

IMPACT 2024, Cargese

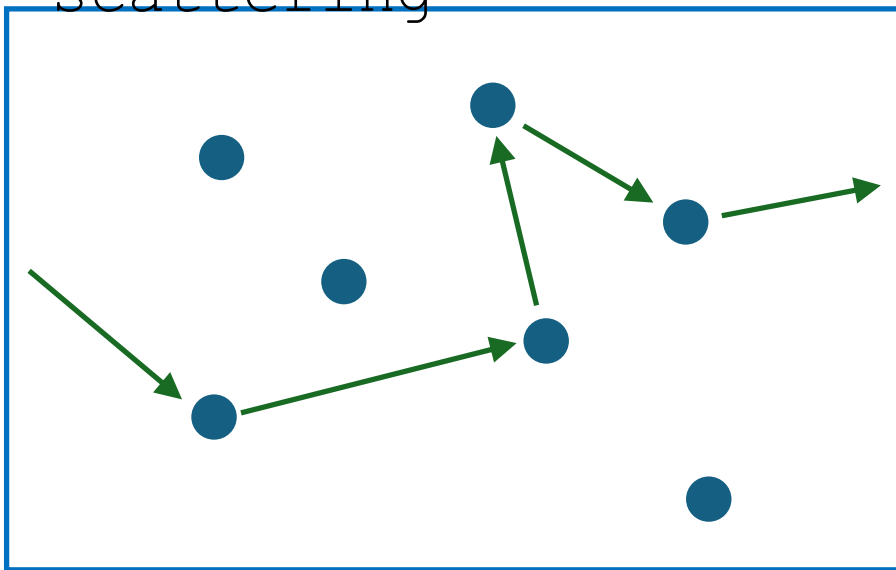
Time-domain interferrometry
of electron weak localization
through Terahertz nonlinear
response

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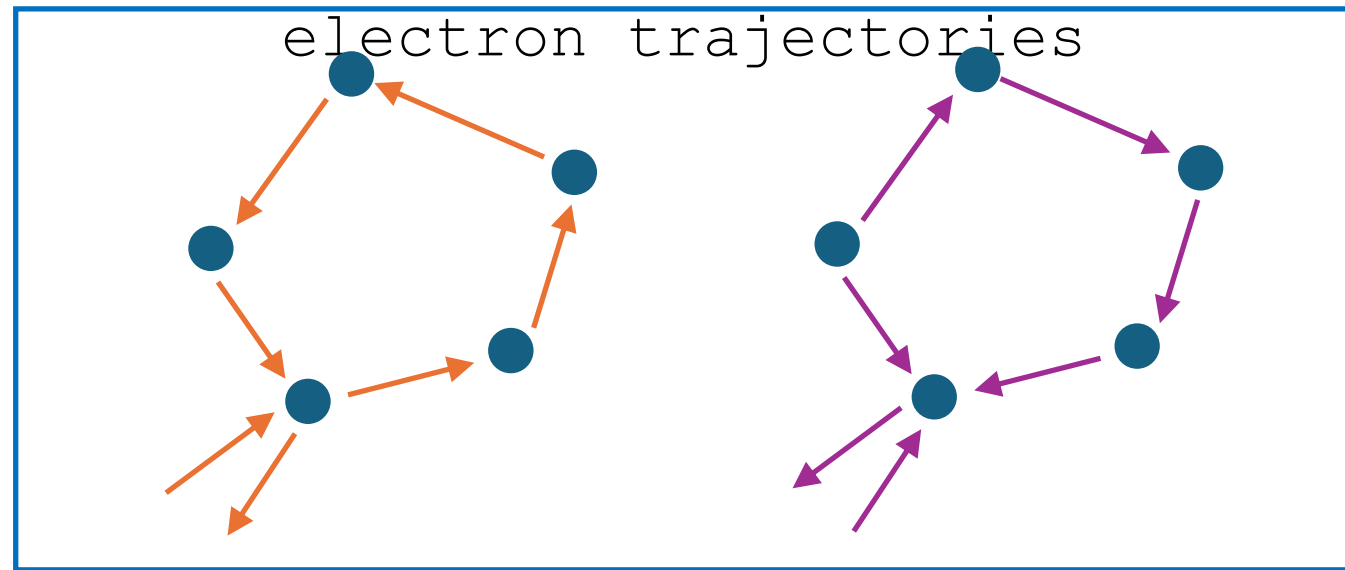
Weak localization in a dirty metal film

Drude : stochastic scattering



$$\sigma_D = \frac{ne^2}{m} \tau_0$$

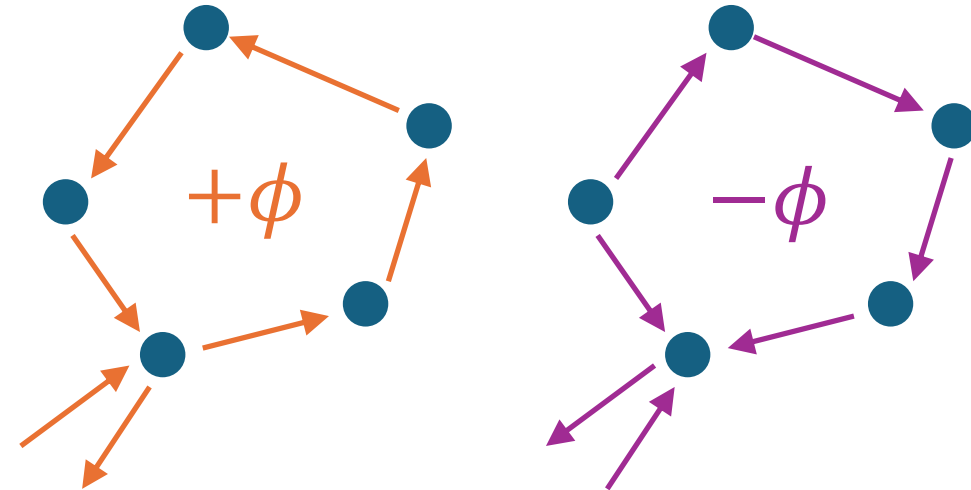
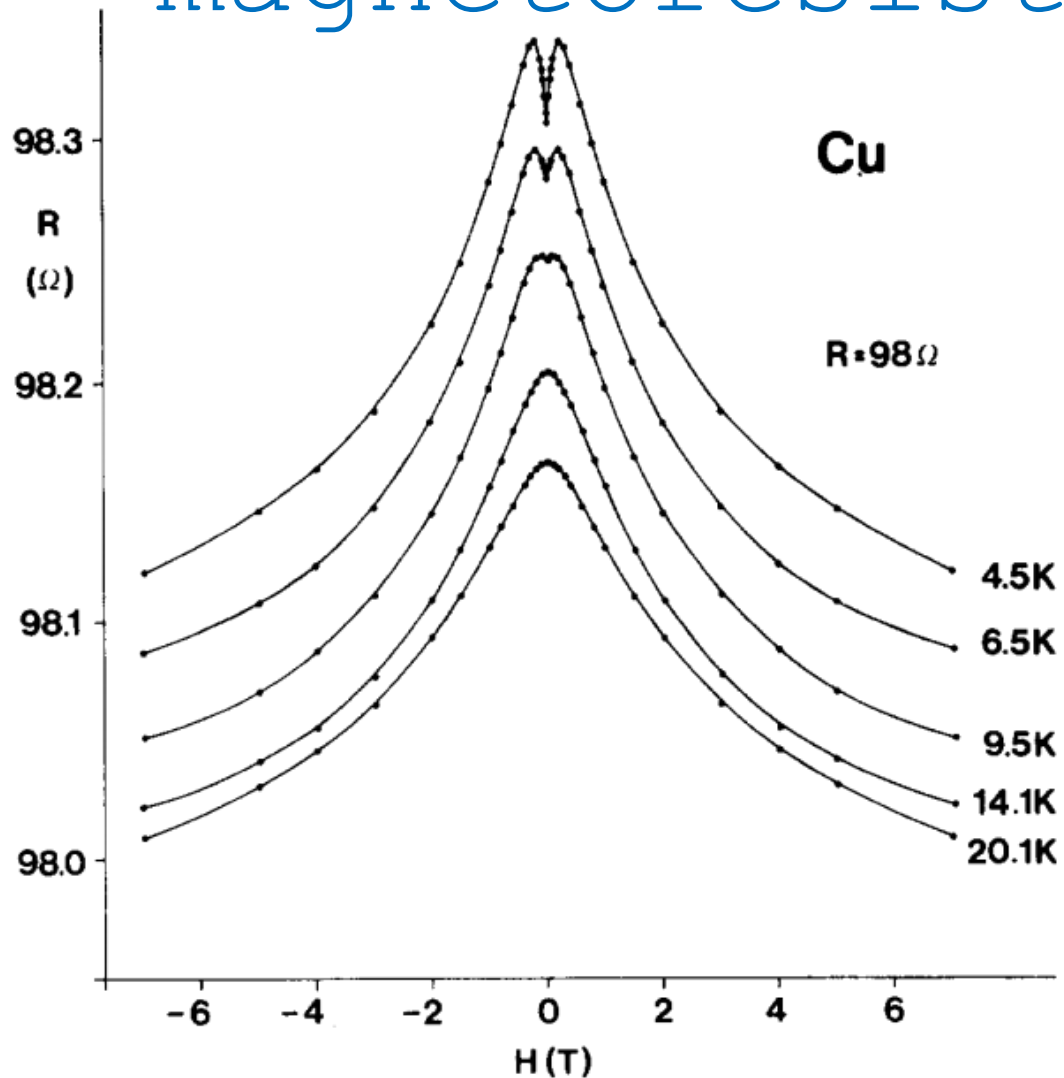
Weak localization: **interference** of a pair of **time reversed** electron trajectories



$$\sigma_{WL} = -\frac{G_0}{2\pi} \ln \frac{\tau_\phi}{\tau_0}$$

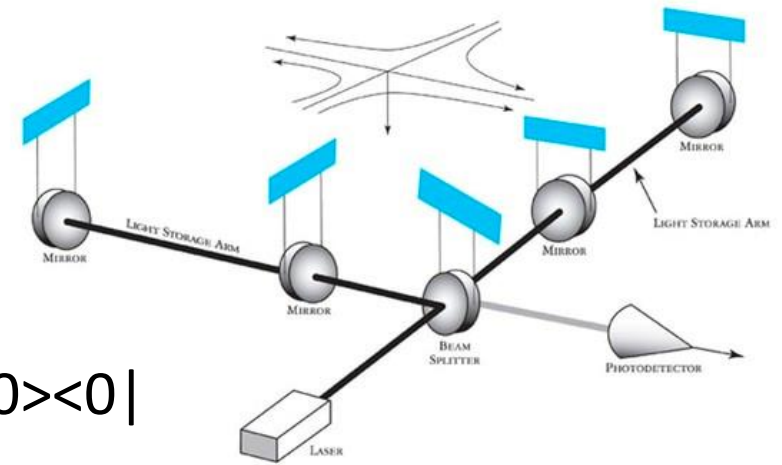
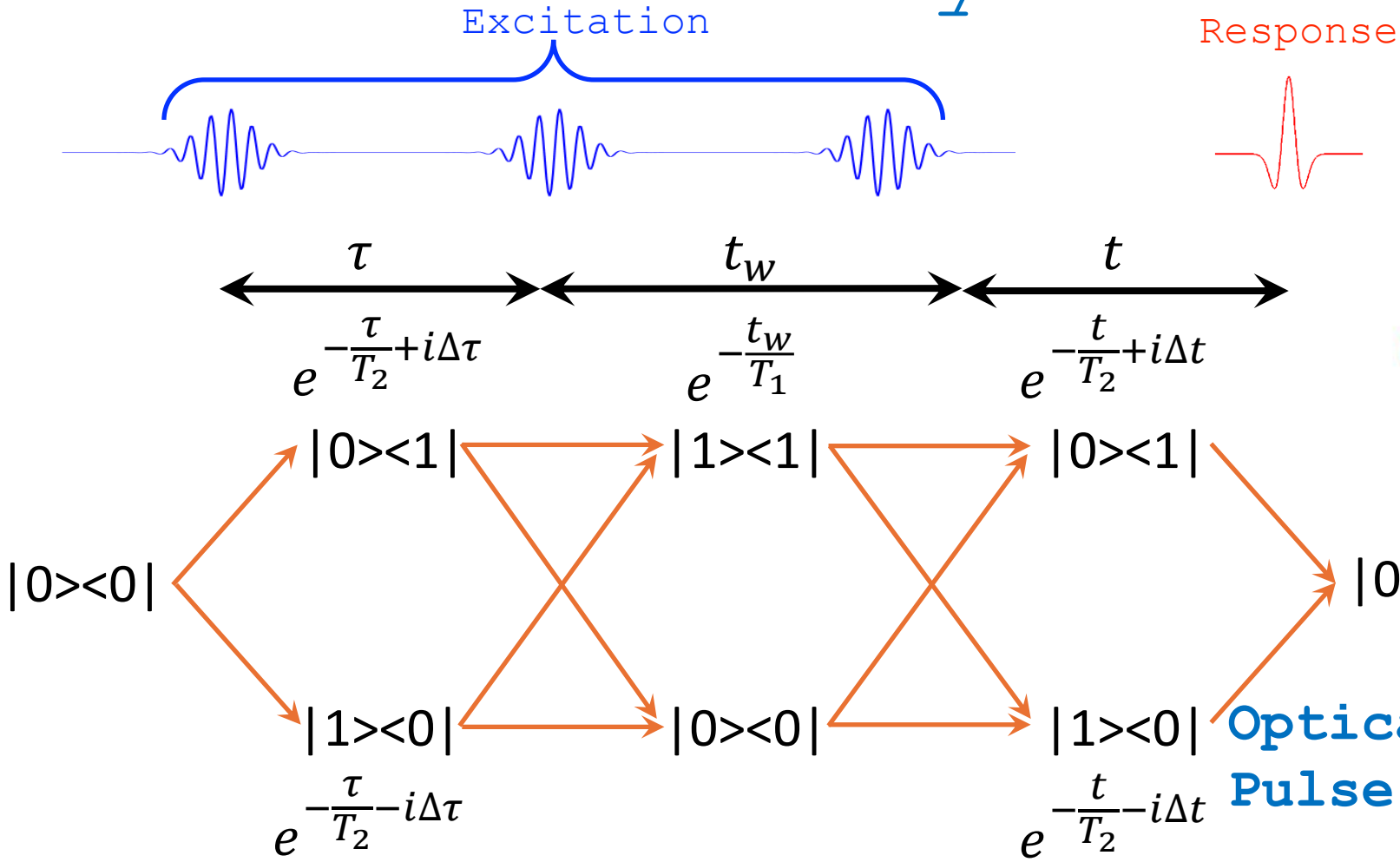
$$\sigma = \sigma_D + \sigma_{WL} \quad \uparrow \quad G_0 \sim 1 / (13k\Omega)$$

Probe weak localization with magnetoresistance



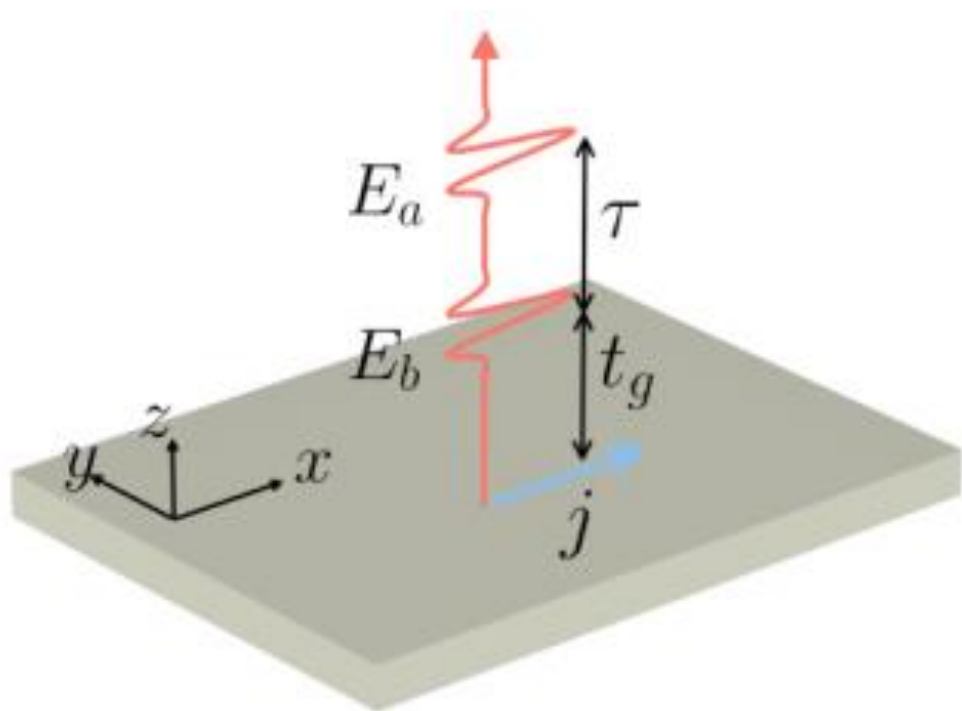
- Time-reversed electron trajectory pair picks up **opposite AB phases** \rightarrow Suppresses WL;
- MR = space domain interferometry;
- **Time domain interferometry?** (independent diagnostic; avoids ...)

Nonlinear optics as interferometry



Optical pulse = Beam splitter
 Pulse delay time = Arm length

Nonlinear response of a dirty metal film



- **Diffusive metal** regime: $\hbar/E_F \ll \tau_{el} \ll \tau_\phi$
 - Omit details specific to band structures, scattering potential, etc. **Universal**.
- $$j(t) = \sigma_D E(t) - \frac{G_0}{2\pi} \int_{-\infty}^t \frac{e^{-\frac{t-t'}{\tau_\phi}}}{t-t'} E(t') dt'$$

↓
 Ohm's law
Linear in
E

↓
 Weak localization
nonperturbative
in E

Symmetry factor $\mathcal{Q} = \begin{cases} 1 & \text{(orthogonal)} \\ -\frac{1}{2} & \text{(symplectic)}. \end{cases}$

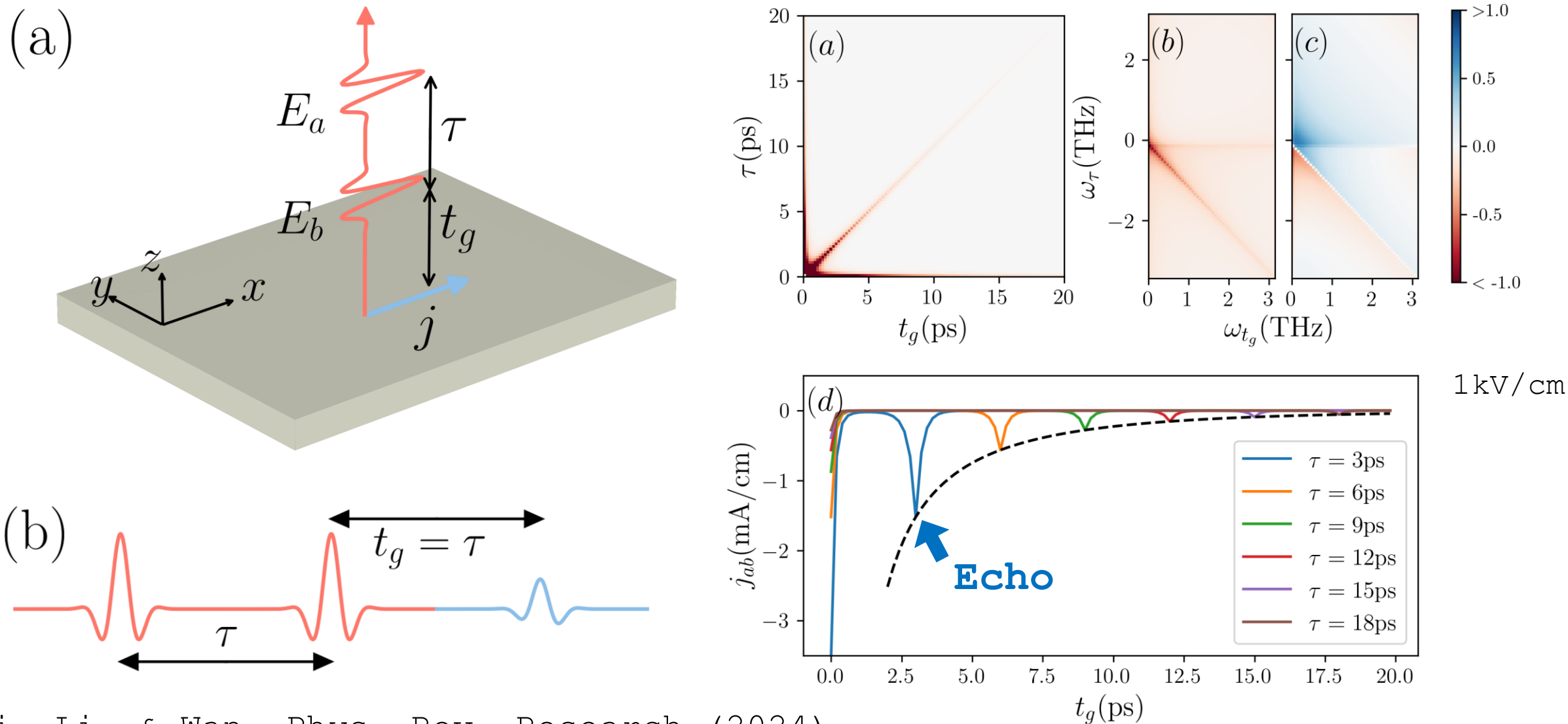
Coherence factor:

$$f(t, t') = \frac{De^2}{\hbar^2} \int_{t'}^t [A(s) + A(t + t' - s) - 2\bar{A}]^2 ds$$

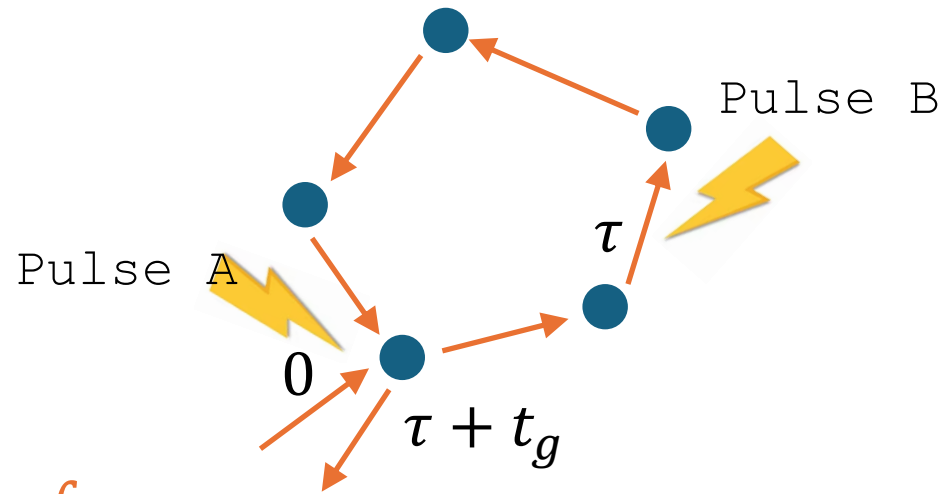
Altshuler, Aronov, & Khmelnitskii, J. Phys. C (1982)

Li, Li, & Wan, Phys. Rev. Research (2024)

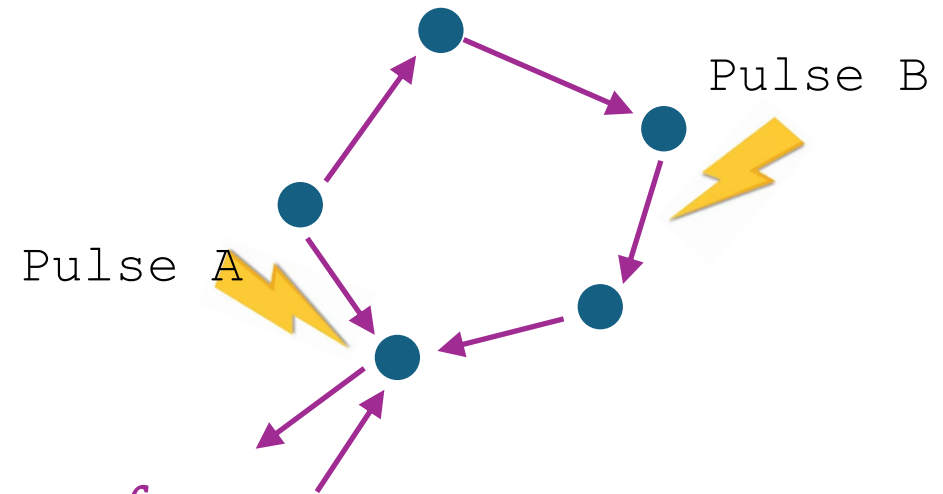
Nonlinear response of a dirty metal film



Current echo



$$\phi = e \int x(s) \cdot E_b(s) ds = x(\tau) \cdot E_b$$

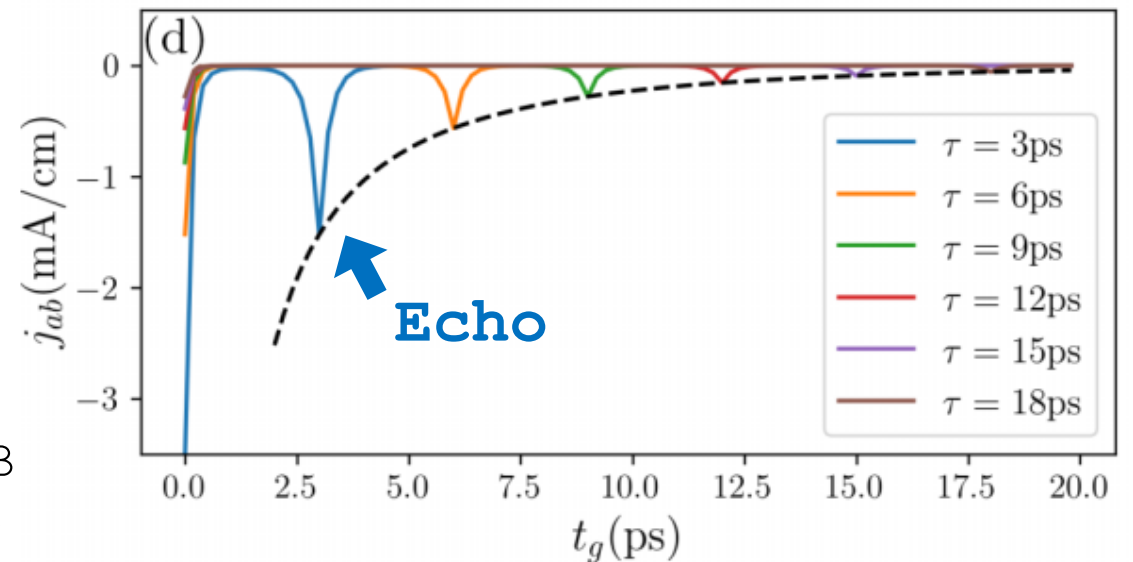


$$\phi = e \int x(\tau + t_g - s) \cdot E_b(s) ds = x(t_g) \cdot E_b$$

- Echo reflects time-domain interference of time-reversed trajectory pairs
- Echo decays as the electron decoheres → **Observing**

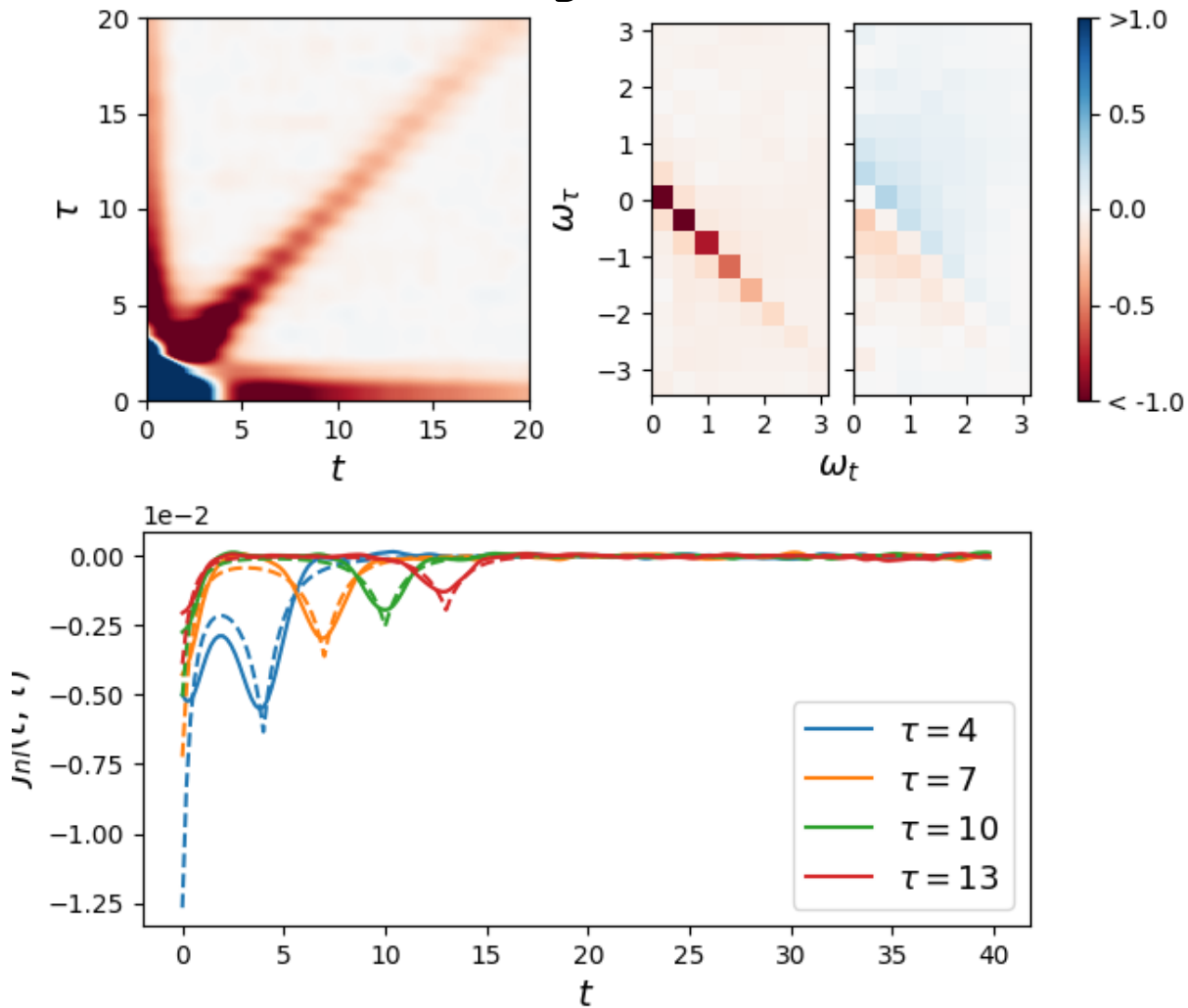
electron decoherence in real

Micklitz, Müller, & Altland, Phys. Rev. B
 Li, ~~Li~~, & Wan, Phys. Rev. Research (2024)

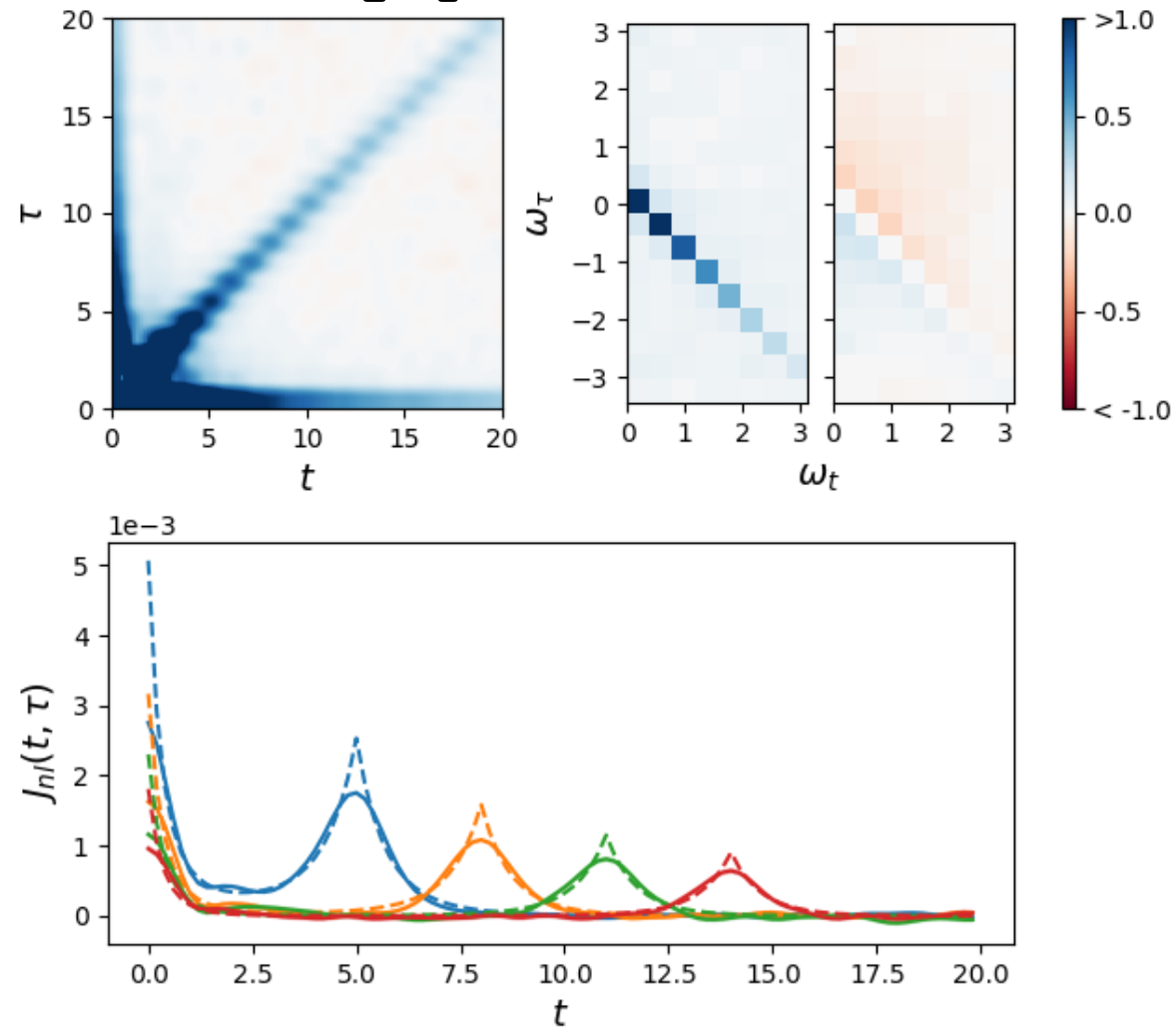


Numerical test

Orthogonal class



Symplectic class



Conclusion and outlook

- ✓ **Current echo** in the THz nonlinear response of a dirty metal film provides a **time-domain interferometry** for electron weak localization.
- ✓ Potentially detectable with 2D coherent spectroscopy.
- ✓ **Complements** nicely the **magnetoresistance** measurement.

Open problems:

➤ Microscopic treatment of **decoherence by el-ph scattering?**

➤ **Decoding the source of decoher**

