VV scattering in P-TDR
(CHAPTER 13.2 Vol 2.2)

A simple summary of what we intend to put in our chapter

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13.2 Heavy Higgs boson and VV scattering

13.2.1 WW scattering in the absence of Higgs boson

13.2.1.1 Semileptonic final state

13.2.1.2 Signal definition and simulation
   13.2.1.2.1 Six fermions final state processes
   13.2.1.2.2 VV-fusion signal selection at partonic level:
      \[ qq \rightarrow qqVV \rightarrow qqVW \rightarrow qq\mu \mu \nu \]
      \[ qq \rightarrow qqVV \rightarrow qqVZ \rightarrow qq\mu \mu \mu \]

13.2.1.3 Data Analysis
   13.2.1.3.1 Signal topology
   13.2.1.3.2 Main backgrounds
   13.2.1.3.3 Signal selection:
      \[ qq \rightarrow qqVV \rightarrow qqVW \rightarrow qq\mu \mu \nu \mu \nu \]
      \[ qq \rightarrow qqVV \rightarrow qqVZ \rightarrow qq\mu \mu \mu \mu \]

13.2.1.4 Results

would it be better not to separate the “no Higgs” and the “heavy-mass Higgs” case?

since in our analysis we study both the cases

already done in CMSJET and in FAMOS

we are moving to ORCA
13.2 Heavy Higgs boson and VV scattering

- In absence of the Higgs particle
  - unitarity violation at 1-1.5 TeV -> new physics must be revealed

- If the Higgs boson exists
  - nature of $V_L V_L$ coupling is an indication of the Higgs mass range
    (useful for a light Higgs)
  - heavy Higgs = resonance in the $M(VV)$ spectrum

  In any case
  we need to verify the unitarity of the VV fusion process at high $M(VV)$
  through a comparison of the measured $\sigma(VV->VV)$ with the SM predictions

  precise knowledge of the signal xsec is essential: any deviation from the expected xsec = new physics
13.2.1.1 Semilept. final state

Our signal channels are

\[
\begin{align*}
qq & \rightarrow qqVV \rightarrow qqVVW \rightarrow qqqq\mu\nu \\
qq & \rightarrow qqVV \rightarrow qqVZ \rightarrow qqqq\mu\mu
\end{align*}
\]

- **clear experimental signature** thanks to the **isolated high** \(p_T\) **muons**
- **quite high BR**
  \[
  \sigma(VV\rightarrow VW) \times BR(V\rightarrow jj) \times BR(W\rightarrow\mu\nu) \approx 170 \text{ fb}
  \]
  \[
  \sigma(VV\rightarrow VZ) \times BR(V\rightarrow jj) \times BR(Z\rightarrow\mu\mu) \approx 25 \text{ fb}
  \]

Hopefully we will have also the \(qq \rightarrow qqVV \rightarrow qqVVW \rightarrow qqqq\nu\nu\) channel with **PHASE + FAMOS**
13.2.1.2 Signal definition and simulation

For a correct $\sigma(VV)$ calculation

- bosons off mass shellness
- spin correlations in the bosons decay
- interference with all irreducible backgrounds
- Gauge invariance

so you need a “signal definition” to isolate the signal from this background at partonic level and “a posteriori”

EVBA approximation

six-fermions approach

generation of signal together with all the irreducible backgrounds
13.2.1.2.1 Six fermion final state processes

- $qq \rightarrow q\bar{q}q\mu\nu$ simulated with PHASE at $O(\alpha_{EW}^6)$

- $qq \rightarrow q\bar{q}qq$ simulated with PHASE at $O(\alpha_{EW}^2)$

- Single top and t\bar{t} EW production

- “Non resonant” diagrams

- 2 bosons produced without undergoing scattering

- Higgsstrahlung, TGC, QGC $\rightarrow$ 3 bosons outgoing

- $qq \rightarrow qqVZ \rightarrow q\bar{q}q\mu\mu$ simulated with MadEvent in the "production times decay" approximation = only on shell bosons (with zero width)

- A study on this approximation validity is on-going (comparison between MadEvent and PHASE)
13.2.1.2.2 VV fusion signal selection

To separate the signal from the irreducible background at partonic level

- $qq \rightarrow q qq q\mu \nu$
  - reject EW top contribution
  - request for two on-shell bosons
  - reject events with three on-shell bosons in the final state

perc. of signal in simulated events

- $qq \rightarrow qqVZ \rightarrow q qq q\mu \nu$
  ... we are working on the signal definition at partonic level ...
A model independent analysis

- no Higgs
- no assumption on the mechanism to restore unitarity
- no degrees of freedom beyond the SM

M(H) = 500 GeV

same analysis cuts valid for any mass (but optimized in the no Higgs case)
13.2.1.3.1 Signal topology

\[ \Delta \eta \]

- *red* tag quarks
- *black* quarks from boson decay

\[ \eta \]

\[ p_T \]

\[ E \]

*arbitrary units*

*E (GeV)*

*eternal units*

*p_T (GeV)*
# 13.2.1.3.2 Main backgrounds

<table>
<thead>
<tr>
<th>process</th>
<th>xsec (pb)</th>
<th>generator</th>
<th>submitted ev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow \bar{t}t \rightarrow 1\mu + X$</td>
<td>622</td>
<td></td>
<td>we can use one of the produced samples</td>
</tr>
<tr>
<td>$pp \rightarrow jjWW \rightarrow jjq\mu\nu$</td>
<td>9</td>
<td></td>
<td>250k</td>
</tr>
<tr>
<td>$pp \rightarrow jjZW \rightarrow jjq\mu\nu$</td>
<td>$3 \times 10^{-3}$</td>
<td>MadEvent</td>
<td>0</td>
</tr>
<tr>
<td>$pp \rightarrow jjZZ \rightarrow jjq\mu\mu$</td>
<td>0.35</td>
<td></td>
<td>250k</td>
</tr>
<tr>
<td>$pp \rightarrow jjWZ \rightarrow jjq\mu\mu$</td>
<td>$0.9 \times 10^{-3}$</td>
<td></td>
<td>50k</td>
</tr>
<tr>
<td>$pp \rightarrow W + n \text{ jets} \rightarrow \mu\nu + n \text{ jets}$</td>
<td>~ (100 -1000)</td>
<td>AlpGen</td>
<td>?</td>
</tr>
<tr>
<td>$pp \rightarrow Z + n \text{ jets} \rightarrow \mu\mu + n \text{ jets}$</td>
<td>~ (100 -1000)</td>
<td>AlpGen</td>
<td>?</td>
</tr>
<tr>
<td>sign + irr. backgr. $pp \rightarrow qqq\mu\nu$</td>
<td>~ 0.7</td>
<td>PHASE</td>
<td>250k / 125k</td>
</tr>
<tr>
<td>sign + irr. backgr. $pp \rightarrow qqVZ \rightarrow qqq\mu\mu$</td>
<td>~ 0.025</td>
<td>MadEvent</td>
<td>550k / 325k</td>
</tr>
</tbody>
</table>

- **not yet generated**
- **submitted to the production**
- **already producted (Digi + SimHits)**

$j = q / g$ (produced via QCD)
(q always producted via EW)
13.2.1.3.3 Signal selection

A *preliminar set of cuts* has been already studied and optimized with CMSJET and FAMOS.

**Signal final state reconstruction**
- ask for central, isolated and quite high $p_T$ muons and high MET (> 20 GeV)
- ask for at least 4 jets with $p_T$ > 30 GeV
- choose the right quarks from the boson decay (high $p_T$, central, near one to the other)

**Background rejection**
- cut against top events (b-tagging)
- requests on jet tag kinematic (very high $\eta$, $\Delta\eta$ and energy)
- cut against jets occupancy (signal = pure EW process)
- request for high $p_T^V$ and high $M(qqVV)$

**L1 trigger:**
- $|\eta|<2.4$, $p_T^\mu > 20$ GeV (inclusive muon)
- $p_T^\mu > 5$ GeV (di-muons)

**First indication from W+4jets:**
- W/Z+n jets will be the most problematic background.

!!! we are moving to ORCA !!!

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13.2.1.4 Results (1)

- Signal reconstruction efficiency as a function of $M(VV)$

**NO HIGGS CASE:**
- $qqqq\mu\mu$ final state
- $qqqq\mu\nu$ final state

![Graph showing reconstruction efficiency](image)
13.2.1.4 Results (2)

- **M(VV) resolution** and M(V→jj) resolution for the two channels
- M(Z→μμ) resolution
- M(W→μν) resolution

- **Number of signal and background events** VS reconstructed M(VV)

- **Significance** \((S/\sqrt{B})\) VS reconstructed M(VV)
Some open issues

- **estimate of theoretical uncertainties** on the signal cross section calculation
  - through a comparison of various signal samples of the $qquq\mu\nu$ final state with **different MC input parameters**
    - scale $Q^2 = M_W^2 + \sum_{i=1}^{6} p_{T_i}^2$
    - PDF set (CTEQ5L)
    - top mass 175 GeV
  - through a **comparison between MadEvent and Phase** in the $qquq\mu\nu$ final state

- how to calculate the **backgrounds cross section from data**
  - not yet considered, probably **not ready for the P-TDR**