Georgia State University

International Workshop NPCQS2012

OIST

Radiation-induced magnetoresistance oscillations: Polarization sensitivity

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Motivation

Differences in theoretical model about polarization sensitivity of microwave induced magneto-resistance oscillations

✓ **Displacement model** [1]

Oscillation-amplitude depends on whether the linearly polarized microwave electric field, E_ω, is parallel or perpendicular to the dc-electric field, E_{DC}.

X **Inelastic model** [2]

Photoconductivity is insensitive to the polarization orientation of the linearly polarized microwave field

✓ **Radiation-driven electron orbit model** [3]

$\gamma < \omega$

Insensitive to the orientation of the microwave polarization direction if $\gamma > \omega$
Where, γ is a material and sample-dependent parameter
ω is the microwave frequency

✓ **Non-parabolicity model** [4]

Radiation induced contribution depends on the relative orientation between DC electric field, E_{DC} , and the electric field of the linearly polarized MW radiation, E_ω.

[1] V. Ryzhii et al., J. Phys.: Cond. Matt. 15, 6855 (2003)
[2] I. A. Dmitriev et al., Phys. Rev. B 71, 115316 (2005)
[3] J. Inarrea et al., Phys. Rev. B 76, 073311 (2007)
[4] A. A. Koulakov et al., Phys. Rev. B 68, 115324 (2003)

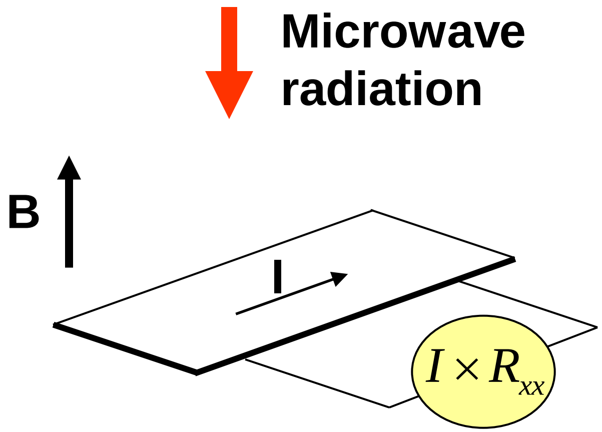
Outline

Brief description about the experiment and the experimental setup

Results and discussion

Conclusions

Experimental design

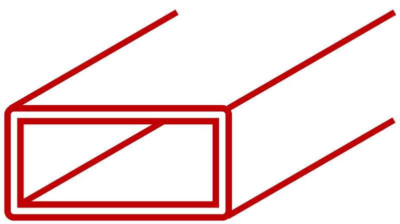


How to change the orientation between the Hall bar device and the MW E-field?

~~Rotate sample and fix MW E-field~~

Fix sample and rotate MW E-field

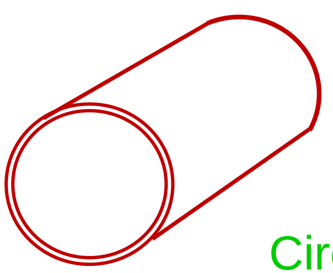
Rectangular waveguide



X

Difficult to rotate the waveguide

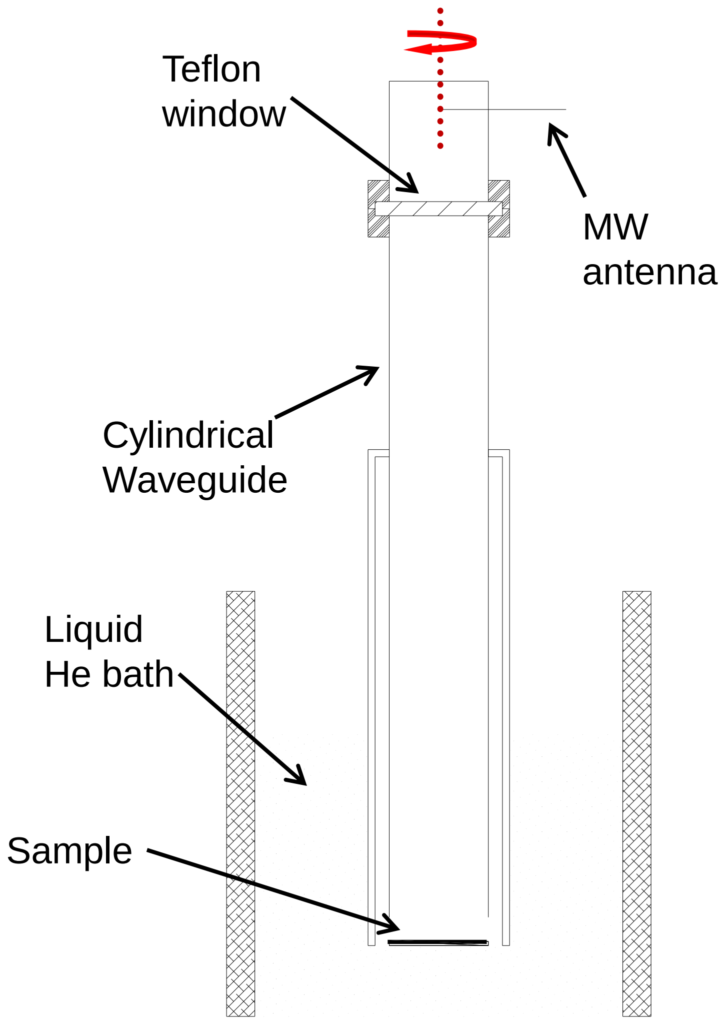
Cylindrical waveguide

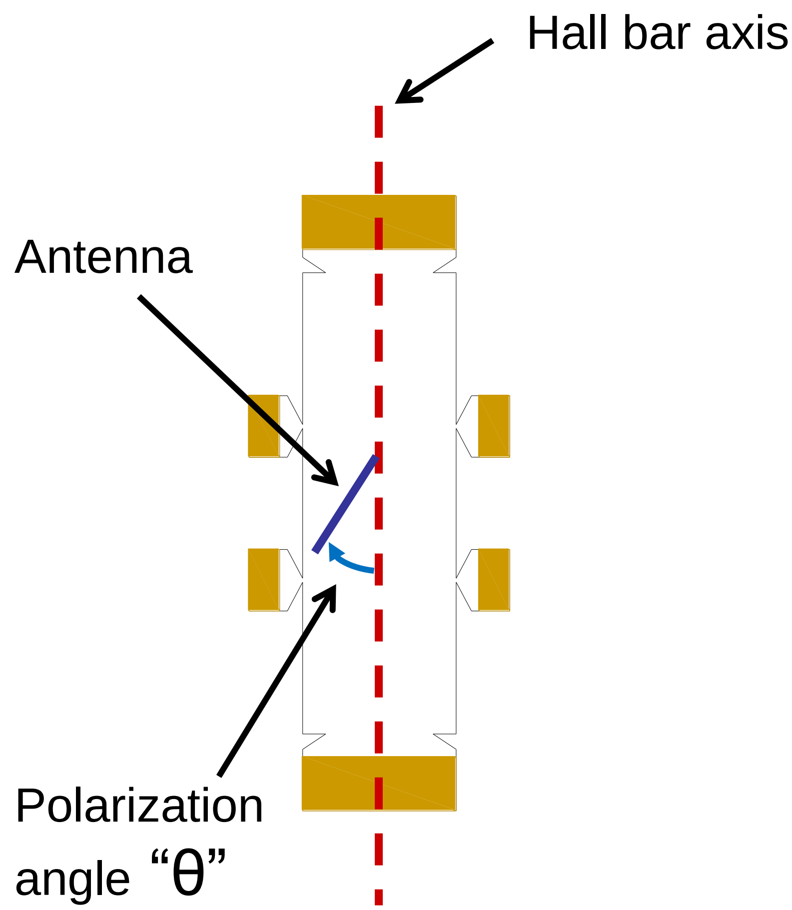


✓

Circular symmetry makes life easier!!!

Experimental setup

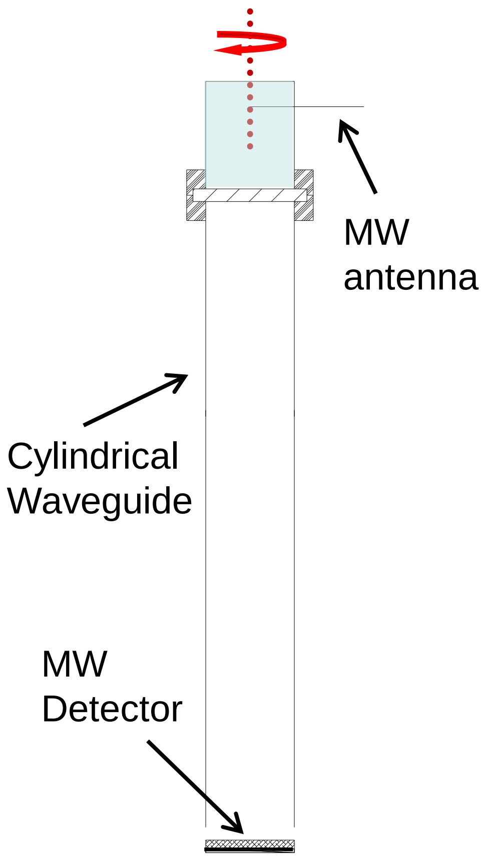


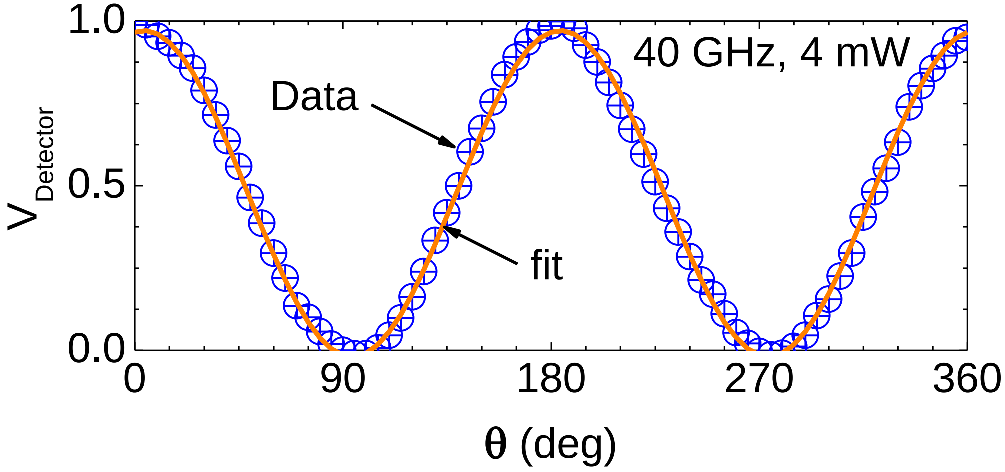


Polarization angle "θ" is the angle between the Hall bar axis and the MW antenna

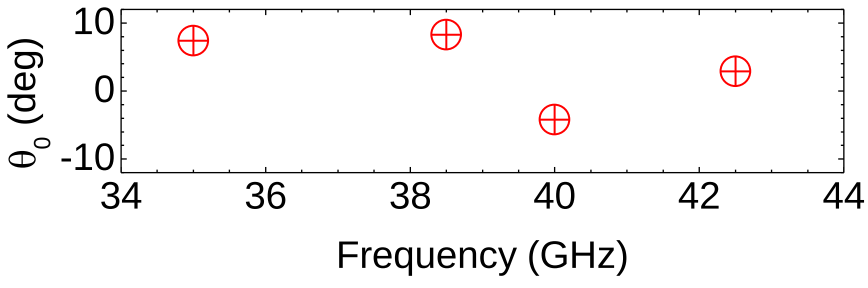
Experimental setup

Is the polarization preserved through the waveguide?





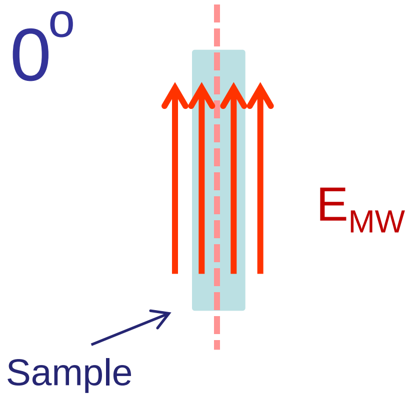
$$V_D \propto \cos^2(\theta) \rightarrow V_D = A + C\cos^2(\theta - \theta_0)$$

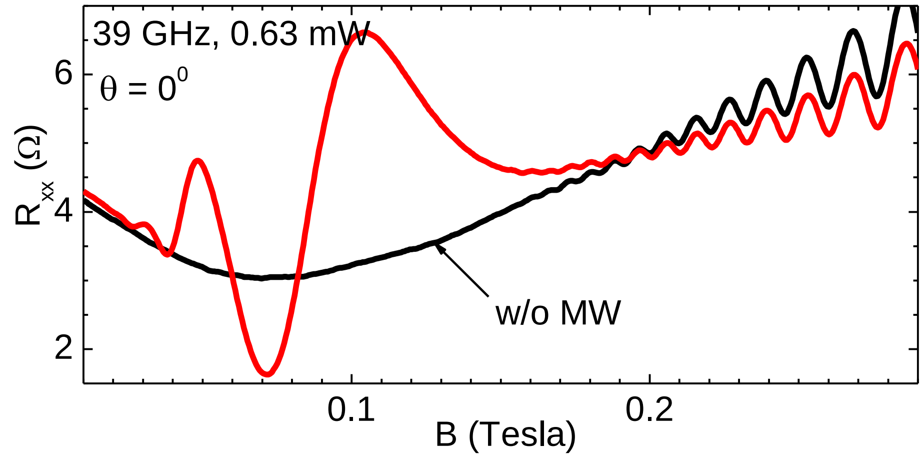


The polarization at the sample-location follows expectations, within an experimental uncertainty of θ_0 ~ 10 degrees.

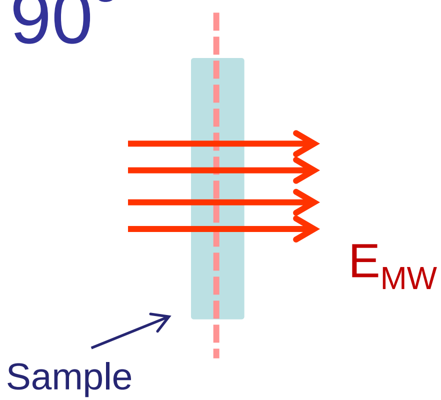
Results

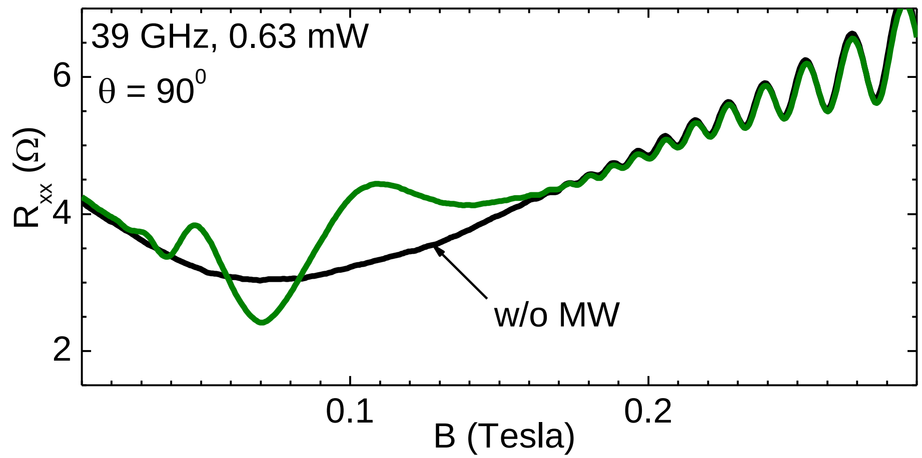
$\theta = 0^o$





$\theta = 90^o$

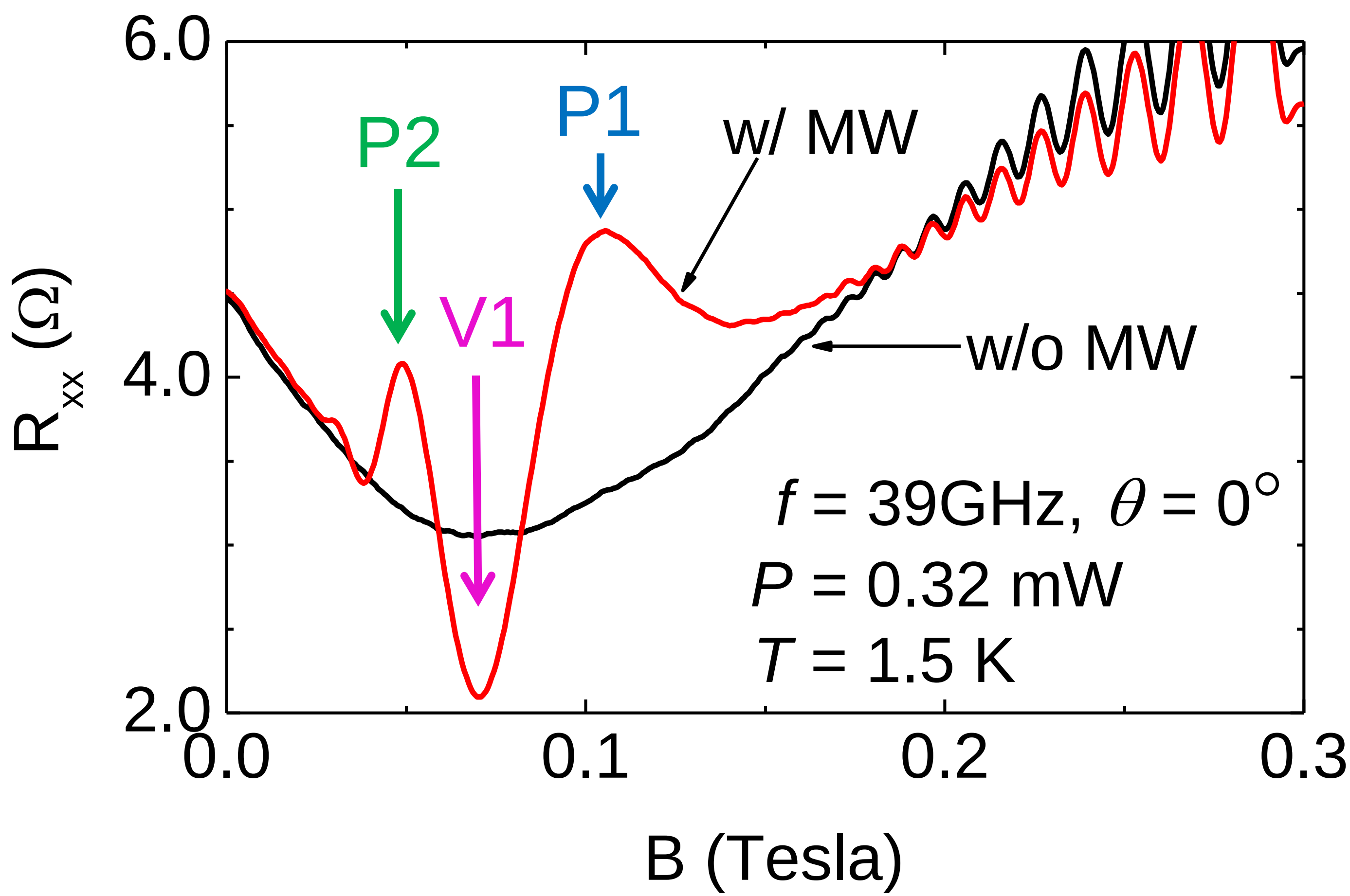




Amplitude of the MW induced magnetoresistance oscillations decreases as θ changes from 0 to π/2

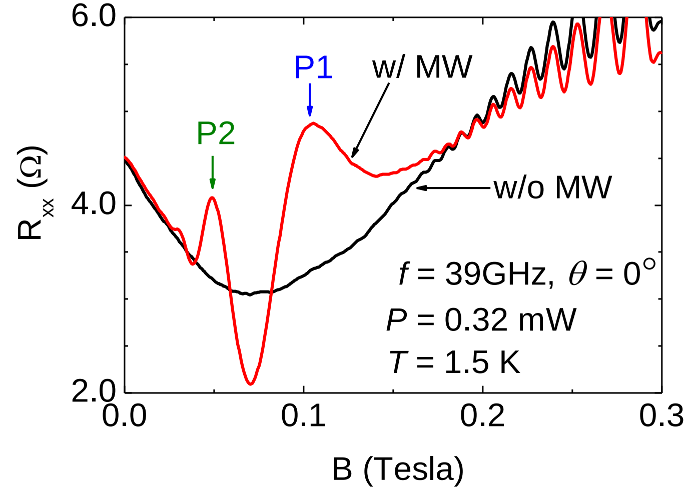
R. G. Mani, A. N. Ramanayaka, and W. Wegscheider, Phys. Rev. B 84, 085308 (2011)

Results: R_{xx} vs. B



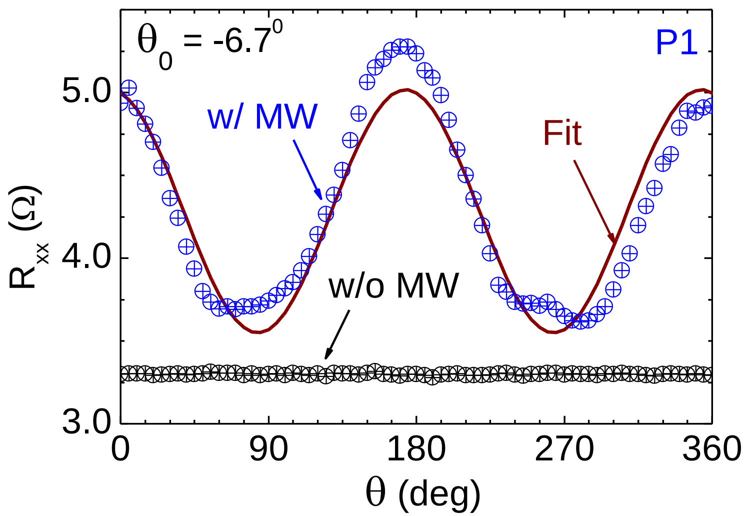
Well developed radiation induced magnetoresistance oscillations can be seen

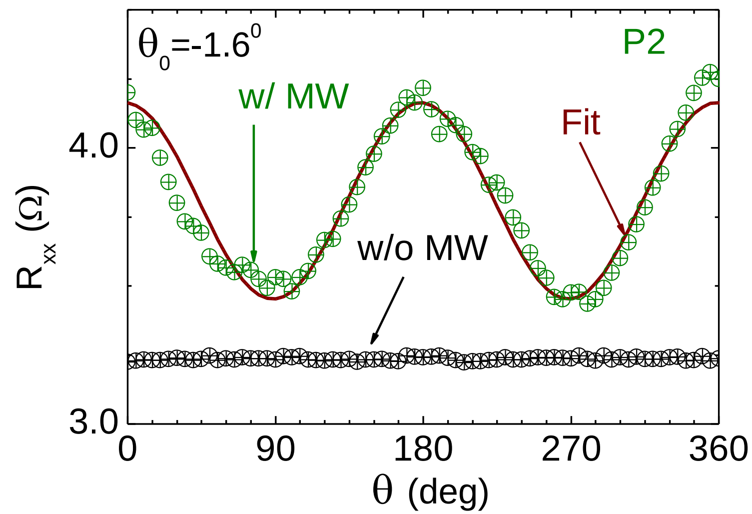
Results: R_{xx} vs. Polarization angle θ



Fit function for a peak:

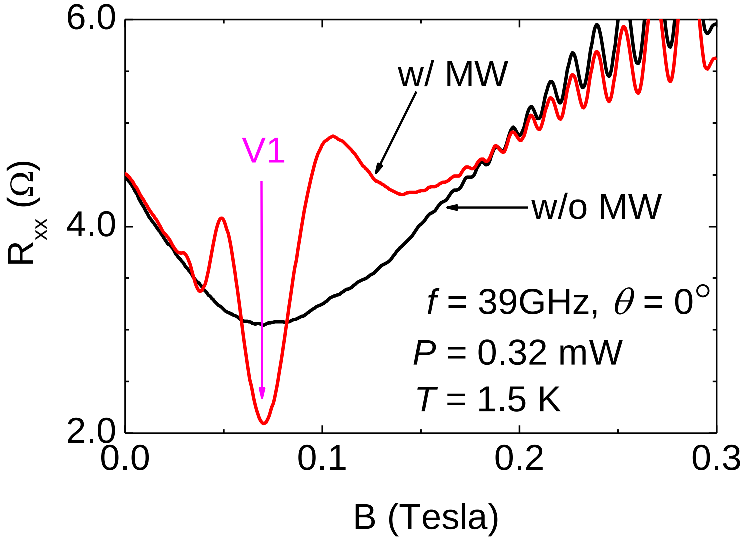
$$R_{xx}(\theta) = A + C\cos^2(\theta - \theta_0)$$





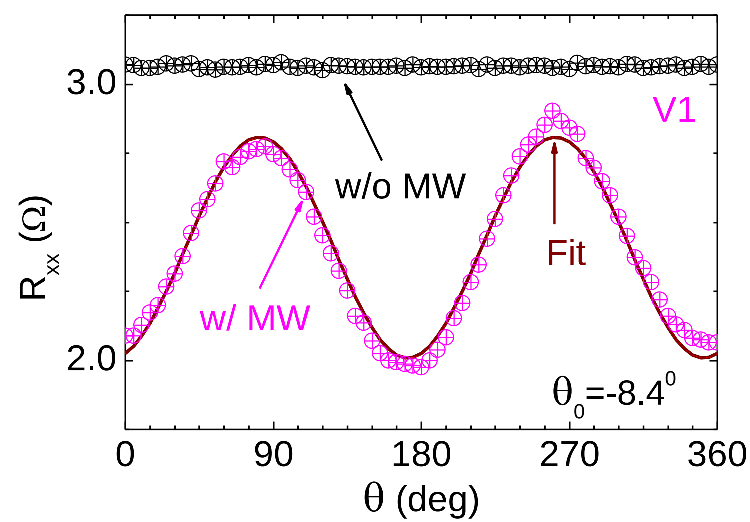
Peaks P1 and P2 follow the expected cosine squared dependence with the polarization angle

Results: R_{xx} vs. Polarization angle θ



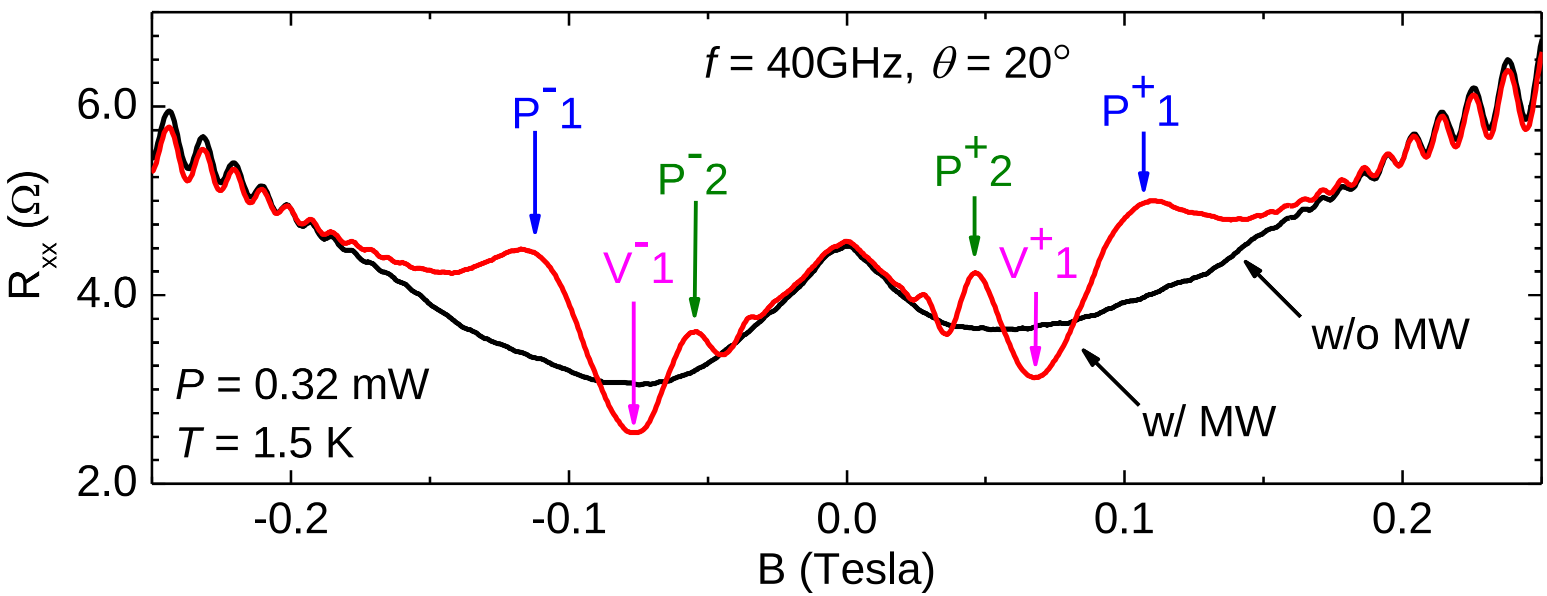
Fit function for a valley:

$$R_{xx}(\theta) = A - C\cos^2(\theta - \theta_0)$$



Valley V1 also follows the expected cosine squared dependence with the polarization angle

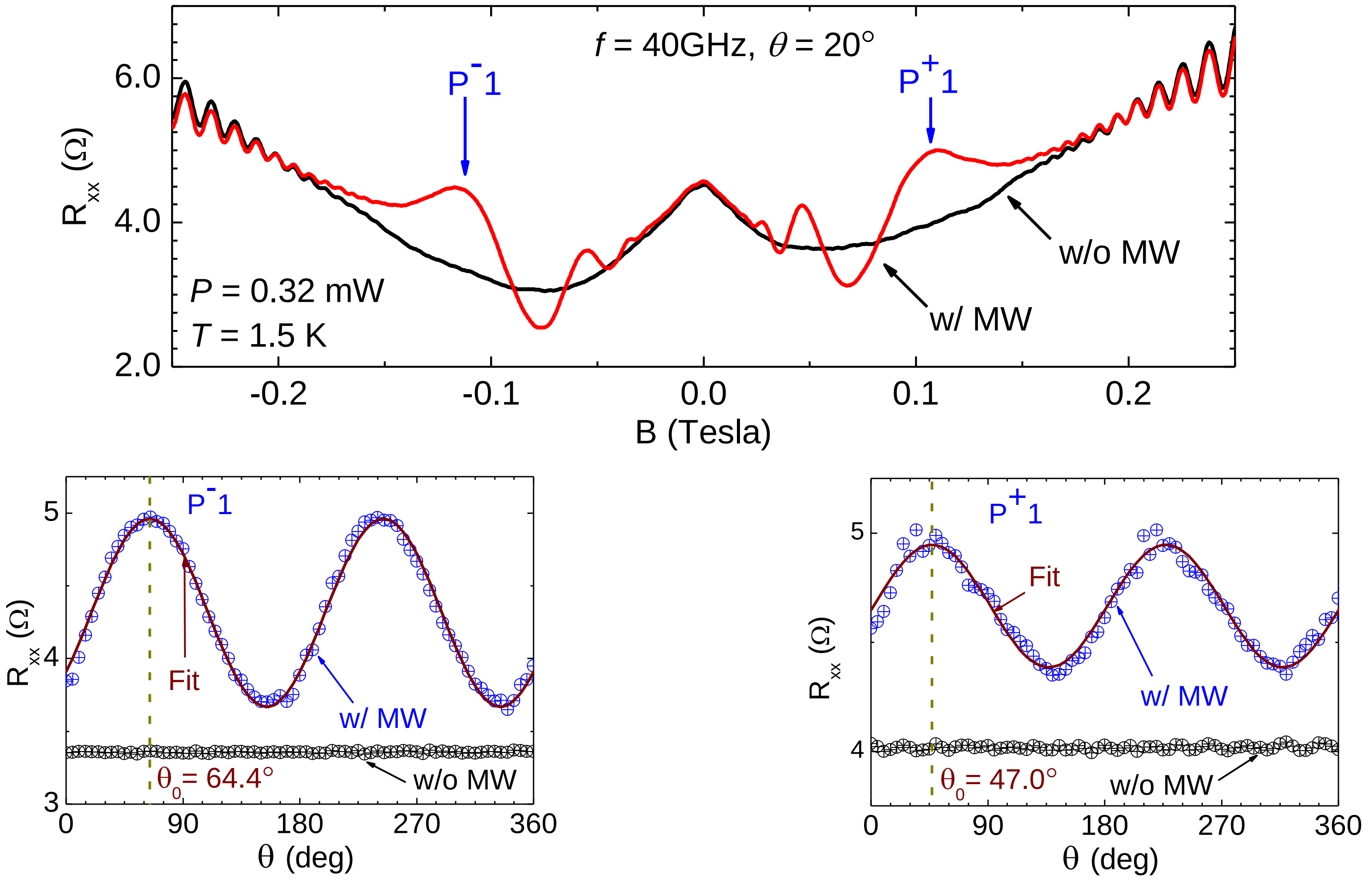
Results: R_{xx} vs. B



P^+1, V^+1, and P^+2 represent the extrema in the B>0 side

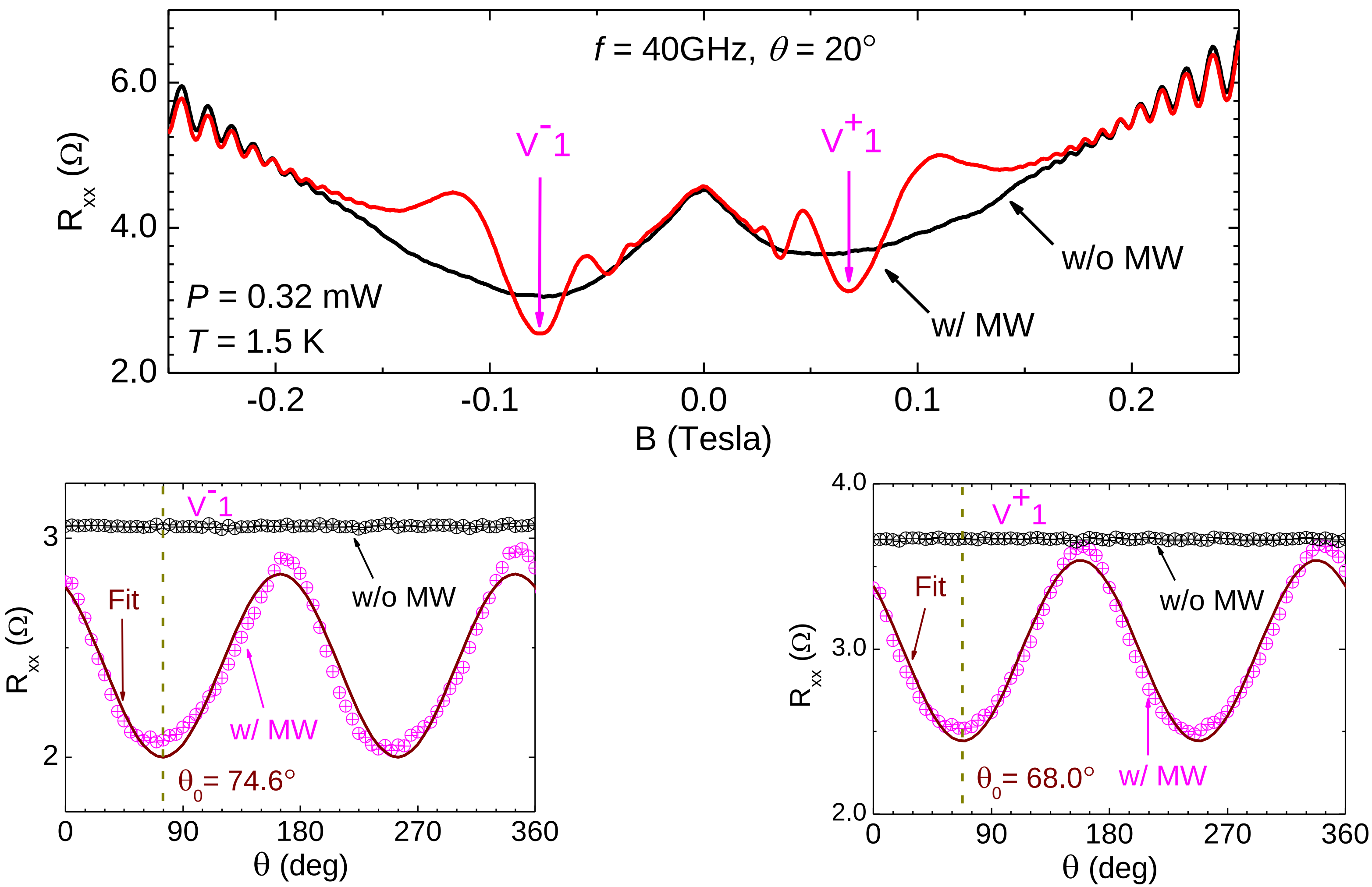
P^-1, V^-1, and P^-2 represent the extrema in the B<0 side

Results: R_{xx} vs. Polarization angle θ



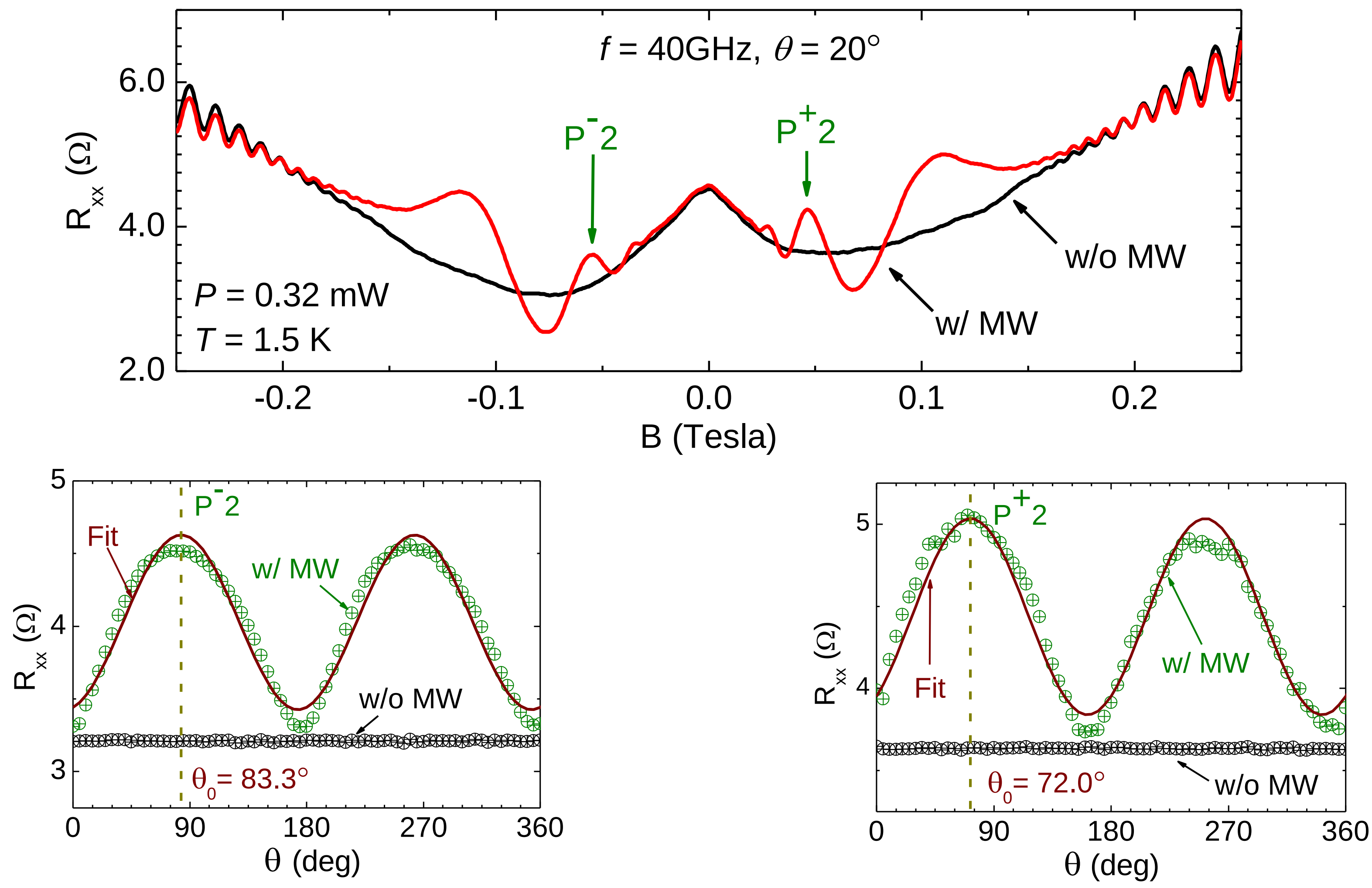
$P^{+}1$ and $P^{-}1$ follows a cosine squared function, yet the value of θ_0 is significantly different.

Results: R_{xx} vs. Polarization angle θ



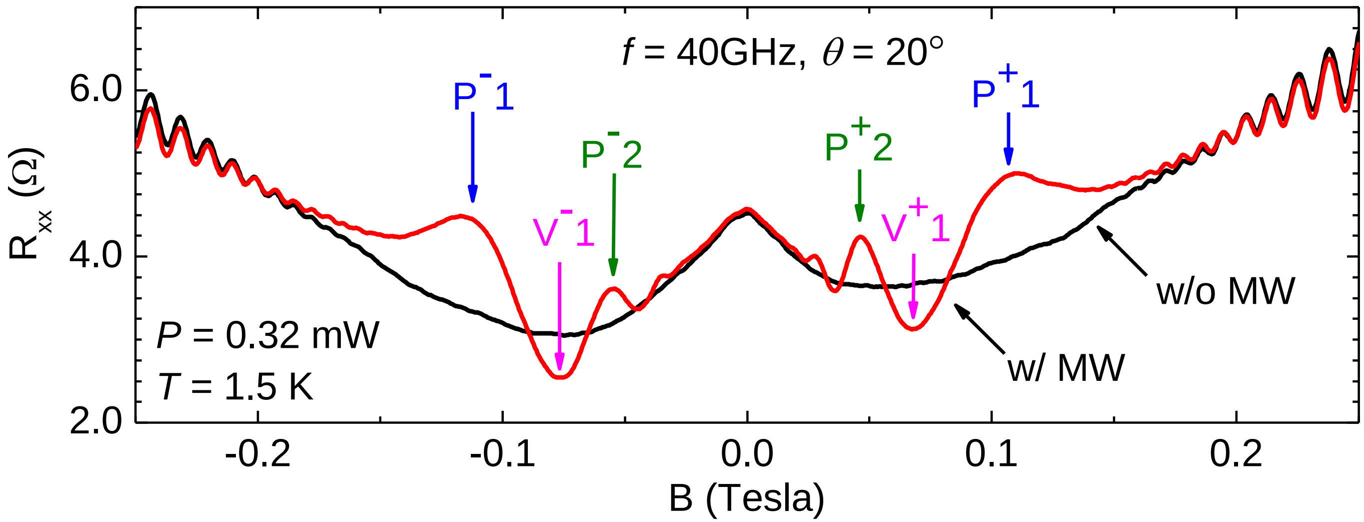
$V^{+}1$ and $V^{-}1$ are sensitive to the MW polarization, yet the value of θ_0 is significantly different.

Results: R_{xx} vs. Polarization angle θ



P^+2 and P^-2 follows a cosine squared function, yet the value of θ_0 is significantly different.

Results: θ_0 at different magnetic fields

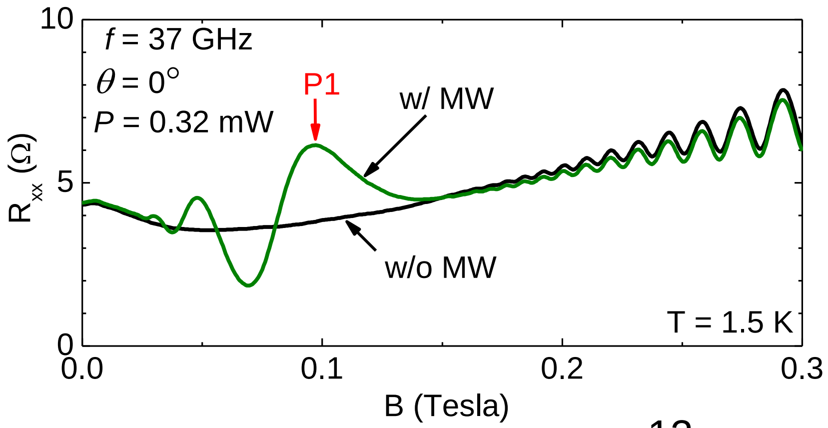


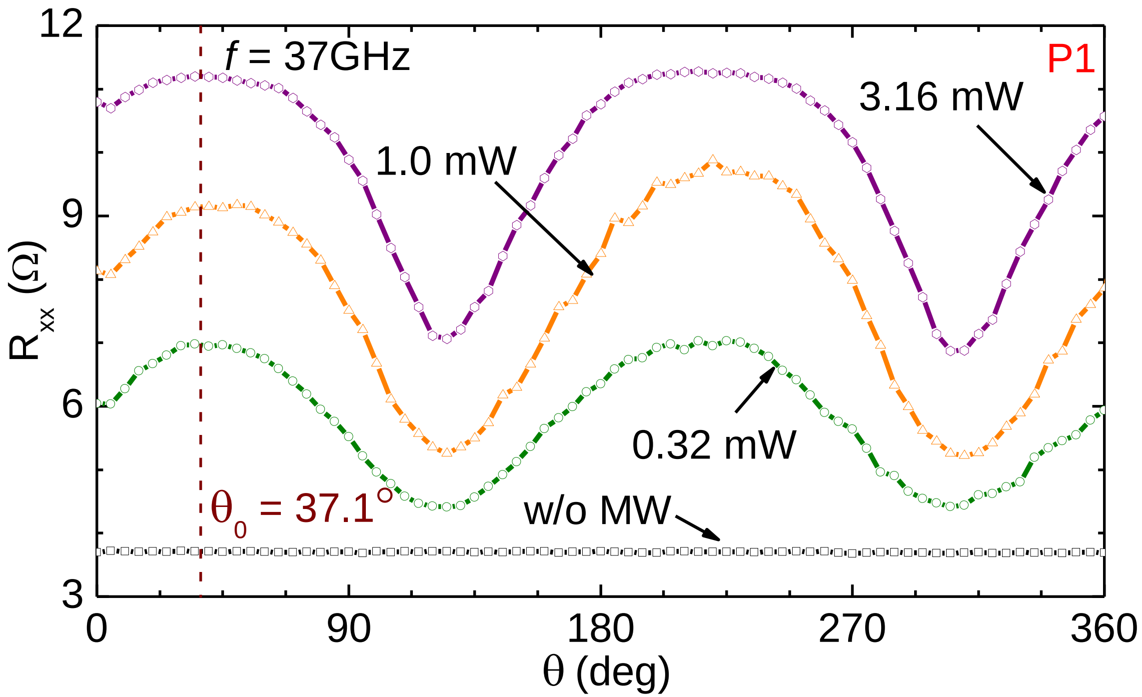
Extrema	θ_0 (deg)
P^-1	64.4
V^-1	74.6
P^-2	83.3

Extrema	θ_0 (deg)
P^+1	47.0
V^+1	68.0
P^+2	72.0

Phase, θ_0, significantly changes with the direction magnetic field, and it is well beyond the experimental uncertainty.

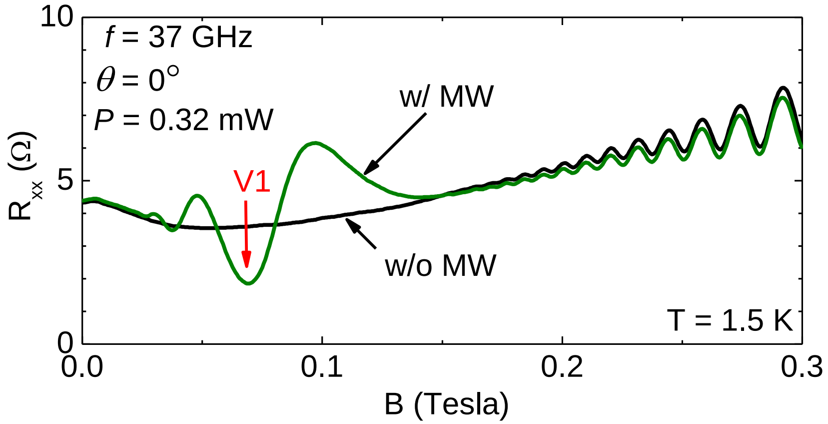
Results: R_{xx} vs. Polarization angle θ for different microwave power



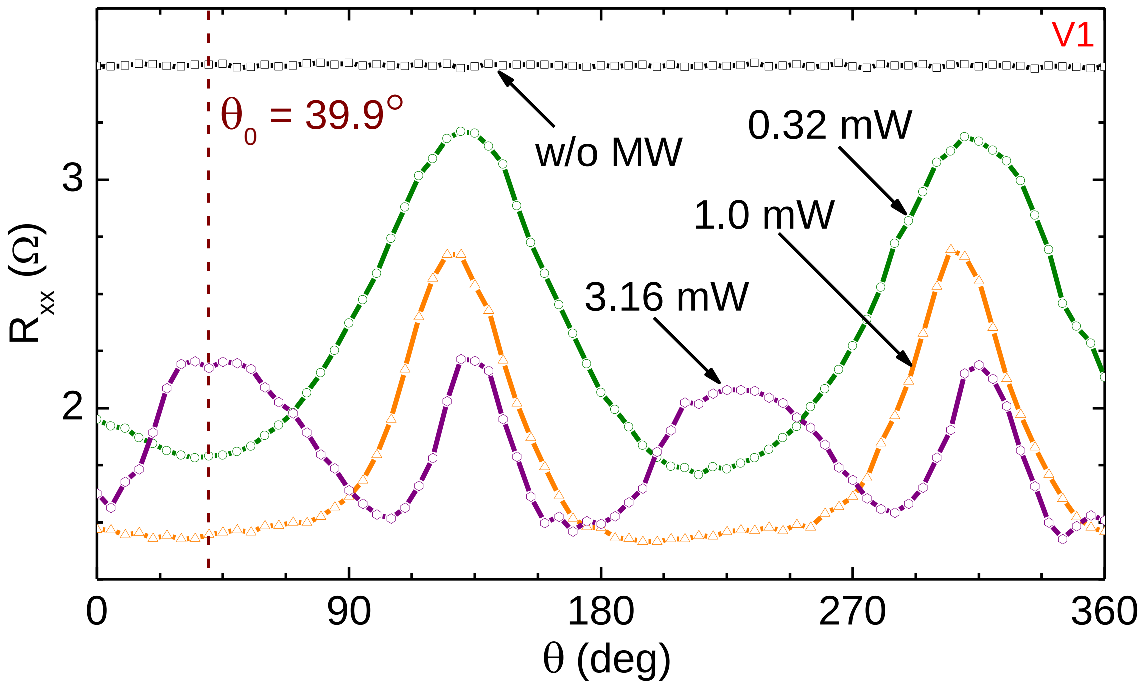


At the peak, P1, phase (θ_0) remains approximately constant for all the power levels.

Results: R_{xx} vs. Polarization angle θ for different microwave power

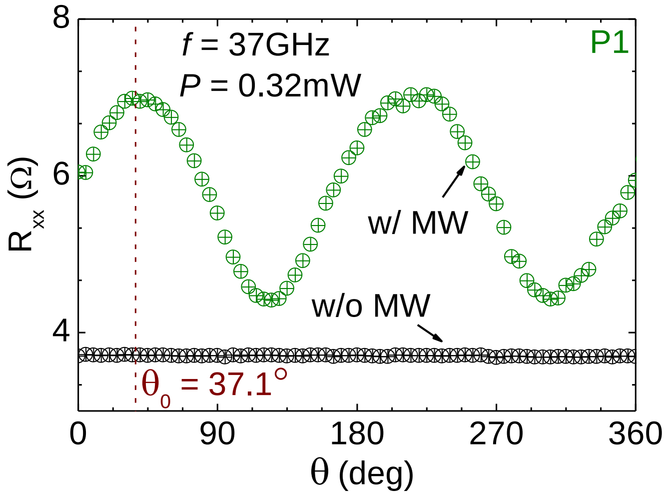


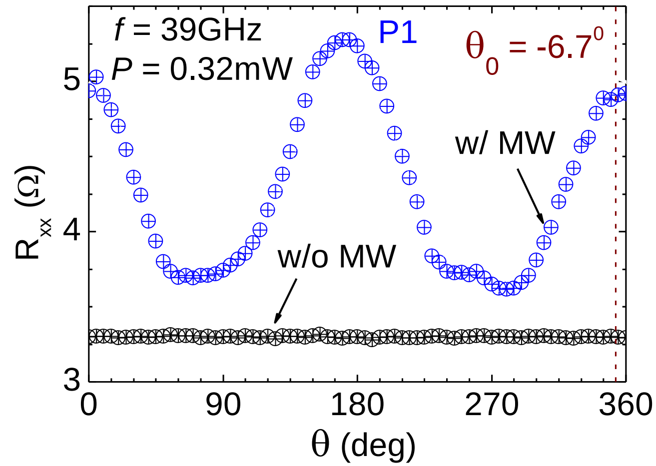
Valleys develop into peaks at higher MW power levels

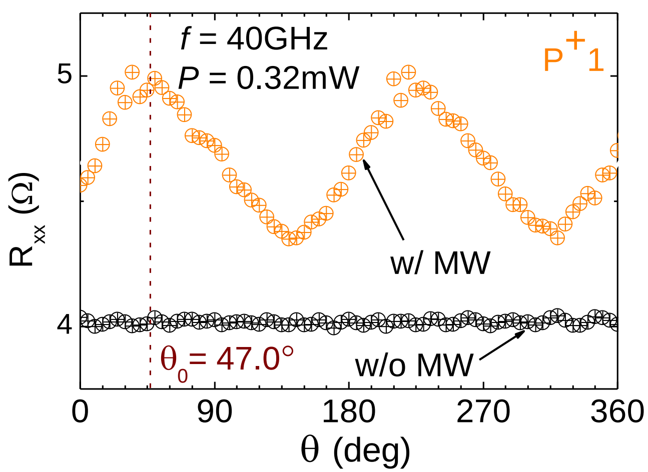


At the Valley, V1, phase (θ_0) remains approximately constant only for the lower power levels.

Results: θ_0 for different microwave frequencies







Frequency	θ_0
37 GHz	37.1^0
39 GHz	-6.7^0
40 GHZ	47.0^0

Value of θ_0 changes with the MW frequency

Discussion: A Theoretical view

PRL **94,** 016806 (2005) PHYSICAL REVIEW LETTERS week ending 14 JANUARY 2005

Theoretical Approach to Microwave-Radiation-Induced Zero-Resistance States in 2D Electron Systems

J. Iñarrea[1,2] and G. Platero[1]

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[2]*Escuela Politécnica Superior, Universidad Carlos III, Leganes, Madrid, 28911, Spain*

(Received 30 July 2004; published 7 January 2005)

We present a theoretical model in which the existence of radiation-induced zero-resistance states is analyzed. An exact solution for the harmonic oscillator wave function in the presence of radiation, and a perturbation treatment for elastic scattering due to randomly distributed charged impurities, form the foundations of our model. Following this model most experimental results are reproduced, including the formation of resistivity oscillations, their dependence on the intensity and frequency of the radiation, temperature effects, and the locations of the resistivity minima. The existence of zero-resistance states is thus explained in terms of the interplay of the electron microwave-driven orbit dynamics and the Pauli exclusion principle.

DOI: 10.1103/PhysRevLett.94.016806 PACS numbers: 73.40.–c, 73.50.–h, 78.67.–n

Discussion: A Theoretical view

The radiation-driven electron orbit theory [§]

The average effective distance advanced upon scattering due to MW radiation is,

$$\Delta X^{MW} = \Delta X^{0} + A\cos\omega\tau$$

$$A = \frac{eE_0}{m^*\sqrt{\dfrac{\omega^2\left(\omega_c^2-\omega^2\right)^2}{\omega^2\cos^2\theta+\omega_c^2\sin^2\theta}+\gamma^4}}$$

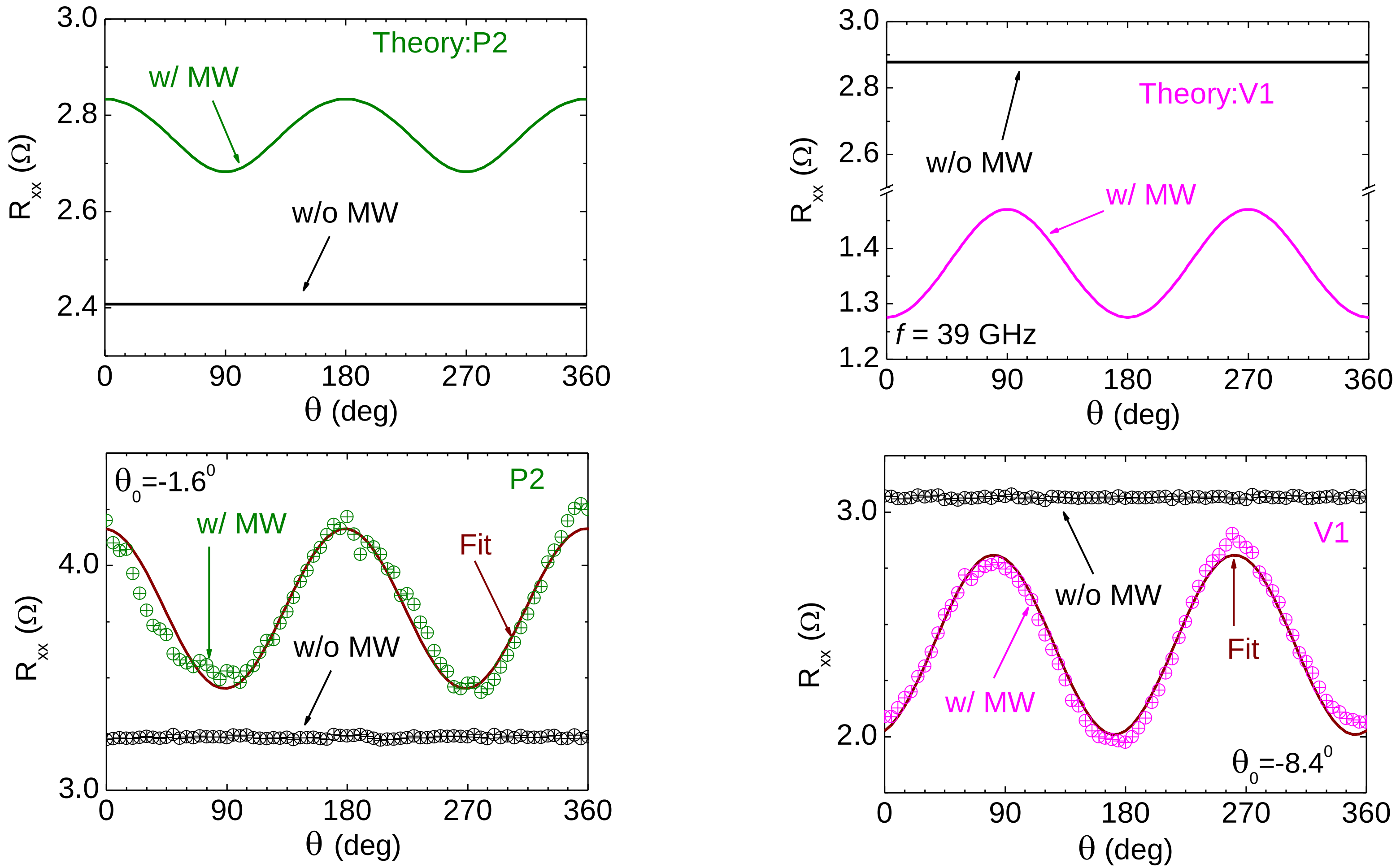
θ: polarization angle

$\gamma > \omega$: A is independent of θ

$\gamma \leq \omega$: A is a function of θ

§ J. Iñarrea and G. Platero, Phys. Rev. Lett. **94, 016806 (2005)**

Discussion: A Theoretical view



Radiation-driven electron orbit theory is in qualitative agreement with the observed angle dependence of radiation induced magnetoresistance oscillation amplitude

Conclusions

Microwave induced magnetoresistance oscillations are sensitive to the polarization direction of the linearly polarized microwaves.

Displacement Model [1]

Inelastic model [2]

Radiation-driven electron orbit model [3]
provided **$\gamma < \omega$**

Non-parabolicity model [4]

The phase shift in the $R_{xx}(\theta)$ response, i.e., θ_0, varies with frequency (f), magnetic field (B), and the sign of B.

Radiation-driven electron orbit theory can be used to *qualitative* predict the polarization angle dependence of microwave radiation induced magnetoresistance oscillation amplitude.

[1] V. Ryzhii et al., J. Phys.: Cond. Matt. 15, 6855 (2003)
[2] I. A. Dmitriev et al., Phys. Rev. B 71, 115316 (2005)
[3] J. Inarrea et al., Phys. Rev. B 76, 073311 (2007)
[4] A. A. Koulakov et al., Phys. Rev. B 68, 115324 (2003)

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Workshop organizers

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Thank you