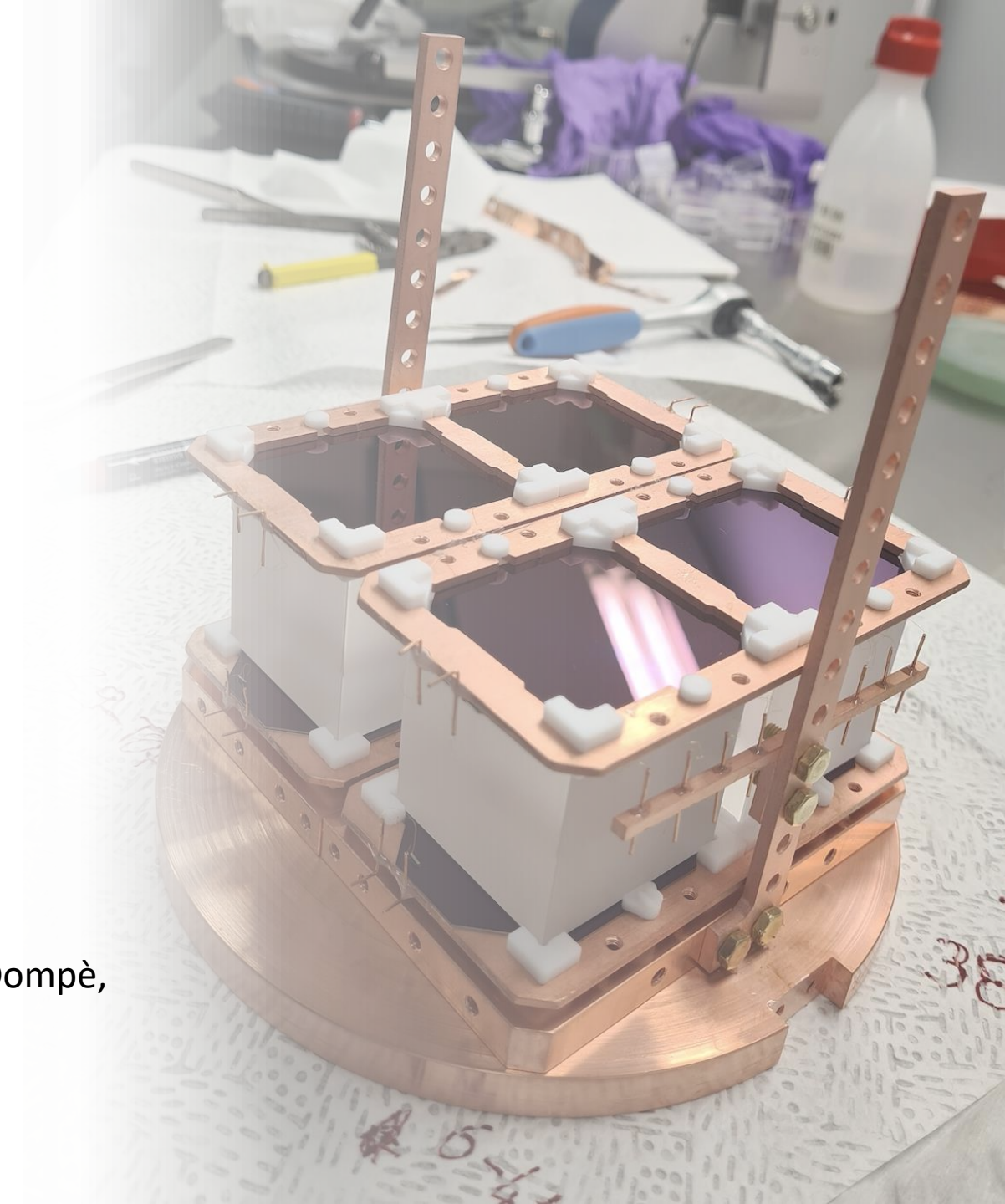
LNGS Hall-C test status

2023 NvDEx & CUPID-China joint meeting, IMP Huizhou



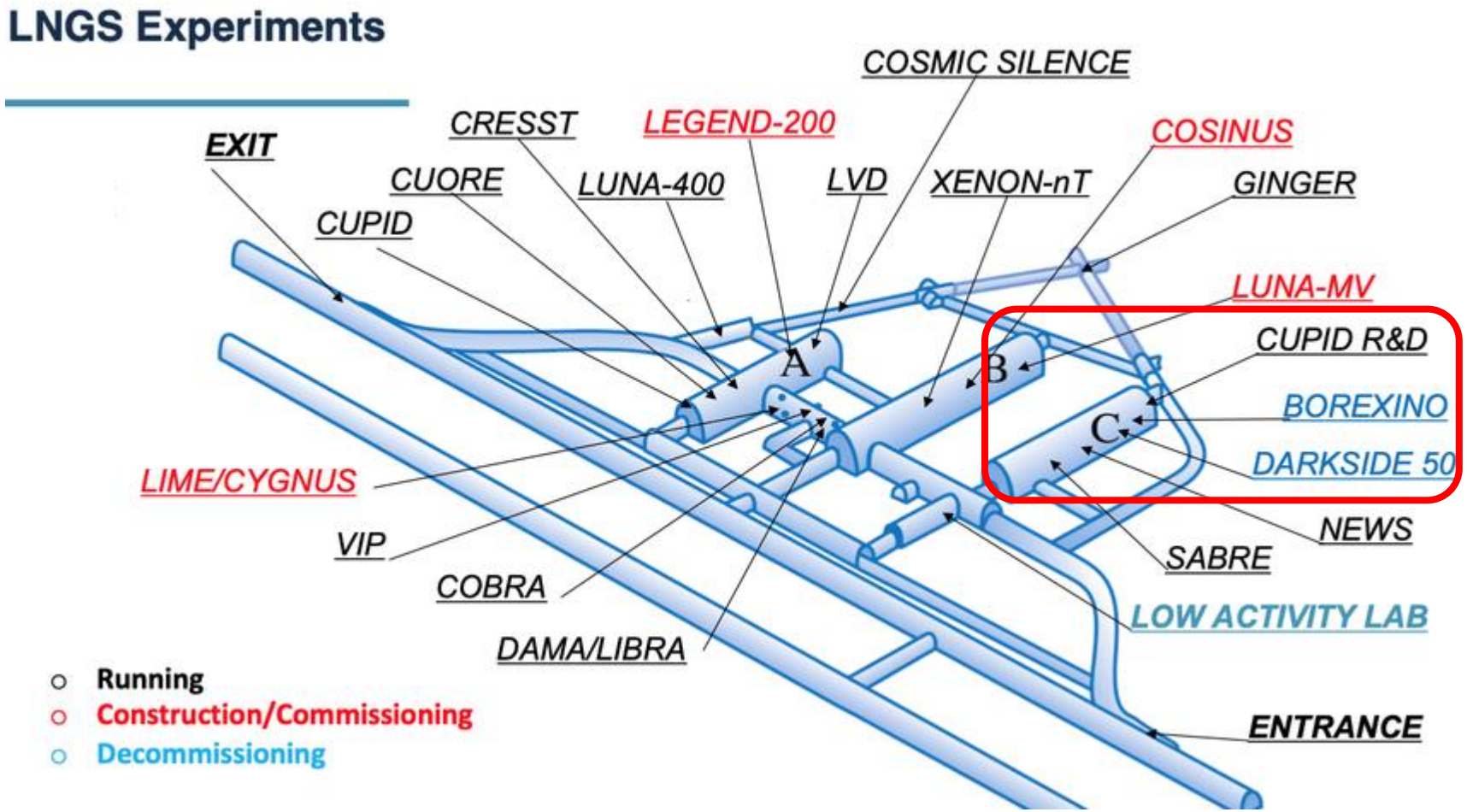
Jiaxuan Cao

On behalf of: Antonio D'Addabbo, Stefano Di Lorenzo, Valentina Dompè,

Massimo Girola, Laura Marini, and many others

2023.12.17

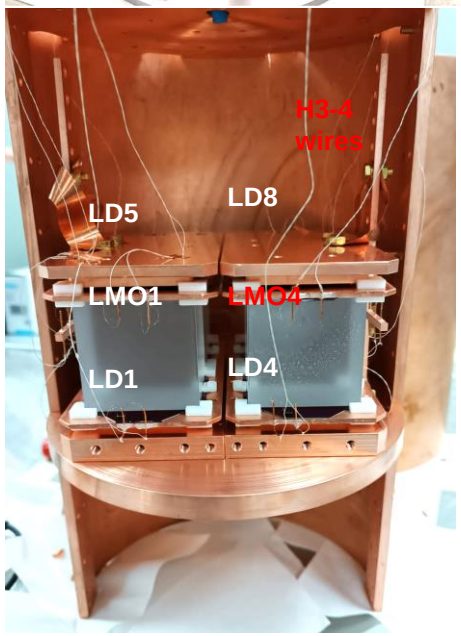
CCVR (CUPID Crystal Validation Run)



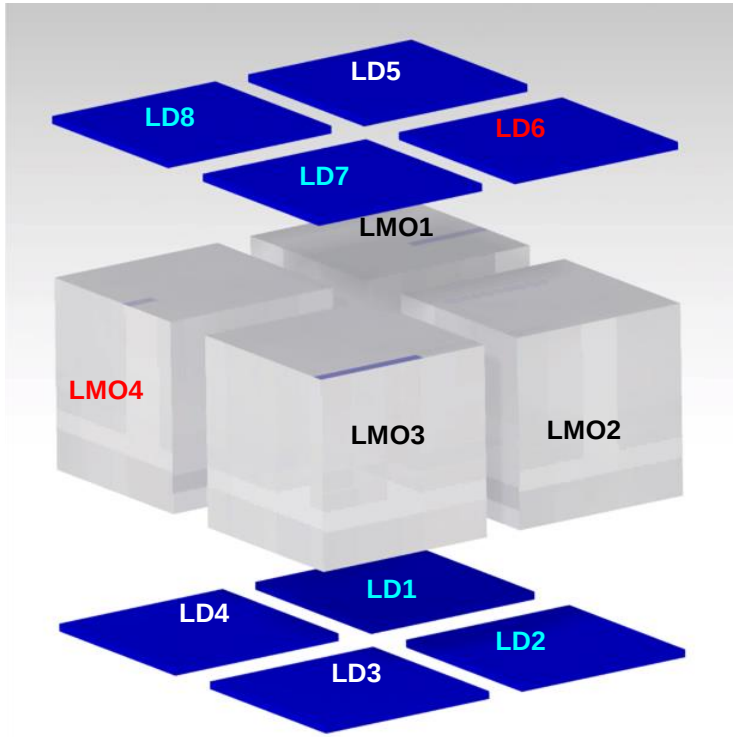
Hall-C Cryostat

Run Performance

Setup



- Russian (NIIC) crystals
- Light Detectors



Cold electronics not working
Dead channels

Working detectors:

- LMO-1
- LMO-2
- LMO-3
- LD-3
- LD-4
- LD-5

Working (LD+LMO) couples:

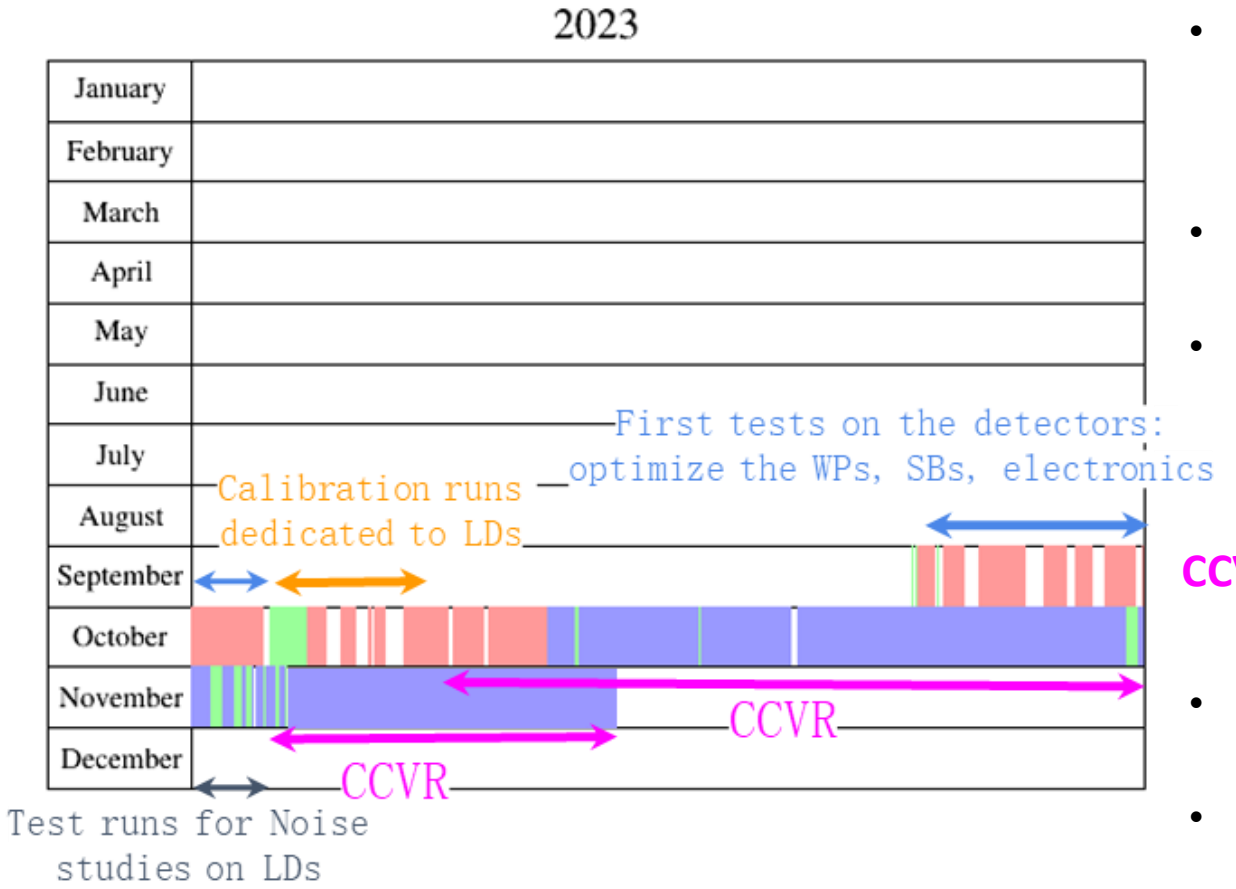
- LMO-1 and LD-5
- LMO-3 and LD-3

Calibration sources:

- External deployable Th-232 strings
- Fe-55 facing LDs

- Note: **the cold electronics EF is not working at the level of the FET** – failed to warm up to its working temepeture.
- Cold electronics S is working but there are no detectors on it.

Data taking



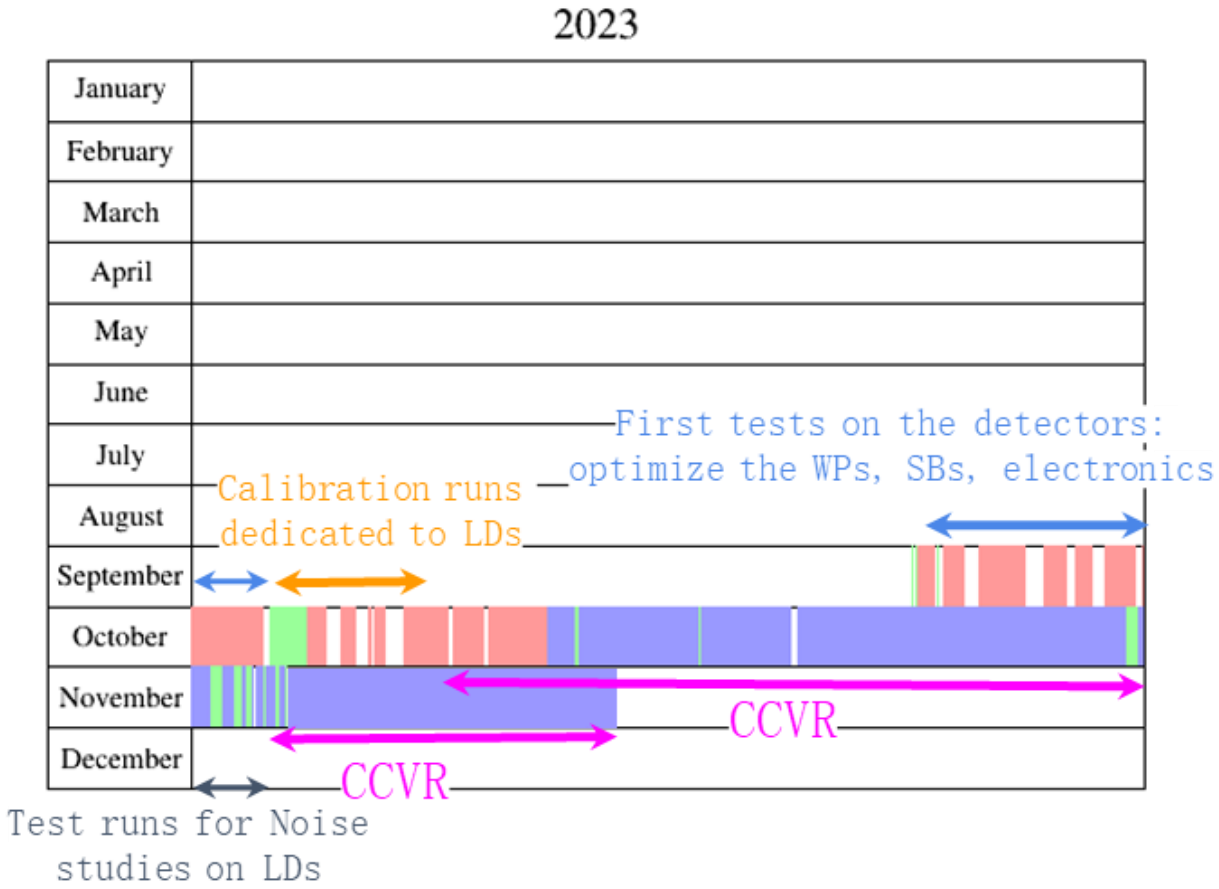
Characterization and study of the response of Light Detectors

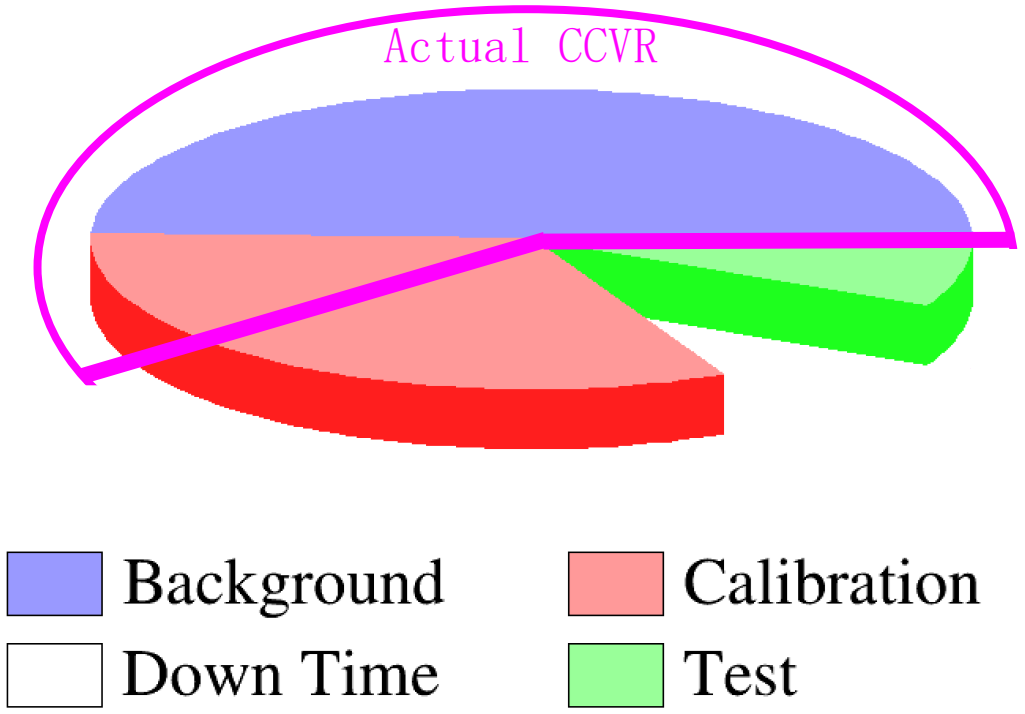
- Dedicated calibration measurements with high-intensity Th-232 sources (Cu X-rays) at various working points.
- Study of the pulse shape at multiple WPs (ohmic, optimal, overbias).
- Scan of the ANPS and noise level at multiple WPs (ohmic, optimal, overbias).

CCVR runs

- study of the contaminants
- detector (LD + LMO) performance
- discrimination power

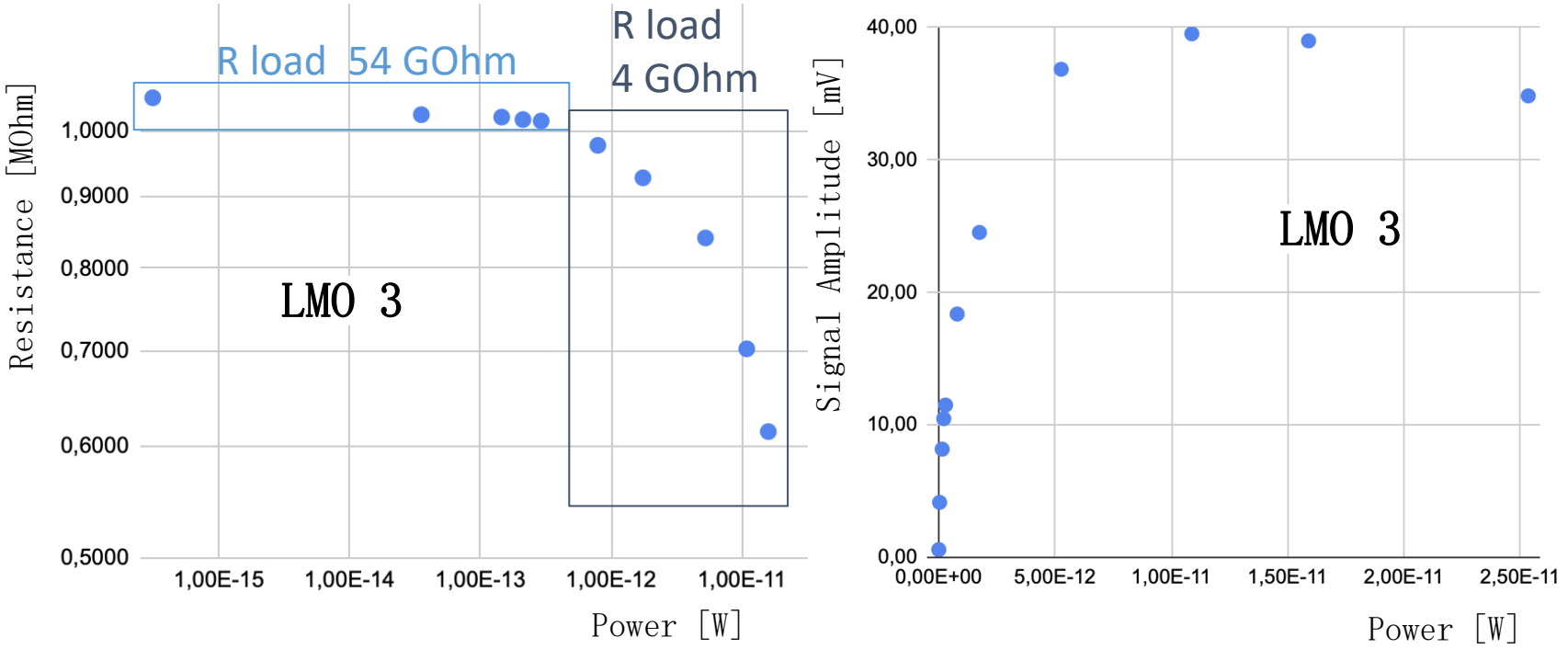
Data taking





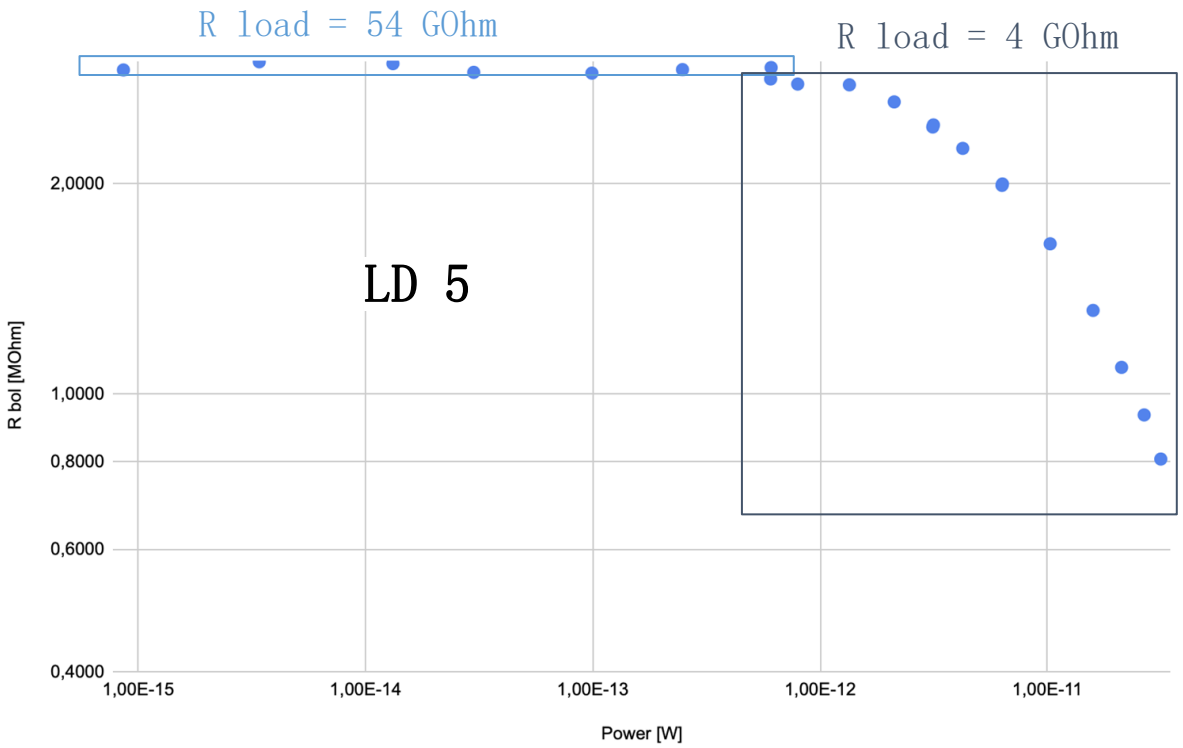
Background: from 12 Oct 2023 to 14 Nov 2023. Bkg run time around 28 days

Load curves on LMO



	LMO 1	LMO 2	LMO 3
Base resistance [MOhm]	1,132	6,573	1,055

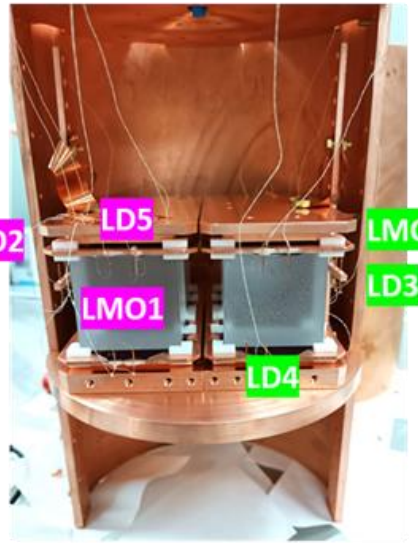
Load curves on LDs

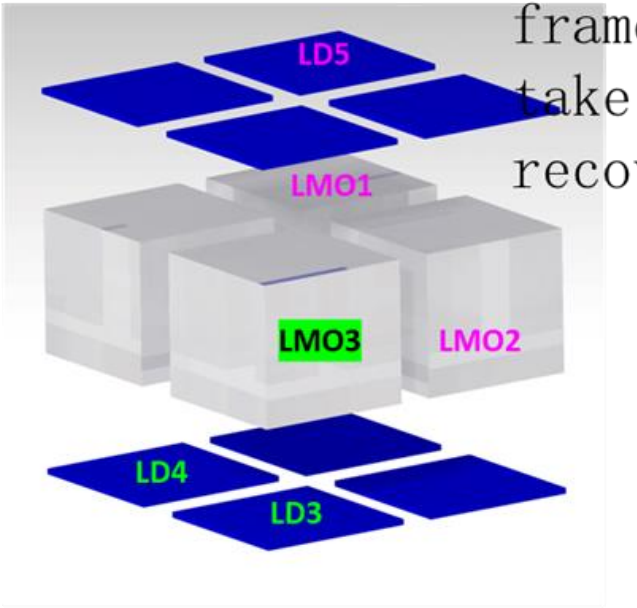


	LD 3	LD 4	LD 5
Base resistance [MOhm]	0,435*	2,887	4,273

*the check with the GND resistance is not ok for this channel so the value of the base resistance is still to confirm

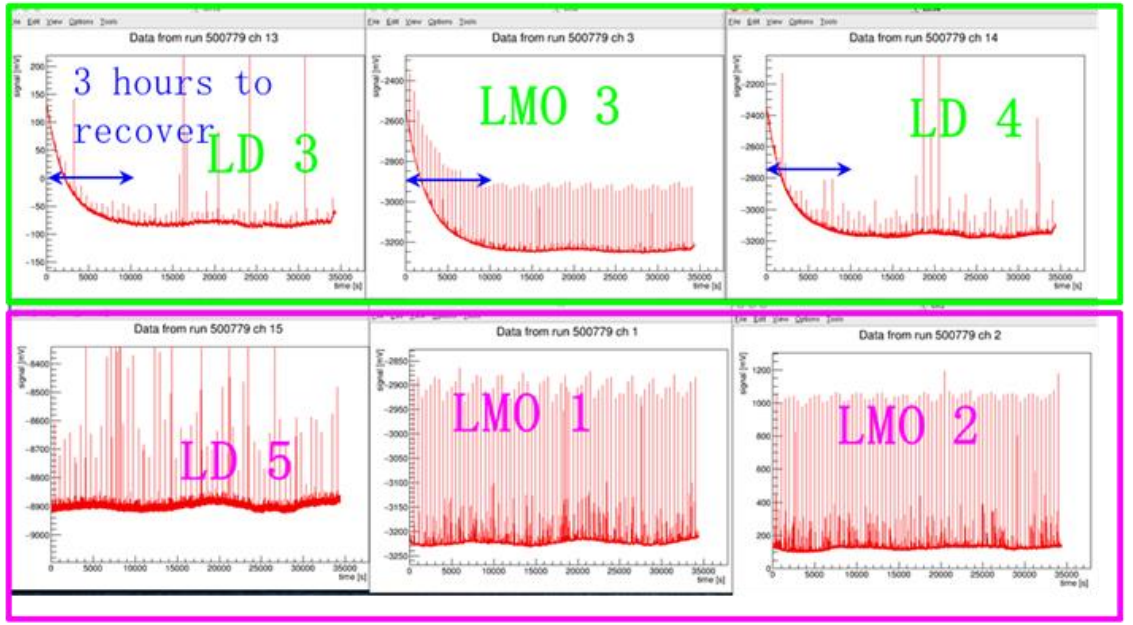
Bad thermalization?



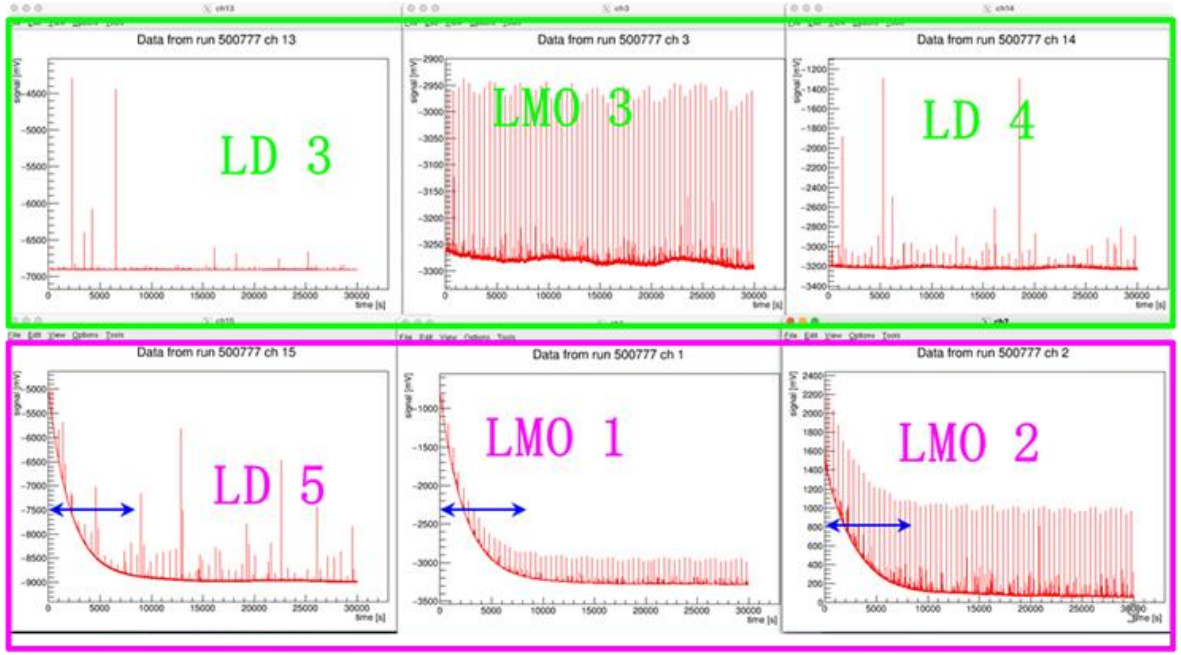


After heating one of the detectors all the other in the same frame warm up and take around 3 hrs to recover

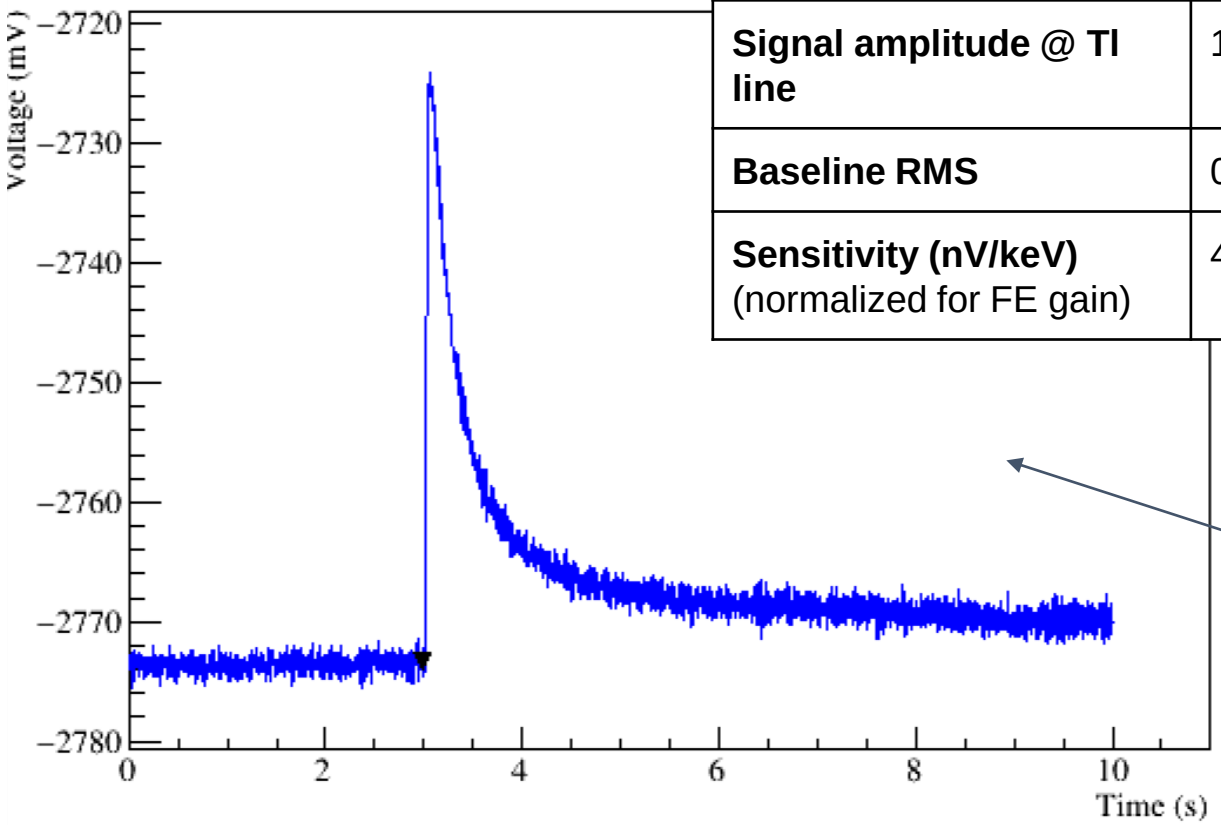
After heating
LD 3



After heating
LD 5



The sensitivity (intrinsic gain) is low!



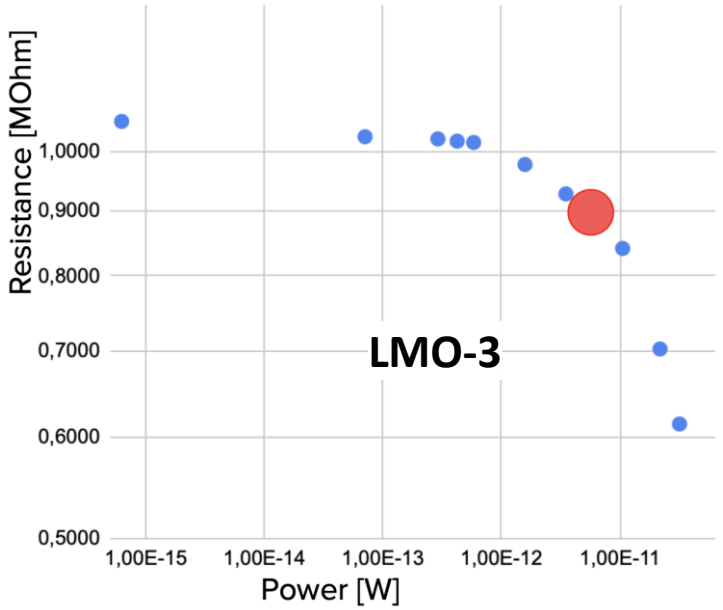
Detector	LMO-1	LMO-2	LMO-3
Signal amplitude @ Tl line	110 mV	330 mV	48 mV
Baseline RMS	0.38 mV	2 mV	0.57 mV
Sensitivity (nV/keV) (normalized for FE gain)	4 nV/keV	12 nV/keV	2 nV/keV

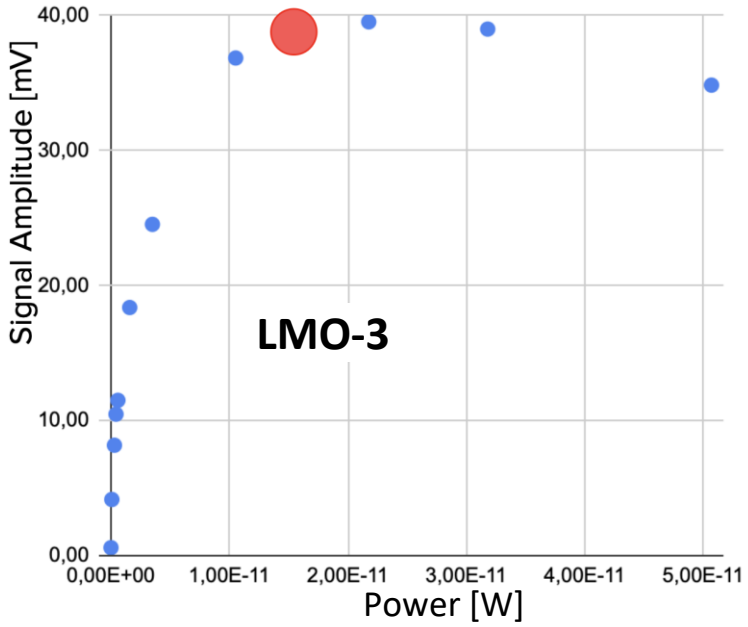
Example:
2615 keV pulse in channel 3 has only ~50 mV amplitude

CCVR Runs

CCVR Runs

- 4,5 days of **calibration**
- ~28 days of **background**



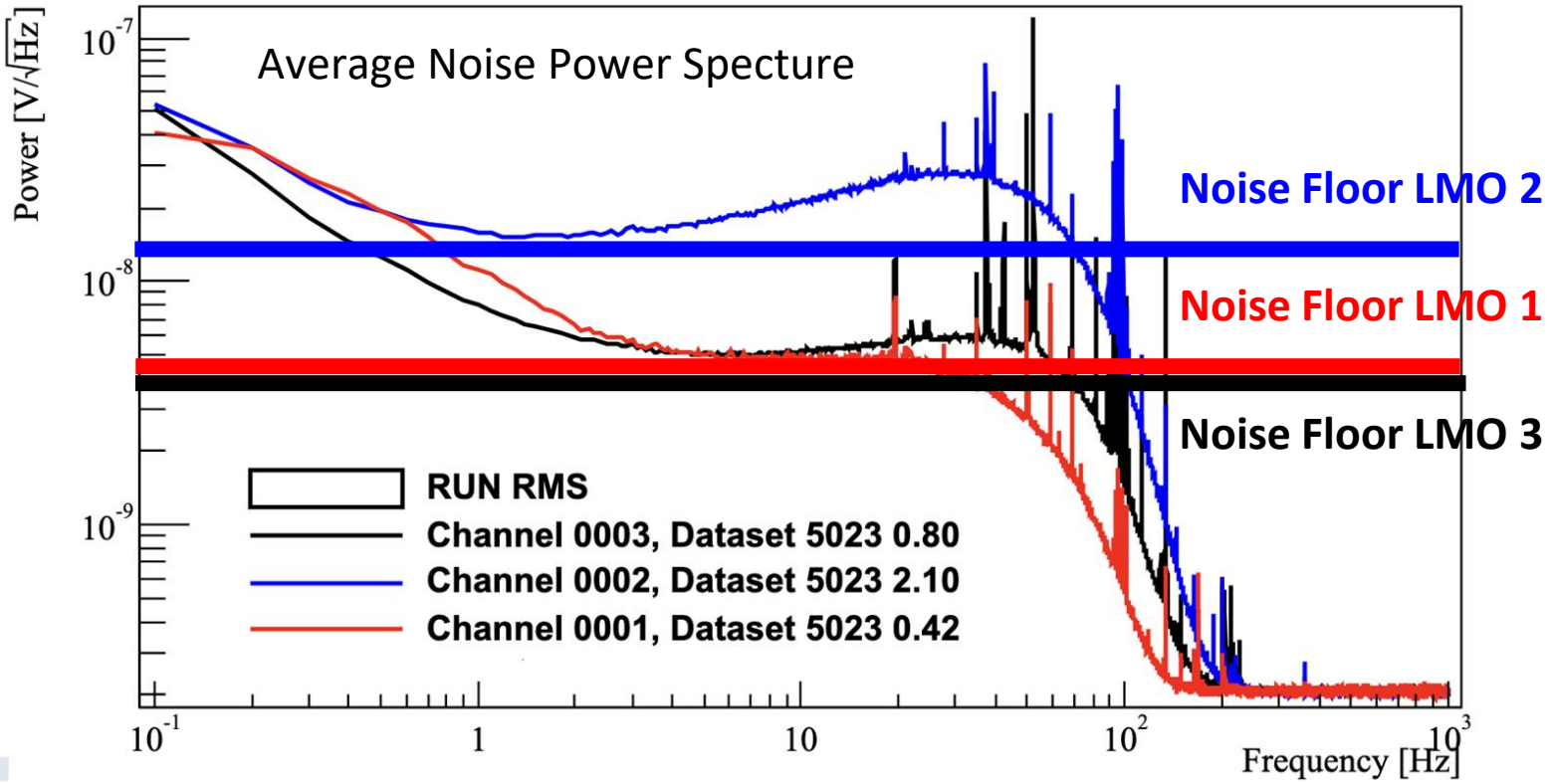


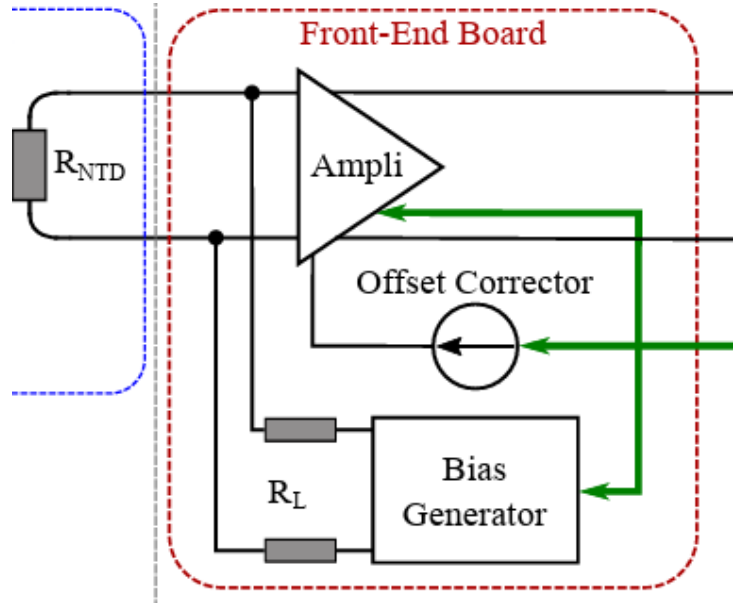
Channel	Gain	R load [GOhm]	V bias [V]	R bol [MOhm]	Sampling Frequency	Bessel cutoff	Window Length
LMO-1	10009	4	10.011	1,1	1 kHz	47 Hz	10 s
LMO-2	10009	4	2.787	5,6	1 kHz	47 Hz	10 s
LMO-3	10009	4	7.124	0,95	1 kHz	47 Hz	10 s

Detector Noise Floor

Noise Sources

- **Johnson noise**
- **Amplifier noise: assume to be 3nV/sqrt(Hz)**
- Vibrations, wires etc.





$$i_n = \sqrt{\frac{4K_B T}{R_L}}$$

$$v_n = i_n \times R_{NTD} = \sqrt{4K_B \times 300\ \mathrm{K} \frac{R_{NTD}^2}{R_L}}$$

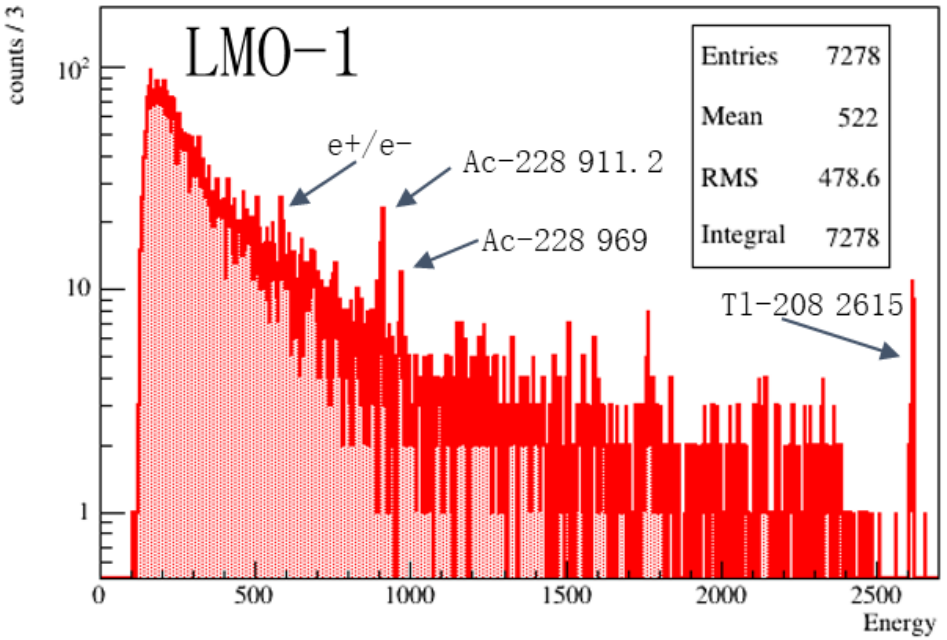
$$N_{Amp} = 3\ \frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}$$

$$N_{Total} = \sqrt{v_n^2 + N_{Amp}^2}$$

There not seem to be additional components of noise above the noise level

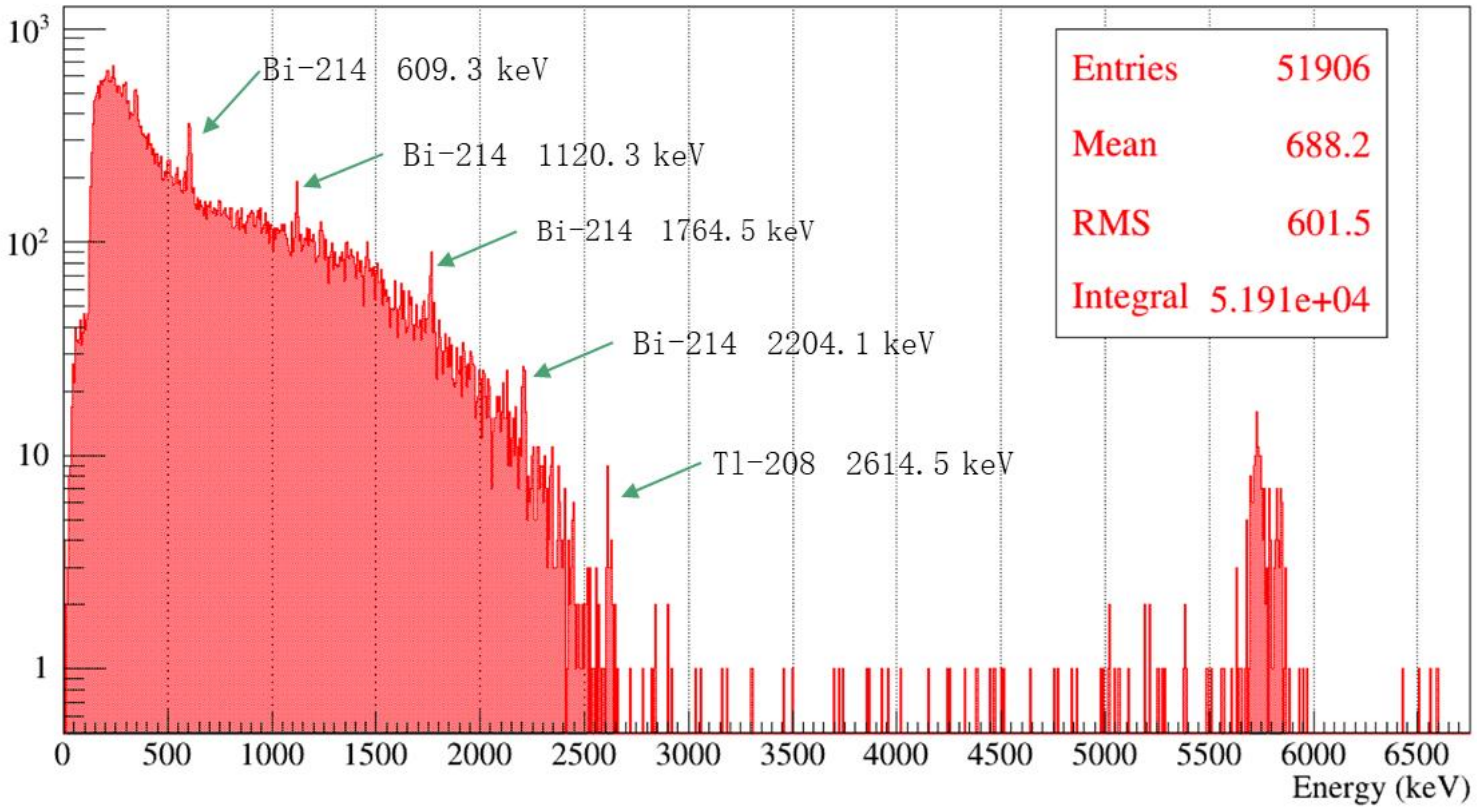
Calibration spectrum

- **Filtered with wOF** using templates from the first 10 days of background
- **Stabilized with pulser**
- Calibration peaks: 511 keV (e+/e-), 2615 keV (Tl line), 911.2 keV and 969 keV (Ac-228)



Detector	LMO-1	LMO-2	LMO-3
2615 Tl line FWHM	~ 10 keV	~ 8.2 keV	~ 22 keV
Baseline Resolution FWHM	~ 10 keV	~ 6.2 keV	~ 20.5 keV

Full statistics total background energy spectrum



Cuts:

RejectBadIntervals

SingleTrigger

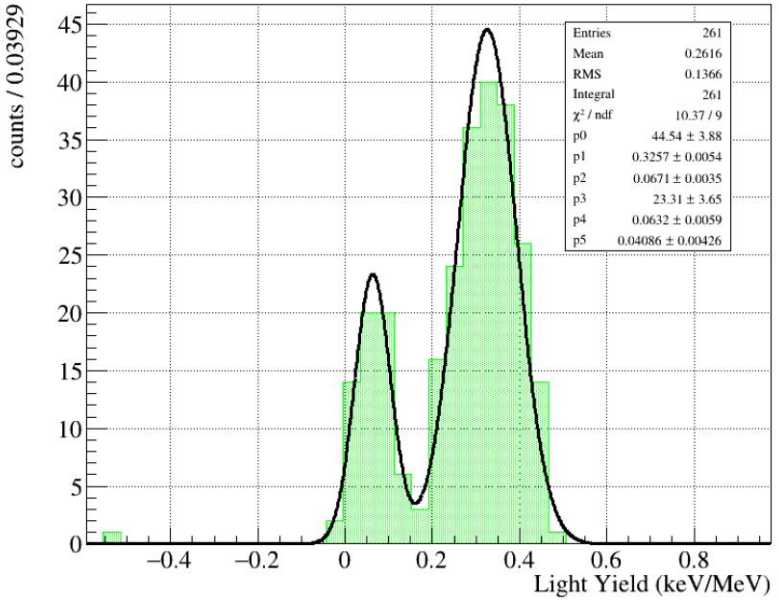
IsSignal

|BaselineSlope|<0.00022

NumberOfPulses==1

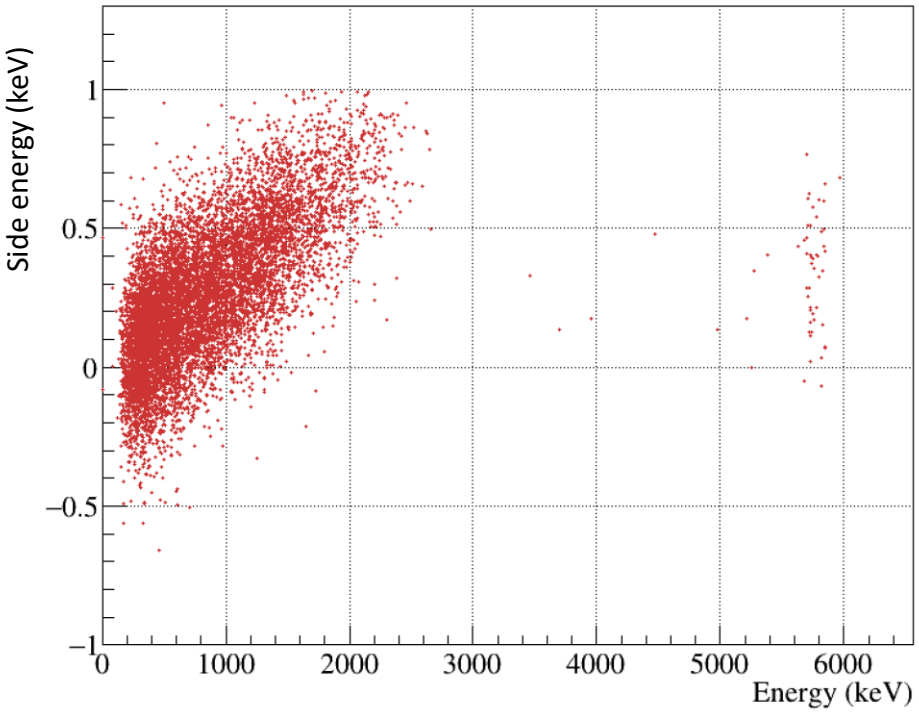
Discrimination power LMO 3/LD 3

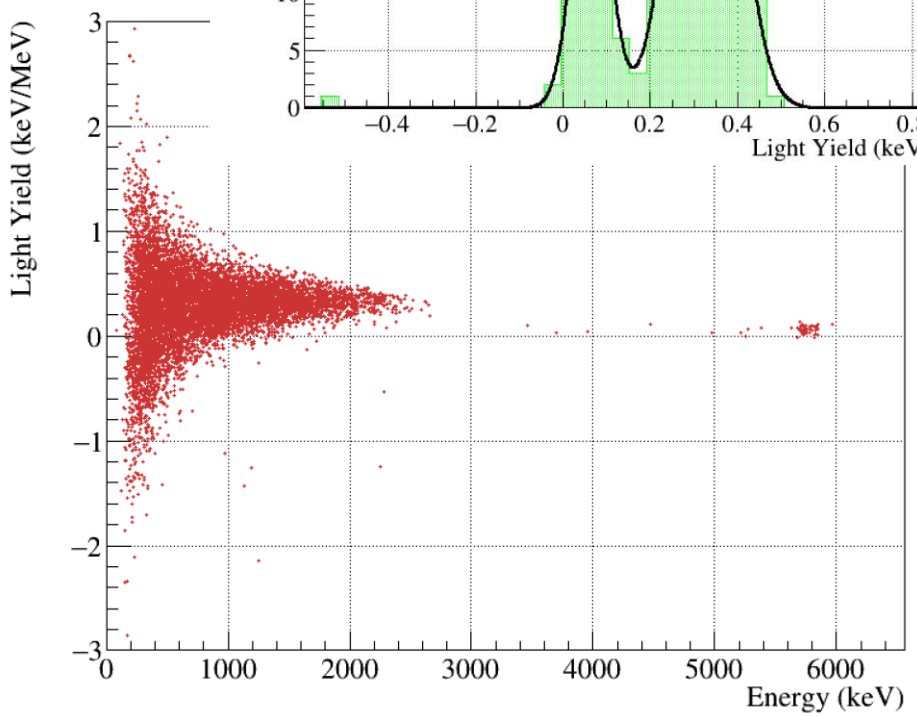
- Discrimination Power (Energy>2 MeV) ~ 3.3
- Light Yield (β/γ) ~ 0.33 keV/MeV

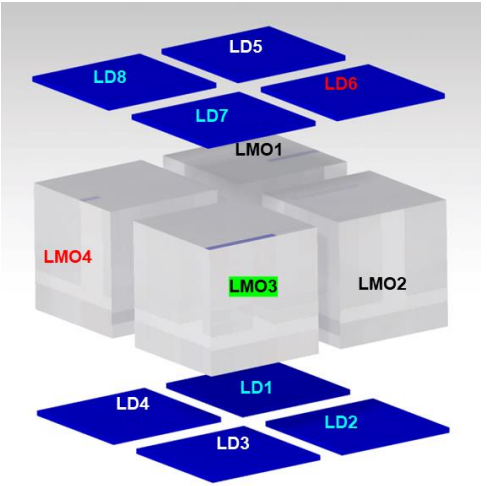


$$DP = \frac{|\mu_{\beta/\gamma} - \mu_{\alpha}|}{\sqrt{\sigma_{\beta/\gamma}^2 + \sigma_{\alpha}^2}}$$

μ: average value
σ: RMS

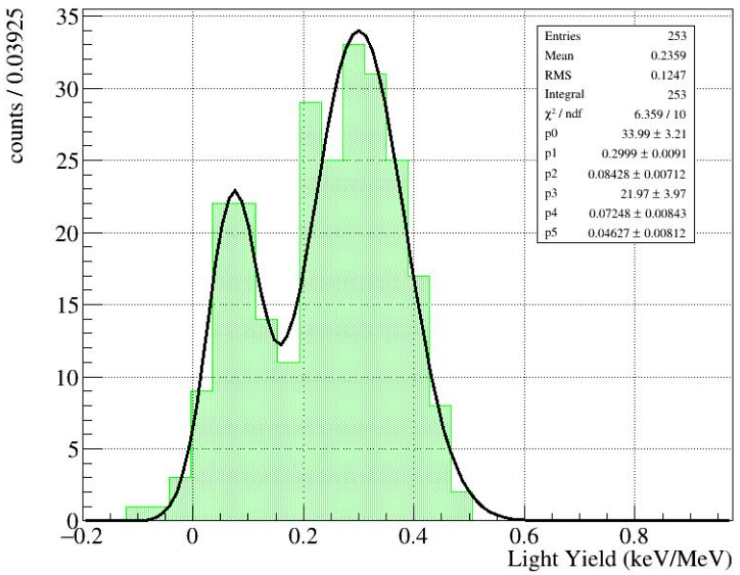






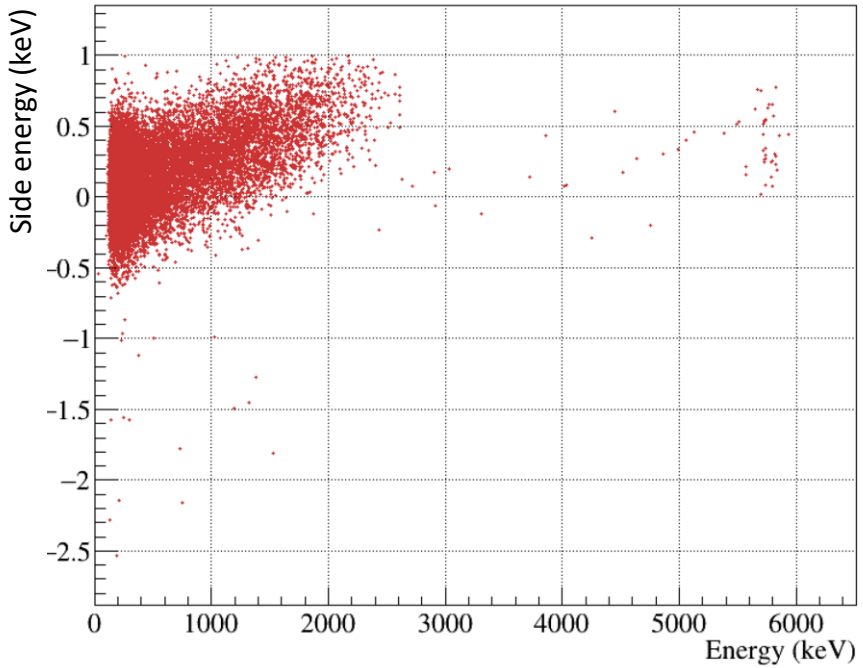
Discrimination power LMO 1/LD 5

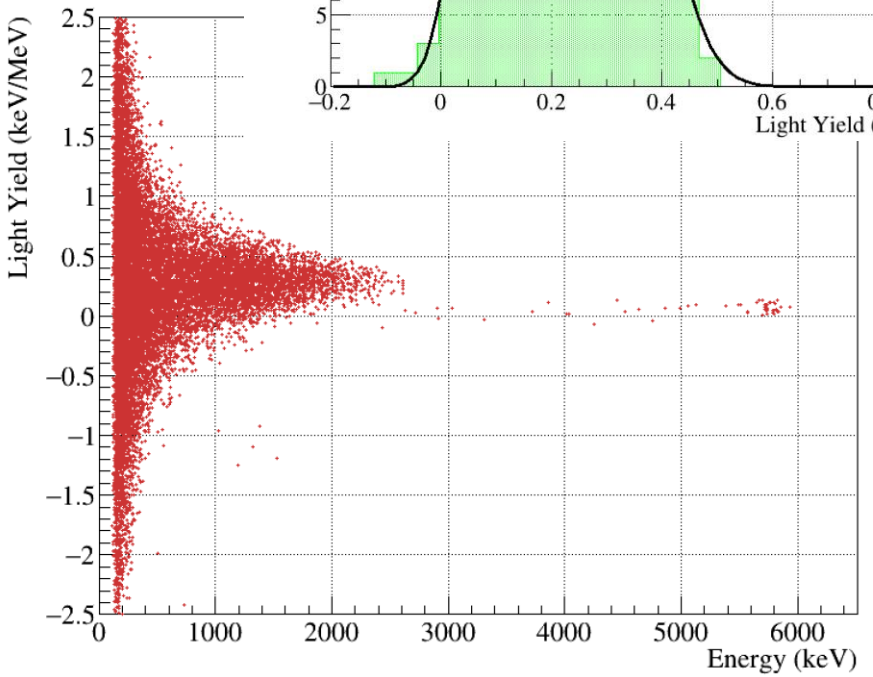
- Discrimination Power (Energy>2 MeV) ~ 2.5
- Light Yield (β/γ) ~ 0.3 keV/MeV

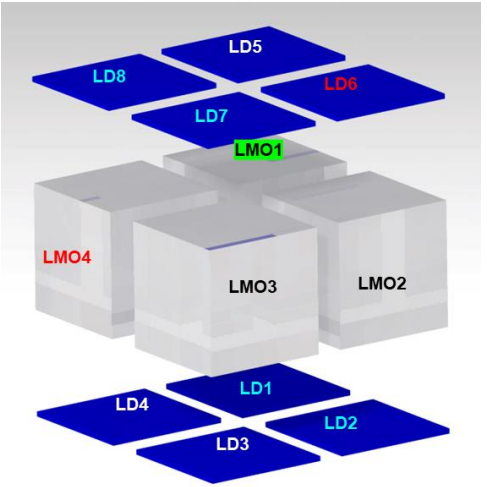


$$DP = \frac{|\mu_{\beta/\gamma} - \mu_{\alpha}|}{\sqrt{\sigma_{\beta/\gamma}^2 + \sigma_{\alpha}^2}}$$

μ: average value
σ: RMS

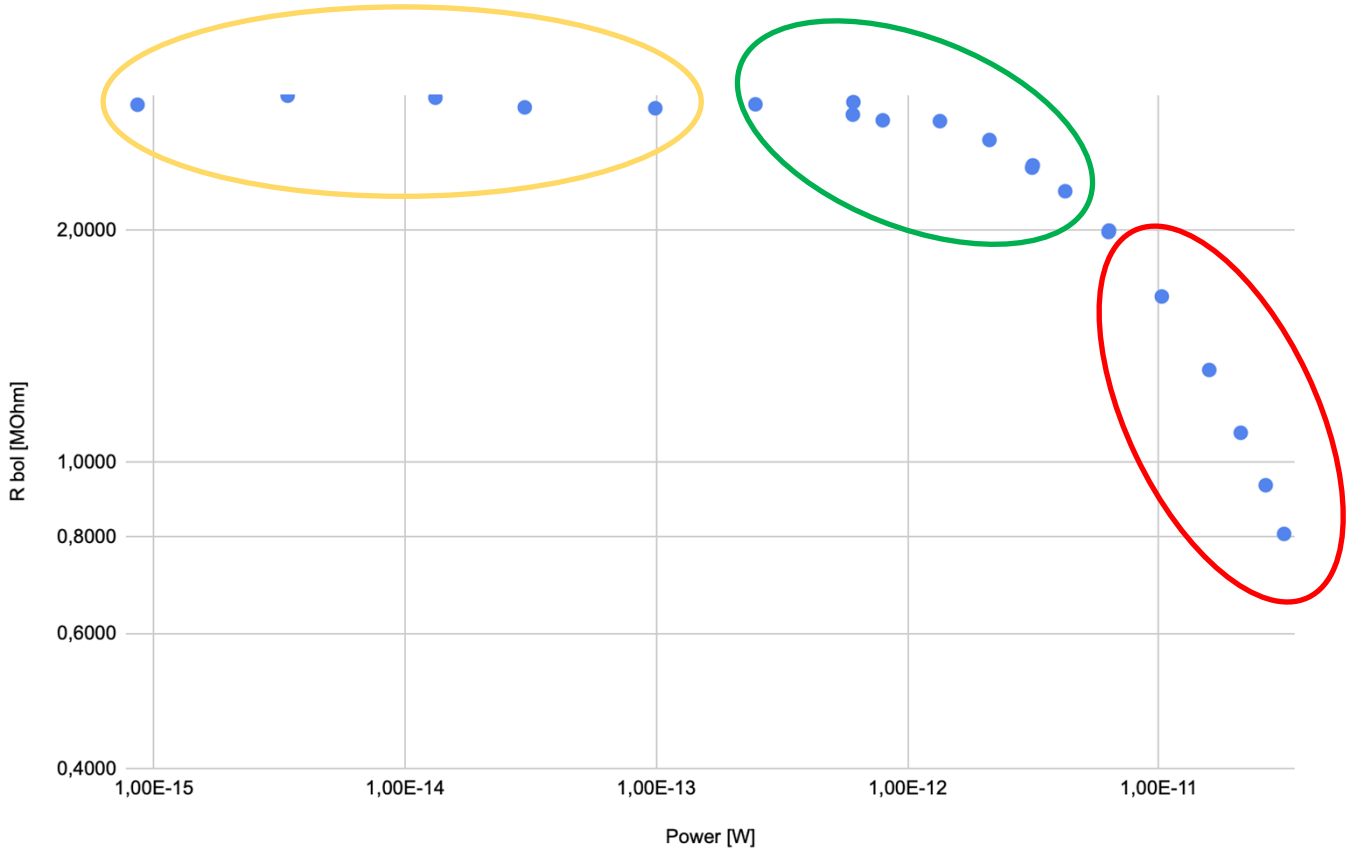


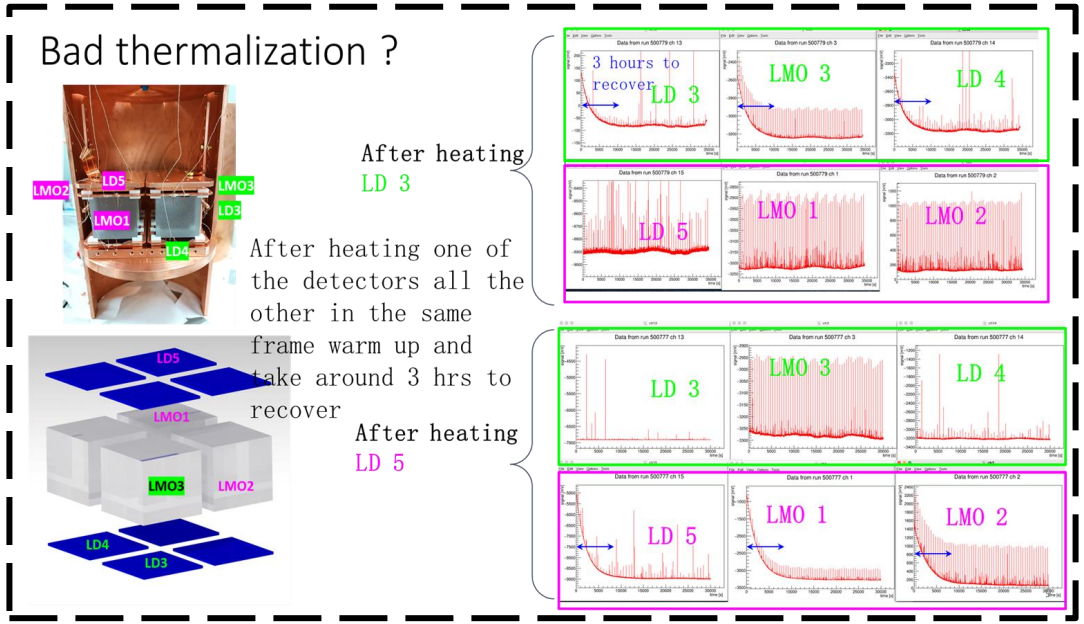




LD Load Curve scan

Test runs for noise studies on LDs





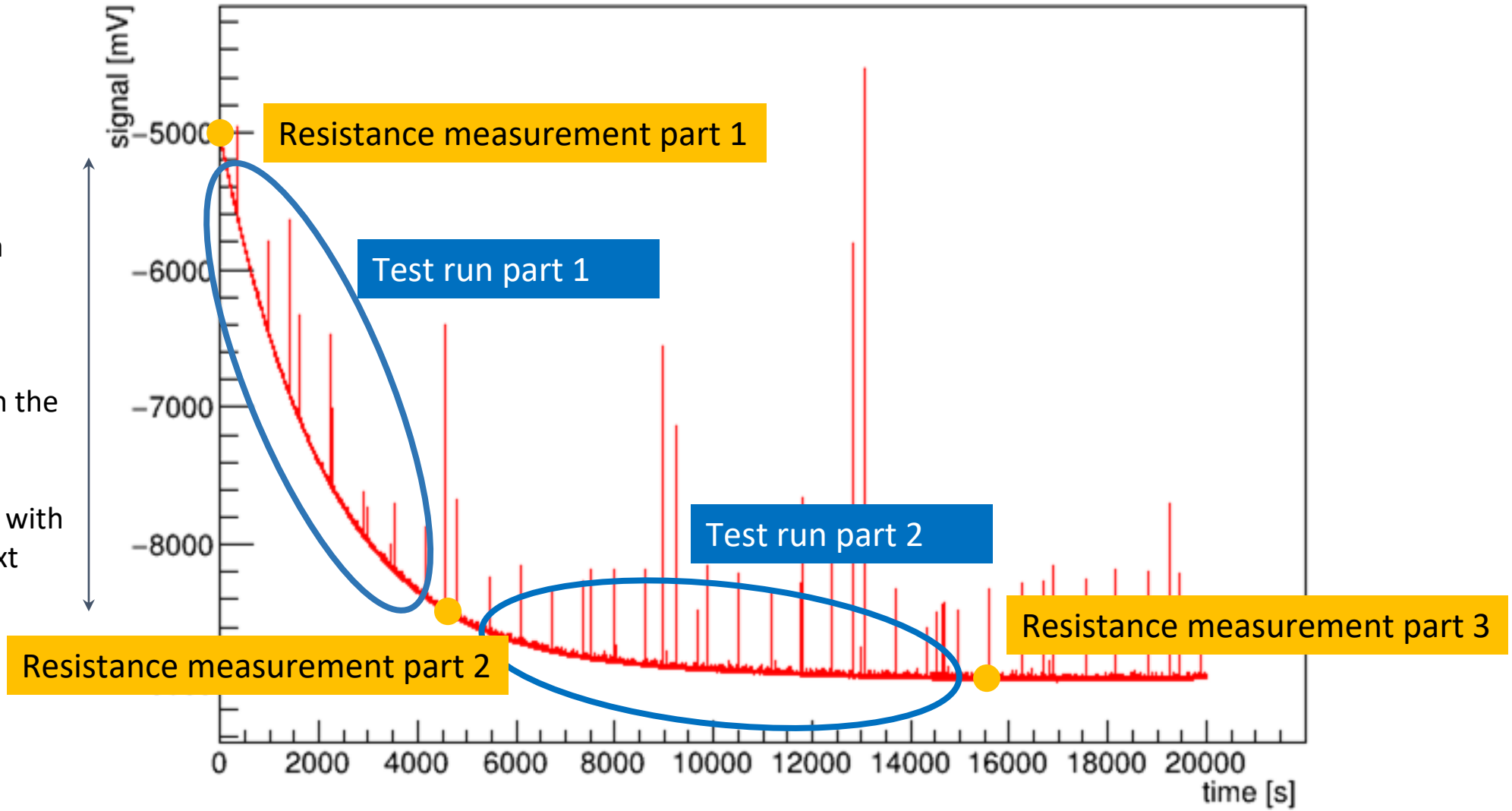
We want to:

- Scan of the ANPS and noise level at multiple working points (ohmic, optimal, overbias).
- But the bad thermalization will influence our measurements.

LC scan process for single WP

This variation translates into a variation of the johnson noise during the measurement in the part 1

we indicate this with bands in the next plots shown



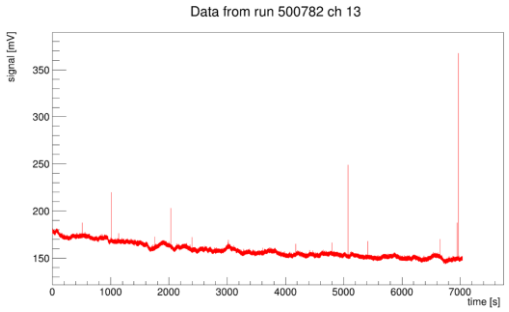
Actual LC scan

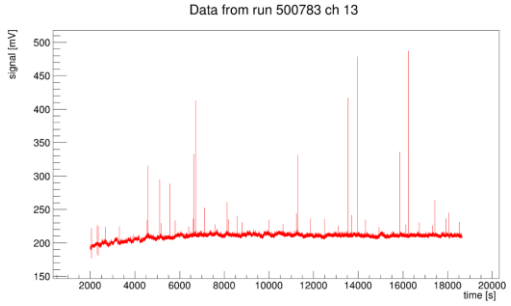
Resistance measurement

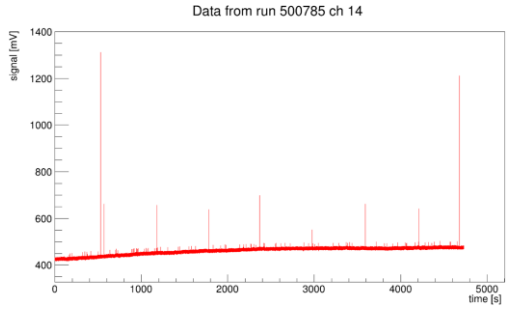
Background run -- WP1
~ 7000 s

Background run -- WP2
~ 16000 s

Background run -- WP3
~ 4800 s





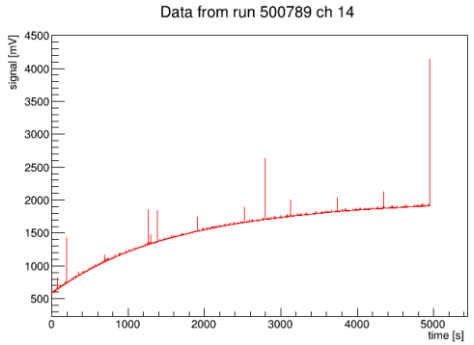


Small power input in the first 3 WP, no obvious heating.

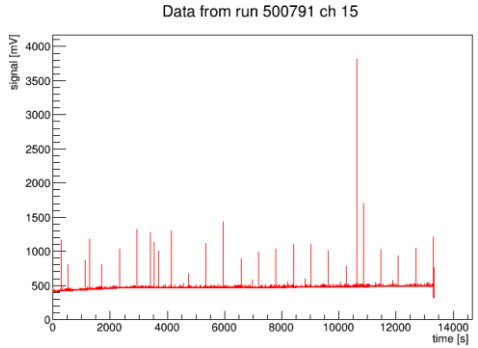
Actual LC scan

Resistance measurement

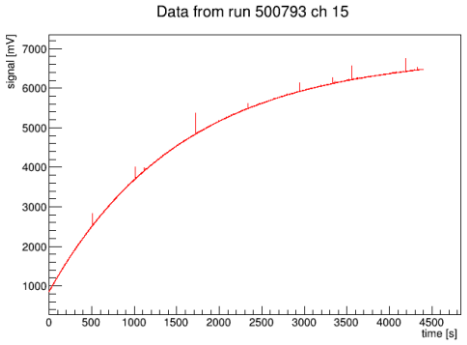
Background run -- WP4-1
~ 5000 s



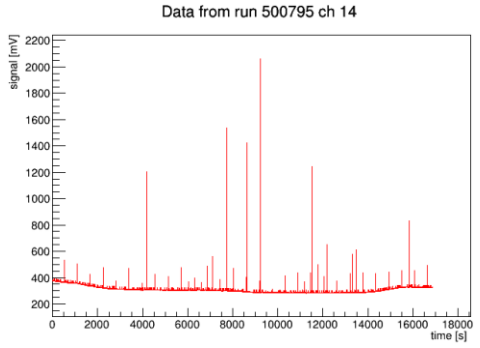
Background run -- WP4-2
~ 13400 s



Background run -- WP5-1
~ 4400 s



Background run -- WP5-2
~ 16900 s



Problem on LD-3

LD-3 fails the test of the 2 MOhm GND resistance.

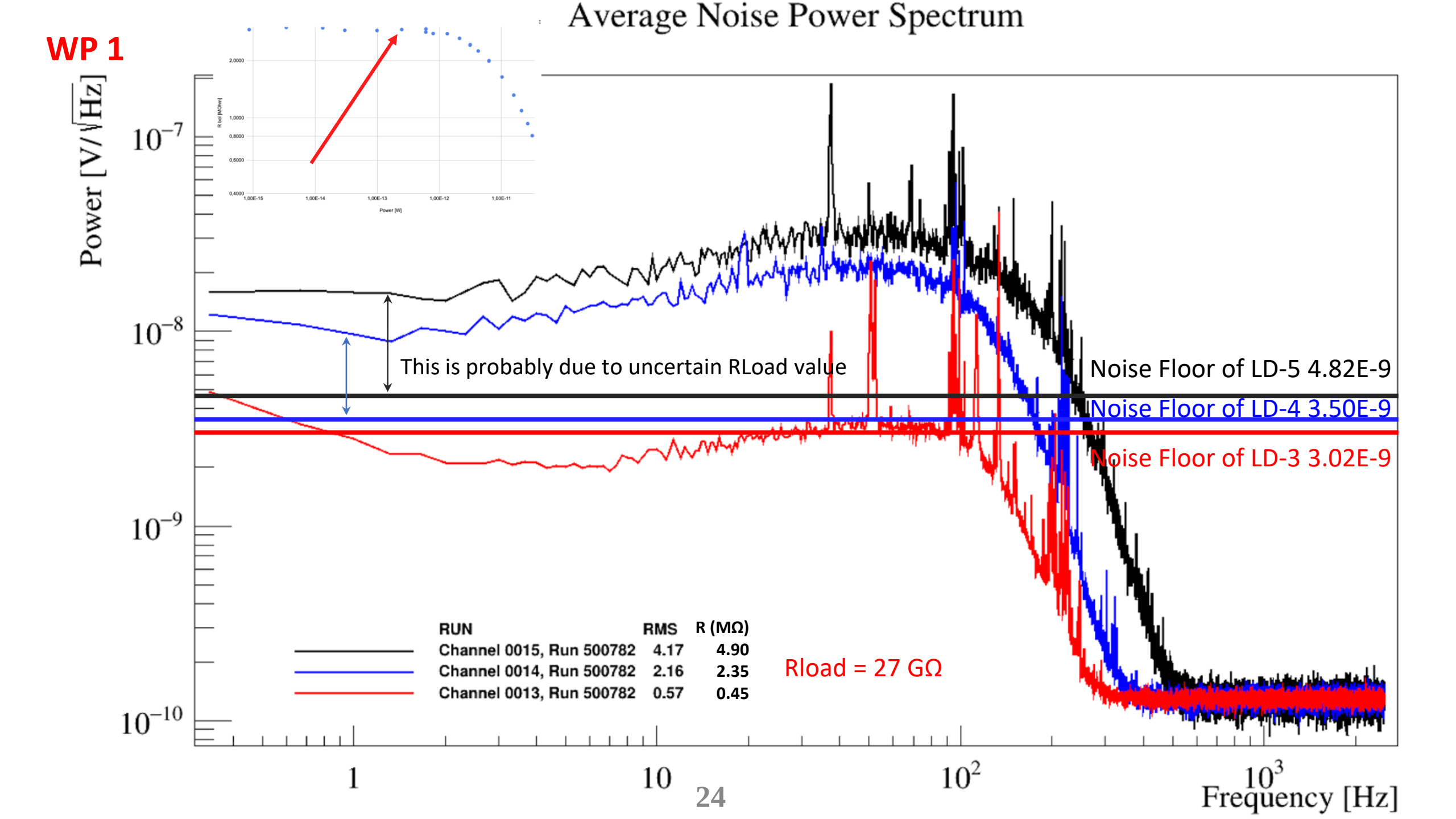
Possible problem in the FE gain → impossible to normalize the noise correctly → we ignore it for the moment

Measurements of the test resistor on the board with the multimeter will help us understand.

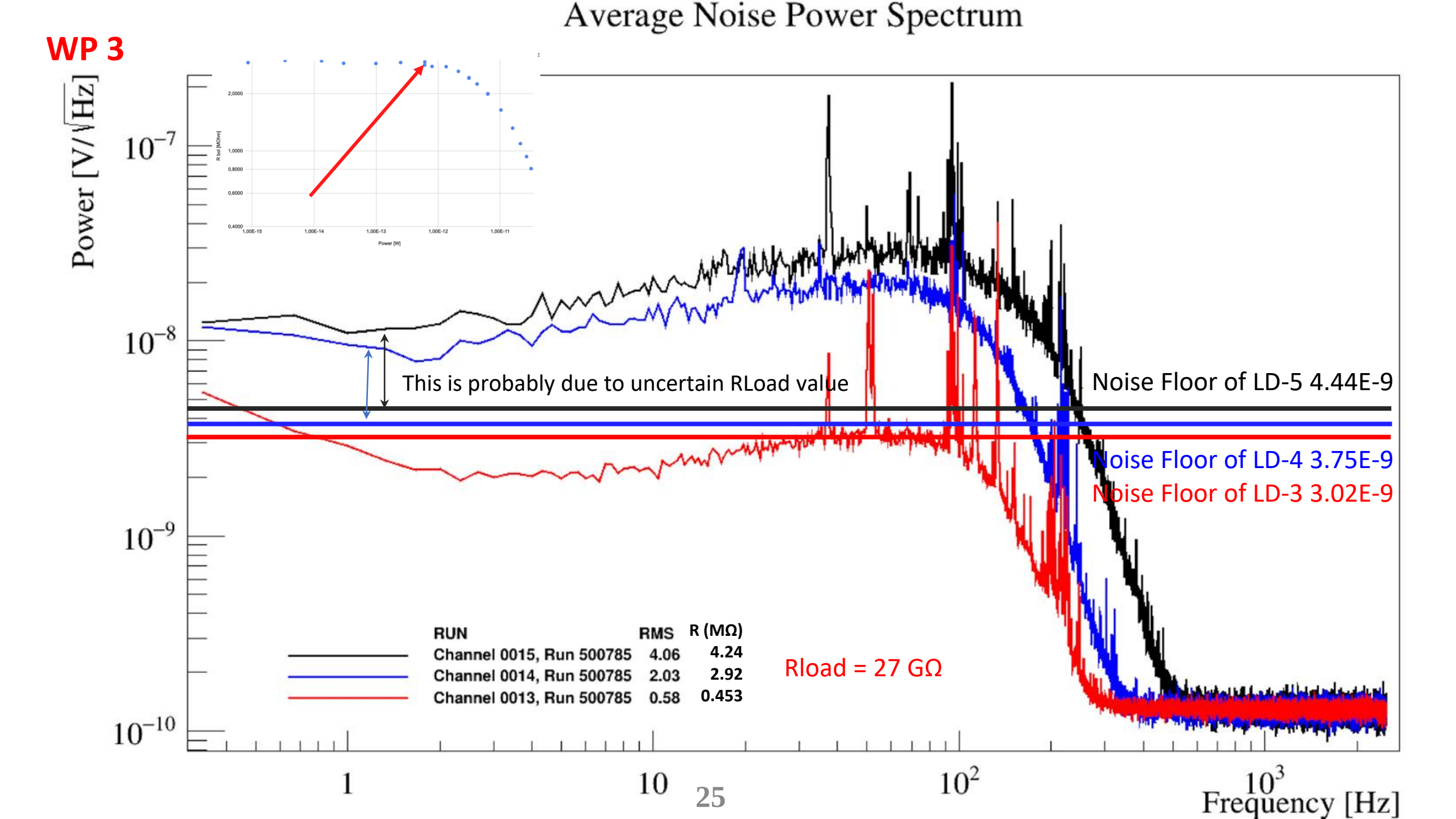
Still, it is working and usable for the CCVR runs

CH	R_load	Gain	V_bias	V+	V-	Vbol	Vbol/gain	R (Mega)	
LD-3-GND	2,70E+10	6623	928	182	343	80,5	0,01215461271	0,7073	
LD-3-GND	2,70E+10	6623	28908	2753	-2232	2492,5	0,3763400272	0,7030	This is supposed to be 2 MOhm
LD-3-GND	2,00E+09	6623	928	845	3185	1170	0,176657104	0,7616	
LD-3-GND	2,00E+09	6623	3597	6415	-2375	4395	0,6635965575	0,7381	
LD-3-GND	2,00E+09	2938	6493	2968	-4056	3512	1,195371001	0,7365	
LD-3-GND	2,00E+09	1046	10011	2874	6731	1928,5	1,843690249	0,7368	PROBLEMS

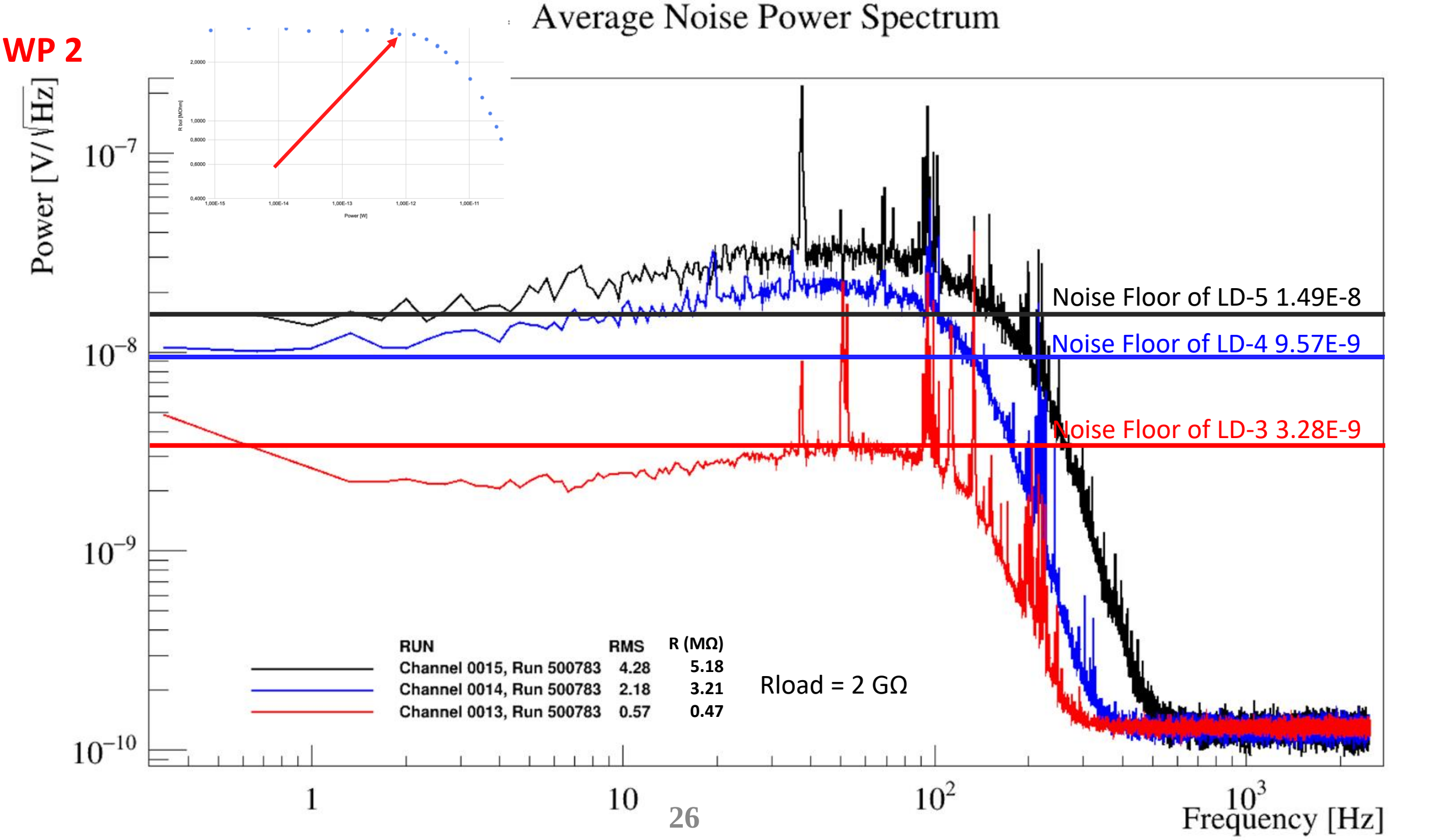
WP 1


Average Noise Power Spectrum
Power [V/√Hz]
10^{-7}
10^{-8}
10^{-9}
10^{-10}
1
10
10^2
10^3
Frequency [Hz]
This is probably due to uncertain RLoad value
Noise Floor of LD-5 4.82E-9
Noise Floor of LD-4 3.50E-9
Noise Floor of LD-3 3.02E-9
RUN RMS R (MΩ)
Channel 0015, Run 500782 4.17 4.90
Channel 0014, Run 500782 2.16 2.35
Channel 0013, Run 500782 0.57 0.45
Rload = 27 GΩ
Power [W]

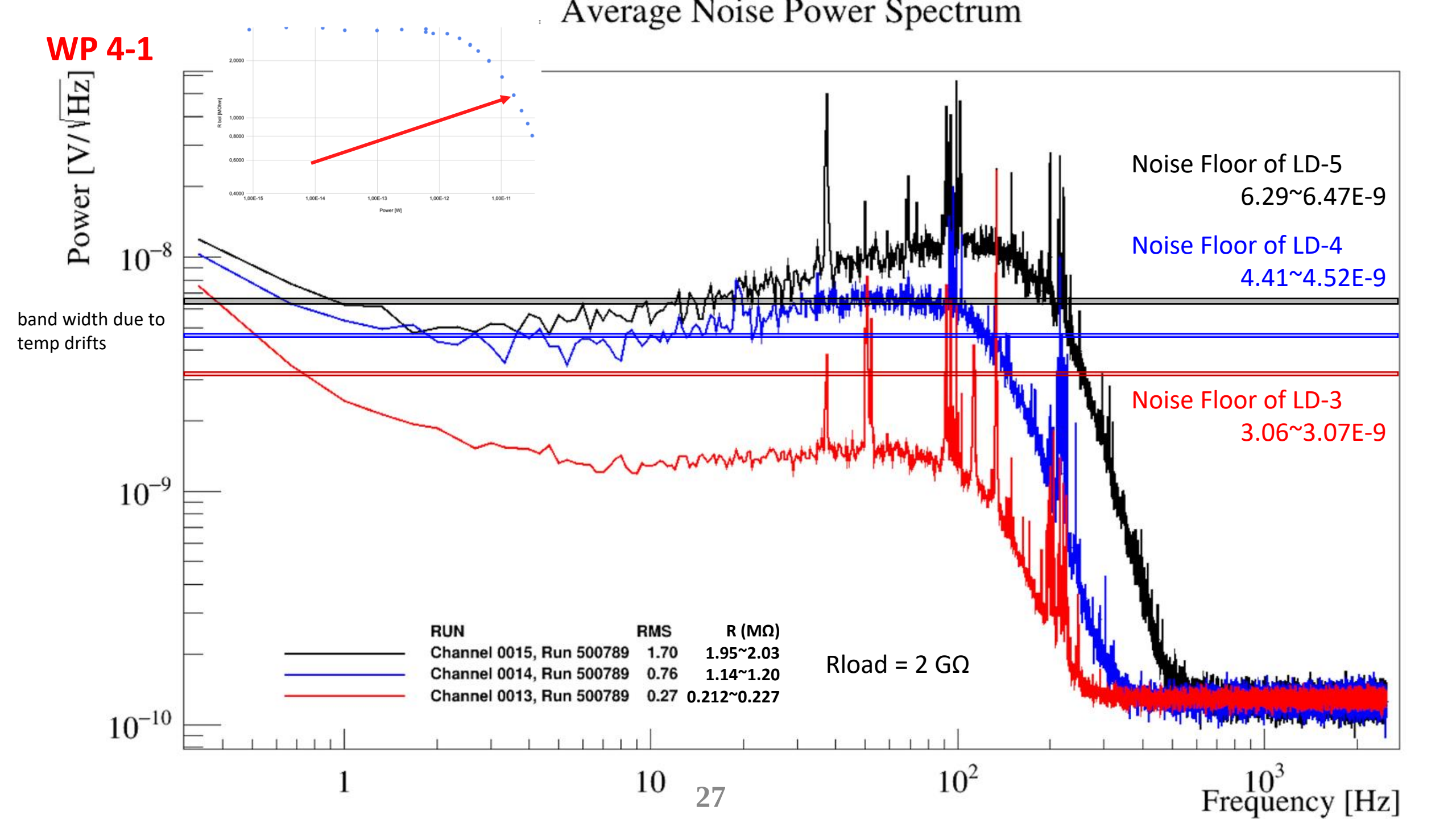
WP 3


Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
This is probably due to uncertain RLoad value
Noise Floor of LD-5 4.44E-9
Noise Floor of LD-4 3.75E-9
Noise Floor of LD-3 3.02E-9
Rload = 27 GΩ
RUN RMS R (MΩ)
Channel 0015, Run 500785 4.06 4.24
Channel 0014, Run 500785 2.03 2.92
Channel 0013, Run 500785 0.58 0.453

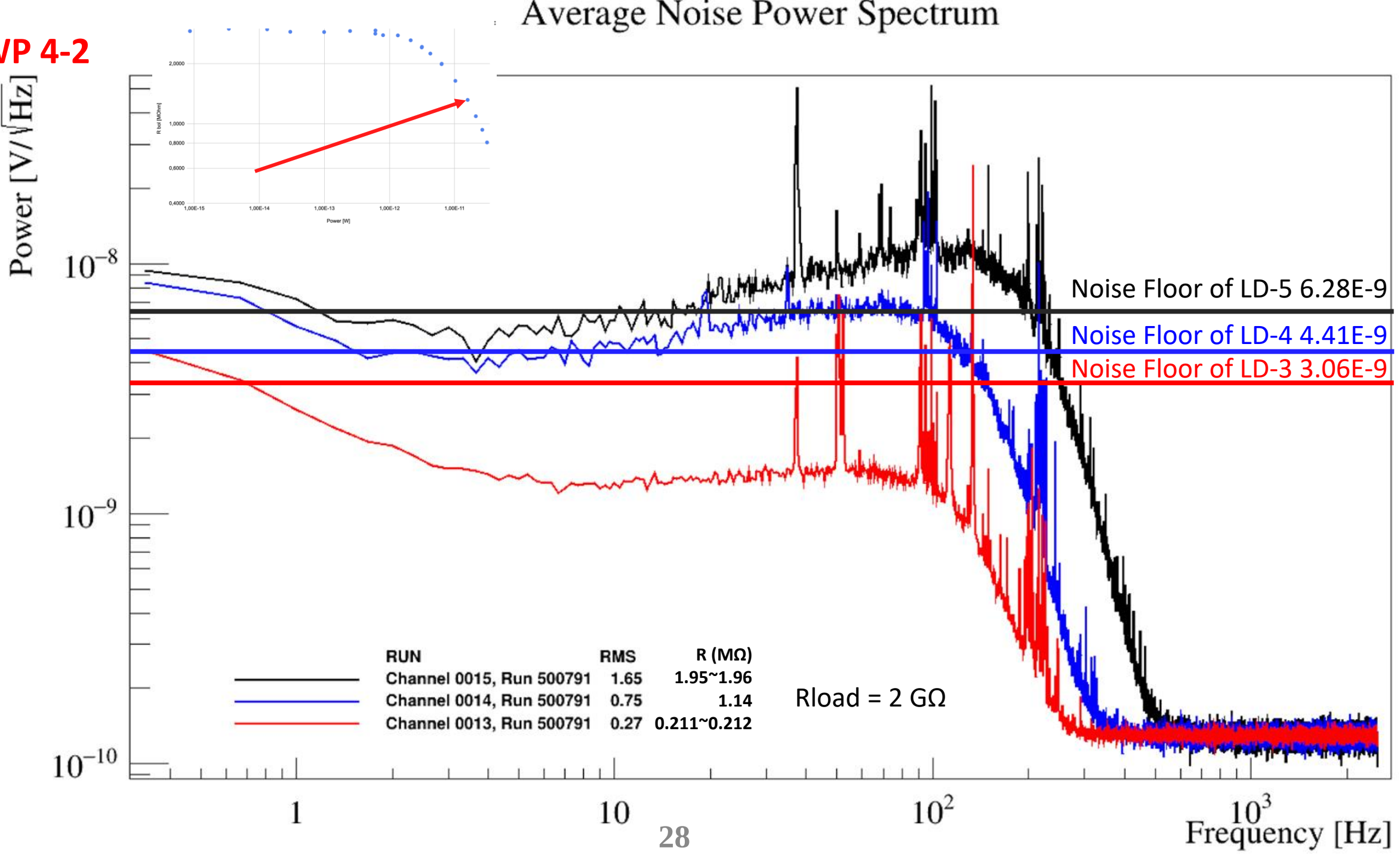
WP 2


Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
Noise Floor of LD-5 1.49E-8
Noise Floor of LD-4 9.57E-9
Noise Floor of LD-3 3.28E-9
RUN RMS R (MΩ)
Channel 0015, Run 500783 4.28 5.18
Channel 0014, Run 500783 2.18 3.21
Channel 0013, Run 500783 0.57 0.47
Rload = 2 GΩ
R bol [MOhm]
Power [W]

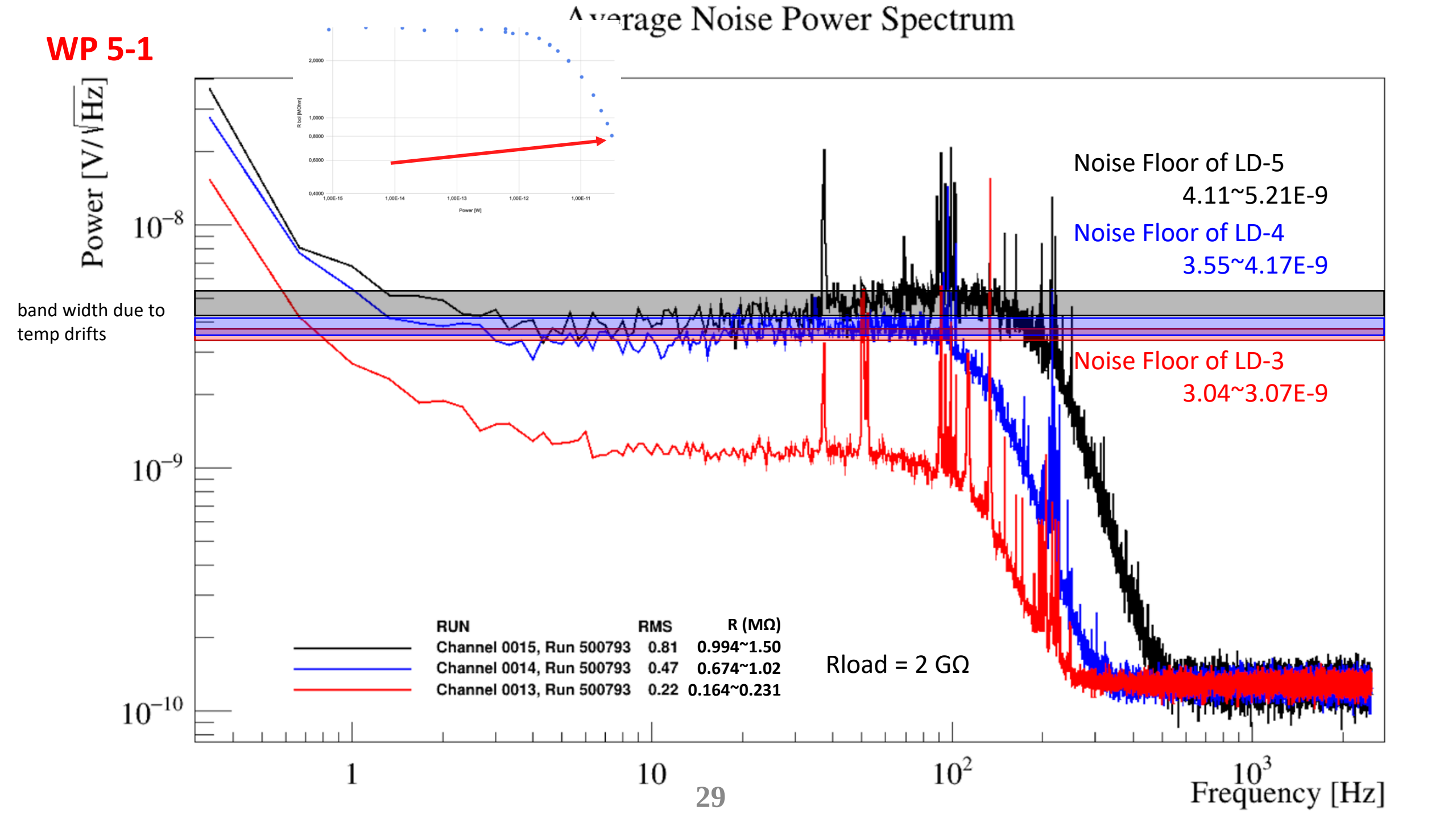
WP 4-1


Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
Noise Floor of LD-5
6.29~6.47E-9
Noise Floor of LD-4
4.41~4.52E-9
Noise Floor of LD-3
3.06~3.07E-9
band width due to temp drifts
RUN RMS R (MΩ)
Channel 0015, Run 500789 1.70 1.95~2.03
Channel 0014, Run 500789 0.76 1.14~1.20
Channel 0013, Run 500789 0.27 0.212~0.227
Rload = 2 GΩ
R bol [MOhm]
Power [W]

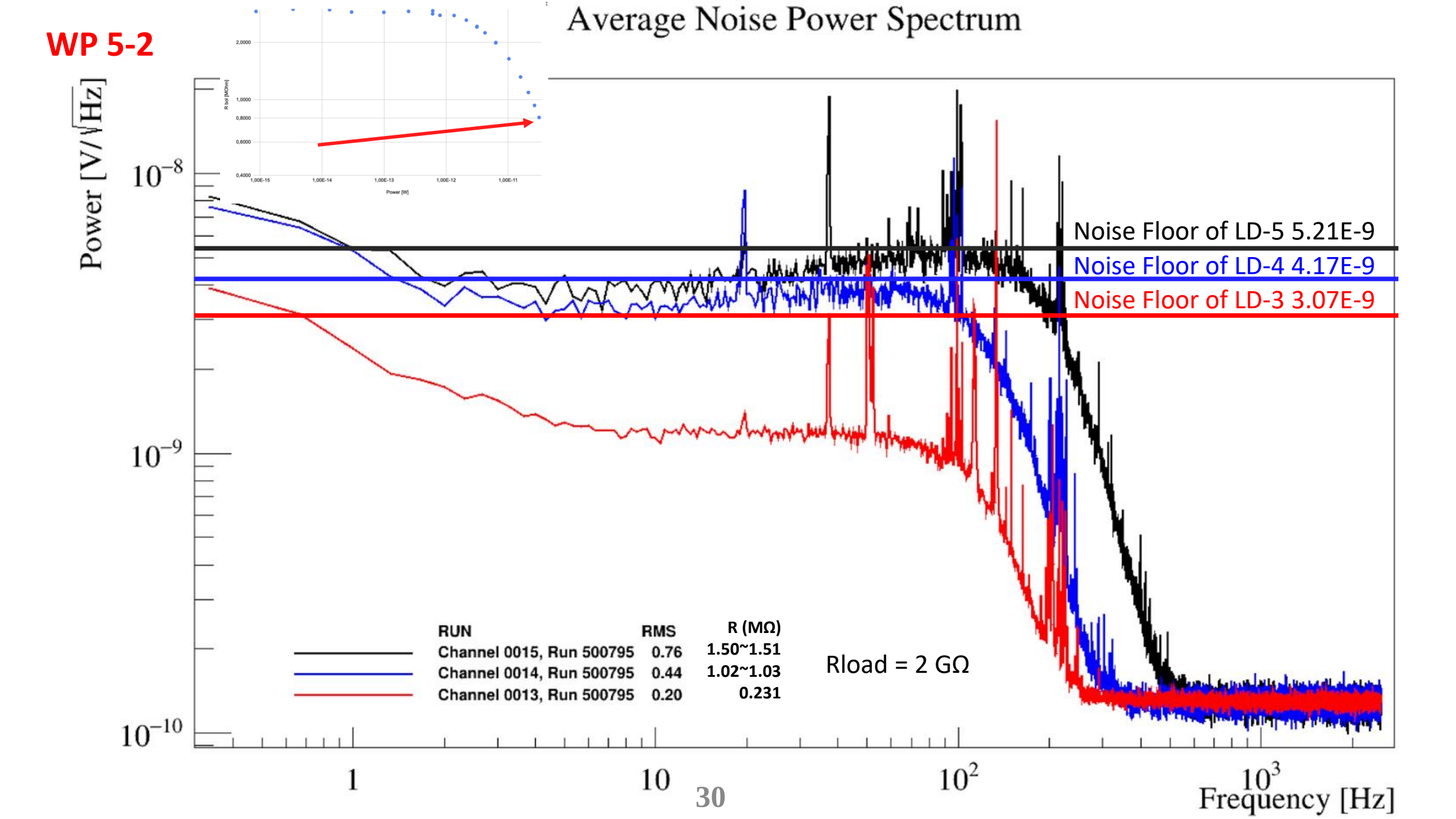
WP 4-2

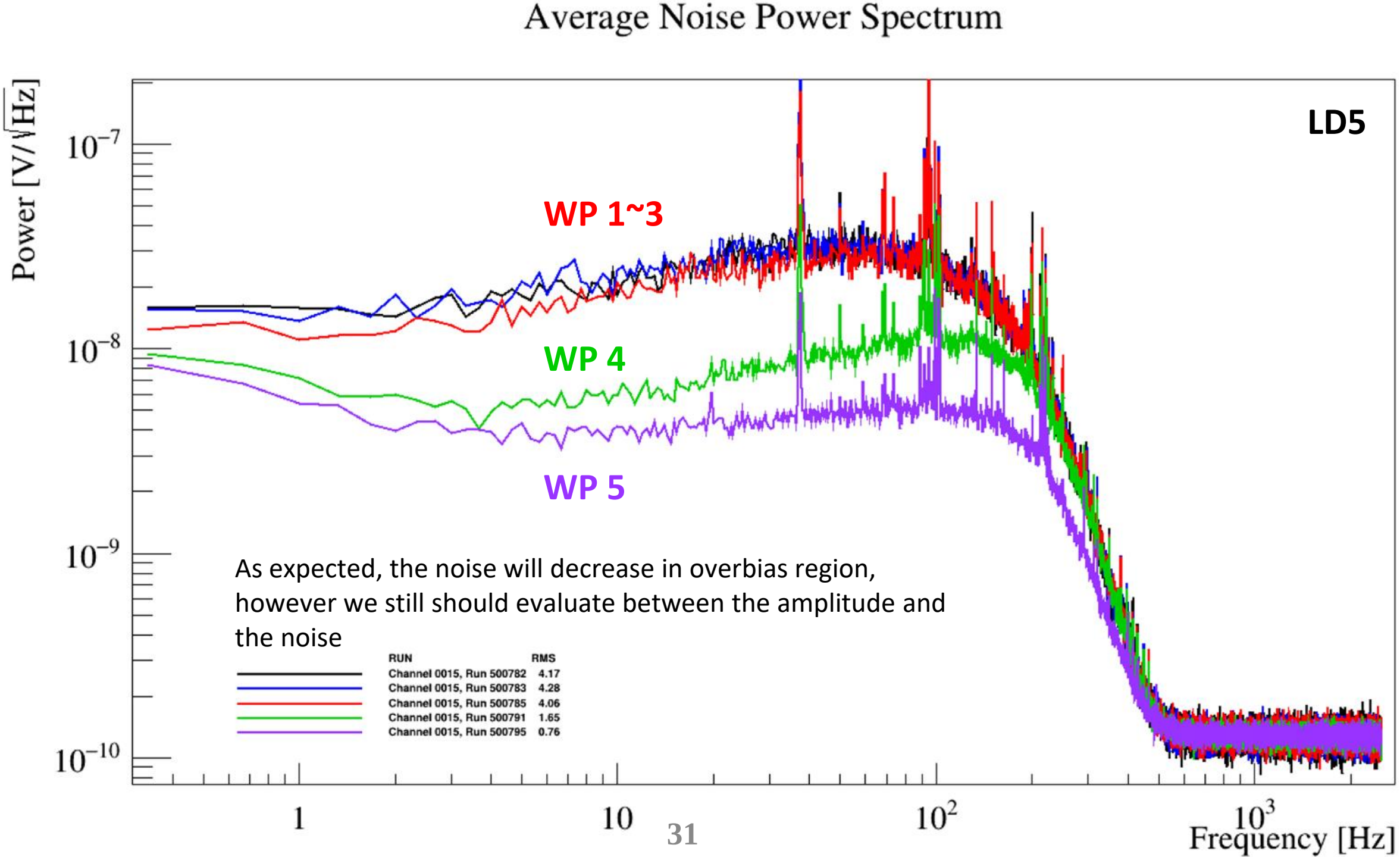

Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
Noise Floor of LD-5 6.28E-9
Noise Floor of LD-4 4.41E-9
Noise Floor of LD-3 3.06E-9
RUN RMS R (MΩ)
Channel 0015, Run 500791 1.65 1.95~1.96
Channel 0014, Run 500791 0.75 1.14
Channel 0013, Run 500791 0.27 0.211~0.212
Rload = 2 GΩ
R bol [MOhm]
Power [W]

WP 5-1


Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
band width due to temp drifts
Noise Floor of LD-5
4.11~5.21E-9
Noise Floor of LD-4
3.55~4.17E-9
Noise Floor of LD-3
3.04~3.07E-9
RUN RMS R (MΩ)
Channel 0015, Run 500793 0.81 0.994~1.50
Channel 0014, Run 500793 0.47 0.674~1.02
Channel 0013, Run 500793 0.22 0.164~0.231
Rload = 2 GΩ
R bol [MOhm]
Power [W]

WP 5-2


Average Noise Power Spectrum
Power [V/√Hz]
Frequency [Hz]
Noise Floor of LD-5 5.21E-9
Noise Floor of LD-4 4.17E-9
Noise Floor of LD-3 3.07E-9
RUN
RMS
R (MΩ)
Channel 0015, Run 500795 0.76 1.50~1.51
Channel 0014, Run 500795 0.44 1.02~1.03
Channel 0013, Run 500795 0.20 0.231
Rload = 2 GΩ
R tot [MOhm]
Power [W]


Average Noise Power Spectrum
Power [V/√Hz]
10^{-7}
10^{-8}
10^{-9}
10^{-10}
LD5
WP 1~3
WP 4
WP 5
As expected, the noise will decrease in overbias region, however we still should evaluate between the amplitude and the noise
RUN RMS
Channel 0015, Run 500782 4.17
Channel 0015, Run 500783 4.28
Channel 0015, Run 500785 4.06
Channel 0015, Run 500791 1.65
Channel 0015, Run 500795 0.76
1
10
10^2
10^3
Frequency [Hz]

Conclusions

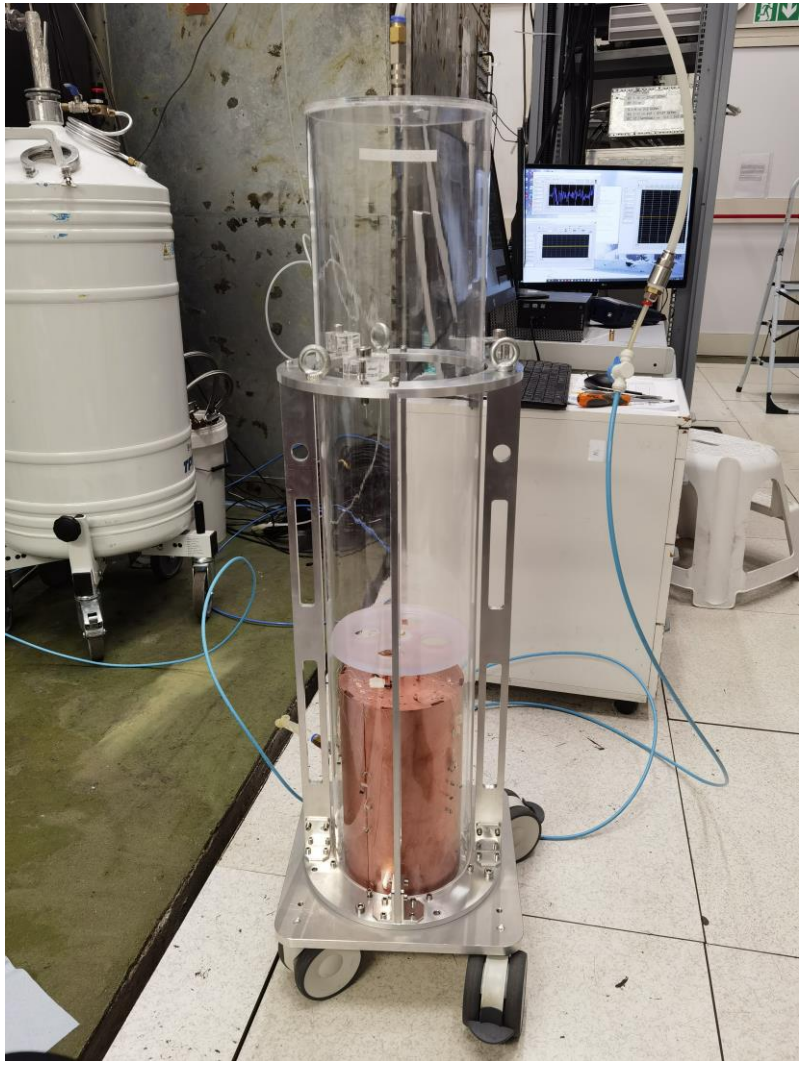
- Light Yield value agrees with previous measurements
- Detectors are not well thermalized resulting in low intrinsic gain
- For LD4 and LD5, they fit the noise floor for most of the time (except for Rload = 27GΩ)
- LD3's noise is always lower than the noise floor (ch13's GND check is not working)
- Noise of the detectors is at the minimum possible level (no additional sources of noise)

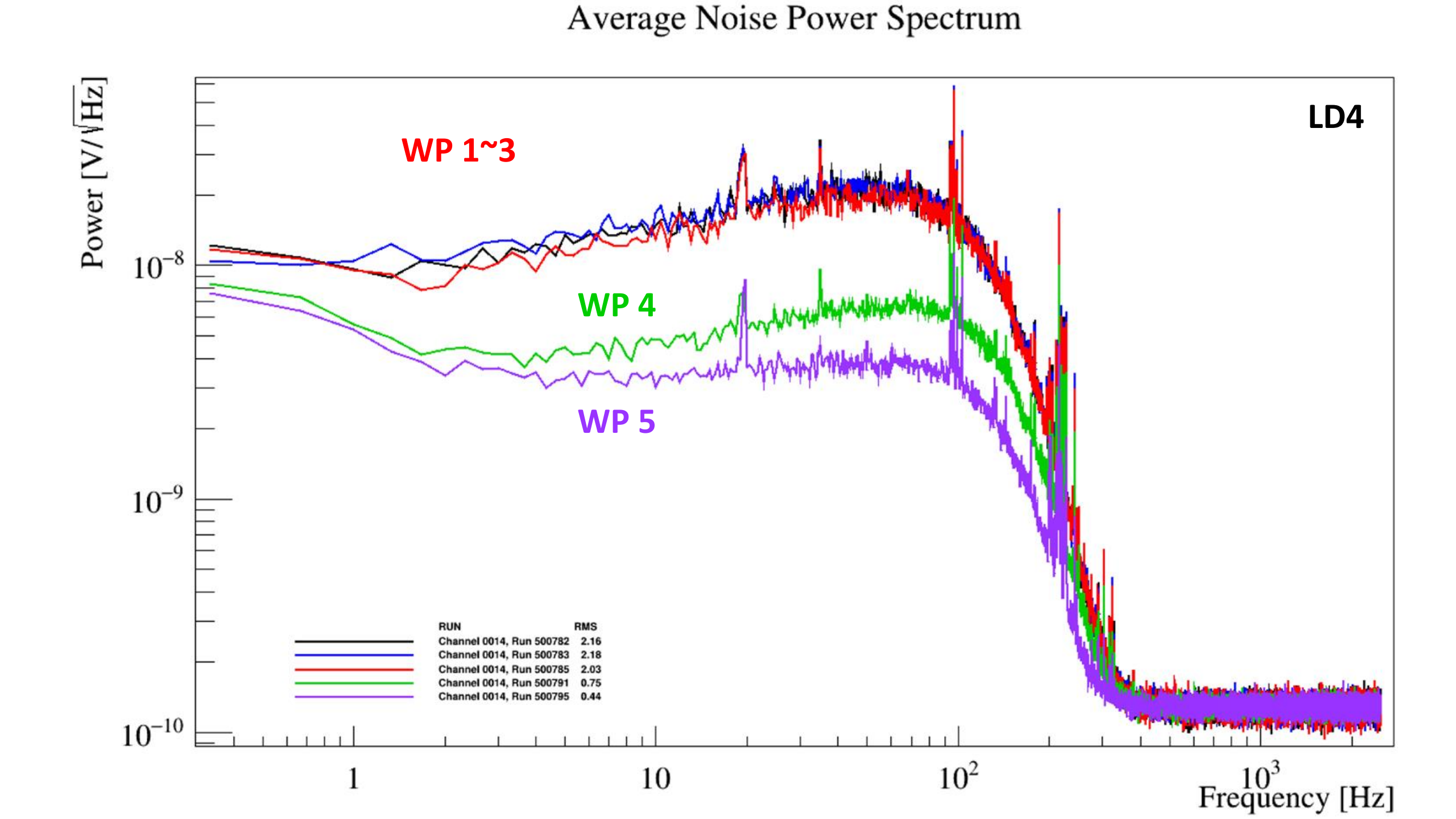
Future Plan

- Check the readout electronic board
  - Is the Rolad in the correct value?
  - ch13's GND check
- Analysis
  - complete analysis of CCVR run
  - estimate the level of contaminants (working on it)
- Next CCVR run will test Chinese crystals
  - 4 crystals under installation

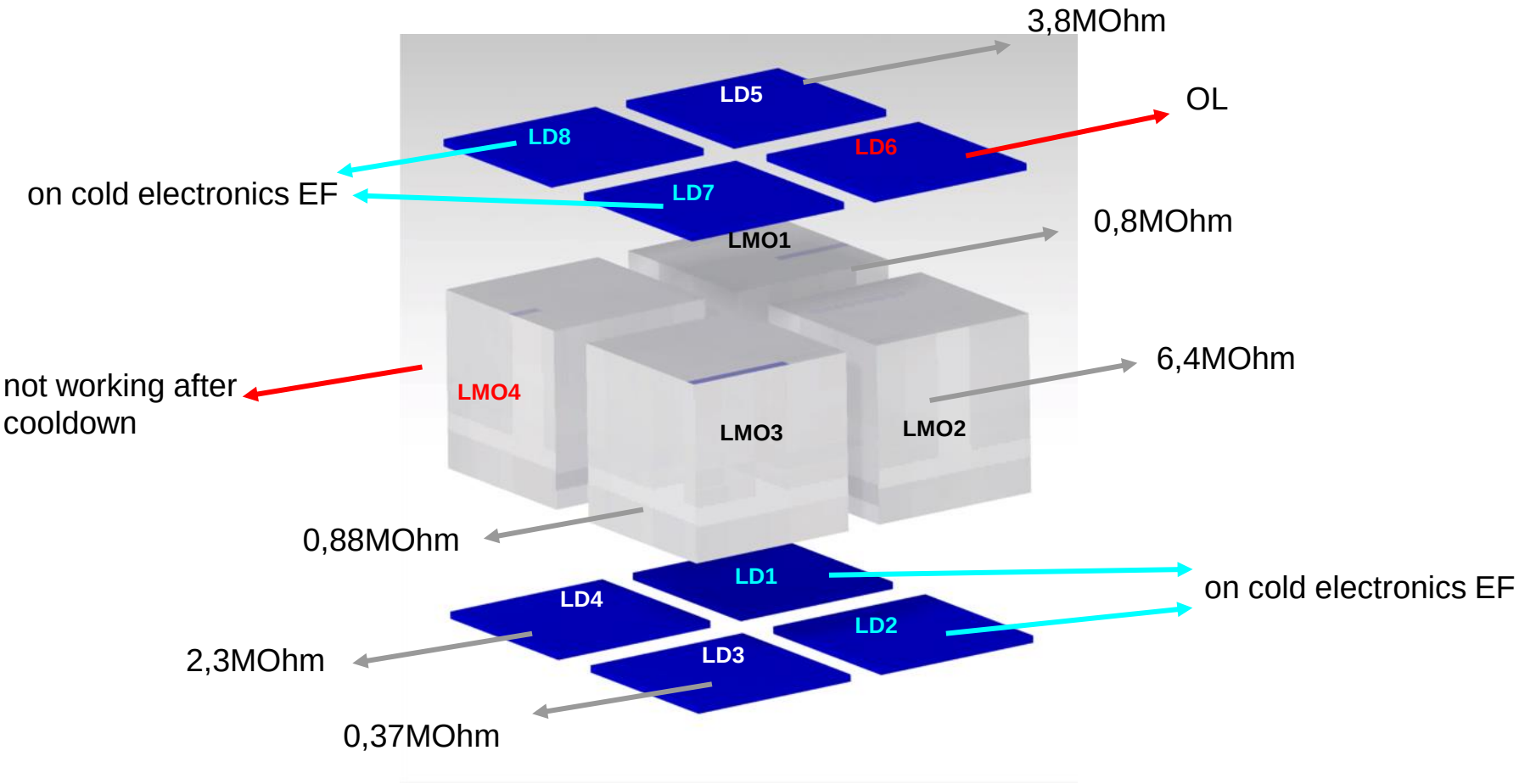
Thanks

Open the cryostat

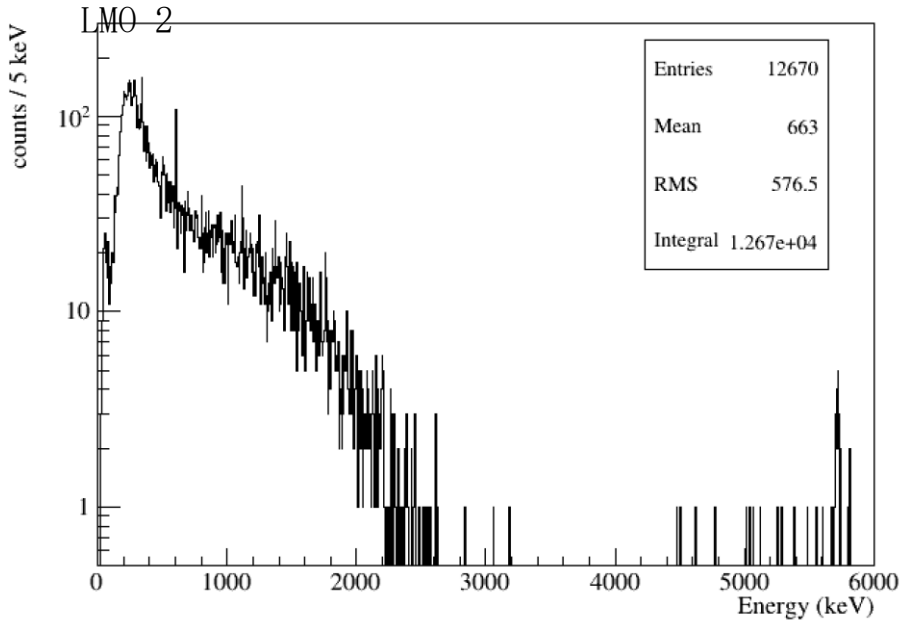



Average Noise Power Spectrum
LD4
WP 1~3
WP 4
WP 5
Power [V/√Hz]
10^{-8}
10^{-9}
10^{-10}
1
10
10^{2}
10^{3}
Frequency [Hz]
RUN RMS
Channel 0014, Run 500782 2.16
Channel 0014, Run 500783 2.18
Channel 0014, Run 500785 2.03
Channel 0014, Run 500791 0.75
Channel 0014, Run 500795 0.44

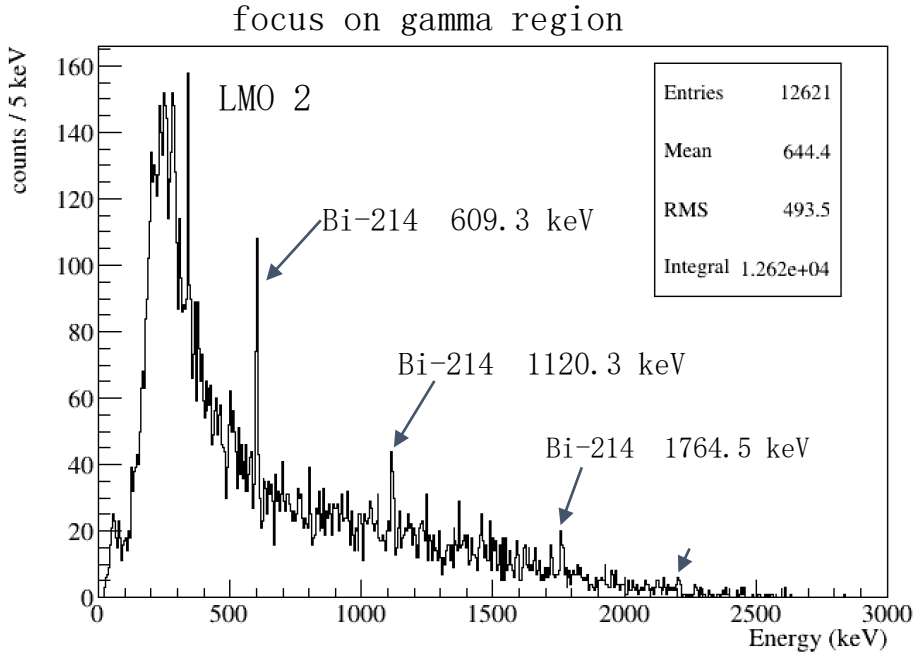
Detectors: 3 LMOs + 3 LDs



Background spectrum



Around **20 days of background** without Bad Intervals



contaminants from the U-238 chain

Detector	**LMO-1**	**LMO-2**	**LMO-3**
Cuts efficiency	~ 78 %	~ 74 %	~ 85 %