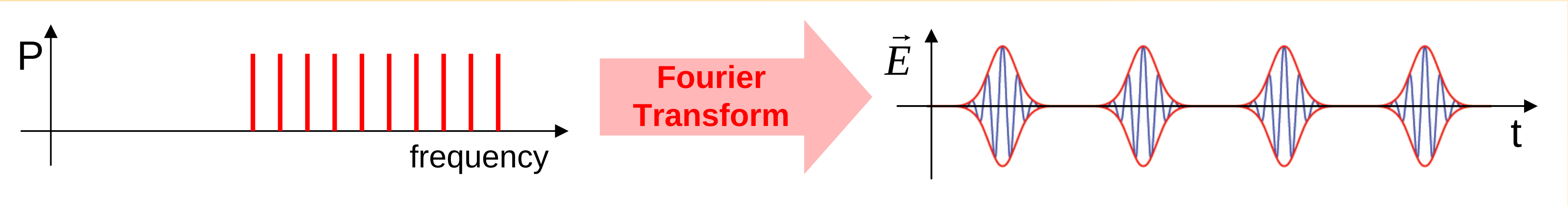
1st Order Coherence

1. What's **coherence**?
2. **Spatial Coherence.**
3. **Temporal Coherence.**
4. 1st order **correlation function.**
5. **Wiener-Khintchine**
6. **Mode-locked lasers**

Optical Frequency Combs

A frequency comb is also a pulsed laser:



A *mode-locked laser* produces the shortest possible pulse:

$$\vec{E}_{total}(t) = \sum_{n=1}^{N} \vec{E}_0 \cos((\omega_0 + n\Delta\omega)t + \phi_n)$$

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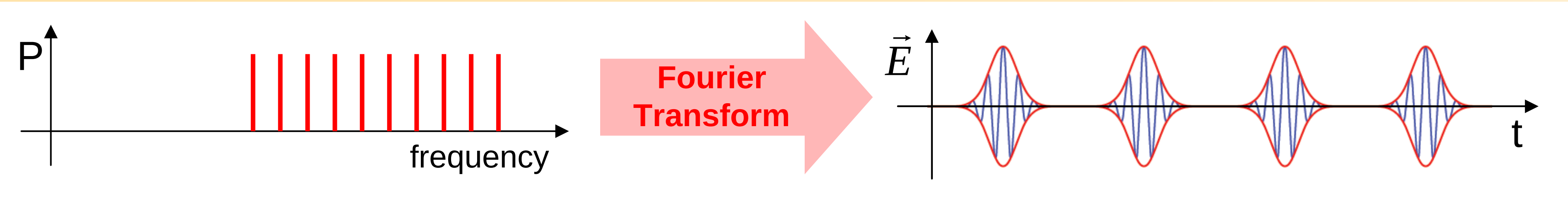

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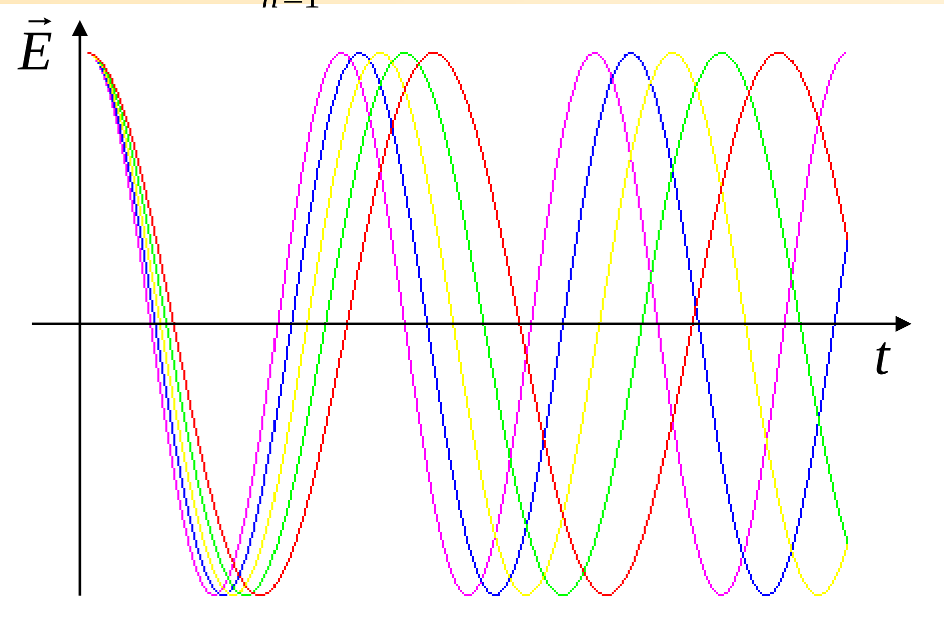

N=5

Δω=ω/10

ϕ_n=0

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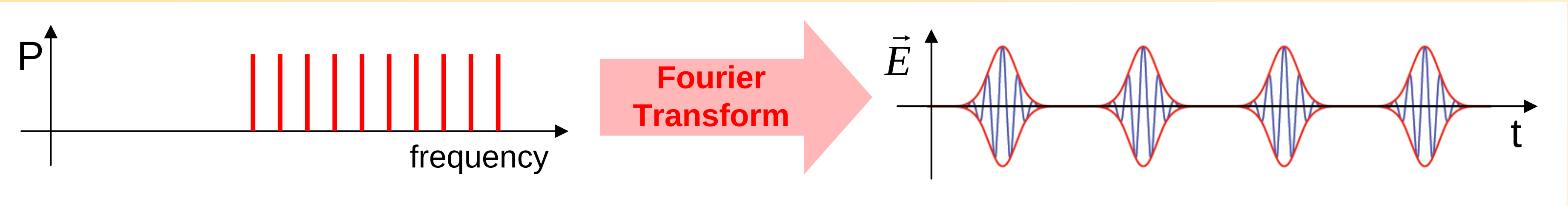

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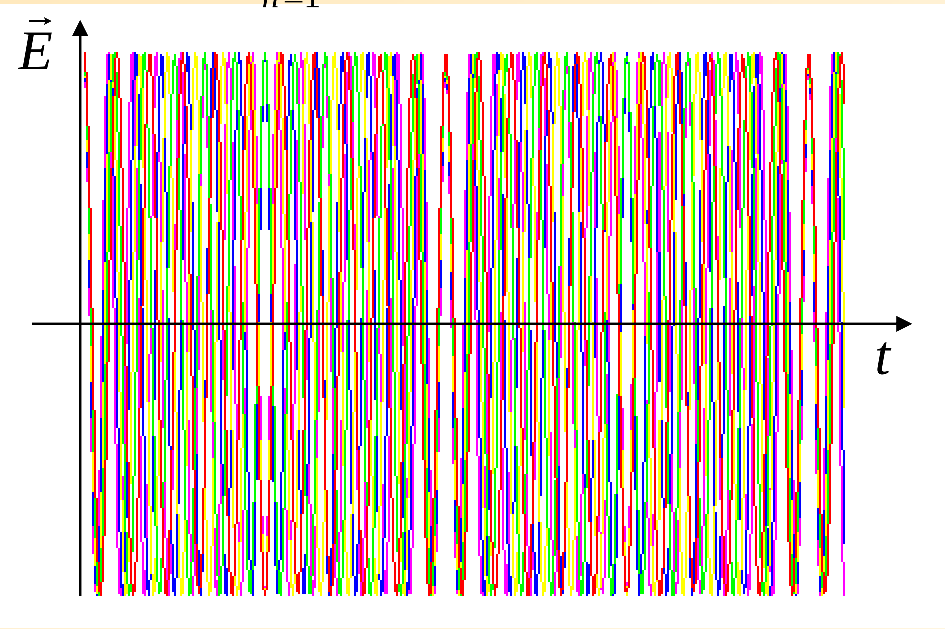

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$\Delta\omega=\omega/10$

$\phi_n=0$

On a longer time scale, the plot repeats every $T=2\pi/\Delta\omega$

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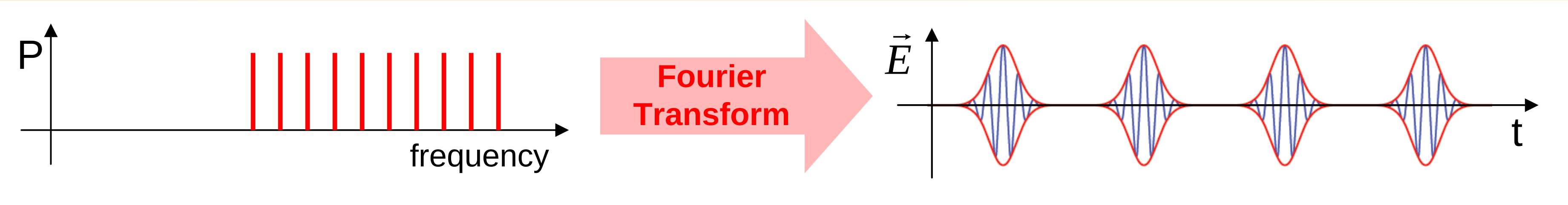

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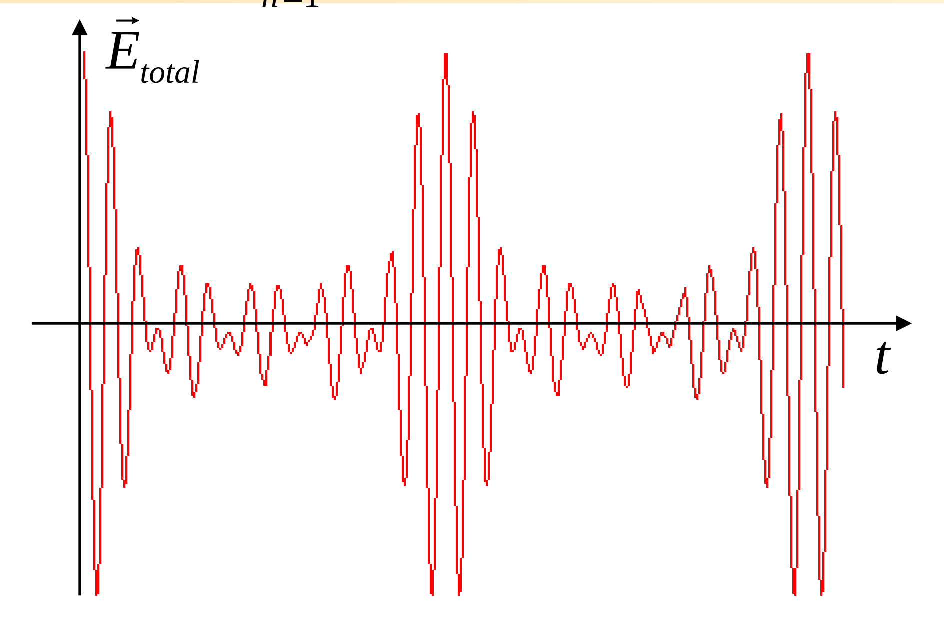
The total electric field is pulsed!!!



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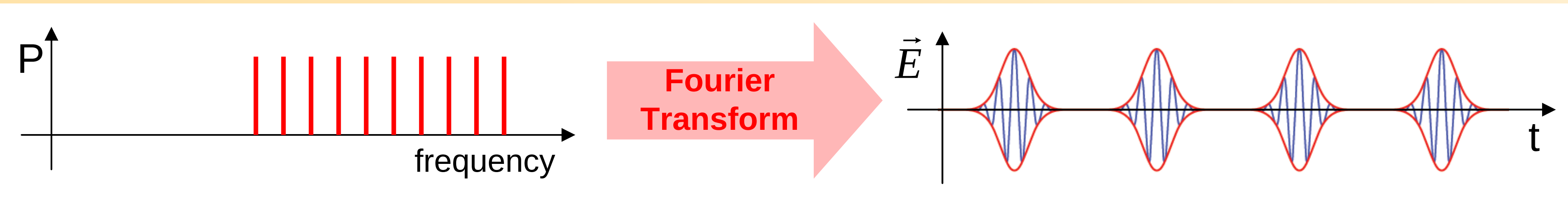

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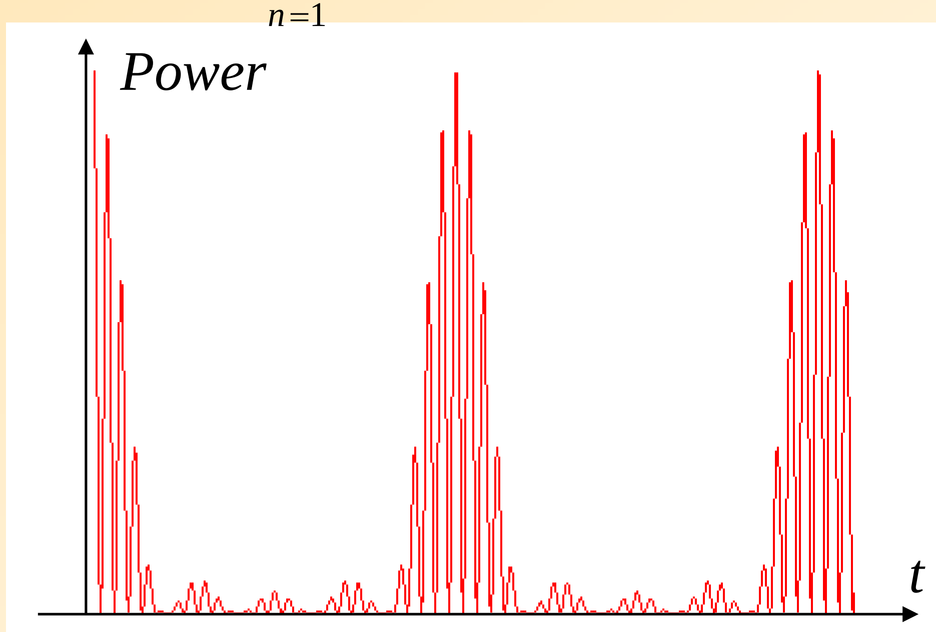
$$\vec{E}_{total}(t) = \sum_{n=1}^{N} \vec{E}_0 \cos((\omega_0 + n\Delta\omega)t + \phi_n)$$

The total power is pulsed!!!



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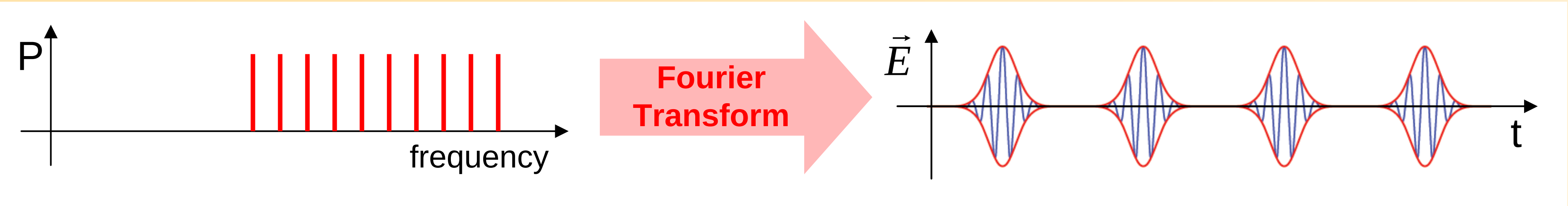

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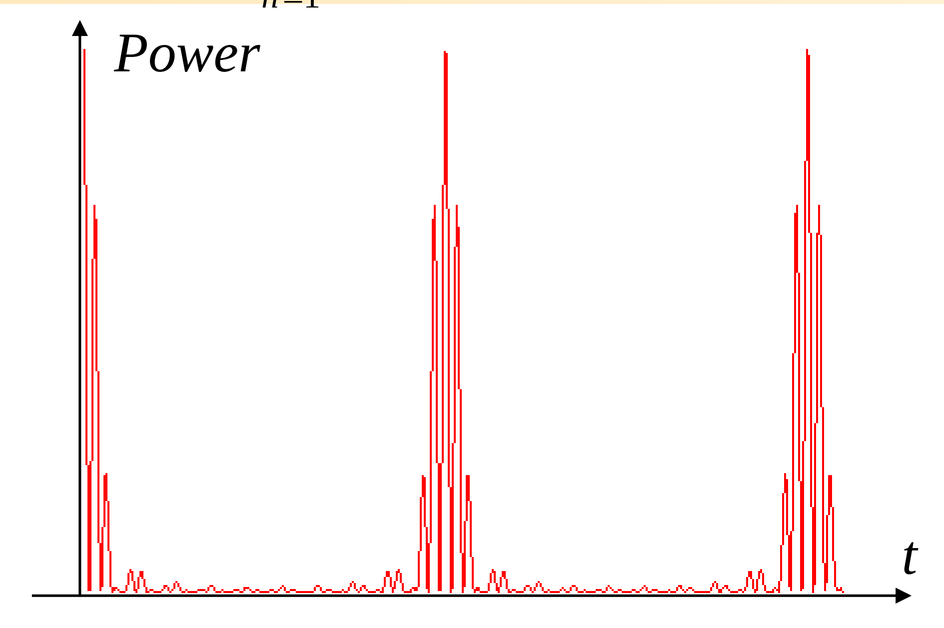
The total power is pulsed!!!

more comb teeth
=
shorter pulses



N=10

$\Delta\omega=\omega/10$

$\phi_n=0$

On a longer time scale, the plot repeats every $T=2\pi/\Delta\omega$

Optical Frequency Combs

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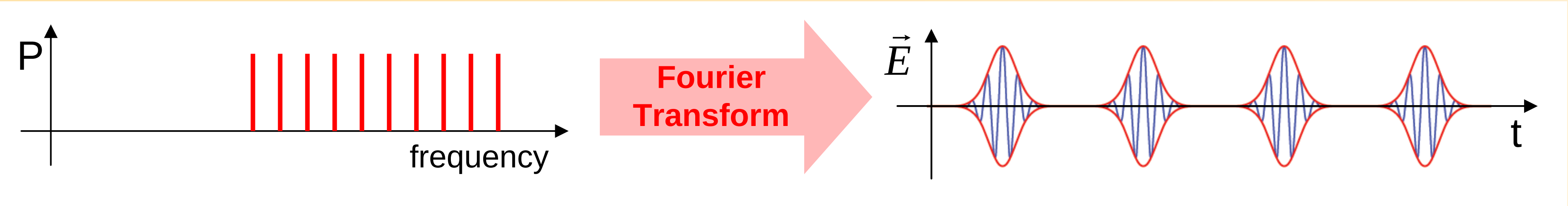

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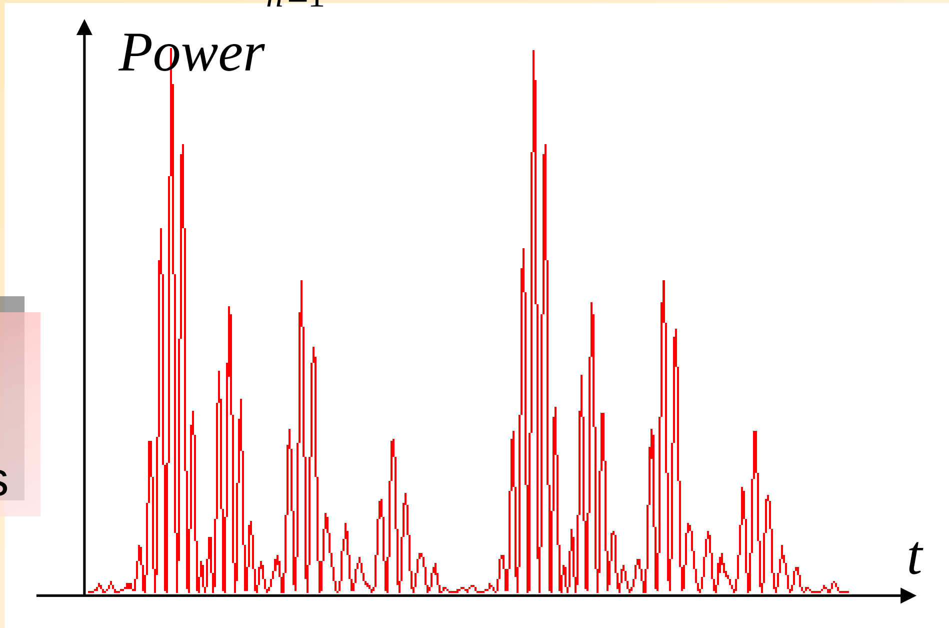


N=10

$\Delta\omega=\omega/10$

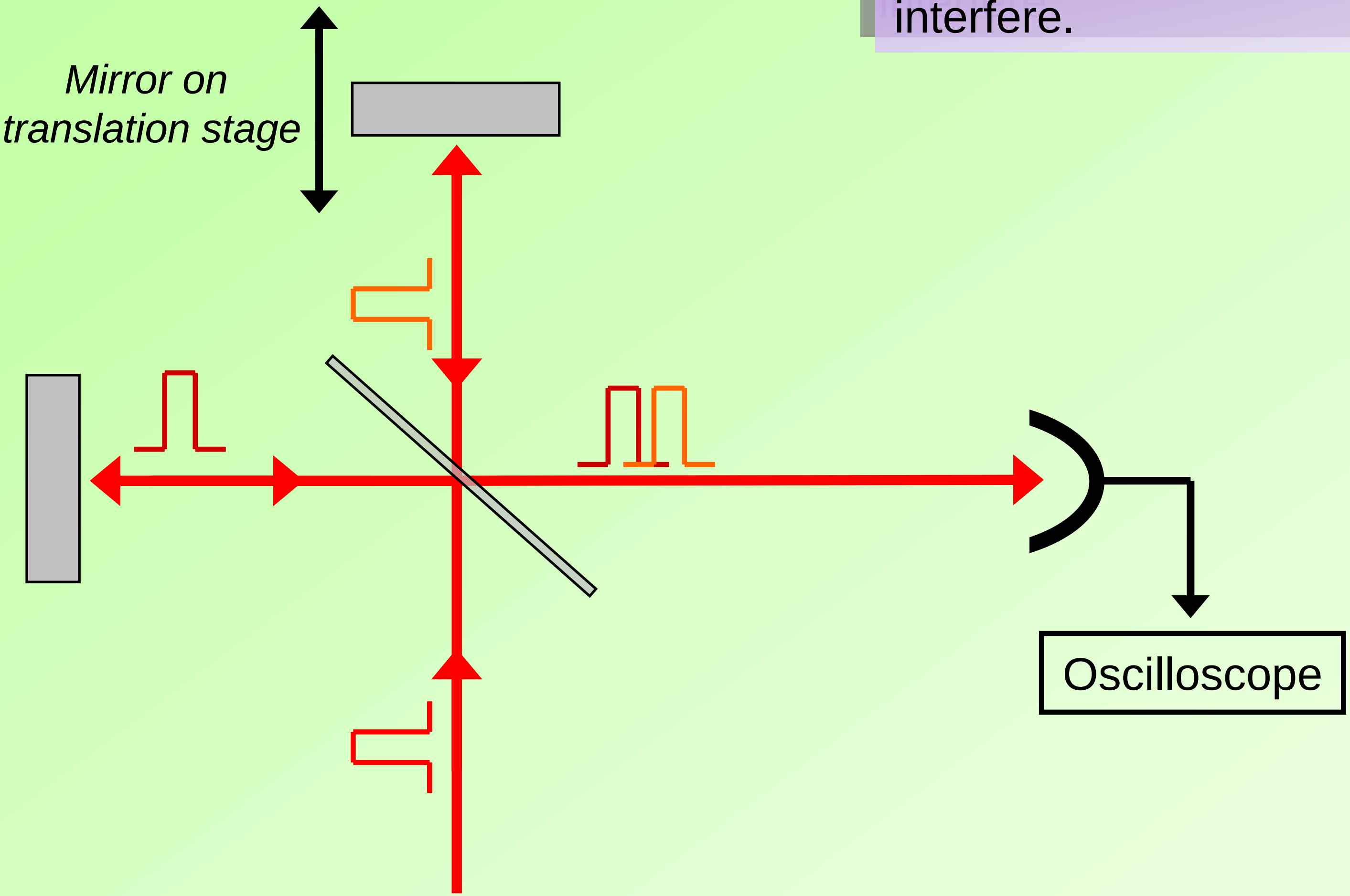
ϕ_n=random

random phases
=
broad random pulses

On a longer time scale, the plot repeats every $T=2\pi/\Delta\omega$

Can you use a Michelson interferometer to measure the pulse time?

Basic principle: When the recombined pulses from both arms overlap, they interfere.



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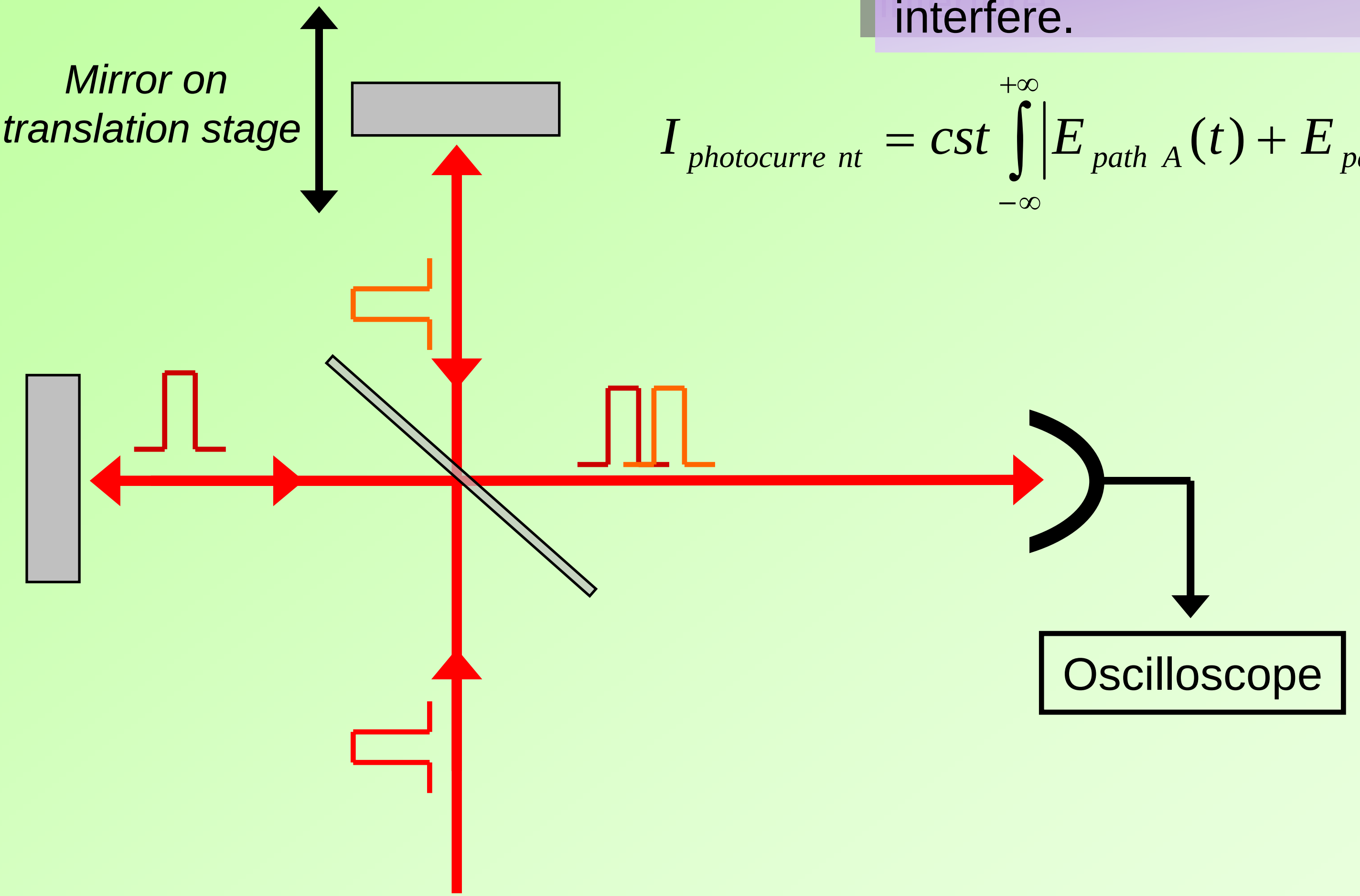
$$I_{photocurrent} = cst \int_{-\infty}^{+\infty} \left| E_{path\ A}(t) + E_{path\ B}(t + t_{delay}) \right|^2 dt$$



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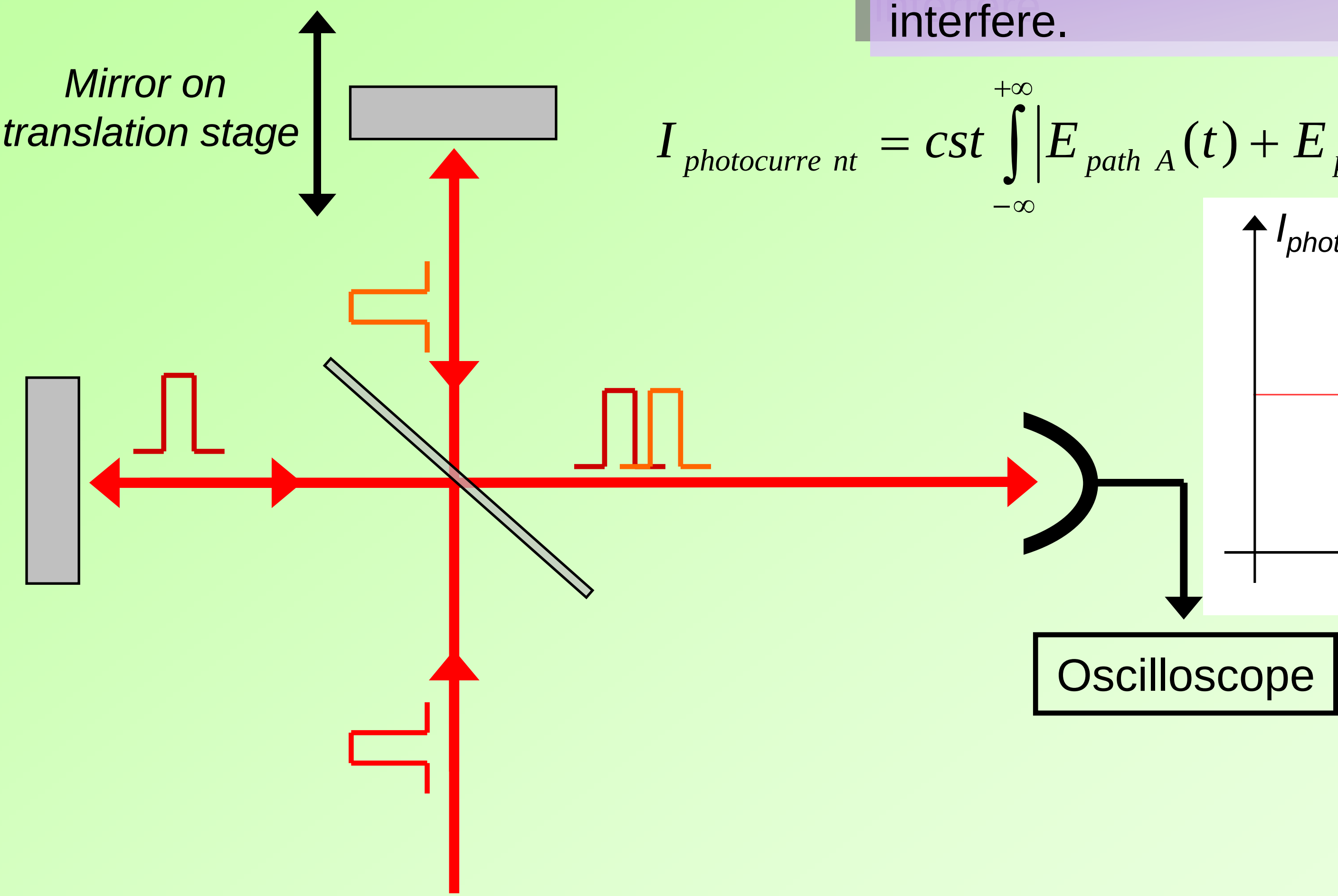

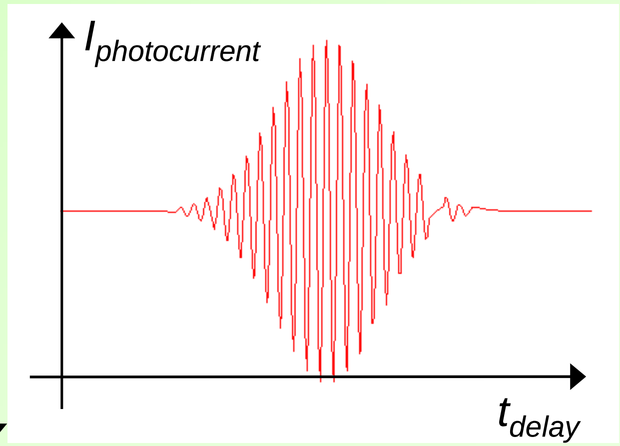

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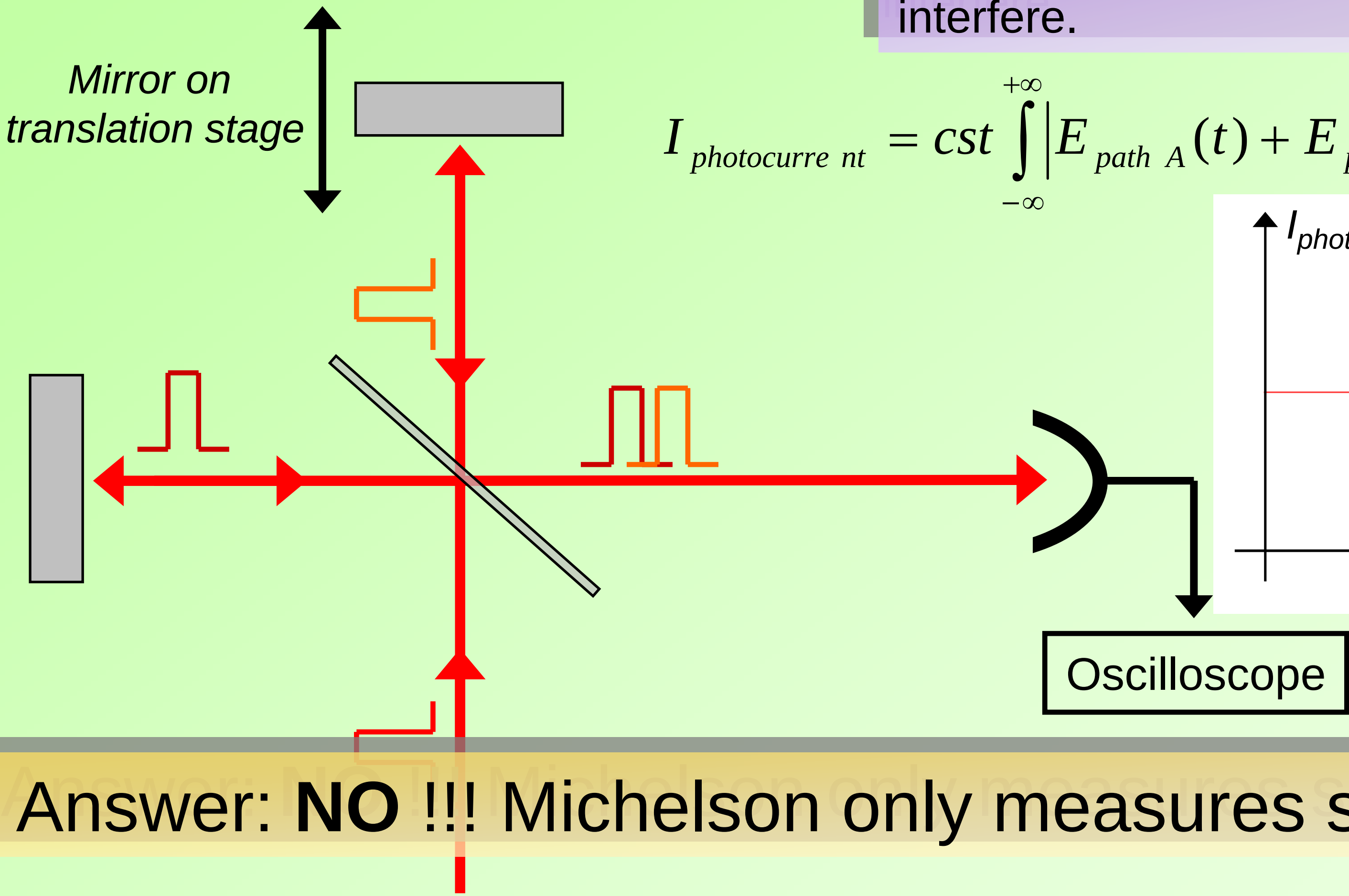

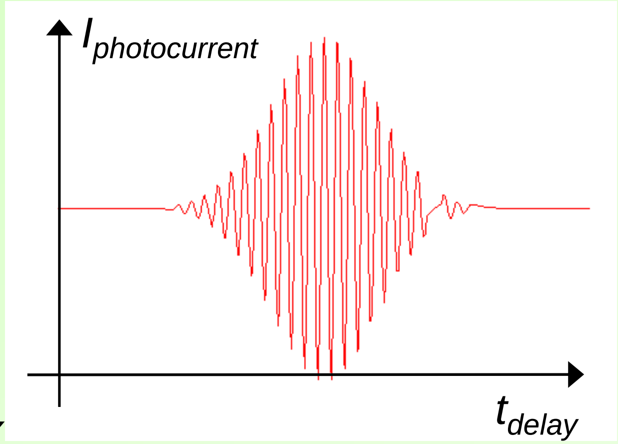

Answer: **NO** !!! Michelson only measures spectral width!

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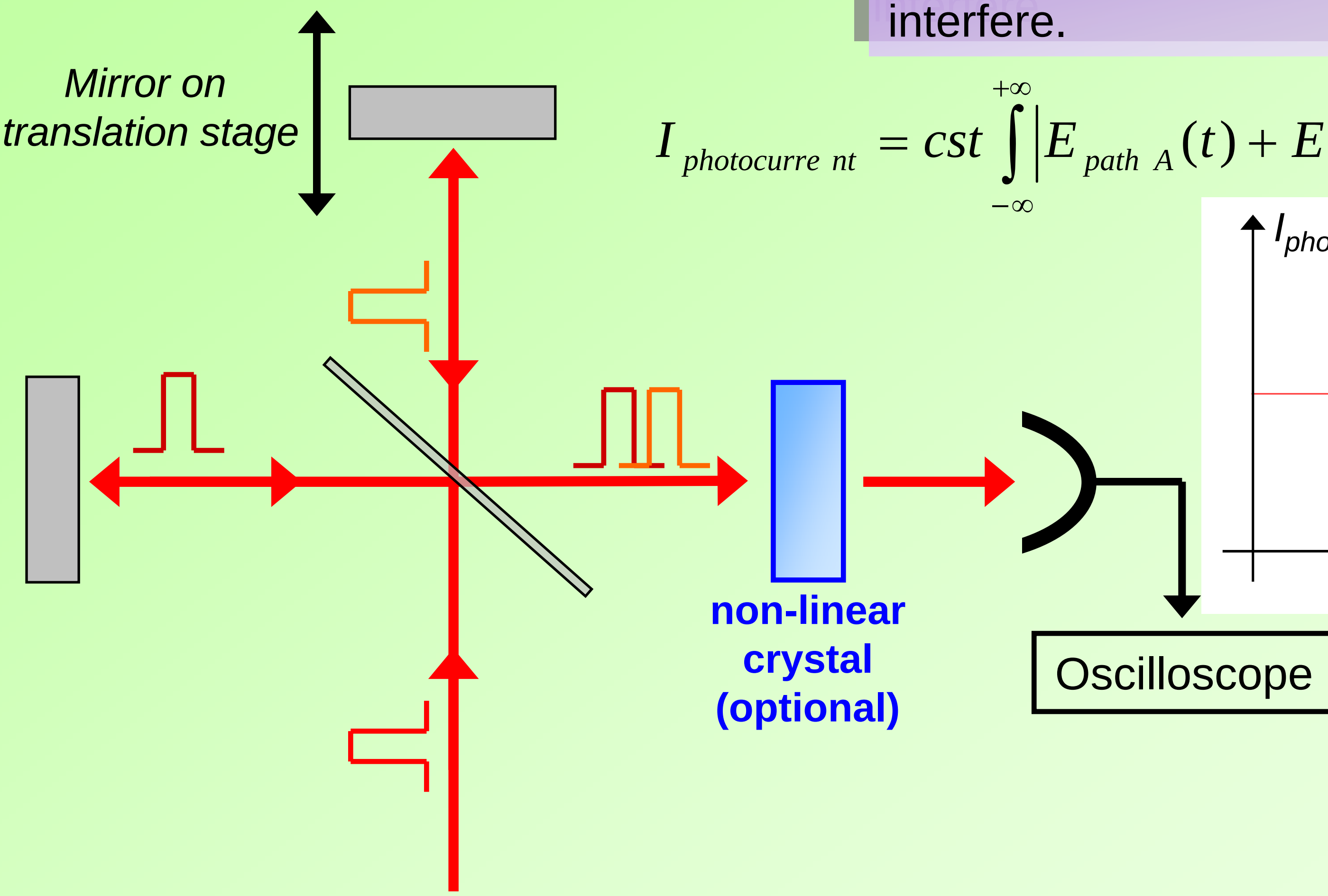
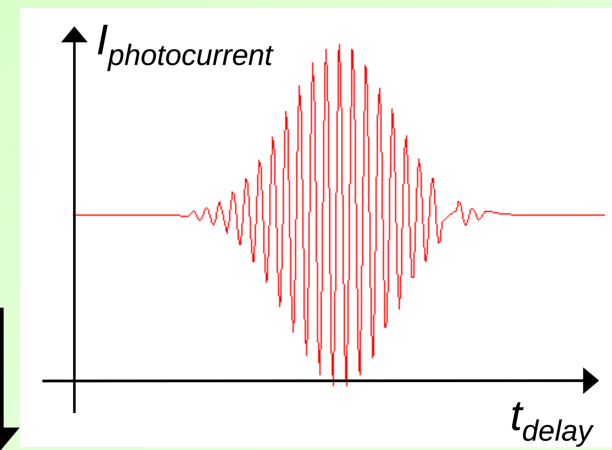




2nd Order Coherence

1. Degree of second order coherence
2. Classical view: Time-domain
3. Quantum view: Coincidence measurements
4. Thermal Light vs. Laser Light
5. Coherence of atomic sources

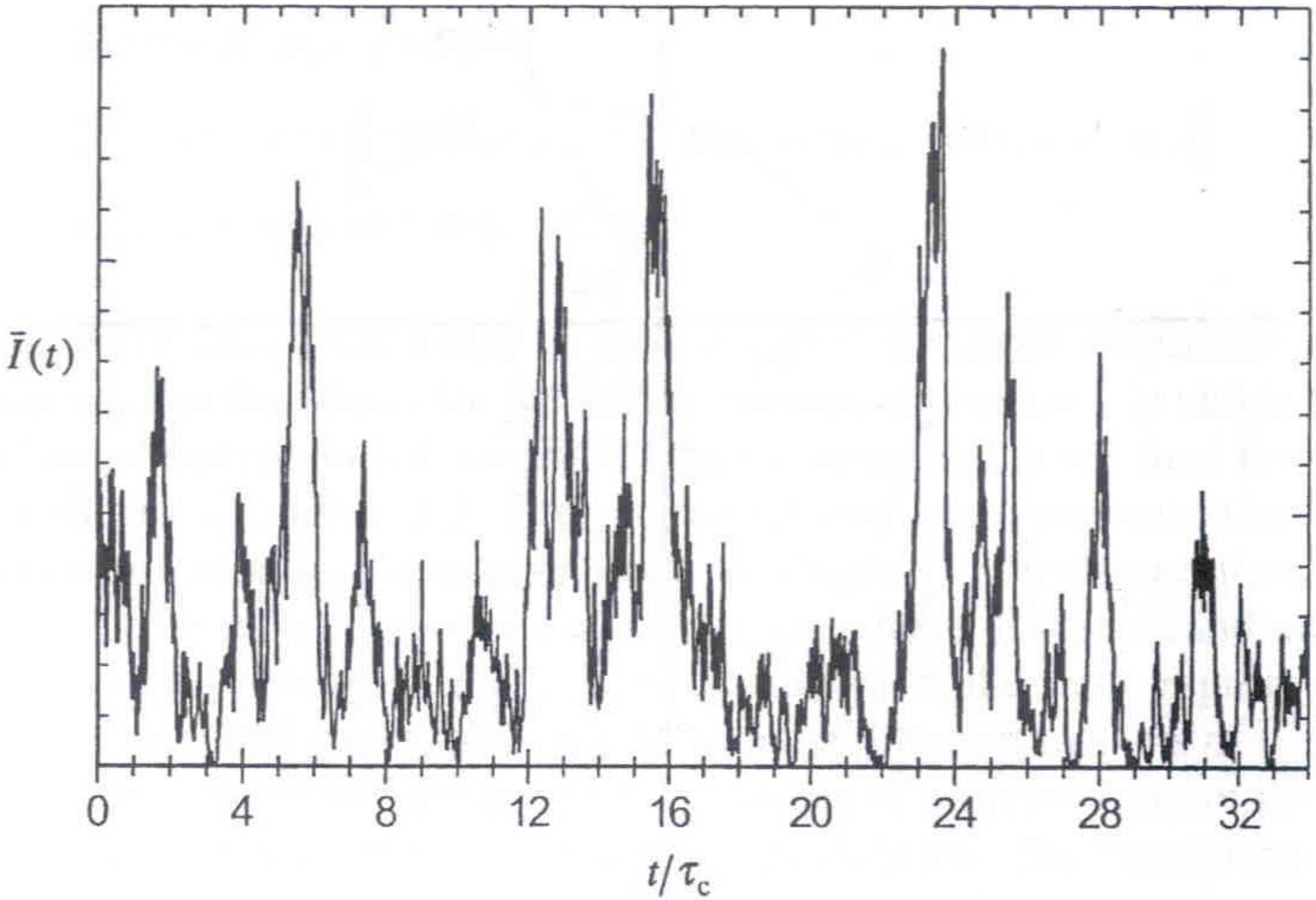
$g^{(2)}(\tau)$
2nd order correlation function

Definition:

$$g^{(2)}(\tau) = \frac{\langle I(t) \cdot I(t+\tau) \rangle}{\langle I(t) \rangle \langle I(t+\tau) \rangle} = \frac{\langle I(t) \cdot I(t+\tau) \rangle}{\langle I(t) \rangle^2}$$

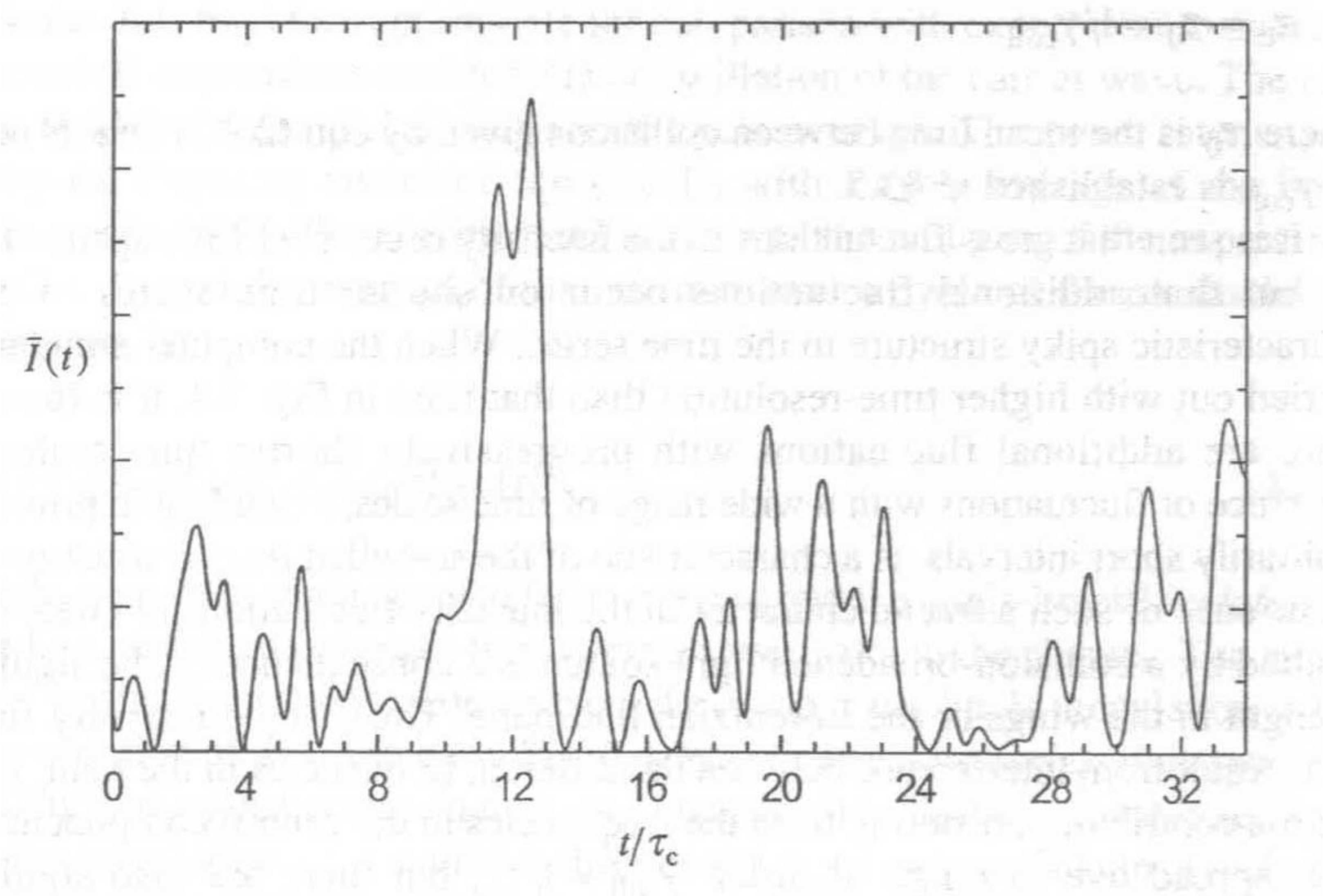
It measures **correlations in the intensity** of the light, instead of correlations in the electric field.

Random Phase Chaotic Light Source *(Lorentzian)*



[computer simulation, from Quantum Theory of Light, by R. Loudon (2000)]

Gaussian Spectrum Chaotic Light Source

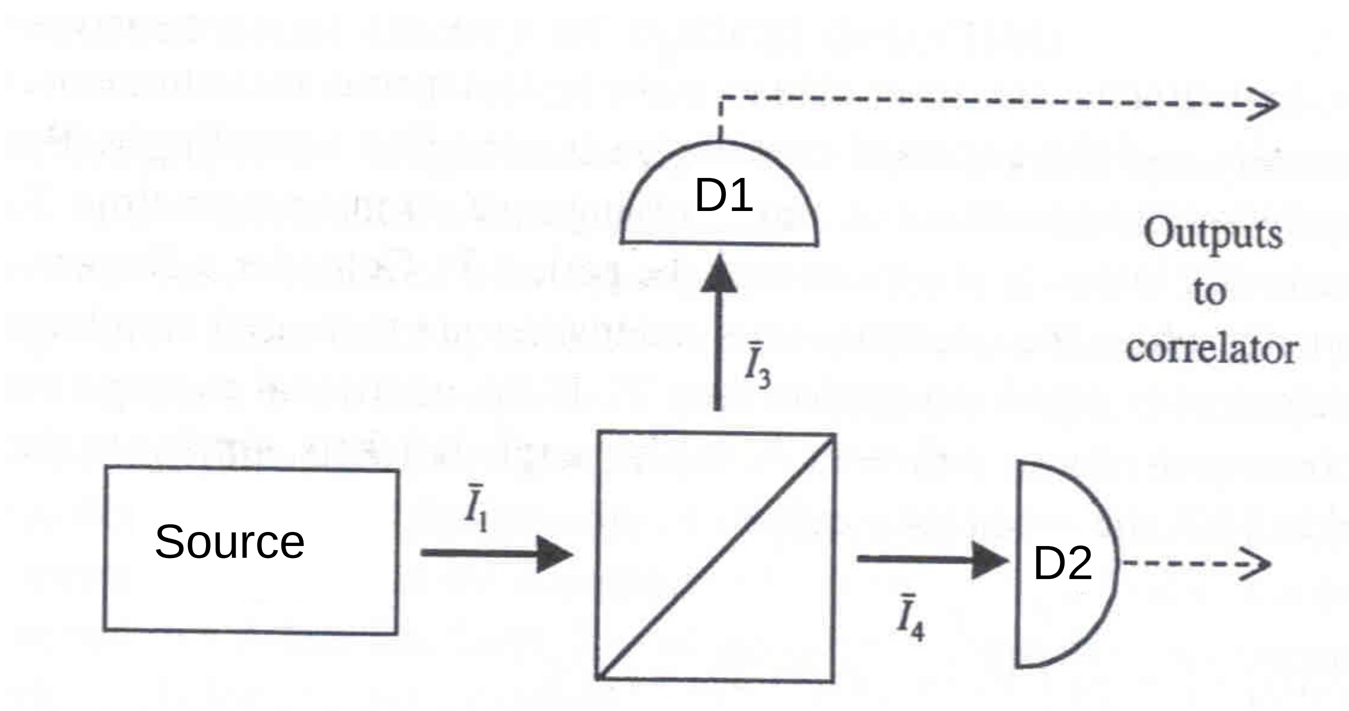


[computer simulation, from Quantum Theory of Light, by R. Loudon (2000)]

Quantum $g^{(2)}(\tau)$: single-photon detection

If you can detect single photons (i.e. PMT or avalanche photodiode), then for very low light levels

$$g^{(2)}(\tau) = \frac{\langle I(t) \cdot I(t+\tau) \rangle}{\langle I(t) \rangle^2} = \frac{\langle n_1(t) \cdot n_2(t+\tau) \rangle}{\langle n_1(t) \rangle \cdot \langle n_2(t+\tau) \rangle}$$



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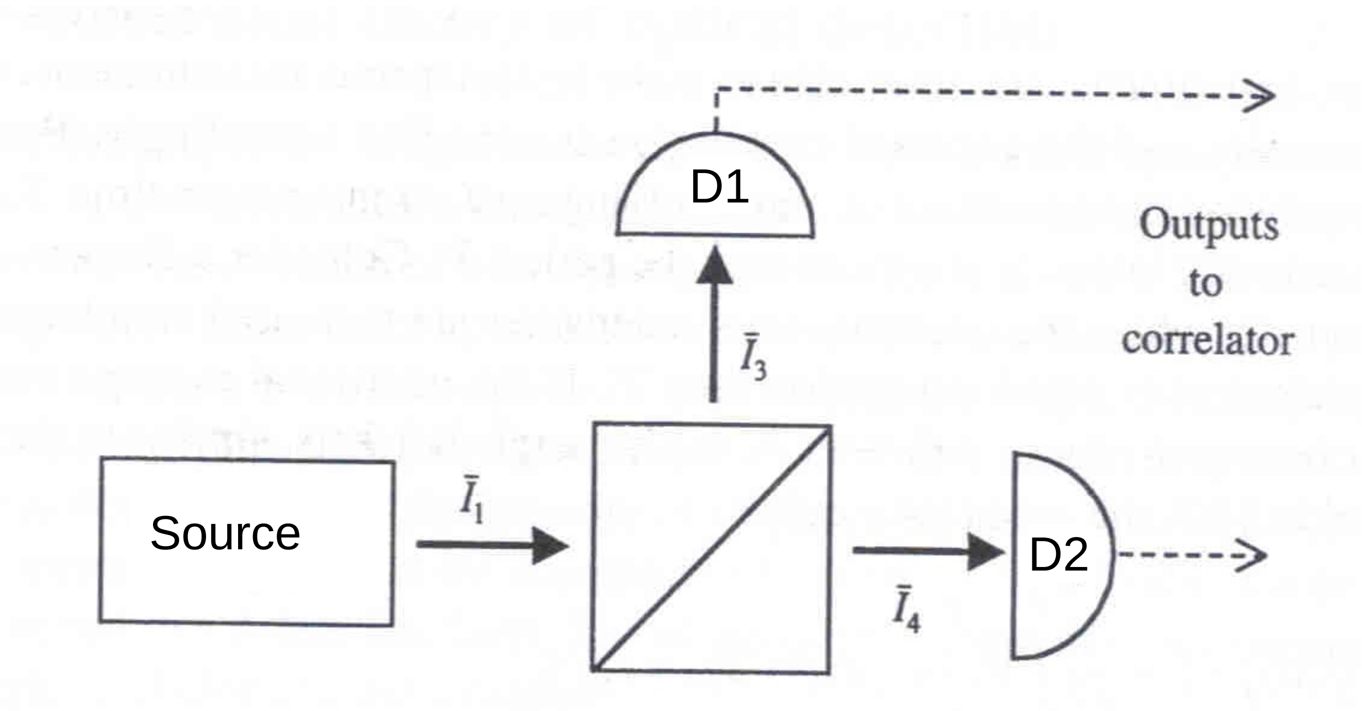
$$\propto \mathrm{P}(t+\tau\,|\,t)$$



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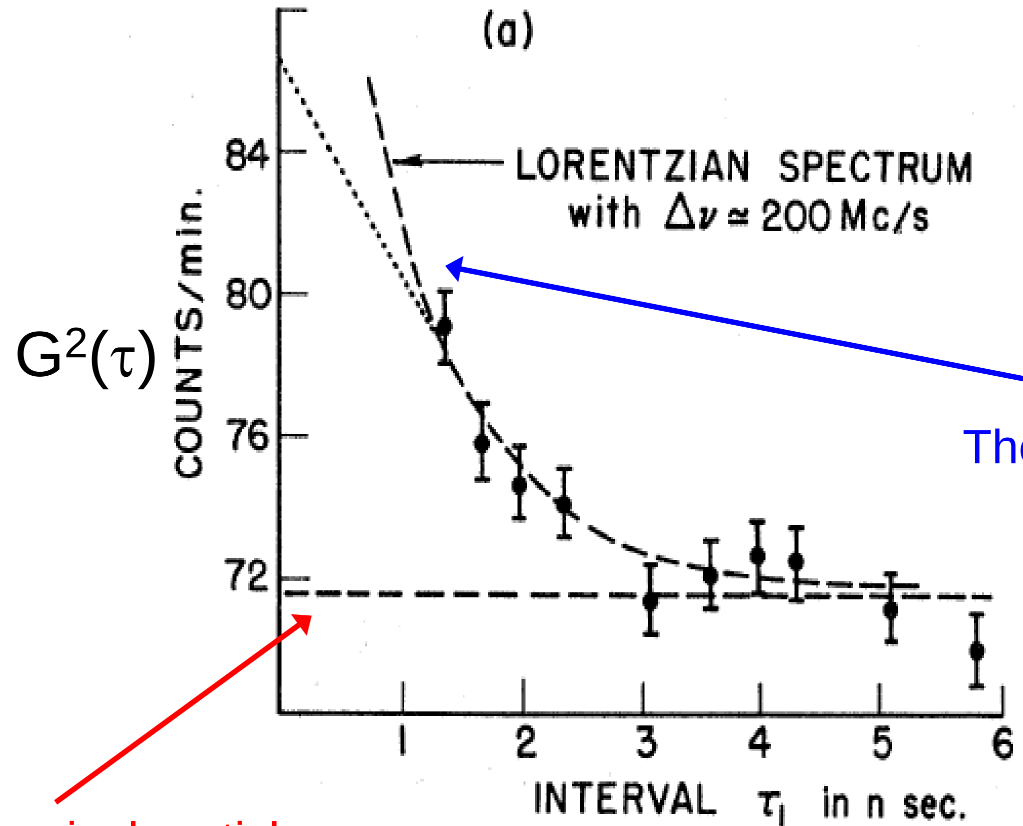
Thermal Photons



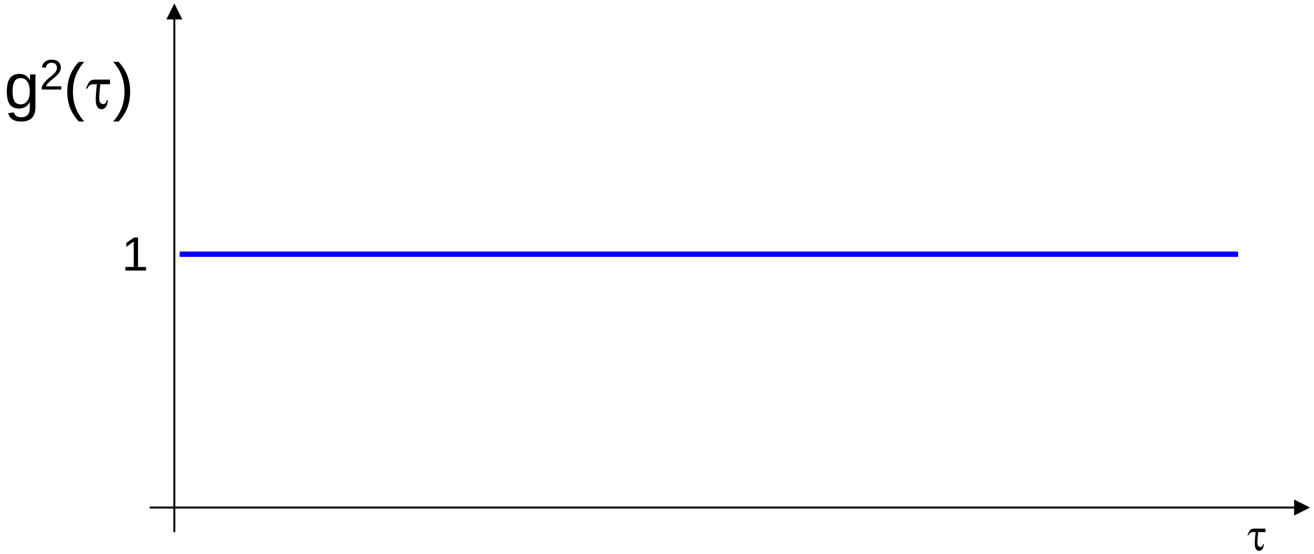
Thermal wave-particles

random classical particles

Thermal photons exhibit "bunching" at short correlation times

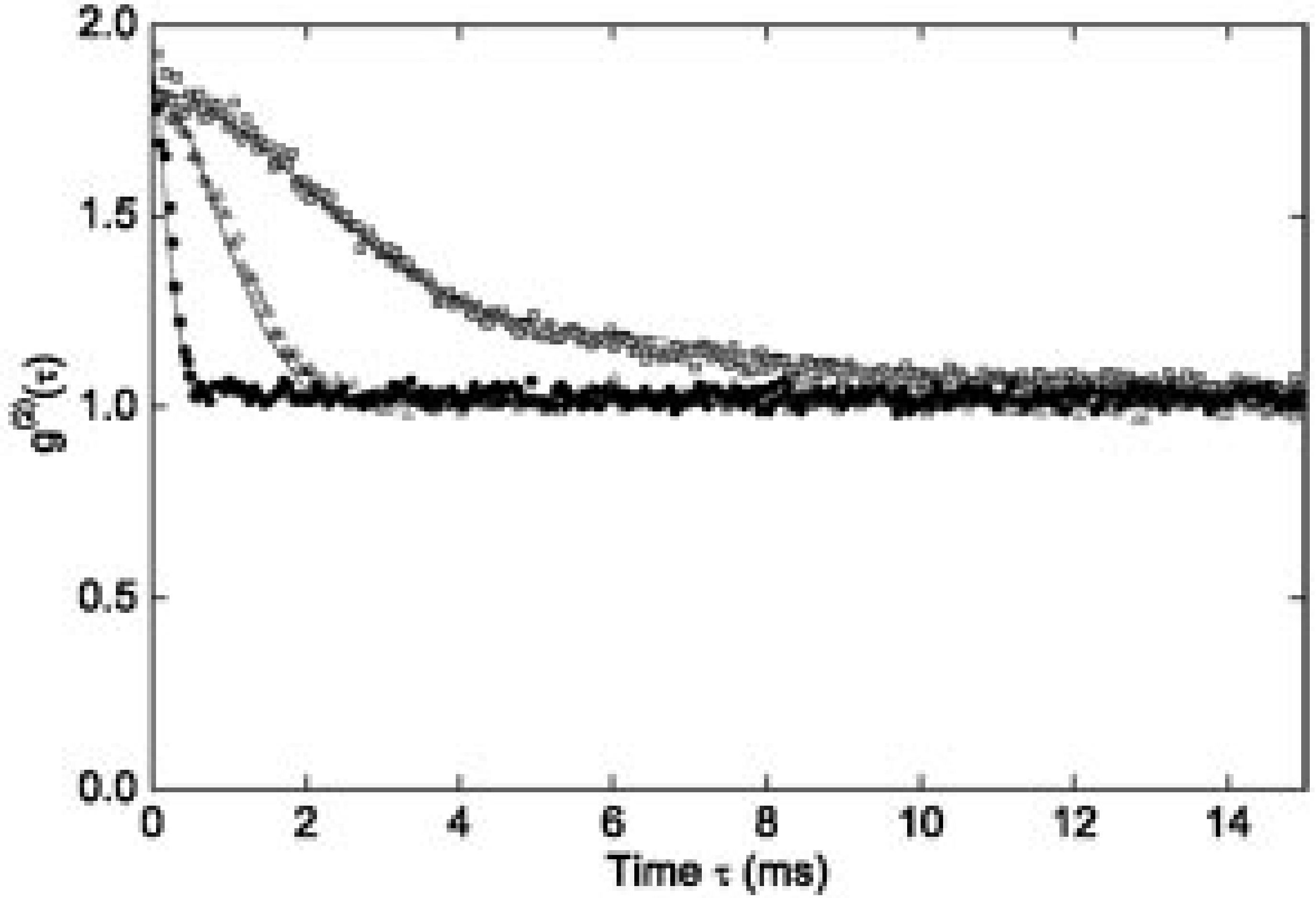
[Figure from Morgan & Mandel, Phys. Rev. 16, 1012 (1966).]

Laser light



Laser light exhibit NO “bunching”.

Thermal Bosonic Atoms

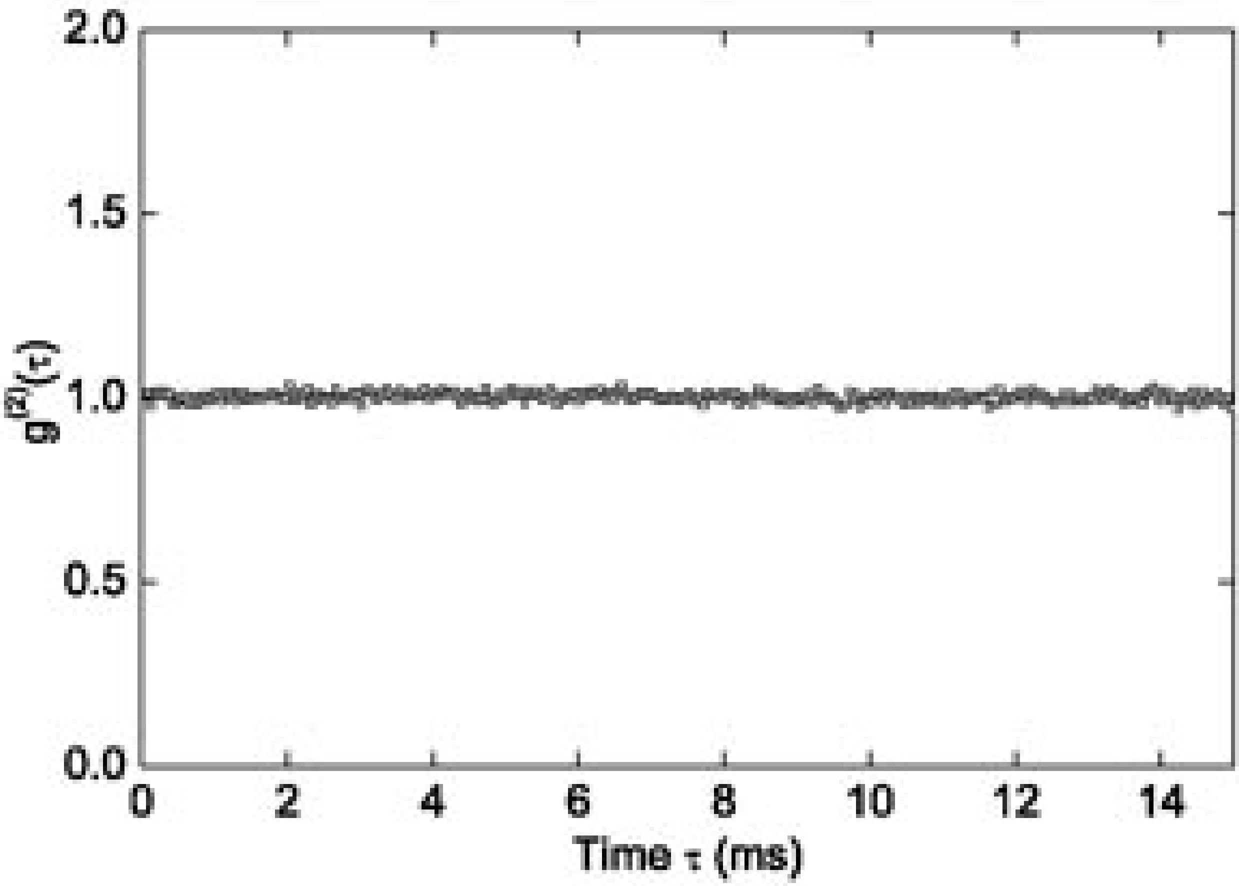


Thermal bosonic atoms are statistically identical to thermal photons !!!

[figure from A. Öttl, S. Ritter, M. Köhl, T. Esslinger, Phys. Rev. Lett. 95, 090404 (2005)]

Coherent Bosonic Atoms (BEC)

In a **Bose-Einstein Condensate (BEC)** all the atoms are in the same state. It is the analog of a laser but with atoms (coherent matter waves).



Atoms in a BEC are statistically identical to laser photons !!!

[figure from A. Öttl, S. Ritter, M. Köhl, T. Esslinger, Phys. Rev. Lett. 95, 090404 (2005)]