Vector Boson Fusion at CMS

HERA-LHC Workshop

Multi-jet Final States and Energy Flows meeting

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Spontaneus Symmetry Breaking

$$SU(2)_L \otimes U(1)_Y$$

The intermediate vector bosons have spin 1 and zero mass. → 2 transverse degrees of freedom

(4 mediators)

Scalar fields have zero mass → 1 d.o.f.

(4 fields)

Simmetry Breaking

3 Goldstone bosons (S=0, m=0)

Higgs Boson (m≠0)

+ the Higgs boson appear

→ 1 degree of freedom

The W e Z bosons become massive → 3 d.o.f. (2 transv. + 1 longitudinal)

The photon remains massless → 2 degrees of freedom

$U(1)_{em}$

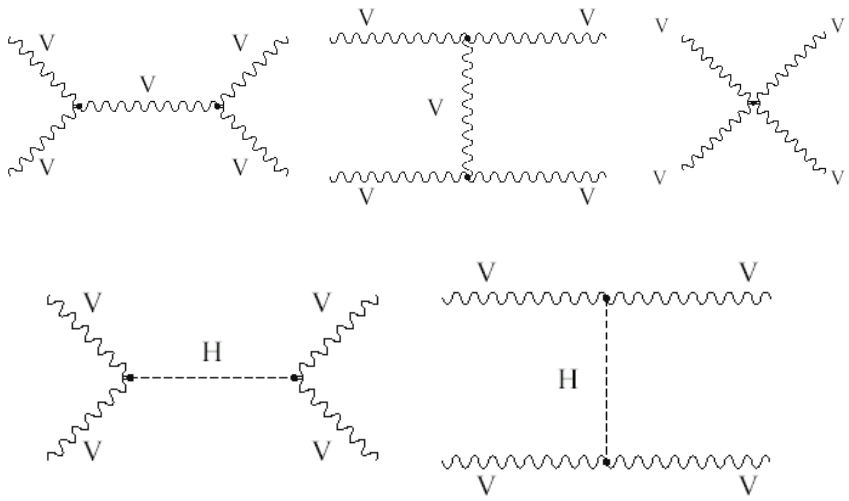
Vector Boson Fusion

The processes which involve the longitudinally polarized vector bosons fusion are very promising channels to study the electroweak symmetry breaking.

Independently of the Higgs boson existence!

- In the case of a light Higgs, it will be possible to observe in the cross section a resonance in correspondence to m_H.
- Otherwise a deviation from the Standard Model cross section (function of VV invariant mass) will be observed.

The processes which involve the V_L violate the unitarity at high energy if the Higgs boson does not exist



The Investigated Channels

Two channels have been studied using Pythia MC generator and the CMS Fast Simulation:

1

$$pp \to V_L V_L j_F j_B \to Z_L Z_L j_F j_B \to \mu^+\mu^- jj\ j_F j_B$$
$$pp \to Z_L W_L j_F j_B \to Z_L W_L j_F j_B \to \mu^+\mu^- jj\ j_F j_B$$

2

$$pp \to V_L V_L j_F j_B \to W_L W_L j_F j_B \to \mu\nu jj\ j_F j_B$$

Signal Samples:
m_H=500GeV
m_H=1000GeV
m_H=10000GeV

No Higgs scenario

Cross section (fb)	m_H=500 GeV	m_H=1000 GeV	m_H=10000 GeV
ZZjj→ μμjjjj	9.1	3.0	1.7
ZWjj→ μμjjjj	0.7	1.0	1.5
WWjj→μνjjjj	64.4	26.9	19.7

The Aims of the Work

- Reconstruct the invariant mass of the VV-fusion system in both channels (μμqqqq and μνqqqq) and estimate the resolution on it.

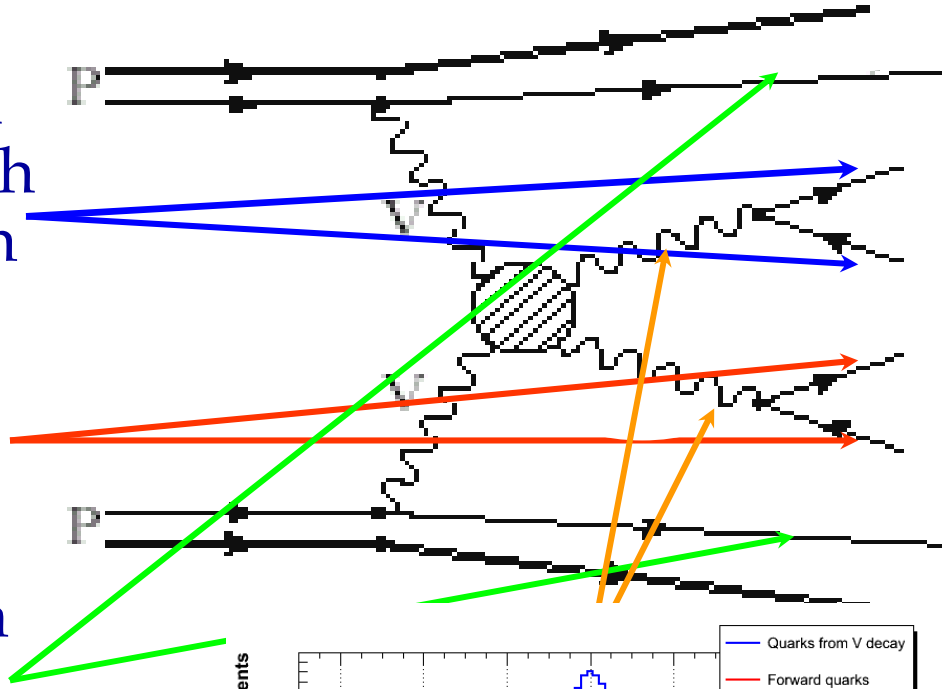
- Estimate the signal over background rate and the selection efficiency as a function of the energy scale of the VV process (M_{inv}(VV)) and the needed luminosity.

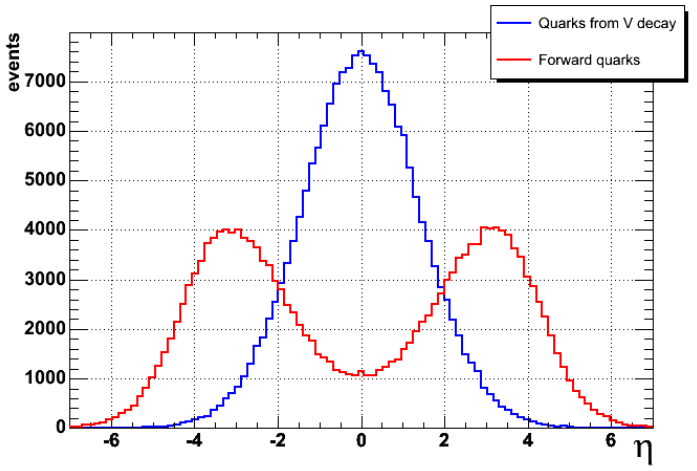
Sigma vs M_{inv}(VV) up-to ~ 2 TeV

The Signal Topology

Experimental signature:

- 1 μ^+ and 1 μ^- (or 1 μ and 1 ν) in the final state, with high P_T and coming from the Z (W) boson.
- 2 jets with high P_T and low η, coming from the vector boson decay.
- 2 energetic jets with high P_T, in the forward-backward regions (large η AND $\Delta\eta$).

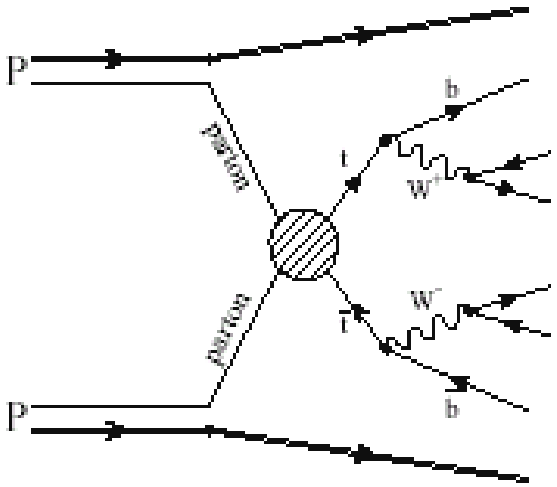


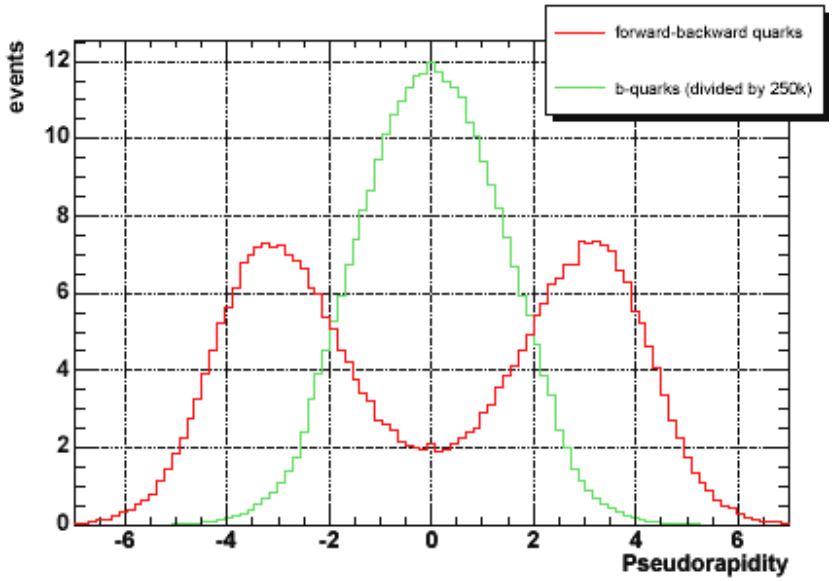


The Backgrounds

The following backgrounds have been taken into account :

$$pp \to t\bar{t} + X \to b\bar{b}\,WW + X \to j_b j_b \mu\mu(\nu) + X$$





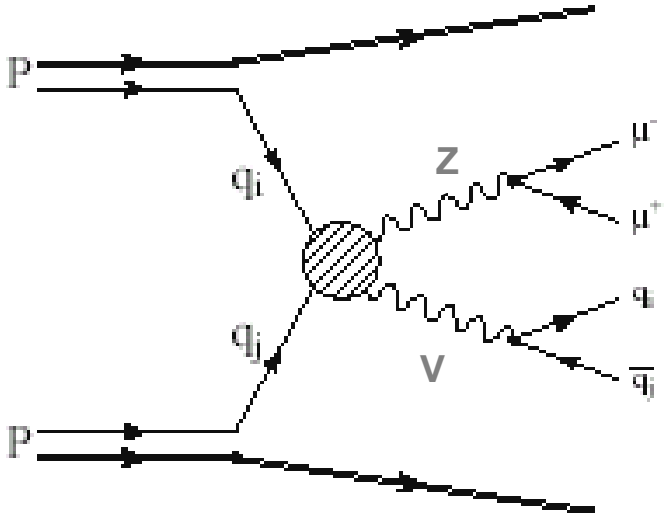
Pseudorapidity distribution

The Backgrounds

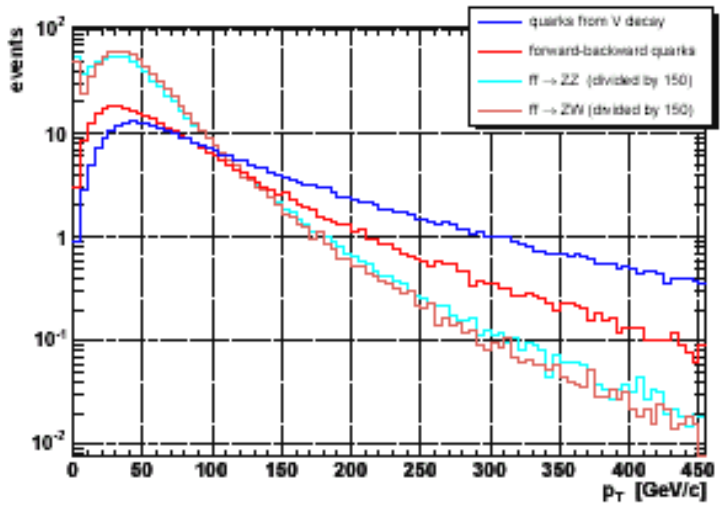
The following backgrounds have been taken into account :

$$pp \to t\bar{t} + X \to b\bar{b}\,WW + X \to j_b j_b \mu\mu(\nu) + X$$

$$pp \to VV + X \to \mu\mu(\nu)\,jj + X$$



P_t distribution



The Backgrounds

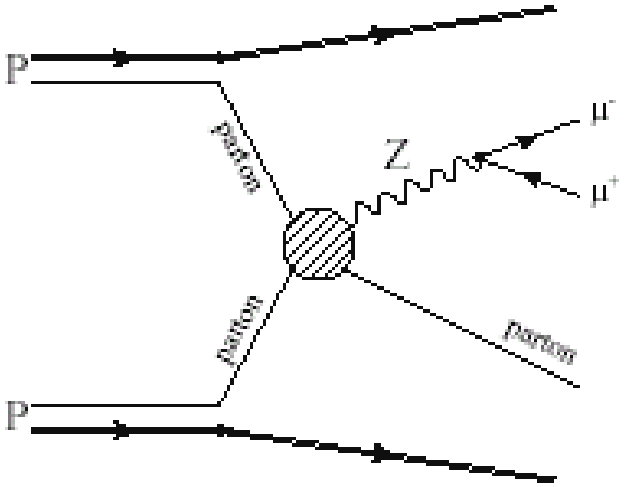
The following backgrounds have been taken into account :

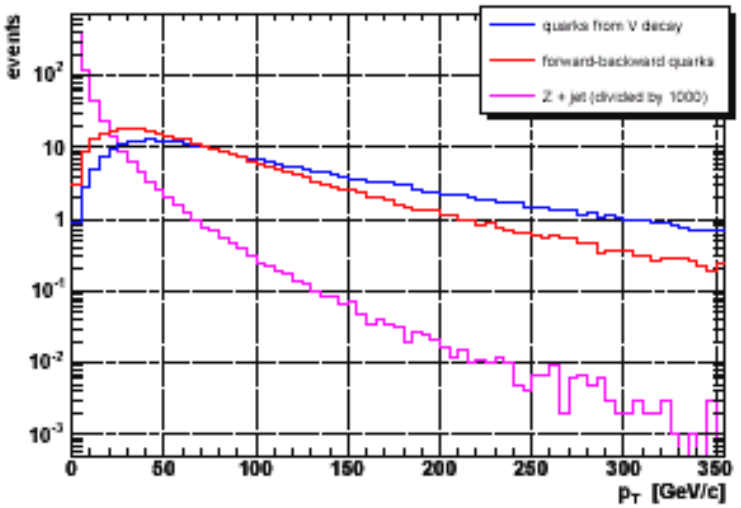
$$pp \to t\bar{t} + X \to b\bar{b}\,WW + X \to j_b\, j_b\, \mu\mu(\nu) + X$$

$$pp \to VV + X \to \mu\mu(\nu)\, jj + X$$

$$\boxed{pp \to V + j_{hard} + X \to \mu\mu(\nu) + j_{hard} + X}$$

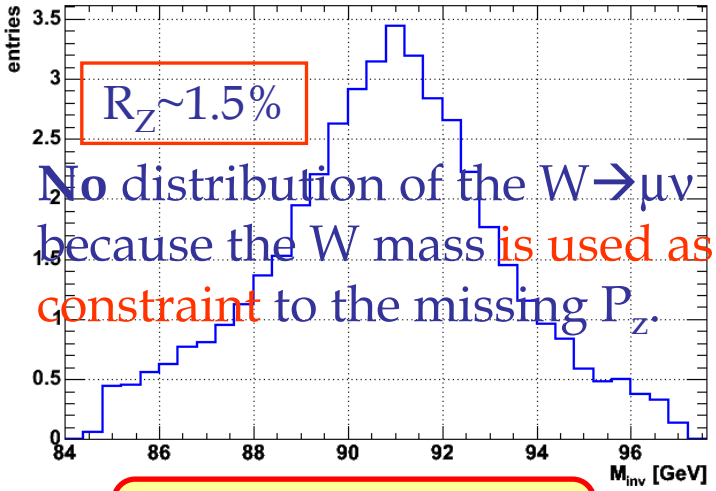
P_t distribution





Vector Bosons Reconstruction

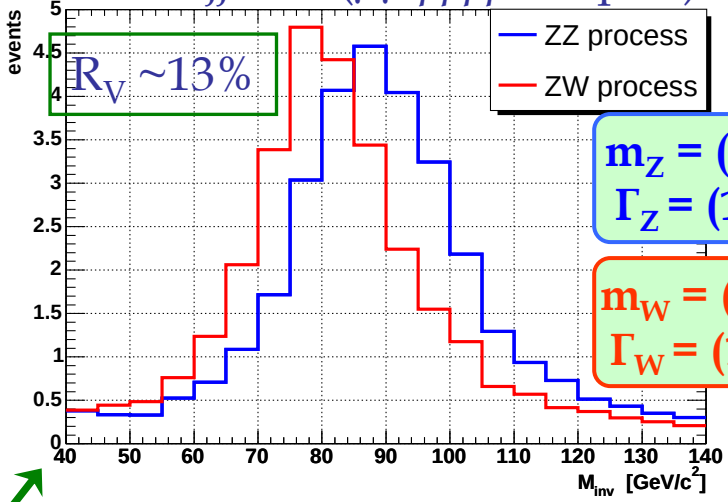
$Z \rightarrow \mu\mu$



No distribution of the W→μν because the W mass is used as a constraint to the missing P_z.

$m_Z = (90.9 \pm 0.7)$ GeV
$\Gamma_Z = (2.1 \pm 0.9)$ GeV

$V \rightarrow jj$ ($\mu\mu qqqq$ samples)



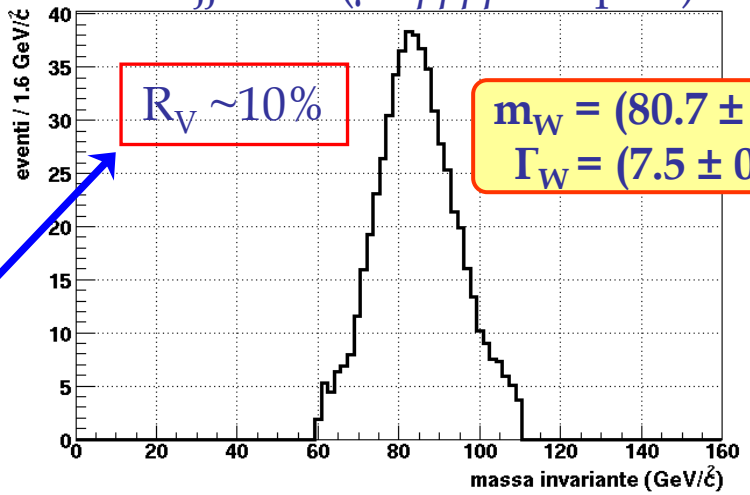
$m_Z = (88 \pm 4)$ GeV
$\Gamma_Z = (11 \pm 4)$ GeV

$m_W = (81 \pm 4)$ GeV
$\Gamma_W = (11 \pm 4)$ GeV

The distance among the two peaks is less than one sigma
→We cannot distinguish them!!
→ we add the two samples

Better resolution because no pile-up had been considered

$V \rightarrow jj$ ($\mu\nu qqqq$ samples)

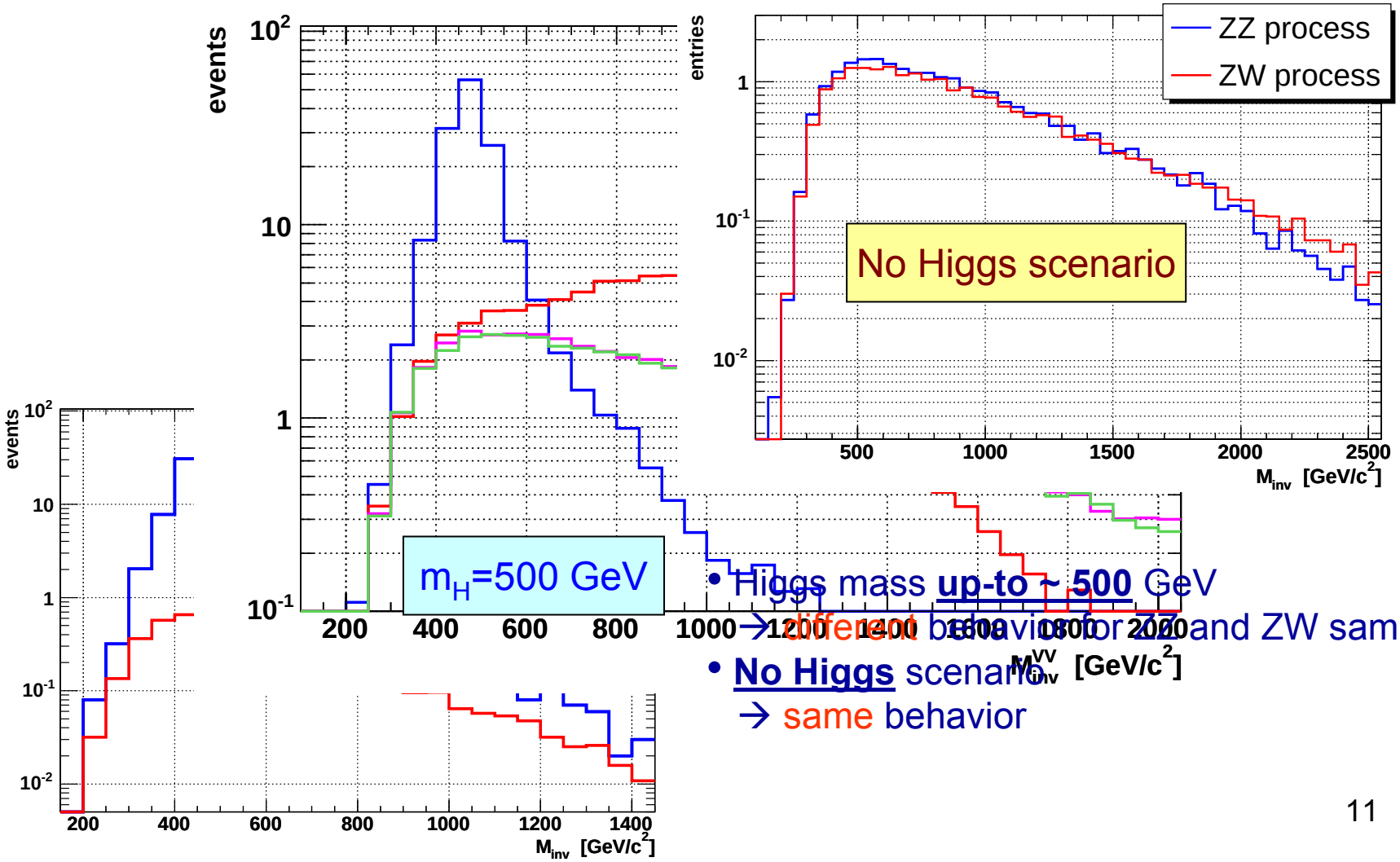


$m_W = (80.7 \pm 0.2)$ GeV
$\Gamma_W = (7.5 \pm 0.2)$ GeV

VV-fusion Invariant Mass

μμqqqq samples

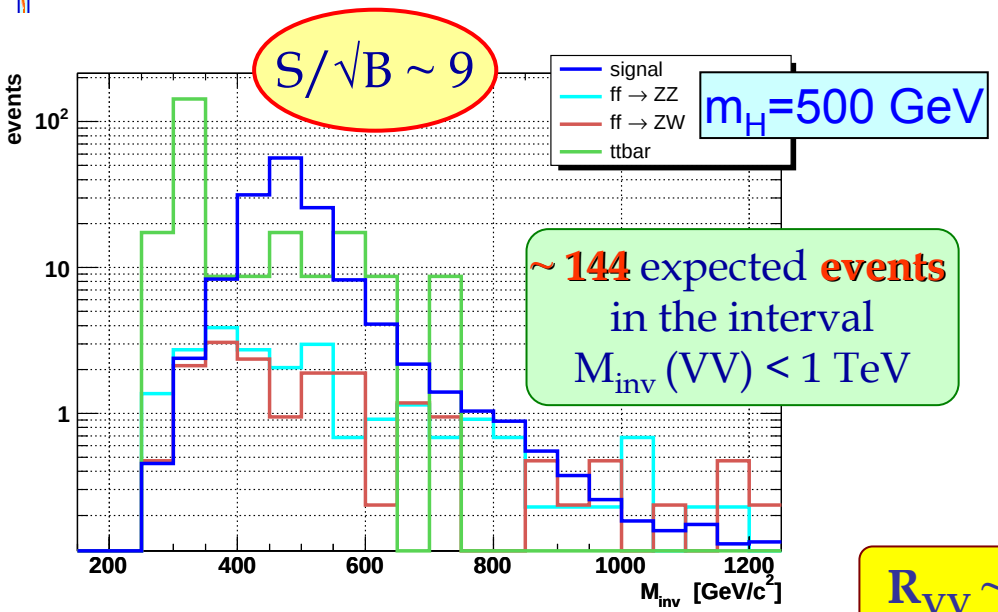
L=100 fb^{-1}



- Higgs mass **up-to ~ 500** GeV
  → different behavior for ZZ and ZW samples
- **No Higgs** scenario
  → same behavior

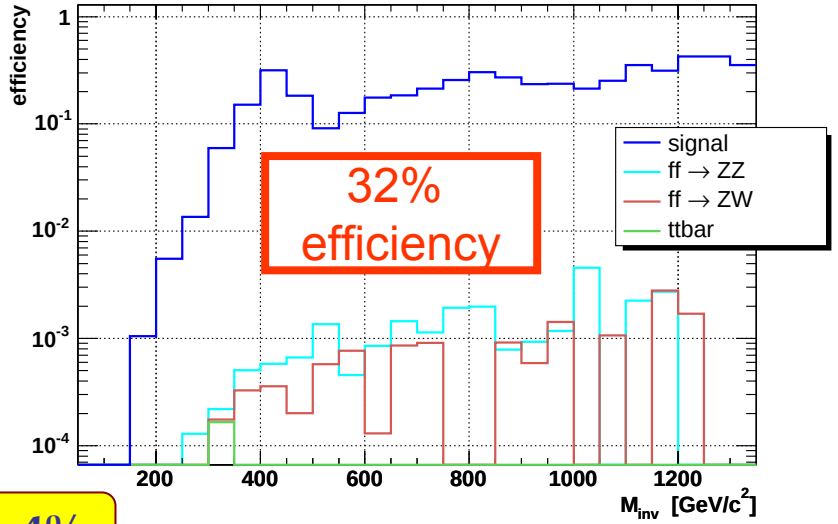
Results for μμqqqq Samples

L=100 fb^{-1}

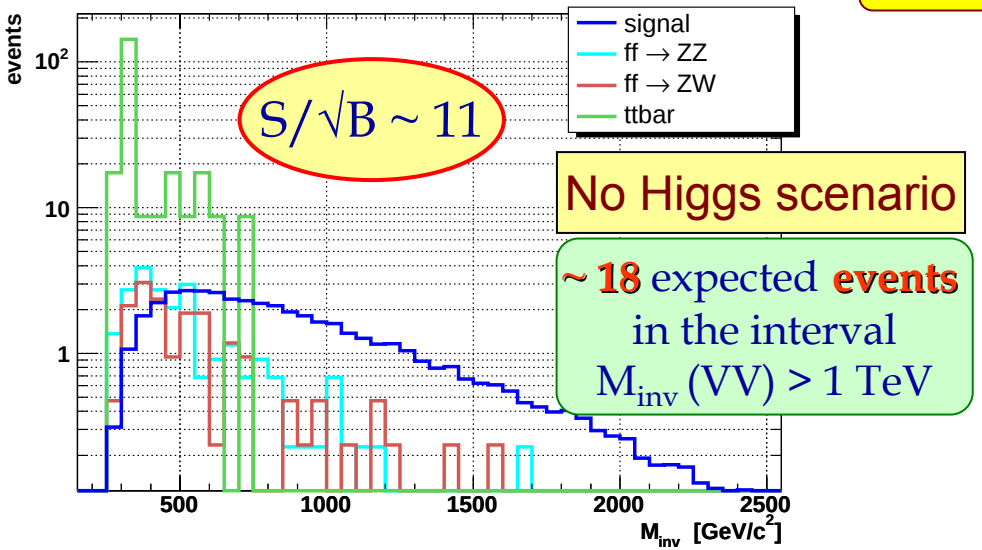


m_H=500 GeV

~ **144** expected **events** in the interval M_{inv} (VV) < 1 TeV

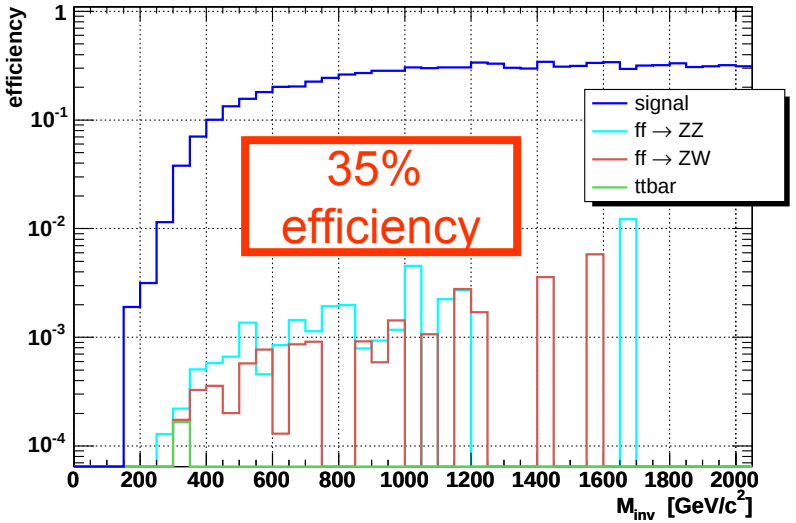


R_{VV} ~ 4%



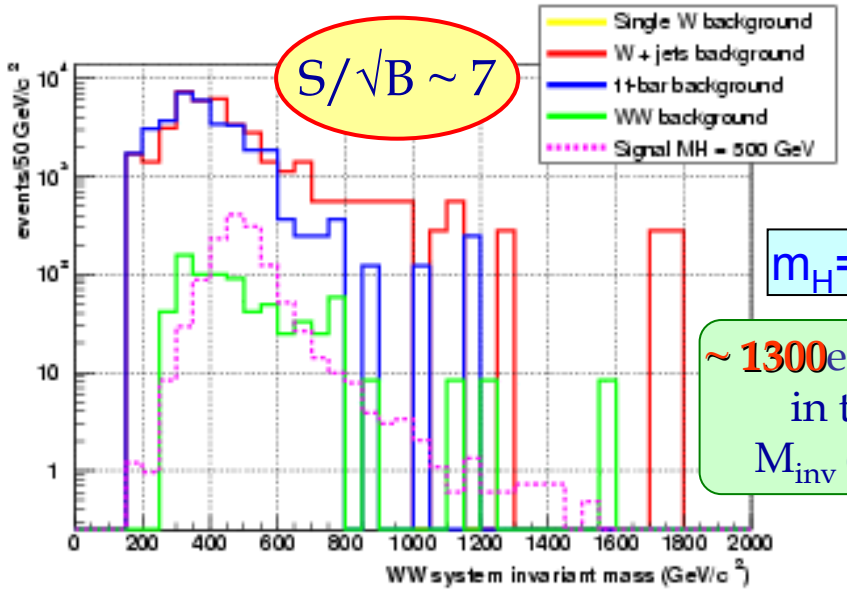
No Higgs scenario

~ **18** expected **events** in the interval M_{inv} (VV) > 1 TeV



Results for μνqqqq Samples

L=100 fb^{-1}



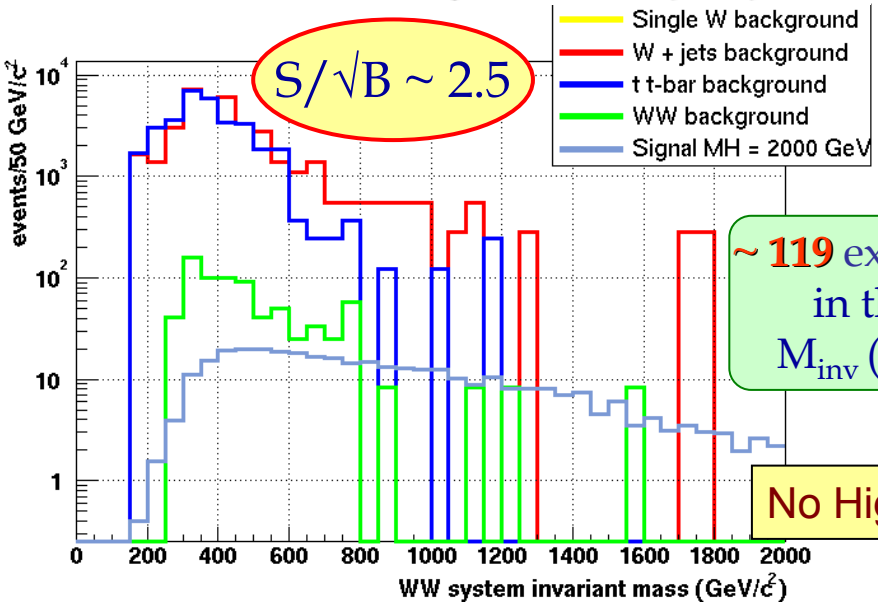
S/√B ~ 7

m_H=500 GeV

~ **1300** expected **events** in the interval M_{inv} (VV) < 1 TeV

25% efficiency

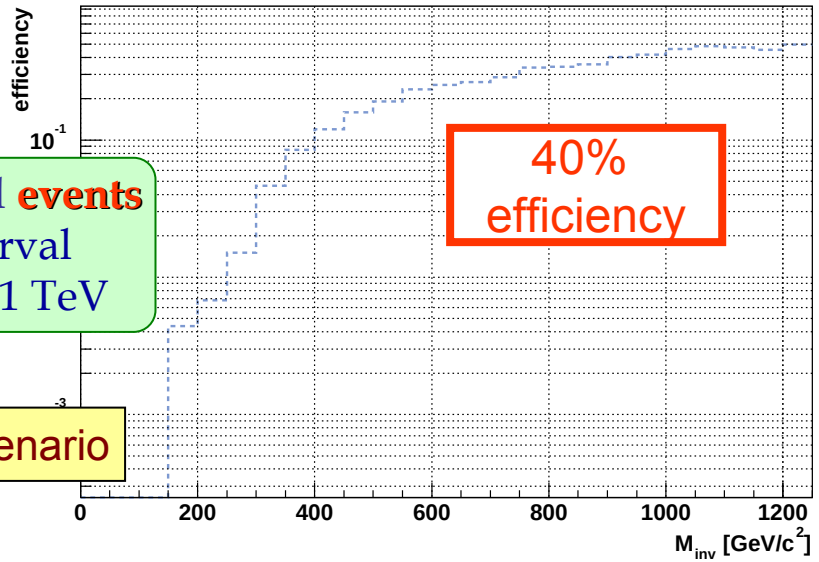
R_{VV} ~ 8%



S/√B ~ 2.5

~ **119** expected **events** in the interval M_{inv} (VV) > 1 TeV

No Higgs scenario



40% efficiency

Problems and Solutions

The Pythia MC generator:

- uses approximations to generate the VV-fusion events;
- does not simulate the **transversely polarized vector bosons**, which are part of the irreducible background.
- does not simulate the **irreducible background**.

Get on to matrix element MC generator(s):

- Phase. For the $\mu\nu qqqq$ channel.
  → $\mu\mu qqqq$ one is not yet implemented!
- MadGraph. For the $\mu\mu qqqq$ channel.

The MC generators

EVBA Approximation

Pythia

T. Sjöstrand

Matrix Element

Phase

E. Accomando, A. Ballestrero
and E. Maina
INFN – Torino University
http://www.to.infn.it/~ballestr/phase/

MadGraph

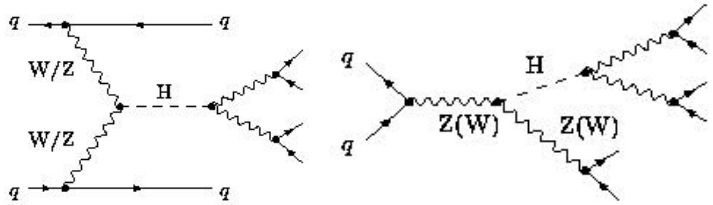
F. Maltoni and T. Stelzer
http://madgraph.hep.uiuc.edu

Complete six fermions final state generator

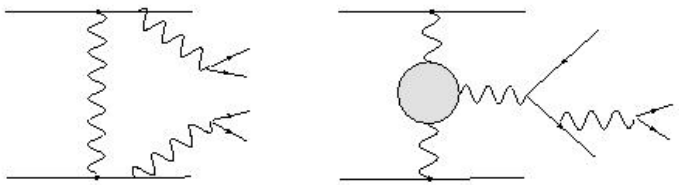
$q_1 q_2 \rightarrow q_3 q_4 q_5 q_6 l \nu \quad O(\alpha_{em}{}^6)$

Some diagrams in Phase

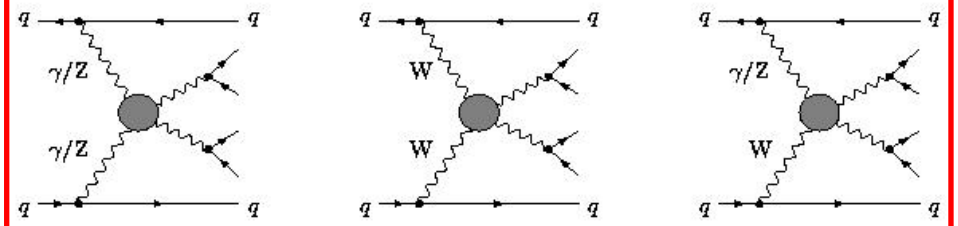
Higgs



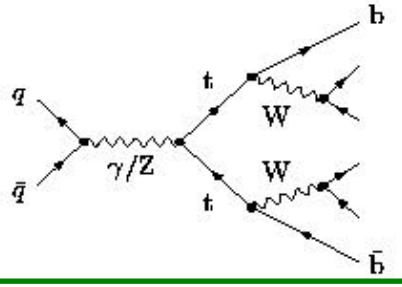
Non resonant



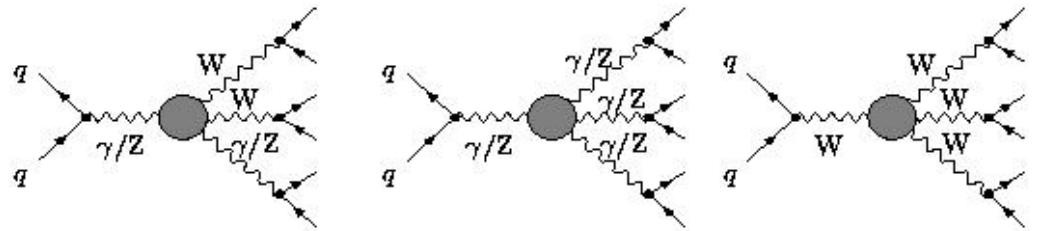
VV-fusion



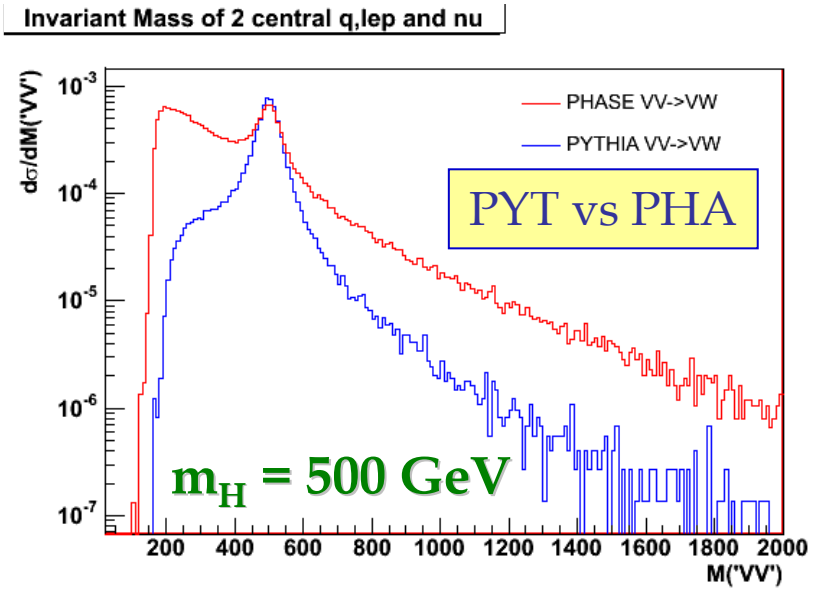
Top Top (only EW)

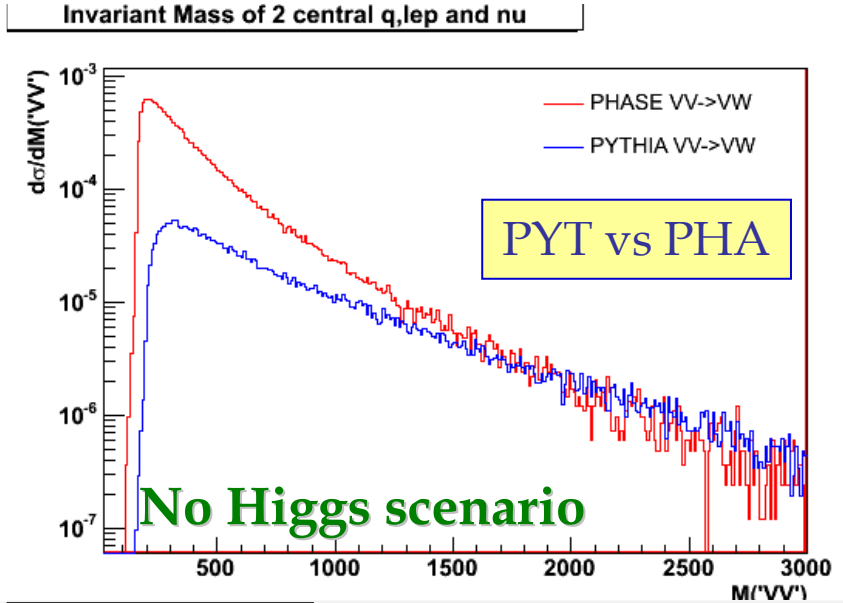


TGC and QGC



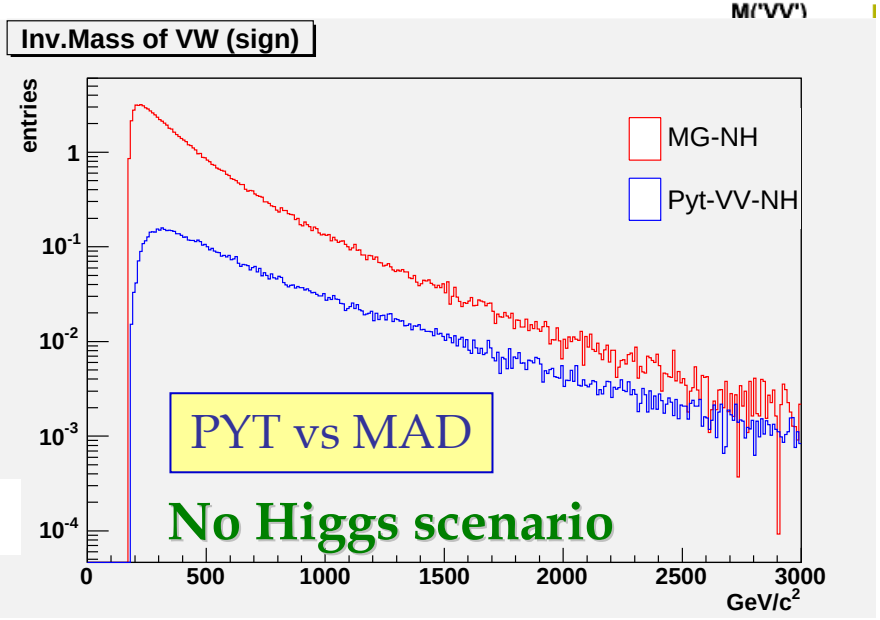
Pythia vs Phase&MadGraph





Big differences all over the spectra, for both the comparisons.

Some difference also among Phase and MadGraph.
→MadGraph samples are produced through on-shell VB.



Summary

From the ***preliminary studies*** made with the **CMS Fast Simulation** we can conclude:

- The investigation at CMS of the VV-fusion processes is possible. **Good resolutions** on the major observables (e.g. $M_{inv}(VV)$ → *the energy scale of the process*) **are achieved**.
  → Bad news: high luminosity is required.

- Further studies with both the matrix element MCs and CMS full simulation are needed.

WW "production and decay" vs full calc.

Comparison of

$$ud \to udc\bar{s}\mu\bar{\nu}_\mu \quad \textbf{and}$$

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

for realistic cuts

- $|\eta(j)| < 6.5$
- $2 < \eta(j_f) < 6.5, \;\; -2 > \eta(j_b) > -6.5, \;\; |\eta(j_c, \mu)| < 3$
- $E(j, \mu) > 20$ GeV, $\;\; P_t(j, \mu) > 10$ GeV
- $M(jj) > 20$ GeV, $\;\; |M(j_c j_c) - M_W| < 20$ GeV, $M_T(\mu\bar{\nu}_\mu) < M_W + 20$ GeV .

a la MADGRAPH ALPGEN or COMPHEP

Difference in total cross sections is ~ 20-30 %
It becomes much higher at high invariant masses.
The difference between a realistic Higgs and no-Higgs is greater for the full calculation but the cross sections at high M_{WW} are lower.