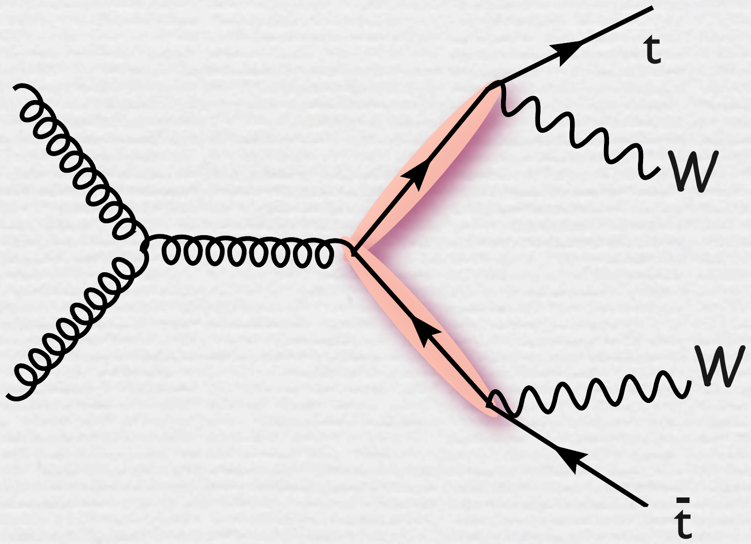
Discovering the top partners at the LHC in same-sign dilepton channel



Roberto CONTINO & Géraldine SERVANT (CERN-TH)

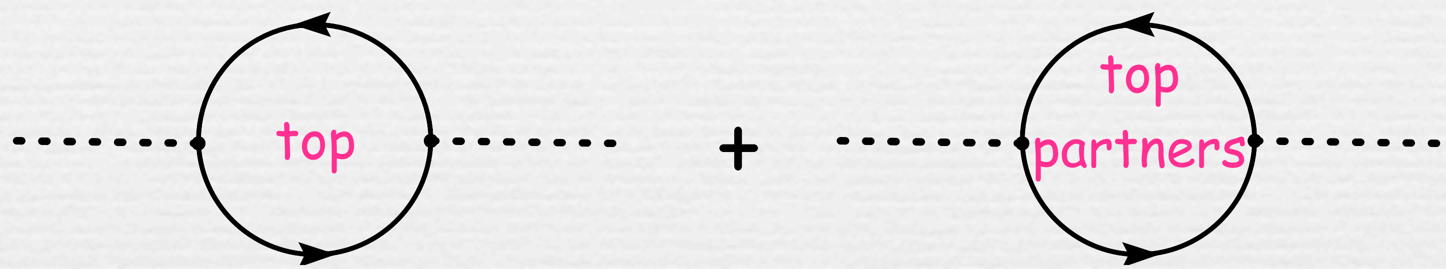
arXiv:0801.1679 [hep-ph]

An alternative to SUSY for solving the UV sensitivity of the Higgs sector

SUSY solution

= finite

Higgs as PGB solution



= finite

The Higgs is the Goldstone Boson of a spontaneously broken global symmetry

e.g. little higgs models

Particularly motivated is the case in which the EWSB sector is strongly interacting (no need of fondamental scalar)

The Higgs is a bound state of the fundamental constituents (Composite Higgs Models)

[Georgi & Kaplan, '80s]

Dual description in terms of higher-dimensional theories

strong sector → warped extra dimension

→ UV completion

→ flavor addressed

resonances of the strong sector (heavy top partners) → Kaluza-Klein excitations

Constraints on the strong sector from LEP precision tests

LEP bound $\Delta\rho \lesssim 2 \times 10^{-3}$ → $\boxed{\text{custodial symmetry}}$ $SU(2)_L \times SU(2)_R \to SU(2)_C$
[Sikivie et al. NPB 173 (1980) 189]

LEP bound $\delta g_{Lb}/|g_{Lb}^{SM}| \lesssim 0.25\%$ → $\boxed{\text{custodial parity}}$ [Agashe, DaRold, R.C., Pomarol PLB 641 (2006) 62]

• **Heavy partners of (t_L , b_L) will form a $(2,2)_{2/3}$** [under $SU(2)_L \times SU(2)_R \times U(1)_X$]

Composite (EW symm. break.) sector:

[mass mixing terms between the 2 sectors]

SM sector:

- $(Q, Q') = (\mathbf{2}, \mathbf{2})_{2/3}$ $\quad Q = \begin{bmatrix} T \\ B \end{bmatrix}$

(t_L ,b_L)

t_R

electric charge +5/3

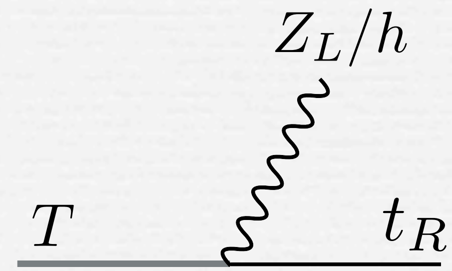
$Q' = \begin{bmatrix} T_{5/3} \\ T_{2/3} \end{bmatrix}$ $\boxed{\to \text{“custodian”}}$

- $(\mathbf{1}, \mathbf{1})_{2/3} = \tilde{T}$

- $\mathcal{H} = (\mathbf{2}, \mathbf{2})_0 = \begin{bmatrix} \phi_0^\dagger & \phi^+ \\ -\phi^- & \phi_0 \end{bmatrix}$

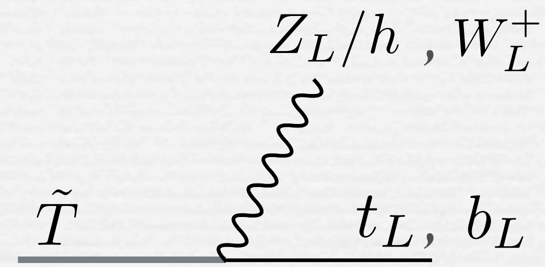
$$Y_* \, \mathrm{Tr}\{\bar{\mathcal{Q}}\, \mathcal{H}\}\, \tilde{T} + h.c$$

These new fermions couple strongly to the 3rd generation SM quarks plus one W_L , Z_L or h



FCNC : absent for a 4th generation !

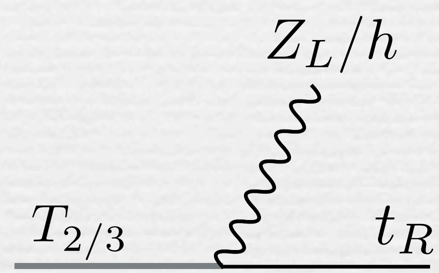
$Y_* \cos\varphi_L \sin\varphi_R$



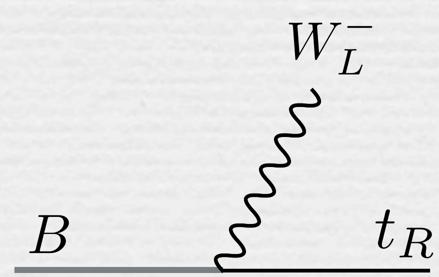
$Y_* \sin\varphi_L \cos\varphi_R$

$$Y_* \,\mathrm{Tr}\{\bar{\mathcal{Q}}\,\mathcal{H}\}\,\tilde{T} + h.c$$

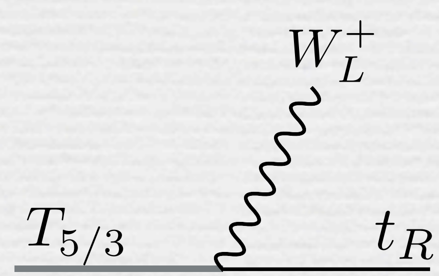
after rotating to mass eigen state basis



$Y_* \sin\varphi_R$



$Y_* \cos\varphi_L \sin\varphi_R$



$Y_* \sin\varphi_R$

Production of the heavy top ($\tilde{T}$, T, $T_{2/3}$) has been studied in the literature

Azuelos et al. Eur.Phys.J. C39S2 (2005) 13 [hep-ph/0402037]

- Single production via bW fusion → best channel: $\tilde{T} \to W^+ b \to l^+ \nu b$

LHC reach with L=300 fb^{-1} : M=2 TeV for λ_T = 1

Azuelos et al. Eur.Phys.J. C39S2 (2005) 13 [hep-ph/0402037]

- Pair production → best channels: $\tilde{T}\bar{\tilde{T}} \to \begin{cases} W^+ b\, W^- \bar{b} \\ W^+ b\, h \bar{t} \\ W^+ b\, Z \bar{t} \end{cases} \to$ final states with 1 charged lepton

L_{disc} =2 (90) fb^{-1} for M=0.5 (1)TeV

J.A. Aguilar-Saavedra PoS TOP2006:003,2006 [hep-ph/0603199] and refs. therein

Production of the heavy bottom (B) studied only recently

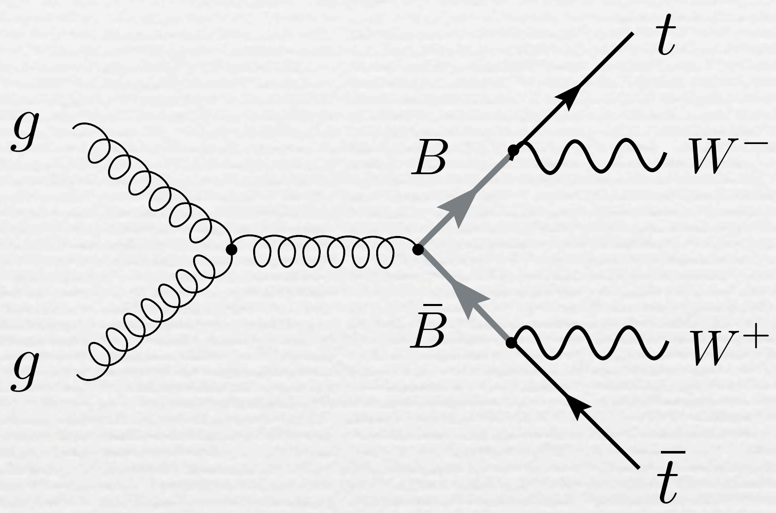
Note:

No direct bound on M_B from Tevatron (no searches for B→tW)

CDF bound on heavy bottom quarks b′, $M_{b'}$ >268 GeV, assumes b′ decays exclusively to bZ

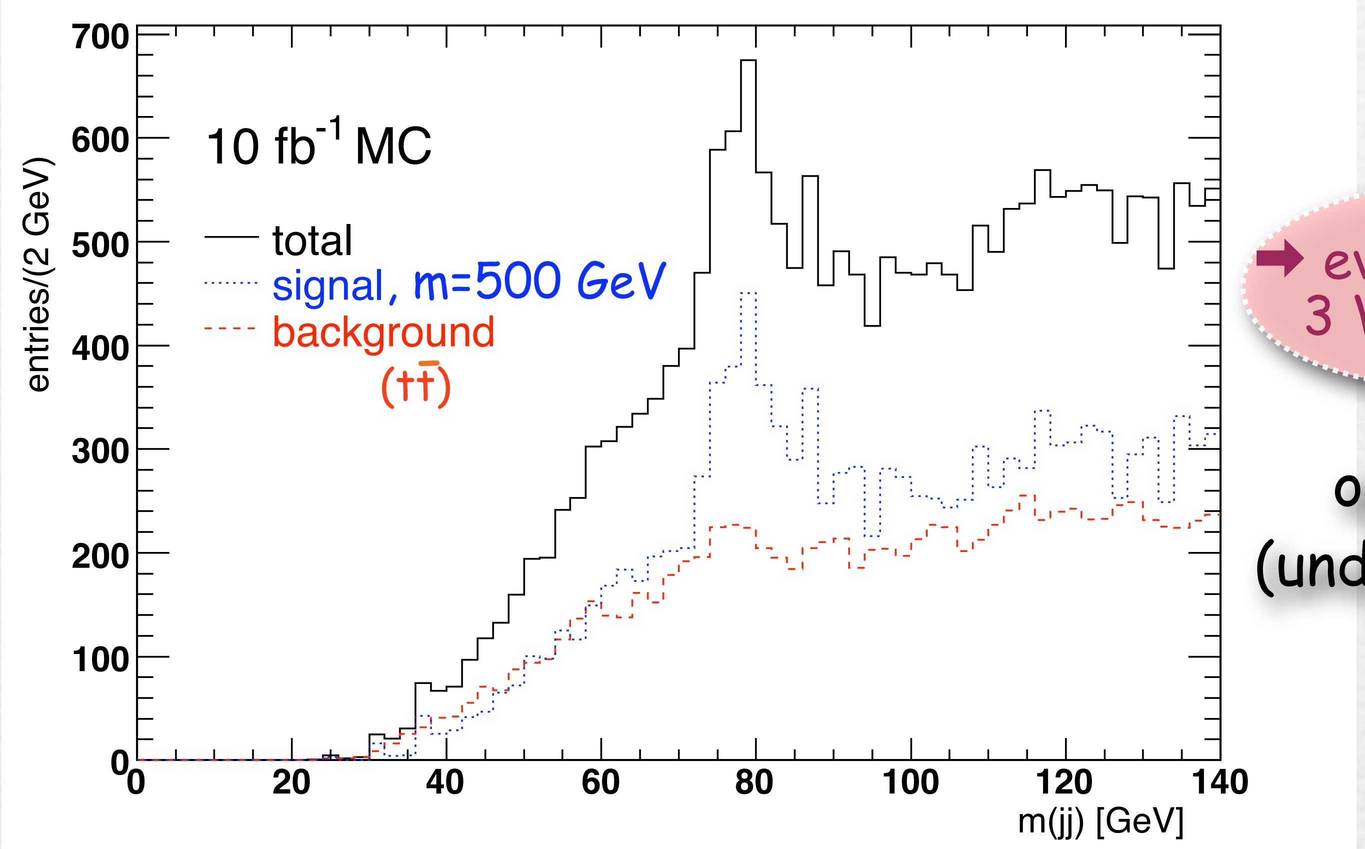
Triggering on one lepton

- Dennis, Karagoz Unel, Tseng & Servant, hep-ph/0701158



hard cut on the total effective mass needed

Dijet mass distribution after eliminating one hadronic W



➜ evidence for 3 W events

optimistic (under revision)

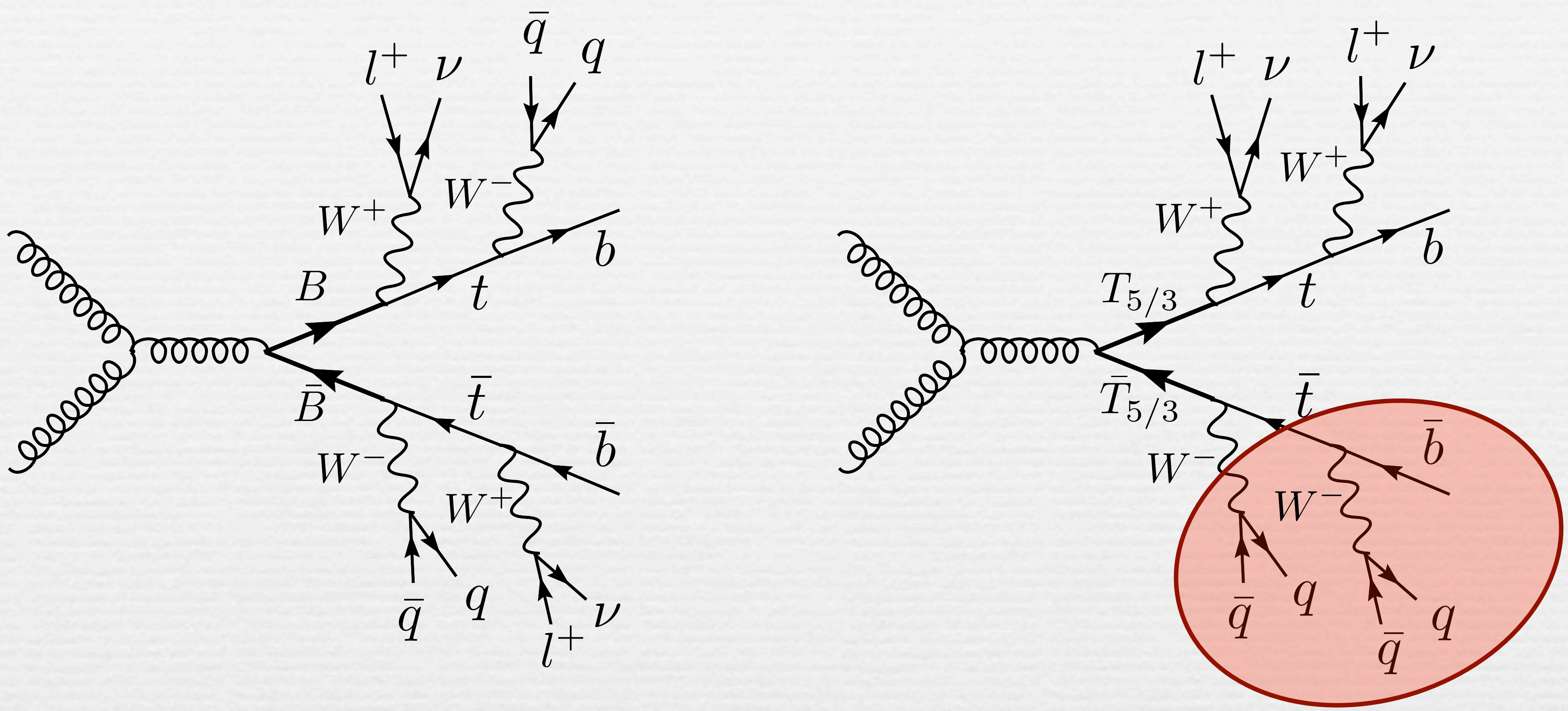
Searches for multi W events in $l^{\pm} + jets + \not{E}_T$ channel suffer from $t\bar{t} + jets$ background

- Skiba, Tucker-Smith, hep-ph/0701247

additional strategy: look for highly boosted top and W and cut on single jet invariant mass

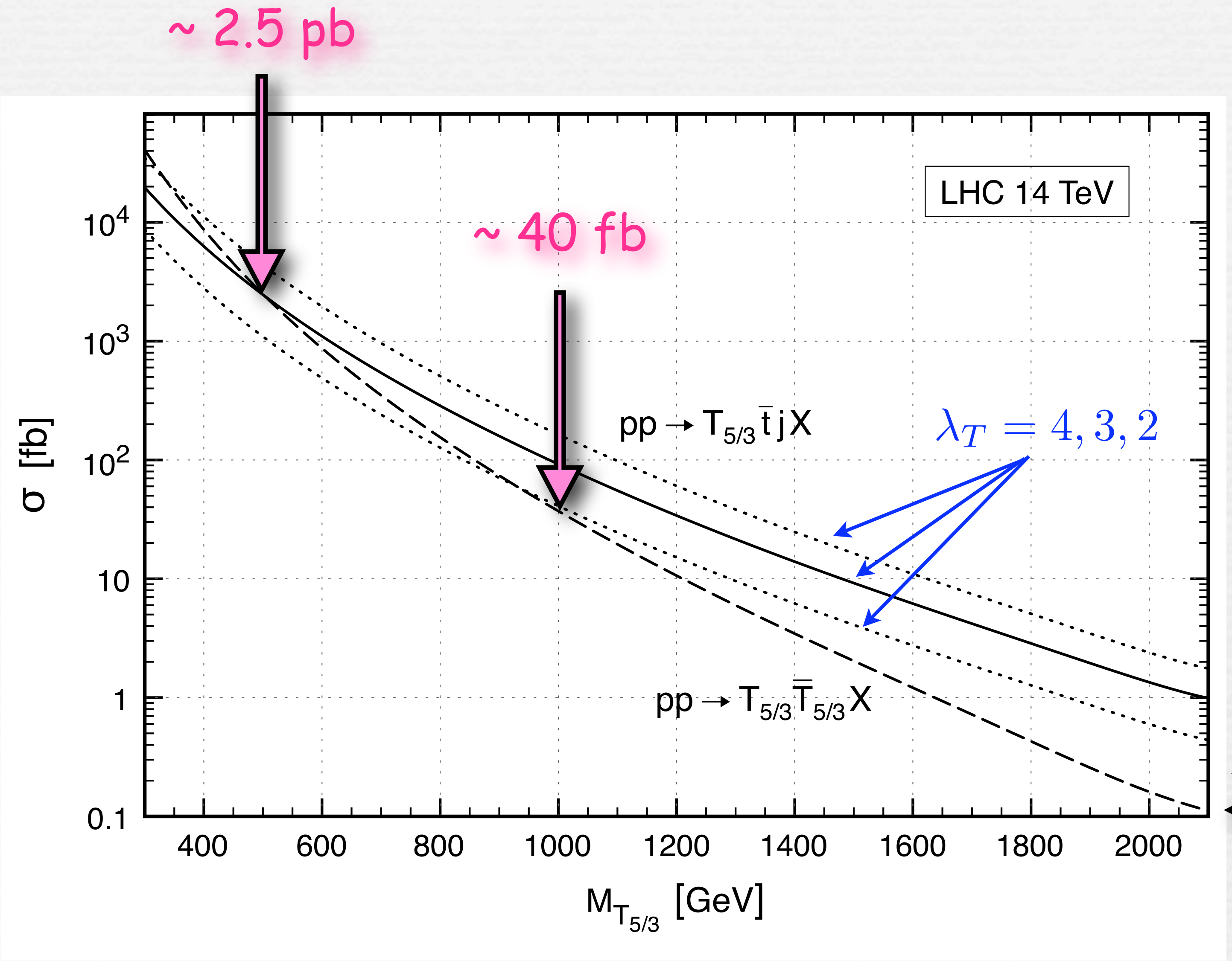
- works only for heavy masses $M_B \gtrsim 1$ TeV
- results depend on the jet energy algorithm used

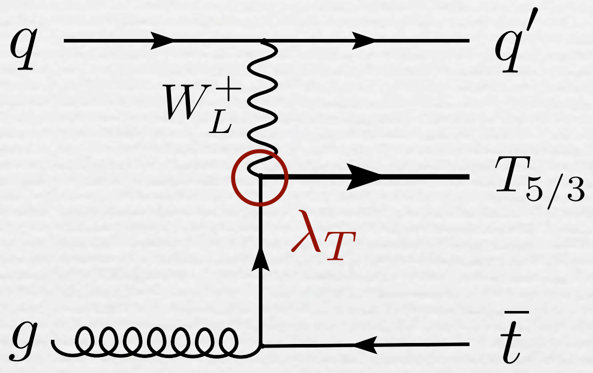
Look for $B\bar{B}$ and $T_{5/3}\ \bar{T}_{5/3}$ in same-sign dilepton final states



- ✔ $t\bar{t} + jets$ is not a background anymore [except for charge mis-ID]
- ✔ For the $T_{5/3}$ case one can reconstruct the resonant (tW) invariant mass

Single versus pair-production





Single production

Pair production proceeds via the usual QCD coupling

Signal & background simulation (final state: $\ell^\pm \ell^\pm$ + *n jets* + $\not{E}_T$)

	σ [fb]	$\sigma \times BR(l^\pm l^\pm)$ [fb]
$T_{5/3}\overline{T}_{5/3}/B\overline{B} + jets \quad (M = 500 \text{ GeV})$	2.5×10^3	104
$T_{5/3}\overline{T}_{5/3}/B\overline{B} + jets \quad (M = 1 \text{ TeV})$	37	1.6
$t\bar{t}W^+W^- + jets \quad (\supset t\bar{t}h + jets)$	121	5.1
$t\bar{t}W^\pm + jets$	595	18.4
$W^+W^-W^\pm + jets \ (\supset hW^\pm + jets)$	603	18.7
$W^\pm W^\pm + jets$	340	15.5

M_h = 180 GeV

Signal and SM background have been simulated using:

- MadGraph/MadEvent [MatrixElement] + Pythia [Showering - no hadronization or underlying event]
- Parton/Jet matching performed following MLM prescription
- Jets reconstructed with a cone algorithm (GetJet) with $\Delta R = 0.4\ ,\ E_T^{min} = 30\,\text{GeV}$
- Jet energy and momentum smeared by $\frac{100\ \%}{\sqrt{E}}$ to simulate the detector resolution

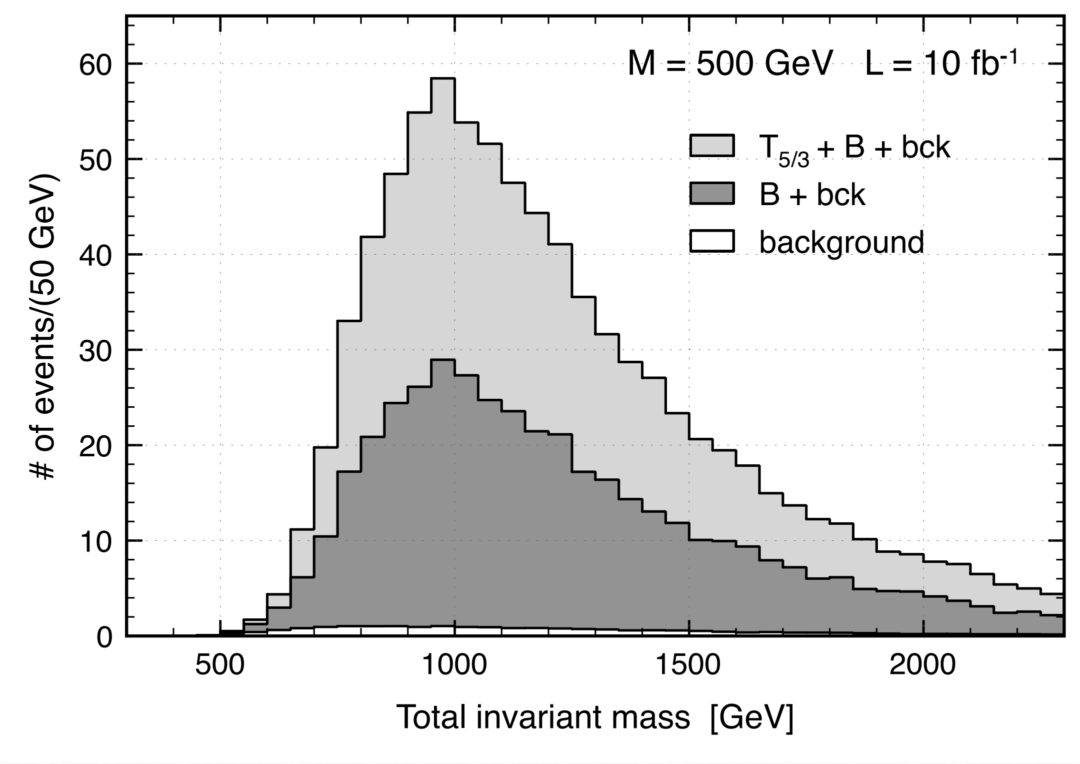
1-Discovery

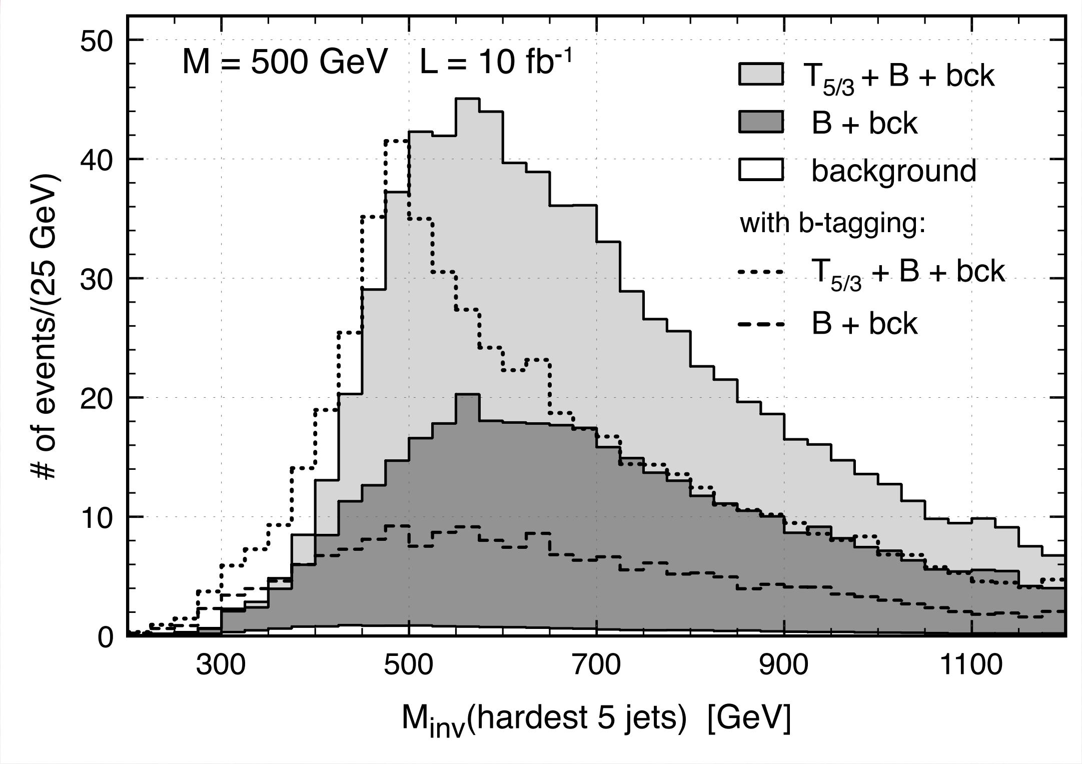
M=500 GeV

Main Cuts:

$l^\pm l^\pm + n\ jets + \not{E}_T \ \ (n \geq 5)$ p$_T$ (any jet) ≥ 30 GeV

$\underline{\text{jets}}: \begin{cases} p_T(1\text{st}) \geq 100 \text{ GeV} \\ p_T(2\text{nd}) \geq 80 \text{ GeV} \\ n_{jet} \geq 5, \quad |\eta_j| \leq 5 \end{cases}$ $\underline{\text{leptons}}: \begin{cases} p_T(1\text{st}) \geq 50 \text{ GeV} \\ p_T(2\text{nd}) \geq 25 \text{ GeV} \\ |\eta_l| \leq 2.4\,, \quad \Delta R_{lj} \geq 0.4 \end{cases}$ $\not{E}_T \geq 20 \text{ GeV}$





-> resonant production at ~ 2M

-> resonance at ~ M

dotted and dashed curves: M$_{inv}$ (hardest 4 jets+b-jet)

almost background free environment !

Discovery potential

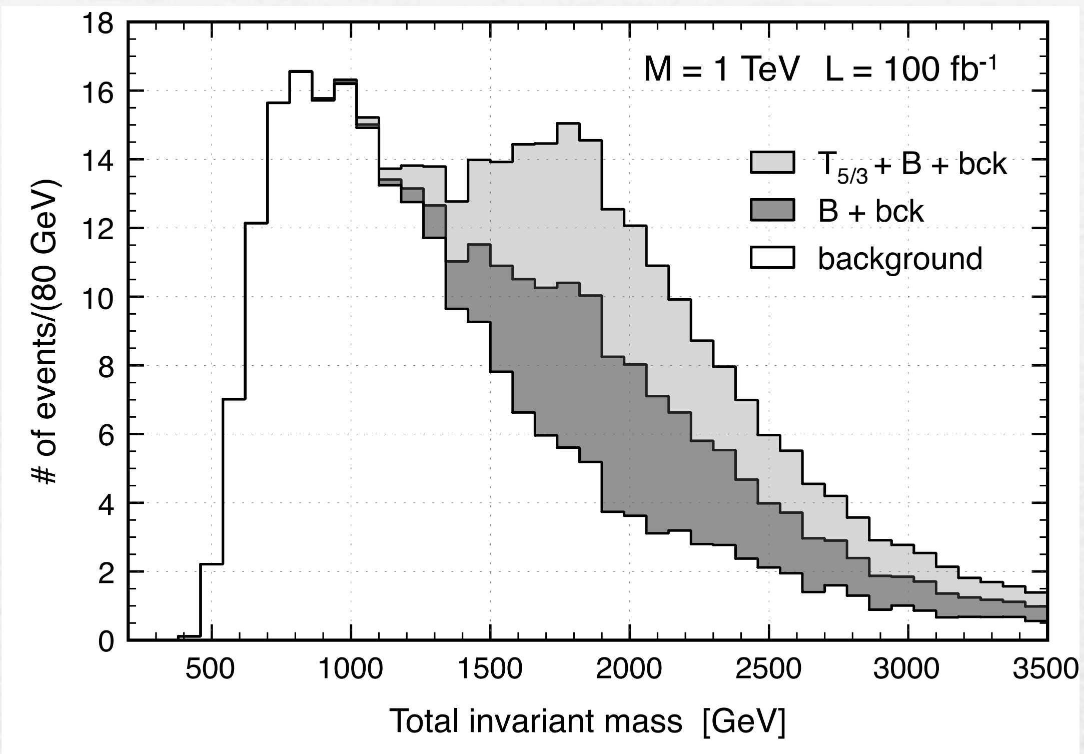
$T_{5/3}$ + B : L$_{disc}$ ≈ 60 pb^{-1}

B only : L$_{disc}$ ≈ 150 pb^{-1}

further confirmation of $T_{5/3}$ pair-production with approximate edge in transverse mass distribution of (llννj)

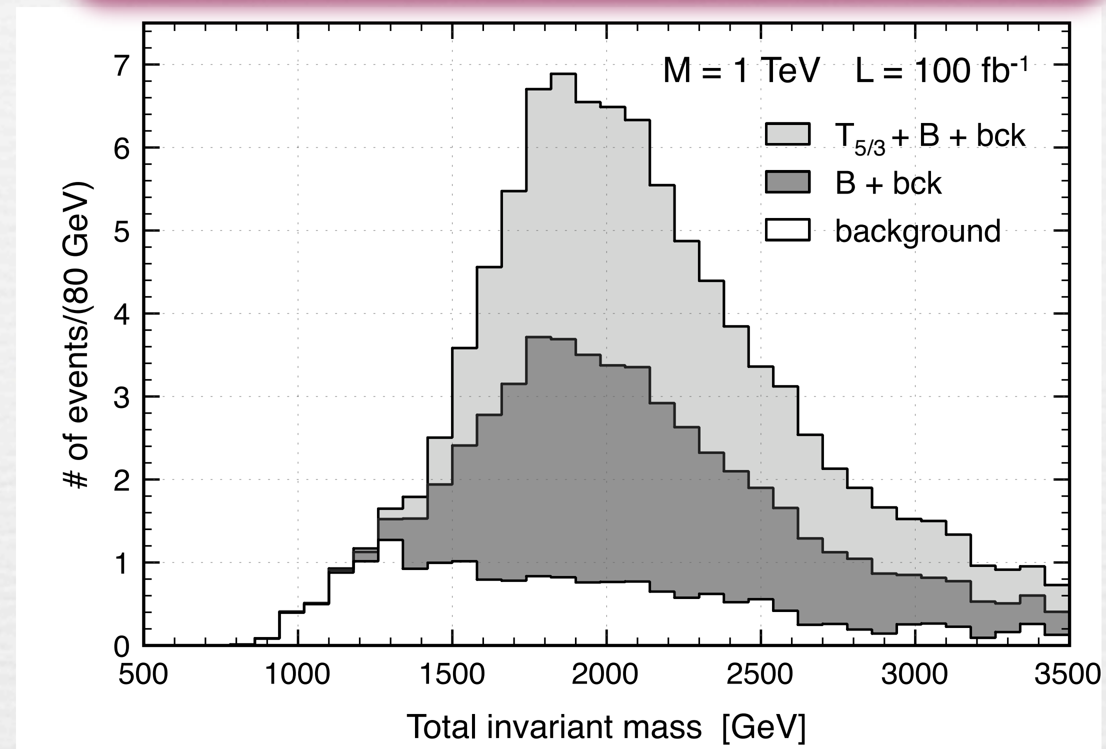
M = 1 TeV

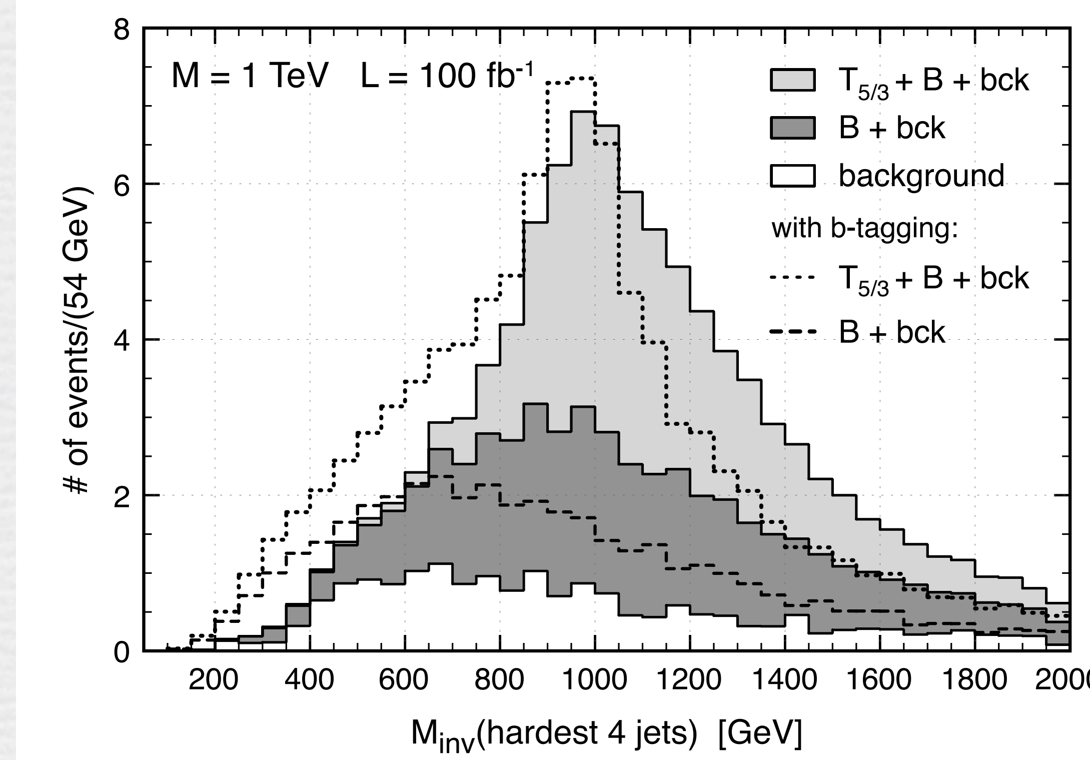
with same cut as before:



with extra cut:

p_T (1st jet) ≥ 200 GeV , $\sum_{i=1,2} |\vec{p}_T(l_i)| \geq 300\,\mathrm{GeV}$





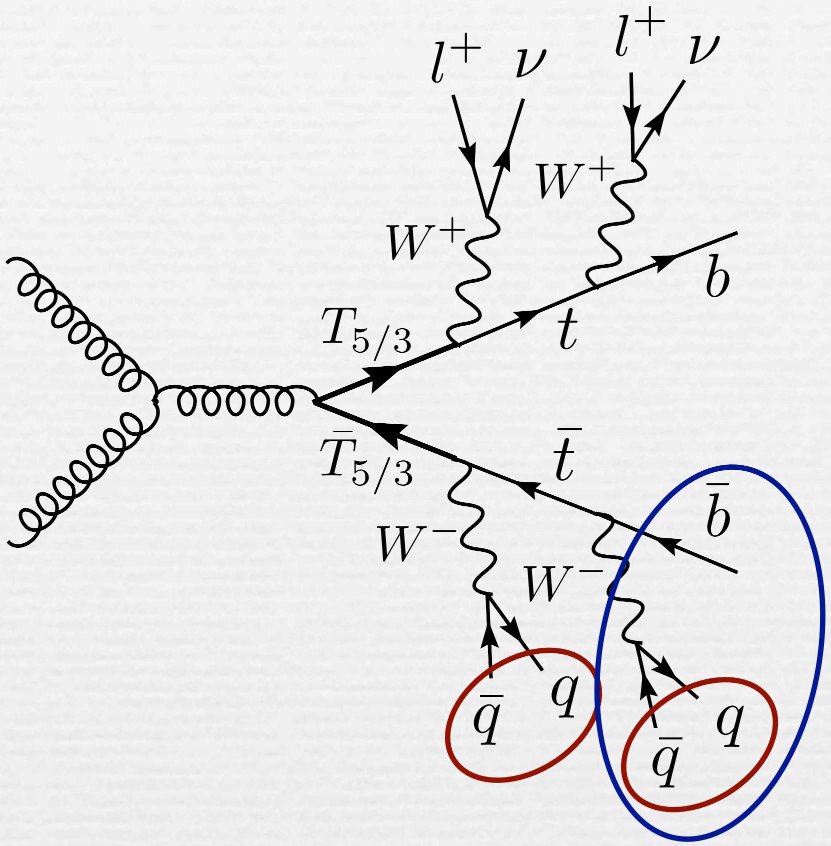
dotted and dashed curves:
M_{inv} (hardest 3 jets+b-jet)

Discovery potential

$T_{5/3}$ + B : $L_{disc} \approx 15\ \mathrm{fb}^{-1}$

B only : $L_{disc} \approx 50\ \mathrm{fb}^{-1}$

2-Mass reconstruction M=500 GeV



1. Reconstruct 2 W's

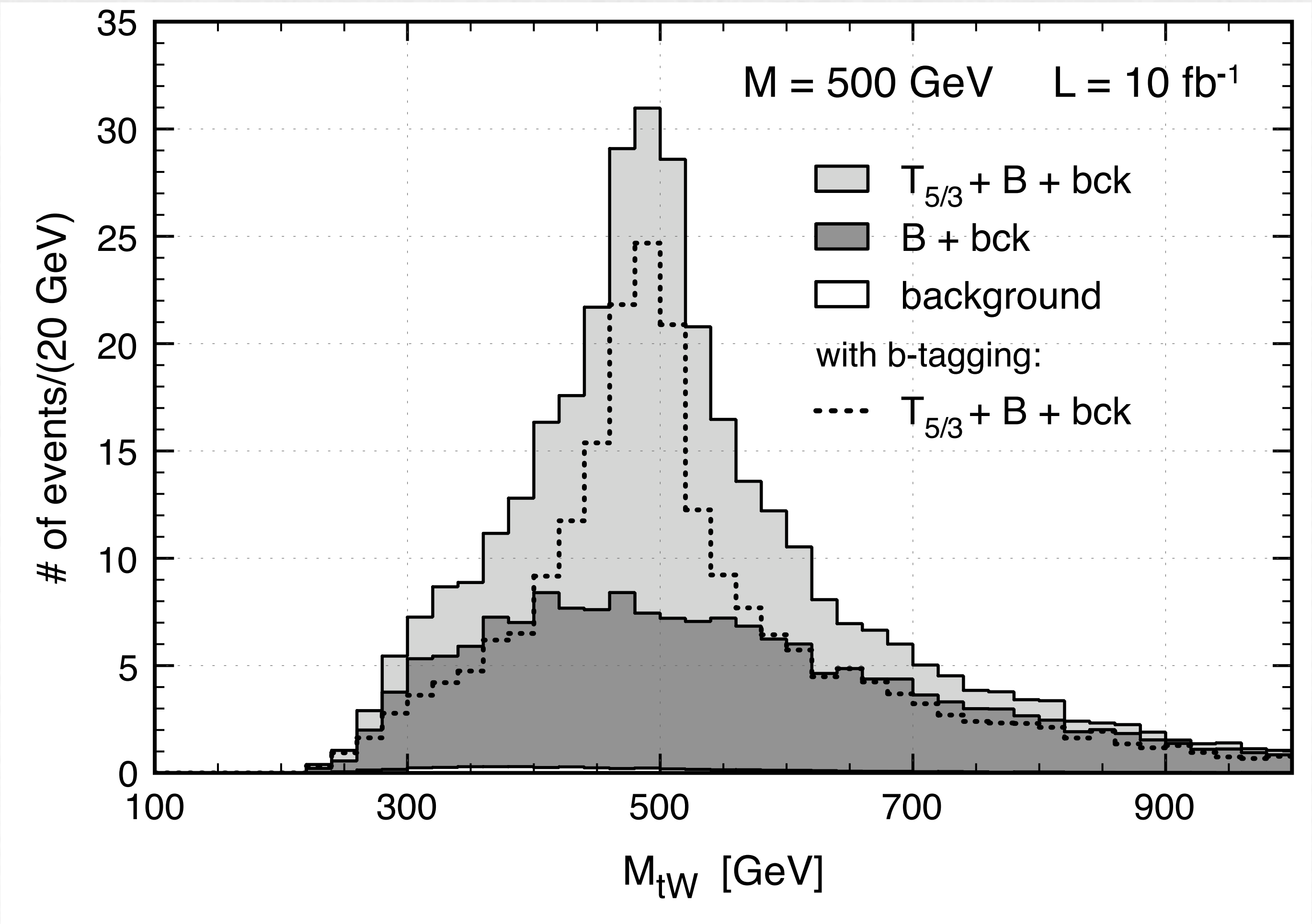
$$|M(jj) - m_W| \leq 20 \text{ GeV}$$

$$\Delta R_{jj}(\text{1st pair}) \leq 1.5$$
$$|\vec{p}_T(\text{1st pair})| \geq 100 \text{ GeV}$$

$$\Delta R_{jj}(\text{2nd pair}) \leq 2.0$$
$$|\vec{p}_T(\text{2nd pair})| \geq 30 \text{ GeV}$$

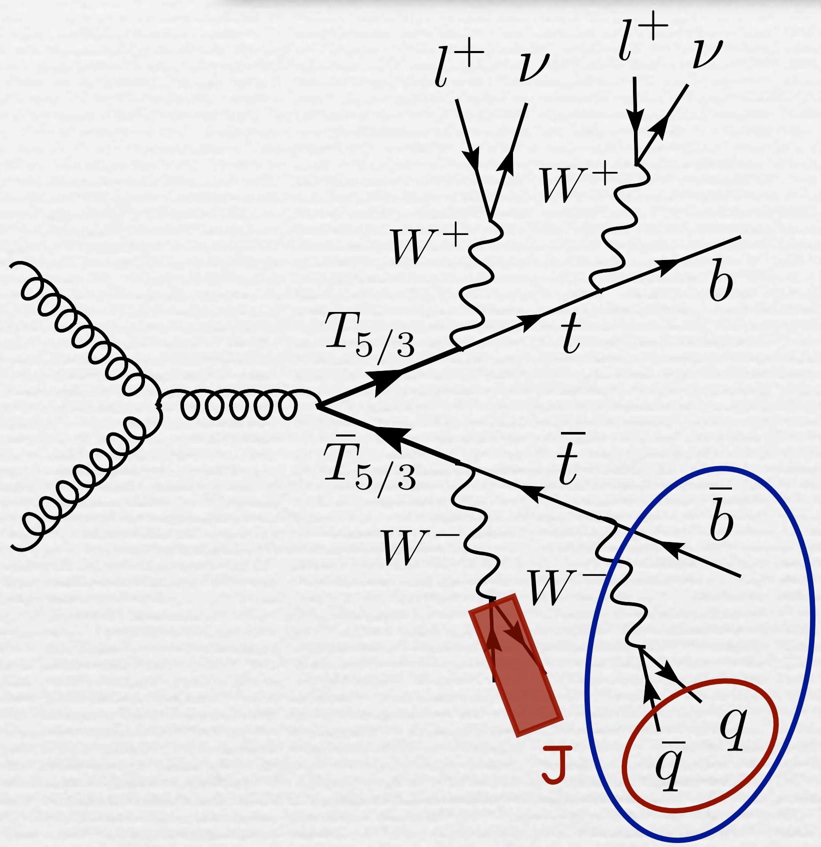
2. Reconstruct 1 top (t=Wj)

$$|M(Wj) - m_t| \leq 25 \text{ GeV}$$



Mass reconstruction   M=1 TeV

Strategy modified since signal events often contain one double jet (a W jet)



1. Reconstruct 1 or 2 W's

$$|M(jj) - m_W| \leq 20 \text{ GeV}$$

$$\Delta R_{jj}(\text{1st pair}) \leq 0.7$$
$$|\vec{p}_T(\text{1st pair})| \geq 250 \text{ GeV}$$

$$\Delta R_{jj}(\text{2nd pair}) \leq 1.5$$
$$|\vec{p}_T(\text{2nd pair})| \geq 80 \text{ GeV}$$

2. Reconstruct 1 top (t=Wj)

i) t=Wj using events with 2 W

ii) t=Wj using events with 1 W

iii) t=jj using events with 1 W

also replace extra "discovery" cuts by :

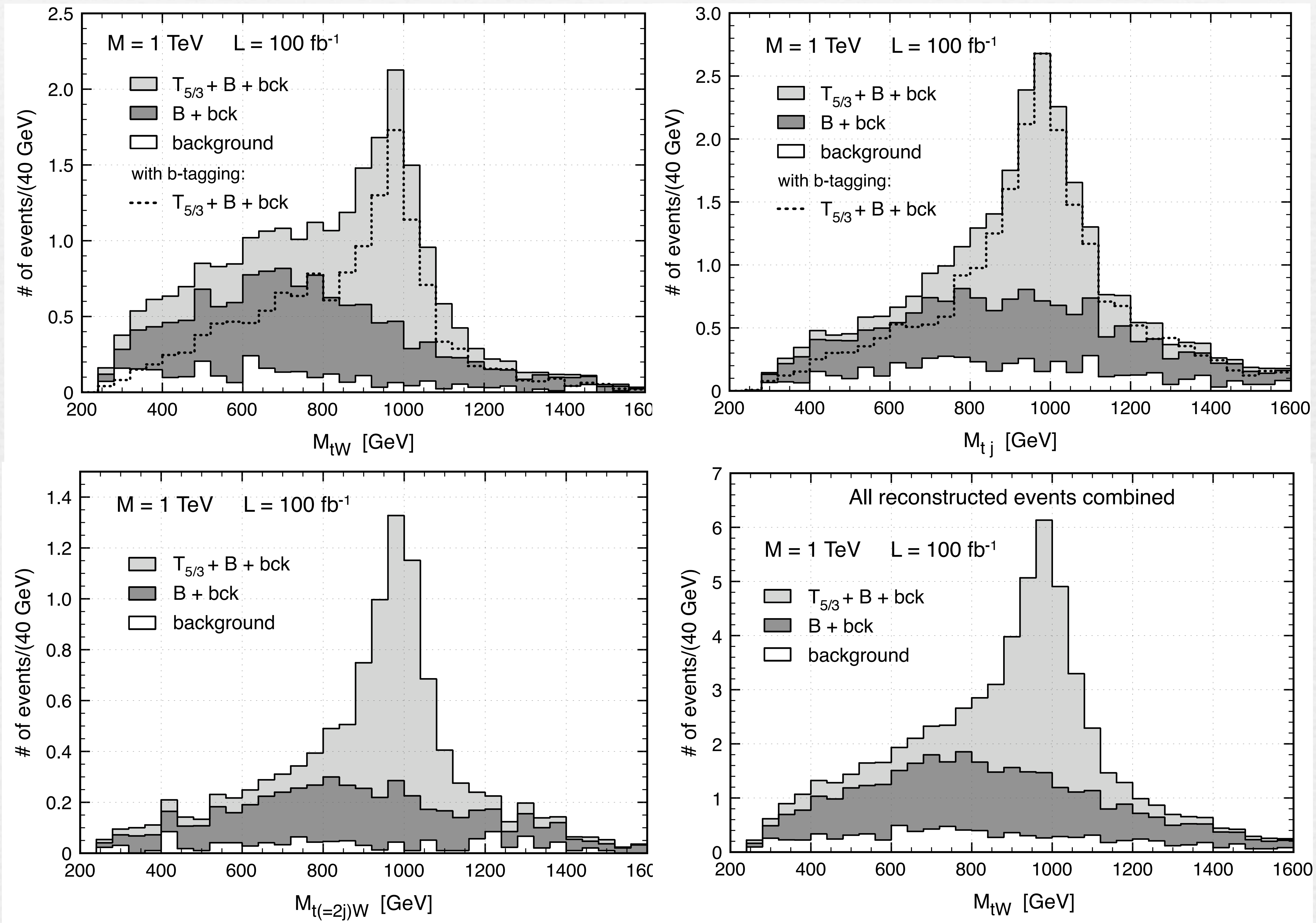
$$M_{inv}(\text{tot}) \geq 1500 \text{ GeV}$$

$$p_T(\text{1st jet}) \geq 200 \text{ GeV}$$
$$p_T(\text{2nd jet}) \geq 100 \text{ GeV}$$

$$p_T(\text{1st lepton}) \geq 100 \text{ GeV}$$

$T_{5/3}$ reconstruction for M=1 TeV

resonant peak seen for all three methods



Conclusion

→ Heavy partners of the top are a robust and well-motivated prediction of a large class of non-supersymmetric models

→ Same-sign dilepton final states are very promising not only for reconstructing the exotic $T_{5/3}$ but also for the discovery of the B

→ early discovery   less than ~ 100 pb^{-1} needed for discovery if M=500 GeV

→ Full ATLAS and CMS simulations underway

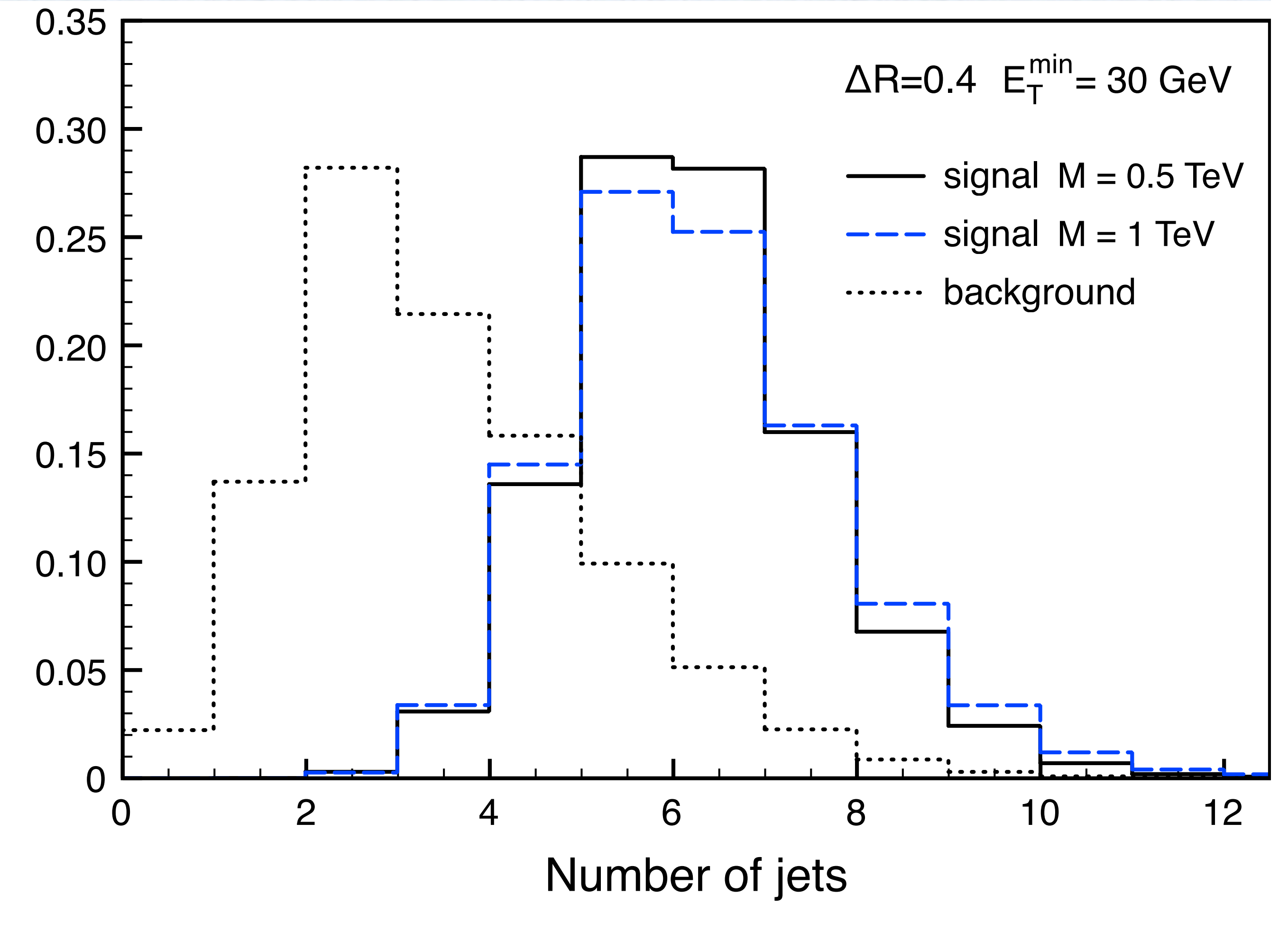
needed

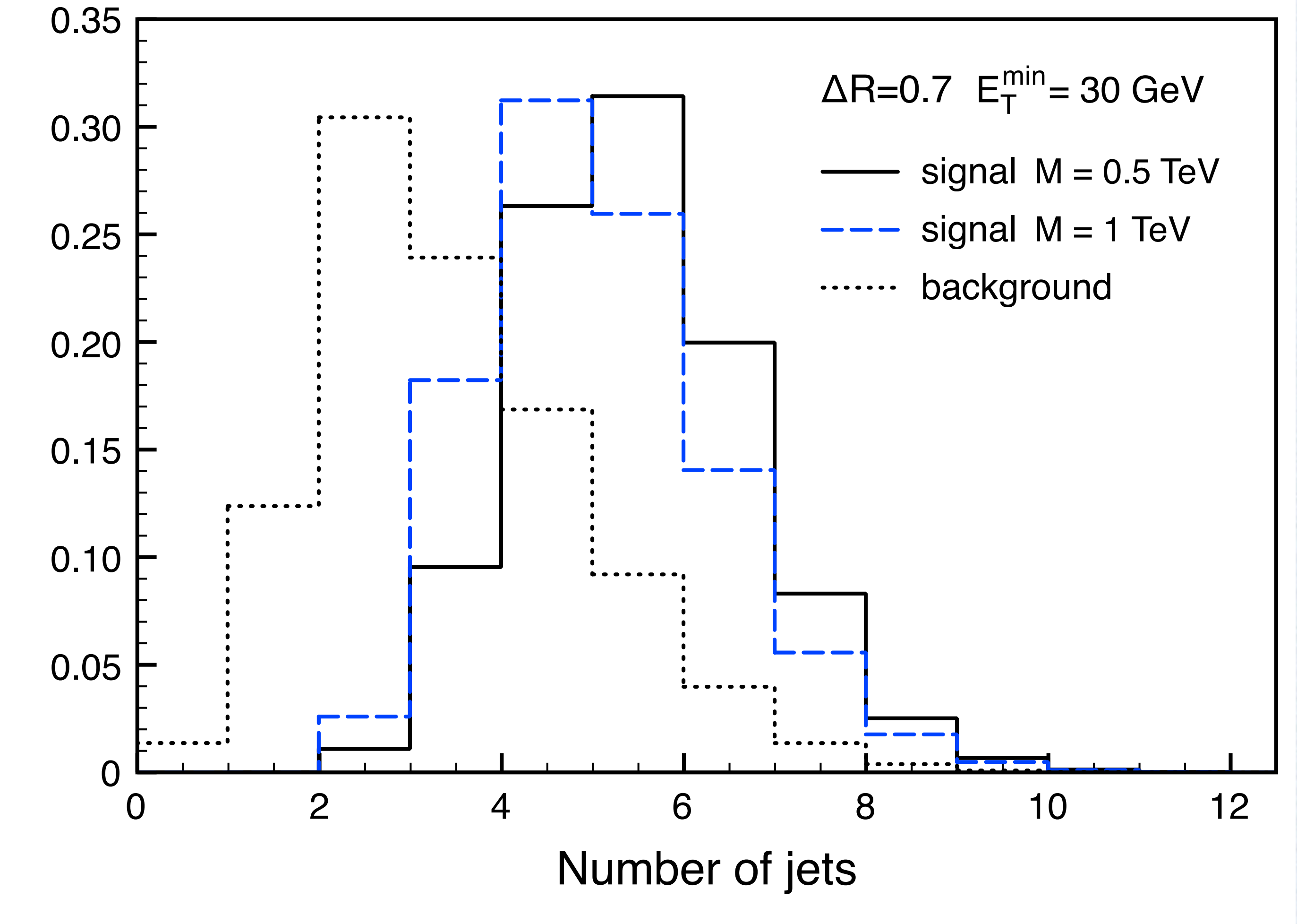
→ include $W\, l^+\, l^-$ + jets and $t\bar{t}$ + jets backgrounds

→ full reconstruction techniques

Annexes

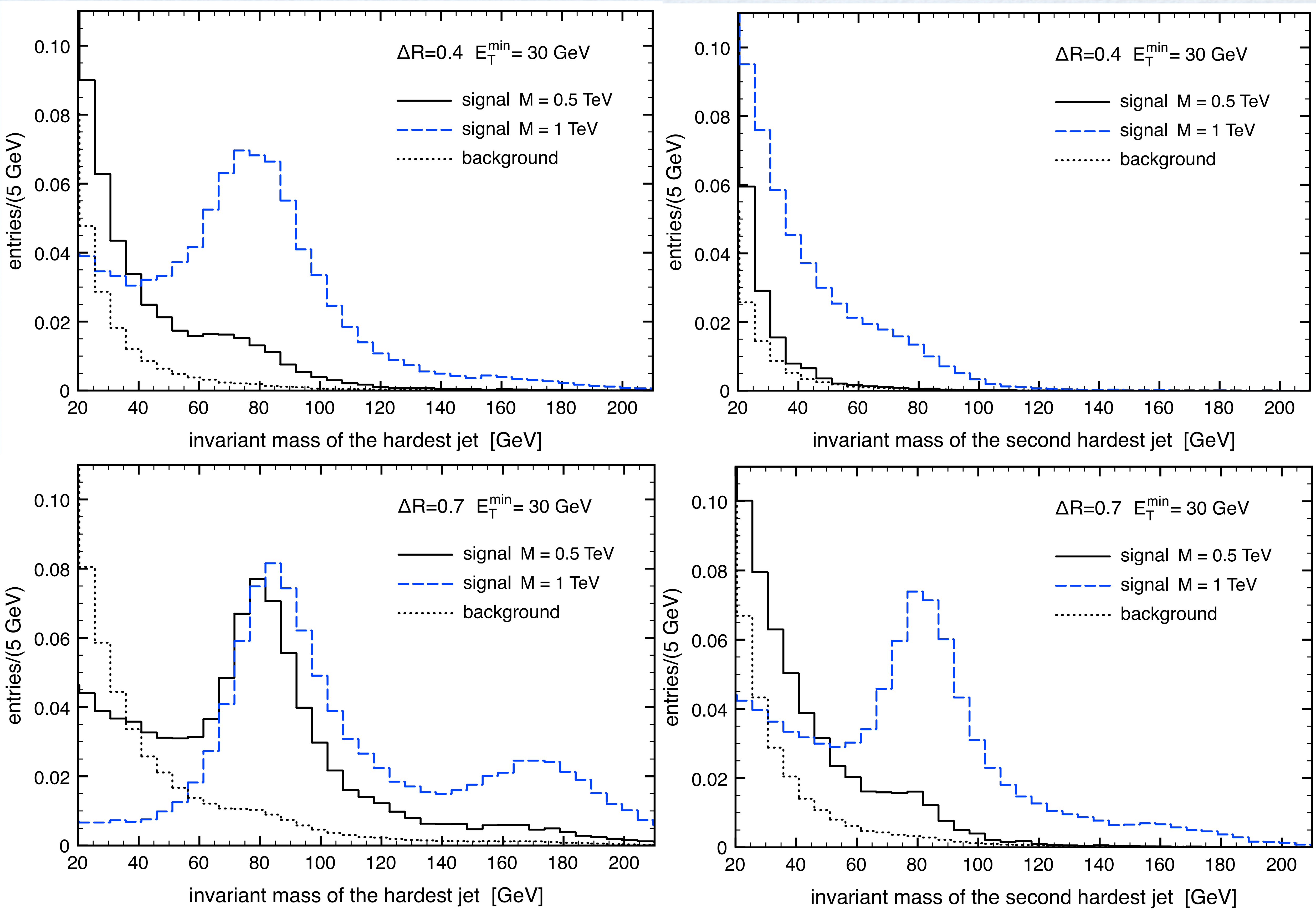
jets - with two different cone sizes



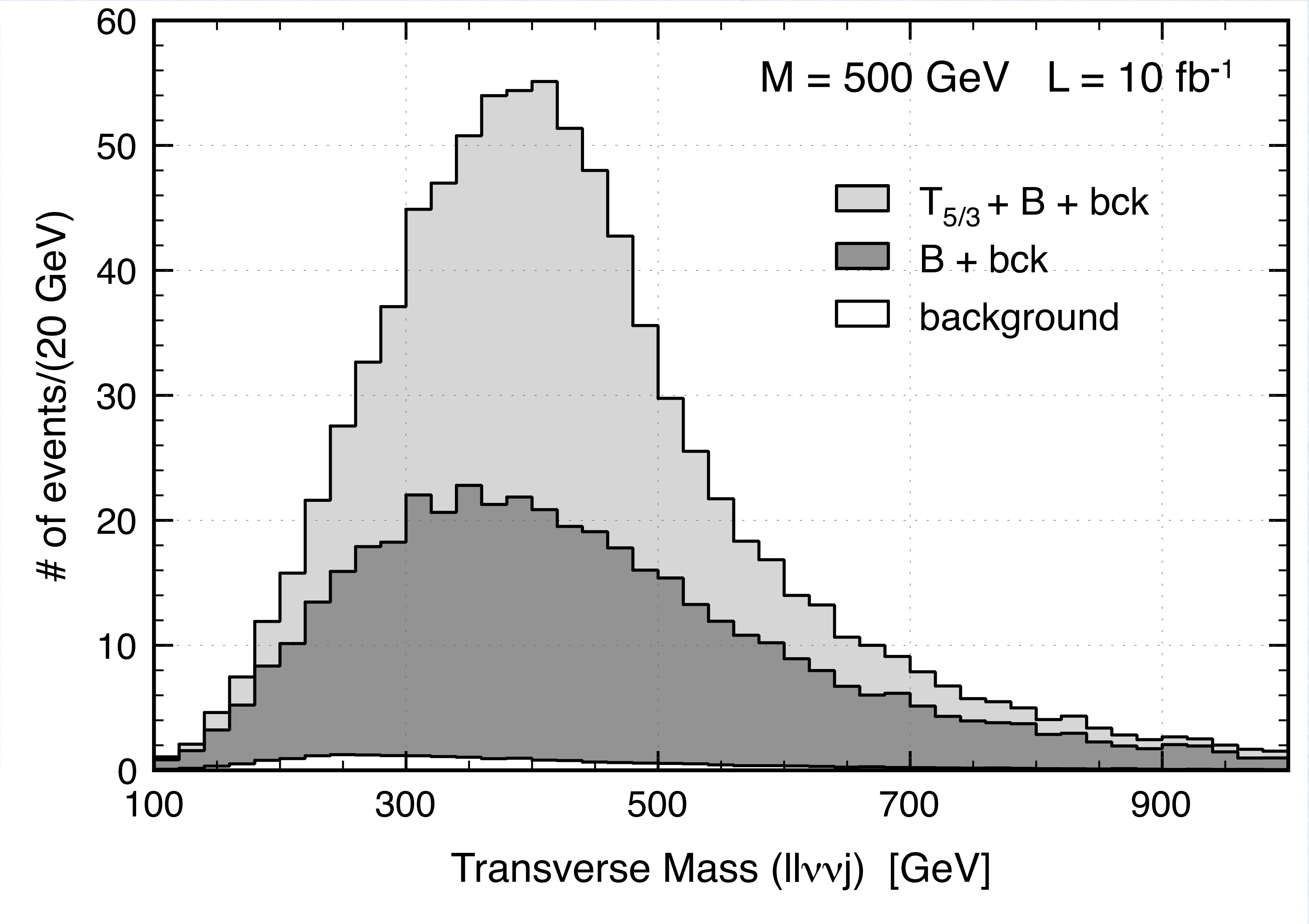


jet invariant mass

with two different cone sizes

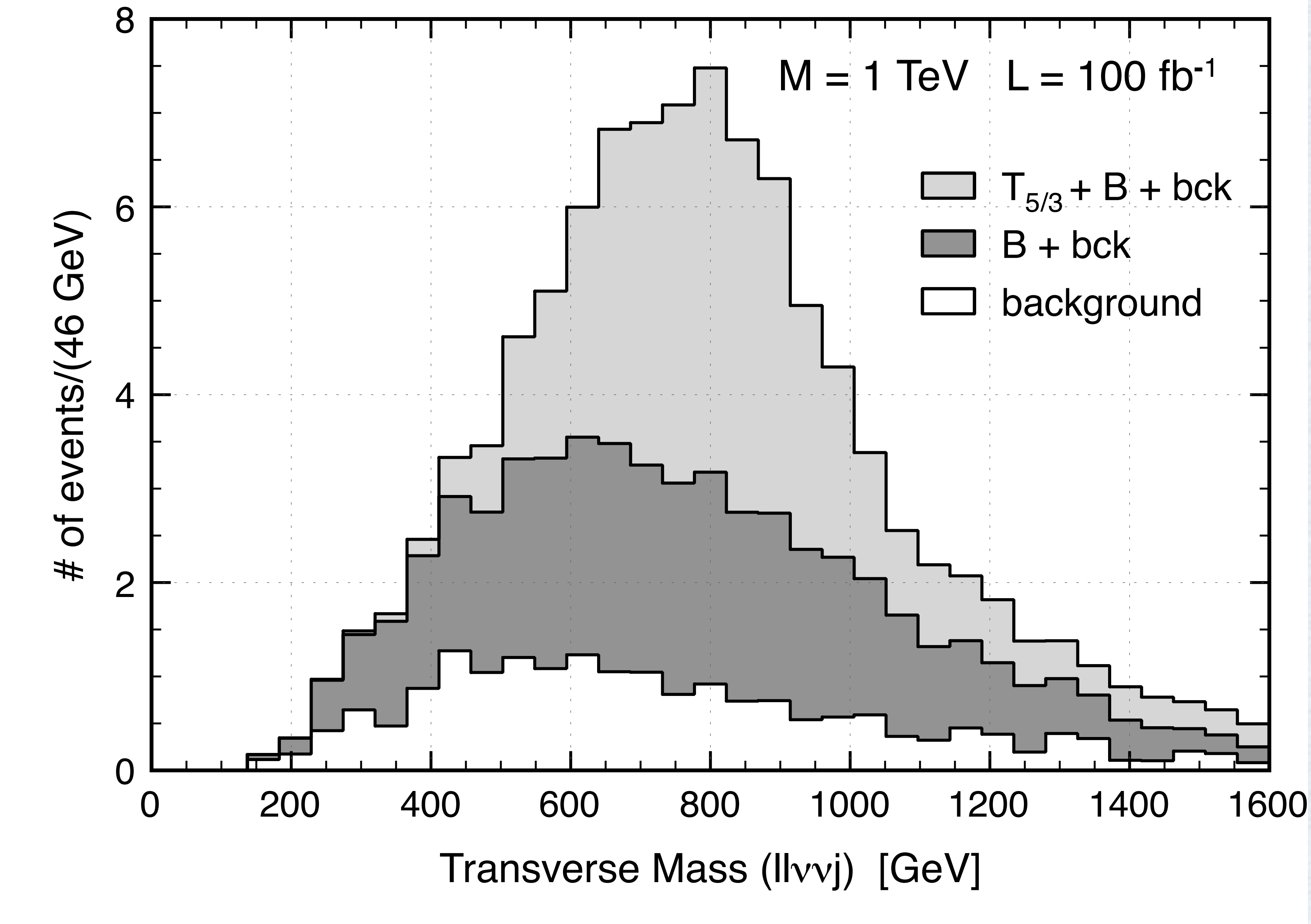


Transverse mass of the (llj) system



(llj) = same-sign leptons + jet closest to the softest lepton

Transverse mass of the (llj) system



(llj) = same-sign leptons + jet closest to the softest lepton