

Little Higgs Searches in ATLAS



Higgs

Little
Higgs

The Little Higgs group of ATLAS

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Little Higgs searches in ATLAS

Non-Standard Higgs Physics

Little Higgs and Phenomenology

Little Higgs model

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• Motivation :
electroweak
hierarchy and fine-tuning problems
Planck

• Quadratic divergences :

SUSY : bosons
Little Higgs : gauge bosons
quarks

cancellations

fermions

new gauge bosons
new quarks

• Higgs fields :

electroweak

pseudo-Goldstone bosons
"light" mass

symmetry breaking

Goldstone bosons
massless

Planck



New particles

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$\phi^0, \phi^+, \phi^{++}$: triplet of heavy Higgses

$$M < 10 \text{ TeV}$$

note: the Standard Model **h** is still there !

T : heavy top

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

$$\begin{aligned} M_h &= 120 \text{ GeV} & M < 0.2 \text{ TeV} \\ M_h &= 200 \text{ GeV} & M < 2 \text{ TeV} \end{aligned}$$

Z_H, W_H^\pm, A_H : heavy Z, W^\pm, γ

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

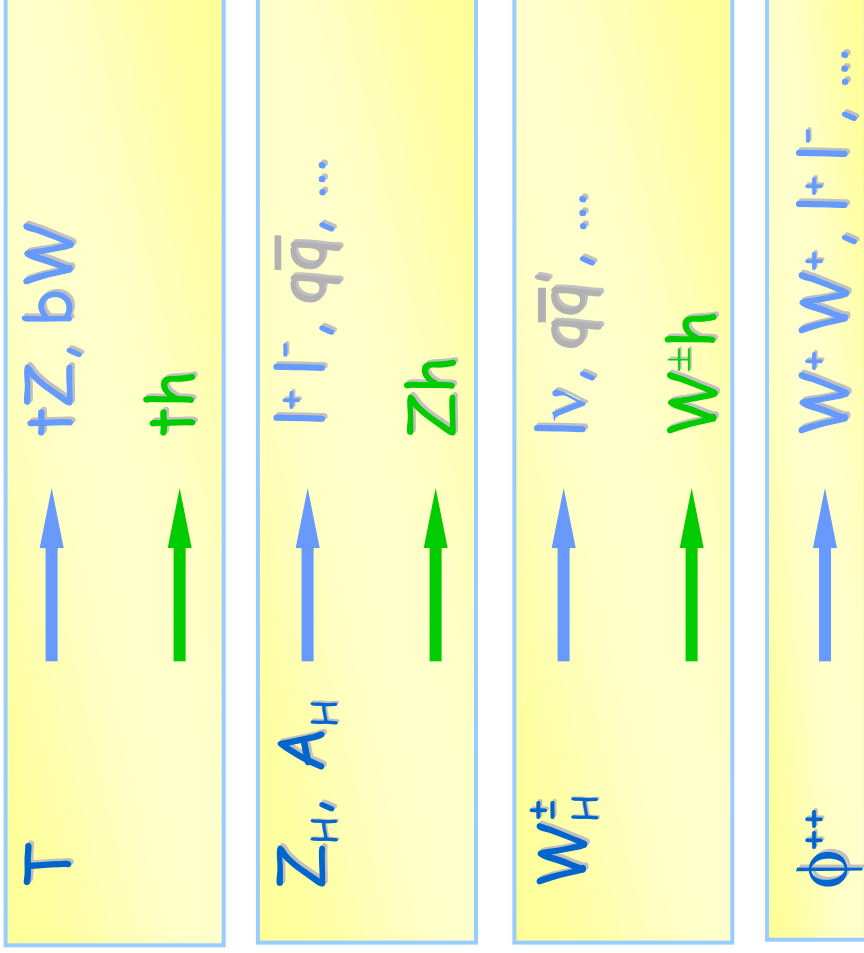
$$M(Z_H) \approx M(W_H^\pm) > M(A_H)$$

$$\begin{aligned} M_h &= 120 \text{ GeV} & M < 2.2 \text{ TeV} \\ M_h &= 200 \text{ GeV} & M < 6 \text{ TeV} \end{aligned}$$



Decays

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discovery
channel —

test of the
model —

very heavy particles
↓
very high p_T final state

The modes $th, Zh, W^\pm h, \dots$ may be difficult to see but are necessary to test the model



We have used the following software for the analysis:

- **Generation: Pythia 6.2**
 - new top: 4th generation quarks (T = t') MSUB(83)
 - new heavy bosons: generated via MSUB(141), MSUB(142)
 - new Higgs sector: generated via MSUB(351)
- **Decays:** modify Pythia decay tables to match Little Higgs model
- **Analysis:** fast simulation of ATLAS

Luminosity: $\int \mathcal{L} dt = 300 \text{ fb}^{-1} = 3 \text{ years of LHC at high-luminosity}$

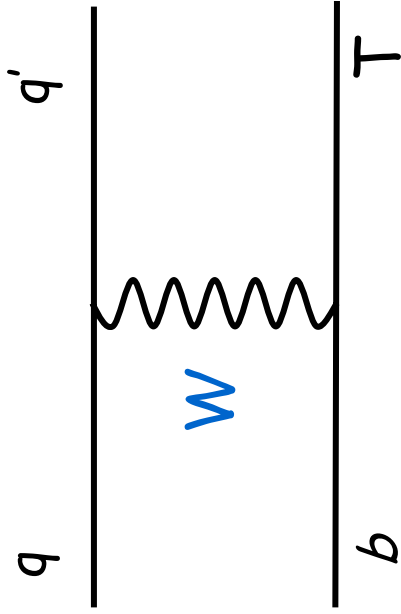


I T studies

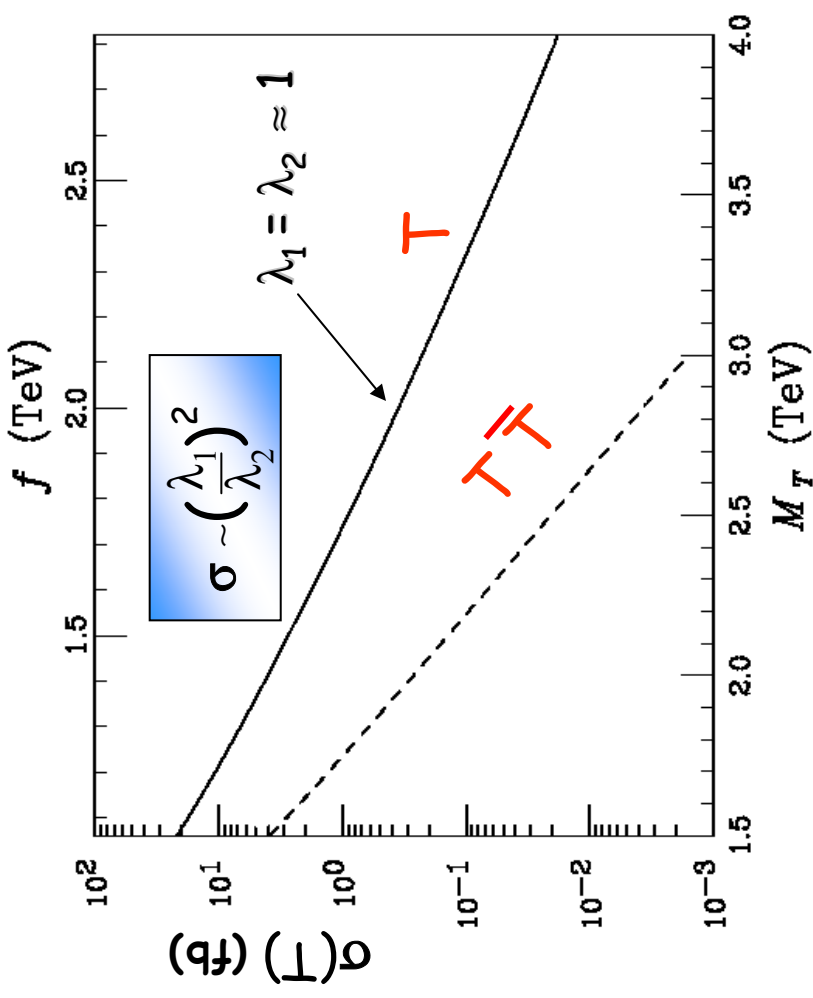
1 T

Heavy top T

- Production mechanism = Wb fusion



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



λ_1, λ_2 : Yukawa couplings

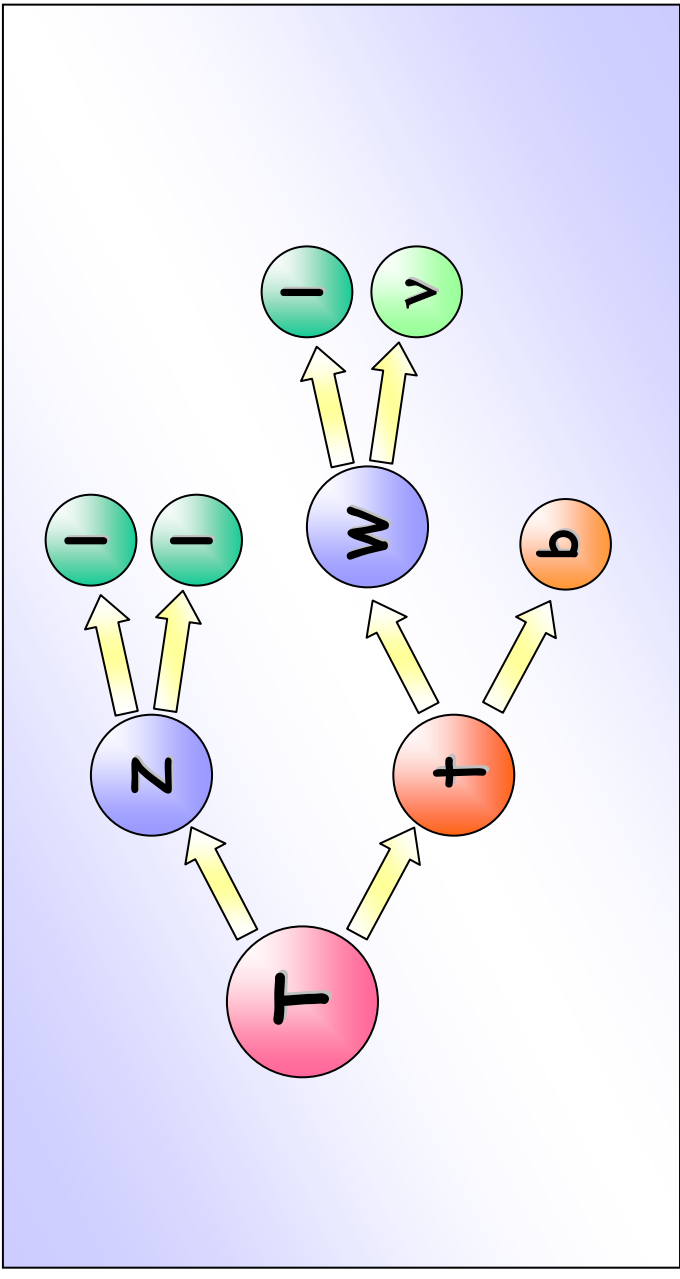


1 T

$T \rightarrow Zt$ (1/2)

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Signal :



$T \rightarrow tZ \rightarrow 3 \text{ leptons} + b\text{-jet} + \cancel{E}_T$

Background :

- $pp \rightarrow TZ$
- $pp \rightarrow WZ$

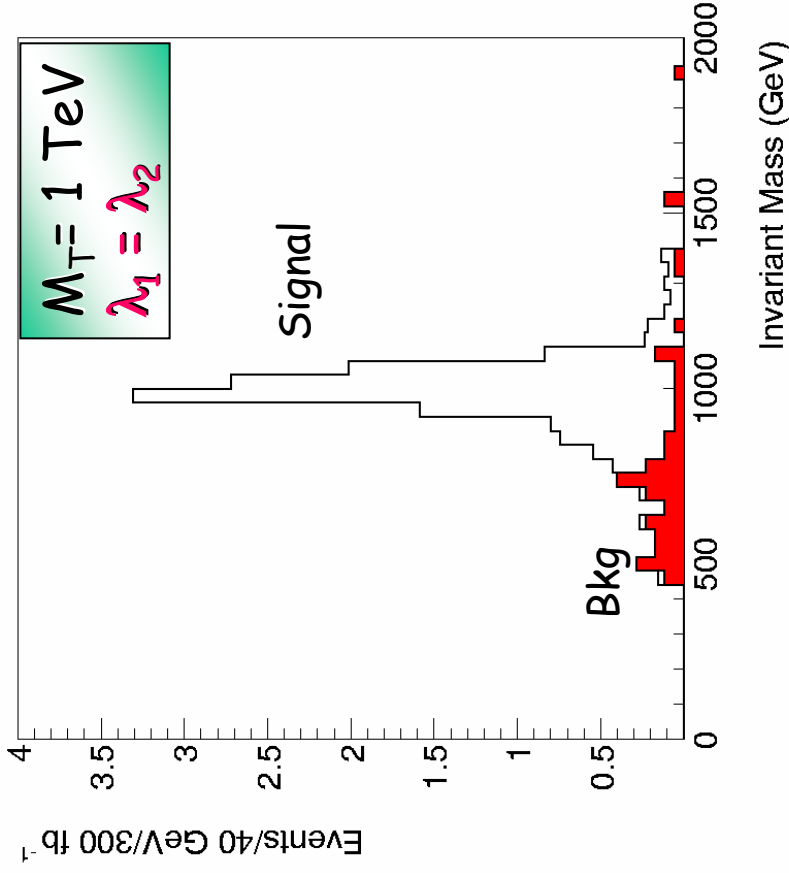


1 T

$T \rightarrow Z\tau$ (2/2)

10

$T \rightarrow tZ \rightarrow 3 \text{ leptons} + b\text{-jet} + \cancel{E}_T$



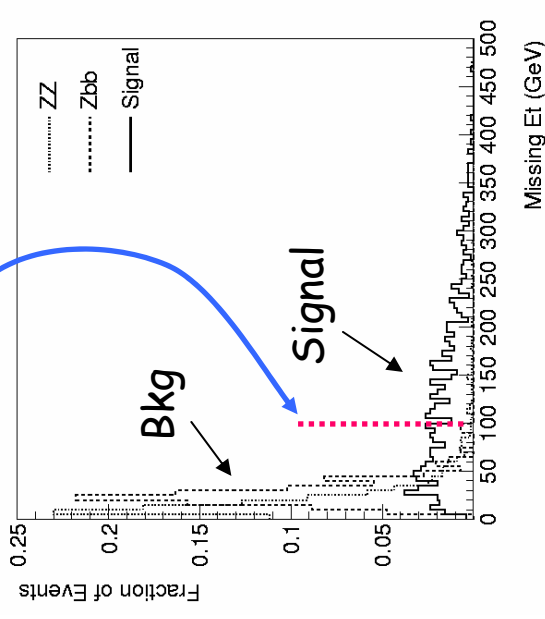
$\int L dt = 300 \text{ fb}^{-1}$

discovery at 5σ if:

- $M_T < 1050 \text{ GeV}$ with $\lambda_1/\lambda_2 = 1$
- $M_T < 1400 \text{ GeV}$ with $\lambda_1/\lambda_2 = 2$

Cuts:

- 3 isolated leptons, $p_T > 40 \text{ GeV}$
 - 2 of them with $M_{ll} = M_Z$
 - 1 of them with $p_T > 100 \text{ GeV}$
- 1 b-jet, $p_T > 30 \text{ GeV}$
- $\cancel{E}_T > 100 \text{ GeV}$

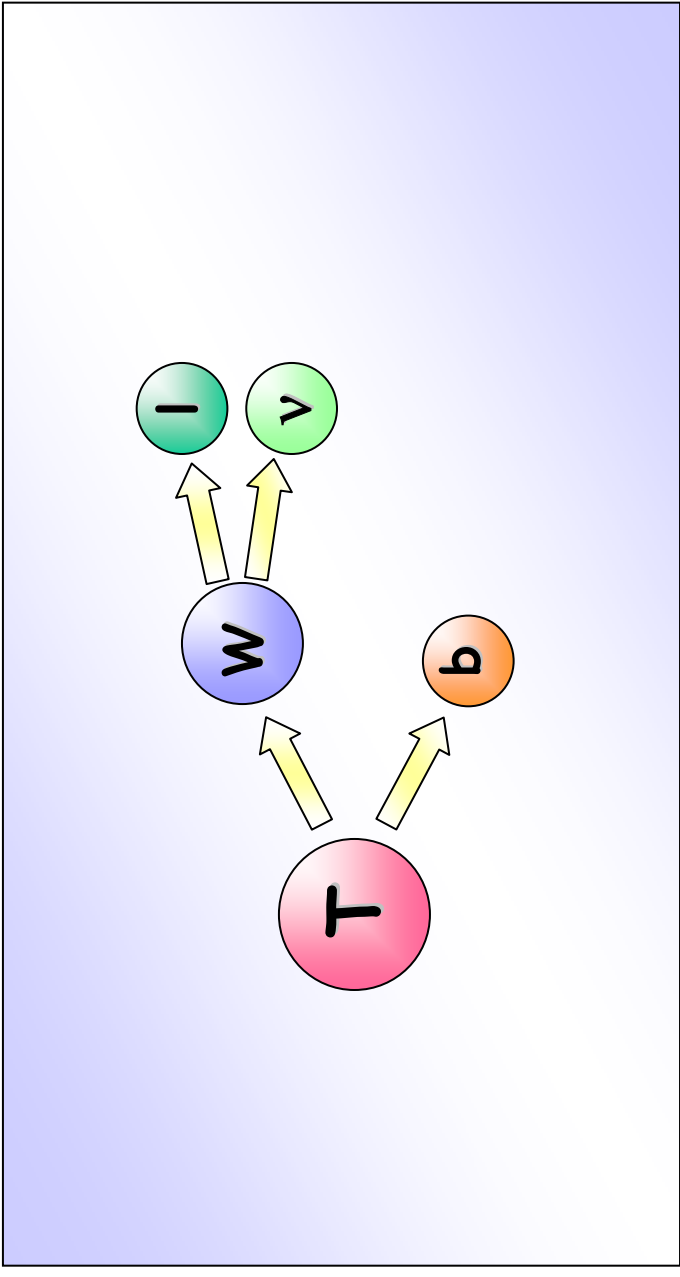


1 T

$T \rightarrow Wb$ (1/2)

11

Signal :



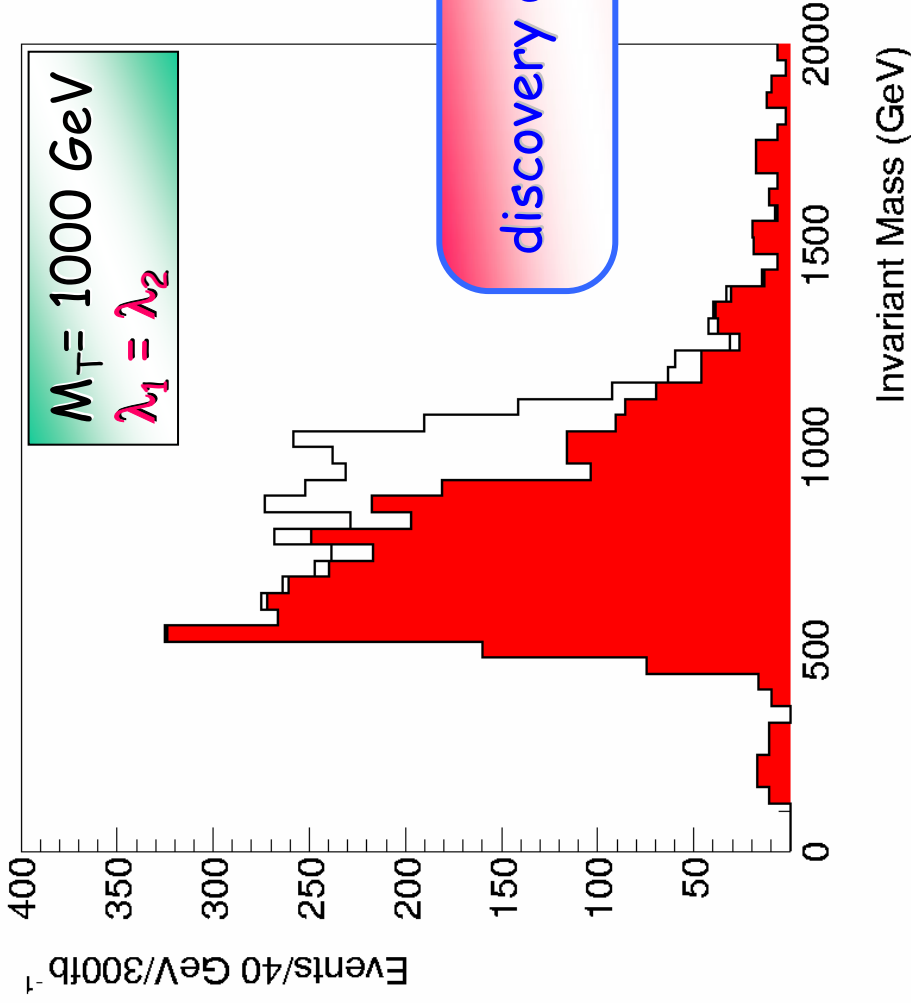
$T \rightarrow Wb \rightarrow 1 \text{ lepton} + b\text{-jet} + \cancel{E}_T$

Background :

- $pp \rightarrow t\bar{t}$
- $pp \rightarrow t$



$T \rightarrow Wb \rightarrow 1 \text{ lepton} + \text{b-jet} + \cancel{E}_T$



Cuts:

- 1 b-jet with $p_T > 200 \text{ GeV}$
- 1 lepton with $p_T > 100 \text{ GeV}$
- $\cancel{E}_T > 100 \text{ GeV}$

$\int L dt = 300 \text{ fb}^{-1}$

discovery at 5σ if : $M_T < 2000 \text{ GeV}$ with $\lambda_1/\lambda_2 = 1$
 $M_T < 2500 \text{ GeV}$ with $\lambda_1/\lambda_2 = 2$

...the most promising channel for T

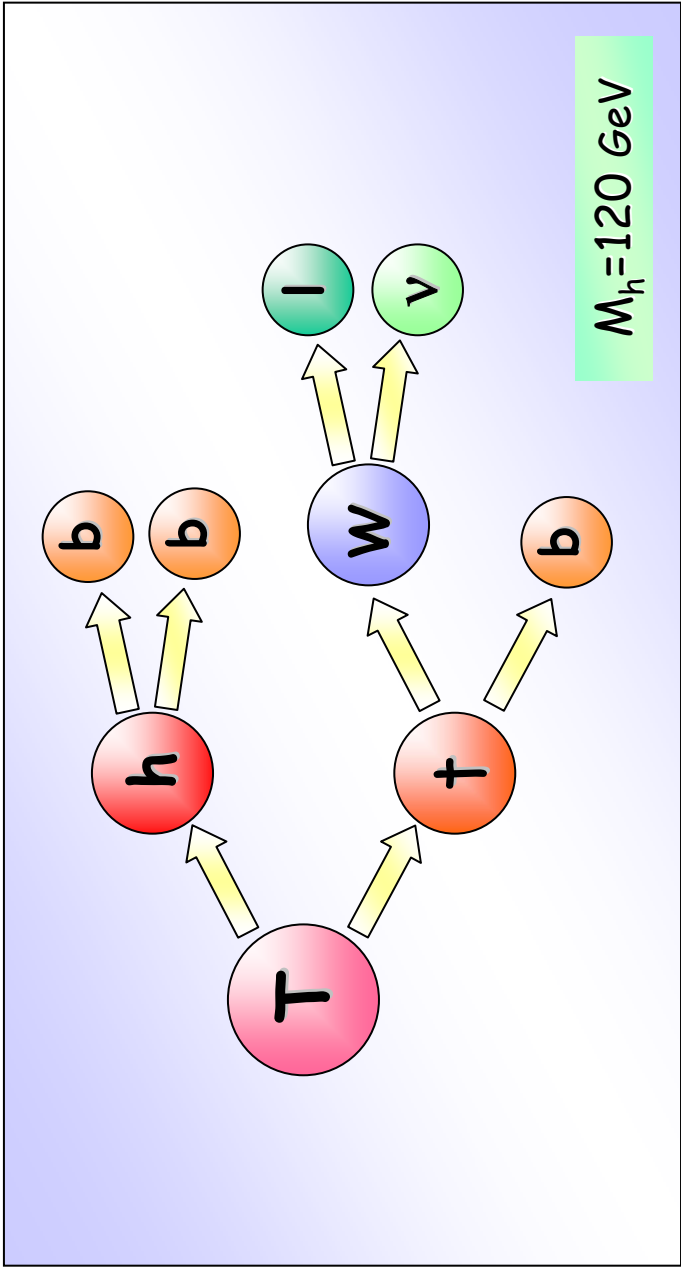


1 T

$T \rightarrow ht$ (1/2)

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Signal :



$T \rightarrow ht \rightarrow 3 \text{ b-jets} + 1 \text{ lepton} + \cancel{E_T}$

Background :

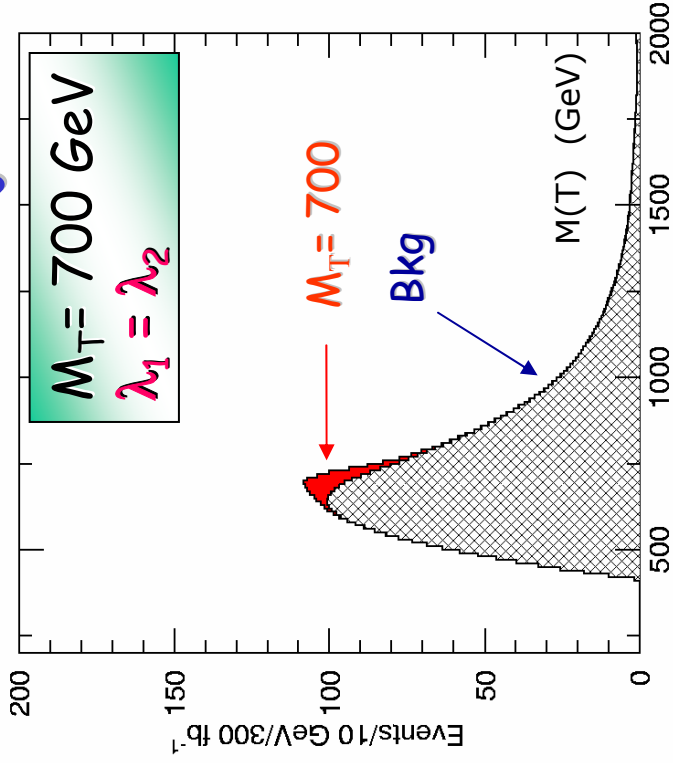
- $pp \rightarrow tt$
- $pp \rightarrow Wbb$



1 T

$T \rightarrow ht$ (2/2)

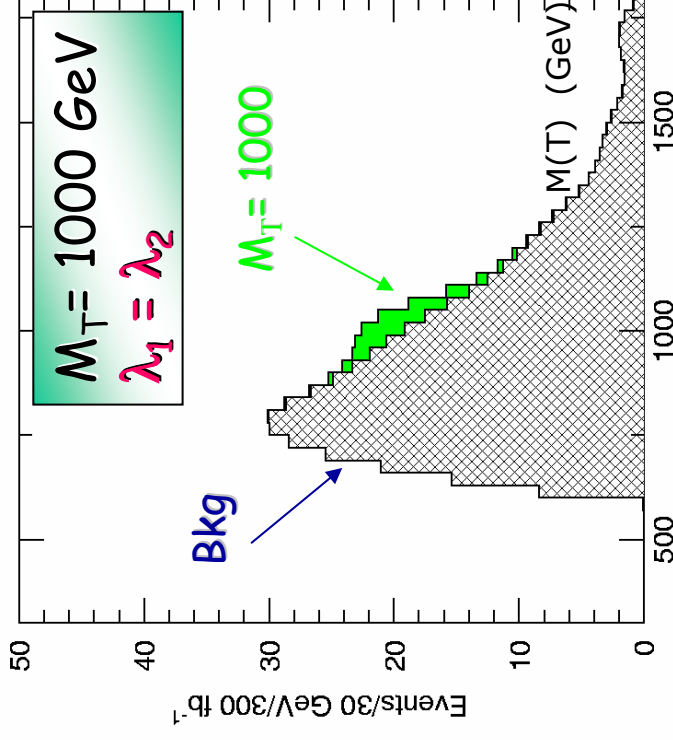
$T \rightarrow ht \rightarrow 3 \text{ b-jets} + 1 \text{ lepton} + \cancel{E}_T$



Cuts:

- $p_T(3\text{-jets}) > 90$ GeV
- $p_T(\text{lepton}) > 70$ GeV

$M_T = 700$: observation at 3σ



Cuts:

- $p_T(3\text{-jets}) > 130$ GeV
- $p_T(\text{lepton}) > 100$ GeV

$M_T = 1000$: observation at 4σ

$\int L dt = 300 \text{ fb}^{-1}$

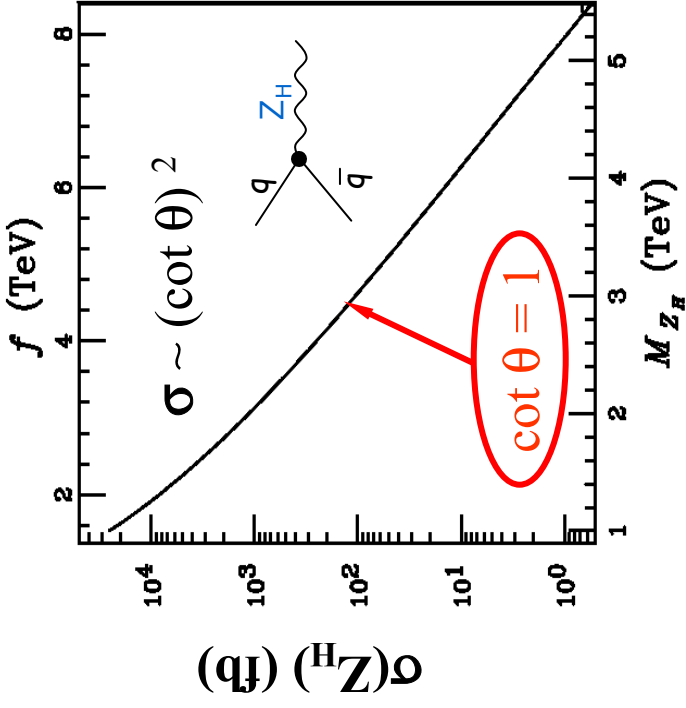


② Z_H, W_H, A_H studies

② Z_H, W_H, A_H

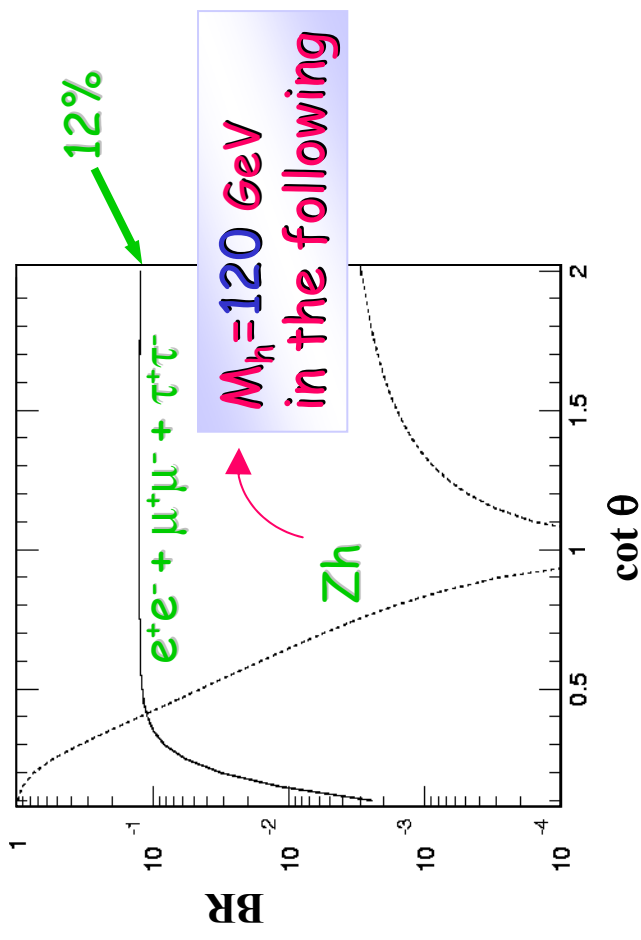
Gauge Boson Z_H

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

NB: $\sigma(W_H) = 2 \sigma(Z_H)$



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

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

NB: $\Gamma(W_H \rightarrow Wh) = \Gamma(W_H \rightarrow Zh)$



Little Higgs searches in ATLAS

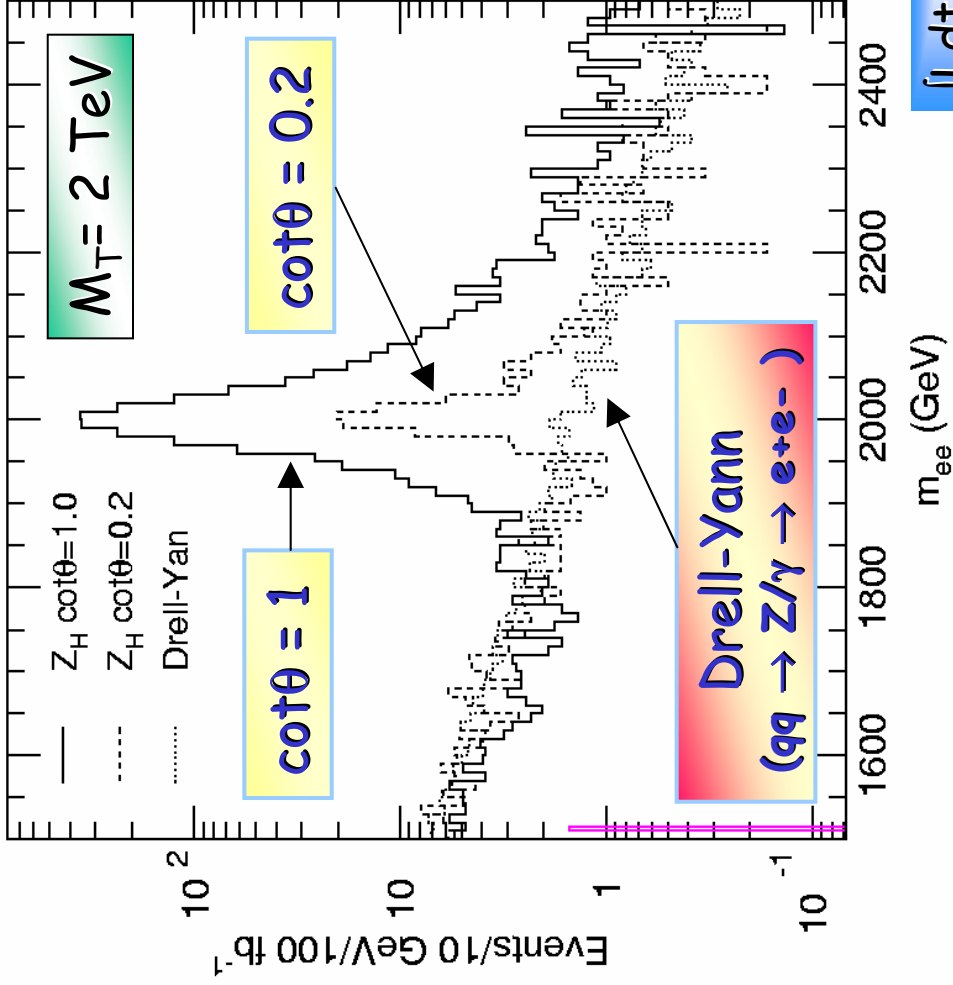
Non-Standard Higgs Physics

CERN - May 15th 2004

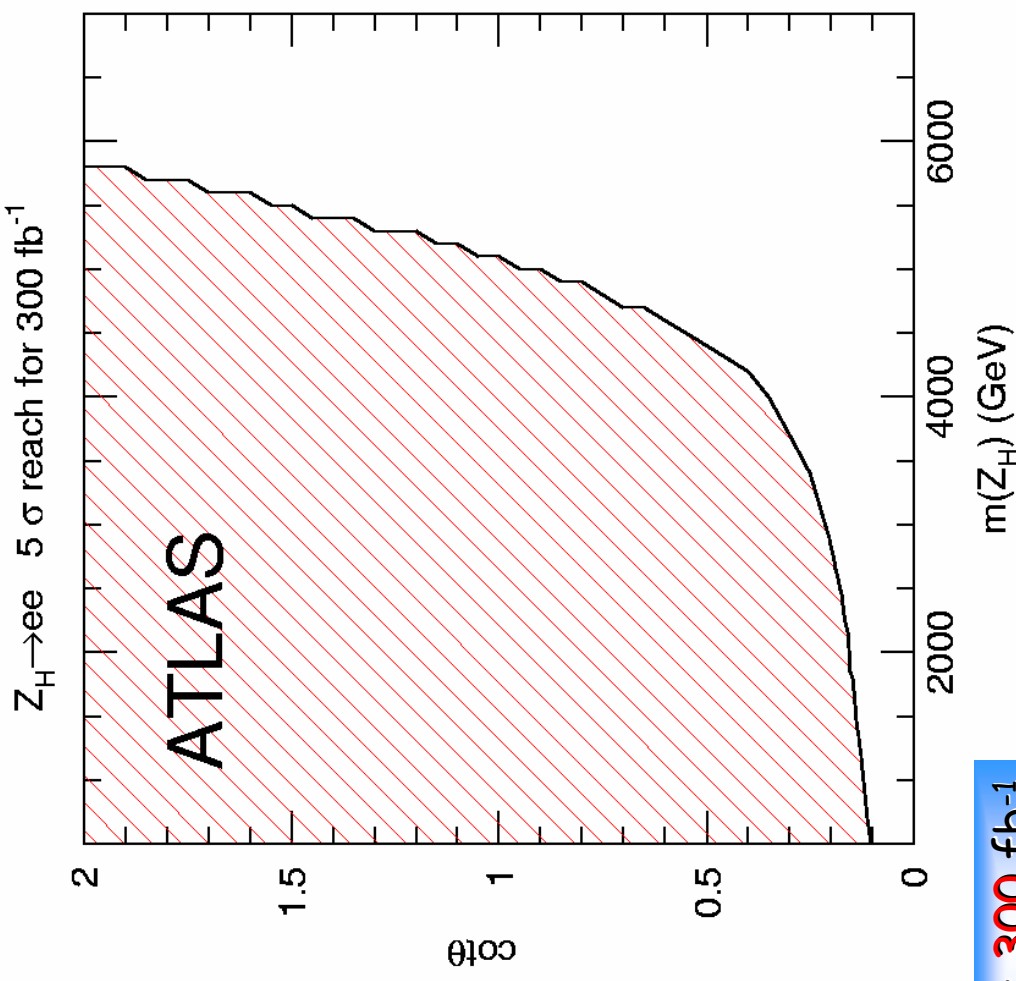
Search for Z_H

② Z_H, W_H, A_H

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



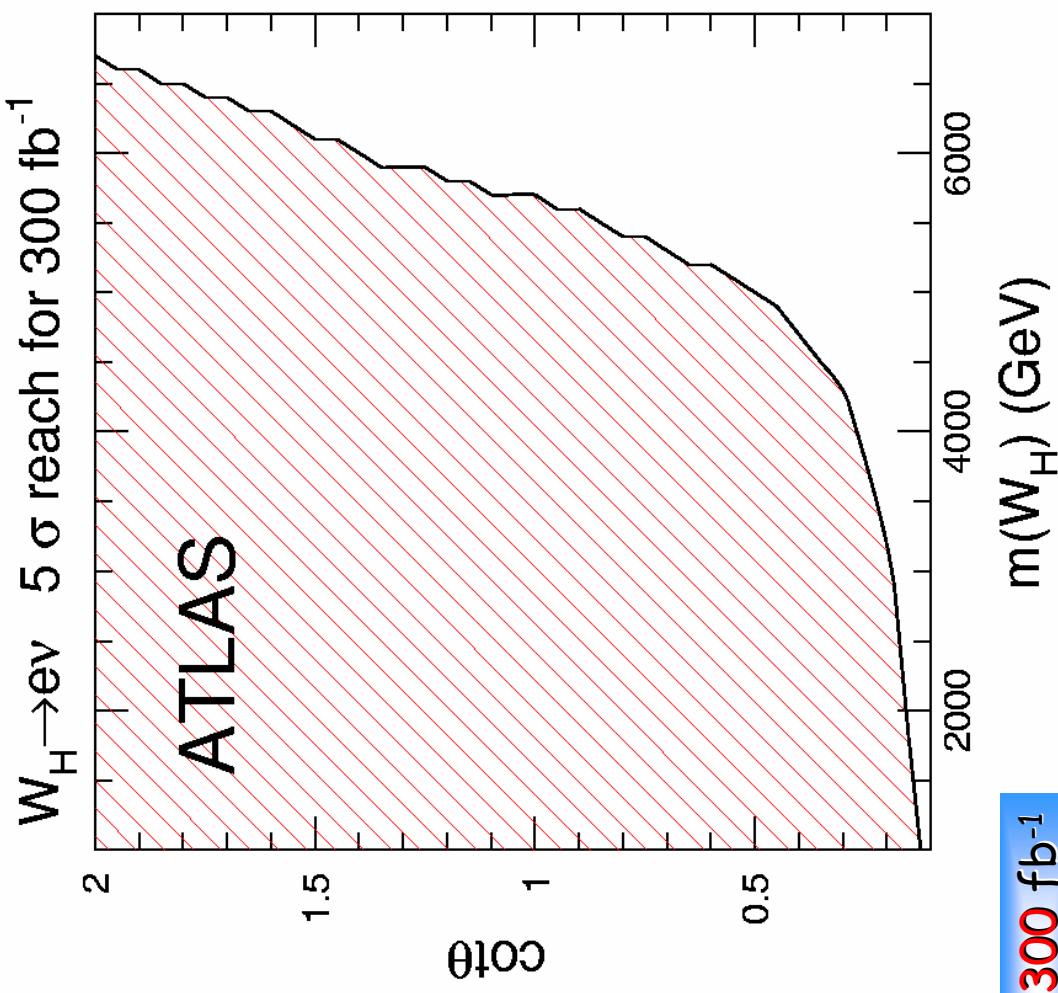
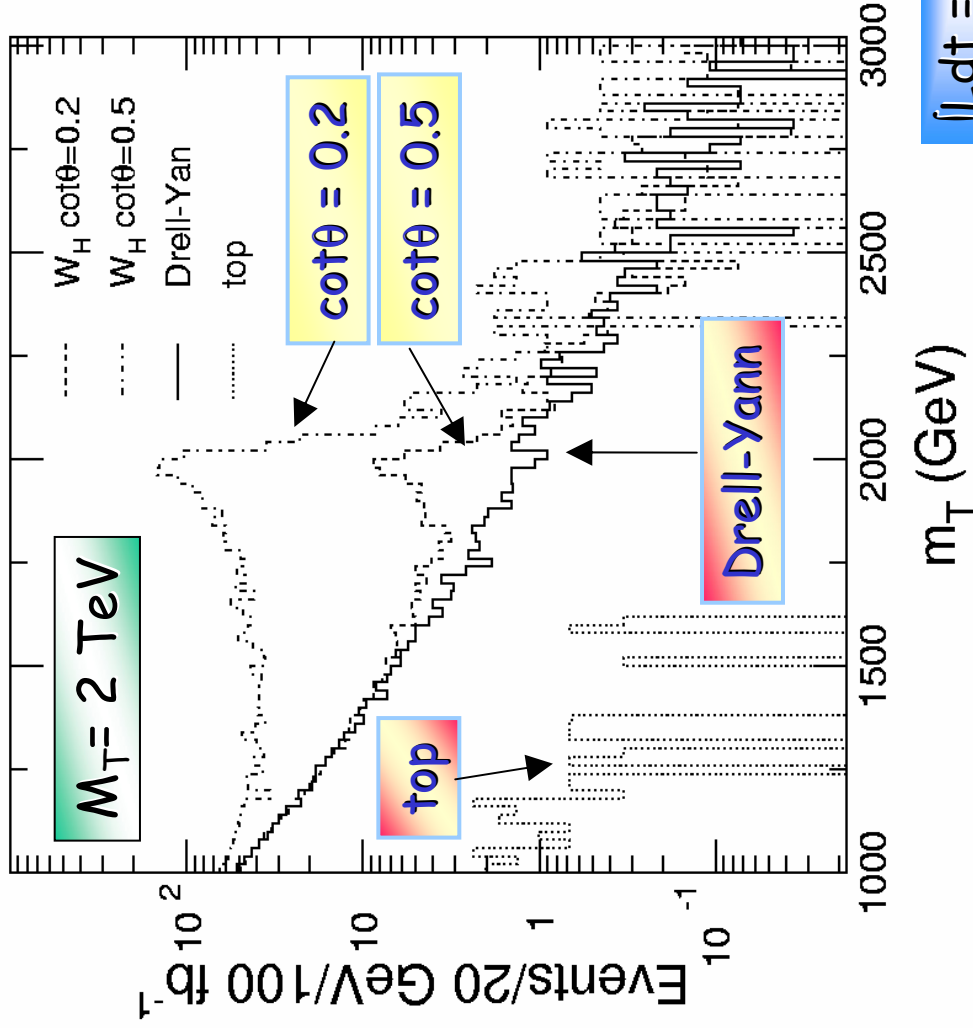
$\int L dt = 300 \text{ fb}^{-1}$



Search for W_H

② Z_H, W_H, A_H

$$q\bar{q} \rightarrow W_H \rightarrow l\nu$$



$$\int L dt = 300 \text{ fb}^{-1}$$

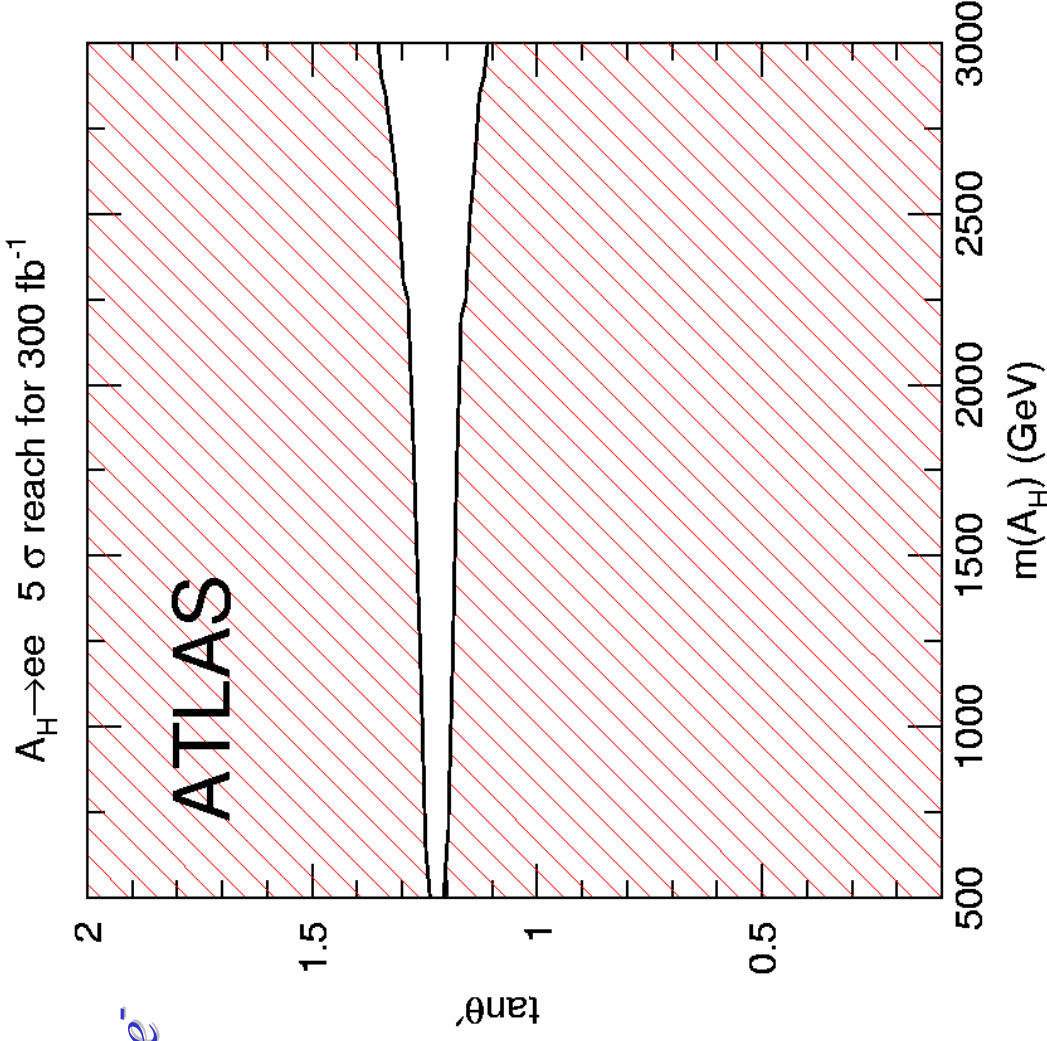


② Z_H, W_H, A_H

Search for A_H

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$$q\bar{q} \rightarrow A_H \rightarrow e^+e^-$$



$$\int \mathcal{L} dt = 300 \text{ fb}^{-1}$$

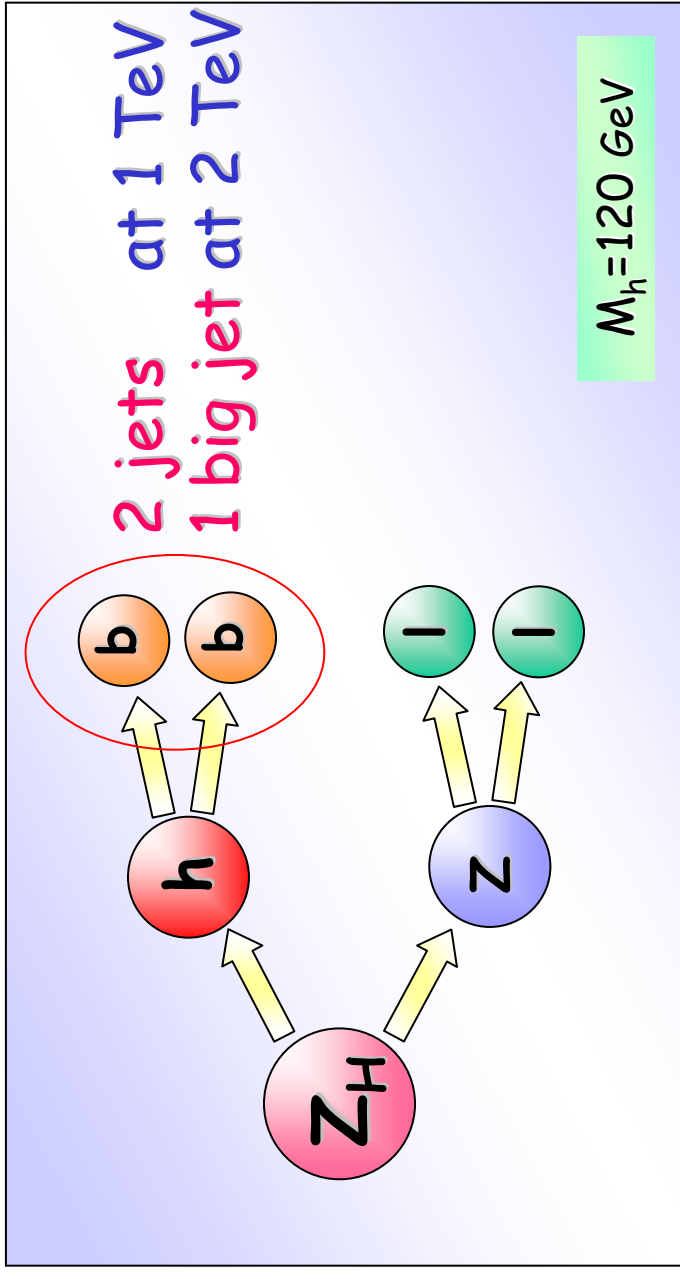


② Z_H, W_H, A_H

$Z_H \rightarrow Zh$ with $h \rightarrow bb$ (1/2)

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Signal :



$Z_H \rightarrow Zh \rightarrow 2 \text{ b-jets} + 2 \text{ leptons}$

Background :

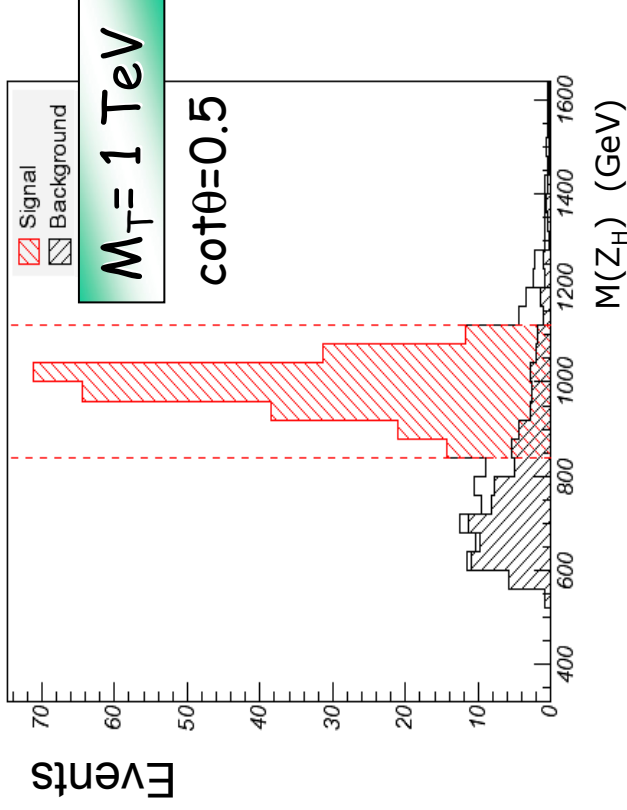
• $pp \rightarrow Z + \text{jets}$



② Z_H, W_H, A_H

$Z_H \rightarrow Zh$ with $h \rightarrow bb$ (2/2)

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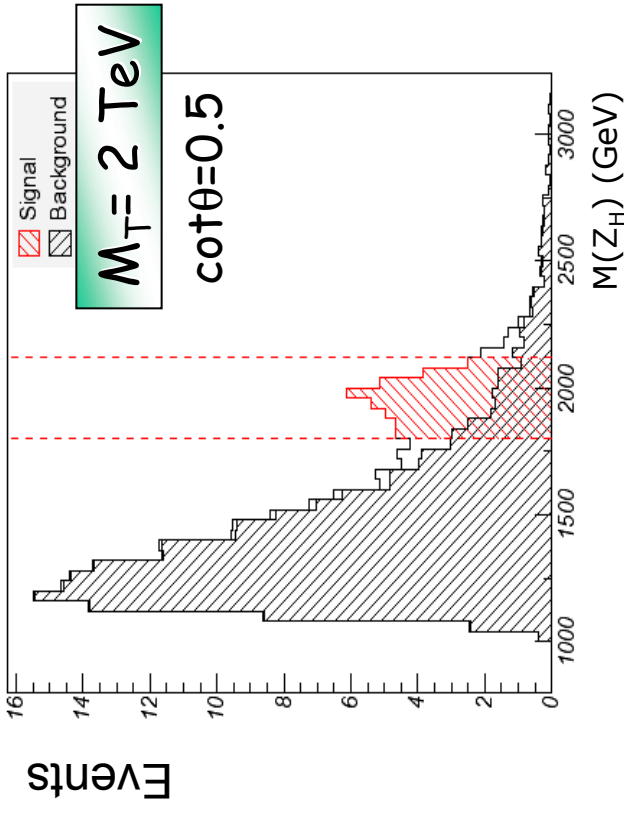
Cuts:

- $p_T(Z) > 250 \text{ GeV}$
- $p_T(h) > 250 \text{ GeV}$
- b-tagging: $\epsilon_b = 50\%$, $R_b = 100$

inside
mass window :

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

$$\int L dt = 300 \text{ fb}^{-1}$$



Cuts:

- $p_T(Z) > 500 \text{ GeV}$
- $p_T(h) > 500 \text{ GeV}$
- b-tagging: $\epsilon_b = 40\%$, $R_b = 100$

inside
mass window :

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



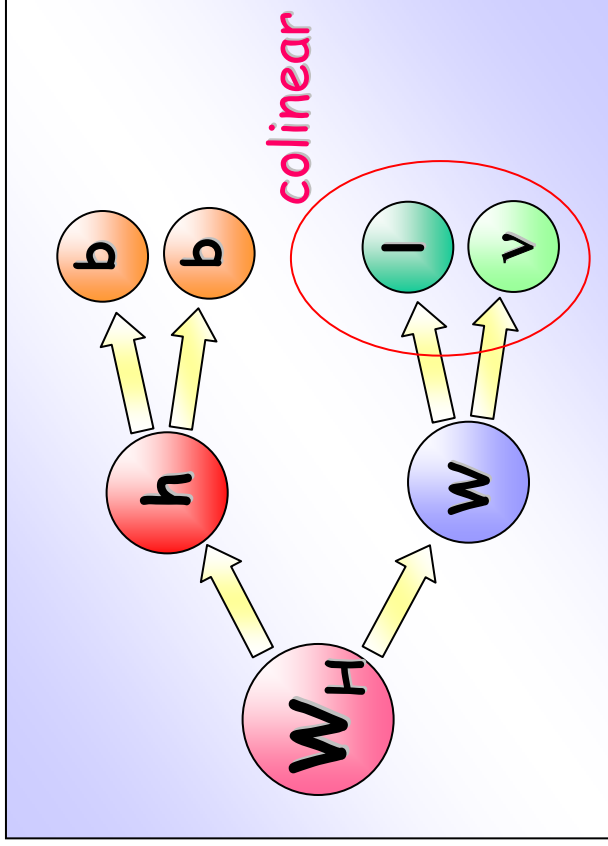
② Z_H, W_H, A_H

$W_H \rightarrow Wh$ with $h \rightarrow bb$

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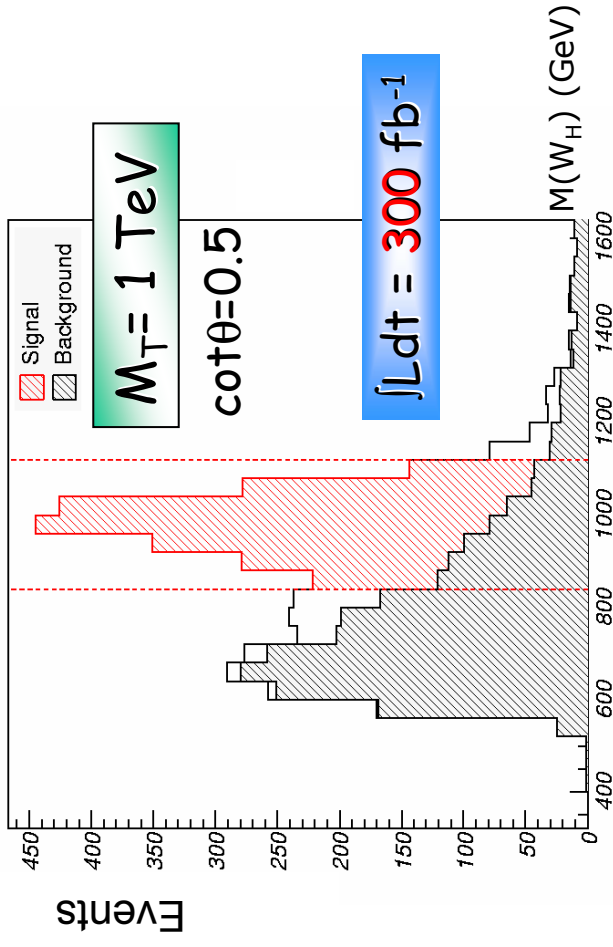
Signal :

$M_h = 120 \text{ GeV}$



Background :

- $pp \rightarrow W + \text{jets}$
- $pp \rightarrow t\bar{t}$



Cuts:

- $p_T(Z) > 250 \text{ GeV}$
- $p_T(h) > 250 \text{ GeV}$
- assume l and ν colinear
- b -tagging: $\epsilon_b = 50\%$, $R_b = 100$

inside
mass window :

$S/\sqrt{B} = 69$



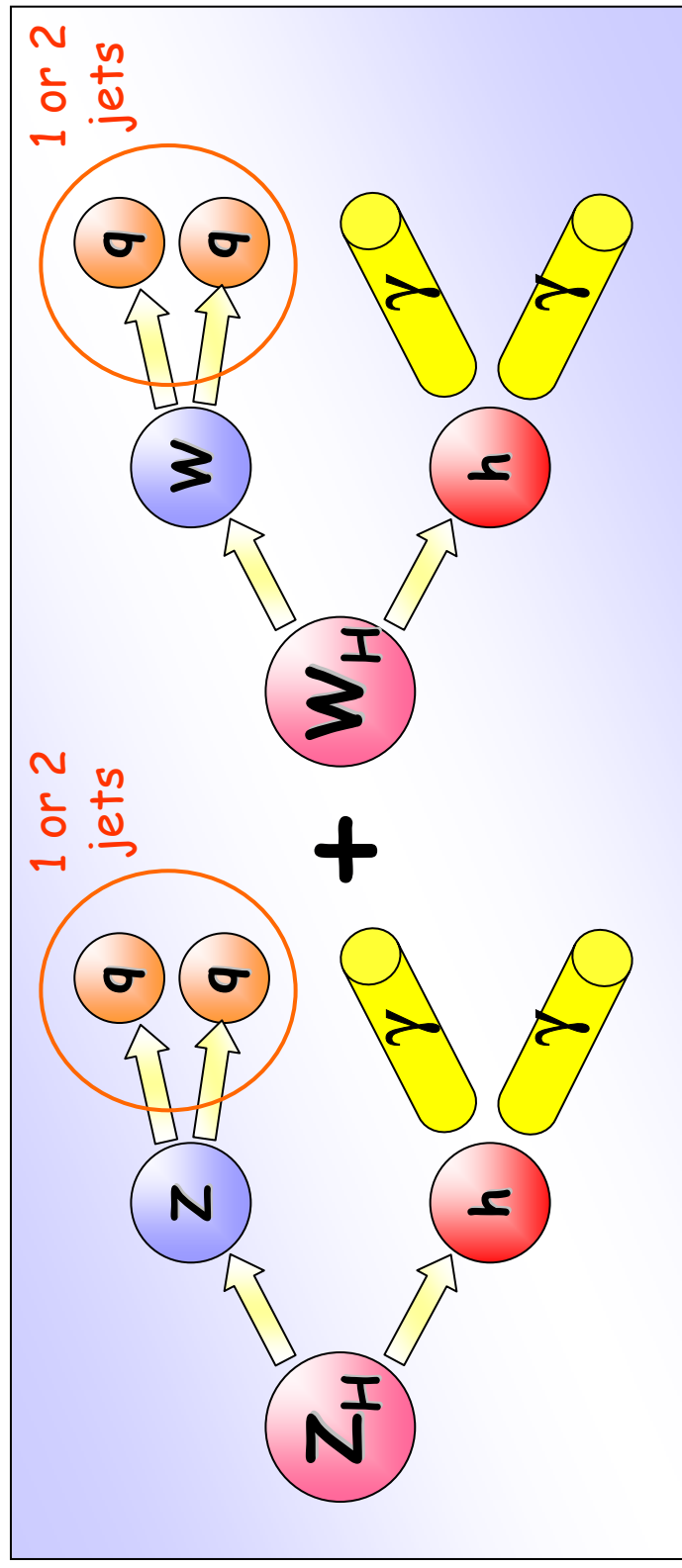
Little Higgs searches in ATLAS

Non-Standard Higgs Physics

CERN - May 15th 2004

$W_H/Z_H \rightarrow W/Z h$ with $h \rightarrow \gamma\gamma$ (1/2)

② Z_H, W_H, A_H



$M_h = 120 \text{ GeV}$

Signal :

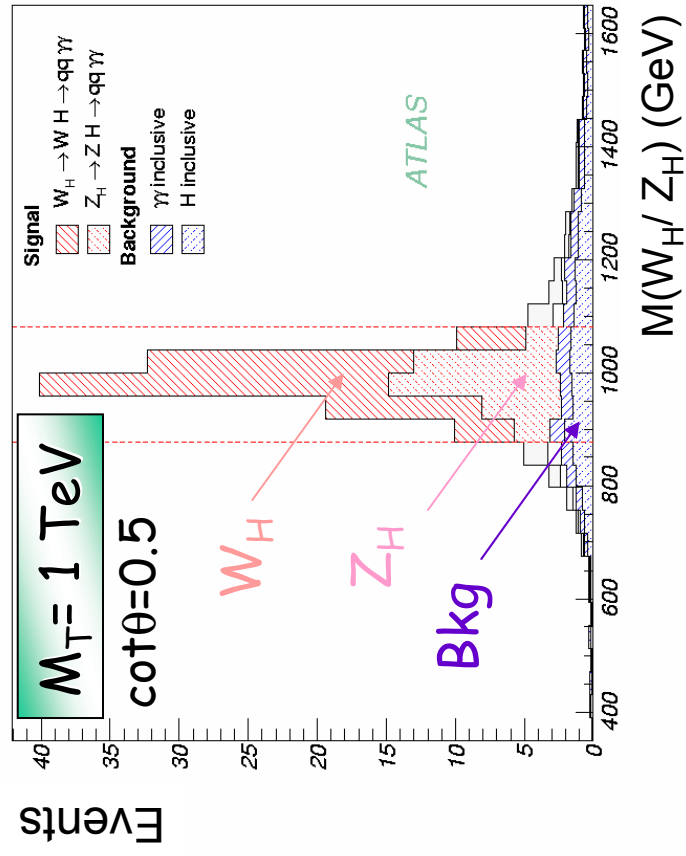
Background :

- inclusive $h(\rightarrow\gamma\gamma)$
- inclusive $\gamma\gamma$ (generated with Dipbox 1.2)



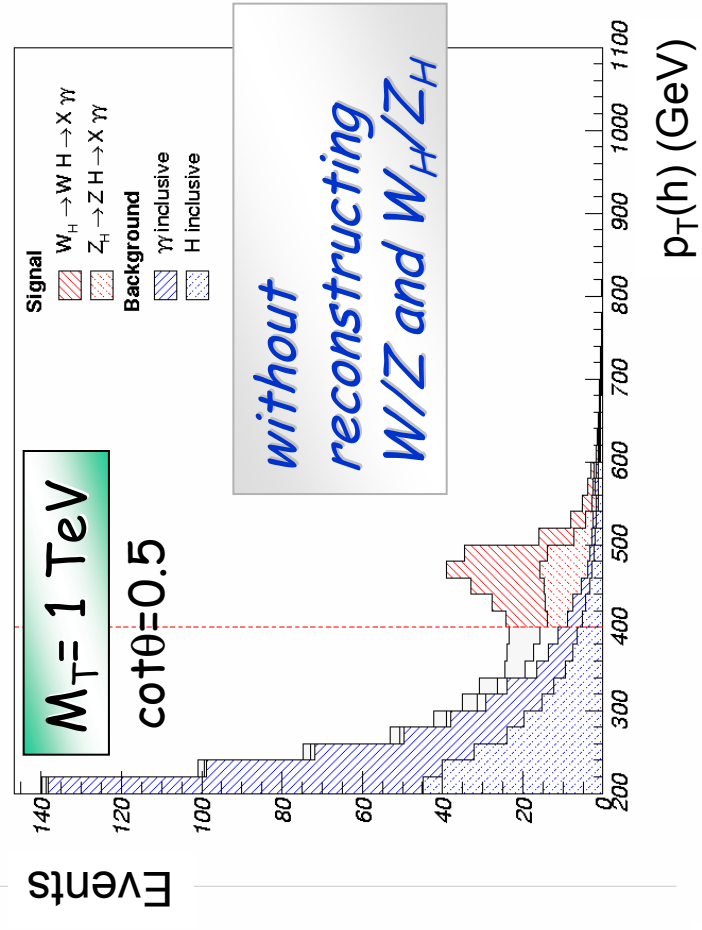
$W_H/Z_H \rightarrow W/Z h$ with $h \rightarrow \gamma\gamma$ (2/2)

② Z_H, W_H, A_H



inside mass window :

$S/\sqrt{B} = 27$



- Cuts:**
- $p_T(W/Z) > 200 \text{ GeV}$
 - $p_T(h) > 400 \text{ GeV}$
 - γ -tagging: $\epsilon_\gamma = 80\%$

$\int L dt = 300 \text{ fb}^{-1}$

$S/\sqrt{B} = 23$

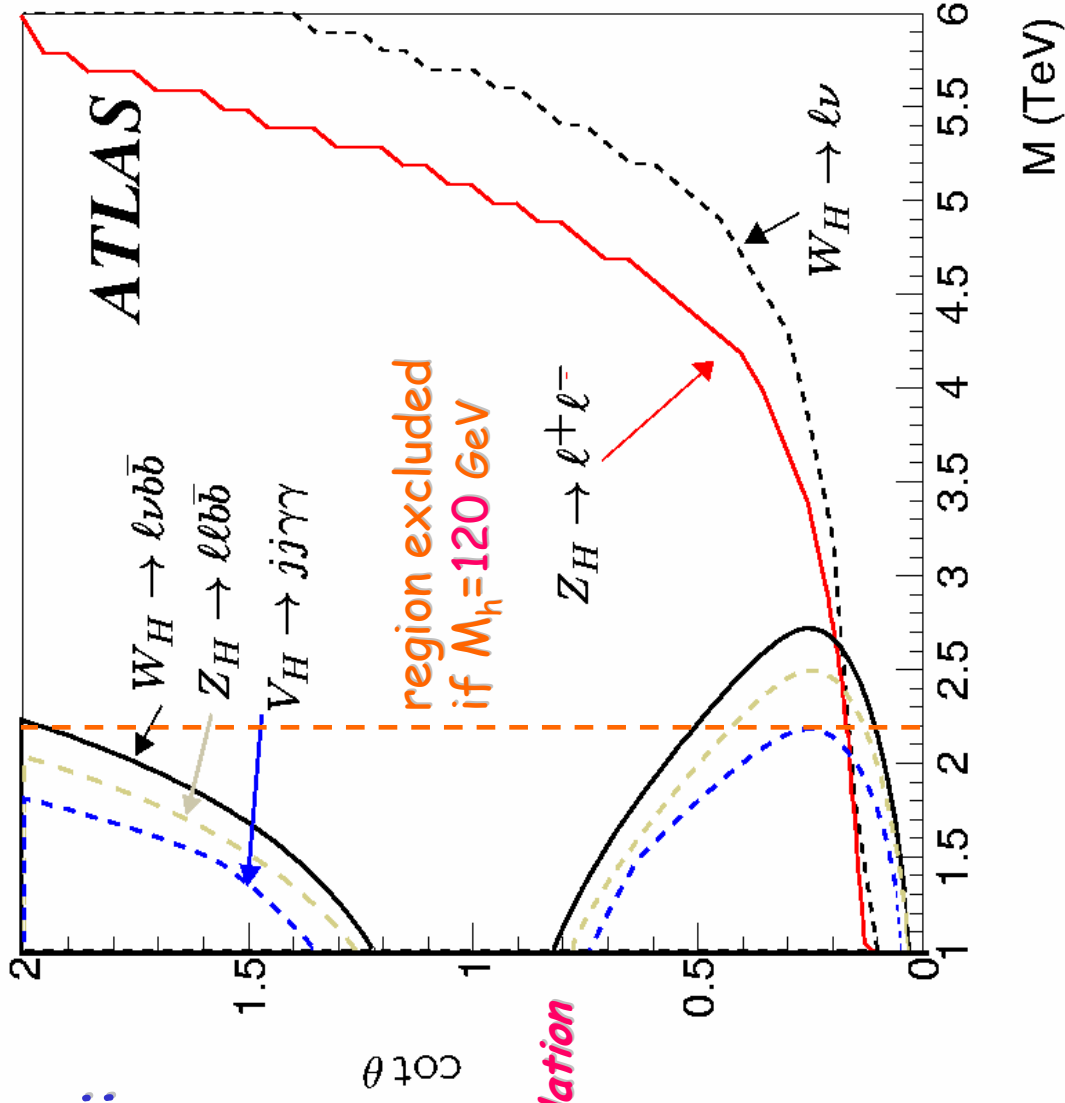


Combined results

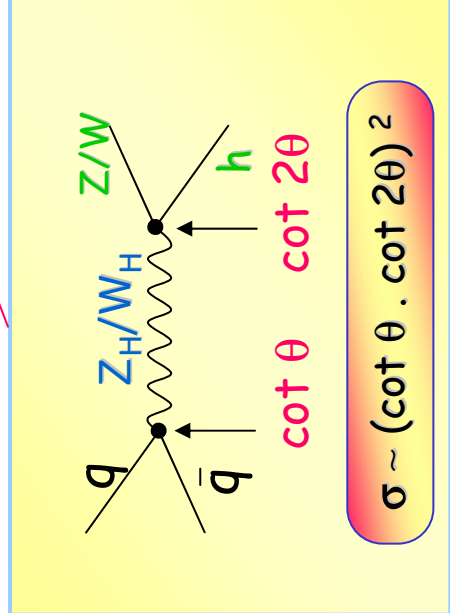
② Z_H, W_H, A_H

Accessible regions
for a 5σ discovery:

$$\int \mathcal{L} dt = 300 \text{ fb}^{-1}$$



extrapolation



Little Higgs searches in ATLAS

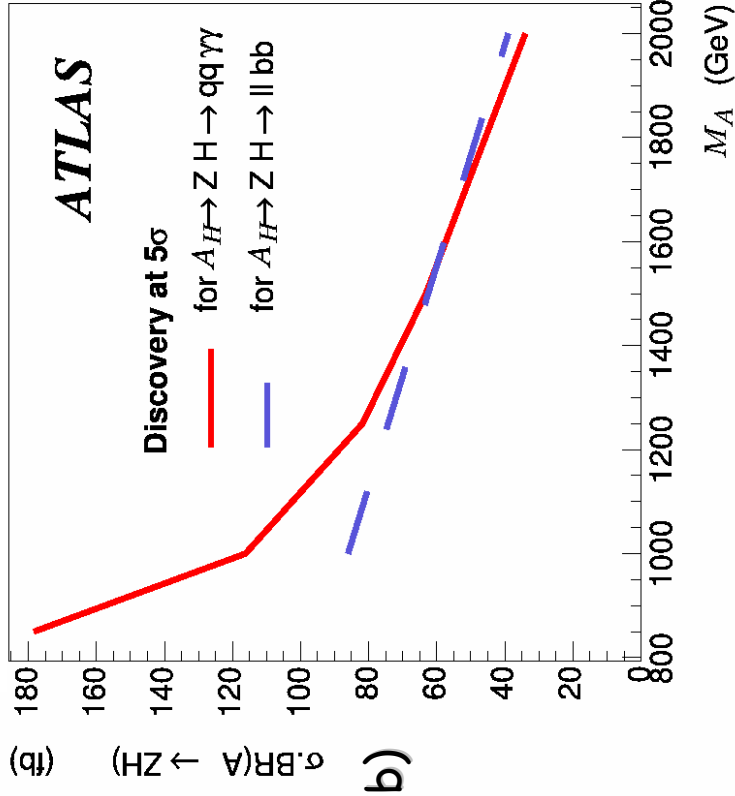
Non-Standard Higgs Physics

② Z_H, W_H, A_H

Deductions for A_H

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- theoretical uncertainties (strong model-dependency) for A_H
- can deduce limits on $\sigma \cdot \text{BR}(A_H \rightarrow Z h)$ 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 $45 \rightarrow 80$ GeV)
 $\Rightarrow W_H/Z_H$ not background for A_H



$\sigma \cdot \text{BR}(A_H \rightarrow Z h)$ min. (fb)

$$\int \mathcal{L} dt = 300 \text{ fb}^{-1}$$



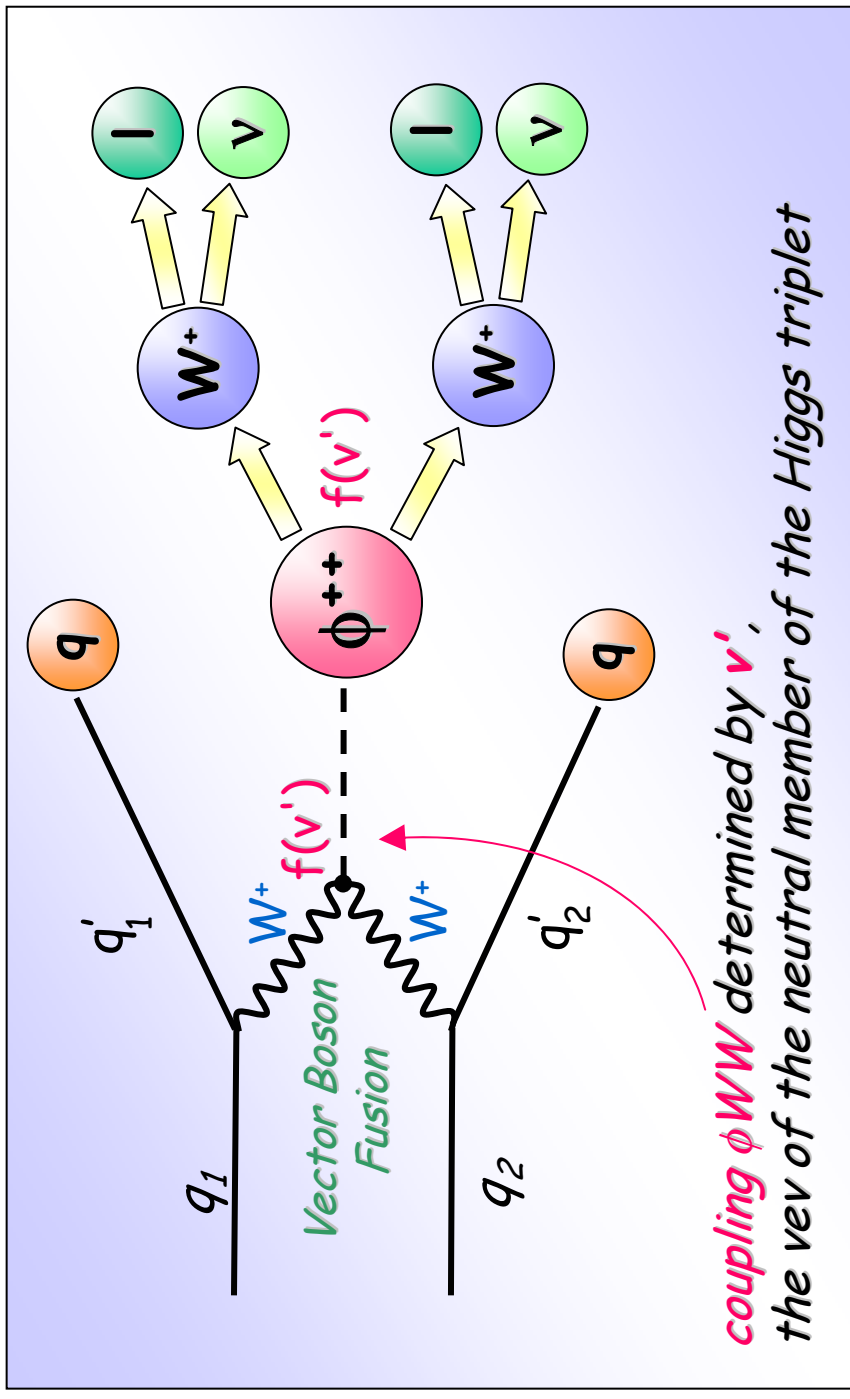
③ ϕ^{++} studies

③ ϕ^{++}

$\phi^{++} \rightarrow W^+ W^+ (1/2)$

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Signal :



Background :

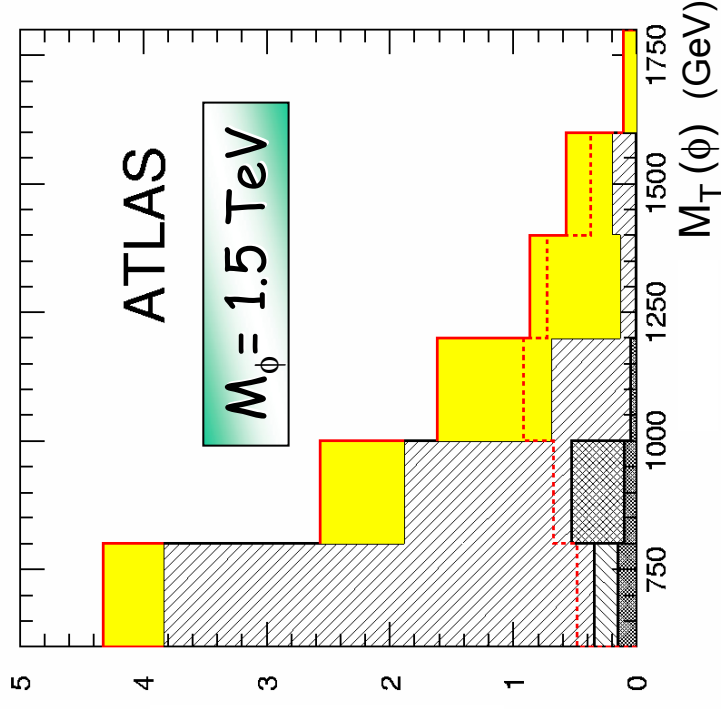
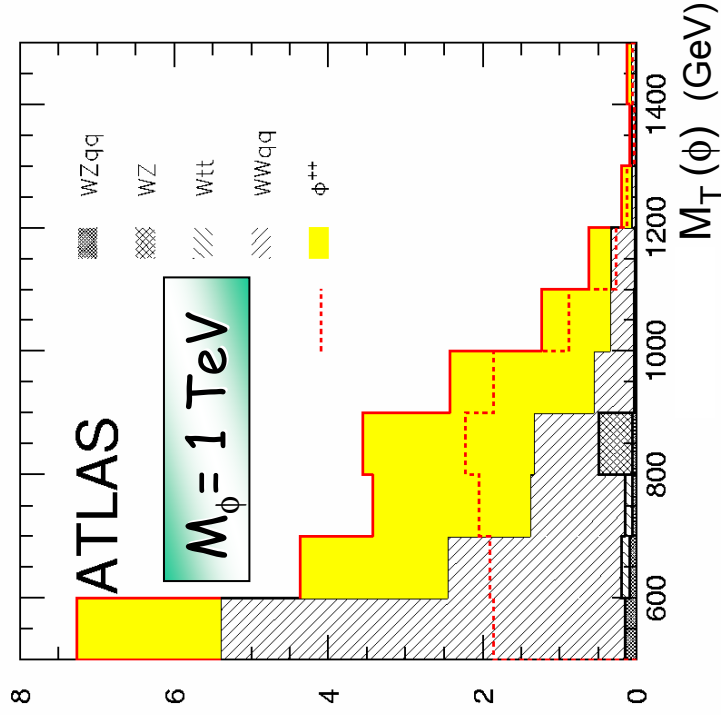
$qqWW$, $qqWZ$, ttW , WZ



$\phi^{++} \rightarrow W^+ W^+ (2/2)$

Cuts:

- leptons: $p_T(l_1) > 150 \text{ GeV}$, $p_T(l_2) > 20 \text{ GeV}$ $|p_T(l_1) - p_T(l_2)| > 200 \text{ GeV}$ $|\eta(l_1) - \eta(l_2)| < 2$
- jets: $E(j_1) > 200 \text{ GeV}$, $E(j_2) > 100 \text{ GeV}$ $|p_T(j_1) - p_T(j_2)| > 200 \text{ GeV}$ $|\eta(j_1) - \eta(j_2)| > 5$
- $E_T > 50 \text{ GeV}$



variable drawn:

$$M_T^2 = \tilde{P}_T \cdot \tilde{P}_T$$

where

$$\tilde{P}_T = \begin{pmatrix} E_1 \\ \tilde{P}_1 \end{pmatrix} + \begin{pmatrix} E_2 \\ \tilde{P}_2 \end{pmatrix} + \begin{pmatrix} E_T \\ \tilde{E}_T \end{pmatrix}$$

$\int L dt = 300 \text{ fb}^{-1}$

$v' > 29 \text{ GeV}$

discovery at 5σ if

$v' > 54 \text{ GeV}$



Conclusion

Conclusion

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All these studies are in the note:

"Exploring Little Higgs Models with ATLAS at the LHC"

SN-ATLAS-2004-038

Work also done on following channels:

- $T \rightarrow th$ and $Z_H \rightarrow Zh$ with $M(h) = 200 \text{ GeV}$
- $\phi^{++} \rightarrow W^+W^+ \rightarrow |vjj$ and $\phi^{++} \rightarrow e^+e^+, \mu^+\mu^+$

The search for particles predicted by the Little Higgs models using the ATLAS detector *is promising!*

A large part of parameter space will be covered!

