Technische Universität Kaiserslautern

# Brillouin-Light-Scattering Spectroscopy

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SFB/TR49 Student Seminar
20th – 21th of July 2010

AG Magnetismus TU Kaiserslautern

OPTIMAS

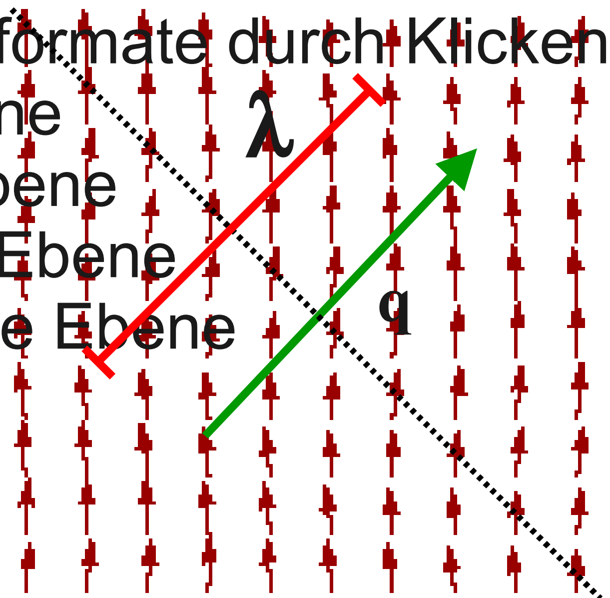
# Content

- Spin waves
- Brillouin Light Scattering (BLS)
  - Quantum mechanical picture
  - Conventional experimental setup
- Applications
  - Time-resolved BLS
  - Phase-resolved BLS
  - Wavevector-resolved BLS
- Summary

# Spin waves

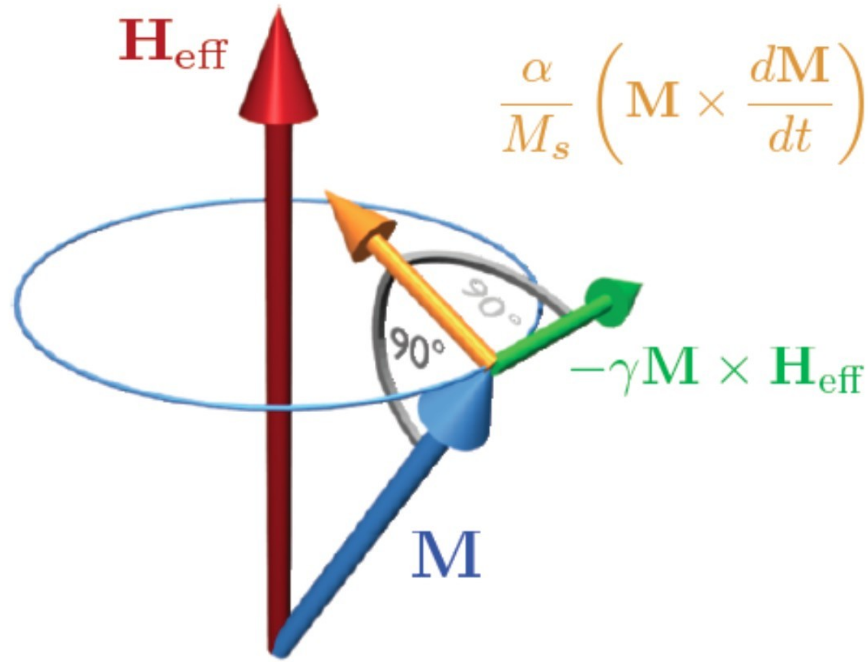
# Spin waves

masterformate durch Klicken bearbeiten
te Ebene
ritte Ebene
Vierte Ebene
• Fünfte Ebene




Landau-Lifshitz and Gilbert equation

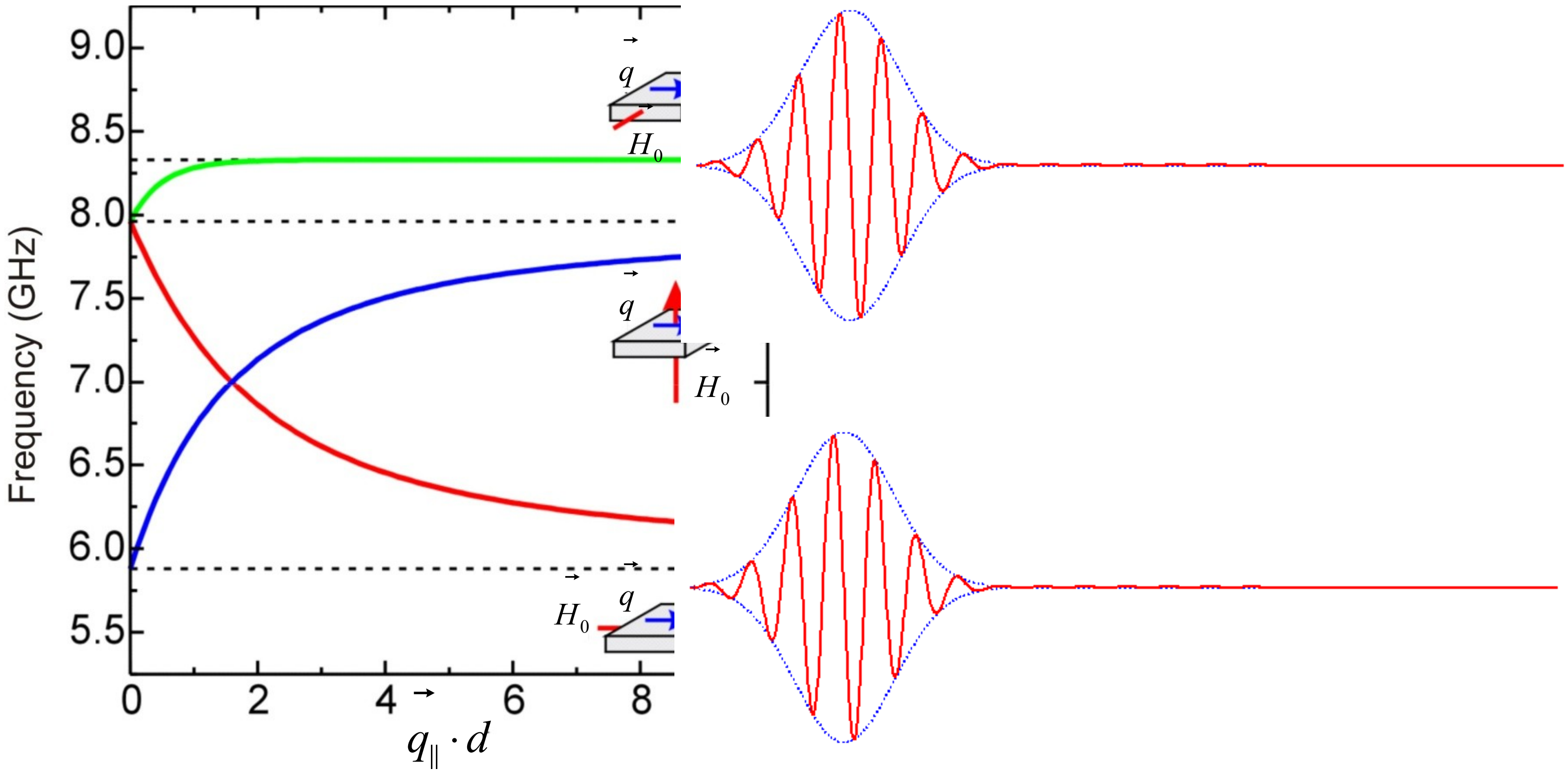
$$\frac{d\vec{M}}{dt} = -\gamma(\vec{M} \times \vec{H}_{eff}) + \frac{\alpha_G}{M_s}(\vec{M} \times \frac{d\vec{M}}{dt})$$



# Spin waves

**Distinction between different energy contributions**

- Exchange energy
  (generated by twist of neighbored spins, short range interaction)
- Dipolar energy
  (generated by magnetic poles in long-wavelength spin waves, long range interaction)



# Brillouin-Light-Scattering

# Inelastically scattered light

## Raman-Scattering

- Optical phonons
- Molecule vibrations

Frequencies up to several THz

Grating spectrometer

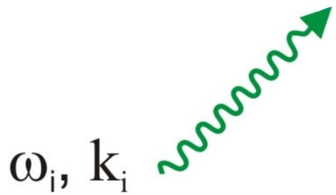
## Brillouin-Light-Scattering

- Acoustic phonons
- Spin waves

Frequencies below ~ 500 GHz

Tandem Fabry-Pérot interferometer

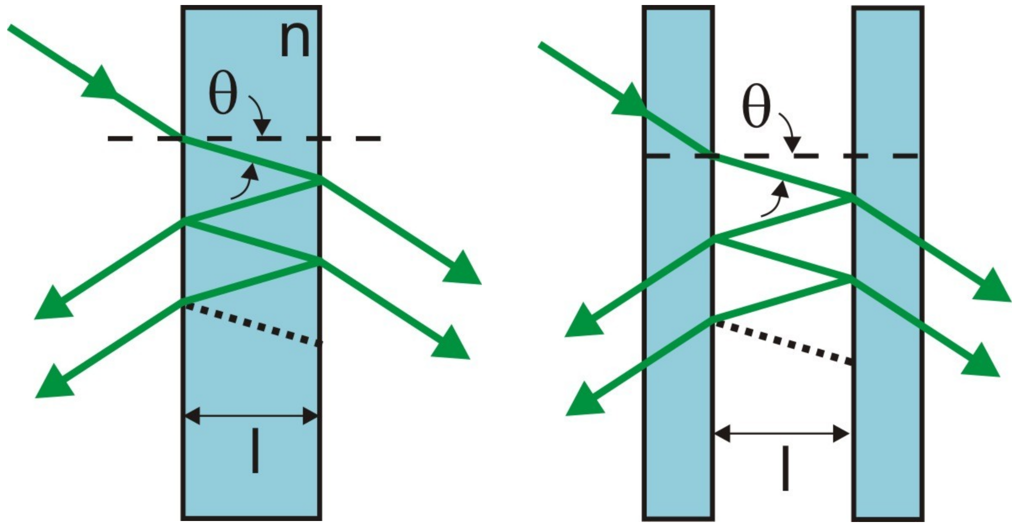
# Brillouin-Light-Scattering




Annihilation (Anti-Stokes)

| | Stokes: | Anti-Stokes: |
|---|---|---|
| Energy conservation law: | ωs = ωi - ω | ωs = ωi + ω |
| Momentum conservation law: | ks = ki - k | ks = ki - k |

# Fabry-Pérot interferometer (FPI)




The functionality of a Fabry-Pérot interferometer is based on multi-beam interference on two plane-parallel surfaces.

The phase difference:

$$\Delta\varphi = \left(\frac{2\pi}{\lambda}\right) 2nl\cos(\theta)$$

# Fabry-Pérot interferometer

**Transmittance and reflectivity**

The transmittance function is given by:

$$T = \frac{(1-R)^2}{1+R^2-2R\cos(\Delta\varphi)} = \frac{1}{1+F\sin^2\left(\Delta\varphi/2\right)},$$

where R is the reflectivity and $F = \frac{4R}{(1-R)^2}$ is the coefficient of the finesse F.

Maximum transmission occurs when

$$2nl\cos(\theta) = m\lambda,$$

$m$ = 1,2,3,…

# Fabry-Pérot interferometer

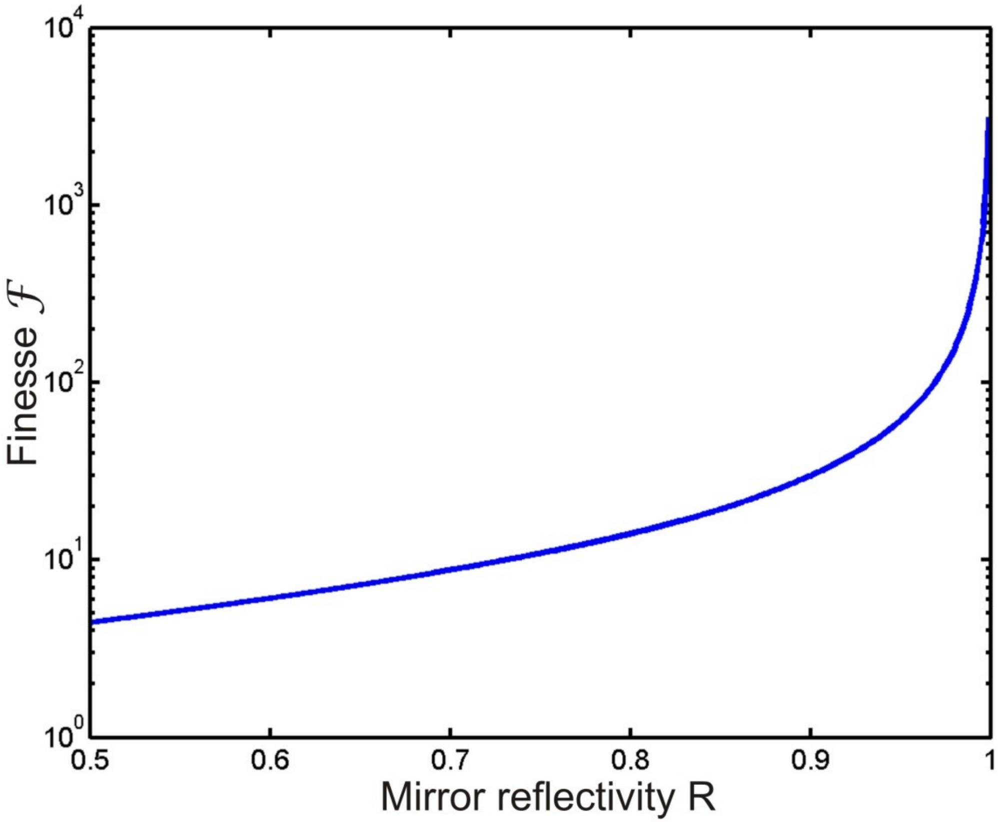
The free spectral range (FSR) is given by :

$$\Delta\lambda = \frac{\lambda_0^2}{2nl\cos\theta + \lambda_0} \approx \frac{\lambda_0^2}{2nl\cos\theta}$$

The finesse F is given by:

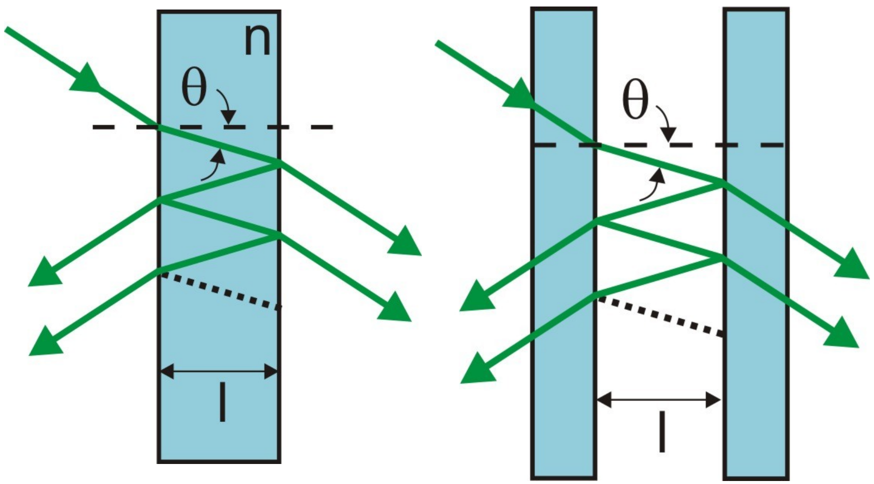
$$F = \frac{\Delta\lambda}{\delta\lambda} = \frac{\pi}{2\arcsin\left(1/\sqrt{F}\right)}$$

$$F \approx \frac{\pi\sqrt{F}}{2} = \frac{\pi\sqrt{R}}{1-R}$$




Our setup: F $\approx 110$

# Fabry-Pérot interferometer




Maximal transmission: $l = m\frac{\lambda}{2}$

- optical bandpass
- freuquency measurement

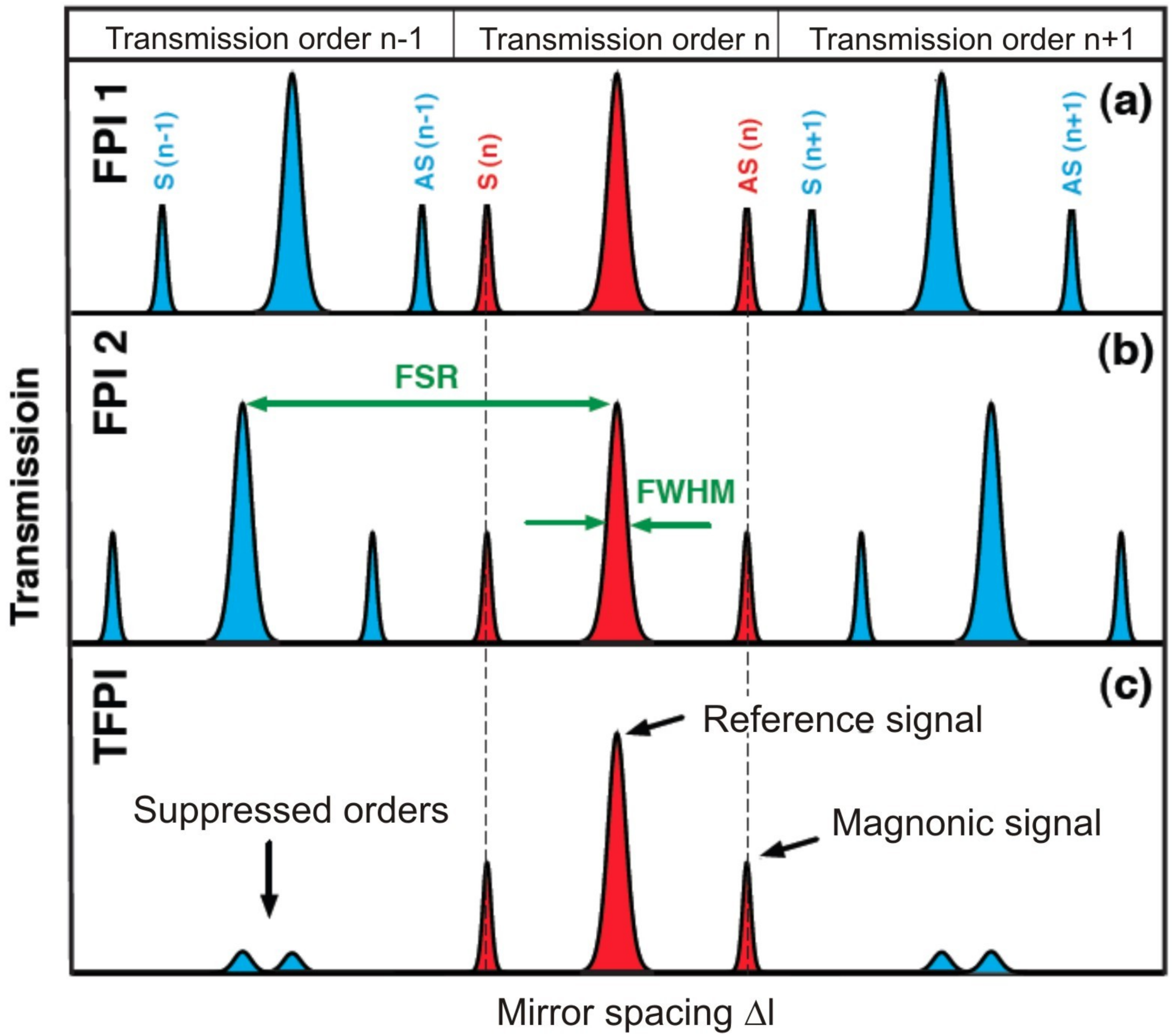
$$\lambda(\Delta l) = \lambda_R\left(1 + \frac{\Delta l}{l_R}\right)$$

Linear relation:

$$\Delta\nu(\Delta l) = |\nu_R - \nu| = \left|\frac{c}{\lambda_R}\left(1 - \frac{1}{1+\frac{\Delta l}{l_R}}\right)\right| = \left|\frac{c}{\lambda_R}\frac{\Delta l}{l_R + \Delta l}\right| \approx \left|\frac{c}{\lambda_R}\frac{\Delta l}{l_R}\right|$$

for lR= 0,3 mm: Δν= 500 GHz

# Operation of the TFPI




Possibility to suppress higher orders.

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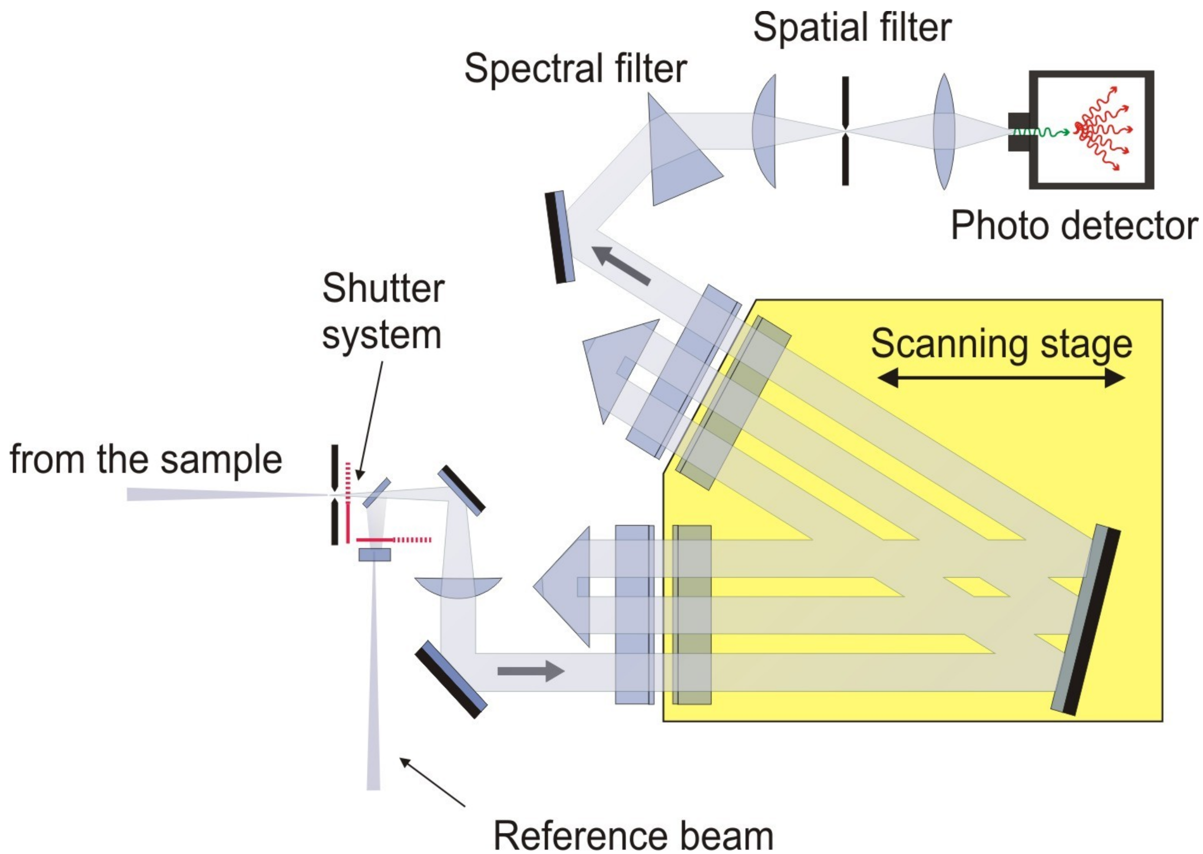
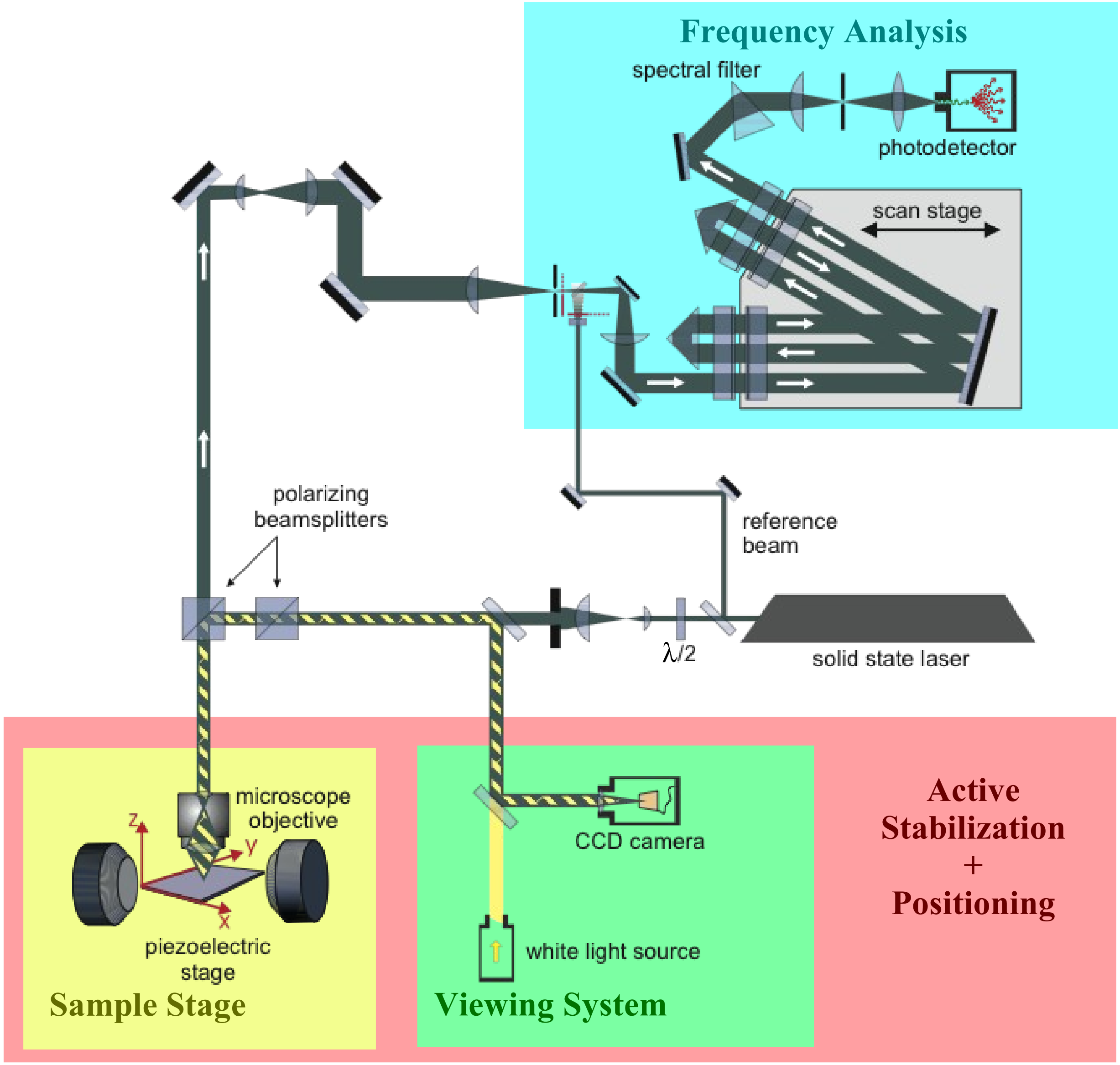
# Multi-pass tandem Fabry-Pérot interferometer (TFPI)




· High contrast: more than 1:1010
· High spectral resolution in the Sub-GHz-Regime (up to 50 MHz)
· Accessible frequency range: 0,2 GHz – 500 GHz

J. Sandercock, www.jrs-si.ch
H. Schultheiß, www.tfpdas.de

# BLS setup




- optical resolution:
  up to 250 nm
- 2D scanning stage

- controlling sample position
  while measuring

- frequency range:
  200 MHz – 1 THz
- spectral resolution:
  up to 50 MHz

- accuracy:
  ***better than 20 nm***
- high reproducibility

**TFPDAS 4**
(www.tfpdas.de)
by H. Schultheiss

# Applications

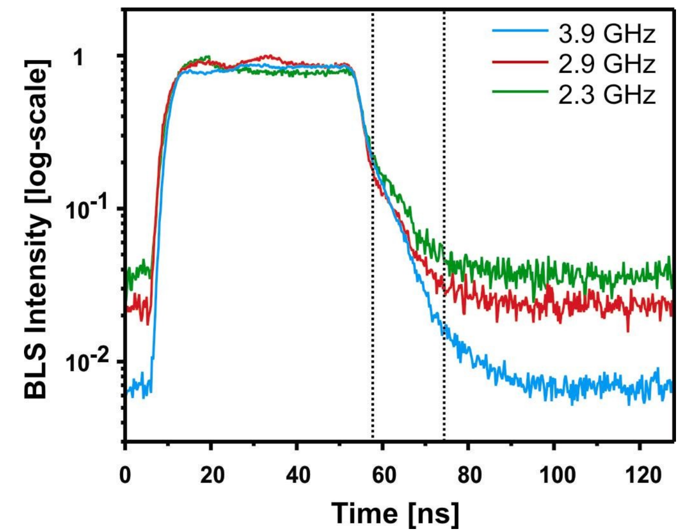
# Applications

1) **Time resolution**
H. Schultheiss et al,
J. Phys. D **41**, 164017 (2008)

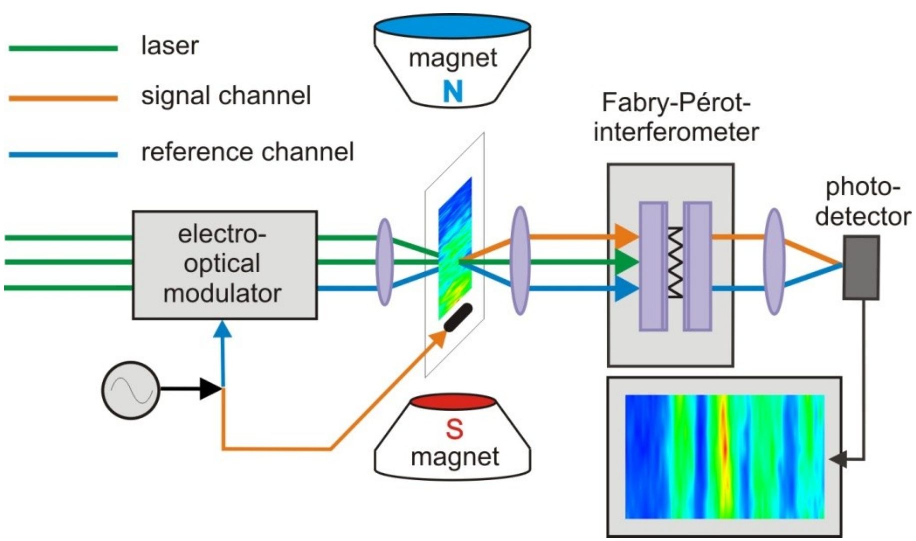
2) **Phase resolution**
A. A. Serga et al., APL **89**, 063506 (2006)
F. Fohr et al., RSI **80**, 043903 (2009)

3) **Wavevector resolution**
C. Sandweg et al,
Rev. Sci. Instrum. 81, 073902 (2010)

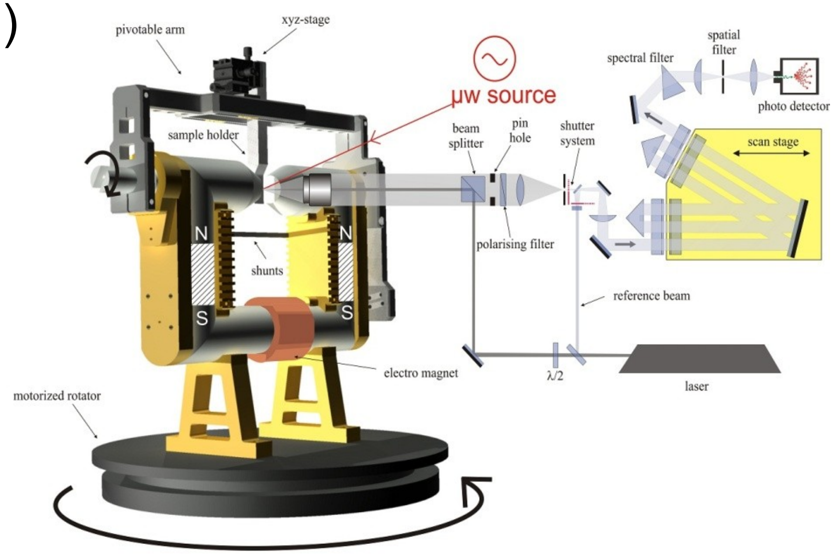
1)




2)



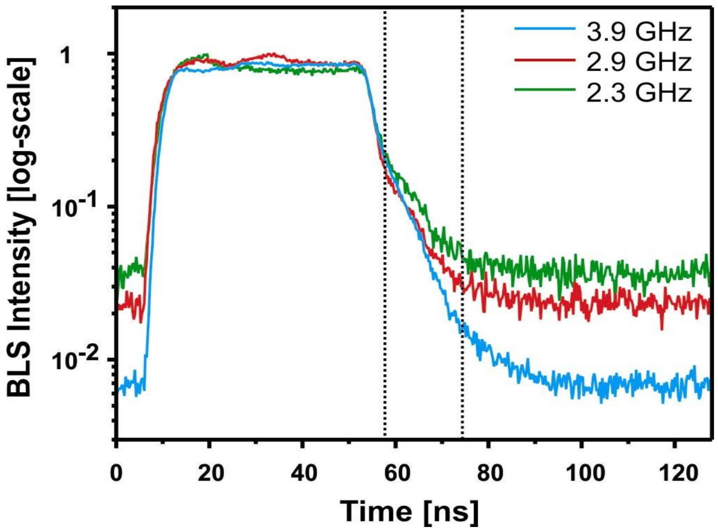

3)



# Applications:

# Time-resolved BLS

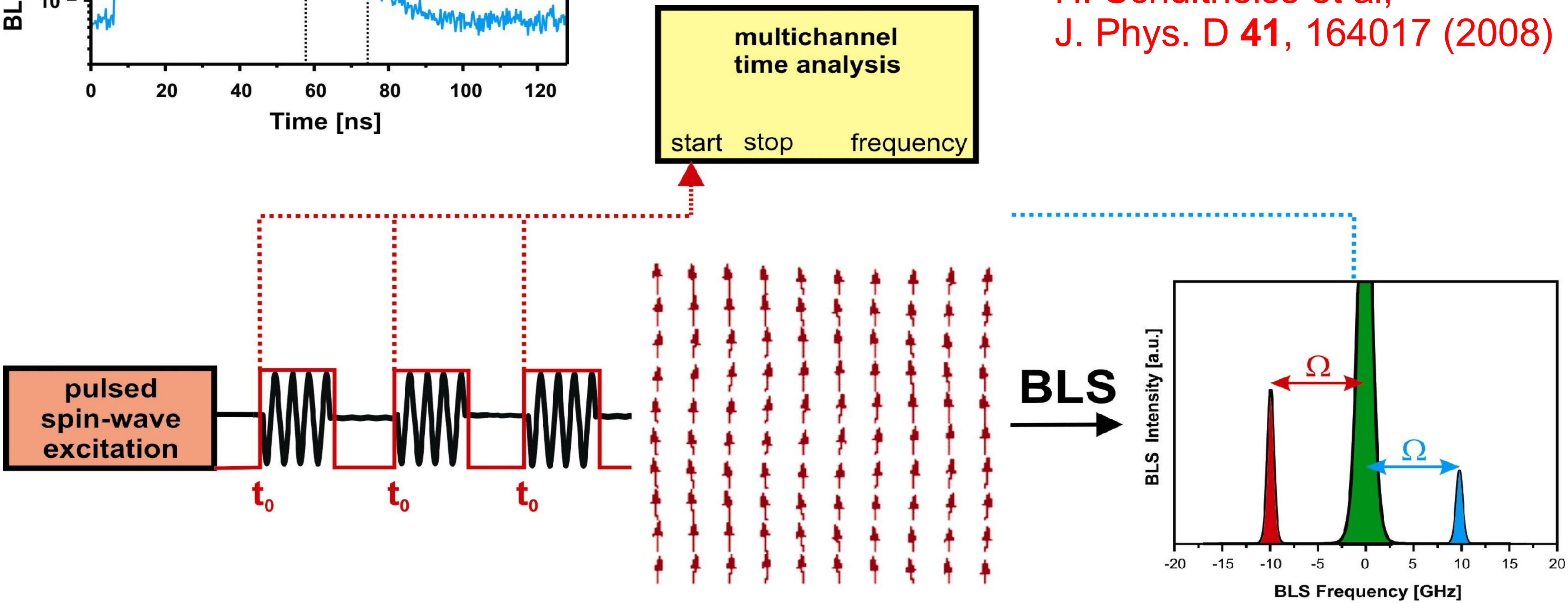
# Time-resolved BLS




Study the decay of spin waves

and the dissipation processes

H. Schultheiss et al,
J. Phys. D **41**, 164017 (2008)



# Applications:

# Phase-resolved BLS

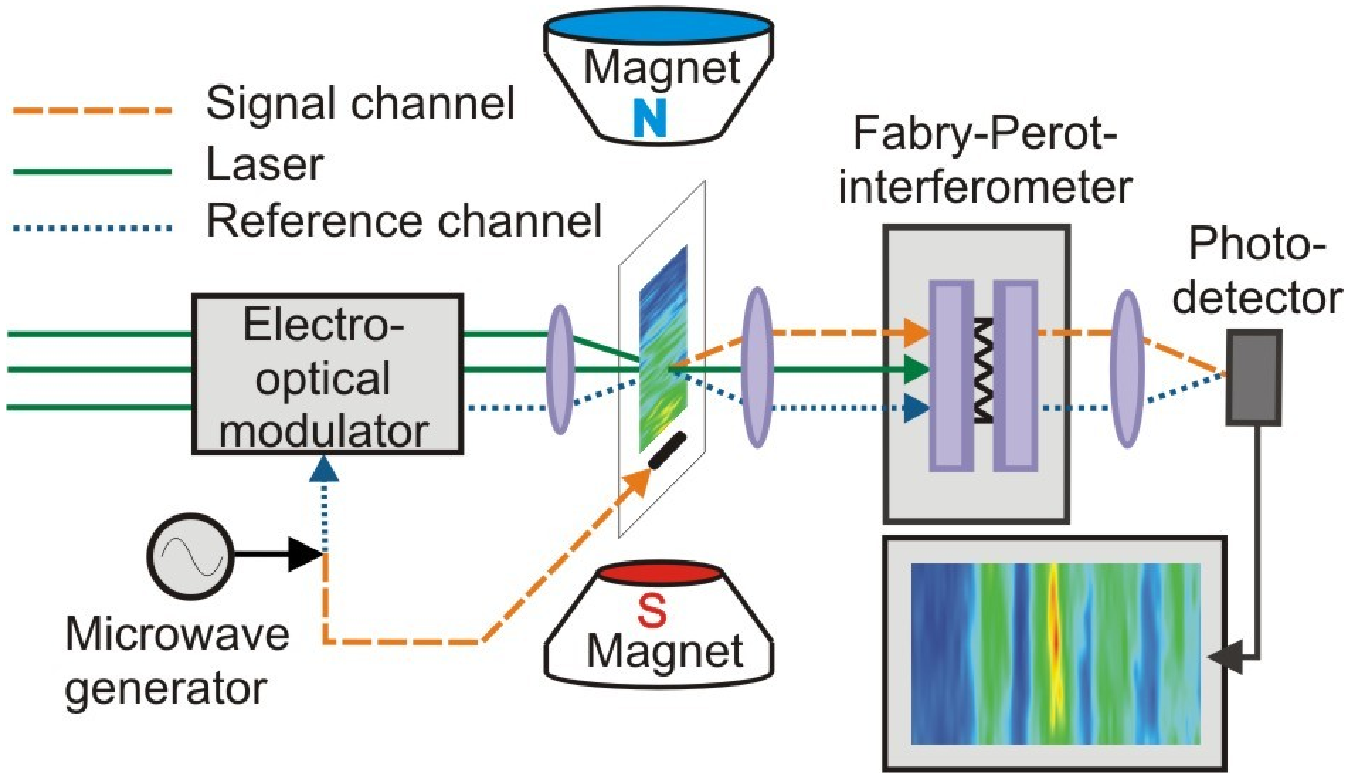
# Phase-resolved BLS

Inelastically scattered light contains phase information

But: BLS signal is proportional to laser intensity

► $I \propto x^2(t) = (A \cdot e^{i(\omega t+\varphi)})^2 = A^2$ ► phase-information is lost!

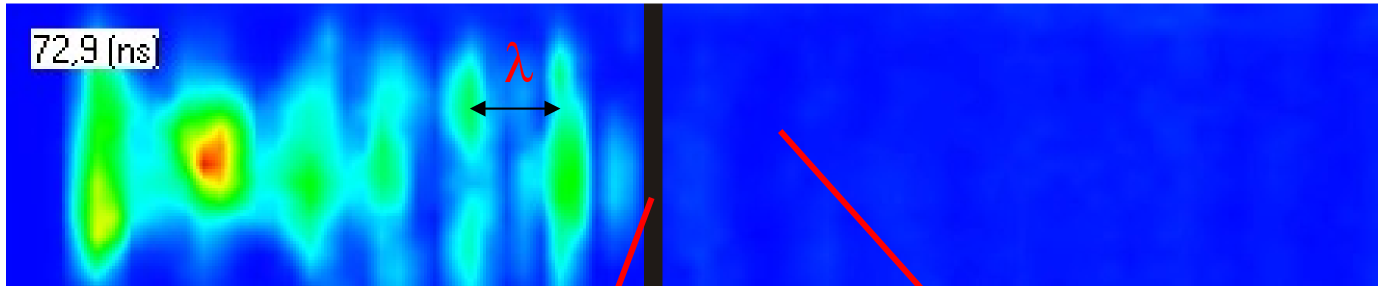
Idea: **interference**!



# Example for phase-resolved BLS: Tunneling

**running spin wave:** wave has not reached the barrier yet

**phase resolved scan:**

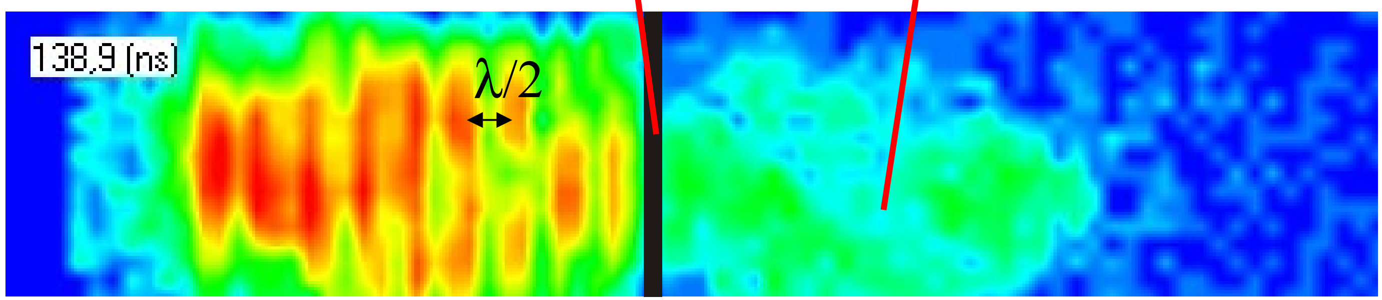



Hext = 1846 Oe
vRF = 7,125 GHz
tpuls = 200 ns

YIG-film (1,6 x 7,7 mm)

barrier (cut, 20 µm)

**standard position scan:**




**standing spin wave:** wave is reflected back and forms a standing wave

T. Schneider: PhD Thesis

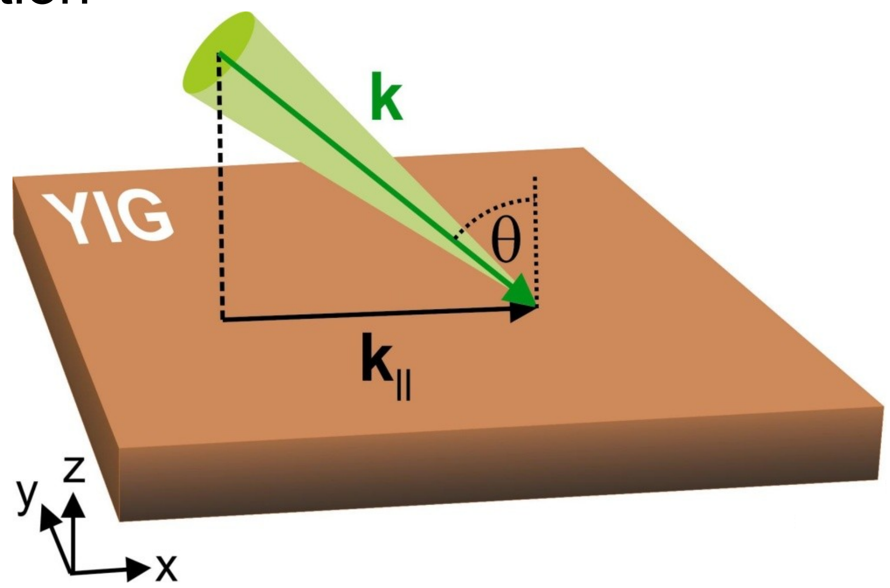
# Applications:

# Wavevector-resolved BLS

# Wavevector-resolved BLS

No translational invariance in z direction

Only **k||** = **k** sin(θ) conserved

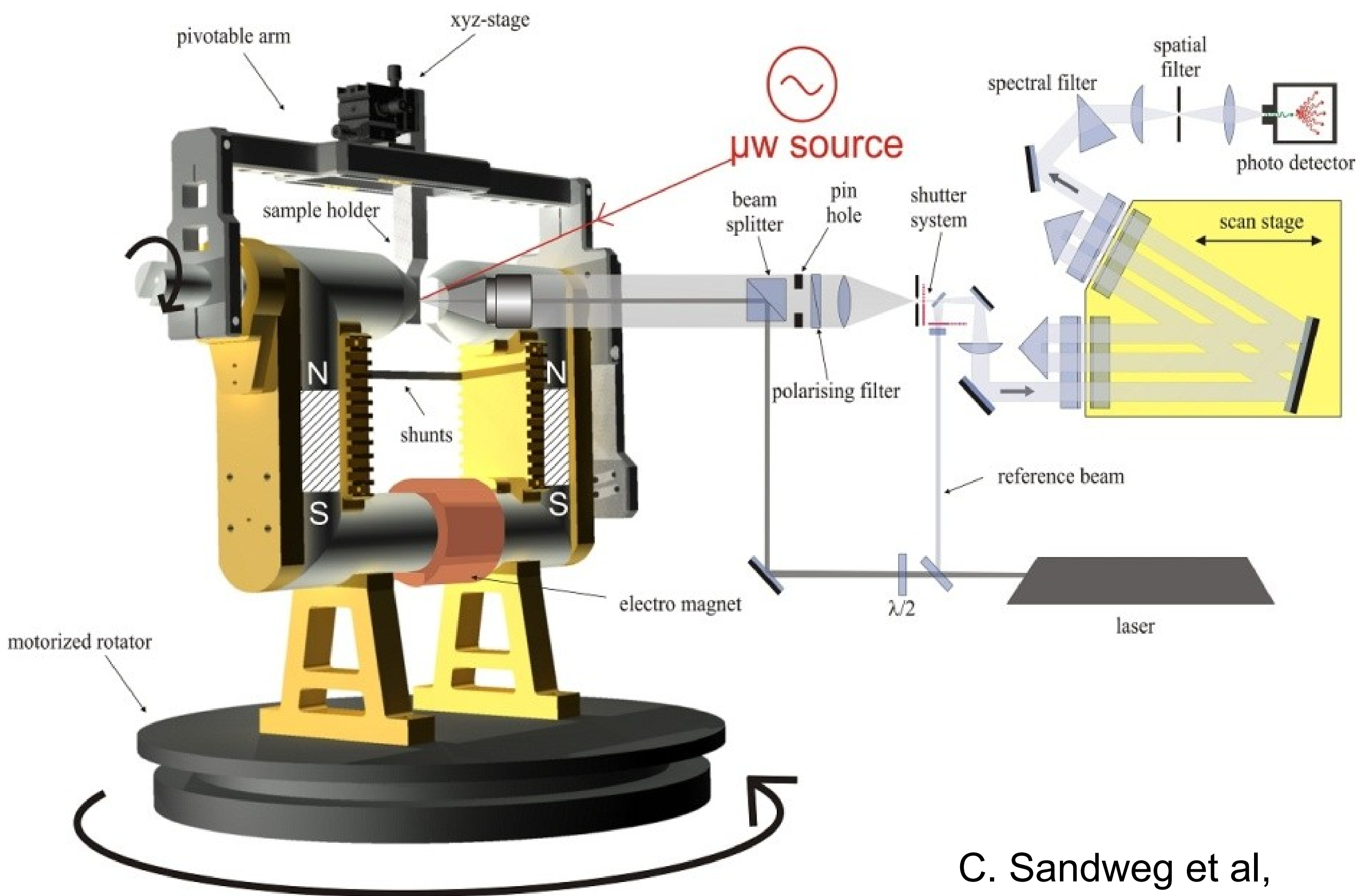



Maximum wavevector: k < 2.10 5 cm-1

(Backscattering geometry: Δk = 2 k||)

# Wavevector-resolved BLS

## Wavevector selection by rotating the sample




C. Sandweg et al,
Rev. Sci. Instrum. 81, 073902 (2010)

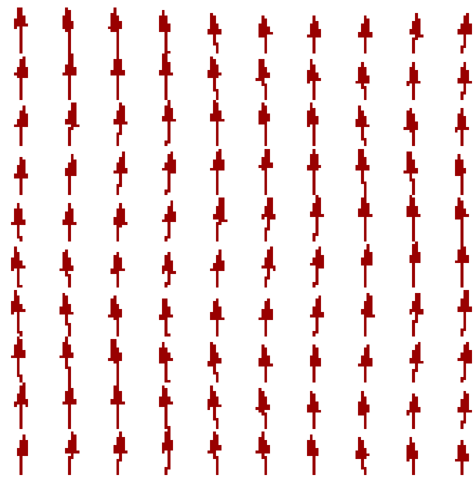
# Summary

## Brillouin light scattering

study spin waves…

…wavevector resolved

…frequency resolved



…time resolved

…phase resolved

…space resolved