HUMBOLDT-UNIVERSITÄT ZU BERLIN

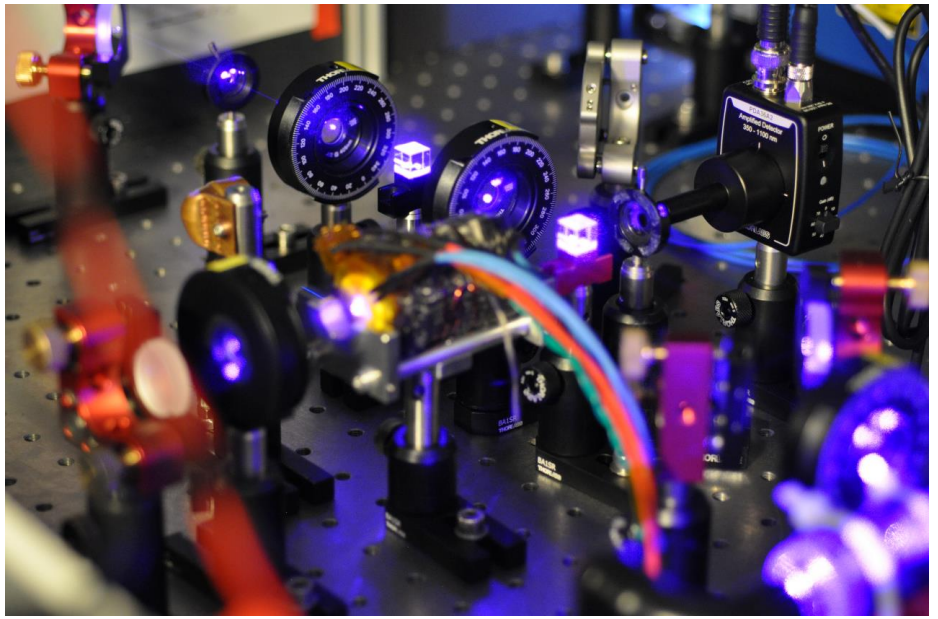
QTutorium

Thermal attenuation noise of optical power from a 420 nm light source in hot ^{85,87}Rb vapor

Student

Julien Kluge

564513



The Idea

Experiment

Dopplerfreie
Sättigungsspektroskopie
in heißen Rubidium Dampf

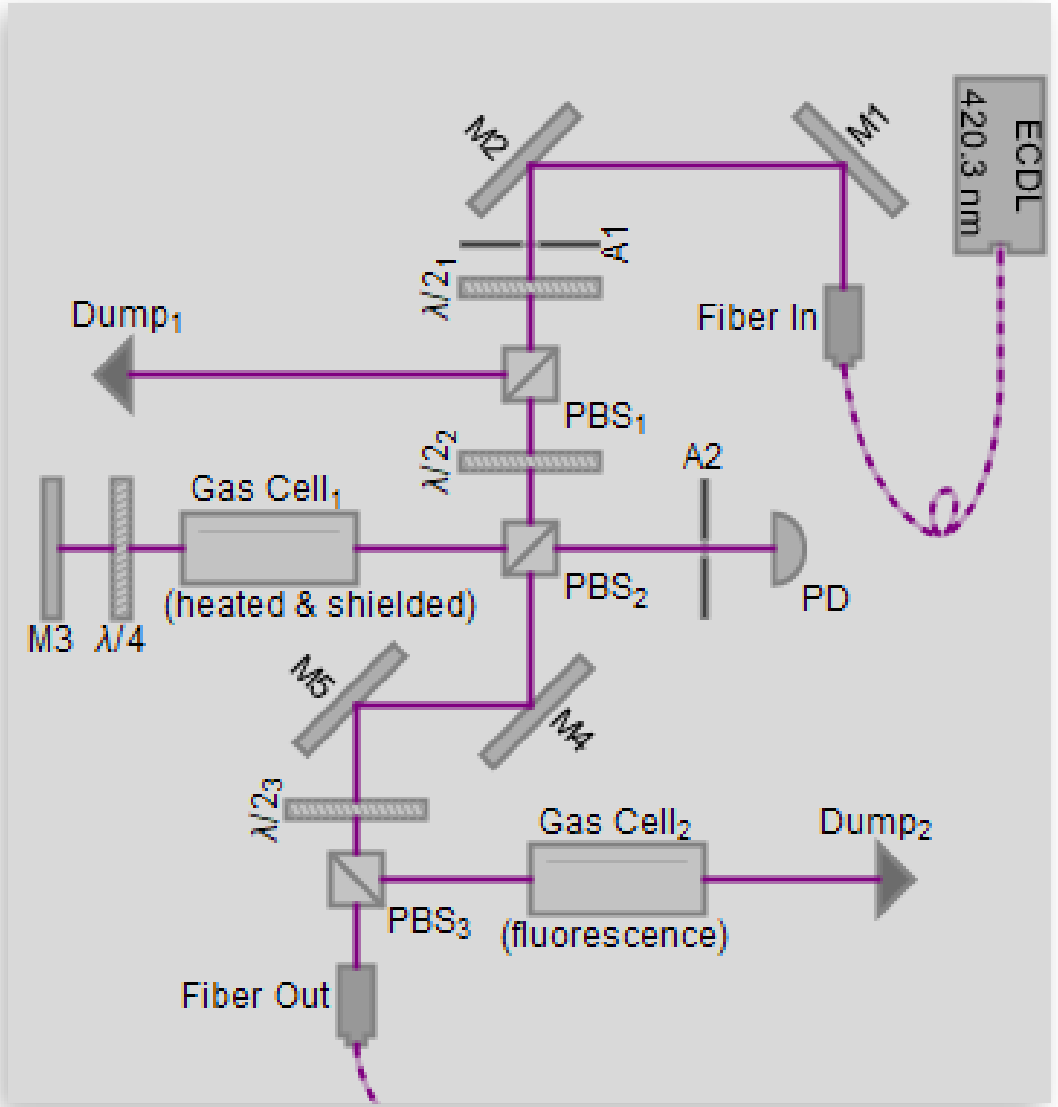
HUMBOLDT-UNIVERSITÄT ZU BERLIN

Direct optical spectroscopy of the 6P manifold in Rubidium

Master thesis

for obtaining the degree
Master of Science (M.Sc.)

Humboldt-Universität zu Berlin
Faculty of Mathematics and Natural Sciences
Department of Physics
AG Optical Metrology



The Idea

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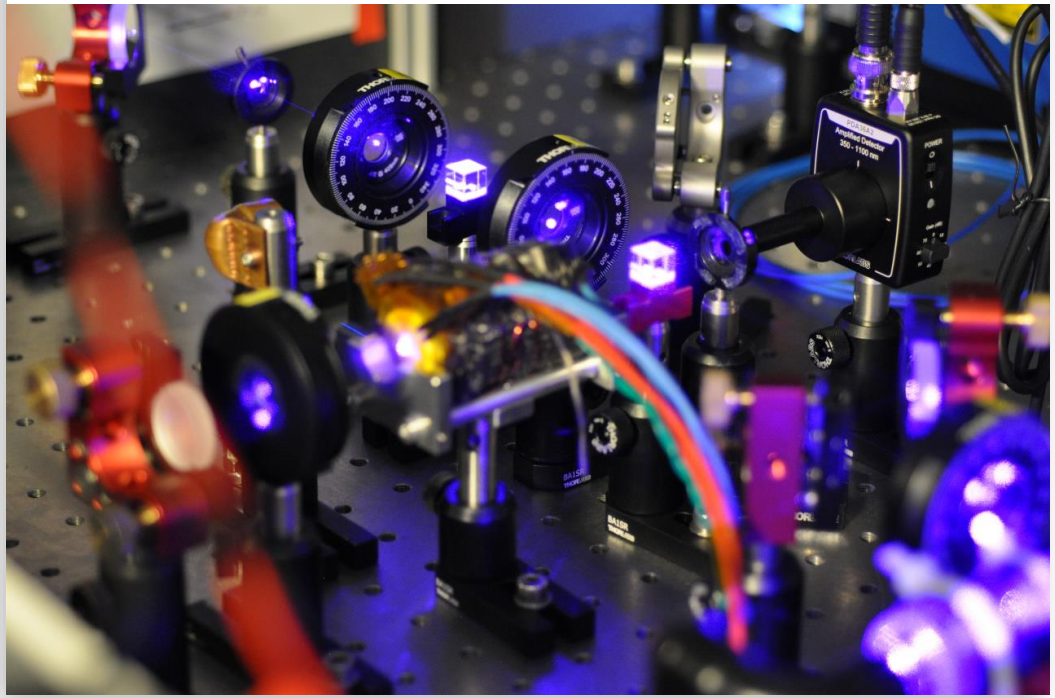
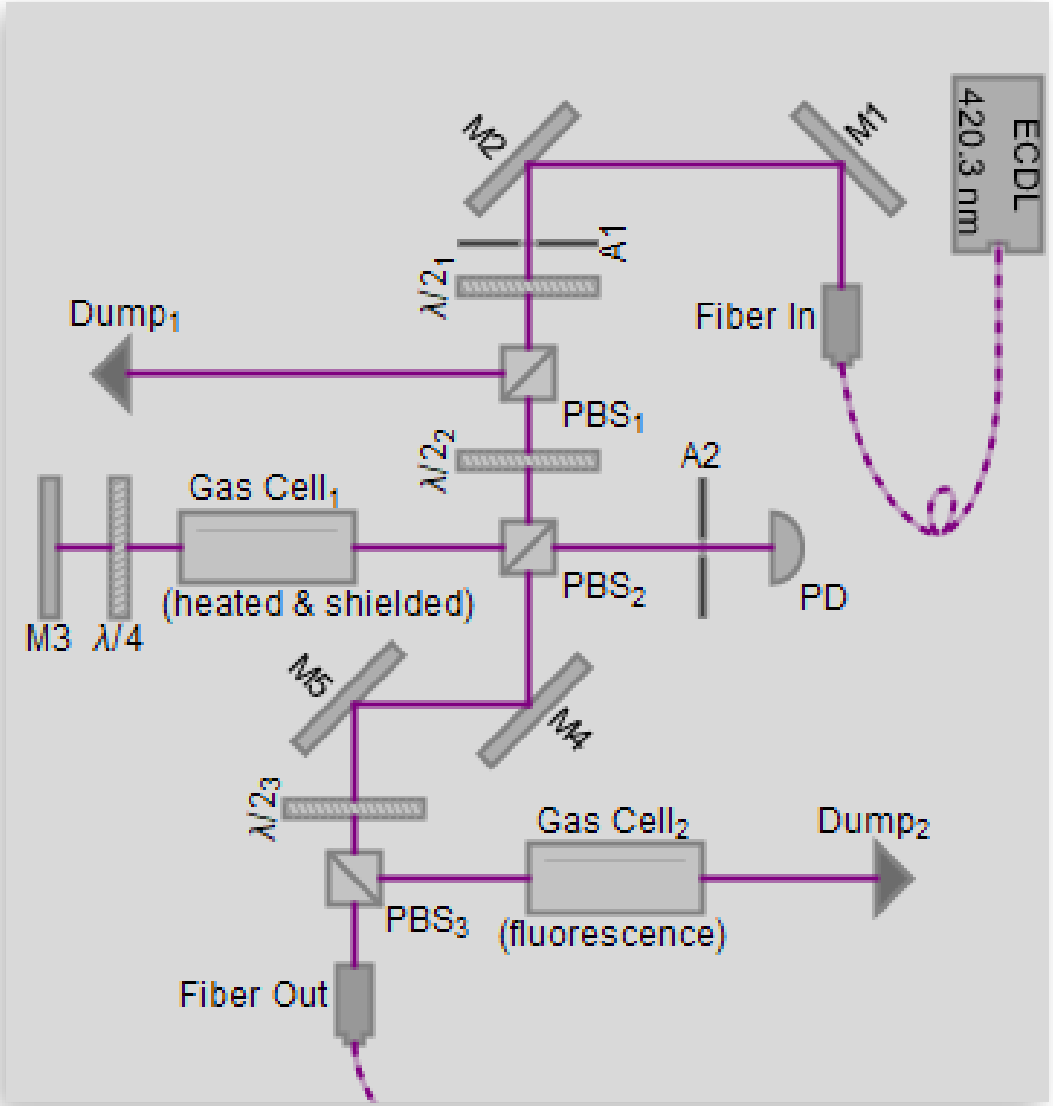


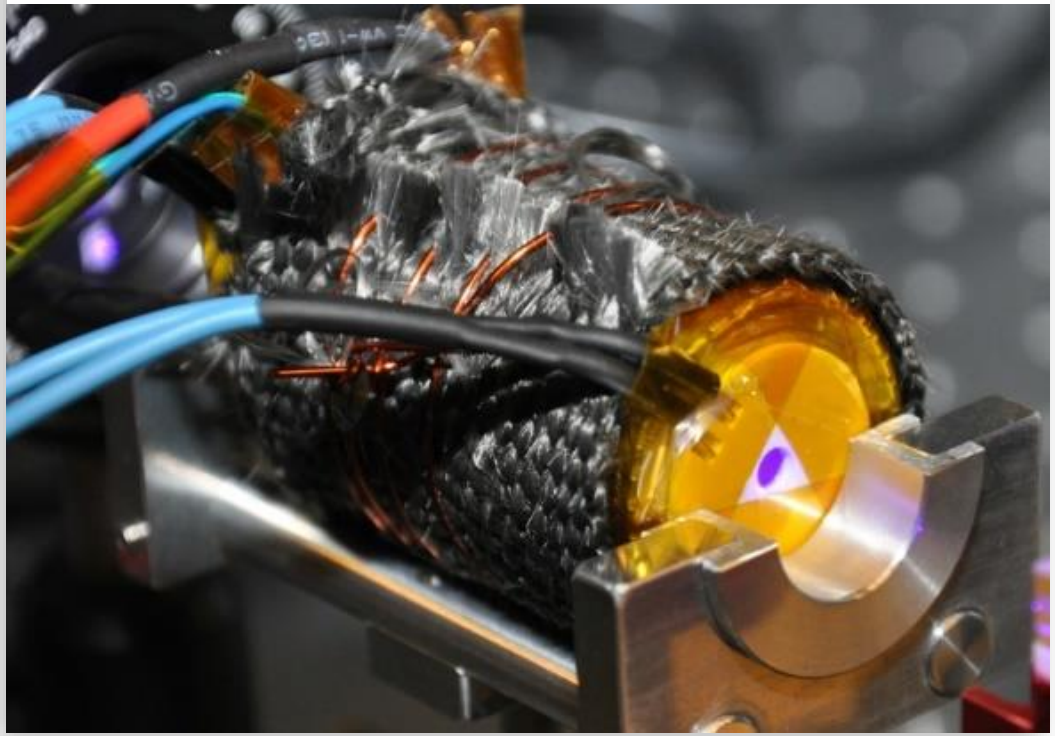


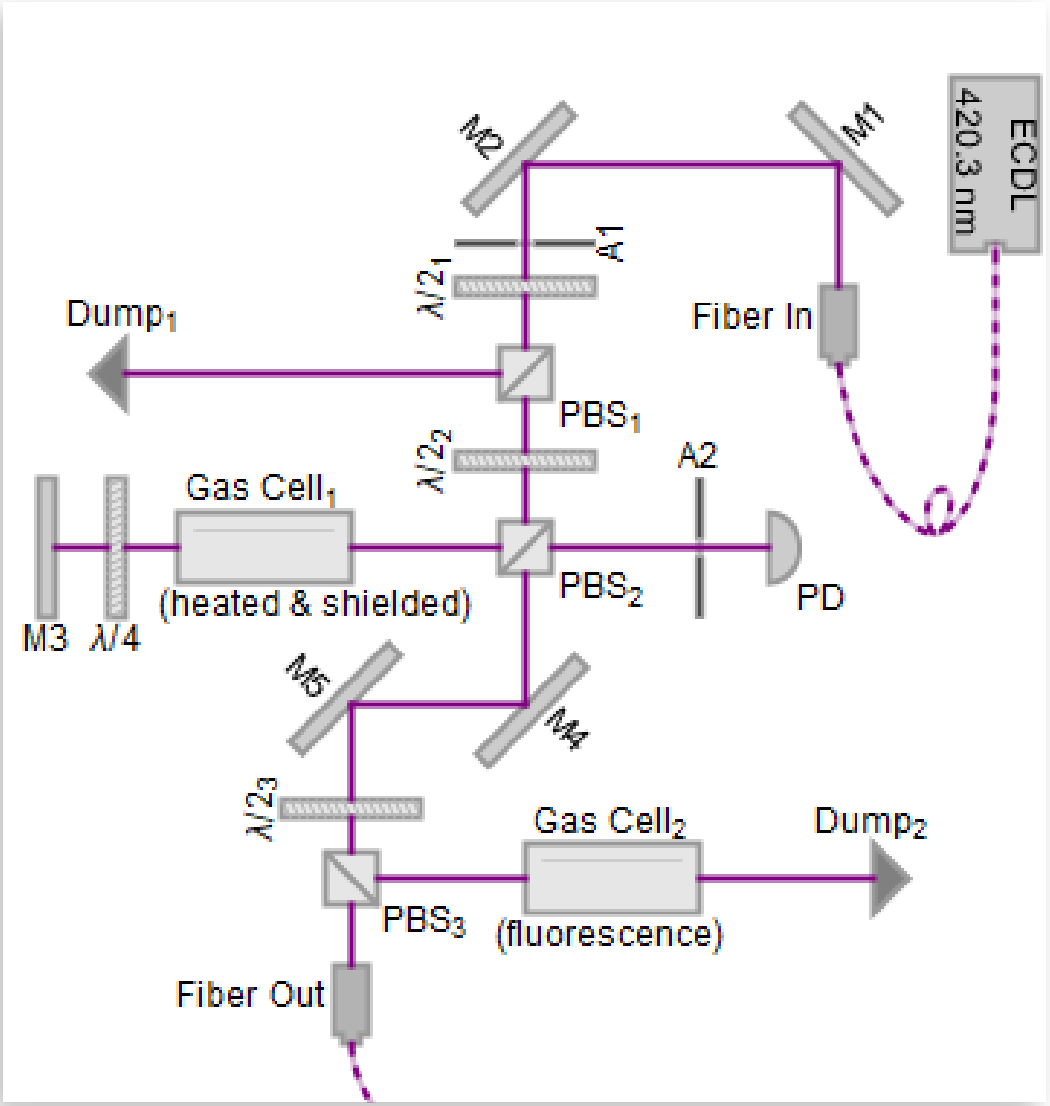
Aufbau

The Idea

Experiment

Dopplerfreie
Sättigungsspektroskopie
in heißen Rubidium Dampf





Gaszelle und Aufbau

Proposed evaluation

Box Müller Transformation

Transformation von uniform verteilten Zahlen zu Gauss-Verteilung

$$Z_1 = \sqrt{-2 \log U_1} \cos(2\pi U_2)$$

$$Z_2 = \sqrt{-2 \log U_1} \sin(2\pi U_2)$$

Scott, D. W. Box Muller transformation. *Wiley Interdisciplinary Reviews: Computational Statistics* **3**, 177 179. issn: 1939-0068 (2011).

Inversion

$$U_1 = \exp\left(\frac{-[Z_1^2 + Z_2^2]}{2}\right)$$

$$U_2 = \frac{1}{2\pi} \arccos\left(-\frac{Z_1}{\sqrt{Z_1^2 + Z_2^2}}\right)$$

Inverse Box Müller Transformation

Proposed evaluation

Box Müller Transformation

Transformation von uniform verteilten Zahlen zu Gauss-Verteilung

$$Z_1 = \sqrt{-2 \log U_1} \cos(2\pi U_2)$$

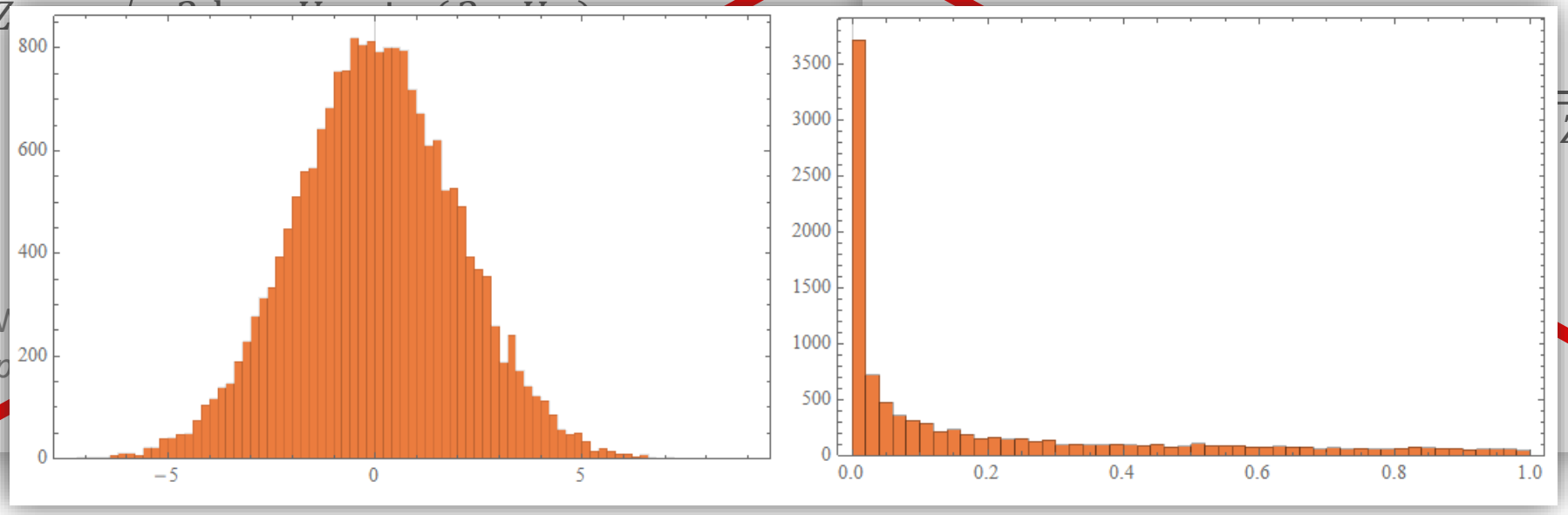
$$Z$$

Scott, D. V
Interdiscip
179. issn

Inversion

$$U_1 = \exp\left(\frac{-[Z_1^2 + Z_2^2]}{2}\right)$$

$$Z_2^2$$



Inverse Box Müller Transformation

New evaluation

Cumulative distribution function

math.stackexchange to the rescue

5

Let $X \sim \mathcal{N}(\mu, \sigma^2)$ have a normal distribution with mean $\mu = 0$ and variance $\sigma^2 = 0.2$, which cumulative distribution function (CDF) is denoted by Φ_X. The variable $Y = 6\Phi_X(X) - 3$ has a uniform distribution over $[-3, 3]$. In facts,

$$\begin{aligned}\mathbb{P}(Y \le t) &= \mathbb{P}\left(\Phi_X(X) \le \frac{t+3}{6}\right) \\ &= \mathbb{P}\left(X \le \Phi_X^{-1}\left(\frac{t+3}{6}\right)\right) \\ &= \Phi_X\left(\Phi_X^{-1}\left(\frac{t+3}{6}\right)\right) \\ &= \frac{t+3}{6},\end{aligned}$$

if $-3 \le t \le 3$, $\mathbb{P}(Y \le t) = 0$ if $t \le -3$, and $\mathbb{P}(Y \le t) = 1$ if $t \ge 3$.

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edited Jul 4 '17 at 12:41

answered Jul 2 '17 at 15:59

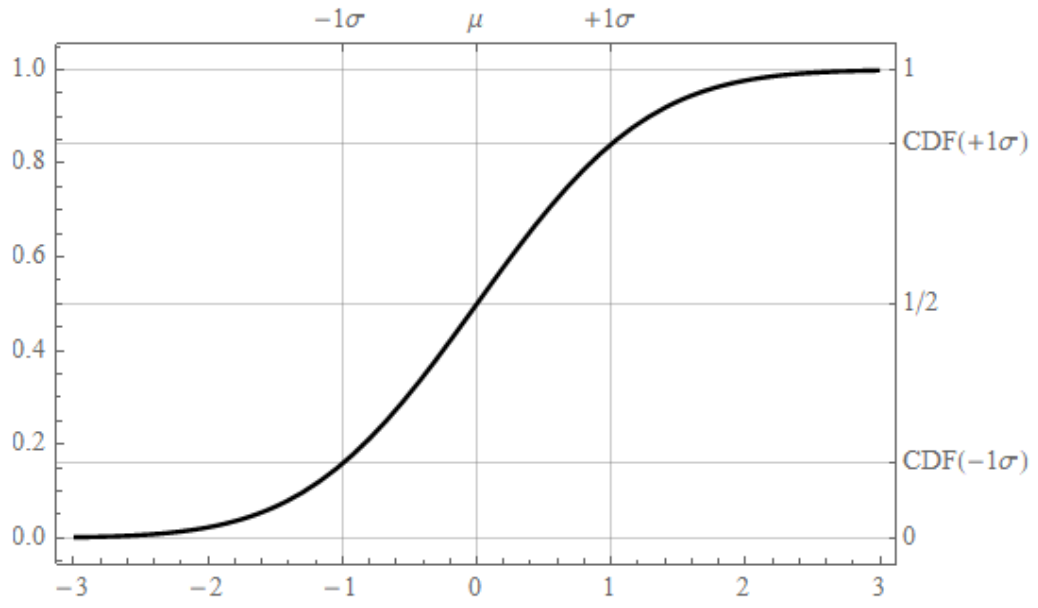
Harry49

12.3k ● 3 ■ 18 ▲ 51

https://math.stackexchange.com/a/2344086/373704

CDF

$$U_1(\mu, \sigma) = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{x - \mu}{\sqrt{2}\,\sigma}\right)\right]$$



New evaluation

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$$\mathbb{P}(Y < t) = \mathbb{P}\left(\Phi_X(X) < \frac{t+3}{6}\right)$$

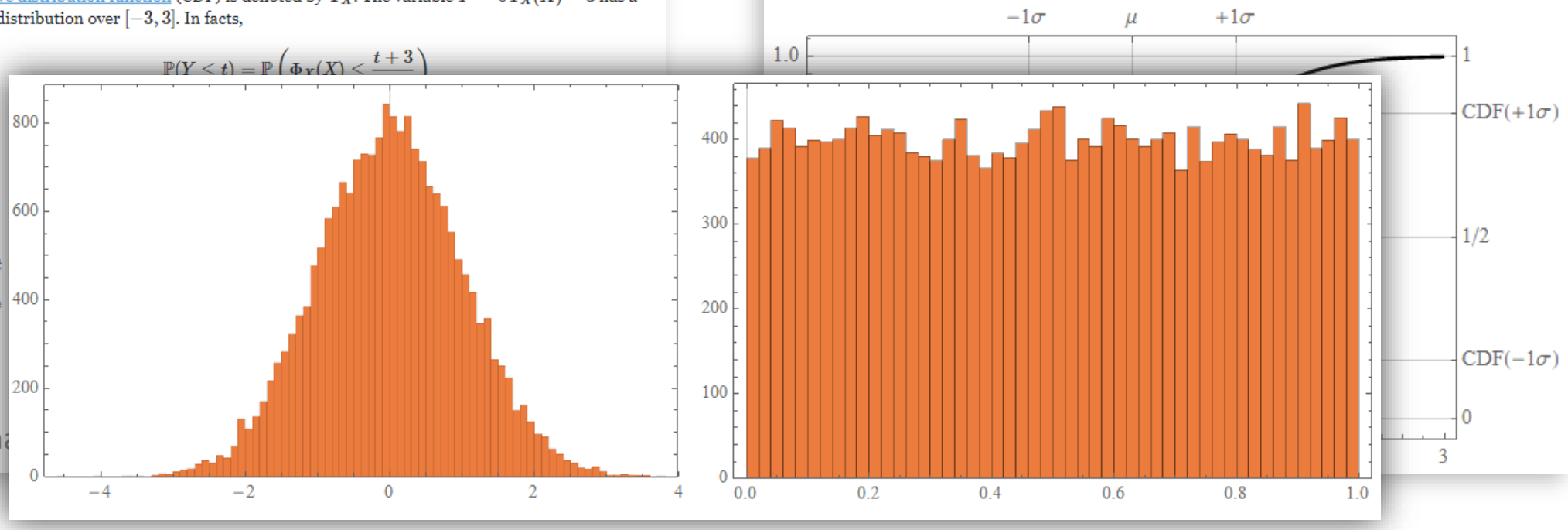
if $-3 \leq t$

share cite

https://ma

CDF

$$U_1(\mu, \sigma) = \frac{1}{2}\left[1 + \text{erf}\left(\frac{x - \mu}{\sqrt{2}\,\sigma}\right)\right]$$

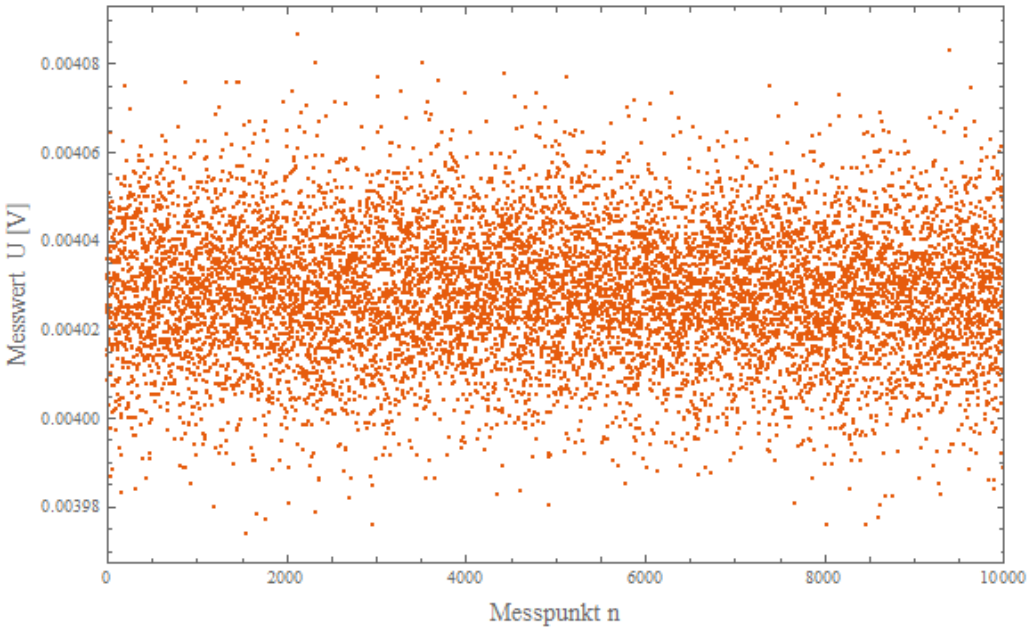


CDF evaluation

First measurements

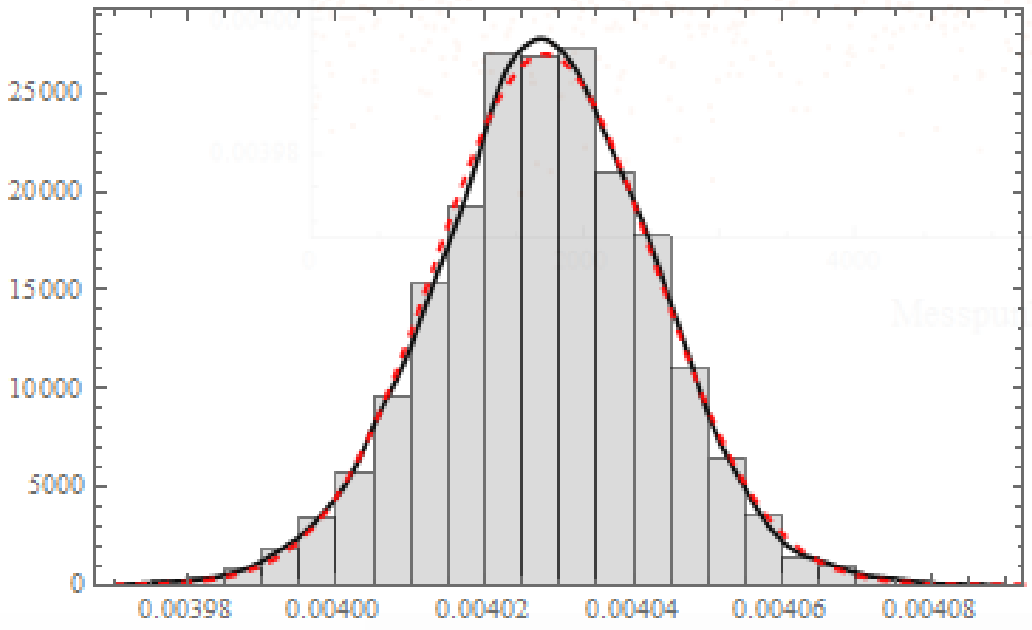
Electrical noise of the PD

Electrical noise of the PD prevalent normal distributed with set gain of 20 dB



Histogram

Perfectly gauss (or is it?)

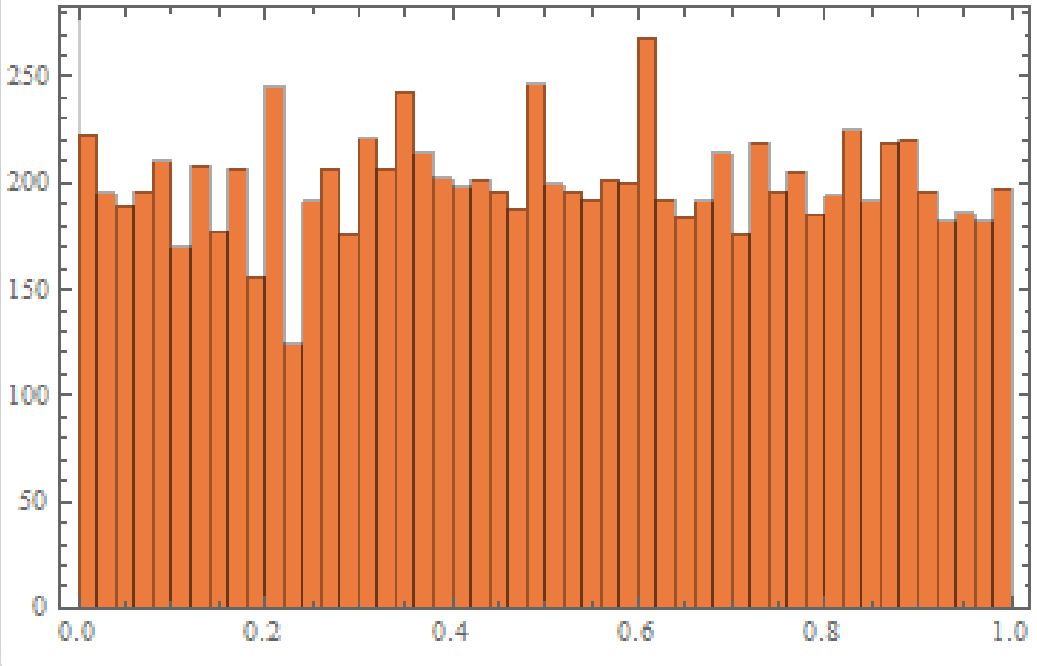


Electrical noise evaluation

First measurements

Electrical noise of the PD

Apply CDF evaluation



Result

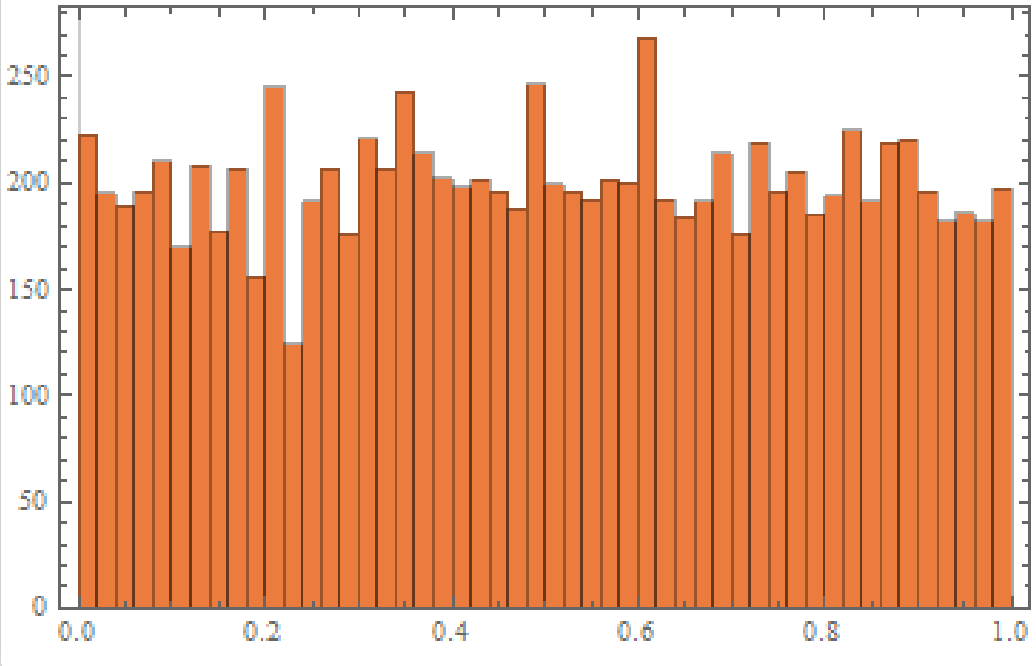
Looks good doesn't it?

Electrical noise evaluation

First measurements

Electrical noise of the PD

Apply CDF evaluation



Electrical noise evaluation

Result

NIST test suite with binarize(uniform*10^6):

First measurements

Number	Name	P-Value	Time
1	MonobitFrequencyTest	3.97792×10^{-111}	0.03125
2	BlockFrequencyTest	2.10146×10^{-11}	0.03125
3	RunsTest	0.000148928	0.046875
4	LongestRunsOnes10000	0.000289803	0.0625
5	BinaryMatrixRankTest	0.347651	0.0625
6	SpectralTest	0.947477	0.15625
7	NonOverlappingTemplateMatching	5.52455×10^{-42}	0.015625
8	OverlapingTemplateMatching	0.000159769	0.015625
9	MaurersUniversalStatisticTest	0.0459829	0.359375
10	LinearComplexityTest	0.994662	2.75
11	SerialTest	$\{1.6818084733 \times 10^{-91\,482}, 2.4336268069 \times 10^{-37\,729}\}$	1.84375
12	ApproximateEntropyTest	$1.899254225243 \times 10^{-5289}$	0.984375
13	CumulativeSumsTest	0.	0.015625
14	RandomExcursionsTest	{{-4., 0.378324}, {-3., 0.784066}, {-2., 0.665949}, {-1., 0.584179}, {1., 0.22782}, {2., 0.189628}, {3., 0.63857}, {4., 0.576152}}	0.15625
15	RandomExcursionsVariantTest	{{-9., 0.431923}, {-8., 0.402784}, {-7., 0.368803}, {-6., 0.35212}, {-5., 0.328443}, {-4., 0.321461}, {-3., 0.300623}, {-2., 0.24681}, {-1., 0.164915}, {1., 0.757621}, {2., 0.24681}, {3., 0.214193}, {4., 0.243443}, {5., 0.303626}, {6., 0.35212}, {7., 0.392041}, {8., 0.425556}, {9., 0.500545}}	0.03125
16	CumulativeSumsTestReverse	0.	0.015625
17	LempelZivCompressionTest	$2.226089178210959 \times 10^{-9\,221\,056}$	1.

First measurements

Wtf…

Number	Name	P-Value	Time
1	MonobitFrequencyTest	3.97792×10^{-111}	0.03125
2	BlockFrequencyTest	2.10146×10^{-11}	0.03125
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16	CumulativeSumsTestReverse	0.	0.015625
17	LempelZivCompressionTest	$2.226089178210959 \times 10^{-9\,221056}$	1.

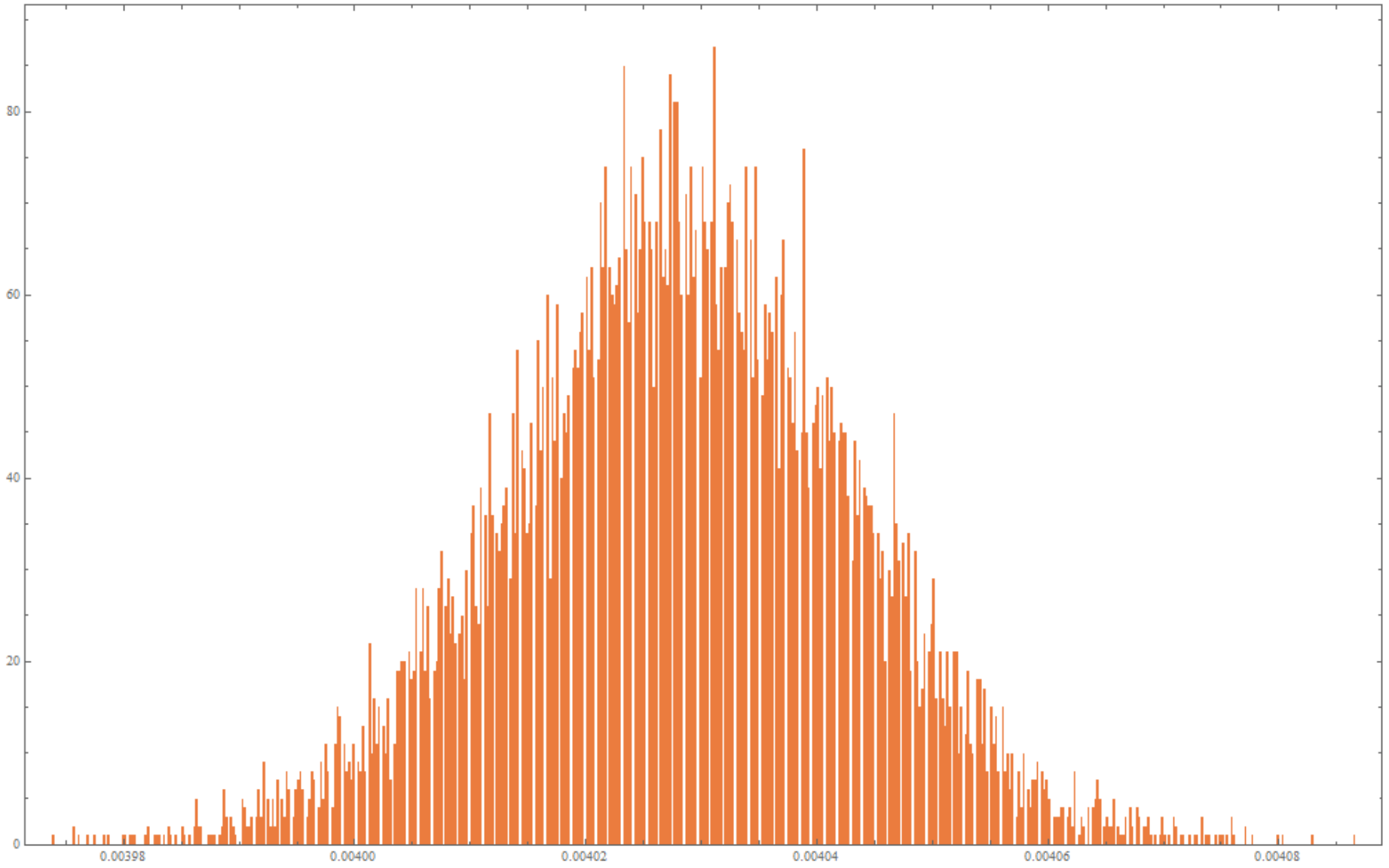
First measurements

Better, but far less data

Again with binarize(uniform)

Number	Name	P-Value	Time
1	MonobitFrequencyTest	0.841481	0.
2	BlockFrequencyTest	0.104708	0.015625
3	RunsTest	0.936555	0.
4	LongestRunsOnes10000	0.653236	0.
5	BinaryMatrixRankTest	0.587007	0.
6	SpectralTest	0.270812	0.015625
7	NonOverlappingTemplateMatching	0.732903	0.
8	OverlapingTemplateMatching	0.106393	0.
9	MaurersUniversalStatisticTest	0.916699	0.
10	LinearComplexityTest	0.469323	0.171875
11	SerialTest	{0.619757, 0.775994}	0.171875
12	ApproximateEntropyTest	0.107842	0.046875
13	CumulativeSumsTest	0.242276	0.015625
14	RandomExcursionsTest	{{-4., 0.31674}, {-3., 0.479924}, {-2., 0.795072}, {-1., 0.394781}, {1., 0.17429}, {2., 0.20817}, {3., 0.396093}, {4., 0.462675}}	0.015625
15	RandomExcursionsVariantTest	{{-9., 0.509517}, {-8., 0.404943}, {-7., 0.361695}, {-6., 0.340356}, {-5., 0.332164}, {-4., 0.363681}, {-3., 0.61067}, {-2., 0.826581}, {-1., 0.254945}, {1., 0.0268567}, {2., 0.0259202}, {3., 0.0619348}, {4., 0.315382}, {5., 0.527089}, {6., 0.423185}, {7., 0.361695}, {8., 0.273909}, {9., 0.304075}}	0.
16	CumulativeSumsTestReverse	0.35393	0.015625
17	LempelZivCompressionTest	$1.331464696271033 \times 10^{-14425\,262}$	0.046875

Electrical noise fault



Electrical noise evaluation

ADC discretization

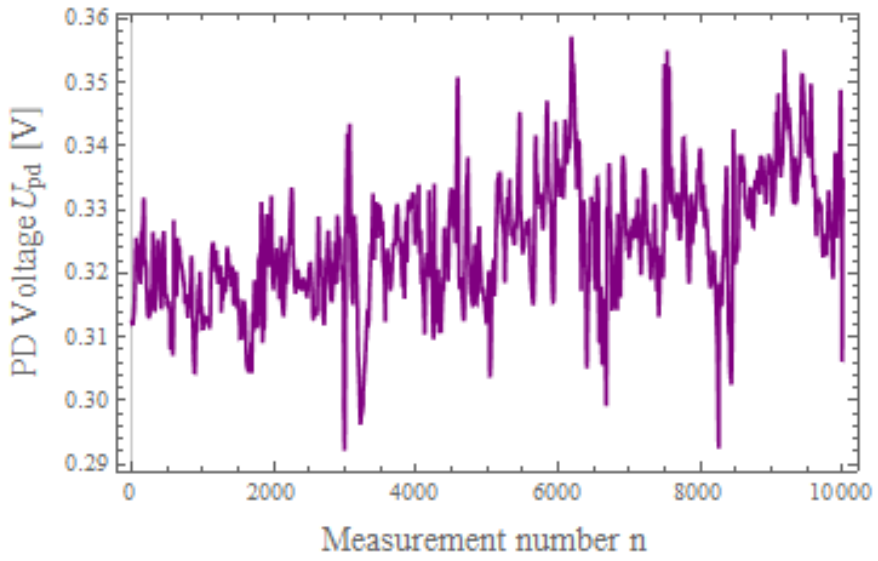
387 different values where measured

equivalent: 300 nV/sample

Laser power attenuation measurement

PD Power measured

Laser power (non-resonant) measured by PD with 5% of intensity and gas cell at 75°C



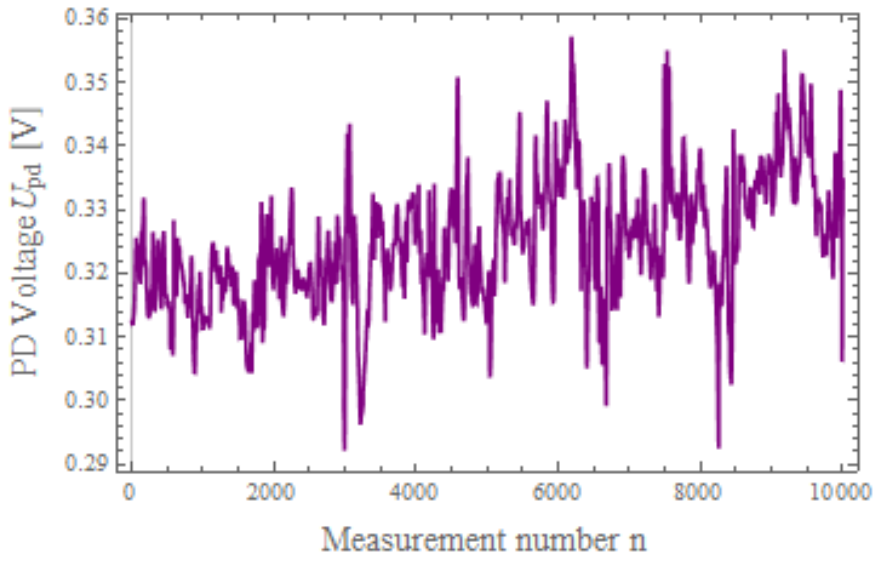
Evaluation

What do we want from that signal?

Laser power attenuation measurement

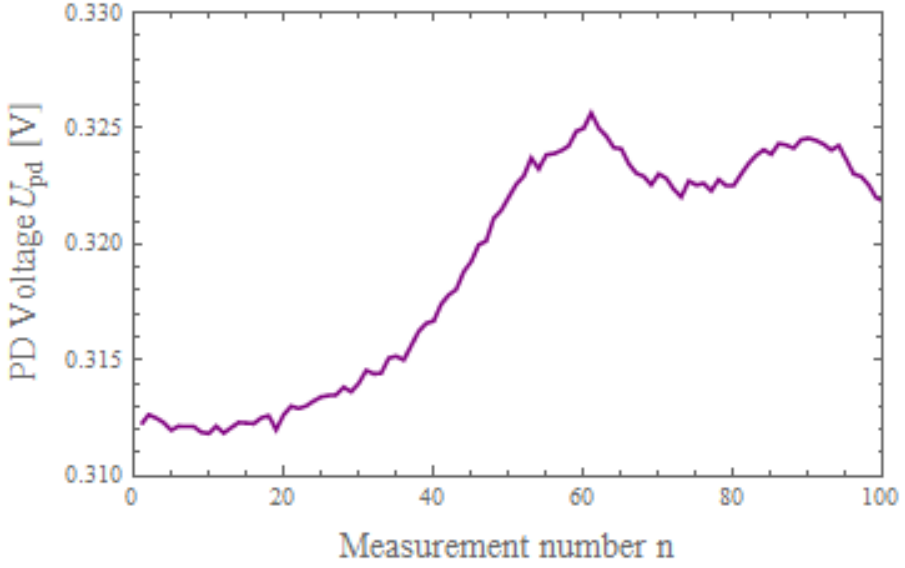
PD Power measured

Laser power (non-resonant) measured by PD with 5% of intensity and gas cell at 75°C



Evaluation

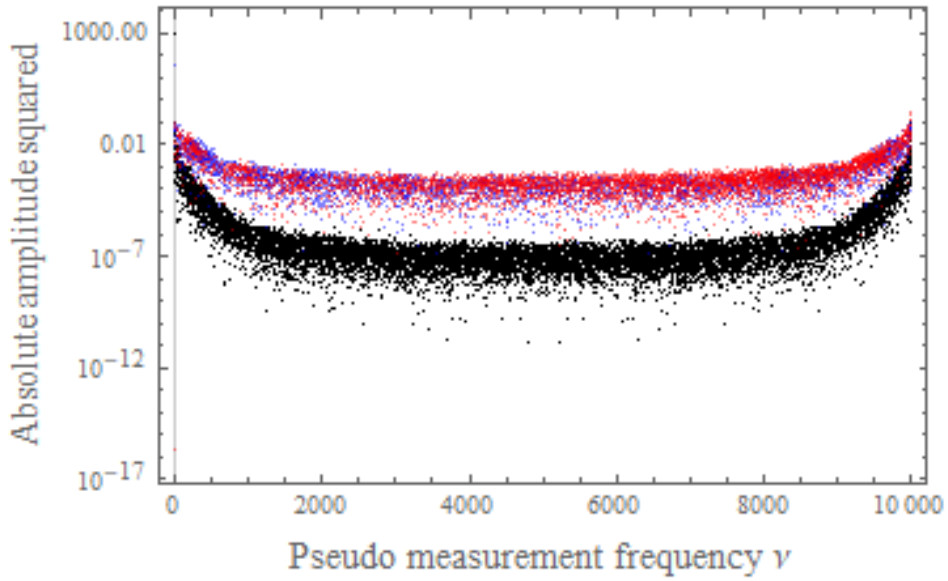
What do we want from that signal?



Laser power attenuation measurement

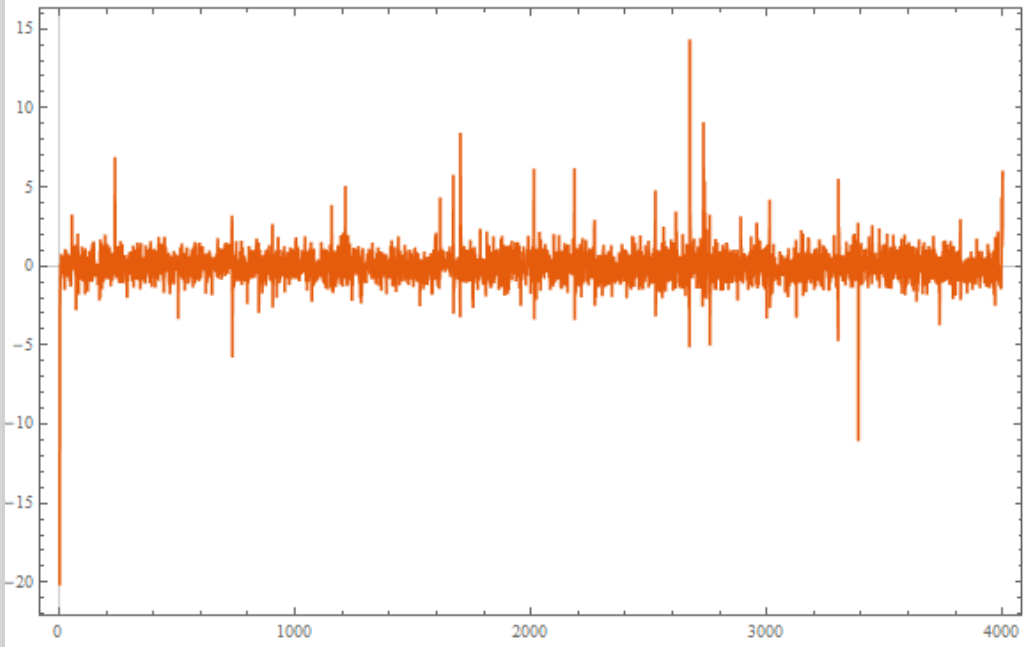
Fourier filtering

Filter out lower frequency components by the means of a FFT



Evaluation

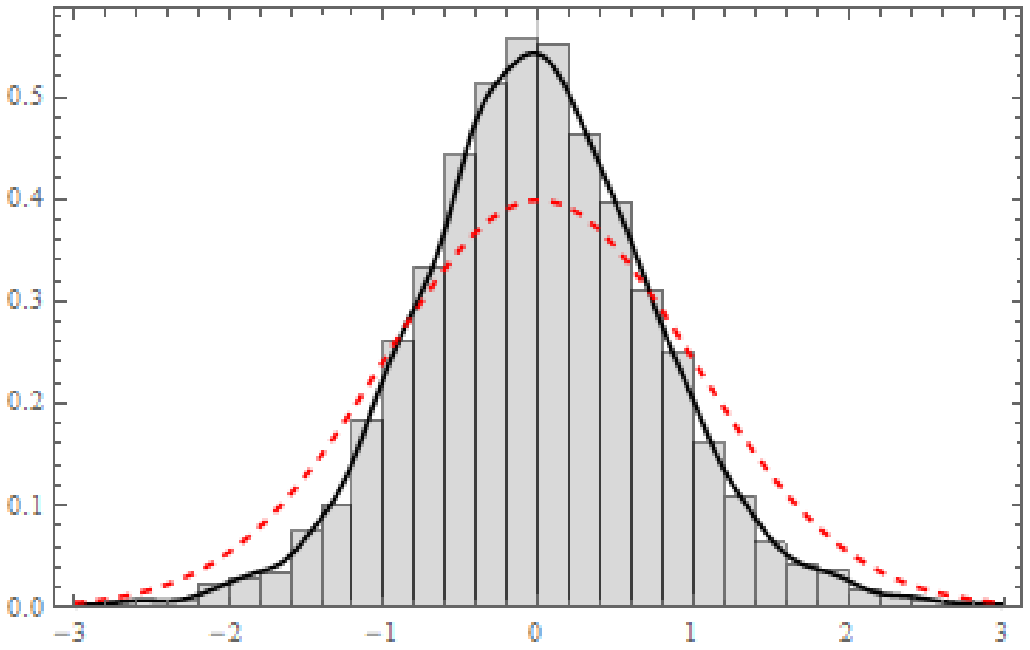
Normed back transformation result:



Laser power attenuation measurement

Histogram

WTF v2

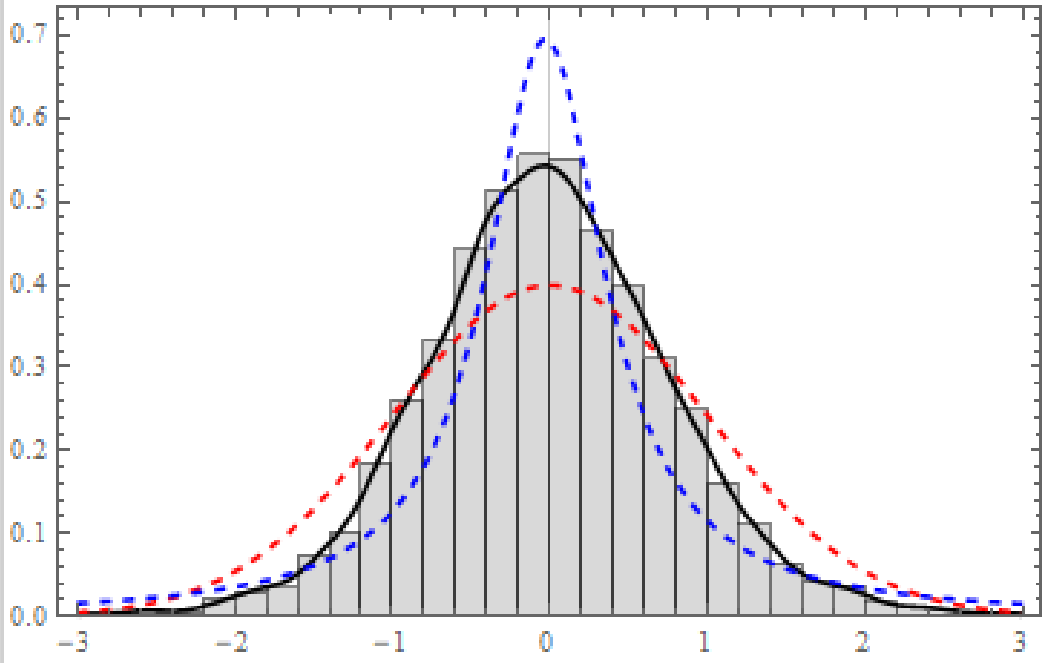


Evaluation

Laser power attenuation measurement

Histogram

WTF v2

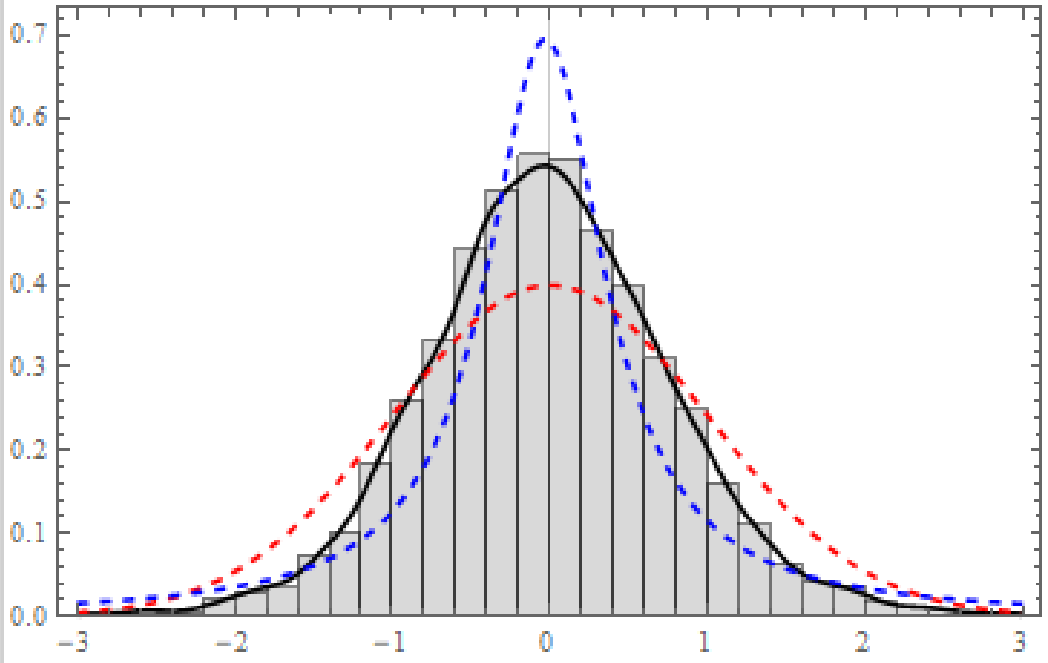


Evaluation

Laser power attenuation measurement

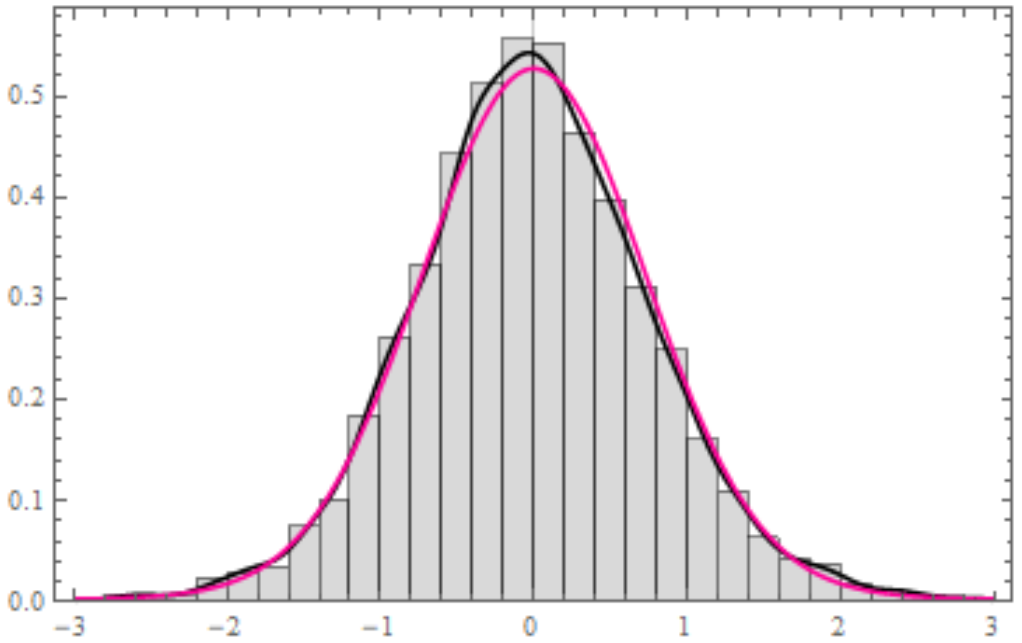
Histogram

WTF v2



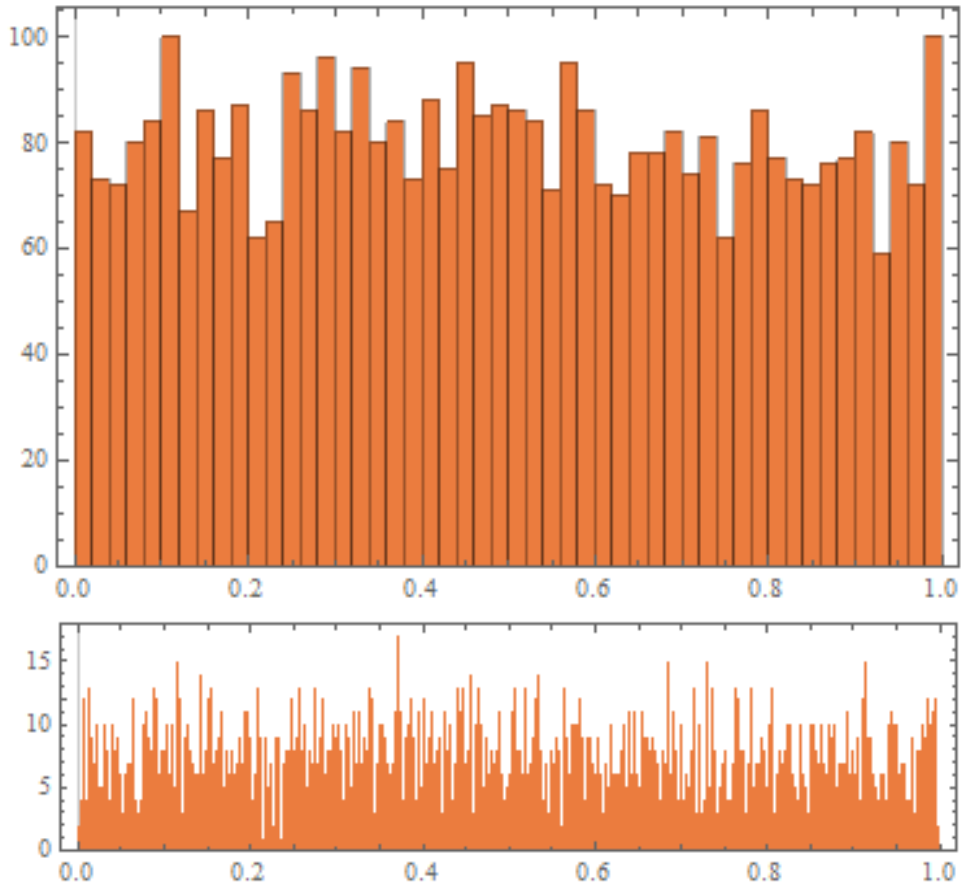
Evaluation

Voigt distribution with
$\sigma = 0.71$ and $\Gamma = 0.054$



Laser power attenuation measurement

CDF



Evaluation

Laser noise evaluation

Laser power attenuation measurement

Number	Name	P-Value	Time
1	MonobitFrequencyTest	8.52249×10^{-29}	0.015625
2	BlockFrequencyTest	0.346865	0.03125
3	RunsTest	0.302571	0.046875
4	LongestRunsOnes10000	0.0596088	0.046875
5	BinaryMatrixRankTest	0.601812	0.046875
6	SpectralTest	0.804172	0.109375
7	NonOverlappingTemplateMatching	0.0795404	0.015625
8	OverlapingTemplateMatching	0.0133263	0.
9	MaurersUniversalStatisticTest	0.955476	0.3125
10	LinearComplexityTest	0.419316	2.67188
11	SerialTest	{0.245029, 0.0560255}	1.89063
12	ApproximateEntropyTest	0.0316065	0.890625
13	CumulativeSumsTest	$-2.65683 \times 10^{-245}$	0.03125
14	RandomExcursionsTest	{{-4., 0.143588}, {-3., 0.769867}, {-2., 0.250748}, {-1., 0.369626}, {1., 0.545633}, {2., 0.426357}, {3., 0.220249}, {4., 0.382739}}	0.09375
15	RandomExcursionsVariantTest	{{-9., 0.454735}, {-8., 0.769371}, {-7., 0.718894}, {-6., 0.27111}, {-5., 0.15187}, {-4., 0.177367}, {-3., 0.118813}, {-2., 0.241706}, {-1., 0.935354}, {1., 0.33039}, {2., 0.281447}, {3., 0.179554}, {4., 0.326581}, {5., 0.892466}, {6., 0.281903}, {7., 0.149939}, {8., 0.160569}, {9., 0.18099}}	0.03125
16	CumulativeSumsTestReverse	$-1.53393 \times 10^{-253}$	0.03125
17	LempelZivCompressionTest	$2.231650903975532 \times 10^{-9.852947}$	0.796875

Laser power attenuation measurement

Number	Name	P-Value	Time
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16	CumulativeSumsTestReverse	$-1.53393 \times 10^{-253}$	0.03125
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00011100110111111011111011011011101110111011101011010111100101101101001001100111110111001110100011101111

Laser noise evaluation

Laser power attenuation measurement

Results

For every measurement:
Monobit test & CumSum test fails

Always compressible

Correlation of successive values suspected

Temperature not dependent

Worse quality than pi or e

schade.

Laser power attenuation measurement

Results

For every measurement:
Monobit test & CumSum test fails

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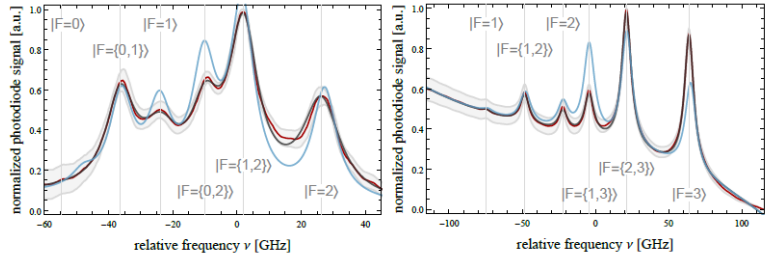
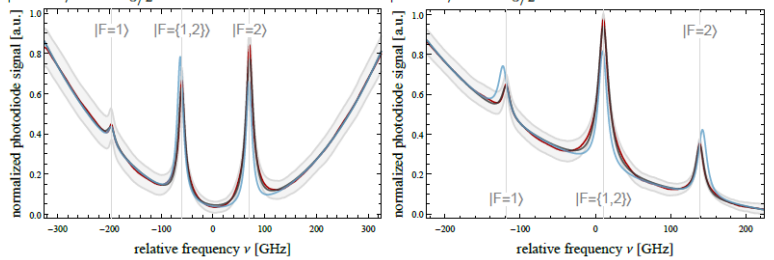
schade.



(a) Doppler free absorption spectrum for $|F=1\rangle \rightarrow 6\mathrm{P}_{3/2}$.

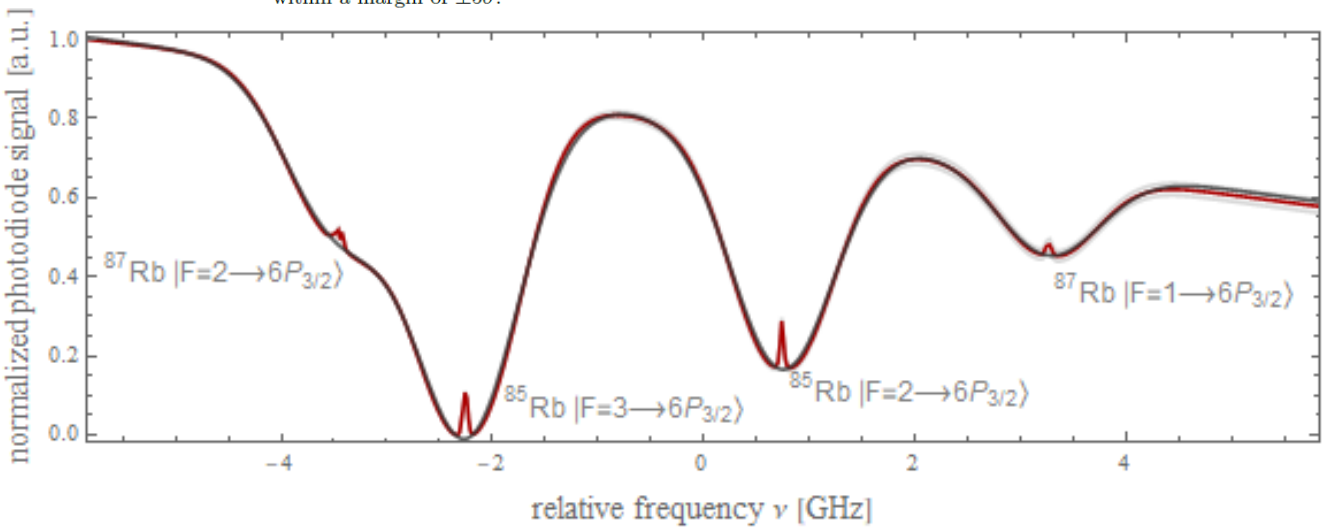
(b) Doppler free absorption spectrum for $|F=2\rangle \rightarrow 6\mathrm{P}_{3/2}$.



(c) Doppler free absorption spectrum for $|F=1\rangle \rightarrow 6\mathrm{P}_{1/2}$.

(d) Doppler free absorption spectrum for $|F=2\rangle \rightarrow 6\mathrm{P}_{2/2}$.

Figure 12: Doppler free absorption spectroscopy signals (red) of ^{87}Rb with Lorentz fits (gray) and theoretical spectrum (blue). The error interval (light gray) is given within a margin of $\pm 5\sigma$.



Vielen Dank für die Aufmerksamkeit