The soft wall model at the LHC

Antonio Delgado
University of Notre Dame

1. Introduction: the soft wall model
2. KK modes: masses and localizations
3. Signals for neutral bosons: $G^{(n)}$, $A^{(n)}$ & $Z^{(n)}$
4. Signals for charged bosons: $W^{(n)}$
5. Conclusions

Work done in collaboration with:
Jorge de Blas, Bryan Ostdiek and Alejandro de la Puente
arXiv:1206.0699 [hep-ph]

- One possible solution for the hierarchy problem is a warped model that appears in soft-wall scenarios ($MAdS_5$):

$$ds^2 = e^{-A(y)}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

$$A(y) = ky - \frac{1}{\nu^2}\log\left(1 - \frac{y}{y_s}\right)$$

$$\nu \in \mathbb{R} \qquad\qquad y_s > y_1$$

- There is a singularity at y_s outside the physical region

KK modes: masses and localizations

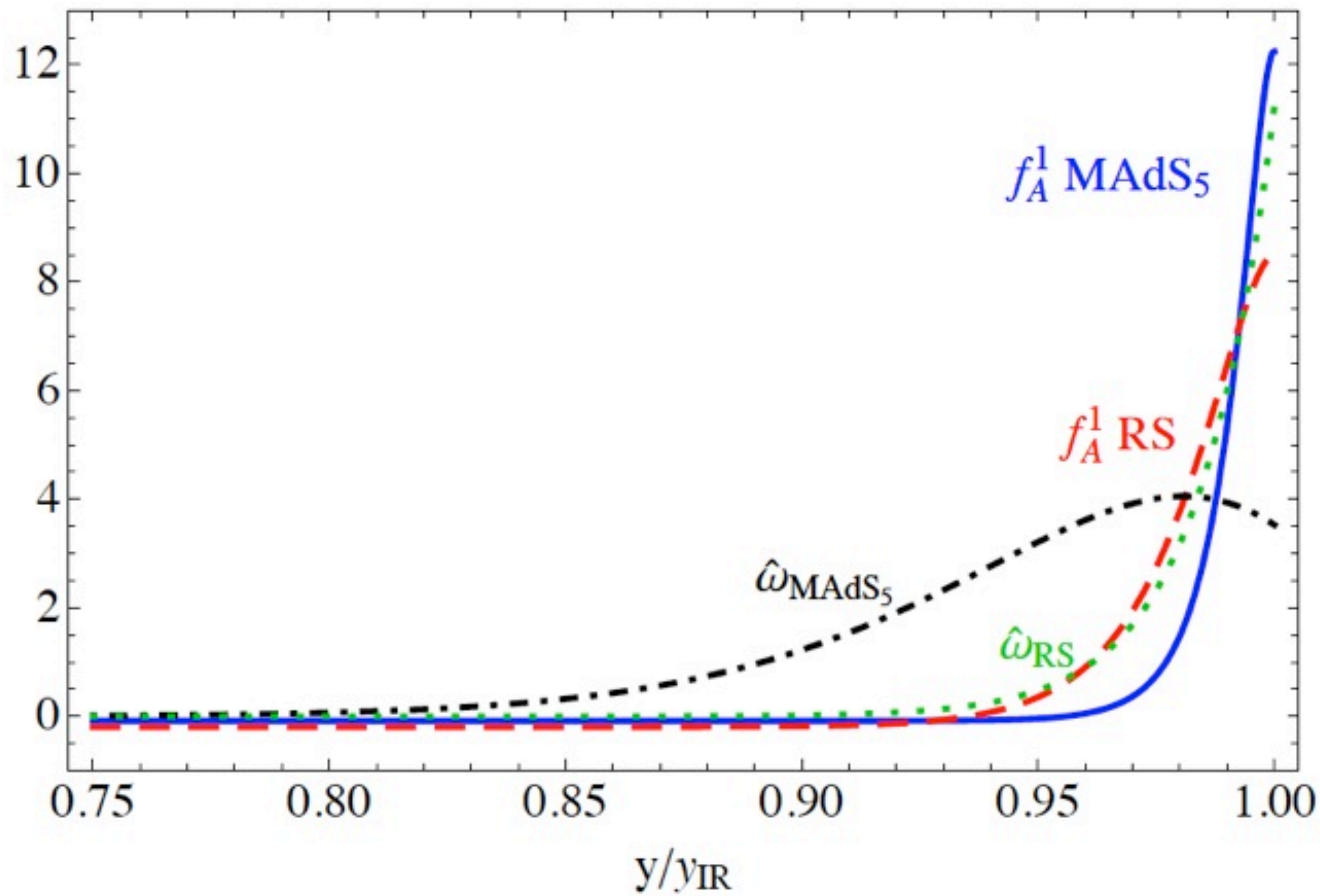
- One performs the usual decomposition on KK modes taking into account the geometry and the background for the Higgs.
- It can only be done numerically.

Cabrer, von Gersdorff, Quiros

$$H(x,y) = \frac{1}{\sqrt{2}} e^{i\chi(x,y)} \begin{pmatrix} 0 \\ h(y) + \xi(x,y) \end{pmatrix}$$

a controls the localization

$$h(y) = c_1 e^{aky} \left(1 + c_2 \int_0^y dy' e^{4A(y') - 2aky'}\right)$$



- Localization of the $A^{(1)}$ and Higgs, the overlap between KK modes and the Higgs is smaller than RS.

- That will imply a smaller coupling between zero modes and KK modes.

- In turn that will mean smaller contributions to S, T & U

- No need for $SU(2)_R$

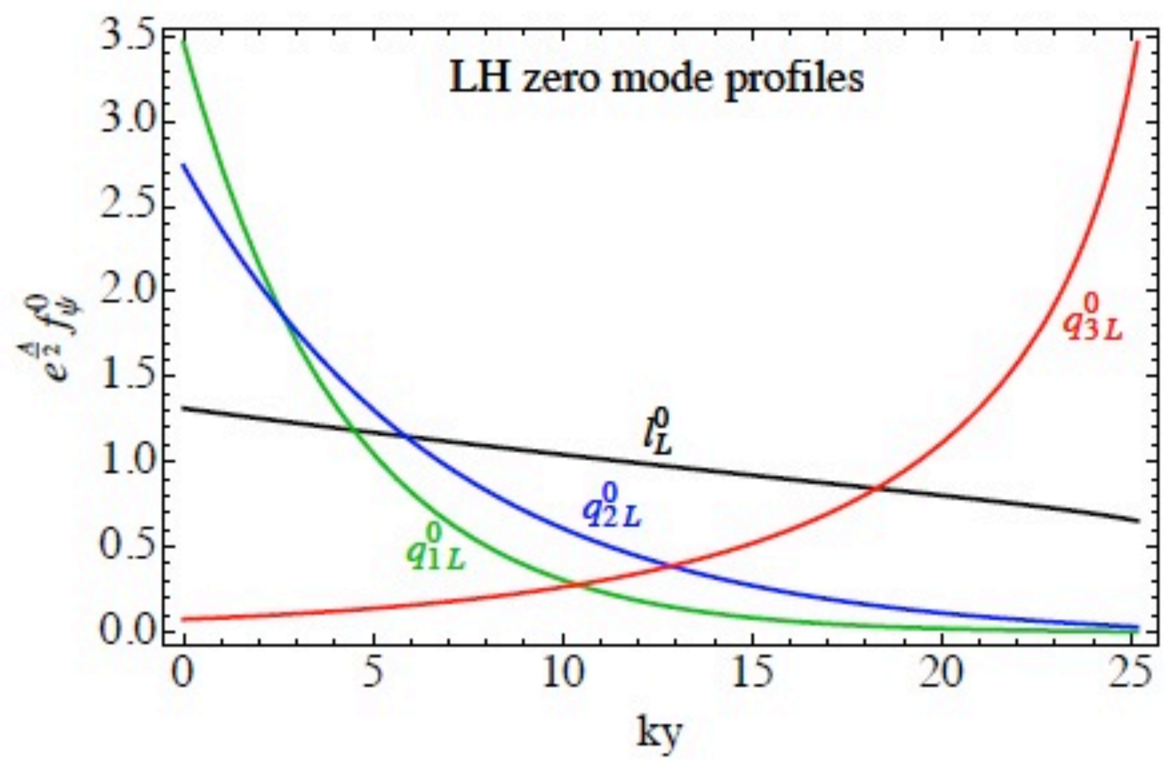
BenchMark	kL_1	ky_1	(ky_s)	ν	a	M_{KK}[TeV]
1	0.3	25	(26.3)	0.55	2.8	2.4
2	0.4	28	(29.6)	0.64	2.5	4.0
3	0.5	30	(31.7)	0.73	2.4	5.2

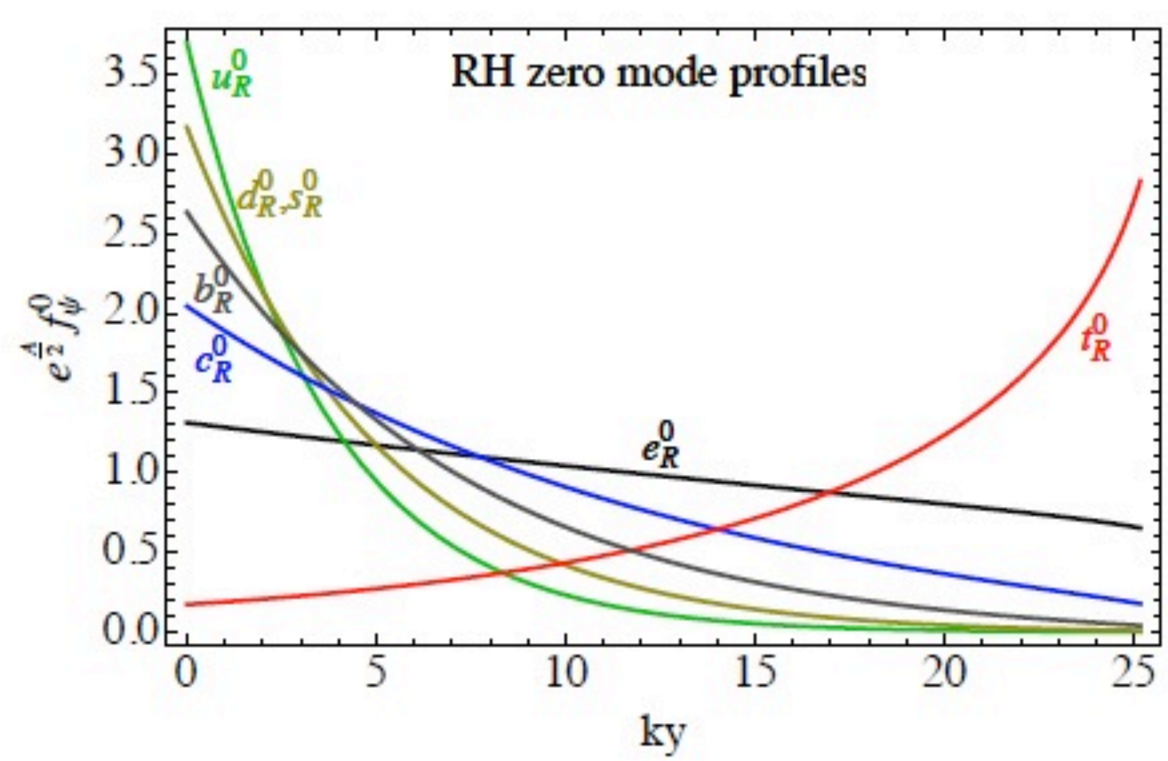
- Fermionic modes are chosen in the following way:

$c_{(u,d)_L} = 0.71$	$c_{(c,s)_L} = 0.63$	$c_{(t,b)_L} = 0.39$
$c_{u_R} = 0.74$	$c_{c_R} = 0.57$	$c_{t_R} = 0.42$
$c_{d_R} = 0.68$	$c_{s_R} = 0.67$	$c_{b_R} = 0.62$

To avoid FCNC:

$$c_{(\ell,\nu_\ell)_L} = c_{\ell_R} = 0.52,\ \ell = e, \mu, \tau$$





Signals for neutral bosons: $G^{(n)}$, $A^{(n)}$ & $Z^{(n)}$

- We are going to analyze the different potential signals for the LHC.
- The model is implemented using FeynRules
- CTEQ6L1 is used for PDFs
- We use MadGraph 5 to calculate the different cross sections.
- We stay at the parton level.

- Decay widths of A_{kk} & Z_{kk}:

Decay channel	Width [GeV]	Branching Ratio
$t\bar{t}$	9.938	0.563
W^+W^-	5.453	0.309
$b\bar{b}$	1.751	0.099
$u\bar{u}$	0.157	0.009
$c\bar{c}$	0.152	0.009
$d\bar{d}$	0.039	0.002
$s\bar{s}$	0.039	0.002
e^+e^-	0.037	0.002
$\mu^+\mu^-$	0.037	0.002
$\tau^+\tau^-$	0.037	0.002
Total	17.641	

A_{kk}

Decay channel	Width [GeV]	Branching Ratio
$b\bar{b}$	15.960	0.493
$t\bar{t}$	11.460	0.354
W^+W^-	2.337	0.072
$Z\ h$	1.847	0.057
$d\bar{d}$	0.179	0.006
$s\bar{s}$	0.179	0.006
$u\bar{u}$	0.140	0.004
$c\bar{c}$	0.138	0.004
$\nu\bar{\nu}$	0.074	0.002
e^+e^-	0.012	$4 \cdot 10^{-4}$
$\mu^+\mu^-$	0.012	$4 \cdot 10^{-4}$
$\tau^+\tau^-$	0.012	$4 \cdot 10^{-4}$
Total	32.352	

Z_{kk}

- Hadronic final states, we have to consider also the G_{kk}:

M_{kk}= 2.4 TeV

Decay channel	Width [GeV]	Branching Ratio
$t\bar{t}$	40.72	0.566
$b\bar{b}$	28.70	0.399
$u\bar{u}$	0.645	0.009
$d\bar{d}$	0.645	0.009
$s\bar{s}$	0.644	0.009
$c\bar{c}$	0.622	0.009
Total	71.979	

- t t-bar is the most promising case.

- The process:

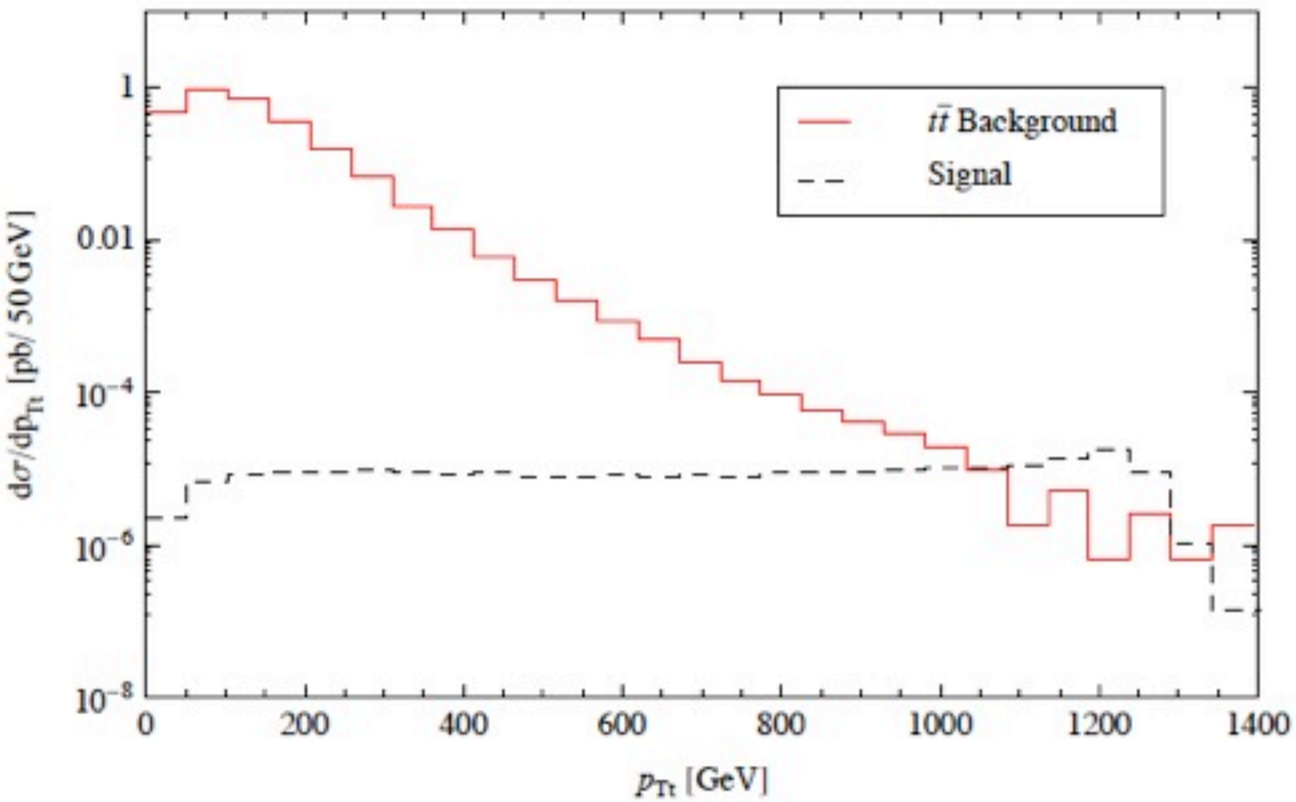
$$p\,p \to \{G_{KK},\, A_{KK},\, Z_{KK}\} \to t\,\bar{t}$$

X	$\sqrt{s} = 8$ TeV $\sigma(pp \to X \to t\bar{t})$[pb]
A_{KK}	$1.28 \cdot 10^{-4}$
Z_{KK}	$8.79 \cdot 10^{-5}$
G_{KK}	$1.11 \cdot 10^{-2}$
All	$1.12 \cdot 10^{-2}$

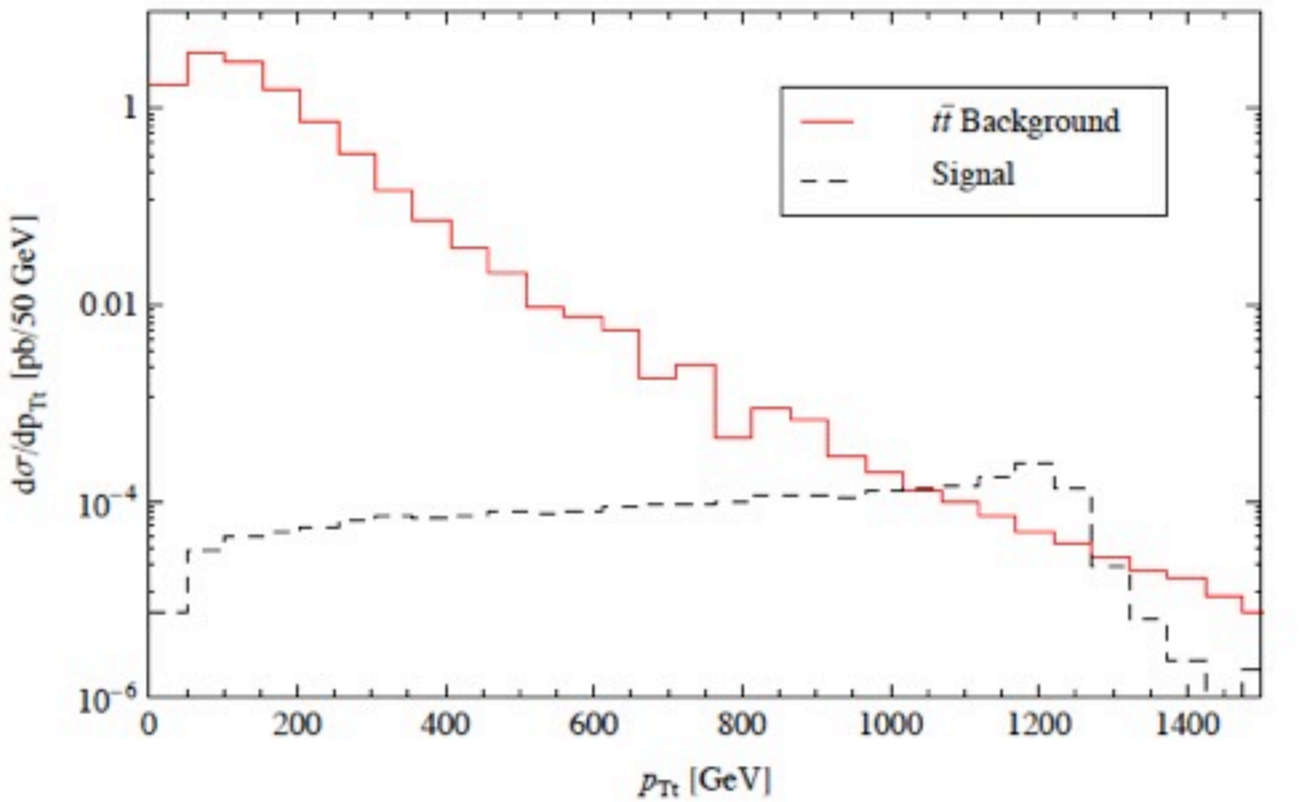
X	$\sqrt{s} = 14$ TeV $\sigma(pp \to X \to t\bar{t})$[pb]
A_{KK}	$1.68 \cdot 10^{-3}$
Z_{KK}	$1.32 \cdot 10^{-3}$
G_{KK}	0.118
All	0.121

It is even promising for LHC_8

- The main background is t-t bar production:



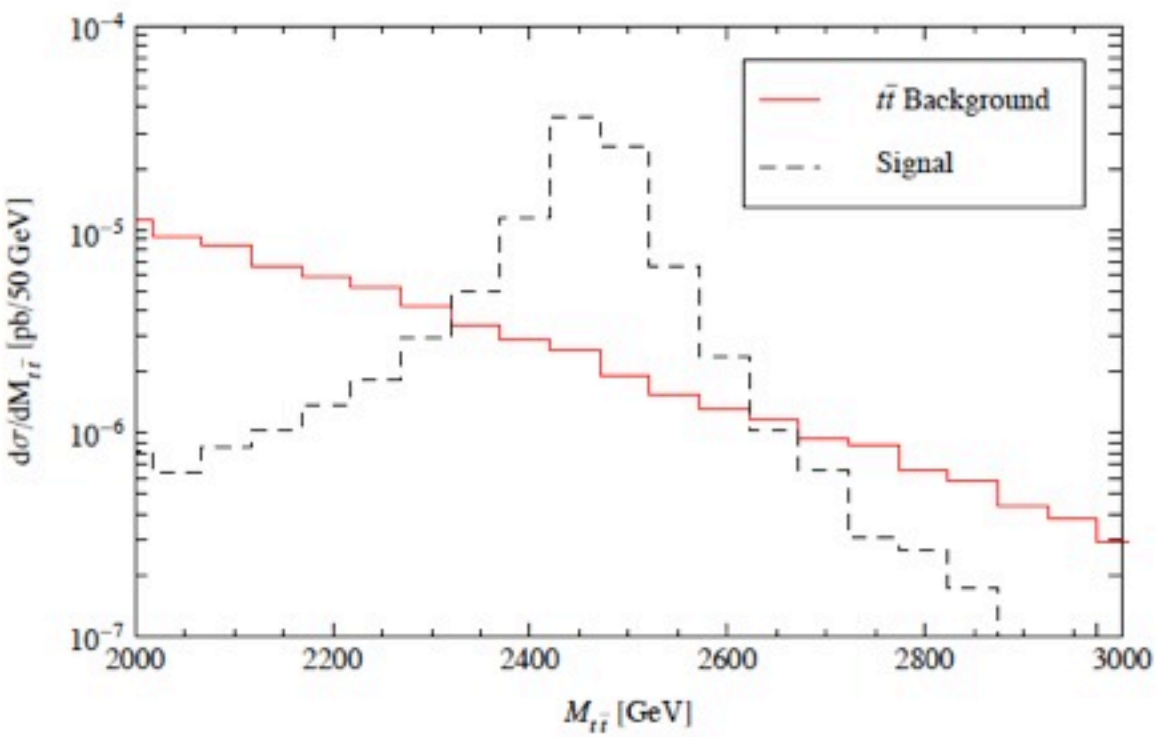
LHC8



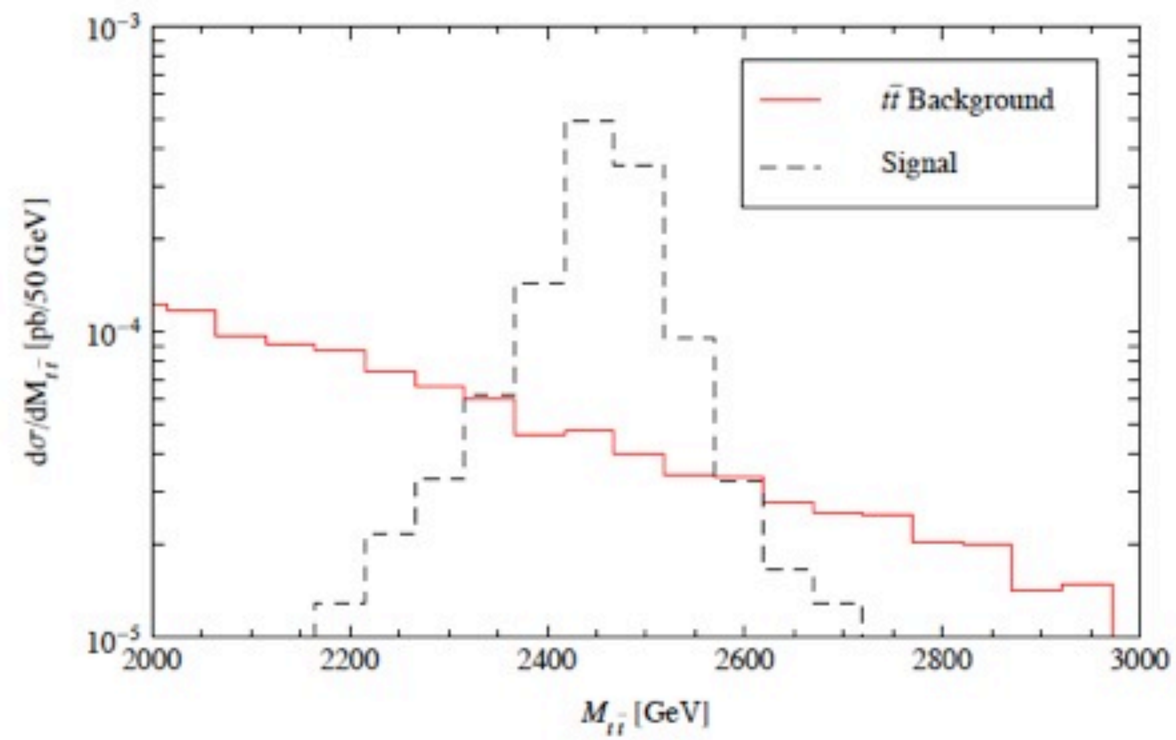
LHC14

Cut P_{Tt}>800 GeV

- Distributions of M_{tt}:



LHC8



LHC14

Cut 2300 GeV<M_{tt}<2600 GeV

- After implementing the cuts we get the following significance:

8 TeV	Basic		$M_{t\bar{t}}$ [TeV] $\in [2300, 2600]$	
10 fb^{-1}	N_{Events}	$\frac{S}{\sqrt{B}}$	Events	$\frac{S}{\sqrt{B}}$
G_{KK}, A_{KK}, Z_{KK}	51	5.7	45	15.9
SM	80		8	

14 TeV	Basic		$M_{t\bar{t}}$ [TeV] $\in [2300, 2600]$	
10 fb^{-1}	N_{Events}	$\frac{S}{\sqrt{B}}$	Events	$\frac{S}{\sqrt{B}}$
G_{KK}, A_{KK}, Z_{KK}	672	21.0	605	47.4
SM	1025		163	

Signals for charged bosons: $W^{(n)}$

Decay channel	Width [GeV]	Branching Ratio
$t\bar{b}$	33.570	0.732
W^+Z	5.764	0.126
W^+H	5.679	0.124
$u\bar{d}$	0.351	0.008
$c\bar{s}$	0.350	0.008
$e^+\nu_e$	0.038	$8 \cdot 10^{-4}$
$\mu^+\nu_\mu$	0.038	$8 \cdot 10^{-4}$
$\tau^+\nu_\tau$	0.038	$8 \cdot 10^{-4}$
$c\bar{d}$	0.019	$4 \cdot 10^{-4}$
$u\bar{s}$	0.019	$4 \cdot 10^{-4}$
$c\bar{b}$	$6 \cdot 10^{-5}$	$1 \cdot 10^{-6}$
$t\bar{s}$	$6 \cdot 10^{-5}$	$1 \cdot 10^{-6}$
$t\bar{d}$	$1 \cdot 10^{-5}$	$2 \cdot 10^{-7}$
$u\bar{b}$	$4 \cdot 10^{-6}$	$8 \cdot 10^{-8}$
Total	45.866	

- Decay width of W_{KK} with M=2.4 TeV

- Possible channels:

$$pp \to W_{KK} \to b\bar{b}\ell\nu_\ell$$
$$pp \to W_{KK} \to \ell\ell\ell\nu_\ell$$

$\sqrt{s}$	$\sigma(pp \to W_{KK} \to tb)$[pb]	BR$(t \to Wb)$	BR$(W \to \ell\nu_\ell)$	Total [pb]
8	$5.10 \cdot 10^{-4}$	1	0.216	$1.10 \cdot 10^{-4}$
14	$7.36 \cdot 10^{-3}$	1	0.216	$1.59 \cdot 10^{-3}$

$\sqrt{s}$	$\sigma(pp \to W_{KK} \to WZ)$[pb]	BR$(W \to \ell\nu_\ell)$	BR$(Z \to \ell^+\ell^-)$	Total [pb]
8	$8.76 \cdot 10^{-5}$	0.216	0.067	$1.27 \cdot 10^{-6}$
14	$1.26 \cdot 10^{-3}$	0.216	0.067	$1.84 \cdot 10^{-5}$

Only the first one is worth studying

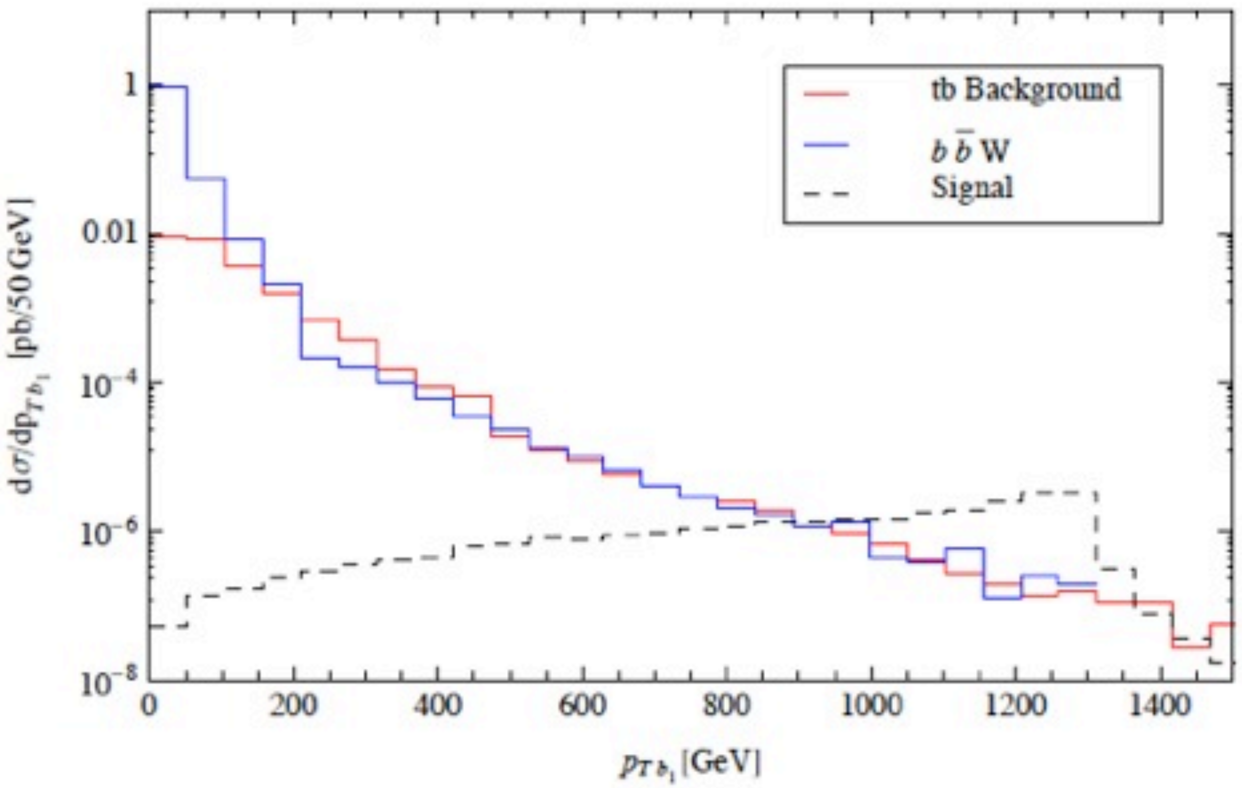
- The irreducible background includes:

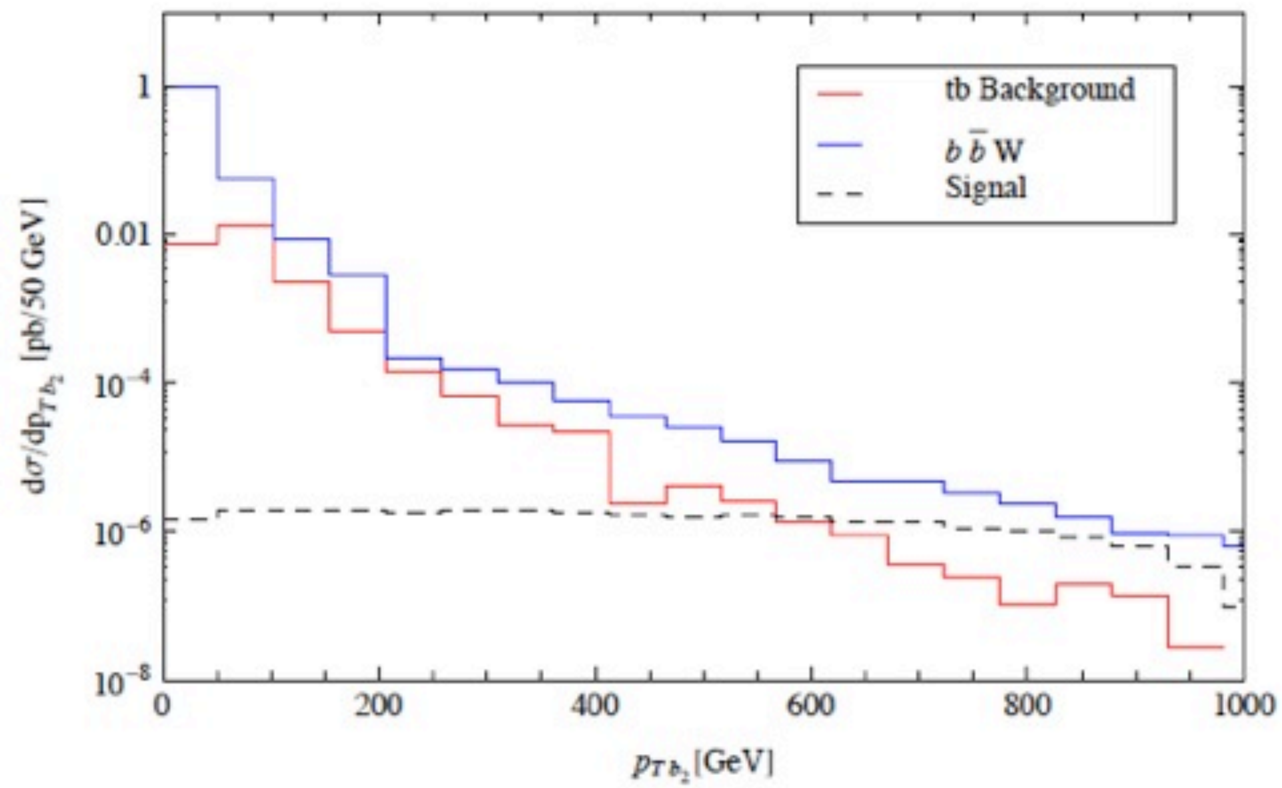
$$pp \to W \to tb$$

No top quark $pp \to gW \to b\bar{b}\ell\nu_\ell$

- Other possible background, if the addtional jet is soft:

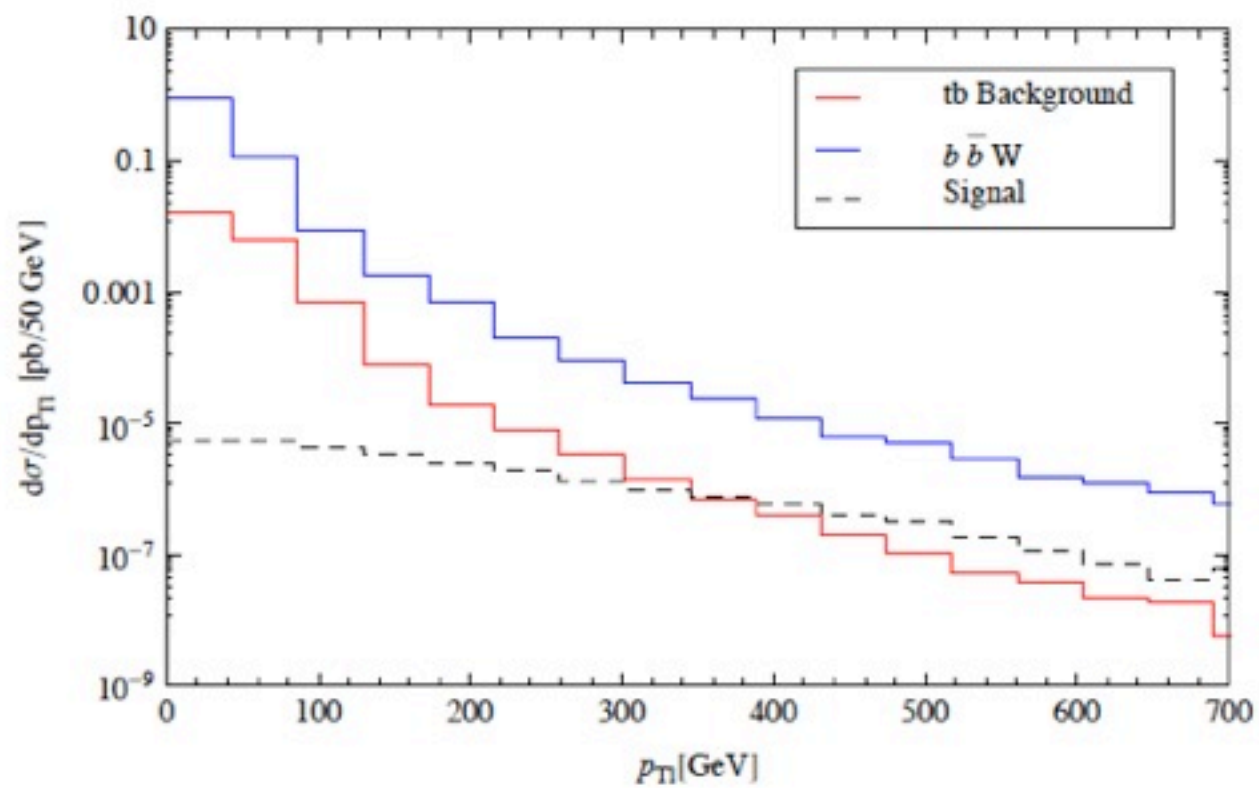
$$pp \to tbj \to b\bar{b}\ell\nu_\ell j$$

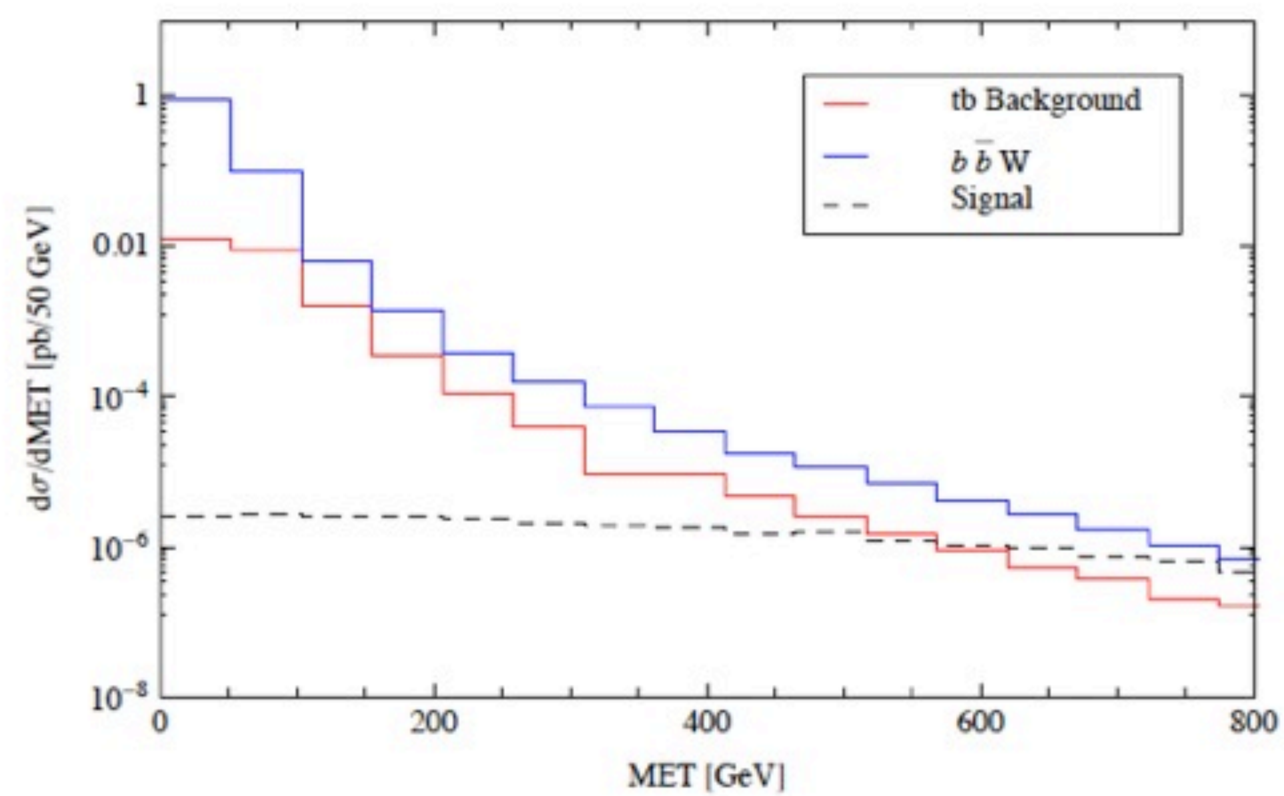

tb Background
$b\,\bar{b}$ W
Signal
$d\sigma/dp_{T\,b_1}$ [pb/50 GeV]
$p_{T\,b_1}$[GeV]

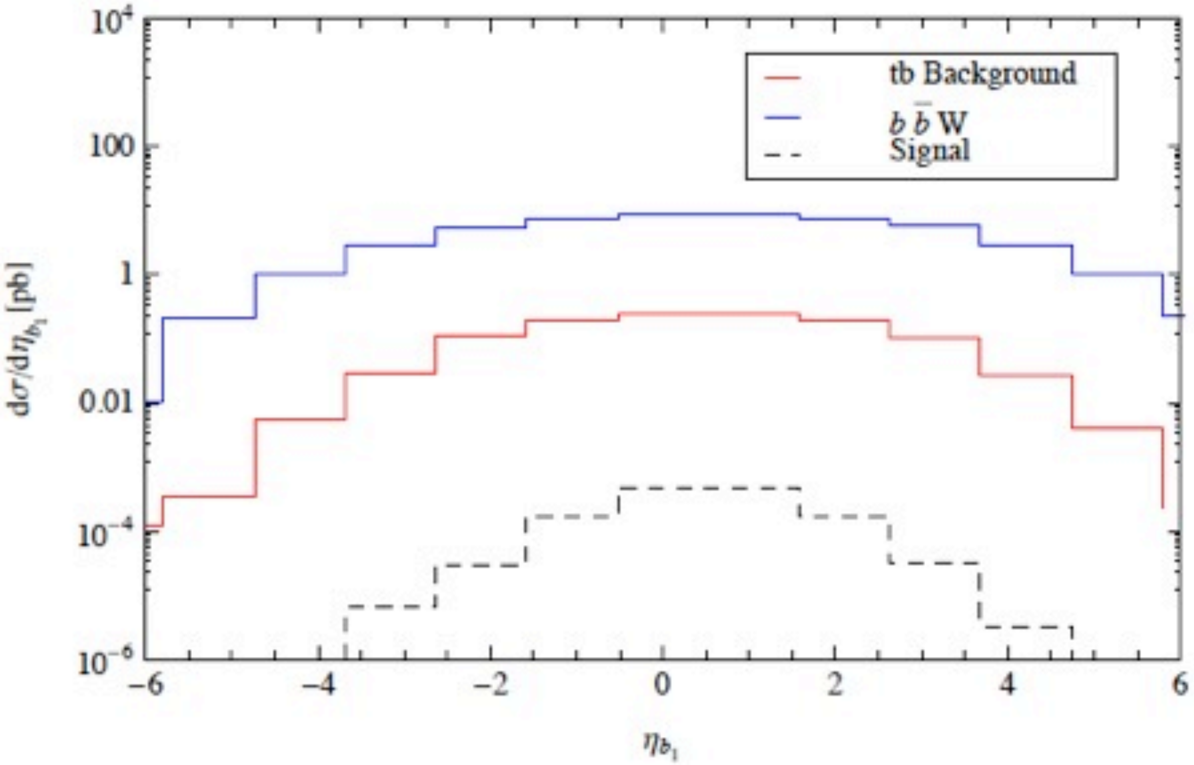

tb Background
$b\,\bar{b}$ W
Signal
$d\sigma/dp_{T\,b_2}$ [pb/50 GeV]
$p_{T\,b_2}$[GeV]

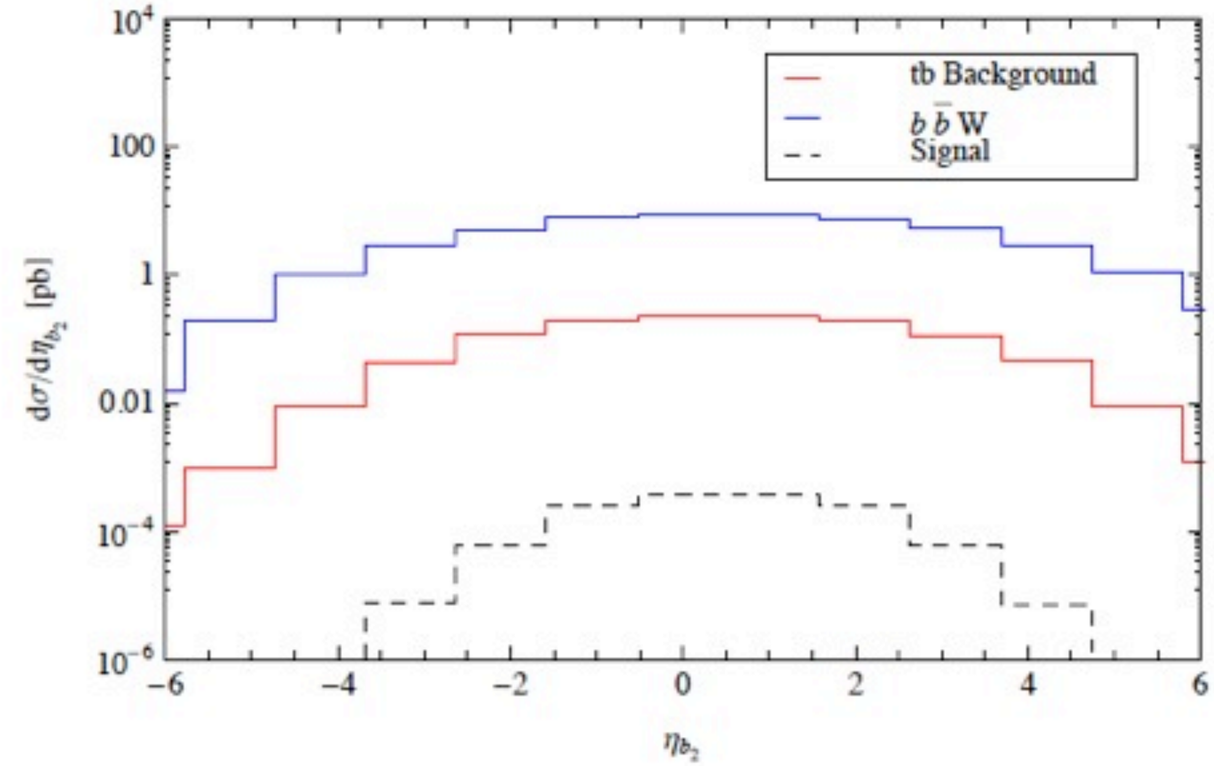
(a)

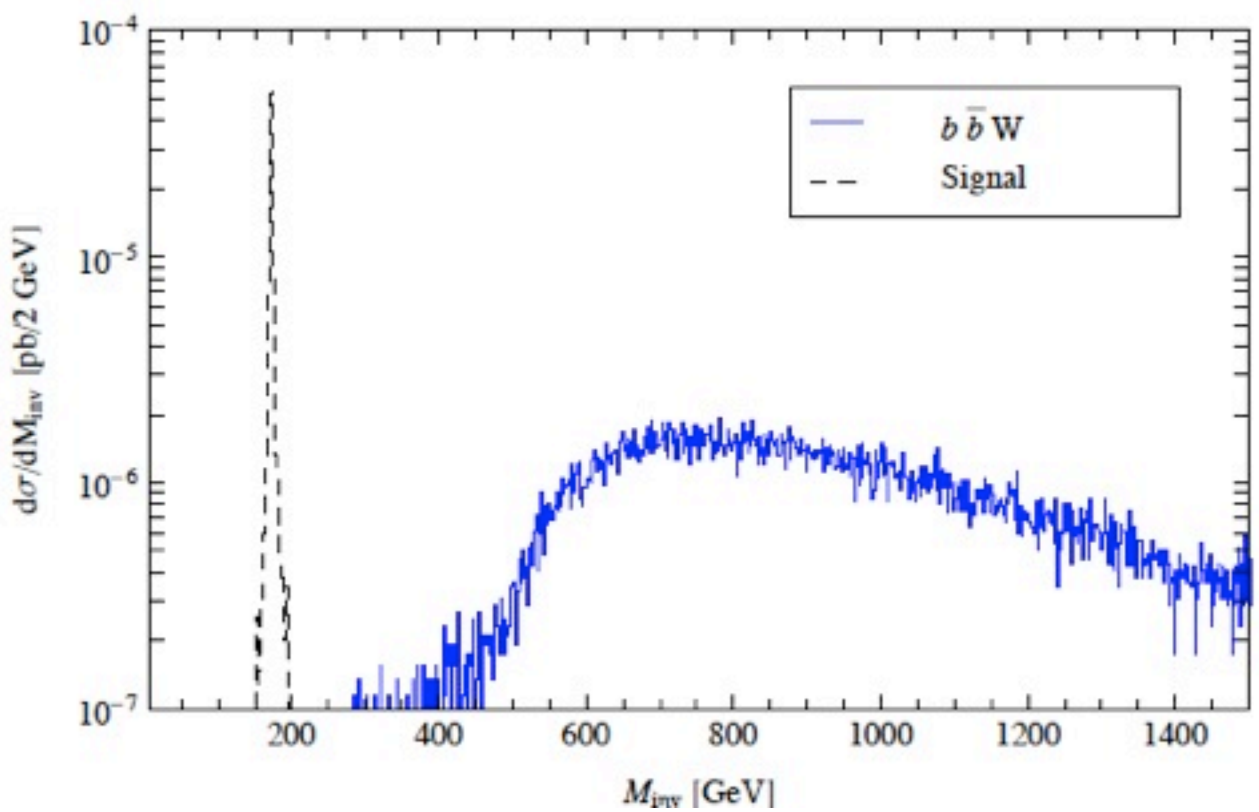
(b)

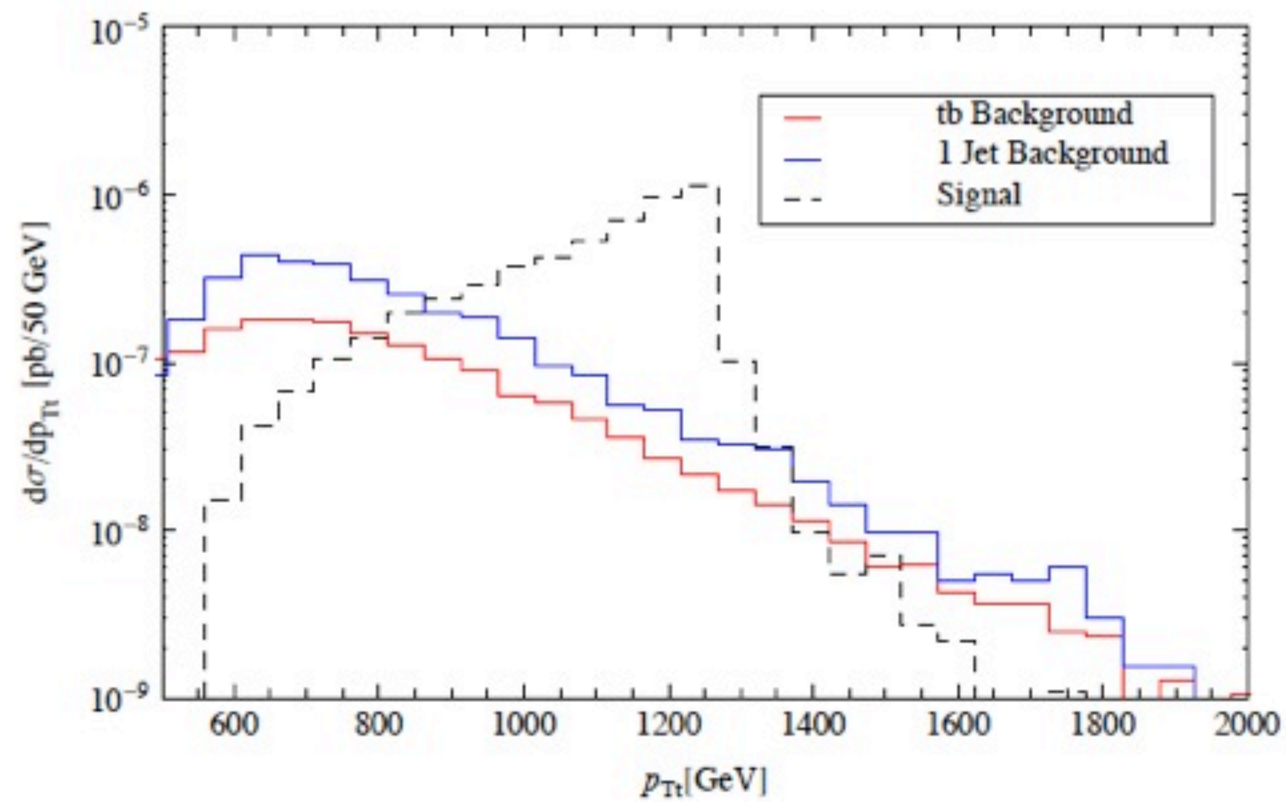

tb Background
$b\,\bar{b}$ W
Signal
$d\sigma/dp_{Tl}$ [pb/50 GeV]
p_{Tl}[GeV]

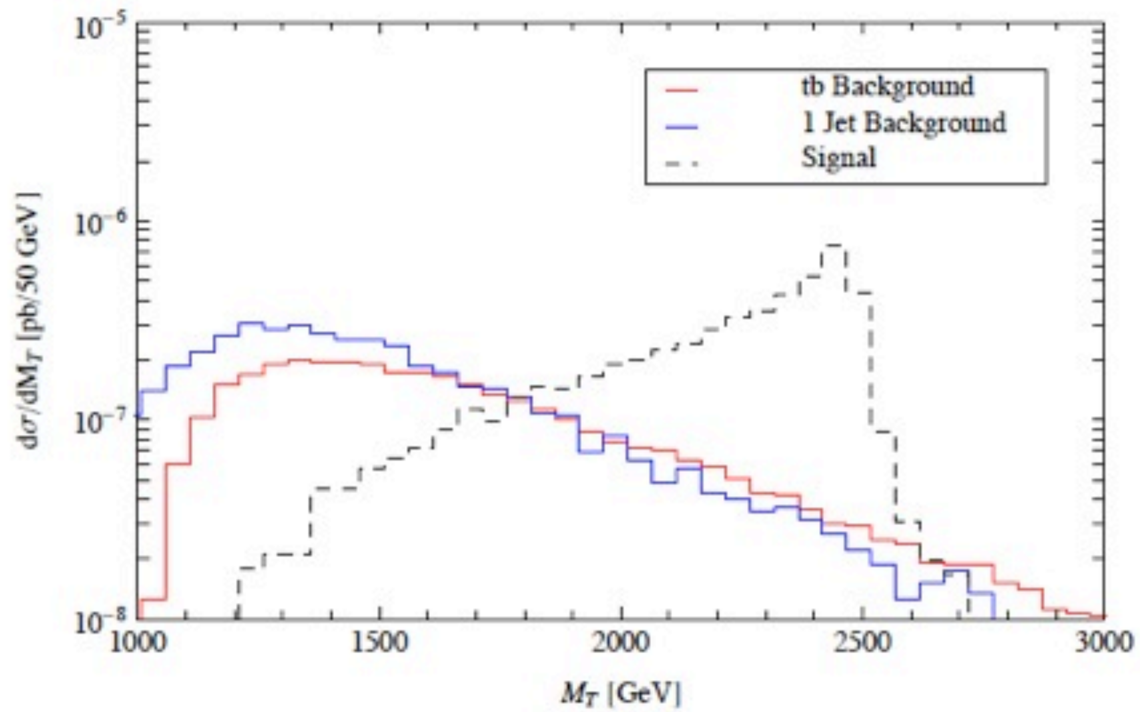

tb Background
$b\,\bar{b}$ W
Signal
$d\sigma$/dMET [pb/50 GeV]
MET [GeV]

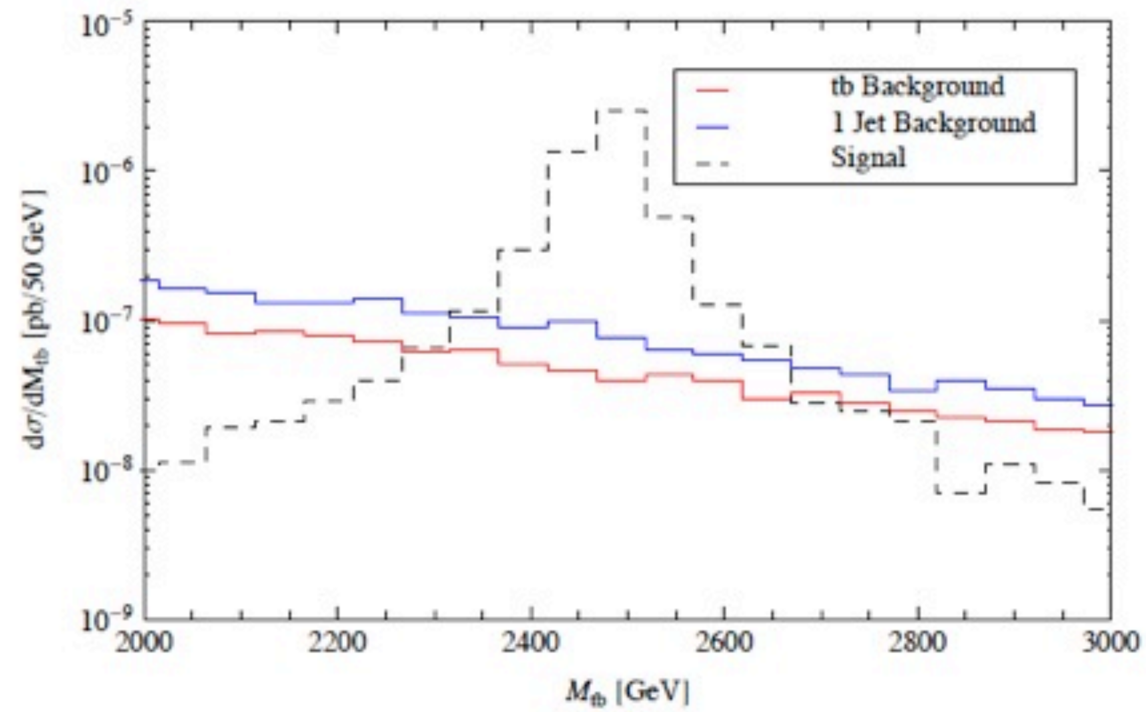

tb Background
$b\,\bar{b}$ W
Signal
$d\sigma/d\eta_{b_1}$ [pb]
η_{b_1}


tb Background
$b\,\bar{b}$ W
Signal
$d\sigma/d\eta_{b_2}$ [pb]
η_{b_2}


$b\,\bar{b}$ W
Signal
$d\sigma/dM_{inv}$ [pb/2 GeV]
M_{inv} [GeV]


tb Background
1 Jet Background
Signal
$d\sigma/dp_{Tt}$ [pb/50 GeV]
p_{Tt}[GeV]





We implement the following cuts:

$$p_{Tb} \geq 200\ \mathrm{GeV}$$
$$p_{T\ell} \geq 150\ \mathrm{GeV}$$
$$\mathrm{MET} \geq 150\ \mathrm{GeV}$$
$$|\eta_b| \leq 3.0$$

14 TeV	Basic		p_{Tt} [GeV] $\in [800, 1400]$		M_T [GeV] $\in [1800, 2500]$		M_{tb} [GeV] $\in [2400, 2700]$	
150 fb^{-1}	N_{Events}	$\frac{S}{\sqrt{B}}$	N_{Events}	$\frac{S}{\sqrt{B}}$	N_{Events}	$\frac{S}{\sqrt{B}}$	N_{Events}	$\frac{S}{\sqrt{B}}$
W_{KK}	40 (24) [14]	5.0 (3.9) [3.0]	38 (23) [13]	9.5 (7.7) [5.3]	34 (20) [12]	9.4 (7.1) [6]	36 (22) [13]	16.1 (12.7) [13]
SM	63 (37) [22]		16 (9) [6]		13 (8) [4]		5 (3) [1]	

(b-tagging) [double b-tagging]

- Events and significance.

- In this talk a class of warped models without custodial symmetry have been introduced.
- The couplings of KK modes to SM fields is weak enough that EWPO allow for O(TeV) masses.
- By the same token production of KK modes will also be reduced.
- KK gluons may be discover in LHC_8 whereas W KK modes need more energy and luminosity.