Probing Technivector Scenarios at the LHC

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+ work in progress

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Motivation:

- Strong EW-scale interactions are a possibility at the LHC...
- Very few DEWSB models studied;
  even fewer implemented in MC programs
- We would like a more general structure than rescaled QCD/Higgsless
  - new spectrum
  - new interactions?
  - better agreement with precision measurements?

and we want to implement it into MC programs

Motivation:

- Strong EW-scale interactions are a possibility at the LHC...
- Very few DEWSB models studied;
  even fewer implemented in MC programs

> Don't be discouraged because simplest TC models (rescaled QCD) ruled out!

- We would like a more general structure than rescaled QCD/Higgsless
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  - new interactions?
  - better agreement with precision measurements?

and we want to implement it into MC programs

Holographic Technicolor:

(for details, see Veronica's talk)

- Holographic Technicolor;
  5D setup, but with non-Ads geometry
  - interval $z \in (\ell_0, \ell_1)$
  - BC break EWSB
  - weakly coupled $W^{\pm}_{1,2}, Z^0_{1,2}$ resonances:

different warp factors for vector, axial

$$\mathcal{L} = -\frac{1}{2g_5^2} \int dx\, \omega_V(z) F_{V,NM} F_V^{NM} + \omega_A(z) F_{A,MN} F_A^{MN}$$

$$\omega_{V,A}(z) = \frac{\ell_0}{z} \exp\left(o_4^{V,A} \left(\frac{z}{\ell_1} \right)^4 \right) \qquad o_V, o_A < 0$$

(Hirn, Sanz '06,'07)

With this new freedom, we get:

Holographic Technicolor: Main results

- We can dial resonance masses;
  $\longrightarrow$ degenerate, inverted spectrum possible!

- Anomalous couplings possible in triboson, 4-boson interactions

$$g_{W_1^- WZ} = g_1 \partial_{[\mu} W^-_{1\nu]} (W^+_{[\mu} Z^0_{\nu]}) + g_2 \partial_{[\mu} W^-_{\nu]} (Z^0_{[\mu} W^-_{1\nu]}) + g_3 \partial_{[\nu} Z^0_{\nu]} (W^-_{[1\nu} W^+_{\nu]})$$

$$g_1 \supset \int_{\ell_0}^{\ell_1} dz\ \omega_V (V_1 A_{W^+} A_Z) \cdots \neq g_3 \supset \int_{\ell_0}^{\ell_1} dz\ \omega_A (V_1 A_{W^+} A_Z) \cdots$$

$\longrightarrow$ nonzero $g_{W_1 W \gamma}$!

- Fermions not modeled in 5D; phenomenological coupling g_{ffV}

Holographic Technicolor: Main results

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  → degenerate, inverted spectrum possible!

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In the end...

$\mathcal{L}($  $)$

Remember: Not a model, rather an orgainizing scheme

Why 5D?

Certainly more ways to get $\mathcal{L}_{spin-1}$:
(mooses, HLS)

5D:

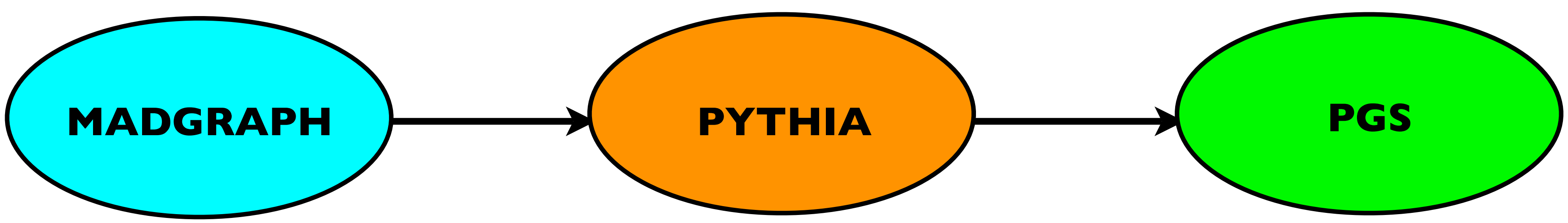
- Flexible spectrum/interactions with only 4 free parameters + no new fields
- Setup easily put into unitary gauge and mass eigenstates

  → Simplifies implementation into MC programs

- Easy to add more resonances later on;
  (isosinglet resonances ω_T, scalars, fermions)

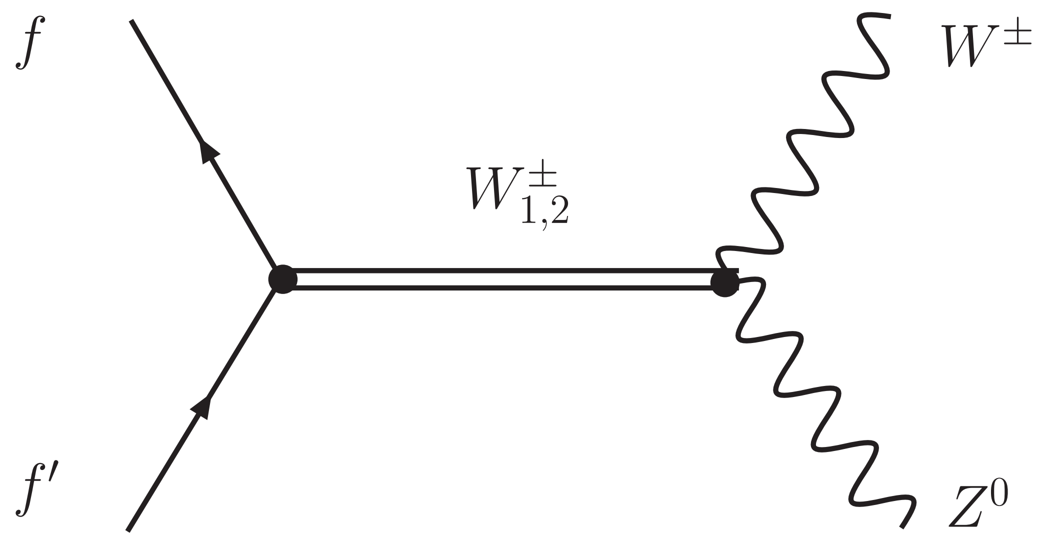
Next step:

- Put first two resonance multiplets + interactions into matrix element generator MadGraph



Low Luminosity Signals: Drell-Yan

- Nonzero fermion-resonance coupling:
  → Drell-Yan is the dominant production mode



- Choosing couplings to satisfy all LEP + Tevatron constraints (contact interactions, direct + indirect bounds),
  we can still get a spectacular signal.

$$\sigma(pp \to W_{1,2} \to WZ) \propto \frac{M^4_{W_{1,2}}}{M_Z^2 M_W^2}$$

Enhancement from decays to longitudinal polarizations

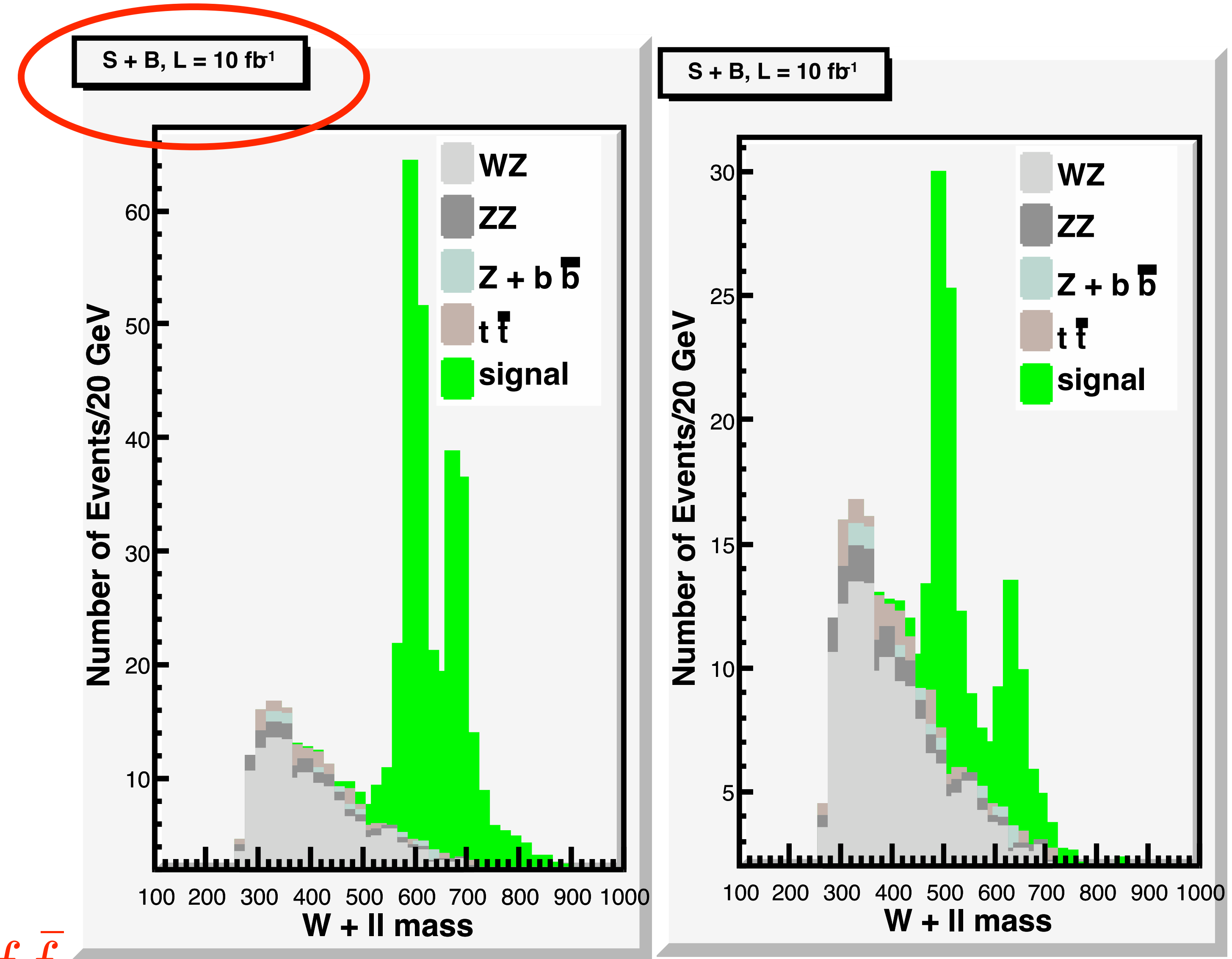
Example: $pp \to W^{\pm}Z \to 3\ell + \nu$

- Two resonances - both couple to

$$W^{\pm}, Z^0$$

- Seen within the first few fb^{-1} at LHC

- Neutral $Z^0_{1,2}$ can be seen in $Z^0_{1,2} \to W^+W^-, f\bar{f}$



1.) $n_{lep} = 3, p_T > 10$ GeV, $|\eta| < 2.5$
$p_T > 30$ GeV for at least one

2.) $|M_{\ell^+\ell^-} - M_Z| < 3.0\Gamma_Z$

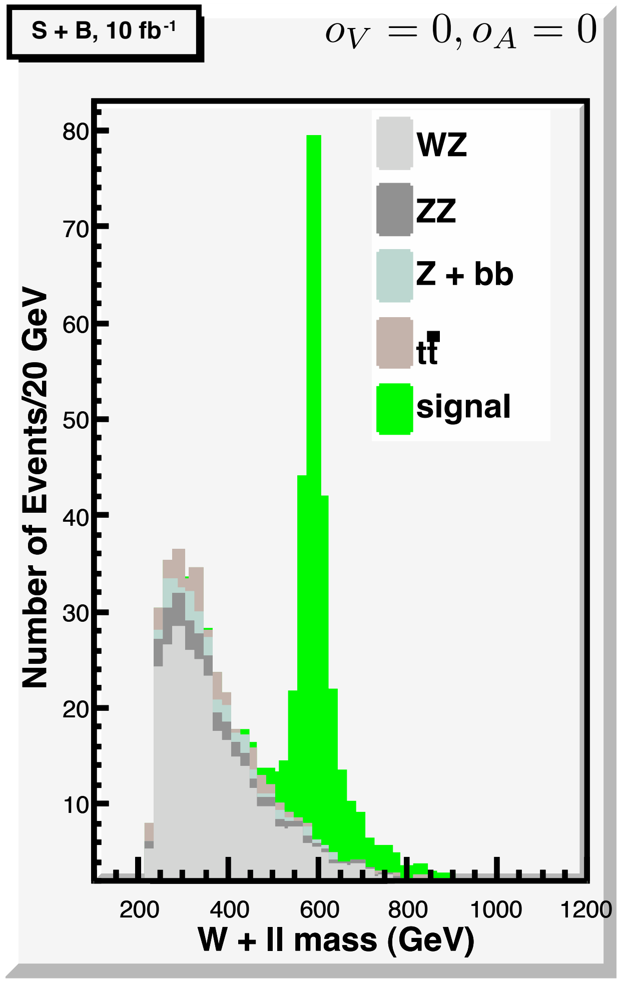
3.) $H_{T,jets} < 125$ GeV

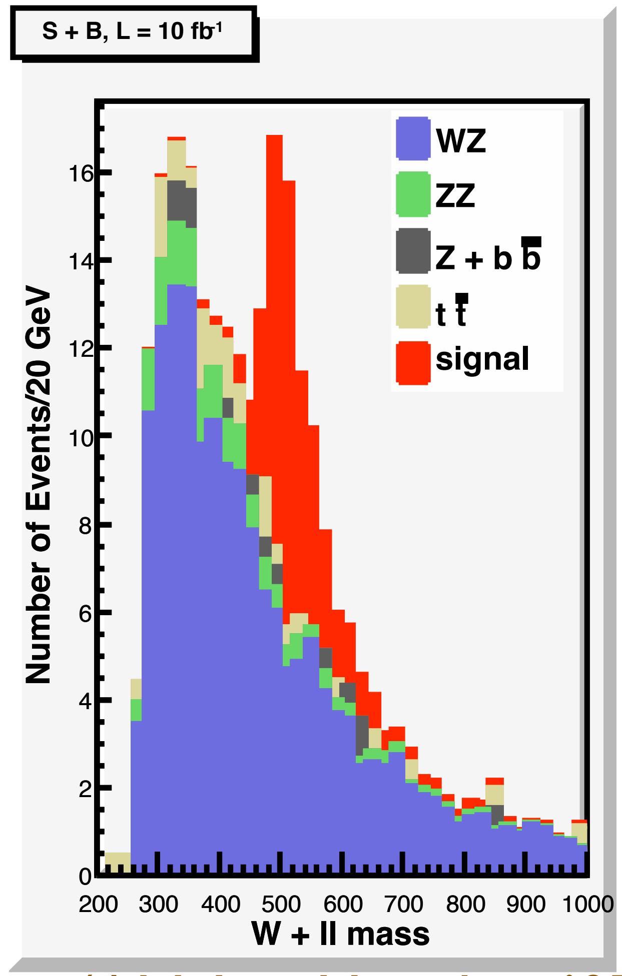
4.) $p_{T,W},\ p_{T,Z} > 100$ GeV

All plots:

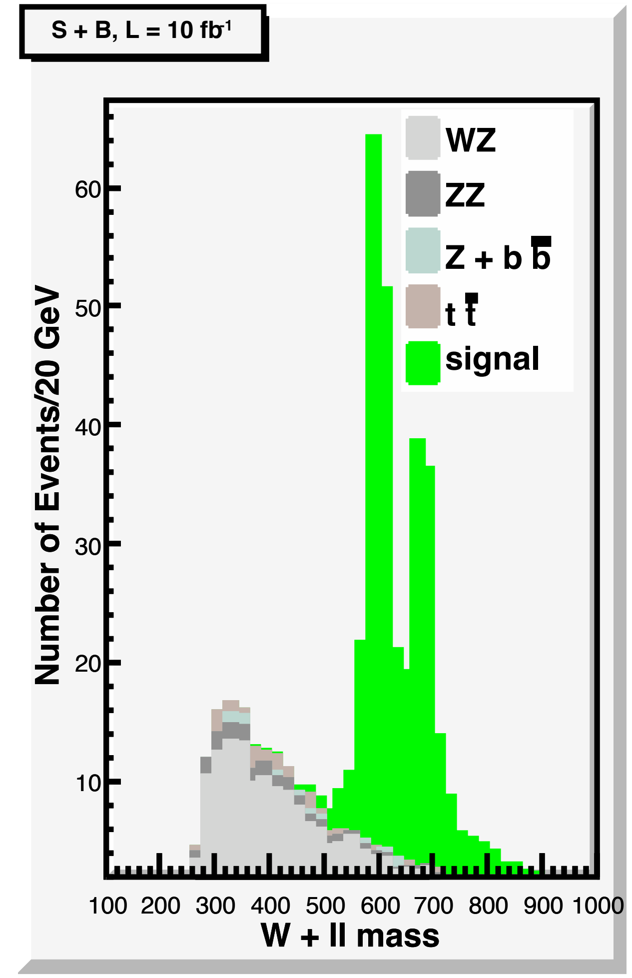
MadGraph ⟶ PYTHIA ⟶ PGS

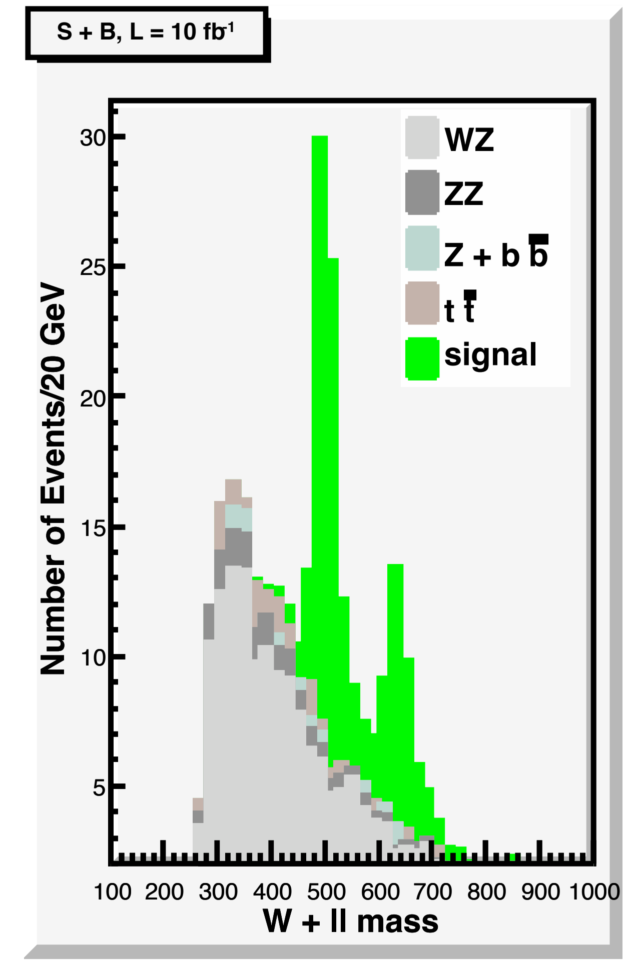
Comparison: $pp \to W^{\pm}Z \to 3\ell + \nu$





(AM, Les Houches ’07)





Pure AdS   Low-Scale TC

Only one peak

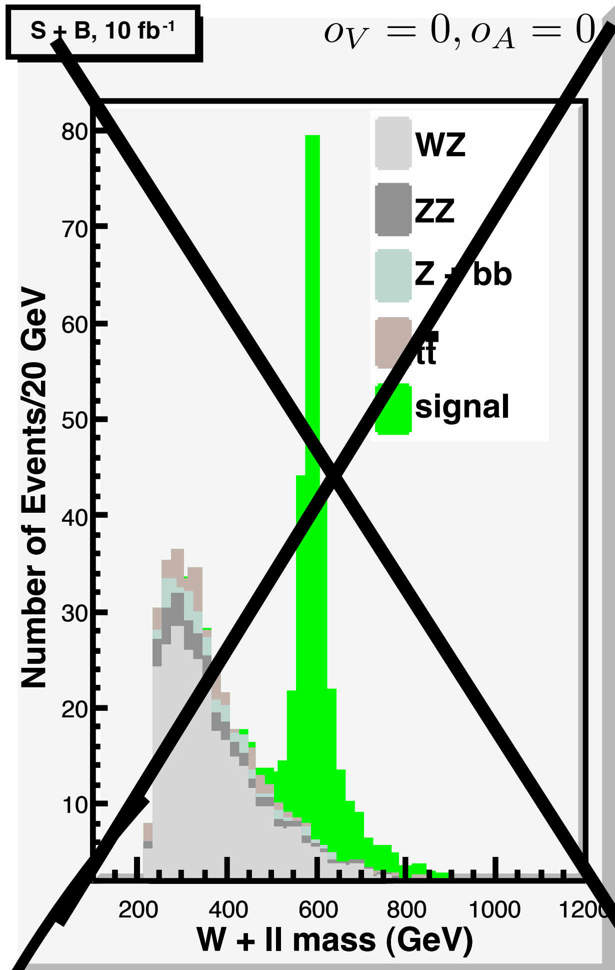
$M_{W_2} \gg M_{W_1}$ or no g_{W_2WZ}

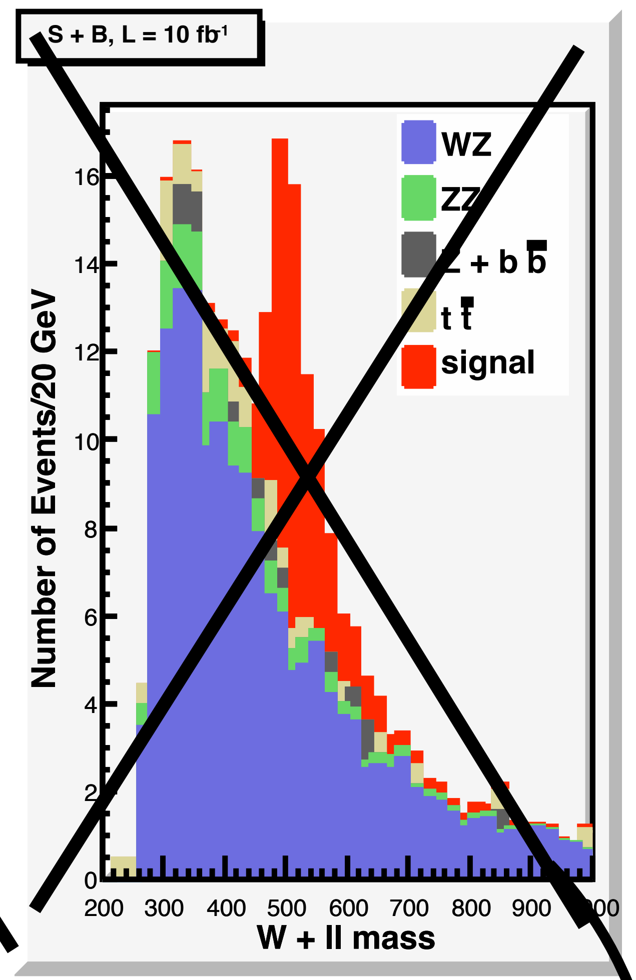
Effective Warp Factors

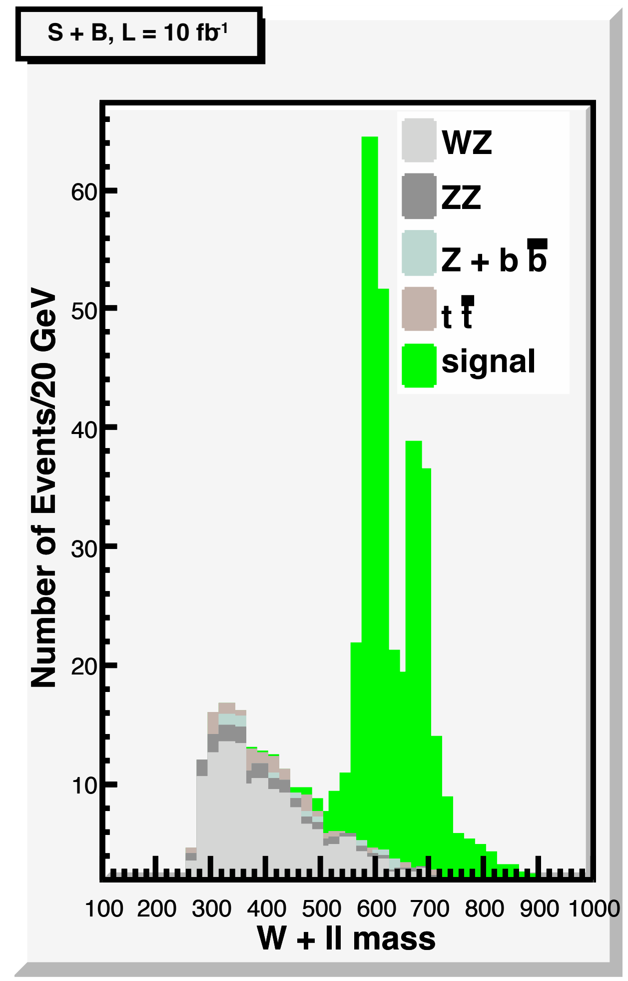
Two peaks

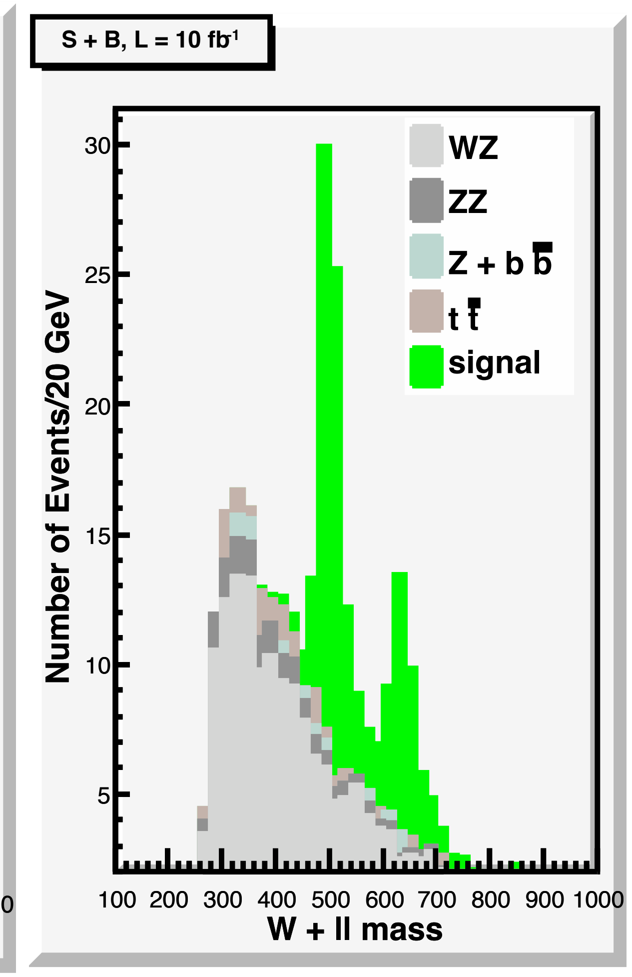
$M_{W_2} \cong M_{W_1}$, $g_{W_2WZ} \neq 0$

Comparison: $pp \to W^{\pm}Z \to 3\ell + \nu$









Pure AdS

Low-Scale TC

Effective Warp Factors

Not allowed by g_{WWZ}

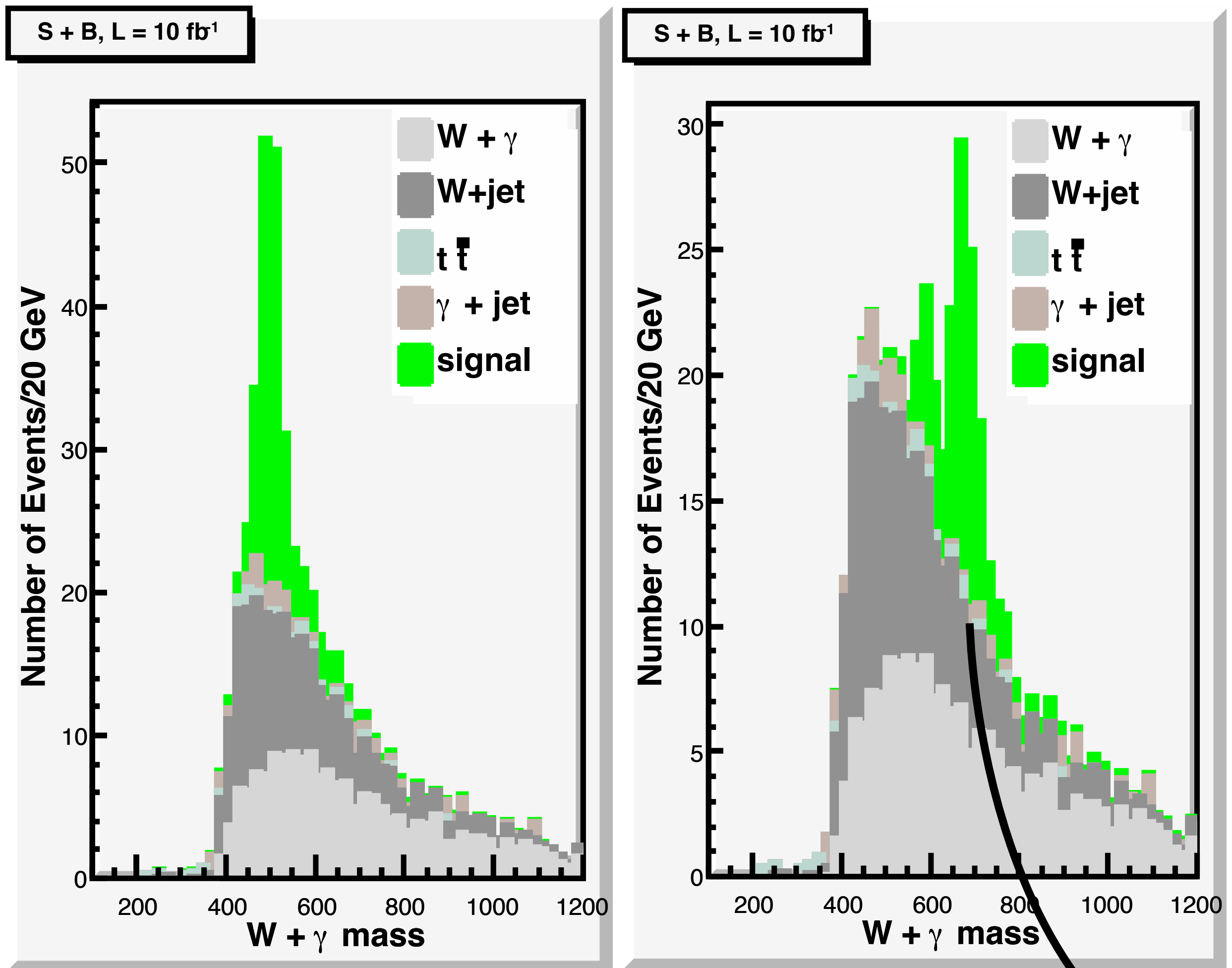
PEW incalculable

Satisfies all experimental constraints

Example: $pp \to W^{\pm}\gamma \to \ell + \nu + \gamma$

When $\omega_V \neq \omega_A$: $g_{\gamma W^+ W_1^-}\partial_{[\mu}\gamma_{\nu]}(W^+_{[\mu}W^-_{1\nu]}) \neq 0$

is allowed, NOT permutations



1.) $n_{lep} = 1, p_T > 10$ GeV, $|\eta| < 2.5$

2.) $n_\gamma = 1, p_T > 180$ GeV, $|\eta| < 2.0$

3.) $p_{T,W} > 180$ GeV

4.) $E_{T,miss} > 20.0$ GeV

$g_{W_1 W \gamma}$

- Does not exist in AdS Higgsless

$g_{H^{\pm} W \gamma}$

- Only at loop level in MSSM/2HDM

Two peaks when:

$M_{W_2} - M_{W_1} \lesssim 90$ GeV

Example: $pp \to W^{\pm}\gamma \to \ell + \nu + \gamma$

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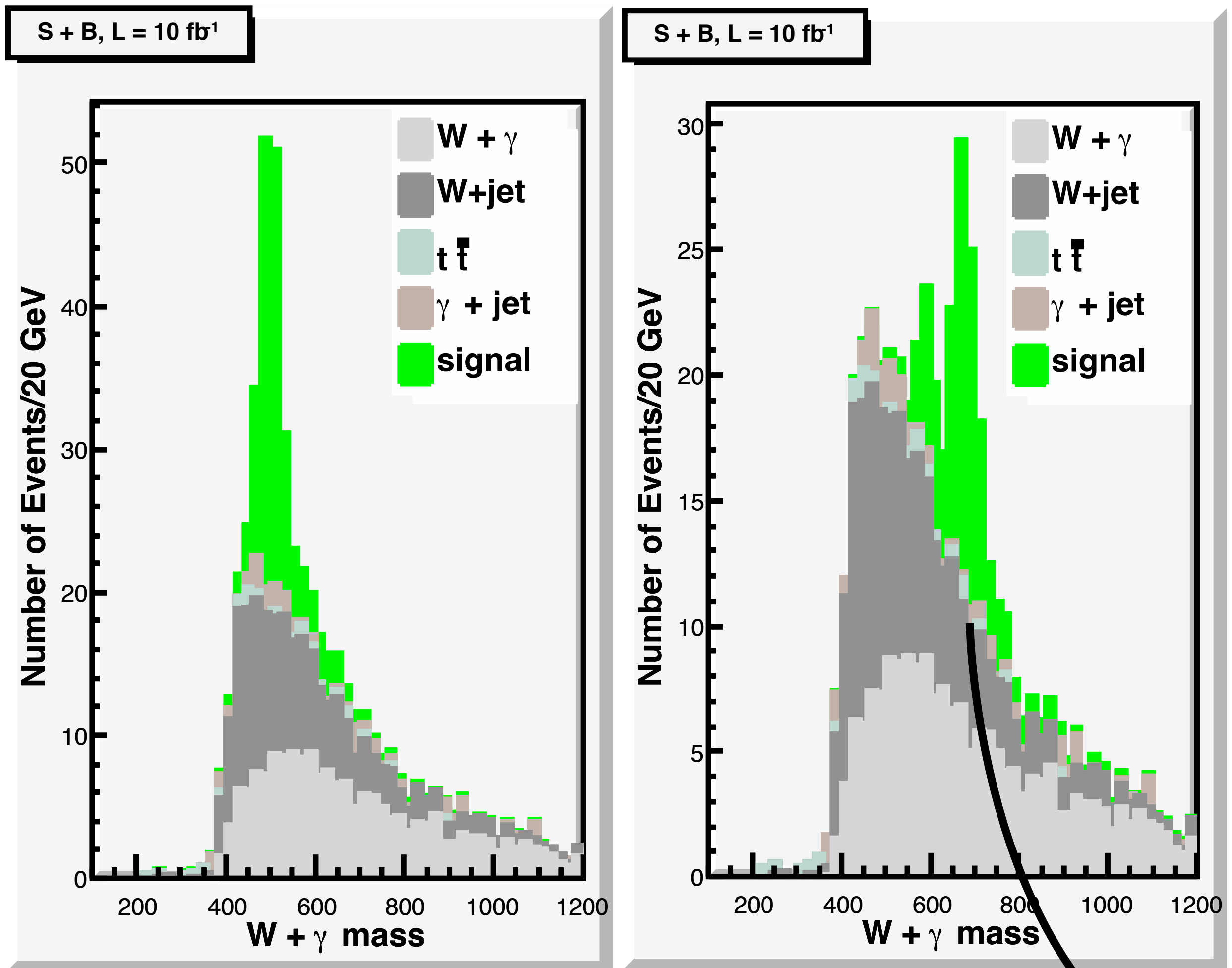

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$g_{W_1 W \gamma}$

- Does not exist in AdS Higgsless

$g_{H^\pm W \gamma}$

- Only at loop level in MSSM/ 2HDM

New Signal!

Two peaks when:

$M_{W_2} - M_{W_1} \lesssim 90$ GeV

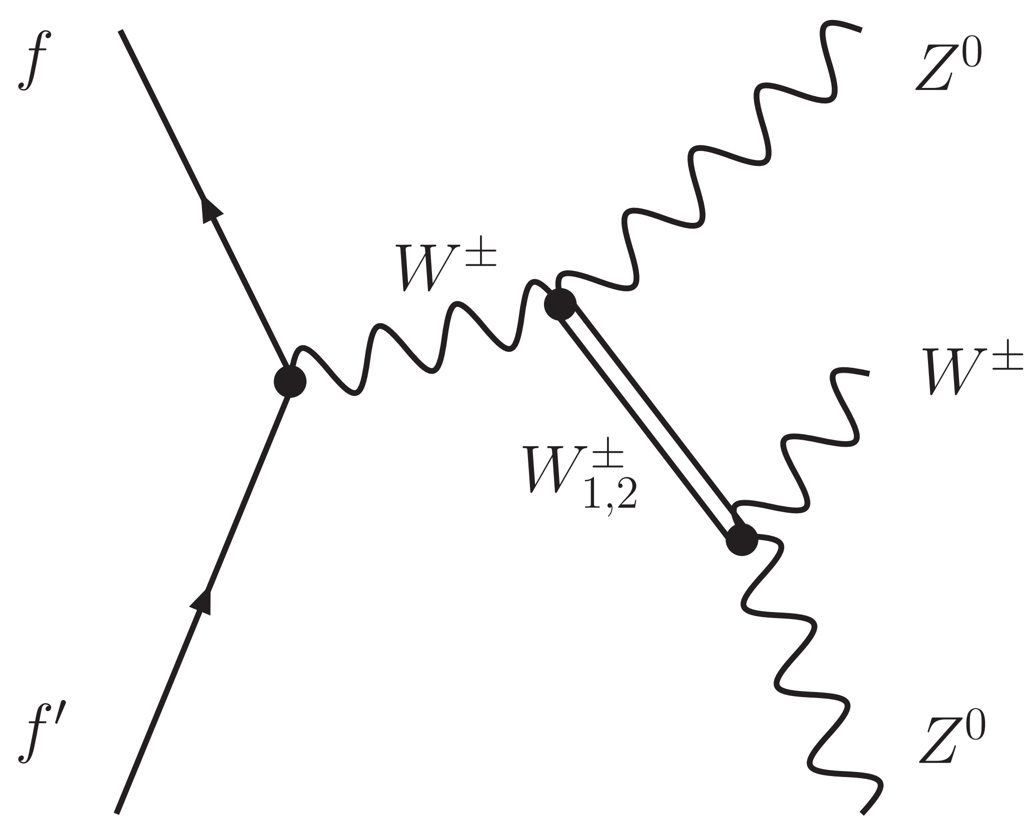
Beyond $M_{W_{1,2}}$:

- These scenarios have largest couplings allowed by experimental constraints; many other scenarios can be studied

- We can also study properties of the resonances with more luminosity
    - Angular distributions
    - Couplings
    - $\dfrac{\Gamma(W_{1,2} \to WZ)}{\Gamma(W_{1,2} \to ff')}$

High Luminosity Signals: Fermiophobic

- 'Ideally delocalized' scenario: resonances decouple from SM fermions $g_{ffV} \cong 0$
- Fine tuned, but very few constraints
- Resonances produced via associated production



Higgsless:

(Matchev, Perelstein '05
He, et al '07)

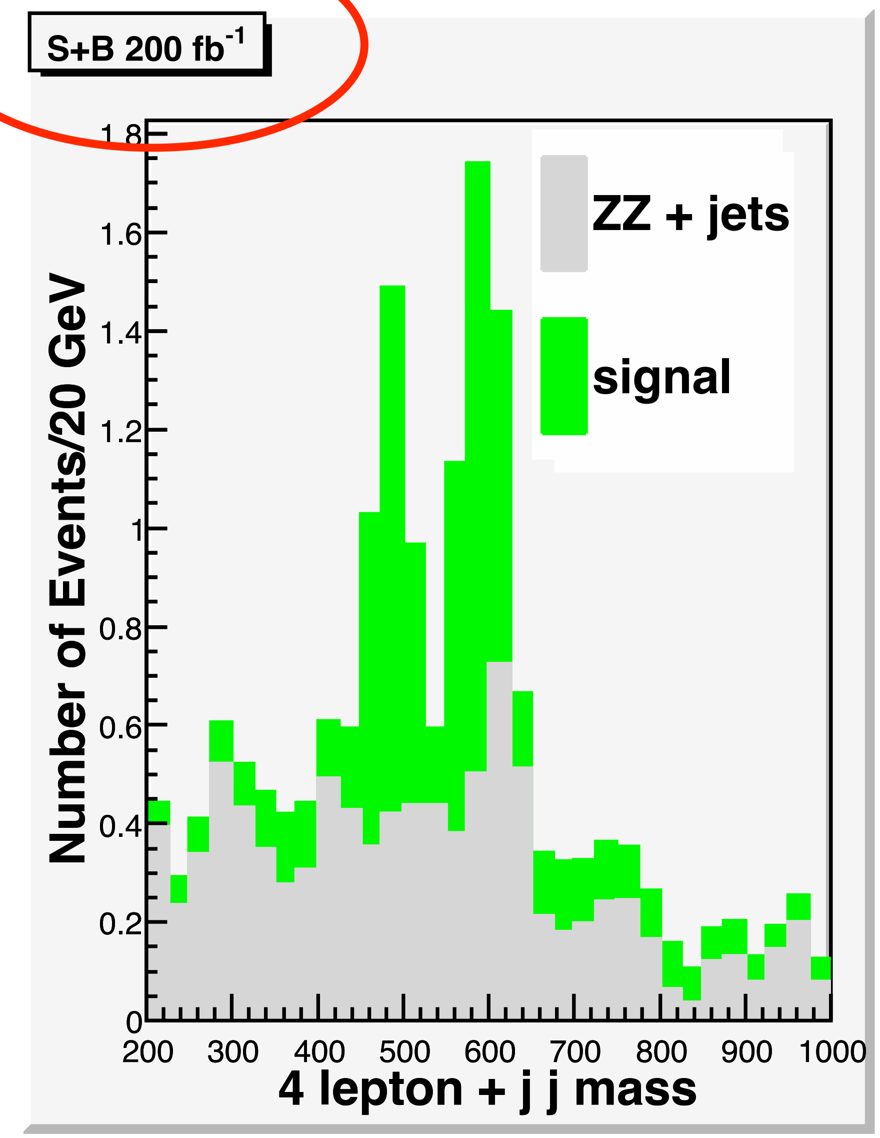
Fermiophobic Example: $pp \to 4\ell + jj$

- High luminosity necessary for discovery $\mathcal{L} \gtrsim 300 \text{ fb}^{-1}$
- Parton level estimates overly optimistic
- More clean signatures:

$$5\ell + \nu$$
$$3\ell + \nu + jj$$

- New signatures:

$$W + \gamma\gamma$$
$$W + \gamma + Z$$



1.) 2 jets, $p_T > 15$ GeV, $|\eta| < 4.5$
$|M_{jj} - M_W| < 20$ GeV

2.) $n_{lep} = 4, p_T > 10$ GeV, $|\eta| < 2.5$

3.) $p_{T,Z_{leading}} > 240$ GeV

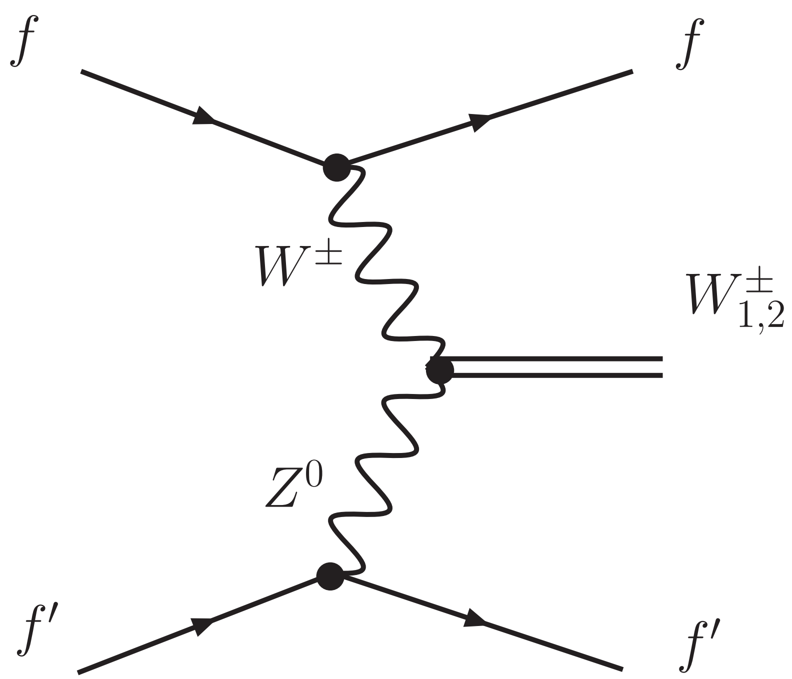
4.) $\sum_{ZZ+jj} p_T < 45$ GeV

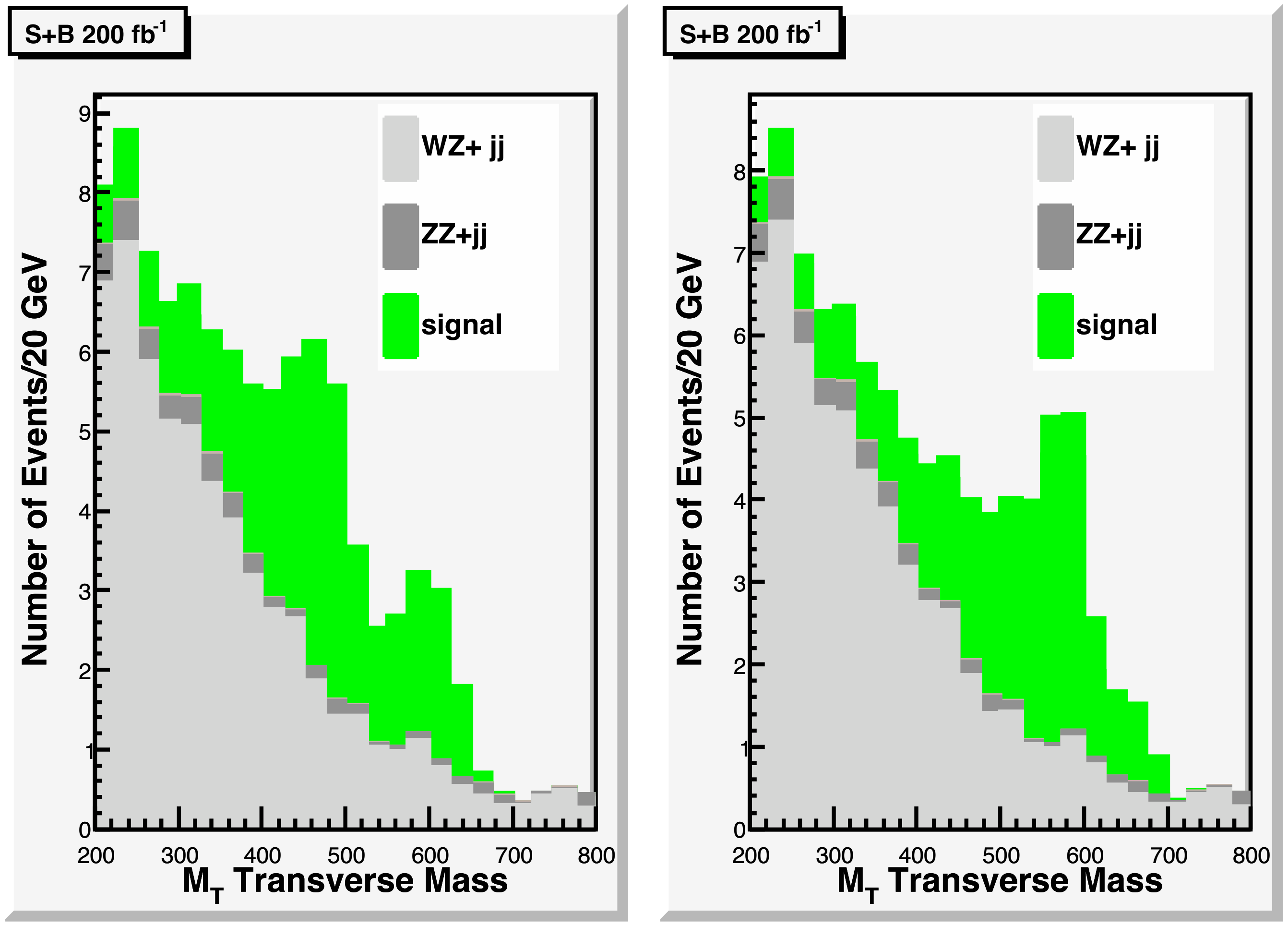
(cuts from He, et al)

Examples III: Vector Boson Fusion (VBF)

Regardless of g_{ffV}, VBF is important to observe at the LHC

Window into $W_L W_L \to W_L W_L$ scattering





- Two edges in M_T

Distinct features even if $g_{ffV} = 0$

1.) $n_{lep} = 3, p_T > 10$ GeV, $|\eta| < 2.5$

2.) $n_{jet} = 2, p_T > 30$ GeV, $2.0 < |\eta| < 4.5$

3.) $\Delta\eta_{jj} > 4.0$

4.) $|M_{\ell^+\ell^-} - M_Z| < 3\Gamma_Z$

5.) $p_{T,W},\ p_{T,Z} > 70$ GeV

(cuts from He, et al)

Conclusions:

- LHC is in the near future, yet detailed phenomenological studies of strong EW physics are lacking:

WHY?

  - simplest models ruled out
  - no models are implemented in parton level generators (yet..).

- 5D Effective warp factor scheme: Generates $\mathcal{L}_{spin-1} + \mathcal{L}_{int}$ with only a few free parameters: $\ell_0, \ell_1, o_V, o_A, g_{ffV}$. We can use it to interpolate between many viable models

- New features in phenomenology:

  2 nearby peaks in Drell-Yan, VBF

  New phenomenology:

  Resonance $-\gamma - W$ couplings

in MadGraph!

- Many more scenarios to be studied!