Graphene

Christian Koch, Aina Marquez
IFAE, July/September 2015

Tutors: Federico Sánchez, José Gabriel Macías, Thorsten Lux

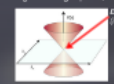
EXCELENCIA SEVERO OCHOA

GOAL

Graphene Detectors in Particle Physics
- **Charged particle (ion) sensors**
- **Photosensors**

Why Graphene?

- Graphene: flat monolayer of carbon atoms packed into a 2D layout
- Interesting electrical properties
- Semiconductor behaviour, with valence and conduction bands meeting at a single point, the Dirac Point



Dirac Point
(max R)

Resistance depends on cone cross-sectional area.

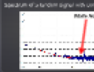
Smaller area implies greater resistance

- When graphene is doped with Quantum Dots, trapped charged particles shift the Dirac Point because of electrical field alterations.

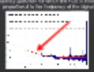
Electrical Noise

- First step towards a graphene detector: characterization of electrical noise
- Two main kinds:

White noise



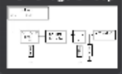
Pink noise



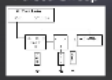
Measurements

- Comparison of PSD for same R resistor and graphene layer (Hf substrate)
- Each sweep measures f and V for the back gated Drain-Source signal.
- Two setups; compare DC and Pulsed for final detector

DC Voltage Sweep



Pulsed Sweep



Procedure

DC Voltage Sweeps
- 3 to 6 takes, 5min each
- 300kS at 1kHz
- 50mV to 1500mV

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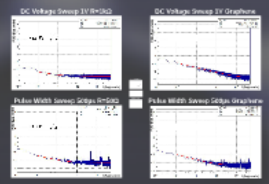
Long Sweeps
- Single takes, 30-120min
- Different voltages
- Both setups
- 1800kS at 1kHz

Plot Results



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- Humidity rises electrical resistance of graphene. Experiments should be carried in Nitrogen. Graphene resistance increased from 1kΩ to 6.2kΩ
- Quantum dots affect conductivity
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Conclusions

- $1/f^{\alpha}$ observed in both graphene and the resistor
  - Resistor $\alpha=1$
  - Graphene $\alpha>1$, usually $\alpha\approx1.2$
- Not originated in power sources
- No difference between direct and pulsed current
- Hysteresis observed: Impurities? Quantum Dots? Water? ...
- Systematic method: lowering the voltage to 0 before each measurement

Systematic measurement methodology developed

Coming soon

Short term
1. Pulsed sweeps with shaper readout
2. Nitrogen medium and temperature monitoring while measuring

Long term
3. New, purer graphene without Quantum Dots
4. SiO_2 substrate

Prezi

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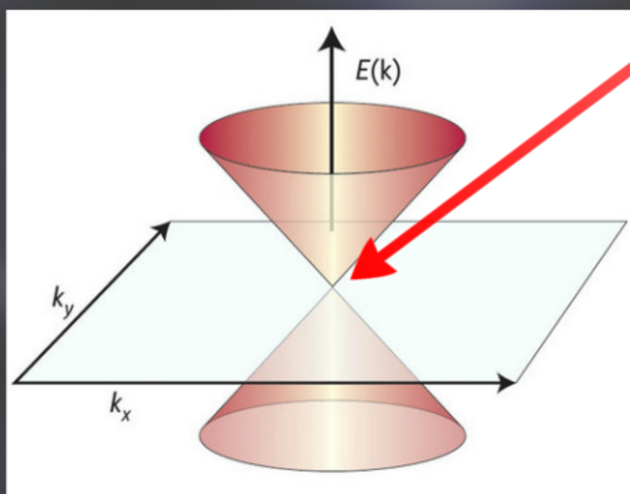

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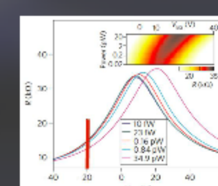

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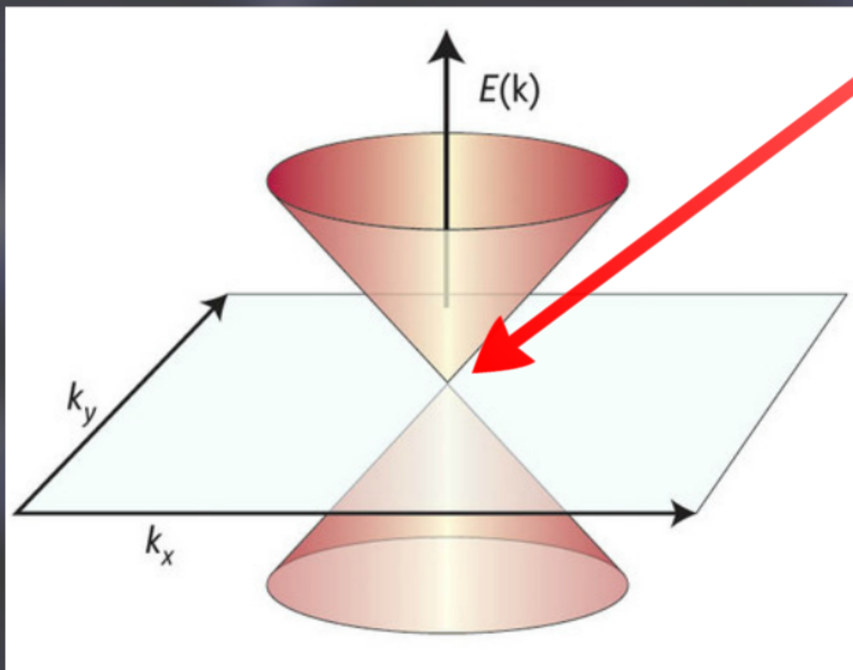

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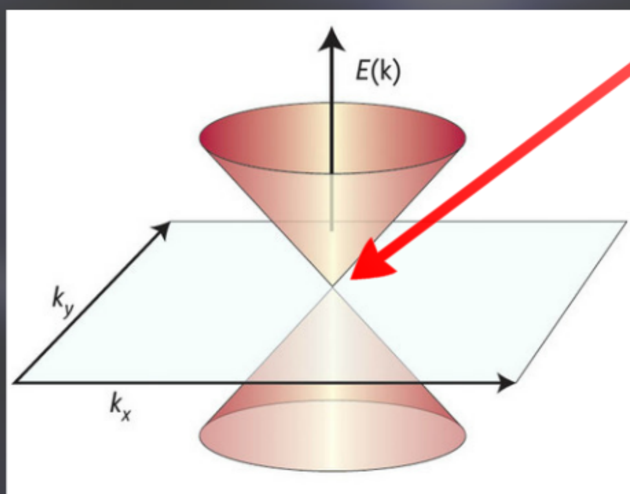

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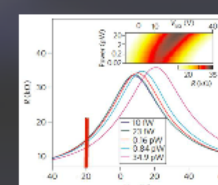
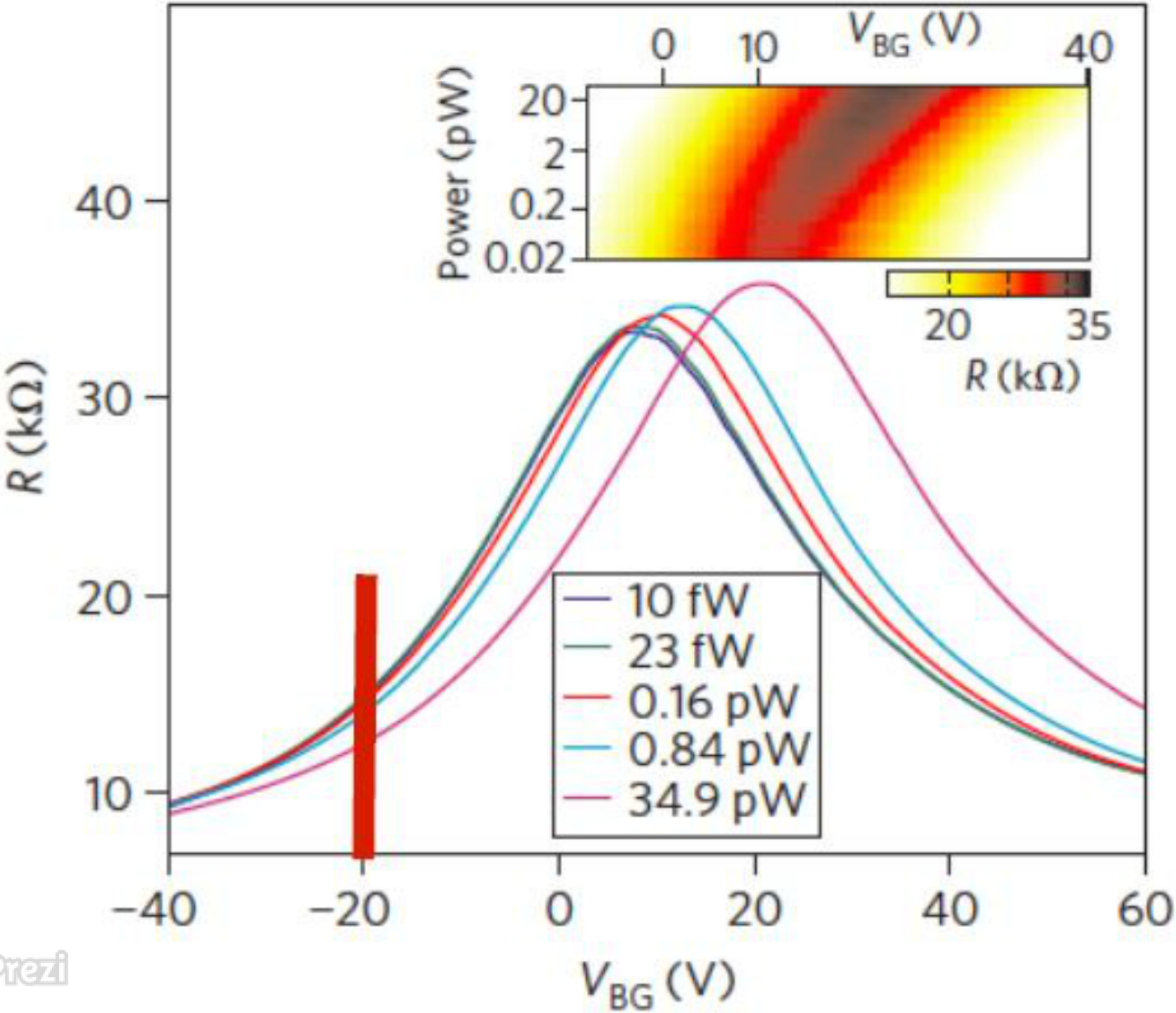




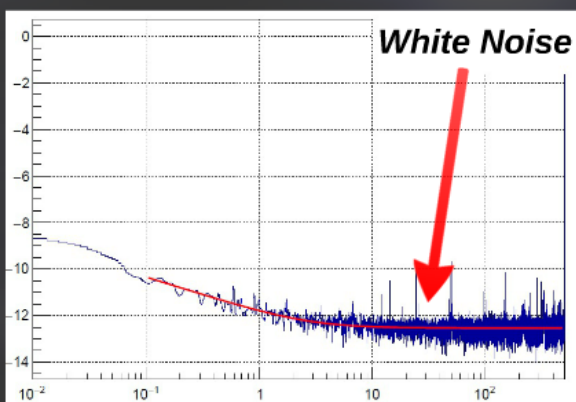
R (kΩ)
40
30
20
10
−40
−20
0
20
40
60
V_BG (V)
10 fW
23 fW
0.16 pW
0.84 pW
34.9 pW
Power (pW)
20
2
0.2
0.02
0
10
40
V_BG (V)
20
35
R (kΩ)

Electrical Noise

- First step towards a graphene detector: characterization of electrical noise
- Two main kinds:

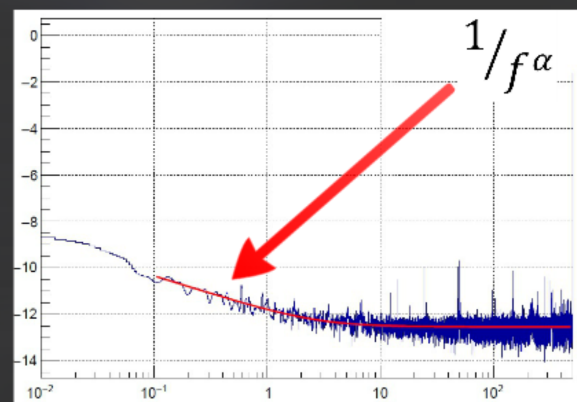
White noise

Spectrum of a random signal with constant PSD



Pink noise

Frequency spectrum for which the PSD is inversely proportional to the frequency of the signal



PSD

- Power Spectral Density is the frequency response of a random or periodic signal
- Distributes the average power as a function of frequency
- Average of the Fourier transform magnitude squared over a large time interval

$$S_x(f) = \lim_{T\to\infty} E\left\{ \frac{1}{2T} \left| \int_{-T}^{T} x(t) e^{-j2\pi ft} dt \right|^2 \right\}$$

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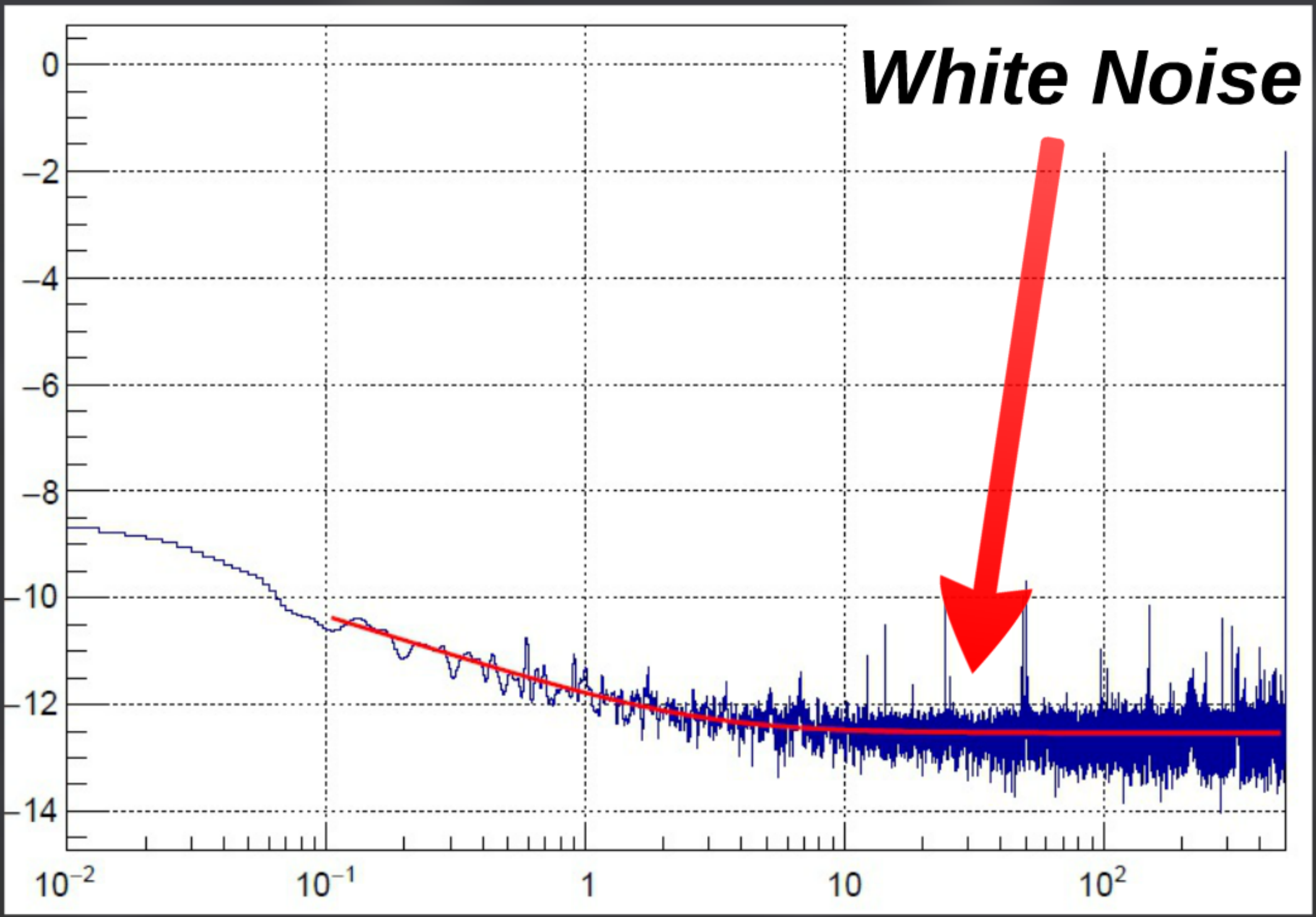

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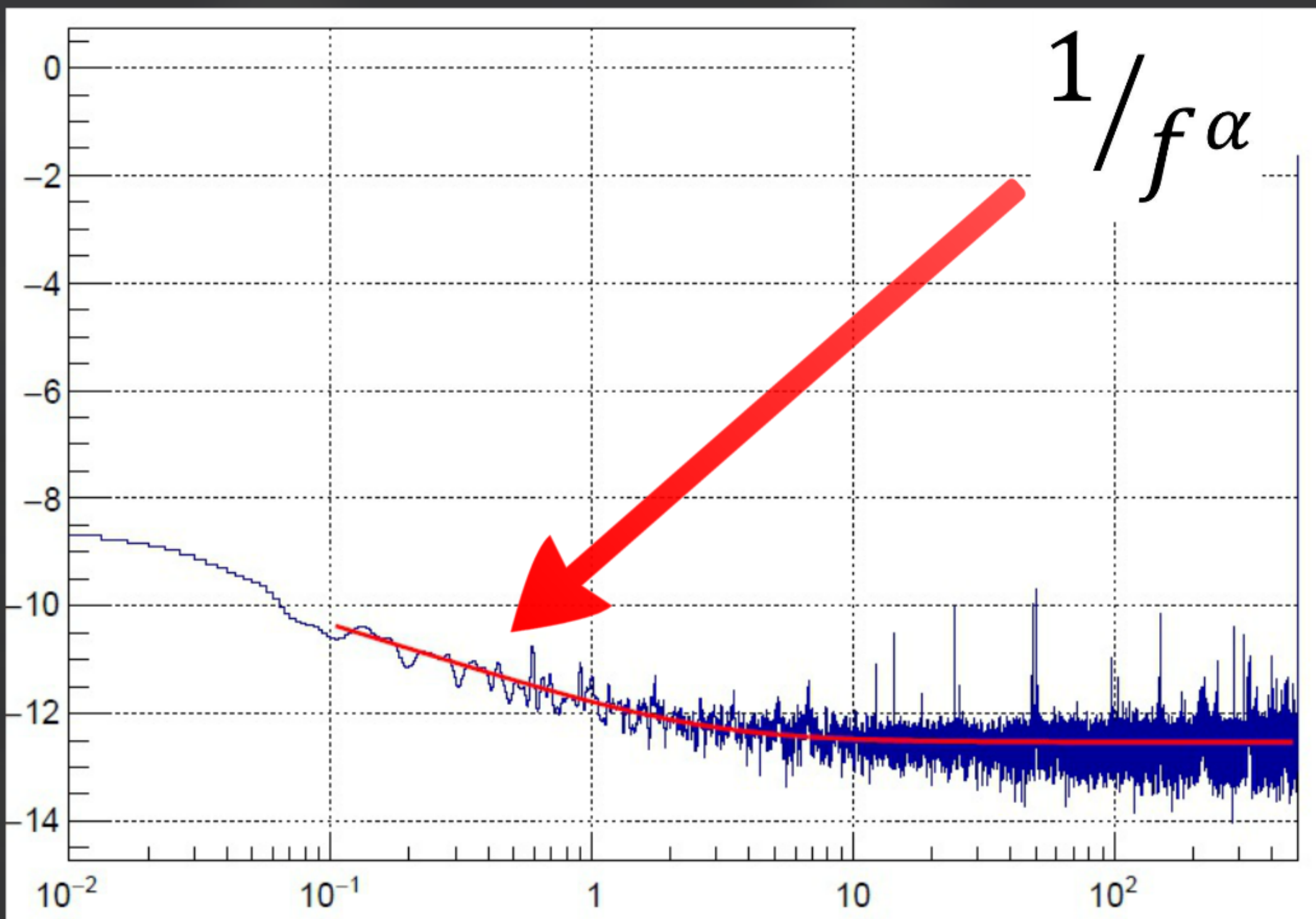

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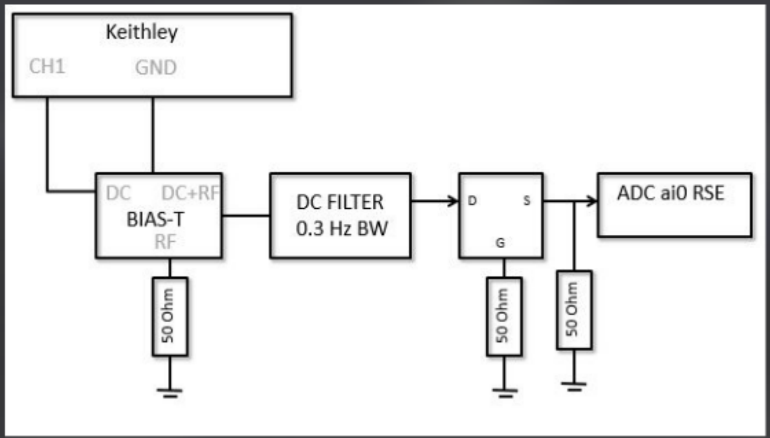
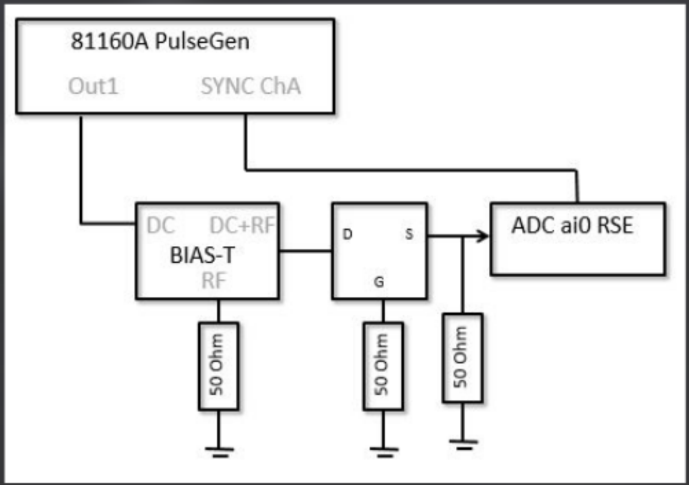


Pulsed Sweep



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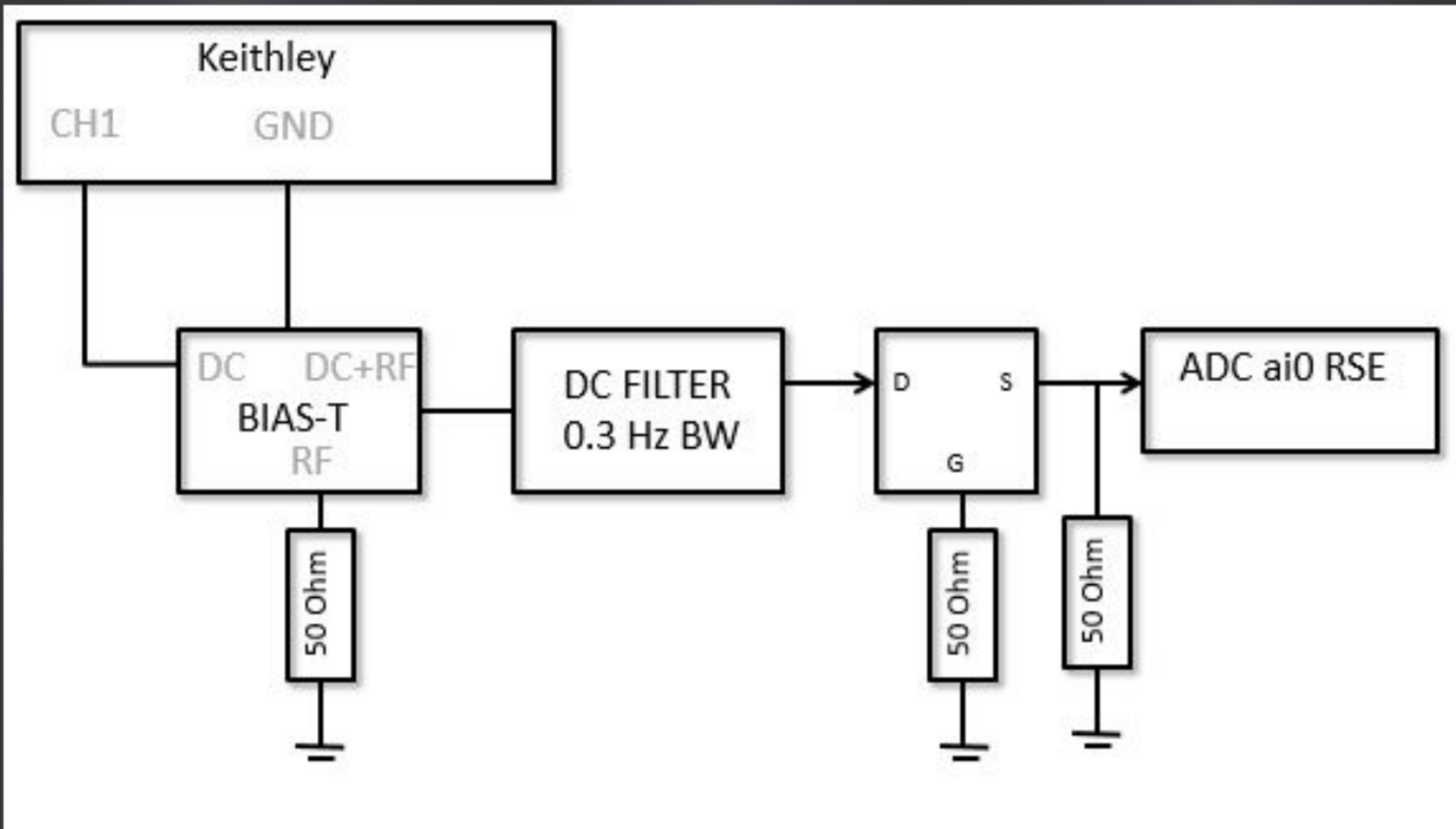

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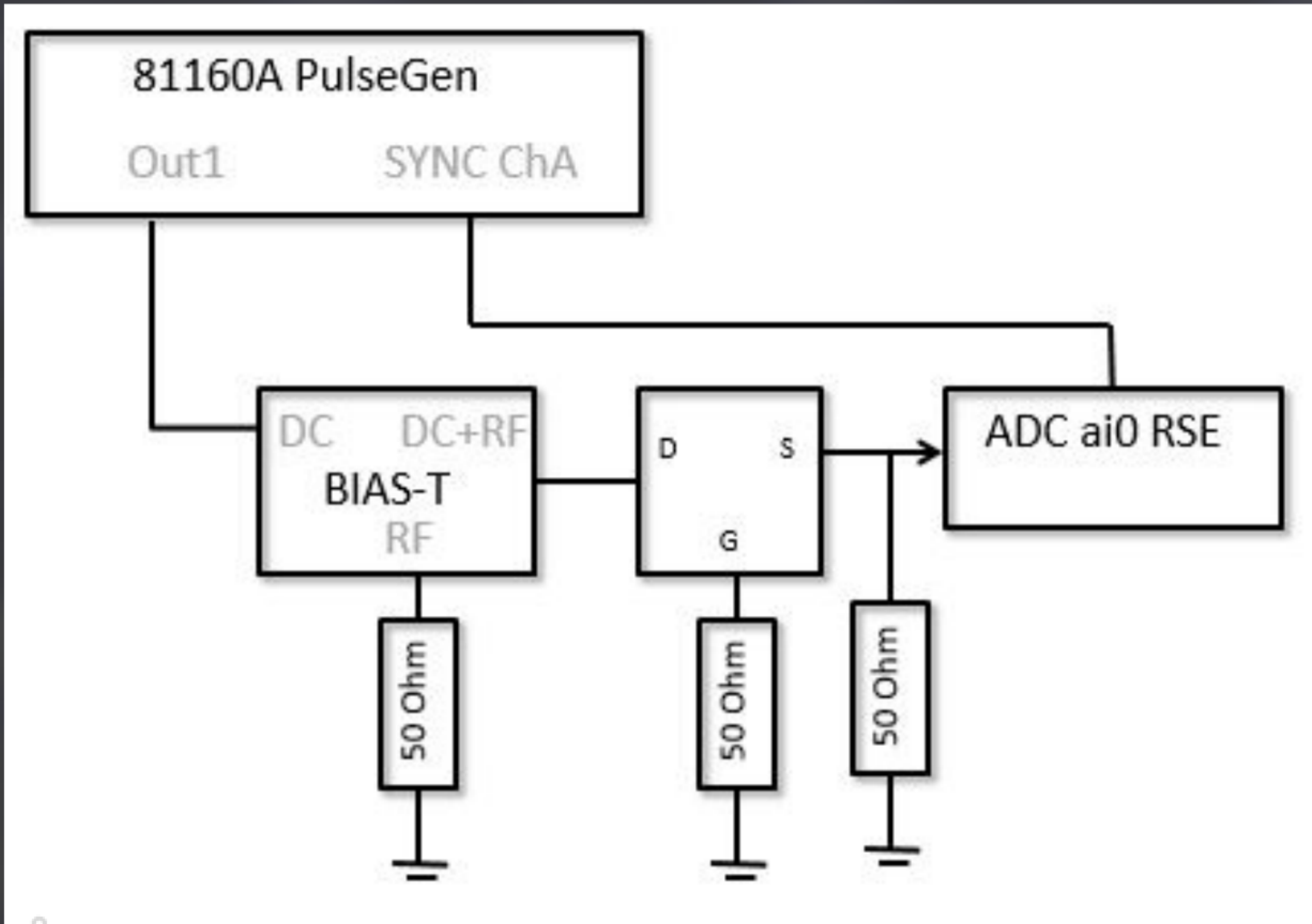

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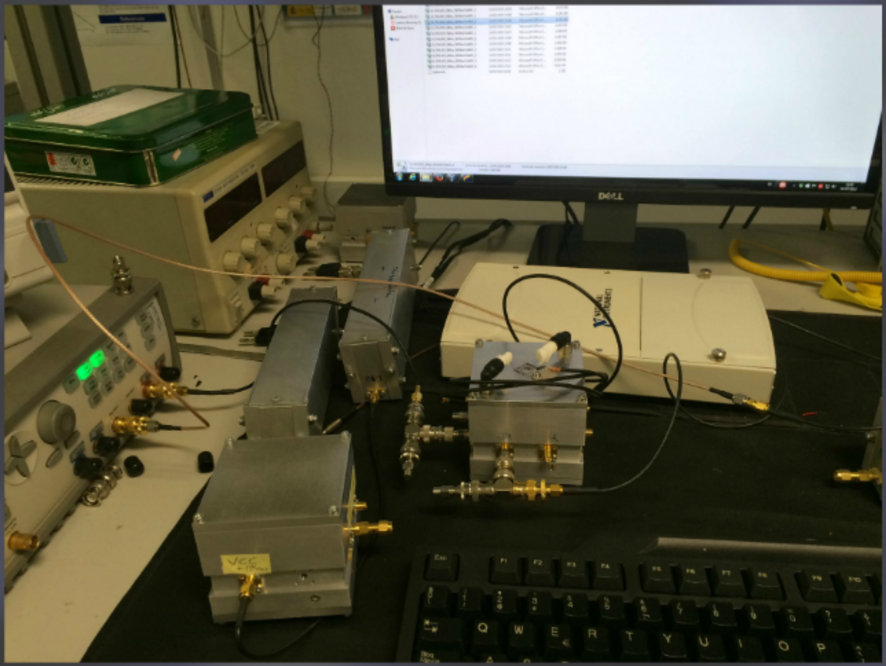
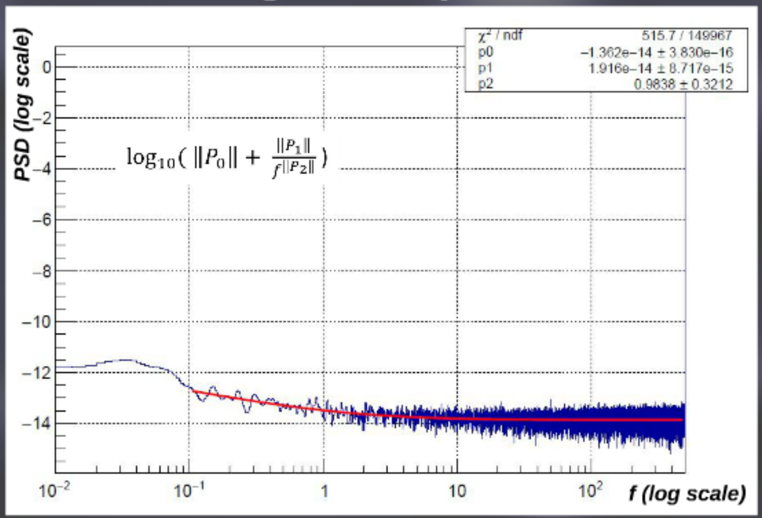


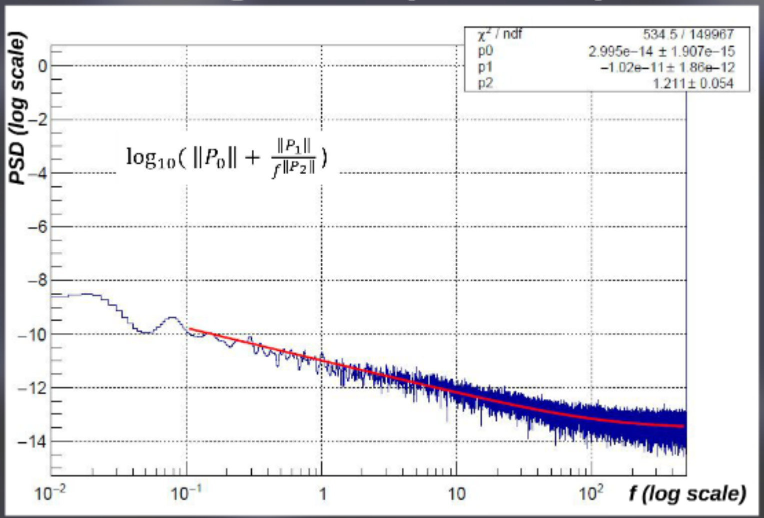
Prezi

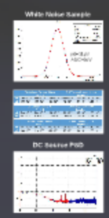
Plot Results

DC Voltage Sweep 1V R=1kΩ

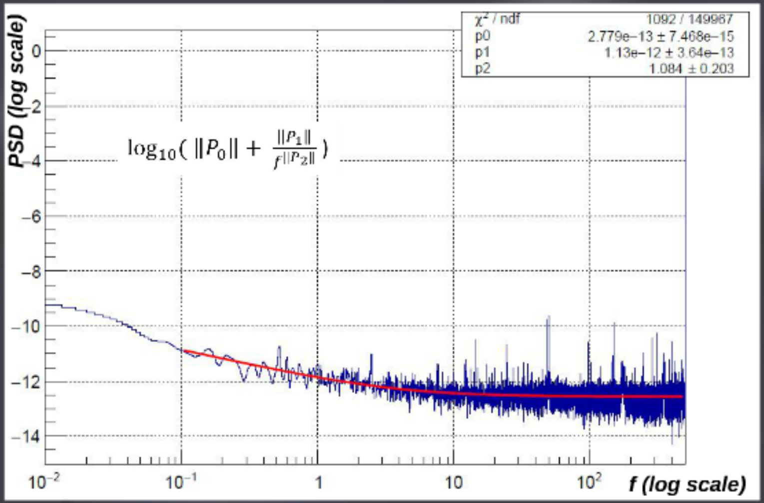


DC Voltage Sweep 1V Graphene

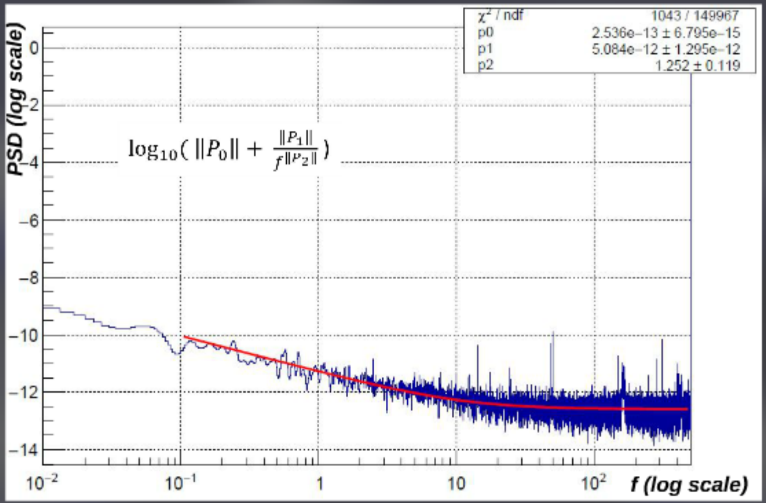




Pulse Width Sweep 500μs R=50Ω



Pulse Width Sweep 500μs Graphene



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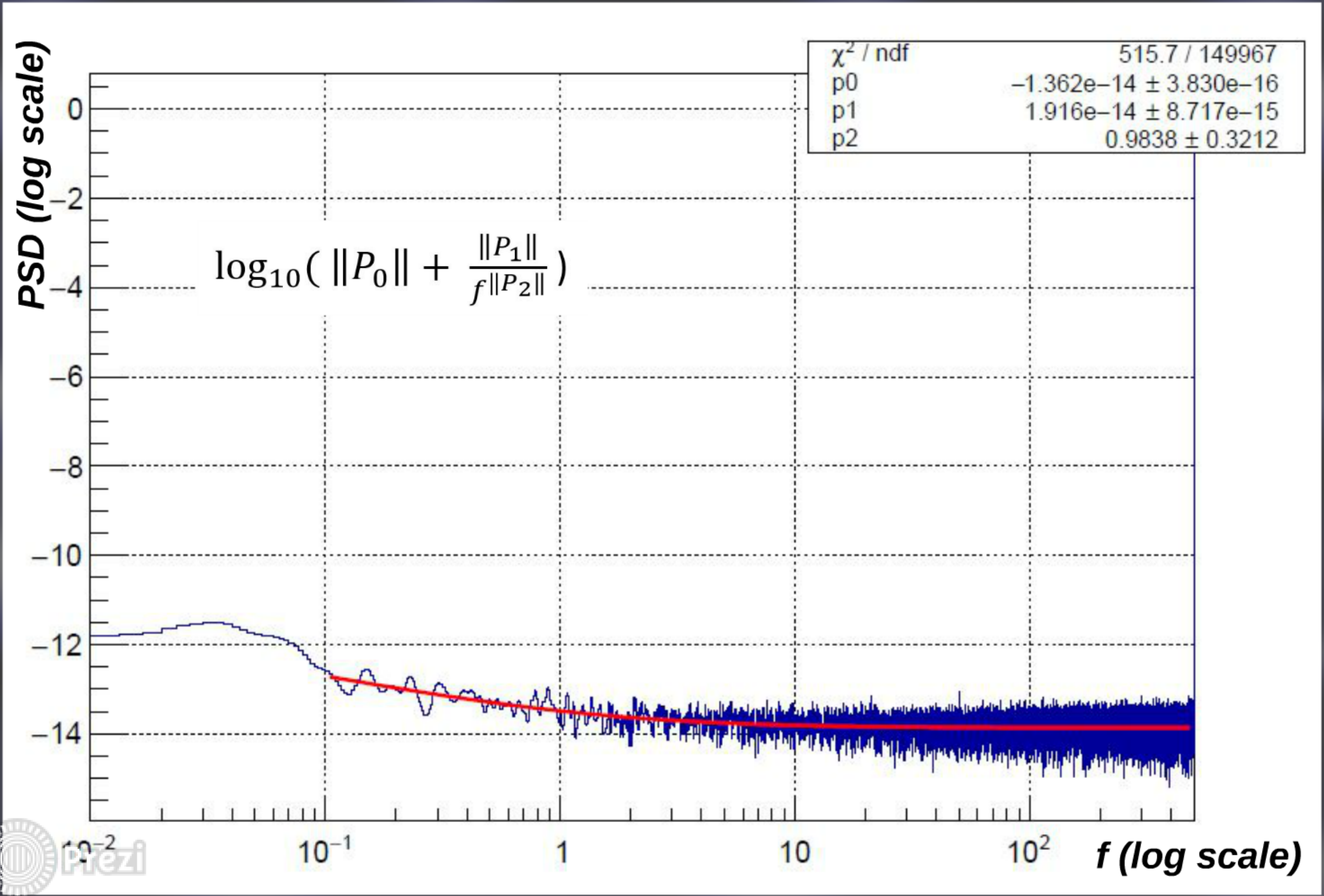

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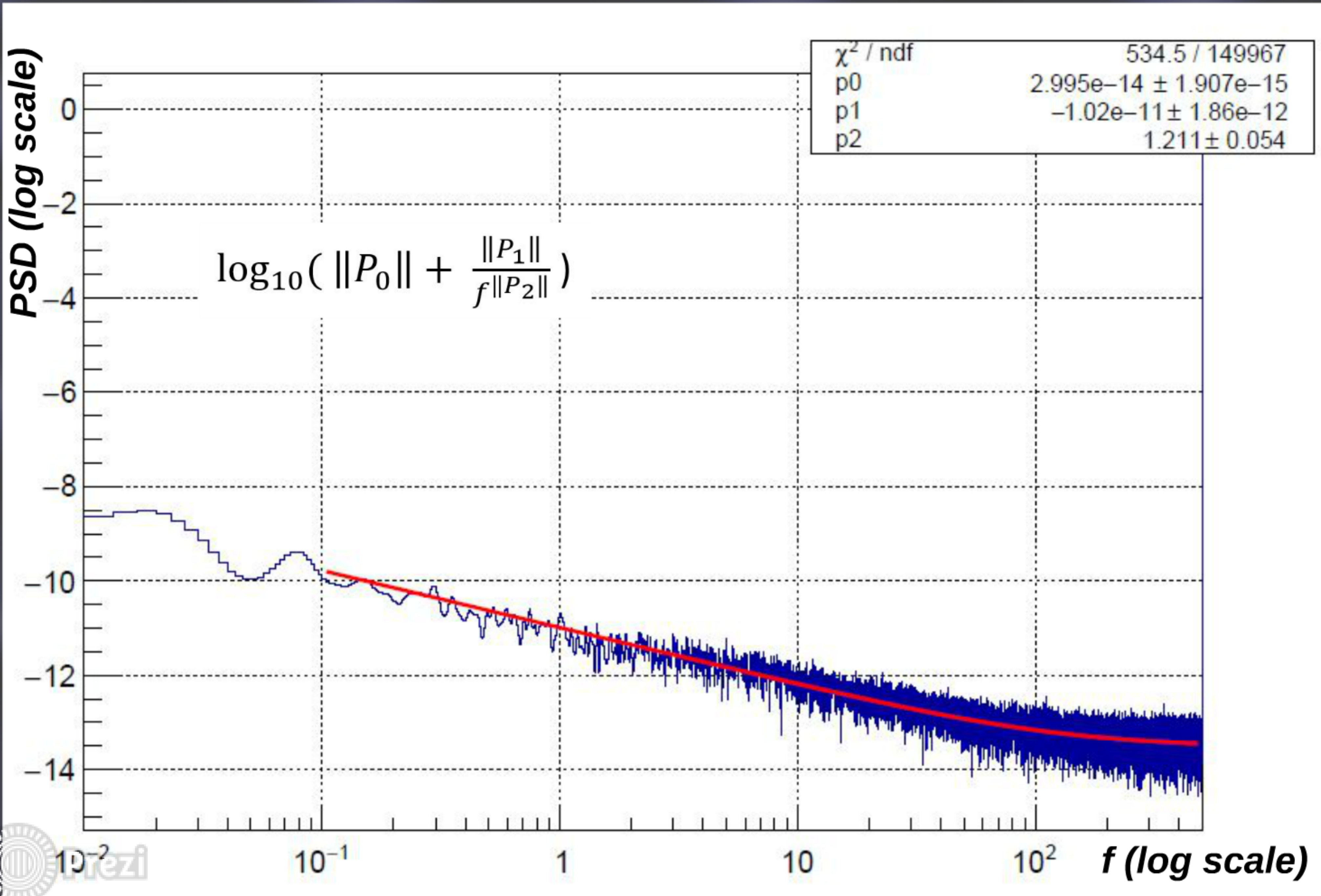

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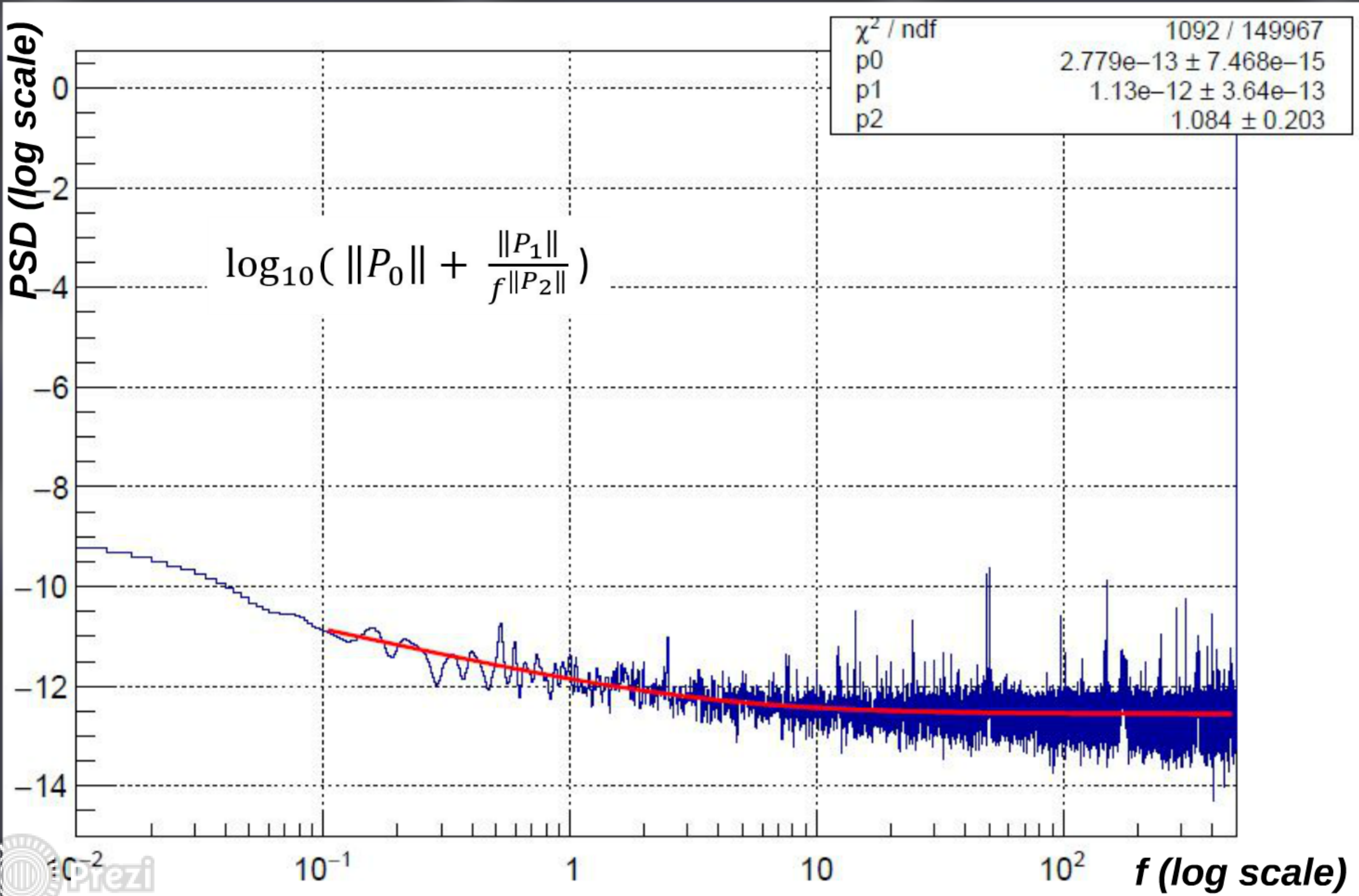
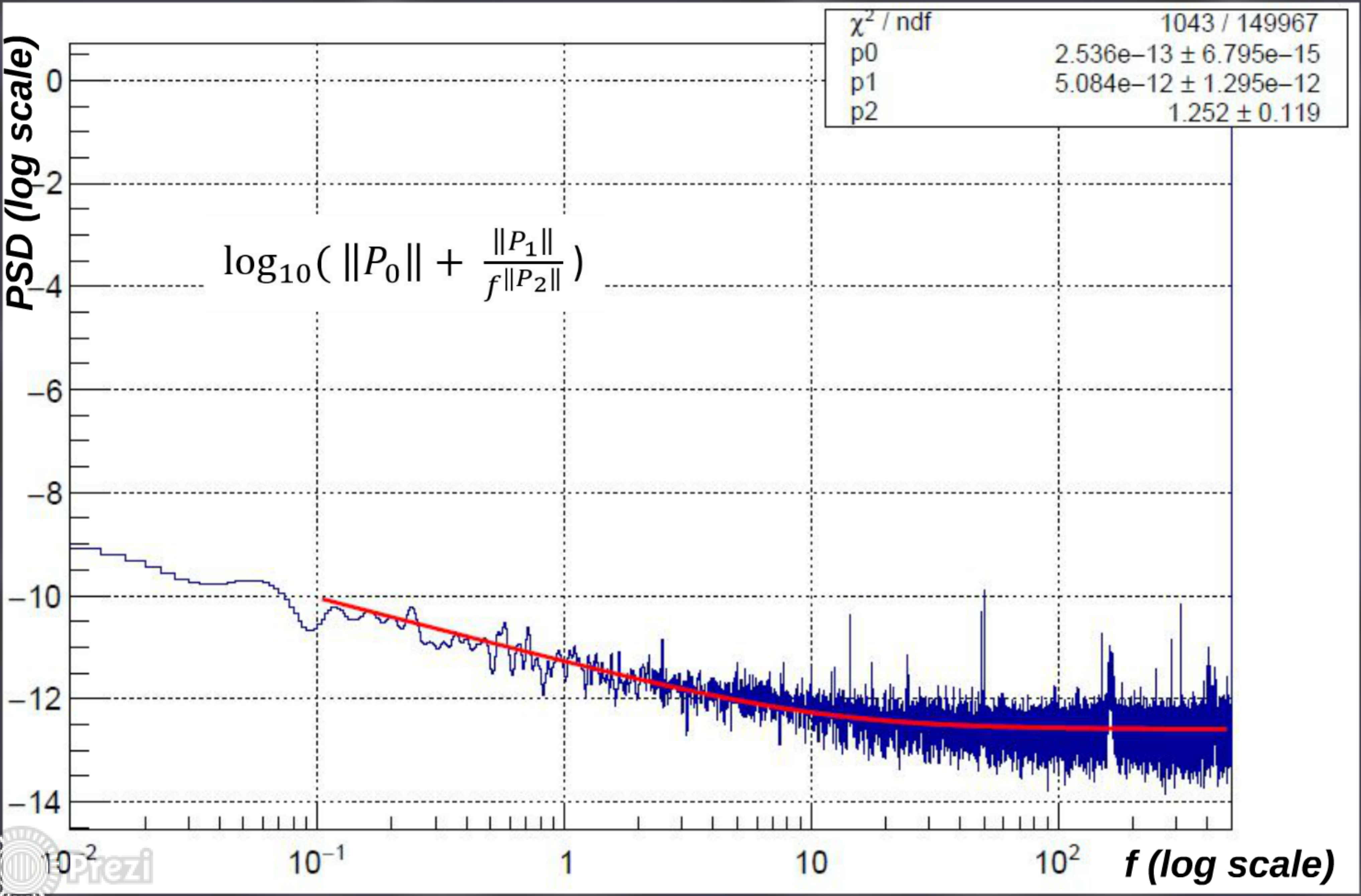


Pulse Width Sweep 500μs Graphene



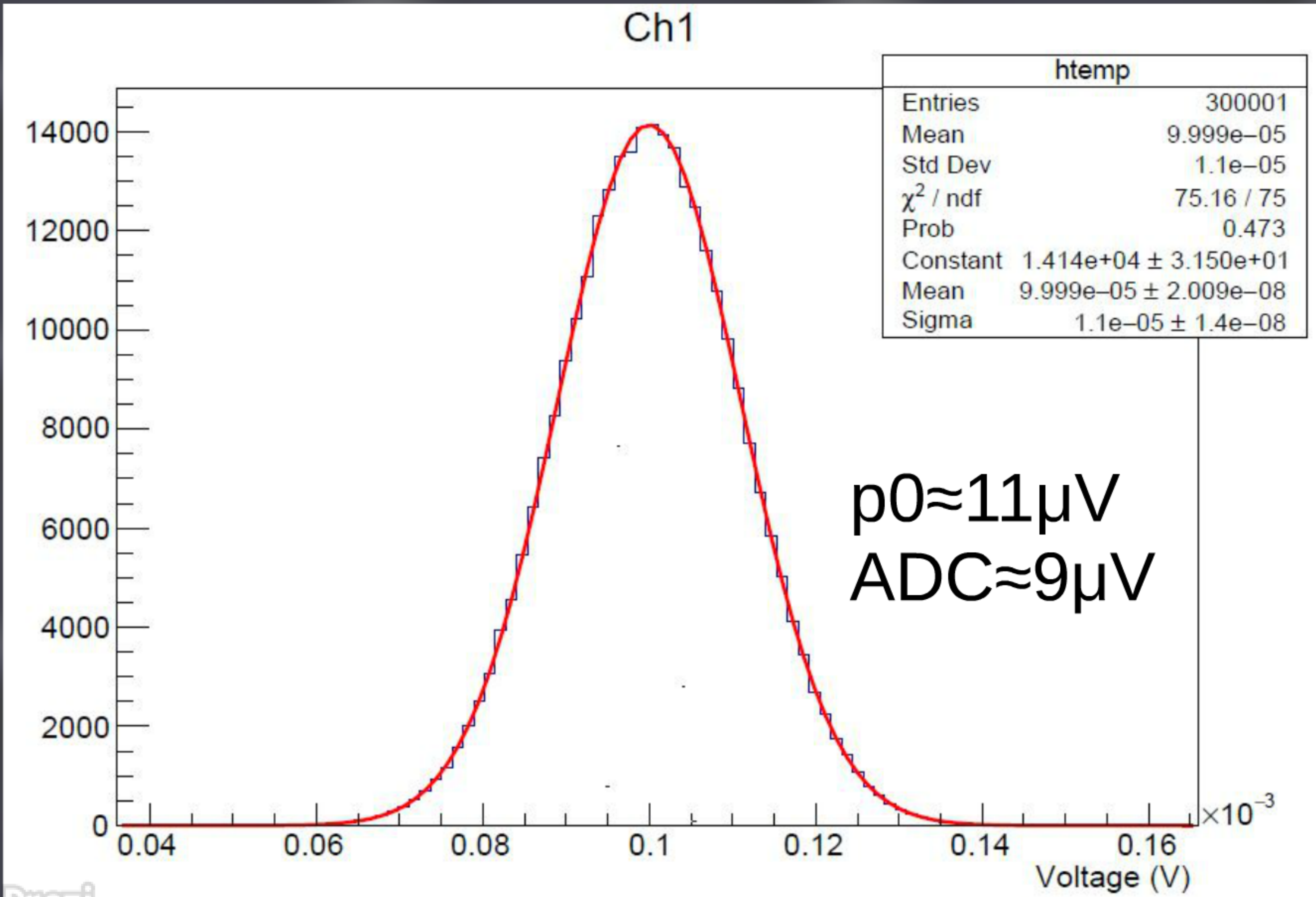
	DC Voltage Sweep 100mV **R=1kΩ**			DC Voltage Sweep 100mV **Graphene**		
p1	$7.94\cdot10^{-14}$	$8.08\cdot10^{-14}$	$7.49\cdot10^{-14}$	$6.89\cdot10^{-14}$	$7.49\cdot10^{-14}$	$8.07\cdot10^{-14}$
p2	$1.09\cdot10^{0}$	$1.08\cdot10^{0}$	$1.07\cdot10^{0}$	$1.12\cdot10^{0}$	$1.14\cdot10^{0}$	$1{,}11\cdot10^{0}$

	DC Voltage Sweep 1V **R=1kΩ**			DC Voltage Sweep 1V **Graphene**		
p1	$5.40\cdot10^{-11}$	$5.34\cdot10^{-11}$	$1.02\cdot10^{-11}$	$1.20\cdot10^{-11}$	$1.12\cdot10^{-11}$	$1.08\cdot10^{-11}$
p2	$9.83\cdot10^{-1}$	$9.75\cdot10^{-1}$	$1.21\cdot10^{0}$	$1.25\cdot10^{0}$	$1.23\cdot10^{0}$	$1.24\cdot10^{0}$

	Pulsed Sweep 500µs **R=50Ω**			Pulsed Sweep 500µs **Graphene**		
p1	$1.13\cdot10^{-12}$	$9.84\cdot10^{-13}$	$9.42\cdot10^{-13}$	$5.08\cdot10^{-12}$	$4.49\cdot10^{-12}$	$4.49\cdot10^{-12}$
p2	$1.08\cdot10^{0}$	$1.14\cdot10^{0}$	$9.26\cdot10^{-1}$	$1.25\cdot10^{0}$	$1.14\cdot10^{0}$	$1{,}25\cdot10^{0}$

DC Source PSD

White Noise Sample



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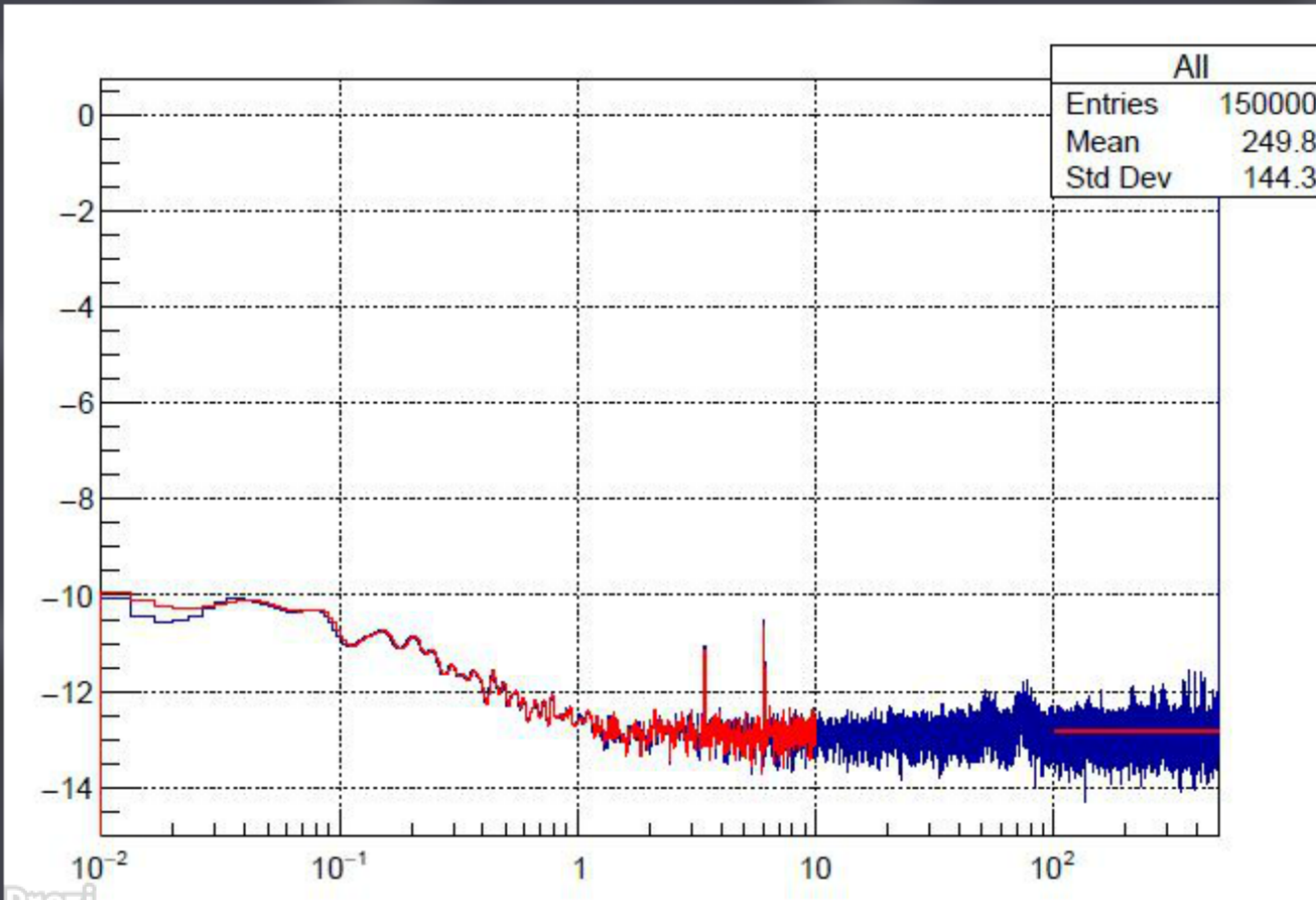
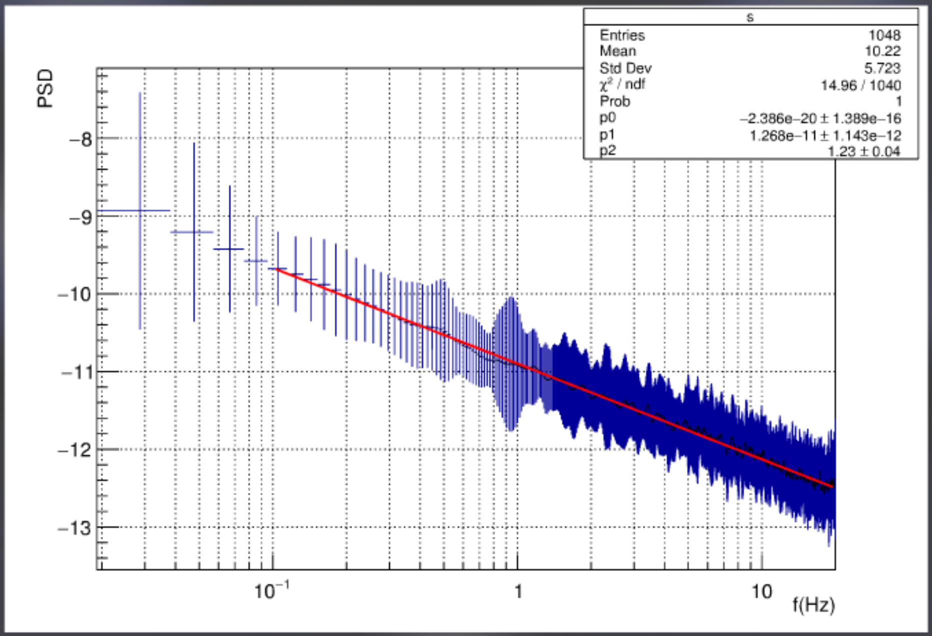
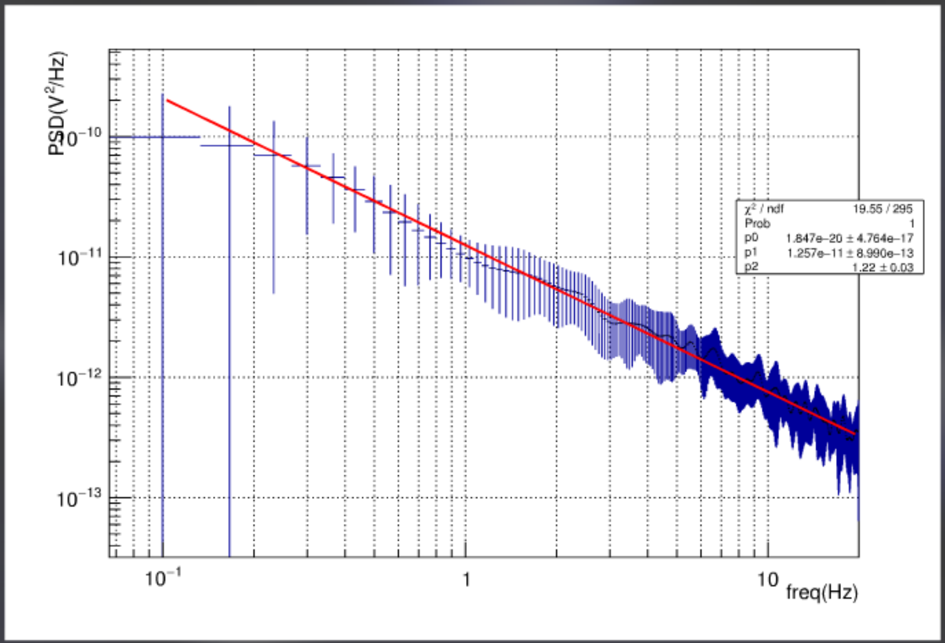


Error Estimation

- Error can be estimated with many measurements or dividing a single long one
- Average and RMS of PSD





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  Graphene resistance increased from 1kΩ to 6.2kΩ
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- $1/f^{\alpha}$ observed in both graphene and the resistor
  - Resistor $\alpha \approx 1$
  - Graphene $\alpha > 1$, usually $\alpha \approx 1.2$
- Not originated in power sources
- No difference between direct and pulsed current
- Hysteresis observed: Impurities? Quantum Dots? Water? ...
- Systematic method: lowering the voltage to 0 before each measurement

Systematic measurement methodology developed

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Bibliography conclusions

- Small collection on graphene noise
- Even smaller on 1/f in graphene
- No results on α (p2) value
- Considerable amount of papers about influence of impurities in graphene resistance (especially water)

Coming soon

Short term

1. Pulsed sweeps with shaper readout
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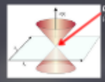

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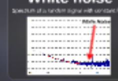

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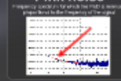

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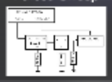

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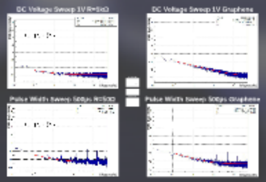

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