SUSY 06, Newport Beach

Recent Developments in Little Higgs Searches at LHC

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on behalf of the ATLAS collaboration

Outline

- The model
- Heavy gauge boson searches
  - Leptonic decays (Eur. Phys. J. **C39S2**, 13 (2005))
  - Hadronic decays NEW!
  - Higgs decays, m_h=200 GeV NEW!
  - Higgs decays, m_h=120 GeV (Eur. Phys. J. **C39S2**, 13 (2005))
- Summary

Little Higgs model

Effective model adressing hierarchy problem

$\Rightarrow$ larger symmetry, broken at high scale

$\Rightarrow$ *introduce heavy top T, heavy Higgses ϕ*

*and **heavy gauge bosons Z_H, W_H, A_H***

Littlest Higgs model [Arkani-Hamed et al., JHEP 207(2002)34]

SU(5) $\rightarrow$ SO(5), scale f~TeV Gauge sector $[SU(2)\otimes U(1)]^2$ SM Higgs

Phenomenology Han et al., Phys.Rev.D67(2003)95004

Gauge sector: parameter θ: mixing angle between W triplets

W_H , Z_H mass degenerate

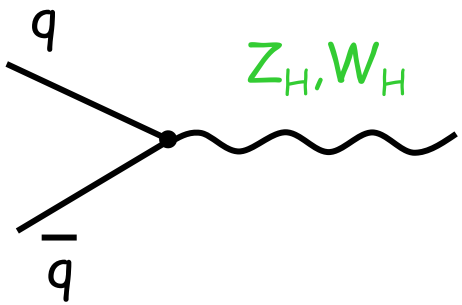
$$M < 6\ TeV \cdot \left(\frac{m_h}{200\ GeV} \right)^2$$

EW fits $\rightarrow$ strong constraints

Little Higgs realized in several models. Similar particle content.

Z_H, W_H production and decays

$q\bar{q}$ anihilation



Fermionic channels:

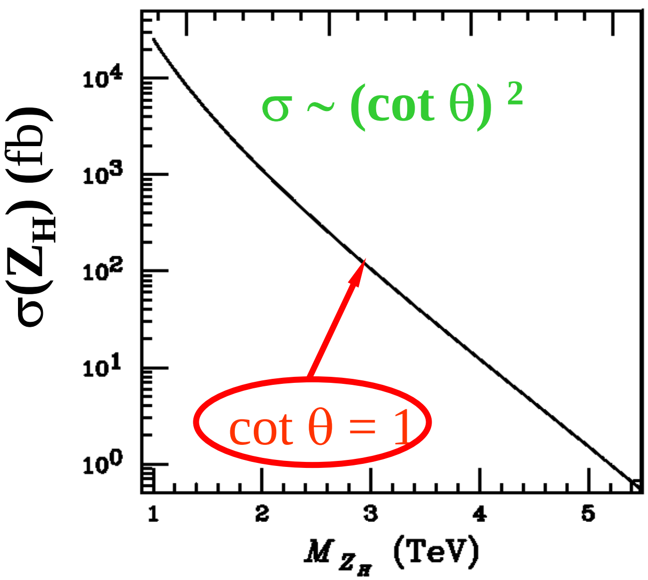
$Z_H \to \ell^+\ell^-, q\bar{q}$

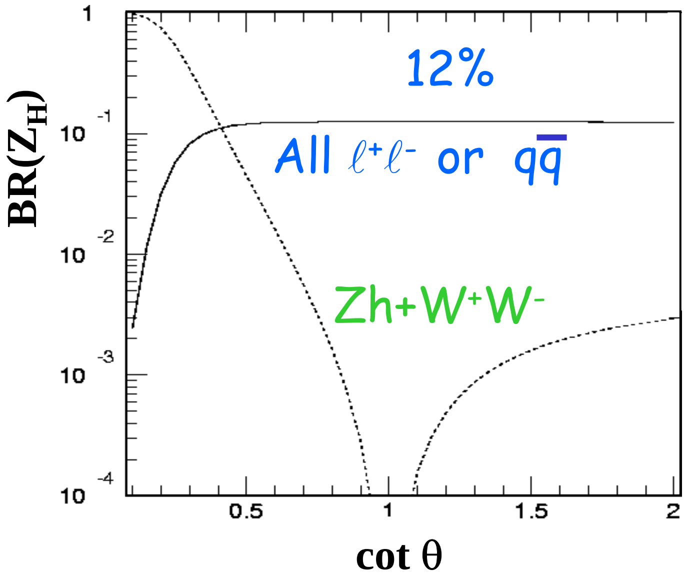
$W_H^\pm \to \ell\nu,\ q\bar{q}$

Bosonic channels:

$Z_H \to Zh,\ W^+W^-$

$W_H^\pm \to W^\pm h,\ W^\pm Z$





$BR(Z_H \to q\bar{q}) = 1/8$
$BR(W_H \to q\bar{q}') = 1/4$

$Br(W_H \to t\bar{b}) = 3 \times Br(W_H \to e\nu)$

$\sigma(W_H) = 2\,\sigma(Z_H)$

$\Gamma_{W_H}(Wh+WZ) = \Gamma_{Z_H}(Zh+WW)$

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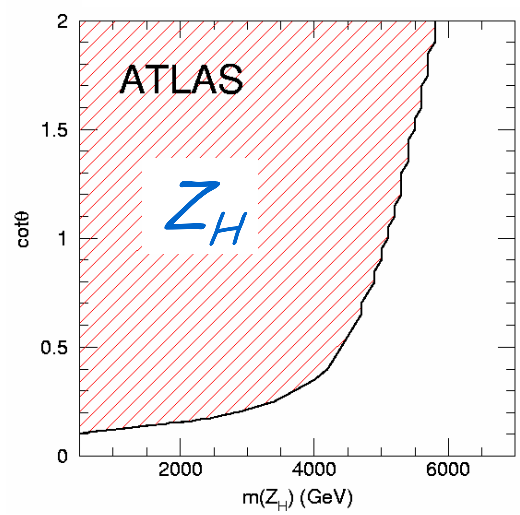
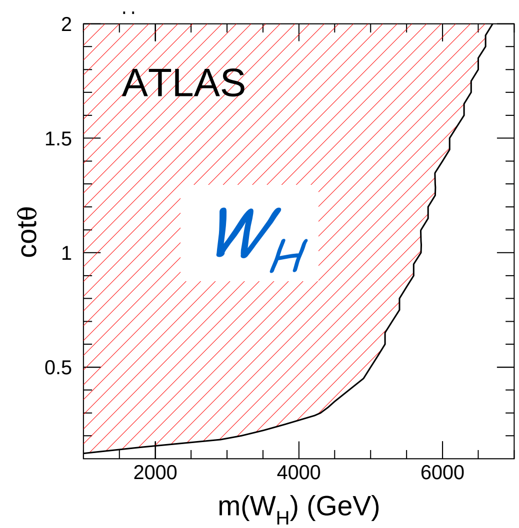
Leptonic V_H decays

$Z_H \to e^+e^-$
$W_H \to e\ \nu$

Discovery channel

With 300 fb^{-1}
= 3 years of LHC high luminosity:





All analyses performed using a *parameterized* simulation of the ATLAS detector (ATLFAST)

ε(lepton tag) = 90%

Poisson significance ($\sim S/\sqrt{B}$) > 5 + $S \geq 10$
in the mass window → discovery

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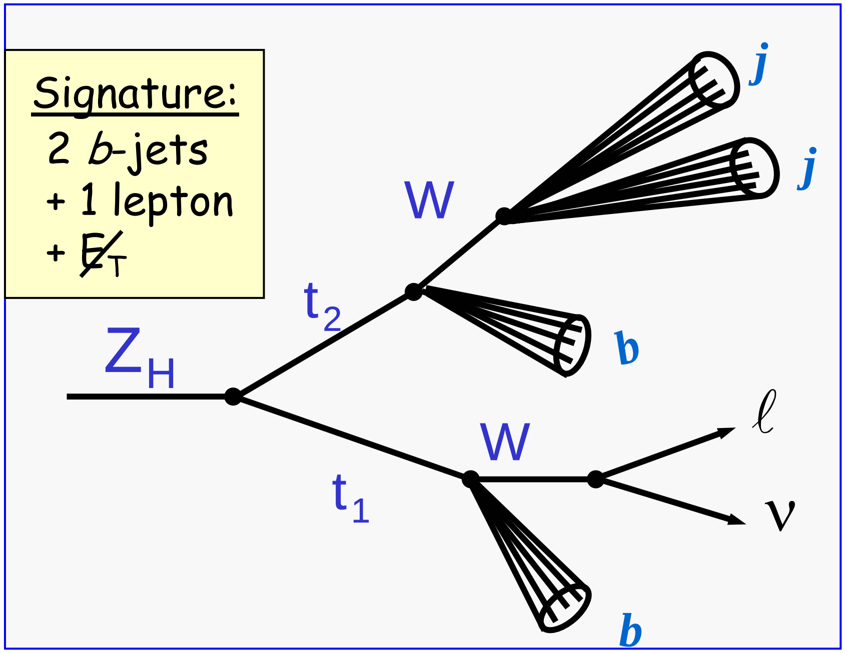
Hadronic V_H decays

NEW!

$V_H = Z_H, W_H$

$(\Delta R)^2 = (\Delta\eta)^2 + (\Delta\phi)^2$
η=pseudo-rapidity,
ϕ=azimuthal angle

$Z_H \to t_1\bar{t}_2\,,\ t_1 \to b\ell\nu\,,\ \bar{t}_2 \to \bar{b}jj$ $(\ell = e,\mu)$



Cuts:

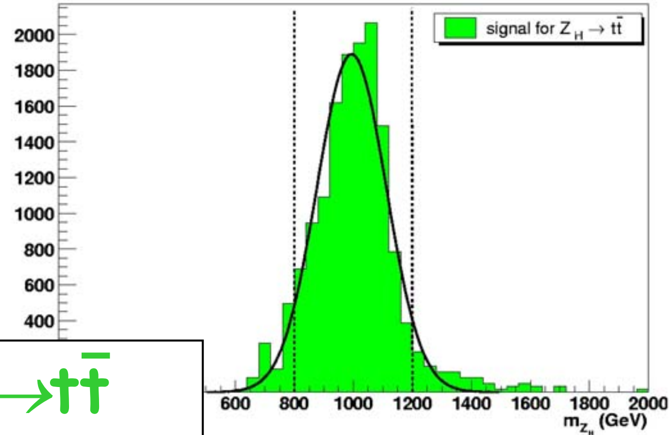
- 1 isol. lepton, $p_T > 25$ GeV
- $\not{E}_T > 25$ GeV
- 2 b-jets, $p_T > 25$ GeV, $\Delta R(b_1\ell) < 2$, $\Delta R(b_2\ell) > 2$
- $t_1 = b_1 + \ell_1 + \not{E}_T$ (with $\nu \,//\, \ell$)
- $t_2 = b_2$ + all jets $\Delta R < 2$
- $p_T(b_2 + j) > 0.25\, M_{Z_H}$

Background: $t\bar{t}$, …, W+jets

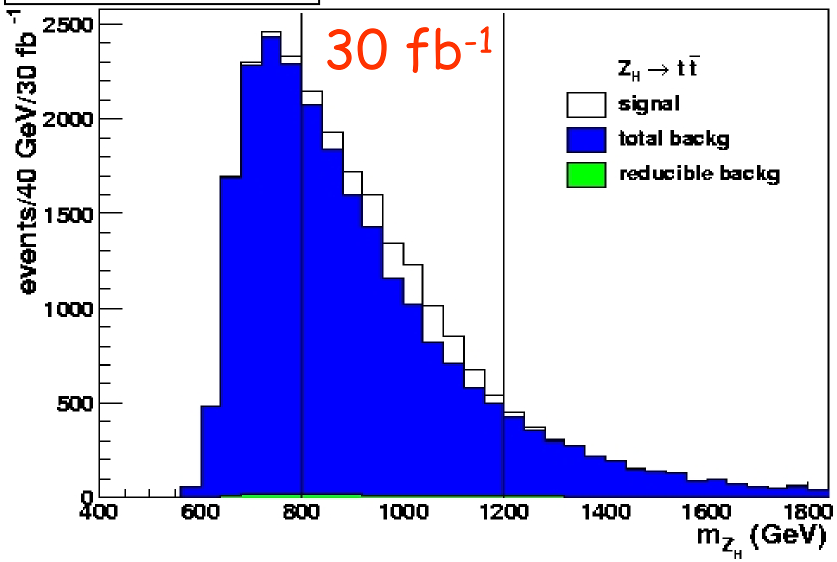
ε(b tag) = 50 (20)%
Ru = 100 (130) M_{Z_H} = 1 (2)TeV
validated with full simulation

ε_{kine} = 27 (21)%, M=1 (2) TeV

Hadronic V_H decays



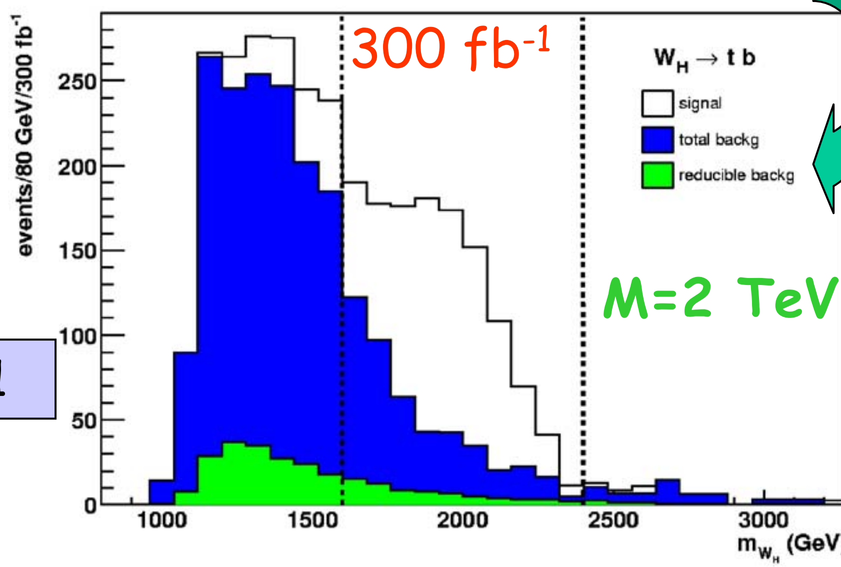
$Z_H \to t\bar{t}$
M=1 TeV



Mass reco. bias: <1%
Mass resolution: ~12%
» natural width: Γ/M = 2% cotθ

Two other modes:
$Z_H \to b\bar{b}$
$W_H \to t\bar{b} \to b\,\ell\,\nu\,\bar{b}$

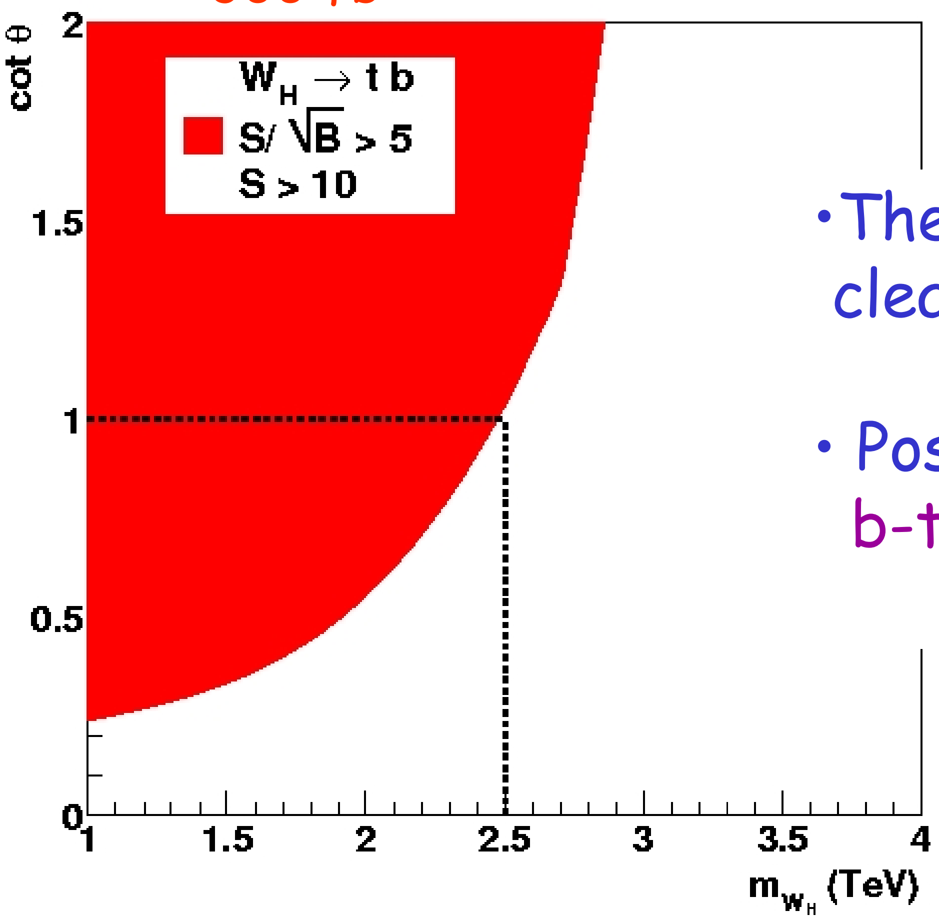
cotθ = 1



Hadronic V_H decays

- The Z_H to $t\bar{t}$ and $b\bar{b}$ decays are difficult to detect

300 fb^{-1}



- The W_H to $t\bar{b}$ decay might yield a signal clearly separable from background
- Possible improvement by optimizing b-tagging at very high p_T

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V_H decays to Higgs (m_h=200 GeV)

NEW!

Assume Higgs discovered

m_h=200 GeV

BR($h \to W^+W^-$) = 74 %
BR($h \to ZZ$) = 26 %

SM Higgs → usual BR

$$V_H \to V_1 h \to V_1 V_2 V_3$$

V = Z,W

Studied channels:
- ◈ $V_H \to$ 3 leptonic V (→ leptons only)
- ✷ $V_H \to$ 2 leptonic V + 1 V → jj

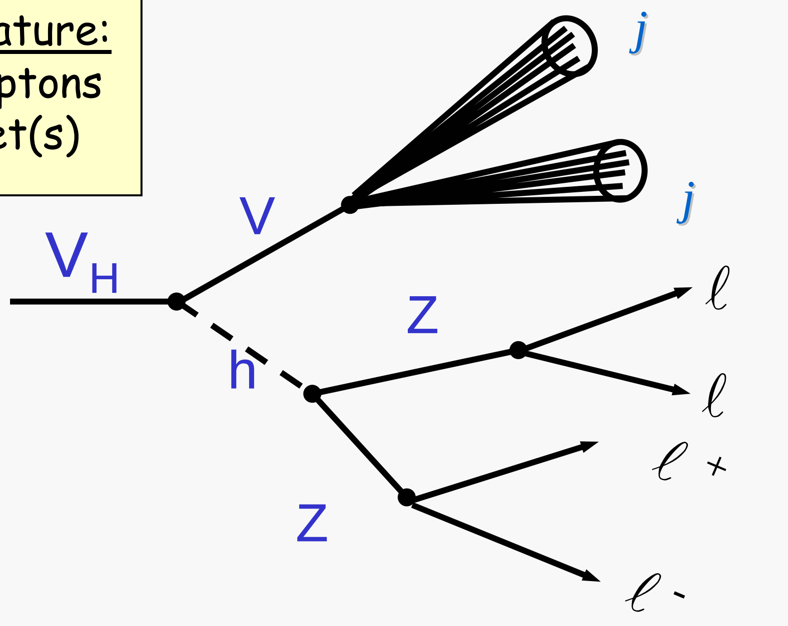
"A" modes: ✷ ($V_1 \to jj$) and ◈ ⇒ isolated leptons
"B" modes: ✷ (V_2 or $V_3 \to jj$) ⇒ lepton in jet

Branching fractions = $4\ 10^{-5}$ - $7\ 10^{-4}$ ($\cot\theta$=0.5)

V_H decays to Higgs (m_h=200 GeV)

$V_H \to Vh \to jjZZ \to jj\, \ell^+\ell^-\ell^+\ell^-$ (ℓ=e,μ) very clean

Signature:
4 leptons
+ jet(s)



Cuts:
- 2 isol. leptons (1,2) $M_{12}= M_Z\pm 15$ GeV
- 2 isol. leptons (3,4) $\Delta R_{1,2-3,4}<1.5$
- $p_T(1+2+3+4)>0.25\, M_{V_H}$
- 1 or 2 jets, $p_T>0.25\, M_{V_H}$ ($\Delta R_{1-2}<1$)
- $m(4l+j)=M_{V_H}\pm 15\%$

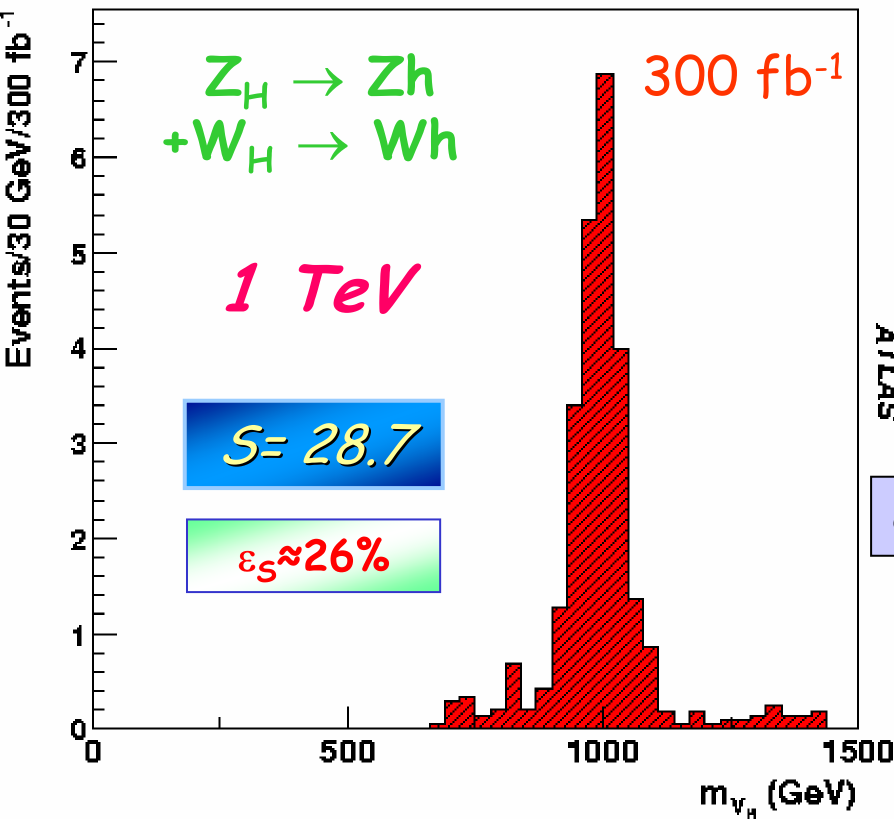
cotθ=0.5

$M(Z_H)$	σ.BR (fb)
1000	0.177
2000	0.009

$M(W_H)$	σ.BR (fb)
1000	0.338
2000	0.018

Background: ~ none

V_H decays to Higgs (m_h=200 GeV)

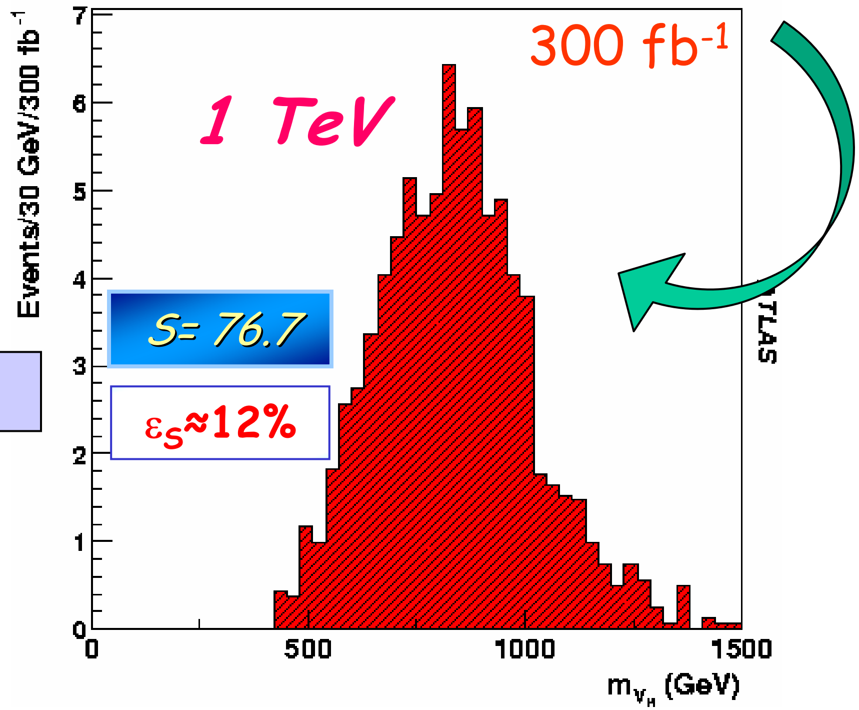


cotθ = 0.5

Two other modes:

$Z_H \to Zh \to \ell^+\ell^- W^+W^- \to \ell^+\ell^-\ell^+\nu\ell^-\nu$

$W_H \to Wh \to \ell\nu W^+W^- \to \ell\nu\ell^+\nu\ell^-\nu$



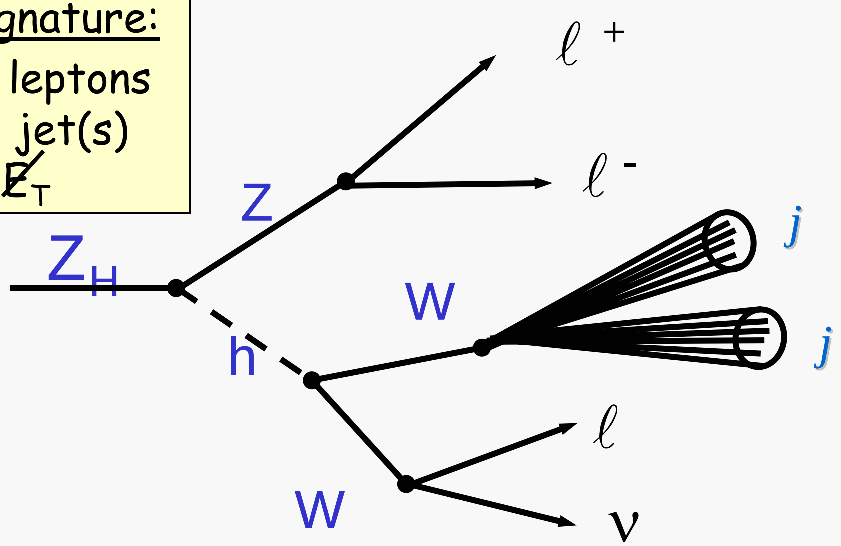
Mass reco. bias: 1%
Mass resolution: 4%

Assume $\vec{p\!\!/} = \vec{p\!\!/}_T \Rightarrow$ bias, poor resolution

V_H decays to Higgs (m_h=200 GeV)

$Z_H \to Zh \to \ell^+\ell^- WW \to \ell^+\ell^- jj\ \ell\nu$ (ℓ=e,μ)

Signature:
3 leptons
+ jet(s)
+ $\not{E}_T$



Cuts:
- 2 isol. leptons (1,2) $M_{12} = M_Z \pm 15$ GeV
- 1 isol. lepton, $W_1 = \ell_3 + \not{E}_T$, $p_T > 50$ GeV
  apply M_W constraint or assume $\nu // \ell_3$
- 1 or 2 jets, $M_j = M_W \pm 15$ GeV
- $p_T(\ell_1+\ell_2+W_1+j) > 100$ GeV

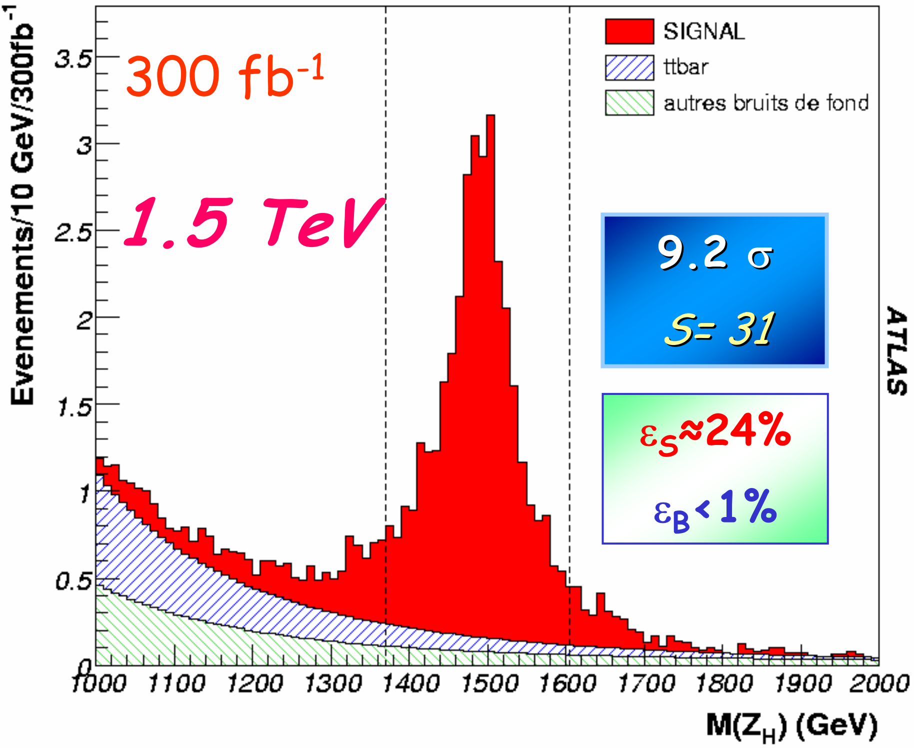
cotθ=0.5

$M(Z_H)$	σ.BR (fb)
1000	3.064
1500	0.645
2000	0.145

Background: $t\bar{t}$, Zh, WZ, ZZ, h

Lack of statistics on background → extrapolated

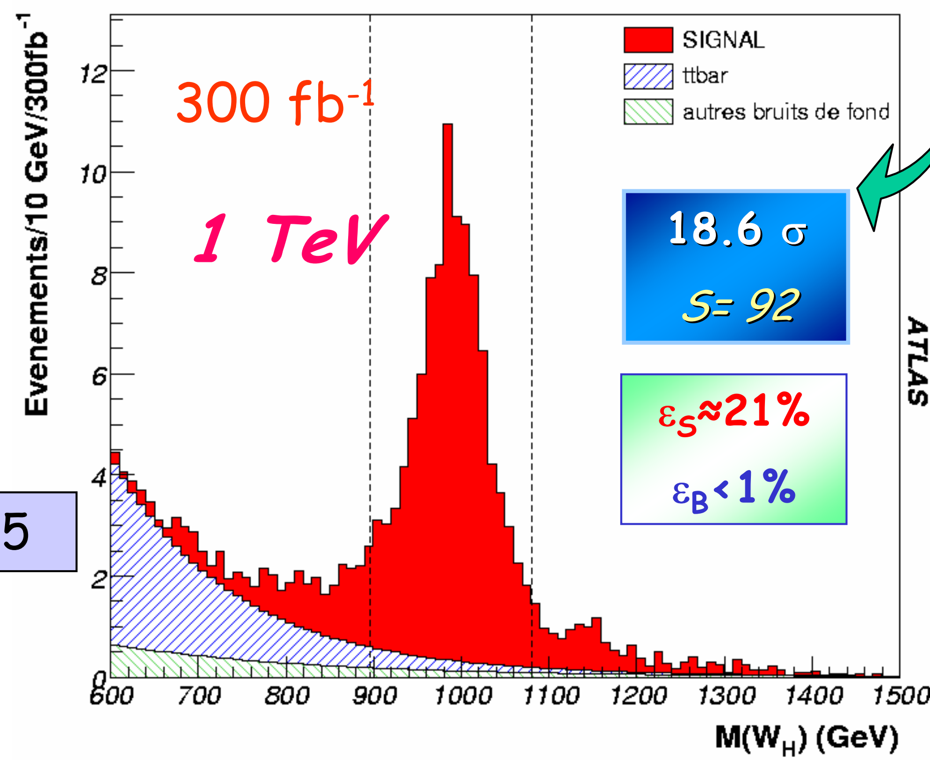
V_H decays to Higgs (m_h=200 GeV)



Two other modes:

$Z_H \rightarrow Zh \rightarrow \ell^+\ell^- ZZ \rightarrow \ell^+\ell^- jj\ \ell^+\ell^-$

$W_H \rightarrow Wh \rightarrow \ell\nu\ ZZ \rightarrow \ell\nu\ jj\ \ell^+\ell^-$

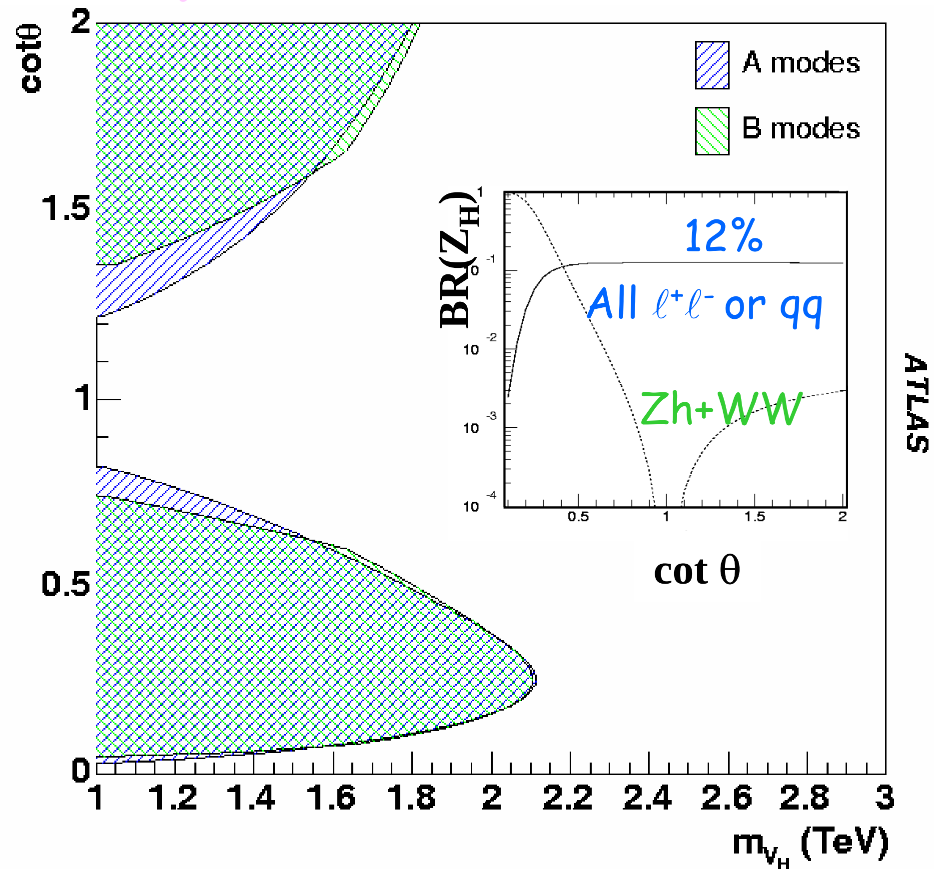


cotθ = 0.5

Mass reco. bias: 1%
Mass resolution: 4%
~same all modes

V_H decays to Higgs (m_h=200 GeV)

$\int Ldt$ = 300 fb^{-1}



Mass reach about 2 TeV, except when cotθ ~ 1

Although ATLFAST lepton isolation criteria were especially tuned (B modes), needs validation with full simulation

M_{V_H} < 6 TeV for m_h = 200 GeV (avoid fine tuning)

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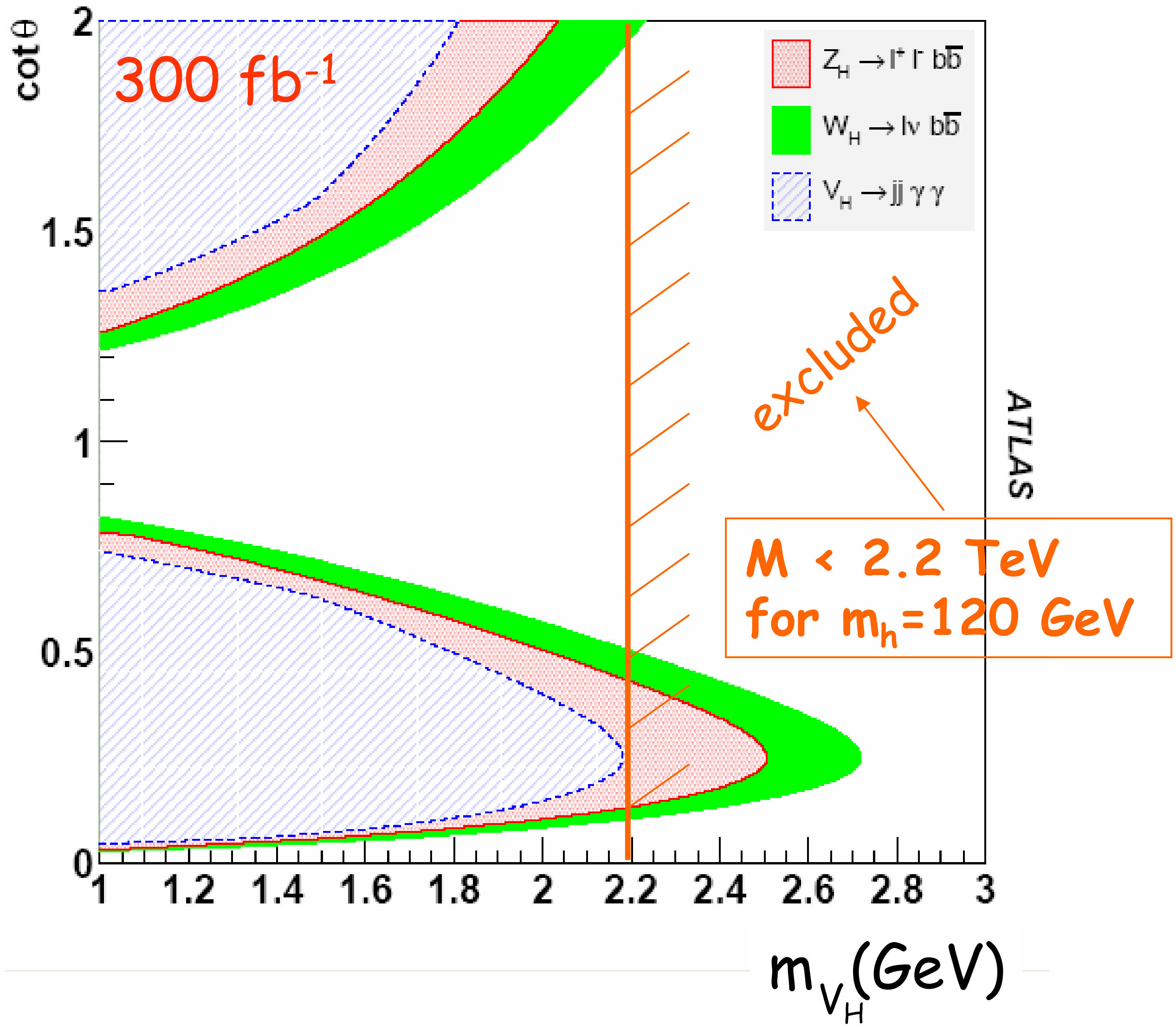
V_H decays to Higgs (m_h=120 GeV)

Earlier results:

BR($h \to b\bar{b}$) = 66 %
BR($h \to \gamma\gamma$) = 0.2 %

$Z_H \to Zh \to jj\gamma\gamma,\ \ell\ell\, b\bar{b}$
$W_H \to Wh \to jj\gamma\gamma,\ \ell\nu\, b\bar{b}$
(ℓ=e,μ)

ε(b tag) = 40-50%
Ru = 100

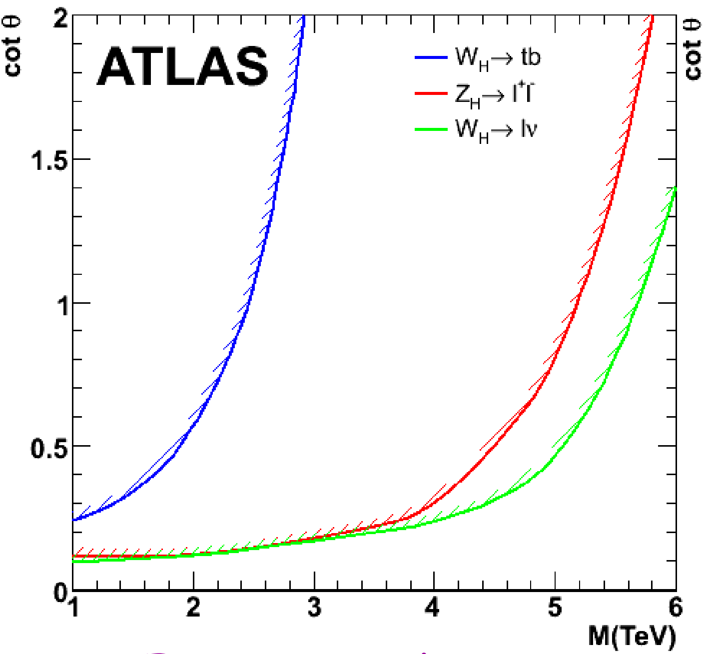


Summary

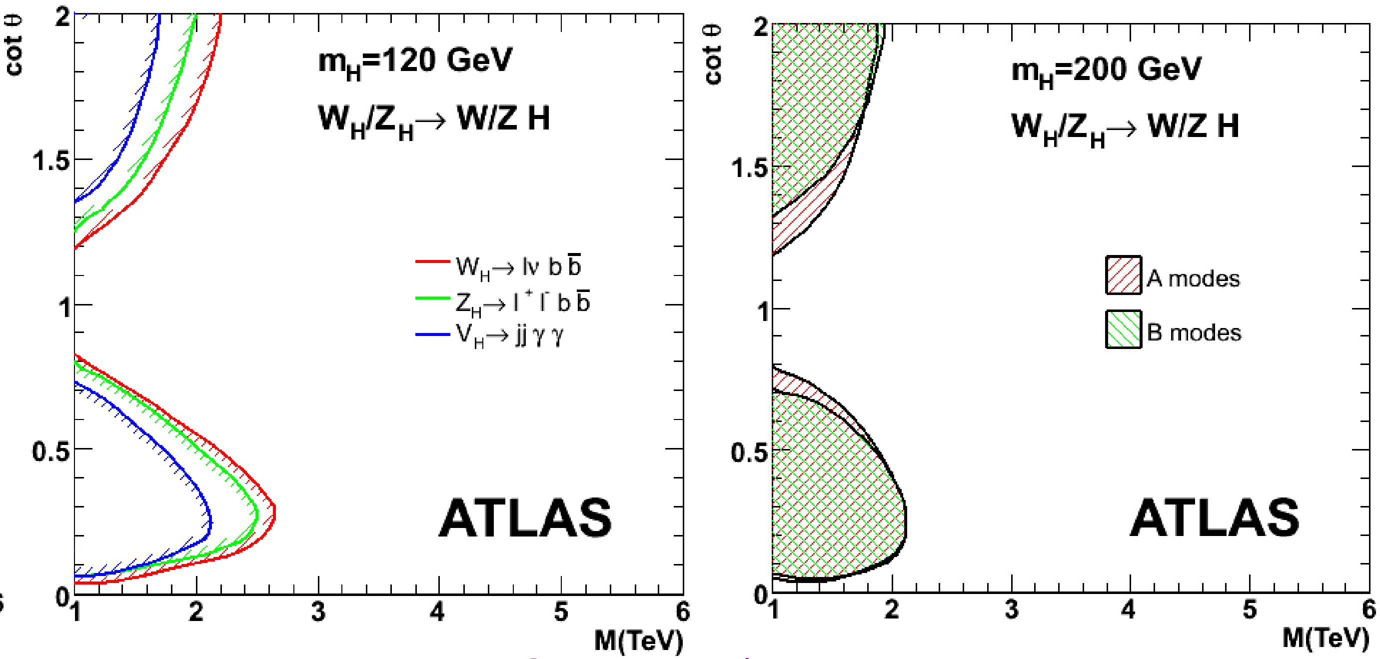
The Z_H, W_H can be discovered up to 5-6 TeV if cotθ large

It may be possible to probe the model up to ~ 2 TeV

- using the $V_H \to Vh$ decay (cotθ ∉ [0.8,1.2])
- using the $W_H \to t\bar{b}$ decay (cotθ > 0.25)



Fermionic decays



Bosonic decays

References:
G. Azuelos *et al.*, Eur. Phys. J. **C39S2**, 13 (2005)
S. Gonzales de la Hoz *et al.*, ATL-PHYS-PUB-2006-003
E. Ros and D. Rousseau, ATL-COM-PHYS-2006-031

Many thanks to

the authors of these analyses, and especially

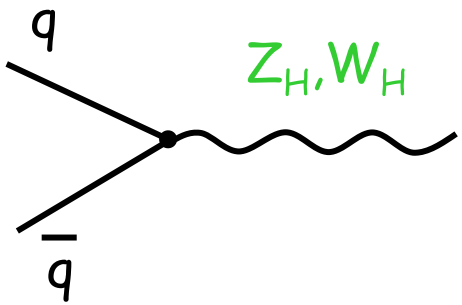
David Rousseau and Matthieu Lechowski

Eduardo Ros and Jose E. Garcia

Backup slides

Z_H, W_H production and decays

$q\bar{q}$ anihilation



Fermionic channels:

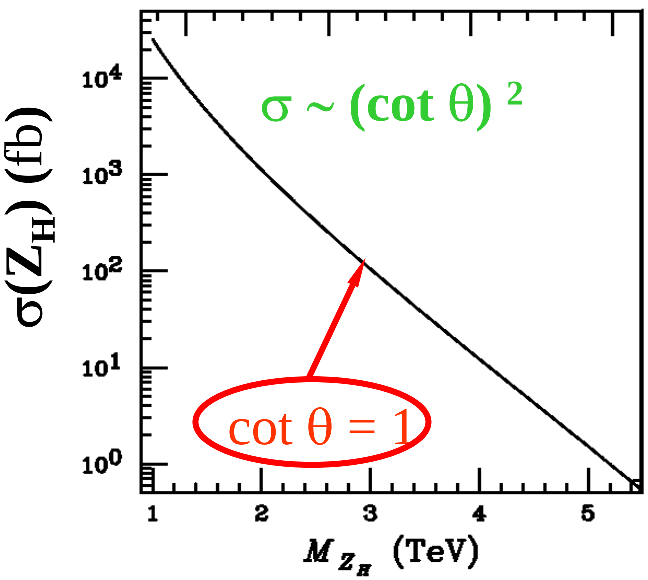
$Z_H \rightarrow \ell^+\ell^-, q\bar{q}$

$W_H^{\pm} \rightarrow \ell\nu, q\bar{q}$

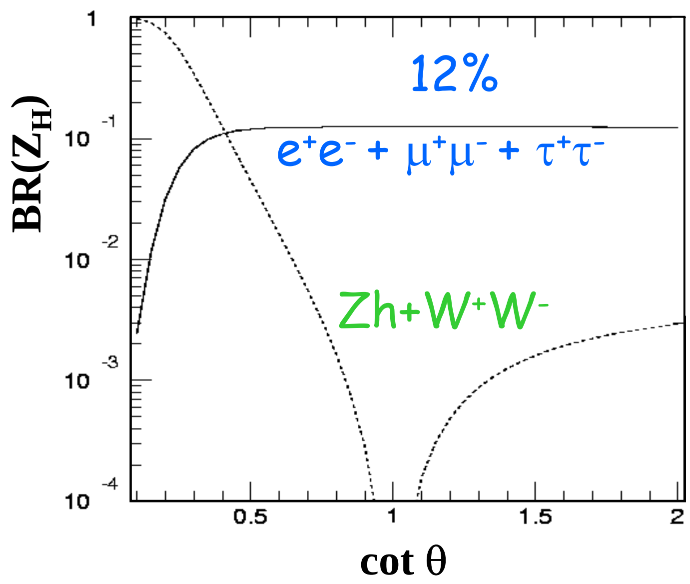
Bosonic channels:

$Z_H \rightarrow Zh, W^+W^-$

$W_H^{\pm} \rightarrow W^{\pm}h, W^{\pm}Z$



$\sigma(W_H) = 2\,\sigma(Z_H)$



$\Gamma_{Z_H}(\ell\bar{\ell}) \sim (\cot\theta)^2$

$\Gamma_{Z_H}(Zh) \sim (\cot 2\theta)^2$

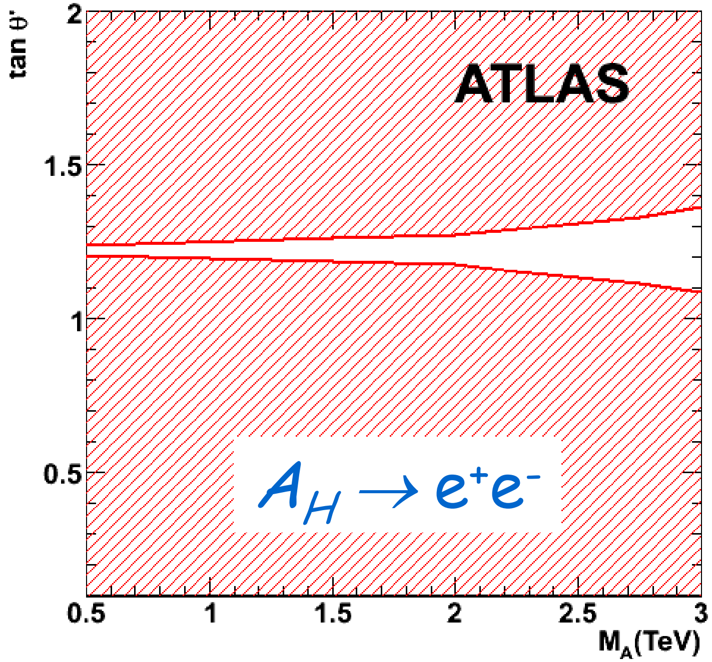
$\Gamma_{Z_H}(W^+W^-) = \Gamma_{Z_H}(Zh)$

$\Gamma_{W_H}(Wh+WZ) = \Gamma_{Z_H}(Zh+WW)$

Deductions for A_H

- theorical uncertainties (strong model-dependency) for A_H
- can deduce limits on $\sigma.BR(A_H \to Z\ h)$ from results for Z_H (same decays)
- hypothesis : favorable cases where $M(W_H/Z_H)$ and $M(A_H)$ are distant for each $M(A_H)$ (resolution of $M(W_H/Z_H)$ being 45 → 80 GeV)

⇒ W_H/Z_H not background for A_H

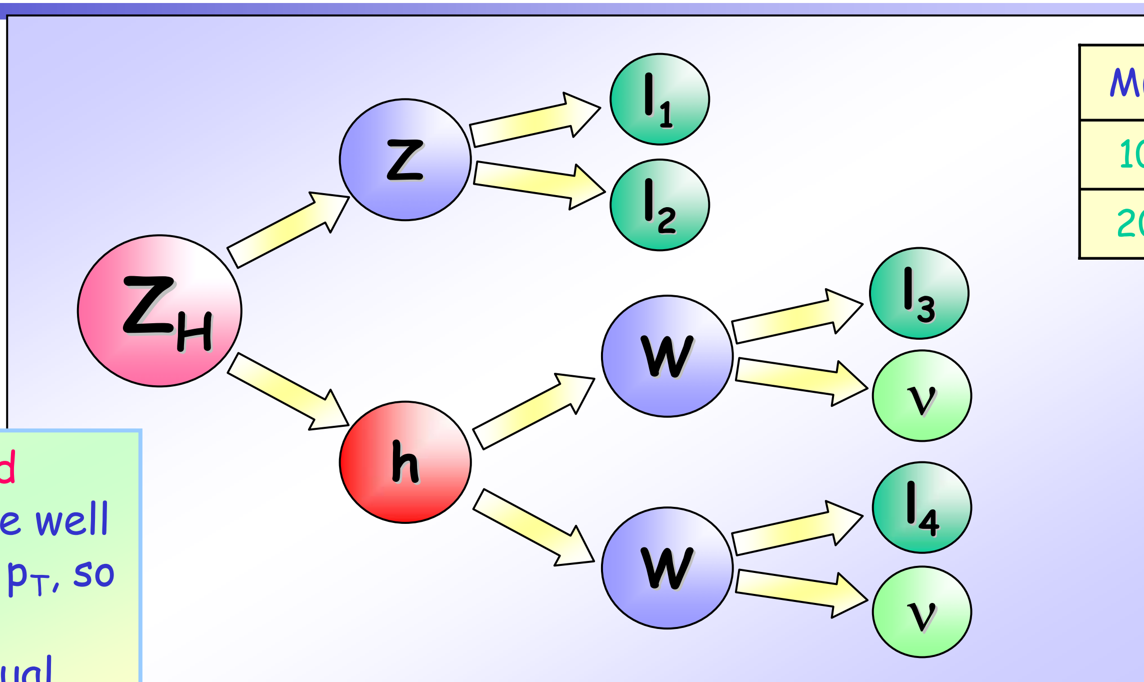


A modes : $Z_H \to Zh \to \ell^+\ell^- W^+W^- \to \ell^+\ell^-\ell^+\nu\ell^-\nu$

$\cot\theta = 0.5$

$M(Z_H)$	$\sigma.BR$ (fb)
1000	0.473
2000	0.023

Signal :



no background considered

hypothesis: all leptons are well isolated and at very high p_T, so the final state should be distinguished from eventual backgrounds

in all the following :

- $|\eta_l| < 2.5$ (Calo's acceptance)
- ε (lepton-tagging) = 90%

Reconstruction:

- l_1 and l_2 same type, opposite charge, $M(l_1 l_2) = M_Z \pm 15$ GeV
- l_3 and l_4 opposite charge
- $p(h) = p(l_3) + p(l_4) + p(\text{miss.})$ with $\vec{p}(\text{miss.}) \,//\, \vec{p}(l_3) + \vec{p}(l_4)$
- *Z_H reconstructed with h and Z*

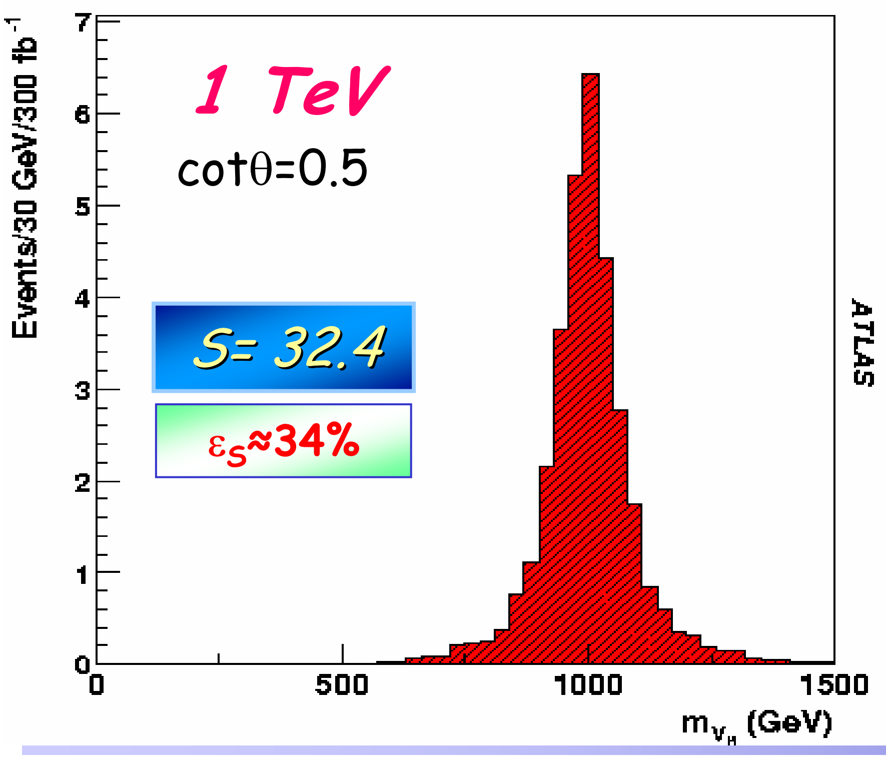
A modes : $Z_H \rightarrow Zh \rightarrow \ell^+\ell^-W^+W^- \rightarrow \ell^+\ell^-\ell^+\nu\ell^-\nu$

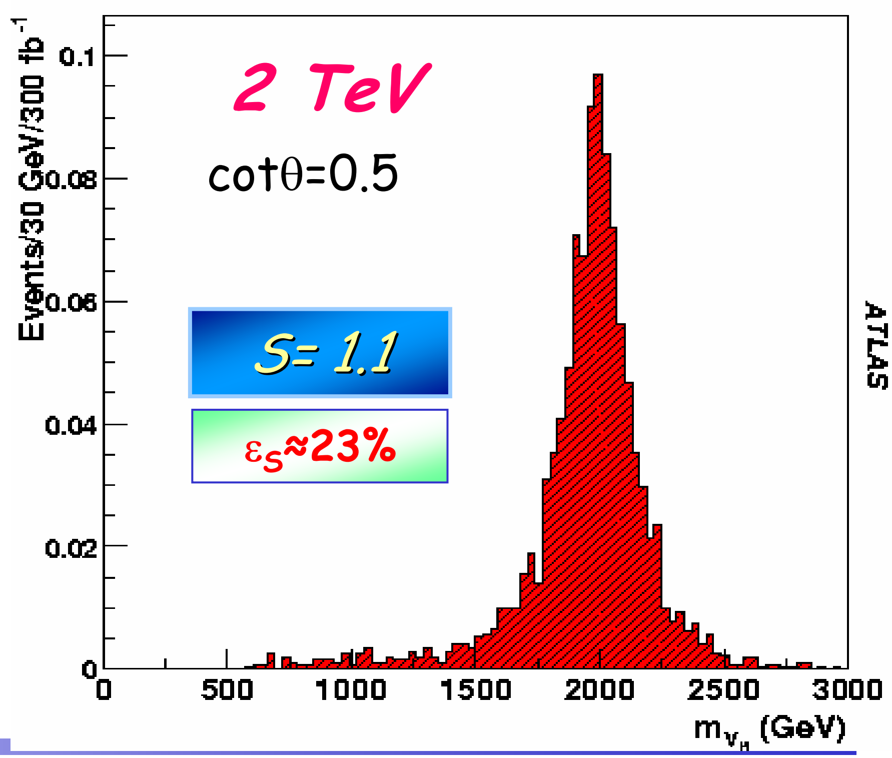
Cuts:

- E_T(miss.) > 50 GeV

1 TeV:
- $p_T(Z)$ > 250 GeV
- $p_T(h)$ > 250 GeV
- $M(Z_H)$ in the range 1000±150 GeV

2 TeV:
- $p_T(Z)$ > 500 GeV
- $p_T(h)$ > 500 GeV
- $M(Z_H)$ in the range 2000±300 GeV



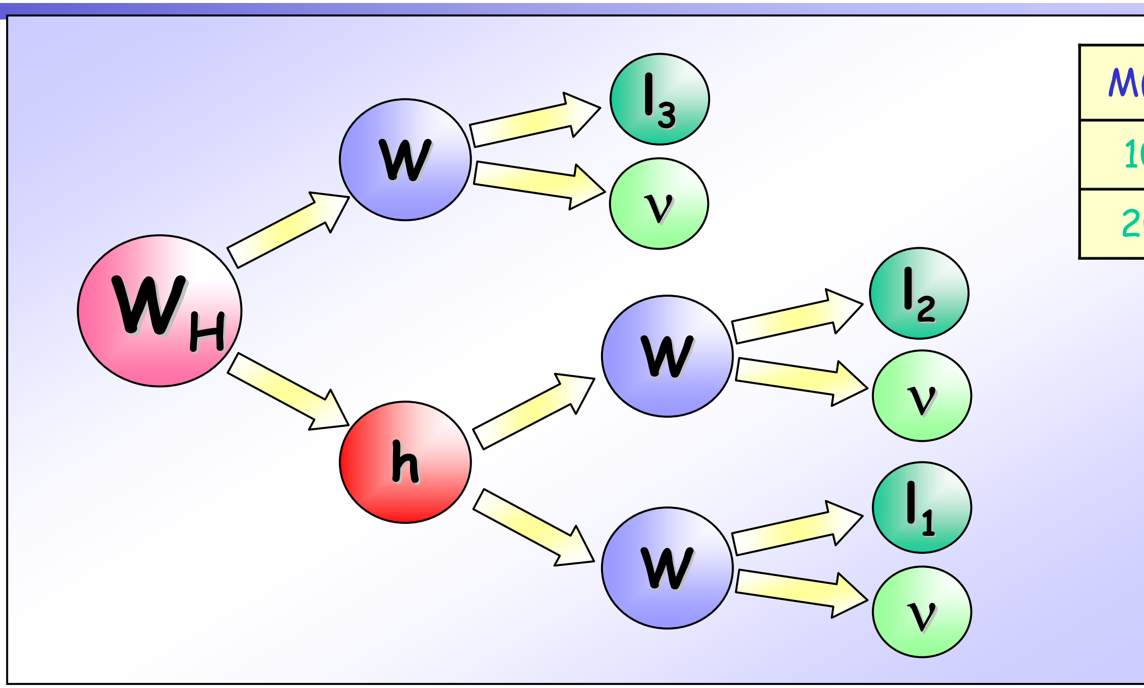


A modes : $W_H \to Wh \to \ell\nu W^+W^- \to \ell\nu\ell^+\nu\ell^-\nu$

cotθ=0.5

$M(W_H)$	σ.BR (fb)
1000	2.883
2000	0.148

Signal :



Reconstruction:

- l_1 and l_2 opposite charge, $\Delta R(l_1,l_2) < 1.5$, p("h without miss.") = $p(l_1) + p(l_2)$
- l_3 , $\Delta R(l_3,$ "h without miss.") > 1.5
- $p(W_H)$ = p("h without miss.") + $p(l_3)$ + p(miss.) with $\vec{p}(\text{miss.}) = \vec{p}_T(\text{miss.})$

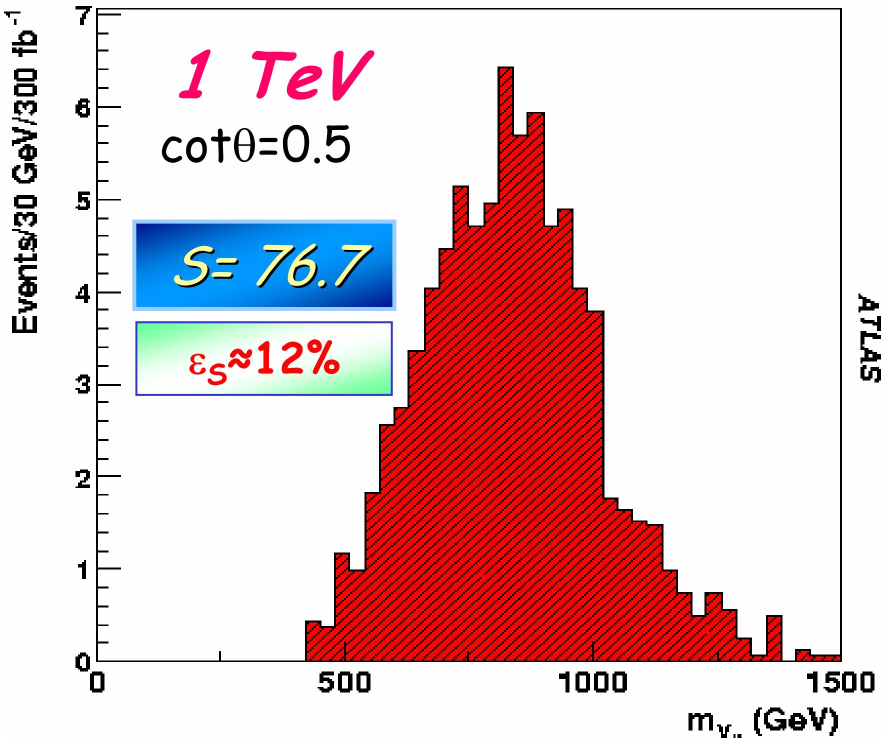
⇒ *only partial reconstruction !*

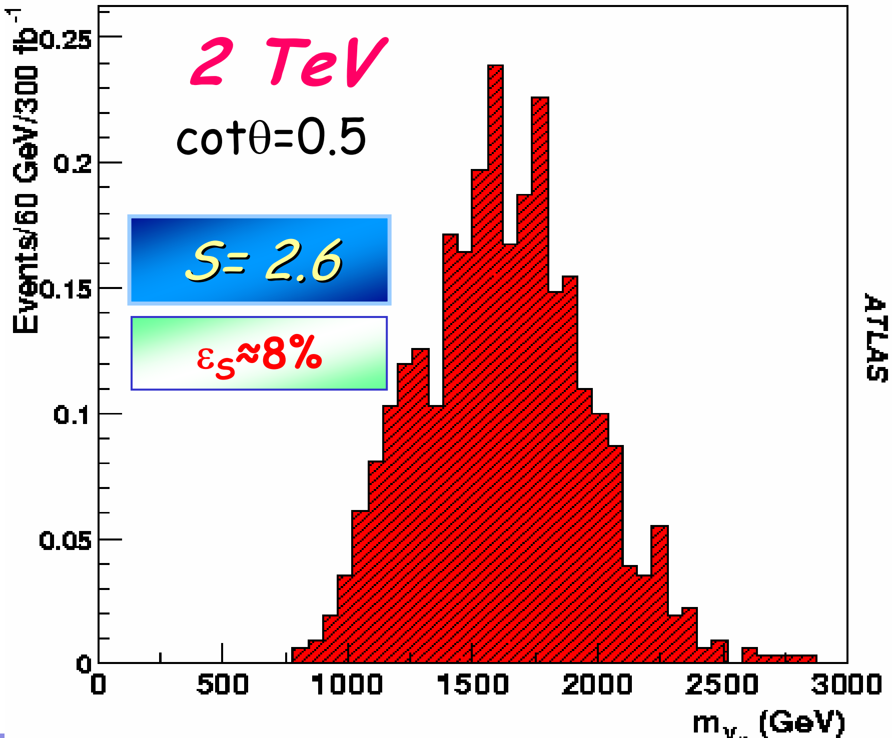
A modes : $W_H \to Wh \to \ell\nu W^+W^- \to \ell\nu\ell^+\nu\ell^-\nu$

Cuts:

- E_T(miss.) > 100 GeV

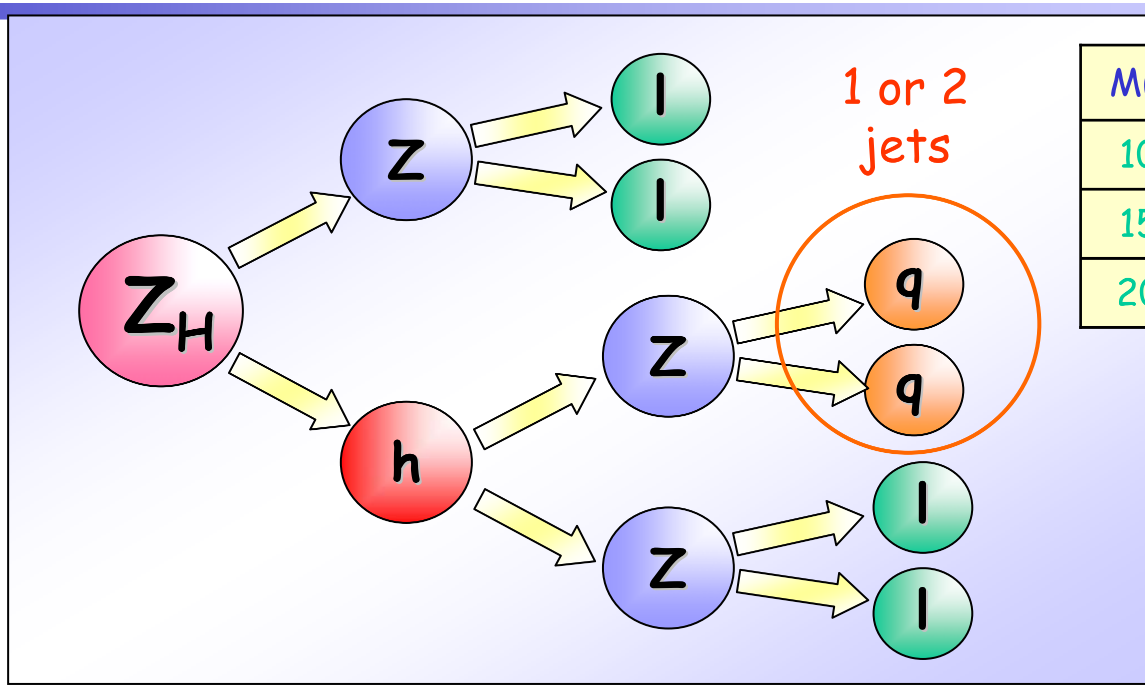
• ***no jet*** with p_T > 100 GeV	• ***no jet*** with p_T > 200 GeV
• $p_T(l_3)$ > 100 GeV	• $p_T(l_3)$ > 200 GeV
• p_T("h without miss.") > 100 GeV	• p_T("h without miss.") > 200 GeV
• $M(Z_H)$ in the range 800±300 GeV	• $M(Z_H)$ in the range 1600±600 GeV





B modes : $Z_H \rightarrow Zh \rightarrow \ell^+\ell^- ZZ \rightarrow \ell^+\ell^- jj\ \ell^+\ell^-$

Signal :



$\cot\theta = 0.5$

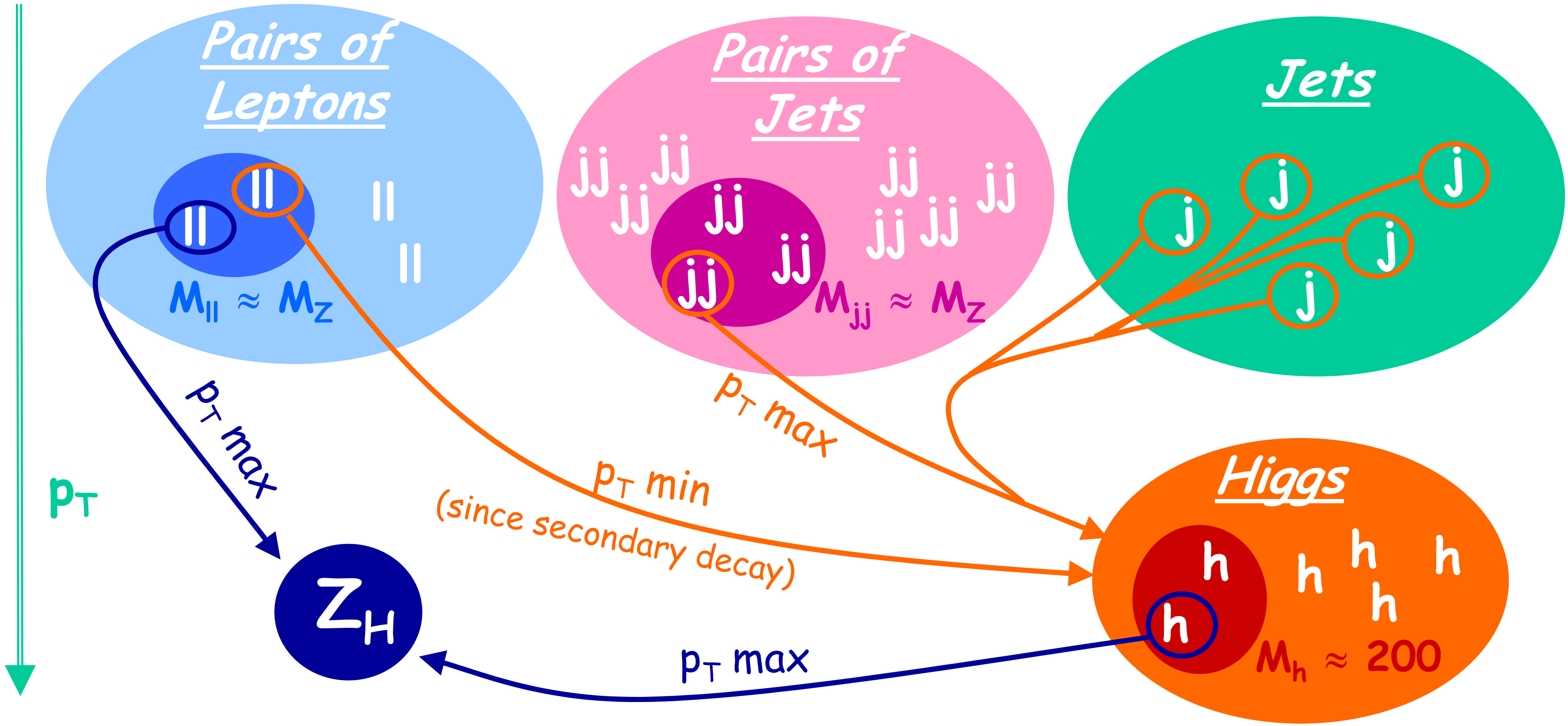
$M(Z_H)$	$\sigma.BR$ (fb)
1000	0.354
1500	0.075
2000	0.017

Background :

- $tt \rightarrow WbWb \rightarrow l\nu b\ l\nu b$ with $b \rightarrow B \rightarrow l\ X$
  - → big cross-section : 3376 fb
- $Zh \rightarrow llZZ \rightarrow llqqll$
  - → same final state : 0.2274 fb
- h, fh, qqh, tth, ZZ, Wh

B modes : Reconstruction

necessary condition: to have ***4 leptons***

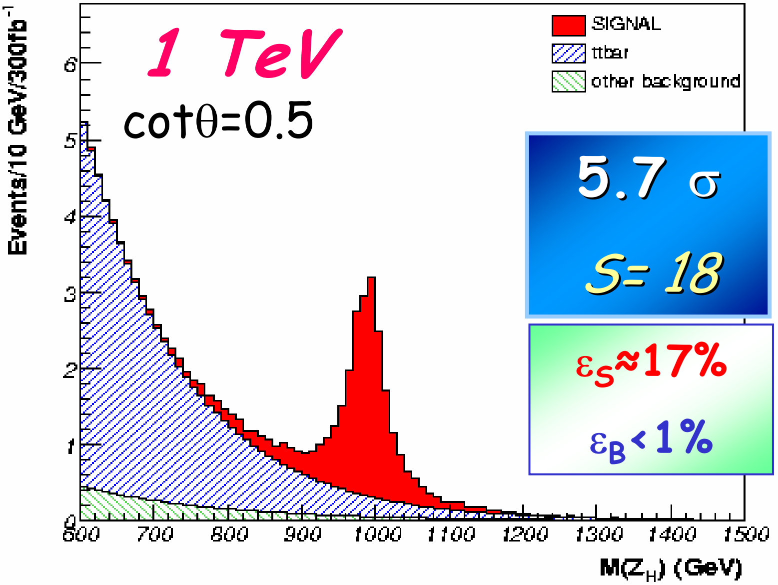


B modes : $Z_H \to Zh \to \ell^+\ell^- ZZ \to \ell^+\ell^- jj\ \ell^+\ell^-$

- $|\eta_l| < 2.5$ (Calorimeter's acceptance)
- ε(identification of lepton) = 90%
- $p_{T\,1\,\text{lepton}} > 30$ GeV *and* $p_{T\,2\,\text{leptons}} > 20$ GeV (LVL1 trigger)

- $|\, M_h - \langle M_h \rangle_{gaussian\ fit} \,| < 2\sigma_{gaussian\ fit}$
- $|\, M_{V_H} - \langle M_{V_H} \rangle_{gaussian\ fit} \,| < 2\sigma_{gaussian\ fit}$
- $p_{T\,\text{pair of jets or big jet}} > 50$ GeV
- $p_{T\,h} > 100$ GeV

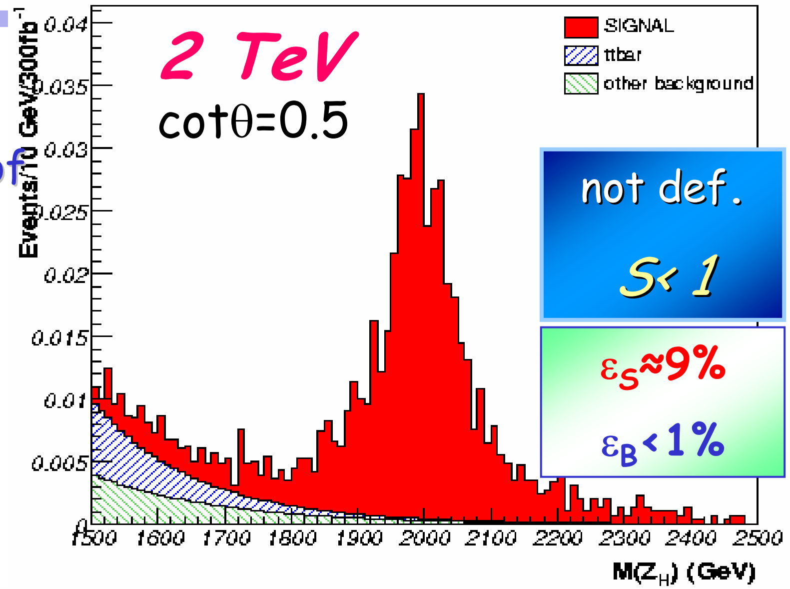
B modes : $Z_H \to Zh \to \ell^+\ell^- ZZ \to \ell^+\ell^- jj\ \ell^+\ell^-$

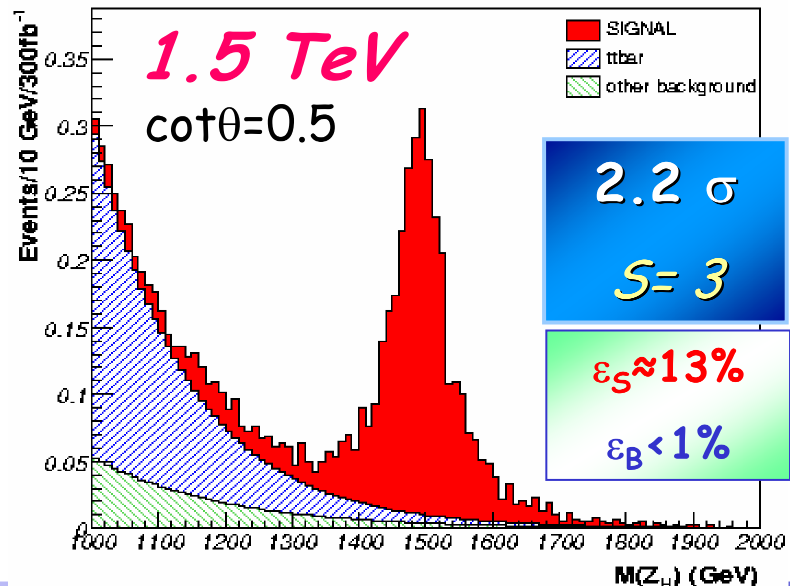


NB:

significance $\neq S/\sqrt{B}$
(due to small number of events and big uncertainties)

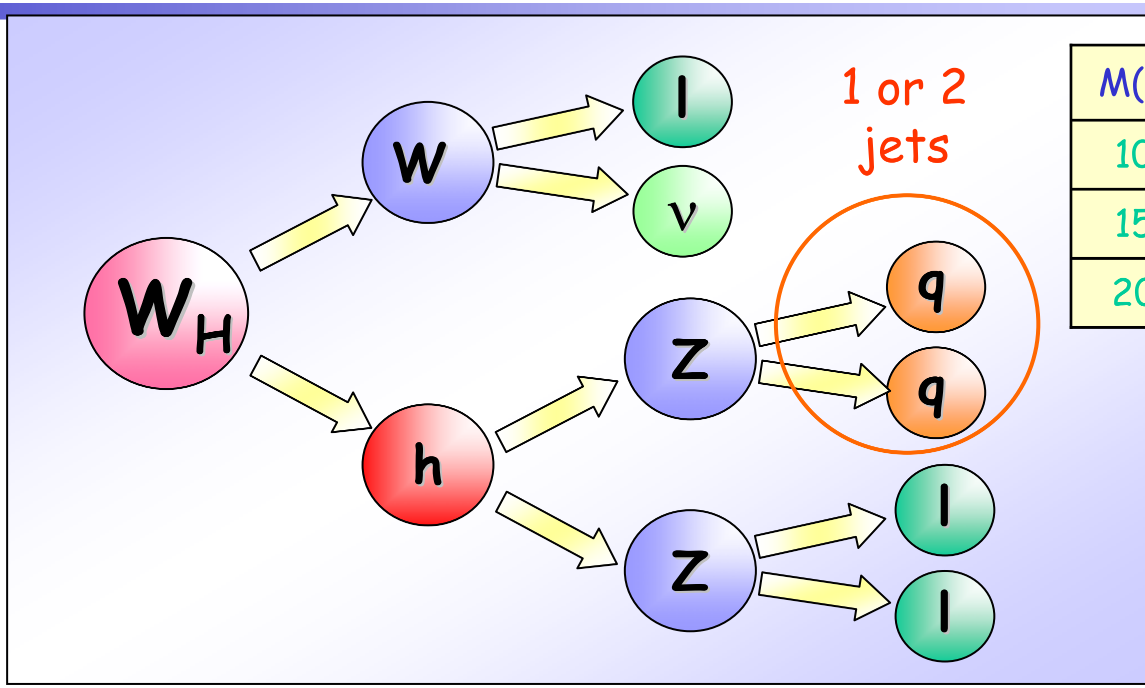
→ use "*PoissonSig*" (Wisconsin's tool)





B modes : $W_H \rightarrow Wh \rightarrow \ell\nu\, ZZ \rightarrow \ell\nu\, jj\, \ell^+\ell^-$

Signal :



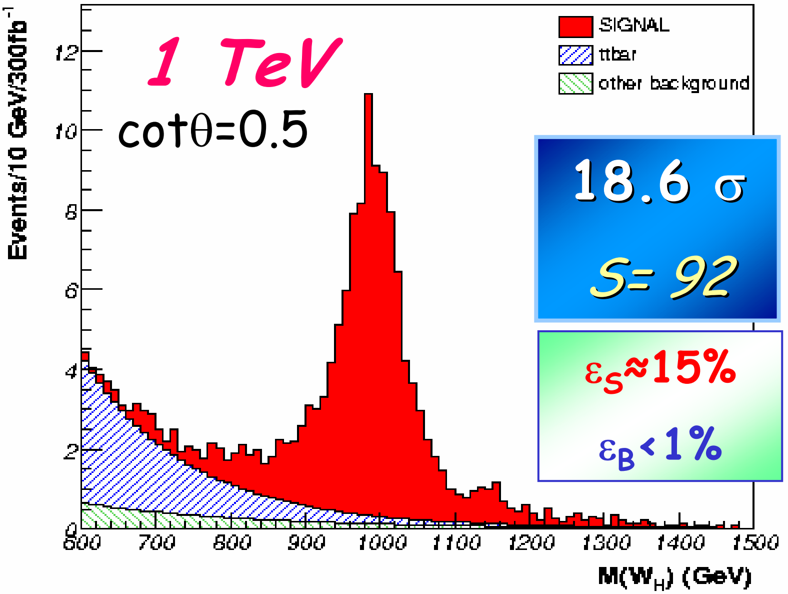
cotθ=0.5

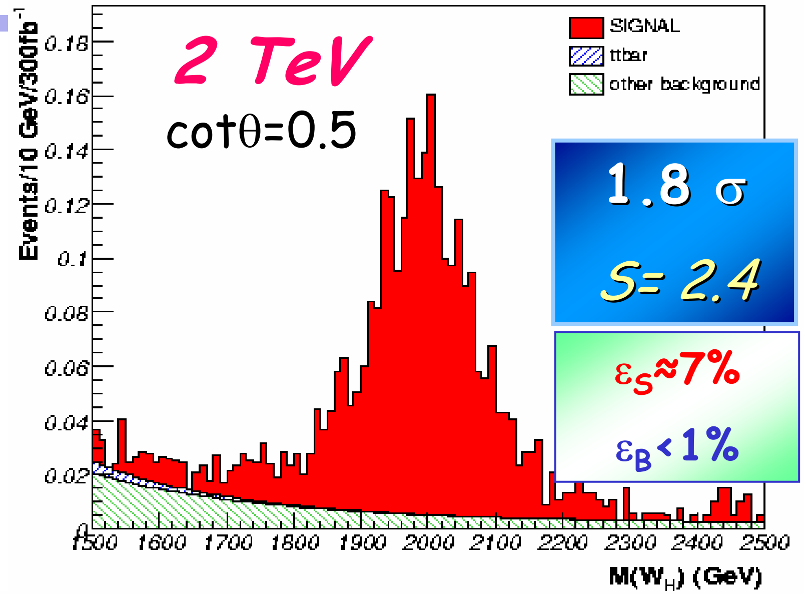
$M(W_H)$	σ.BR (fb)
1000	2.162
1500	0.468
2000	0.111

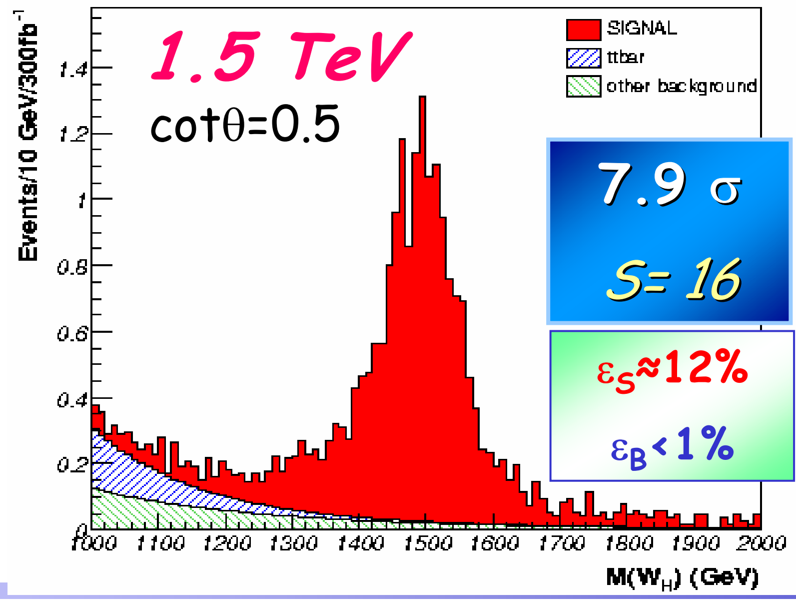
Background :

- tt → 3376 fb
- Zh → llWW → llqqlν
  → same final state : 2.028 fb
- h, fh, qqh, tth, ZZ, Wh, WZ

B modes : $W_H \to Wh \to \ell\nu ZZ \to \ell\nu\, jj\, \ell^+\ell^-$







The littlest Higgs Model