# "Decoherence and Superselection in QED and Quantum Gravity"

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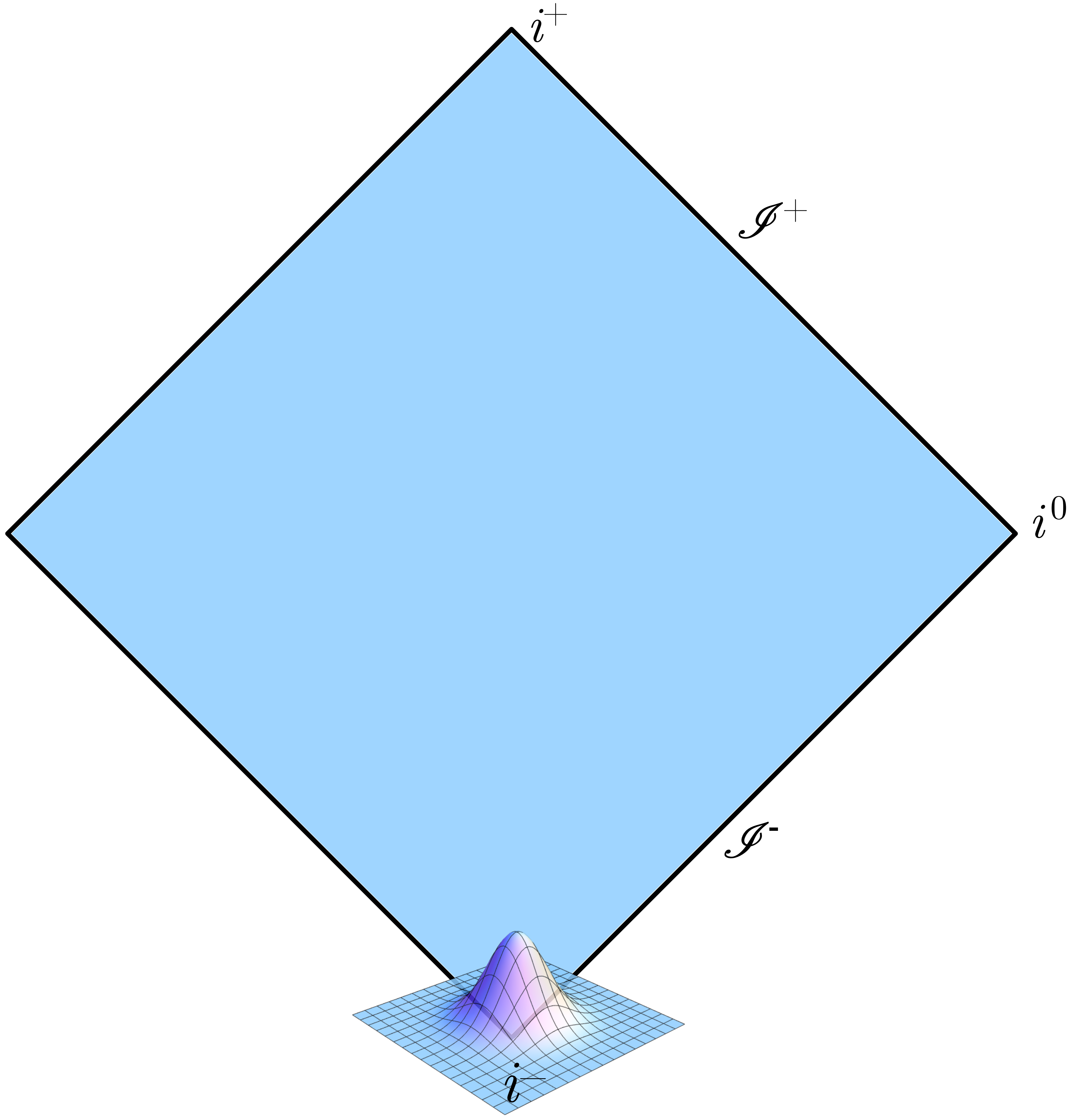
## Review: Charge Superselection

- $\hat{Q}_{i^0} \equiv \int_{\mathbb{S}^2} d\Omega \hat{E}_r(\Omega)$ is the total electric charge.
- $[\hat{Q}_{i^0}, \hat{O}] = 0$ for any local, gauge-invariant observable $\hat{O}$.
- This implies $\langle q \,|\, \hat{O} \,|\, q' \rangle = 0$ for $q \neq q'$.
    - Thus, quantum interference is forbidden between states of distinct total charge.
    - The space of states decompose into "superselection sectors" labelled by total charge.
    - Superpositions of differently charged states are totally decohered.

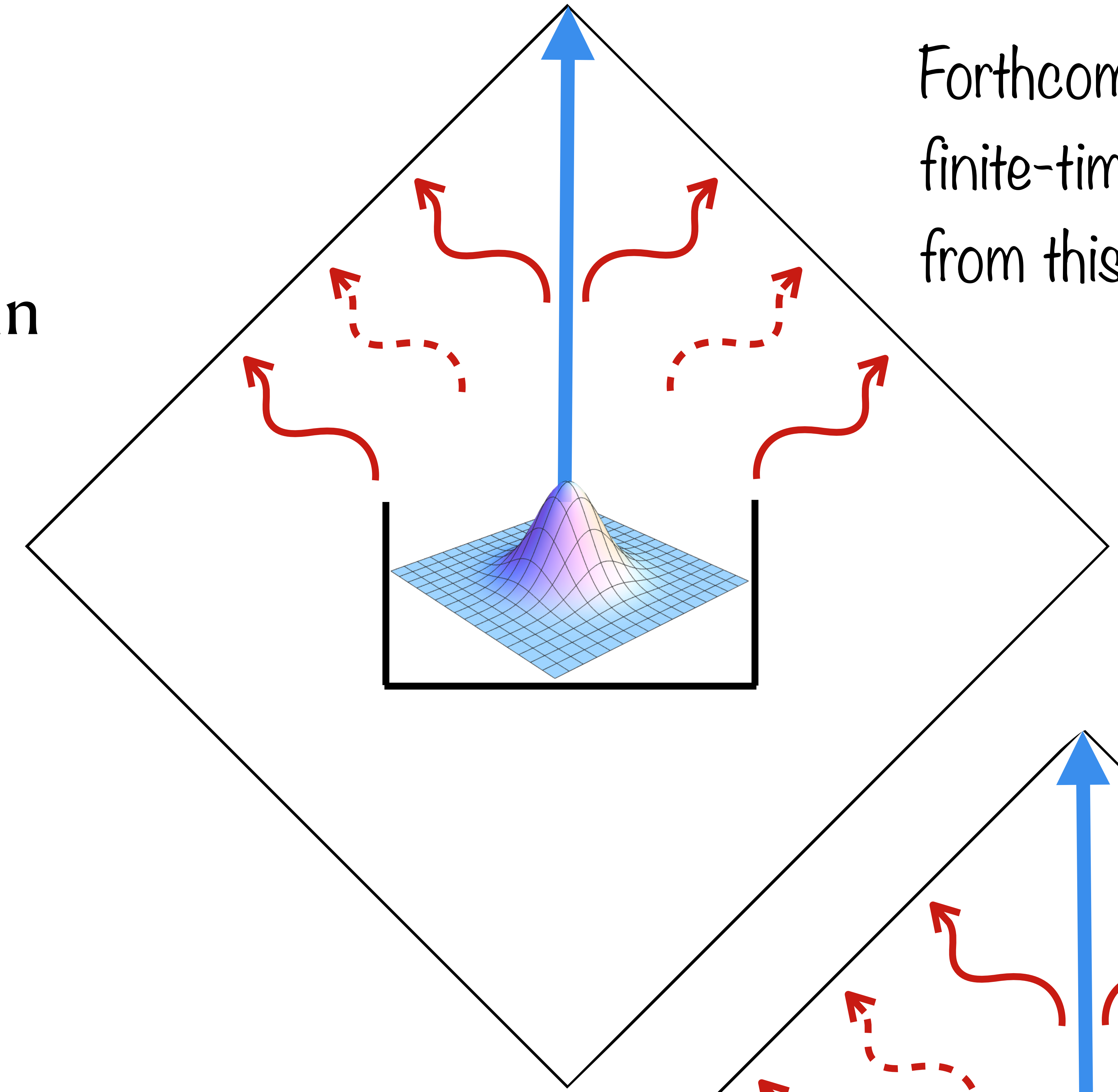
# Undressed Electron Wavepackets are Translation Invariant

- In asymptotically flat spacetime (e.g. scattering), there are infinitely many more "**asymptotic charges**": $\hat{Q}_{i^0}(\lambda) \equiv \int_{\mathbb{S}^2} d\Omega \hat{E}_r(\Omega)\lambda(\Omega)$ for any function $\lambda$.
- An "undressed" electron wavepacket in QED: $|\Psi\rangle = \int_{\mathscr{H}} d^3p\, f(p)\,|p)_{i^-} \otimes |\Omega\rangle_{\mathscr{I}^-}$.
- Any spacetime translation by $\Delta x$: $(p, \Omega|\ \hat{O}\ |p', \Omega) \to (p, \Omega|\ \hat{O}\ |p', \Omega) \cdot e^{ig(p-p', \Delta x)}$
- Electron momenta $|p, \Omega)$ are eigenstates of $\hat{Q}(\lambda)$, so like before $(p, \Omega|\ \hat{O}\ |p', \Omega) = 0$ for $p \neq p'$.
- Therefore $\langle \Psi | \hat{O} | \Psi \rangle$ is spacetime translation invariant.
- Theorem: on gauge-invariant observables, "undressed electron/positrons" are spacetime translation invariant in the bulk.

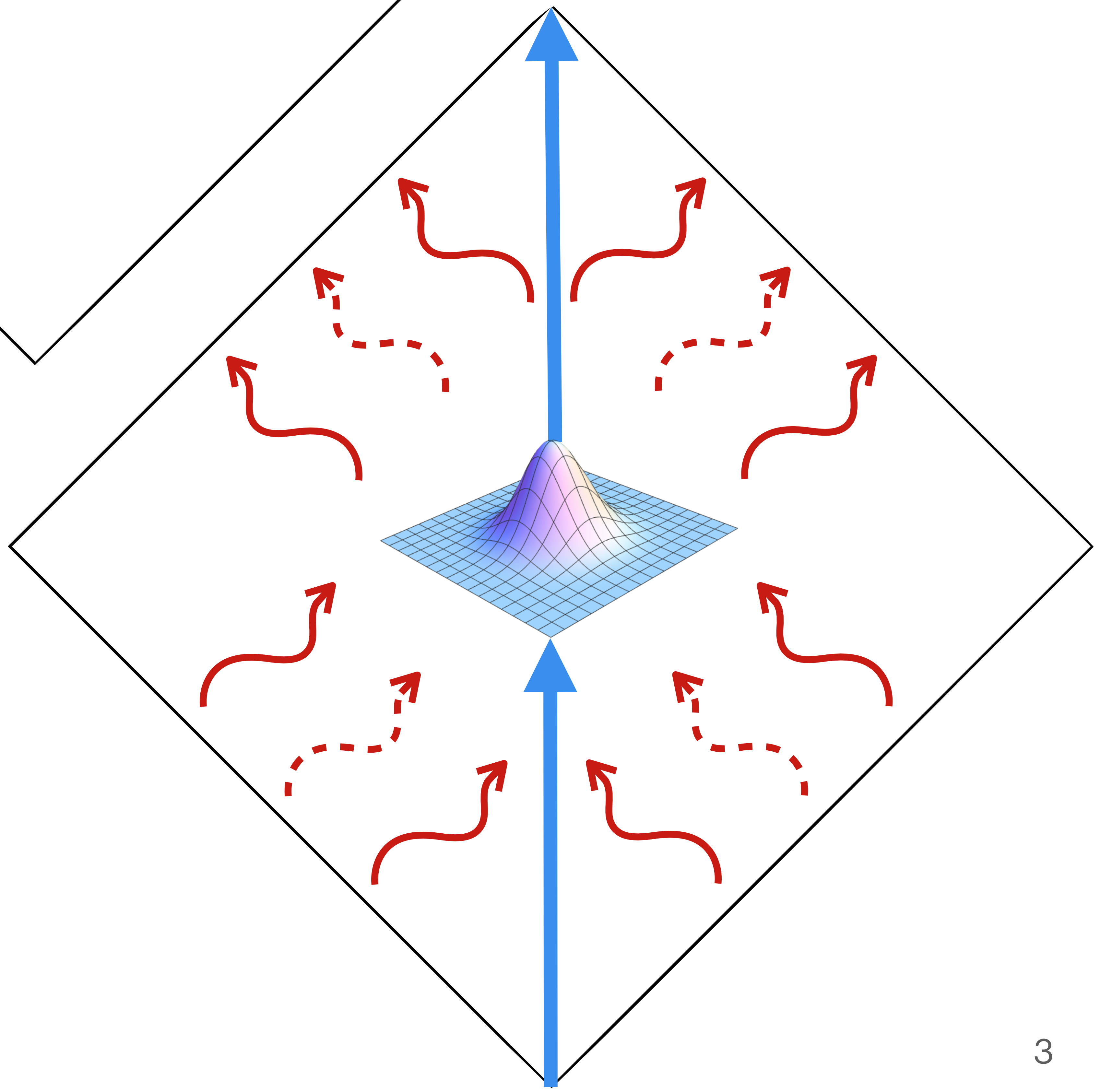


# Physical States of QED

- Alice releases an electron from a screening potential in the bulk: $\hat{Q}_{i^0}(\lambda)\,|\Psi\rangle_{\mathrm{FK}} = 0.$
- Symmetry constraints then force soft, entangled radiation to $\mathscr{I}^+$:
$$|\Psi\rangle_{\mathrm{FK}} = \int_{\mathscr{H}} d^3p\, f(p)\,|p)_{i^+} \otimes |\Phi_p\rangle_{\Delta_p, \mathscr{I}^+}$$
such that $\hat{Q}(\lambda)\,|\Psi\rangle_{\mathrm{FK}} = 0.$
    - These states were introduced by Fadeev and Kulish in 1970, to regulate IR divergences of the $S$ matrix.
- **The only pure states on the local, gauge-invariant algebra of QED are eigenstates of $\hat{Q}(\lambda)$.**
- To produce a bulk electron in *scattering theory*, use this (time-reversed) final data as initial data. Hence initial states have maximal entanglement between $i^-$ and $\mathscr{I}^-$, with an infinite number of coherent soft photons at $\mathscr{I}^-$.

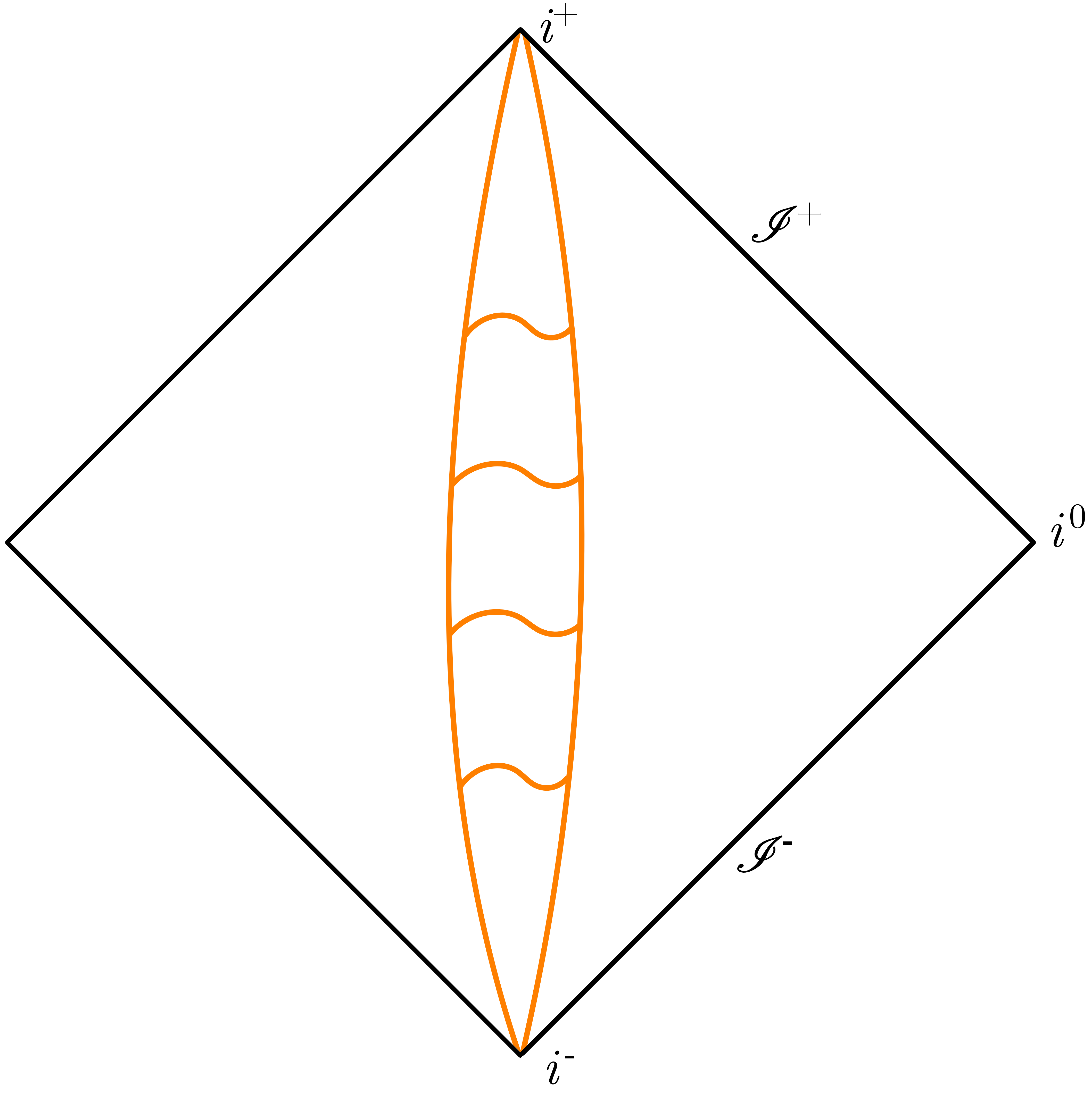


Forthcoming paper: finite-time effects from this!



# Quantum Gravitational Scattering

- Nonlinear quantization of GR on the asymptotic boundary [Ashtekar, 1981] again decoheres momenta, by $\hat{Q}^{\mathrm{GR}}_{i^0}(\lambda) \equiv \int_{\mathbb{S}^2} d\Omega\ \hat{E}_{rr}(\Omega)\lambda(\Omega)$.
- Massive particle: the QED resolution has no analog [Prabhu, Satishchandran, Wald, 2022], because gravity cannot be screened.
- All states on the **local**, gauge-invariant algebra of quantum gravitational scattering are spacetime translation invariant.
- But there aren't any "local, gauge-invariant" observables!
- In quantum gravity, all bulk states on the gauge-invariant algebra pertain to *relational* observables (i.e., nonlocal observables / **extended objects**).



# Questions?

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