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

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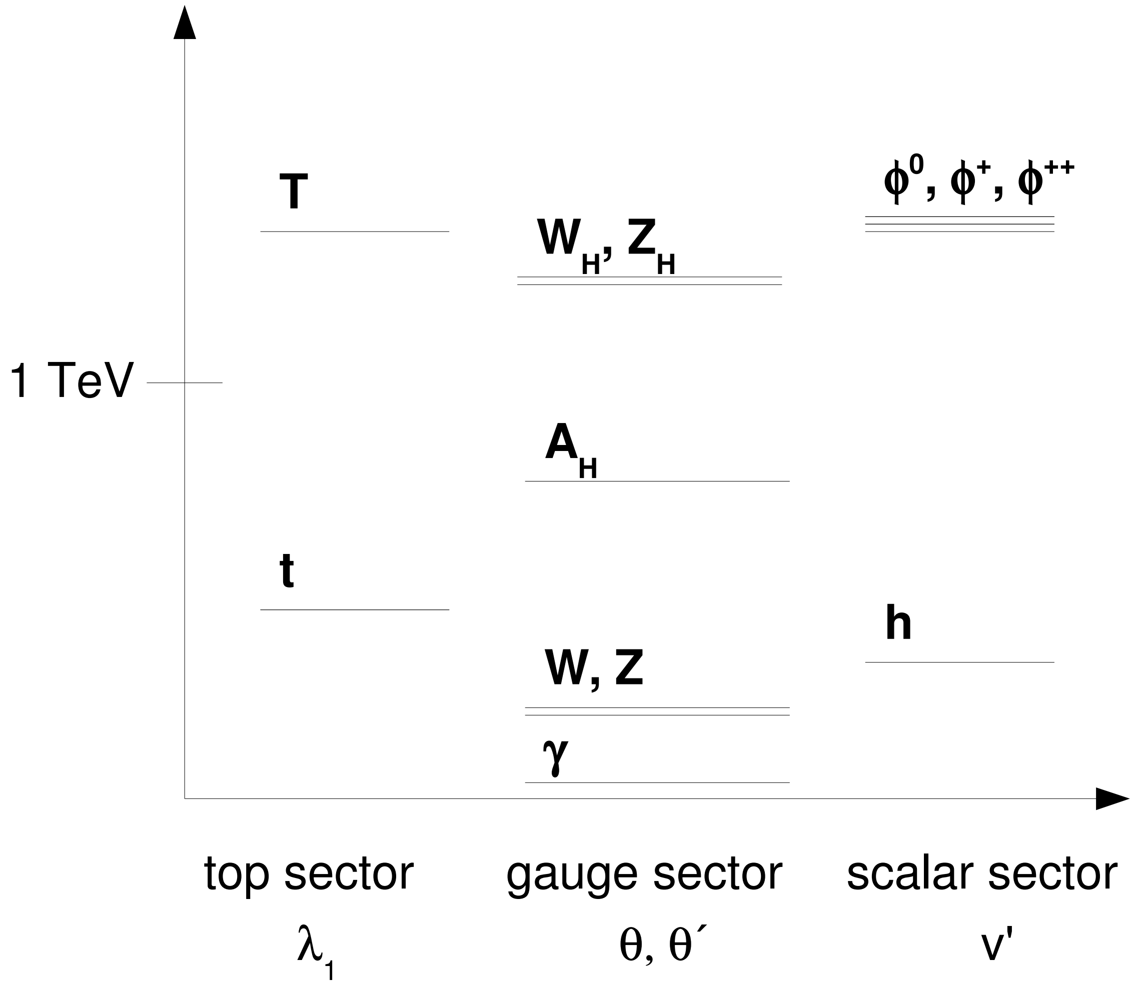
Particle spectrum – Little Higgs

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

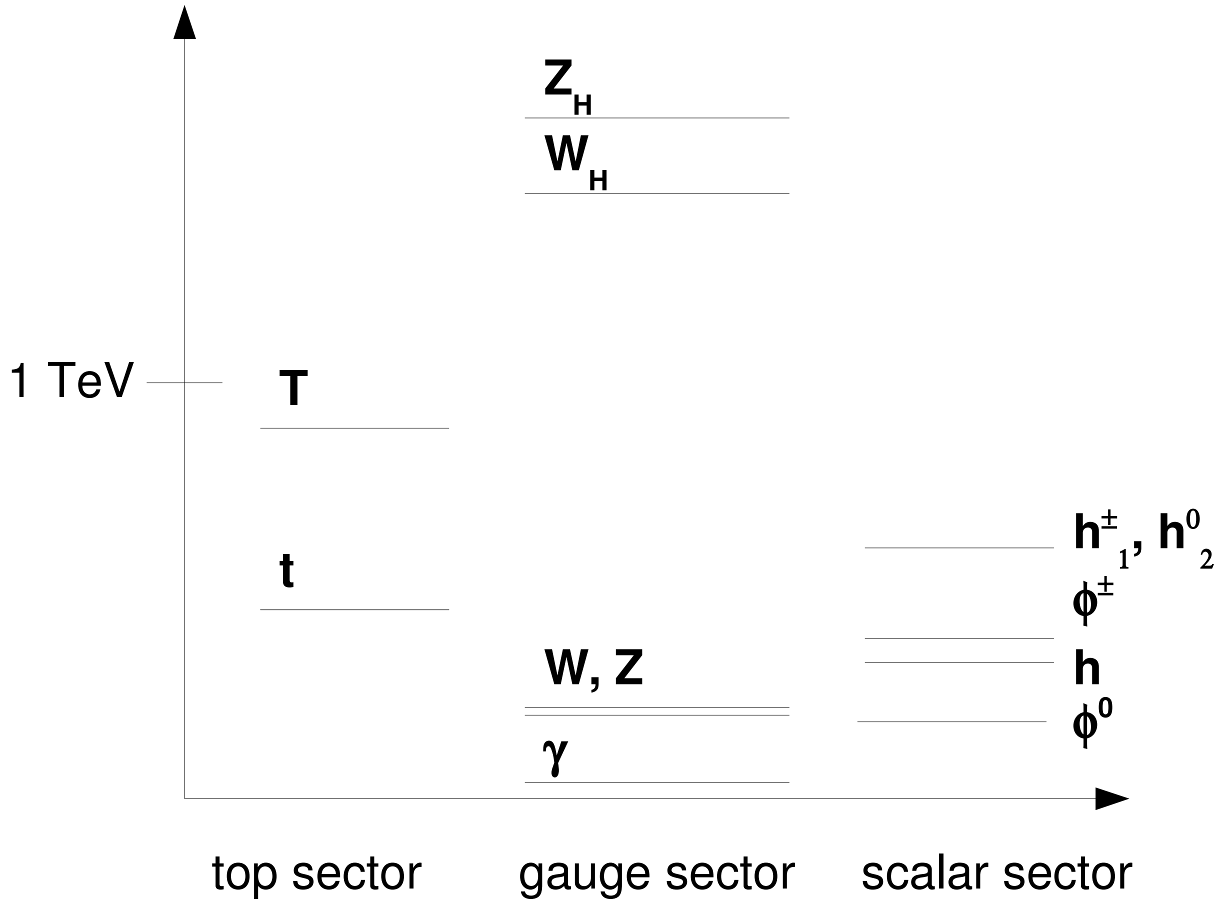


- masses of T, W_H, Z_H, ϕ not fixed by the model
- After fixing the masses, free parameters (λ_1, θ, θ', v') remain that affect cross-sections
- W_H is LEFT-handed

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 scaler sector ($\mathbf{h}^0_2$ is dark matter candidate)
- W_H is RIGHT-handed

Theory: Chacko et al. (hep-ph/0506256)
Phenomenology:
Goh and Su (hep-ph/0608330)

Phenomenology – little Higgs

$Z_H \rightarrow e^+e^-$ BR ~ 4 %

$W_H \rightarrow e\nu_e$ BR ~ 8 %

mass reach ~ 5 TeV (cot θ = 1)

Other decays:

$W_H \rightarrow tb$ BR ~ 25 %

mass reach ~ 2.5 TeV (cot θ = 1)

Model test:

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

mass reach ~ 2 TeV (cot θ = 0.3,
decay absent for cot θ = 1)

ATLAS study published in:
EPJ C39S2, 13 (2005)
Other studies:
ATL-PHYS-2006-003

Phenomenology – LR twin Higgs

$Z_H \to e^+e^-$ BR ~ 2.5 %

$W_H \to e\,\nu_R$ not considered

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

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

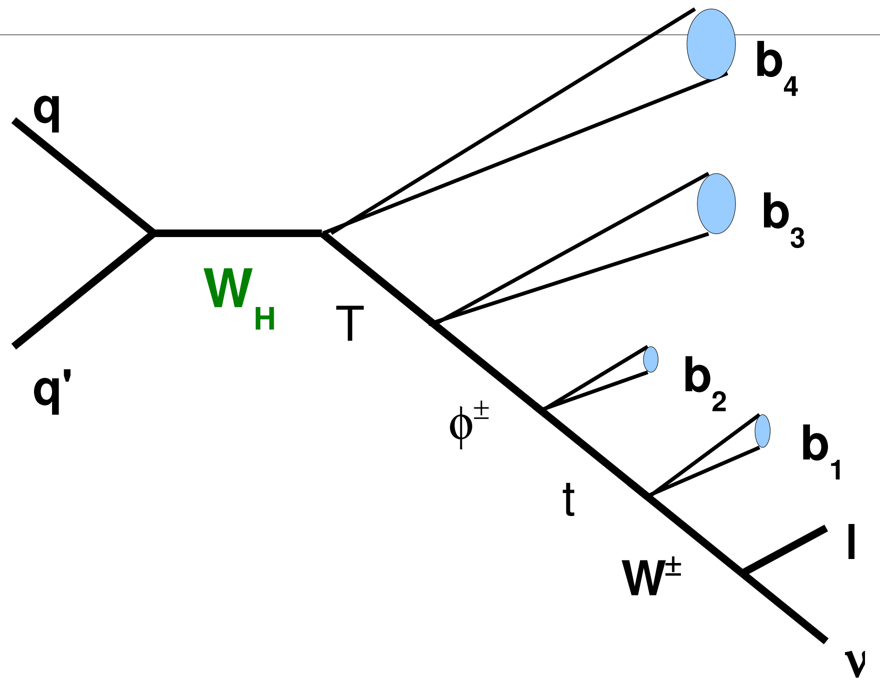
$W_H \to Tb$
- ↳ $\phi^\pm b$
  - ↳ tb
    - ↳ Wb
      - ↳ $l\nu$

$W_H \to \phi^\pm \phi^0$
- ↳ bb
- ↳ tb
  - ↳ Wb
    - ↳ $l\nu$

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

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

Signature for W_H (1 TeV/c^2) → Tb



	$\langle p_T \rangle$ (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%)
$\phi^{\pm}$	200	tb	(100%)
t	175	Wb	(100%)
W	80	lν	(21%)

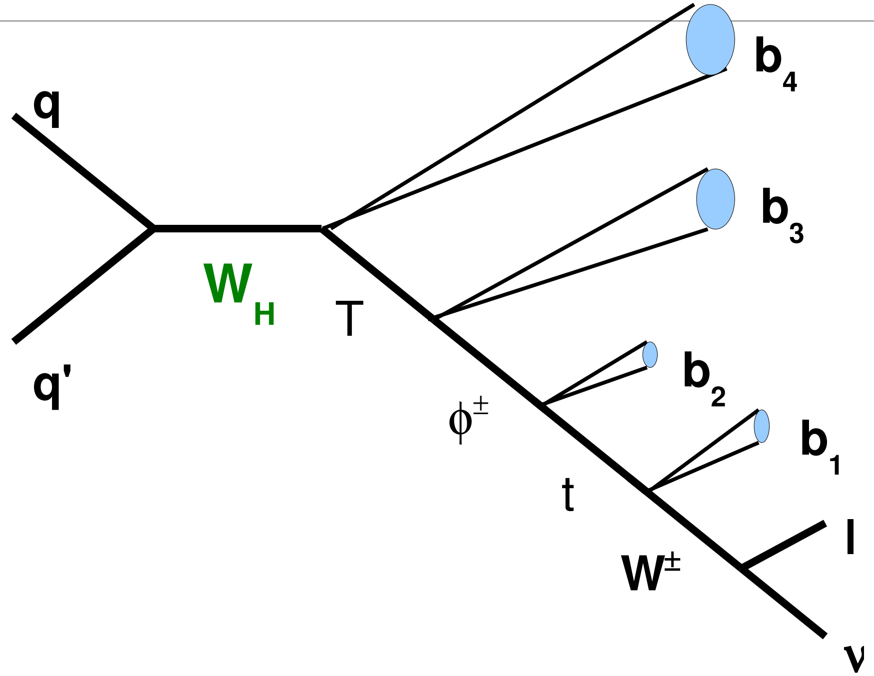
Simulation: Pythia + ATLFAST

X-section: σ = 30 pb x BR

Background: tt, W+jets

Luminosity: L = 30 fb^{-1}

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



Reconstruct masses

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

E_T^{miss} > 25 GeV/c

assume p_z^{ν} // p_z^{l} to reconstruct W

ε_l = 90% (trigger + lepton ID)

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

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

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

$T+b_4 \rightarrow W_H$ $p_T(b_4) > 150$ GeV/c

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

Additional cuts

m(t) < 250 GeV/c^2

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

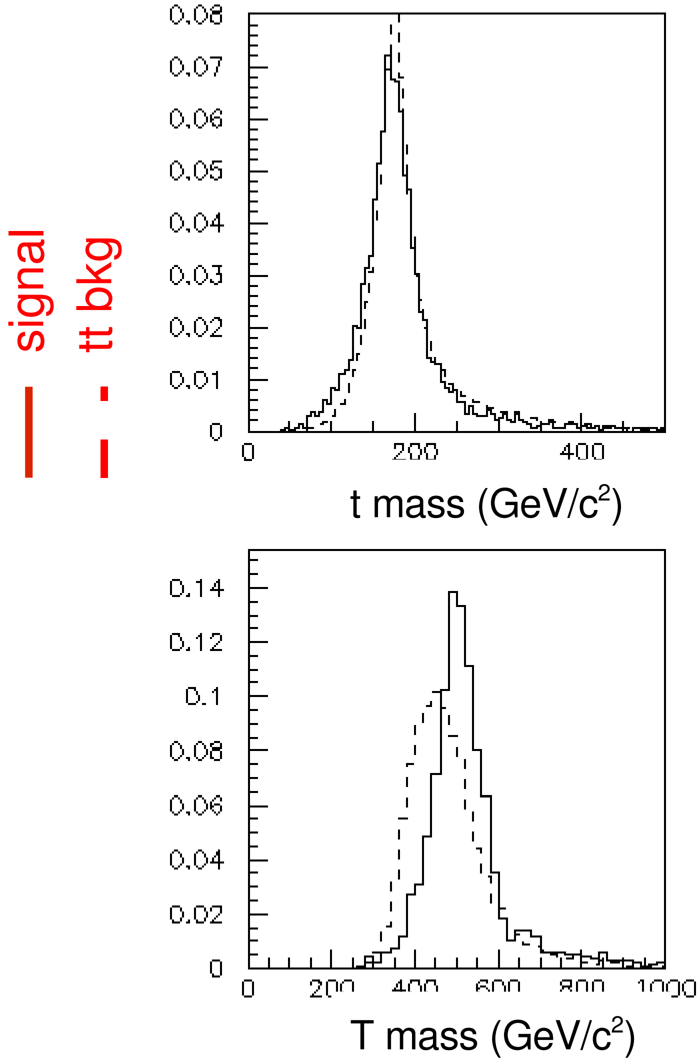
m(T) < 700 GeV/c^2

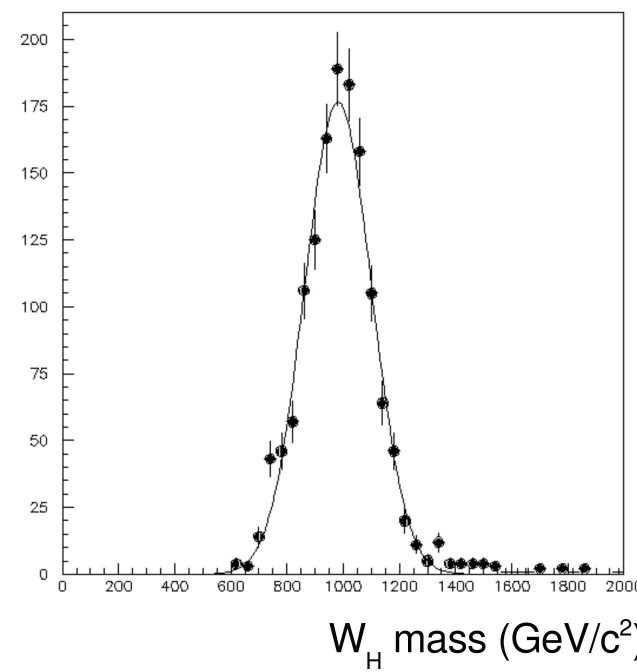
p_T (T) > 150 GeV/c (jacobean peak)

Efficiency (kin. cuts only):

ε_{kin} ~ 12 %

W_H (1 TeV/c^2) → Tb mass reconstruction





Reconstructed mass and width:

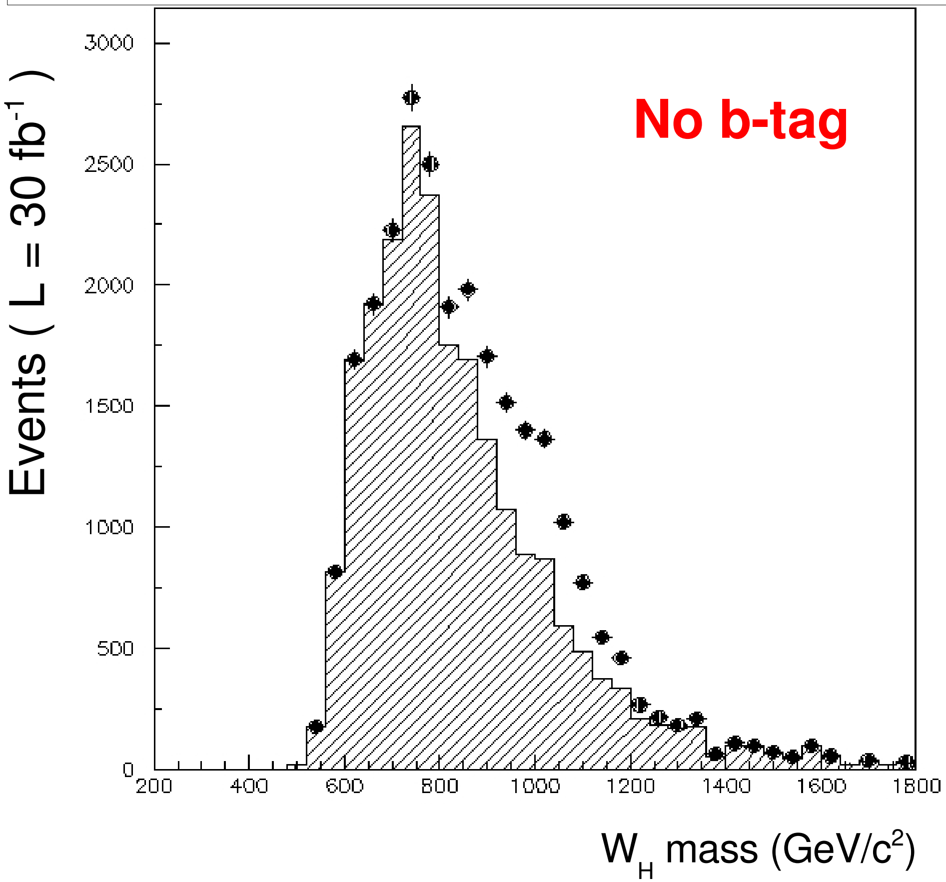
m = 982 GeV/c^2

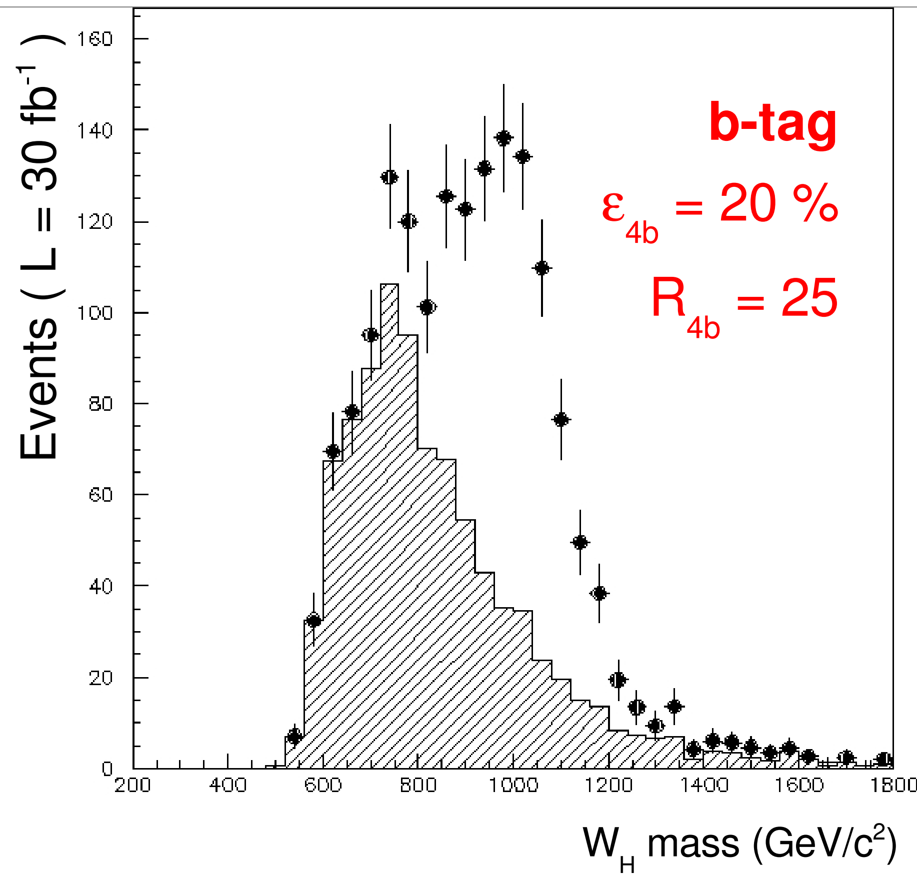
σ = 120 GeV/c^2

Remark:

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

W_H (1 TeV/c^2) → Tb signal/bkg for L=30 fb^{-1}

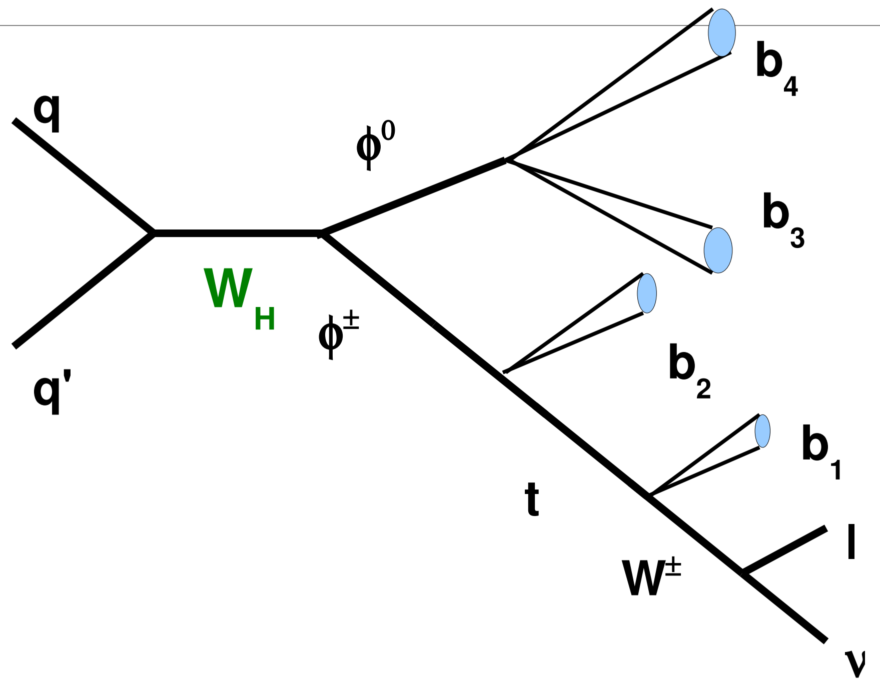




N_{sig} = 3253
N_{tt} = 9427
N_{wj} = 319
$N/\sqrt{B}$ = 33

N_{sig} = 651
N_{tt} = 377
N_{wj} ~ 0
$N/\sqrt{B}$ = 33

Signature for W_H (1 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%)
$\phi^\pm$	200	tb	(100%)
ϕ^0	100	bb	(80%)
t	175	bW	(100%)
W	80	lν	(21%)

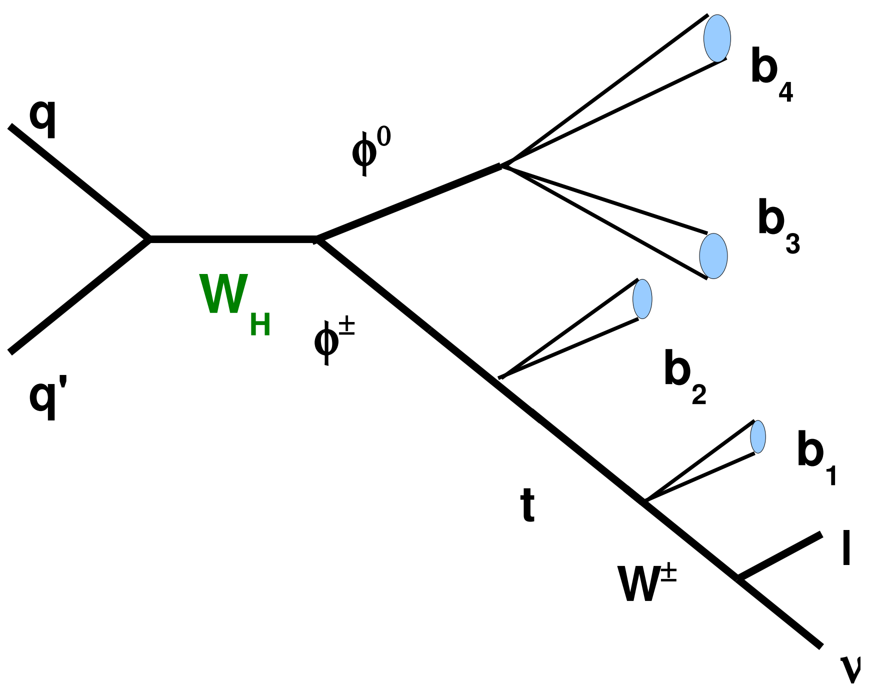
Simulation: Pythia + ATLFAST

X-section: σ = 30 pb x BR

Background: tt, W+jets

Luminosity: L = 30 fb^{-1}

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



Efficiency (kin. cuts only):

ε_{kin} ~ 8 %

Reconstruct masses

$l+\nu \rightarrow W$ p_T (l) > 25 GeV/c, E_T^{miss} > 25 GeV/c

assume p_z^{ν} // p_z^{l} to reconstruct W

ε_l = 90% (trigger + lepton ID)

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

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

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

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

| η | < 2.5 for all leptons and jets

Additional cuts

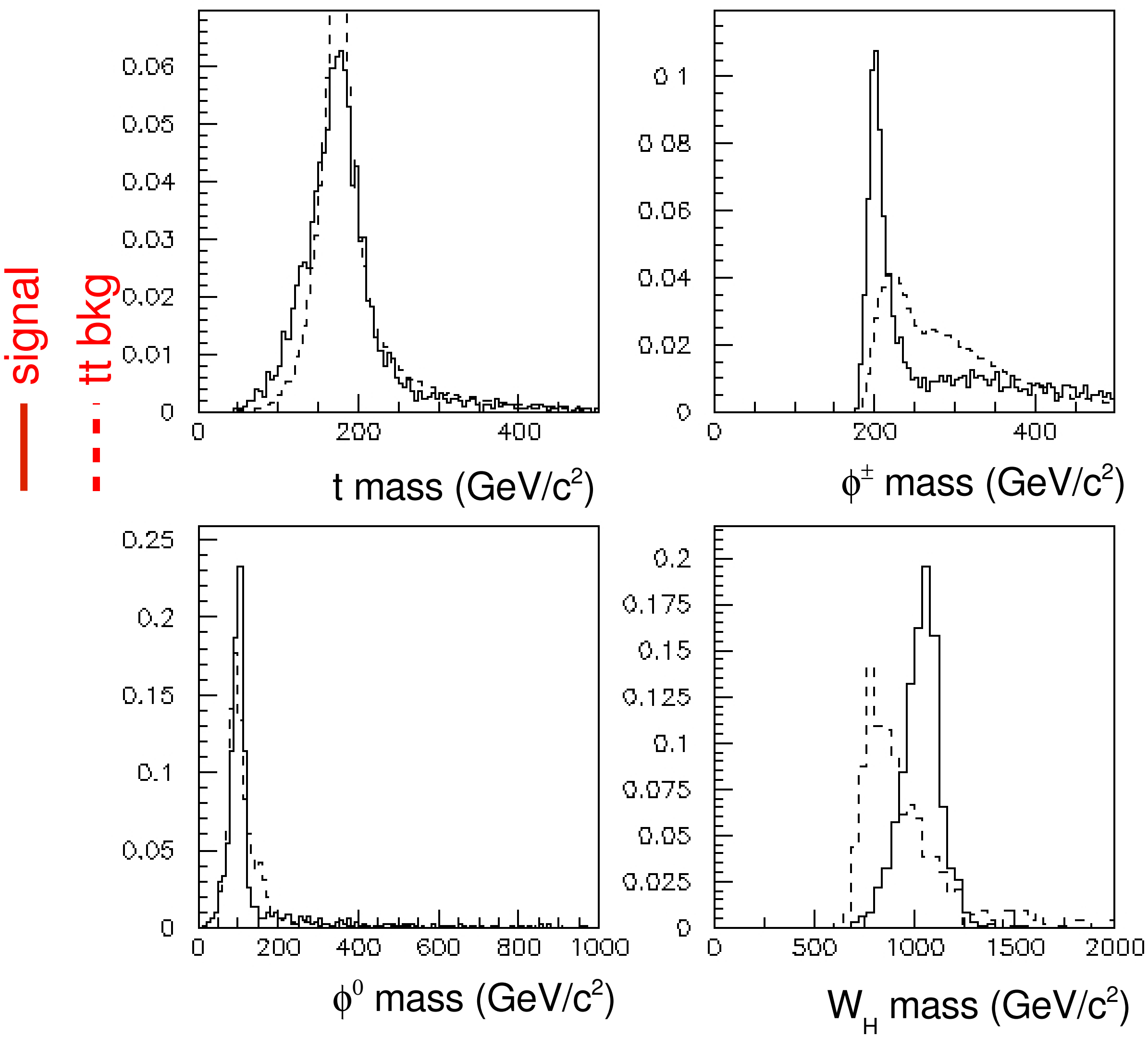
m(t) < 250 GeV/c^2

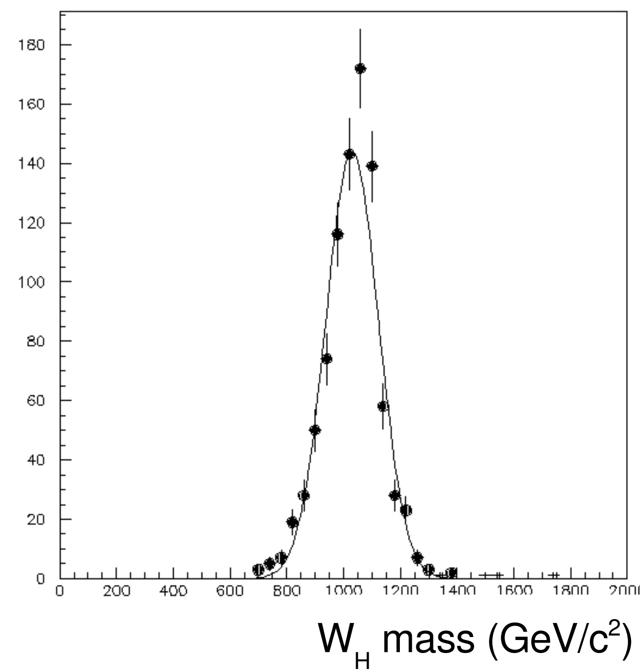
m($\phi^{\pm}$) < 250 GeV/c^2

m(ϕ^0) < 150 GeV/c^2

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

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





Reconstructed mass and width:

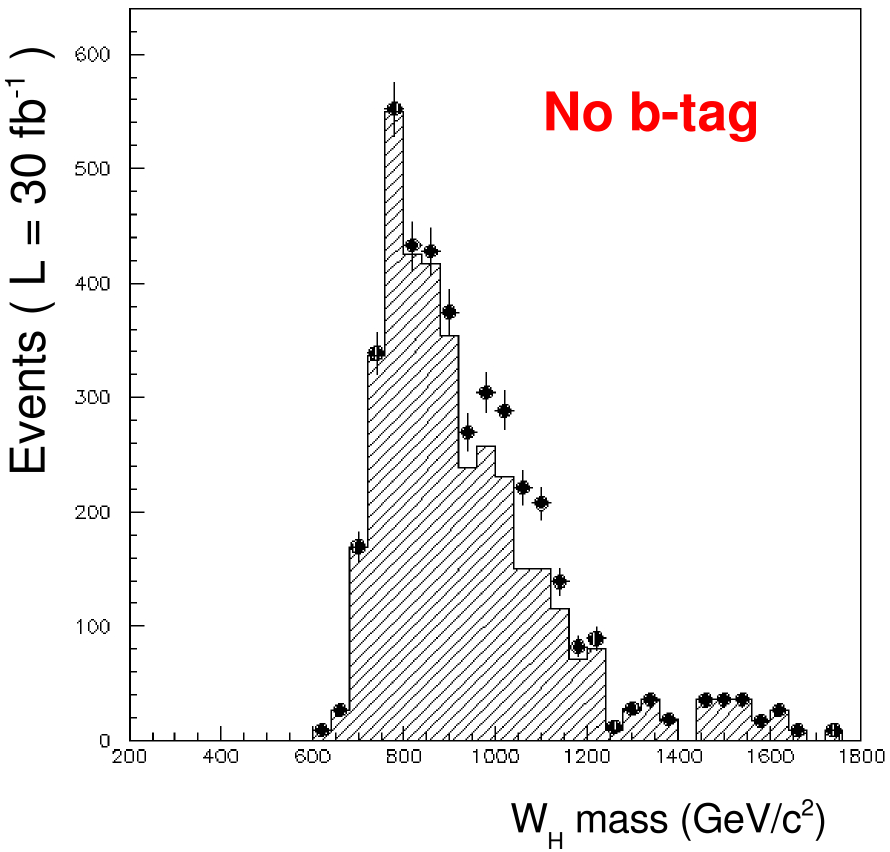
m = 1030 GeV/c^2

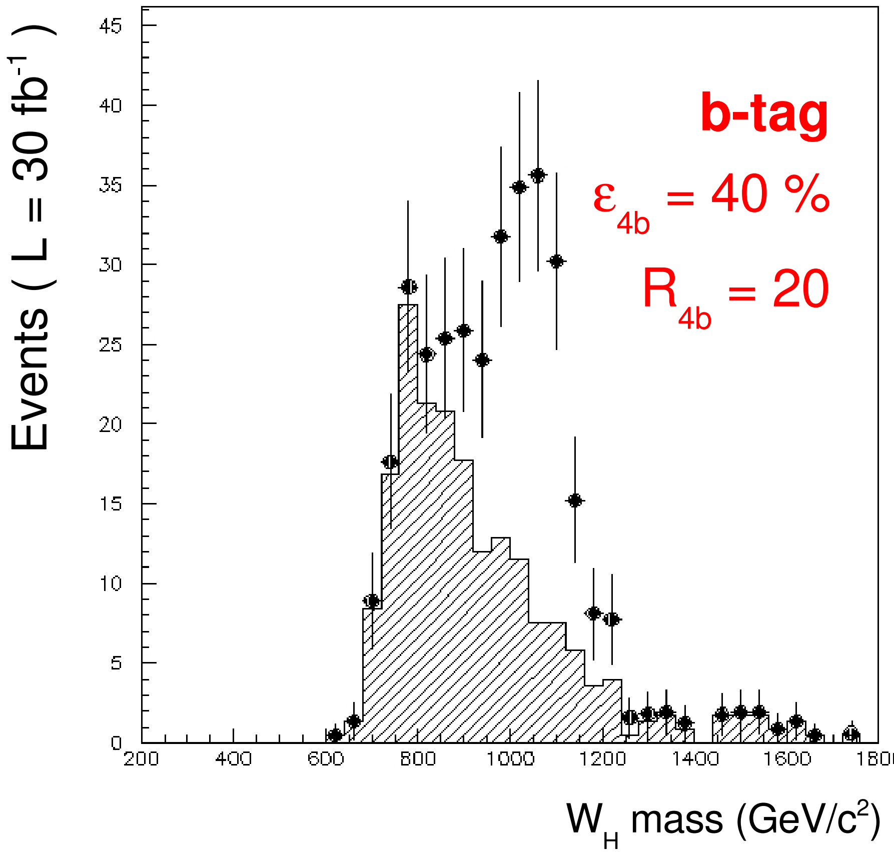
σ = 93 GeV/c^2

Remark:

Γ (W_H) = 24 GeV/c^2

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





N_{sig} = 337

N_{tt} = 1958

N_{wj} = 171

N/√B = 7

N_{sig} = 135

N_{tt} = 98

N_{wj} ~ 0

N/√B = 14

other W_H ($1 TeV/c^2$) decays

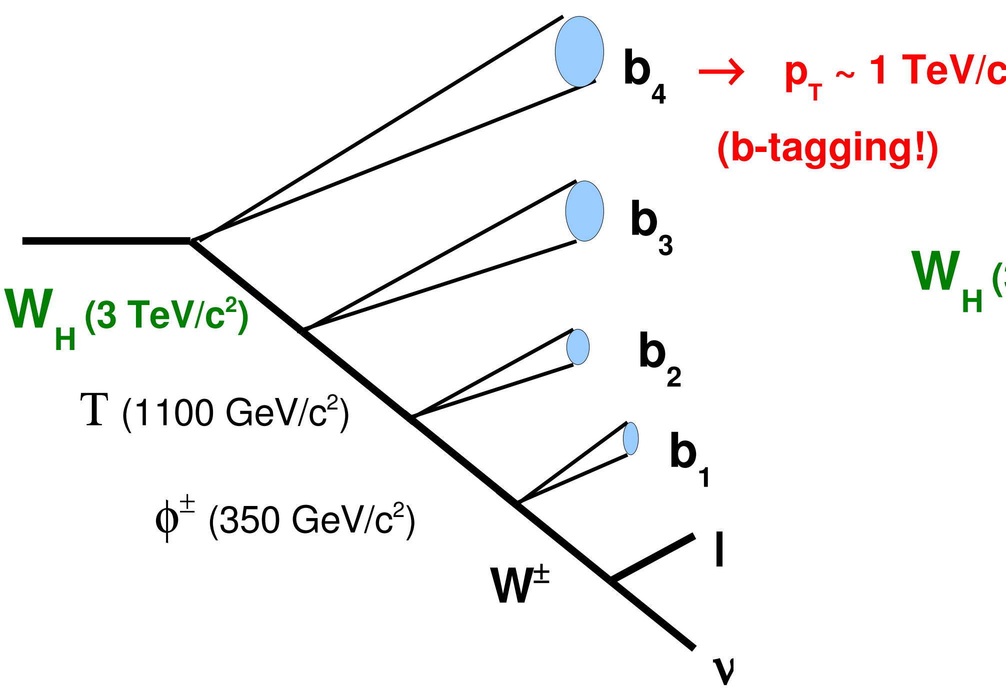
Decay	signature	total B.R.	comment
$W_H \to Tb \to \phi^{\pm}bb$	$\to 4b + l + E_t^{miss}$	3.2 %	this contribution
$\to bWb$	$\to 2b + l + E_t^{miss}$	0.4 %	
$\to thb$	$\to 4b + l + E_t^{miss}$	0.4 %	
$\to tZb$	$\to 2b + 3l + E_t^{miss}$	0.01 %	very small rate/no bkg.
$\to t\phi^0 b$	$\to 4b + l + E_t^{miss}$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

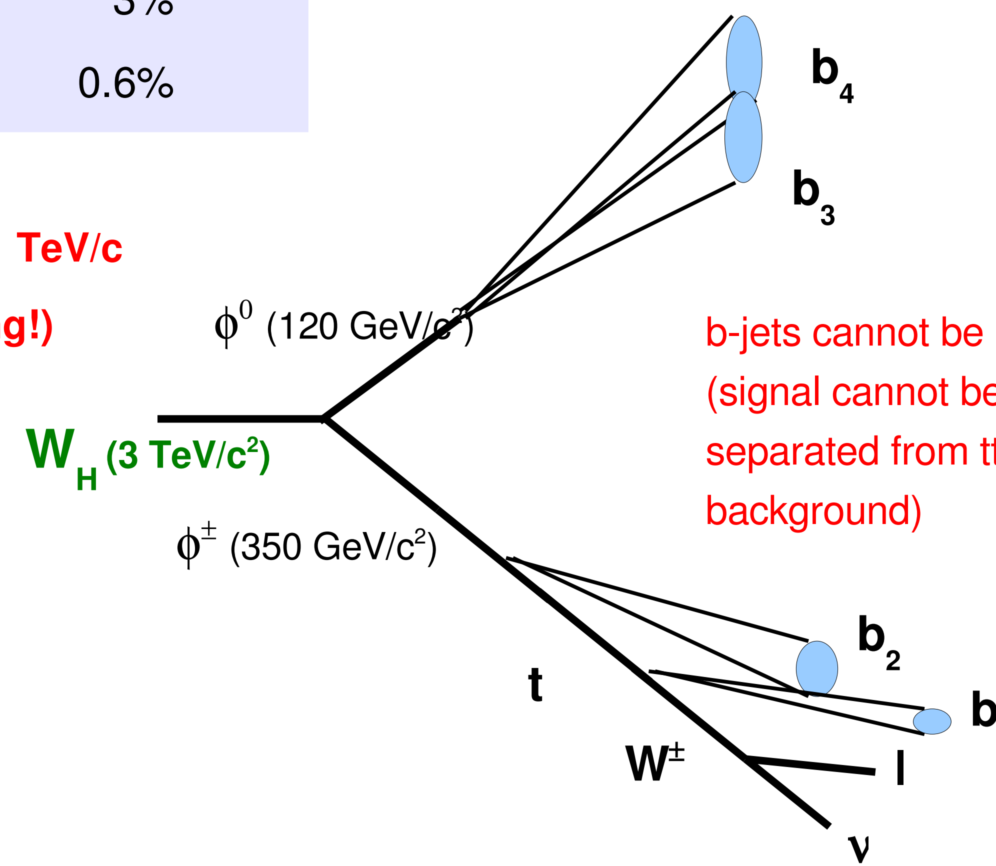
Twin Higgs decay table for M=150 GeV [M is T-t mixing parameter]

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

Mass dependence

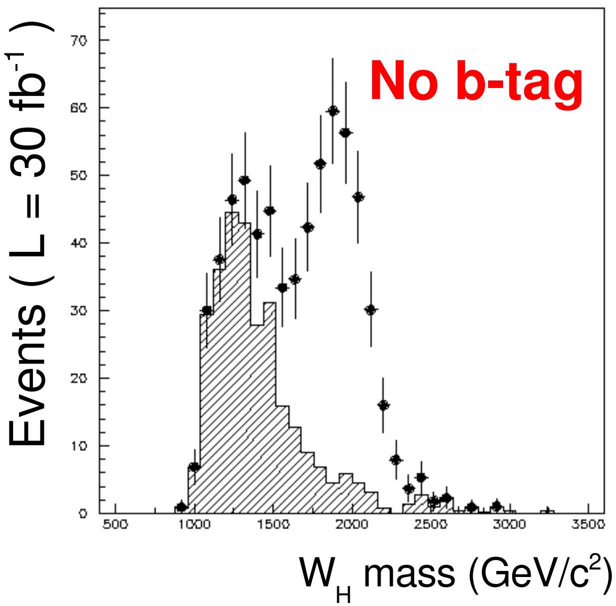
$m(W_H)$	1 TeV/c^2	2 TeV/c^2	3 TeV/c^2
σ(pb)	30	2	0.2
M_T (GeV/c^2)	500	800	1100
BR ($W_H \to Tb$)	20%	25%	25%
BR ($W_H \to \phi^{\pm}\phi^0$)	3%	3%	3%
BR ($W_H \to tb$)	4%	3%	0.6%

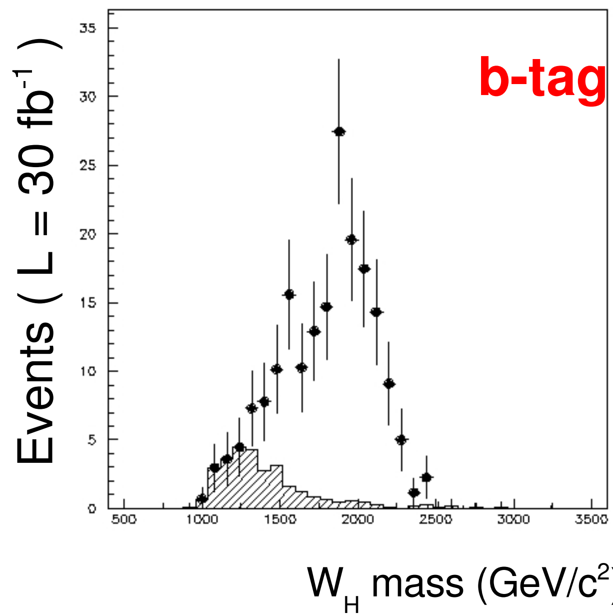




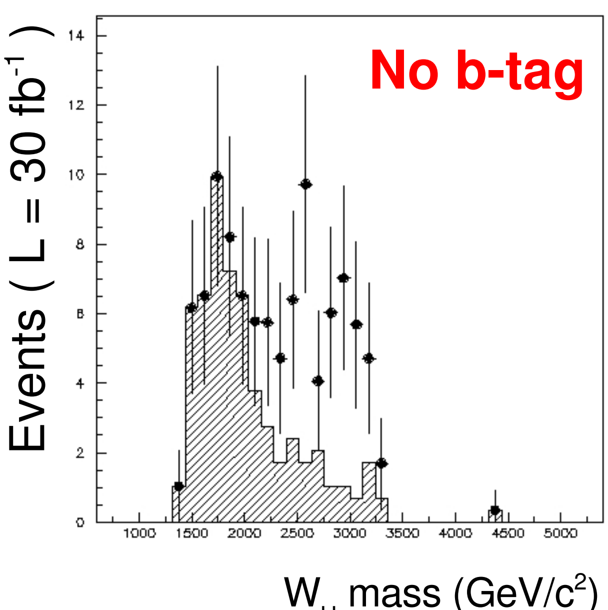
b-jets cannot be resolved (signal cannot be separated from tt background)

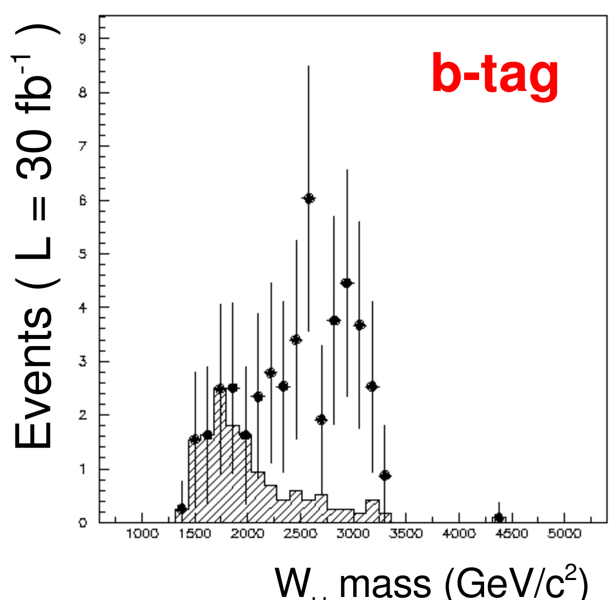
$W_H \to Tb$, $m(W_H) = 2{,}3\ TeV/c^2$





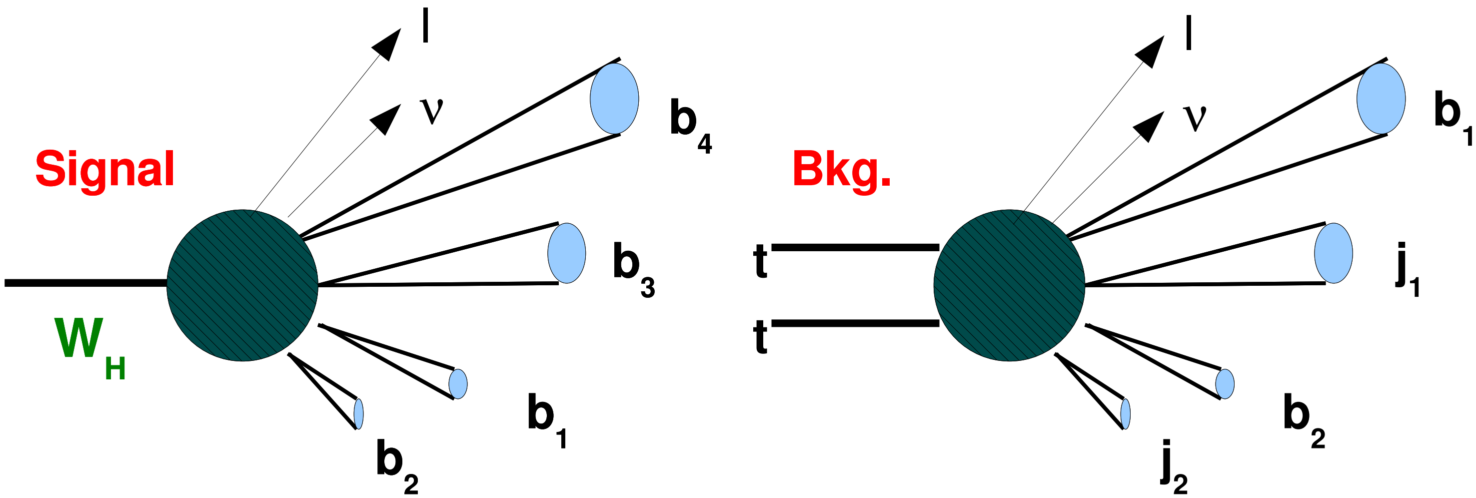
2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
$N/\sqrt{B}$	43	55





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



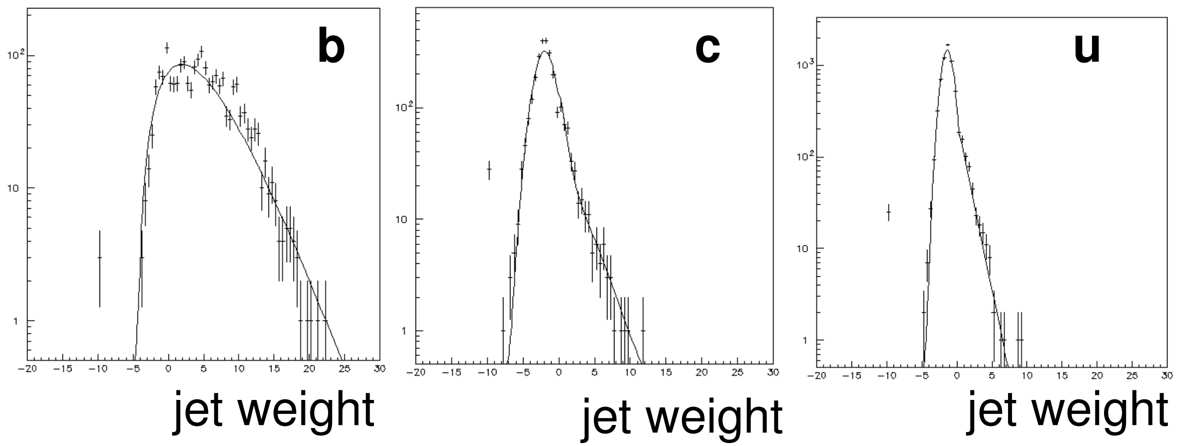
How to tag a signal of 4 b-jets against a background of 2 b + 2 j ?

Standard efficiency-rejection curves approach is inefficient for multi-jet final states

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)



ε_b = 50%

p_T = 100 GeV/c → R_u = 130

p_T = 500 GeV/c → R_u = 60

Parameterisation

b-jets → $w^a e^{-bw}$

c-jets → $w^c e^{-dw}$ + gaussian

u-jets → e^{-ew} + gaussian

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

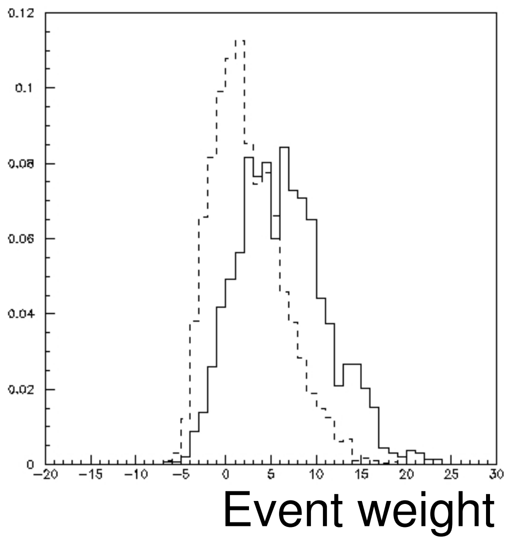
multi b-jet likelihood:

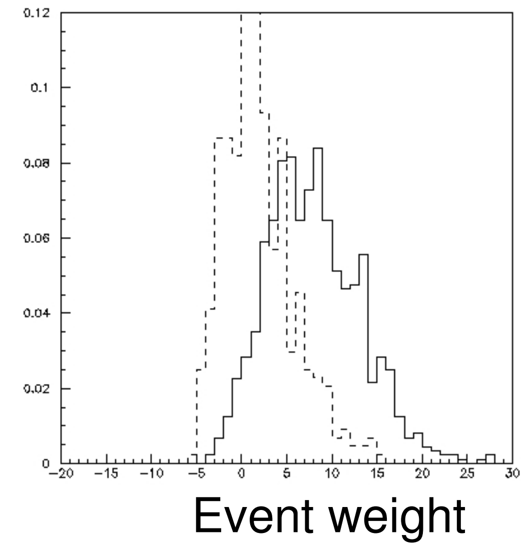
$$W_{event} = \sum_{jets} w_j$$

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

$W_H \to Tb \to 4b + l + E_t^{miss}$

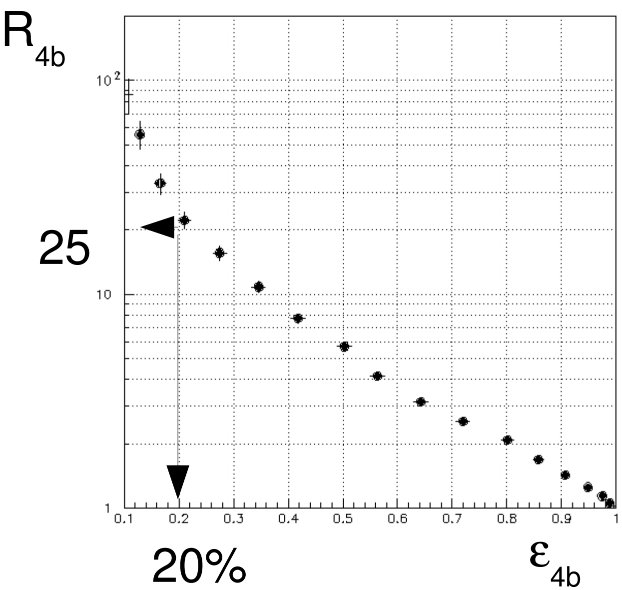
$W_H \to \phi^{\pm}\phi^0 \to 4b + l + E_t^{miss}$





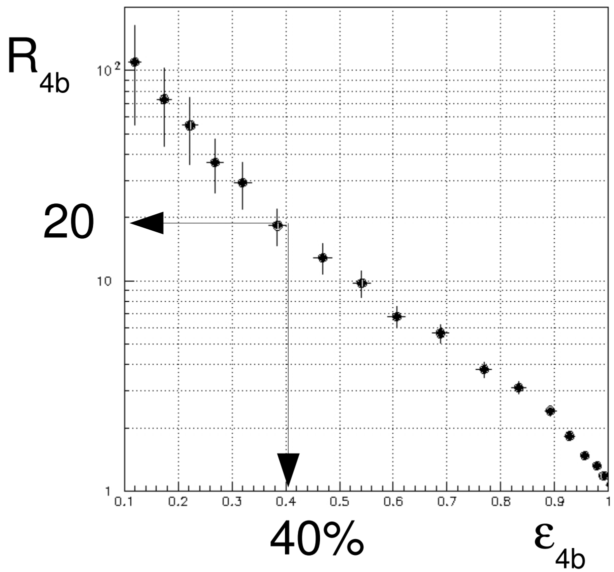
signal

tt background



ε_{4b} = signal efficiency

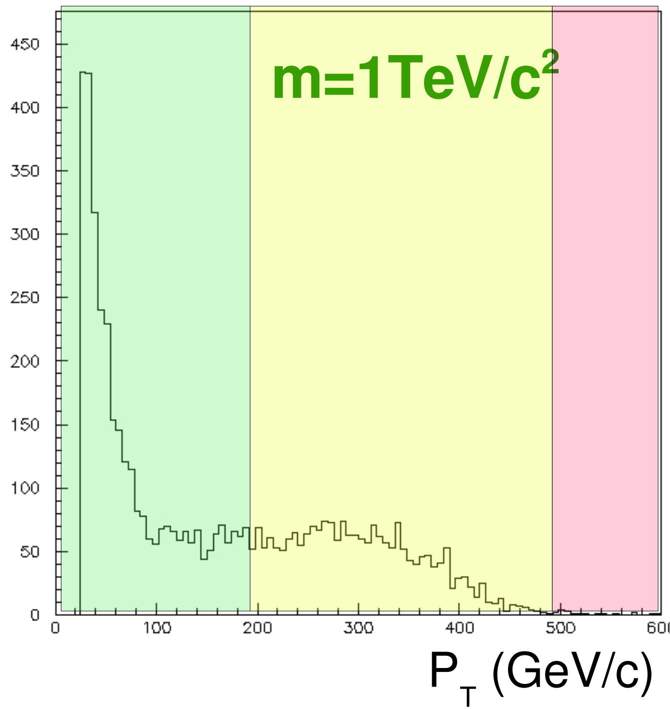
R_{4b} = rejection against tt background

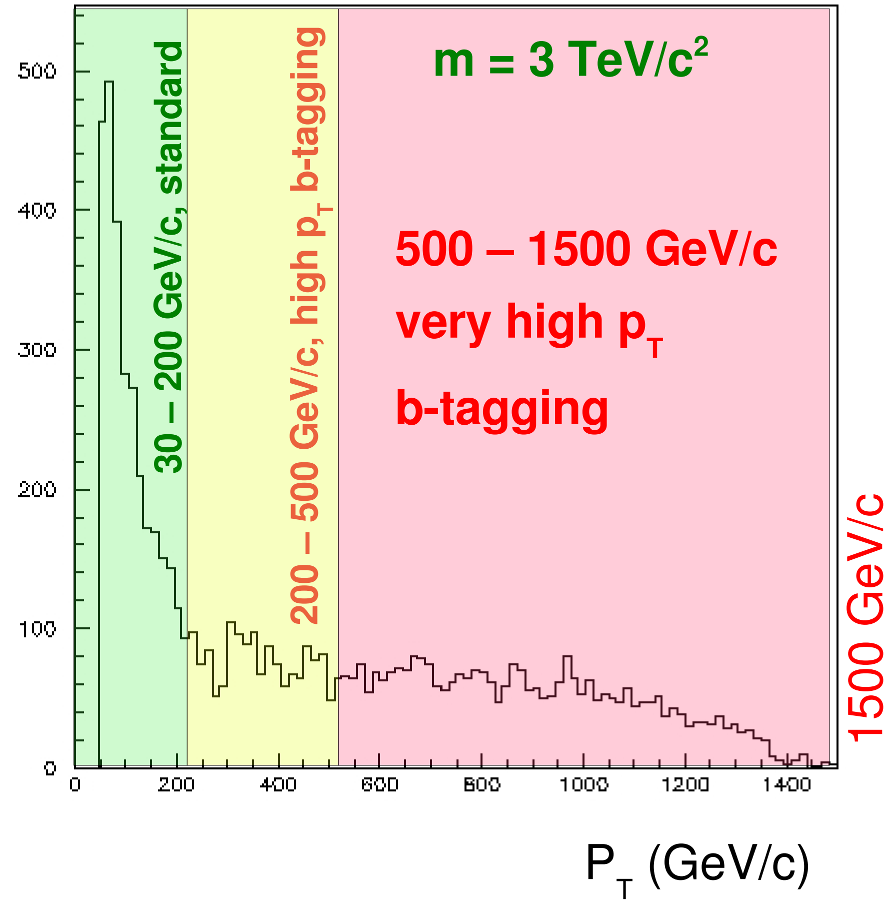


p_T distribution of b-jets

P_T spectrum for b-jets in

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

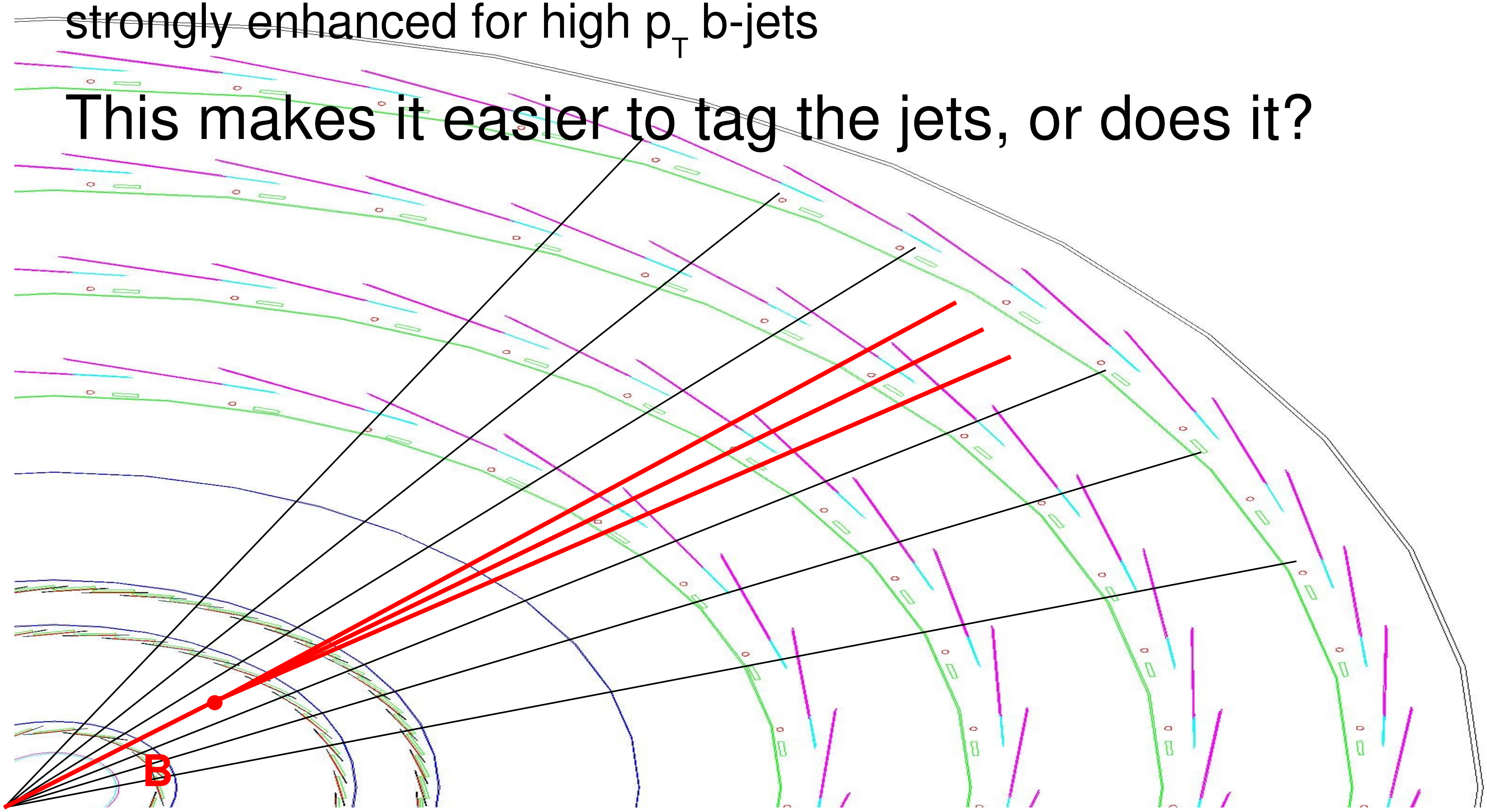




Very high p_T b-tagging (I)

$L = c\,\tau\,\gamma$ –> 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?

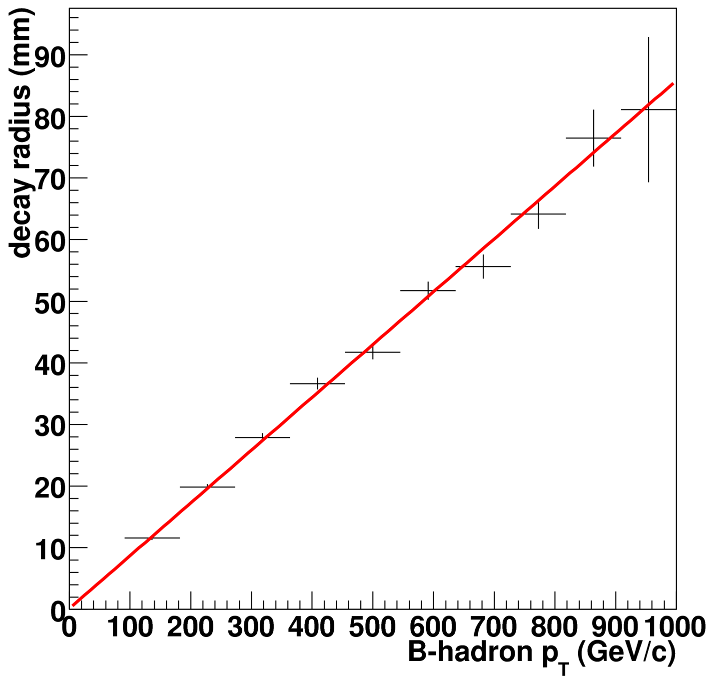


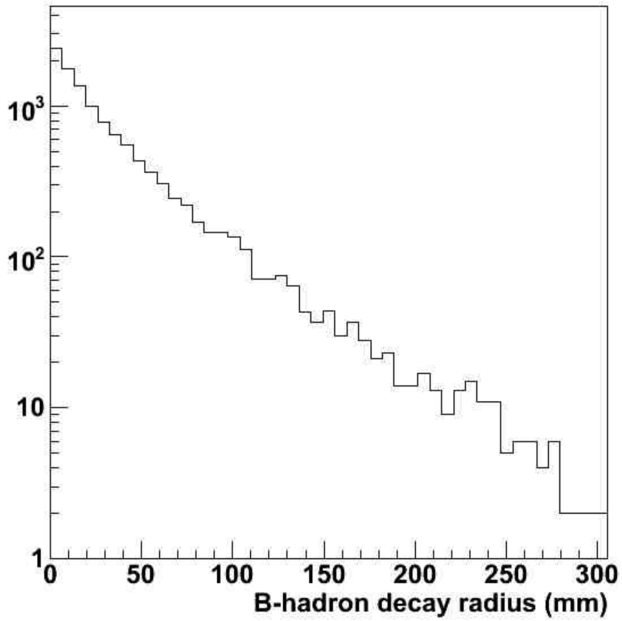
Very high p_T b-tagging (II)

$L = c\,\tau\,\gamma$

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

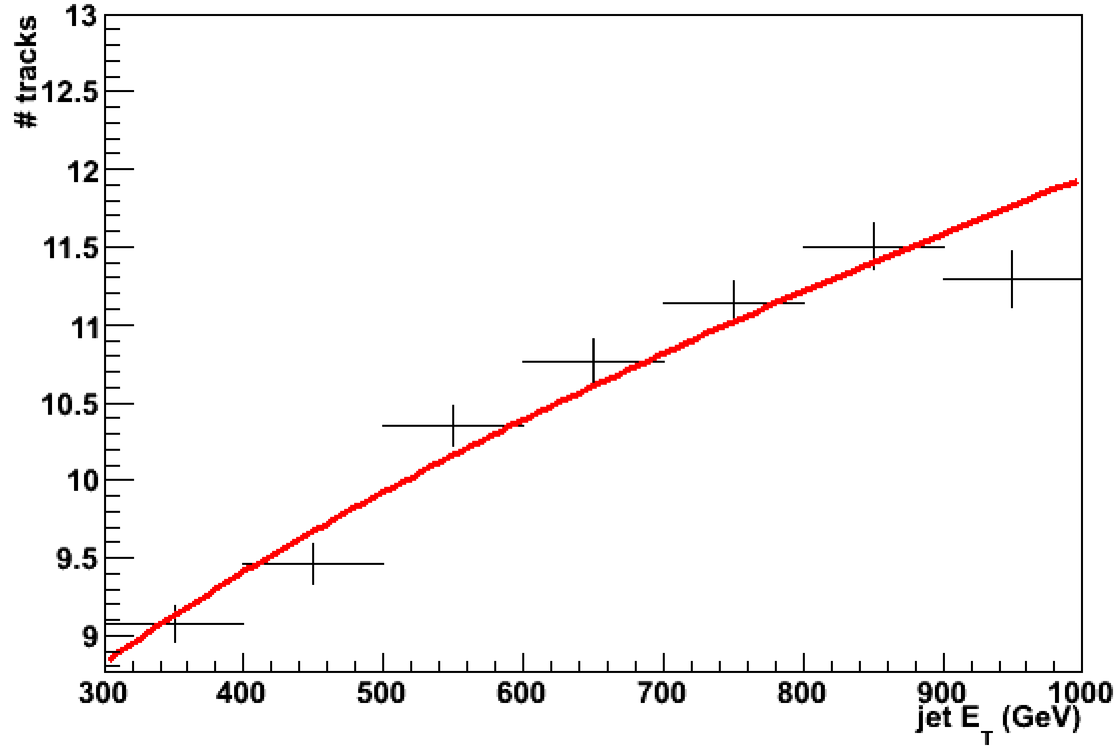
B-layer





Decay radius distribution for B-hadrons in Z'->bb events ($m_{Z'}$ = 2 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

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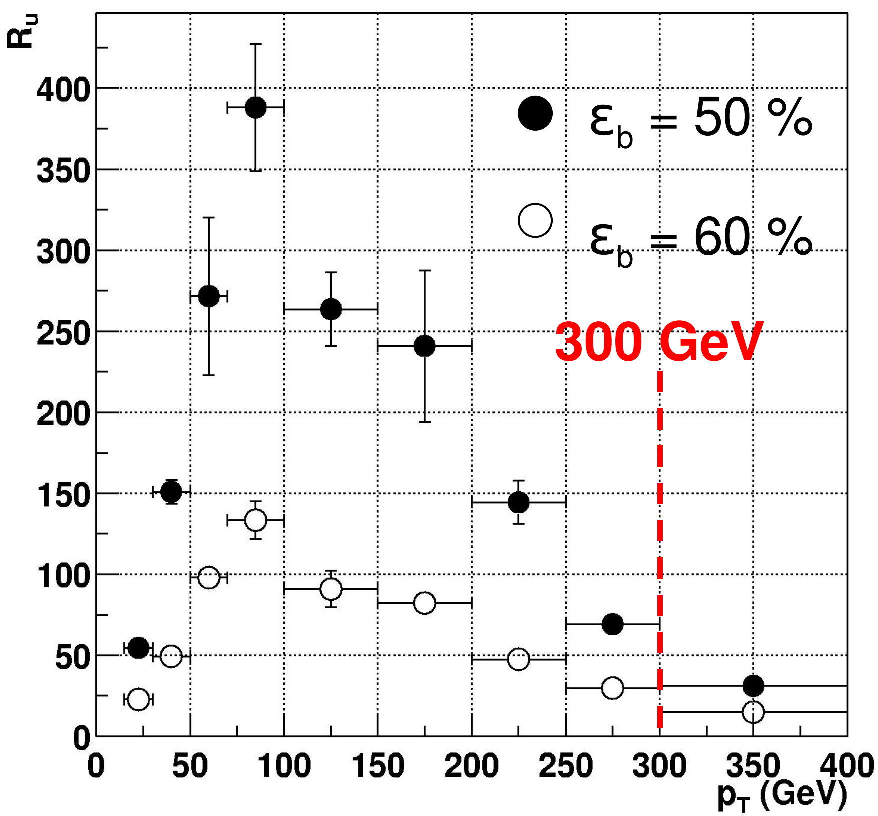

2D algorithm – DC1 data

pp → W H (120 + 400 GeV)
↳ b b

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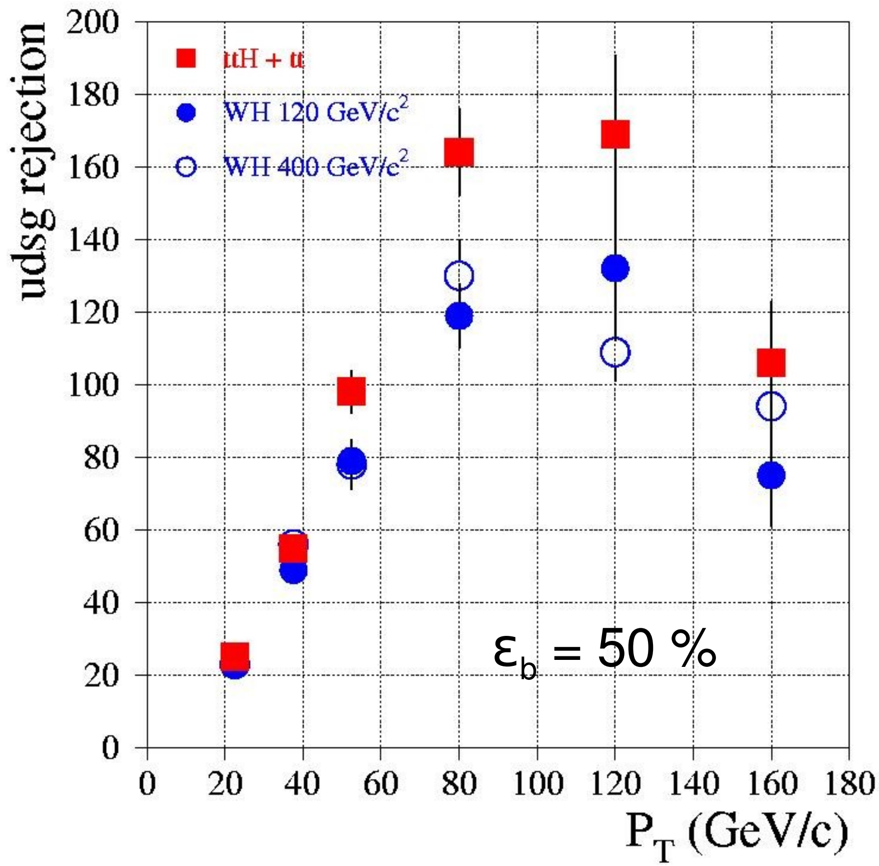
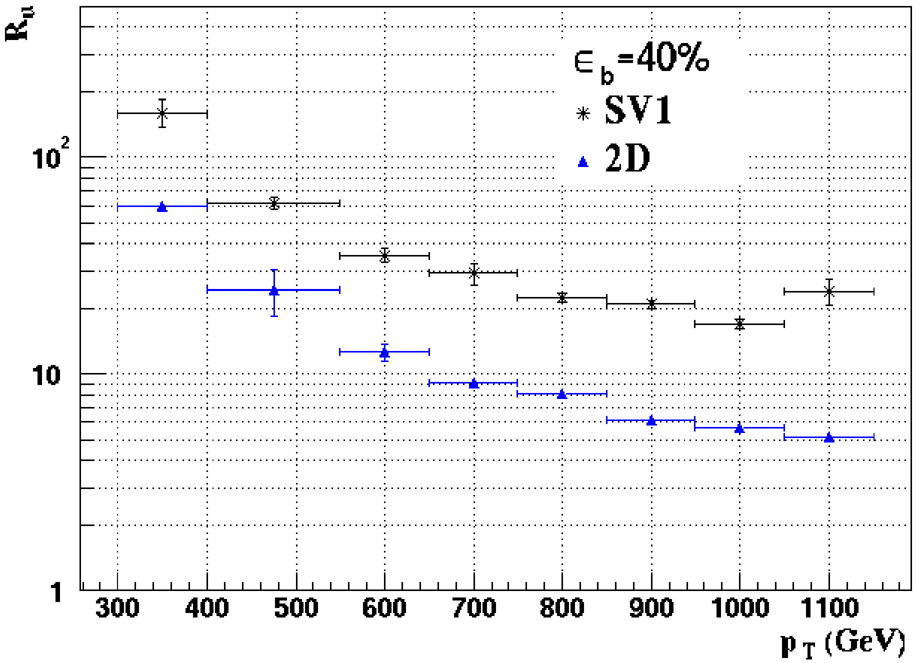


2D algorithm – DC1 data

W H + t t samples

p_T dependence in Z_H (2 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

  $W_H \to Tb \to \phi^{\pm}bb \to tbbb \to Wbbbb \to 4b + l + E_t^{miss}$

  can be observed with ATLAS and L=30 fb^{-1} for masses up to m (W_H) ~ 3 TeV/c^2
- Other decays like $W_H \to \phi^{\pm}\phi^0 \to 4b + l + E_t^{miss}$ can be observed for m (W_H) ~ 1 TeV/c^2
- b-tagging for high p_T (p_T > 200 GeV/c) and very high p_T (p_T > 500 GeV/c) is very important to identify these signatures