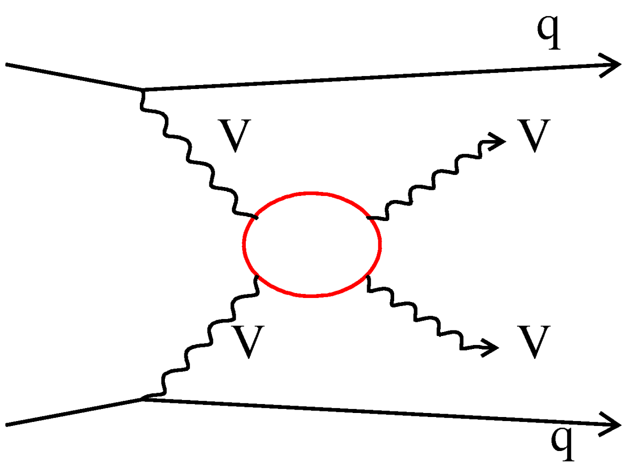
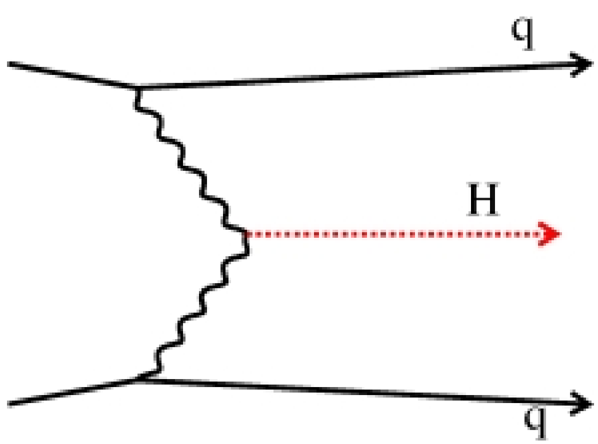
Vector Boson Fusion with ATLAS

G. Azuelos
on behalf of the ATLAS collaboration

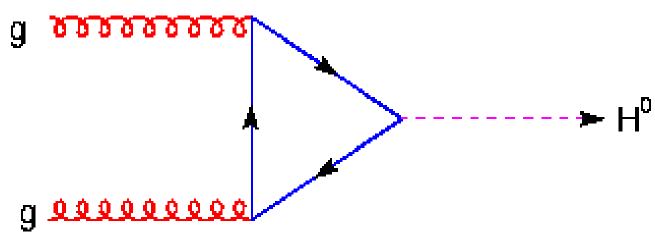


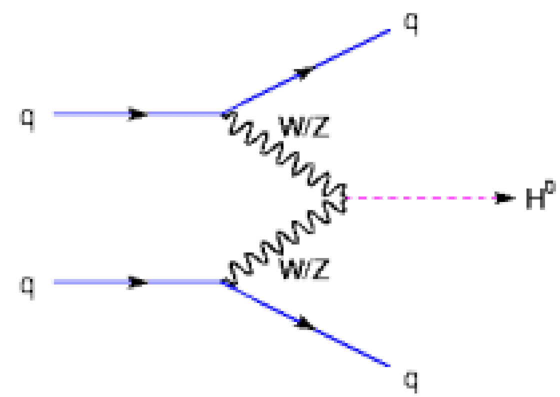


- **Motivations**
- **Observability of the Higgs**
  - qq H $\rightarrow$ qq WW$^{(*)}$
  - qq H $\rightarrow$ qq $\tau\tau$
  - …more channels
- **Strong Symmetry Breaking**

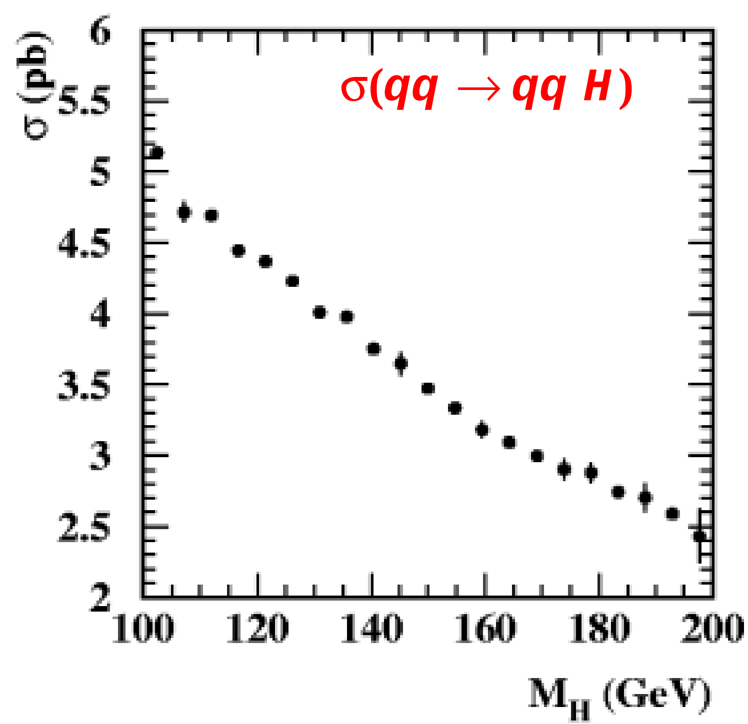
Motivations

- **Forward jet tagging allows rejection of backgrounds**

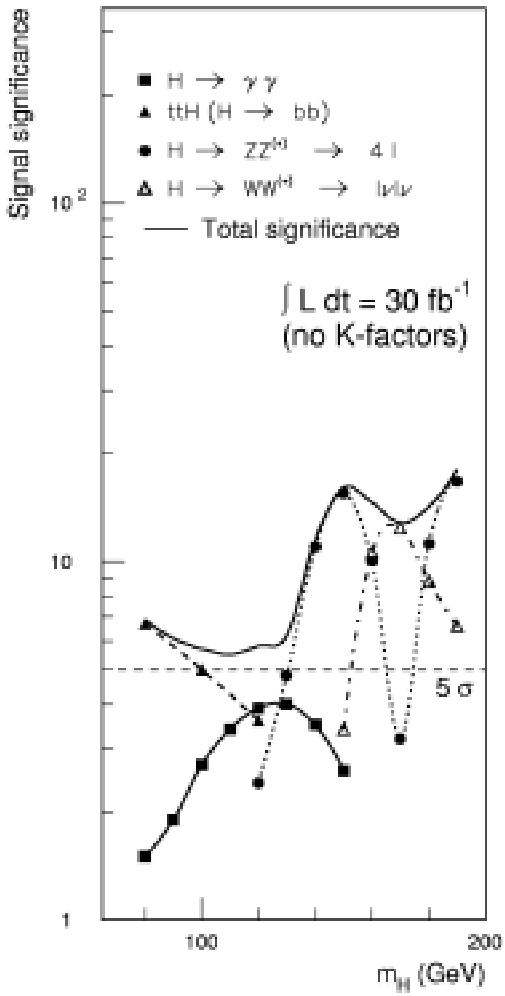




  - *relative rates ~ 5:1*
  - No colour exchange between forward quarks



If a lepton is present in the signal, for trigger, then Z+jets background is a background to the gg fusion process.



Searching and studying the Higgs boson

- complementary channels of Higgs discovery
  - Search for an intermediate mass Higgs is most important, difficult (but quite feasible) at LHC
  - several channels of H decay, not feasible in gg production process, but feasible in VBF production (suggested by D. Zeppenfeld, D. Rainwater et al., *see plenary talks, D. Zeppenffeld and K. Jacobs*)

$qq \to Hqq \to \gamma\gamma\, qq$ ⟶ $H \to \gamma\gamma$ is principal channel for $m_H \sim 120$ GeV

$qq \to Hqq \to W^{(*)}W^{(*)}\, qq \to e^{\pm}\mu^{\mp} p_T^{miss}\, jj$ ⟶ for $m_H \sim 170$ GeV (also 115 GeV)

$qq \to (H/A)\, qq \to \tau^+\tau^-\, qq \to \ell^{\pm} h^{\mp} p_T^{miss}\, jj$

$qq \to WH\, qq \to \ell\nu\, b\bar{b}\, qq \to \ell\nu\, b\bar{b}\, jj$

- Yukawa couplings (to τ, b) and HWW coupling
  → *next talk*

Strong Symmetry Breaking

- In the absence of a low-mass Higgs:
  - Unitarity violation in VV scattering at high energies

$$A = \frac{g^2 s}{8M_W^2}(1+\cos\theta^*)$$

  - By the Equivalence theorem

$$\mathcal{A}(V_L V_L \to V_L V_L) = \mathcal{A}(\omega\omega \to \omega\omega) + \mathcal{O}(M_W/E_W)$$

ω are the Goldstone bosons of EWSB

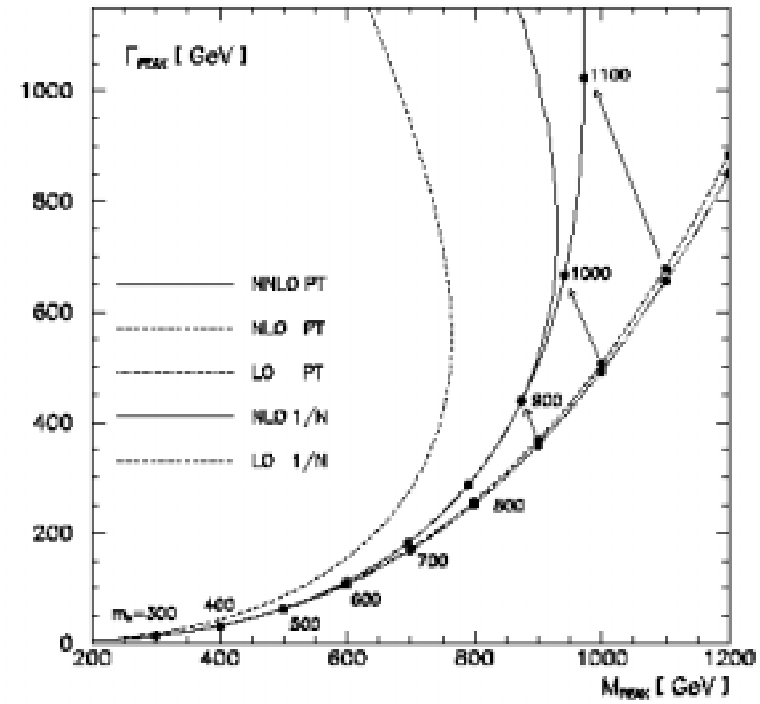
$$a_0^0(\omega^+\omega^- \to \omega^+\omega^-) \xrightarrow[s \gg m_h^2]{} -\frac{m_h^2}{8\pi v^2}$$

  - unitarity condition

$$\left| a_L(s) - \frac{i}{2} \right| \le \frac{1}{2}$$

implies new physics at **O (1 TeV)**

Higgs mass saturation



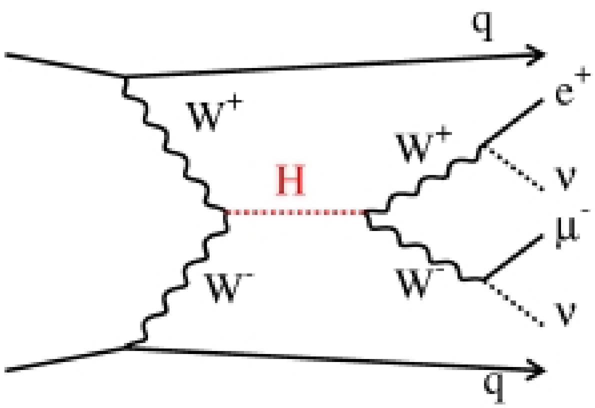
Perturbative and nonperturbative Higgs signals
Adrian Ghinculov and Thomas Binoth hep-ph/9807227

Implementation of codes into PYTHIA

- **Codes for signal and background, obtained from D. Zeppenfeld and D. Rainwater, were added, as external proceses, into PYTHIA.**
  - background codes
    - $WWjj$ (QCD and EW graphs)
    - $\gamma\gamma jj$, $\tau\tau jj$ (QCD and EW graphs)
    - Zjj (EW)
    - $t\bar{t}$ + jets
  - Better evaluation of multijet events
    - 2 jets in final state
  - Colour connections of partons
  - Unweighted events (almost…)
  - Choice of structure functions
  - Detector simulation : Atlfast
  - Comparison at parton level, and large MC production

$qq \rightarrow qq\ H \rightarrow qq\ WW^{(*)}$

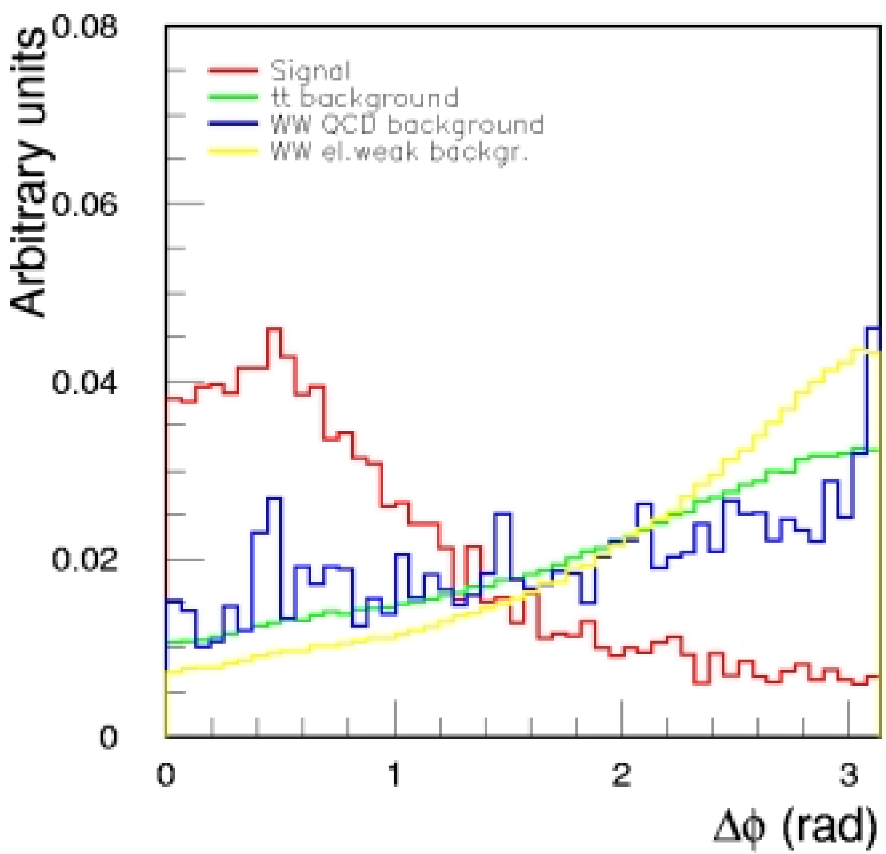
- **Main characteristics of signal**
  - forward jets
  - centrally produced leptons
  - no colour exch. between initial state quarks
  - anti-correlation of W spins

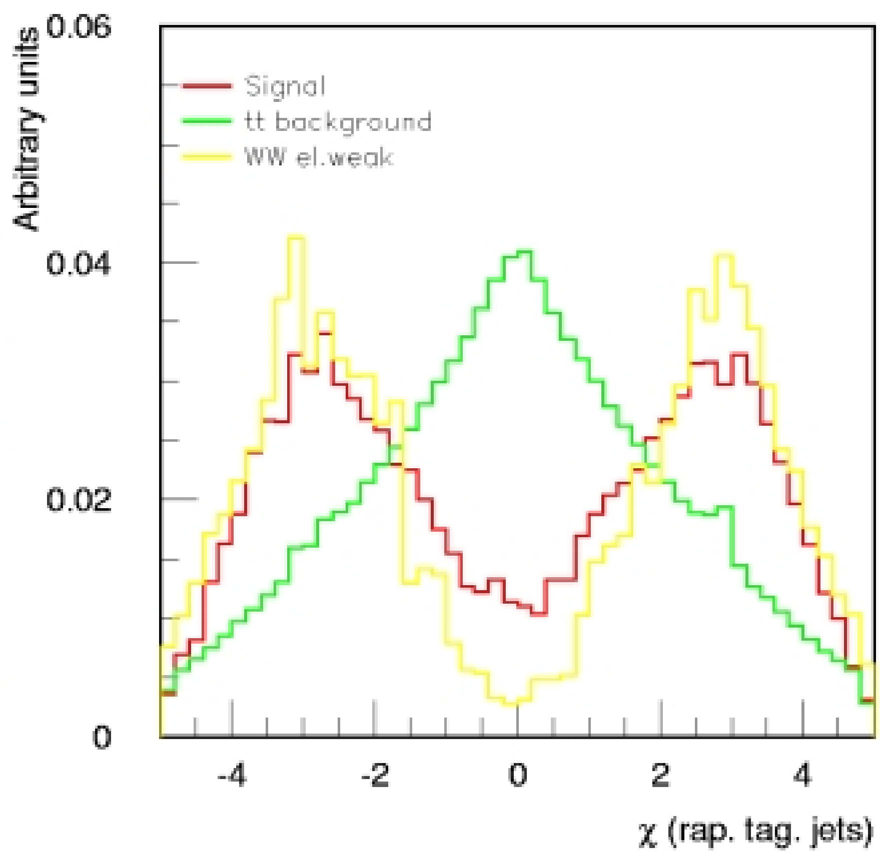


- **Main backgrounds (from m.e. codes and PYTHIA)**
  - $t\bar{t}$-0j , $t\bar{t}$-1j, $t\bar{t}$-2j
  - WW + jets, EW and QCD
  - Z + jets
  - $\tau\tau$ +jets
- **Signal**
  - PYTHIA 6.1, LO cross sections, CTEQ5L
  - BR from HDECAY

Basic selection criteria

- 2 leptons, p_T > 20 GeV, $|\eta|$ < 2.5
- 2 tag jets, opposite hemispheres, $\Delta\eta$ > 4.4
- angular cuts, because of spin correlations
- ***test of*** τ jet ($Z \rightarrow \tau\tau$)

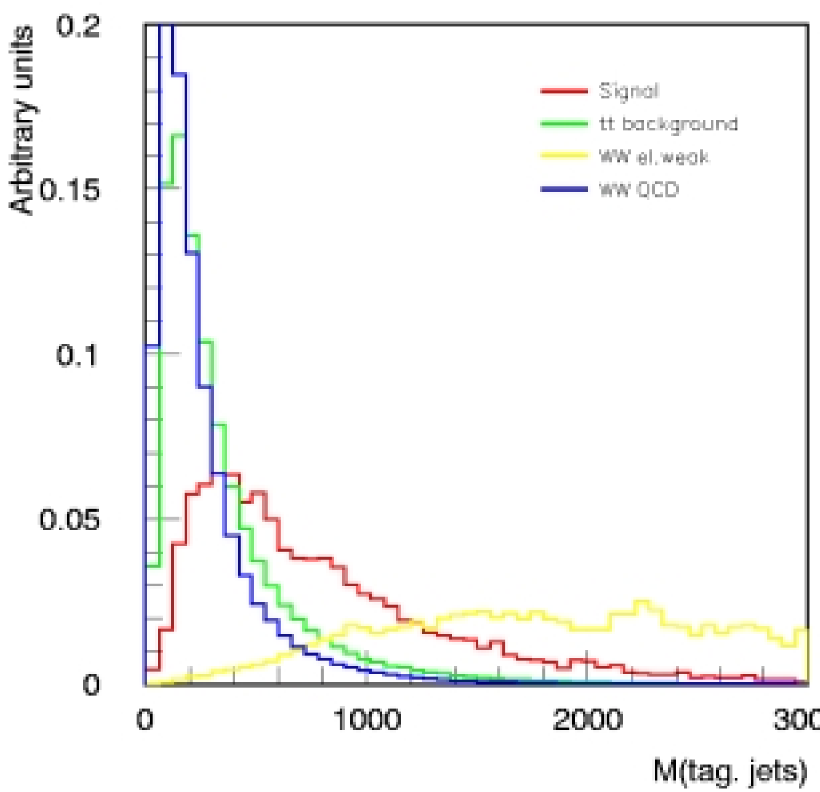


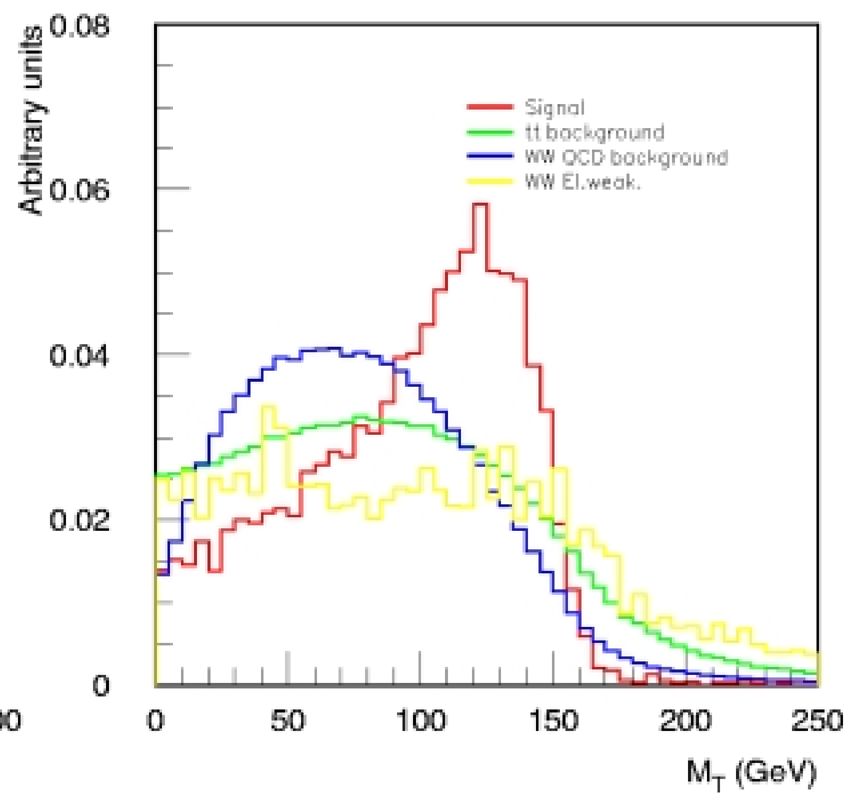


- central jet veto: no extra central jet

Cut	Higgs Signal	Background	S/B
15 GeV, $-3.2 < \eta < 3.2$	4.29 fb	2.56 fb	1.7
20 GeV, $-3.2 < \eta < 3.2$	4.52 fb	3.41 fb	1.3
20 GeV, $\eta_{tag-} < \eta < \eta_{tag+}$	4.83 fb	4.45 fb	1.1

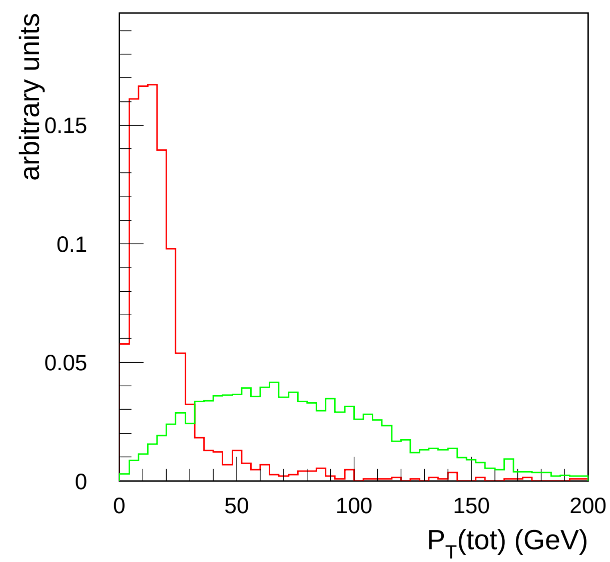
- jet mass: $m_{jj} > 650$ GeV

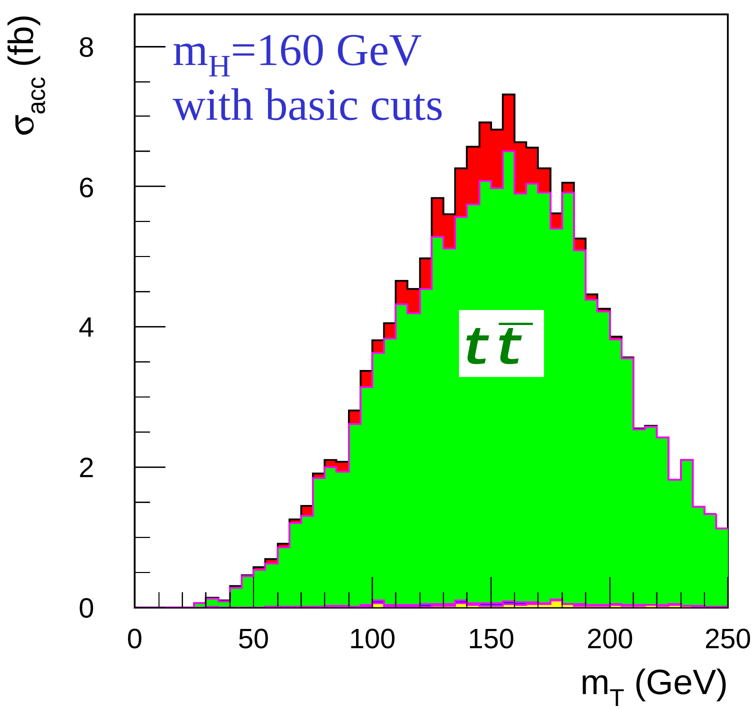


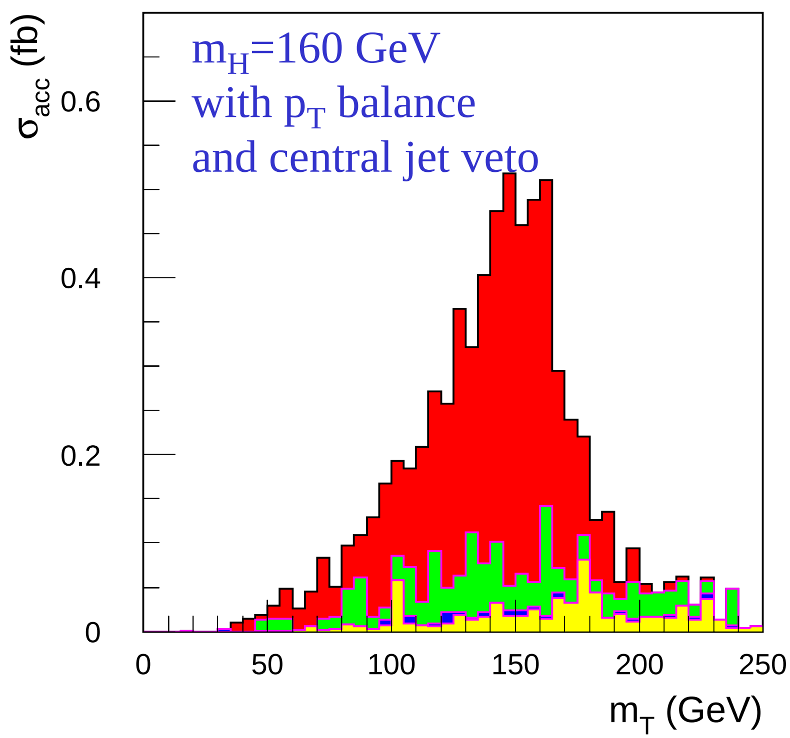


- p_T balance < 30 GeV

$$\vec{p}_T = \sum \left(\vec{p}_T(\ell_1) + \vec{p}_T(\ell_2) + \vec{p}_T(miss) + \vec{p}_T(tag_1) + \vec{p}_T(tag_2) \right)$$







Expected signals and backgrounds

m_H = 160 GeV	Signal (fb)	ttbar	WW (EW)	WW (QCD)	$\tau\tau$ (EW)
Basic cuts (leptons, tag jets)	10.07	136.07	0.93	0.71	0.15
mass cut m_{jj} < 600 GeV	7.29	61.00	0.82	0.31	0.14
PT-balance < 30 GeV	6.22	7.33	0.77	0.13	0.12
veto of add. jet	5.01	1.31	0.71	0.09	0.09

As a function of m_H :

m_H	110	120	130	140	150	160	170	180	190	200
σ (fb)	0.10	0.39	1.09	2.00	3.15	5.01	5.30	4.67	3.71	2.84

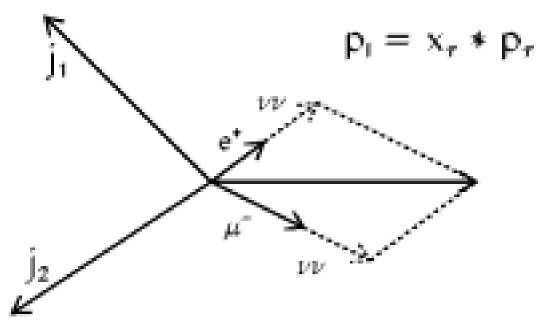
(background = 2.20 fb)

$qq \to qq\, H \to qq\, \tau\tau \to qq\, e^{\pm}\mu^{\mp}\, \nu\nu\nu\nu$

- **background processes**
  - $H \to W^+W^-$
  - $\tau\tau$ jj (QCD and EW) (large QCD uncertainties)
  - $t\bar{t}$, $b\bar{b}$, +jets
  - W+W- jj (QCD and EW)
- **reconstruction of $\tau\tau$:**

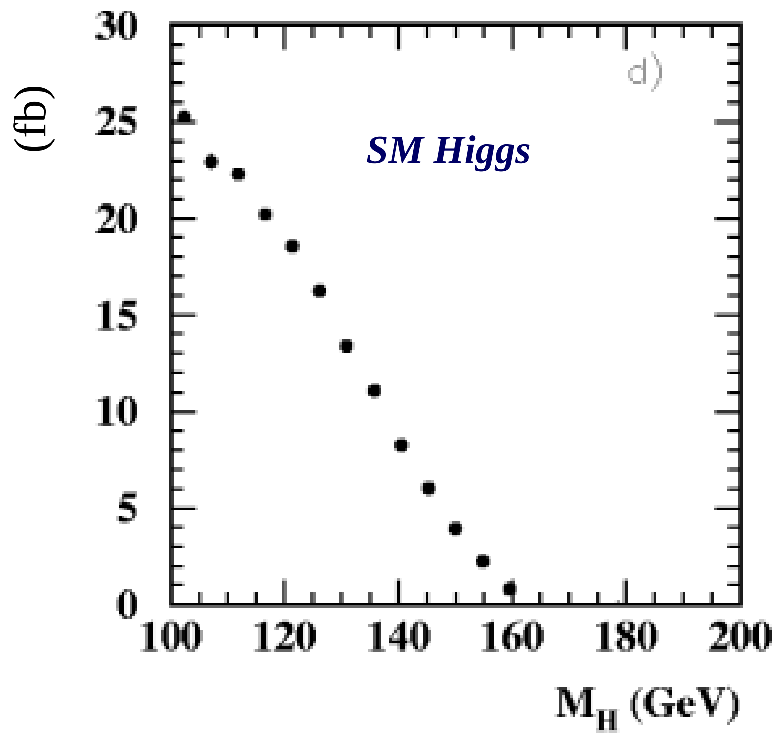
assuming direction of neutrino is

n:



$$p_{TH} = p_{T\tau 1} + p_{T\tau 2} = p_{Te} + p_{T\mu} + \not{p}_T$$

$$M_{\tau\tau} = \frac{m_{e\mu}}{\sqrt{x_{\tau 1} \cdot x_{\tau 2}}}$$



$$\sigma \cdot BR(H \to \tau^+\tau^-) \cdot BR(\tau^+\tau^- \to e^{\pm}\mu^{\mp}\nu\nu)$$

BR($H \to \tau\tau$) ~ 6.0 % at m_H = 120 GeV

selection (comparison with hep-ph/9911385)

$p_T^{miss} > 30GeV$

Jets :

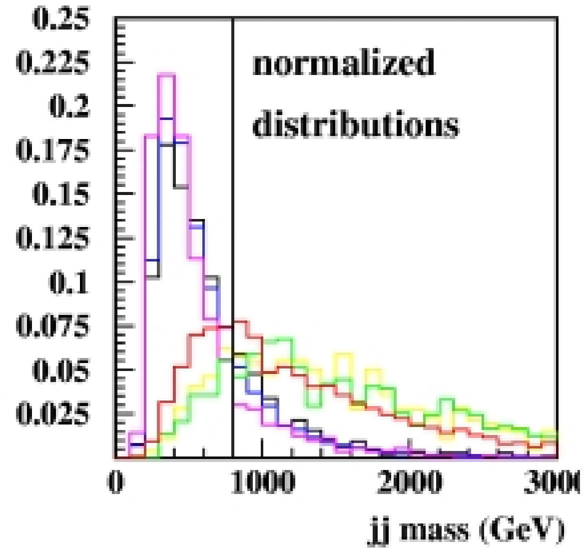
$p_{T_{j1}} > 40\ GeV, \quad p_{T_{j2}} > 20\ GeV, \quad |\eta| < 5.0$

$\Delta R_{jj} \geq 0.7$

$p_{T_\ell} > 10\ GeV, \quad |\eta| < 2.5, \quad \Delta R_{j\ell} \geq 0.7$

$|\eta_{j1} - \eta_{j2}| > 4.4, \quad \eta_{j1} \cdot \eta_{j2} < 0$

$M_{jj} > 800\ GeV$



Leptons :

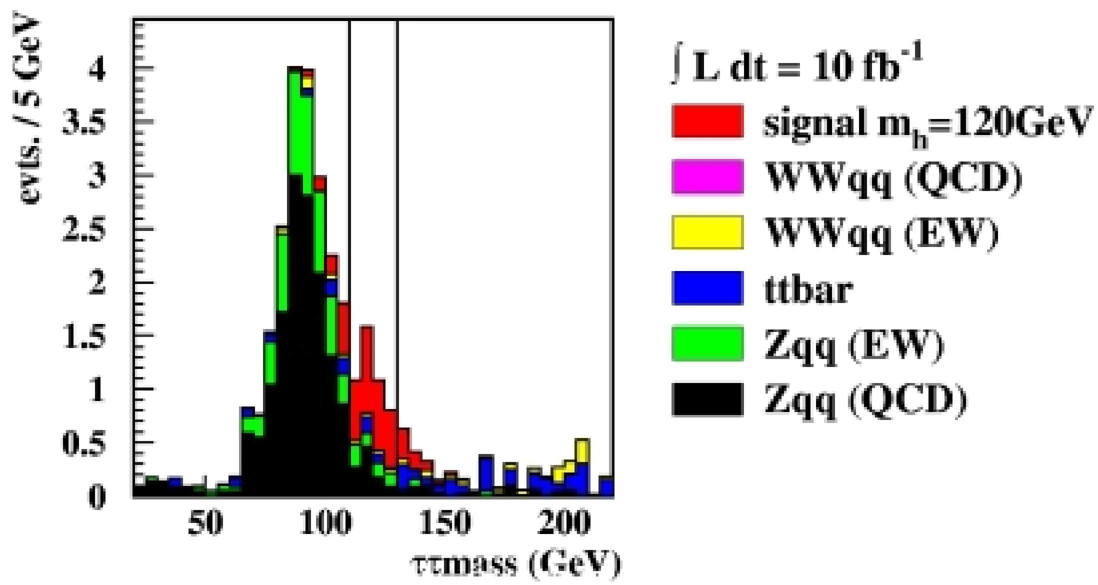
$0.4 < \Delta R_{e\mu} < 2.6, \quad \cos\phi_{e\mu} > -0.9$

$\eta_{j,\min} + 0.7 < \eta_{\ell 1,\ell 2} < \eta_{j,\max} - 0.7$

$x_{\tau 1}, x_{\tau 2} > 0, \quad x_{\tau 1}^2 + x_{\tau 2}^2 < 1$

forward jet tagging

mini jet veto



$qq \rightarrow qq\ H \rightarrow qq\ \tau\tau \rightarrow qq\ e^{\pm}\mu^{\mp}\ \nu\nu\nu\nu$

For m_H = 120 GeV, 110 GeV < $M_{\tau\tau}$ < 130 GeV,
in fb

cuts	Signal	H -> WW	QCD tautaujj	EW tautaujj	ttbarjj	bbbarjj	QCD WWjj	EW WWjj
forward tag	0.466	0.017	2.48	0.112	1.53	0.051	0.047	0.262
pt miss	0.403	0.015	1.18	0.078	1.18	0.0	0.029	0.208
jj mass	0.288	0.014	0.205	0.061	0.25	0.0	0.003	0.206
non-tau	0.274	0.009	0.202	0.059	0.067	0.0	0.002	0.026
delta R emu	0.265	0.009	0.164	0.052	0.061	0.0	0.002	0.025
mini-jet veto	0.260	0.007	0.133	0.050	0.036	0.0	0.002	0.025
pt jet1 > 40 GeV	0.256	0.007	0.100	0.048	0.036	0.0	0.001	0.025

For 30 fb^{-1}

$N_B \sim N_B$ (Zeppenfeld)
$N_S \sim ½\ N_S$ (Zeppenfeld)

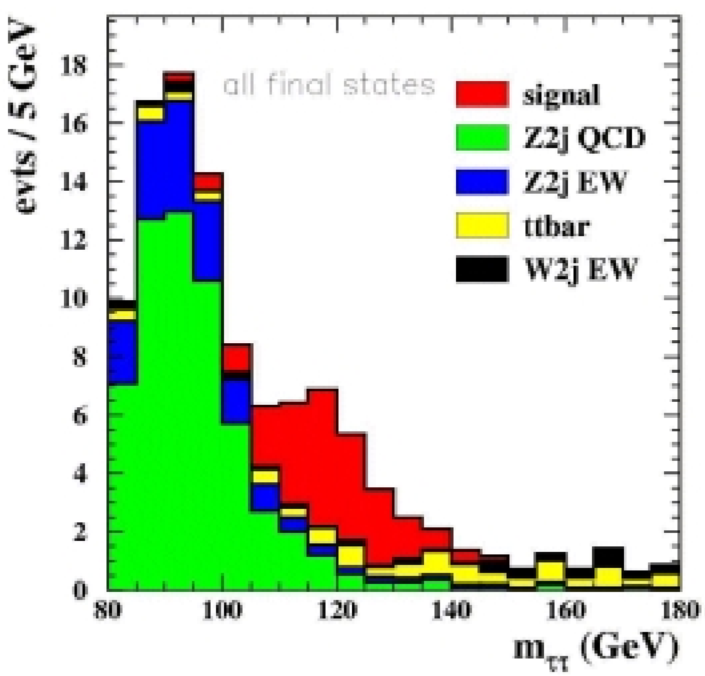
m_{H^0}	110	115	120	125	130	135	140	145	150
$\varepsilon \cdot \sigma(fb)$	0.30	0.32	0.26	0.22	0.22	0.17	0.15	0.09	0.05
N_S	9.0	9.6	7.8	6.6	6.6	5.1	4.5	2.7	1.5
N_B	14.6	9.3	6.1	5.2	3.8	3.3	2.9	2.5	2.1
S/B	0.6	1.0	1.3	1.3	1.7	1.5	1.6	1.1	0.7
$S/\sqrt{B}$	2.4	3.1	3.2	2.9	3.4	2.8	2.6	1.7	1.0

$qqH \to qq\,\tau\,\tau \to qq\, l\,\nu\,\nu\, l\,\nu\,\nu$

ATLAS:

transparency from K. Jakobs

- Similar basic cuts as in WW analysis
- Tau mass reconstruction using collinear approximation
- Optimized cuts for eμ, ee and μμ channels



$m_H = 115$ GeV

30 fb^{-1}

all channels
(eμ best channel)

S = 17.3 events

B = 11.4 events

S/B > 1

Combined significance (ee, μμ, eμ):

m_H (GeV)	110	115	120	125	130	140	150
10 fb^{-1}	2.2	2.6	2.6	2.4	2.3	1.3	0.6 σ
30 fb^{-1}	3.8	4.3	4.3	4.1	3.8	2.7	1.4 σ

Preliminary, no systematics yet, l-had channel to be added

*) More details in talk by G. Azuelos

Karl Jakobs Fermilab Higgs workshop, May 2001

$qq \to qq\ H \to qq\ \tau\tau \to qq\ l^{\pm}\nu\nu\ \ j\nu$

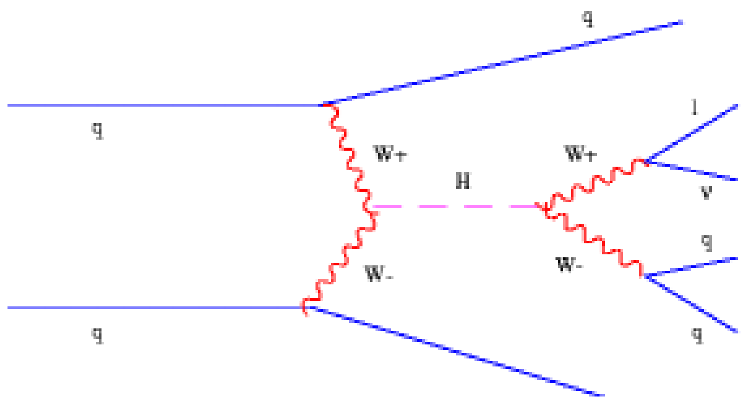
- **preliminary!**
  - tau jet identification
  - p_T^{miss} requirement
  - p_T (lepton, jet) requirement
  - isolation of leptons, jets
  - opening angle between τ's
  - m_{jj} requirement for forward tagging jets

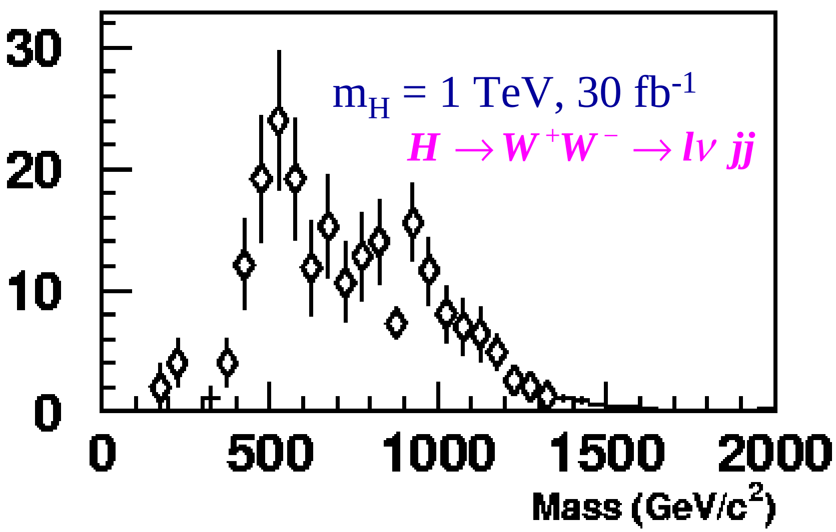
  working on calibration of high energy jets

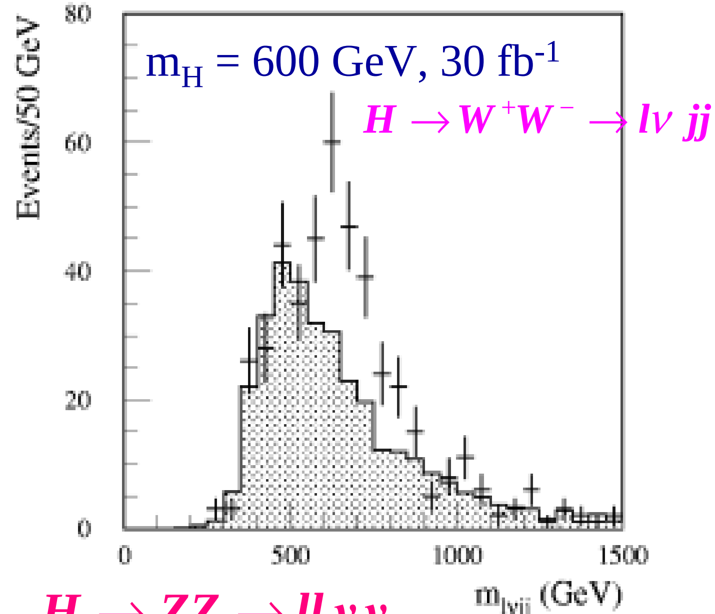
30 fb^{-1}, m_H=	110	115	120	130	140	150
# *ev, signal*	6.8	6.1	5.8	5.0	3.0	1.8
backgrounds	4.1	2.4	1.9	0.9	0.7	0.7

Strong Symmetry Breaking

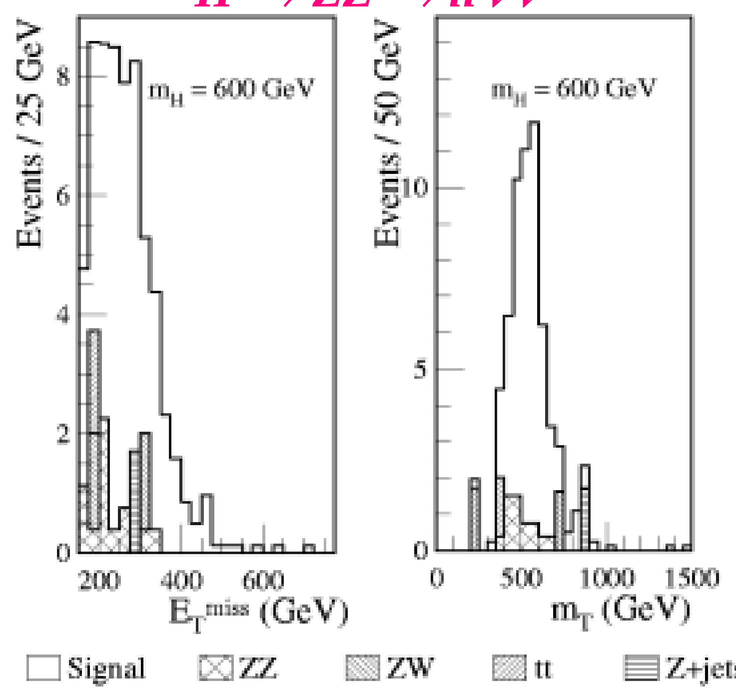
- **Very heavy Higgs (LO)**





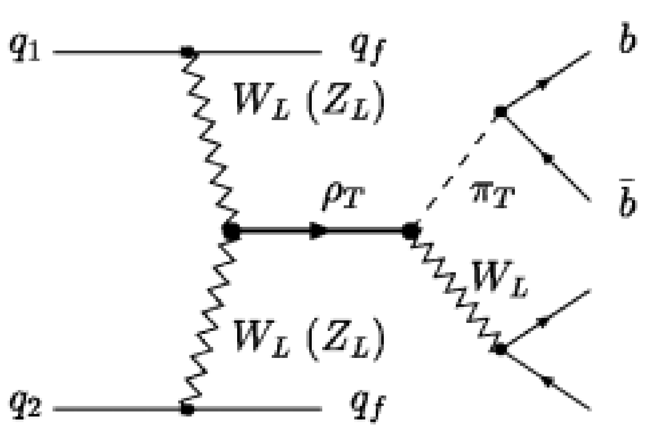


$H \to ZZ \to ll\,\nu\,\nu$



Absence of Higgs

- **technicolor:**
  - In analogy with QCD, a new interaction technicolor between techniquarks has its chiral symmetry broken by condensates
  - (light) technipions produced $\rightarrow$ longitudinal component of gauge bosons $\rightarrow$ mass
  - extended technicolor, walking, TopColor assisted TC … to give mass to fermions, to inhibit FCNC 's, to be consistent with top mass
  - **model of Lane et al.**
    - Multiscale technicolor model, with one full generation of techniquarks, $SU(N_{TC})$, $N_{TC} = 4$
    - many technipions, including color octets, mixing between long. Gauge bosons and technipions
    - **Resonances predicted**, as in QCD:



With a given choice of parameters, cross sections and BR 's can be evaluated

production mainly by qq fusion, but **VBF would be a complement to discovery channel (ATL-phys-99-021)**

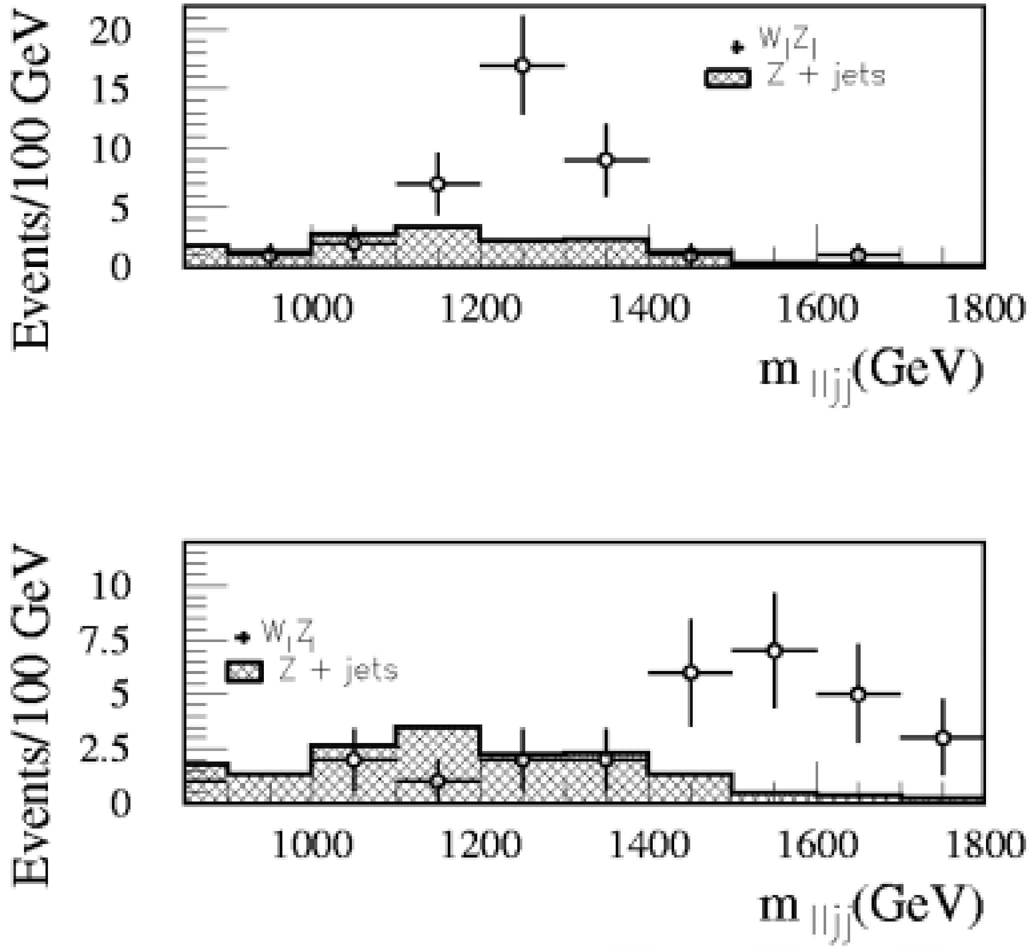
VBF in ChL model

- **2 leading parameters, beyond LO, in general quadrilinear coupling of Vector bosons**

$$L^{(4)} = a_4 (tr\, D_\mu U D^\mu U^\dagger)^2 + a_5 (tr\, D_\mu U D^\nu U^\dagger)^2$$

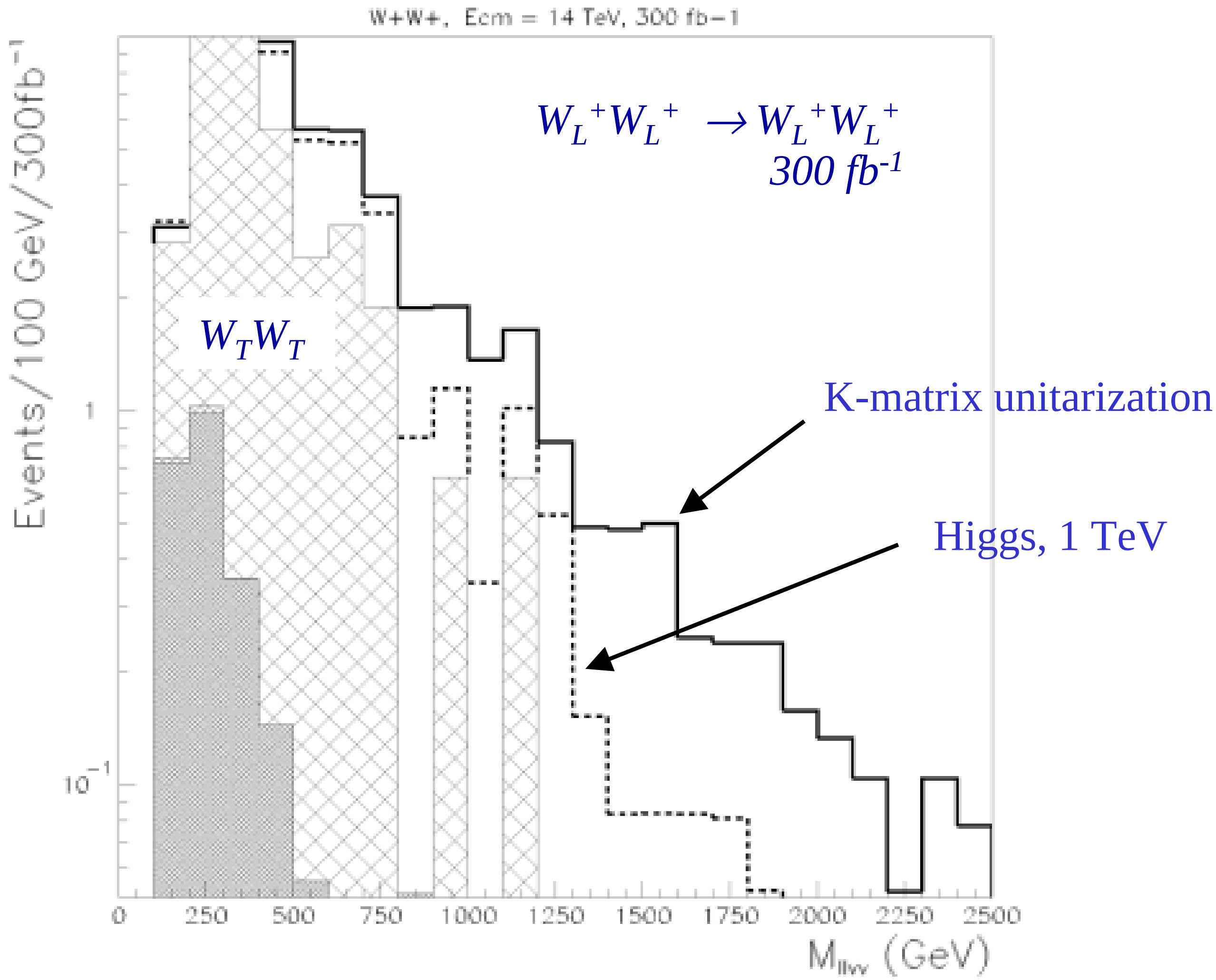
Given a_4, a_5, and Inverse Amplitude Method for unitarization of amplitudes, possible resonances appear:

$WZ \to WZ \to jj\, l^+ l^-$, $300\ fb^{-1}$



$W_L^+W_L^+$ (non-resonant VBF)

- study regularization of VV scattering amplitudes
  - requires good knowledge of backgrounds



Conclusions

- **VBF is a possible discovery channel at the LHC**

  - studied: $\begin{cases} H \to WW^{(*)} \to e\mu\, p_T^{miss} \\ H \to \tau\tau \to e\mu\, p_T^{miss},\ \ eh\, p_T^{miss} \end{cases}$

    with
    - matrix element calculations from D. Zeppenfeld
    - signals and backgrounds
    - fast Monte-Carlo simulation of the ATLAS detector
  - more channels under study:
    - $H \to \gamma\gamma$
    - $H \to b\bar{b}$?
  - important process in strong symmetry breaking scenario
    - resonant and non-resonant VV scattering