Contributions to Higgs production in Vector Boson Fusion at $\mathcal{O}(\alpha_s^2 \alpha^3)$

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Introduction

**Higgs discovery at LHC**

**Vector Boson Fusion:** $qq' \rightarrow qq'H$

- important Higgs discovery mode at LHC
- allows measurement of $HVV$ couplings

→ precise predictions for VBF necessary

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Vector Boson Fusion

VBF characteristics
- t-channel $W/Z$ exchange
  $\to$ 2 jets at high rapidities
- no color exchange
  no central hadronic activity
- $H$ decay products at low rapidities

QCD background
- much jet activity in central detector region

$\to$ suppression of VBF background possible
QCD corrections

- total rates [Han, Valencia, Willenbrock ’92] [Djouadi, Spira ’00]
- distributions [Figy, Oleari, Zeppenfeld ’03] [Barger, Campbell ’04]

virtual corrections

real corrections

- no color exchange
  → only corrections to structure functions
  → read radiation in forward/backward region

⇒ distinctive kinematics not changed at NLO
- size: ±5 . . . 10%
- scale uncertainty ∼ 2%
virtual 2-loop

\[ \rightarrow \text{no color exchange} \]

(1-loop)\(^2\)

\[ \rightarrow \text{color exchange} \]

gluon induced processes \( gg \rightarrow q\bar{q}H \)

leading order, loop induced

finite, gauge invariant

\[ \rightarrow \text{this talk} \]
consider: $gg \rightarrow q\bar{q}H$ and crossed processes ($q\bar{q} \rightarrow ggH$ and $qg \rightarrow qgH$)

sample diagrams for $gg \rightarrow q\bar{q}H$

external quarks: sum over 5 light flavours, taken as massless

diagrams with resonant $Z$ boson
- resonant and nonresonant diagram sets separately gauge invariant
- resonant diagrams: $gg \rightarrow HZ^* \rightarrow Hq\bar{q}$
  $\rightarrow$ NNLO corrections to Higgsstrahlung
  suppressed by VBF cuts on invariant jet-jet mass
  $\rightarrow$ exclude, use only non-resonant diagrams

initial state radiation diagrams
- amplitude diverges for soft or collinear final state quarks
  $\rightarrow$ real corrections to $\bar{q}g \rightarrow \bar{q}H$
  require 2 non-collinear well separated hard jets using cuts $\rightarrow$ finite cross section
Calculation

• ’t Hooft-Feynman gauge

• generation by FeynArts

• evaluation using Mathematica / FormCalc
  → standard matrix elements and coefficients containing tensor loop integrals
  → translation to C++ code for numerical evaluation

• tensor loop integrals
  3/4 point integrals: Passarino-Veltman reduction
  5 point integrals:
    numerical instabilities from inverse Gram determinants in tensor reduction
  → alternative reduction avoiding leading inverse Gram determinants

[Denner, Dittmaier ’02]

using loop integral library by A. Denner

• phase space integration: VEGAS
  distributions possible
checks of the calculation

- finiteness
  no UV, IR, collinear divergences in full amplitude

- gauge invariance
  matrix element: \( \mathcal{M} = \epsilon_\mu(k_1)\epsilon_\nu(k_2)\mathcal{M}^{\mu\nu} \)
  gauge invariance requires:
  \[
  k_1\mu\epsilon_\nu(k_2)\mathcal{M}^{\mu\nu} = \epsilon_\mu(k_1)k_2\nu\mathcal{M}^{\mu\nu} = 0
  \]
  \(\rightarrow\) checked numerically

phase space cuts

minimal cuts

\(p_{Tj} > 20\) GeV, \(|\eta_j| < 5\), \(R > 0.6\)

\[
R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}
\]

\(\rightarrow\) 2 well separated hard jets

additional VBF cuts

\(|\Delta \eta| > 4.2\), \(\eta_1 \cdot \eta_2 < 0\)

\(m_{jj} > 600\) GeV

\(\rightarrow\) separation of VBF process from background
Results for LHC: total cross section

parton densities: MRST nnlo

\[ gg \rightarrow q\bar{q}H \]
\[ q\bar{q} \rightarrow ggH \]

\[ \sqrt{s} = 14 \text{ TeV} \]

VBF LO: \( \sigma \approx 1 \text{ pb} \) with vbf cuts

- \( W \) threshold in loops visible
- VBF cuts: strong suppression
$m_H = 120 \text{ GeV, minimal cuts}$

- Rapidity gap: smaller than for vector boson fusion (peak at $\Delta \eta \approx 4.5$)
- Dijet invariant mass: rapid falloff
conclusions

- vector boson fusion important Higgs production channel at LHC

- no color exchange at LO and NLO
  - color exchange contributions only at NNLO

- $gg \rightarrow q\bar{q}H$ and crossed processes
  - finite, gauge invariant subset of NNLO corrections with color exchange

- $\sigma \sim 5 \text{ fb}$ for 100 GeV Higgs with minimal cuts
  - strong suppression by additional VBF cuts