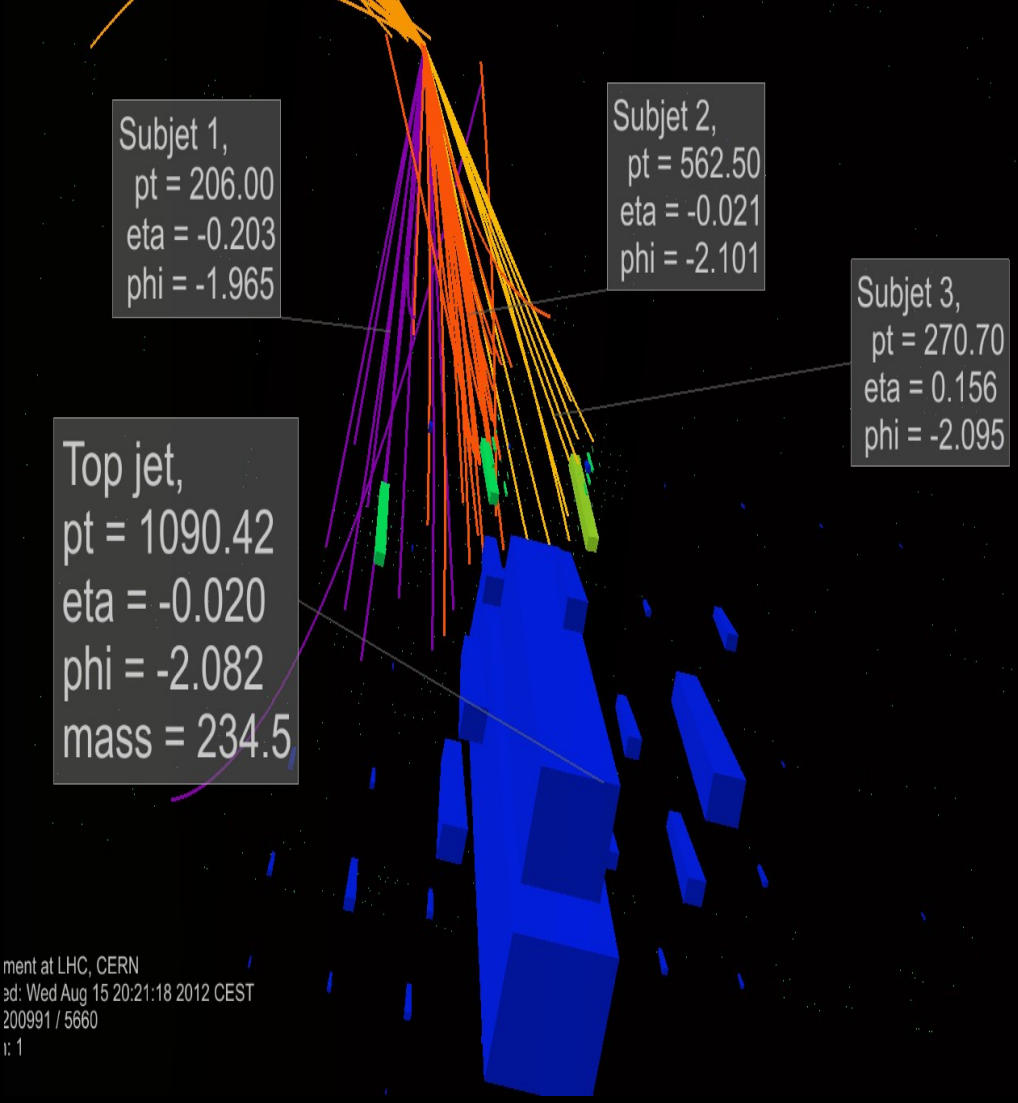

BSM searches with top quarks at CMS

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National Taiwan University

For the CMS collaboration

Pheno 2014

May 2014, Pittsburgh

BSM analyses and top/bottom quarks at CMS

- **Vector–like quarks – *strong couplings to 3rd generation***
  - T′ (charge 2/3) Physics Letters B 729 (2014) 149
  - b′(charge –1/3) CMS–PAS–B2G–12–019, 12–021, 13–003
  - T′ charge 5/3 hep–ex:1212:2391

- **Heavy gauge bosons *decaying to 3rd generation quarks***
  - W′ hep–ex:1402.2176
  - Z′, RS KK gluon Phys.Rev.Lett. 111 (2013) 211804

Analyses @ 8TeV 19.6fb–1 of LHC collisions in 2012

- **Top pairs, excitations and other *top decays***
  - RS t* hep–ex:1311.5357
  - RS t*, ~b CMS–PAS–B2G–12–008
  - Baryon n. violation Physics Letters B 731 (2014) 173

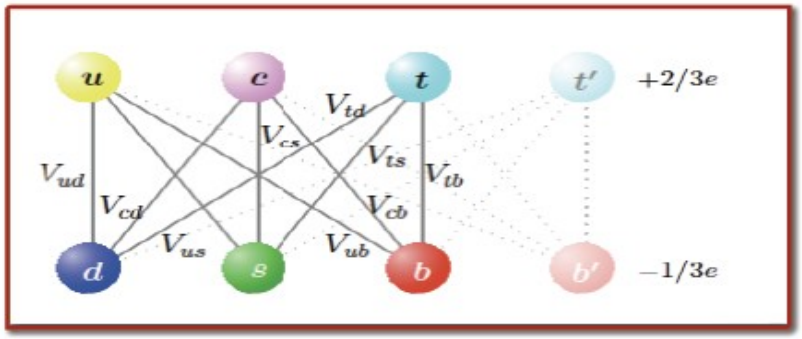
- **Dark matter searches – *large couplings to 3rd generation***
  - DM candidates CMS–PAS–B2G–12–022, 13–004

Vector–like quarks

• **"Vector–like quarks":** Both left– and right–handed chiralities have the same representation under SU(2), i.e. their couplings to W,Z are symmetric ("vector–like").
• Bare mass terms invariant under EWK gauge transformations: Independent of Higgs couplings and **not ruled out by the Higgs boson** discovery. (Unlike a sequential 4th generation of quarks.)

• Appearing in several BSM models to cancel radiative divergences in Higgs mass: Little Higgs, composite Higgs, extra dimensions, non–MSSM Susy, GUTs, top condensate, ...
• **Mass of at most ~1TeV.**
• Mixing mainly with 3rd generation quarks.
• Decays: **T′ –> b W, t Z, t H**
b′ –> t W, b Z, b H

• Most democratic combination of these branching ratios for EWK singlets: 50–25–25% ("benchmark branching ratios").



Substructure techniques for boosted objects

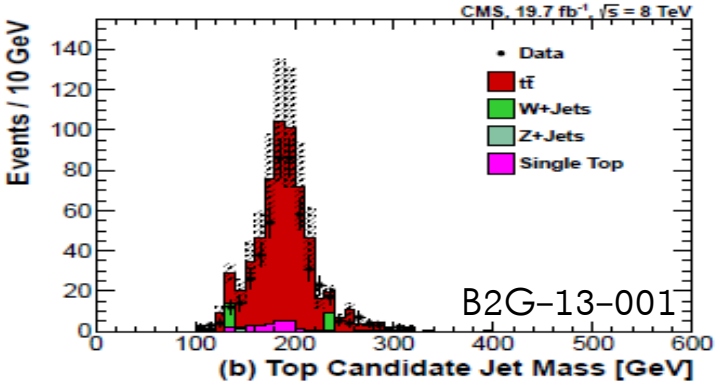
Large Lorentz boost i.e. E >= 2m: Tops, W, Z, Higgs → collimated hadronic decays.

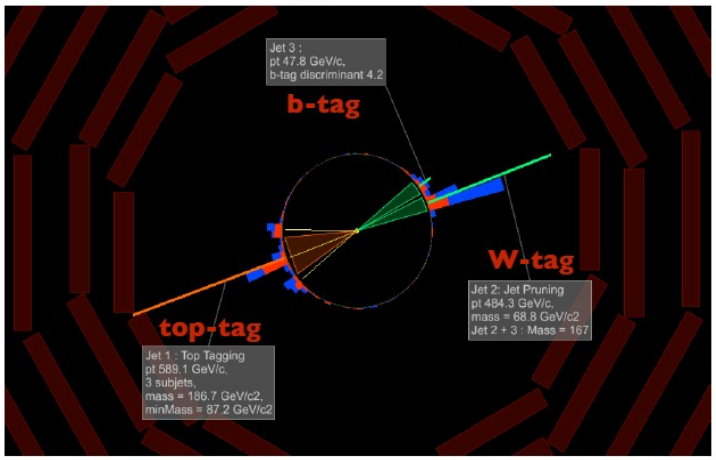
The toolkit for "boosted tagging" includes:

- **"Fat jets":** Jets reconstructed with the Cambridge–Aachen clustering algorithm. Wide cone (R=0.8) to capture all decay products. JHEP (97) 08, 001
- **N–subjettiness:** Algorithm for checking the compatibility with having 1/2/3 subjets (weighted clustering). ArXiv:1108.2701
- **Pruning:** Algorithm for removing soft and wide–angle hadronic clusters. ArXiv:0903.5081
- **"CMS top tagger":** The combined power of pruning and N–subjettiness.
- **More top–tagging:** Algorithm for identifying the subjets of the decay products (iterative un–doing of the clustering).

JME–10–013, JME–13–007
ArXiv:0806.0848, ArXiv:1209.4397, ArXiv:1204.2488

Mass distribution for fully–merged top candidate jets:



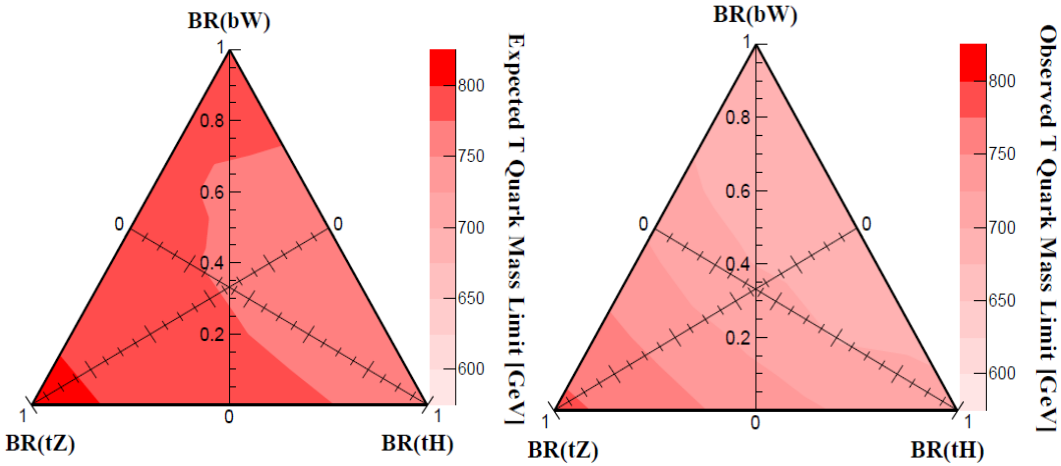


Vector–like quarks

B2G–12–015: Inclusive search for a vector–like T quark with charge 2/3

T′ mass limit for the range of branching fractions: 690–782GeV (expected: 762–813GeV)

- T′ –> b W, T′ –> t Z, T′ –> t H. At least 1 W decays leptonically.
- Single lepton, opposite / same sign dilepton, trilepton channels.
- Jet substructure techniques for highly boosted t, W, Z.



Expected / observed mass limits as functions of branching ratios of the three decay channels

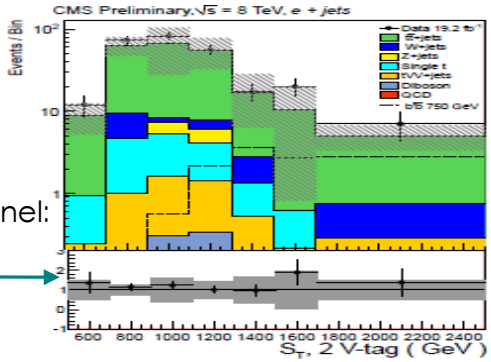
Vector–like quarks

B2G–12–019: Search for pair–produced vector–like quarks of charge –1/3 in lepton+jets final state

b′ mass for benchmark BRs: 700GeV (exp: 689GeV)

- b′ –> t W, b′ –> b Z, b′ –> b H.
- Exactly 1 W in the event decays leptonically.
- Special tagging for boosted W, Z, H.

More than two boosted taggings, electron channel: Distribution of sum of all transverse energies

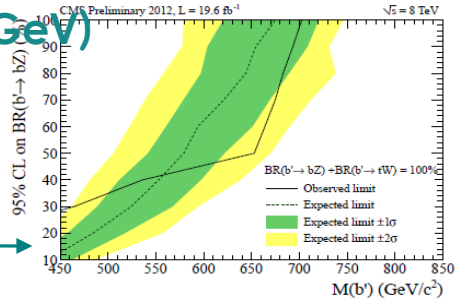


B2G–12–021: Search for pair–produced vector–like quarks of charge –1/3 in dilepton+jets final state

b′ mass limit for BR(bZ)=1: 700GeV (exp: 680GeV)

- b′ –> t W, b′ –> b Z
- One dilepton pair in the event.

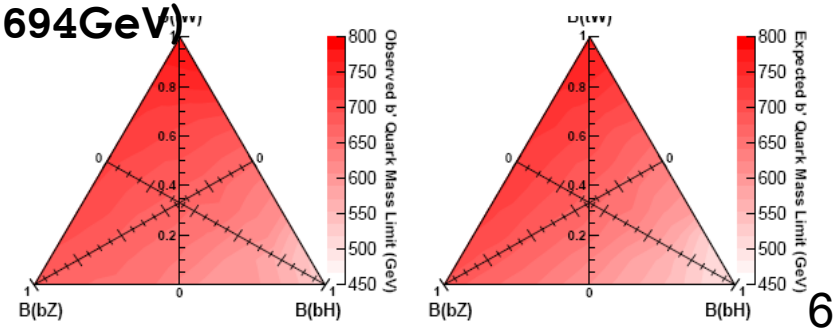
Exclusion limit on BR(bZ) as a function of b′ mass



B2G–13–003: Search for vector–like b′ pair production with multilepton final states

b′ mass for benchmark BRs: 694GeV (exp: 694GeV)

- b′ –> t W, b′ –> b Z, b′ –> b H.
- >= 3 leptons in the event.
- e, μ, hadronically decaying τ.



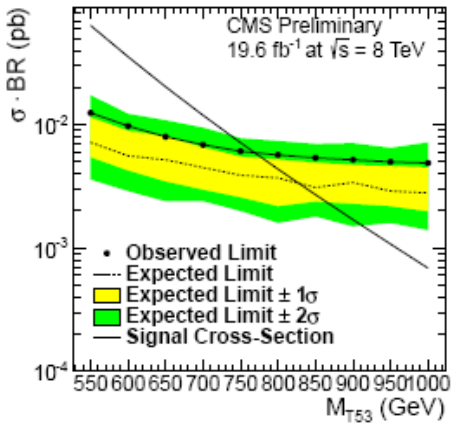
Vector–like quarks

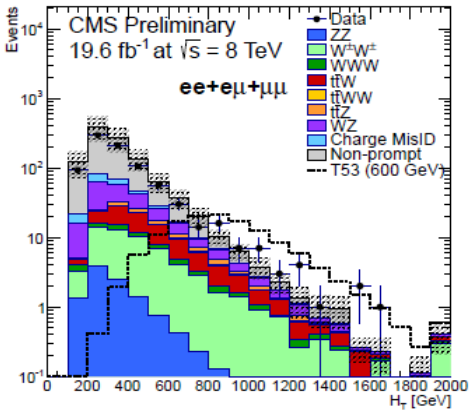
• **Heavy top partner with charge 5/3** (e.g. composite Higgs models).
Dirac particle, not contributing to / excluded by Higgs cross–sections.

B2G–12–012: Searches for top partners with charge 5e/3 in the same–sign dilepton final state

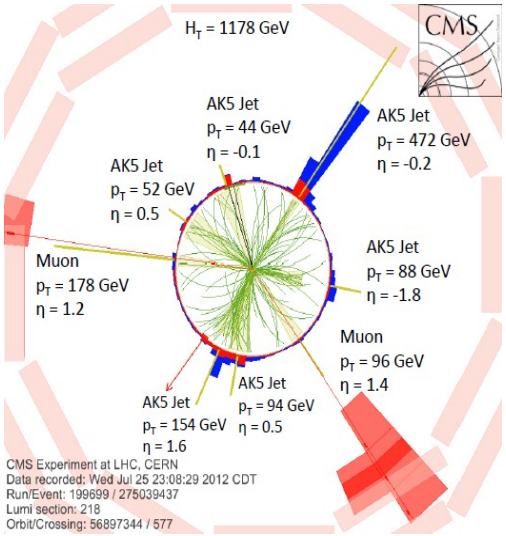
T(5/3) mass limit: 770GeV (exp: 830GeV)

- T(5/3) → t W^+ → b W^+ W^+. Same sign dileptons.
- 2 Ws decay leptonically, 2 Ws decay inclusively.
- Boosted tops: top–tagging
- Boosted Ws: jet pruning





HT (sum of pt of all jets)
All channels' combination



Heavy gauge bosons

W′ $\left(\rightarrow t\,\bar{b} + b\,\bar{t}\right)$

- Little Higgs models, extra dimensions, technicolour...
- For left–handed couplings, there is interference with SM production W–>tb:
- Constraints are set on an arbitrary set of left– and right–handed couplings. The quoted results on the mass limit apply on purely right–handed couplings and to left–handed couplings when ignoring interference with SM.

Z′ $\left(\rightarrow t\,\bar{t}\right)$

- Generic new gauge boson appearing in many models, presumed to couple more strongly to tops.
- Here: leptophobic topcolor.

RS KK gluons

- Kaluza–Klein excitations of gluons in models of warped extra dimensions.
- Enhanced couplings to $t\,\bar{t}$.

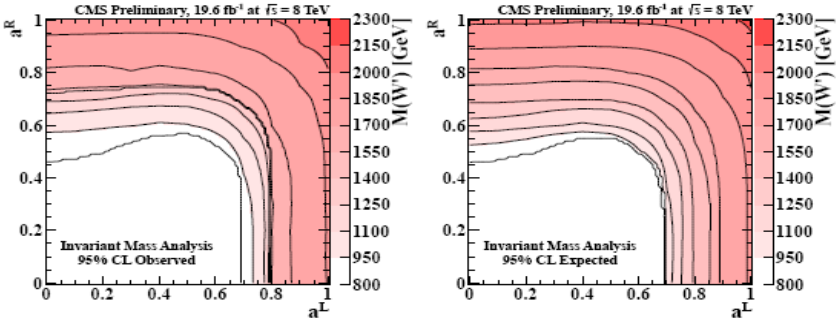
Heavy gauge bosons

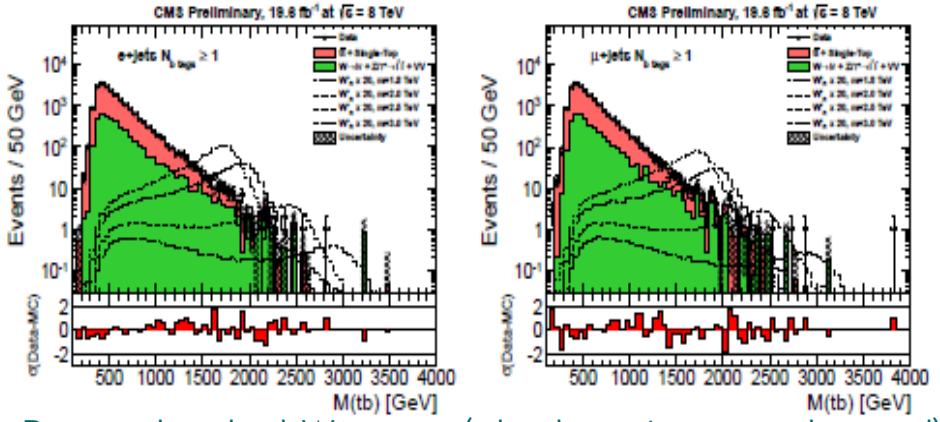
B2G-12-010 Search for narrow t+b resonances in the leptonic final state

W′ mass limit: 2.03TeV (exp: 2.09TeV)

Limits on couplings of W′ to SM quarks.

- W′ –> t b, t –> b W –> b l ν.





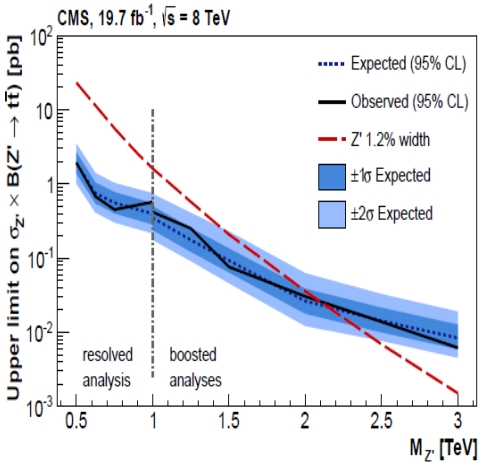
Reconstructed W′ mass (electron / muon channel)

Model	Observed Limit	Expected Limit
$Z', \Gamma_{Z'}/M_{Z'} = 1.2\%$	2.1 TeV	2.1 TeV
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

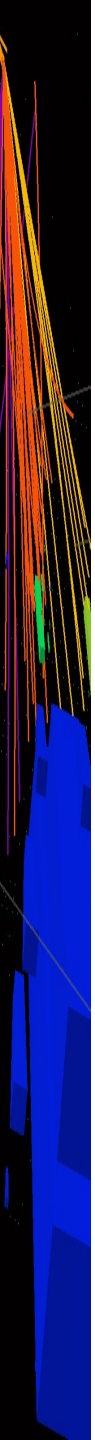
New heavy scalars: $\sigma < 0.8/0.3$ pb for mass 500/750 GeV.

B2G-13-001 Searches for anomalous $t\bar{t}$ production

Bump hunt in $t\bar{t}$ with three interpretations.



- Semi-leptonic W decays: resolved / boosted tops
- All-hadronic W decays: from boosted tops (top tagging)



Excitations and top decays

t* –> t g (dominant decay mode)

• Excitation of top with spin 3/2. Consistent with SM Higgs production.

• Found in string realizations of the RS model.

$\tilde{b}$ –> t + jet (dominant mode: $\tilde{b} \rightarrow t\, s$)

• R–parity–violating MSSM with minimal flavour violation: $\tilde{b}$ is the lightest supersymmetric particle.

• Similar kinematics as t* above, lower production rate.

Baryon number violating top decays

• Occurring in Susy, GUTs, black hole physics, ...

• Already studied in nucleons, mesons, τ, Z.

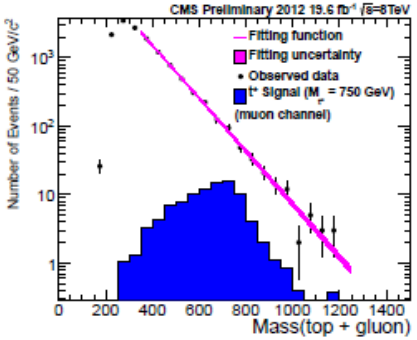
Excitations and top decays

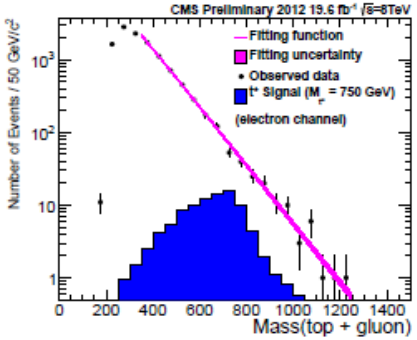
B2G-12-014: Searches for production of excited top quarks in the lepton+jets final state

t* mass limit: 790GeV (exp: 738GeV)

- t* -> t g. Single lepton final states.

Reconstructed t+gluon mass and background fit (muon / electron channel)

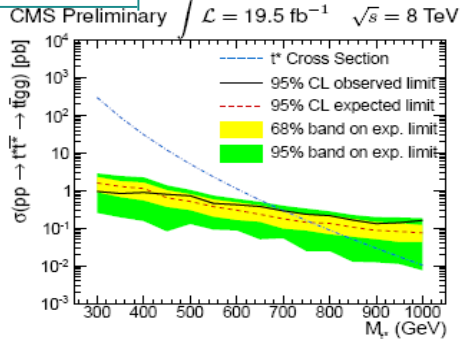


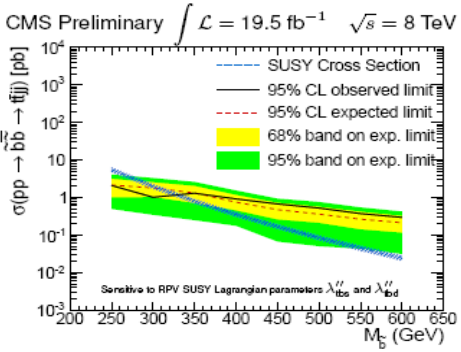


B2G-12-008: Search for pair production of resonances to a top quark plus jet in states with two leptons

t* mass limit: 300-703GeV (exp: 763GeV)

$\tilde{b}$ mass limit: 250-326GeV (exp:298GeV)





- t -> b W, W -> l l.

B2G-12-023: Search for baryon number violating top quark decays

Branching fraction of the decay to 1 μ/e + jets: 0.0016 (exp: 0.0029) / 0.0017 (exp: 0.0031)

	95% CL Upp. lim.	Exp. lim.	68% exp. lim. range
Muon ch.	0.0016	0.0029	[0.0017, 0.0042]
Electron ch.	0.0017	0.0031	[0.0018, 0.0045]
Combined	0.0015	0.0029	[0.0016, 0.0042]

- $t \to \bar{b}\,\bar{c}\,\mu^+$, $t \to \bar{b}\,\bar{u}\,e^+$

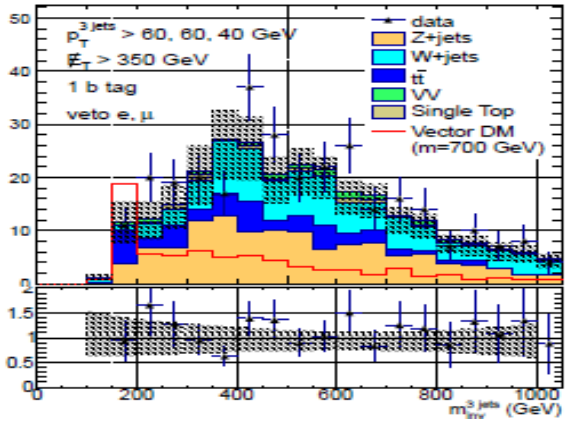
Dark matter searches

- **Vector and scalar candidates** coupling to top. Production by FCNC.
- **Dirac fermions** with scalar–type interaction to quarks. Significant with 3rd gen.

B2G–12–022: Search for new physics in single top + missing transverse energy final states

Scalar DM mass limit: 327GeV (exp: 343GeV)
Vector DM mass limit:655GeV (exp: 668GeV)

- t–> b W. W decays hadronically.

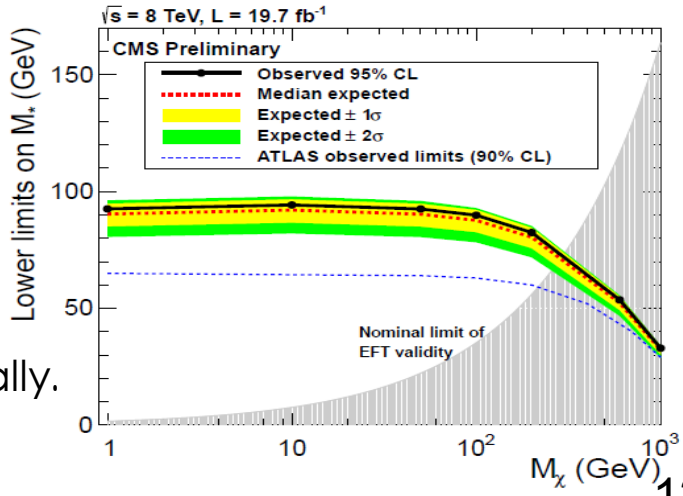


Invariant mass of the three leading jets, in b–tagged events.

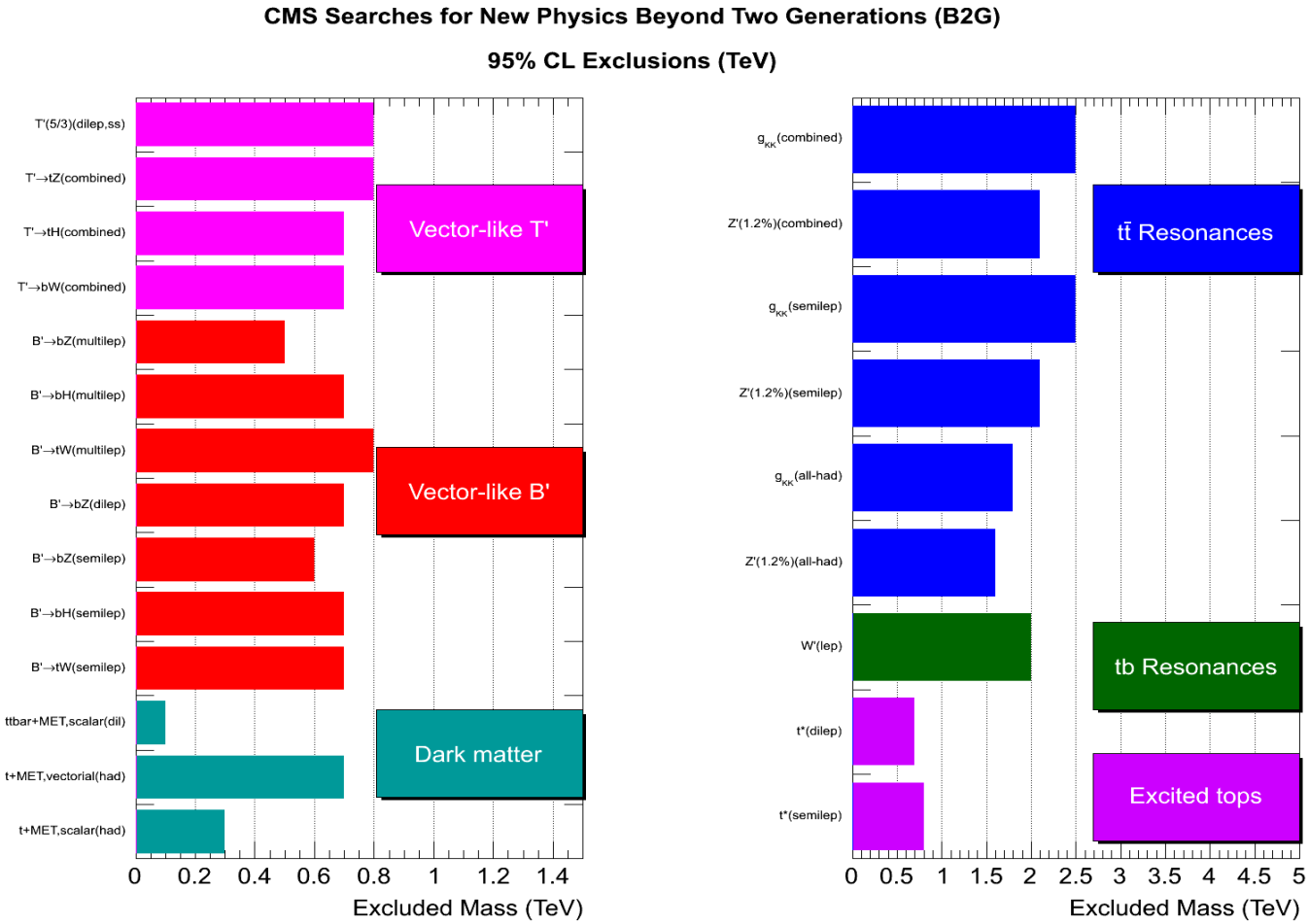
B2G–13–004 Search for production of DM in association with top pairs in the dilepton final state

Limits on the interaction scale of DM to top as a function of the DM candidate mass

- $t\,\bar{t}$ in dilepton events: t–> b W, W decays leptonically.



Analyses' summary



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

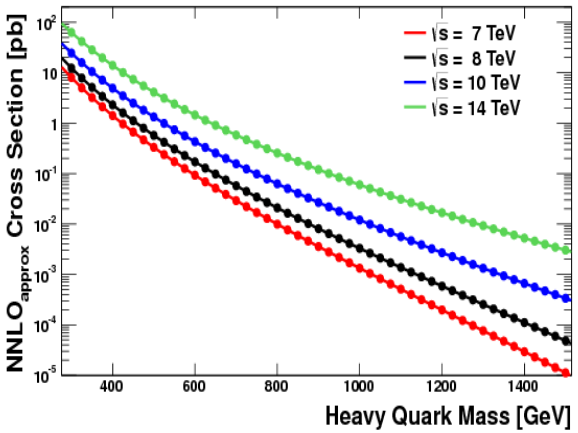
Prospects

A rich program for new physics with 3rd generation quarks at CMS.

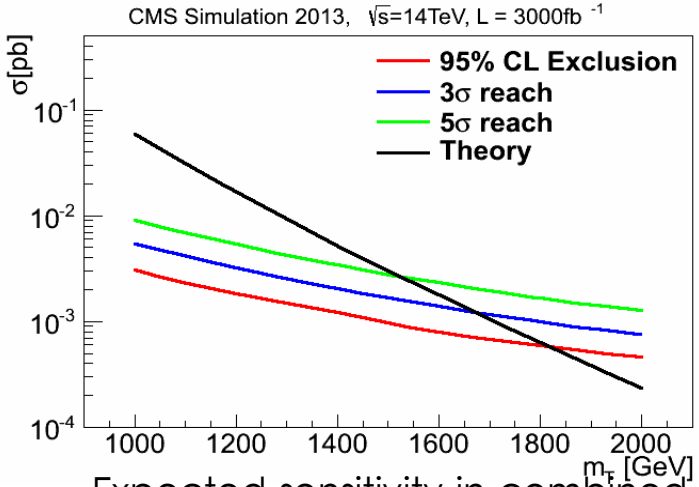
Run I was great and held a discovery … well, even though it was not BSM … :)

Run II ?

Prospects for T′ at 14TeV:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/FTR13026

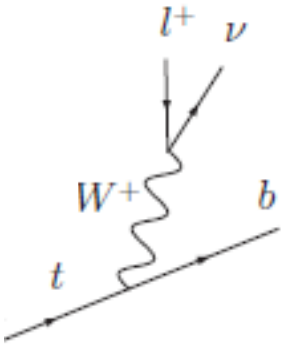


T′ pair production cross–sections

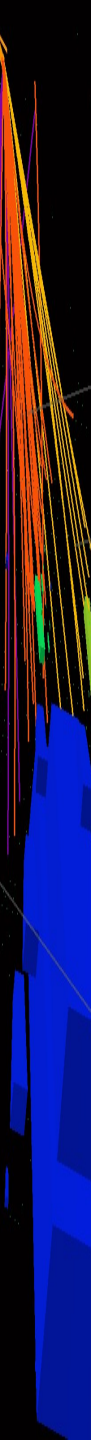


Expected sensitivity in combined multilepton and single–lepton + jets

Thank you!



t o p



Back - up

B2G 12-015

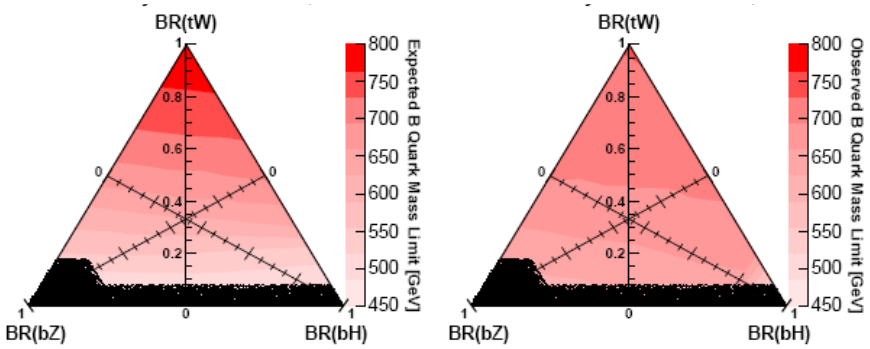
Table 1: Number of events predicted for background processes and observed in collision data in the signal sample.The uncertainty in the total background expectation reflects the correlation in the systematic uncertainties of the individual contributions.

lepton flavor	muon	electron
$t\bar{t}$	36700±5500	35900±5400
single top	2190±1101	2100±1000
W	19200±9700	18200±9200
Z	2170±1100	2000±1000
multijets	0	1680±620
$t\bar{t}$ W	144±72	137±68
$t\bar{t}$ Z	109±54	108±54
$t\bar{t}$ H	570±280	570±285
WW/WZ/ZZ	410±205	400±200
total background	61500±13700	61100±13500
data	58478	57743

B2G 12-019

Table 1: Number of data and expected events with statistical uncertainties in the electron and muon channels after the full event selection.

Background process	e+jets events	μ+jets events
$t\bar{t}$ +jets	11397 ± 85	9550 ± 79
W+jets	1247 ± 37	1137 ± 37
Multijet	1072 ± 19	505 ± 4
Single top	775 ± 17	683 ± 17
Z+jets	222 ± 22	238 ± 23
$t\bar{t}$ V+jets	92 ± 1	82 ± 1
Diboson (WW, WZ, ZZ)	43 ± 2	34 ± 2
Total background	14846 ± 99	12229 ± 91
Data	14640	11695



B2G 12-021

Table 1: Event yields for the data and background. The background is obtained using a data-driven method. The background errors include both statistical and systematic uncertainties.

Channel	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Expected background in data	379 ± 70	534 ± 79
Observed events	334	542

B2G 13-003

N_{OSSF}	on- or off-Z	S_T (TeV)	$N_{\tau_h} = 0, N_{b\text{-jets}} = 0$ obs	exp	$N_{\tau_h} \geq 1, N_{b\text{-jets}} = 0$ obs	exp	$N_{\tau_h} = 0, N_{b\text{-jets}} \geq 1$ obs	exp	$N_{\tau_h} \geq 1, N_{b\text{-jets}} \geq 1$ obs	exp
0	-	> 2.0	0	< 0.02	0	0 ± 0.02	0	0 ± 0.02	0	0 ± 0.02
0	-	$1.5 - 2.0$	0	< 0.02	0	0 ± 0.02	0	0 ± 0.02	0	0 ± 0.02
0	-	$1.0 - 1.5$	0	< 0.02	0	0 ± 0.02	0	0 ± 0.02	0	0.007 ± 0.02
0	-	$0.6 - 1.0$	0	< 0.02	0	0.12 ± 0.11	0	0.05 ± 0.05	†0	0.12 ± 0.1
0	-	$0.3 - 0.6$	0	0.09 ± 0.06	1	0.5 ± 0.19	0	0.001 ± 0.02	0	0.28 ± 0.12
0	-	$0 - 0.3$	0	0.05 ± 0.05	2	1.1 ± 0.45	0	0.0003 ± 0.02	0	0.25 ± 0.16
1	offZ	> 2.0	0	< 0.02	0	0 ± 0.02	0	0 ± 0.02	0	0 ± 0.02
1	onZ	> 2.0	0	< 0.02	0	0 ± 0.02	0	0 ± 0.02	0	0 ± 0.02
1	offZ	$1.5 - 2.0$	0	< 0.02	0	0.007 ± 0.02	0	0 ± 0.02	0	0 ± 0.02
1	onZ	$1.5 - 2.0$	0	< 0.02	0	0.02 ± 0.03	0	0.01 ± 0.03	0	0.007 ± 0.02
1	offZ	$1.0 - 1.5$	0	0.002 ± 0.02	0	0.12 ± 0.07	†0	0.03 ± 0.04	0	0.02 ± 0.02
1	onZ	$1.0 - 1.5$	1	0.06 ± 0.06	0	0.1 ± 0.07	0	0.11 ± 0.08	0	0.04 ± 0.04
1	offZ	$0.6 - 1.0$	0	0.06 ± 0.04	2	0.48 ± 0.17	0	0.06 ± 0.07	†0	0.3 ± 0.13
1	onZ	$0.6 - 1.0$	0	0.43 ± 0.15	0	1.7 ± 0.6	0	0.5 ± 0.29	†0	0.7 ± 0.33
1	offZ	$0.3 - 0.6$	0	0.27 ± 0.11	4	2.1 ± 0.5	0	0.33 ± 0.17	0	1.2 ± 0.43
1	onZ	$0.3 - 0.6$	5	1.8 ± 0.47	10	12 ± 3	2	1 ± 0.5	2	1.6 ± 0.5
1	offZ	$0 - 0.3$	2	0.48 ± 0.18	18	8.3 ± 2.1	0	0.04 ± 0.04	1	0.6 ± 0.3
1	onZ	$0 - 0.3$	2	3 ± 0.9	43	41 ± 10	2	0.07 ± 0.04	2	1 ± 0.4
2	offZ	> 2.0	0	$1e\text{-}05 \pm 0.02$	-	-	0	0 ± 0.02	-	-
2	onZ	> 2.0	0	0.002 ± 0.02	-	-	0	0.02 ± 0.03	-	-
2	offZ	$1.5 - 2.0$	0	0.0002 ± 0.02	-	-	0	0 ± 0.02	-	-
2	onZ	$1.5 - 2.0$	0	0.05 ± 0.03	-	-	0	0.01 ± 0.02	-	-
2	offZ	$1.0 - 1.5$	0	0.01 ± 0.02	-	-	0	0 ± 0.02	-	-
2	onZ	$1.0 - 1.5$	1	0.6 ± 0.26	-	-	†0	0.1 ± 0.05	-	-
2	offZ	$0.6 - 1.0$	0	0.11 ± 0.04	-	-	0	0.14 ± 0.08	-	-
2	onZ	$0.6 - 1.0$	4	5.9 ± 2.0	-	-	1	1 ± 0.39	-	-
2	offZ	$0.3 - 0.6$	3	1 ± 0.3	-	-	1	0.22 ± 0.1	-	-
2	onZ	$0.3 - 0.6$	26	42 ± 10	-	-	4	3.2 ± 1	-	-
2	offZ	$0 - 0.3$	7	8.2 ± 2.3	-	-	0	0.18 ± 0.07	-	-
2	onZ	$0 - 0.3$	*135	122 ± 29	-	-	1	1 ± 0.26	-	-
Total4	All	All	186	187 ± 39	80	68 ± 15	11	8.3 ± 2.7	5	6.3 ± 1.6

Table 2: Observed yields for four lepton events from 19.5 fb^{-1} recorded in 2012. The channels are broken down by the number of and mass of any opposite-sign same-flavor pairs (whether on or off Z), whether the leptons include taus, whether there are any b jets present and the S_T. Expected yields are the sum of simulation and data-driven estimates of backgrounds in each channel. The channels are exclusive. Channels marked with an asterisk are used as control regions and are excluded from the limit calculations. Also, those channels with a dagger mark are used in the limit setting procedure and are representative of the top most sensitive channels for the b' decay with mass of 500 GeV where $\mathcal{B}(b' \to bH) = 1.0$.

B2G 13-003

N_{OSSF}	$m(\ell^+\ell^-)$ (GeV)	S_T (TeV)	$N_{\tau_h}=0$, $N_{b\text{-jets}}=0$ obs	$N_{\tau_h}=0$, $N_{b\text{-jets}}=0$ exp	$N_{\tau_h}=1$, $N_{b\text{-jets}}=0$ obs	$N_{\tau_h}=1$, $N_{b\text{-jets}}=0$ exp	$N_{\tau_h}=0$, $N_{b\text{-jets}}\geq 1$ obs	$N_{\tau_h}=0$, $N_{b\text{-jets}}\geq 1$ exp	$N_{\tau_h}=1$, $N_{b\text{-jets}}\geq 1$ obs	$N_{\tau_h}=1$, $N_{b\text{-jets}}\geq 1$ exp
0	-	>2.0	0	<0.02	0	0.04 ± 0.05	0	0 ± 0.02	0	0 ± 0.22
0	-	$1.5-2.0$	0	0.07 ± 0.06	0	0.18 ± 0.19	0	0.05 ± 0.06	0	0.46 ± 0.28
0	-	$1.0-1.5$	0	0.21 ± 0.18	2	2.6 ± 1.2	0	0.36 ± 0.14	2	3.9 ± 2
0	-	$0.6-1.0$	†3	3.1 ± 1	†26	28 ± 12	2	4.9 ± 1.9	†46	58 ± 28
0	-	$0.3-0.6$	32	27 ± 10	289	290 ± 129	42	39 ± 17	410	480 ± 241
0	-	$0-0.3$	72	79 ± 22	1194	1324 ± 330	37	32 ± 15	316	331 ± 160
1	>105	>2.0	0	0.001 ± 0.02	0	0 ± 0.21	0	0 ± 0.03	0	0 ± 0.21
1	<75	>2.0	0	0.004 ± 0.02	0	0 ± 0.21	0	0.01 ± 0.04	0	0 ± 0.21
1	onZ	>2.0	0	0.2 ± 0.12	0	0.009 ± 0.21	0	0.04 ± 0.06	0	0.04 ± 0.05
1	>105	$1.5-2.0$	0	0.15 ± 0.09	0	0.22 ± 0.22	0	0.08 ± 0.05	0	0.2 ± 0.18
1	<75	$1.5-2.0$	1	0.11 ± 0.08	0	0.03 ± 0.05	0	0.07 ± 0.05	0	0.06 ± 0.07
1	onZ	$1.5-2.0$	3	1.1 ± 0.6	0	0.31 ± 0.17	1	0.28 ± 0.18	0	0.25 ± 0.12
1	>105	$1.0-1.5$	2	1 ± 0.4	1	1.3 ± 0.6	0	0.5 ± 0.22	1	2.1 ± 1.2
1	<75	$1.0-1.5$	0	1.1 ± 0.38	1	0.9 ± 0.44	†1	0.6 ± 0.27	0	1 ± 0.7
1	onZ	$1.0-1.5$	11	15 ± 6.9	9	5.9 ± 1.6	2	3.3 ± 1.2	1	1.7 ± 0.6
1	>105	$0.6-1.0$	13	10 ± 2.4	21	23 ± 7.2	†7	7.4 ± 2.4	23	28 ± 14
1	<75	$0.6-1.0$	14	10 ± 3.6	21	11 ± 3.4	†4	8.3 ± 2.6	†14	12 ± 6
1	onZ	$0.6-1.0$	106	111 ± 40	108	70 ± 17	†16	24 ± 7	17	17 ± 4.7
1	>105	$0.3-0.6$	63	65 ± 12	285	372 ± 96	36	35 ± 13	169	187 ± 94
1	<75	$0.3-0.6$	84	86 ± 21	290	279 ± 71	52	56 ± 22	167	171 ± 87
1	onZ	$0.3-0.6$	*669	735 ± 166	*2099	2705 ± 772	122	108 ± 24	325	284 ± 73
1	>105	$0-0.3$	180	195 ± 33	1620	1712 ± 482	17	17 ± 6.4	97	79 ± 35
1	<75	$0-0.3$	617	644 ± 102	10173	9211 ± 2694	62	74 ± 28	297	288 ± 97
1	onZ	$0-0.3$	*4255	4439 ± 691	*49916	49192 ± 14670	*140	149 ± 24	795	826 ± 229
Total3	All	All	6125	6430 ± 916	66055	65233 ± 19038	541	564 ± 150	2680	2774 ± 903

Table 3: Observed yields for three lepton events. The channels are broken down by the number of and mass of any opposite-sign, same-flavor pairs (whether on or off Z), whether the leptons include taus, whether there are any b jets present and the S_T. Expected yields are the sum of simulation and data-driven estimates of backgrounds in each channel. The channels are exclusive. Channels marked with an asterisk are used as control regions and are excluded from the limit calculations. Also, those channels marked with a dagger are a representative subset of the top most sensitive channels for the b' decay, with a mass of 500 GeV and $\mathcal{B}(\mathrm{b}' \to \mathrm{bH}) = 1.0$, which are used in the limit setting procedure.

B2G 12-012

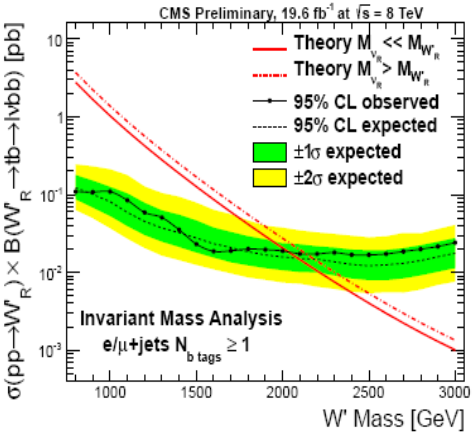
	PSS MC	Non-Prompt	Charge Mis-ID	Total Expected	Observed
ee	0.7 ± 0.2	1.9 ± 1.2	0.06 ± 0.02	2.6 ± 1.3	0
eμ	1.9 ± 0.4	0.6 ± 0.9	0.05 ± 0.01	2.5 ± 1.0	6
$\mu\mu$	1.3 ± 0.3	0.2 ± 0.6	-	1.5 ± 0.7	5
All	3.9 ± 0.8	2.6 ± 1.8	0.1 ± 0.02	6.6 ± 2.0	11

Table 6: Summary table of expected and observed events for all channels. The expected yield is composed of the prompt, same-sign ("PSS") contribution from simulation, the contribution due to fake leptons ("Non-prompt"), and that due to charge misidentification. All systematic uncertainties are included.

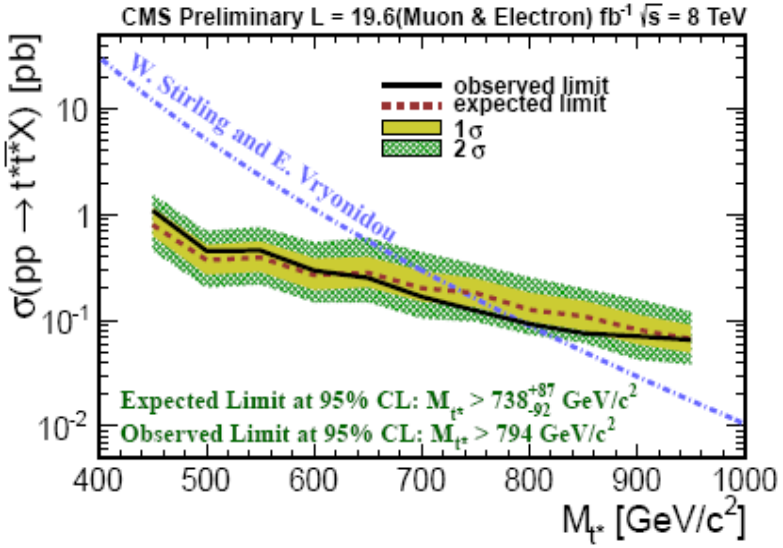
B2G 12-010

Table 1: Number of selected data, signal, and background events. For the background samples, the expectation is computed corresponding to an integrated luminosity of 19.6 fb^{-1}. The final column for each channel includes the following cuts: $p_T^{top} > 85\,GeV$, $p_T^{jet1,jet2} > 140\,GeV$, $130 < M_{top} < 210\,GeV$.

Process	Number of Events					
	Electrons			Muons		
	b-tagged jets		Additional cuts	b-tagged jets		Additional cuts
	= 1	≥ 1		= 1	≥ 1	
Data	63050	72696	20238	62955	72820	20639
Signal:						
s-channel	176	269	86	197	299	96
$M(W'_R =) 1700$ GeV	90	117	84	77	99	70
$M(W'_R =) 1900$ GeV	41	52	37	35	44	31
$M(W'_R =) 2100$ GeV	19	24	17	16	20	14
Background:						
$t\bar{t}$	36169	44575	14663	36989	45703	14923
t-channel	2124	2484	823	2287	2662	866
tW-channel	2571	2934	959	2659	3033	979
$W(\to \ell\nu)$+jets	19707	20263	3687	19438	20108	3717
$Z/\gamma^*(\to \ell\ell)$+jets	1492	1575	271	1505	1578	293
WW	206	216	50	220	226	49
Total Background	62269	72047	20452	63098	73310	20826
MC / Data	0.988	0.991	1.011	1.002	1.007	1.009



B2G 12-024


CMS Preliminary L = 19.6(Muon & Electron) fb-1 √s = 8 TeV
σ(pp → t*t̄*X) [pb]
W. Stirling and E. Vryonidou
observed limit
expected limit
1σ
2σ
Expected Limit at 95% CL: Mt* > 738+87-92 GeV/c2
Observed Limit at 95% CL: Mt* > 794 GeV/c2
Mt* [GeV/c2]

B2G 13-001

Table 2: Number of expected and observed events in the boosted analyses.

Sample	Semi-Leptonic $N_{\text{b-tag}} = 0$	Semi-Leptonic $N_{\text{b-tag}} \geq 1$	All-Hadronic $M_{\text{t}\bar{\text{t}}} \geq 1\,\text{TeV}$
$\text{t}\bar{\text{t}}$	5440 ± 520	9090 ± 870	510 ± 90
NTMJ	–	–	6600 ± 200
Others	5880 ± 820	1070 ± 380	–
Total SM	11320 ± 1300	10160 ± 1300	7110 ± 410
Data	10305	10159	6887

B2G 12-023

Table 1: Muon analysis: assumed cross-section values, expected (as discussed in Section 6) and observed yields in the basic and tight selection for an assumed *BR* value of zero. The "Corrected basic" and "Tight" columns report the yields in the basic and tight selection, respectively, after the normalisation procedure described in section 8 and applied only to the $t\bar{t}$ and tW processes. The reported uncertainties are statistical plus systematic.

Dataset	Cross Section (pb)	Basic	Corrected basic	Tight
$t\bar{t}$	234	37100 ± 7800	38600 ± 3900	2200 ± 270
$W + jets$	37500	6300 ± 3200	6300 ± 3200	230 ± 120
$Z + jets$	3500	380 ± 190	380 ± 190	32 ± 18
tW	22.2	1160 ± 250	1210 ± 240	51 ± 11
$t - channel$	87.1	250 ± 130	250 ± 130	5.7 ± 3.0
$s - channel$	5.55	32 ± 16	32 ± 16	0.85 ± 0.52
WW	54.8	87 ± 43	87 ± 43	3.1 ± 1.7
WZ	33.2	41 ± 21	41 ± 21	1.43 ± 0.78
ZZ	17.7	5.6 ± 2.8	5.6 ± 2.8	0.50 ± 0.28
$t\bar{t}W$	0.23	129 ± 64	129 ± 64	6.0 ± 3.0
$t\bar{t}Z$	0.17	79 ± 40	79 ± 40	4.2 ± 2.1
QCD	-	790 ± 550	790 ± 550	118 ± 59
Total exp.	-	46000 ± 10000	47951 ± 220	2660 ± 140
Data	-	47951 ± 220	47951 ± 220	2614 ± 51

B2G 12-023

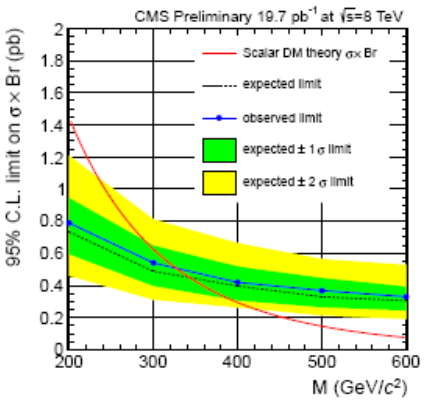
Table 2: Electron analysis: assumed cross-section values, expected (as discussed in Section 6) and observed yields in the basic and tight selection for an assumed *BR* value of zero. The "Corrected basic" and "Tight" columns report the yields in the basic and tight selection, respectively, after the normalisation procedure described in section 8 and applied only to the $t\bar{t}$ and tW processes. The reported uncertainties are statistical plus systematic.

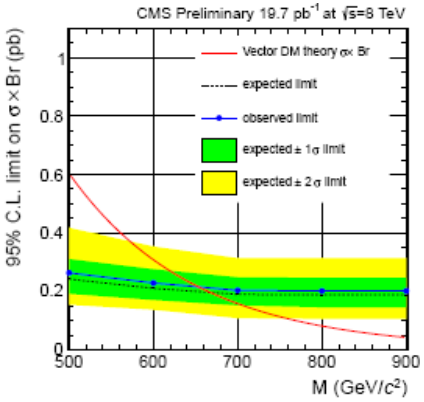
Dataset	Cross Section (pb)	Basic	Corrected basic	Tight
$t\bar{t}$	234	36500 ± 7100	38200 ± 3800	2030 ± 200
$W + jets$	37500	6500 ± 3300	6500 ± 3300	240 ± 120
$Z + jets$	3500	760 ± 380	760 ± 380	85 ± 45
tW	22.2	1120 ± 190	1170 ± 180	37.3 ± 7.5
$t - channel$	87.1	230 ± 120	230 ± 120	6.6 ± 3.6
$s - channel$	5.55	27 ± 14	27 ± 14	0.70 ± 0.50
WW	54.8	78 ± 39	78 ± 39	3.7 ± 2.0
WZ	33.2	45 ± 23	45 ± 23	2.1 ± 1.1
ZZ	17.7	11.1 ± 5.6	11.1 ± 5.6	1.40 ± 0.70
$t\bar{t}W$	0.23	132 ± 66	132 ± 66	6.3 ± 3.2
$t\bar{t}Z$	0.17	86 ± 43	86 ± 43	4.4 ± 2.2
QCD	-	2900 ± 1400	2900 ± 1400	330 ± 160
Total exp.	-	48300 ± 9500	50108 ± 220	2740 ± 140
Data	-	50108 ± 220	50108 ± 220	2703 ± 52

B2G 12-022

Table 5: Total number of selected events in data compared to the background prediction for E_T^{miss} >350 GeV. The background yields are given with statistical (first) and systematic (second) uncertainties. Uncertainty on the simulated backgrounds ($t\bar{t}$, single top, and VV) are presented as a square sum of the uncertainties from all of the sources. The QCD background is calculated using all of the other backgrounds and data in Eq. 4. Uncertainty on the QCD background is 100% correlated with uncertainties on other backgrounds and therefore is dismissed. The final uncertainty on the sum of all backgrounds is the squre sum of uncertainties on all but QCD backgrounds.

# of b tags	Zero CSVm b tag	One CSVm b tag
$t\bar{t}$	6±0±5	12±0±12
W+jets	18±9±7	3±1±2
Z+jets	103±33±9	11±10±1
Single top	2±1±1	1±1±1
VV	5±0±0	0±0±0
QCD	6	1
sum	140±36	28±16
Data	143	30





B2G 13-004

Background Source	Yield
$t\bar{t}$	$0.87 \pm 0.18 \pm 0.27$
Single top	$0.48 \pm 0.46 \pm 0.09$
Di-boson	$0.32 \pm 0.09 \pm 0.05$
Drell-Yan	$0.19 \pm 0.14 \pm 0.03$
One Mis-ID lepton	$0.02 \pm 0.07 \pm 0.02$
Double Mis-ID leptons	$0.00 \pm 0.00 \pm 0.00$
Total Bkg	$1.89 \pm 0.53 \pm 0.39$
Data	1
Signal	$1.88 \pm 0.11 \pm 0.07$

Table 2: Observed data and expected number of background events after final selection cuts, and expected number of signal events for a dark matter particle with mass $M_\chi = 100$ GeV and the interaction scale $M_* = 100$ GeV.