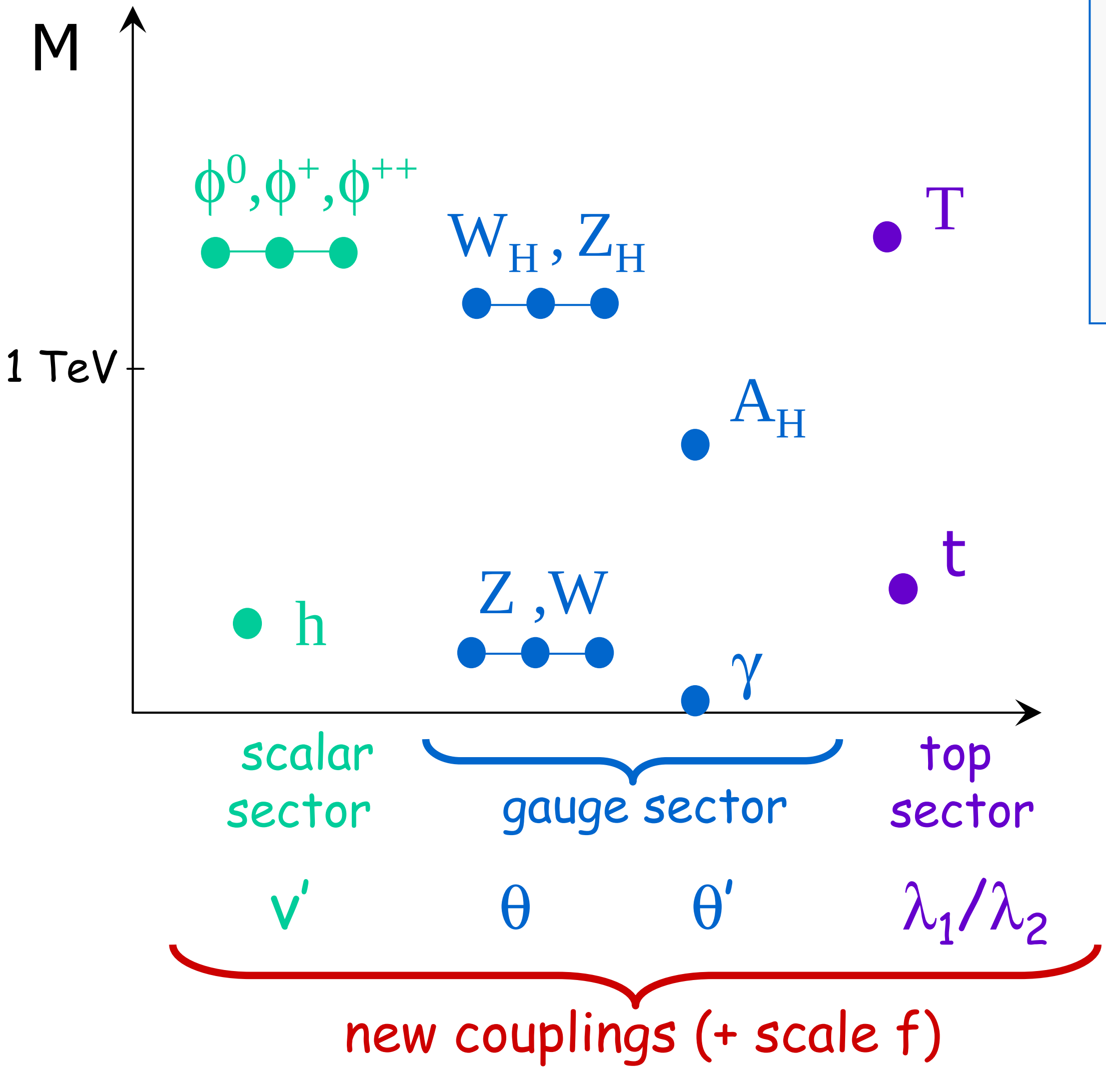
LITTLE HIGGS SEARCHES AT LHC

on behalf of ATLAS Collaboration

presented by: Jose E. Garcia *(IFIC-Valencia)*

Particle Spectrum



Littlest Higgs model

$SU(5) \rightarrow SO(5)$

Gauge sector $\rightarrow [SU_2 \otimes U_1]^2$

SM Higgs

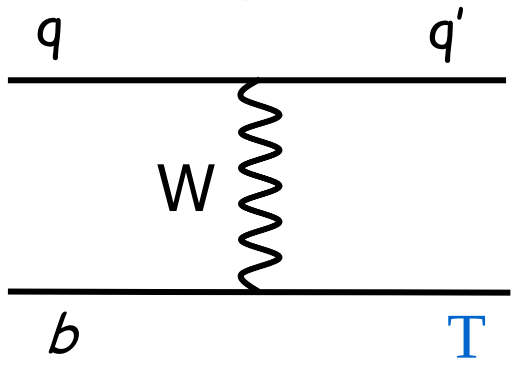
Arkani-Hamed et al., JHEP 207 (2002) 34

Phenomenology

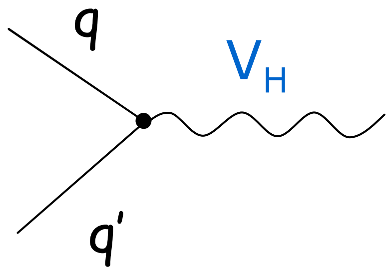
- *Han et al., Phys. Rev. D67 (2003) 95004*
- *Burdman et al., hep-ph/0212228*

Strategies at LHC

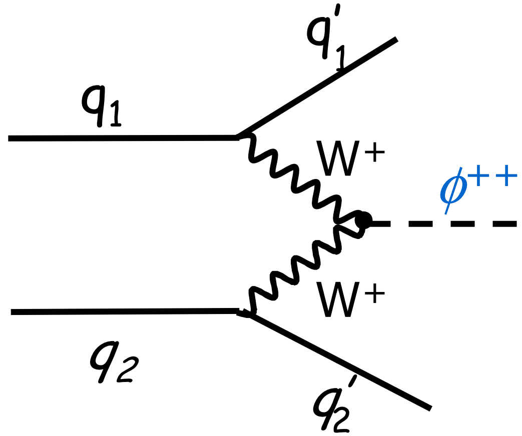
T



V_H



ϕ^{++}



Wb fusion

$\sigma \sim (\lambda_1)^2$

$\lambda_1/\ \lambda_2 \sim 1$ suppressed by *b-quark* PDF.

$T \to$ bW, tZ, th

$q\bar{q}$ annihilation

$\sigma \sim (\cot\theta)^2$

Wide range in *cot* θ possible.

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

$V_H \to$ V h (V is Z or W)

VBF mechanism

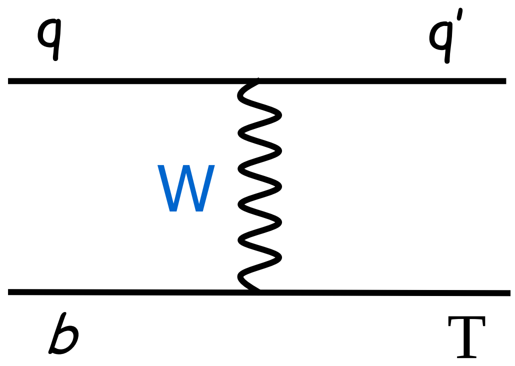
$\sigma \sim (v')^2$

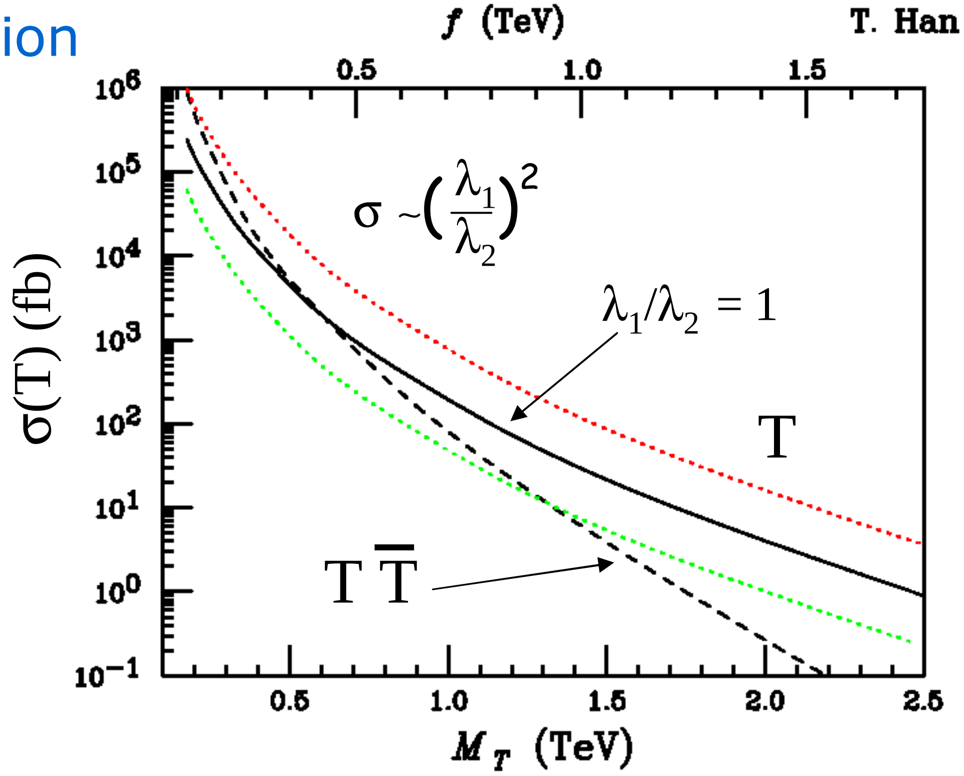
v' should be small

$\phi^{++} \to W^+W^+$

heavy top T

- Production mechanism = Wb fusion





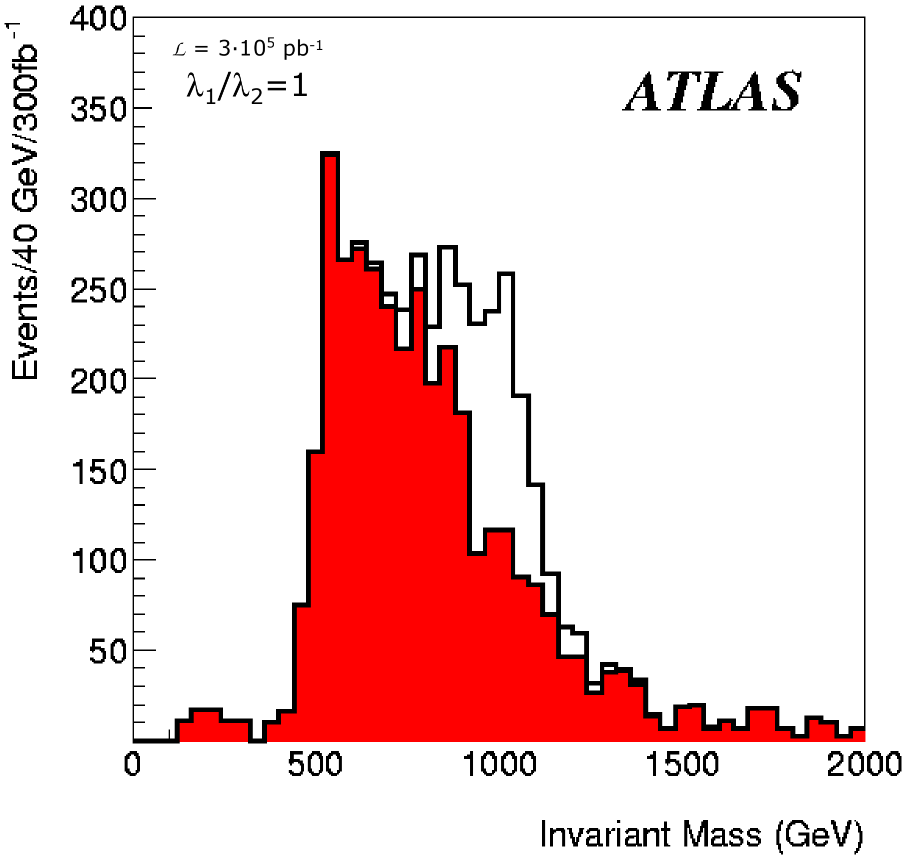
BR	$T \rightarrow$	bW	50 %
	$T \rightarrow$	tZ	25 %
	$T \rightarrow$	th	25 %

λ_1, λ_2 Yukawa couplings of T and t

$$\frac{\Gamma}{M} \approx \frac{1}{16\pi} \approx 2\ \%$$

$T \rightarrow Wb$

$T \rightarrow Wb \rightarrow$ b-jet + lepton + $\not{E}_T$



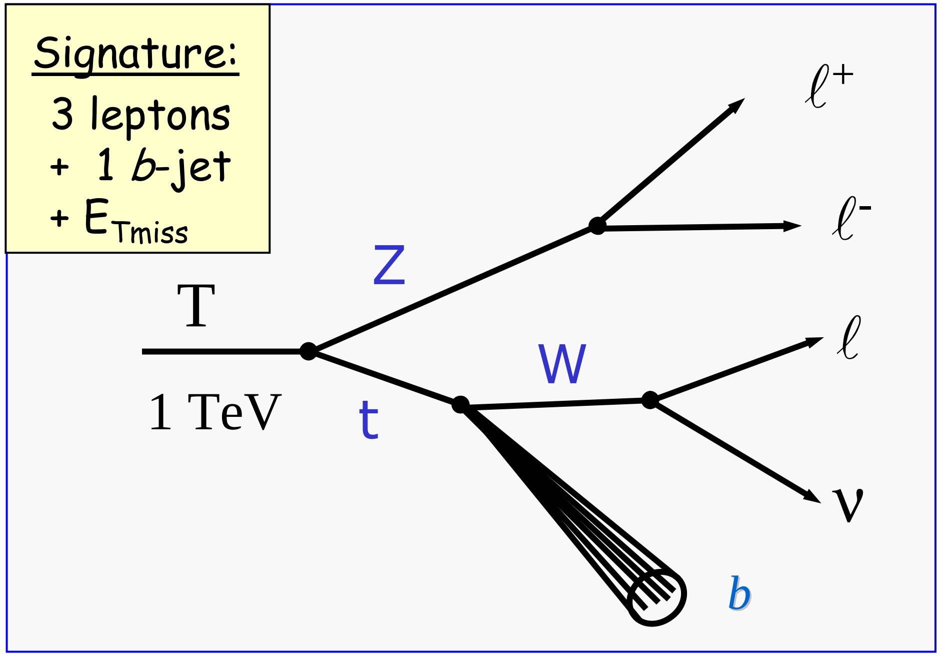
Cuts:
- p_T(jet) > 200 GeV
- p_T(lepton) > 100 GeV
- E_T > 100 GeV

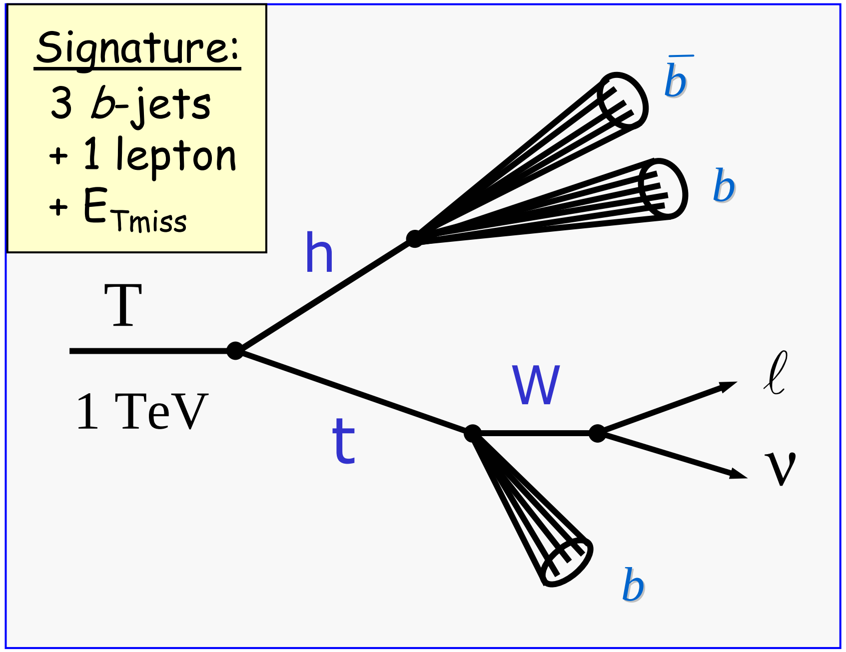
1 b-tag required

Backgrounds: $t\bar{t}$, t, $Wb\bar{b}$

Signal with 5σ for M_T < 2000 GeV

$T \rightarrow Zt$ and $T \rightarrow ht$





BKG tbZ, tZ,WZ

clear peak but poor statistics

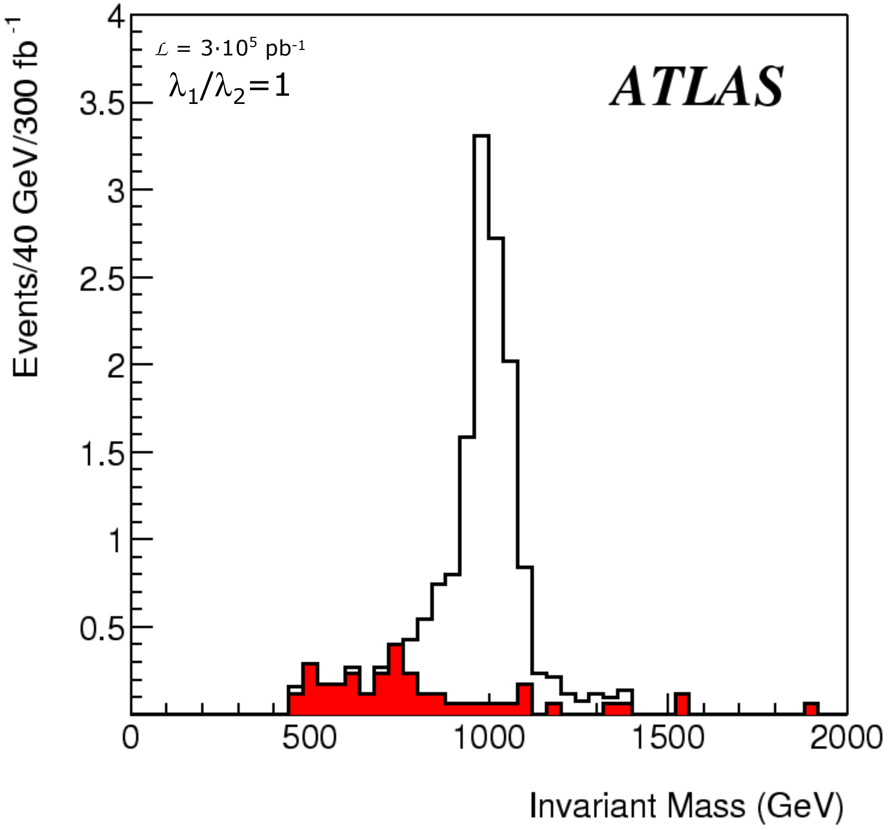
BKG $t\bar{t}$, $Wb\bar{b}$

Not distinguishable peak

$T \rightarrow Zt$ signal

M_T = 1 TeV

$T \rightarrow tZ \rightarrow$ 3 leptons + b-jet + $\not{E}_T$



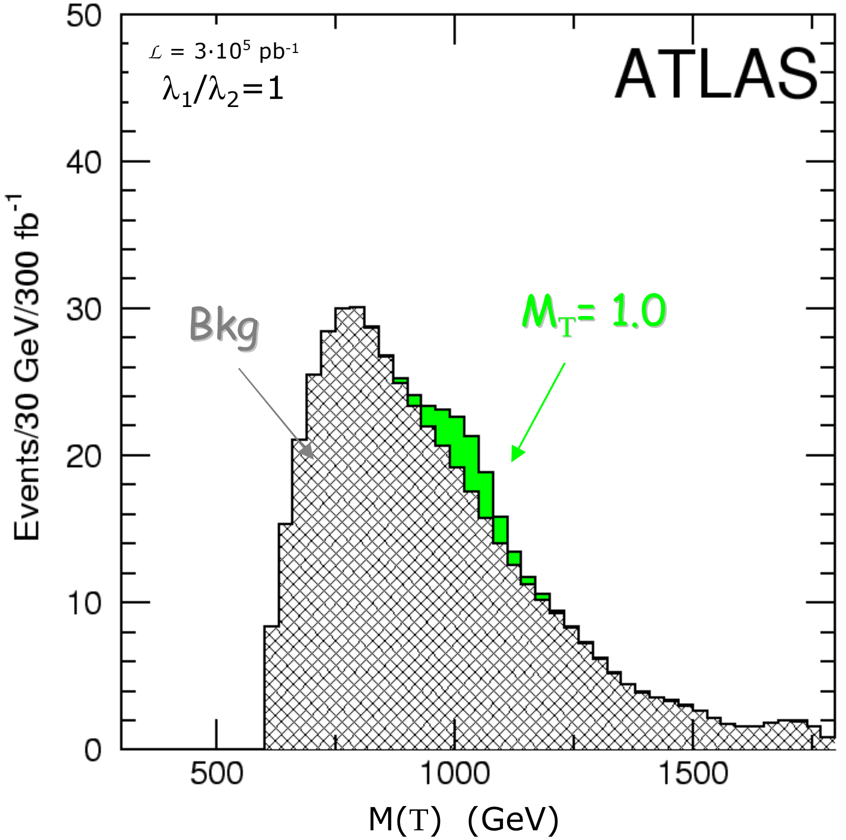
Cuts:
- *3 isolated leptons (2 of them with $M_{\ell^+\ell^-} = M_Z$)*
- 1 b-jet
- $\not{E}_T$ > 100 GeV

Signal with 5σ for M_T < 1050 GeV

$T \rightarrow ht$ signal

M_T= 1 TeV

$T \rightarrow ht \rightarrow$ 3 b-jets + lepton + $\not{E}_T$

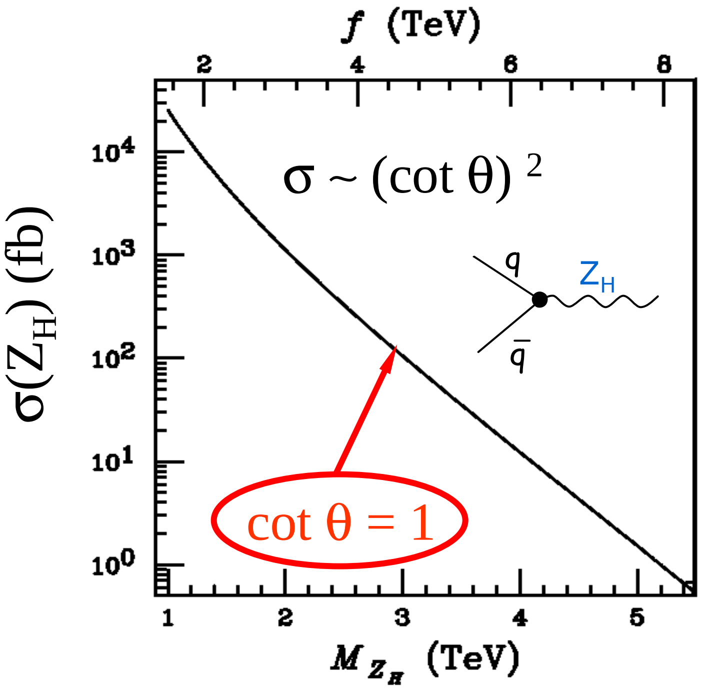


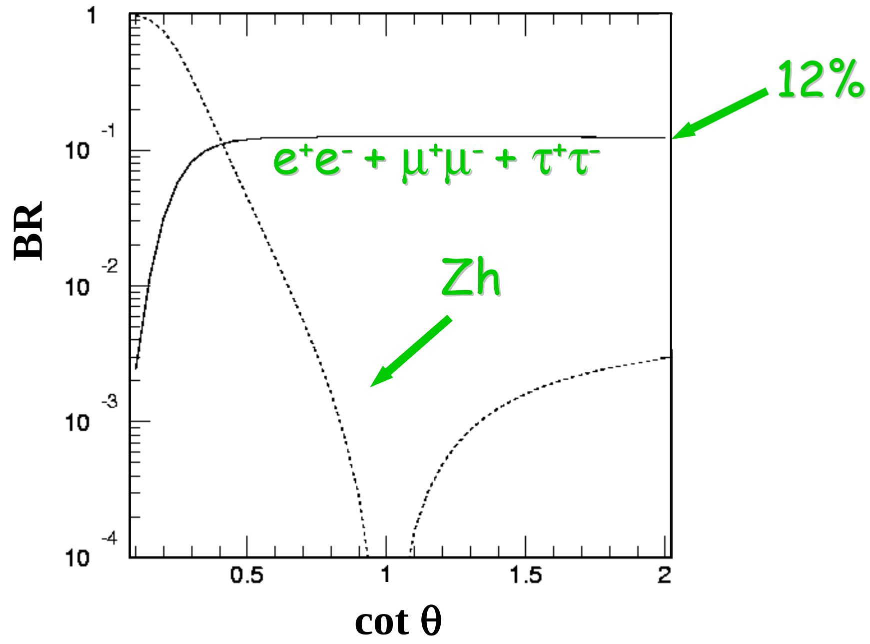
Cuts:

- p_T(3-jets) > 130 GeV
- p_T(lepton) > 100 GeV
- 110 < M_h < 130 GeV

At least 1 b-tag

Gauge Boson Z_H





Once a mass is given, the only free parameter in the model is, θ.

$$\Gamma(\ell\bar{\ell}) \sim (\cot\theta)^2$$
$$\Gamma(Zh) \sim (\cot 2\theta)^2$$

Search for Z_H

$M(Z_H)$ = 2 TeV $\mathcal{L} = 3 \cdot 10^5$ pb [1]

$q\bar{q} \longrightarrow Z_H \longrightarrow e^+e^-$

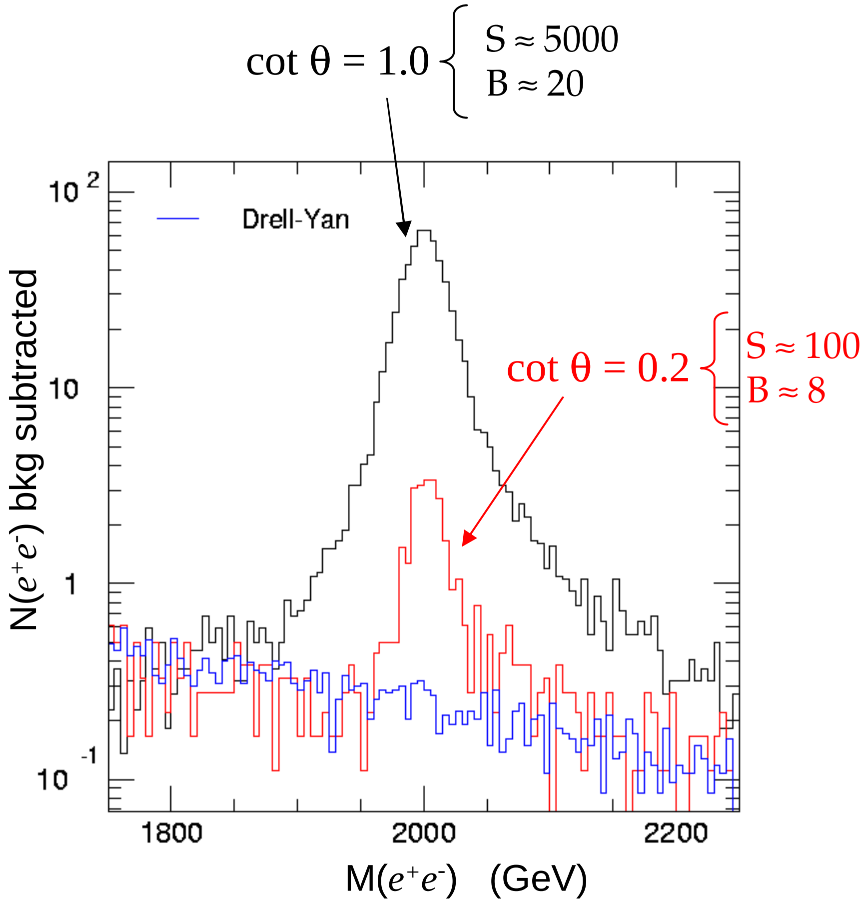
slight improvement is reached using also $\mu^+\mu^-$

Selection cuts:

- 2 isolated electrons with $p_T > 20$ GeV and $|\eta| < 2.5$
- minimum invariant mass equal to 800 GeV

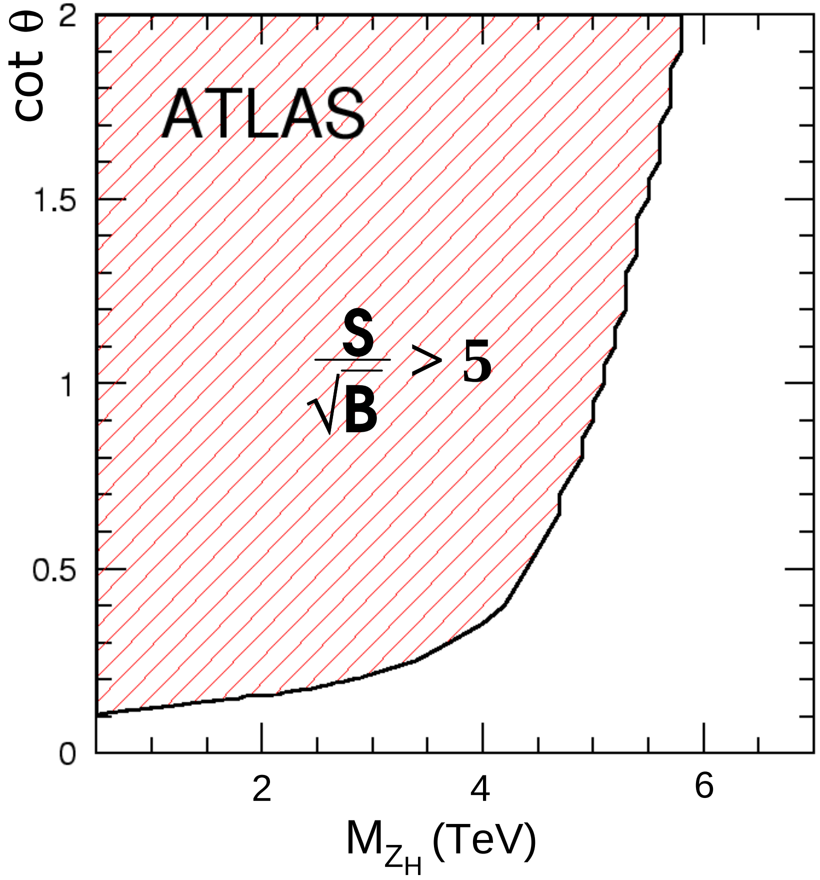
Background:

Drell-Yan ($q\bar{q} \rightarrow Z/\gamma \rightarrow e^+e^-$)



Discovery region for Z_H

$\mathcal{L} = 3 \cdot 10^5\ \mathrm{pb}^{\ 1}$



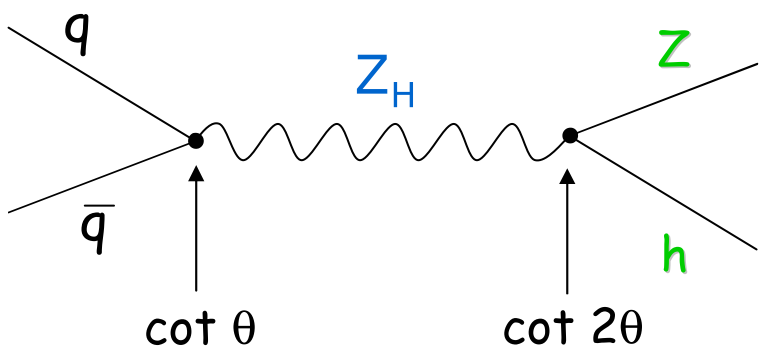
- $\sigma(Z_H)$ decreases as M increases
- $\sigma(Z_H) \sim (\cot\theta)^2$

  $BR(Z_H \longrightarrow e^+e^-)$ drops for $\cot\theta \to 0$

- If Z_H is found, $\cot\theta$ can be extracted from $\sigma(Z_H)$ and $\Gamma(Z_H)$

$$\frac{\Gamma}{M} = [\ 3.4\ (\cot\theta)^2 + 0.071\ (\cot 2\theta)^2]\ \%$$

$Z_H \rightarrow Zh$



m_h = 120 GeV

$BR(h \longrightarrow b\bar{b}) = 66\ \%$

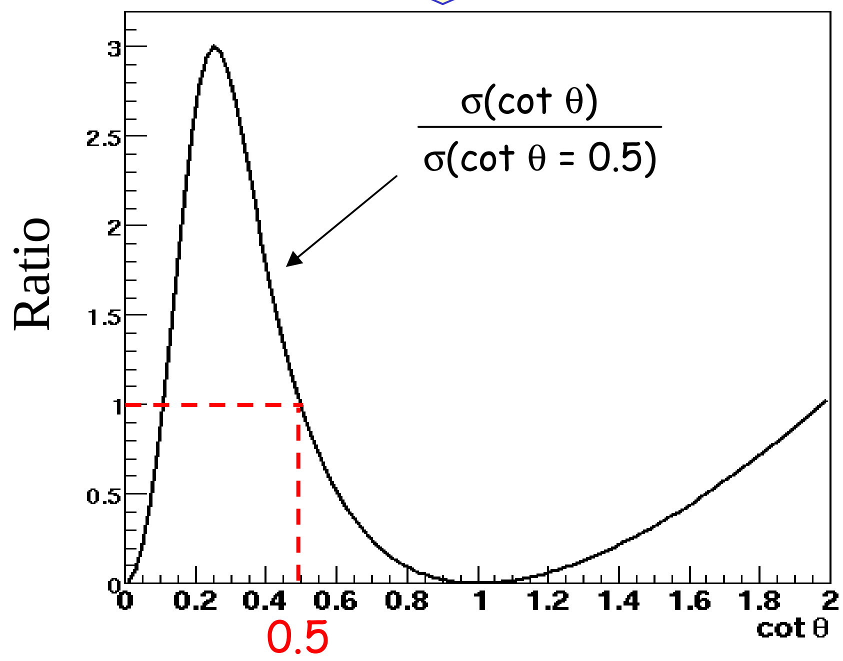
$BR(h \longrightarrow \gamma\gamma) = 0.2\ \%$

m_h = 200 GeV

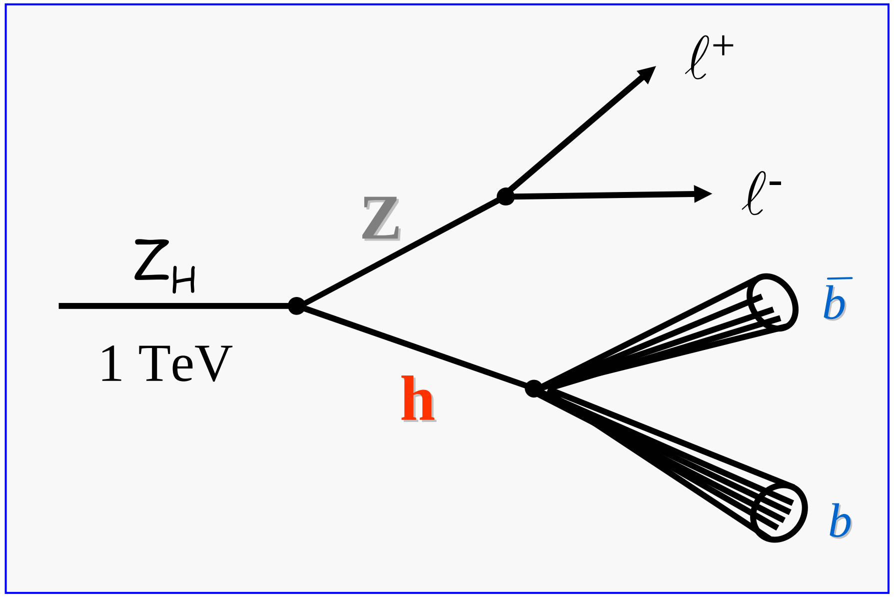
$BR(h \longrightarrow W^+W$ $) = 74\ \%$

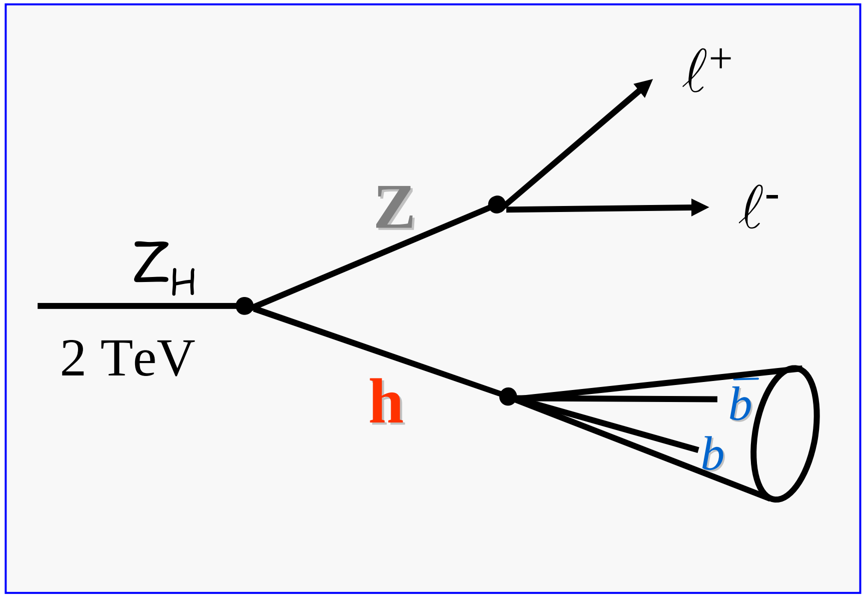
$BR(h \longrightarrow ZZ) = 26\ \%$

$\sigma \sim (\cot\theta \cot 2\theta)^2$



$Z_H \to Zh$ with $h \to b\bar{b}$



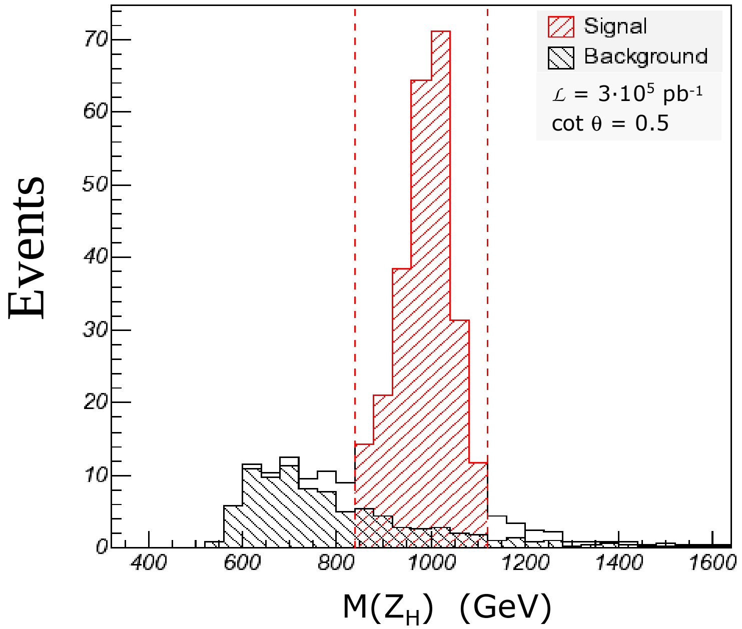


Cuts	Cuts
$\|\eta\| < 2.5$ (jets and leptons) $P_T(Z) > 250$ GeV $P_T(h) > 250$ GeV b-tagging	$\|\eta\| < 2.5$ (jets and leptons) $P_T(Z) > 500$ GeV $P_T(h) > 500$ GeV b-tagging

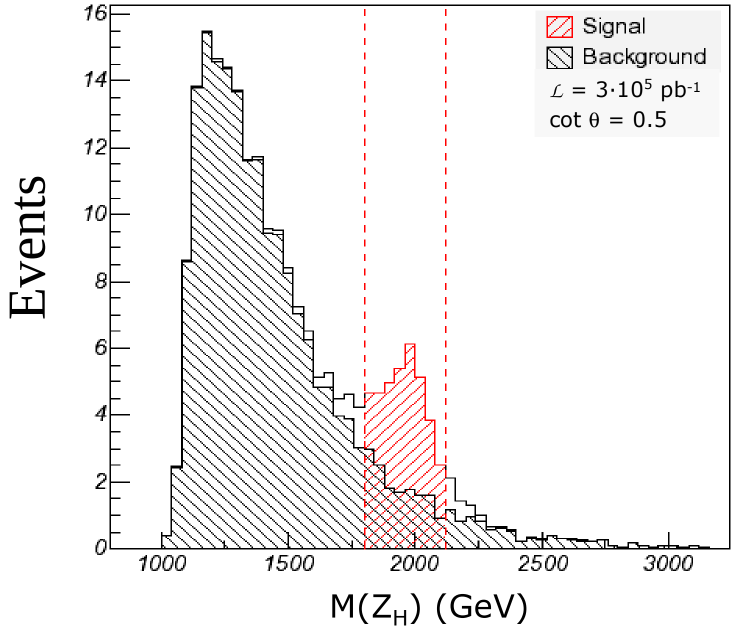
Background: Z + jets

$Z_H \to Zh$ signal

M_{Z_H} = 1 TeV



M_{Z_H} = 2 TeV



b-tag: ε_b = 50%, R_u = 100

Inside mass window:

S = 195
B = 16

$$\frac{S}{\sqrt{B}} = 50$$

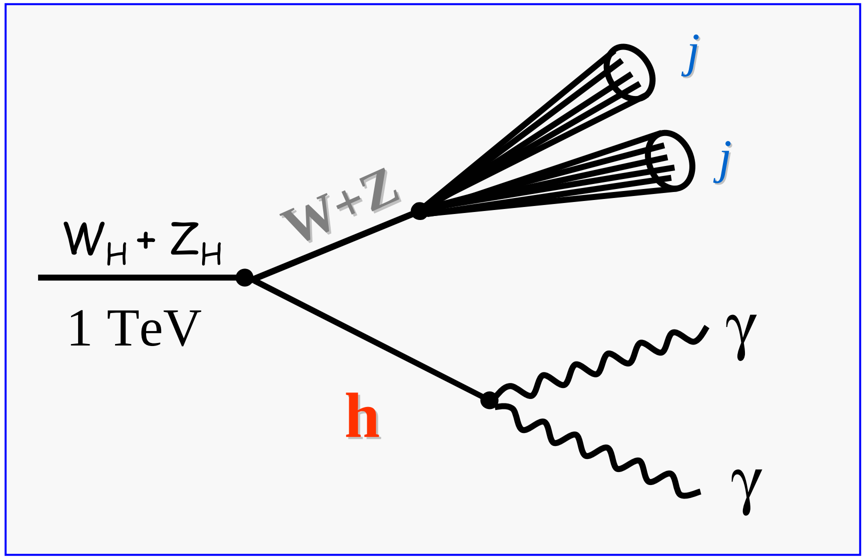
b-tag: ε_b = 40%, R_u = 100

Inside mass window:

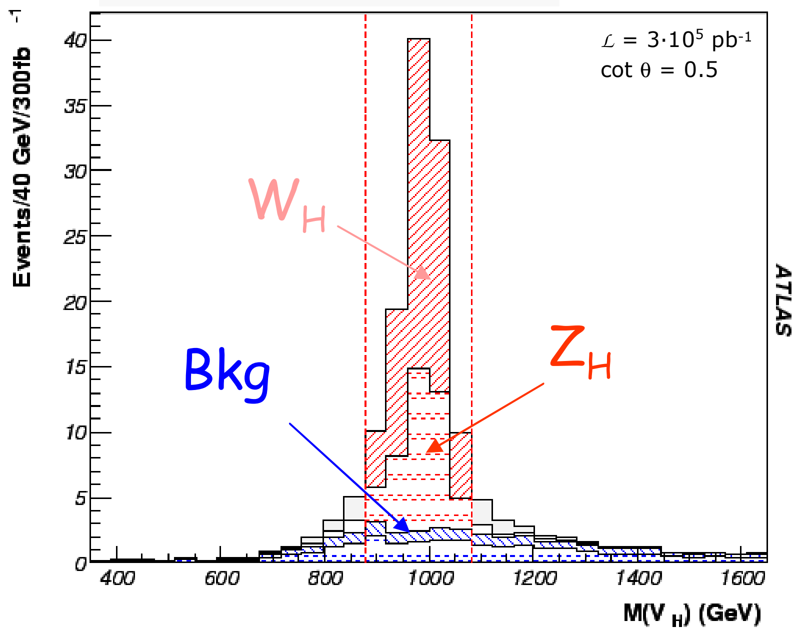
S = 15
B = 8

$$\frac{S}{\sqrt{B}} = 5$$

$W_H / Z_H \to W/Z\ h$ with $h \to \gamma\gamma$



$M_{Z_H} = M_{W_H} = 1$ TeV



Cuts

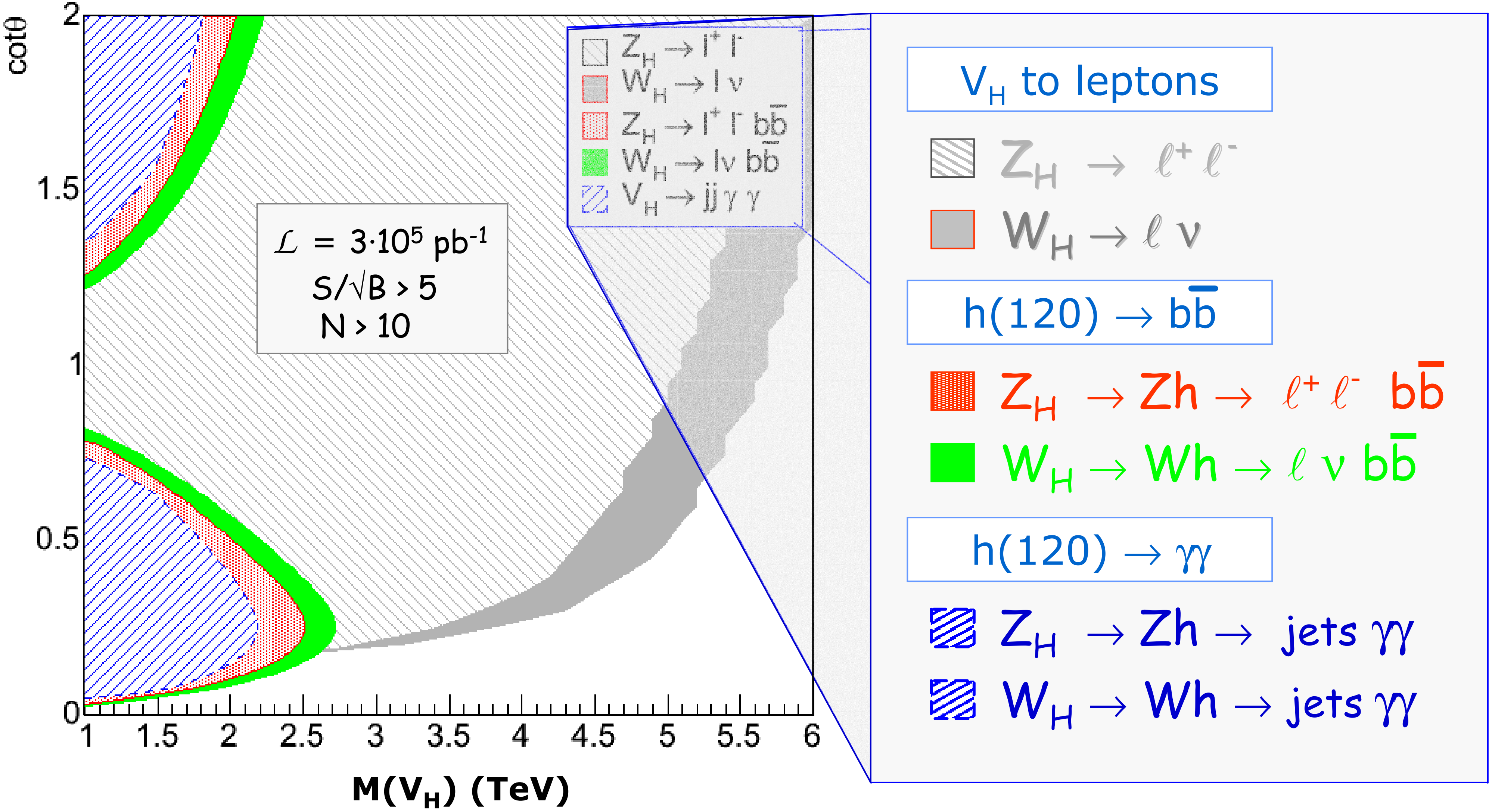
$|\eta(\gamma)| < 2.5$
$P_T(\gamma) > 25$ GeV
$P_T(h) > 400$ GeV
γ-tagging, $\varepsilon(\gamma) = 80\%$

$S(W_H \to Wh) = 64$
$S(Z_H \to Zh) = 33$ } 97

$B(h$ inclusive$) = 8$
$B(\gamma\gamma$ inclusive$) = 5$ } 13

$$\frac{S}{\sqrt{B}} = 27$$

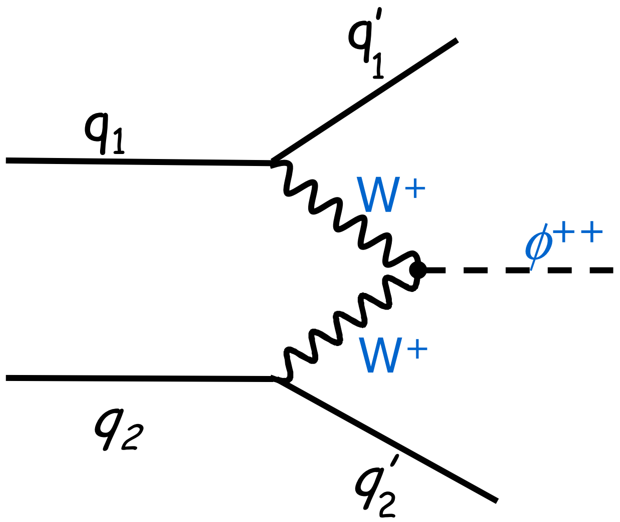
Discovery region for V_H



New Higgs ϕ^{++}

- Production: VBF mechanism

(vector boson fusion)

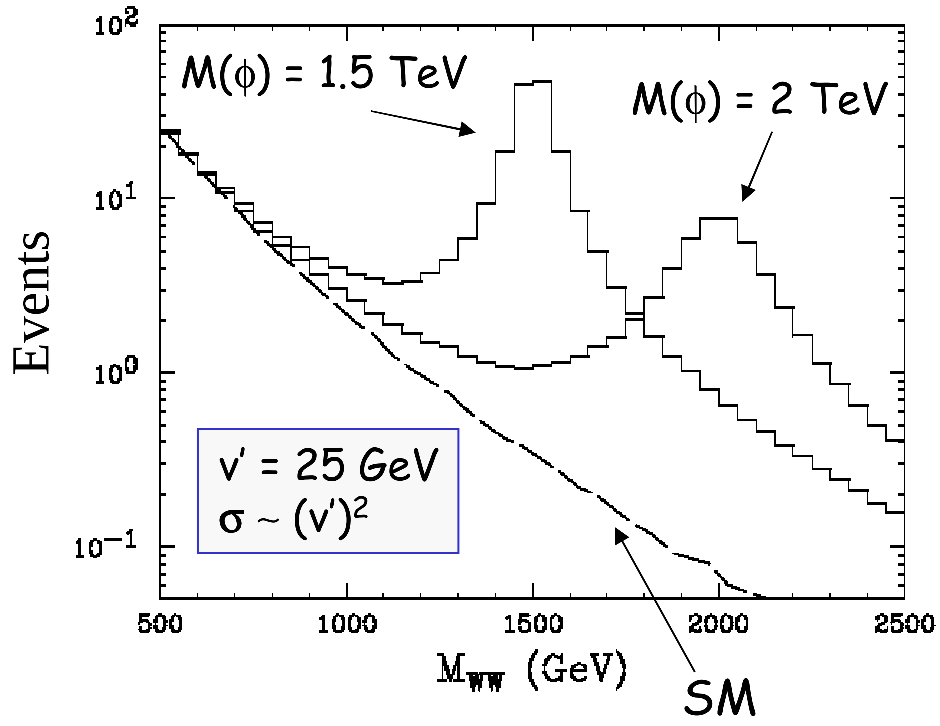


Decay: $\phi^{++} \rightarrow W^+W^+$

Decay of ϕ^{++} to leptons is suppressed in this model

$\mathcal{L} = 3 \cdot 10^5$ pb [1]

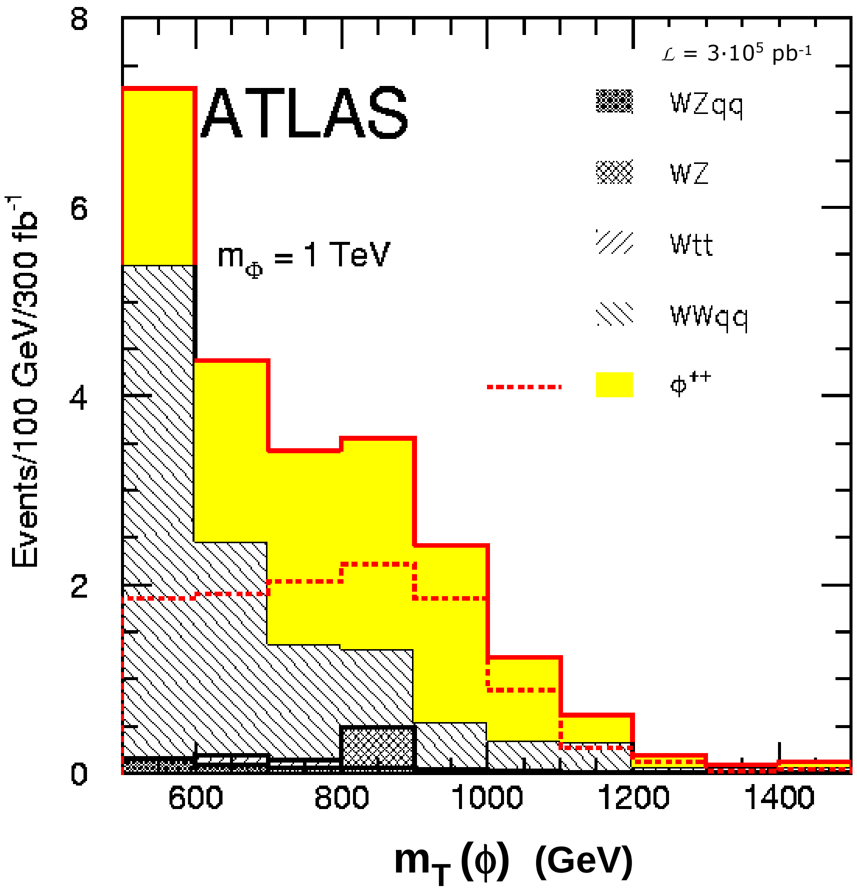
$W^+W^+ \rightarrow \phi^{++} \rightarrow W^+W^+$



$\phi^{++} \rightarrow W^+W^+$

$\phi^{++} \rightarrow W^+W^+ \rightarrow \ell^+\ell^+\nu\nu$

Bkg: WWqq, WZ
WZqq, $Wt\bar{t}$



Main cuts:

- 2 forward jets (E > 100 GeV)
- 2 leptons (charge +)
- P_T(lepton 1) > 150 GeV
- P_T(lepton 2) > 20 GeV
- $\not{E}_T$ > 50 GeV

- m_T > 500 GeV

$$m_T = (E(\ell_1) + E(\ell_2) + |\vec{\not{p}}_T|)^2 + (\vec{p}(\ell_1) + \vec{p}(\ell_2) + \vec{\not{p}}_T)^2$$

Outlook and Summary

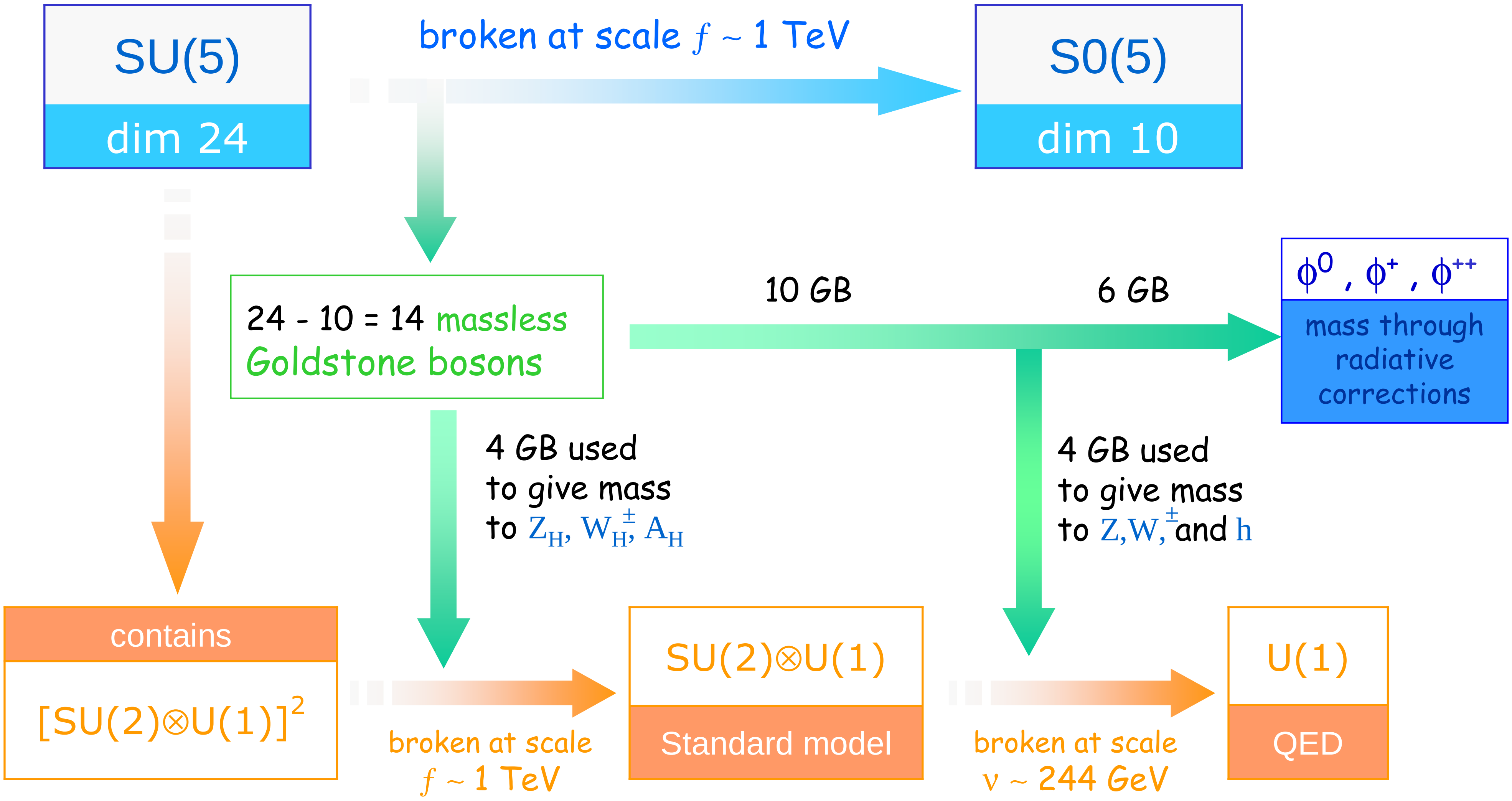
- Searches for the new particles predicted by Littlest Higgs model at LHC have been performed. Heavy Top and new Gauge boson sector are observable over a large range of parameter.
- "Toy" model used for the study severely constrained by electro-weak measurements
- Little Higgs idea is realized in several different models: *SU(5)/SO(5),SU(6)/SP(6),* Minimal moose *$SU(3)^2/SU(3)$* and general mooses *$SU(3)^n/SU(3)^k$, etc*. They have similar particle content and are less constrained.
- More detailed information on the ATLAS searches can be found in *G. Azuelos et al., hep-ph/0402037*

LITTLE HIGGS SEARCHES AT LHC

on behalf of ATLAS Collaboration

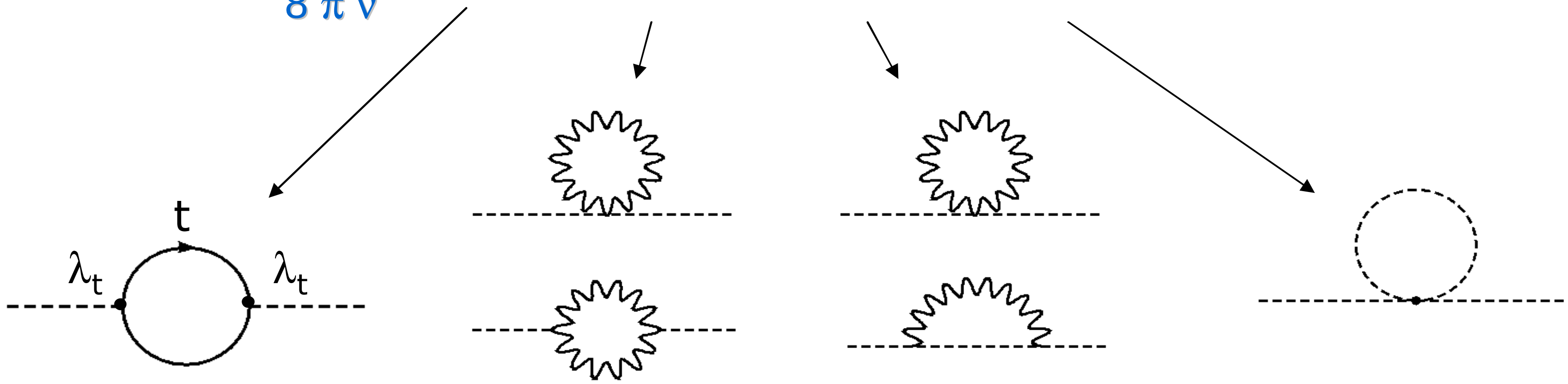
presented by: Jose E. Garcia *(IFIC-Valencia)*

The Littlest Higgs model



Corrections

$$\delta m_h^2 = \frac{3\,\Lambda^2}{8\,\pi^2 v^2}\left(4m_t^2 - 2M_W^2 - 4M_Z^2 - m_h^2\right)$$



Minimum needed to cancel all loops

T	heavy top	⇒	new EW singlet
W_H, Z_H	heavy gauge bosons	⇒	new SU(2)⊗U(1) symmetry
Φ	heavy higgs bosons	⇒	many new Goldstone bosons EW triplet (ϕ^0 , ϕ^+ , ϕ^{++})

Mass Range

Upper limits: to avoid fine tuning scale → $f < 1\ \text{TeV} \cdot \left(\frac{m_h}{200\,GeV}\right)^2$

T ⟹ $M < 2\ \text{TeV} \cdot \left(\frac{m_h}{200\,GeV}\right)^2$

$m_h = 120$ GeV	$M < 0.2$ TeV
$m_h = 200$ GeV	$M < 2$ TeV

$W_H^{\pm}, Z_H, A_H$ ⟹ $M < 6\ \text{TeV} \cdot \left(\frac{m_h}{200\,GeV}\right)^2$

$m_h = 120$ GeV	$M < 2.2$ TeV
$m_h = 200$ GeV	$M < 6$ TeV

ϕ ⟹ $M < 10$ TeV

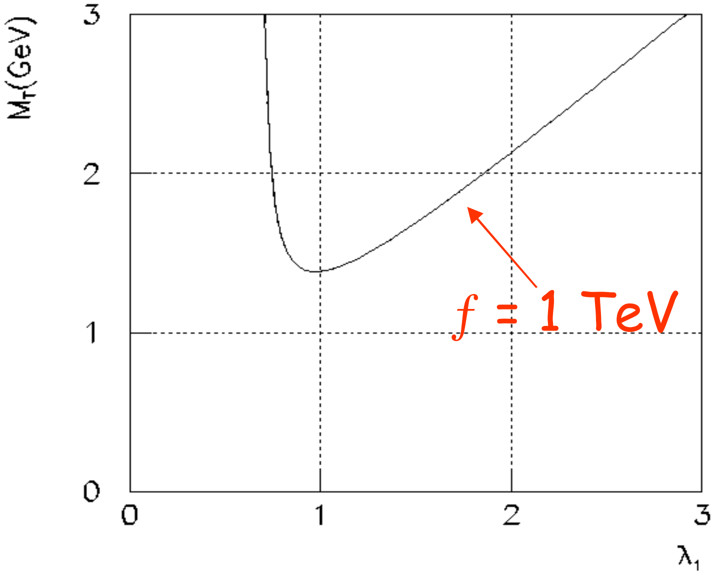
Little Higgs t and χ will mix → standard top t, heavy top T

$$M_t \approx \frac{\lambda_1 \lambda_2}{\sqrt{\lambda_1^2 + \lambda_2^2}}\, v + O\left(\frac{v^2}{f^2}\right) \qquad M_T \approx \sqrt{\lambda_1^2 + \lambda_2^2}\, f + O\left(\frac{v^2}{f^2}\right)$$

v = electroweak scale = 244 GeV
f = heavy scale ~ 1 TeV
λ_1, λ_2 = Yukawa couplings O(1)

λ_2 can be eliminated using SM top mass

→ 2 new free parameters, f, λ_1



$$M_T \approx 1.4 f \frac{\lambda_1}{\sqrt{2.1 - \frac{1}{\lambda_1^2}}}$$

f > 1 TeV
(EW data!)

but if M_T is too large → fine tuning

Littlest Higgs: particle content and couplings

new particles	couplings	mass
T	$\lambda_1 \quad \lambda_2$	$M_T = \sqrt{\lambda_1^2 + \lambda_2^2}\; f + O\left(\frac{v^2}{f^2}\right)$
$W_H^{\pm},\ Z_H$	$c = \cos\theta \quad s = \sin\theta$	$M_{Z_H} = M_{W_H} = m_w \left(\frac{f}{v}\right) \frac{1}{sc} + O\left(\frac{v^2}{f^2}\right)$
A_H	$c' = \cos\theta' \quad s' = \sin\theta'$	$M_{A_H} = M_Z \sin^2\theta_W \left(\frac{f}{v}\right) \frac{1}{5s'c'} + O\left(\frac{v^2}{f^2}\right)$
$\phi^0,\ \phi^+,\ \phi^{++}$	$v \quad v'$	$M_\phi^2 = \frac{2m_h^2 f^2}{v^2} \frac{1}{\left[1-(4v'f/v^2)^2\right]}$

New constants: scale f and λ_1, θ, θ', v'

weakness of the model

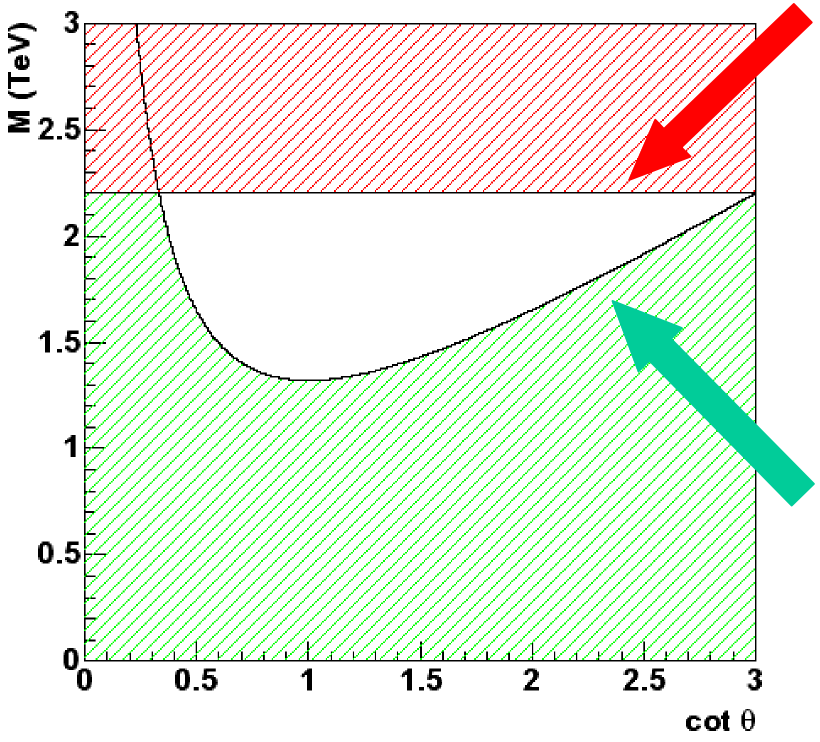
- No relations between these new constants
- A_H couplings not fixed by the model
- EW data $\rightarrow f \leftarrow$ fine tuning
  2 TeV < f < 4 TeV

Expectations for Z_H

$$M(Z_H) \approx m_W\,(f/v)\,[\cot\theta + 1/\cot\theta]$$

- f = scale for new physics
- v = Fermi scale (244 GeV)

Avoid fine tuning ⇒ M < 2.2 TeV (assuming m_h = 120 GeV)



M expected in 1-2 TeV region with wide range of cot θ parameter.

Agree with EW data ⇒ f > 2 TeV

b-tagging

M_{Z_H} = 1 TeV $\langle p_T(b) \rangle$ = 220 GeV

M_{Z_H} = 2 TeV $\langle p_T(b\bar{b}) \rangle$ = 800 GeV