Magnetic torque anomaly in Dirac semimetal Cd_3As_2

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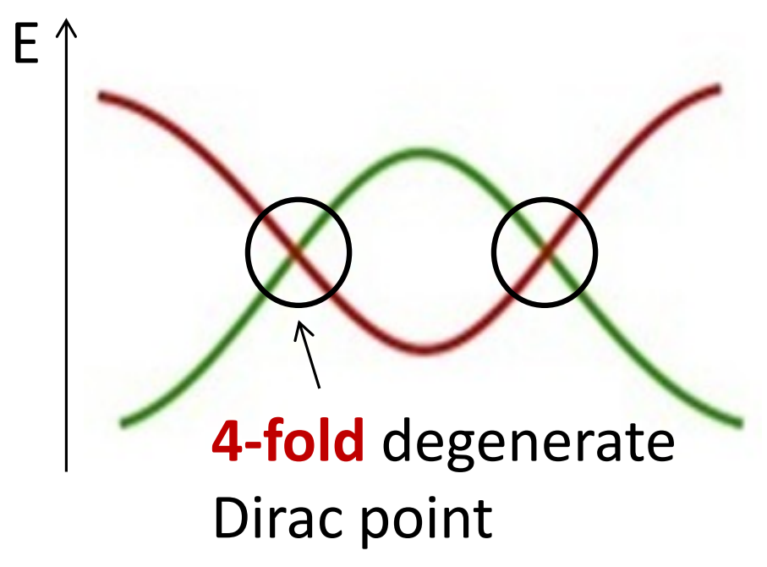
3D Dirac semimetal

Dirac dispersion in 3D (k-space) ⟶ **3D analogue of graphene.**

Dirac fermion physics:

- High mobility and low effective mass.
- Large LMR.
- Interesting transport properties.
- Fundamental physics (Dirac/Weyl).

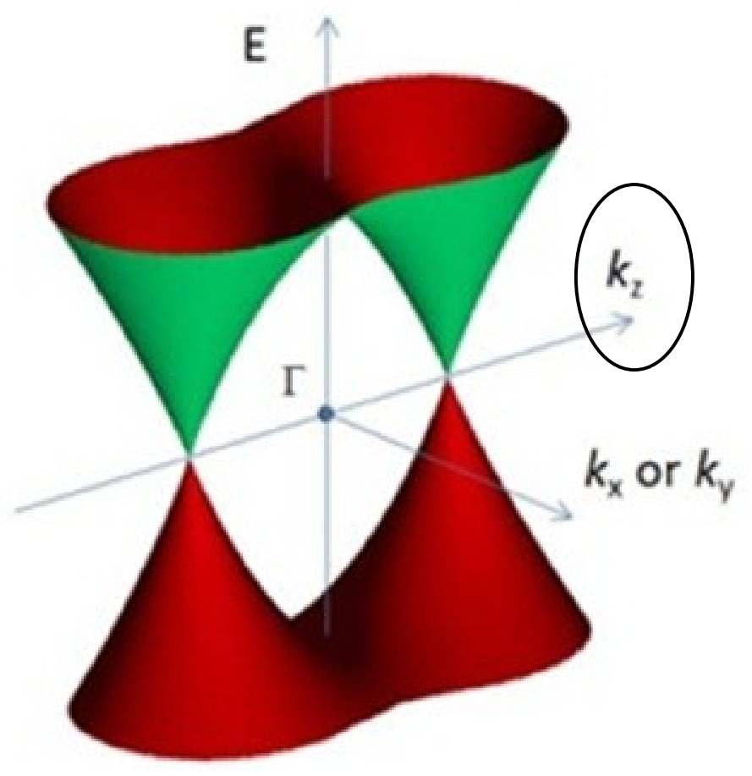


Cd_3As_2

⟶ 3D Dirac semimetal with symmetry protected pair of Dirac points at Z-Γ-Z line.

Single crystals synthesized by modified CVD technique.

B-field along symmetry axis can splits Dirac point in two **Weyl points.**



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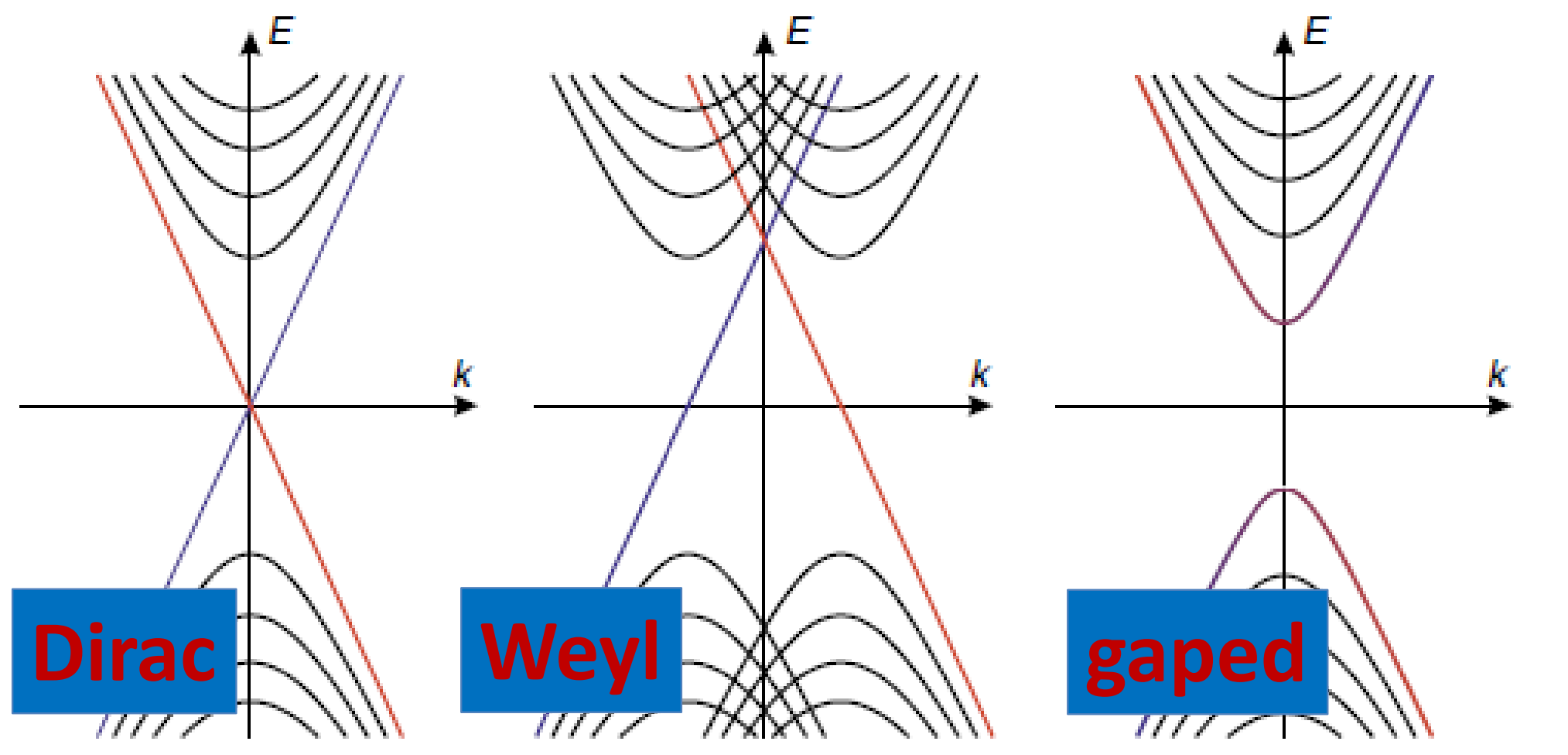

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Field along symmetry axis

Field perp. to symmetry axis

Transport measurements

$m_c^* = 0.028 m_e$

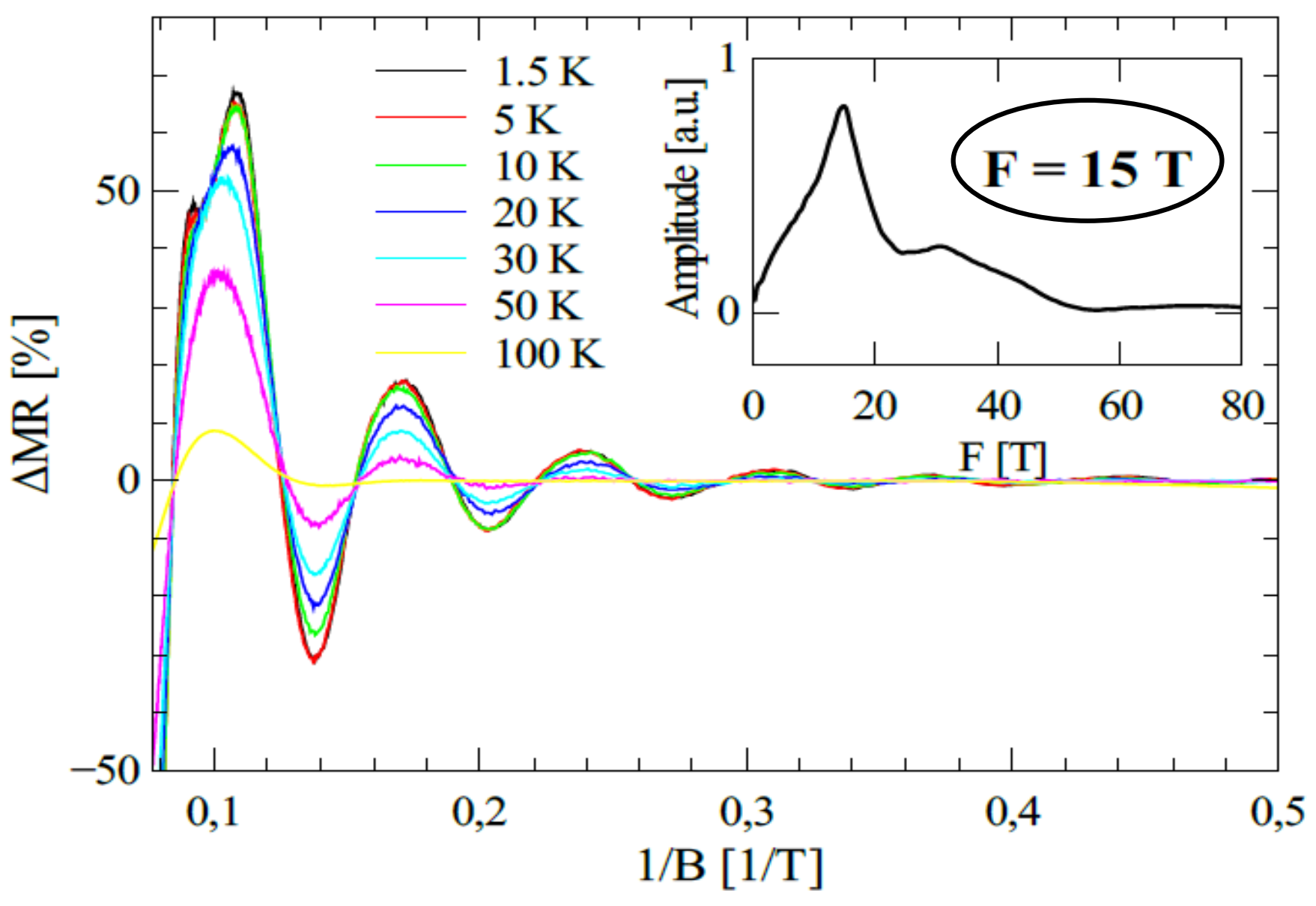
$T_D = 35.7$ K

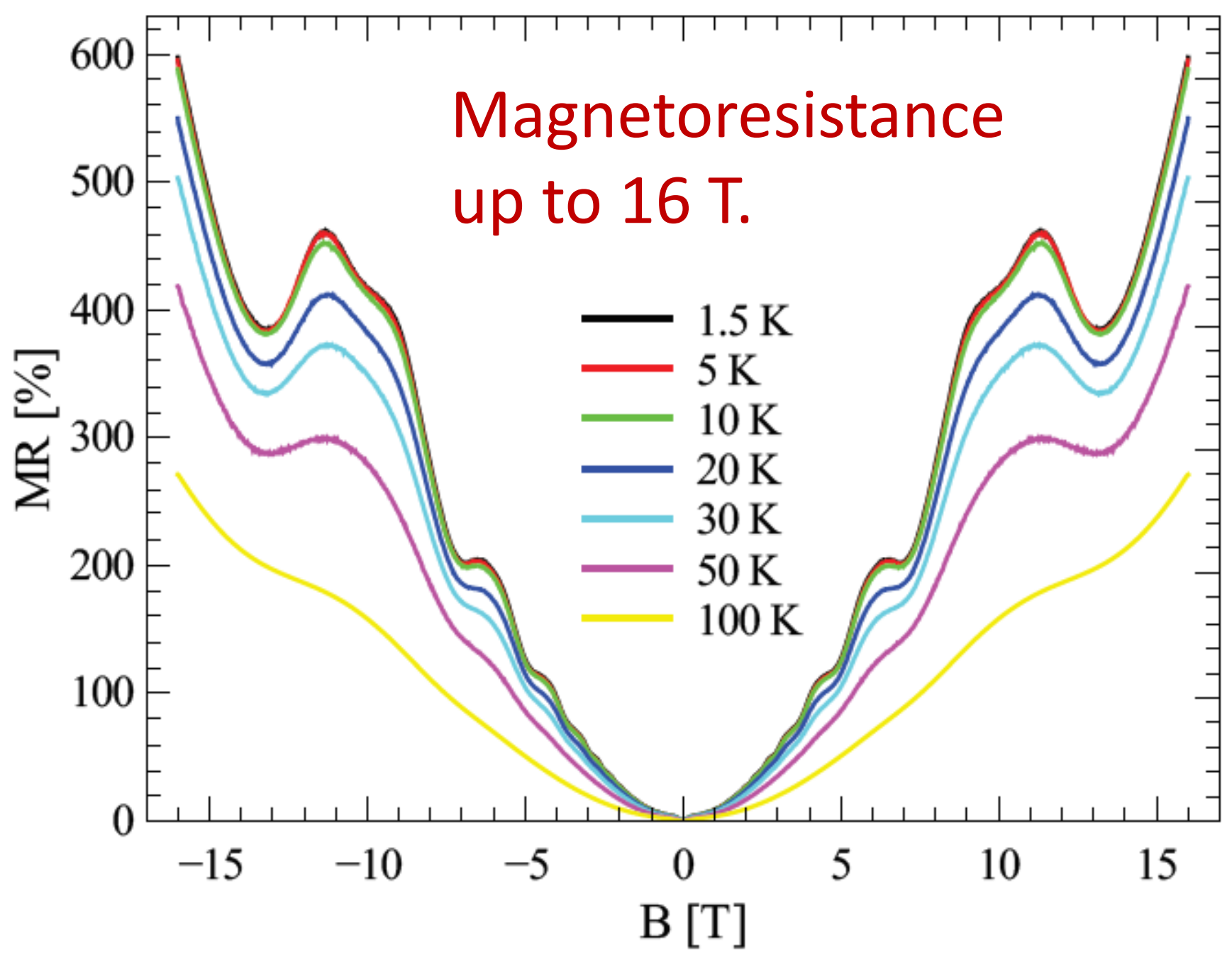
$\tau_Q = 2.14 \cdot 10^{-13}$ s

$\mu = 1.34 \cdot 10^4$ cm²/Vs

$n = 3.28 \cdot 10^{17}$ cm⁻³

$E_F = 124$ meV





Magnetization in the quantum limit

Energy levels in B-field for different types of electrons [1]:

$$\varepsilon_{n,k} = \begin{cases} \frac{\hbar e B}{m}(n+\gamma) + \frac{\hbar^2 {k_z}^2}{2m} & \text{Trivial } (\gamma = \frac{1}{2}) \\ \hbar v_F \sqrt{2B(n+\gamma) + {k_z}^2} & \text{Weyl } (\gamma = 0) \\ \hbar v_F \sqrt{2B(n+\gamma+C^2 sin^2\theta) + {k_z}^2} & \text{Dirac } (\gamma = 0) \end{cases}$$

θ – angle between B and line connecting two Dirac points
C – material dependent parameter

Cause of nontrivial **Berry phase.**
There is a zero LL at $\varepsilon = 0$.

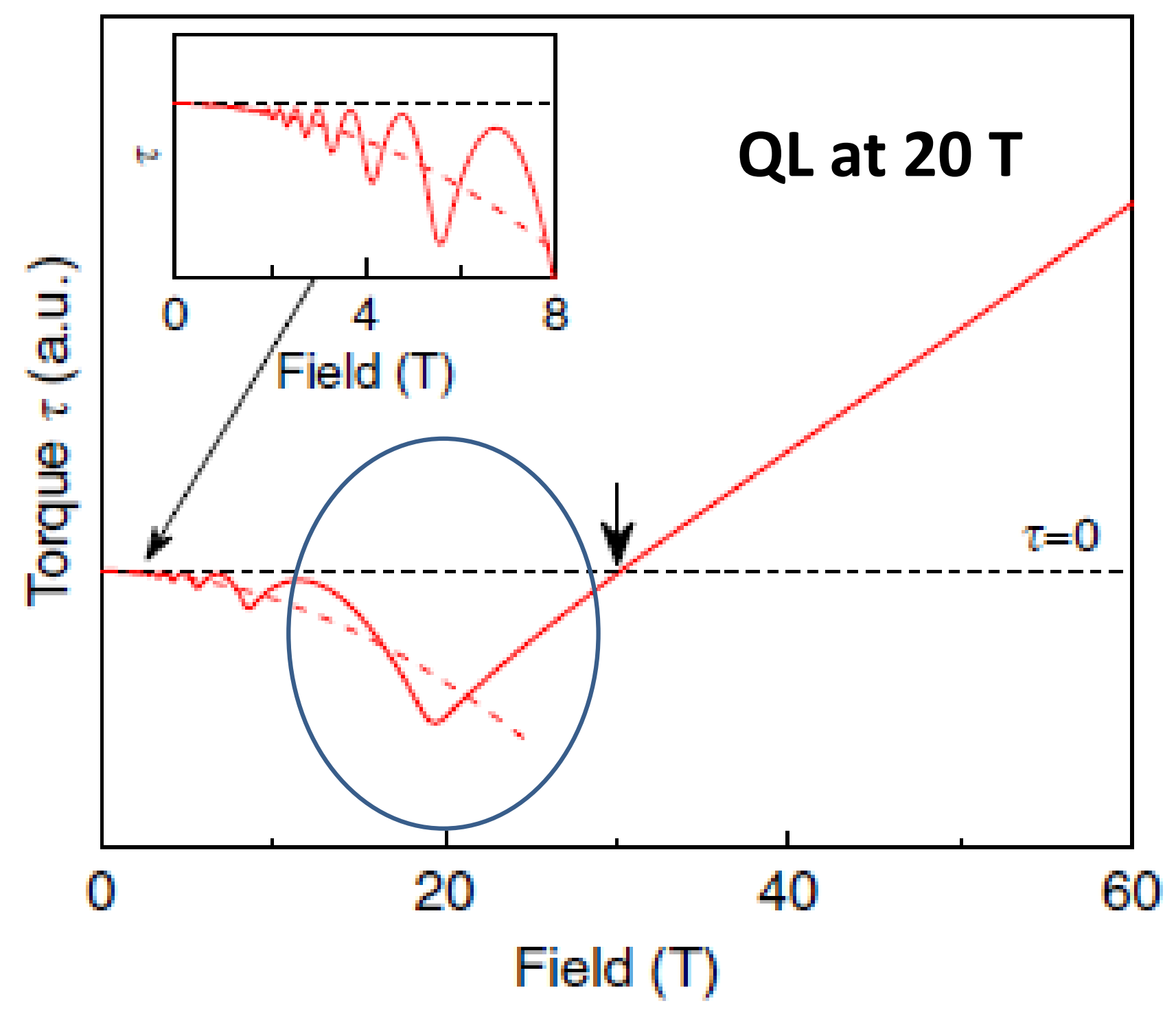
Weyl:
~~$n > 0$ paramagnetic~~
$n < 0$ diamagnetic

Paramagnetic response dies in QL:
$M_{n=0} = -\frac{\partial \varepsilon_{0,k}}{\partial B} = 0$
Magnetic anomaly

Magnetic torque $T = \vec{M} \times \vec{B}$ in QL can distinguish between gaped and Weyl fermions.

Dirac → B-field perpendicular to the symmetry axis ⟶ gaped semimetal
Dirac → B-field in the direction of the symmetry axis ⟶ weyl

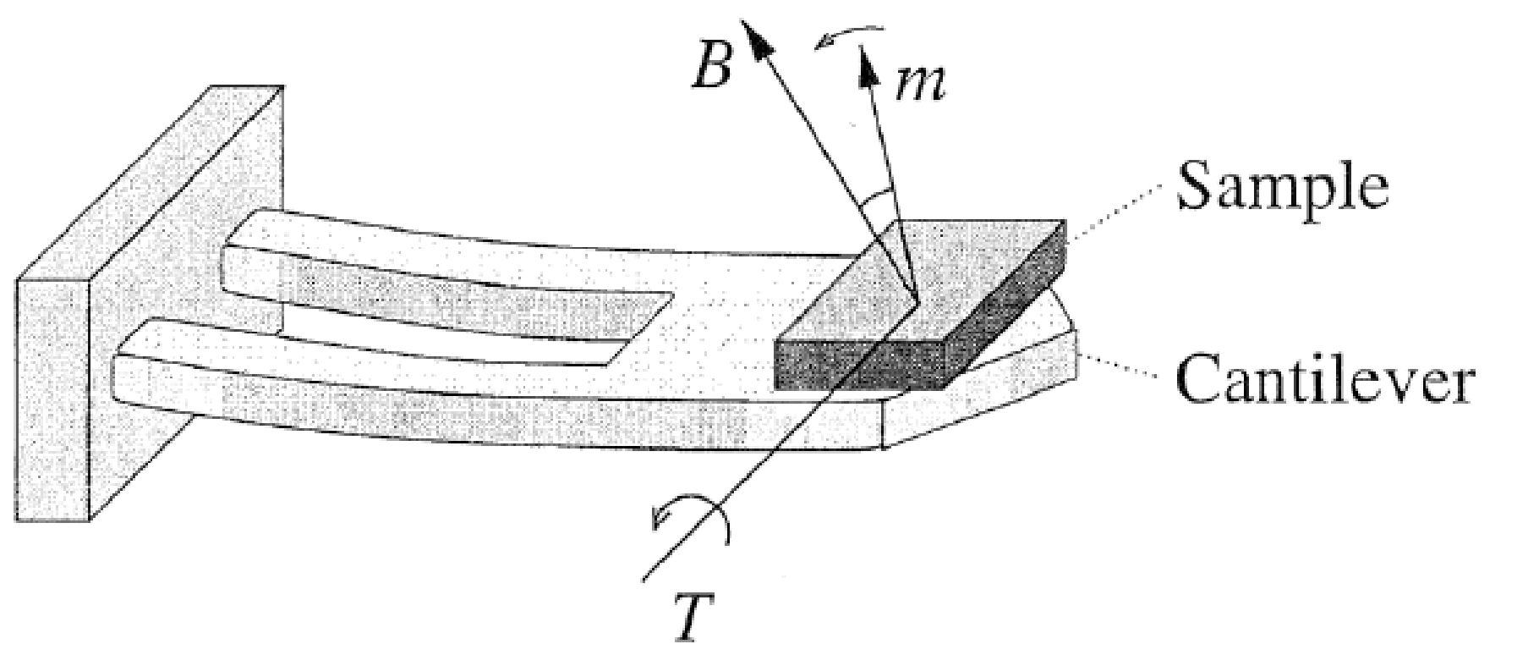
Simulated behaviour of torque near the quantum limit [1]:



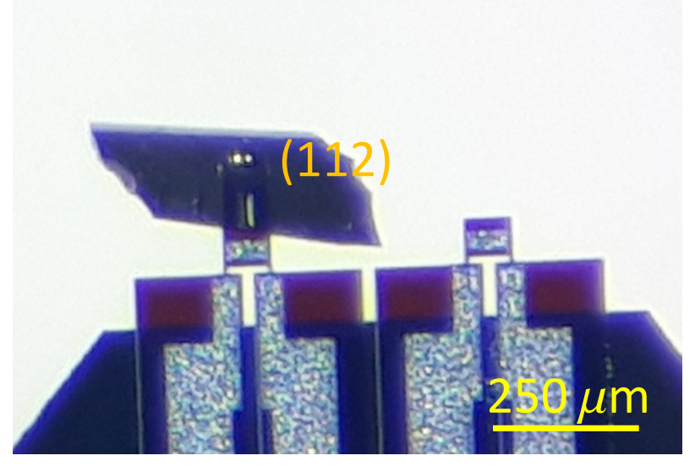
Weyl – change from diamagnetic to paramagnetic response leading to the torque reversal.

Magnetic torque measurements

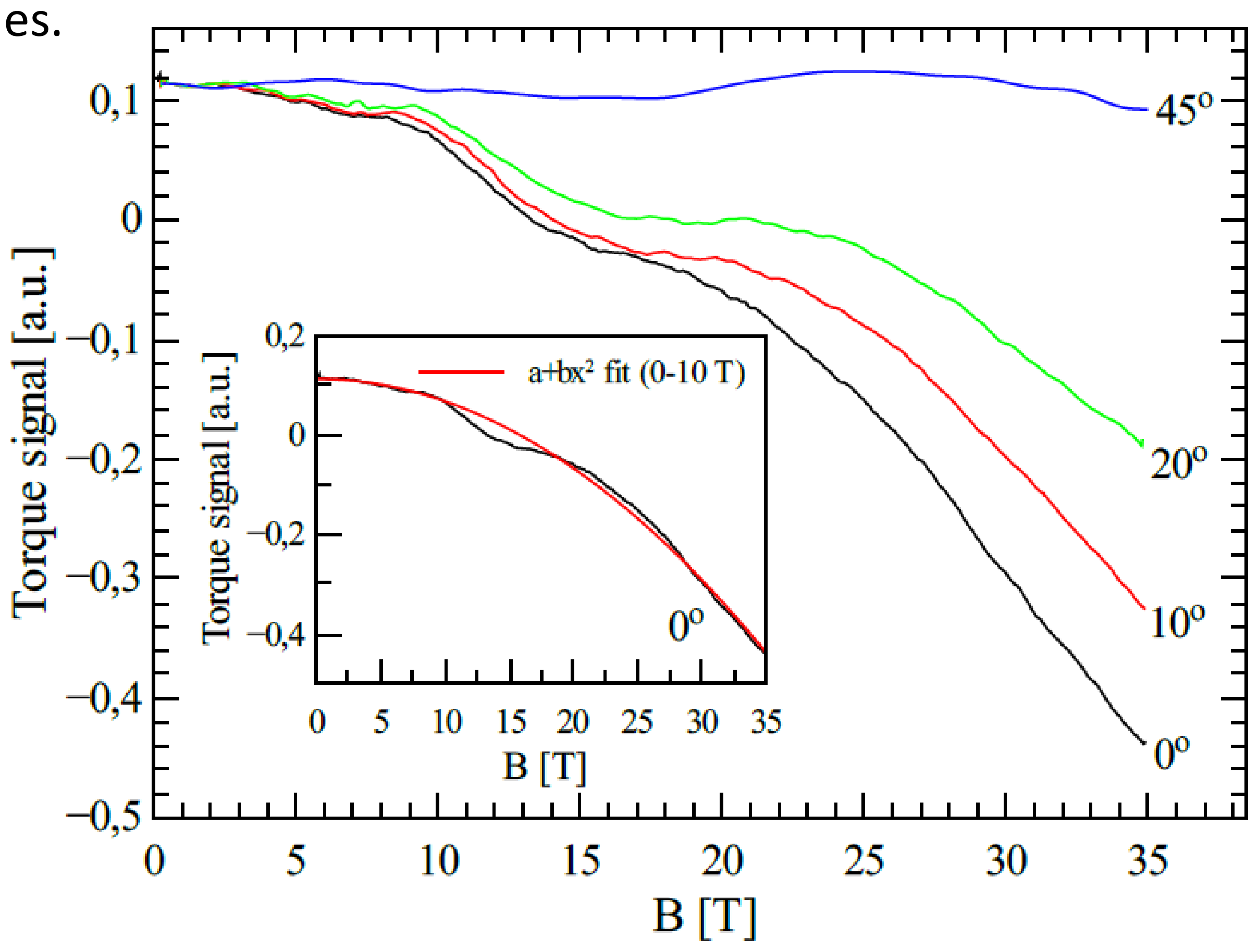
- By **piezoresistive cantilever technique**.
- Two different samples glued on different planes.
- At 4.2 K up to 35 T.

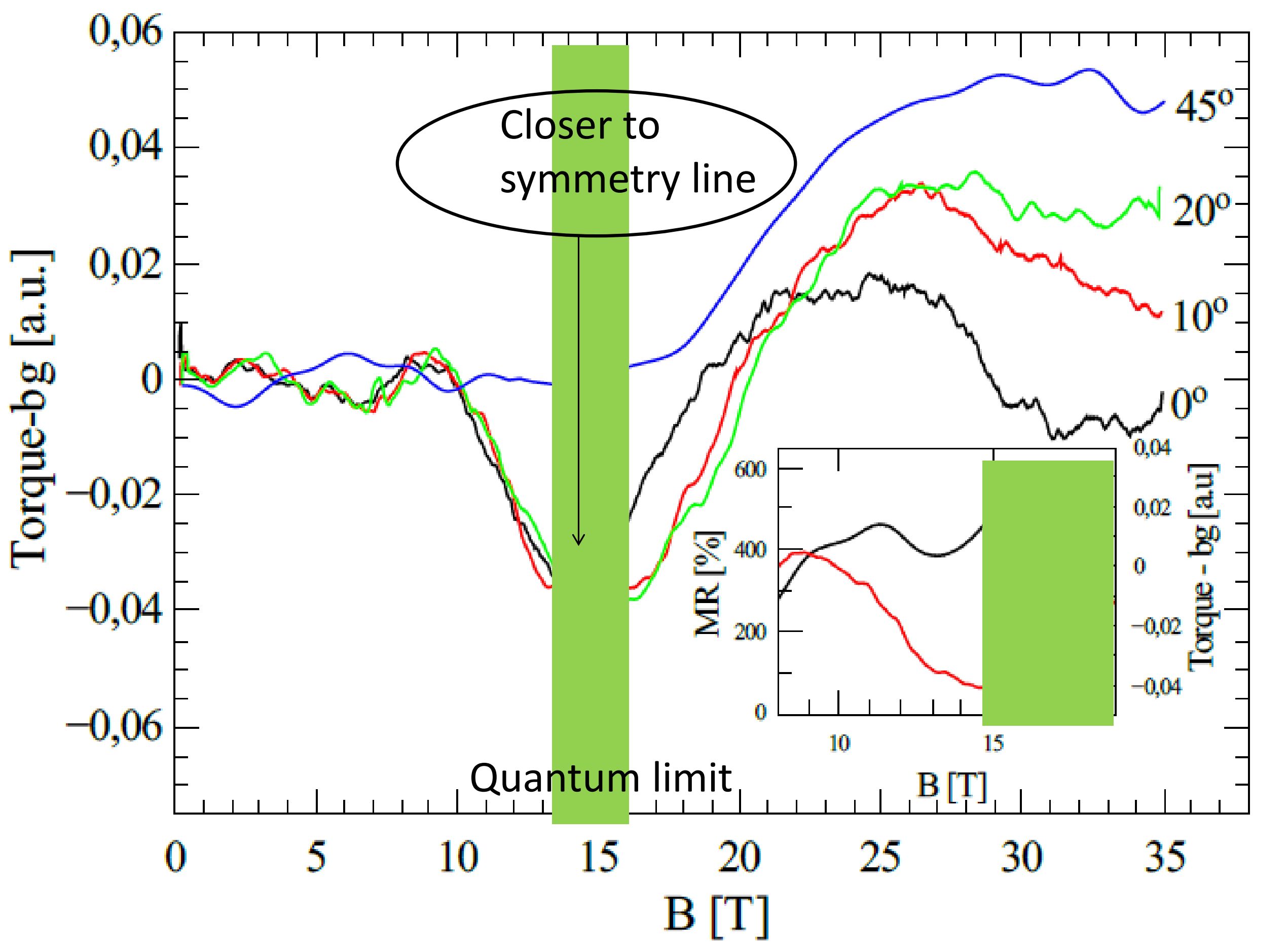


If material posses anisotropy, sample produces torque on lever, $T = \vec{M} \times \vec{B} \propto B^2$.



Angle is between field direction and normal to the sticking plane.





By entering the quantum limit torque anomaly appears. Anomaly and change in torque slope is highly suppressed at 45^o.

Quantum limit appears at the same field for different field directions indicating the sphericity of the Fermi surface (confirmed in SdH oscillations).

Conclusion

- Succsesfully synthesized low charge concetration Cd_3As_2 samples with lower quantum limit (Cd_3As_2 usually has F around 45-50 T).
- SdH oscillations reveal spherical Fermi surface leading to very small torque signal. In samples with higher charge concentration the Fermi surface is ellipsoidal [2].
- Anomalus and angle dependent torque signal near the quantum limit associated to transition between Dirac and Weyl semimetal has been found.

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Acknowledgments

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References:

[1] Moll, P. J. *et al.* (2016). Magnetic torque anomaly in the quantum limit of Weyl semimetals. *Nature Communications*, *7*.
[2] Borisenko, S. *et al.* (2014). Experimental realization of a three-dimensional dirac semimetal. *Physical Review Letters*, *113*(2).