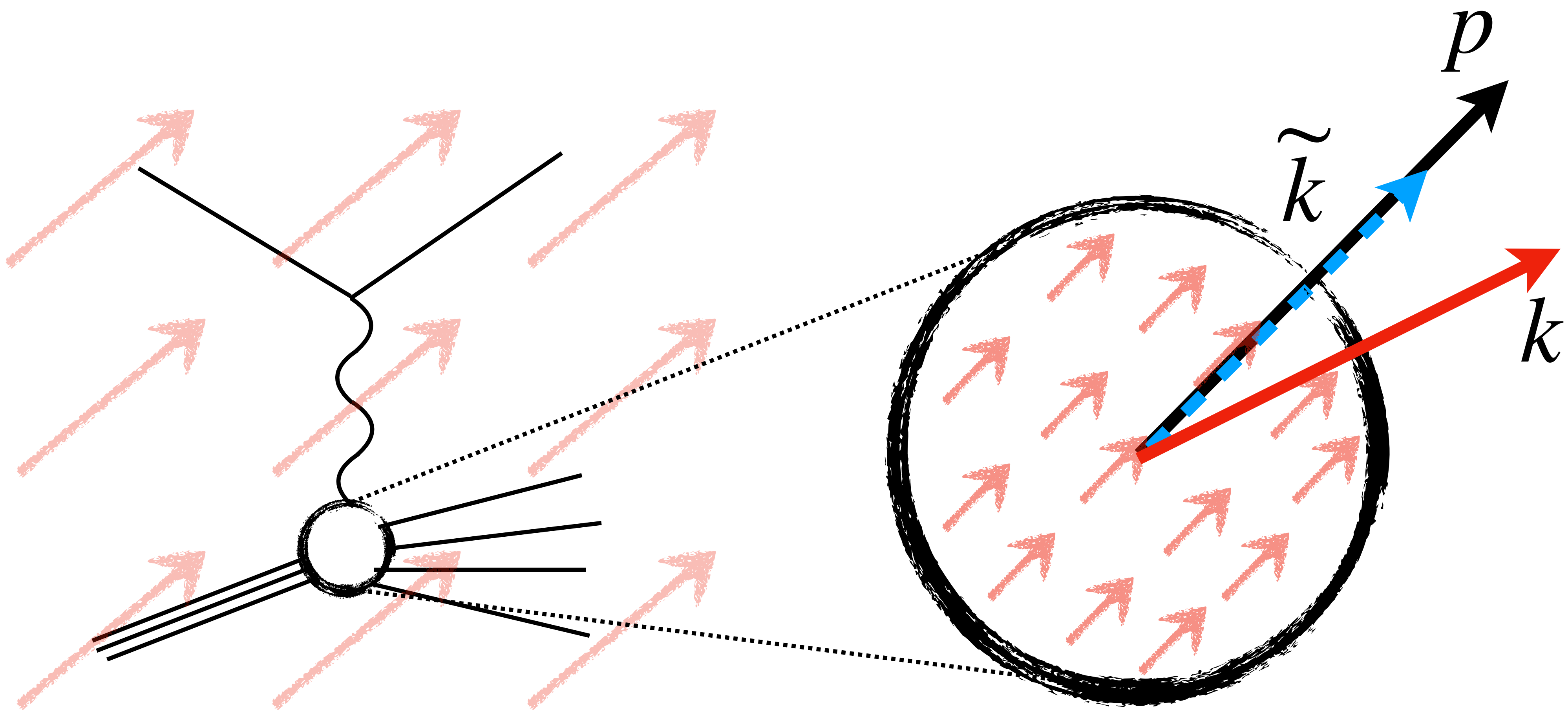
Lorentz violation analysis with ZEUS data



Nathan Sherrill
Indiana University

ZEUS meeting, January 2020

http://www.indiana.edu/~iucss/

In collaboration with Enrico Lunghi

Talk overview

What is Lorentz violation?

How to search for Lorentz violation?

Effects on high-energy hadrons

Application: deep inelastic scattering

Estimates for colliders

An analysis with real data

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Based on: arXiv:1911.04002; PRD **98**, 115018 (2018); PLB **769**, 272 (2017)

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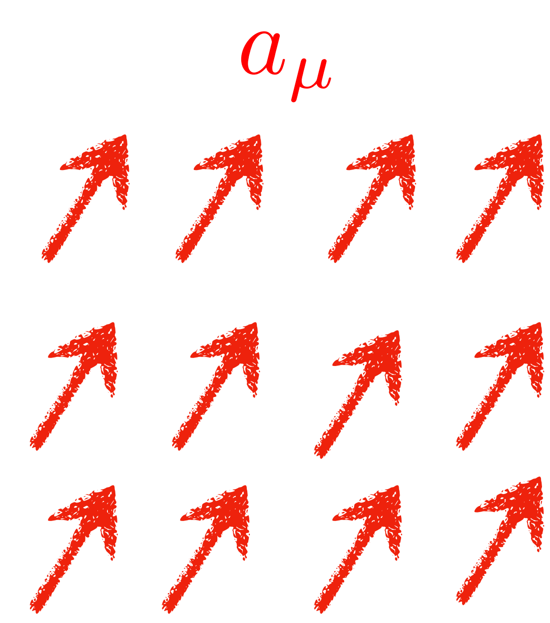

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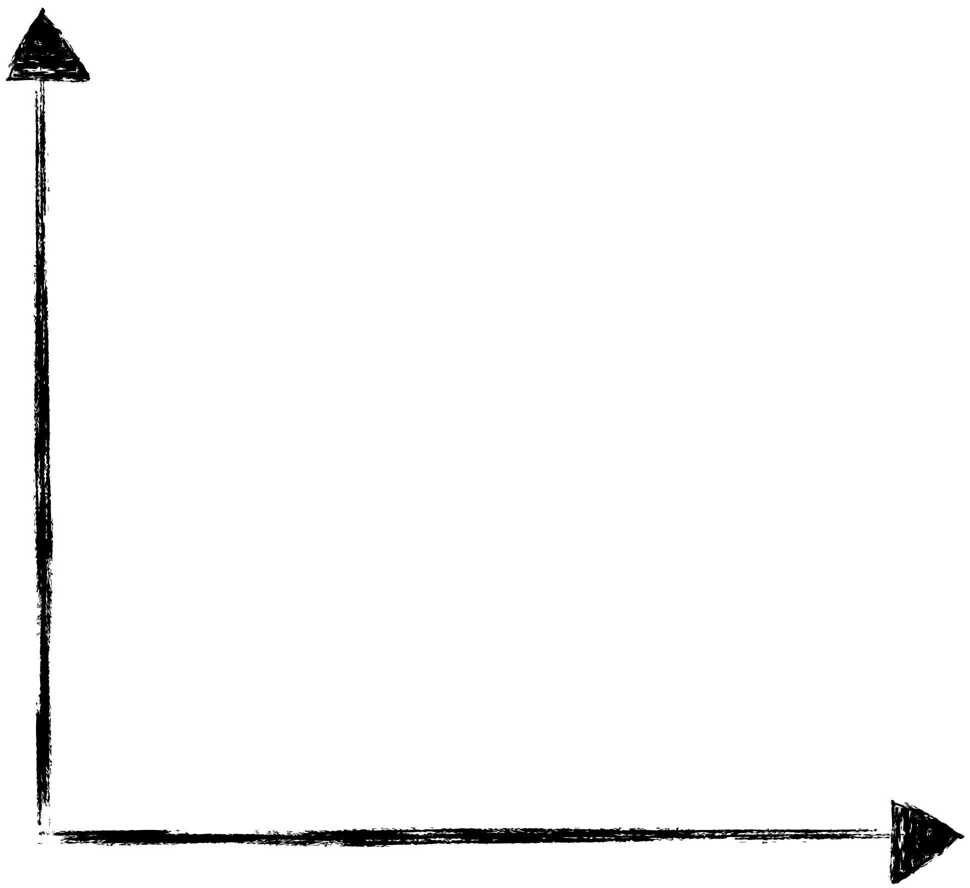

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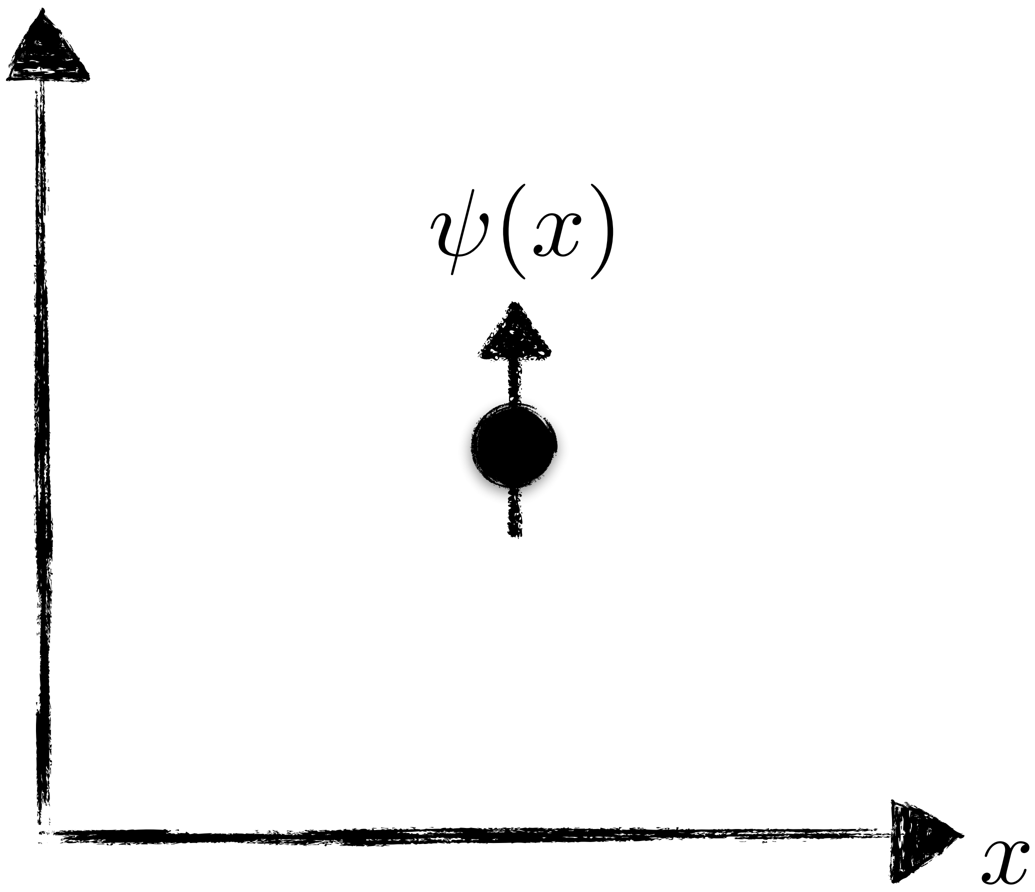

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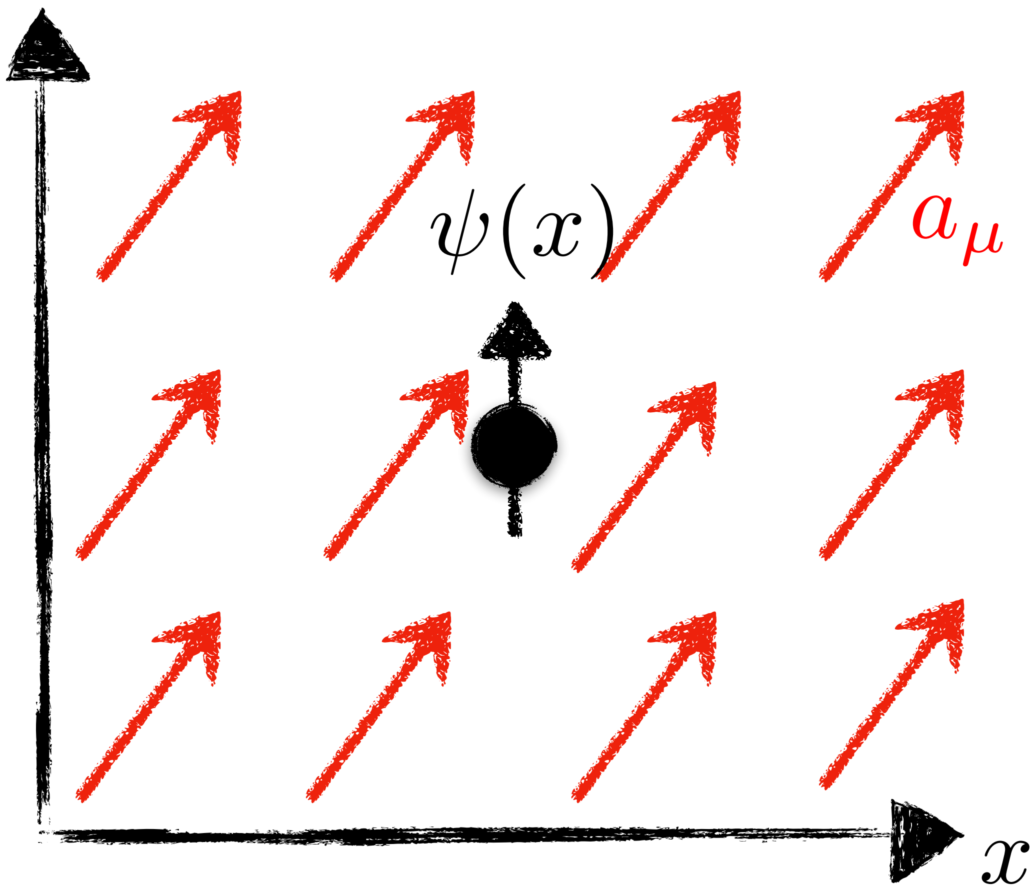

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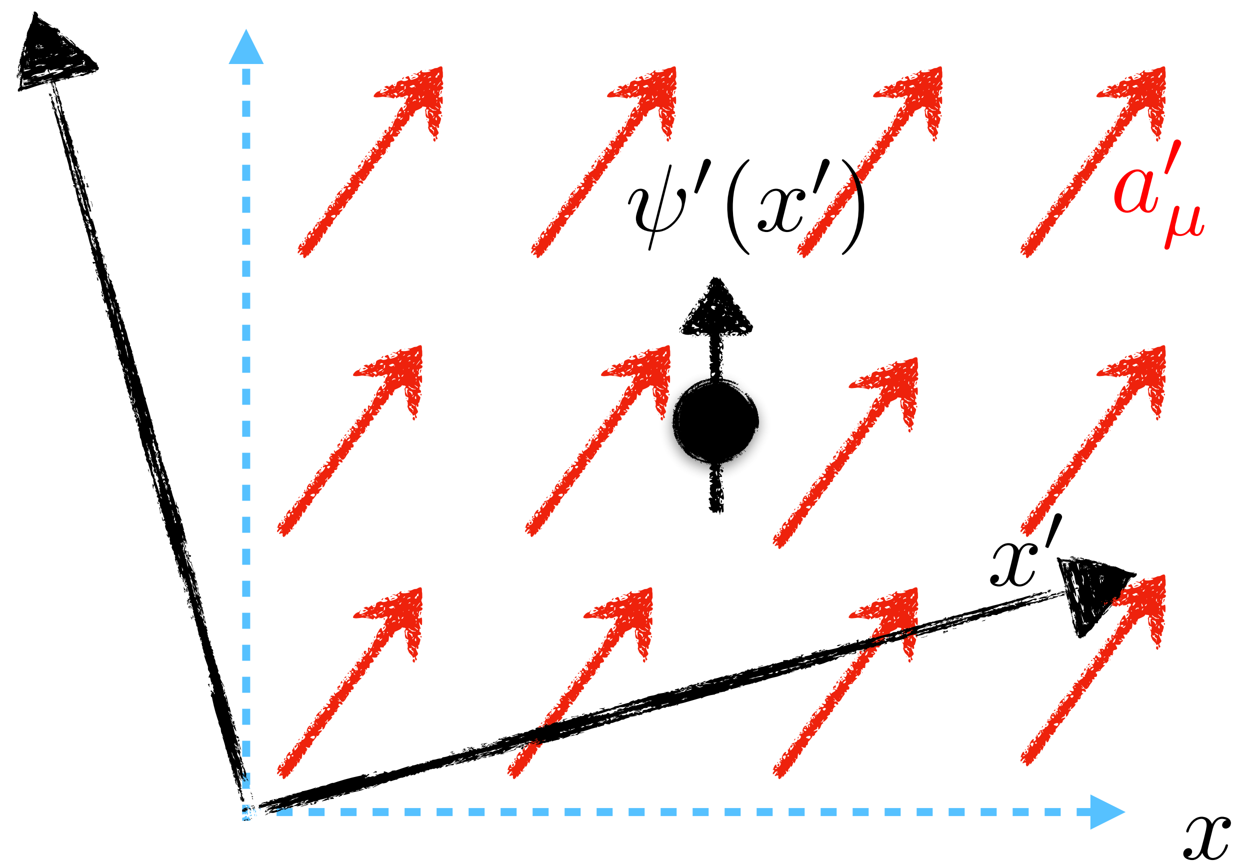

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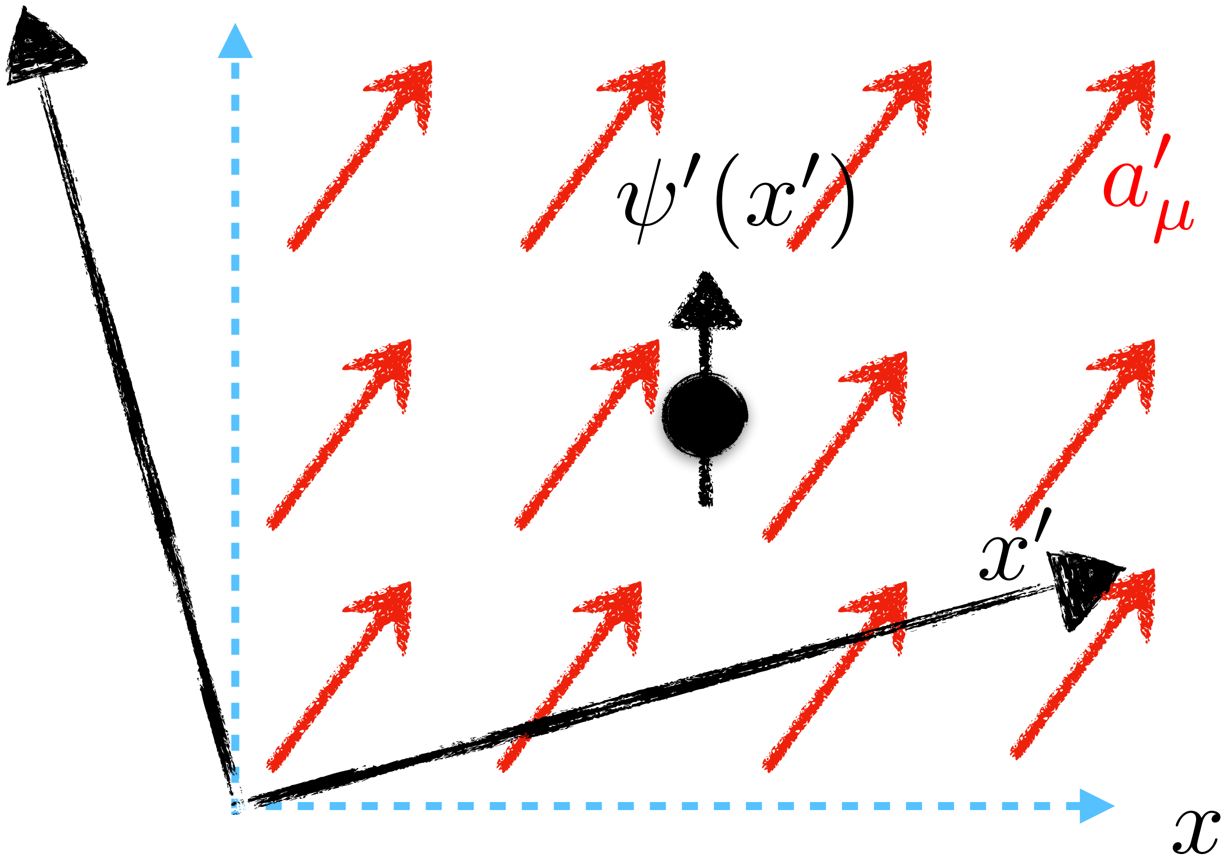

$$a^\mu \to \Lambda^\mu{}_\nu a^\nu$$

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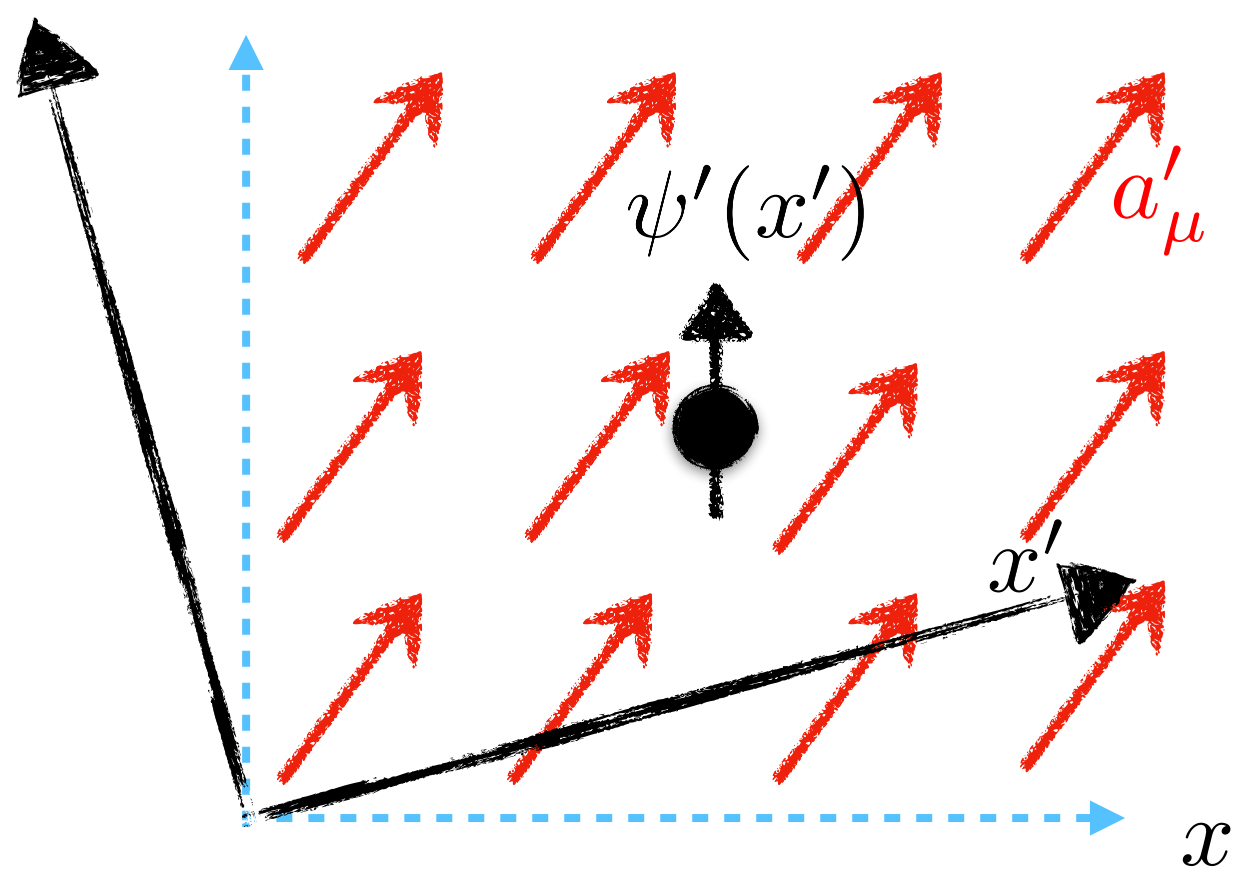

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Under an OLT the background a_μ transforms like an ordinary four vector

Hence, there is no change in the physics; the background cannot be seen by performing observer transformations (changing coordinates)

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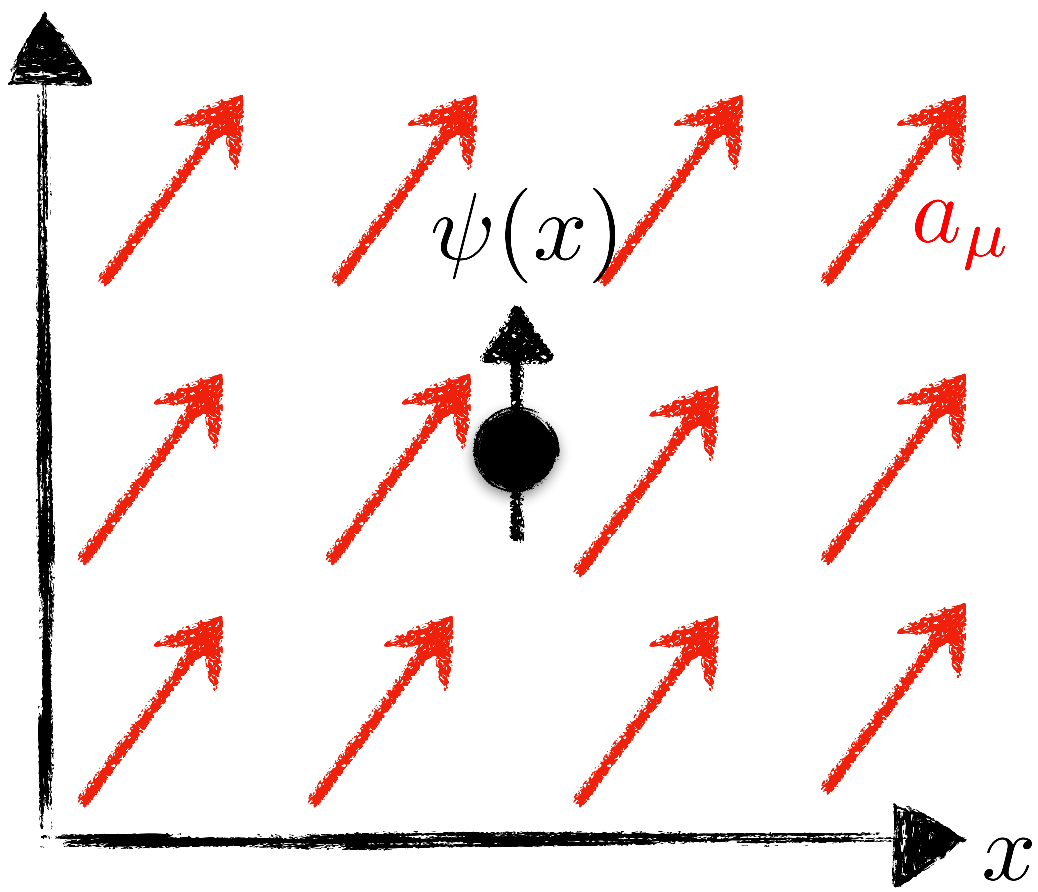

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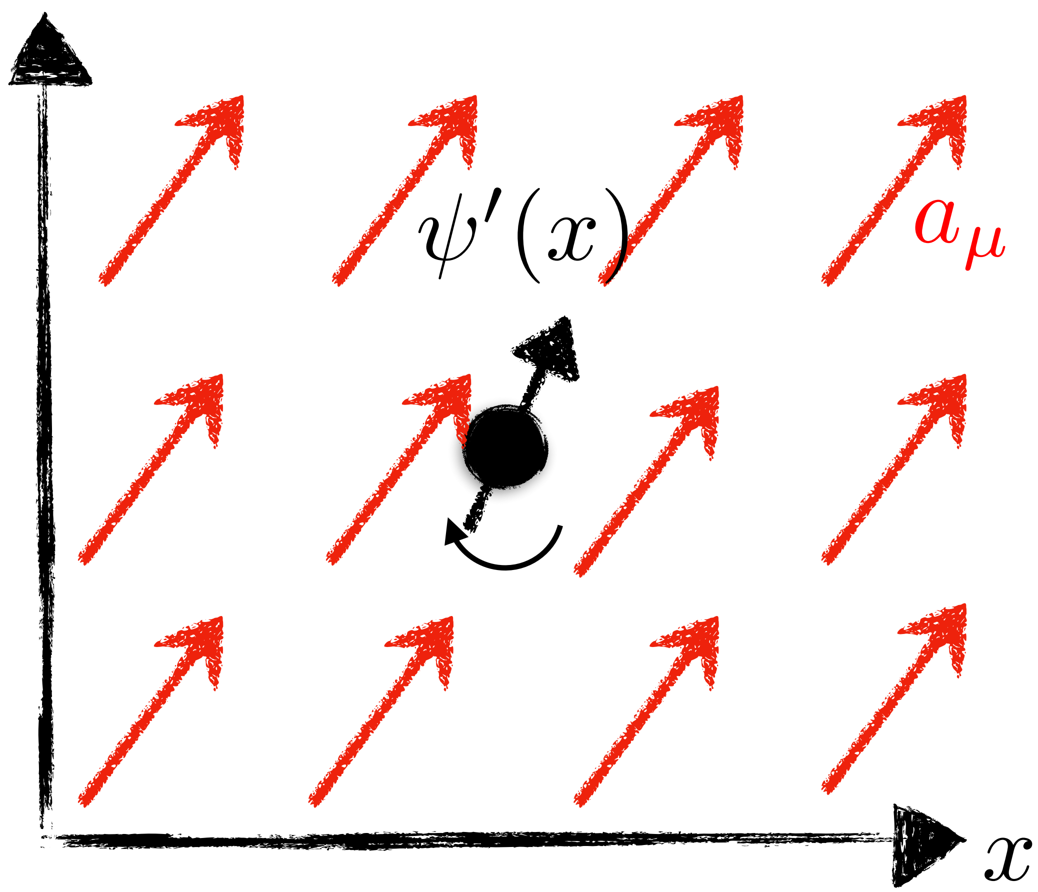

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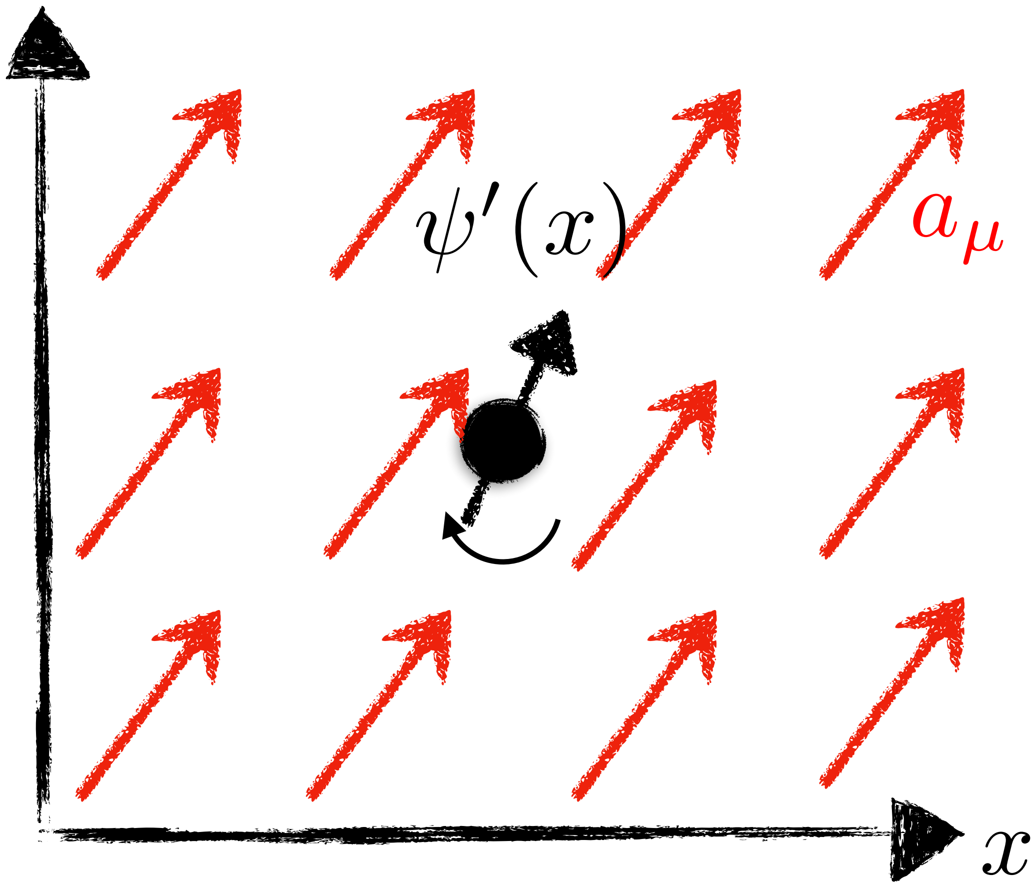

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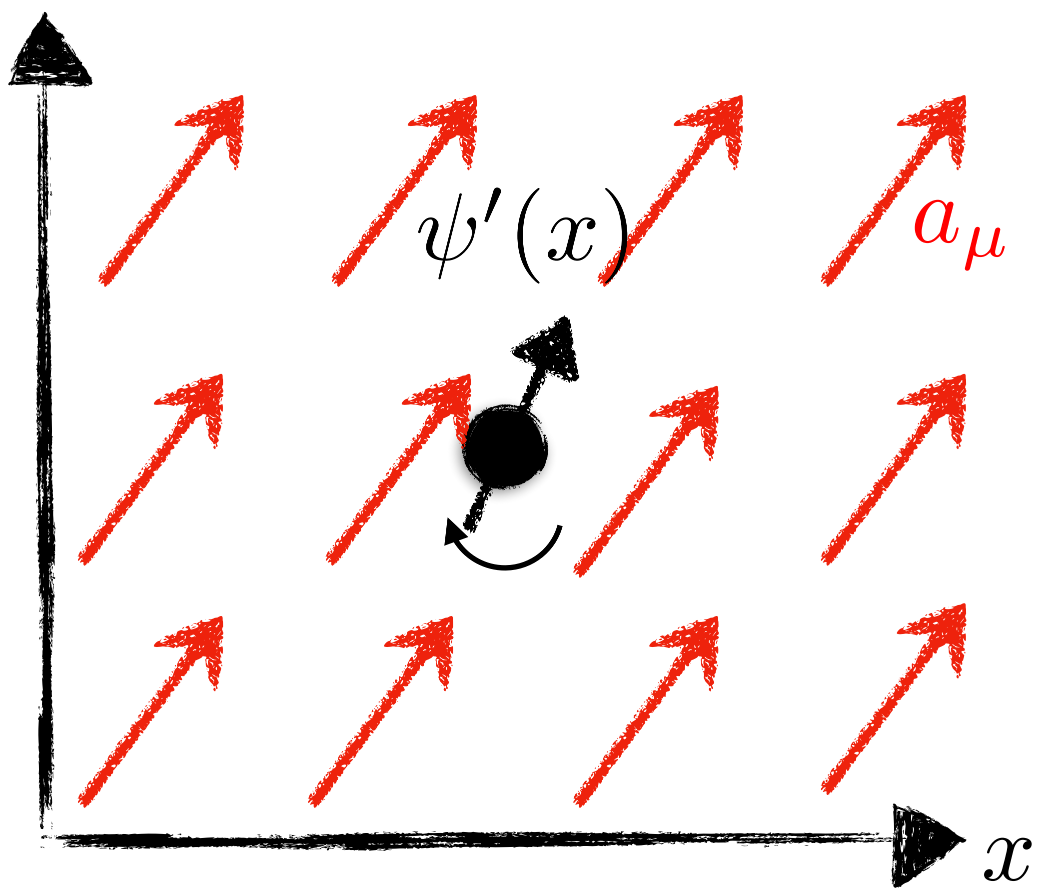

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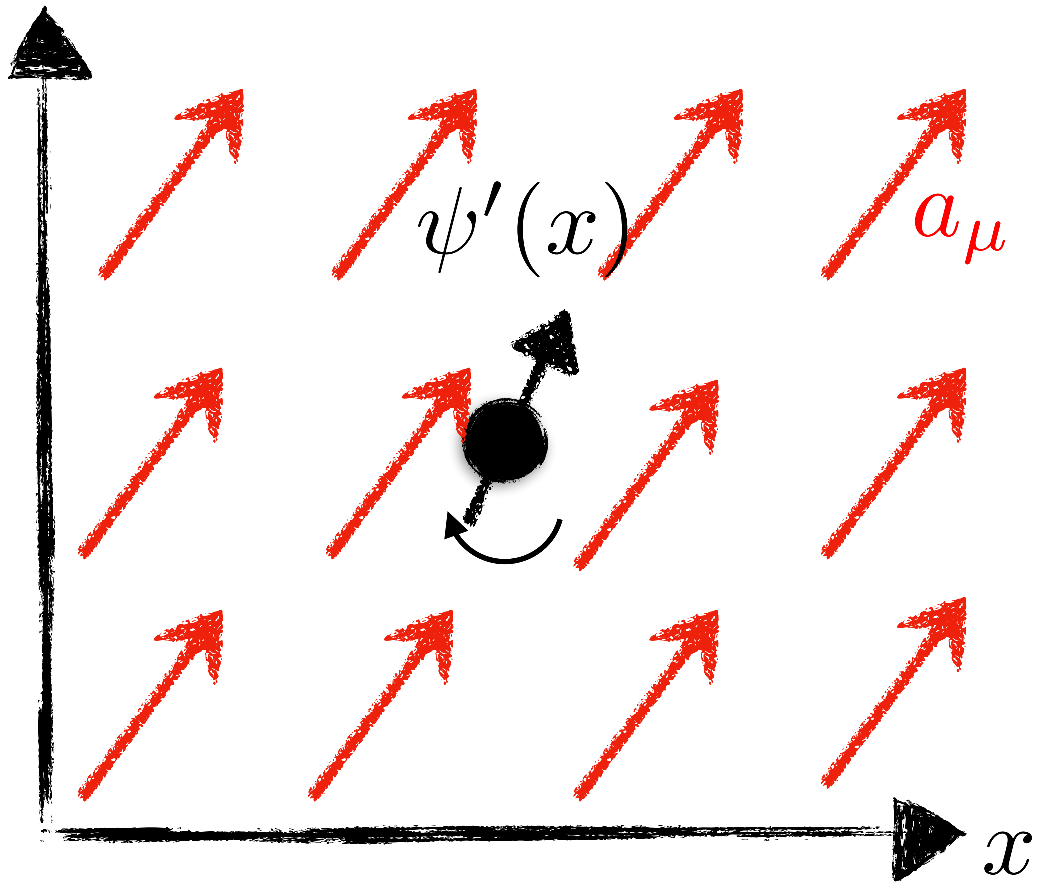

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The rotated system obeys a different physical law than the same system with rotated coordinates $\Rightarrow$ Lorentz violation!

How to search for Lorentz violation?

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We use a model-independent, effective field theory framework: the Standard-Model Extension (SME)*

*D. Colladay, V. A. Kostelecký, PRD 55, 6760 (1997); PRD 58, 1166002 (1998)
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- "Coefficients for Lorentz violation"
- Observer Lorentz tensors
- Coupling constants
- Necessarily small (perturbative)
- Experimentally accessible!

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January 2020 update of *Reviews of Modern Physics* **83**, 11 (2011) [arXiv:0801.0287]

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Combination	Result	System	Ref.
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<u>Much of the QCD sector is yet to be explored!</u>

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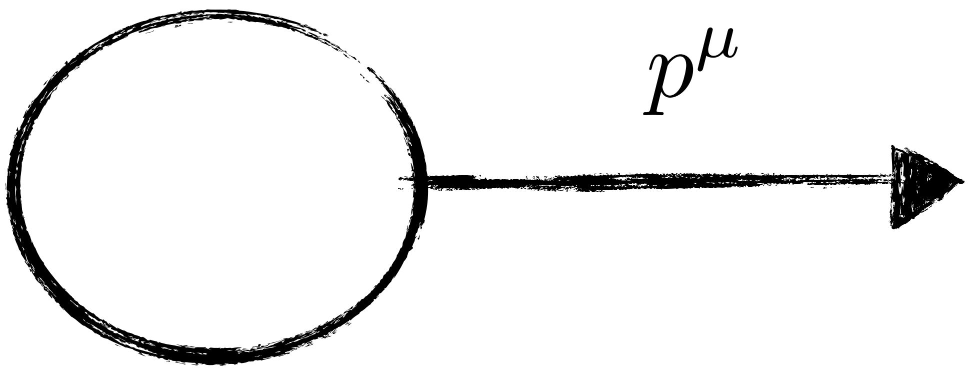

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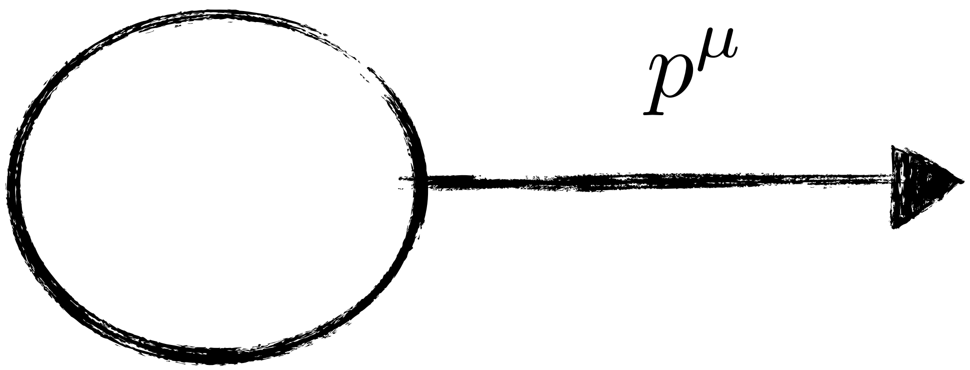

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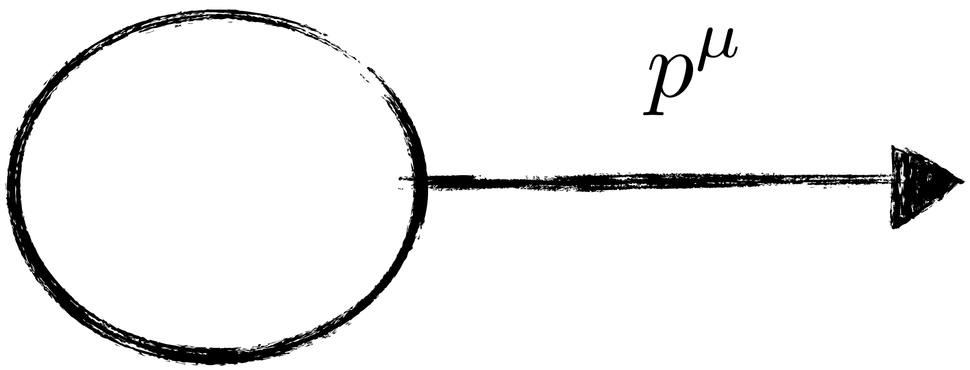

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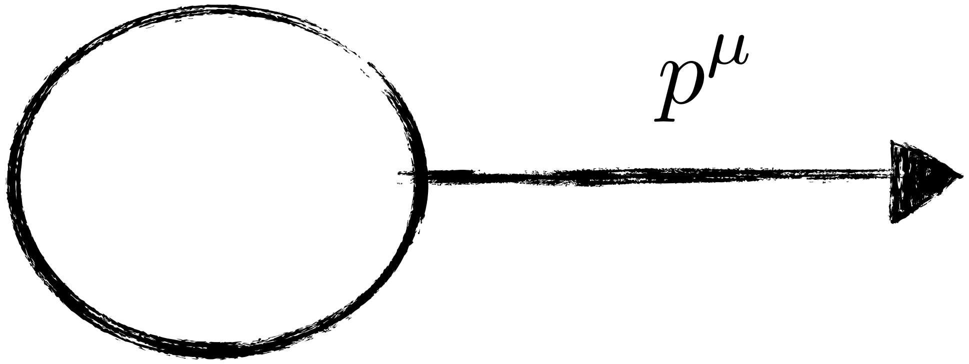

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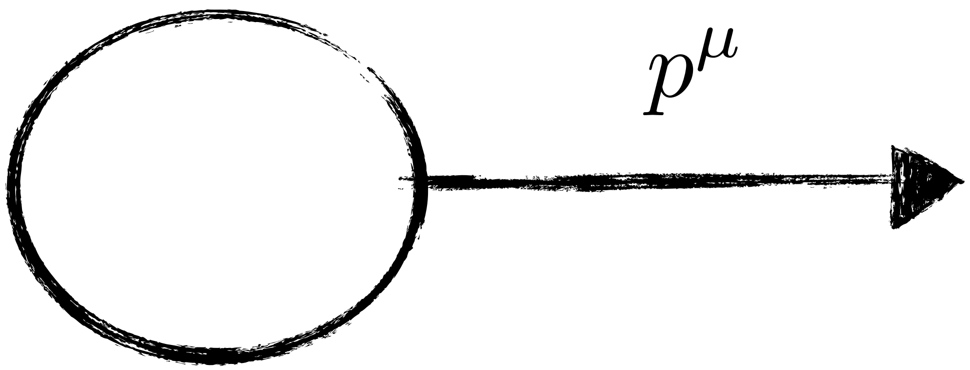

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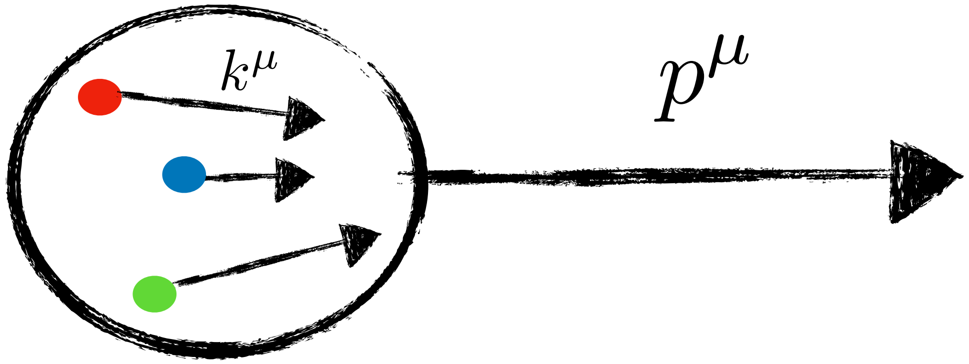

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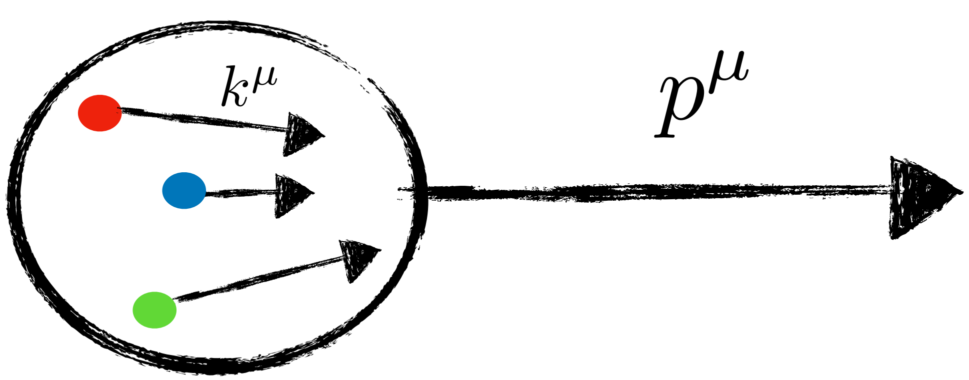

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Fraction of plus momenta is boost invariant, leading to familiar parameterization for high-energy, massless, on-shell partons within hadrons

$$\xi \equiv k^+/p^+$$

$$k^\mu = \xi p^\mu$$

Covariant expression; can be used in any frame

Quark-sector Lorentz-violating effects

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Massless quarks modified by Lorentz-violating effects

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We consider the following (spin-independent, flavor-diagonal) effects

$$\begin{aligned}\mathcal{L} = \sum_{f=u,d} \tfrac{1}{2}\bar{\psi}_f\gamma^\mu iD_\mu\psi_f &+ \tfrac{1}{2}(c_f^{(4)})^{\mu\nu}\bar{\psi}_f\gamma_\mu iD_\nu\psi_f \\ &- (a_f^{(5)})^{\mu\alpha\beta}\bar{\psi}_f\gamma_\mu iD_{(\alpha}iD_{\beta)}\psi_f + \text{h.c.}\end{aligned}$$

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Modified Dirac equation

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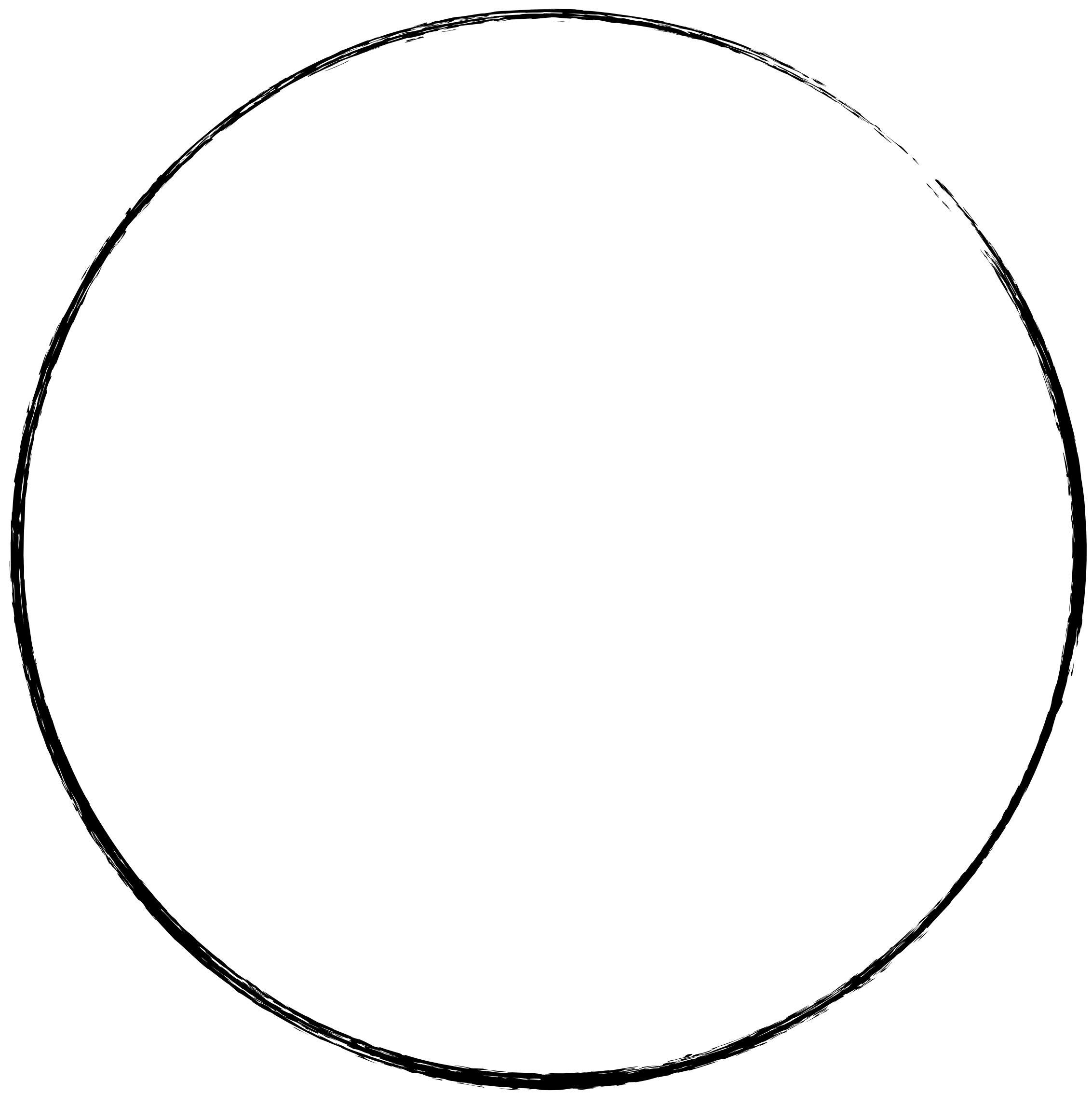
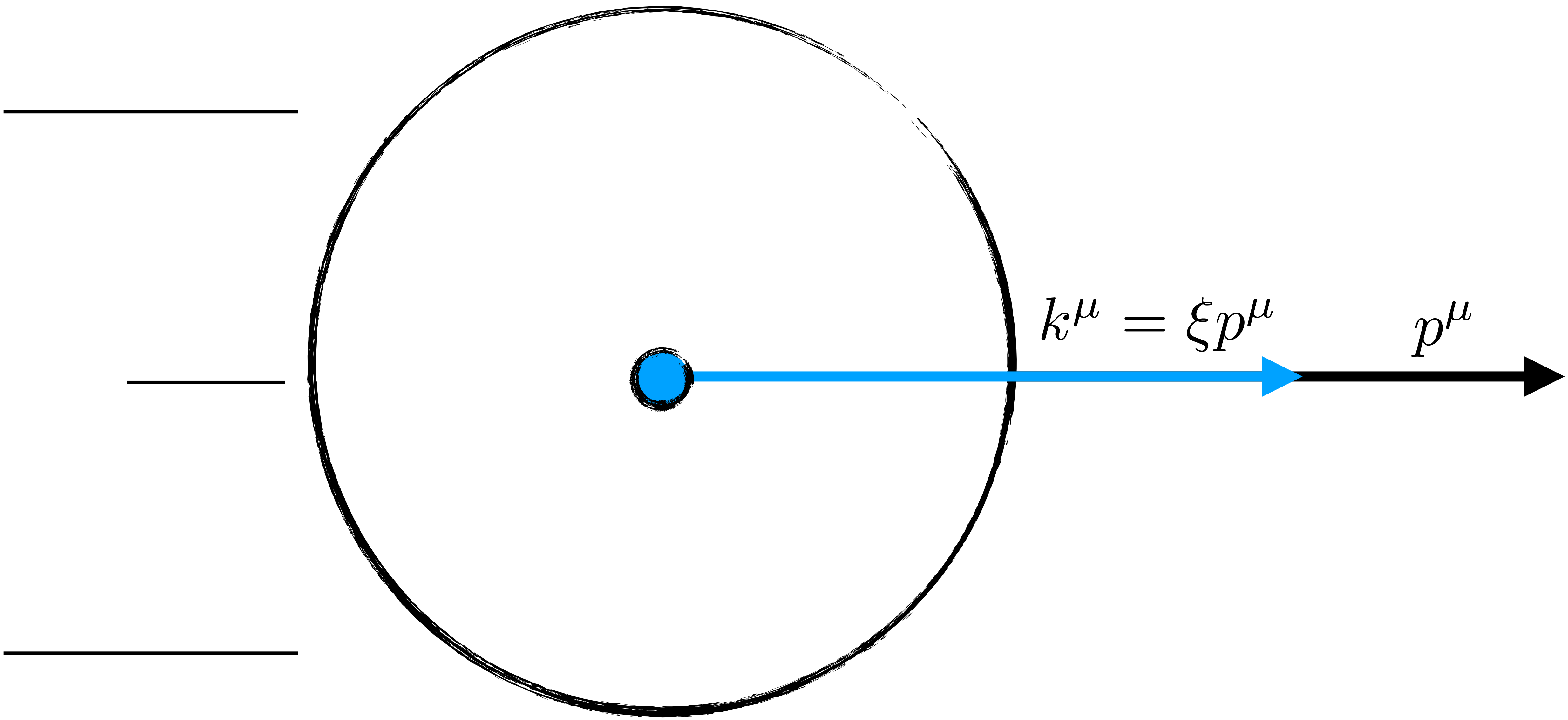
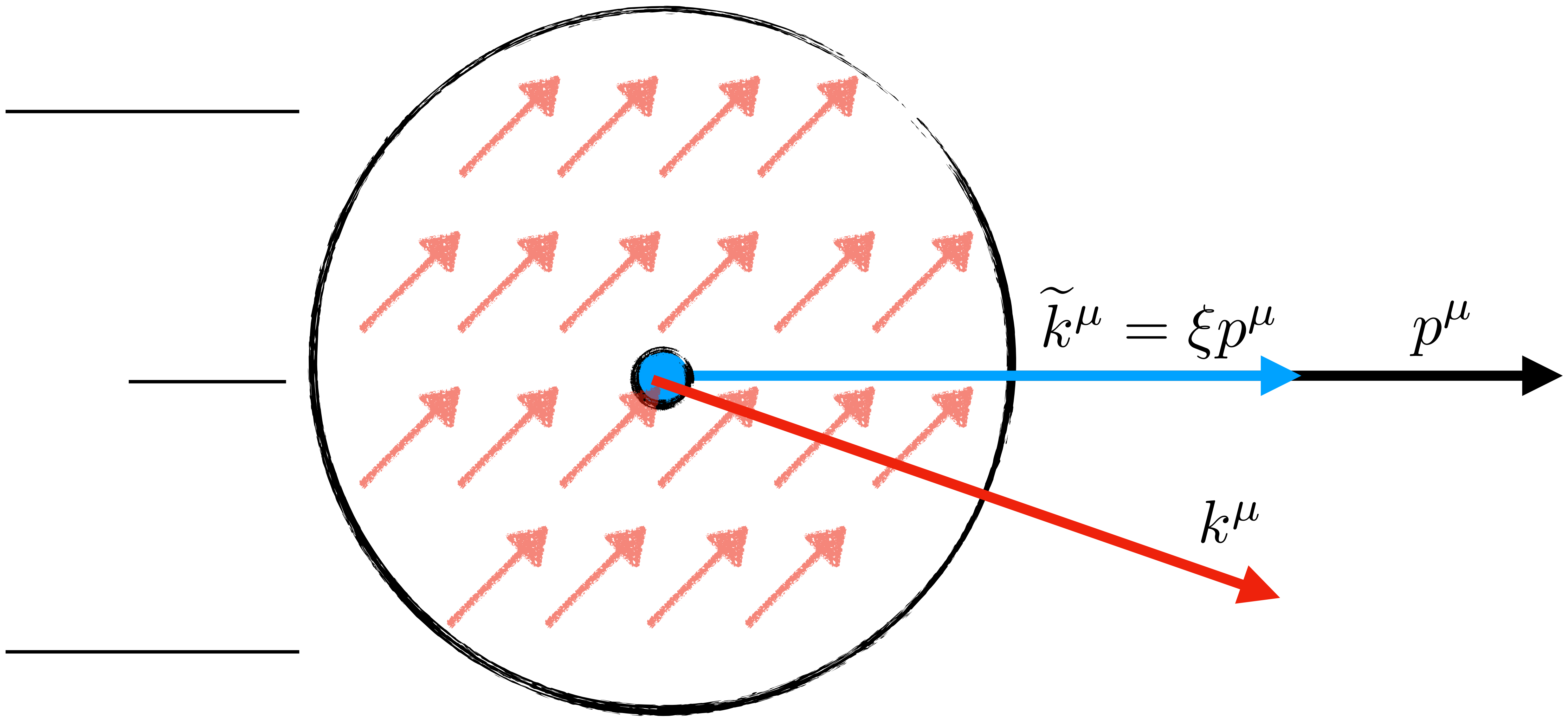
Instead, for a covariant definition to be retained $\widetilde{k}^\mu = \xi p^\mu$





$k^{\mu} = \xi p^{\mu}$
p^{μ}



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Application I: deep inelastic scattering (DIS)

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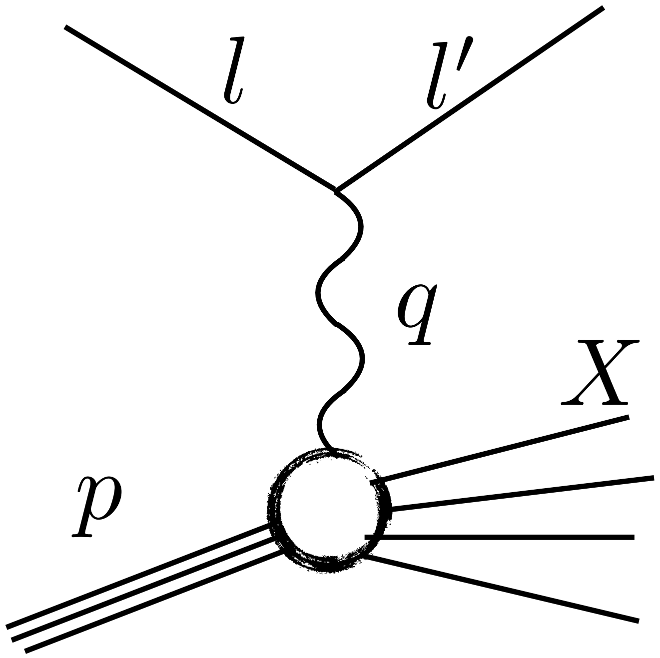

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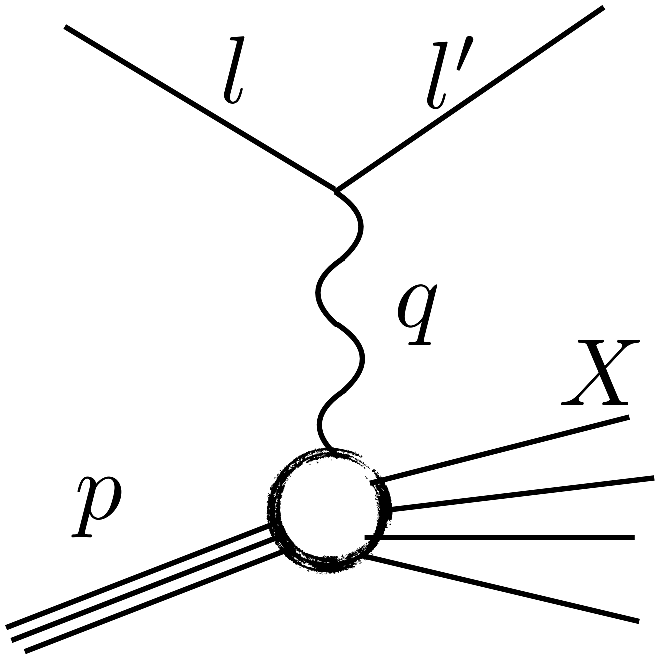

$$T_{\mu\nu} = i \int d^4 w e^{iq\cdot w} \langle p, s | \mathrm{T} j_\mu^\dagger(w) j_\nu(0) | p, s \rangle_c$$

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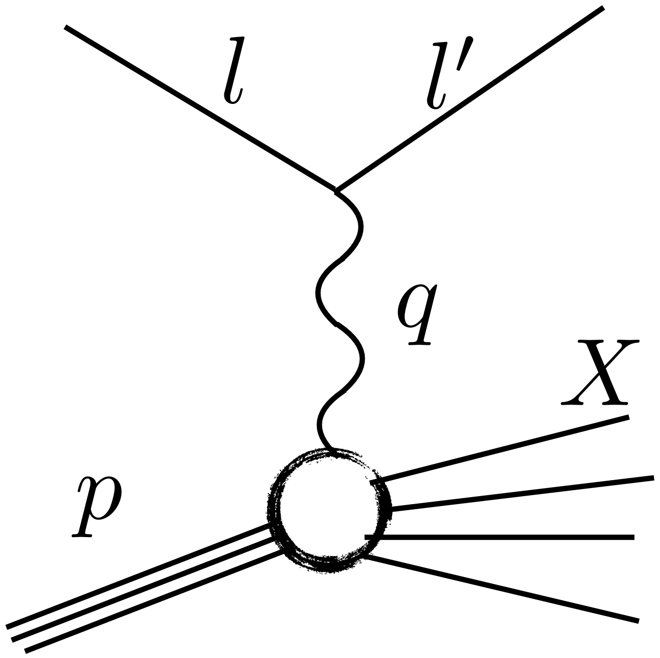

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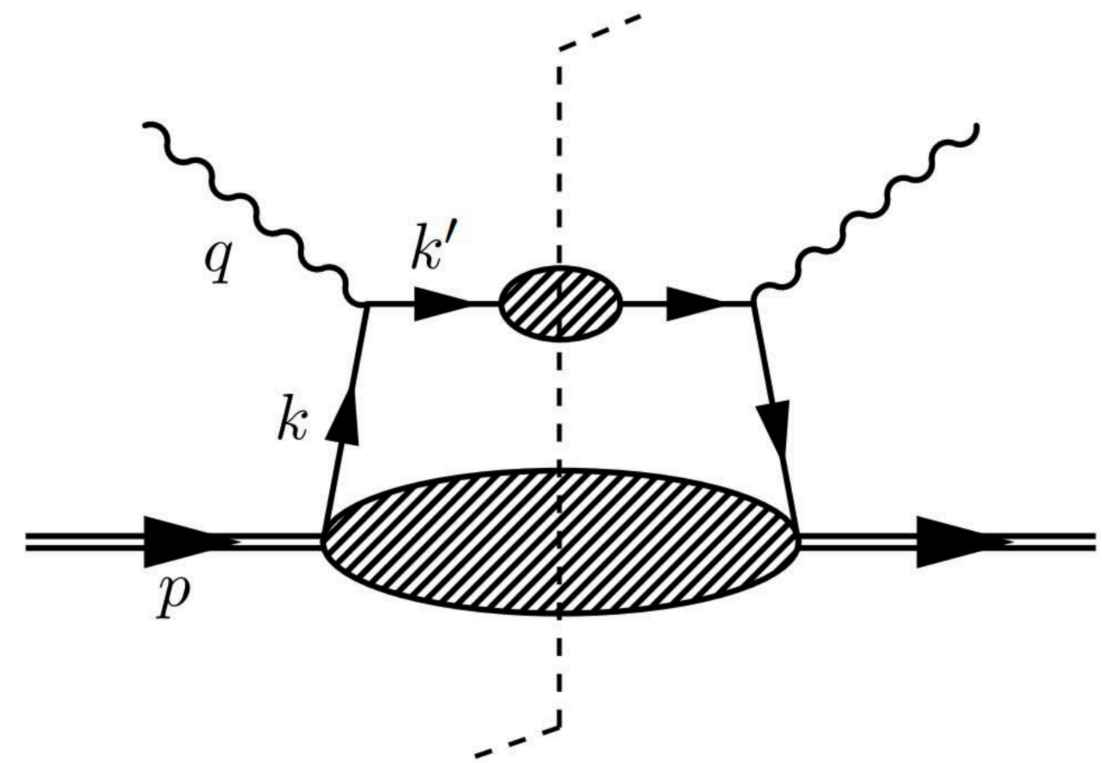

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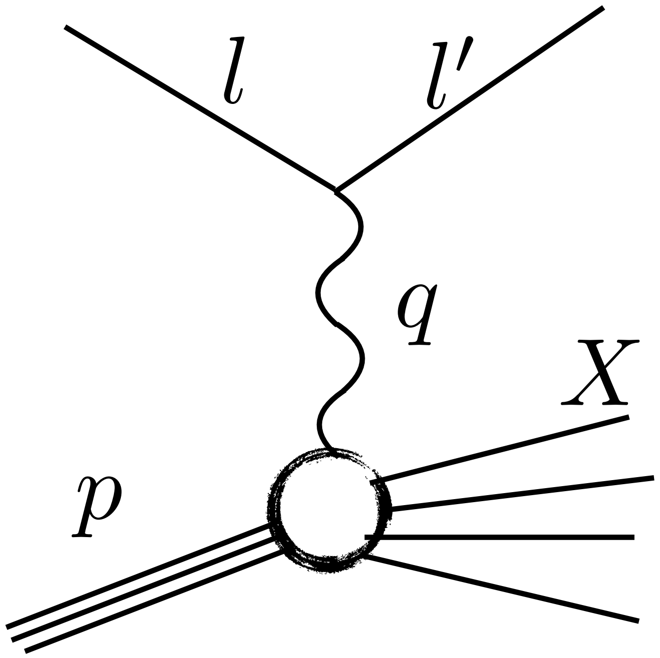

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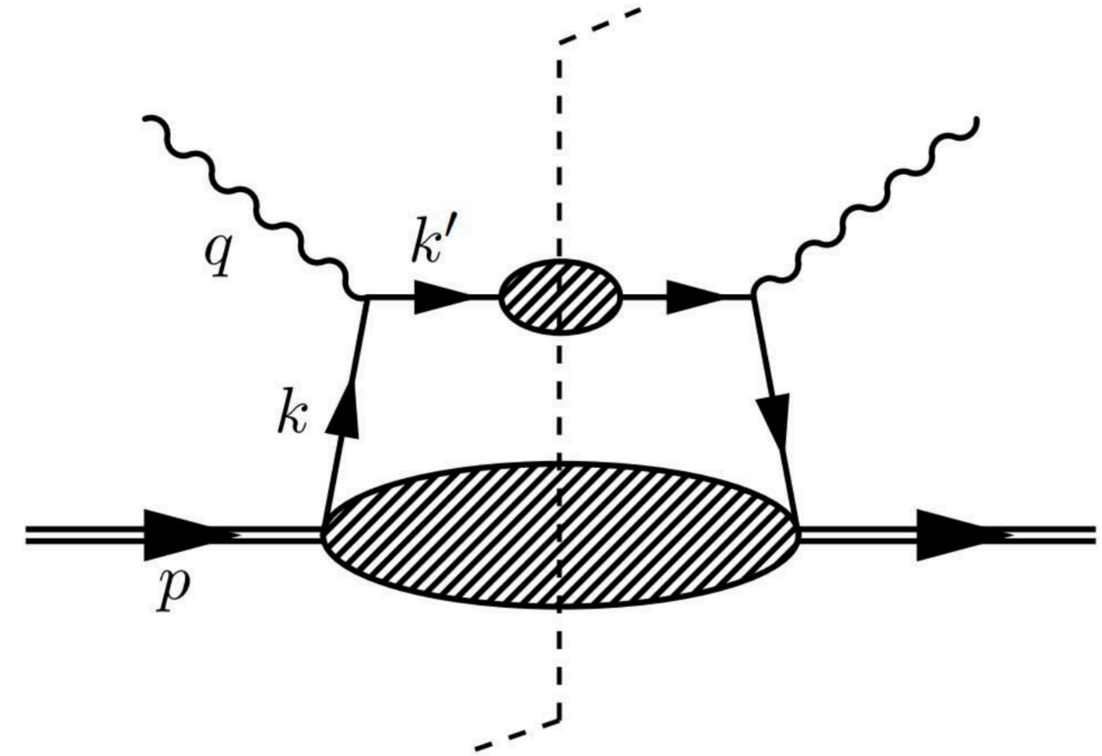

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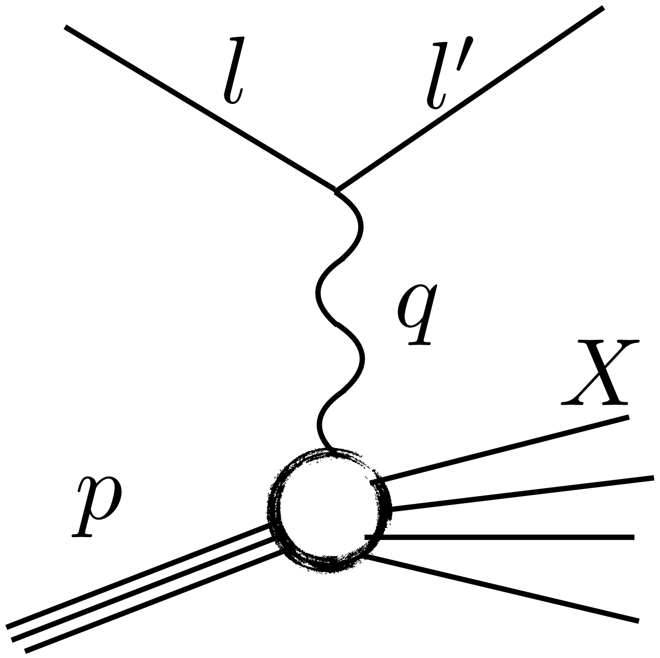

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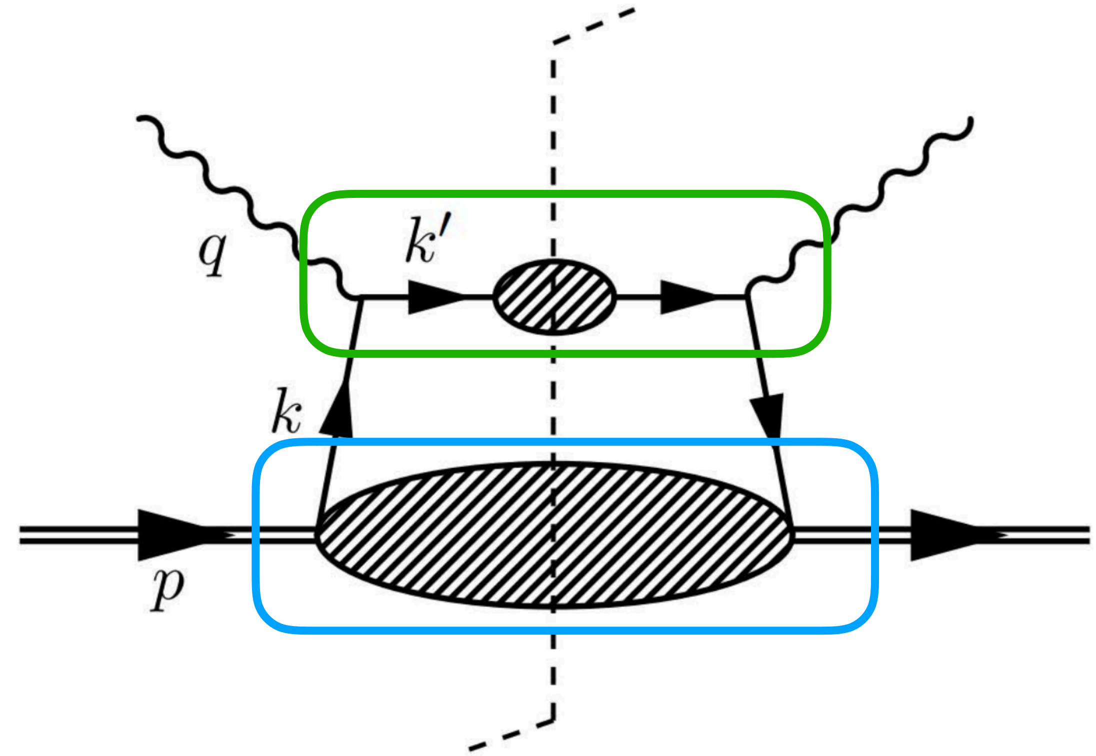

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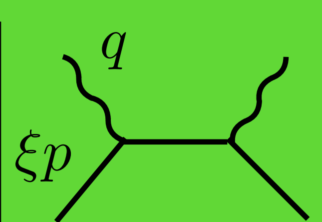

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- kinematical corrections
- radiative effects

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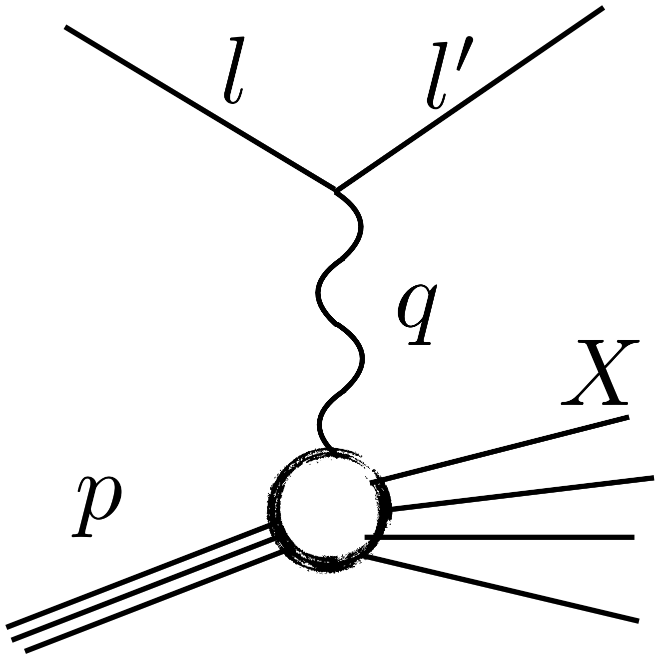

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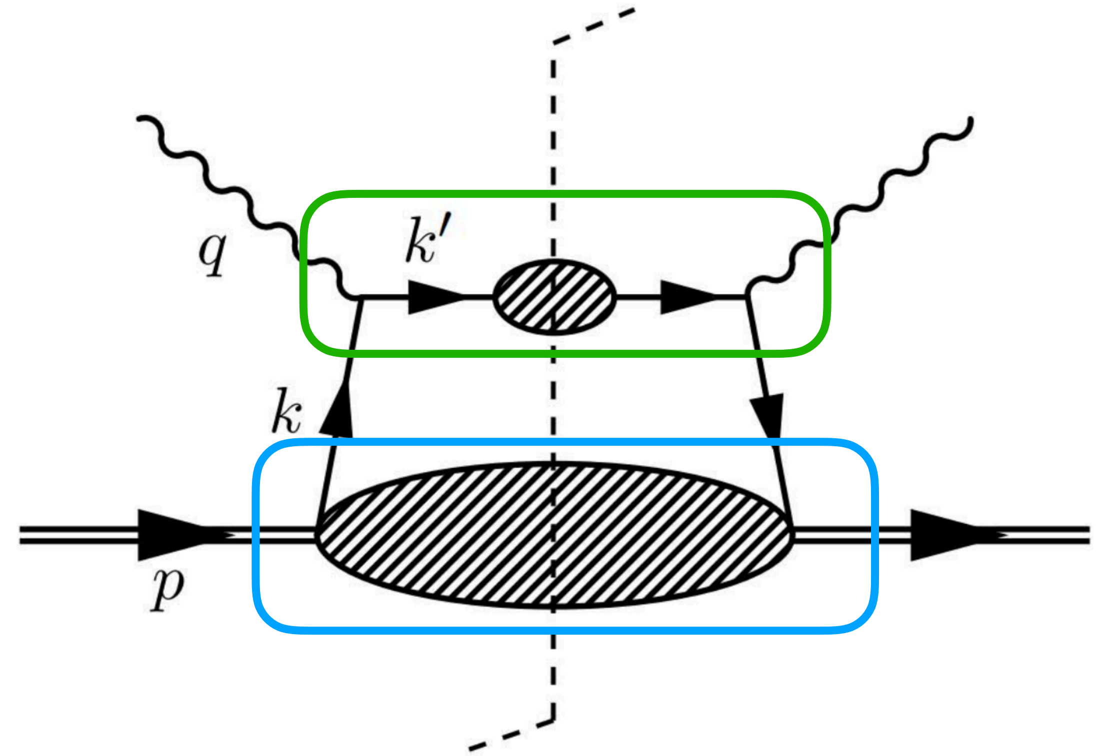

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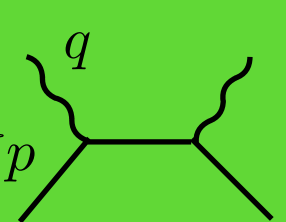
$\sim \left| \right.$  $\left. \right|^2 + \cdots$

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What happens when Lorentz violation is present?

Application I: deep inelastic scattering (DIS)

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In the presence of Lorentz violation, factorization occurs in a modified Breit frame

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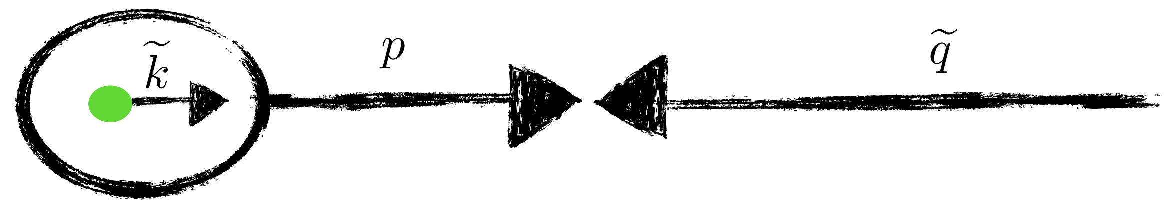

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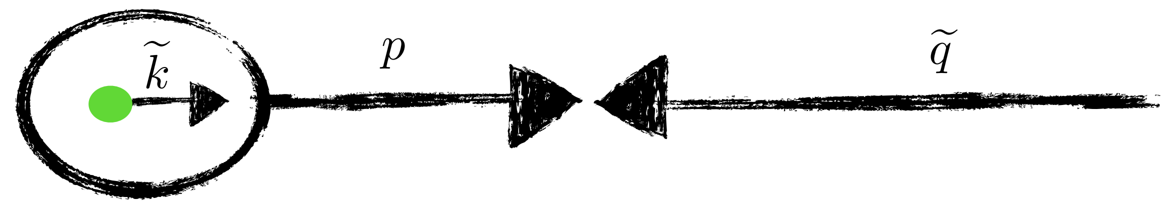

Calculate the imaginary part of internal propagator

$$\mathrm{Im}\frac{1}{\widetilde{k}^2 + i\epsilon} = -\pi\left[\delta(\widetilde{k}^2)\theta(k^0) + \delta(\widetilde{-k}^{\,2})\theta(-k^0)\right]$$

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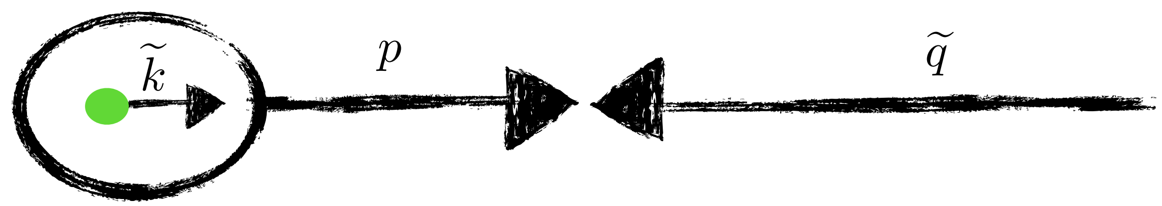

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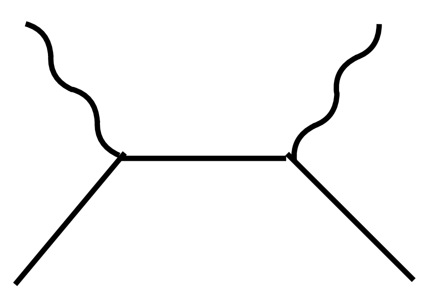
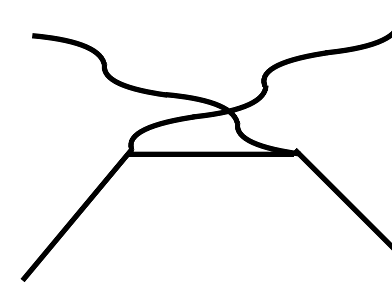
Antiquark initiated

Contributes to





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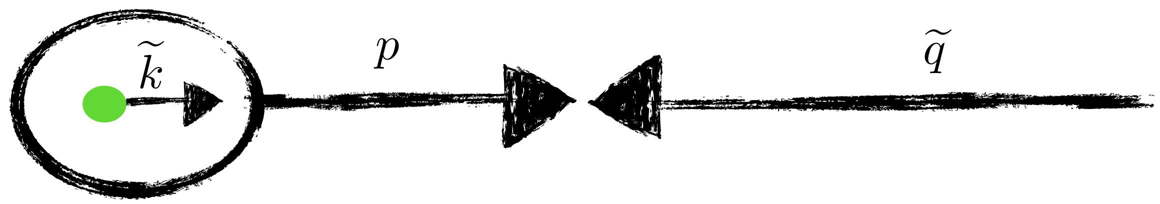

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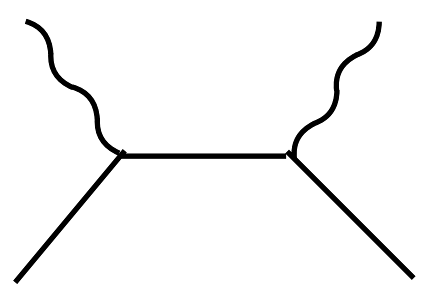

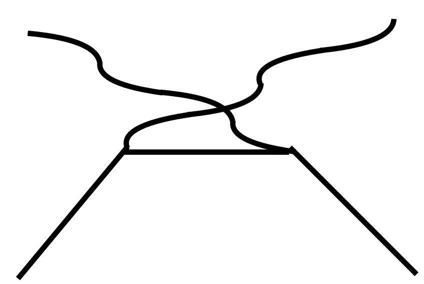

Will focus on quark contribution

Application I: deep inelastic scattering (DIS)

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Example: $\mathcal{L}_c \supset \frac{1}{2} c_f^{\mu\nu} \bar{\psi}_f(x) i\gamma_\mu \overleftrightarrow{\partial}_\nu \psi_f(x)$

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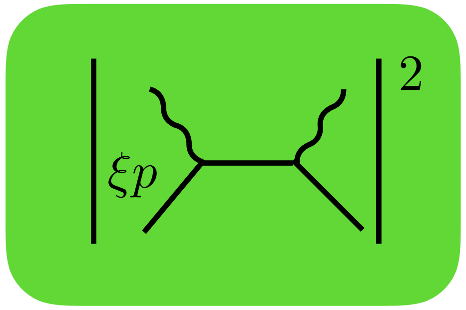

$$\sim \quad \mathrm{Tr}\left[(\gamma^\mu + c_f^{\alpha\mu}\gamma_\alpha)\frac{1}{(\xi p^\alpha + q^\alpha + c_f^{\alpha\beta} q_\beta)\gamma_\alpha + i\epsilon}(\gamma^\nu + c_f^{\alpha\nu}\gamma_\alpha)\gamma_\beta \xi p^\beta\right]$$

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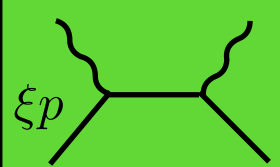
$\Bigg|$  $\Bigg|^2$

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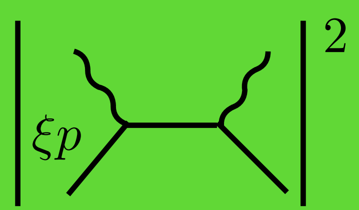

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$\langle$hadron$|\Gamma^+|$hadron$\rangle$ $\sim \quad f_f(\xi, \cdots) = \int \frac{d\lambda}{2\pi} e^{-i\xi p\cdot n\lambda} \langle p|\bar{\psi}(\lambda \widetilde{n}_f)\frac{\gamma_\mu n^\mu}{2}\psi(0)|p\rangle$

$\widetilde{n}_f \rightarrow n^\mu + c_f^{\mu\alpha} n_\alpha$

"Shifted" conventional scenario

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Using data from HERA, the LHC, and the future electron-ion collider (EIC) we obtain *estimates* on the sensitivity to the coefficients of interest

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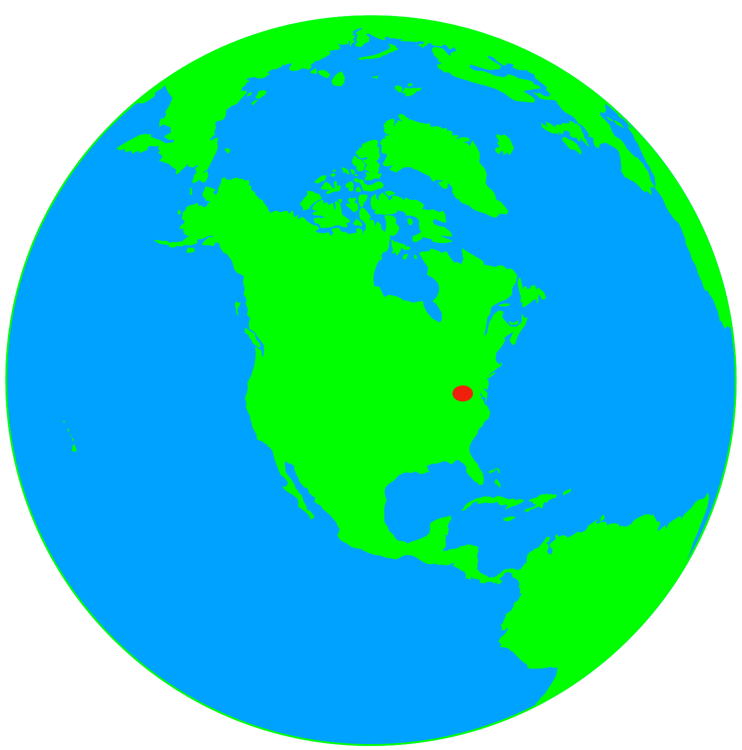

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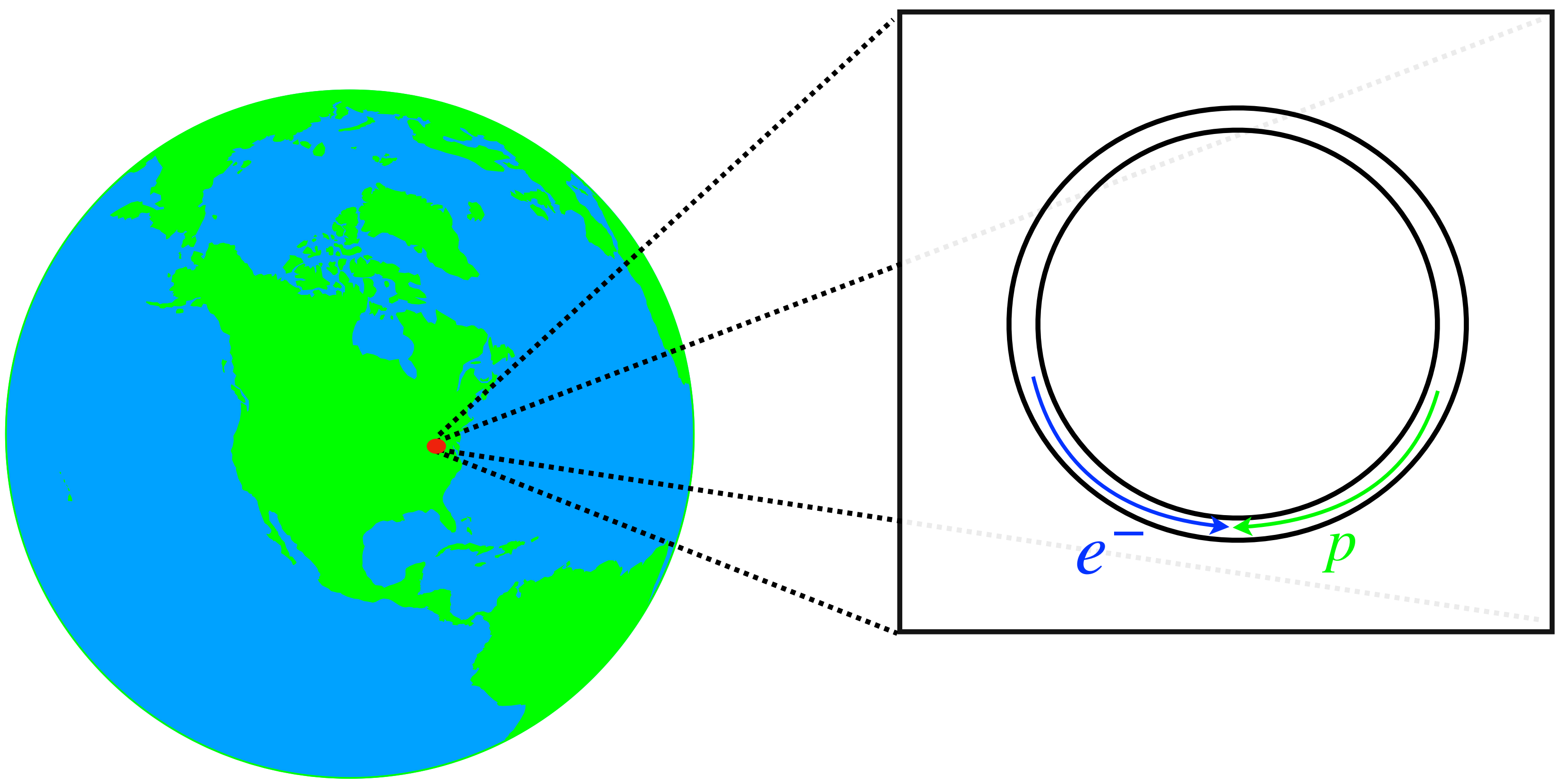

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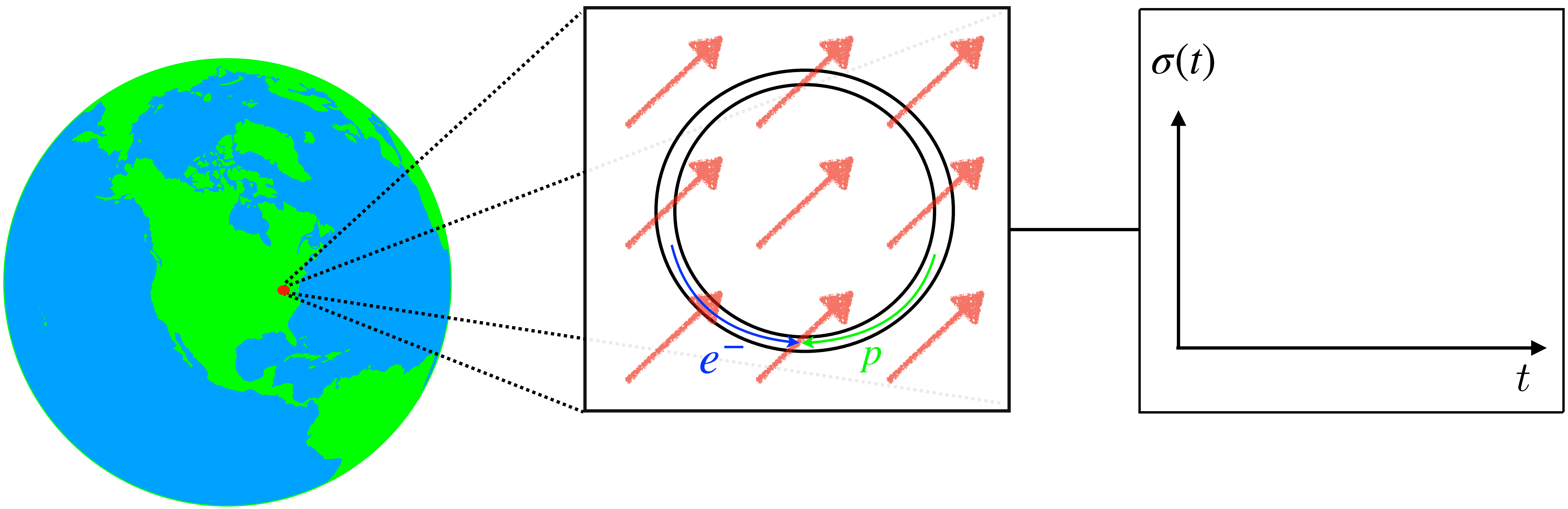

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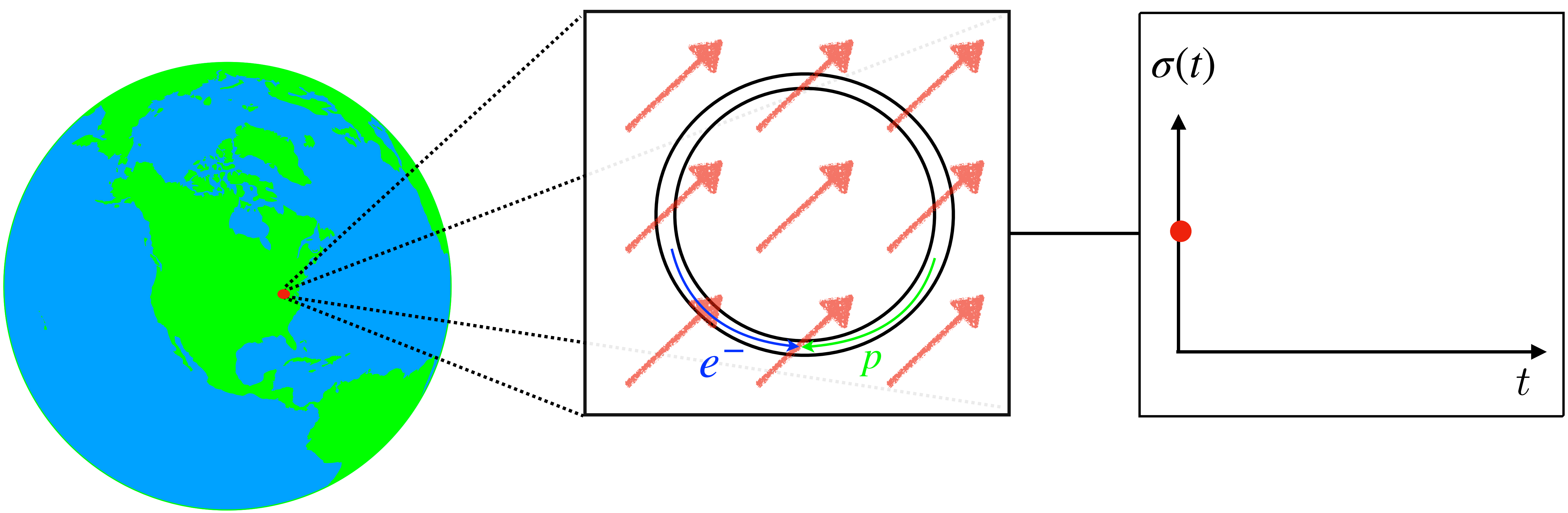

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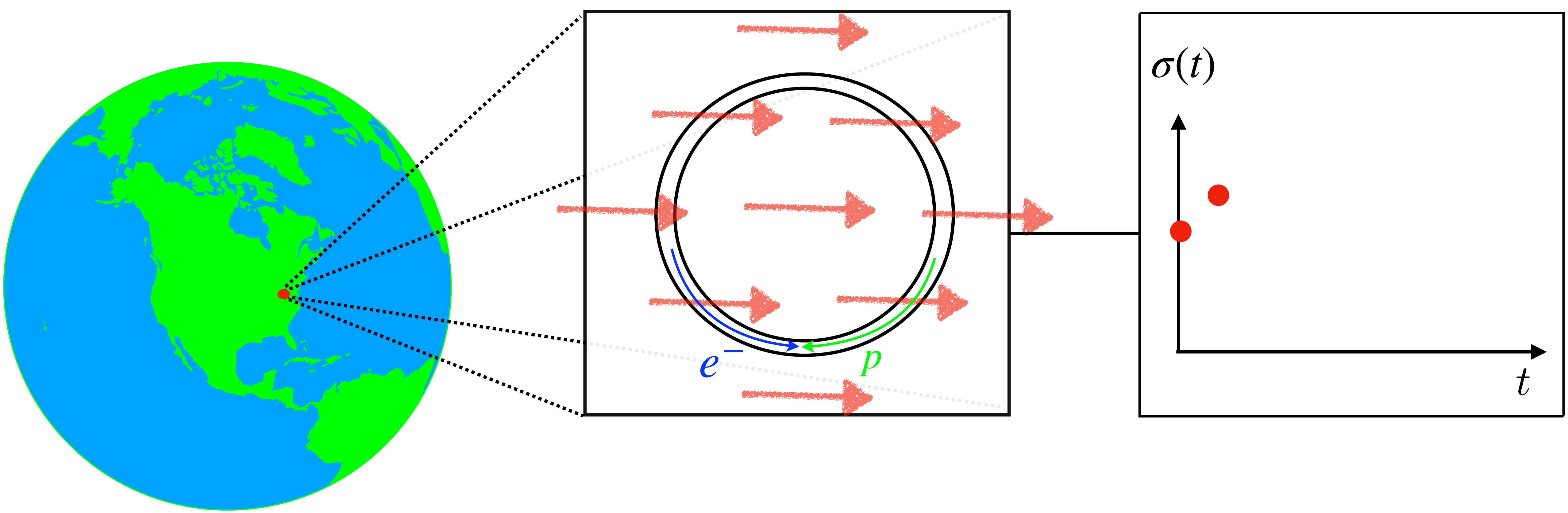

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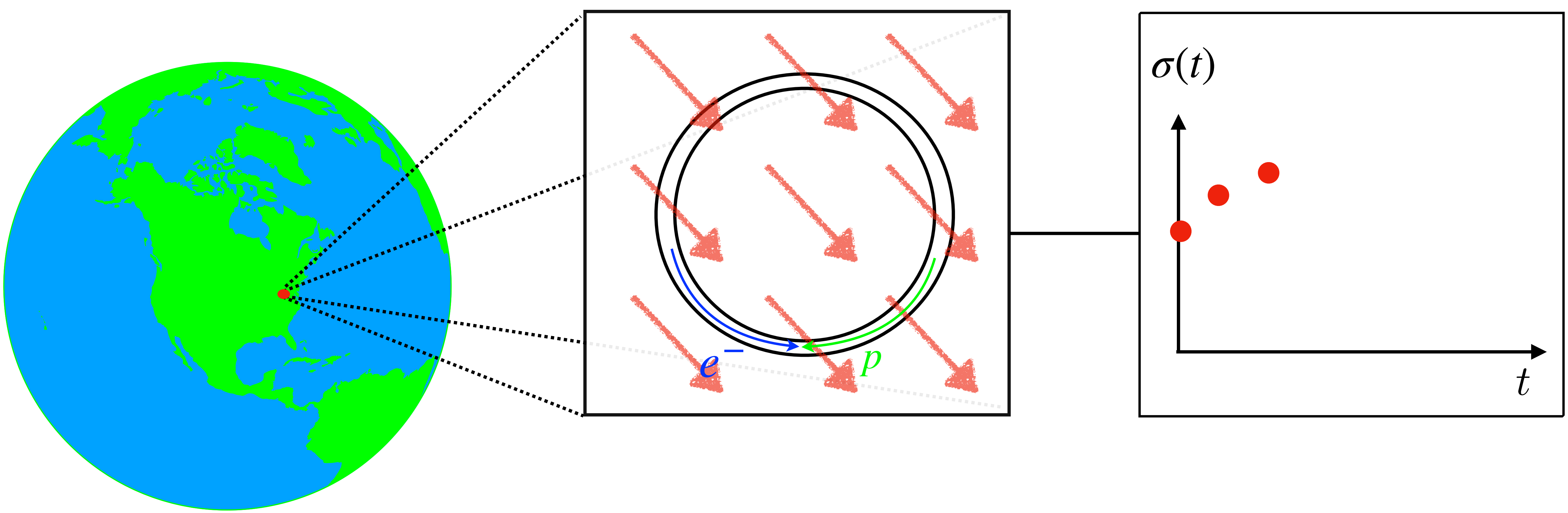

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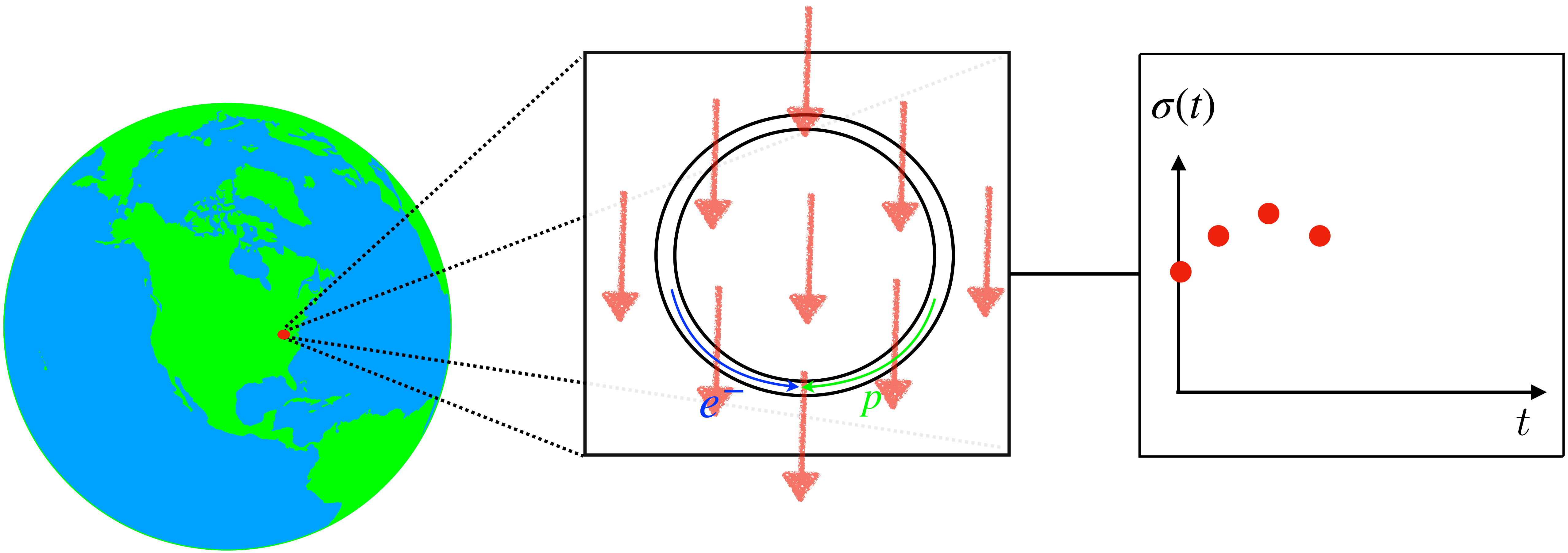

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Technique relies on coefficient combinations that exhibit sidereal time dependence

$\sim$ **23 hrs 56 mins**

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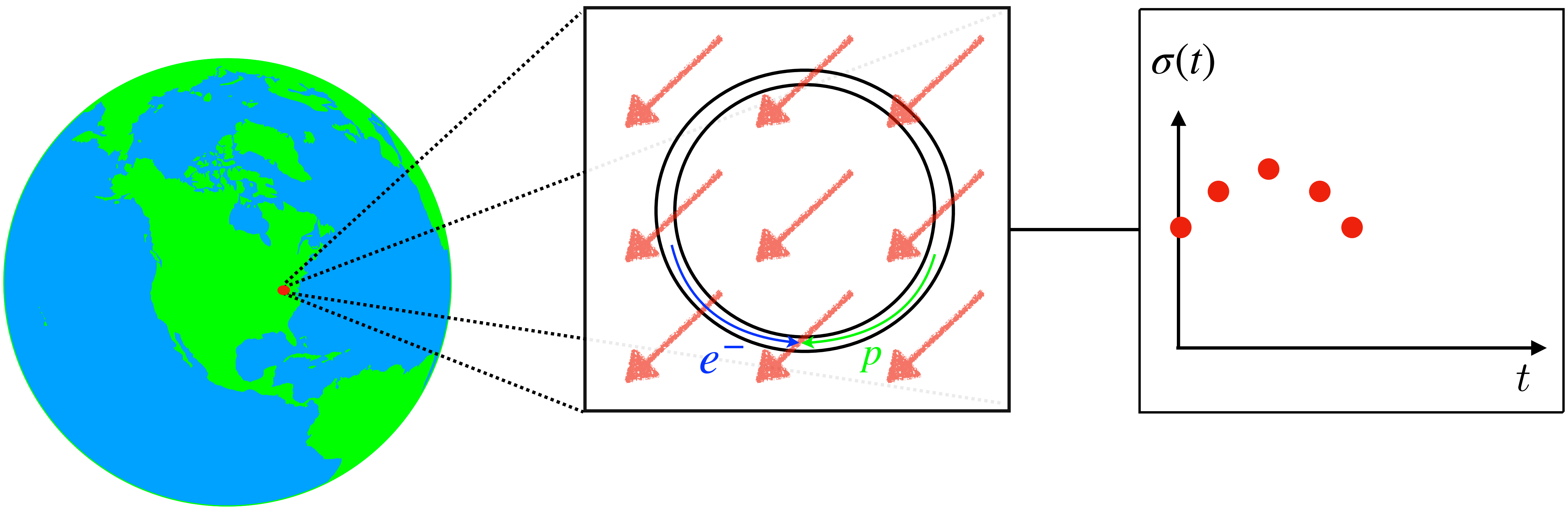

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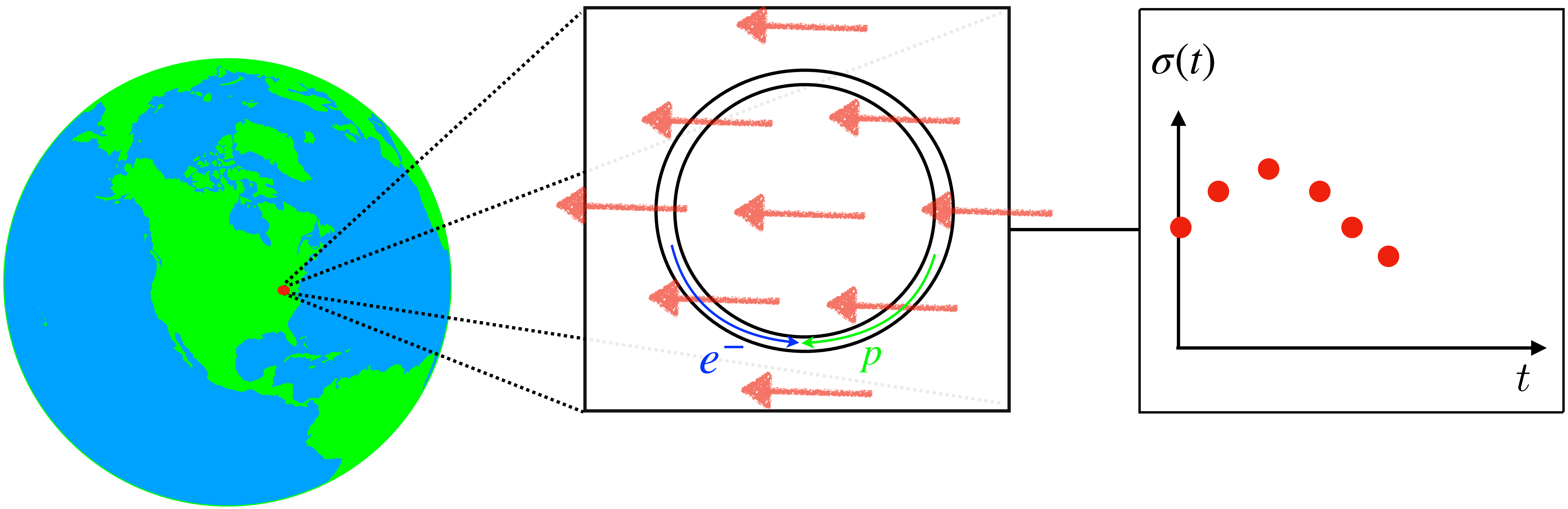

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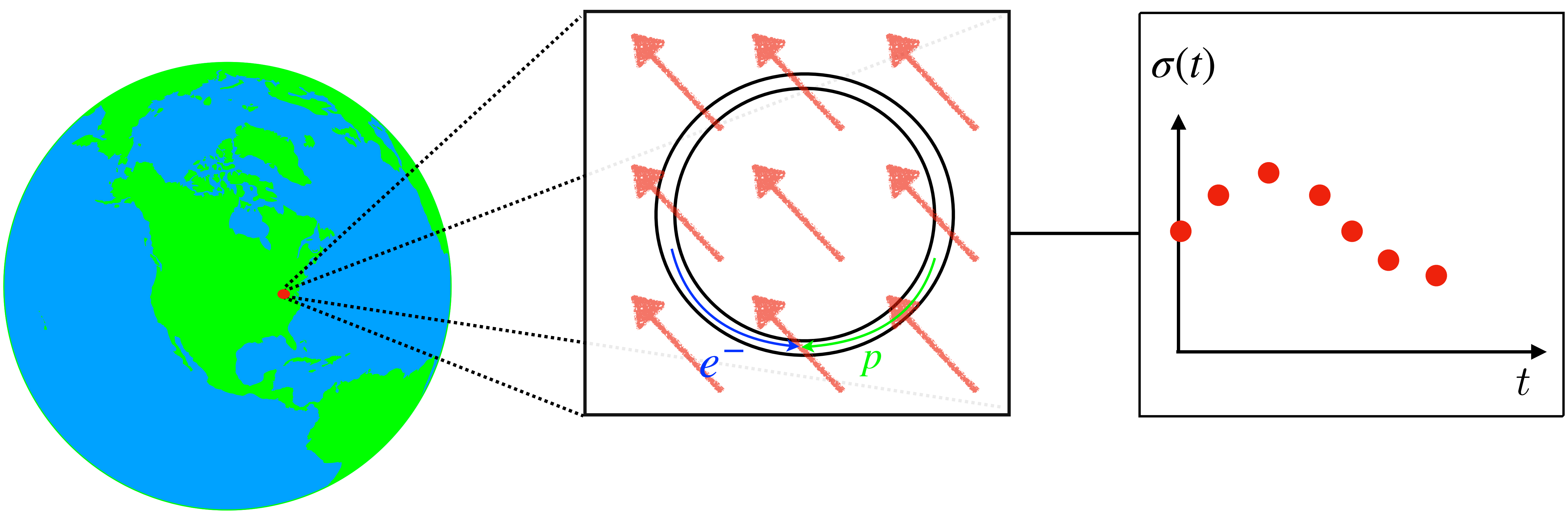

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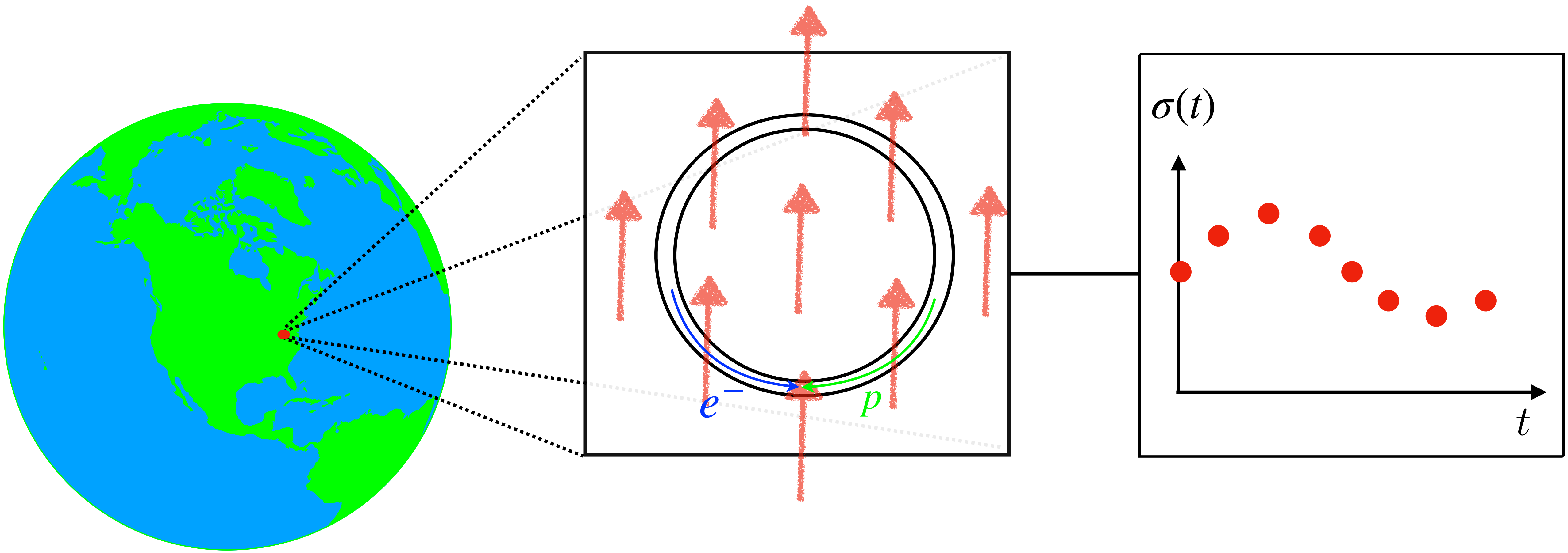

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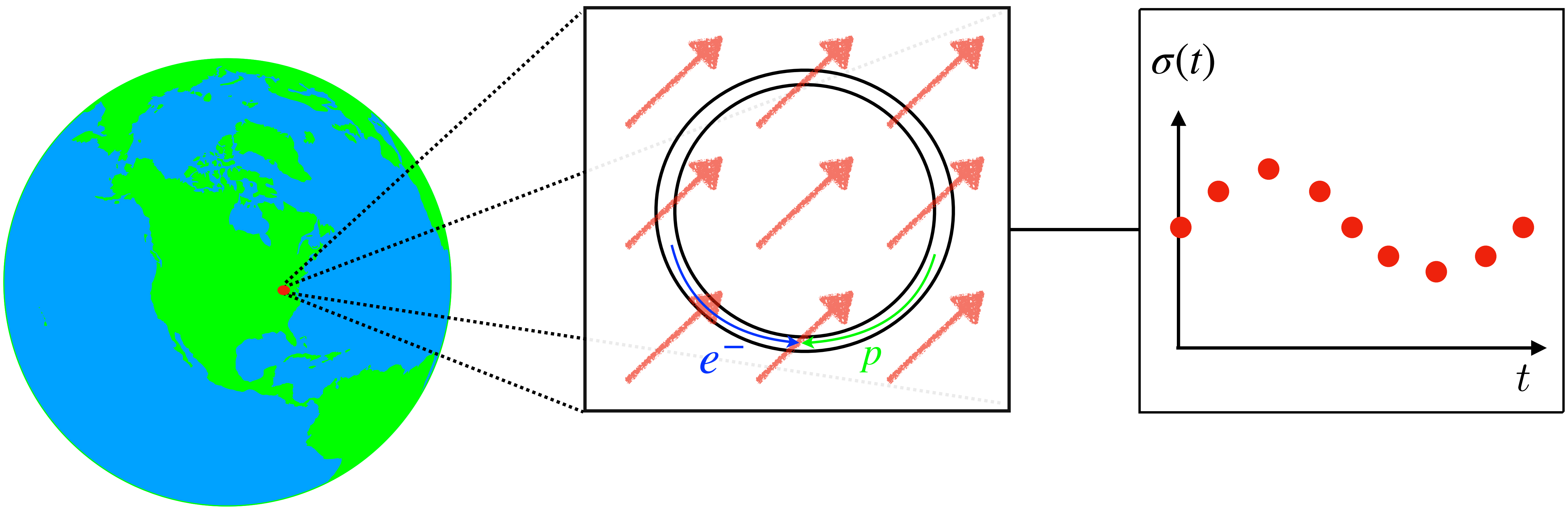

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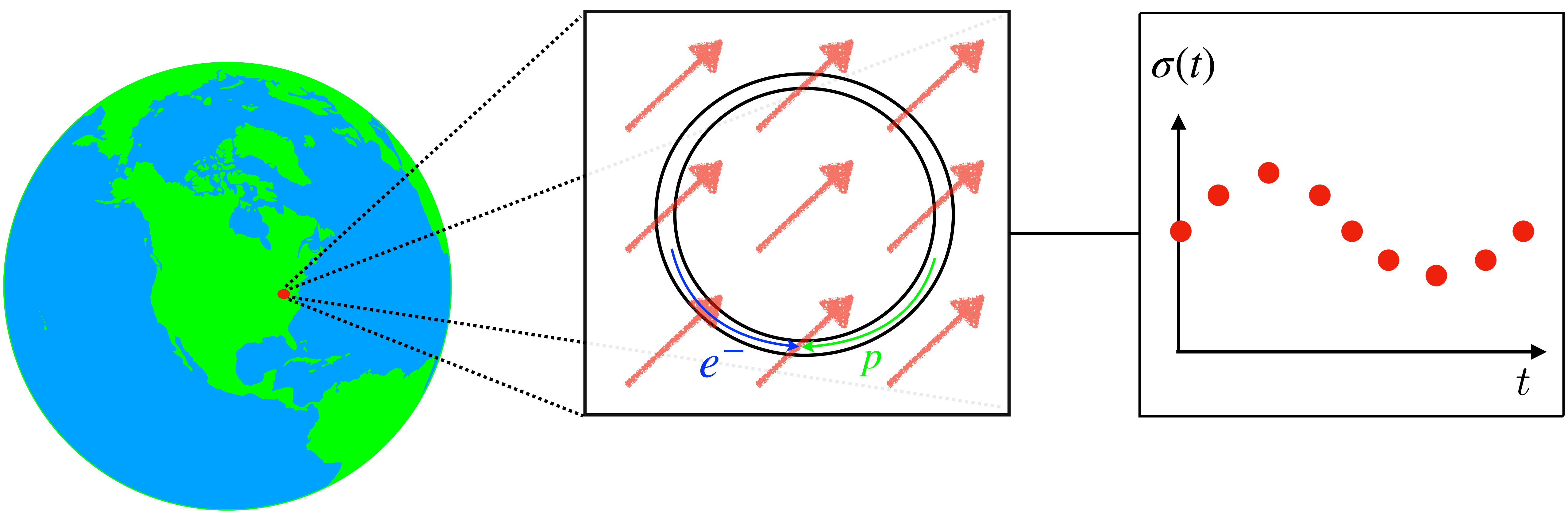

Coefficients also depend on laboratory colatitude and beam directions!

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Extract bounds on coefficients: Using H1 and ZEUS combined 644 neutral-current DIS measurements (Eur. Phys. J. C75 (2015)). For each (x,Q) value:

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$$\chi_i^2(x, Q^2, c_f^{\mu\nu}) = \sum_{m,n}^{n_{\mathrm{bins}}} [\sigma^{\mathrm{SME}}(c_f^{\mu\nu}) - \sigma_i^{\mathrm{exp}}]_m C_{mn}^{-1} [\sigma^{\mathrm{SME}}(c_f^{\mu\nu}) - \sigma_i^{\mathrm{exp}}]_n$$

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- Minimize and extract 95% CL constraint

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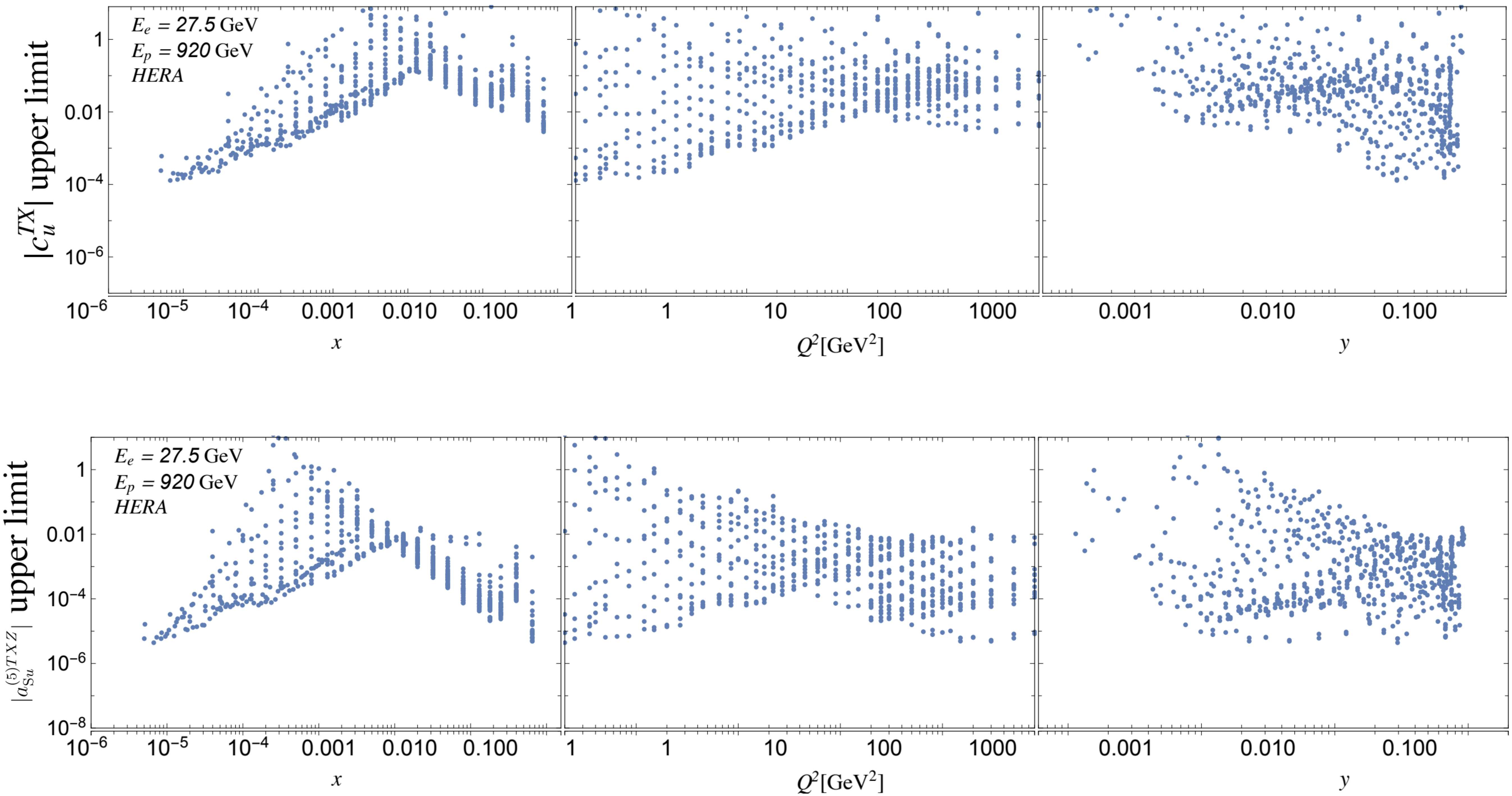

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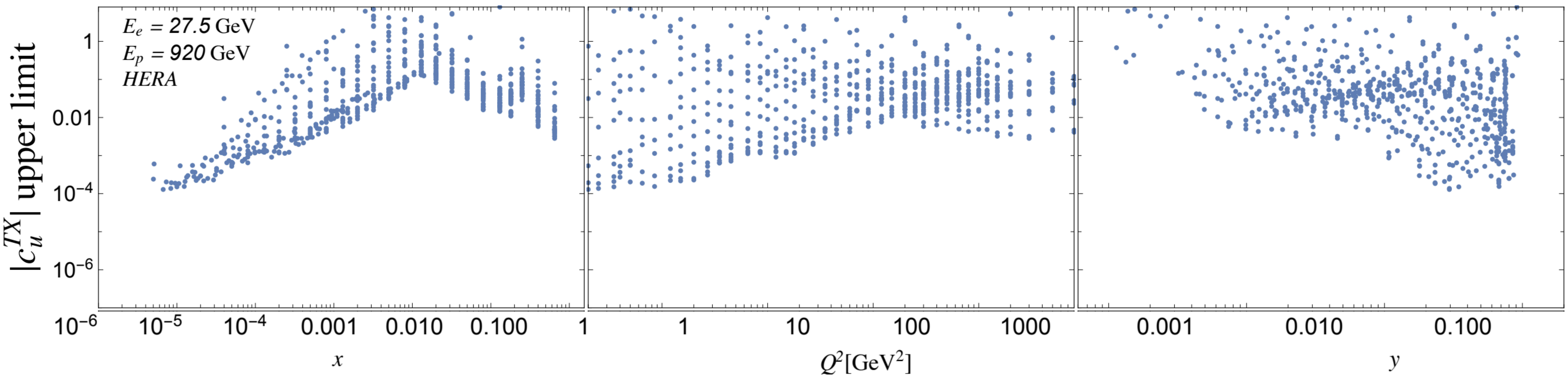

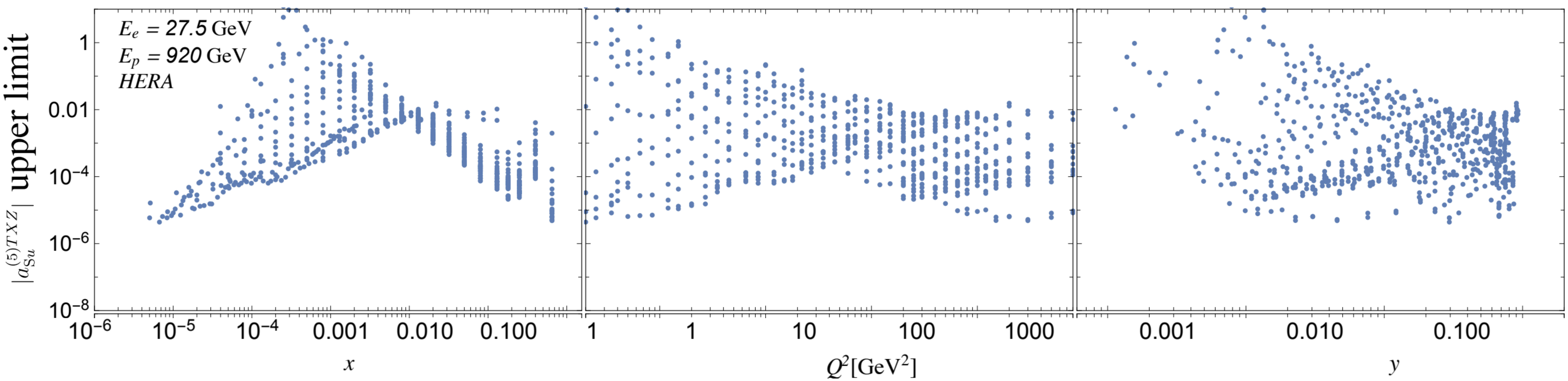

Generally speaking, region of most sensitivity at low x, low-moderate Q, and higher collision energies

An actual experimental search

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What is needed (?):

- Cross sections as functions of (x, Q) in (4-8) bins of sidereal time
- Understanding of systematics: which uncertainties matter over the course of a few hours in a day? E.g., beam luminosity ~ constant?
- Since SME cross section is different in each bin, can construct observables that partially shield against systematics

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Thank you!