

Signatures with multiple b-jets in the Left-Right twin higgs model

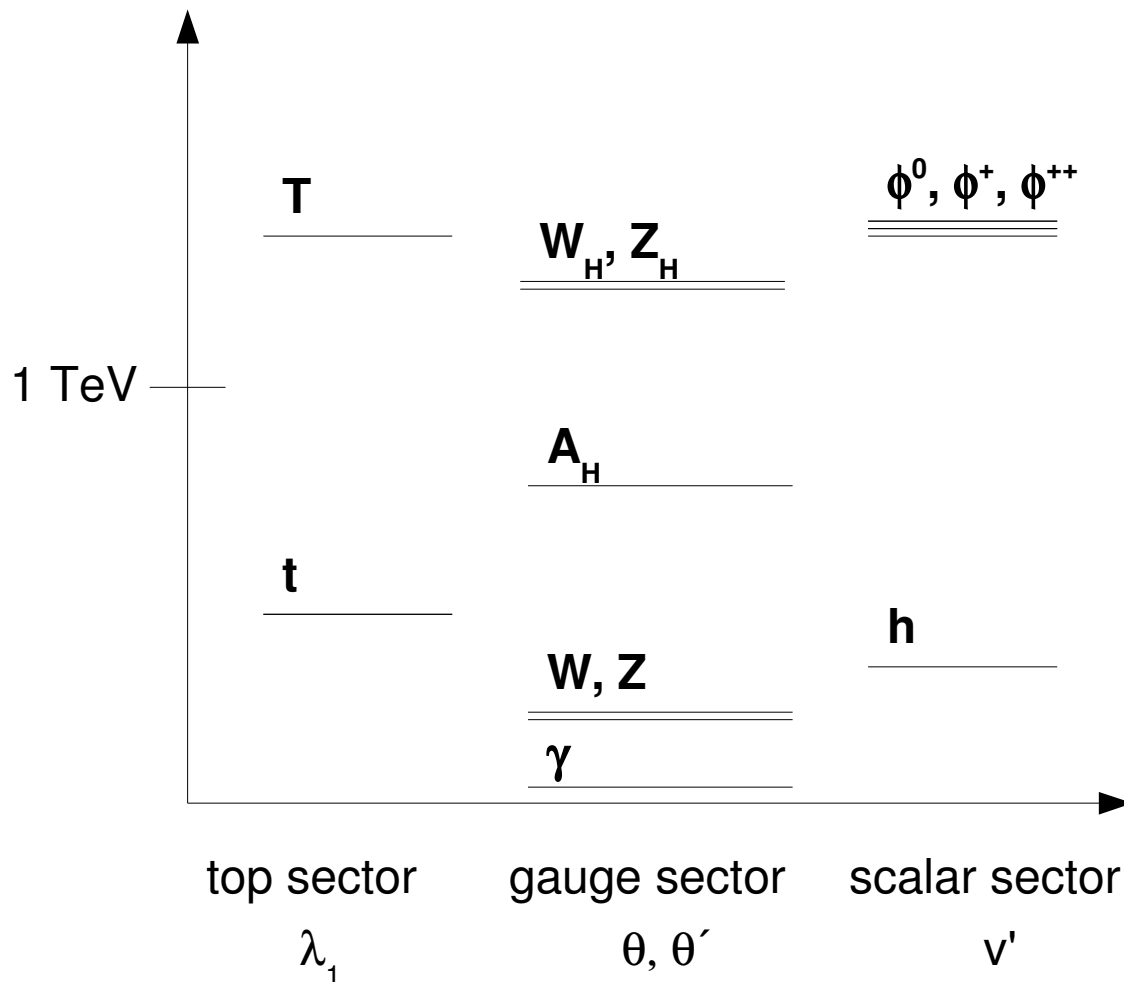
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ATLAS exotics WG – 6th june 2007

Particle spectrum – Little Higgs

Symmetry

$$SU(5) \rightarrow [SU(2) \otimes U(1)]^2$$



→ masses of T, W_H, Z_H, ϕ not fixed by the model

→ After fixing the masses, free parameters ($\lambda_1, \theta, \theta', v'$) remain that affect cross-sections

→ W_H is LEFT-handed

Theory: Arkani-Hamed et al.

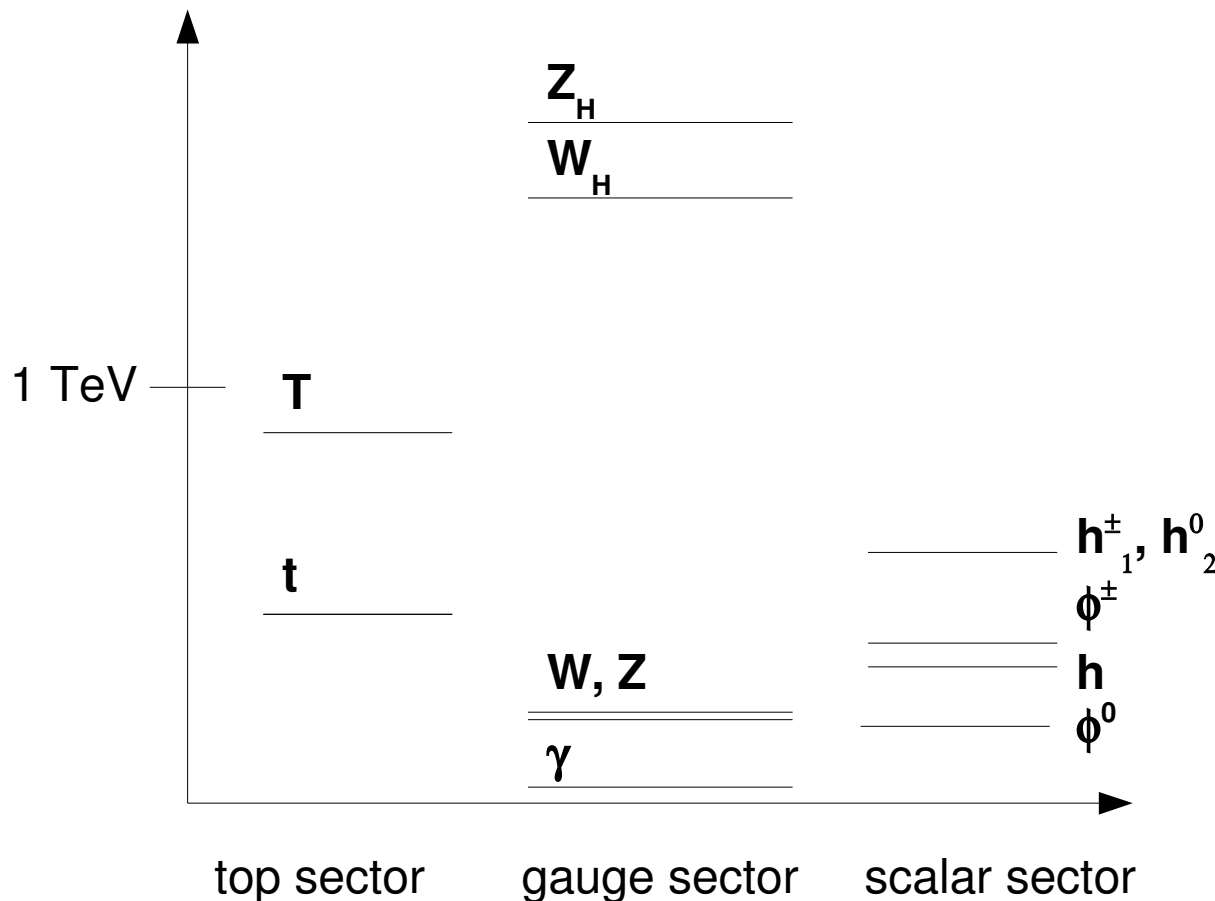
Phenomenology:

Han et al.

Particle spectrum – twin Higgs

Symmetry

$$U(4) \otimes U(4) \rightarrow SU(2)_L \otimes SU(2)_R \otimes U(1)$$



- masses of T , W_H , Z_H , ϕ , h not fixed by the model
- After fixing the masses, **NO** free parameters remain, cross-sections can be computed
- No A_H (photon partner)
- More complex scalar sector (h^0_2 is dark matter candidate)
- W_H is RIGHT-handed

Theory: Chacko et al.

Phenomenology:

Goh and Su, hep-ph/0508330

Phenomenology – little Higgs

$$Z_H \rightarrow e^+e^- \quad \text{BR} \sim 4\%$$

$$W_H \rightarrow e\nu_e \quad \text{BR} \sim 8\%$$

mass reach ~ 5 TeV ($\cot \theta = 1$)

Other decays:

$$W_H \rightarrow tb \quad \text{BR} \sim 25\%$$

mass reach ~ 2.5 TeV ($\cot \theta = 1$)

Model test:

$$Z_H \rightarrow Zh \rightarrow l^+l^-bb$$

mass reach ~ 2 TeV ($\cot \theta = 0.3$,
decay absent for $\cot \theta = 1$)

ATLAS study published in:
EPJ C39S2, 13 (2005)

Other studies:

ATL-PHYS-2006-003

Phenomenology – LR twin Higgs

$$Z_H \rightarrow e^+e^-$$

BR ~ 2.5 %

$$W_H \rightarrow e \nu_R$$

not considered

Other decays ($W_H \rightarrow tb$ is suppressed):

$$W_H \rightarrow T b$$

$$\hookrightarrow \phi^\pm b$$

$$\hookrightarrow t b$$

$$\hookrightarrow W b$$

$$\hookrightarrow l \nu$$

$$W_H \rightarrow \phi^\pm \phi^0$$

$$\hookrightarrow b b$$

$$\hookrightarrow t b$$

$$\hookrightarrow W b$$

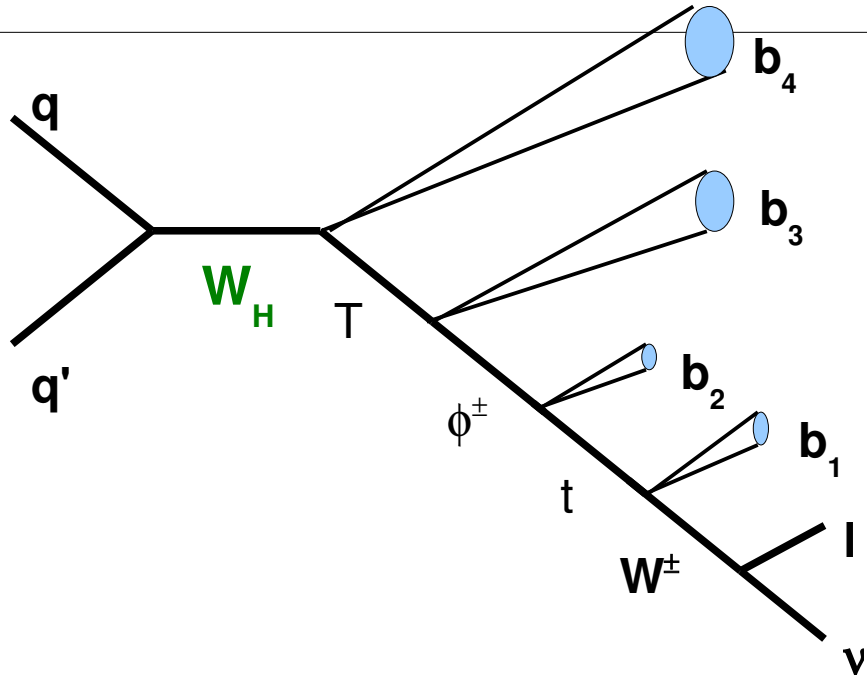
$$\hookrightarrow l \nu$$

Absence of W_H leptonic decay may allow to distinguish Little Higgs from LR twin Higgs

Signature: $4 b + l + E_T^{\text{miss}}$

These decays provide a model test (not present in Little Higgs)

Signature for $W_H (1 \text{ TeV}/c^2) \rightarrow T b$

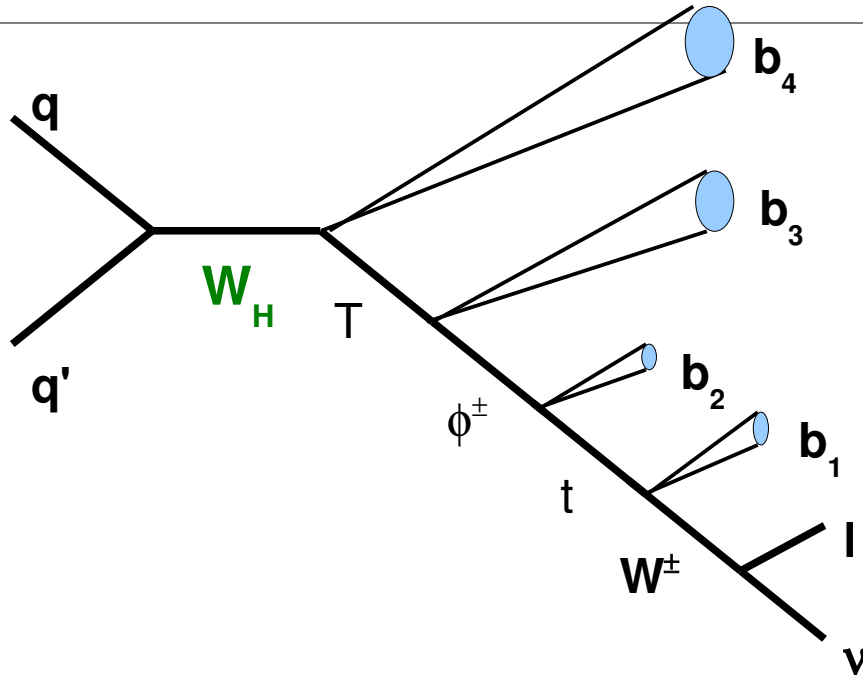


	$\langle p_T \rangle$ (GeV)
b_1	95
b_2	34
b_3	201
b_4	277
l	67
ν	80

particle	mass (GeV)	decay	BR
W_H	1000	Tb	(20%)
T	500	$\phi^\pm b$	(80%)
ϕ^\pm	200	tb	(100%)
t	175	Wb	(100%)
W	80	$l\nu$	(21%)

Simulation: Pythia + ATLFAST
X-section: $\sigma = 30 \text{ pb} \times \text{BR}$
Background: $tt, W+\text{jets}$
Luminosity: $L = 30 \text{ fb}^{-1}$

$W_H (1 \text{ TeV}/c^2) \rightarrow \text{Tb}$ selection cuts



Efficiency (kin. cuts only):

$$\varepsilon_{\text{kin}} \sim 12 \%$$

Reconstruct masses

$$l + \nu \rightarrow W \quad p_T(l) > 25 \text{ GeV}/c,$$

$$E_T^{\text{miss}} > 25 \text{ GeV}/c$$

assume $p_z^\nu // p_z^l$ to reconstruct W

$\varepsilon_l = 90\%$ (trigger + lepton ID)

$$W + b_1 \rightarrow t \quad 25 < p_T(b_1) < 200 \text{ GeV}/c$$

$$t + b_2 \rightarrow \phi^\pm \quad 25 < p_T(b_2) < 100 \text{ GeV}/c$$

$$\phi^\pm + b_3 \rightarrow T \quad p_T(b_3) > 100 \text{ GeV}/c$$

$$T + b_4 \rightarrow W_H \quad p_T(b_4) > 150 \text{ GeV}/c$$

$|\eta| < 2.5$ for all leptons and jets

Additional cuts

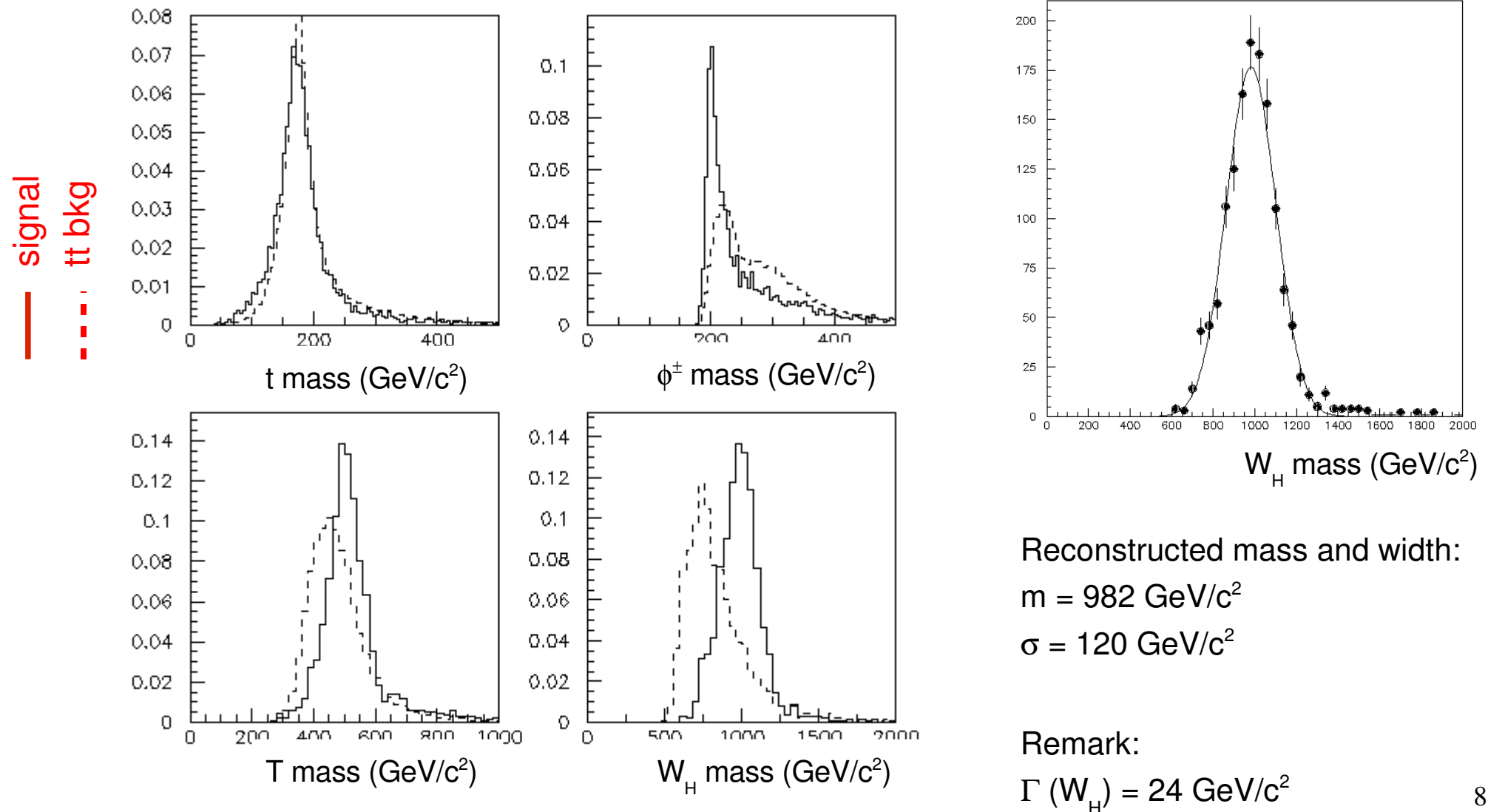
$$m(t) < 250 \text{ GeV}/c^2$$

$$m(\phi^\pm) < 250 \text{ GeV}/c^2$$

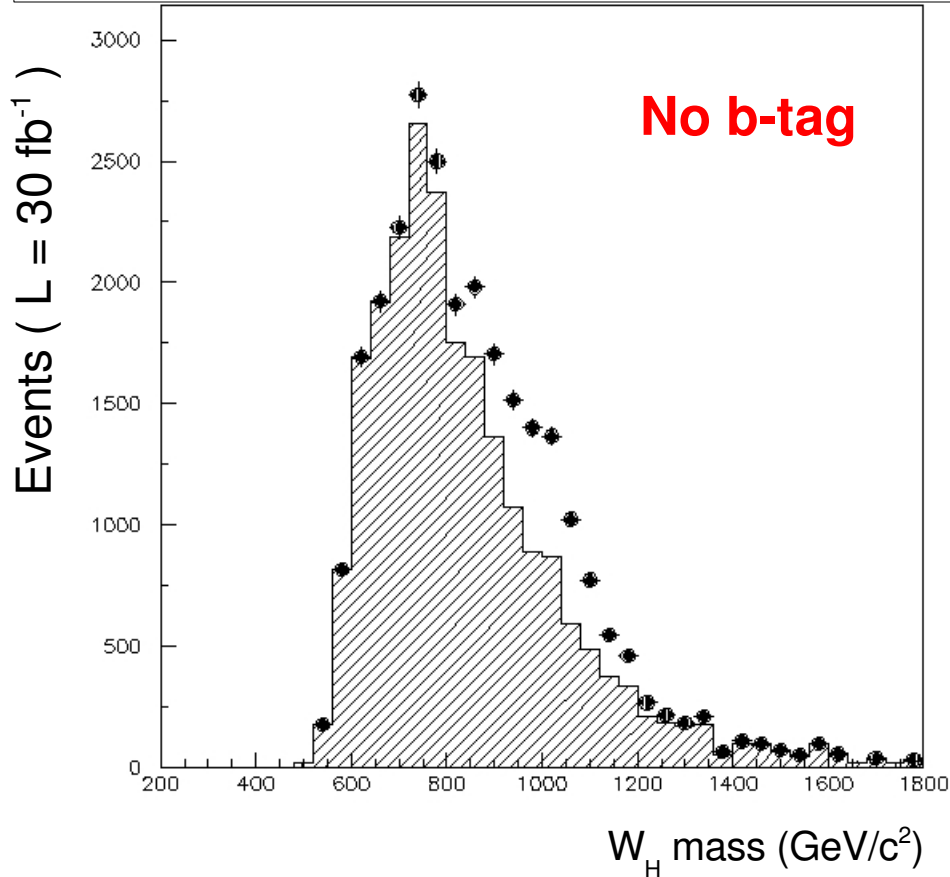
$$m(T) < 700 \text{ GeV}/c^2$$

$$p_T(T) > 150 \text{ GeV}/c \text{ (jacobian peak)}$$

$W_H (1 \text{ TeV}/c^2) \rightarrow T b$ mass reconstruction



W_H (1 TeV/c²) \rightarrow Tb signal/bkg for L=30 fb⁻¹

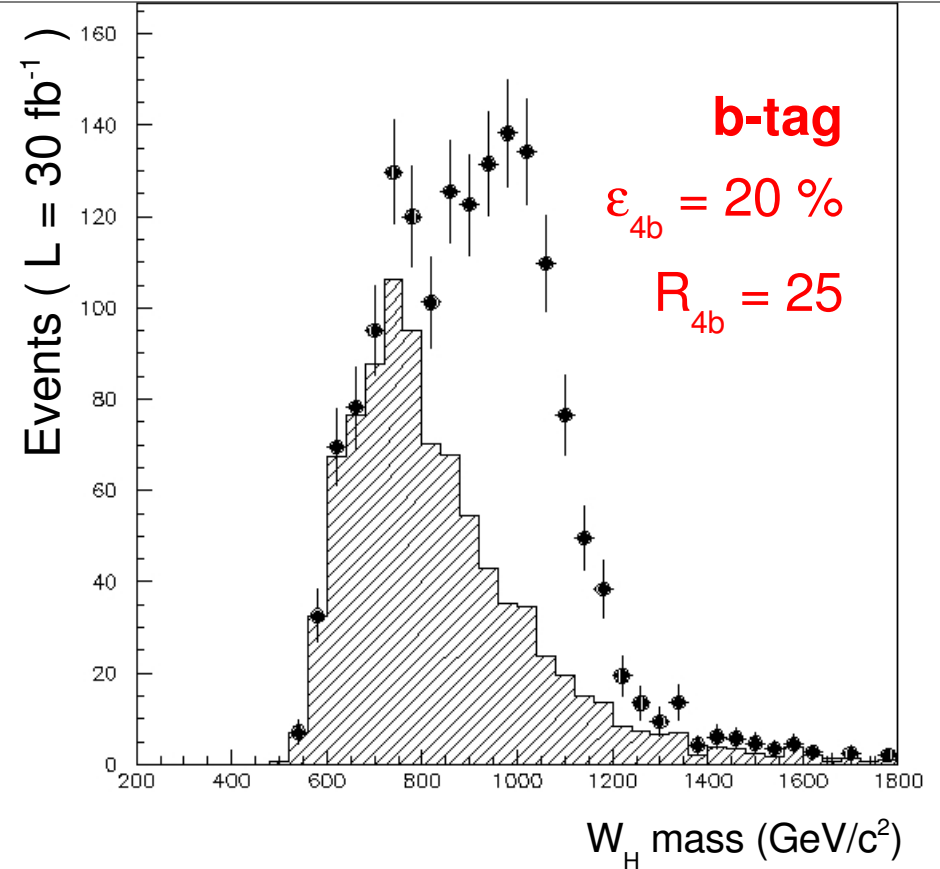


$$N_{\text{sig}} = 3253$$

$$N_{\text{tt}} = 9427$$

$$N_{\text{wj}} = 319$$

$$N/\sqrt{B} = 33$$



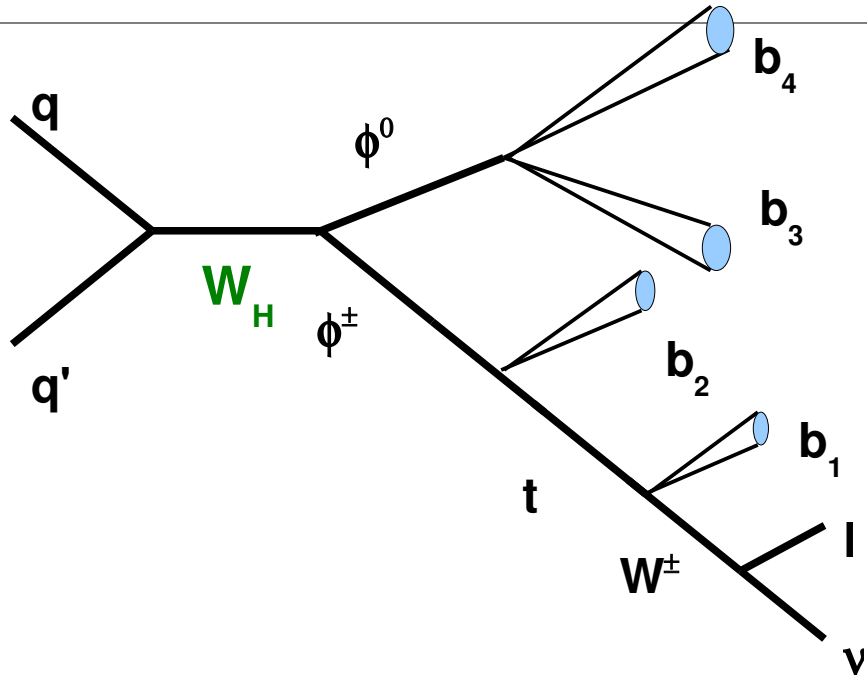
$$N_{\text{sig}} = 651$$

$$N_{\text{tt}} = 377$$

$$N_{\text{wj}} \sim 0$$

$$N/\sqrt{B} = 33$$

Signature for $W_H (1 \text{ TeV}/c^2) \rightarrow \phi^\pm \phi^0$

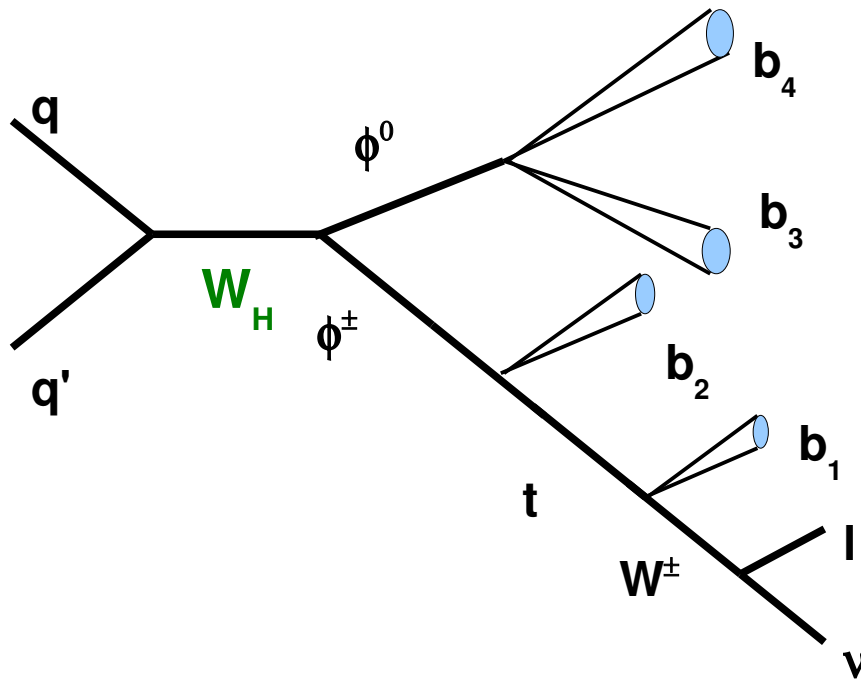


	$\langle p_T \rangle$ (GeV)
b_1	148
b_2	52
b_3	200
b_4	200
l	100
ν	121

particle	mass (GeV)	decay	BR
W_H	1000	$\phi^\pm \phi^0$	(3%)
ϕ^\pm	200	tb	(100%)
ϕ^0	100	bb	(80%)
t	175	bW	(100%)
W	80	lv	(21%)

Simulation: Pythia + ATLFAST
X-section: $\sigma = 30 \text{ pb} \times \text{BR}$
Background: tt, W+jets
Luminosity: $L = 30 \text{ fb}^{-1}$

$W_H (1 \text{ TeV}/c^2) \rightarrow \phi^\pm \phi^0$ selection cuts



Efficiency (kin. cuts only):

$$\epsilon_{\text{kin}} \sim 8 \%$$

Reconstruct masses

$$l + \nu \rightarrow W \quad p_T(l) > 25 \text{ GeV}/c,$$

$$E_T^{\text{miss}} > 25 \text{ GeV}/c$$

assume $p_z^\nu \parallel p_z^l$ to reconstruct W

$$\epsilon_l = 90\% \text{ (trigger + lepton ID)}$$

$$W + b_1 \rightarrow t \quad 25 < p_T(b_1) < 300 \text{ GeV}/c$$

$$t + b_2 \rightarrow \phi^\pm \quad 25 < p_T(b_2) < 150 \text{ GeV}/c$$

$$b_3 + b_4 \rightarrow \phi^0 \quad p_T(b_3, b_4) > 25 \text{ GeV}/c$$

$$\phi^\pm + \phi^0 \rightarrow W_H$$

$$|\eta| < 2.5 \text{ for all leptons and jets}$$

Additional cuts

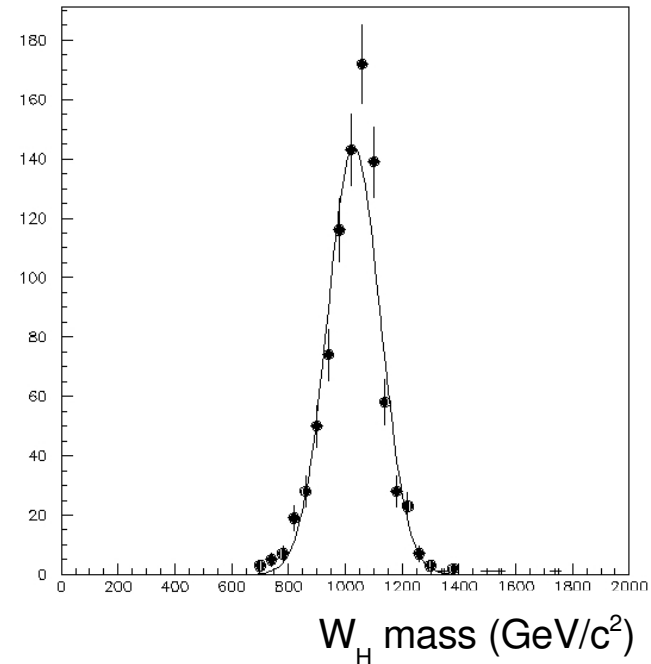
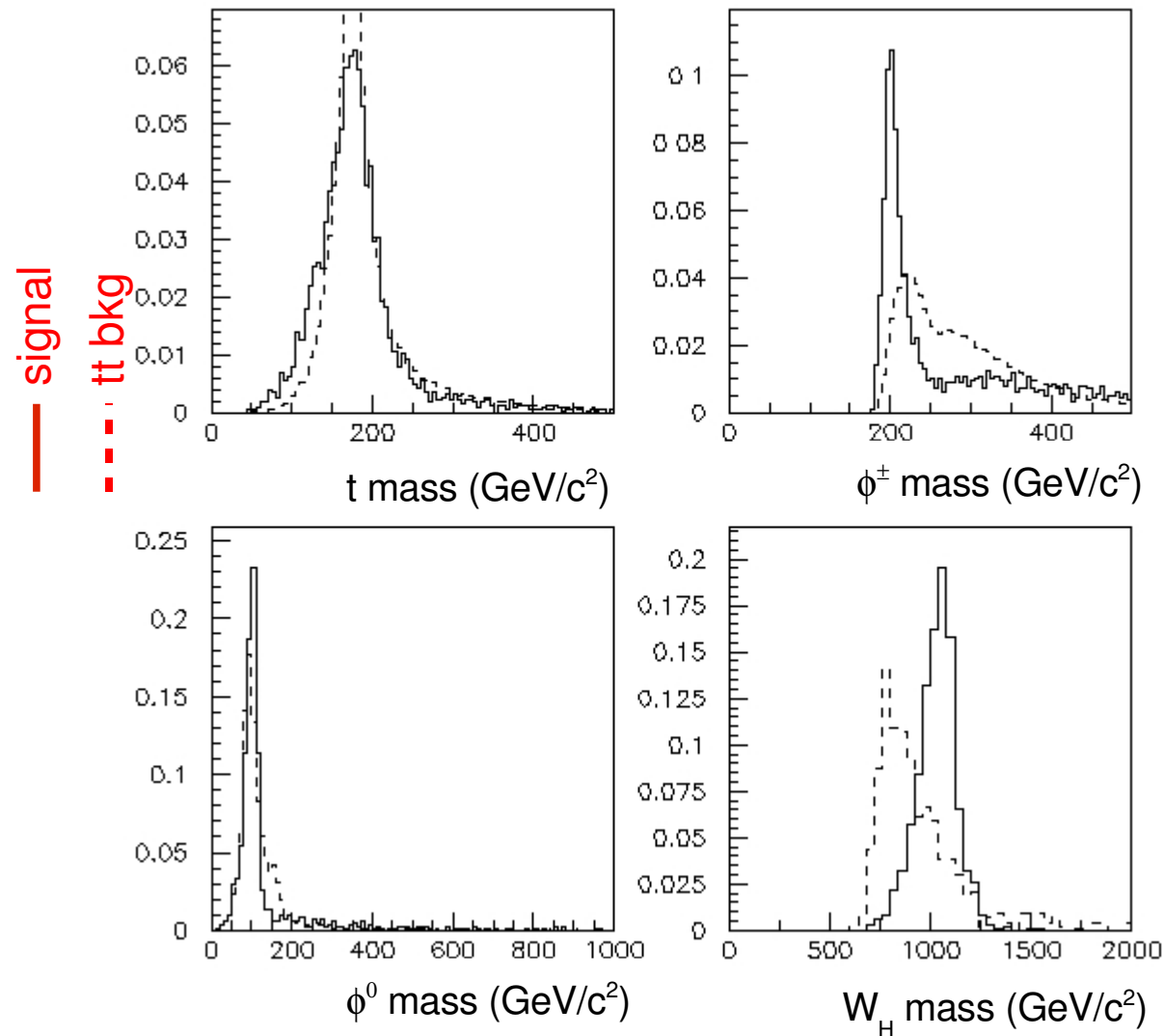
$$m(t) < 250 \text{ GeV}/c^2$$

$$m(\phi^\pm) < 250 \text{ GeV}/c^2$$

$$m(\phi^0) < 150 \text{ GeV}/c^2$$

$$p_T(\phi^\pm, \phi^0) > 300 \text{ GeV}/c \text{ (jacobian peak)}$$

$W_H (1 \text{ TeV}/c^2) \rightarrow \phi^\pm \phi^0$ mass reconstruction



Reconstructed mass and width:

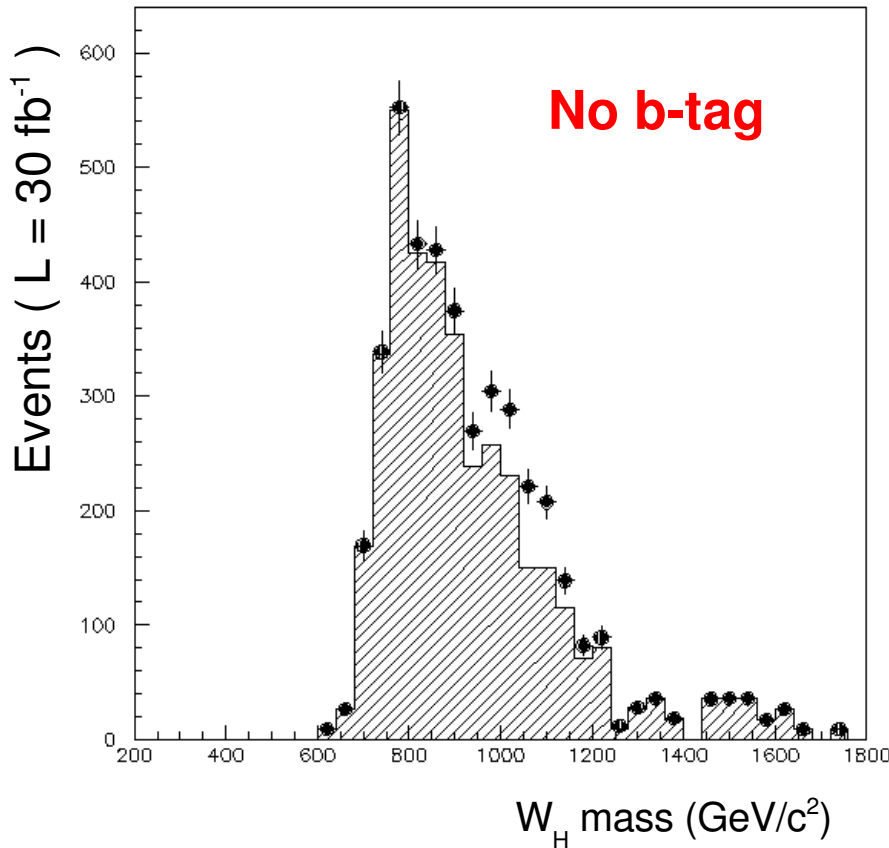
$$m = 1030 \text{ GeV}/c^2$$

$$\sigma = 93 \text{ GeV}/c^2$$

Remark:

$$\Gamma(W_H) = 24 \text{ GeV}/c^2$$

$W_H (1 \text{ TeV}/c^2) \rightarrow \phi^\pm \phi^0$ signal/bkg for $L=30 \text{ fb}^{-1}$

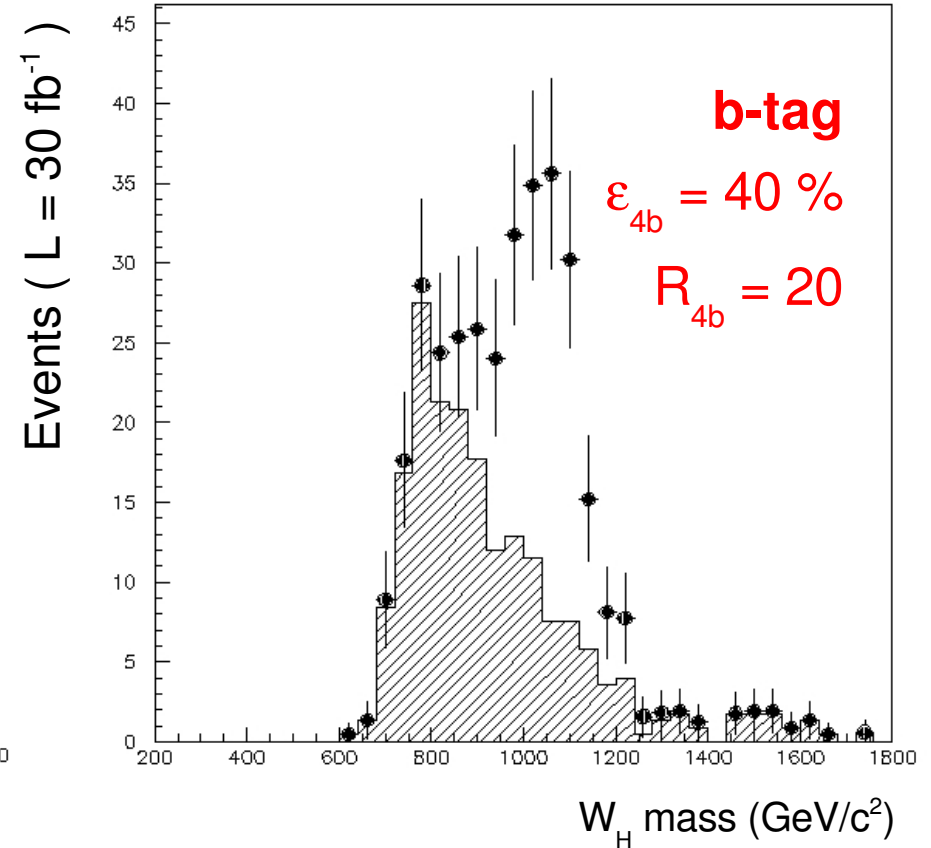


$$N_{\text{sig}} = 337$$

$$N_{\text{tt}} = 1958$$

$$N_{\text{wj}} = 171$$

$$N/\sqrt{B} = 7$$



$$N_{\text{sig}} = 135$$

$$N_{\text{tt}} = 98$$

$$N_{\text{wj}} \sim 0$$

$$N/\sqrt{B} = 14$$

other W_H ($1\text{TeV}/c^2$) decays

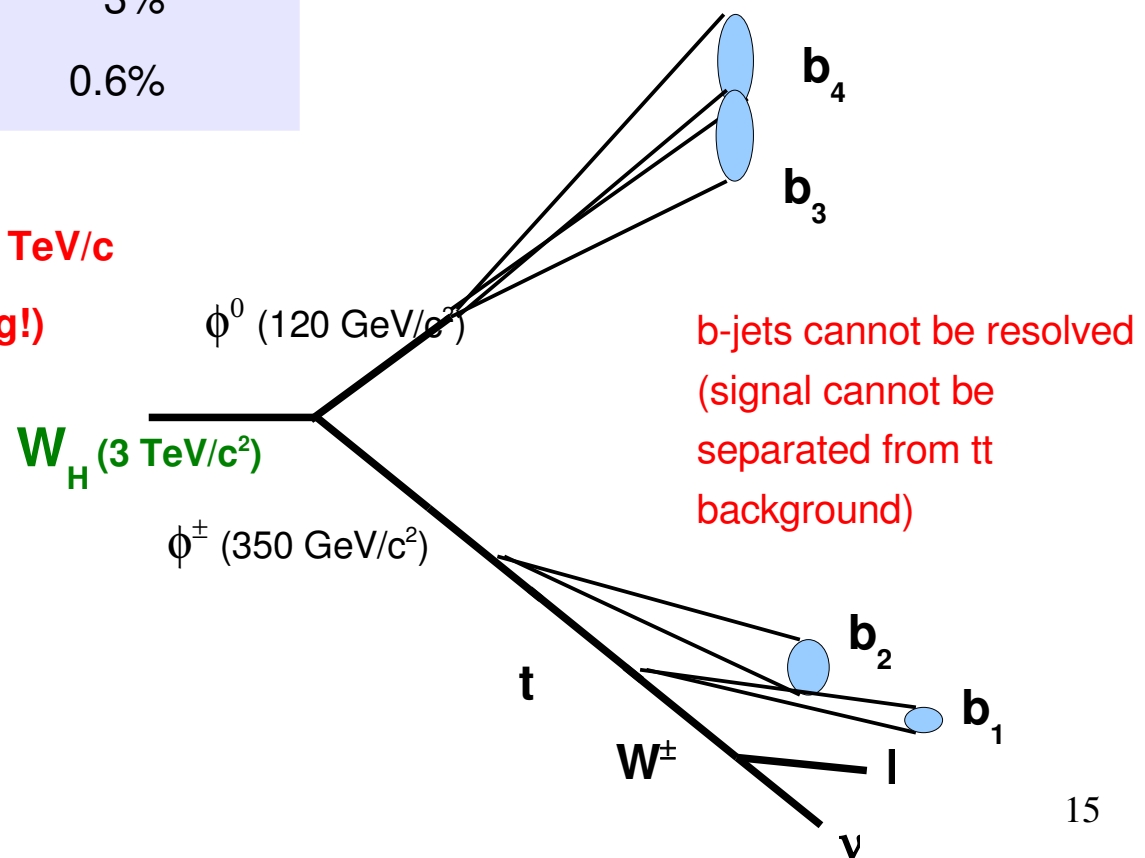
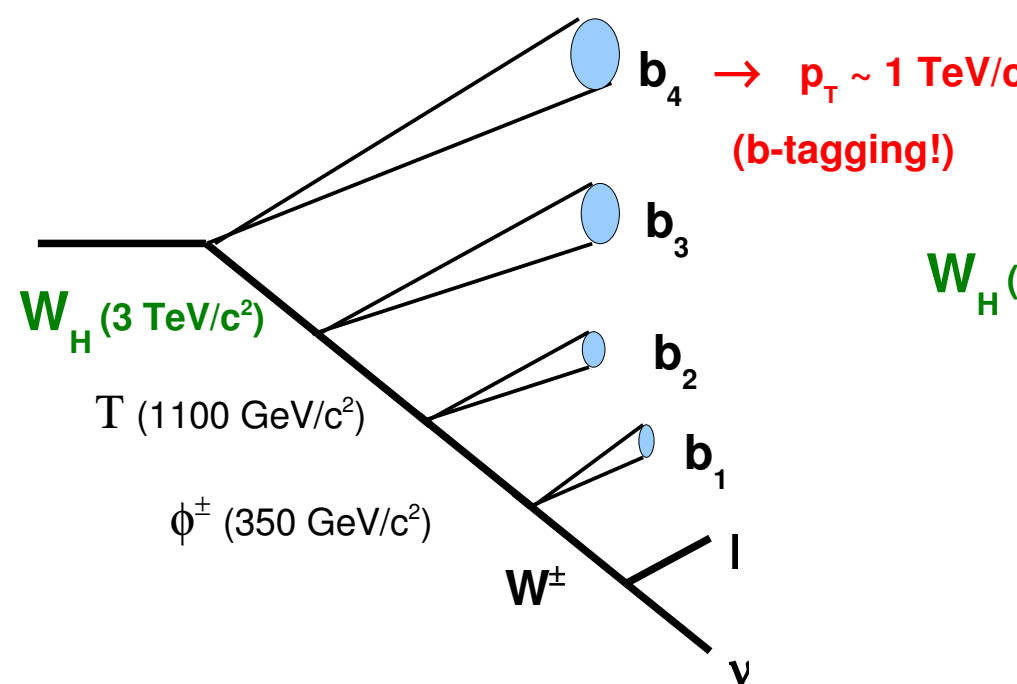
Decay	signature	total B.R.	comment
$W_H \rightarrow Tb \rightarrow \phi^\pm bb$	$\rightarrow 4b + l + E_t^{\text{miss}}$	3.2 %	<u>this contribution</u>
$\rightarrow bWb$	$\rightarrow 2b + l + E_t^{\text{miss}}$	0.4 %	
$\rightarrow thb$	$\rightarrow 4b + l + E_t^{\text{miss}}$	0.4 %	
$\rightarrow tZb$	$\rightarrow 2b + 3l + E_t^{\text{miss}}$	0.01 %	very small rate/no bkg.
$\rightarrow t\phi^0 b$	$\rightarrow 4b + l + E_t^{\text{miss}}$	0.1 %	
$\rightarrow tb$	$\rightarrow 2b + l + E_t^{\text{miss}}$	0.8 %	cf. LittleHiggs BR=5%
$\rightarrow \phi^\pm \phi^0$	$\rightarrow 4b + l + E_t^{\text{miss}}$	0.5 %	<u>this contribution</u>
$\rightarrow qq$	$\rightarrow 2 \text{ jets}$	73 %	QCD di-jet background

Twin Higgs decay table for $M=150\text{ GeV}$ [M is T-t mixing parameter]

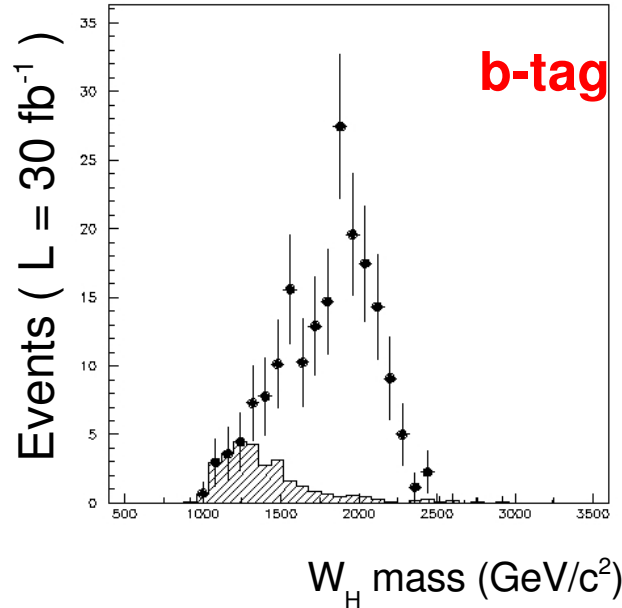
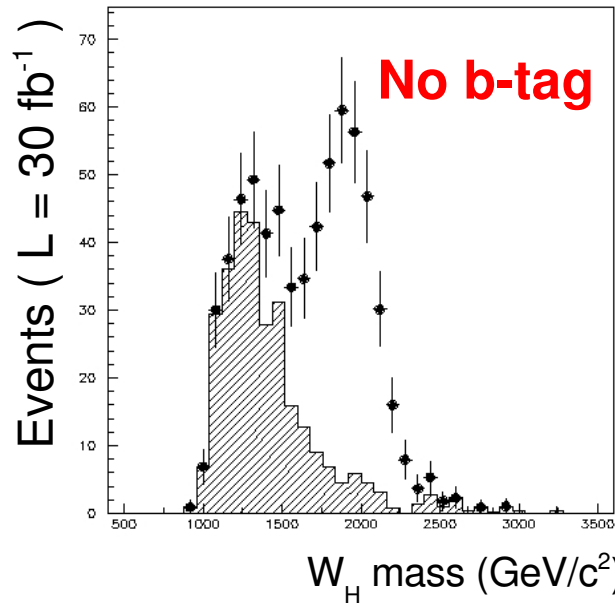
Remark: None of the above decays are visible for $M \rightarrow 0$

Mass dependence

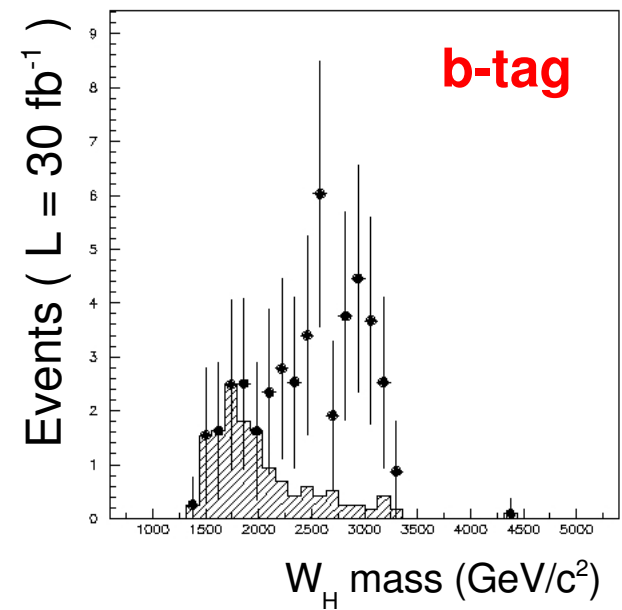
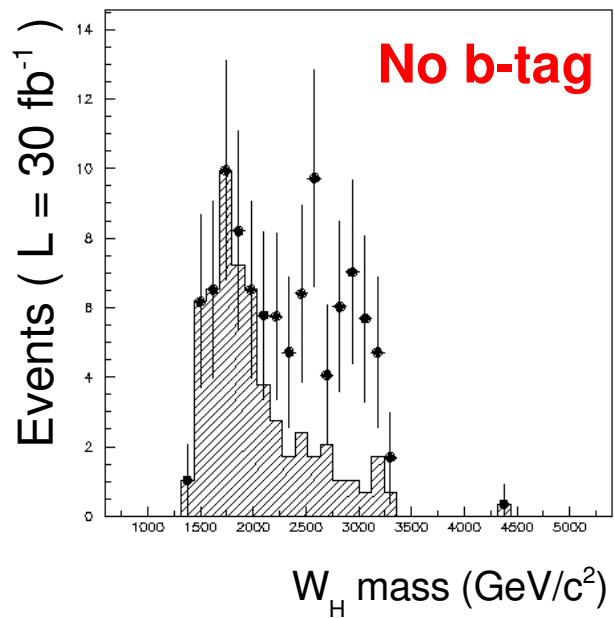
$m(W_H)$	1 TeV/c ²	2 TeV/c ²	3 TeV/c ²
$\sigma(\text{pb})$	30	2	0.2
$M_T (\text{GeV}/c^2)$	500	800	1100
BR ($W_H \rightarrow T\mathbf{b}$)	20%	25%	25%
BR ($W_H \rightarrow \phi^\pm\phi^0$)	3%	3%	3%
BR ($W_H \rightarrow t\mathbf{b}$)	4%	3%	0.6%



$W_H \rightarrow Tb, m(W_H) = 2,3 \text{ TeV}/c^2$

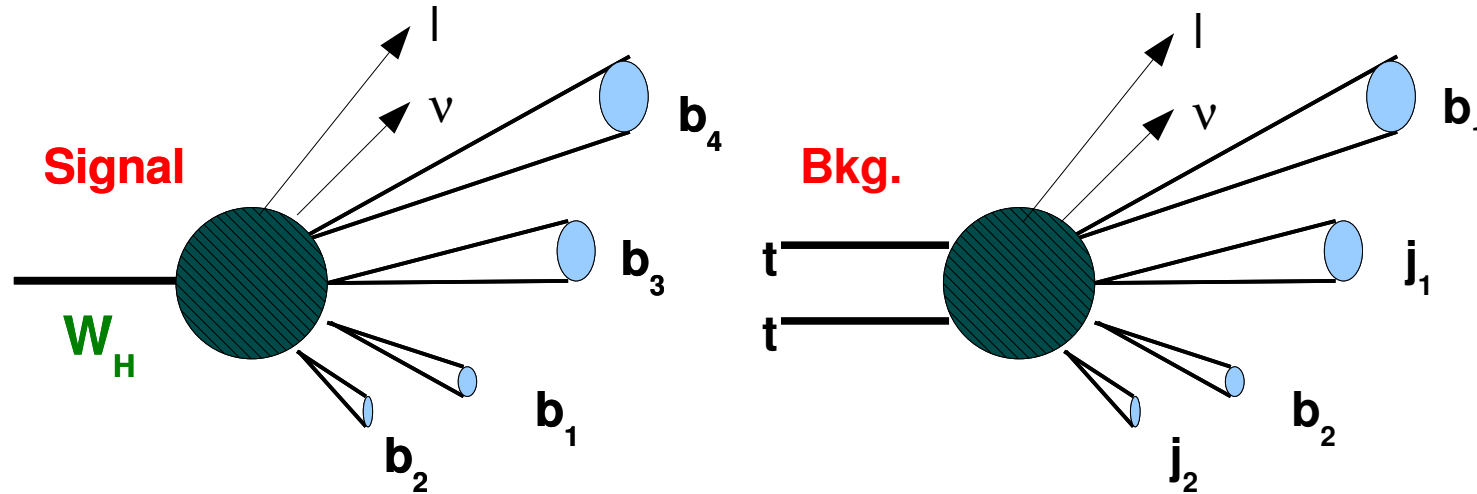


2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
N/\sqrt{B}	43	55



3 TeV	no b-tag	b-tag
N_{sig}	38.3	26.8
N_{tt}	11.3	2.8
N_{wj}	1.4	-
N/\sqrt{B}	11	16

b-tagging: multi-jet final states

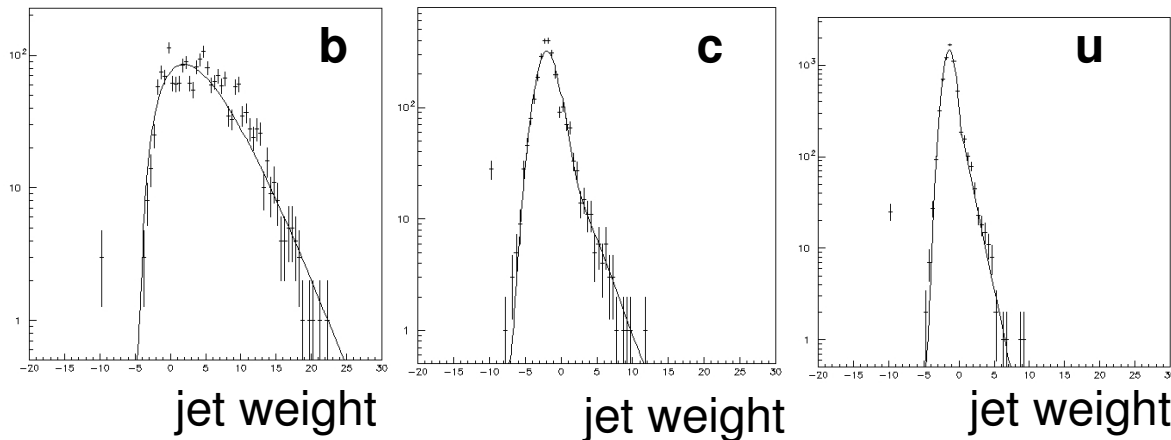


How to tag a signal of 4 b-jets against a background of 2 b + 2 j ?

Construct a 4 b-jet likelihood from individual jet weights.

b-tagging likelihood weights

b-tag likelihood “weights” for $60 < p_T < 100$ GeV/c (2D signed IP significance algorithm - DC1 data)



$$\epsilon_b = 50\%$$

$$p_T = 100 \text{ GeV/c} \rightarrow R_u = 130$$

$$p_T = 500 \text{ GeV/c} \rightarrow R_u = 60$$

Parameterisation

$$\text{b-jets} \rightarrow w^a e^{-bw}$$

$$\text{c-jets} \rightarrow w^c e^{-dw} + \text{gaussian}$$

$$\text{u-jets} \rightarrow e^{-ew} + \text{gaussian}$$

a,b,c,d,e determined on
full simulation for several
 p_T bins

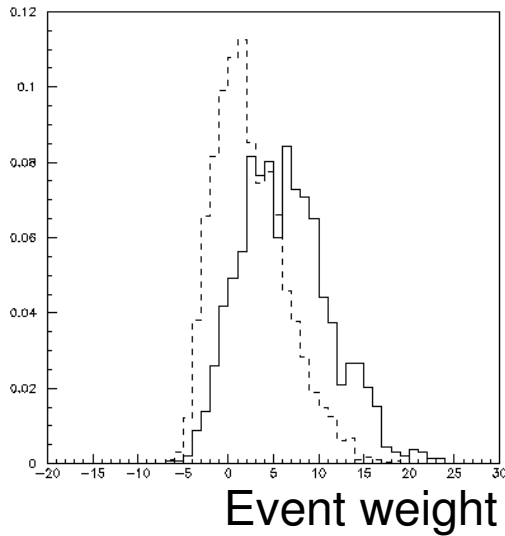
multi b-jet likelihood:

$$W_{\text{event}} = \sum_{\text{jets } j} w_j$$

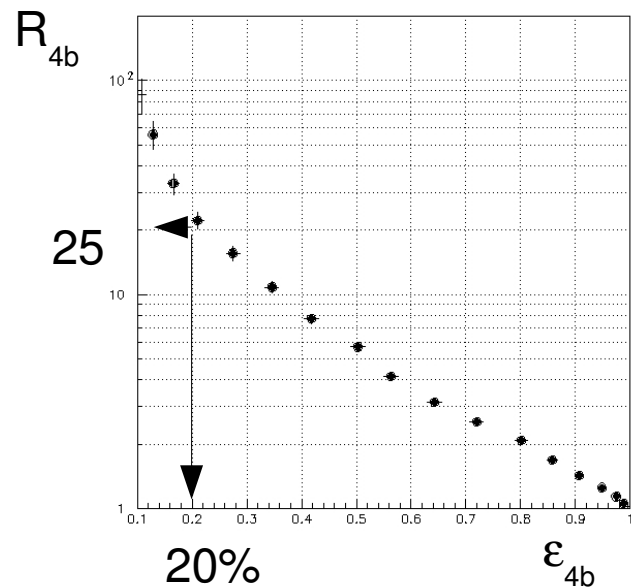
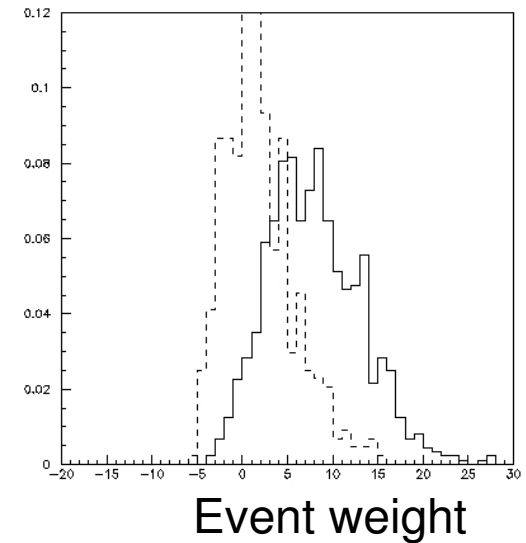
b-tagging for $m(W_H) = 1 \text{ TeV}/c^2$

$$W_H \rightarrow T_b \rightarrow 4b + l + E_t^{\text{miss}}$$

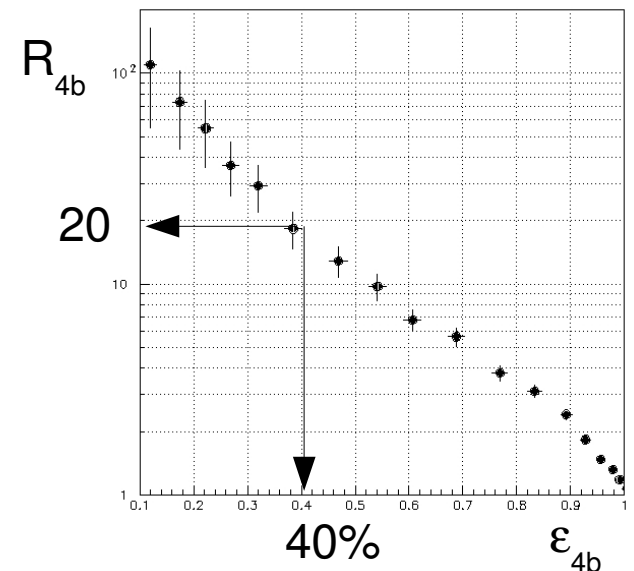
$$W_H \rightarrow \phi^\pm \phi^0 \rightarrow 4b + l + E_t^{\text{miss}}$$



— signal
- - - tt background



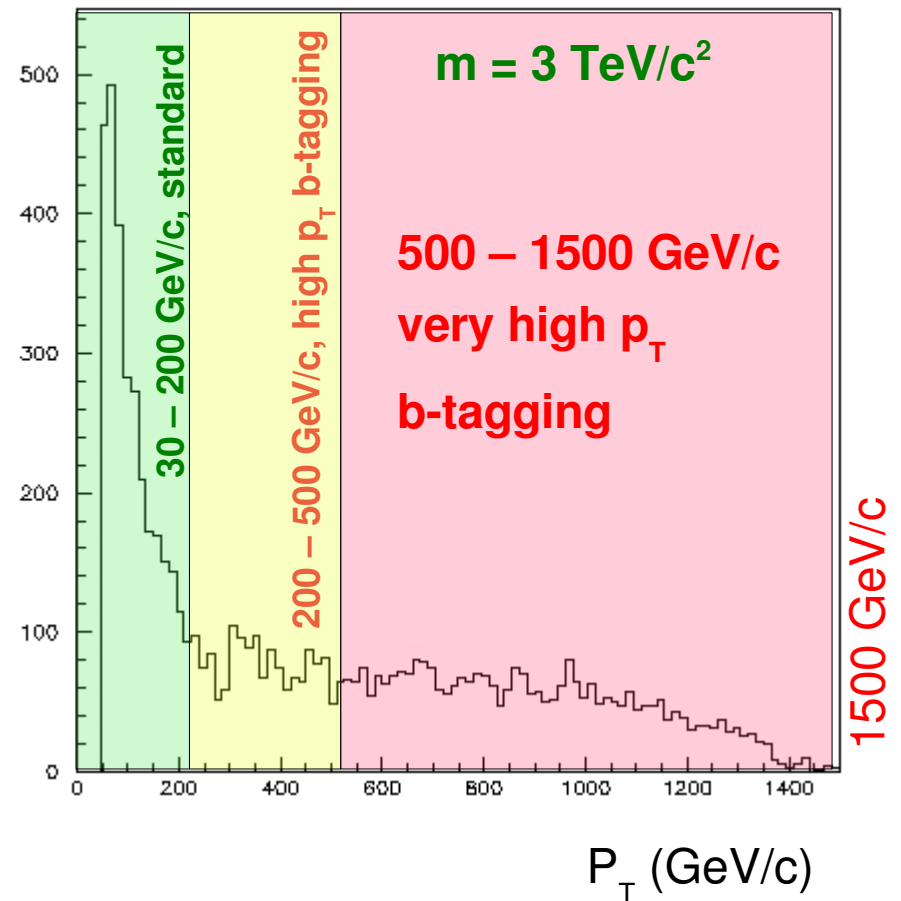
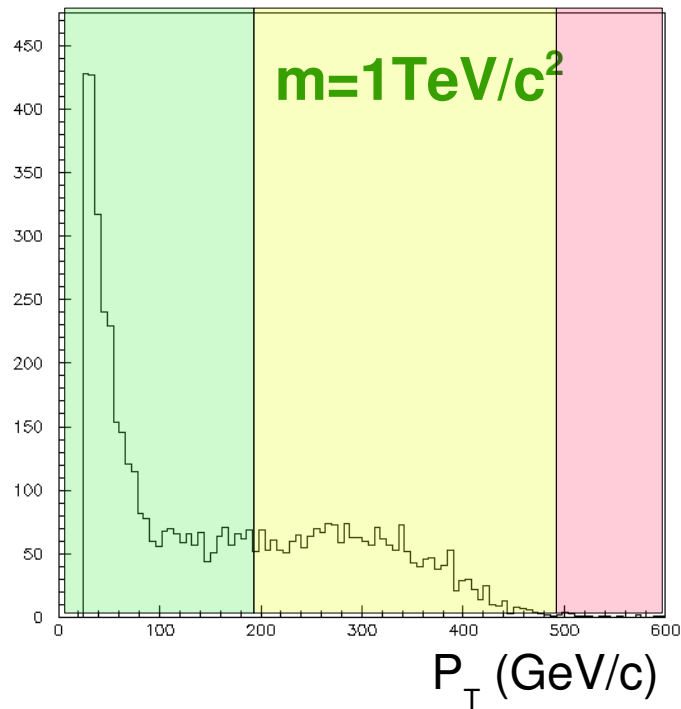
ϵ_{4b} = signal efficiency
 R_{4b} = rejection against
tt background



p_T distribution of b-jets

P_T spectrum for b-jets in

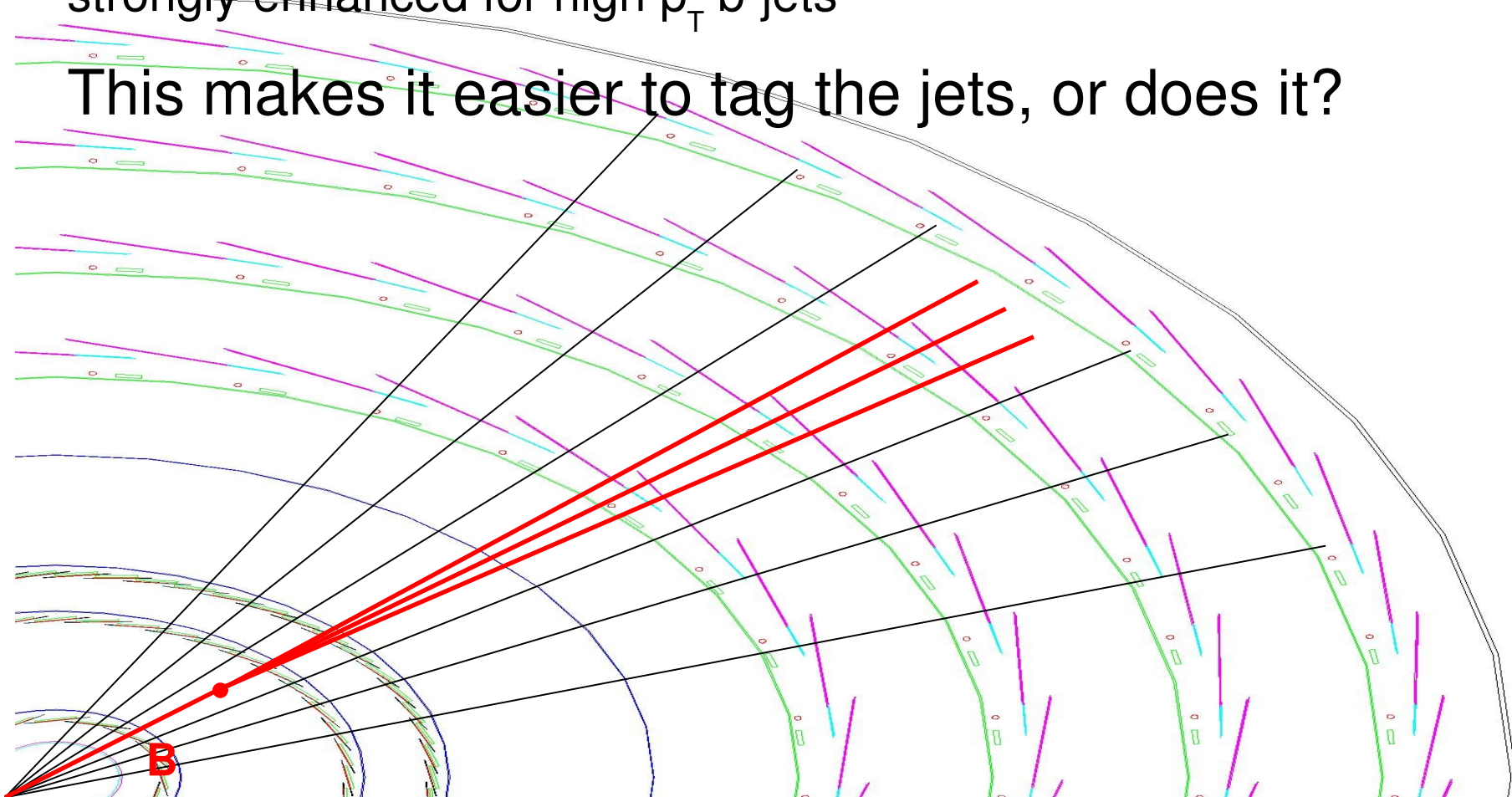
$$W_H \rightarrow T b \rightarrow 4 b + l + E_T^{\text{miss}}$$



Very high p_T b-tagging (I)

$L = c \tau \gamma \rightarrow$ THE experimental signature for b-tagging is strongly enhanced for high p_T b-jets

This makes it easier to tag the jets, or does it?

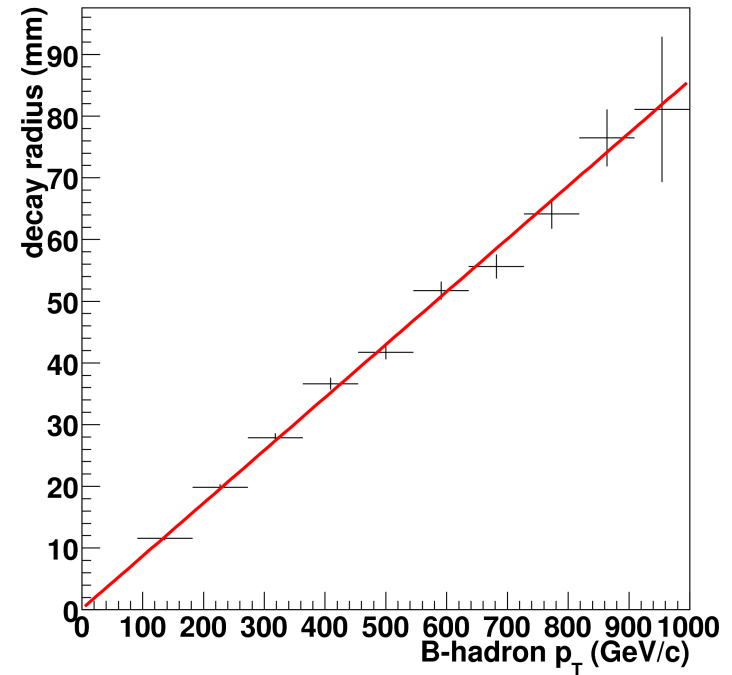
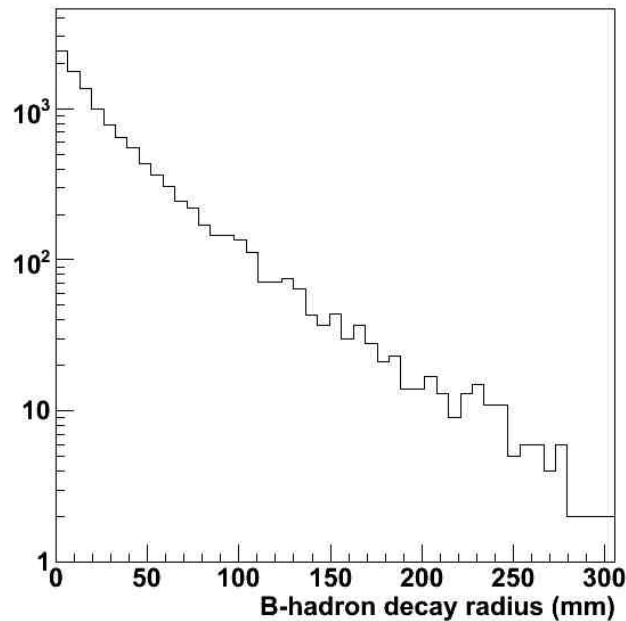


Very high p_T b-tagging (II)

$$L = c \tau \gamma$$

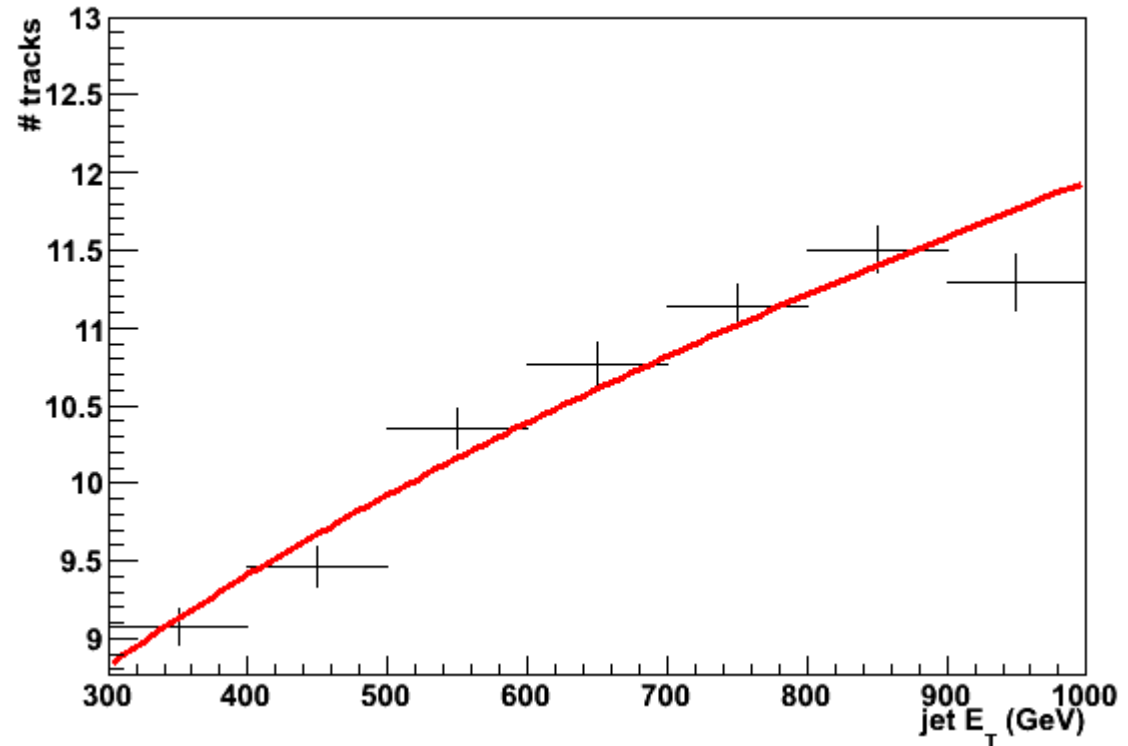
Average decay radius of B hadrons
versus B-hadron transverse
momentum


B-layer



Decay radius distribution for
B-hadrons in $Z' \rightarrow bb$ events
($m_{Z'} = 2 \text{ TeV}$)

Very high p_T b-tagging (III)



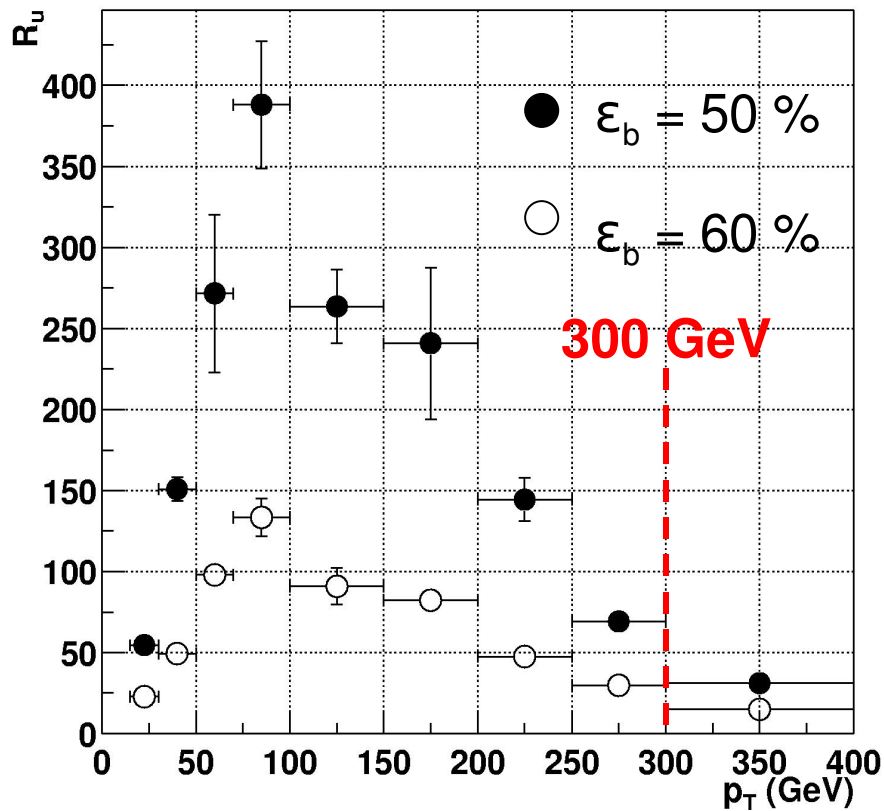
Number of tracks in jet (core) increases with jet E_T

jet core is getting very dense (shared hits in pixel detector)

tracks from B-decay = constant: relative weight tracks from B-decay decreases

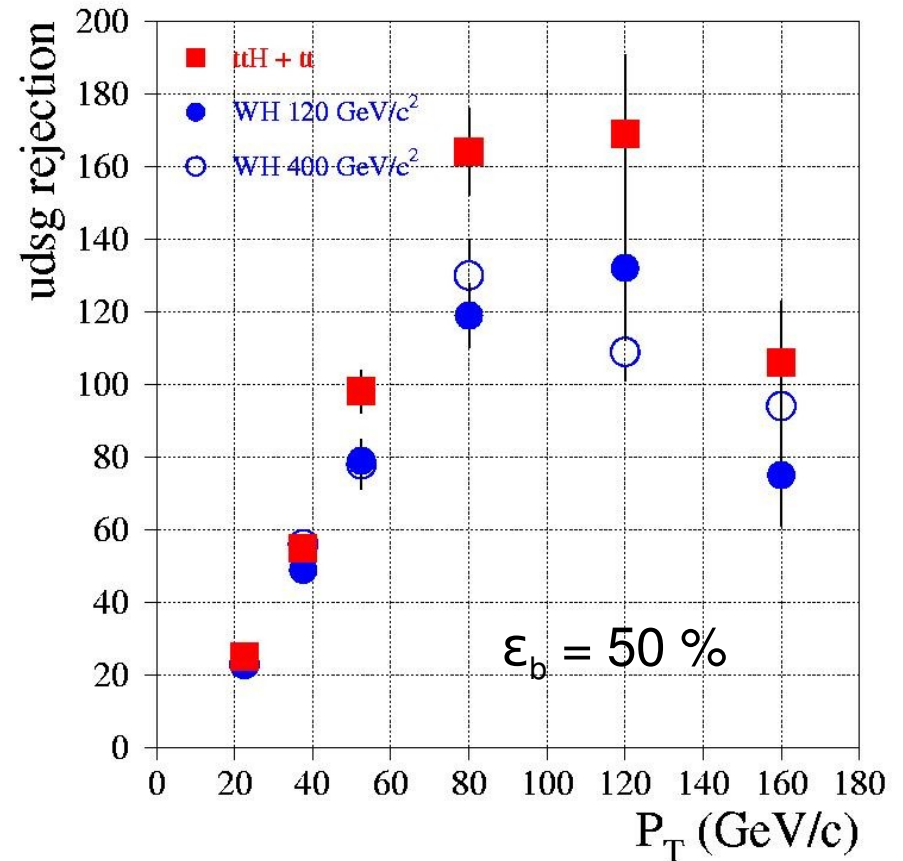
p_T dependence of b-tagging

ATL-COM-INDET-2003-017



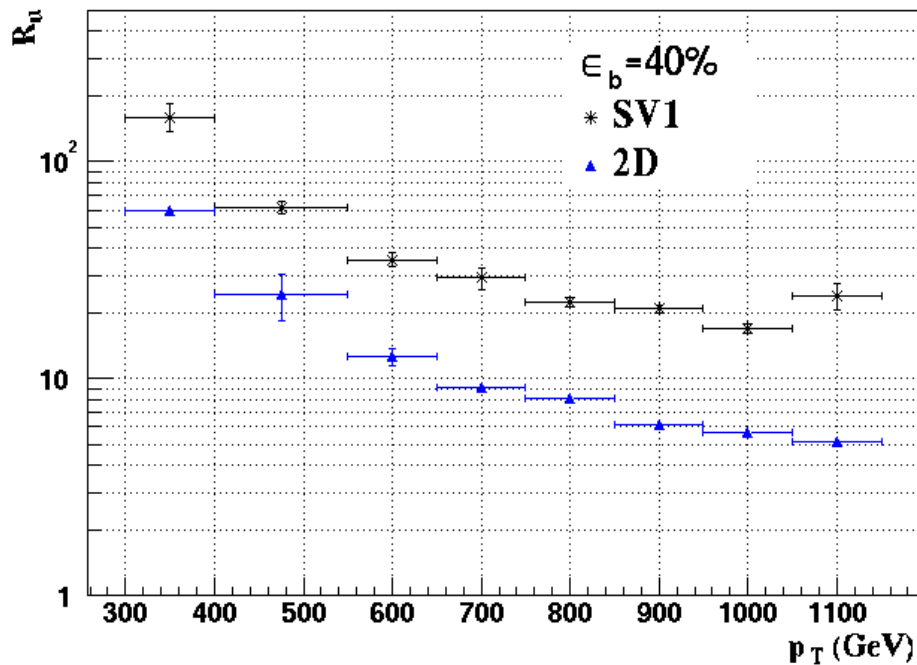
2D algorithm – DC1 data
 $pp \rightarrow W H (120 + 400 \text{ GeV})$
 \downarrow
 $b b$

ATL-PHYS-2004-006



2D algorithm – DC1 data
 $W H + t\bar{t}$ samples

p_T dependence in Z_H ($2 \text{ TeV}/c^2$) \rightarrow bb samples



Full simulation

“Rome” samples = DC1 geometry

SV1 = secondary vertex based b-tag algorithm

2D = signed IP significance tagger

Studies ongoing on CSC samples
(= DC3 geometry with updated material and residual misalignment)

Standard ATLAS tagging algorithms, without retuning

Summary and conclusions

- Twin Higgs model with LR symmetry and $M > 0$ predicts signatures with multiple b-jets in the final state

- The decay chain

$$W_H \rightarrow T b \rightarrow \phi^\pm b b \rightarrow t b b b \rightarrow W b b b b \rightarrow 4 b + l + E_t^{\text{miss}}$$

can be observed with ATLAS and $L=30 \text{ fb}^{-1}$ for masses up to $m(W_H) \sim 3 \text{ TeV}/c^2$

- Other decays like $W_H \rightarrow \phi^\pm \phi^0 \rightarrow 4 b + l + E_t^{\text{miss}}$ can be observed for $m(W_H) \sim 1 \text{ TeV}/c^2$

- b-tagging for high p_T ($p_T > 200 \text{ GeV}/c$) and very high p_T ($p_T > 500 \text{ GeV}/c$) is very important to identify these signatures