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The oblique Hanle effect in graphene: A novel approach to determine spin lifetime anisotropy

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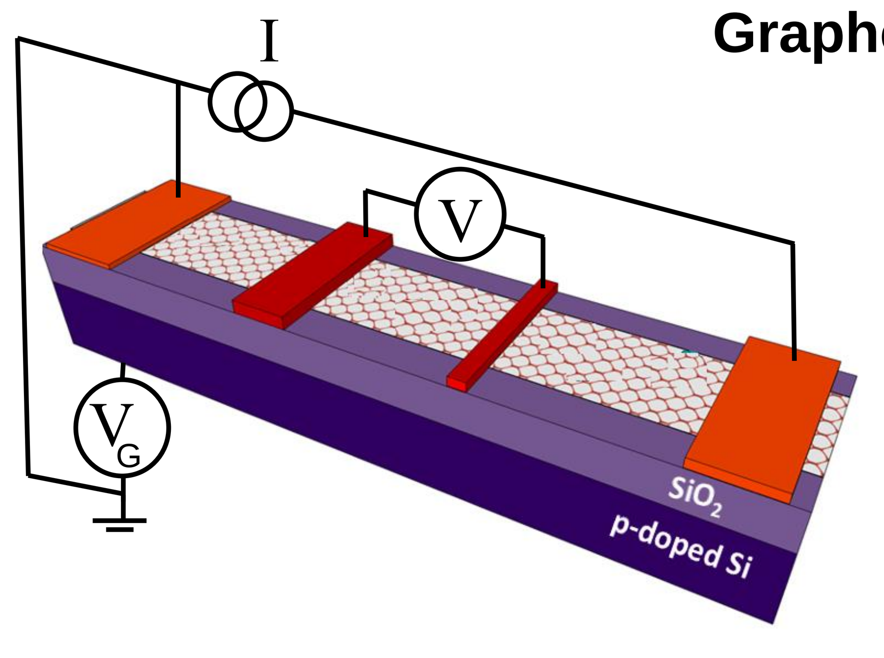
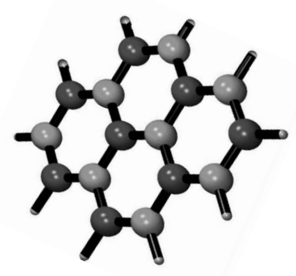
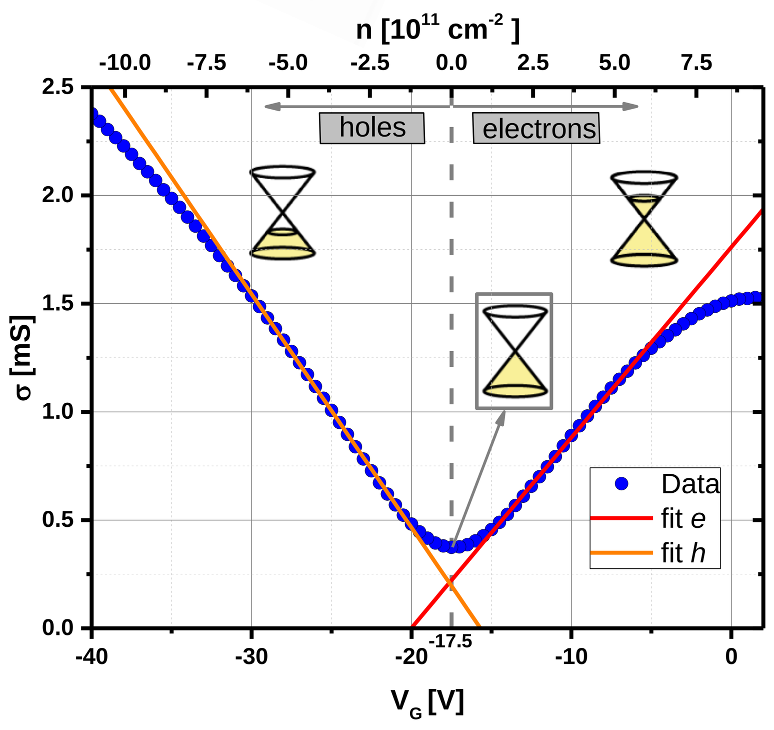
Abstract

Spintronics make use of the spin degree of freedom of the electron in addition to (or instead of) its charge. **Graphene**, a true two-dimensional material consisting of a hexagonal lattice of carbon atoms, presents itself as an excellent material to transport spin currents since it exhibits long spin lifetimes. However, the main microscopic mechanisms for **spin relaxation** in graphene, which limit the spin lifetime, remain elusive. A key property to solve this puzzle is the **spin lifetime anisotropy** ζ, which is the ratio of the in-plane and out-of-plane spin lifetimes [1]. In previous reports [2], the spin lifetime anisotropy has been determined by spin transport measurements with large magnetic fields (>1T) applied perpendicular to the graphene plane, rendering it useless at low carrier densities. With the use of **non-local lateral spinvalves (NLSV)**, we demonstrate a conceptually new approach to extract ζ by performing spin precession measurement at low fields (~ 0.1T) [3], overcoming the aforementioned limitation.

Graphene







✓ The (local) conductivity measurement allows to extract carrier mobility:

μ_e = (1.12 ± 0.03) · 10^4 cm²/ (Vs)

μ_h = (1.35 ± 0.01) · 10^4 cm²/ (Vs)

Graphene spintronics

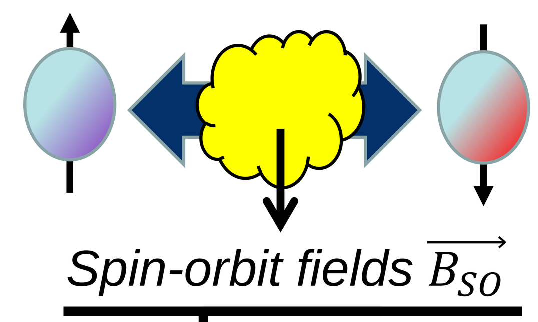
✓ *Why graphene?*

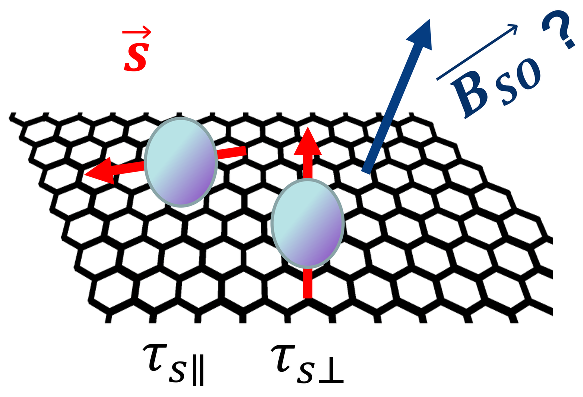
- *tunable system*
- *large spin diffusion lifetimes*

↕

! *Lower than predicted by theory*

! *Dominant spin relaxation mechanism unknown*



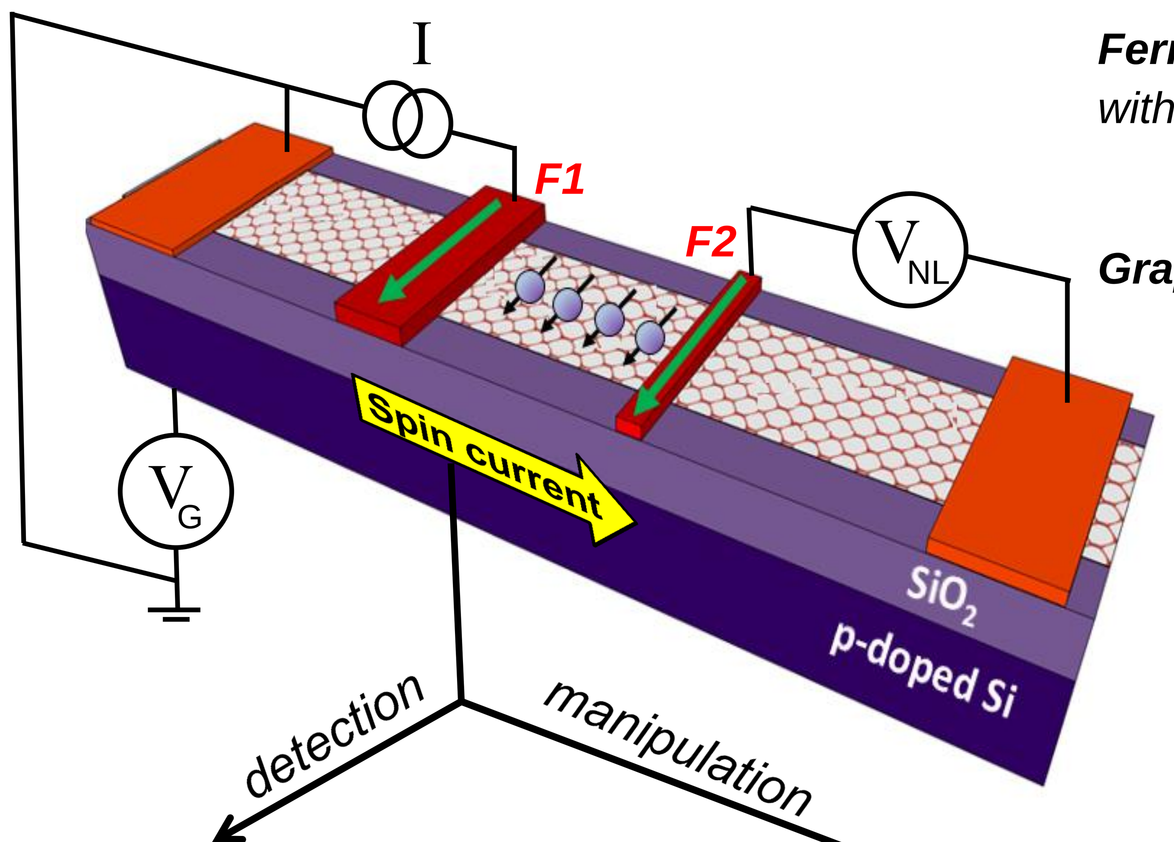


$$E_{SO} = -g\mu_B \vec{s}\cdot\overrightarrow{B_{SO}} \longleftrightarrow \tau_s(E_{SO})$$

Spin lifetime anisotropy: $\zeta = \frac{\tau_{s\perp}}{\tau_{s\parallel}}$

provides valuable information on $\overrightarrow{B_{SO}}$

NLSV : Operating principle



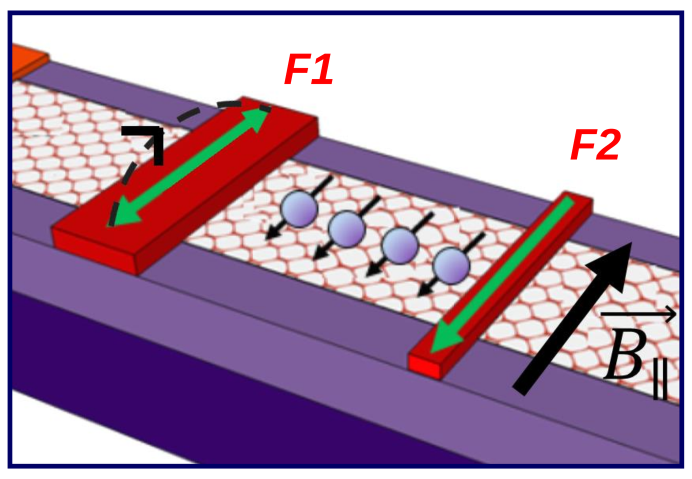
Ferromagnetic nanowires (F) *with magnetic moment **M** :* *spin injector and detector*

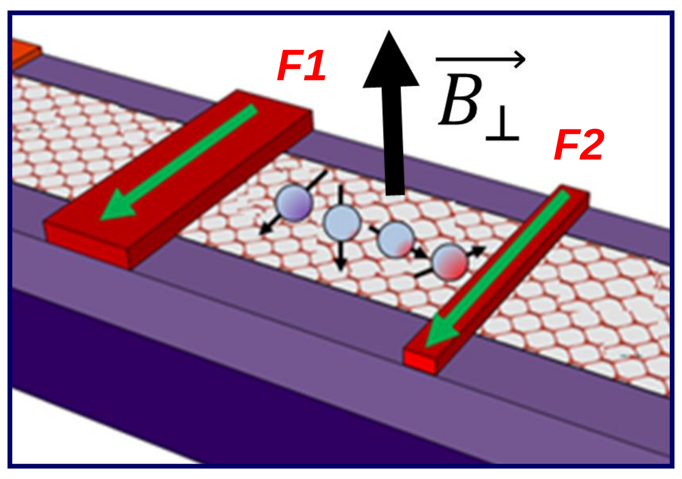
Graphene: *spin transport channel*

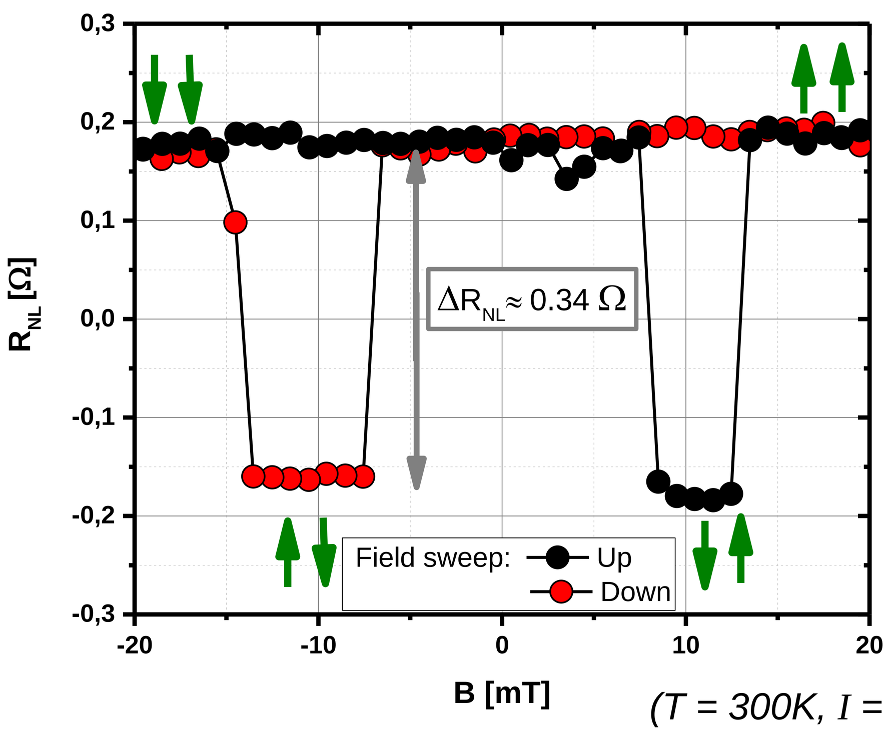
$$\lambda_s = \sqrt{D_s \tau_s}$$

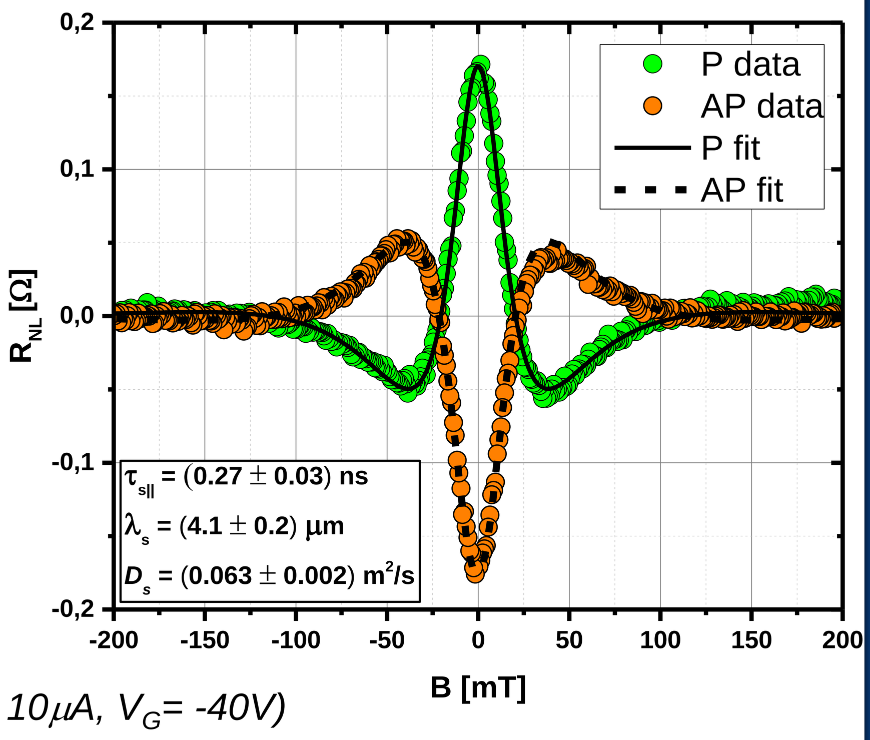
flipping the ferromagnets → **spinvalve effect:**

Spin precession → **Hanle effect:**







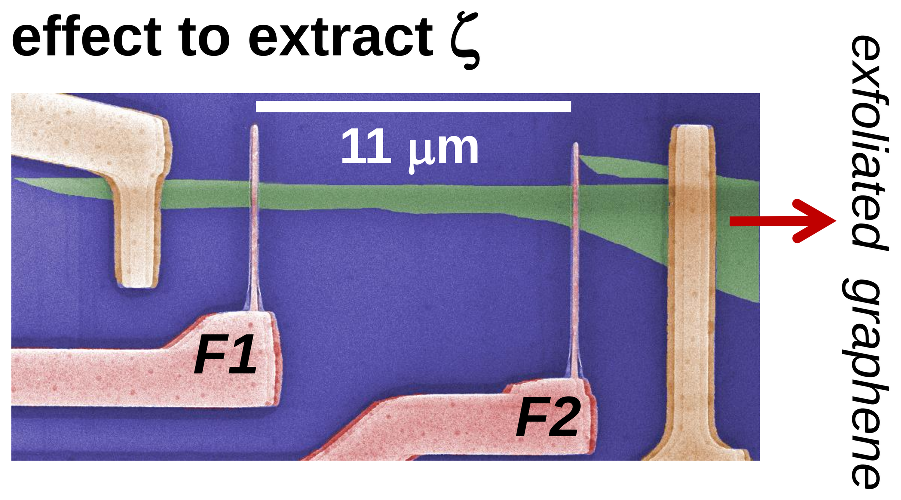


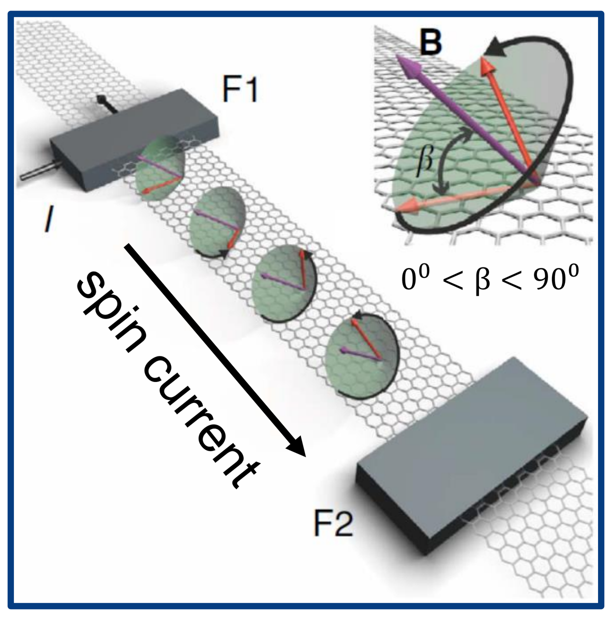
(T = 300K, I = 10µA, V_G = -40V)

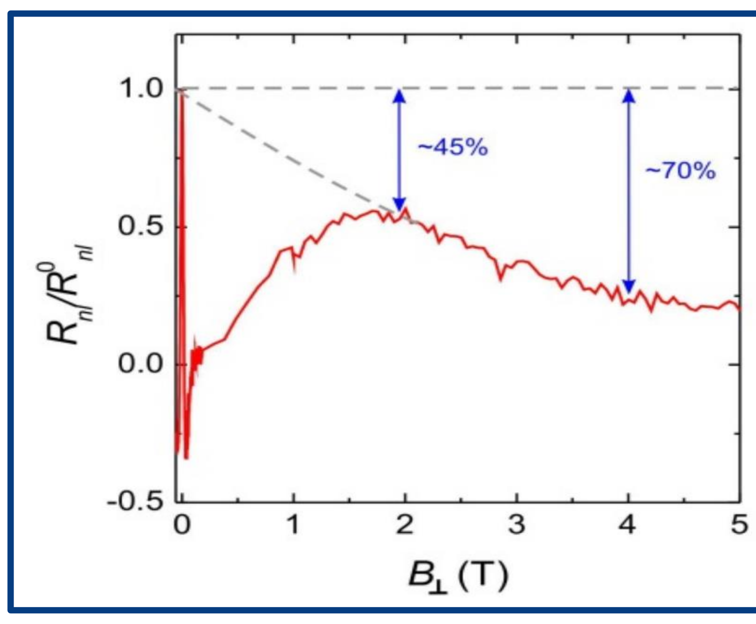
Oblique Hanle effect to extract ζ

✓ *Experimental procedure:*

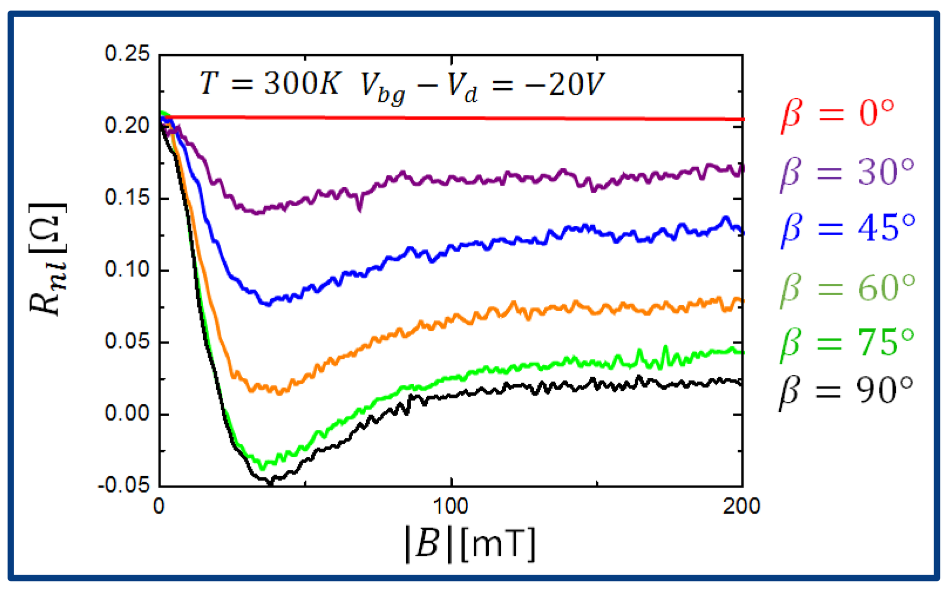
1. *Extract $\tau_{s\parallel}$ via conventional Hanle measurements*
2. *Oblique Hanle measurements to extract ζ as single fit parameter*

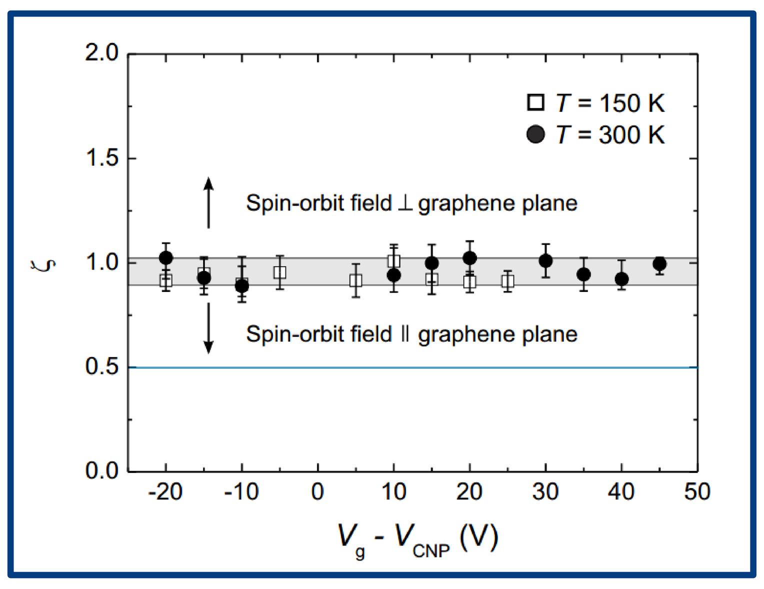






✗ *high field method ?*





Conclusions and outlook

- ✓ The spin lifetime anisotropy ζ is important to unravel the spin relaxation mechanisms in graphene, and other 2D materials in general.
- ✓ We demonstrated a reliable approach to determine ζ using spin precession measurements. In our samples we find $\zeta \sim 1$, hinting to $\overrightarrow{B_{SO}}$ due to random impurities.
- ✓ Further implementation of this method in other samples (e.g. other graphene sources, different substrates, heterostructures, adatoms,…) leads to a better understanding and better controllability of spin-orbit fields and spin relaxation in graphene.

References:

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