Little Higgs Searches with ATLAS

The Little Higgs task force

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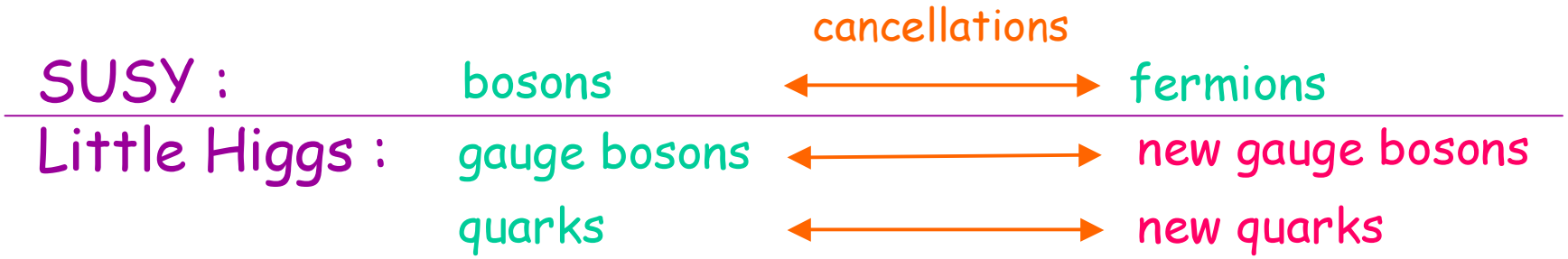
presented by: M. LECHOWSKI *(LAL-Orsay)*

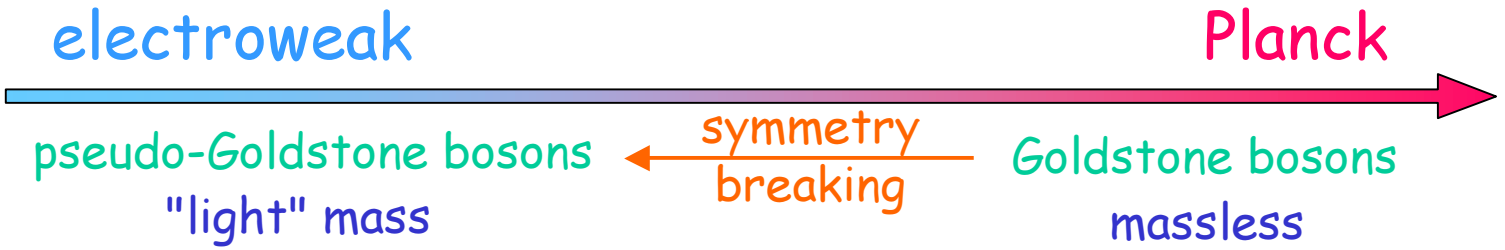
Little Higgs model

- **Motivation :**

- **Quadratic divergences :**



- **Higgs fields :**



We have to look for the following particles:

① T heavy top

② $W_H^{\pm}$ → heavy $W^{\pm}$ Z_H → heavy Z A_H → heavy γ

③ Higgs triplet $\phi^0, \phi^+, \phi^{++}$ heavy Higgs bosons

described in :

arXiv:hep-ph/0301040 Phenomenology of the Little Higgs Model

Mass Range

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

- T →

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

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

- $W_H^{\pm}$, Z_H, A_H →

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

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

$M(W_H^{\pm}) \approx M(Z_H)$

- ϕ → M < 10 TeV

Decays

$T \rightarrow tZ,\ bW$

$\rightarrow th$

$Z_H, A_H \rightarrow \ell^+\ell^-, q\bar{q}, \ldots$

$\rightarrow Zh$

$W_H^{\pm} \rightarrow \ell\nu, q\bar{q}', \ldots$

$\rightarrow W^{\pm}h$

$\phi^{++} \rightarrow W^+W^+, \ell^+\ell^-, \ldots$

discovery channel

test of the model

very heavy particles
↓
very high p_T final state

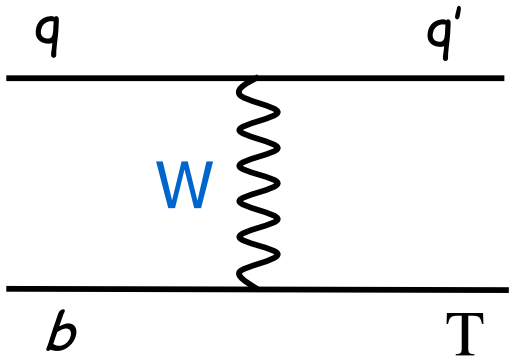
The modes th, Zh, $W^{\pm}h$, … may be difficult to see but are necessary to test the model

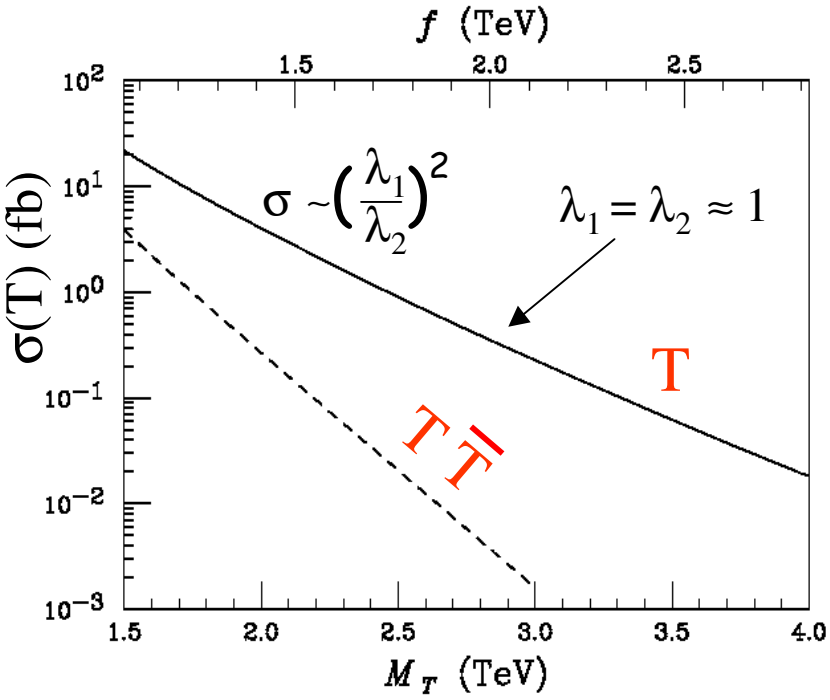
We have used the following software for the analysis:

- 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

Heavy top T

- Production mechanism = Wb fusion





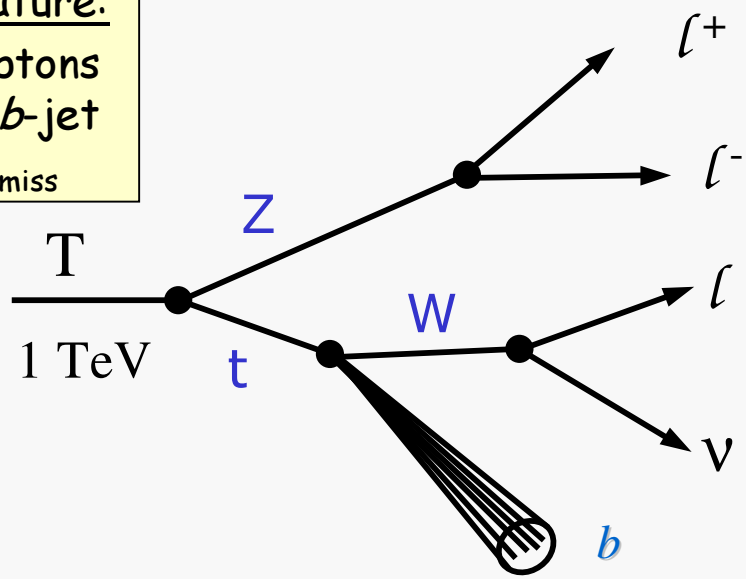
BR
- T → bW 50 %
- T → tZ 25 %
- T → th 25 %

λ_1 , λ_2 Yukawa couplings

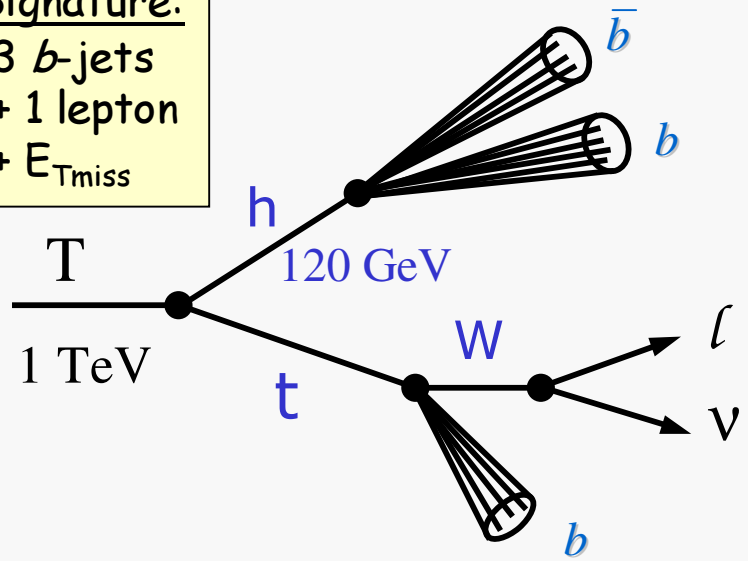
$$\frac{\Gamma}{M} \approx \frac{1}{16\pi} \approx 2\ \%$$

T searches

Signature:
3 leptons
+ 1 *b*-jet
+ E_{Tmiss}



Signature:
3 *b*-jets
+ 1 lepton
+ E_{Tmiss}



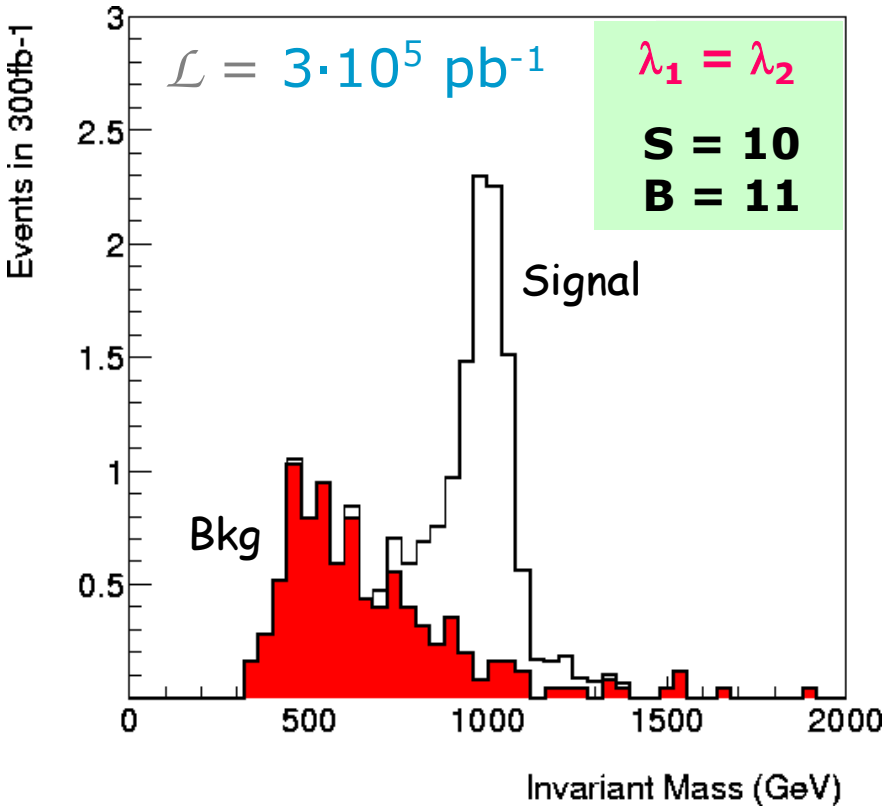
Background: $pp \rightarrow tZ$
$pp \rightarrow WZ$

Background: $pp \rightarrow tt$
$pp \rightarrow Wbb$

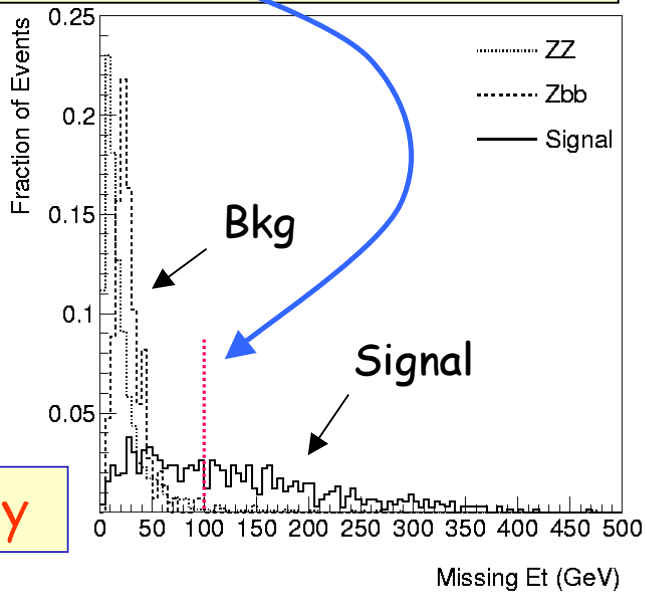
$T \rightarrow Zt$ signal

M_T= 1 TeV

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



Cuts:
- *3 isolated leptons, p_T>30 GeV (2 of them with $M_{\ell\ell} = M_Z$)*
- 1 b -jet
- $\not{E}_T$ > 100 GeV

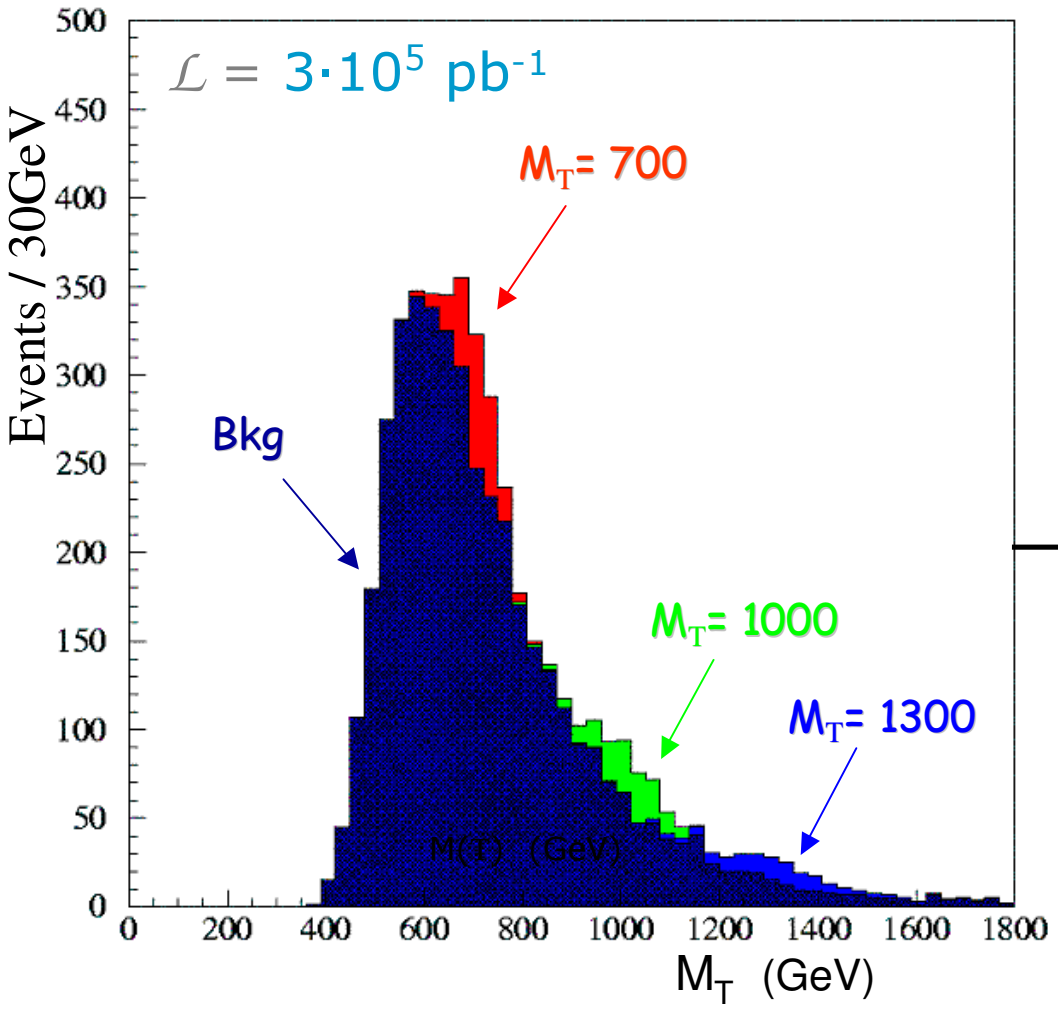


$S/\sqrt{B} > 5$ $(S \geq 10)$ in the window mass $\rightarrow$ discovery

$T \rightarrow ht$ signal

M_T= 700, 1000, 1300 GeV

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



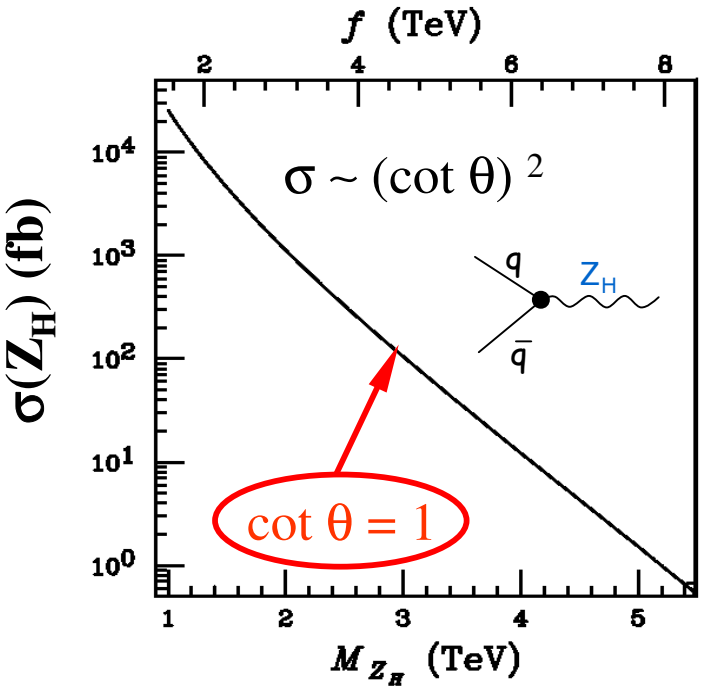
Cuts:
- p_T(3-jets) > 80 GeV
- p_T(lepton) > 70 GeV
- in window mass of H

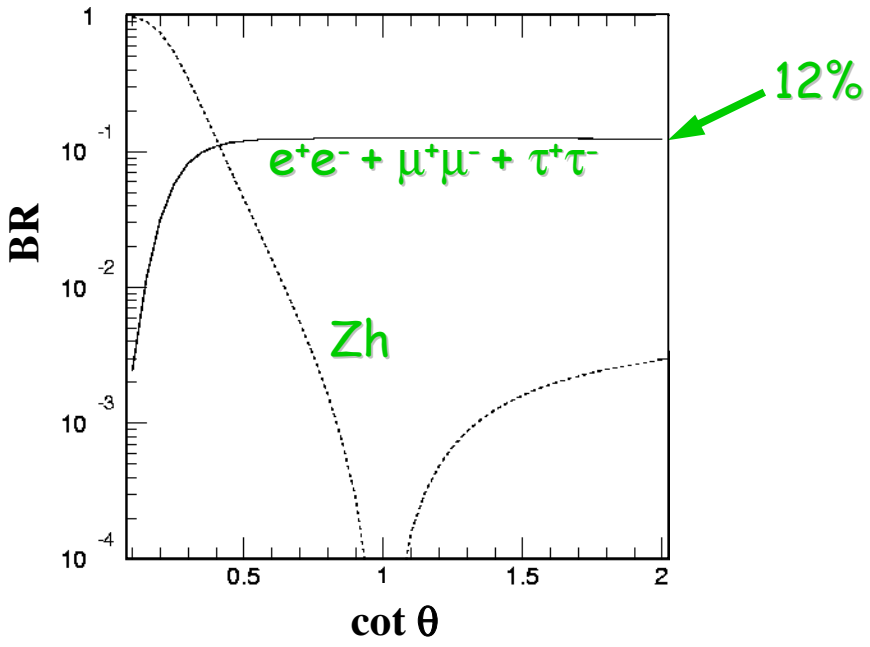
At least 1 b-tag

using cross-sections to achieve 3σ observations :

M_T= 700 at 3σ σ.BR(T→ht) > 525 fb
M_T= 1000 at 3σ σ.BR(T→ht) > 220 fb
M_T= 1300 at 3σ σ.BR(T→ht) > 210 fb

Gauge Boson Z_H





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

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

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

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

NB: $\Gamma(Wh)$ for $W_H = \Gamma(Zh)$ for Z_H

Search for Z_H

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

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

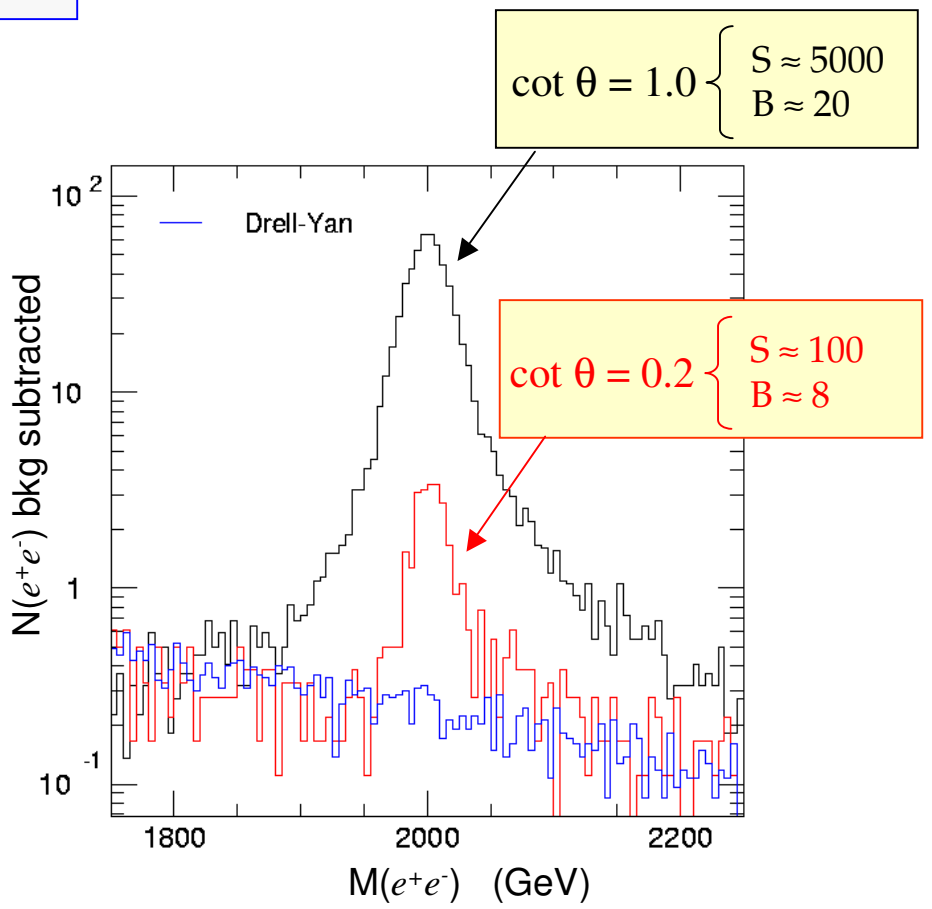
$M_{Z_H} = 2$ TeV

Selection cuts:

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

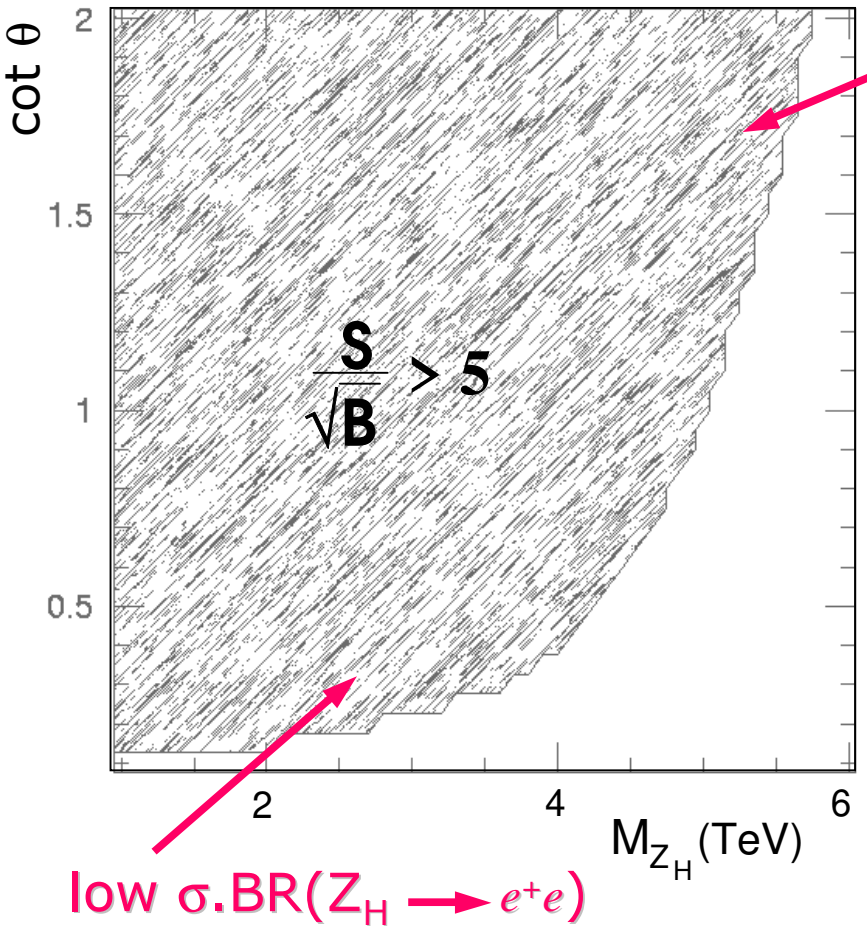
Background:

Drell-Yan ($q\bar{q} \rightarrow Z/\gamma \rightarrow e^+e^-$)
other bkg's are under evaluation



Discovery region for Z_H

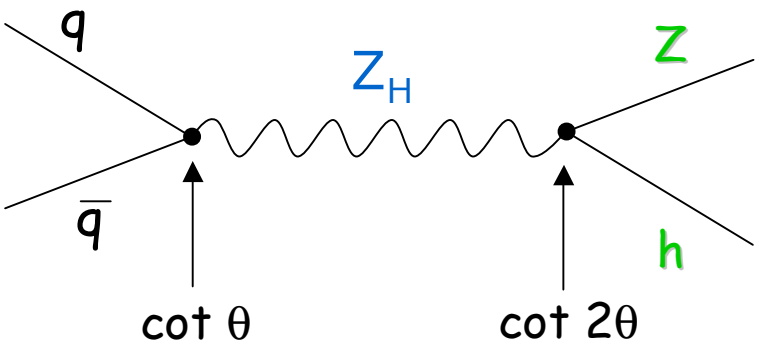
$\mathcal{L} = 3 \cdot 10^5$ pb^{-1}



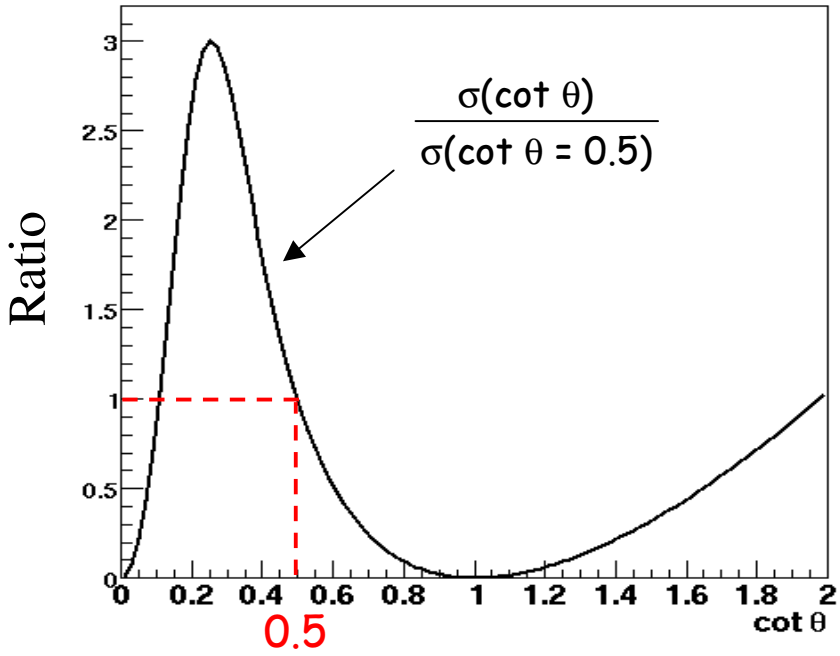
If Z_H is found, cot θ can be extracted from σ(Z_H) and Γ(Z_H)

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

$Z_H \longrightarrow Zh$



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



$m_h = 120$ GeV

BR(h ⟶ bb) = 66 %

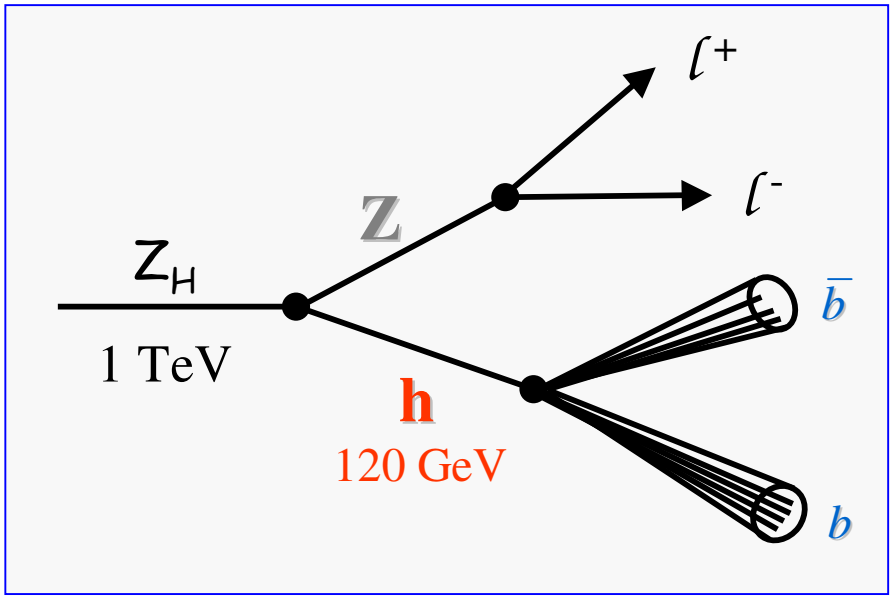
BR(h ⟶ γγ) = 0.2 %

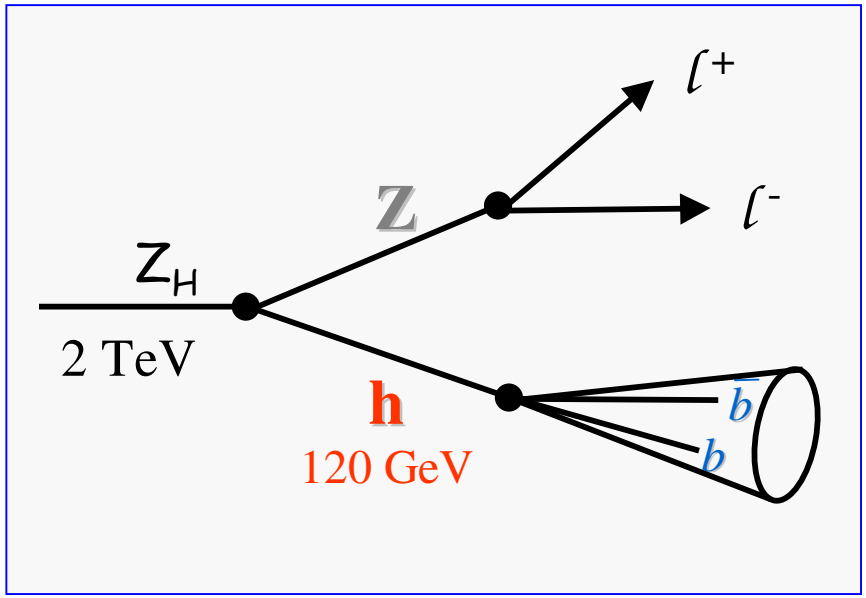
$m_h = 200$ GeV

BR(h ⟶ W^+W^-) = 74 %

BR(h ⟶ ZZ) = 26 %

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

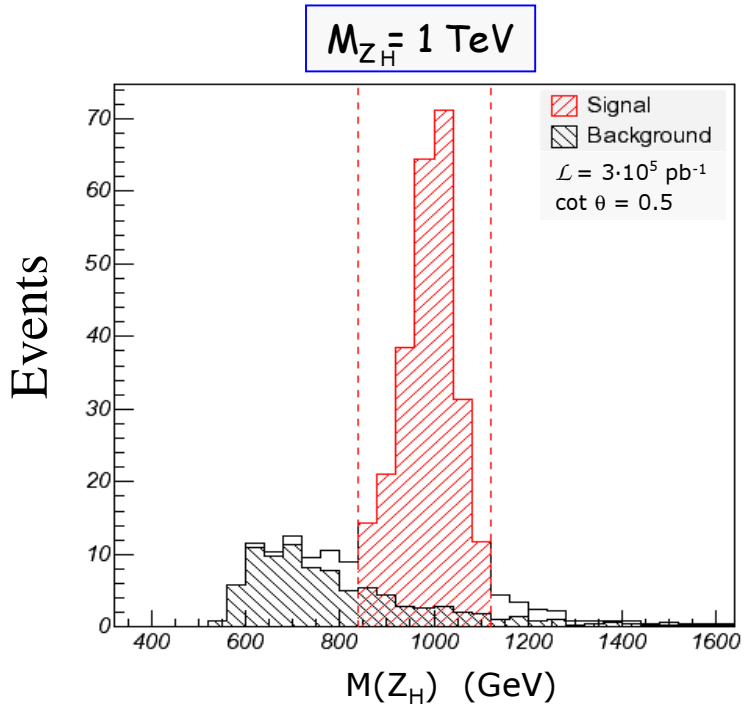


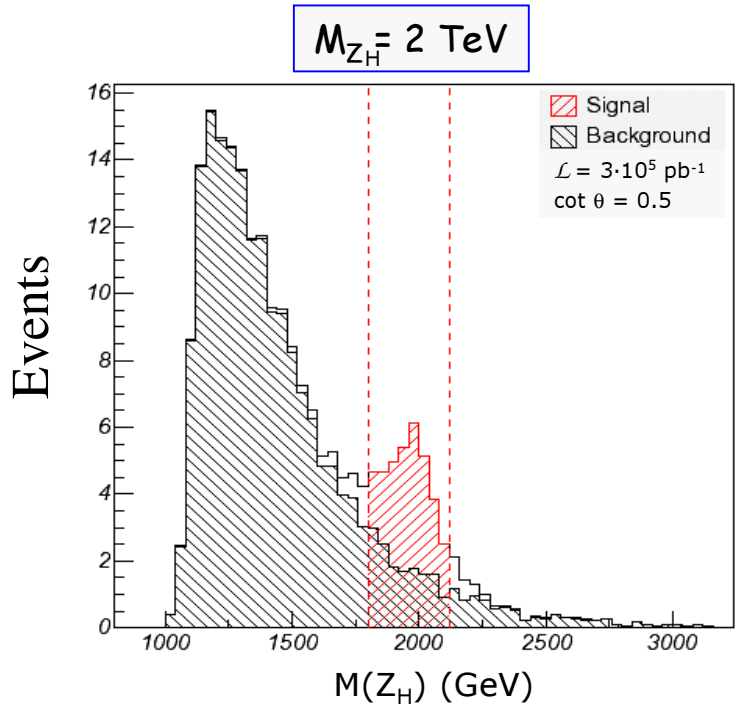


Cuts	Cuts
$\|\eta\| < 2.5$ (jets and leptons)	$\|\eta\| < 2.5$ (jets and leptons)
$P_T(Z) > 250$ GeV	$P_T(Z) > 500$ GeV
$P_T(h) > 250$ GeV	$P_T(h) > 500$ GeV
b-tagging	b-tagging

Background: Z + jets

Signal and background



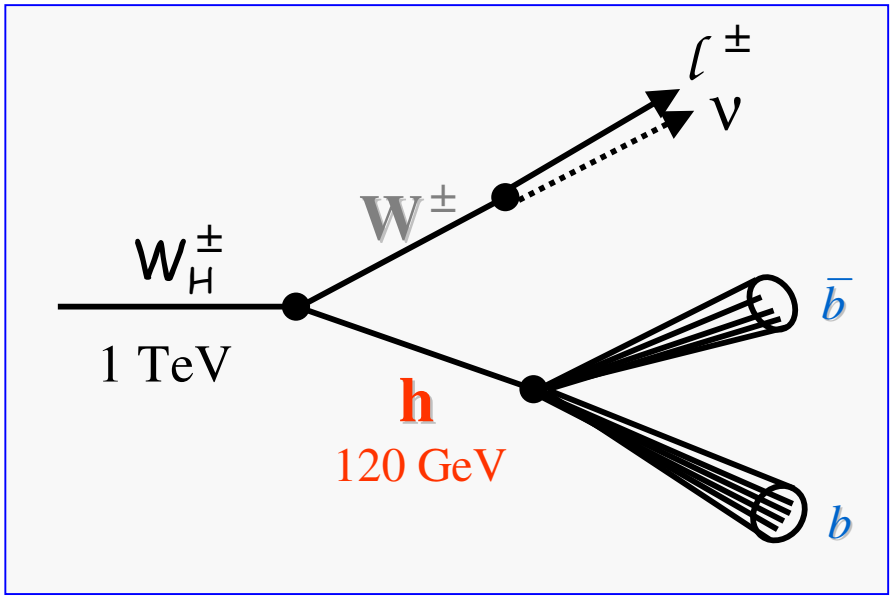


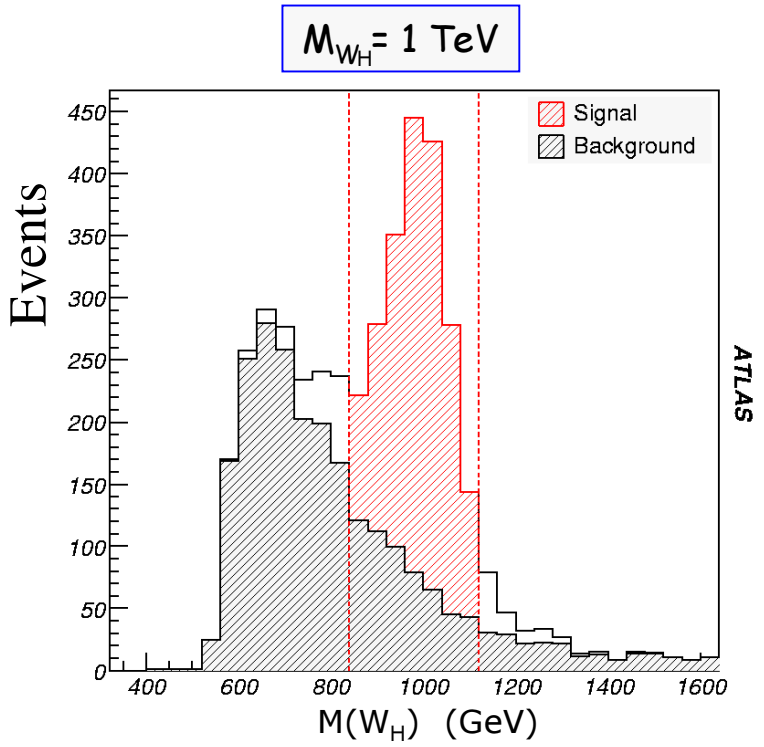
b-tag: ε_b = 50%, R_u = 100 *
Inside mass window:
S = 195
B = 16
$\frac{S}{\sqrt{B}} = 50$

* from full sim.

b-tag: ε_b = 40%, R_u = 100 *
Inside mass window:
S = 15
B = 8
$\frac{S}{\sqrt{B}} = 5$

$W_H^{\pm} \rightarrow W^{\pm} h$ with $h \rightarrow b\bar{b}$





Cuts

$|\eta| < 2.5$ (jets and leptons)

assume ν **colinear to** ℓ for W_H reconstruction

$P_T(Z) > 250$ GeV

$P_T(h) > 250$ GeV

b-tagging

Background: W + jet , $t\bar{t}$

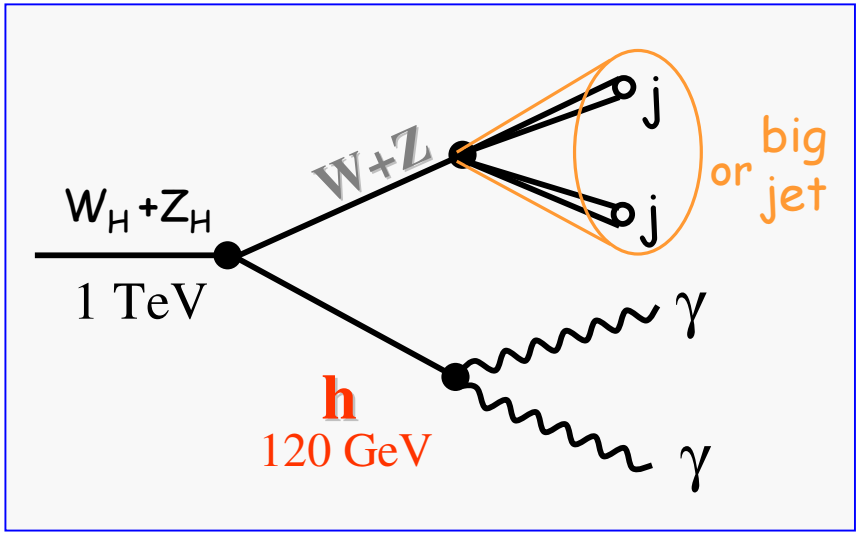
b-tag: $\varepsilon_b = 50\%$, $R_u = 100$

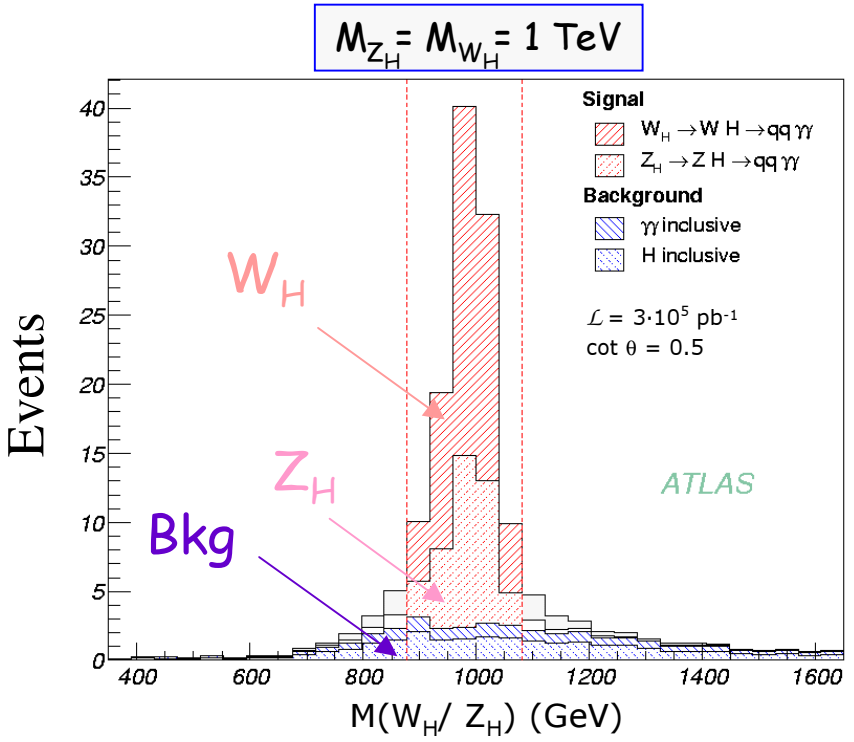
Inside mass window:

S = 1499
B = 471

$$\frac{S}{\sqrt{B}} = 69$$

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





Cuts

$|\eta(\gamma)| < 2.5$ $\quad P_T(\gamma) > 25$ GeV

$m(h) \approx 120$ GeV $\quad P_T(h) > 400$ GeV

γ-tagging, $\varepsilon(\gamma) = 80\%$

$P_T(W/Z) > 200$ GeV

inside mass window

Background: $h(\to\gamma\gamma)$ inclusive
$\gamma\gamma$ inclusive

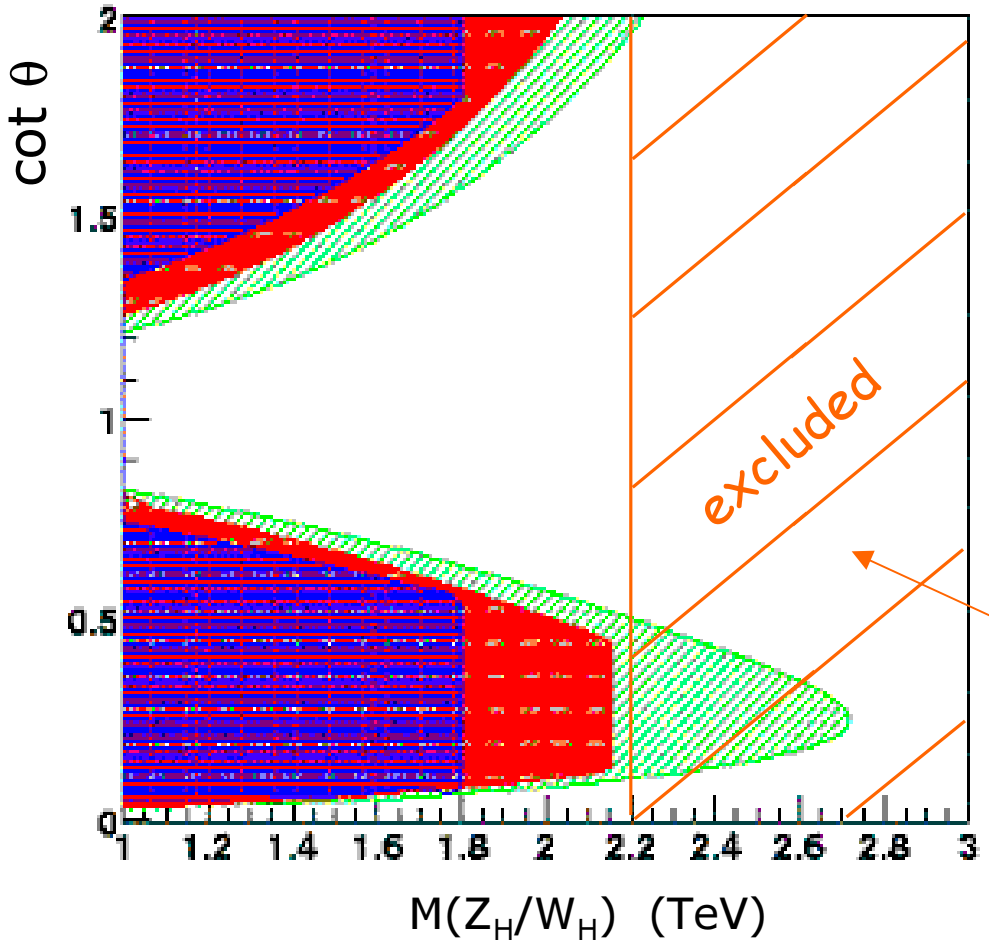
$S(W_H \to Wh) = 64$
$S(Z_H \to Zh) = 33$
} 97

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

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

* 23 without reconstructing W/Z

Regions with $S/\sqrt{B} > 5$ and $S > 10$



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

$Z_H/W_H \rightarrow jj\ \gamma\gamma$

$Z_H \rightarrow \ell\ell$ bb

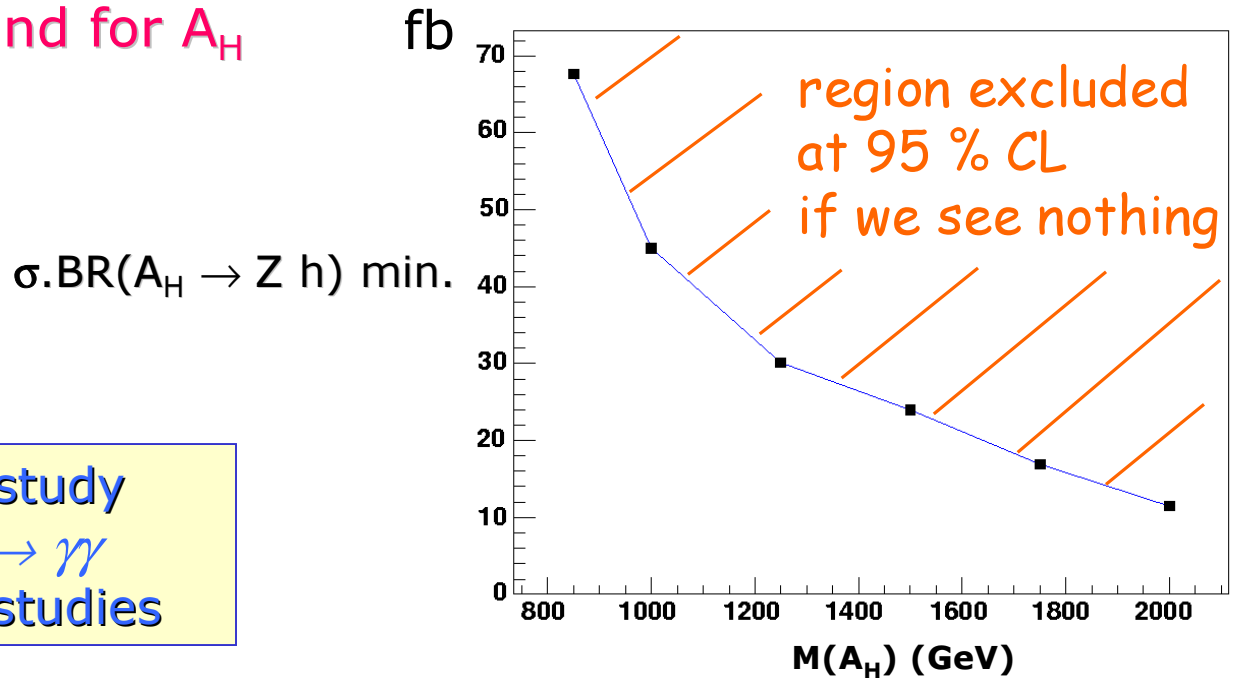
$W_H \rightarrow \ell\nu$ bb

M < 2.2 TeV *for* $m_h = 120$ GeV

Deductions for A_H

- theorical uncertainties (strong model-dependency) for A_H
- can deduce limits on $\sigma.BR(A_H \rightarrow Z\ h)$ 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

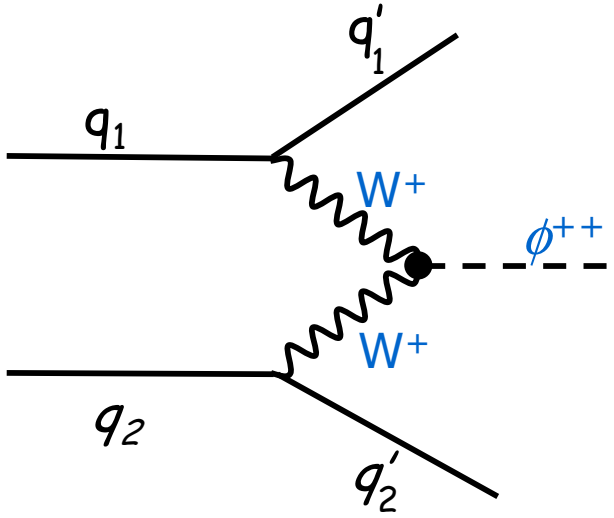


- deduced only from study $Z_H \rightarrow Z\ h$ *with* $h \rightarrow \gamma\gamma$
- can combine other studies

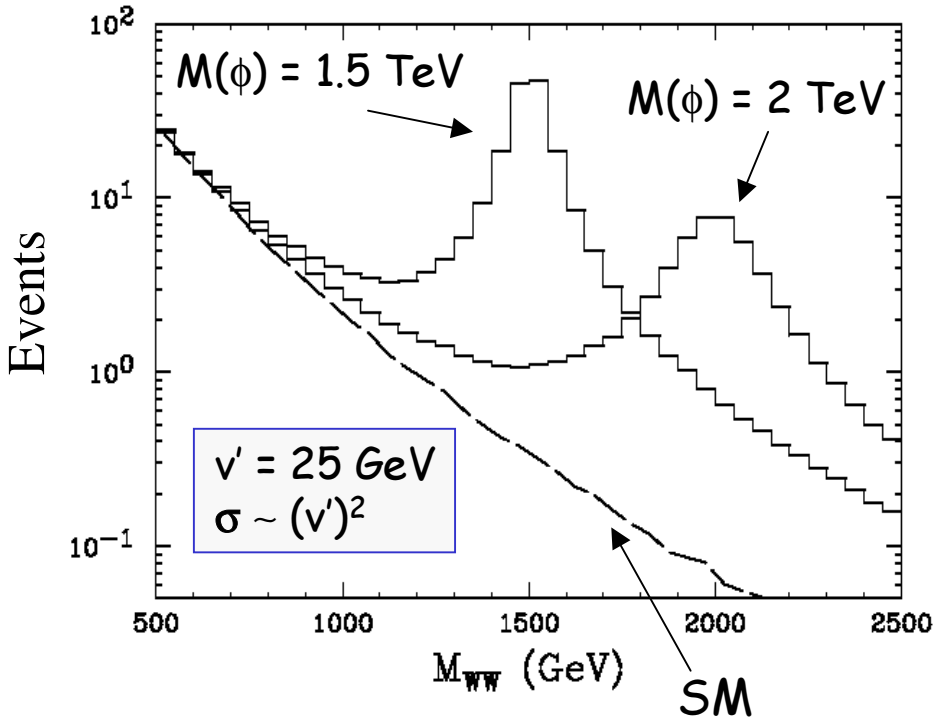
New Higgs ϕ^{++}

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

- Production: VBF mechanism
  (vector boson fusion)



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



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

might be suppressed

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

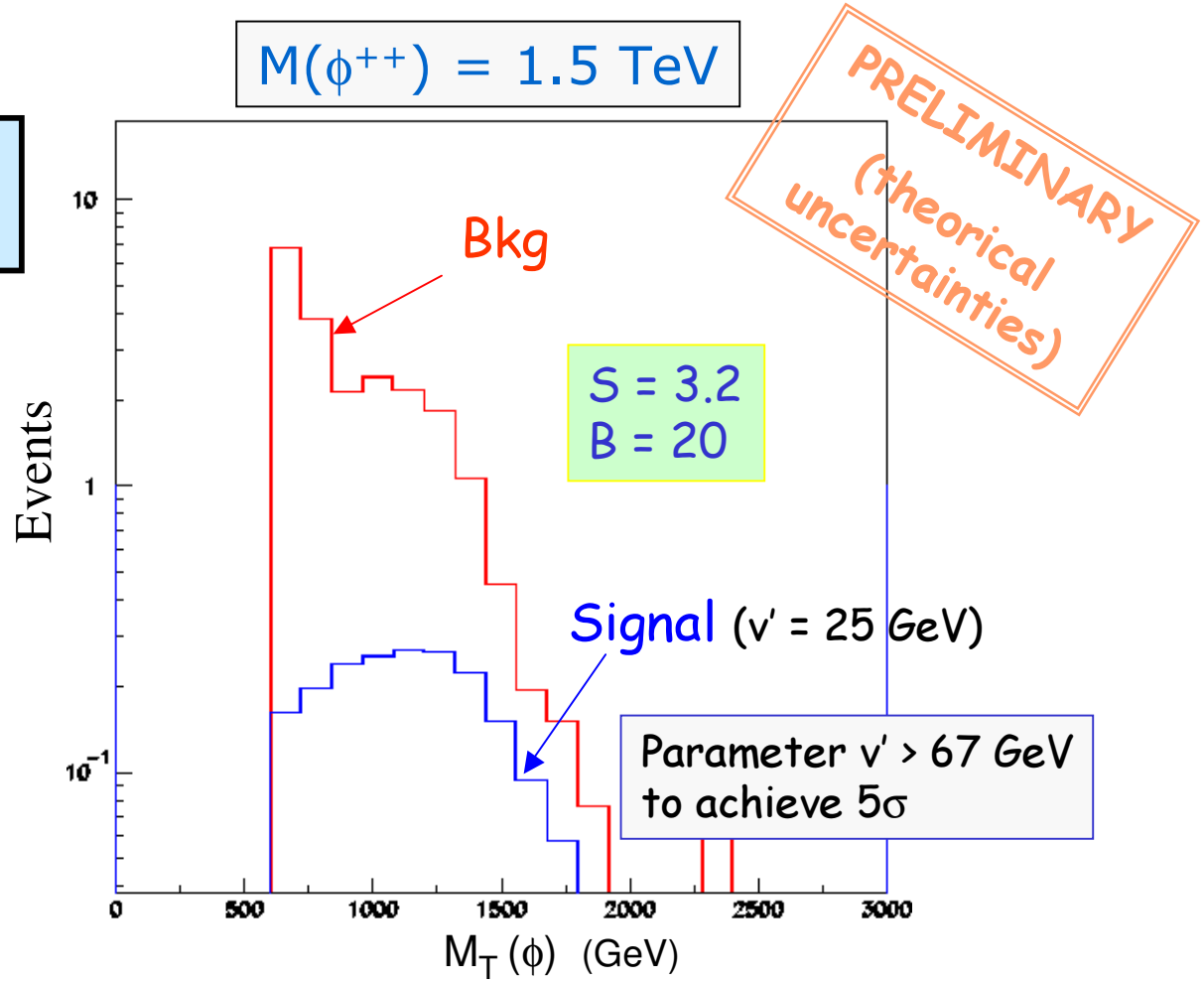
$\mathcal{L} = 3 \cdot 10^5$ pb^{-1}

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

Background: WWqq, WZ
WZqq, Wtt

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

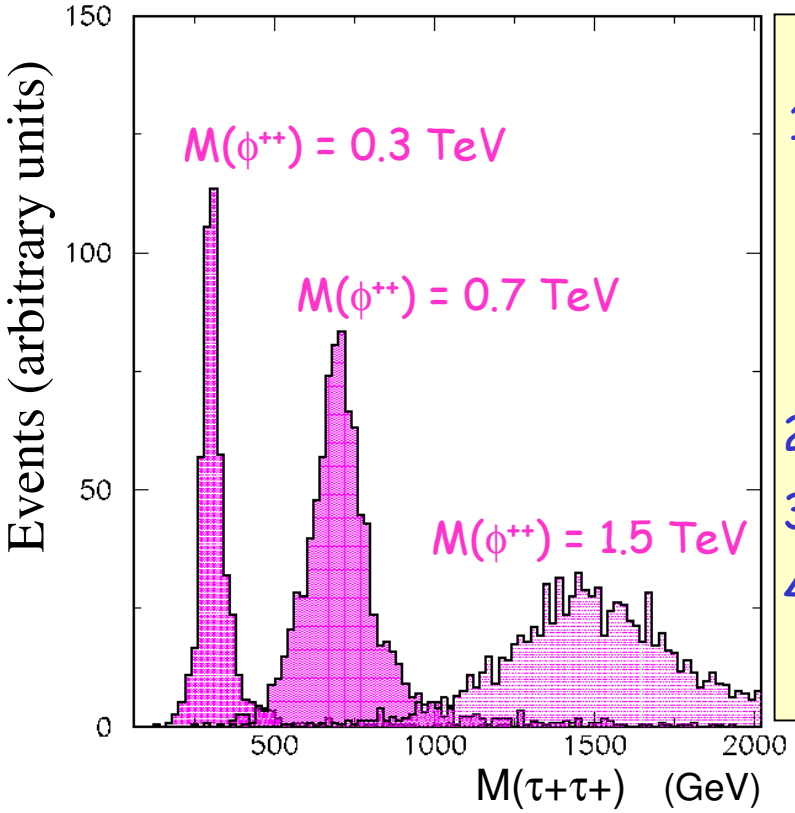


$\phi^{++} \rightarrow \tau^+ \tau^+$

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

(Couplings might be suppressed in the little Higgs model)

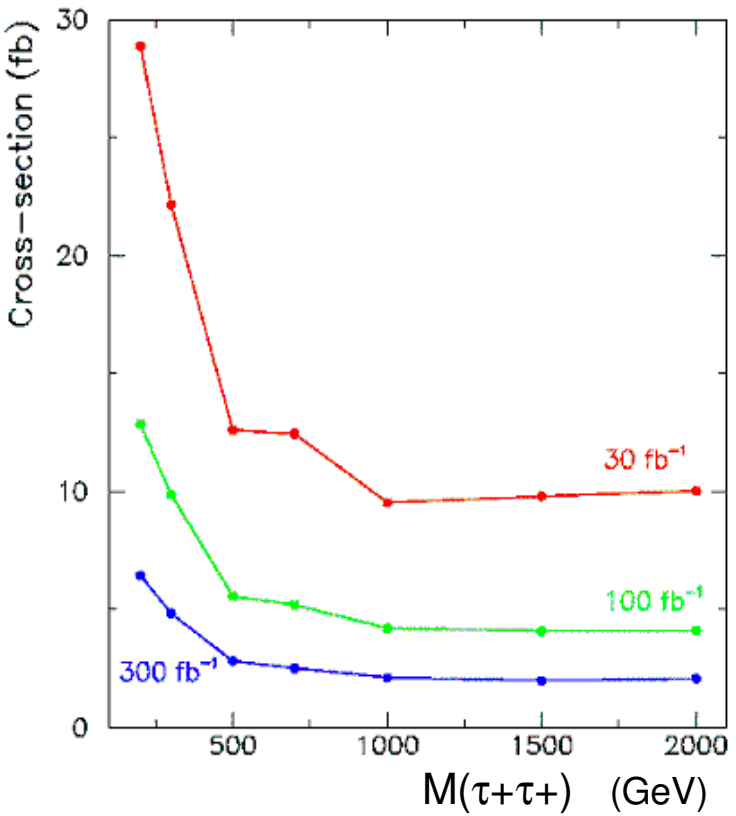
Background: WWjj, $t\bar{t}$



Main cuts :

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

Required σ.BR($\phi^{++} \rightarrow \tau^+\tau^+$) (fb) for 5$\sigma$ discovery :



Summary

$T \rightarrow tZ \rightarrow 3\ell\ b\nu$			M=1 TeV : $S/\sqrt{B} > 5$ $(\lambda_1 = \lambda_2)$
$\rightarrow th \rightarrow 3b\ \ell\nu$			M=0.7, 1→1.3 TeV : visible at 3σ for $\sigma.BR(T \rightarrow th) > 525, 220$ fb
$Z_H \rightarrow e^+e^-$			easily visible for M < 2TeV
	$\rightarrow Zh$	$\rightarrow \ell^+\ell^-\ b\bar{b}$	M=1 (2) TeV : $S/\sqrt{B}$=50 (5) (cotθ=0.5)
$W_H^{\pm}$	$\rightarrow qq\ \gamma\gamma$		M=1 (2) TeV : $S/\sqrt{B}$=27 (5) (cotθ=0.5)
	$\rightarrow W^{\pm}h$	$\rightarrow qq\ \gamma\gamma$	
	$\rightarrow \ell^{\pm}\nu\ b\bar{b}$		M=1 TeV : $S/\sqrt{B}$=69 (cotθ=0.5)
$\phi^{++} \rightarrow W^+W^+ \rightarrow \ell^+\ell^+\nu\nu$			M=1.5 TeV : visible at 5σ for v' > 67GeV
$\rightarrow \tau^+\tau^+ \rightarrow 3b\ \ell^+\nu$			M=0.7→1.5 TeV : visible at 5σ for $\sigma.BR(\phi^{++} \rightarrow \tau^+\tau^+) > 2$fb

discovery channel

test of the model

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

Conclusions

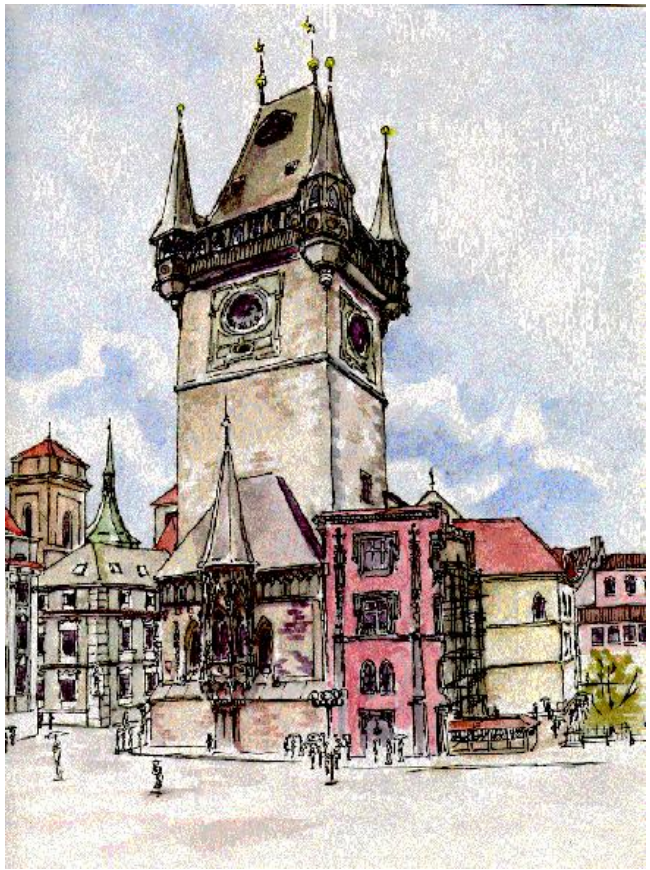
Work also done on following channels:

(but no time to show)

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

The search for particles predicted by the Little Higgs models using the ATLAS detector has started.

A large part of parameter space will be covered.



Additionnal slides

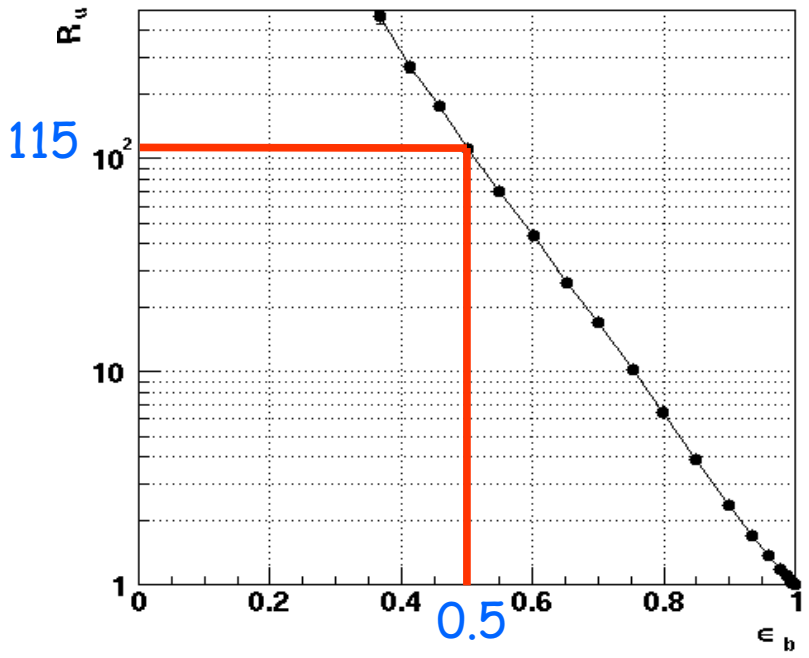
- b-tagging for $Z_H \rightarrow Zh$ *with* $h \rightarrow bb$

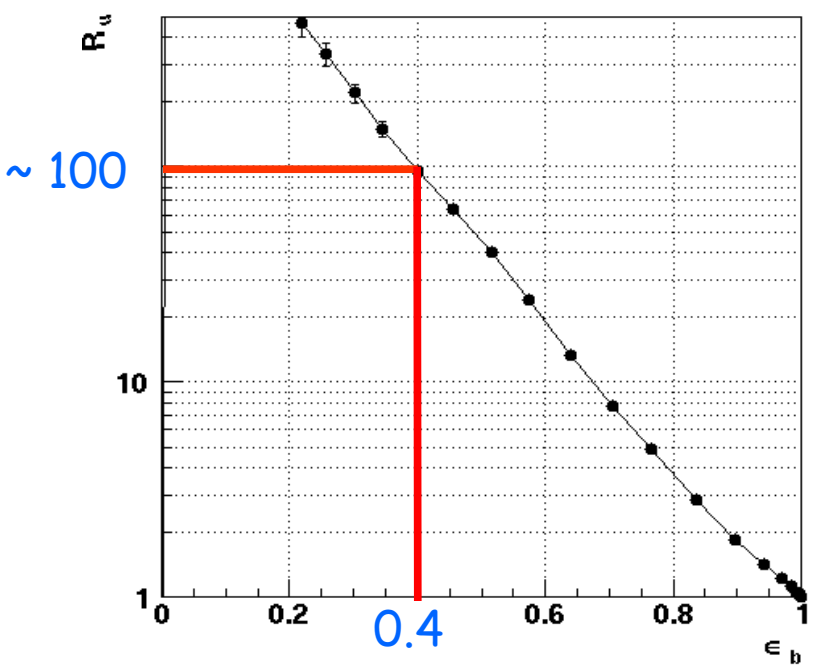
- without reconstructing W/Z for $W_H / Z_H \rightarrow W/Z\ h$ *with* $h \rightarrow \gamma\gamma$

b-tagging

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

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



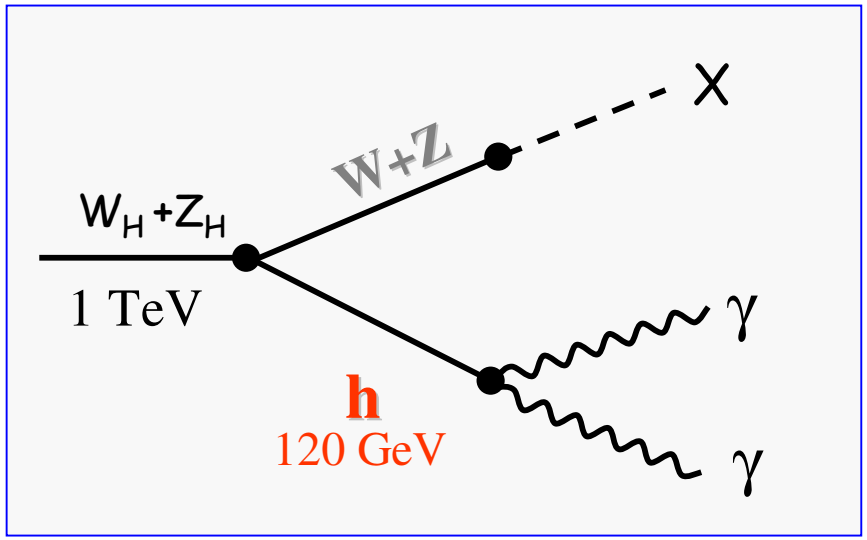


WH(400) from DC1 data

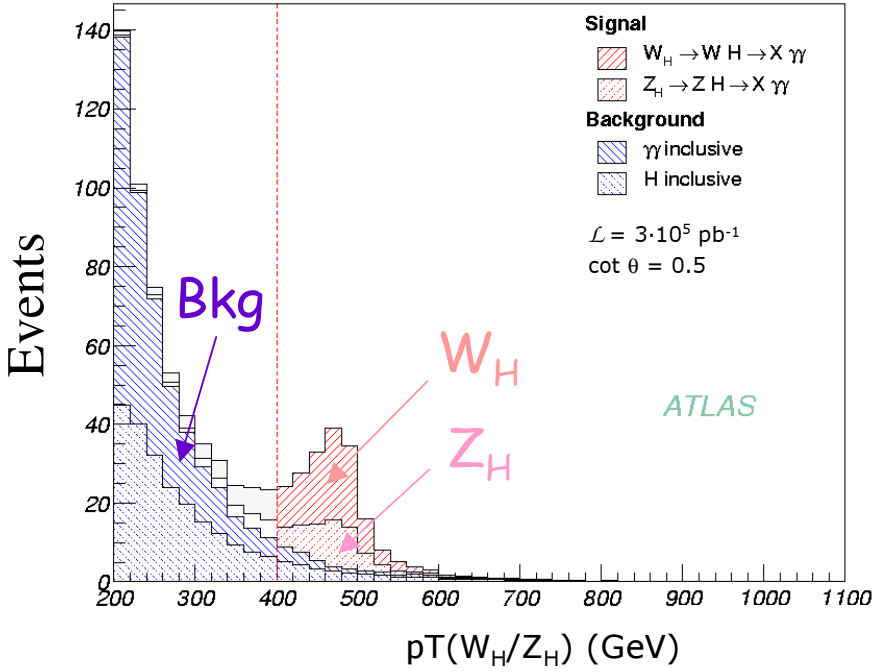
→ $b\bar{b}$

Full simulation of double *b*-jets

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



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



Cuts

$|\eta(\gamma)| < 2.5$ $\quad P_T(\gamma) > 25$ GeV

$m(h) \approx 120$ GeV $\quad P_T(h) > 400$ GeV

γ-tagging, $\varepsilon(\gamma) = 80\%$

Background: $h(\rightarrow\gamma\gamma)$ inclusive
$\gamma\gamma$ inclusive

$S(W_H \rightarrow Wh) = 107$
$S(Z_H \rightarrow Zh) = 53$ } 160

$B(h$ inclusive$) = 31$
$B(\gamma\gamma$ inclusive$) = 17$ } 48

$$\frac{S}{\sqrt{B}} = 23$$