Charged Higgs Pair Production Through Vector-Boson Fusion

Master's thesis project

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June 20, 2024

Problems with the SM

The Standard Model (SM): successful, yet incomplete description of particle physics

- Hierarchy problem: Higgs mass much lighter than Planck mass
  - Divergences in higher order quantum corrections
  - Fine-tuning necessary
- Baryogenesis (imbalance of matter vs antimatter)
- Dark matter
- Other: gravity, strong CP problem, neutrino oscillations, ...

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$\rightarrow$ **Supersymmetry (SUSY)**

Minimal supersymmetric Standard Model

- SUSY: Spacetime symmetry between bosons and fermions: each SM particle has a superpartner
- Particle physics: Minimal supersymmetric Standard Model (MSSM)
  - Some superparticles candidates for dark matter
  - Hierarchy problem: SUSY counterterm cancel divergencies
  - Baryogenesis at supersymmetric GUT scale through proton decay

2HDM

- Higgs sector of MSSM: Two-Higgs-Doublet Model (2HDM)

$$\Phi_1 = \begin{pmatrix} \Phi_1^0 \\ \Phi_1^- \end{pmatrix} \text{ with } Y_1 = 1 \quad \text{and} \quad \Phi_2 = \begin{pmatrix} \Phi_2^+ \\ \Phi_2^0 \end{pmatrix} \text{ with } Y_2 = -1$$

  - Two Higgs doublets preserve cancellation of chiral anomalies
  - Unlike in SM, cannot use conjugate $\tilde{\Phi}$ for up-type fermion masses
- 2HDM not exclusive to MSSM!

2HDM

- Gives rise to five Higgs bosons:

h^0	light scalar
H^0	heavy scalar
A^0	heavy pseudoscalar
$H^\pm$	pair of charged scalars

  $\rightarrow$ four masses m_h, m_H, m_A, $m_{H^\pm}$
- Vacuum expectation values (VEVs) of $\langle\Phi_1\rangle$ and $\langle\Phi_2\rangle$

$$\frac{\langle\Phi_1\rangle}{\langle\Phi_2\rangle} = \tan\beta$$

- Mixing angle α between CP-even states h, H

Six parameters m_h, m_H, m_A, $m_{H^\pm}$, $\tan\beta$, α

2HDM

Existence of charged Higgs mass eigenstates $\rightarrow$ non-minimal Standard Model, i.e. extension of Higgs sector

possibly MSSM/SUSY

New physics and phenomenology

No experimental data/confirmation

Process

Goal: Computing cross section and NLO corrections of this process

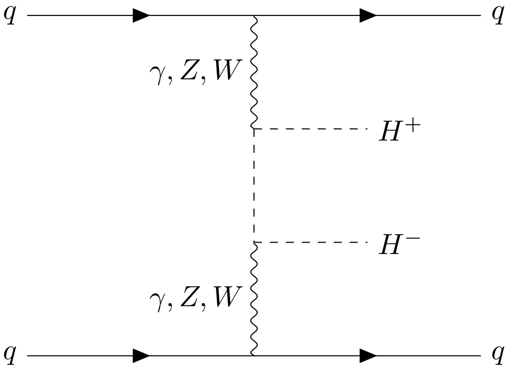


Figure: Feynman diagram of $qq \to qqV^*V^* \to qqH^+H^-$

Process

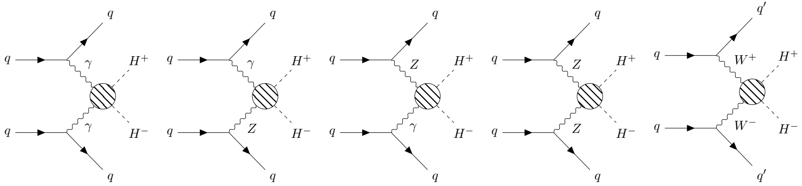
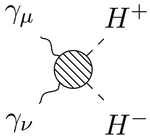


Figure: Contributing processes

Process: Computing electroweak S-Matrix elements

$$\mathcal{M}^{\gamma\gamma}_{\mu\nu} =$$



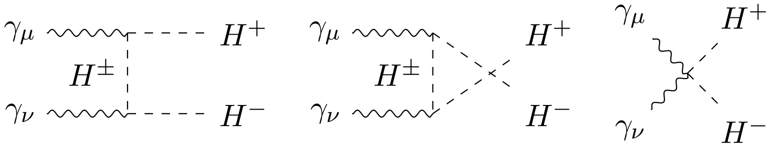


Figure: Feynman diagrams contributing to $\mathcal{M}^{\gamma\gamma}_{\mu\nu}$

Process: Full process

What about the full diagram including fermion lines?

Deep inelastic scattering

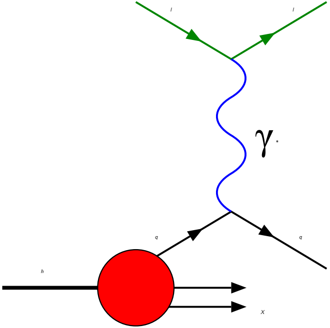


Figure: DIS of a lepton (green) on a hadron (red)

- Approximation at high energies: hadrons composed of **partons** (parton model, Feynman)
- Effective Feynman rule of qqV^*-vertex

$$\propto W^{\mu\nu}$$

hadronic tensor

Hadronic tensor

$$W^{\mu\nu} = F_1\left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) + \frac{F_2}{xpq}\left(p^\mu - \frac{pq}{q^2}q^\mu\right)\left(p^\nu - \frac{pq}{q^2}q^\nu\right) - \frac{iF_3}{2pq}\varepsilon_{\mu\nu\sigma\rho}p^\sigma p^\rho$$

p, q fermion and virtual boson momenta, respectively

F_1, F_2, F_3 dimensionless structure functions from DIS $\rightarrow$ known from DIS and depend on axial and vector coupling contants of quarks to vector bosons

Hadronic tensor

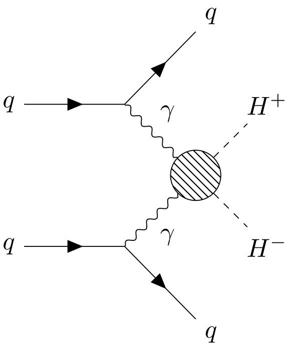


Figure:
$qq \to qq\gamma^*\gamma^* \to qqH^+H^-$

For full cross section, contract $\mathcal{M}^{V_1V_2}_{\mu\nu}$ with respective hadronic tensors $W^{\mu\nu}_{V_1V_2}$ and square it

$$\sum_{V_{1,\ldots,4}=\gamma,Z} \mathcal{M}^{V_1V_2}_{\mu\nu}\mathcal{M}{*}^{V_3V_4}_{\rho\sigma}W^{\mu\rho}_{V_1V_3}W^{\nu\sigma}_{V_2V_4} + \mathcal{M}^{WW}_{\mu\nu}\mathcal{M}{*}^{WW}_{\rho\sigma}W^{\mu\rho}_{WW}W^{\nu\sigma}_{WW}$$

$\rightarrow$ differential cross section also depends on structure functions F_1, F_2 and F_3

Structure functions in parton model

- F_1, F_2 only depend on Bjorken scaling x

$$F_2 = 2xF_1 \quad \text{with} \quad x = \frac{Q^2}{2Pq} \quad \text{measure for inelasticity}$$

- At LO, no colour exchange between quark lines $\rightarrow$ QCD corrections only at NLO and are known! Replace

$$F_i \rightarrow F_i + \Delta F_i$$

for NLO-corrected cross section