Exotic searches in the same-sign dilepton channel

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Outline

Same-sign phenomenology

- Motivations
- BSM models
- SM processes
- Data-driven backgrounds
- Selection

8 TeV searches

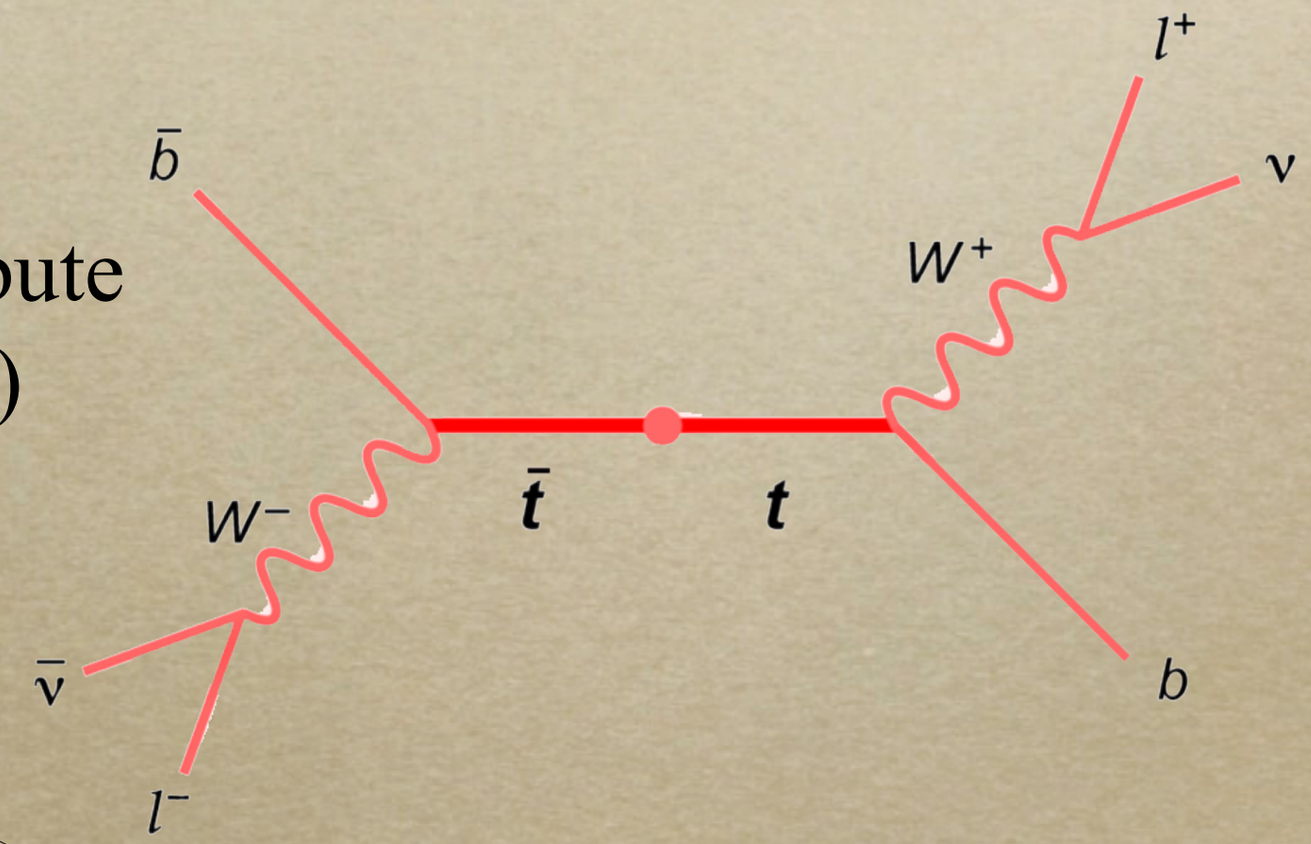
- CMS (VLQ, T5/3)
- ATLAS (VLQ, XD, SUSY, T5/3)

Same-sign dilepton phenomenology

Requiring 2 SS leptons suppresses the main background **ttbar**

→ **rare SM processes** contribute

- W/Z boson + top decays (ttV)
- ttVV, ttH
- Dibosons (VV)
- Tribosons VVV

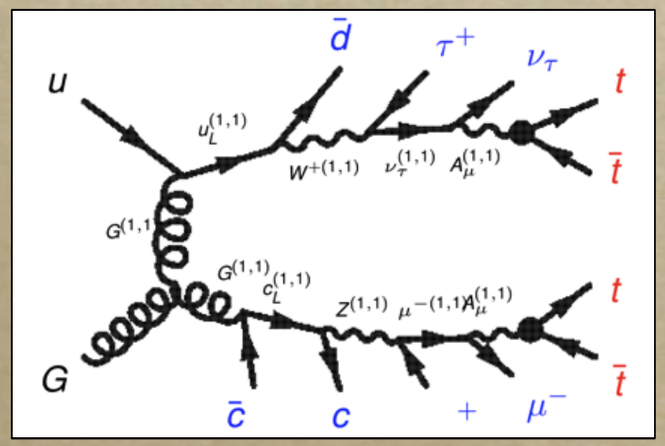


can be rejected by requiring additionnal bjets

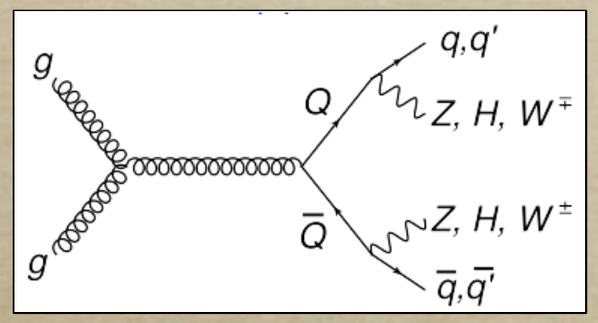
<u>Very pure channel</u> :
highly sensitive to BSM

Same-sign dilepton phenomenology

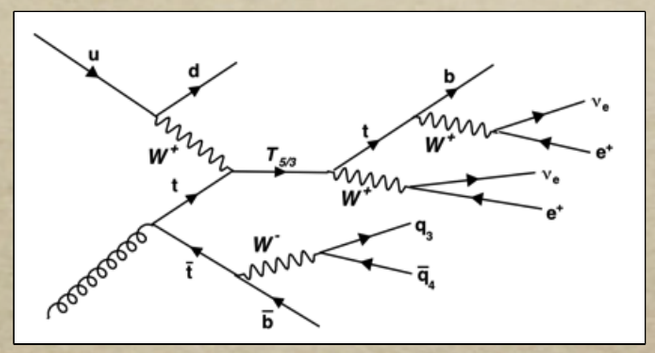
Many BSM models have 2SSL final states



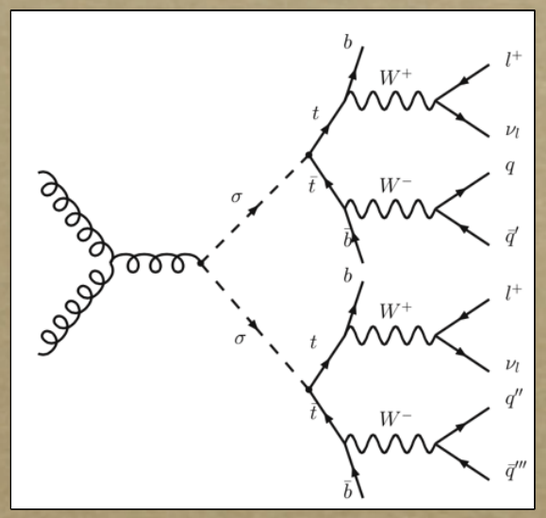
BSM 4tops (2UED-RPP)



VLQ (pair production)

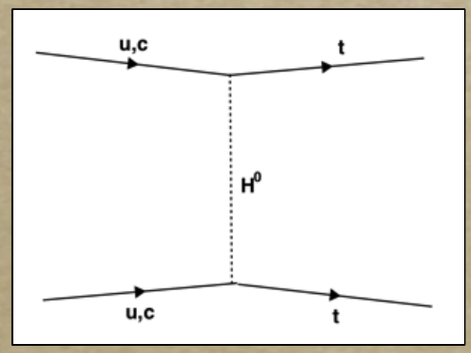


VLQ single production (here T5/3)

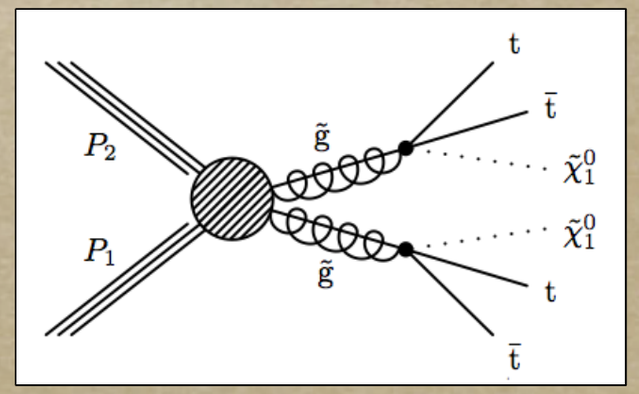


BSM 4tops (sgluons)

Common final states :
- 2 SS leptons
- ≥ 2 jets (incl. bjets)
- large MET
- large HT



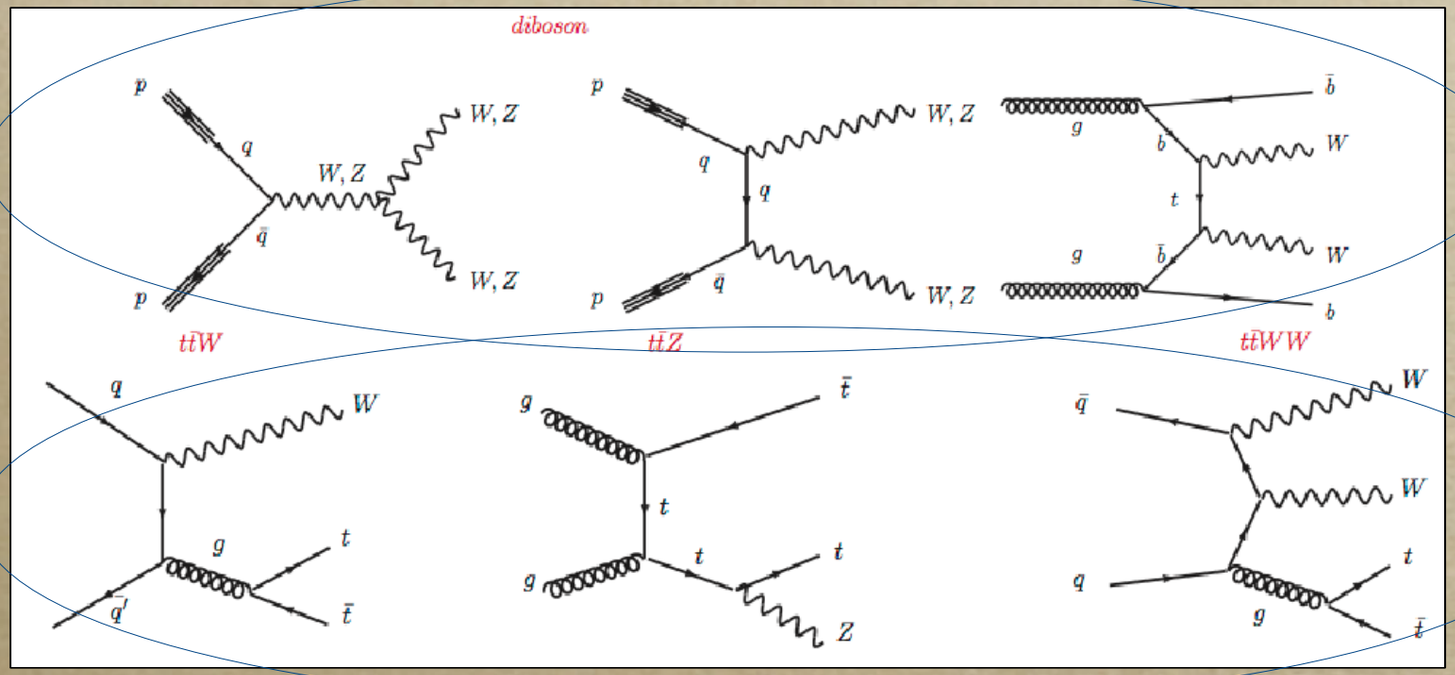
FCNC (tt)



SUSY

Same-sign dilepton phenomenology

SM processes with real 2lSS events



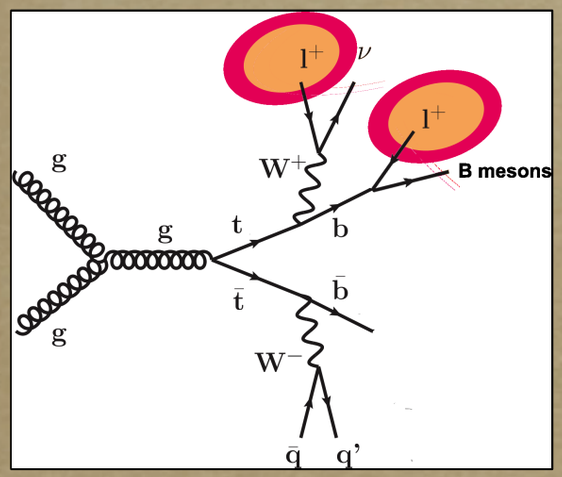
Dibosons ~ 10 pb

+ others :
VVV ~ 10 fb
VH ~ 100 fb
ttH ~ 30 fb
tV ~ 10 fb

ttV(V) ~ 400 fb

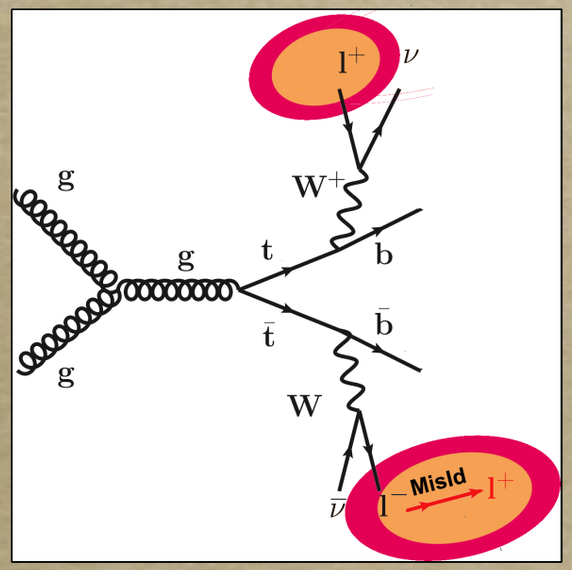
MC simulations

Instrumental backgrounds



Fakes/non-prompt (trident electrons, B decays)

Charge mis-identification for electrons only



Data-driven methods

Data driven methods

Fakes/non-prompt

The fake lepton should not pass the selection criteria

How to estimate it ?

Define 2 quality definitions :
- *loose* with relaxed criteria (ID/isolation)
- *tight* standard analysis definition

Then, estimate in data the probability for **a loose lepton to pass tight criteria** in CR and apply it in SR

Charge mis-identification

The electron's charge is wrong (high pT or tridents)

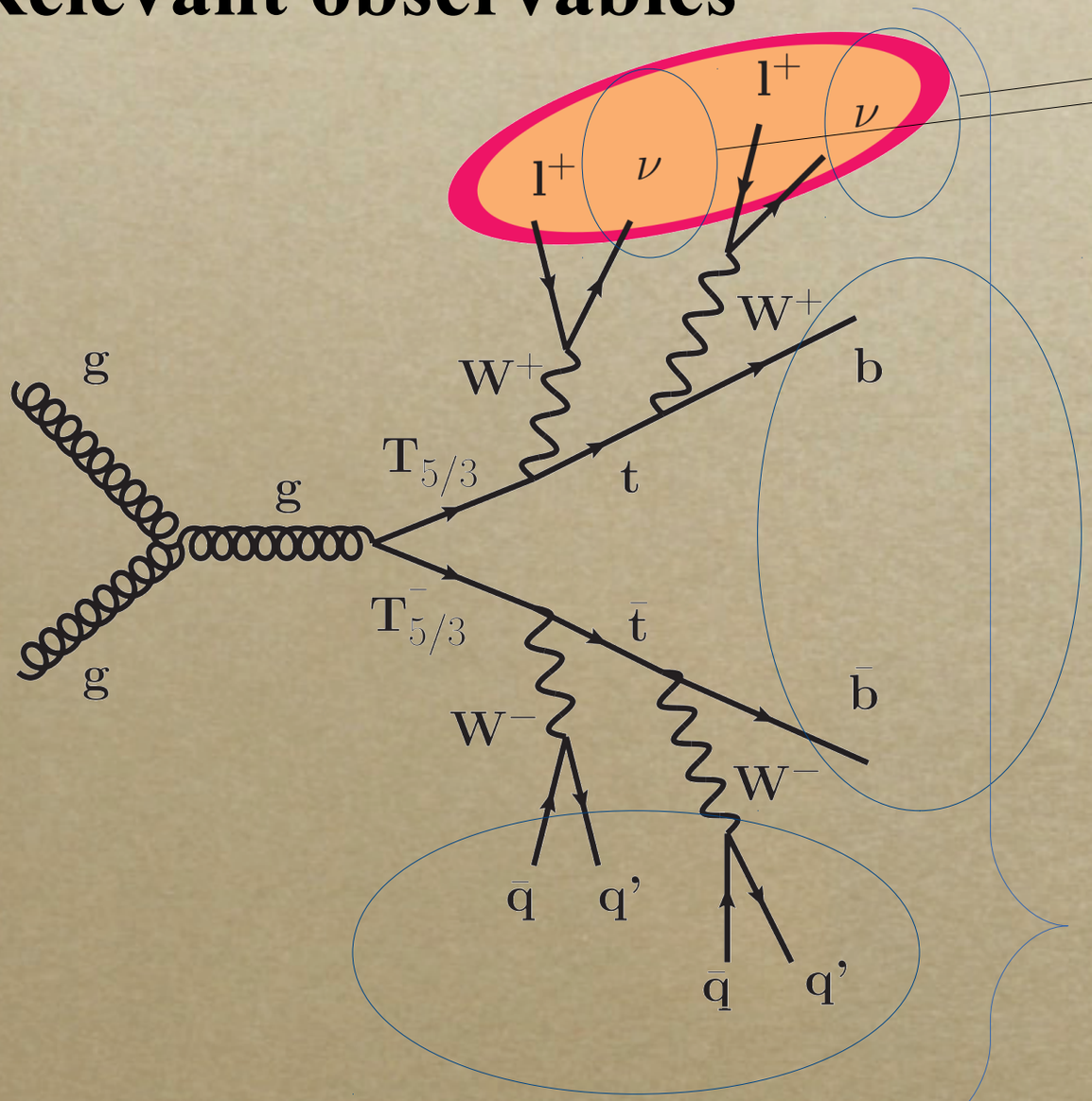
How to estimate it ?

Estimate the probability of flipping the charge in a pure region ($Z \rightarrow e^+e^-$) in data

Then, apply the probability to MC simulation of the contributing processes **requiring OS events**

Analysis selection

Relevant observables



MET

+ isolation / overlap criteria :

ΔR(lep,jet)
ΔR(e,mu)

Nb b-jets

HT sum of |pT| of leptons and jets

Nb jets

French lab involvements

ATLAS

- Clermont
- Saclay

20.3 ifb common analysis (VLQ, 4tops, T5/3) at 8 TeV in 2lSS+3l

→ will focus on this analysis
(but also present CMS ones quickly)

- Clermont
- Saclay
- Grenoble

Run2 preparation for early searches : both exotic (VLQ, XD, SUSY) and SM (4tops)

CMS

As far as I know, no French CMS group working in 2lSS searches

ATLAS generic search

CERN-PH-EP-2015-060

*8 SR * 7 channels (ee,em,mm,eee,eem,emm,mmm)*

Definition			Name
$e^{\pm}e^{\pm} + e^{\pm}\mu^{\pm} + \mu^{\pm}\mu^{\pm} + eee + ee\mu + e\mu\mu + \mu\mu\mu$, $N_j \geq 2$			
400 GeV $< H_T <$ 700 GeV	$N_b = 1$	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	SRVLQ0
	$N_b = 2$		SR4t0/VLQ1
	$N_b \geq 3$		SR4t1/VLQ2
$H_T \geq 700$ GeV	$N_b = 1$	40 GeV $< E_{\mathrm{T}}^{\mathrm{miss}} <$ 100 GeV	SRVLQ3
		$E_{\mathrm{T}}^{\mathrm{miss}} \geq 100$ GeV	SRVLQ4
	$N_b = 2$	40 GeV $< E_{\mathrm{T}}^{\mathrm{miss}} <$ 100 GeV	SR4t2/VLQ5
		$E_{\mathrm{T}}^{\mathrm{miss}} \geq 100$ GeV	SR4t3/VLQ6
	$N_b \geq 3$	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	SR4t4/VLQ7

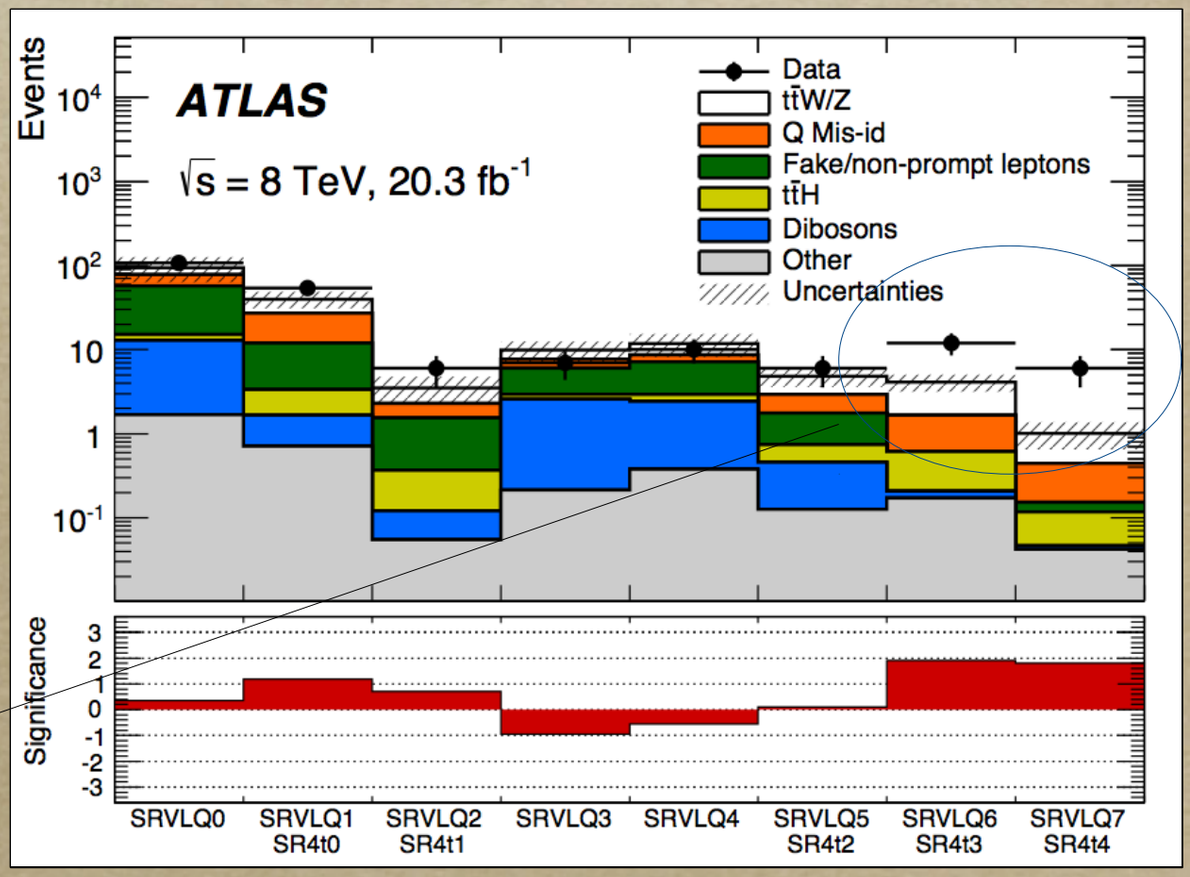
Selection observables : Nb(jet), Nb(bjet), HT, MET

	SRVLQ6/SR4t3	SRVLQ7/SR4t4
$t\bar{t}W/Z$	$2.46 \pm 0.11 \pm 1.06$	$0.57 \pm 0.05 \pm 0.25$
$t\bar{t}H$	$0.44 \pm 0.04 \pm 0.06$	$0.08 \pm 0.02 \pm 0.02$
Dibosons	$0.04 \pm 0.12 \pm 0.03$	$0.00 \pm 0.12 \pm 0.00$
Fake/Non-prompt	$0.00 \pm 1.02 \pm 0.28$	$0.04 \pm 0.83 \pm 0.24$
Q mis-Id	$1.09 \pm 0.14 \pm 0.34$	$0.30 \pm 0.09 \pm 0.10$
Other bkg.	$0.23 \pm 0.08 \pm 0.05$	$0.14 \pm 0.08 \pm 0.08$
Total bkg.	$4.3 \pm 1.1 \pm 1.1$	$1.1 \pm 0.9 \pm 0.4$
Data	12	6
p-value	0.029	0.036

Various signals (VLQ, b', single T5/3, 4tops)

⟶ common SR's, different interpretations

Cut and count analysis



2.5σ excess observed in SRVLQ6&7

ATLAS generic search

CERN-PH-EP-2015-060

Fakes : matrix method

Observed in data

$$\begin{pmatrix} N^{tt} \\ N^{tl} \\ N^{lt} \\ N^{ll} \end{pmatrix} = \mathbf{M} \begin{pmatrix} N^{ll}_{rr} \\ N^{ll}_{rf} \\ N^{ll}_{fr} \\ N^{ll}_{ff} \end{pmatrix}$$

Estimation

Tight = leptons passing the analysis criteria (isolation, tight ++)
Loose = medium++ electrons, tight muons, no isolation

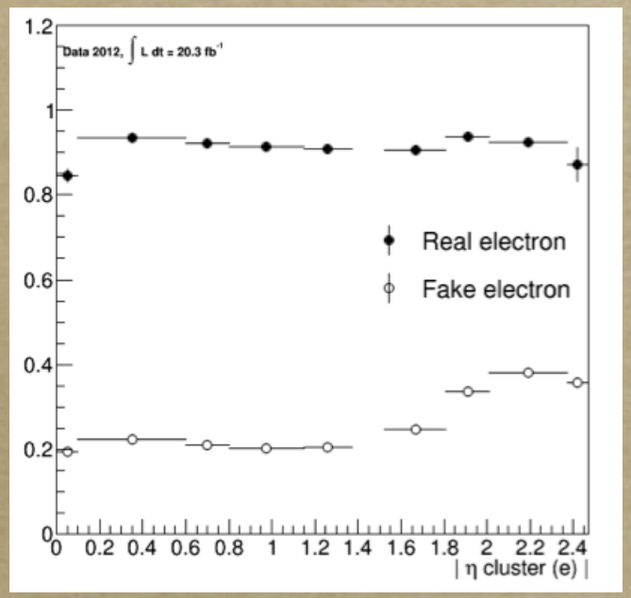
Real efficiencies (r) extracted from high MET or mT(W) region
Fake eff. (f) from low MET, mT(W) or high |d0sign| region

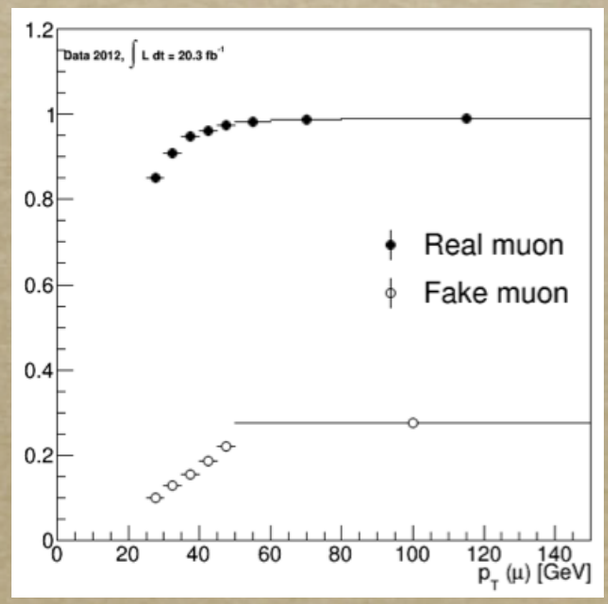
$$\mathbf{M} = \begin{pmatrix} r_1 r_2 & r_1 \overline{f_2} & \overline{f_1} r_2 & \overline{f_1} \overline{f_2} \\ r_1 \overline{r_2} & r_1 \overline{f_2} & \overline{f_1} \overline{r_2} & \overline{f_1} \overline{f_2} \\ \overline{r_1} r_2 & \overline{r_1} f_2 & \overline{f_1} r_2 & \overline{f_1} f_2 \\ \overline{r_1} \overline{r_2} & \overline{r_1} \overline{f_2} & \overline{f_1} \overline{r_2} & \overline{f_1} \overline{f_2} \end{pmatrix}$$

$$\begin{aligned} N^{tt}_{fake} &= N^{tt}_{rf} + N^{tt}_{fr} + N^{tt}_{ff} \\ &= r_1 f_2 N^{ll}_{rf} + f_1 r_2 N^{ll}_{fr} + f_1 f_2 N^{ll}_{ff} \end{aligned}$$

Systematics : choice of the regions, statistics, MC substraction
→ 70 % uncertainty in final SR

Cross-checked with OS regions, different triggers, other isolation, to understand the excess.





ATLAS generic search

CERN-PH-EP-2015-060

Misid likelihood method

$$N_{ij}^{ss} \simeq (\epsilon_i + \epsilon_j) N_{ij}$$

Charge flip for electron i and j

SS/OS events in Z peak → charge flip probability as f(pT, eta)
Extrapolated to high pT with ttbar MC truth matching

Systematics : likelihood stat, pT extrapolation, Z peak definition, fake removal)
→ 30 % uncertainty in final SR

Trident fake lepton overlap removed

Charge flip prob.

$\|\eta\|$ range	p_T range				
	[0, 50] GeV	[50, 80] GeV	[80, 100] GeV	[100, 200] GeV	[200, 1000] GeV
[0, 0.8]	0.000565	0.000708	0.00178	0.0024	0.00427
[0.8, 1.1]	0.000909	0.002	0.00739	0.00869	0.0168
[1.1, 1.37]	0.0025	0.00162	0.00552	0.0066	0.00686
[1.52, 1.8]	0.00844	0.0087	0.0195	0.0266	0.0303
[1.8, 2.3]	0.0128	0.0155	0.0393	0.0467	0.055
[2.3, 2.6]	0.0315	0.0349	0.053	0.0606	0.123

Sample	ee	$e\mu$	$\mu\mu$
Q mis-Id	$136 \pm 2 \pm 41$	$118 \pm 1 \pm 35$	—
Fake/Non-prompt	$153 \pm 11 \pm 107$	$225 \pm 11 \pm 158$	$29 \pm 3 \pm 20$
$t\bar{t}W/Z$	$4.57 \pm 0.19 \pm 1.88$	$14.2 \pm 0.3 \pm 5.8$	$8.43 \pm 0.27 \pm 3.56$
$t\bar{t}H$	$0.39 \pm 0.04 \pm 0.04$	$1.31 \pm 0.08 \pm 0.13$	$0.76 \pm 0.06 \pm 0.07$
Dibosons	$5.57 \pm 0.45 \pm 1.08$	$15.9 \pm 0.8 \pm 2.9$	$9.00 \pm 0.58 \pm 1.79$
Other bkg.	$0.32 \pm 0.11 \pm 0.11$	$0.75 \pm 0.20 \pm 0.20$	$0.27 \pm 0.06 \pm 0.06$
Total bkg.	$299 \pm 11 \pm 115$	$375 \pm 11 \pm 162$	$47 \pm 3 \pm 20$
Data	271	307	52

Sample	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
Fake/Non-prompt	$8.0 \pm 2.3 \pm 5.6$	$13.2 \pm 2.4 \pm 9.2$	$17.9 \pm 2.8 \pm 12.5$	$1.34 \pm 0.55 \pm 0.94$
$t\bar{t}W/Z$	$1.20 \pm 0.09 \pm 0.46$	$2.55 \pm 0.13 \pm 0.87$	$3.38 \pm 0.16 \pm 1.15$	$2.70 \pm 0.14 \pm 1.00$
$t\bar{t}H$	$0.07 \pm 0.02 \pm 0.01$	$0.28 \pm 0.03 \pm 0.03$	$0.32 \pm 0.03 \pm 0.03$	$0.14 \pm 0.02 \pm 0.01$
Dibosons	$5.78 \pm 0.51 \pm 1.14$	$6.78 \pm 0.57 \pm 1.33$	$8.42 \pm 0.57 \pm 1.78$	$9.23 \pm 0.65 \pm 1.82$
Other bkg.	$0.04 \pm 0.02 \pm 0.02$	$0.11 \pm 0.02 \pm 0.02$	$0.12 \pm 0.02 \pm 0.02$	$0.15 \pm 0.03 \pm 0.03$
Total bkg.	$15.1 \pm 2.4 \pm 5.7$	$22.9 \pm 2.5 \pm 9.4$	$30.1 \pm 2.8 \pm 12.7$	$13.6 \pm 0.9 \pm 2.4$
Data	15	18	36	14

Yields in validation region for all the background in 2lSS and 3l channels

ATLAS generic search

CERN-PH-EP-2015-060

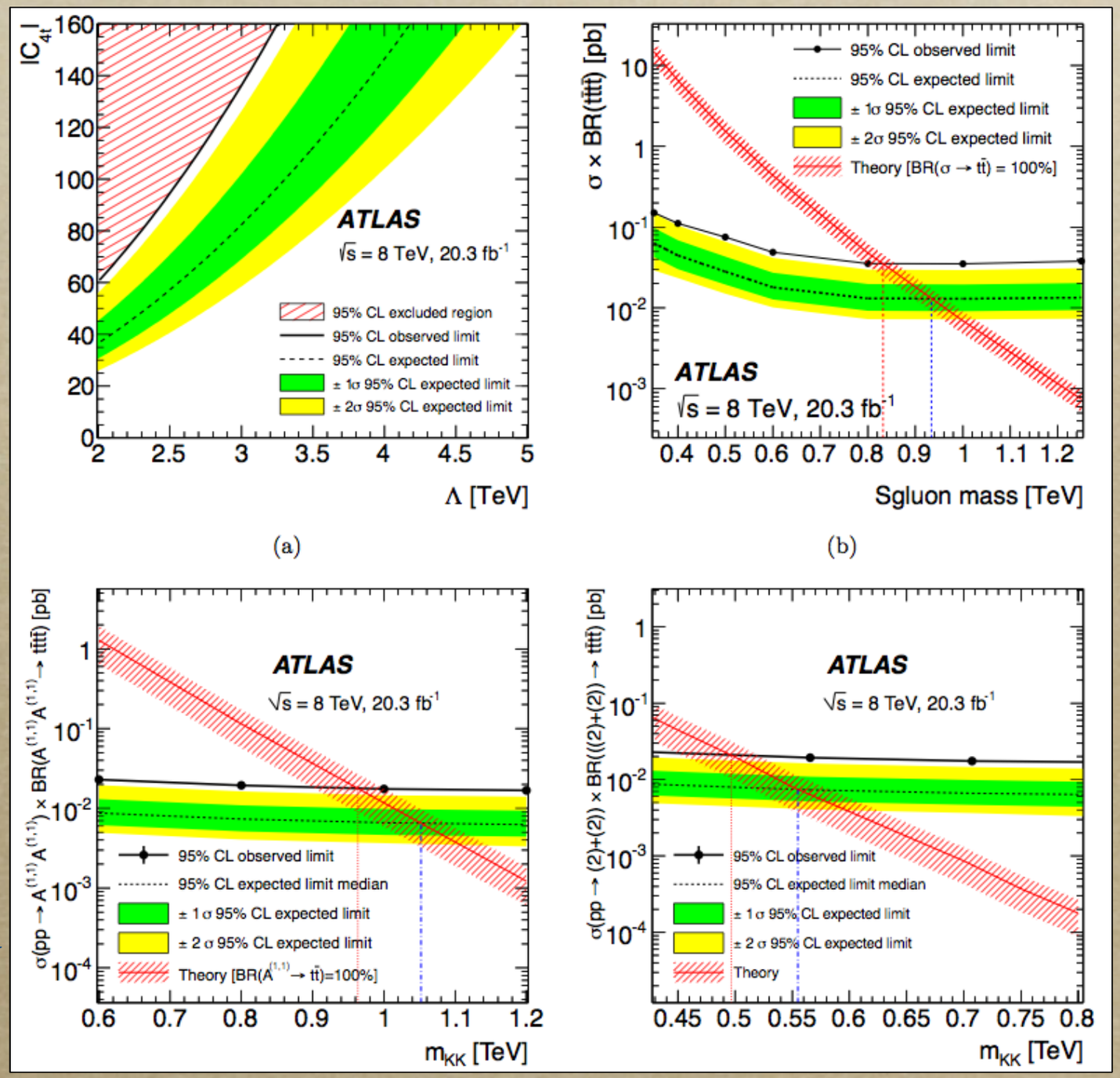
Exclusion limits : 4tops

For 3 models :
- contact interaction
- 2UED-RPP
- sgluon

Limit at 95 % CL on SM cross-section : **σ > 70 fb**

BSM contact interaction : **$|C|/\Lambda^2$ >15.1** and cross-section **σ > 61 fb**

Sgluons limit at 95 % CL **m>0.83 TeV**



ATLAS generic search

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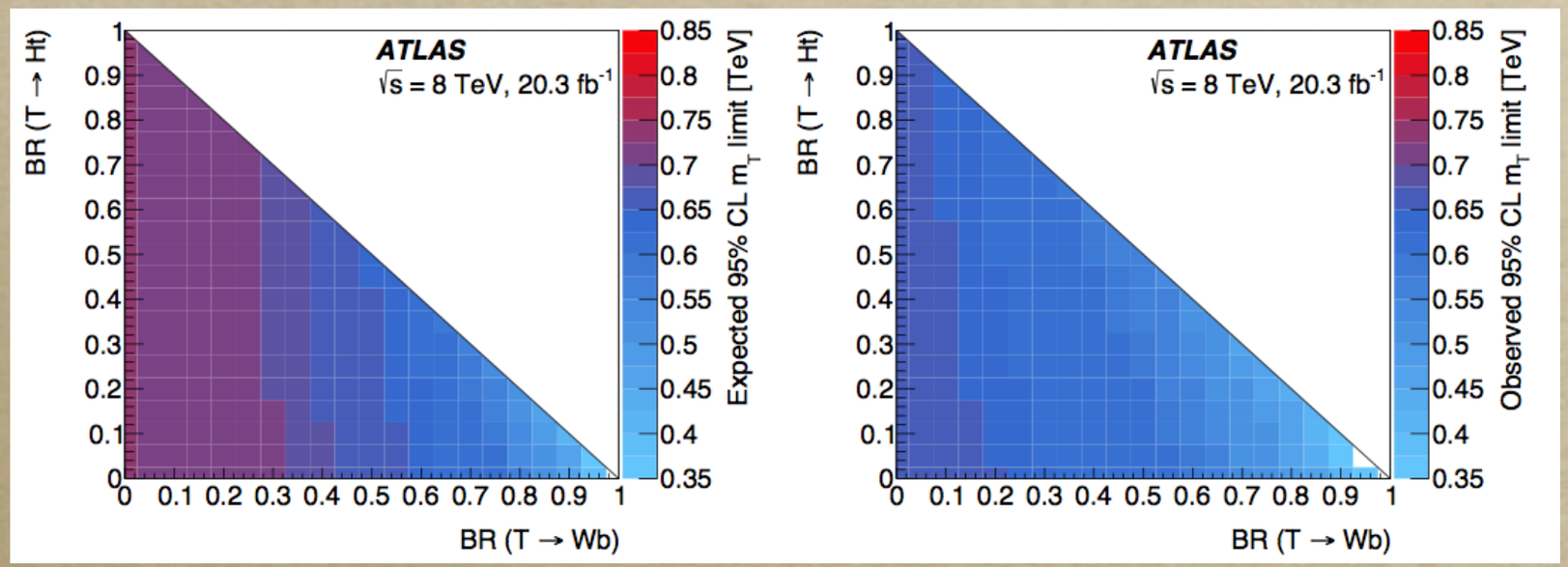
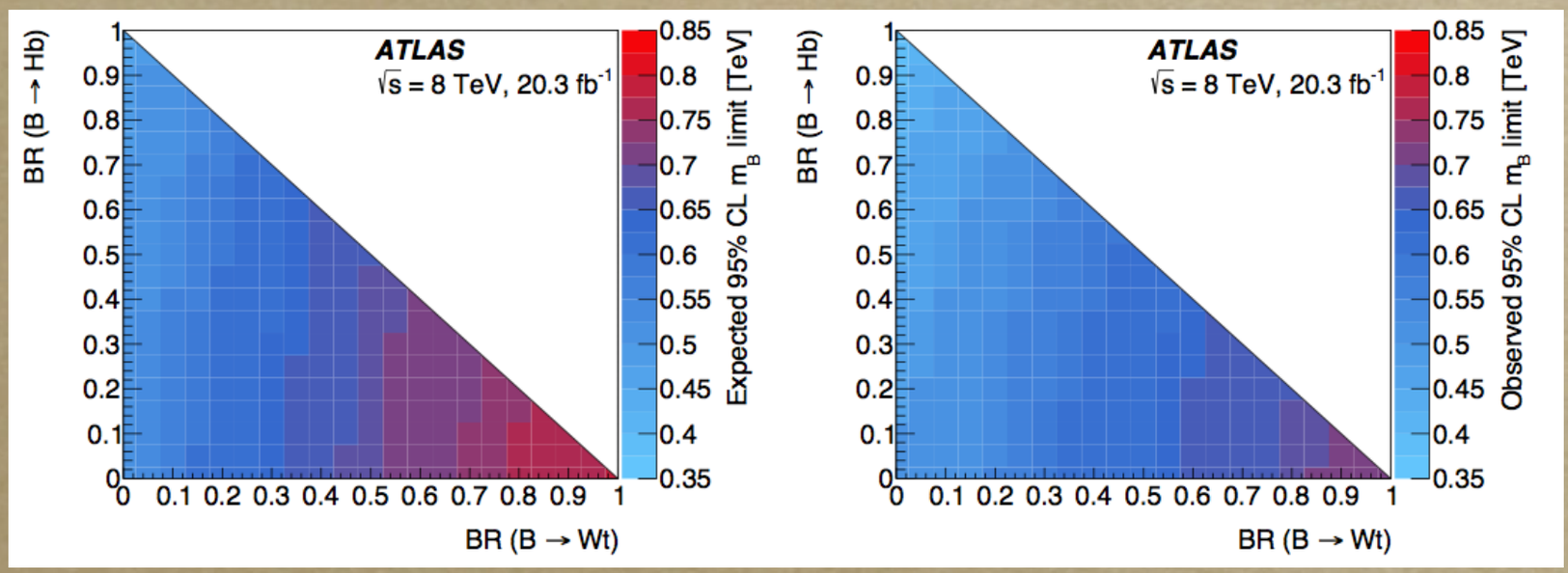
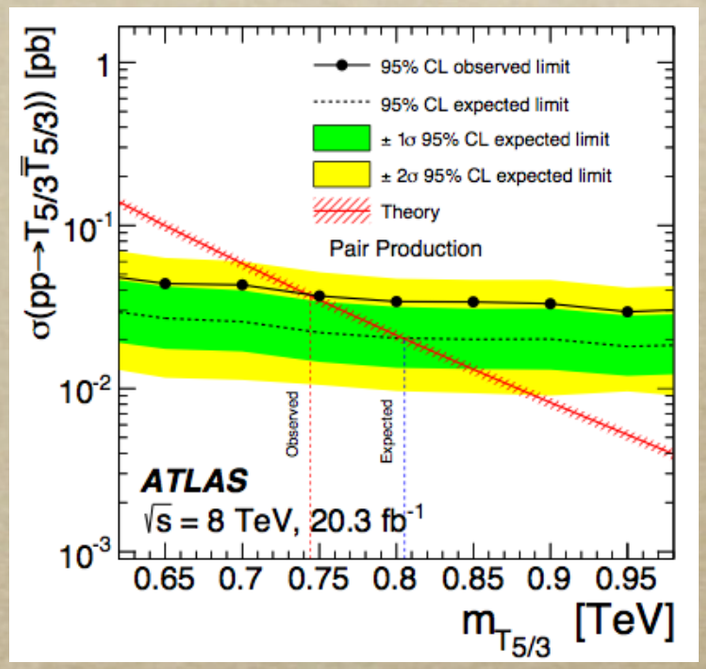
Exclusion limits : VLQ TT, BB and T5/3

For various BR (T → Wb) and (T → Ht)







T5/3 → tW 100 %

Single production too conservative

m(T5/3)>0.74 TeV (PP)

m(T5/3)>0.75 TeV (PP+SP)

Assuming singlet BR : **m(B)>0.62 TeV** and **m(T)>0.59 TeV**

ATLAS generic search

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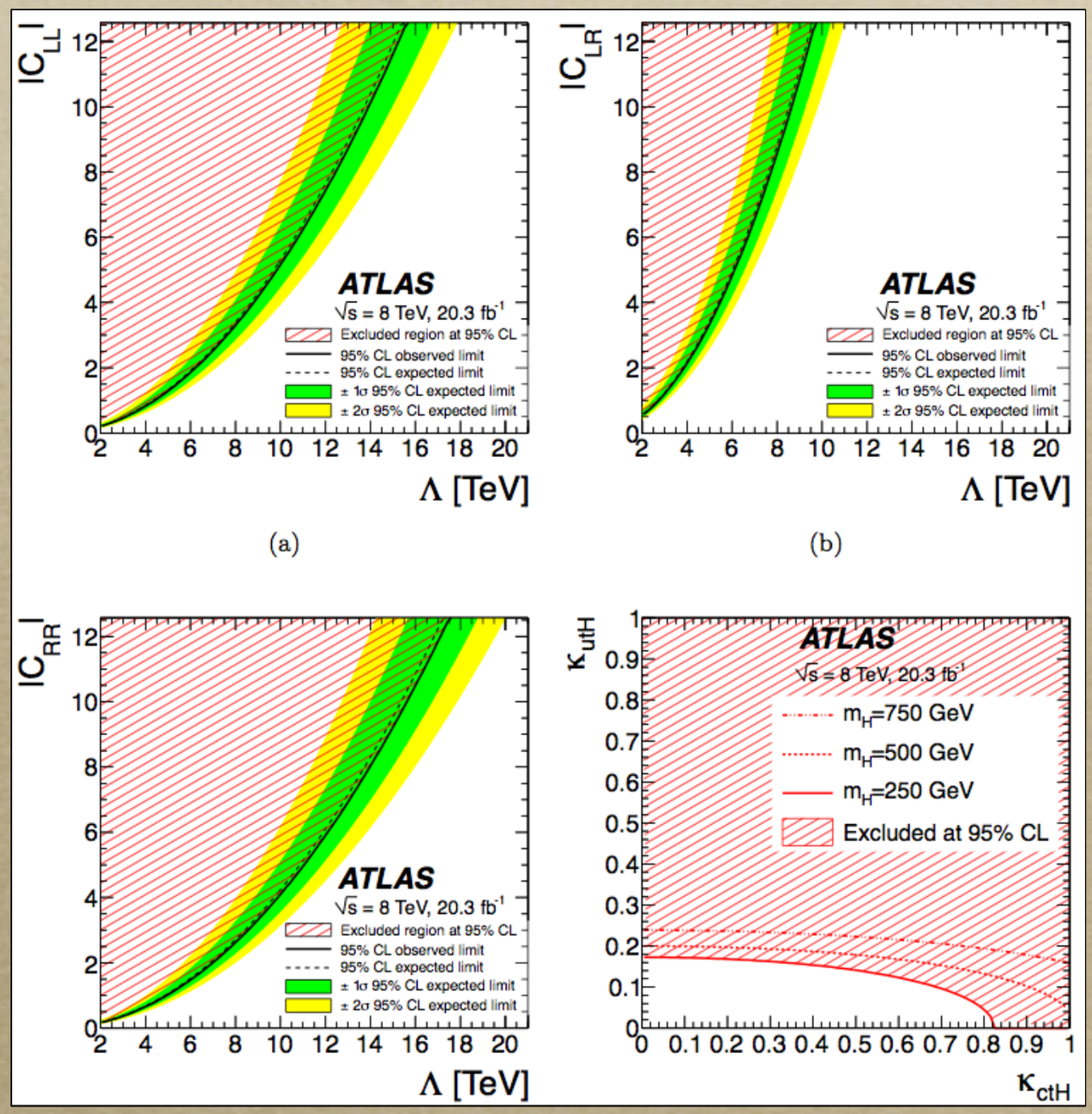
Exclusion limits : tt

Tested for 3 chiralities (LL, RR, LR)
No excess found in tt specific regions

Model	$\sigma(pp \to tt)$ [fb] Exp.	Obs.	Coupling const. Observed
Contact interaction model			$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]
Left-left	64	62	0.053
Left-right	53	51	0.137
Right-right	40	38	0.042
Higgs-like FCNC model			κ_{utH} or κ_{ctH}
$uu \to tt$ ($m_H = 125$ GeV)	37	35	0.16
$uu \to tt$ ($m_H = 250$ GeV)	21	20	0.17
$uu \to tt$ ($m_H = 500$ GeV)	12	11	0.20
$uu \to tt$ ($m_H = 750$ GeV)	9.3	8.4	0.24
$cc \to tt$ ($m_H = 250$ GeV)	71	69	0.81
$cc \to tt$ ($m_H = 500$ GeV)	37	35	1.02
$cc \to tt$ ($m_H = 750$ GeV)	28	27	1.29

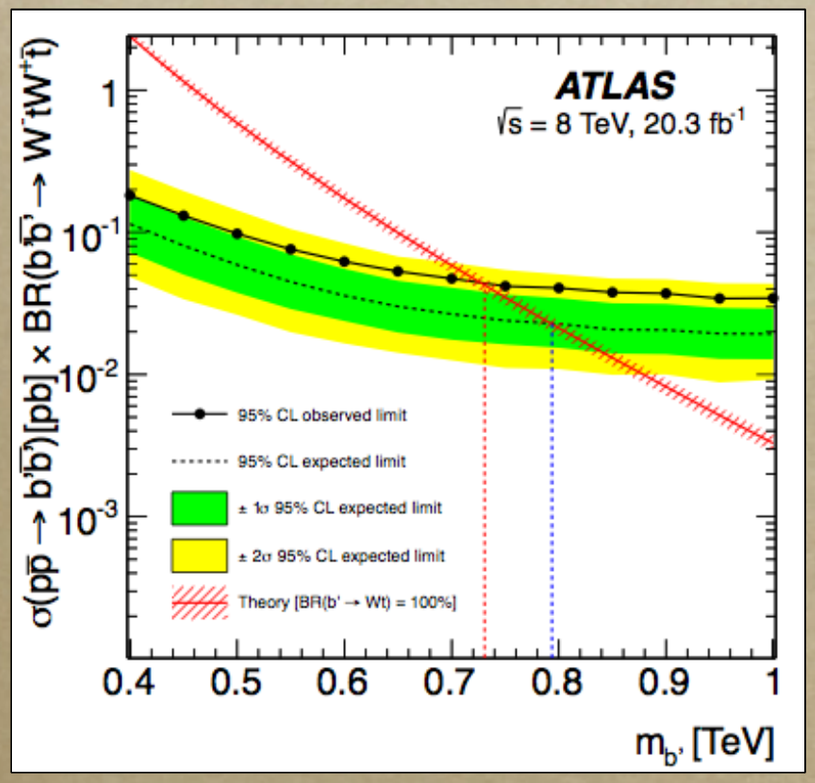
$$\mathcal{L}_{tt} = \frac{1}{2}\frac{C_{\mathrm{LL}}}{\Lambda^2}(\bar{u}_{\mathrm{L}}\gamma^{\mu}t_{\mathrm{L}})(\bar{u}_{\mathrm{L}}\gamma_{\mu}t_{\mathrm{L}}) + \frac{1}{2}\frac{C_{\mathrm{RR}}}{\Lambda^2}(\bar{u}_{\mathrm{R}}\gamma^{\mu}t_{\mathrm{R}})(\bar{u}_{\mathrm{R}}\gamma_{\mu}t_{\mathrm{R}}) - \frac{1}{2}\frac{C_{\mathrm{LR}}}{\Lambda^2}(\bar{u}_{\mathrm{L}}\gamma^{\mu}t_{\mathrm{L}})(\bar{u}_{\mathrm{R}}\gamma_{\mu}t_{\mathrm{R}}) - \frac{1}{2}\frac{C'_{\mathrm{LR}}}{\Lambda^2}(\bar{u}_{\mathrm{L}a}\gamma^{\mu}t_{\mathrm{L}b})(\bar{u}_{\mathrm{R}b}\gamma_{\mu}t_{\mathrm{R}a})$$



ATLAS generic search

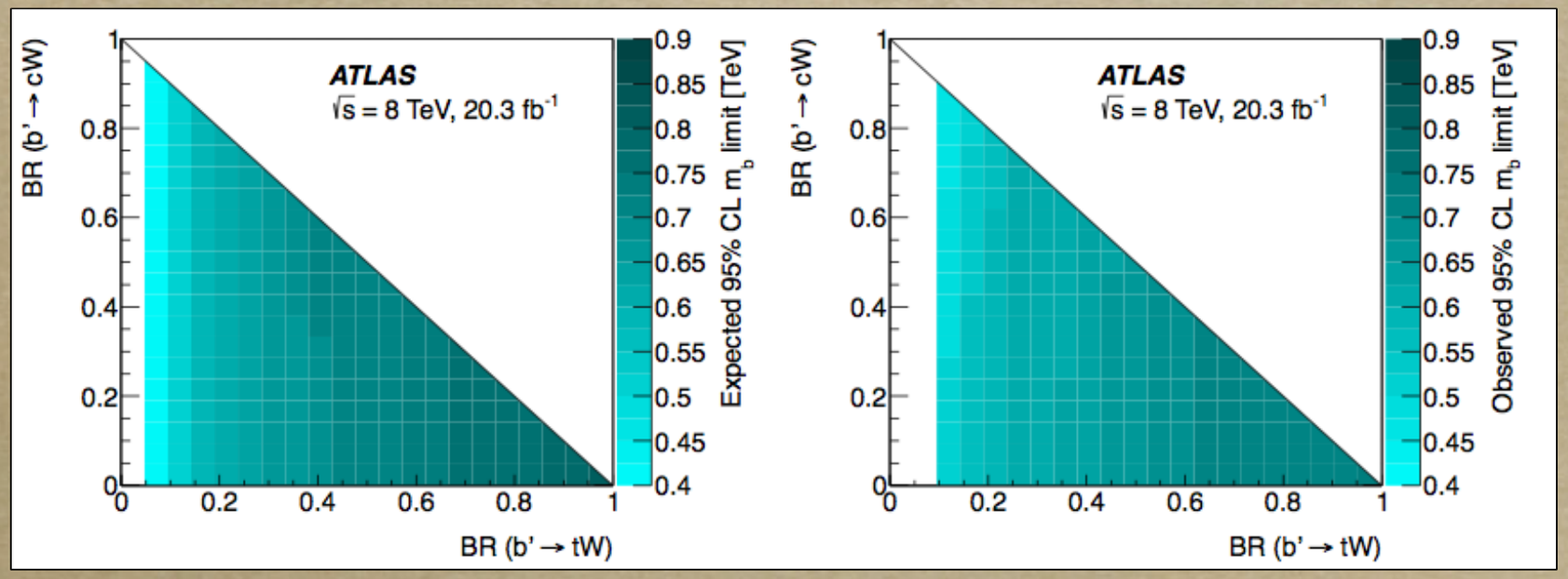
CERN-PH-EP-2015-060

Exclusion limits : b'



For BR(b' → tW)=100 %
b' pair production excluded at 95 % CL for
m(b') < 0.73 TeV

With different BR(b' → tW) and BR(b' → cW)



CMS VLQ B with charge -1/3

B2G-12-020-PAS

Selected events :
- 2l SS strict (no 3l)
- at least 4 jets
- ST = HT + MET regions
(5 bins * 3 channels)

For BR(tW)=100 %, CL limit
m(B) > 0.8 TeV

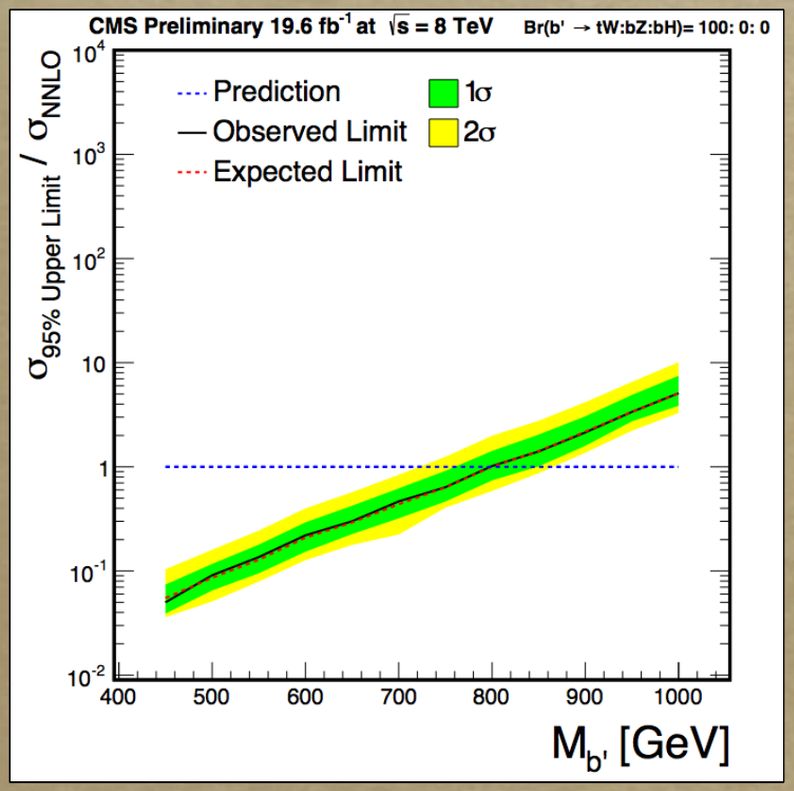
Also for various BR

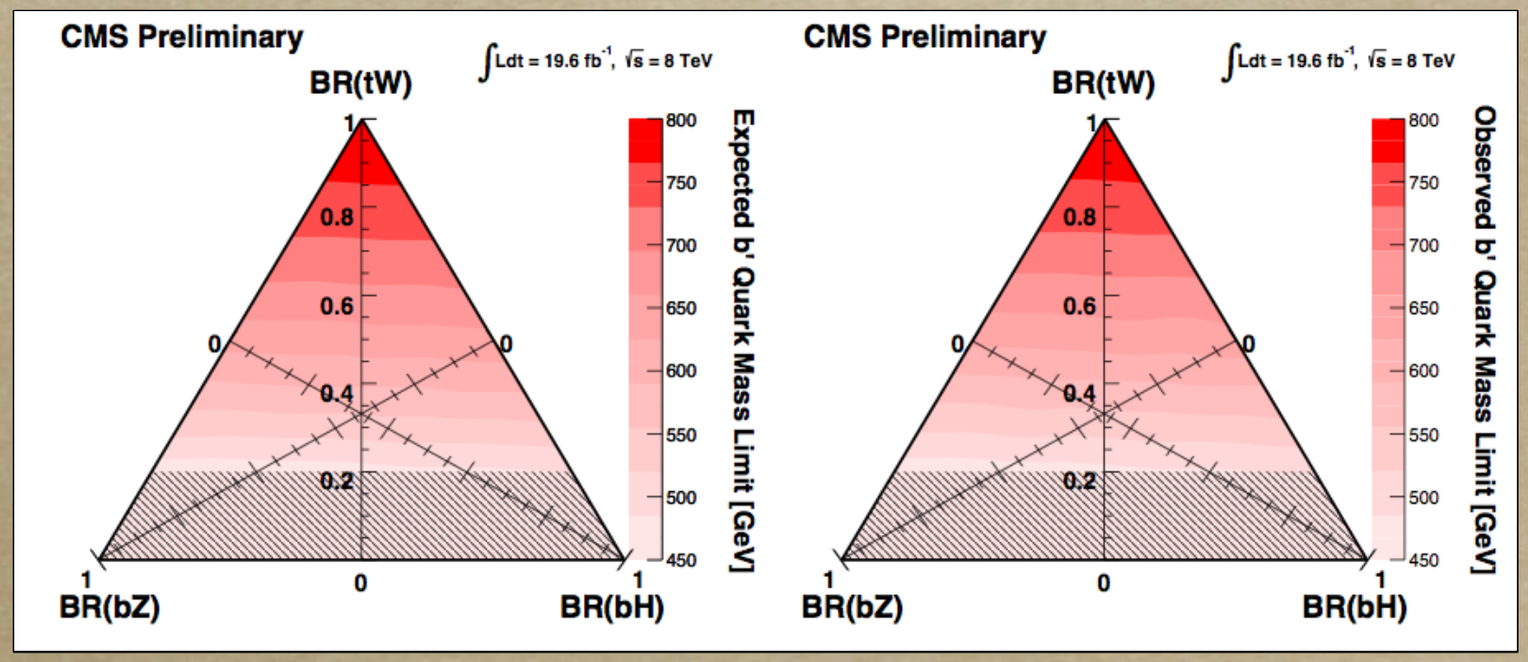
$\mu\mu$	$600 \leq S_T < 800$	$800 \leq S_T < 1200$
Data	5	6
Background Estimation	6.45 ± 0.67 (stat.) ± 2.03 (sys.)	3.39 ± 0.44 (stat.) ± 1.17 (sys.)
Prompt-Prompt	4.13	2.84
Prompt-NonPrompt	2.23	0.53
NonPrompt-NonPrompt	0.08	0.03
Charge Flip	0.00	0.00
ee	$600 \leq S_T < 800$	$800 \leq S_T < 1200$
Data	5	4
Background Estimation	8.67 ± 0.79 (stat.) ± 2.83 (sys.)	4.52 ± 0.56 (stat.) ± 1.43 (sys.)
Prompt-Prompt	3.58	2.42
Prompt-NonPrompt	4.31	1.66
NonPrompt-NonPrompt	0.15	0.14
Charge Flip	0.63	0.30
μe	$600 \leq S_T < 800$	$800 \leq S_T < 1200$
Data	9	8
Background Estimation	14.14 ± 1.33 (stat.) ± 4.31 (sys.)	10.77 ± 1.15 (stat.) ± 3.28 (sys.)
Prompt-Prompt	7.14	5.86
Prompt-NonPrompt	6.55	4.62
NonPrompt-NonPrompt	0.13	0.13
Charge Flip	0.32	0.15

Cut and count analysis

MisId rates estimated from MC : systematics ~30 %

Fakes estimated with MM : systematics ~50 %





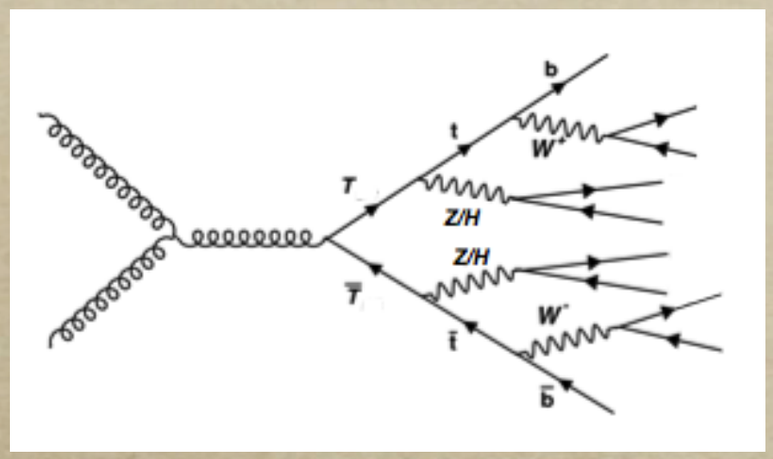
CMS VLQ T with charge 2/3

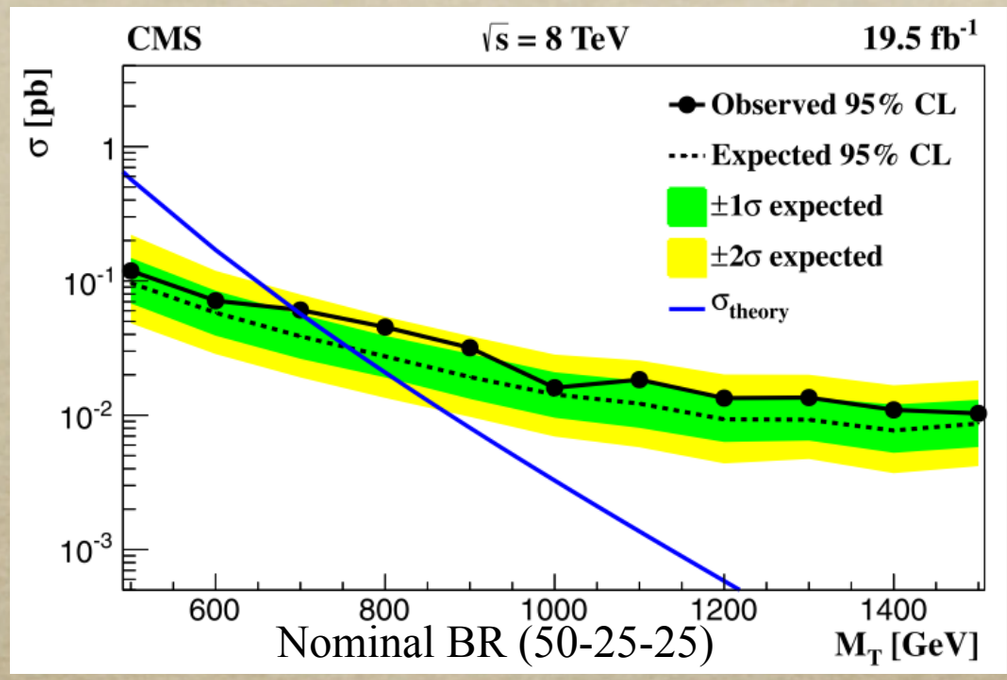
Physics Letters B 729 (2014) 149–171

Selected events :

- T → tZ/H (no bW)
- 2l SS, pT>20 GeV
- at least 3 jets
- HT > 500 GeV
- ST = HT + MET > 700 GeV

Cut and count analysis





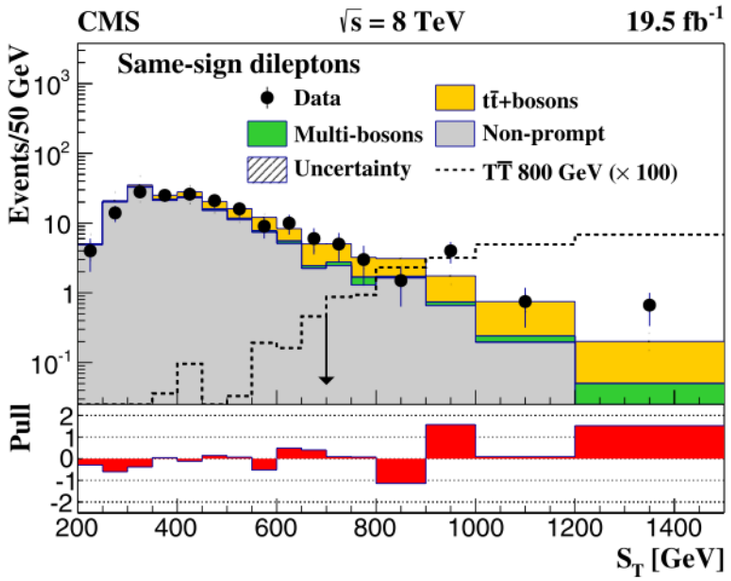


Fig. 5. Observed and expected distributions of S_T for the same-sign dilepton sample. The arrow indicates the chosen requirement.

Channel	SS
$t\bar{t}$	–
Single top quark	–
Z	–
$t\bar{t}W$	5.8 ± 1.9
$t\bar{t}Z$	1.83 ± 0.93
WW	0.53 ± 0.29
WZ	0.34 ± 0.08
ZZ	0.03 ± 0.00
WWW/WWZ/ZZZ/WZZ	0.13 ± 0.07
$t\bar{t}WW$	–
Charge misidentification	0.01 ± 0.00
Non-prompt	7.9 ± 4.3
Total background	16.5 ± 4.8
Data	18

For BR(tW)=100 %, CL limit

m(T) > 0.7-0.78 GeV

(BR dependant)

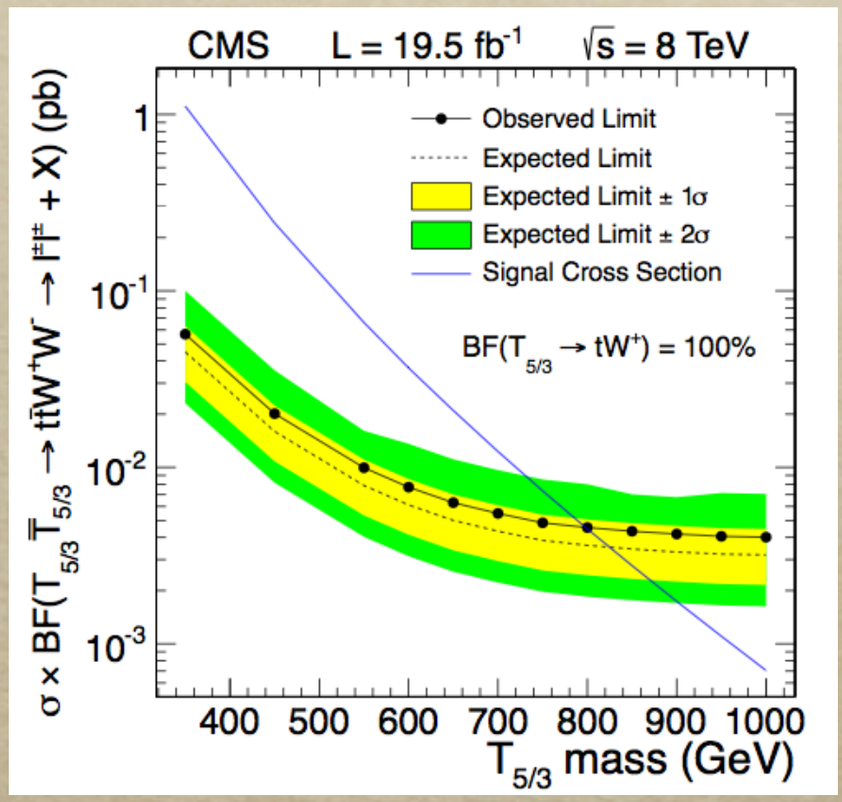
CMS VLQ T5/3

CMS-B2G-12-012

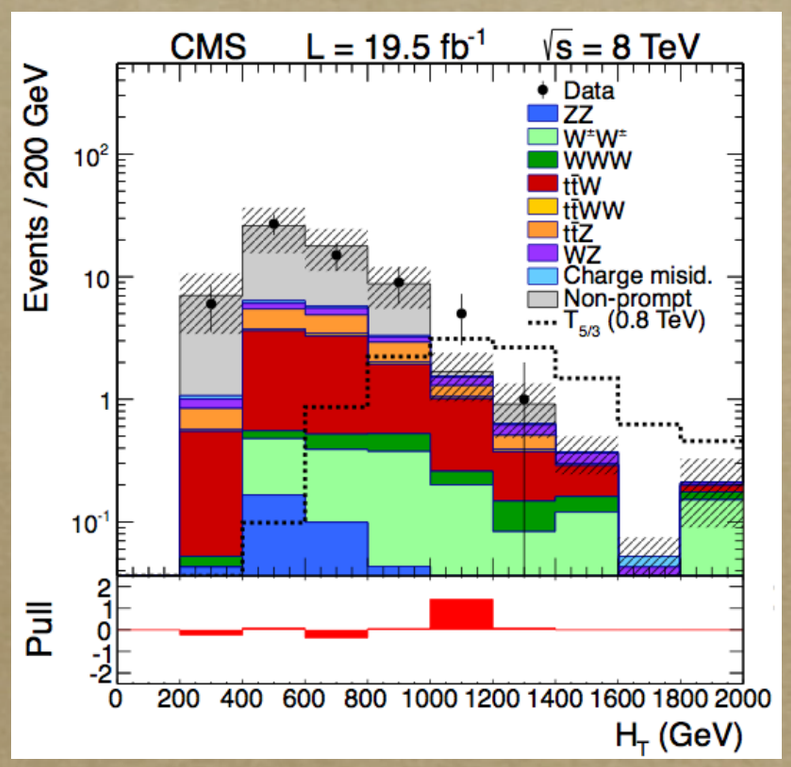
Selected events :
- Pair prod only
- Boosted analysis (enhances 10-20%)
- 2l SS
- at least 5 constituents
- HT > 900 GeV

Cut and count analysis

95 % CL limit
m(T5/3) > 0.8 GeV



No excess found



Channel	ee	eμ	μμ	All
Same-sign	0.8 ± 0.2	1.9 ± 0.4	1.3 ± 0.3	4.0 ± 0.8
Chrg. misid.	0.06 ± 0.02	0.04 ± 0.01	—	0.11 ± 0.02
Non-prompt	1.9 ± 1.2	0.6 ± 0.9	0.3 ± 0.6	2.8 ± 1.9
Tot. bkgnd	2.7 ± 1.3	2.5 ± 1.0	1.6 ± 0.7	6.8 ± 2.1
Obs. events	0	6	3	9
$T_{5/3}$	2.1 ± 0.1	4.7 ± 0.3	2.8 ± 0.2	9.7 ± 0.5

Conclusions

Same-sign used for VLQ searches : very pure channel but needs some work on data-driven methods

CMS does not see any excess, ATLAS has one.

Run2 preparation : new members from Clermont/Grenoble, new signals … so new physics ?