~ P T O L E M Y ~
HV stabilization system

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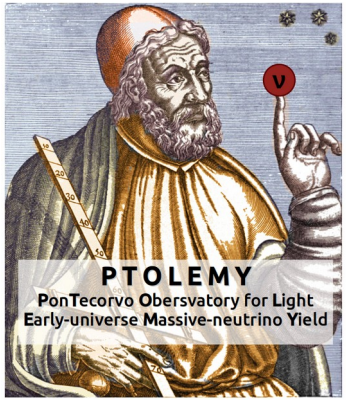
On behalf of LNGS Group



PTOLEMY Collaboration Meeting
Zandvoort aan Zee, 2022, October 6-7

Motivations and goals

Tritium end point 18.6 keV → order of 20kV electric field to slow electrons down to ~100 eV (TES redout)

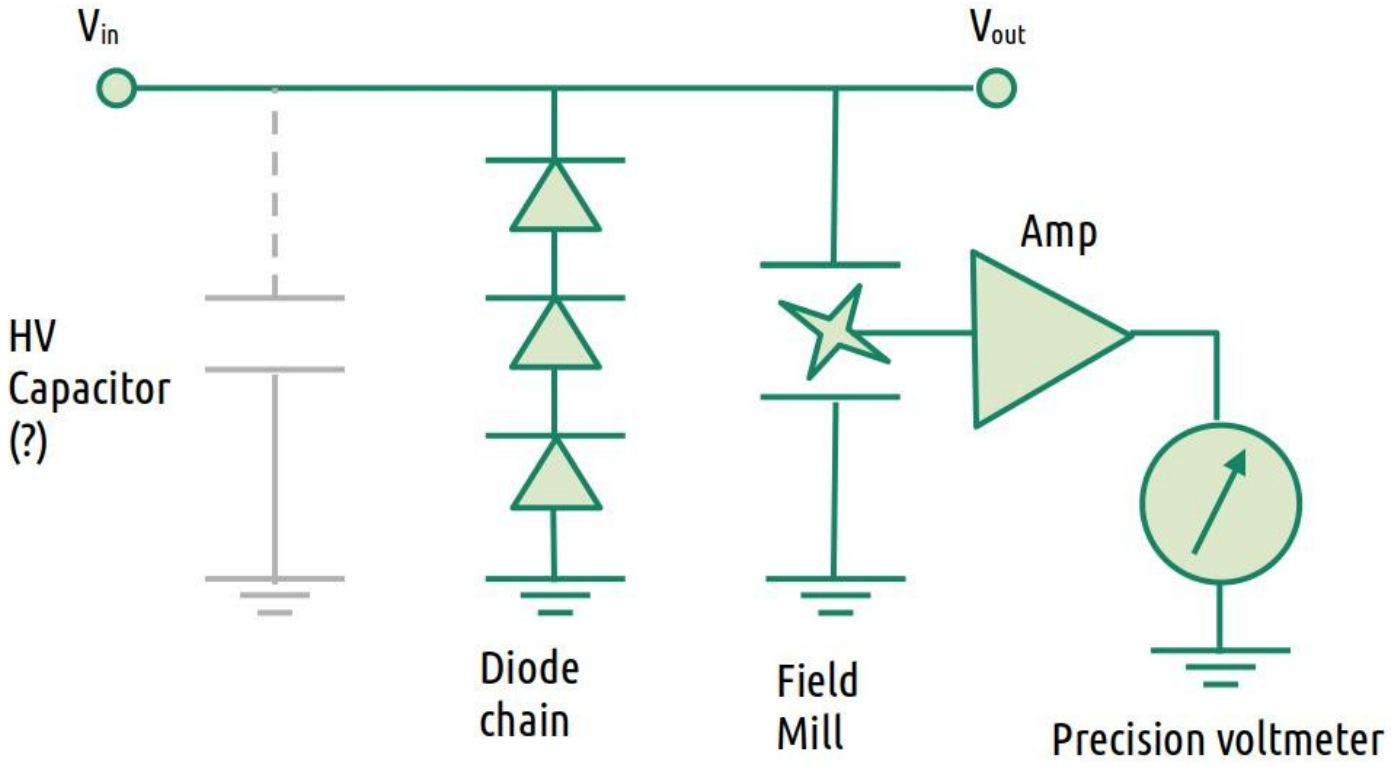
Resolution δE ~ δV: for δE ~ 50 meV requires δV better than ~10 mV over 20 kV Stability
$\delta V/V \sim 0.5 \times 10^{-6}$

Strategies:

- HV capacitors
- high precision voltage reference diodes
- combination of the two (?)

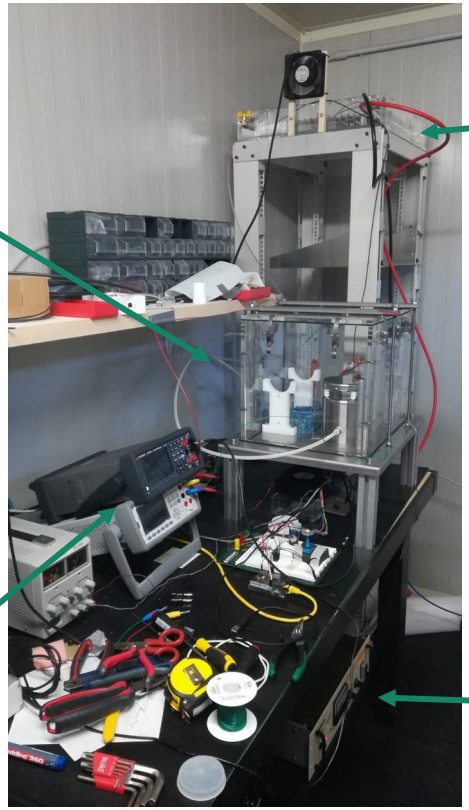
Field (Voltage) readout:
Non invasive Field Mill technology

Setup scheme

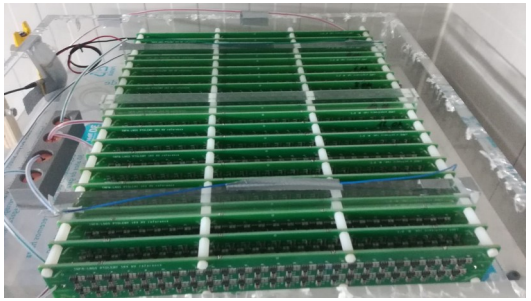


Basic experimental setup (old config)

Field mill box



Diodes box



High precision voltmeter
Keysight®

Power supply
Bertan®

Experimental Campaign

(over 95 long runs with THP sensors)

- **Campaign I: HdM with high voltage capacitors**
  → low noise, air conditioning, N2 purging
- **Campagin II: Underground, DarkSide Area, capacitors**
  → noisy, grounding issue, Hall C conditioning,N2 purging
- **Campaing III: Undergound, Mosca-B area, capacitors**
  → noisy, grounding issue, Hall C conditioning, N2 purging
- **Campaing IV: HdM, capacitors & diods**
  → moderate noise, new sensors added, air conditioning
  + local fans, N2 purging
- **Campaign V: high precision stability, climatic chamber** NEW

Ptolemy HV Run D

	Run	Type	Date	Location	Heater	N2 flux	Capacitor
Campaign I	1	normal		HdM	off	off	yes
	2	normal		HdM	off	off	yes
	3	junk		HdM			yes
	4	junk		HdM			yes
	5	normal		HdM	off	off	yes
	6	test		HdM			yes
	7	normal		HdM	on	on	yes
	8	test	15 feb 2021	HdM	on	off	yes
	9	junk		HdM			yes
	10	normal	22 feb 2021	HdM	on	on	yes
	11	test	22 feb 2021	HdM	on	on	yes
	12	normal	23 feb 2021	HdM	on	on	yes
	13	normal	25 feb 2021	HdM	on	on	yes
	14	junk		HdM			yes
	15	junk		HdM			yes
	16	normal	27 feb 2021	HdM	on	on	yes
	17	junk		HdM			yes
	18	normal	01 mar 2021	HdM	on	on	yes
	19	junk		HdM			yes
	20	junk		HdM			yes
	21	junk		HdM			yes
	22	junk		HdM			yes
	23	junk		HdM			yes
	24	normal	03 mar 2021	HdM	on	on	yes
	25	normal	03 mar 2021	HdM	on	on	yes
	26	test		HdM			yes
	27	normal	5 mar 2021	HdM	on	on	yes
	28	unknonw		HdM			yes
Campaing II	29	normal	18 mar 2021	DS10 platform	off	on	yes
	30	test		DS10 platform			yes
	31	normal	19 mar 2021	DS10 platform	off	on	yes
	32	test		DS10 platform			yes
	33	test		DS10 platform			yes
	34	test		DS10 platform			yes
	35	background		DS10 platform			yes
	36	unknown		DS10 platform			yes
	37	unknown		DS10 platform			yes
	38	unknown		DS10 platform			yes
	39	unknown		DS10 platform			yes
	40	normal		DS10 platform	off	on	yes
	41	unknown		DS10 platform			yes
Campagin III	42	normal	10 may 2021	Mosca-B	off	on	yes
	43	normal	07 jun 2021	Mosca-B	off	on	yes
	44	junk		Mosca-B			yes
	45	normal	07 jun 2021	Mosca-B			yes
Campaign IV	46	test		HdM			yes
	47	normal	20 jul 2021 (?)	HdM	on	on	yes
	48	normal	27 otl 2021	HdM	on	on	yes
	49	normal		HdM	on	on	yes
	50	normal		HdM	n.a.	n.a.	yes
	51	normal		HdM	n.a.	n.a.	yes
	52	normal		HdM	n.a.	n.a.	yes
	53	normal		HdM	n.a.	n.a.	yes
	54	normal		HdM	n.a.	n.a.	
	55	test		HdM			
	56	test		HdM			
	57	test		HdM			
	58	test		HdM			
	59	test		HdM			
	60	test		HdM			
	61	test		HdM			

Measures and Analysis

HV readout (Field mill or direct)

- Keysight voltmeter 6.5 digits
- Keysight voltmeter 7.5 digits
- LeCroy 12 bit oscilloscope

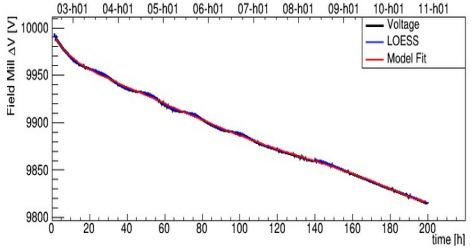
Sensor redout

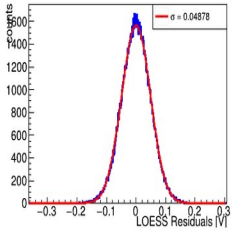
T1: Field mill plexiglass box
T2: Field mill plexiglass box
T3: Motor cage (recent)
T4: diode chip
P1: Field mill plexiglas box
P2: Motor cage
H: Field mill plexiglass box

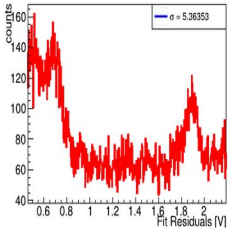
Analysis

- Residuals WRT local regression smoothing (model independent)
- Residuals WRT polynomial fit
- Sensors' correlation
- Fast fourier transform
- Digital filtering

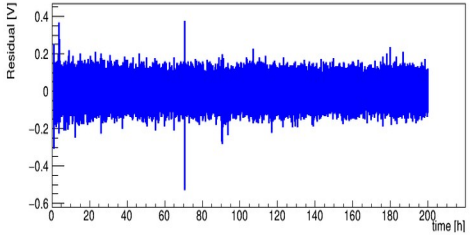
Capacitor (700 μF) only measurement

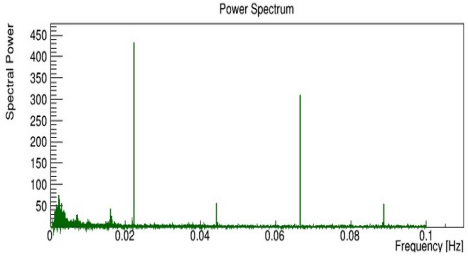


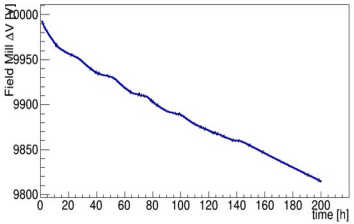


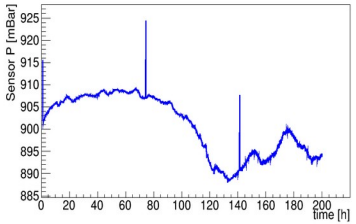


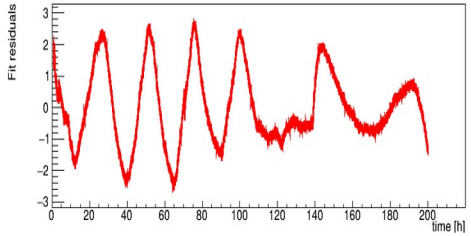
– decay issue
– strong dependence upon temperature
– 0.02 Hz oscillation (largely investigated)
– spikes (unknown origin)

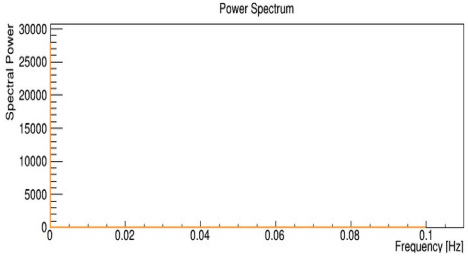


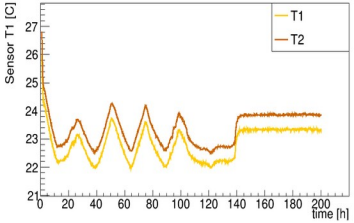


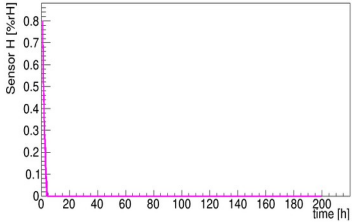




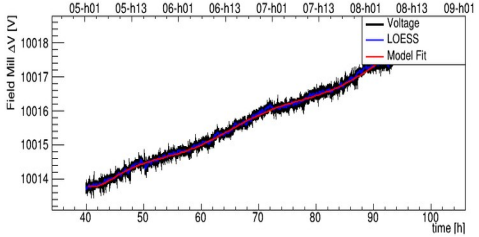


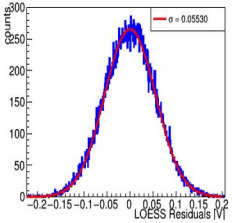


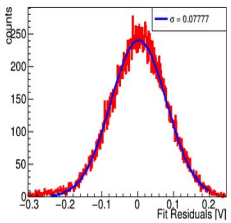




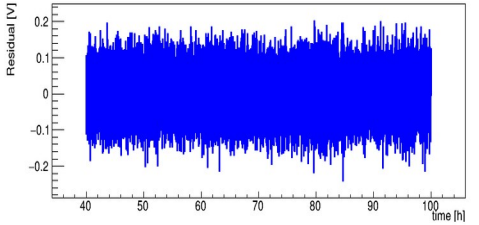
Capacitor + diodes

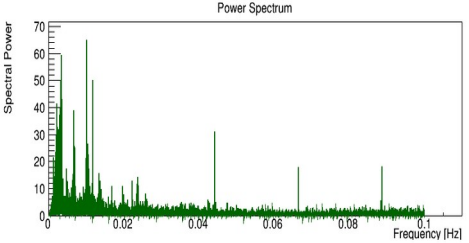


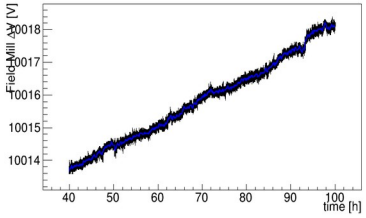


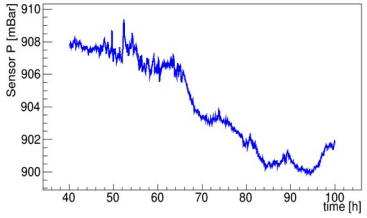


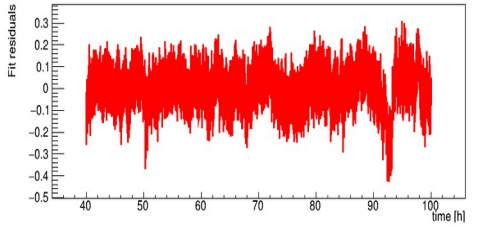
– trend driven by environmental parameters
– 50 mV resolution dominated by FM measurement
– spurious frequencies

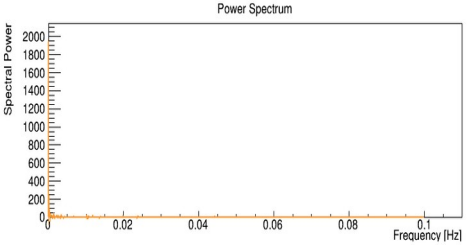


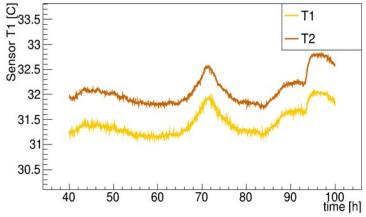


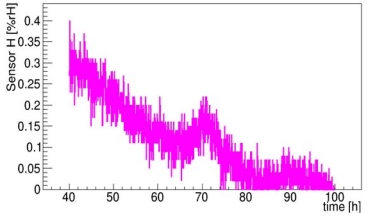




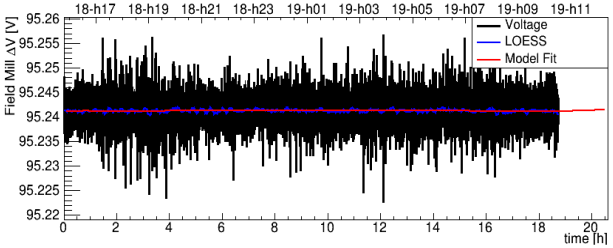


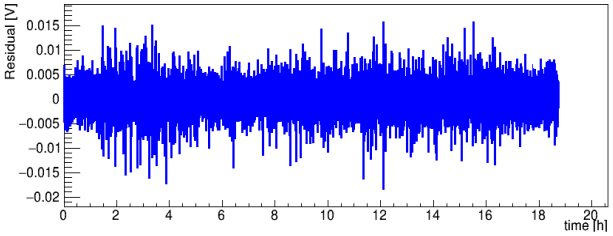


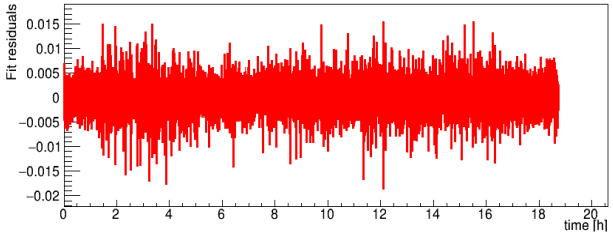


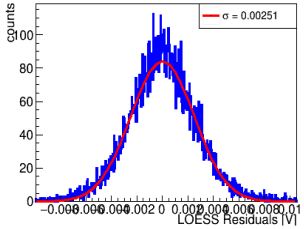


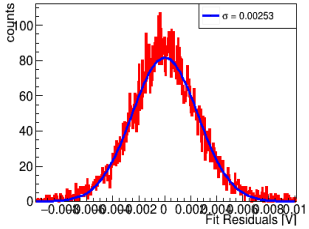
Field mill frequency-induced

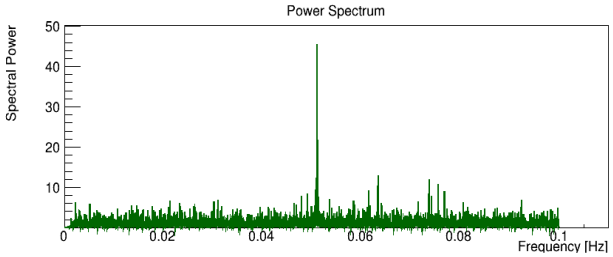


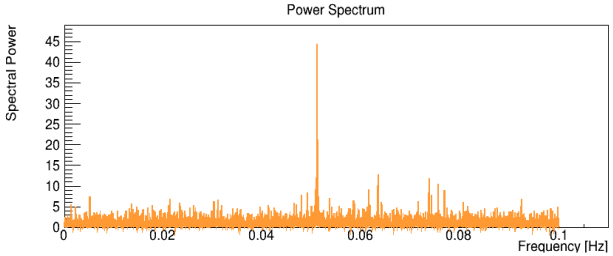








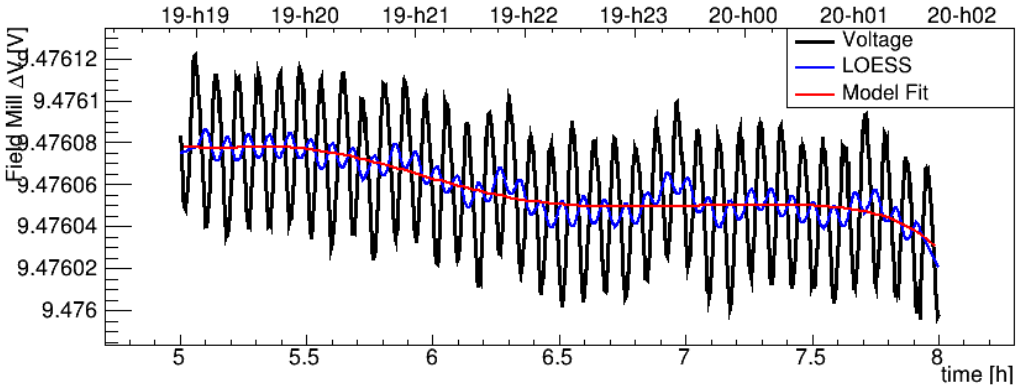




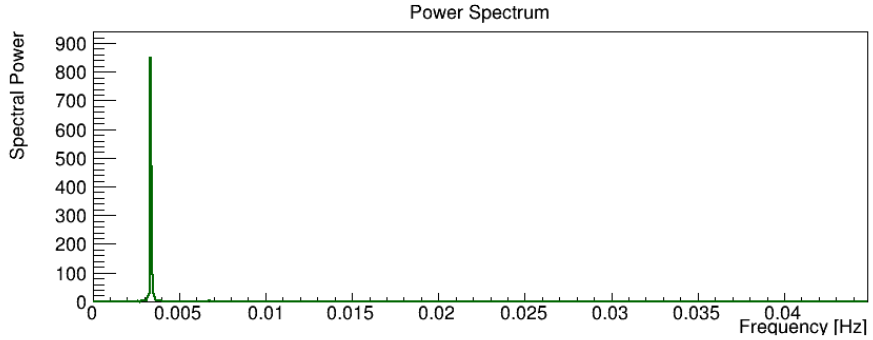
Long range oscillations seems not to depend on FM frequency instability

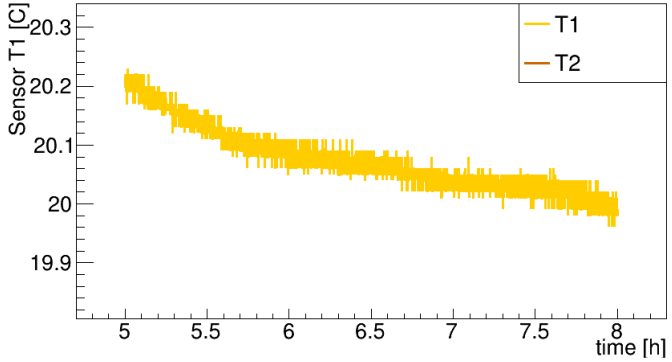
$\delta f/f \sim 2.5\ 10^{-7}$

Oscillation investigation: battery 9V

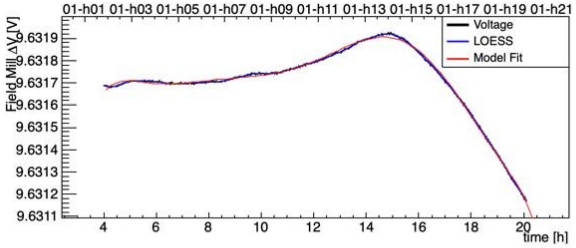


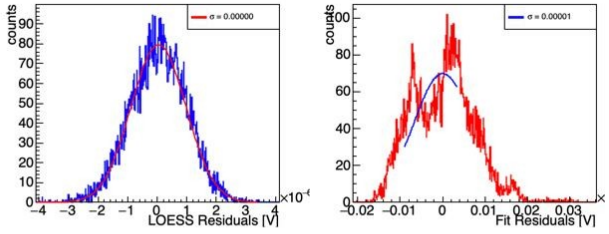
-- 3 mHz (5' period) frequency originated by the voltmeter self-calibration.
-- correlation with temperature
~ $\delta V/V \sim 10^{-5}$

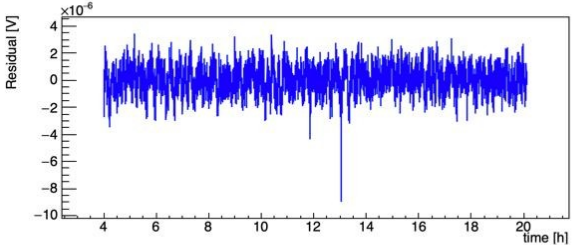


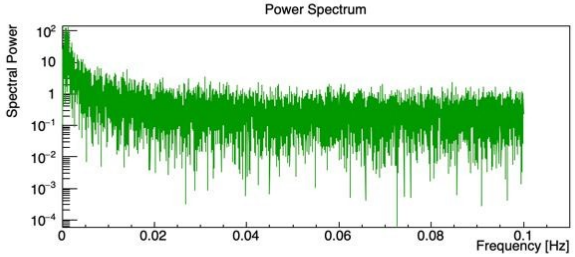


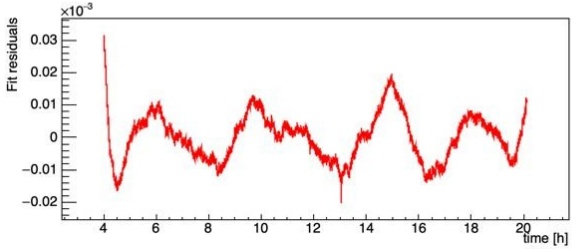
Battery with conditioning off

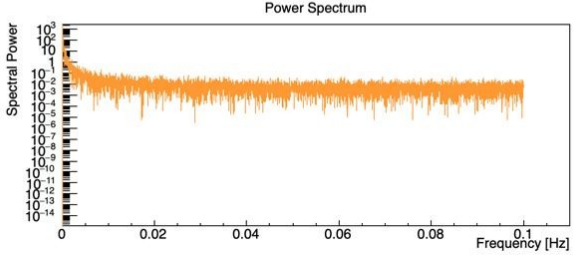










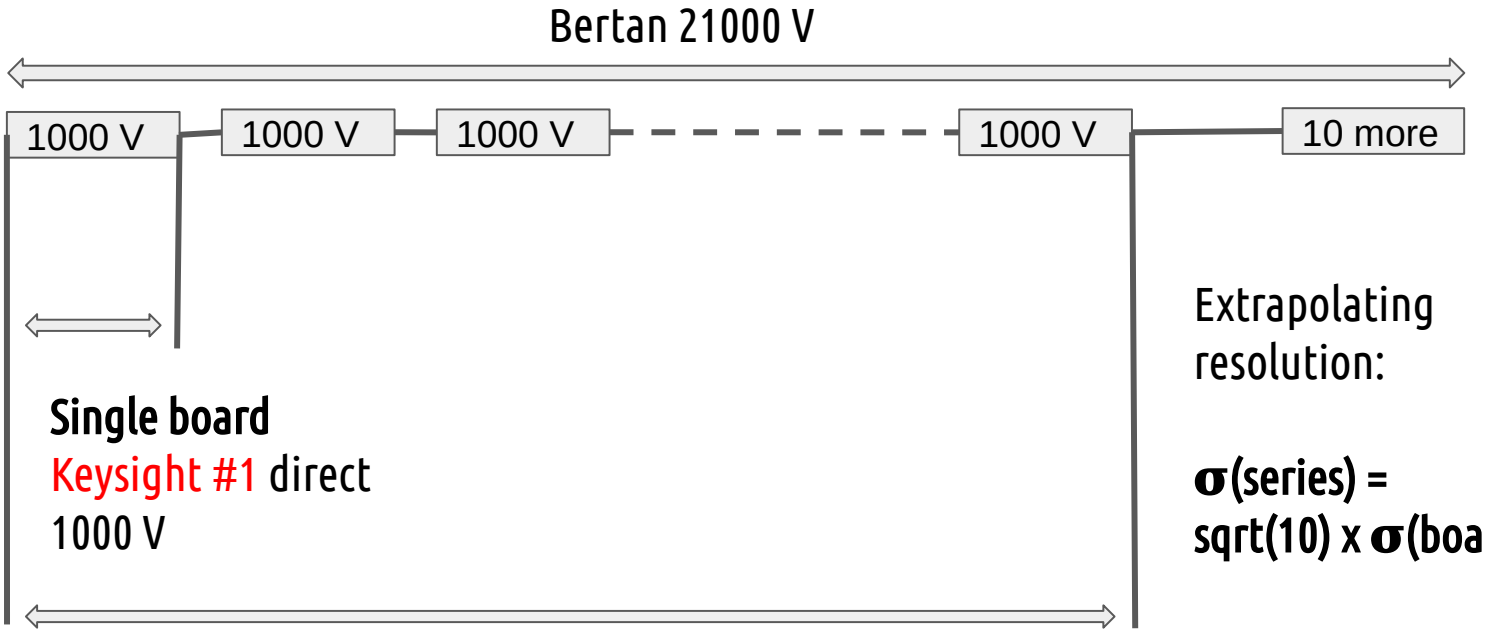


– 5’ sinusoidal oscillation absent

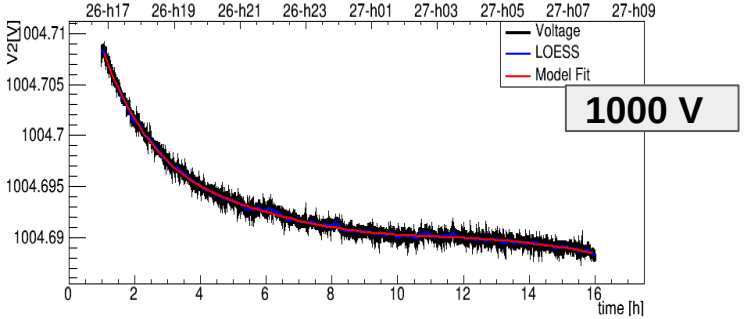
– the self-calibration of the Keysight is enhanced by the conditioning (???)

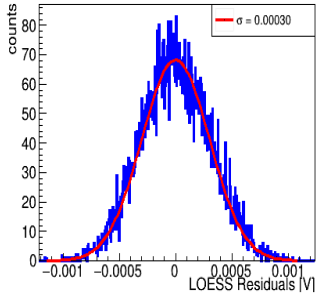
Thermal stabilization required requested!

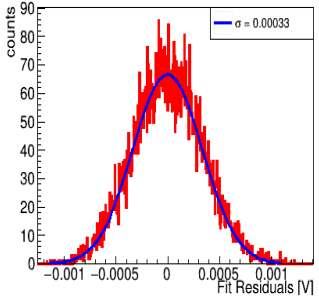
Investigating the diode intrinsic stability



Intrinsic diode resolution

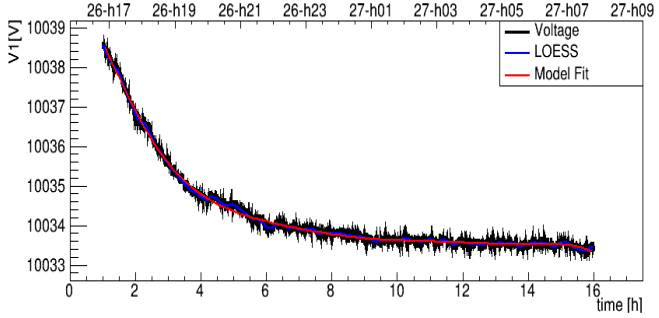


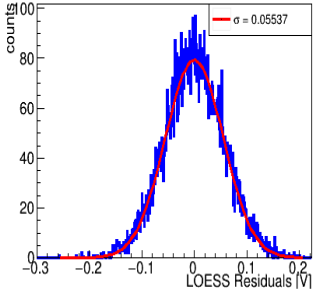


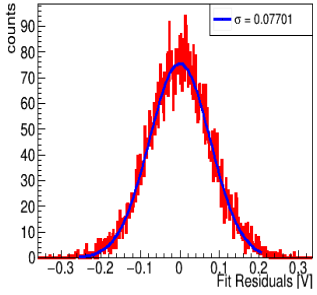


Single board

σ = 0.3 mV
(over 1000 V)







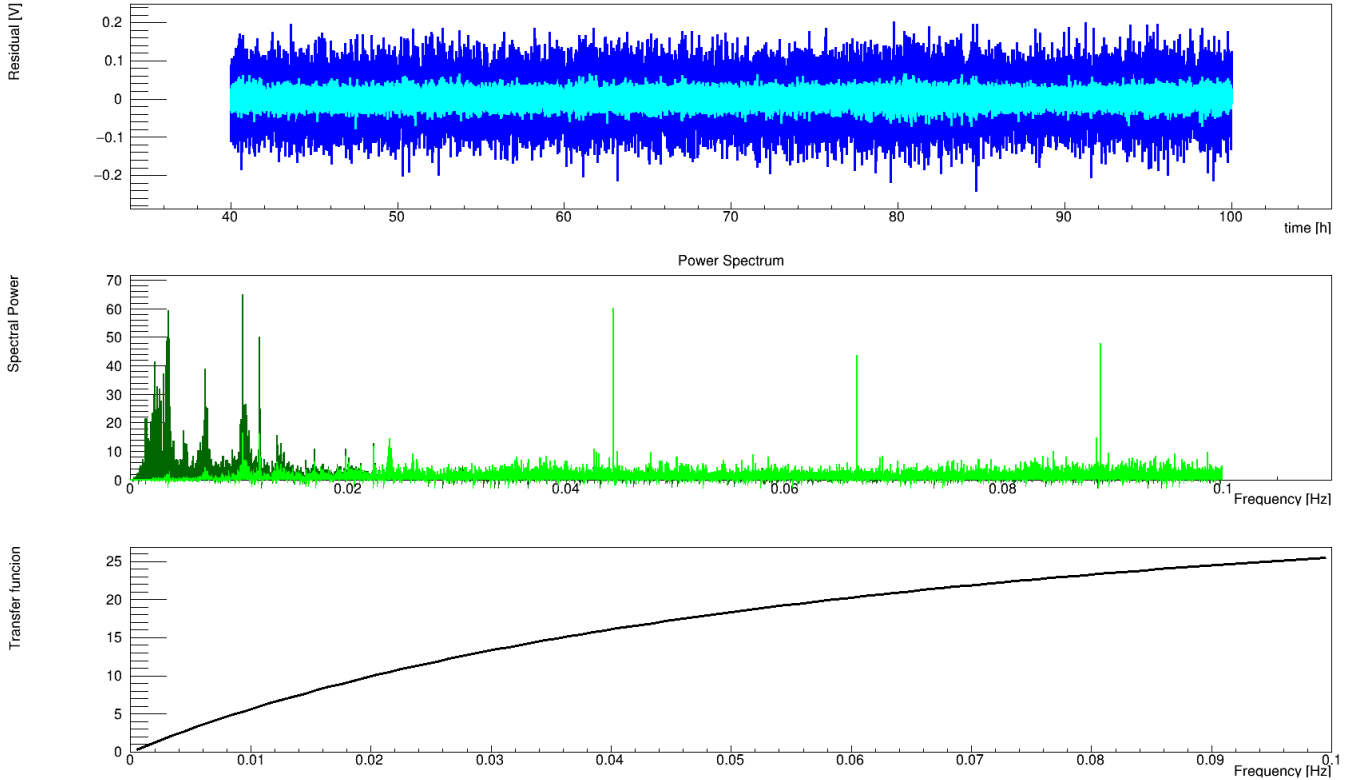
10 board series

sigma = 50 mV

σ(intrisic) = sqrt(10) x 0.3 ~ 1mV (<< 50 mV !!!)

The intrinsic resolution is way better than the present measurement method!!!

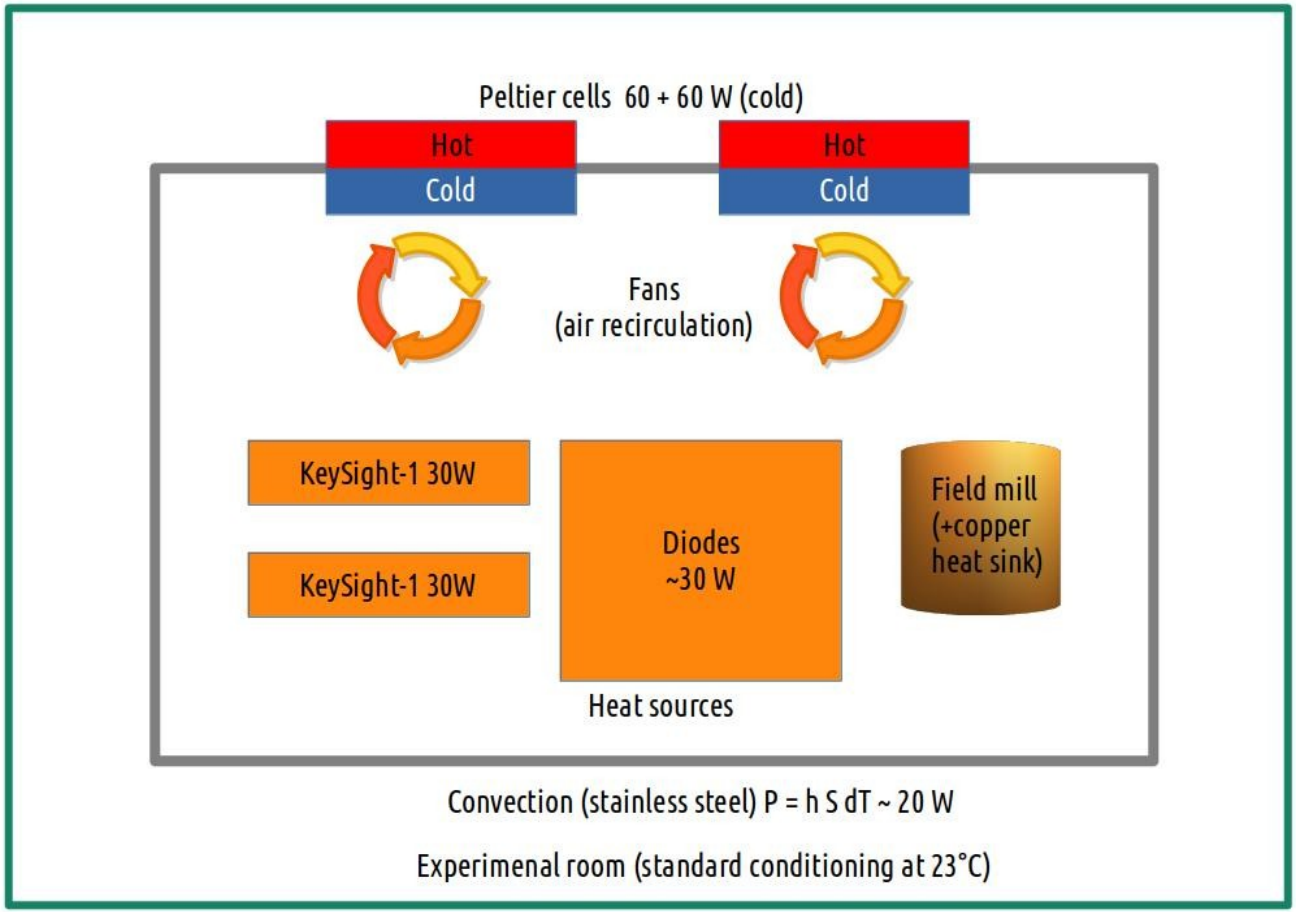
FTT and digital filtering



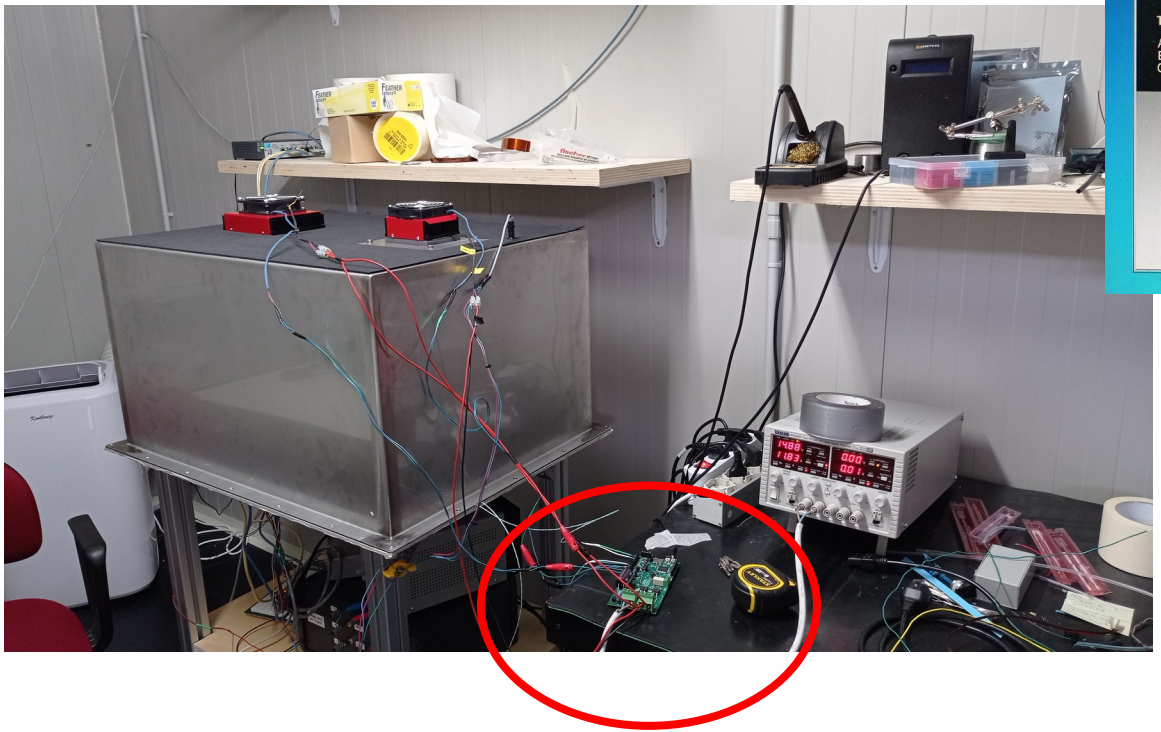
RC high pass digital filtering

A big component of the noise comes from the Keysight

Thermal stabilisation: climatic chamber (< 0.1 °C)



Climatic chamber

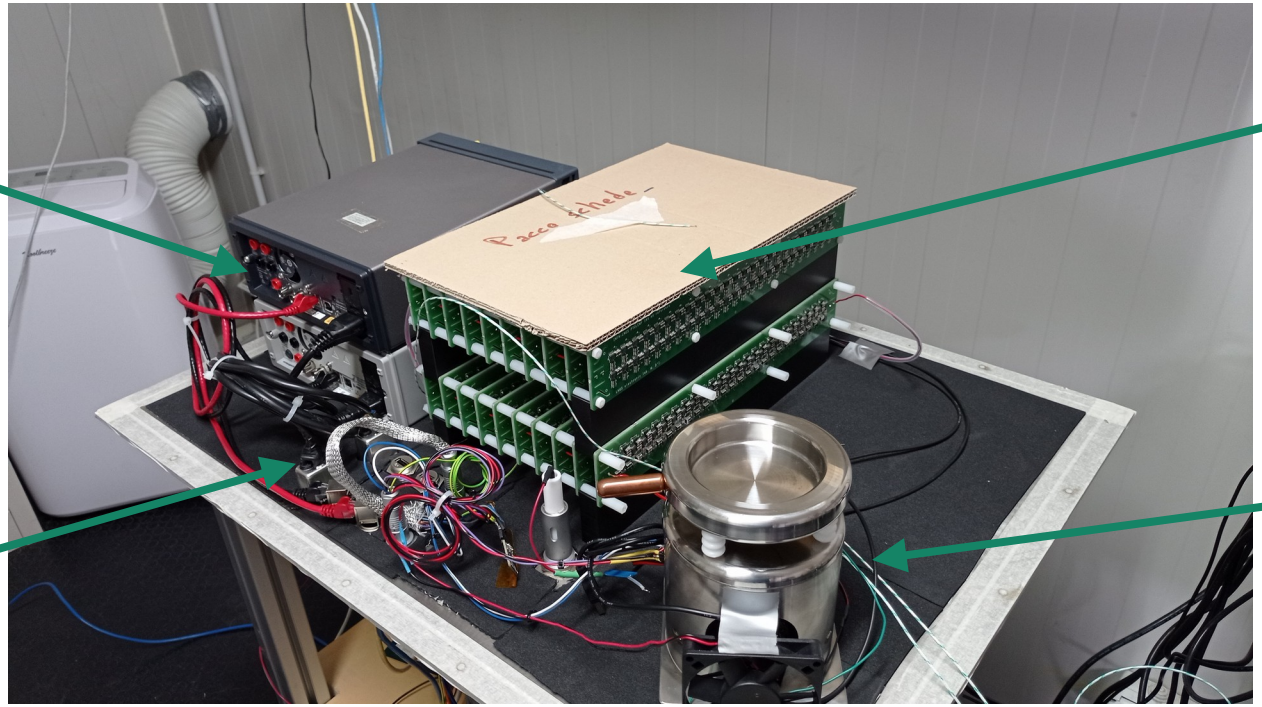


controller

Action: pulse-width modulation (Peltier current)

Mode:
-thermostat
- PID (manual)
- PID (auto)

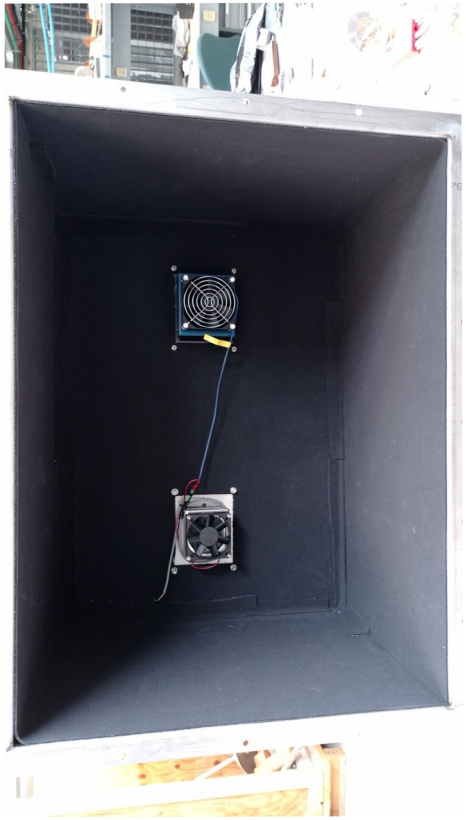
Inside the box: new set-up



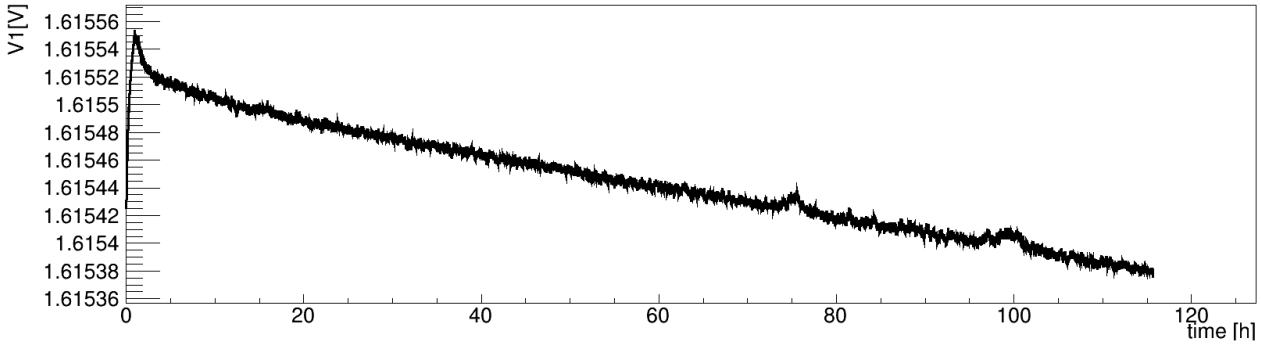
Inside the box: new set-up

Neoprene jacket installation

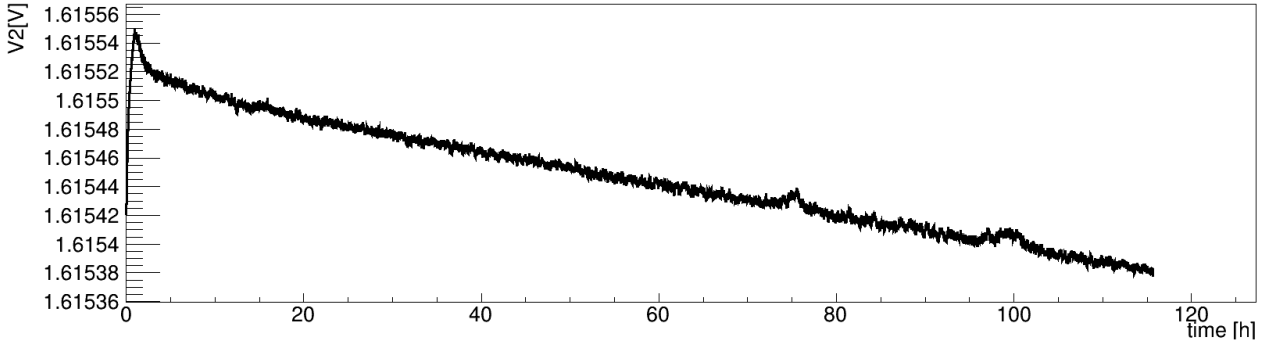
Climatic chamber commissioning at LNGS (Sep 2022)



Preliminary test 1: Battery 1.6 V

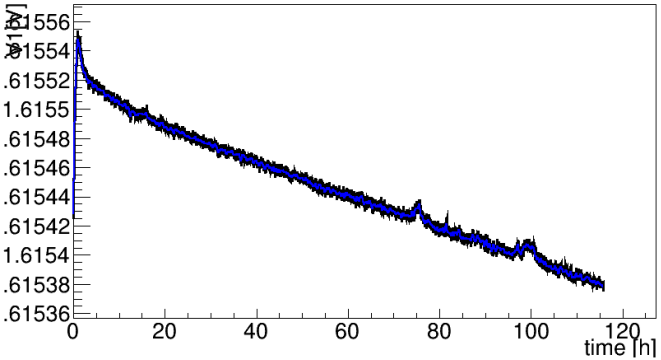


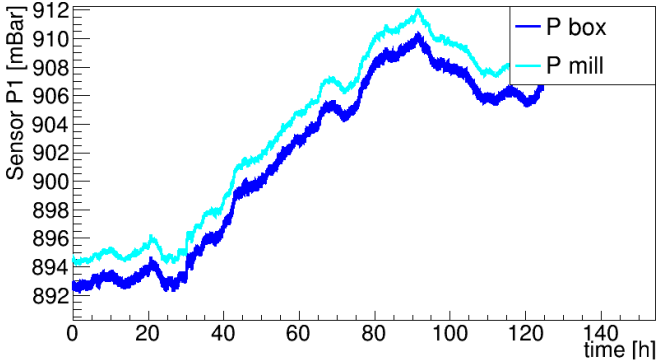
KeySight #1
Precision 6.5 digits

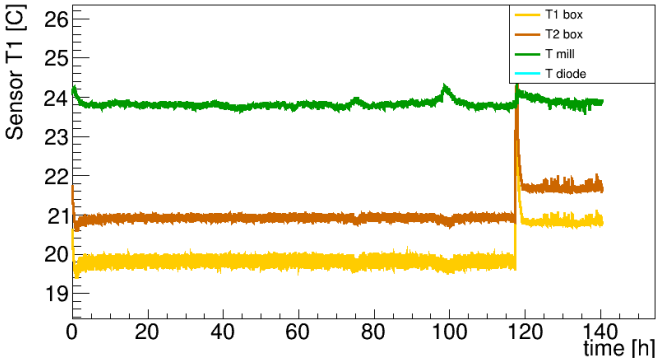


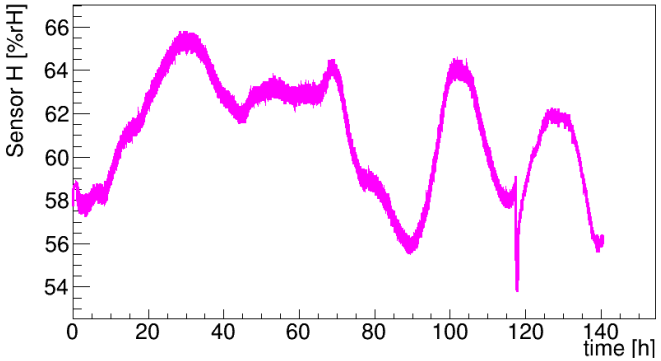
KeySight #1
Precision 7.5 digits

KeySight #1: V1









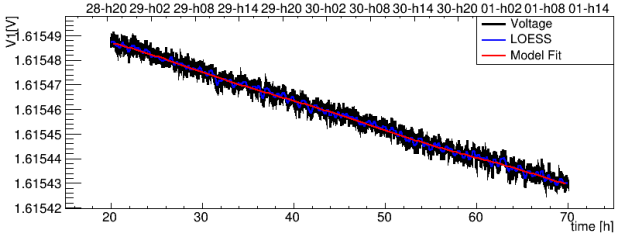
- thermostat mode

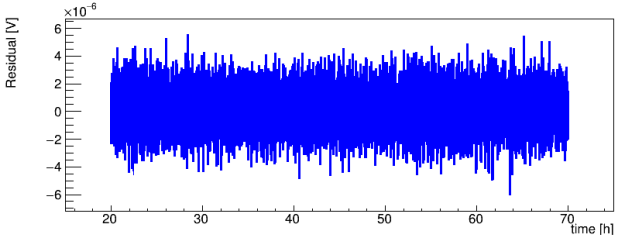
- stability within 0.1°C

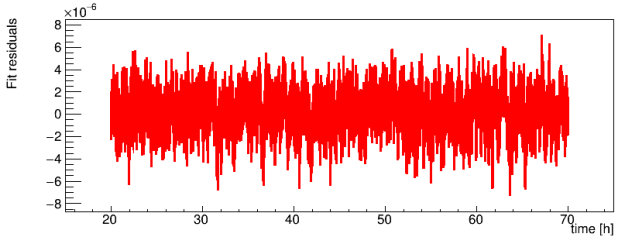
- correlation with temperature variation

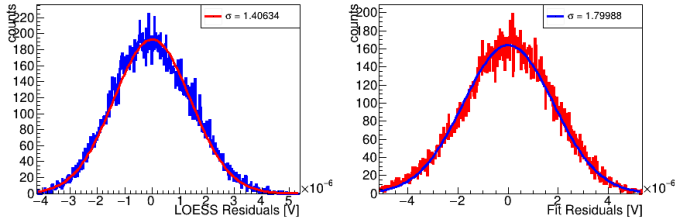
- no evident correlation with P and rH

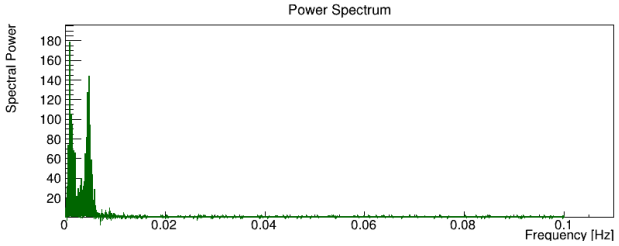
V1 Selection (stable subset)

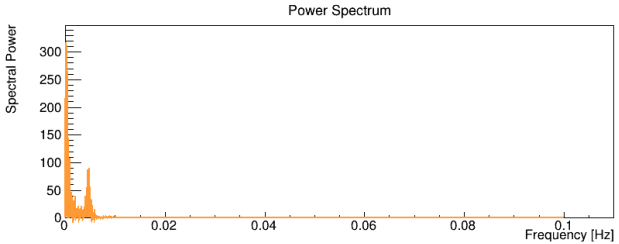










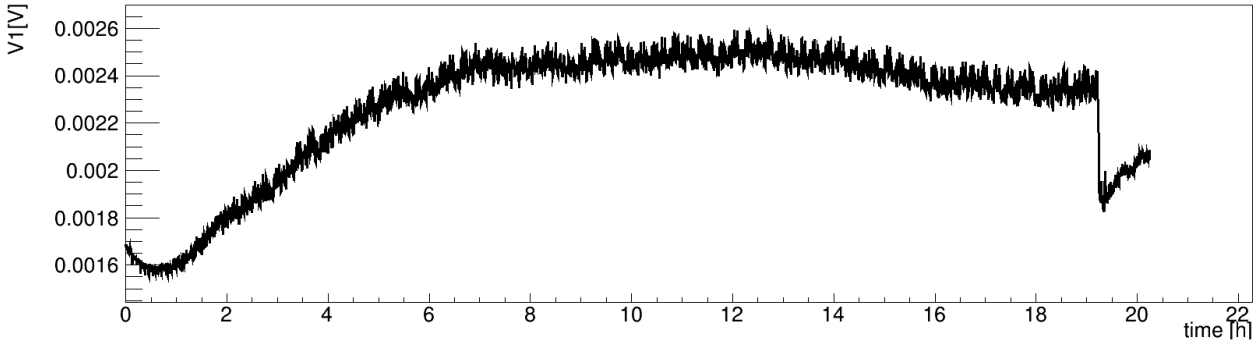


- Both V1 and V2 stable at $\delta \sim 7 \times 10^{-7}$

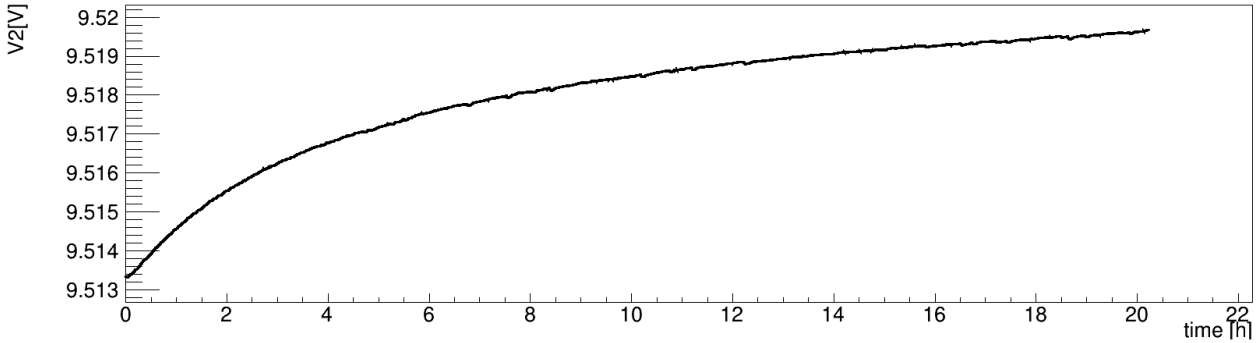
(→ 13 meV at 18.6 kV)

- 5' min spurious frequency still present, but less significant

Preliminary test 1: Battery 9 V + (null) field mill

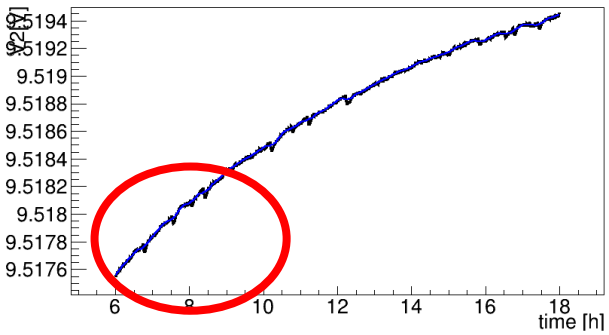


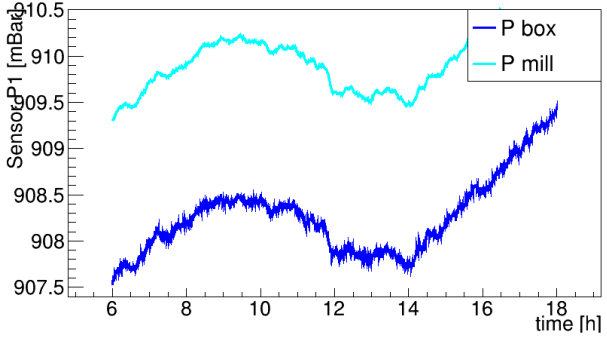
KeySight #2
(Null) field mill

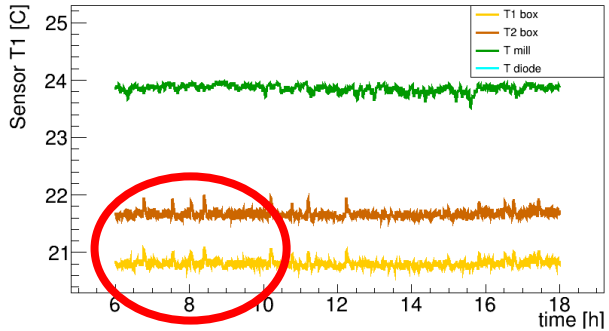


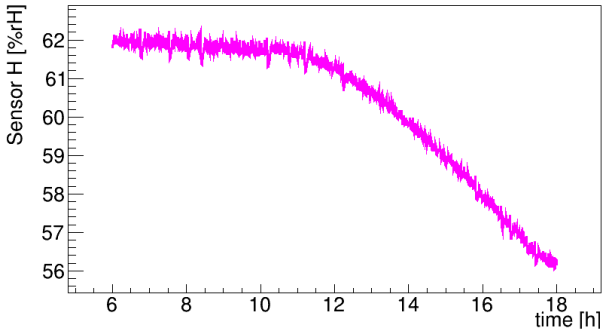
KeySight #1
Battery 9V

Environmental parameter correlation





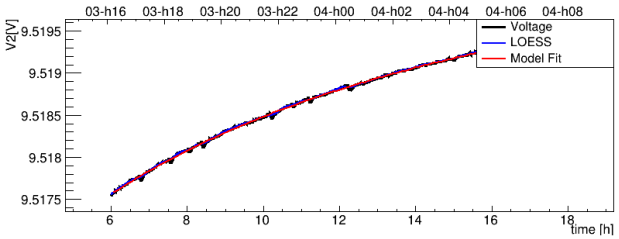


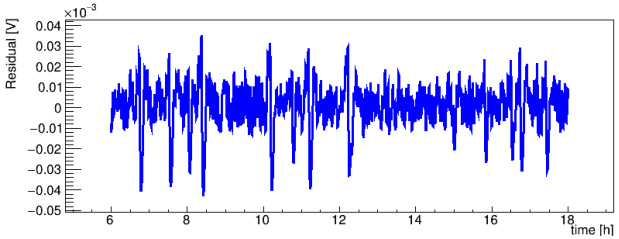


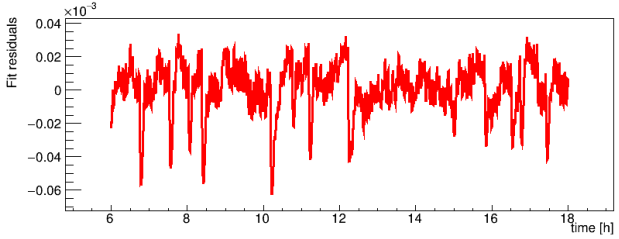
-- Correlation with very small temperature spikes (~0.1--0.3 °C)

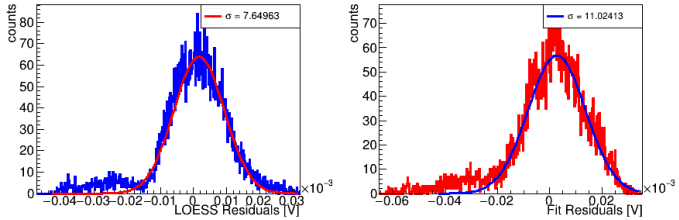
- PID instead of thermostat needed

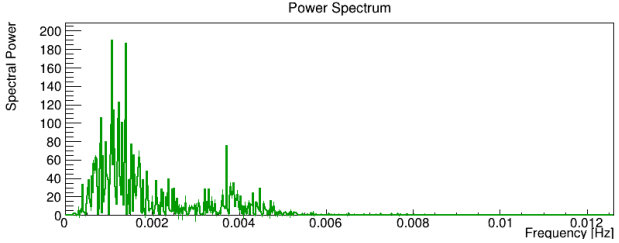
Battery 9V selection

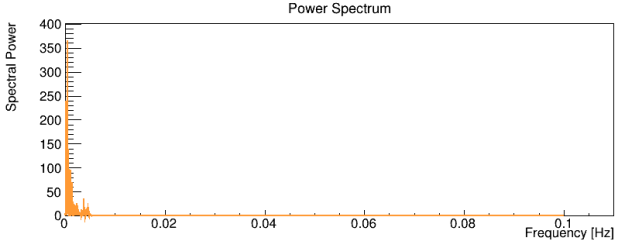








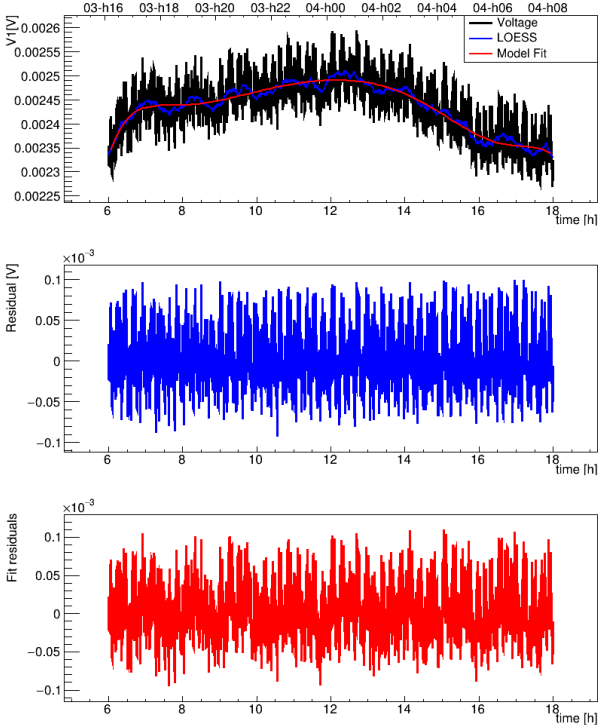


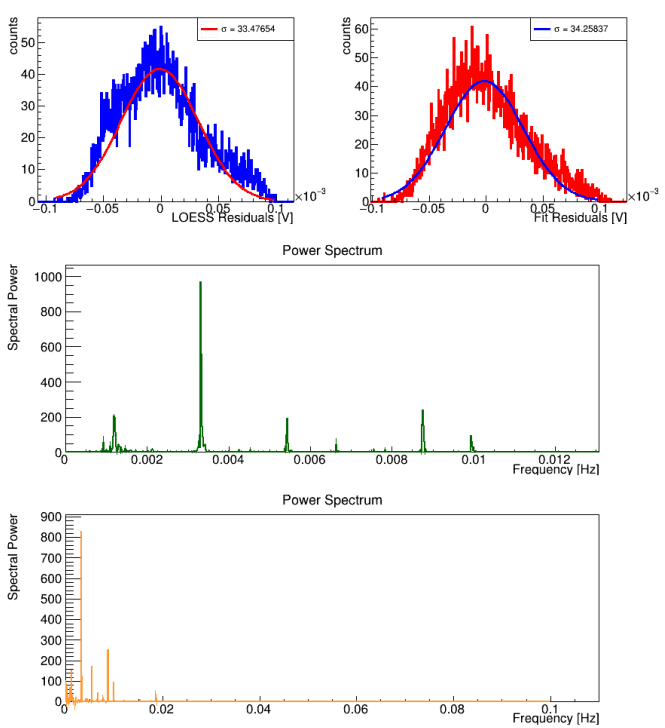


-- unless the temperature correlated spikes the resolution is comparable to first test (~7 uV over 9.4 V)

- 3 mHz frequency

Field mill selection





-- Noise dominated by 3 mHz (5') recalibration cycle

-- σ ~ 30 mV (largely affecting the amplified signal)

--to be investigated (with KeySight company)

Conclusions and Perspectives

- resent resolution of the diode ~50 mV, limited by the measurement method (factor 5 from the goal
- The intrinsic resolution of the diodes at 20 kV is ~ 1.4 mV (well below the requirement)
- Key requirements for reaching the goal **(climatic chamber):**
  – environmental parameter stabilization (dT ~ 0.1°C or better , stable pressure and humidity 0% (N2)) → to be improved with PID controller
  – Precision voltmeter self-calibration control investigation
- Next runs: HV on (5kV, 10kV, 20kV with N2)

Thank you very much!