Study of VV-scattering processes as a probe of electroweak symmetry breaking

Pietro Govoni, on behalf of the CMS collaboration
Università and INFN Milano-Bicocca

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Why VV scattering

- In the symmetry breaking mechanism the Higgs gives mass to W and Z (*i.e.* their **longitudinal polarization**)

- VV scattering is the key process to **probe EWSB**
  - If the Higgs exists a resonance will be observed in the M(VV) spectrum in correspondence of M(H)

  - Without the Higgs the **V_L's interact strongly** at high energy and the $V_L V_L$ cross section violates the unitarity at M(VV) ~ 1 TeV
    →deviation from SM prediction

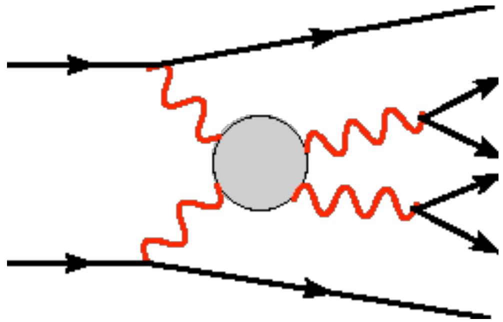
- The large M(VV) region gives indications on the M(H) range

- Whether H exists or not $V_L V_L$ should be studied in detail to **verify if weak or strong interactions occur**

Analyzed processes

- qq → qqVV has been analyzed with different final states
  - qqVW (qqqqμν/qqqqeν) highest BR
  - qqVZ (qqqqμμ/qqqqee) no neutrinos!
  - qqZZ (qqμμμμ/qqeeee) low BR, but clean
  - qqZW (qqμμμν) interesting for no-Higgs
  - $qqW^{\pm}W^{\pm}$ ($qq\mu^{\pm}\nu\mu^{\pm}\nu$) interesting for no-Higgs

- All processes have
  - High p_T lepton(s) ⇒Trigger
  - 2 "tag" jets in the fwd/bkd region to identify a *6-fermion process*



Two different scenarios have been considered: **Higgs** (M_H=500 GeV) and **no-Higgs** (or $M_H=\infty$)

N. Amapane *et al.* Study of VV-scattering processes as a probe of electroweak symmetry breaking, CMS AN-2007/005

MC Generator for Signal

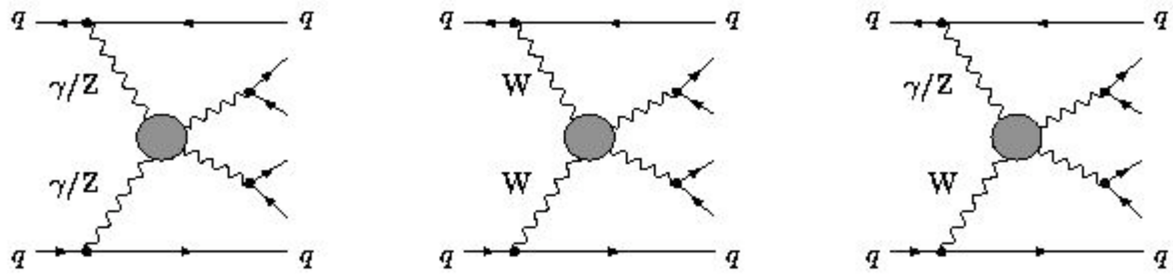
Phantom* is a full six fermions final state generator

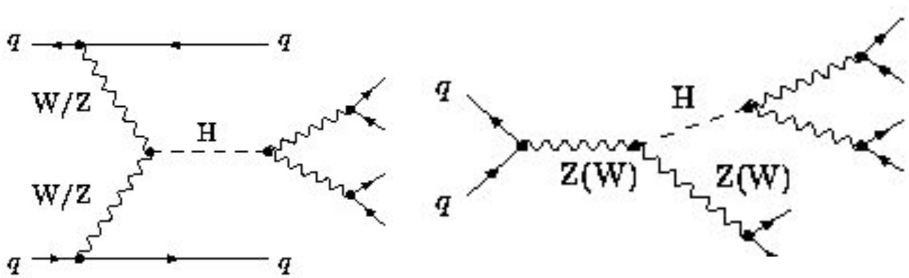
- exact matrix elements, no approximation
- generates all EW processes with six fermions in the final state at α_{EW}^6:
  - *VV-scattering + irreducible background (top-top, single top, non resonant, three bosons from TGC & QGC …)*

*Phantom: A.Ballestrero, G.Bevilacqua, A.Belhouari, E.Maina (Torino Theory Dep)
It generates all processes with 6 fermions in the final state at
$\alpha_{EW}^6 + \alpha_{EW}^4 x \alpha_{QCD}^2$.

Some Phantom diagrams

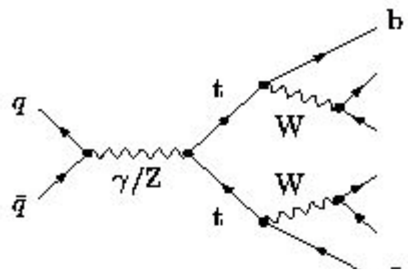
VV-fusion →



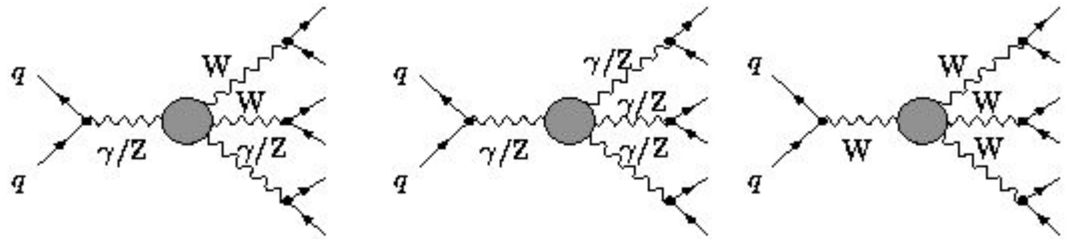


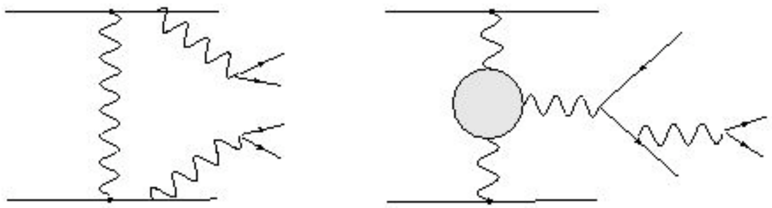
← Higgs

top-top (EW) →



TGC & QGC →





← VV and non resonant

Signal definition

- The **signal** has to be defined “a posteriori” with a series of kinematical cuts:
  - 2 on-shell bosons (±10 GeV)
  - No third boson
  - No single top or top-top produced

  Always selecting the correct flavors combinations

- The **irreducible background** is defined with the same kinematics cuts.

Phantom cross sections

Two scenarios

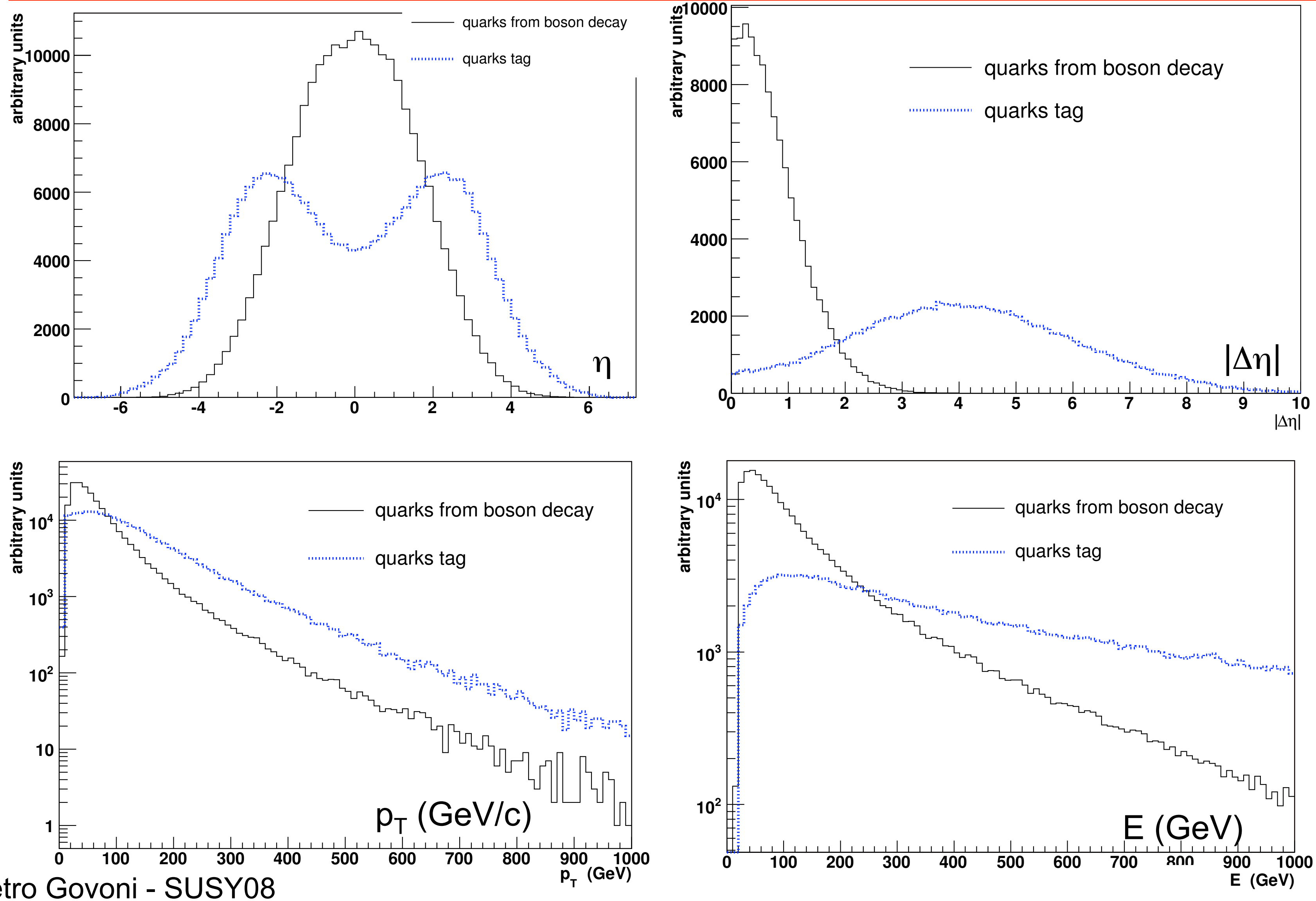
- M(H) = 500 GeV
- no-Higgs *or* M(H) = ∞ to describe the no-Higgs case

	$qqqq\mu\nu/e\nu$				$qqqq\mu\mu/ee$			
	no-Higgs		500 GeV		no-Higgs		500 GeV	
	σ (pb)	perc.	σ (pb)	perc.	σ (pb)	perc.	σ (pb)	perc.
total	0.689	100%	0.718	100%	0.0305	100%	0.0350	100%
signal	0.158	23%	0.184	26%	0.0125	41%	0.0165	47%
top	0.495	72%	0.494	69%	0.0137	45%	0.0137	39%
non resonant	0.020	3%	0.023	3%	0.0030	10%	0.0035	10%
three bosons	0.016	2%	0.017	2%	0.0012	4%	0.0014	4%

	$qq\mu\mu\mu\mu/eeee$				$qq\mu\mu\mu\nu$				$qq\mu^{\pm}\nu\mu^{\pm}\nu$			
	no-Higgs		500 GeV		no-Higgs		500 GeV		no-Higgs		500 GeV	
	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.	σ (fb)	perc.
total	0.180	100%	0.310	100%	4.182	100%	4.152	100%	4.29	100%	4.16	100%
signal	0.120	66.4%	0.229	74.1%	1.317	31.5%	1.281	30.8%	3.26	76%	3.11	75%
top	0	0%	0	0%	1.817	43.5%	1.828	44.01%	0	0%	0	0%
non resonant	0.0364	20.2%	0.0533	17.2%	0.673	16.1%	0.651	15.7%	0.47	11%	0.46	11%
three bosons	0.0241	13.4%	0.0268	8.66%	0.375	8.9%	0.392	9.5%	0.56	13%	0.58	14%

⇒ Cross sections for the analyzed final states vary of three orders of magnitude (0.1 → 100 fb)

q from V decay & q_{tag} topology



Main Backgrounds

- **V+jets** (critical for semileptonic) (σ = 4÷2500 pb)
- **VV+jets** (critical for totally leptonic) (σ = 0.2÷60 pb)
- **tt+jets** (σ = 60÷200 pb)

The official CMS production (made with ALPGEN) was used

Selection cuts

- μ: p_T > 20 GeV e: E/p>0.8 , |1/E-1/p|<0.01 , H/E <0.02, Track Iso.

- $W \to \mu\nu, e\nu$
  - Fix p_z with $(p_\mu+p_\nu)^2 = M_W^2$
  - MET > 30 GeV; MET/HT > 0.07
- $Z \to \mu\mu, ee$
  - $p^+_z * p^-_z > -2000\ GeV^2$
  - choose pair with largest p_T
  - $81 < M_Z < 101$ GeV
  - p_T^Z>100 GeV

Jets: p_T>30 GeV

- Tag jets:
  - p_T>30 GeV, E_j > 100 GeV
  - $|\eta|$ >1 for at least one tag jet
  - Pair with largest M_{jj}

    close jets merged
  - $|\Delta\eta|$ > 1.5
  - M_{jj} > 500 GeV
- $V \to jj$
  - Couple of jets with minimum $\Delta\eta$

Final cuts:

- M_{VWjj} > 1000 GeV
- b-tagging

Some additional small difference from one channel to the other are present

Invariant Mass Resolution

Important to:

- discriminate signal from background
- define the energy scale at which Symmetry breaks

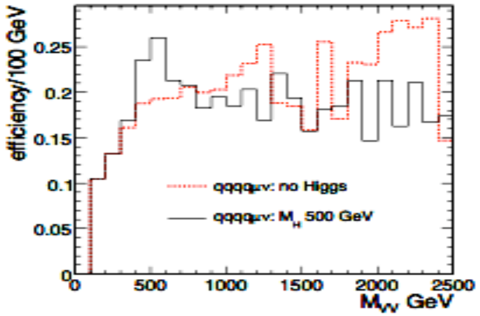
	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$	$qq\mu\mu\mu\nu$
$Z \to ll$	—	—	1.5%	1.5%	1.5%	2.0%	2.1%
$W/Z \to jj$	27%	20.5%	20%	25%	—	—	—
$VV \to 4f$	22%	19.0%	9.5%	9.5%	1.1%	1.5%	9.4%

M_V and M_{VV} resolution for the various final states

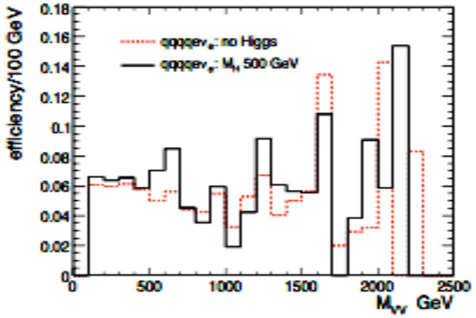
Quite **poor** V→jj resolution:

This results in a lower efficiency and S/√B.

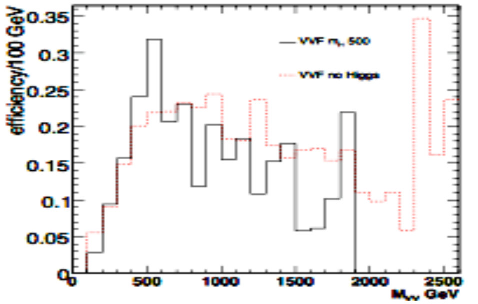
Efficiency



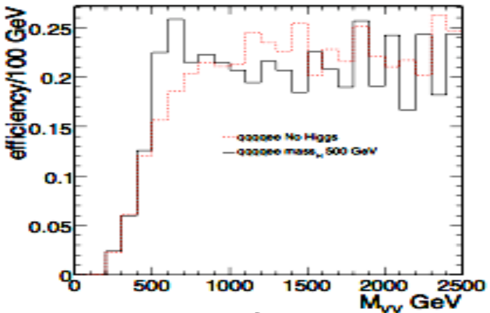
qqqqμν final state



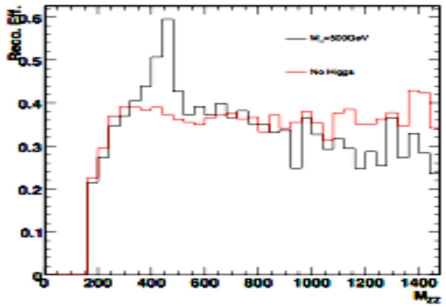
qqqqeν final state



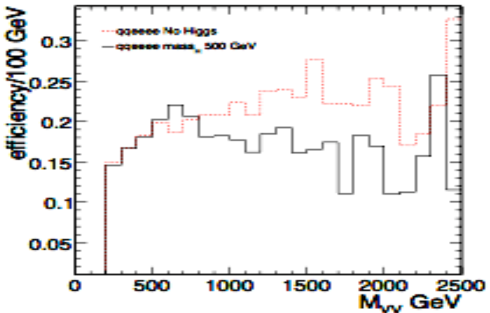
qqqqμμ final state



qqqqee final state



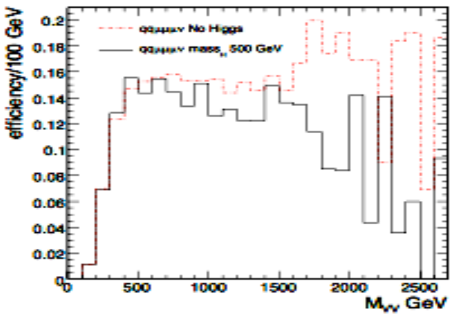
qqμμμμ final state



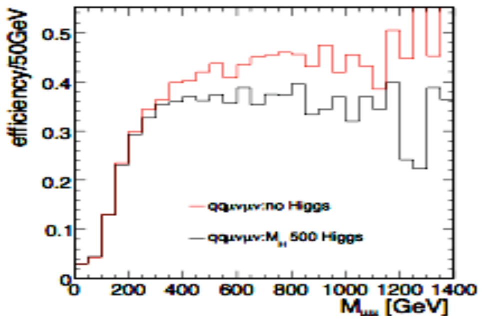
qqeeee final state

M_H=500

No-Higgs

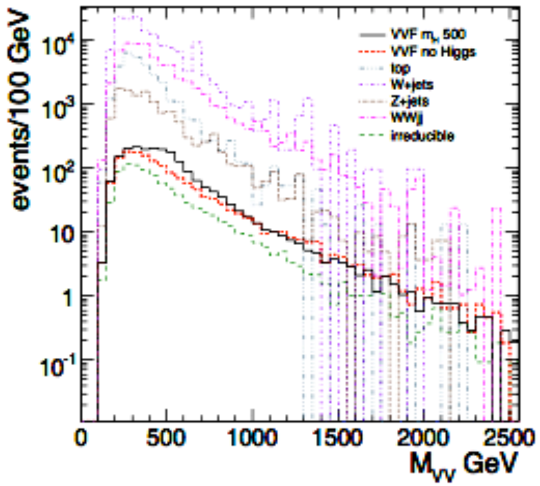


qqμμμν final state

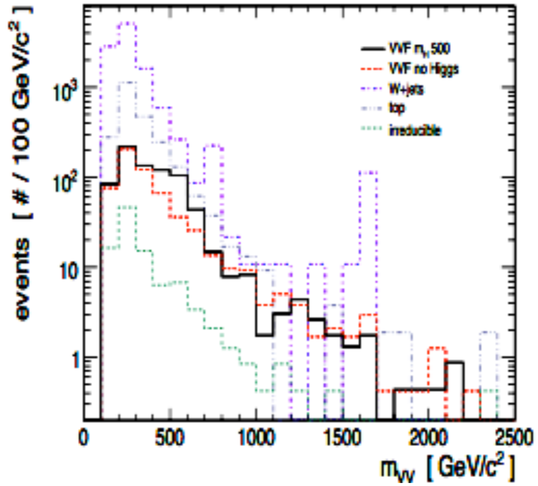


qqμνμν final state

Signal and Background

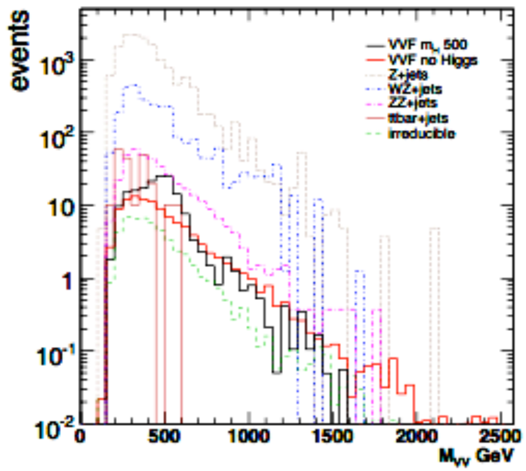


qqqqμν final state

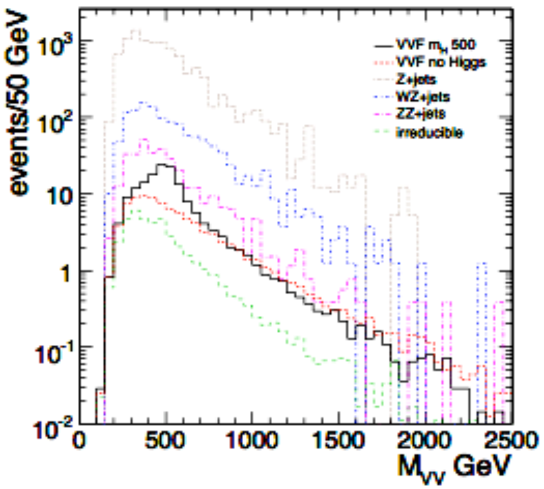


qqqqeν final state

M_H=500
No-Higgs

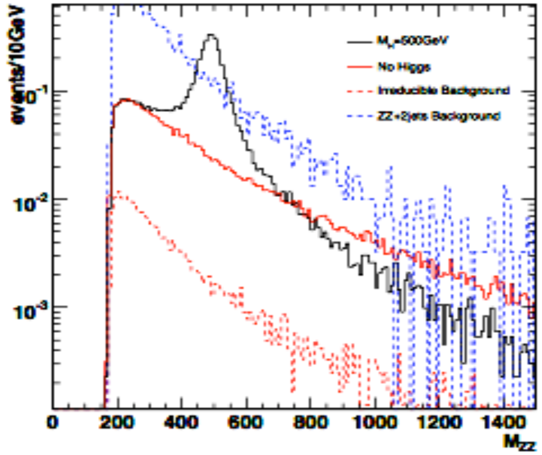


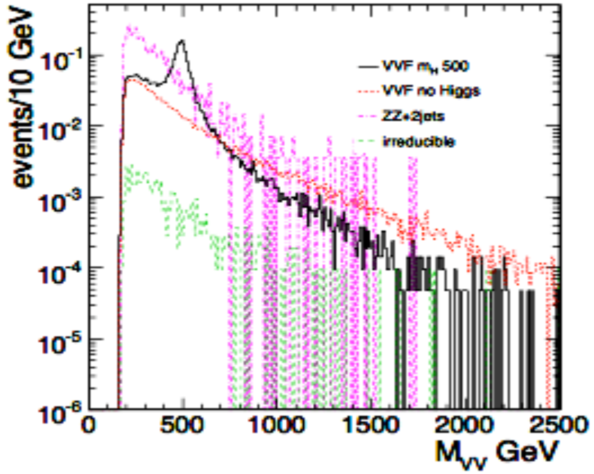
qqqqμμ final state



qqqqee final state

Signal and Background



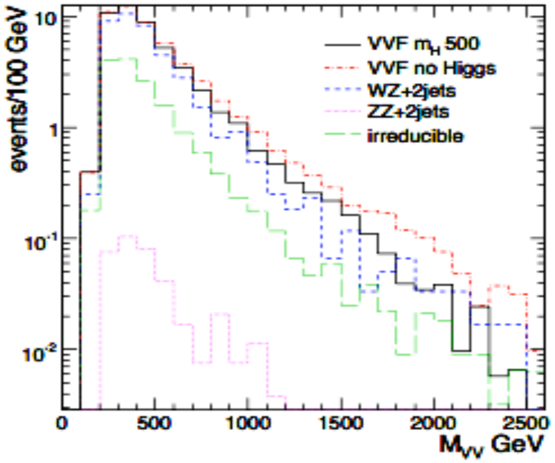


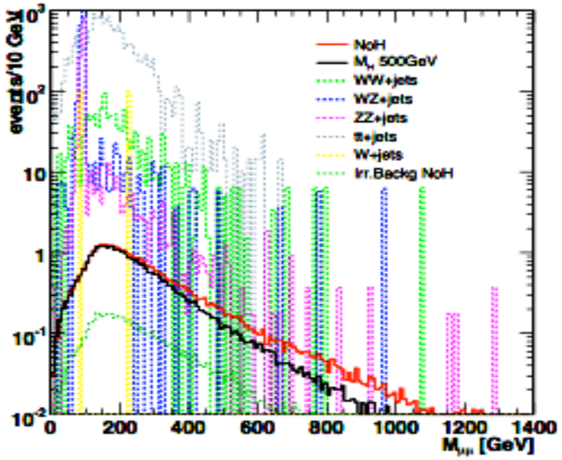
M_H=500

No-Higgs

qqμμμμ final state

qqeeee final state





qqμμμν final state

qqμ±νμ±ν final state

Results for 60 fb^{-1}

	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$	$qq\mu\mu\mu\nu$	$qq\mu^{\pm}\nu\mu^{\pm}\nu$
signal	111	26	5	10	0.16	0.2	2.7	8.3
W + n jets	5570	166	-	-	-	-	-	0
Z + n jets	499	-	205	580	-	-	0	-
$t\bar{t}$	446	19	0	0	-	-	0	664
ZZ + n jets	-	-	10	17	0.3	0.2	0.02	110
ZW + n jets	-	-	139	93	-	-	2.21	20
WW + n jets	3094	-	-	-	-	-	-	37
irreducible backgrounds	47	3	1	1	0.009	0.001	0.09	1.3
backgrounds	9656	187	355	691	0.31	0.201	2.3	832
significance	1.13	1.87	0.28	0.38	0.27	0.39	1.51	0.29

no Higgs case

	$qqqq\mu\nu$	$qqqqe\nu$	$qqqq\mu\mu$	$qqqqee$	$qq\mu\mu\mu\mu$	$qqeeee$
signal	703	309	86	100	3.1	3.5
W + n jets	34840	1383	-	-	-	-
Z + n jets	3094	-	3798	4660	-	-
$t\bar{t}$	5976	609	30	14	0	-
ZZ + n jets	-	-	125	184	2.6	2.9
ZW + n jets	-	-	781	615	0	-
WW + n jets	16133	-	-	-	0	-
irreducible backgrounds	220	23	20	20	0.036	0.04
backgrounds	60263	2015	4754	5493	2.6	2.94
significance	2.86	6.72	1.24	1.34	1.66	1.76

Two different approaches for $4q\mu\nu$ and $4qe\nu$:
- high efficiency to study the high M_{VV} region
- high significance for a discovery

Higgs with m_H=500 GeV

The High Mass region

The cross section $\sigma(qq \rightarrow qqVV)$ and the V polarization depends on the presence or not of the Higgs:

$\mathbf{V_T}$ is independent with respect to the Higgs (~NO coupling)

$\mathbf{V_L}$ couples to Higgs $\Rightarrow$ explodes* at high masses if the Higgs does not exist

- If the Higgs exists, $V_L V_L$ dominates under the peak, while at high masses (M(VV) > 1TeV) $V_T V_T$ dominates
- If the Higgs does not exist V_L and V_T are of the same order at M > 1TeV

* Violation of unitarity not strongly felt at LHC because E_{cm} is still too low and PDFs rapidly decrease

Polarization

PROCESS $ud \rightarrow udW^+W^- \rightarrow udc\bar{s}\mu\bar{\nu}_\mu$

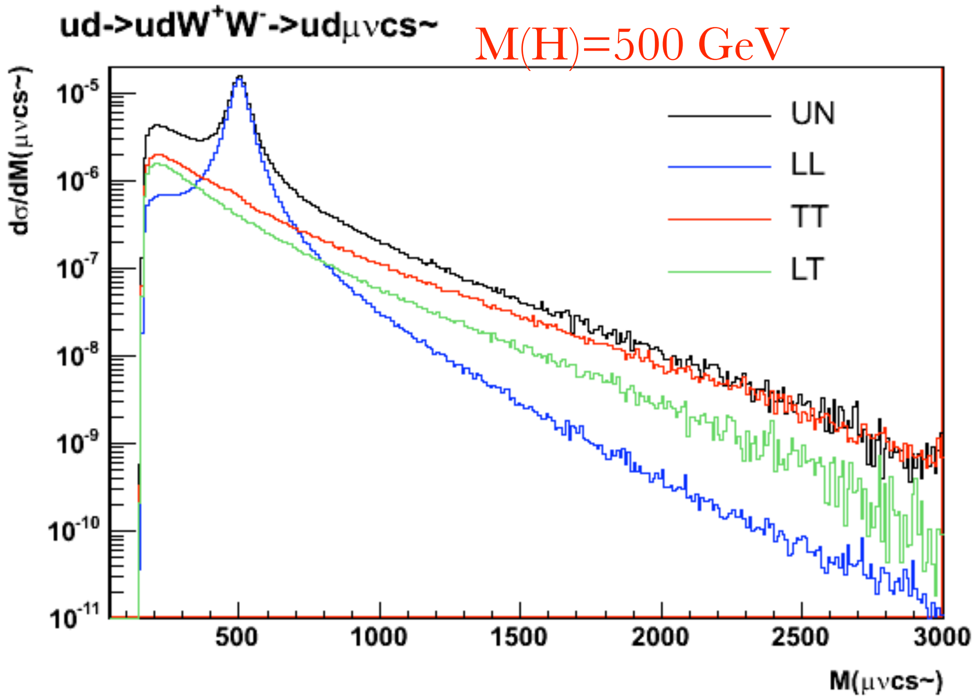
$1 < \eta(d) < 5.5$ $\quad -1 > \eta(u) > -5.5$
$E(u,d,c,s,\mu) > 20$ GeV $\quad P_t(u,d,c,s,\mu) > 10$ GeV
$70 < M(sc, \mu\nu) < 90$

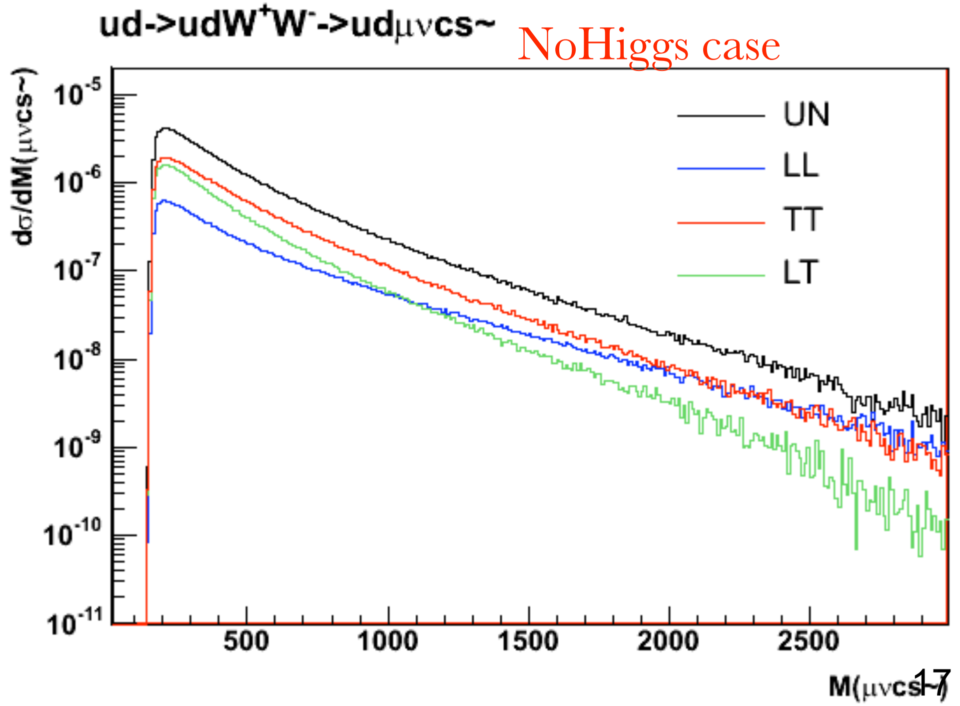
The V_L's are coupled to the Higgs and they are the ones sensitive to the EWSB.

The behavior of the LL cross section can give information on the scale at which the symmetry breaks.

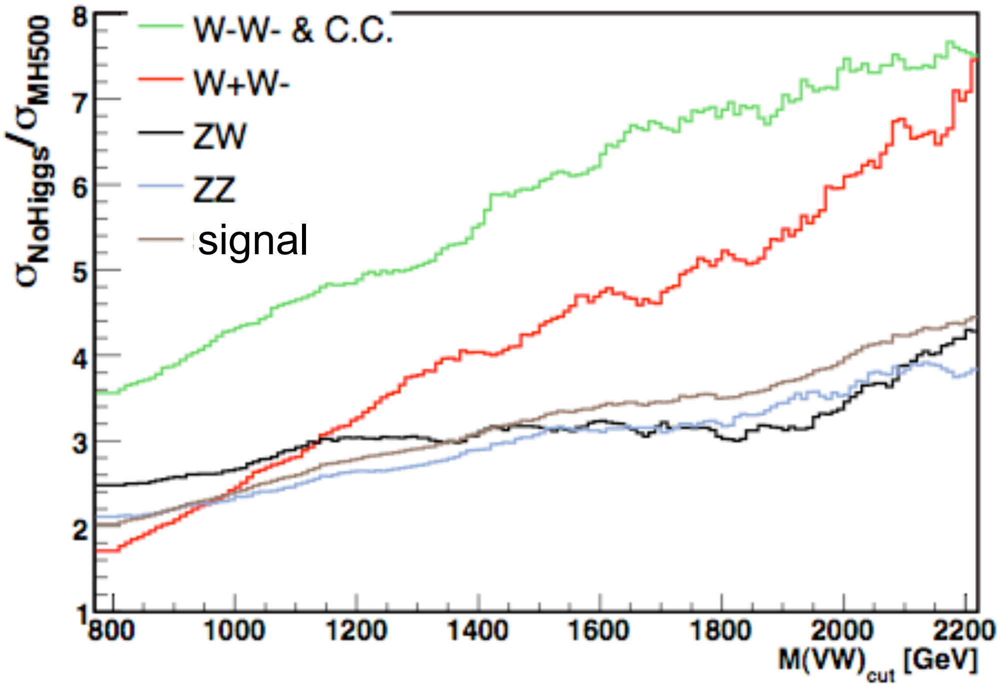
At large M(VV) the TT cross section is of the same order as the LL and σ_{tot} (MH=500) ~σ_{tot} (noHiggs)

E. Accomando *et al.* Boson-boson scattering and Higgs production at the LHC from a six fermion point of view: four jets + lν processes at $O(\alpha^6_{em})$





The ratio no-Higgs/Higgs at parton level



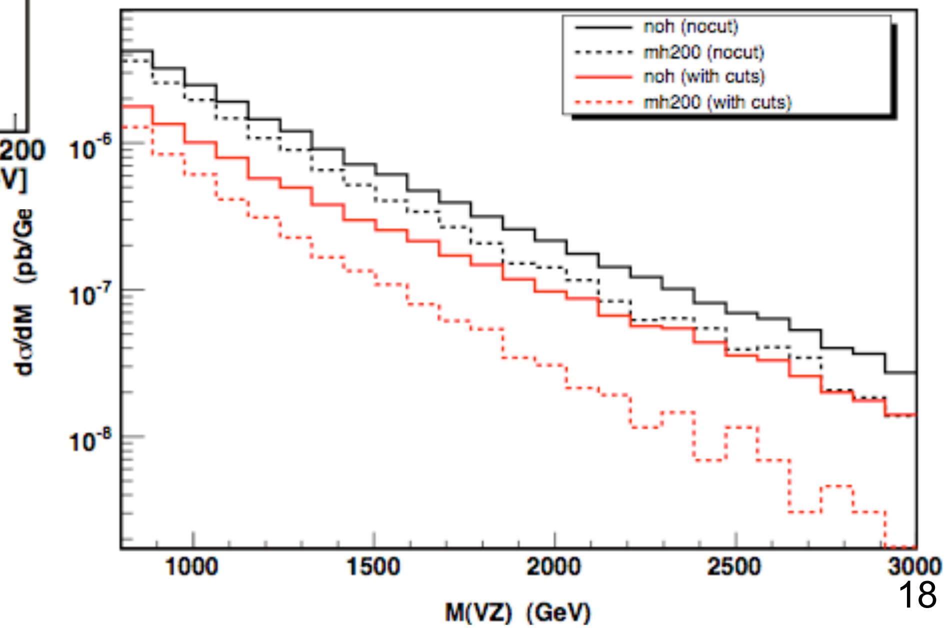
final state qqqq$\mu\nu$

A neural network has been trained to discriminate Higgs from no-Higgs at large M(VV).

Very good discrimination can be achieved. Certain channels are more sensitive.

final state qqqq$\mu\mu$

A cut on $|\eta_V| < 2$ as been applied to enhance the difference between Higgs and no-Higgs at large M(VV).



No-Higgs/Higgs in the detector

- At **reconstructed level**, additional cuts have been added to enhance the difference between the Higgs and the no-Higgs scenarios

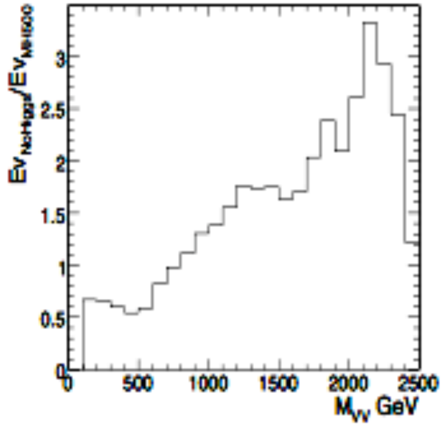
  $\Rightarrow |\eta_V| < 2$, $|\eta_j - \eta_V| > 0.7$

- The ratio

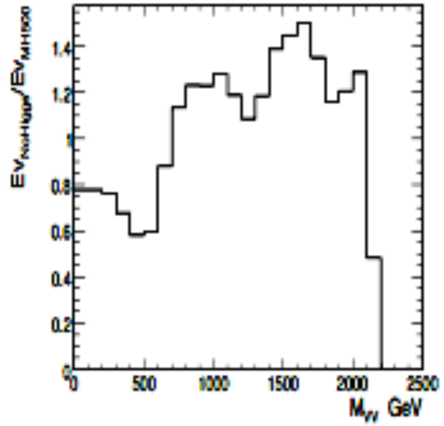
$$\frac{\int_{M_{cut}}^{\infty} dM_{VV} \frac{d\sigma_{noHiggs}}{dM_{VV}}}{\int_{M_{cut}}^{\infty} dM_{VV} \frac{d\sigma_{M_H=500}}{dM_{VV}}}$$

has been plotted as a function of M(VV)

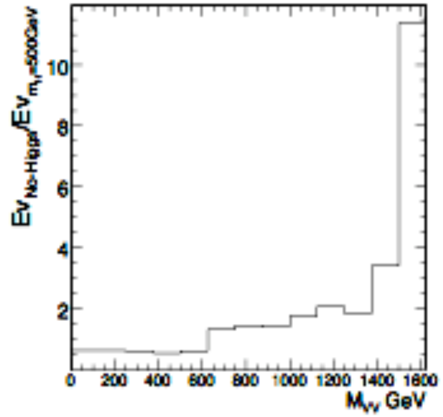
Ratio no-Higgs/Higgs



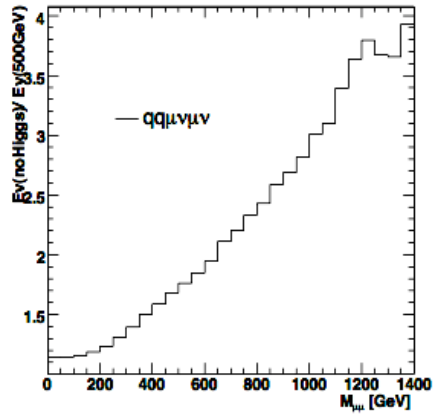
qqqqμν final state



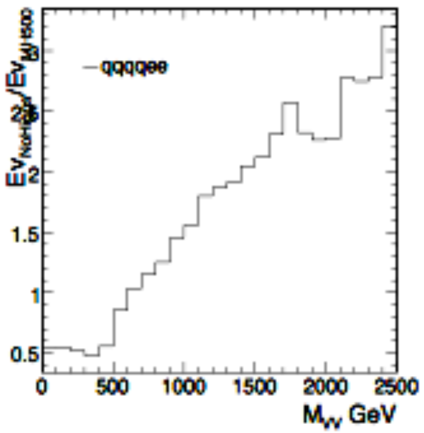
qqqqeν final state



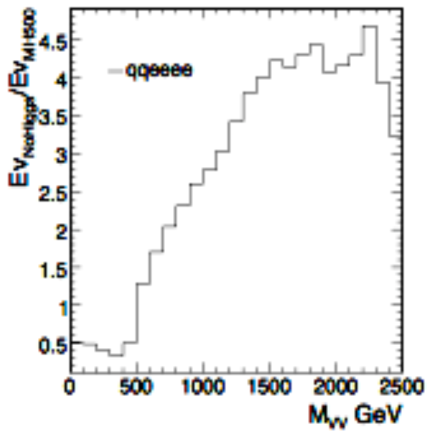
qqqqμμ final state



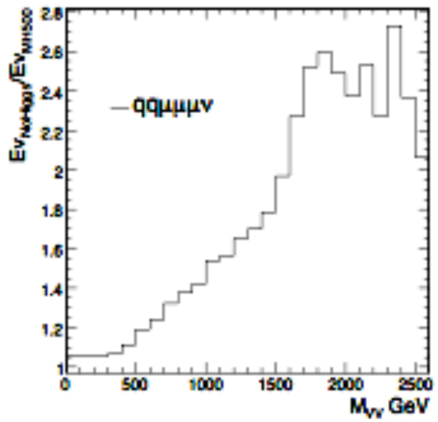
qq$\mu^{\pm}\nu\mu^{\pm}\nu$ final state



qqqqee final state



qqeeee final state



qqμμμν final state

Summary

- VV-scattering holds the key to understand the Electroweak Symmetry Breaking
- this analysis shows a way to probe the EWSB in a model independent way
- at LHC, in the high luminosity phase, encouraging results have been found