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

fast simulation study of the ATLAS reach

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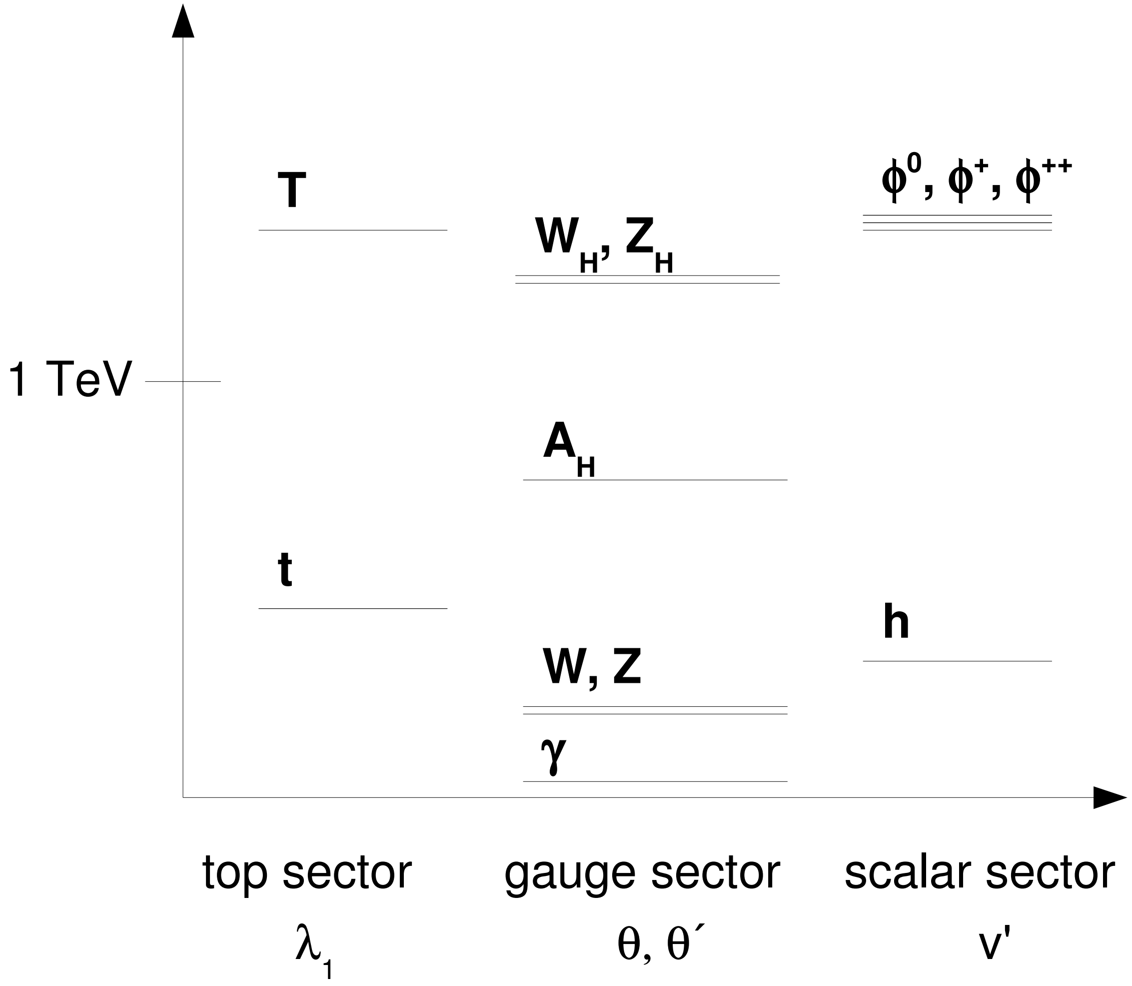
Les Houches BSM working group
Twin Higgs discussion session
23rd june 2007

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 (λ_1, θ, θ', v') remain that affect cross-sections
- W_H is LEFT-handed

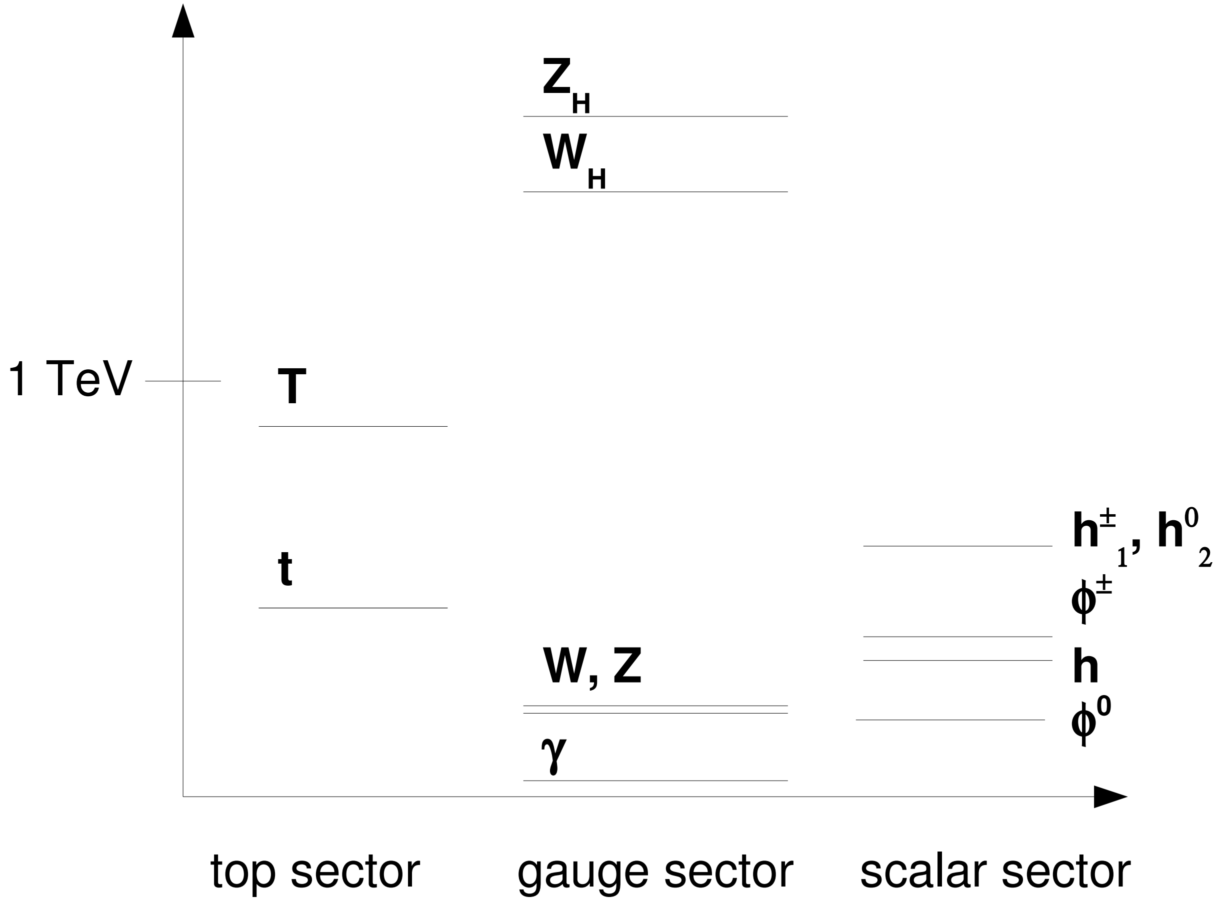
Theory: Arkani-Hamed et al.

Phenomenology:

Han et al.

Particle spectrum – twin Higgs

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



- 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 (**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

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

$W_H \rightarrow e\nu_R$ not considered

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

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

$W_H \rightarrow Tb$

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

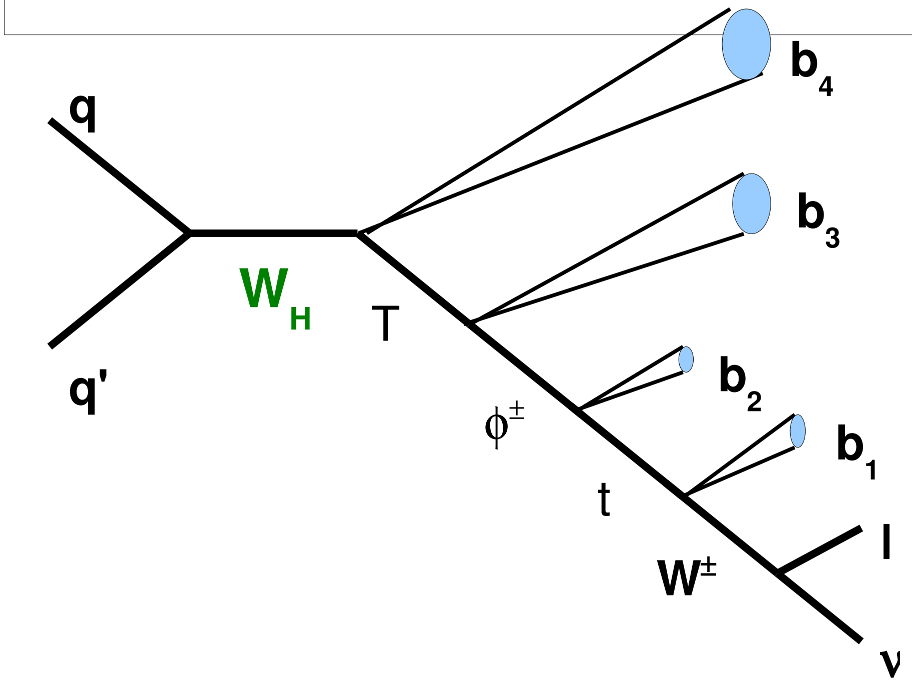
$W_H \rightarrow \phi^\pm\phi^0$

- ↳ 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

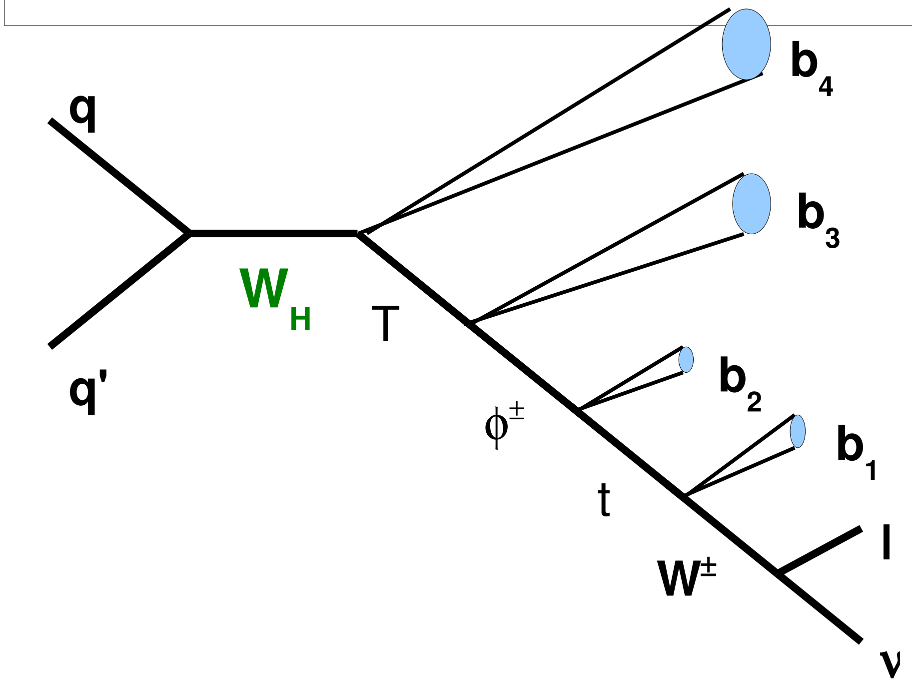


	$\langle p_T \rangle$ (GeV)
b_1	95
b_2	34
b_3	201
b_4	277
l	67
ν	80

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) → 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

| η | < 2.5 for all leptons and jets

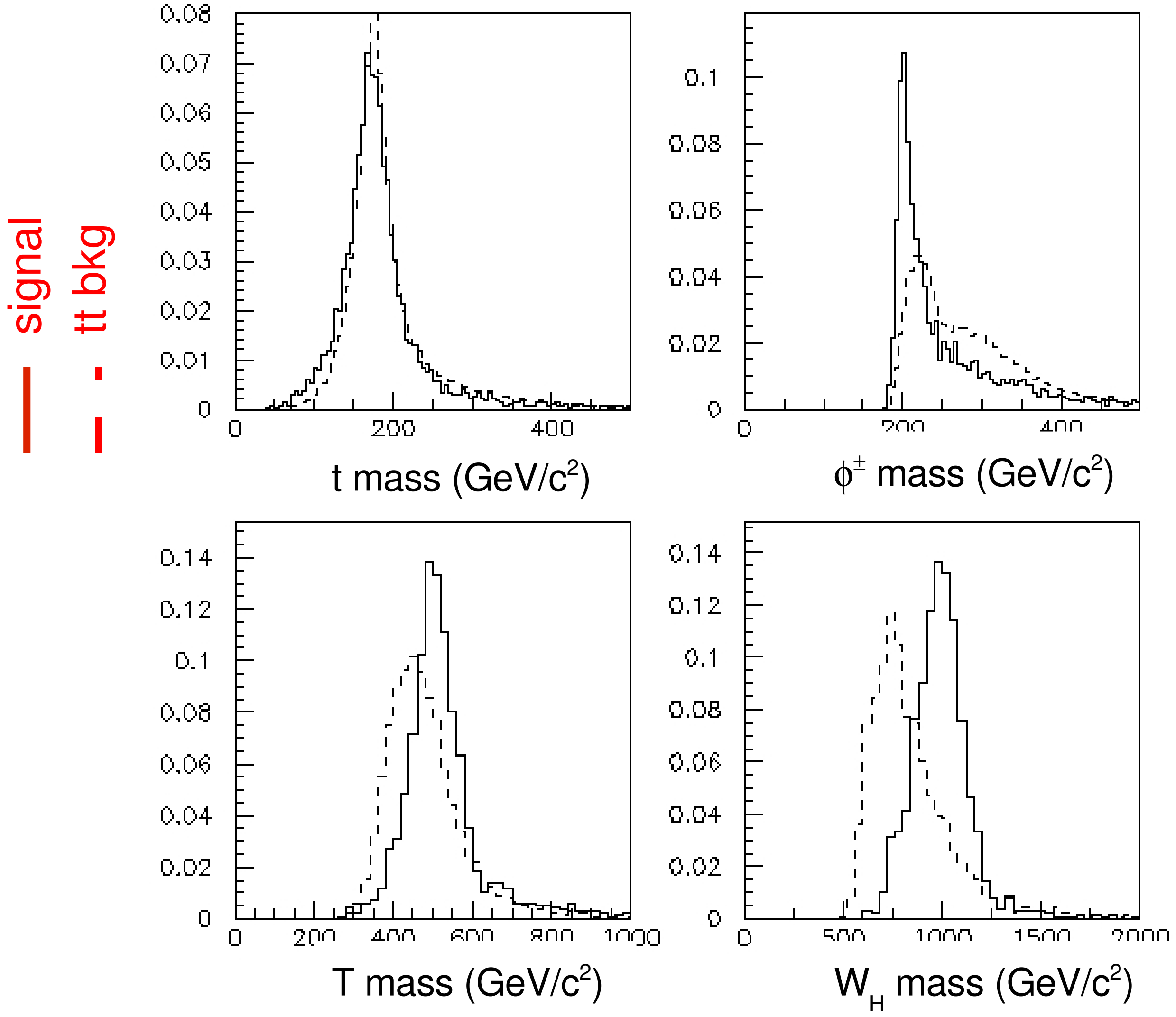
Additional cuts

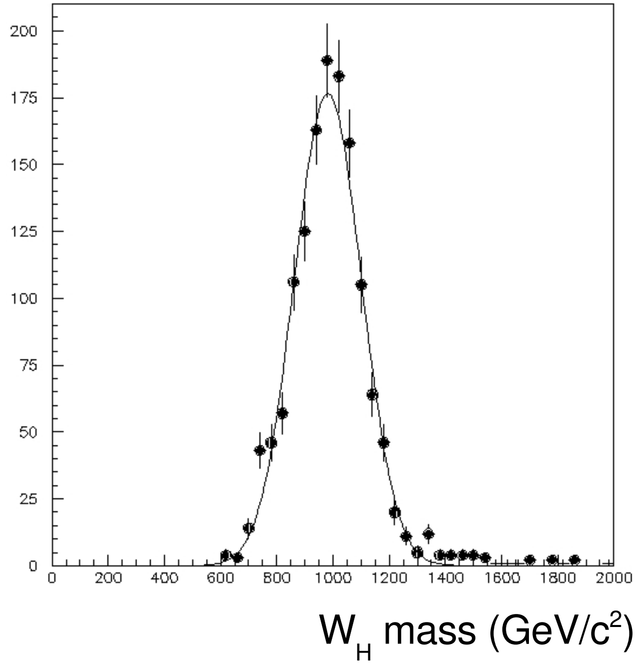
m(t)	< 250 GeV/c^2
m($\phi^\pm$)	< 250 GeV/c^2
m(T)	< 700 GeV/c^2
p_T (T)	> 150 GeV/c (jacobean peak)

Efficiency (kin. cuts only):

ε_{kin} ~ 12 %

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





Reconstructed mass and width:

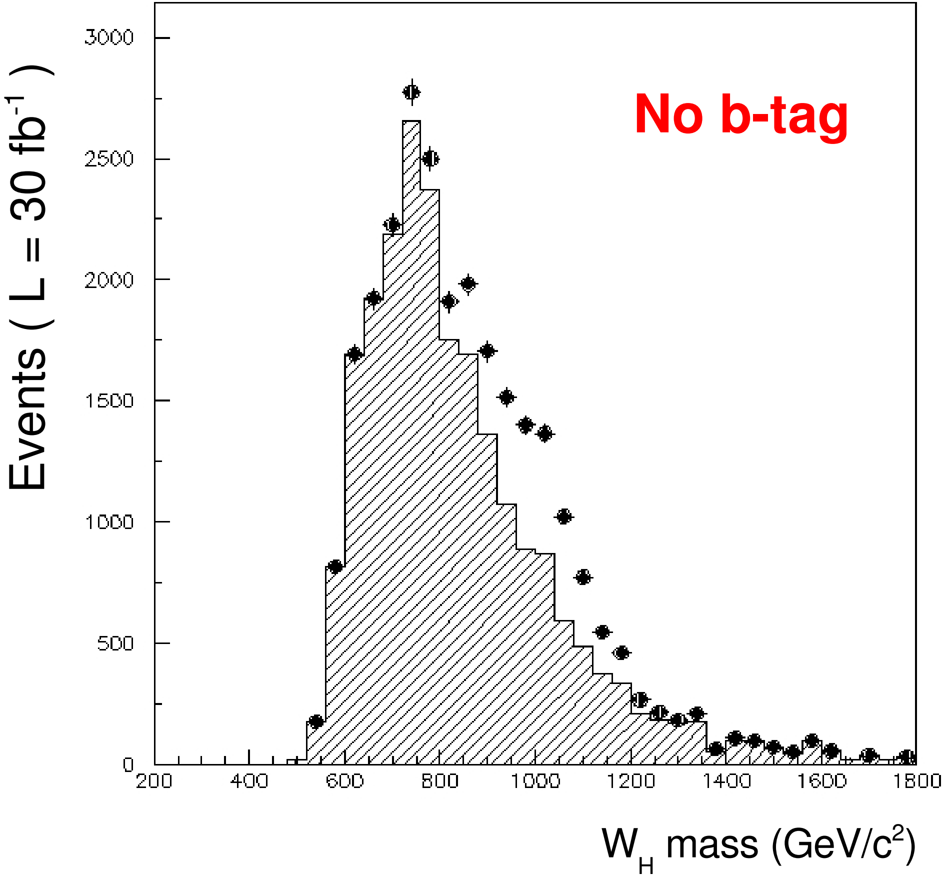
$m = 982$ GeV/c^2

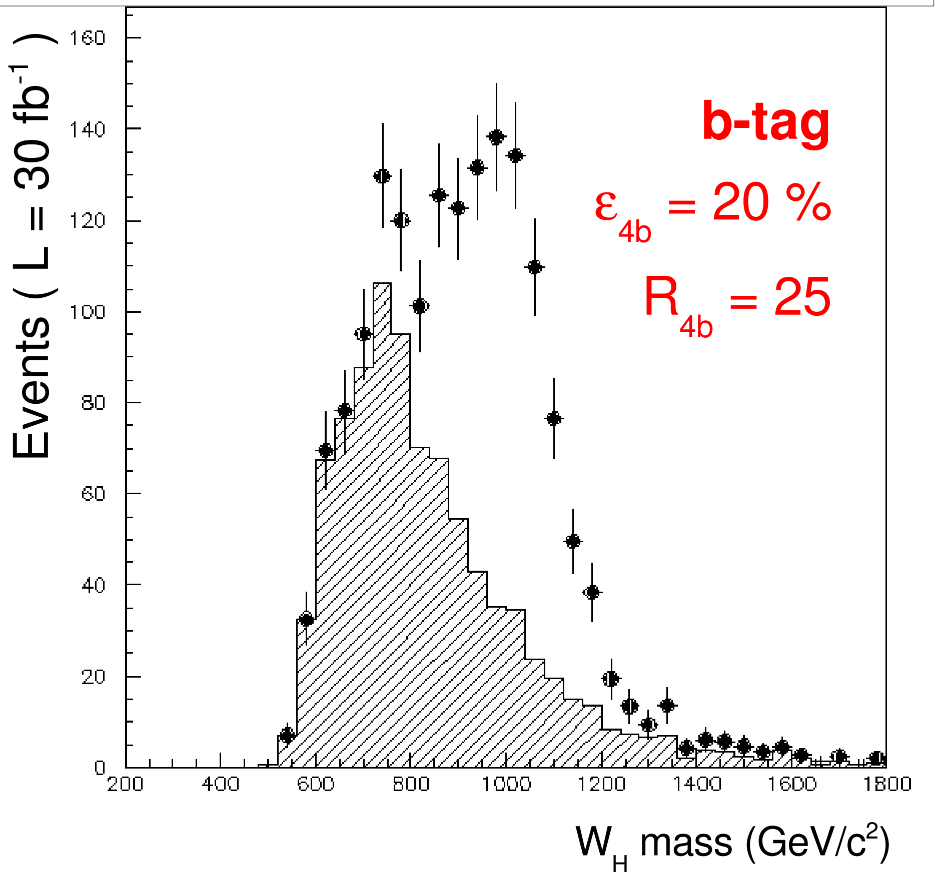
$\sigma = 120$ GeV/c^2

Remark:

Γ (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

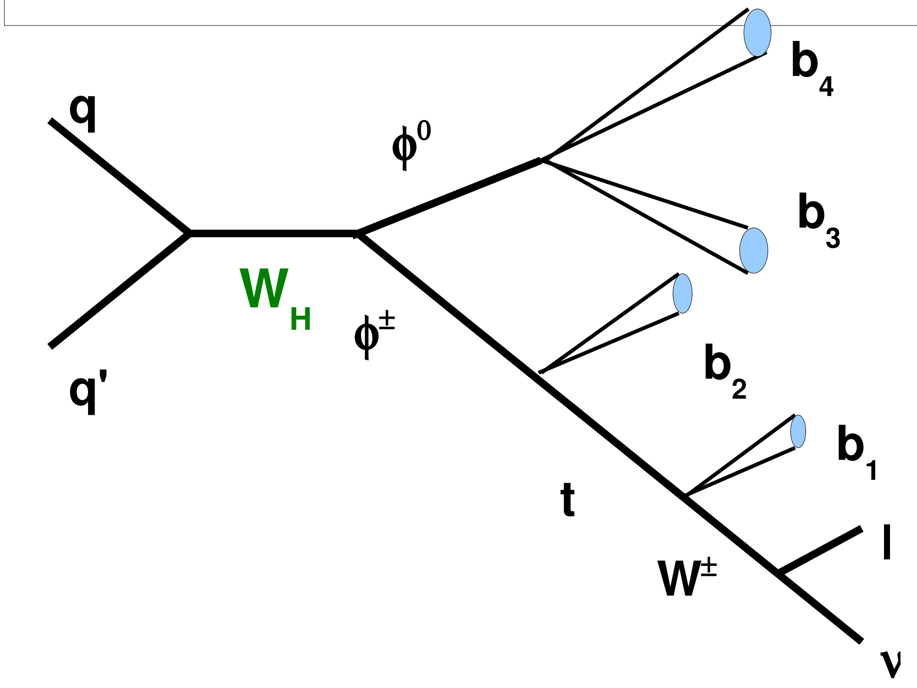
N_{sig} = 651

N_{tt} = 377

N_{wj} ~ 0

$N/\sqrt{B}$ = 33

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

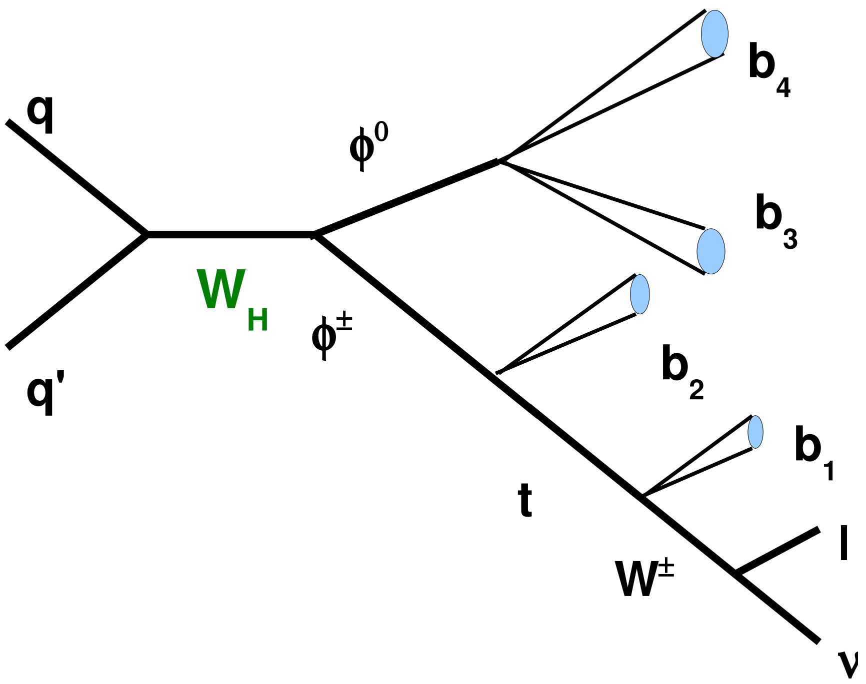


	$\langle p_T \rangle$ (GeV)
b_1	148
b_2	52
b_3	200
b_4	200
l	100
ν	121

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%)

<u>Simulation:</u>	Pythia + ATLFAST
<u>X-section:</u>	σ = 30 pb x BR
<u>Background:</u>	tt, W+jets
<u>Luminosity:</u>	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

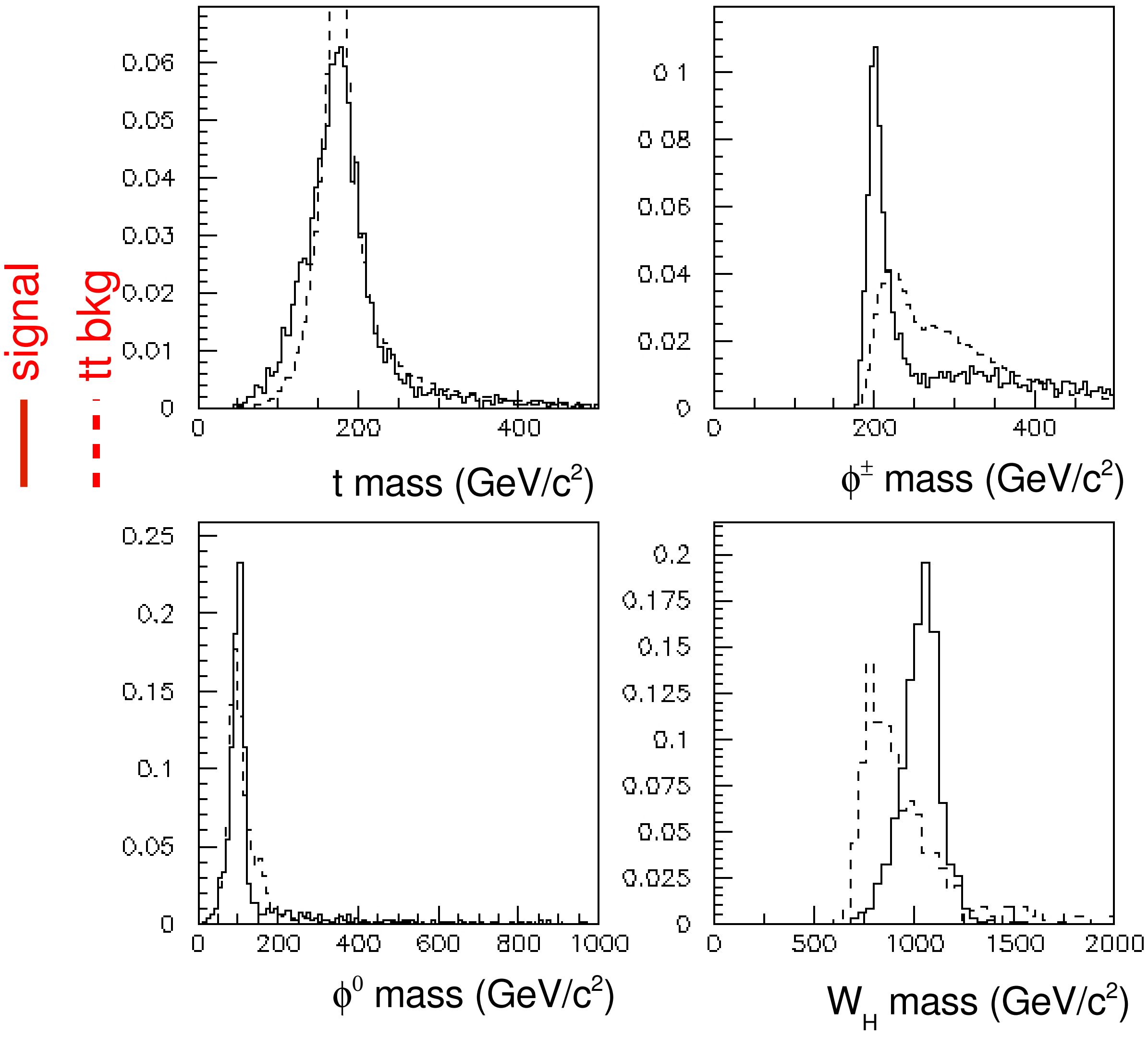
m(t) < 250 GeV/c^2

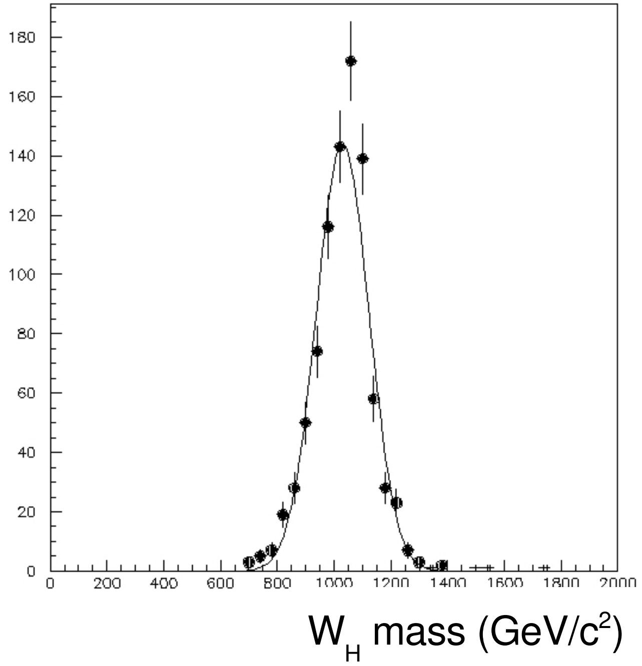
m($\phi^{\pm}$) < 250 GeV/c^2

m(ϕ^0) < 150 GeV/c^2

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

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





Reconstructed mass and width:

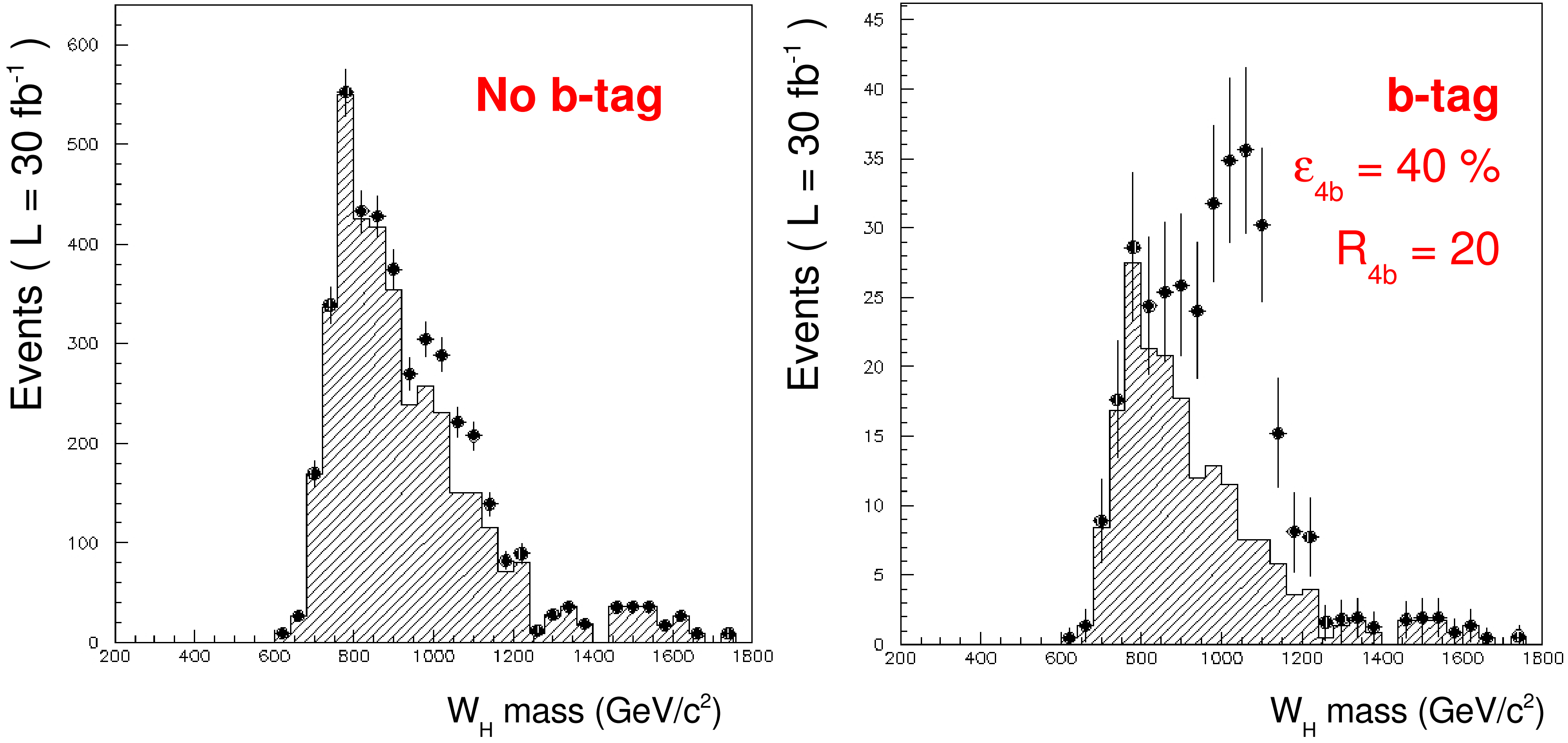
$m = 1030$ GeV/c^2

$\sigma = 93$ GeV/c^2

Remark:

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

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

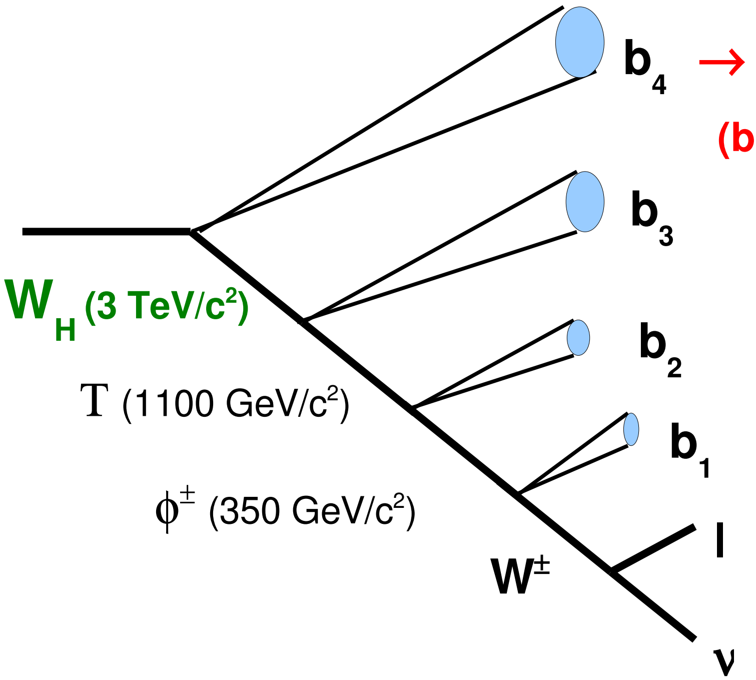
Decay	signature	total B.R.	comment
$W_H \to Tb \to \phi^{\pm}bb$	$\to 4b + l + E_t^{miss}$	3.2 %	this contribution
$\to bWb$	$\to 2b + l + E_t^{miss}$	0.4 %	
$\to thb$	$\to 4b + l + E_t^{miss}$	0.4 %	
$\to tZb$	$\to 2b + 3l + E_t^{miss}$	0.01 %	very small rate/no bkg.
$\to t\phi^0 b$	$\to 4b + l + E_t^{miss}$	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 $M \to 0$

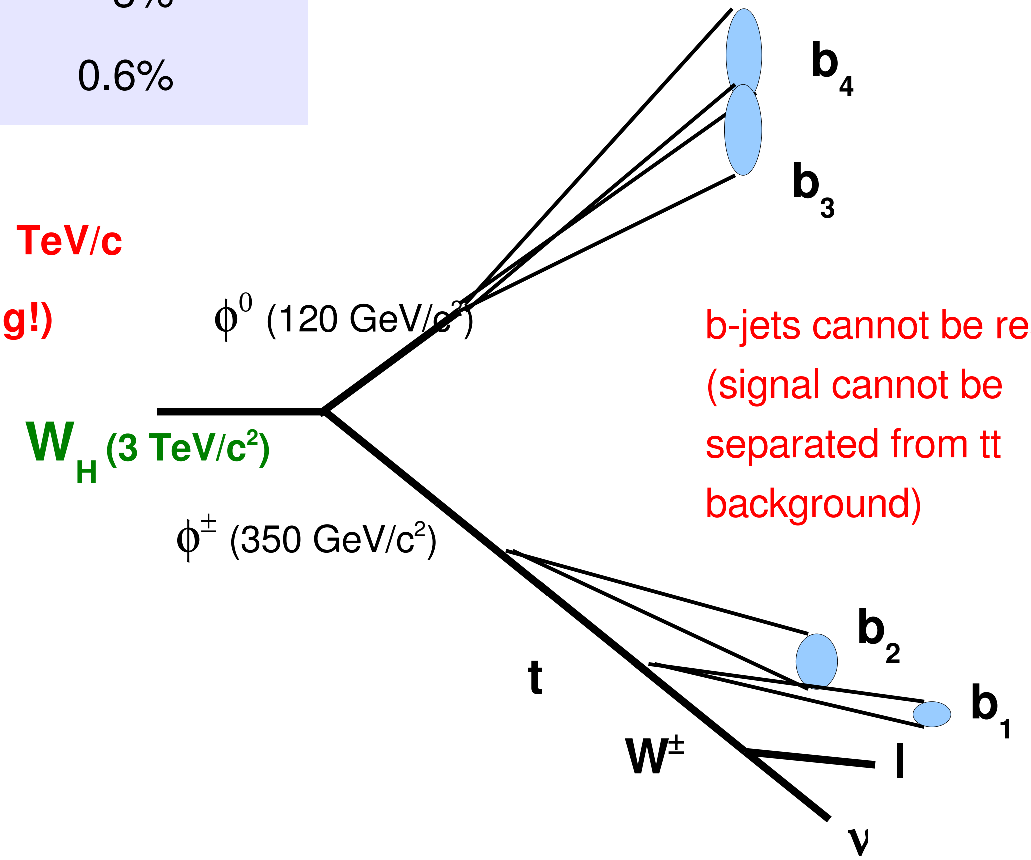
Mass dependence

m (W_H)	**1 TeV/c²**	**2 TeV/c²**	**3 TeV/c²**
σ(pb)	30	2	0.2
M_T (GeV/c²)	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%



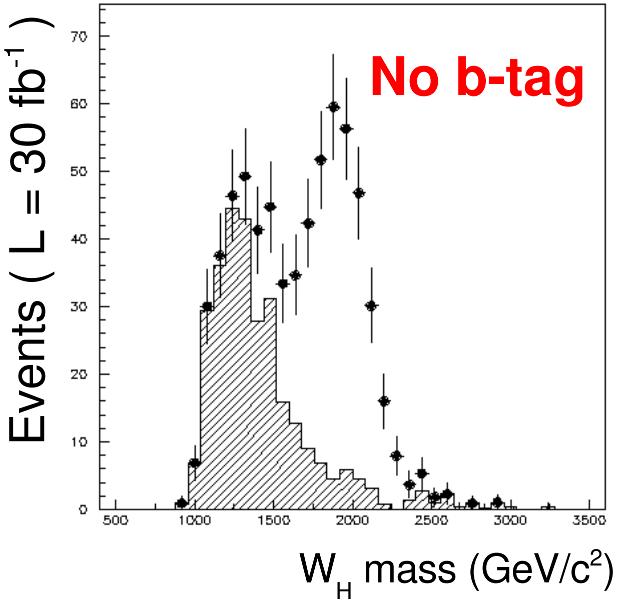
→ p_T ~ 1 TeV/c

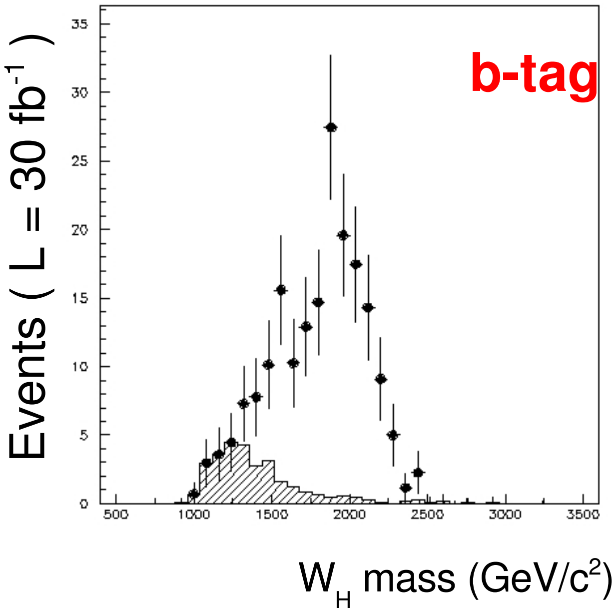
(b-tagging!)



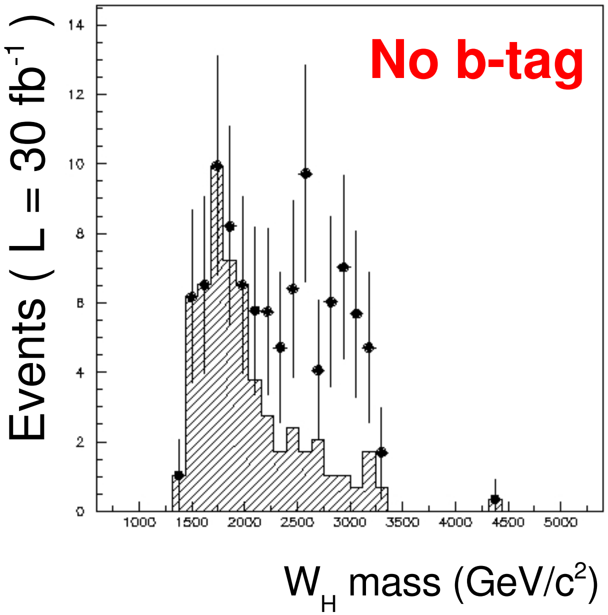
b-jets cannot be resolved (signal cannot be separated from tt background)

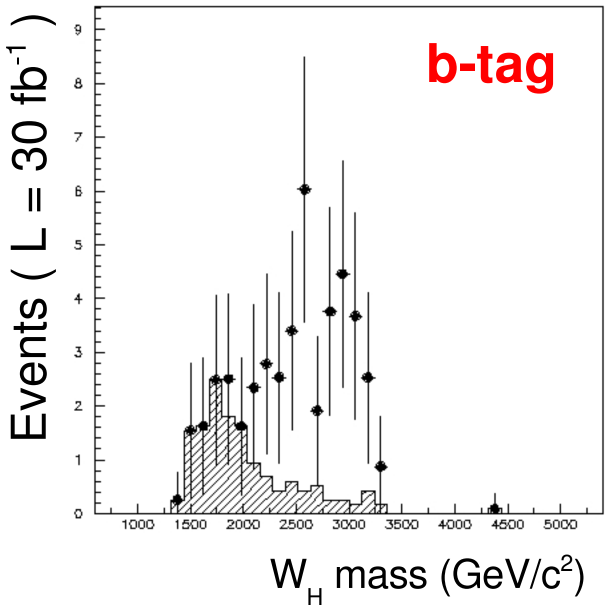
$W_H \rightarrow Tb$, $m(W_H) = 2,3\ \mathrm{TeV}/c^2$





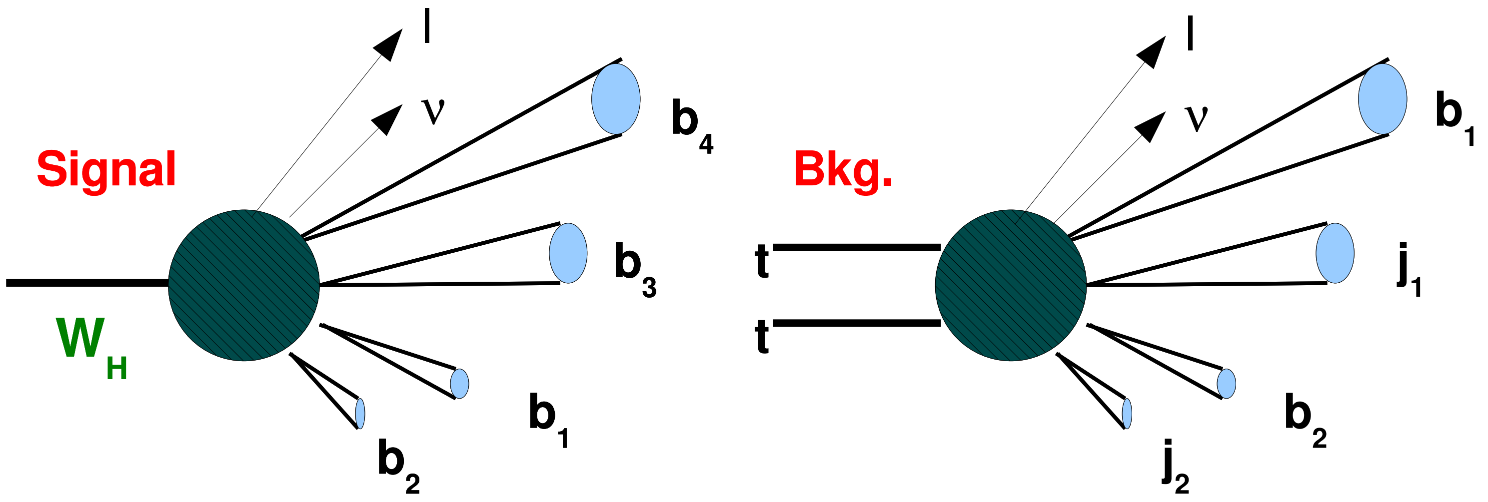
2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
$N/\sqrt{B}$	43	55





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



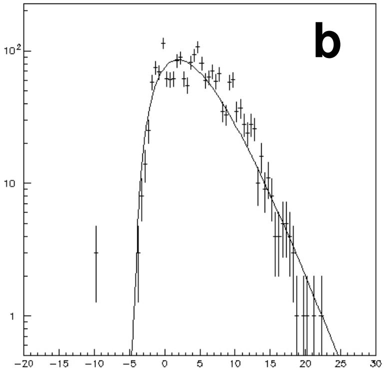
How to tag a signal of 4 b-jets against a background of 2 b + 2 j ?

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

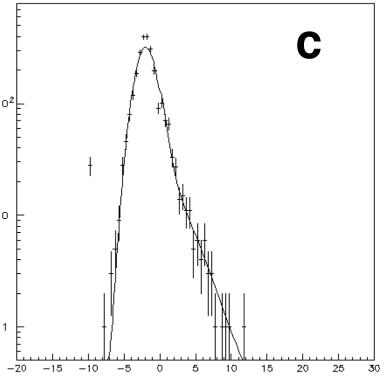
Construct a 4 b-jet likelihood from individual jet weights.

b-tagging likelihood weights

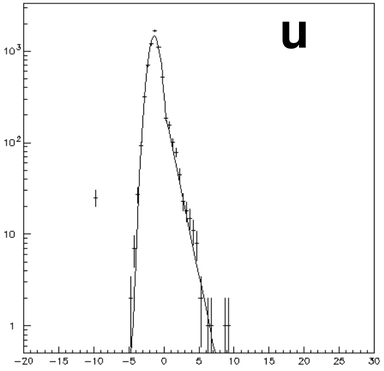
b-tag likelihood “weights” for $60 < p_T < 100$ GeV/c (2D signed IP significance algorithm - DC1 data)



jet weight



jet weight



jet weight

$\varepsilon_b = 50\%$

$p_T = 100$ 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

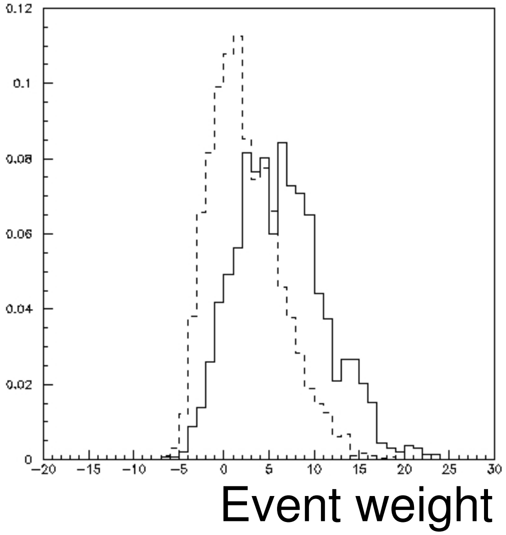
multi b-jet likelihood:

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

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

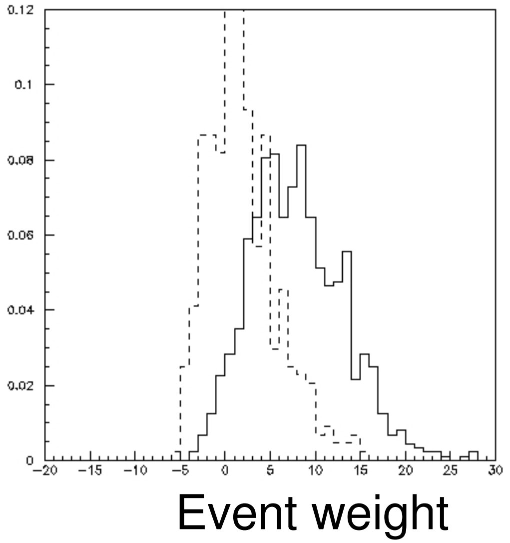
$W_H \to Tb \to 4b + l + E_t^{miss}$

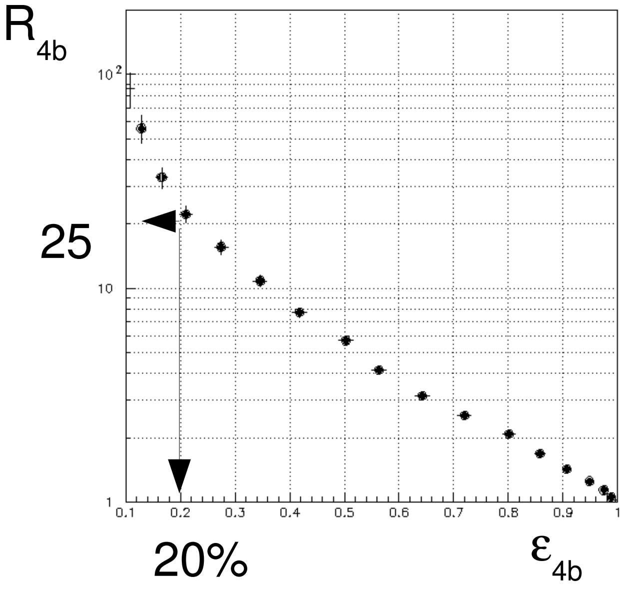
$W_H \to \phi^\pm\phi^0 \to 4b + l + E_t^{miss}$



signal

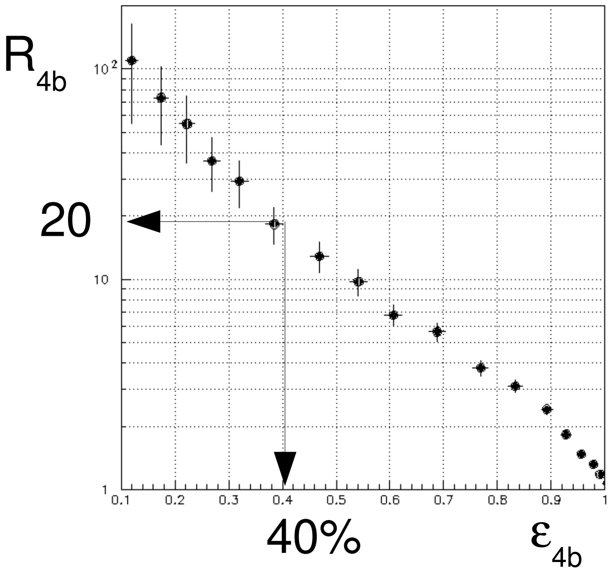
tt background





ε_{4b} = signal efficiency

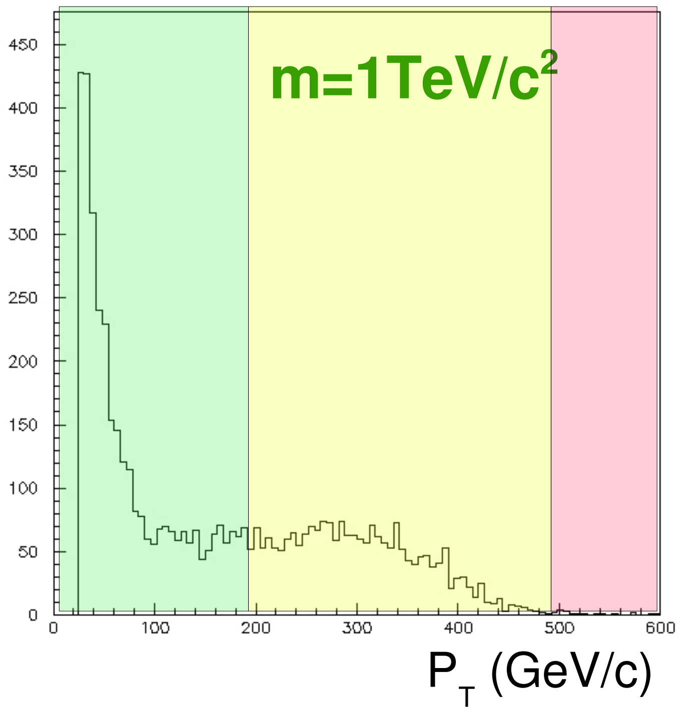
R_{4b} = rejection against tt background

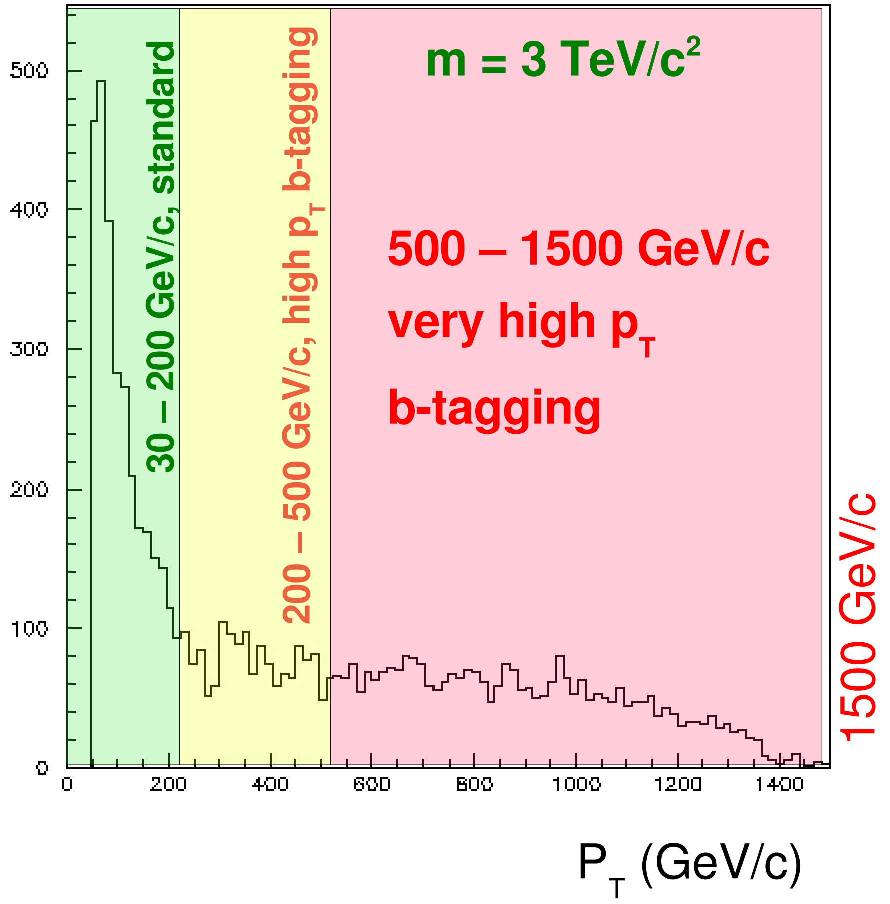


p_T distribution of b-jets

P_T spectrum for b-jets in

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

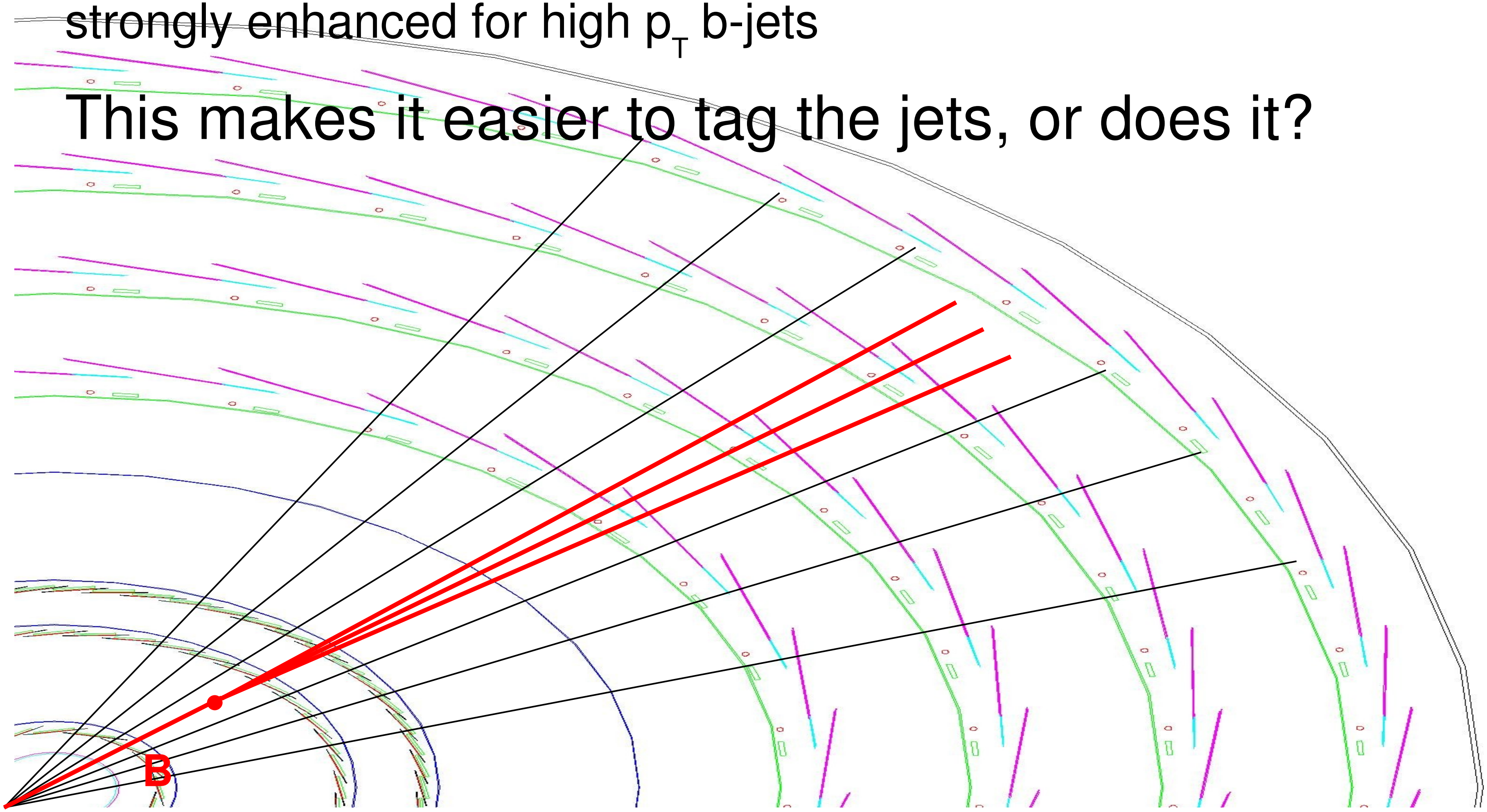




Very high p_T b-tagging (I)

$L = c\,\tau\,\gamma$ –> 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?

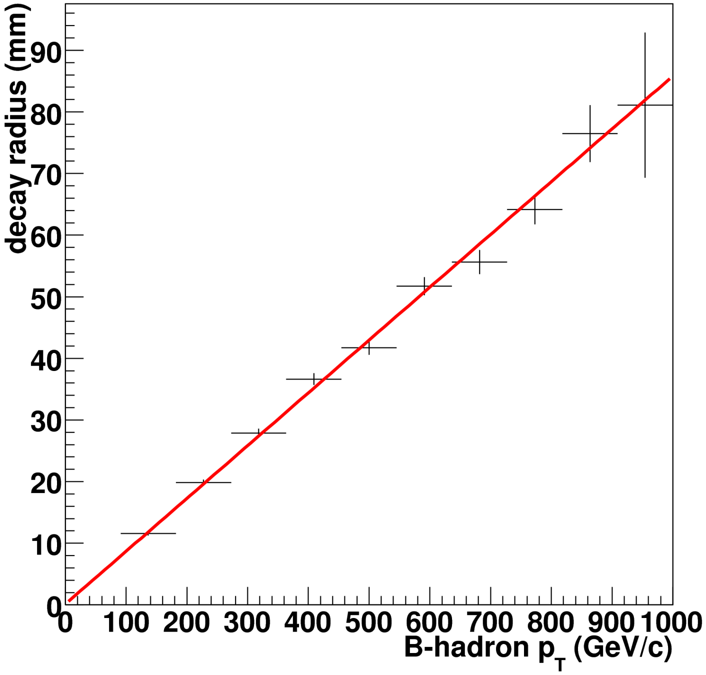


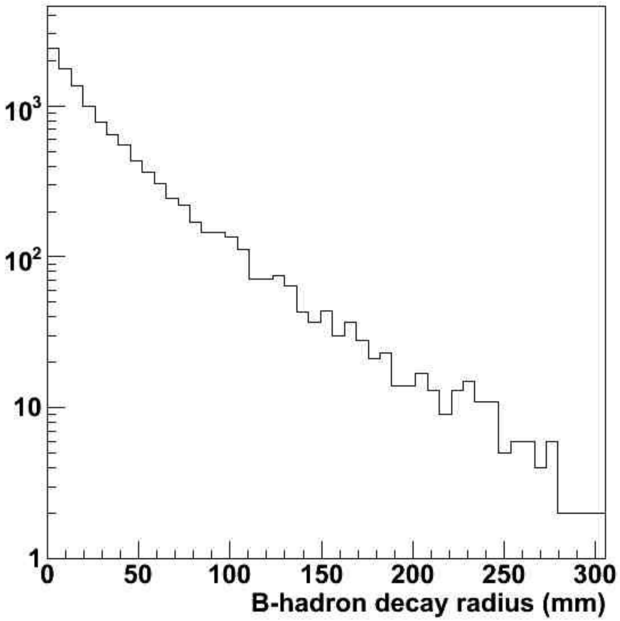
Very high p_T b-tagging (II)

$L = c \tau \gamma$

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

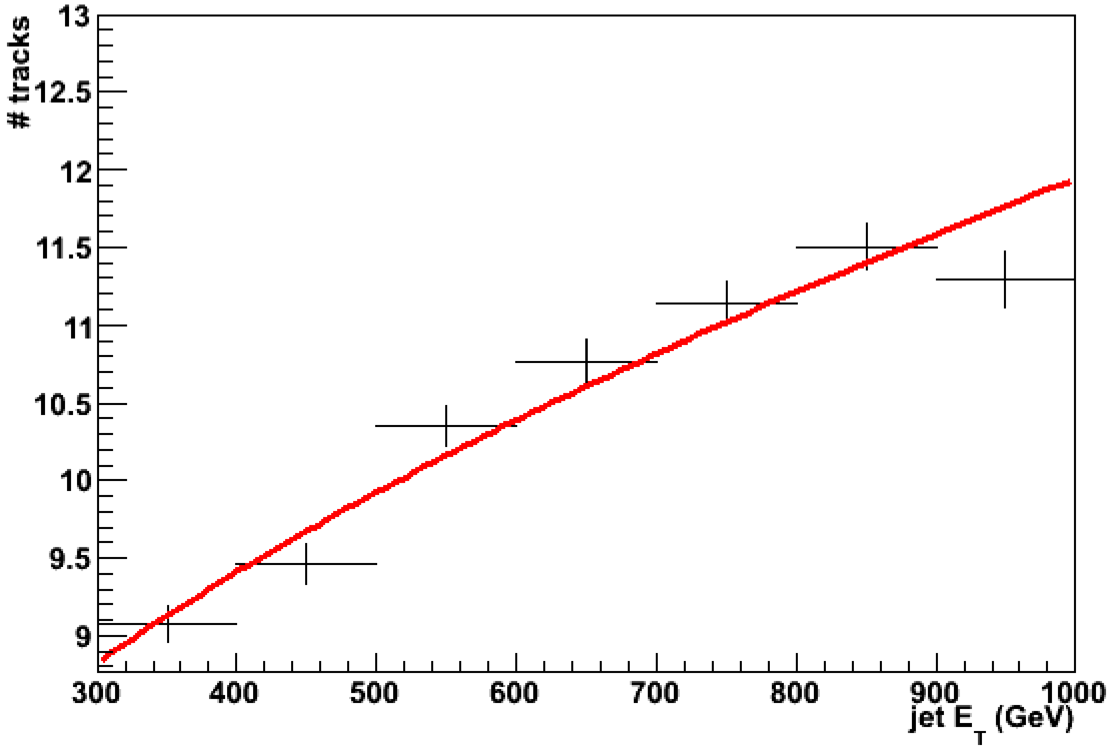
B-layer





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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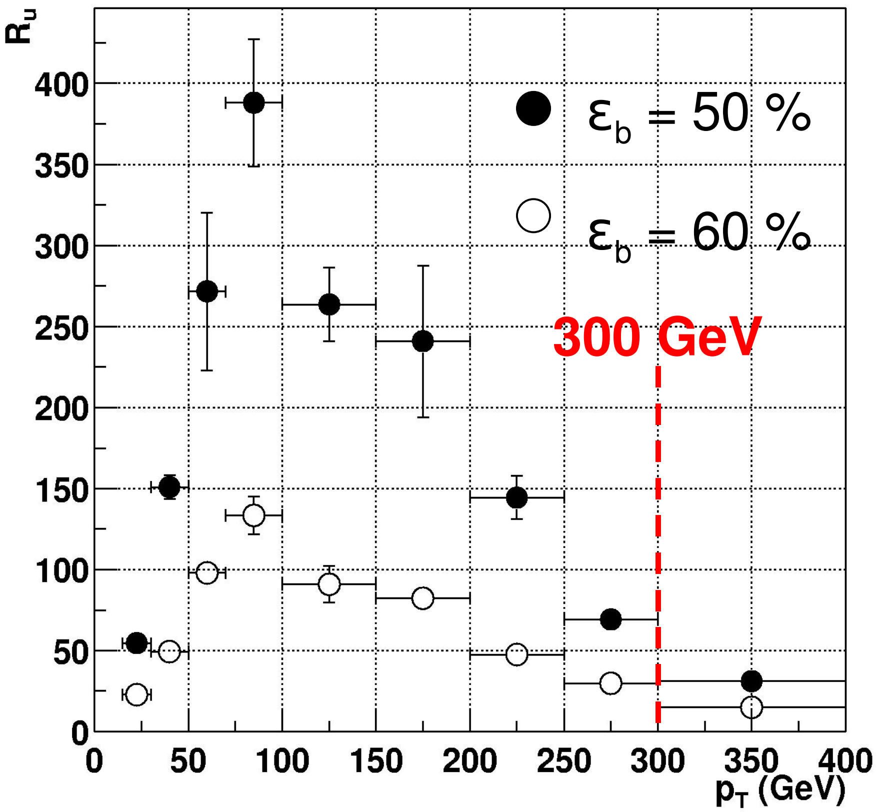

2D algorithm – DC1 data

pp → W H (120 + 400 GeV)

b b

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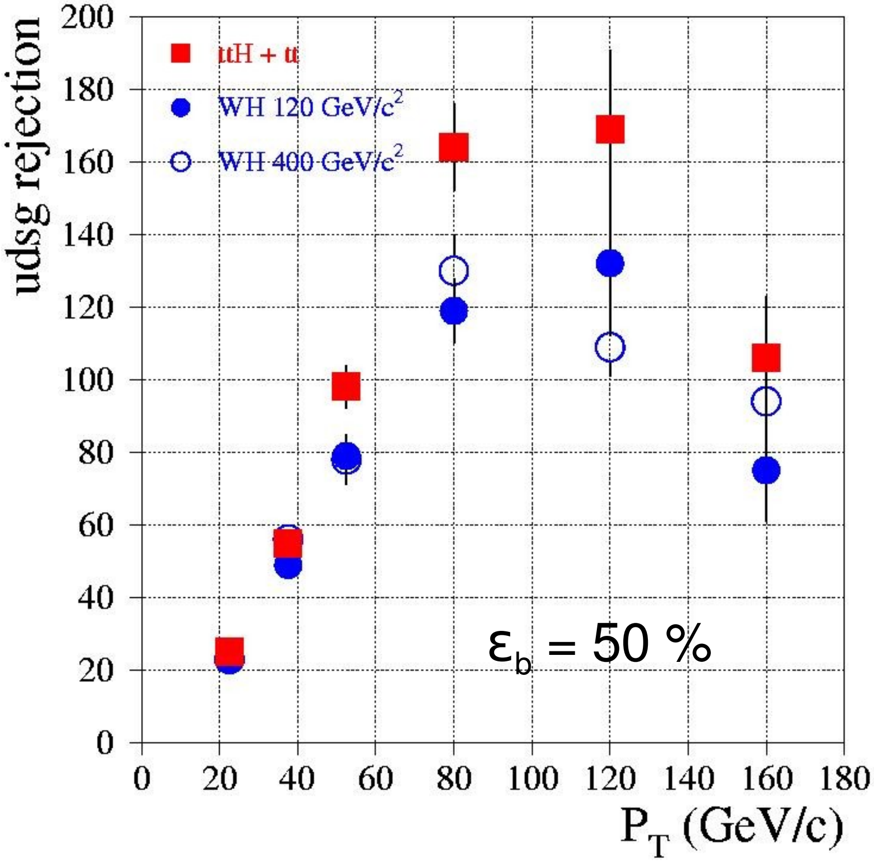
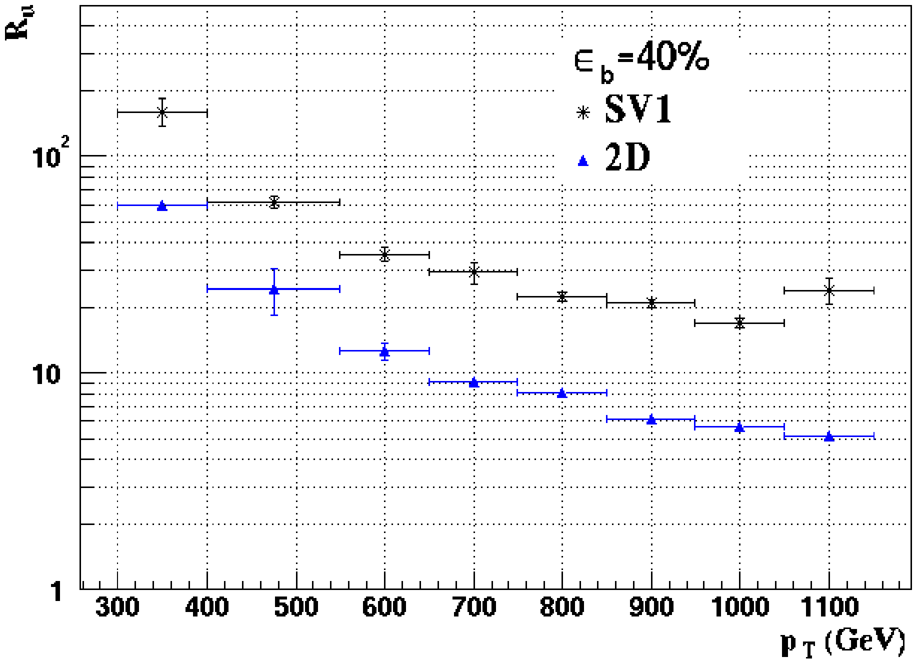


2D algorithm – DC1 data

W H + t t samples

p_T dependence in Z_H (2 TeV/c^2) → 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

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

  can be observed with ATLAS and $L=30\ fb^{-1}$ for masses up to $m\,(W_H) \sim 3\ TeV/c^2$
- Other decays like $W_H \rightarrow \phi^{\pm}\phi^{0} \rightarrow 4b + l + E_t^{miss}$ can be observed for $m\,(W_H) \sim 1\ TeV/c^2$
- 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

Discussion

The work presented today is just the first step:

fast simulation (with some feedback from full simulation)

of ONE experiment's (ATLAS) potential for

ONE promising final state

(in terms of feasibility of signal isolation, mass reach, and added value to distinguish models)

for ONE set of parameters

(mixing parameter M of t-t_H known to have big impact on phenomenology)

Discussion

Home-work for experiments/experimentalists; further signatures:

$Z_H \to e^+e^-$	**discovery BSM (little Higgs study, e+e- group)**
$Z_H \to TT, tt, tT$ (M large)	**TT -> 6 b + 2 W**
$W_H \to e\,\nu_R$	**2 l + jets (ATLAS phys. TDR)**
$W_H \to tb$	**polarization**
$t_H \to tZ \to 2b + 3l + E_T^{miss}$	**background-free**

Higgs sector? (depending on μ_r)

M=0? replace $\phi^\pm \to tb$ by $\phi^\pm \to \tau\,\nu_\tau$

Discussion

Home-work for experiments/experimentalists; add the development of efficient algorithms for:

high p_T b-tagging

To the to-do list:

high p_T muon/electron trigger (isolation)

top mono-jet ID/reconstruction

polarization ($W_H \to tb$)

Discussion

Home-work for experiments/experimentalists: develop:

realistic experimental strategy

(i.e. template kinematical reconstruction on masses of different particles involved in cascade)

Discussion

Wish list for our theory friends:

Exact values of σ, Γ, BR for all possible channels and all combinations of parameters

DONE!

define bench mark points,

- **M=0, 10, 150 GeV**
- **μ_r = O(100 GeV), O(1 TeV)**

BACKUP SLIDES

Theoretical motivation

The problem (known as (little) hierarchy or fine-tuning problem, or LEP-paradox):

“radiative corrections to the Higgs mass up to ultra-violet cut-off Λ yield a Higgs mass of order Λ unless there is a very delicate cancellation” (following approximately the phrasing [SN-ATLAS-2004-038])

The solution(s):

“[the instability of the SM under quantum corrections] suggests the existence of new physics at or close to a TeV that protects the Higgs mass parameter of the SM against radiative corrections”. (hep-ph/0506256)

- SUSY (with R-parity)
- (Large) Extra Dimensions
- .... (fill in your favourite solution here)

Theoretical motivation (II)

Alternative solution: ***"the Higgs is naturally light because it is the pseudo-Goldstone boson of an approximate global symmetry"***

(*phrasing from hep-ph/0506256***)**

- **embed SM in larger symmetry group.**
- **Counterparts to SM particles are of the same statistics**
- **The larger symmetry, broken at some high scale Λ_H, protects the Higgs mass from one-loop corrections quadratic in Λ_H.**

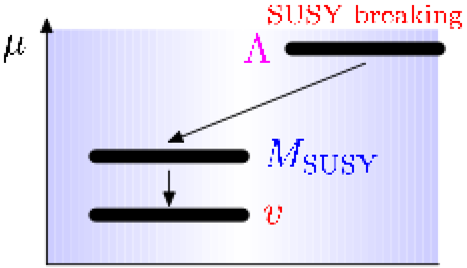
(originally proposed in the 1970s, see Georgi and Pais, Phys. Rev. D 10, 539 (1974), Kaplan, Georgi, Dimopoulos, Phys. Lett. B 136, 183 (1984),

Supersymmetry?

Possible solution: Indirect (dynamical) scale generation

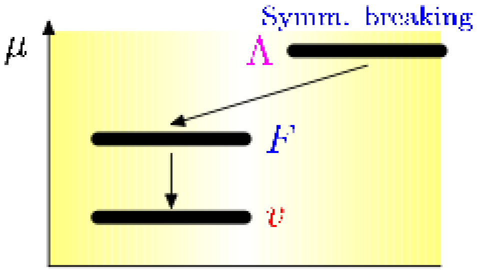
Supersymmetric Models:

- Field condensation in new (hidden) sector with SUSY
  $\Rightarrow$ SUSY breaking $\Rightarrow$ Scale generation
- Scalars are present because of SUSY
- Scalar potential by radiative corrections
- Top sector triggers EWSB



Little Higgs Models:

- Field condensation in new sector with global symmetry
  $\Rightarrow$ spontaneous symmetry breaking $\Rightarrow$ Scale generation
- Scalars are present because of Goldstone theorem
- Scalar potential by radiative correctons
- Top sector triggers EWSB



Theoretical motivation (III)

Little Higgs model (Arkani-Hamed, Cohen, Georgi, JHEP 0207, 020 (2002), Phys. Lett. B 513, 232 (2001))**:electroweak symmetry breaking be the result of strong dynamics**

Model is severely constrained by precision electroweak data (Csaki et al., hep-ph/0211124, Hewett, Petriello, Rizzo, hep-ph/0211218)

Constraints are lifted by other models with similar LHC phenomenology (Chang, hep-ph/0306034, Kaplan and Schmaltz, hep-ph/0302049)

LHC reach studied in detail in SN-ATLAS-2004-038 (hep-ph/0502037)

Theoretical motivation (V)

Twin Higgs model

Introduce discrete symmetry: each SM particle is interchanged with a corresponding particle transforming under a twin SM gauge group.

EW precision data reproduced by construction: although new particles may be light they do not transform under the SM gauge groups. New physics is not necessarily charged under SM gauge groups!

Mirror Twin Higgs model (Chacko, Goh, Harnik, hep-ph/0506256)**:**

Discrete symmetry is identified with mirror parity.

Collider phenomenology: invisible Higgs decay (ILC)

LR Twin Higgs model (Chacko, Goh, Harnik, JHEP 0601, 108 (2006))**:**

Discrete symmetry is identified with Left-Right symmetry.

Collider phenomenology: new particles around the electroweak scale (Goh, Suh, hep-ph/0608330)