Final states with third generation quarks at 13 TeV

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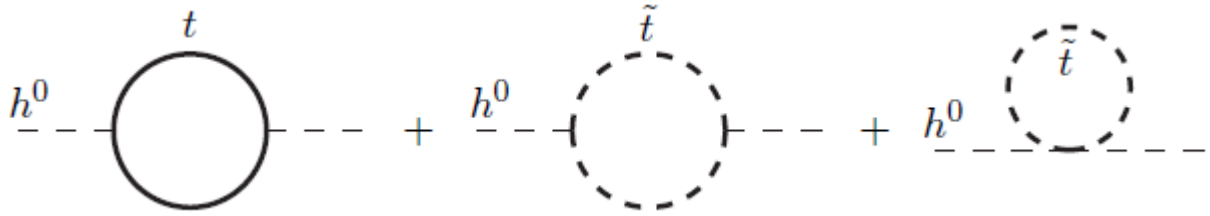
Motivation

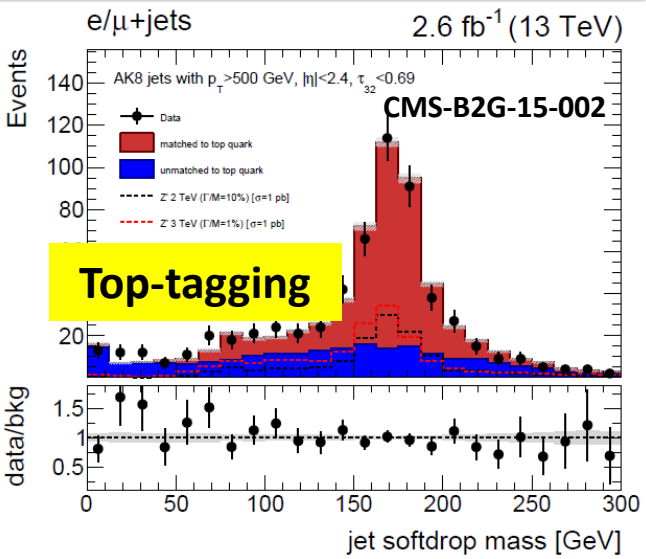
- Top quark radiative corrections to Higgs mass can be canceled by new particles:
  - Top squarks in supersymmetry
  - Vector-like quarks in Composite Higgs Models

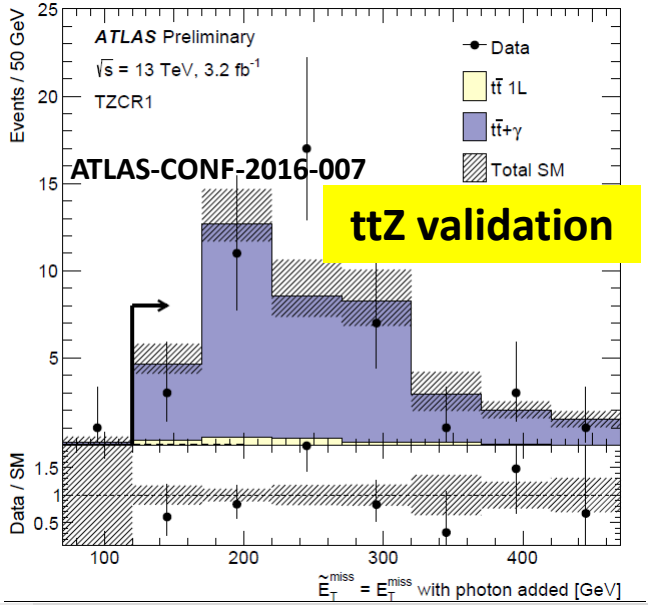


- Those particles would decay into Standard Model (SM) top and bottom quarks
- Other new physics theories suggest that new gauge interactions with enhanced couplings to third generation quarks
  - W', Z', axigluons, pseudoscalar Higgs bosons,...
  - Searched for resonances in $t\bar{t}$ or tb invariant mass

Improvements at 13 TeV

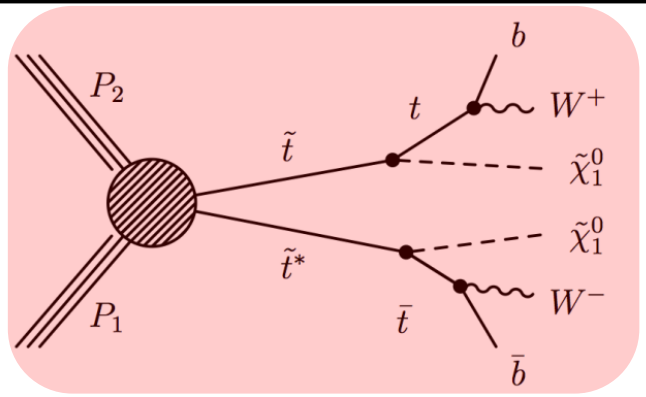
- At 13 TeV probing higher masses:
  - Further developing targeted selections for boosted top quark decays:
    - Top-tagging, W-tagging, Higgs-tagging for the hadronic final states
    - Dedicated isolation variables with smaller isolation cones or using the relative momentum between the lepton and closest jet
  - Other backgrounds increase in importance and require new data-driven techniques:
    - E.g. new data-driven method for $t\bar{t}Z$ using $t\bar{t}\gamma$ events for ATLAS 1l stop search
    - Dedicated single top control regions
  - Also trying to cover difficult corners





Supersymmetry searches

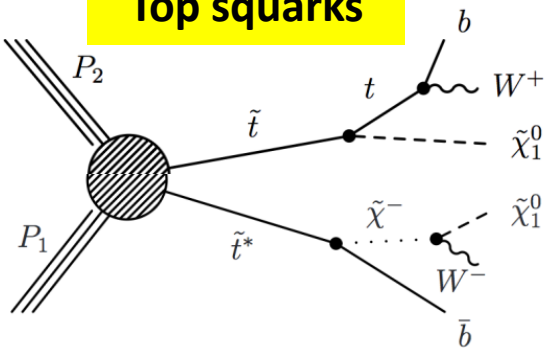
- Top squark pair production



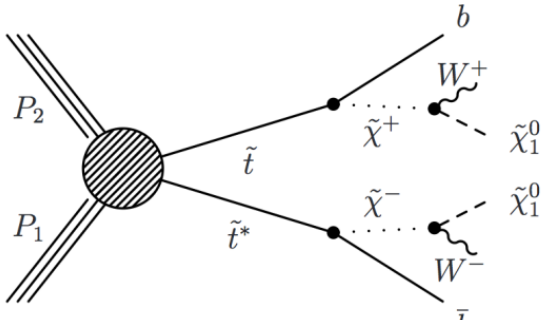
Both decay

$\tilde{t} \rightarrow t\chi_1^0$

Top squarks



Mixed decay:
when BR ≠100%

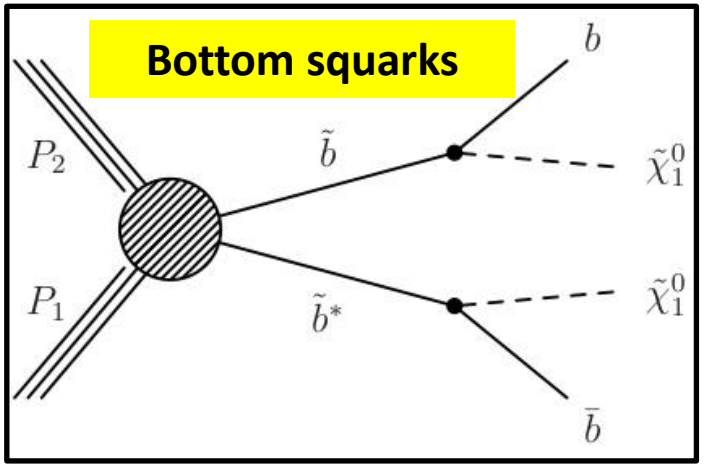


Both decay

$\tilde{t} \rightarrow b\chi^{\pm} \rightarrow bW^{\pm}\chi_1^0$

- Bottom squark pair production with $\tilde{b} \rightarrow b\chi_1^0$ decay
- Gluino induced top pair production in talk from **Henning Kirschenmann**
  - Dedicated model from ATLAS with $\Delta M(\tilde{t}, \chi_1^0)$=5 GeV

Bottom squarks



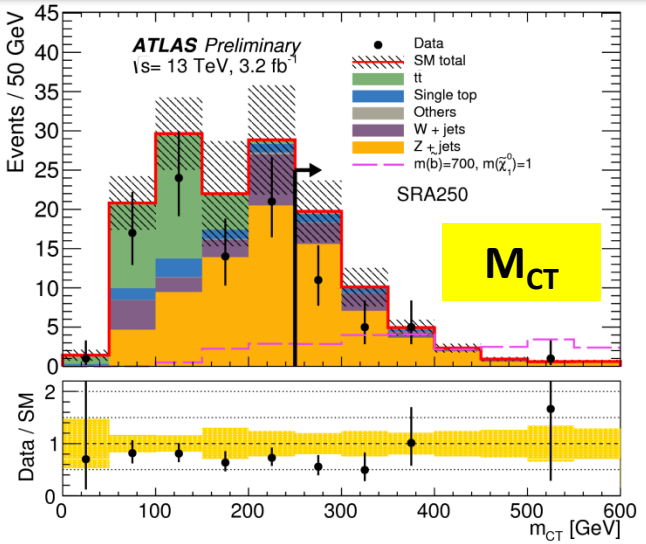
Search for bottom squarks

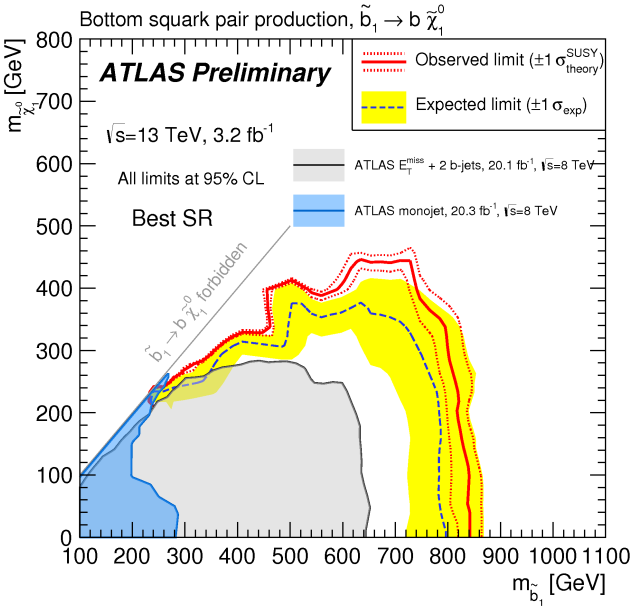
ATL-CONF-2015-066

- Final state: 2 bottom quarks, no leptons, MET>250 GeV
- Veto events with ≥ 4jets
- Two dedicated SRs:
  - For large $\Delta M(\tilde{b}, \chi_1^0)$:
    - two leading jets b-tagged,
    - M_{bb}>200 GeV
    - M_{CT}>250,350,450 GeV

$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$$

  - For small $\Delta M(\tilde{b}, \chi_1^0)$:
    - leading, high p_T (>300 GeV), non b-tagged ISR jet
    - Higher MET cut, with MET opposite to leading jet
- Background prediction
  - Z+jets: 2l CR with SFOS, 76<M(ℓ,ℓ)<106 GeV
  - $t\bar{t}$: 1l CR
  - Single-top and W+jets for non-compressed

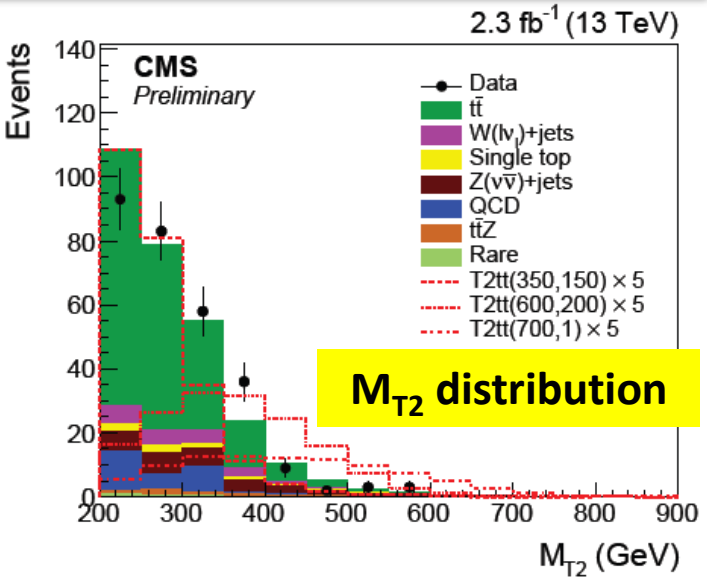


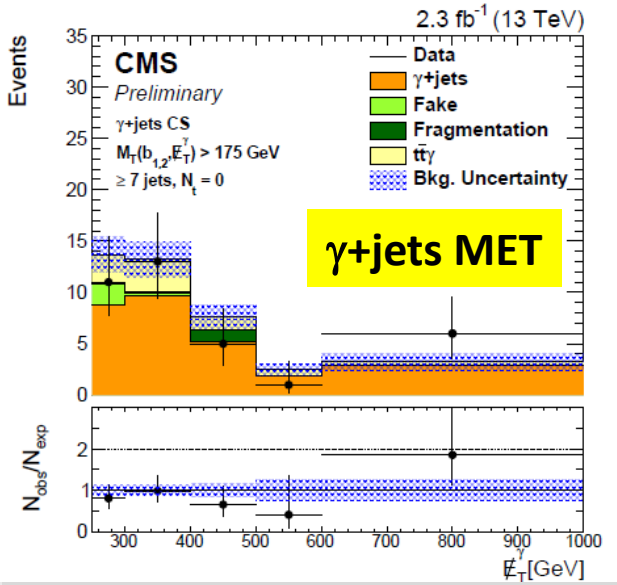


All-hadronic stop search

CMS-SUS-16-007

- Final state is $t\bar{t}$ +MET ($\tilde{t} \rightarrow t\chi_1^0$ decay)
- Exploit differences in b-jet multiplicity, top-tagging, (against EWK), $\Delta\phi$(jets, MET) (against QCD) and the MET spectrum (against $t\bar{t}$)
  - Use M_T(b,MET) or M_{T2} binning to discriminate further against $t\bar{t}$
- Lost lepton background from 1l CR using data-MC SFs
- Z+jets: normalization from 2l CR, binning in MET, MT(b, MET), N_{jet}…from γ+jets CR or loose Z+jets selection
- Multi-jet background: estimate background in CR created by inverting the cut on $\Delta\phi$(jets, MET)
- $t\bar{t}Z$ from simulation



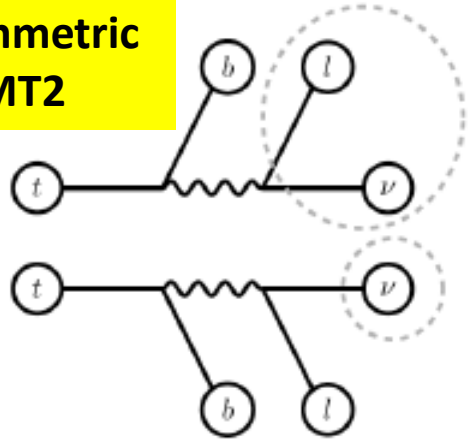


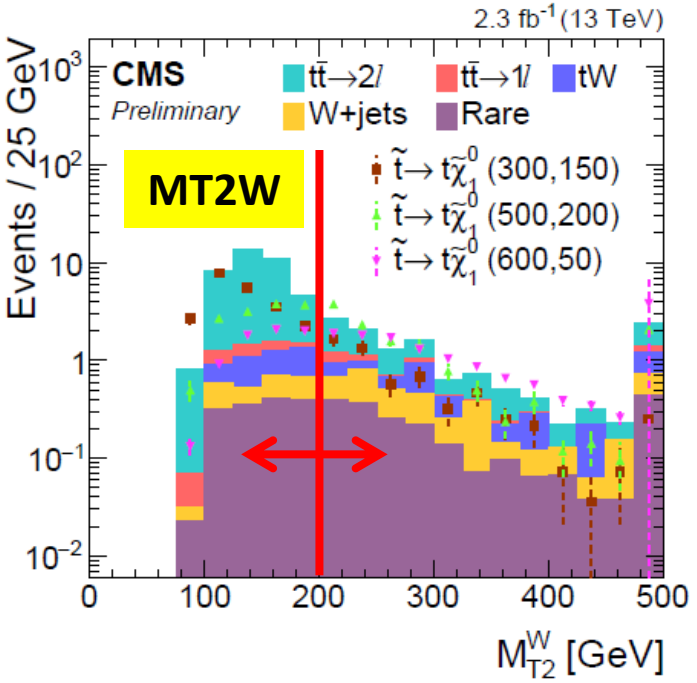
Single-lepton stop search

ATLAS-CONF-2016-007
CMS-SUS-16-002

- Selection:
  - 1 e/μ and large MET
  - At least one b-tagged jet (suppress EWK bkgs)
  - Large M_T (suppress W+jets and $t\bar{t} \rightarrow 1l$)
  - No extra e/μ/τ (against $t\bar{t} \rightarrow 2l$)
  - Extra kinematic cuts to reduce $t\bar{t} \rightarrow 2l$:
    - Asymmetric M_{T2}, topness, M_{T2}^{W}
    - Binning used for low $\Delta M(t, \chi_1^0)$ (CMS)
  - At least 4 jets for bulk of T2tt
    - $t\bar{t} \rightarrow 2l$ only has two jets without ISR
    - Loosened for alternative models and boosted scenario (CMS)
  - Large-R jets and higher MET cuts (ATLAS) used for high stop masses
    - Target boosted tops

Asymmetric MT2

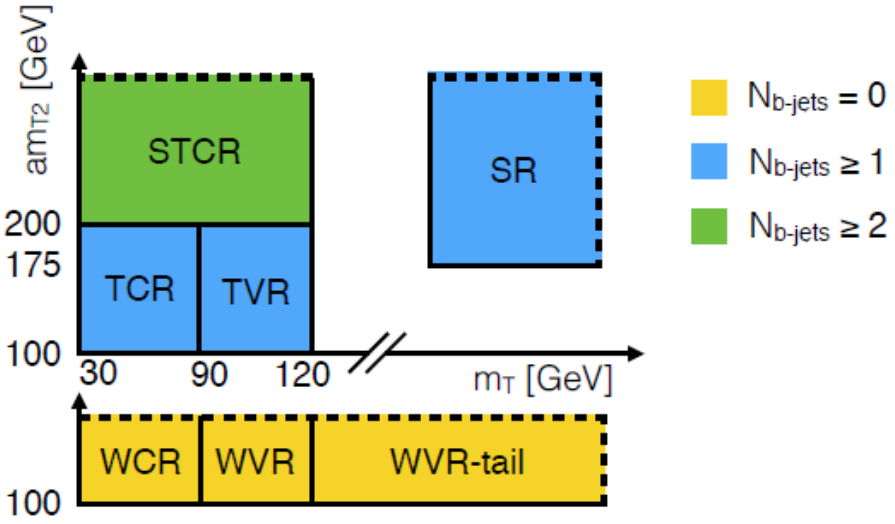


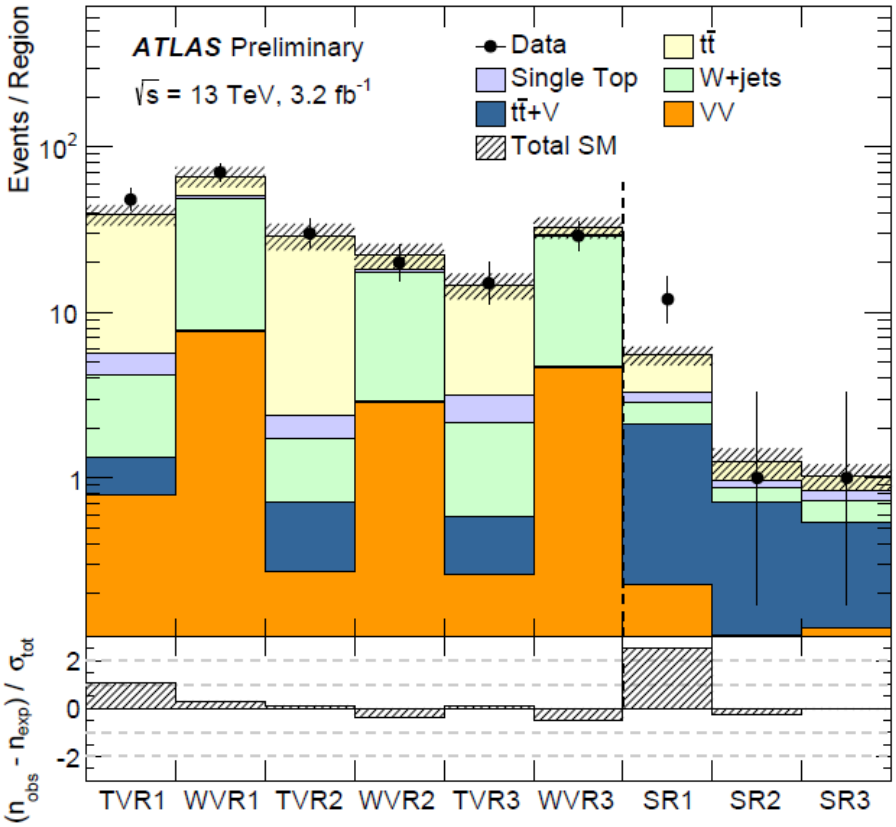


Single-lepton stop search

ATLAS-CONF-2016-007

- Major backgrounds estimated from dedicated control regions
  - Single top (STCR), $t\bar{t}$ (TCR), W+Jets (WCR)
- Extra checks in validation regions
  - E.g. 2l CR for $t\bar{t} \rightarrow 2l$
- Also $t\bar{t}\,\gamma$ to predict $t\bar{t}\,Z$



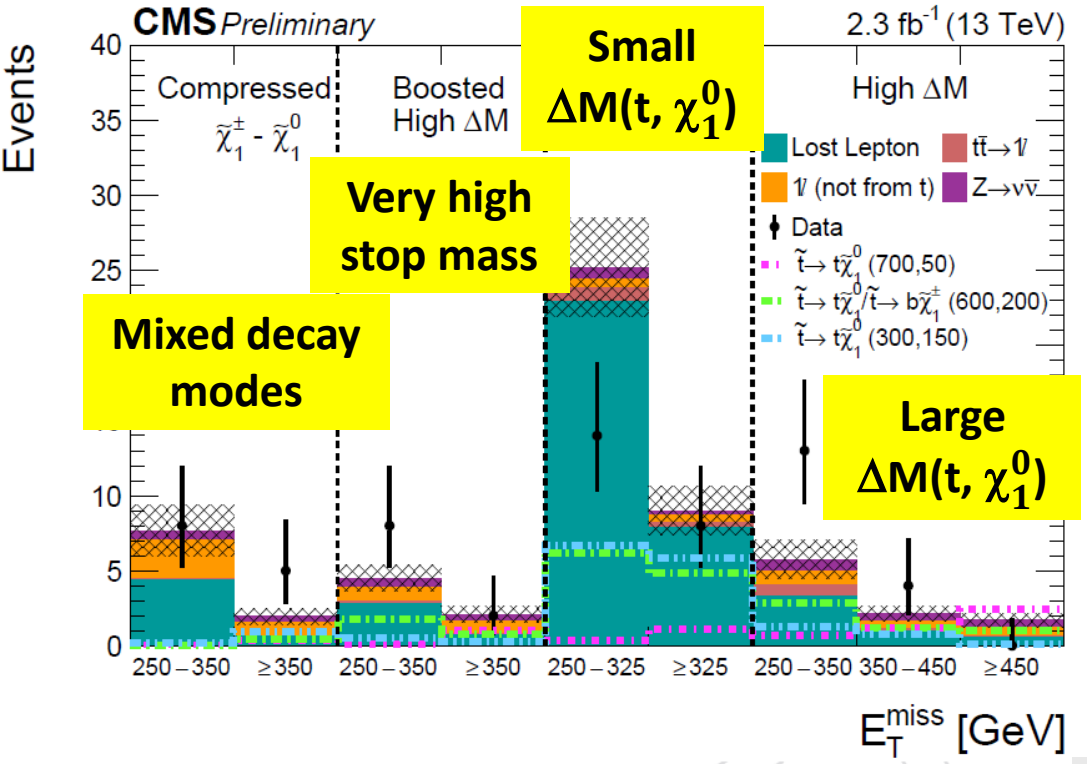


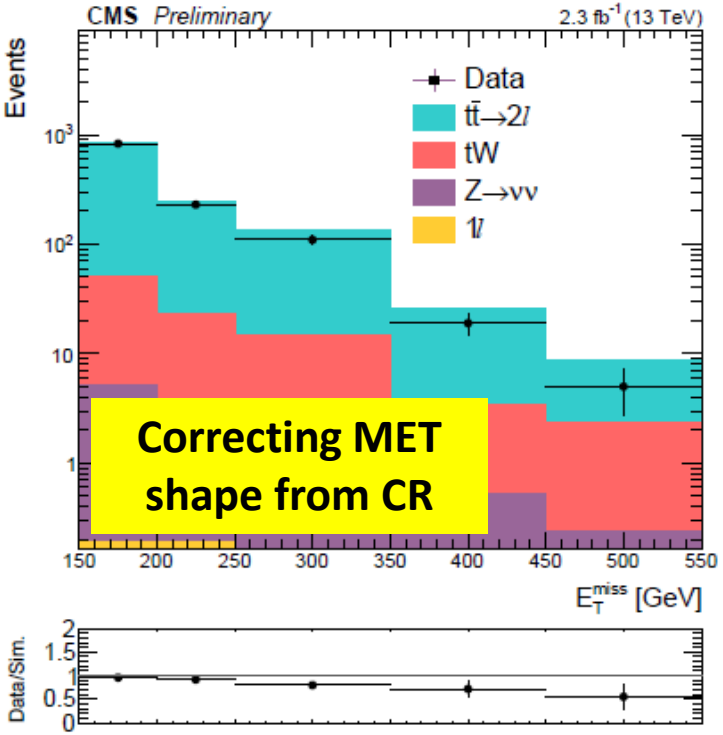
- 2.3σ excess in SR1
  - Region with moderate MET cut and no large R-jets, optimized for heavy neutralino masses

Single-lepton stop search

CMS-SUS-16-002

- Slightly different way of targeting major backgrounds
  - $t\bar{t} \rightarrow 2l$ from 2l CR
  - W+Jets from 0 b-tag CR
  - MET distribution and (b-)jet multiplicity corrected with dedicated CRs
- Minor backgrounds from simulation

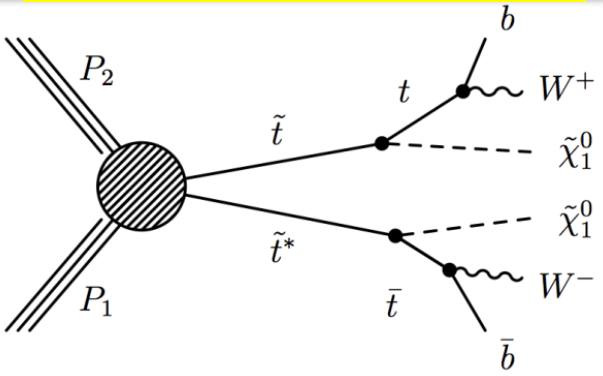


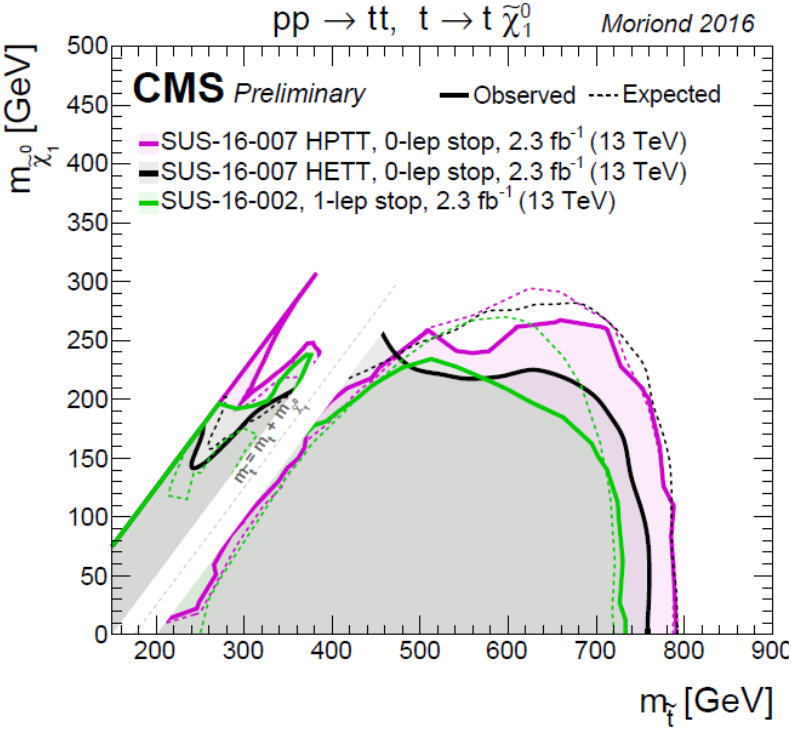


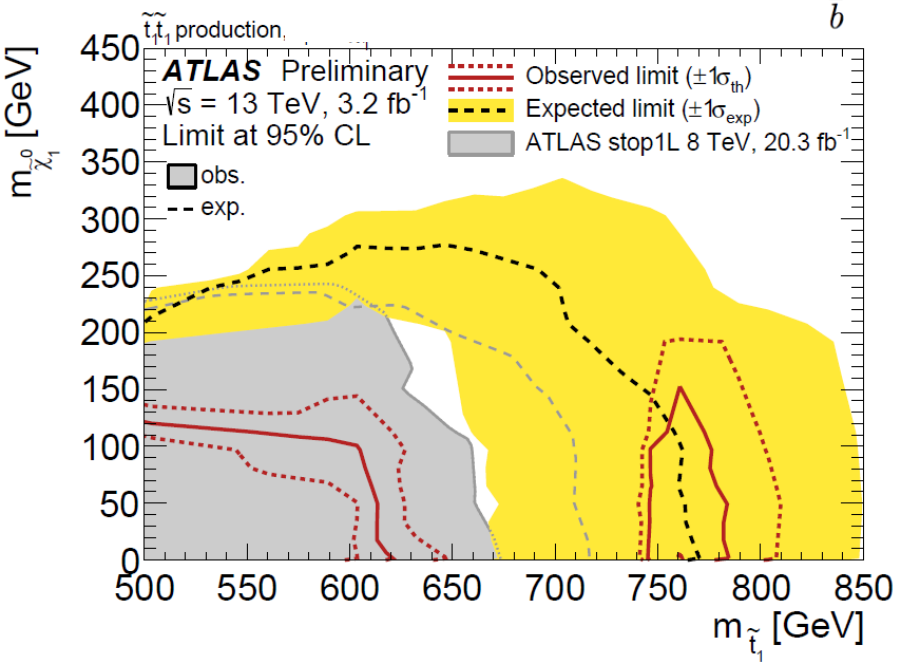
Stop decaying to top+LSP

ATLAS-CONF-2016-007
CMS-SUS-16-002
CMS-SUS-16-007

- Model where both legs decay: $\tilde{t} \rightarrow t\chi_1^0$
- Excluded up to 790 GeV $\tilde{t}$ masses for 0 GeV χ_1^0 mass and 250 GeV χ_1^0 mass for a 600 GeV $\tilde{t}$







- Additional results for models with both top decay modes (CMS) and gluino-induced stop production (ATLAS)

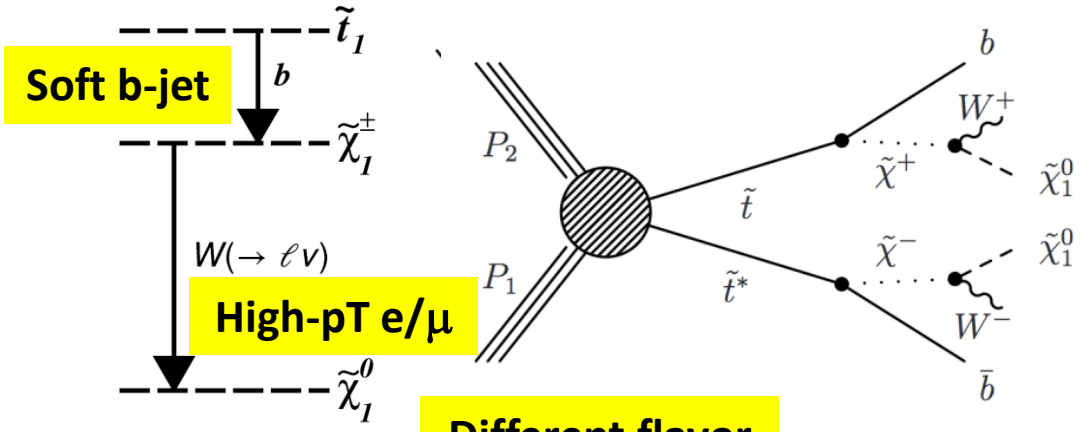
Dilepton stop search

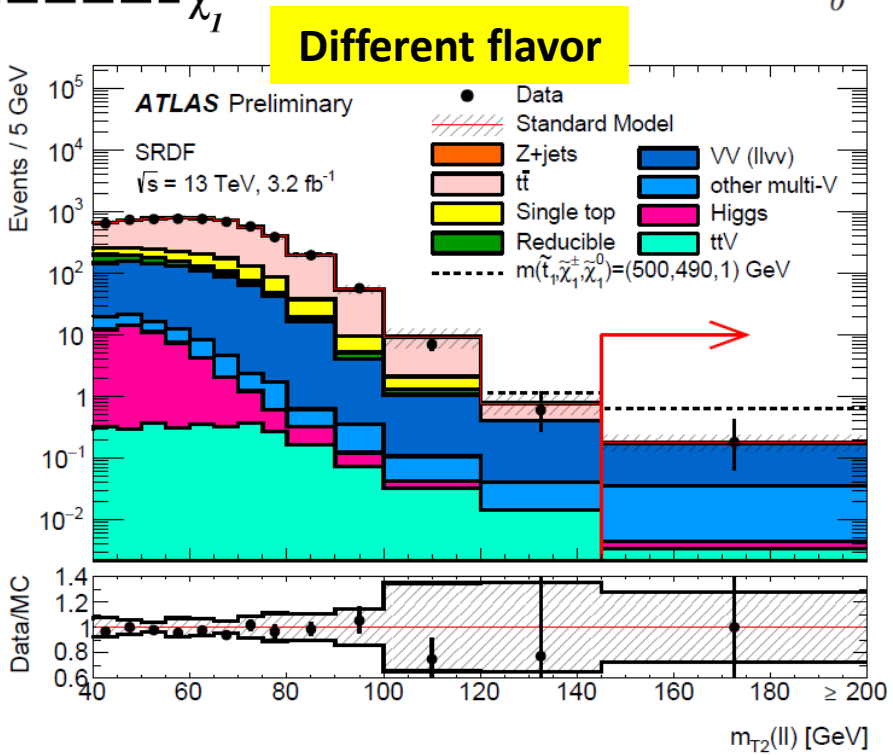
ATLAS-CONF-2016-009

- Targeting stop decay to bottom+chargino with small $\Delta M(\tilde{t}, \chi_1^{\pm})$
- 2 leptons, no b-jet requirement
- Separate different flavor and same flavor dileptons
  - Extra cut on Z candidate mass for SF
- M_{T2}>145 GeV
- Extra cut on

$$R_1 = \frac{MET}{MET + \sum_{i=1}^{2} p_{T,\ell_i i} + \sum_{k=1}^{2} p_{T,j_k}}$$

to reduce Z/γ+jets

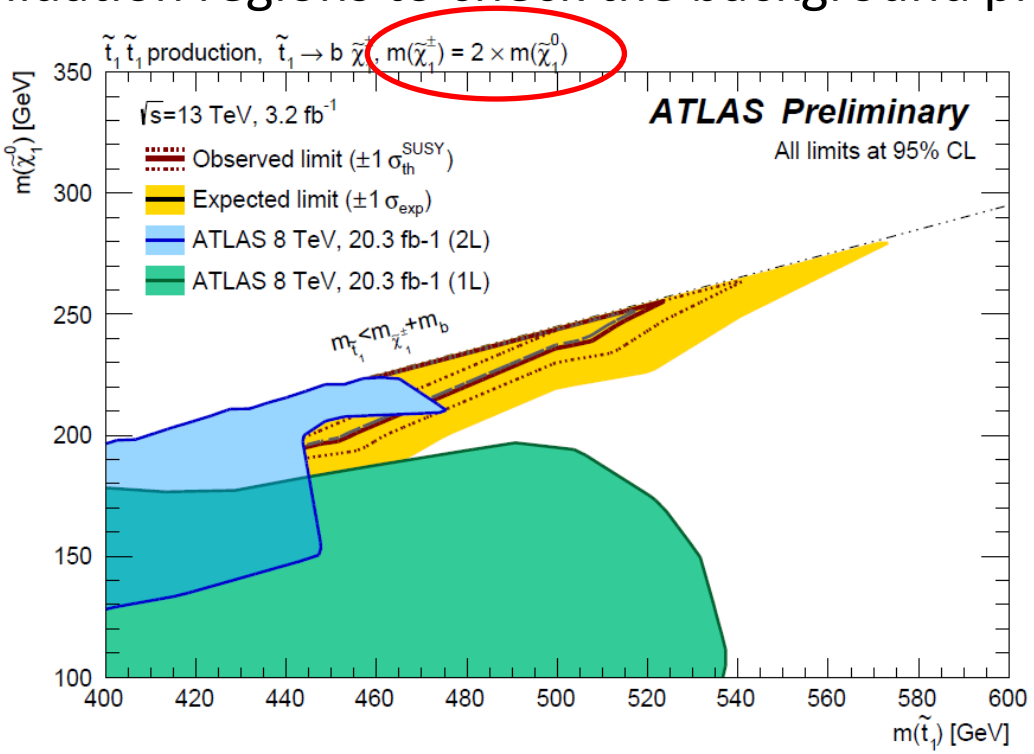




Dilepton stop search

ATLAS-CONF-2016-009

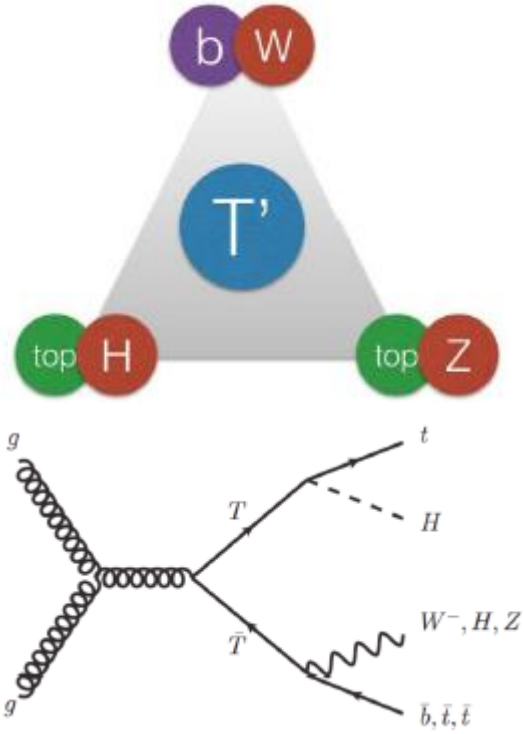
- Non-prompt and misidentified leptons from loose-tight method
- Simultaneous fit for other background between:
  - Signal regions
  - $t\bar{t}$ CR: DF CR with $60<M_{T2}<110$ GeV
  - $\ell\ell\nu\nu$ diboson CR: SF CR with Z candidate, large M_{T2} and large R_1
  - Additional validation regions to check the background prediction

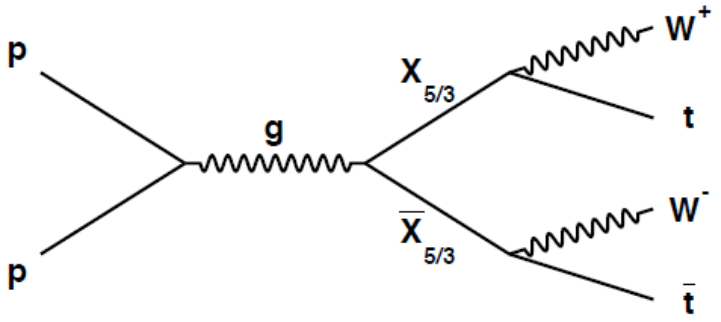


Vector-like quarks

CMS-B2G-15-006
ATLAS-CONF-2016-013

- Some non-SUSY models predict vector-like quarks (VLQ) that stabilize the Higgs mass calculation (e.g. little Higgs, composite Higgs, extra dimensions)
- Pair production or single production of vector-like T quark with charge 2/3e:
  - Decay to bW, tZ or tH
- Some models also predict exotic top partners like $X^{5/3}$

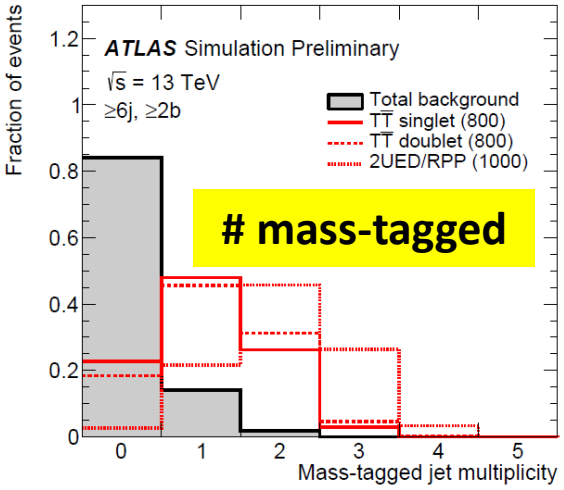


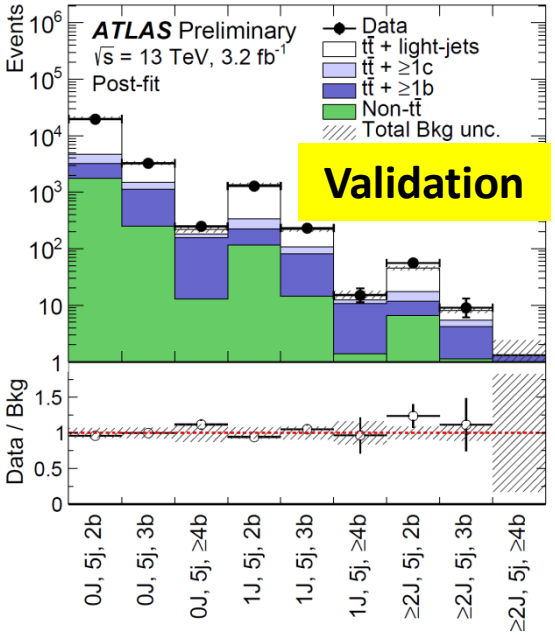


Search for pair production of VLQs

ATLAS-CONF-2016-013

- Focus on T quark pair production with at least 1 T decaying to tH
  - 1l final state
  - Assume H→ $b\bar{b}$
  - Interpretation in $t\bar{t}t\bar{t}$ production
- At least 6 jets with 2 b-tagged
- 100 GeV mass-tagged jets for top and Higgs candidates
- 11 search regions
  - Number of mass-tagged jets (0,1,≥2)
  - Number of b-tagged jets (2,3,≥4)
  - Invariant mass $b\bar{b}$ pair with smallest angular separation
- Data from simulation except for multijet backgrounds (data-driven)
- Validation regions with lower jet multiplicity

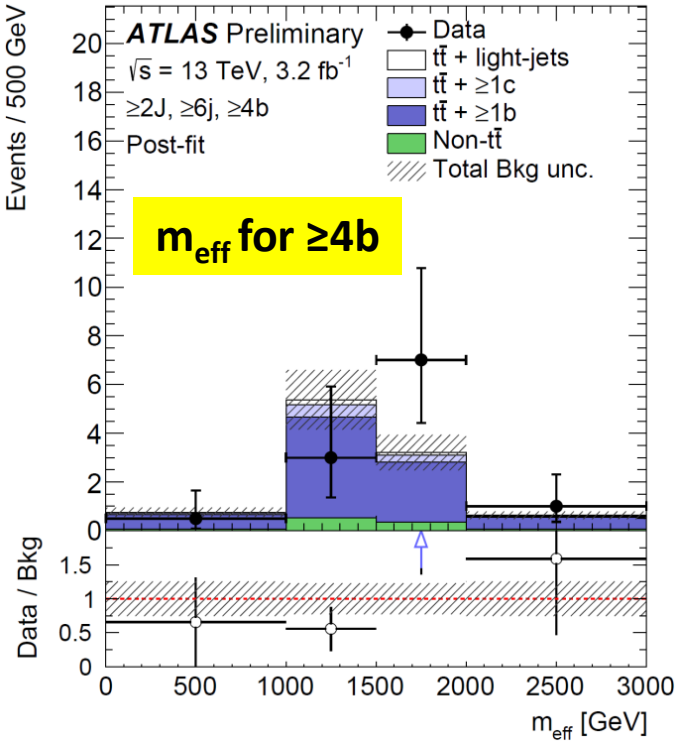


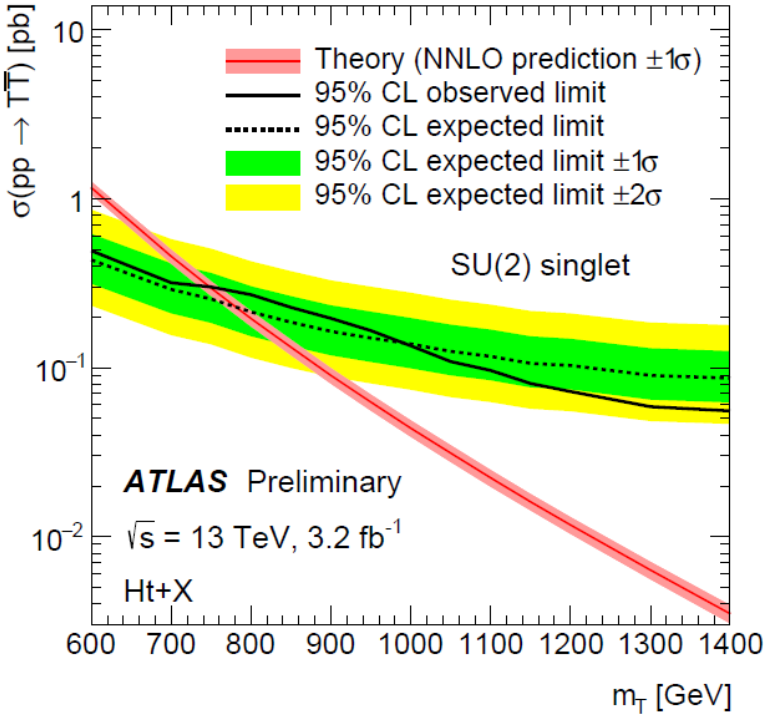


Search for pair production of VLQs

ATLAS-CONF-2016-013

- Fit $m_{eff} = MET + p_{T,\ell} + \sum_{i=1}^{2} p_{T,j_k}$
- Limits on $T^{2/3}$ better than 8 TeV limits by ~50-100 GeV
- ATLAS-CONF-2016-007 (1l stop) also reinterpreted the results for T→tZ with Z→νν

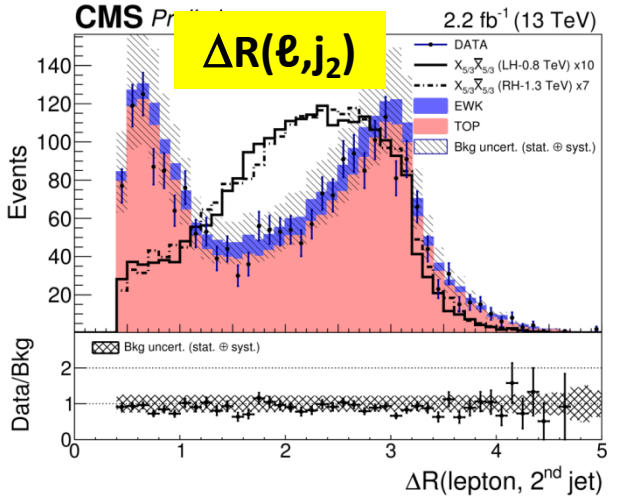


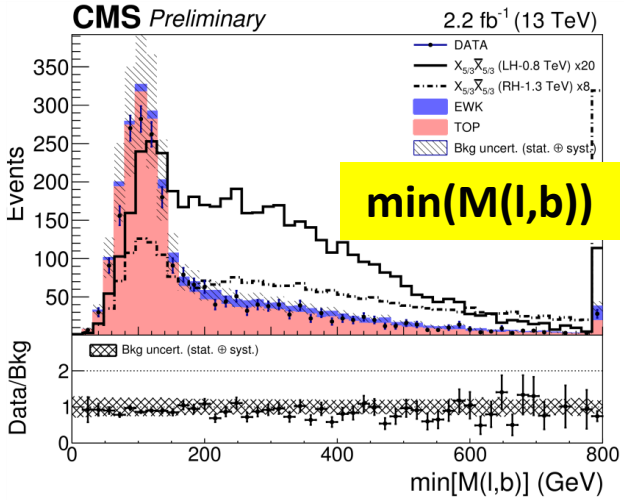


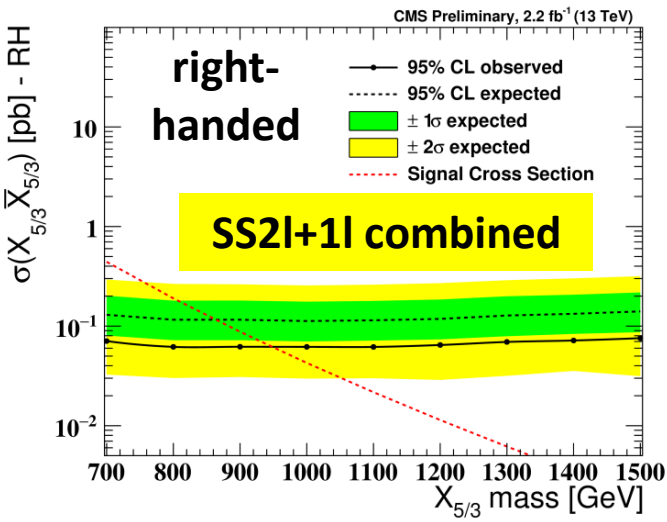
Search for top partners with charge 5/3

CMS-B2G-15-006

- Top partner with charge 5/3 decays to W boson and top quark
  - Search in same-sign 2ℓ final state in **Clint Richardson**'s **YSF** talk
  - Focus here on 1l+jets final state
    - ≥ 4 jets, MET>100 GeV, ΔR(ℓ,2nd jet)>1
    - 1 or ≥ 2 b-jets, 0 or 1 boosted W (pruned mass and n-subjettiness)
  - Check the background modeling in ΔR(ℓ,2nd jet)<1 sideband
    - V+jets CR: 0 b-tagged jets
    - $t\bar{t}$ CR: at least 1 b-tagged jet
  - Fit min(M(l,b)) spectrum







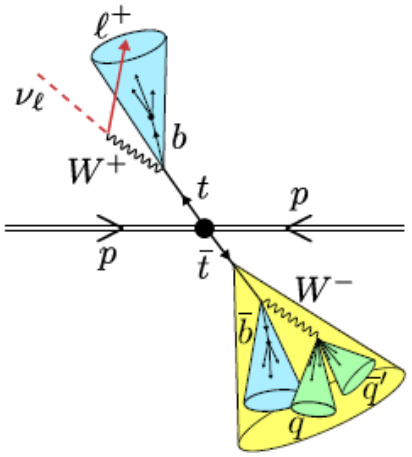
$t\bar{t}$ resonances search

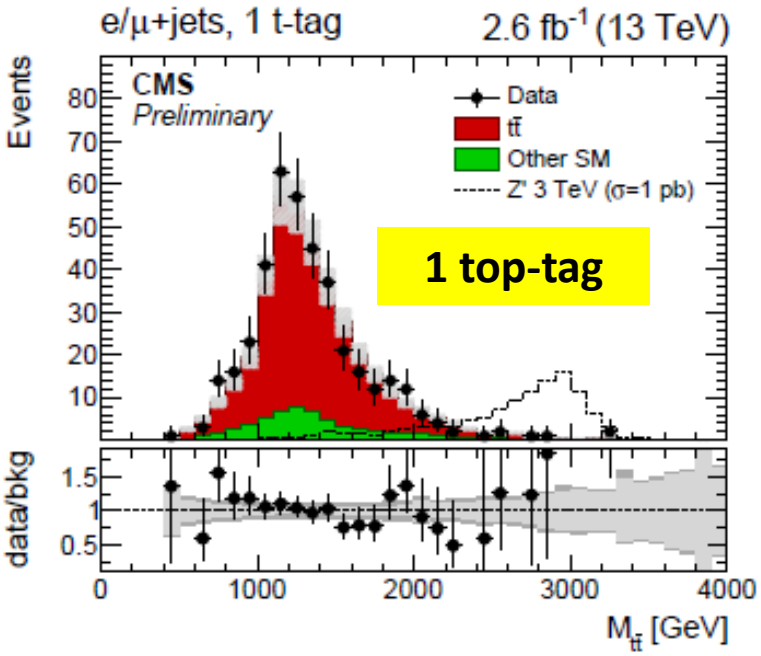
CMS-B2G-15-002

- Search for $t\bar{t}$ resonance in 1l final state
  - Use dedicated isolation variables
  - Tighter MET and jet cuts in electron channel
  - Kinematic variable based on consistency with top pair hypothesis

$$\chi^2 = \left[\frac{M_{\text{top}}^{\text{lep}} - \bar{m}_{\text{top}}^{\text{lep}}}{\sigma_M^{\text{lep}}}\right]^2 + \left[\frac{M_{\text{top}}^{\text{had}} - \bar{m}_{\text{top}}^{\text{had}}}{\sigma_M^{\text{had}}}\right]^2$$

  - Three search region:
    - 1 top-tag
    - 0 top-tag, 1 b-tag
    - 0 top-tag, 0 b-tag
  - Simultaneous fit:
    - M(t,$\bar{t}$) spectrum in $t\bar{t}$-dominated low M(t,$\bar{t}$)
    - M(t,$\bar{t}$) spectrum in W+jets CR: invert cut on top system χ^2
    - M(ℓ,ℓ) spectrum in DY CR: 2l

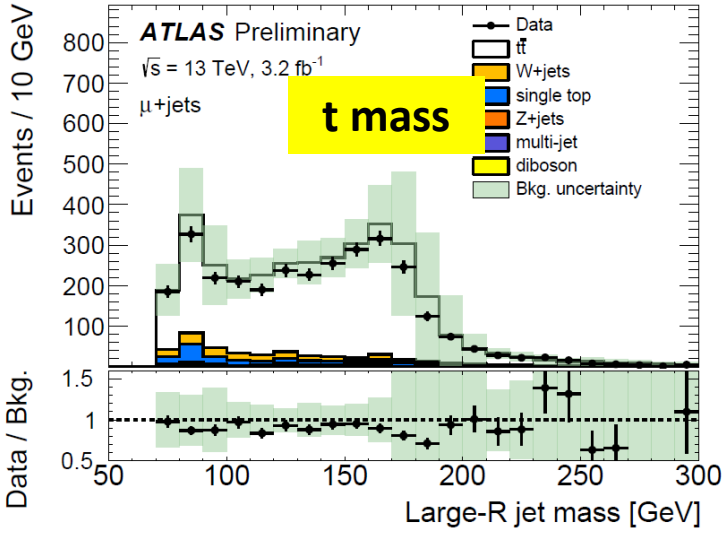


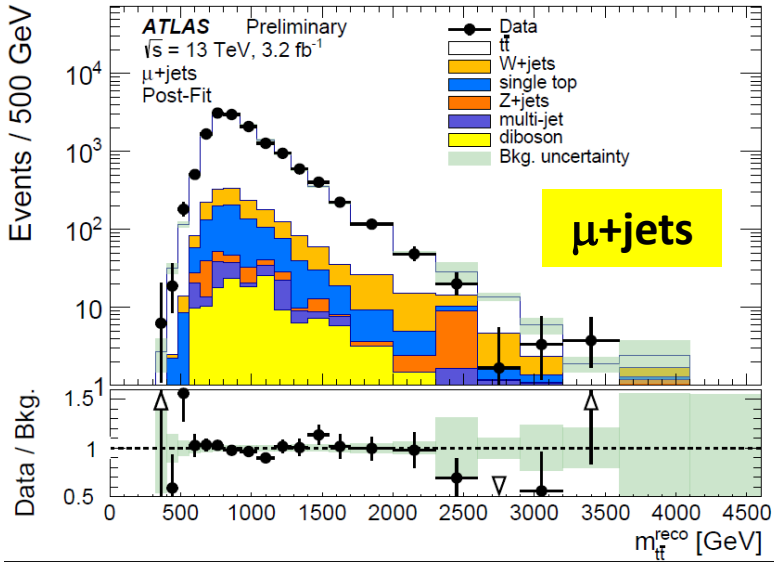


$t\bar{t}$ resonances search

ATLAS-CONF-2016-014

- Search for $t\bar{t}$ resonance in 1l final state
  - Use dedicated isolation variables
  - At least one b-tagged jet needed
  - Leptonic top candidate from lepton and small-R jet
  - Large R-jet for top-tagging:
    - Jet mass and n-subjettiness
    - Back-to-back to lepton
- Fit M($t,\bar{t}$) spectrum
- Background estimates:
  - W+jets background normalized from charge asymmetry in data and MC
  - Multi-jet leptons using sideband with loose leptons
  - $t\bar{t}$ from simulation

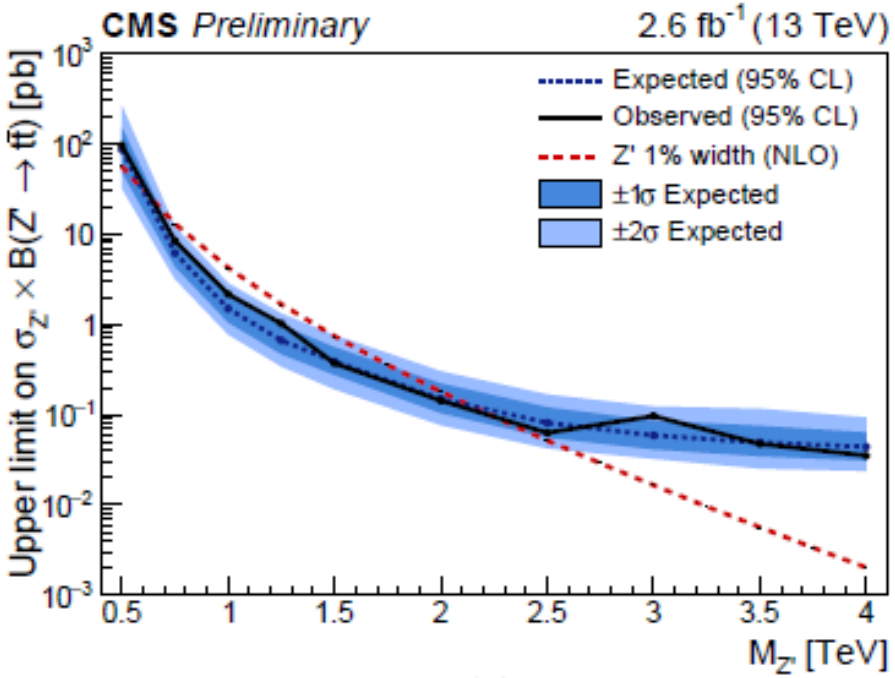


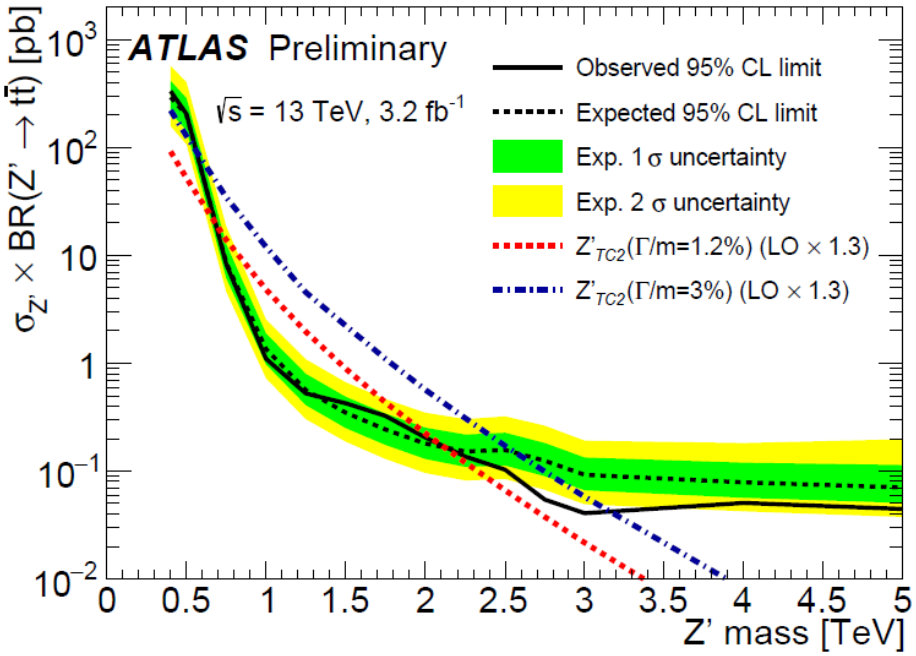


$t\bar{t}$ resonances search

CMS-B2G-15-002
ATLAS-CONF-2016-014

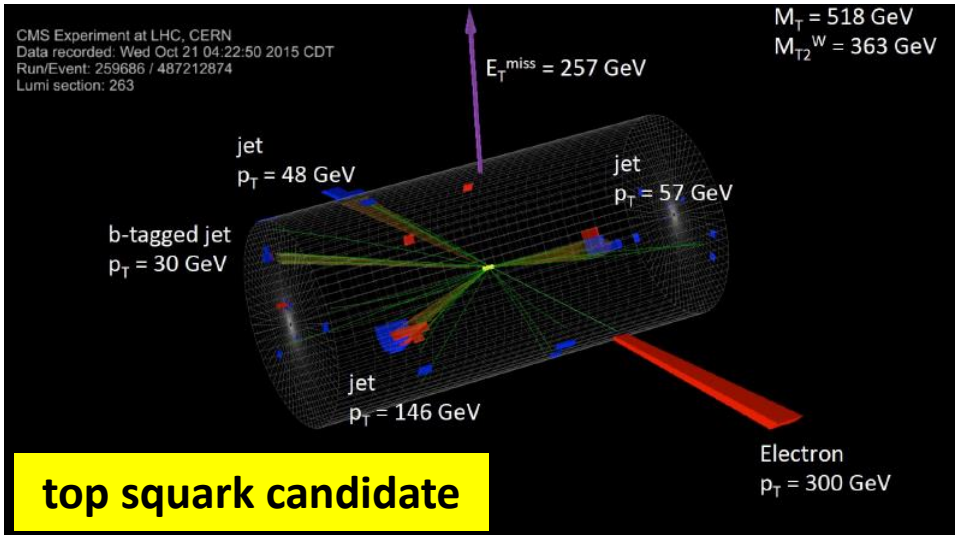
- Exclusion in narrow-width top-color Z'
  - Slightly different width: 1.2% (ATLAS) vs. 1% (CMS)
  - Not stronger yet than full combination of 0l, 1l and 2l at 8 TeV
- Search for tb resonance search in back-up
- Search for $b\bar{b}$ resonances in "Final states with high-p_T jets" talk from **Clemens Lange**





Conclusions

- CMS and ATLAS searched for new physics with t- and b-quarks at 13 TeV
  - Top and bottom squarks in different final states
  - $t\bar{t}$, $b\bar{b}$ and tb resonances
  - Heavy top partners in 1l and same-sign dilepton final states
- Analyses are pushing exclusions to higher masses:
  - More boosted objects
  - Different background composition requires new techniques
- Individual analyses surpassing 8 TeV sensitivity, eagerly awaiting more data



Back-up

Documentation

- Top squarks:
  - 0l: CMS-SUS-16-007
  - 1l: ATLAS-CONF-2016-007, CMS-SUS-16-002
  - 2l: ATLAS-CONF-2016-009
- Bottom squarks:
  - ATLAS-CONF-2015-066
- Third generation resonances:
  - $t\bar{t}$ CMS-B2G-15-002
  - $b\bar{b}$ ATLAS-CONF-2016-014
  - tb CMS-B2G-15-004
- Vector like quarks:
  - CMS-B2G-15-006
  - ATLAS-CONF-2016-013
  - Reinterpretation stop analysis: ATLAS-CONF-2016-007

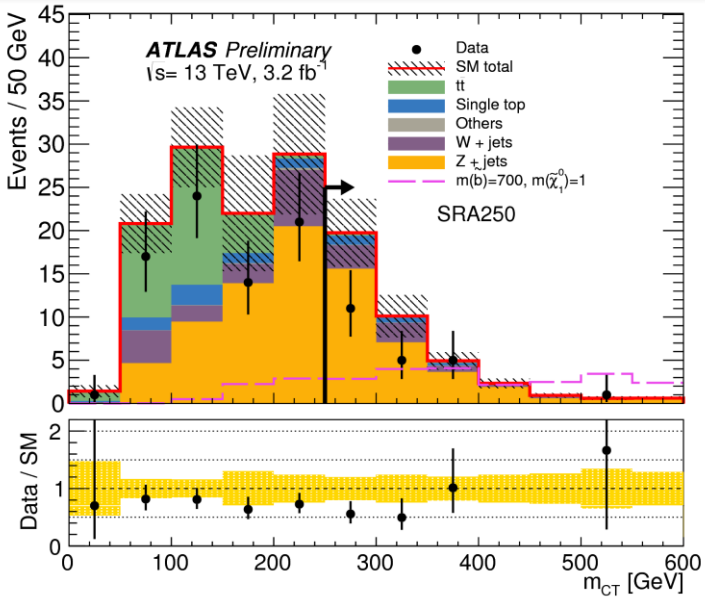
Search for bottom squarks

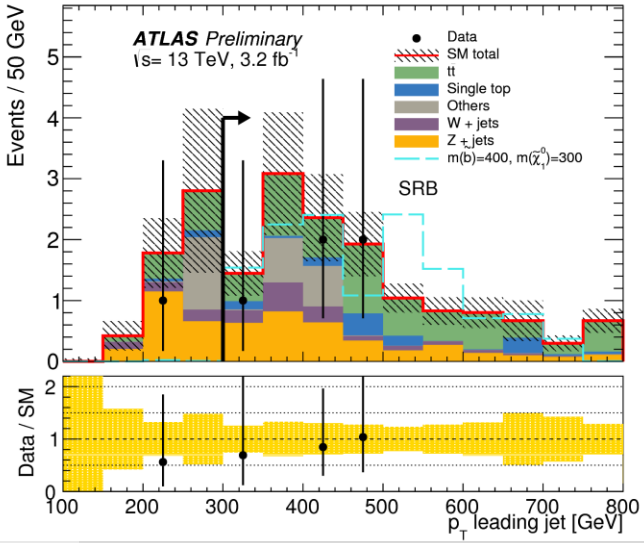
ATL-CONF-2015-066

- Final state: 2 bottom quarks, no leptons, MET>250 GeV
- Veto events with ≥ 4jets
- Two dedicated SRs:
  - SRA: For large $\Delta M(\tilde{b}, \chi_1^0)$:
    - two leading jets b-tagged,
    - M_{bb}>200 GeV
    - M_{CT}>250,350,450 GeV

$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [p_T(v_1) - p_T(v_2)]^2$$

  - SRB: For small $\Delta M(\tilde{b}, \chi_1^0)$:
    - leading, high p_T (>300 GeV), non b-tagged ISR jet
    - Higher MET cut, with MET opposite to leading jet



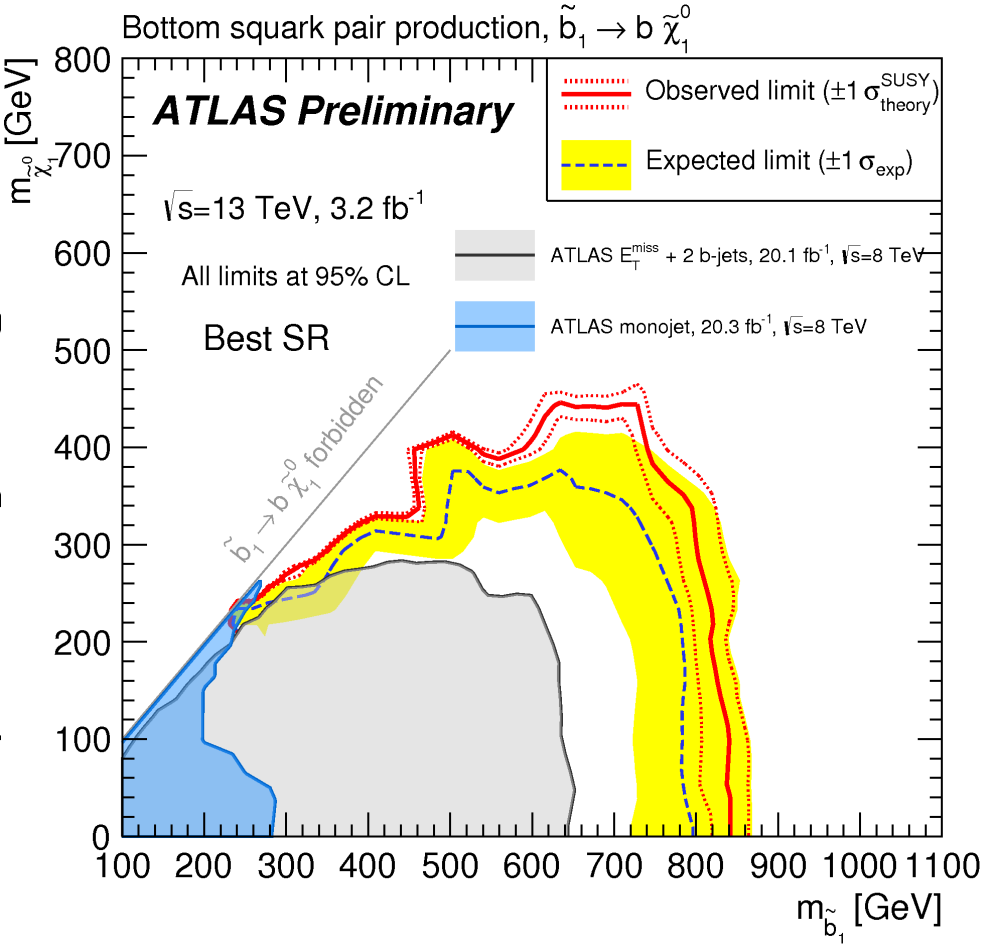


Background estimation

ATL-CONF-2015-066

- Background normalization in different control regions:
  - Z+jets: 2l CR with SFOS with 76<M(ℓ,ℓ)<106 GeV
  - $t\bar{t}$: 1l CR, M(b,b) <200 GeV for CRA
  - Single-top: 1l CR with M(ℓ,b)>170 GeV
  - W+Jets: 1l CR with only 1 b-tagged jet

For SRA estimates

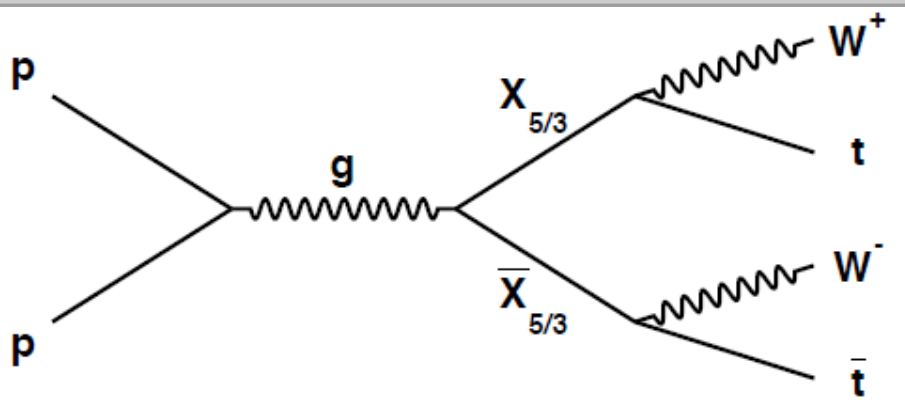


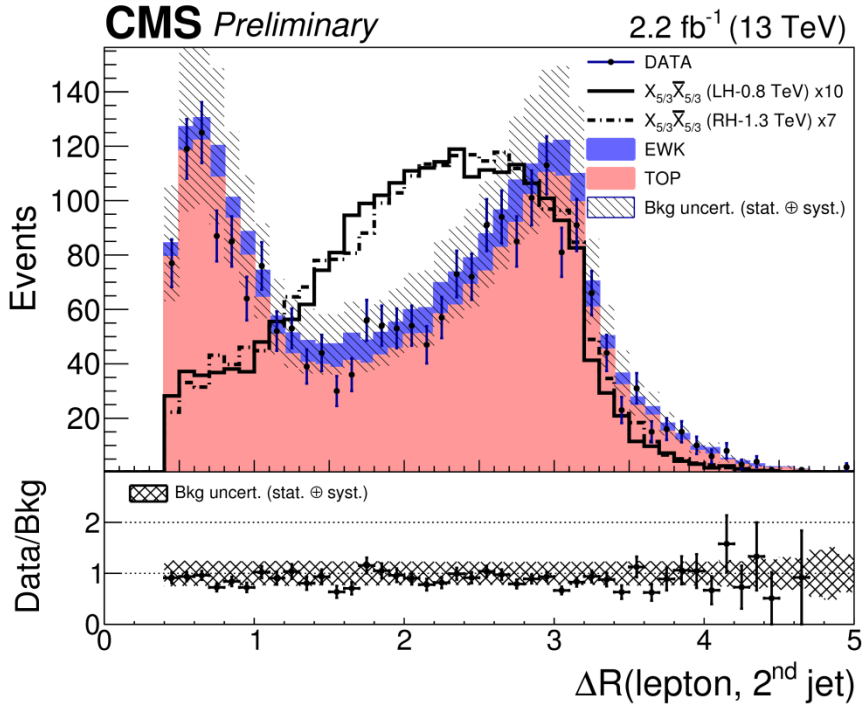
- No excess observed

Search for top partners with charge 5/3

CMS-B2G-15-006

- Heavier stop partners can cancel the divergent terms in the Higgs mass calculation
- Top partner with charge 5/3 deacys to W boson and top quark
  - Search in SS final state in **Clint Richardson**'s **YSF** talk
  - Focus here on 1l+jets final state
    - At least 4 jets
    - 1 or ≥ 2 b-jets
    - MET>100 GeV
    - Number of boosted W-jets
    - $\Delta R(\ell, 2^{nd}\ \text{jet})>1$

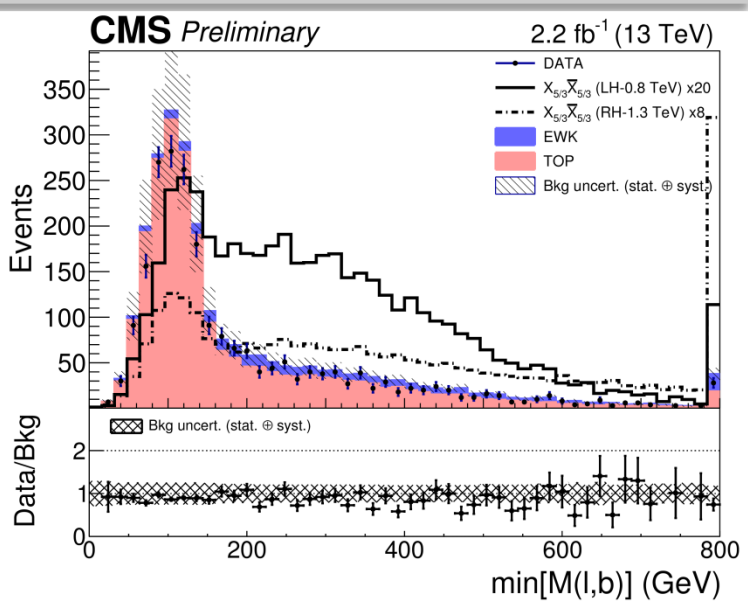


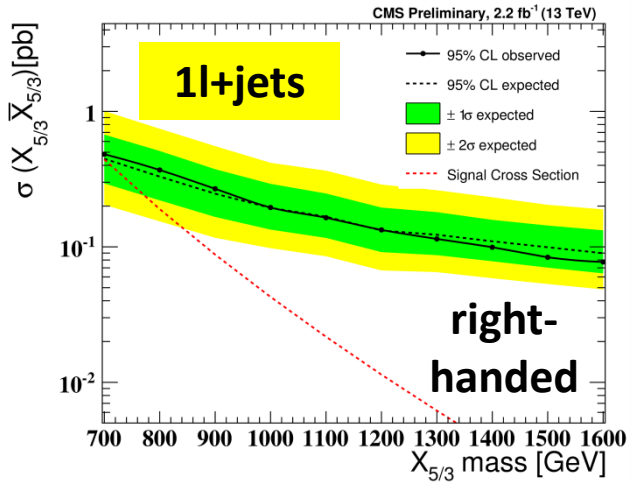


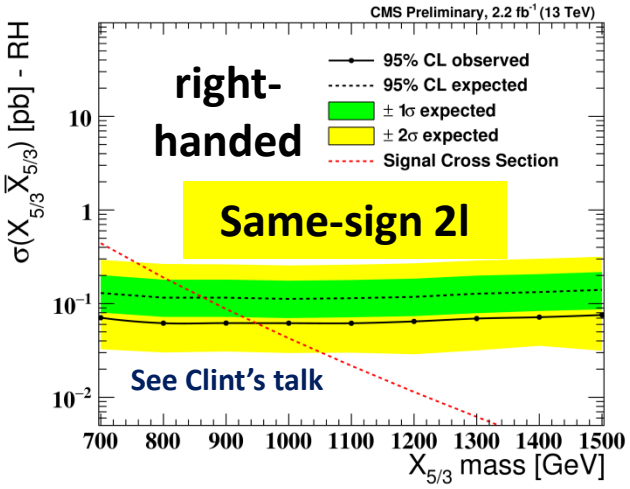
Search for top partners with charge 5/3

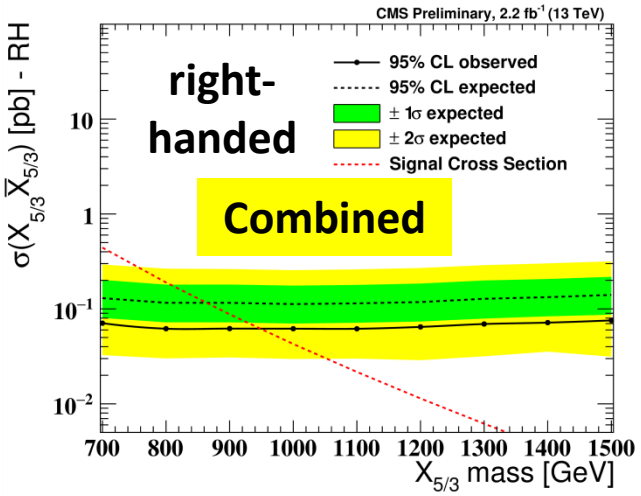
CMS-B2G-15-006

- Check the background modeling in $\Delta R(\ell, 2^{nd}\ \text{jet}) < 1$ sideband
  - V+jets CR: 0 b-tagged jets
  - tt CR: at least 1 b-tagged jet
  - Derive systematic uncertainties on data-MC agreement
- Fit the M(l,b) mass spectrum
- No excess observed









W'→tb search

CMS-B2G-15-004

- Search for W' coupling to third generation
  - One very high p_T lepton (>180 GeV)
  - One very boosted jet (p_T >450 (350) GeV)
  - 1 or ≥2 b-tagged jets
  - MET>50 (120) GeV
  - Top reconstruction:
    - Chose jet that gives best top mass candidate
      - Cut on mass and p_T top candidate
    - Highest-p_T unused jet is b-candidate
- Use the 0 b-tag region to get shape and normalization for W+jets
  - Also check modeling heavy-flavor and light-flavor components
- Check the top p_T distribution in 2 independent CRs (low mass and dilepton) and derive corrections
- Look for excess in M(t,b) spectrum