New physics searches at ATLAS and CMS (not involving the Higgs boson)

If that rumour does not crosses this room....
… life still could be exciting!

Alexandra Carvalho, on behalf of ATLAS and CMS collaborations

Top-LHC-France 2017 4-5 March, Marseille

Università degli Studi di Padova

Outline

I am supposed to tell you about all the CMS and ATLAS searches on new resonances

There are a lot of them for a 50min talk, will present the results done with the 13 TeV dataset, even thoungh I might have left some of the results uncovered

- Searches for:
  - Di-jet and dilepton resonances
  - Di-top resonances
  - Di-boson resonances
  - Vector-Like Quarks

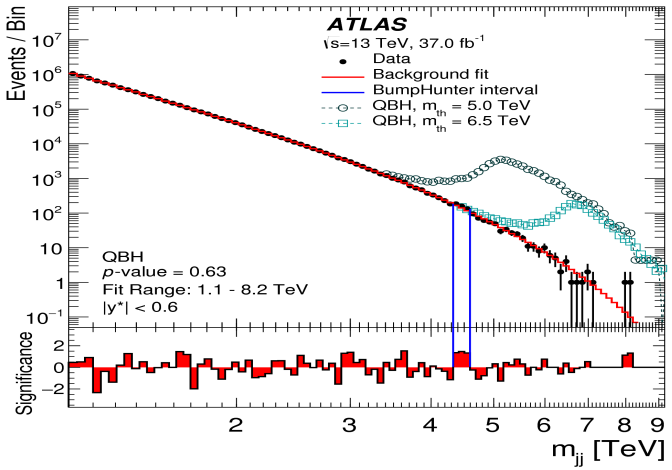
Di-jet resonances

Typical analysis strategy: a bump-hunt on top of a strictly falling QCD BKG (data driven)

ATLAS

High Mass (HM): 1 - 8 TeV

- HT > 250 GeV and |Δyjj| < 1.3



Low Mass (LM): 200 GeV – 1 TeV

- Isolated Photon as trigger (ΔR > 0.85)
  - Photon pT > 150 GeV , |Δyjj| < 1.6
  - Jet (gluon) pT > 350 GeV , |Δyjj| < 1.2
    - pT cut In leading jet of 430 GeV

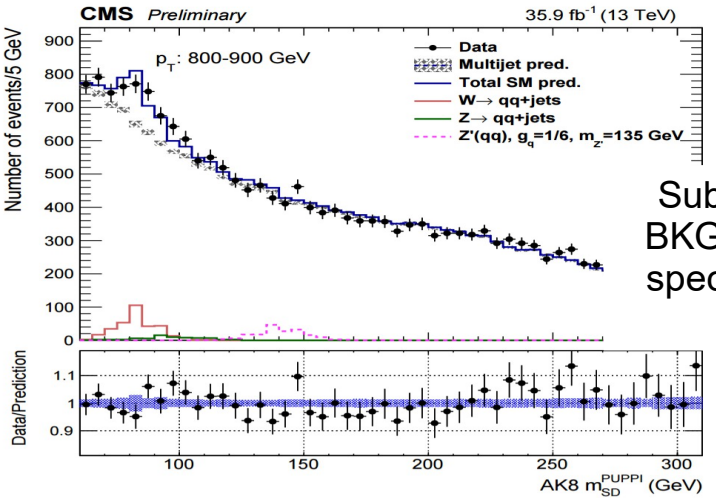
CMS

|Δηjj| < 1.3 helps to reject BKG

- LM (500 GeV – 2 TeV): HT > 250 GeV
  - possible due to data scouting (trigger level jets)
- HM (1 TeV – 8 TeV): HT > 900 GeV

Very Low Mass (LM): 50 GeV – 300 GeV

- Additional handle asking for associated jet with pt > 350 GeV
- The Z'->jj resonance that recoil appear as one merged jet (jet substructure is used)



Subtraction of the EW BKG makes the multijet spectra strictly falling to be fitted

CMS-EXO-16-056 ATLAS-CONF-2016-021 (High mass) | CMS-EXO-17-001 ATLAS-CONF-2016-070 (Low mass)

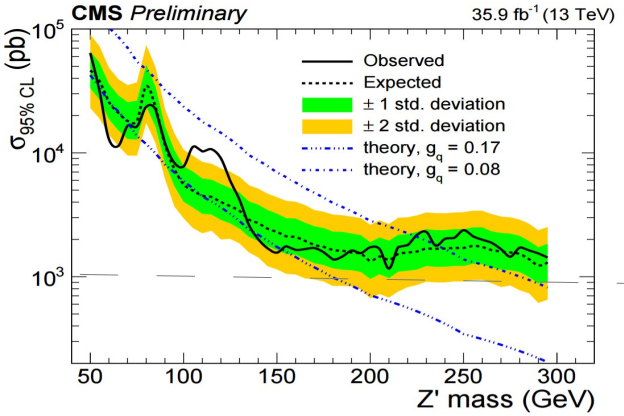
Di-jet resonances: Benchmarks and results – including 2016 data

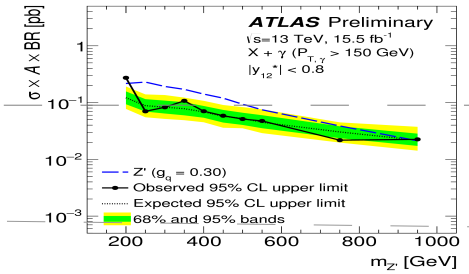
ATLAS, different hiphotheses for signal width are tested, using a gausian modeling

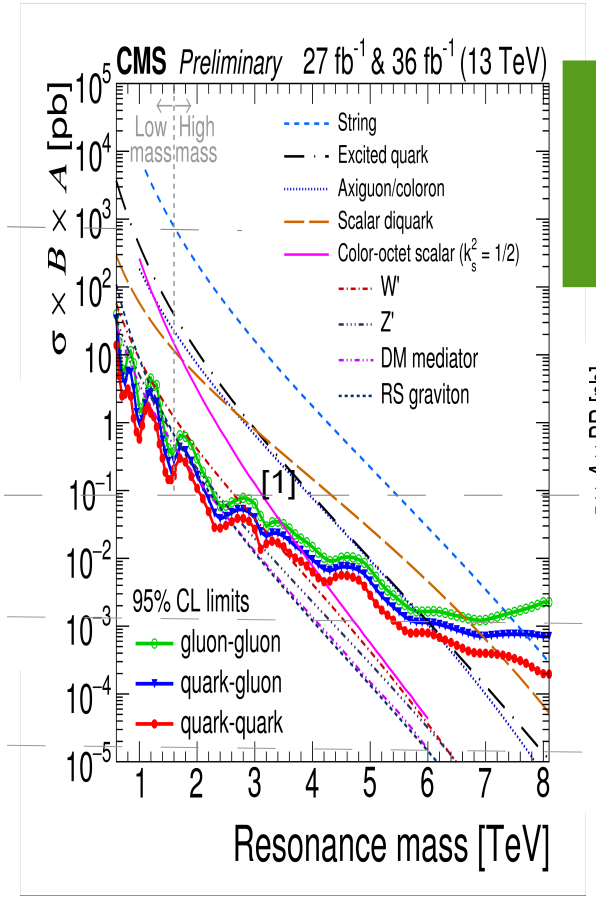
LM: Z' HM: W', Z', KK-graviton and excited quark

CMS, search for narrow width signal, using a gaussian modeling

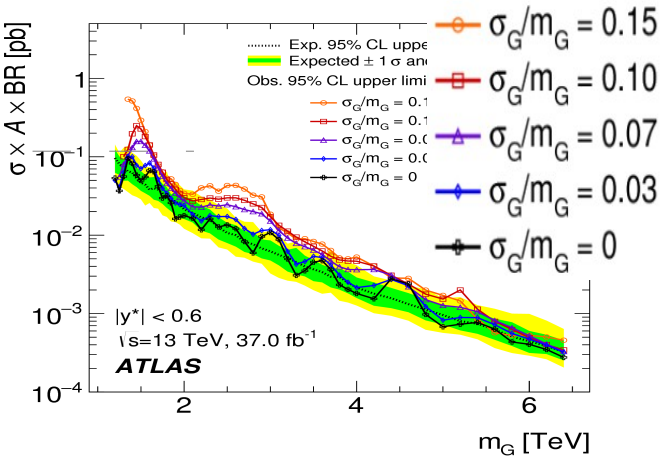
HM/LM: many hiphoteses for resonance spin and color,
additional interpretations in a DM model, Z' mediated







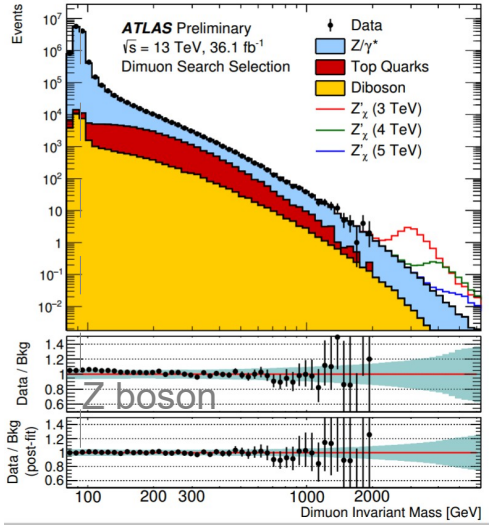
Appart from the wide coverage of model hiphoteses and couplings, there is no sign of a di-jet resonance

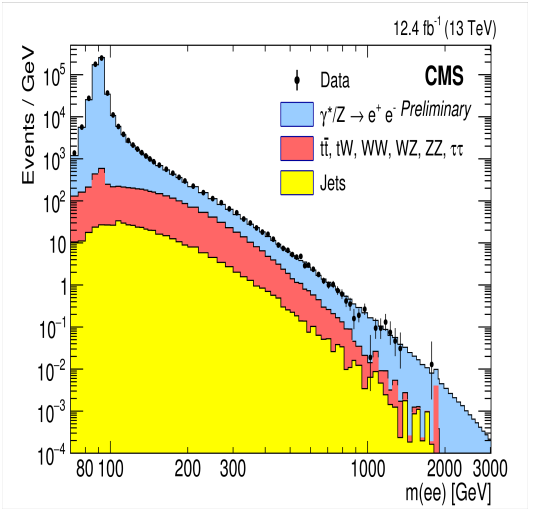


CMS-EXO-16-056 ATLAS-CONF-2016-021 (High mass) | CMS-EXO-17-001 ATLAS-CONF-2016-070 (Low mass)

Di-lepton (electron/muon) resonances

Di-lepton resonances can be additional gauge bosons / vectors or RS KK-gravitons
ATLAS results are for 2016 13 TeV dataset while CMS combines the 13 TeV 2015 dataset with the 8 TeV

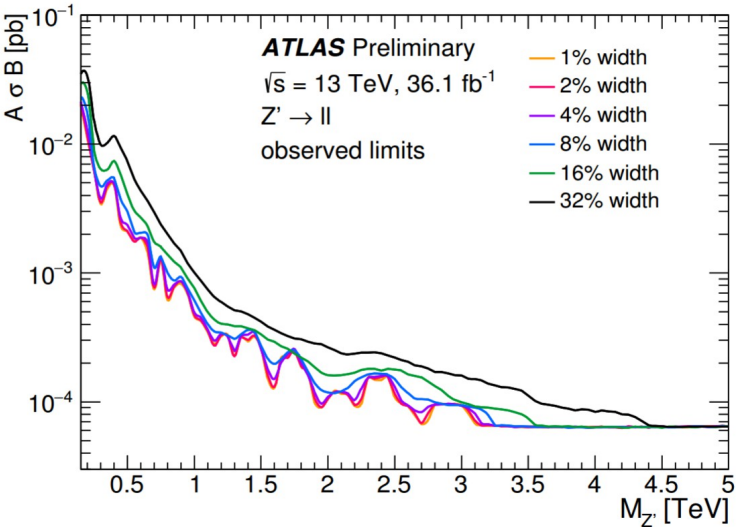


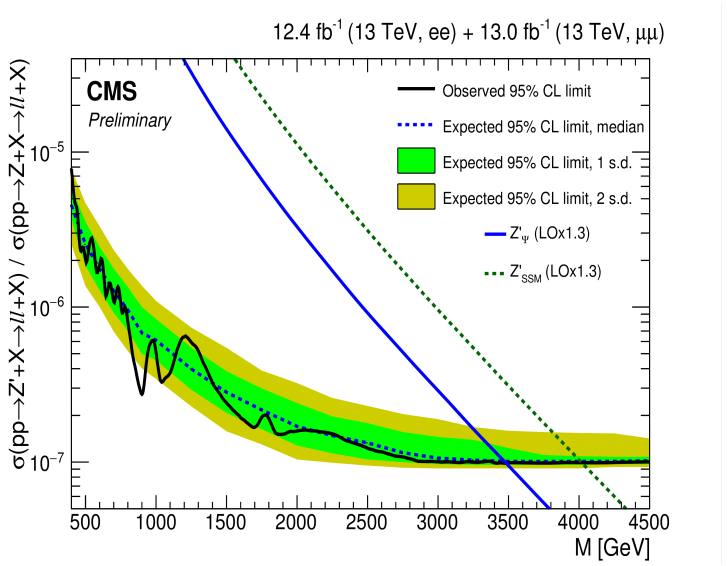


BKG modelling:

- **Di-muon:** extracted from Monte Carlo templates
- **Di-electron:** the additional QCD BKG (fakes) are estimated from data-driven method

The di-lepton invariant mass is used to extract signal





ATLAS-CONF-2017-027 | CMS-EXO-16-031

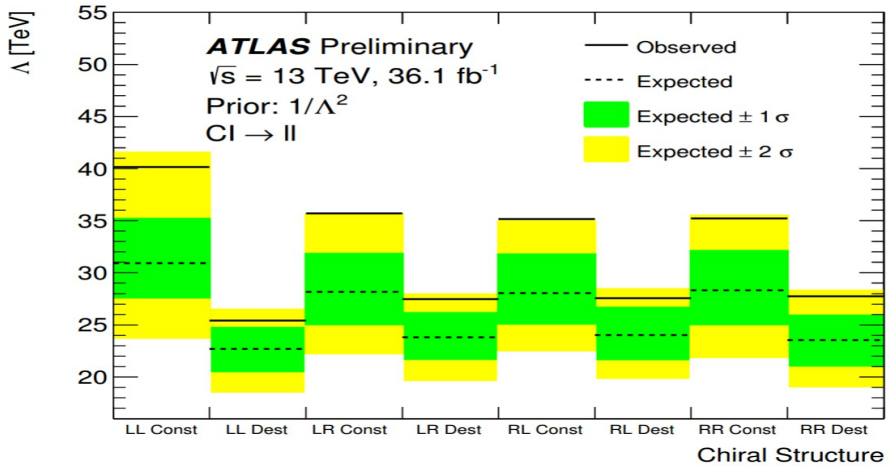
Constraints in 4-fermion interactions

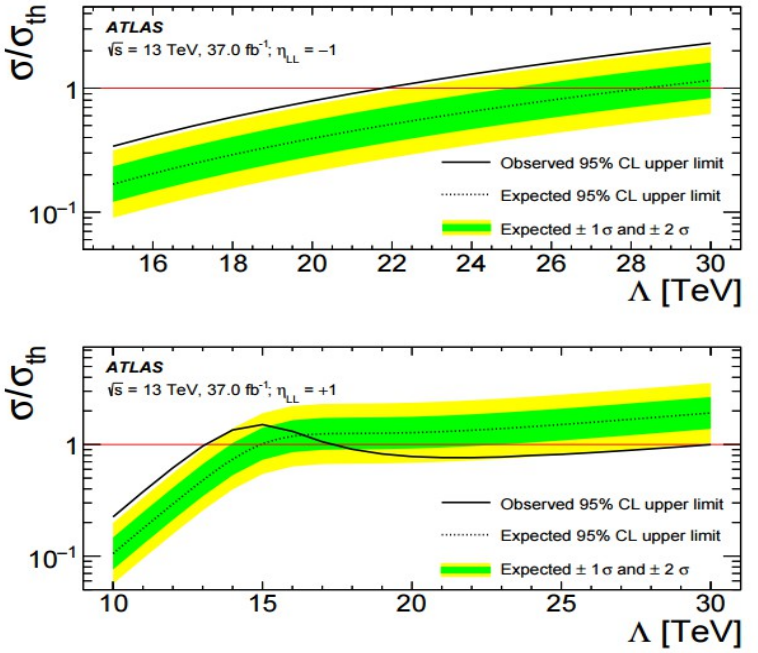
ATLAS uses the (very same) searches for di-jets and dileptons to constrain four fermion contact interactions

$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{LL}\,(\bar{q}_L\gamma_\mu q_L)\,(\bar{\ell}_L\gamma^\mu \ell_L) + \eta_{RR}(\bar{q}_R\gamma_\mu q_R)\,(\bar{\ell}_R\gamma^\mu \ell_R) + \eta_{LR}(\bar{q}_L\gamma_\mu q_L)\,(\bar{\ell}_R\gamma^\mu \ell_R) + \eta_{RL}(\bar{q}_R\gamma_\mu q_R)\,(\bar{\ell}_L\gamma^\mu \ell_L)\right],$$

where g is a coupling constant set to be $\sqrt{4\pi}$

$$\mathcal{L}_{qq} = \frac{2\pi}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)\right],$$



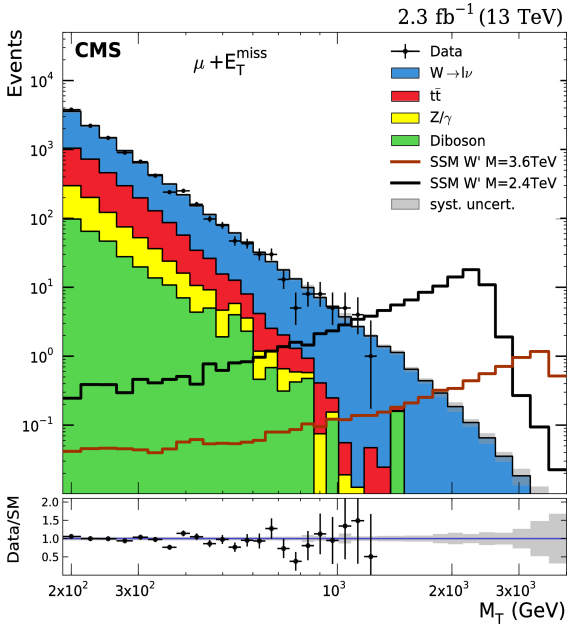


Stringent bounds in the energy scale of a four fermion interaction are set

ATLAS-CONF-2017-027 | ATLAS-CONF-2016-084 (High mass)

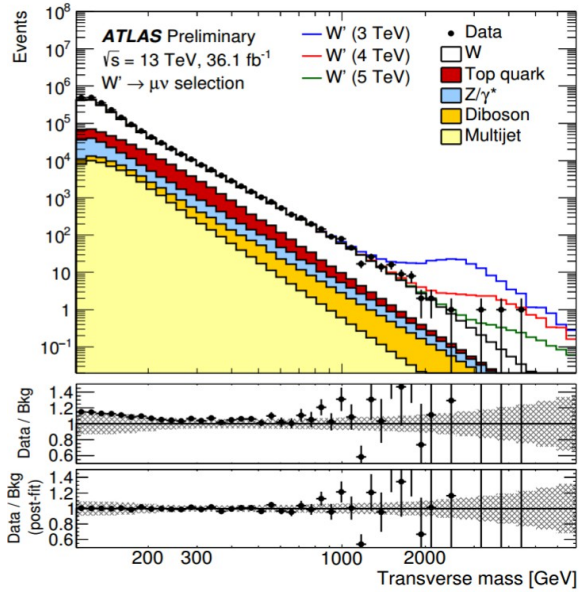
W' (electron/muon + MET) resonances

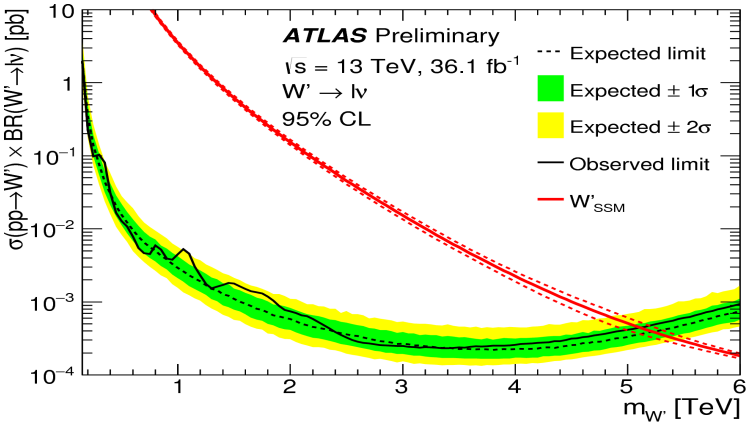
Candidates resonances can be additional gauge bosons / vectors
ATLAS results are for 2016 13 TeV dataset while CMS combines the 13 TeV 2015 dataset with the 8 TeV

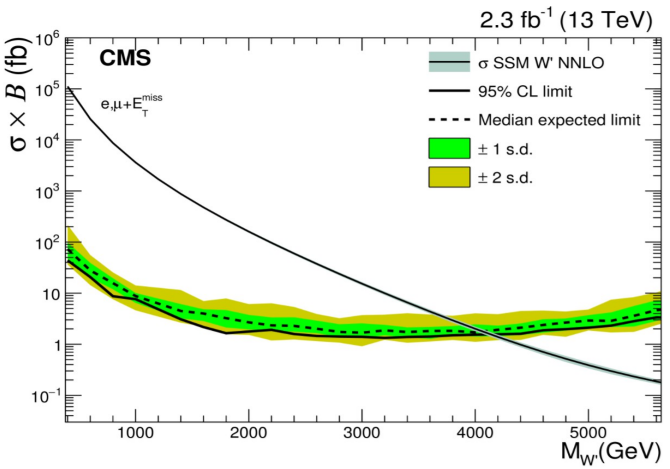


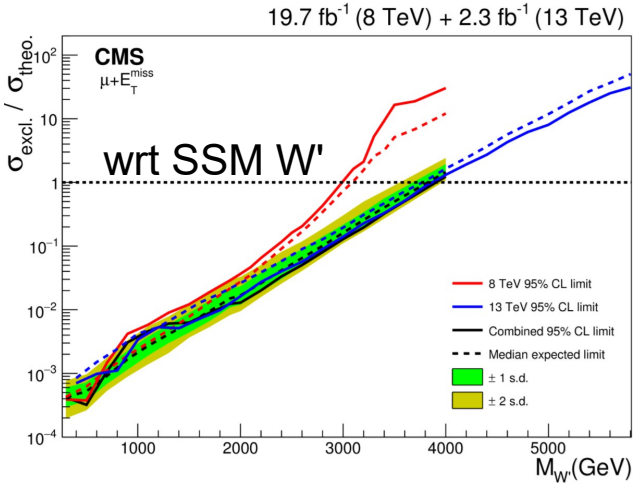
BKG modelling = now both muon and electron channel
- EW components: extracted from Monte Carlo templates
- the additional QCD BKG (fakes) are estimated from data-driven method

The transverse mass is used to extract signal





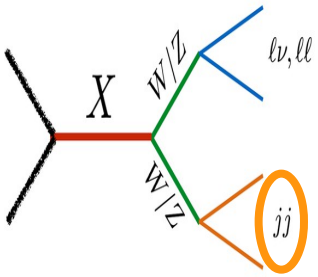




ATLAS-CONF-2017-016 | CMS-EXO-15-006

Heavy Di-(Heavy)boson resonances

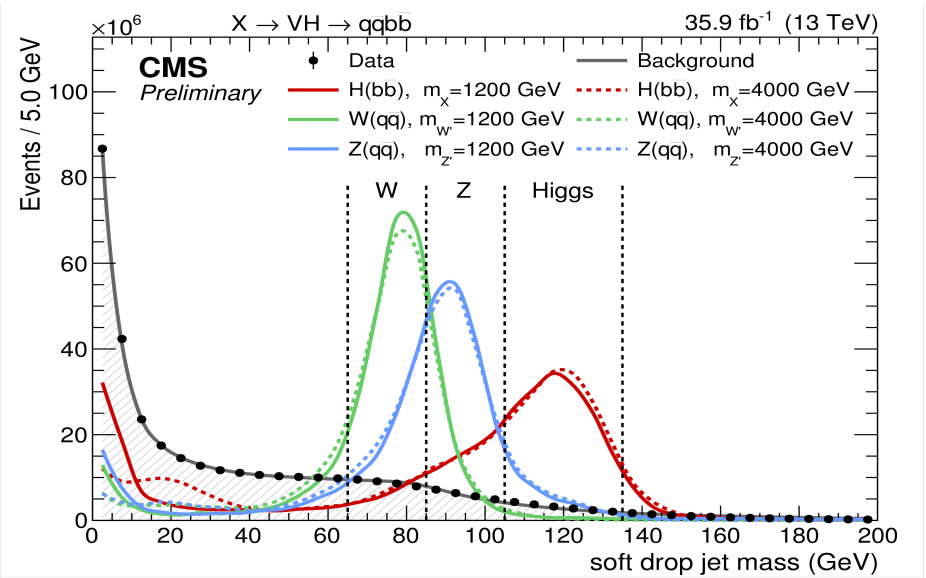
The public searches use as benchmarks the case of a Z' / W' / KK-graviton / scalar
The range of the searches can cover resonanceswith masses up to few TeV



	Fat jet taggers	
ATLAS	J = Anti-KT (R=1.0) D-tag #tracks for categorization Trimmed mass	pTJ> 200 GeV |ηJ| < 2.0
CMS	J = Anti-KT (R=0.8) PUPPI (pileup mitigation) Nsubjetiness for categorization Soft Drop mass	pTJ> 200 GeV |ηJ| < 2.5

The experiments are not capable to fully separate a hadronic Z/W with a mass cut in the fat jet.

- ATLAS optimize selections to different signal hiphotheses
  - Results presented in partially overlapping final states WW, WZ and ZZ
- CMS construct exclusive categories in the fat jet groomed mass in a same search



Di-(Heavy)boson resonances

In all the searches signal is extracted from bump-hunt on top of a strictly falling BKG in the spectrum of the reconstructed resonance

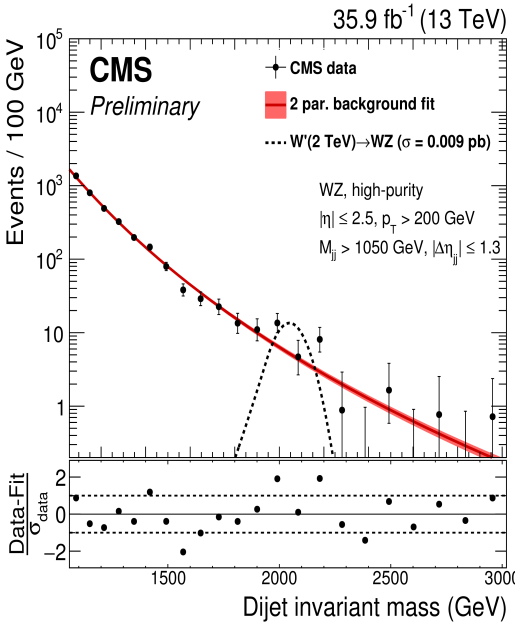
Searches @13 TeV				
Lumi (/fb)	JJ	lvJ	llJ	vvJ
ATLAS	15.5	13.2		
CMS	35.9	12.9		

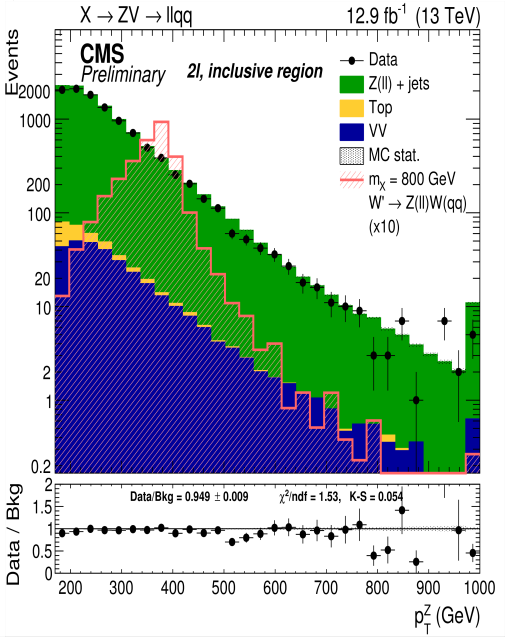
Fully hadronic: data-driven BKG

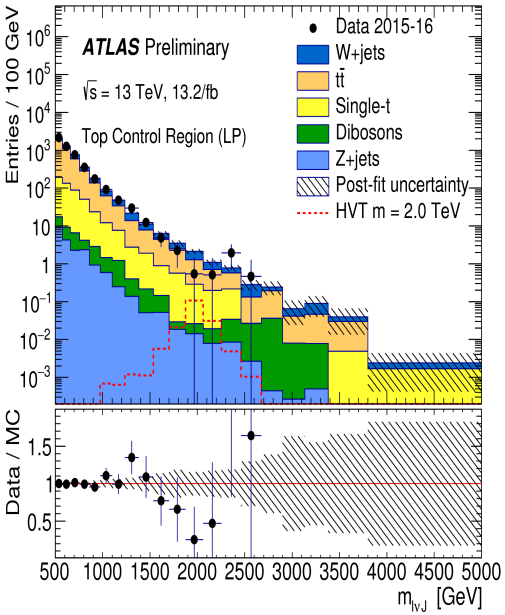
Additional angular cut in ATLAS (CMS) $|\Delta y12|<1.2$ ($|\Delta\eta|<1.3$)

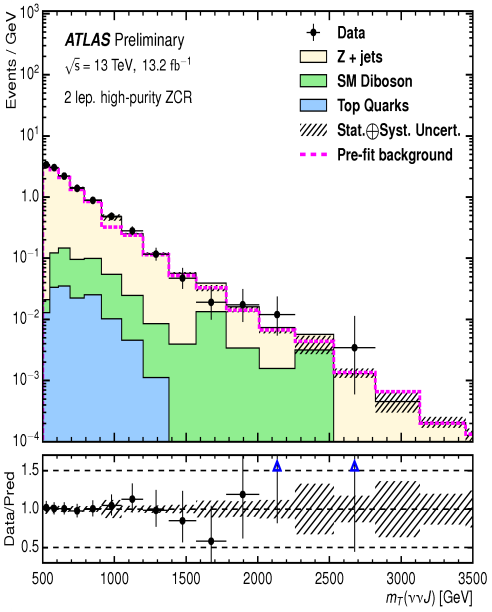
Semi-leptonic: BKG estimated MC templates

In the lvJ and vvJ cases the leptonic W is reconstructed under hiphotheses to the neutrino involving the balancing transverse momenta and the imposition of the W mass value









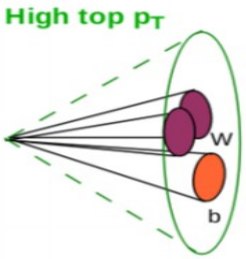
ATLAS: Results are made in terms of mass for total width calculated in specific BSM scenarii (~narrow)
CMS: Results are made in terms of mass and resonance total width (up to 30%)

ATLAS-CONF-2016-055 ATLAS-CONF-2016-08 ATLAS-CONF-2016-06 | CMS-B2G-17-001 CMS-B2G-17-002 CMS-B2G-17-022

Di-top resonances

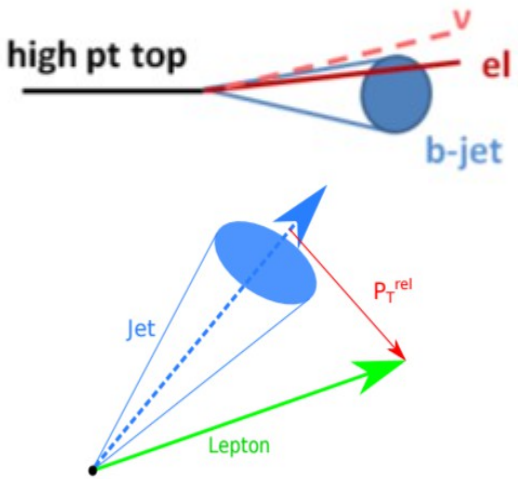
If the resonance mass ranges from 1 TeV to 4 TeV the top wiil manisfest boosted

Hadronic top-tagger



	CMS	ATLAS
large jet def	anti-kt (R=0.8)	anti-kt (R=1.0)
jet cleaning	Soft drop	Trimming
top tagger (t-tag)	$\tau_{32} < 0.69$ $110 < M_{SD} < 210$	τ_{32} and m_{jet} cut optimised to have 80% eff

Leptonic top-tagger



CMS:

$$\Delta R(l; jet) > 0.4 \text{ or } p_T^{rel} > 20\text{GeV}$$

$$(p_T^{miss} + p_T^{l}) > 150\,GeV$$

Select jet in $\Delta R(lep; jet) < 1.2$

The 4-momentum of the top is obtained by kinematic fit

ATLAS:

Isolation cut applied with pT dependant cone (mini-isolation)

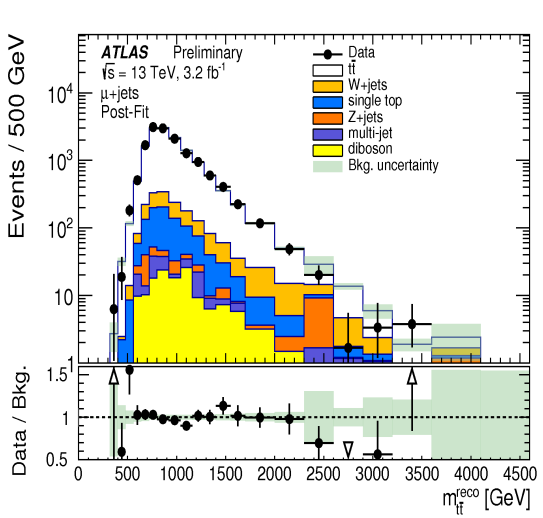
leptonic b-jet : highest pT jet within ΔR(let; jet) < 1.5

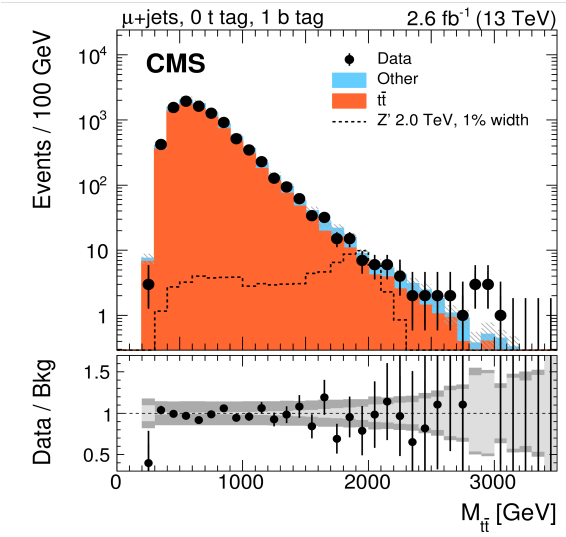
** In the scalar caseboth signal and BKG are produced by gluon fusion producing a non trivial interference pattern, no result with 13 TeV data is released. ATLAS have the study with 8 TeV data ()

Di-top resonances

The public searches use as benchmarks the case of a Z' / KK-graviton / KK-gluon

Semi-leptonic





CMS:

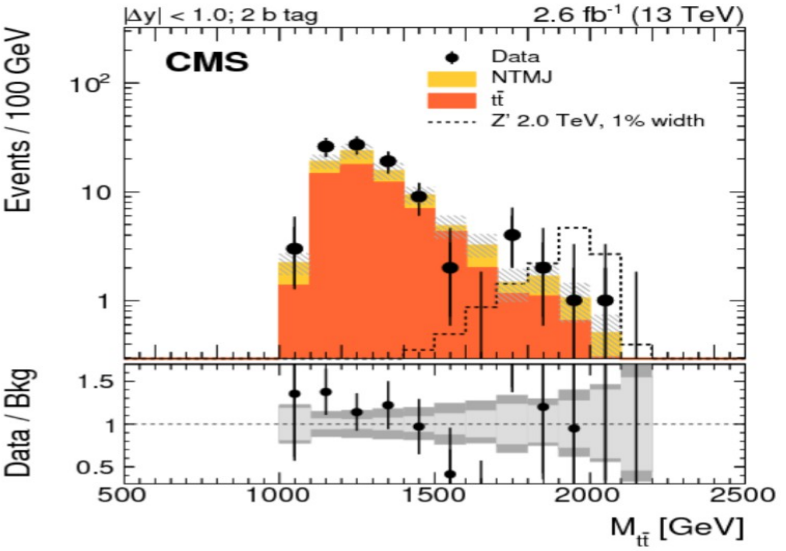
Categorize events in 6 region (e,μ)×
(1 t-tag, 0 t-tag+1 b-tag, 0 t-tag+0 b-tag)

$p_t^{miss} > 120GeV$ supresses the multijet BKG (fakes)

ATLAS:

Only 2 regions (e, mu),
with >1 t-tag and >1 b-tagged track-jet.
The BKG from fakes is estimated from data using the matrix method

Fully hadronic (CMS)



Categorization in 1 or 2 b-tags and difference in rapidity

The requirement of 2 t-tag fat jet highly supress the QCD background. Remaining QCD background (NTMU) estimated from data

Results considering the total width of the resonance up to 30% of its mass

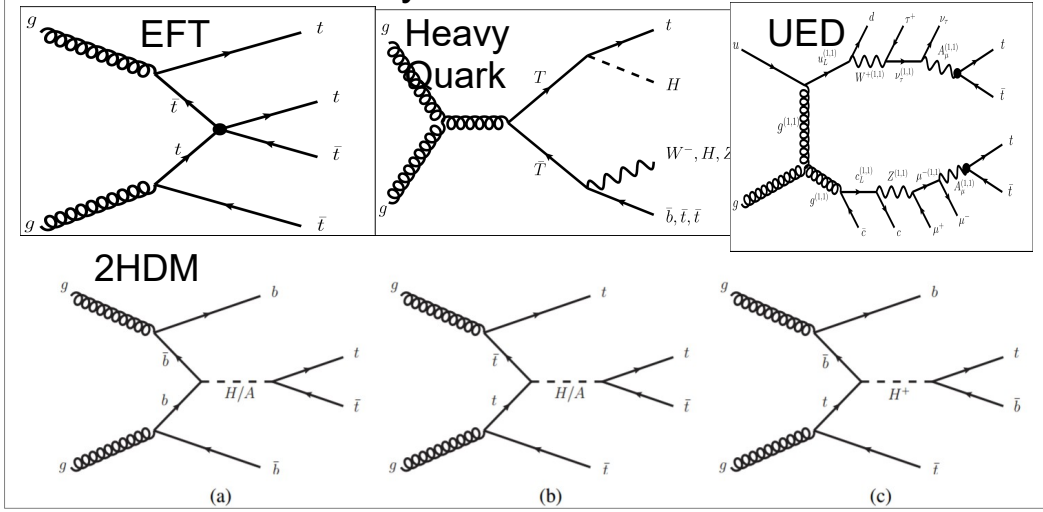
ATLAS-CONF-2016-014 | CMS-B2G-16-015

Di-top + more heavy flavour

Diferent BSM phenomena can appear in final states with many top quarks+b-quarks:

- Four fermion interactions, exotic production/decays of Heavy Quarks/Scalars/Vectors

Cases considered by ATLAS-CONF-2016-10:



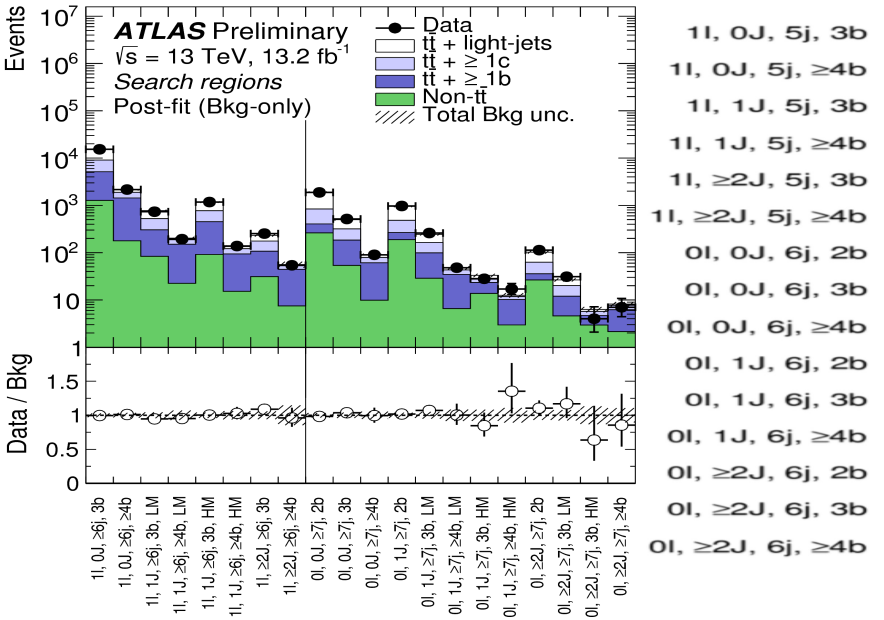
All those signals can have in comon the presence of leptons plus (b) jets

Preselection requirements		
Requirement	1-lepton channel	0-lepton channel
Trigger	Single-lepton trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
Leptons	=1 isolated e or μ	=0 isolated e or μ
Jets	≥5 jets	≥6 jets
b-tagging	≥2 b-tagged jets	≥2 b-tagged jets
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV
Other $E_{\mathrm{T}}^{\mathrm{miss}}$-related	$E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV	$\Delta\phi_{\mathrm{min}}^{4j} > 0.4$

20 categories based in nulber of objects are constructed to search for a signal

Background from ttbar is completely estimated by MC templates in validation regions,

(the non ttbar BKW is V+jets and single top)



No signs of BSM are found, but competitive limits are set in the benchmark models.

In special for the non-resonant production:

SM kinematics: the obs. 95% CL limits on 15 X SM

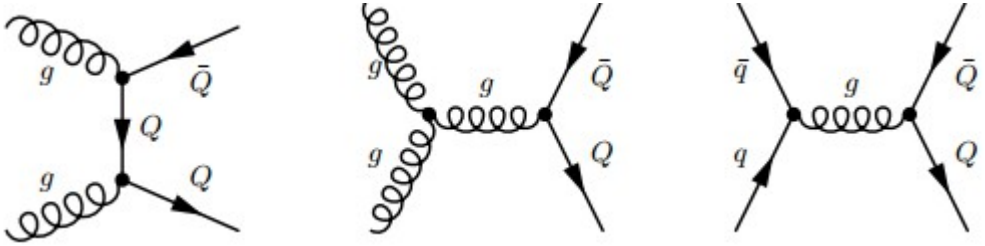
EFT four-top contact interaction:
effective coupling: |C4t| / Λ^2 < (3.0 TeV)^2

Vector Like Quarks – what to look for?

Partners of the 3rd generation in a minimal particle content

Decays: V + b-jet / V + top, where (V = W , Z or H)

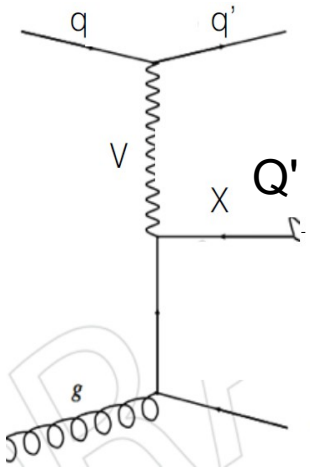
Pair production: it hapens by only QCD will be always present, the production rate is model-independent



EW single production: Model dependent prod. rate

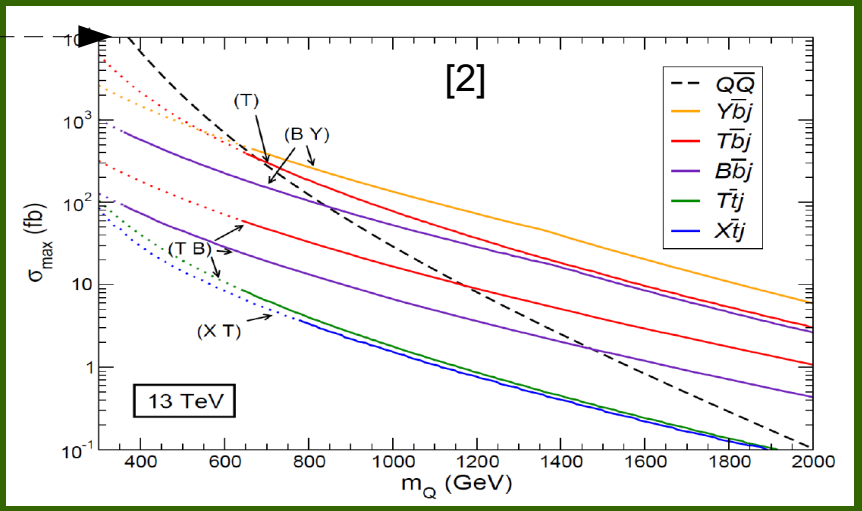
In typical cases for the EW coupling strenght Ssingle > Sdouble for mQ' >~ 1 TeV

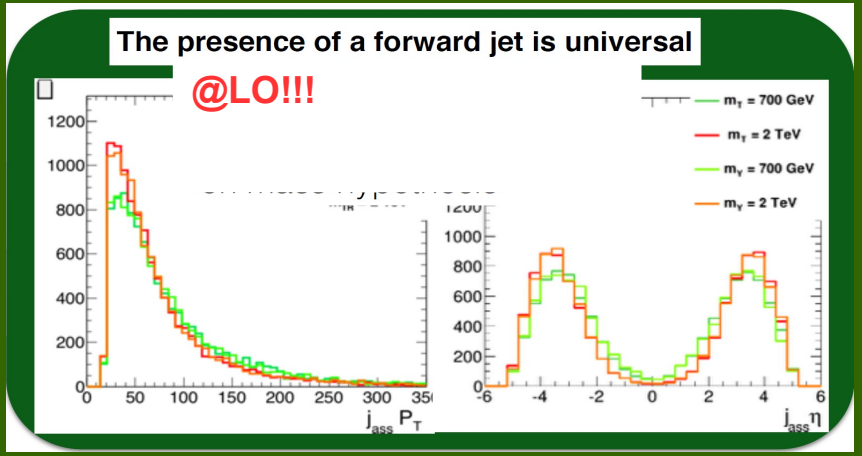
Leading signal process topology is 2->3 [1]



Its chirality influence pheno, specially if we have boosted t's

Pheno:





See S. Beauceron talk for more on 3th gen. Q' phenomenology

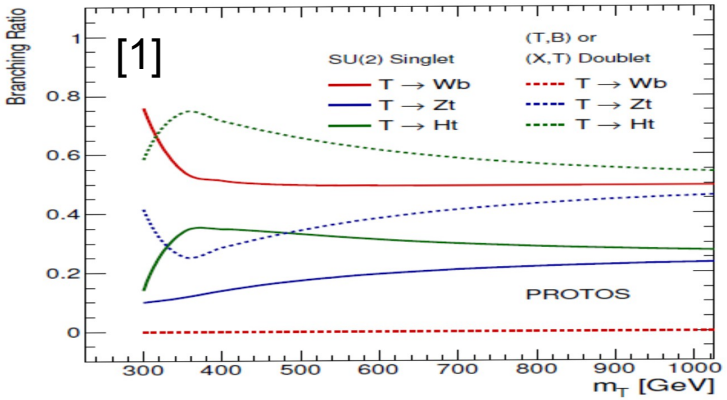
[1] D.Barducci, A.Belyaev, M.Buchkremer, G.Cacciapaglia, A.Deandrea, S. De Curtis , J.Marrouche, S.Moretti, L.Panizzi'14, O.Matsedonskyi, G.Panico, A.Wulzer'14, [2] J.Aguilar-Saavedra, R.Benbrik, S.Heinemeyer,M.Perez-Victoria'13 ...

Vector Like Quarks – how to look for?

Quark partners generation, in a minimal particle content

The Branching Fractions of Q' in SM particles is benchmark deppendent, three aproaches are usually taken:

Explicit calculations on specific representations



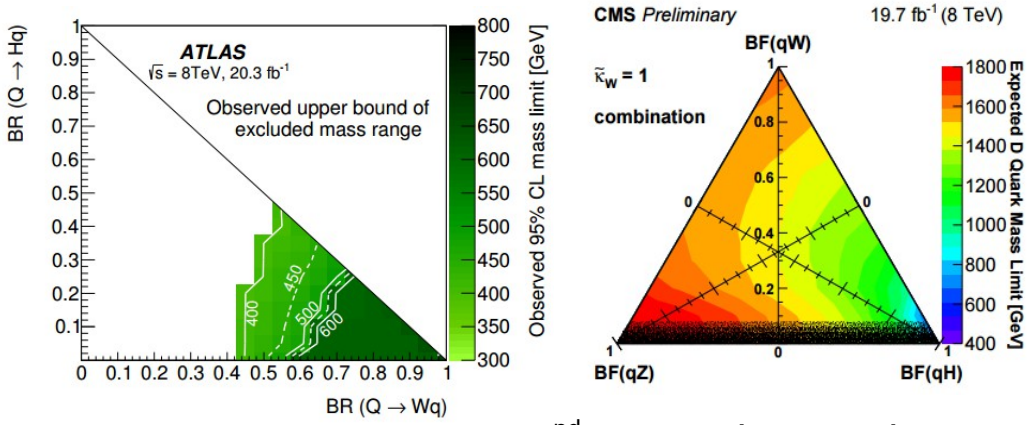
ATLAS 3rd generation results

Assimptotic limits on specific quark representations based in the Equivalence Theorem [2]

BR	Wt	Wb	Zt	Zb	ht	hb	Chirality
T23 singlet	0	1/2	1/4	0	1/4	0	L
T23 doublet	0	0	1/2	0	1/2	0	R
X53 doublet	1	0	0	0	0	0	L/R
B13 singlet	1/4	0	0	1/2	0	1/2	L
B13 doublet	1	0	0	0	0	0	R
Y43 triplet	0	1	0	0	0	0	L/R

CMS 3rd generation single prod. results

Model independent limits in terms of BRs [3]



Pair production and 1st /2nd generation results

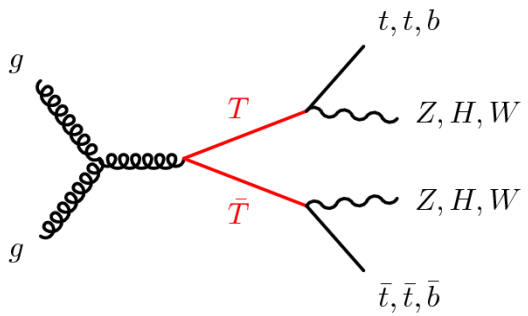
- If there are more than one quark multiplet and they mix with each other, the branching fractions are not constrained to be ~ the equivalence theorem result!

[1] J.Aguilar-Saavedra, R.Benbrik, S.Heinemeyer,M.Perez-Victoria'13
[2] Benjamin W. Lee, C. Quigg, H.B. Thacker'77
[3] Examples of scans from: ATLAS: 1509.04261 | CMS: B2G-12-016

Vector Like Quarks - ATLAS

Top Partners (3rd generation), in a minimal particle content

Several final states with many boosted top-quaks and bosons
= the dominant BKGs are typically ttbar and V+jets =
The searches are classified by final state: **Results for pair production**



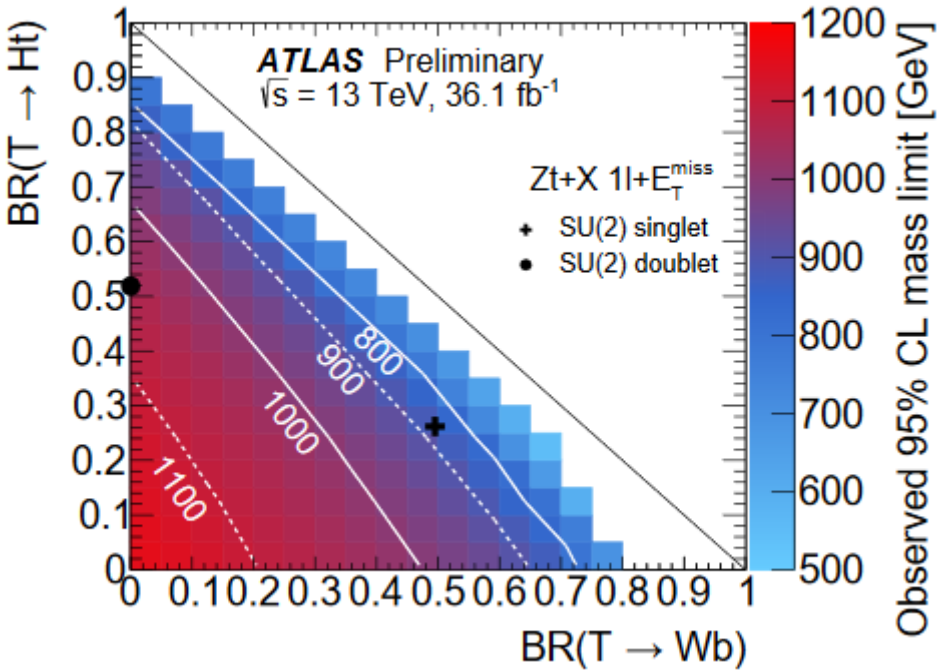
Selections are optimized to a 1 TeV T', when 80% BR(Zt) and BR(Wb)=BR(Ht)

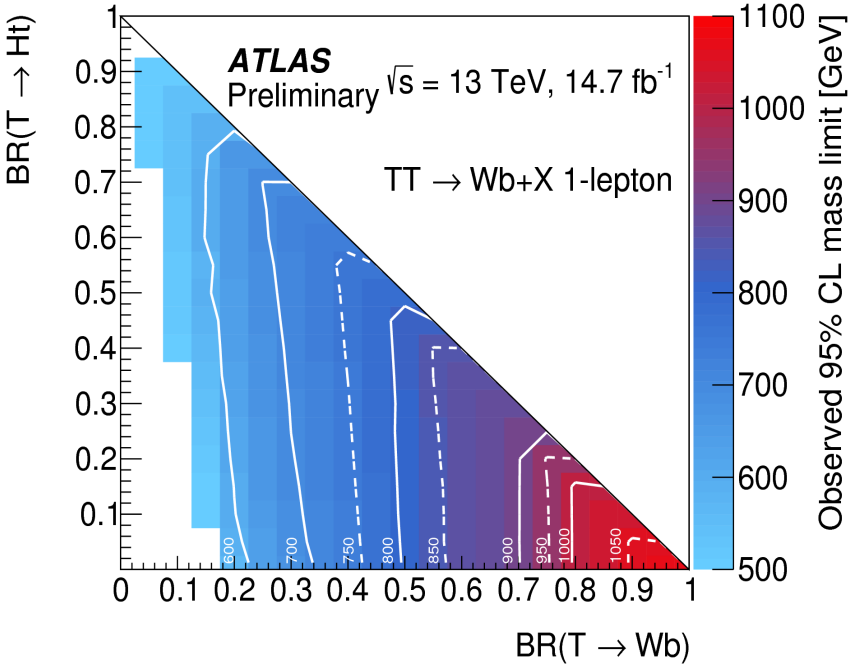
- Z(vv)t+X

  One signal region is constructed, the limit is set from a couting experiment

- W(lv)+b

  The mass of the (boosted) leptonic W is recosntructed and fitted





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Vector Like Quarks - CMS

Top Partners (3rd generation), in a minimal particle content

Several final states with many boosted top-quaks and bosons
= the dominant BKGs are typically ttbar and V+jets =
The searches are classified by final state: **Results for single and pair production**

Pair production: l+jets (14.7/fb)

16 categories based on lepton flavor (e, μ), the # of b tagged AK4 jets (0, 1, 2, ≥ 3), and the # of W tagged jets (0, ≥ 1).

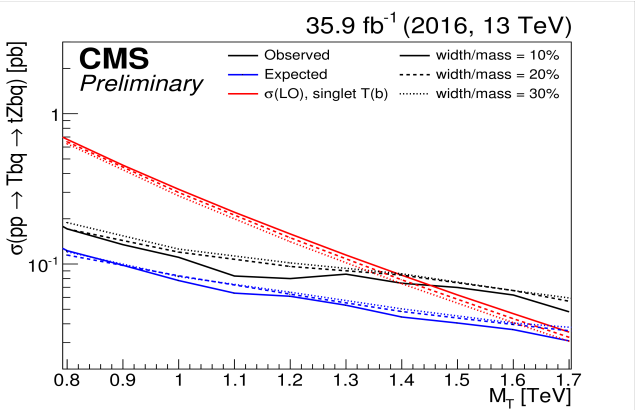
Signal extracted from min(Mass(l,b))
(optimal to T>Wb reco)

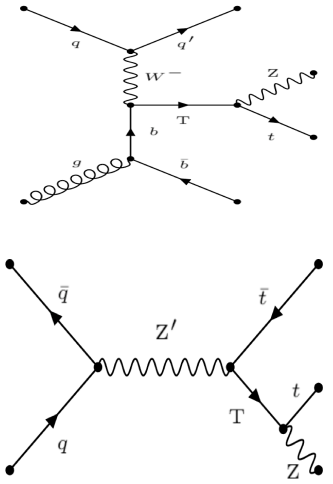
B(T → bW)	B(T → tH)	B(T → tZ)	Expected [GeV]	Observed [GeV]
0.50	0.25	0.25	743	750
1.00	0.00	0.00	853	876
0.80	0.20	0.00	812	824
0.80	0.00	0.20	808	828
0.60	0.40	0.00	778	780
0.60	0.20	0.20	772	778
0.60	0.00	0.40	768	774
0.40	0.60	0.00	727	731
0.40	0.40	0.20	707	714
0.40	0.20	0.40	< 700	< 700
0.40	0.00	0.60	< 700	< 700
0.20	any	any	< 700	< 700
0.00	any	any	< 700	< 700

Single production: T'>Z(ll)t

Both SM-like and exotic production

- 2 isolated opposite sign e/μ with pt(l1) >120 GeV
- Ttbar is reconstructed as: resolved, semi-resolved, boosted
- Categorization as function of the presence os a foward jet,
- The T' mass is reconstructed and fitted





CMS-B2G-16-002 CMS-B2G-17-007

Conclusions

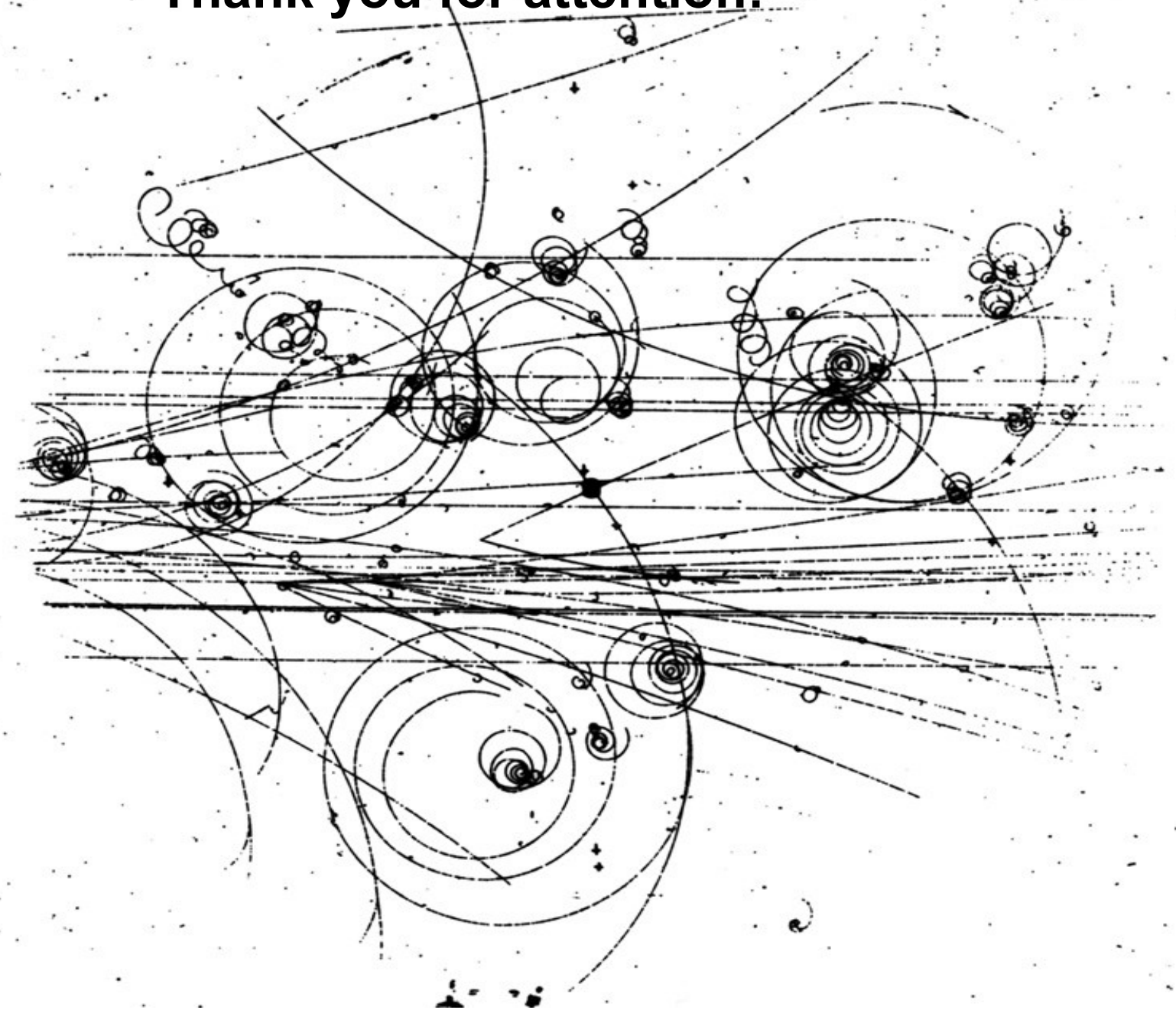
The data are in good agreement with the background expectations in all channels

No evidence for a significant deviation from the SM expectations is observed.

Yet!

We can carry on with this nice Workshop

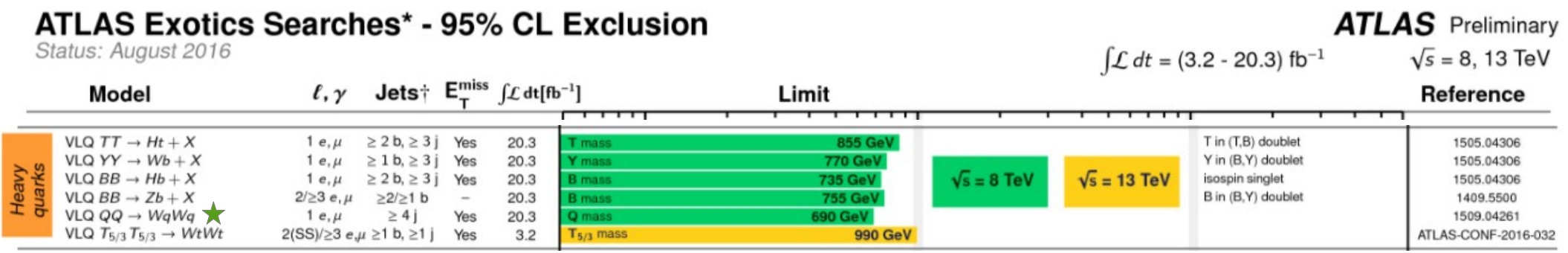
Thank you for attention!



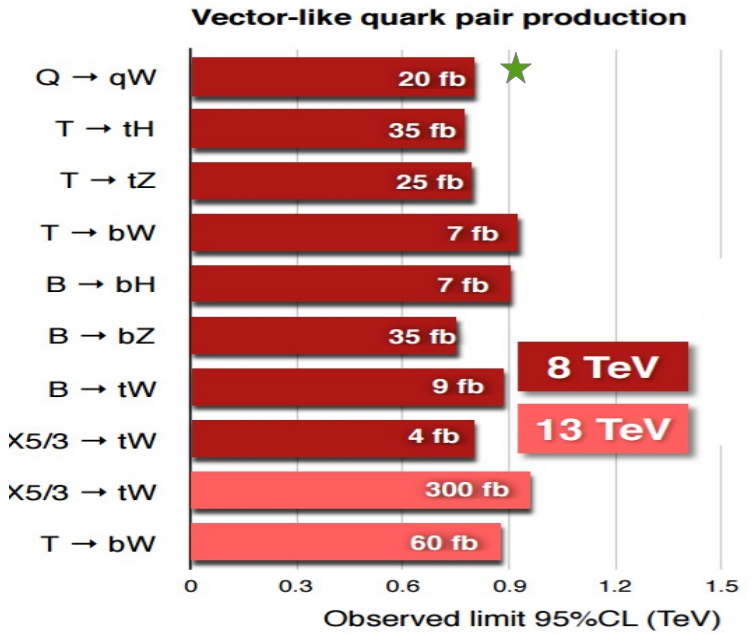
Summary of ATLAS and CMS bounds

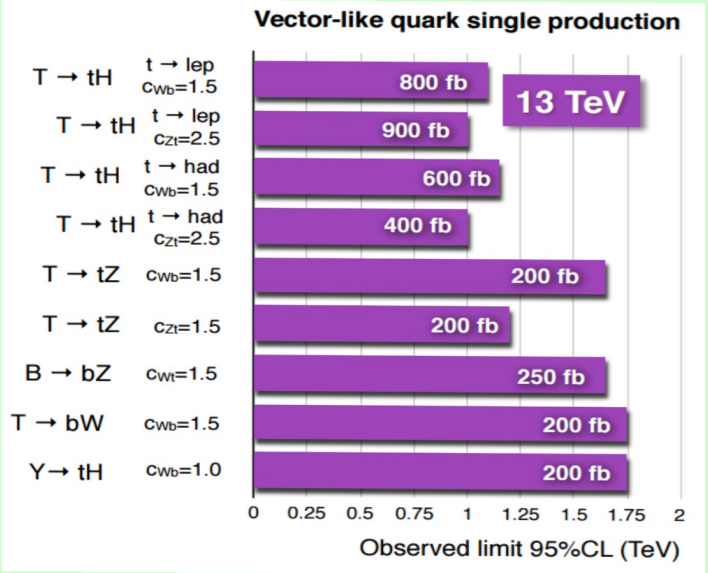
Quark partners, in a minimal particle content

Limits in pair production in usual benchmarks are in the ballpark of ~900 GeV, most of the limits are for partners of the 3th generation of quarks. The only theory dependency is in the Q' BRs



CMS





Limits in VLQ mass are coupling-deppendent, they are is an indicative of points where the signal is a narrow resonance.

Reasonable values for the couplings are c ~ 1 [1] (VLQ coupling ~ gw)

★ 1st /2nd generation

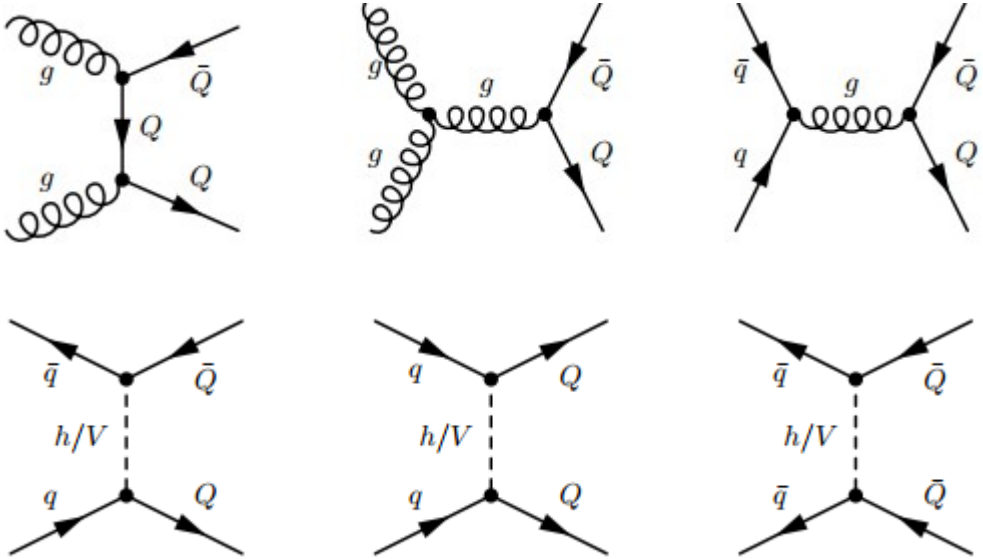
[1] Notation of: Andrea De Simone, Oleksii Matsedonskyi, Riccardo Rattazzi, Andrea Wulzer'12

How do they appear at colliders?

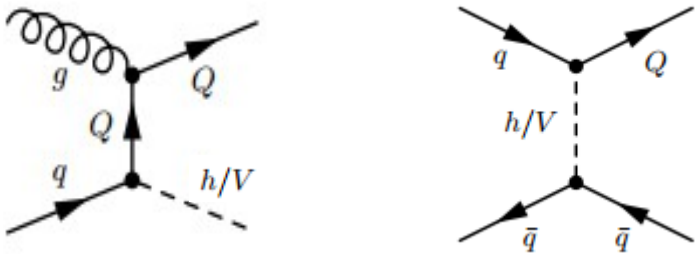
Narrow Width Partners of the 1st /2nd generation in a minimal particle content

Decays: V + jet where (V = W , Z or H) ==> boosted bosons to tag

Pair production: Besides the model-independent QCD, there is a model dependent EW production [1]

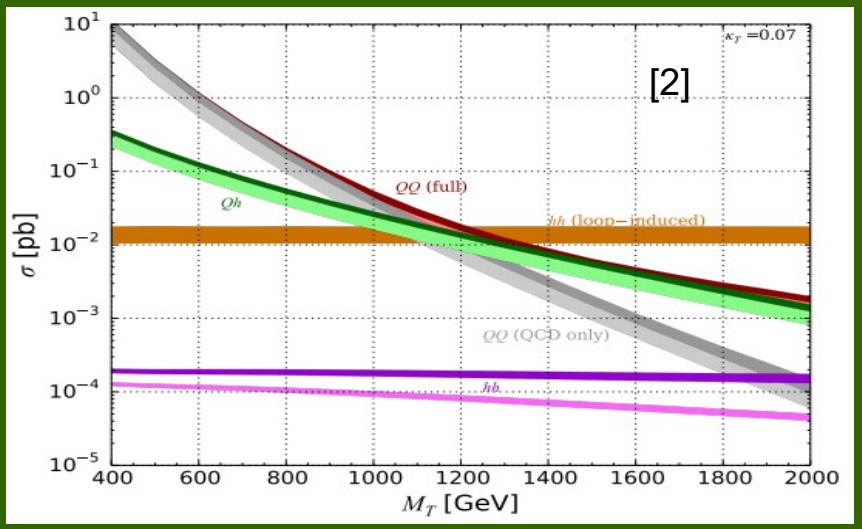


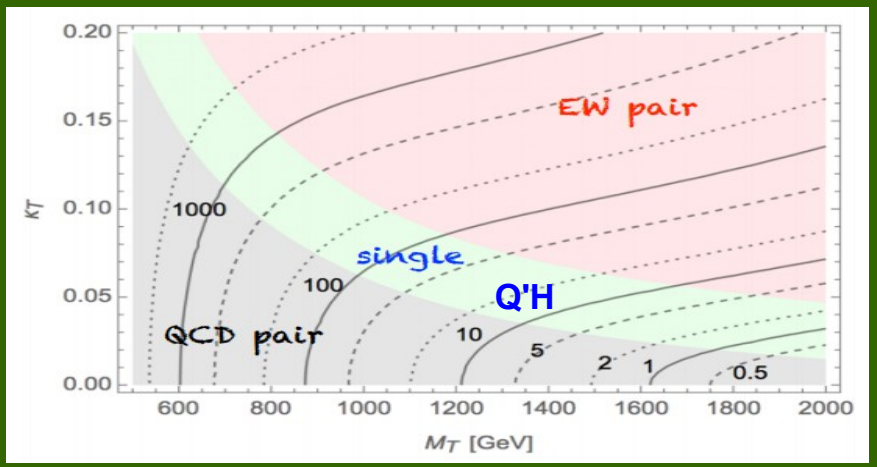
EW single production: Model dependent prod. rate



Pheno: Expl. if a 1th gen. coupling only to H

Which channel is dominant is tricky to say...





[1] See for example: G.Cacciapaglia, A.Deandrea, N.Gaur, D.Harada, Y.Okada, L.Panizzi'15.

[2] Giacomo Cacciapaglia, Haiying Cai, A.C., Aldo Deandrea, Thomas Flacke, Benjamin Fuks3, Devdatta Majumder and Hua-Sheng Shao