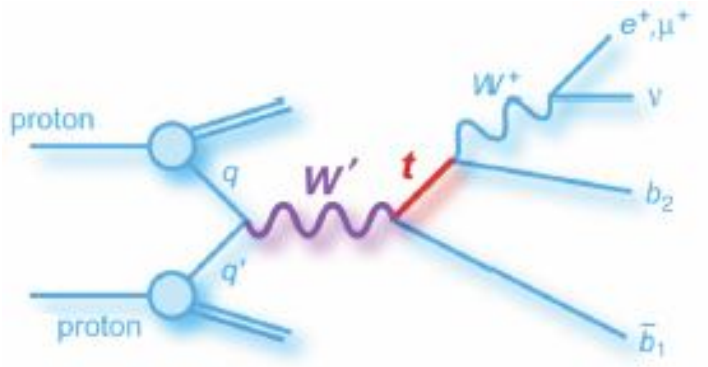
Direct BSM Searches in Single Top-Quark Signatures

Top-LHC France – Lyon 21-22/03/13



Julien Donini

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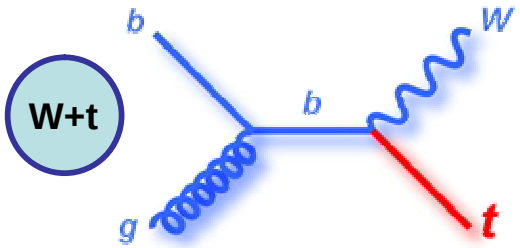
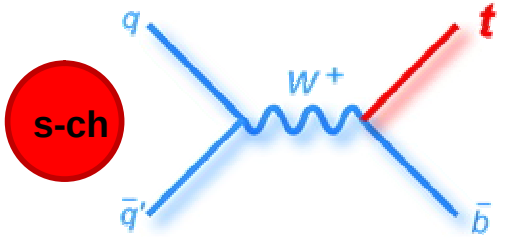
‘Direct’ searches with single top

Search for new (heavy) particles - not necessarily resonances



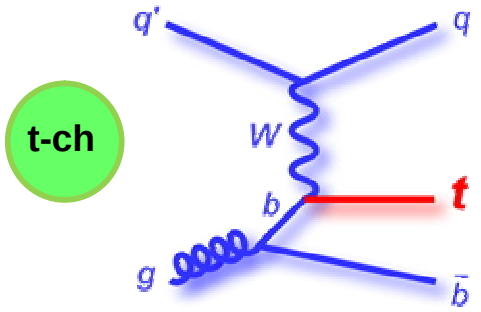
→ Excited quarks

→ Charged Higgs



→ Charged W-like bosons (W’)

→ Composite models (top-pion)



→ New intermediate particles suppressed as $1/M^2$

→ Any top+X searches

Ex: monotop top + MET

W'→tb searches

- **Search for W' boson(s)**
  - Predicted by many extensions of the SM
  - L/R models, KK excitations, Little Higgs, …
- **Why search for W'→tb decay**
  - More model independent than leptonic decay
  - Probe leptophobic sector
  - BSM dynamics could explain high top mass
- **Model independent approach**
  - Effective Left-Right model (Sullivan arXiv:1208.4858v1)
  - W' with left-handed, right-handed or mixed couplings

$$\mathcal{L} = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma_\mu \left(g'^R_{i,j}(1+\gamma^5) + g'^L_{i,j}(1-\gamma^5) \right) W'^\mu f_j + h.c.$$

$W'_R \rightarrow tb$ search (1.1 fb^{-1}, 7 TeV)

PRL 109, 081801 (2012)

Signature: e/μ+2jets, 1-2 btags
- p_T(lep,jet)>25 GeV, MET> 25 GeV
- m_T(W)+MET>60 GeV

Method: fit reco. m_{tb} spectrum

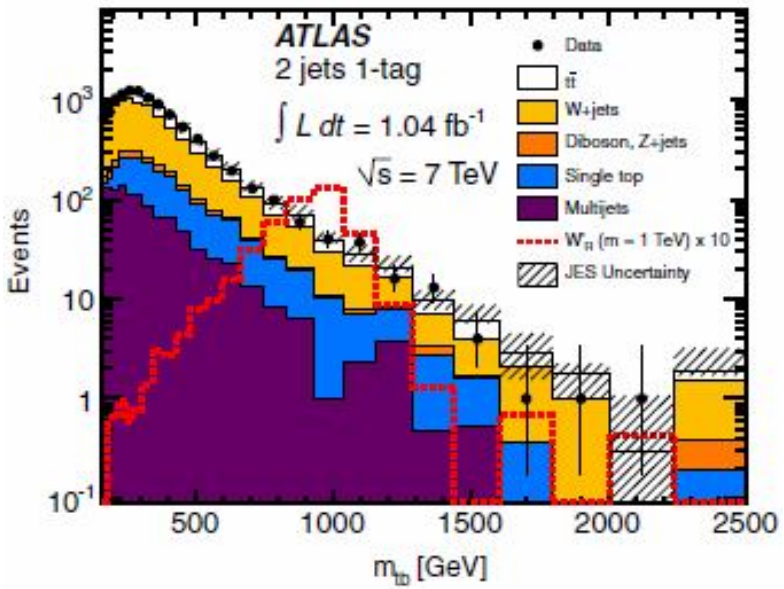
Bckgd: W+jets/QCD rate data-derived

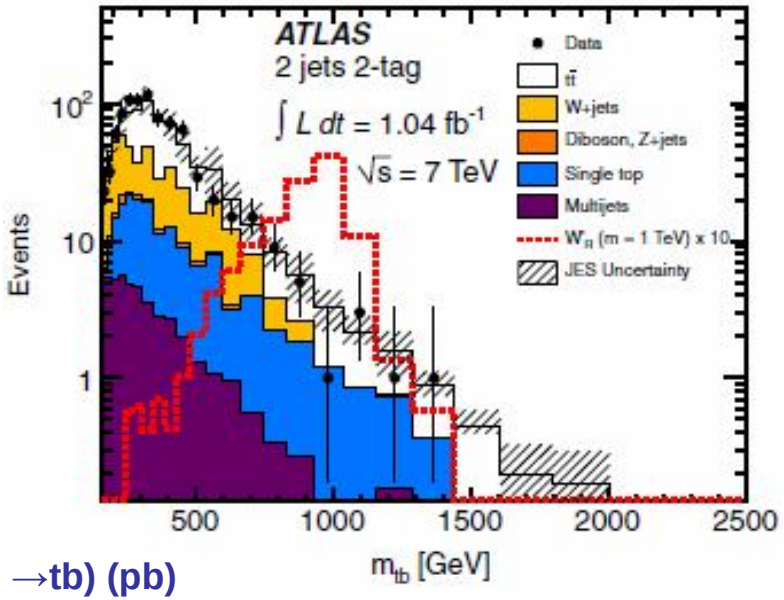
Signal model: Pythia …

Theory: Z. Sullivan Phys. Rev. D 66, 075011 (2002).

$m_{W'_R}$ [GeV]	$\mathcal{B}(W'_R \rightarrow tb)$	$\sigma \times \mathcal{B}$ [pb]
500	0.298 ± 0.002	54.6 ± 2.1
750	0.319 ± 0.001	10.9 ± 0.6
1000	0.326 ± 0.001	2.92 ± 0.18
1250	0.328 < 0.001	0.91 ± 0.07
1500	0.330 < 0.001	0.31 ± 0.03
1750	0.331 < 0.001	0.11 ± 0.01
2000	0.332 < 0.001	0.044 ± 0.005

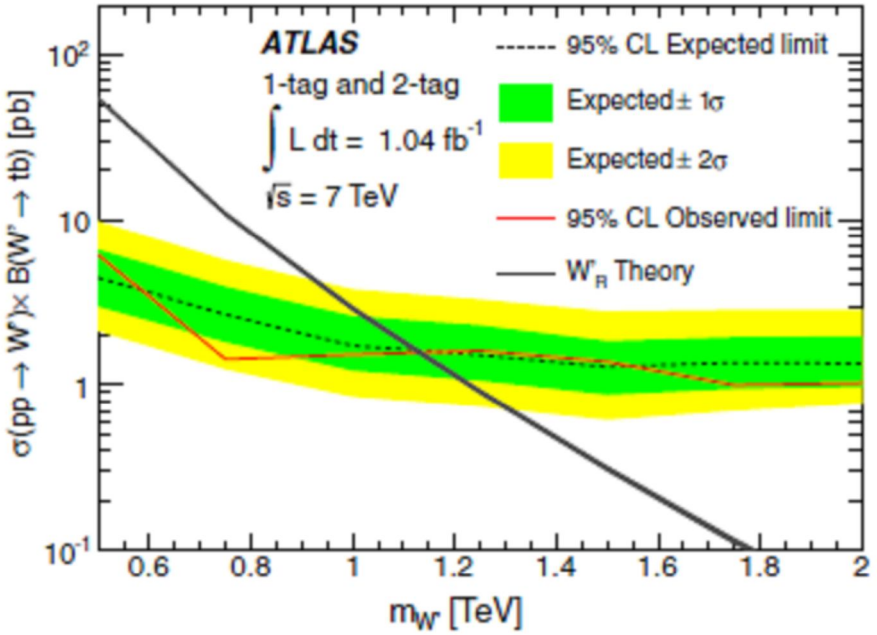
NLO production cross section times branching fraction B(W' →tb) (pb)





$W'_R \rightarrow tb$ search (1.1 fb^{-1}, 7 TeV)

Samples	Single-tagged	Double-tagged
W + jets	5970 ± 1000	290 ± 180
Multijets	1120 ± 560	47 ± 47
$t\bar{t}$	1560 ± 130	360 ± 30
Single top	1240 ± 90	120 ± 10
Diboson, Z + jets	320 ± 120	14 ± 2
Total prediction	10 200 ± 1200	830 ± 190
Data	10428	844



Search for excess: sliding window (BumpHunter tool)

→ No significant excess founds

95% C.L cross-section limit: Bayesian approach (BAT)

m(W') > 1.13 TeV at 95% C.L

LPC: 8 TeV analysis ongoing on right/left W' boson search

$W'_{R,L} \rightarrow tb$ search (5.0 fb^{-1}, 7 TeV)

Physics Letters B 718 (2013)

Signature: e/μ+jets, 1-2 btags

- $p_T(e/\mu)>35/32$ GeV, MET(e/μ)> 35/20 GeV
- $p_T(j_1)>100$ GeV, $p_T(j_2)>40$ GeV

Method: fit reco. m_{tb} / BDT spectrum

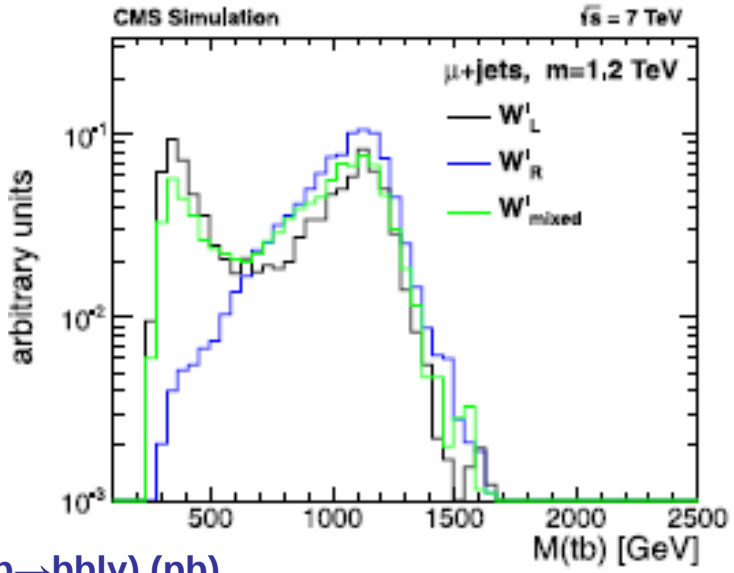
- m_{tb} analysis specific: $p_T(top)>75$ GeV, $p_T(j_1, j_2)>100$ GeV, $130<M(top)<210$ GeV
- BDT analysis: ~40 (!) input variables

Bckgd: W+jets rate data-derived

Signal model: CompHep

- right/left/mixed W' couplings
- Interference between single-top s-channel and W'_L included
- NLO corrections on rate and shape

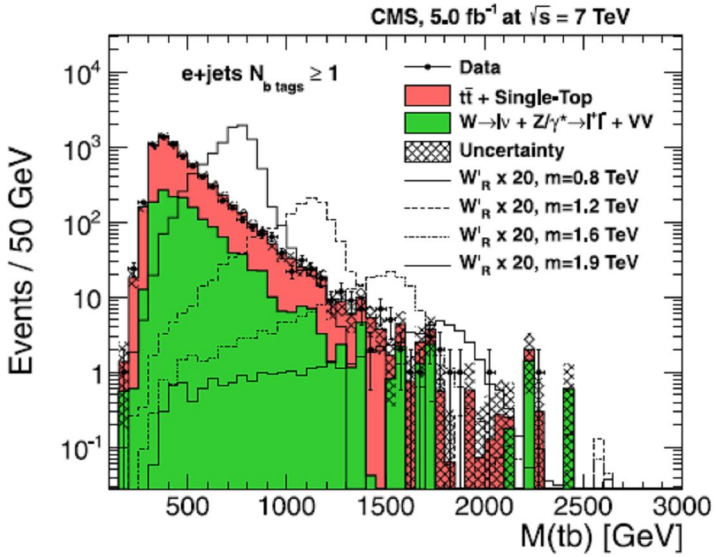
$M_{W'}$ (TeV)	$M_{\nu_R} \ll M'_W$			$M_{\nu_R} > M'_W$		
	σ_R	σ_L	σ_{LR}	σ_R	σ_L	σ_{LR}
0.9	1.17	2.28	3.22	1.56	3.04	4.30
1.1	0.43	1.40	1.85	0.58	1.86	2.47
1.3	0.17	1.20	1.39	0.23	1.60	1.85
1.5	0.07	1.13	1.21	0.099	1.51	1.62
1.7	0.033	1.12	1.15	0.044	1.50	1.54
1.9	0.015	1.11	1.13	0.020	1.49	1.51

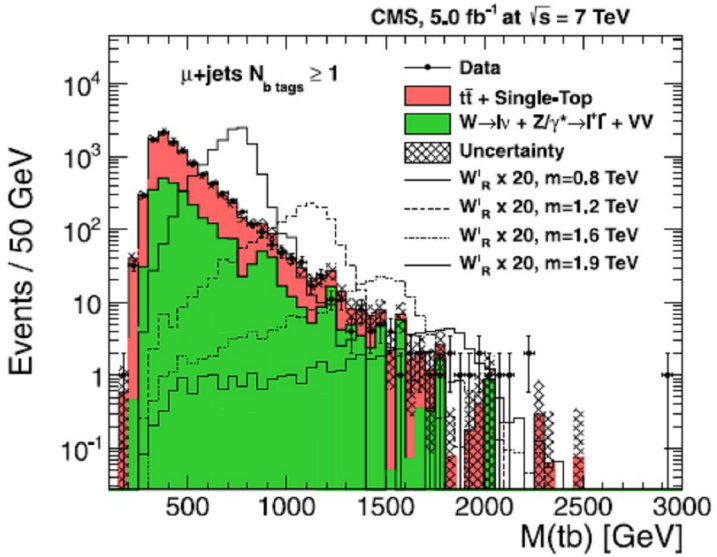


NLO production cross section times branching fraction B(W' →tb→bblν) (pb)

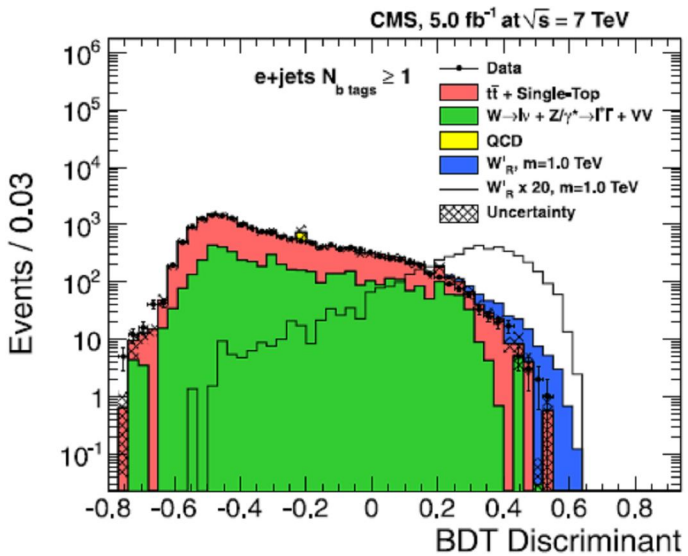
$W'_{R,L} \rightarrow tb$ search (5.0 fb^{-1}, 7 TeV)

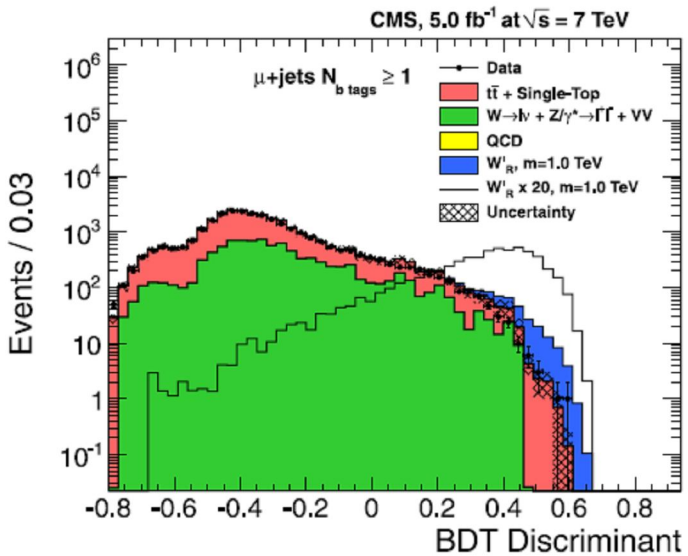
Inv. mass analysis





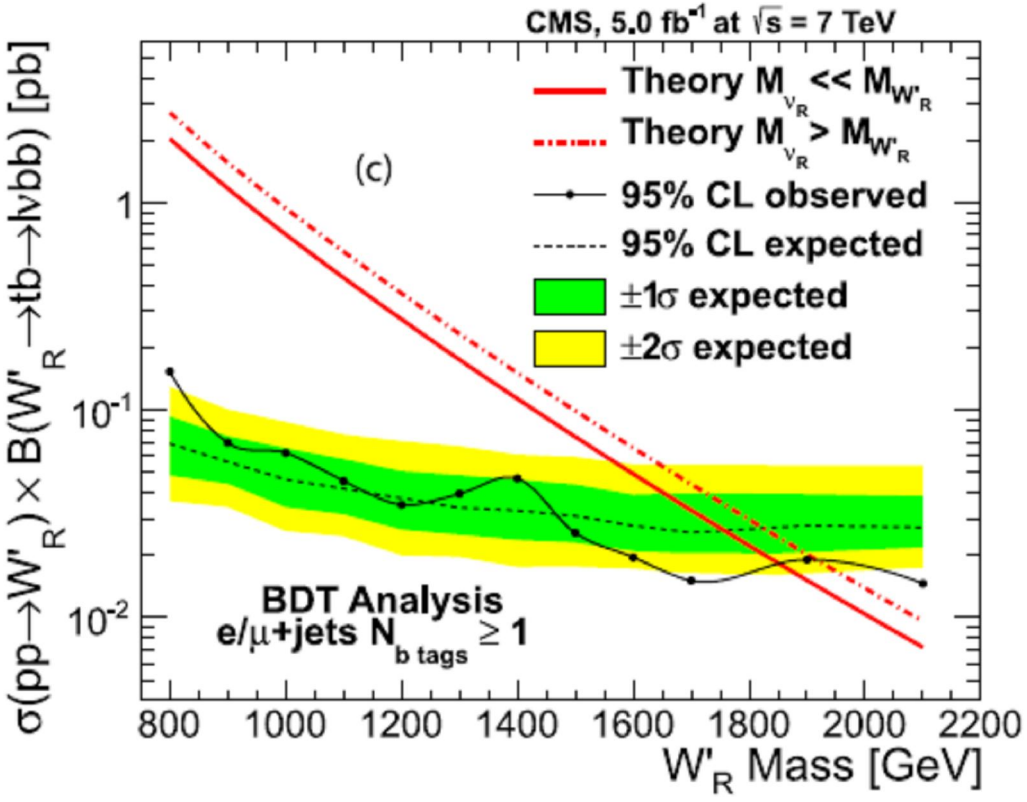
BDT analysis





$W'_{R,L} \rightarrow tb$ search (5.0 fb^{-1}, 7 TeV)

No significant excess observed
→ Limits sets using **CL_s** method
- W' right/left and max. mixed
- W'_L interference term included
- both scenario of $m(\nu_R)$



95% C.L. limits on W' mass

Analysis	$(a^L, a^R) = (0, 1)$		$(a^L, a^R) = (1, 0)$	$(a^L, a^R) = (1, 1)$
	$M_{\nu_R} > M_{W'}$	$M_{\nu_R} \ll M_{W'}$	$M_{\nu_R} \ll M_{W'}$	$M_{\nu_R} \ll M_{W'}$
BDT	1.91 TeV	1.85 TeV	–	–
Invariant mass	–	–	1.51 TeV	1.64 TeV

$W'_{R,L} \rightarrow tb$ search (5.0 fb^{-1}, 7 TeV)

Limits on coupling strength a^R and a^L

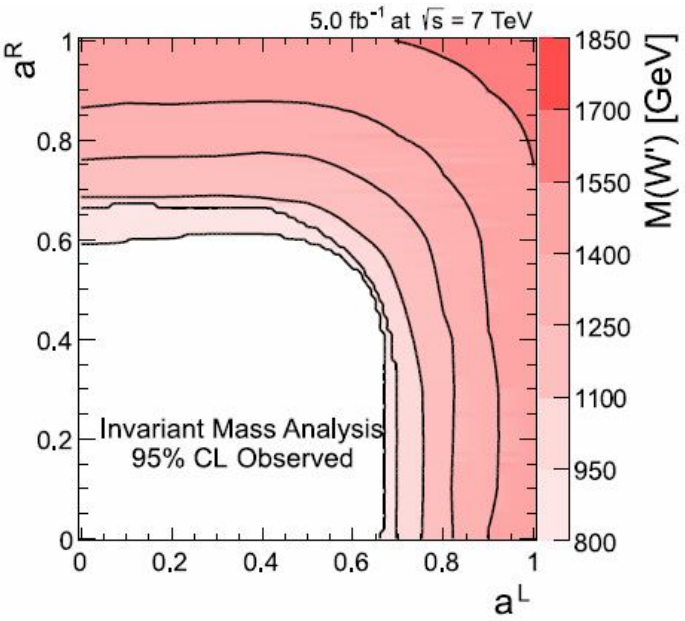
$$\mathcal{L} = \frac{V_{f_i f_j}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu [a^R_{f_i f_j}(1+\gamma^5) + a^L_{f_i f_j}(1-\gamma^5)] W'^\mu f_j + \text{h.c.},$$

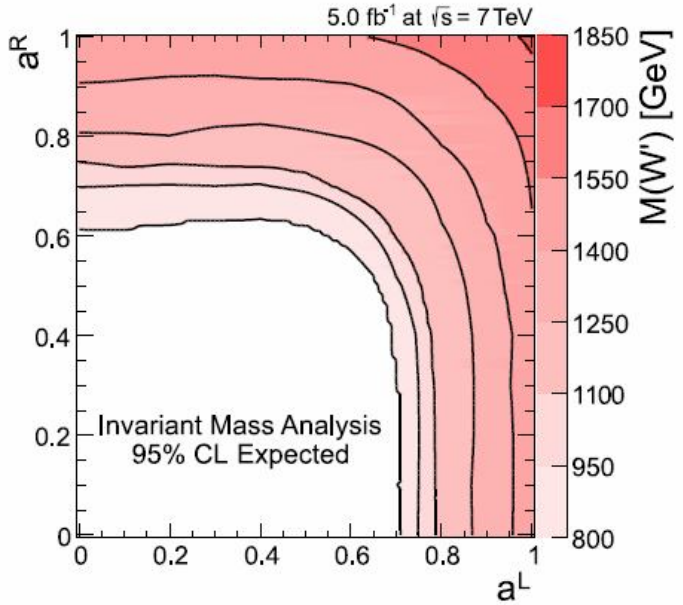
Procedure

- assume that a_{ud} (W' prod) and a_{tn} are the same
- vary a^L and a^R from 0 to 1
- reweight m_{tb} template for each value of a^L and a^R

$$\sigma = \sigma_{SM} + a^L_{ud} a^L_{tb} (\sigma_L - \sigma_R - \sigma_{SM}) + \left((a^L_{ud} a^L_{tb})^2 + (a^R_{ud} a^R_{tb})^2\right)\sigma_R + \frac{1}{2}\left((a^L_{ud} a^R_{tb})^2 + (a^R_{ud} a^L_{tb})^2\right)(\sigma_{LR} - \sigma_L - \sigma_R)$$

- Compute limit for each a^L, a^R ,m(W') hypothesis
- Compare to theory and set limits in a^R, a^L plane





Reach for W' boson at √s= 7/8 TeV

Z. Sullivan et al., arXiv:1208.4858v1 (2012)

Pheno analysis based on effective W' boson Lagrangian

- consider pure Right/Left W' boson couplings
- For W'_L assess effects of destructive/constructive interferences
- simple cut-based analysis performed at 7 & 8 TeV
- set exclusion limits on cross-section and couplings

Event selections

Lead jet	$E_{Tj_1} > 0.2 m_{W'}$	$\lvert\eta_{j_1}\rvert < 2.5$
b-tagged jet	$E_{Tb} > 20$ GeV	$\lvert\eta_b\rvert < 2.5$
Leading $e^{\pm}$ or $\mu^{\pm}$	$p_{Tl_1} > 20$ GeV	$\lvert\eta_{l_1}\rvert < 2.5$
Second $e^{\pm}$ or $\mu^{\pm}$	$p_{Tl_2} < 10$ GeV; or	$\lvert\eta_{l_2}\rvert > 2.5$
Missing E_T	$\not{E}_T > 20$ GeV	
Reconstructed top	$M_{l\nu b} < 200$ GeV	
W' mass window	$0.75 m_{W'} < M_{l\nu bj} < 1.1 m_{W'}$	

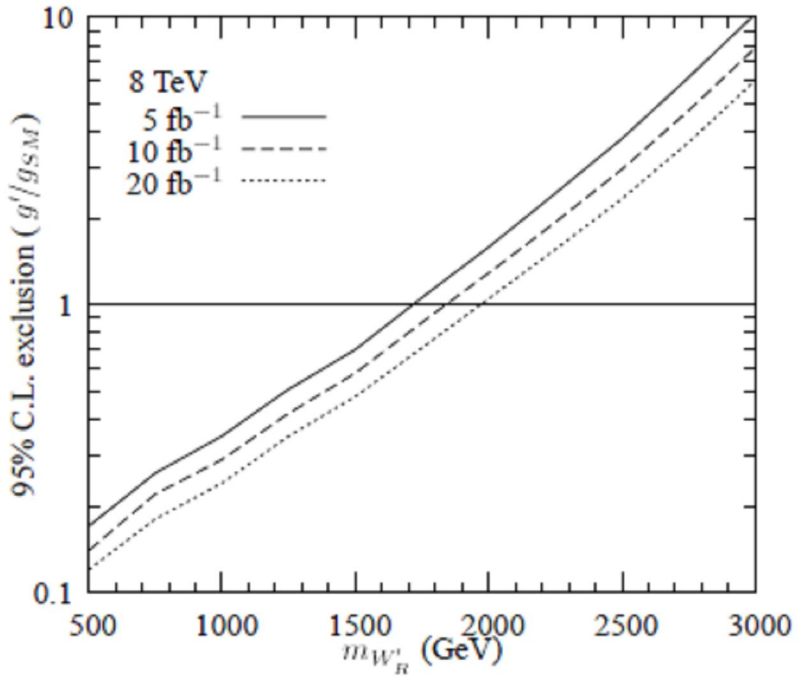
Mass Limits (5 fb^{-1})	7 TeV	8 TeV
W'_R	1.8 TeV	1.7 TeV
W'_L	1.7-1.9 TeV	1.6-1.7 TeV

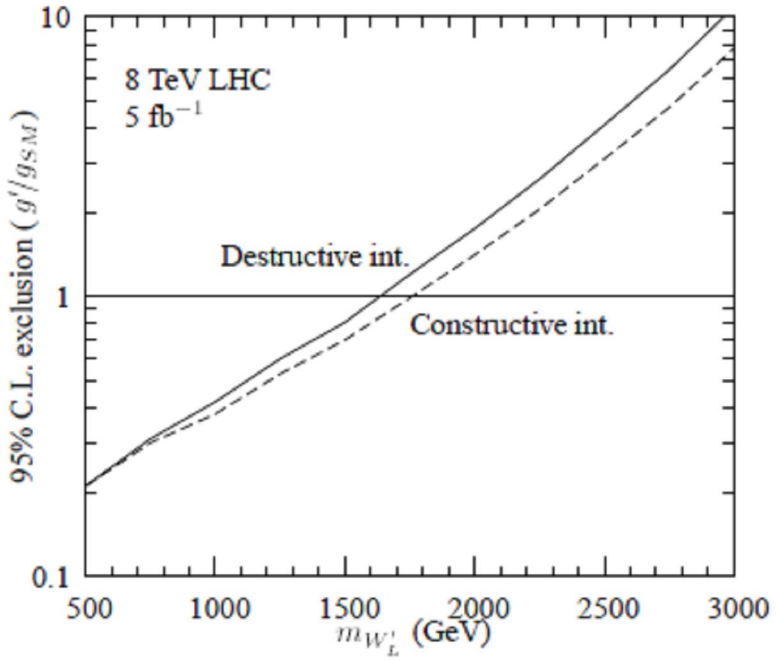
Reach slightly worse at 8 TeV (gluon initiated bckgd grow faster that quark initiated signal)

Limits on couplings

Exclusion Limit on coupling can be derived from cross-section limit

→ $\sigma(pp \to W' \to tb)$ scales roughly as ~ $(g'/g_{SM})^2$





Important to show exclusion for values larger than 1

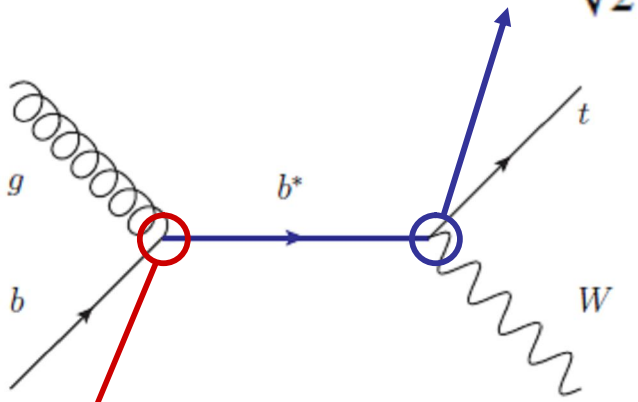
- theory remains perturbative up to g'/g_{SM} ~ 5
- but W' boson width scales as $(g'/g_{SM})^2$ → effect non negligible for g'/g_{SM} > 2-3 and need to be properly simulated.

b* search (4.7 fb^{-1}, 7 TeV)

arXiv:1301.1583v1 (submitted to PLB)

Single b*-quark produced through chromomagnetic interaction and decays to a W+t search performed in dilepton and lepton+jets final states and combined

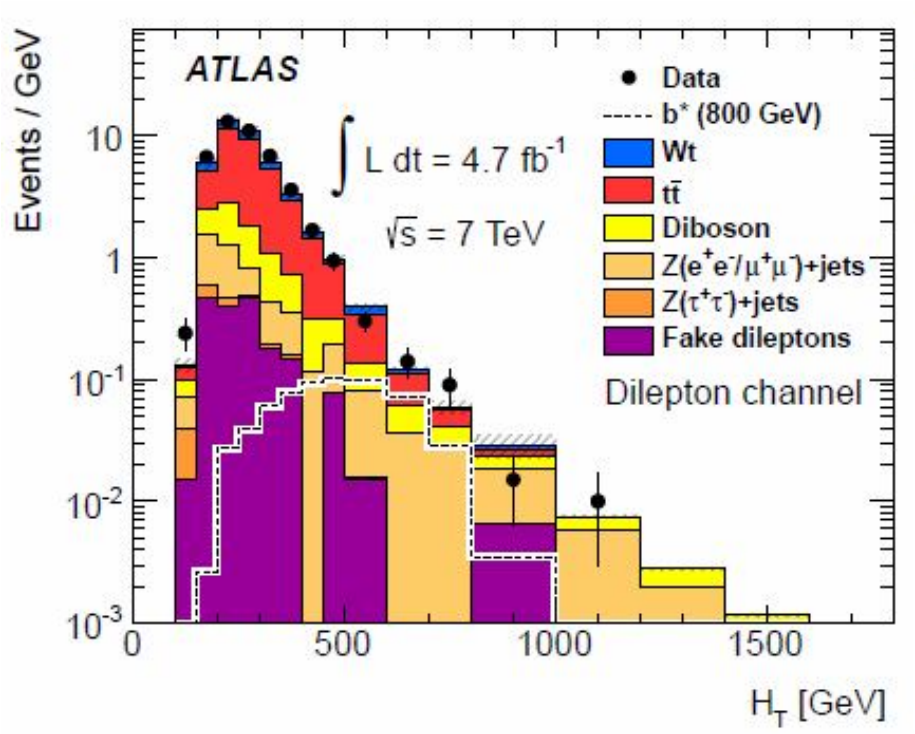
$$\mathcal{L} = \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t}\gamma^\mu \left(g_L P_L + g_R P_R\right) b^* + \text{h.c.}$$

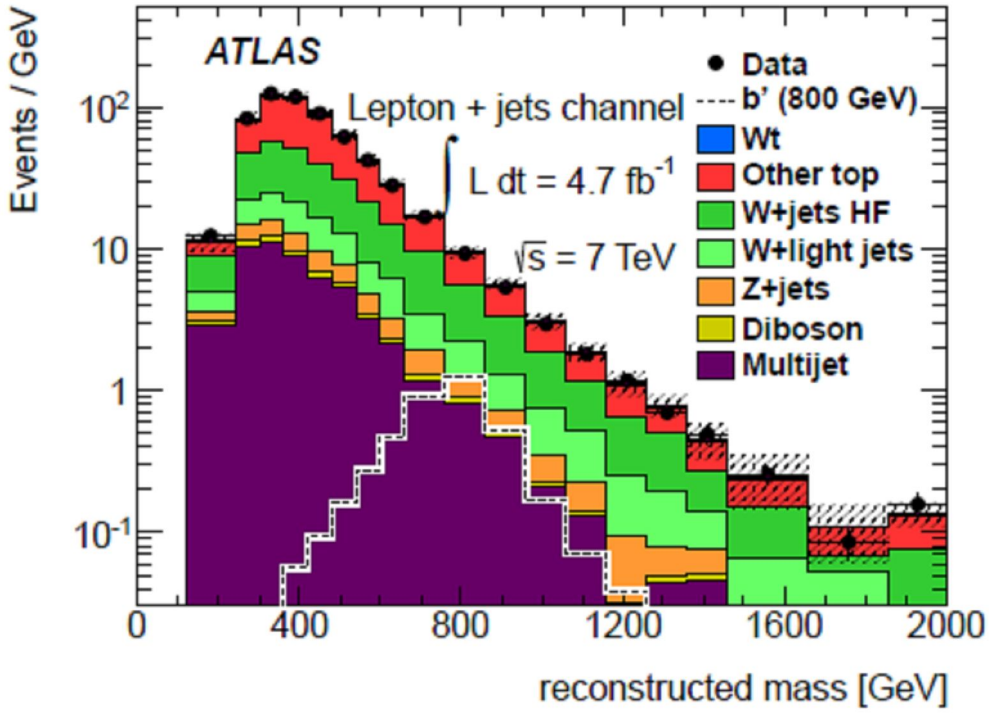


$$\mathcal{L} = \frac{g_s}{2\Lambda} G_{\mu\nu}\, \bar{b}\, \sigma^{\mu\nu} \left(\kappa_L^b P_L + \kappa_R^b P_R\right) b^* + \text{h.c.}$$

Signal model: MadGraph, generated right/left/vector-like processes

b* search

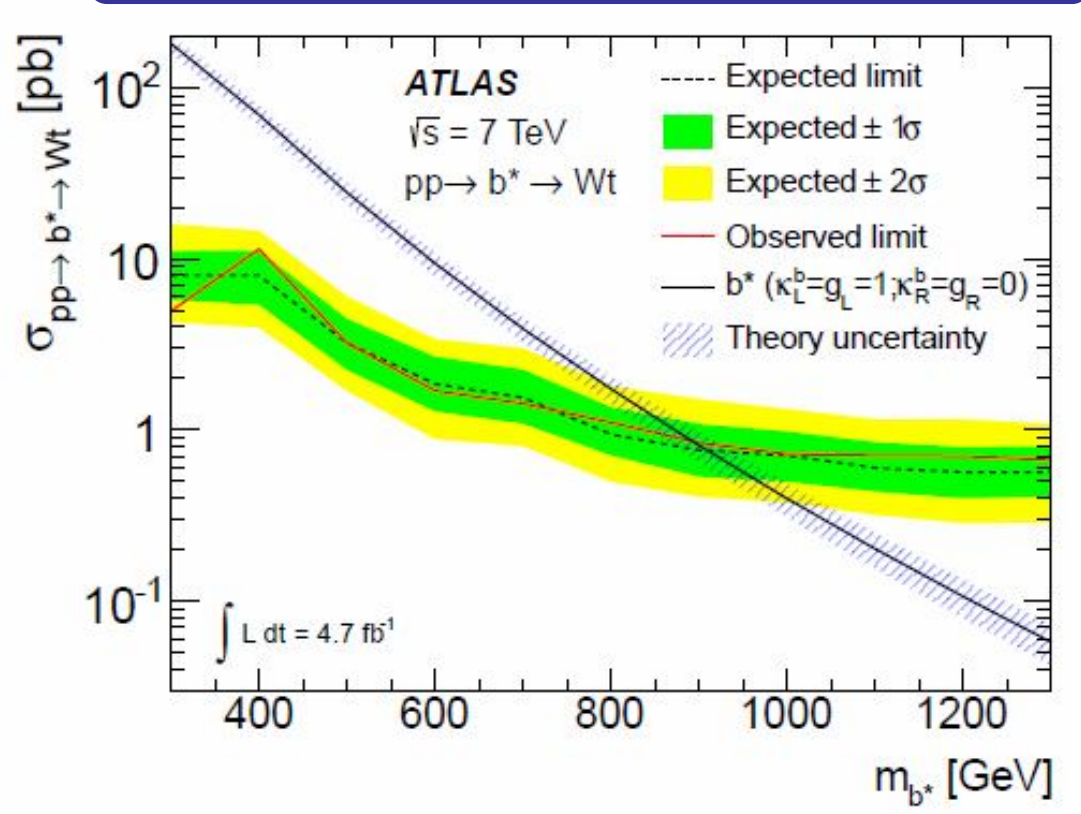




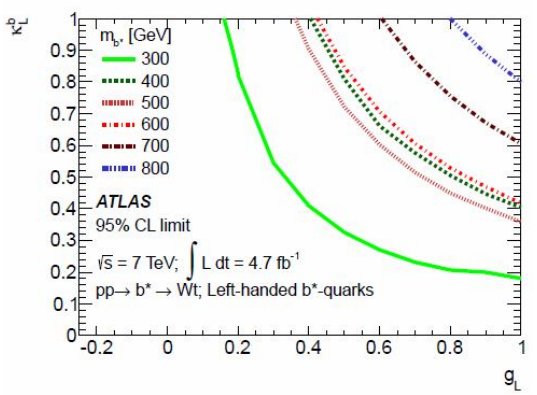
Discriminant distributions for each channel are combined using Bayesian method

b* search

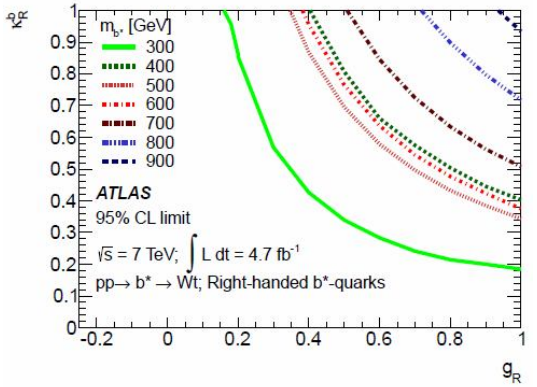
Limits on b* mass and couplings: $K_{L,R}$, $g_{L,R}$



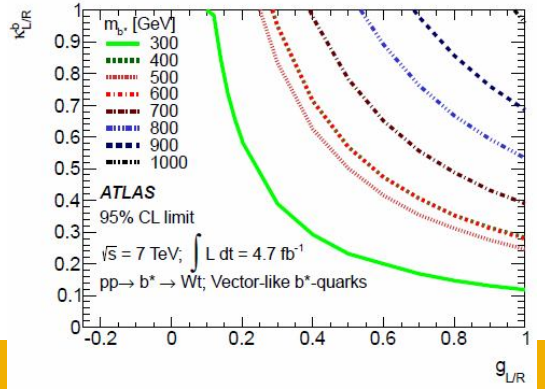
m(b*)>870 GeV at 95% C.L
(benchmark scenario)



(a)



(b)



Monotop searches

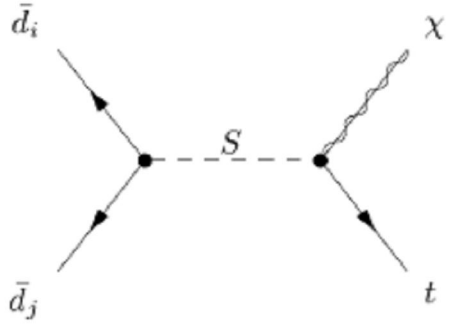
Slides from Timothée !

- Many BSM models predict final states with a single top quark + $\not{E}_T$, e.g. :

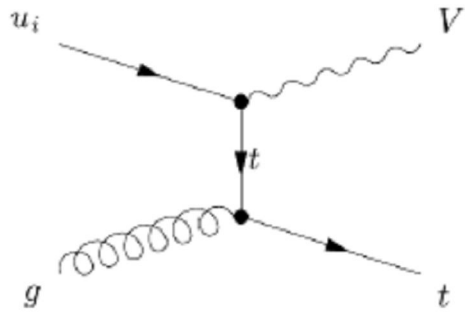
  $ug \to \tilde{u}_i \tilde{\chi}_0^1 \to t\tilde{\chi}_0^1\tilde{\chi}_0^1$ (2-neutralinos in R-parity violating SUSY)

  $\bar{d}\bar{d} \to V \to t\bar{\nu}$ (leptoquark decay in $SU(5)$ theories)

- A signature-based approach in new physics searches can be followed
- Phenomenological description with a most general effective Lagrangian
  Phys.Rev. D84 (2011) 074025 (*J. Andrea, B. Fuks*)



Resonant production



FC non resonant production

- New particules introduced with associated effective couplings

field	charge	spin	color multiplicity	antiparticle = particle	comment
	invisible particles				
ϕ	0	0	1	yes	non resonant production
χ	0	1/2	1	yes	resonant production
V	0	1	1	yes	non resonant production
	resonnances				
φ	$\pm 2/3$	0	3	no	decays into $t+\chi$
X	$\pm 2/3$	1	3	no	decays into $t+\chi$
$\tilde{\varphi}$	$\pm 1/3$	0	3	no	4-f effective interaction

Monotop searches

- Five scenarios defined in Phys.Rev. D84 (2011) 074025 (*J. Andrea, B. Fuks*)

Scenario	model type	mass of invisible state	σ_{tot} [pb] @8 TeV
S1	scalar resonance m_φ= 500 GeV	m_χ= 50 GeV	1.68
S2	vector resonance m_χ= 500 GeV	m_χ= 300 GeV	6.20
S3	flavour changing interaction (spin 0)	m_ϕ= 300 GeV	1.05
S4	flavour changing interaction (spin 1)	m_V= 50 GeV	186.7
S5	4-fermions effective interaction (m_Φ= 3 TeV)	m_χ= 0 GeV	2.7×10^{-4}

- Limits on cross-section vs. invisible state mass can be used to set limits on effective couplings and constrain new physics
- Result from CDF hadronic channel analysis in non-resonnant case :
  $\sigma \lesssim 0.5$ pb for a mass between 0 and 150 GeV at $\sqrt{s} = 1.96$ TeV
  Phys.Rev.Lett. 108 (2012) 201802
- Indirect constraint on monotop production in resonant case :
  use of LHC results on hadronic Z decays, K^0-$\overline{K^0}$ mixing or dijet production
  Phys.Rev. D86 (2012) 034008 (*Wang et al.*)
- Ongoing analyzes @8 TeV in leptonic and hadronic channel in ATLAS and CMS

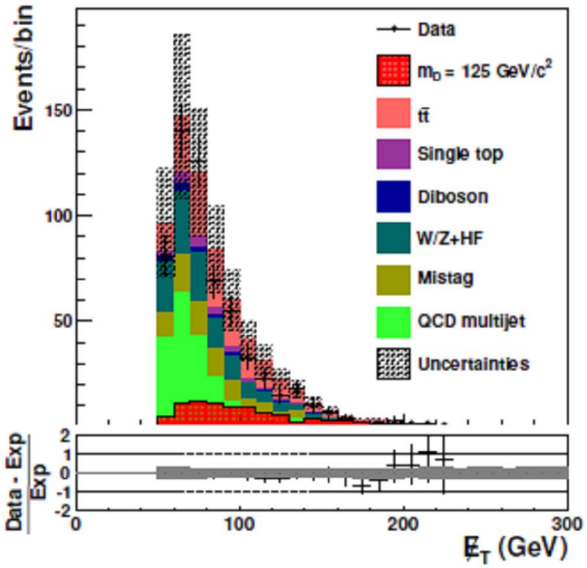
Conclusion and outlook

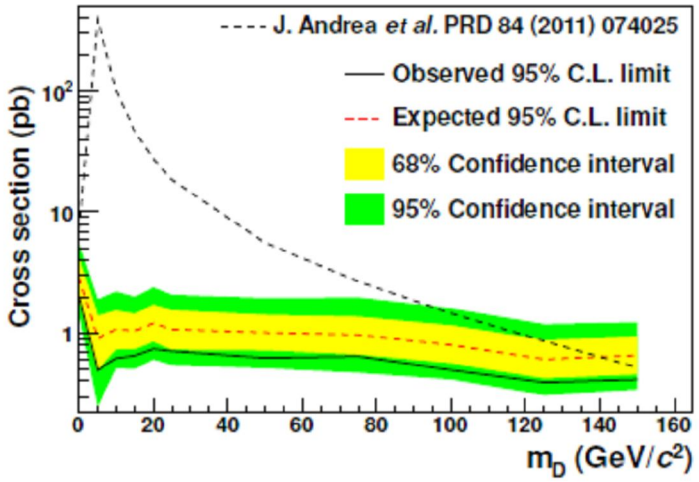
- **BSM searches in single-top physics at LHC**
  - Performed in parallel with indirect and SM measurements
  - So far search for W' boson, b* quark
  - Next: W' update, search for monotop events
  - Limits on couplings is as (more?) important as limits on masses
- **Future analysis paths**
  - Invest in boosted top topologies
  - Investigate full hadronic searches
- **Conclusion**
  - Rich sector, many interesting BSM signatures
  - Maintaining contact with your (favorite) theorists is very important

Backup material

CDF result

- Selection of events with monotop topology in hadronic channel
- Trigger : 2 calorimeter clusters + missing $\not\!\!E_T$
- $\not\!\!E_T$ distribution used as discriminative variable
- Result : $\sigma(p\bar{p} \to t + D) \lesssim 0.5\text{pb}$ for a mass between 0 and 150 GeV



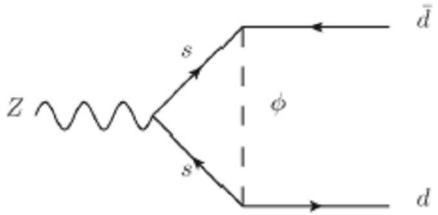


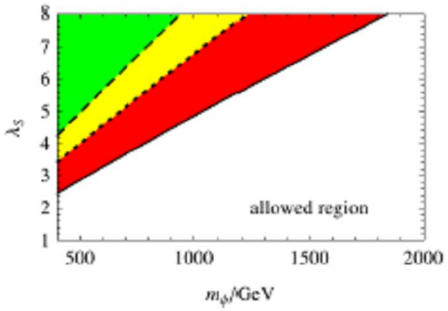
Phys.Rev.Lett. 108 (2012) 201802

Indirect constraints on resonant monotop production

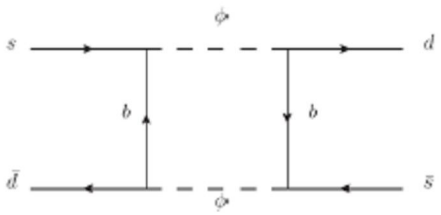
- For some cases, limits on the coupling of the scalar resonance ϕ to SM quarks can be set

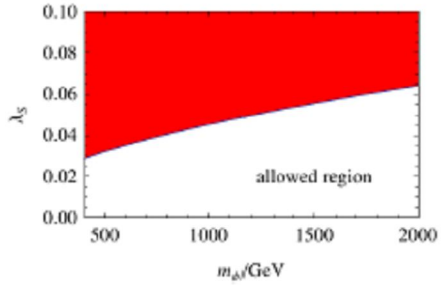
Using R_τ, with or without ϕ coupling to b, or using R_b



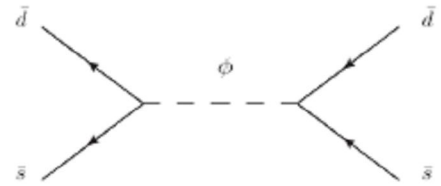


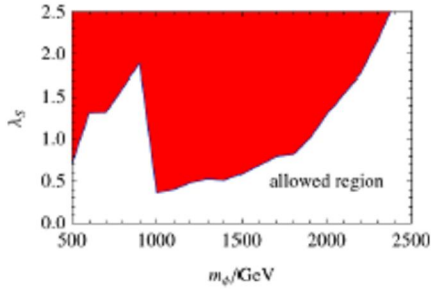
Using $m_{K_L} - m_{K_S}$, with ϕ coupling to b
$\Rightarrow$ contribution from $bb \to \phi$ can be neglected





Using di-jet cross-section, with ϕ coupling to b and hypotheses on the invisible particle





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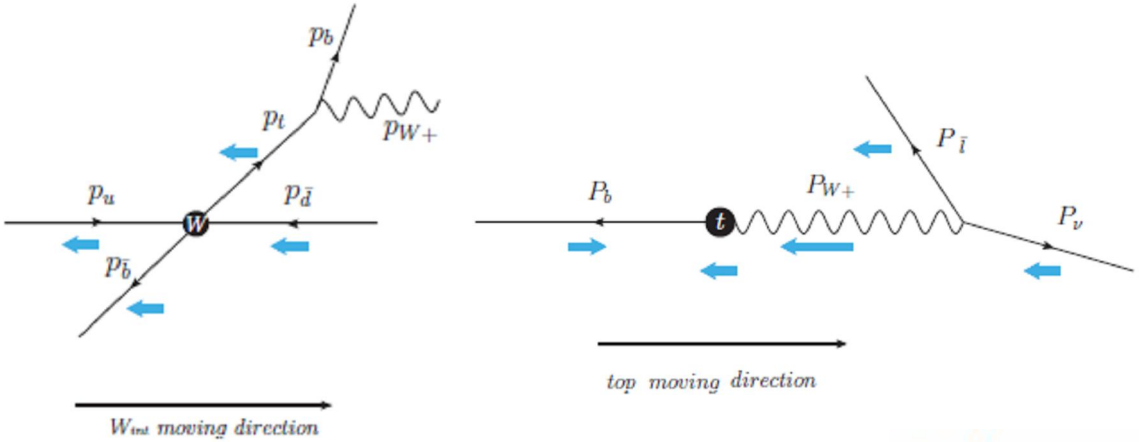
Chirality and helicity

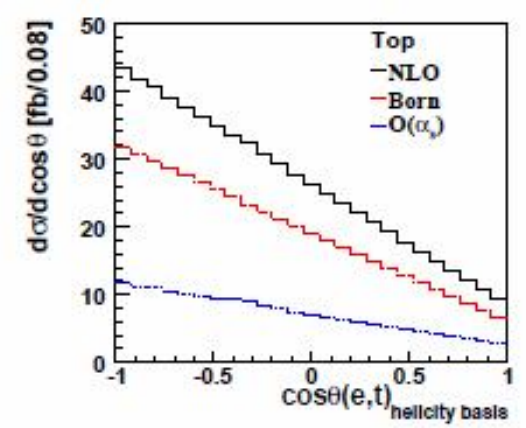
Spin correlation in qq' → W' → tb

- Impacts angular correlations in top production and decay
- See for example: http://arxiv.org/abs/0911.0620



The lepton moves in the direction of the top spin

- W/W'$_L$: opposite to top moving direction
- W'$_R$: same direction



Ex: SM single-top s-channel