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Generator of arbitrary classical photon statistics

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Outline

- Photon statistics
- Obtaining intensity distribution from statistics
- Experimental generation and detection
- Results

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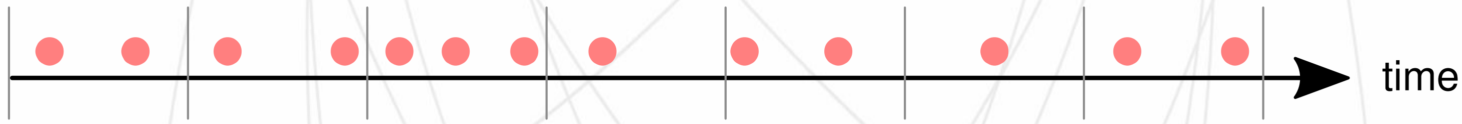
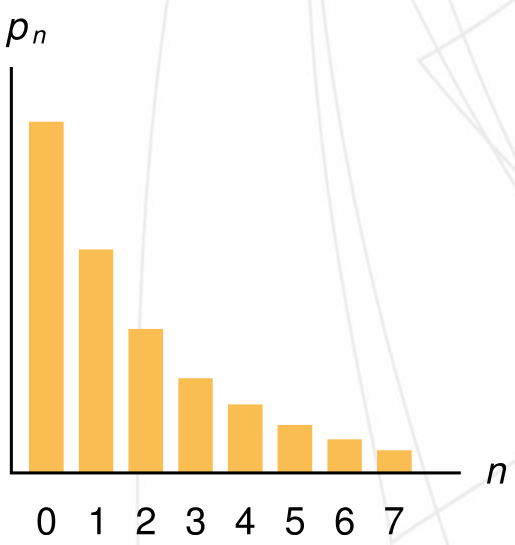
Photon statistics





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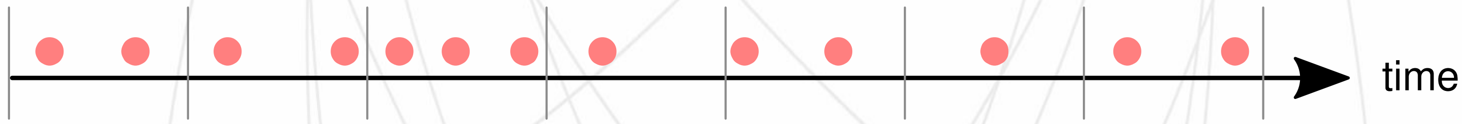
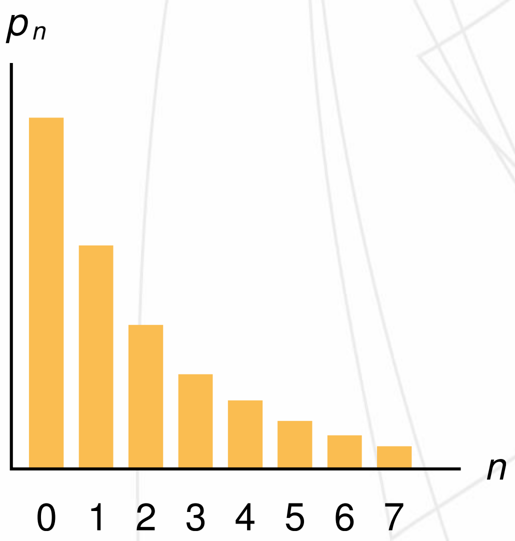
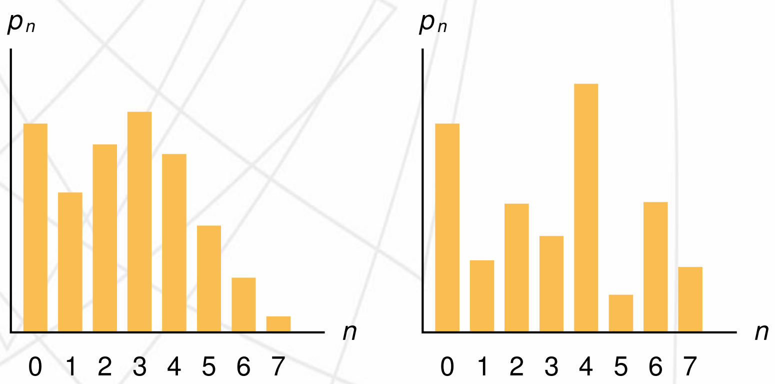




We want arbitrary statistics:



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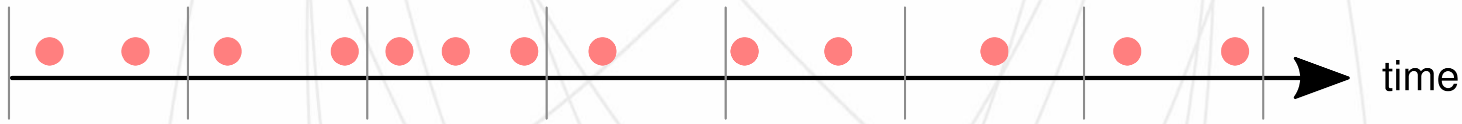
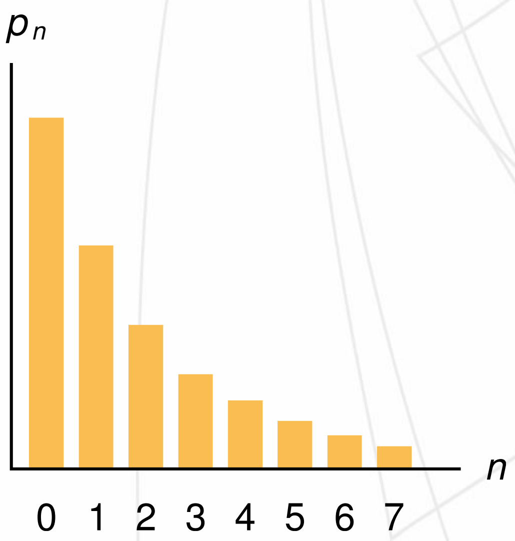
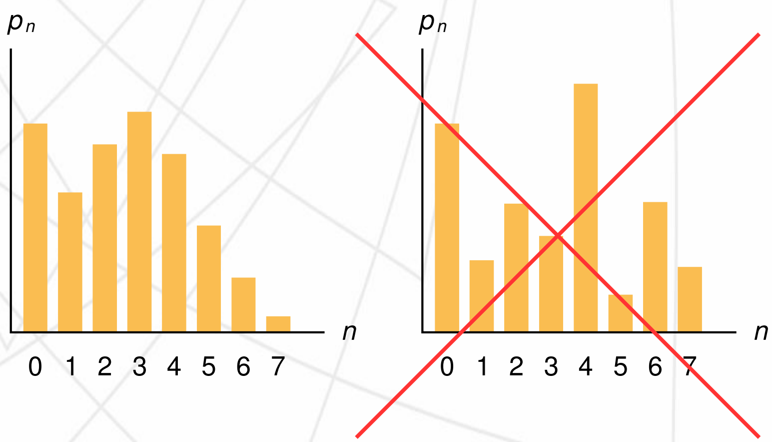
Photon statistics





We want arbitrary ***classical*** statistics:



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Motivation

- Detector metrology
- Improving efficiency of nonlinear phenomena
- Simulating fading channels and noise
- Generating asymmetric and heavy-tailed statistics

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Semi-classical view on photon statistics

Constant integrated intensity W: $p_n = \frac{W^n}{n!} e^{-W}$

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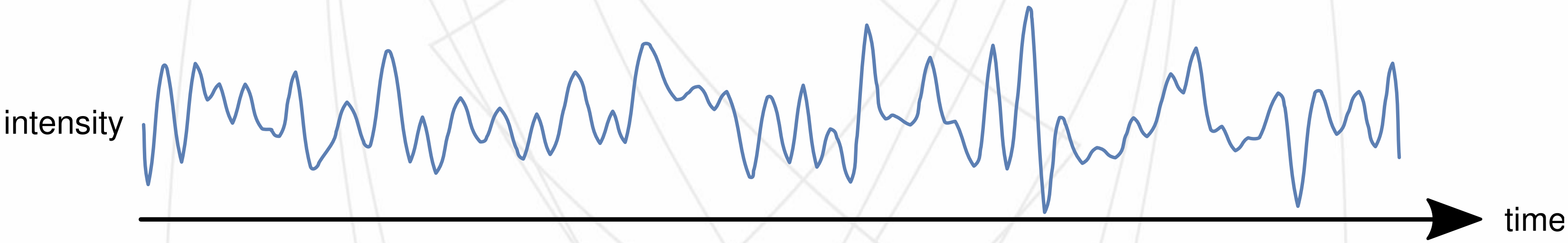


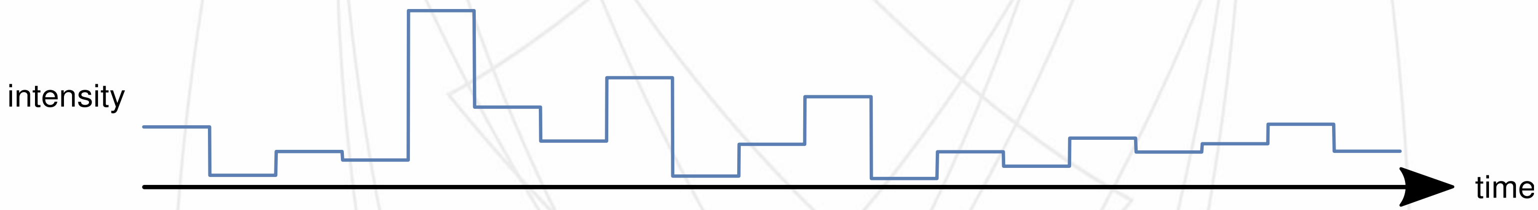
Mandel's formula: $p_n = \left\langle \frac{W^n}{n!} e^{-W} \right\rangle_W = \int_0^\infty \frac{W^n}{n!} e^{-W} P(W)\, dW$

Inversion is hard: $P(W) = f(p_n)$

Bédard, J. Opt. Soc. Am. 57, 1201 (1967)
Byrne, Haughton, Jiang, Inverse Probl. 9, 39 (1993)
Earnshaw, Haughey, Rev. Sci. Instruments 67, 4387 (1996)

Discrete case

Discrete levels W_i : $$p_n = \sum_i \frac{W_i^n}{n!} e^{-W_i} P(W_i) = \sum_i A_{ni} P_i \qquad P_i \geq 0, \quad \sum P_i = 1$$



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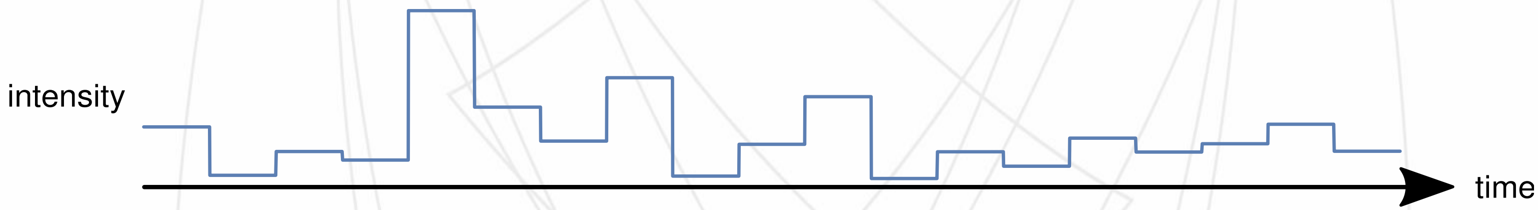
Discrete case

Discrete levels W_i : $p_n = \sum_i \frac{W_i^n}{n!} e^{-W_i} P(W_i) = \sum_i A_{ni} P_i$ $P_i \geq 0$ $\sum P_i = 1$

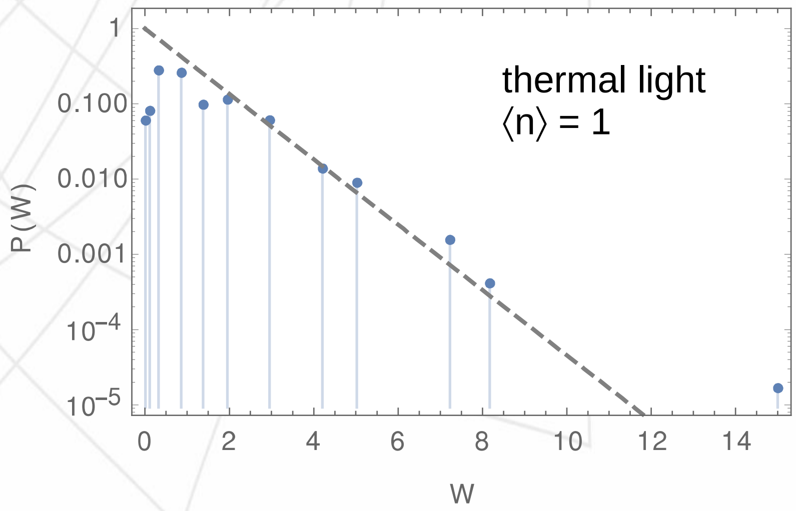


Non-negative least squares (NNLS) for underdetermined case

$n_{max} \leq 16$

$i \leq 127$

For all data we use perfect solutions for $n \leq n_{max}$



C. L. Lawson and R. J. Hanson, Solving Least Squares Problems (SIAM, 1987).

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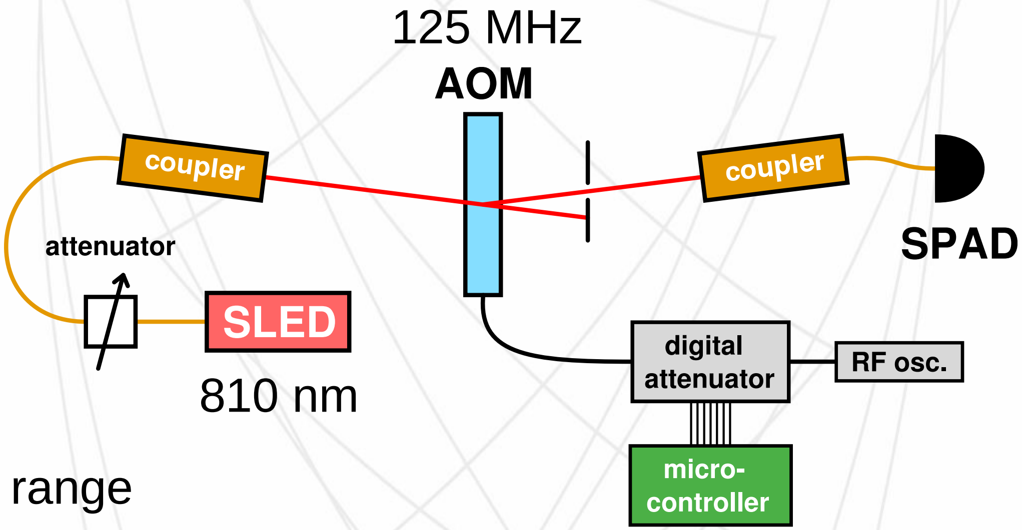
Experimental modulation



32 dB dynamic range

128 attenuation levels

300 ns response time

Detection and timing

Detector recovery time ≪ detection window ≪ modulation period ≪ measurement time

23 ns 10 μs 1 ms 100 s

Detection model: recovery time + afterpulses (with twilight pulses) with a fixed temporal distribution
→ parameters measured separately and used for all data
accuracy $\delta p \sim 10^{-4}$

Verify accurate generation for cw using SPAD ⇒ works just as well for pulsed

Specify p_n → Get P(W)

Measure data

compare

Model detector response

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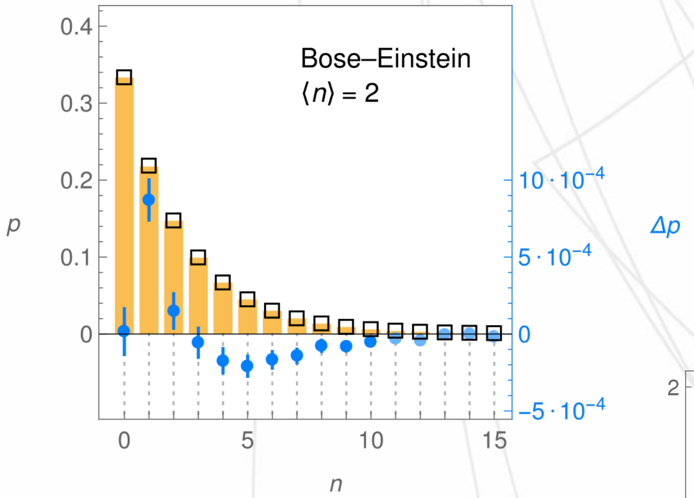
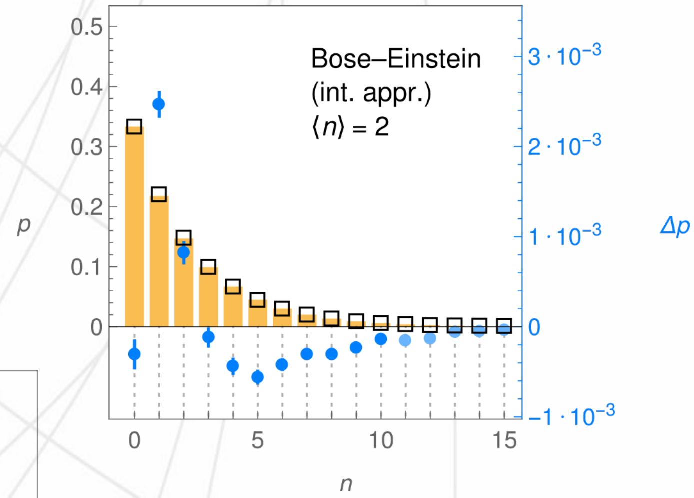
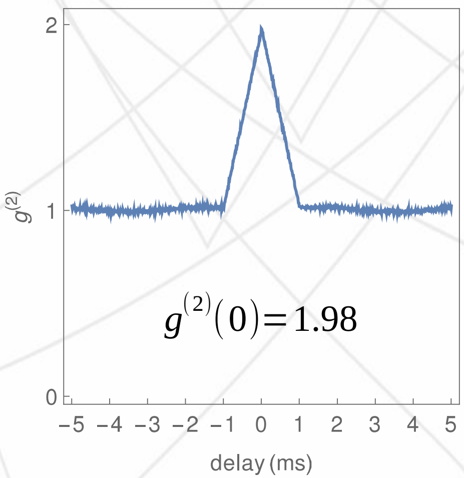
Data





Total variation distance < 3.5×10^{-3}



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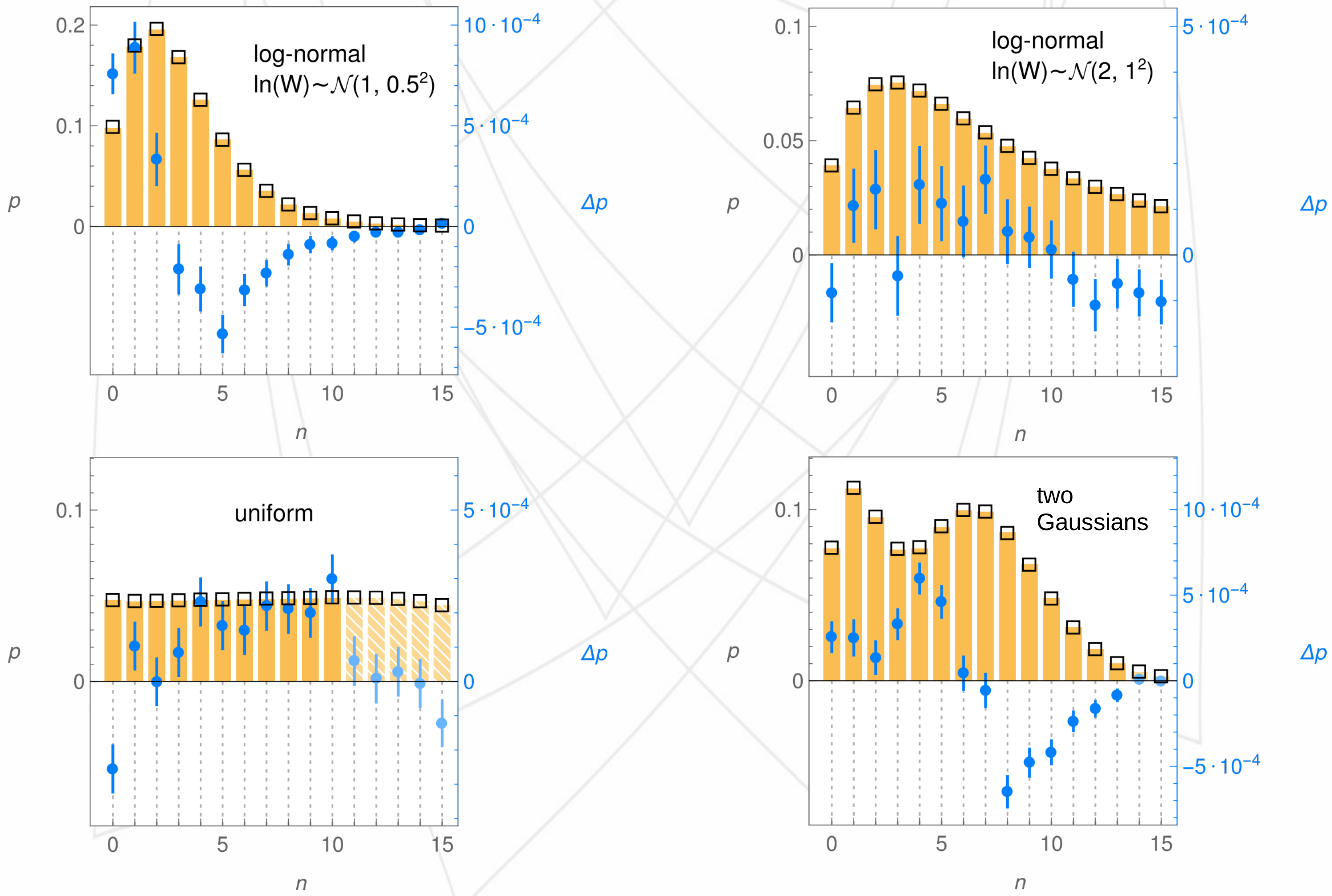
Data



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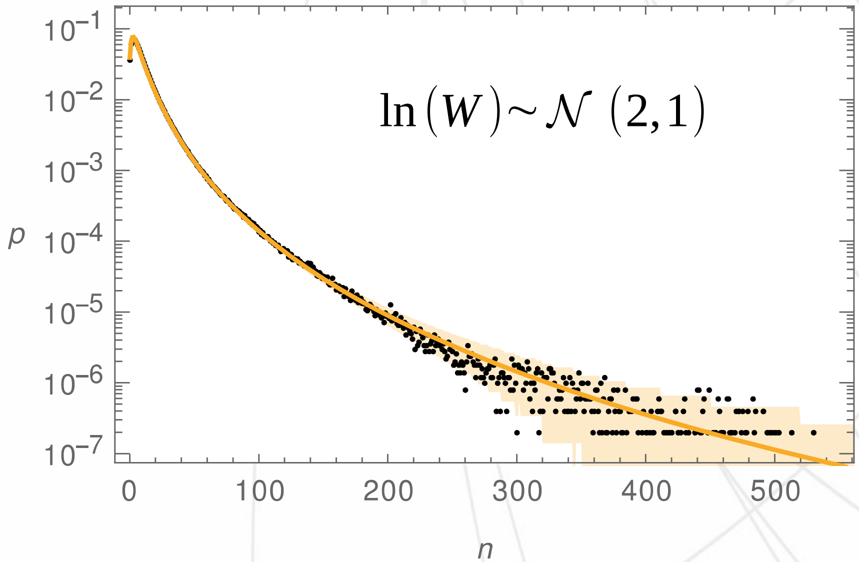
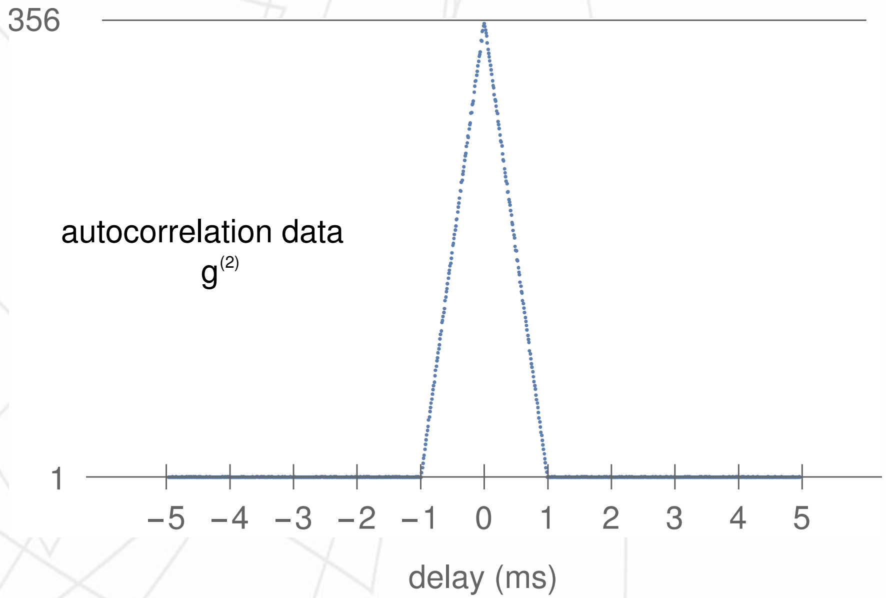
Exploring the extremes





Heavy-tailed scaling

High bunching

The main limit: dynamic modulation range

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Scope and extensions

Dynamic range: chained modulators

Same setup works for pulsed regime, but different PNRD needed (already works for 20-nm spectrum)

Pulsed: possible repetition rate of 2 MHz

Speed: electro-optical or electro-absorption modulation (40 GHz)
EOM downside: lower range (20 dB) and bad stability

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Conclusion

We demonstrated highly accurate generation of photon statistics

We proposed an efficient inversion method to obtain intensity distribution

The concept can be easily extended to any form of modulation

Thank you for your attention

GAČR
CZECH SCIENCE FOUNDATION

I. Straka, J. Mika, M. Ježek, Opt. Express 26, 8998 (2018).

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