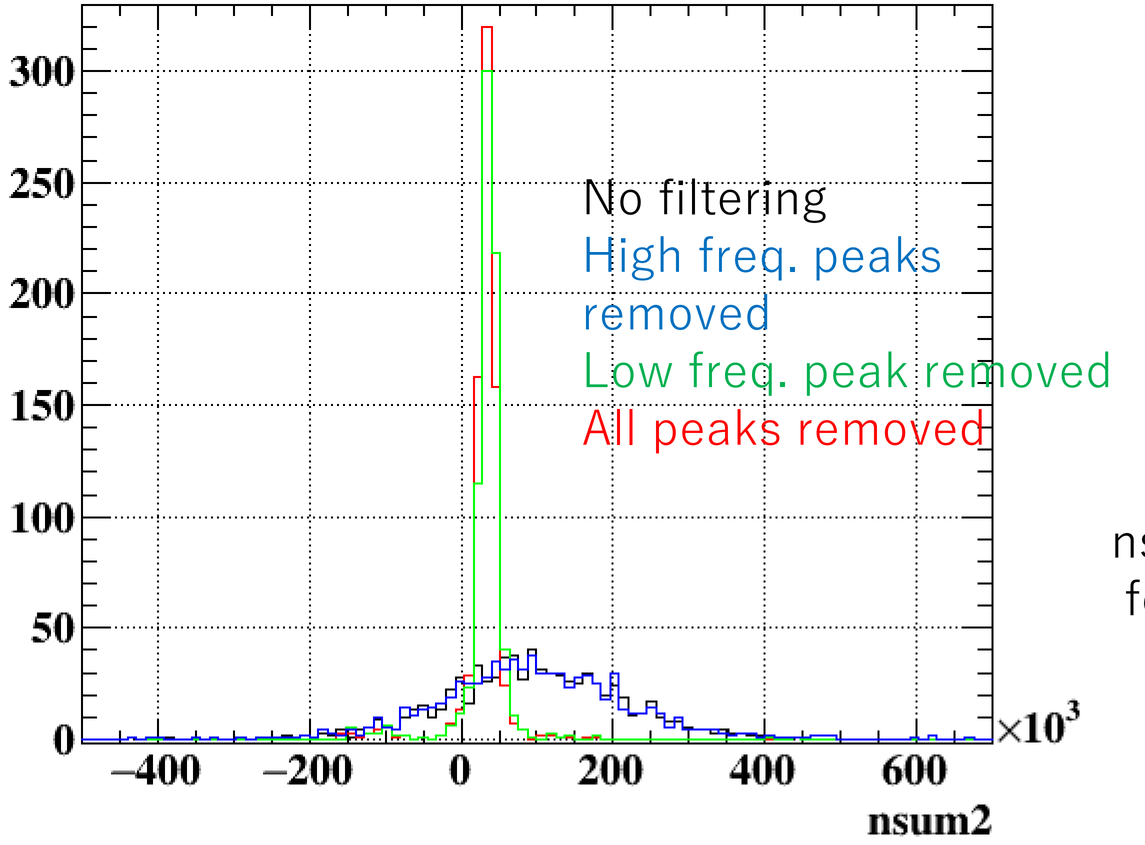
MPPC sum waveform for one pedestal event



In this filter, I manually remove the noise frequency peaks.

Effect of noise in RMS of nsum2

I checked the nsum2 (N_{photon} sum after coverage correction) distribution of the pedestal run.



nsum2 RMS

1.3×10^5

1.2×10^5

1.2×10^5

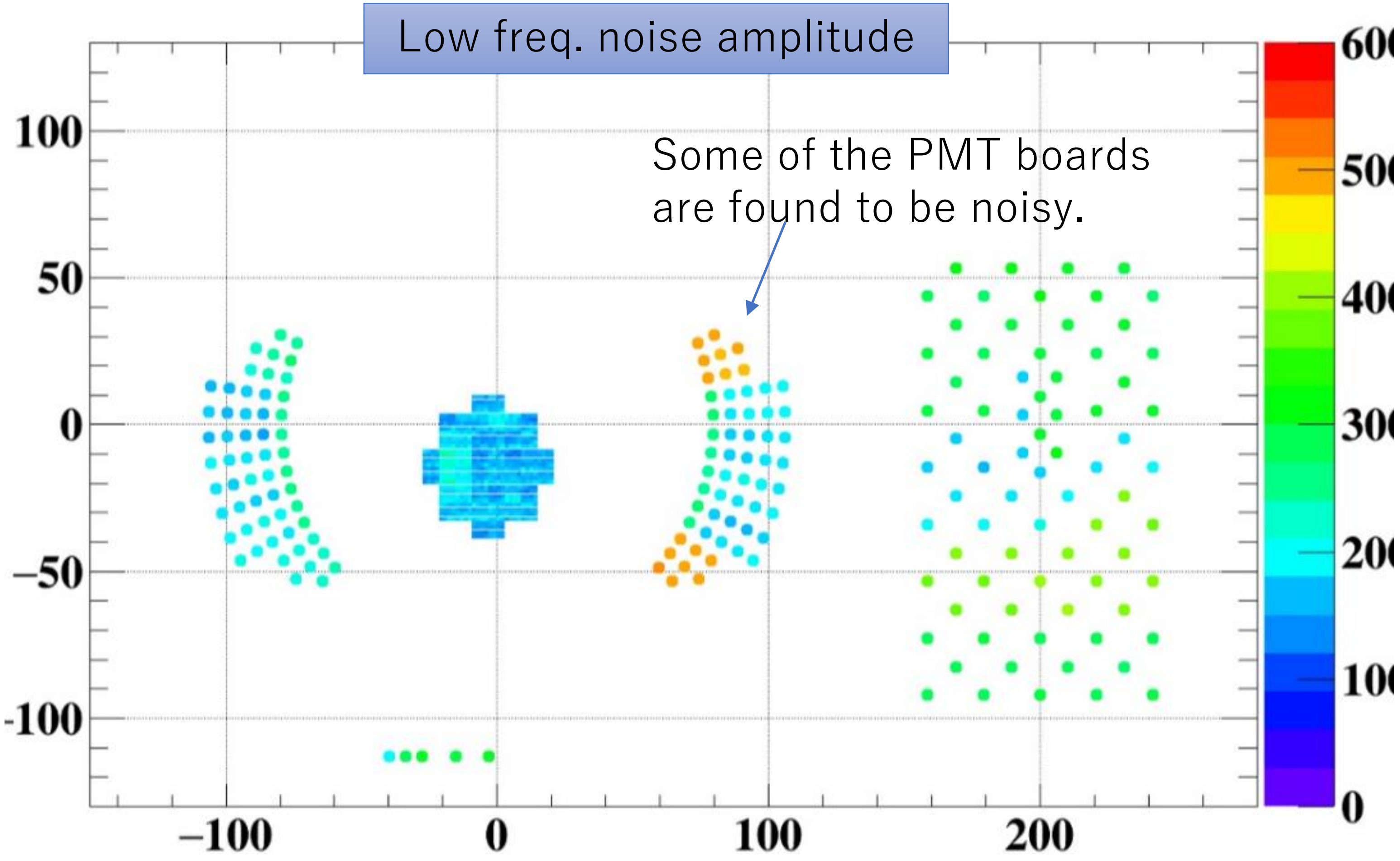
1.1×10^4

nsum2 mean ~1.3×10^7 for 52.8MeV γ

Low frequency noise significantly affects the energy resolution.
Other frequency components are not important, but it may affect timing.

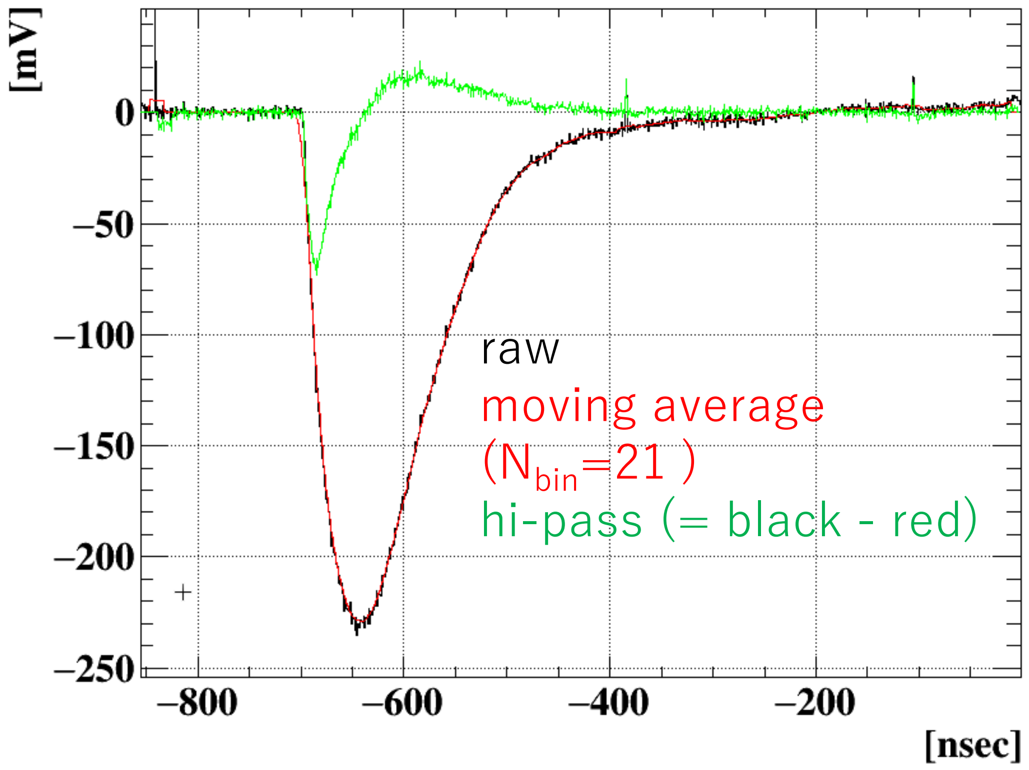
FFT noise map update

- Added PMT
- At the previous meeting, low freq. noise amplitude map was wrong because it was calculated including the overall offset of the waveform.



Hi-pass filter

Hi-pass = Subtract moving-averaged waveform from raw waveform



i^{th} bin value of moving average with N_{bin} = M:

$$y[i] = x[i] - \frac{1}{M}\sum_{j=1}^{M} x[i - M + j]$$

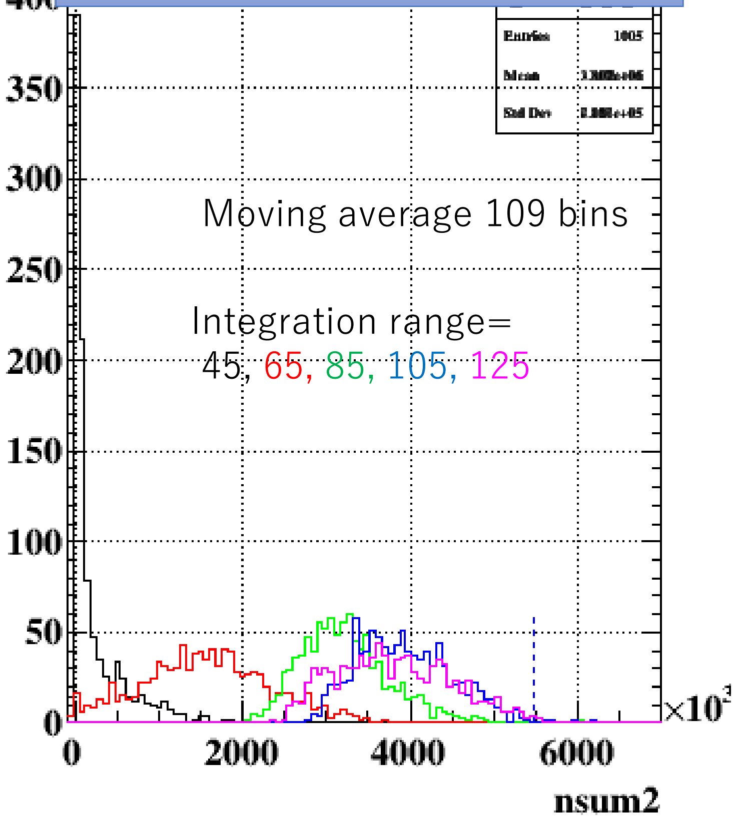
M: number of bins

Hi-pass filter can be used for reducing low frequency noise.
N_{bin} was 109 in MEG. → cutoff frequency ~11MHz

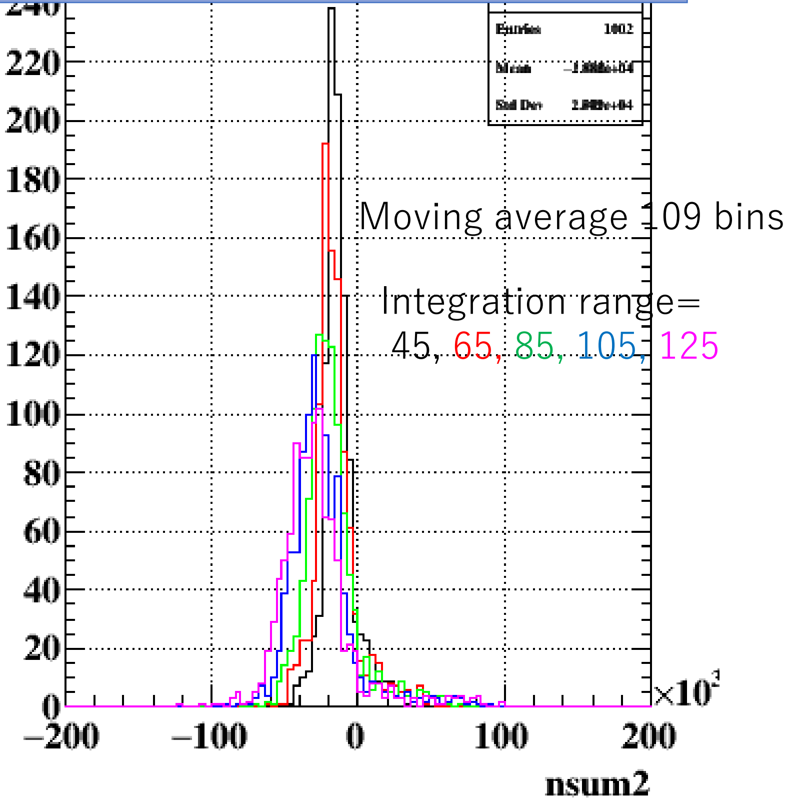
Hi-pass filter

With hi-pass filter, both signal charge and noise RMS reduces.
We scanned over moving average bins and integration ranges to find a best configuration which minimizes (noise RMS) / (signal charge).

Signal charge (RMD run)



Noise charge (pedestal run)



In the best configuration (109 bins, 85 ns range), noise/signal reduced by half compared to the normal case.

Covariance matrix (very very preliminary)

In order to discuss the total amount of noise, correlation of noise must be taken into account.
Correlation matrix is useful for quantifying the correlation among channels.

Covariance of X and Y is:

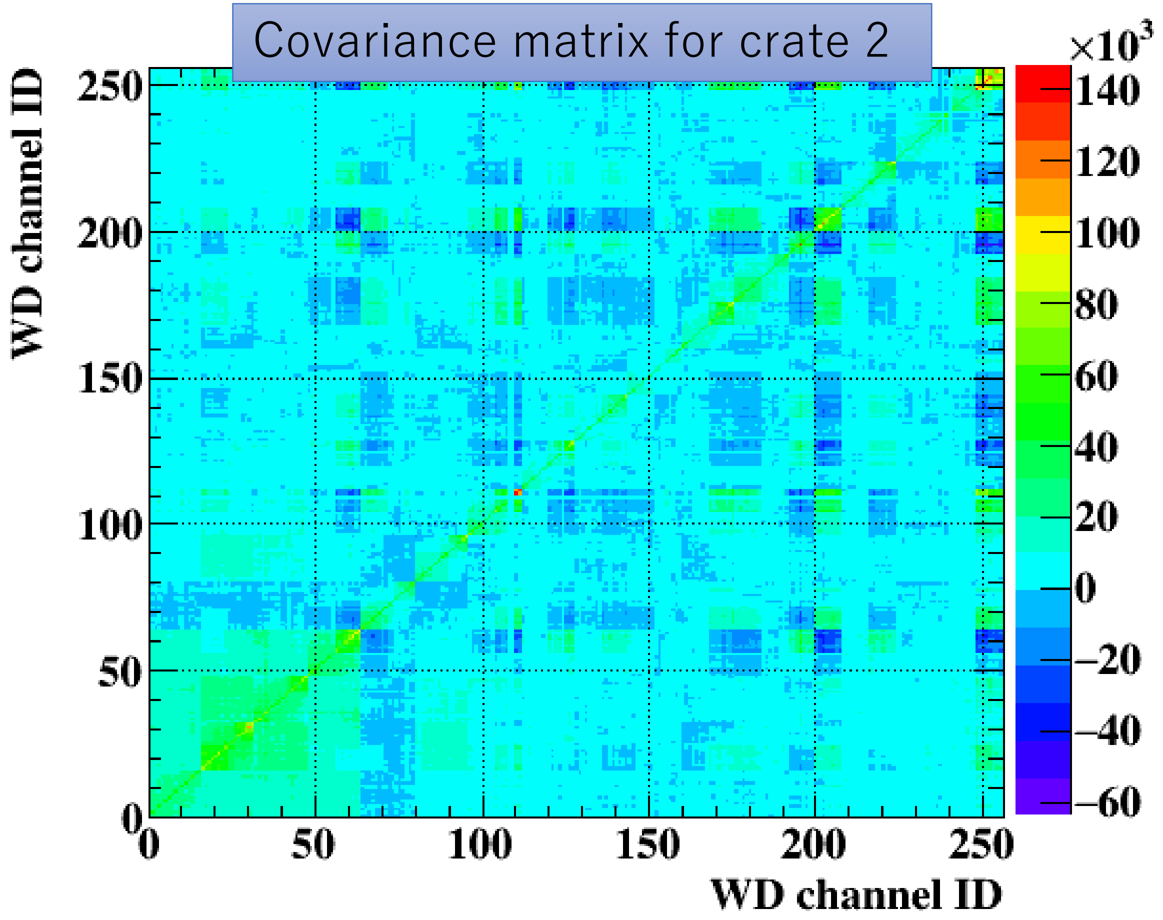
$$\rho_{X,Y} = \mathrm{E}[(X-\mu_X)(Y-\mu_Y)]$$

In this case, X and Y are N_{photon} (corrected by coverage) of each channel.

Diagonal term and off-diagonal term corresponds to the independent noise and correlated noise.

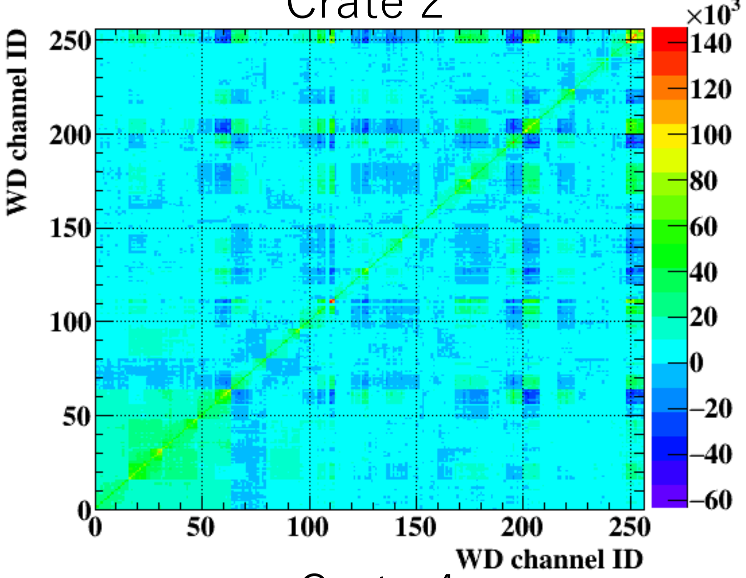
Positive: Normal correlation
Negative: Anti- correlation

Total sum of all elements in the matrix is equal to the square of the variance of the sum of all channels.

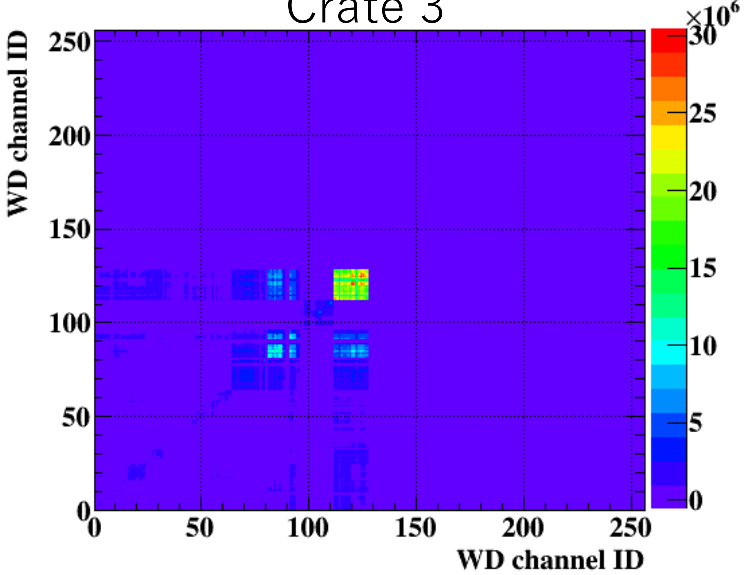


Covariance matrices for four crates

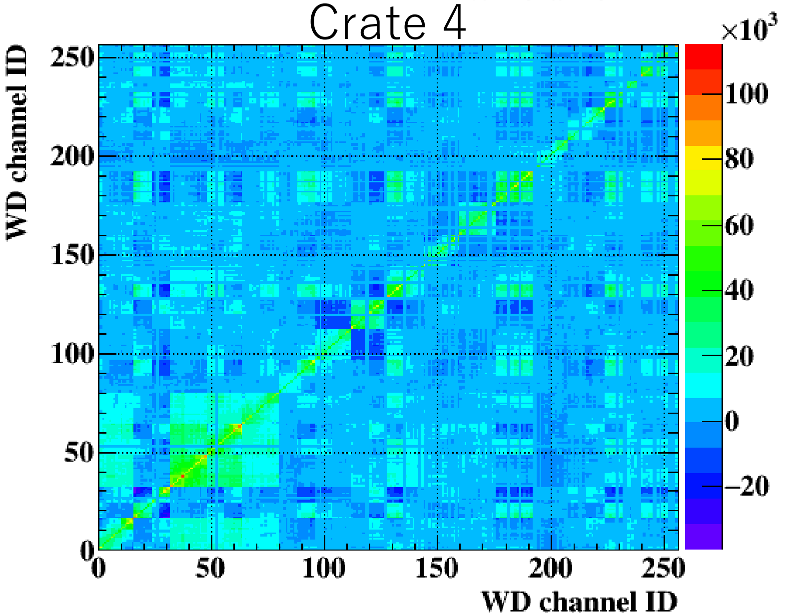
Crate 2



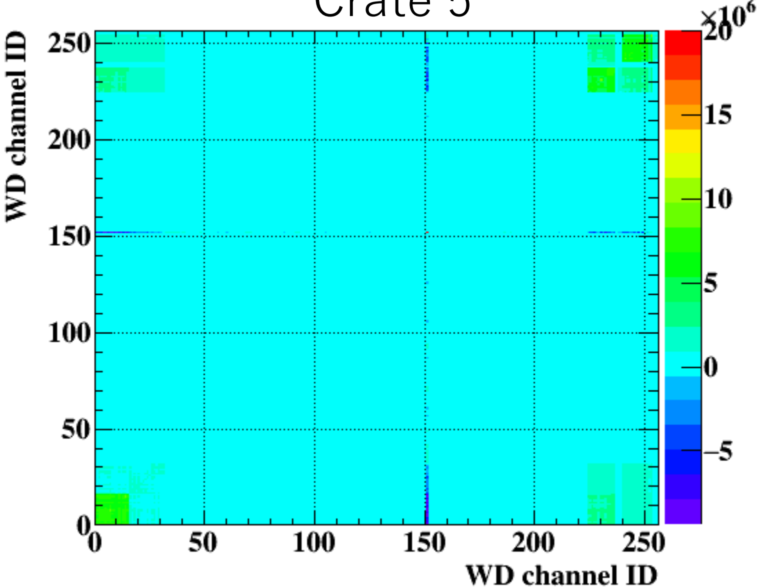
Crate 3



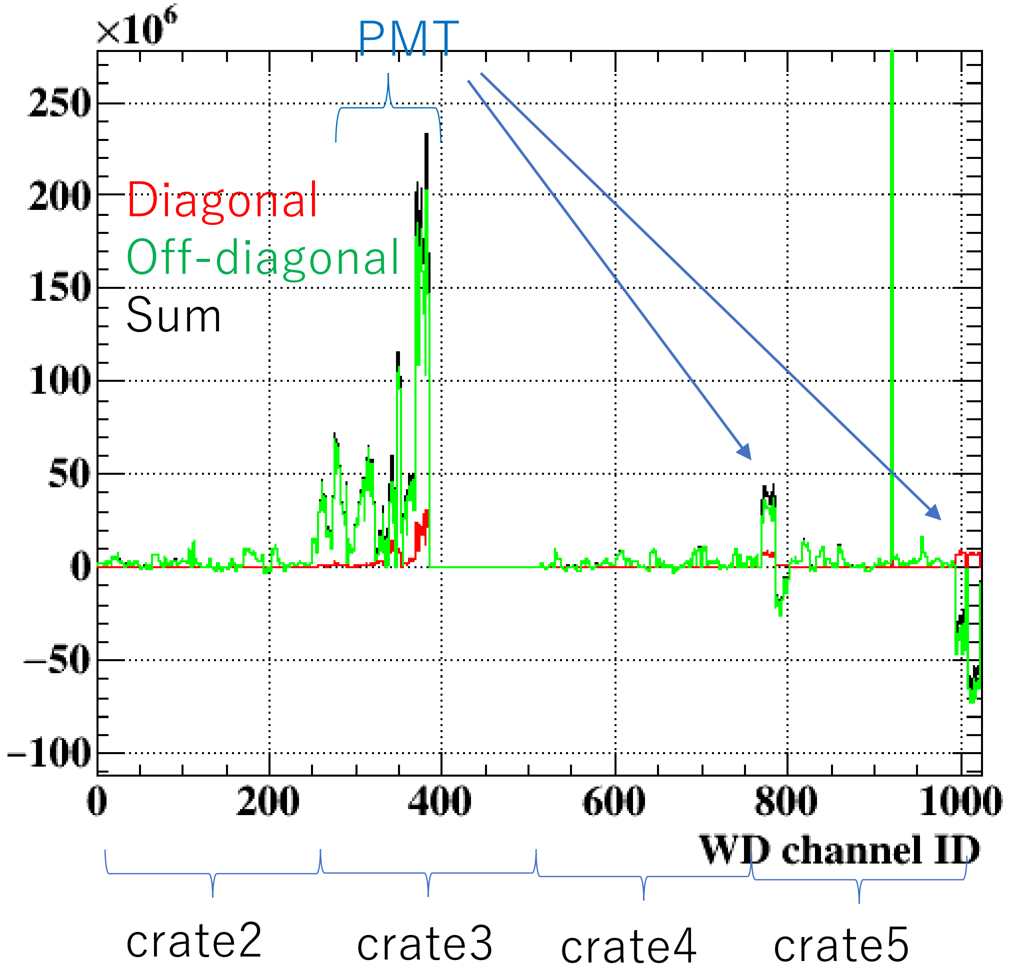
Crate 4



Crate 5



Covariance matrix projected in 1D



Integral of this histogram is equal to the RMS of the total N_{photon} (corrected by coverage).

Off-diagonal term (correlated noise) is large.

PMT have larger coverage (noise itself is not significantly different compared to MPPC), so it seems to affect the total RMS significantly.

Summary

We have much more information, but we do not have conclusion yet.

- We have not yet found a good way to reduce the noise.
  - Changing the grounding scheme did not help (so far).
  - Ferrite core did not reduce the noise.
  - Cable seems to affect the noise, but the behavior is not understood.

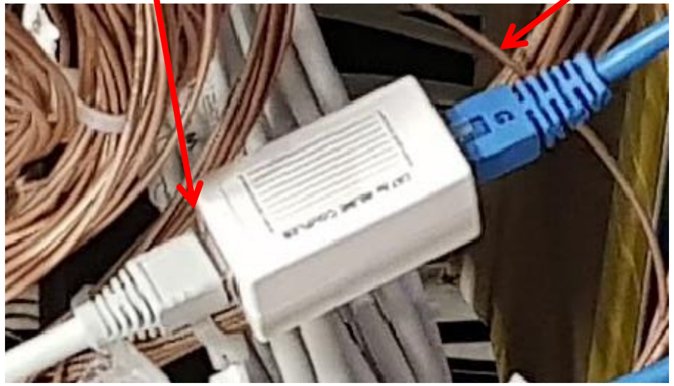
- Analysis tools have been developed.
  - Notch filter study showed that low freq. noise significantly affects the energy resolution.
  - Low freq. noise map is updated. Some PMT boards are noisy.
  - Noise reduced after the beam test, but the reason is unknown.
  - Hi-pass filter can be used for improving noise/signal ratio.
  - Covariance matrix can be used for quantitative comparison of noise from different channels.

Backup

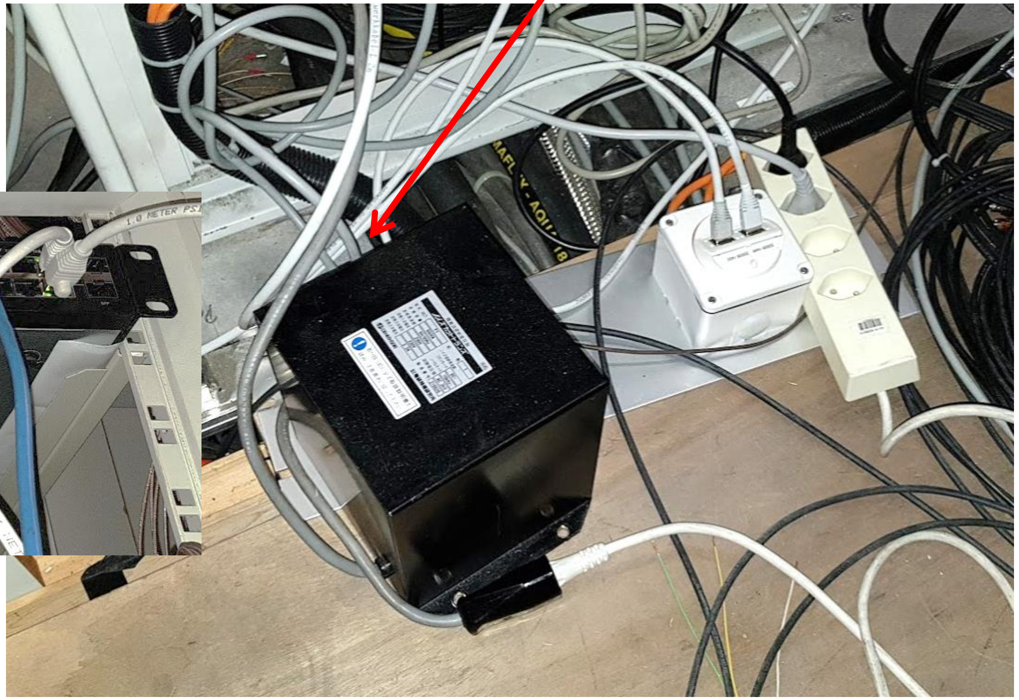
Ground connection change

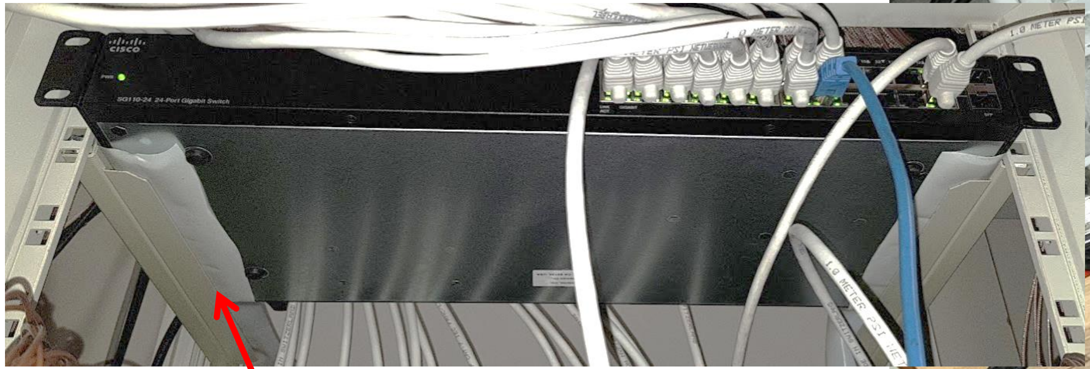
metal shield LAN cable

plastic shield LAN cable



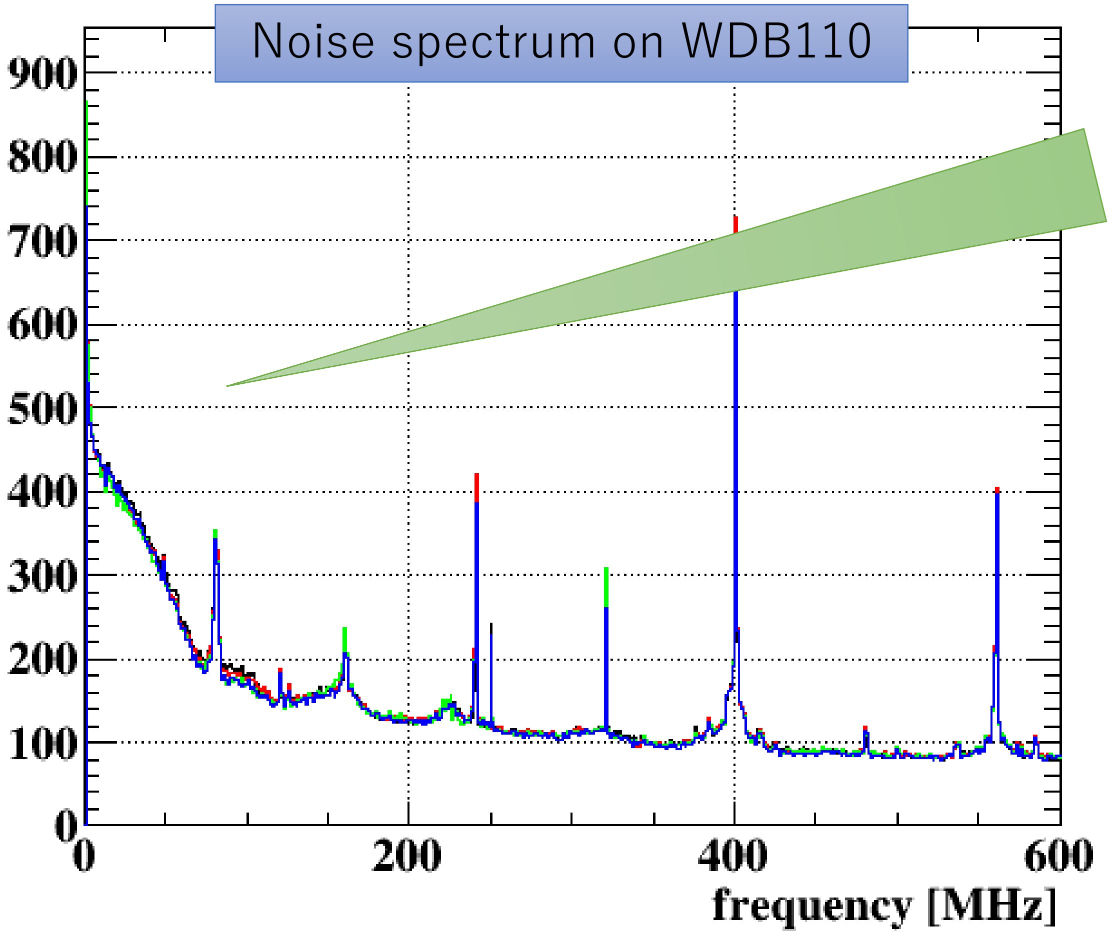
noise cut trans.

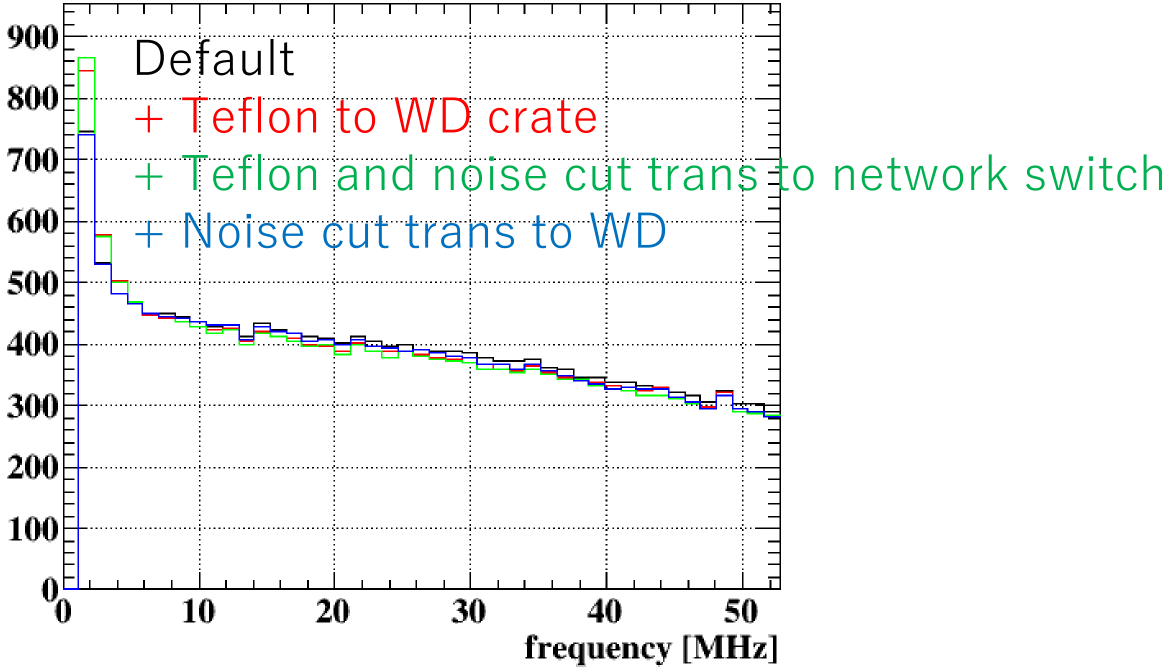




Teflon sheet

Ground connection change

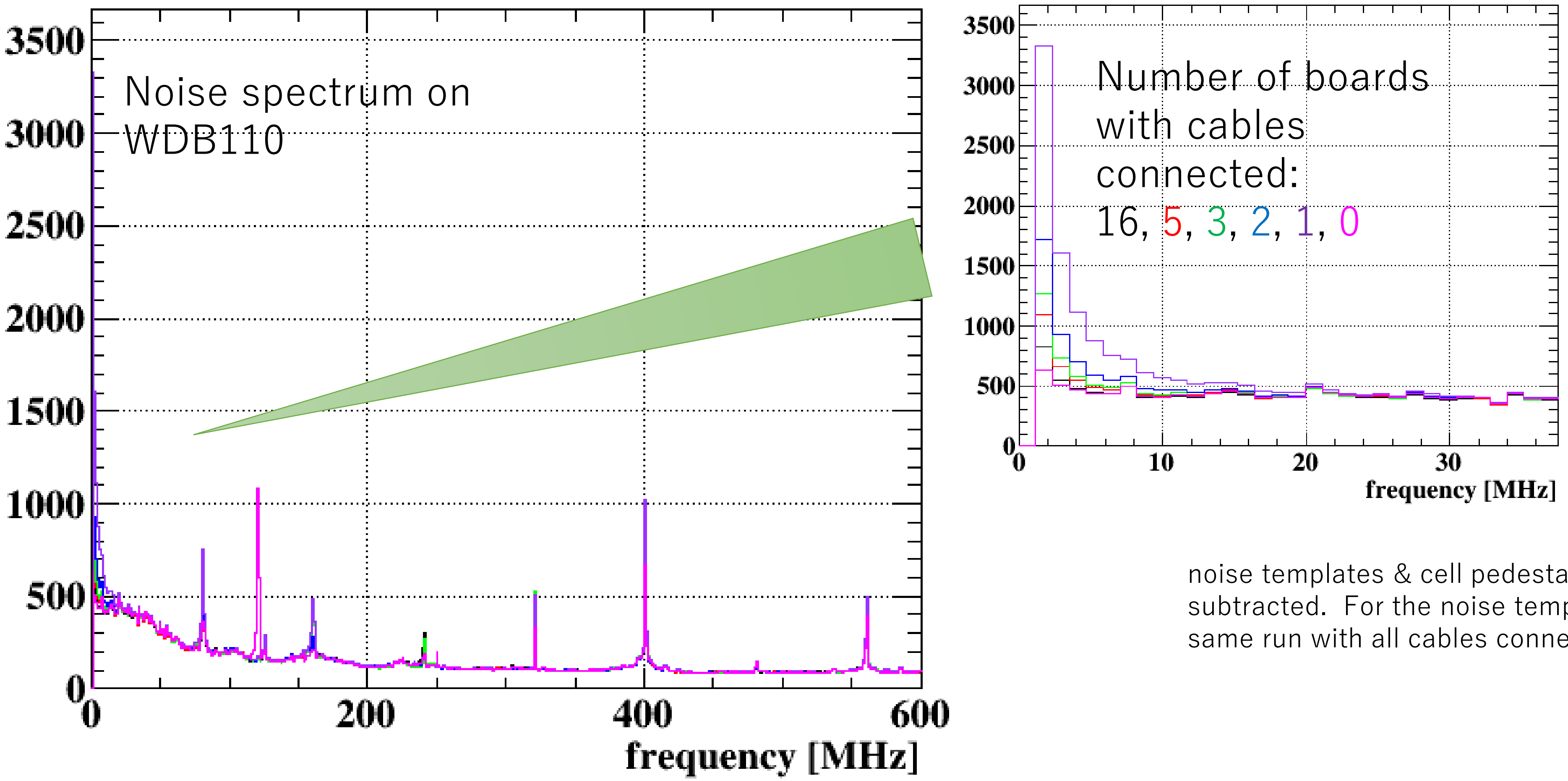




Low freq. noise does not improve.

Effect of removing cables

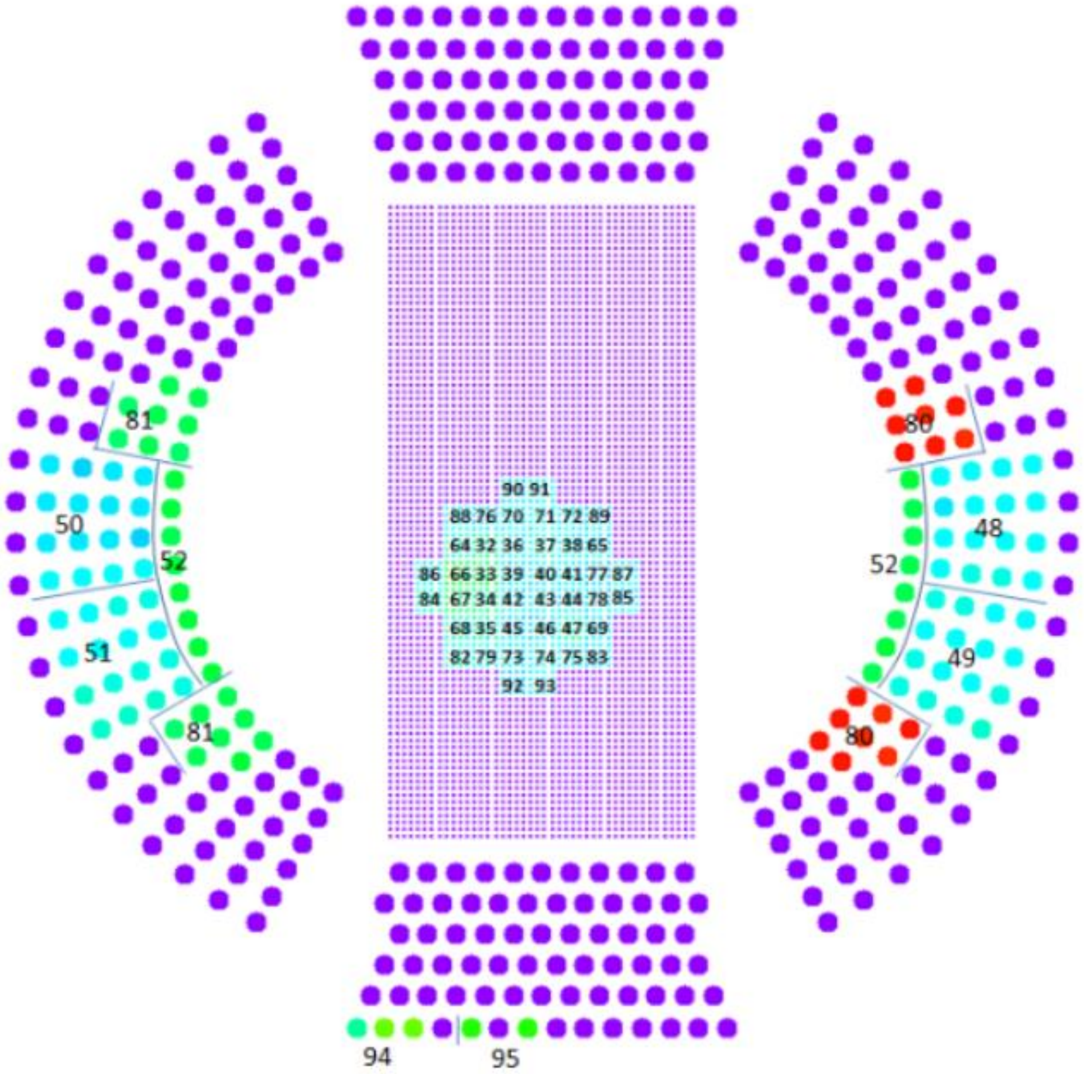
I checked the effect of removing cables from WD.



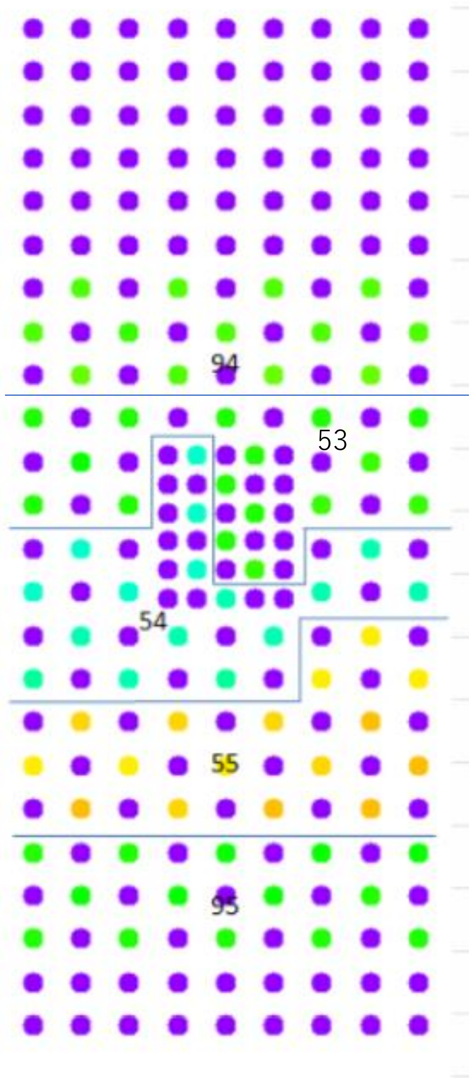
noise templates & cell pedestals are all subtracted. For the noise template file, I used same run with all cables connected.

Low frequency component significantly changed.

WDB map

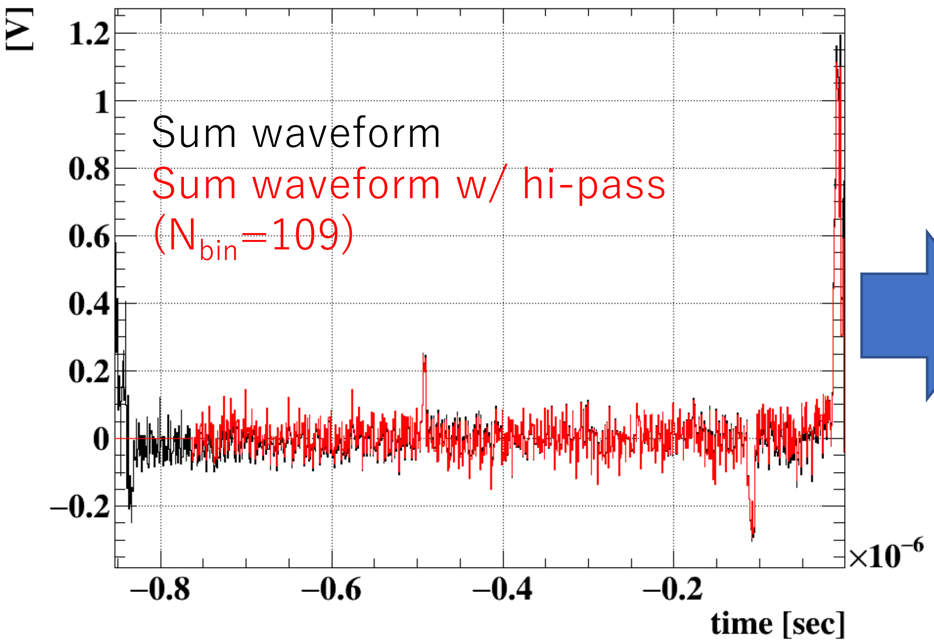


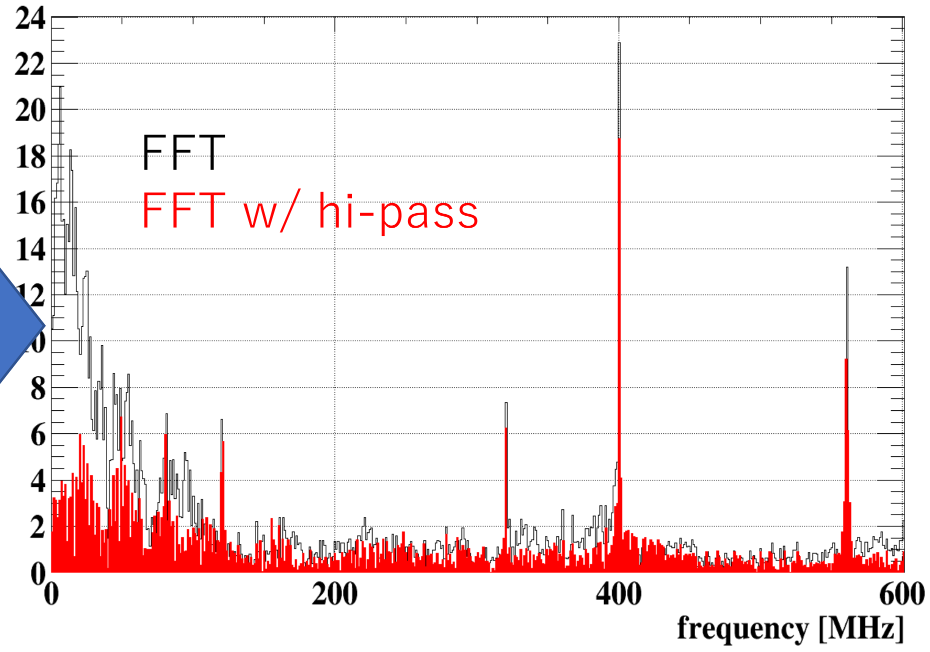
81
50
52
51
81
90 91
88 76 70 71 72 89
64 32 36 37 38 65
86 66 33 39 40 41 77 87
84 67 34 42 43 44 78 85
68 35 45 46 47 69
82 79 73 74 75 83
92 93
80
48
52
49
80
94
95



94
53
54
55
95

FFT after hi-pass filter

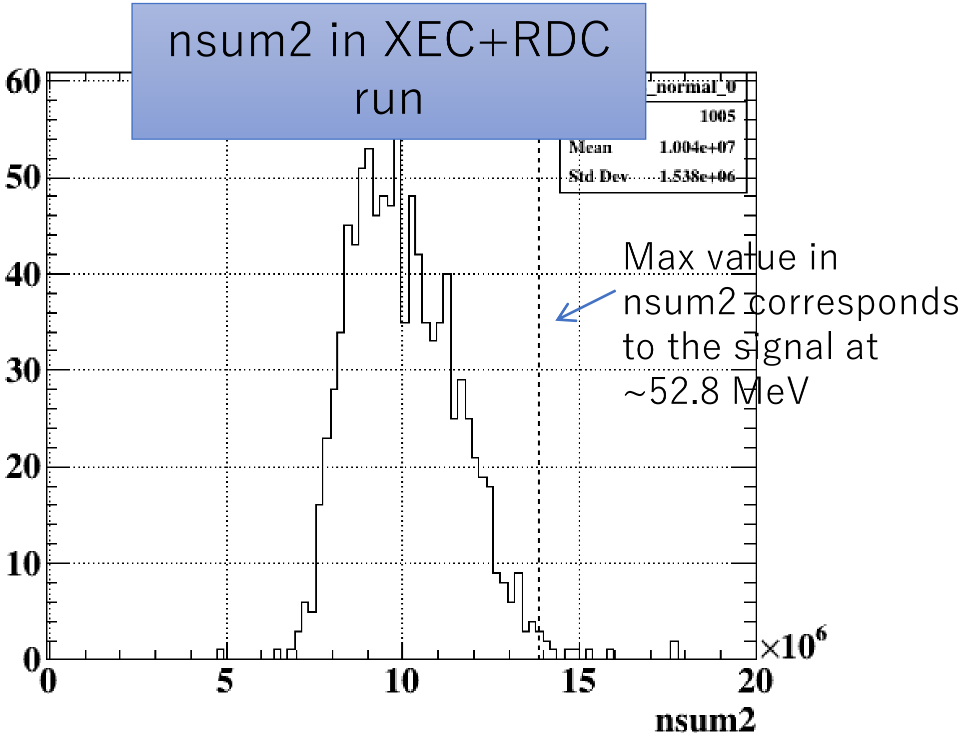


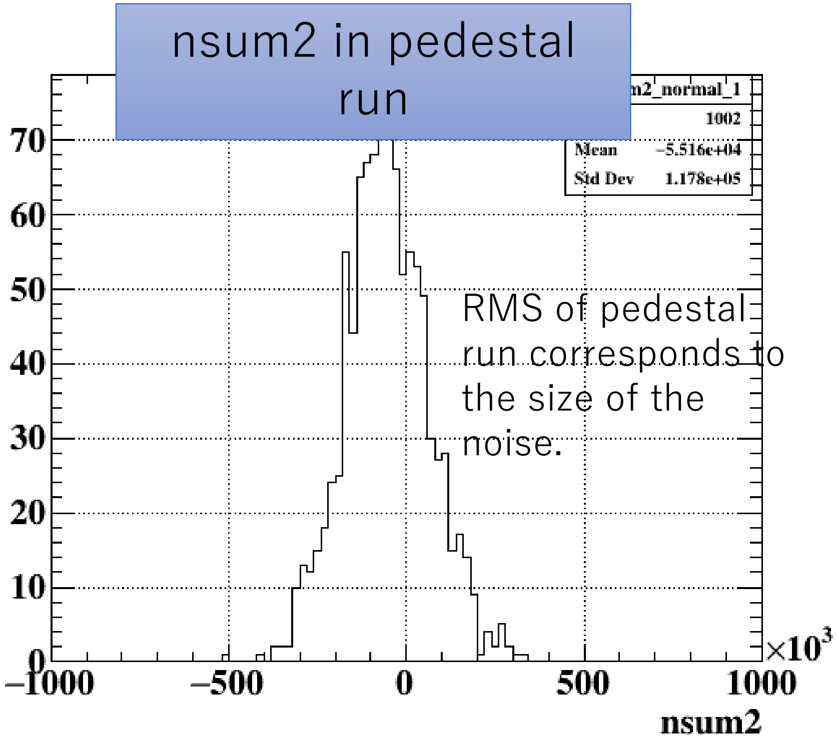


Hi-pass filter reduces the low frequency component.
It also reduces the signal charge.
Number of bins and integration range must be optimized.

Evaluation of noise effect

Previously, I evaluated the effect of noise by comparing the RMS of charge in the pedestal run to the charge in XEC+RDC run.

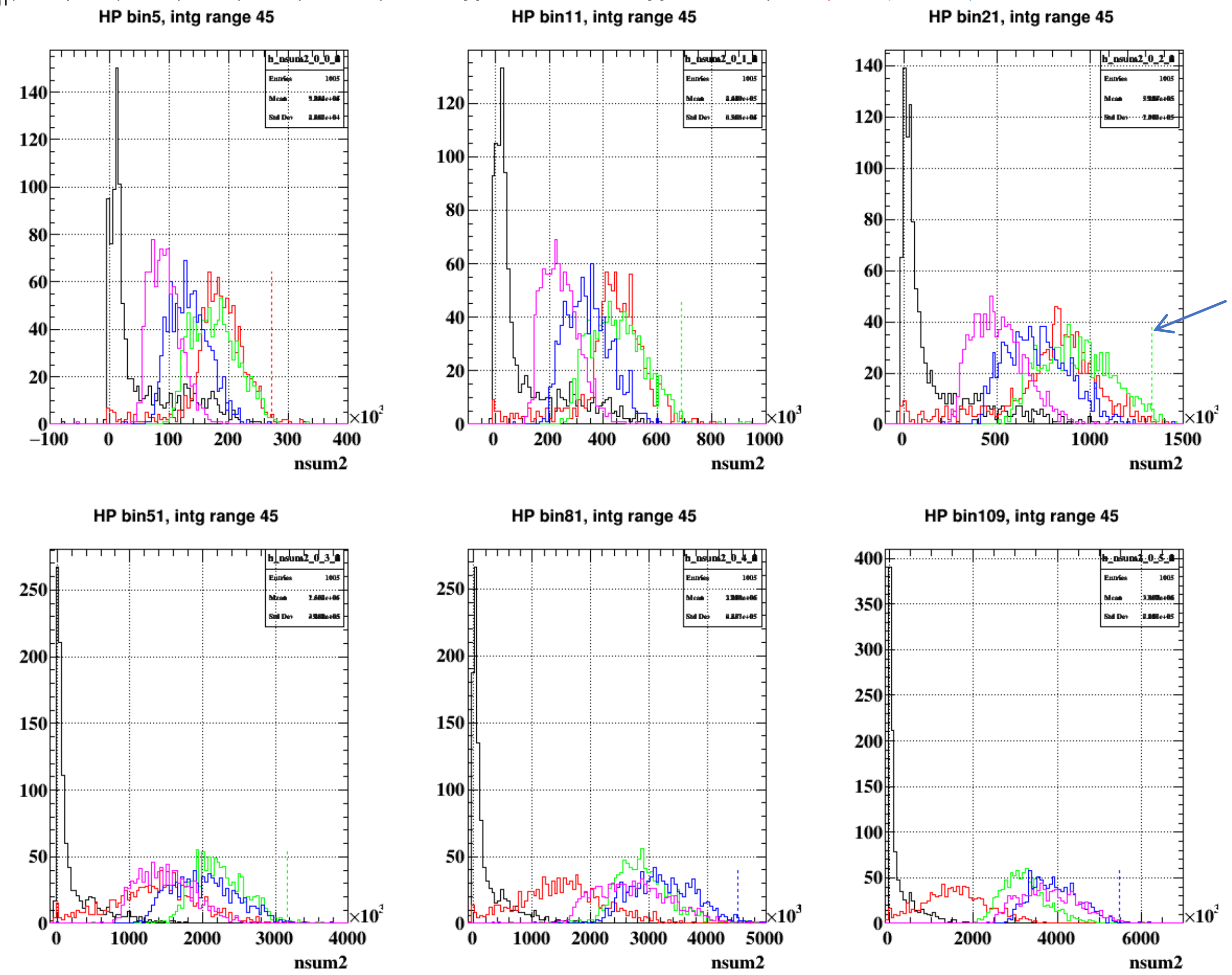




The effect of the noise is ~1% of the signal (after all DRSNoiseSubtraction applied.)

Signal size with hi-pass filter

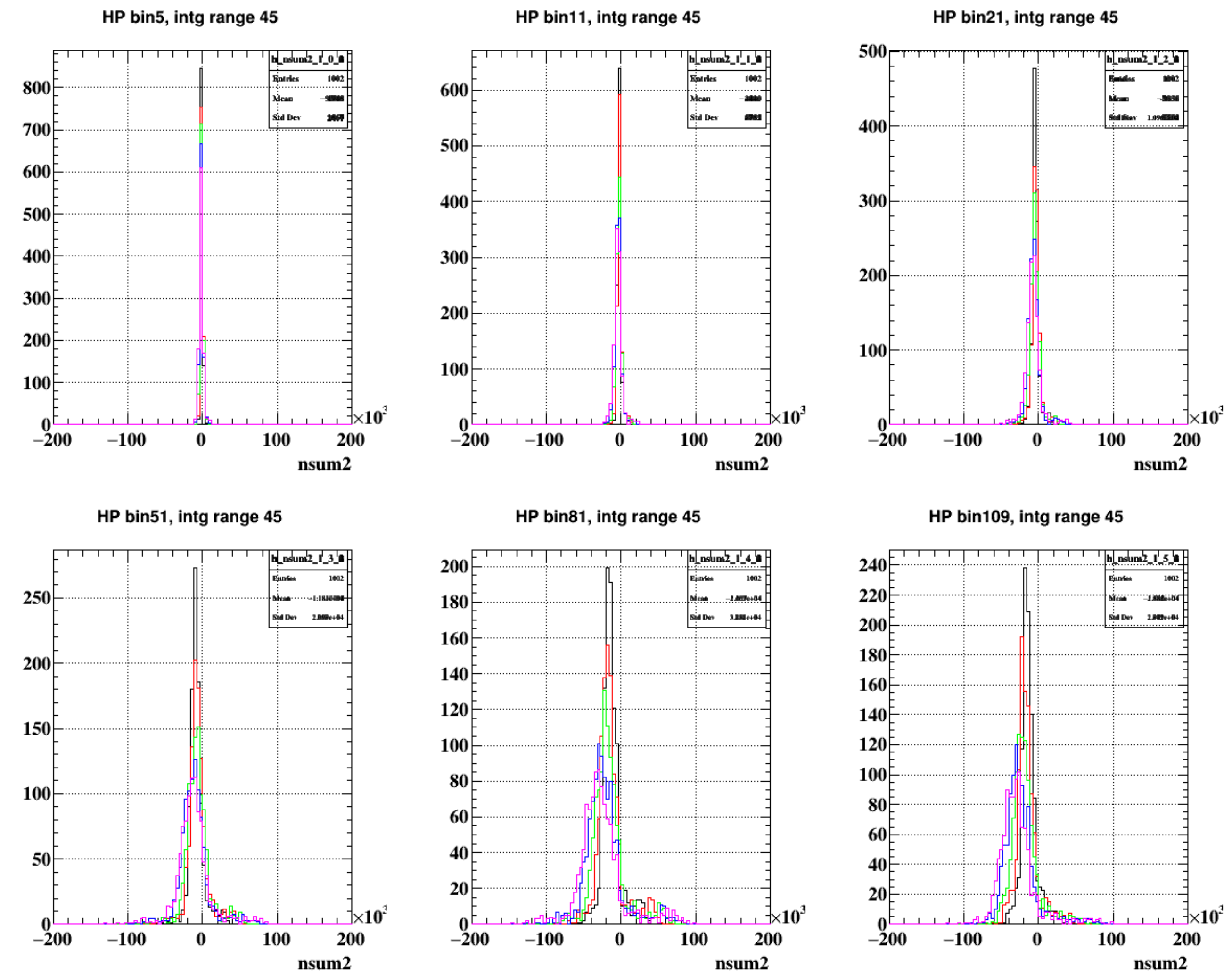
I checked the nsum2 of hpcharge in XEC+RDC beam run (run312653).
Hpcharge strongly depends on the Nbin and integration range, so I tested various configurations.
N_{bin}=5,11, 21, 51, 81, 109, Integration range= 45, 65, 85, 105, 125



For each N_{bin} settings, I searched for the best charge integration range which maximizes nsum2.

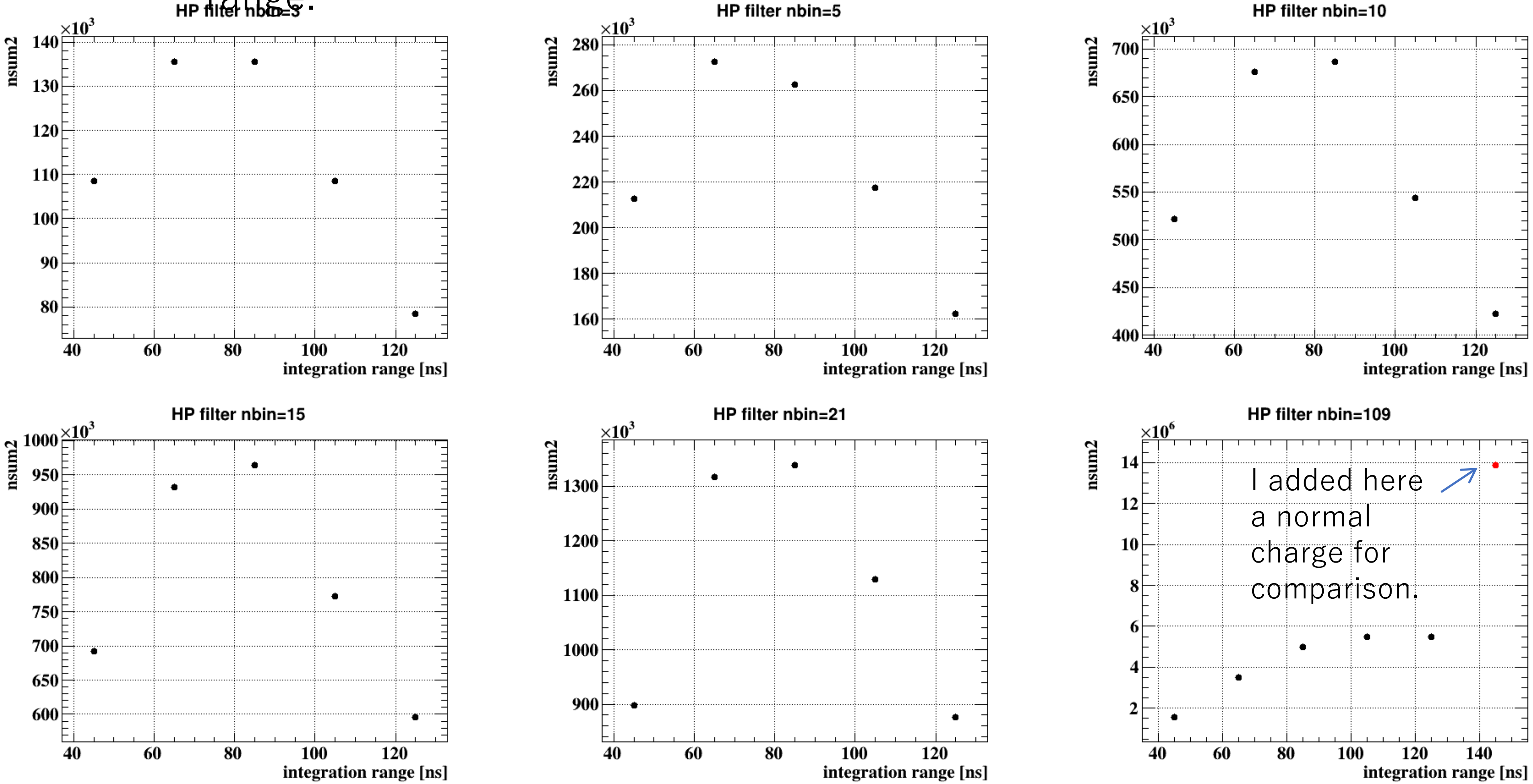
Number of bins and noise RMS

I also checked the RMS of nsum2 in pedestal run.
Again, the RMS depends on N_{bin} and the integration range.



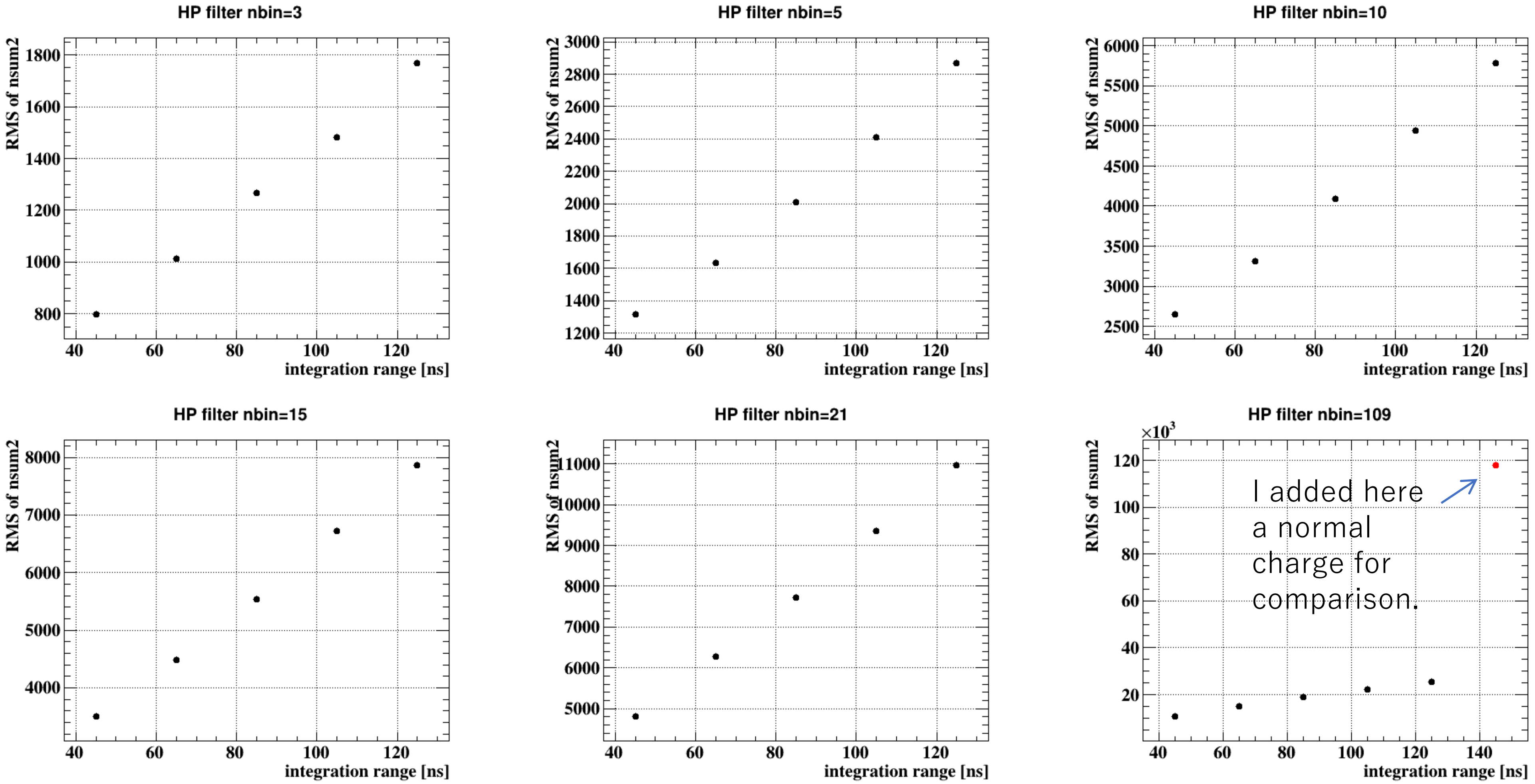
nsum2 calculated with various integration range

Signal size in XEC+RDC run depends on the integration range.



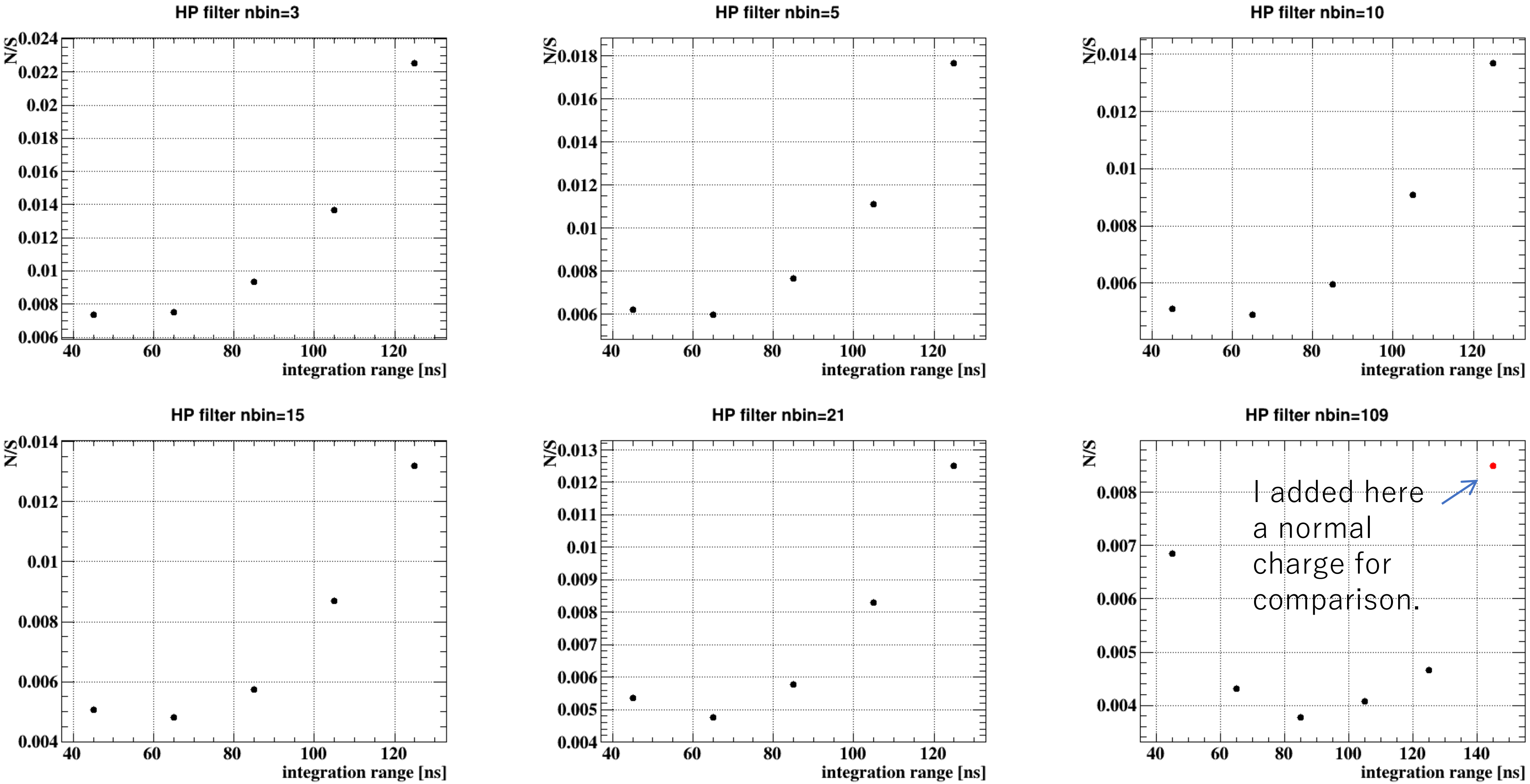
RMS at various integration range

RMS in pedestal run also depends on the integration range.



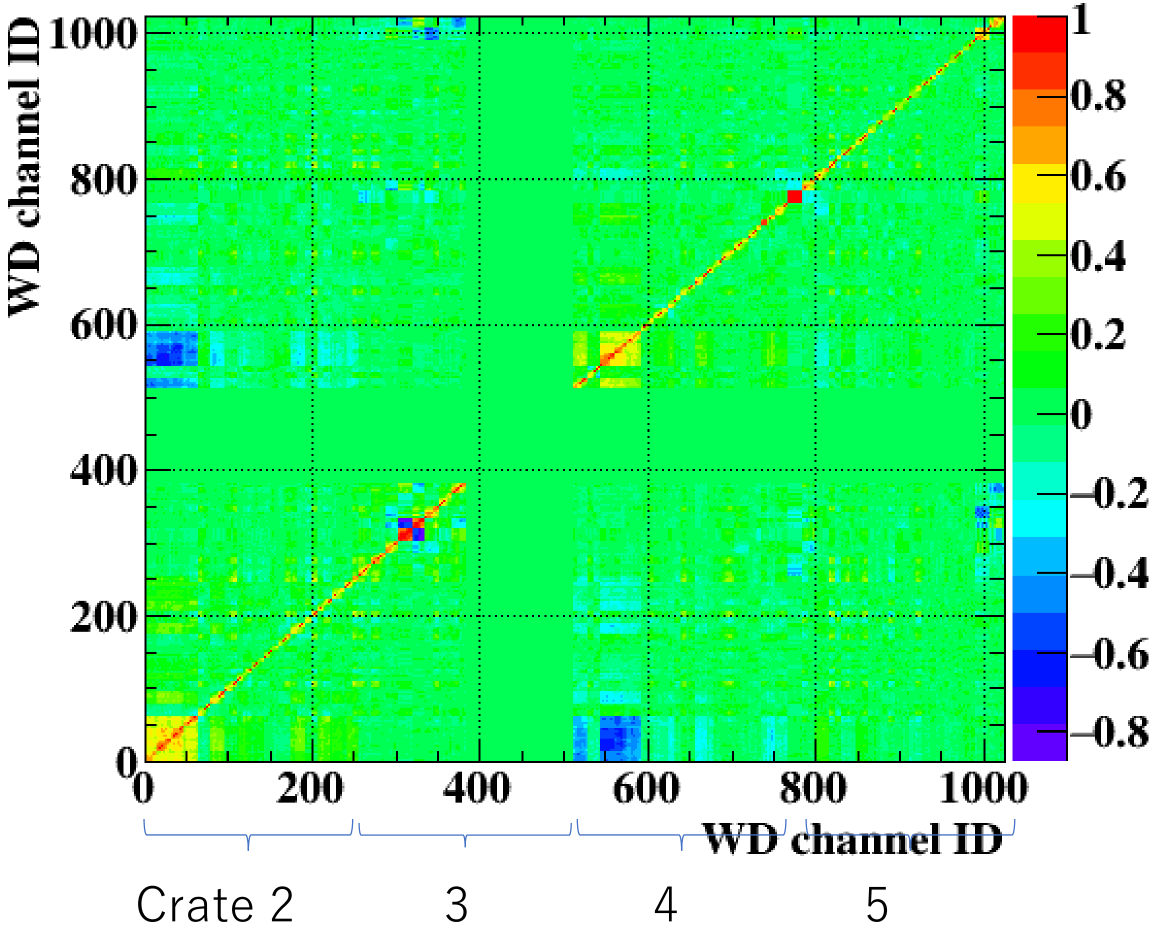
N/S at various integration range

I checked the size of the noise w.r.t. signal.



N/S can be reduced down to ~0.4% with hi-pass filter.

Correlation matrix



Correlation of variable X and Y:

$$\rho_{X,Y} = \frac{\mathrm{E}[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y}$$

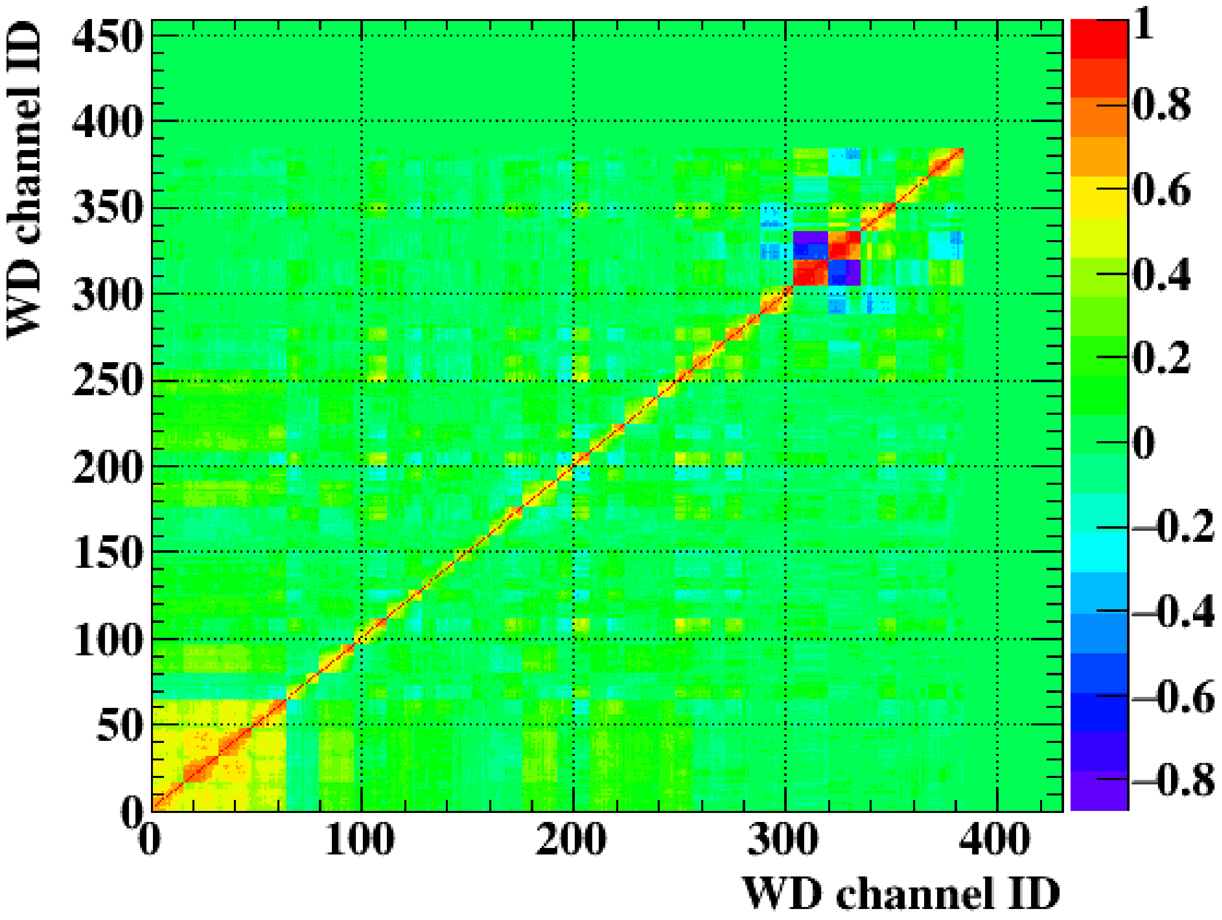
In this case, each variables (bins) are the charge of each channel.

$\rho_{XY}>0$: normal correlation
$\rho_{XY}<0$: anti- correlation

Diagonal term is 1 by definition.

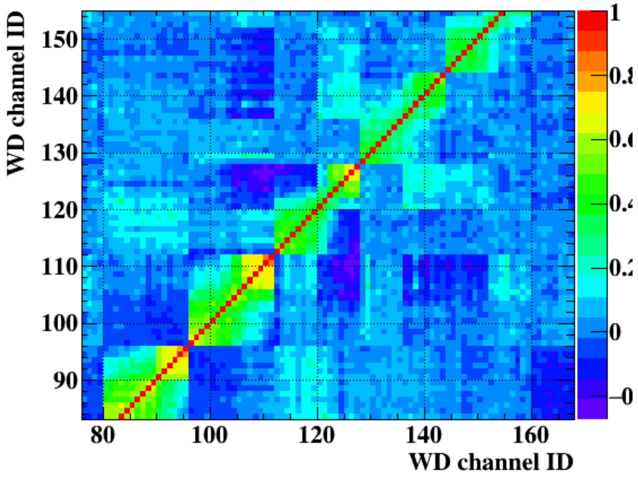
Some channels are anti-correlated (!)

Correlation matrix around first crate

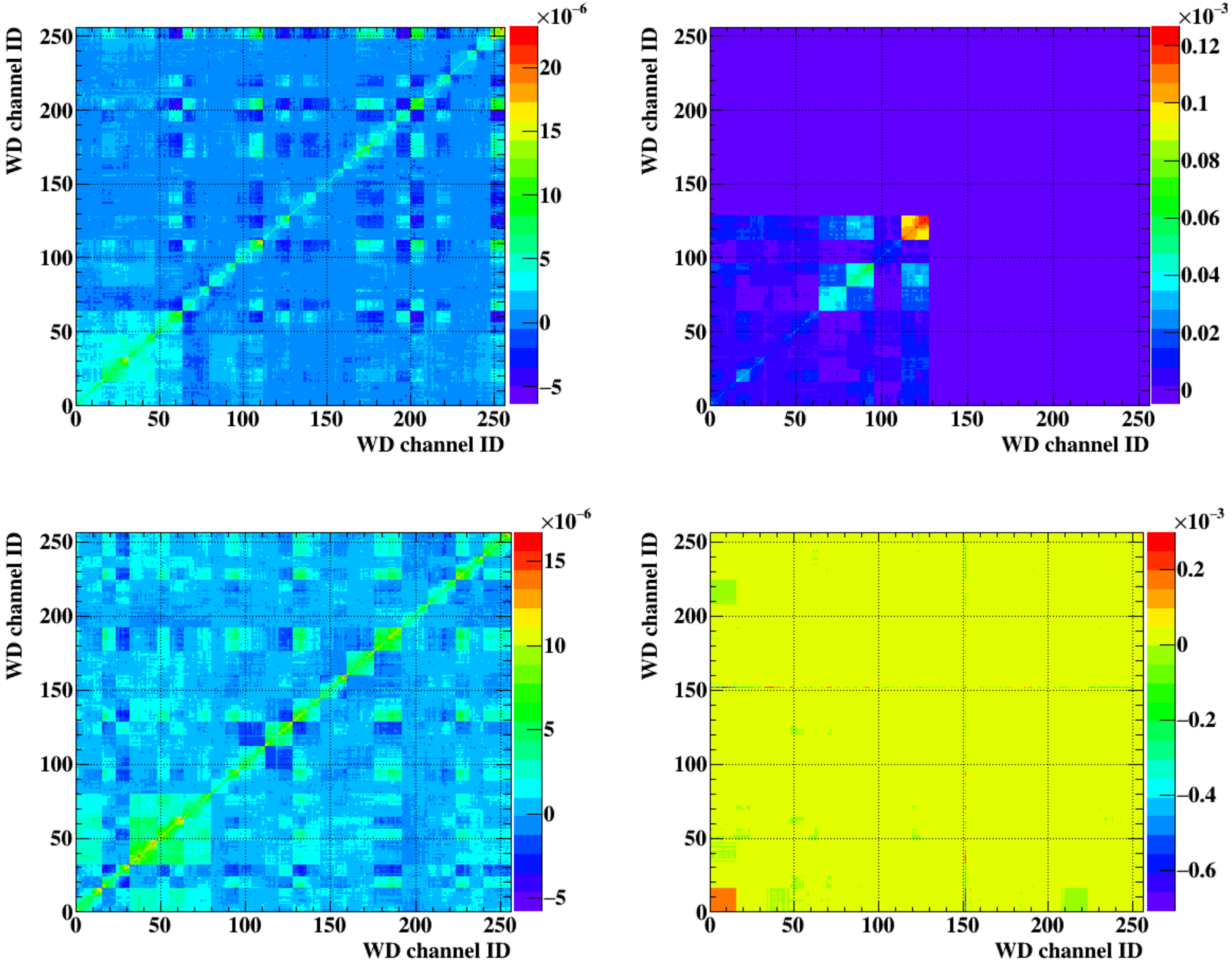


Same plot, zoomed in around crate 2.

Positive correlation can be seen between the channels in same board, but the correlation factor also seems to depend on channel on each WDB



Covariance matrices with charge



Covariance matrix projected, charge