Update on the Left-Right twin higgs model

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ATLAS overview week
exotic physics group meeting
Wed. Oct. 10, 2007

Outline

- **Introduction**
- **Twin Higgs model parameters/benchmark points**
- **$Z_H \rightarrow e^+e^-$: towards a model-independent fit**
- **W_H : high p_T b-tagging**
- **future plans**

further information:

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

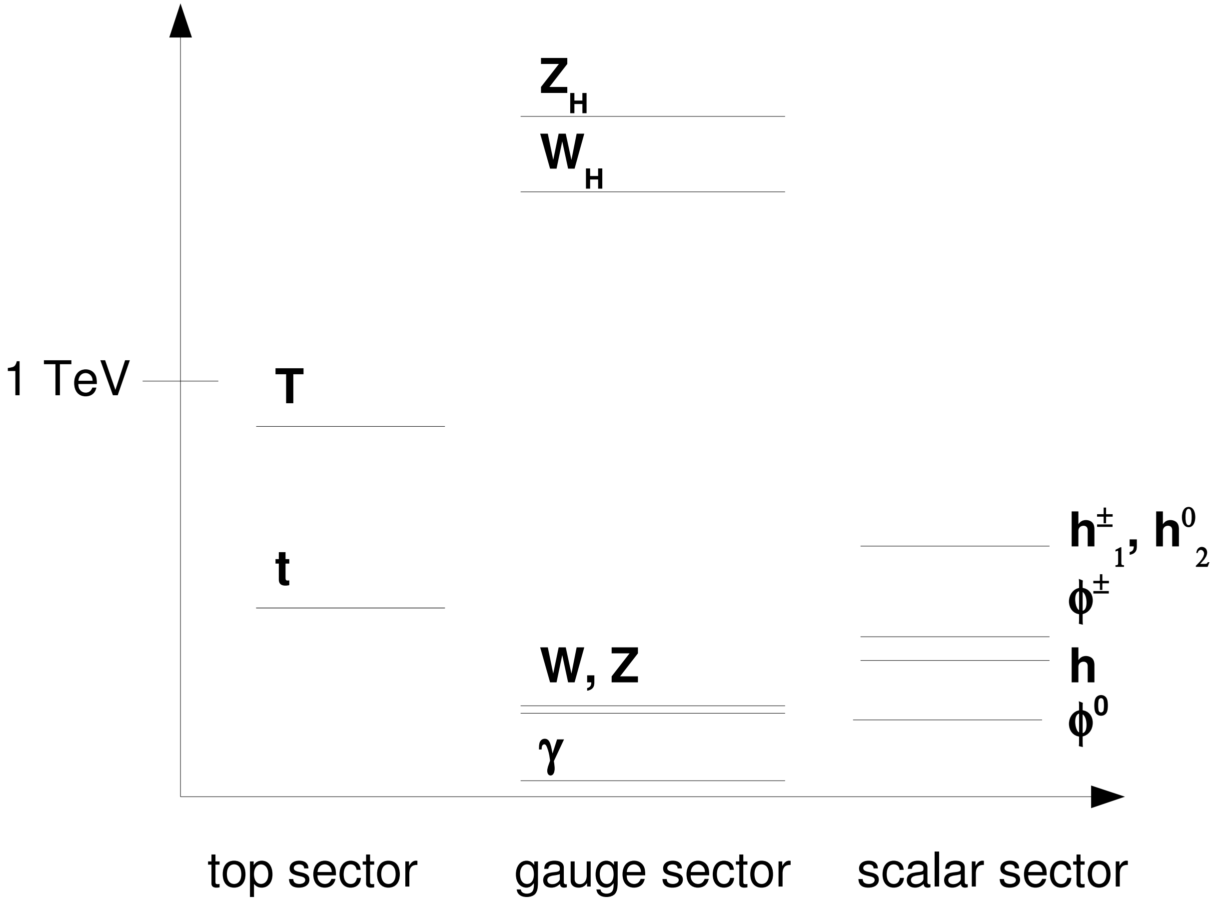
ATLAS b-tagging workshop (Marseille, May 2007): http://indico.cern.ch/conferenceOtherViews.py?confId=14475

ATLAS flavour tagging meeting: http://indico.cern.ch/conferenceDisplay.py?confId=21733

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

Particle spectrum

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)

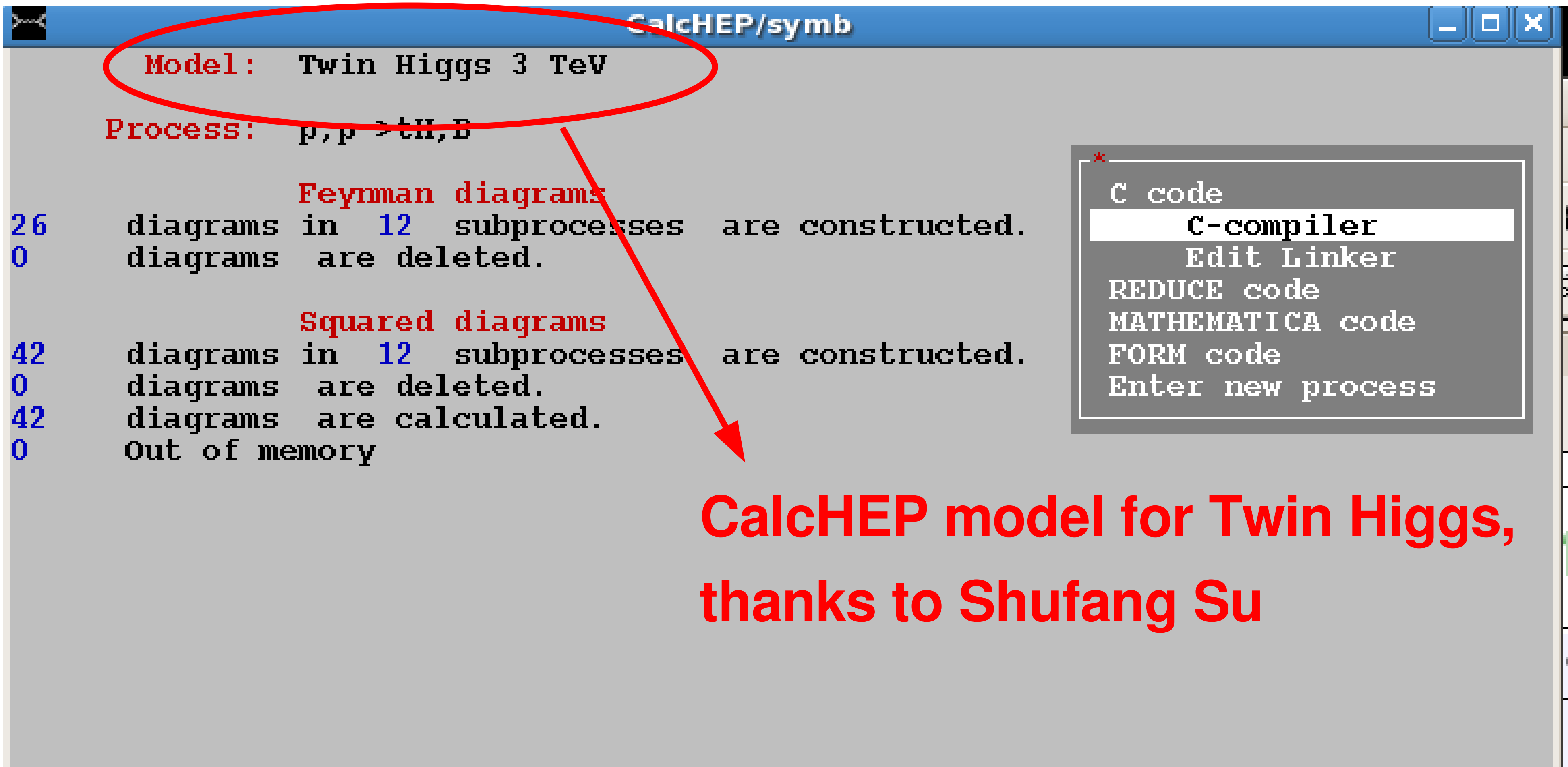
Phenomenology

$Z_H \rightarrow e^+e^-$	likelily discovery channel BR ~ 2.5 %
$Z_H \rightarrow Zh$	not studied so far
$W_H \rightarrow e\,\nu_R$	not studied so far. Absence of W_H leptonic decay allow to distinguish Little Higgs from LR twin Higgs
$W_H \rightarrow tb$	much reduced BR with respect to little Higgs
$W_H \rightarrow Tb$ ↳ $\phi^{\pm}b$ ↳ tb ↳ Wb ↳ $l\nu$	Cascade decays with signature: $4\ b + l + E_T^{miss}$ model test (not present in Little Higgs) First results reported in june http://indico.cern.ch/conferenceDisplay.py?confId=16473

Model parameters/benchmark points

Discussion with theorists (Shufang Su) during Les Houches workshop:

Compare our Pythia implementation of the cascade decays with calcHep predictions.



```
     Model:   Twin Higgs 3 TeV

   Process:   p,p ->tH,B

              Feynman diagrams
26     diagrams in  12  subprocesses  are constructed.
0      diagrams  are deleted.

              Squared diagrams
42     diagrams in  12  subprocesses  are constructed.
0      diagrams  are deleted.
42     diagrams  are calculated.
0      Out of memory
```

CalcHEP model for Twin Higgs, thanks to Shufang Su

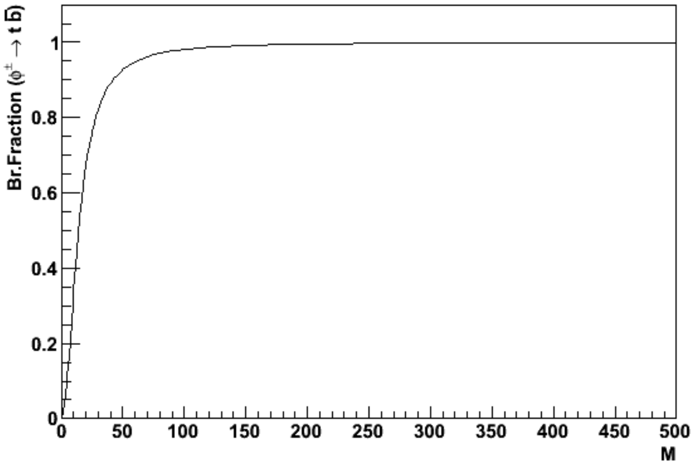
Model parameters/benchmark points

In Les Houches: lively discussion on the dependence of the phenomenology on model parameters:

- μ: introduces mass shift of the Higgs sector
- M: mixing T-t, determines branching ratio

Currently, benchmark points are all for M=150.

At very low M cascade decays through $\phi \to tb$ "disappear".



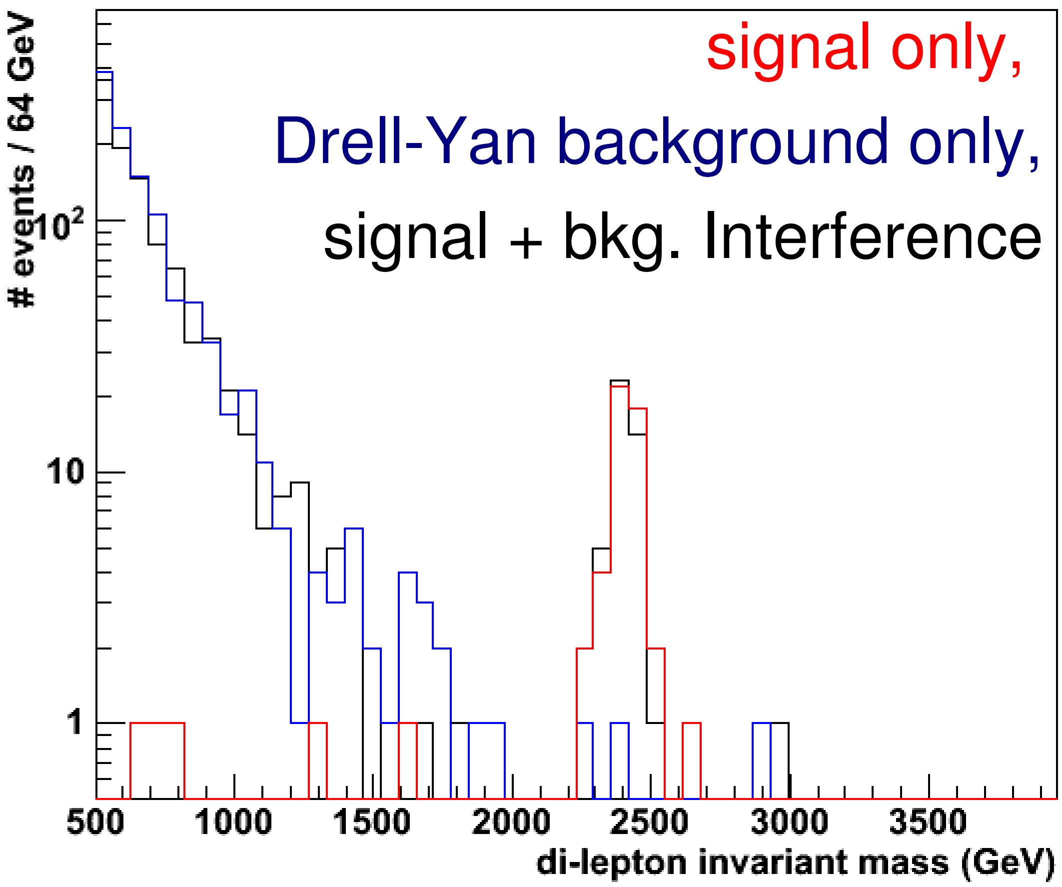
http://ific.uv.es/~vos/Atlas/TwinHiggs/BenchmarkPoints.html

Di-leptons

$Z_H \rightarrow$ di-leptons

likely discovery channel for LR twin Higgs model.

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



Di-leptons (with S. Ferrag)

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)

“Generator level” di-lepton discovery reach based on classical S/√(S+B) analysis in 2σ mass window, S. Ferrag.

To be extended to a method taking full advantage of the invariant mass spectrum.

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

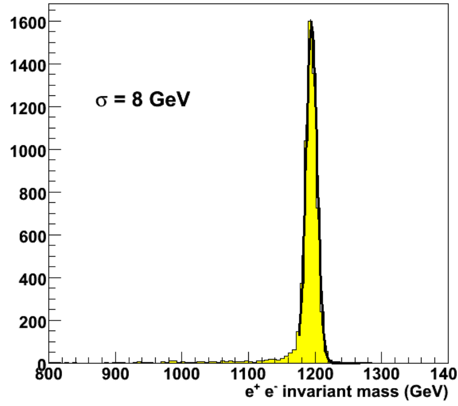
ATLFAST mass resolution for heavy resonances

Electrons:

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

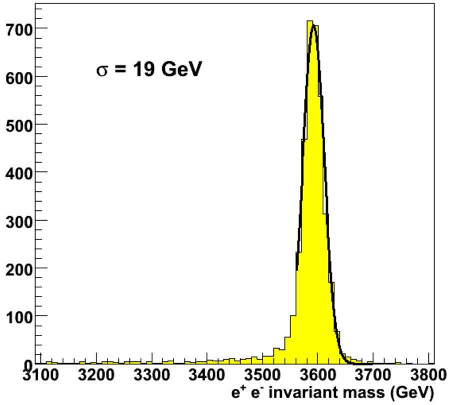
ΔM (e^+e^- @ 1.2 TeV)

0.7 % / 8 GeV



ΔM (e^+e^- @ 3.5 TeV)

0.5 % / 19 GeV

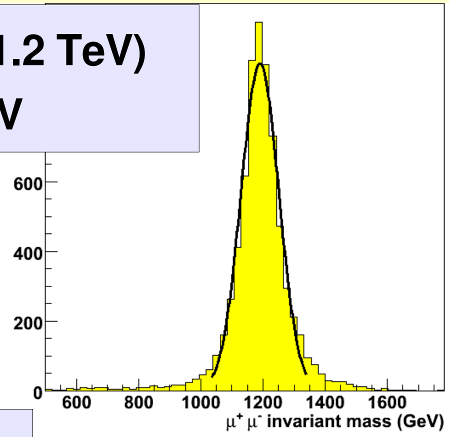


Muons:

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

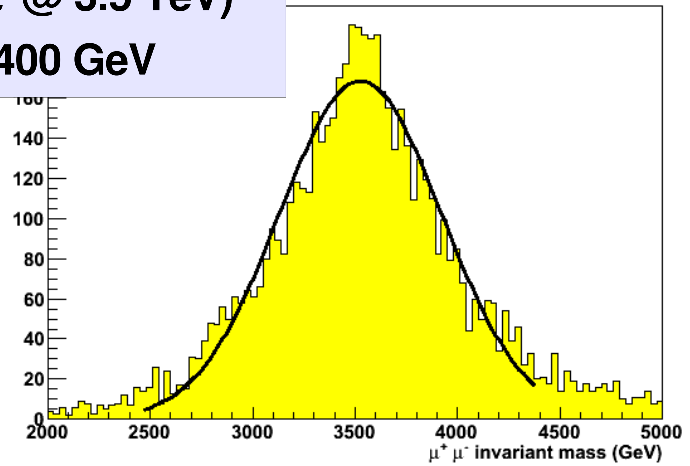
ΔM ($\mu^+\mu^-$ @ 1.2 TeV)

5 % / 61 GeV



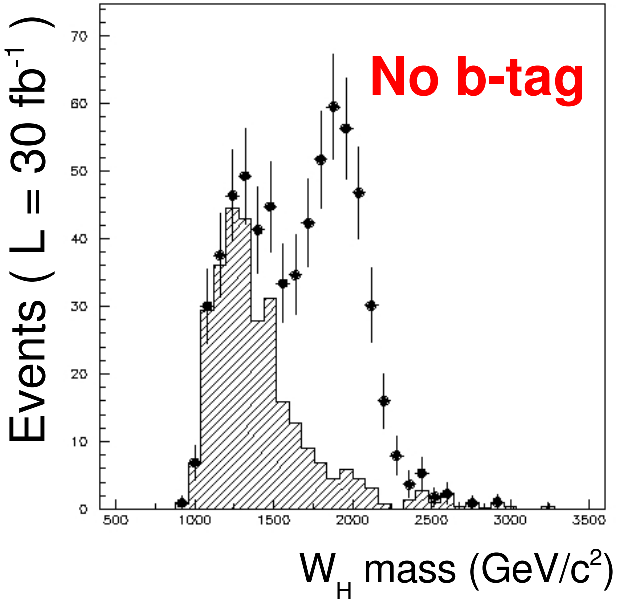
ΔM ($\mu^+\mu^-$ @ 3.5 TeV)

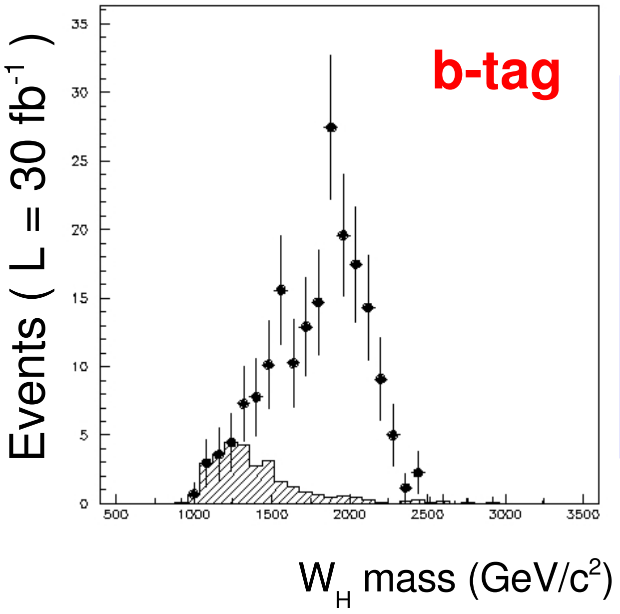
11 % / 400 GeV



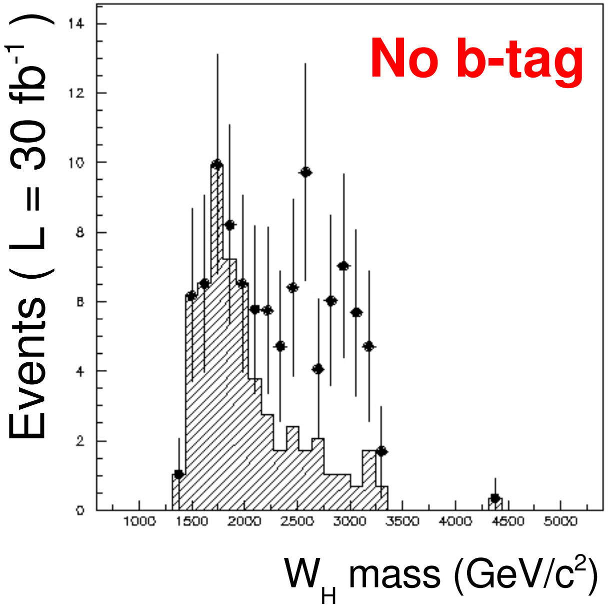
$W_H \rightarrow Tb$ cascade decays

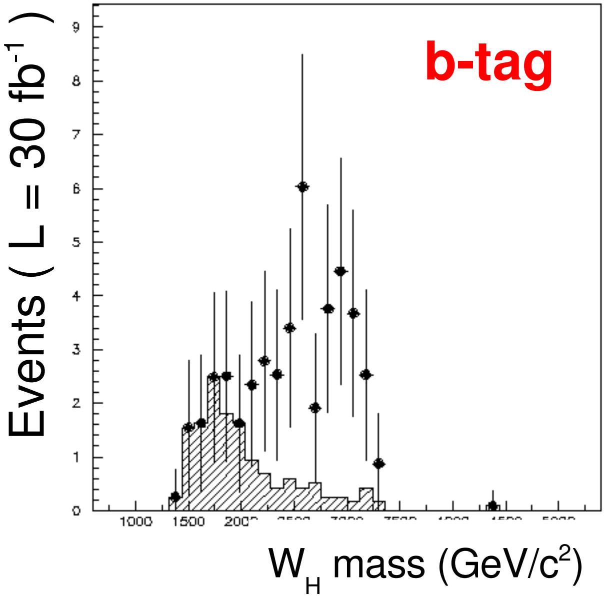
For details, see: http://indico.cern.ch/conferenceDisplay.py?confId=16473





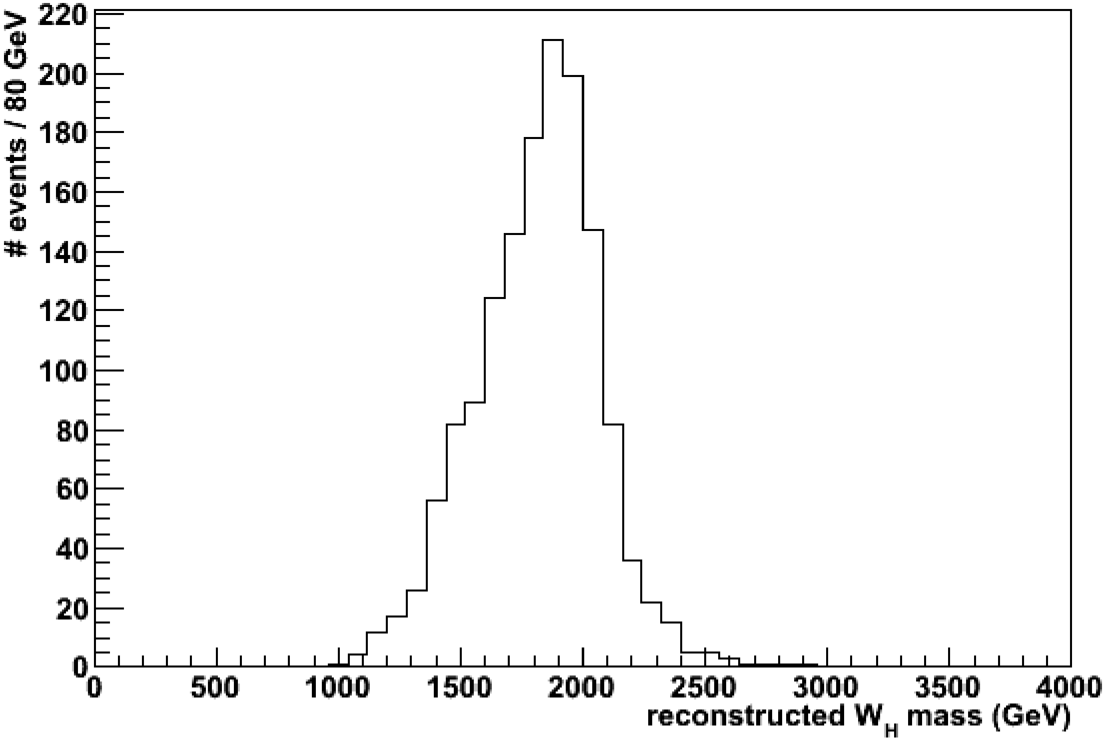
2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
$N/\sqrt{B}$	43	55





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

$W_H \rightarrow$ Tb, m(W_H) = 2 TeV/c^2



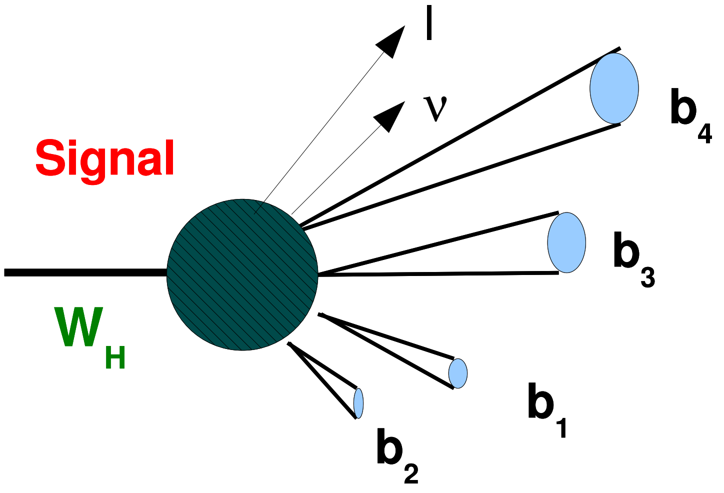
Reprocessing the analysis using official tools and model parameters.

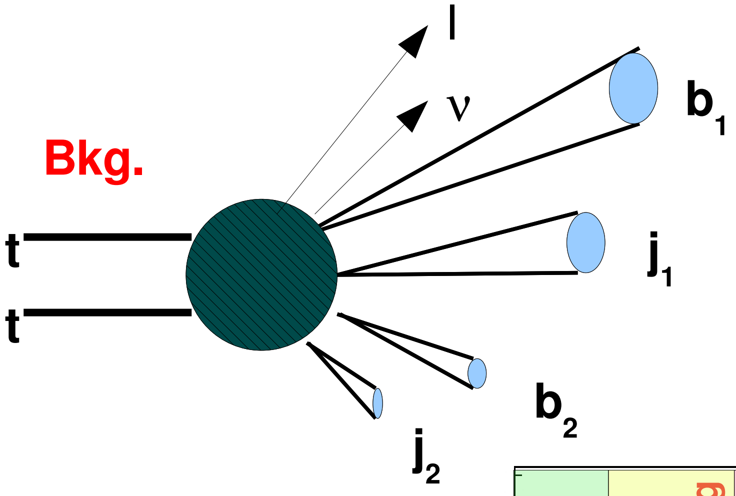
ATHENA 12.0.6
“Les Houches” benchmark points

Reconstruction of W_H cascade (nominal mass = 2 TeV)

Step-by-step comparison hasn't yielded nasty surprises so far

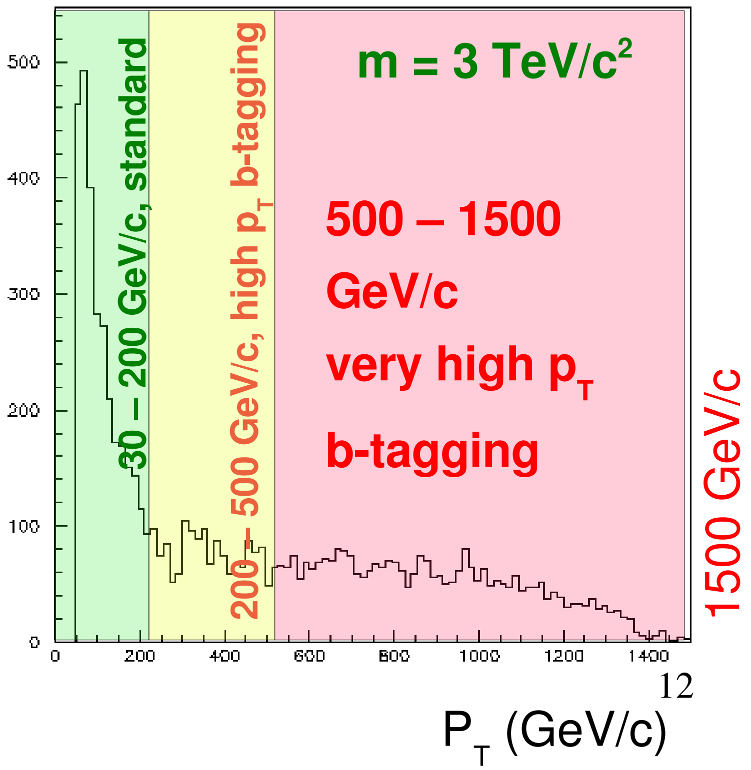
tagging multi-jet events with high p_T b-jets





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

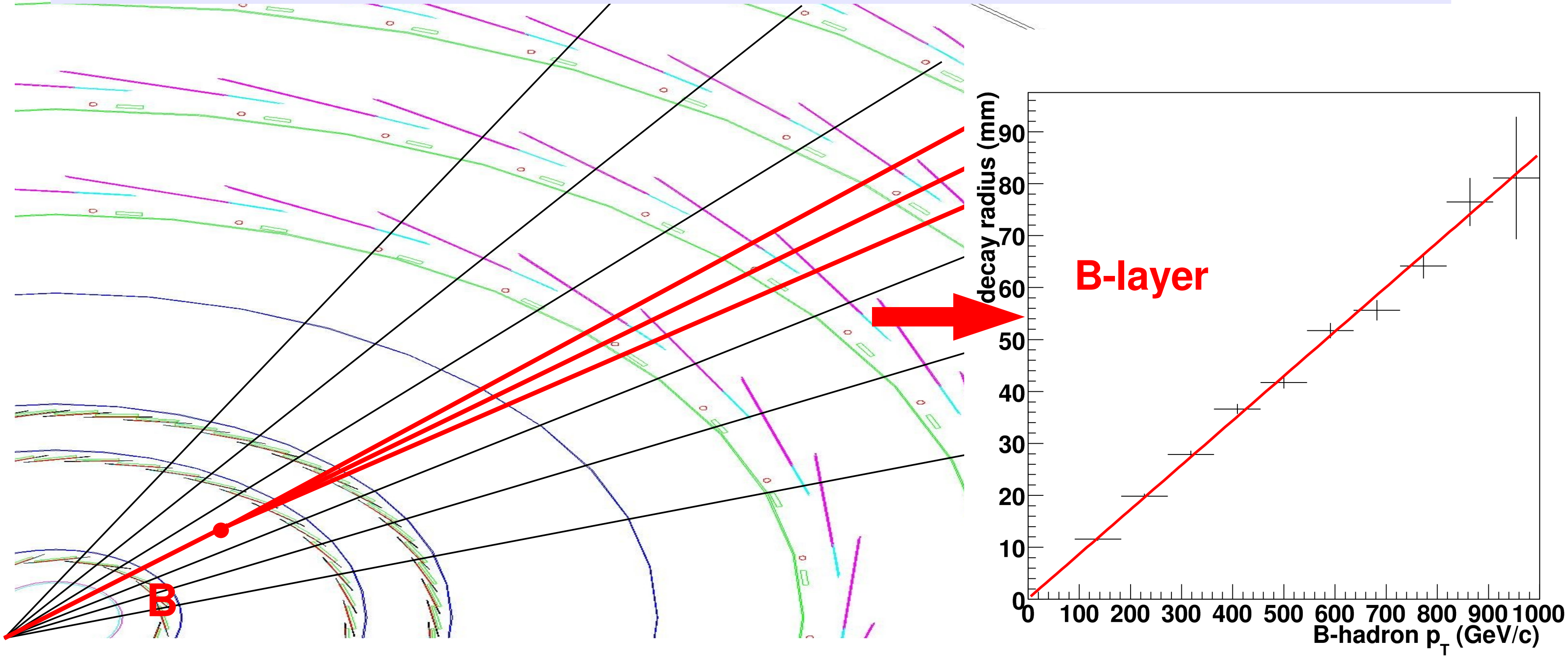
For multi-jet final states, with large variations in jet energy, **a 4 b-jet likelihood** from individual jet weights, is much more efficient than standard efficiency-rejection curves approach .



Very high p_T b-tagging (I)

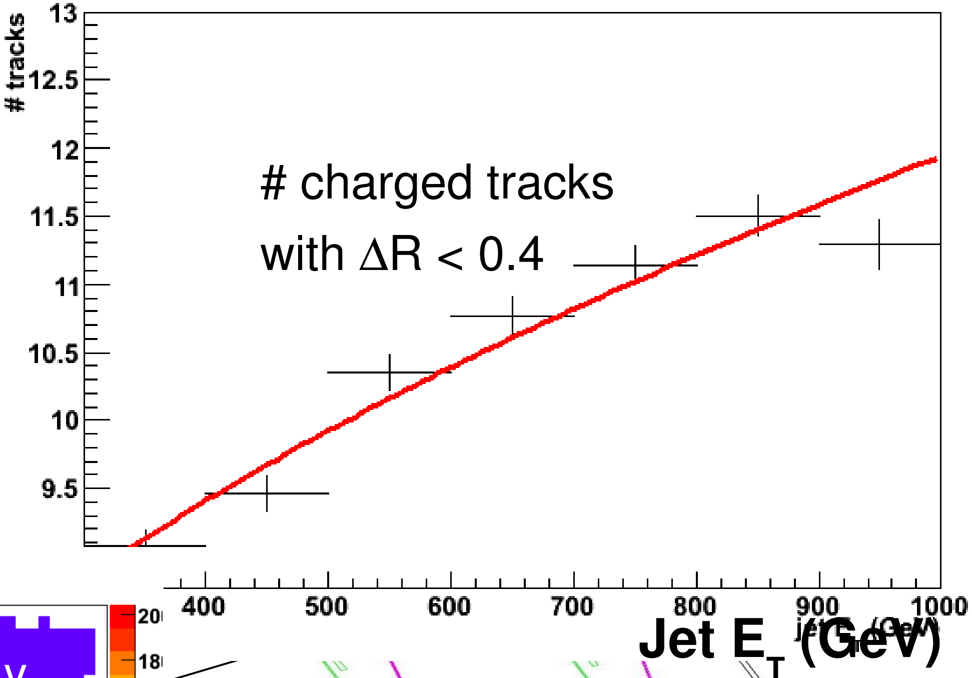
Decay length $L = \gamma c \tau \rightarrow$ strongly enhanced for high p_T b-jets

A significant fraction of B/D hadrons decays is close to and even beyond the B-layer

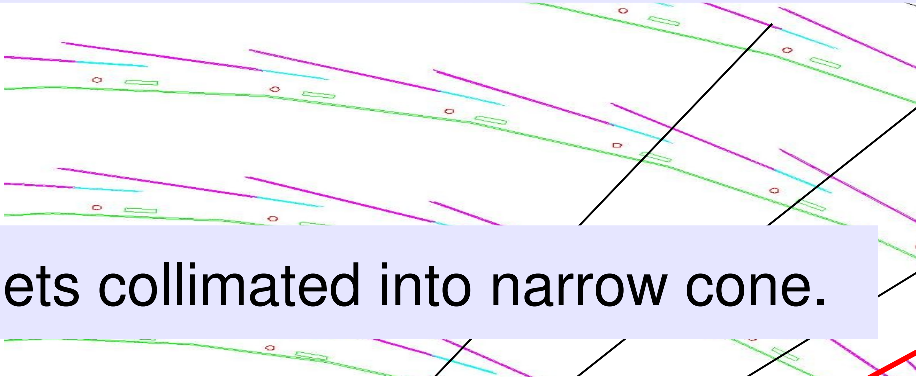


Very high p_T b-tagging (II)

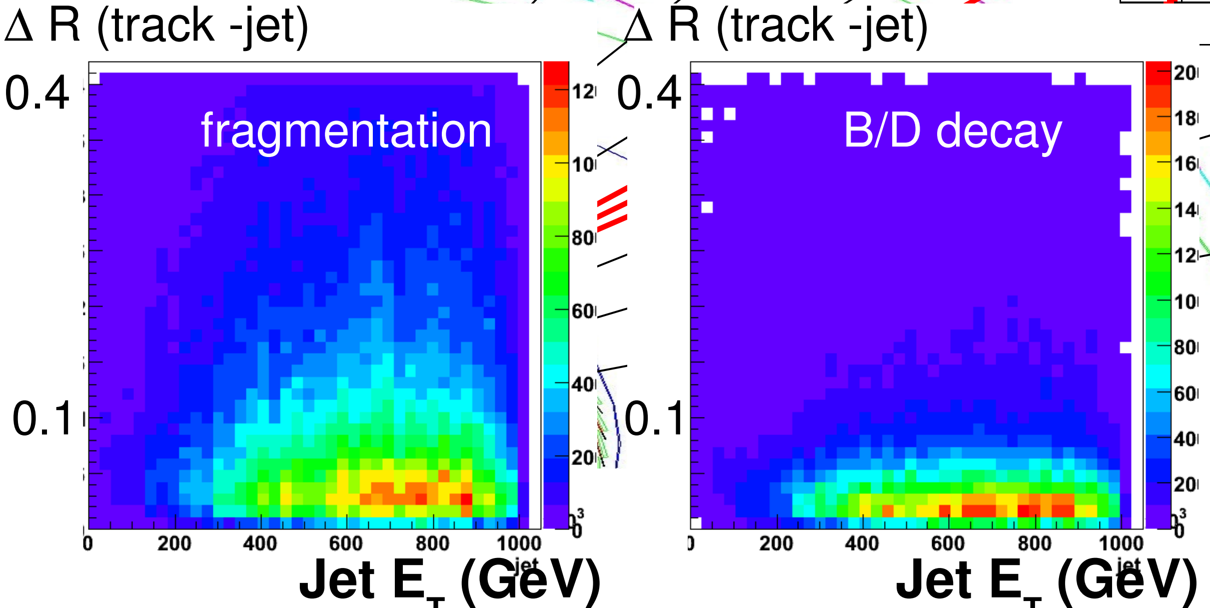
number of (fragmentation) tracks increases signficantly

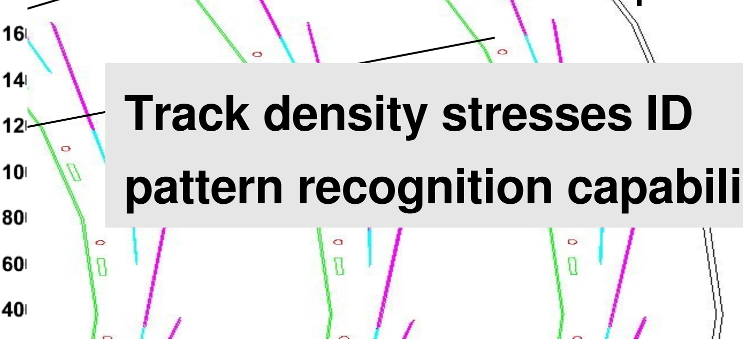


charged tracks with $\Delta R < 0.4$



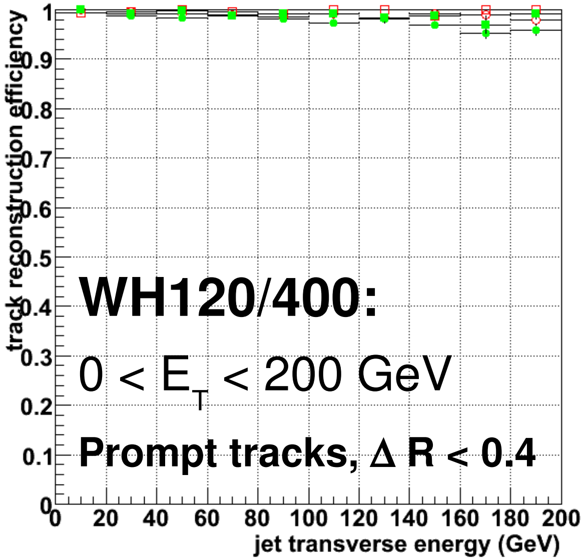
jets collimated into narrow cone.





Track density stresses ID pattern recognition capabilities

Tracking in very high p_T jets (I)



WH120/400:

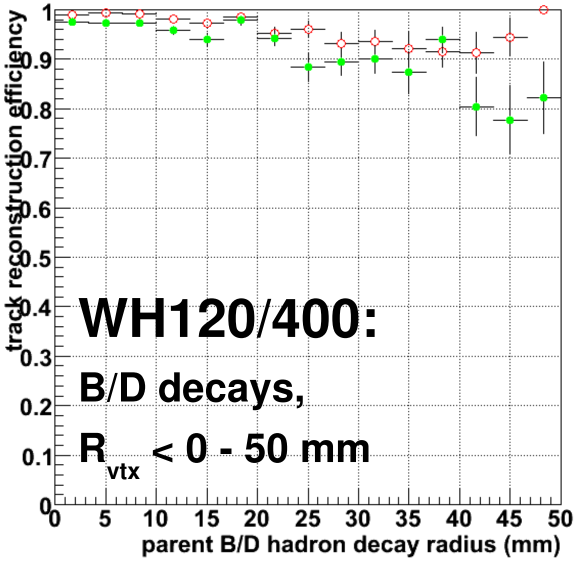
$0 < E_T < 200$ GeV

Prompt tracks, $\Delta R < 0.4$

Reconstruction efficiency for "good" tracks >90% inside highest p_T jets!

IpatRec

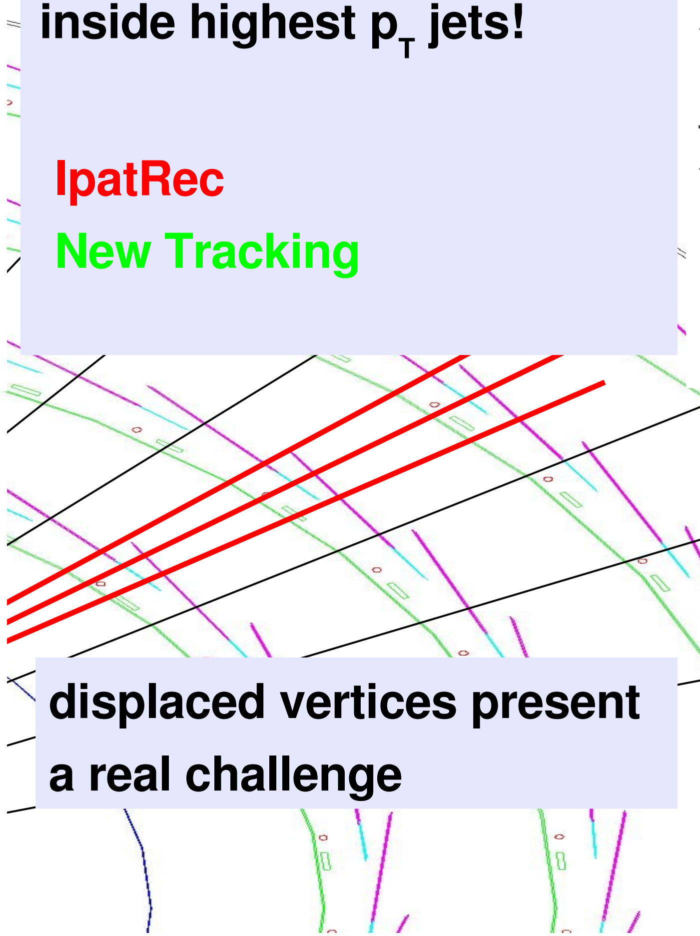
New Tracking



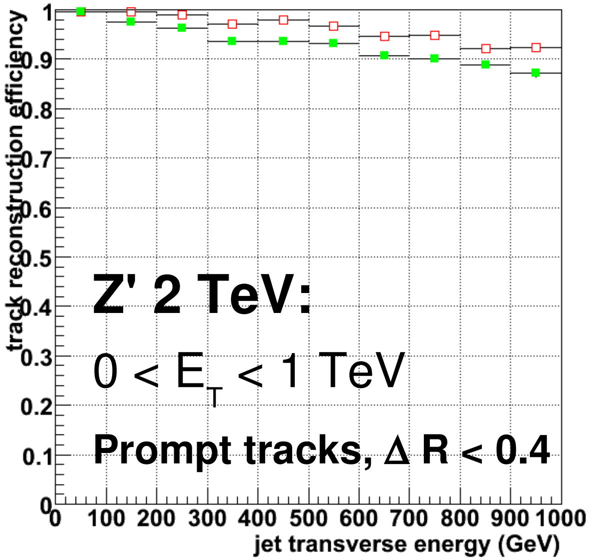
WH120/400:

B/D decays,

R_{vtx} < 0 - 50 mm



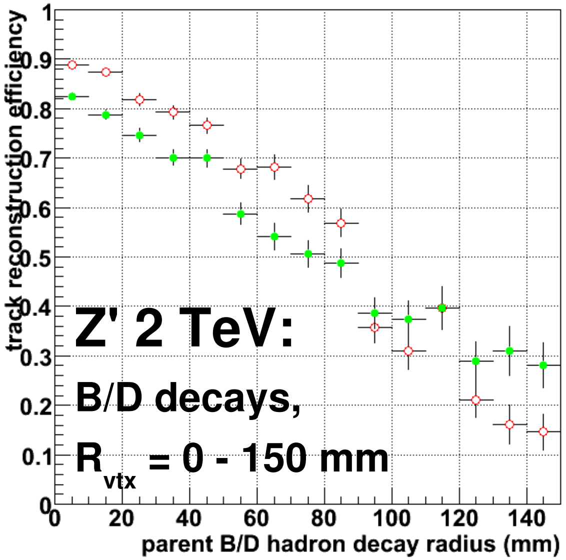
displaced vertices present a real challenge



Z' 2 TeV:

$0 < E_T < 1$ TeV

Prompt tracks, $\Delta R < 0.4$

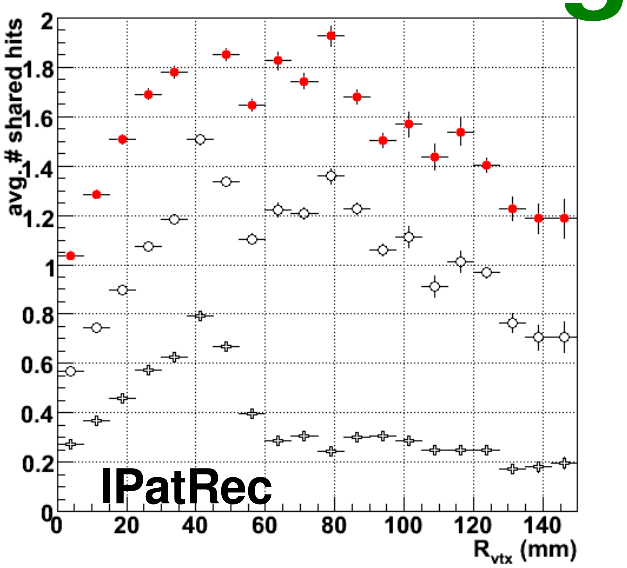


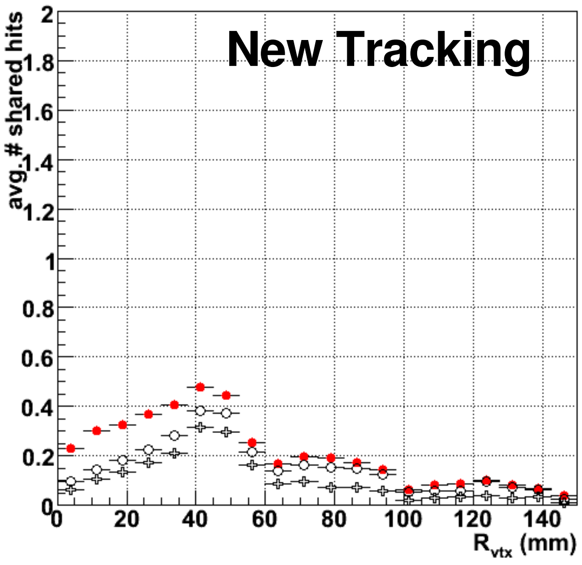
Z' 2 TeV:

B/D decays,

R_{vtx} = 0 - 150 mm

Tracking in very high p_T jets (II)





The sharing of hits becomes inevitable in dense jet cores, especially in case of displaced vertices

Situation dealt with quite differently by IpatRec and New Tracking (AmbiguityResolver)

Average number of shared hits per track, considering only efficient tracks from B/D decay

- ● **total**
- ○ **in pixel detector**
- ✚ **in B-layer**

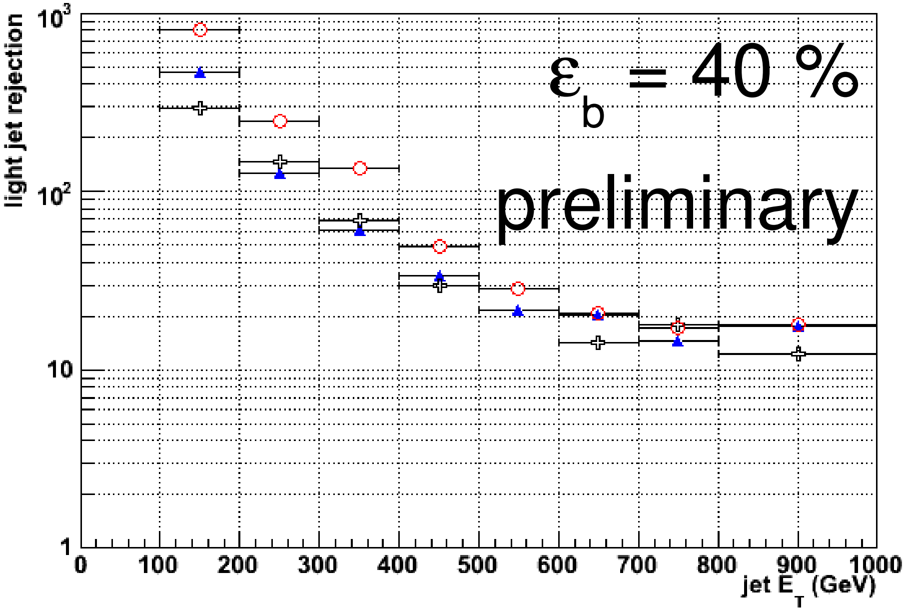
Tested several causes/remedies (in ATHENA 13) suggested by tracking experts (A. Salzburger, W. Liebig and others).

T. Lari working on tags for **pixel detector clusterizer** – test the impact of different algorithms on our sample

Different seeding schemes (back-tracking)...

Plenty of other possibilities

b-tagging in high p_T jets

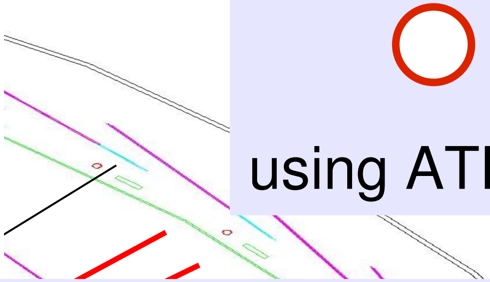


✚ **SV1**

▲ **IP2D**

○ **combined**

using ATHENA 12.0.6,



B-tagging: mismatch of low p_T track quality cuts and high p_T reality. Re-tune parameters:

- **IpatRec tracks**
- **B-layer hit**
- **shared hits**
- **minimal track p_T**
- **jet-track association Δ R**

The high p_T b-tagging performance is not brilliant, but:

- greatly improved with respect to 12.0.6 out-of-the-box
- recovered previous “Rome” results with realistic assumptions on material, alignment
- results compatible with ATLFAST parameterization used for Twin Higgs study
- standard algorithm – works at low p_T as well. No recalibration of likelihoods

Thanks to b-tagging group (M. Lehmacher, V. Kostyukhin, L. Vacavant) for very useful discussions.

Summary and conclusions

- **LR Twin Higgs benchmark points defined**
- **First look at di-lepton decay of heavy Z boson, likely discovery channel**
- **b-tagging for high and very high p_T jets in a “realistic environment” yields adequate performance for reconstruction of cascade decays**
- **The cascade decay**

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

  can be observed with ATLAS and L=30 fb^{-1} for masses up to m (W_H) ~ 3 TeV/c^2
- **Starting to document some of this work (b-tagging CSC note, Twin Higgs ATLAS communication)**

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

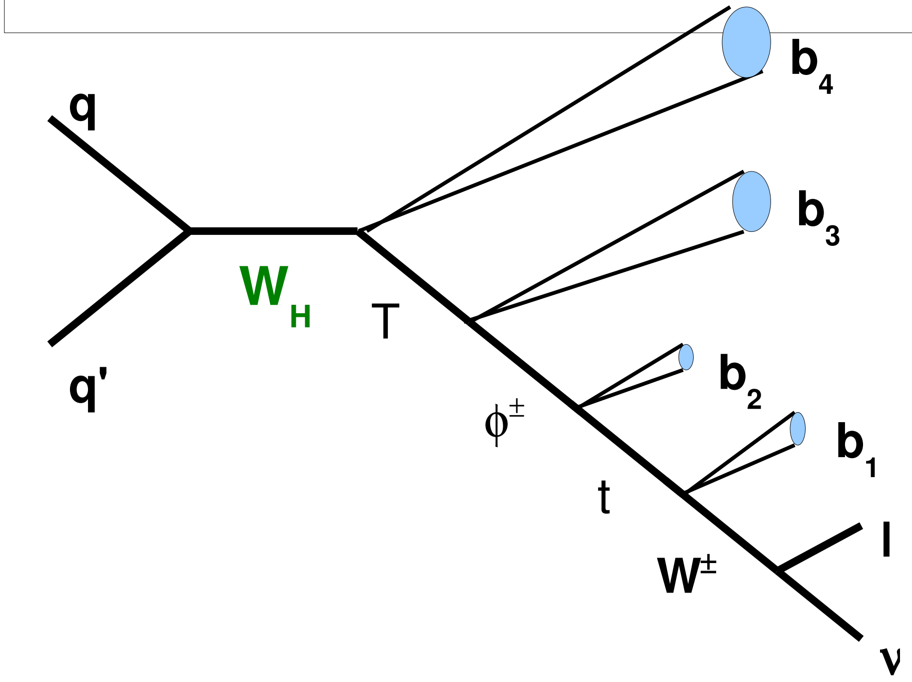
other W_H (1TeV/c^2) decays

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 $M \to 0$

Signature for W_H (1 TeV/c^2)→ Tb



	$<p_T>$ (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%)

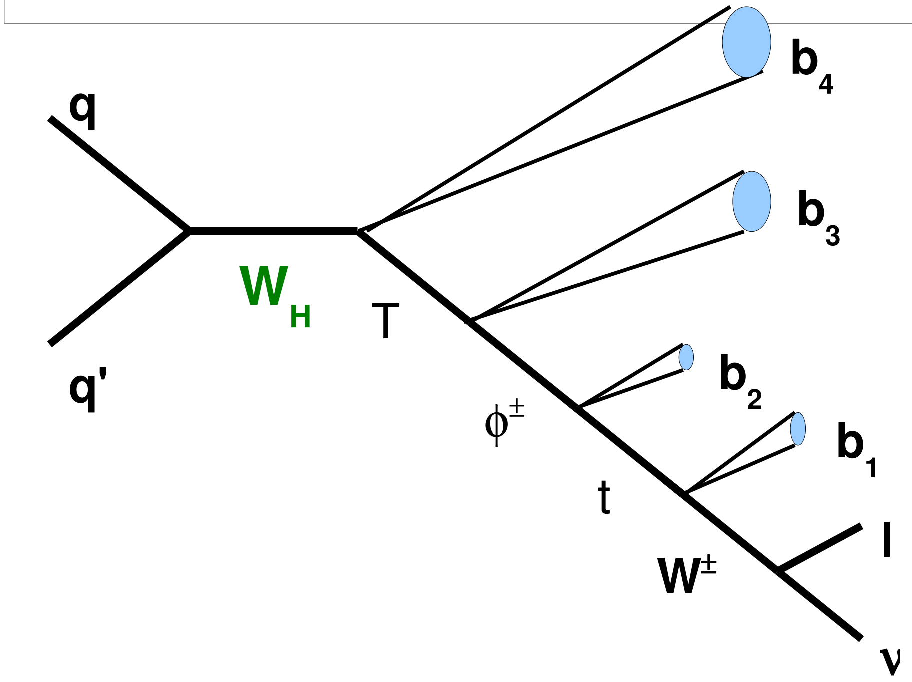
Simulation: Pythia + ATLFAST

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



Efficiency (kin. cuts only):

ε_{kin} ~ 12 %

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)

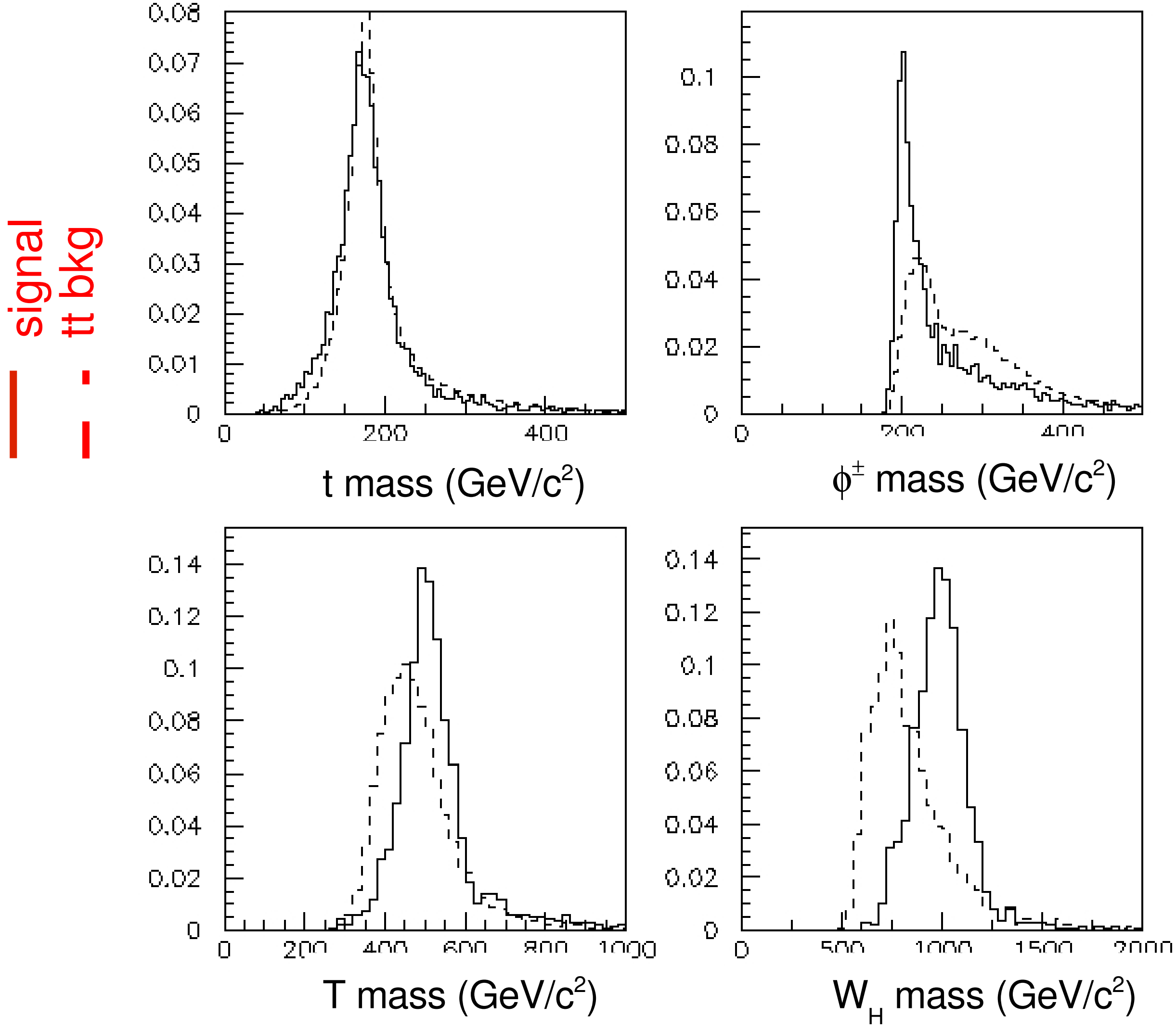
$W+b_1 \rightarrow t$	25 < p_T (b_1) < 200 GeV/c
$t+b_2 \rightarrow \phi^\pm$	25 < p_T (b_2) < 100 GeV/c
$\phi^\pm+b_3 \rightarrow T$	p_T (b_3) > 100 GeV/c
$T+b_4 \rightarrow W_H$	p_T (b_4) > 150 GeV/c

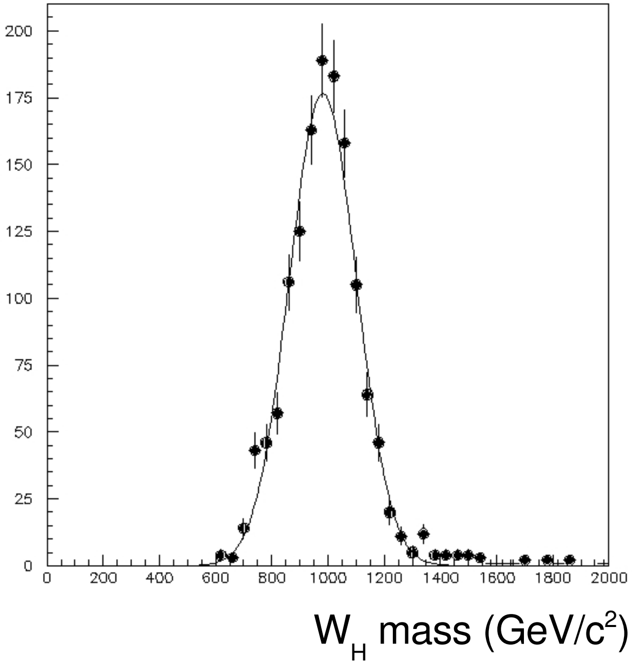
| η | < 2.5 for all leptons and jets

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)

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





Reconstructed mass and width:

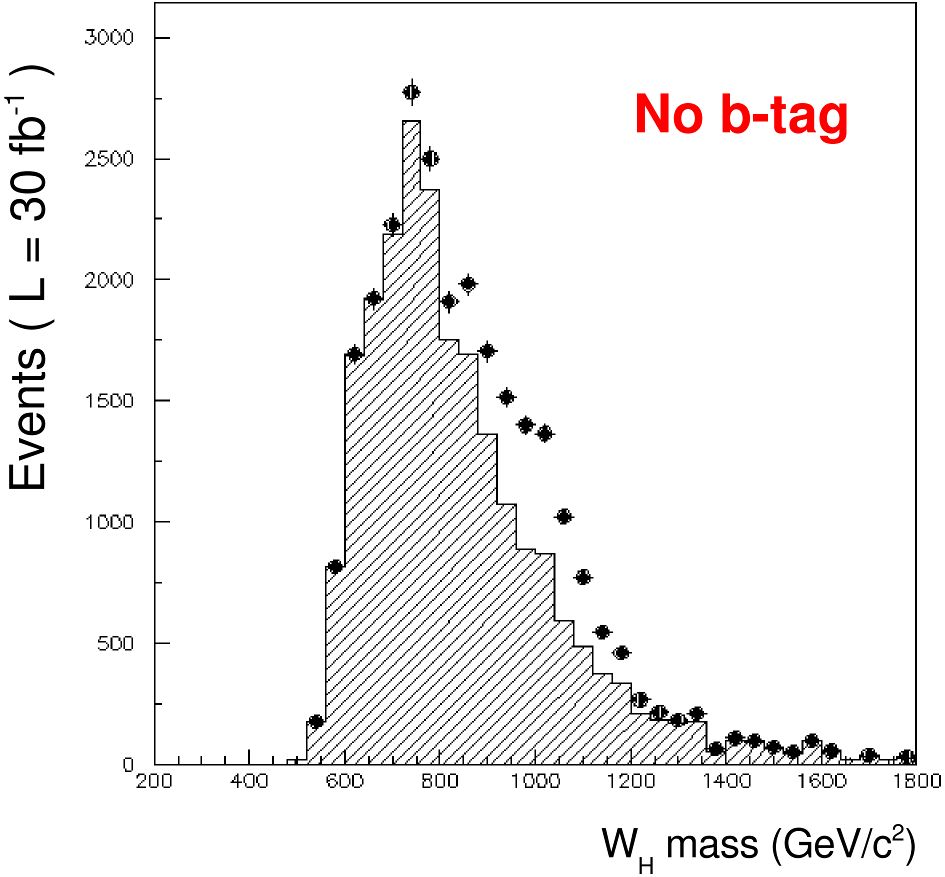
m = 982 GeV/c^2

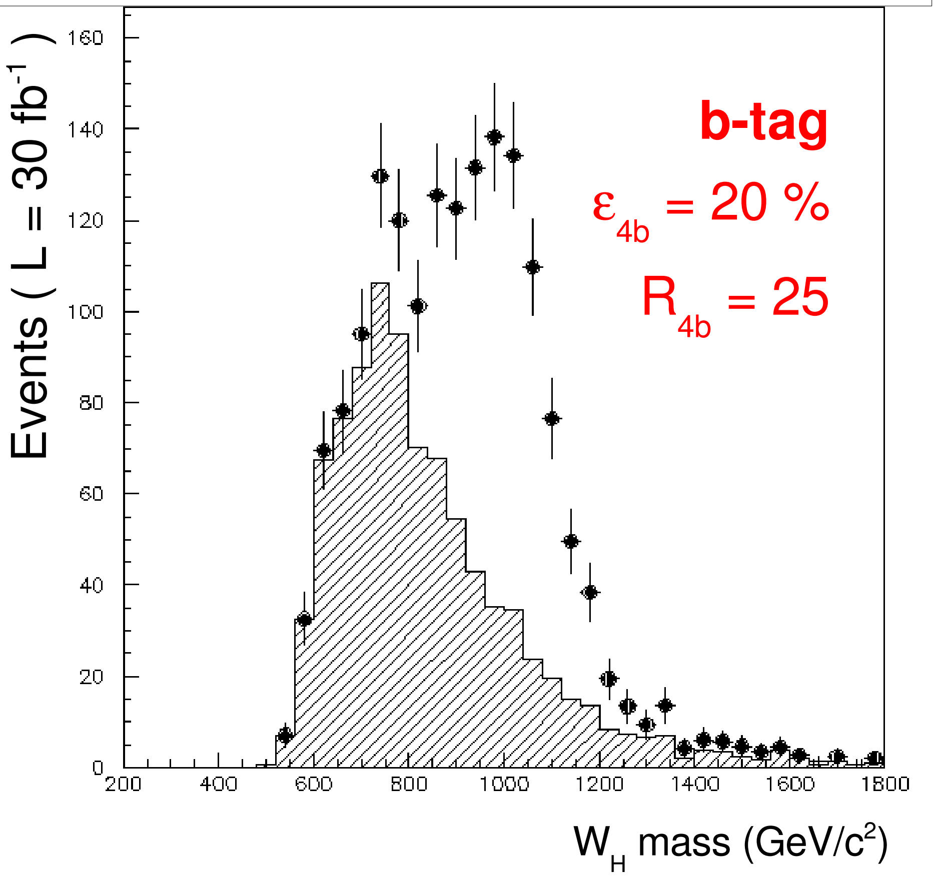
σ = 120 GeV/c^2

Remark:

Γ (W_H) = 24 GeV/c^2

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





N_{sig} = 3253

N_{tt} = 9427

N_{wj} = 319

N/√B = 33

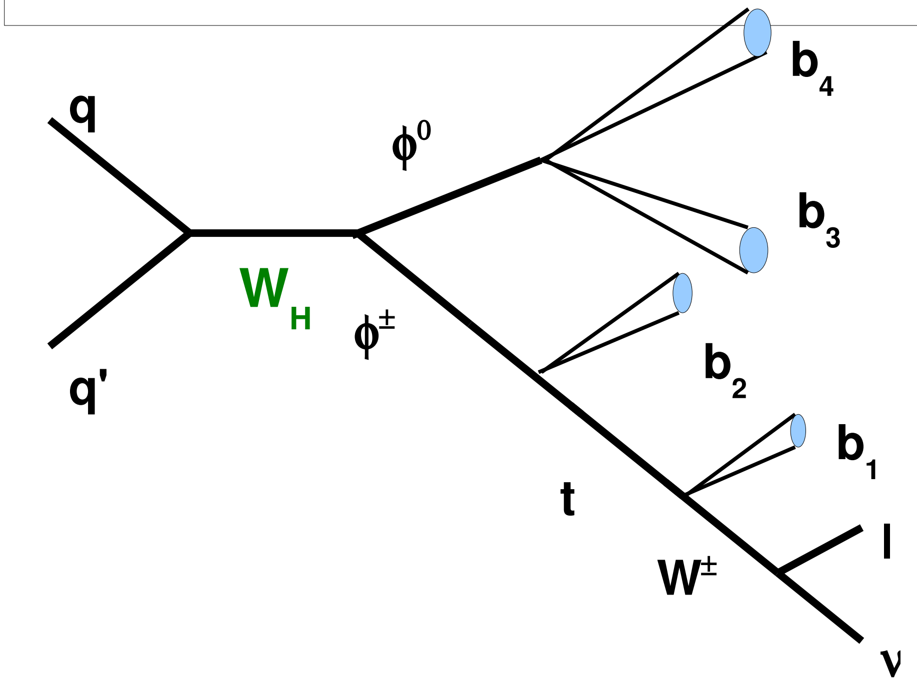
N_{sig} = 651

N_{tt} = 377

N_{wj} ~ 0

N/√B = 33

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%)

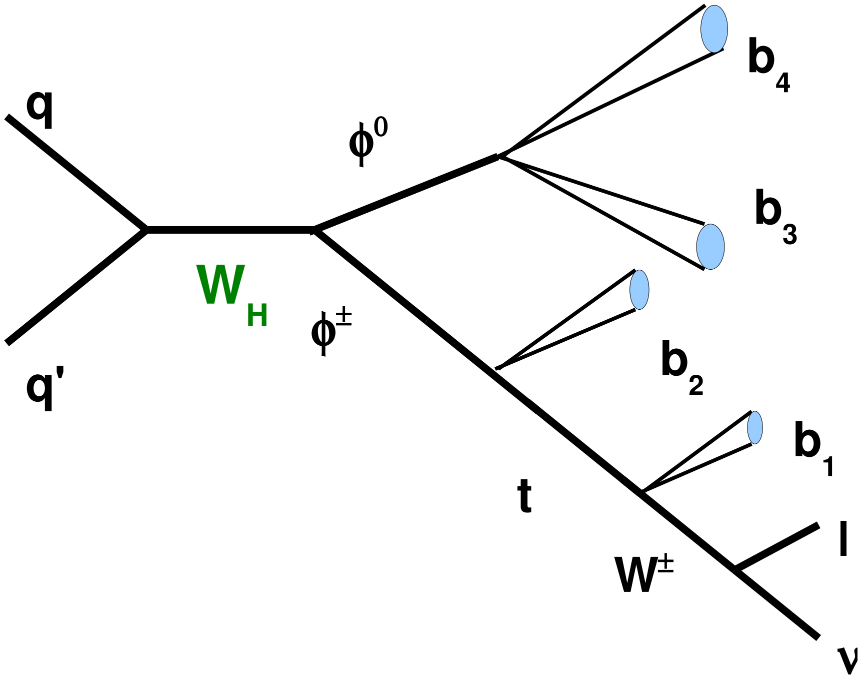
Simulation: Pythia + ATLFAST

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

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

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

assume $p_z^{\nu} \,//\, p_z^{l}$ to reconstruct W

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

$W+b_1 \rightarrow t$ $\quad 25 < p_T(b_1) < 300$ 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

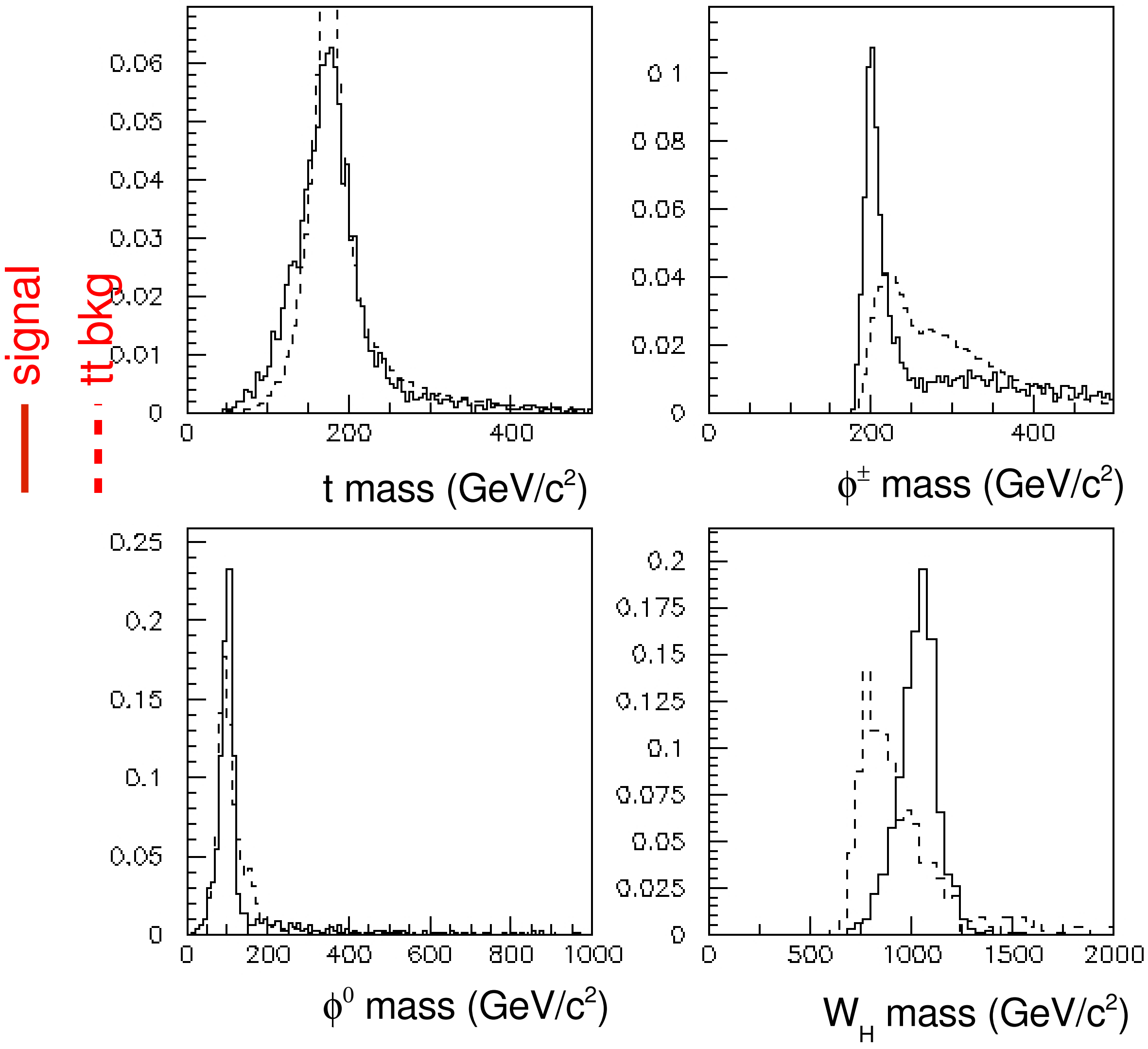
$m(t) < 250$ GeV/c^2

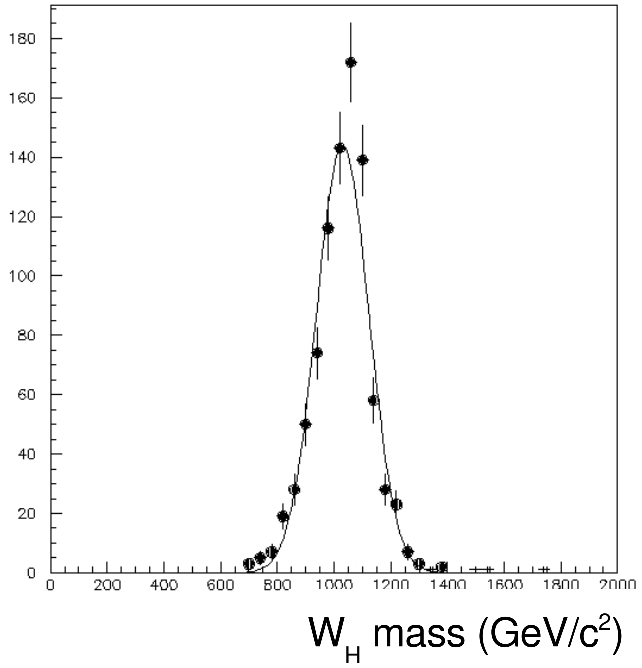
$m(\phi^{\pm}) < 250$ GeV/c^2

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

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

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





Reconstructed mass and width:

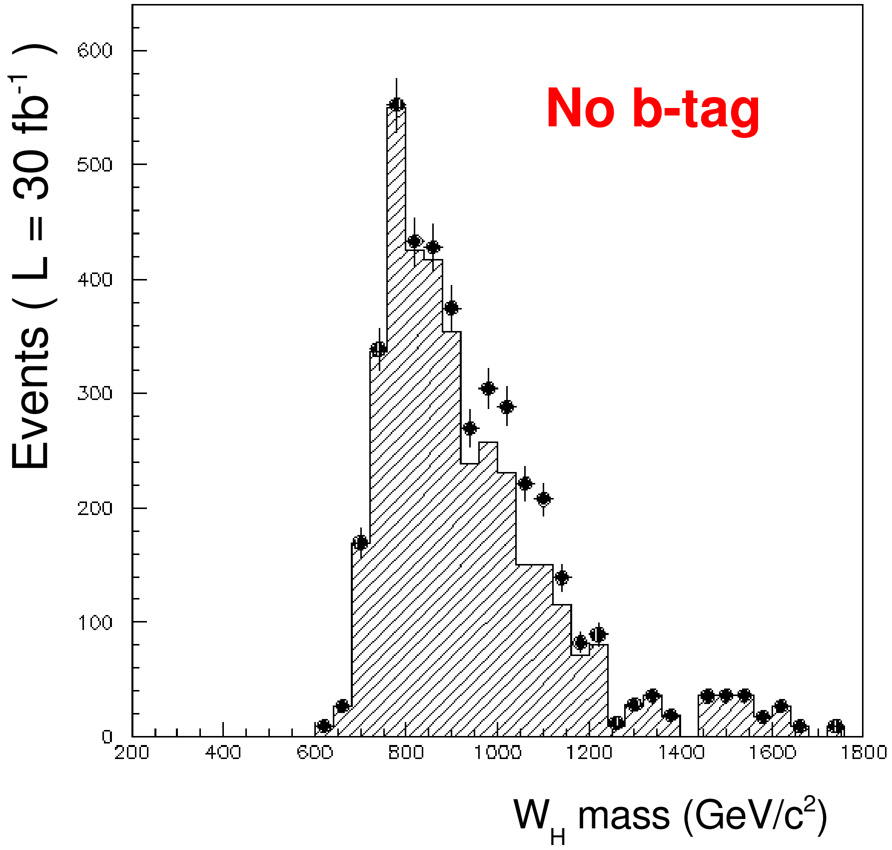
$m = 1030$ GeV/c^2

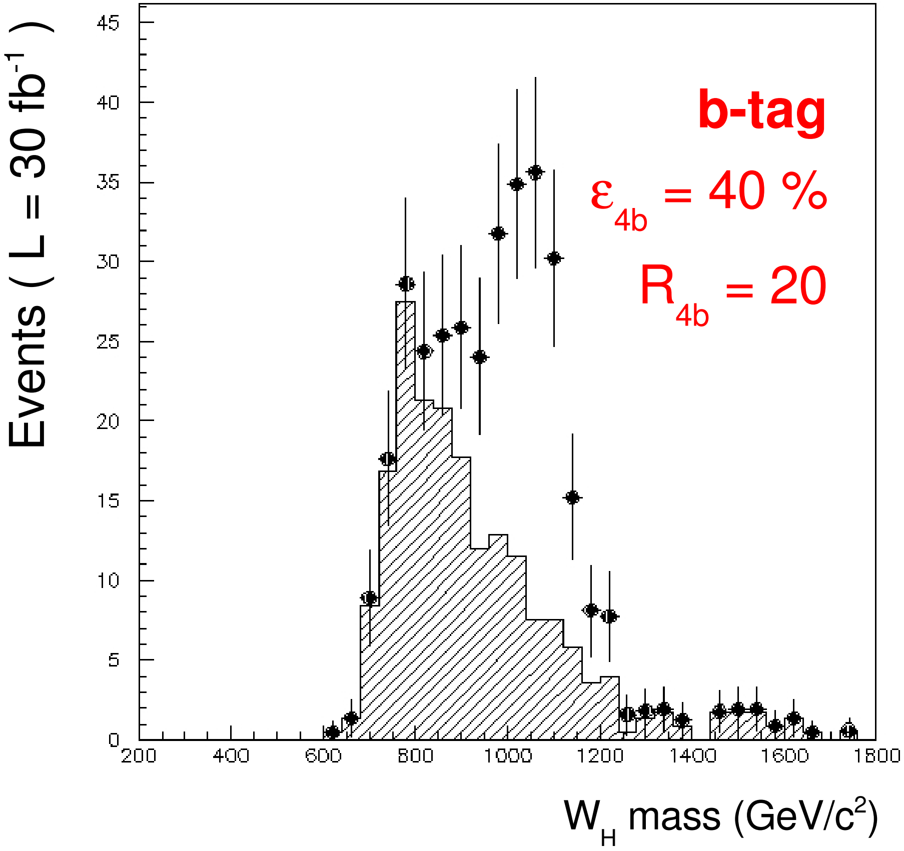
$\sigma = 93$ GeV/c^2

Remark:

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

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





N_{sig} = 337

N_{tt} = 1958

N_{wj} = 171

N/√B = 7

N_{sig} = 135

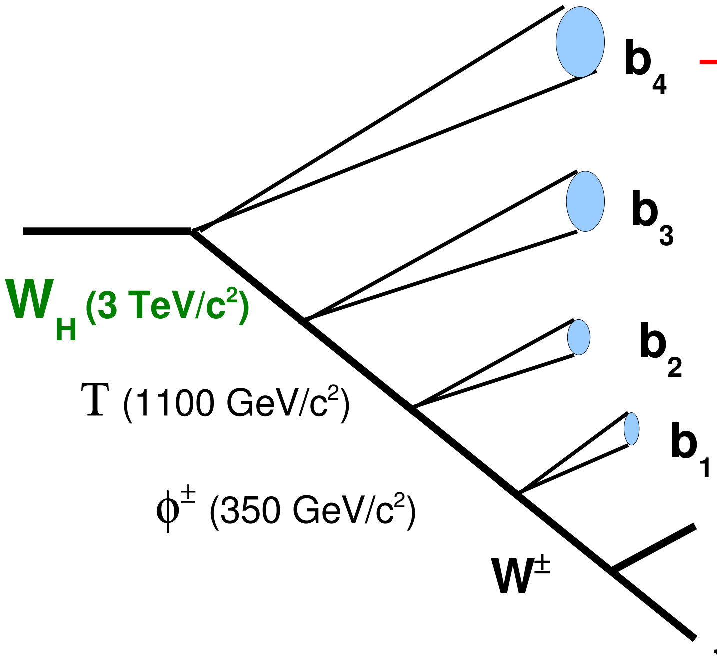
N_{tt} = 98

N_{wj} ~ 0

N/√B = 14

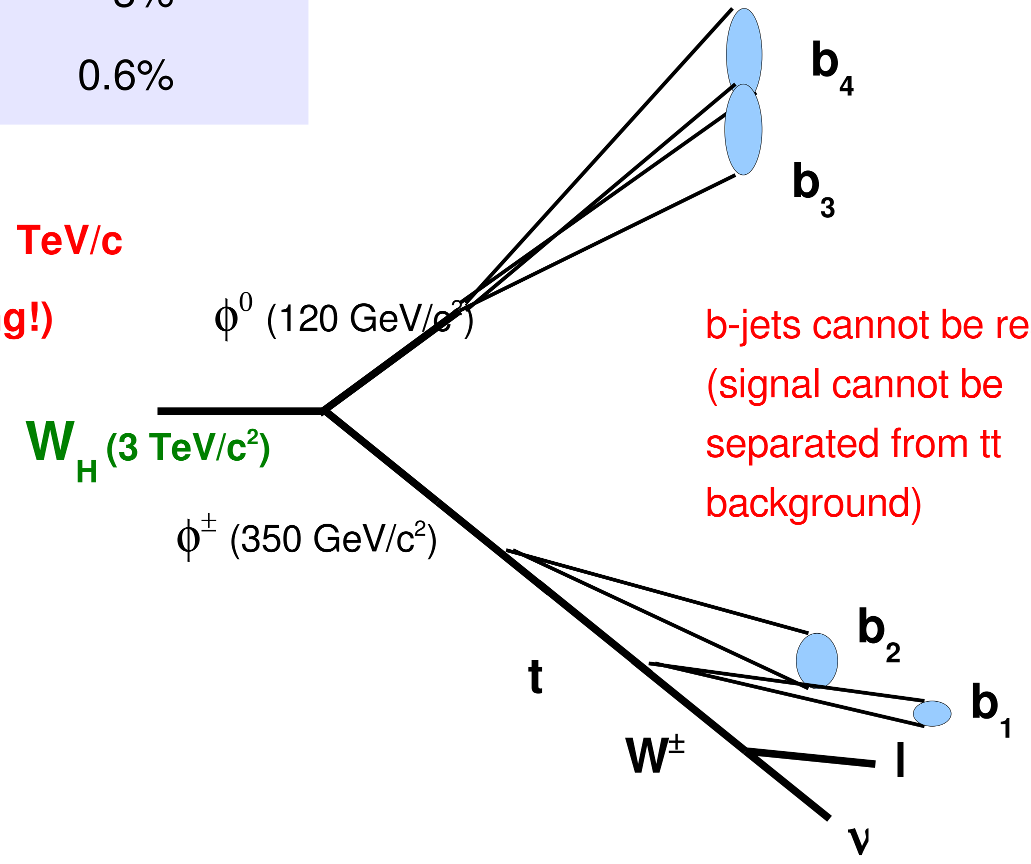
Mass dependence

$m (W_H)$	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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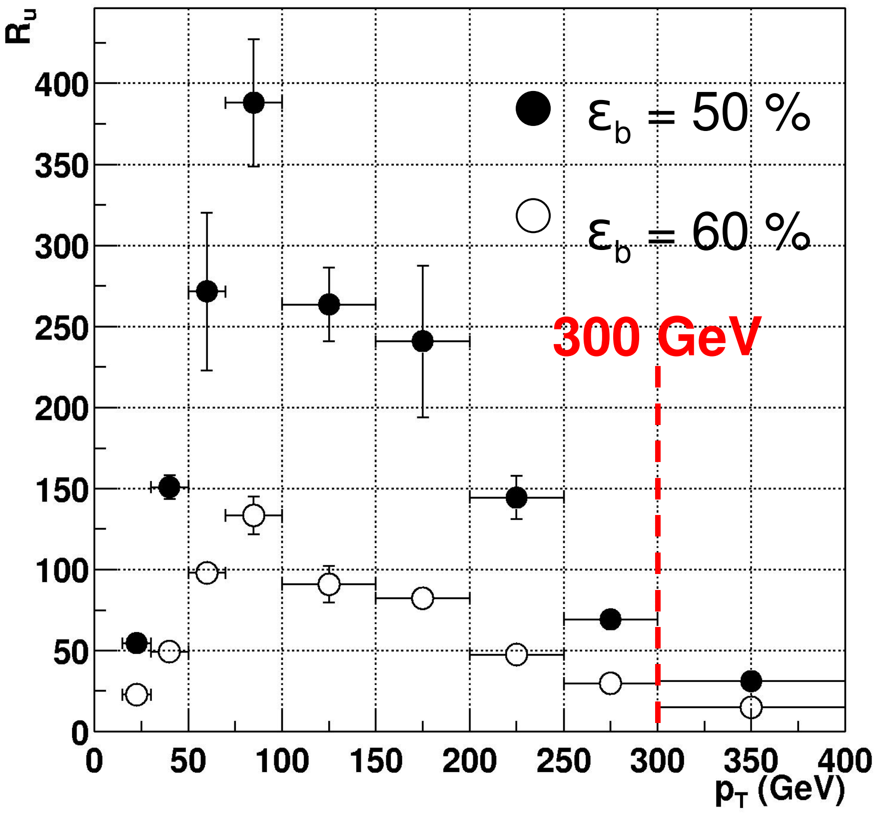

2D algorithm – DC1 data

pp → W H (120 + 400 GeV)

↳ b b

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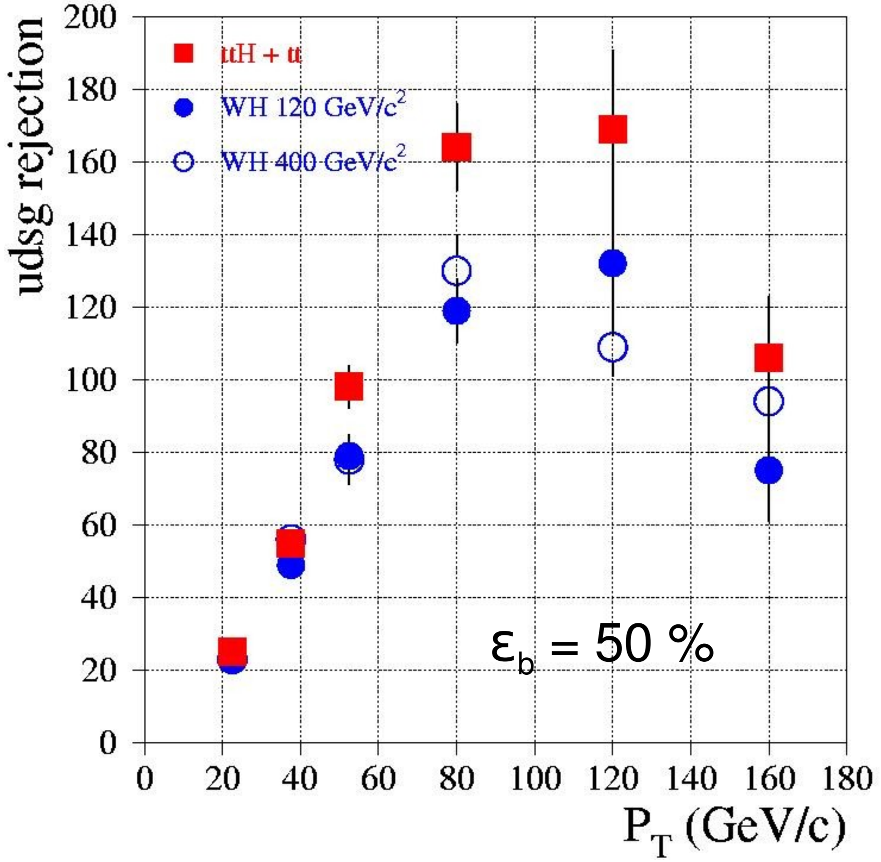
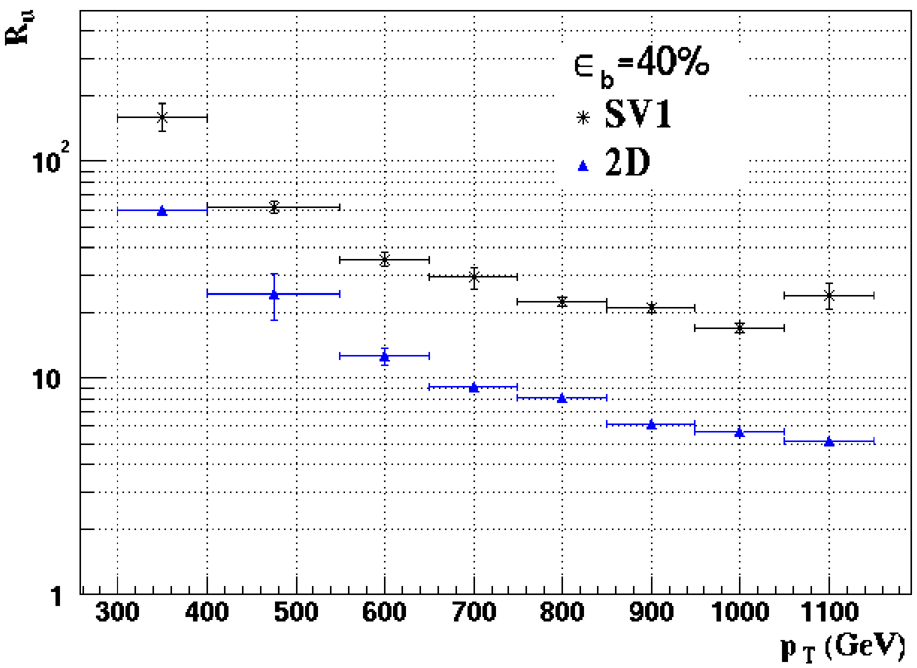


2D algorithm – DC1 data

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

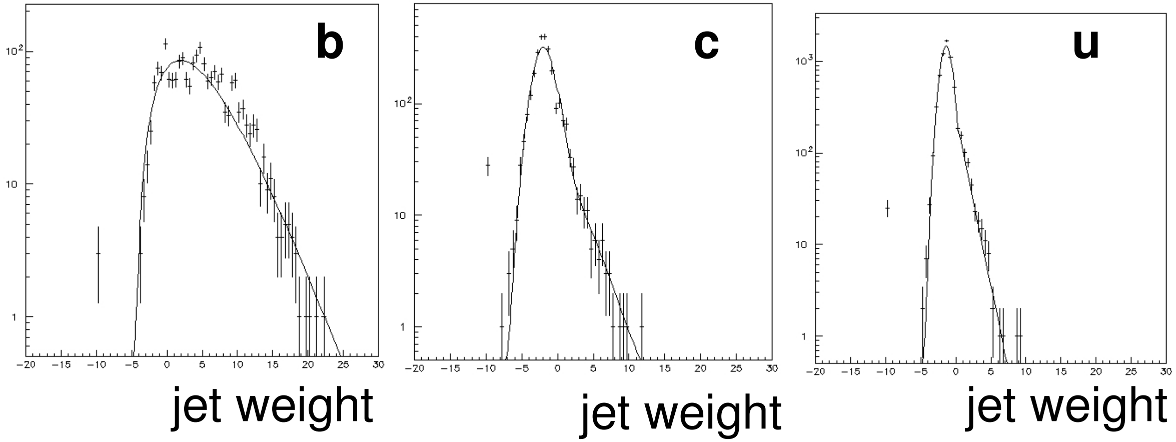
2D = signed IP significance tagger

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

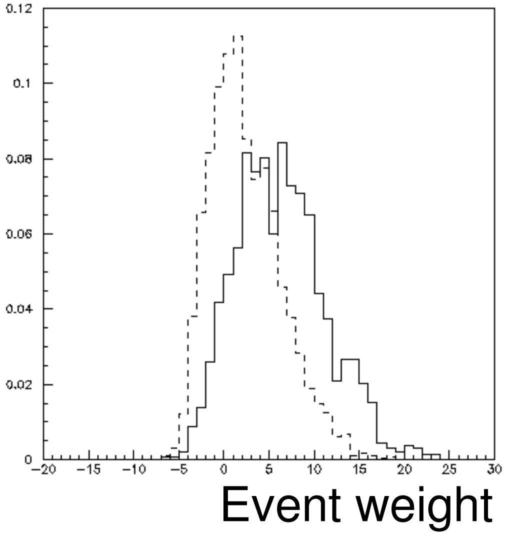
a,b,c,d,e determined on full simulation for several p_T bins

multi b-jet likelihood: $W_{event} = \sum_{jets} w_j$

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

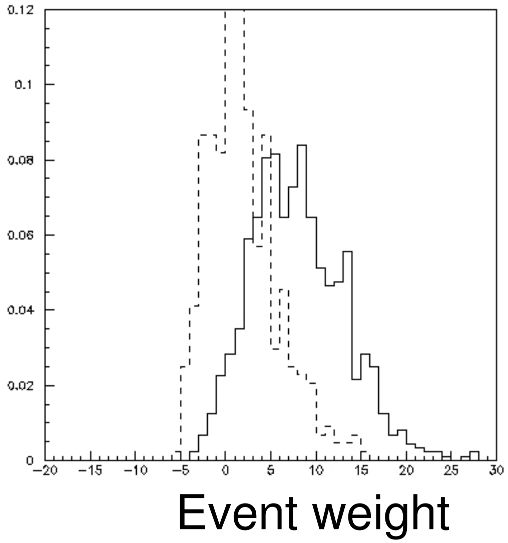
$W_H \rightarrow Tb \rightarrow 4b + l + E_t^{miss}$

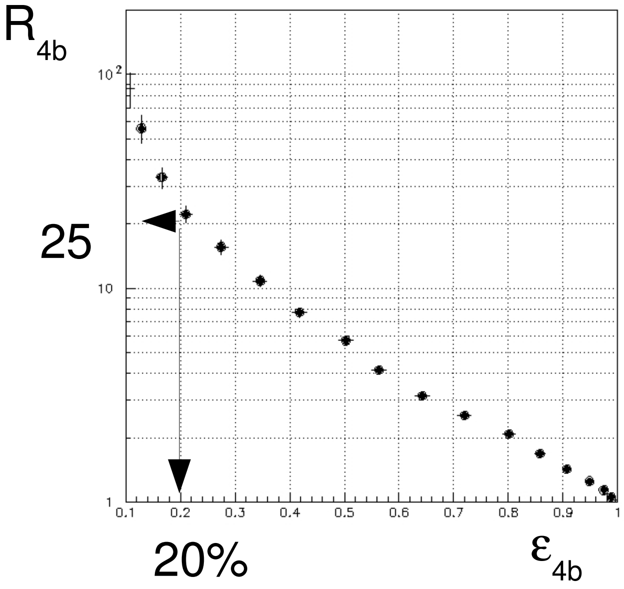
$W_H \rightarrow \phi^{\pm}\phi^{0} \rightarrow 4b + l + E_t^{miss}$



signal

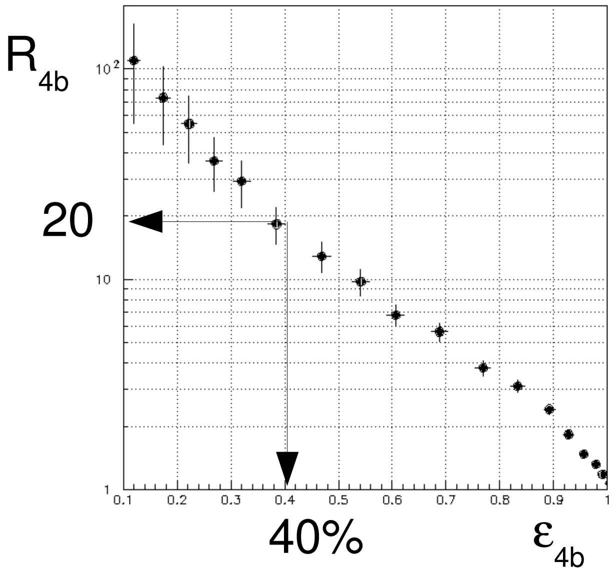
tt background





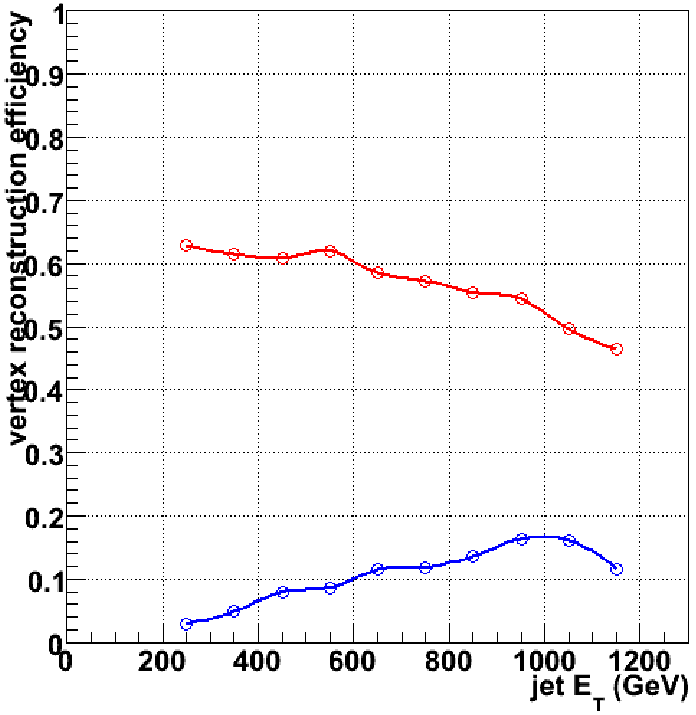
ε_{4b} = signal efficiency

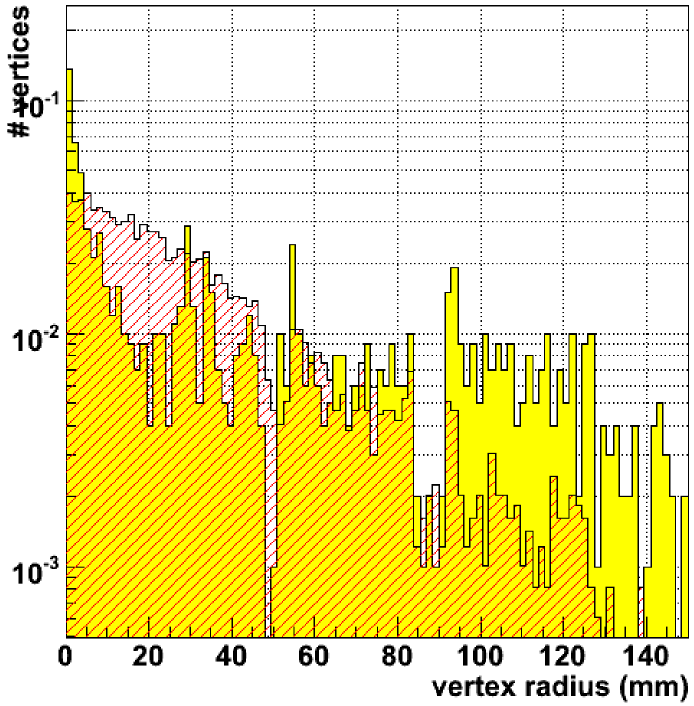
R_{4b} = rejection against tt background



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