Search for the production of an excited bottom quark decaying to tW in proton-proton collisions at $\sqrt{s} = 8$

Sarmad Masood Shaheen
On behalf of CMS Collaboration

中国物理学会高能物理分会第十二届全国粒子物理学术会议定于 2016

smshaheen@ihep.ac.cn

Aug 24, 2016

Institute of High Energy Physics
Chinese Academy of Sciences

Outline

The resulst of the today's talk has already been published JHEP 01 (2016) 166. CMS@IHEP group performed measurement in Lepton+jets channel thus made a major contribution.

- Motivation
- Theoretical overview
- Event Selection, backgound estimation and limit setting in:
  - All-hadronic
  - lepton+jets
  - Dilepton Channels
- Combination
- Systematics
- Results and summary

Motivation

- Standard Model is not the whole story of high energy physics.
- still need answers for:
  - Neutrino mass
  - Dark matter/ dark energy
  - Hierarchy Problems
  - Gravity

    for which SM offers no explanation.
- The existance of excited quarks has been predicted by a variety of models.
  - Warped Extra Dimensions: JHEP 0801 (2008) 069
  - Randall-Sundrum models: Phys.Rev.Lett. 100 (2008) 171604
  - Composite Higgs models: JHEP 1207 (2012) 158, Phys.Rev. D86 (2012)
  - Composite quark models: Phys.Lett. B396 (1997) 161-166
- Today's talk will cover the first search for an excited third-generation bottom quark(b^*) at CMS using 8TeV data using the tW decay mode.
- Searches b^*quark has been perfromed by CMS in gb decay mode resulting in an exclusion region between 1.2 and 1.6 TeV. Phys. Rev. D 91 (2015) 052009
- Searches have also been carried out by ATLAS with a lower limit on b^*quark mass of about 1 TeV. Phys. Lett. B 721 (2013) 171

Theoretical Overview

- A strong interaction of gluon and bottom quark can produce b*.
- The following Langrangian explains the corresponding interaction.

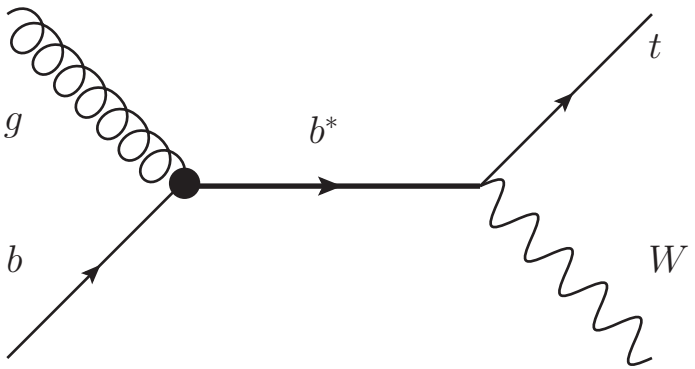
$$\mathcal{L} = \frac{\mathbf{g_s}}{2\Lambda} G_{\mu\upsilon} \overline{b} \sigma^{\mu\upsilon} (\kappa_L^b P_L + \kappa_R^b P_R) b^* + h.c$$

where Λ is the scale of compositness choosen to be the b*mass, h.c is hermitian conjugate.
Phys. Rev. D 42 (1990) 815

- The weak decay of b* can be explained by the langrangian:

$$\mathcal{L} = \frac{\mathbf{g_2}}{\sqrt{2}} W_\mu^+ \overline{t} \gamma^\mu (\mathbf{g}_L P_L + \mathbf{g}_R P_R) b^* + h.c$$

- Can be left-handed, right-handed or vector-like.

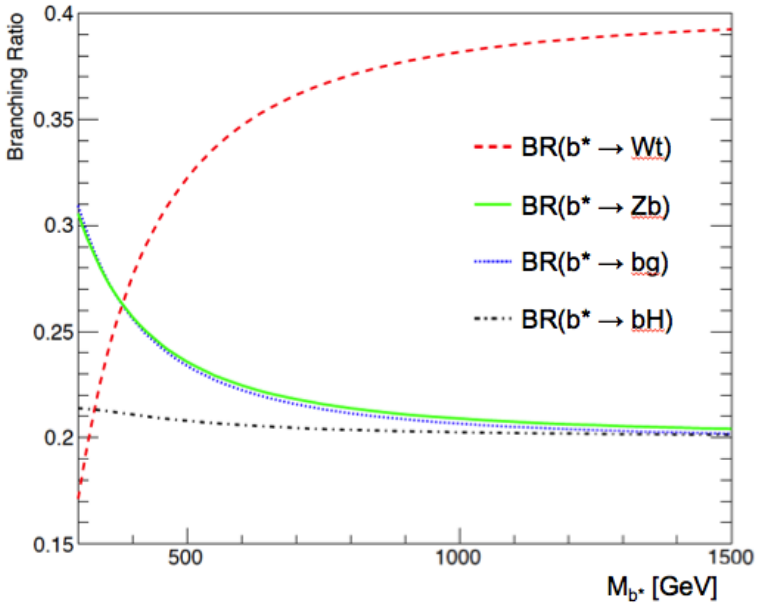


Analysis Approach

- b*can decay to gb, bZ, bH and tW.
- Increasing branching ratio for tW compels to search for b*in tW decay mode.

- The tW final states results in the following channels.
  All hadronic
  Lepton+jets
  Dilepton
- Used the signal samples:
  - Left-handed: which requires $g_L = 1,\ \kappa_L^b = 1,\ g_R = 0,\ \kappa_R^b = 0$
  - Right-handed requiring: $g_L = 0,\ \kappa_L^b = 0,\ g_R = 1,\ \kappa_R^b = 1$
  - Vector-like: $g_L = 1,\ \kappa_L^b = 1,\ g_R = 1,\ \kappa_R^b = 1$
- The results have been performed for the unit coupling($g_L,\ \kappa_L^b,\ g_R,\ \kappa_R^b = 1$) and have been extrapolated for κ-g plane.

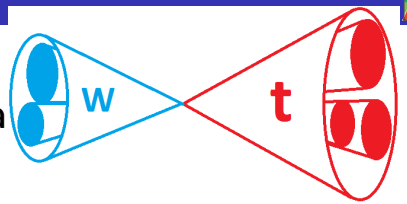
Phys. Rev. D 86 (2012) 094006



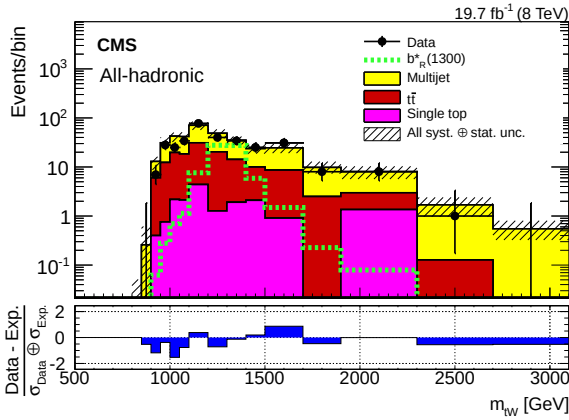
All hadronic channel

Event Selection and Background Estimation

- Characterized by a top and W boson decaying hadronically.
- Top and W daughters are highly boosted. thus reconstructed as a single jet.
- used trigger with H_T>750, where H_T is the scaler sum of transverse momenta of the all the jet candidates.
- Two CA(Cambridge-Aachen) jets with p_T at least 425 GeV.
- One jet is W-tagged and other is t-tagged. W and t-tagging algorithems are used.
- Main backgrounds are multijet and $t\bar{t}$ event.
- Multijet background estimated from data.
  - Control region has been defined by selecting a W-tagged jet in the region $30 < m_{jet} < 70$GeV or $m_{jet} > 100$GeV.
  - Measure the top-mistagging rate for multijets in control region.
  - Apply this top-mistagging rate to the pre top-tagged sample in the Signal region.
- $t\bar{t}$ background is estimated from data
  - The control region has been defined by invering W tagging requirements($m_{jet} > 130$GeV and $\tau_2/\tau_1 > 0.5$)..
  - Performed a fit to the invariant mass of the top quark candidate.
- Single top from MC prediction

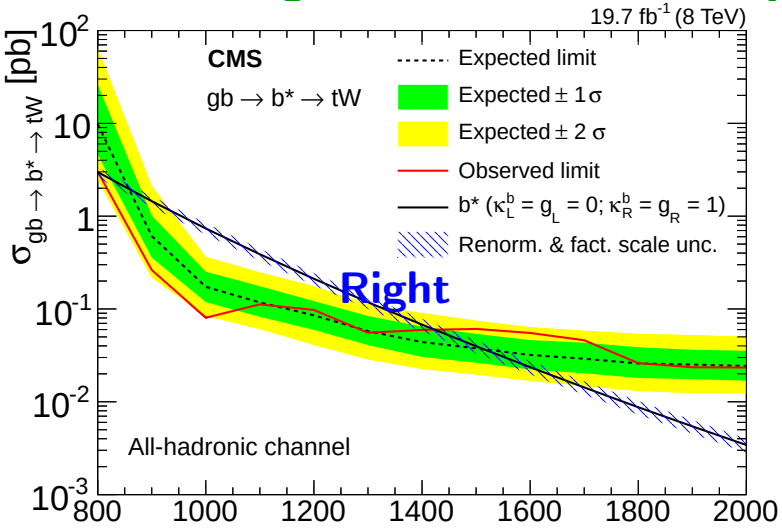


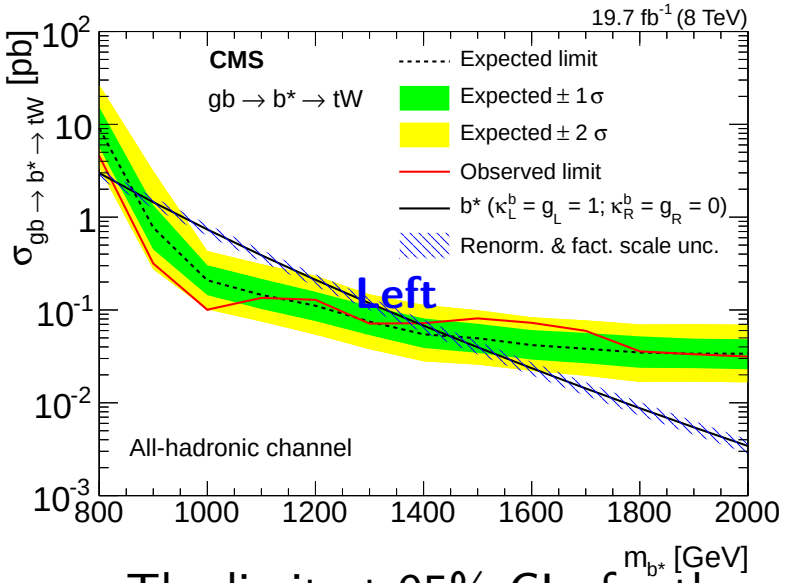
Sample		Yield ± stat. ± syst.
b^*_L	800 GeV	26.0 ± 1.9 ± 7.4
b^*_L	1300 GeV	57.8 ± 0.6 ± 4.0
b^*_L	1800 GeV	4.1 ± 0.0 ± 0.2
b^*_R	800 GeV	33.4 ± 2.2 ± 9.1
b^*_R	1300 GeV	72.5 ± 0.6 ± 4.8
b^*_R	1800 GeV	5.4 ± 0.0 ± 0.3
$t\bar{t}$		129 ± 3 ± 42
Single top		19.0 ± 2.9 ± 6.5
Multijet		211 ± 0 ± 38
SM expected		359 ± 4 ± 57
Data		318

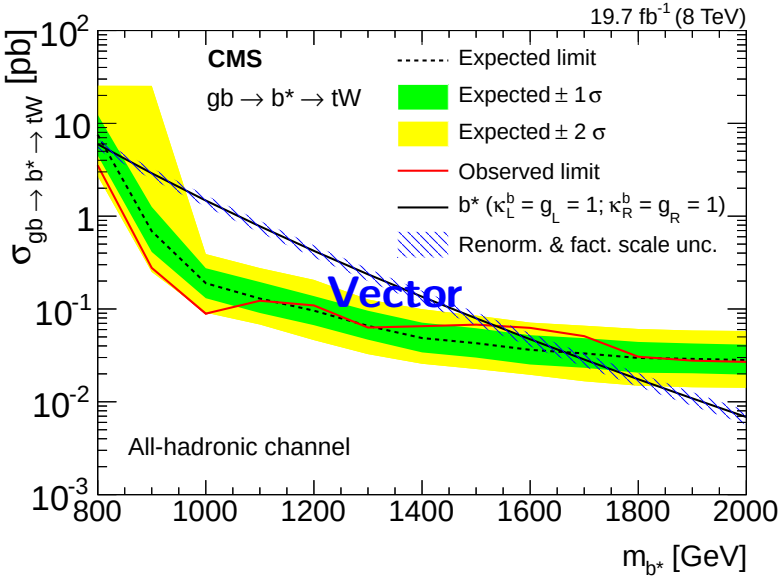


Limit Setting

- A binned maximum likelihood fit to the tW invariant mass has been perfromed to extract the signal cross section. Basyesian method has been used to set the limits







- The limit at 95% CL, for the case of unit couplings, on b*quark mass in the all-hadronic case.

	Left-handed	Right-handed	Vector-like
Expected	890 - 1460	889 - 1520	842 - 1670
Observed	858 - 1390	803 - 1430	1540

- The observed distributions are consistent with those from the background only prediction.

Lepton+Jets Channel

Event Selection and Background Estimation

Event Selection

- Exactly one isolated electron or muon + a b jet, at least two light flavor jets.
- Signal is defined by requiring:
  exactly three jets with $p_T > 40$ GeV, $|\eta| < 2.4$. One of the three jets must be a b jet which satisfies the b-tagging selection:
  exactly one electron with $p_T > 130$ GeV and $|\eta| < 2.4$ (Electron Channel) or:
  exactly one muon with $p_T > 130$ GeV and $|\eta| < 2.1$(Muon Channel).
- Veto on additional loose electron/muon.

Background Estimation

- Contributions of Single top, ttbar, diboson, Z+jets processes are taken from MC.
- Multijet background is estimated from data:
  - Electron channel:by performing a fit to the E_T^{miss}
  - Muon channel: by performing a fit to the transverse mass of W boson decaying leptonically.

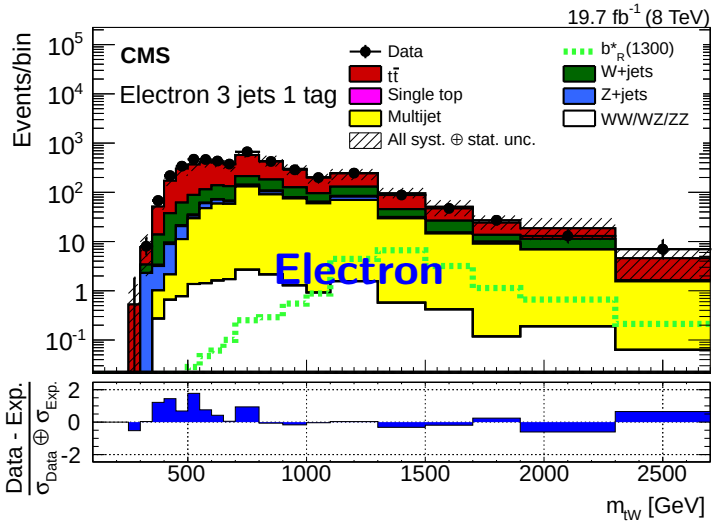
  Multijet background from control sample is normalized to the fitted yield.
- W+jets background is estimated by performing a template fit to the reconstructed invariant mass of W boson and a b jet.
  W+jets template is taken from simulation and normalized to fitted yield.

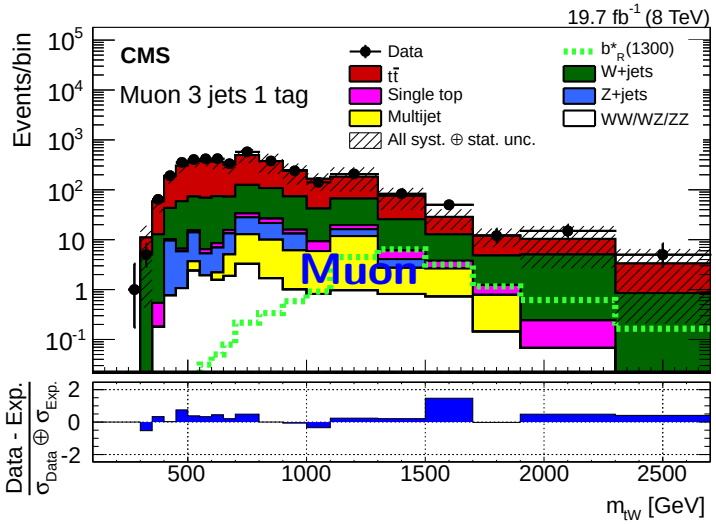
Event yield and data/MC Comparison

The following table showes the event yield after the final selection, normalized to an integrated luminosity of 19.7 fb^{-1}.

Sample	Yield ± stat. ± syst. Electron channel	Yield ± stat. ± syst. Muon channel
b^*_L 800 GeV	300 ± 6 ± 50	311 ± 6 ± 51
b^*_L 1300 GeV	11.9 ± 0.2 ± 3.3	12.7 ± 0.2 ± 3.5
b^*_L 1800 GeV	0.8 ± 0.0 ± 0.3	0.7 ± 0.0 ± 0.3
b^*_R 800 GeV	383 ± 6 ± 63	396 ± 7 ± 66
b^*_R 1300 GeV	18.5 ± 0.2 ± 5.0	18.2 ± 0.2 ± 4.9
b^*_R 1800 GeV	1.0 ± 0.0 ± 0.4	1.0 ± 0.0 ± 0.4
$t\bar{t}$	2581 ± 23 ± 370	2736 ± 23 ± 400
Single top	364 ± 4 ± 78	387 ± 4 ± 84
WW/WZ/ZZ	17.9 ± 1.2 ± 2.7	19.4 ± 1.4 ± 3.4
W+jets	671 ± 100 ± 230	639 ± 87 ± 150
Z+jets	92 ± 15 ± 33	80 ± 13 ± 33
Multijet	678 ± 100 ± 150	48^{+78}_{-48} ± 23
SM expected	4404 ± 150 ± 470	3909 ± 120 ± 440
Data	4368	3887

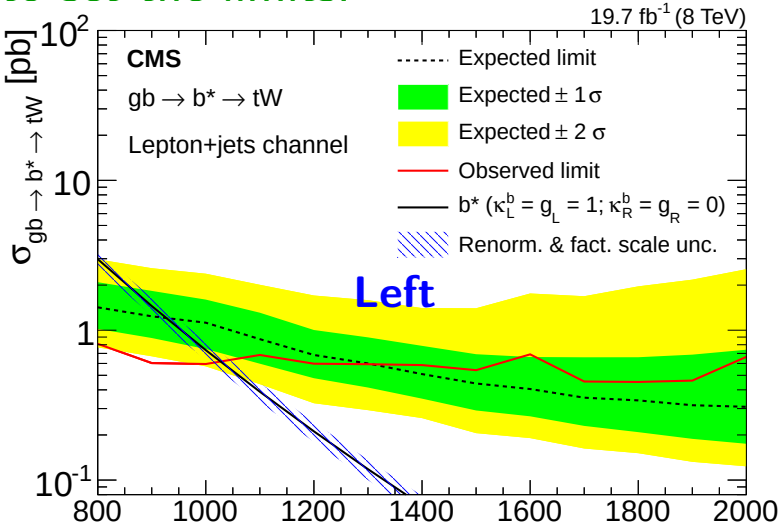
Invariant mass in data compared with the SM background estimation

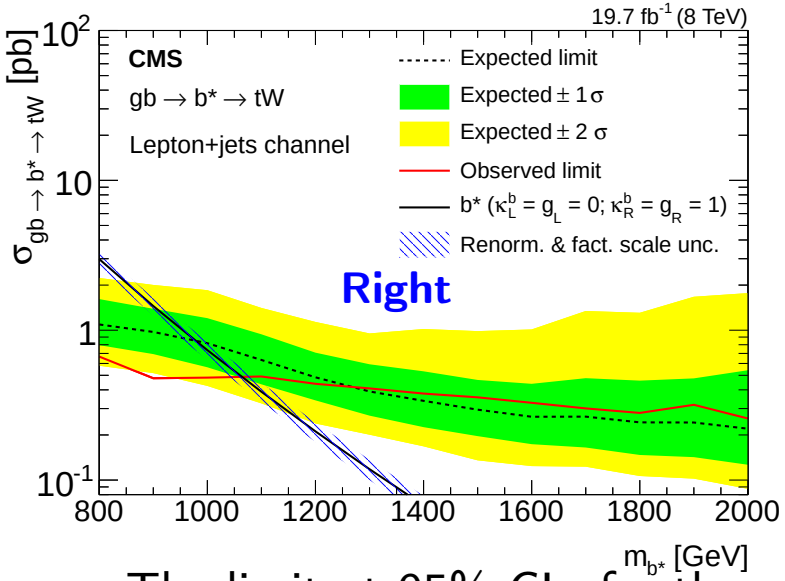


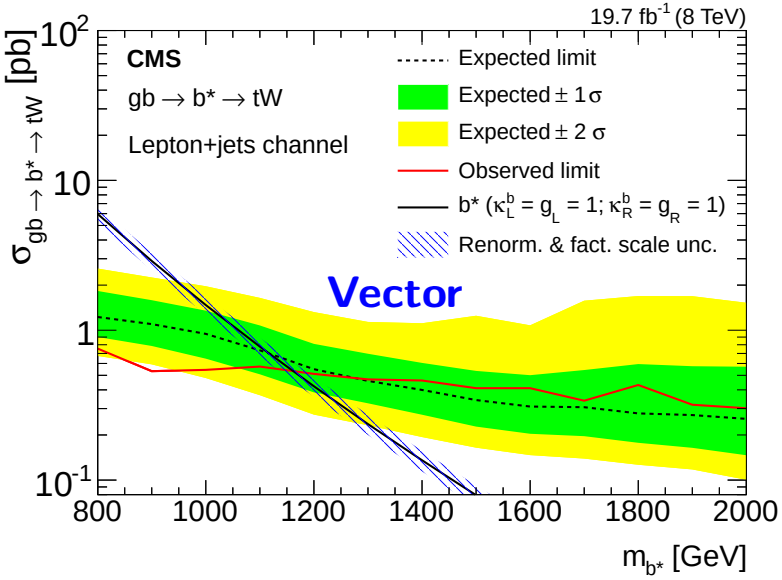


Limit Setting

- A binned maximum likelihood fit to the tW(lepton+jets+MET) invariant mass has been perfromed to extract the signal cross section. Basyesian method has been used to set the limits.







- The limit at 95% CL, for the case of unit couplings, on b*quark mass in lepton+jet channel.

	Left-handed	Right-handed	Vector-like
Expected	935	985	1130
Observed	1030	1070	1170

- The observed distributions are consistent with those from the background only prediction.

Dilepton Channel

Event selection and background estimation

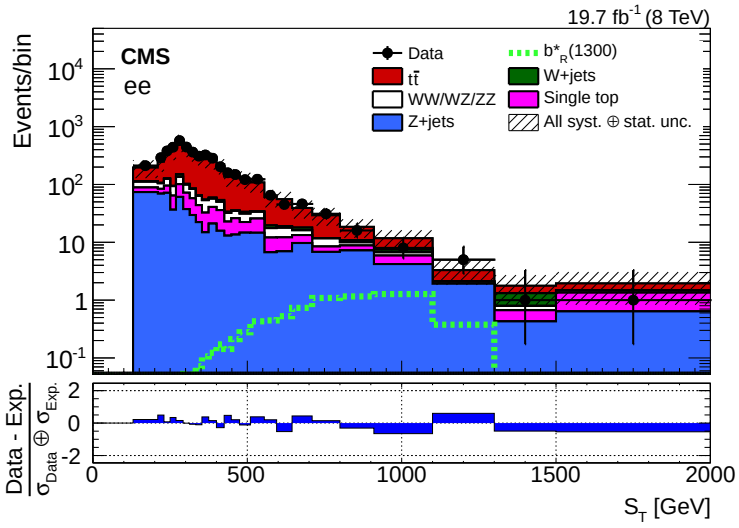
Event selection

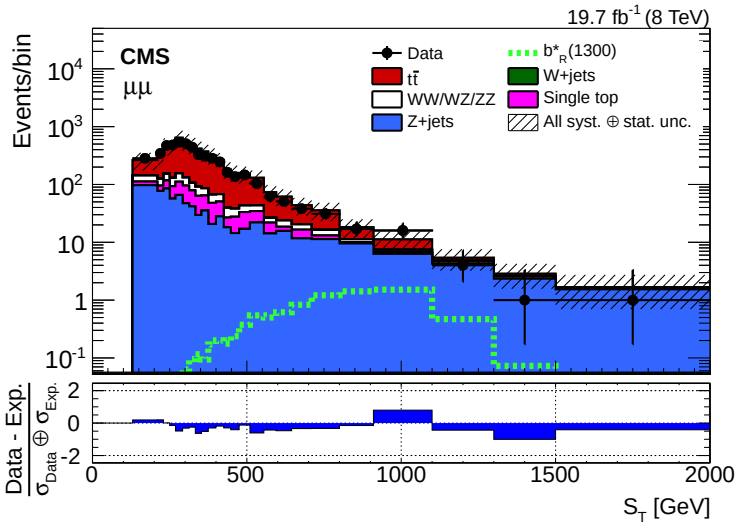
- Characterized by two isolated, oppositely charged electrons or muons and at least one jet.
- Signal region is defined by having:
  jet with $p_T > 30$ and $|\eta| < 2.5$
  Two leptons having $p_T > 30$ and $|\eta| < 2.5(2.4)$ for electrons(Muons)
- Required to have opposite charge, $\Delta R(l,l) > 0.3$

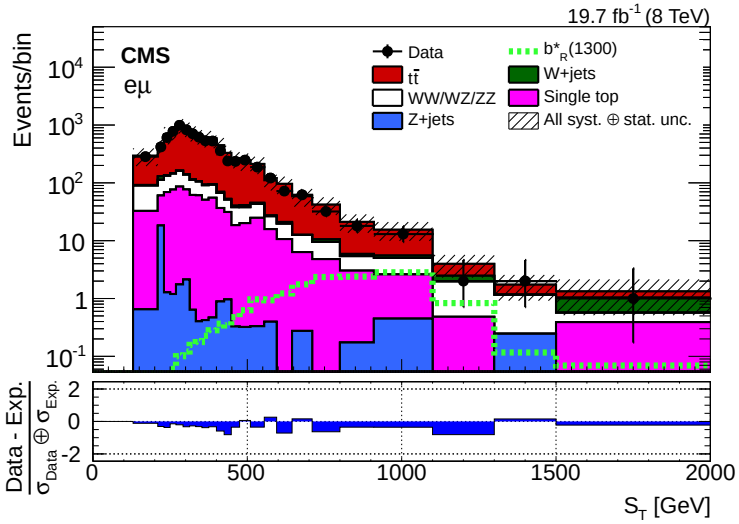
Background Estimation

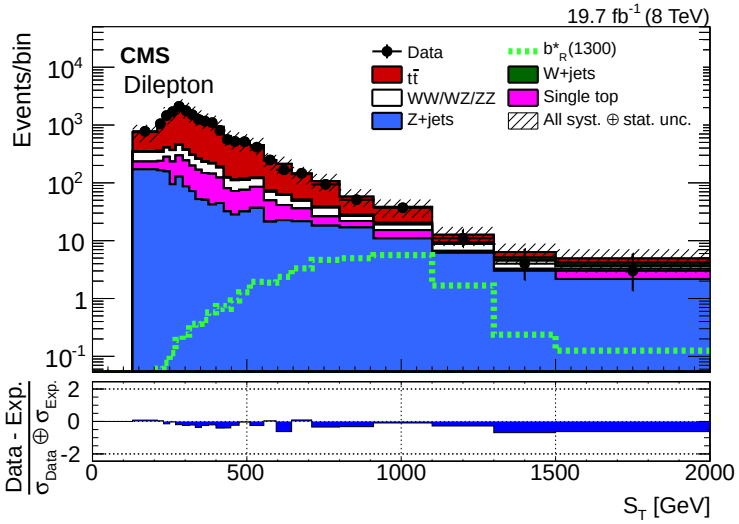
- Main backgrounds are $t\bar{t}$, single top quark, W+jets, Z+Jets and diboson.
- Dominating backgrounds are predicted by simulation.
- $E_T^{miss} > 40$ GeV to reduce top quark background(30%), W+jets(50%), diboson(60%) and Z+jets(95%)
- Most of diboson background is removed by requiring: m(2l)>120 GeV
- Multijet and W+jets background:
  Study has been performed using the same sign events.
  Multijet is found to be negligible.
  W+jets agrees well with the MC simulation prediction.
  Confirmation of the correct simulation of the dominant background sources has been made by comparing the control regions with the data.

Background estimation



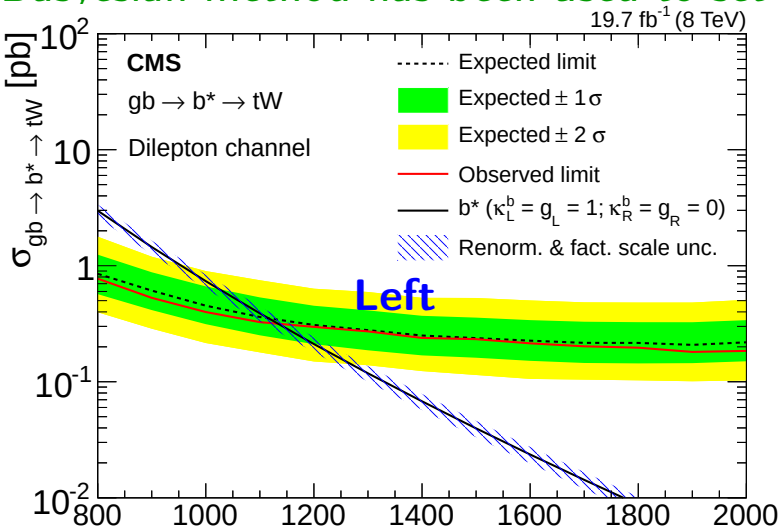


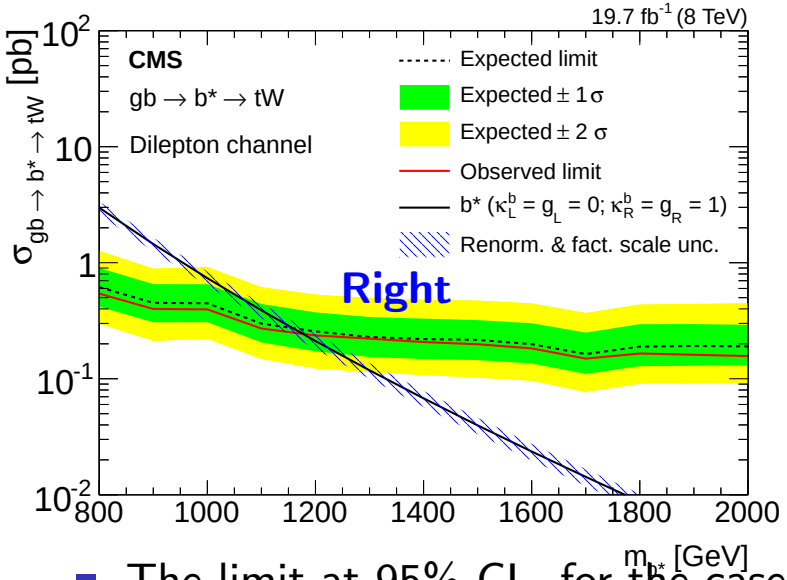


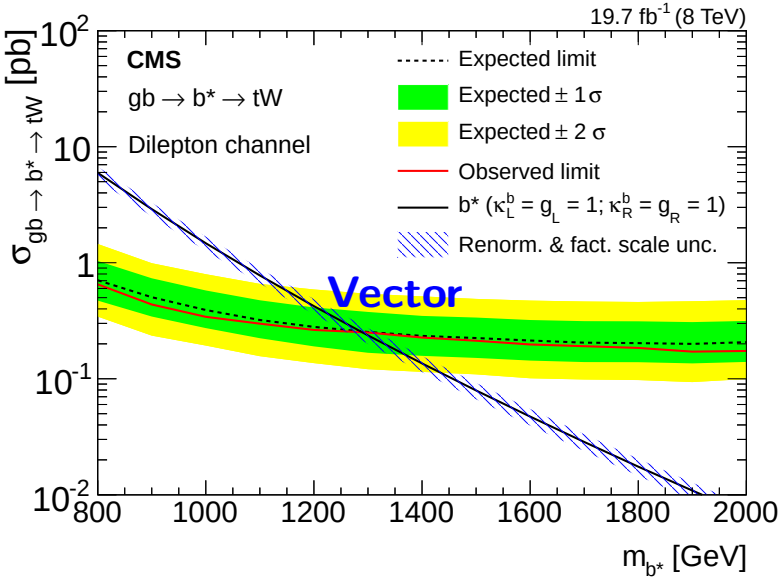


Limit Setting

- A binned maximum likelihood fit to the scaler sum S_T of the p_T of the two leading leptons, the jet with the highest p_T and E_T^{miss} has been performed to extract signal cross section. Basyesian method has been used to set the limits.







- The limit at 95% CL, for the case of unit couplings, on b*quark mass in dilepton channel.

	Left-handed	Right-handed	Vector-like
Expected	1120	1170	1290
Observed	1140	1180	1290

- The observed distributions are consistent with those from the background only prediction.

Limit Combination

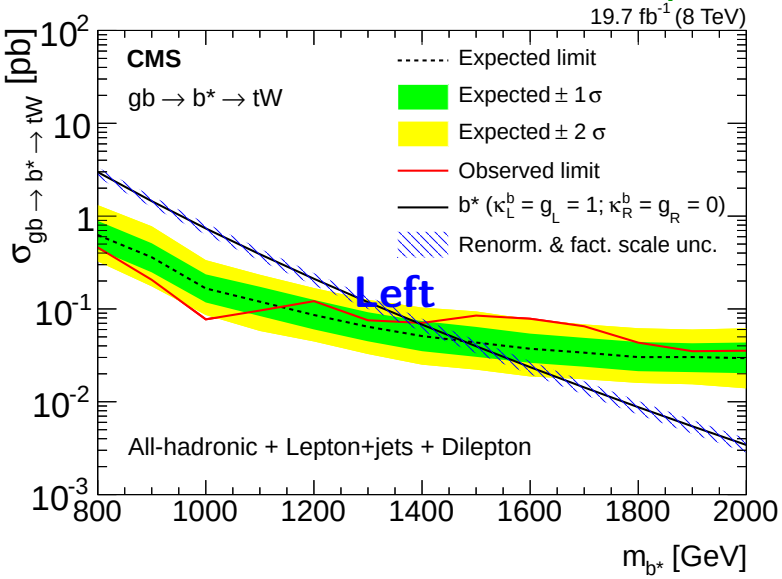
- All the channels are combined to enhance the sensitivity of the upper limit on the gb $\rightarrow$ b$^*\rightarrow$ tW production cross section.
- The overlap of the signal region events is negligible. No overlapping for all hadronic and other channels.
- Bayesian method(as implemented in the Theta framework) using likelihood composed of Poisson probabilities for each bin.
- Systematic uncertainties, for all the channels and their combination can be divided into:
  theoretical uncertainty
  background normalization uncertainty
  instrumental uncertainty and
  measurement-related uncertainty.
- Systematic uncertainties affecting both shape and event yield are taken into account.
  Shape of each distribution in each channel is determined and normalization is set to 1 and then estimate is made.
  Upper and lower distributions are obtained(normalized to one) and event yield is estimated for the two limiting cases.

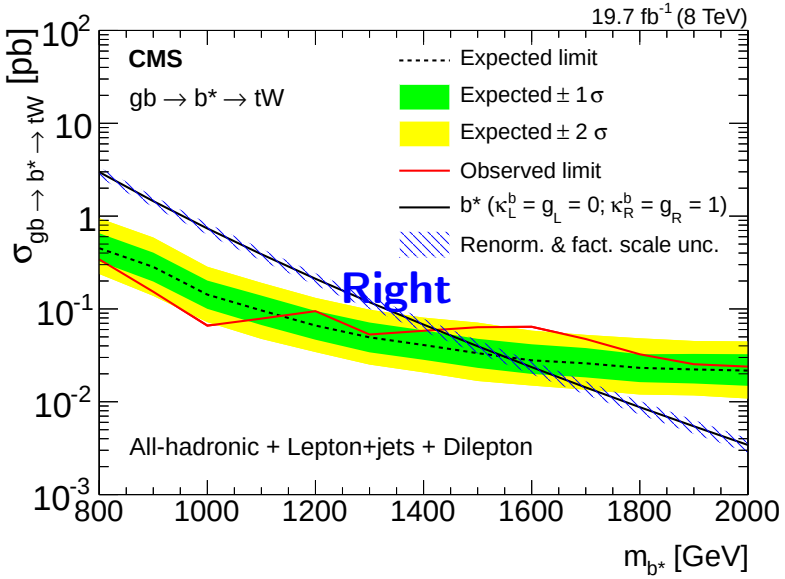
Systematic Uncertainty

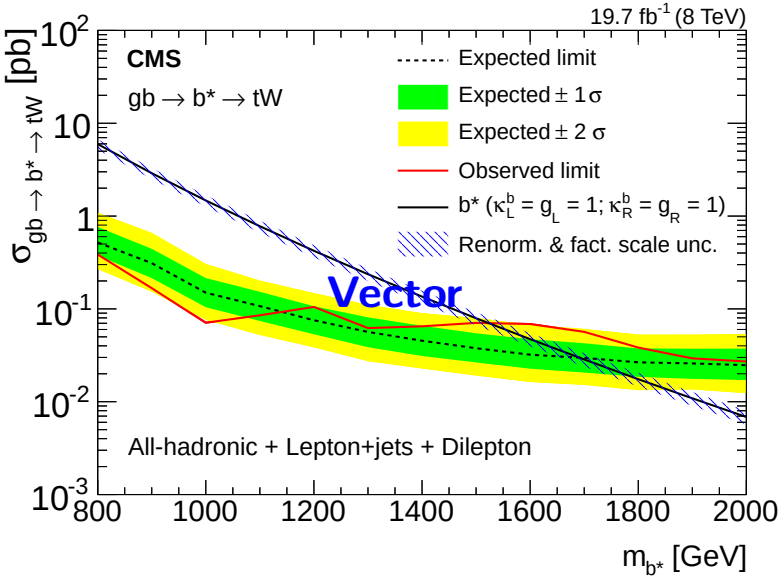
Source of uncertainty	Uncertainty	All-hadronic	Lepton+jets	Dilepton
Integrated luminosity	2.6%	$\oplus$	$\oplus$	$\oplus$
$t\bar{t}$ cross section	5.3%		$\oplus$	$\oplus$
$t\bar{t}$ normalization from data	22%	$\odot$		
Single top quark t-channel σ	15%	$\oplus$	$\oplus$	
Single top quark tW-channel σ	20%	$\oplus$	$\oplus$	$\oplus$
Single top quark s-channel σ	30%	$\oplus$	$\oplus$	
Diboson cross section	30%		$\oplus$	$\oplus$
Z+jets cross section	20%		$\oplus$	$\oplus$
W+jets cross section	8%			$\odot$
Double lepton triggers	2%			$\odot$
Dilepton muon ID and isolation	2%			$\odot$
Dilepton electron ID and isolation	2%			$\odot$
Dilepton pileup uncertainty	2.6%			$\odot$
W tagging	8%	$\odot$		
t tagging	13%	$\odot$		
Unclustered energy (E_T^{miss} uncertainty)	10%		$\odot$	
Single-lepton triggers	$\pm 1\sigma(p_T, \eta)$		$\odot$	
H_T trigger	$\pm 1\sigma(p_{T1} + p_{T2})$	$\odot$		
Electron ID and isolation	$\pm 1\sigma(p_T, \eta)$		$\odot$	
Muon ID and isolation	$\pm 1\sigma(p_T, \eta)$		$\odot$	
Jet energy scale	$\pm 1\sigma(p_T, \eta)$	$\oplus$	$\oplus$	$\oplus$
Jet energy resolution	$\pm 1\sigma(\eta)$	$\oplus$	$\oplus$	$\oplus$
Pileup uncertainty	$\pm 1\sigma$		$\odot$	
b tagging efficiency	$\pm 1\sigma(p_T, \eta)$		$\odot$	
b mistagging rate	$\pm 1\sigma(p_T, \eta)$		$\odot$	
Multijet background	sideband	$\odot$	$\odot$	
W+jets background	sideband		$\odot$	
PDF uncertainty	$\pm 1\sigma$		$\odot$	
$t\bar{t}$ μ_R and μ_F scales	$4Q^2$ and $0.25Q^2$	$\oplus$	$\oplus$	$\oplus$
Top quark mass	$\pm$ 1 GeV for m_{top}		$\odot$	
Simulation statistical uncertainty		$\odot$	$\odot$	$\odot$

Limit Setting

- A binned maximum likelihood fit to the scaler sum S_T of the p_T of the two leading leptons, the jet with the highest p_T and E_T^{miss} has been performed to extract signal cross section.







- The limit at 95% CL, for the case of unit couplings, on b*quark mass in all-hadronic, lepton+jets and dilepton channel.

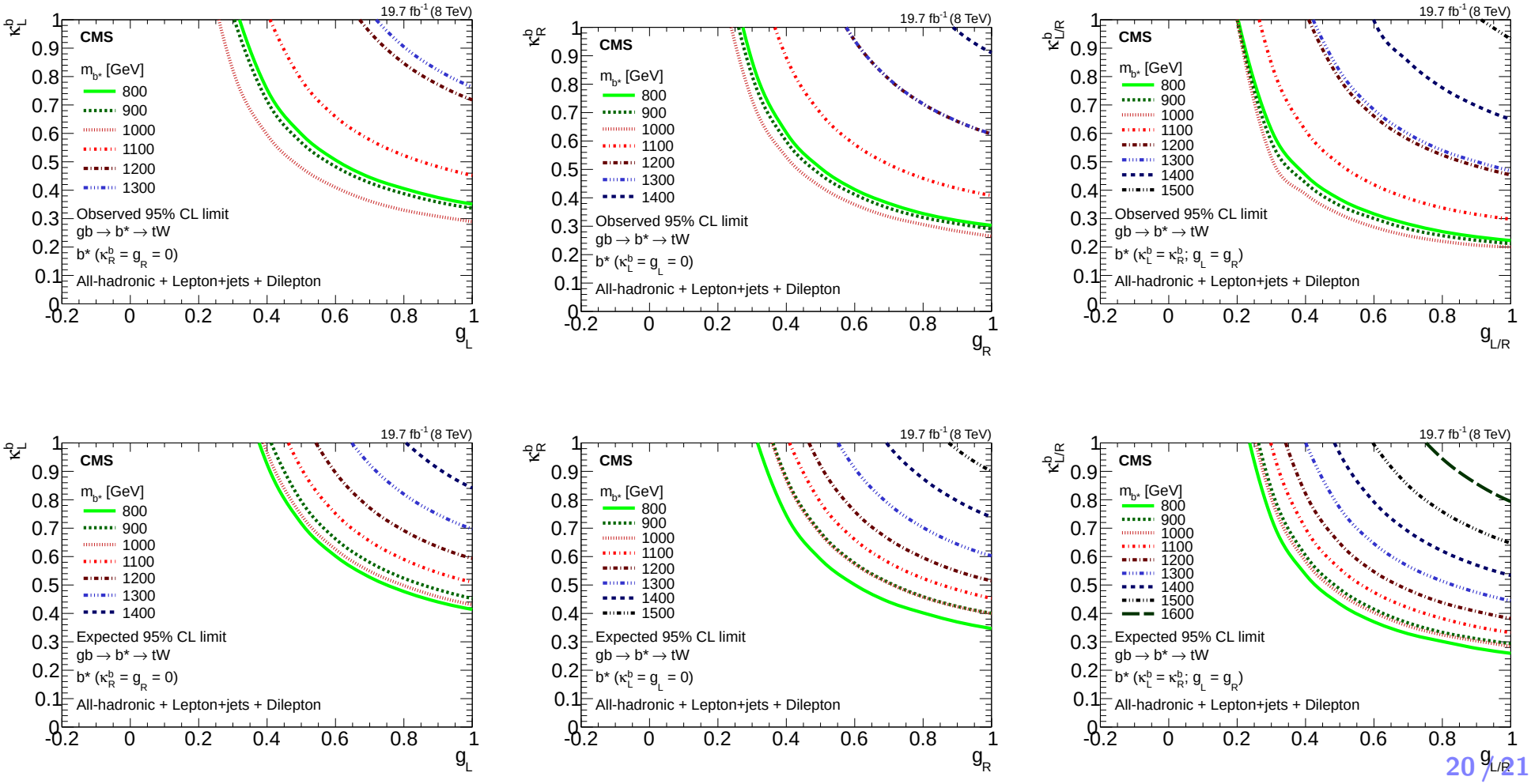
	Left-handed	Right-handed	Vector-like
Expected	1480	1560	1690
Observed	1390	1430	1530

- The observed distributions are consistent with those from the background only prediction.

Limits in κ and g plane

- The upper limits on the cross section times branching fraction generalized as a function of couplings κ and g.
  Top: Observed
  Bottom:Expected

Left Handed | Right Handed | Vector Like



Summary

- A search for $b^* \rightarrow tW$ has been performed in all-hadronic, lepton+jets and dilepton channel in tW final state.
- Results are found consistent with SM expectations.
- Upper limits are set at 95% confidence level on the product of cross section and branching fraction.
- Sensitivity on the upper limit has been increased by performing the combination of all-hadronic, lepton+jets and dilepton channel in tW final state.
- Excited bottom quarks are excluded with masses below 1390, 1430, and 1530 GeV for left-handed, right-handed, and vector-like b^*quark.
- Mass limits are also extrapolated to the two dimensional κ-g coupling plane.