Little Higgs Searches with ATLAS

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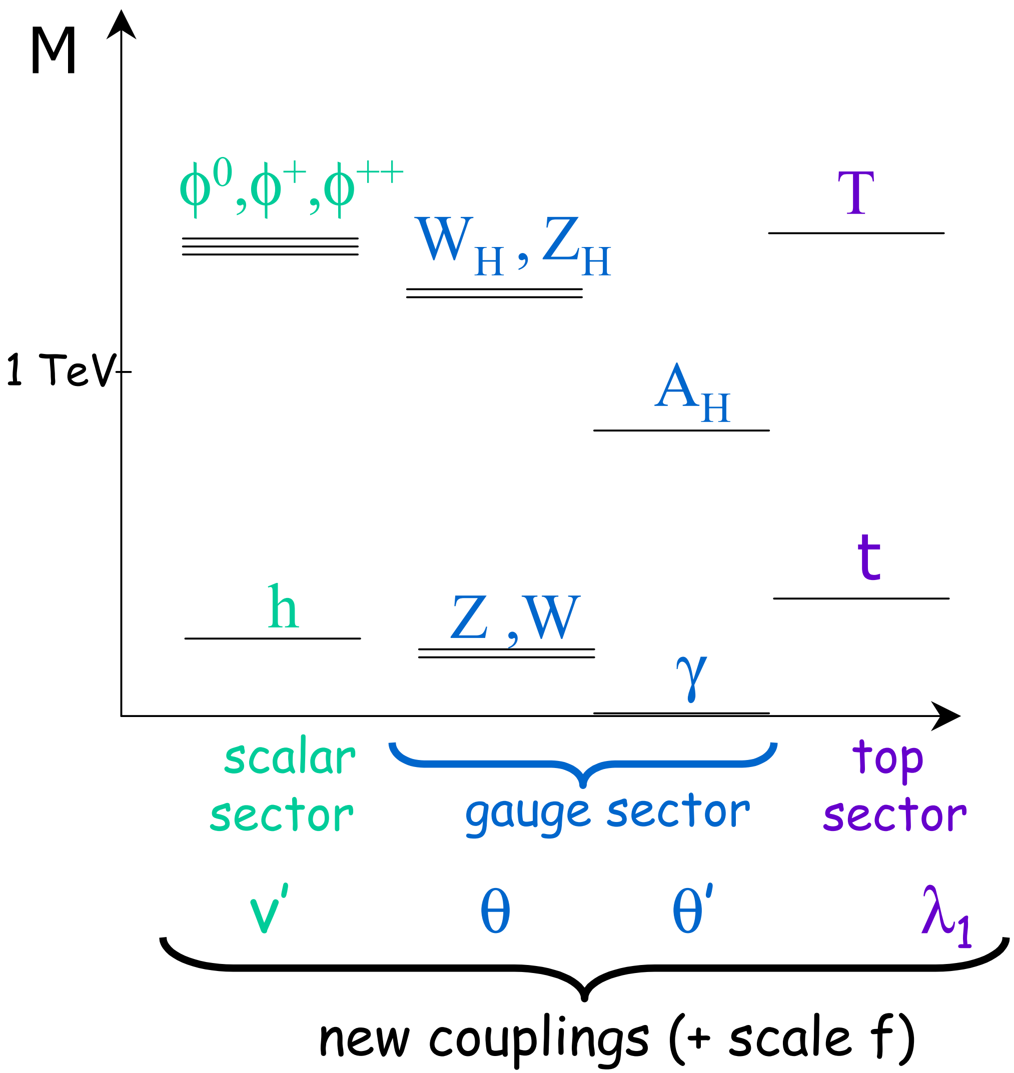
Particle Spectrum



Littlest Higgs model

SU(5) → SO(5)

Gauge sector → $[SU_2 \otimes U_1]^2$

Only 1 Higgs doublet

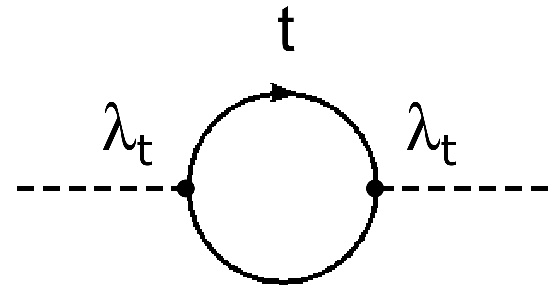
- Arkani-Hamed et al., JHEP 207 (2002) 34

Phenomenology

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

Cancellation of top-quark loop (1)

$$m_h^2 = \underbrace{m_h^2(0)}_{\text{base mass}} + \underbrace{\delta m_h^2}_{\text{loop corrections}}$$



+ Λ^2 divergence

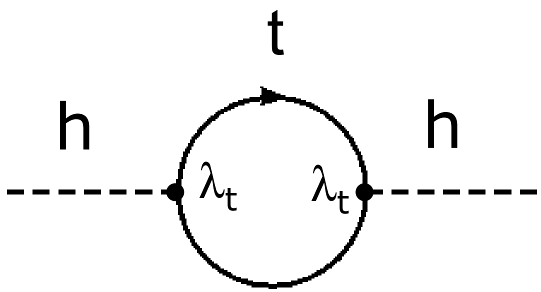
(boson loop) = - (fermion loop)

→ need boson loop to cancel this divergence

→ need supersymmetry

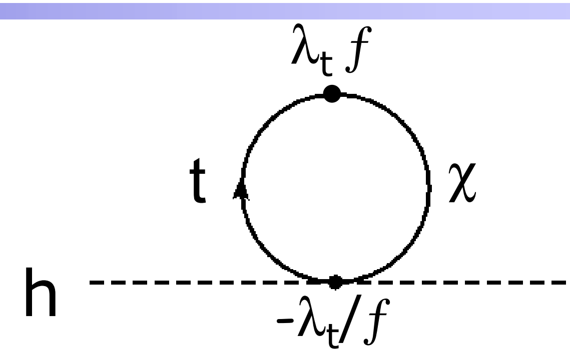
Not really true ………

Cancellation of top-quark loop (2)



+ λ_t^2 tt hh

(t = top quark, λ_t = Yukawa coupling)

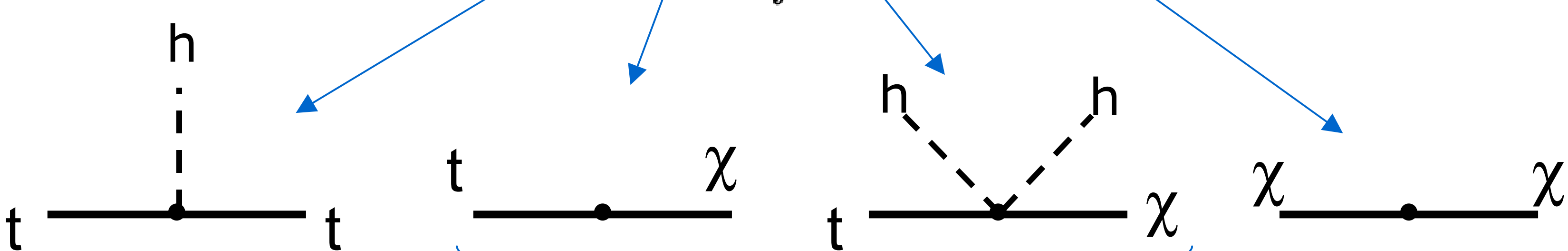


$- \lambda_t \not{f} \frac{\lambda_t}{\not{f}} = - \lambda_t^2 \rightarrow - \lambda_t\, t\, \chi\, hh$

(χ = heavy top, f = new scale ~ 1 TeV)

New couplings in the Lagrangian

$$\lambda_1 [\, \bar{t} t h + f \bar{t} \chi - \frac{hh}{f} \bar{t} \chi \,] + \lambda_2 f \bar{\chi} \chi$$



can be implemented with Goldstone bosons

Cancellation of top-quark loop (3)

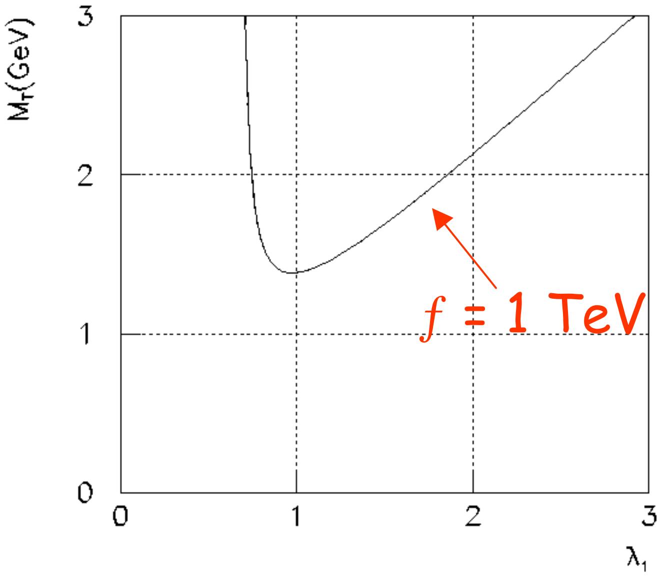
t and χ will mix $\rightarrow$ standard top t, heavy top T

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

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

$\rightarrow$ 2 new free parameters, f, λ_1



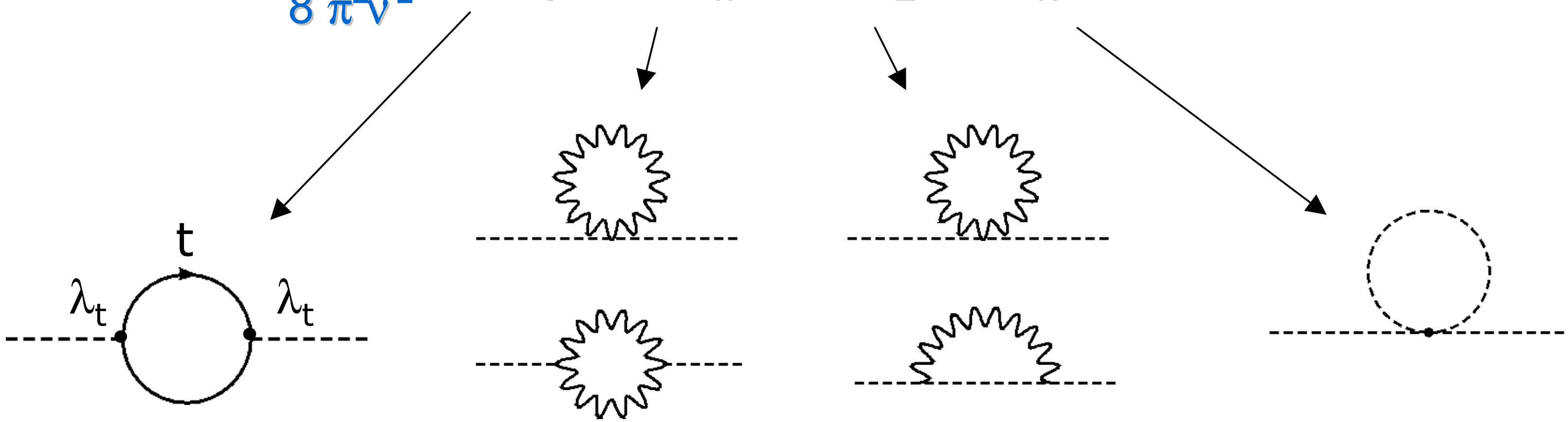
$$M_T \approx 1.4 f \frac{\lambda_1}{\sqrt{2.1 - \frac{1}{\lambda_1^2}}}$$

f > 1 TeV
(EW data!)

but if M_T is too large $\rightarrow$ fine tuning

Other loops

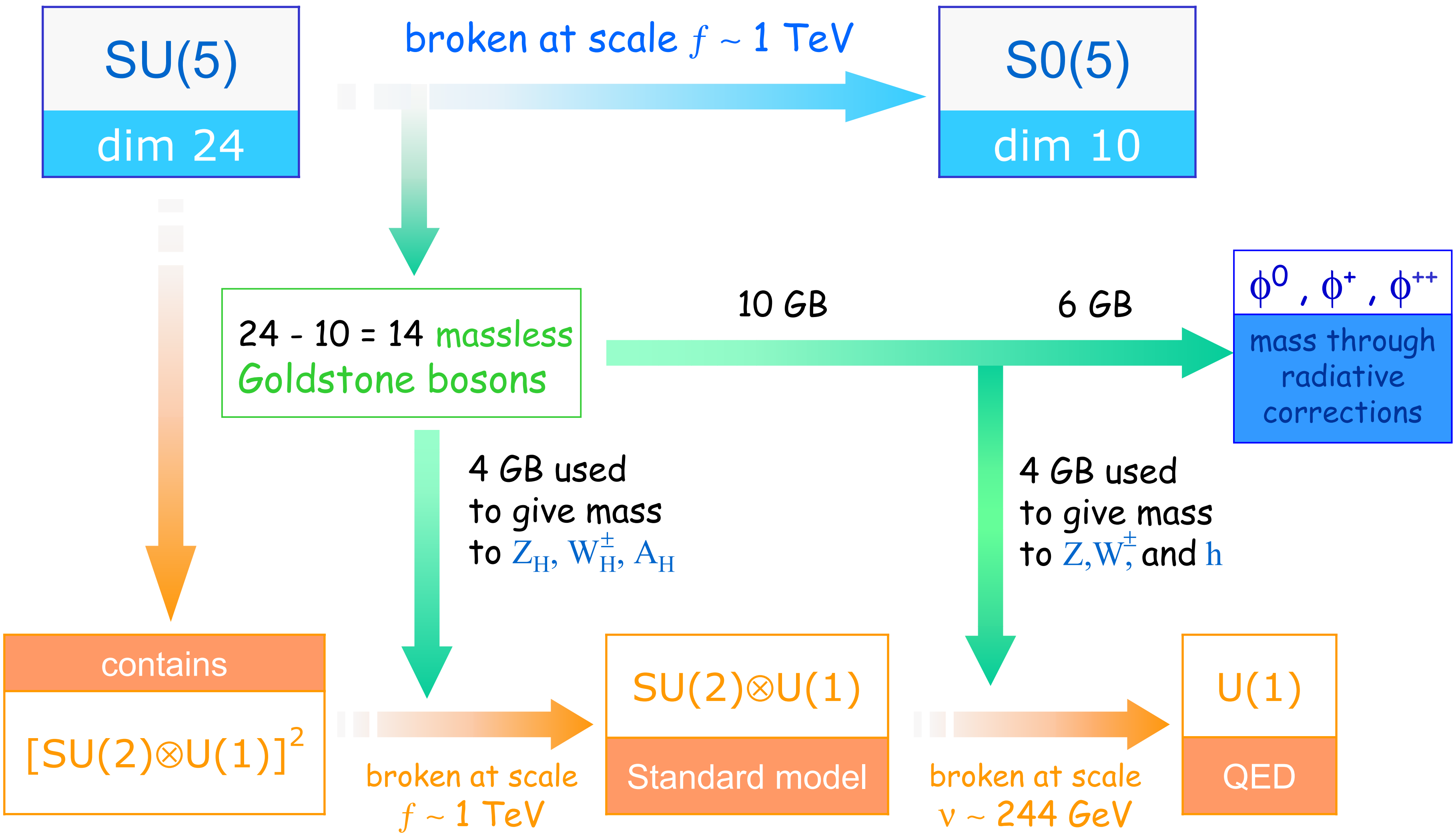
$$\delta m_h^2 = \frac{3\Lambda^2}{8\pi^2 v^2}\left(4m_t^2 - 2M_W^2 - 4M_Z^2 - m_h^2\right)$$



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^{++})

The Littlest Higgs model



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	$c'=\cos\theta' \quad s'=\sin\theta'$	$M_{A_H} = M_Z \sin^2\theta_W\left(\frac{f}{v}\right)\frac{1}{5s'c'} + O\left(\frac{v^2}{f^2}\right)$
$\phi^0,\ \phi^+,\ \phi^{++}$	$v \quad v'$	$M_\phi^2 = \frac{2m_h^2 f^2}{v^2}\frac{1}{\left[1-(4v'f/v^2)^2\right]}$

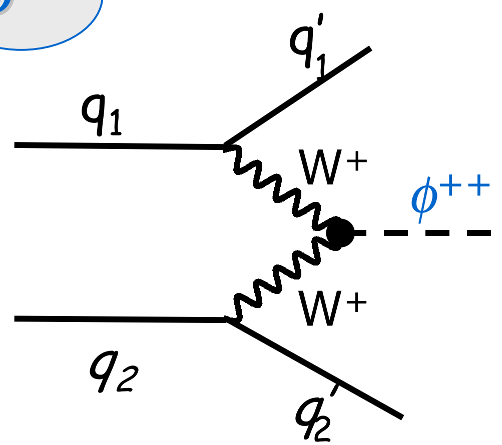
New constants: scale f and λ_1, θ, θ', v'

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

Strategies at LHC

ϕ^{++}



VBF mechanism

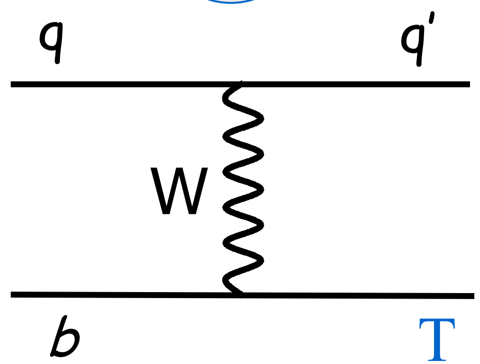
$\sigma \sim (v')^2$

v′ should be small

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

large SM bkg

T



Wb fusion

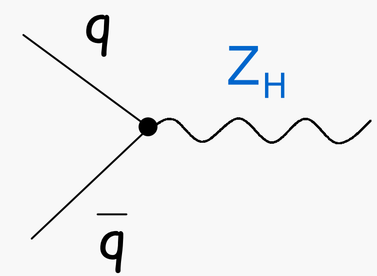
$\sigma \sim (\lambda_1)^2$

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

$T \rightarrow$ bW, tZ

clear signal

Z_H



$q\bar{q}$ annihilation

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

Wide range in $\cot\theta$ possible.

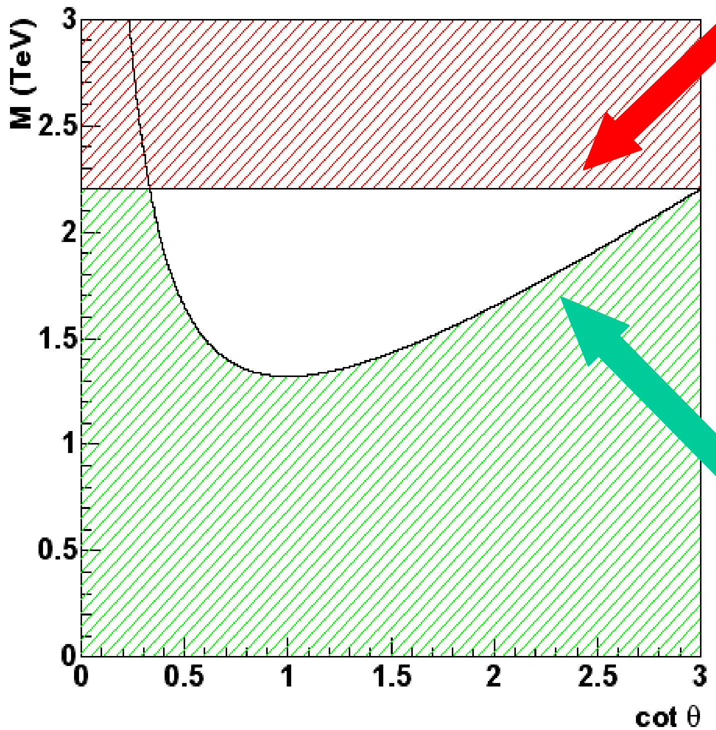
$Z_H \rightarrow$ e^+e^-

clear signal

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)

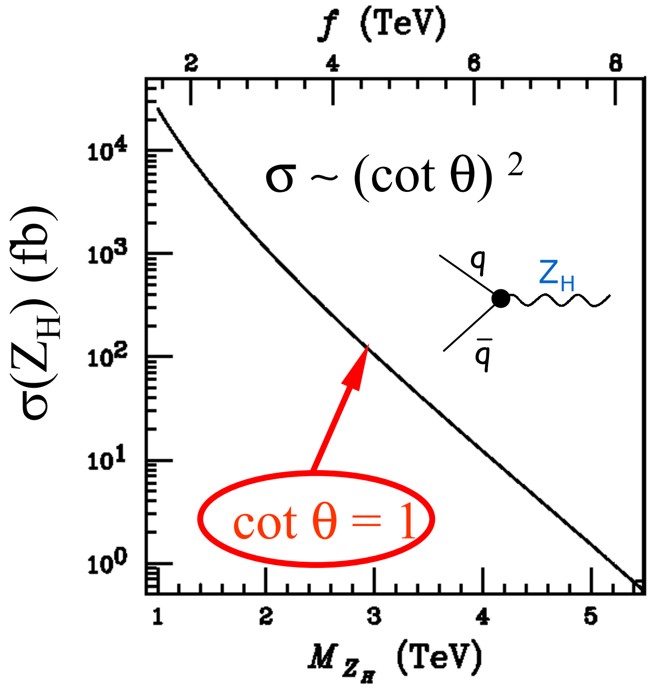


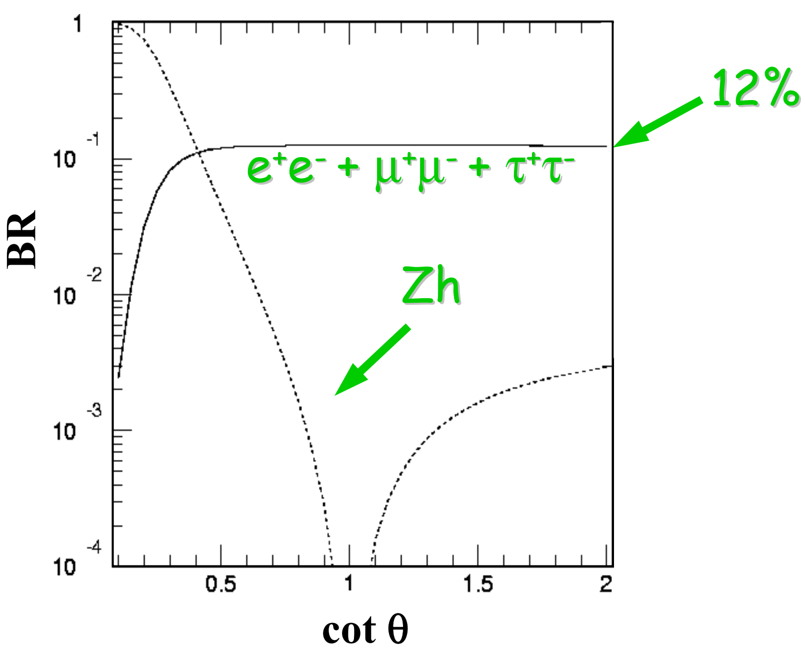
Avoid fine tuning ⇒ $M < 2.2$ TeV (assuming $m_h = 120$ GeV)

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

Agree with EW data ⇒ $f > 2$ TeV

Gauge Boson Z_H





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

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

$\Gamma(Zh) \sim (\cot 2\theta)^2$

Search for Z_H

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

$\mu^+\mu^-$ not used due to invariant mass resolution

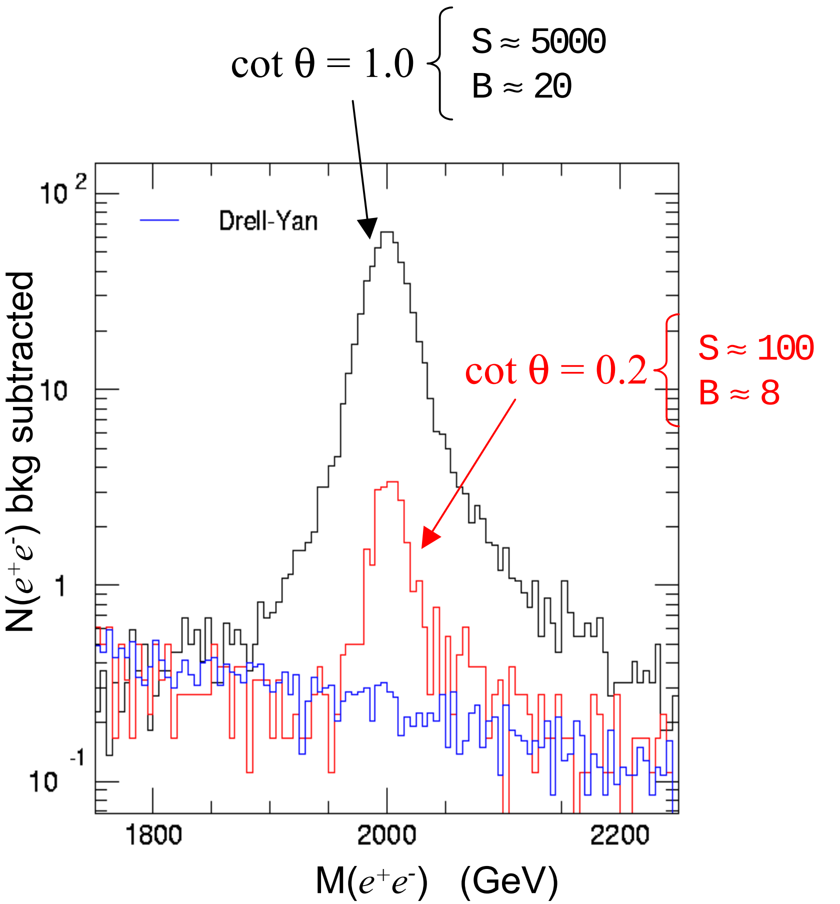
Selection cuts:

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

Background:

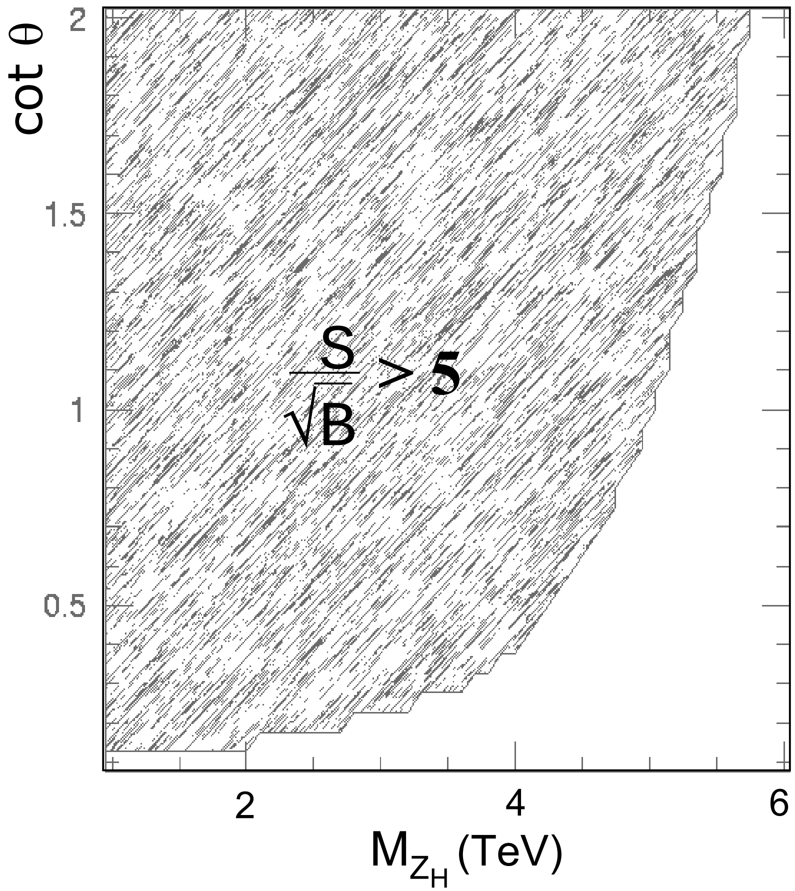
Drell-Yan ($\bar{q}q \rightarrow Z/\gamma \rightarrow e^+e^-$)

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



Discovery region for Z_H

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



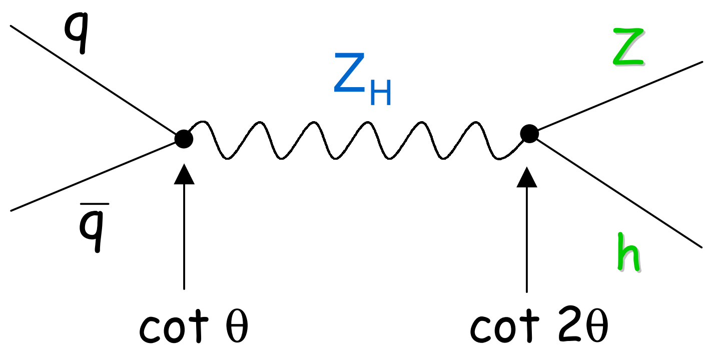
- $\sigma(Z_H)$ decreases as M increases
- $\sigma(Z_H) \sim (\cot\theta)^2$

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

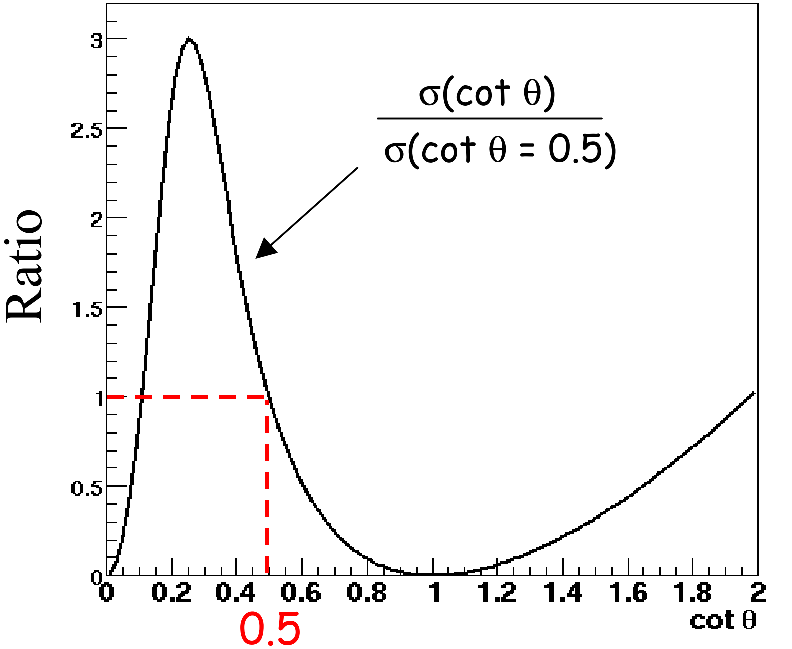
- If Z_H is found, $\cot\theta$ can be extracted from $\sigma(Z_H)$ and $\Gamma(Z_H)$

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

$Z_H \longrightarrow Zh$



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



$m_h = 120$ GeV

$BR(h \longrightarrow bb) = 66\ \%$

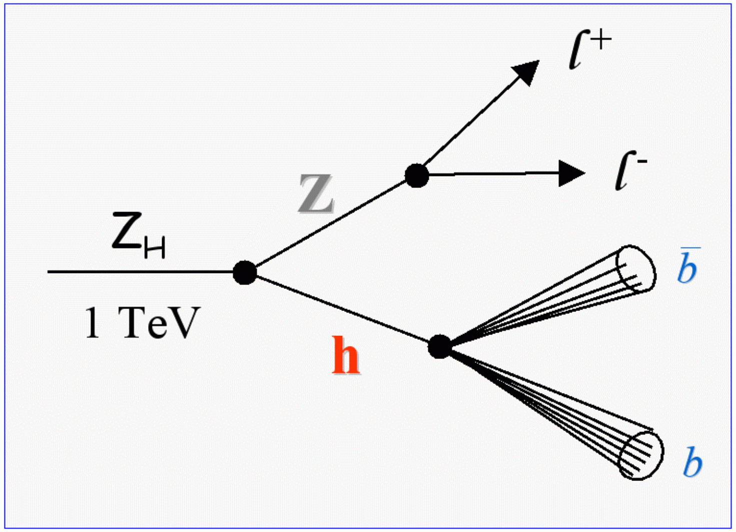
$BR(h \longrightarrow \gamma\gamma) = 0.2\ \%$

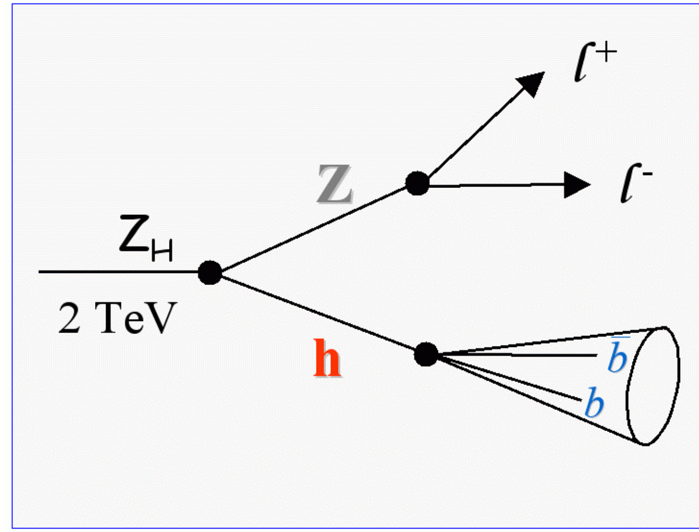
$m_h = 200$ GeV

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

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

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



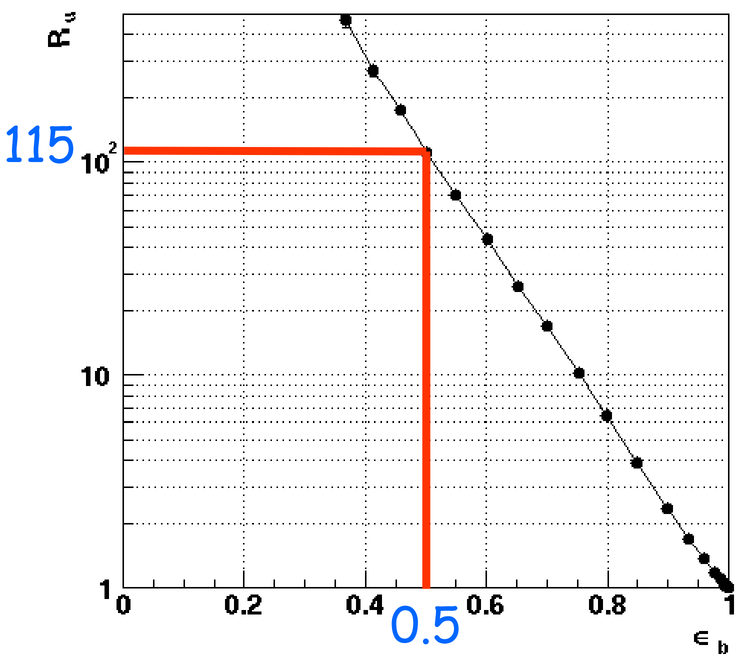


Cuts	Cuts
$\lvert\eta\rvert < 2.5$ (jets and leptons)	$\lvert\eta\rvert < 2.5$ (jets and leptons)
$P_T(Z) > 250$ GeV	$P_T(Z) > 500$ GeV
$P_T(h) > 250$ GeV	$P_T(h) > 500$ GeV
b-tagging	b-tagging

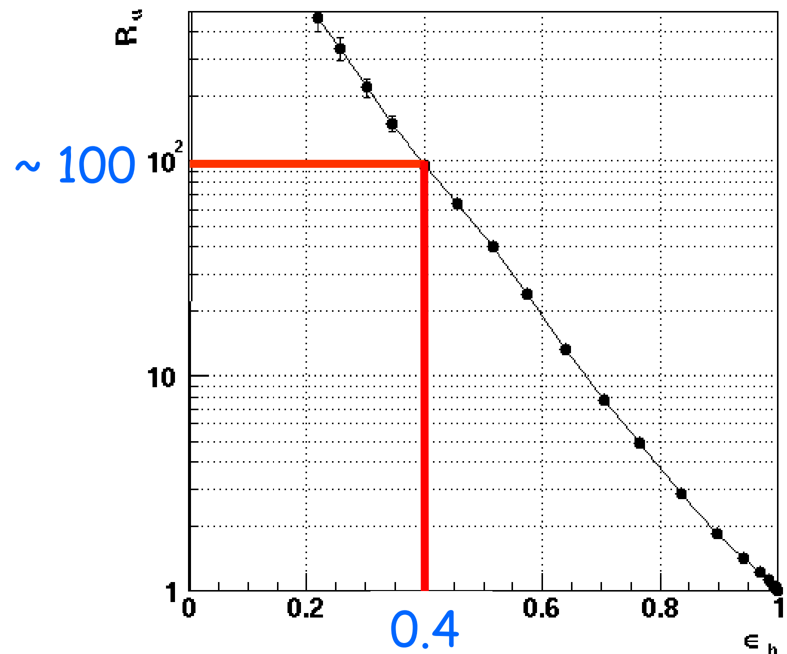
Background: Z + jets

b-tagging

M_{Z_H}= 1 TeV $<p_T(b)> =$ 220 GeV

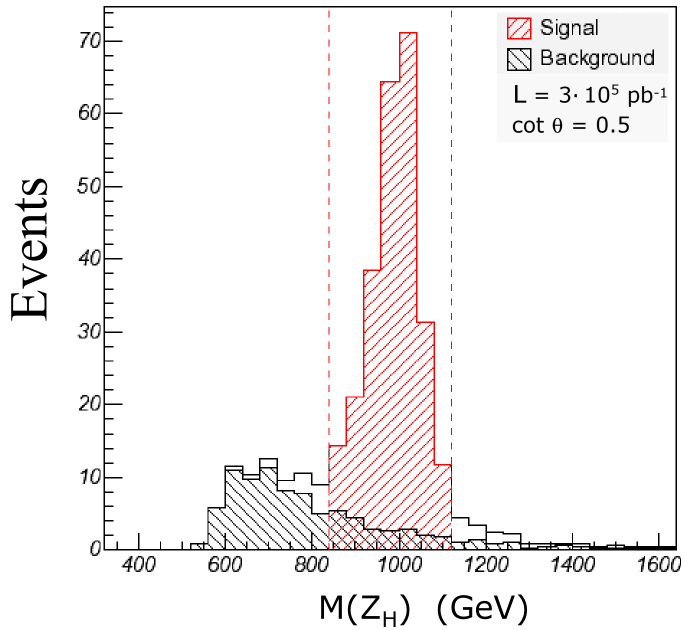


M_{Z_H}= 2 TeV $<p_T(b\bar{b})> =$ 800 GeV

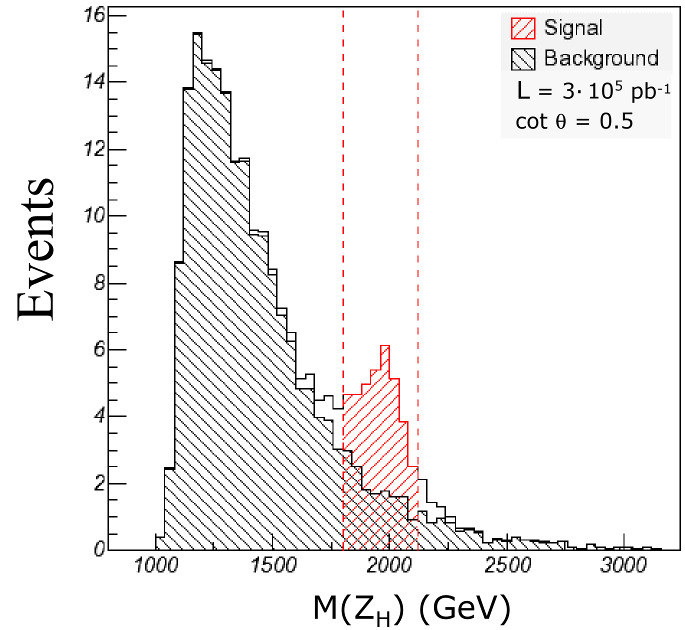


Signal and background

M_{Z_H} = 1 TeV



M_{Z_H} = 2 TeV



b-tag: ε_b = 50%, R_u = 100

Inside mass window:

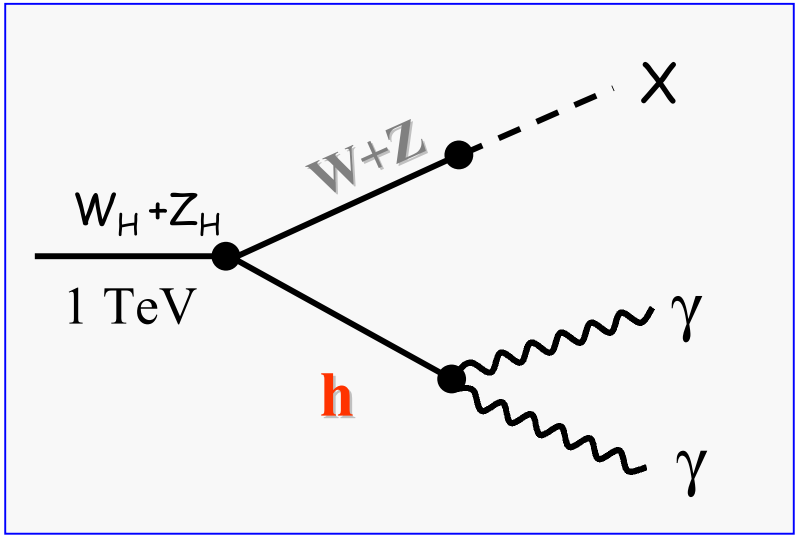
S = 195, B = 16 } $\frac{S}{\sqrt{B}} = 50$

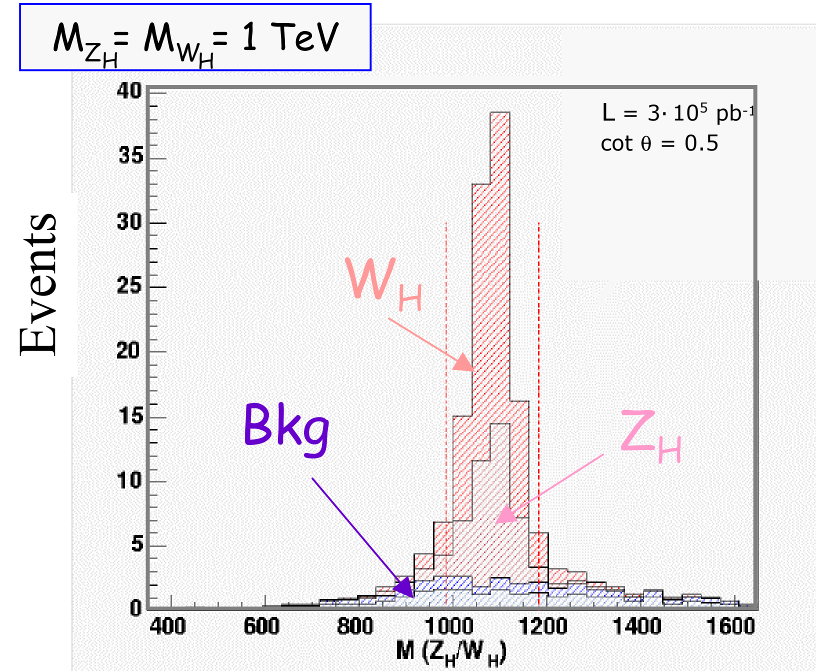
b-tag: ε_b = 40%, R_u = 100

Inside mass window:

S = 15, B = 8 } $\frac{S}{\sqrt{B}} = 5$

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





Cuts

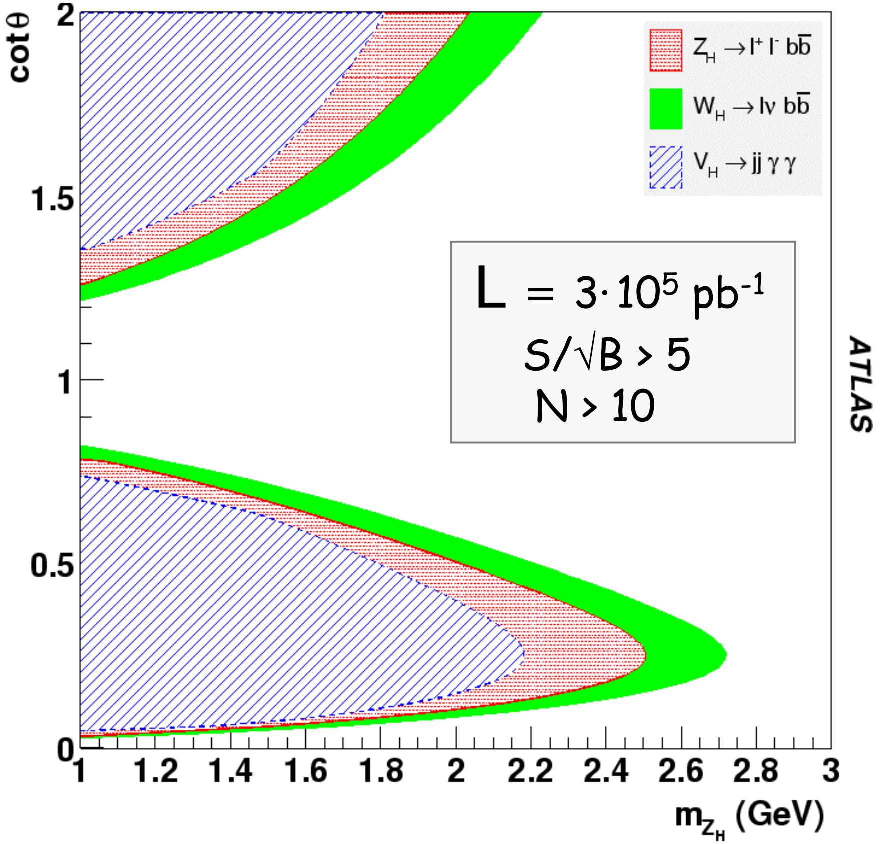
- $|\eta(\gamma)| < 2.5$
- $P_T(\gamma) > 25$ GeV
- $P_T(h) > 400$ GeV
- γ-tagging, $\varepsilon(\gamma) = 80\%$

$S(W_H \rightarrow Wh) = 65$
$S(Z_H \rightarrow Zh) = 33$ } 98

$B(h\ \text{inclusive}) = 7$
$B(\gamma\gamma\ \text{inclusive}) = 4$ } 11

$$\frac{S}{\sqrt{B}} = 29$$

Discovery region for $Z_H \to Zh$



$h(120) \to b\bar{b}$

$Z_H \to Zh \to \ell^+\ell^- b\bar{b}$

$W_H \to Wh \to \ell\nu\, b\bar{b}$

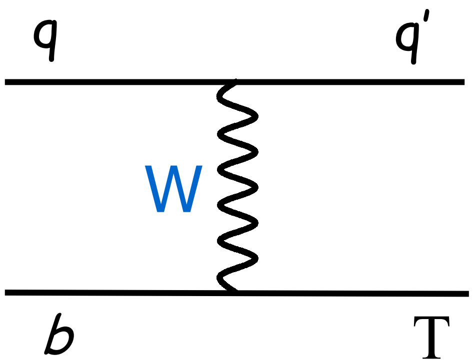
$h(120) \to \gamma\gamma$

$Z_H \to Zh \to$ jets $\gamma\gamma$

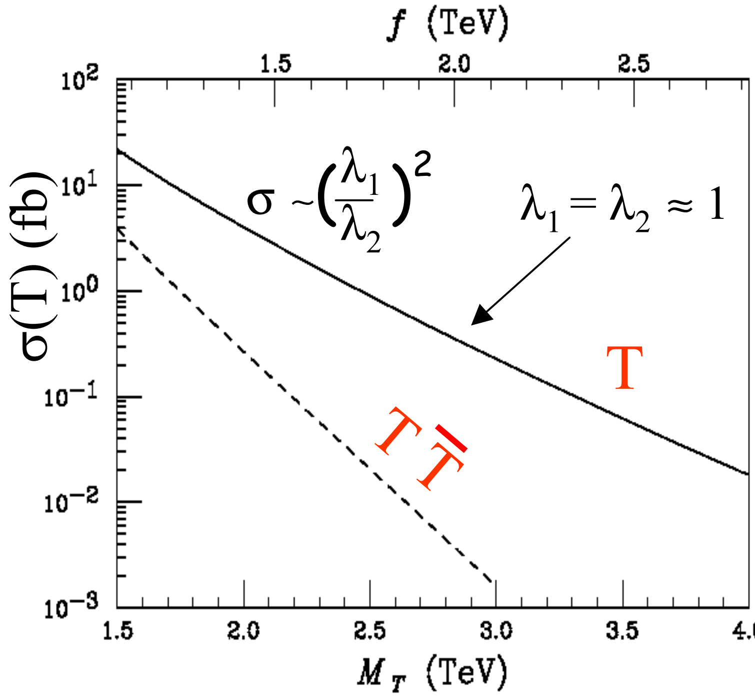
$W_H \to Wh \to$ jets $\gamma\gamma$

heavy top T

- Production mechanism = Wb fusion



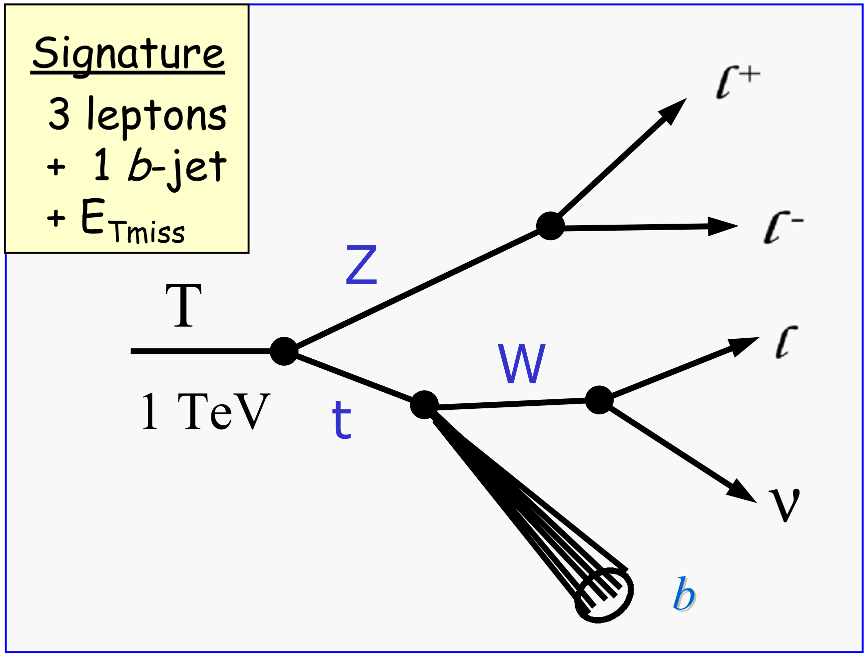
BR
- $T \rightarrow bW$ 50 %
- $T \rightarrow tZ$ 25 %
- $T \rightarrow th$ 25 %

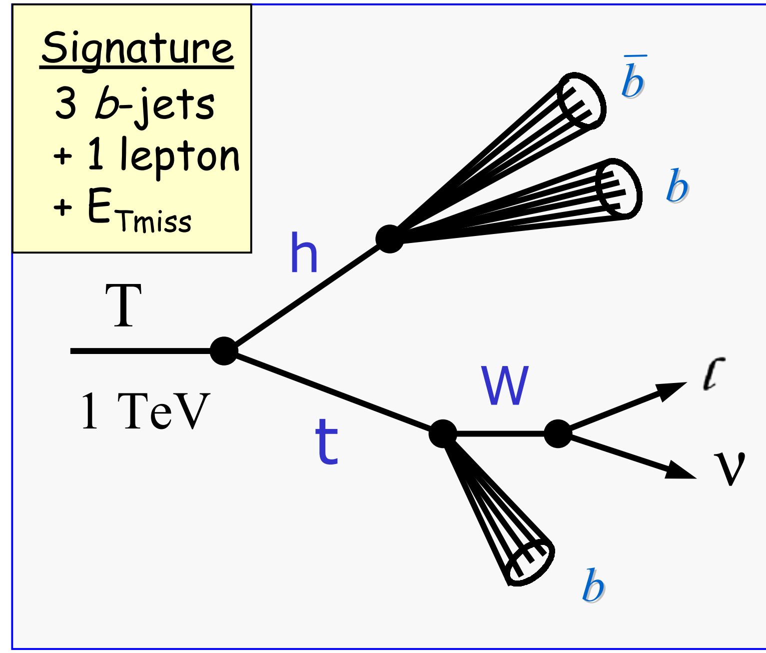


λ_1, λ_2 Yukawa couplings

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

T searches





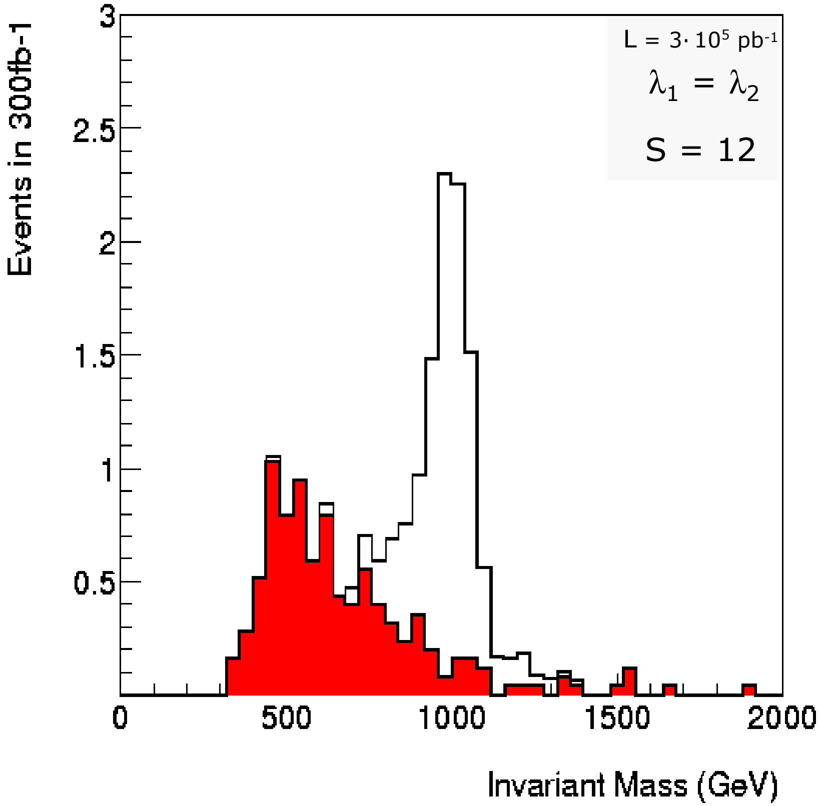
BKG

$pp \to tZ$	$pp \to tt$
$pp \to WZ$	$pp \to Wbb$

$T \to Zt$ signal

M_T= 1 TeV

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



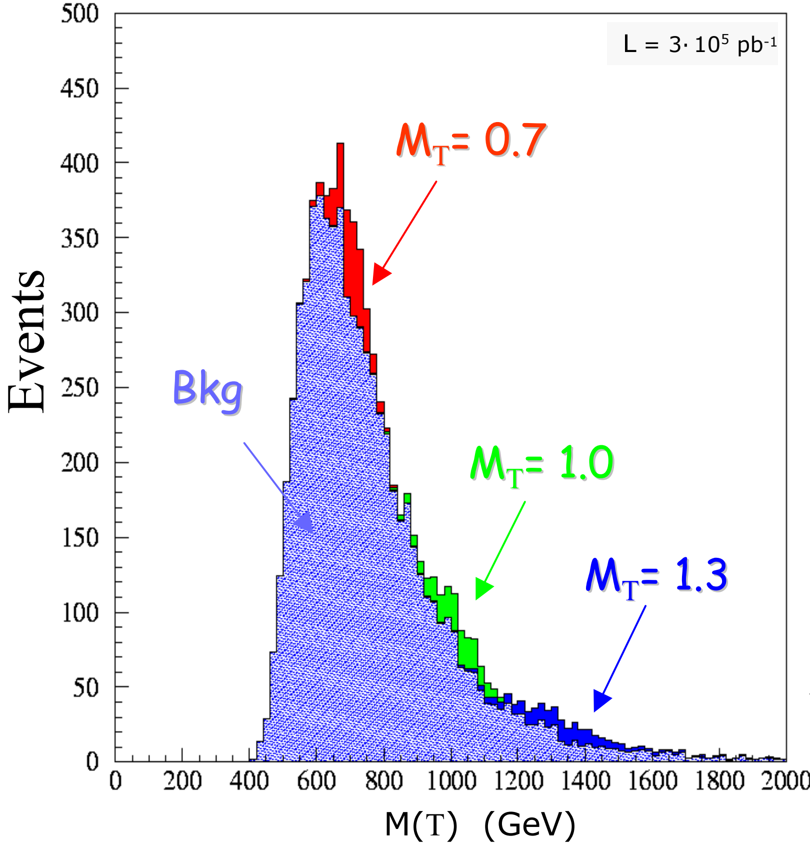
Cuts:

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

$T \rightarrow ht$ signal

M_T = 0.7, 1.0, 1.3 TeV

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



Cuts:

- p_T(3-jets) > 90 GeV
- p_T(lepton) > 70 GeV
- 100 < M_h < 140 GeV

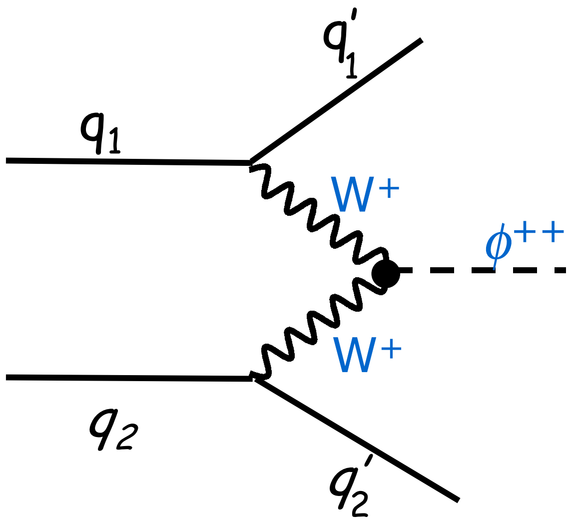
At least 1 b-tag

→ X-sections to achieve 3σ observations

New Higgs ϕ^{++}

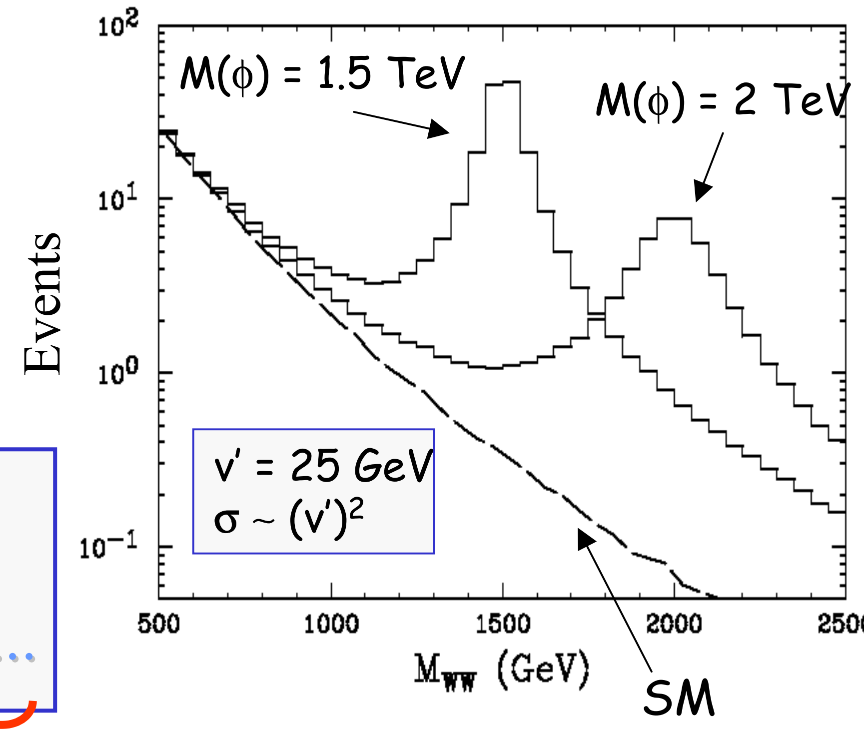
- Production: VBF mechanism

(vector boson fusion)



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

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



Decays
$\phi^{++} \rightarrow W^+W^+$
$\phi^{++} \rightarrow \tau^+\tau^+, e^+e^+, \ldots$

might be suppressed

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

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

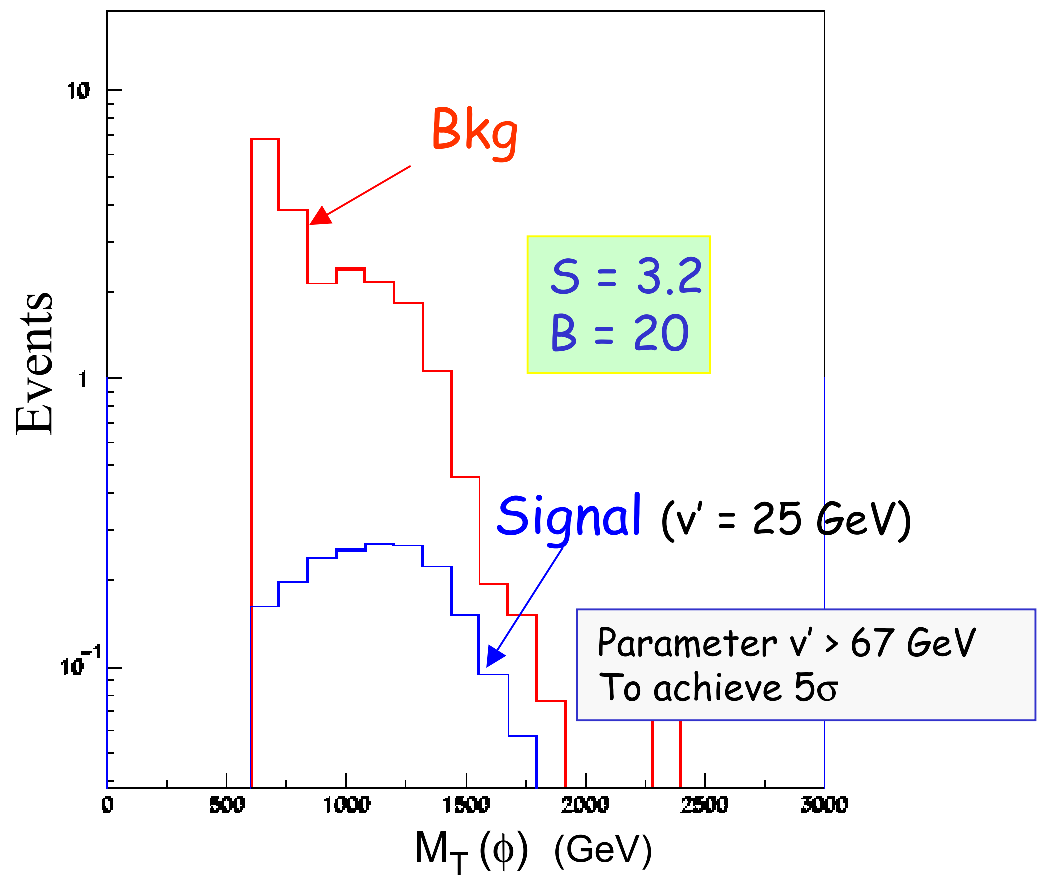
$L = 3\cdot 10^5\ pb^{-1}$

$M(\phi^{++}) = 1.5$ TeV

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

Main cuts:

- 2 forward jets
- P_T(lepton 1) > 100 GeV
- P_T(lepton 2) > 50 GeV
- $\not{E}_T$ > 50 GeV
- M_T > 600 GeV



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

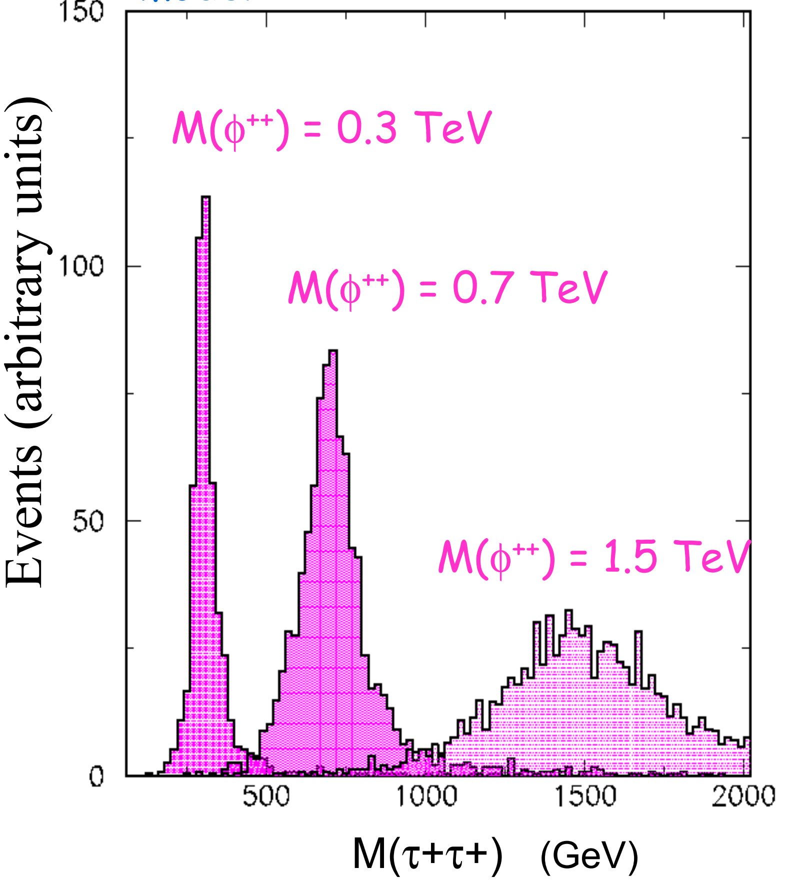
$\phi^{++} \to \tau^+\tau^+ \to$ lepton + jet

Bkg: $WWjj$, $t\bar{t}$

Main cuts:

- Forward jet tag
  $P_T(j_1) > 40$ GeV
  $P_T(j_2) > 20$ GeV
  $|\Delta\eta| < 3.8$
  $M_{jj} > 600$ GeV
- Central jet veto
- τ selection cuts
- Same charge for τ-jet and lepton

Couplings might be suppressed in the little Higgs model



Outlook

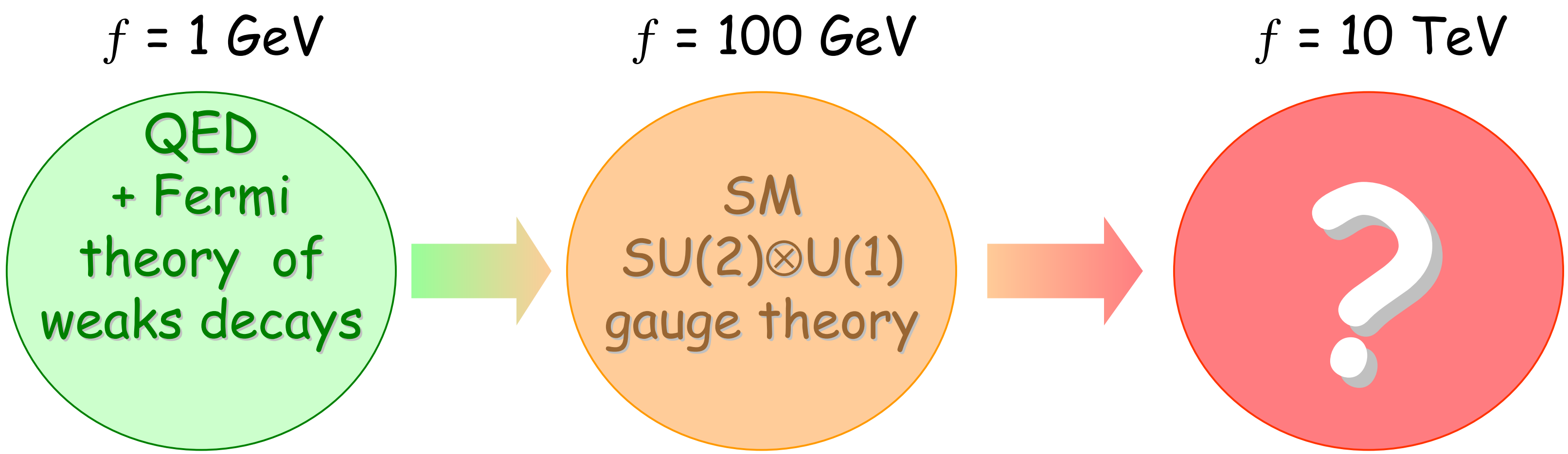
Work in progress

- $h(200) \rightarrow ZZ, W^+W^-$
- A_H and W_H production and decay
- $T \rightarrow Zt, Zh, bW$
- $\phi^{++} \rightarrow W^+W^+$

Other models

$$\underbrace{SU(5)}_{\text{1 higgs doublet}} \rightarrow \underbrace{SU(4),\ SU(6),\ SO(5)}_{\text{2 higgs doublets}}$$

Little higgs models are an alternative to supersymmetry at 1 TeV scale



‘ Subtle is the Lord, but not malicious ’

This time the Lord has been too subtle…