Quantum pumping in graphene

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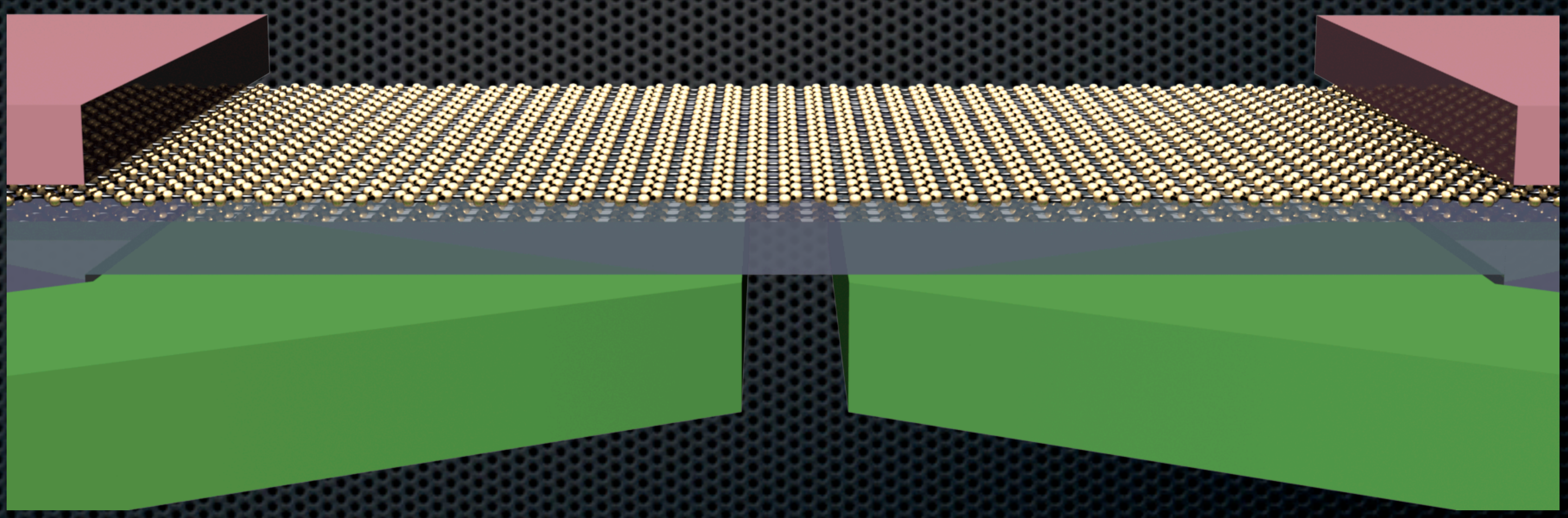
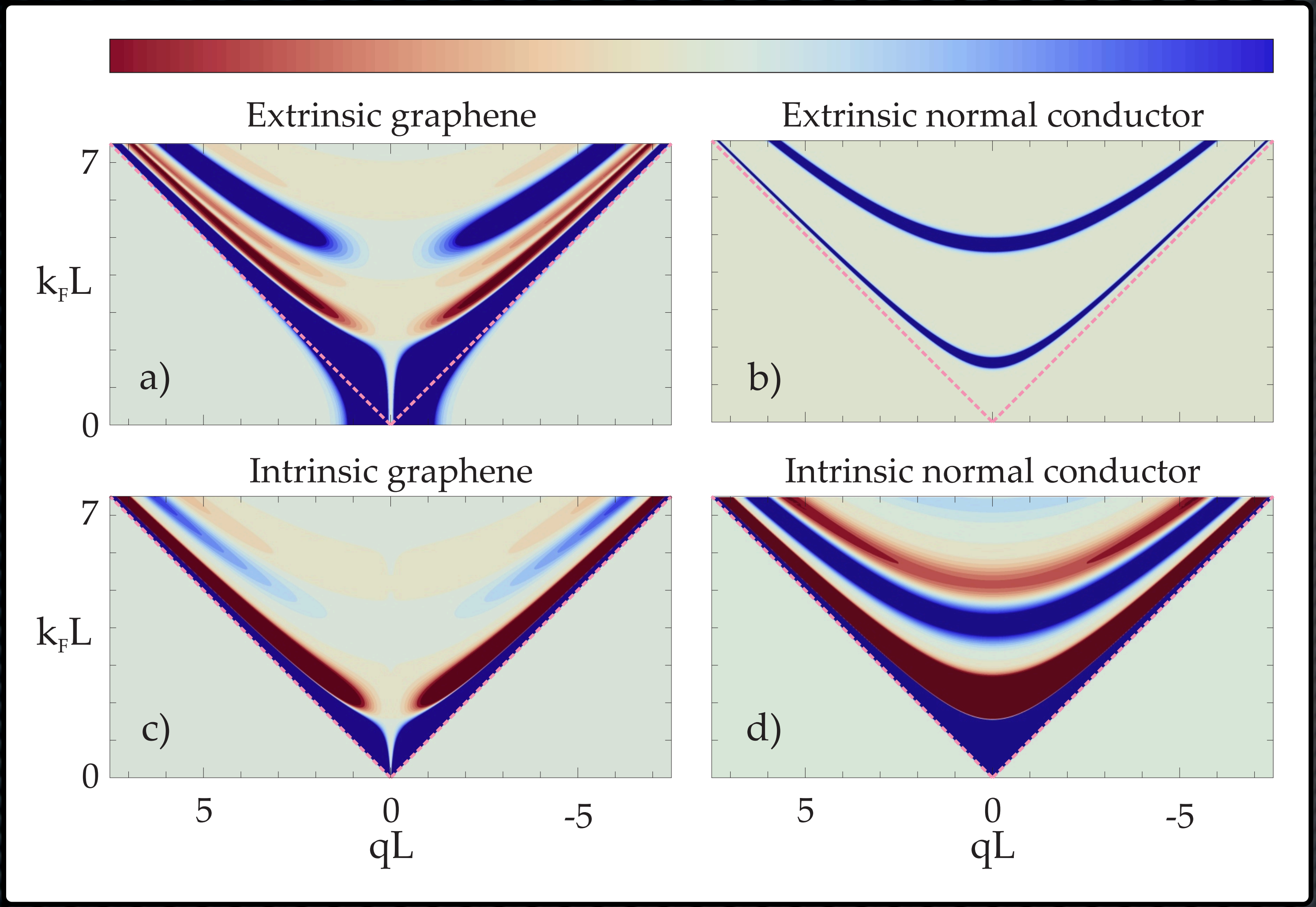
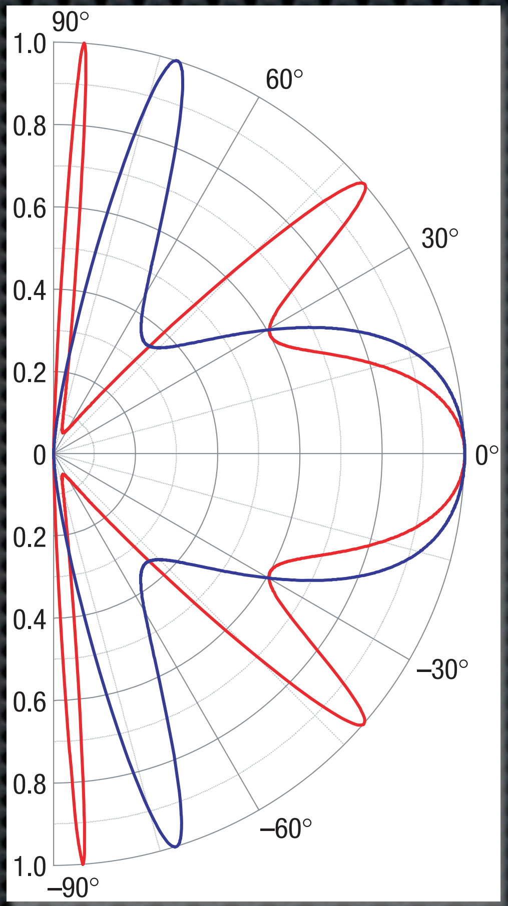


Pumping response: comparison

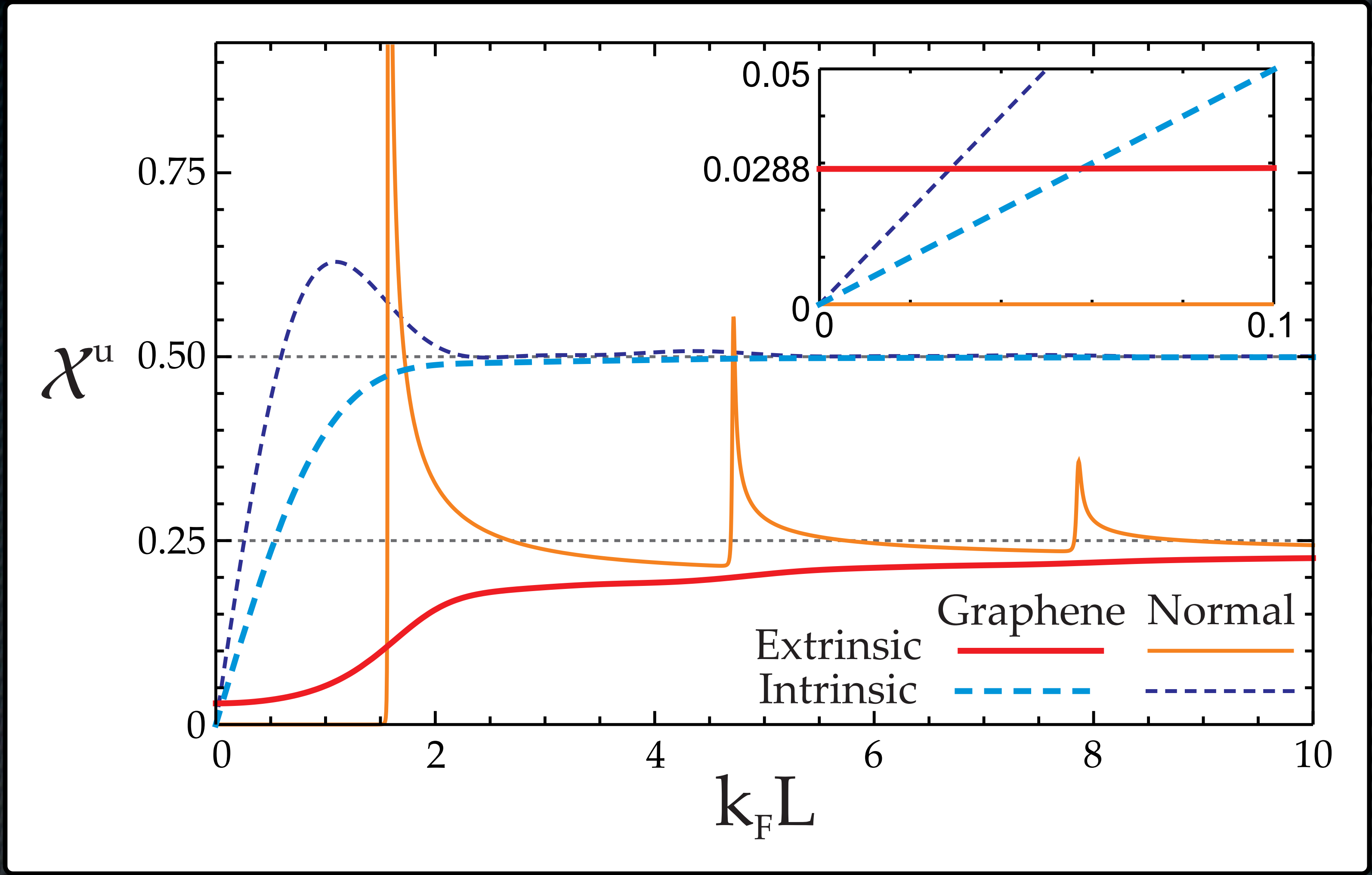




Klein scattering: angular transmission through a potential step in graphene

- Evanescent modes ($|q| > k_F$) can only pump charge in extrinsic graphene pumps, close to the Dirac point ($k_F=0$).
- Reason: in graphene, evanescent modes penetrate deeply into the pump because of chirality-suppressed backscattering (Klein's paradox), with energy dependent scattering amplitudes.
- Propagating mode $q=0$ cannot be pumped in graphene, also because of Klein's paradox (pinned transmission $T=1$ insensitive to driving).

Total pumping response (wide and short pumps)



- Extrinsic normal pumps are closed due to Fermi velocity mismatch, hence the doping threshold and the peaked structure (subbands).
- At the Dirac point, extrinsic graphene pumps have a saturating χ^u due to the contribution of evanescent modes. It takes the universal value:

$$\chi^u(0) = \int_0^\infty dq \frac{\sinh^2(q)\,[2q\cosh(2q) - \sinh(2q)]}{\pi q^3 \cosh^4(2q)} = 0.0288$$