BSM physics: Strong SuSy production searches at ATLAS & CMS

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ATLAS SUSY searches

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

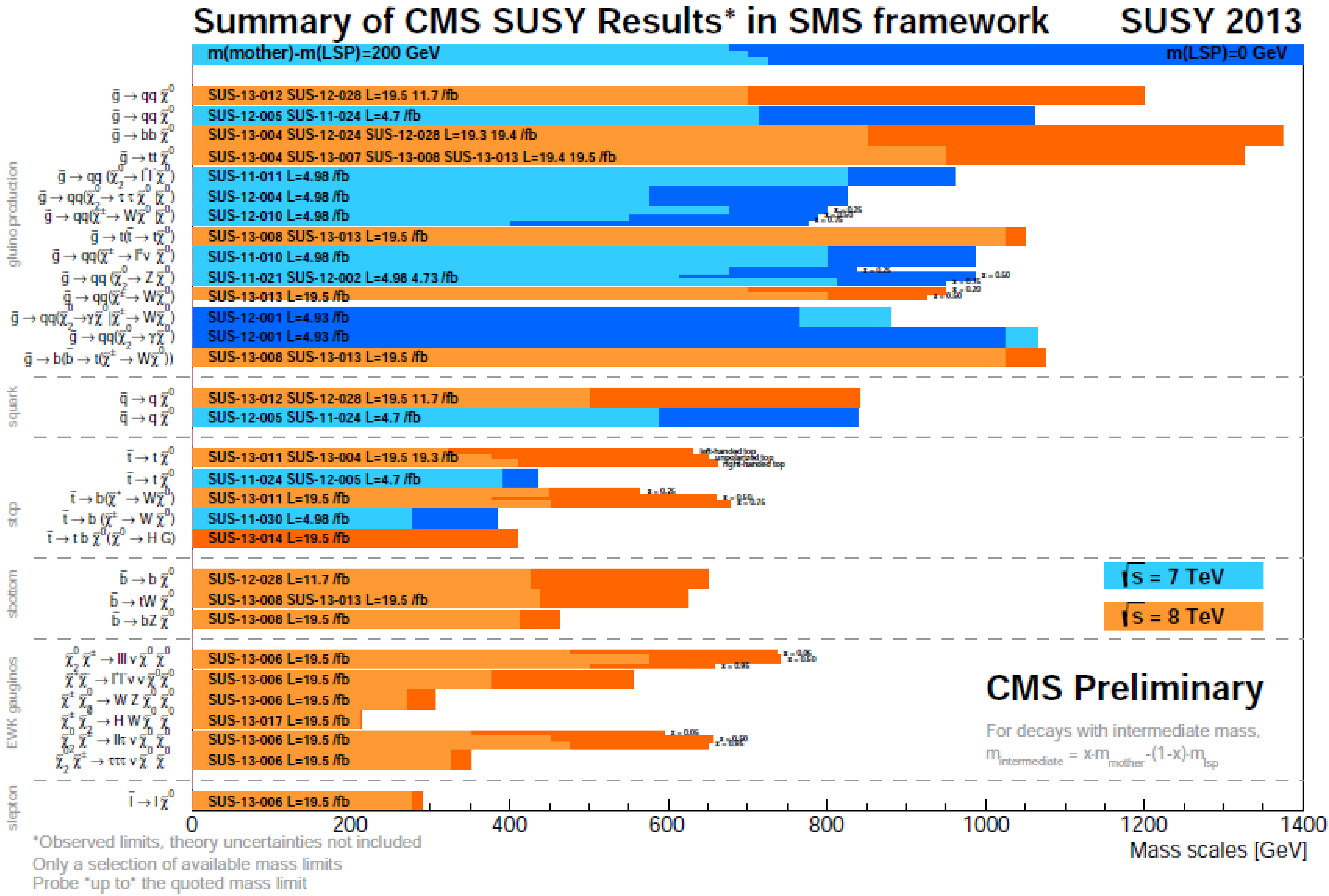
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	740 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm \to qqW^\pm\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	$\tan\beta$<15	1208.4688
	GMSB ($\tilde{\tau}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$	1.4 TeV	$\tan\beta$>18	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	-	Yes	4.8	$\tilde{g}$	1.07 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	1209.0753
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	$m(\tilde{H})$>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	$m(\tilde{g})>10^{-4}$ eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2013-061
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2013-061
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$	275-430 GeV	$m(\tilde{\chi}_1^\pm)=2\, m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-220 GeV	$m(\tilde{\chi}_1^0)=m(\tilde{t}_1)-m(W)$-50 GeV, $m(\tilde{t}_1)<<m(\tilde{\chi}_1^\pm)$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$	225-525 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-065
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e,μ	1 b	Yes	20.7	$\tilde{t}_1$	200-610 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$	320-660 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-200 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV	ATLAS-CONF-2013-068
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$	500 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$	271-520 GeV	$m(\tilde{t}_1)=m(\tilde{\chi}_1^0)$+180 GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	85-315 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	125-450 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	180-330 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	600 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	3 e,μ	0	Yes	20.7	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	315 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	285 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	$m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	22.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	ATLAS-CONF-2013-057
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<$\tan\beta$<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	1 e,μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$	1.2 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.7	$\tilde{\chi}_1^\pm$	760 GeV	$m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.7	$\tilde{\chi}_1^\pm$	350 GeV	$m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0	ATLAS-CONF-2013-036
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$	880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e,μ (SS)	1 b	Yes	14.3	sgluon	800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

CMS SUSY searches



Outline & Scope

Disclaimer: 5+5 results among n for strong Susy production

- ***Gluino** searches*
- ***3rd generation squarks** searches*
  - *The case for*
- *Stop & Sbottom searches*
- *"Naturalness"*
- *Conclusions & prospects*

Results:

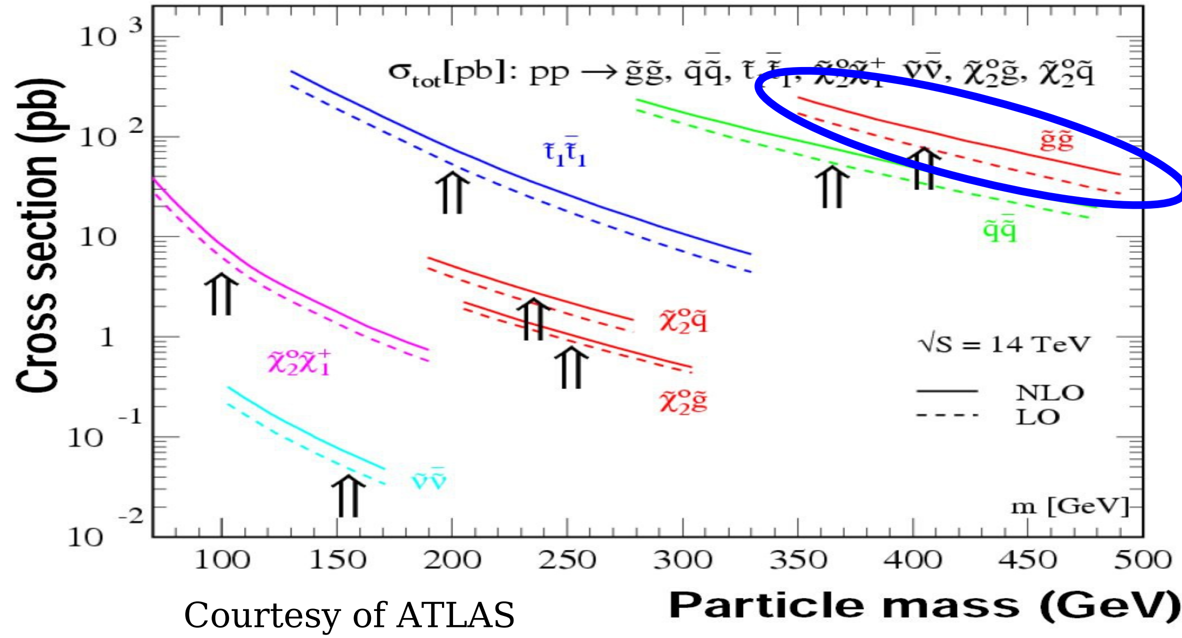
- *Cover the 8 TeV data taking period: ~20 fb^{-1}*
- *Are with R_P conservation hypothesis*
- *90% of cases: Based on simplified models*

Gluino searches

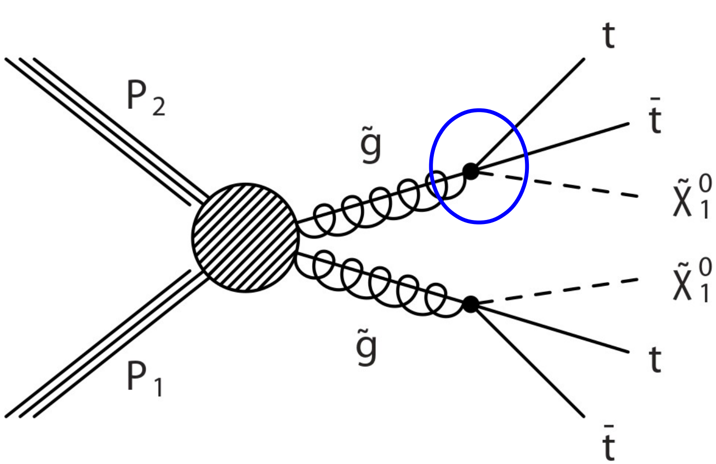
IF SUSY exists
&
IF LHC can produce it:

Gluino pair production:
Most abundant source of
SUSY production @ LHC

Understood to be a well explored avenue in SUSY searches…



Courtesy of ATLAS



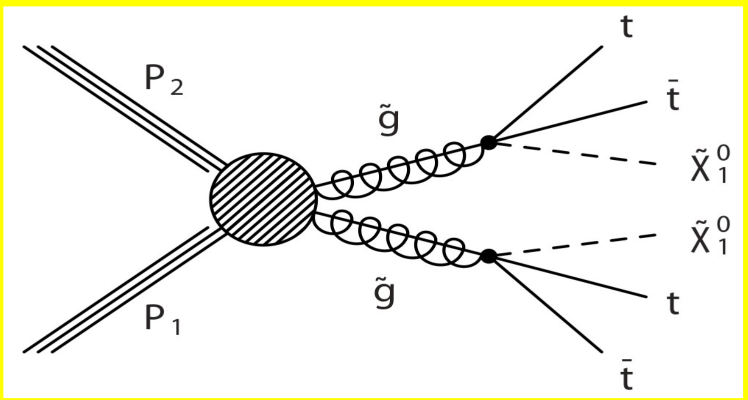
LHC's energy reach allows $\mathbf{\tilde{g} \rightarrow t t \tilde{\chi}^0_1}$:

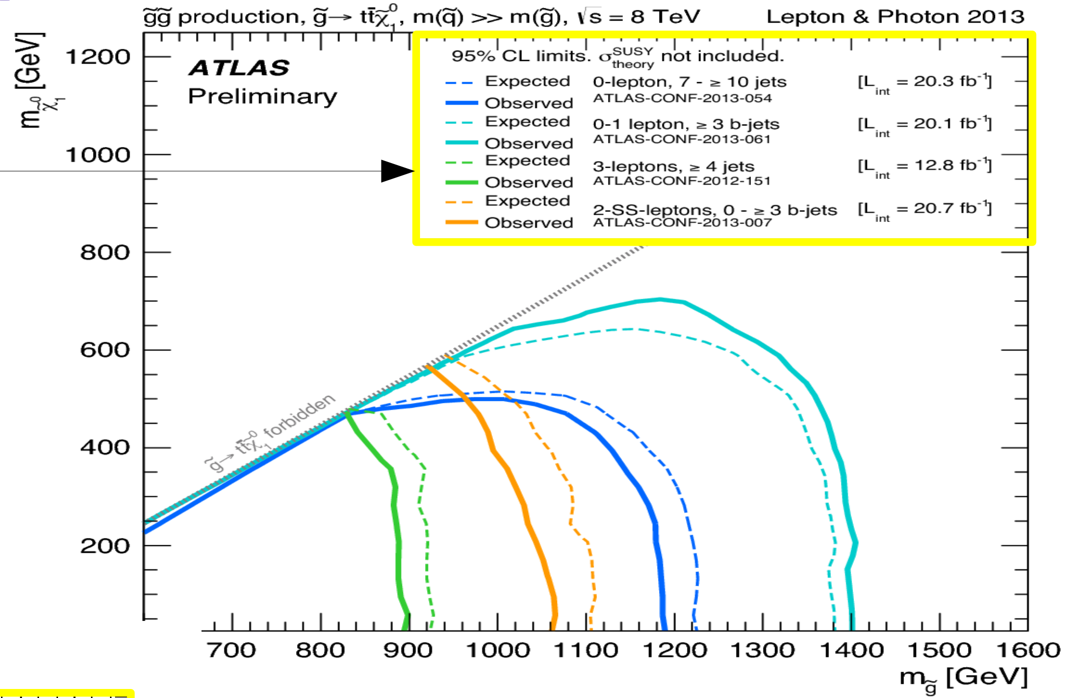
- Rather low background: 4tops
- Cross-checks across 5 final states in case of discovery
- Hypothesis: $m(\tilde{g}) \ll m(\tilde{q})$

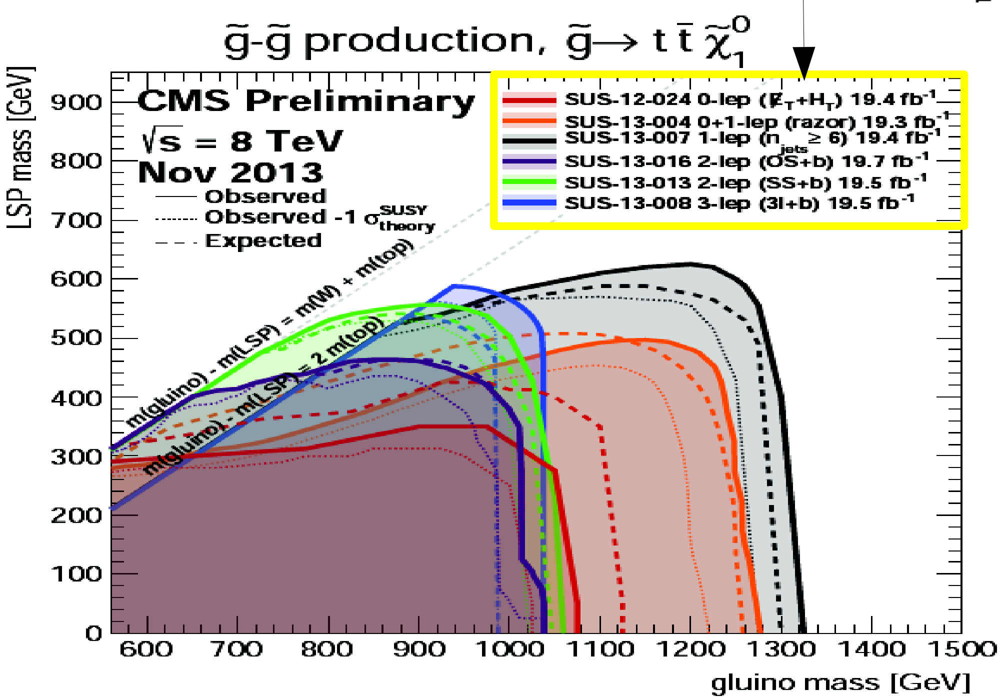
Candle production- & decay-mode for $\tilde{g}$ searches @ LHC

Gluino searches

A production- & decay-mode well explored:





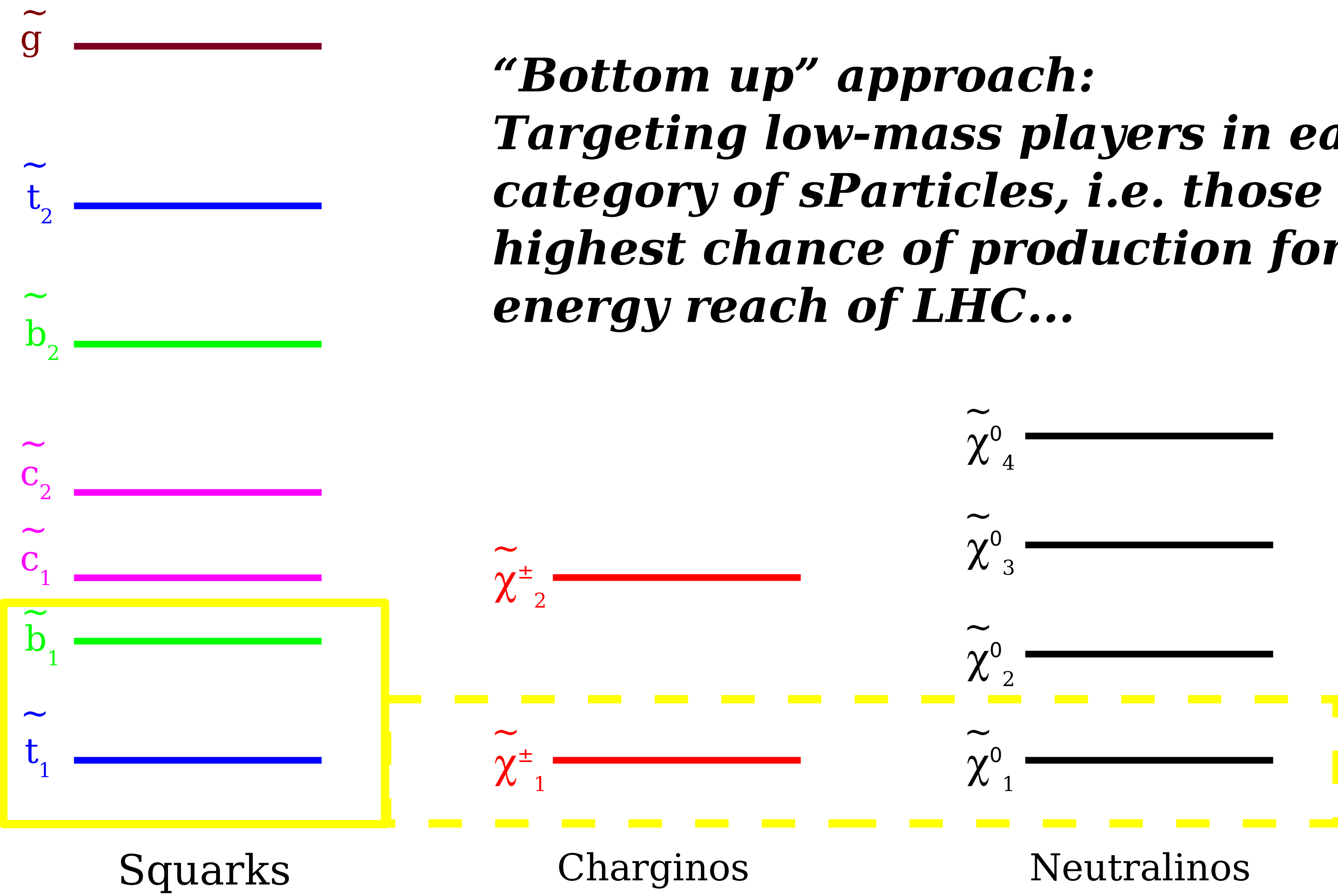


Both experiments have sensitivity to:

- $m(\tilde{g}) \sim O(\mathrm{TeV}/c^2)$!
- for $m(\tilde{\chi}^0{}_1) \sim 700\ \mathrm{GeV}/c^2$

Type of searches

"Bottom up" approach:
Targeting low-mass players in each category of sParticles, i.e. those with highest chance of production for the energy reach of LHC…



The case for 3^{rd} generation squarks

$\tilde{t}_1$: Dynamic reason to be @ bottom of sParticles

MSSM lagrangian with soft breaking terms :

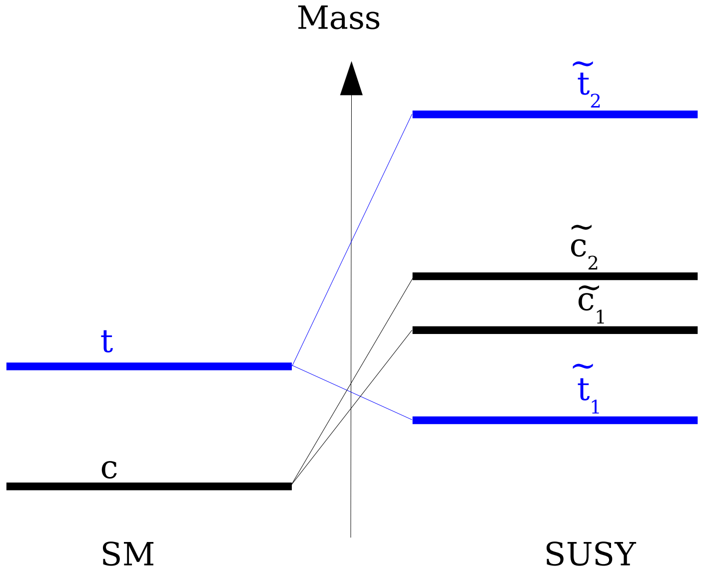
Quark left- & -right superpartners (scalars) can strongly mix to form mass eigenstates :

$$M^2_{\tilde{q}} = \begin{pmatrix} \tilde{M}^2_Q + M^2_Q + M^2_Z(\frac{1}{2} - \frac{2}{3}sin^2\theta_W)cos2\beta & M_Q(A_T + \frac{\mu}{tan\beta}) \\ M_Q(A_T + \frac{\mu}{tan\beta}) & \tilde{M}^2_U + M^2_Q + \frac{2}{3}M^2_Z sin^2\theta_W cos2\beta \end{pmatrix}$$

"Up" squarks

A_T : Tri-linear (stop) mixing term

M_Q = SM quark mass



Mass difference of quark superpartners:
Proportional to $M_Q = M_t$:

Strong mixing in the stops $\tilde{t}_{1,2}$ sector

→ $\tilde{t}_1$ might be the lightest squark

Lightest Neutralino $\tilde{\chi}^0_1$ stable: Natural candidate for Cold Dark Matter

Observed **$\Omega_{CDM}h^2$ = 0.111±0.006 @ 95% CL** (WMAP) well explained

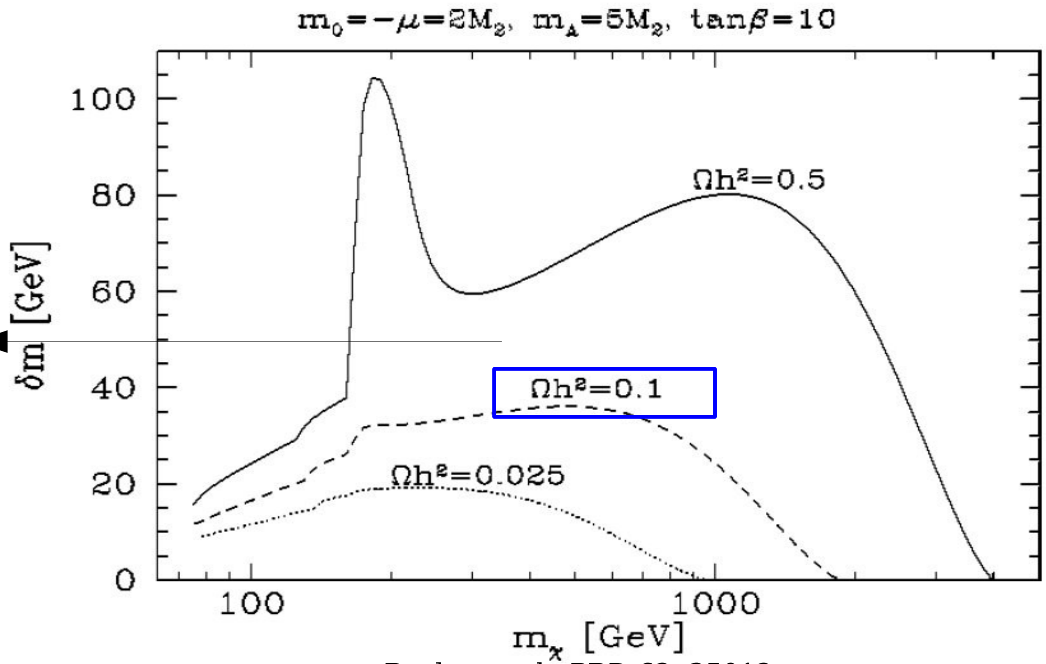
IF $\delta m = m(\tilde{P}) - m(\tilde{\chi}^0_1)$ small: Co-annihilations dominate

- $\tilde{\chi}^0_1 \tilde{t}_1 \rightarrow tg, tH^0_i, bH^+$
- $\tilde{t}_1 \tilde{t}^{(*)}_1 \rightarrow t\bar{t}, gg, H^0_i H^0_j, H^- H^+, b\bar{b}$

Is stop/sbottom degenerate with LSP ?

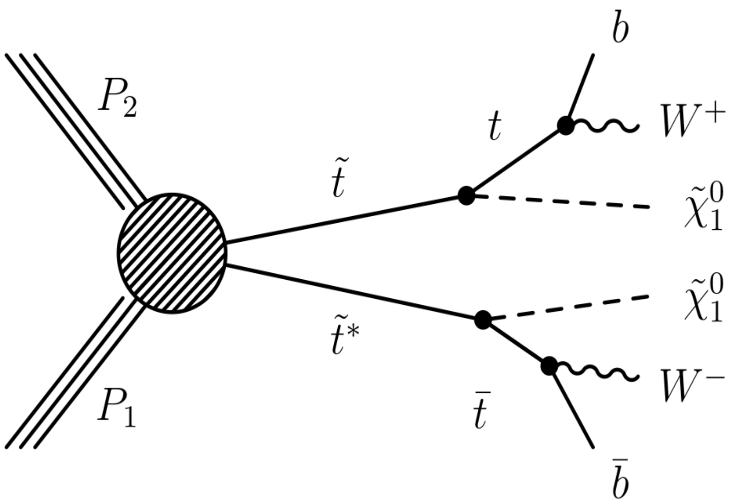
$\Delta m = M(\tilde{t}_1) - M(\tilde{\chi}^0_1) \leq 50\ GeV/c^2$

...Soft decay products



Boehm et al., PRD 62, 35012

Experimental look @



CMS PAS-SUS-13-015

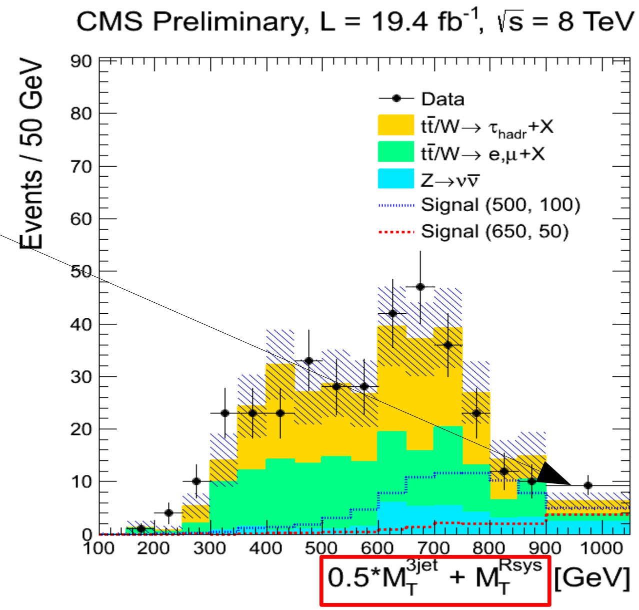
- **Preselection:**
  - Lepton veto
  - $p_T(j_{1,2}) > 70$ $p_T(j_{3,4}) > 50$ $p_T(j_5) > 30$ GeV/c
  - N(b jet)≥1
  - $\Delta\phi(p_T(j_{1,2,3}), p_T^{miss}) > 0.5, 0.5, 0.3$ rad.
  - Trigger: $p_T(j_{1,2}) > 50$ GeV/c & $p_T^{miss} > 80$ GeV

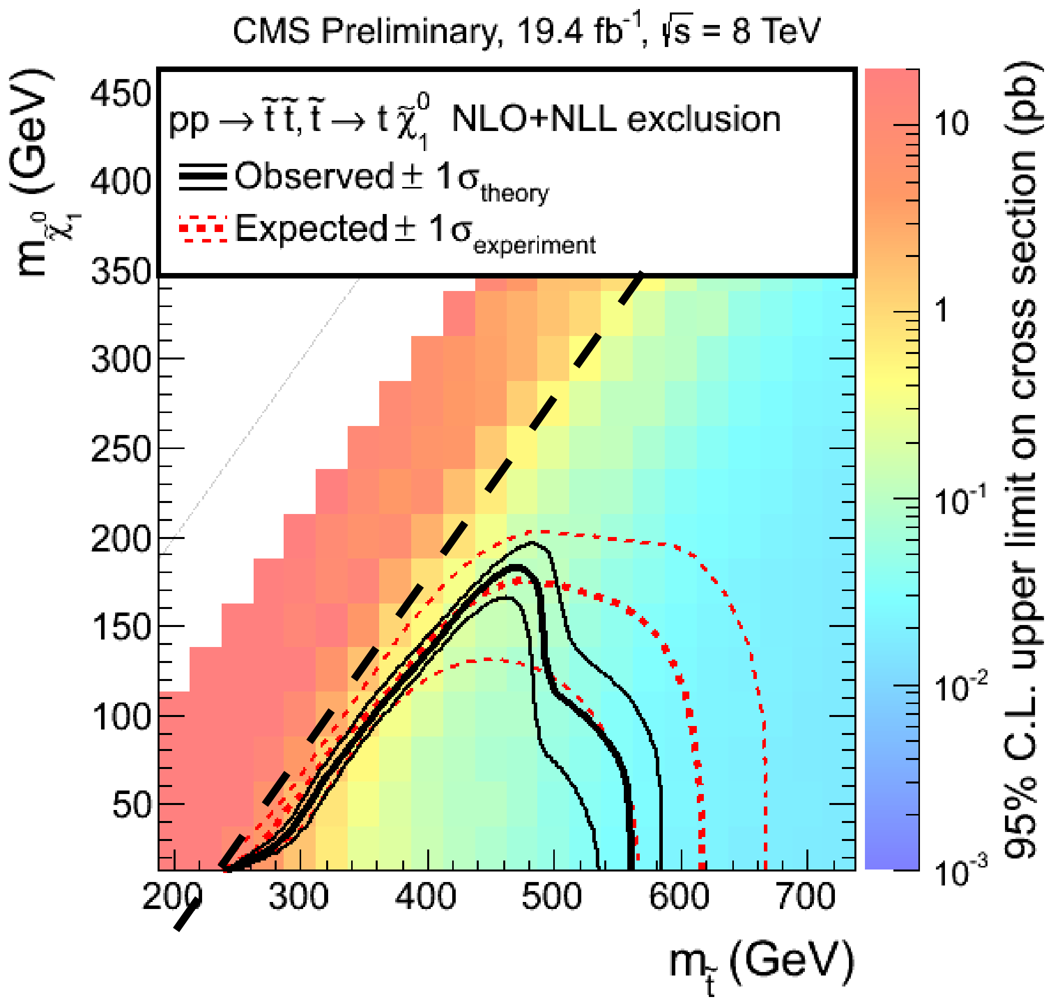
- **Top reconstruction:**
  - *top1*: Full top reconstruction w 3 jets out of ≥5: *3-jet*
  - *top2*: Partial top reconstruction: Remnant jets out of ≥5: *Rsys*
    - Gain signal acceptance while kinematically constraining top
- **Topological requirement:** Form 2 invariant transverse masses assuming invisible particles as massless:
  - $M_T^{3\text{-}jet} = m(3\text{-}jet) \oplus p_T^{miss}$
  - $M_T^{Rsys} = m(Rsys) \oplus p_T^{miss}$

- **Selection:** Cut & Count
  - Topological cut on $(M_T^{3\text{-}jet}, M_T^{Rsys})$
  - Signal Regions (SRs): Defined with N(b jet) & p_T^{miss}

$\tilde{t}_1$ all hadronic: Topological selection. Interpretation

- Interesting S↔B separation by topological view across 2 kinematic variables
- No excess observed in Data, further confirmed in SRs (backup)

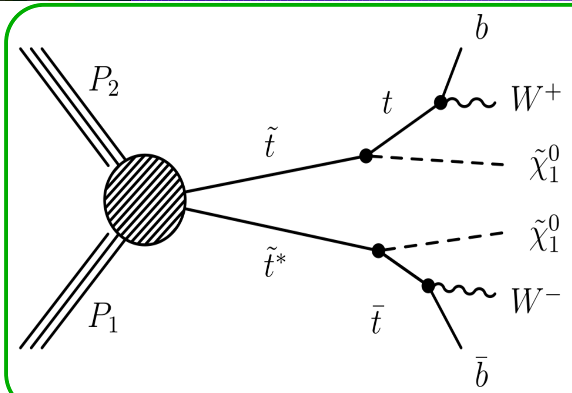


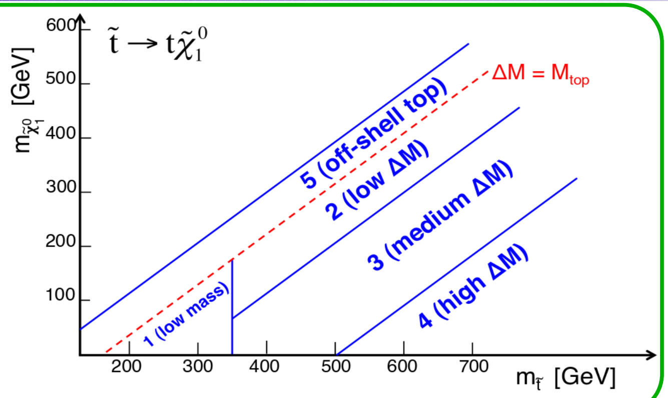


- **$\tilde{t}_1 \rightarrow t\,\tilde{\chi}^0_1$ w on-shell top**: Comparable sensitivity from other signatures
- **$\tilde{t}_1 \rightarrow t^*\,\tilde{\chi}^0_1$ w off-shell top:** $m(\tilde{t}_1) < m(t)+m(LSP)$:

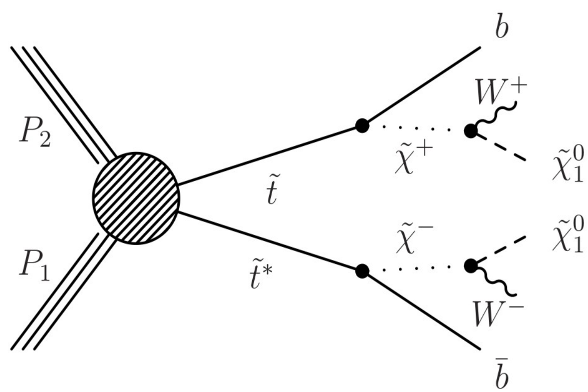
  No sensitivity because top kinematics reconstruction

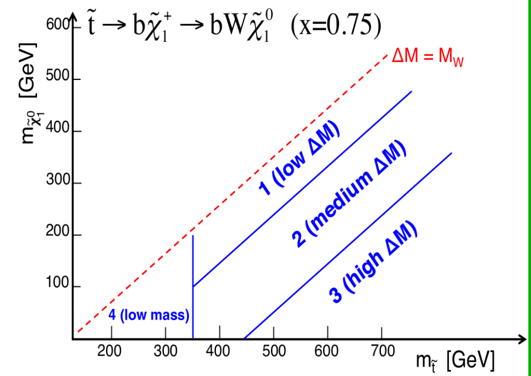
$\tilde{t}_1$ semi-leptonic: 2 decay modes & Δm



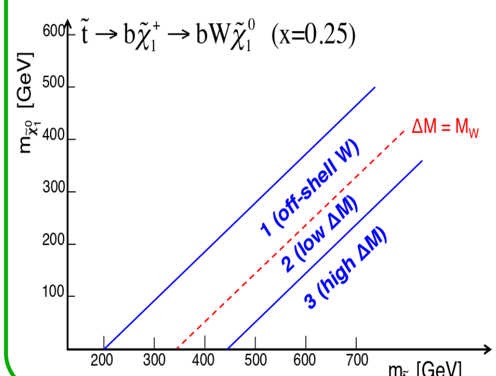


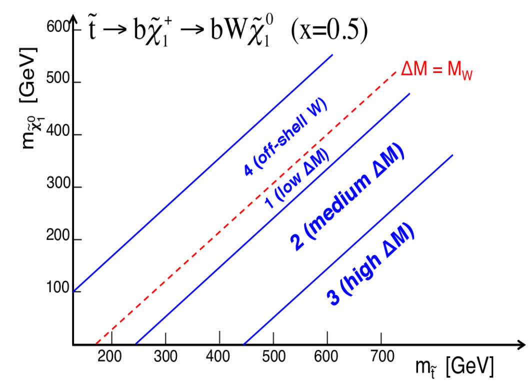
CMS
EPJC 73 (2013) 2677





Phenomenology, i.e. difference of kinematics vs
1) decay-modes
2) masses regions
→ Selection

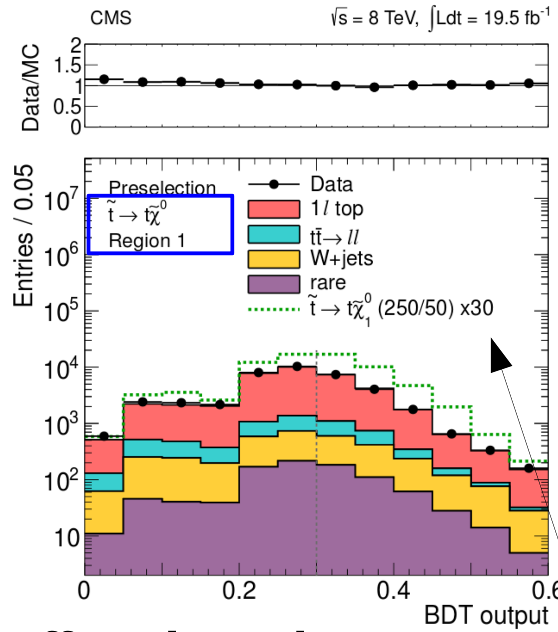


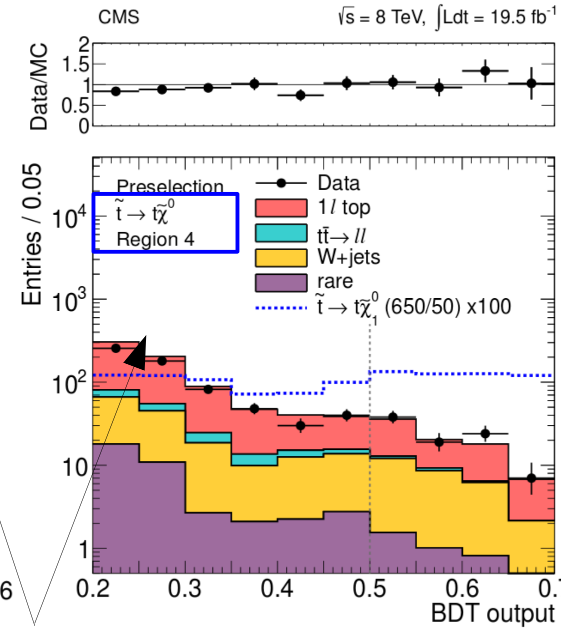


$\tilde{t}_1$ semi-leptonic: Selection

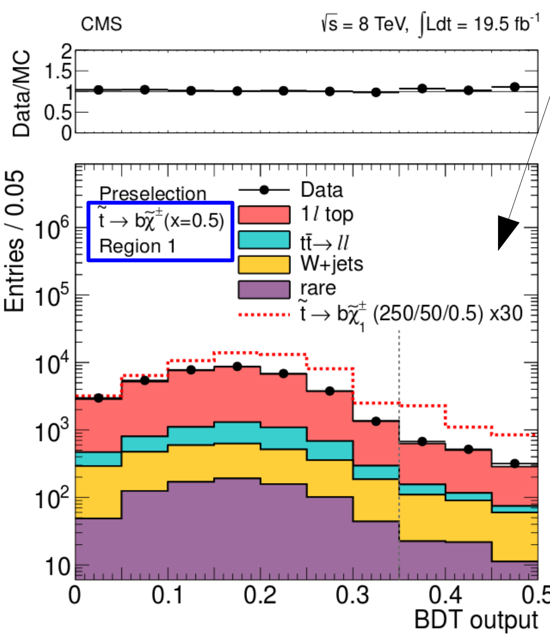
Preselection:

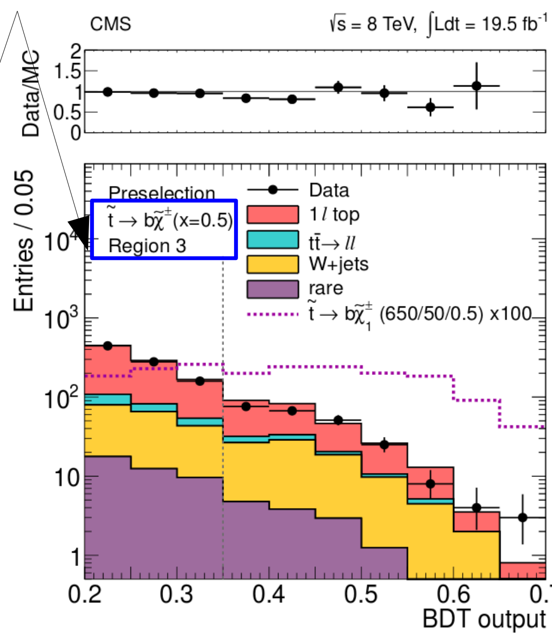
- $p_T(e,\mu)>30$ GeV/c
- N(jet)≥4 w $p_T(j)>30$ GeV/c
- N(b jet)≥1
- MET>100 GeV
- $M_T>150$ GeV: Reduces ttbar(1l)





Clear Δm effect through BDT output



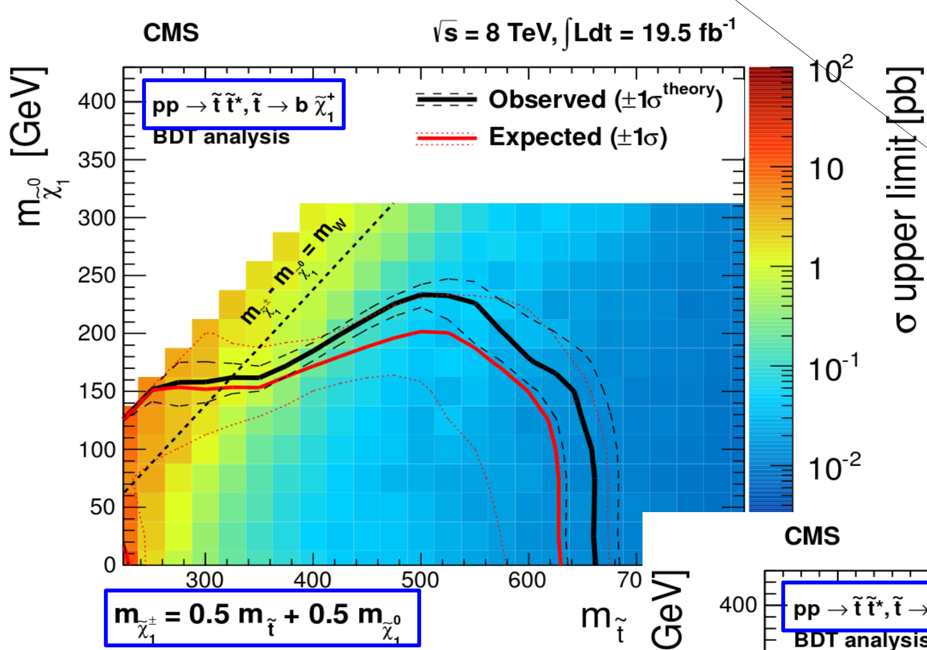


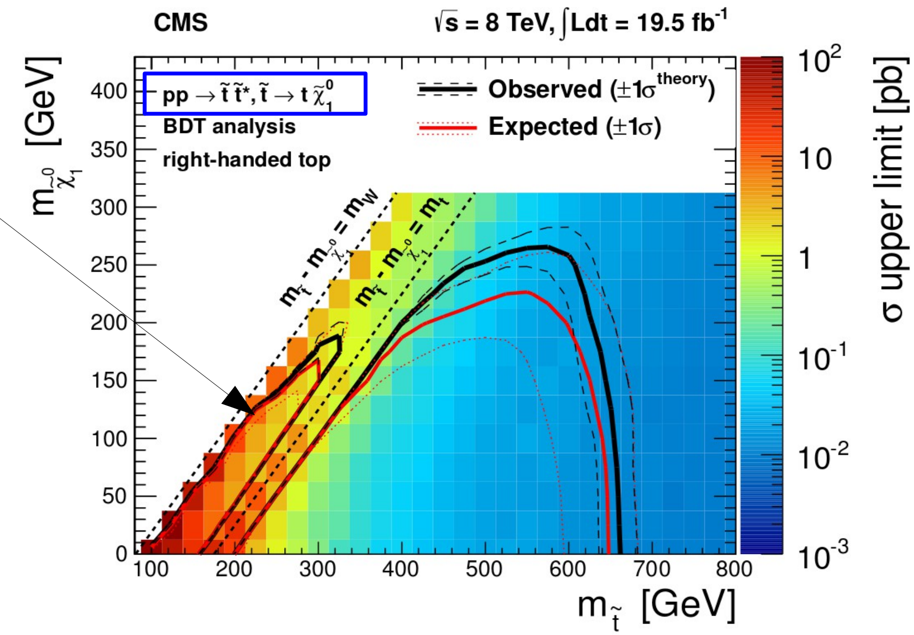
Selection:
Boosted Decision Tree

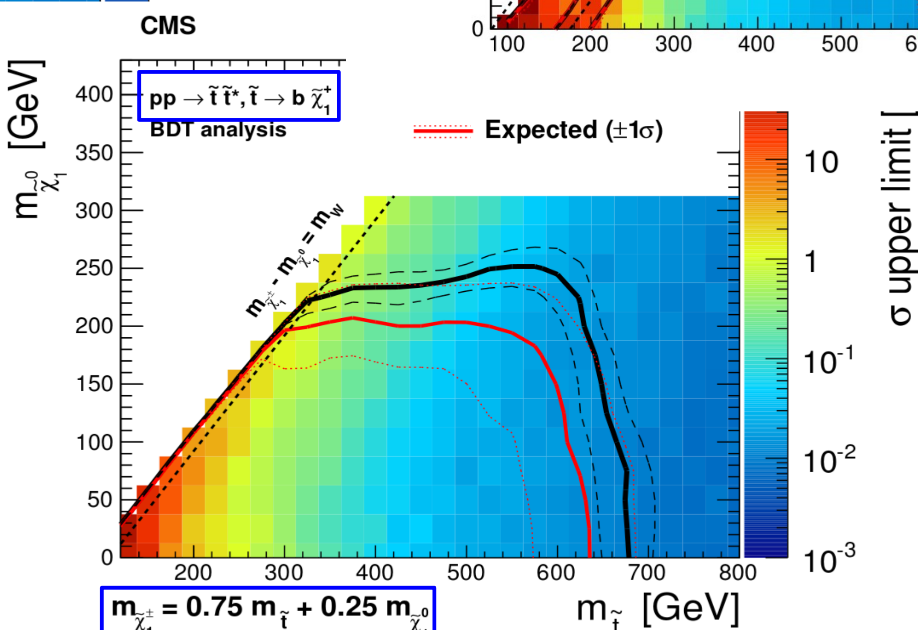
- Topological & kinematic variables fed to BDT
- Signal Regions (SRs): Specific BDT training / Δm

$\tilde{t}_1$ semi-leptonic: Interpretation for $\tilde{t}_1 \to t\,\tilde{\chi}^0_1$, $b\,\tilde{\chi}^\pm_1$

- Sensitivity at low Δm: Selection variables independent of top reco.
- Specific BDT training for t* region: Sensitivity up to $m(\tilde{\chi}^0_1)$~180 GeV/c^2







$\tilde{t}_1$ & $\tilde{b}_1$: 0 lepton + 2b + MET

Selection: Cut & Count. Same final state:

- Scrutinized by topological & kinematic variables
- SRs: 2: For high & low $\Delta m = m(\tilde{t}_1/\tilde{b}_1) - m(\tilde{\chi}^0_1)$, both interpreted for direct $\tilde{t}_1$ ($b\tilde{\chi}^{\pm}_1$) & $\tilde{b}_1$ production

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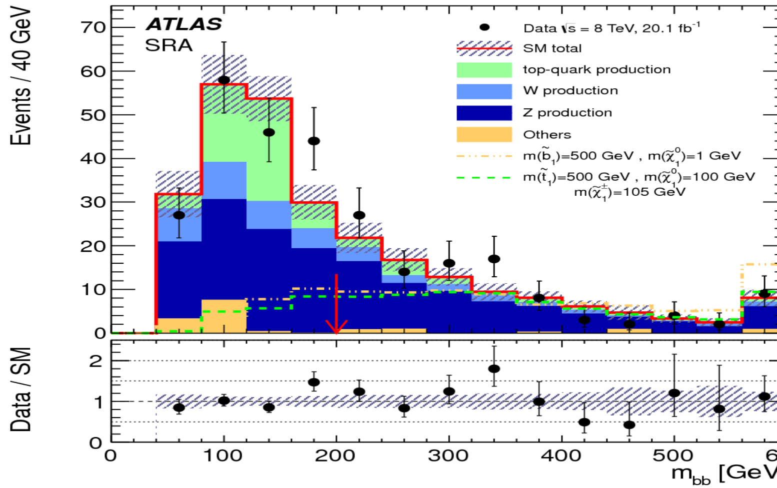
m(bb):
Invariant mass of the 2 b-tagged jets

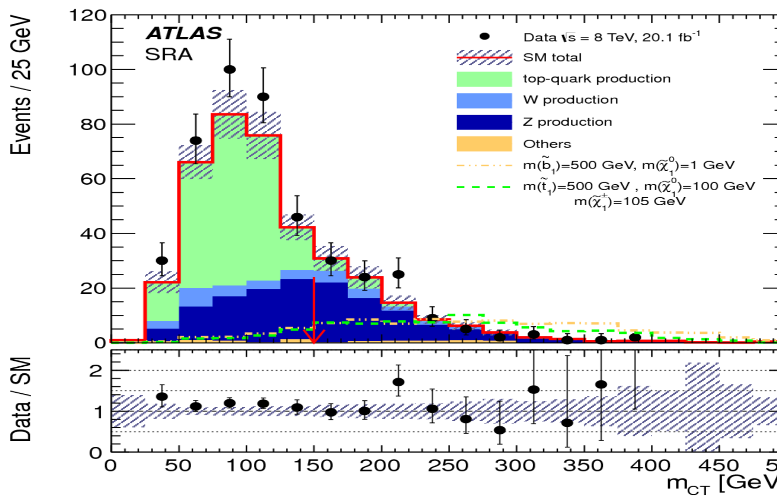
$\mathbf{m^2_{CT}(v_1,v_2)} = [E_T(v_1)+E_T(v_2)]^2 - [p_T(v_1)-p_T(v_2)]^2$:
Measure masses of pair-produced semi-invisibly decaying heavy particles:
$\tilde{t}_1/\tilde{b}_1 \rightarrow X\ \chi^0_1$

$$\Delta\phi_{\min} = \min\left(|\phi_1 - \phi_{p_T^{miss}}|, |\phi_2 - \phi_{p_T^{miss}}|, |\phi_3 - \phi_{p_T^{miss}}|\right)$$

$$m_{\mathrm{eff}}(k) = \sum_{i=1}^{k} (p_T^{\mathrm{jet}})_i + E_T^{\mathrm{miss}}$$: Both reduce multijet

$$H_{T,3} = \sum_{i=4}^{n} (p_T^{\mathrm{jet}})_i$$





High Δm

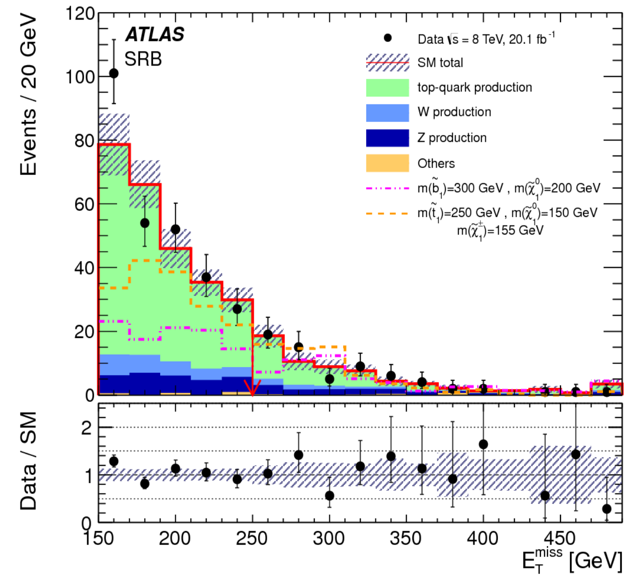
Low Δm

Description	Signal Regions	
	SRA	SRB
Event cleaning	Common to all SR	
Lepton veto	No e/μ after overlap removal with $p_T > 7(6)$ GeV for $e(\mu)$	
E_T^{miss}	> 150 GeV	> 250 GeV
Leading jet $p_T(j_1)$	> 130 GeV	> 150 GeV
Second jet $p_T(j_2)$	> 50 GeV,	> 30 GeV
Third jet $p_T(j_3)$	veto if > 50 GeV	> 30 GeV
$\Delta\phi(p_T^{miss}, j_1)$	-	> 2.5
b-tagging	leading 2 jets ($p_T > 50$ GeV, $\|\eta\| < 2.5$)	2nd- and 3rd-leading jets ($p_T > 30$ GeV, $\|\eta\| < 2.5$)
	$n_{b\text{-jets}} = 2$	
$\Delta\phi_{min}$	> 0.4	> 0.4
$E_T^{miss}/m_{eff}(k)$	$E_T^{miss}/m_{eff}(2) > 0.25$	$E_T^{miss}/m_{eff}(3) > 0.25$
m_{CT}	$> 150, 200, 250, 300, 350$ GeV	-
$H_{T,3}$	—	< 50 GeV
m_{bb}	> 200 GeV	—

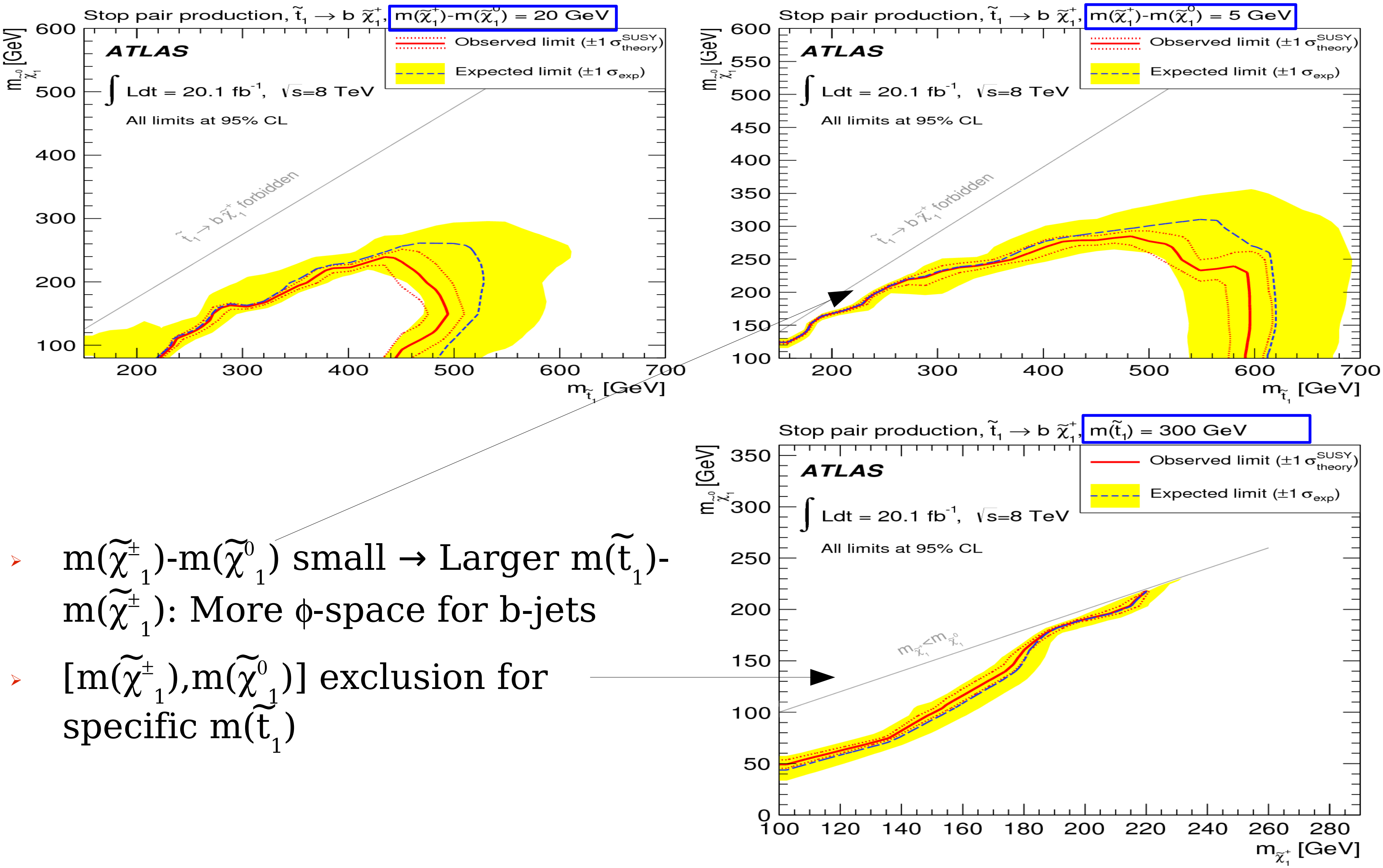
Taking advantage of ISR jet:
High p_T, MET
Back to MET
Not a b jet

Opt. for different Δm

Benefit of larger ϕ-space



Hypothesis: 3^{rd} generation squarks decay exclusively via: $\tilde{t}_1 \rightarrow b\tilde{\chi}^{\pm}_1$

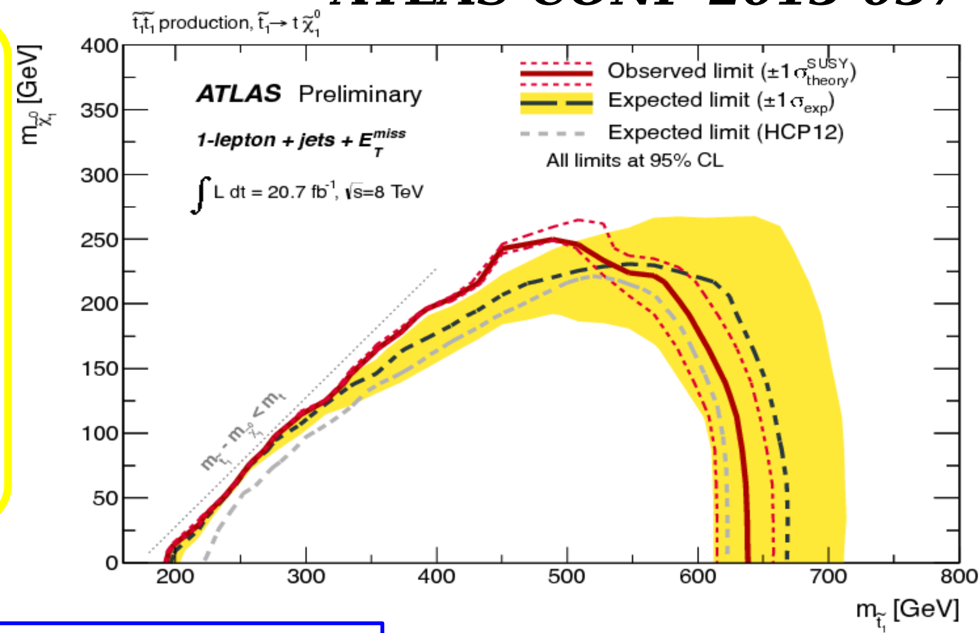


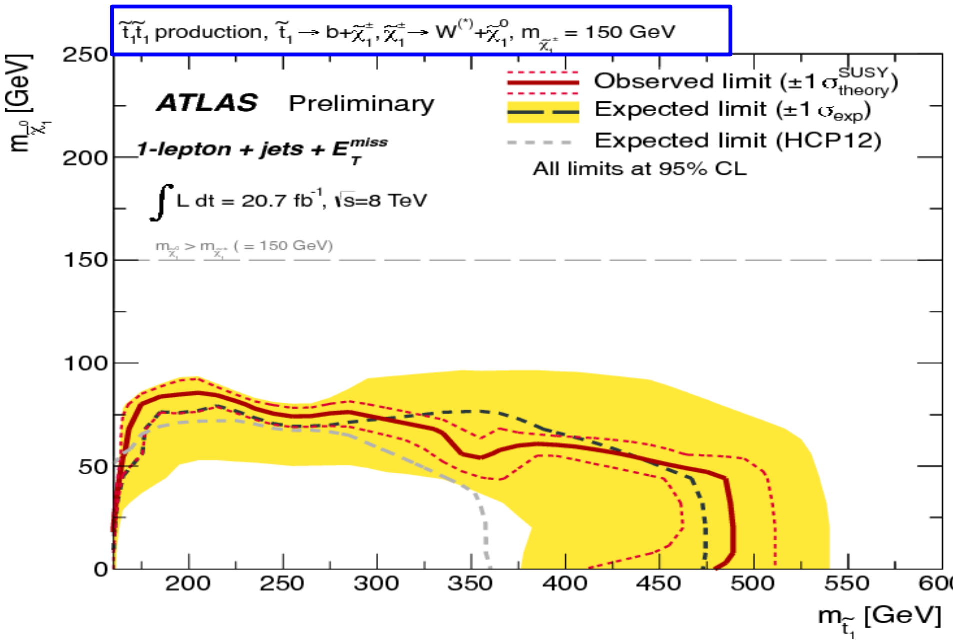
- $m(\tilde{\chi}^{\pm}_1)$-$m(\tilde{\chi}^{0}_1)$ small → Larger $m(\tilde{t}_1)$-$m(\tilde{\chi}^{\pm}_1)$: More ϕ-space for b-jets
- [$m(\tilde{\chi}^{\pm}_1)$,$m(\tilde{\chi}^{0}_1)$] exclusion for specific $m(\tilde{t}_1)$

ATLAS-CONF-2013-037

Selection: Cut & Count

- SRs: Sensitivity to different decay-modes & kinematics:
  - 3 / decay-mode, vs Δm
  - Handles: MET, MET/$\sqrt{H_T}$, $m_{eff}=p_T(l)+p_T(jets)+MET$, m_{T2}
  - m(jjj) for $\tilde{t}_1 \rightarrow t\tilde{\chi}^0_1$

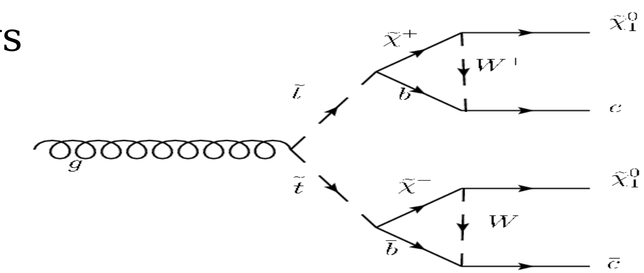




Kinematic domain: $m(\tilde{t}_1) < m(b) + m(W^{\pm}) + m(\tilde{\chi}^0_1)$

ATLAS-CONF-2013-068

Complementary to 2-body ($t\tilde{\chi}^0_1$, $b\tilde{\chi}^{\pm}_1$) & 3-body ($bW^{\pm}\tilde{\chi}^0_1$) decays

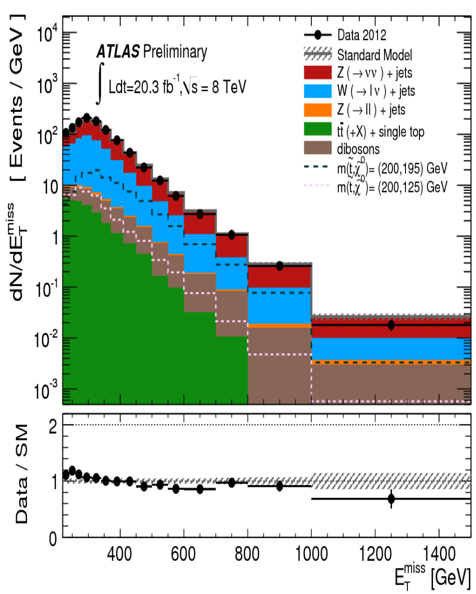


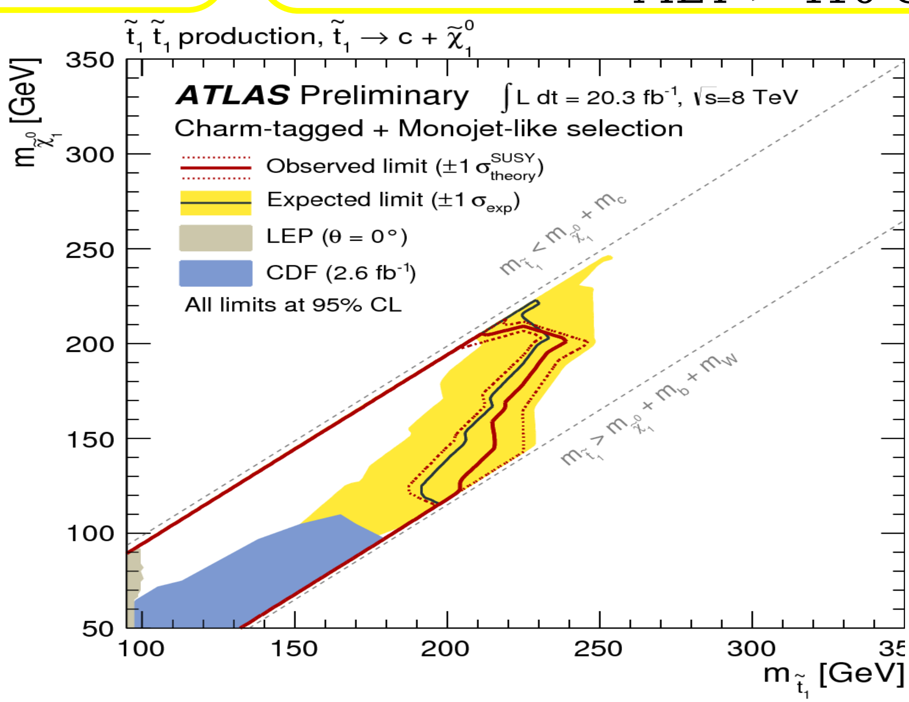
Preselection:
- N(jet)≥1 w p_T(j) > 120 GeV/c
- MET > 150 GeV

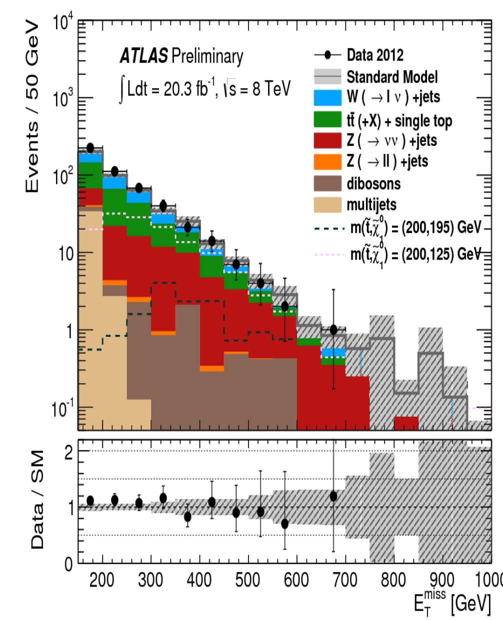
Selection: Cut & Count

Low Δm: Small ϕ-space:
- N(jet)≤3 w p_T(j) > 30 GeV/c
- ISR jet: p_T(j1) > 280 GeV/c
- MET > 220 GeV

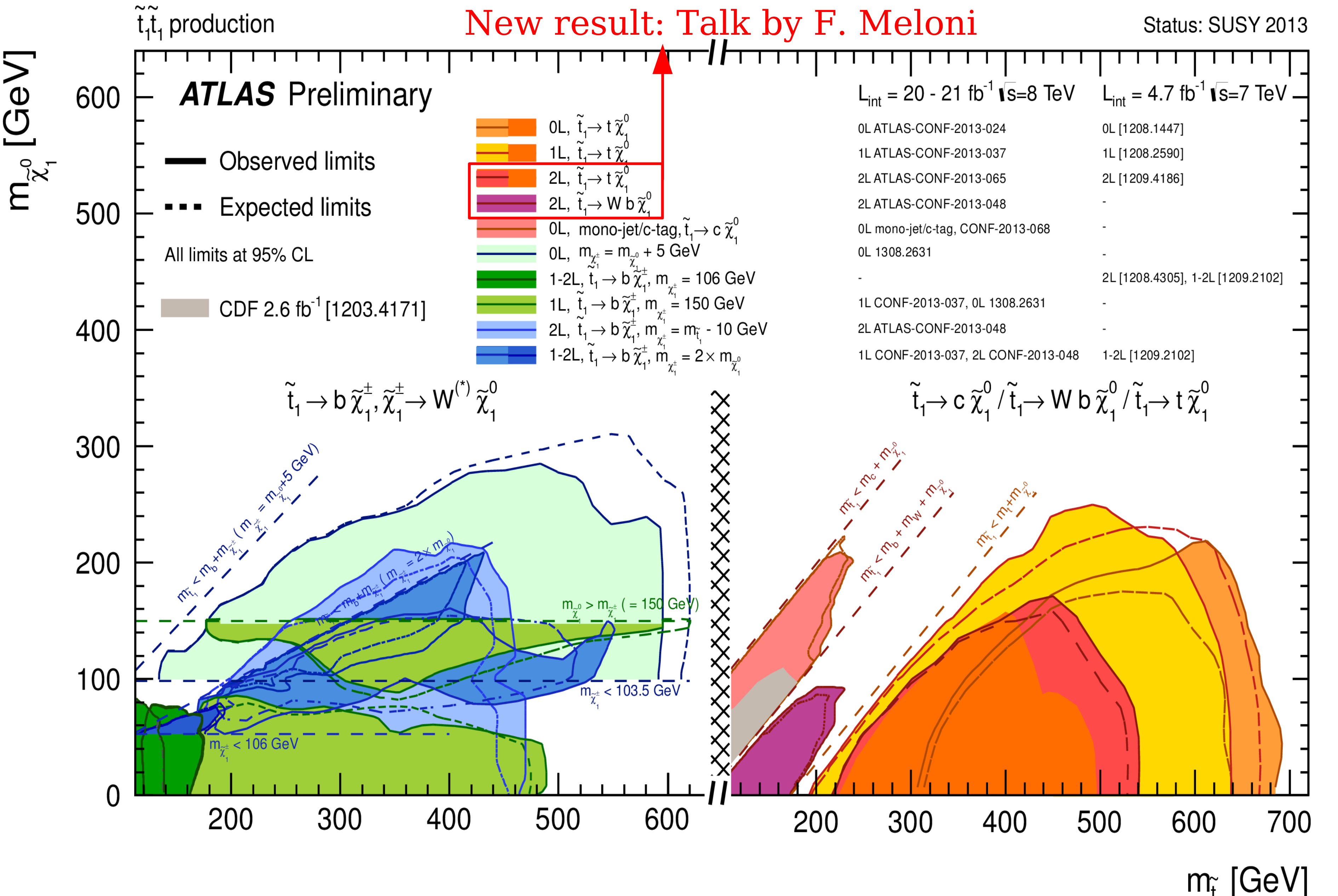
Moderate Δm: *Charm-tagging* enhances signal purity
- p_T(j1) > 270 GeV/c
- + N(add. jet)≥3 w p_T(j)>30 GeV/c
- MET > 410 GeV







$\tilde{t}_1$ searches across decay-modes & signatures



Experimental look @ sbeauty

$\tilde{b}_1$: Interpretation

Hypothesis: 3rd generation squarks decay exclusively via: $\tilde{b}_1 \rightarrow b\tilde{\chi}^0_1$

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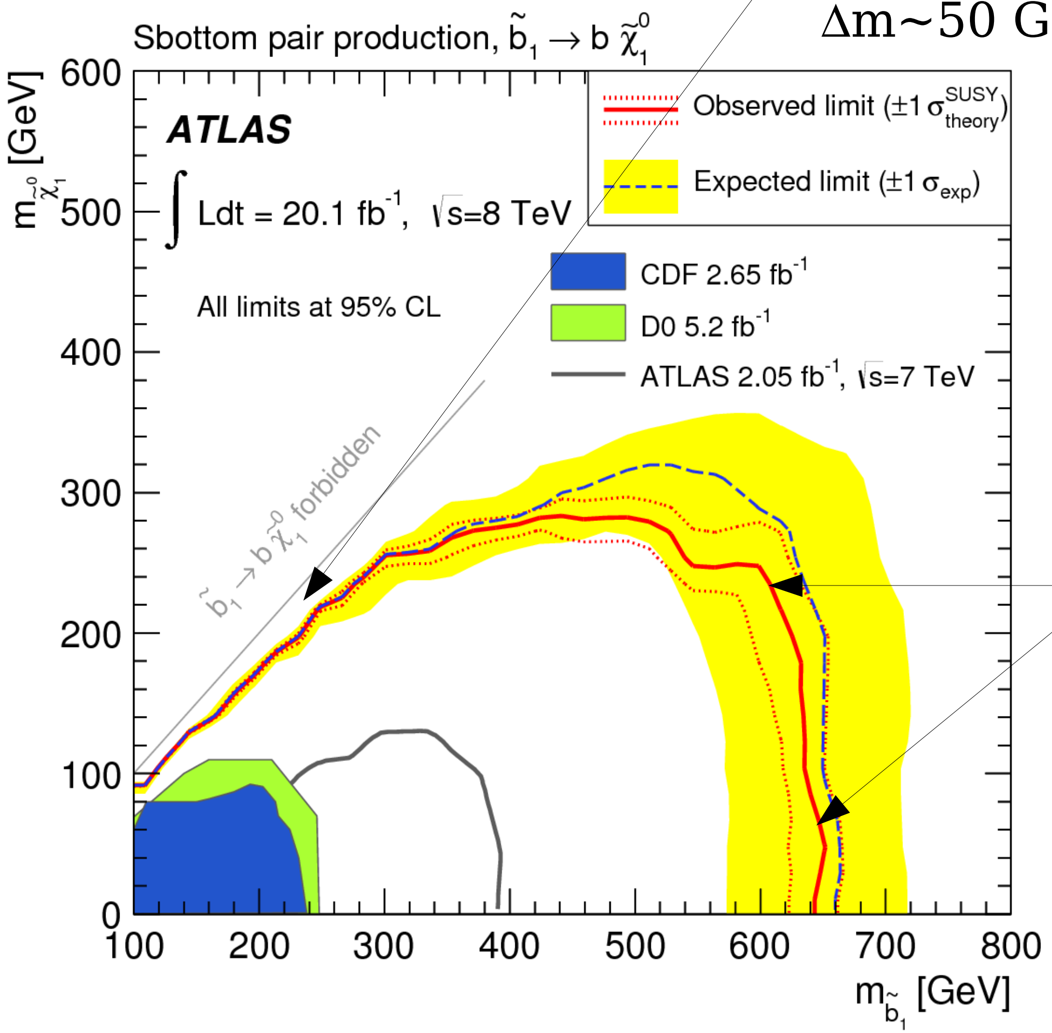
Low Δm: Sensitivity achieved thank to SR w ISR requirement. Sensitivity down to Δm~50 GeV/c² for m($\tilde{t}_1$)<300 GeV/c²



High Δm: Sensitivity achieved thank to differential cut on m_{CT}

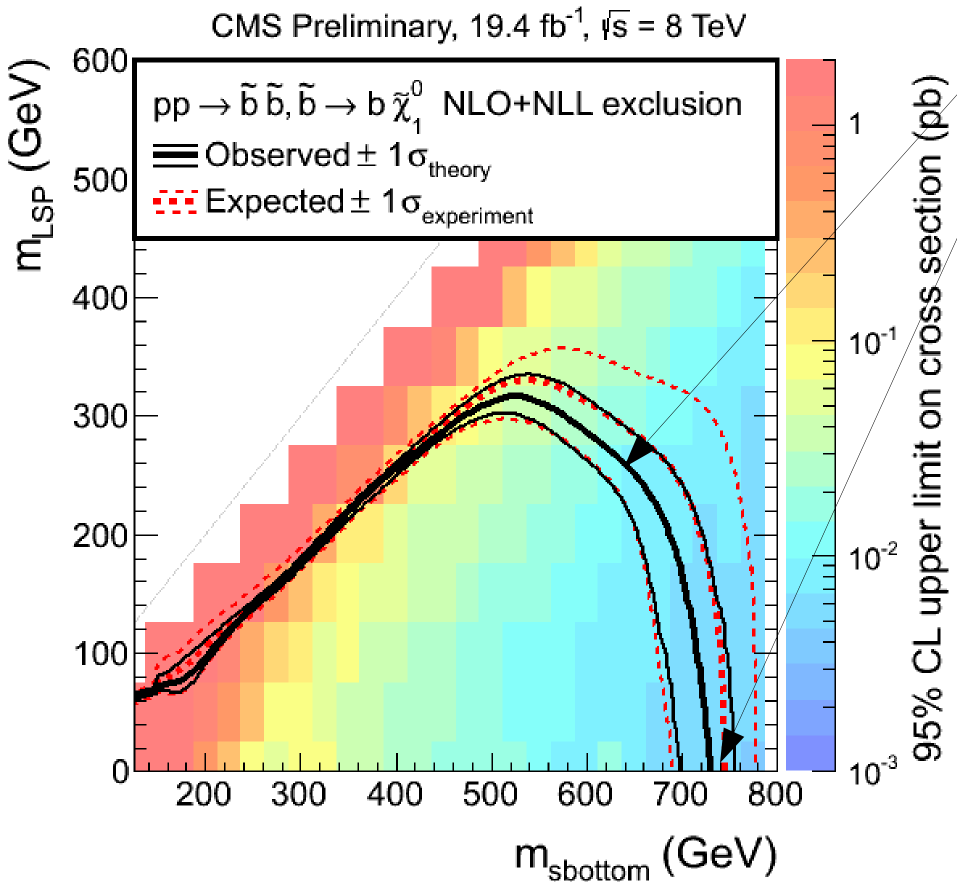
$\tilde{b}_1$ search: Mainly based on b-tagging & m_{CT}

CMS PAS-SUS-13-018

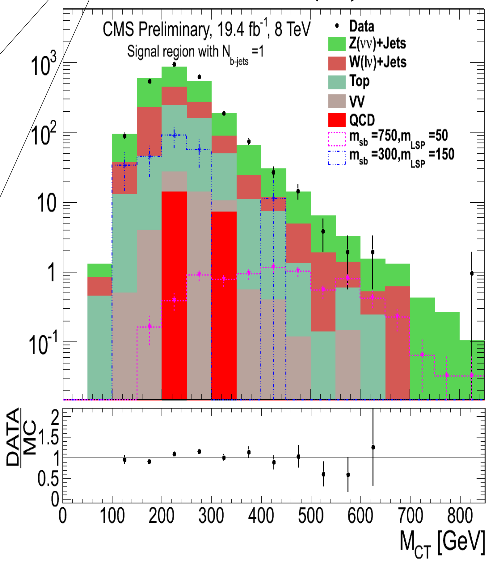
Preselection:

- N(jets)≥2 w $p_T(j) > 70$ GeV/c
- N(b)≥1. $\Delta\phi(b_1,b_2) < 2.5$ if N(b)=2
- H_T/MET > 250/175 GeV
- M_T(j2,MET) > 200 GeV

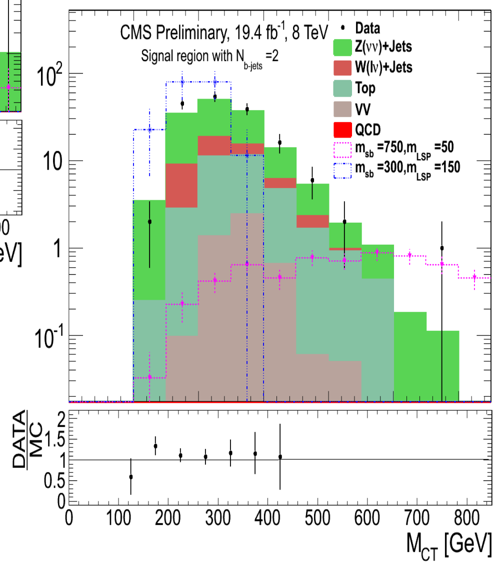
Selection: Cut & Count
SR binned in [m_{CT} , N(b)] to increase sensitivity across ($m(\tilde{b}_1)$,$m(\tilde{\chi}^0_1)$)



SR: N(b)=1

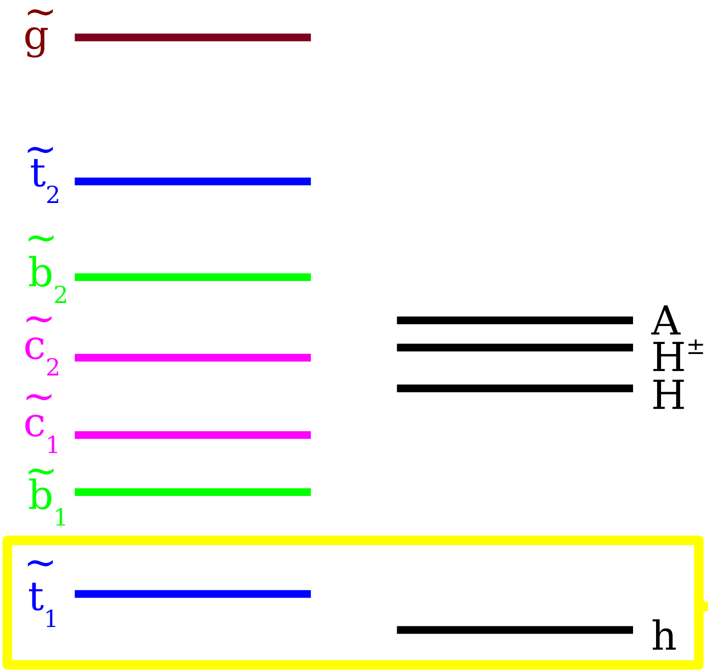


SR: N(b)=2

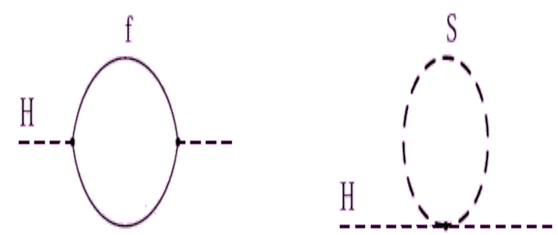


"Naturalness": Stop and… Higgs

***Idea*: If *only stop has O(GeV) mass among sParticles, close enough to Higgs*: Enough to "stabilize" the Higgs mass problem**



$$\Delta m_H^2 = \frac{\lambda_f^2}{16\pi^2}\cdot\left[-2\Lambda_{UV}^2 + \ldots\right]$$



$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\cdot\left[\Lambda_{UV}^2 - \ldots\right]$$

Explore SUSY scenarios, i.e. mass hierarchies, where $\tilde{t}_1$ & higgs/higgsinos are light

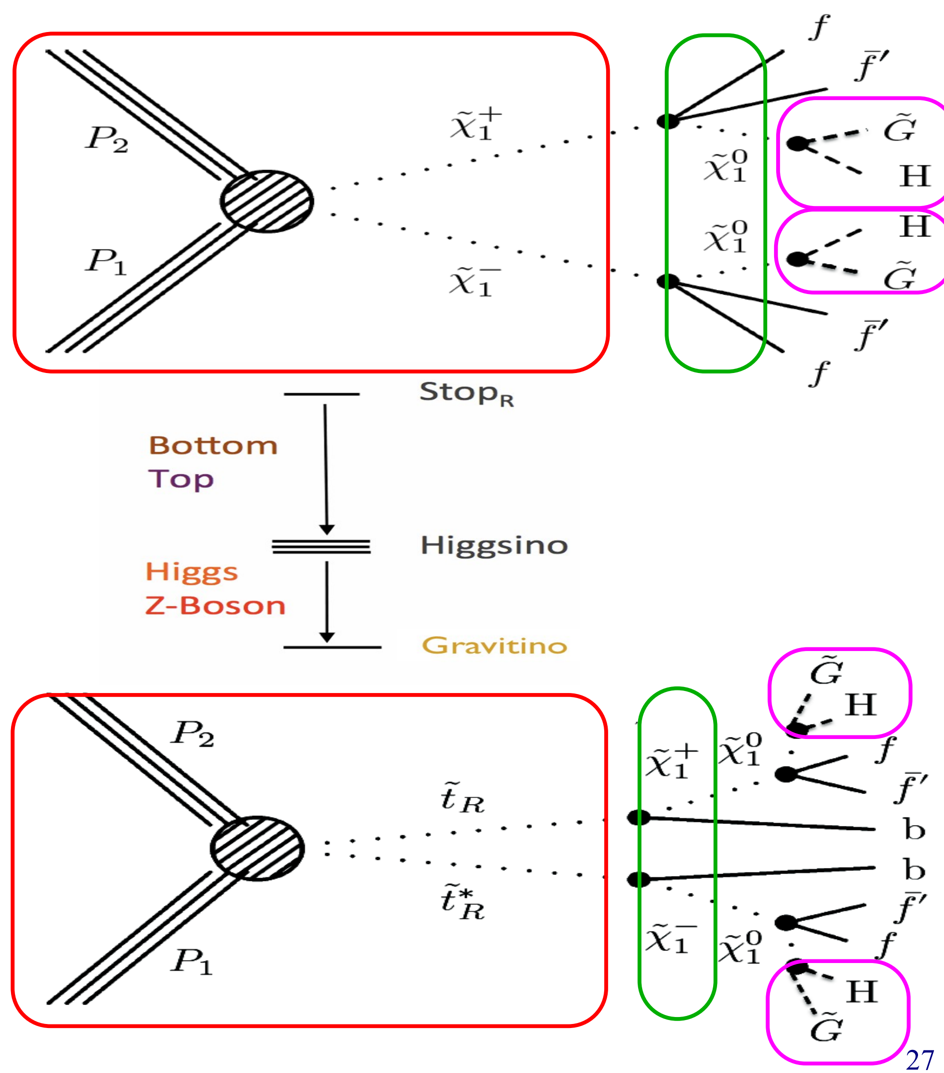
- Decoupled regime: h "SM like": h → γγ, {H,H$^\pm$,A} much heavier
- Meanwhile: Start looking @ this physics within (more) constrained models…

"Natural SUSY":
Masses of the stop & the higgsinos light

CMS PAS-SUS-13-014
ArXiv:1312.3310

$\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^{0}$: Almost pure Higgsinos → Degenerate in mass

- Higgsino production mode:
  - Direct: EW
  - Strong $\tilde{t}_R\tilde{t}_R$ production
- Decay modes:
  - $\tilde{t}_R \rightarrow b\tilde{\chi}_1^{\pm}, t\tilde{\chi}_{1,2}^{0}$
  - Degenerate $\tilde{\chi}_1^{\pm},\tilde{\chi}_{1,2}^{0}$:
    $\tilde{\chi}_1^{\pm},\tilde{\chi}_{1,2}^{0} \rightarrow W^*,Z^*\, \tilde{\chi}_1^{0} \rightarrow ff'\tilde{\chi}_1^{0}$
  - Model-dependance: GMSB:
    $\tilde{\chi}_1^{0} \rightarrow \tilde{G}$ H: Dominates for significant part of parameter space, including low tanβ, and negative values of μ



<u>Final state</u>: HH, MET, +2b/2t for strong production

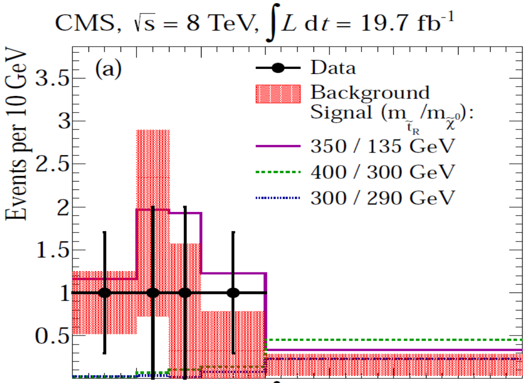
"Naturalness": Stop & Higgs

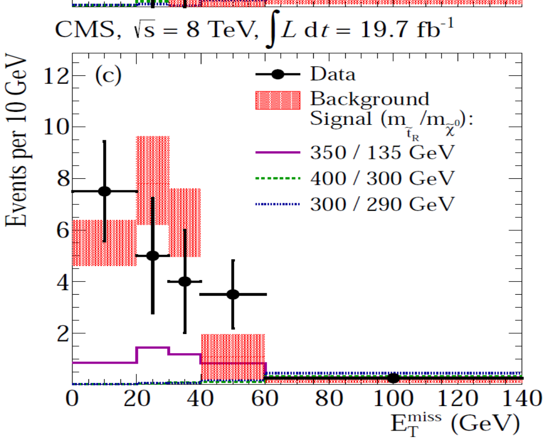
Selection: C & C

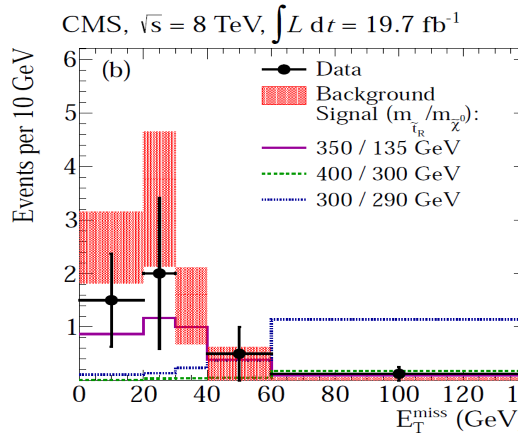
- At least one $H \rightarrow \gamma\gamma$: Take advantage of known m(H)
- N(jet)≥2 from either other H, or $\tilde{t}_R$ decays
  - 2 satisfy loose b-tagging / At least one satisfies medium b-tagging

3 Signal regions:

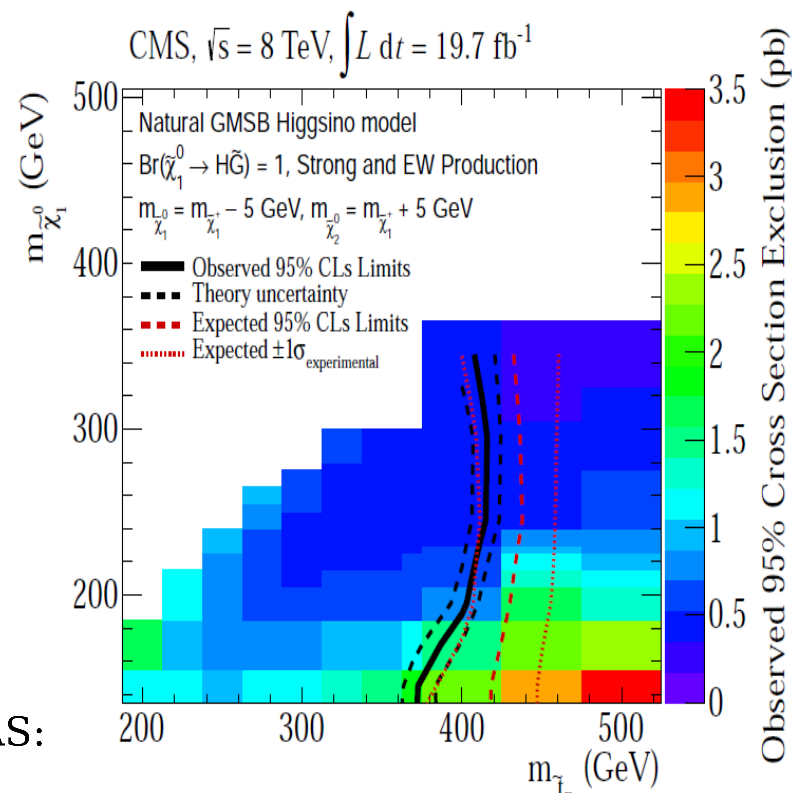
- a) N(b)≥3: Larger Δm
- b) N(b)=2 & m(bb) ∈ [95,155] GeV → Small $\Delta m = m(\tilde{t}_R) - m(H)$
- c) N(b)=2 & m(bb) off-Higgs mass: Larger Δm







Similar search by ATLAS: CERN-PH-EP-2014-035

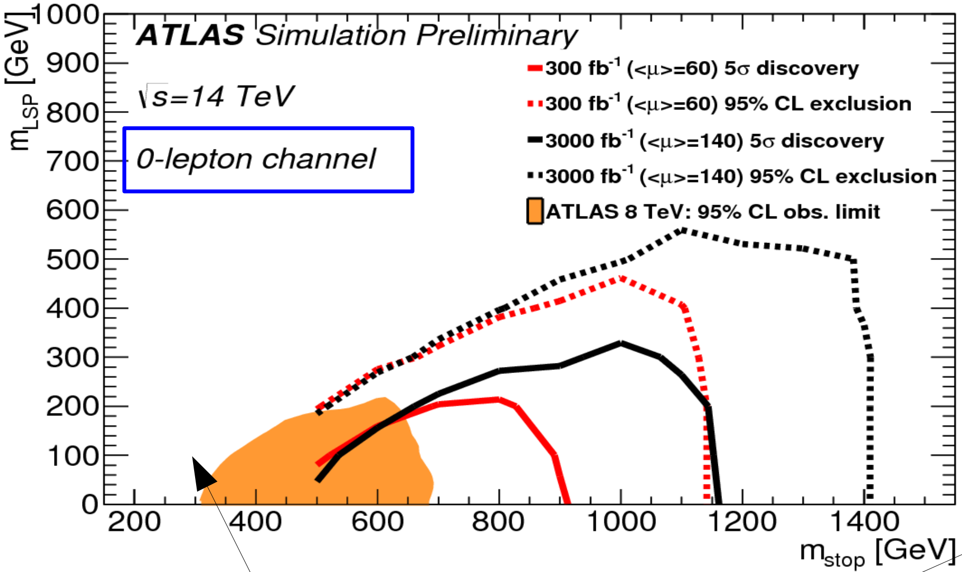


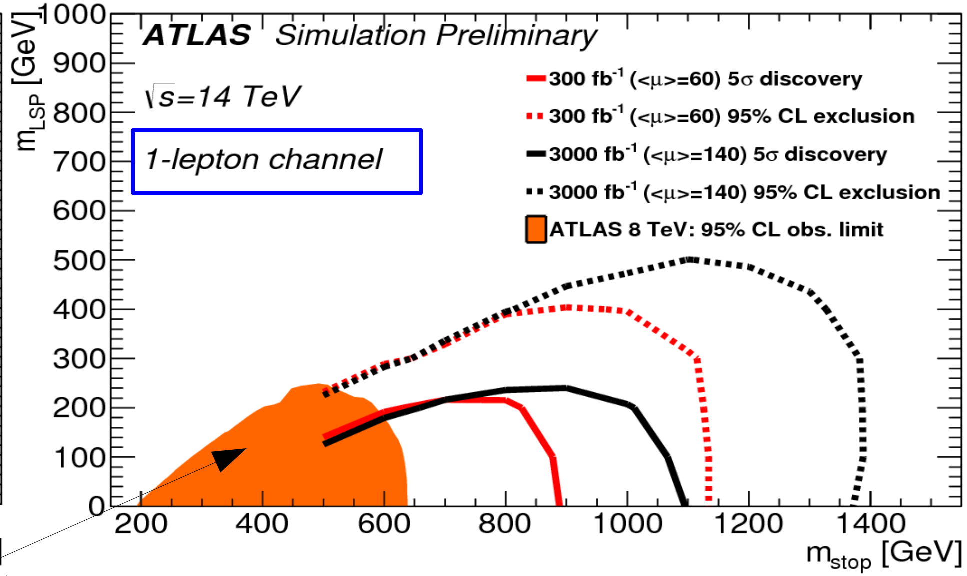
Conclusions

8 TeV campaign: Opportunity for both experiments to cover *from* gluino *down to* 3rd generation squark searches

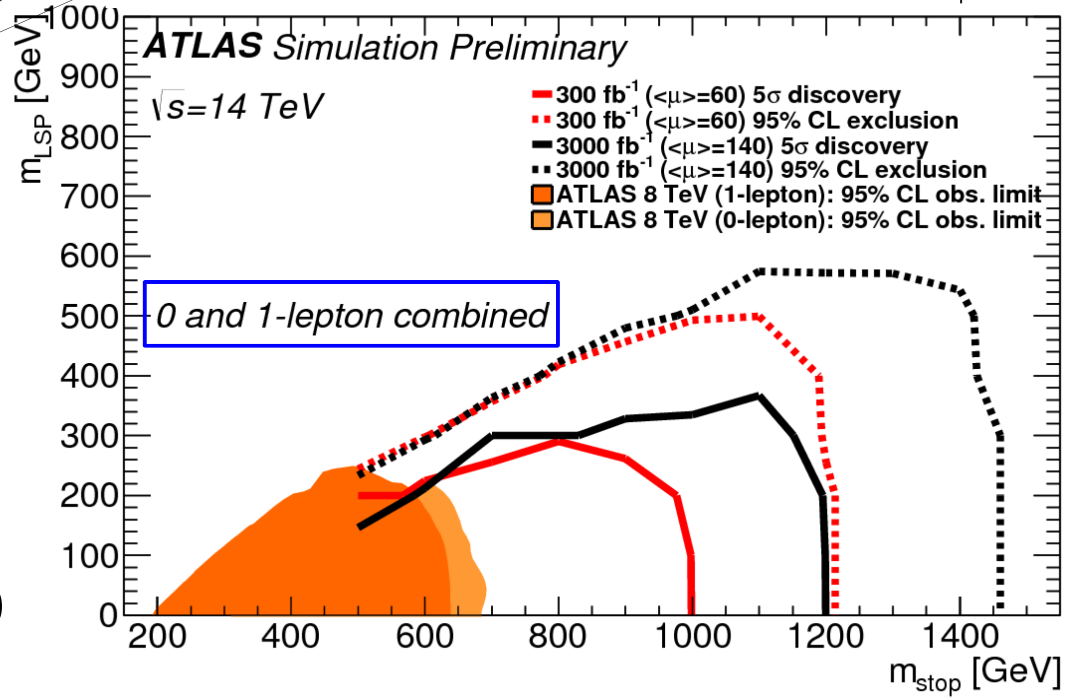
- **Gluino searches:** Now in the TeV/c^2 field...
- **3rd generation searches:**
  - Pertinent:
    - Dynamic/Robust reason to be ~low mass **if** SUSY realized
    - *Have a good profile* in view of cosmological argument
  - Challenging:
    - Low σ...
    - In *cosmological scenario*: *Sitting on top/left-side* of SM
  - $\mathbf{\tilde{t}_1/\tilde{b}_1}$: To be actively pursued during coming years...
    - $\tilde{t}_1$: Covered across 4 decay-modes !
    - Domain of sensitivity: $m(\tilde{q}_3,\tilde{\chi}^0_1) < \sim(700,300)$ GeV/c^2
  - Trying to be as generic, i.e. as *case-covering*, as possible: Cover the same object through different:
    - Decay-modes
    - Masses of produced ($\tilde{q}_3$) / intermediate / final ($\tilde{\chi}^0_1$) sParticles

Perspectives...





- 1-lepton searches (generally) more sensitive at low Δm: Lower lepton/jet thresholds
- At high Δm: Quite similar performance across final states
- **If** nature realizes SUSY **&** $m(\tilde{t}_1)\sim O(\text{TeV})$ **&** $\tilde{t}_1 \to t\tilde{\chi}^0_1$ favoured: Watch within $(m(\tilde{t}_1), m(\tilde{\chi}^0_1)) \in (1.2\text{TeV}, 400\text{GeV})$ area…



Backup slides

SUperSYmmetry

"Generalize" the spin of known fields

SUperSYmmetry : spin particle ½ ↔ spin partner 0
spin particle 1 ↔ spin partner ½

Names		spin 0	spin 1/2
squarks, quarks (×3 families)	Q	$(\widetilde{u}_L \ \ \widetilde{d}_L)$	$(u_L \ \ d_L)$
	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$
sleptons, leptons (×3 families)	L	$(\widetilde{\nu} \ \ \widetilde{e}_L)$	$(\nu \ \ e_L)$
	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$
Higgs, higgsinos	H_u	$(H_u^+ \ \ H_u^0)$	$(\widetilde{H}_u^+ \ \ \widetilde{H}_u^0)$
	H_d	$(H_d^0 \ \ H_d^-)$	$(\widetilde{H}_d^0 \ \ \widetilde{H}_d^-)$

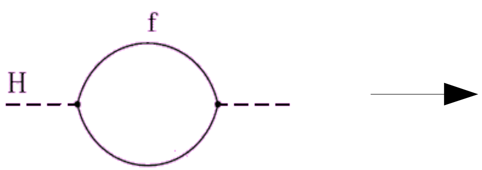
Names	spin 1/2	spin 1
gluino, gluon	$\widetilde{g}$	g
winos, W bosons	$\widetilde{W}^\pm \ \ \widetilde{W}^0$	$W^\pm \ \ W^0$
bino, B boson	$\widetilde{B}^0$	B^0

Observed SUSY particles with same mass than Standard-Model partners ? No !

SUSY : A broken symmetry !
Physical sParticles: Mixture of super-partners

- Charginos ($\chi^\pm$) / Neutralinos (χ^0) : Bino/Wino ↔ Higgs (charged/neutral)
- Squarks, Sleptons : Mixture of $f_L \leftrightarrow f_R$

- Admitting existence of a Higgs Boson
  - Considering Gauge boson scatterings at High-Energy
  - **Requiring Unitarity of scattering amplitudes**
    - **$m_H \sim O(100\ GeV/c^2)$**
- **Consider Higgs mass correction from fermionic loop:**



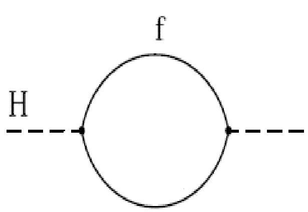
$$\Delta m_H^2 = \frac{\lambda_f^2}{16\pi^2}\cdot\left[-2\Lambda_{UV}^2+...\right]$$

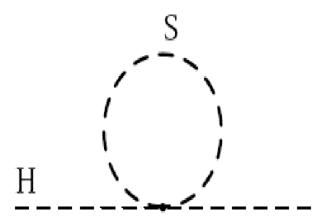
Λ_{UV}: Energy-scale at which new physics alters the Standard-Model (momentum cut-off regulating the loop-integral)

If $\Lambda_{UV} \sim M_P$ -> $\Delta m^2_H \sim O(10^{30})$ larger than m_H !!!

And all Standard-Model masses indirectly sensitive to Λ_{UV} !!!

$$\Delta m_H^2 = \frac{\lambda_f^2}{16\pi^2}\cdot\left[-2\Lambda_{UV}^2+...\right]$$





$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\cdot\left[\Lambda_{UV}^2-...\right]$$

Δm^2_H quadratic divergence cancelled :

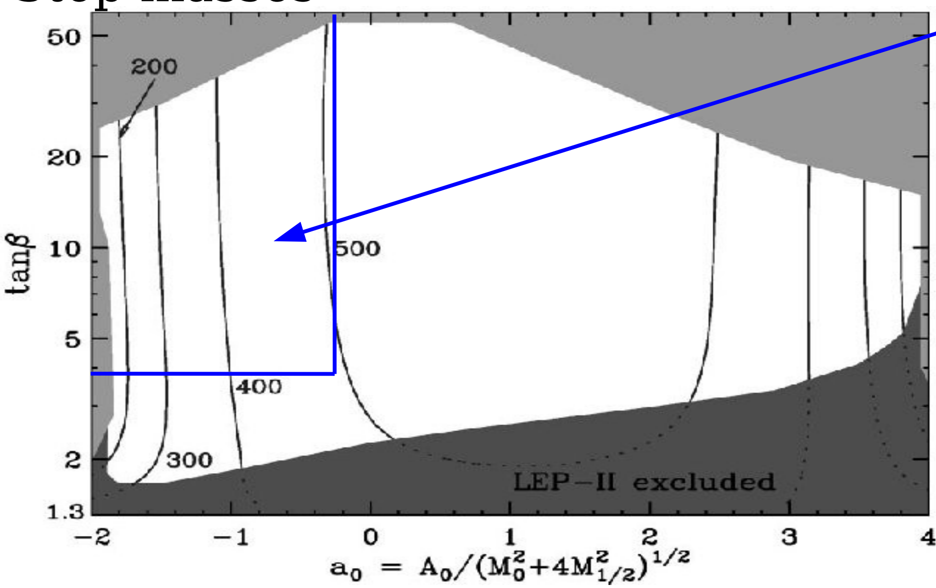
Hierarchy problem naturally solved !

Stop/Higgs yukawa coupling

$M(h) = f\,[\,M(\tilde{q},\tilde{t}_{1,2})\,]$

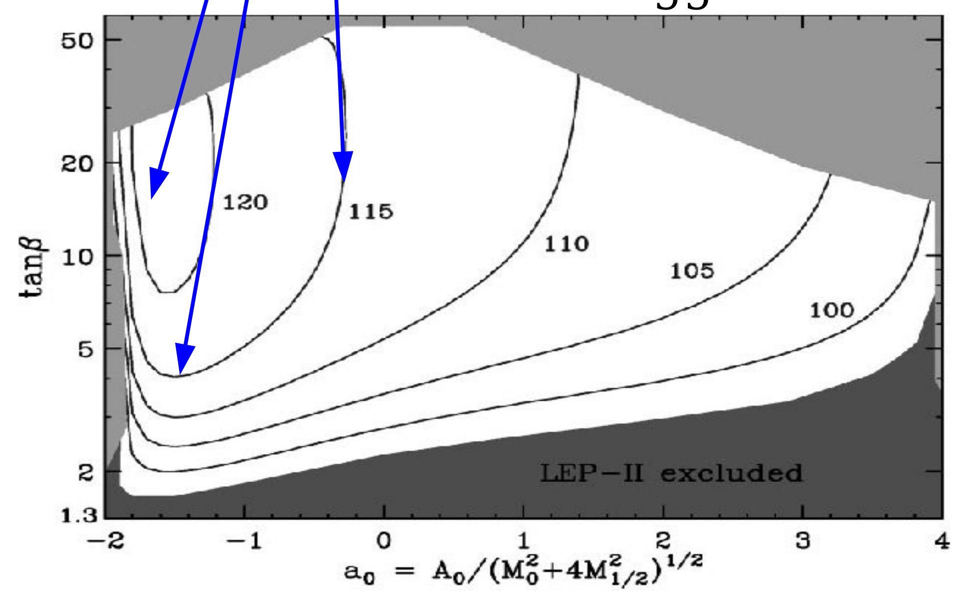
Higgs & stop searches in inter-relation with each other

Stop masses



Demina et al., PRD 62, 35011

Higgs masses



3^{rd} generation & Cold Dark Matter

Lightest Neutralino $\tilde{\chi}^0_1$ stable: Natural candidate for Cold Dark Matter

$0.1 < \Omega_{CDM}h^2 < 1$: "Reproduced" in most of SUSY parameter space…

…if $\tilde{\chi}^0_1\tilde{\chi}^0_1$ annihilation : Only process changing N(Superparticles)

IF : $\delta m = M(\tilde{P}) - M(\tilde{\chi}^0_1)$ small, co-annihilations dominates $\rightarrow \Omega_{CDM}h^2 \approx 0.1$

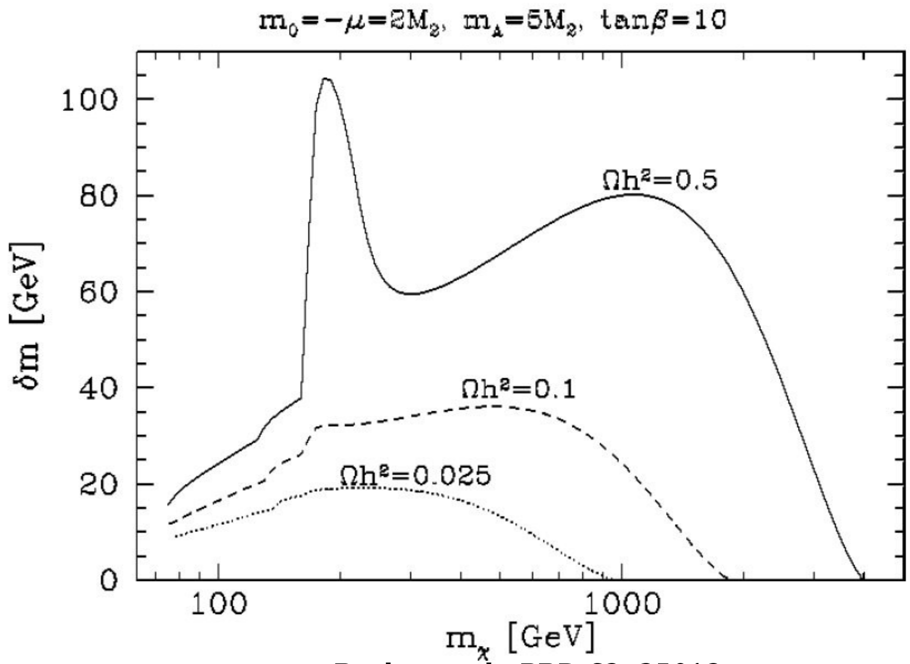
- $\tilde{\chi}^0_1\,\tilde{t}_1 \rightarrow tg,\ tH^0_i,\ bH^+$
- $\tilde{t}_1\,\tilde{t}^{(*)}_1 \rightarrow t\bar{t},\ gg,\ H^0_iH^0_j,\ H^-H^+,\ b\bar{b}$

$\Delta m = M(\tilde{t}_1) - M(\tilde{\chi}^0_1) \leq 50\ GeV/c^2$:

Compatible with

$\mathbf{\Omega_{CDM}h^2 = 0.11 \pm 0.01}$ **@ 95% CL**

(WMAP)



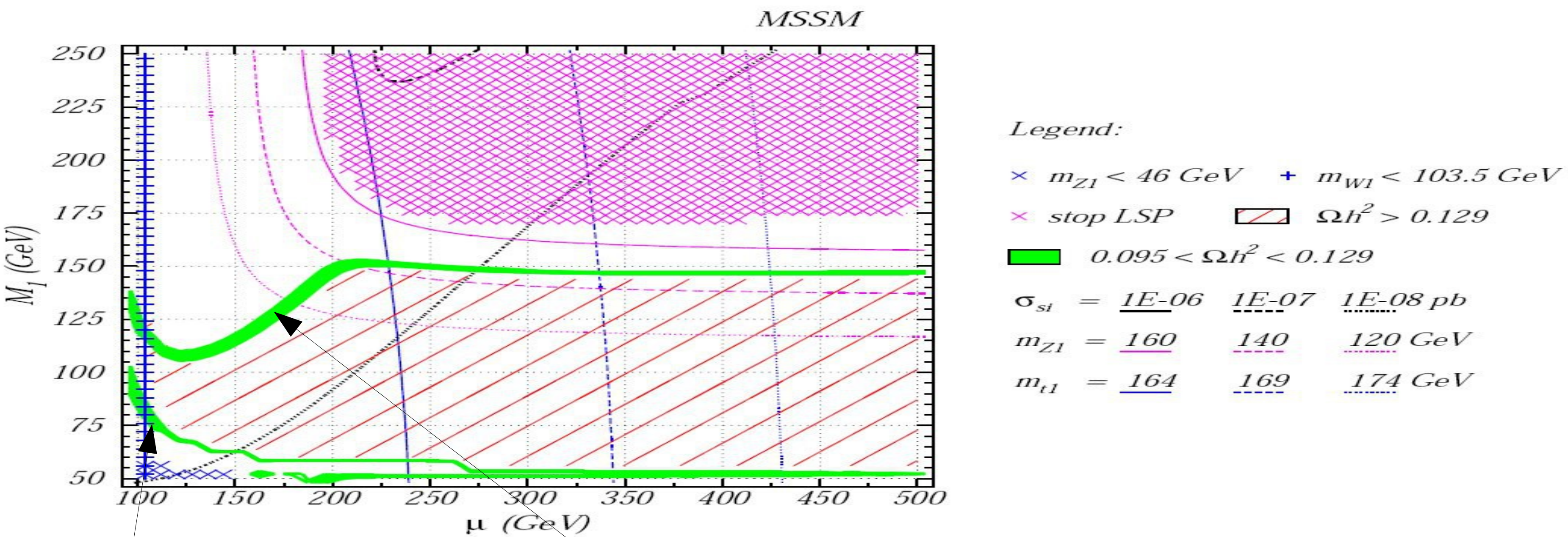
Boehm et al., PRD 62, 35012

Exciting times for HEP in view of Cosmology Data:

Is stop/sbottom degenerate with LSP ?

$\tilde{t}_1$: Constraints from cosmology data

$\Omega_{CDM}h^2 = 0.11 \pm 0.01$: Constraints the MSSM parameter space



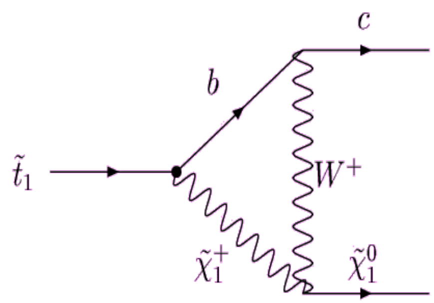
Balazs et al. : hep-ph/0403224

$\chi^0_1\chi^0_1$ --> h,H annihilations

- $\tilde{t}_1$ / $\tilde{\chi}^0_1$ **co-annihilation**
- Experimentally : Special interest for light $\tilde{t}_1$
- Data from cosmology: Improving precision -> Shrinks the (μ,M_1) band !

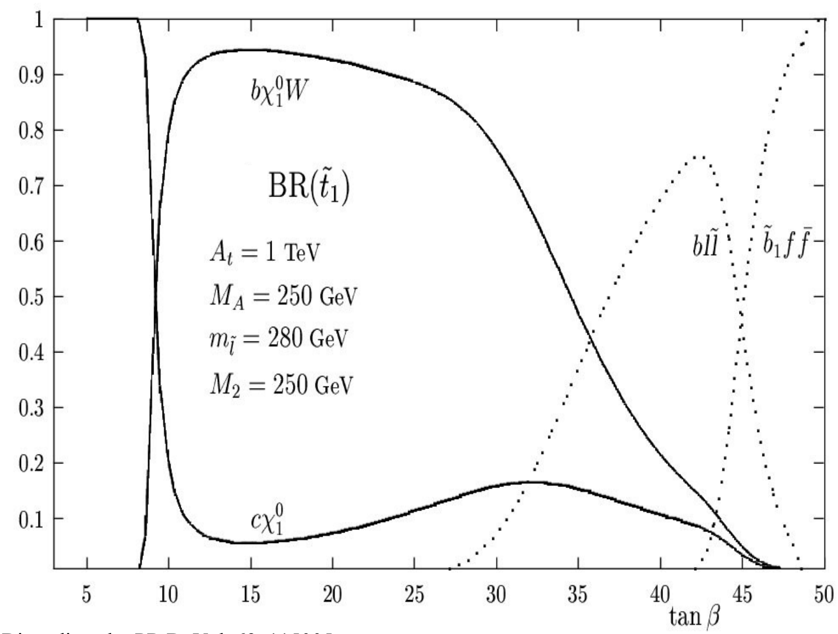
$\tilde{t}_1$: Which stop decays ?

Is c $\tilde{\chi}^0_1$ the only / best window to search for stops ?

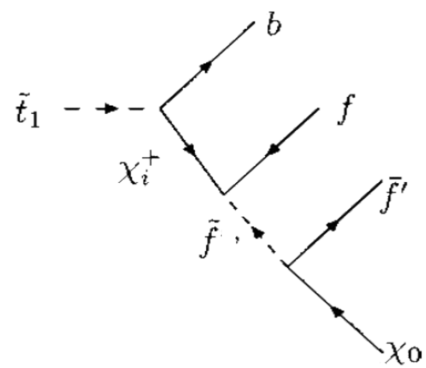


- Big contribution **if** $\log(\Lambda_{GUT}^2/M_W^2) \sim 65$: By choice !
  MSSM: Squark mass unification at low energy…
- $|V_{bc}| \sim 0.05$
- Prefered at low tanβ: Excluded by LEP Higgs searches

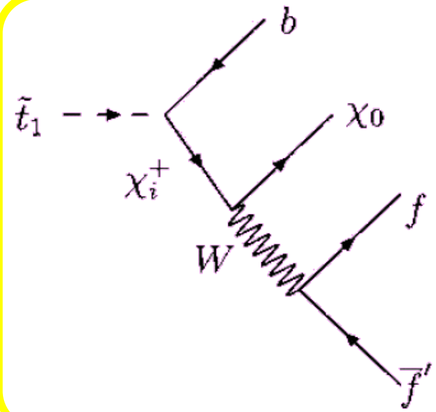
2/3-body decays



Djouadi et al. : PR D, Vol. 63, 115005



- f' = sneutrino
  f = lepton   f' = neutrino
- Contributes more
  if $M(\tilde{\nu}) \sim 80$ GeV/c^2
- Br ($\tilde{\chi}^\pm$ -> $\tilde{\nu}$ lept) = 1/3

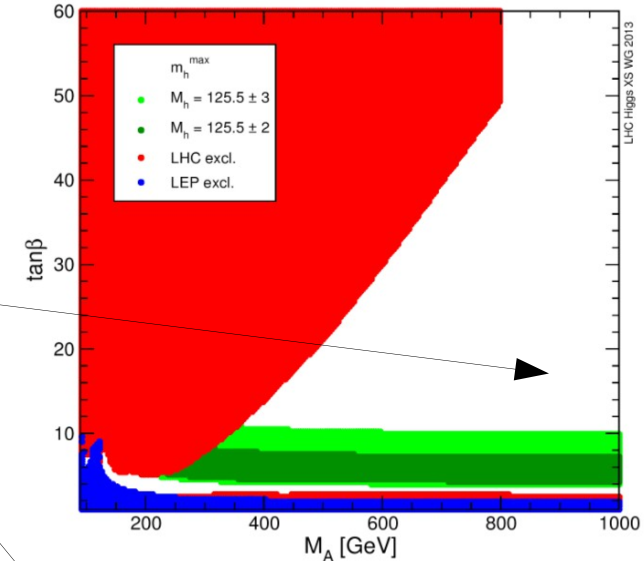


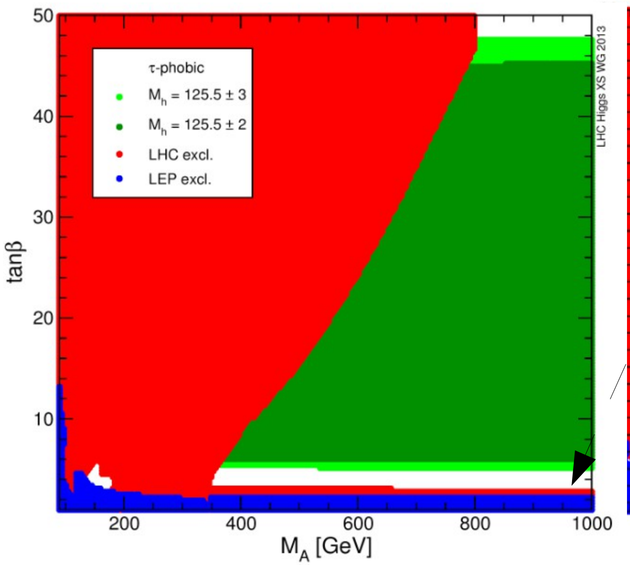
- **No hypothesis on $M(\tilde{\nu})$**
- **Dominating over a large parameter space**

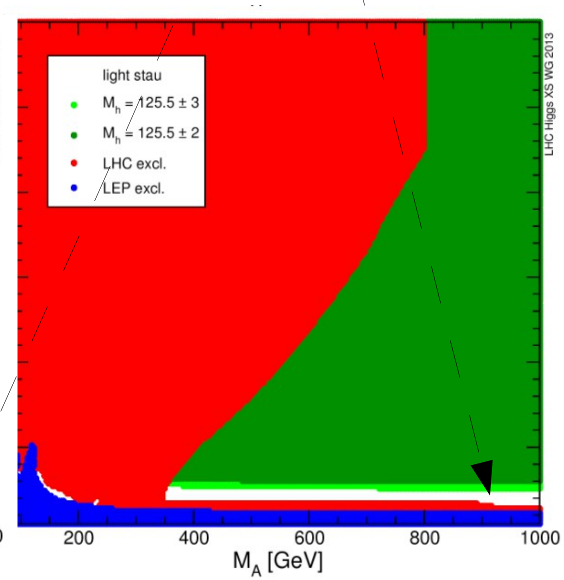
No SUSY so far...

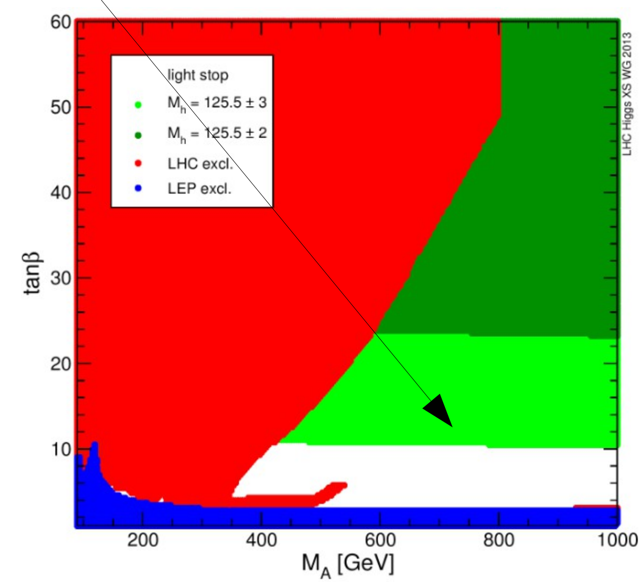
Excerpts from the
“Handbook of LHC Higgs Cross Sections: 3. Higgs Properties” (arXiv:1307.1347)

The Higgs measurement still leaves quite open spaces, depending on MSSM scenarios...



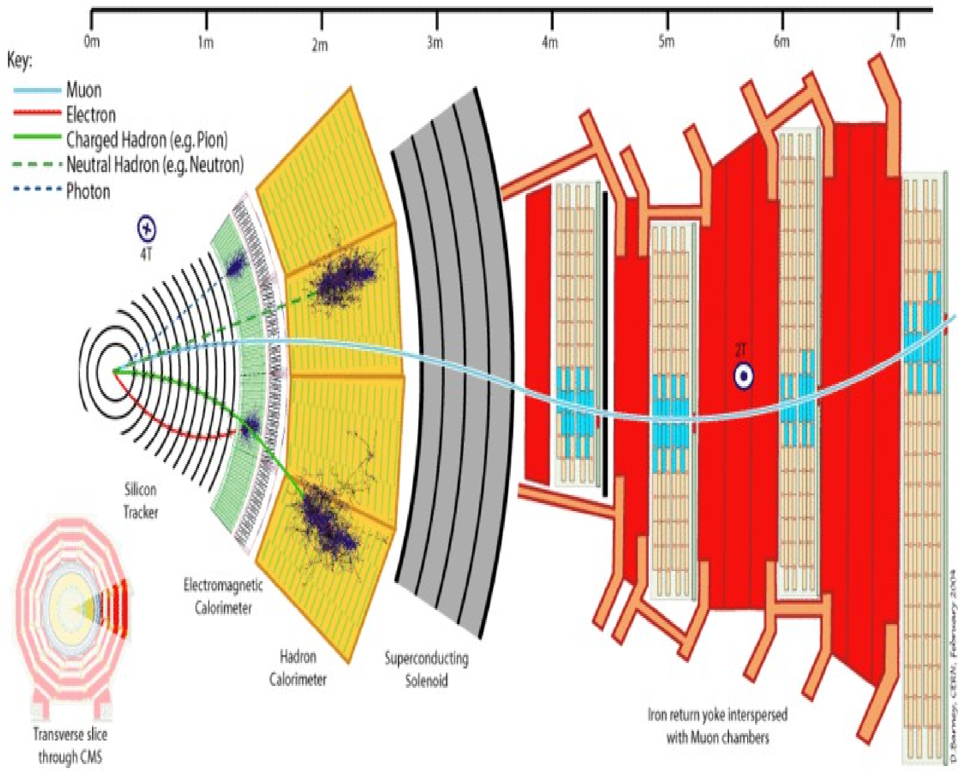


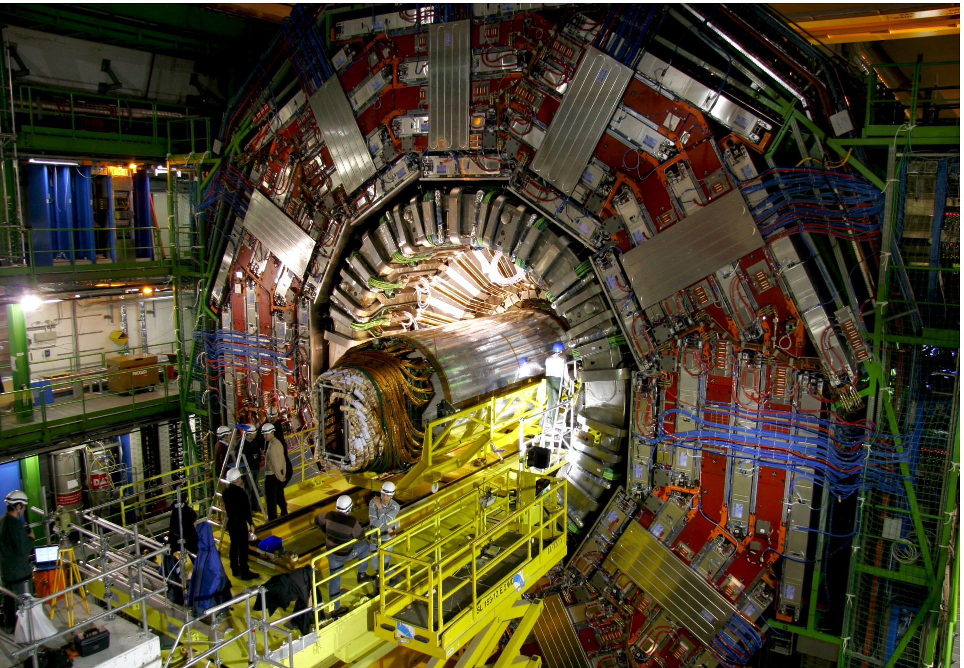




CMS detector

- **Tracker:**
  - 13/14 silicon layers in Barrel (B) / End-Cap (EC)
- **EM calorimeter:**
  - $PbWO_4$ crystals, extremely dense & optically clear material
- **HAD calorimeter**:
  - Layers of dense material (brass or steel) interleaved with tiles of plastic scintillators

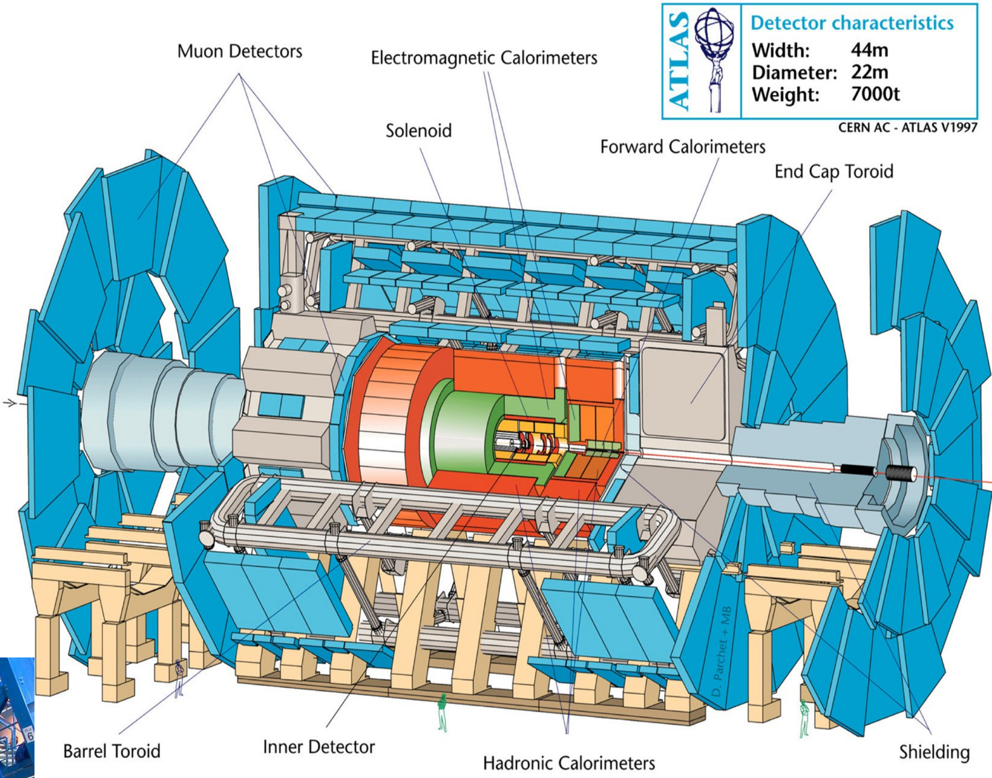


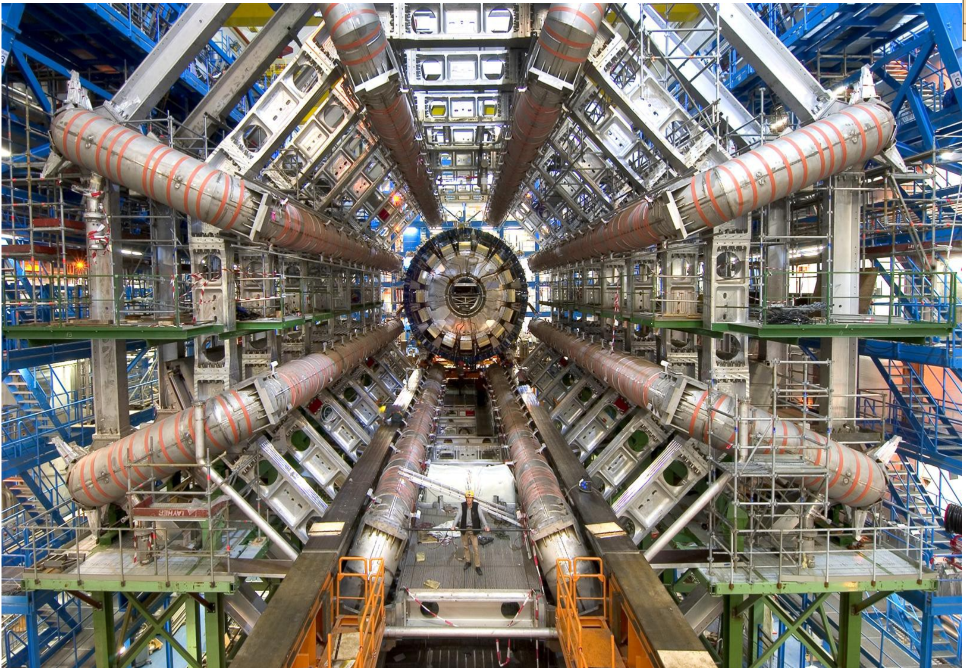


- **Magnet:** 3.8T / Return yoke after...
- **Muon system:**
  - Drift-Tube (B): Measure
  - Cathod-Strip-Chamber (EC): Measure & Trigger
  - Resistive-Plate-Chamber: Trigger

ATLAS detector

- **Inner detector:** Provide info about p_T & identity of charged particles:
  - 3 layers of Pixel Detector
  - 4 layers of SCT
  - Transition Radiation Tracker
- **EM calorimeter:**
  - Liquid Ar / Lead + Stainless steel
- **HAD calorimeter**:
  - Steel / Scintillating tiles





- **Magnet:**
  - Inner solenoid: 2T
  - Outer toroid: 0.5 → 1T
- **Muon system:**
  - Magnetic field from 3 toroids
  - CSC, Monitored-DT, RPC
  - For trigger: MDT, RPC

“General” searches

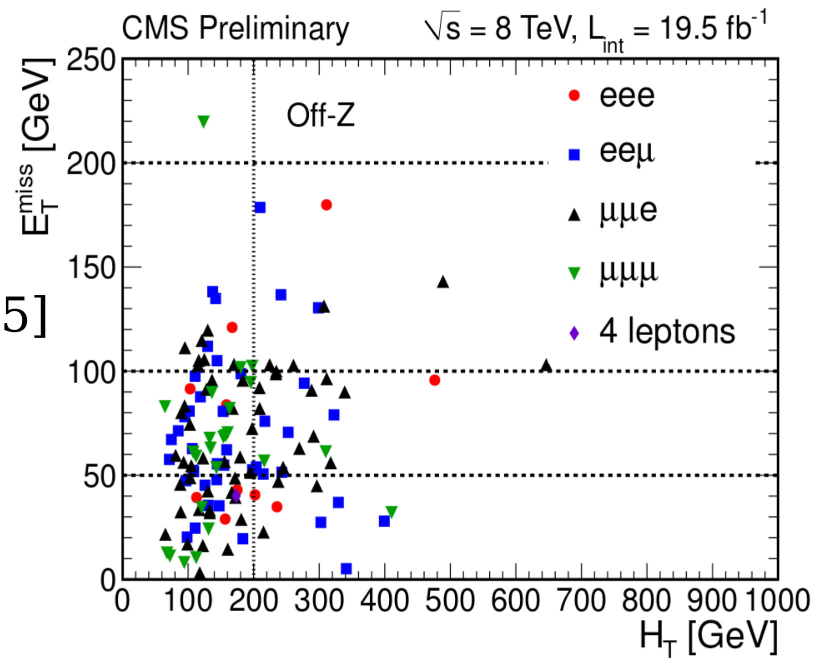
Searches motivated by models of new physics, including SUSY, that involve strong production processes & cascade decays producing many jets and missing momentum from unobserved, weakly interacting particles

3 lepton search: Outlook

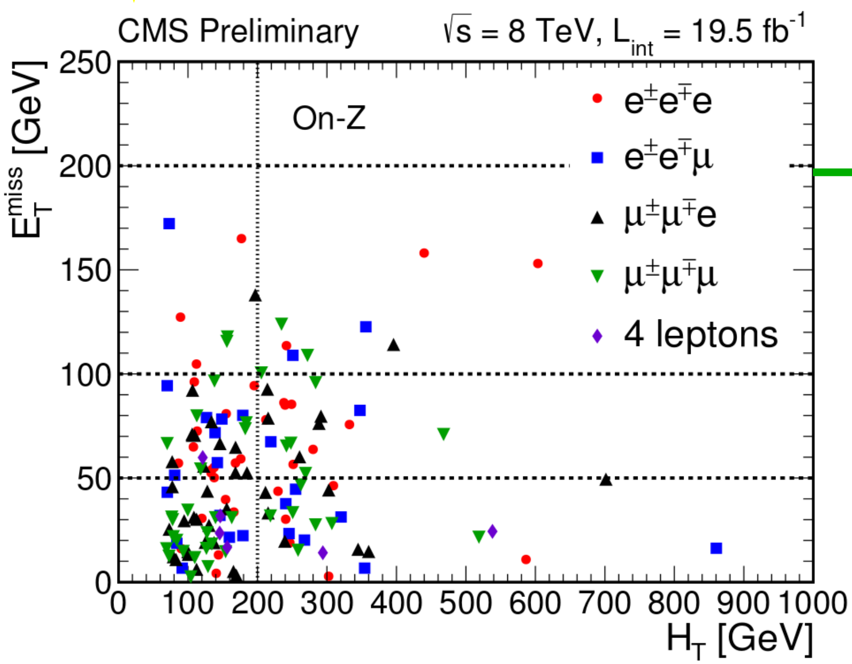
Preselection:

- p_T(lepton1,2,3)>20,10,10 GeV/c
- p_T(j)>30 GeV/c
  - N(jet)≥2
  - H_T>60 GeV
- MET>50 GeV
- N(b jet)≥1

M(ll)∉[75,105]



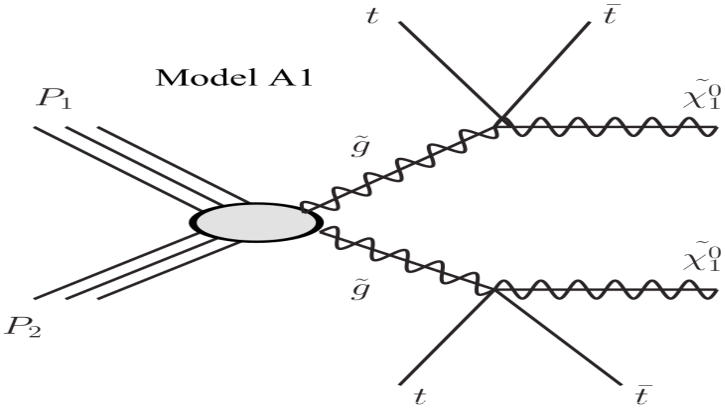
M(ll)∈[75,105]

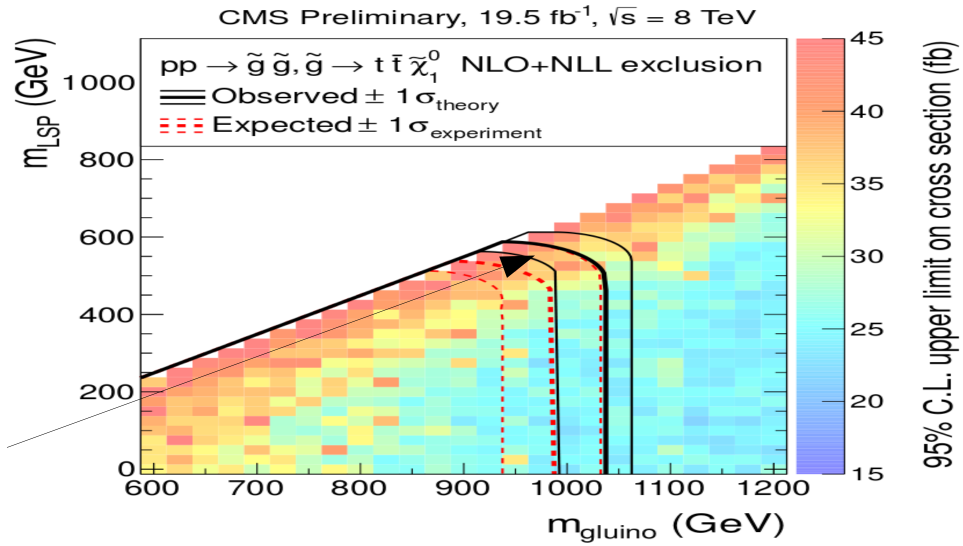


Variable	Baseline	Search Regions		
Sign/Flavor	3 e/μ	On-Z	Off-Z	
$N_{\text{b-jets}}$	≥ 1	1	2	≥ 3
N_{jets}	≥ 2	2–3	≥ 4	
H_T (GeV)	≥ 60	60–200	≥ 200	
E_T^{miss} (GeV)	≥ 50	50–100	100–200	≥ 200

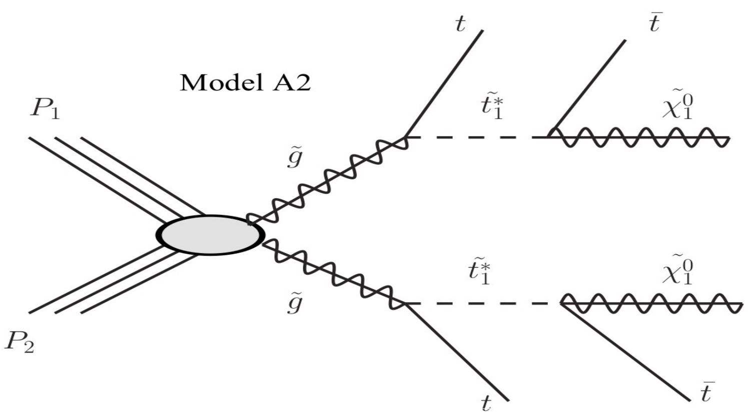
PAS-SUS-13-008

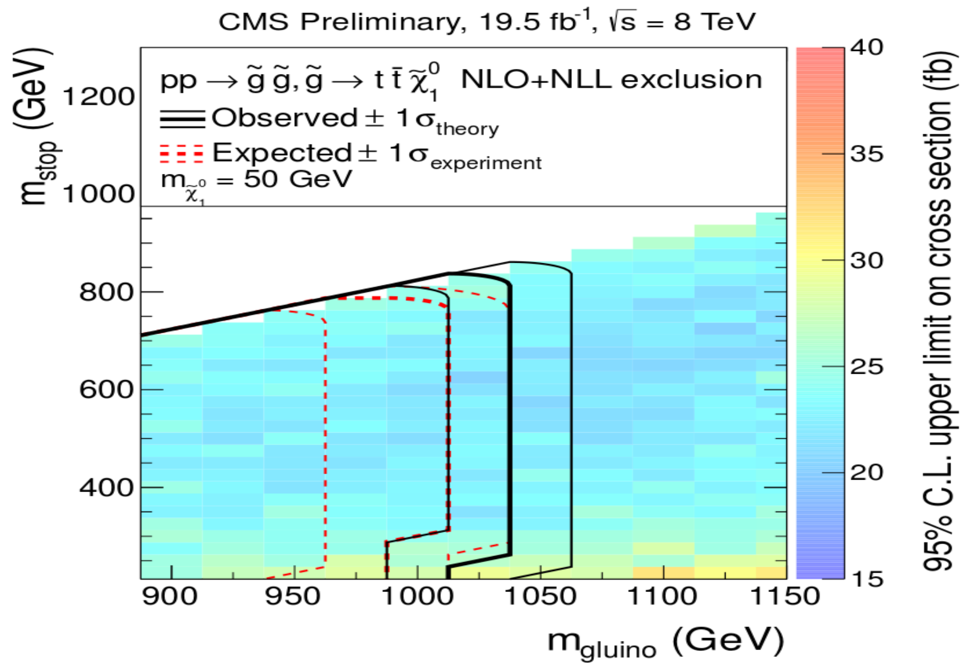
3 lepton search: Results & Interpretations





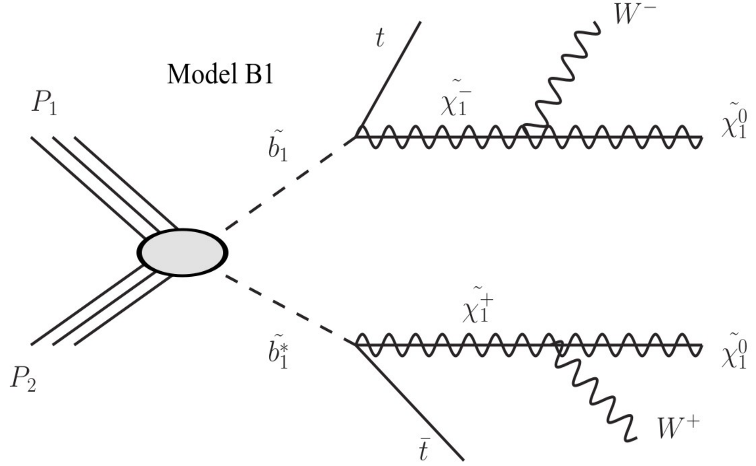
Testing a $\tilde{t}_1$ production via gluino pair production

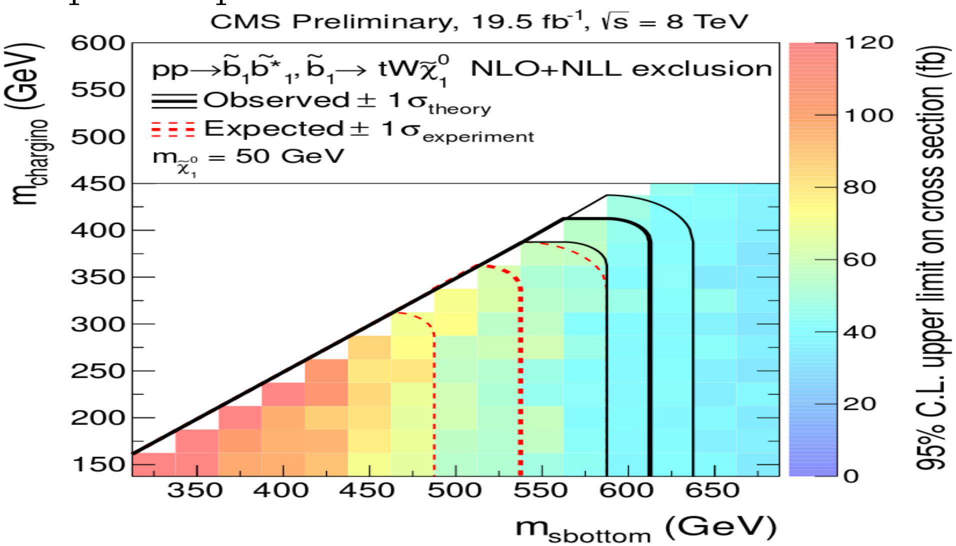


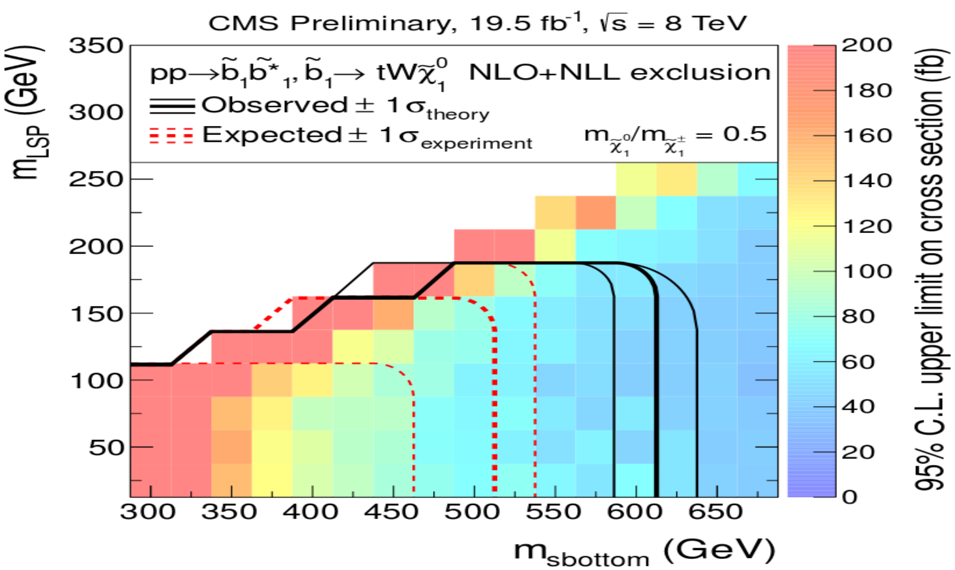


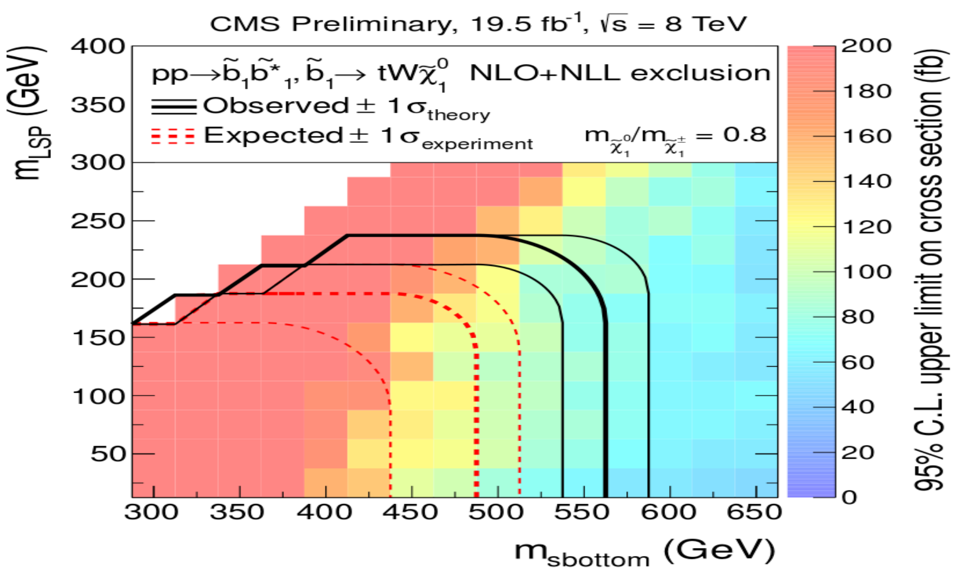
3 lepton search: Results & Interpretations

Testing direct $\tilde{b}_1$ pair production with $\tilde{b}_1 \rightarrow t\,\tilde{\chi}^{\pm}_1$ decays: To be as generic as possible, have to consider different $\tilde{\chi}^{\pm}_1$ & $\tilde{\chi}^{0}_1$ hypothesis:



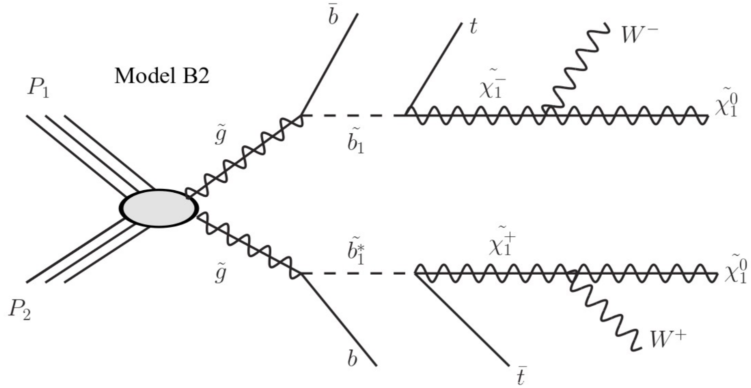


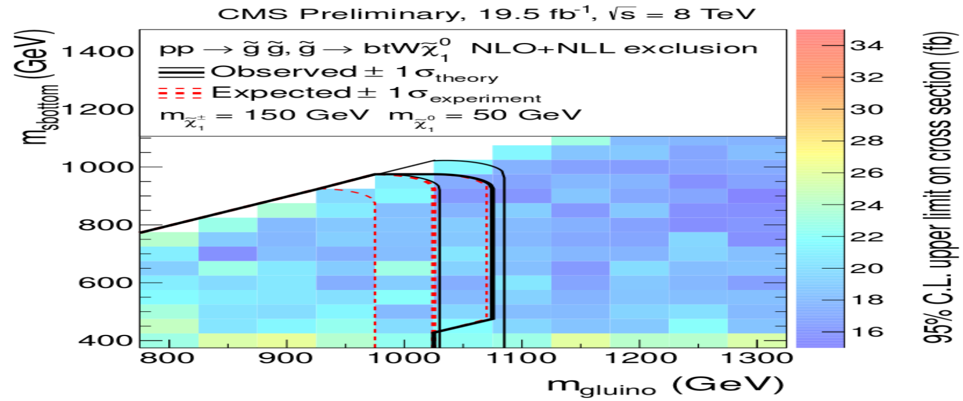


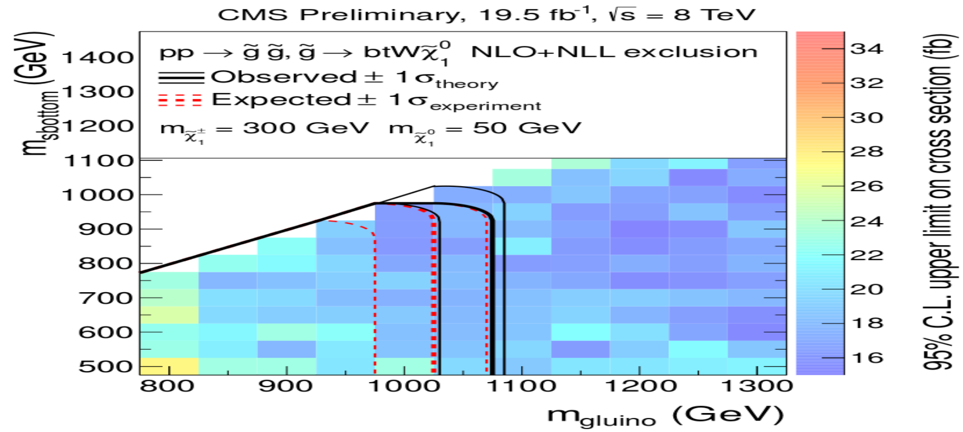


3 lepton search: Results & Interpretations

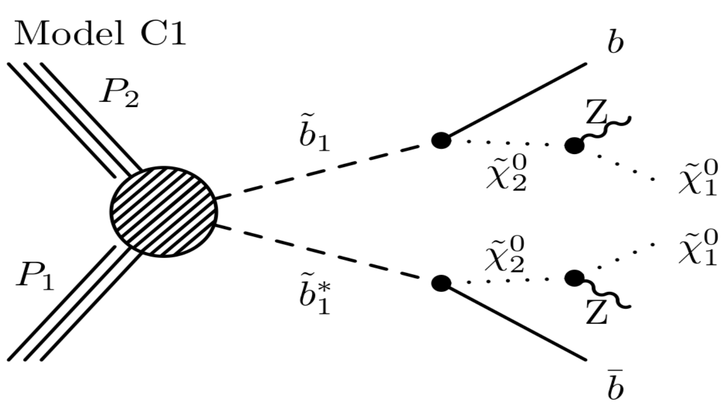
Testing a $\tilde{b}_1$ production via gluino pair production with $\tilde{b}_1 \rightarrow t\,\tilde{\chi}^{\pm}_1$ decays

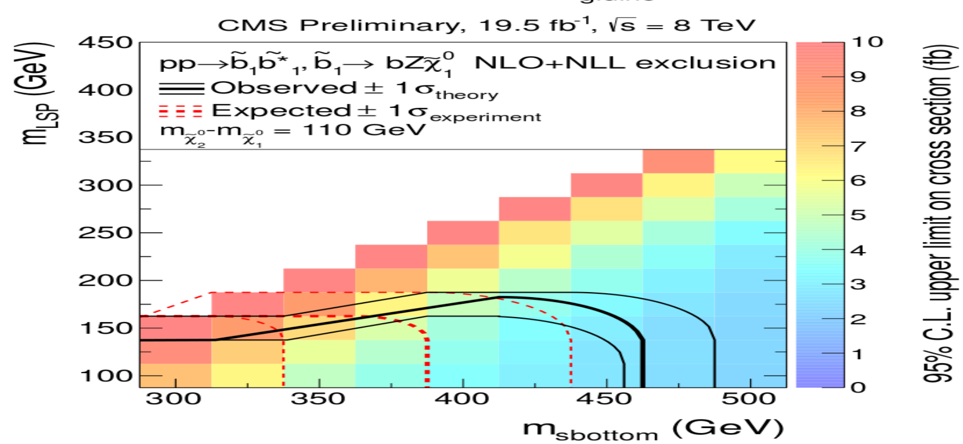




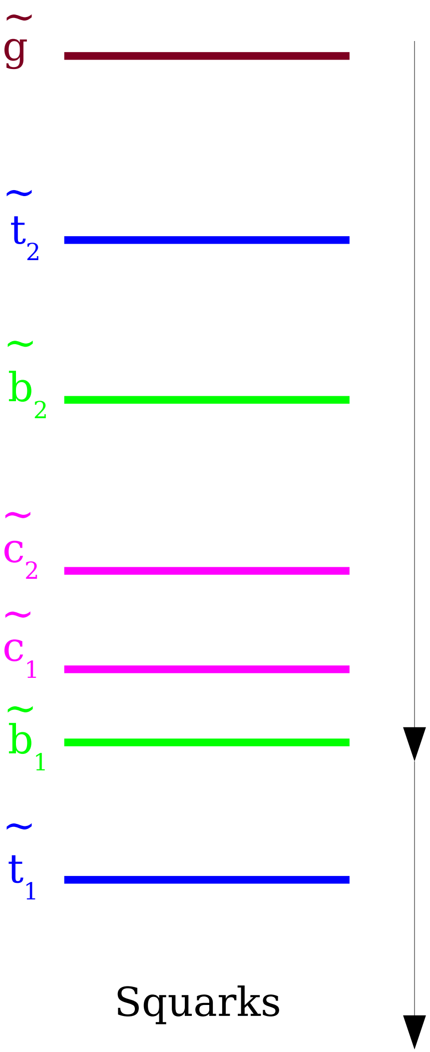


Testing direct $\tilde{b}_1$ production via "higher mass players": $\tilde{\chi}^0_2$





"General" searches,
Gluino oriented searches:



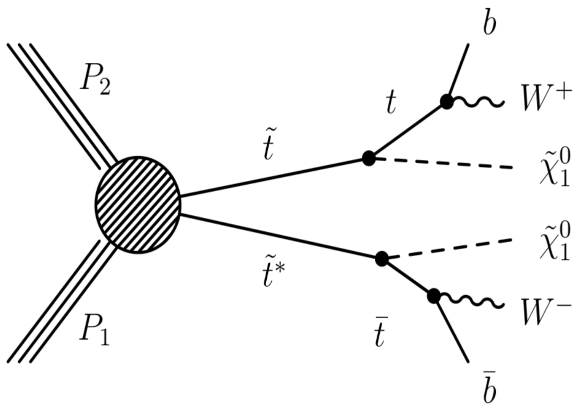
b

- *Frequently high jet, missing energy*
- *Capture physics picture of long decay chains*
- *Decay chains can involve higher mass players*
- *Since many "SUSY actors" involved: They are frequently quite specific in mass-hierarchy, thus quite model-dependent*

$\to \tilde{t}\,\tilde{\chi}^{\pm}_{1} \to t\,W^{\pm}\,\tilde{\chi}^{0}_{1}$

$\to b\,\tilde{\chi}^{0}_{2} \to b\,Z^{0}\,\tilde{\chi}^{0}_{1}$

$\tilde{t}_1$ all hadronic

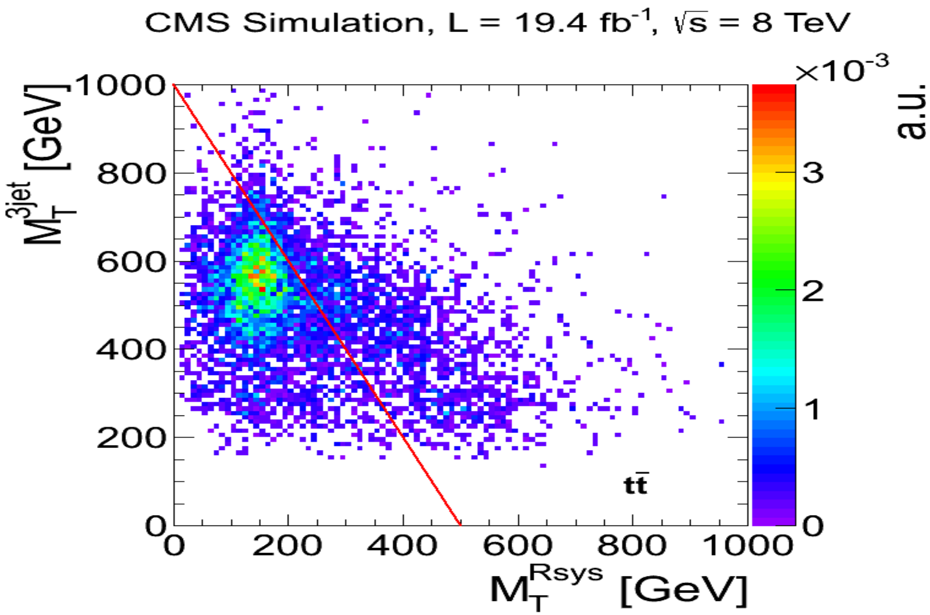


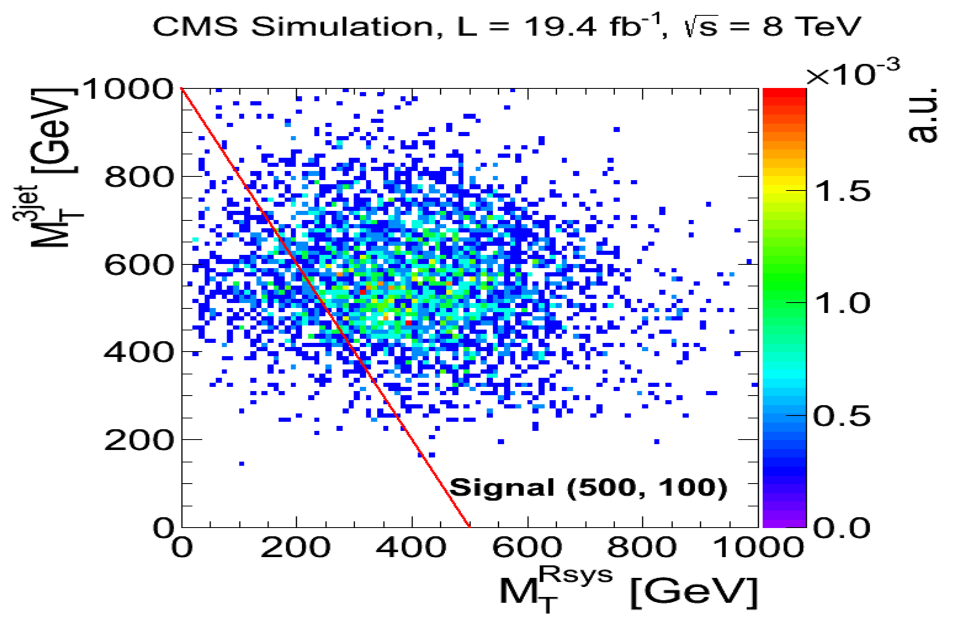
- **Preselection:**
  - Lepton veto: ttbar & Wjets minimization
  - $p_T(j_{1,2}) > 70$ $p_T(j_{3,4}) > 50$ $p_T(j_5) > 30$ GeV/c
  - N(b jet)≥1
  - $\Delta\phi(p_T(j_{1,2,3}),p_T^{miss}) > 0.5,0.5,0.3$ rad.: QCD suppression
  - Trigger: $p_T(j_{1,2}) > 50$ GeV/c + $p_T^{miss} > 80$ GeV

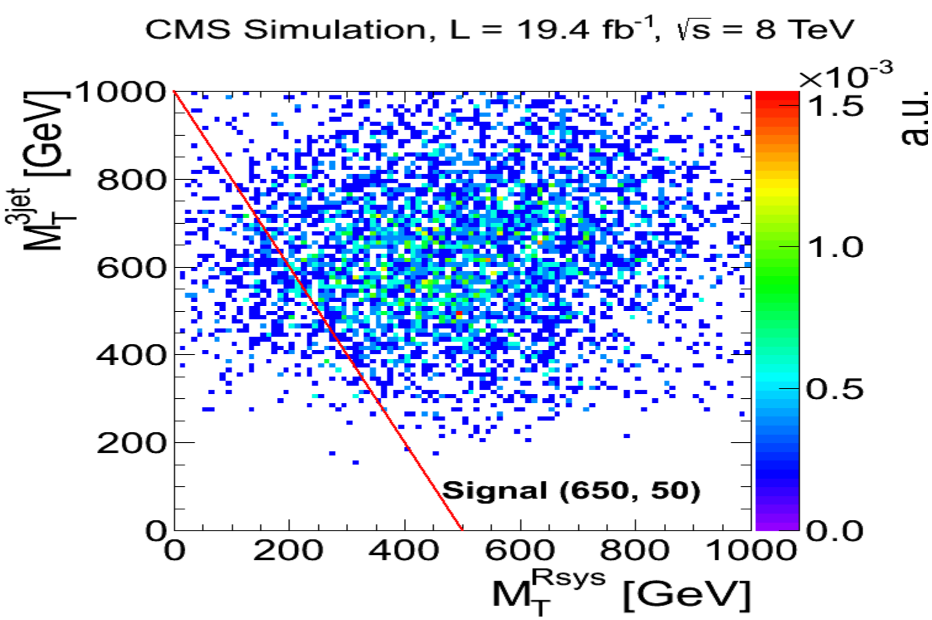
- **Top reconstruction:**
  - *top1*: Full top reconstruction w 3 jets out of ≥5: *3-jet*
    - $m(j_2j_3)/m(j_1j_2j_3)$, $m(12)/m(j_1j_2j_3)$, $m(j_1j_3)/m(j_1j_2j_3)$: Consistent with m(W)/m(top)
    - $m(j_1j_2j_3) \in [80,270]$ GeV/c^2
    - Combinations: m(3-jet) closest to m(top) is selected
  - *top2*: Partial top reconstruction: Invariant mass of remnant jets out of ≥5: *Rsys*
    - No full kinematic reconstruction as above
    - Differential reconstruction for N(jet) ≥3 & =2
      - e.g. N(jet) ≥3: N(b jet)≥1 & $m(j_mj_n)_{m,n\neq btag} \in [80,270]$ GeV/c^2

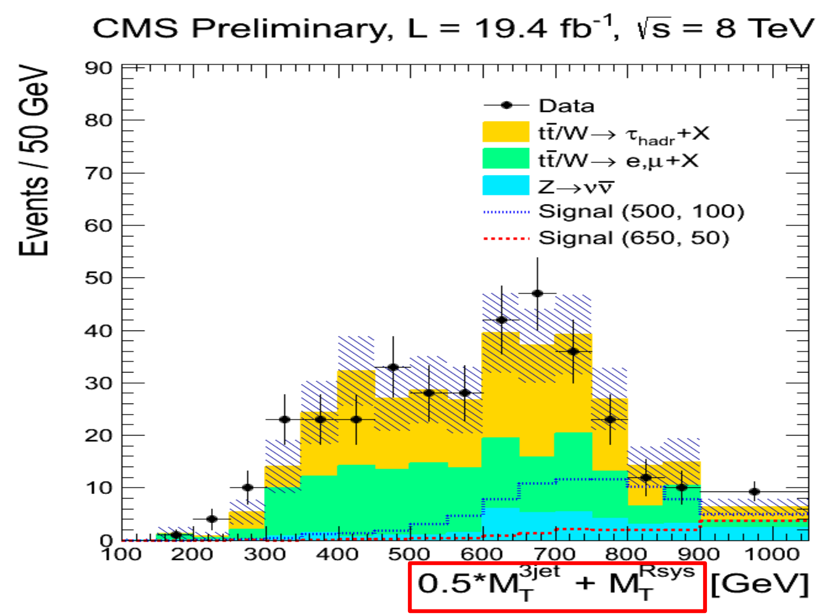
- **Topological requirement:** Form 2 invariant transverse masses assuming invisible particles as massless:
  - $M_T^{3\text{-jet}} = m(3\text{-jet}) \oplus p_T^{miss}$
  - $M_T^{Rsys} = m(Rsys) \oplus p_T^{miss}$

$\tilde{t}_1$ **all hadronic:** Topological selection









$\tilde{t}_1$ all hadronic: Data-Driven background

- **Hadronic decay of τ leptons produced in W boson decays:**
  - Estimated from a data sample of μ+jets events with $M_T < 100$ GeV/c^2
  - μ+jets & τ_h+jets arise from same process: Hadronic component of the two samples is the same except for the response of the detector to the muon or τ_h jet:

    μ in data replaced by a τ_h with randomly sampled p_T, then differences of response corrected
- **Lost leptons from a W boson decaying to e or μ:**
  - Estimated from a μ+jets sample selected with same criteria as for search
  - Corrected for IDentification & ISOlation efficiencies derived from Data
- **Z boson decaying into neutrinos:**
  - Z(νν)+jets simulation corrected with Scale-Factor, itself validated with Z(μμ)+jets events
- **Multijet production:**
  - Due to the p_T^{miss} & Δϕ requirements, the QCD multijet background contribution in the search region is nearly negligible

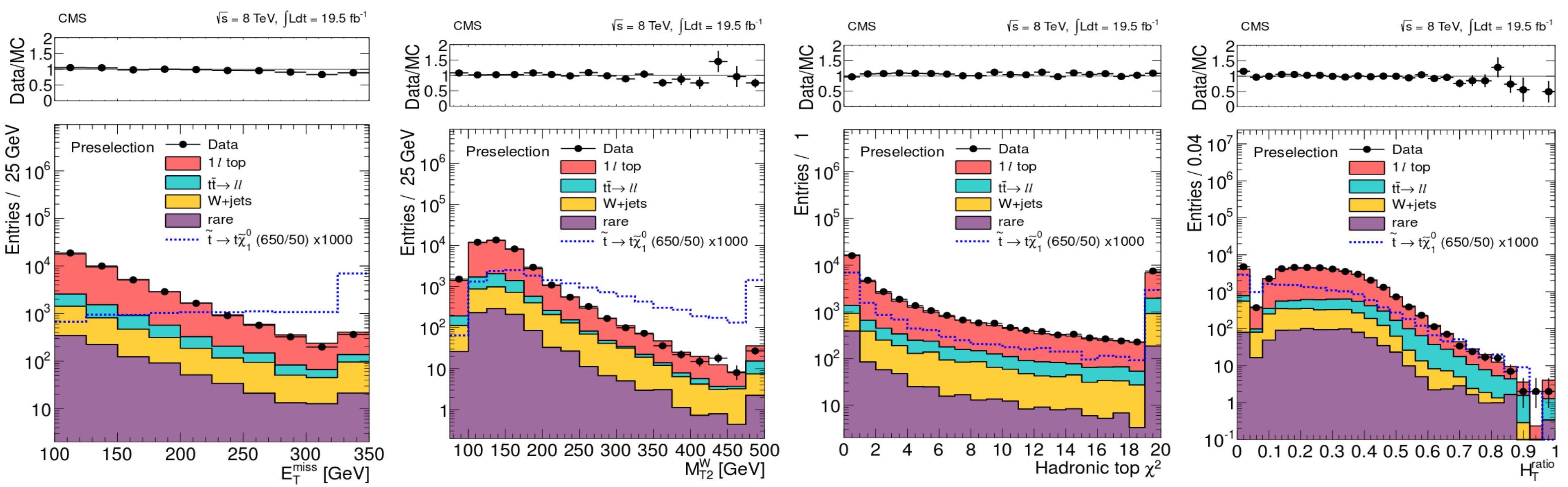
$\tilde{t}_1$ all hadronic: Expected SM background & signals

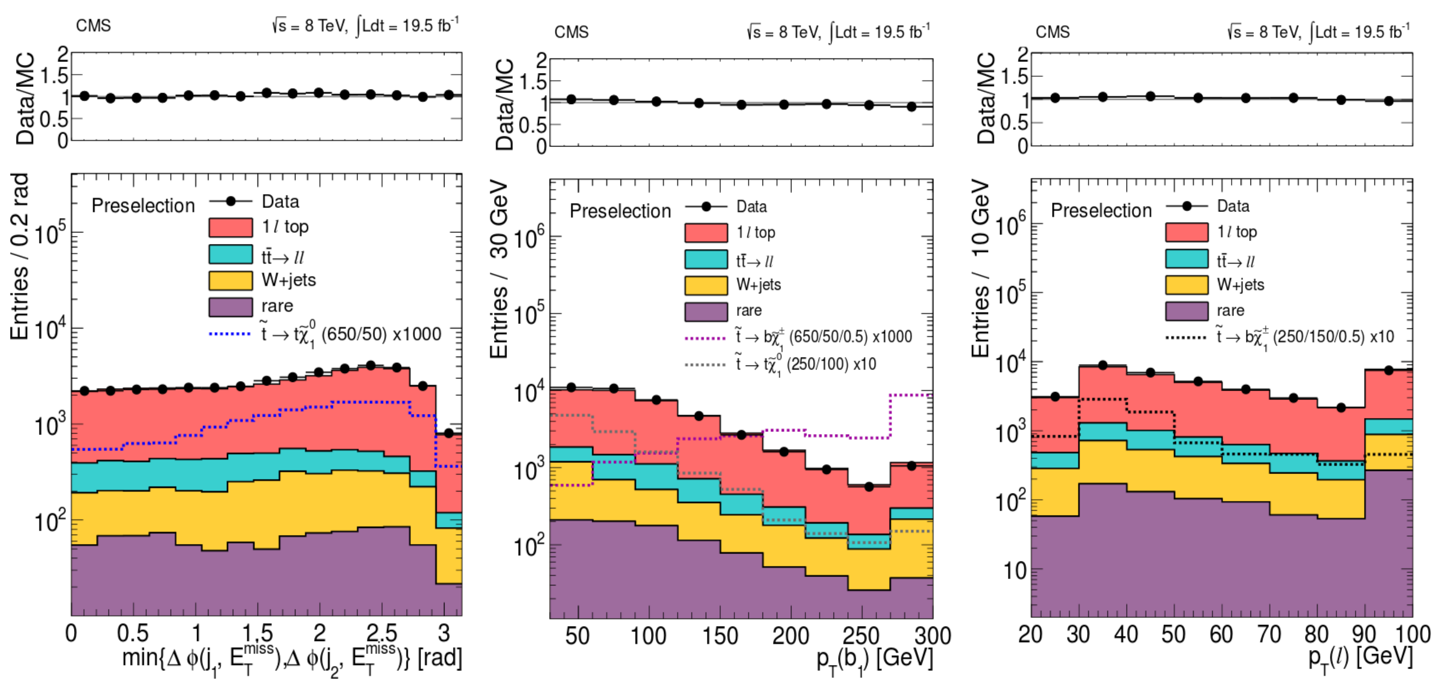
Process	e, μ vetos	jet counting	$\Delta\phi(\vec{p}_T^{miss}, \vec{p}_T^{jet})$	$N_{b\text{-jets}} \geq 1$	top reco. + kinematic cuts
$t\bar{t}$	2652858 ± 746	626652 ± 363	364869 ± 277	314179 ± 257	229.7 ± 6.9
$W \to \ell\nu$	1097574 ± 624	38143 ± 122	24594 ± 98	4767 ± 43	28.6 ± 3.2
$Z \to \nu\bar{\nu}$	1053228 ± 425	9518 ± 27	6760 ± 23	1276 ± 10	28.2 ± 1.2
QCD	1955905397 ± 674400	85334931 ± 123627	48350298 ± 93847	9516527 ± 41181	116.4 ± 72.5
single top	1618682 ± 4685	51918 ± 623	29453 ± 468	24270 ± 433	24.4 ± 4.6
$t\bar{t}Z$	2033 ± 6	1121 ± 5	676 ± 4	587 ± 3	9.3 ± 0.4
$t\bar{t}W$	2088 ± 7	1096 ± 5	645 ± 4	548 ± 4	3.3 ± 0.3
ZZ	280826 ± 99	2203 ± 9	1239 ± 7	524 ± 4	0.9 ± 0.2
WZ	490185 ± 179	4086 ± 16	2312 ± 12	757 ± 7	0.7 ± 0.2
WW	728425 ± 287	5435 ± 25	3076 ± 19	768 ± 9	0.9 ± 0.3
Total (no QCD)	7925899 ± 4817	740177 ± 732	433625 ± 554	347676 ± 506	325.9 ± 9.1
Signal (350, 0)	8802 ± 53	3113 ± 31	2505 ± 28	2200 ± 26	182.9 ± 7.6
Signal (500, 100)	927 ± 6	419 ± 4	360 ± 3	314 ± 3	85.9 ± 1.7
Signal (650, 50)	152 ± 1	75 ± 1	66 ± 1	58 ± 1	22.7 ± 0.4

$\tilde{t}_1$ all hadronic: Expected SM background & signals

	$p_T^{miss} > 200$ GeV, $N_{b\text{-jets}} \geq 1$	$p_T^{miss} > 350$ GeV, $N_{b\text{-jets}} \geq 1$	$p_T^{miss} > 200$ GeV, $N_{b\text{-jets}} \geq 2$	$p_T^{miss} > 350$ GeV, $N_{b\text{-jets}} \geq 2$
$t\bar{t}$	153.8 ± 5.7	18.9 ± 2.0	63.4 ± 3.7	6.3 ± 1.2
$W \to \ell\nu$	22.9 ± 2.9	5.8 ± 1.4	3.9 ± 1.2	1.1 ± 0.6
$Z \to \nu\bar{\nu}$	25.0 ± 1.2	8.4 ± 0.6	4.6 ± 0.5	1.3 ± 0.2
QCD	1.1 ± 0.6	$0.0^{+0.5}_{-0.0}$	$0.0^{+0.5}_{-0.0}$	$0.0^{+0.5}_{-0.0}$
single top	17.5 ± 3.9	5.2 ± 2.1	7.0 ± 2.5	1.8 ± 1.2
$t\bar{t}Z$	7.8 ± 0.4	2.3 ± 0.2	4.2 ± 0.3	1.4 ± 0.2
$t\bar{t}W$	2.4 ± 0.2	0.3 ± 0.1	1.1 ± 0.2	0.1 ± 0.1
ZZ	0.8 ± 0.2	0.3 ± 0.1	0.2 ± 0.1	$0.0^{+0.1}_{-0.0}$
WZ	0.5 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	$0.0^{+0.1}_{-0.0}$
WW	0.8 ± 0.3	0.1 ± 0.1	0.3 ± 0.2	$0.0^{+0.2}_{-0.0}$
Total (no QCD)	231.5 ± 7.6	41.2 ± 3.3	84.7 ± 4.6	12.0 ± 1.8
Data	254	45	83	15
Signal (350, 0)	162.8 ± 7.2	11.3 ± 1.9	84.4 ± 5.2	7.5 ± 1.5
Signal (500, 100)	83.2 ± 1.7	33.7 ± 1.1	48.1 ± 1.3	19.8 ± 0.8
Signal (650, 50)	22.4 ± 0.4	15.8 ± 0.3	13.1 ± 0.3	9.3 ± 0.2

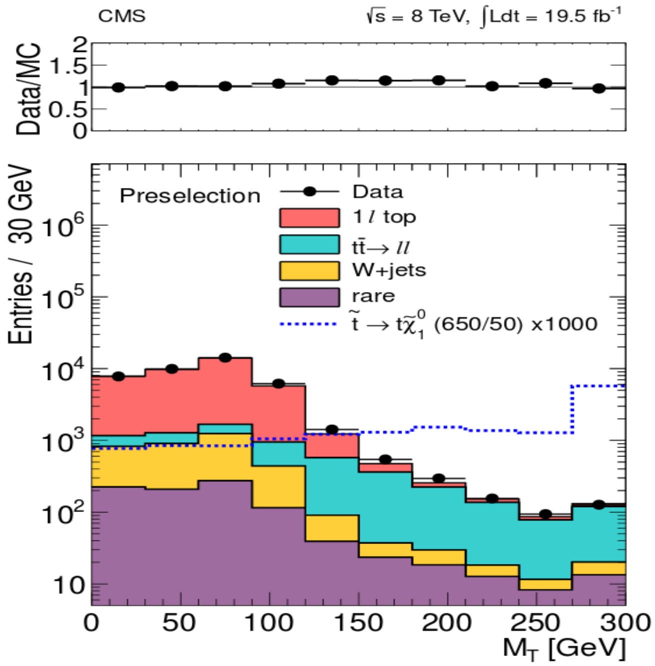
$\tilde{t}_1$ **single lepton**: Selection variables: Kin. & Topo.





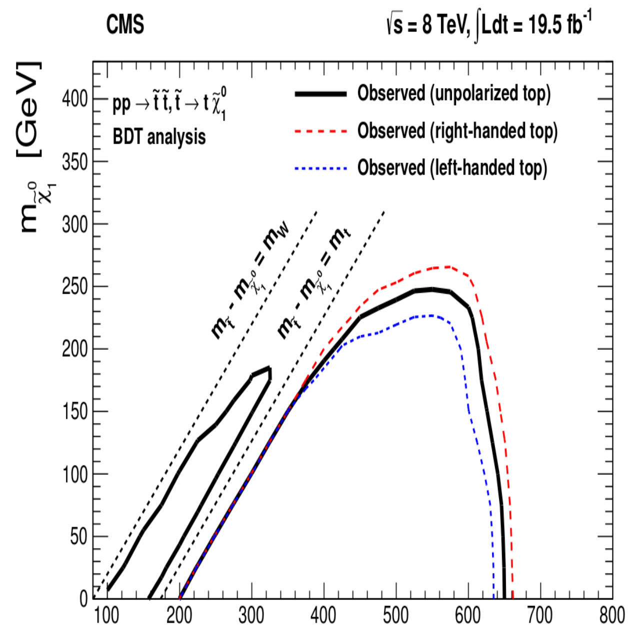
$\tilde{t}_1$ **single lepton**: Background determination

Idea: Use the M_T peak region, where we know well the SM background, to predict background in the tails



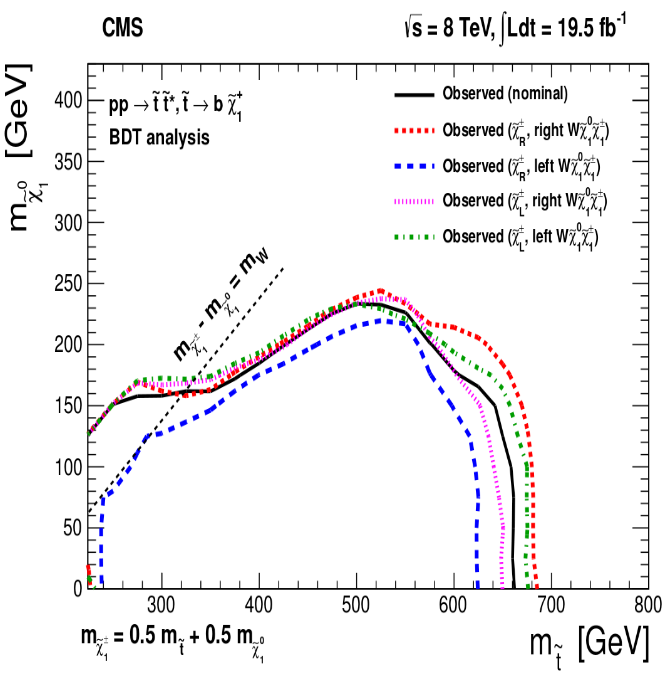
$$N_{predicted}(B) = N_{MC}(SR)\ .\ [N_D(peak)/N_{MC}(peak)]\ .\ [N_{MC}(SR)/N_{MC}(peak)]$$

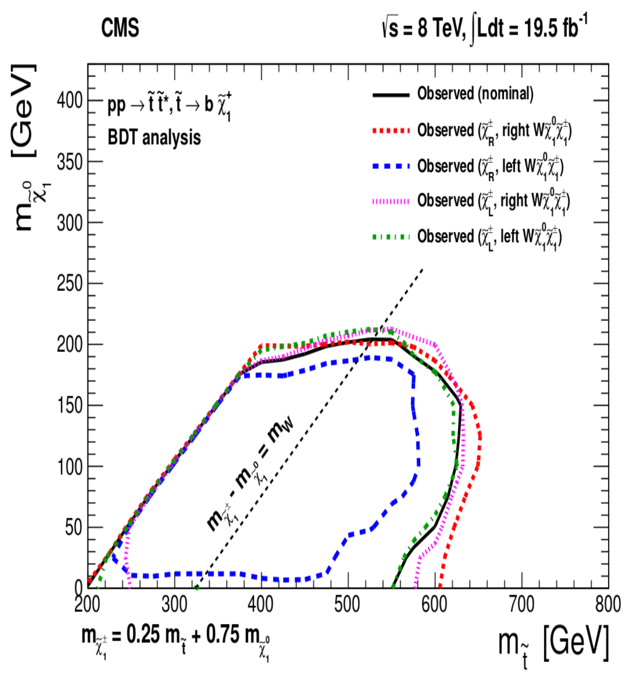
$\tilde{t}_1$ single lepton

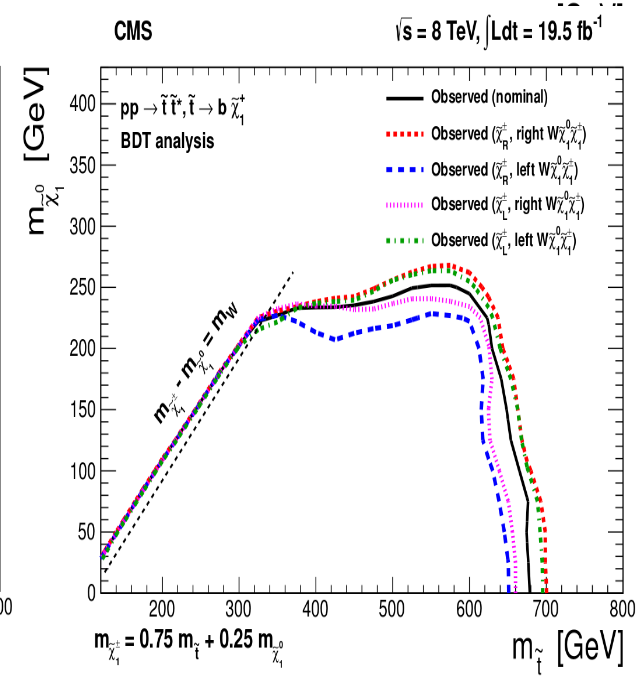


Acceptances depend on top polarization in $\tilde{t}_1 \to t\,\tilde{\chi}^0_1$

Acceptances depend on $\tilde{\chi}^{\pm}_1$ polarization & ($\tilde{\chi}^{\pm}_1 W \tilde{\chi}^0_1$) coupling in $\tilde{t}_1 \to b\,\tilde{\chi}^{\pm}_1$ decays





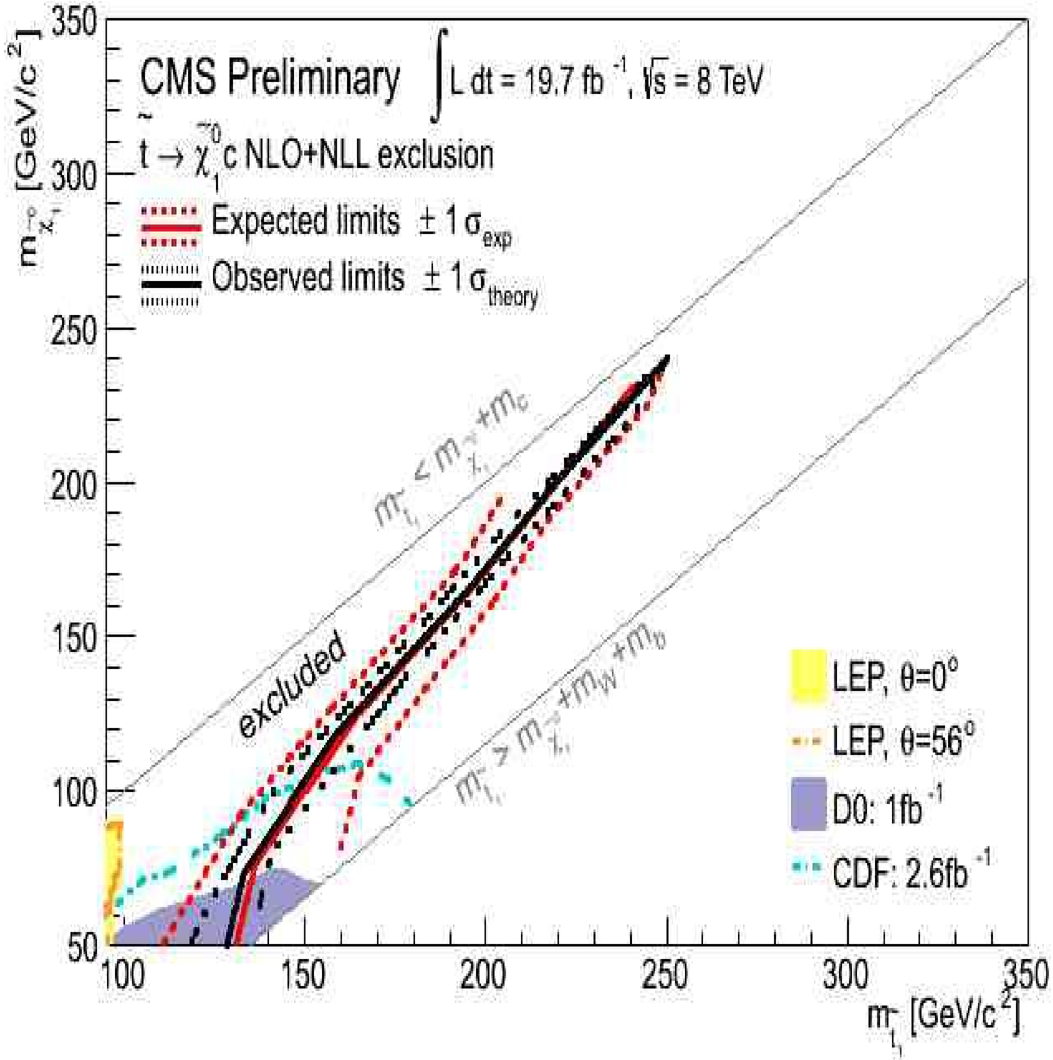


$\tilde{t}_1 \rightarrow c\, \tilde{\chi}^0_1$

CMS PAS-SUS-13-009

- p_T(j1,2)>110,60 GeV/c: Keeps soft charm jets 'invisible' while maintaining a low QCD
- MET>250 GeV
- $\Delta\phi$(j1,j2)<2.5: Reduce QCD
- Lepton veto

- Search performed in 7 inclusive bins of p_T(j1)



$\tilde{t}_1$ & $\tilde{b}_1$: Background determination

- **SR A:**
  - Dominating background: Z+HF-jets / Z→νν
  - W+HF-jets / W→l±: Non-reconstructed lepton or l= τ → had
  - Control-regions w N(l)=1,2:
    - N(l)=2: SF & OS dilepton w m(ll)∈[75,105]: Enriched in Z. p_T(l) vectorially added to p_T^{miss}: Mimic expected MET from Z→νν events
    - N(l)=1: M_T∈[40,100]: Enriched in ttbar & W+Jets

Contributions of ttbar, Z+Jets & W+Jets:

Simultaneously estimated with profile likelihood in 3 control-regions

CRA_1L	CRA_SF	CRA_DF
One e or μ	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$	$e^{\pm}\mu^{\mp}$
Veto additional lepton candidates ($p_{\mathrm{T}}(e)$ >7 GeV $p_{\mathrm{T}}(\mu)$ >6 GeV)		
Only two reconstructed jets with $p_{\mathrm{T}} > 50$ GeV		
$p_{\mathrm{T}}(j_1) > 130$ GeV $p_{\mathrm{T}}(j_2) > 50$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV	$p_{\mathrm{T}}(j_1) > 50$ GeV $p_{\mathrm{T}}(j_2) > 50$ GeV $E_{\mathrm{T}}^{\mathrm{miss}}$(lepton-corrected) > 100 GeV	$p_{\mathrm{T}}(j_1) > 130$ GeV $p_{\mathrm{T}}(j_2) > 50$ GeV $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV
Two reconstructed b-jets ($p_{\mathrm{T}} > 50$)		
40 GeV $< m_{\mathrm{T}} <$ 100 GeV	75 GeV $< m_{\ell\ell} <$ 105 GeV	$m_{\ell\ell} > 50$ GeV
$m_{\mathrm{CT}} > 150$ GeV	lepton $p_{\mathrm{T}} > 90$ GeV	$m_{\mathrm{CT}} > 75$ GeV
—	$m_{bb} > 200$ GeV	—

$\tilde{t}_1$ & $\tilde{b}_1$: Background determination

- **SR B:**
  - Dominating background: ttbar
  - W+HF-jets / W→$l^{\pm}$

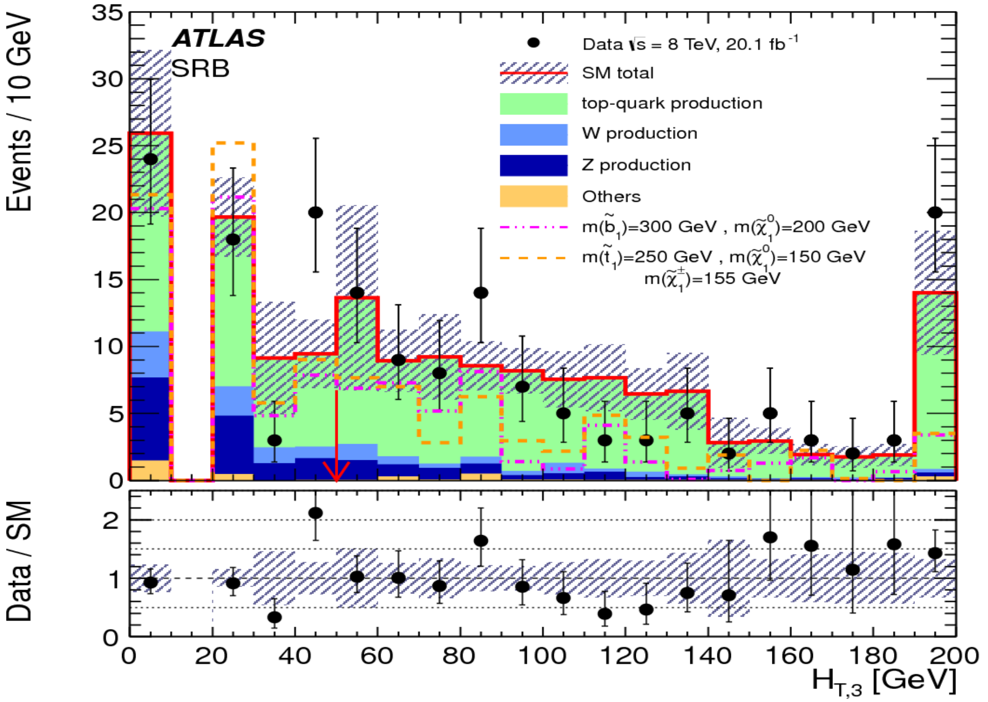
Contributions of ttbar & W+Jets:

Simultaneously estimated with profile likelihood in 2 control-regions

CRB_1L	CRB_SF
One e or μ	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$
Veto additional lepton candidates ($p_T(e) > 7$ GeV $p_T(\mu) > 6$ GeV)	
Only three reconstructed jets with $p_T > 30$ GeV	
$p_T(j_1) > 130$ GeV $E_T^{miss} > 120$ GeV	$p_T(j_1) > 50$ GeV E_T^{miss}(lepton-corrected) > 100 GeV
j_1 anti b-tagged; j_2 and j_3 b-tagged	
40 GeV $< m_T <$ 100 GeV	75 GeV $< m_{\ell\ell} <$ 105 GeV
—	Lepton $p_T > 90$ GeV
$H_{T,3} < 50$ GeV	

$\tilde{t}_1$ & $\tilde{b}_1$: Final numbers

Channel	SRA, m_{CT} selection					SRB
	150 GeV	200 GeV	250 GeV	300 GeV	350 GeV	
Observed	102	48	14	7	3	65
Total SM	94 ± 13	39 ± 6	15.8 ± 2.8	5.9 ± 1.1	2.5 ± 0.6	64 ± 10
Top-quark	11.1 ± 1.8	2.4 ± 1.4	0.44 ± 0.25	< 0.01	< 0.01	41 ± 7
Z production	66 ± 11	28 ± 5	11.4 ± 2.2	4.7 ± 0.9	1.9 ± 0.4	13 ± 4
W production	13 ± 6	4.9 ± 2.6	2.1 ± 1.1	1.0 ± 0.5	0.46 ± 0.26	8 ± 5
Others	4.3 ± 1.5	3.4 ± 1.3	1.8 ± 0.6	0.12 ± 0.11	$0.10^{+0.12}_{-0.10}$	2.0 ± 1.0
Multijet	0.21 ± 0.21	0.06 ± 0.06	0.02 ± 0.02	< 0.01	< 0.01	0.16 ± 0.16

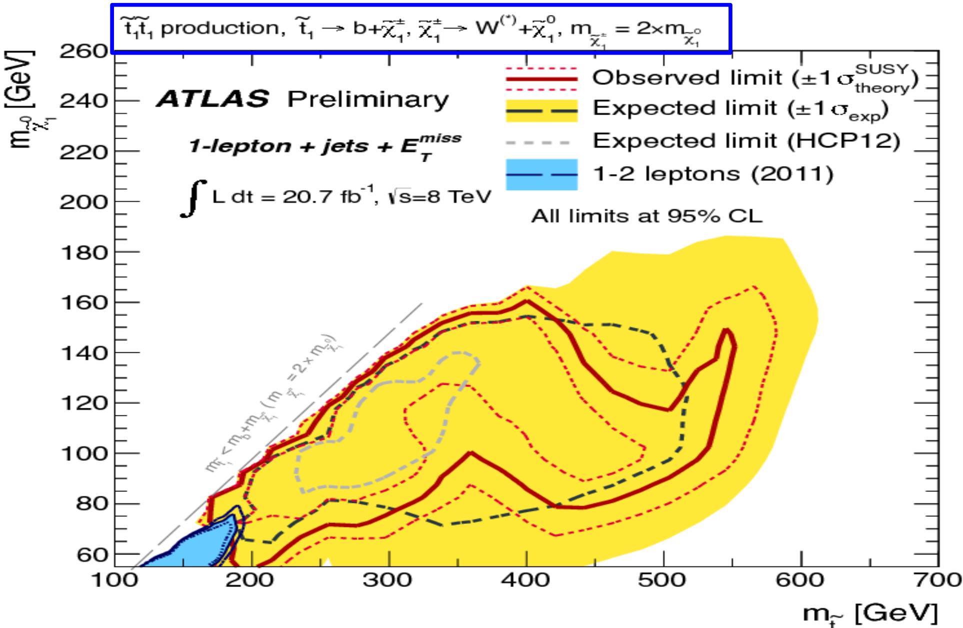


$\tilde{t}_1$ semi-leptonic: ...at a glance

m_{T2}: Generalization of m_T applied to signatures with 2 undetected particles, to further reduce the dileptonic tt background. For an event characterized by 2 one-step decay chains, a & b, each producing a missing particle C, the m_{T2} value of the event is defined by the minimization over all possible 2-momenta, p_{Ta}, p_{Tb}, such that their sum gives the observed missing transverse momentum pT_{miss}:

$$m_{T2} \equiv \min_{\vec{p}^{\,C}_{Ta} + \vec{p}^{\,C}_{Tb} = \vec{p}^{\,\text{miss}}_{\text{T}}} \{\max(m_{Ta}, m_{Tb})\}$$

where $m_{Ti} = m_T$ of branch i for a given hypothetical allocation (p^C_{Ta}, p^C_{Tb}) of the missing particle momenta



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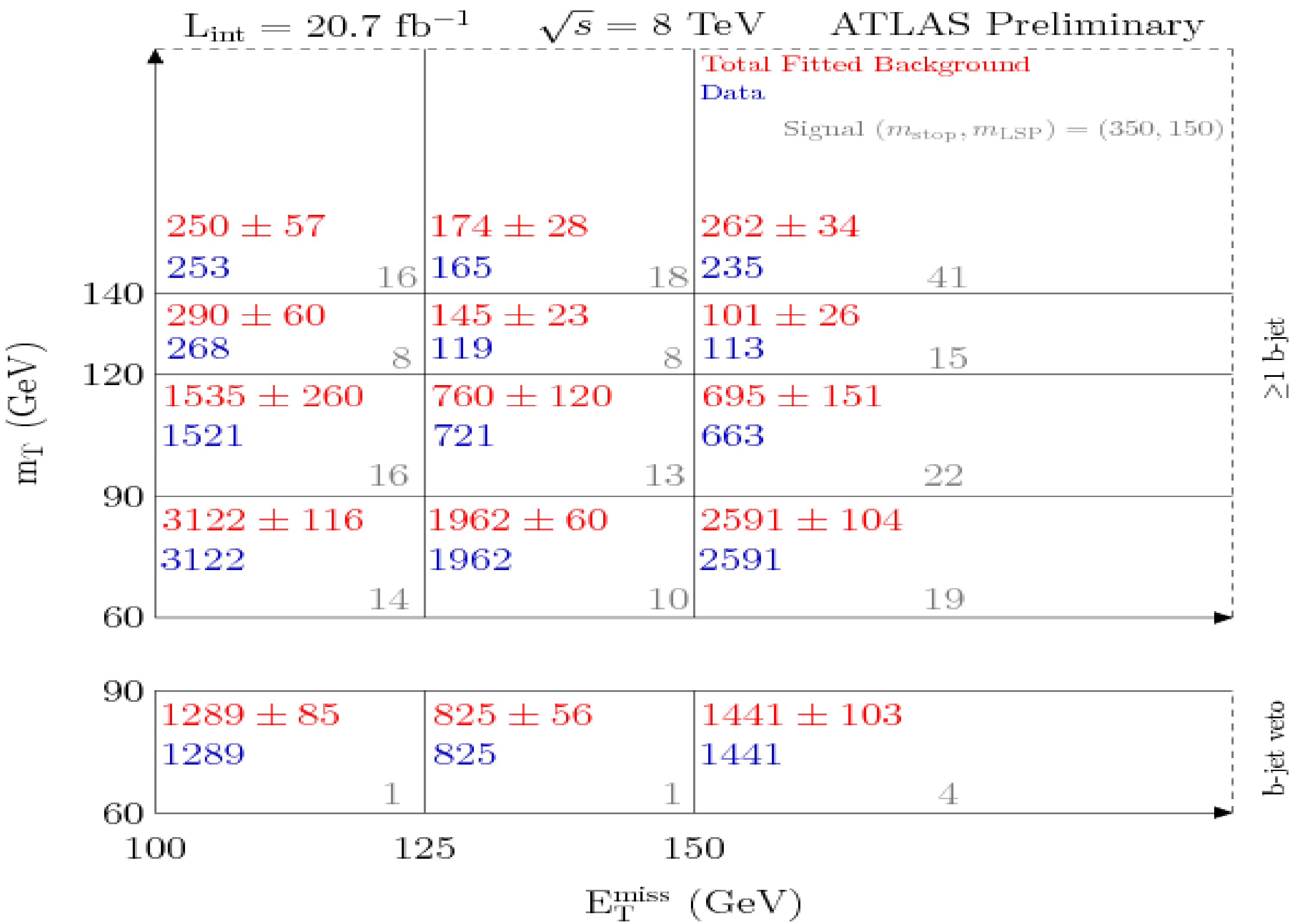
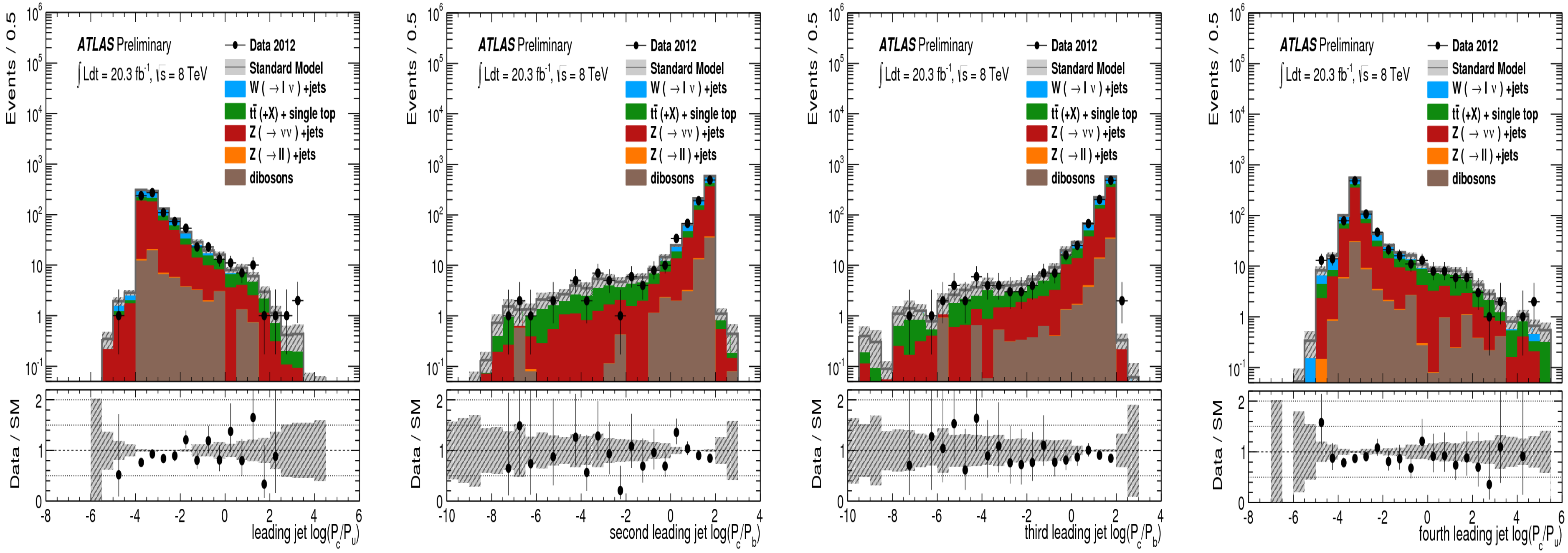
Background modeling: Each SR binned & shape-fit



$\tilde{t}_1 \to c\,\tilde{\chi}^0_1$: Charm-tagging

- Multivariate techniques to combine information from the impact parameters of displaced tracks and topological properties of secondary and tertiary decay vertices reconstructed within the jet
- → 3 weights P_u, P_b & P_c targeting light-flavour & gluon, b- & c-quark jets
- Anti-b & anti-u discriminators: Anti-b=$\log(P_c/P_b)$ Anti-u=$\log(P_c/P_u)$
- Medium operating point: Anti-b>-1 Anti-u>-0.82
  - Efficiency(c-tag)~20%. Rejection(b/u/τ) ~ 5/140/10
- Loose operating point: Anti-b>-1
  - Efficiency(c-tag)~95%. Rejection(b) ~ 2



$\tilde{t}_1 \rightarrow c\,\tilde{\chi}^0_1$

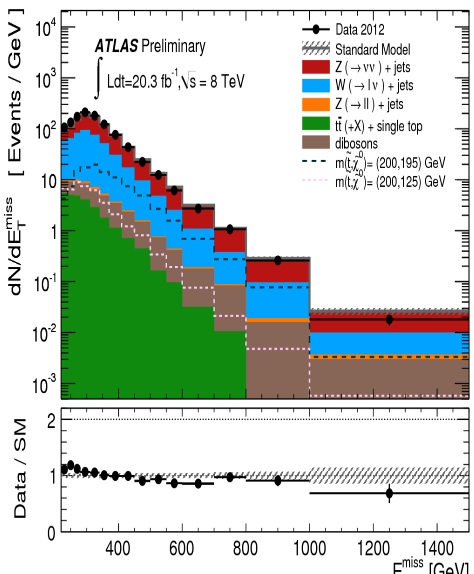
Selection: Cut & Count

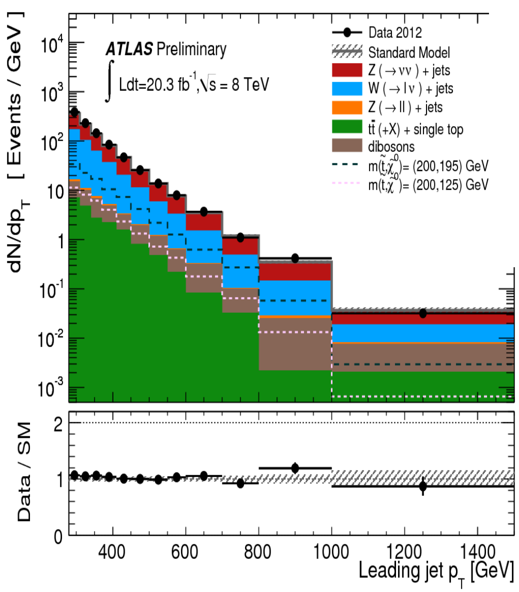
Low Δm: Small ϕ-space:

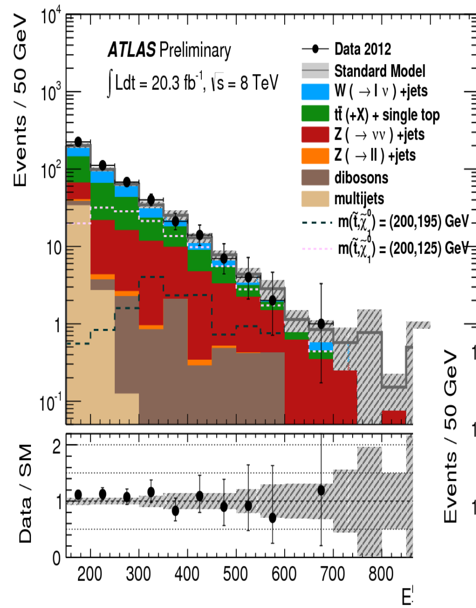
- N(jet)≤3 w $p_T(j) > 30$ GeV/c
- ISR jet: $p_T(j1) > 280$ GeV/c
- MET > 220 GeV

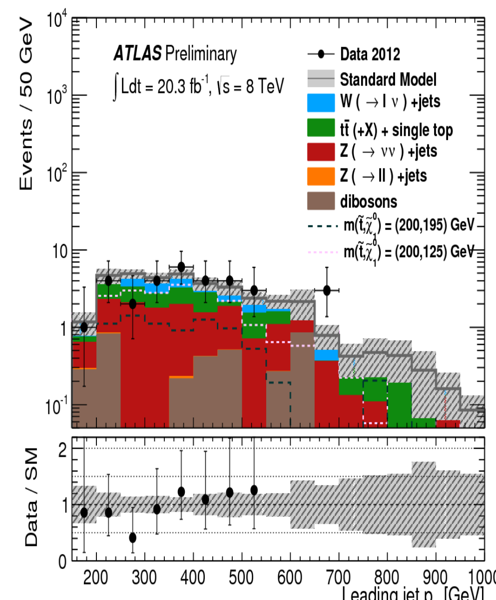
Moderate Δm: *Charm-tagging* enhances signal purity

- $p_T(j1) > 270$ GeV/c
- + N(add. jet)≥3 w $p_T(j)>30$ GeV/c
- MET > 410 GeV





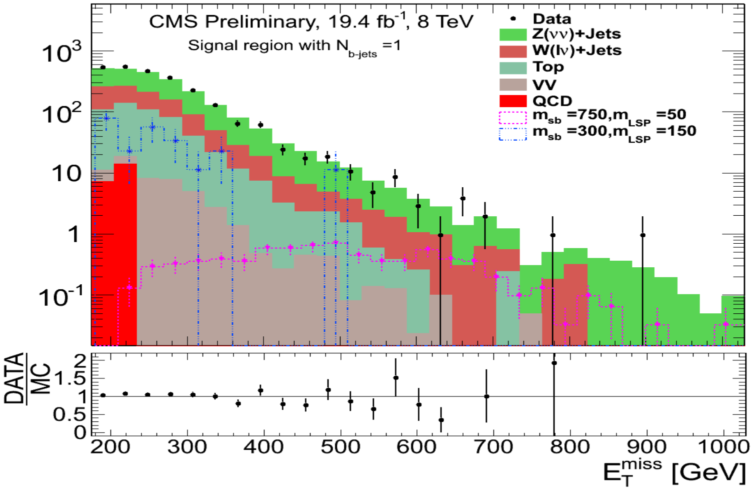


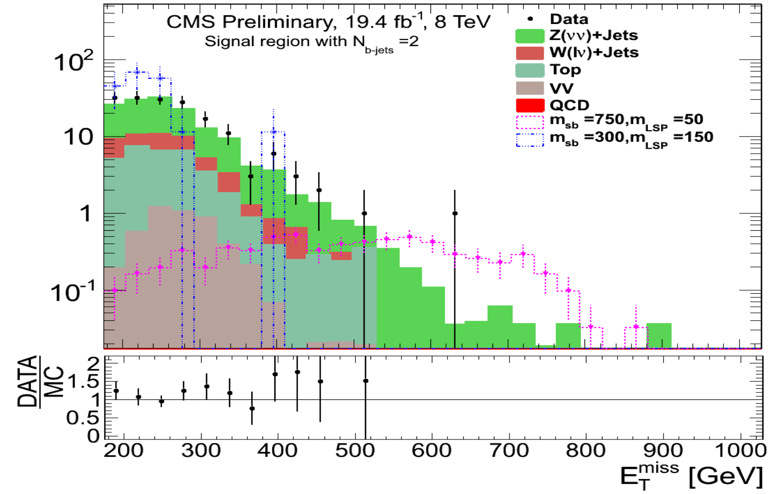


$\tilde{t}_1 \to c\,\tilde{\chi}^0_1$: Background determination

- **Z+jets→νν**: Use MC normalized using data in control regions
- **W+jets→l±**: Use MC normalized using data in control regions
- ttbar:
  - Low Δm: ttbar negligible; taken from MC
  - High Δm: MC normalized in top-enriched control region, obtained mainly w b-tagging
- WW, WZ, ZZ: Rather small; taken from MC
- QCD: From Data
  - Sample of low-MET seed events is selected from data
  - Response function, R, quantifying the fluctuation in measured jet pT, is measured. R includes effects of jet mis-measurements & contribution from neutrinos in HF decays. Initial estimate of the response function is obtained from the MC
  - R modified by smearing seed events, until good agreement is observed between smeared data & data in control regions sensitive to this jet response
  - Seed events are then smeared with the adjusted response function from (3).

$$N(\mathrm{Z}(\to \nu\bar{\nu}) + \mathrm{jets})_{signal} = (N^{data}_{W\to\mu\nu,control} - N^{non-W}_{W\to\mu\nu,control}) \times \frac{N^{MC}(\mathrm{Z}(\to \nu\bar{\nu}) + \mathrm{jets})_{signal}}{N^{MC}_{W\to\mu\nu,control}}$$





	M_{CT} <250 GeV $N_{\text{b-jets}}$=1	250< M_{CT} <350 GeV $N_{\text{b-jets}}$=1	350< M_{CT} <450 GeV $N_{\text{b-jets}}$=1	M_{CT} > 450 GeV $N_{\text{b-jets}}$=1
$Z(\nu\bar{\nu})$+jets	848±12±79	339±8.1±52	48±3.0±6.0	8.1±1.6±1.7
Top+$W(\ell\nu)$+jets	645±24±57	381±17±38	36±4.9±5.7	7.8 ±2.6±2.0
QCD	25.3±9±5.2	16±7.4±2.8	$1.0^{+1.2}_{-1.0}$	$1.0^{+1.2}_{-1.0}$
Rare processes	18 ± 9.2	18±8.9	1.1±0.5	0.3±0.1
Total Background	1536±102	754±68	86±10	17 ±4.1
Data	1556	807	101	23

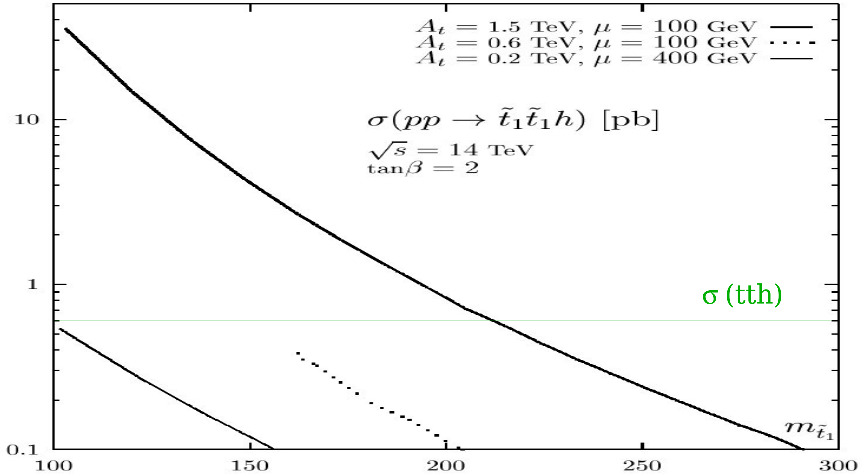
	M_{CT} <250 GeV $N_{\text{b-jets}}$=2	250< M_{CT} <350 GeV $N_{\text{b-jets}}$=2	350< M_{CT} <450 GeV $N_{\text{b-jets}}$=2	M_{CT} > 450 GeV $N_{\text{b-jets}}$=2
$Z(\nu\bar{\nu})$+jets	60±3.4±7.1	28±2.4±3.8	3.9±0.9±1.0	0.7±0.6±0.6
Top+$W(\ell\nu)$+jets	29±2.9±5.5	17±2.5±3.3	2.4±0.9±0.6	0.2±0.2
QCD	1.9±0.7±0.4	1.2±0.8±0.2	0.1±0.1	0.1±0.1
Rare processes	1.8 ± 0.9	3.4±1.7	0.1±0.1	0.1±0.1
Total Background	93±10	50±6.4	6.5±1.7	1.0 ±0.9
Data	101	55	8	1

"Naturalness": Stop and... Higgs

Idea: If only stop is low mass among sParticles: Enough to cure the hierarchy problem. One preferred phenomenological windows for this is:

Decoupled regime: Light h "SM like": h → γγ, {H,H$^{\pm}$,A} much heavier

Coupling : $g_{h\tilde{t}\tilde{t}}$ = ... + [$-m_{\tilde{t}}^2 + m_{\tilde{t}} \sin 2\theta_t (A_T + \mu/\tan\beta)/2$] / M_Z^2



Djouadi et al., PRL 80, 1830

- $A_T \sim 0$: $\sigma(\tilde{t}\,\tilde{t}\,h) = 2\,\sigma(\tilde{t}_1\tilde{t}_1 h) \geq \sigma(tth)$
- A_T intermediate: Destructive interference
- A_T (very) large: $\sigma(\tilde{t}_1\tilde{t}_1 h) > \sigma(tth)$ for $m(\tilde{t}_1) < 220$ GeV/c^2

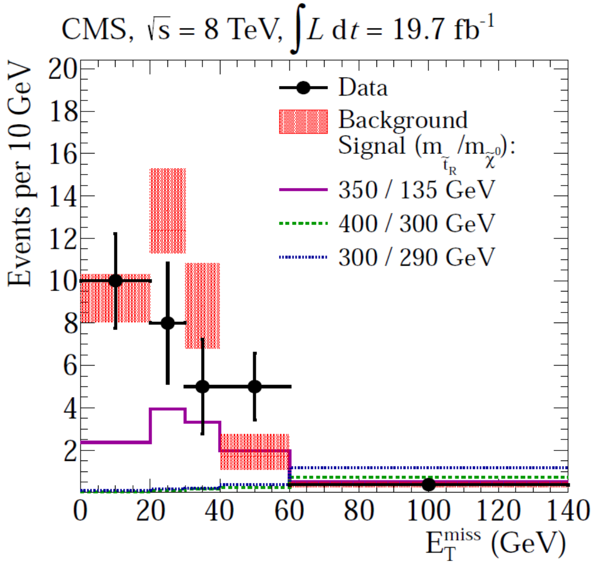
- For parts of SUSY "mass space" : $\sigma(\tilde{t}_1\tilde{t}_1 h) \gtrsim \sigma(tth)$
- An experimental measure of Γ(ff' MET jj γγ) – Γ_{SM}(tth) →
  - Any significant deviation from 0 → BSM, pointing to $\tilde{t}_1$
  - Test of scalar potential (soft breaking of SUSY)
  - **Largest electroweak MSSM coupling**

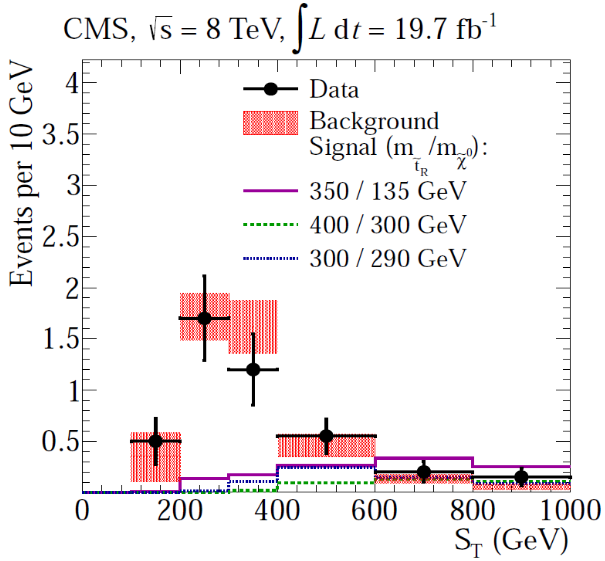
“Naturalness”: Stop & Higgs

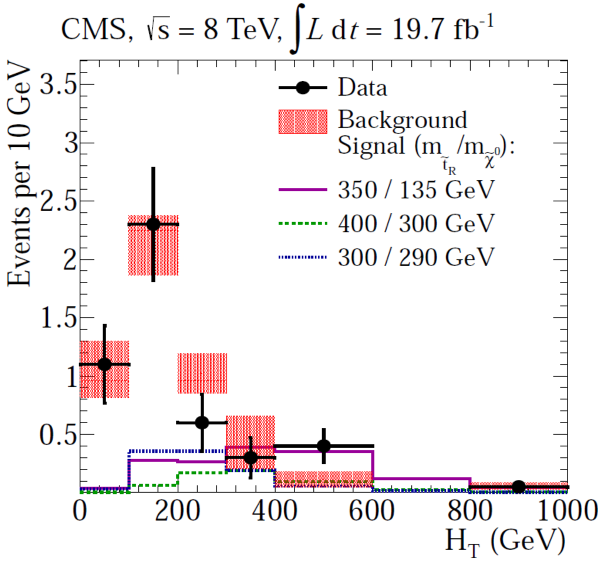
Diminish SM background:

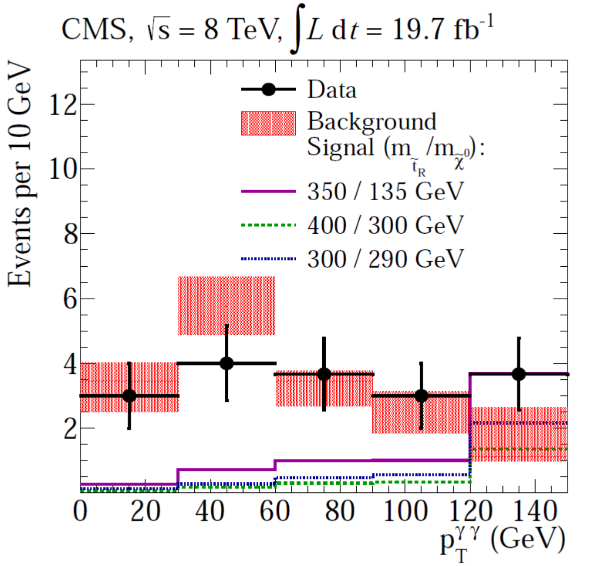
- At least $H \to \gamma\gamma$: Take advantage of known m(H)
  - Allows to use $m(\gamma\gamma)$ sidebands for estimation of the background from data, w/o sensitivity to exact composition of the background, which is dominated by QCD production of $\gamma\gamma bb$ events and γb+jet events with jet misidentified as a γ
- $E(\gamma_1,\gamma_2) > 45, 25$ GeV
- $m(\gamma\gamma) \in$
  - [120,131] GeV : Signal region
  - [103,118] & [133,163] GeV: Lower & Upper side-band regions
- N(jet)≥2 from either other H, or t_R decays

Kinematic distributions before event categorization:

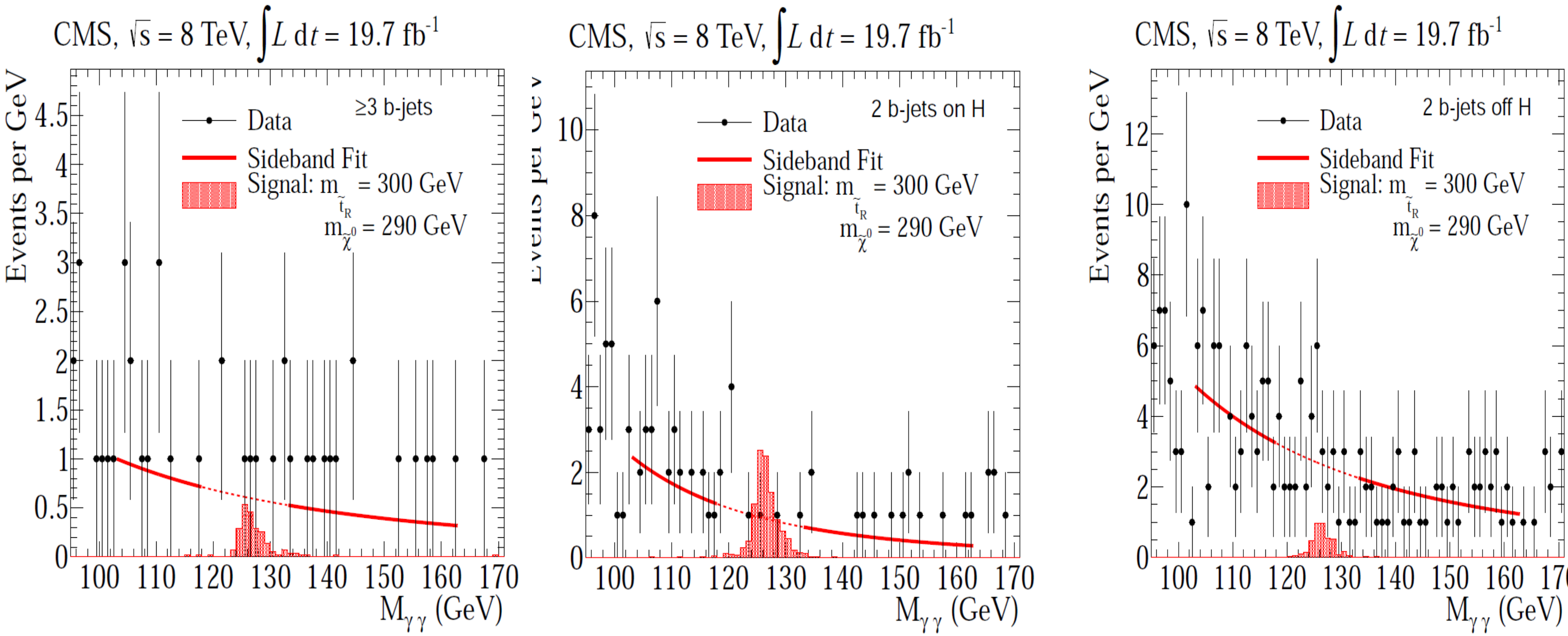








m(γγ) in the 3 Signal Regions:



ATLAS-CONF-2013-061

View on
3[rd] generation squark ⇌ Higgs sector:

$\tilde{b}_1 \rightarrow b\, \tilde{\chi}^0_2$

$\tilde{\chi}^0_2 \rightarrow h\, \tilde{\chi}^0_1$