Top-philic W' Searches at the LHC

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Based on the work with Edmond L. Berger, Qing-Hong Cao, and C.–P. Yuan, in preparation

Motivation

- Searches for W' resonance are usually studied in the $l\nu$, $t\bar{b}$, and WZ channels at the Tevatron and LHC.
- It is possible that some exotic W' may be discovered in new production channels.

Top-philic W' model

- A W' only couples to the third-generation quarks.

New discovery channel

- No direct search constraint:
  - W' s-channel production is forbidden (PDF flavors);
  - W' t-channel is suppressed and not for discovery (no resonance peak).
- Need new channel: associated production of W' and top through bg fusion.

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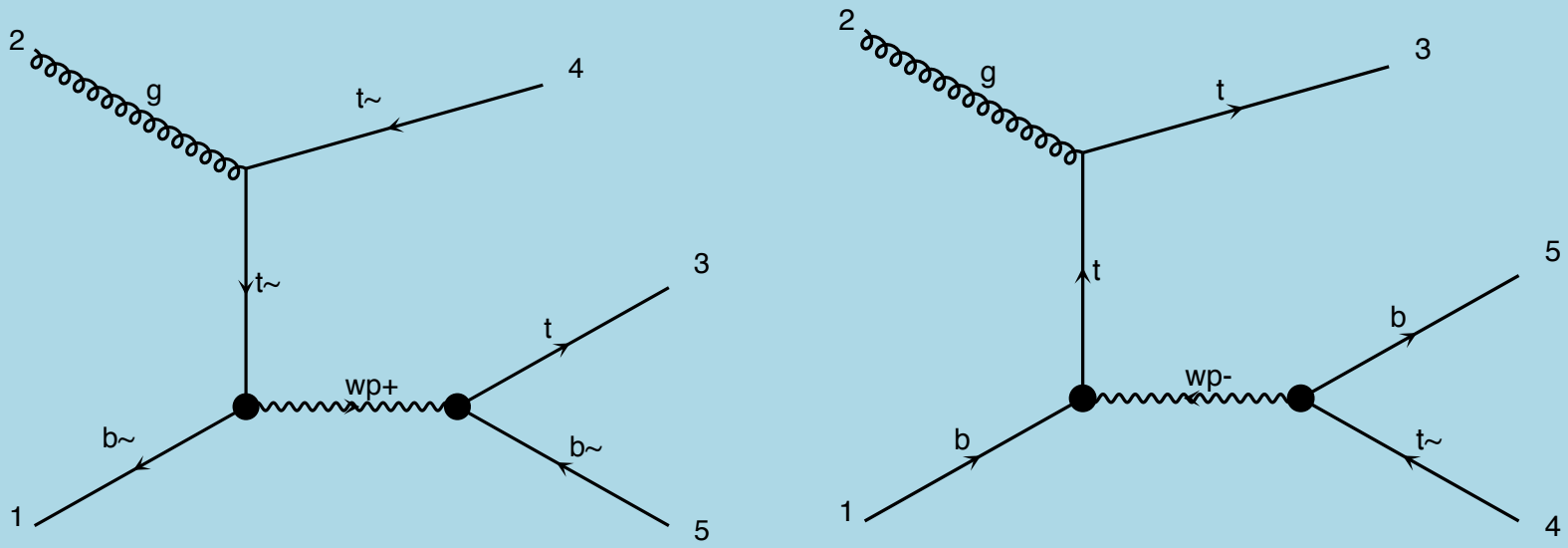
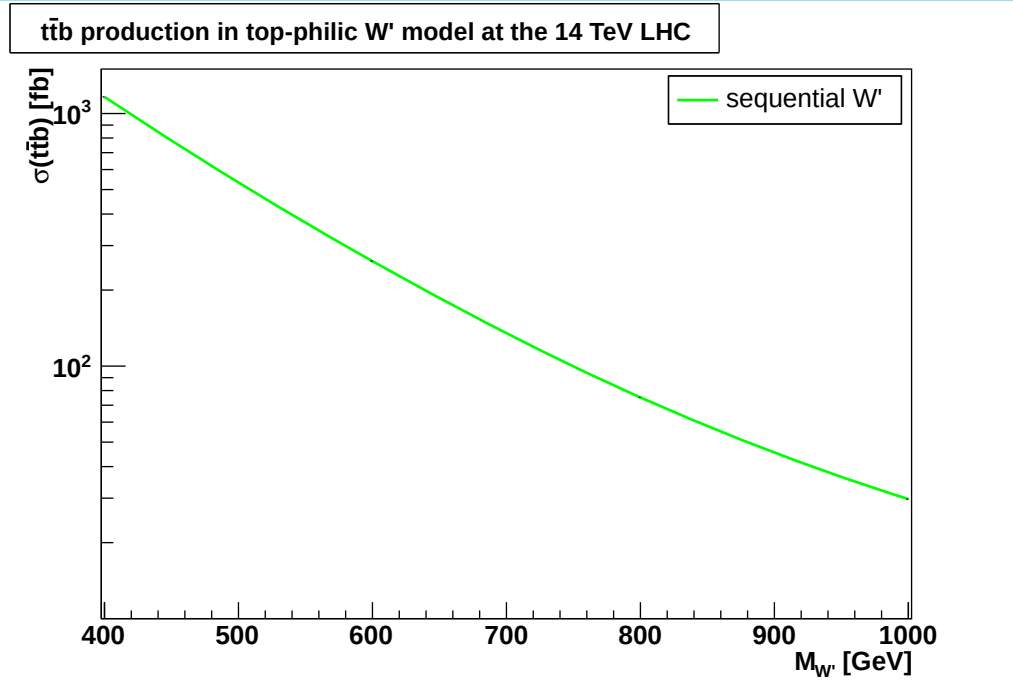
Representative Feynman diagrams



- W' Resonance is constructed from either $(t\bar{b})$ or $(\bar{t}b)$ (non-distinguishable);
- Since Br$(W'^{+} \to t\bar{b}) \sim 1$, W' decay back to $t\bar{b}$ final state (BGs: $t\bar{t}j$).

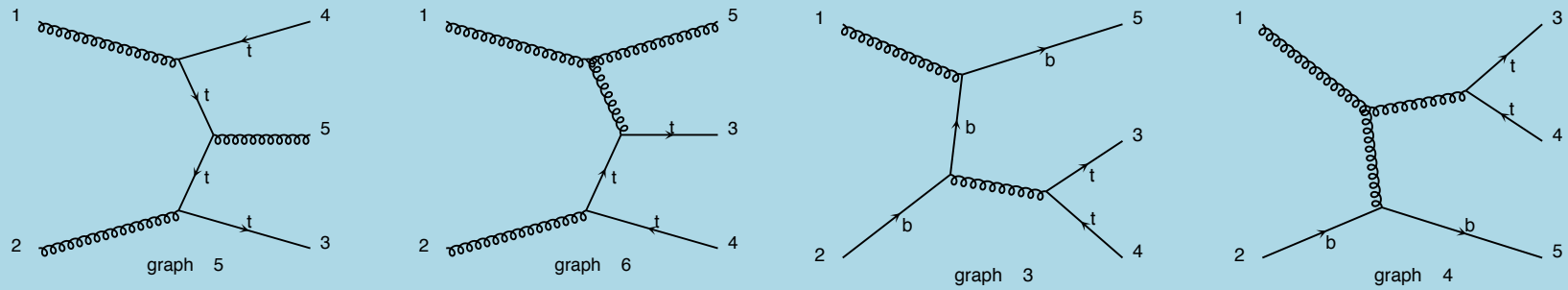
- Although SM BGs $t\bar{t}j$ rate are much larger than signal rate, we show it is promising to discover W' at the 14 TeV LHC with $\mathcal{L} = 100\ fb^{-1}$.

cross section for top-philic W' with g_W coupling



- $\mathcal{L} = i\frac{g_2}{\sqrt{2}}\bar{\psi}_b(f_{W'L}P_L + f_{W'R}P_R)\gamma^\mu\psi_t W'^+_\mu + h.c.;$
- The cross section with generic couplings by scaling $\sigma(g_{W'}) \sim (f^2_{W'L} + f^2_{W'R})\sigma(g_W)$.

Main SM backgrounds: $t\bar{t}j$ and $t\bar{t}b$



BG production rates

- top pair plus light jet $t\bar{t}j$: $900\,\text{pb}$ with $p_\perp(j) > 10\,\text{GeV}$;
- top pair plus b jet $t\bar{t}b$: $6\,\text{pb}$ with $p_\perp(b) > 10\,\text{GeV}$.

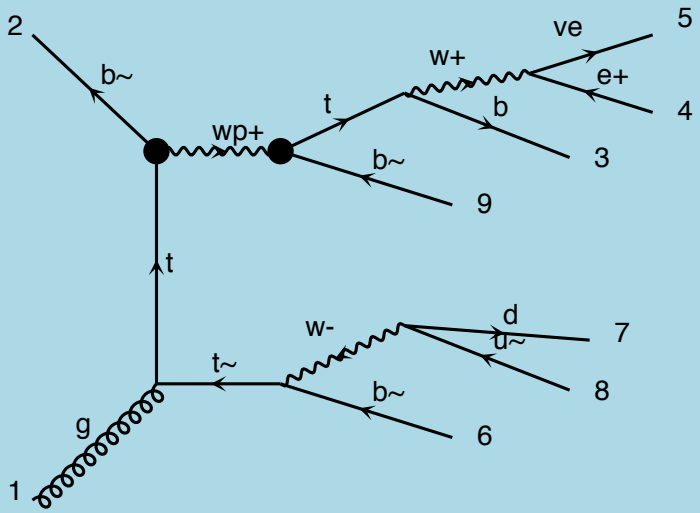
How to suppress the large BGs?

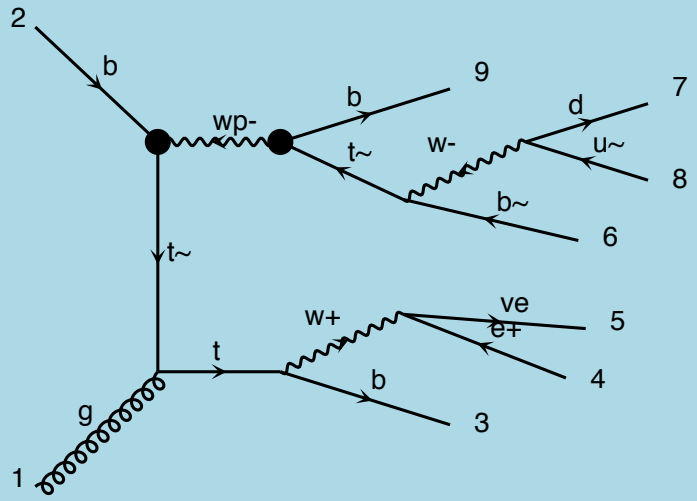
- Focus on top pair lepton + jet final state in this talk;
- Use 1 TeV W' with g_W coupling ($f_{W'L} = 1$, $f_{W'R} = 0$) as template.

Discriminator

Kinematics of signal and BGs

Signal: 5 jets + isolated l + met





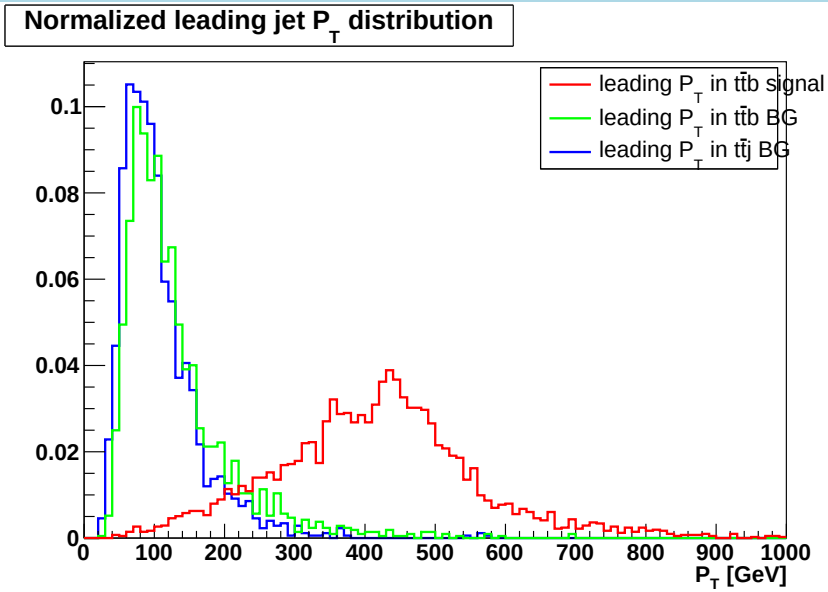
Kinematic features

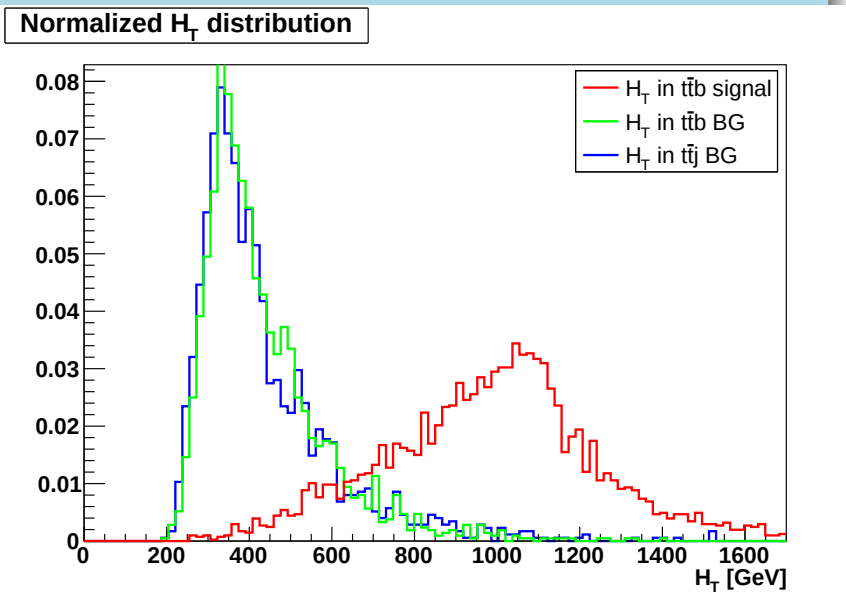
- Discriminator 1: Hard $p_\perp$ cuts for $p_\perp$ ordered 5 jets;
  - Signal: extra boosted b-jet from W' decay;
  - BGs: mainly QCD radiations;
- Discriminator 2: H_T cut and invariant mass cut;
  - Signal: W' mass sets scale of this process;
  - BGs: $t\bar{t}$ invariant mass near threshold dominate.

Discriminator

1 TeV W' with g_W coupling

Distributions with only basic selection cuts





Further discrimination

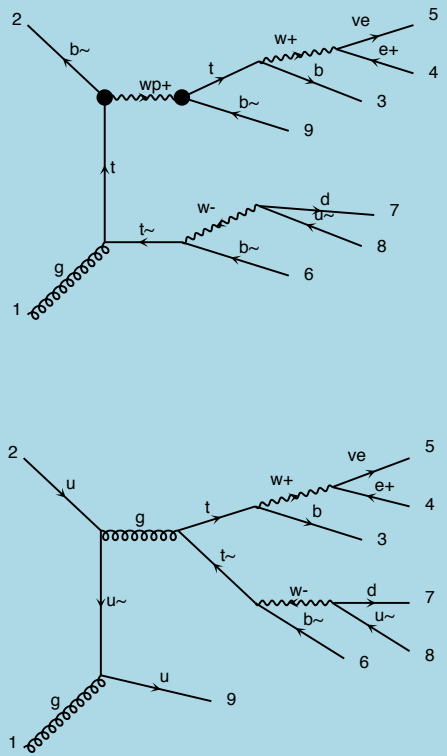
- $t\bar{t}b$ BG is suppressed; Still large $t\bar{t}j$ rate after cuts;
- Tag the extra jet!

Extra jet b-tagging

- Signal: b-jet, BG: light jet;
- Need full event reconstruction.

Solve combinatorial ambiguity: χ^2 minimization

- Loop over all combinations of 5 jets;
- Pick up the combination which minimizes the following χ^2:
  $\chi^2 = \frac{(M_W - M_{jj})^2}{\Delta M_W^2} + \frac{(M_t - M_{jl\nu})^2}{\Delta M_t^2} + \frac{(M_t - M_{jjj})^2}{\Delta M_t^2}$;
- Reconstruction efficiency compared with MC truth: $\epsilon_{\text{extra b}} = 99.4\%$, $\epsilon_{\text{lep t}} = 98.9\%$, $\epsilon_{\text{had t}} = 92.3\%$.



At least one b-tagging

- After reconstructing the extra jet, picking up the events with the extra jet tagged will suppress the $t\bar{t}j$ BG efficiently.

Monte Carlo simulation

- Setup: 1 TeV W' with g_W coupling at the 14 TeV LHC;
- Event generator: MadGraph 5 to generate signal and BG events.

Analysis in different cut level

- smearing visible final states with no cuts ($p_\perp > 10$ GeV);
- basic $p_\perp$, η, ΔR and met cuts;
- $p_\perp$ ordered jet cuts and H_T cuts;
- full event reconstruction;
- total $M_{t\bar{t}b(j)}$ mass cut and reconstructed $M_{W'}$ window cuts;
- extra jet b-tagging with at least one b-tagging.

Significance at the 14 TeV LHC with $\mathcal{L} = 100\ fb^{-1}$

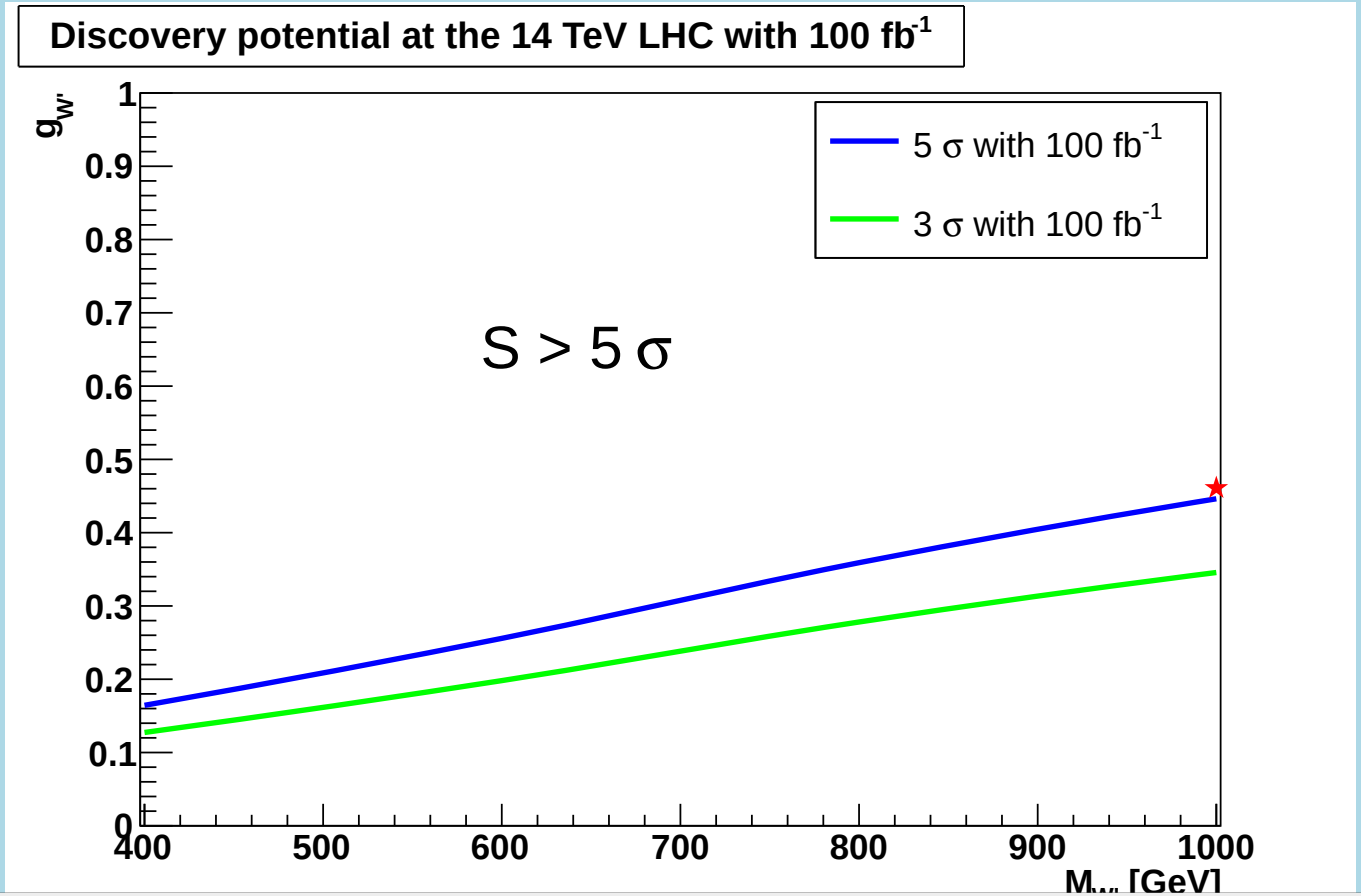
- Significance definition: $S = \frac{N_{signal}}{\sqrt{N_{bg}}}$.
- $S = 5.34$ for 1 TeV W' with g_W coupling after all cuts.

Discovery potential

Parameter scan

- Lower the W' mass will increase the signature space for discovery.

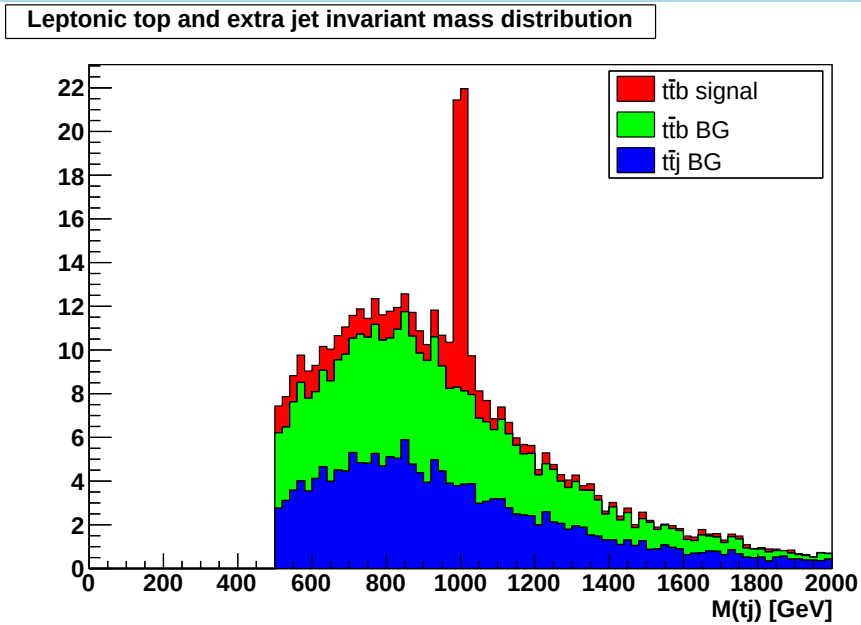
Discovery potential on the parameter contour $(g_{W'}, M_{W'})$

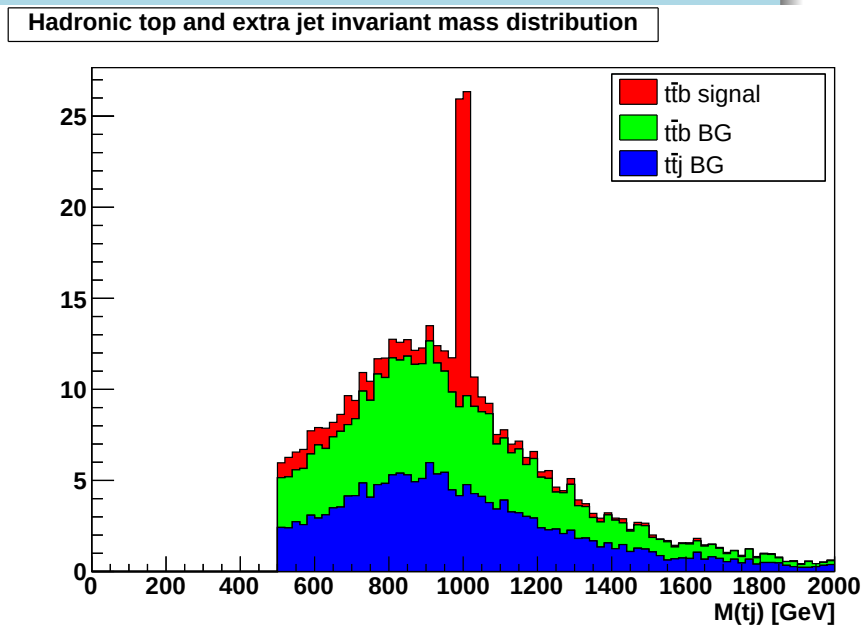


Peak for W' discovery

Invariant mass distribution

1 TeV W' with g_W coupling





Signature: Resonance Peak around $M_{W'}$ mass

- Peaks in two inv. mass distributions:
  - Reconstructed leptonic decaying top and extra jet inv. mass distribution;
  - Reconstructed hadronic decaying top and extra jet inv. mass distribution.

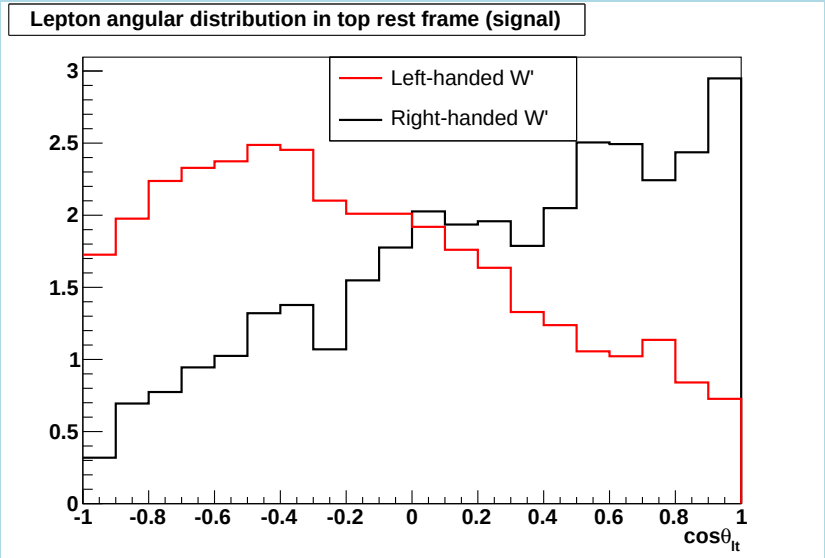
Shape for model identification

Lepton angular distribution

Distinguish top-philic W' models

- Top quark polarization is correlated to the W' chiral couplings;
- lepton angular distribution with the top direction in top rest frame;
  - Signal: Peaked in different region;
  - BGs: nearly flat distribution.

Distinguish 1 TeV left-handed and right-handed W' models with g_W coupling

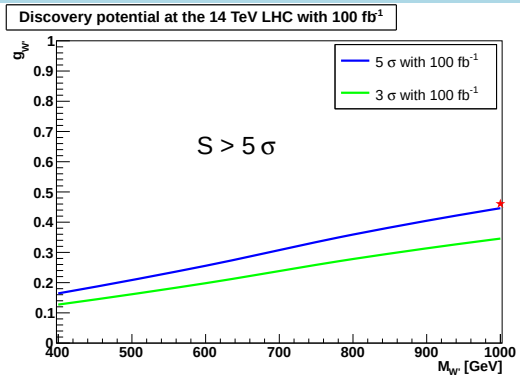


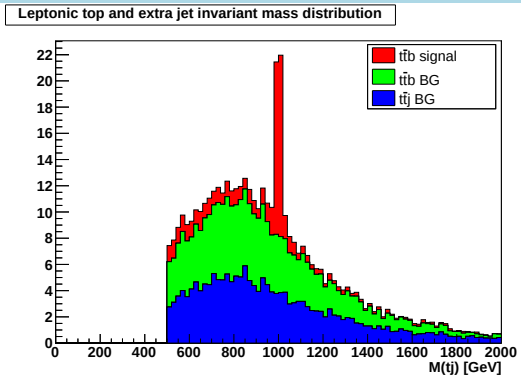
- Charged lepton moves backward for left-handed top, forward for right-handed top.

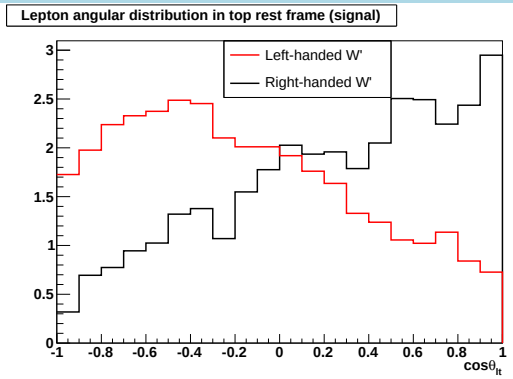
Summary

- It is promising to discover the top-philic W' at the LHC 14 TeV with $\mathcal{L} = 100\ fb^{-1}$, after optimized signal and background discrimination.

Rate for potential, Peak for discovery, Shape for discriminition





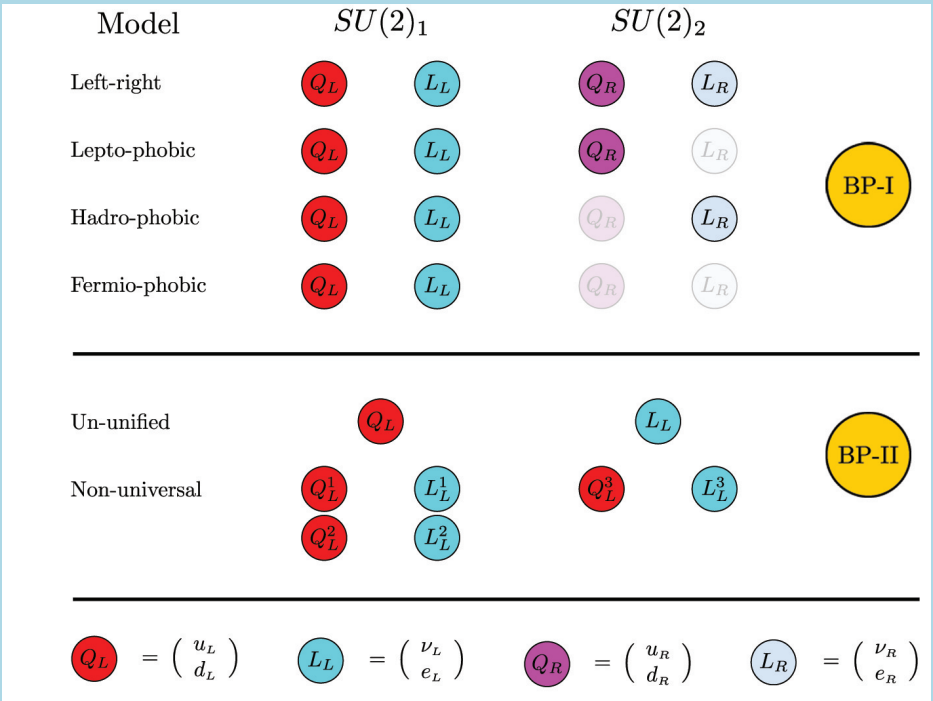


- Even in a model-independent way, as a possible signature, the top pair and a hard b-jet final state is worth to look at.

Thank You!

My Pheno 2010 talk

- Classify $SU(2)_1 \times SU(2)_2 \times U(1)$ models based on two breaking pattern;
- Top-philic W' model as one specific example in breaking pattern II: $SU(2)_1 \times SU(2)_2 \to SU(2)_L$ at TeV scale.



Model Lagrangian

- Chiral coupling: $\mathcal{L} = i\frac{g_2}{\sqrt{2}}\bar{\psi}_b(f_{W'L}P_L + f_{W'R}P_R)\gamma^\mu\psi_t W'^+_\mu + h.c.$;
  - Scenario (pure left-handed coupling): $f_{W'L} = f$, and $f_{W'R} = 0$;
  - Scenario (pure right-handed coupling): $f_{W'L} = 0$, and $f_{W'R} = f$;
  - Scenario (Vector-like coupling): $f_{W'L} = f$, and $f_{W'R} = f$.

Model parameter constraints

- Escape from most of low energy and LEP constraints, except $Zb\bar{b}$ and $B_d - \bar{B}_d$ mixing at one-loop order;
- No direct search constraint from Tevatron and LHC at all.

Benchmark parameter point

- Template (1 TeV W' with g_W coupling): $f_{W'L} = 1$, and $f_{W'R} = 0$;
- Do similar study for other parameter points.

Backup Slide 3

Extra b-jet

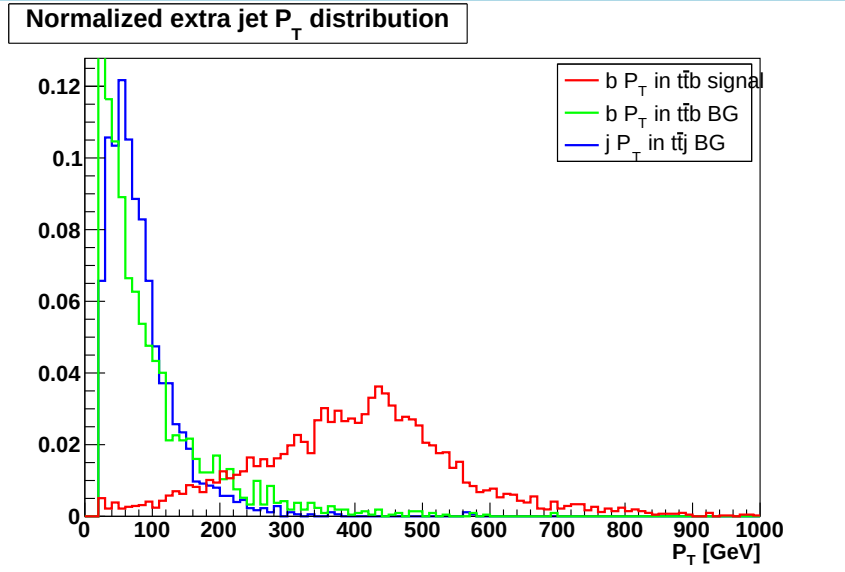
Efficiency

- The efficiency for the leading jet identified as the extra jet is 81.62%.

B-tagging in this process

- Make use of high event reconstruction efficiency;
- Tag the extra jet to suppress $t\bar{t}j$ bg.

Extra jet (MC truth) plot



Backup Slide 4

Cuts for 1 TeV W' with g_W coupling

Basic selection cuts:

- Acceptance cuts:
  - $P_\perp(j) > 20$ GeV, $|\eta(j)| < 2.5$;
  - $P_\perp(l) > 20$ GeV, $|\eta(l)| < 2.5$;
  - $E_\perp(met) > 20$ GeV.
- Isolation cuts:
  - $\Delta R(j,j) > 0.4$;
  - $\Delta R(j,l) > 0.4$.

Gaussian Smearing

- Gaussian resolution parametrization $\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \otimes b$;
- For lepton: $a = 5\%$ and $b = 0.55\%$; For jet: $a = 100\%$ and $b = 5\%$.

- Neutrino solutions: pick up neutrino p_z momenta with

Kinematic cuts:

- Hard $p_\perp$ ordered cuts:
  - $P_\perp$(leading) > 250 GeV;
  - $P_\perp$(sub-leading) > 120 GeV;
  - $P_\perp$(sub-leading) > 40 GeV.
- H_T cut and total invariant mass cuts:
  - $H_T = \sum |p_\perp(vis)| > 900$ GeV;
  - $M_{t\bar{t}b} > 1100$ GeV.
- W' resonance invariant mass window cuts:
  - $M_{\bar{t}b} > 500$ GeV;
  - $950 < M_{tb} < 1150$ GeV.

At least one b-tagging

- Use rejection sampling method to mimic the tagging efficiency:
  - b-tagging efficiency: 60%;
  - light-jet mis-tag efficiency: 0.5%.

Event numbers at the 14 TeV LHC with $\mathcal{L} = 100\ fb^{-1}$

cut level (scale: GeV)	Signal	$t\bar{t}b$ bg	$t\bar{t}j$ bg
no cuts ($p_\perp > 10$)	757	1.78×10^5	2.74×10^7
basic $p_\perp$, η, ΔR cuts	235	3875	445971
$p_\perp$ ordered jet cuts	185	1592	183188
HT cuts ($H_T > 900$)	135	432	54534
inv. cuts ($M_{ttb} > 1100$)	135	407	51570
inv. cuts ($M_{\bar{t}b} > 500$)	115	336	37431
inv. mass window cuts	54	36	3783
extra jet b-tagging	33	23	13

Backup Slide 6

Top quark spin