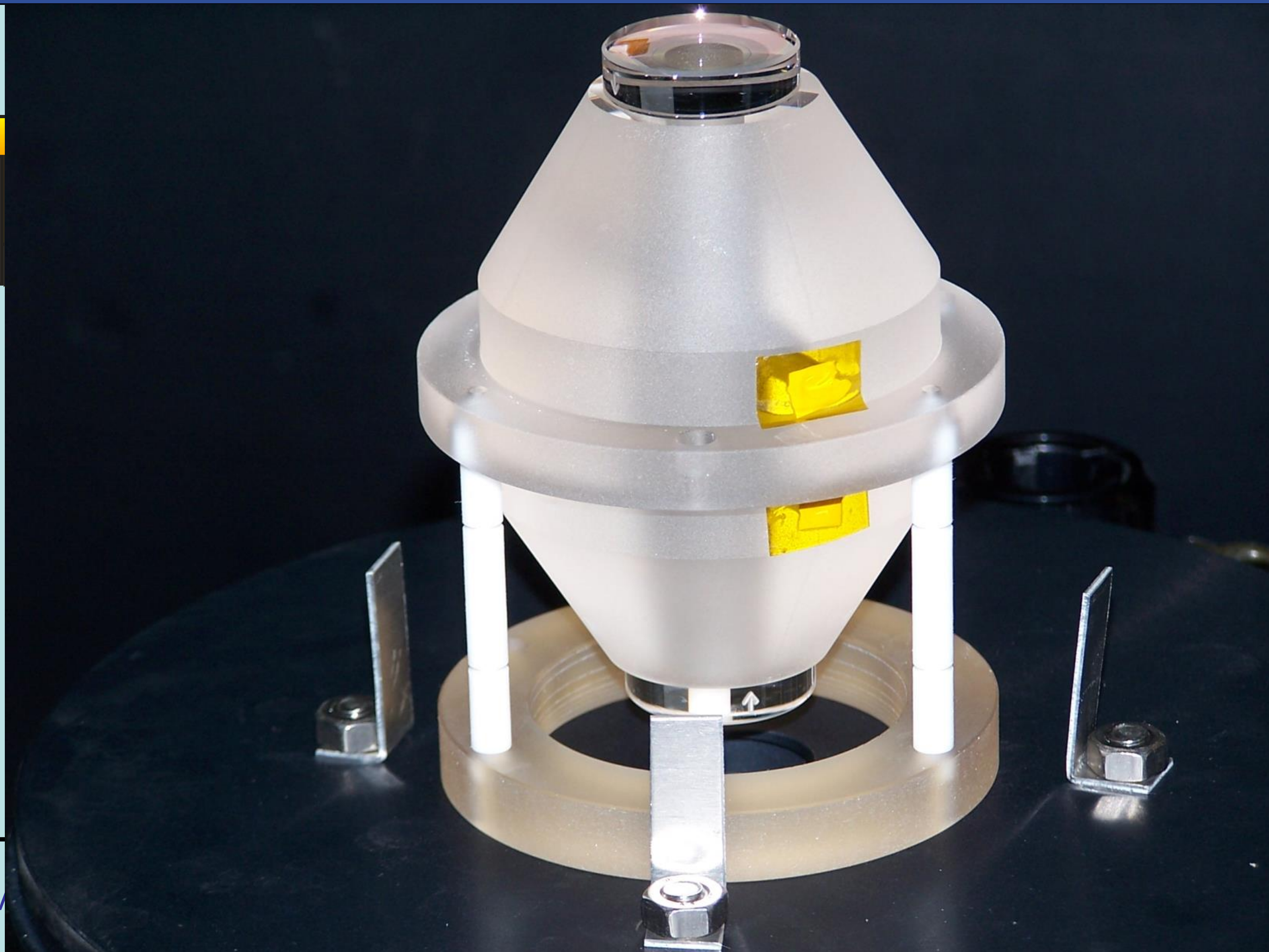
Hydrogen 1s-2s experiment

Possible goals of improving laser system

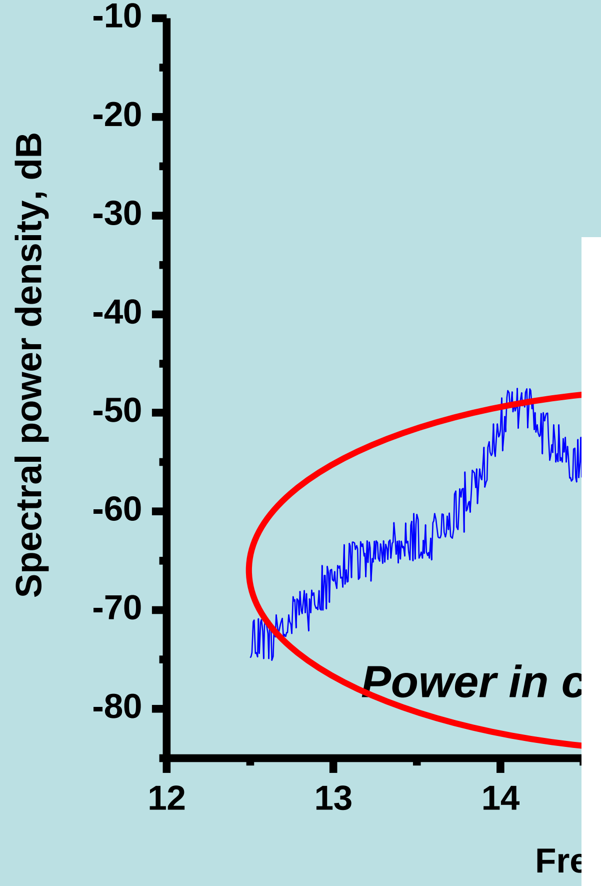
- Improving resolution by decreasing the linewidth. For this purpose we need to improve reference cavity.

- Possibility of new experiments – 1s-2s spectroscopy of Tritium in Karlsruhe. Carrier collapse problem of ECDL laser.

Vertical cavity



Spectrum of ECDL locked to the cavity



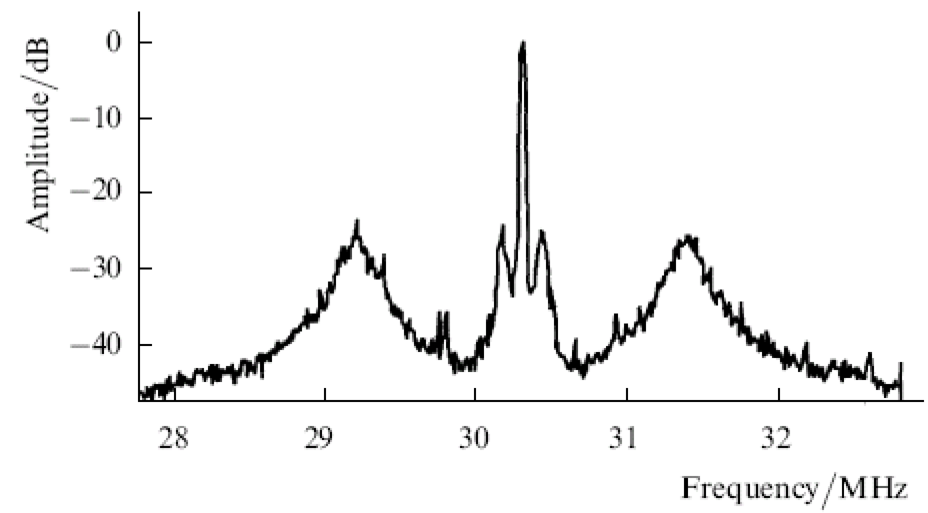


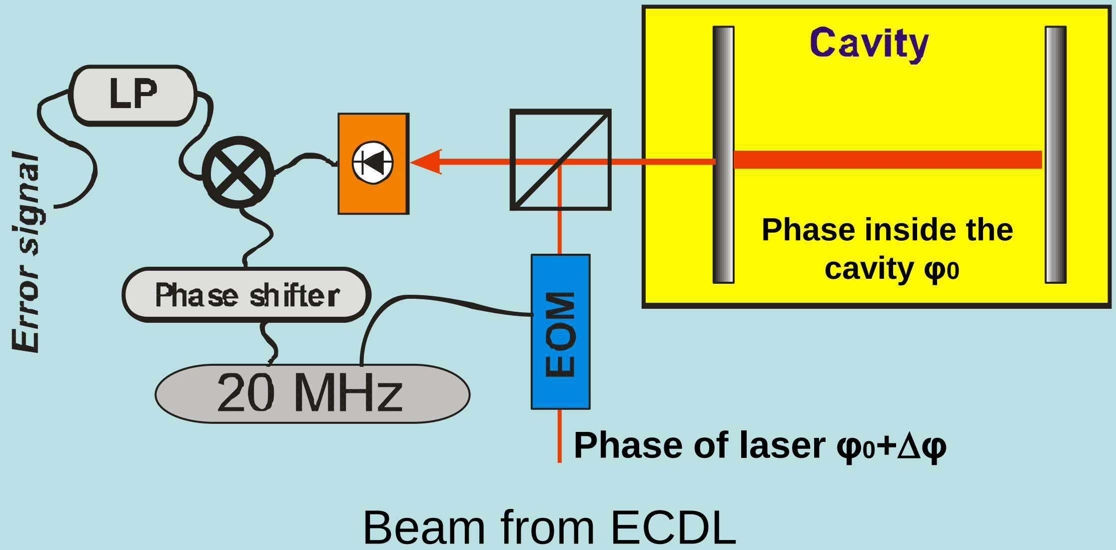
Figure 8. Spectrum of the closed-loop beat note when the PFD is set for analog + digital operation; the record is the average of four scans of the spectrum analyser; the resolution bandwidth is 10 kHz.

N.Beverini, M. Prevedelli, F. Sorrentino, B. Nushkov, A. Ruffini
Quantum electronics **34,** 559-564 (2004)

PDH Lock

RF Error signal for feedback

$$U_{error} \propto \Delta f$$



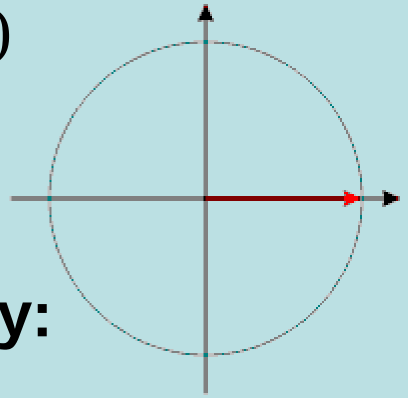
If laser frequency is in resonance with cavity mode then Error Signal

$$U_{error} \propto \Delta\varphi$$

Carrier collapse - theory

- **Consider the process** $E = E_0 \cos(\omega t + \varphi(t))$

with phase jitter $\varphi(t)$ **:** $\left\langle e^{i\varphi(t)} \right\rangle_t \neq 0$



If random phase $\varphi(t)$ **is distributed normally:**

$$p(\varphi) \propto \exp\left(-\frac{\varphi^2}{2\varphi_{rms}^2} \right)$$

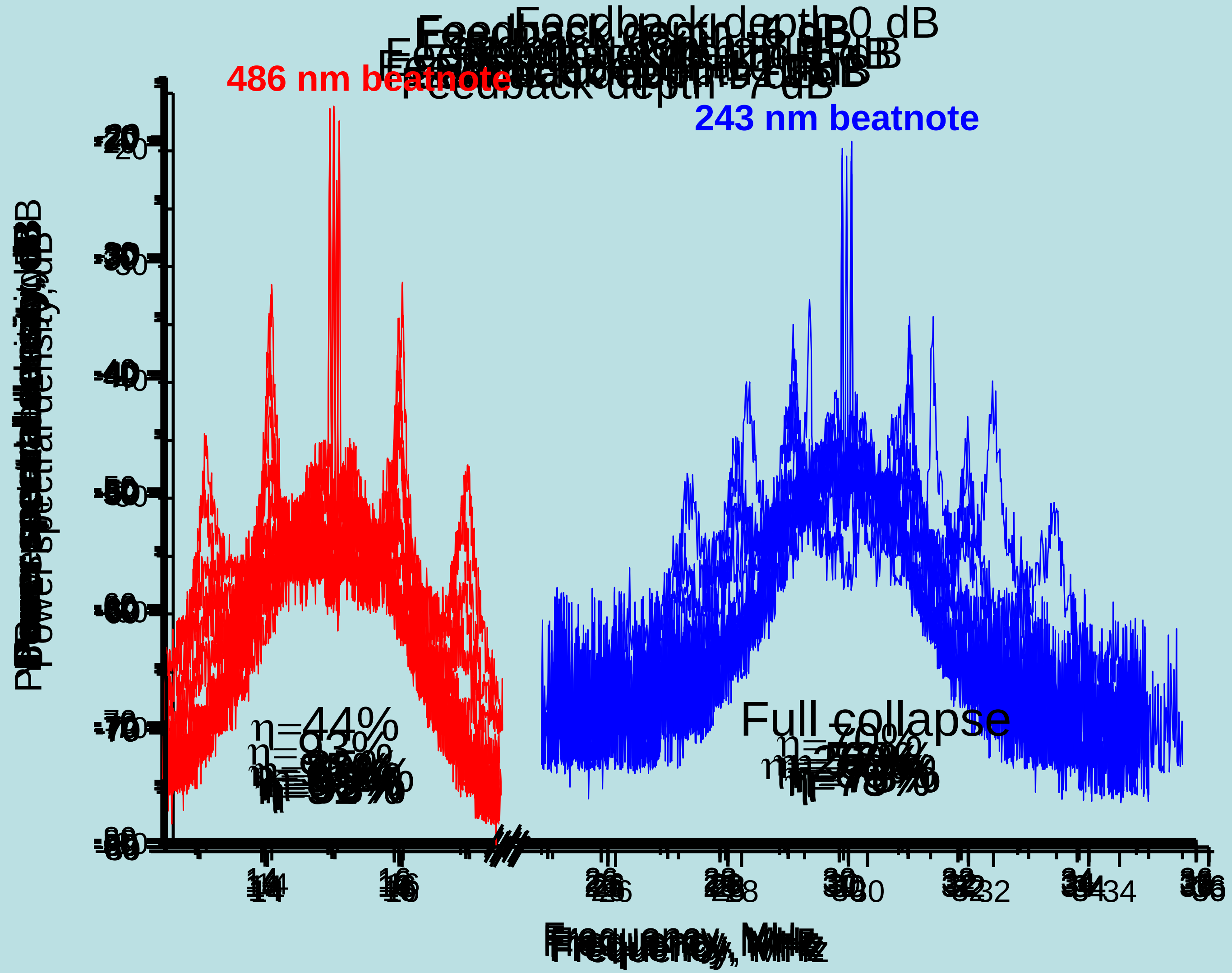
Then spectrum of the process contains δ-function (carrier). Fraction of power in carrier: $\eta = \exp\left(-\varphi_{rms}^2\right)$

Consequently after frequency doubling:

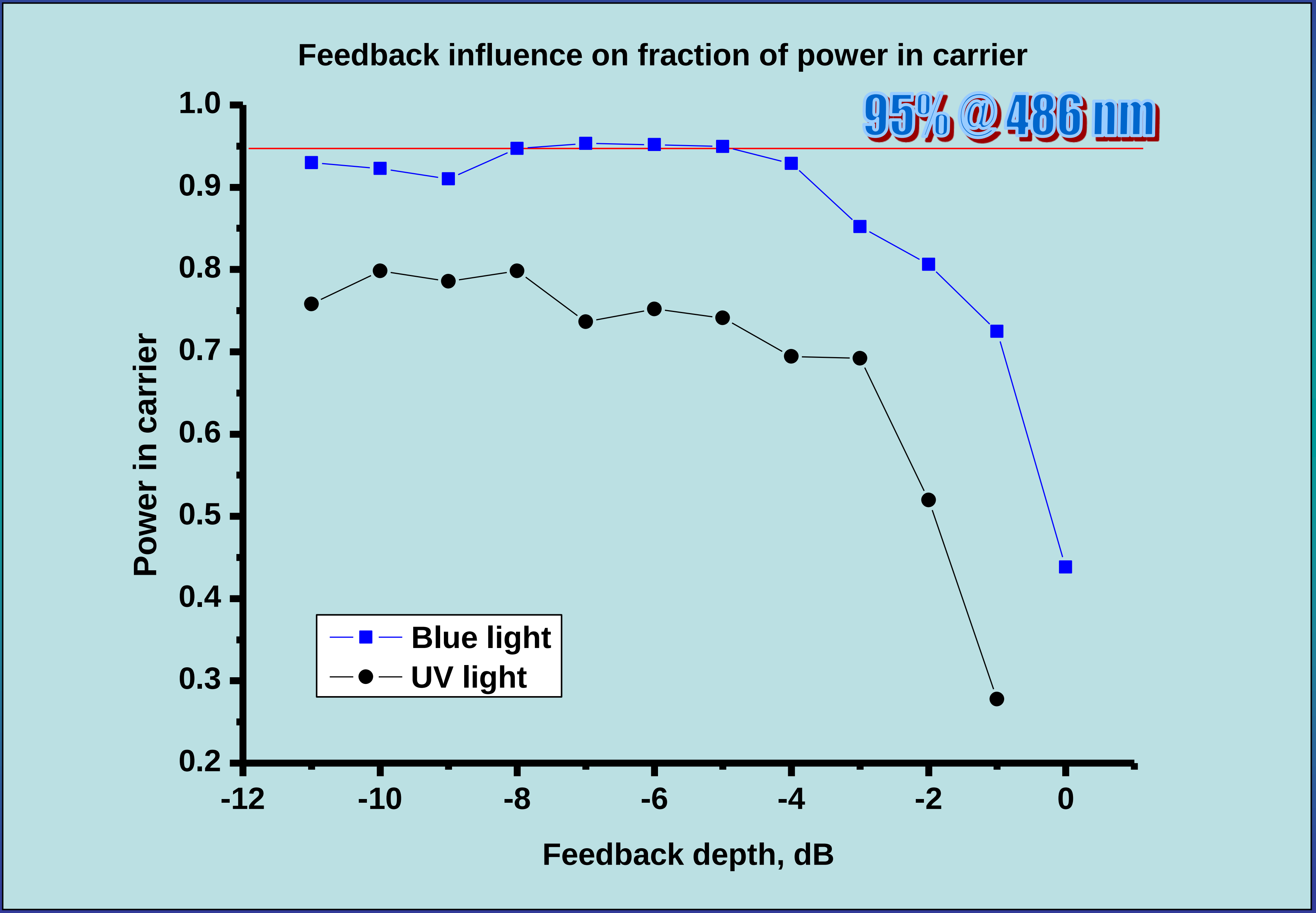
$$\eta' = \exp\left(-(2\varphi_{rms})^2\right) = \exp\left(-4(\varphi_{rms})^2\right) = \eta^4$$

In 8-photon process $\eta_{eff} = \eta_{IR}^{64}$

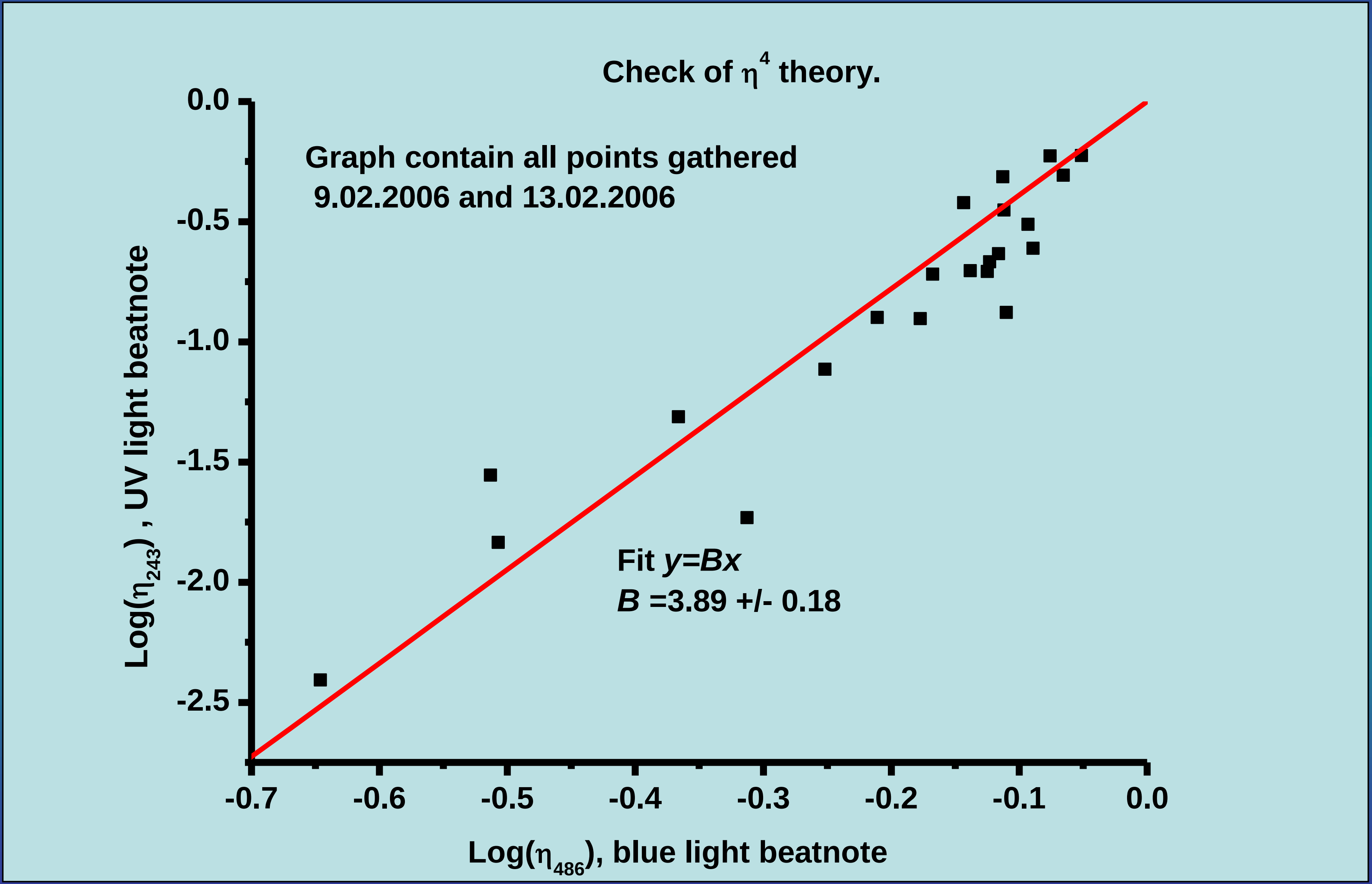
Carrier collapse in pictures



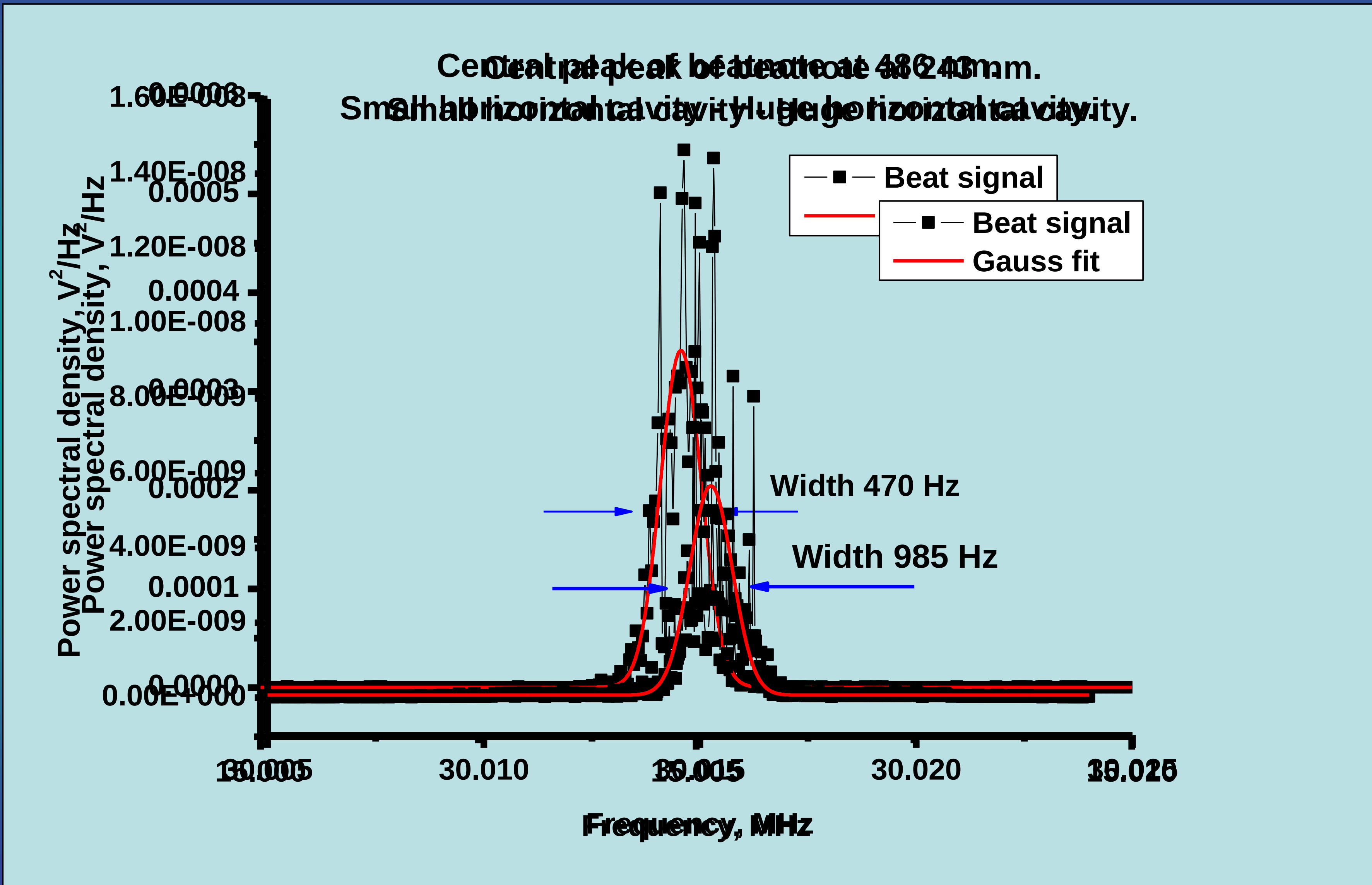
Feedback depth



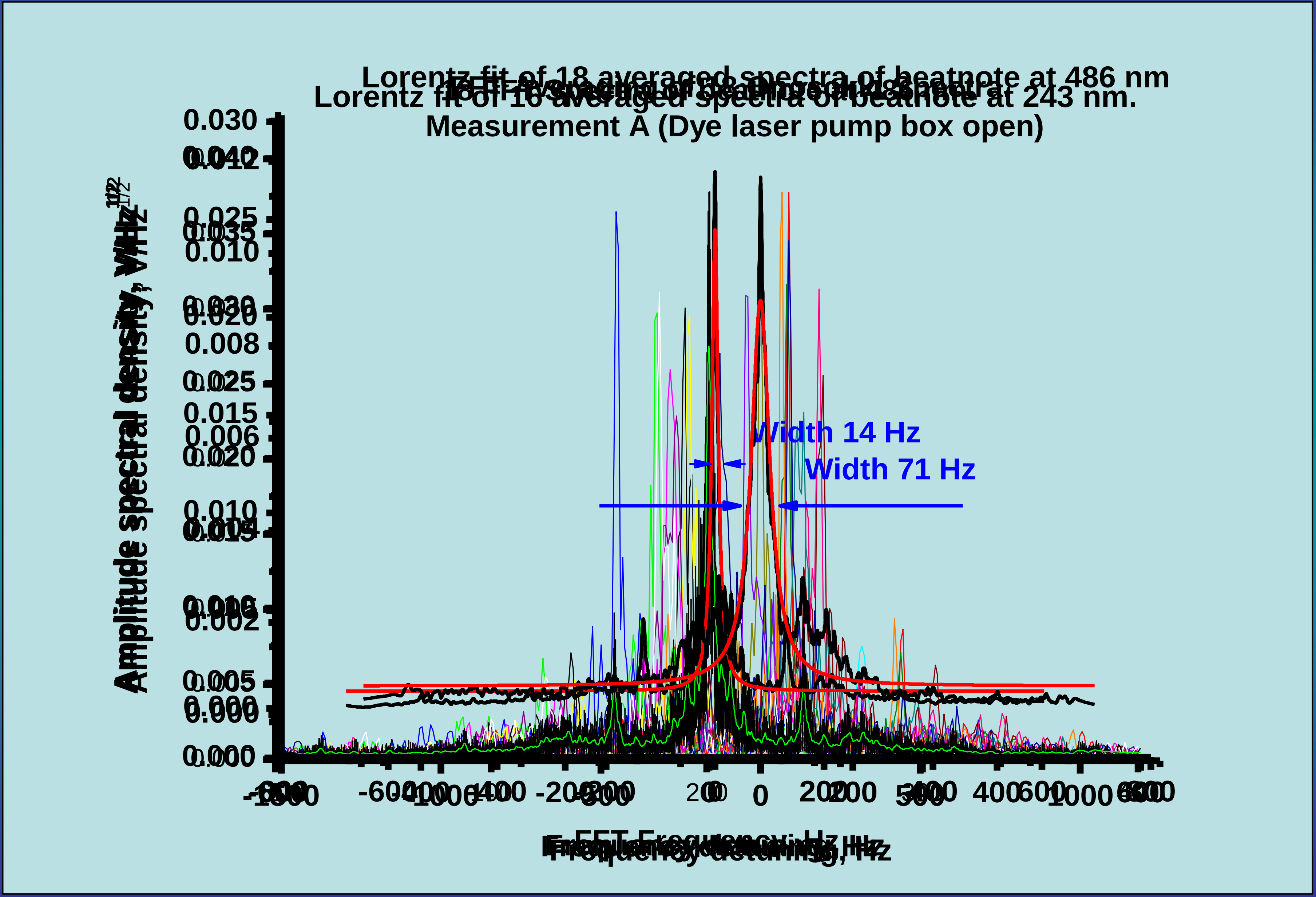
Check of carrier collapse formula



Central peak of small horizontal cavity

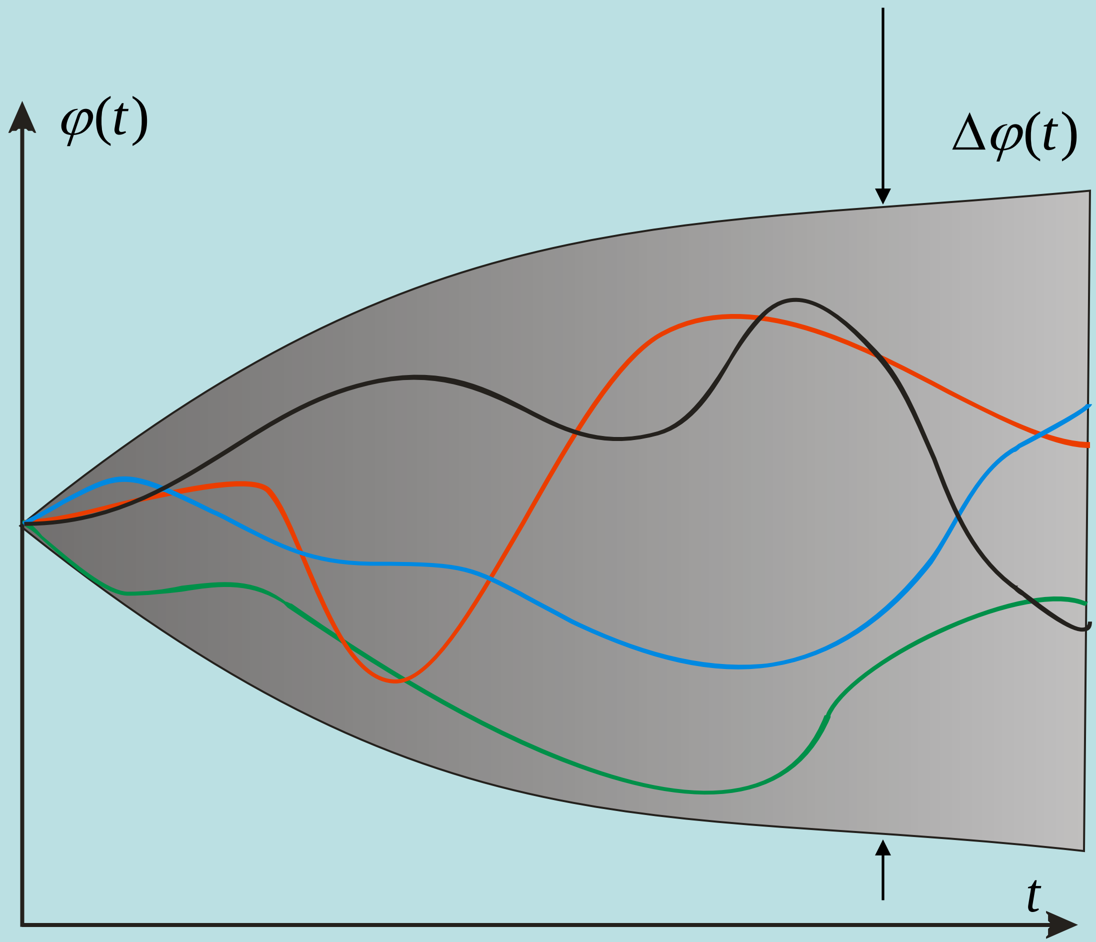


Central peak with vertical cavity



Why 2? Why 4?
How to estimate linewidth

$$E(t) = E_0 \cos\left(\omega t + \varphi(t)\right)$$



The moment τ :

$$\Delta\varphi(\tau) = 1$$

The linewidth could be estimated as:

$$\Delta\omega \approx \frac{1}{\tau}$$

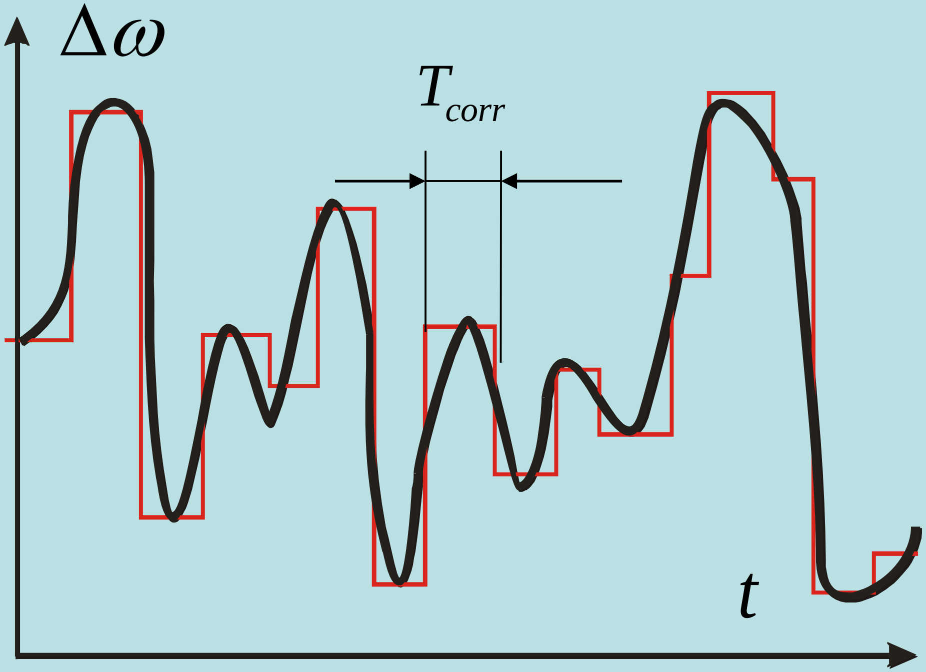
Why 2? Why 4?
Frequency noise model

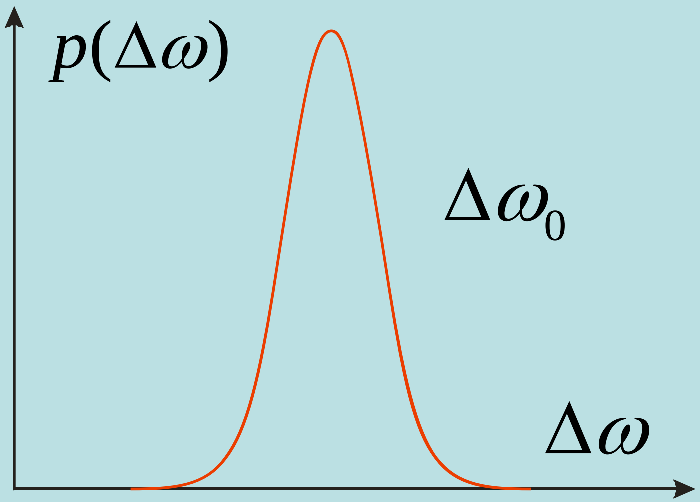
$$E = E_0 \cos\left(\omega t + \int \Delta\omega dt\right)$$

Two important parameters

modulation depth $\Delta\omega_0$

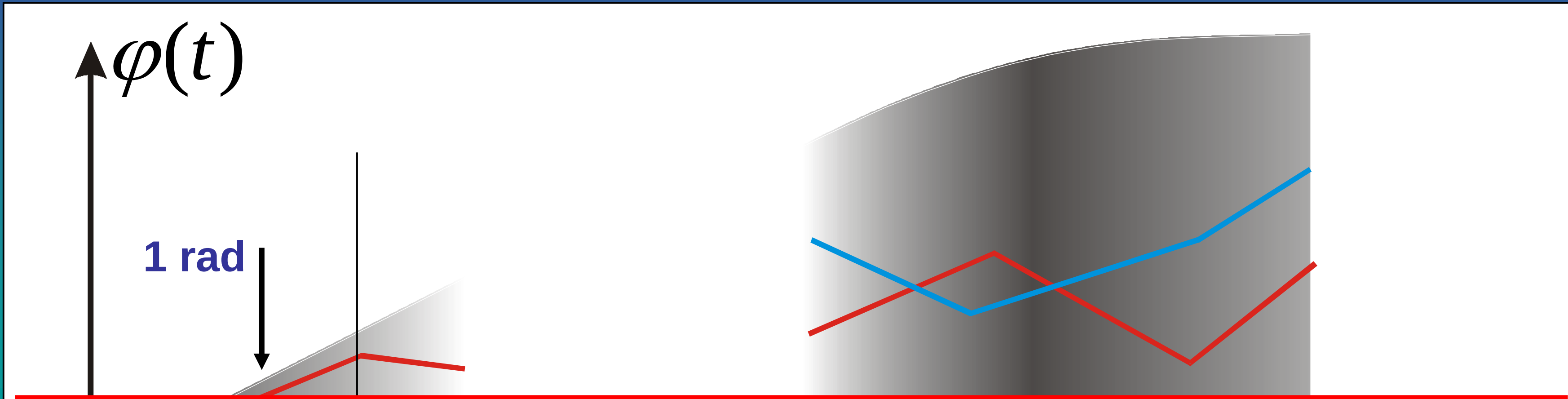
and correlation time T_{corr}





Why 2? Why 4?

Linear phase drift and phase diffusion



Summary: Two principal cases:

$$\Delta\omega \gg 1/T_{corr}$$

Deep frequency noise. Gaussian profile. After frequency doubling linewidth increases twice.

$$\Delta\omega \ll 1/T_{corr}$$

Fast frequency noise. Lorentz profile. After frequency doubling linewidth increases by the factor 4.