SEARCHES FOR SUSY/DARK MATTER WITH TOP QUARKS

Top2015 - 8th International Workshop on Top Quark Physics
17 September 2015

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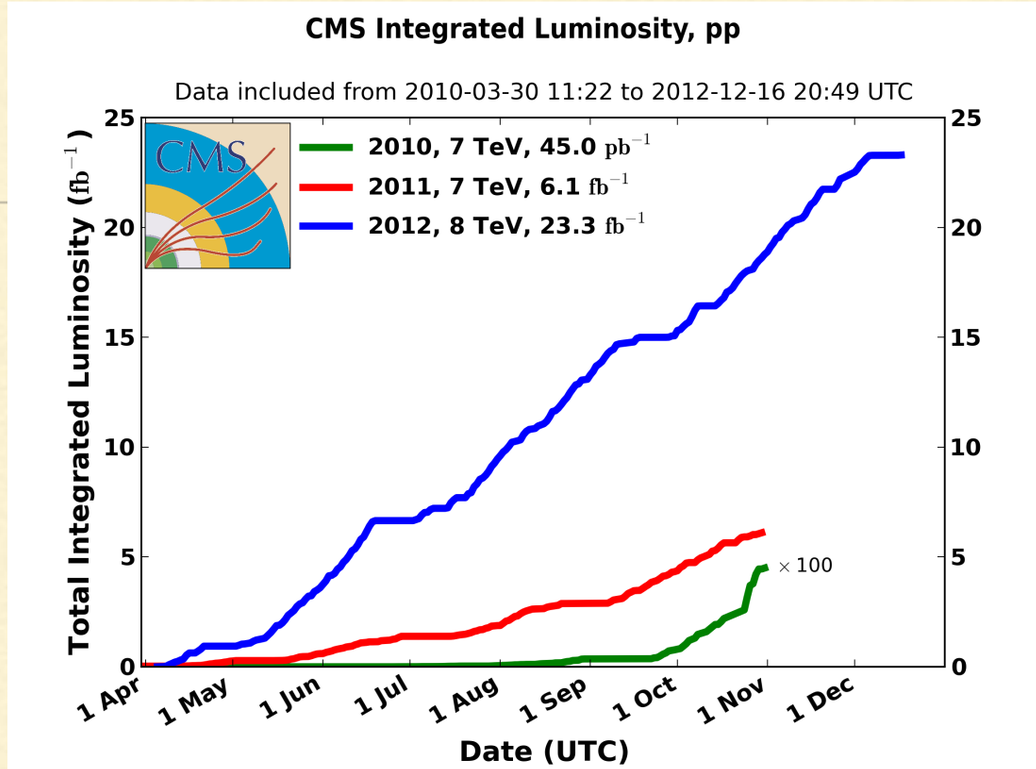
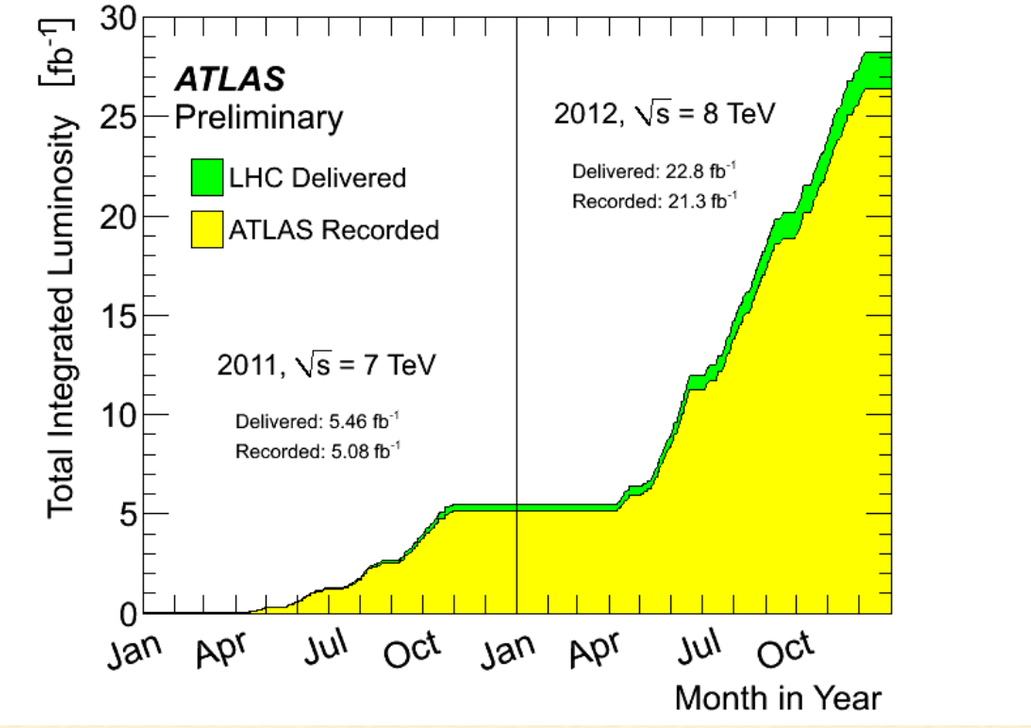
on behalf of the ATLAS and CMS Collaborations

CONTENT

- **Part I**
  - Introduction: natural SUSY
  - Third generation squark searches
- **Part II**
  - Dark Matter + t/tt searches
  - MonoTop searches
- **Summary**





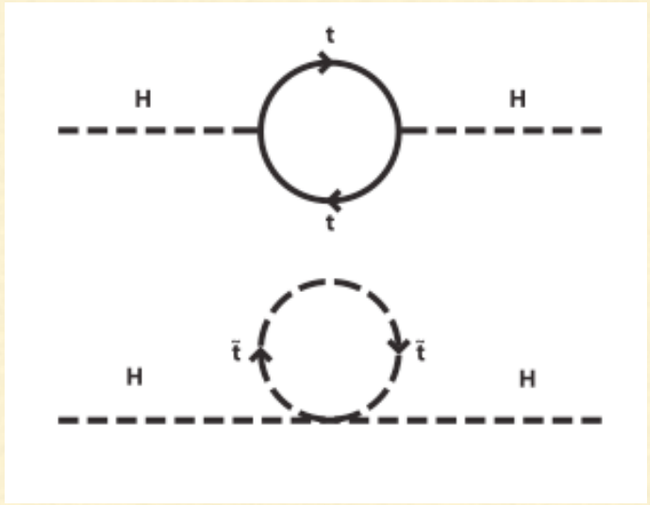
Results shown are all with full 2012 dataset (~20 fb^{-1} at √s=8 TeV)

INTRODUCTION: NATURAL SUSY

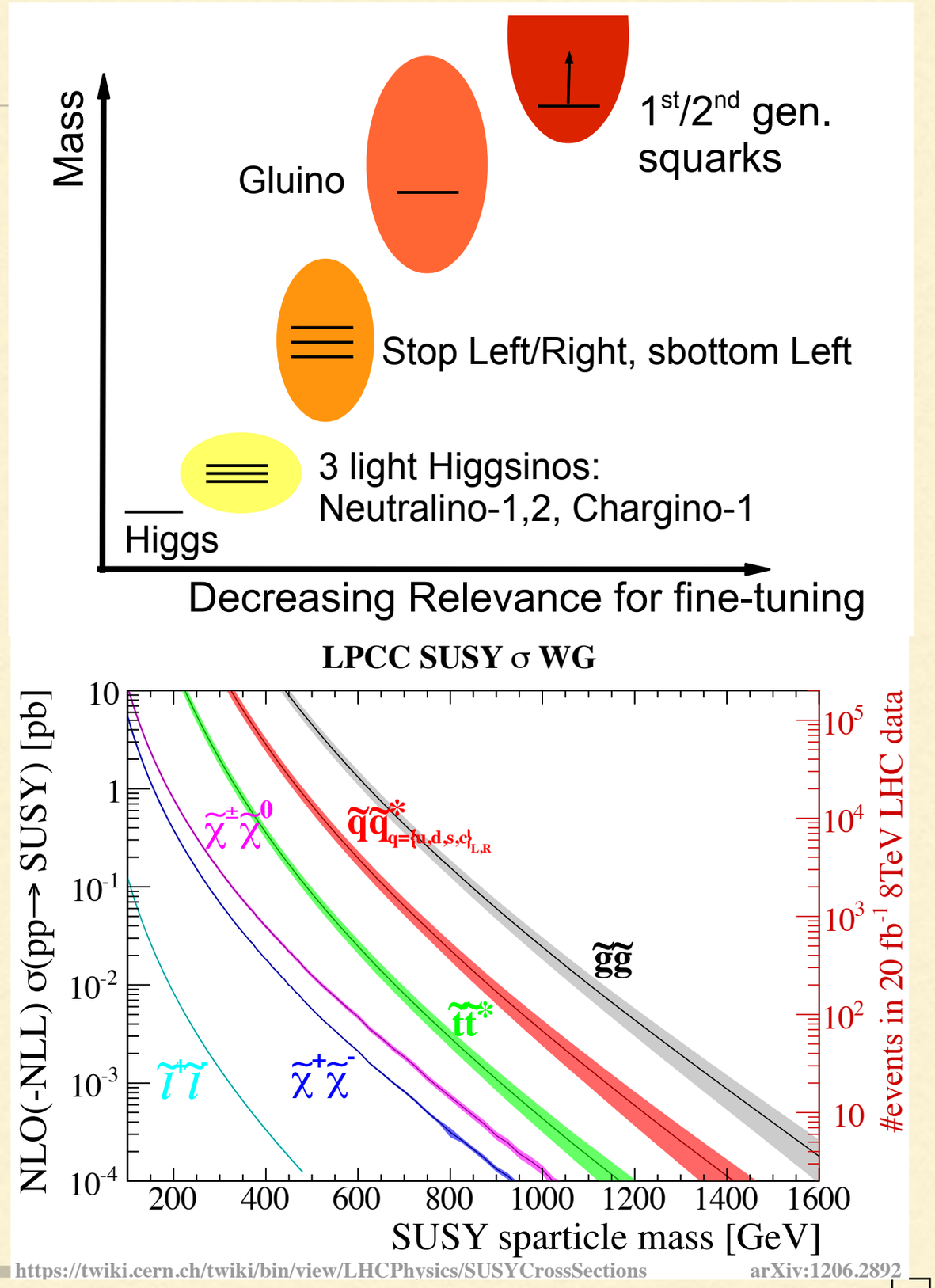
SM - huge radiative corrections to Higgs mass ⇒ high-levels of fine tuning

SUSY - corrections to the Higgs (soft) mass are driven by the top/stops system,
Natural SUSY - low fine tuning:

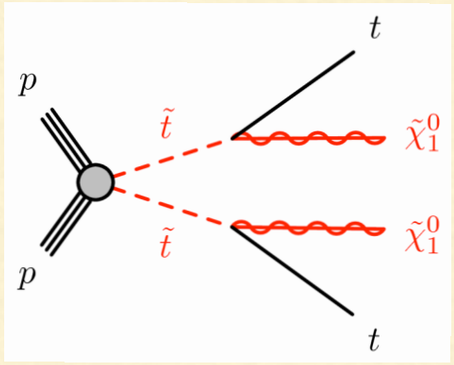
- average mass of two Stops in the sub-TeV range
- at least one light Sbottom (part of the LH multiplet)

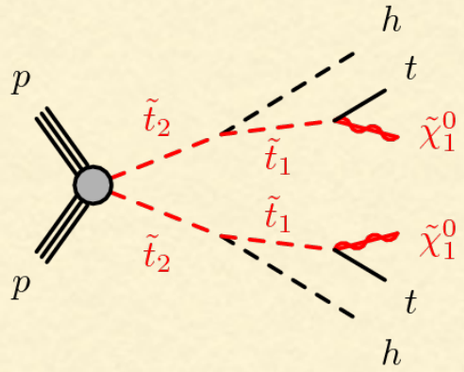


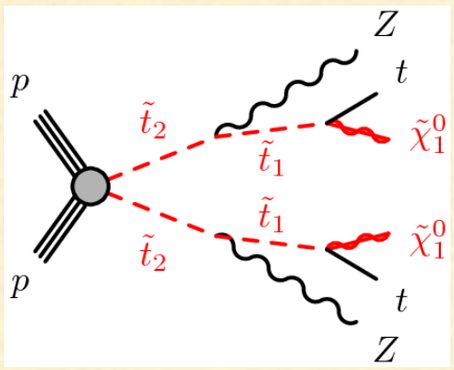
Light 3rd generation (≤ 1 TeV) preferred by naturalness.

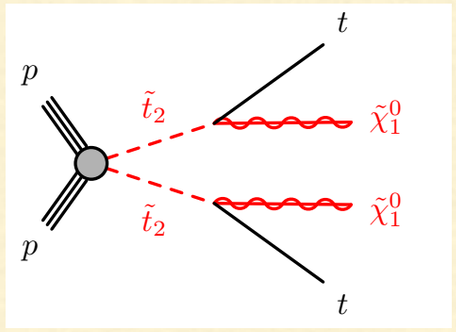


Direct Stop1,2 production

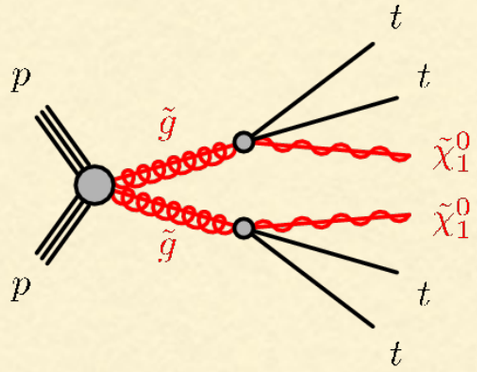


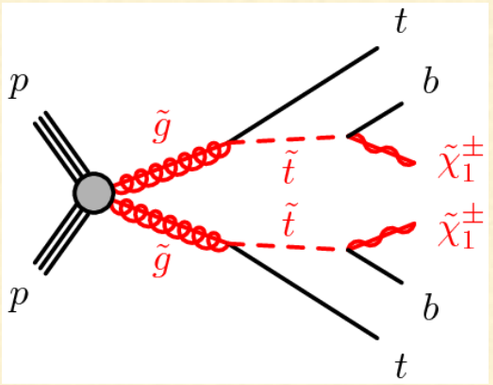


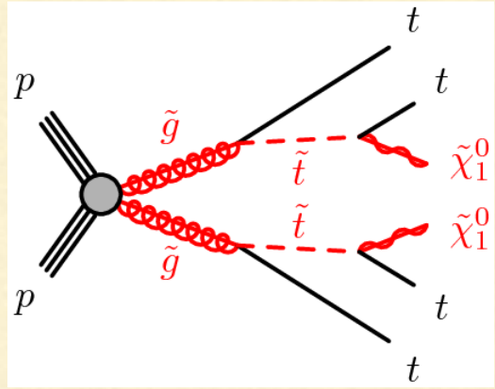


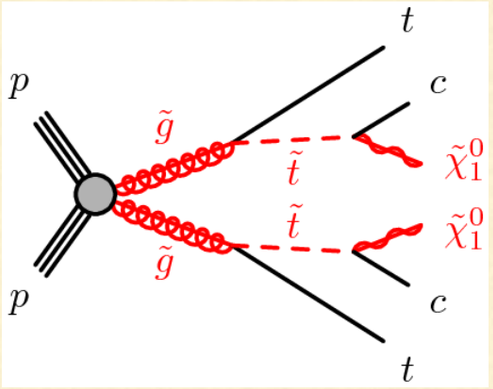


Gluino Mediated Stop production









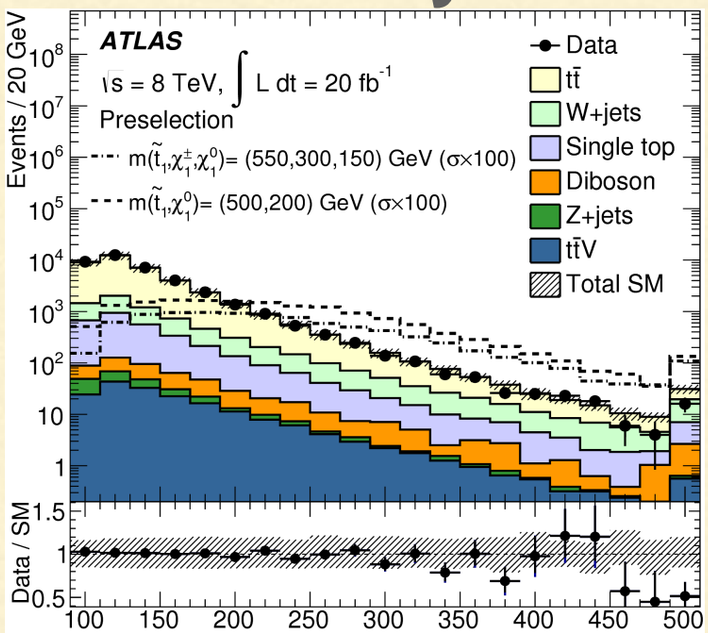
Simplified models:

~ Decoupled sparticle spectra, particles of no interest considered very massive, isolated single production and decay mode

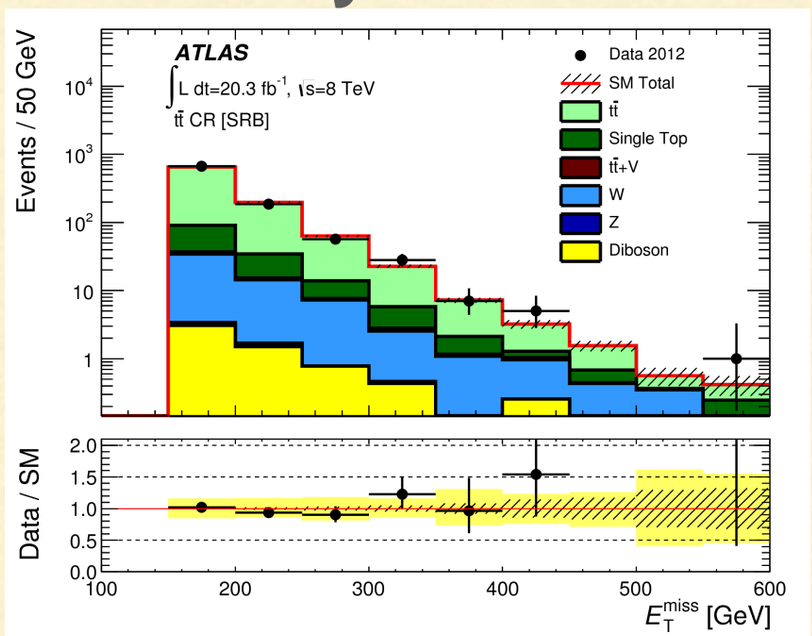
~ Decay BR are assumed to be 100% into a selected mode

ATLAS:TT + ETMISS

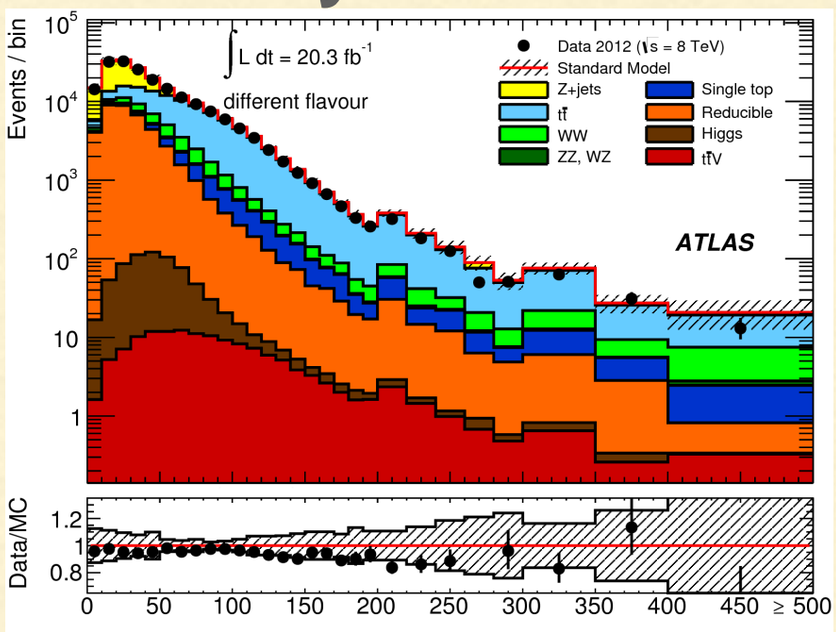
1L+4J



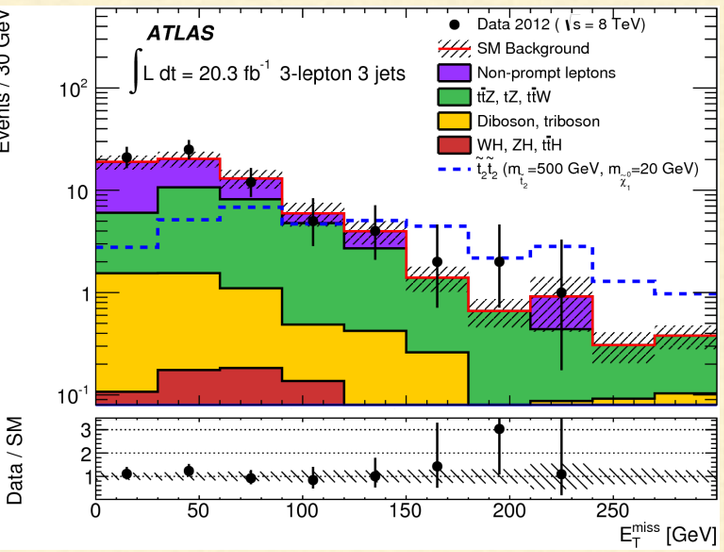
1L+6J



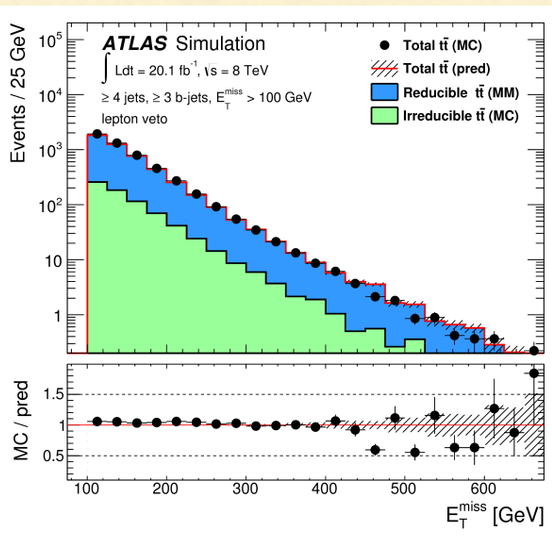
2L+2J



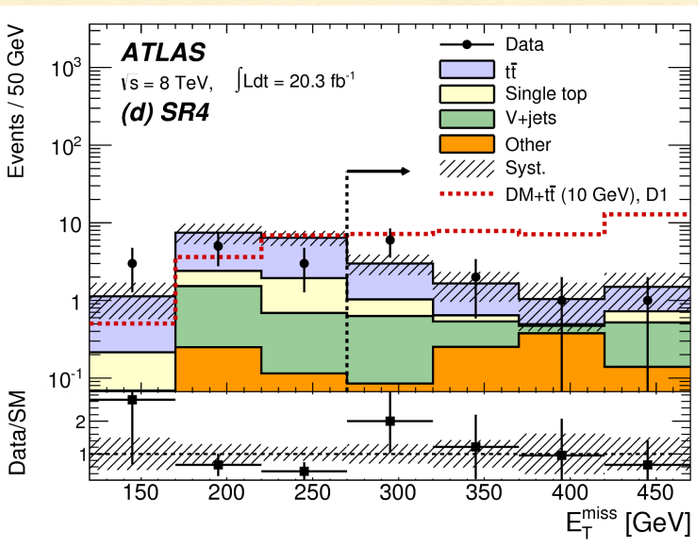
3L+3J



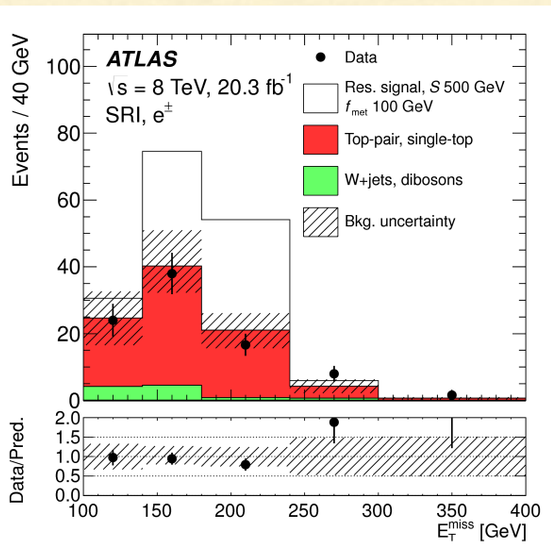
4J+3b



1L + 4jets

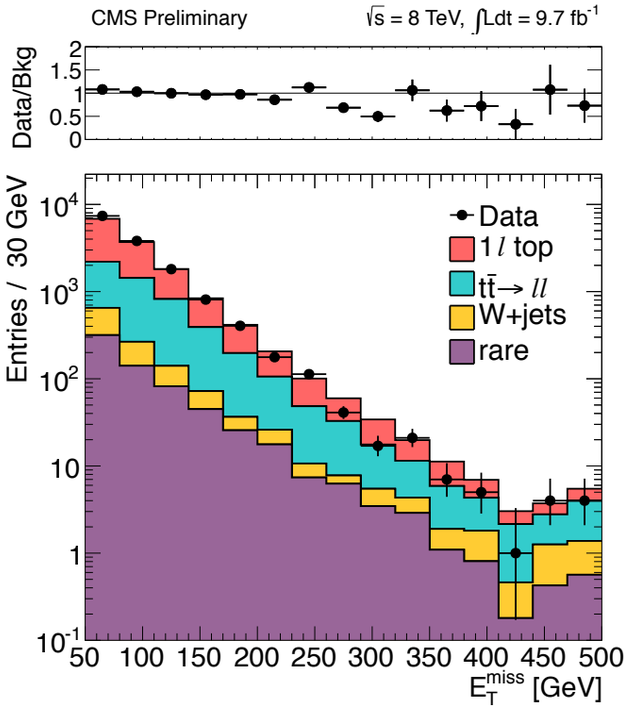


1L+1b

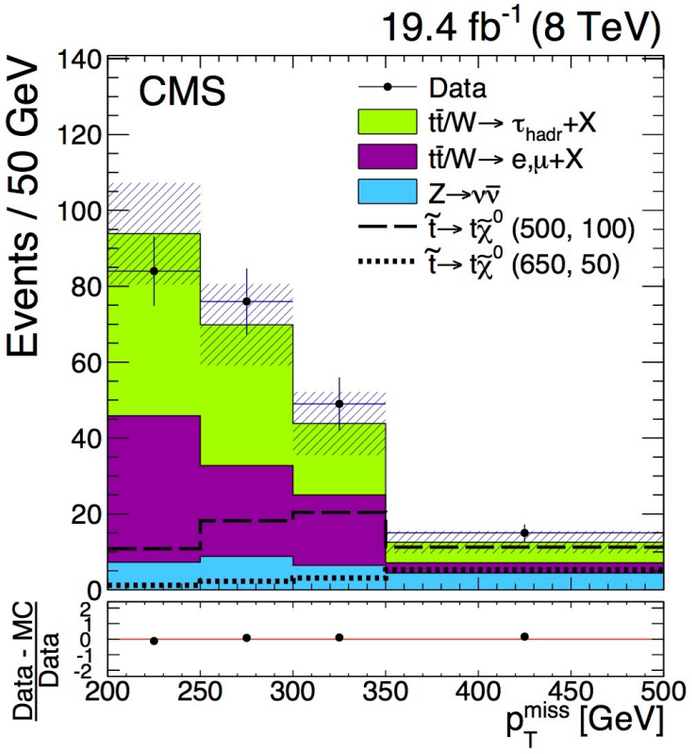


CMS: TT + ETMISS

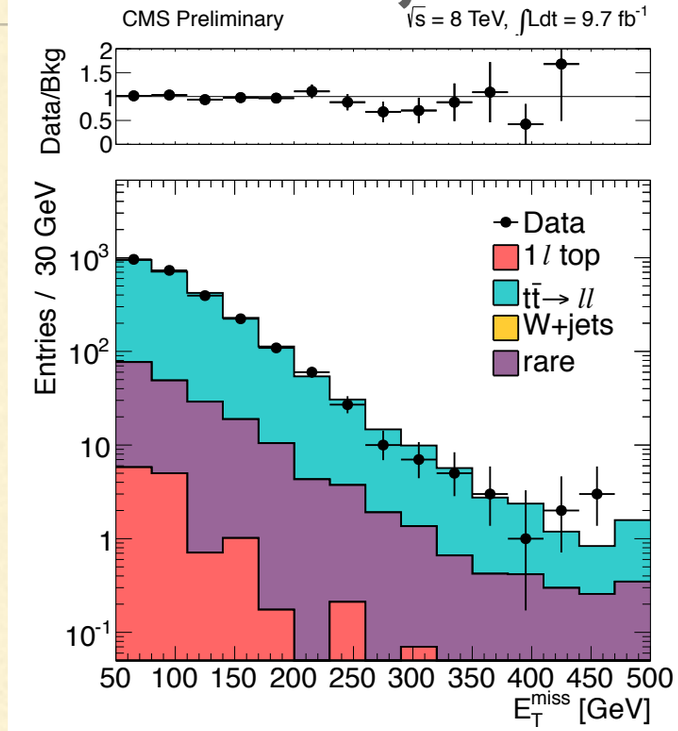
1L+1track+1b



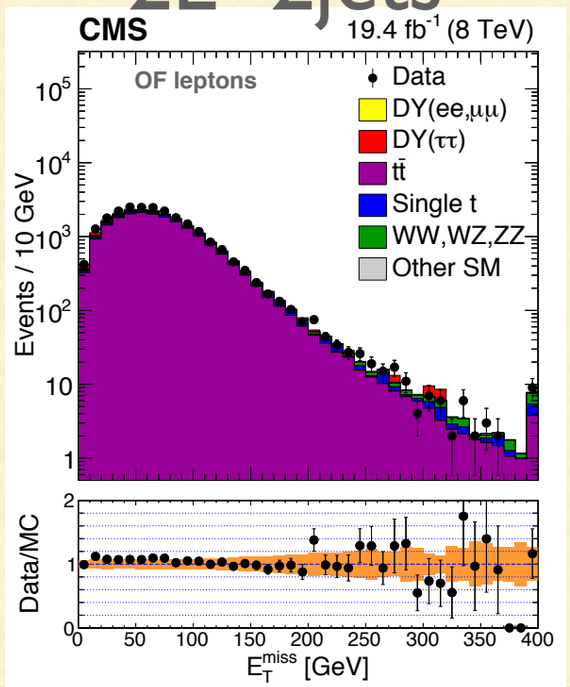
0L+jets



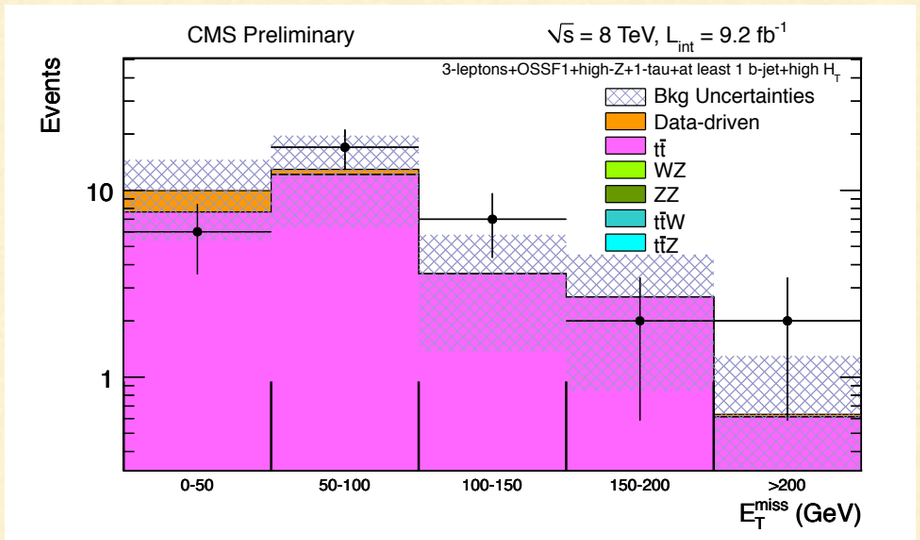
2L+2bjets



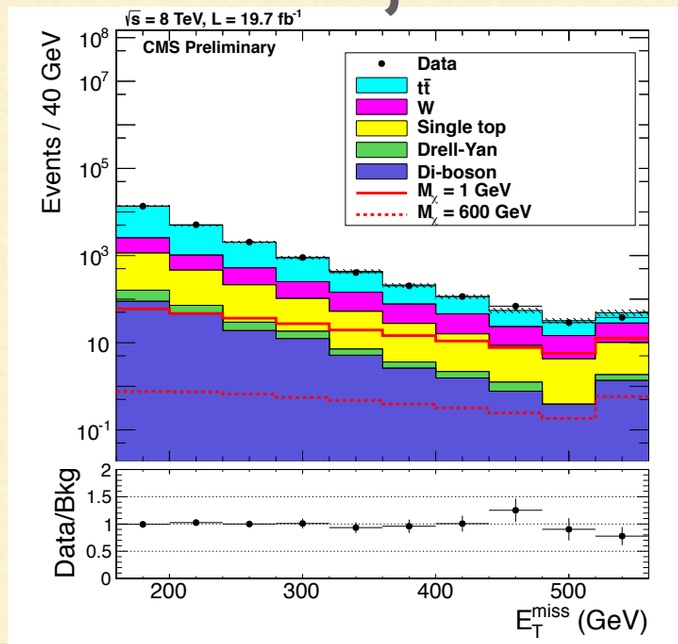
2L+2jets



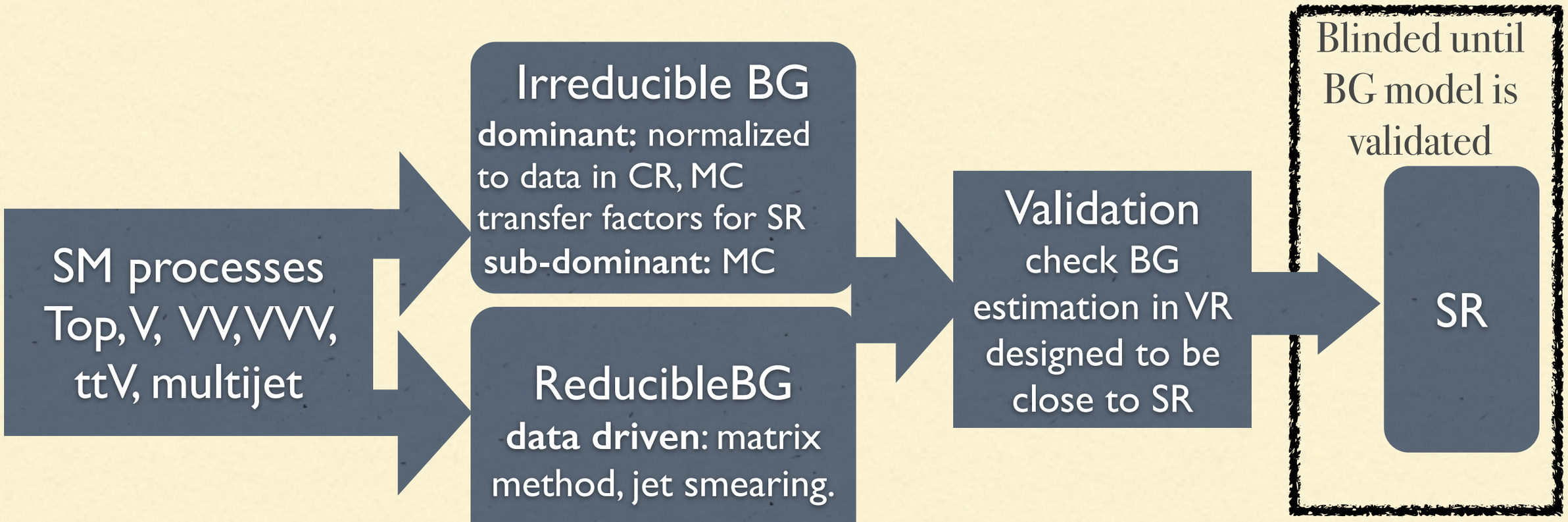
3L+1b



1L+3jets



ATLAS: SM BG ESTIMATION



Light 3rd generation ⇒ very SM like

Direct production cross section small ⇒ need precise measurements of SM tails

Notations: Standard Model - SM, Background - BG, Monte Carlo - MC, Control Region - CR, Validation Region -VR, Signal Region - SR, Transfer Factor - TF.

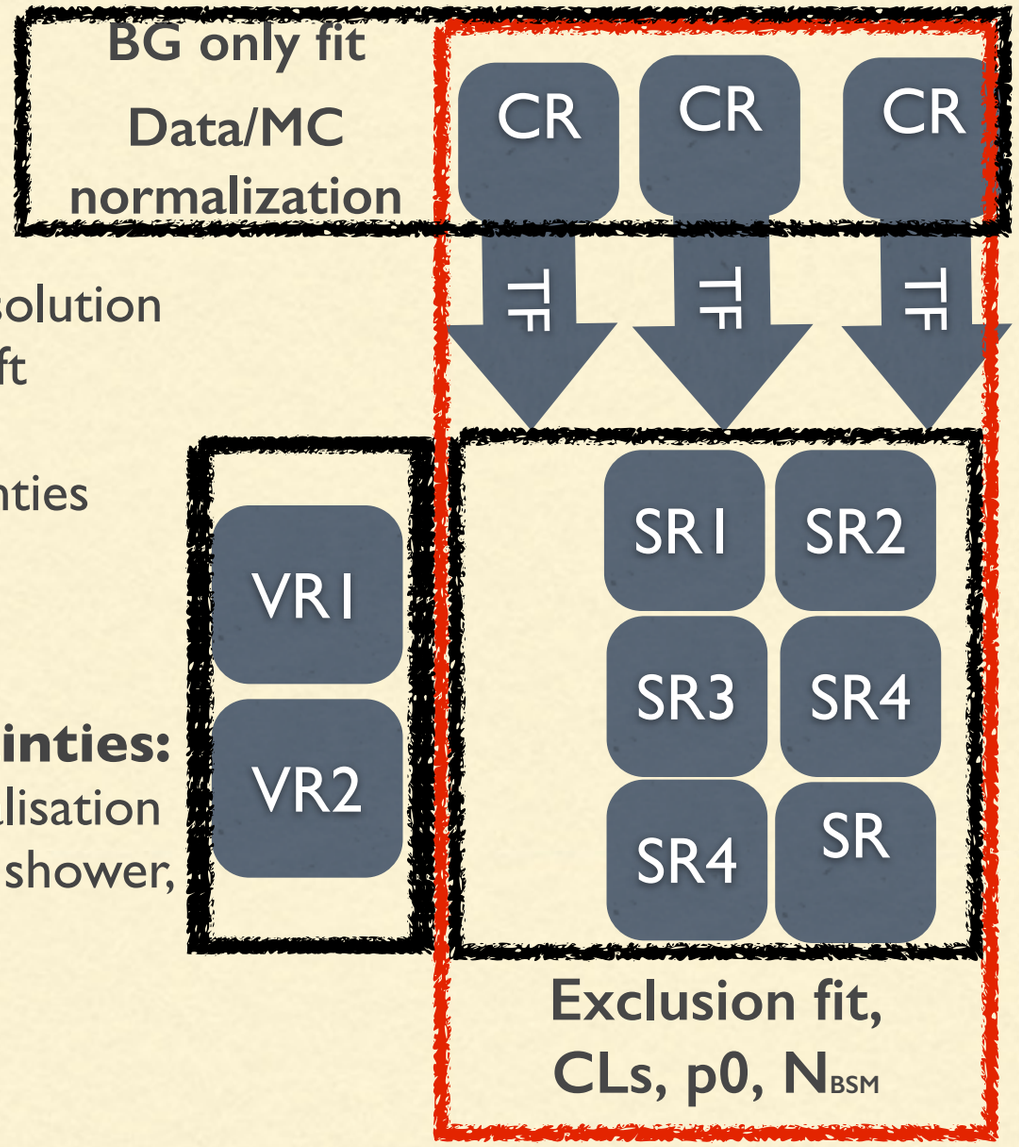
ATLAS: SYSTEMATICS & COMBINED FIT

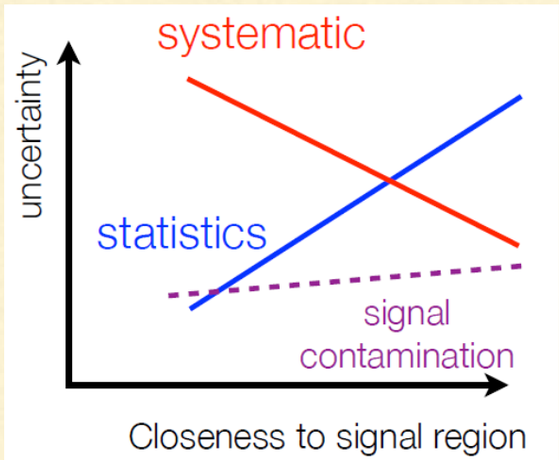
Detector systematics:

- Jet Energy Scale (JES)
- Jet Energy Resolution (JER)
- b-tagging uncertainties
- Lepton ID, energy scale & resolution
- Missing Transverse Energy soft component
- Trigger: scale factor uncertainties
- Luminosity uncertainty
- Pileup

BG MC modeling uncertainties:
generator choice, PDF, renormalisation and factorization scales, parton shower, ISR/FSR.

Signal systematics:
• ISR/FSR, parton shower, PDF, renormalisation and factorization scales and strong coupling (α_s) uncertainty.





multiple SRs per analysis

1. if SRs overlap use one with best expected sensitivity,
2. if SRs are orthogonal do statistical combination for model dependent exclusion reach + signal contribution in CRs, but use 1 most sensitive SR bin for discovery fits + no signal contribution in CRs.

TT(T)+ ETMISS SEARCHES AT LHC

note: comprehensive list of all public ATLAS and CMS physics results.

CMS, SUSY,

- 0L, top pair reconstruction - PAS-SUS-13-023
- 0L + multijet - JHEP 1503.08037,
- 0L + MT2 variable - JHEP 05 (2015) 078,
- inclusive razor - PRD 91, 052018 (2015),
- bjet + 4 W bosons - PLB 745 (2015) 5,
- Stop2, H/Z tagged - PLB 736 371 (2014),
- >=3L, PRD 90, 032006 (2014),
- Multijets - JHEP 06 (2014) 055,
- SS dileptons + jets - JHEP 01 (2014) 163,
- 1L + jets(2bjets) - PLB 733 328 (2014),
- 1L mva - EPJC 73 (2013) 2677,
- 0L + jets(bjet), HT&MET - PLB 725 243 (2013),

CMS, B2G

- Dark Matter in Association with Top Quark Pairs in 1L final state - JHEP 06 (2015) 121
- Dark Matter in Association with Top Quark Pairs in the Di-lepton Final State - B2G-13-004
- Search for new physics with monotop final states in pp collisions at = 8 TeV - Phys. Rev. Lett. 114 (2015) 101801.

ATLAS, SUSY, Run 1 summary papers:

- Third generation squarks (direct production), submitted to EPJC, e-print arXiv:1506.08616,
- Inclusive squark/gluino searches, submitted to JHEP, e-print arXiv:1507.05525,

ATLAS, Exotics,

- Search for dark matter in events with heavy quarks and missing transverse momentum, EPJC 75 (2015) 92,

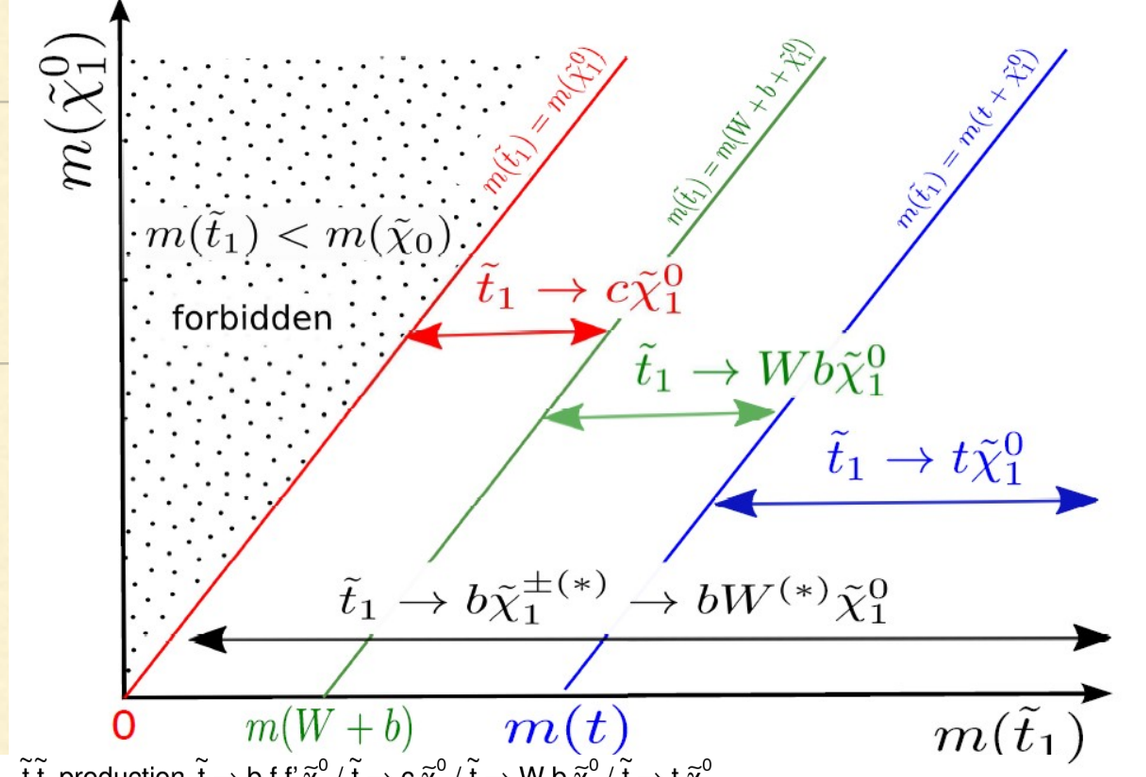
ATLAS, Top,

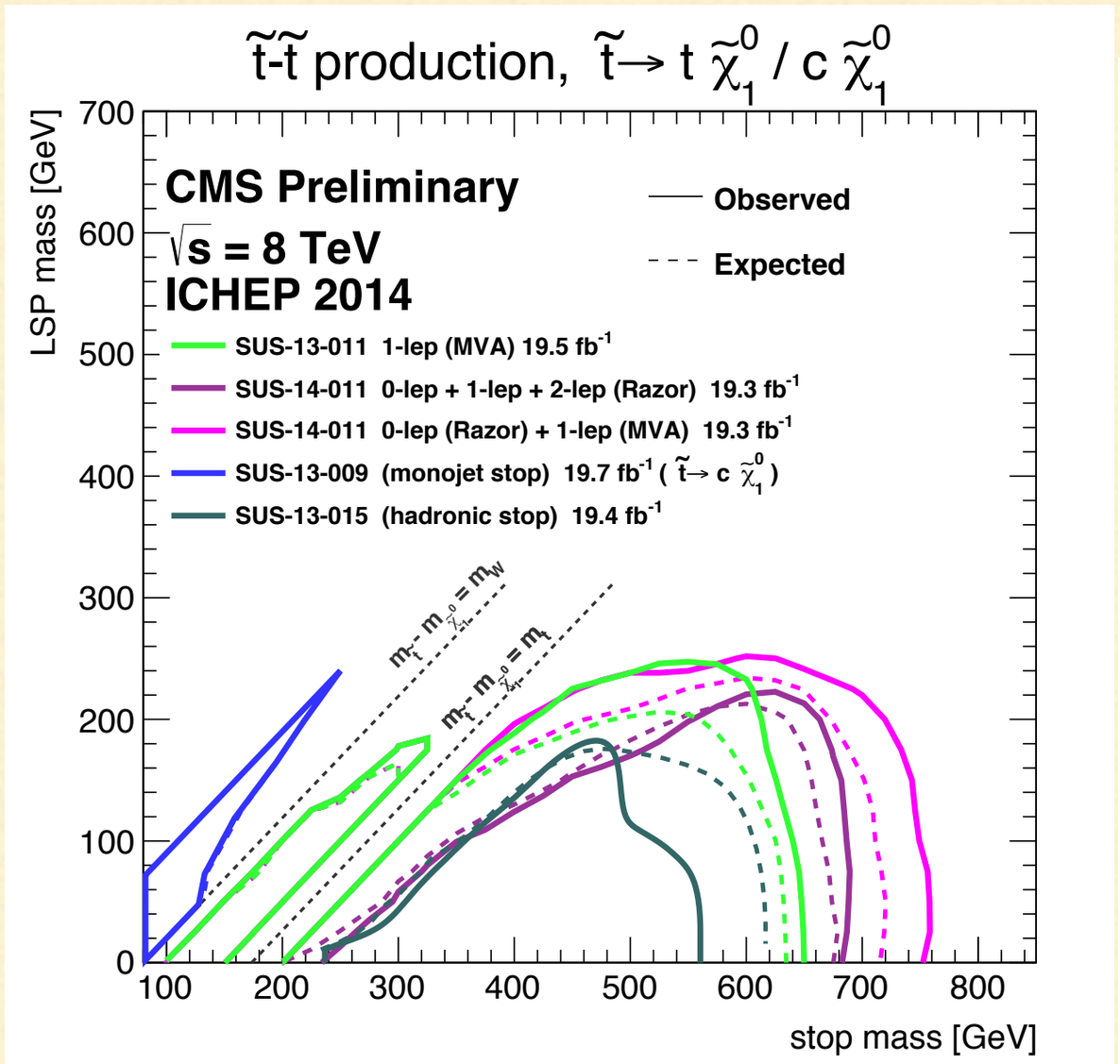
- Search for invisible particles produced in association with single-top-quarks, Eur. Phys. J. C (2015) 75:79.

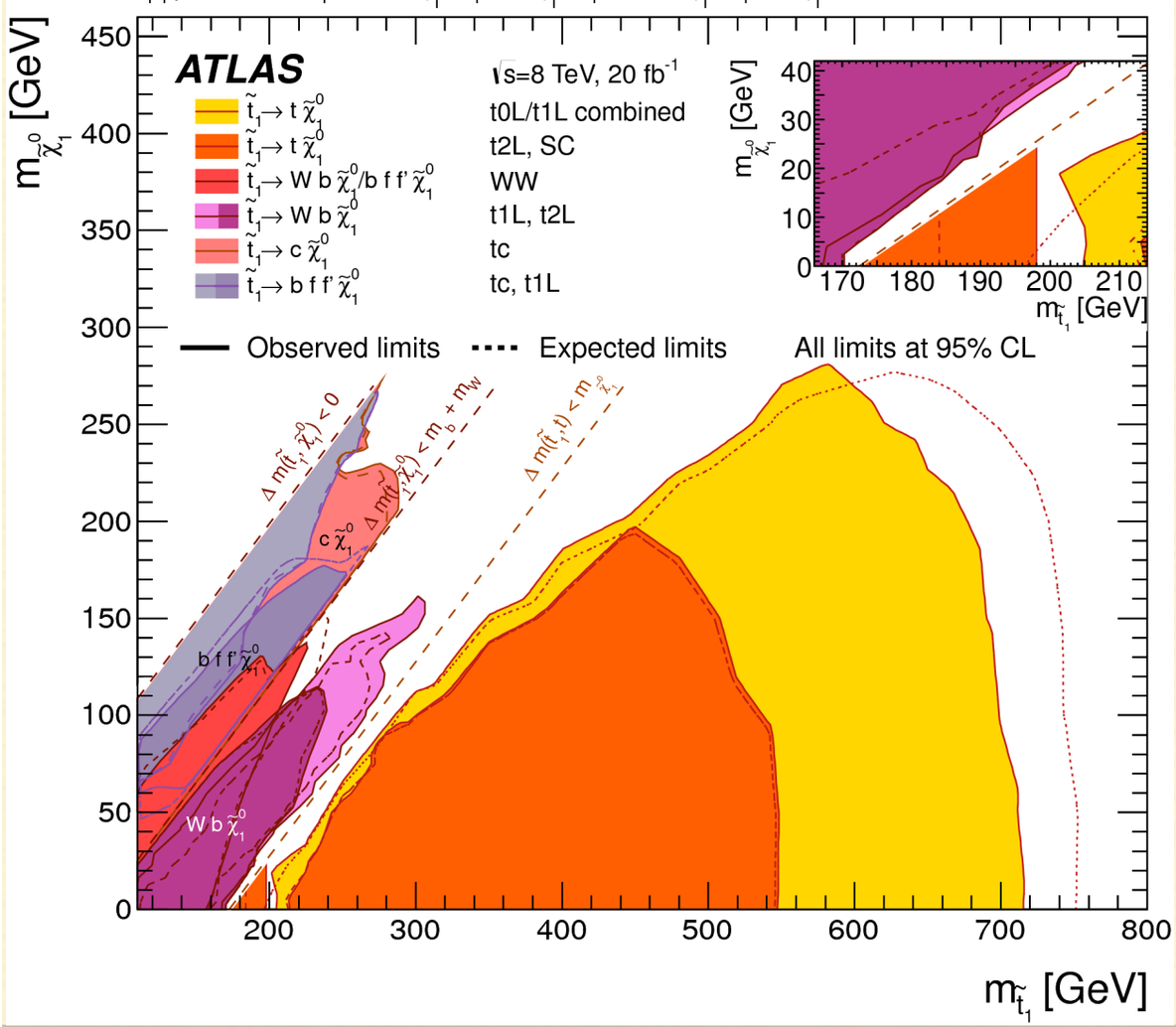
CMS, Top,

Measurements of the inclusive top-quark pair production cross section in the eμ decay channel in pp collisions at $\sqrt{s}$= 7 and 8 TeV - PAS TOP-13-004

SUMMARY OF STOP SEARCHES AT LHC



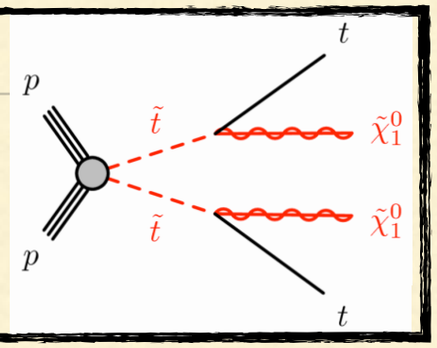


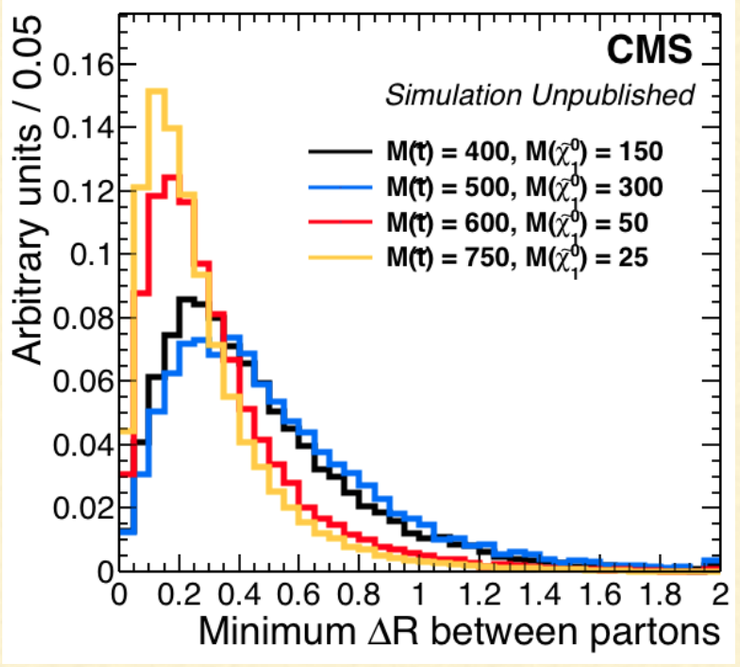


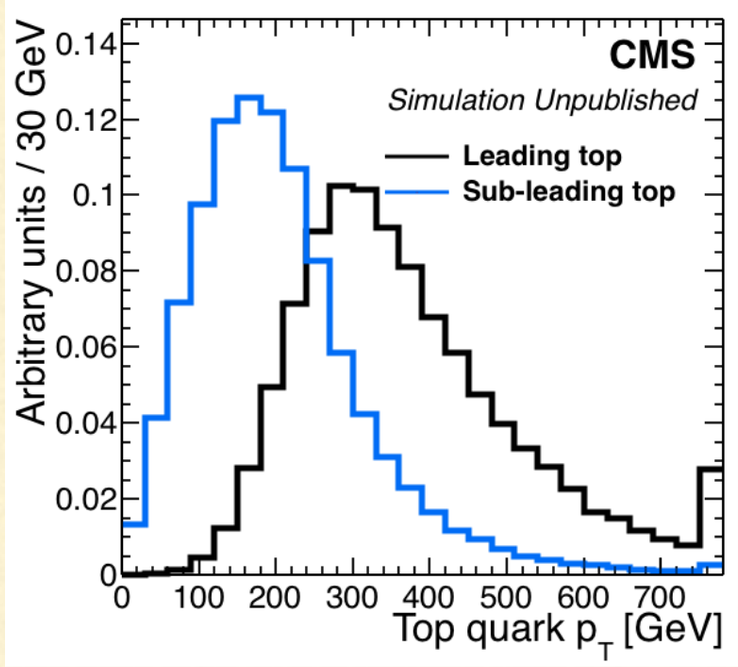
CMS: STOP SEARCHES

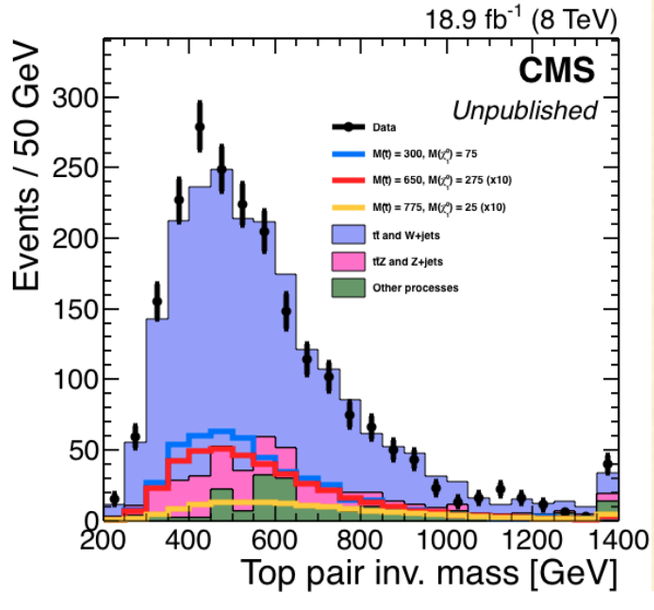
PAS-SUS-13-023

Signal



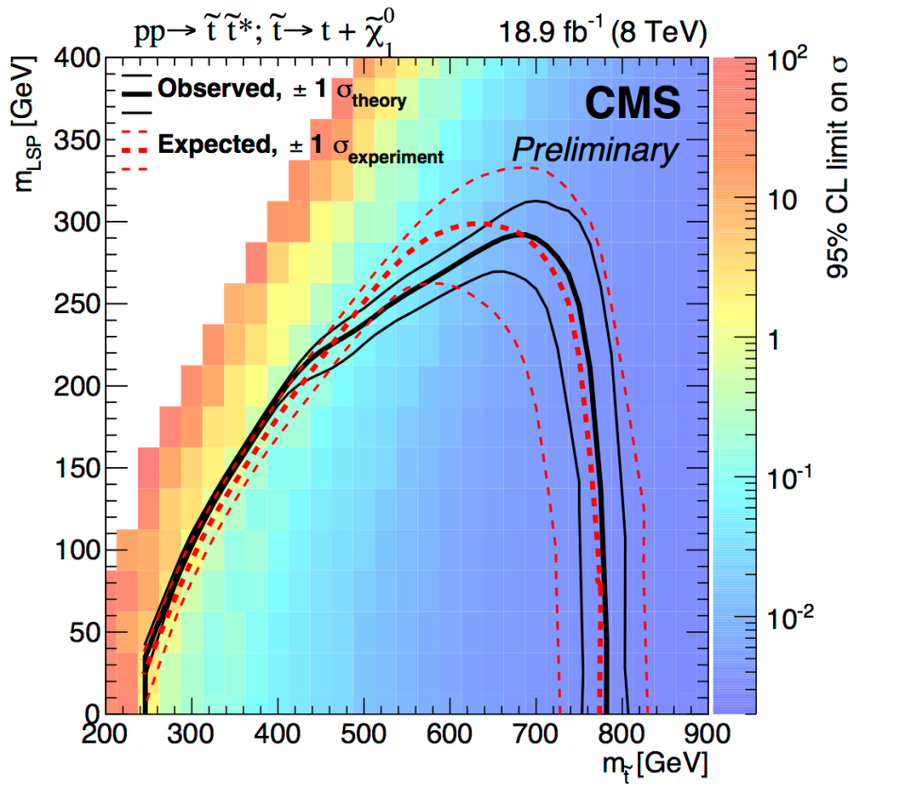






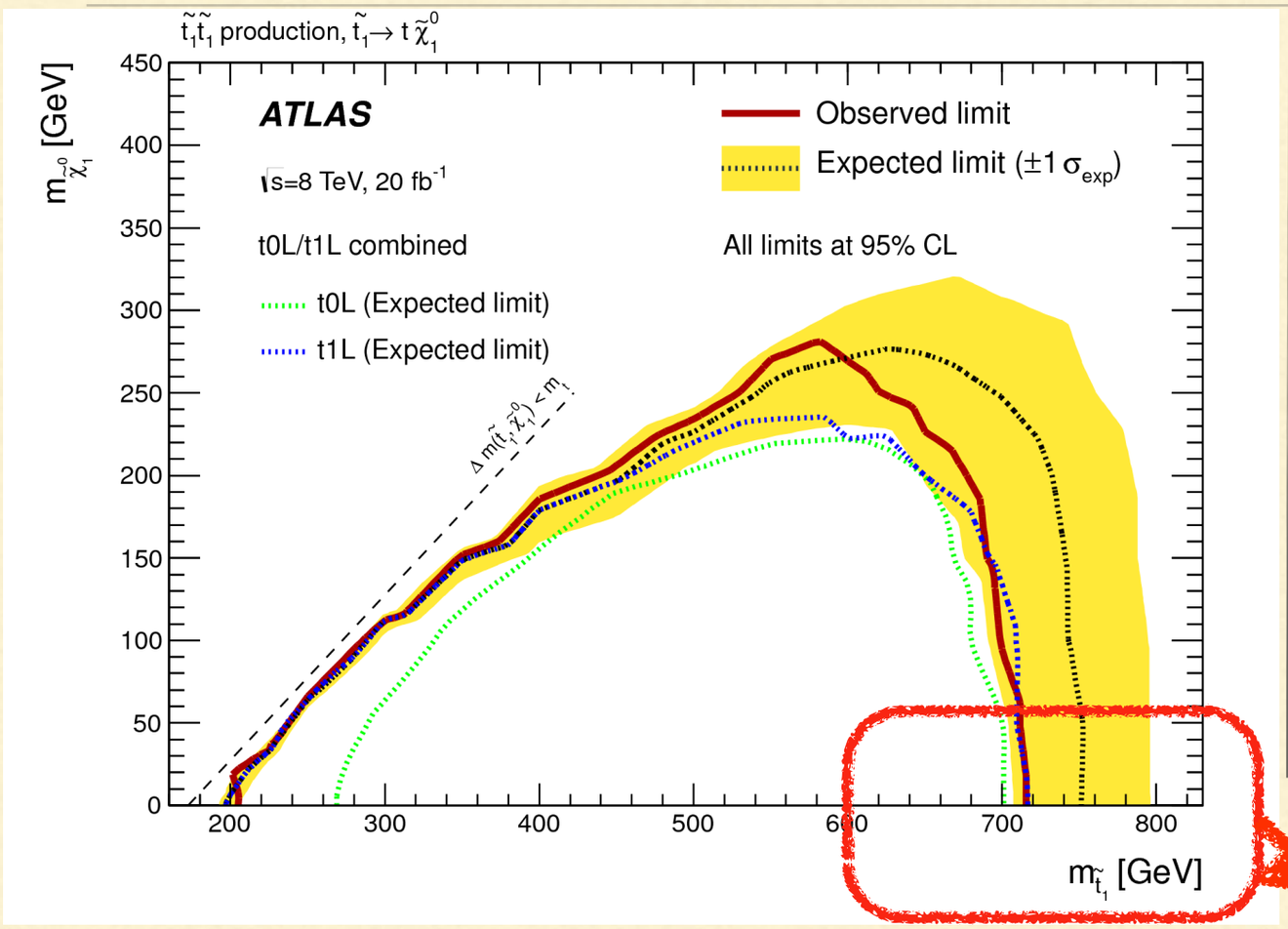
Dedicated high efficiency top pair reconstruction
input "fat jets", CA ΔR=1, split into smaller sub-jets
MVA-based top pair reconstruction: choose best pair of "top candidates"

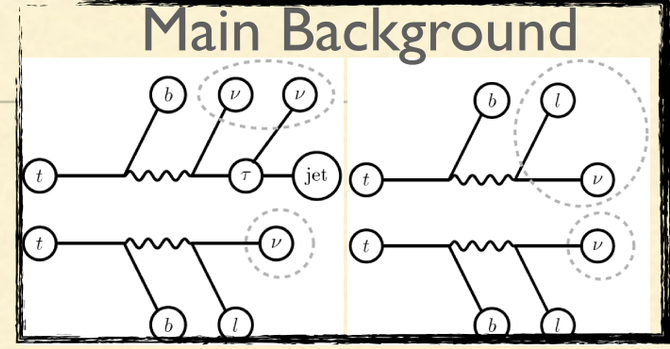
4 BDTs (optimised for different stop mass), 24 input variables, including MET, "top candidate" MVA values for object ID



ATLAS: STOP SEARCHES

arXiv: 1506.08616





1L, >= 4jets, >=1b/2b-jets, mT >120 to 200 GeV, 130 < m(jjj) < 205 GeV, Etmiss >100 to 275GeV, **amT2**>170 to 200 GeV, **mT2_tau**>80 GeV.
2D binned shape fit: mT [60-140-]GeV and Etmiss [100-150-] GeV.
mostly stop-right handed vs purely stop-left handed ⇒ drop of the sensitivity (~75GeV) ⇒

lepton kinematics depends on Top polarisation.
Main Backgrounds: tt, ttV, V+jets.

0L, >=6jets, >=2bjets, Etmiss > 200 to 350GeV, mT(b-jet,Etmiss) >175GeV, tau veto.
Full reconstruction of tt (3 closest jets in $\eta - \phi$ plane), 2 top with 80 < m(jjj) < 270 GeV.
Analysis insensitive to Stop polarization (L/R).
Main Backgrounds: tt, Z+jets, ttV.

m_Stop-m_LSP>>m_Top, Boosted Regime

0L, 4-5 resolved jets, 2 fat jet anti-kt R=0.8/1.2 top mass asymmetry, $\mathcal{A}_{m_t} = \frac{|m^0_{\text{jet},R=1.2} - m^1_{\text{jet},R=1.2}|}{m^0_{\text{jet},R=1.2} + m^1_{\text{jet},R=1.2}}$.

1L, 4 resolved jets, 1 fat jet anti-kt R=1.0

CONSTRAINTS FROM TT CROSS SECTION MEASUREMENTS

Constraint from Top spin measurement shown by J.Linacre

PAS-TOP-13-004

arXiv: 1506.08616

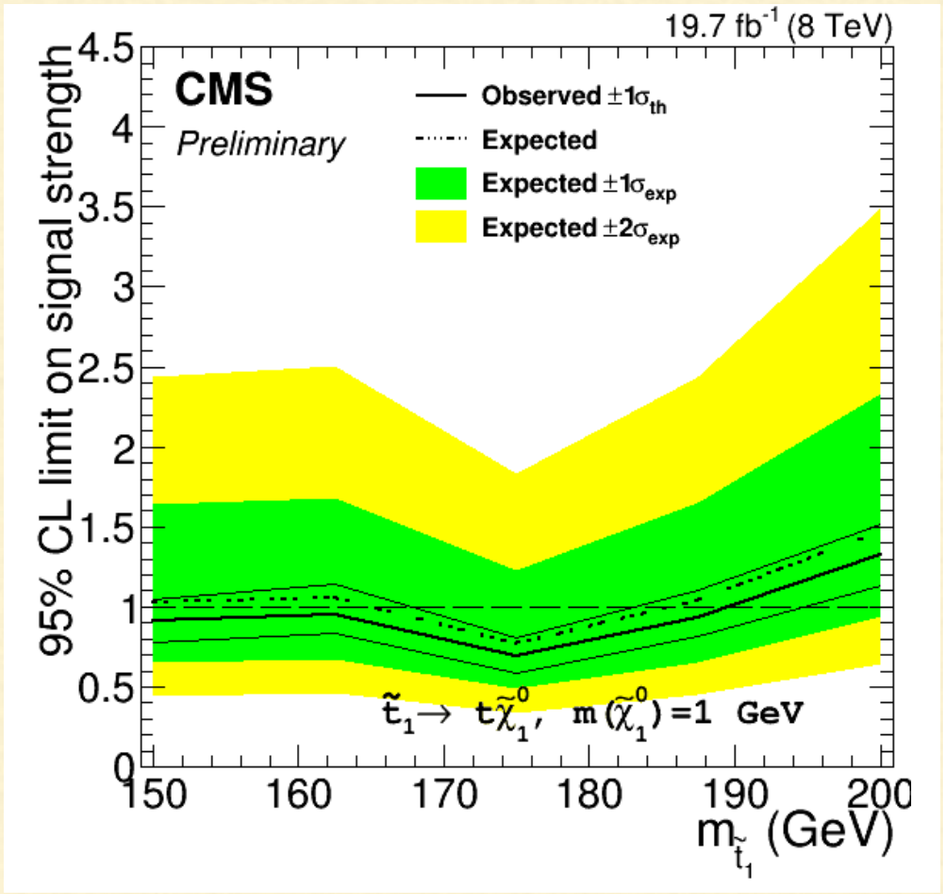
CMS method: template fit

data set: 7TeV + 8TeV

channel: emu OS , 0,1,2,3+ bjet bins

σ(7 TeV) = 174.5 ± 2.1(stat) $^{+4.5}_{-4.0}$(syst) ± 3.8(lumi) pb (+3.6% -3.4%)

σ(8 TeV) = 245.6 ± 1.3(stat) $^{+6.6}_{-5.5}$(syst) ± 6.5(lumi) pb (+3.8% -3.5%)



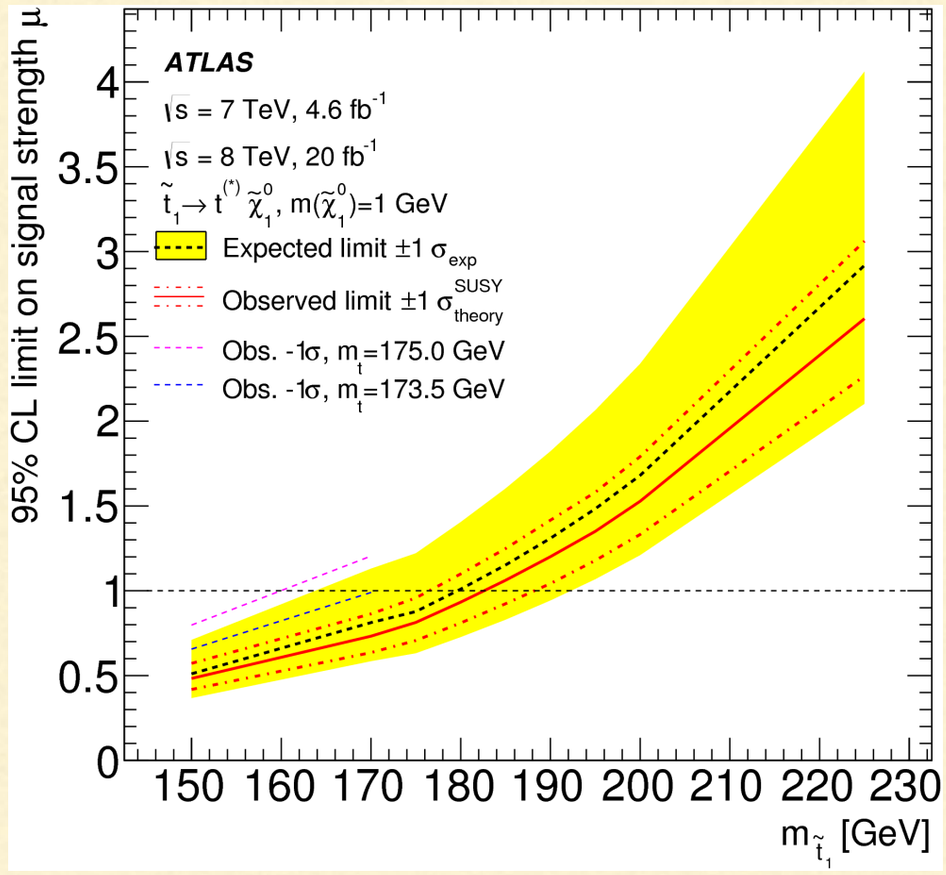
ATLAS method: cut and count

data set: 7TeV + 8TeV

channel: 2L OS, 1, 2 bjets

$\sigma_{t\bar{t}} = 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3\,\text{pb}\ (\sqrt{s} = 7\,\text{TeV})$

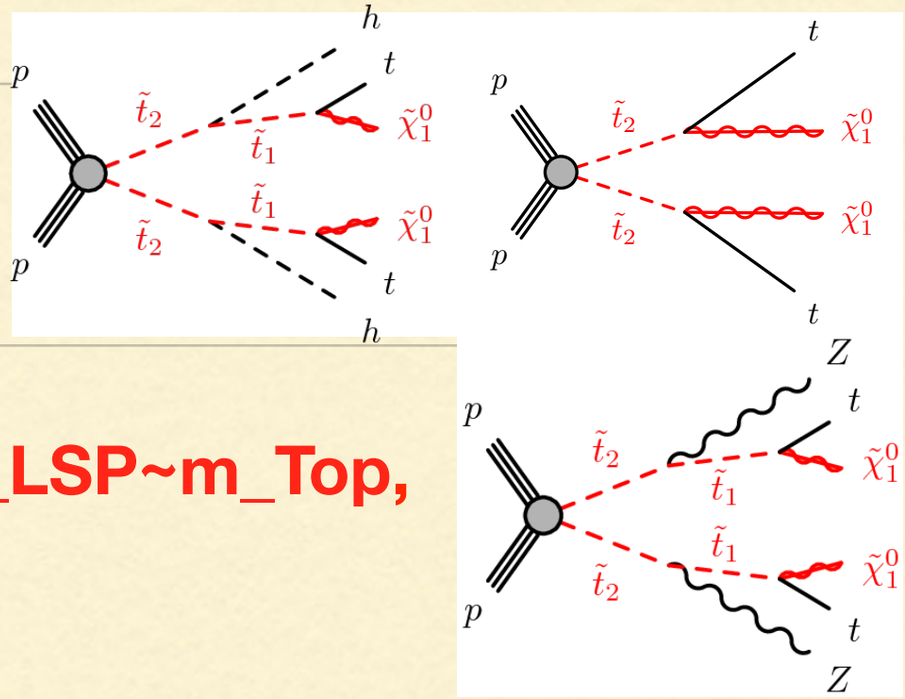
$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}\ (\sqrt{s} = 8\,\text{TeV})$



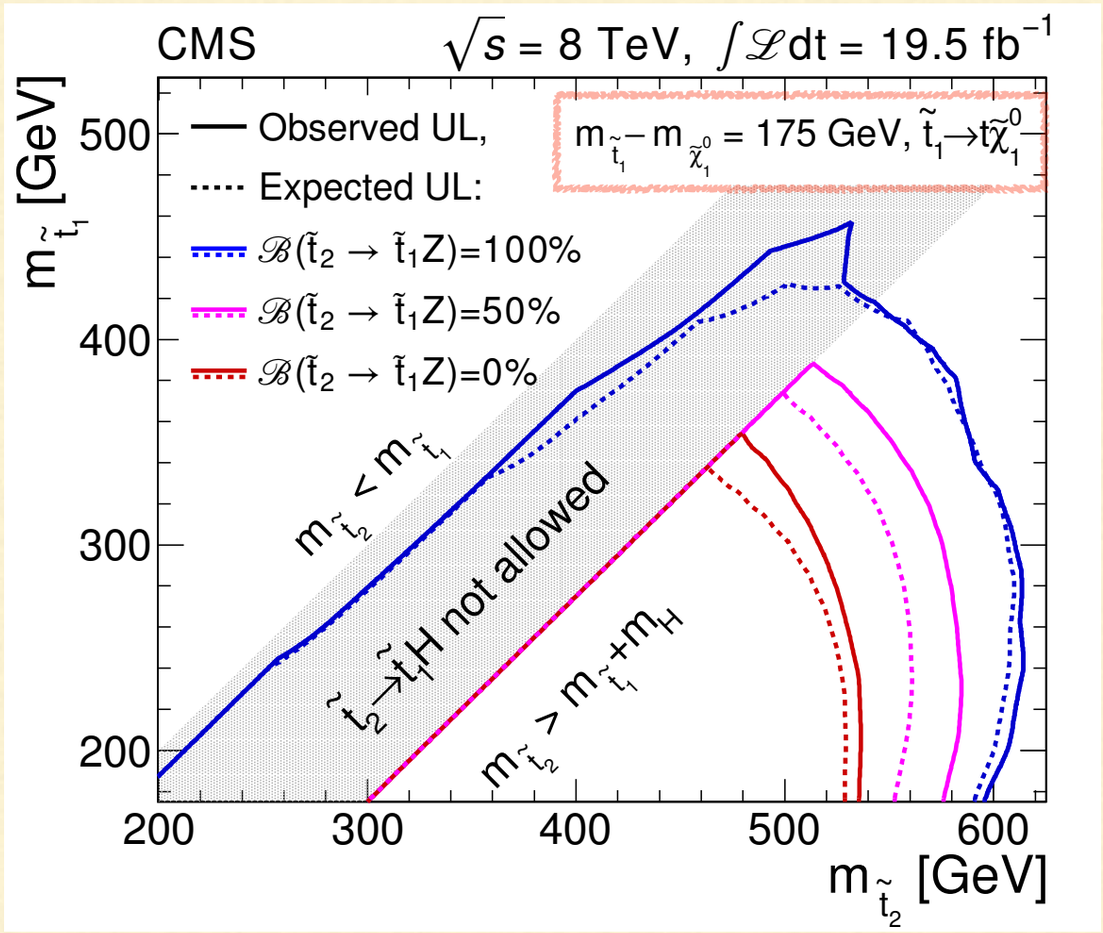
Extra contribution to tT production with soft missing energy – >180 GeV stop-pair contribution is 32 pb at 8 TeV c.f. QCD tT of ~250 pb.

CMS: STOP2 SEARCHES

PLB 736.371



Target the challenging phase space m_Stop1-m_LSP~m_Top, (stealth) stop1 and Z or H.



Final states with H -> bb, ZZ, WW

Selection: 1L, 2L (SS, OS), and ≥3L + b-jet (up to 4),

dominant background: fake leptons, VV.

ATLAS: STOP2 SEARCHES

arXiv: 1506.08616

Final states with Z

2L (SS), 3L(2L OSSF), Z(ll), + jets + 1bjets + Etmiss

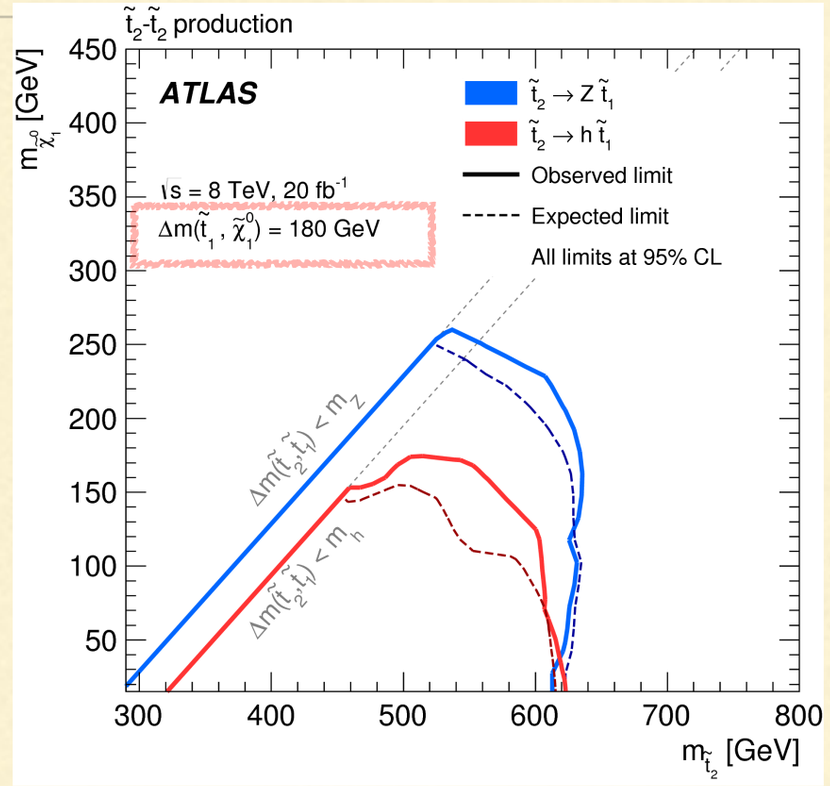
dominant background, ttV, fake leptons.

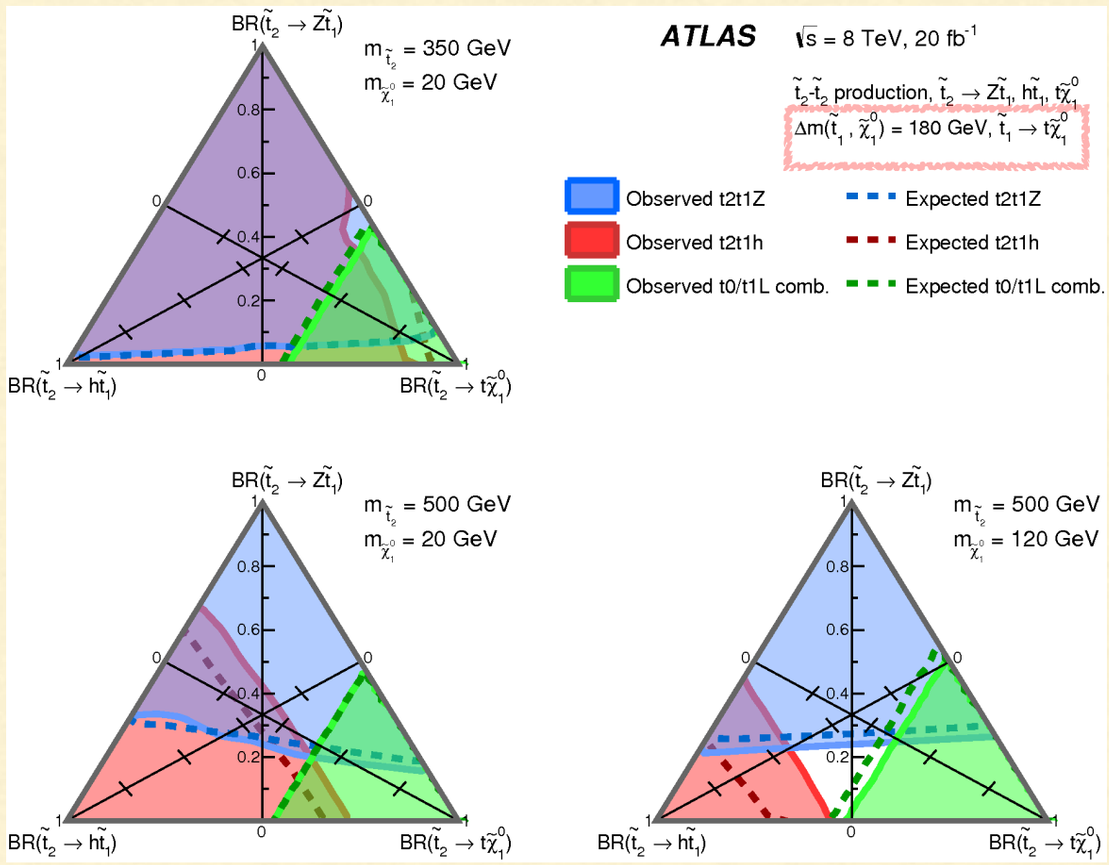
Final states with H

1L , Etmiss > 50 GeV, >=6jets, >=2bjets (binning: 2,3,4+ bjets), mTw > 130GeV, final discriminating variable HT - scalar sum of all jets and etmiss.

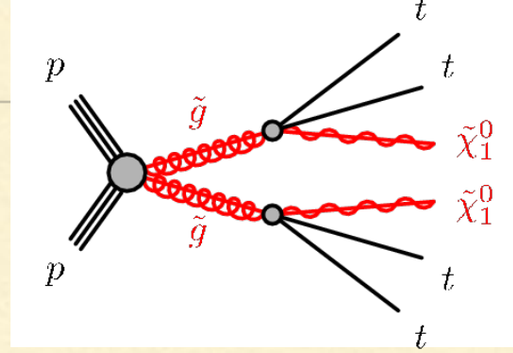
key relevance tthf modelling: tt+bb with POWHEG and reweighted to a full NLO calculation performed in SHERPA 1.4.1+OpenLoops.

ttcc and ttll re-weighting done using 7TeV differential cross section measurement.





GLUINO-MEDIATED STOP PRODUCTION



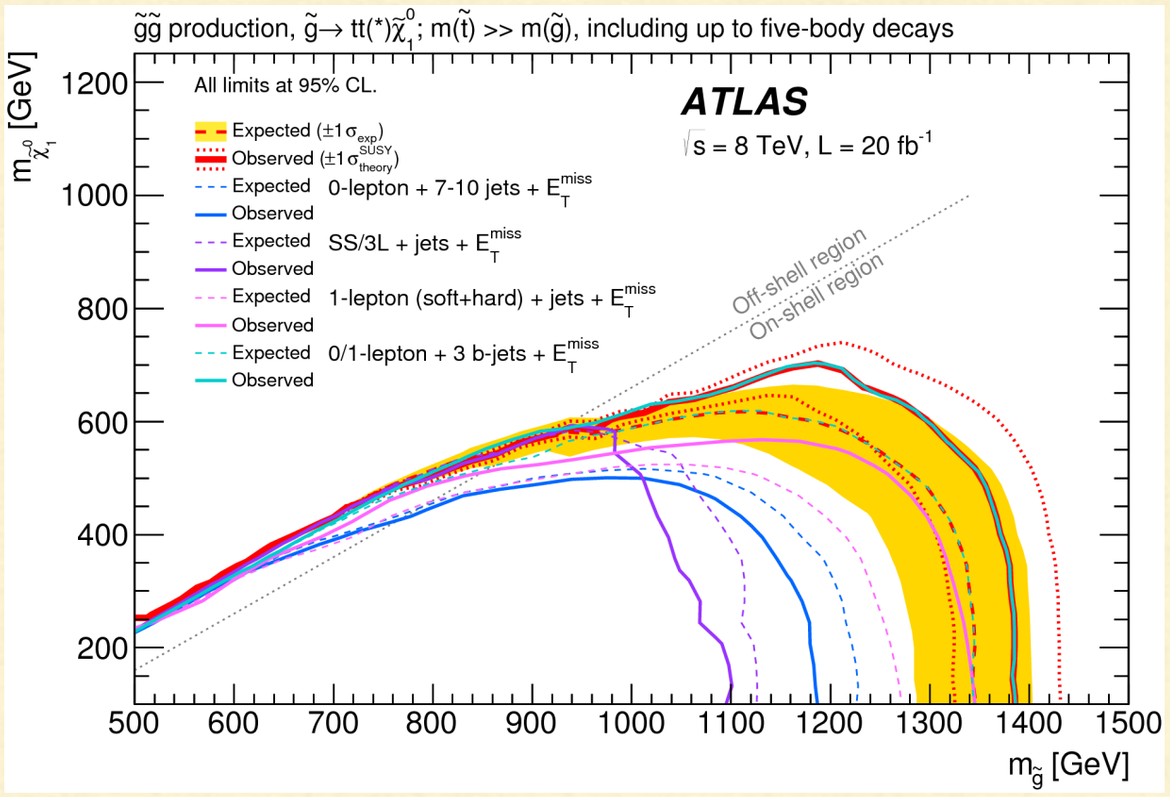
arXiv: 1507.05525

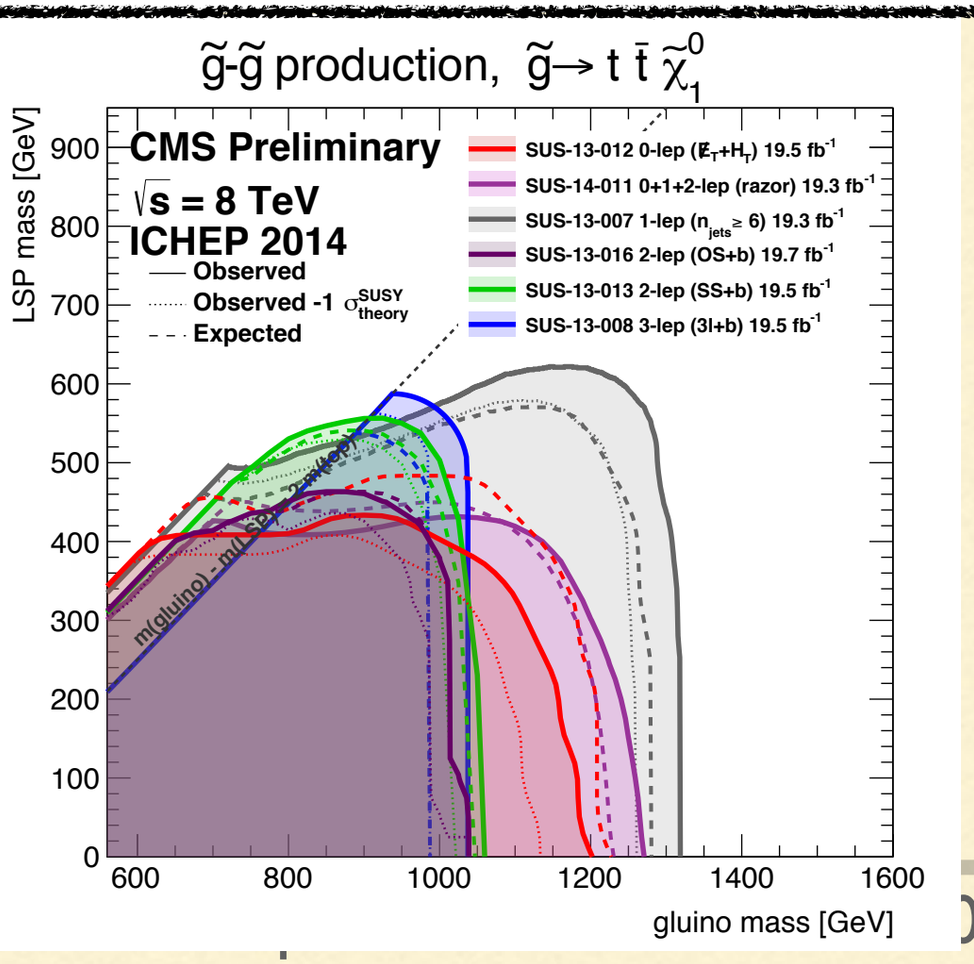
PLB 733.328

Gluino decays via on- or off-shell stop gives 4t + Etmiss => high object multiplicity

0L + ≥4 jets or ≥7 jets, ≥3 bjets
1L + ≥6 jets, ≥3 bjets
High Etmiss, mt, meff (scallar sum of jets+Etmiss)
dominant background, fake b, ttHF, ttZ/h.

1 lepton + 6 jets + 2 *b*-tags
H_T > 400 GeV & $S^{lep} = E/_T + p^{lep}$ > 250 GeV
dominant background: dileptonic tt





INTRODUCTION: DM+HF

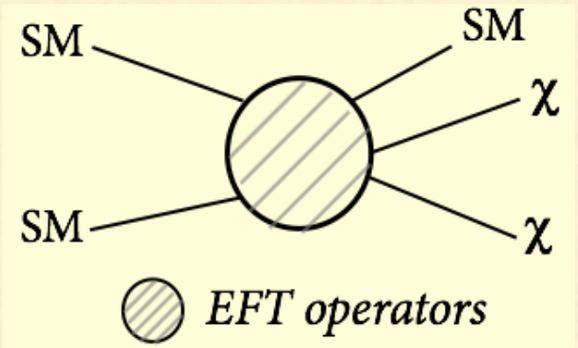
DM likely to be 'non-baryonic cold dark matter' → 'WIMP' → BSM

Properties of low mass DM:

- Pair produced (stable)

- Mediating particle not directly observed → Effective Field Theory(EFT)

WIMP-DM (χ)	ID	interaction	Operator	G_χ
Dirac scalar	D1	quarks	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
Dirac vector	D5	quarks	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
Dirac axial-vector	D8	quarks	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
Dirac tensor	D9	quarks	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
Dirac scalar	D11	gluons	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
complex scalar	C1	quarks	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
complex scalar	C5	gluons	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$

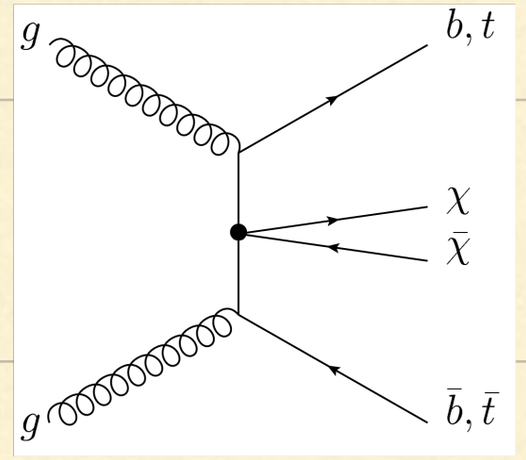


Sensitivity for a scalar interaction can be improved by searching for final states with third generation quarks, two free parameters:

mχ - mass of DM candidate

M* - effective mass scale of the interaction

DM+TT RESULTS

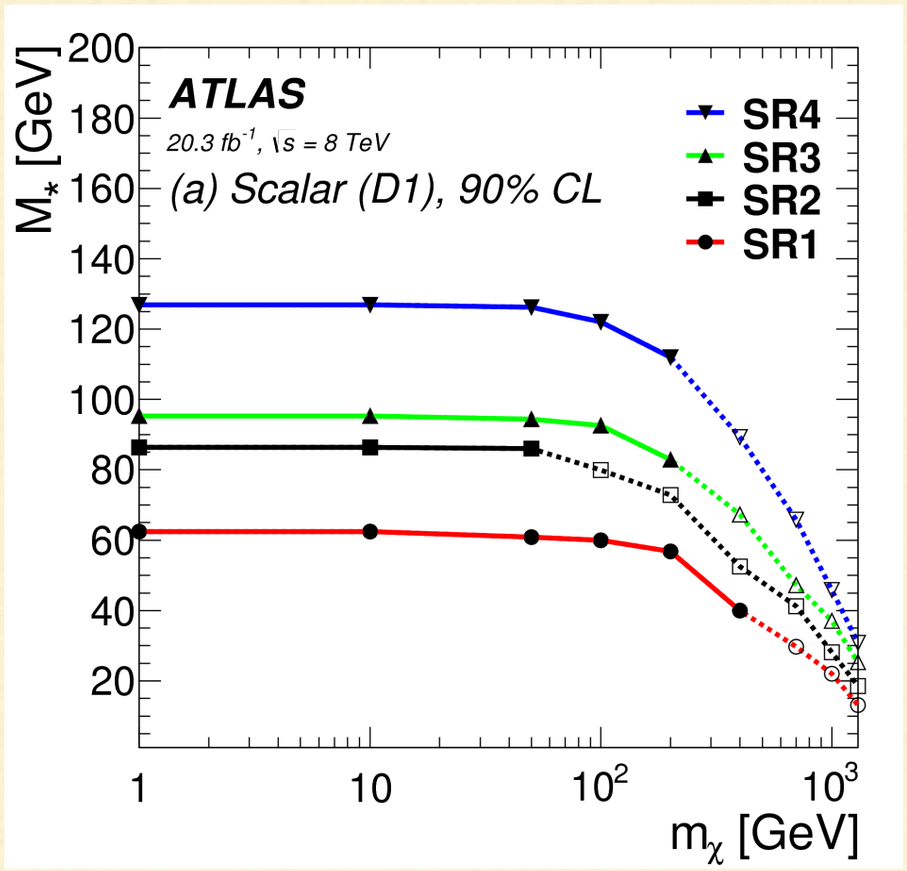


EPJC 75 (2015) 92

ATLAS

==1L, >=4jets, >=1bjets, MET>270GeV,
mT > 130 GeV, amT2 > 190 GeV, topness>2,

dominant background: dileptonic tt

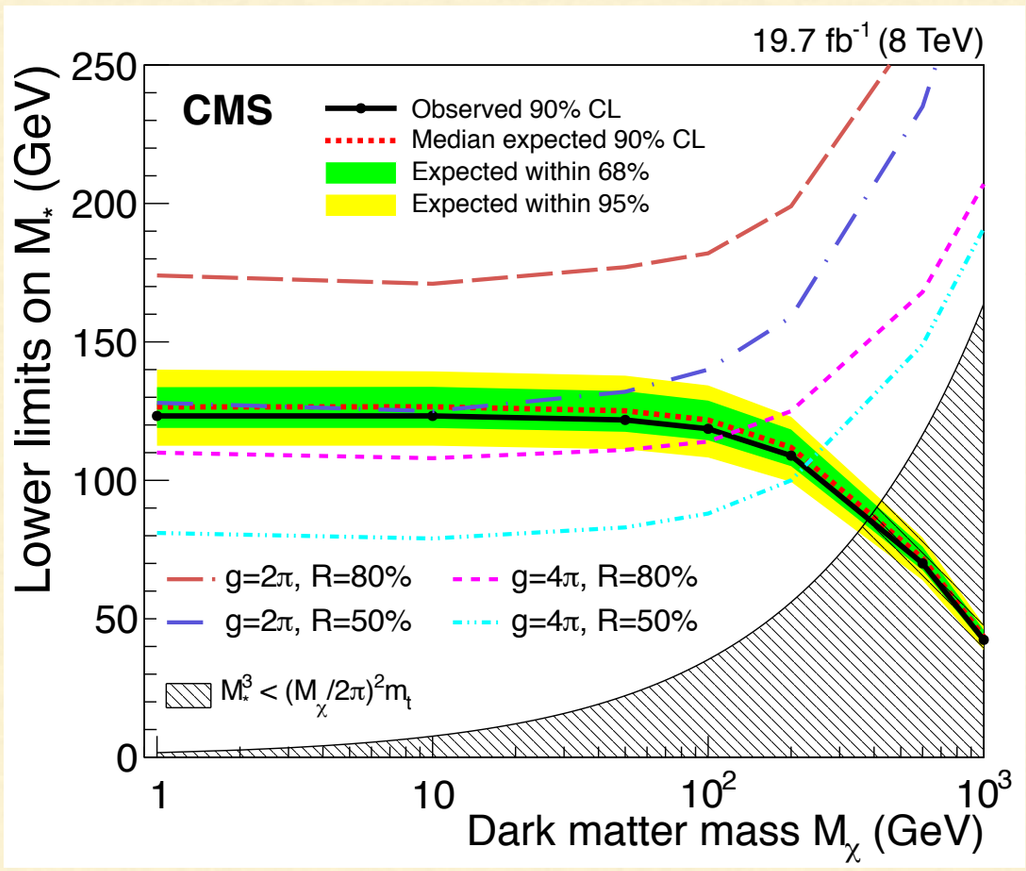


JHEP 06 (2015) 121

CMS

==1L, >=3jets, >=1bjets, MET>320GeV,
mT > 160 GeV, mT2w > 200 GeV

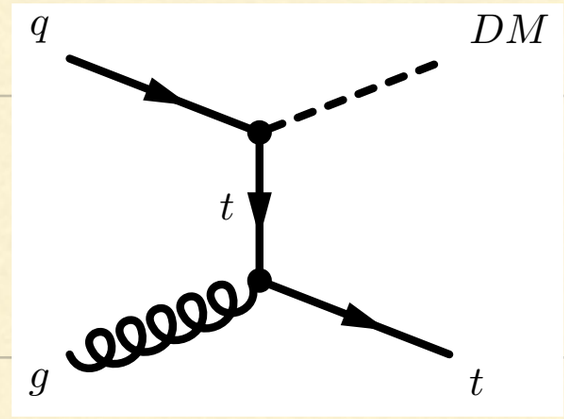
dominant background: dileptonic tt

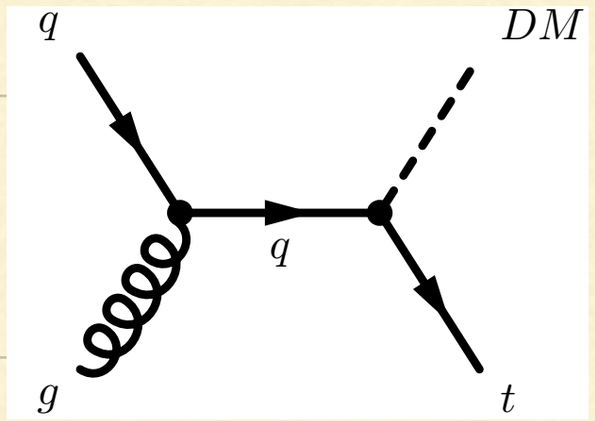


EFT are valid only for high mass mediators (> O(TeV)) and rather light dark matter candidates O(GeV)

CMS: DM+T

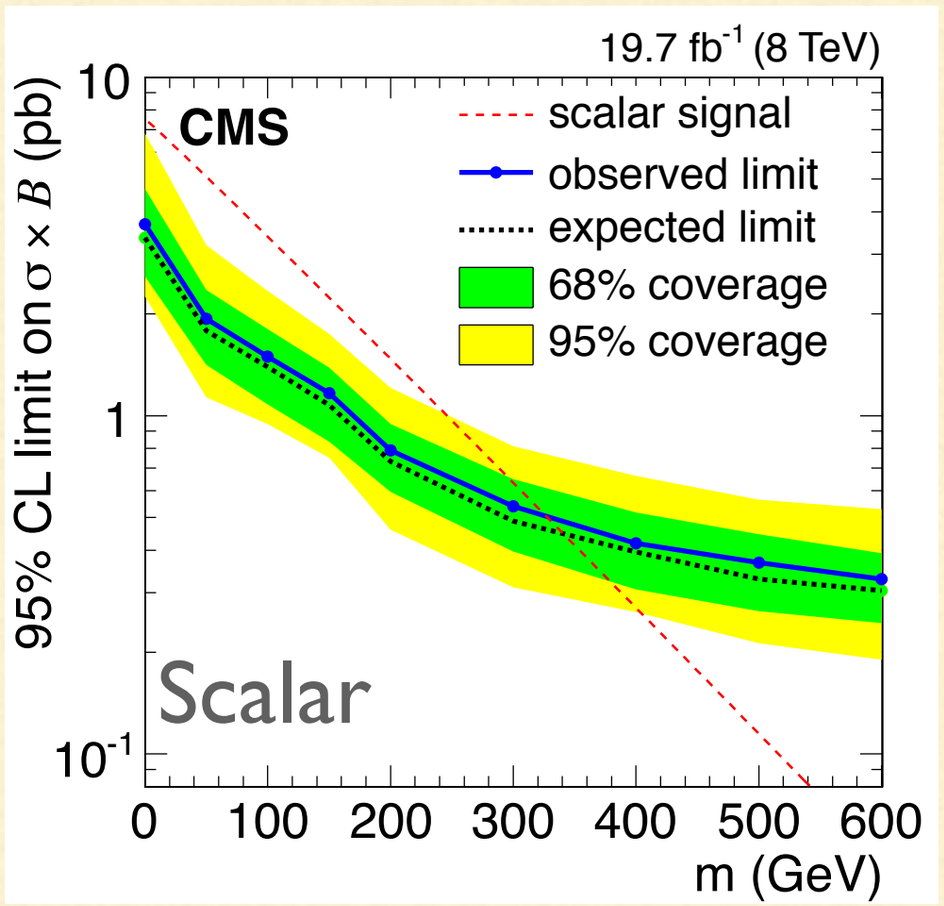
PRL 114 (2015) 101801

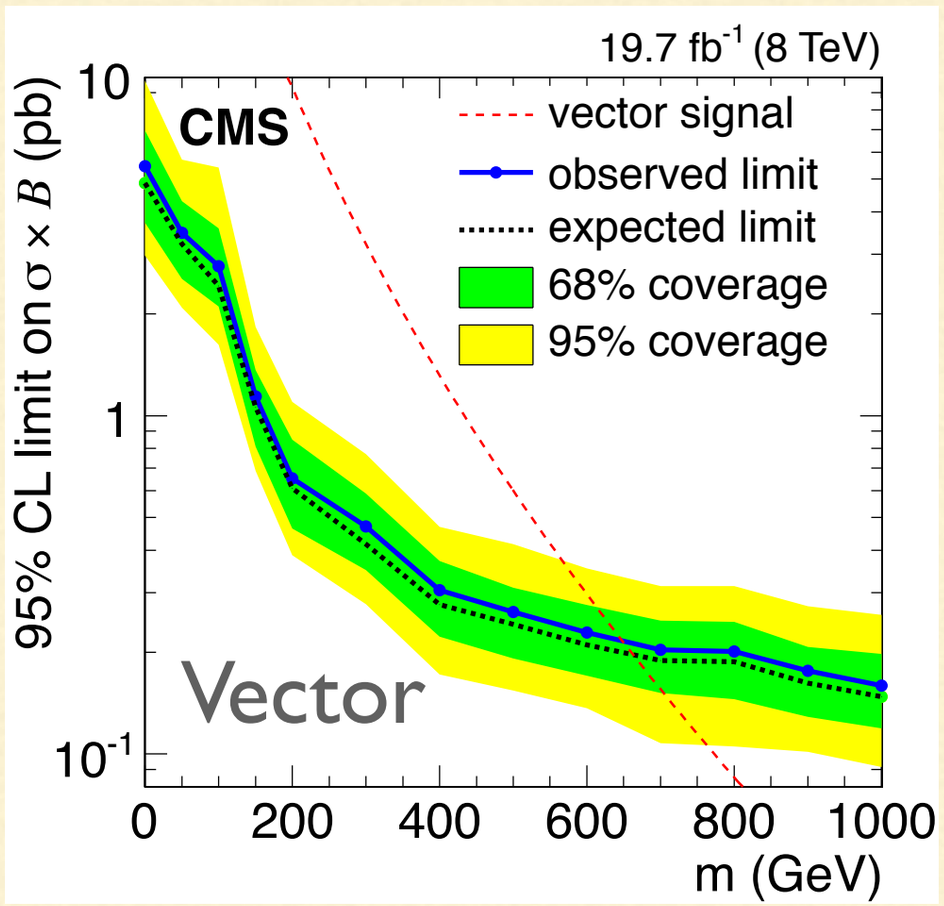




t → bW → bqq'

Selection: 0L, 3jets, mjjj<250GeV, MET>350GeV; dominant background: tt, Vjets.





the observed lower limits on mass for invisible particles are set at 330 GeV (scalar) and 650 GeV (vector). For a coupling constant aFC = 0.2 these limits increase to 530 and 930 GeV .

ATLAS: TOP+INVISIBLE

EPJC (2015) 75:79

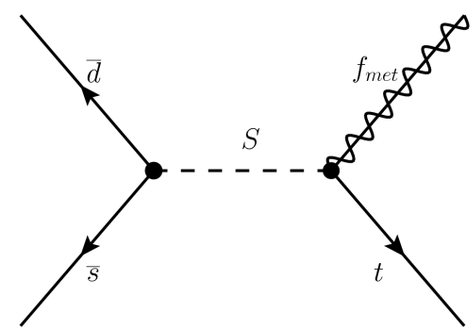
t → bW → blnu

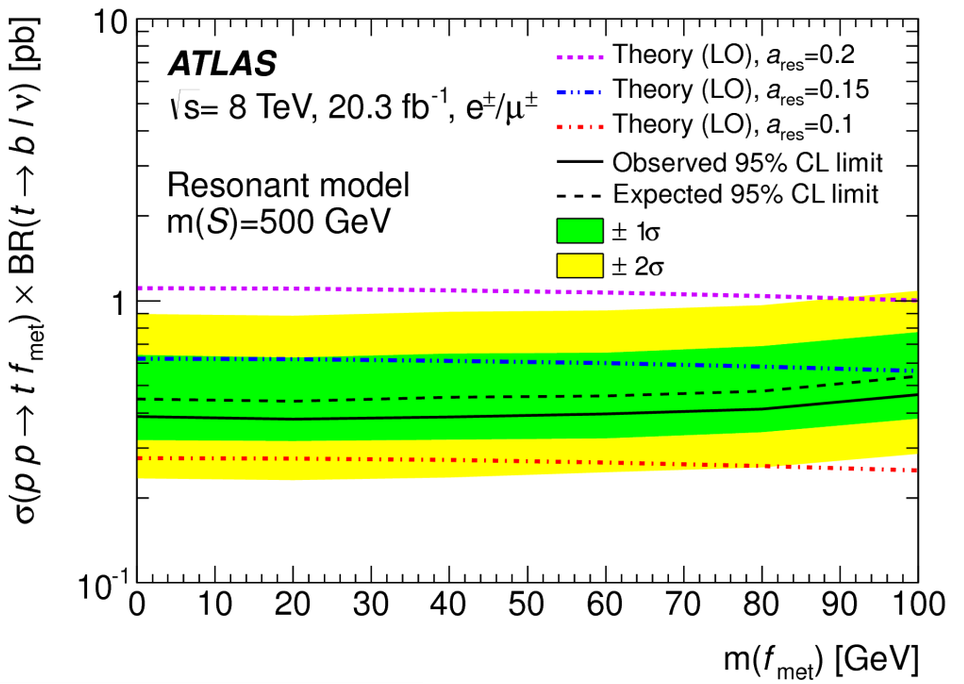
1L + ==1bjet + Etmiss>35GeV

- SRI (resonant model optimisation):
  $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 210$ GeV and $|\Delta\phi(\ell, b)| < 1.2$
- SRII (non-resonant model optimisation):
  $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 250$ GeV and $|\Delta\phi(\ell, b)| < 1.4$

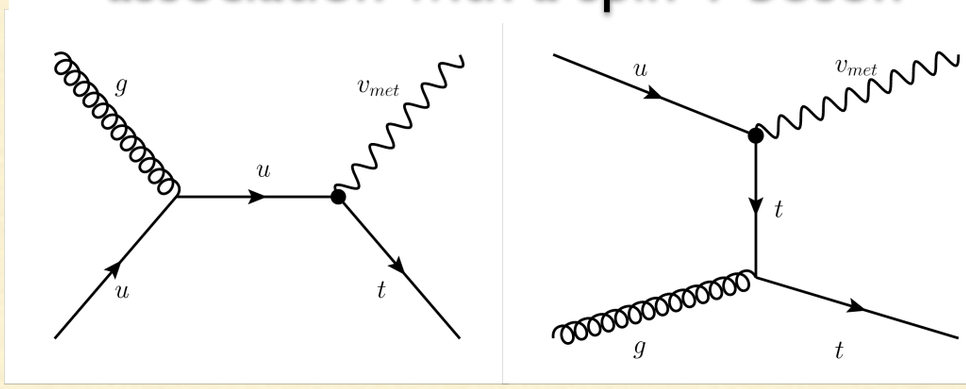
dominant background: dileptonic tt, Wjets

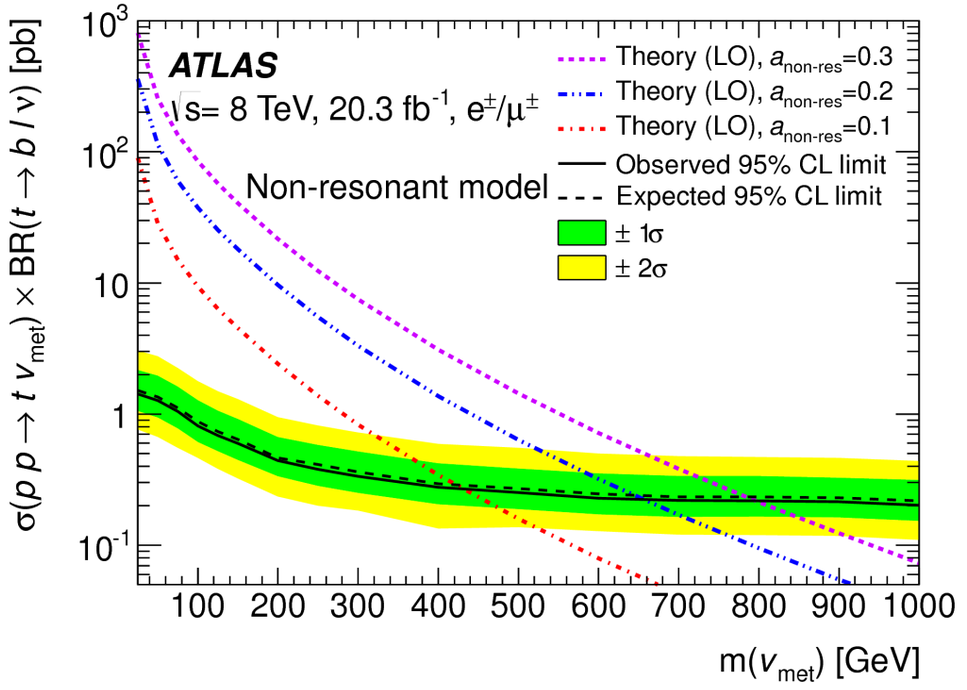
production of a coloured scalar resonance Stop quark and a spin-1/2 fermion





production of a top quark in association with a spin-1 boson





SUMMARY

- Very diverse Top final states in searches, Top+Etmiss, TT+Etmiss, 4Top+Etmiss
- Covering all Top decays, full hadronic, semi-leptonic, dileptonic
- SM Top plus extra Etmiss means not fully reconstructed events, objects out of acceptance or wrong ID
- Most relevant:
  - ~good Top theory modelling in all corners
  - ~Efficient and robust Top reconstruction for all topologies

BACKUP