

大学院集中講義

講義名：物理化学特別講義 I

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タイトル：Scattering amplitudes in gauge theories

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講義要旨：

In quantum field theories, scattering amplitudes are calculated perturbatively by using the plane wave solutions of the equations of motion of participating particles and their Green's functions (propagators). In gauge theories, the Green's functions of the gauge bosons are found only after gauge fixing. The most popular method is covariant gauge fixing, including Feynman, Landau, and R_ξ gauges. The common feature among all covariant gauges is to constrain only the total derivative of gauge fields, $\partial_\mu A(x)^\mu$. Accordingly, all three helicity components of spin-1 polarization and all (Feynman) or some of the spin-0 component are allowed to propagate, while no spin-0 component propagates in the Landau gauge. A common feature of all covariant gauges is the gauge cancellation among interfering Feynman amplitudes: each Feynman amplitude contains unphysical gauge-dependent terms which are cancelled only after summing over all interfering amplitudes. In the case of QED and QCD, the gauge cancellation problem appears from 2 to 3 processes, because individual diagrams for 2 to 2 processes have only one diagram per off-shell gauge boson, and hence they are separately gauge invariant. In the case of the EW theory, covariant R_ξ quantization gives unphysical gauge-dependent terms even in the 2 to 2 scattering amplitudes when massive weak bosons appear in the final state. The unphysical gauge-dependent terms cancel only after summing over all the diagrams.

In this series of seven lectures, I will introduce the Feynman Diagram (FD) gauge: in unbroken gauge theories, QED and QCD, the gauge boson polarization component proportional to its four momentum is not allowed to propagate. In the case of the EW theory, the helicity 0 polarization component proportional to the weak boson four momentum mixes with the spin-0 Goldstone mode. Both propagators are obtained by light-cone quantization, and by choosing the light-cone vector along the opposite direction of the three momentum of the virtual gauge boson. Accordingly, if there are n virtual gauge bosons and m on-shell weak bosons in one scattering amplitude, it depends on $n + m$ different light-cone gauge vectors. The total sums of the amplitudes are identical among all covariant gauges and the FD gauge.

The striking feature of the FD gauge amplitudes is that individual Feynman amplitudes obey the canonical scaling law dictated by the number/dimension of vertices and propagators, and hence there is no unphysical cancellation among interfering amplitudes. It gives us two obvious advantages over

the covariant gauge: 1) numerical programs do not suffer from loss of digits due to violent gauge cancellation at high energies; 2) we can study interference among Feynman amplitudes by using physics intuition.

Although the physical meaning of the FD gauge amplitudes is not yet completely understood, you can already check all the above statements for an arbitrary process in the SM and BSM by using the new HELAS codes with MadGraph. Students and researchers are encouraged to contribute to the new development and understanding of quantum gauge theories.

References:

- 1: arXiv:2003.03003 (QED, QCD)
- 2: arXiv:2203.10440 (EW)
- 3: arXiv:2211.14562 (LC to FD gauge)
- 4: arXiv:2405.01256 (BSM with SMEFT)
- 5: arXiv:2407.11527 (QCD 1-loop)
- 6: arXiv:2603.01139 (phase space)

内容 :

Lec.1 Scattering amplitudes in perturbative QFT (Quantum Field Theory)

Lec.2 QED

Lec.3 QCD

Lec.4 EW theory 1

Lec.5 EW theory 2

Lec.6 SMEFT

Lec.7 Radiative corrections

セミナー題目 : How theorists contribute to discover toponium at the LHC?