Non Standard Higgs with ATLAS

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CP violation and Higgs,
CERN, 3 Dec 2004

ATLAS studies…

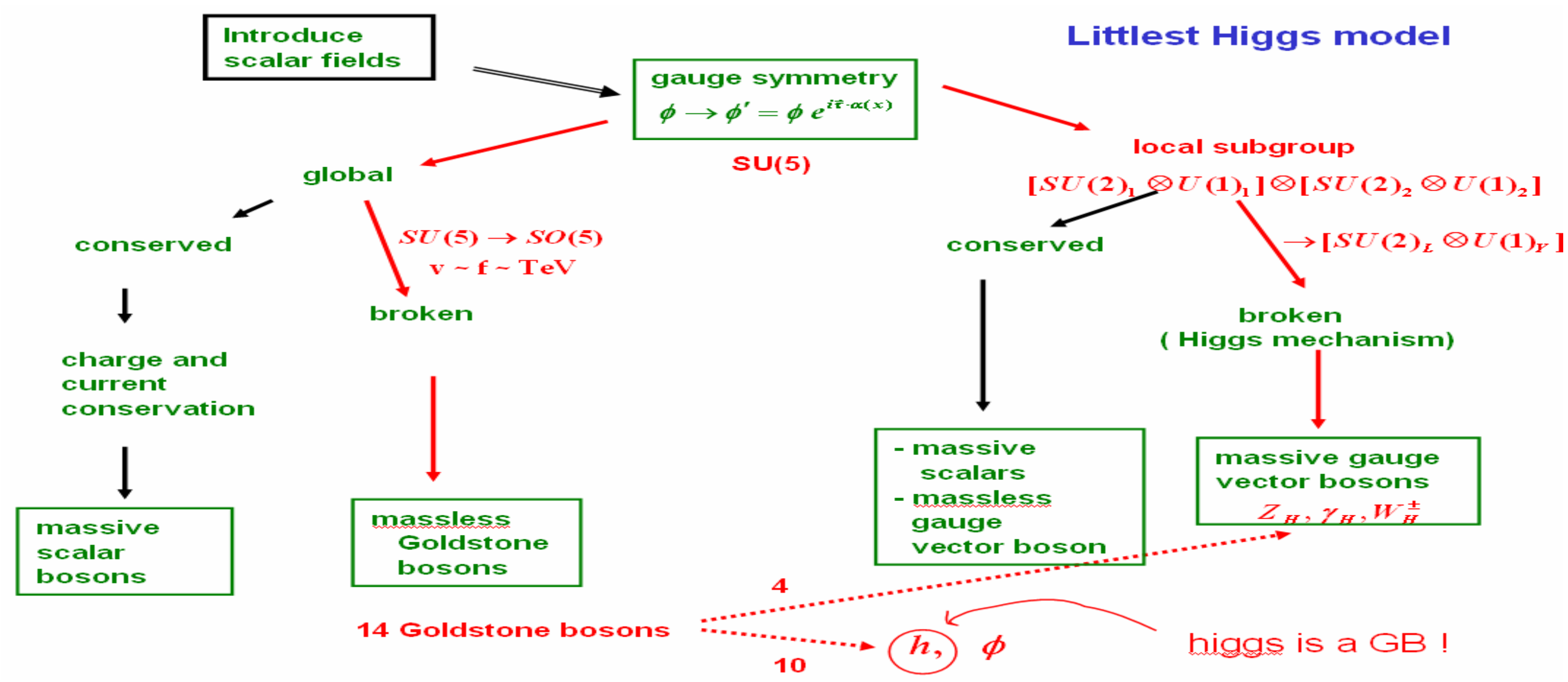
- Little Higgs
- Doubly Charged Higgs in the Left-Right Model
- Radion in Sandrum-Randall model
- Heavy Higgs or no Higgs
- Vector boson scattering at high masses
- Chiral Lagrangien Model
- Lepton Flavour violation in 2 Higgs doublets model type-III
- Invisibly decaying Higgs: VBF,ttH,ZH or WH

The Little Higgs Models

Hierarchy problem through loop corrections to the Higgs Mass: Λ is an uv cut-off

- from the top loop $\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2$
- from the W/Z loops $\delta m_h^2 \sim \alpha_w \Lambda^2$
- from the Higgs loop $\delta m_h^2 \sim \frac{\lambda}{16\pi^2}\Lambda^2$

Arrange new particles from scheme with conbination of symmetry breaking (global, local…) to cancel these effects (Arkani-Hamed, Georgi, Burdman, Schmalz, …)



Particle Content

① T heavy top (M <~ 2 TeV)

② $W_H^{\pm}$ → heavy $W^{\pm}$ Z_H → heavy Z A_H → heavy γ (M <~ 6 TeV)

③ Higgs triplet ϕ^0 , ϕ^+ , ϕ^{++} (M <~ 10 TeV)

heavy Higgs bosons

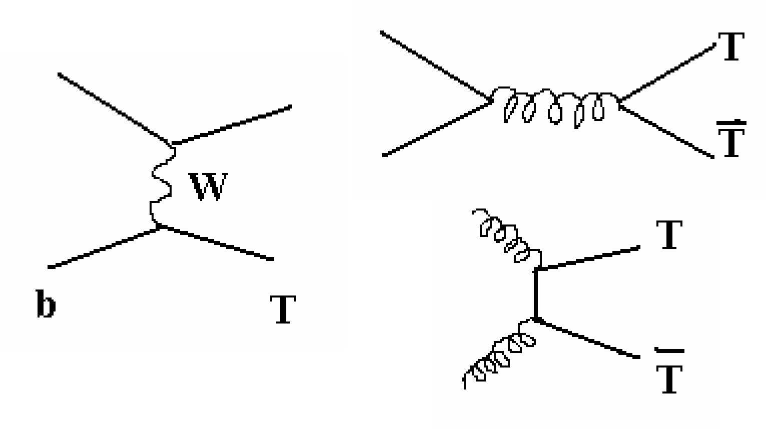
T. Han et al hep-ph/0301040 : **Phenomenology of the Little Higgs Model**

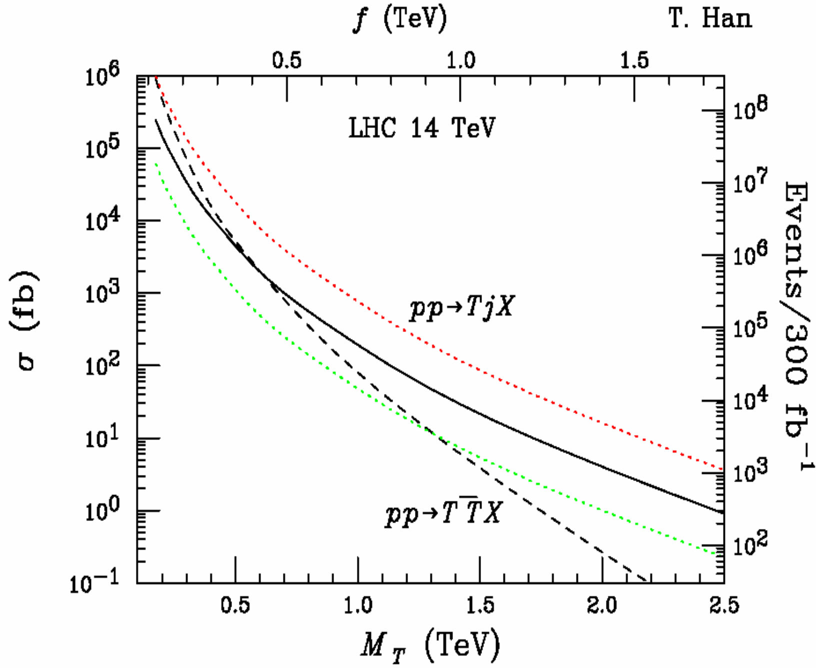
G. Azuelos et al SN-ATLAS-2004-038: **Analysis in ATLAS**

Heavy quark T (I)

Couplings: $\lambda_1(iQht_r + fT_Lt_rhh^\dagger) + \lambda_2 f(T_LT_R)$

Single and double production:





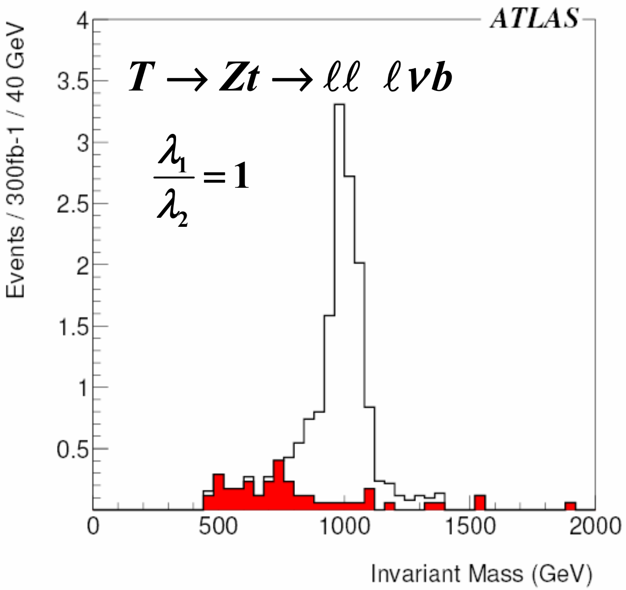
3 decay modes with widths:

$$\Gamma(T \to t\,h) = \Gamma(T \to tZ) = \frac{1}{2}\Gamma(T \to bW) = \frac{\kappa^2}{32\pi} M_T$$

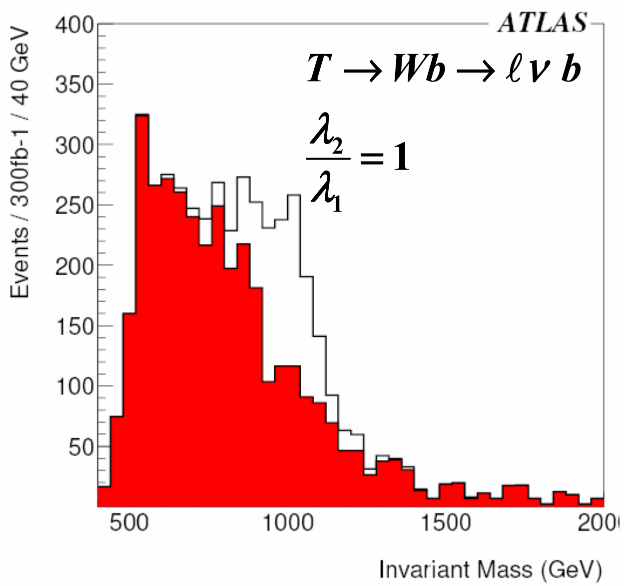
$$\kappa = \frac{\lambda_1^2}{\sqrt{\lambda_1^2 + \lambda_2^2}}$$

BR
- T → bW 50 %
- T → tZ 25 %
- T → th 25 %

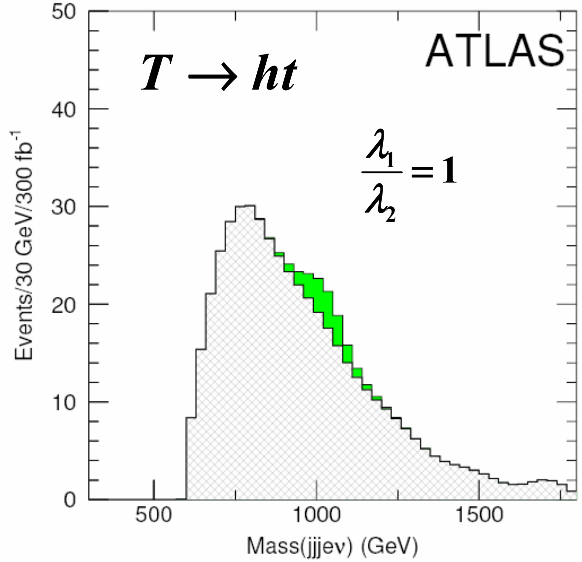
Sensitivity to the heavy quark T



$m_T \sim 1$ TeV



$m_T \sim 2.1$ TeV



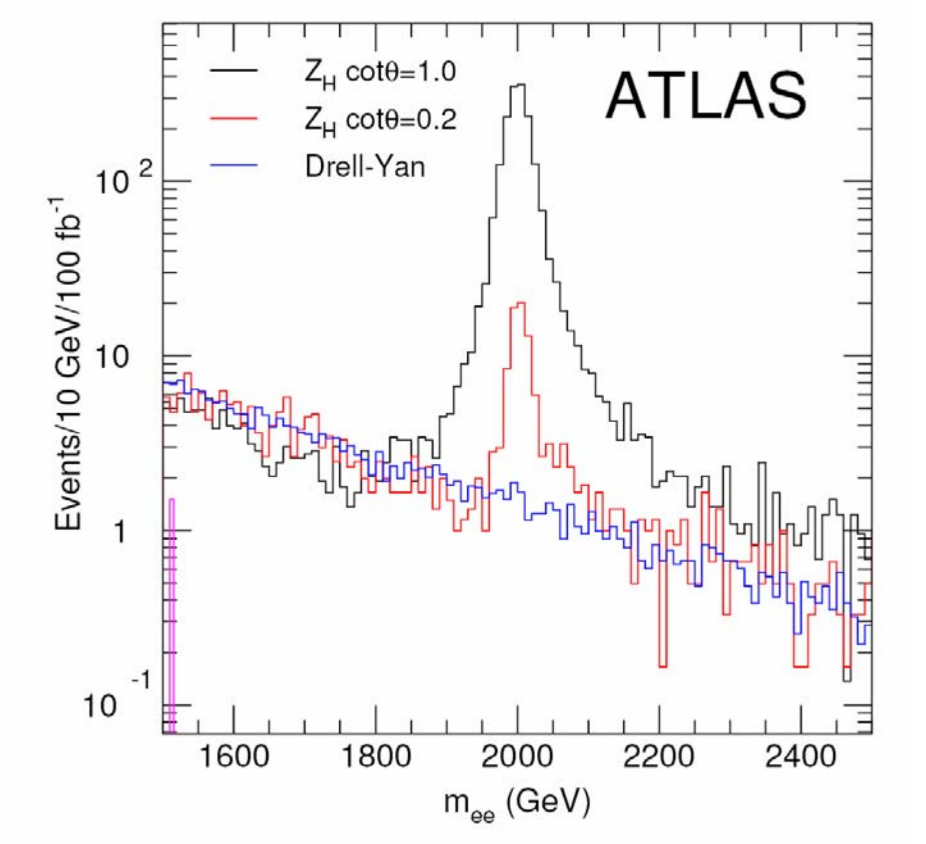
$m_T \sim 1$ TeV

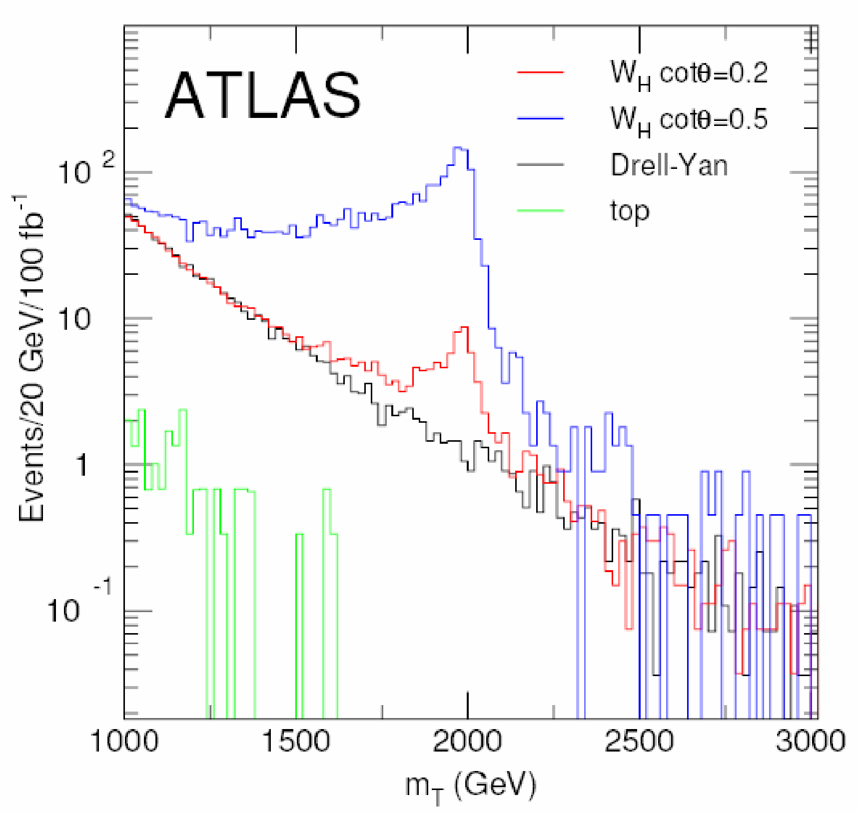
n Isolated leptons
E_t
b-jet tagging

Heavy Gauge Bosons Z_H, W_H

W_H, Z_H, A_H arise from $[SU(2) \otimes U(1)]^2$ symmetry

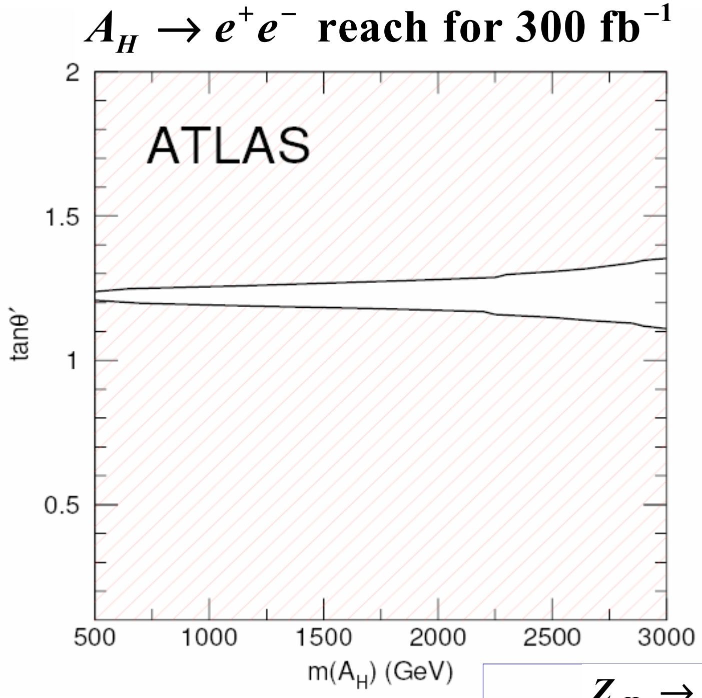
$\rightarrow$ 2 mixing angles (like θ_W): θ for Z_H
θ' for A_H

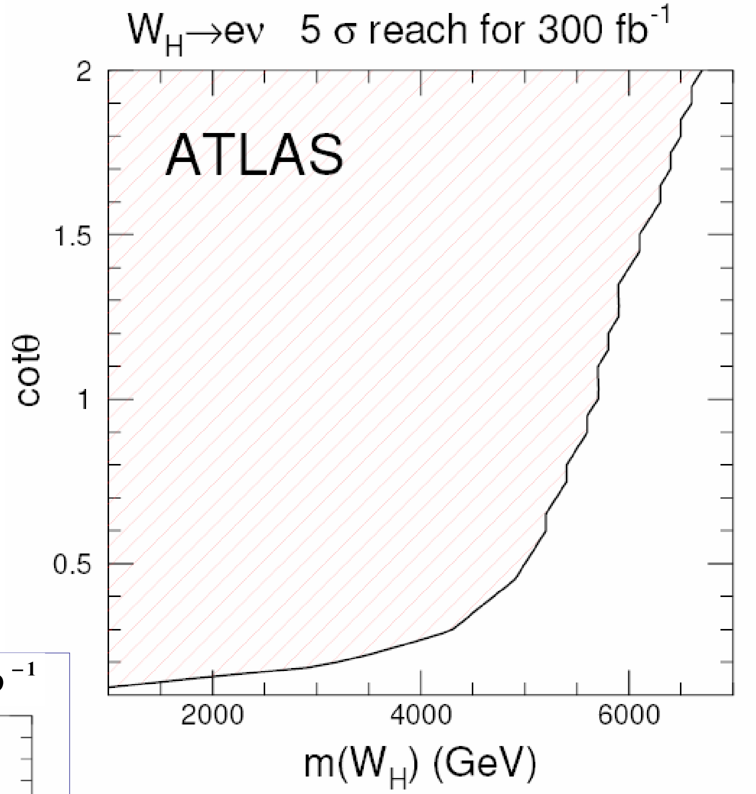


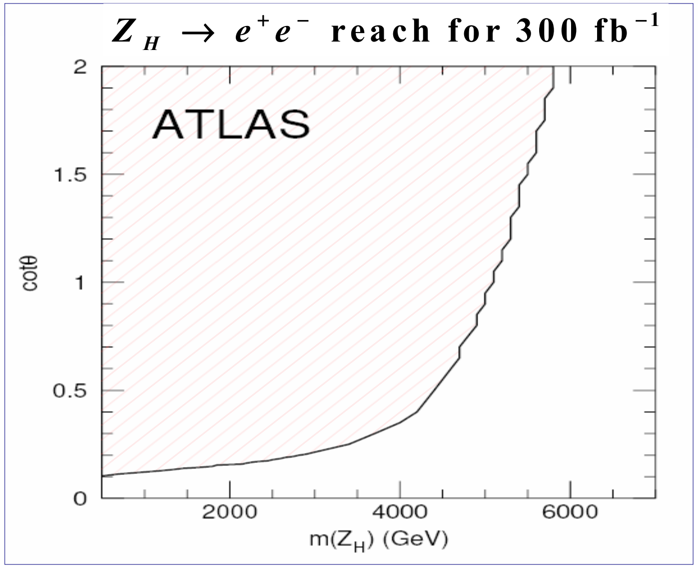


2 isolated electrons
minimum of invariant mass=800 GeV

Sensitivity to heavy gauge bosons Z_H, W_H

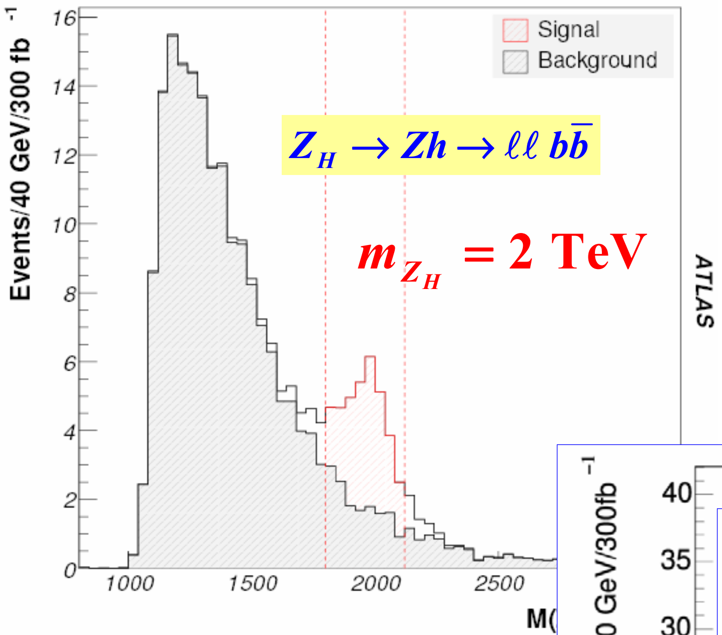




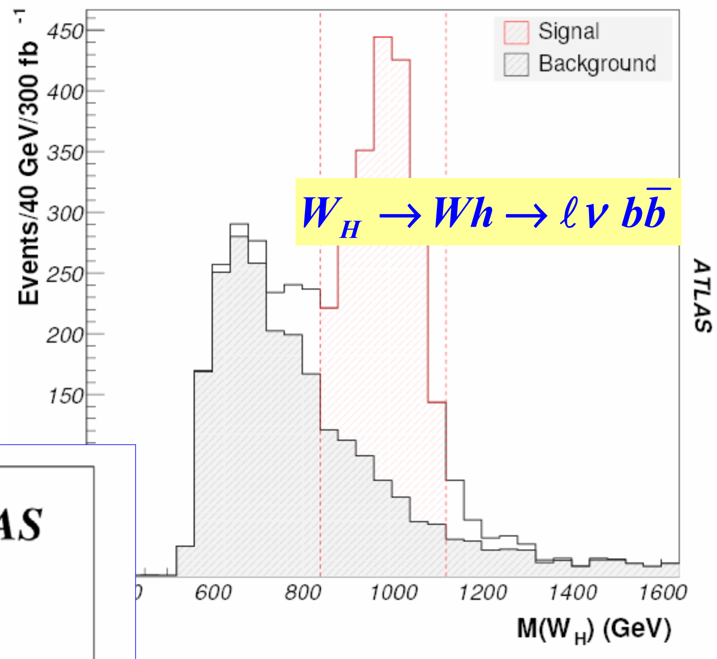


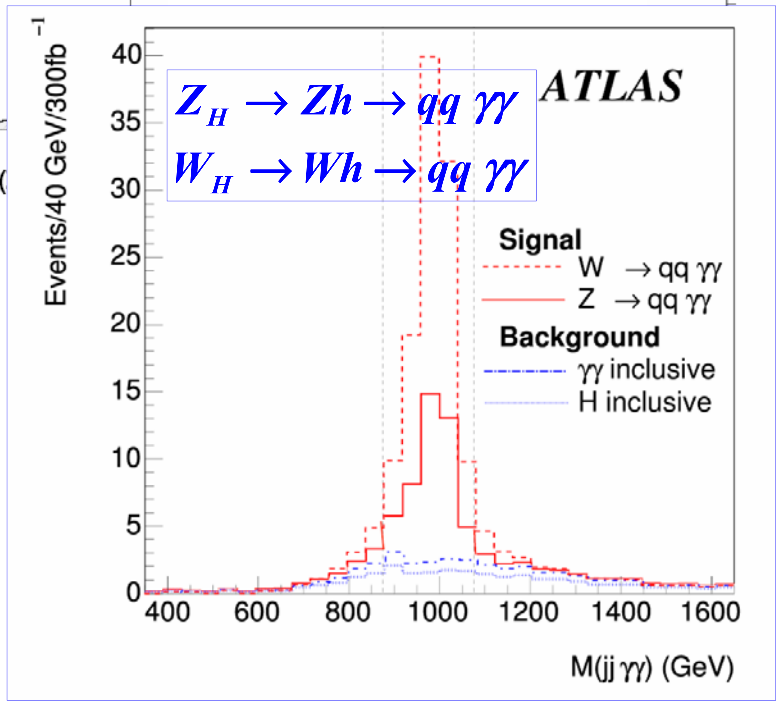
Higgs-Gauge boson couplings

Measurement of $Z_H \rightarrow Zh$ and $W_H \rightarrow Wh$ couplings needed to test model



isolated leptons





b-tagging at high energy

b-tag: $\varepsilon_b = 40\%$, $R_u = 100$

Inside mass window:

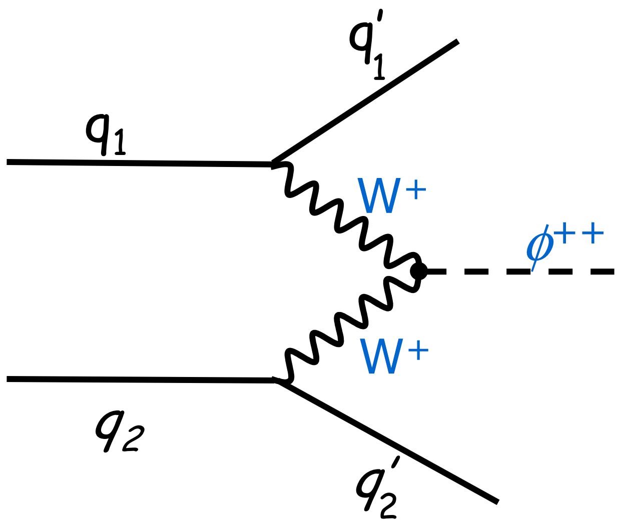
$$\left.\begin{array}{l} S = 15 \\ B = 8 \end{array}\right\} \frac{S}{\sqrt{B}} = 5$$

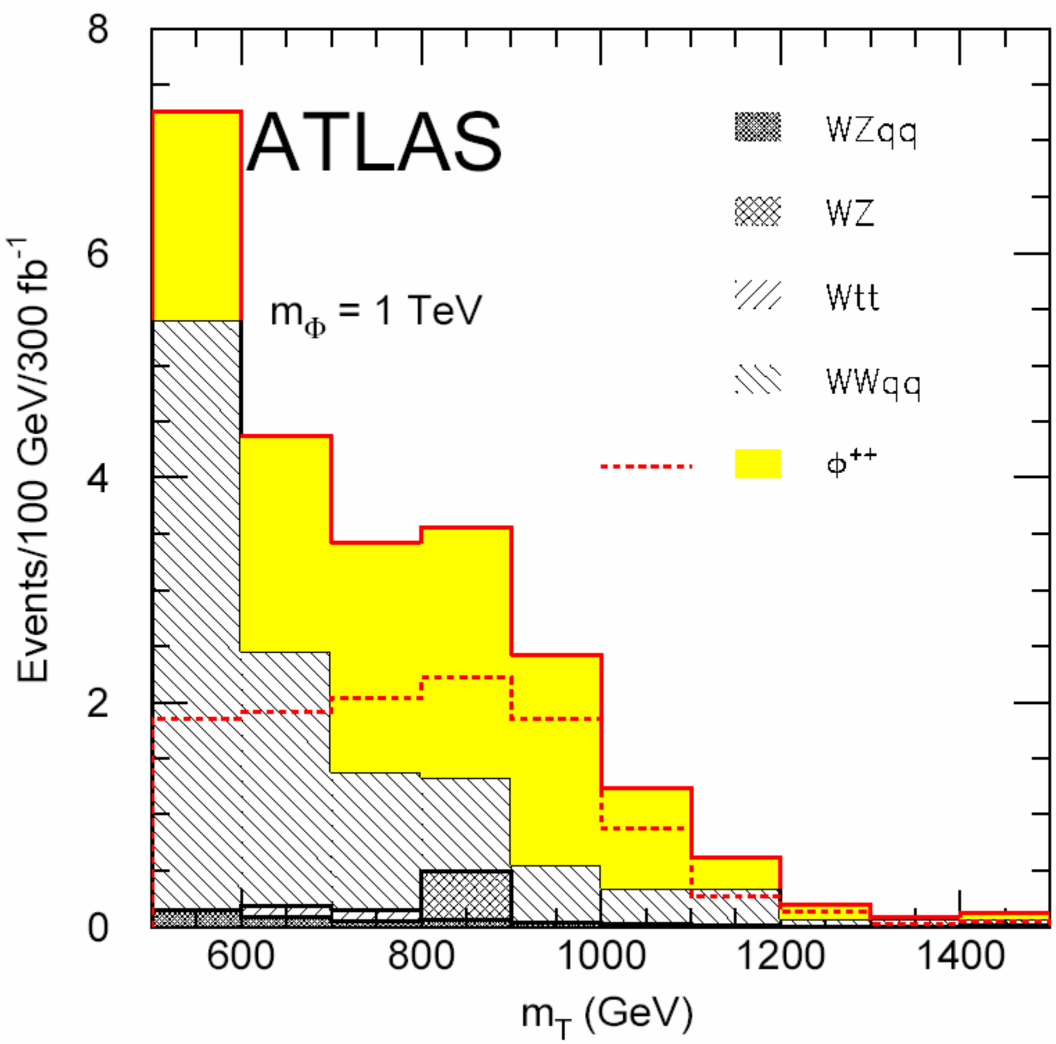
Extra Higgs Φ^{++}

Φ^{++} produced by WW fusion

Two reconstructed, positively charged leptons

Two jets with PT>15GeV, with Rapidities of opposite sign, Separated in pseudporapidity ($|\eta_1-\eta_2|$> 5)





Δ^{++}:Physics motivation

G. Azuelos, K. Benslama and J. Ferland ATL-PHYS-2004-025

L-R symmetric model would be a natural extension of the SM

- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- predicts new fermions and new gauge bosons:
  heavy Majorana neutrinos, W_R
- predicts new Higgs sector

$$\Delta_R = (\Delta_R^0, \quad \Delta_R^+, \quad \Delta_R^{++})$$

$$\Delta_L = (\Delta_L^0, \quad \Delta_L^+, \quad \Delta_L^{++})$$ (if Lagrangian is invariant under $L \leftrightarrow R$ symmetry)

$$\phi_{1,2}^0, \quad \phi_{1,2}^{\pm}$$

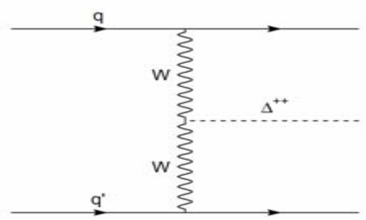
Parameters: $k_1 \quad k_2 \quad v_L \quad v_R$ $\qquad k=\sqrt{k_1^2+k_2^2} \sim 250 GeV$

$$\rho = \frac{M_{W_L}^2}{\cos^2\theta_W M_{z1}^2} \sim \frac{1+2v_L^2/k^2}{1+4v_L^2/k^2} \Rightarrow v_L \leq 9\ GeV$$

In this analysis: $m_{W_R}^2 = g_R^2 v_R^2 / 2, \qquad g_R = g_L \approx 0.64$

Δ^{++}:Production at LHC and decay

Production:



$$\frac{1}{\sqrt{2}} g_R^2 v_R W_R^- W_R^- \Delta_R^{++}$$

β's are small in realistic models and Yukawa couplings (to quarks) is << gauge coupling

$$v_L << v_R \qquad g_R \sim g_L$$

$$v_L \leq 9 GeV \qquad M_{W_R}^2 \sim g_R^2 (2v_R^2 + k_1^2)$$

Decay:

$$\Delta_{R,L}^{++} \rightarrow l^+ l'^+$$

$$\Delta_{R,L}^{++} \rightarrow W_{R,L}^+ W_{R,L}^+$$

$$\Delta_{R,L}^{++} \rightarrow W_{R,L}^+ h^+$$

$W_{R,L}^+ W_{R,L}^+ \delta^0$, $h^+ h^+ h^0$, $h^+ h^+ \delta^0$ } Kinematically Suppressed or disallowed

Left Δ^{++}: cross sections

Signals: $\Delta_L^{++} \to \ell^+\ell^+$, $l = e, \mu$

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

$Mass_{\Delta^{++}}$ (GeV)	σ (fb) for ν_L=5GeV	σ (fb) for ν_L=9GeV
300	1.75	5.68
400	1.14	3.69
500	0.77	2.50
600	0.56	1.82
700	0.42	1.33
800	0.32	1.02

Background: $Wt\bar{t}$, $W^+W^+(QCD)$, $W^+W^+(EW)$, $WZqq$, $t\bar{t}$

Background	Number of Events	$\sigma \times BR$ (fb)
$pp \to Wt\bar{t}$	200 000	23
$qq \to W^+W^+ qq$	100 000	37
$qq \to WZqq$	27 000	28.6
$qq \to t\bar{t}$ P_t 10-200 GeV	8 000 000	90 800
$qq \to t\bar{t}$ P_t 200 GeV-∞	2 000 000	14 100

The gauge bosons are
required to decay leptonically

$\Delta_L^{++} \to l^+ l^+$

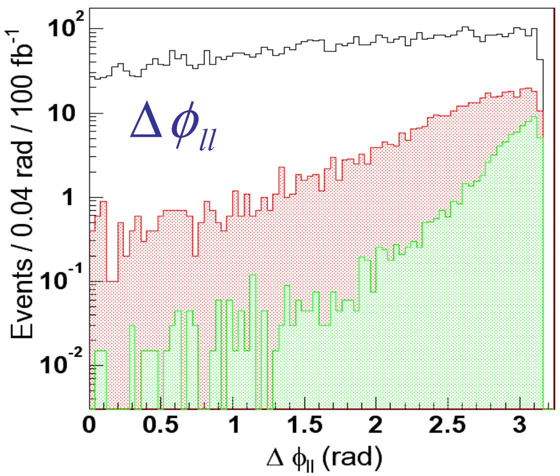
Signal : consider $\Delta_L^{++} \to \ell^+ \ell^+$, only e or μ (no quarks)

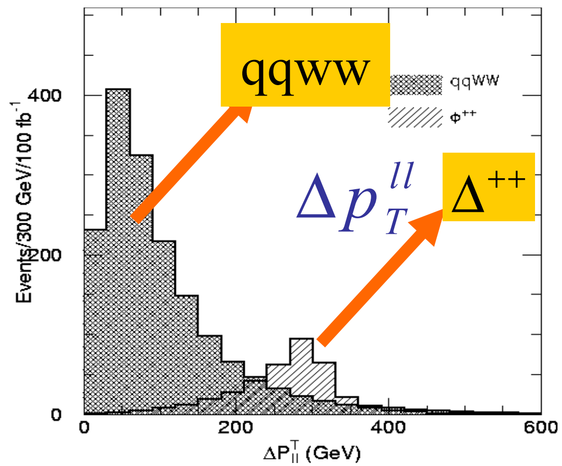
cuts

$$nlep = 2$$

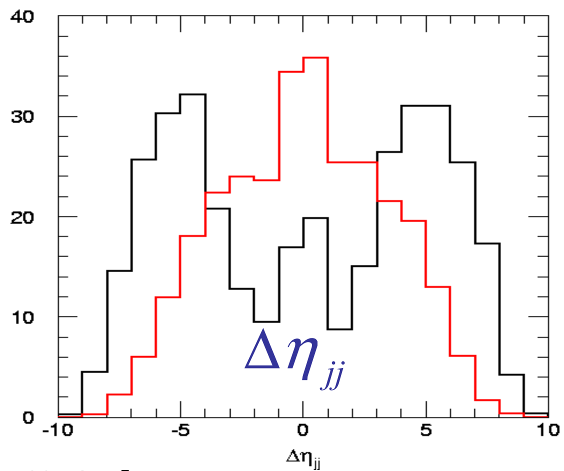
$$\Delta\phi_{ll} > 2.5$$

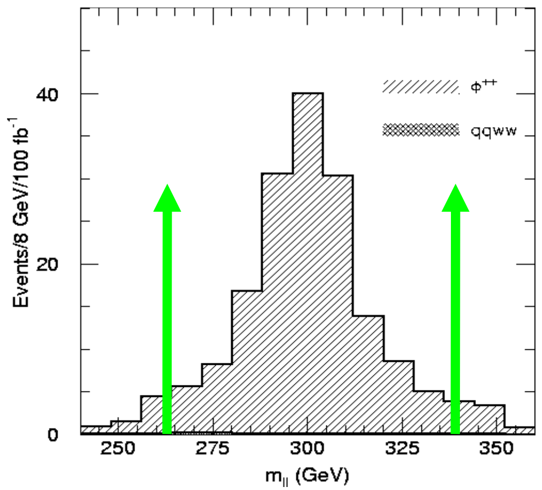
$$\Delta P_T^{ll} = f(M_{ll})$$





Forward jets tagging:
E_j1>200 GeV, E_j1>200 GeV
well separated in eta



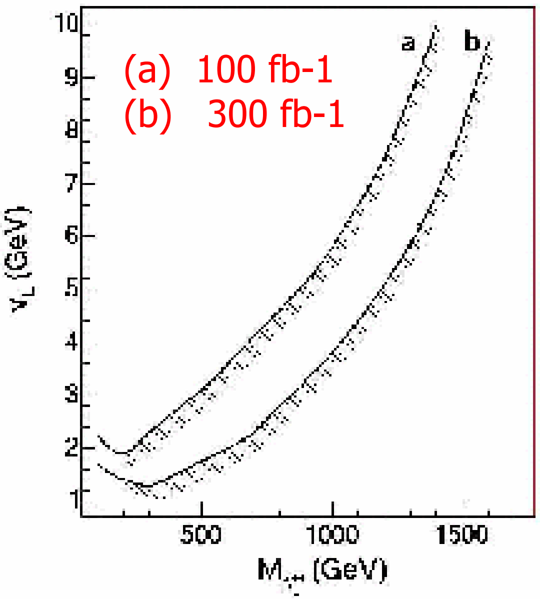


Missing transverse momentum cut

Left Δ⁺⁺: results

$$\Delta_L^{++} \to \ell^+ \ell^+$$

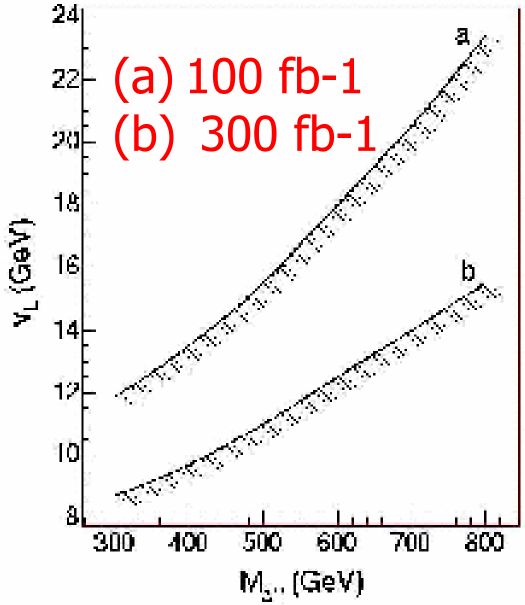
Discovery reach



Also

For: $\Delta_L^{++} \to \tau^+ \tau^+ \to l^+ l^+ P_{miss}^T + X$

with backgrounds: $W t\bar{t}$, W^+W^+qq, $WZqq$, $t\bar{t}$

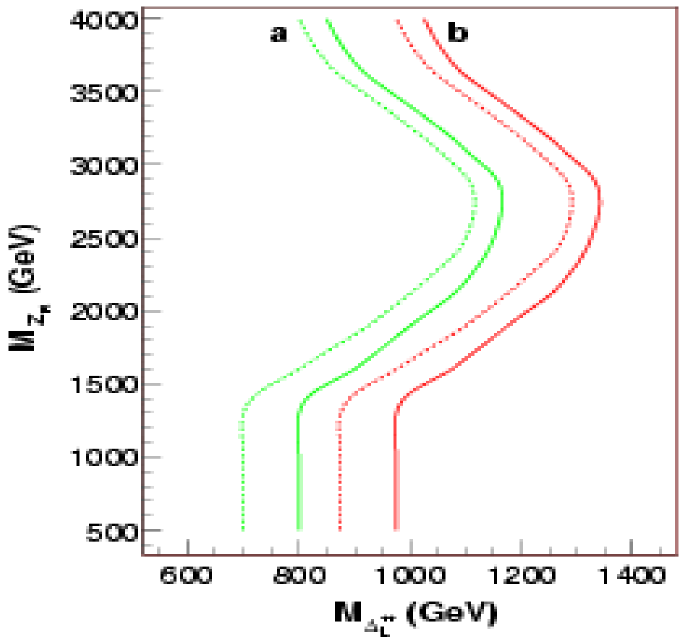


Results are also found for Right Δ++

Pair Production

$$\Delta_L^{++}\Delta_L^{--} \rightarrow l^+l^+l^-l^-$$

(a) 100 fb-1
(b) 300 fb-1



Dashed =4 leptons are observed

Full = 3 leptons are observed

Results are also found for Right Δ++

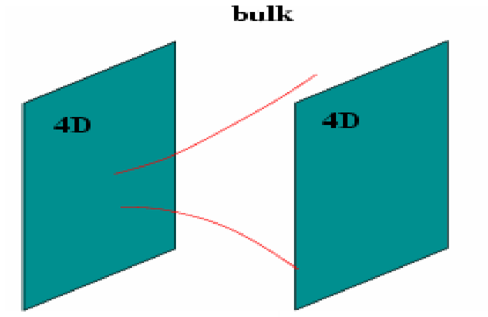
Radion in Randall-Sundrum model

- **1 extra dimension with non factorizable geometry**:

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2, \quad y = r_c\phi$$

$$(k \sim M_{Pl}) \Rightarrow \text{ 3D distances shrink with } y$$

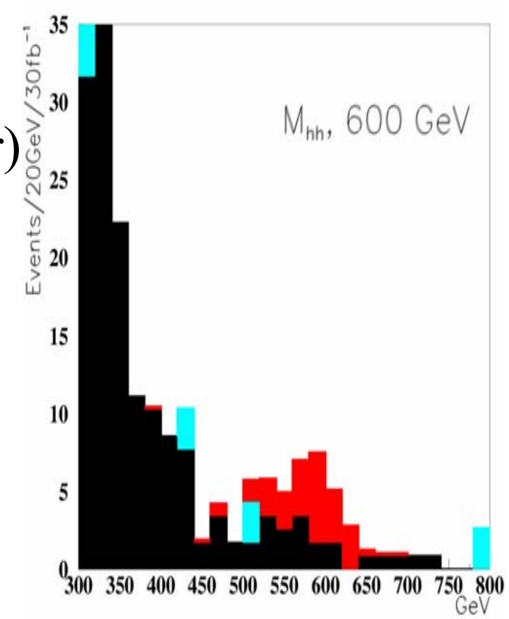
5-D Planck scale $M_{Pl}^2 = \frac{M_5^3}{k}\left(1 - e^{-2kr_c\pi}\right)$



New physics scale in SM brane: $\Lambda_\pi = M_{pl}e^{-kr_c\pi}$, $kr_c\pi$ □ 35 $\Rightarrow \Lambda_\pi$ □ TeV

- **Phenomenology:** ***(Radion)*** G. Giudice, R. Rattazzi, J.D. Wells hep-ph/0002178
  - -scalar field to stabilize the distance between branes
    Goldberger and Wise (PRL 83 (1999) 4922)
  - -coupling similar to Higgs, mixes with Higgs (ξ parameter)
  - -narrow width

- **Analysis in ATLAS:** G.Azuelos et al SN-ATLAS-2002-019
  - -signal $\phi \rightarrow hh \rightarrow b\bar{b}\,\tau^+\tau^-$ and $\phi \rightarrow hh \rightarrow \gamma\gamma\, b\bar{b}$
  - -background: $t\bar{t}, \quad Z + jets, \quad W + jets$



- **Sensitivity: (30 fb^{-1})**
  - -1st channel: ***1.0* TeV** for m_ϕ = 600 GeV
  - -2nd channel: ***2.2* TeV** (0.6 TeV) for m_ϕ = 300 (600 GeV)

Invisibly decaying Higgs

Motivation:

- Usual decay modes could be suppressed when the Higgs decay is open to new invisible particles
- Estimate the sensitivity to H→ invisible mode:

$$\xi^2 = Br(H \to inv)\frac{\sigma_{pp\to H+X}}{\sigma^{SM}_{pp\to H+X}}$$

With X=$t\bar{t}$, W or Z, qq

P. Gagnon ATL-PHYS-2003-011
B.P. Kersevan et al ATL-PHYS-2003-028
L. Neukermans et al ATL-PHYS-2003-006

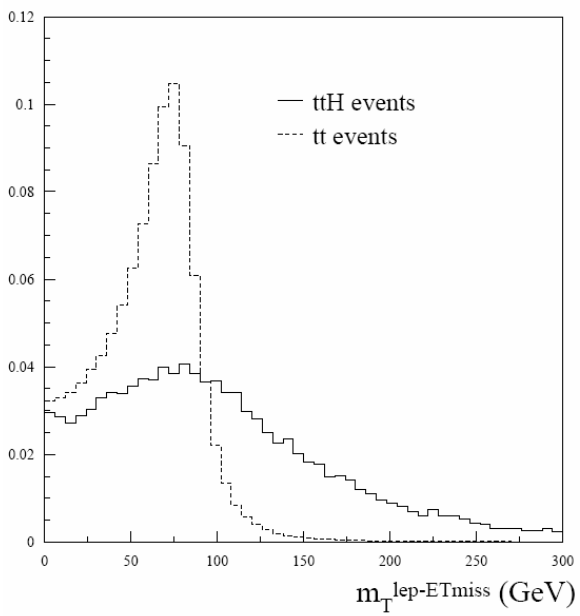
Signals:	Backgrounds:
$pp \to VH, V = Z, W$	$ZZ(\ell\ell\nu\nu), Zincl., Z \to \nu\nu, WZ(\ell\nu\nu\nu), Wincl, t\bar{t} \to b\bar{b}, W \to \ell\nu$
$pp \to t\bar{t}H$	$t\bar{t}Z(Z \to \nu\nu), t\bar{t}, t\bar{t}W(W \to \ell\nu), b\bar{b}W(W \to l\nu), b\bar{b}Z, (Z/\gamma^* \to \ell\ell)$
$pp \to qqH$	$Zjj, Wjj, QCDjj$

Excellent understanding of the kinematics in both signal and backgrounds

Invisibly decaying Higgs:ttH

Cross sections:

Process	Generator	σ $(\sigma \times BR)$
$t\bar{t}H$	PYTHIA	
$m_H = 100$ GeV		910 fb
$m_H = 120$ GeV		520 fb
$m_H = 140$ GeV		320 fb
$m_H = 160$ GeV		210 fb
$m_H = 200$ GeV		100 fb
$t\bar{t}Z,\ Z \to \nu\nu$	AcerMC	190 fb
$t\bar{t}$	PYTHIA, HERWIG	490 000 fb
$t\bar{t}W,\ W \to \ell\nu$	AcerMC	140 fb
$b\bar{b}W,\ W \to \ell\nu$	AcerMC	73 000 fb
$b\bar{b}Z,\ Z/\gamma^* \to \ell\ell$	AcerMC	61 400 fb



Cuts:

Process	$t\bar{t}H$ PYTHIA	$t\bar{t}Z$ AcerMC	$t\bar{t}$ PYTHIA	$t\bar{t}$ HERWIG
Trigger lepton	22%	22%	22%	22%
2 b-jets + 2 jets	5.0%	4.8%	4.9%	5.2%
rec. t-quark (jjb)	2.6%	2.4%	2.4%	2.6%
$m_T^{\ell,\not{E}_T} > 120$ GeV	0.87%	0.93%	$4.1 \cdot 10^{-4}$	$5.2 \cdot 10^{-4}$
$\not{E}_T > 150$ GeV	0.41%	0.53%	$2.3 \cdot 10^{-5}$	$3.7 \cdot 10^{-5}$
$\sum p_T^{rec} > 250$ GeV	0.40%	0.51%	$2.0 \cdot 10^{-5}$	$3.2 \cdot 10^{-5}$
$\sum R_{jj} < 2.2$	0.28%	0.35%	$7.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$

Sensitivity:

Higgs mass	$\xi^2[\%](t\bar{t}H)$ all $t\bar{t}$	$\xi^2[\%](t\bar{t}H)$ (lep-had) $t\bar{t}$	$\xi^2[\%](VBF)$
$m_H = 100$ GeV	42.2	26.5	12.1
$m_H = 120$ GeV	55.7	27.4	10.3
$m_H = 140$ GeV	75.4	47.4	9.8
$m_H = 160$ GeV	95.6	60.2	9.9
$m_H = 200$ GeV	154.3	97.1	10.7

Heavy or no Higgs boson

- There exist models where the Higgs boson can be heavy, in spite of EW precision measurements
  - example:
    - mH can be as large as ~ 500 GeV, in presence of anomalous gauge boson couplings

      (O. Nachtmann, hep-ph/0404006)

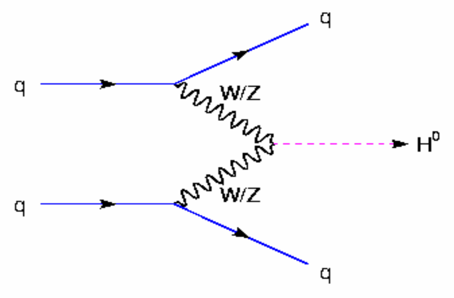
- Dynamical theories
    - little higgs model: pseudo-Goldstone particle and Higgs triplet
    - top-quark condensation see-saw:

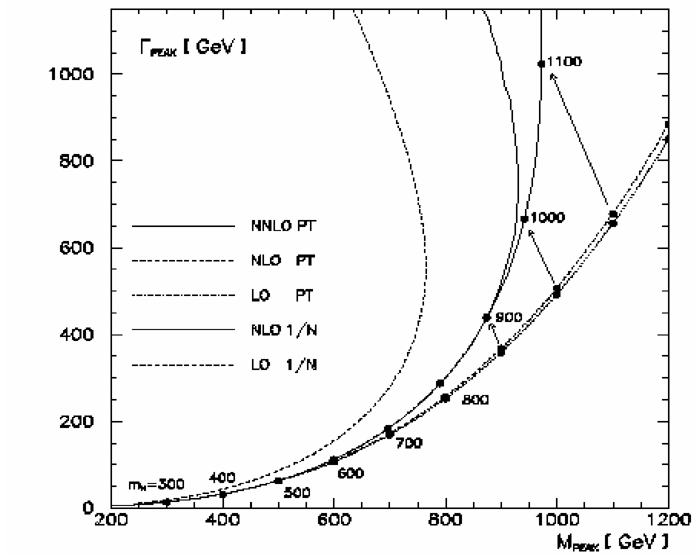
      (B.A. Dobrescu and C. Hill, Phys. Rev. Lett. 81 (1998) 2634)

      - new vector-like (i.e. SU(2)W-singlet) quarks $\bar{\chi}_{L,R}$ which mixes with the top quark
        - » similar to heavy T quark in little higgs model
      - Higgs is the condensate $\langle \bar{\chi}_R t_L \rangle$, with mass ~ 500-600 GeV
    - extended technicolor models
    - Chiral Lagrangian model

Vector boson scattering at high mass

- experimentally, gauge boson scattering:
  - competes with gluon fusion mechanism
  - signature of forward jet tagging
  - measure of HVV coupling
    - width saturates for high masses in SM

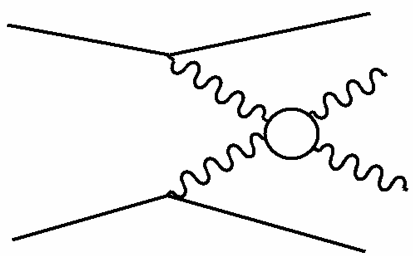




Perturbative and nonperturbative Higgs signals

Adrian Ghinculov and Thomas Binoth

hep-ph/9807227



- golden mode: $H \to ZZ \to 4\ell$
- at high masses, WZ, WW scattering

Strong Symmetry Breaking

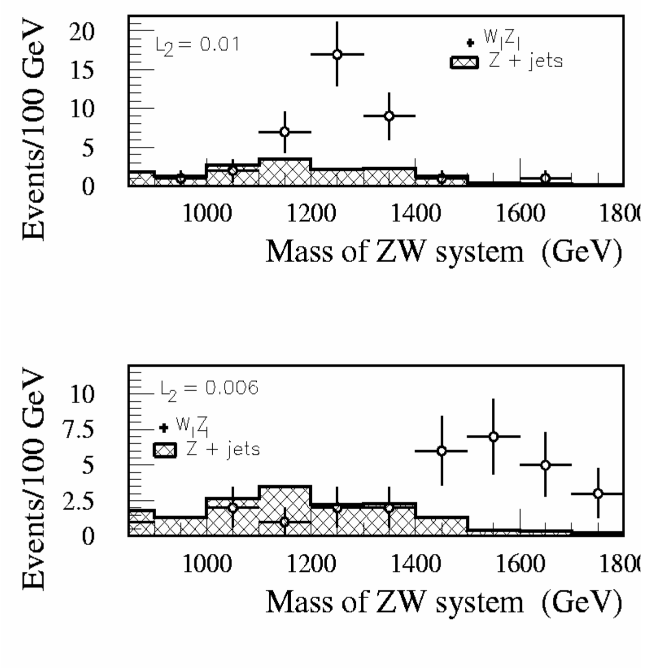
- *WZ (I,J = 1,1)* scattering in ChL Model, with IAM, with parameters for resonance at 1.2 and 1.5 TeV:

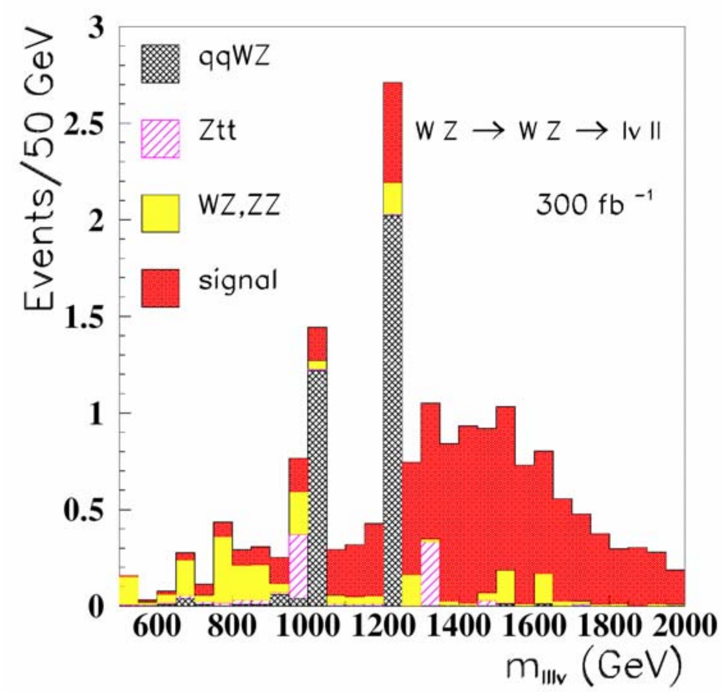
$$qq \to qq\,WZ \to qq\ j\,j\,\ell\ell$$

with forward jet tagging, 300 fb^{-1}

A. Miagkov, ATL-PHYS-99-06

GA, superLHC: hep-ph/0204087





Worst case scenario: non-resonant excess
→ W^+W^+ scattering, … need good understanding of backgds.

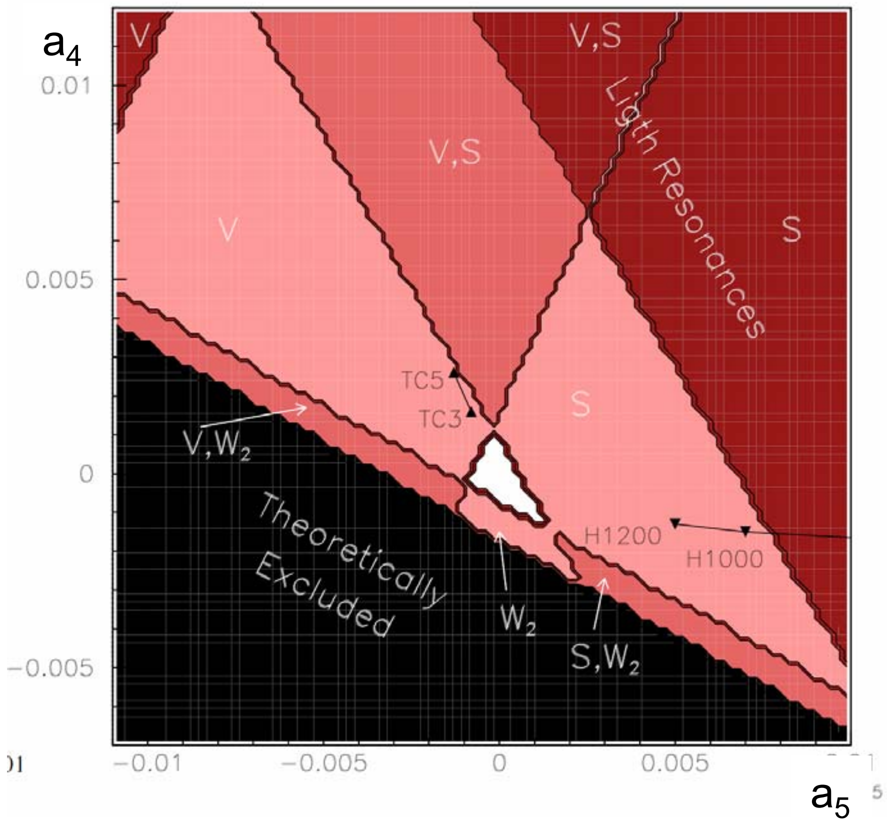
Chiral Lagrangian Model

$$\boldsymbol{L}\ (\text{VB scattering}) = a_4\left[Tr\left(V_\mu V_\nu\right)\right]^2 + a_5\left[Tr\left(V_\mu V^\mu\right)\right]^2$$

- Expansion in derivatives:
  - with 2 parameters a_4 and a_5, and appropriate unitarization procedure, any scenario described, with of without resonance

CERN 2000-004
Pelaez, hep-ph/9912224
Pelaez, hep-ph/9609427

after unitarization



Lepton-Flavor Violation in 2HDM-III

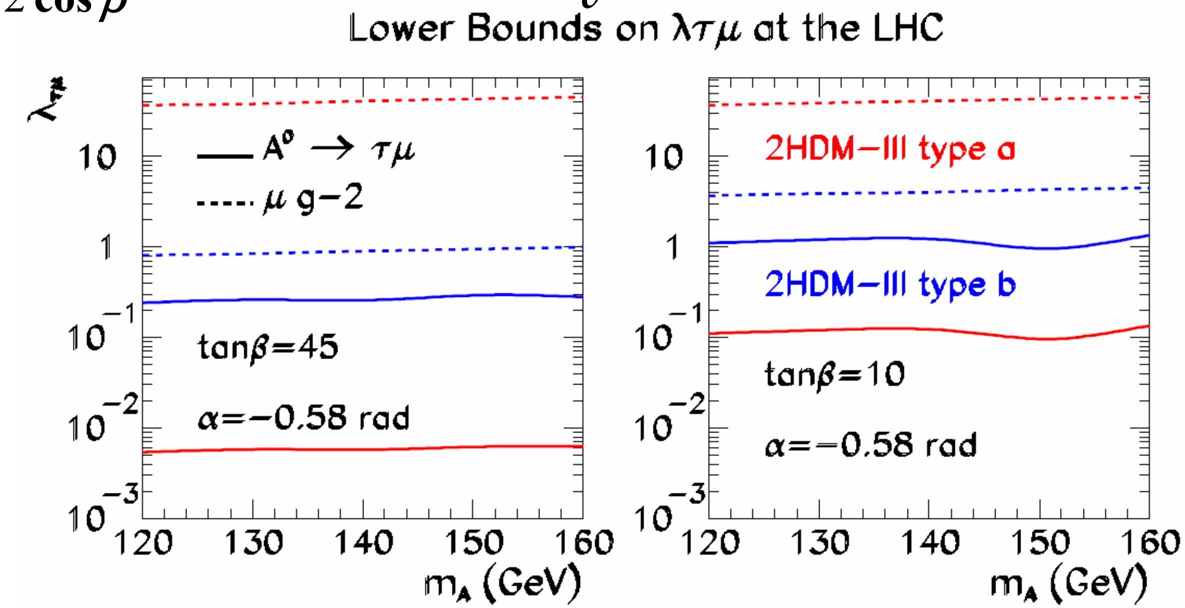
2-Higgs Doublet Model, type III:

- 2 neutral scalars ⇒ 2 Yukawa couplings to fermions

$$L_Y = -f_{ij}\bar{\Psi}_i\Psi_j\varphi_1 - g_{ij}\bar{\Psi}_i\Psi_j\varphi_2$$

- after diagonalisation of mass matrix $M_{ij} = f_{ij}\langle\varphi_1\rangle + g_{ij}\langle\varphi_2\rangle$
  f_{ij} and g_j are not diagonalised ⇒ LFV
- Type III: no discrete symmetry (such as requiring up and down quarks to each couple to only one Higgs field) to protect from LFV

$$L_{LFV} = \xi_{ij}\frac{\cos(\alpha-\beta)}{\sqrt{2}\cos\beta}\bar{l}_i l_j h + h.c., \quad \xi_{ij} = \lambda_{ij}\frac{m_i m_j}{v}$$



Bounds from A → τμ better than from (g-2) of muon

K. Assamaga, Deandrea, PA Delsart, ATL-PHYS-2002-017, or Phys.Rev. D67 (2003) 035001

Conclusion

Lot of possible SM extension higgses are studied in ATLAS

Little Higgs Model should be tested at the LHC: either we find it or it disappears

Δ^{++} predicted in the LR Symmetric Model should yield a striking signature at LHC.

Invisible Higgs study is open tool to test non standard higgs

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