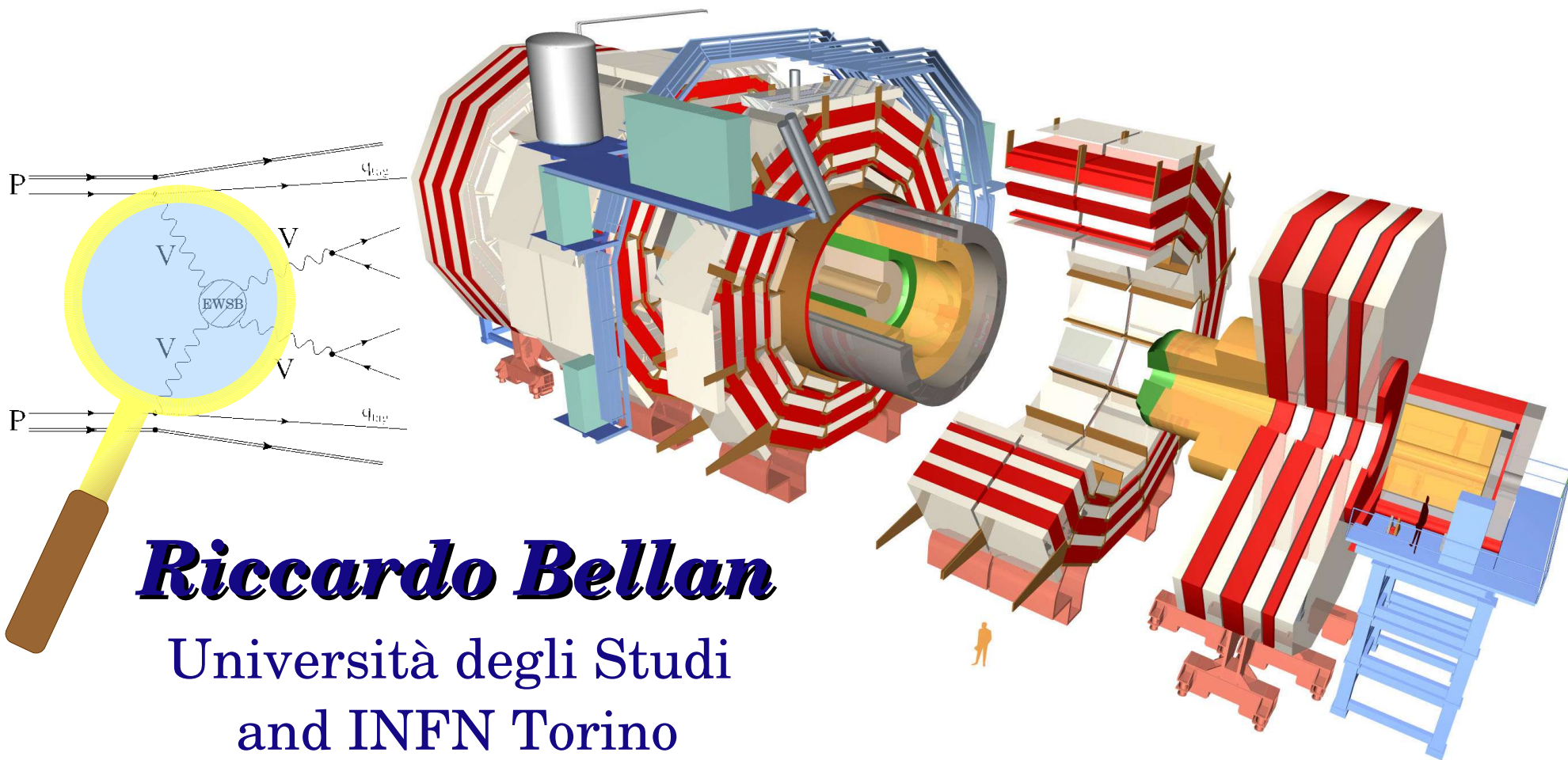


VV-Fusion at CMS



Riccardo Bellan

Università degli Studi
and INFN Torino

FrontierScience 2005

LHC: physics and detectors

No-Higgs Scenario

No-Higgs scenario

New physics *must*
occur to restore it!

Unitarity Violation in the **Vector Boson fusion** processes

Outline

- VV-Fusion as a tool to investigate EWSB:
 - ElectroWeak Symmetry Breaking (EWSB);
 - Unitarity Violation.
 - VV-Fusion processes.
- Monte Carlo event generators for VV-Fusion:
 - Important points in choosing the right MC;
 - PHASE, MadGraph and Pythia: some comparisons.
- Preliminary results with simulated data:
 - CMS “Very” Fast Simulation (CMSJet);
 - CMS Full Simulation (OSCAR/ORCA).

VB Polarization in ElectroWeak Interactions

$SU_L(2) \otimes U_Y(1)$ Model

4 massless vector bosons



2 TRANSVERSE d.o.f.
of polarization for each.

Phenomenological Pattern

✓ 1 massless VB (photon)



2 Transverse d.o.f. of polarization.

✓ 3 massive VBs (W^\pm and Z)



3 d.o.f. of polarization for each:
2 Transverse and **1 Longitudinal**

ElectroWeak Symmetry Breaking

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3 Goldstone Bosons

($m=0$, $S=0$) **EWSB**

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3 d.o.f. of polarization for each:
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In the SM:

Higgs Mechanism

1 Isodoublet,

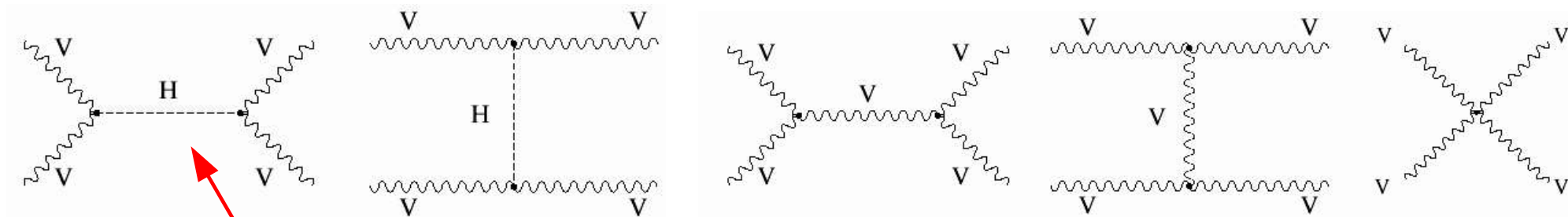
with 4 massless scalar fields
and $v_{ev} \neq 0$

✗ 1 Higgs Boson,
scalar and massive

VV - Fusion

The processes which involve the **fusion** of **longitudinally** polarized **vector bosons** are very promising channels to study the EWSB...

...with



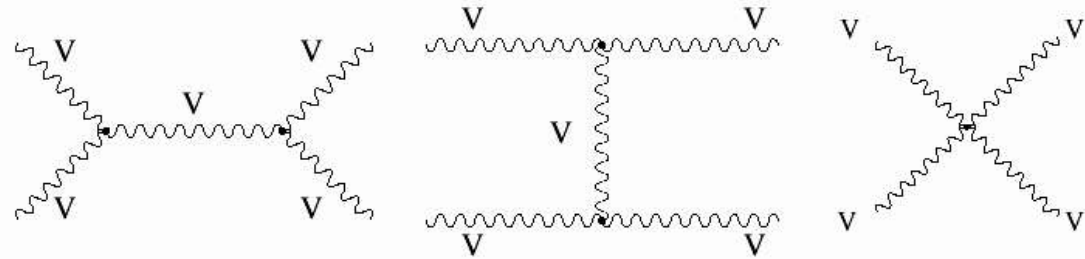
In the case of a Higgs, it will be possible to observe in the cross section a resonance in correspondence to m_H

VV - Fusion

The processes which involve the **fusion** of **longitudinally** polarized **vector bosons** are very promising channels to study the EWSB...

...or without

$$M \sim \frac{G_F S}{\sqrt{2}} (1 + \cos \theta_{cm})$$



Without the Higgs
the amplitude of
longitudinally polarized
vector boson fusion
violate the unitarity



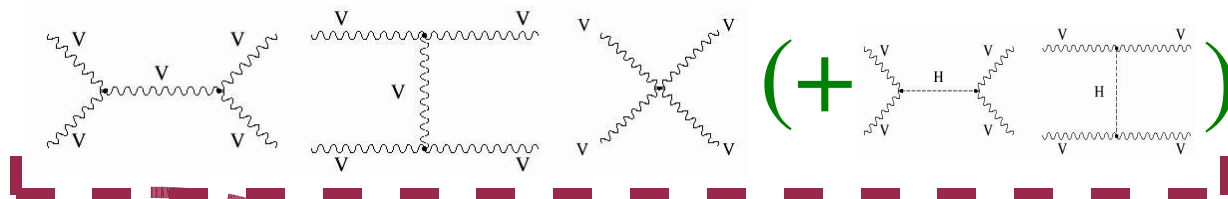
A deviation from the Standard Model cross section (as a function of VV invariant mass) will be observed in the range 1-2 TeV



Accessible at LHC!

VV-Fusion Processes at LHC

The VV scattering processes *cannot be studied as they are* ... we haven't V-beams!

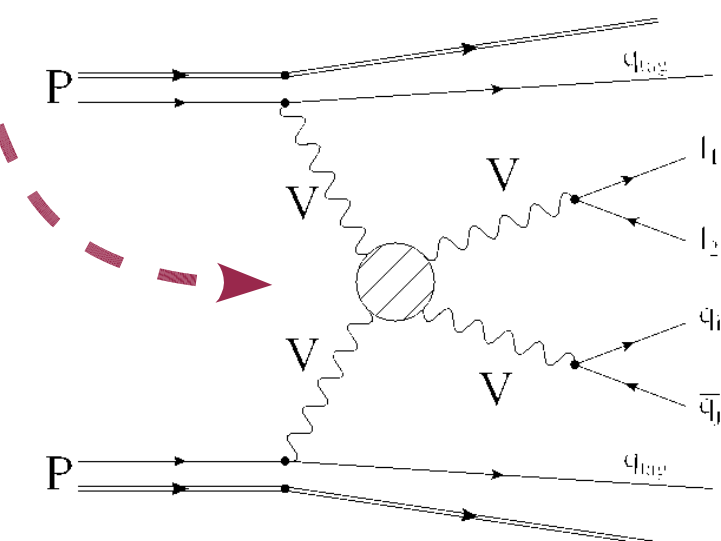


Therefore we have to **extract them from more complex processes**, like the **proton-proton collision**, and to select particular decay modes of the VBs.

➔ For **our analysis** we have chosen the **semileptonic decays** of the VBs:

$$pp \rightarrow j_F j_B \mu \nu jj$$

$$pp \rightarrow j_F j_B \mu \mu jj$$



Other problems

Theo

Spe

The processes become “two fermions into 6 fermions final state”!!

@LHC ($\sqrt{s} = 14 \text{ TeV}$, $\mathcal{L}_L = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, $\mathcal{L}_H = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)

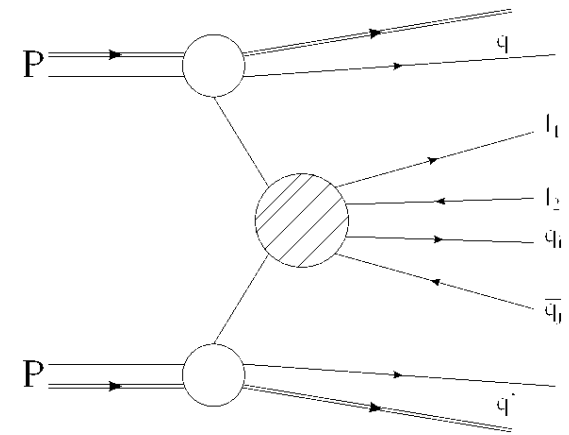
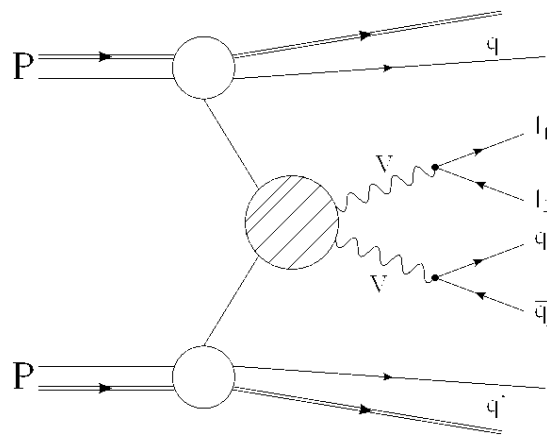
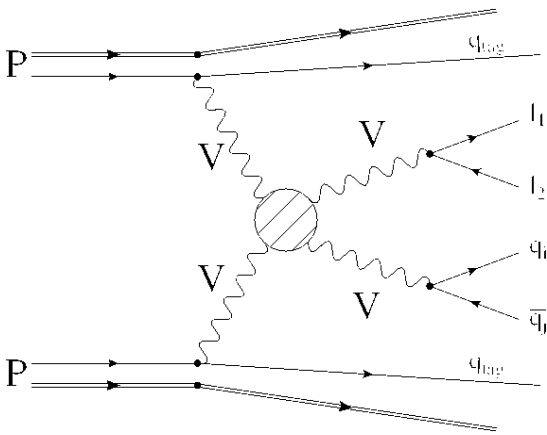
➔ A lot of **background** and **pile-up** effect!!

Theoretical Problems

- ⇒ Generate the events with the complete calculation
- ⇒ New Signal definition

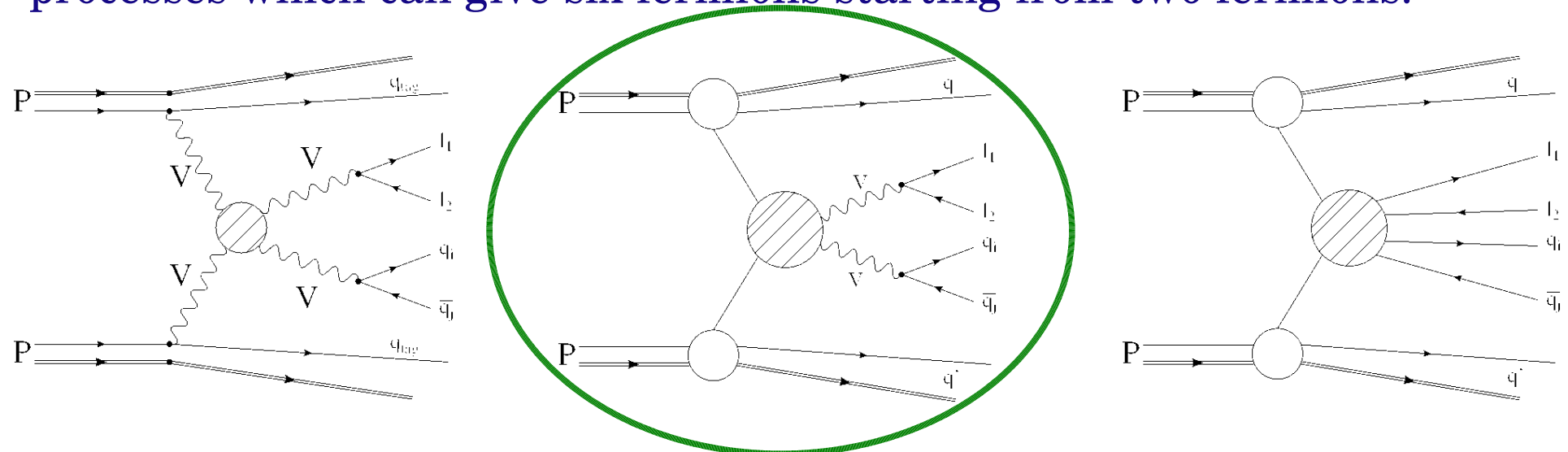
Calculating Six Fermions Final State

Since we have a **six fermions final state**, we cannot neglect the other processes which can give six fermions starting from two fermions.



Calculating Six Fermions Final State

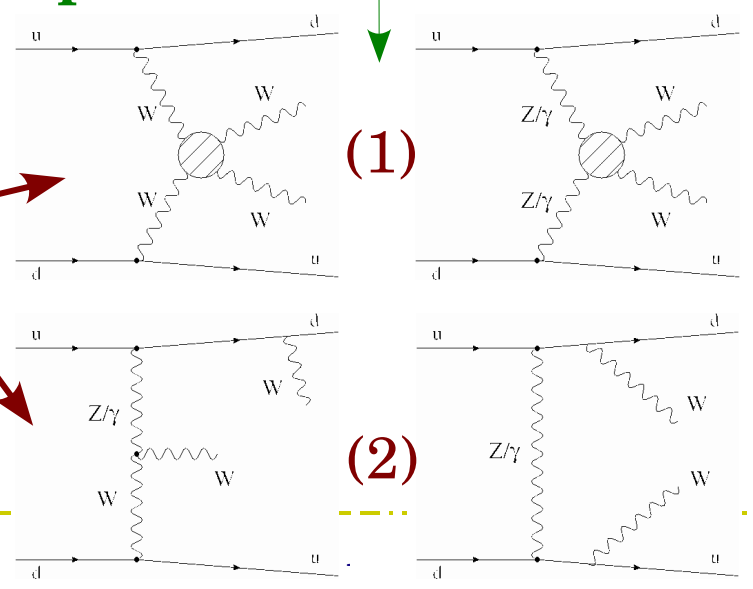
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Example of the effect: $ud \rightarrow udW^+W^-$

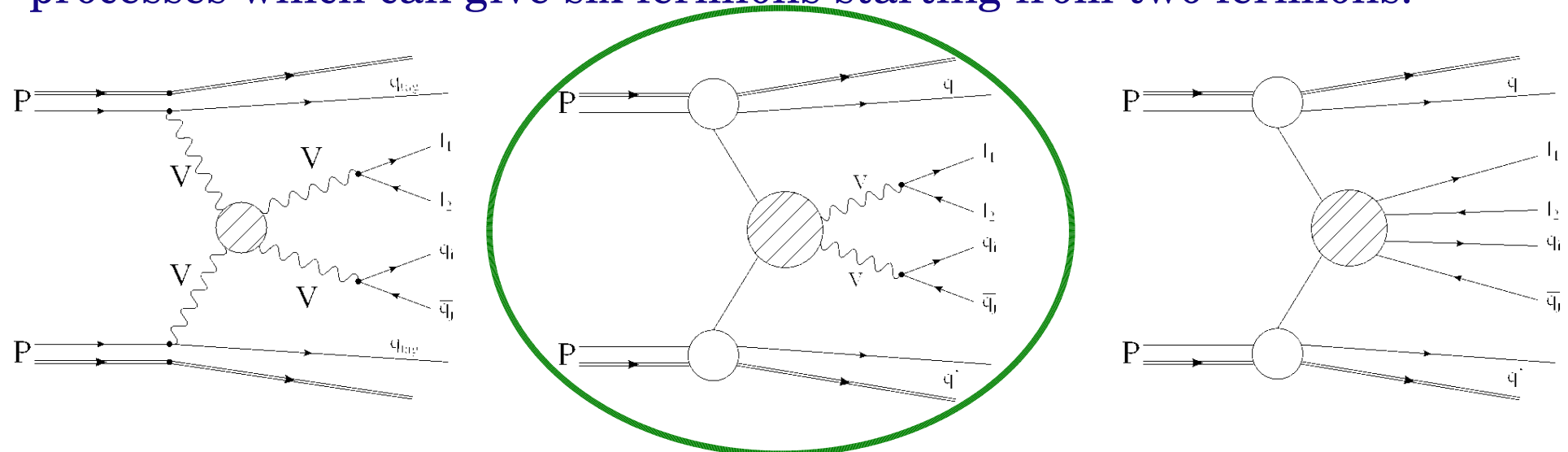
The two sets are not separately gauge invariant!!

Considering only one of them it may be dangerous!



Calculating Six Fermions Final State

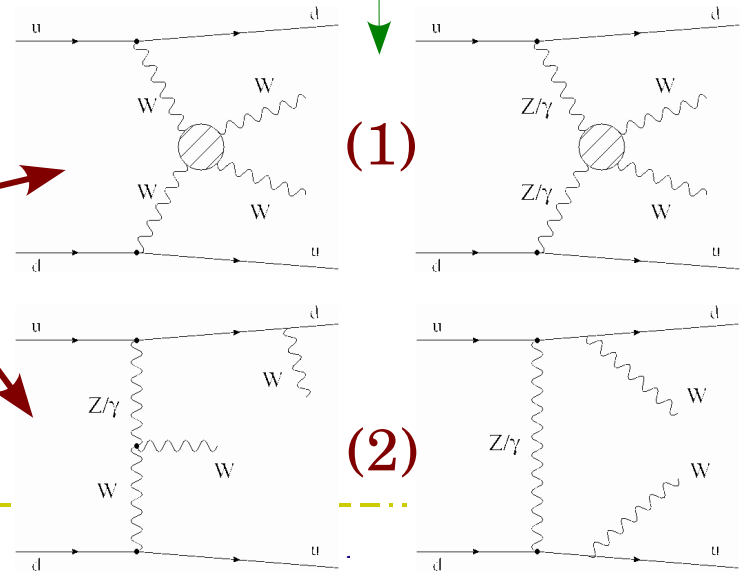
Since we have a **six fermions final state**, we cannot neglect the other processes which can give six fermions starting from two fermions.



Example of the effect: $ud \rightarrow udW^+W^-$

The two sets are not separately gauge invariant!!

Considering only one of them it may be dangerous!



Large cancellations from **negative interference** occur

No-Higgs	Cross Section (pb)
WW fusion	0,25
all diagrams	0,0186

In the Feynman gauge

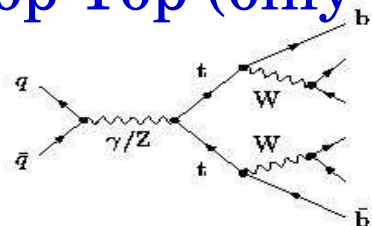
Complete Calculation

PHASE MC Generator

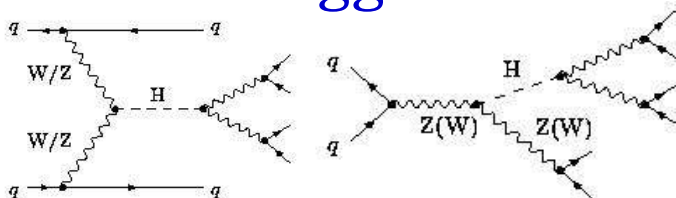
has been designed to generate
the complete processes

“two quarks into six fermions”[‡]

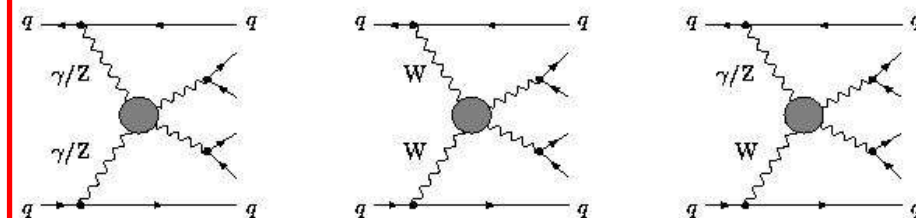
Top Top (only EW)



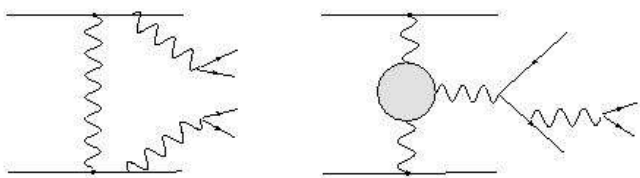
Higgs



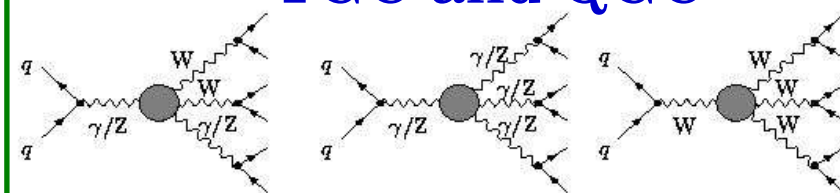
VV-fusion



Non resonant



TGC and QGC



‡ At the order of α_{em}^6

Signal Definition

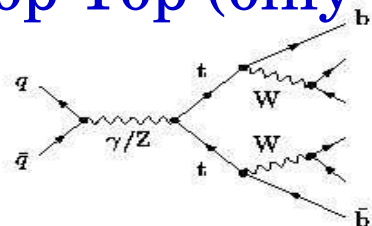
PHASE MC Generator

has been designed to generate
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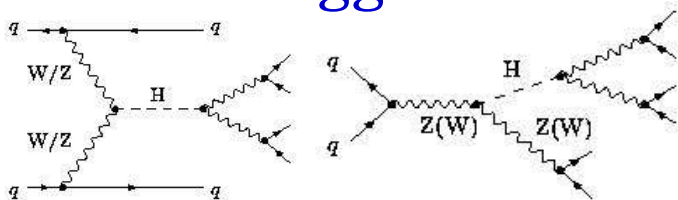
“two quarks into six fermions”[‡]

Generate the complete process
2 quarks into 6 fermions

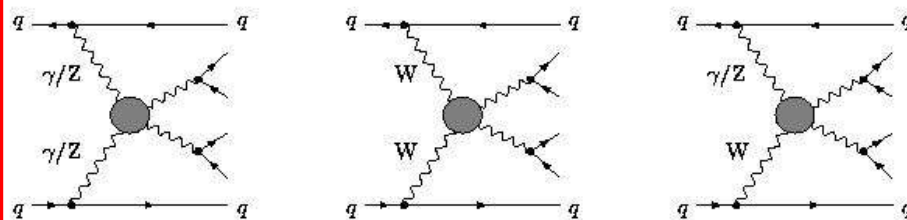
Top Top (only EW)



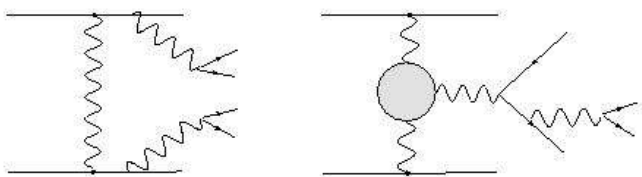
Higgs



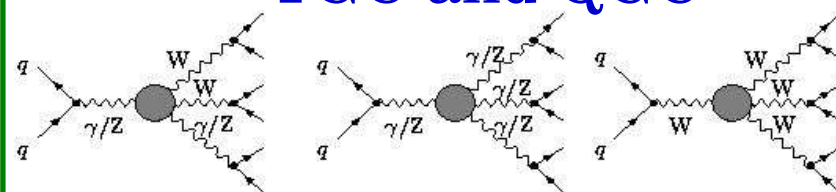
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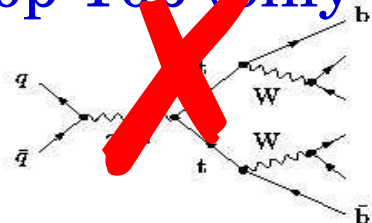
‡ At the order of α^6_{em}

PHASE MC Generator

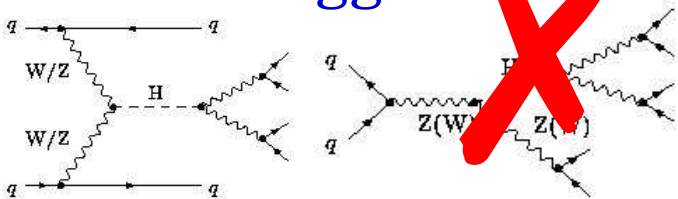
has been designed to generate the complete processes

“two quarks into six fermions”‡

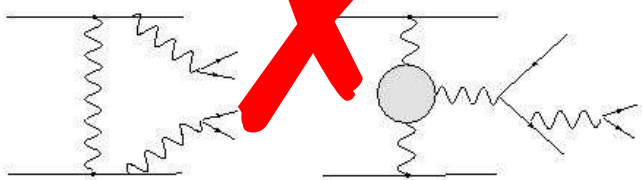
Top Top (only EW)



Higgs



Non resonant

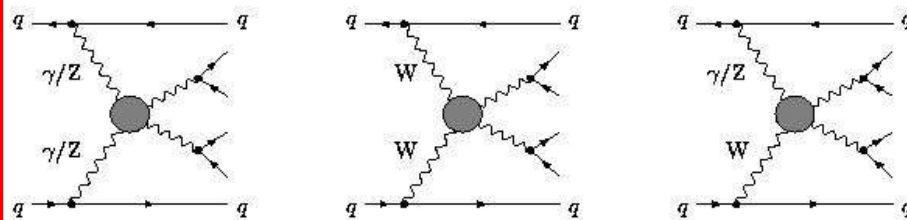


Generate the complete process
2 quarks into 6 fermions

only after the generation

impose the cuts (at parton level)
to extract **the signal**

VV-fusion



TGC and QGC



Signal Definition

★ Cuts against:

- The **top-top** and the **single top**;
- **Three vector boson** in the final state.

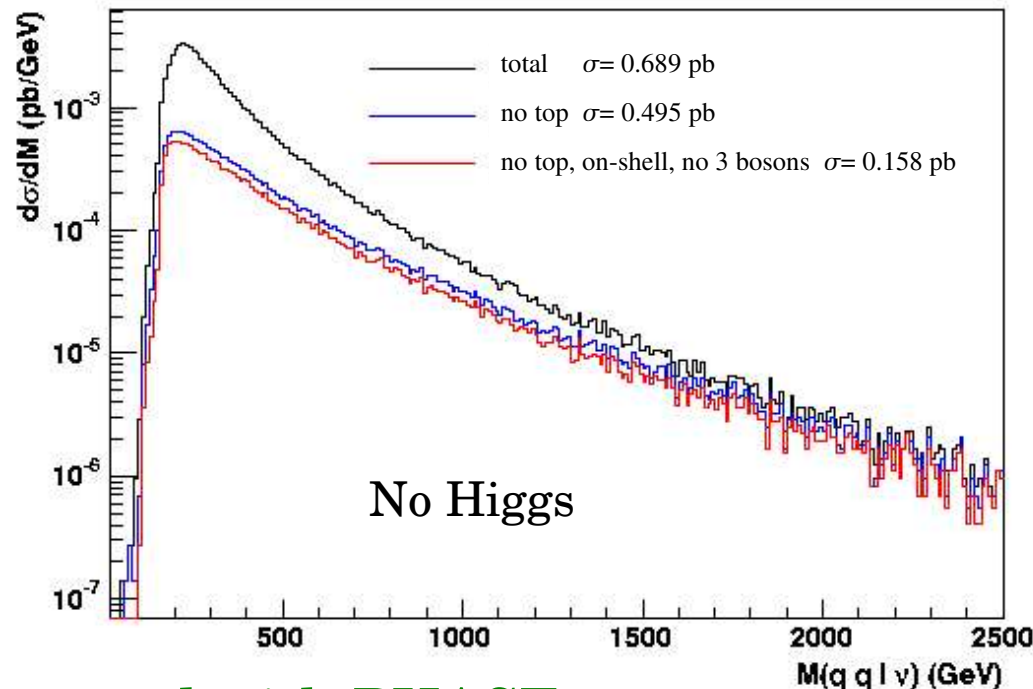
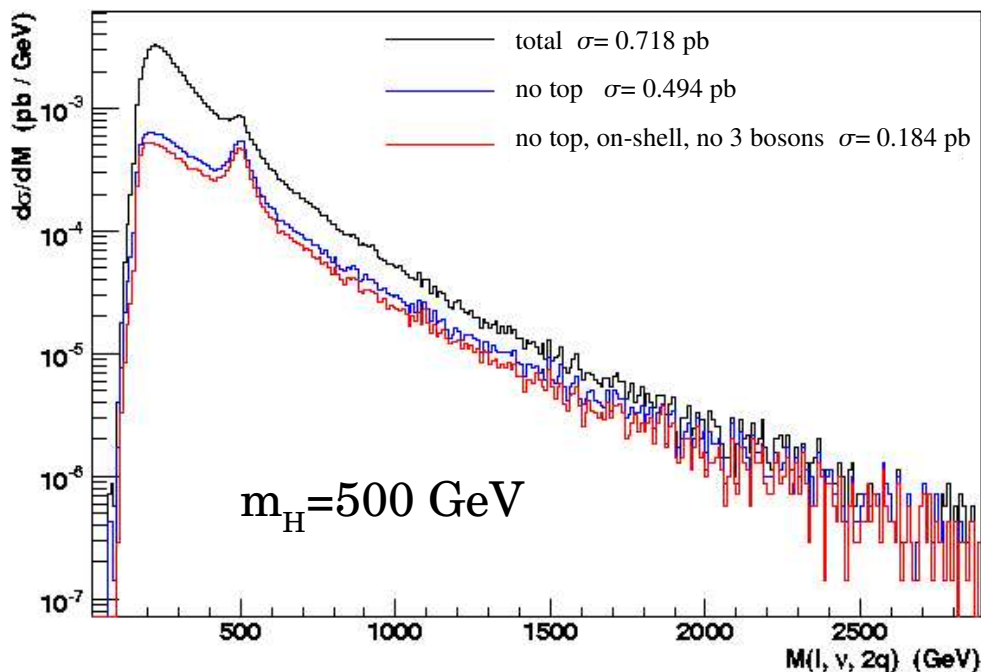
→ Reduction of **70%**[†]

→ Reduction of **2%**[†]

★ Request:

- **Two “on-shell” vector bosons** in the final state. → Reduction of **3%**[†]

[†] of the total cross section



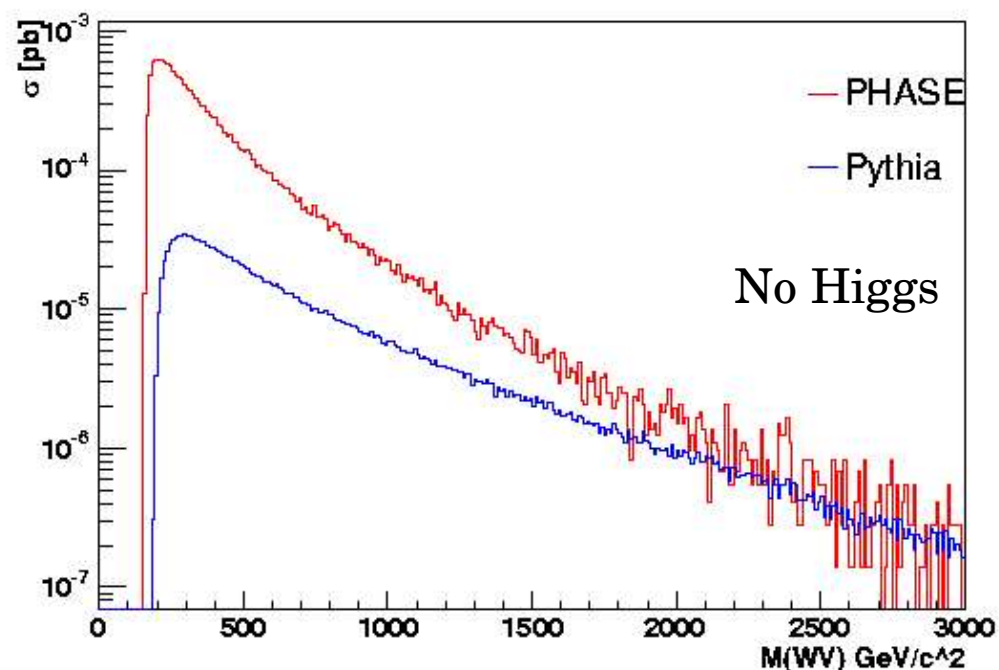
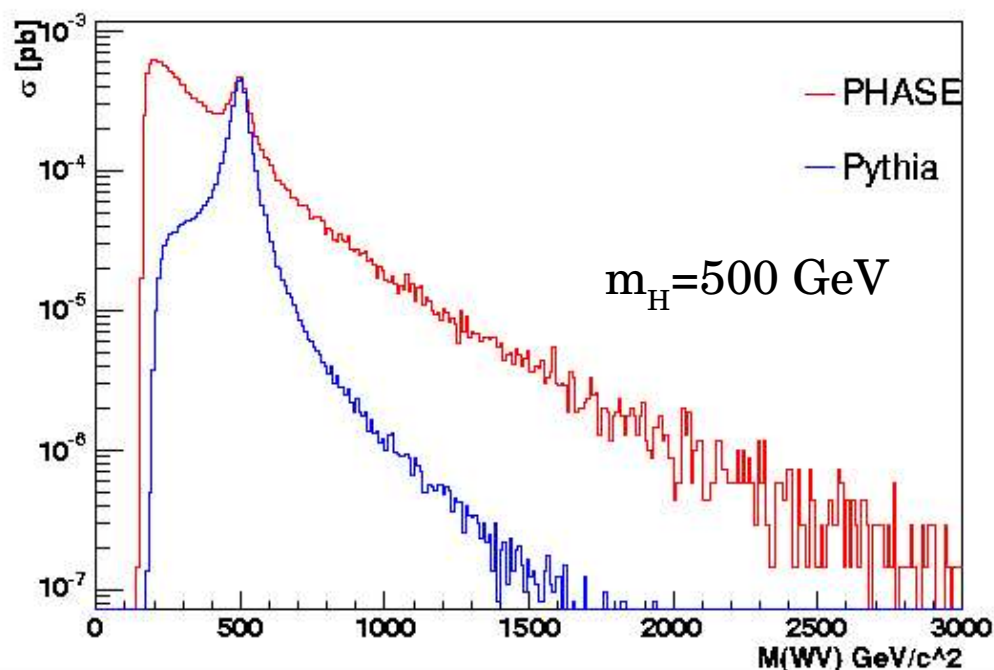
Events have been generated with PHASE

Monte Carlo Comparisons

Pythia vs Phase

- ◆ EWBA
 - ◆ Only the LL polarization
- in the channel: $qq \rightarrow q_F q_B \quad qq \mu\nu$

- ◆ Complete calculation
- ◆ All the polarizations



Big differences all over the spectra, for both the comparisons

Monte Carlo Comparisons

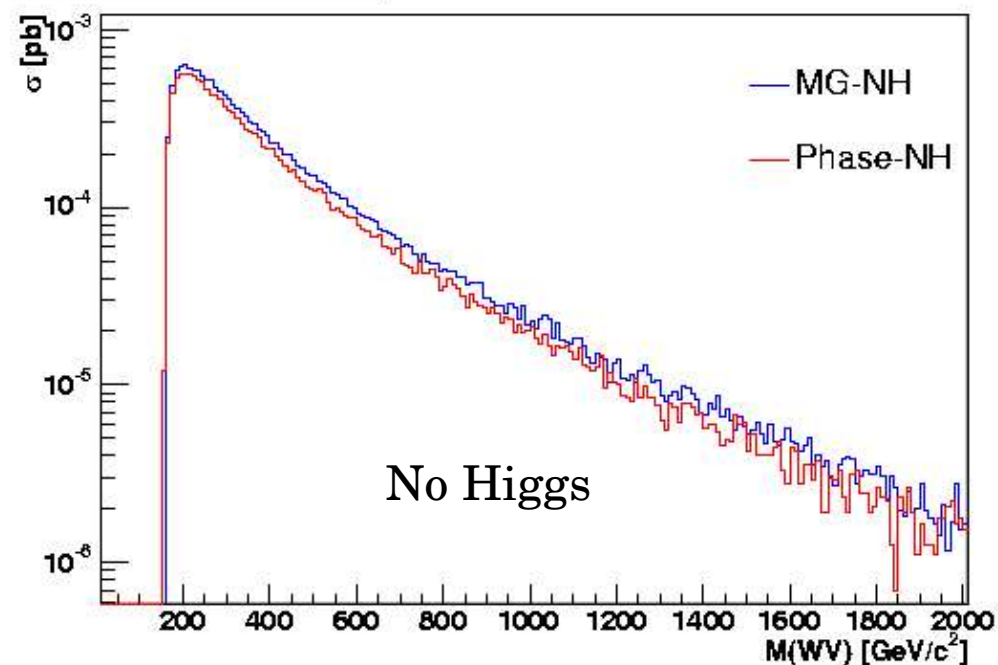
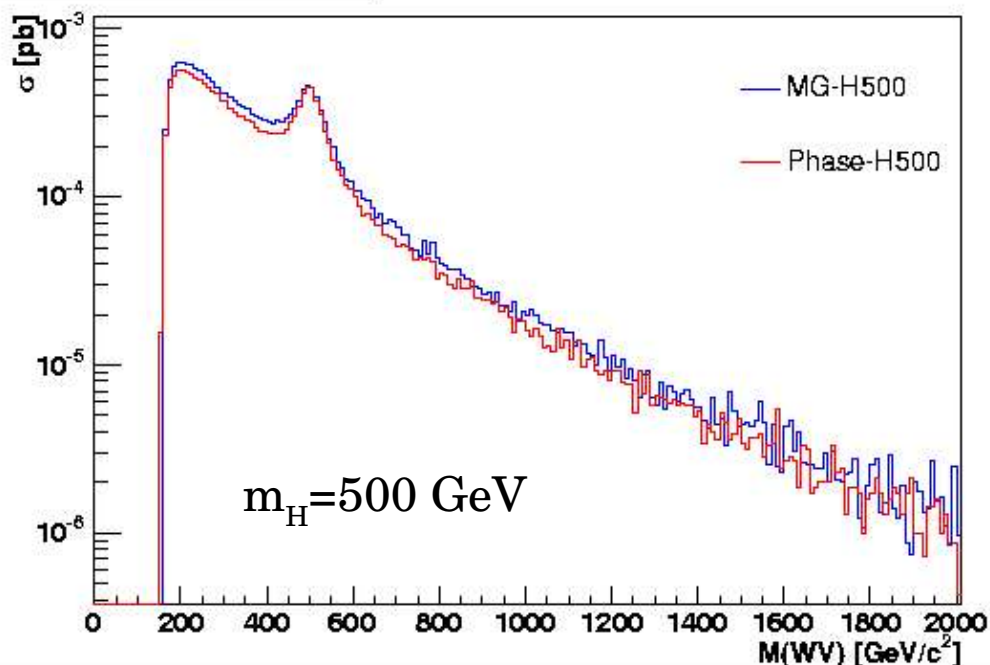
MadGraph vs Phase

- ◆ Production and Decay
- ◆ Zero-width VBs
- ◆ All the polarizations

in the channel:

$$qq \rightarrow q_F q_B \quad qq \mu\nu$$

- ◆ Complete calculation
- ◆ All the polarizations



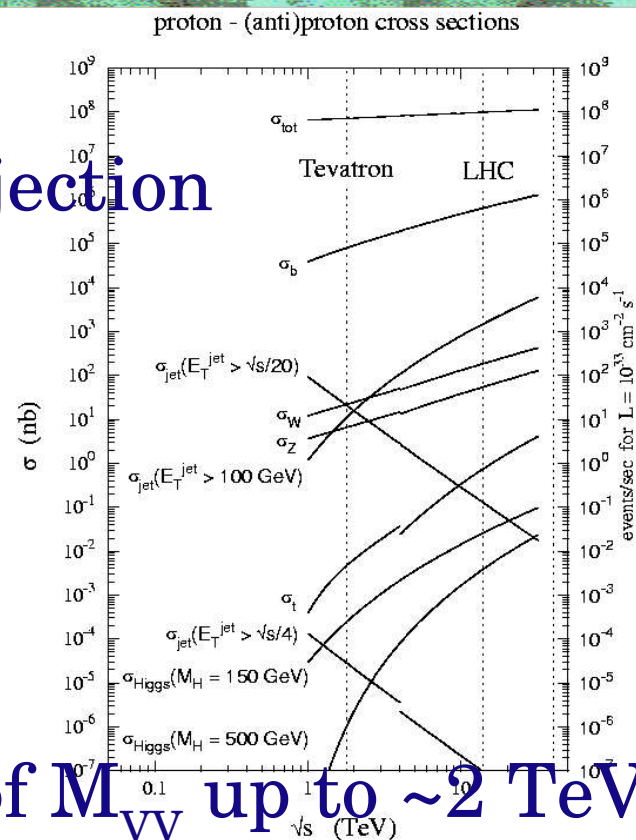
There is a difference of 20% over all the spectra, for both the comparisons. We are investigating the mismatch!

Experimental Problems

⇒ Background estimation and Rejection

⇒ Pile-up Jets Rejection

⇒ Measure the σ_{VV} as a function of M_{VV} up to ~ 2 TeV and estimate the resolution on it



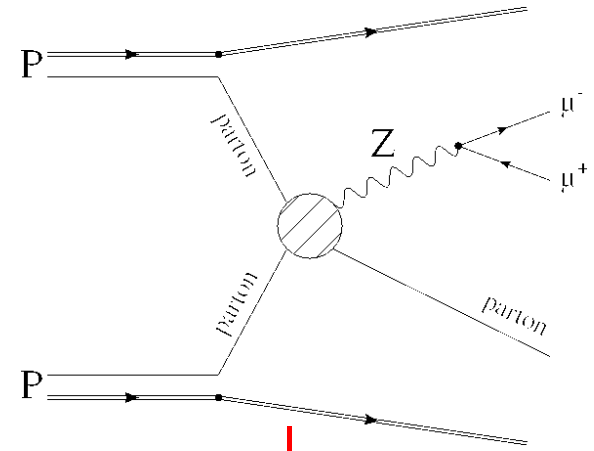
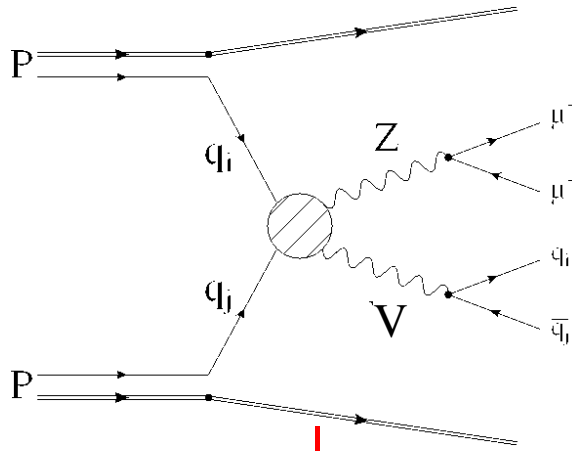
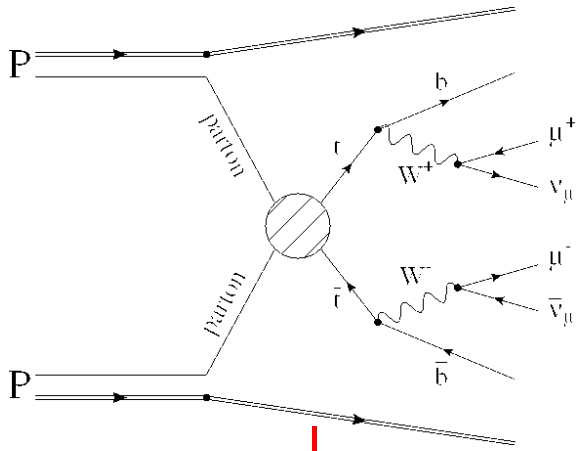
Caveat: up to now the studies have been made with **Pythia** (for the Signal and Background Generation) and with the “very” fast simulation of the CMS detector (\rightarrow **CMSJet**).

Further studies with **FAMOS-Phase** and **OSCAR/ORCA-MadGraph** **are in development!**

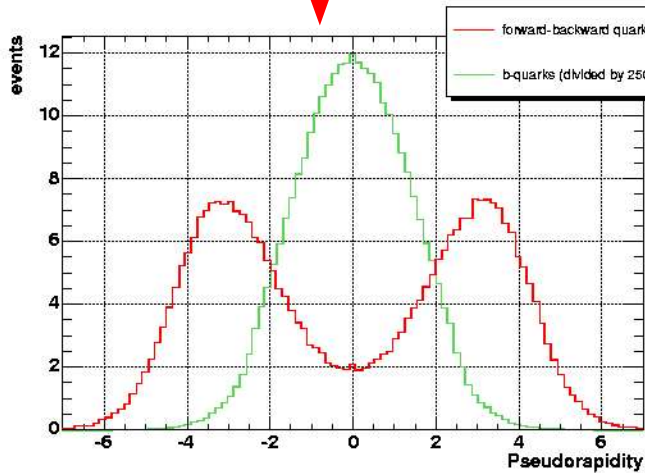
Backgrounds

for $pp \rightarrow j_F j_B \mu\mu jj$ sample

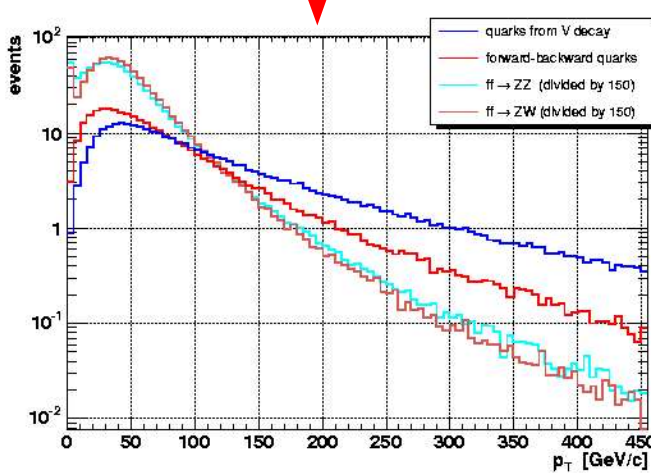
Generated with pythia



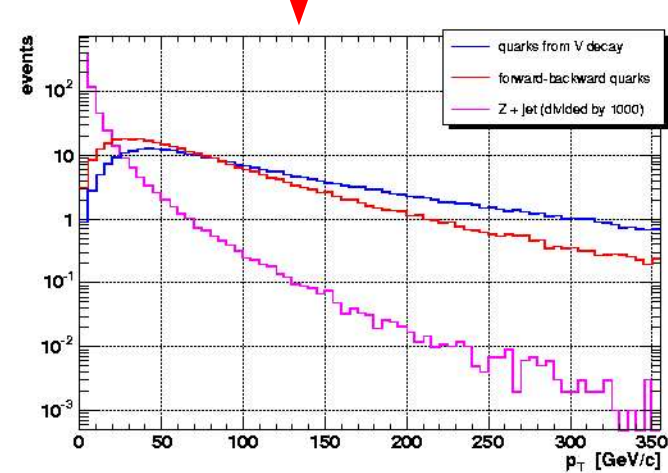
Most important cut



$\sigma \sim 620 \text{ pb}$



$\sigma \sim 655 \text{ fb}$



$\sigma \sim 14 \text{ nb}$

... the signal $\Rightarrow \sigma_{500} \sim 9.8 \text{ fb}$ & $\sigma_{\text{no-H}} \sim 3.1 \text{ fb}$

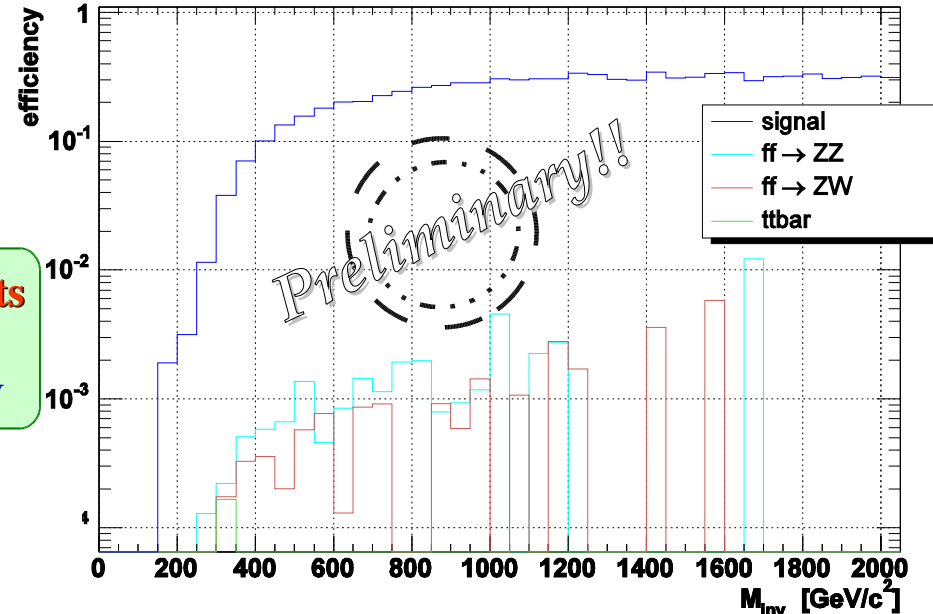
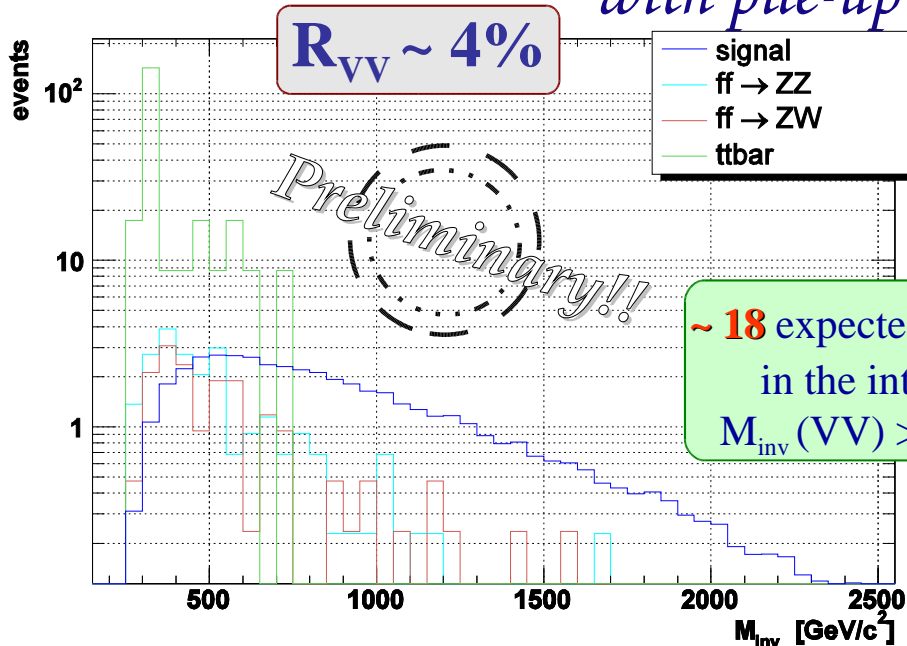
Preliminary Results

No-Higgs scenario

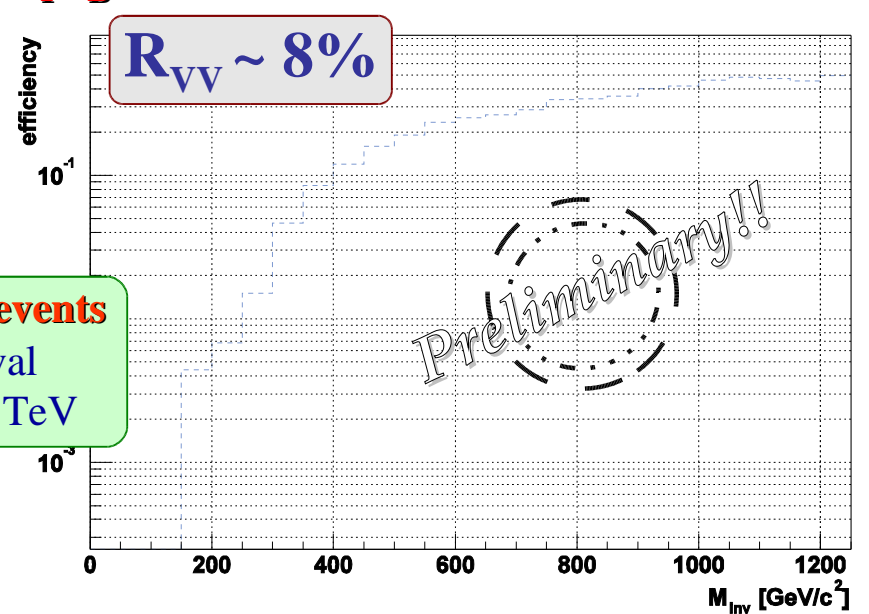
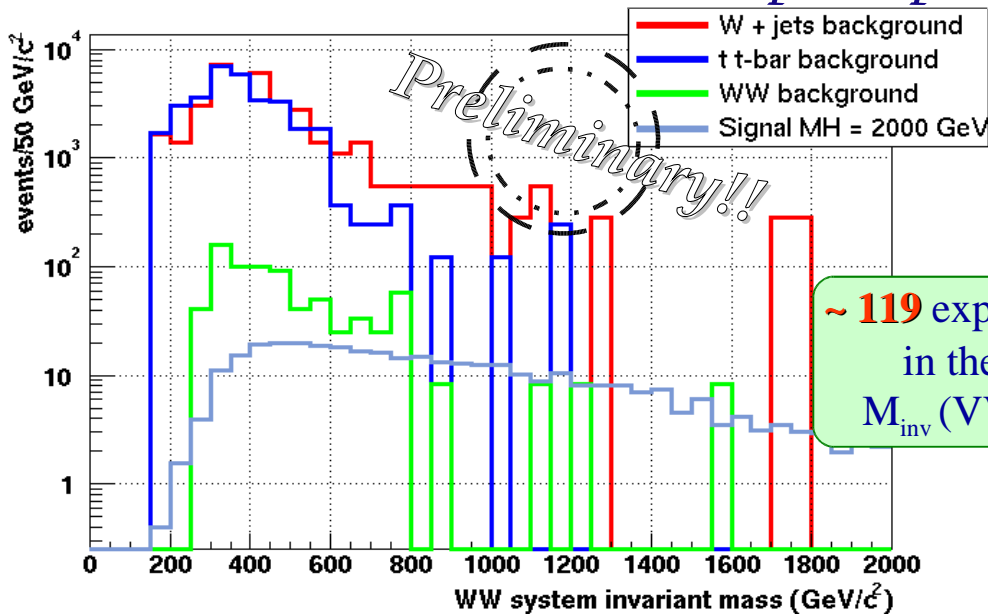
1y @ high luminosity: $\mathcal{L}=100 \text{ fb}^{-1}$

CMSJet

with pile-up $pp \rightarrow j_F j_B \mu\mu jj$



without pile-up $pp \rightarrow j_F j_B \mu\nu jj$



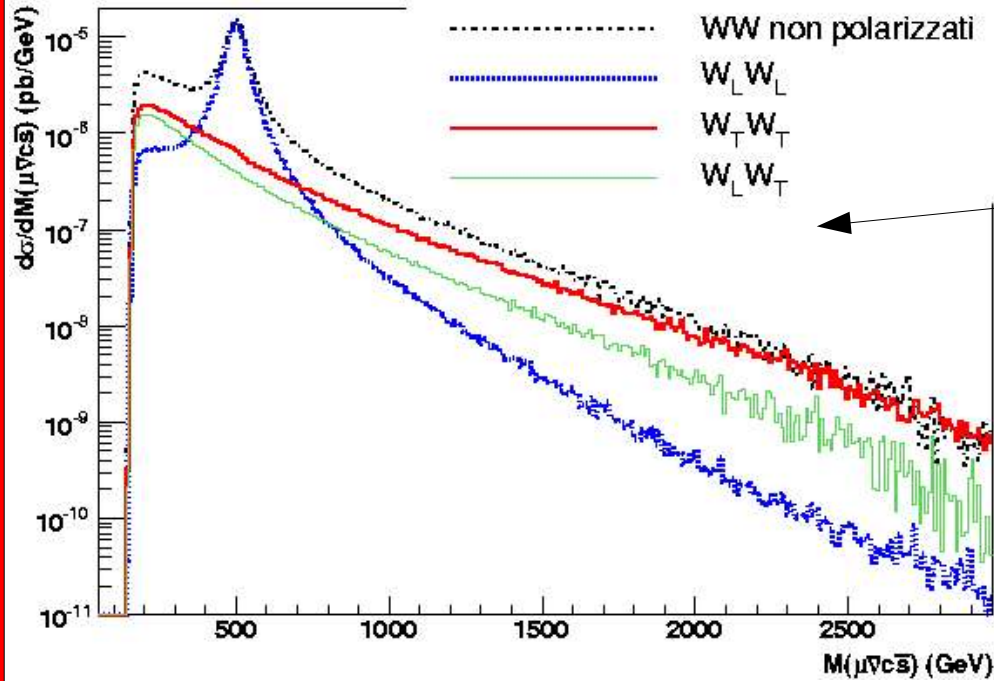
Summary

- ◆ VV-Fusion will probe the EWSB in a model independent way.
- ◆ From the **preliminary studies** we can conclude:
 - **The investigation** at CMS of the VV-fusion processes is possible:
 - » **Good resolutions** on the major observables
(e.g. $M_{\text{inv}}(\text{VV})$ *the energy scale of the process*) **are achieved**.
 - » **High luminosity is required**.
 - **More Background** must be considered:
 - » $pp \rightarrow \text{VVjj} \rightarrow \ell\ell+4j$, $O(\alpha_{\text{em}}^4 \alpha_{\text{strong}}^2)$ with MadGraph.
 - » $pp \rightarrow V+nj \rightarrow \ell\ell+nj$ ($n=1,5$) with AlpGen.
- ◆ Further studies with the **Full Simulation** of the CMS detector have started:
 - **Preliminary resolution** ($pp \rightarrow \mu\mu 4j$ channel): $R_{\text{VV}} \sim 7.3\%$.

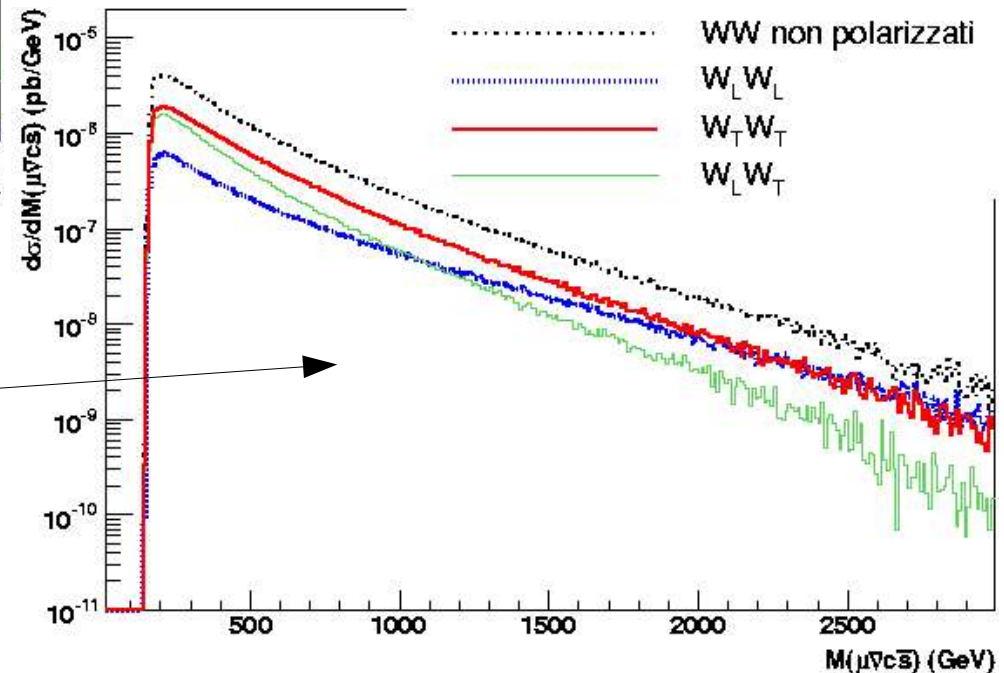
Backup Slides

Polarized Cross Sections

$ud \rightarrow udW^+W^-$



Higgs with 500 GeV mass



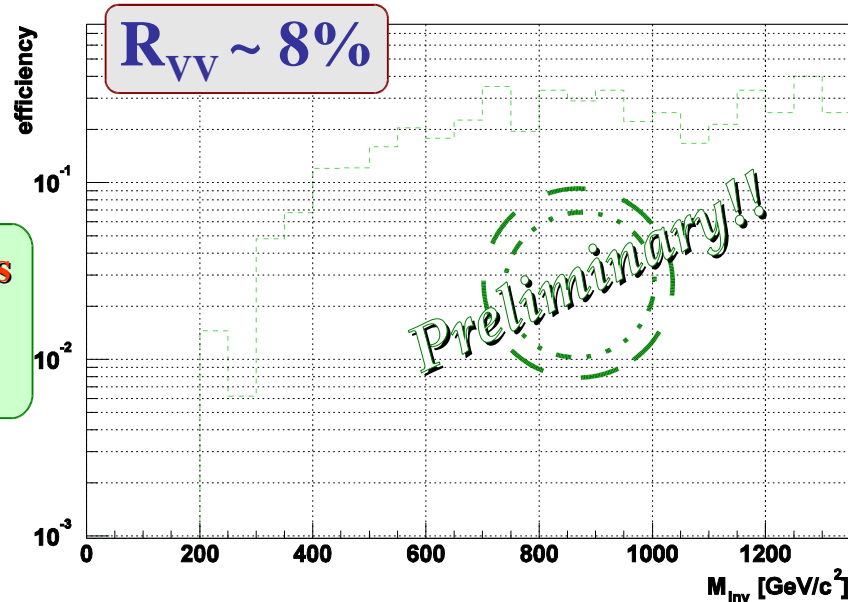
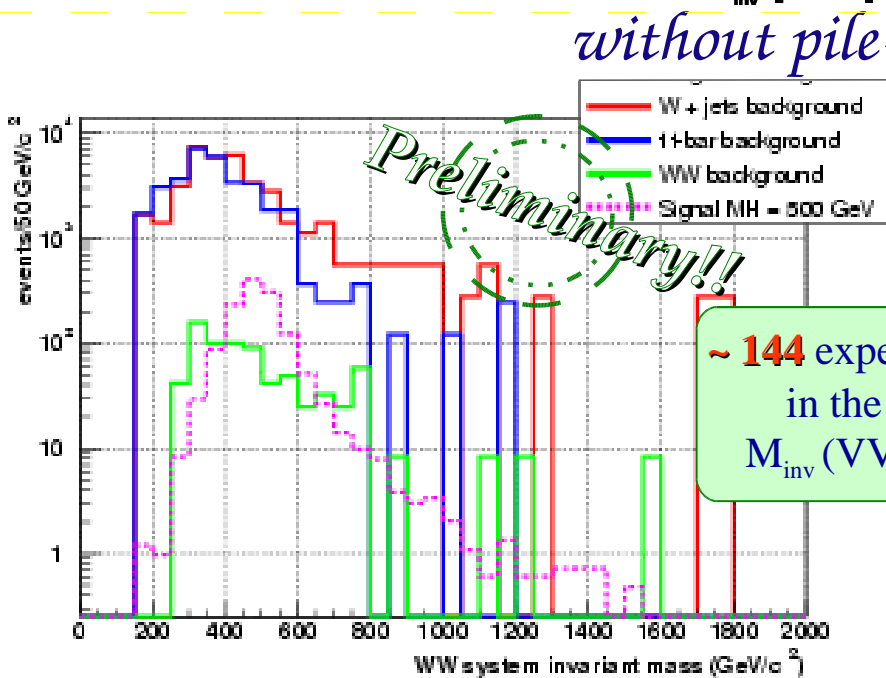
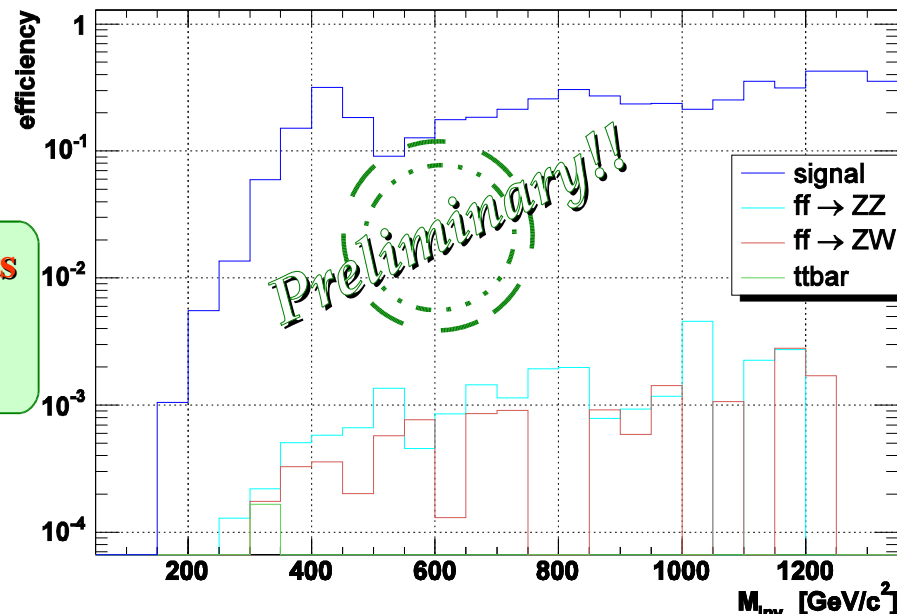
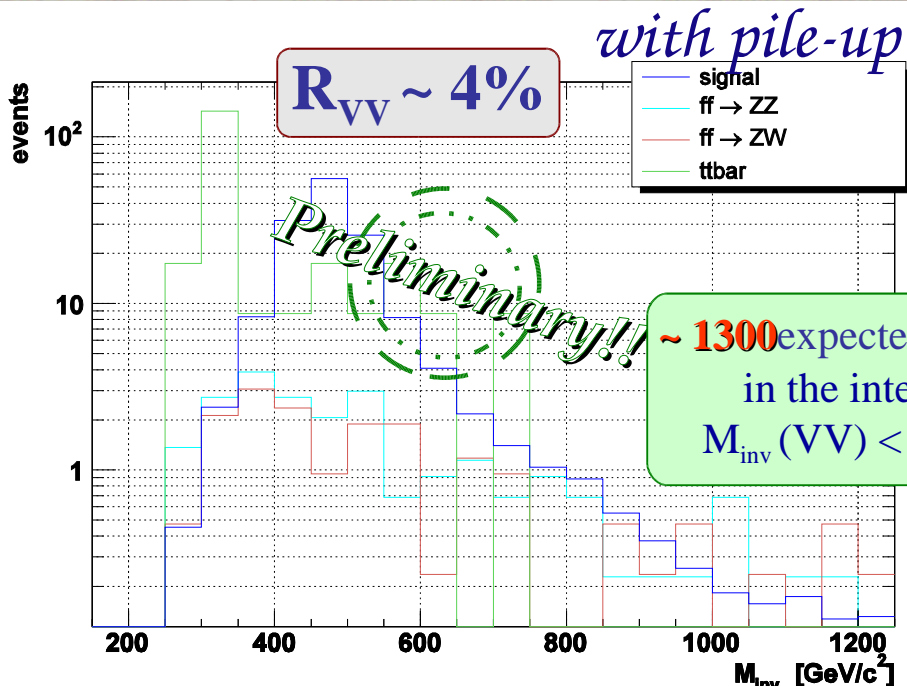
No Higgs scenario

Preliminary Results

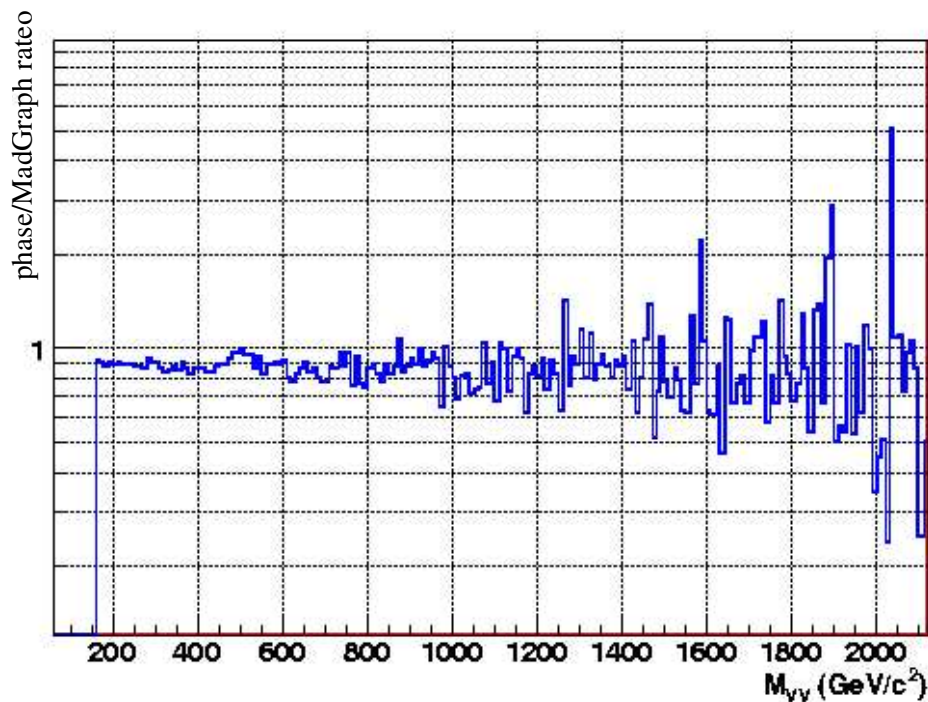
$m_H = 500 \text{ GeV}$

1y @ high luminosity: $\mathcal{L}=100 \text{ fb}^{-1}$

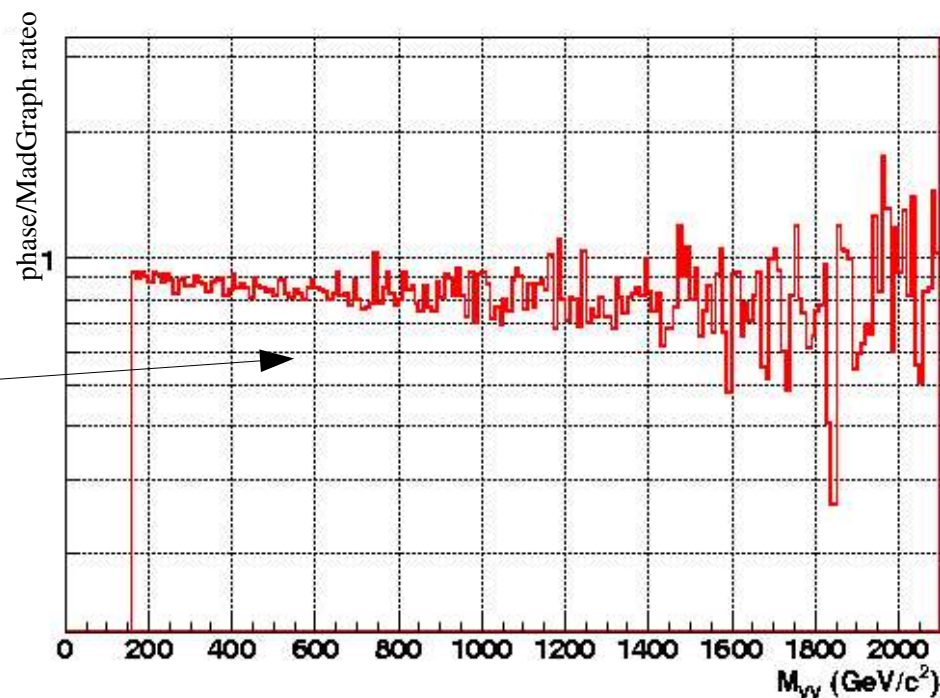
CMS Jet



MadGraph vs Phase



Higgs with 500 GeV mass



No Higgs scenario