The LR Twin Higgs note

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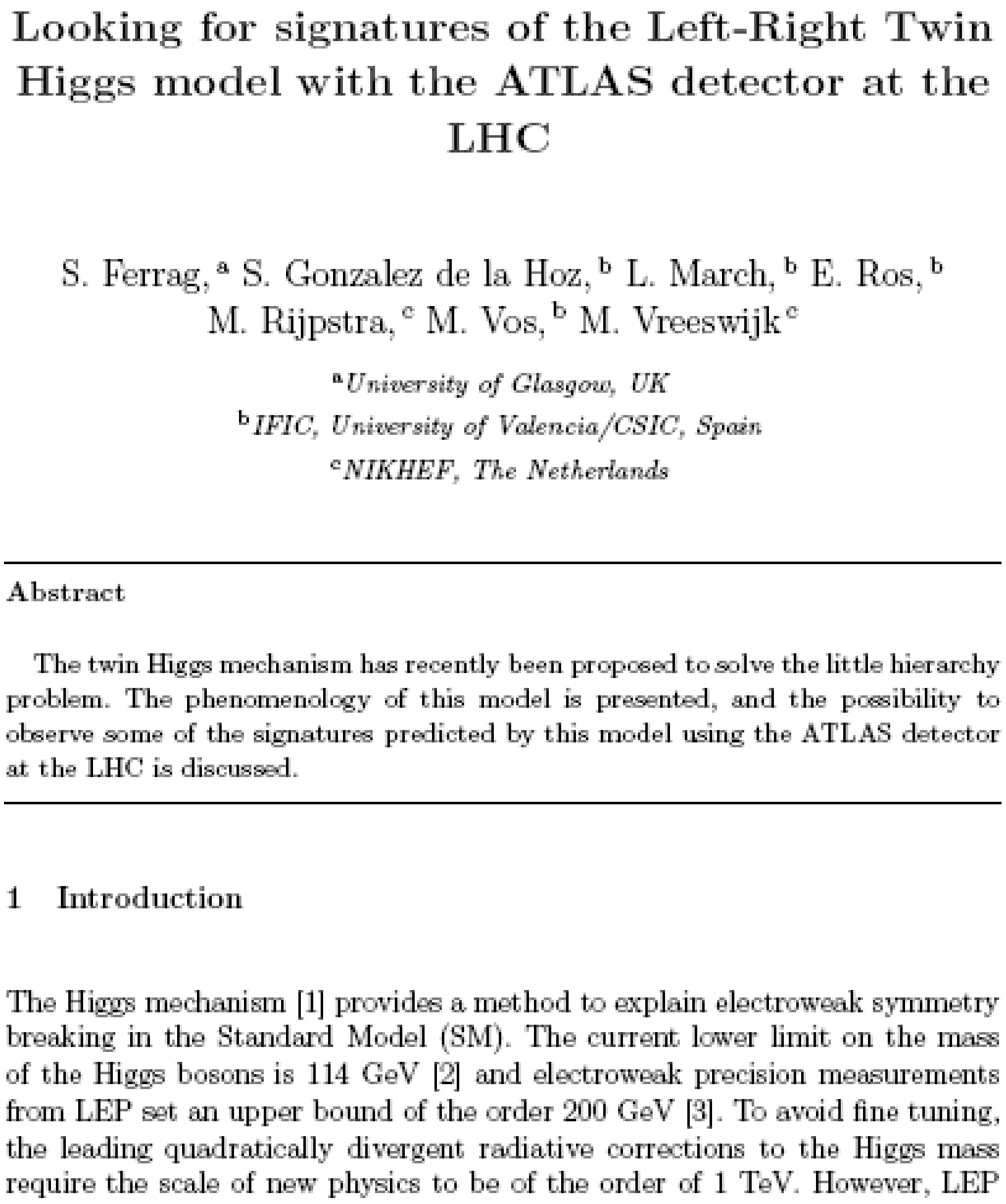
ATLAS Trigger & Physics Week
exotic physics group meeting
Wed. Nov. 7, 2007



Looking for signatures of the Left-Right Twin Higgs model with the ATLAS detector at the LHC

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Abstract

The twin Higgs mechanism has recently been proposed to solve the little hierarchy problem. The phenomenology of this model is presented, and the possibility to observe some of the signatures predicted by this model using the ATLAS detector at the LHC is discussed.

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1 Introduction

The Higgs mechanism [1] provides a method to explain electroweak symmetry breaking in the Standard Model (SM). The current lower limit on the mass of the Higgs bosons is 114 GeV [2] and electroweak precision measurements from LEP set an upper bound of the order 200 GeV [3]. To avoid fine tuning, the leading quadratically divergent radiative corrections to the Higgs mass require the scale of new physics to be of the order of 1 TeV. However, LEP

Further information

further information:

October 2007 Exotics group meeting:

http://indico.cern.ch/conferenceDisplay.py?confId=20696

June 2007 Exotics group meeting:

http://indico.cern.ch/conferenceDisplay.py?confId=16473

Les Houches workshop on physics at TeV colliders:

di-lepton group (S. Ferrag), twin Higgs session (S. Su, M. Vos)

http://www.lpthe.jussieu.fr/LesHouches07Wiki/index.php/Session_II

ATLAS b-tagging workshop (Marseille, May 2007):

http://indico.cern.ch/conferenceOtherViews.py?confId=14475

ATLAS flavour tagging meeting:

http://indico.cern.ch/conferenceDisplay.py?confId=21733

Webpage: http://fiic.uv.es/~vos/Atlas/TwinHiggs/

Outline

CHAPTER	RESPONSIBLE	RESULTS	TEXT
1-3) Introduction	All	OK	OK
4) $Z_H \to e^+e^-$	Valencia/Glasgow	partially	
5) $Z_H \to Zh$	Valencia	NO	NO
6) $W_H \to tb$	NIKHEF	just started	
7) $W_H \to Tb$	Valencia	OK	OK
8) $W_H \to \phi^\pm \phi^0$	Valencia	OK	OK
9 Conclusion	All	NO	NO
App A: multi b-jet	Valencia	OK	OK
App B: high pT b-tag	Valencia	OK	OK

Di-leptons – mass resolution

Mass	Natural width (GeV)	Di-lepton mass resolution (GeV)	
		Electrons	Muons
1.2 TeV	24	8	60
3.6 TeV	75	19	400

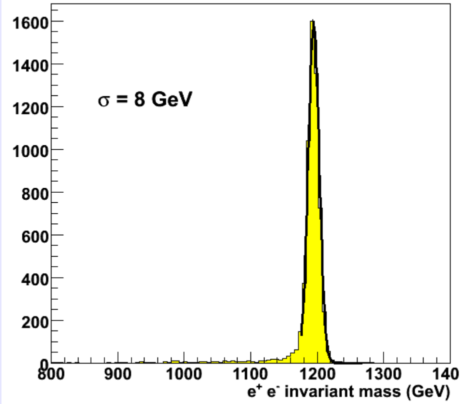
ATLFAST mass resolution for heavy resonances

Electrons:

$\Delta E/E = a / \sqrt{E} \oplus b\ \%$

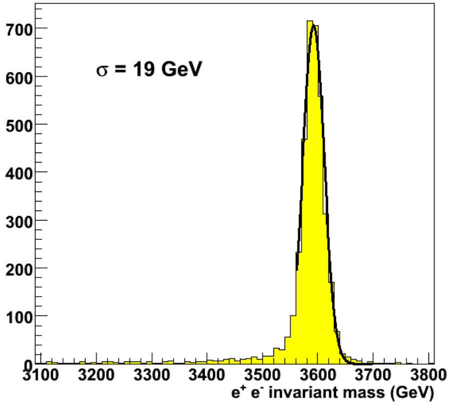
ΔM (e^+e^- @ 1.2 TeV)

0.7 % / 8 GeV



ΔM (e^+e^- @ 3.5 TeV)

0.5 % / 19 GeV

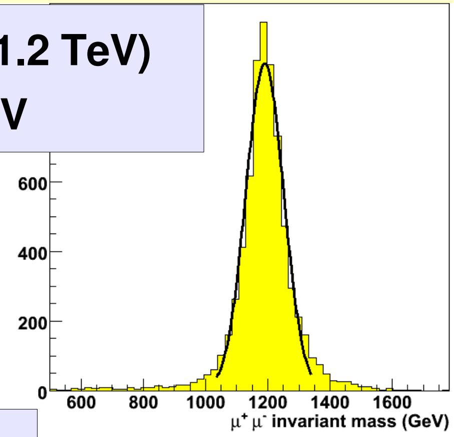


Muons:

$\Delta p_T / p_T = c \times p_T$

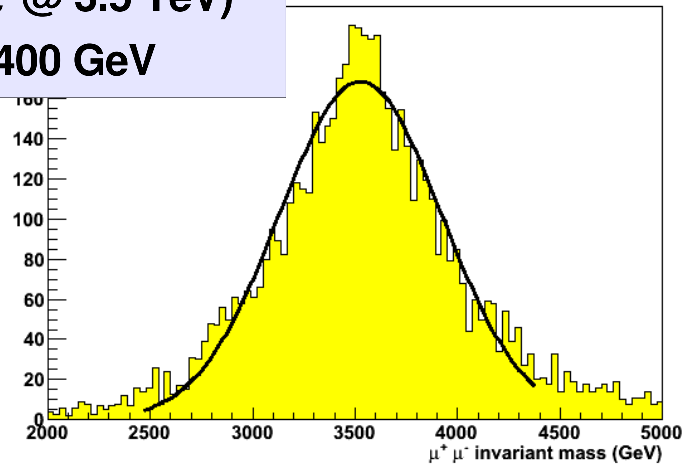
ΔM ($\mu^+\mu^-$ @ 1.2 TeV)

5 % / 61 GeV



ΔM ($\mu^+\mu^-$ @ 3.5 TeV)

11 % / 400 GeV



Di-leptons – trigger/reco efficiency

ATLFAST typically gives 90 % efficiency for any lepton

Should we be worried that 500 GeV electrons are significantly different?

On standard AODs reconstructed with 12.0.6
Trigger (EF) efficiency for Z' (1 TeV) → e^+e^-:

e25i	50 %
e60	84 %
γ60	97 %

Di-leptons

$Z_H \rightarrow$ di-leptons

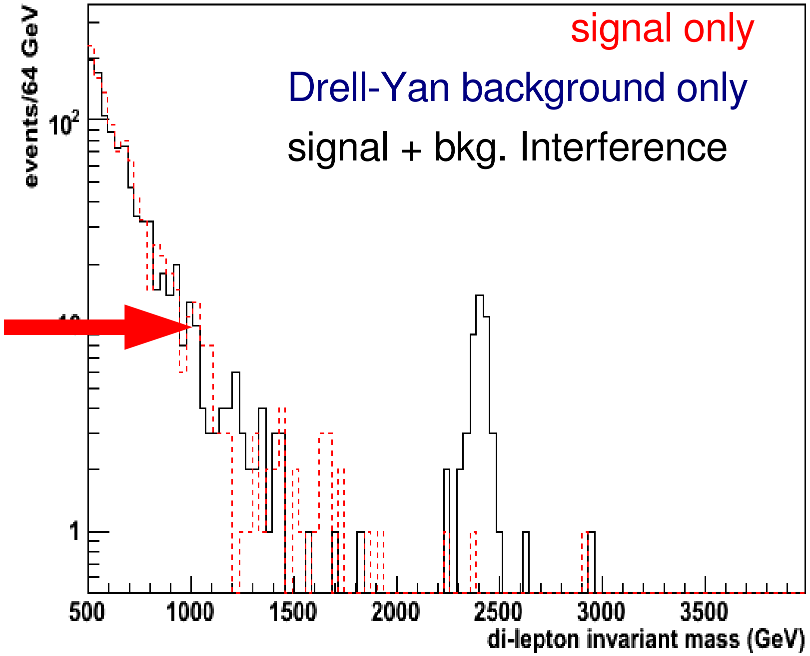
likely discovery channel

for LR twin Higgs model.

Redo with ATLFAST in ATHENA 12.0.6 (M.V.)

Redo using full interference fit (S.F.)

di-lepton mass distribution for 10 fb^{-1}



Mass	luminosity for 3 sigma (fb^{-1})		luminosity for 5 sigma (fb^{-1})	
1196 GeV	0.068	(0.079)	0.19	(0.22)
1495 GeV	0.19	(0.19)	0.52	(0.52)
2407 GeV	2.04	(2.09)	5.5	(5.5)
3587 GeV	~ 27	(28)	~75	(77)

$W_H \to tb$

Twin Higgs

$W_H \to tb$

$m(W_H)$	1 TeV/c^2	2 TeV/c^2	3 TeV/c^2
σ(pb)	30	2	0.2
BR ($W_H \to$ tb)	4%	3%	0.6%

T- t Mixing
parameter
M = 150 GeV

The same signature was studied in the framework of the littlest Higgs model

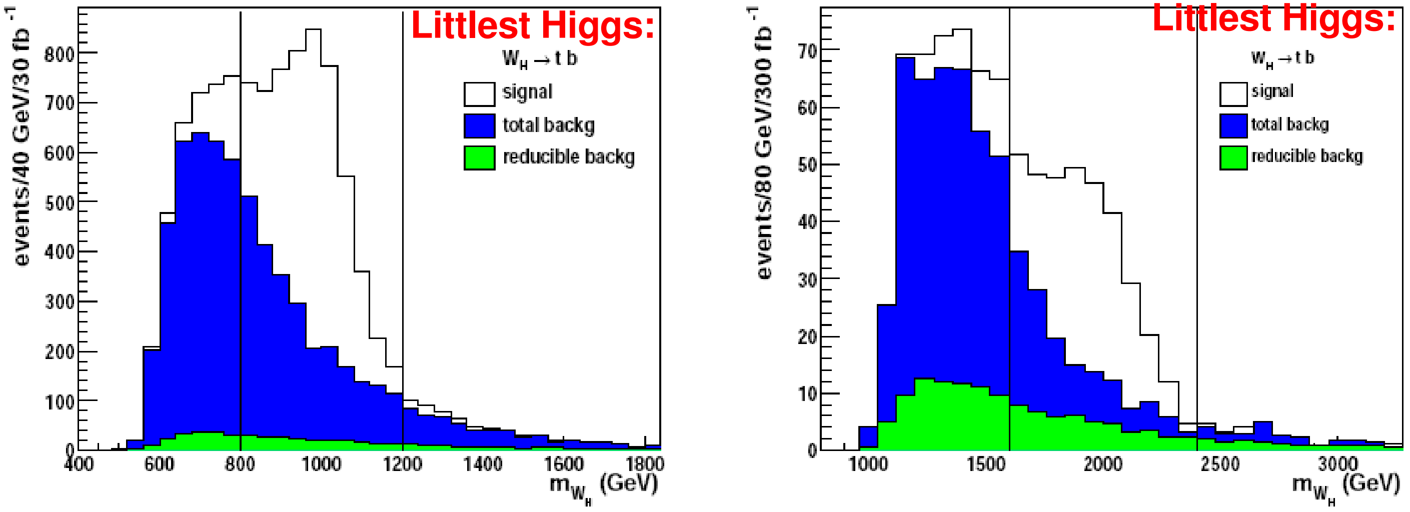
Cross-section similar to case cot $\theta = 1$, BR was 25 % in littlest Higgs model.

As for cascade decays, non-zero t-T mixing is required for this decay to be present

Littlest Higgs:

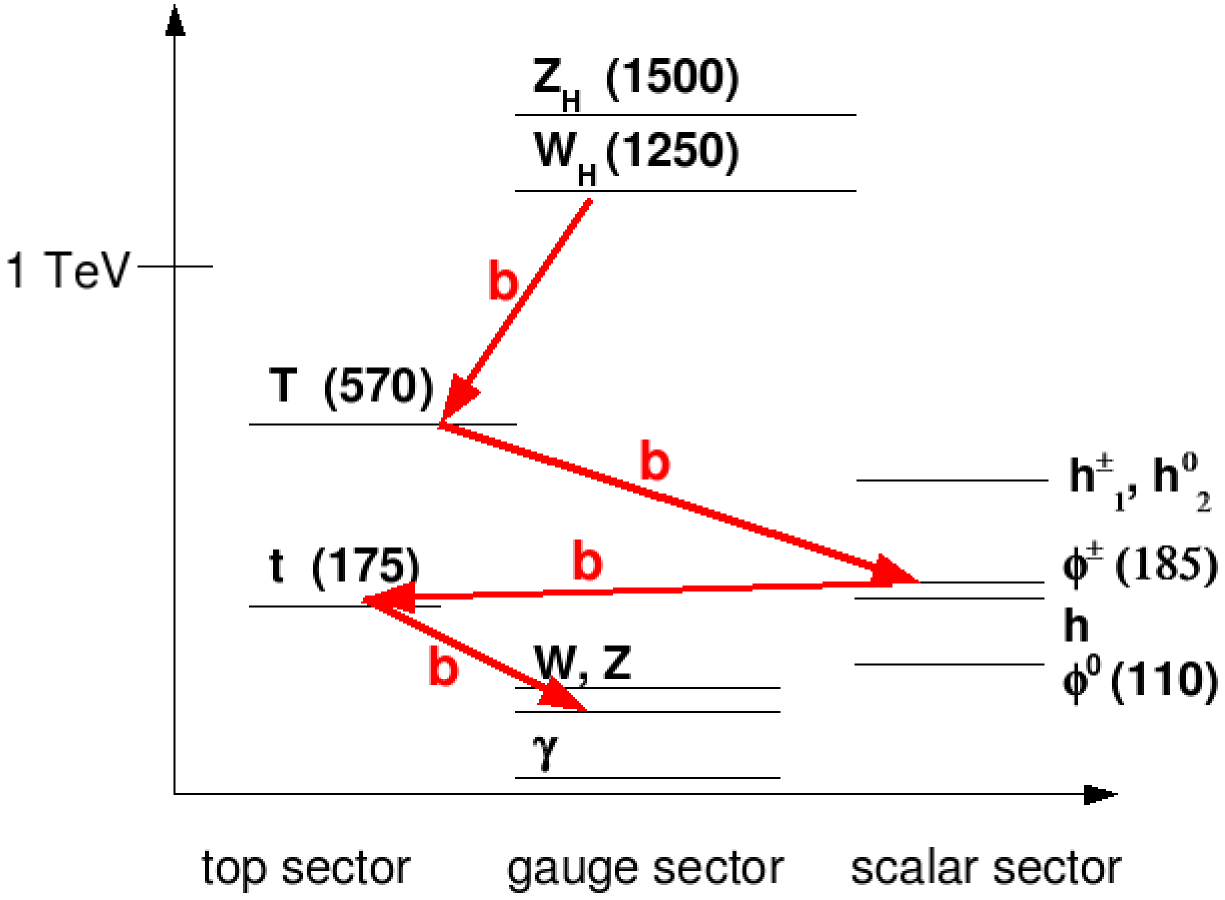
reconstructed W_H mass

(PHYS-PUB-2006-003).



M. Rijpstra and M. Vreeswijk (NIKHEF) have picked up this final state: expect ATLFAST mass reach in time for final version of Twin Higgs note.

Signature for W_H (1.25 TeV/c^2)→ Tb

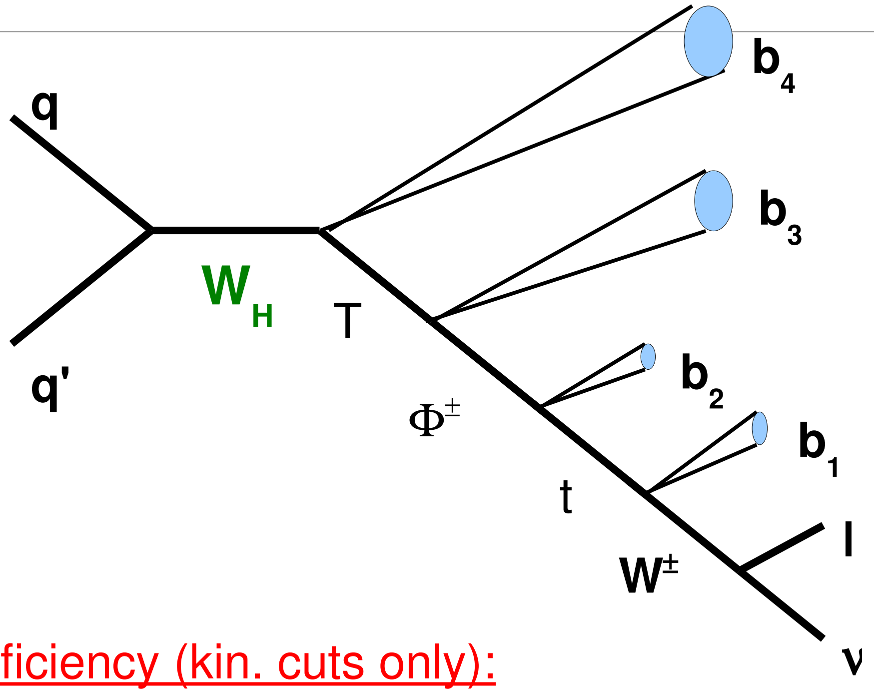


Two threats:

for small f, the charged Higgs boson $\phi^\pm$ decay into tb is not kinematically allowed ($\phi^\pm \rightarrow$ qq', where q,q'=u,d,s,c)

for small values of the T-t mixing parameter M $\rightarrow 0$, the decay $\phi^\pm \rightarrow$ tb vanishes

Signature for W_H (1.25 TeV/c^2)$\to$ Tb



Efficiency (kin. cuts only):

$\varepsilon_{kin} \sim 12$ %

Simulation: Pythia + ATLFAST

X-section: $\sigma = 30$ pb x BR

Background: tt, W+jets

Luminosity: L = 30 fb^{-1}

Reconstruct masses

$l+\nu \to W$ 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)

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

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

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

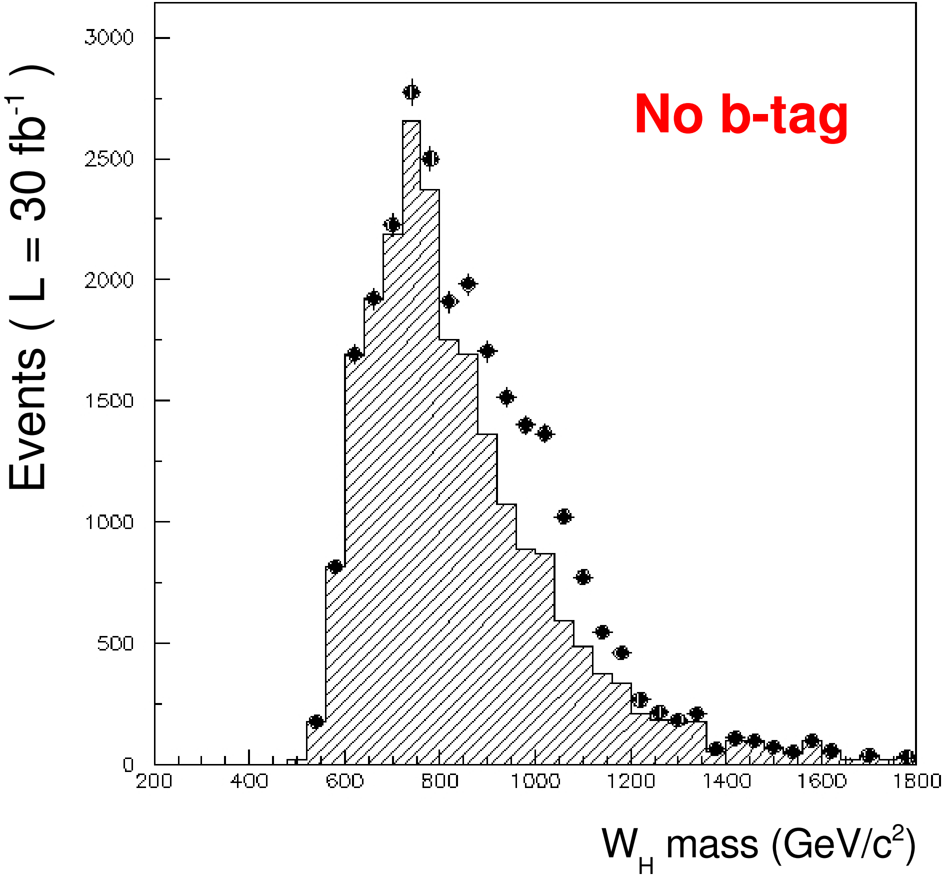
$T+b_4 \to W_H$ p_T (b_4) > 150 GeV/c

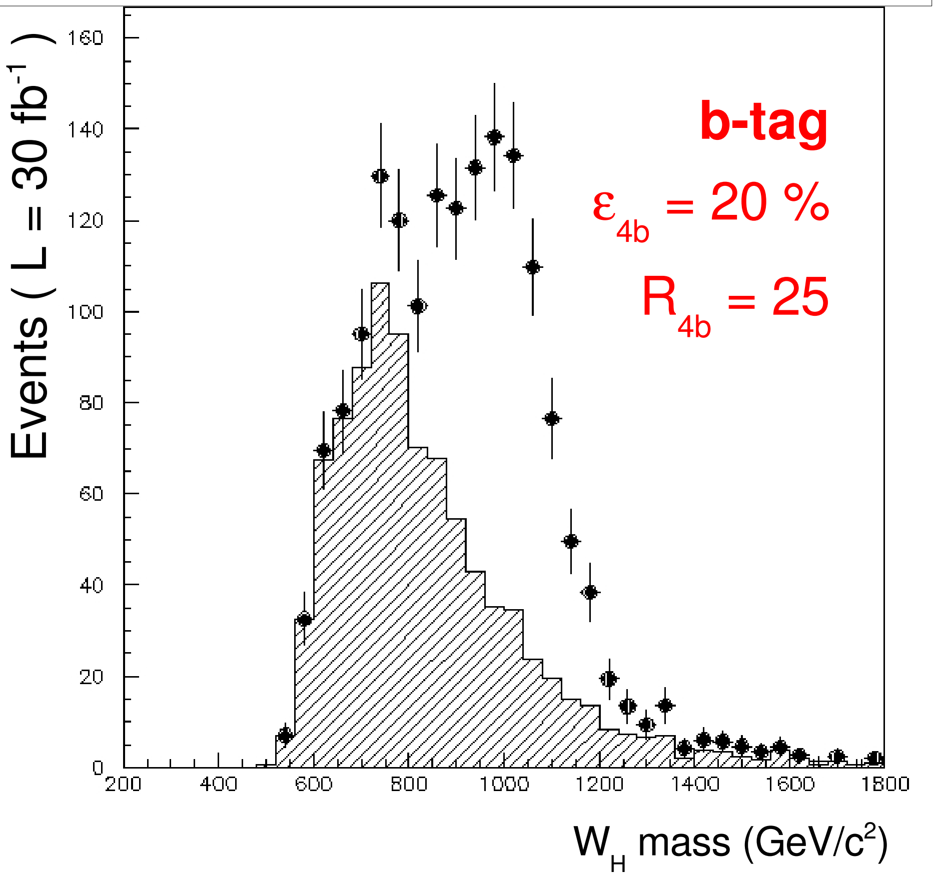
| η | < 2.5 for all leptons and jets

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)

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





N_{sig} = 3253

N_{tt} = 9427

N_{wj} = 319

N/√B = 33

N_{sig} = 651

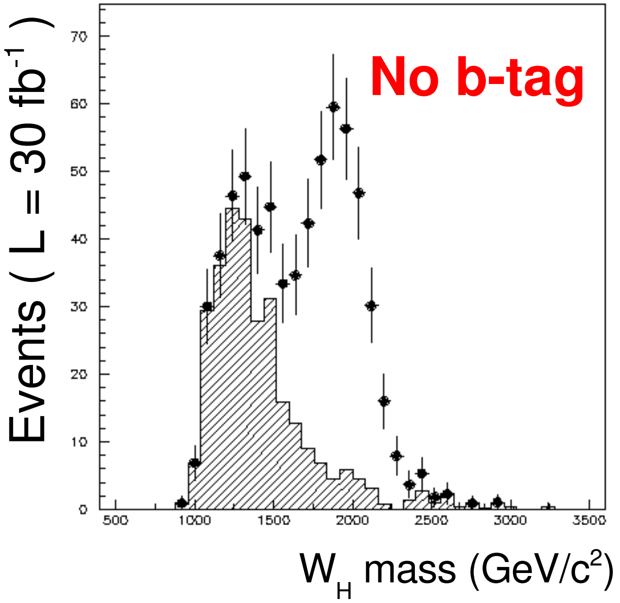
N_{tt} = 377

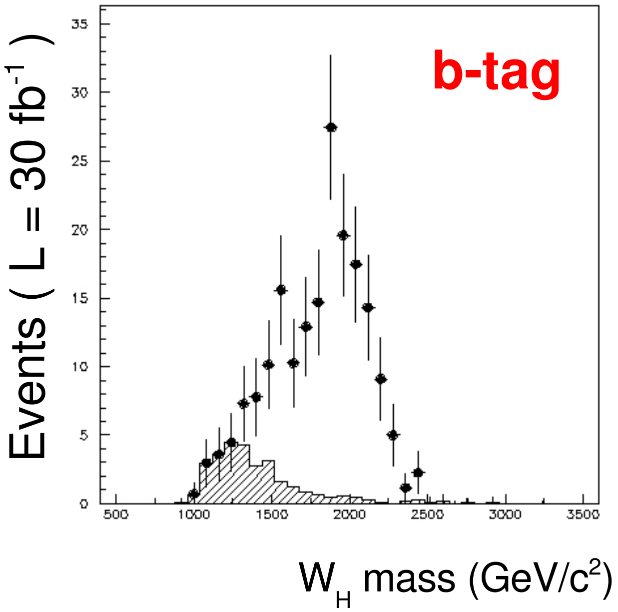
N_{wj} ~ 0

N/√B = 33

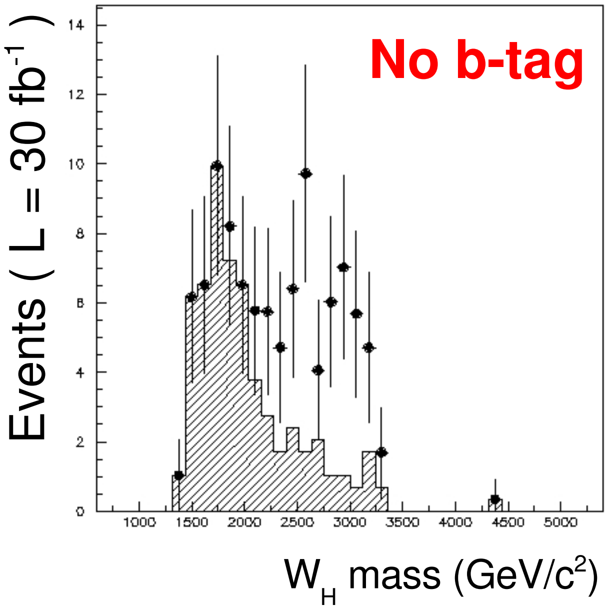
$W_H \rightarrow$ Tb cascade decays

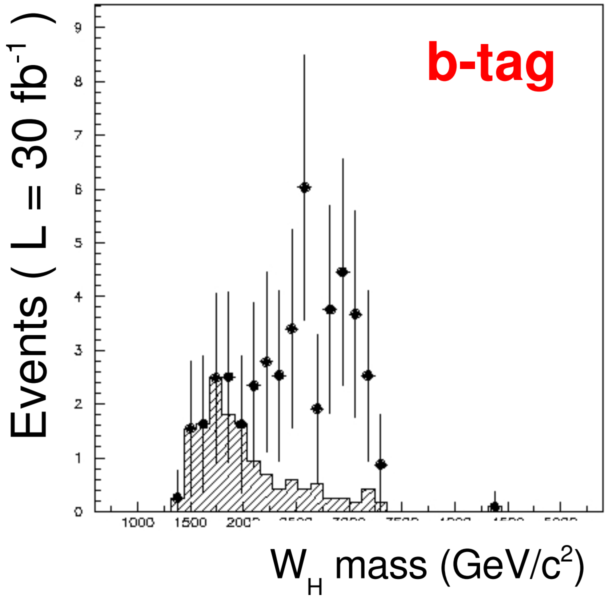
For details, see: http://indico.cern.ch/conferenceDisplay.py?confId=16473





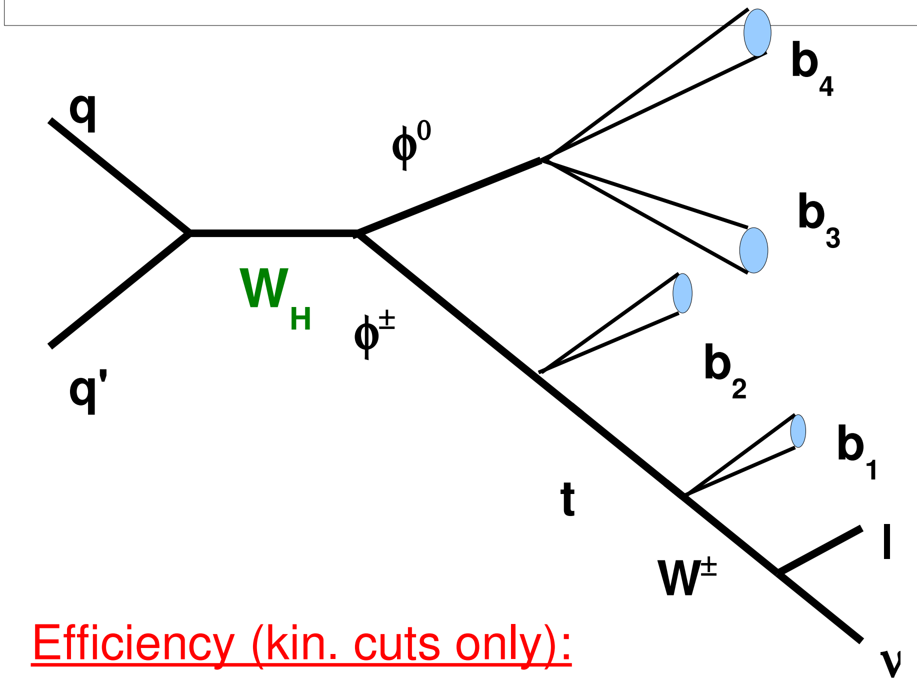
2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
$N/\sqrt{B}$	43	55





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

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



Efficiency (kin. cuts only):

$\varepsilon_{kin} \sim 8$ %

Simulation:	Pythia + ATLFAST
X-section:	σ = 30 pb x BR
Background:	tt, W+jets
Luminosity:	L = 30 fb^{-1}

Reconstruct masses

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

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

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

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

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

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

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

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

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

Additional cuts

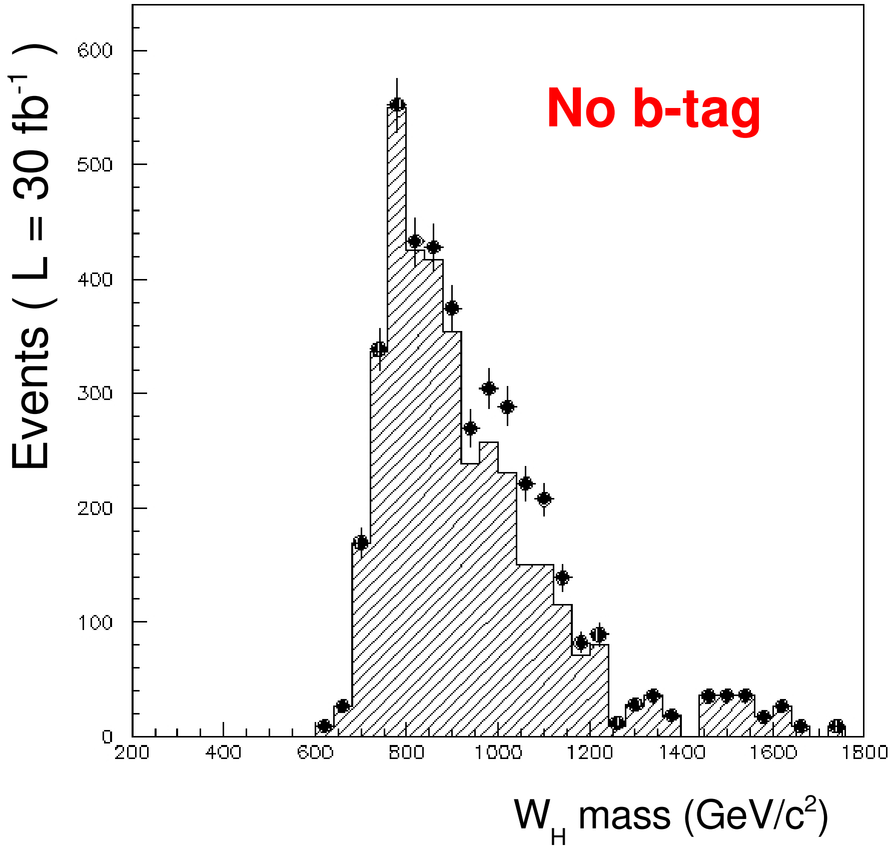
$m(t) < 250$ GeV/c^2

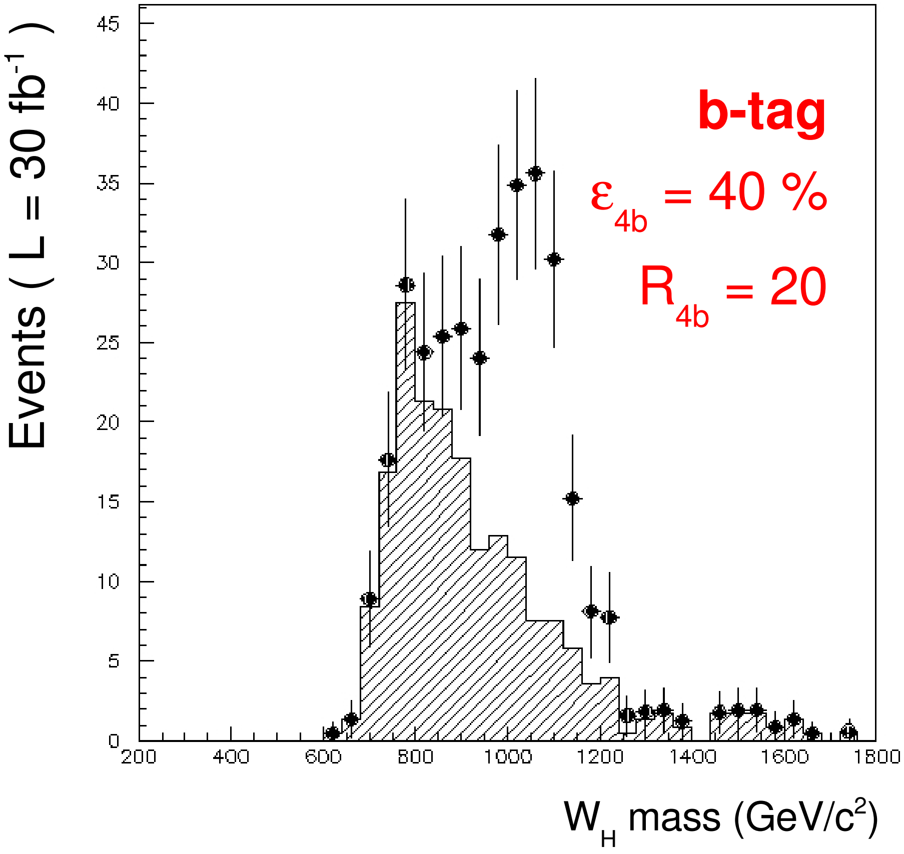
$m(\phi^{\pm}) < 250$ GeV/c^2

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

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

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





N_{sig} = 337

N_{tt} = 1958

N_{wj} = 171

$N/\sqrt{B}$ = 7

N_{sig} = 135

N_{tt} = 98

N_{wj} ~ 0

$N/\sqrt{B}$ = 14

Summary and outlook

- **Study key signatures of the LR Twin Higgs model.**
- **Several signatures well advanced**

$$W_H \to Tb$$

$$W_H \to \phi^{\pm}\phi^{0}$$

- **Others (hopefully) evolving quickly**

$$Z_H \to e^+e^-$$

$$W_H \to Tb$$

$$Z_H \to Zh$$

- **Good progress in the write-up of an ATLAS note:**

  next draft expected 30th of November.

BACKUP SLIDES

Theoretical motivation

The (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 canonical recipee: “[the instability of the SM under quantum corrections] *suggests the existence of new physics at or close to a TeV* [i.e. SUSY (with R-parity), (Large) Extra Dimensions] *that protects the Higgs mass parameter of the SM against radiative corrections*”. (hep-ph/0506256)

Theoretical motivation (I)

Alternative solution to the (little) hiearchy problem:

“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))

Theoretical motivation (II)

Twin Higgs model *Introduces a discrete symmetry: each SM particle is interchanged with a corresponding particle transforming under a twin SM gauge group.* EW precision data reproduced by construction: 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)

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

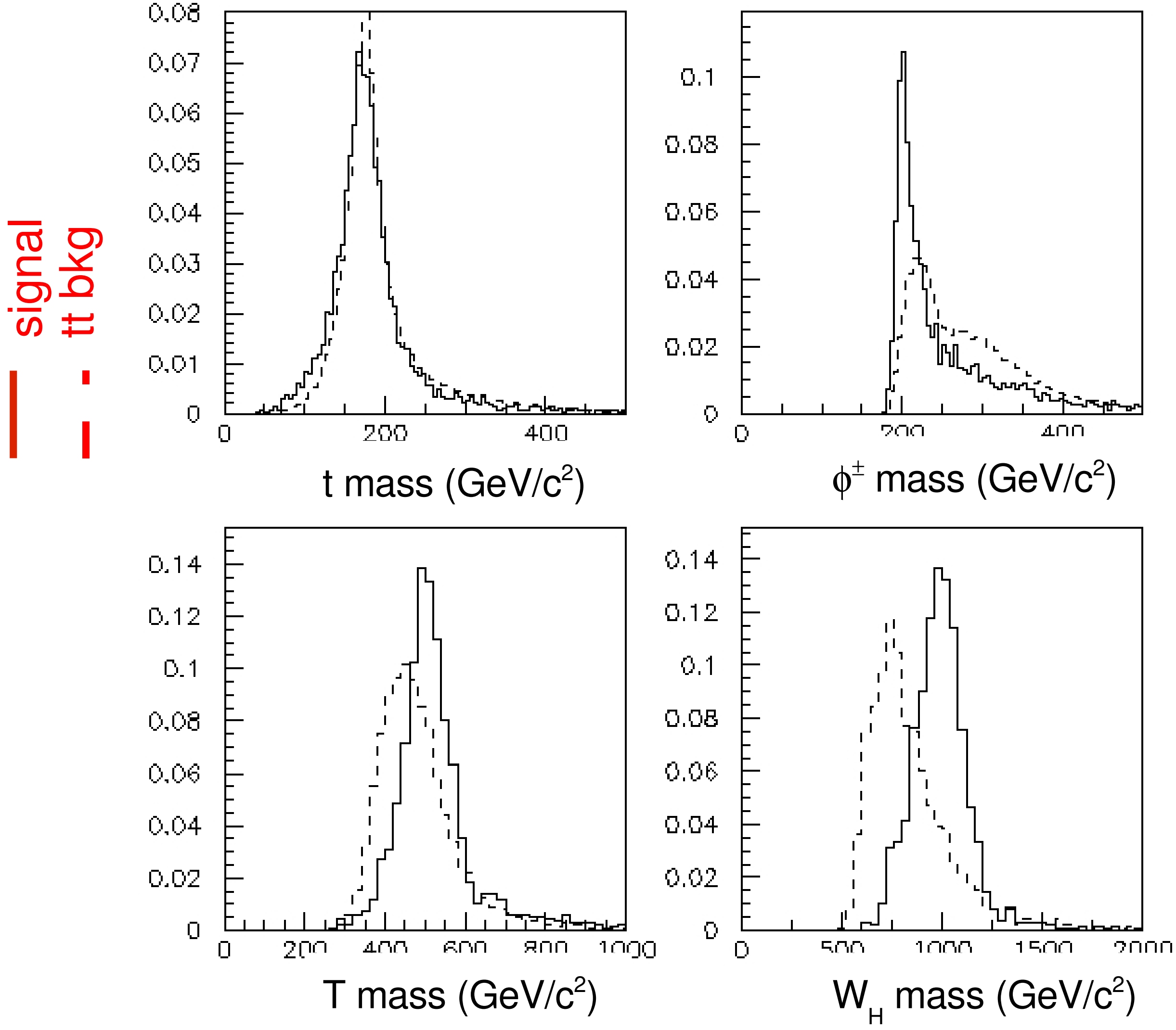
other W_H ($1\,\mathrm{TeV}/c^2$) decays

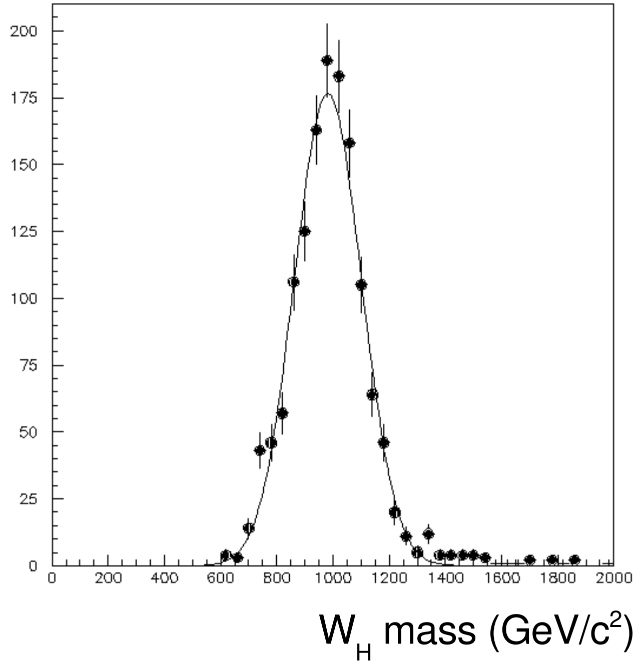
Decay	signature	total B.R.	comment
$W_H \to Tb \to \phi^{\pm}bb$	$\to 4b + l + E_t^{miss}$	3.2 %	this contribution
$\to bWb$	$\to 2b + l + E_t^{miss}$	0.4 %	
$\to thb$	$\to 4b + l + E_t^{miss}$	0.4 %	
$\to tZb$	$\to 2b + 3l + E_t^{miss}$	0.01 %	very small rate/no bkg.
$\to t\phi^0 b$	$\to 4b + l + E_t^{miss}$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

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





Reconstructed mass and width:

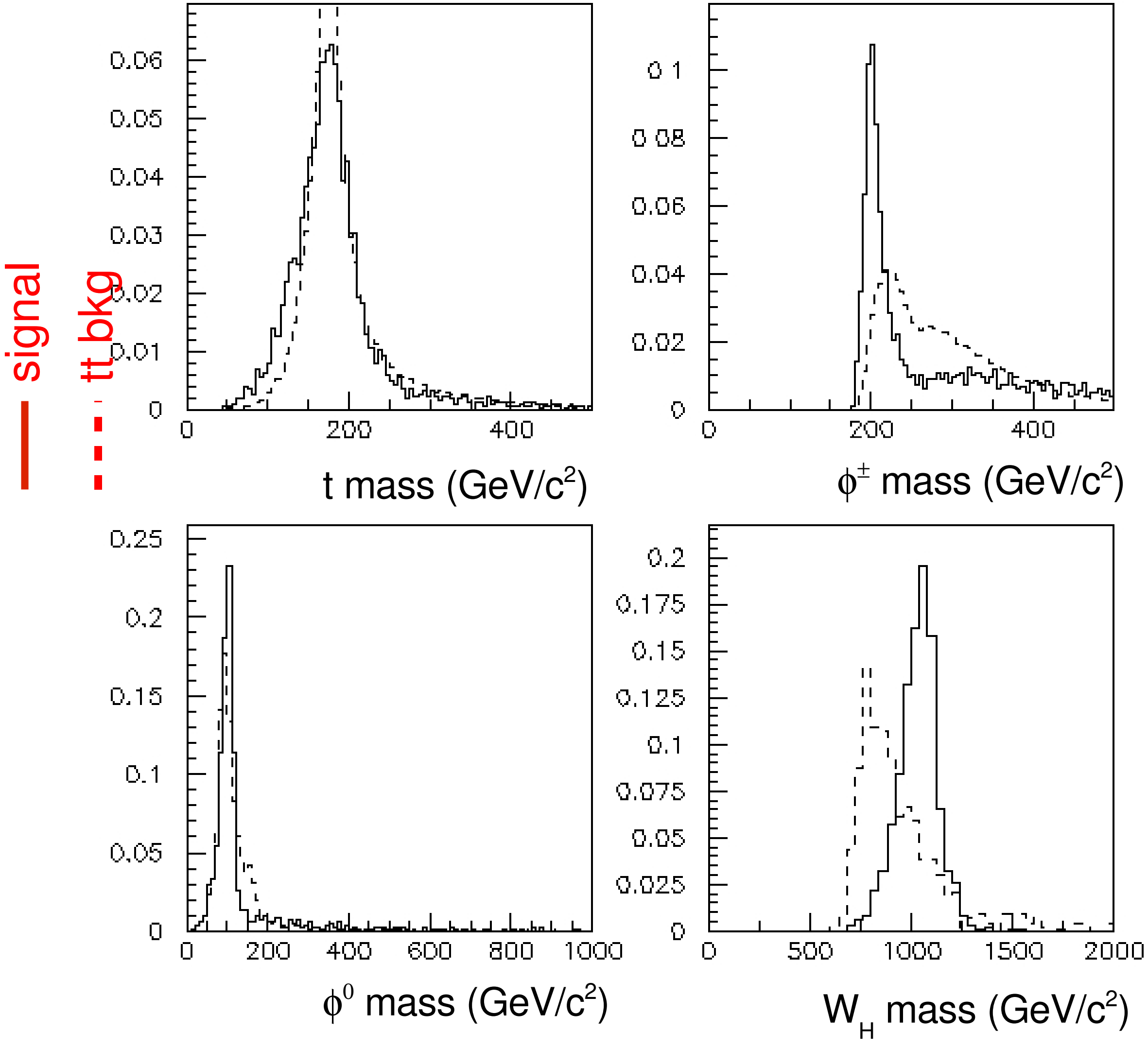
m = 982 GeV/c^2

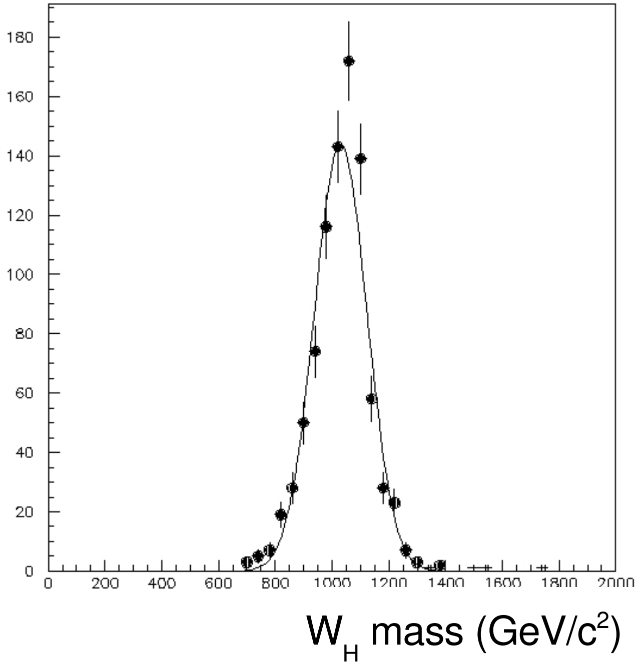
σ = 120 GeV/c^2

Remark:

Γ (W_H) = 24 GeV/c^2

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





Reconstructed mass and width:

$m = 1030$ GeV/c^2

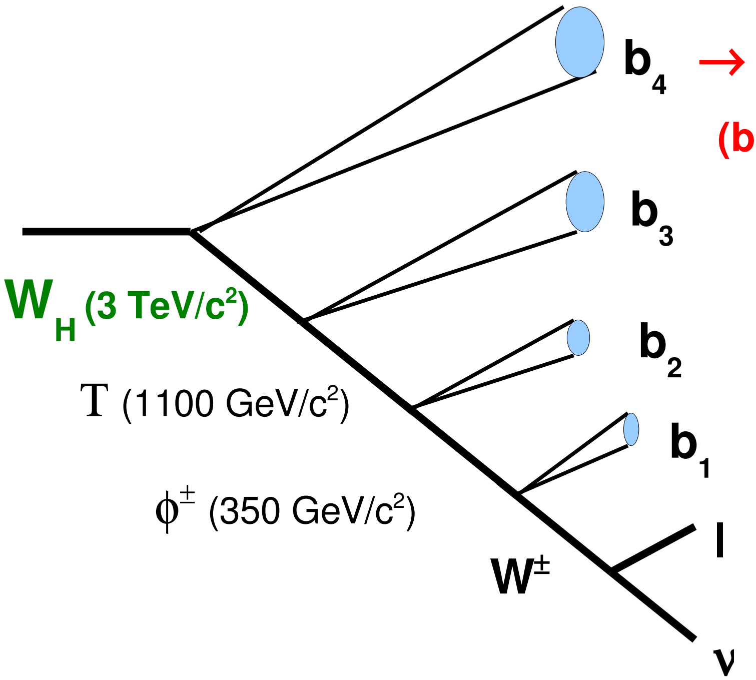
$\sigma = 93$ GeV/c^2

Remark:

Γ (W_H) = 24 GeV/c^2

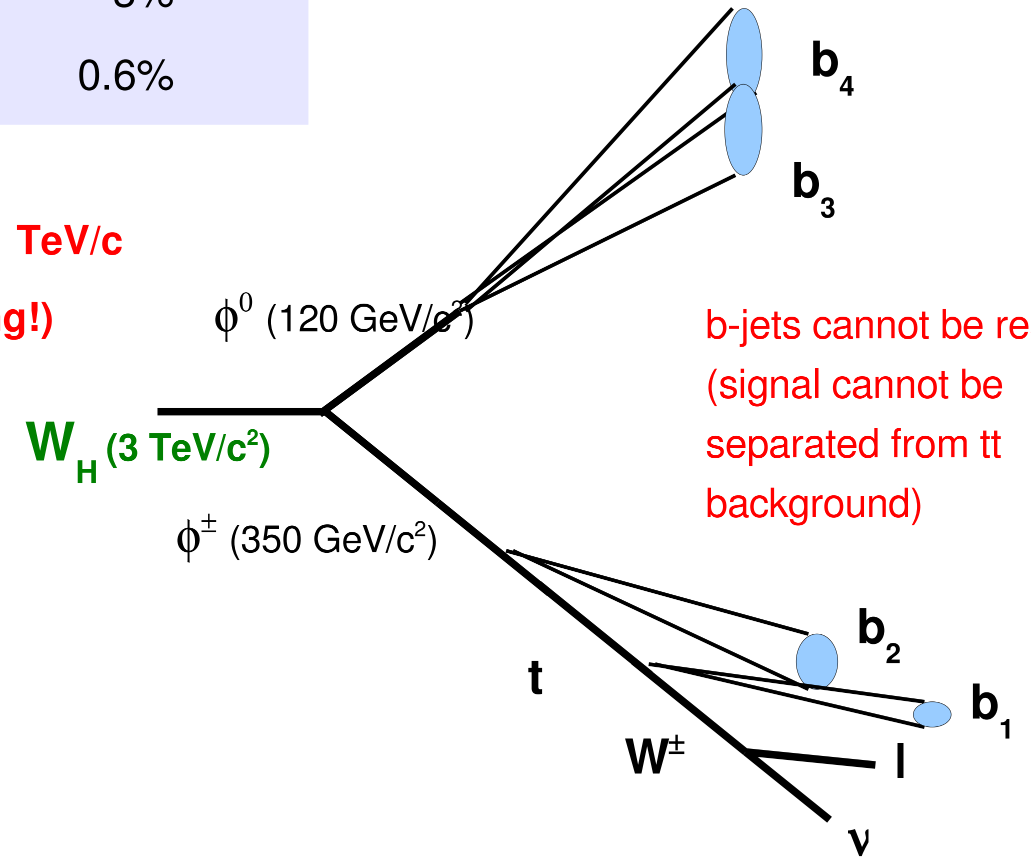
Mass dependence

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%



→ p_T ~ 1 TeV/c

(b-tagging!)



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

p_T dependence of b-tagging

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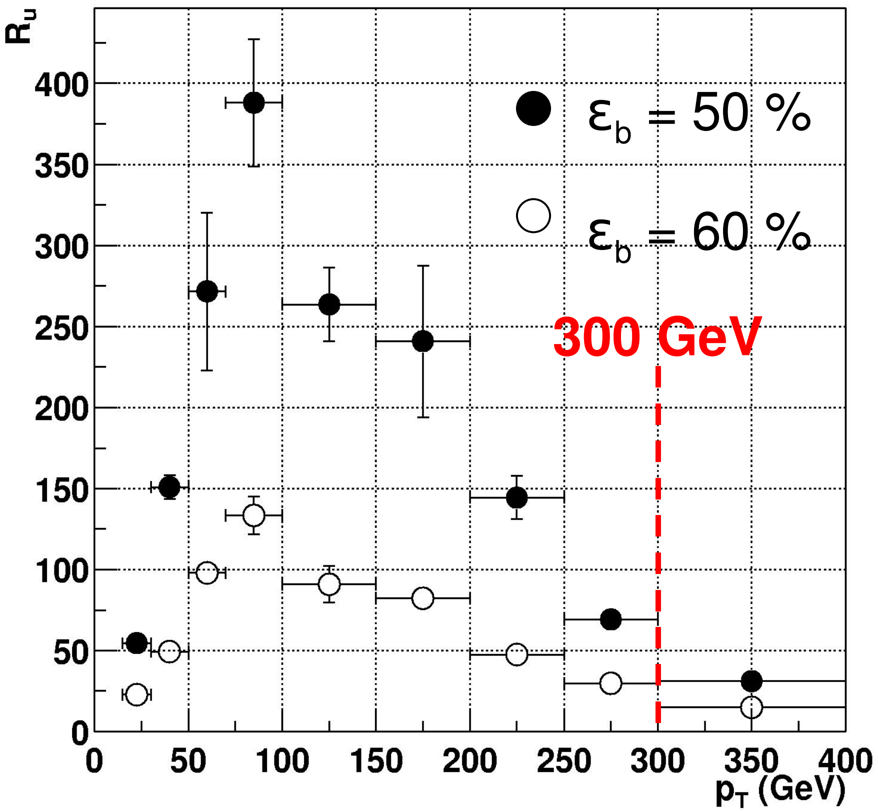

2D algorithm – DC1 data

pp → W H (120 + 400 GeV)

b b

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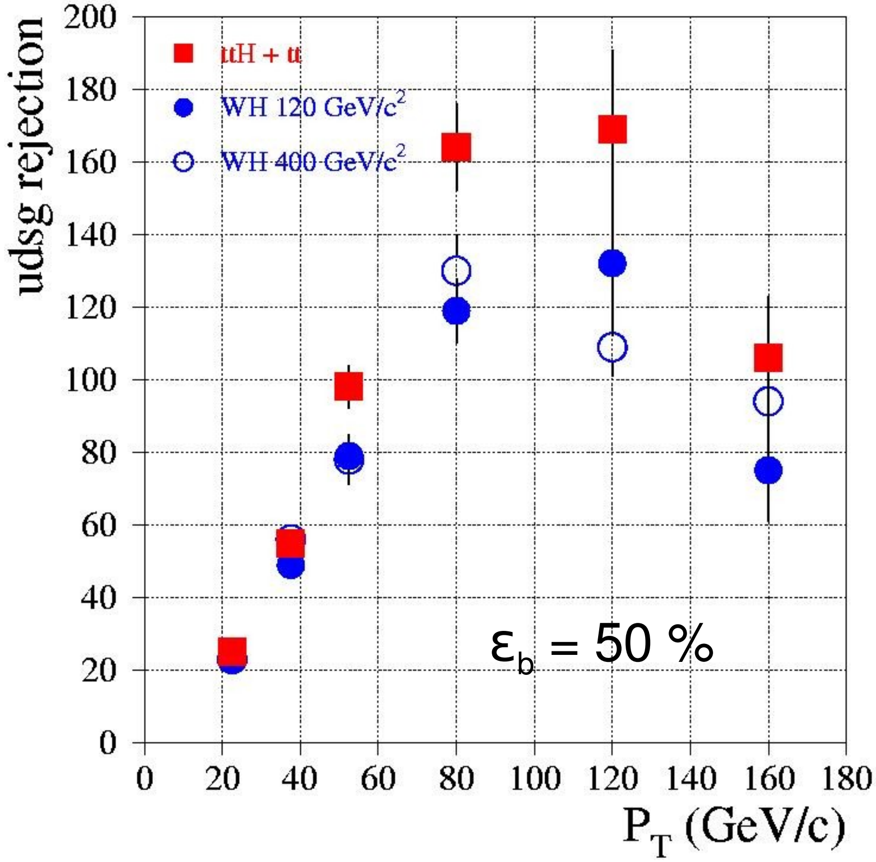
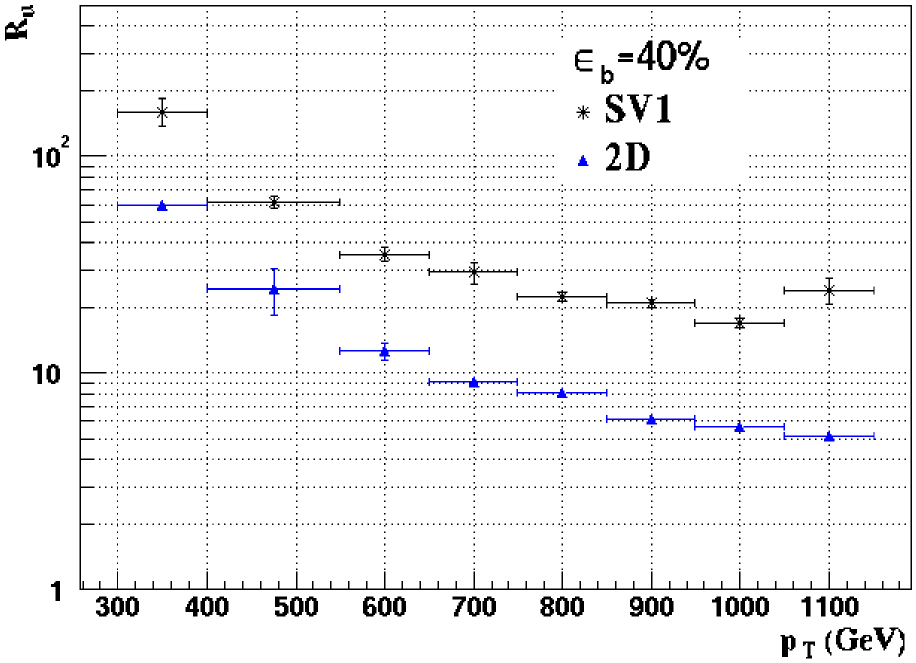


2D algorithm – DC1 data

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

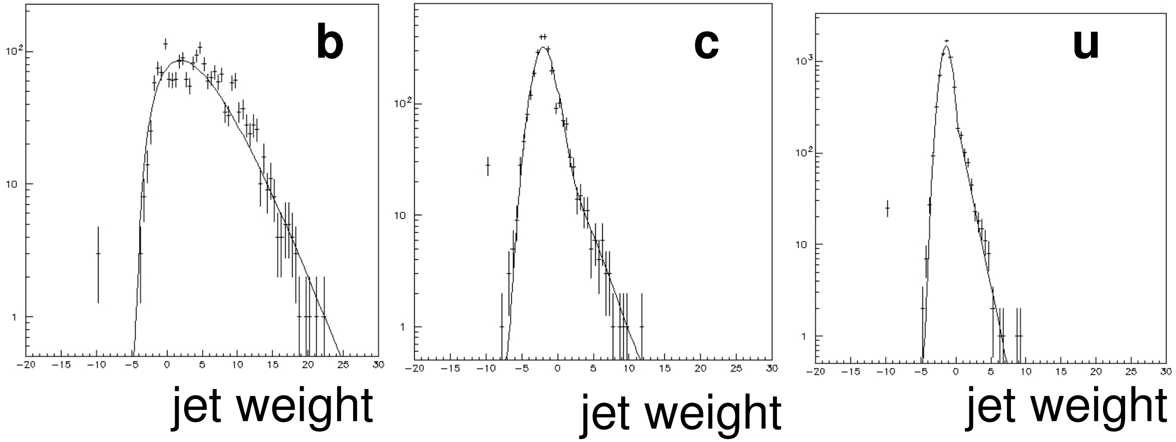
2D = signed IP significance tagger

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

Standard ATLAS tagging algorithms, without retuning

b-tagging likelihood weights

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



$\varepsilon_b = 50\%$

$p_T = 100$ 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

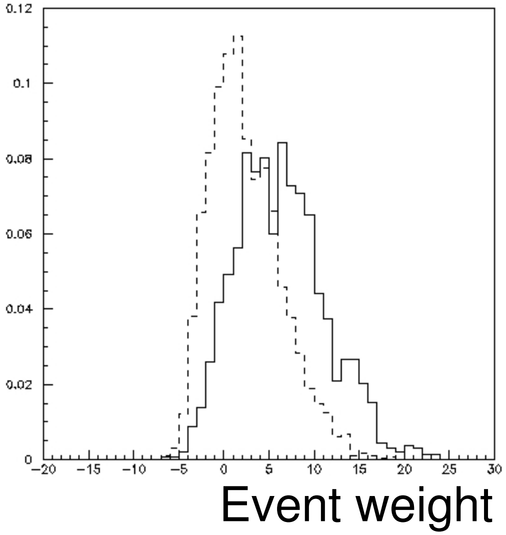
multi b-jet likelihood:

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

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

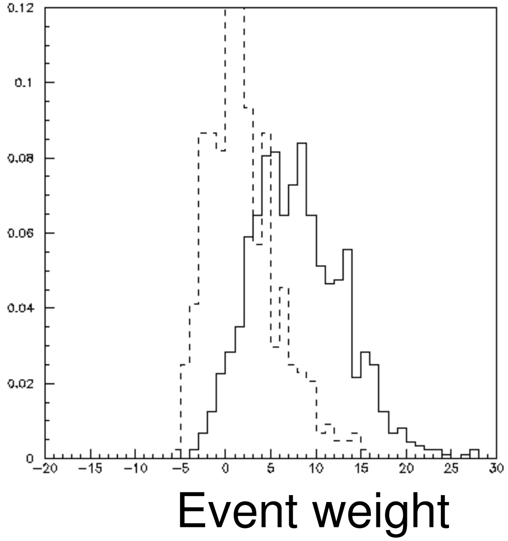
$W_H \to Tb \to 4b + l + E_t^{miss}$

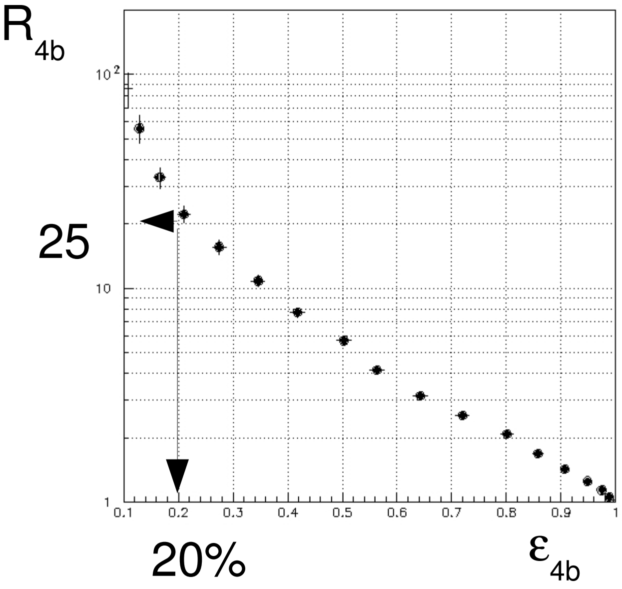
$W_H \to \phi^{\pm}\phi^{0} \to 4b + l + E_t^{miss}$



signal

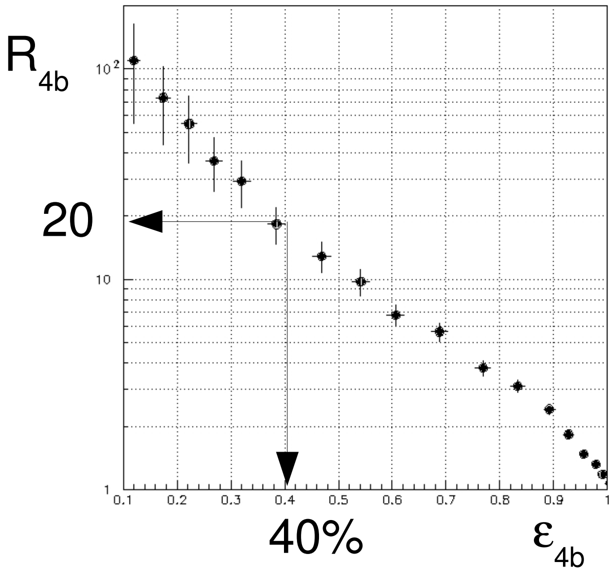
tt background





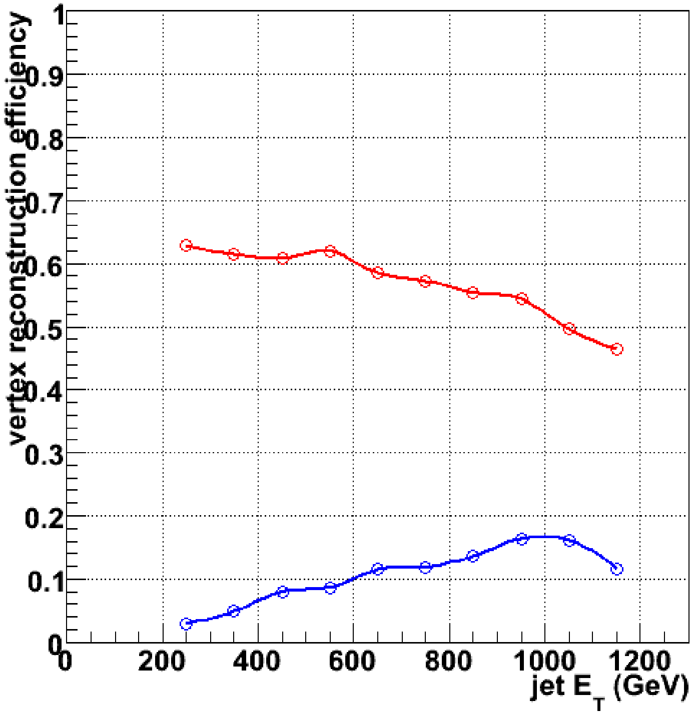
ε_{4b} = signal efficiency

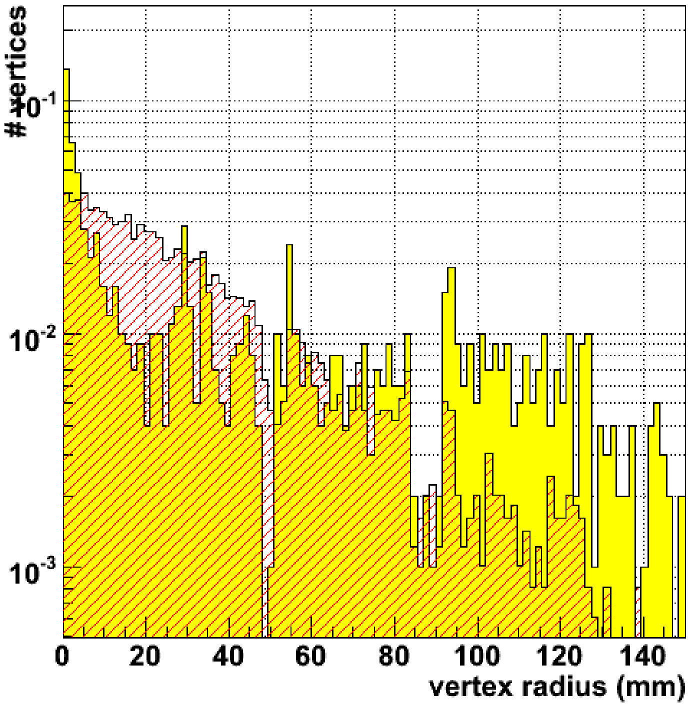
R_{4b} = rejection against tt background



vertexing in high p_T jets

VkalVrt: Vertex reconstruction efficiency in b-jets and light jets





VkalVrt: reconstructed vertex radius distribution for b-jets and light jets