Searches for new physics in the Top Sector at the LHC

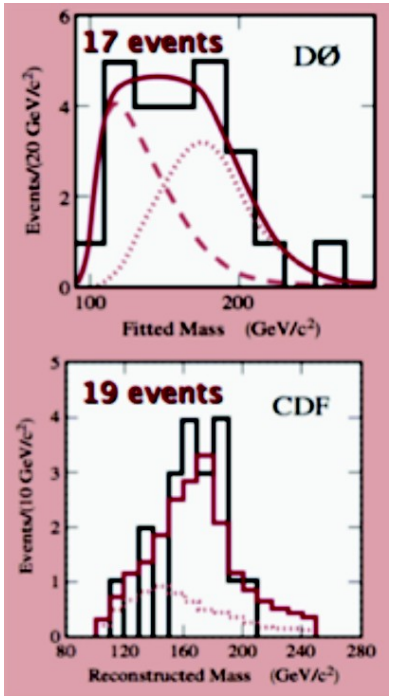
Davide Gerbaudo

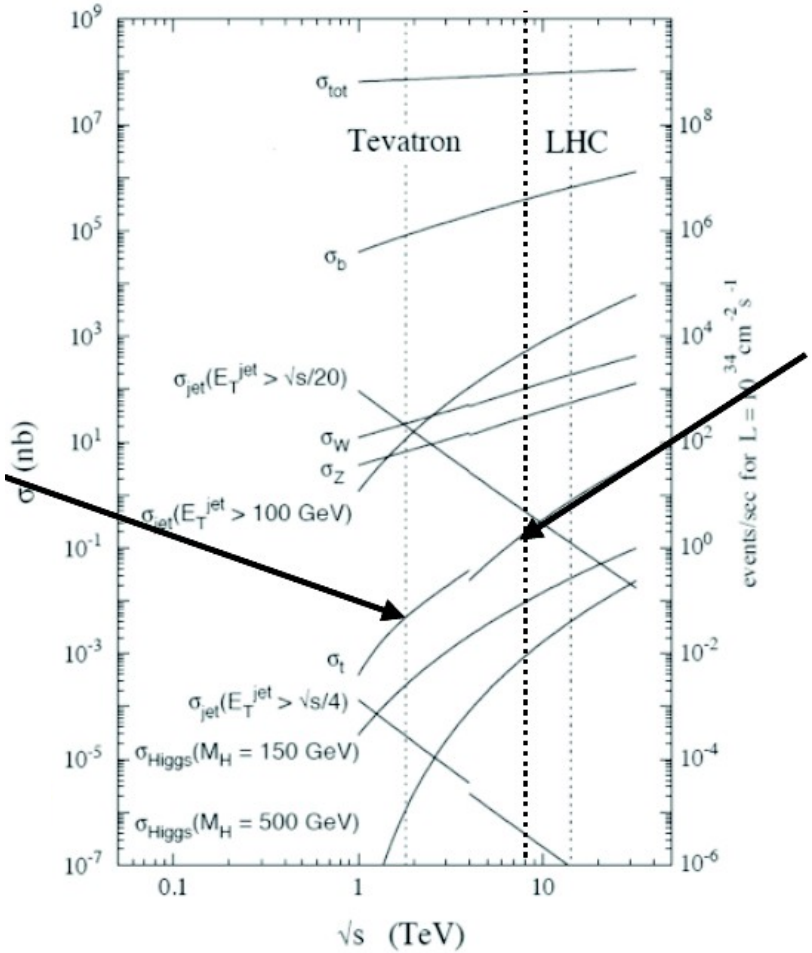
On behalf of the CMS and ATLAS collaborations

Fermilab, April 2015

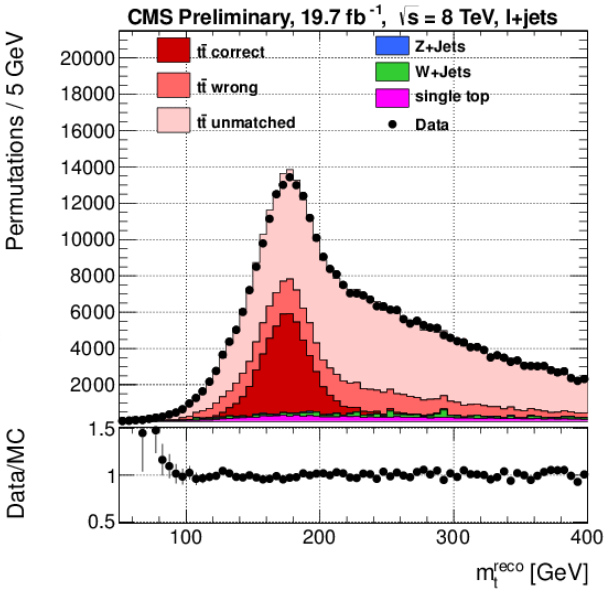
20 Years Collecting Top Quarks

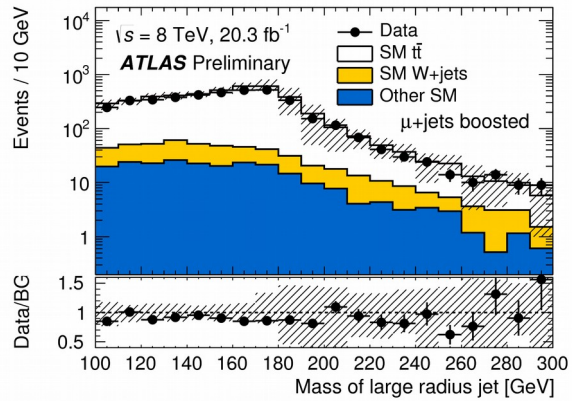
1995



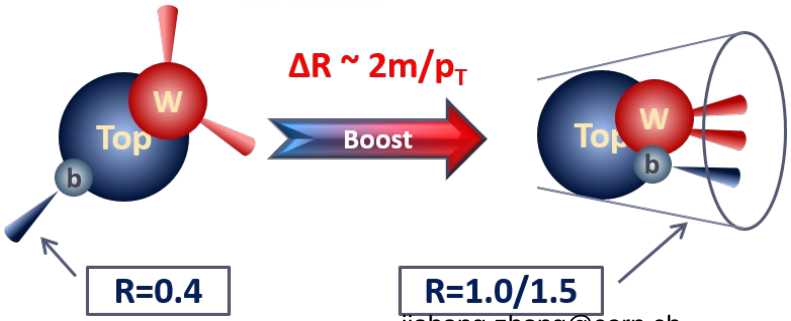


2015





LHC top searches and measurements entering the TeV-scale
→ **Boosted** top quarks



Efficient hadronic top-tagging:

- **large R** jet as top candidate, less combinatorics
- jet **substructure** can be exploited for powerful discriminants

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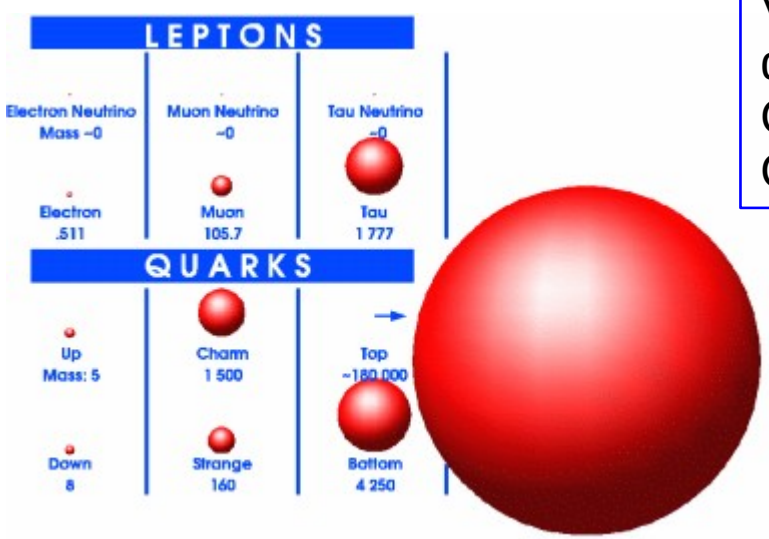
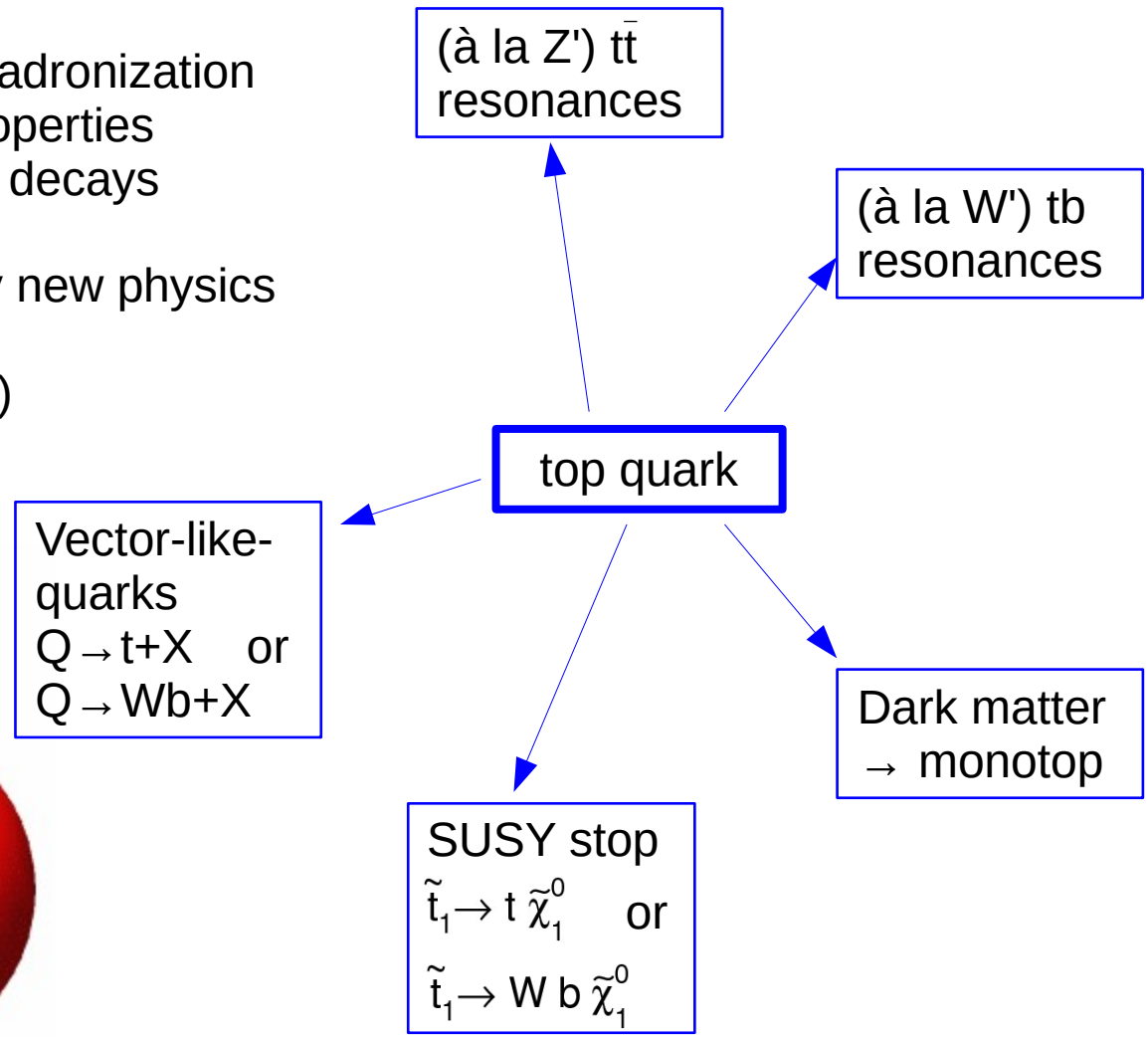
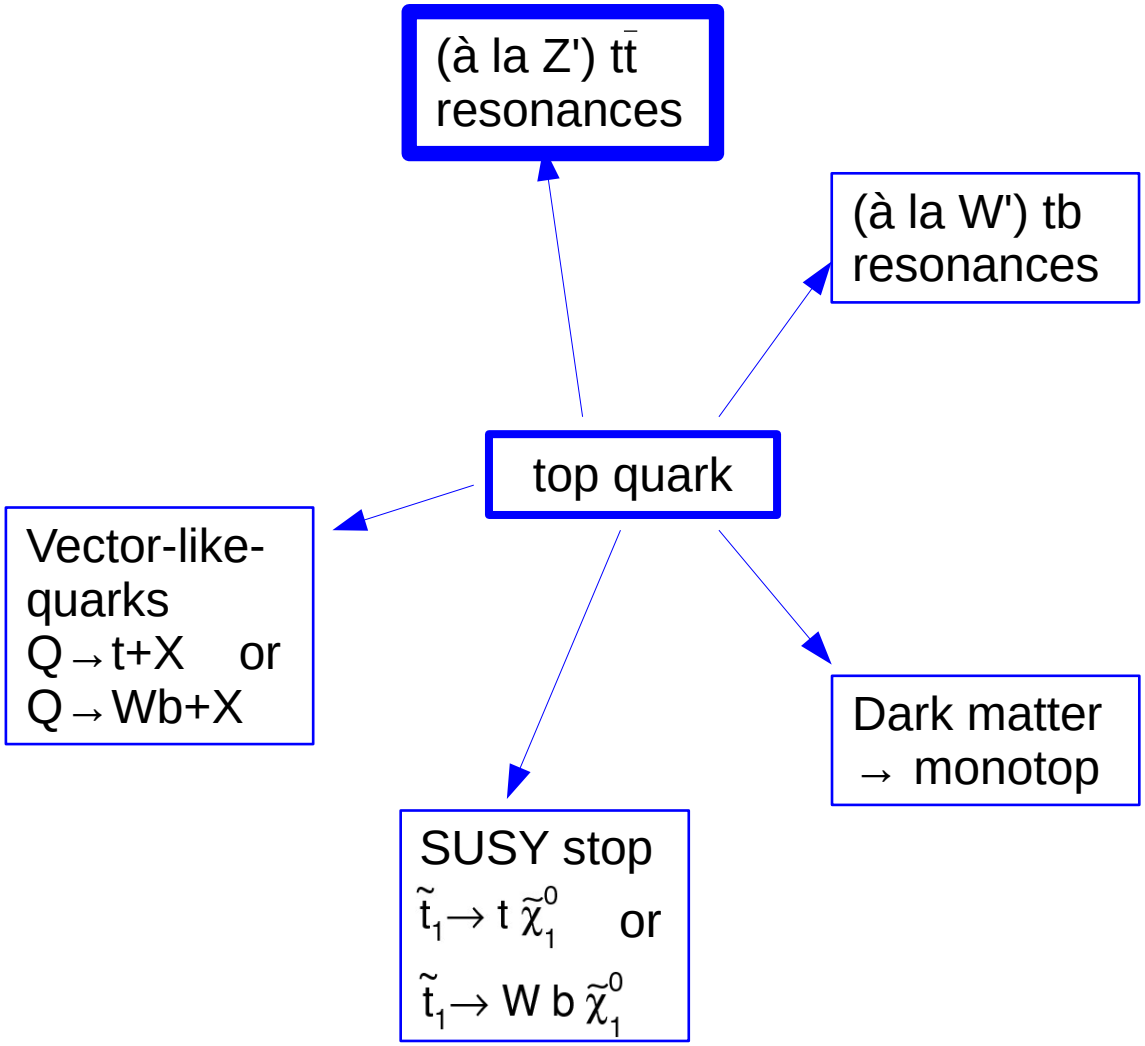
Top Quark and New Physics

Several reasons for which final states containing top quarks are an excellent means to probe new physics:

- the **top quark decays** before hadronization
  - direct studies of top-quark properties
  - search for new physics in top decays
- the **top quark is heavy**
  - it plays a special role in many new physics models
  - large BR(heavy particle $\rightarrow$ t+X)





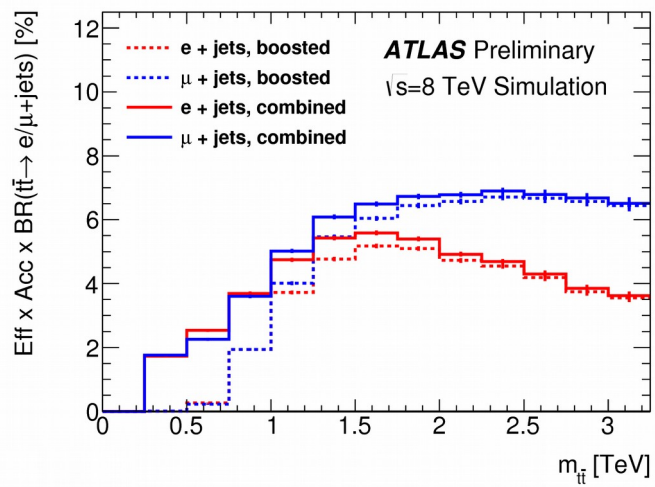

(à la Z') $t\bar{t}$ resonances
(à la W') tb resonances
top quark
Vector-like-quarks
$Q \to t+X$ or
$Q \to Wb+X$
Dark matter
$\to$ monotop
SUSY stop
$\tilde{t}_1 \to t\,\tilde{\chi}_1^0$ or
$\tilde{t}_1 \to W\,b\,\tilde{\chi}_1^0$

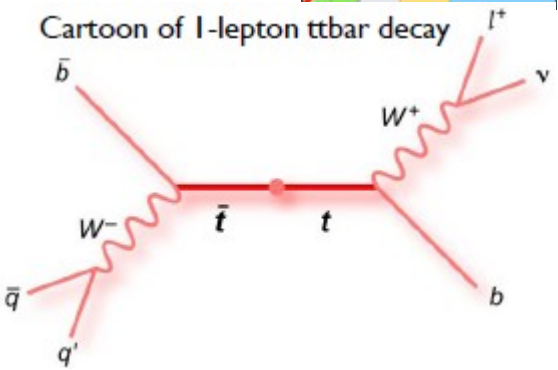
ATLAS: $t\bar{t}$ resonances in ℓ+jets

ATLAS-CONF-2015-009 **New!**

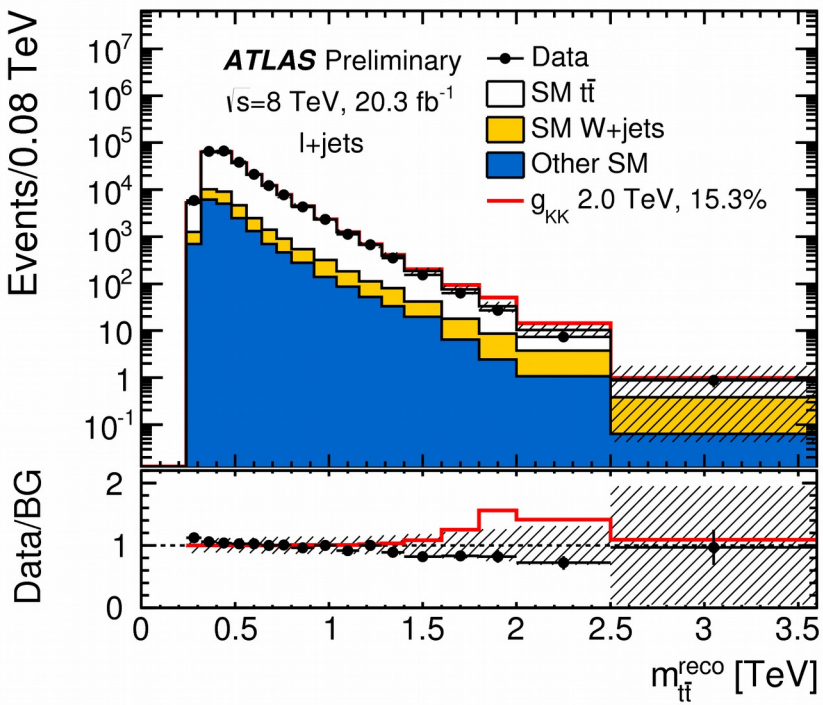
Resolved + boosted selections:

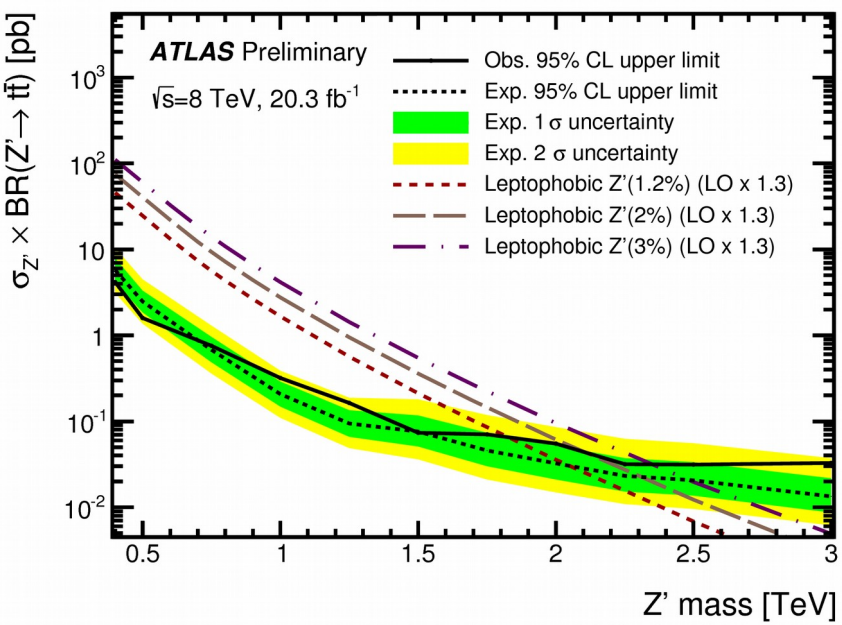
- Resolved: $t\bar{t}$ with ℓ+υ+4 small R jets; choose kinematically best combination
- Boosted:
  - **leptonic top** = ℓ+υ+small R jet
  - **hadronic top** = large R jet with high mass, hard substructure



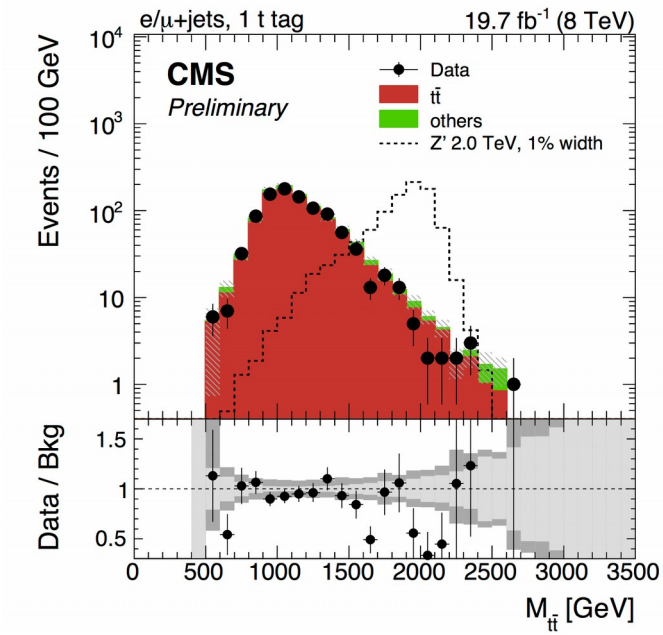


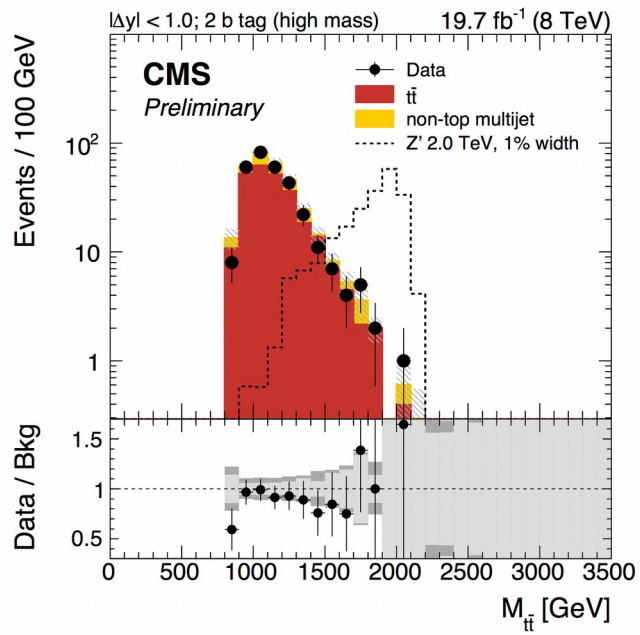
- Wide mass range covered
- Resolution ~10%
- Narrow leptophobic Z' excluded up to 1.8TeV

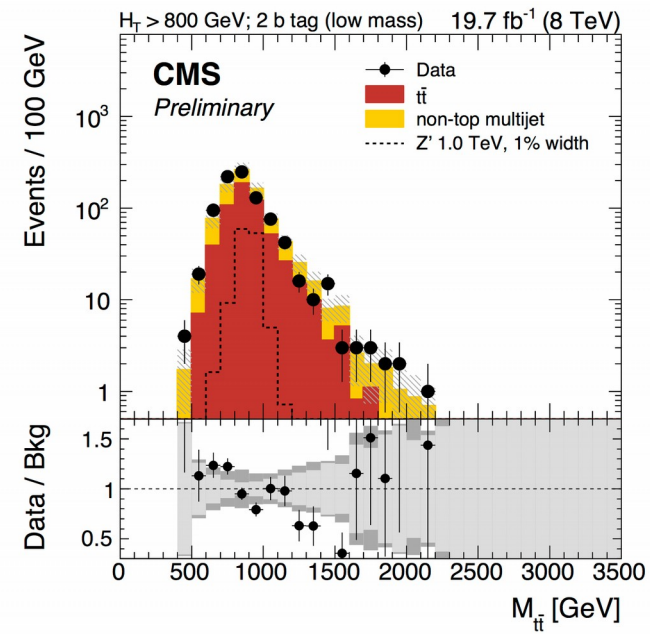


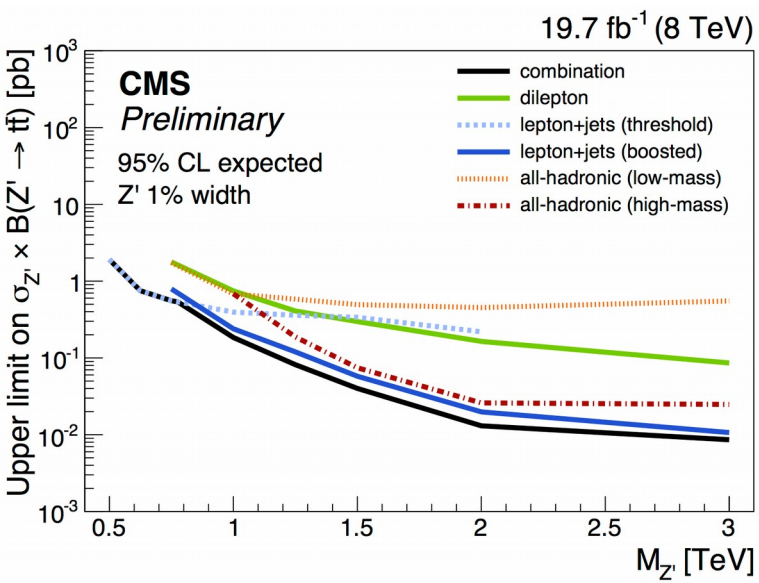


CMS: $t\bar{t}$ resonances in all final states
CMS B2G-13-008 **New!**



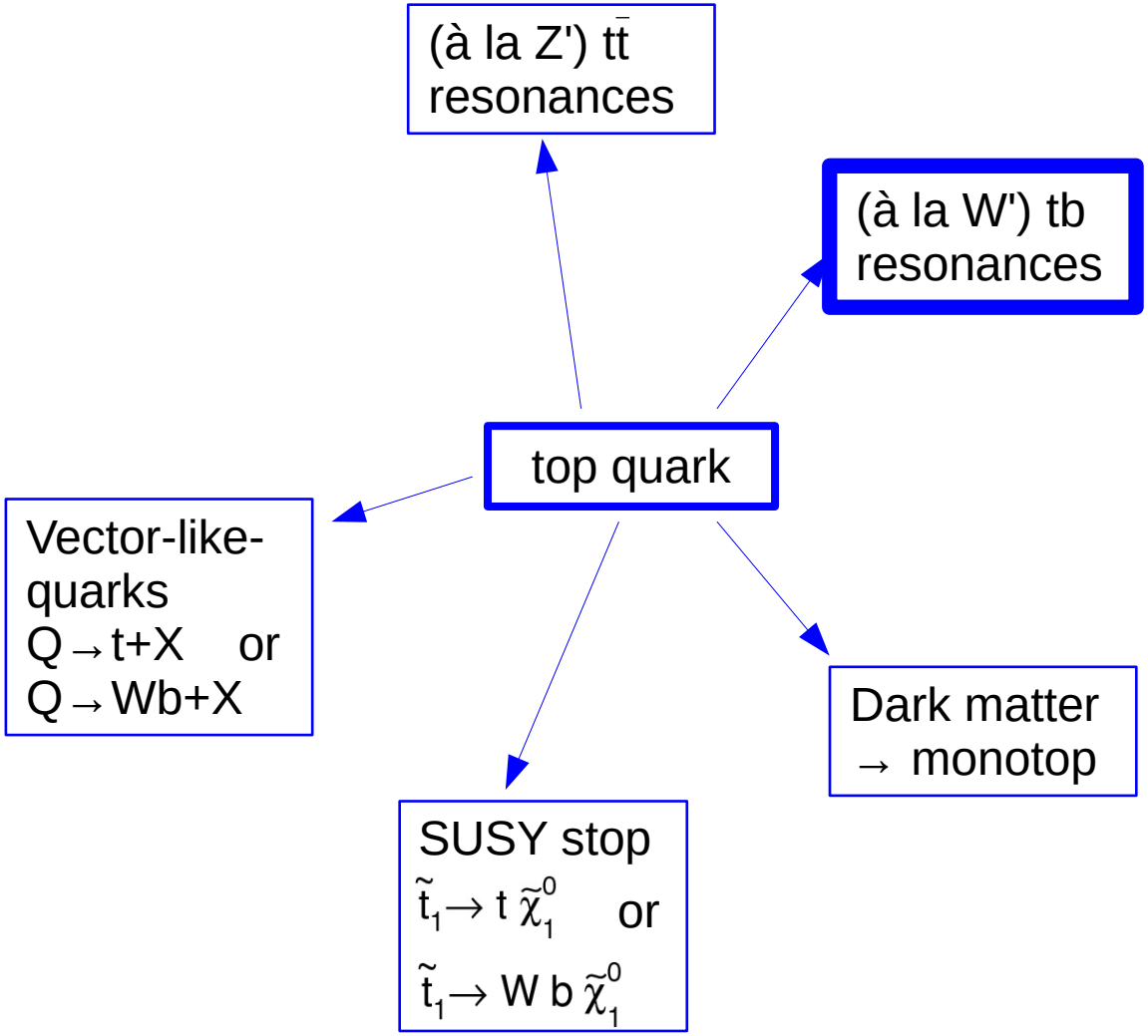






Optimized for boosted tops, using jet substructure.
Consider all three possible top-pair decays:

signal hypothesis	mass limit [TeV]							
	dilepton channel		lepton+jets channel		all-hadronic channels		**combined**	
	obs.	exp.	obs.	exp.	obs.	exp.	obs.	exp.
$Z', \Gamma_{Z'}/M_{Z'} = 1.2\%$	1.5	1.4	2.3	2.2	2.1	2.1	**2.4**	**2.4**
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$	2.2	2.1	2.8	2.7	2.5	2.5	**2.9**	**2.8**
RS KK gluon	2.0	1.8	2.5	2.5	2.3	2.4	**2.8**	**2.7**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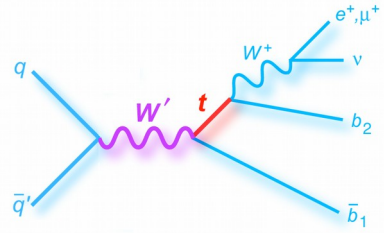
CMS: W' → tb



- **Single lepton** (e/μ) final state
- Missing E_T
- ≥2 jets (small-R), at least 1 b-tag
- top p_T reweighting derived in control region
- Exclude W'_R up to 2.03 TeV

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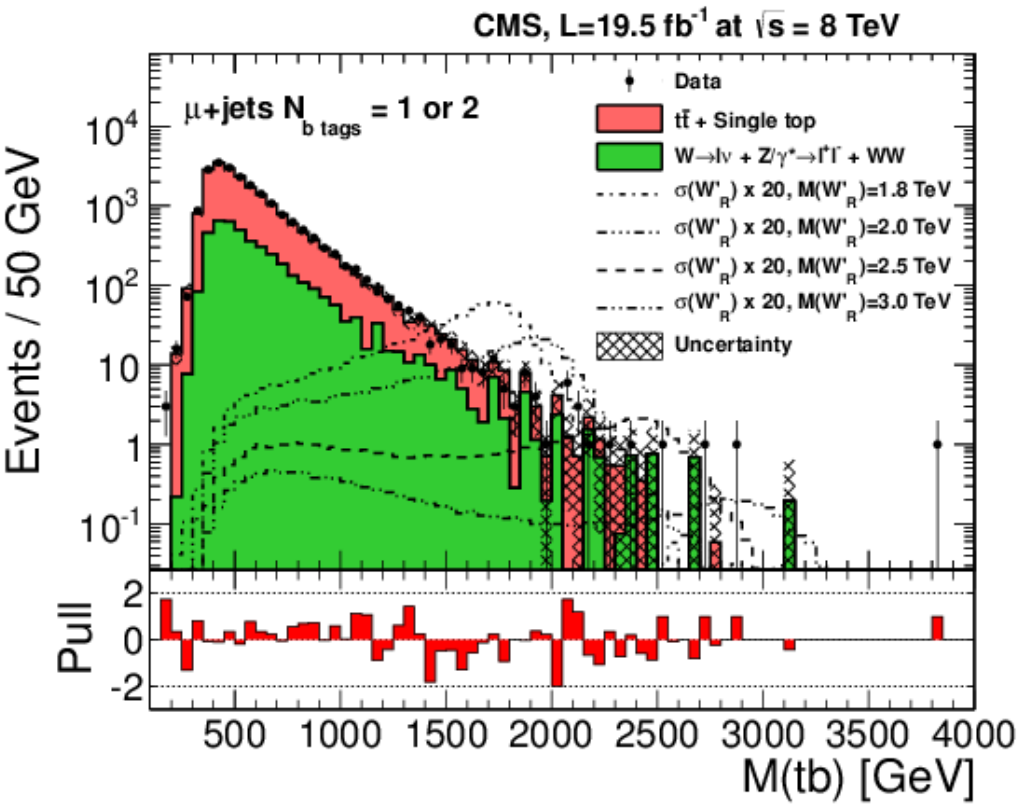
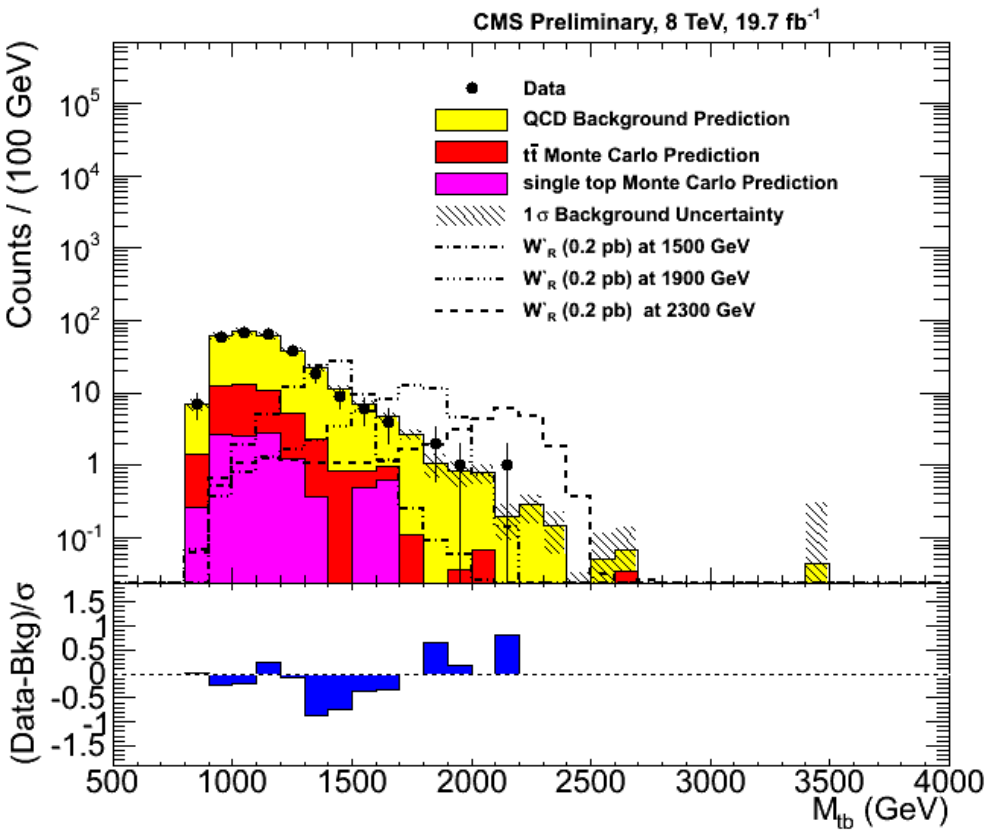
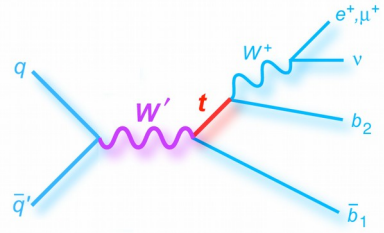


- **All-hadronic** final state
- Focus on di-jet topology, with one b-jet and one large-R top-jet (substructure)
- Exclude W'_R up to 2.0 TeV

PAS B2G-12-009



ATLAS: W' → tb



Single-lepton (e/μ) final state

- Missing E_T
- 2 or 3 jets (small-R), 2 b-tags
- BDT discriminant, inputs:
  - m(tb), p_T(t), etc.
- Exclude W'_R (W'_L) as heavy as 1.92 (1.80) TeV

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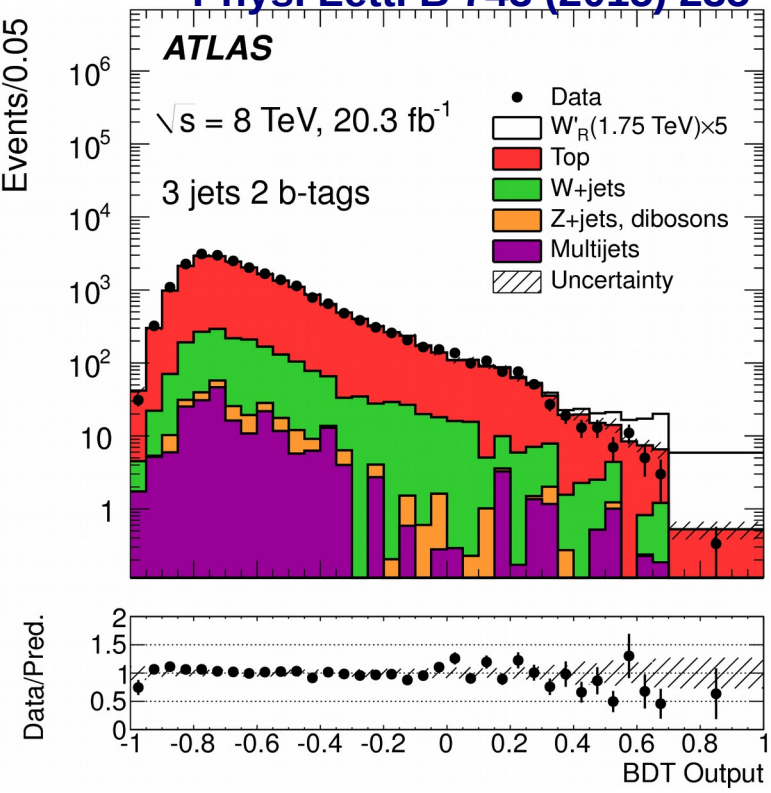
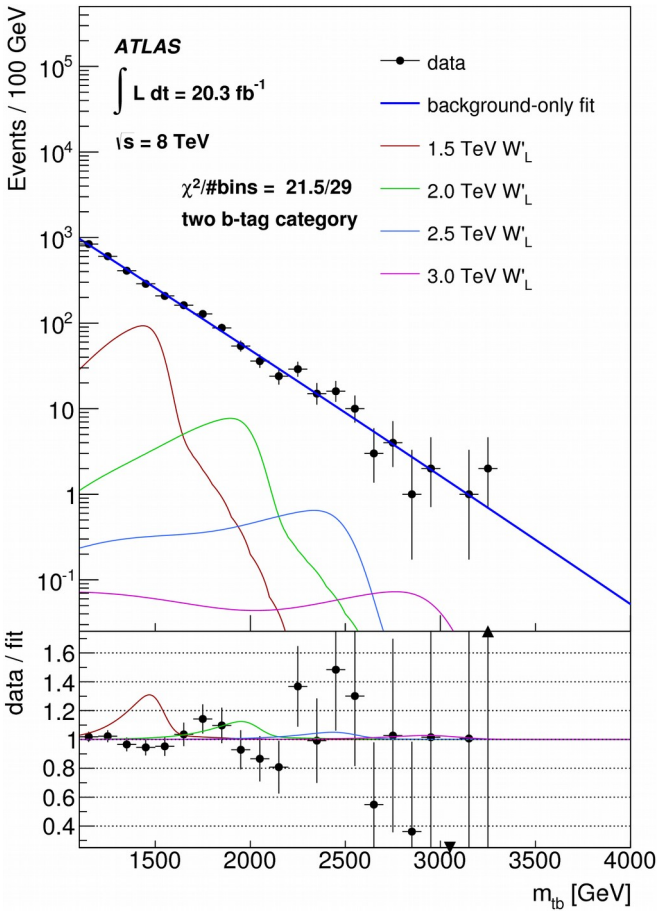


All hadronic final state, two jets with ΔR>2.0

- One b-tagged R=0.4 jet, one R=1.0 **t-tag** jet,
- Two categories based on b-tag of top candidate
- jet substructure, N-subjettiness

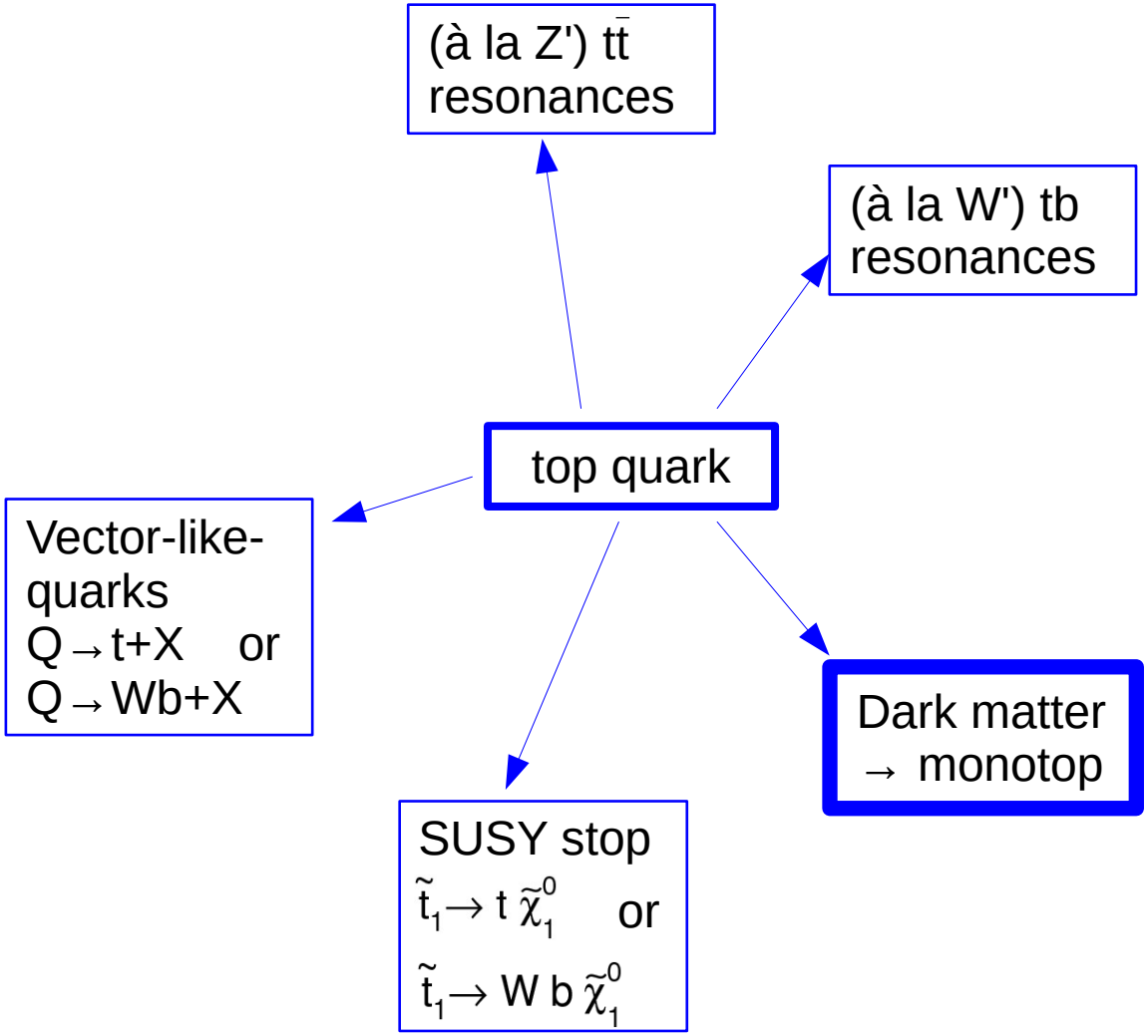


- Unbinned lhood fit on m(tb)
- Bkg estimation from data

Exclude:

- W'_L up to 1.68 TeV
- W'_R up to 1.76 TeV

1408.0886 [hep-ex]
Submitted to EPJC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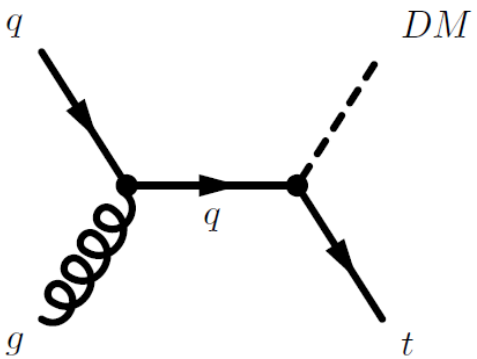
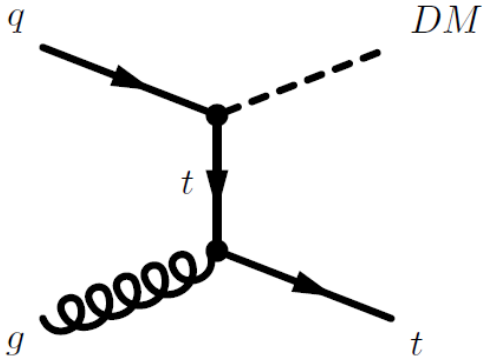
CMS: all-hadronic monotop

WIMP probe complementary to monojet and monophoton DM searches

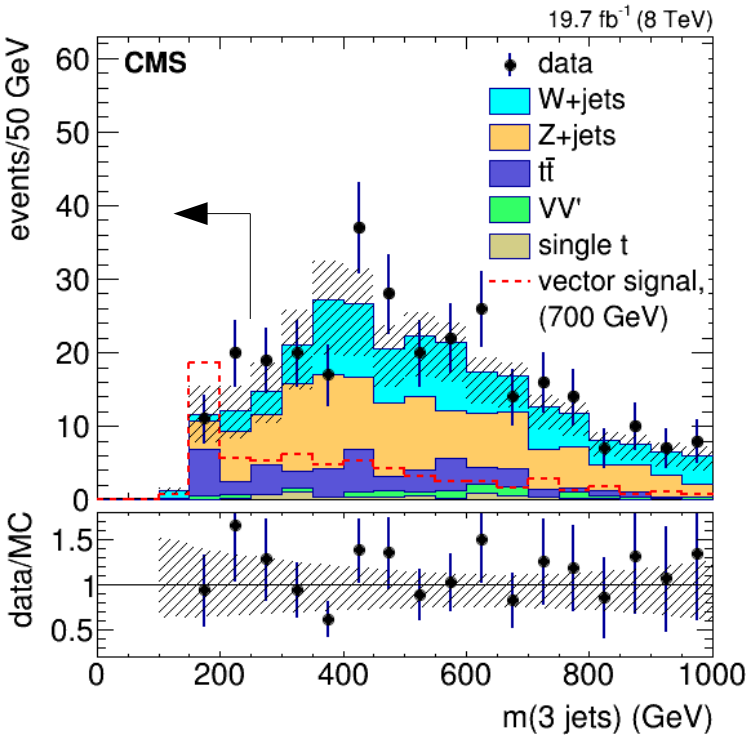
- Large missing E_T
- Three high-p_T jets
- One b-tag
- Exclusion up to
  - 350 GeV (scalar)
  - 630 GeV (vector)

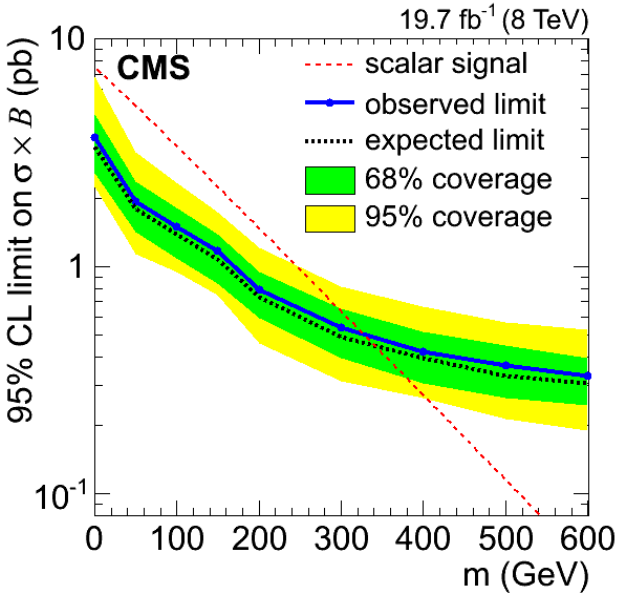


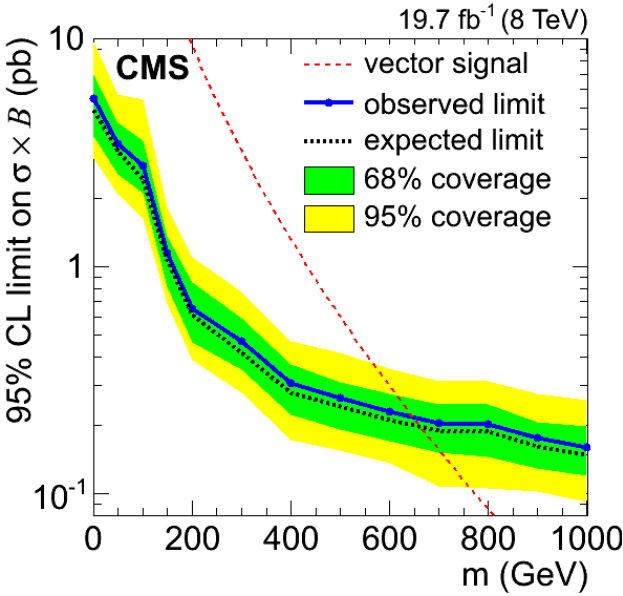


CMS B2G-12-022

Phys. Rev. Lett. 114 (2015) 101801

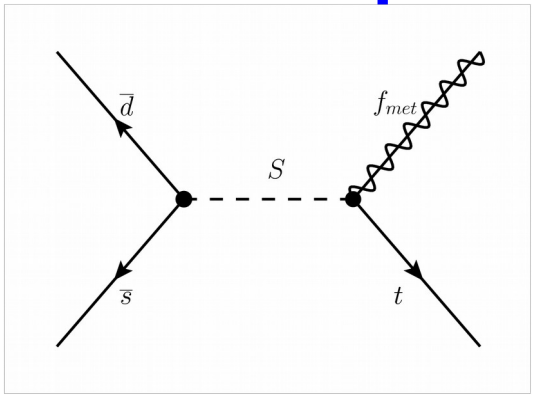






ATLAS: ℓ+jets monotop

- $t \rightarrow Wb$ ($W \rightarrow \ell\upsilon$) + missing E_T
- $t\bar{t}$ ($\rightarrow$ dilepton) is the main background
- $m_T(\ell$, missing $E_T)$ and $\Delta\Phi(\ell, b)$ are the main discriminating variables



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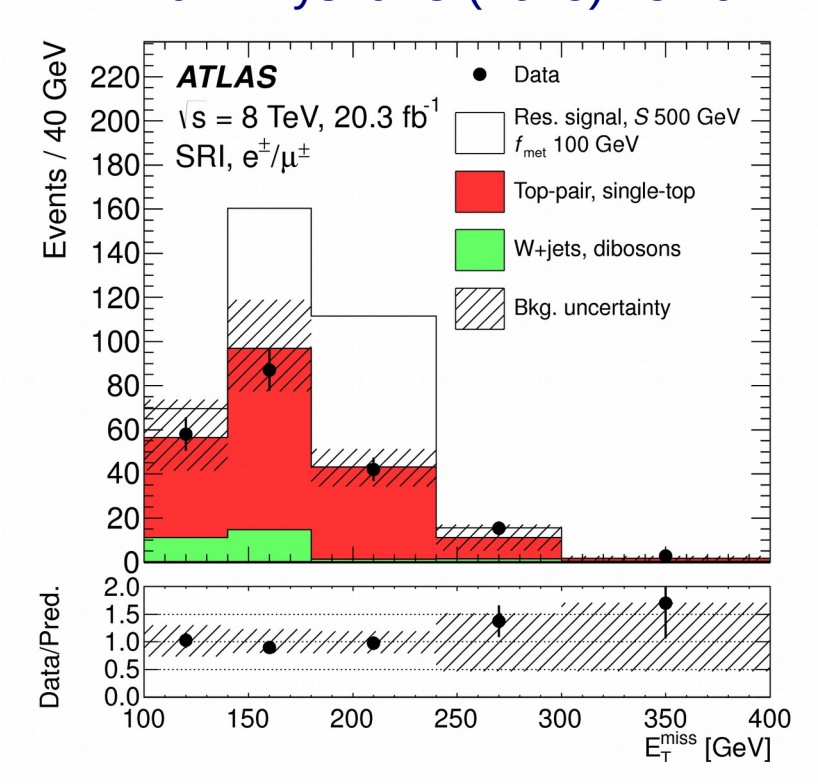
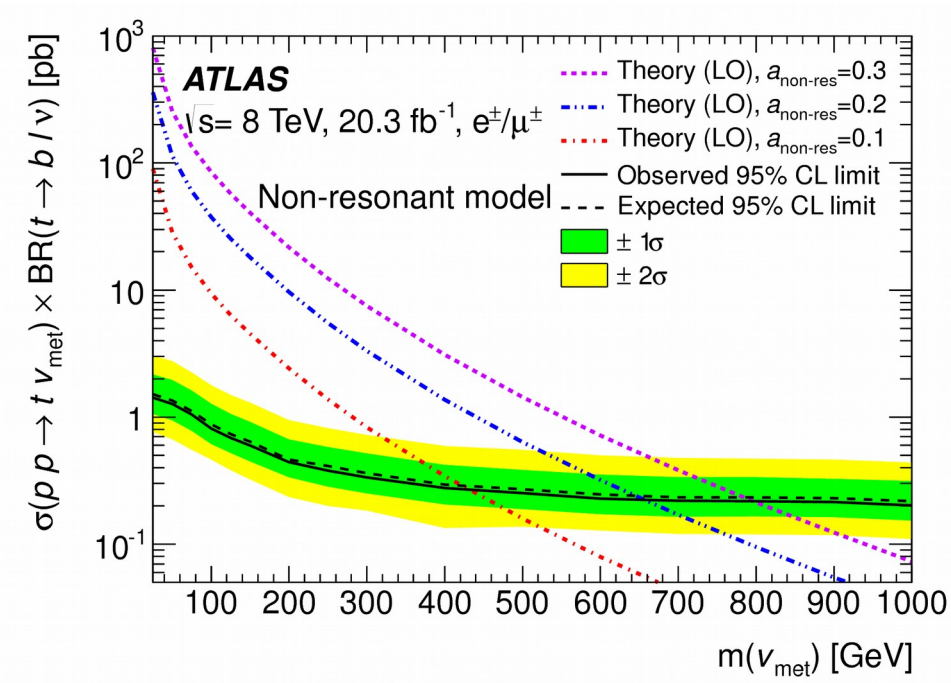
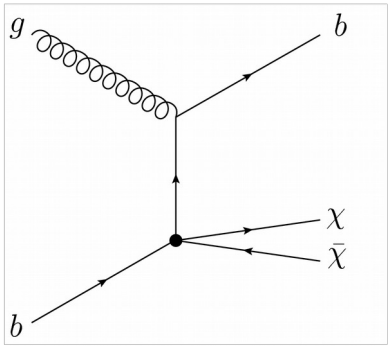


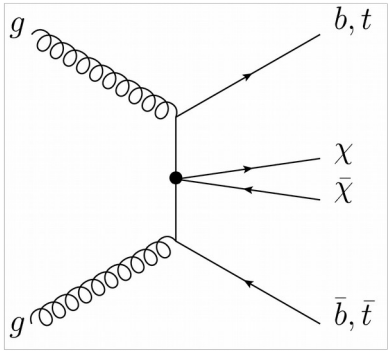
Interpretation: many theories predicting monotop $\rightarrow$ use effective models:

- resonant production of spin-0 $\rightarrow t_R f_{1/2}$
- non-resonant production of spin-1 + t_R



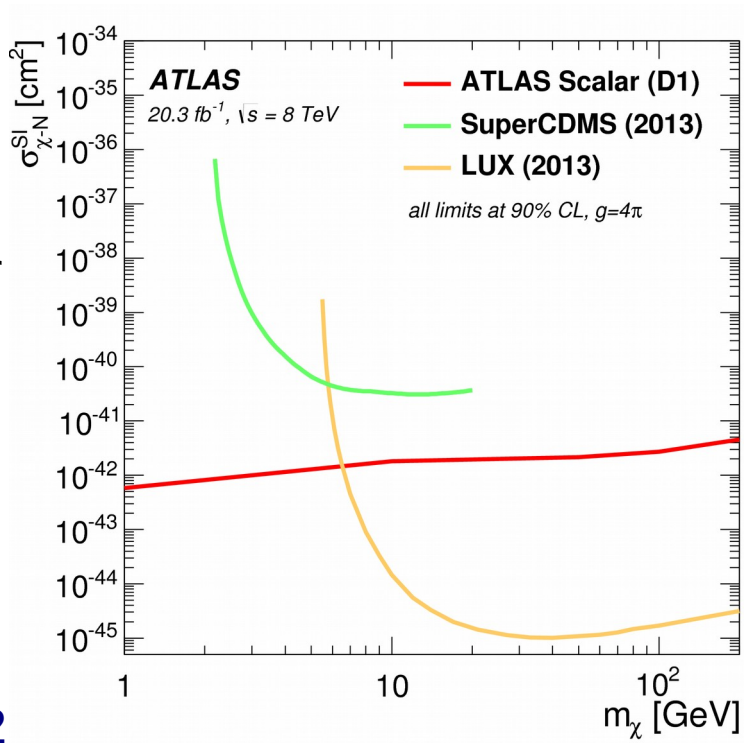
ATLAS: Dark Matter + HF

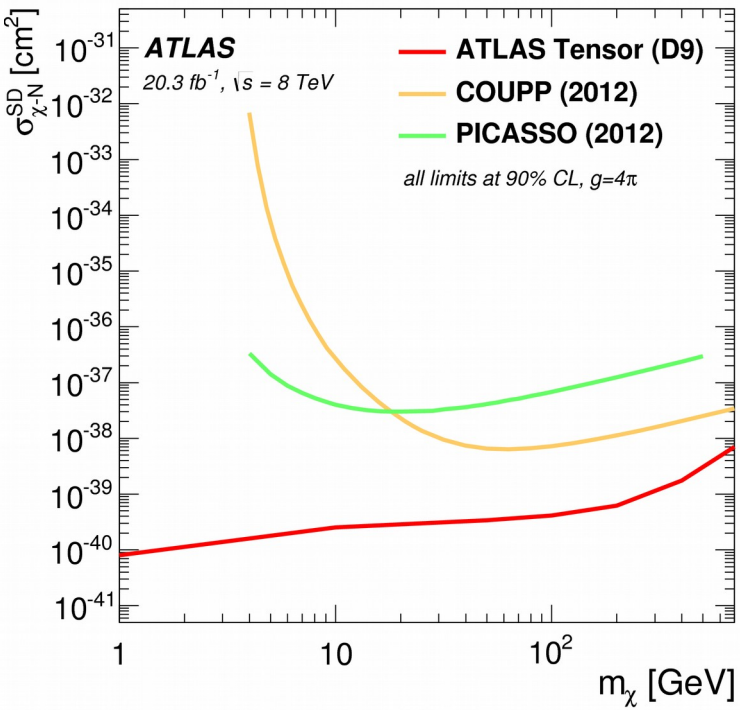




Dark matter pair production with t or b:

- large missing E_T
- at least one high-p_T jet
- four selections:
  - one or two b-jets
  - two top quarks, both with hadronic decays or one hadronic and one leptonic
- optimized selection with several advanced variables: razor, am_{T2}, topness





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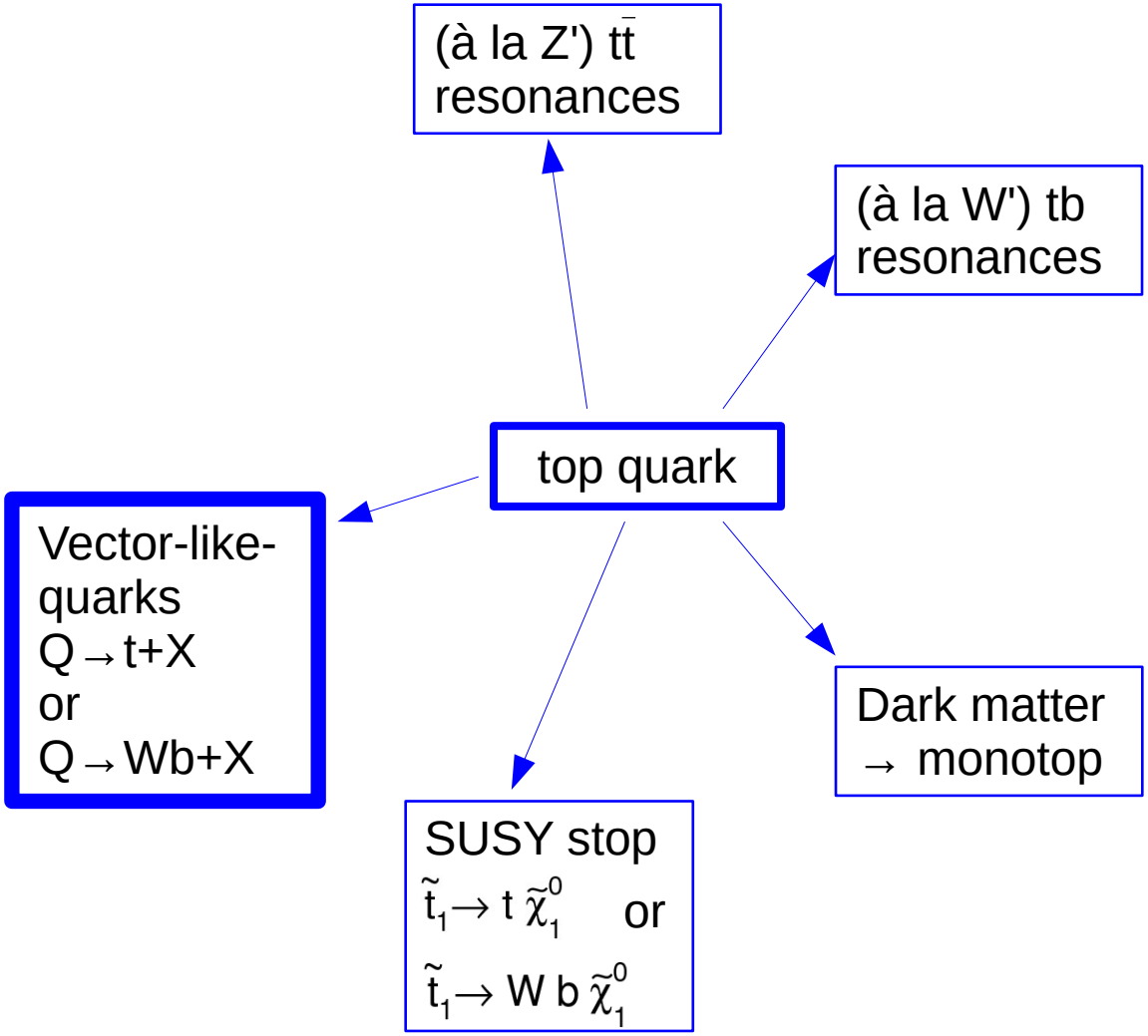
Strong limits in the **low mass region**, relevant to recent claims by DAMA/LIBRA, COGENT, CDMS, Fermi-LAT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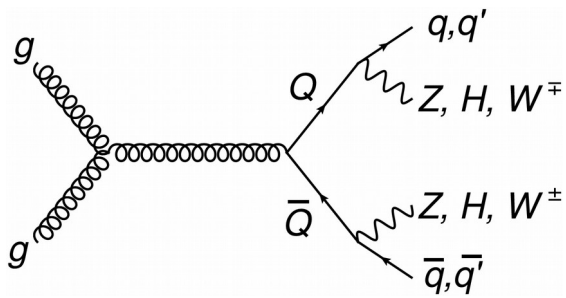
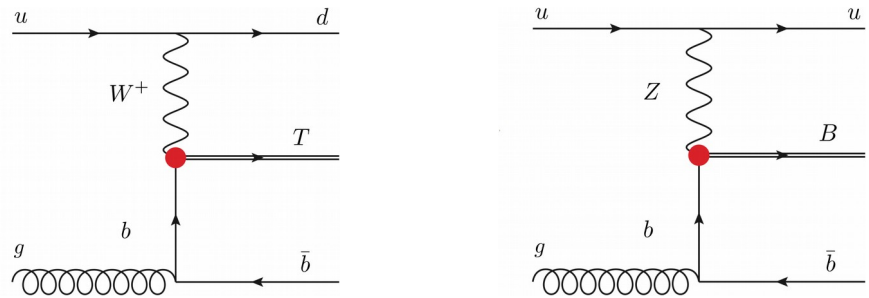
VLQ production and decay

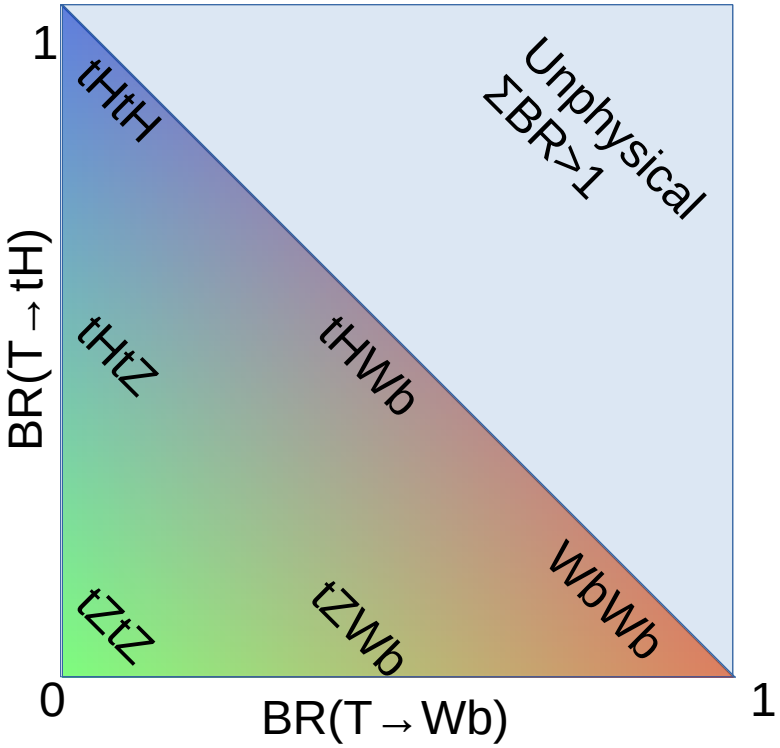
Pair Production



Single Production



Possible final states for $T\bar{T}$



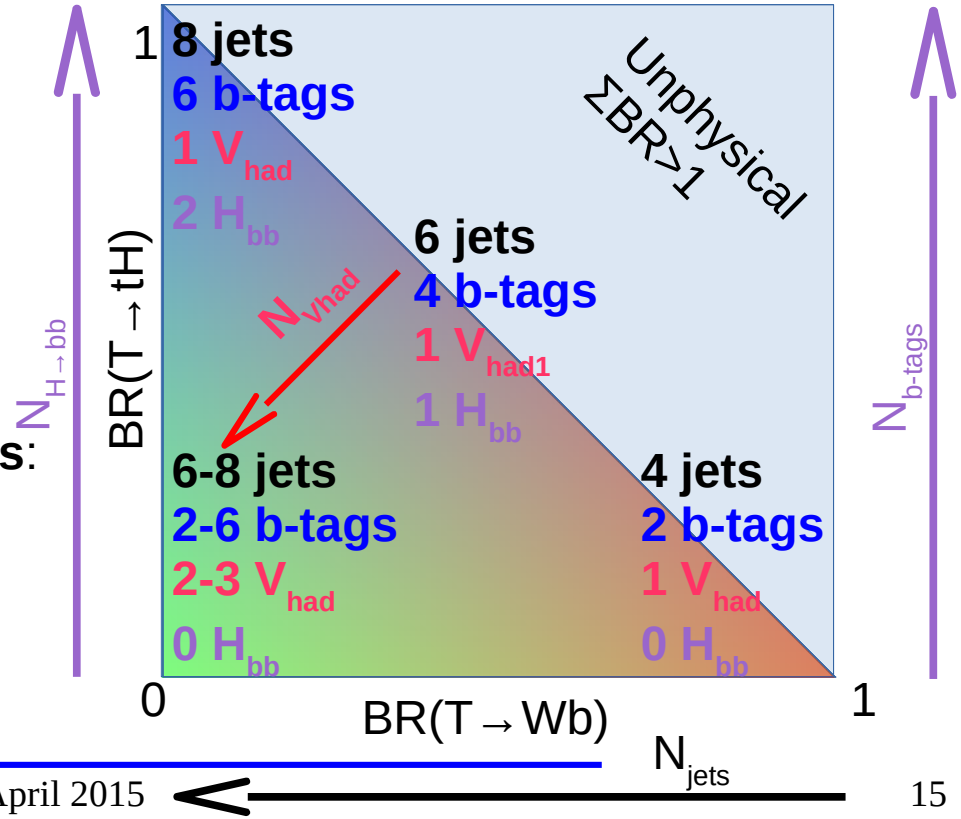
Decays:

- T→Wb/Zt/Ht
- B→Wt/Zb/Hb

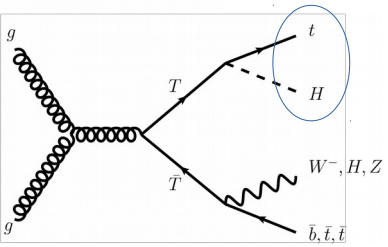
Rich signatures:

- top quarks
- b jets
- V_{had}→jj/J
- H→$b\bar{b}$.

Possible signatures for $T\bar{T}$ (ℓ+jets)



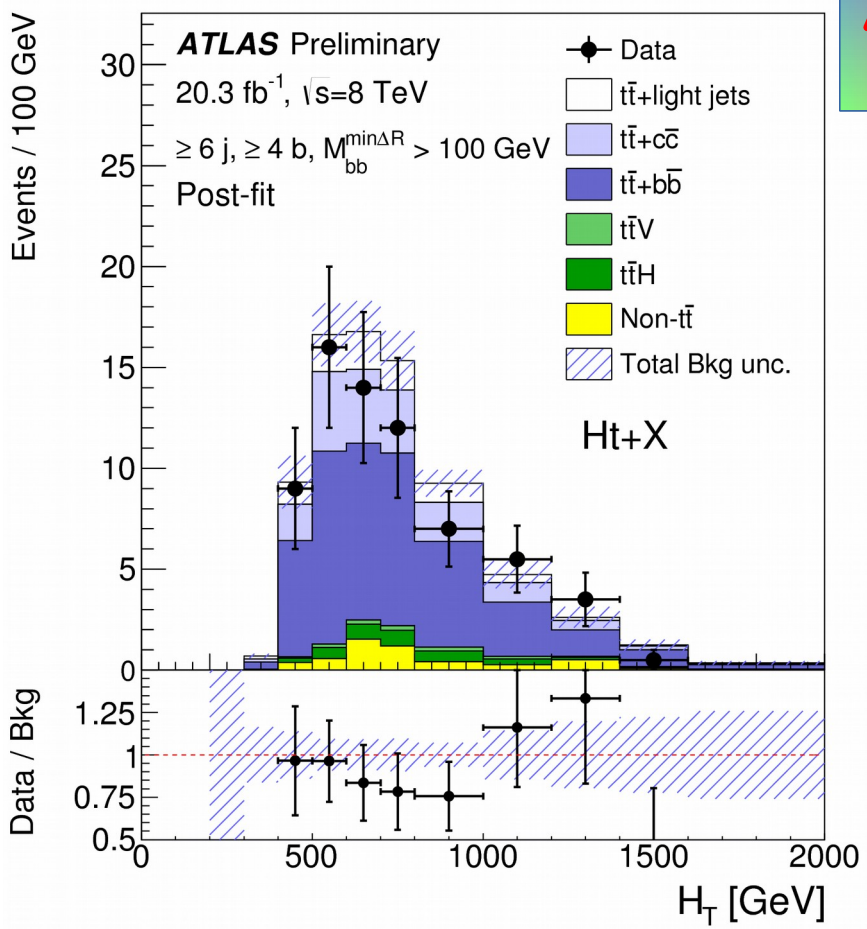
ATLAS: VLT



New! Ht+X

- dominant $H \rightarrow bb$
- $N_{jet} \geq 5$, $N_{b\text{-}jet} \geq 2$
- 8 channels, largest s/b for $N_{jet} \geq 6$, $N_{b\text{-}jet} \geq 4$

ATLAS-CONF-2015-012

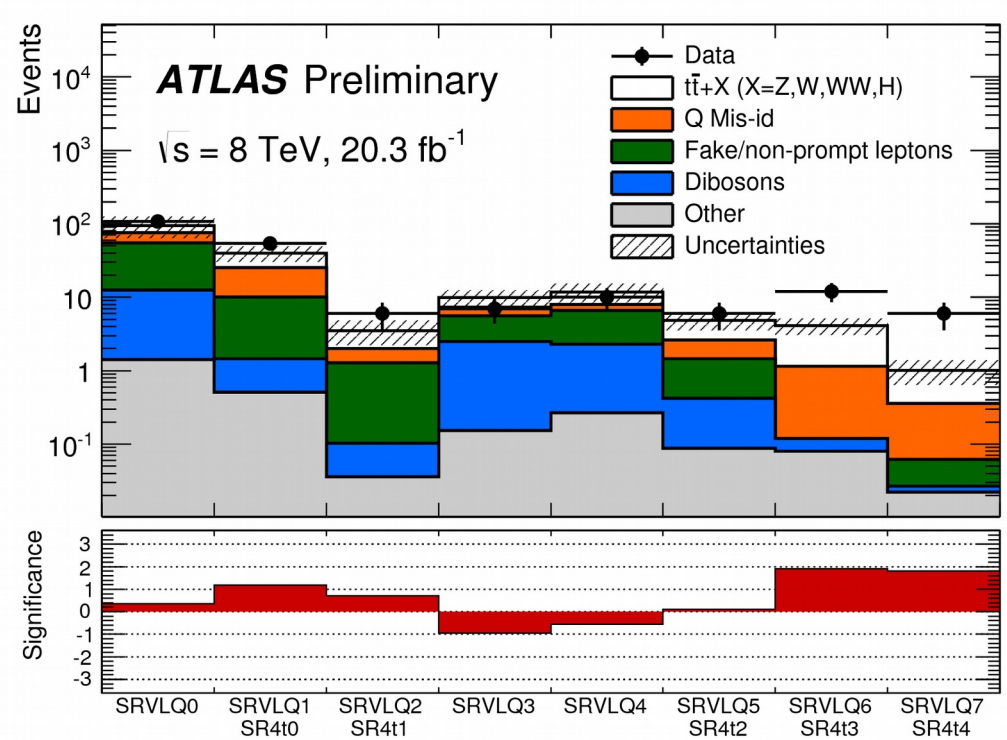


New!

Same-sign dilepton/trilepton (+ b-jets)

- SS 2ℓ or 3ℓ, $N_{b\text{-}jet} \geq 1$, missing E_T, H_T
- sensitive to VLQ and several other BSM models
- 11 SR based on charge, H_T, $N_{b\text{-}jets}$, missing E_T

CERN-PH-EP-2015-060



2.2σ 2.4σ

ATLAS: VLT

$T\bar{T} \rightarrow Zt+X$:

- $\ell\ell$ consistent with a high-p_T Z, allow 3rdℓ
- $N_{jet} \geq 2$, $N_{b\text{-}jets} \geq 1$
- selections optimized on N_ℓ, $N_{b\text{-}jets}$, $N_{fwd\text{-}jets}$
- discriminant m_{Zb} or H_T

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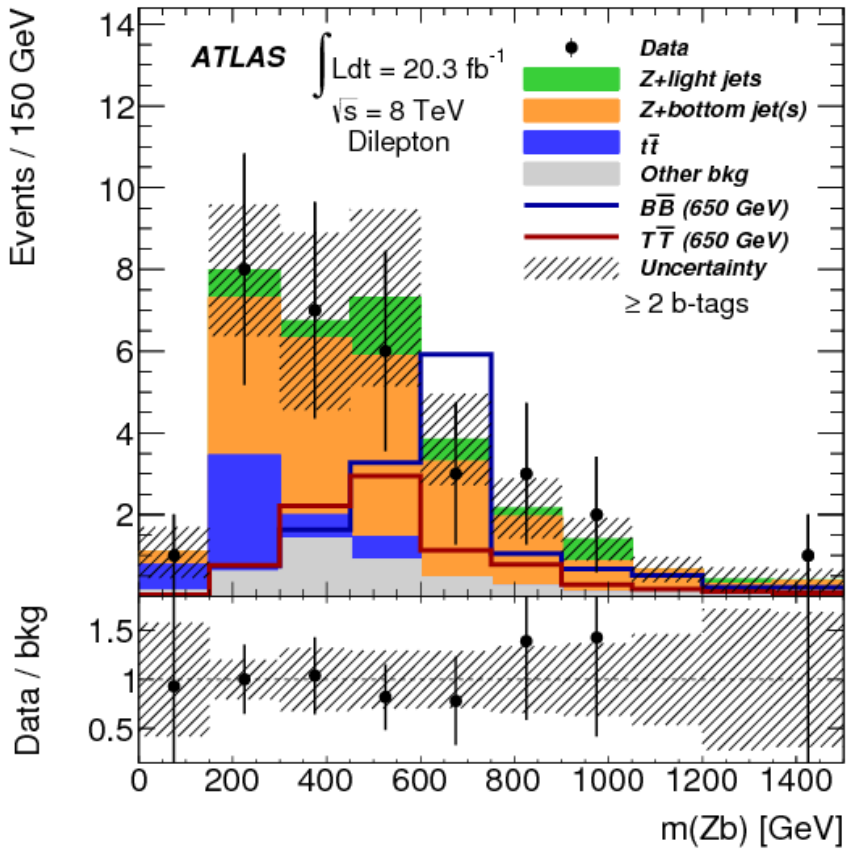
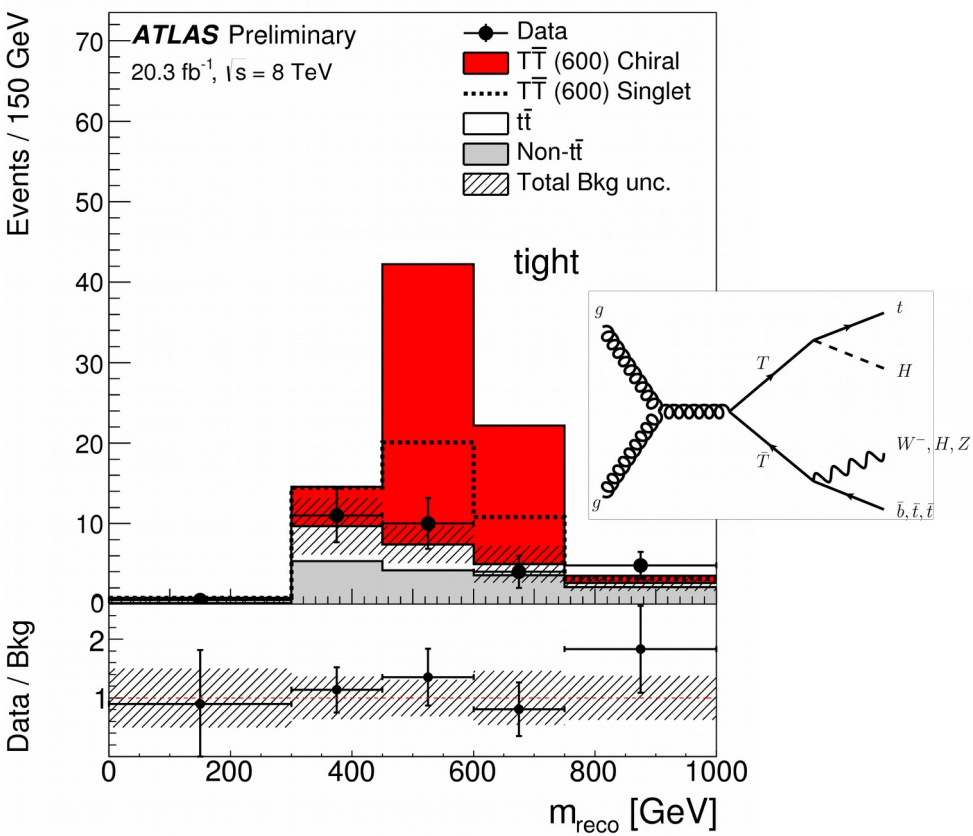


Wb+X **New!**

- optimized for $T\bar{T} \rightarrow WbWb$
- one $W \rightarrow \ell\upsilon$
- one W_{had}, boosted or resolved
- kinematic req. to suppress $t\bar{t}$

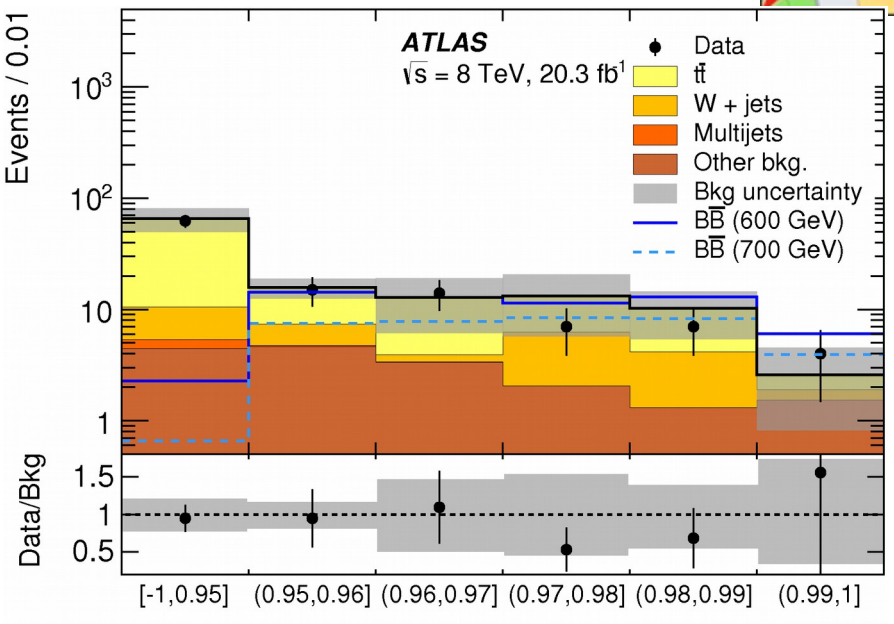
ATLAS-CONF-2015-012



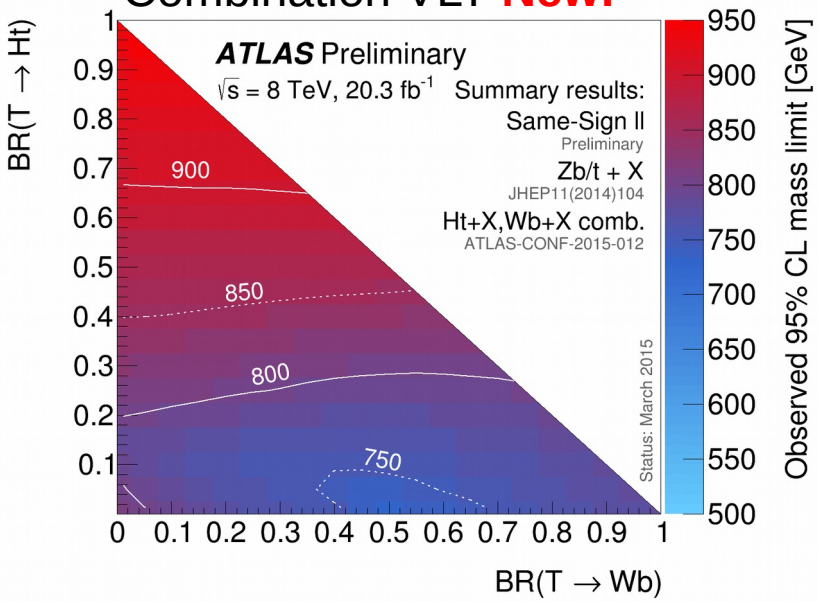
ATLAS: VLB in ℓ+jets

1503.05425 [hep-ex] **New!**

- Assuming allowable decay modes are: B → Wt/Zb/Hb
- Consider subsets with 1 or more reconstructed hadronic boson
- Do not measure charge
  → also set limits on $T_{5/3}$ → Wt >840GeV

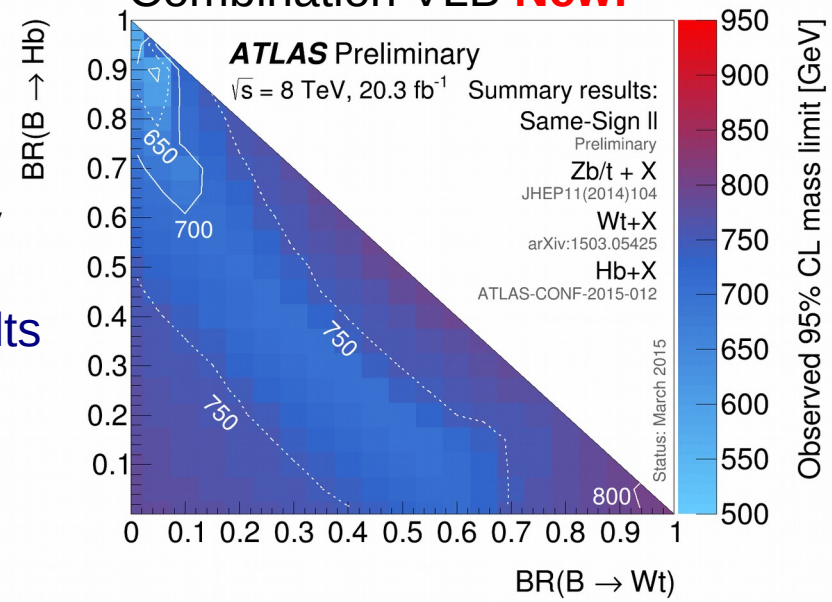


Combination VLT **New!**



For more summary plots, see the ExoticsPublicResults

Combination VLB **New!**

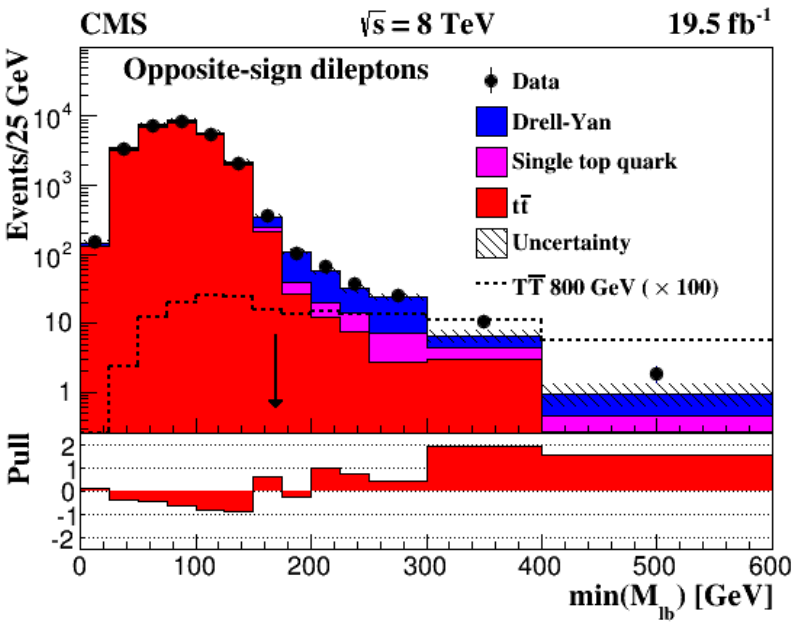


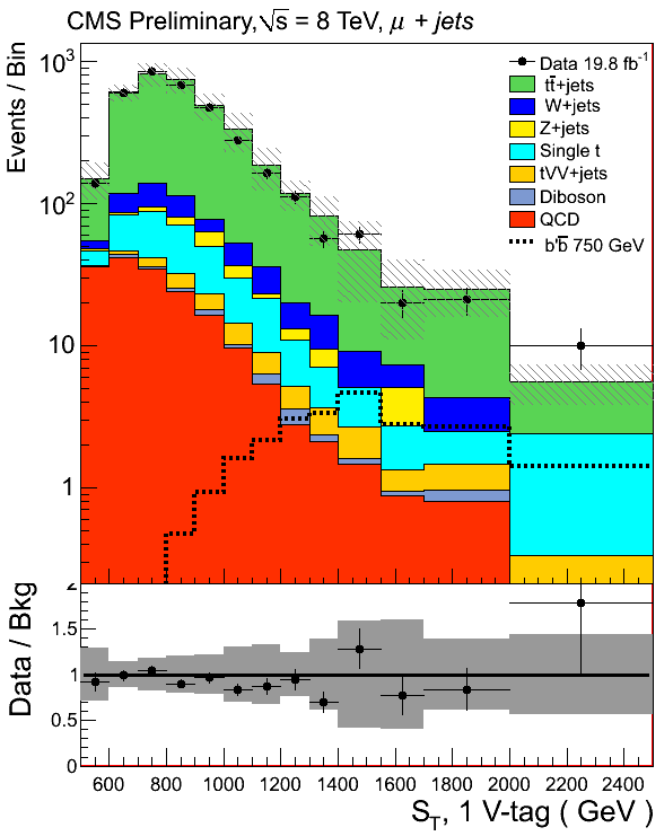
CMS: inclusive VLT & VLB

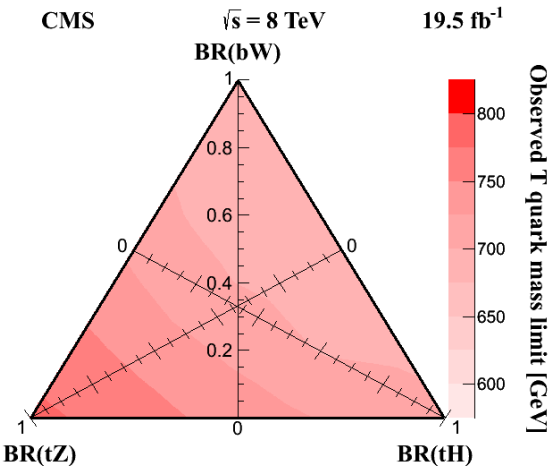
Comprehensive searches for $T\bar{T}$ and $B\bar{B}$ in:

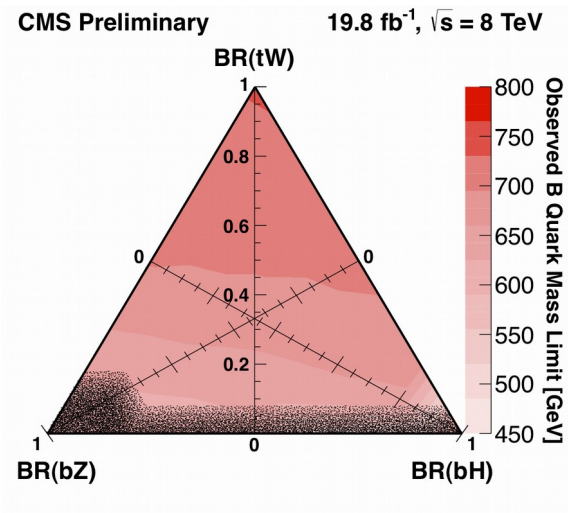
Phys. Lett. B729 (2014) 149-171
- Single lepton
- Multilepton
  - Opposite-sign, on/off-Z
  - Same-sign
  - Trilepton

CMS-PAS-B2G-12-019
- Single lepton
- ≥4 jets, ≥1 b-jet
- 0, 1, 2≥ V-tags



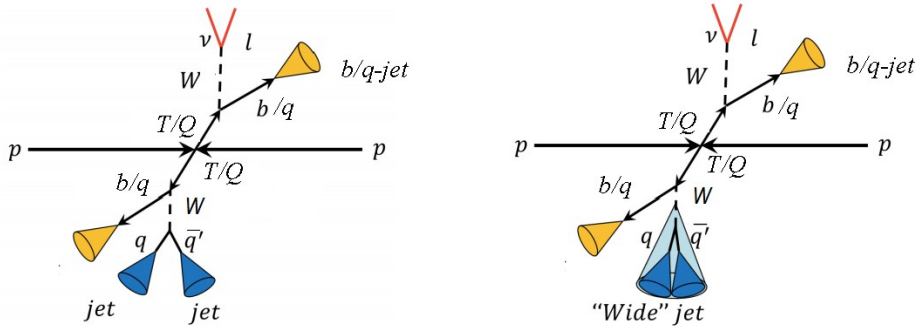




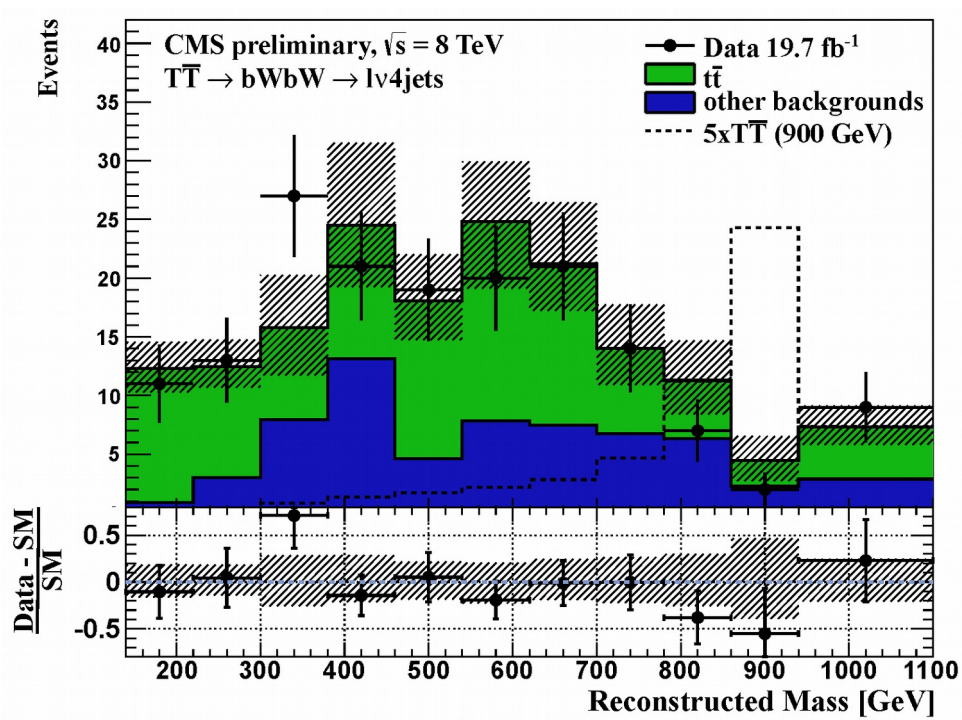


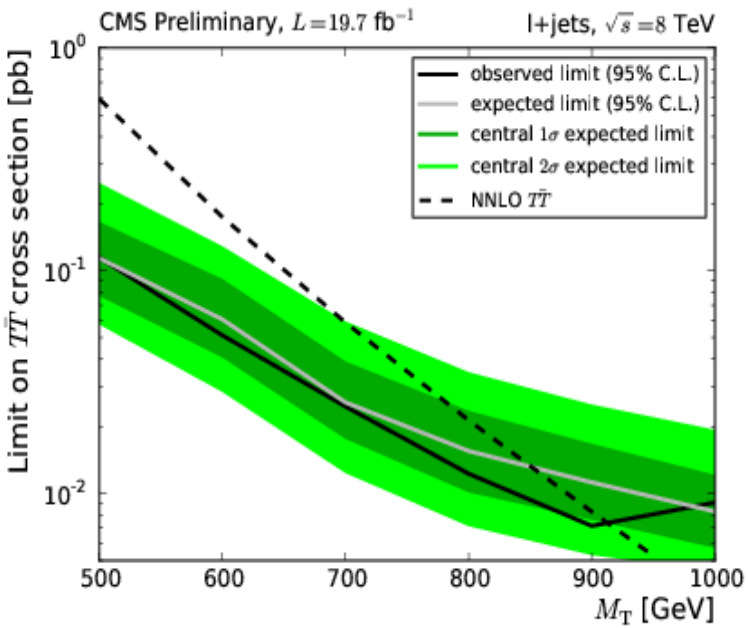
CMS: VLQ ℓ+jets

New!
CMS-PAS-B2G-12-017



- Assume BR(T→Wb)=BR(Q→Wq)=100%
- For the hadronic W, consider both
  - resolved decay
  - boosted decay



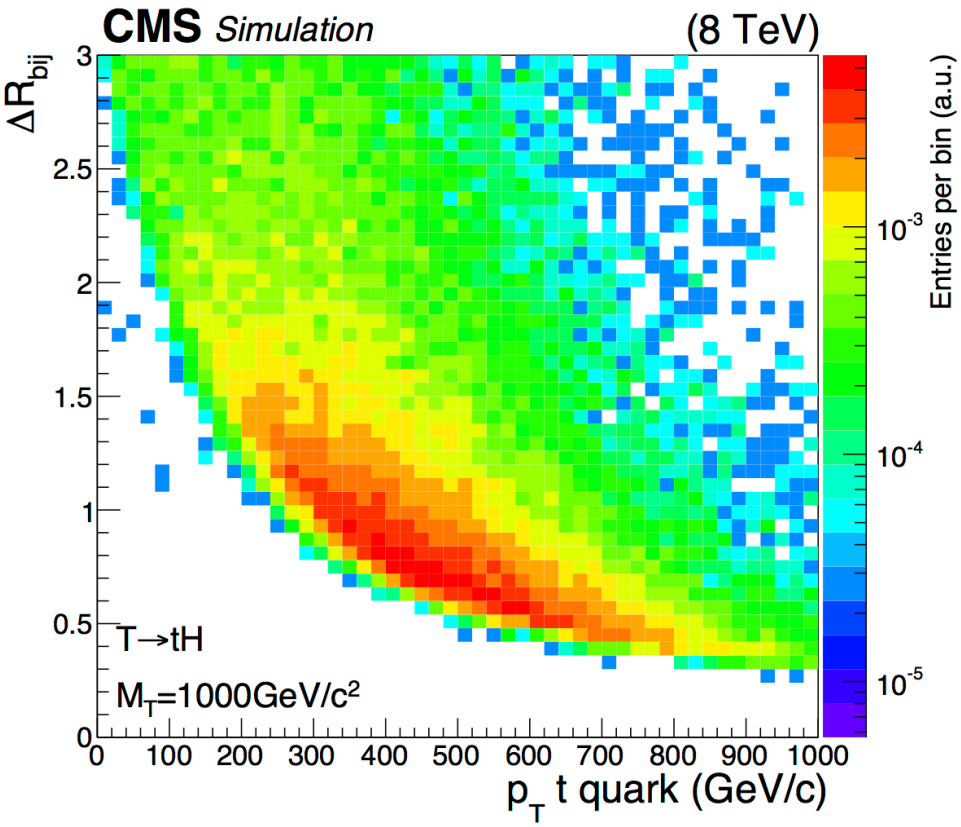


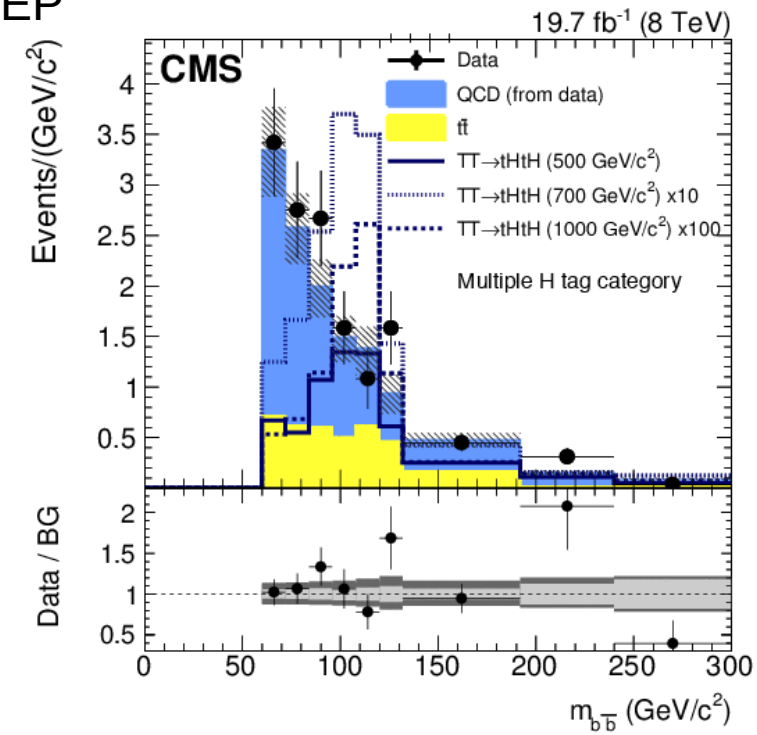
CMS: VLQ all-had

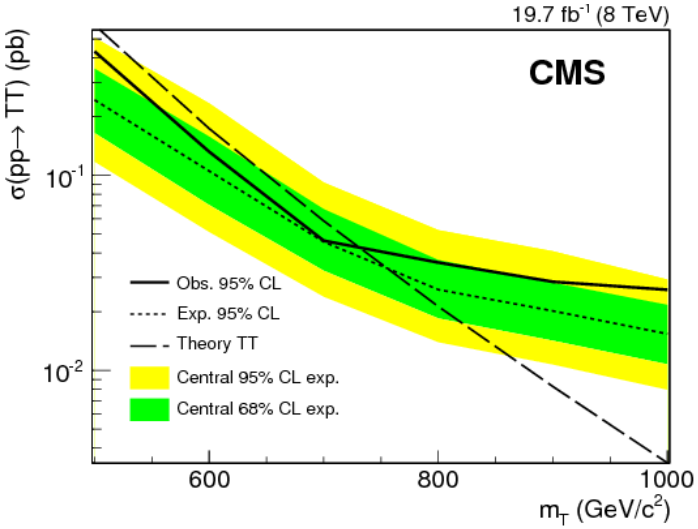
New! submitted to JHEP
1503.01952 [hep-ex]

- ≥2 high-p_T CA jets (R=1.5)
- ≥1 top candidate (HEP top tagger)
- ≥1 Higgs candidate

For the first time: tagging boosted Higgs with a combination of jet substructure and b-tagging.

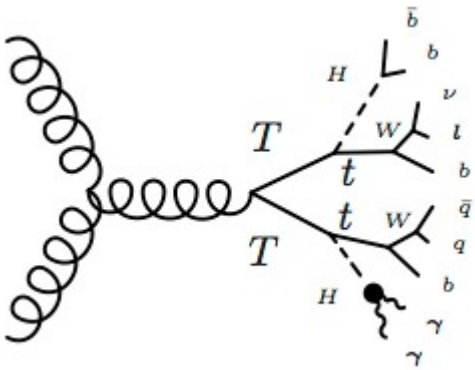




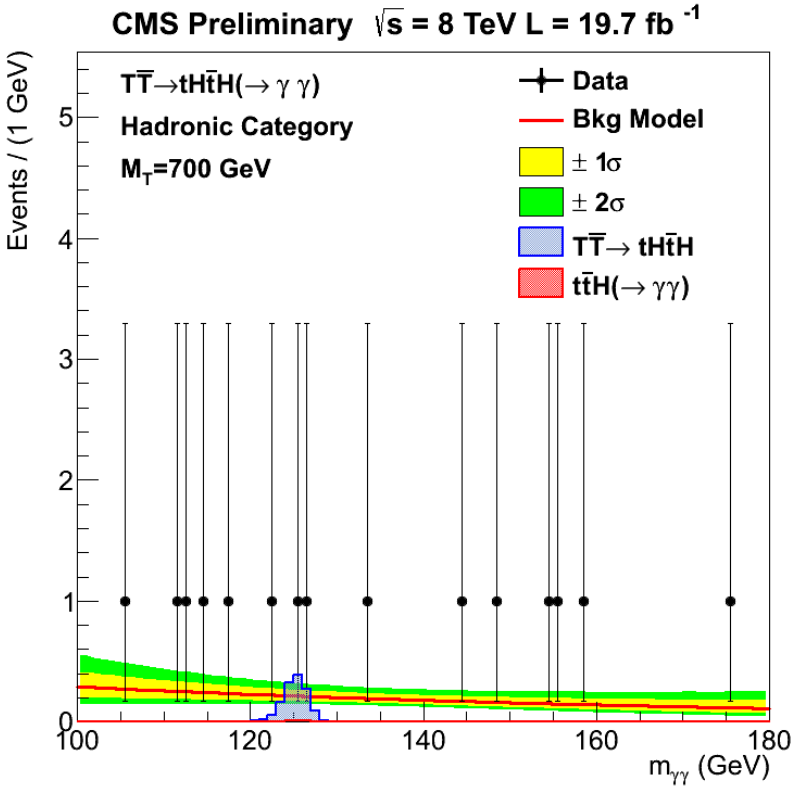


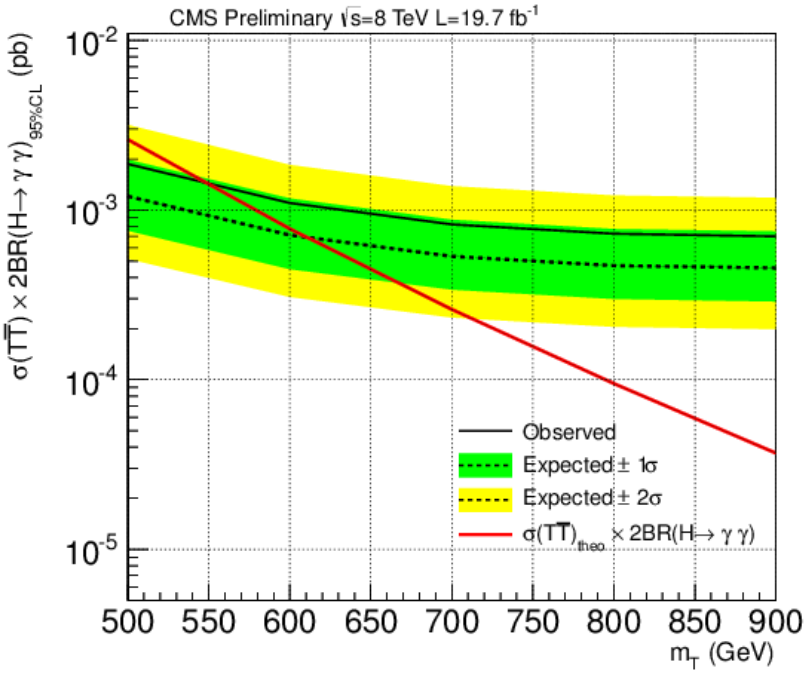
CMS: VLQ Ht+X, H → γγ

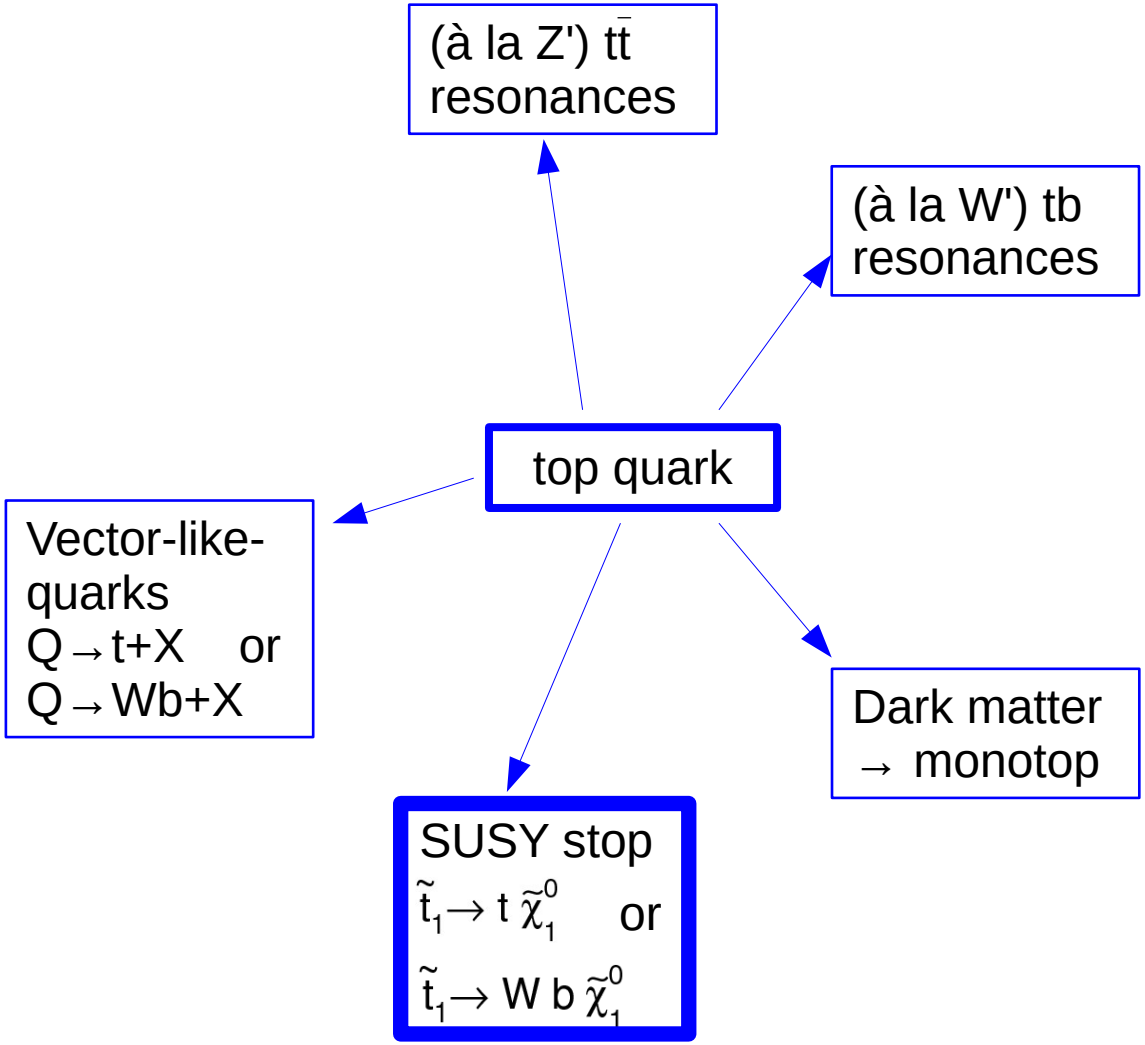
- One Higgs boson required to decay H → γγ
  - Low BR, high purity
  - Hadronic (W → qq) and leptonic (W → ℓυ) channels
- Loose kinematic selection (H_T)



CMS-PAS-B2G-14003

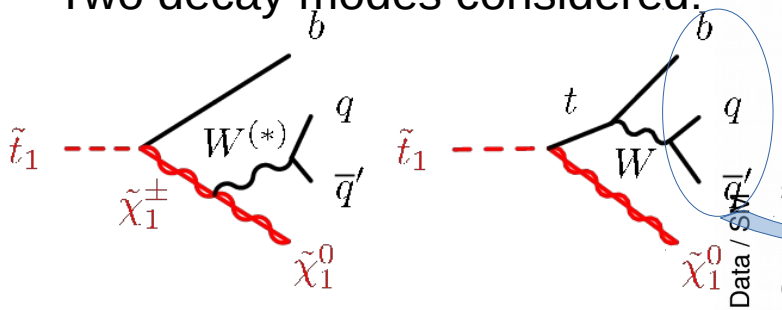


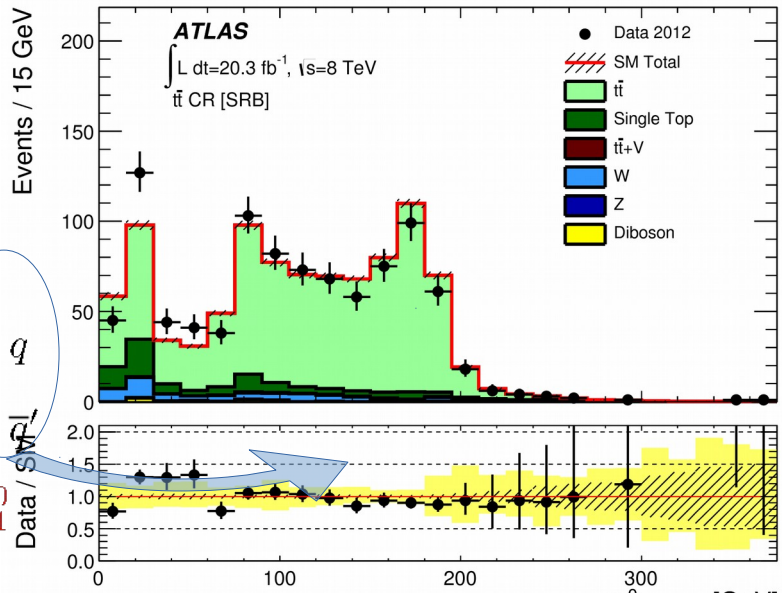



(à la Z') $t\bar{t}$ resonances
(à la W') tb resonances
top quark
Vector-like-quarks
$Q \to t+X$ or
$Q \to Wb+X$
Dark matter
$\to$ monotop
SUSY stop
$\tilde{t}_1 \to t\,\tilde{\chi}_1^0$ or
$\tilde{t}_1 \to W\,b\,\tilde{\chi}_1^0$

ATLAS: stop

Pair produced stop detected in **all-hadronic** top decays:
JHEP 09 (2014) 015
Two decay modes considered:





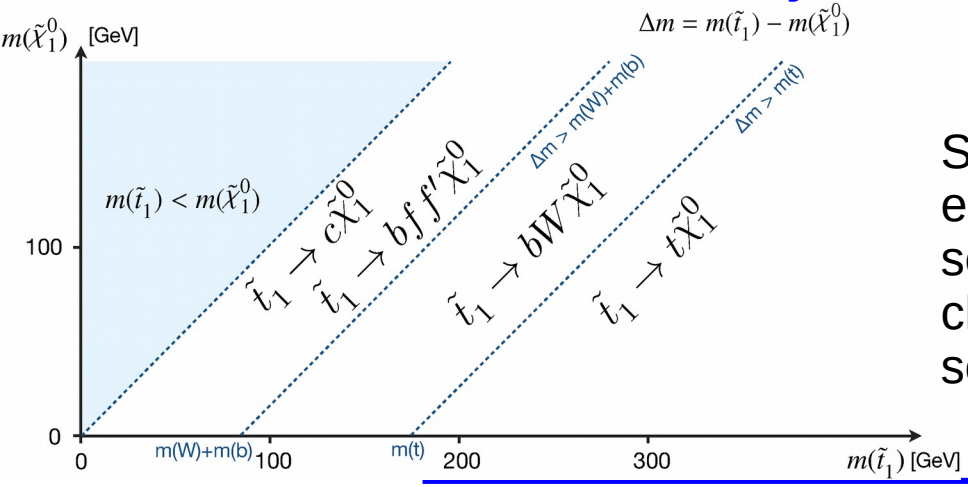
Three categories considered:

- fully resolved (6 jets)
- partially resolved (2 jets reclustered with R=1.2)
- five jets

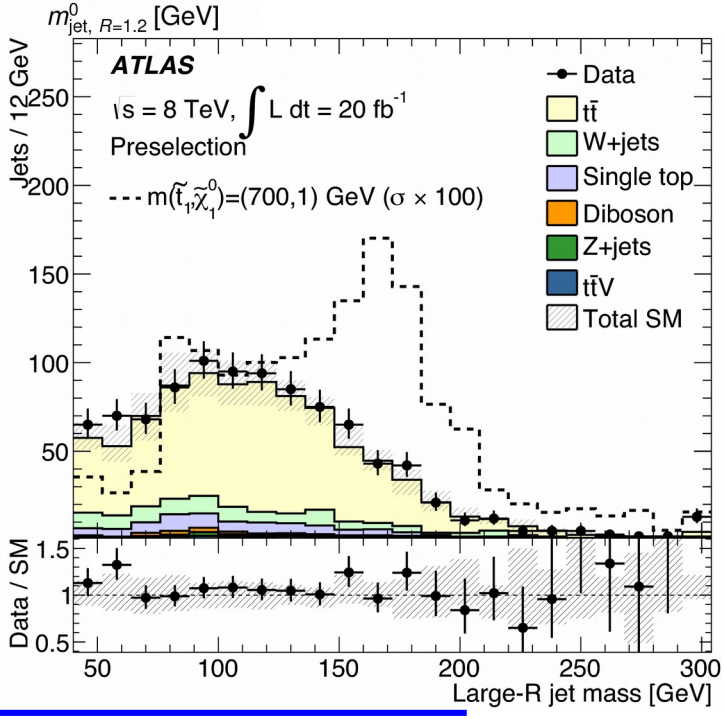
Most discriminating variable: missing E_T

Pair produced stop detected in **ℓ+jets** top decays:
JHEP11(2014)118

Several signal regions accounting for different **mass hierarchies** and **decay modes**



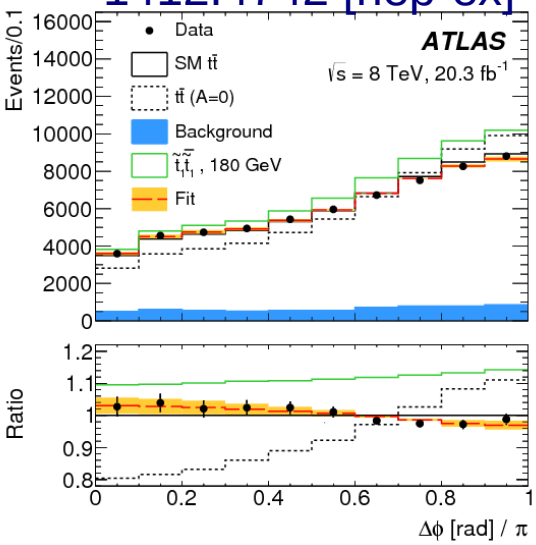
Shape fits enhance sensitivity in challenging scenarios

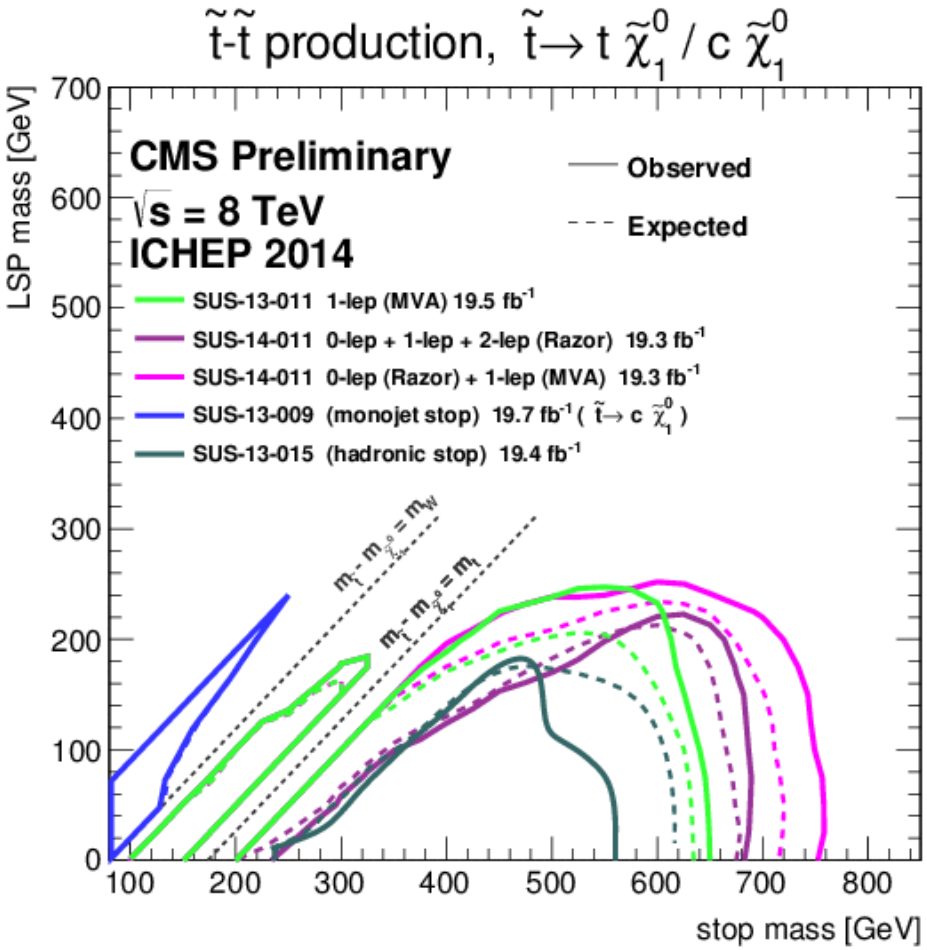


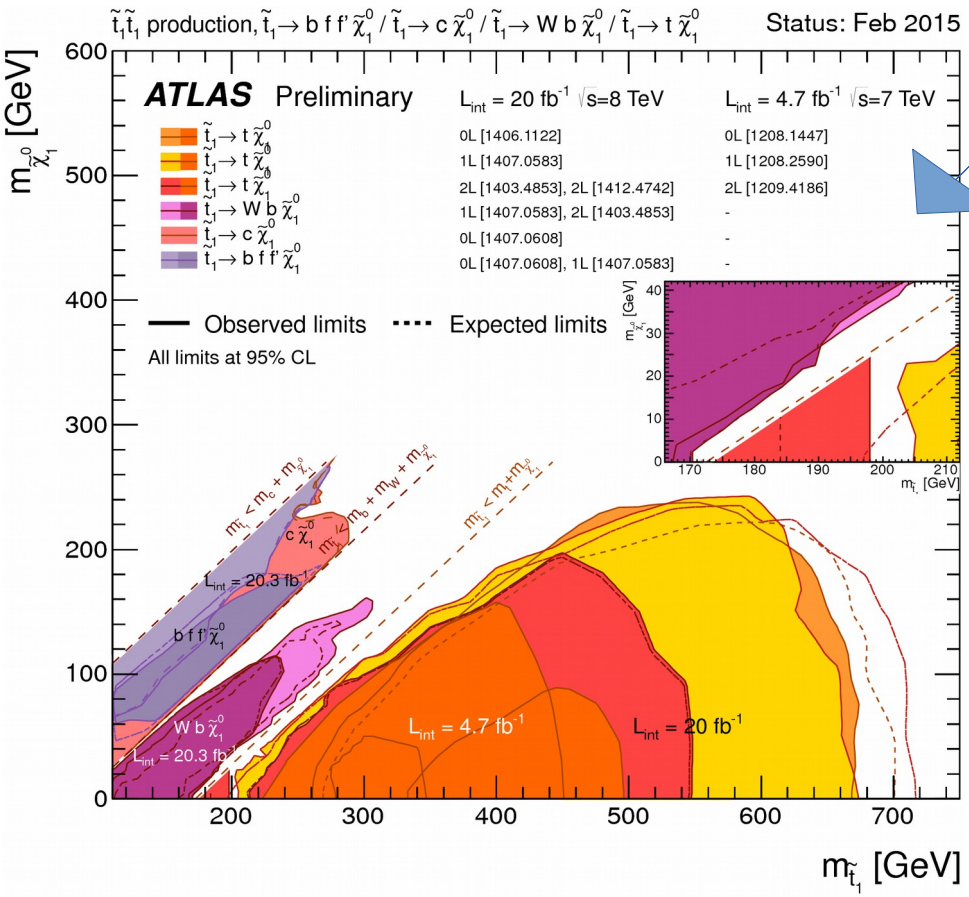
Stop Searches

Impressive coverage already reached last year
Detailed $t\bar{t}$ measurements made it possible to probe the stealth stop region $(m_{\tilde{t}} \sim m_t)$
→ see yesterday's talk by Frederic Deliot

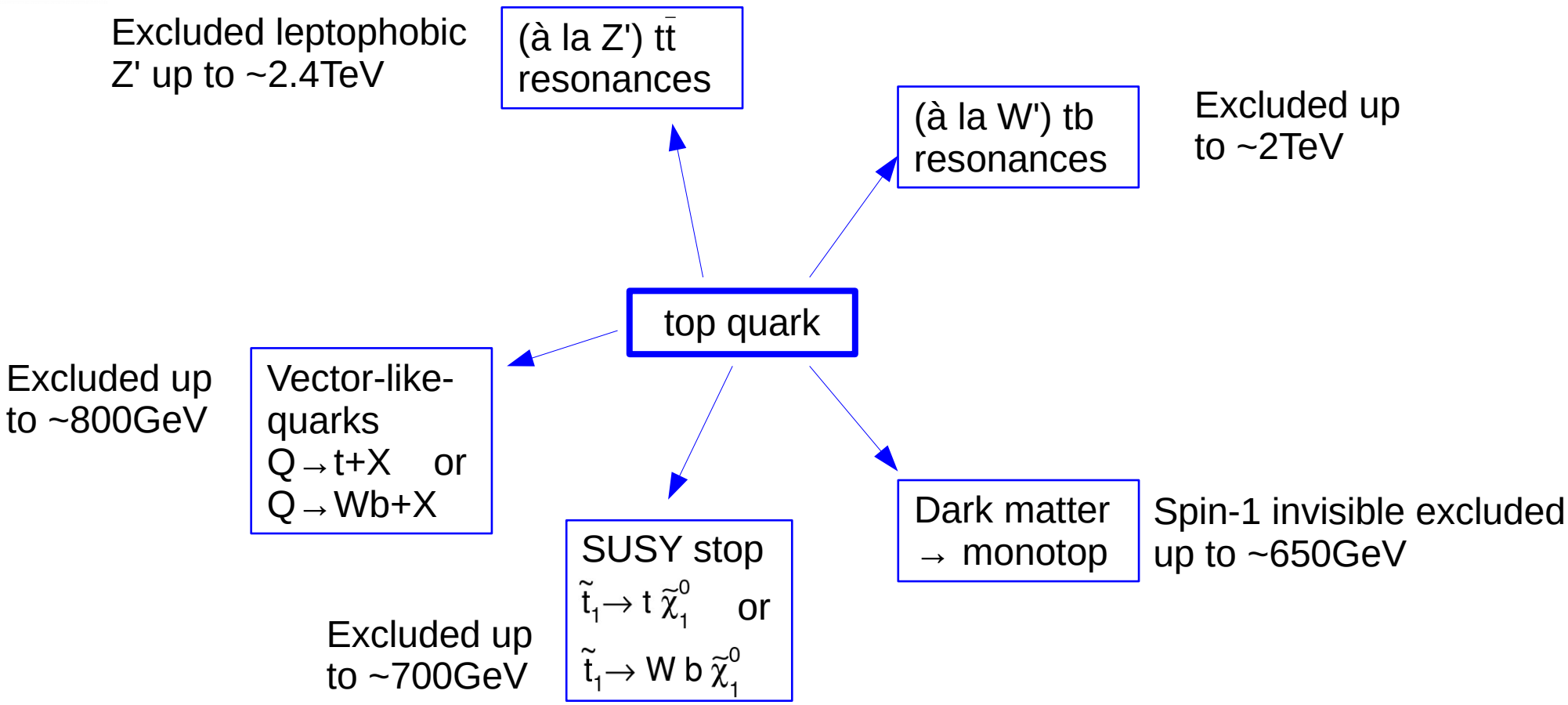
1412.4742 [hep-ex]







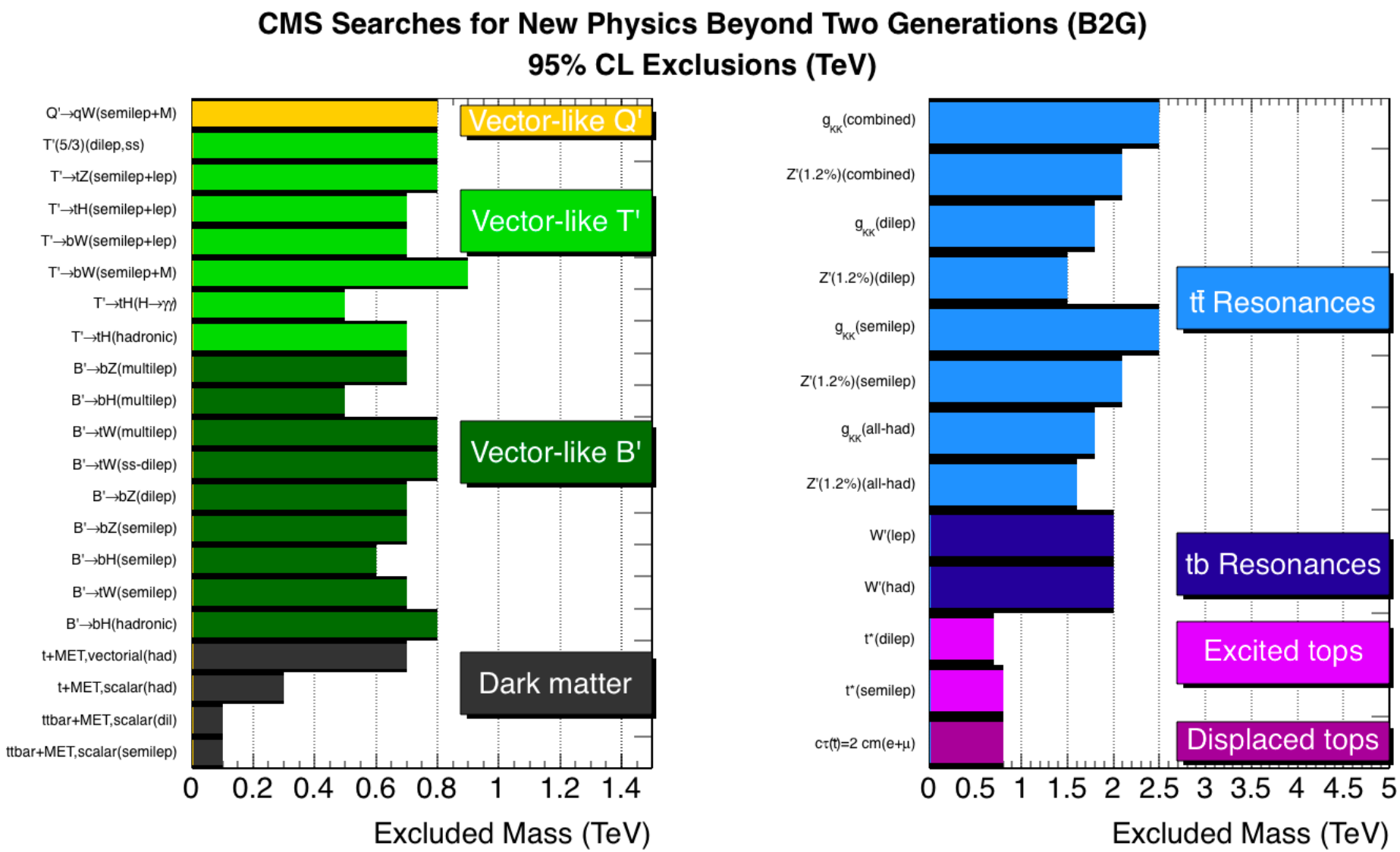
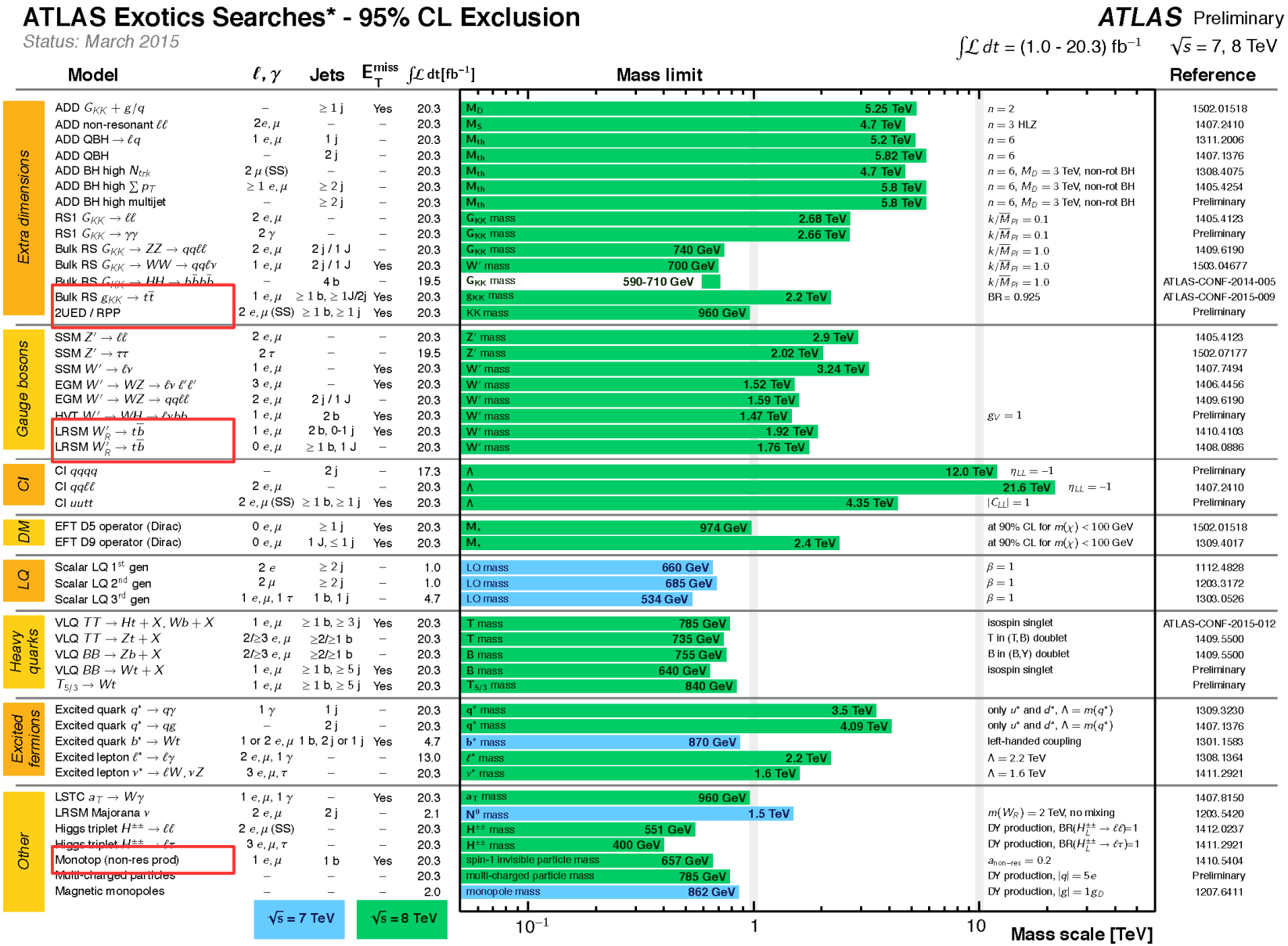
Outlook



- Top turns 20, and plays a **central role** in many searches for new physics at the LHC
- **New tools**, such as top tagging and reconstruction of boosted objects, are key in many of these searches
- Looking forward to the next 20 years of top physics; hopefully it will lead to the observation of new physics!

Extra

CMS B2G Summary



ATLAS Exotics Summary