Little Higgs Task Force

S. Asai, G. Azuelos, K. Bensalma, D. Costanzo, G. Couture, J.E. Garcia,
I. Hinchliffe, N. Kanaya, M. Lechowski, R. Mehdiyev,
G. Polesello, E. Ros, D. Rousseau

August 26, 2003

ATLAS

Atlas and the Little Higgs

- What is the Little Higgs
- Generic Signals
- Atlas Simulations
- Conclusions and future

Hierarchy problem revisited

All data consistent with SM ($g-2$???)

New particles of mass $\lesssim 10\mathrm{TeV}$ are constrained EW fits, FCNC limits etc

Calculate with a cut off $\Lambda = 10TeV$

top loop $\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim (2TeV)^2$

W/Z loops $\delta m_h^2 \sim \alpha_w\Lambda^2 \sim -(750GeV)^2$

Higgs loop $\delta m_h^2 \sim \frac{\lambda}{16\pi^2}\Lambda^2 \sim -(1.25m_h)^2$

$m_h^2 \sim (100GeV)^2$

Fine tuning of Higgs mass seems to require something else $\sim 1\mathrm{TeV}$

Most dangerous terms are top loop, Higgs loop, W/Z loops

Solve these and problem is $\gtrsim 10\mathrm{TeV}$ where we know nothing

SUSY solves it up to $\sim M_{Planck}$ by removing all quadratic divergences.

Can arrange ad-hoc cancellations by adding a few particles but need a symmetry

Little Higgs models

- Models try to arrange new particles to cancel these effects
- Do this by extending the symmetries of the Standard Model so that the cancellations are forced by the new symmetries
- Need a theory with a broken global symmetry to get a massless Goldstone boson.
- Must break the symmetry "in a small way" so that this Goldstone Boson can have interactions and a VEV and play the role of the Higgs.
- Will solve the hierarchy problem; cancellations will appear as needed
- The models are not simple (they may be "elegant") and not complete.

The basic concept

- Start with a group G, break it to H at scale Λ (think of 10 TEV)
- Don't worry about the rest of the physics at this scale
- H must contain standard model $SU(2)_L \times U(1)$
- Get rid of the "extra" Goldstone bosons by gauging part of G so that
  (a) Some are eaten
  (b) part of symmetry is broken and others can get a mass.
- Introduce small explicit breaking if needed

An Illustration

- $G = SU(5)$ $H = SO(5)$: $(5^2 - 1) - 5 \times 4/2 = 14$ Goldstone bosons

- Classify them according to weak $SU(2)_L \times U(1)$

  $$\begin{array}{ccccccccccc} 1_0 & \oplus & 3_0 & \oplus & 2_{1/2} & \oplus & 2_{-1/2} & \oplus & 3_1 & \oplus & 3_{-1} \\ X & & Y & & h & & h^\dagger & & \phi & & \phi^\dagger \end{array}$$

- Gauge subgroup $SU(2) \times U(1) \times SU(2) \times U(1)$ and break to $SU(2)_L \times U(1)$
  X and Y are eaten
  $\Rightarrow$ 4 Gauge bosons (Z) of mass $g\Lambda \sim 1$ TeV

- Compute most general 1-loop correction to Goldstone Boson couplings from gauge interactions
  Generates mass $g\frac{\Lambda}{4\pi}$ for ϕ
  Generates $(hh^\dagger)^2$
  But h stays massless

See [5] for details

How to Cancel the Top Loop

- add $SU(2)_L$ singlet quarks T_L and T_R – T_R has same coupling as t_R

- Embed $SU(2)_L$ in global $SU(3)$ (fits inside the $SU(5)$)

$$\begin{pmatrix} t_L \\ b_L \\ T_L \end{pmatrix}$$

- Global $SU(3)$ is broken and the couplings of Goldstone bosons are known

  Qt_r loop from first term is canceled by $T_L t_r$ loop from third!!!

$$\lambda_1(iQht_r + fT_Lt_r - \frac{1}{2f}T_Lt_rhh^\dagger) + \lambda_2 f(T_LT_R)$$

Add Breaking term $\lambda_2 f(T_LT_R)$

T_L marries combination of T_R and t_R and gets mass of order $\lambda_2 f$

Remaining combination is right handed top

Top mass constraint implies $\frac{1}{\lambda_1} + \frac{1}{\lambda_2} \sim 2$

LHC signals

What is the minimal stuff??

- Something to cancel the top loop.
  In the example this is T decays via $T \to Zt$, $T \to Wb$, $T \to ht$ with BR in the proportion $1 : 2 : 1$
  Ratio is test of model

- Something to deal with the W loop
  In the example this is the gauge bosons of the other $SU(2) \times U(1)$.
  Once the masses are specified their couplings have one free parameter (θ)

- Something to deal with the H loop
  In the example this is the Higgs triplet ϕ which is produced via WW fusion

- Very small effects $< 5\%$ in $h \to gg$ and $h \to \gamma\gamma$

Masses and decays are model dependent. Higgs sector is most model dependent

Expected range of masses

- Fine tuning means that $f = \frac{\Lambda}{4\pi} < 1TeV(\frac{m_H}{200GeV})^2$
- $m_T < 2TeV(\frac{m_H}{200GeV})^2$
- $M_{W_H} < 6TeV(\frac{m_H}{200GeV})^2$
- $m_\phi < 10TeV$

Some phenomenology is discussed by [11] and [10]

But...

- This model is well defined and can be tested
- No custodial SU(2) symmetry and therefore potentially large corrections to $M_W = M_Z \cos\theta_W$ [12] – Disaster
- E-W fits constrain $f > 4TeV$
- this implies $m_T > 8TeV$ and the fine tuning problem is back with a vengeance

This particular model is dead
However another model may be OK
Factors of 2 might save it e.g. $f > 2TeV$ and $m_T = f$ lower m_T by factor of 4.
There are other viable models, but we need a defintite one for simulation

New Quark

Properties determined by two parameters λ_1/λ_2 and mass.

Two production mechanisms $qb \to q'T$ and $gg \to T\overline{T}$: Former depends on $t - T$ mixing and therefore on λ_1/λ_2

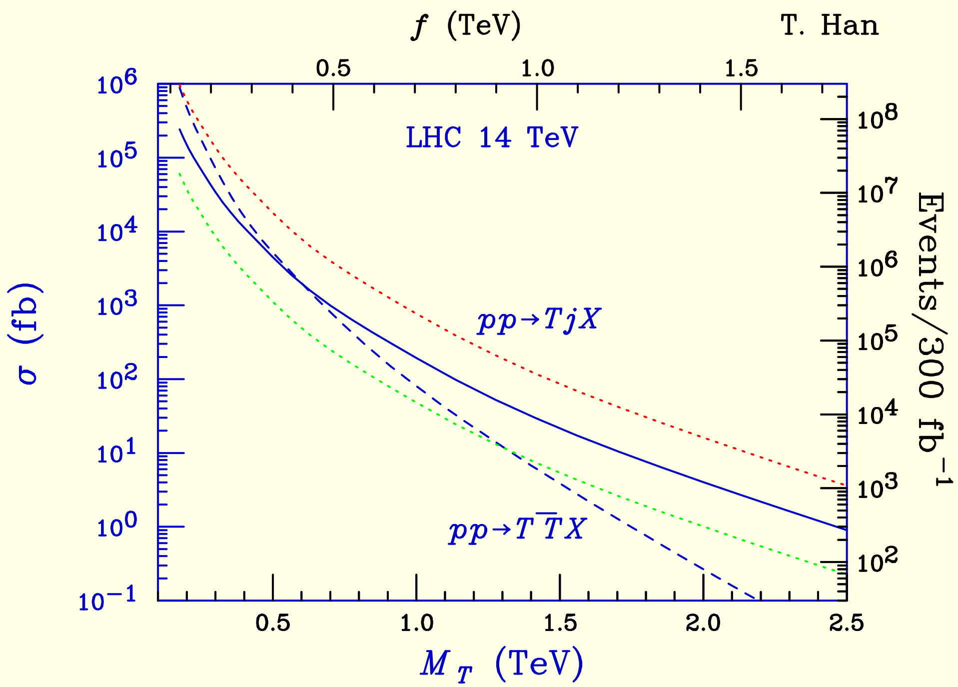


Figure from Han

Single production dominates at large masses

Three single production curves are for $\lambda_1/\lambda_2 = 2, 1, 0.5$

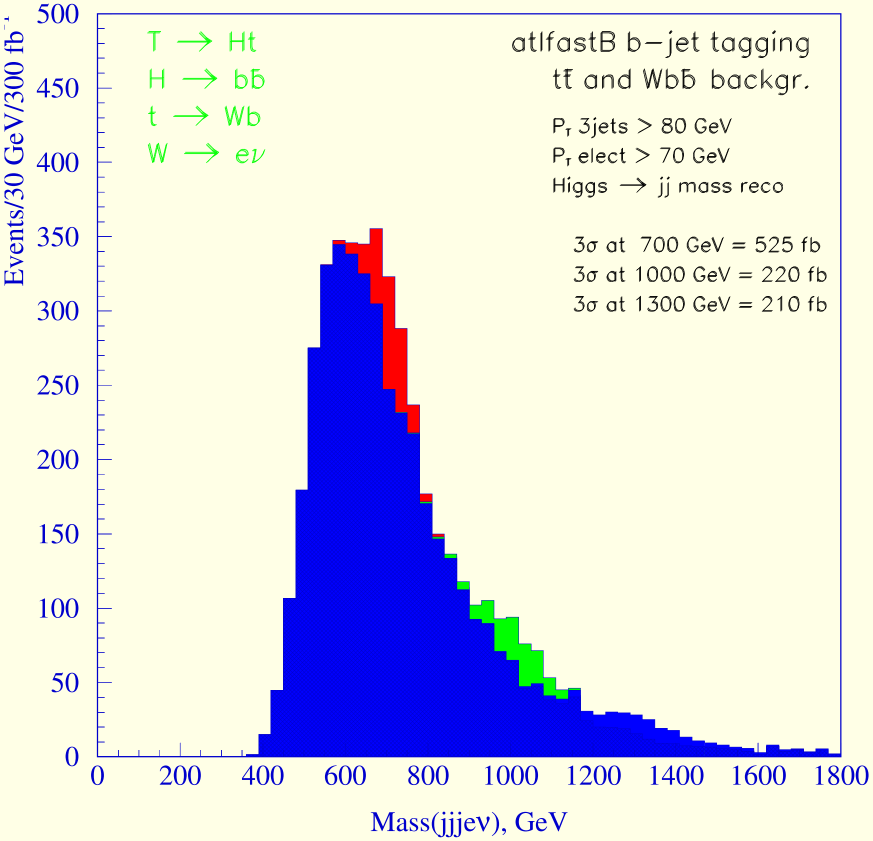
Width is small

Single Production is used in the following: note recoil jet.

$T \rightarrow ht$

Reconstruct from $h \rightarrow bb$ and $t \rightarrow b\ell\nu$

One isolated e or μ with $p_T > 70$ GeV and $\mid \eta \mid < 2.5$.
Three jets with $p_T > 80$ GeV.
Four jets with $p_T > 15$ GeV.
At least one jet tagged as a $b-$jet
Mass of dijet system within 20 GeV of Higgs mass (assumed to be 120 GeV)

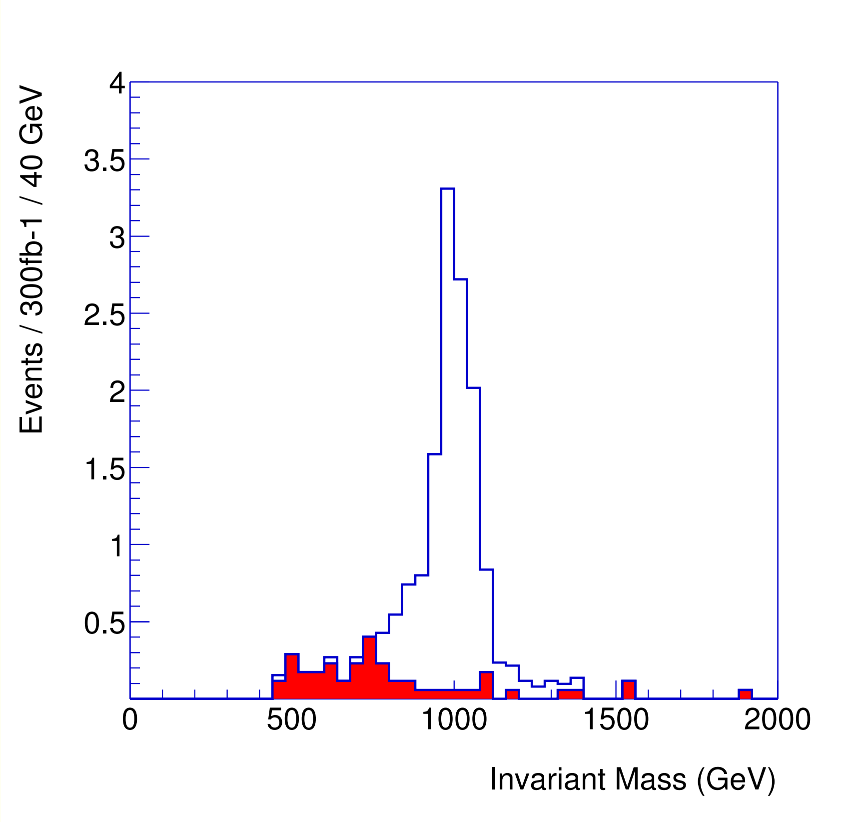


Background dominated by $t\bar{t}$

$T \rightarrow Zt$

Reconstruct from $Z \rightarrow \ell^+\ell^-$ and $t \rightarrow b\ell\nu$

Three isolated leptons (either e or μ) with $p_T > 40$ GeV and $|\eta| < 2.5$ one of which has $p_T > 100$ GeV
No other leptons with $p_T > 15$ GeV
One pair of leptons within 10 GeV of Z mass.
$\not{E}_T > 100$ GeV
At least one tagged $b-$ jet with $p_T > 30$ GeV



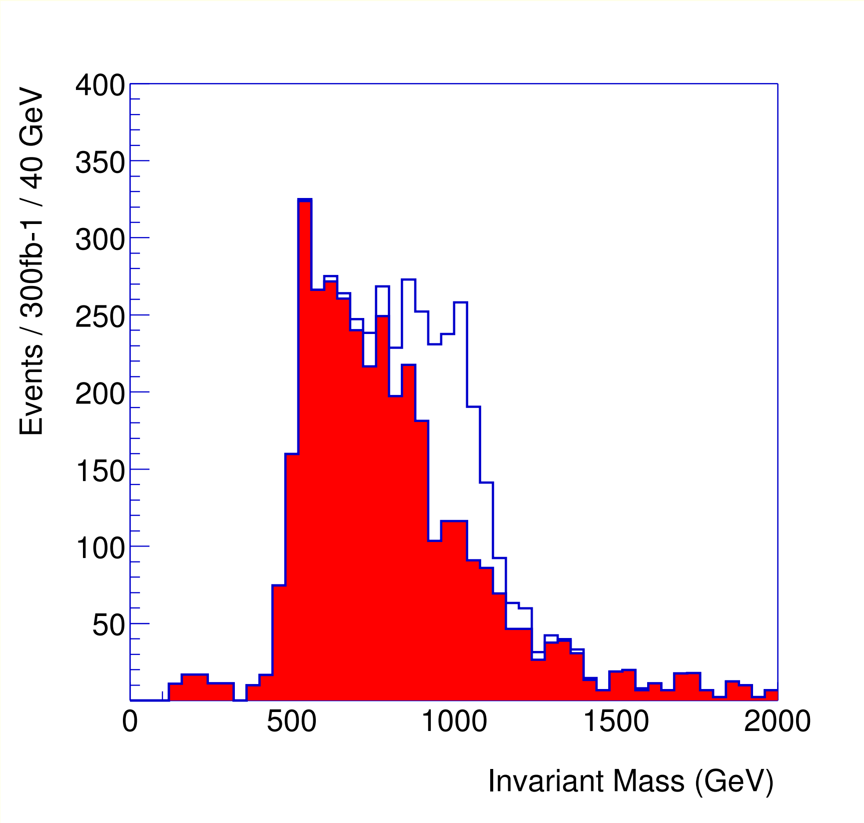
Backgr

is dominated by tbZ

$T \rightarrow Wb$

Reonstruct from $T \rightarrow b\ell\nu$

One isolated lepton (either e or μ) with p_T >100 GeV and $\mid \eta \mid < 2.5$
No other leptons with $p_T > 15$ GeV
No more than 2 jets with $p_T > 50$ GeV and $M(j1, j2) > 200$ GeV
$\not{E}_T > 100$ GeV
at least one tagged $b-$ jet with $p_T > 200$ GeV



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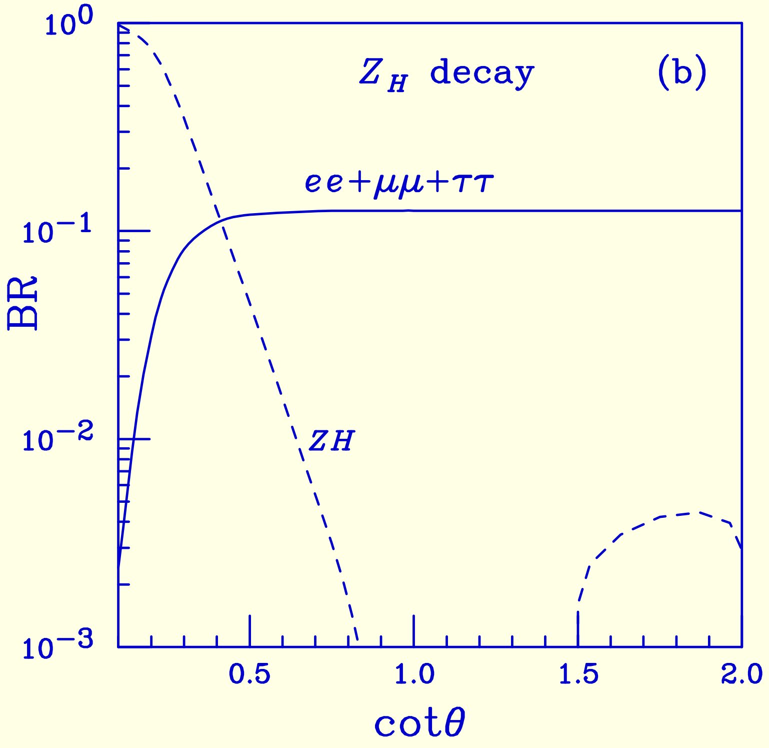
is dominated by $t\bar{t}$

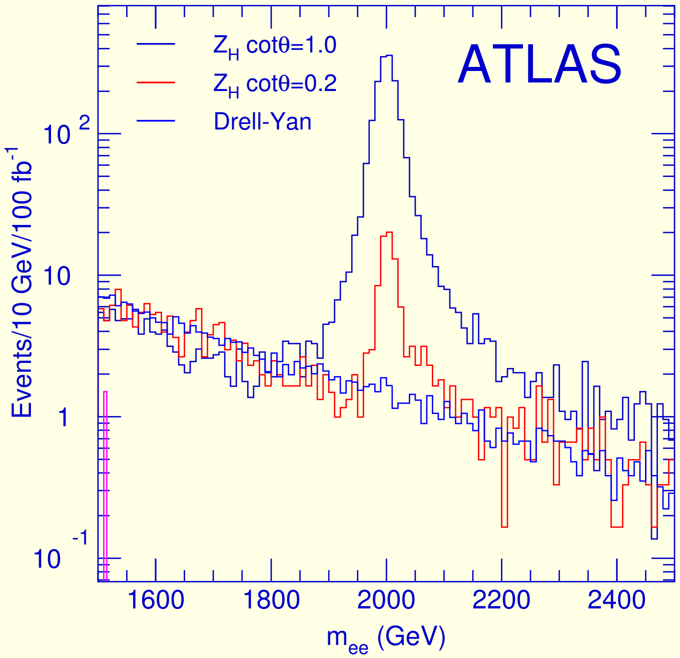
New Bosons

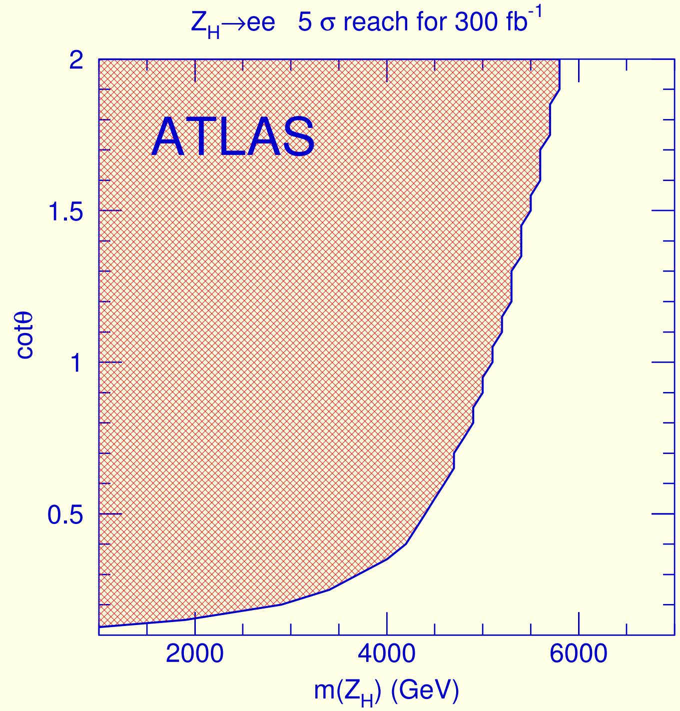
Expect two neutral and two charged: $Z_H, A_H, W_H^{\pm}$ Model has two additional couplings corresponding to the extra $SU(2) \times U(1)$,
Specify these using two angles θ and θ' ($c.f.\ \theta_W$)

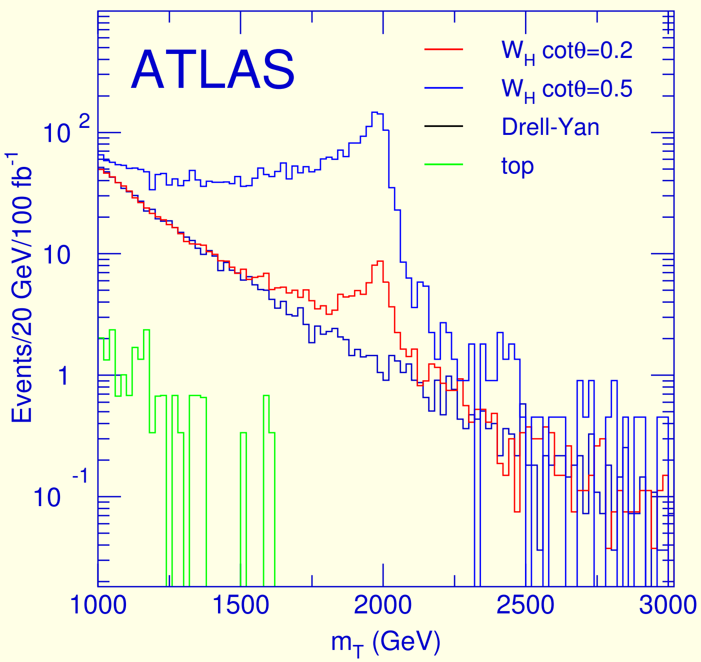


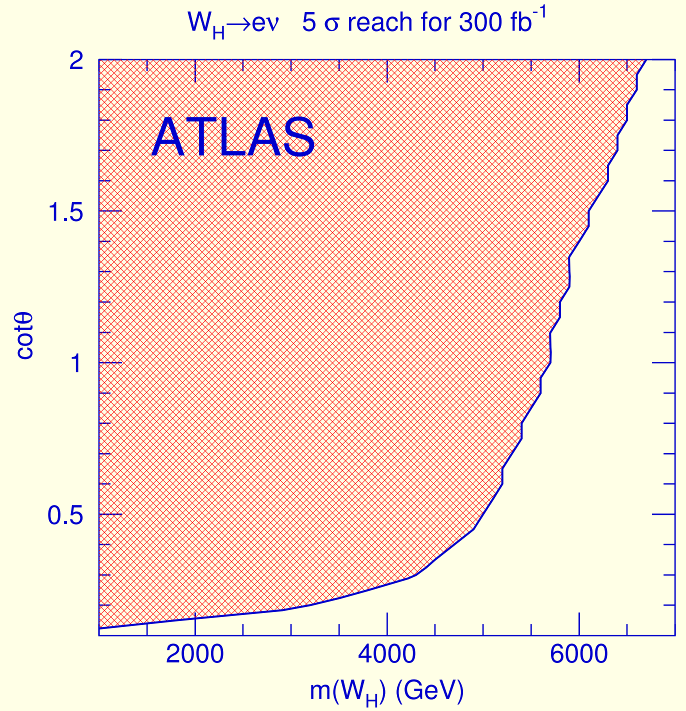
New Bosons – Leptonic decays

Clear signal over Drell-Yan background. Plot shows 2 TeV mass for Z_H







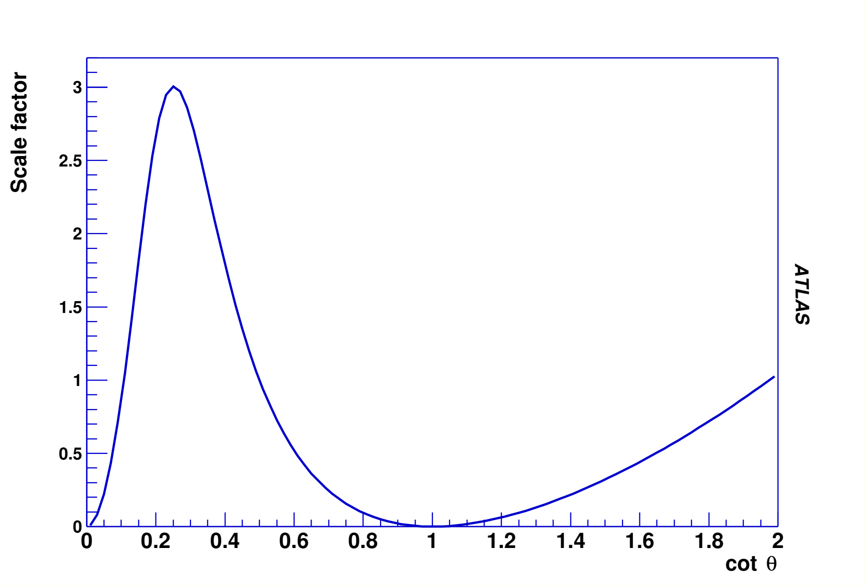


Clear signal in transverse mass of lepton and missing E_T

Plot shows 2 TeV mass for W_H

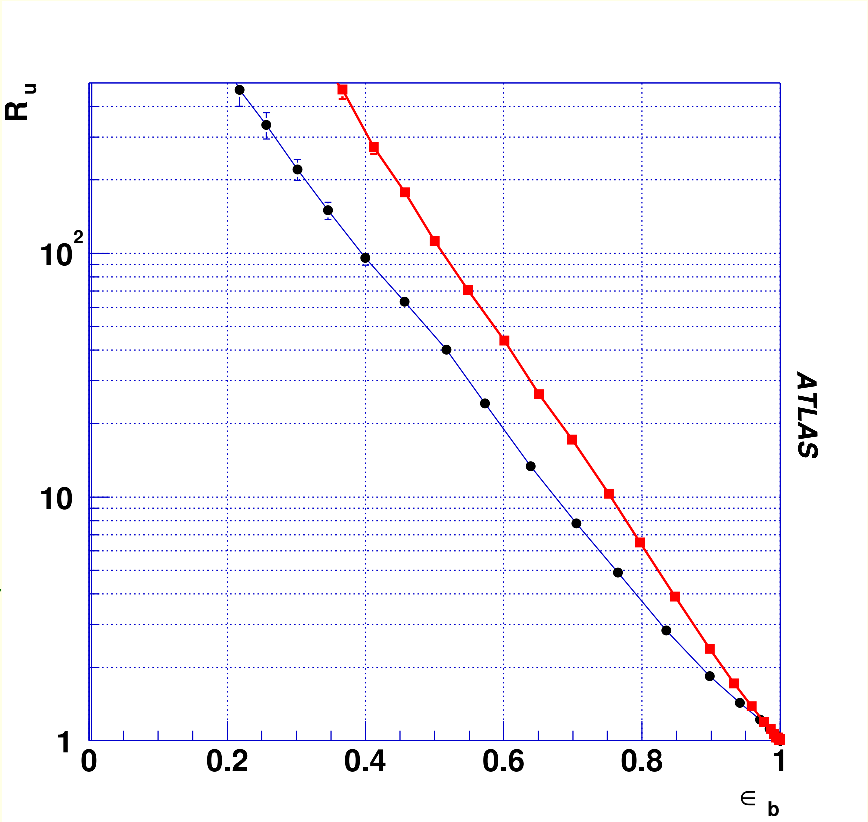
New Bosons – Cascade decay $Z_H \to Zh$

Production rate and Branching ratio depends on θ



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

$b - jets$ from h (mass 120 GeV assumed) are larger p_T than older samples
$b - tagging$ was validated with full simulation in this case



Plot show tagging efficiency vs rejection of light quark jets
Red line is old benchmark of Wh production
Black line is this case
Tagging is worse but adequate

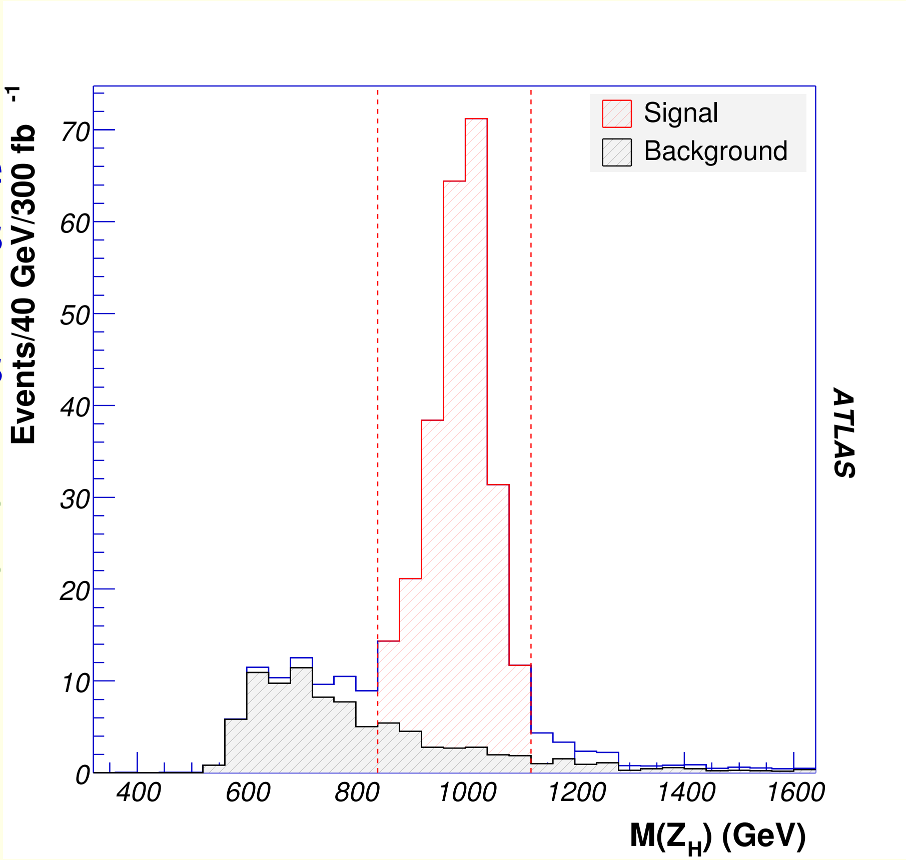
$Z_H \to Zh \to\to b\bar{b}\ell^+\ell^-$

Two leptons of opposite charge and same flavor with $p_T > 6(5)$ GeV for muons (electrons) and $\mid \eta \mid < 2.5$

The lepton pair should have a mass between 76 and 116 GeV

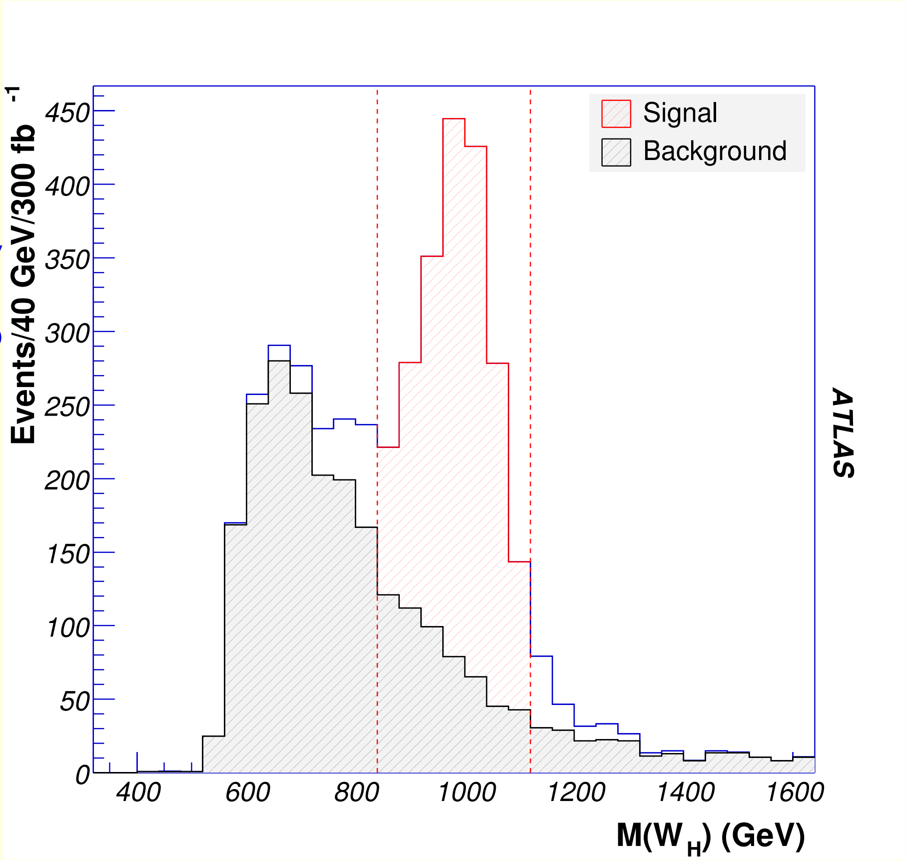
Two reconstructed $b-jets$ with $p_T > 25$ and $\mid \eta \mid < 2.5$, which are within $\Delta R < 1.5$

The $b{-}jet$ pair should have a mass between 60 and 180 GeV



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

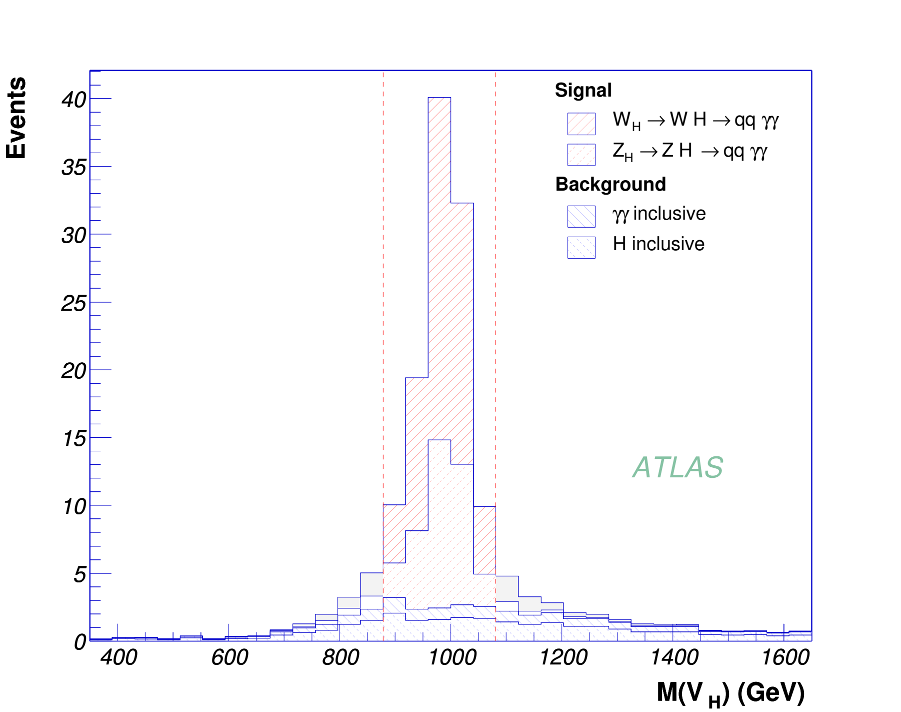
One isolated e or μ with $p_T > 25$ GeV and $|eta| < 2.5$. $\not{E}_T > 25$ GeV Two reconstructed $b-jets$ with $p_T > 25$ and $\mid \eta \mid < 2.5$, which are within $\Delta R < 1.5$ The $b-jet$ pair should have a mass between 60 and 180 GeV



$Z_H \to Zh$, $h \to \gamma\gamma$

Must use all hadronic mode of Z: Cannot distinguish W_H from Z_H

Two isolated photons one having $p_T(1) >$ 25 GeV, $p_T(2) > 40$ GeV.
$M(\gamma\gamma) = m_h \pm 2\sigma$
The jet pair with invariant mass closest to M_W is selected.
Pair has a combined $p_T > 200$ GeV



Can also extract signal via Jacobion peak in the P_T dist of Higgs

Extra Higgs

$\phi^{+}+$ produced by WW fusion: So must use the forward tagging jets

Two reconstructed positively charged isolated leptons (electrons or muons) with $|\eta| < 2.5$

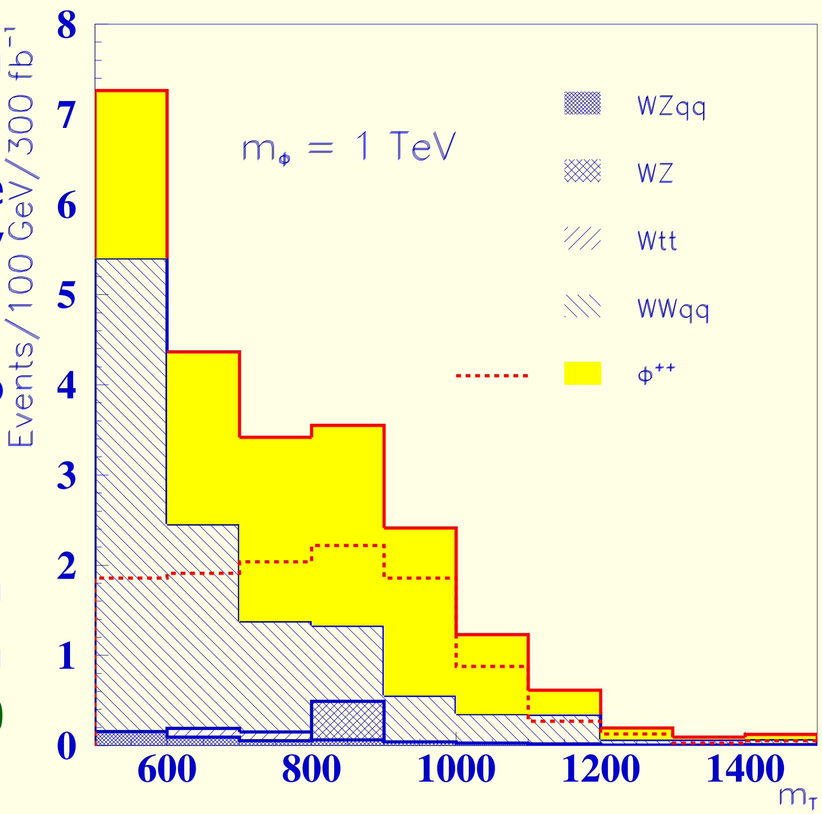
one of the leptons was required to have $p_T > 150$ GeV and the other $p_T > 20$ GeV

$|p_{T1} - p_{Ts}| > 200$ GeV

the difference in pseudorapidity of the two leptons $|\eta_1| - |\eta_2| < 2.$

$\not{E}_T > 50$ GeV

Two jets each with $p_T > 15$ GeV, with rapidities of opposite sign, separated in rapidity $|\eta_1 - \eta_2| > 5$; one jet has $E > 200$ GeV and the other $E > 100$ GeV



Summary of sensitivity

- T Observable in both $h(120)t$ (up to mass of 1.2 TeV) and Zt (up to mass 1.0 TeV: Wb is observable up to 1.3 TeV for $\lambda_1/\lambda_2 = 1$
- Z_H observable in e^+e^- to mass of 4.5 TeV for $\cot\theta = 0.5$
  $Z_H \to Zh(120) \to Zb\bar{b}$ observable for mass up to 2 TeV
  $Z_H \to Zh(120) \to Z\gamma\gamma$ observable for masses up to 1.1 TeV
- ϕ^{++} may be observable in W^+W^+ at 1.5 TeV

ATLAS can almost cover the full space

What next?

- Some more channels to look at: $T \rightarrow bW$, $h(200)$
- Some models have two doublet Higgs structure: reinterpret MSSM
- Produce note by end of June?

Refs

References

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