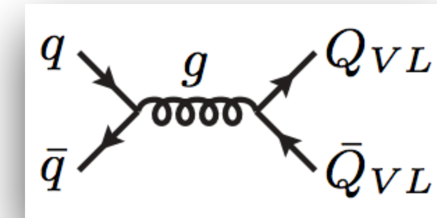
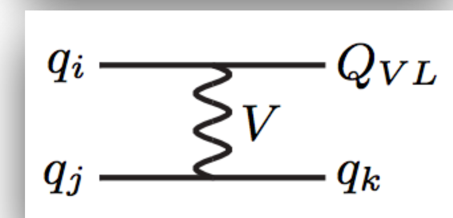
Searches for other heavy resonances with 13 TeV data

(boosted ttbar, vector-like quarks, ...)

[Noam Tal Hod]
TRIUMF

On behalf of ATLAS & CMS

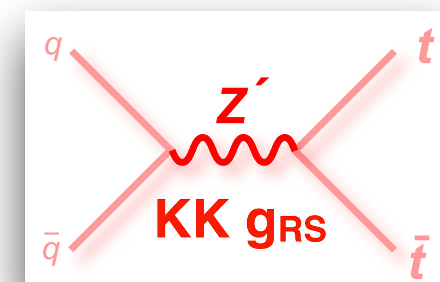




Vector-like quarks (VLQs)

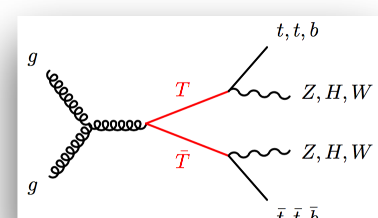
- could damp the unnaturally large corrections to m_H
- predominantly decaying via t/b+V, e.g. **T⟶Wb / Zt / Ht**

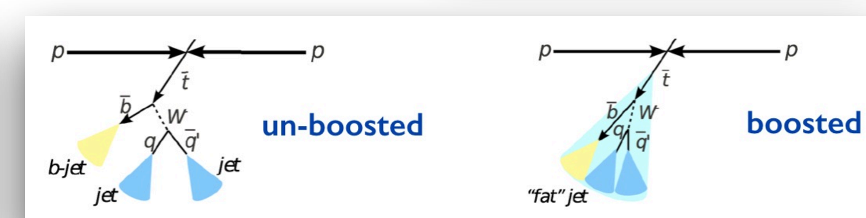
Top partners from Composite Higgs models could also address naturalness



New heavy bosons with enhanced couplings to 3rd generation

- Z' and W' models, RS models with KK gluons
- Little Higgs models, 2HDM, and more





Jet substructure for largeR jets

- final states with several tops and V-bosons
- boosted tops/bosons can appear merged in the detector ($\Delta R \sim 2m/p_T$)
- different grooming algorithms and tagging approaches (see backup)

The searches in this talk

Vector Like Quarks

- Single VLT: tZ($\ell\ell$)+X
- VLT pair: tZ(νν)+X (1ℓ)
- VLT pair: Wb+X (1ℓ)
- VLT pair: tH(bb)+X (0ℓ,1ℓ)

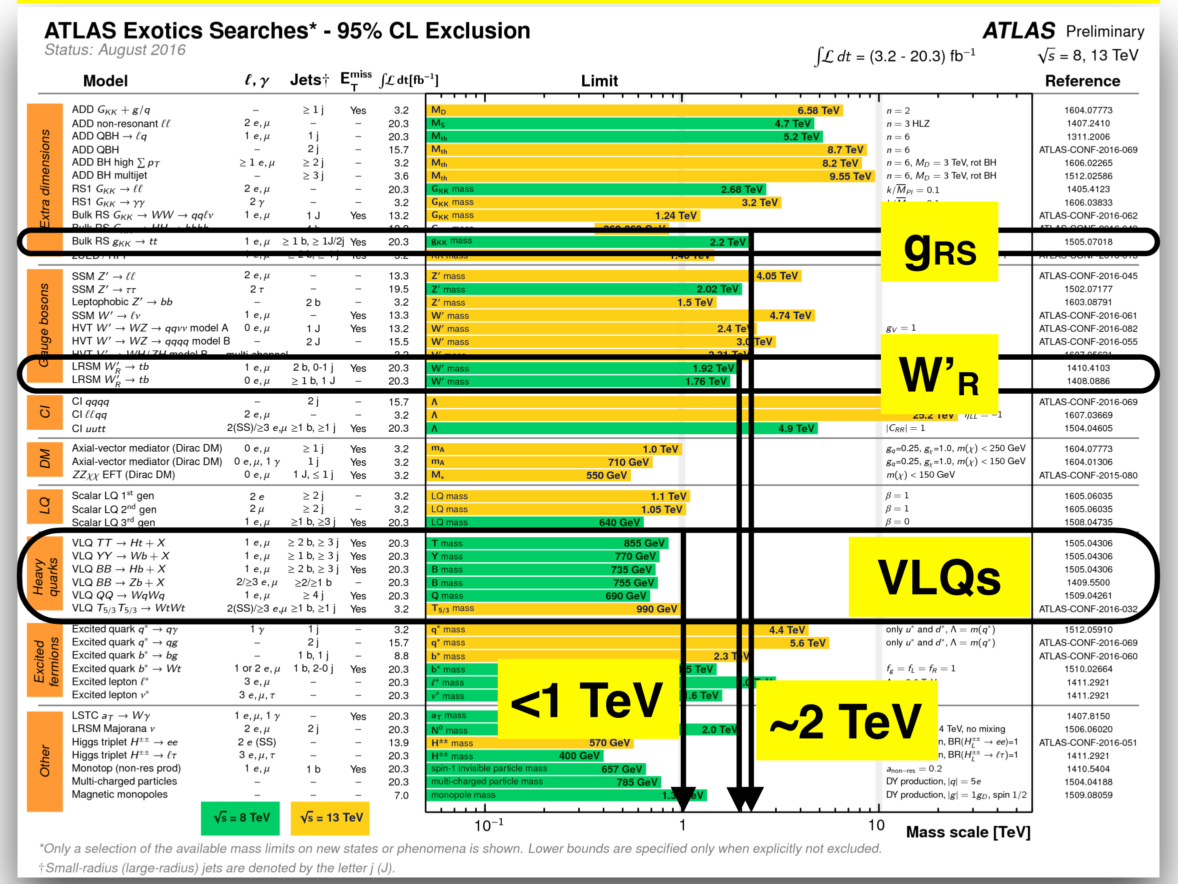
Top partners

- $X_{5/3}$ (same-sign $\ell\ell$)

New heavy bosons

- W'⟶bt$_\ell$
- Z'⟶$t_h t_h$

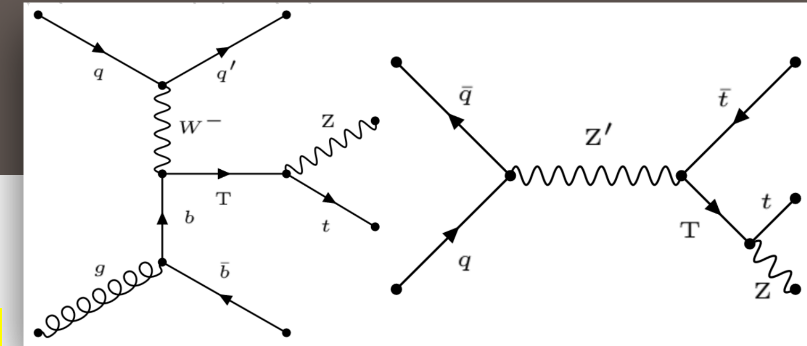
Where did we stand *approximately*?



and more in the backup

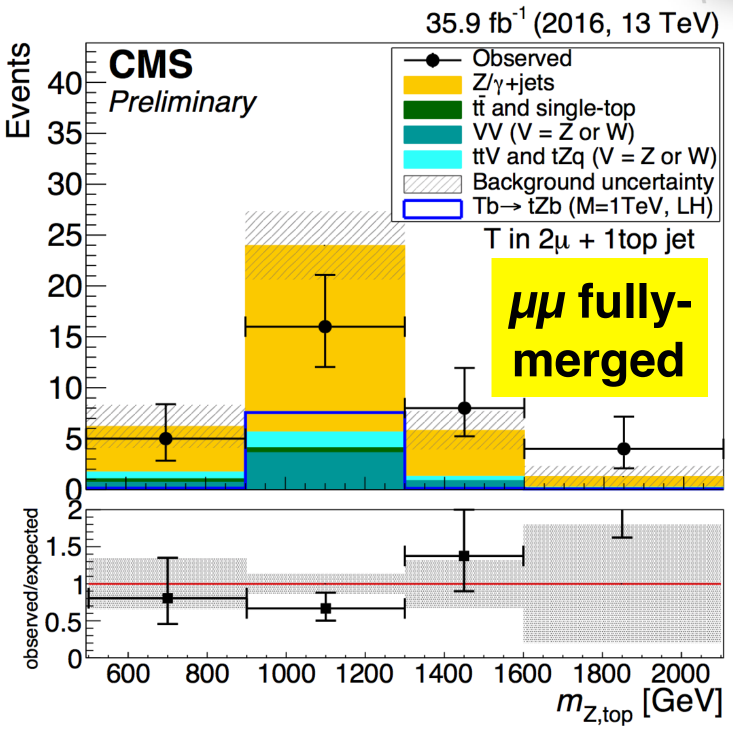
CMS-B2G-17-007
2016 data, ~35.9 fb^{-1}

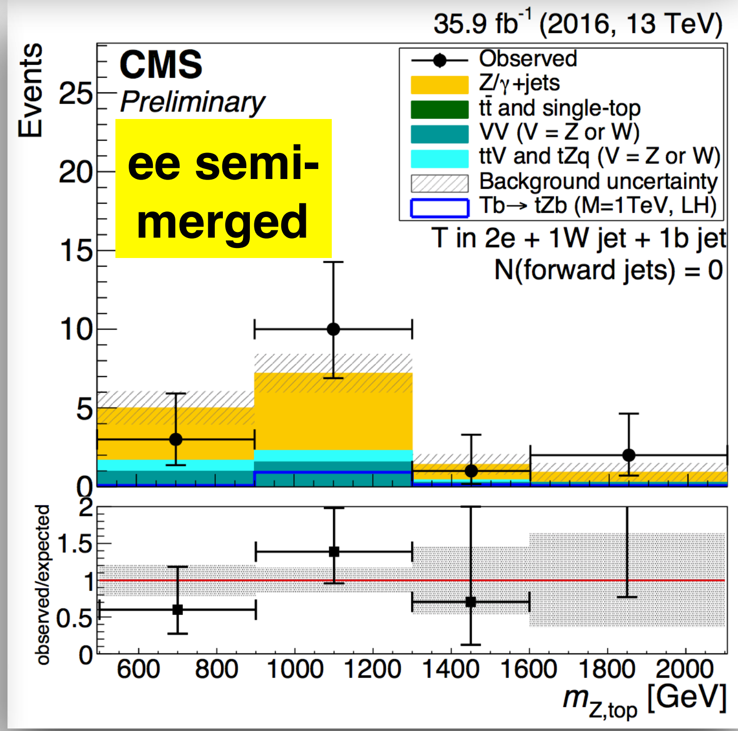
tZ($\ell\ell$)+X

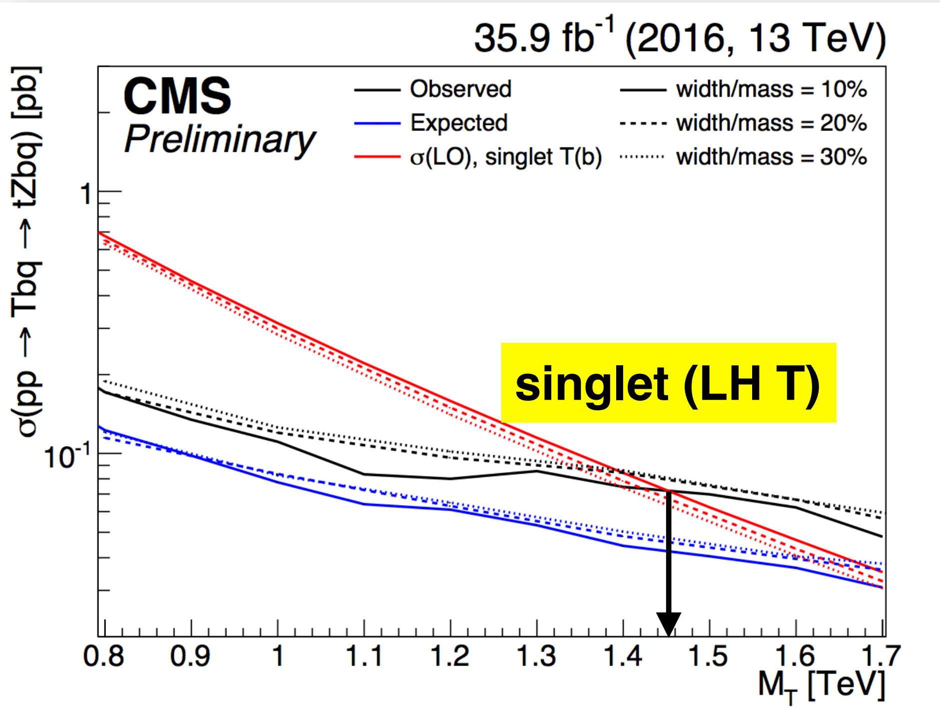


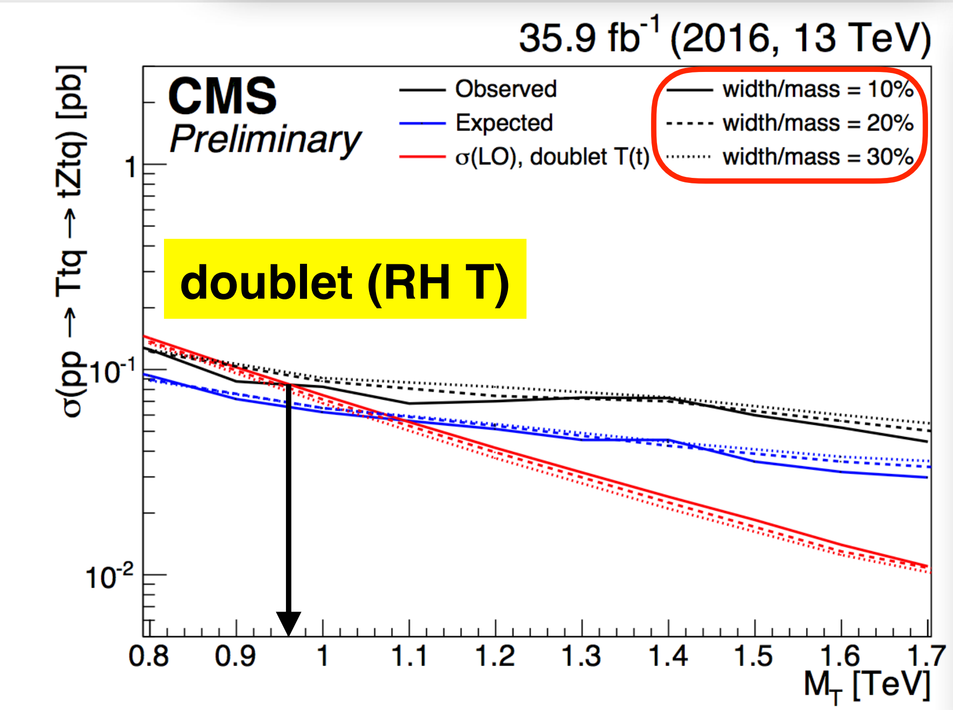
- Optimised for single **VLT⟶tZ($\ell\ell$)**
- **$\ell\ell$(small ΔR)+jets (≥1b)**
- Bkg from a CR with b-jet veto
  - Z+jets(>80%), ttV, tZq, tt
- Use tagged **t- and W-jets**
- Categorise by leptons and top:
  - fully-/semi-merged/resolved
  - number of forward jets (0,≥1)
- 10%-45% uncertainty: low stat in the CR impact on the normalisation

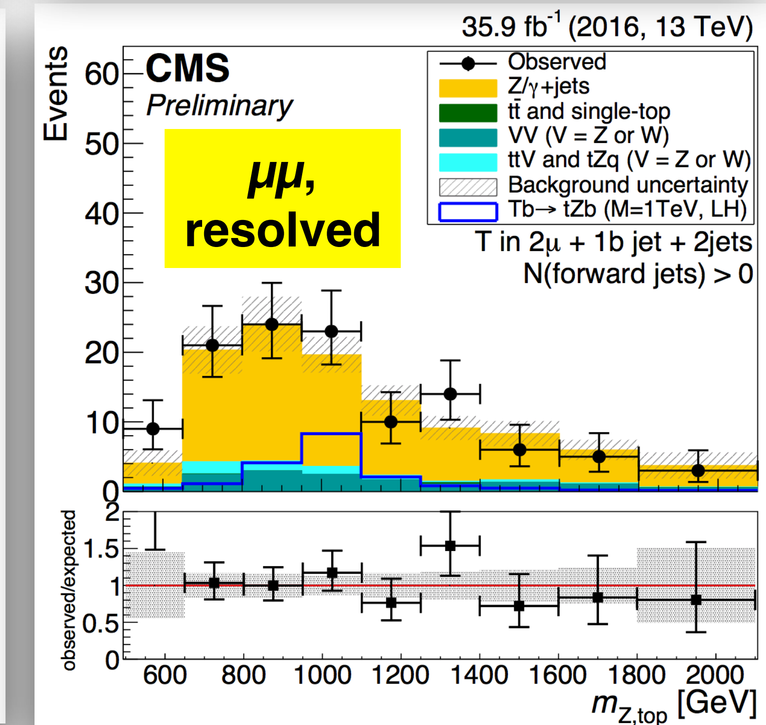
plots showing Mass(Z+top)





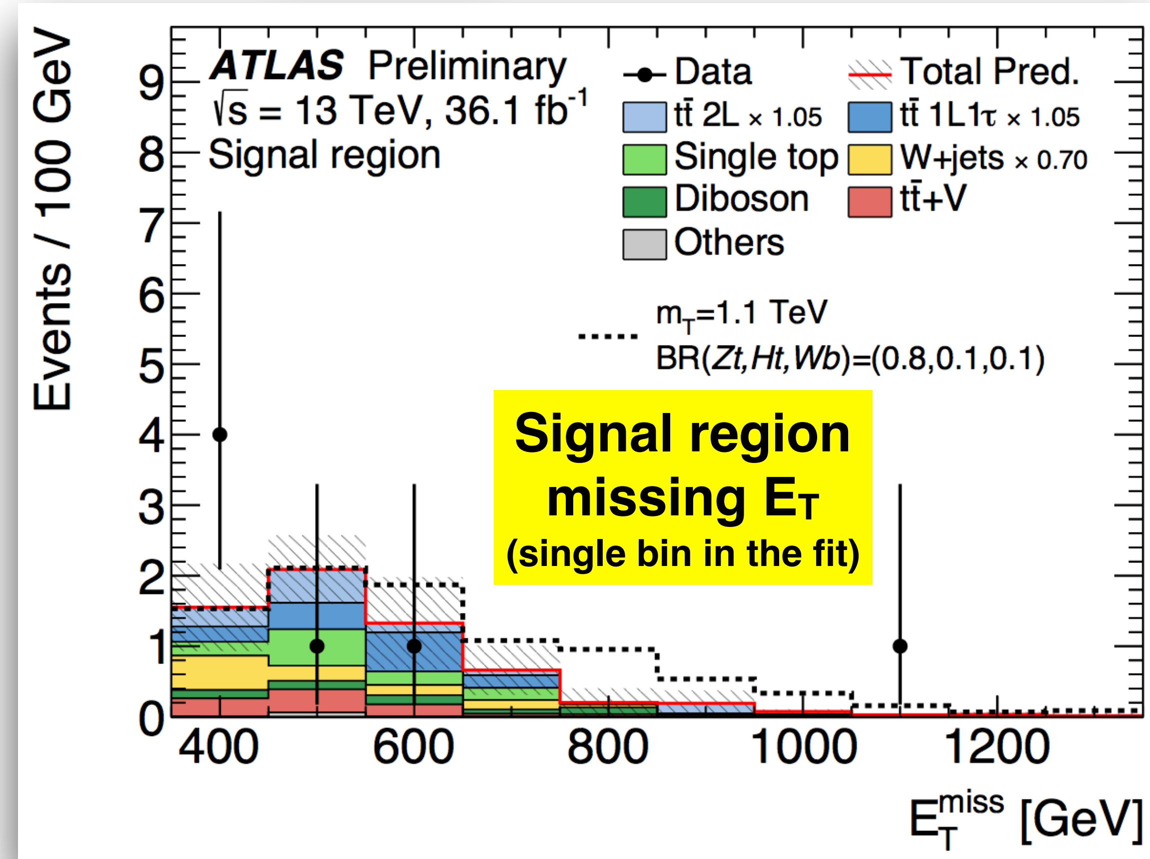


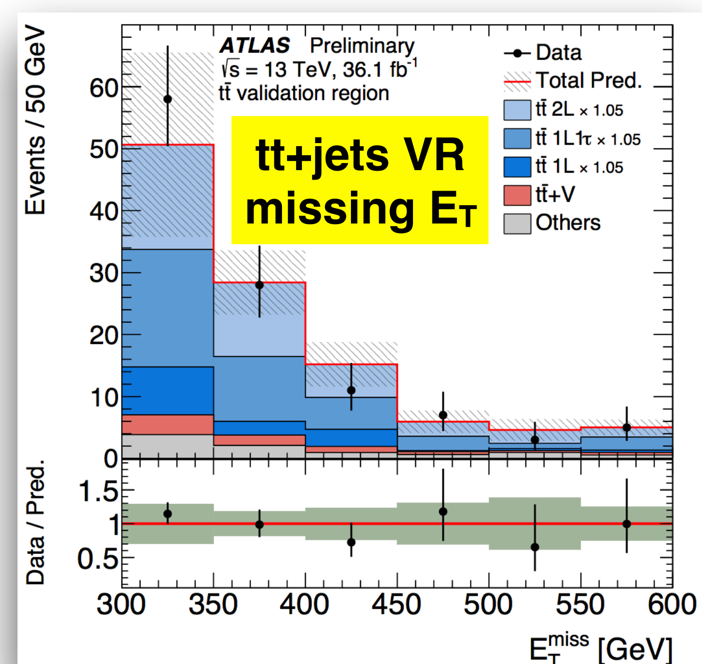


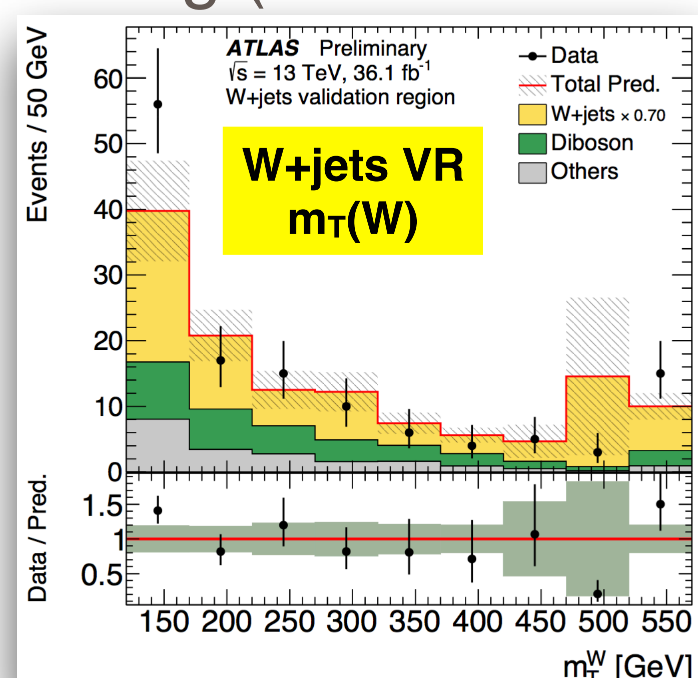


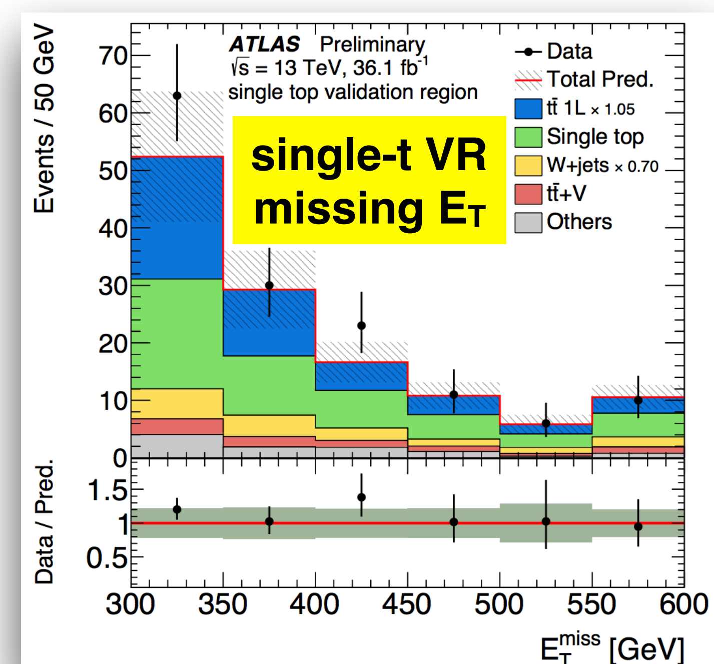
tZ(νν)+X (1ℓ) NEW!

- Optimised for **TT⟶Z(νν)t+X**
- **1ℓ+≥4jets+≥2Jets+MET (≥1b)**
- Bkg: tt, W+jets and single-t
- **Categorise** by object multiplicities, by kinematics and by
  - **m_{T2}** variants (generalised m_T for two undetected particles
  - **MHT_{sig}** = (MHT−100GeV)/σ_{MHT}
    - MHT: vector -Σp_T(leptons+jets)
    - σ_{MHT} from per-event JER
- ~17% uncertainty from tt modelling (< stat uncertainty)



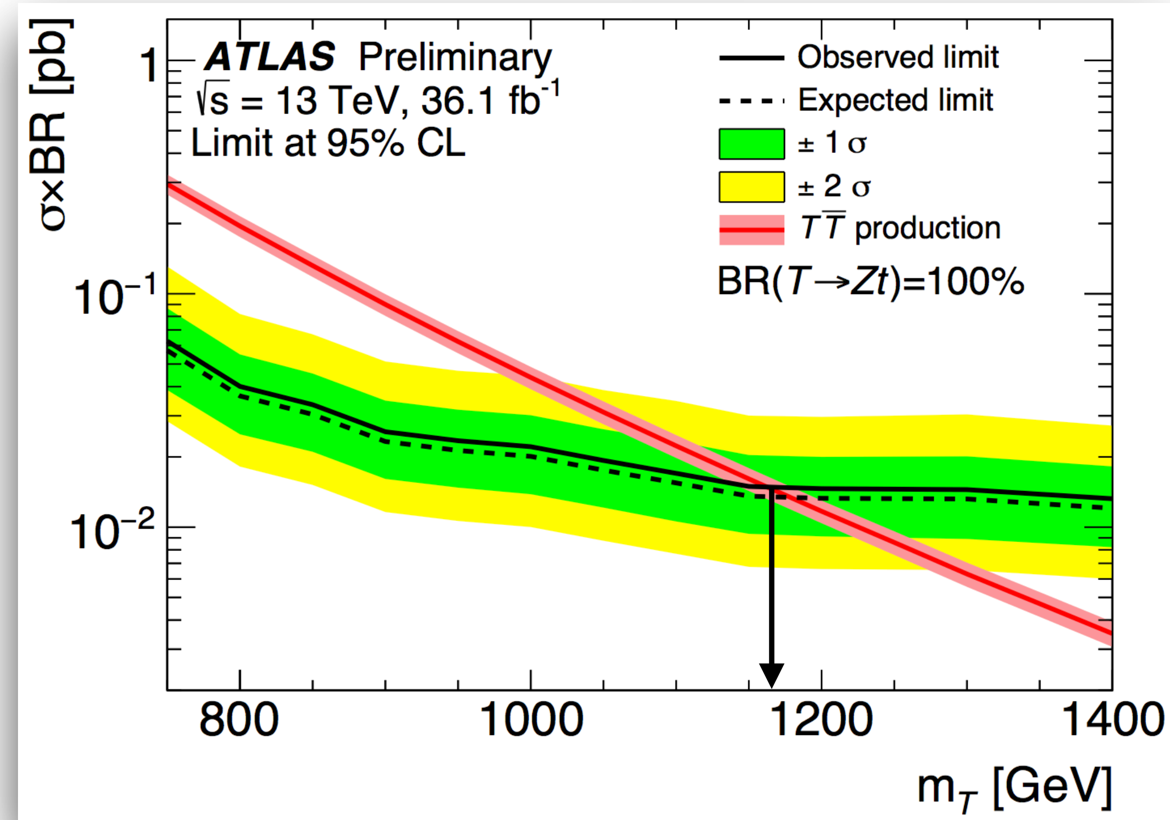






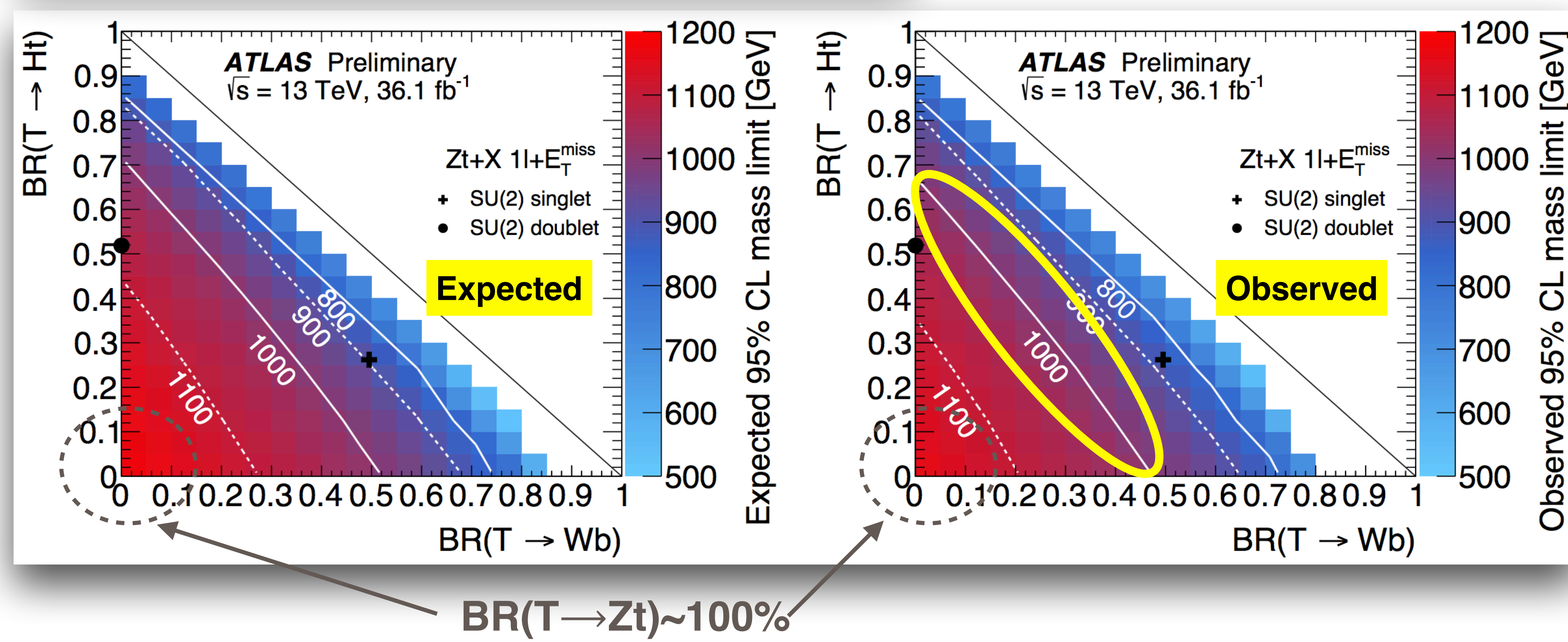
tZ(νν)+X (1ℓ)

NEW!



Limits on m(T) [GeV]

- **Pure T⟶Zt** 1160 (1170)
- **Singlet** 870 (890)
- **Doublet** 1050 (1060)



m(T) below ~1 TeV excluded for:

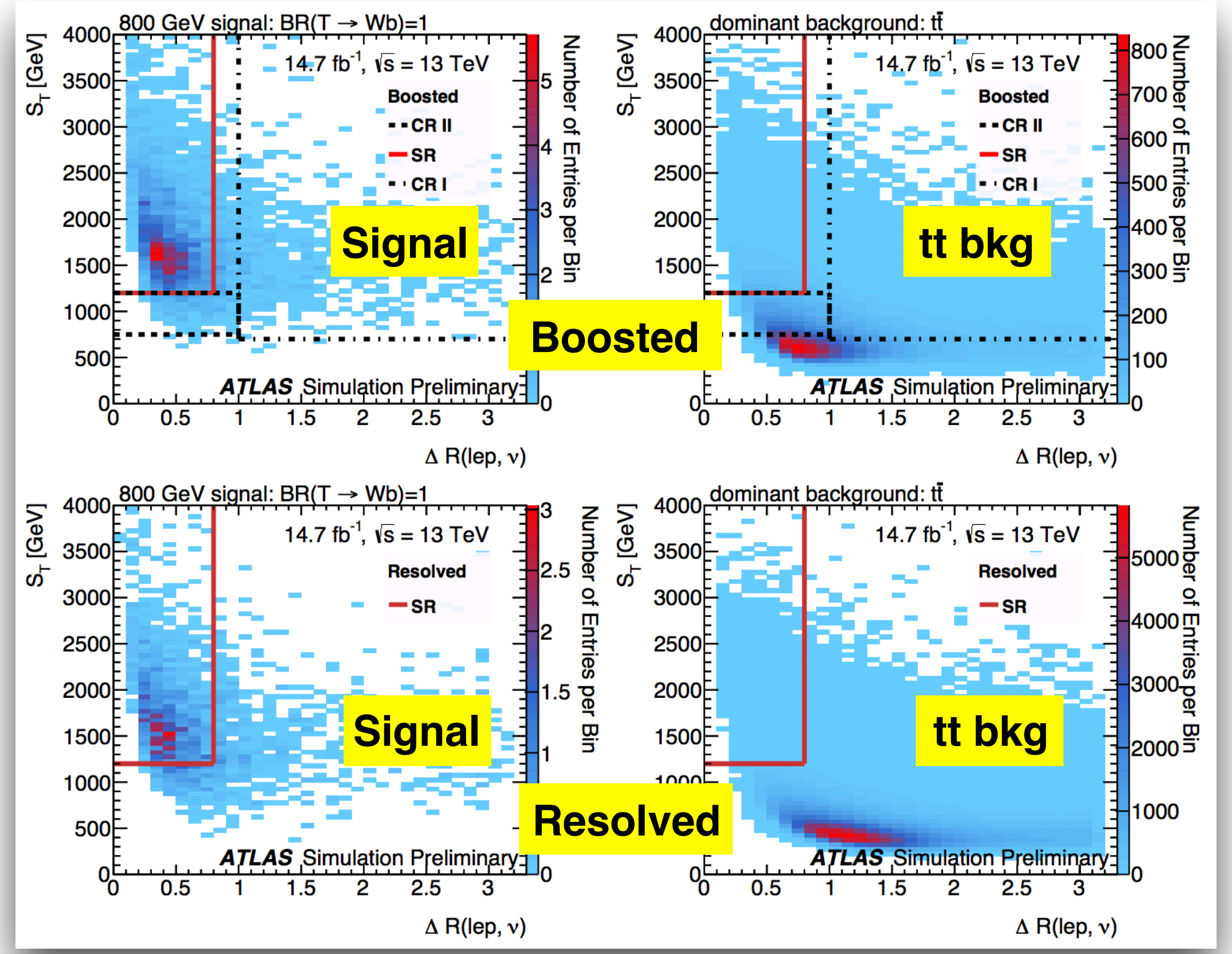
- BR(T⟶Ht)<65% at BR(T⟶Wb)~0
- BR(T⟶Wb)<45% at BR(T⟶Ht)~0

Wb+X (1ℓ)

- Optimised for **TT⟶W(ℓv)b+Wb**/X
- **1ℓ+jets+MET, ≥1b**
- **Tagged W-jets** are vetoed if they are also tagged as top-jets
- **W(ℓv)**: m_W constraint to get p_z(v)
- Bkg: tt+jets, W+jets, single-t and multijet (from data, 100% uncert.)

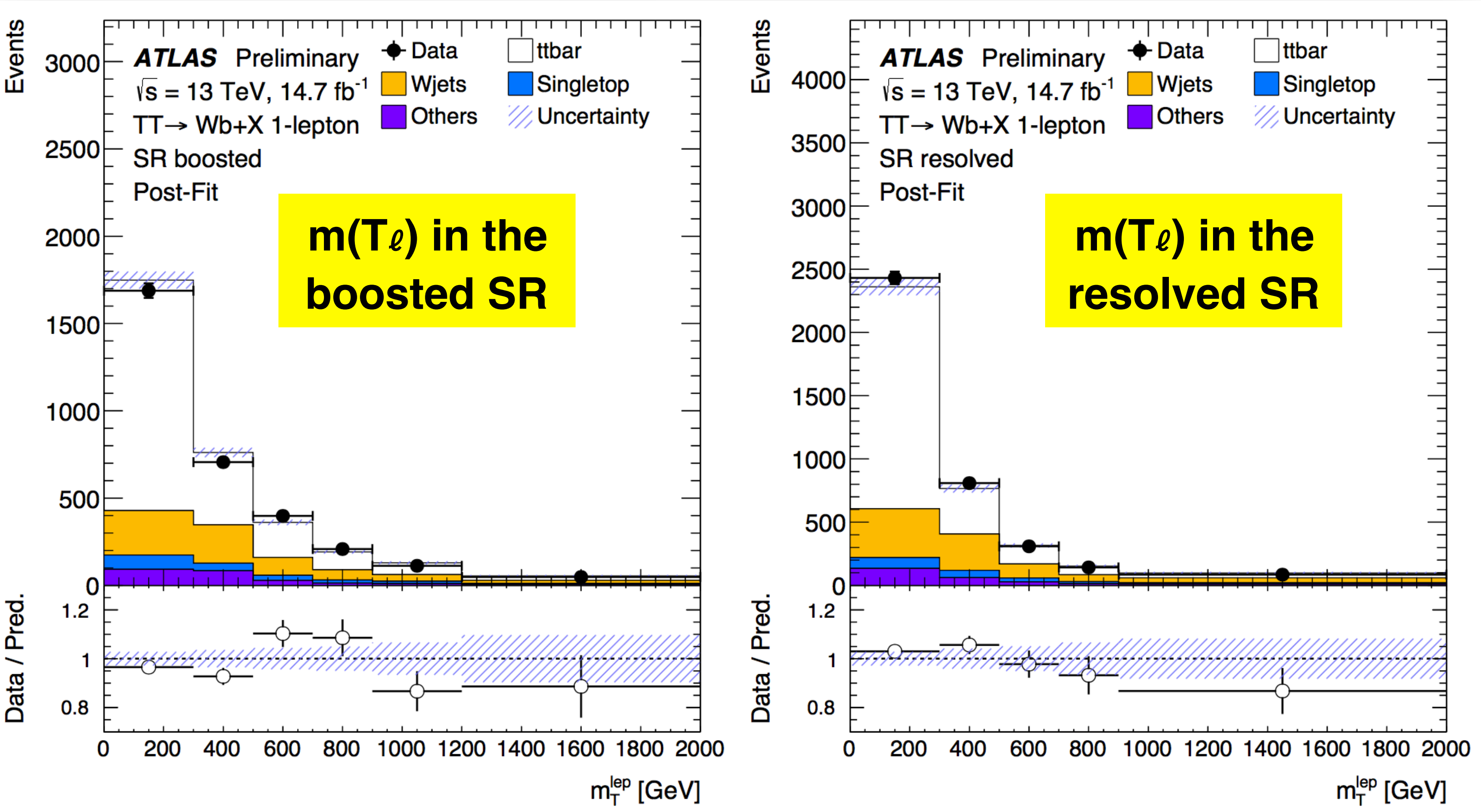
- **TT reconstruction:**
  - pair W_h and W_ℓ with all signal jets to define T_h and T_ℓ
  - best configuration is the one minimising $\Delta m = |m(T_h) - m(T_\ell)|$

Plots sowing S_T=$p_T(\ell)$+Σp_T(jets)+MET **vs** ΔR(v,ℓ)

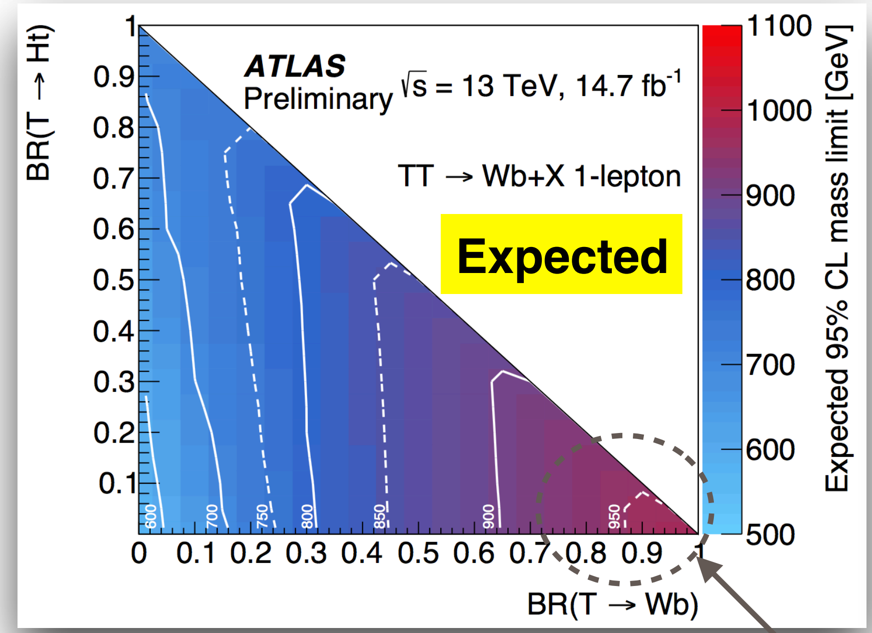


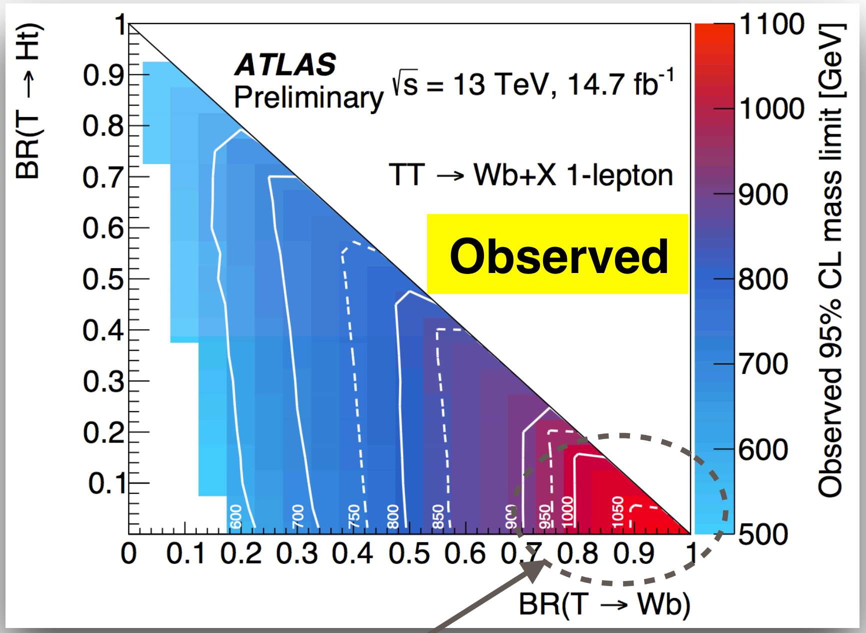
Categorise by S_T and by the
- hadronic W⟶J/jj decay (boosted/resolved)
- ΔR(ℓ,v)

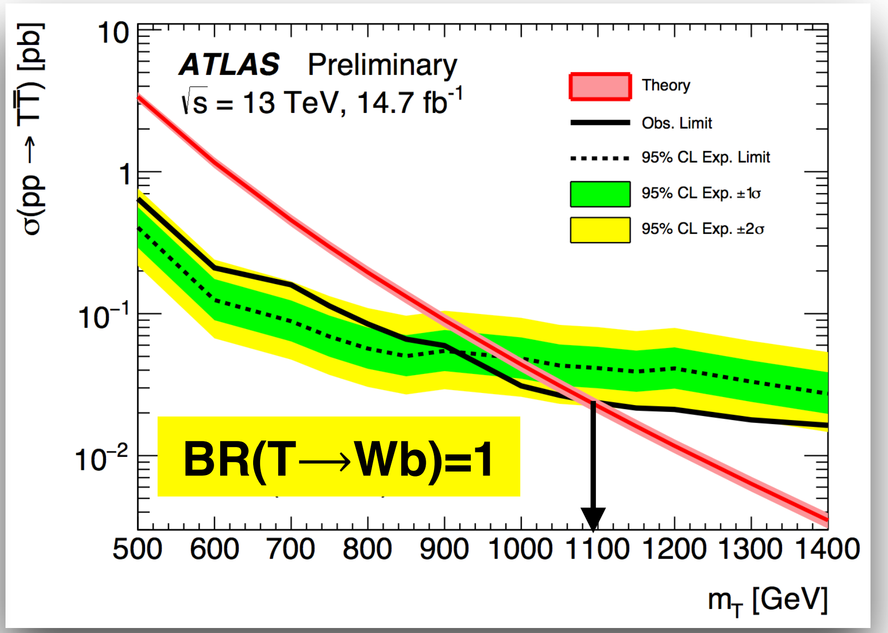
Wb+X (1ℓ)



- Final discriminant is **m(Tℓ)** due to cleaner top reconstruction
- **Limits**:
  - **BR(T⟶Wb)=1**: m(T)<1090 GeV (980 GeV)
  - **SU(2) singlet**: m(T) <810 GeV (870 GeV)



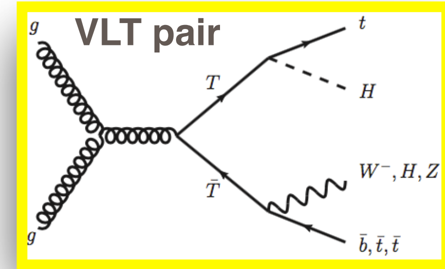


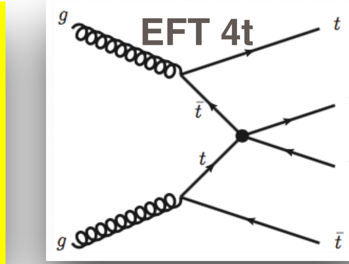


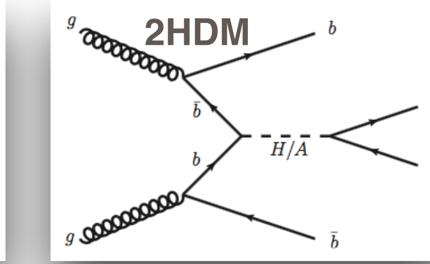
BR(T⟶Wb)~100%

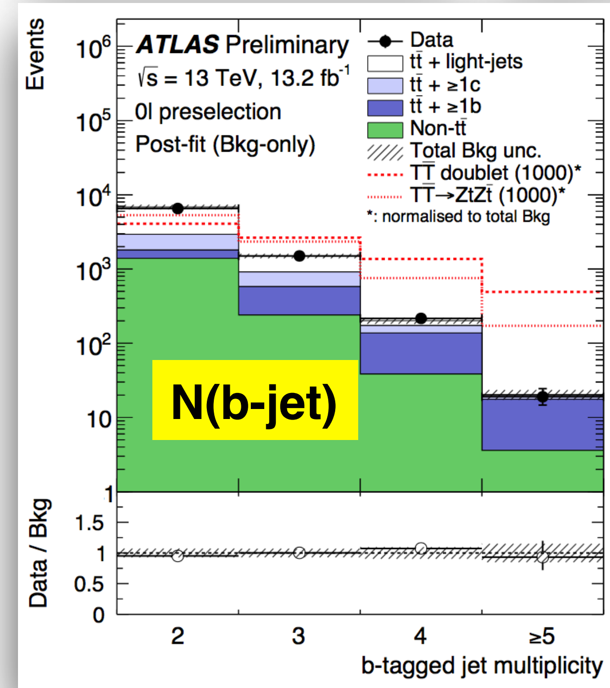
tH(bb)+X (0ℓ,1ℓ)

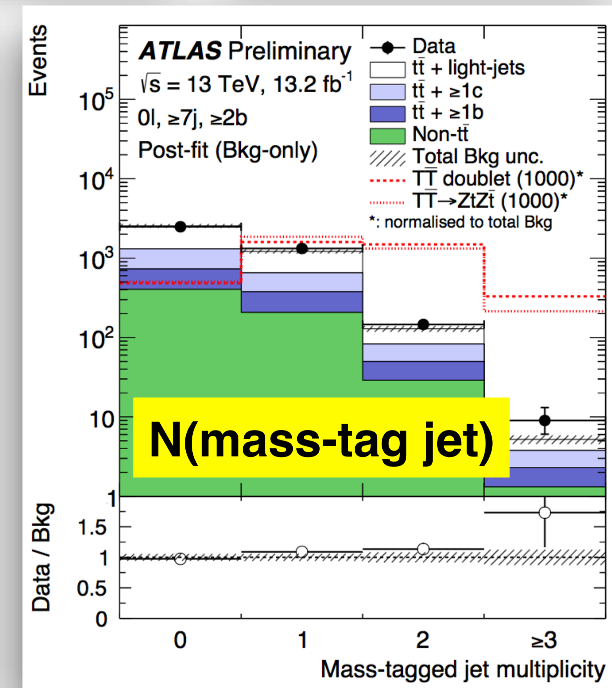
- Optimised for **TT⟶tH(bb)+X**
- **1ℓ/0ℓ+jets+MET (≥2b)**
- **Tagged t/H-jets** with ≥2 subjets
- Bkg: tt+jets, single-top and V+jets
- Categorise by multiplicities and by
  - $m(bb,\Delta R_{min})$ - signal peaks at m_H
  - $m_T(b)_{min}$ - signal peaks at m_t
  - m_{eff} - signal peaks at ~ 2m(T)
- ~50%(⟶16%) uncertainty from tt modelling in the most sensitive SR

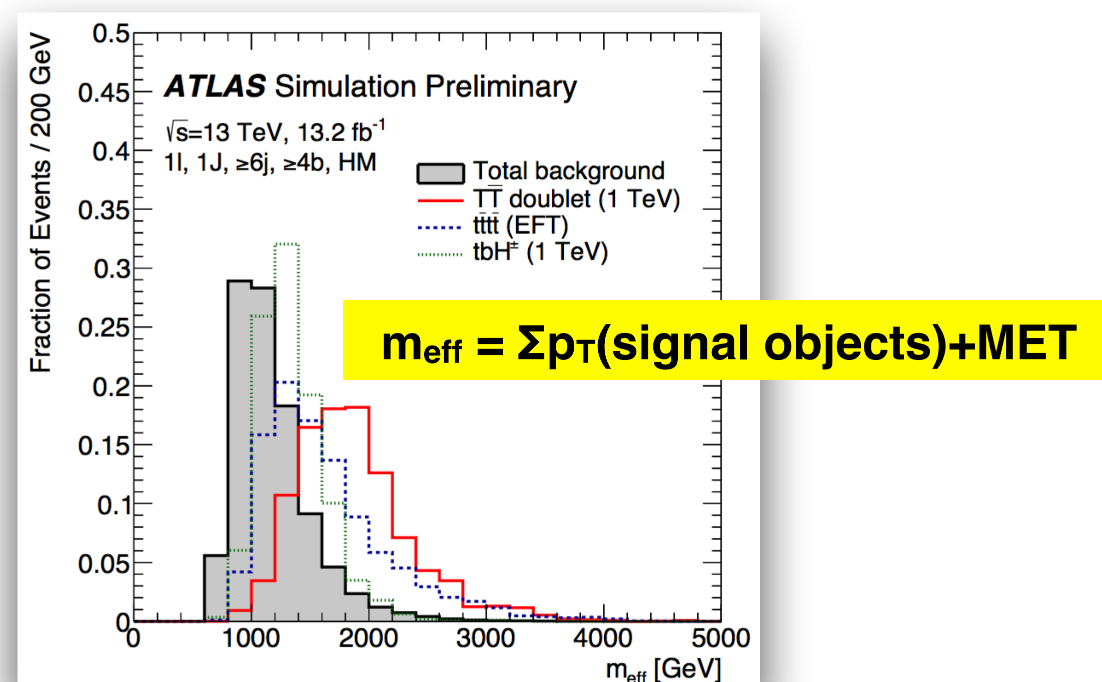


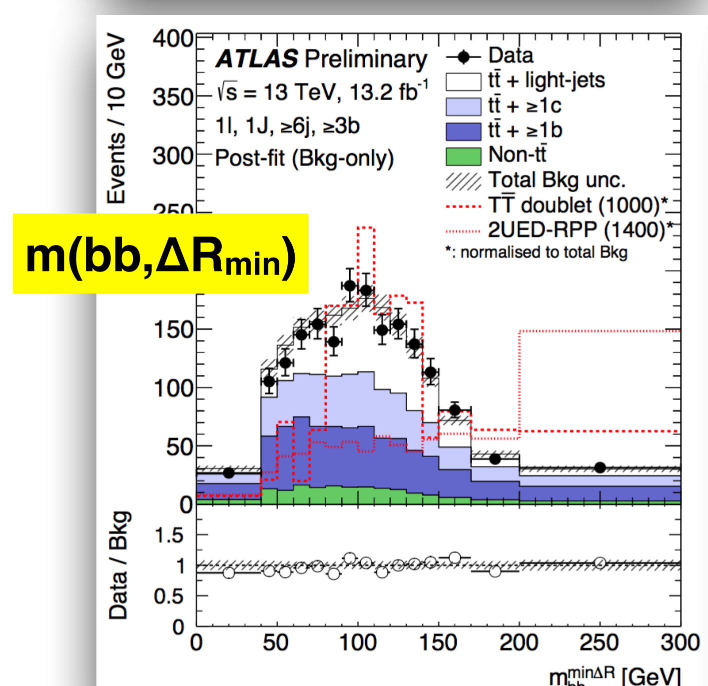


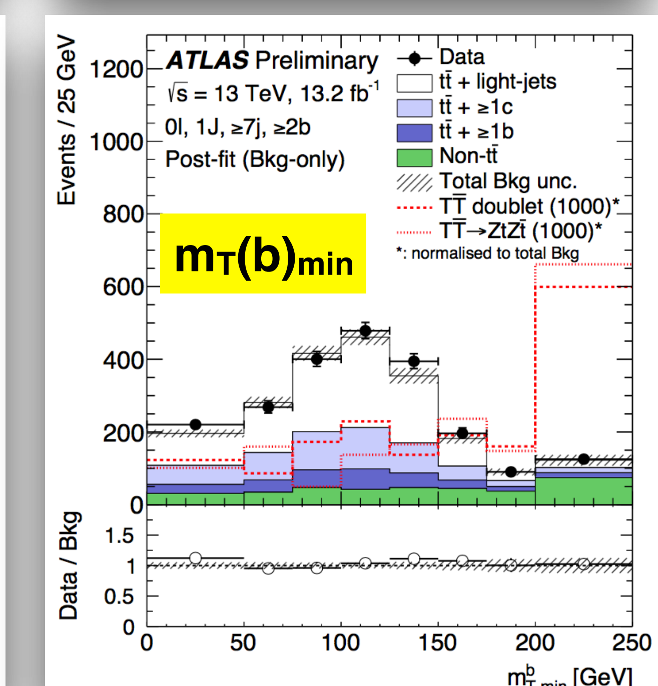




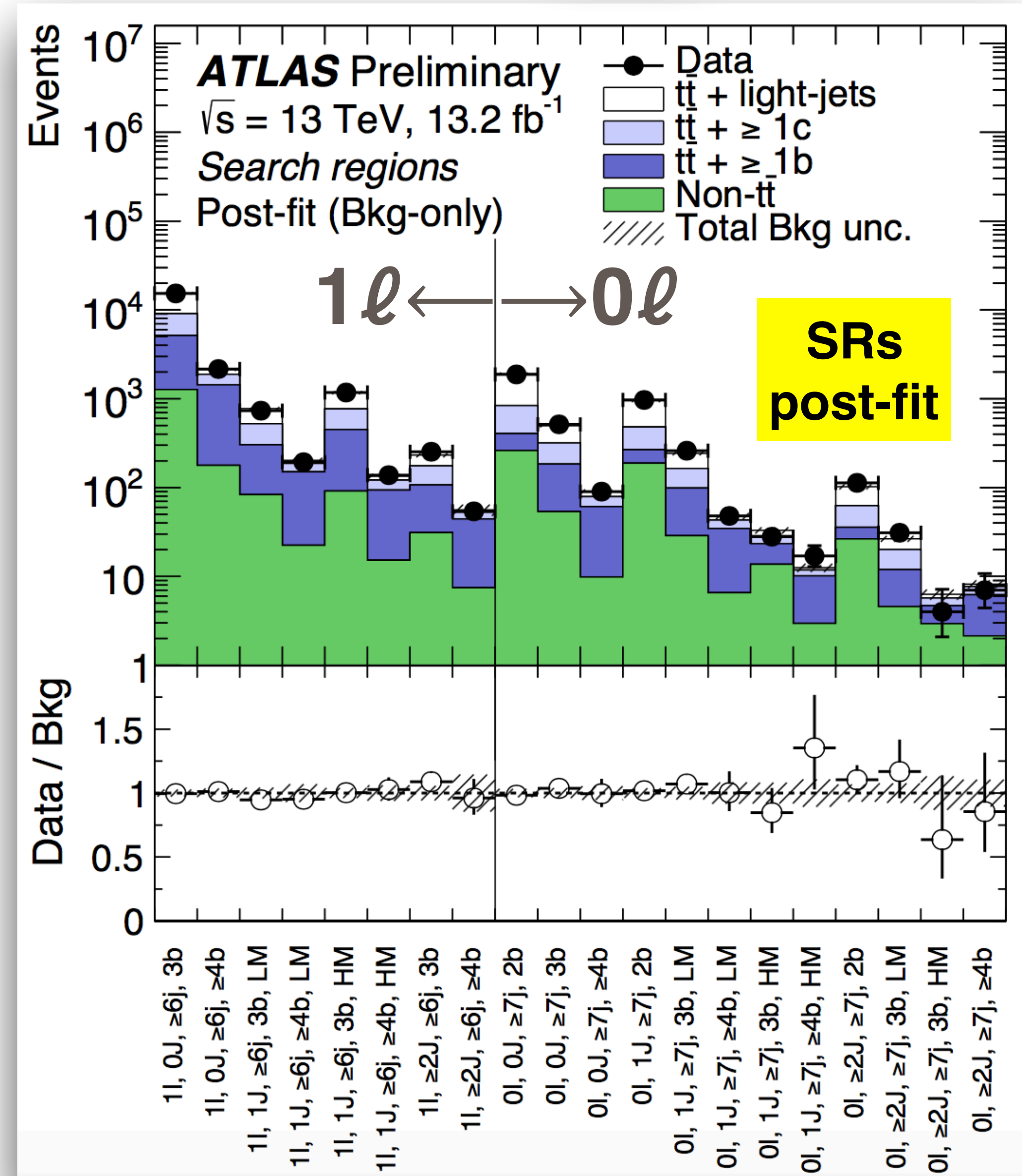


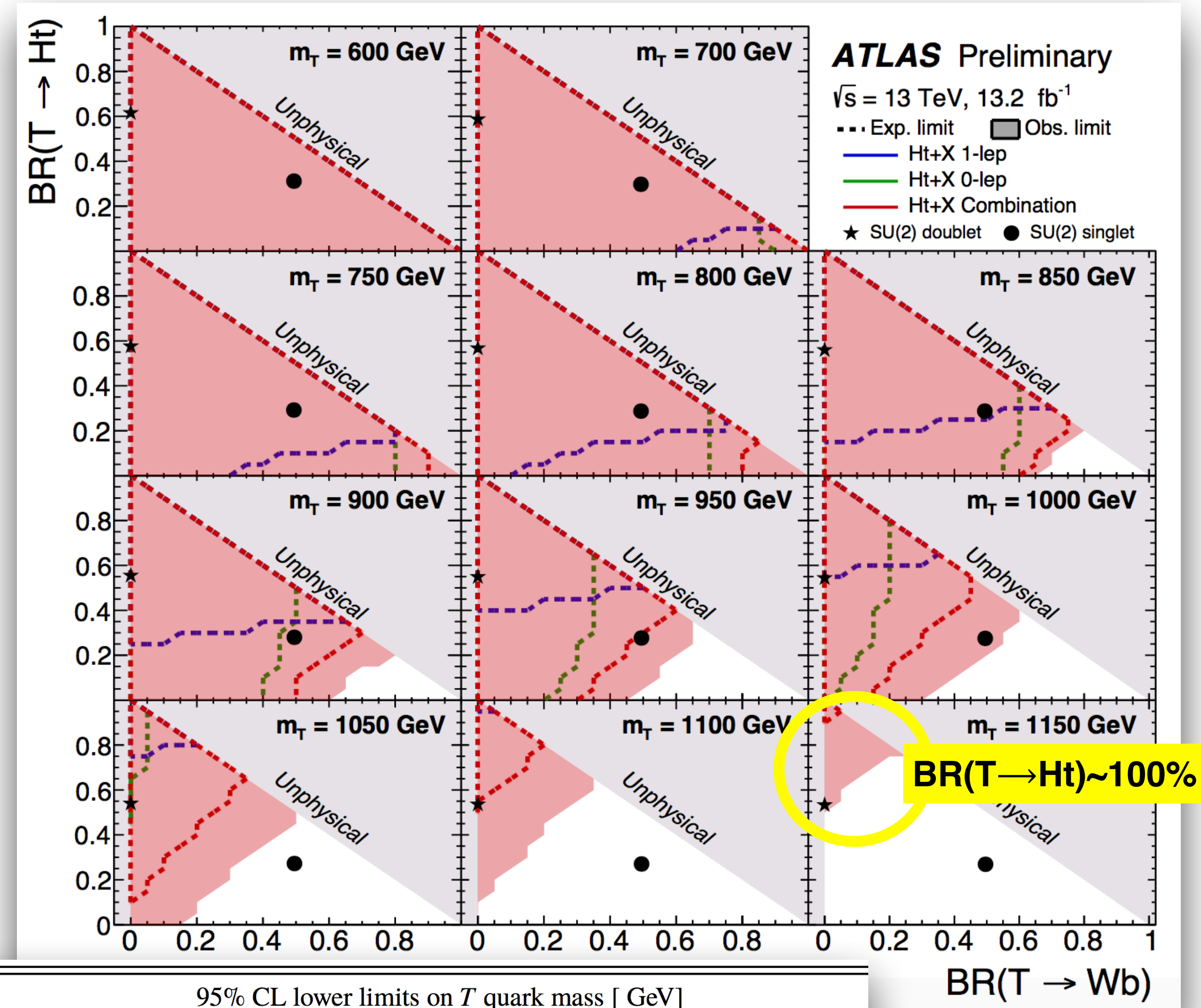






H(bb)t+X (0ℓ,1ℓ)





95% CL lower limits on T quark mass [GeV]

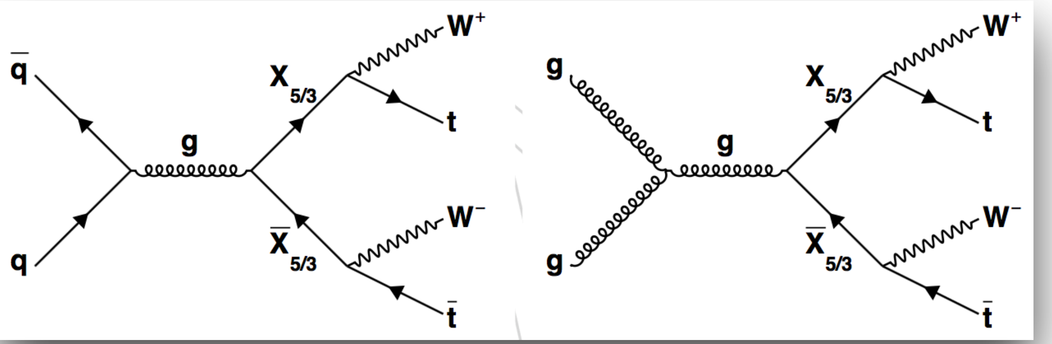
Search	BR($T \to Ht$) = 1	BR($T \to Zt$) = 1	Doublet	Singlet
1-lepton channel	1180 (1120)	740 (820)	1060 (1000)	900 (880)
0-lepton channel	1090 (1070)	1060 (1010)	1090 (1060)	950 (890)
Combination	**1200 (1160)**	**1100 (1040)**	**1160 (1110)**	**1020 (960)**
Previous ATLAS $T\bar{T} \to Ht$+X searches (1-lepton)				
Run 2 (3.2 fb^{-1})	900 (980)	700 (740)	800 (900)	750 (780)
Run 1	950 (880)	750 (690)	860 (820)	760 (720)

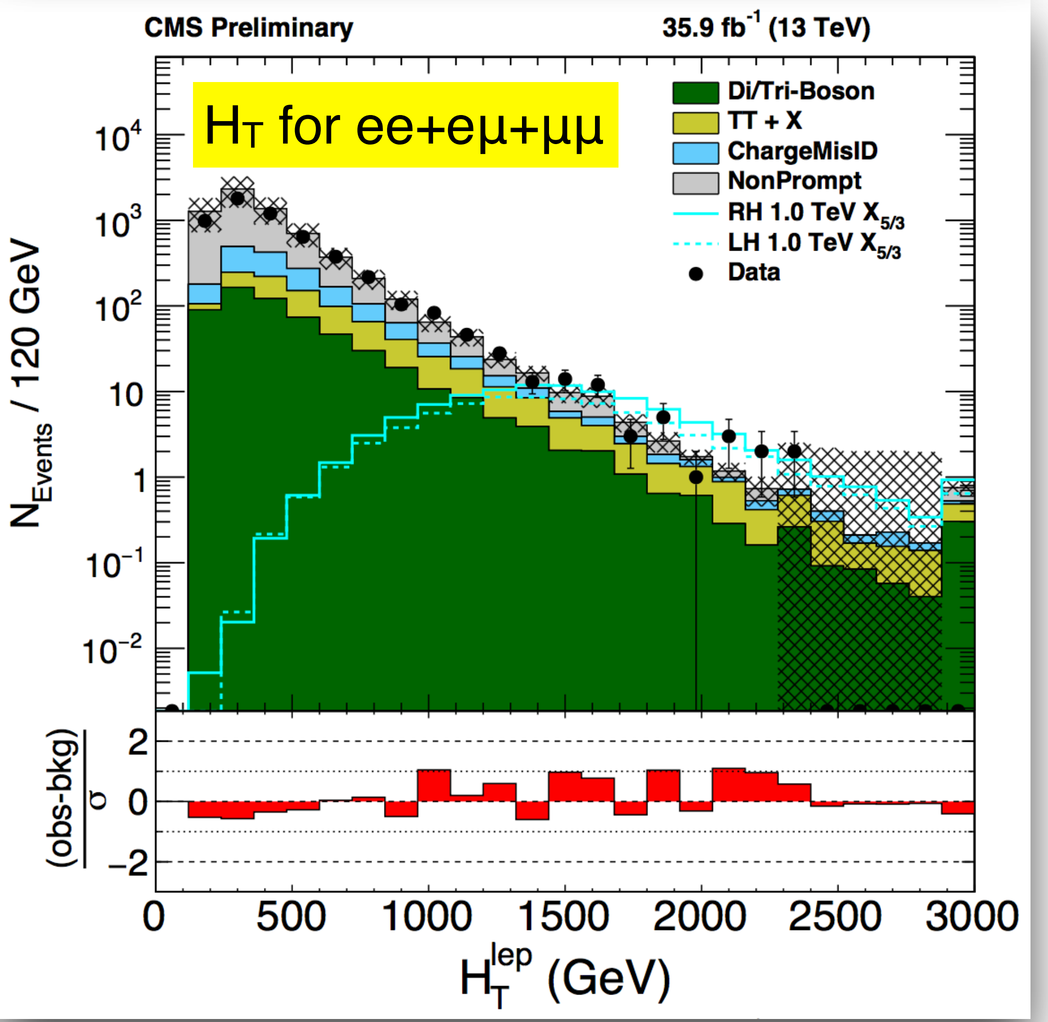
More results for **EFT 4t** and **2HDM** are in the conf note linked above

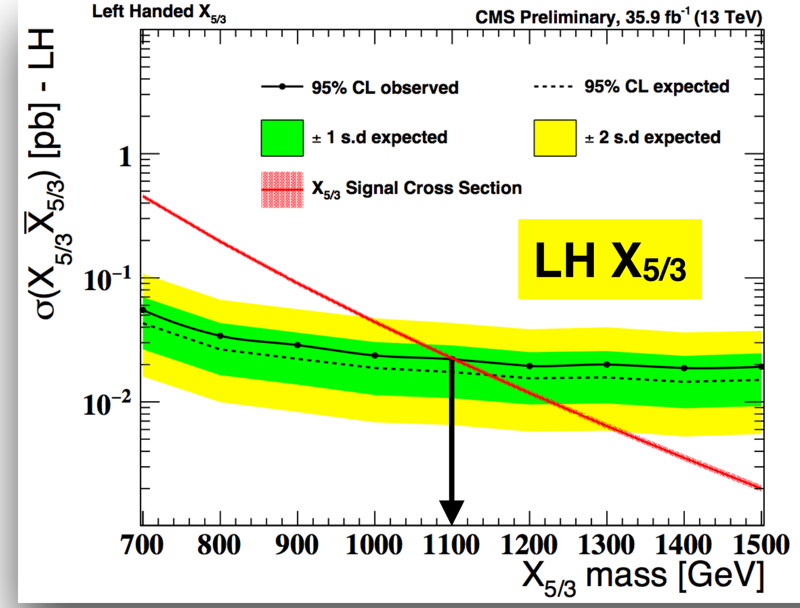
$X_{5/3}$ (SS-$\ell\ell$)

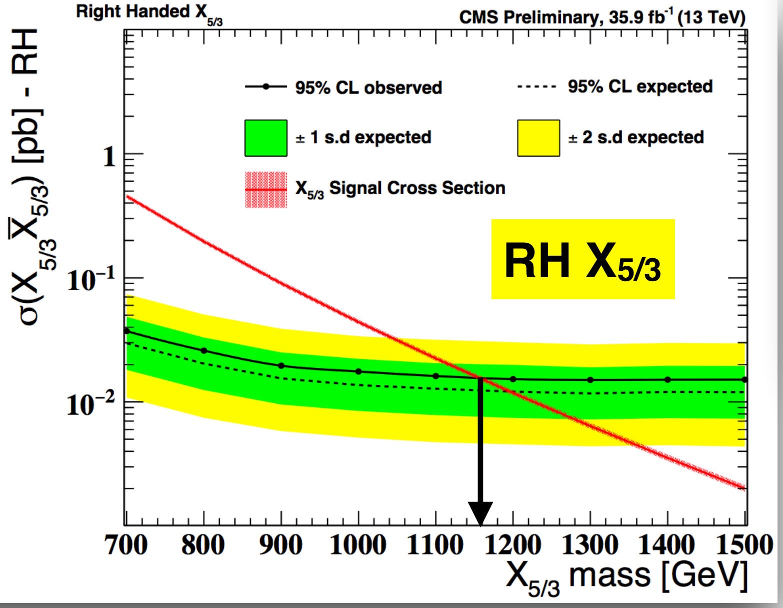
NEW!

- Pair production of top-partners: **$X_{5/3} \longrightarrow W^+t(bW^+)$**
- $W^+W^+ \longrightarrow \ell^+\ell'^+\nu\nu'$ with the other $W^-W^- \longrightarrow$jets
- **$\ell\ell$+≥5(jets & leptons), H_T>1.2 TeV**
- Stringent requirements on the electrons' charge
- Bkg estimation:
  - **prompt SS**: mostly diboson (from simulation)
  - **prompt OS**: OS events reweighted by charge mis-id prob. (data driven, ~30% uncertainty)
  - **non-prompt SS**: heavy flavour, fakes etc. (data driven, ~50% uncertainty)









*2015 data analysis with both SS-$\ell\ell$ and ℓ+jets final states: B2G-15-006

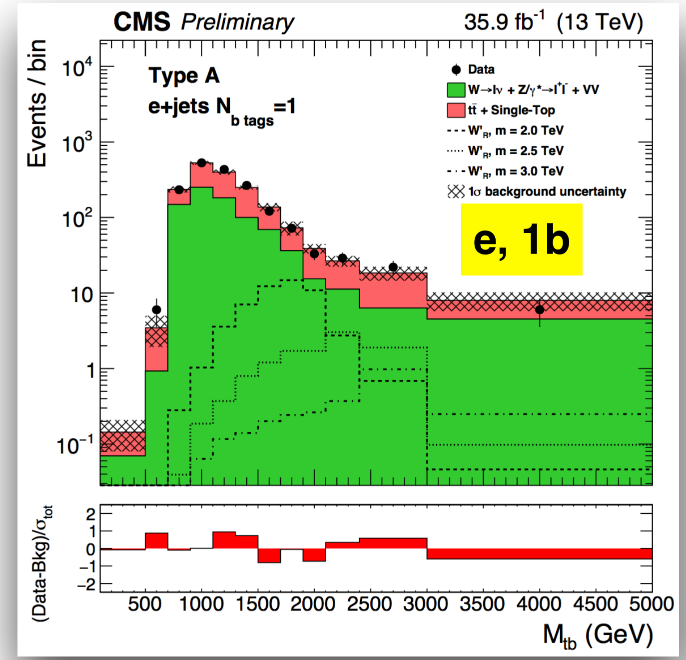
NEW!

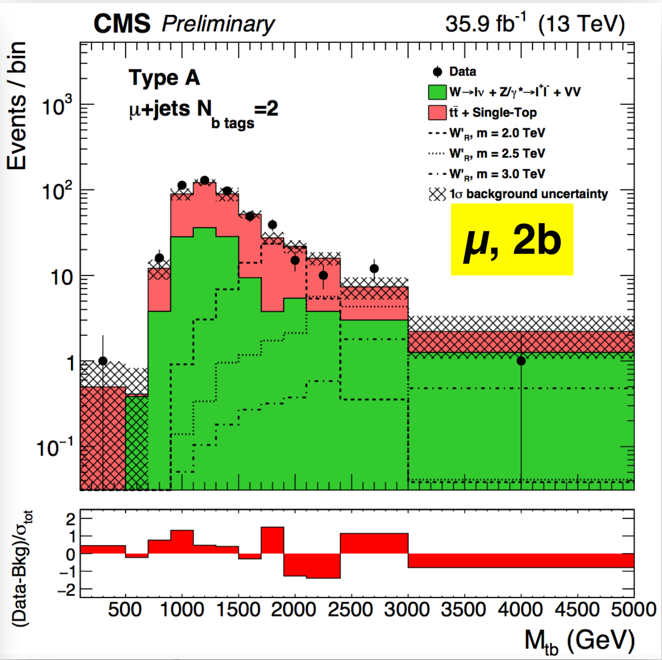
W'$\longrightarrow$btℓ

$$\mathcal{L} = \frac{V_{q_i q_j}}{2\sqrt{2}} g_W \bar{q}_i \gamma_\mu \left(a^R_{q_i q_j}(1+\gamma^5) + a^L_{q_i q_j}(1-\gamma^5) \right) W' q_j + \text{h.c.}$$

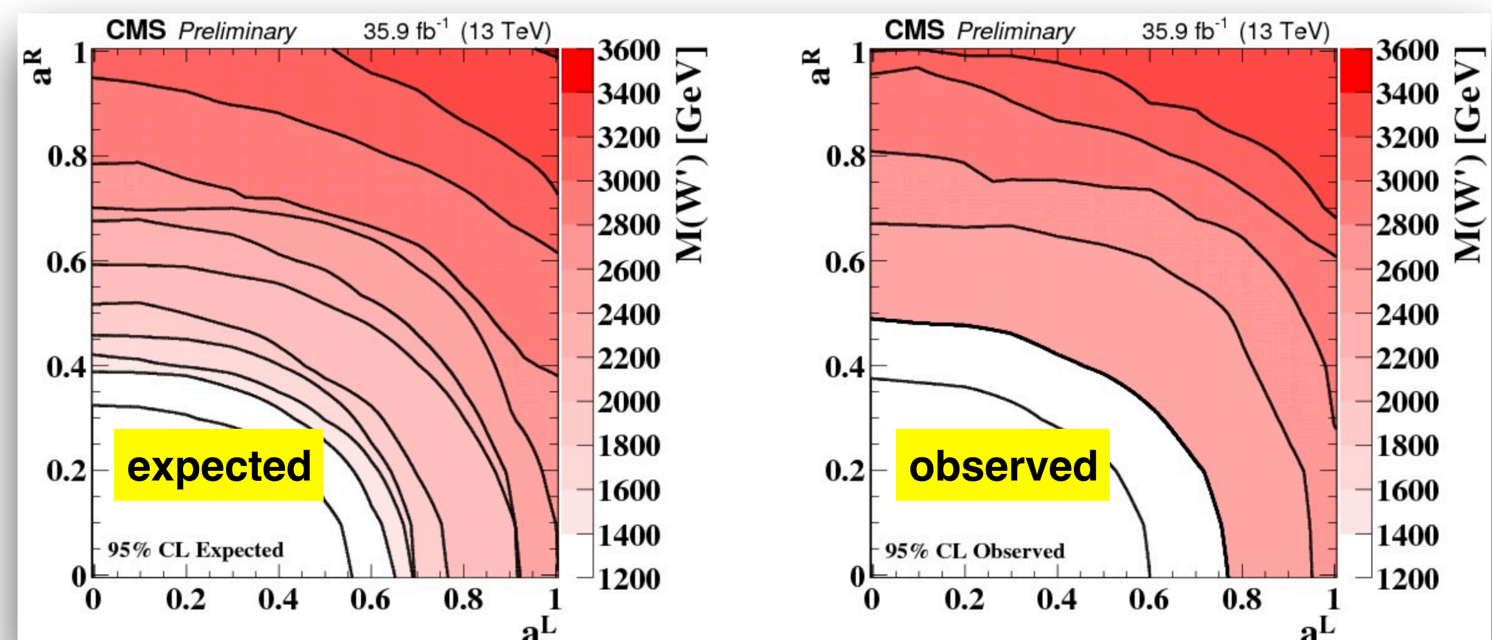
- W' could couple more strongly to 3rd generation quarks
- Heavy W' $\Longrightarrow$ boosted top $\Longrightarrow$ b+ℓ overlap
- **1ℓ+≥2jets+MET (≥1b)**
- Bkg: tt+jets and W+jets from MC (& CRs)
- **Best top in m_t**: from m_W constraint to get $p_z(\nu)$, combined with j_1 or j_2
- **W'**: the "best" top and highest p_T jet
- ~15% uncertainty due to each top p_T reweighting and renorm'+factor' scale

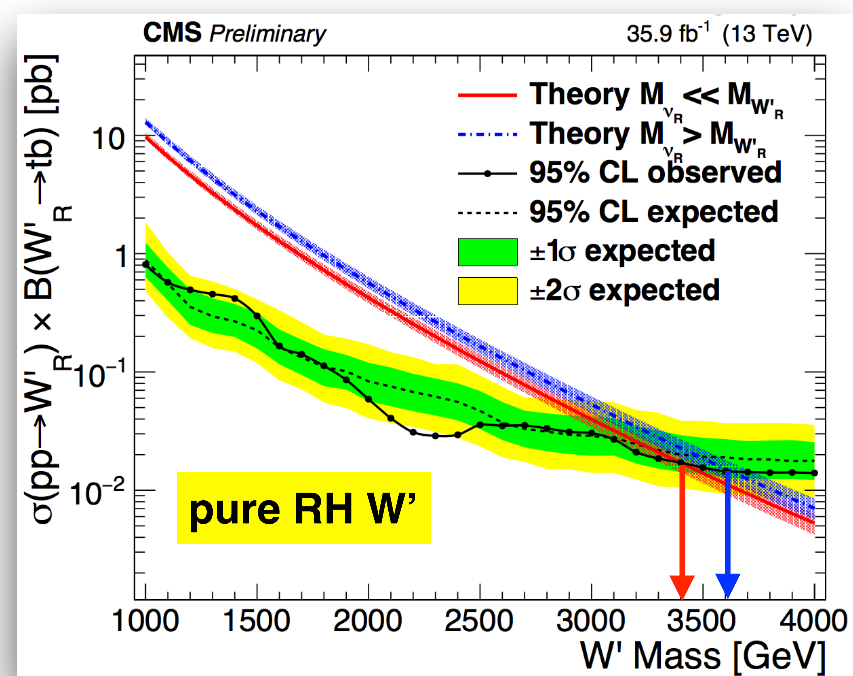
Plots showing m(t+b)





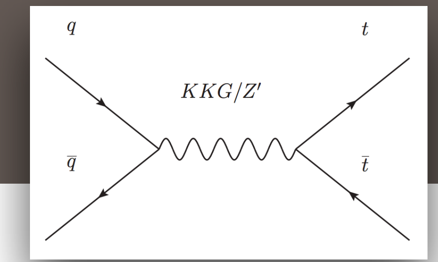
Categorise by ℓ and by number of b-tags (1,2) and by Type A/B with **Type A:** $p_T(t)$>650 and $p_T(j_1+j_2)$>700 GeV (otherwise Type B)





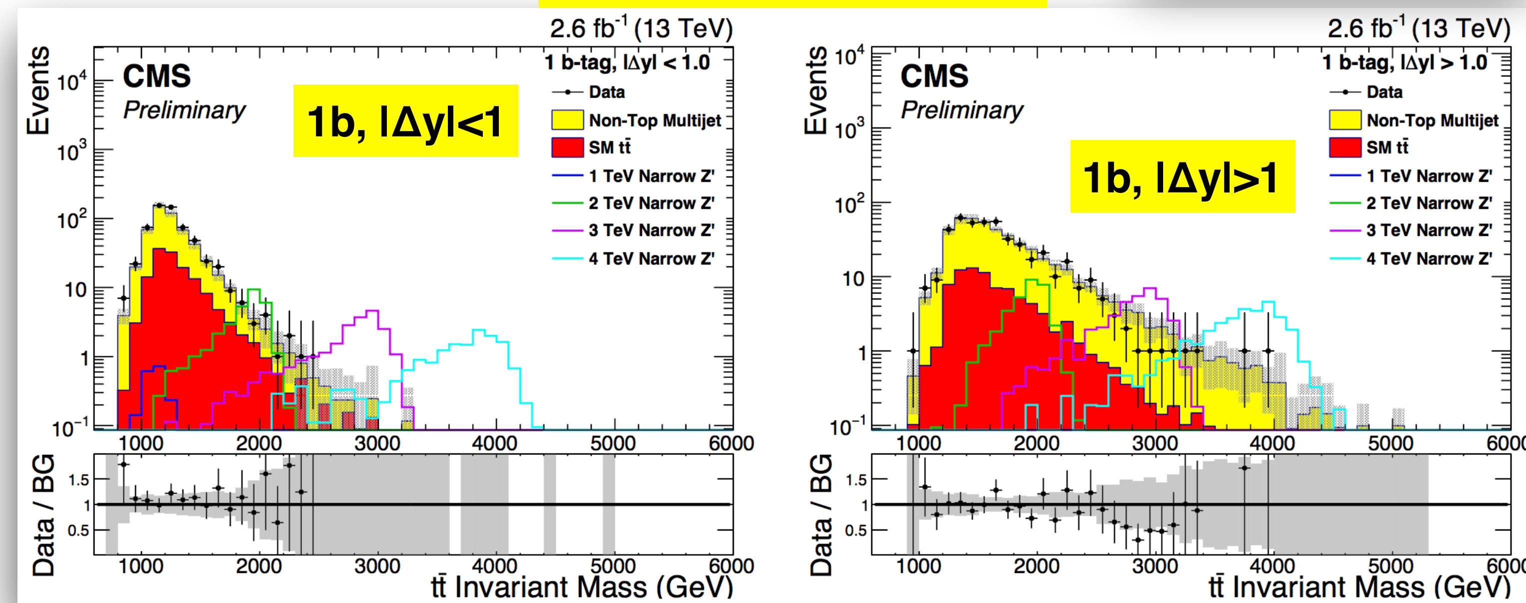
$$\sigma = (1-a_L^2)\sigma_{SM} + \frac{1}{a_L^2+a_R^2}\left(a_L^2(a_L^2-a_R^2)\sigma_L + a_R^2(a_R^2-a_L^2)\sigma_R + 4a_L^2a_R^2\sigma_{LR} - 2a_L^2a_R^2\sigma_{SM}\right)$$

$Z' \to t_h t_h$



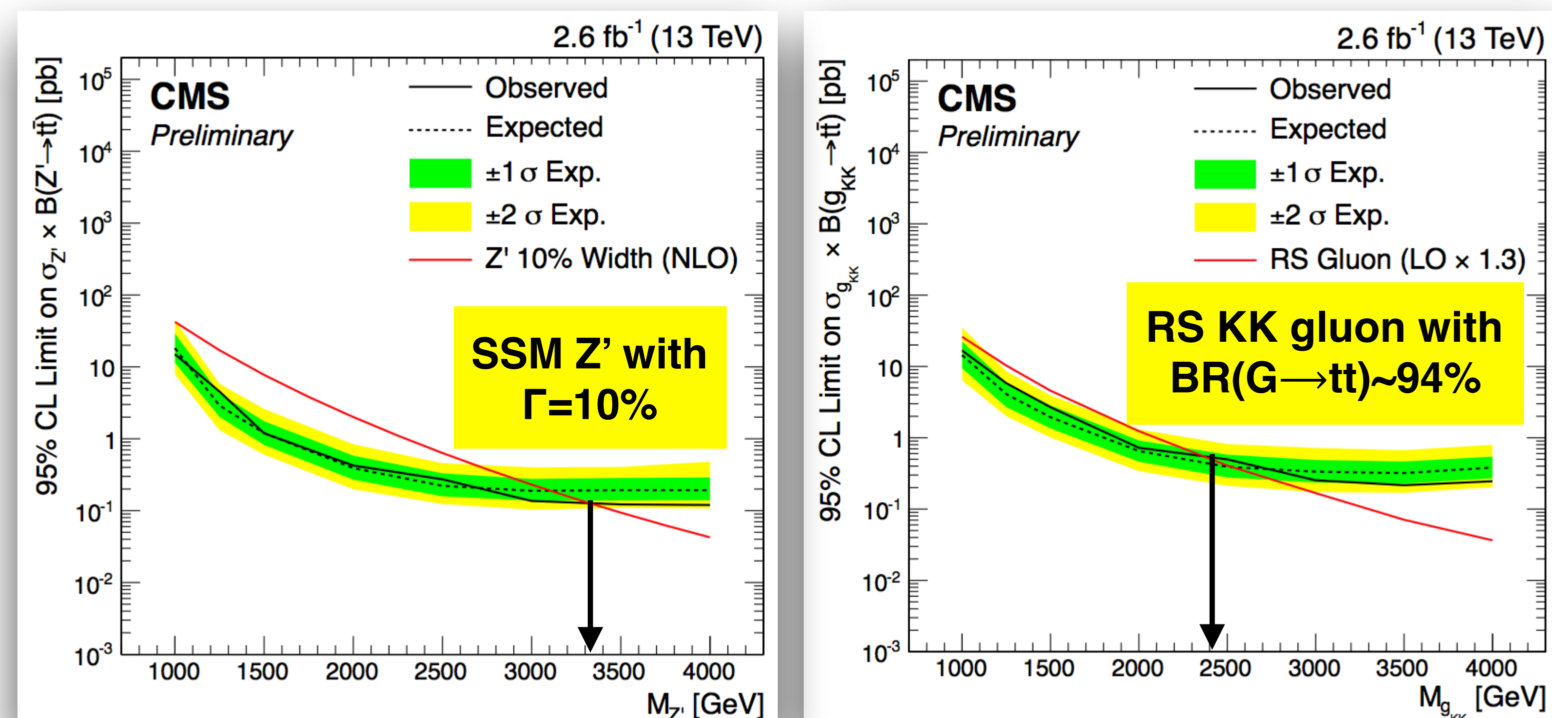
- **SSM Z' and RS KK gluons**
  - Test $\Gamma_{Z'}$ of 1%, 10%, 30%, i.e. $<\sigma_{det}$, $\sim\sigma_{det}$, $>\sigma_{det}$
- Heavy Z' ⟹ boosted tops ⟹ bW(qq') overlap ⟹ **2 largeR, high p_T t-jets**
- Bkg: multijet and tt+jets
  - multijet bkg: using mis-tag (top) rate from a CR
- ~20% uncertainty on the top-jet tagging efficiency

Plots showing m(t+t)



Categorise by $|\Delta y_{JJ}|$ and by the number of Jets having ≥1b-subjet (0,1,2 for the leading JJ only)

Mass Exclusion Limits		
Signal Model	Exclusion Ranges (TeV)	
	Expected	Observed
Z' (1% Width)	1.2 – 1.6	1.4 – 1.6
Z' (10% Width)	1.0 – 3.1	1.0 – 3.3
Z' (30% Width)	1.0 – 3.7	1.0 – 3.8
RS Gluon	1.0 – 2.5	1 – 2.4



Equivalent Z'⟶tt (boosted) searches in ℓ+jets: ATLAS-CONF-2016-014 and B2G-15-006

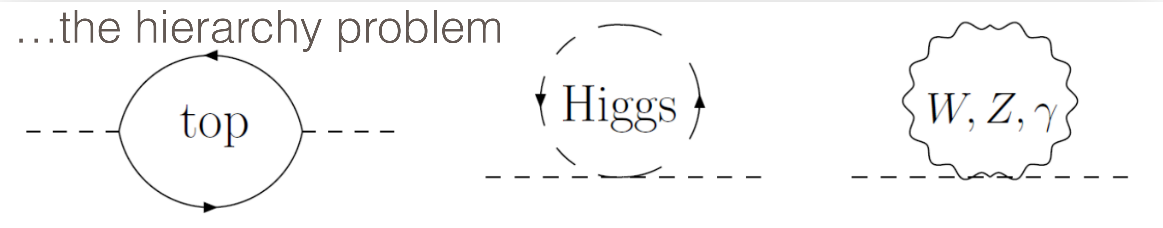
Conclusions

- Presented the newest searches data with 3rd generation final states
- These searches are using advanced jet substructure & b-tagging techniques
- No significant excess/deficit is observed by both experiments yet
  - **What's next for the VLQs and naturalness relationship?**
    - LHC $\sqrt{s}$ will not be improved dramatically soon
    - Luminosity will increase significantly but…
      - mild gain in sensitivity to VLQ mass (while σB will scale as expected)
      - will it be enough for seeing VLQs at (or above) m~1 TeV?
    - looking at more exotic cases with e.g. exotic productions
  - **New bosons may still hide at low masses due to weak couplings**
    - various analyses are starting to look more carefully over there
    - switching-on the SM interference may have interesting impact as well
- I will not tell you to "stay tuned for more results in the coming months!"

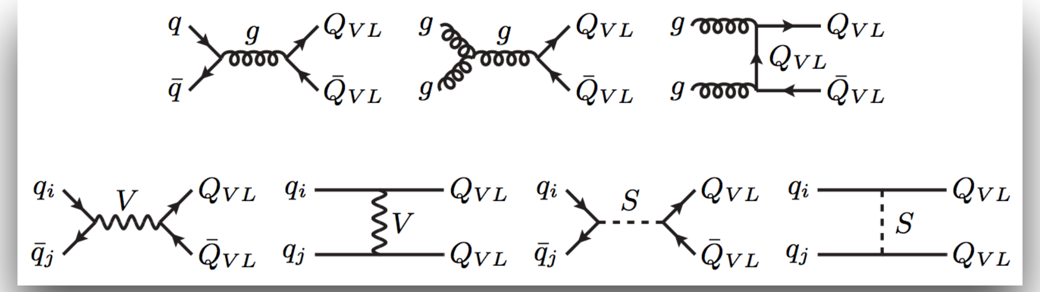
BACKUP

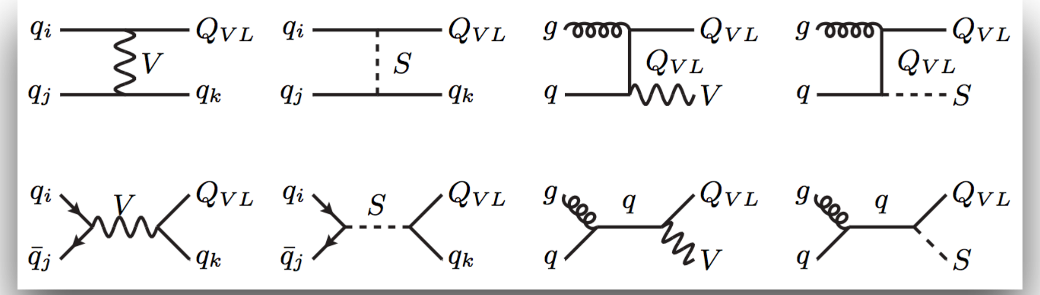
Motivation

- Divergent contributions to the Higgs mass in the SM
- Cancellation may come from models beyond the SM

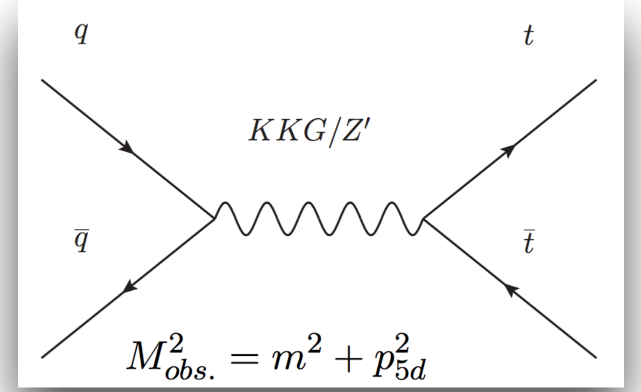


- **VLQs** appear in several SM extensions like SUSY, extra dimensions, composite Higgs, little Higgs etc
  - spin-½ coloured particles with L/R components that transform similarly under the SM
  - mixing predominantly with the 3rd generation quarks of the SM (1st/2nd not excluded)
  - masses not generated by Yukawa coupling to Higgs
  - flavour-changing neutral current decays, as well as charged-current: T⟶Wb,Zt,Ht, B⟶Wt,Zb,Hb
  - small mass splitting in the same multiplet is required so e.g. T⟶WB is kinematically forbidden





- **New heavy bosons** also appear in SM extensions like Z' and W', little Higgs models, 2HDM, Randall-Sundrum Kaluza Klein gluons etc
  - may have enhanced couplings to the 3rd generation fermions of the SM



Jet substructure 1

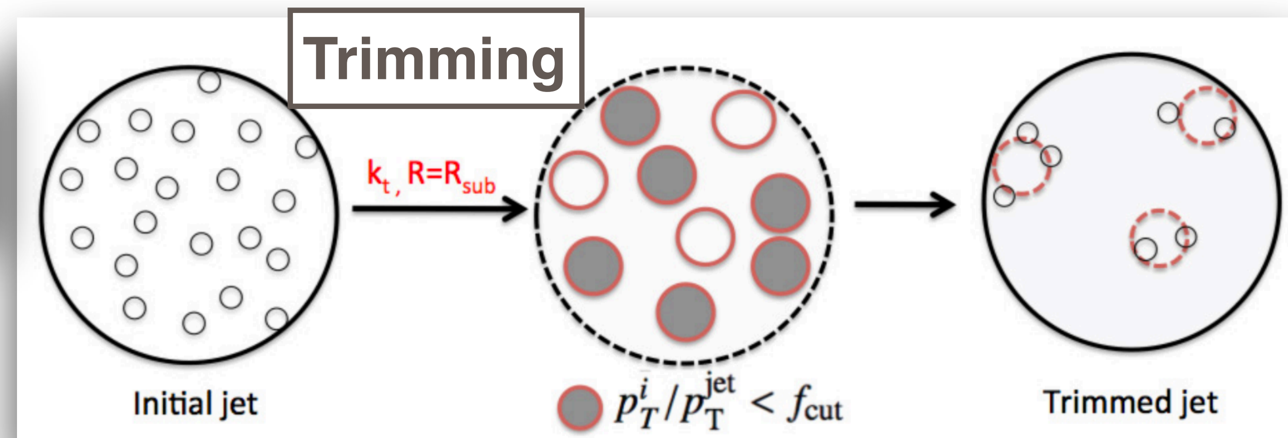
- Decays of boosted massive particles (t,Z,W) appear merged in the detector
  - we have much more of these topologies at 13 TeV compared to 8 TeV
  - the average angular separation between the decay products is $\Delta R \sim 2m/p_T$

- Must develop largeR-Jet techniques with different grooming algorithms, input variables, tagging approaches etc.
  - Jet grooming is used to remove soft contaminations from PU, UE and ISR

- Jet grooming **examples**
  - **Trimming:** Jets built with the anti-k_t algorithm using R~1, trimmed using R~0.2 subjets, removing those whose p_T fraction is e.g. <5% of the jet p_T
  - **Soft-drop:** remove soft, wide-angle constituents. Degree of grooming is controlled by z_{cut} and β with $\beta \longrightarrow \infty$ returning an ungroomed jet

$$\text{Soft Drop Condition:} \quad \frac{\min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

Soft-drop: given a jet of radius R_0 with only 2 constituents. Can be extended to >2 constituents



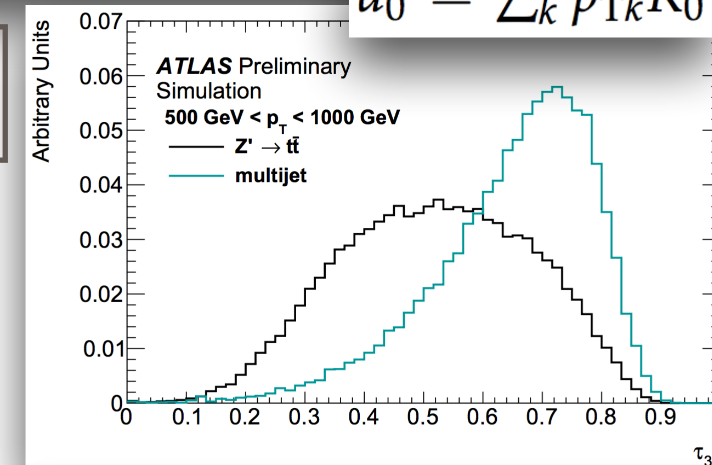
Jet substructure 2

- **N-subjettiness, τ_N**: the degree to which a largeR Jet is composed of N smallR subjets
  - Using the distance from a jet constituent to the nearest subjet axis
  - Discriminate N from (N–1)-body structures within jets using the ratio τ_N/τ_{N-1}
    - τ_{21} (τ_{32}) used to separate 2(3)-subjets from 1(2)-subjet structures for e.g. W's (tops)

$$\tau_N = \frac{1}{d_0}\sum_k [p_{\mathrm{T}k} \min(\Delta R_{1,k}, \Delta R_{2,k}, \ldots \Delta R_{N,k})]$$

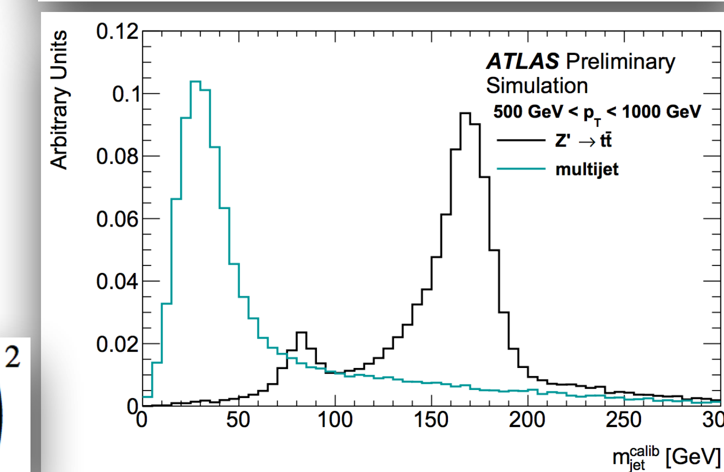
$$d_0 = \sum_k p_{\mathrm{T}k} R_0$$

For $p_T(t)$>500 GeV:
$\Delta R \sim 2m/p_T$ <~ 0.7



- **Jet mass**: the difference between the squared sums of the energies and momenta of the constituents

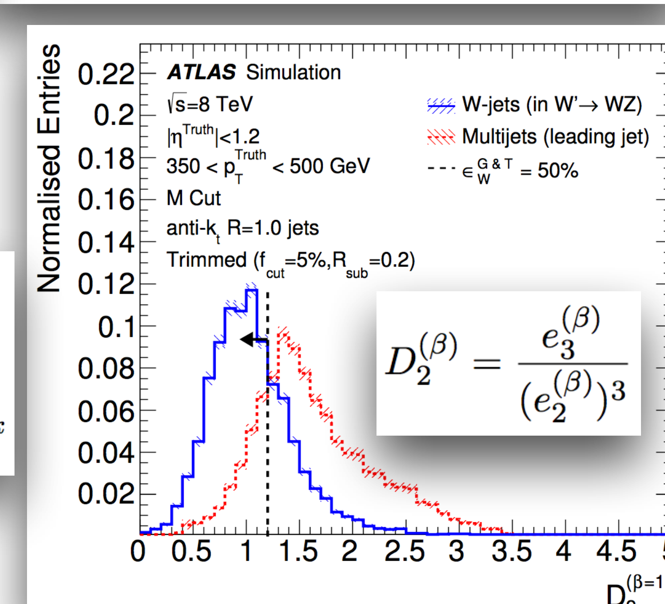
$$M^2 = \left(\sum_i E_i\right)^2 - \left(\sum_i p_i\right)^2$$



- **Energy correlation functions, $e_n^{(\beta)}$**: The ratio, D_N^β, of the normalised n-point ECFs is used to identify boosted, N-prong jets

$$e_2^{(\beta)} = \frac{1}{p_{TJ}^2}\sum_{1\le i<j\le n_J} p_{Ti}p_{Tj}R_{ij}^\beta\ ,$$

$$e_3^{(\beta)} = \frac{1}{p_{TJ}^3}\sum_{1\le i<j<k\le n_J} p_{Ti}p_{Tj}p_{Tk}R_{ij}^\beta R_{ik}^\beta R_{jk}^\beta$$



$$D_2^{(\beta)} = \frac{e_3^{(\beta)}}{(e_2^{(\beta)})^3}$$

- Promising **machine-learning** taggers will use these variables (and others) as inputs

b-taggigng

ATLAS

- Jets containing b-hadrons are tagged via an algorithm that uses multivariate techniques to combine information from the impact parameters of displaced tracks as well as topological properties of secondary and tertiary decay vertices reconstructed within the jet
- For each jet, a value for the multivariate b-tagging discriminant is calculated
- The jet is considered b-tagged if this value is above a given threshold
- The threshold used corresponds to an average 77% efficiency to tag a b-quark jet, with a light-jet rejection factor of ~126 and a charm-jet rejection factor of ~4.5, as determined for jets with p_T>20 GeV and $|\eta|<2.5$ in simulated tt events

CMS

- Jets are clustered from objects reconstructed by the particle-flow algorithm
- Simple Secondary Vertex (SSV) algorithms use the significance of the flight distance (the ratio of the flight distance to its estimated uncertainty) as the discriminating variable
- Combined secondary vertex (CSV) algorithm involves the use of secondary vertices, together with track-based lifetime information
- The threshold used results in a b-tagging efficiency of ~80% and misidentification rates from light flavour jets of about 1%.
- Can be applied both to AK4 jets and the subjets of AK8 jets

tt + HF jets (0ℓ,1ℓ)

1ℓ

Search regions (≥6 jets)				
Mass-tagged jet multiplicity	b-jet multiplicity	$m_{bb}^{\min\Delta R}$	m_{eff}	Channel name
0	3	-	> 400 GeV	0J, ≥6j, 3b
0	≥4	-	> 400 GeV	0J, ≥6j, ≥4b
1	3	< 100 GeV	> 700 GeV	1J, ≥6j, 3b, LM
1	3	> 100 GeV	> 700 GeV	1J, ≥6j, 3b, HM
1	≥4	< 100 GeV	> 700 GeV	1J, ≥6j, ≥4b, LM
1	≥4	> 100 GeV	> 700 GeV	1J, ≥6j, ≥4b, HM
≥2	3	-	-	≥2J, ≥6j, 3b
≥2	≥4	-	-	≥2J, ≥6j, ≥4b
Validation regions (5 jets)				
Mass-tagged jet multiplicity	b-jet multiplicity	$m_{bb}^{\min\Delta R}$	m_{eff}	Channel name
0	3	-	> 400 GeV	0J, 5j, 3b
0	≥4	-	> 400 GeV	0J, 5j, ≥4b
1	3	-	> 700 GeV	1J, 5j, 3b
1	≥4	-	> 700 GeV	1J, 5j, ≥4b
≥2	3	-	-	≥2J, 5j, 3b
≥2	≥4	-	-	≥2J, 5j, ≥4b

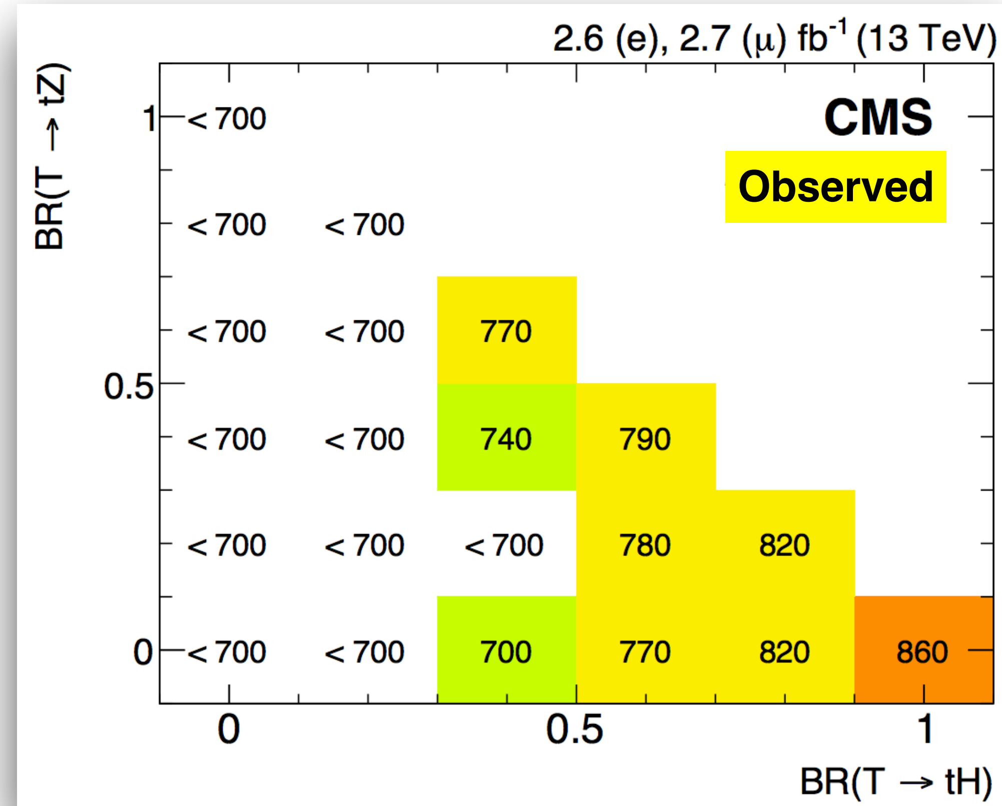
0ℓ

Search regions (≥7 jets)			
Mass-tagged jet multiplicity	b-jet multiplicity	$m_{\mathrm{T,min}}^{b}$	Channel name
0	2	-	0J, ≥7j, 2b
0	3	-	0J, ≥7j, 3b
0	≥4	-	0J, ≥7j, ≥4b
1	2	-	1J, ≥7j, 2b
1	3	< 160 GeV	1J, ≥7j, 3b, LM
1	3	> 160 GeV	1J, ≥7j, 3b, HM
1	≥4	< 160 GeV	1J, ≥7j, ≥4b, LM
1	≥4	> 160 GeV	1J, ≥7j, ≥4b, HM
≥2	2	-	≥2J, ≥7j, 2b
≥2	3	< 160 GeV	≥2J, ≥7j, 3b, LM
≥2	3	> 160 GeV	≥2J, ≥7j, 3b, HM
≥2	≥4	-	≥2J, ≥7j, ≥4b
Validation regions (6 jets)			
Mass-tagged jet multiplicity	b-jet multiplicity	$m_{\mathrm{T,min}}^{b}$	Channel name
0	2	-	0J, 6j, 2b
0	3	-	0J, 6j, 3b
0	≥4	-	0J, 6j, ≥4b
1	2	-	1J, 6j, 2b
1	3	-	1J, 6j, 3b
1	≥4	-	1J, 6j, ≥4b
≥2	2	-	≥2J, 6j, 2b
≥2	3	-	≥2J, 6j, 3b
≥2	≥4	-	≥2J, 6j, ≥4b

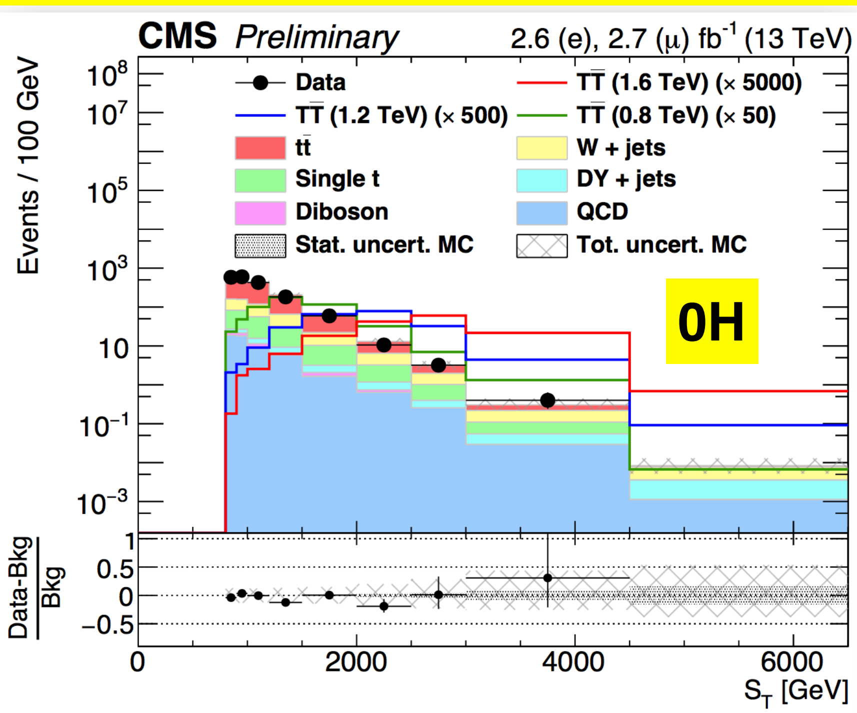
tt + jets (1ℓ)

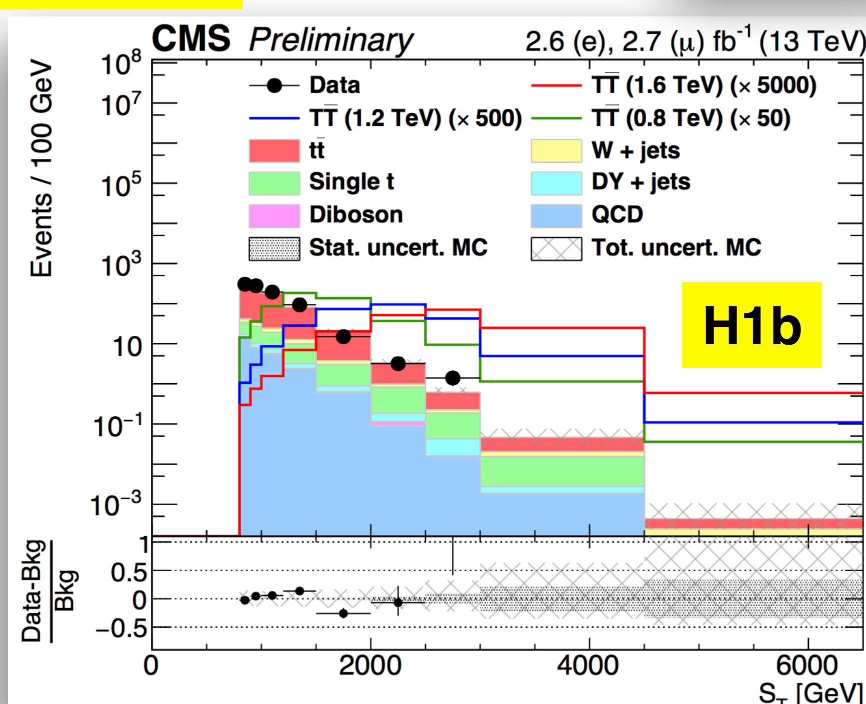
- Optimised for **TT⟶H(bb)t**+X
- **1ℓ+≥2Jets+≥3jets (≥1b)**
- **H-tagged jets**: with ≥1b-subjet
- Multijet bkg taken from simulation
- **Categorisation**:
  - **H2b**: ≥1 H-tag with 2 sub-b-jets
  - **H1b**: ≥1 H-tag with 1 sub-b-jets
  - **0H**: zero H-tags

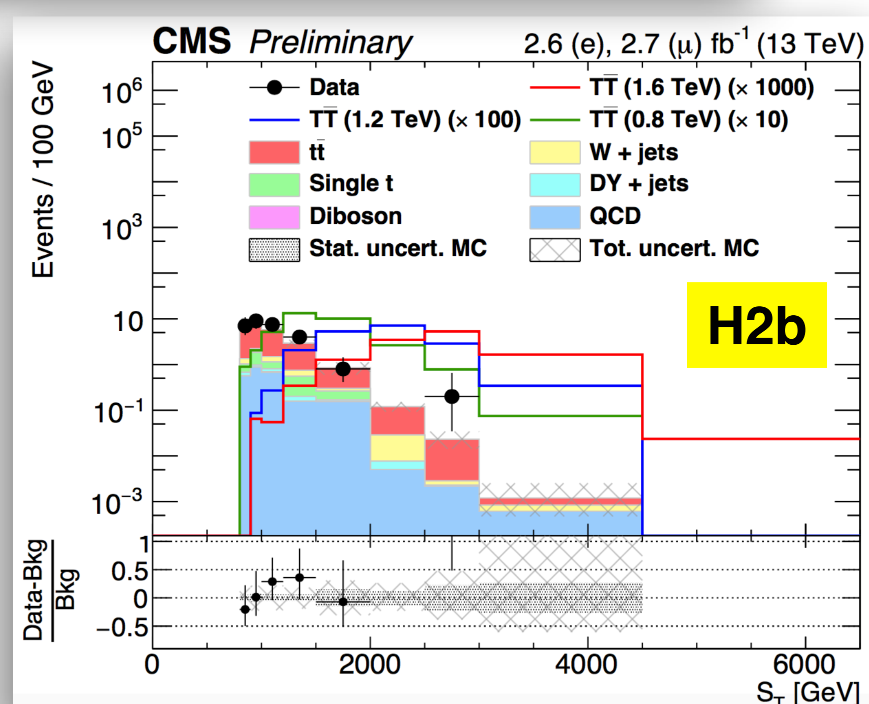
Excluding T quarks with masses below 860 (870) GeV, assuming BR(T⟶Ht)=1



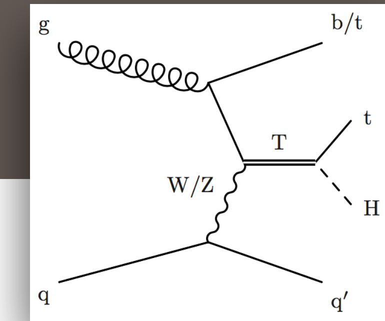
Plots showing $S_T = \Sigma p_T$(all signal objects)+MET







Single VLT (0ℓ,1ℓ)



0ℓ

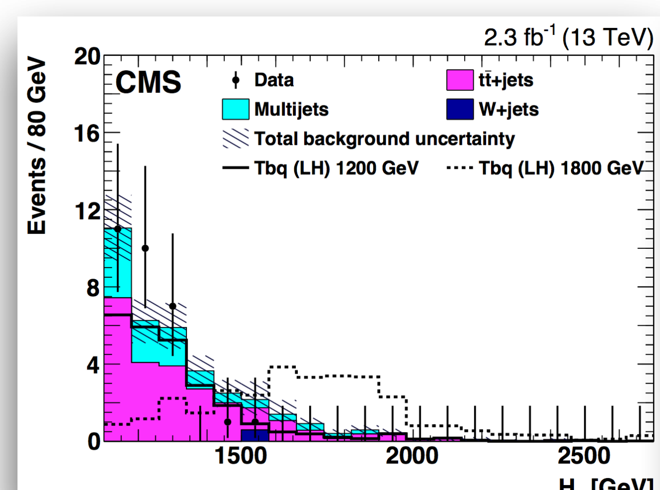
- **≥1Jet+≥4jets and H_T>1100 GeV**
- **H-tagged**: τ_2/τ_1<0.6, pruned mass in 105-135 GeV and p_T>300 GeV
- **t-tagged**: τ_3/τ_2<0.54, soft-drop mass in 110-210 GeV, p_T>400 GeV and subjet b-tag
- **The p_T leading H-jet + t-jet with ΔR(H,t)>2 are paired to form the T candidate**
- Bkg: tt+jets, multijet(data), and W+jets
- Data/MC ratio in H_T is fitted with a linear function after preselection.
- The H_T distributions of MC backgrounds are reweighted using this fit

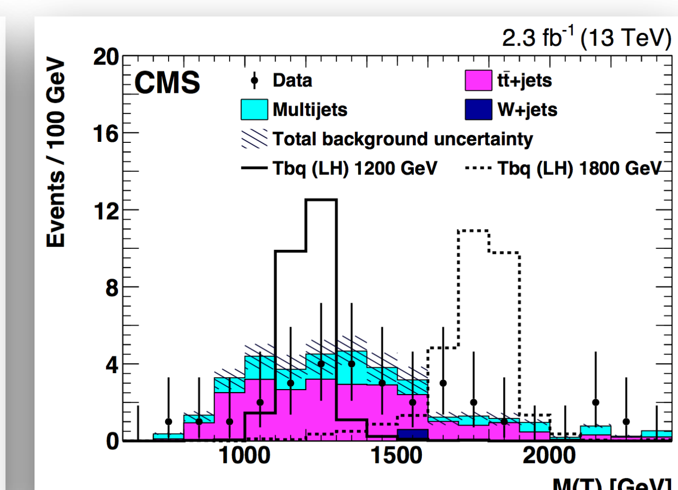
Focus on T⟶H(bb)t

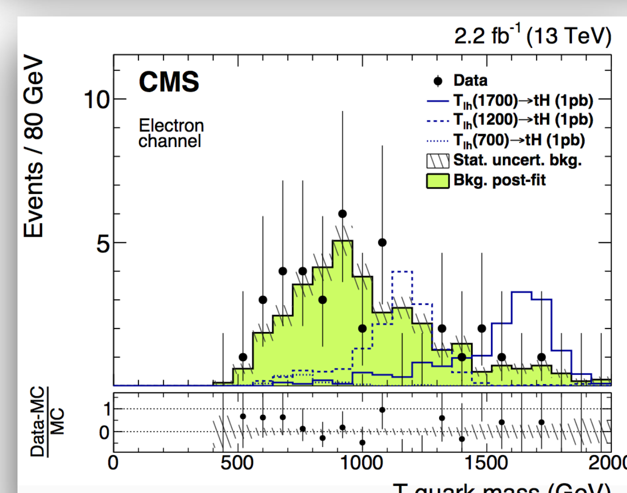
1ℓ

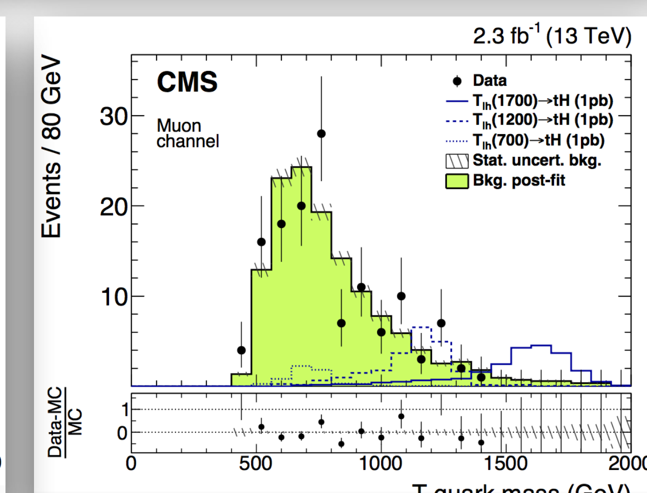
- ≥2jets (could be forward, i.e. |η|>2.4)
- ≥1H-tag, 90<m_J<160 GeV, ΔR(J,ℓ)>1
- Tops: m_W constraint to get $p_z(\nu)$ with all jets (no b-tagging), p_T(t)>100 GeV
- T⟶tH candidate: X^2 algorithm for all pairing combinations with ΔR(t,H)>2
- SR: H with 2b-subjets and ≥1 fwd jet

$$\chi^2 = \left(\frac{M_{\mathrm{H,MC}} - M_{\mathrm{H}}}{\sigma_{M_{\mathrm{H}},\mathrm{MC}}}\right)^2 + \left(\frac{M_{\mathrm{t,MC}} - M_{\mathrm{t}}}{\sigma_{M_{\mathrm{t}},\mathrm{MC}}}\right)^2 + \left(\frac{\Delta R(\mathrm{t,H})_{\mathrm{MC}} - \Delta R(\mathrm{t,H})}{\sigma_{\Delta R,\mathrm{MC}}}\right)^2$$





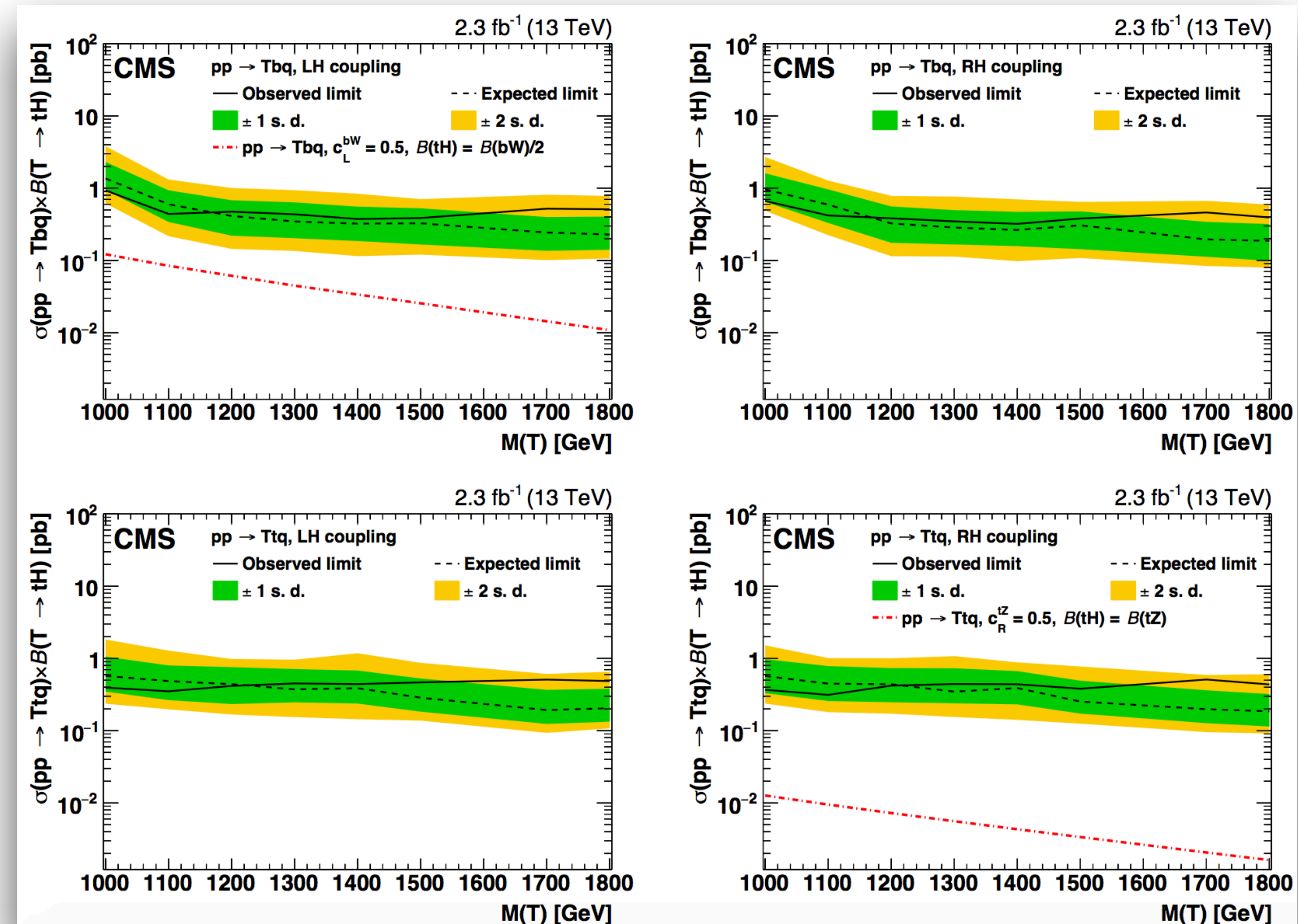




Single VLT (0ℓ,1ℓ)

0ℓ

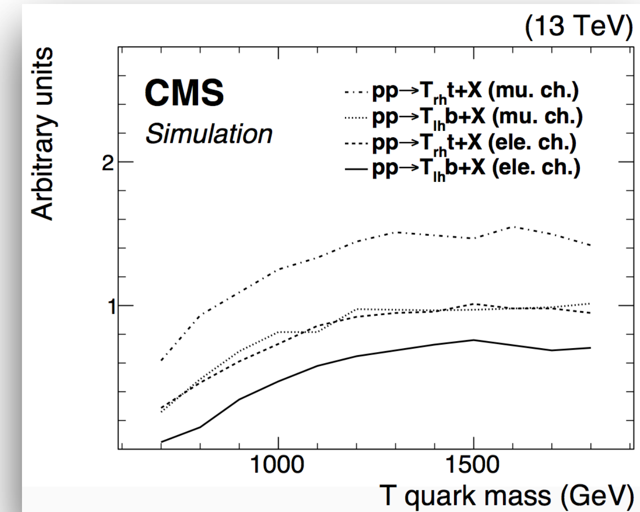
Assuming T quark width of 10 GeV. Analysis insensitive for this assumption up to Γ(T)~10%



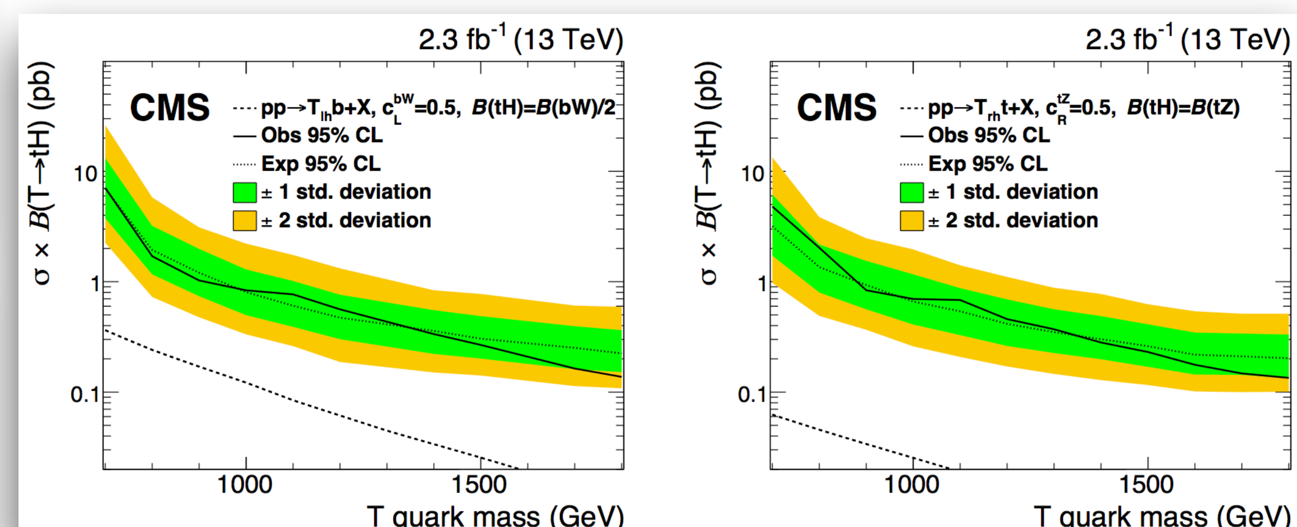
Mass (GeV)	pp → Tbq (LH)		pp → Tbq (RH)		pp → Ttq (LH)		pp → Ttq (RH)	
	Limits in pb							
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
1000	0.93	1.36	0.66	0.96	0.40	0.57	0.37	0.57
1100	0.44	0.60	0.42	0.59	0.35	0.48	0.31	0.45
1200	0.47	0.41	0.38	0.32	0.42	0.44	0.42	0.44
1300	0.44	0.35	0.35	0.28	0.45	0.37	0.44	0.35
1400	0.37	0.32	0.32	0.26	0.44	0.39	0.44	0.39
1500	0.39	0.33	0.38	0.31	0.47	0.28	0.38	0.25
1700	0.52	0.24	0.46	0.20	0.51	0.19	0.51	0.20
1800	0.51	0.23	0.39	0.19	0.49	0.20	0.44	0.18

1ℓ

Signal efficiency: including BR(t⟶ℓ+jets)× BR(H⟶bb)~8%

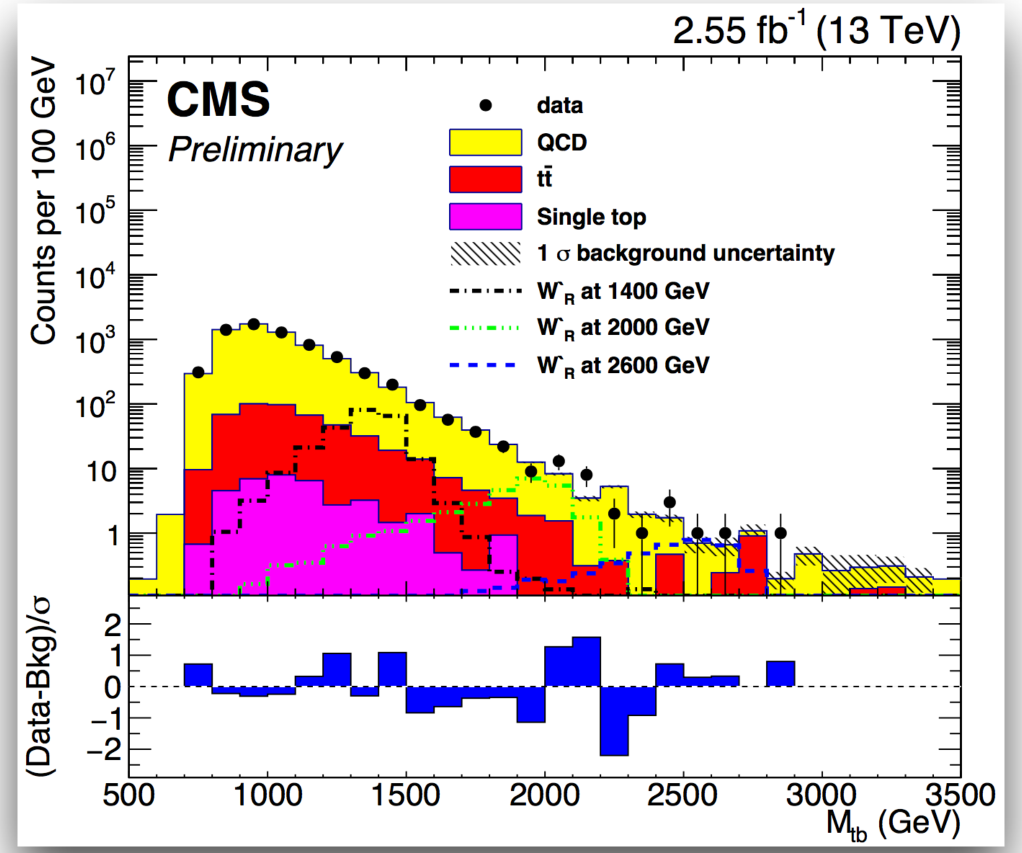


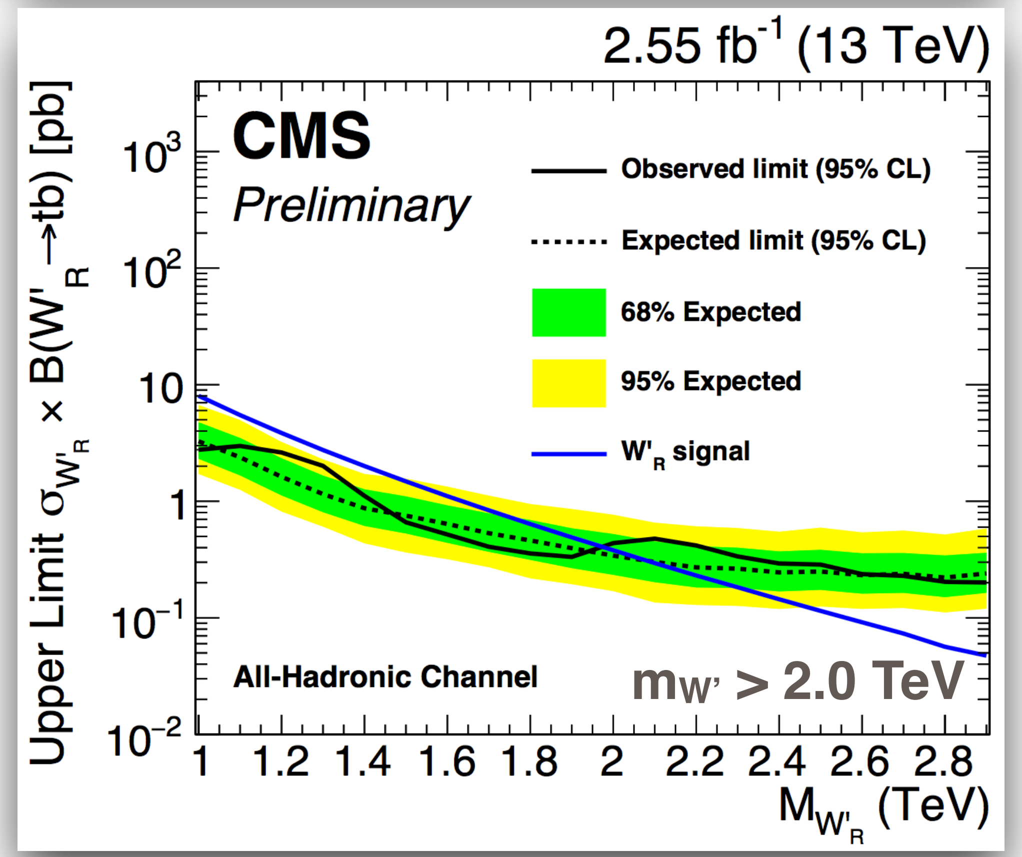
Excluded cross sections are ~order of magnitude higher than the predictions and the current data do not place constraints on this model
The sensitivity of the 2 analyses is comparable



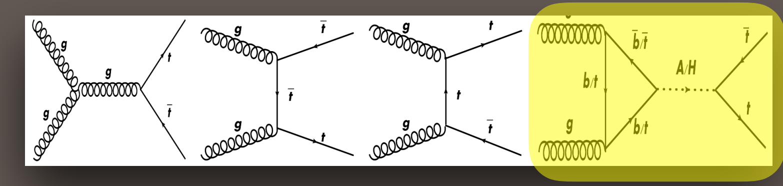
W'⟶bt$_h$

- W' width is set to 3% of the W' mass
- Heavy W' ⟹ boosted top ⟹ b-jet and W⟶qq' overlap ⟹ **single, largeR jet (t-jet)**
- **≥2Jets (≥1 b-tagged)**
- Top-tagging (0.3% mis-tag rate working point):
  - soft-drop declustered Jets, $110<m_J<210$ GeV
  - N-subjettiness with $\tau_{32}<0.61$
  - subjet b-tagging
- **The b-jet from the W':**
  - highest-p_T, loosely b-tagged jet
  - away from the t-jet in $|\Delta\phi|>\pi/2$ and $|\Delta y|<1.3$
  - soft-drop mass <70 GeV
    - for tt bkg, this jet has mass $>m_W$ or even $>m_t$
- Bkg: tt+jets, single-top & multijet
- Multijet bkg is estimated using the average b-tagging rate measured in a QCD-enhanced CR





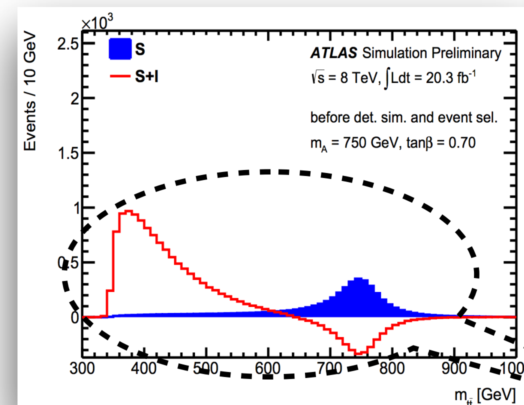
H/A⟶$t_h t_\ell$ 8 TeV(!)

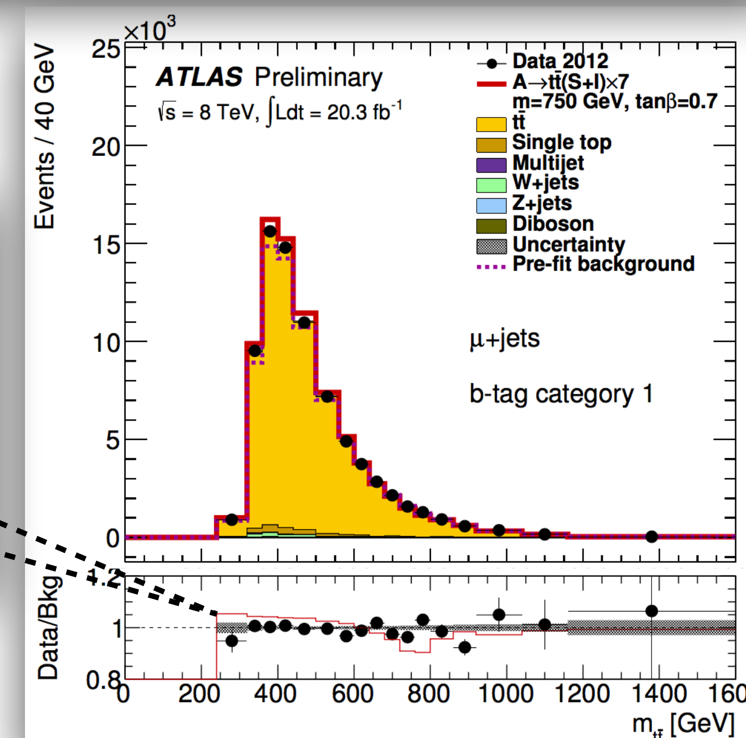


- Focus on 2HDM gg⟶H/A production
  - reinterpretation of JHEP 08 (2015) 148
  - first analysis to include SM interference
  - assume type-II 2HDM with sin(α–β)=1 and no mass degeneracy between H/A
  - check m_S=500/750 GeV and low tanβ

$$\chi^2 = \left[\frac{m_{jj}-m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb}-m_{jj}-m_{t_h-W}}{\sigma_{t_h-W}}\right]^2 + \left[\frac{m_{j\ell\nu}-m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 + \left[\frac{(p_{T,jjb}-p_{T,j\ell\nu})-(p_{T,t_h}-p_{T,t_\ell})}{\sigma_{\mathrm{diff}p_T}}\right]^2.$$

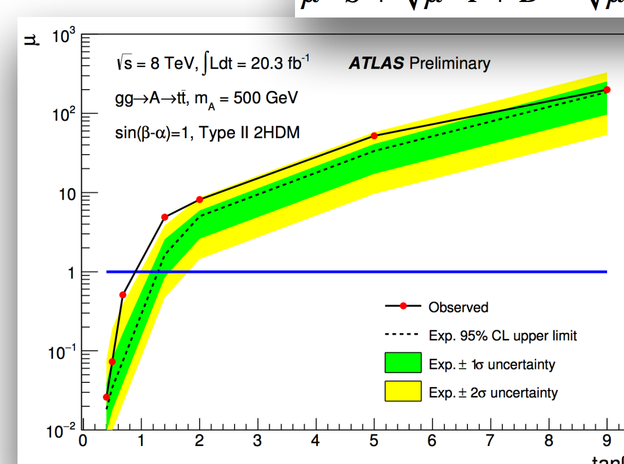
- 1ℓ+jets+MET **resolved** (and boosted)
- m_W constraint to get $p_z(\nu)$
- **χ^2 algorithm for objects assignment**
- Categorise by ℓ and number of b-tags
- S+I shape@NLO: same k-factor as for S
- Scan √μ with μ=1 being the exact model hypothesis while μ=0 is the SM ttbar only

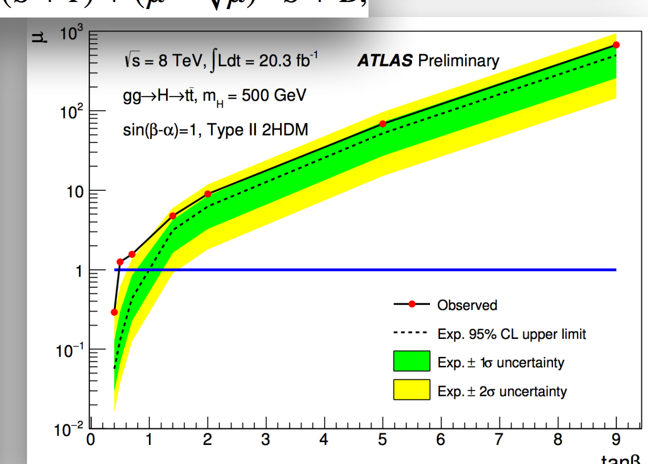




- **tanβ>0.85 (0.45) for $m_{A(H)}$=500 GeV**
- no tanβ value is excluded for $m_{A(H)}$=750

$$\mu\cdot S + \sqrt{\mu}\cdot I + B = \sqrt{\mu}\cdot(S+I) + (\mu-\sqrt{\mu})\cdot S + B,$$





Scan √μ with μ=1 being the exact model hypothesis while μ=0 is the SM ttbar only