Title: Lorentzian non-locality and off-shell modes

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Abstract:

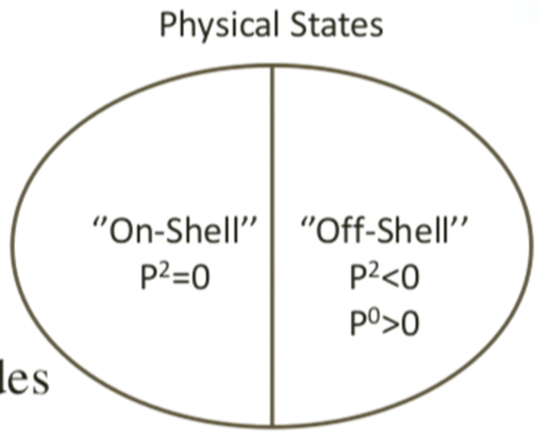
Summary: Motivations

- Lorentz transformation is a very well tested symmetry of nature.
- Combining LI and LQFT results in a very successful framework in physics.
- Focus only on LI in the context of field theory → non-local evolution
- Causal Lorentzian non-locality
    - New phenomena
    - Constraining non-locality scale
- Fundamental or effective non-locality
- Inspired by Causal set (but not restricted to)
- Attention: field theory in continuum flat space-time (-+++) with modified evolution law

Summary: Results

Modifying a massless **scalar** field evolution (can also be extended to massive scalar field)

1. Continuum of particles



2. Modification to scattering amplitudes
   - Feynman Green's function
   - Amplitudes assigned to initial or final states
3. $\sigma(p_1 \ldots p_n) \neq 0$ iff $p_i^2=0$ for $i=1,\ldots,n$

Outline

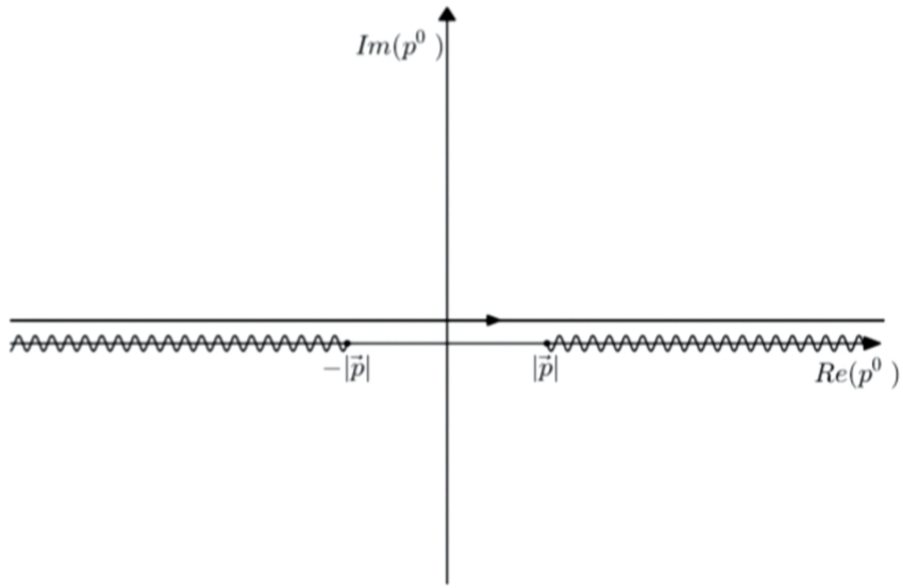
- Summary: motivations and results
- Causal Lorentzian Evolution
- Quantization
- Concluding Remarks

Causal Lorentzian Evolution

- Massless scalar field $$\Box\phi = J(x)$$
- The new evolution is obtained by $\Box \rightarrow \tilde{\Box}$
$$\tilde{\Box}\phi = J(x)$$
- $\tilde{\Box}$ required to be:
    1. Linear
    2. Real
    3. Poincare invariant
    4. Local at low energies: $\tilde{\Box}$ is in essence a modification of $\Box$ at high energies.
    5. Stable
    6. Causal (=retarded)
- 1+2+3: $\tilde{\Box}e^{ip\cdot x} = B(p)e^{ip\cdot x}$ $\quad B(p) = B(sgn(p^0), p\cdot p)$
$$B(-sgn(p^0), p_\mu p^\mu) = B^*(sgn(p^0), p_\mu p^\mu)$$
- 4: $B(p) \xrightarrow{p\cdot p\rightarrow 0} -p\cdot p$

Causal Lorentzian Evolution

Stability and Causality:



For example: $G^R(x,y) = \int \frac{d^4p}{(2\pi)^4} \frac{1}{B(p)} e^{ip\cdot(x-y)}$

Quantization

The goal is to find a quantum theory which in classical limit reduces to EOM $\tilde{\Box}\phi = J(x)$

Method I: SJ Quantization

- Only needs the retarded Green's function

Method II: Double path integral

- Gives a retarded EOM in the classical limit

Note: Feynman path integral does not work.

Physical States

$$\langle \hat{\phi}(x)\hat{\phi}(y)\rangle = \int \frac{d^4p}{(2\pi)^4}\tilde{W}(p)e^{ip\cdot(x-y)}$$

$$\tilde{W}(p) > 0 \quad \text{iff} \quad p^2 \leq 0 \;\&\; p^0 > 0$$

- There is a continuum of massive particles

$$\tilde{W}(p) = 2\pi\delta(p^2)\theta(p^0) + \text{finite terms}$$

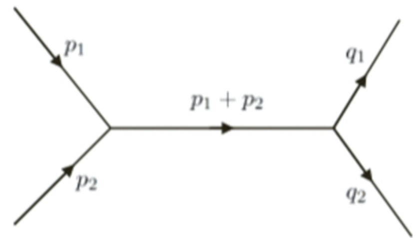
originating from the pole

Originating from the cut

Interacting Theory

Feynman rules with modified Feynman Green's(?) function and amplitudes for external legs

For example $\frac{\lambda}{3!}\phi^3$:



Note: p&q are 4-momenta not 3-momenta

$$S_{q_1 q_2, p_1 p_2} = \frac{-i\lambda^2}{(2\pi)^8}\sqrt{\tilde{W}(p_1)\tilde{W}(p_2)\tilde{W}(q_1)\tilde{W}(q_2)}\left[\tilde{G}^F(p_1+p_2) + \tilde{G}^F(p_1-q_1) + \tilde{G}^F(p_1-q_2)\right]\delta^{(4)}\left(\sum p - \sum q\right)$$

$$\tilde{G}^F(p) = \frac{\theta(p^0)}{B(p)} + \frac{\theta(-p^0)}{B^*(p)}$$

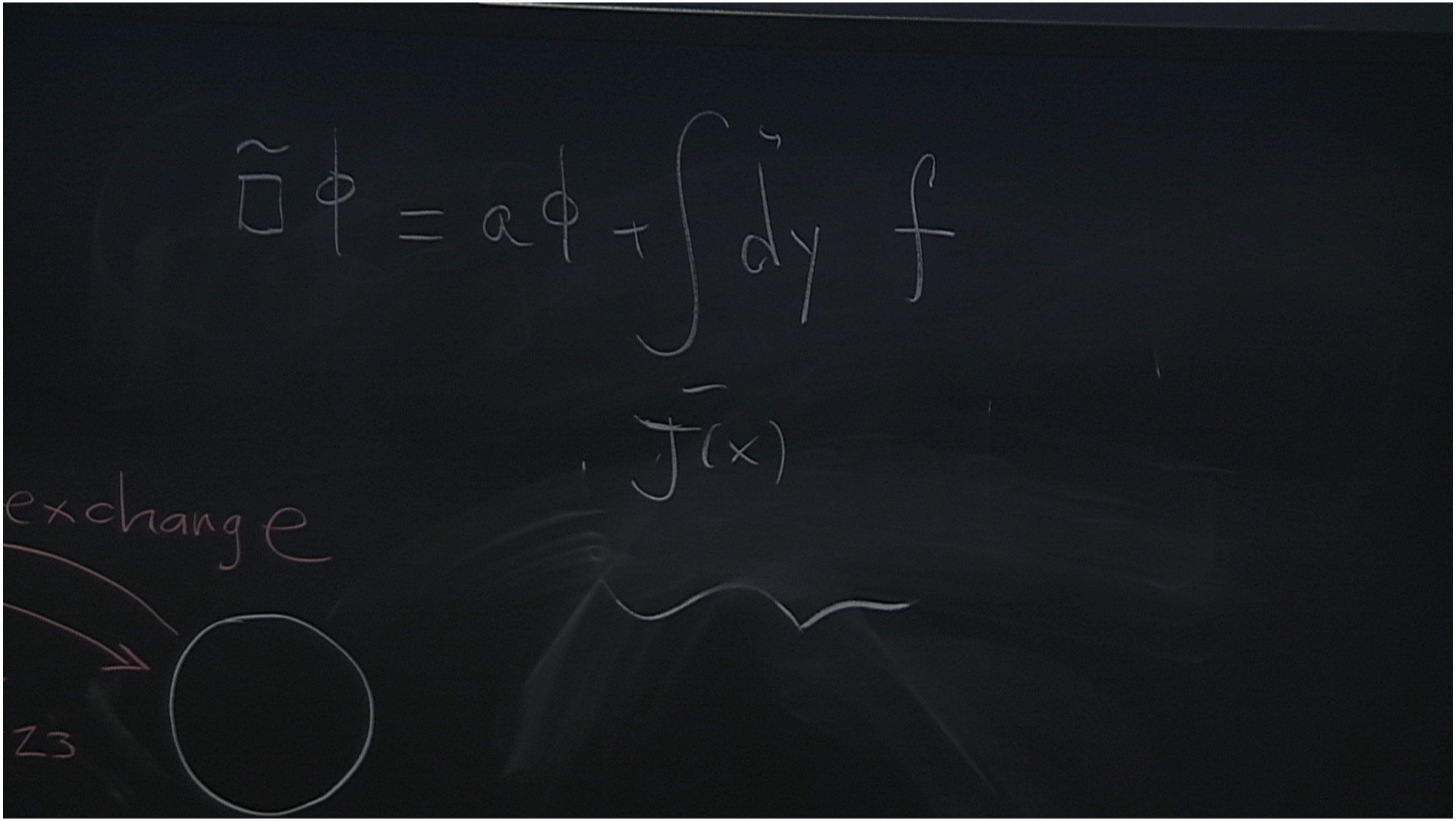
Concluding Remarks

- The resulting theory is unitary with finite total cross section.
- Causal Lorentzian evolution results into a continuum of massive particles. **Causality** (retardedness) is crucial.
- Implementing non-locality in the kinetic term rather than interaction
- $\sigma(p_1 p_2) \neq 0$ iff $p_i^2=0$ for i=1,2

There is no way of detecting off-shell modes through scattering → candidate for dark matter

- In a concrete model, non-locality scale can be constrained using the abundance of dark matter.
- Extension to massive scalar field (✓) and other fields (✗)
- Predictions:
  - no detection of dark matter
  - missing energy in scattering experiments

$$\left(\frac{E_{cm}}{E_{nl}}\right)^{2n}, \quad n = 1, 2, \cdots$$



□̃ φ = aφ + ∫ dỹ f
J̄(x)
exchange
Z3