Signatures of Landau Level Crossings in a Two-Dimensional Electron Gas

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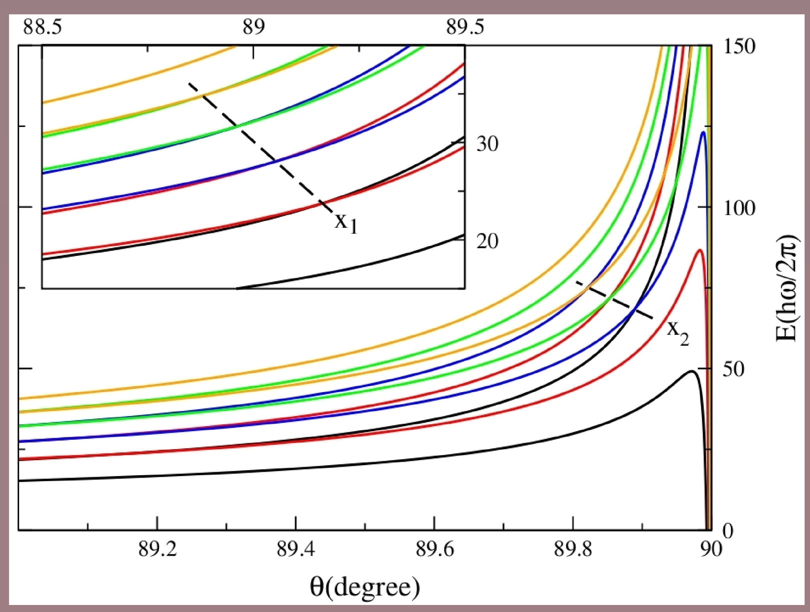
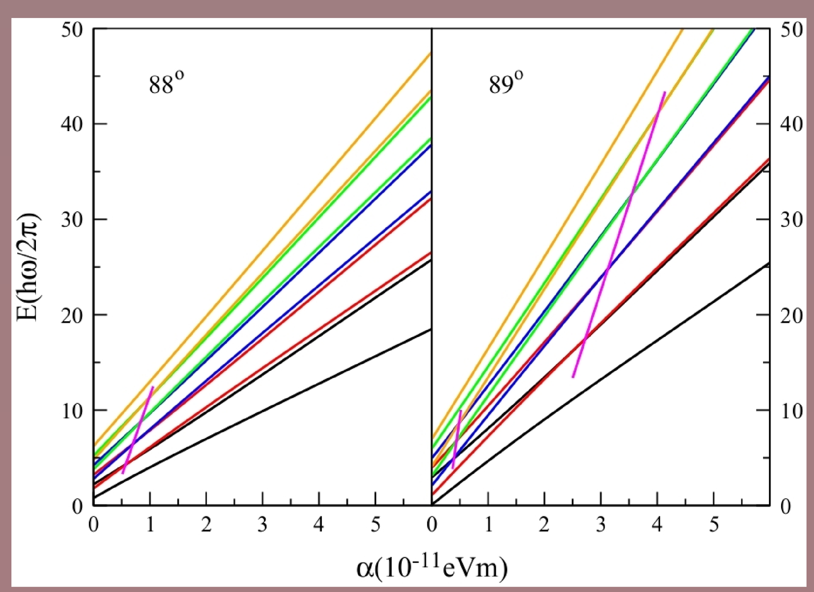
Landau level crossings: suppressed no more



Crossings are suppressed at small and intermediate tilts.



Hamiltonian

$$H = H_0 + H_R + H_Z = \frac{\hbar^2 \vec{k}^2}{2m^*} + \alpha(\vec{\sigma} \times \vec{k}) \cdot \hat{z} - \vec{\mu} \cdot \vec{B}$$

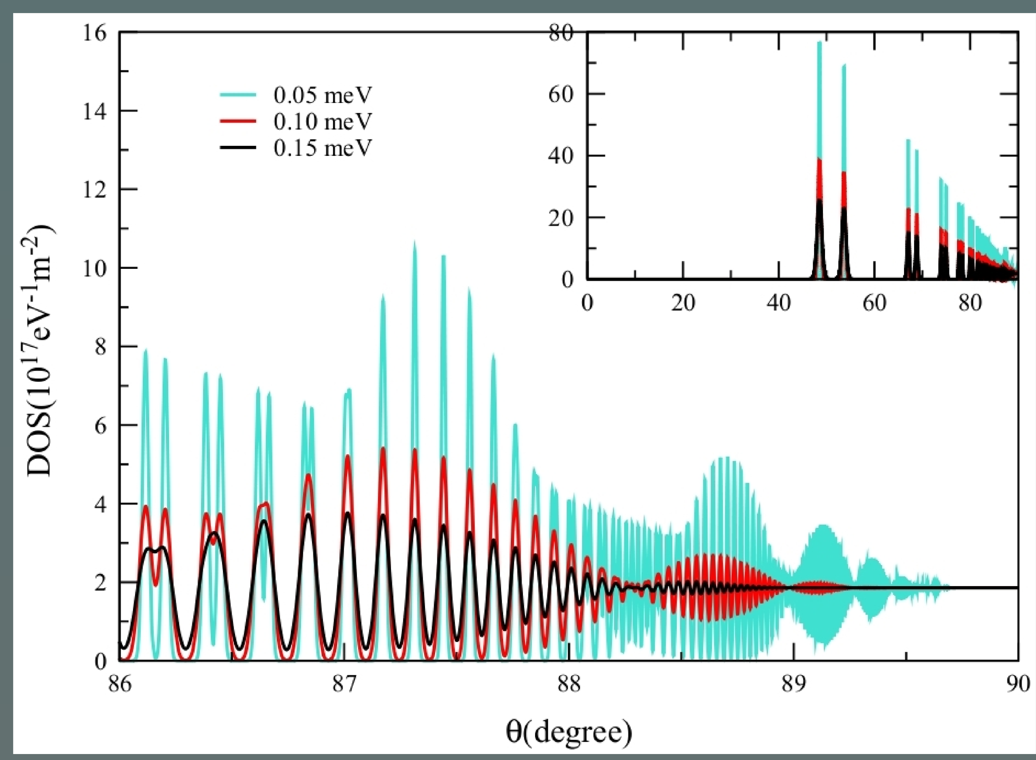
Trick: Crossing states have equal probability amplitude [1].

$$E_n^{\pm} = n + \frac{1}{2} + \frac{\Upsilon}{2}(\sqrt{n+1} + \sqrt{n}) \pm \frac{1}{2}\sqrt{[\Upsilon(\sqrt{n+1} - \sqrt{n}) + 2\Omega_z]^2 + 4\Omega_+\Omega_-}$$

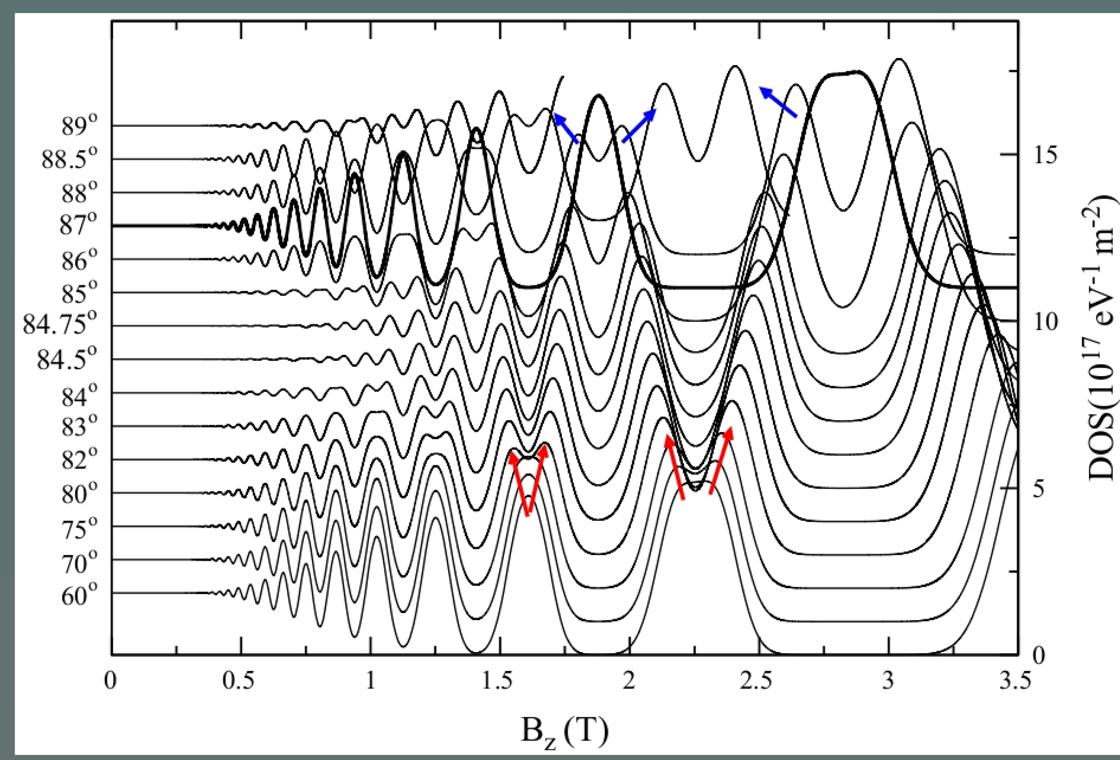
$$\mathrm{DOS}(E) = \frac{eB_\perp}{h} \sum_n \left(\frac{1}{2\pi}\right)^{1/2} \frac{1}{\Gamma} \exp\left[-\frac{(E - E_n^{\pm})^2}{2\Gamma^2}\right]$$

Large tilting and strong Rashba interaction reveal crossings that are suppressed at small tilts and weak Rashba potential.

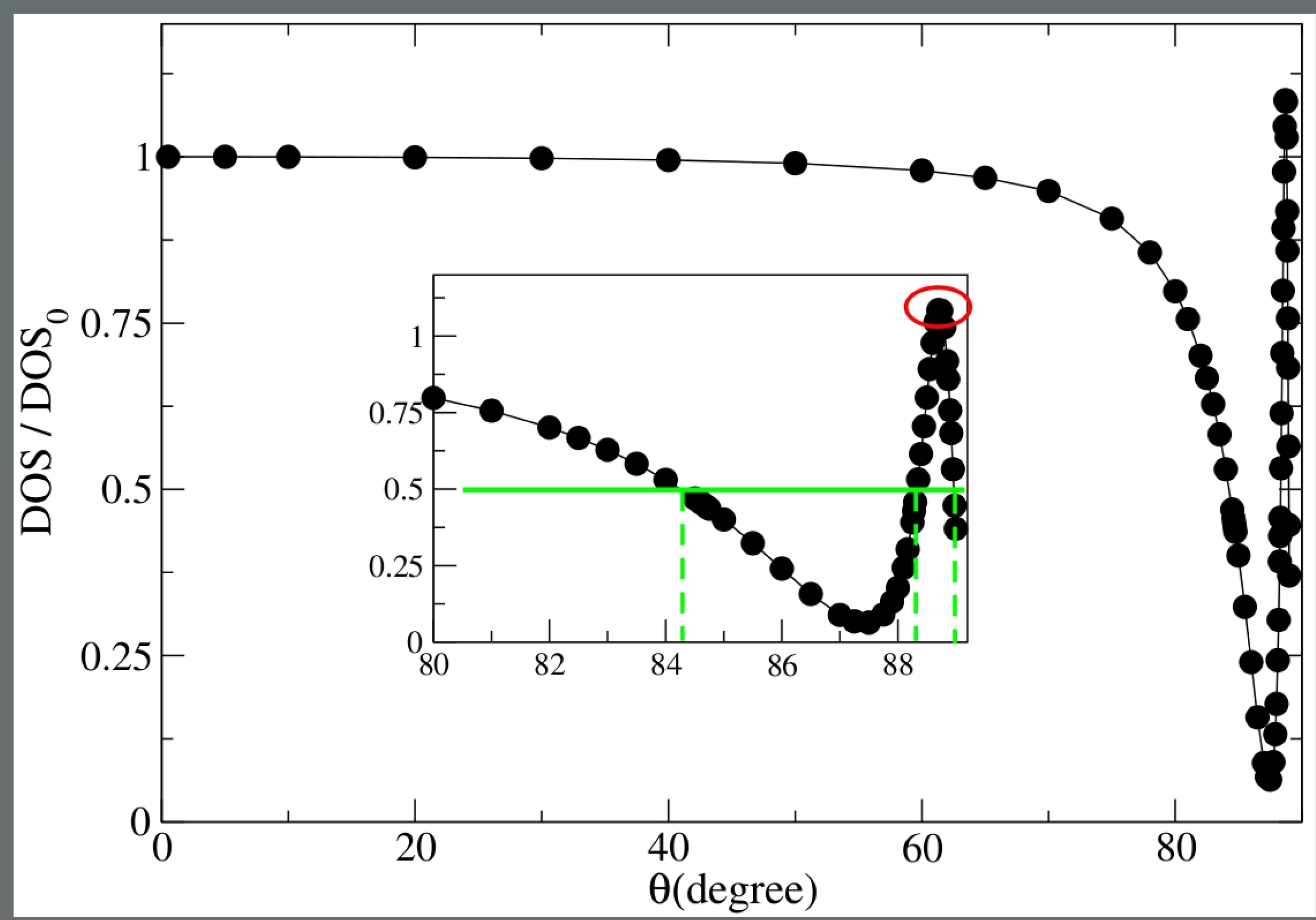
Crossing fingerprints



DOS shows beats at large tilts. No beats are observed at small and intermediate angles.



DOS shows how the spin gap gradually increases until it equals the Landau gap and consequently gives rise to crossings.



The evolution of the peak height at $B_z \approx 1.02$ T. The trend shows an increasing depth (or spin splitting) until it reaches a maximum around 87.5°. This is the same angle where simultaneous LL crossings occur [2] and this was observed experimentally [3]. Aside from the usual beating patterns, we discover here another way of detecting LL crossings.

The green solid line marks $\mathrm{DOS}/\mathrm{DOS}_0$ = ½ with corresponding angles $\theta_{ps} \approx$ 84.2°, 88.3°, 88.9°. At around these same angles do we observe the DOS phase reversal accompanying a minimized DOS amplitude [2].

Another remarkable feature is the maximum peak surpassing DOS_0 around 88.7° (red circle). This is contrary to expectations if one considers solely the DOS prefactor being proportional to B_z. In the perspective of LL crossing, however, this θ coincides to another crossing point.

Summary and Conclusion

- Large tilting of a two-dimensional electron gas in a magnetic field with Rashba spin-orbit interaction reveals rich physics which are otherwise concealed when only smaller angles are considered.
- Large tilting gives way to the LL crossings that are suppressed at lower tilts.
- Tracing a single LL peak monitors the spin splitting gap (depicted as a dip).
- The maximum splitting (deepest dip) coincides to simultaneous crossings for a given angle. Tilting further, the following tallest peak points to the next crossing point.
- On top of the standard DOS beating patterns, we showed explicitly how the extrema of the dip are signatures of LL crossings.

References

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[3] A.T. Hatke, M.A. Zudov, L.N. Pfeiffer, K.W. West, Phys. Rev. B 85, 241305(R) (2012).
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