TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Brillouin light scattering observations of thermal modes in yttrium iron garnet films

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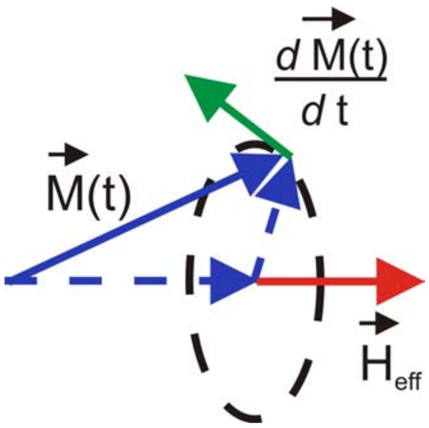
Spin Waves

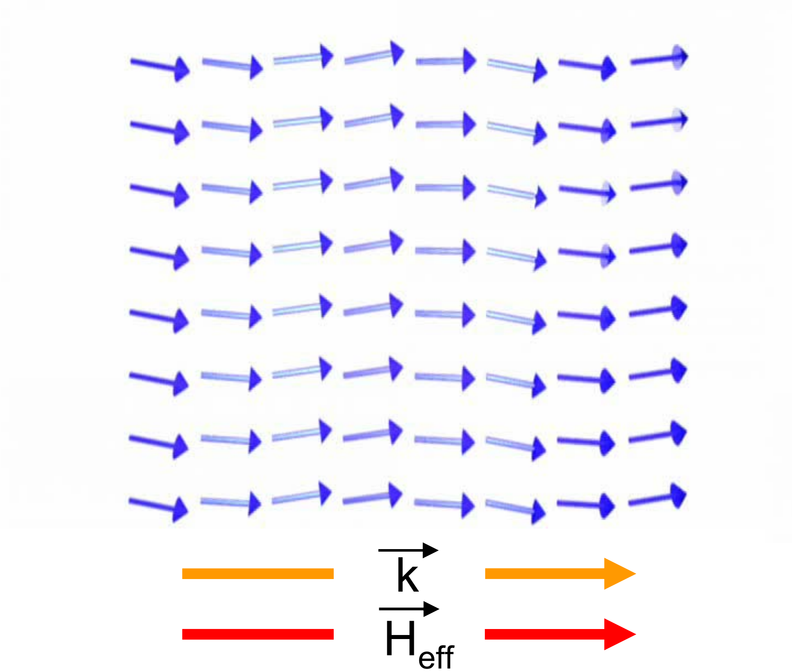
Landau-Lifshitz Equation

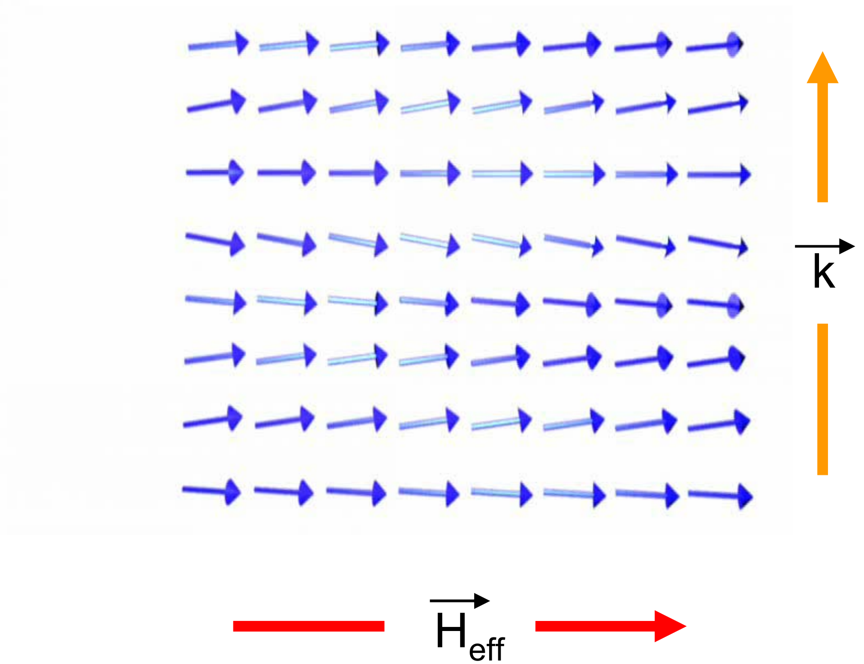
$$\frac{d\vec{M}}{dt} = -\gamma\left(\vec{M}\times\vec{H}_{eff}\right)$$

- torque equation
- dissipationless
  - conservation of $|\vec{M}|^2$
  - extension with e.g. Gilbert damping term



Collective Spin Oscillations



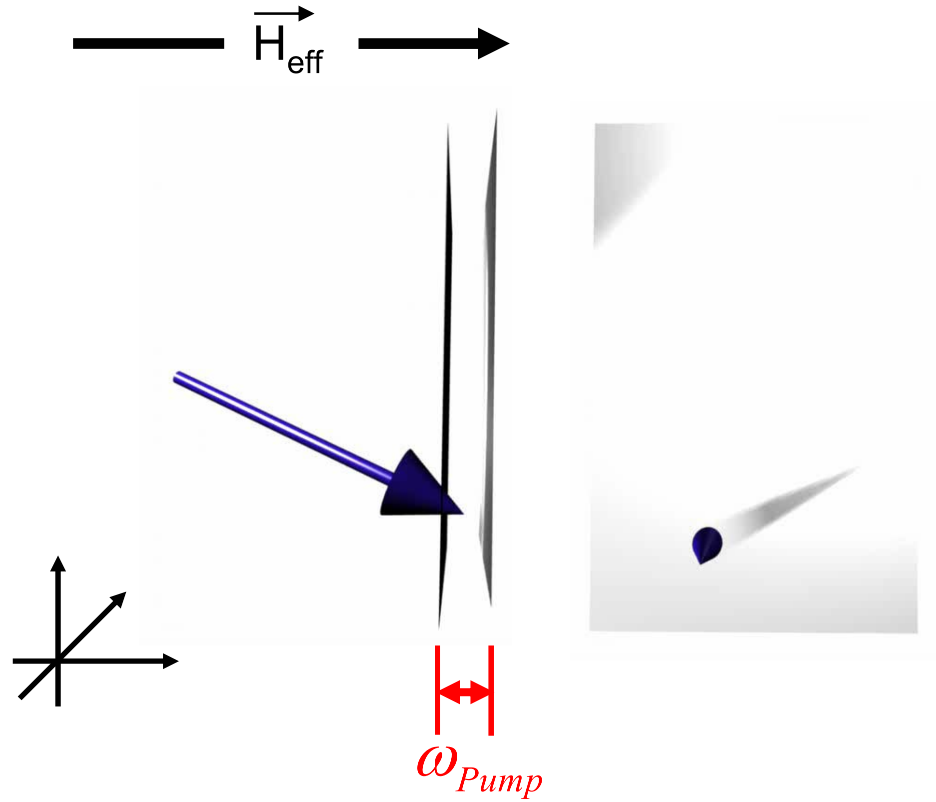


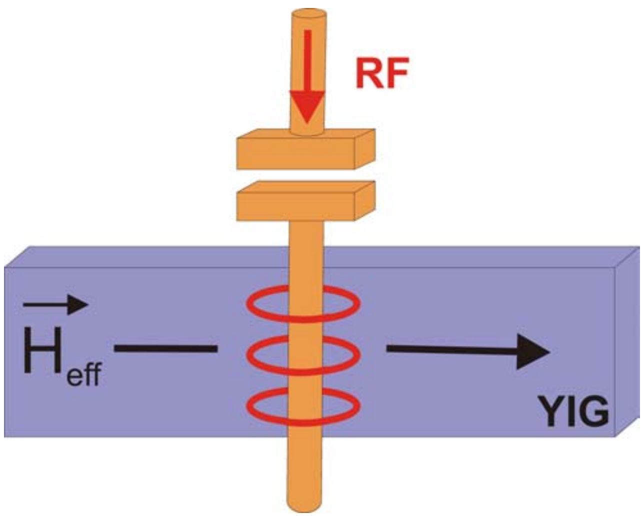
Parametric Amplification

Principals

Parallel Pumping

- prerequisite:
  ellipticity given through crystalline anisotropy and shape
- threshold process

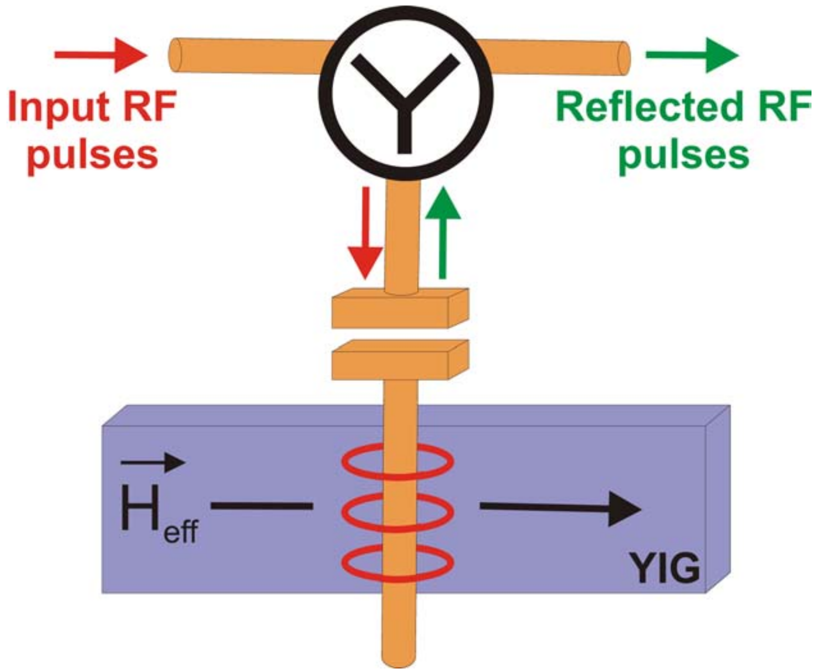




- resonator design to increase effective pumping power
- pumping frequency determined by geometry of pumping resonator

Pumping Threshold

Experimental Setup

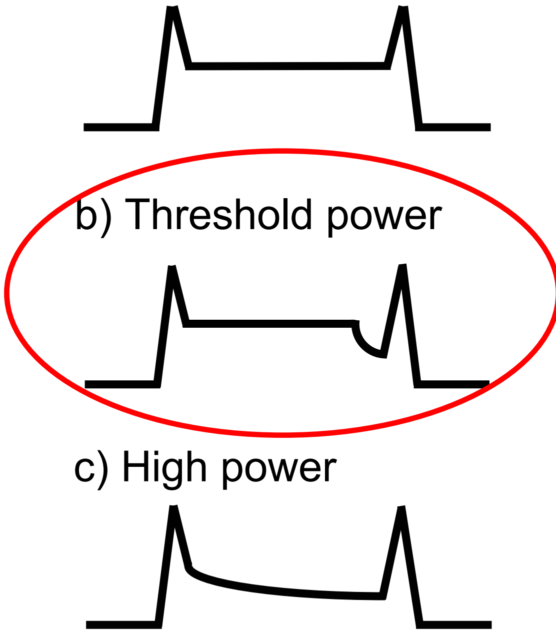


Reflected signal on oscilloscope

a) Low power

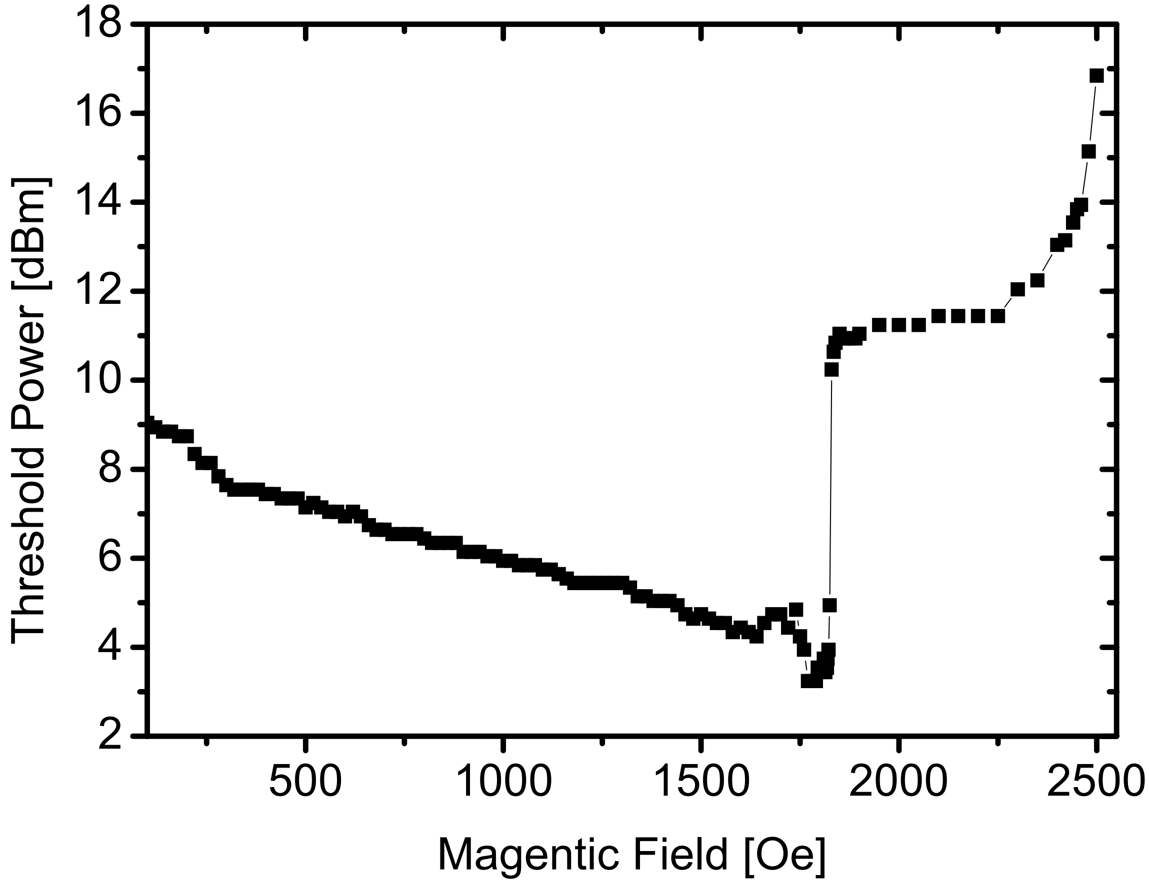
b) Threshold power

c) High power

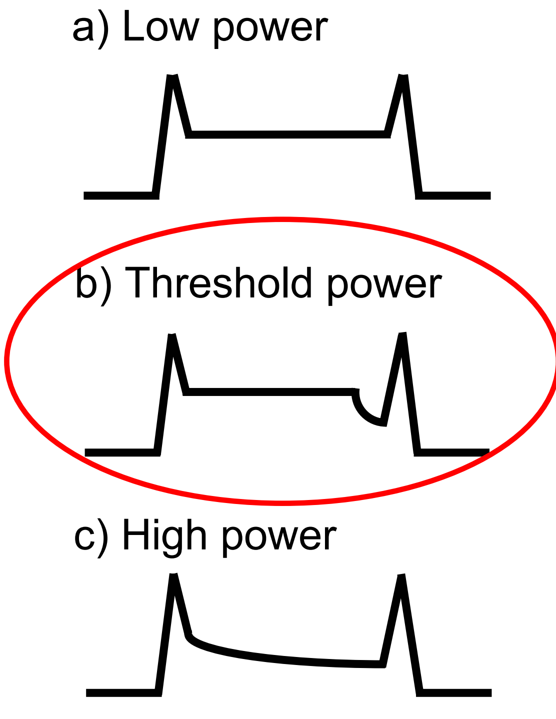


Measurement Results

Pumping frequency $\omega_P = 2\pi \cdot 14.13$ GHz
Pumping duration $\tau = 20$ µs
Repetition time $t = 1$ ms



Reflected signal on oscilloscope



Pumping Threshold

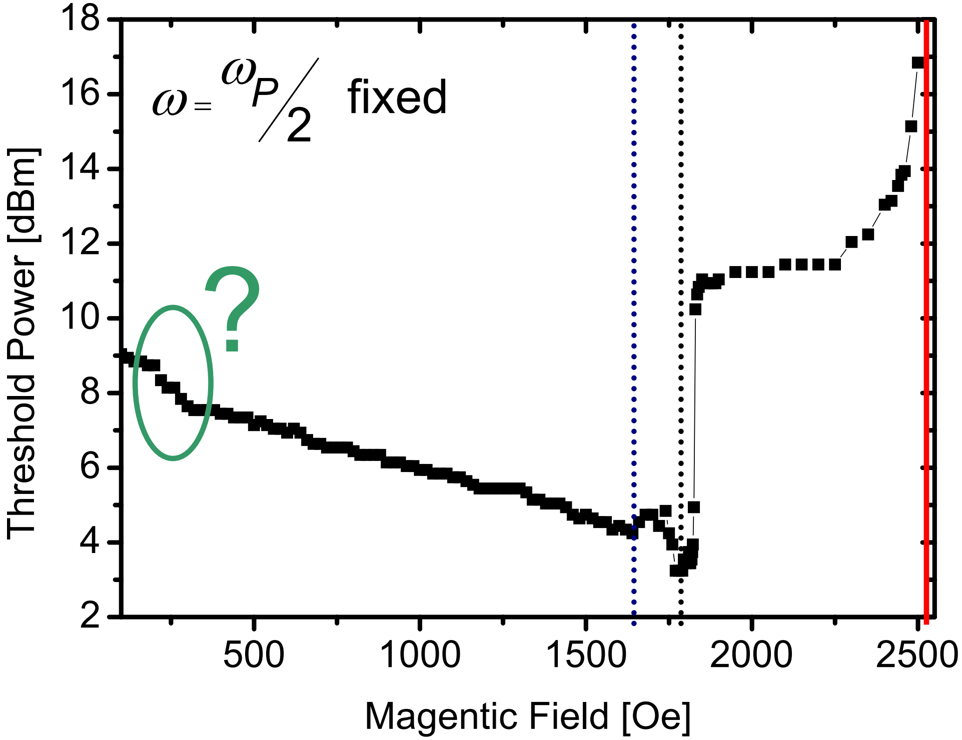
Pumping frequency	$\omega_P = 2\pi \cdot 14.13$ GHz
Pumping duration	$\tau = 20$ µs
Repetition time	$t = 1$ ms

$$\omega_H = \gamma \cdot H_{eff}$$

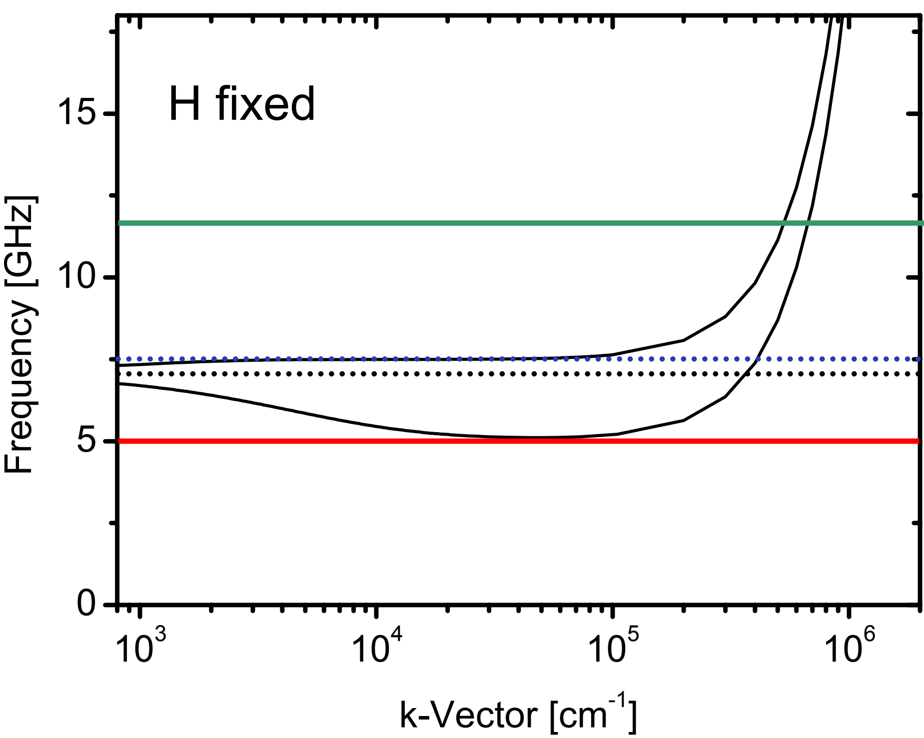
$$\omega_{FMR} = \gamma \cdot \sqrt{H_{eff} \cdot (H_{eff} + 4\pi M_s)}$$

$$\omega_S = \gamma \cdot (H_{eff} + 2\pi M_S)$$

Butterfly Curve



Dispersion Curves



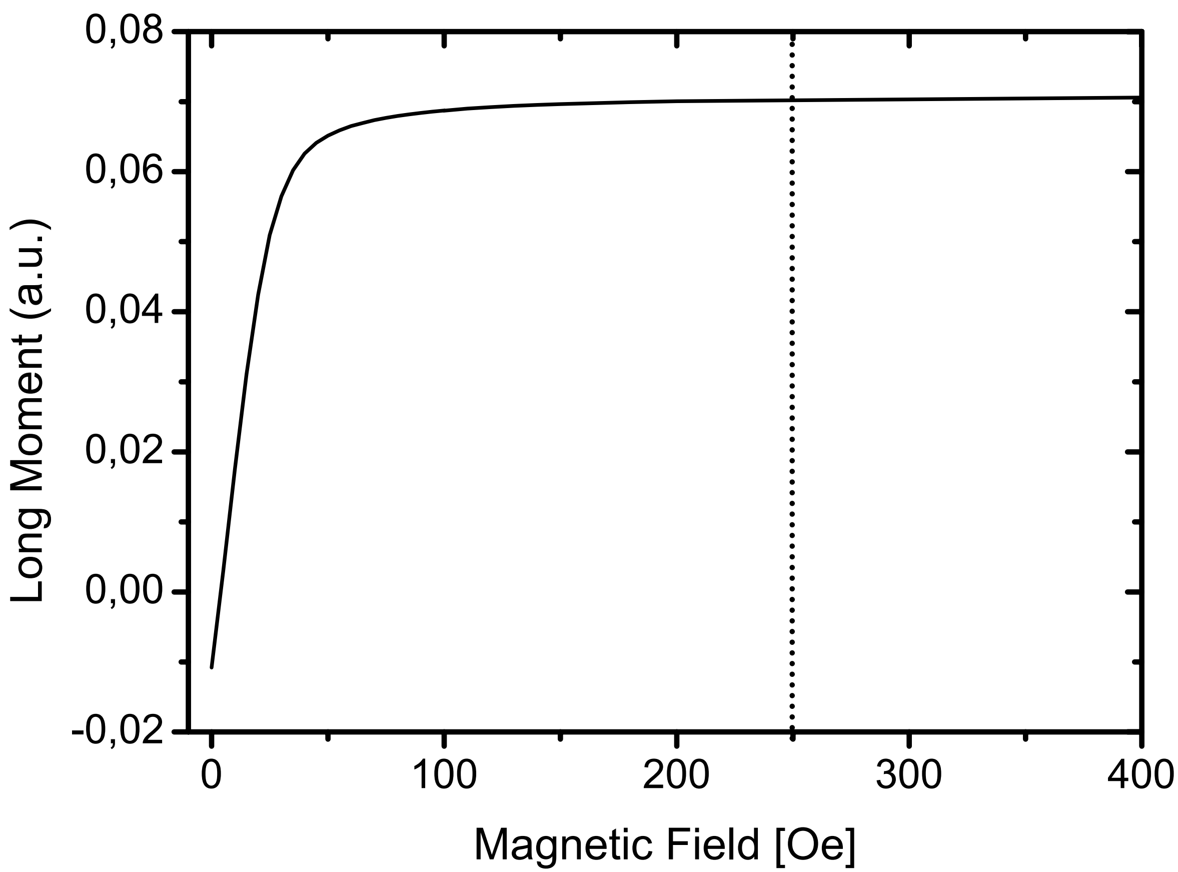
Magnetization

Principal

Setup

Results

SQUID Measurement of the magnetisation at room temperature



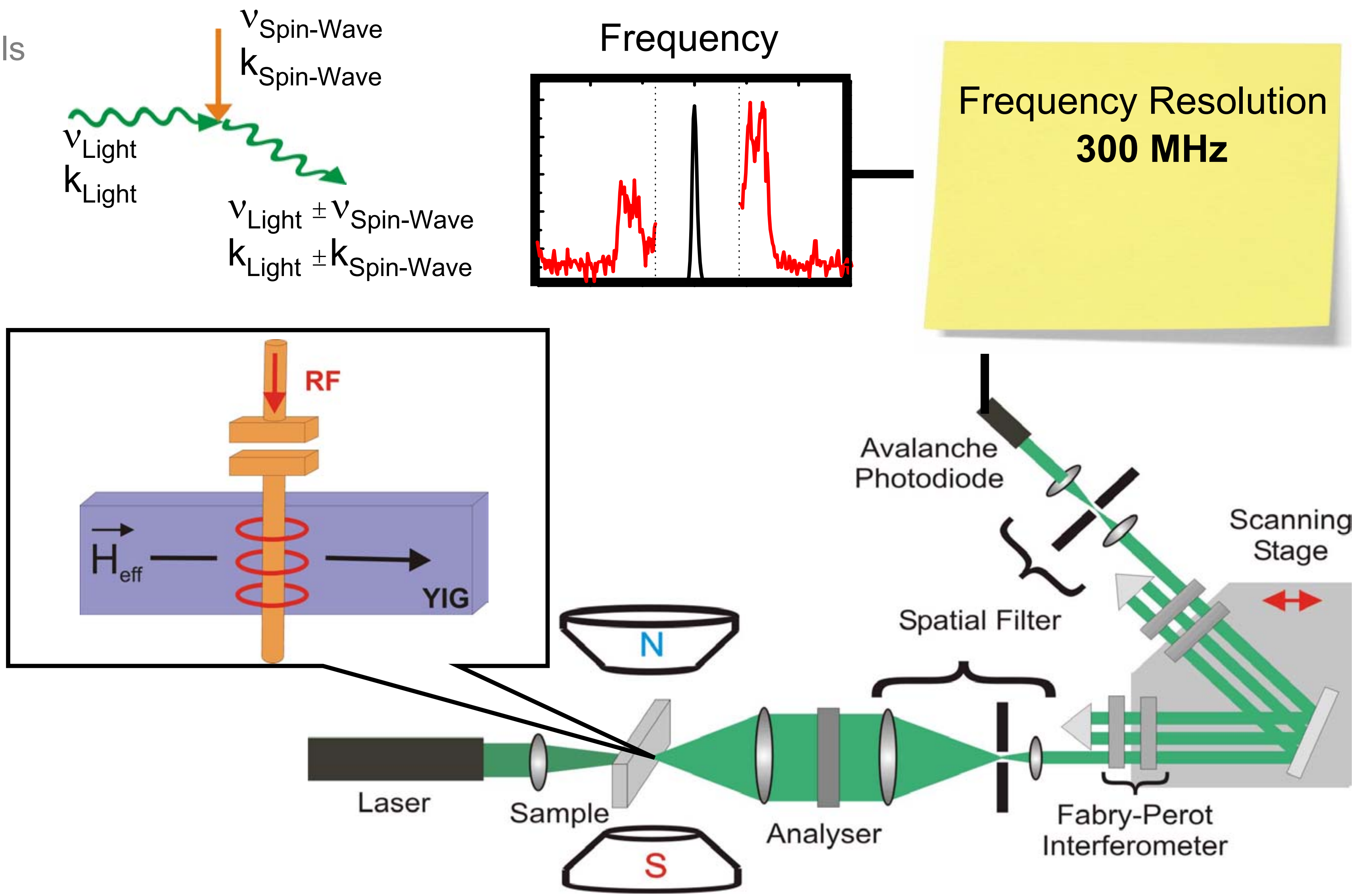
- single-domain-state for magnetic field of 250 Oe

Brillouin Light Scattering

Principals

Setup

Results



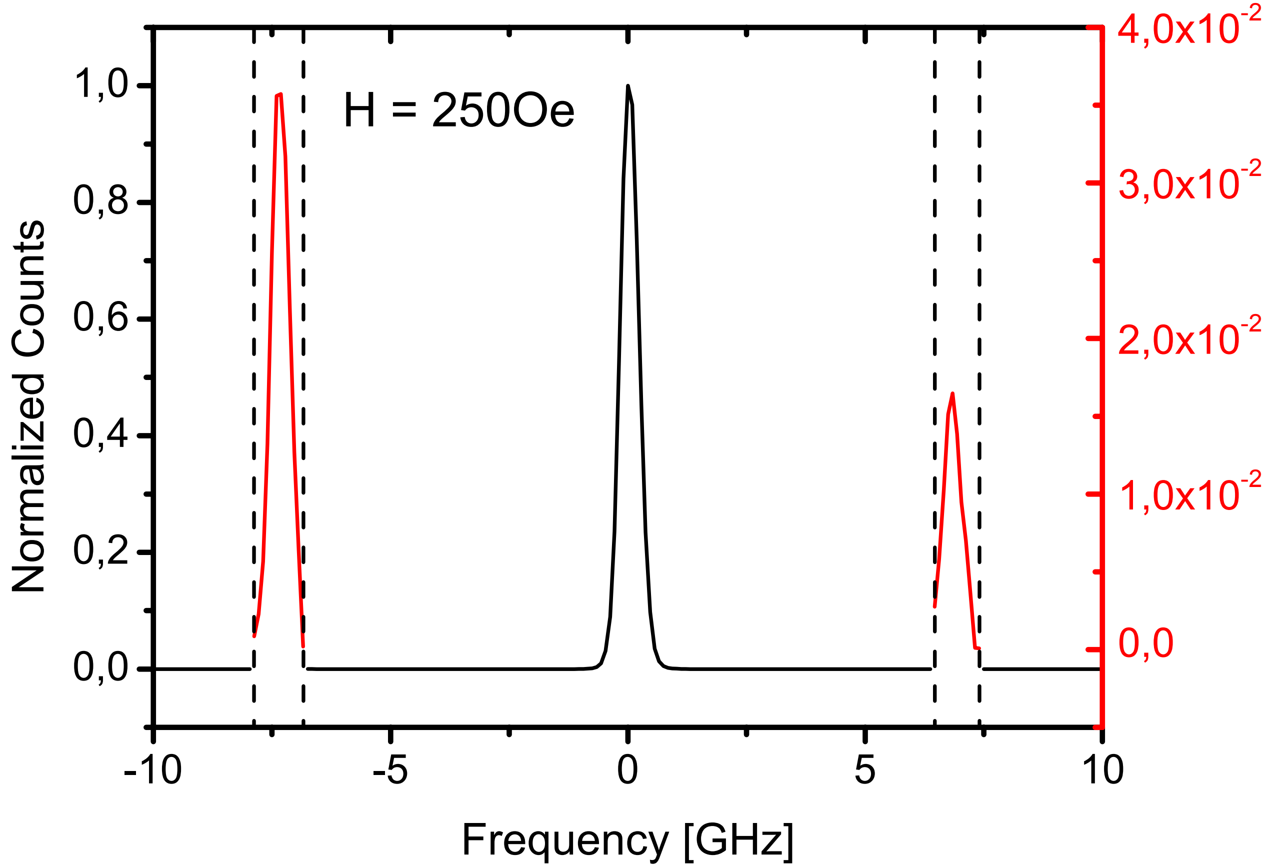
Signal Amplification

Pumping frequency $\omega_P = 2\pi \cdot 14.11\,\text{GHz}$

Pumping duration $\tau = 10\ \mu s$

Repetition time $t = 500\ \mu s$

⇒ Observation of strong BLS signal at $\omega_p/2$

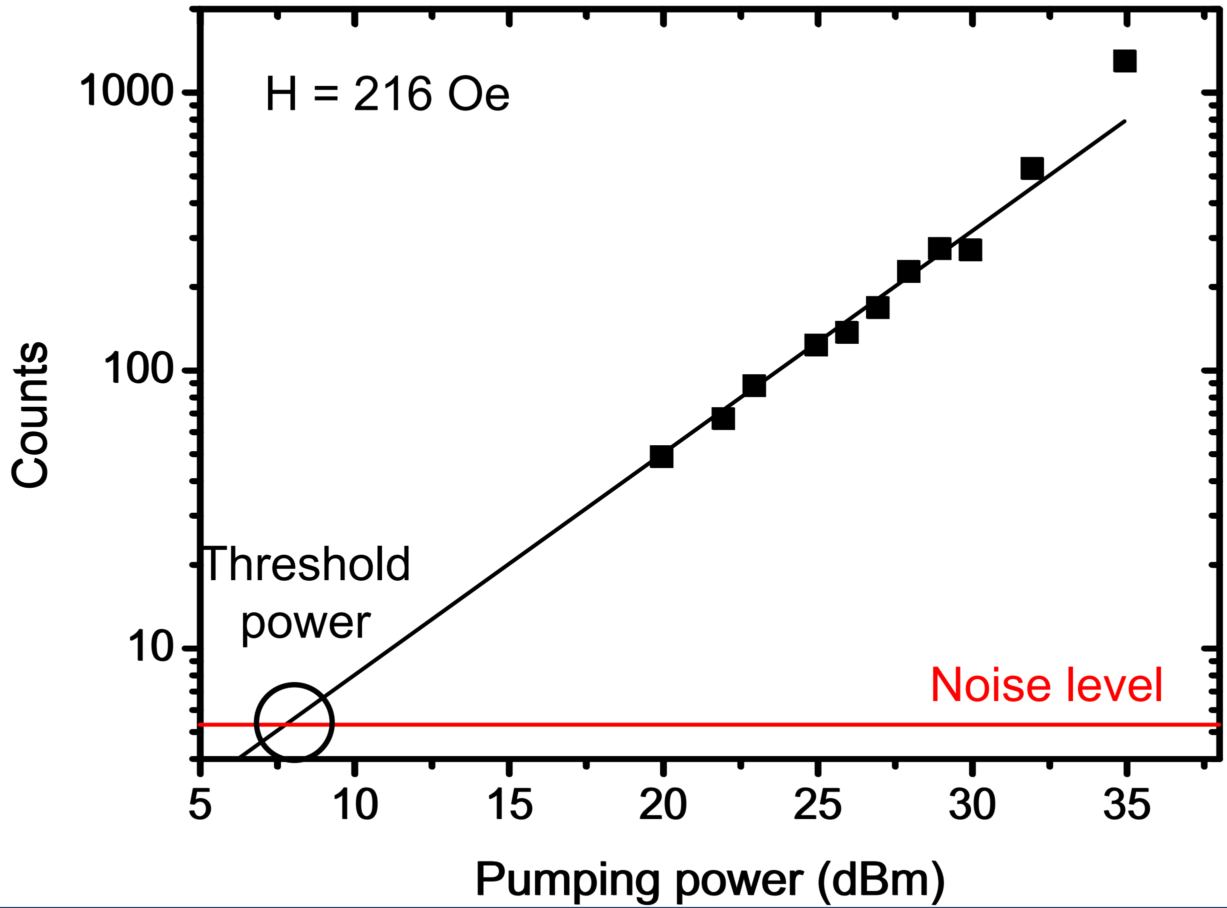


Variation of Pumping Power

Pumping frequency $\omega_P = 2\pi \cdot 14.11\,\text{GHz}$

Pumping duration $\tau = 10\ \mu\text{s}$

Repetition time $t = 500\ \mu\text{s}$



linear dependence of signal intensity on pumping power

⇓

estimate for threshold power: 6 dBm

⇓

consistent with microwave data

Signal Amplification

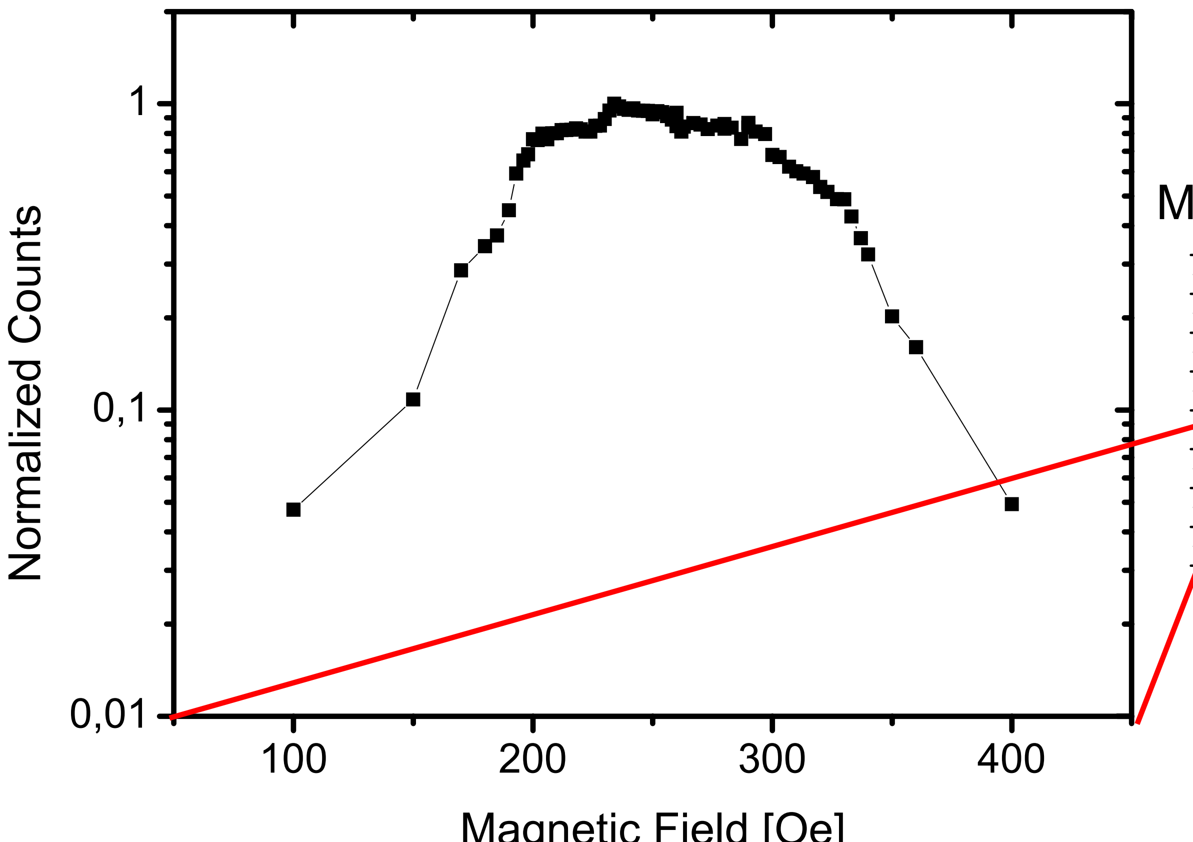
- Observation of thermal spin wave
- Observation of parametric amplification

Pumping frequency
$\omega_P = 2\pi \cdot 14.11\,\text{GHz}$

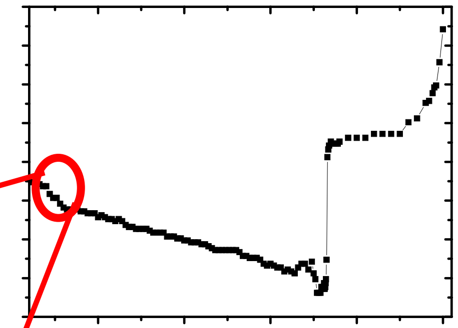
Pumping duration
$\tau = 2.5\ \mu s$

Repetition time
$t = 50\ \mu s$

BLS measurement



Microwave measurement



Thermal Signal

Principals

Setup

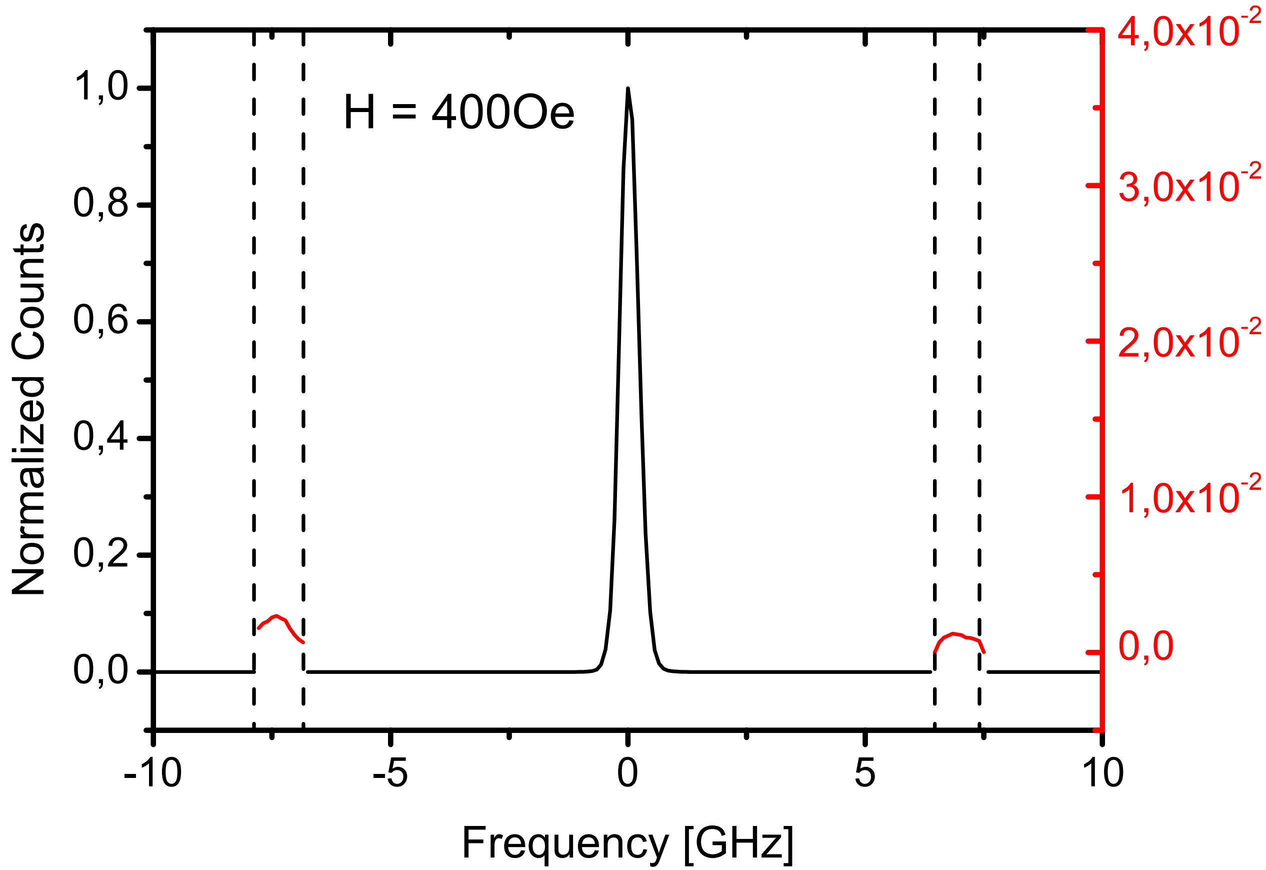
Results

Pumping frequency $\omega_P = 2\pi \cdot 14.11$ GHz

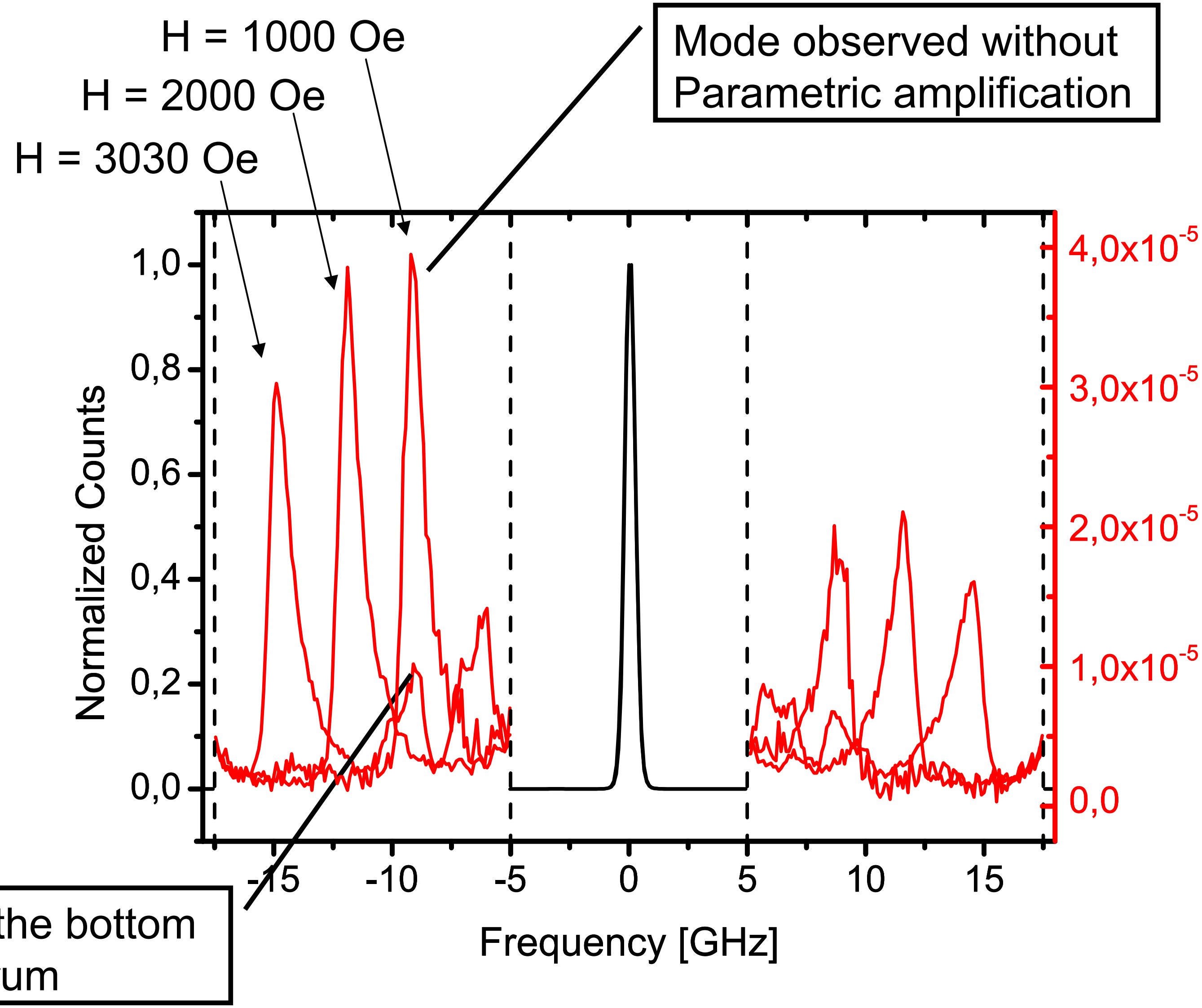
Pumping duration $\tau = 10\ \mu$s

Repetition time $t = 500\ \mu$s

⇨ Observation of BLS signal even for



Thermal Excitation

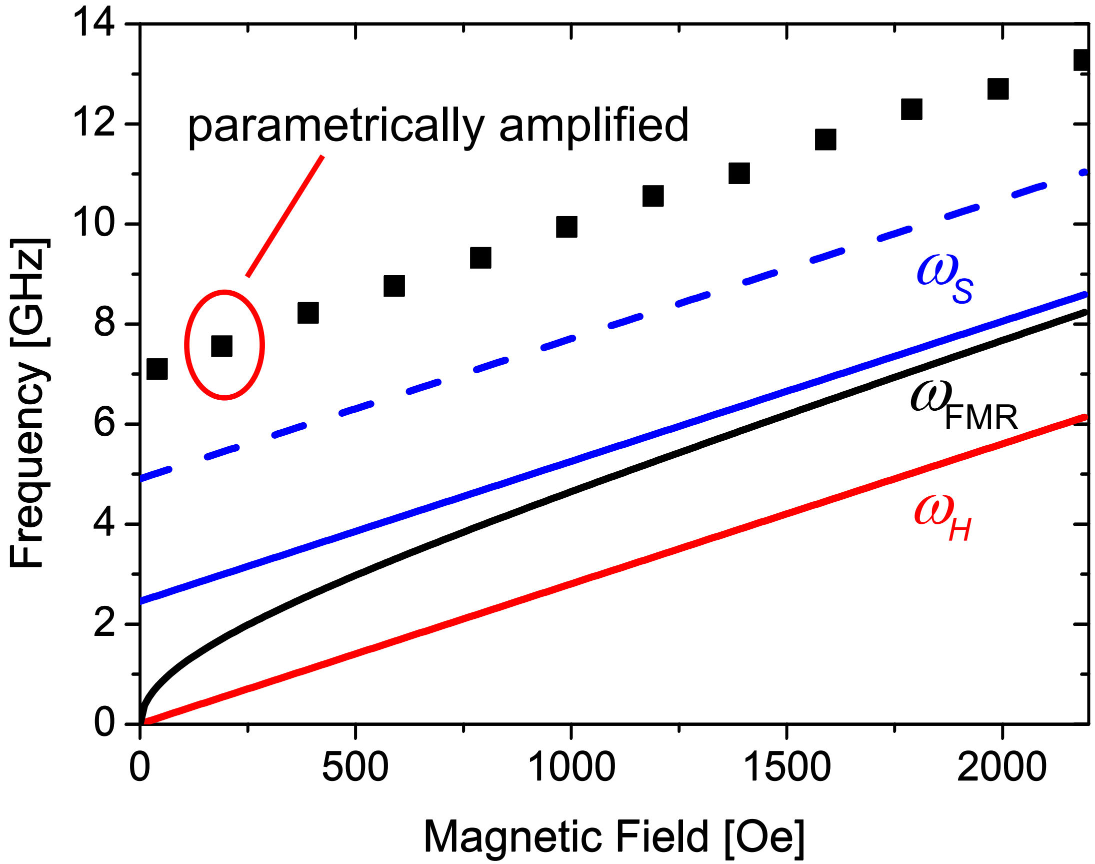


Magnetic Field Variation

Principals

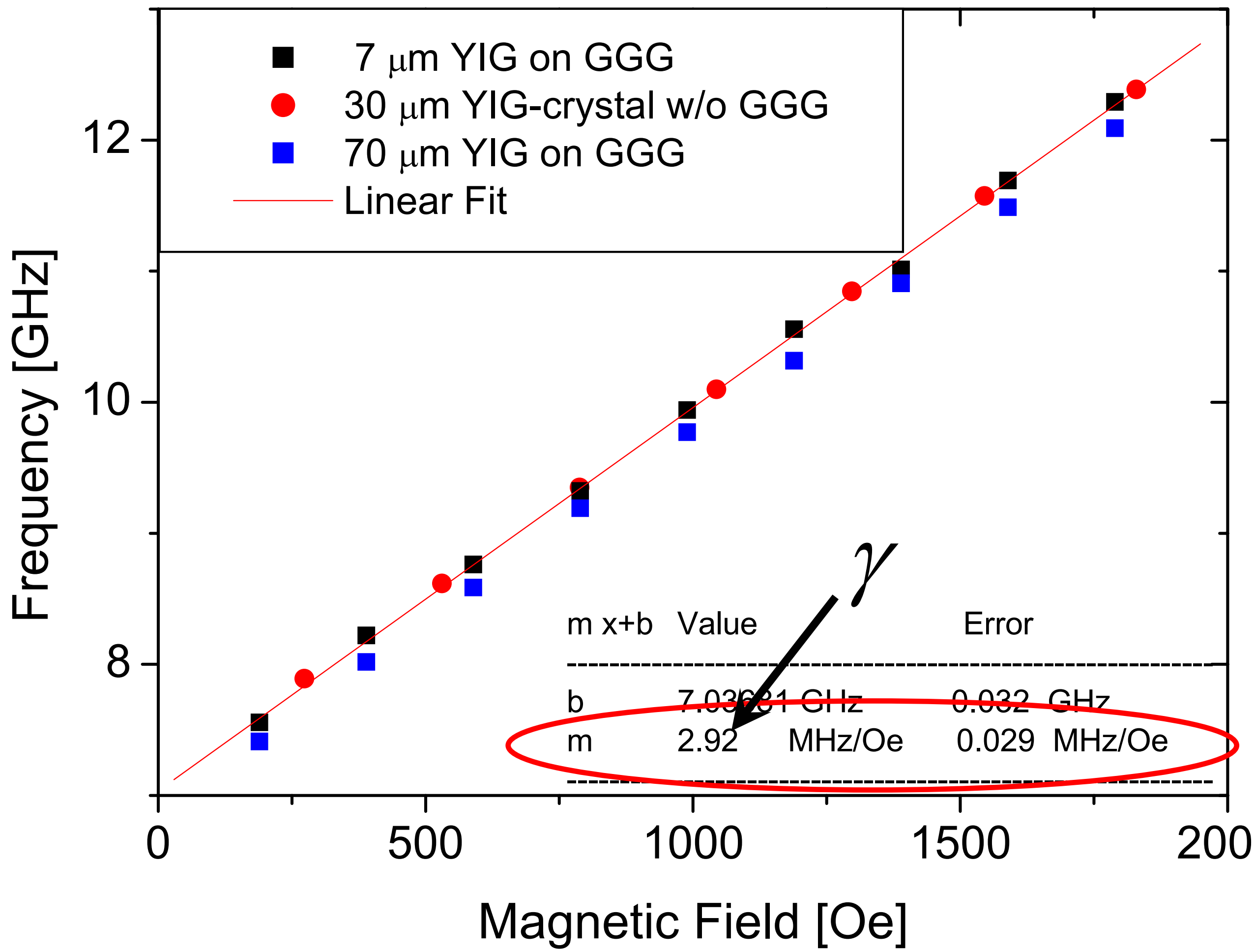
Setup

Results



- large initial energy gap
- above dipole spectrum limits

Thickness Variation



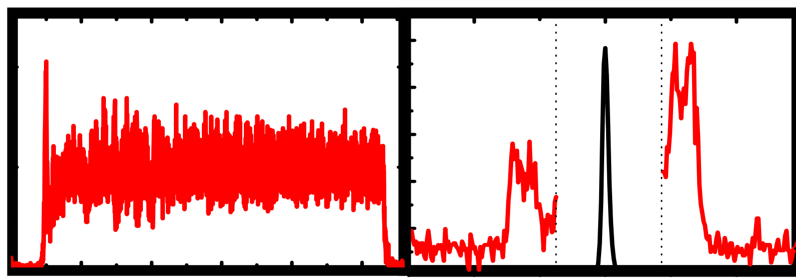
- linear dependence on the external magnetic H_{eff} from 40 Oe to 3000 Oe
- no significant thickness dependence

Brillouin Light Scattering

Principals

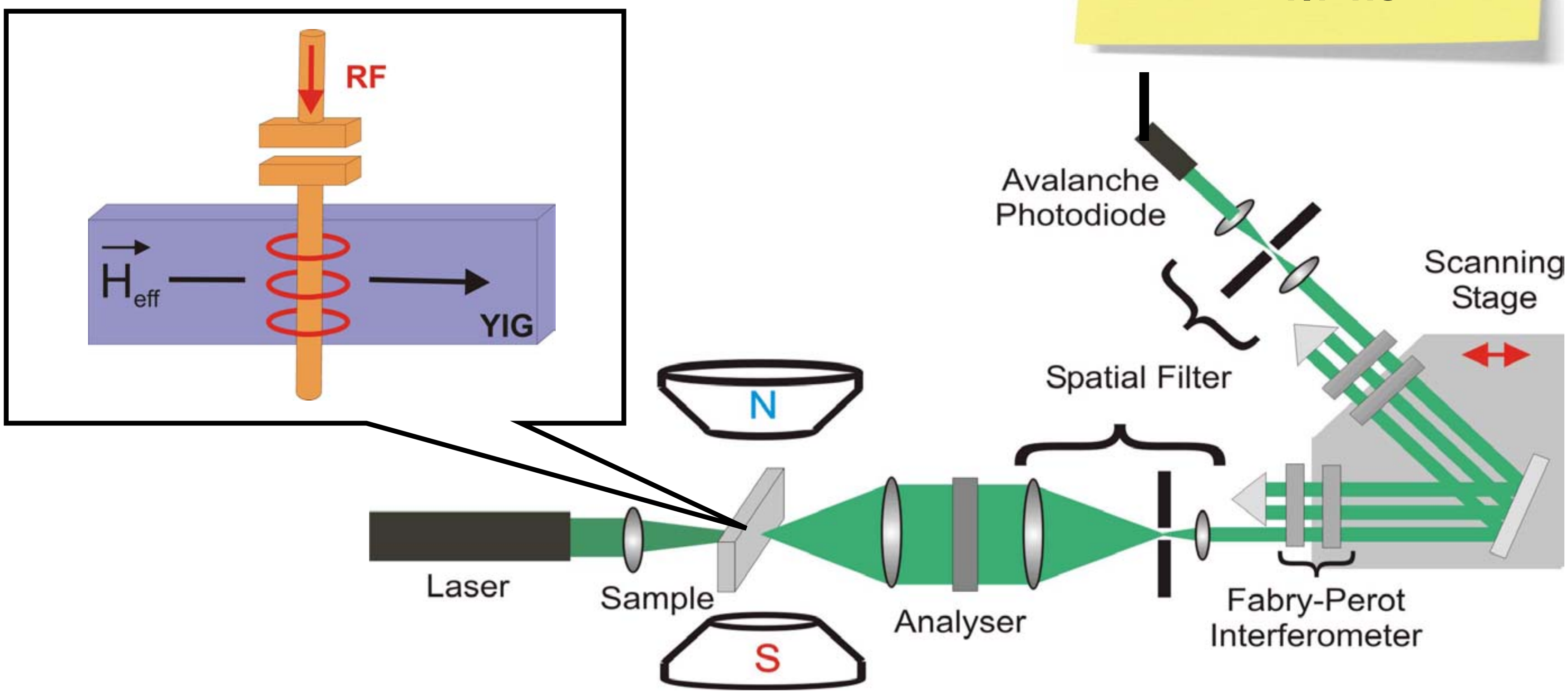
Setup

Results



Frequency Resolution
300 MHz

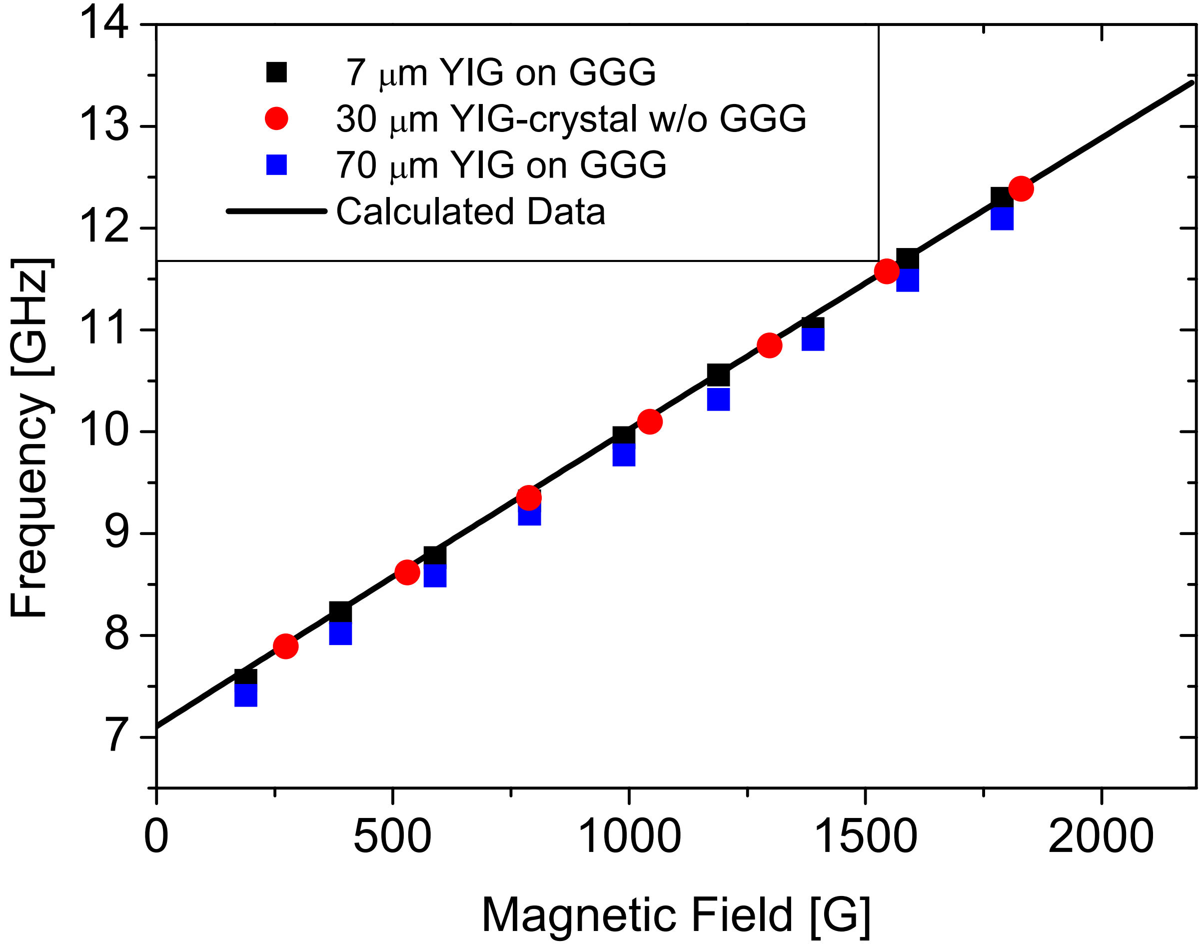
Temporal Resolution
1.7 ns



Calculated Data

Frequency calculated according to

$$\omega = \gamma \cdot \sqrt{\left(H + Dk^2\right) \cdot \left(H + Dk^2 + 4\pi M \sin^2\theta\right)}$$ with $k = 5{,}9 \cdot 10^5 cm^{-1}$, $\theta = 90°$



Calculated Data

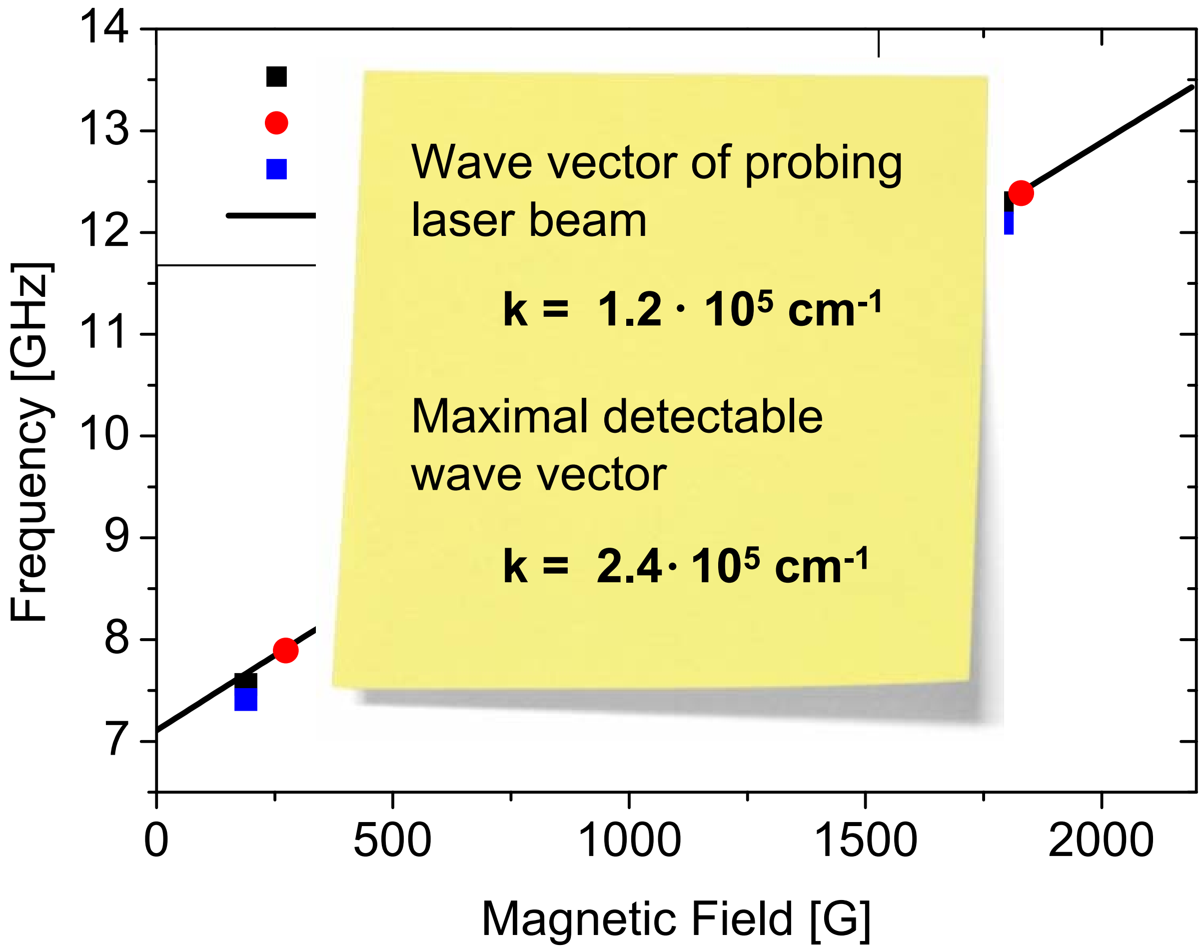
Principal

Setup

Results

Frequency calculated according to

$$\omega = \gamma \cdot \sqrt{\left(H + Dk^2\right) \cdot \left(H + Dk^2 + 4\pi M \sin^2\theta\right)} \quad \text{with} \quad k = 5{,}9 \cdot 10^5 cm^{-1},\ \theta = 90°$$



Summary

- Observation of unknown, thermally excited mode

  above the spectrum of dipole-dominated modes

  optical observation indicates not to large wave vector

  independent of film thickness

- Parametric amplification was observed

  fast exponential decay at intermediate pumping powers

  even faster decay at high pumping powers

  transitional oscillations

- Interpretation: Evanescent surface wave

Summary

**Thank you
for your attention**