Search for natural SUSY

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VI Workshop Italiano sulla Fisica p-p a LHC
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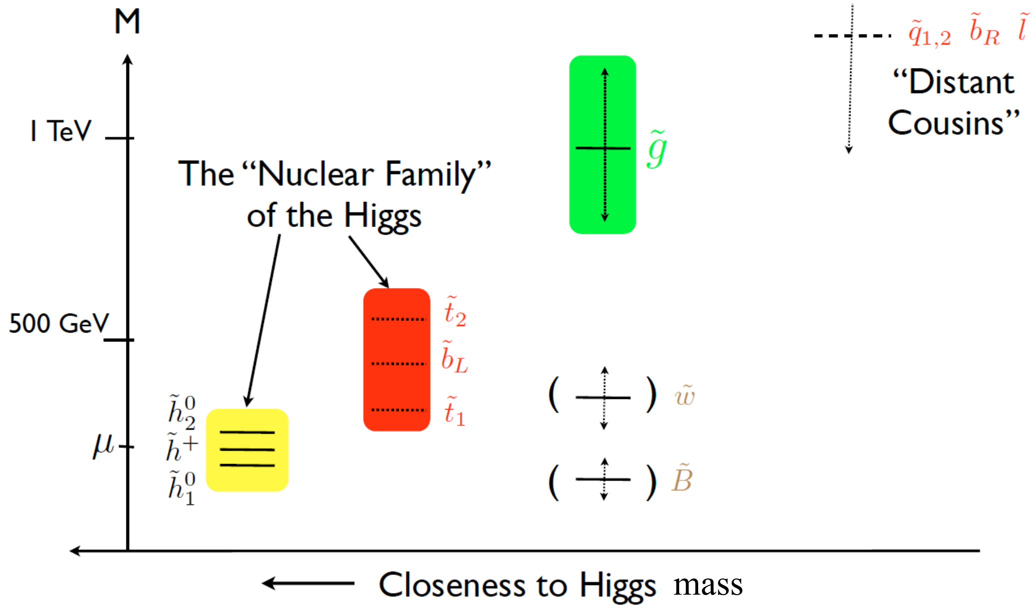
Natural SUSY



Hierarchy problem: requires cancellation of the quadratically divergent loop corrections to the Higgs boson mass in SM

$$\frac{m_h^2}{2} \approx -|\mu|^2 + m_u^2 + \ldots$$

$$\delta m_u^2 \approx -\frac{3y_t^2}{8\pi^2}(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + A_t^2)\log M/m_{\tilde{t}}$$

$$m_{\tilde{b}_L}$$

$$\delta m_{\tilde{t}}^2 \approx \frac{8\alpha_s}{3\pi} m_{\tilde{g}}^2 \log M/m_{\tilde{t}}$$

$$m_Z^2 = -2\frac{(\tan\beta)^2 m_{H_u}^2 - m_{H_d}^2}{(\tan\beta)^2 - 1} - 2\mu^2$$

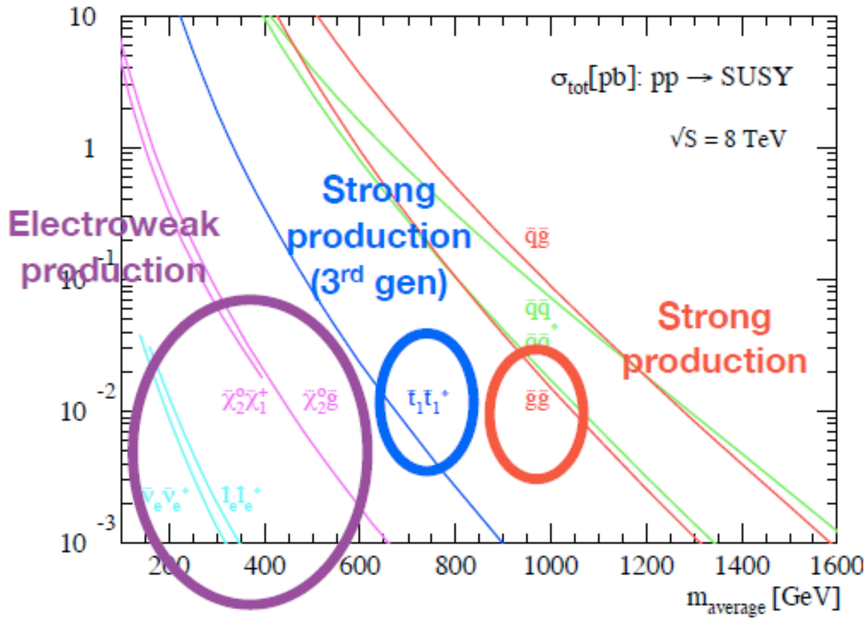
"Natural SUSY" implies relatively low masses for

- ✦ 3rd generation squarks
  - ✦ stop, sbottom
- ✦ gluinos
- ✦ Higgsinos (→charginos, neutralinos)

SUSY search strategy

- Strong production of squark and gluinos
  - large cross-section
  - inclusive searches: jet + E_T^{miss} + (0/1/2) leptons

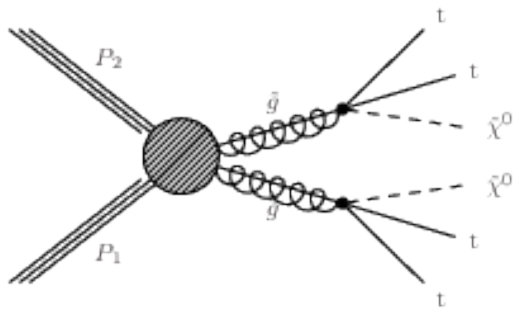
- EWKinos and third generation squarks
  - low mass required by naturalness
  - more likely accessible at the LHC, but cross sections are much smaller
  - dedicated searches optimized on the signal kinematics



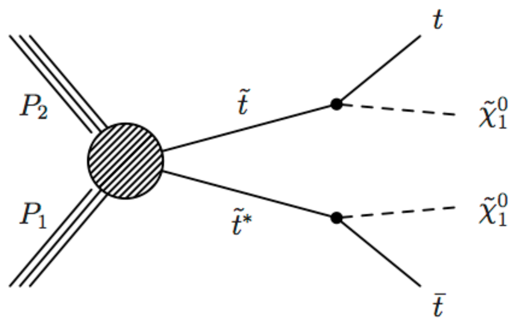
Taken from http://www.thphys.uni-heidelberg.de/~plehn/index.php?show=prospino&visible=tools

Look for:

- 3rd generation squarks in gluino decay
- direct production of light stop/sbottom
- EW production of gauginos



gluino mediated production



direct production

SUSY models

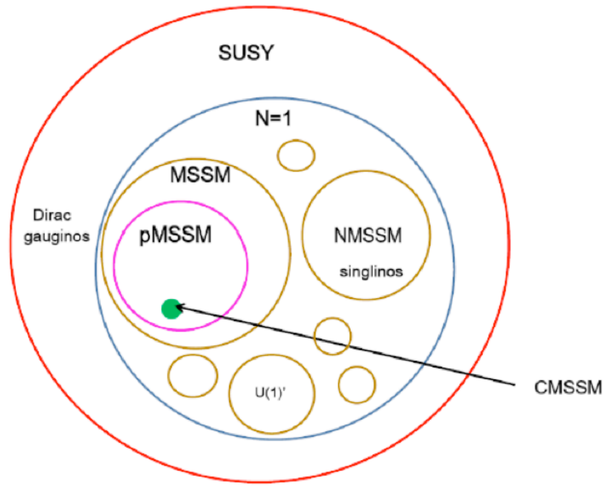
- **CMSSM** - UV models with few parameters, e.g., mSUGRA
  - are very predictive and very constrained by multiple sources.
  - They are phenomenologically limited, experiencing tension.

- **pMSSM** - reduces the number of MSSM parameters with experimentally motivated assumptions.
  - Can lead to complex spectra and decay patterns.
  - Less constrained SUSY.

- **Simplified Models** - only constrain the sparticles populating a given channel, but there are no correlations between different searches or other experiments (e.g., DM) and can be unphysical in some limits
  - Generate events with given decay chain on both legs
  - Assume 100% BR in both legs and the
  - SUSY production cross-section
  - Express reach in the plane determined by the involved masses

largely used in natural susy search

SUSY Theory phase space



T. Rizzo (SLAC Summer Institute, 01-Aug-12)

MSSM: 29 sparticles + 5 Higgs undiscovered

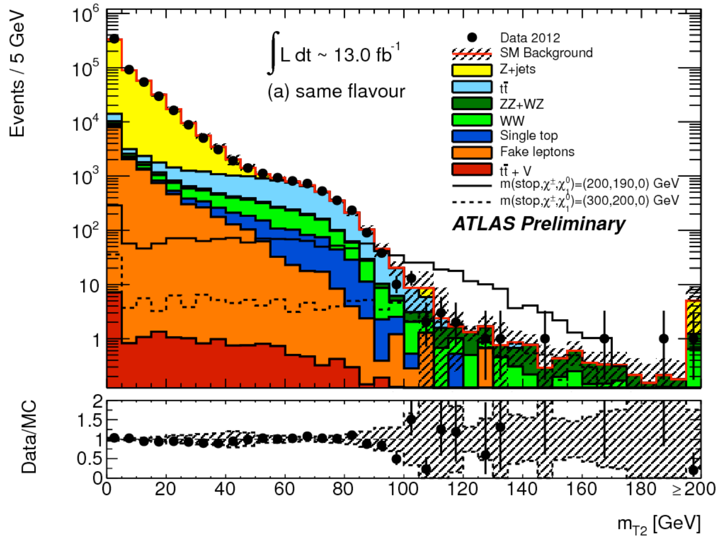
Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

Strategies for natural SUSY search

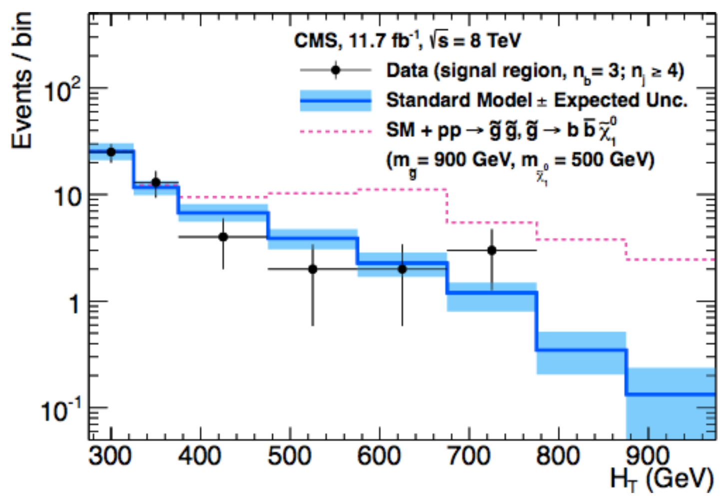
- ✦ ATLAS
  - ✦ Assumes a particular simplified model
  - ✦ Identify the corresponding signatures based on the kinematics (depends on the decay and mass spectrum)

- ✦ CMS
  - ✦ Maintain the characteristic of an inclusive search
  - ✦ Specialize the SR on the base of the assumption of some simplified model

ATLAS-CONF-2012-167



CMS-SUS-12-028



- ✦ For both experiment then
  - ✦ Cut & count experiments (though work in progress on MVA)
  - ✦ Derive the limits (so far)
  - ✦ Reinterpretation on some compatible scenarios

- ✦ Common features to all these analysis:
  - ✦ RPC assumed (LSP stable, large E_T^{miss})
  - ✦ Signal discrepancy expected in the tails
  - ✦ Fighting with low statistic
  - ✦ Data @13TeV is needed to progress in the searches

Searches tools

A number of variables (sometimes quite complex) used to discriminate from signal to background

Scalar sum of the pT of jets (+ lepton)

$$H_T = \sum p_T^l + \sum p_T^{jet}$$

Effective mass: $H_T + E_T^{miss}$

$$m_{eff} = \left(\sum_{i=1}^{Nlep} p_{T,i}^l \right) + \sum_{i=1}^{Njet} p_{T,i} + E_T^{miss}$$

Transverse mass:

$$m_T = \sqrt{2 p_T E_T^{miss} (1 - cos(\Delta\phi(p_T, E_T^{miss})))}$$

Stransverse mass: minimization performed on all possible decomposition of the p_T^{miss}

$$m_{T2}(\mathbf{p}_T^{\ell_1}, \mathbf{p}_T^{\ell_2}, \mathbf{p}_T^{miss}) = \min_{\mathbf{q}_T + \mathbf{r}_T = \mathbf{p}_T^{miss}} \left\{ \max[\, m_T(\mathbf{p}_T^{\ell_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{r}_T)\,] \right\}$$

Cotransverse mass: E_T and p_T of the visible particle in the event

$$m_{CT}^2(v1, v2) = (E_T(v1) + E_T(v2))^2 - (\mathbf{p}_T(v1) - \mathbf{p}_T(v2))^2$$

ATLAS

CMS

- alpha_t
  - = 0.5 perfect balanced dijet event;
  - < 0.5 jet mismeasurement
  - > 0.5 recoil against genuine E_T^{miss}

$$\alpha_T = \frac{E_T^{jet_2}}{M_T} = \frac{E_T^{jet_2}}{\sqrt{\left(\sum_{i=1}^2 E_T^{jet_i}\right)^2 - \left(\sum_{i=1}^2 p_x^{jet_i}\right)^2 - \left(\sum_{i=1}^2 p_y^{jet_i}\right)^2}}$$

- razor: decomposition of the particle boost,

$$R = \frac{M_R^T}{M_R}$$

M_R is defined using momentum after trasformation, assuming jet have the same momentum

$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

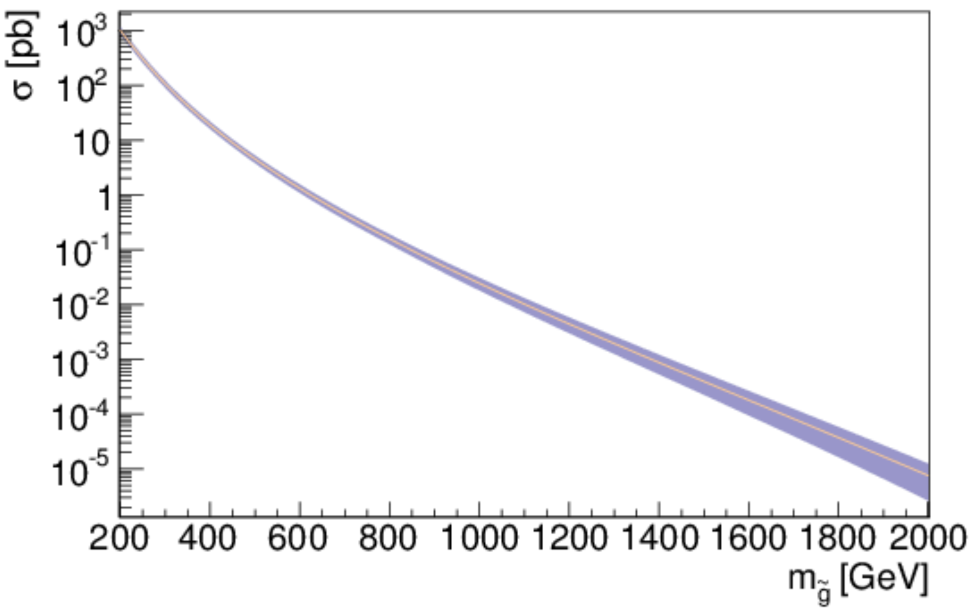
M_T^R is defined using transverse quantities and it is MET-related

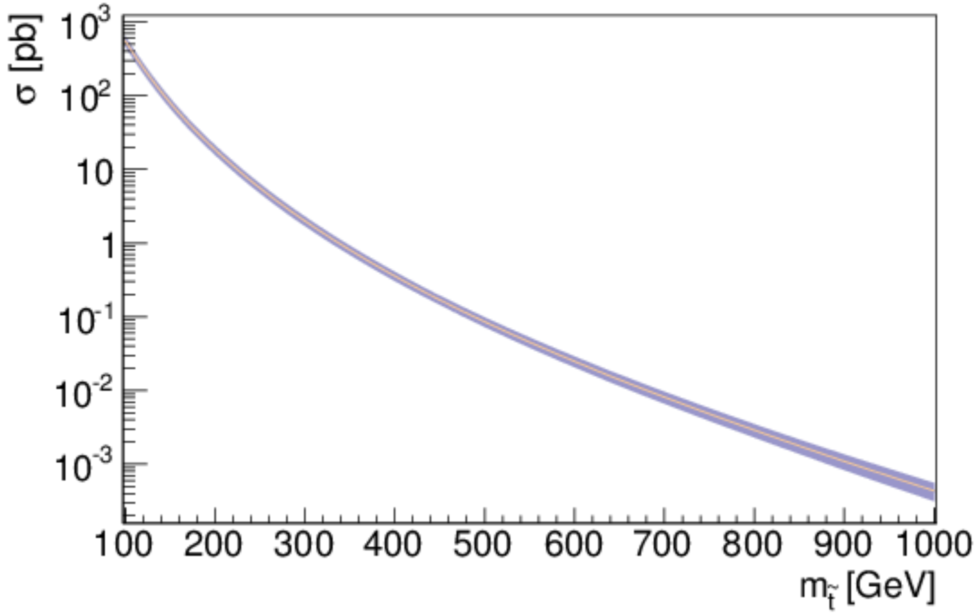
$$M_R^T = \sqrt{\frac{\not{E}_T(p_T^{j_1} + p_T^{j_2}) - \vec{\not{E}}_T \cdot (\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}$$

Cross Section and Limits

A common approach has been taken by ATLAS and CMS concerning

- SUSY cross sections with uncertainties
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections
- representation of the exclusion limits
  - expected and observed limits (+ 1σ band)





Gluino mediated searches

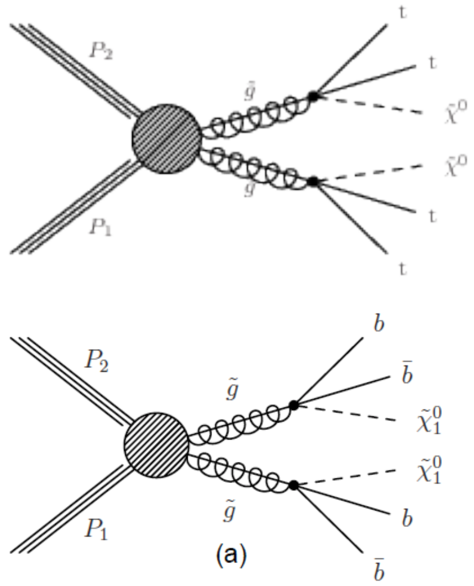
Sensitive to model in which squarks (except 3rd gen) are much heavier than gluinos

Depending on the decay of the stop/sbottom quarks, several signatures are possible

$\tilde{g} \to b\,\tilde{b}_1$
- ↳ $t\,\tilde{\chi}_1^{\pm}$ — Gluino-stop ($b\tilde{\chi}_1^{\pm}$) degenerate ($m_{\tilde{\chi}_1^{\pm}}, m_{\tilde{\chi}_1^{0}}$)

$\tilde{g} \to t\,\tilde{t}_1$
- ↳ $b\,\tilde{\chi}_1^{\pm}$ — Gluino-stop ($b\tilde{\chi}_1^{\pm}$) on-shell
- ↳ $t\,\tilde{\chi}_1^{0}$
  - Gluino-stop ($t\tilde{\chi}_1^{0}$) off-shell ($m_{\tilde{g}} < m_{\tilde{t}} + m_t$)
  - Gluino-stop ($t\tilde{\chi}_1^{0}$) on-shell ($m_{\tilde{g}} > m_{\tilde{t}} + m_t$)

(the two $\tilde{\chi}_1^{\pm}$ cases): $\tilde{\chi}_1^{\pm} \to W^{\pm(*)}\tilde{\chi}_1^{0}$



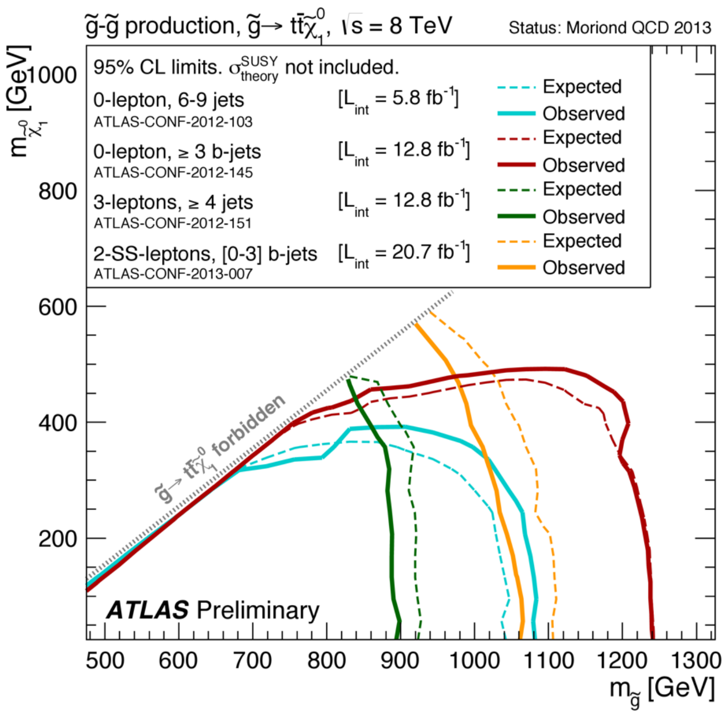
(a)

- ✦ multijet (> 6, some of which b-tagged) + E_T^{miss}
  - ✦ all hadronic or 1lepton signature
- ✦ Final states with multiple W bosons decaying leptonically (+bjets)
  - ✦ 2 leptons SS signatures (gluino is a strongly interacting Majorana particle) ⇒ small SM background
  - ✦ events with ≥ 3 lep + multiple jets → suppression of charge flip and fakes

Gluino mediated (gtt) search

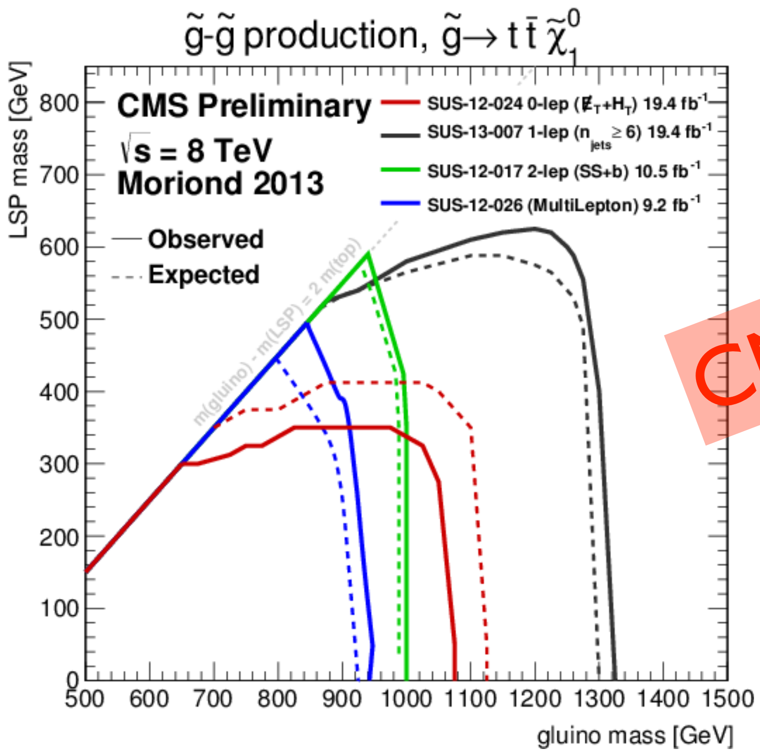
ATLAS

https://twiki.cern.ch/twiki/pub/AtlasPublic/CombinedSummaryPlots/GttSummary_MoriondQCD2013.pdf



✦ **full had. ($\geq$ 4-6jet, $\geq$3 b, E_T^{miss}):**
m_{eff} + E_T^{miss} (ATLAS-CONF-2012-145)

✦ **2lep SS + jet, bjet, E_T^{miss}:**
m_T + m_{eff} (ATLAS-CONF-2013-007)



CMS

✦ **full had. ($\geq$ 3jet, $\geq$1 b, E_T^{miss}):**
H_T + E_T^{miss} (CMS-SUS-12-024)

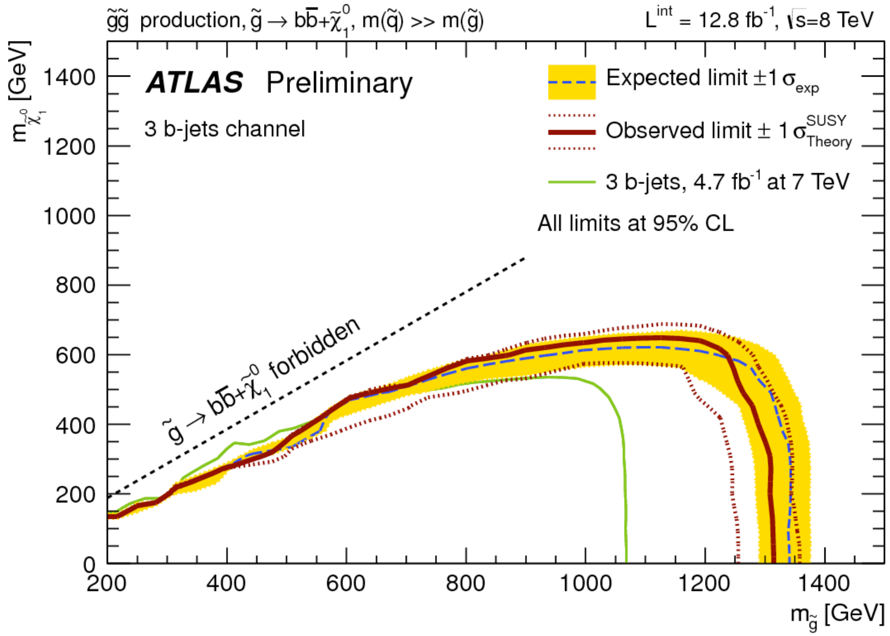
✦ **1lep + $\geq$ 6jet, $\geq$2 b, E_T^{miss} :**
H_T + E_T^{miss} + S_T^l + $\Delta\varphi$ (CMS-SUS-12-007)

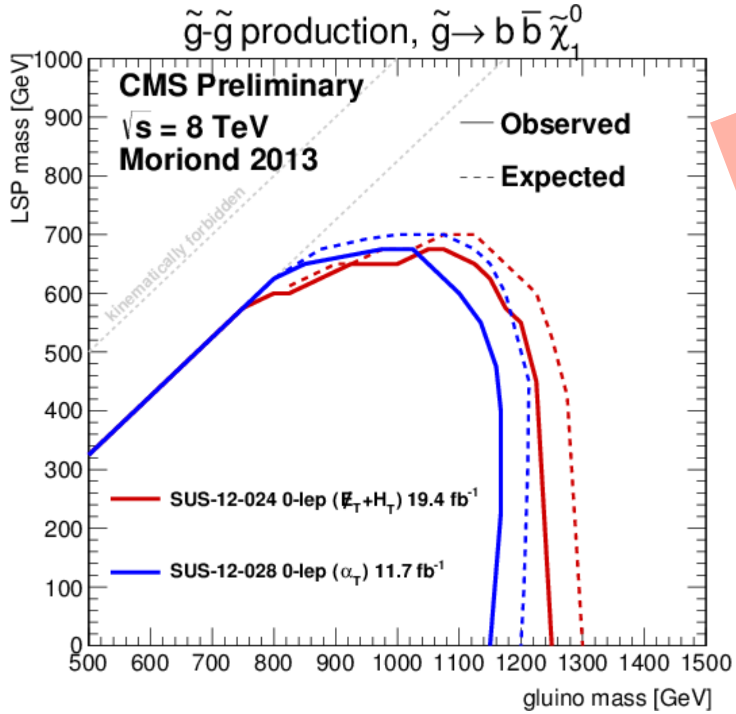
✦ **2lep SS + $\geq$2 b:**
H_T + E_T^{miss} + Njet (CMS-SUS-12-017)

✦ **$\geq$3 lep + jets + E_T^{miss} :**
H_T + E_T^{miss} + Njet (CMS-SUS-12-026)

Gluino mediated (gbb) search

ATLAS-CONF-2012-145



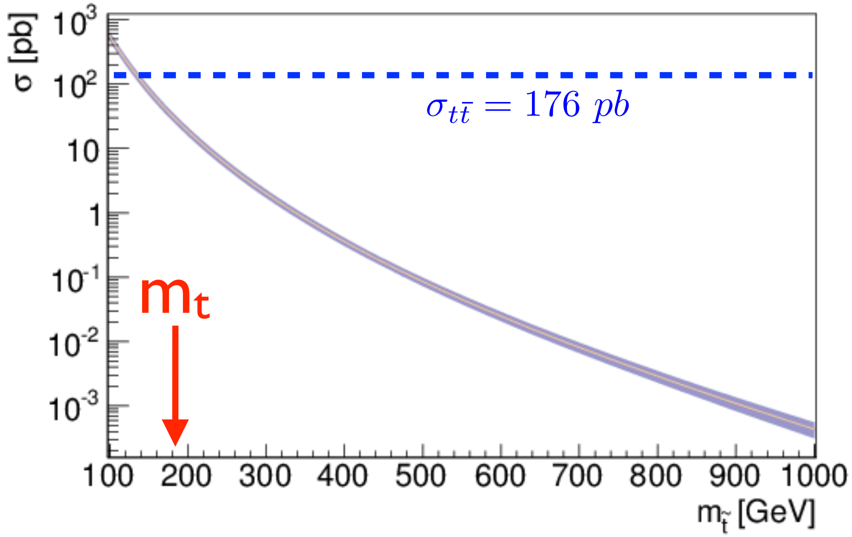


✦ **full had. (≥ 4-6jet, ≥3 b, E_T^{miss}):** m_{eff} + E_T^{miss} (ATLAS-CONF-2012-145)

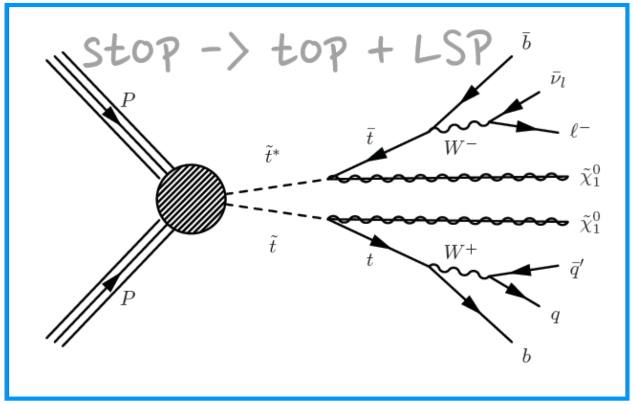
✦ **full had. (jet + E_T^{miss}):** α_T , H_T (CMS-SUS-12-028)

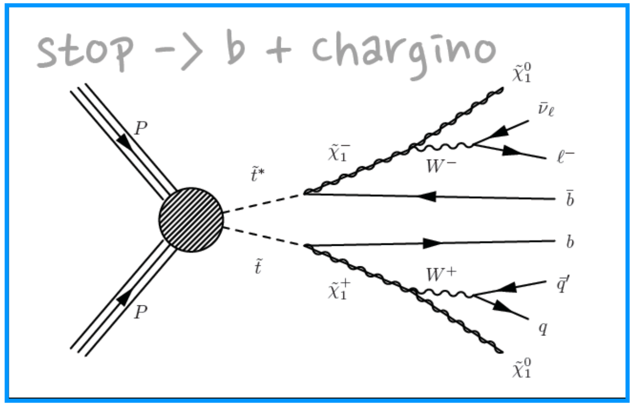
✦ **full had. (≥ 3jet, ≥1 b, E_T^{miss}):** H_T + E_T^{miss} (CMS-SUS-12-024)

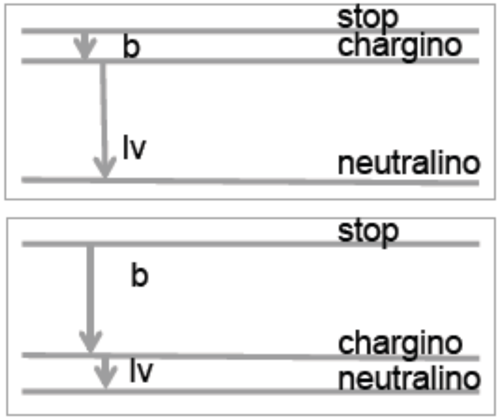
Direct stop production searches



- The cross section for stop pair production falls rapidly with increasing stop mass
  - region at high mass: small cross section, irreducible top pair background but one can cut on hard kinematics if m(stop)-m(LSP) large
  - for mass stop around mass top: need for powerful discriminating variables
    - it's about 10 times smaller then ttbar production since stop is a scalar







Mass difference among sparticles is an important parameter for the kinematic of the events
→ analysis sensitivity highly affected

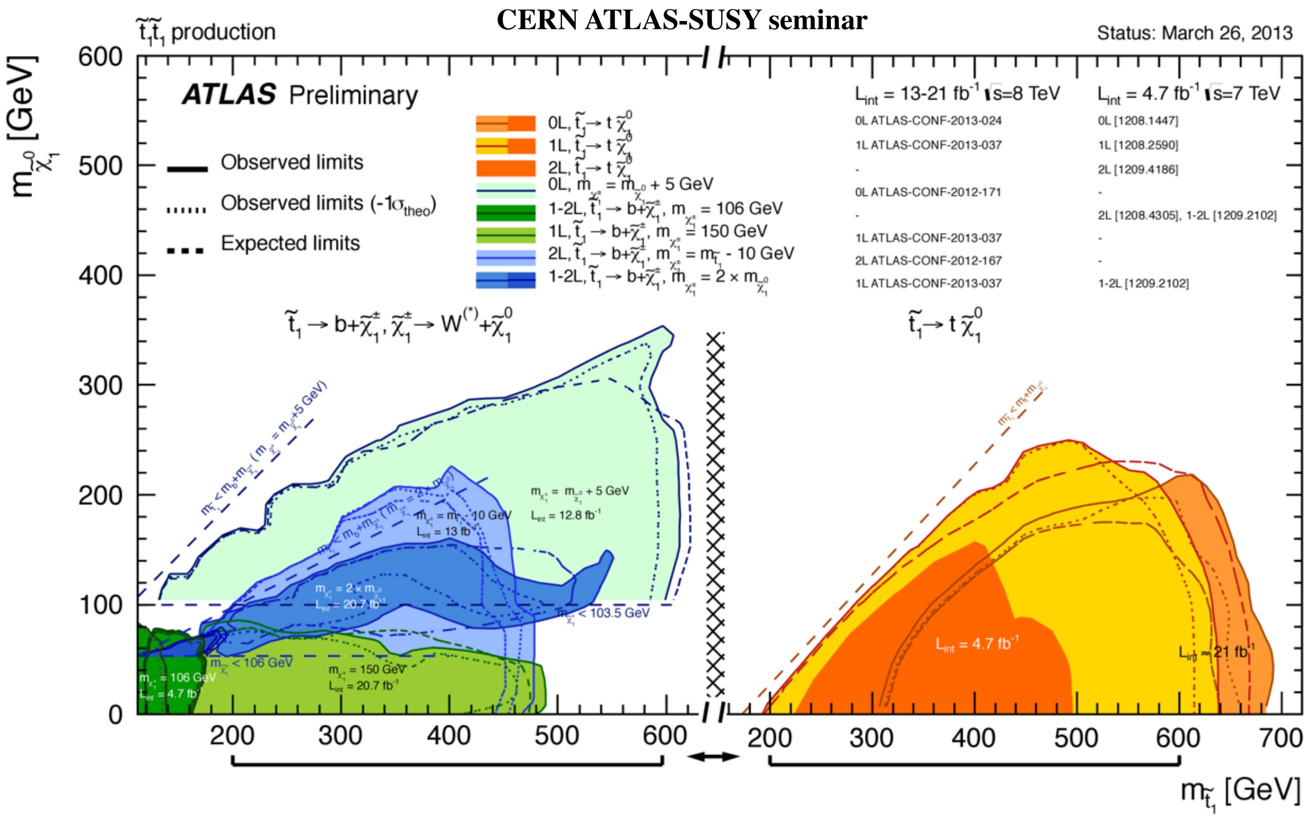
Direct Stop results

ATLAS

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

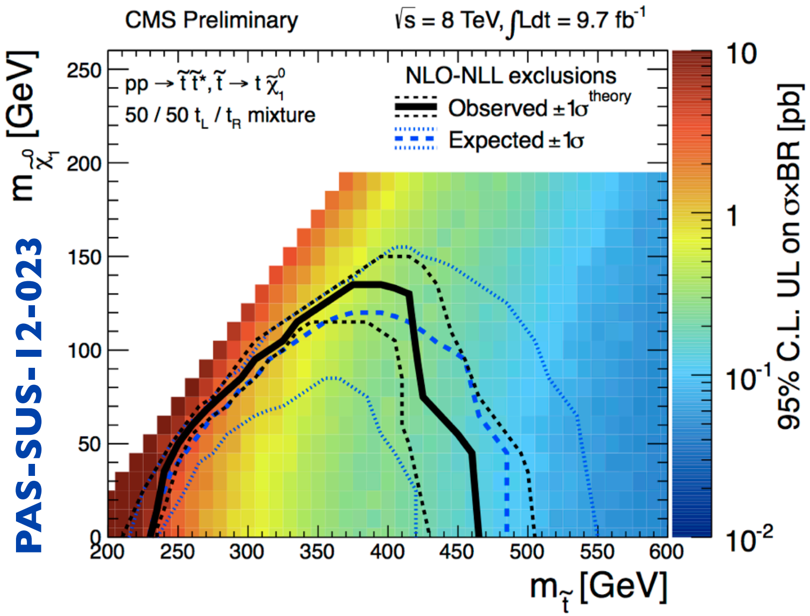
$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$

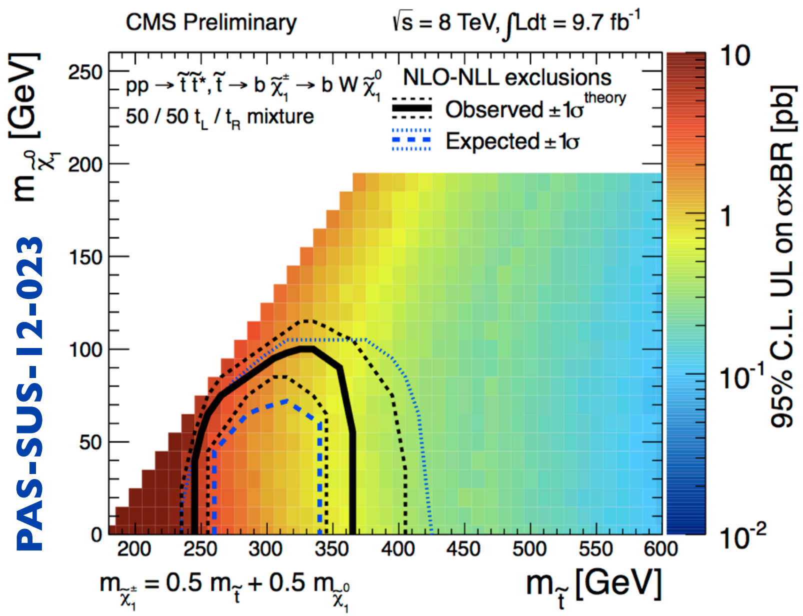
https://twiki.cern.ch/twiki/pub/AtlasPublic/CombinedSummaryPlots/ATLAS_directstop_all_March13.pdf



$\tilde{t}\tilde{t}$ (light), $\tilde{t}\rightarrow b\tilde{\chi}_1^{\pm}$: 1/2 lep (+ b-jet) + $E_{T,miss}$	L=4.7 fb^{-1}, 7 TeV [1208.4305, 1209.2102]
$\tilde{t}\tilde{t}$ (medium), $\tilde{t}\rightarrow b\tilde{\chi}_1^{\pm}$: 1 lep + b-jet + $E_{T,miss}$	L=20.7 fb^{-1}, 8 TeV [ATLAS-CONF-2013-037]
$\tilde{t}\tilde{t}$ (medium), $\tilde{t}\rightarrow b\tilde{\chi}_1^{\pm}$: 2 lep + $E_{T,miss}$	L=13.0 fb^{-1}, 8 TeV [ATLAS-CONF-2012-167]
$\tilde{t}\tilde{t}$ (heavy), $\tilde{t}\rightarrow t\tilde{\chi}_1^0$: 1 lep + b-jet + $E_{T,miss}$	L=20.7 fb^{-1}, 8 TeV [ATLAS-CONF-2013-037]
$\tilde{t}\tilde{t}$ (heavy), $\tilde{t}\rightarrow t\tilde{\chi}_1^0$: 0 lep + 6(2b-)jets + $E_{T,miss}$	L=20.5 fb^{-1}, 8 TeV [ATLAS-CONF-2013-024]
$\tilde{t}\tilde{t}$ (natural GMSB) : Z($\rightarrow$ll) + b-jet + $E_{T,miss}$	L=20.7 fb^{-1}, 8 TeV [ATLAS-CONF-2013-025]
$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1$+Z : Z($\rightarrow$ll) + 1 lep + b-jet + $E_{T,miss}$	L=20.7 fb^{-1}, 8 TeV [ATLAS-CONF-2013-025]

Direct Stop results





1lep + jets, ≥1 b, E_T^{miss} : M_T + E_T^{miss} (CMS-SUS-12-023)

Exclusive analysis published so far

More exclusive analysis (Atlas-like) coming soon with full statistics

Direct Sbottom search

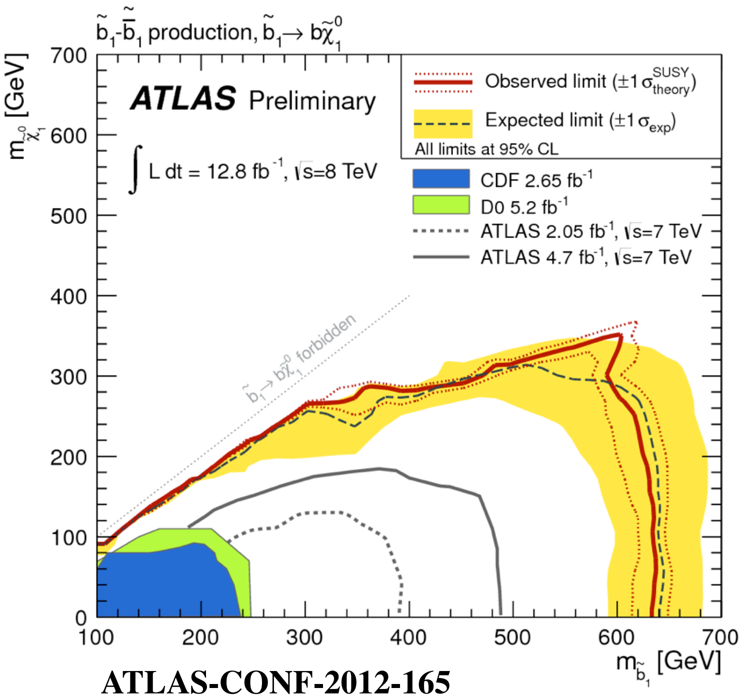
ATLAS

0lep + 2b + E_T^{miss}

cut on E_T^{miss}, b-tagging, E_T^{miss}/m_{eff}, m_{CT}, H_T

mct limited from above by:

$$M_{CT}^{MAX} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$



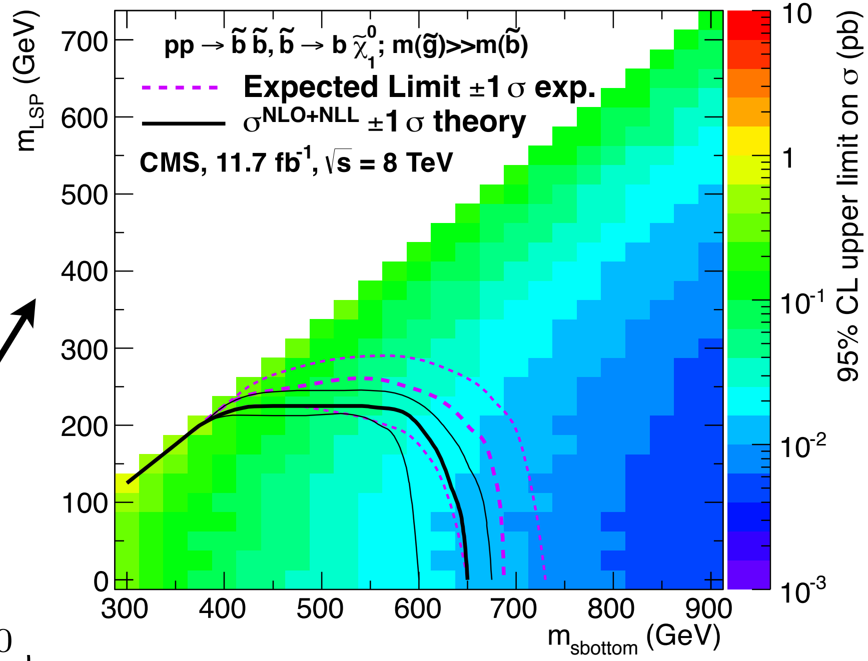
ATLAS-CONF-2012-165

CMS

$\tilde{b} \to t\tilde{\chi}_1^{\pm}$

2lep SS + ≥2 b: H_T + E_T^{miss} + Njet
(CMS-SUS-12-017)

full had. (jet + E_T^{miss}): α_T, H_T
(CMS-SUS-12-028)

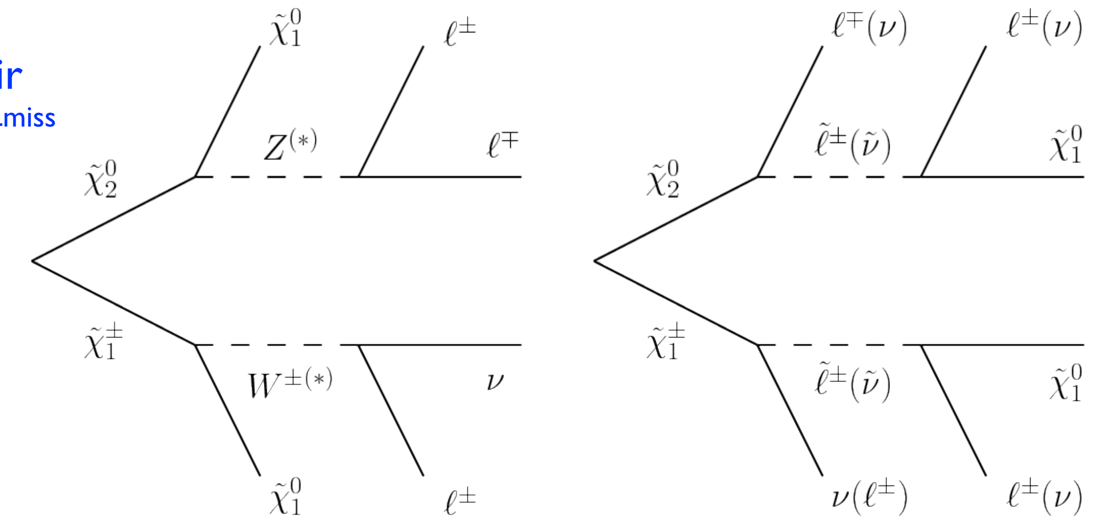


$$\tilde{b}_1\tilde{b}_1 \to (b\tilde{\chi}_1^0)(b\tilde{\chi}_1^0)$$

EWKino search

- Mass eigenvalues generated through the mixing of gauge eigenvalues
- Depending on the mixing matrix neutralinos and charginos may be wino-, bino- or higgsino- like
  - this affects the preferred decay mode through bosons (W,Z,H)
  - naturalness requires that the higgsino is light
- Depending of the mass hierarchy, chargino and neutralino decay can proceed either via sleptons or via SM boson
- Preferred signature for direct ewkino pair production is multilepton final state + E_T^{miss}

NAMES	SPIN	GAUGE EIGENSTATES	MASS EIGENSTATES
Neutralinos	1/2	$\tilde{B}^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0$	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
Charginos	1/2	$\tilde{W}^\pm, \tilde{H}_u^+, \tilde{H}_d^-$	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$



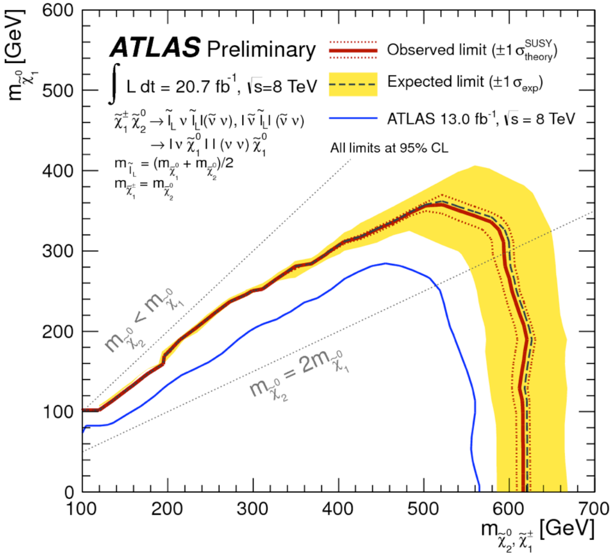
EWKino search

ATLAS

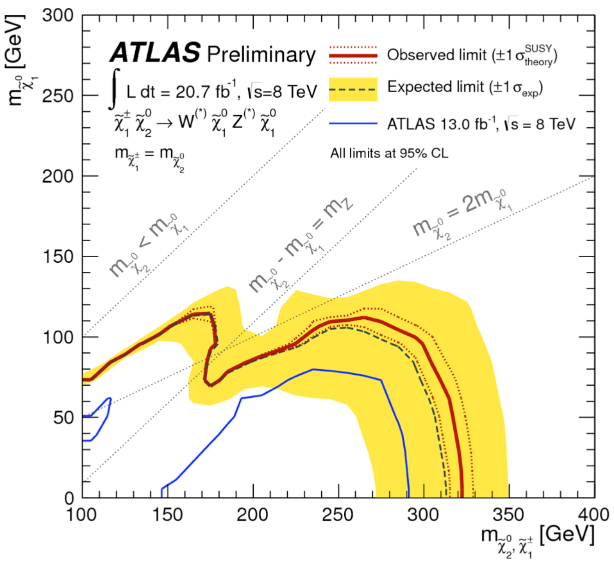
CMS

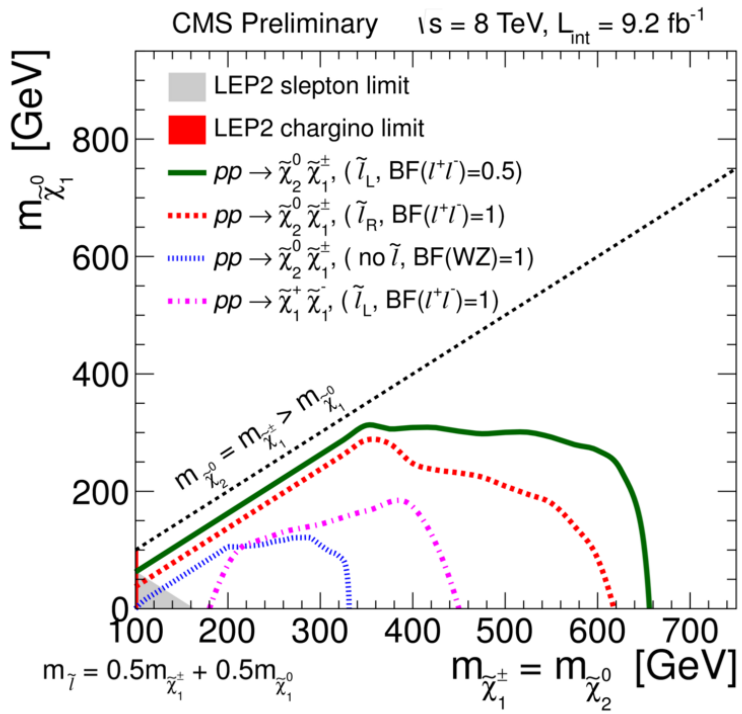
Limits drawn in simplified models scenario
with decay either via slepton and gauge boson

ATLAS-CONF-2013-035



ATLAS-CONF-2013-035





CMS-SUS-12-022

Italian contrib. to ATLAS natural SUSY search

- Italian SUSY group: **Lecce**, **Milano**, **Pavia**, **Udine**
  - working together since few years as a group **(** regular weekly meeting, mailing list and twiki page for info sharing)
  - different experience and competence complements each other
  - well integrated in the DirectStop subgroup (T. Lari convener of the subgroup)
  - 2-lepton signature investigated

Paper & conf note

Search for a heavy top-quark partner in final states with two leptons with the ATLAS detector at the LHC - *JHEP11(2012)094 - Sept. 2012*

top+neutralino, 7TeV, 4.7 fb^{-1}

Search for a supersymmetric top-quark partner in final states with two leptons in sqrt(s) = 8 TeV pp collisions using 13 fb^{-1} of ATLAS data - *ATLAS-CONF-2012-167 - Dec.2012*

b+chargino

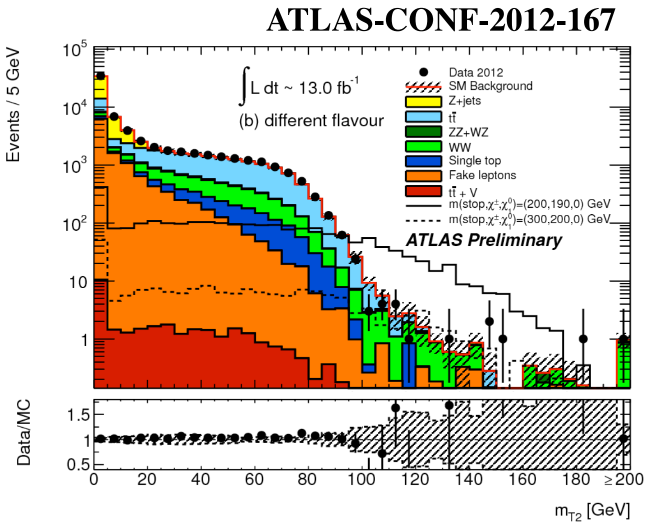
Update of the analysis for 20 fb^{-1} to be shown at LHCp, results still embargoed

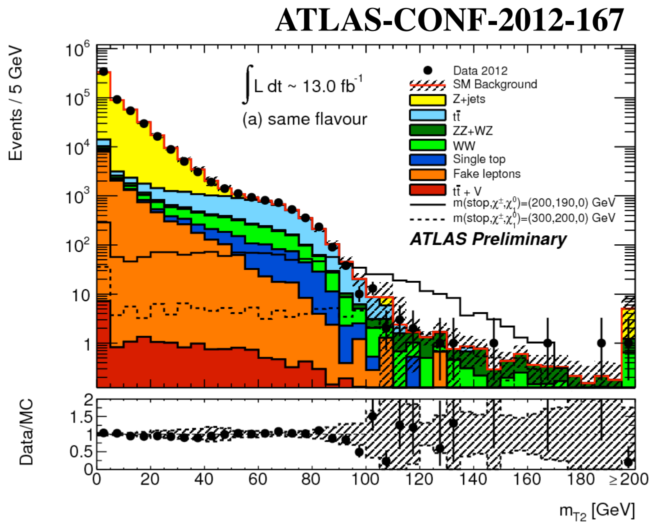
Italian contrib. to ATLAS natural SUSY search

- Sensitive to direct stop pair production, with stop decaying in

  $$\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to bl\nu\tilde{\chi}_1^0$$

  on both legs (2-lep OS signature)





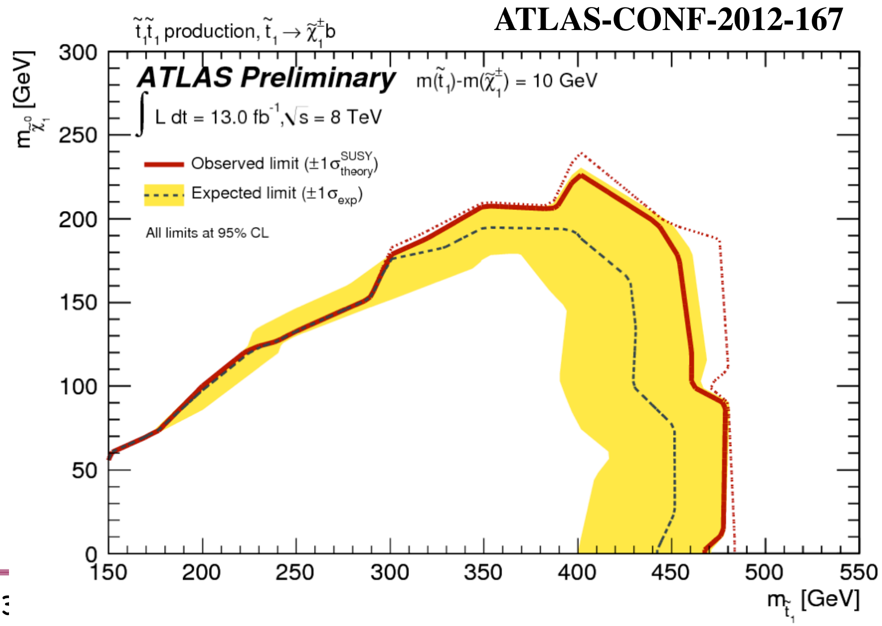
- Main backgrounds:
- tt, dibosons
- fake or non isolated lepton, tt+W/Z, Wt, Z+jet

Selection mainly based on m_{T2}

$$m_{T2}(\mathbf{p}_T^{\ell_1}, \mathbf{p}_T^{\ell_2}, \mathbf{p}_T^{\text{miss}}) = \min_{\mathbf{q}_T + \mathbf{r}_T = \mathbf{p}_T^{\text{miss}}} \left\{ \max[\, m_T(\mathbf{p}_T^{\ell_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{r}_T)\,] \right\}$$

4 different signal regions (m_{T2}> 90, 100, 110)

2 channels (same and different flavor of the lepton)



updated to 21 fb^{-1} - results not yet public

Conclusions

- Huge effort in addressing search for natural SUSY search
  - 3rd generation squark in either direct or gluino mediated production
  - EWKinos
- Most of the analysis have been already updated with the full 2012 data statistic
  - Some new results at various stage of the approval procedure
    both analysis update and new analysis
- No evidence found so far, limits mostly drawn in simplified model scenario
- Large fraction of the analysis optimized using simplified models:
  - check that all possible model grids are covered
  - try to cover the "holes" as much as possible
- Looking for signals in the tails: higher statistic and higher $\sqrt{s}$ will help
  - Start thinking about 13 TeV analysis
- Large phase-space of the SUSY models still uncovered
  - Still a lot of work to do

Backup slides

Analysis Details
ATLAS

ATLAS Direct Stop search (0-lep)

21 fb^{-1} @ 8 TeV

ATLAS-CONF-2013-24

- Sensitive to direct stop pair production

$$\tilde{t}_1\tilde{t}_1 \rightarrow (t\tilde{\chi}_1^0)(t\tilde{\chi}_1^0)$$

  with top decaying fully hadronic
- Main backgrounds:
  - semilep tt (lepton mis-id), Z(→νν)+HF, tt+ Z(→νν)
  - QCD multijets, W/Z+jets, W+HF, tt+W(W), dibosons

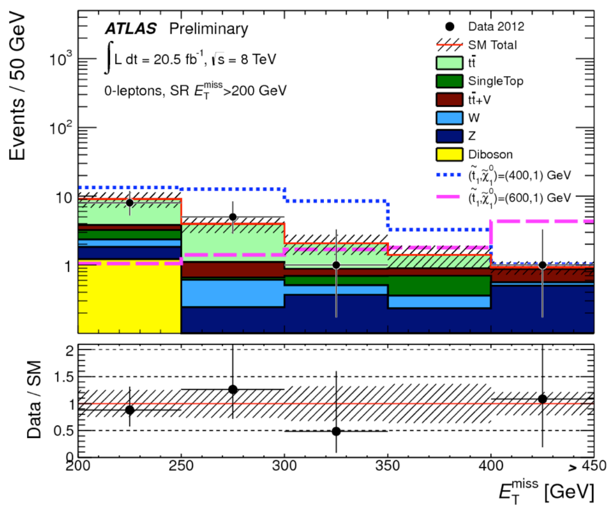
E_T^{miss} trigger: E_T^{miss} >130 GeV

Request of

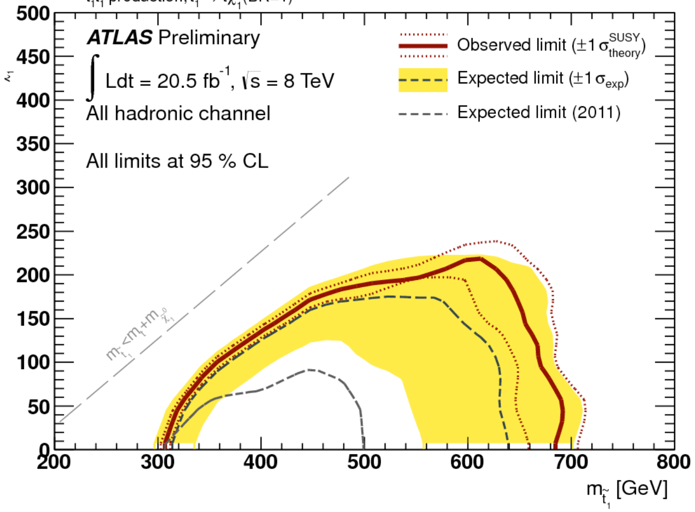
- at least 6 jets (p_T > 80, 80, 35, 35, 35, 35 GeV)
- 2 b-tagged jets

Three Signal region based on E_T^{miss} (200, 300, 350 GeV)

ATLAS-CONF-2013-024



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$(BR=1) **ATLAS-CONF-2013-024**



no excess observed → limits

Simplified model scenario:

$$320 < m(\tilde{t}_1) < 660\ GeV \qquad m(\tilde{\chi}_1^0) = 1\ GeV$$

$$400 < m(\tilde{t}_1) < 620\ GeV \qquad m(\tilde{\chi}_1^0) = 150\ GeV$$

21 fb^{-1}@ 8 TeV

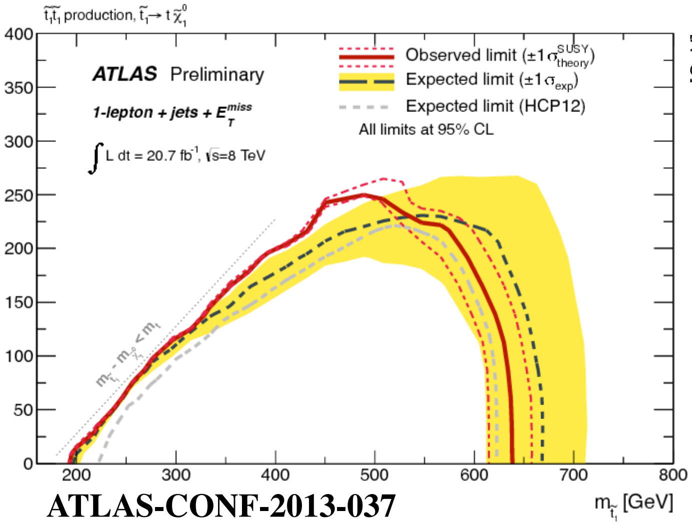
ATLAS-CONF-2013-37

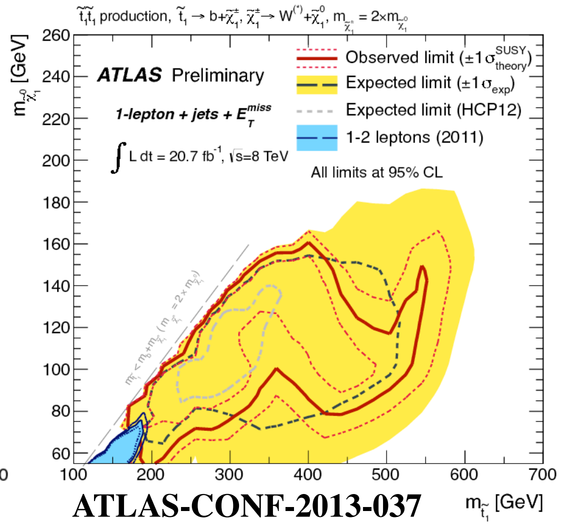
ATLAS Direct Stop search (1-lep)

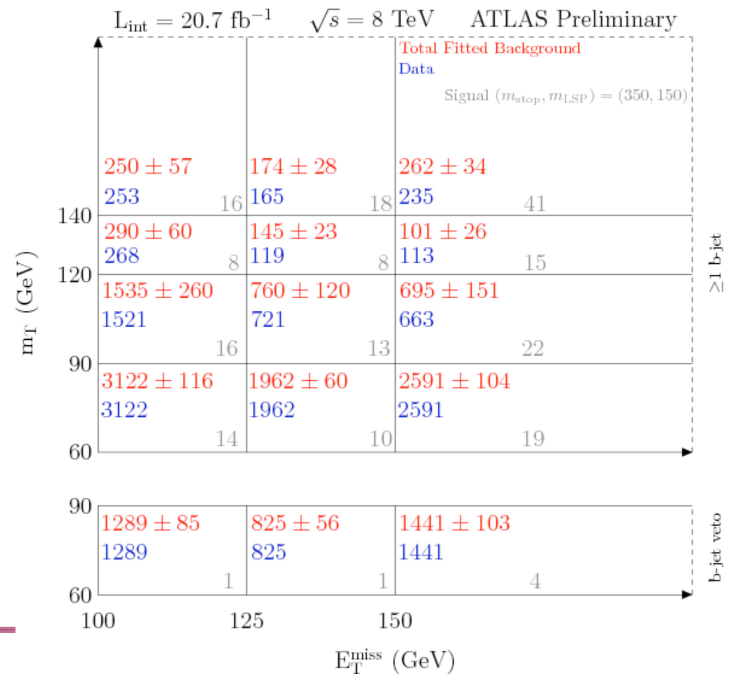
- Sensitive to direct stop pair production with both stop decaying either
  $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ or $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$ $(\tilde{\chi}_1^{\pm} \rightarrow W^{(*)}\tilde{\chi}_1^0)$
  (two different simplified model, BR 100%)
- Main background:
  - dilep tt (1lepton mis-id, ouside acceptance, hadronically decaying τ lep)

6 SR:
3 for top-neutralino scenarion +
3 for b+chargino scenario)

signature: 1 lepton + jets + E_T^{miss}
quite complex event selection:
✦ using combination of b-tagging, E_T^{miss}, $E_T^{miss}/\sqrt{H_T}$, m_{T2}, m_{eff}, H_T
✦ shape-fit in (m_T-E_T^{miss})







ATLAS-CONF-2013-037

ATLAS Direct Stop search (Z+bjet)

- Sensitive to direct stop pair production with stop mass

$$m(\tilde{t}_1) \geq m(t) + m(\tilde{\chi}_1^0)$$

interpreted both in

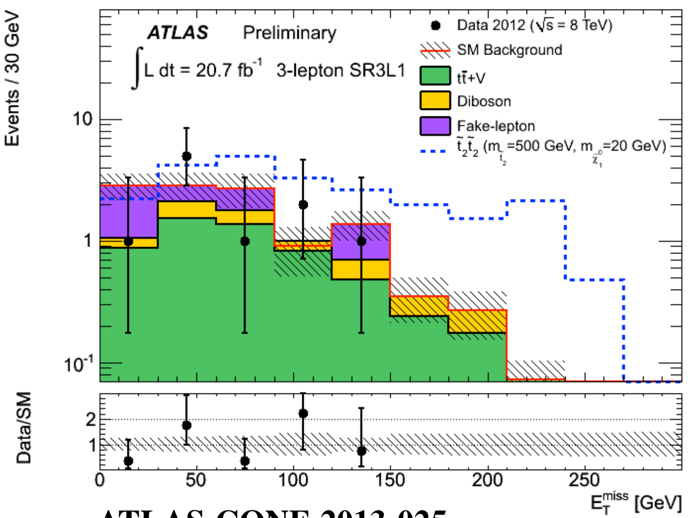
  - GMSB models (stop decaying to neutralino, being NLSP)

$$\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$$

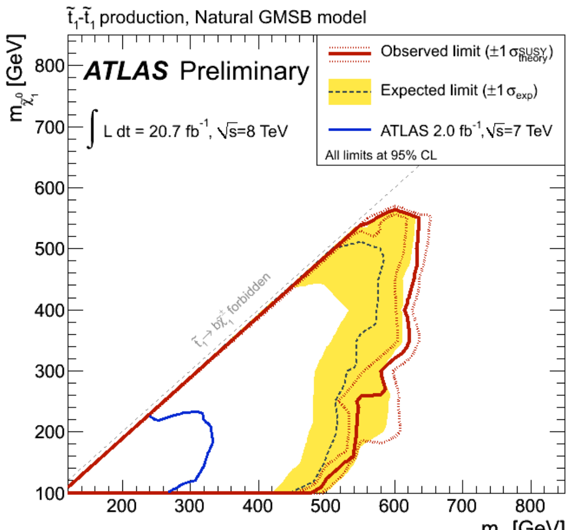
  - Simplified model with

$$\tilde{t}_2 \rightarrow Z\tilde{t}_1$$

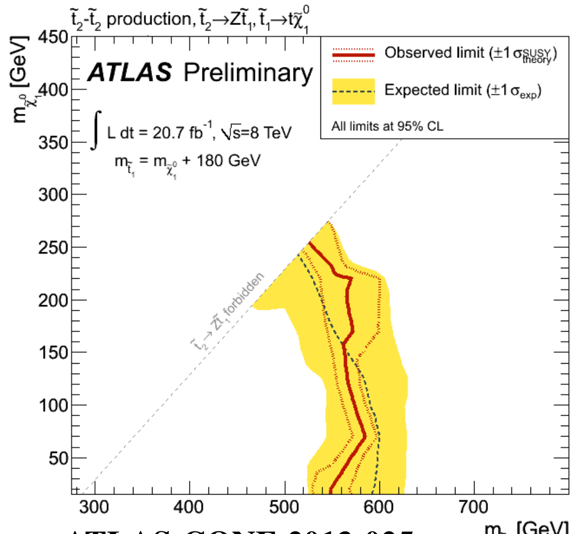
- Looking for signature with 2-3 lep + b + E_T^{miss}
  - m(ll) = m(Z)
- Main background:
  - dilep tt, Z+jets (2-lep)
  - tt+Z, di- and tri-boson, fake lepton (3-lep)
- 5 SR: E_T^{miss} and p_T(ll) selection
  - 3 for 2lep
  - 2 for 3lep



ATLAS-CONF-2013-025



ATLAS-CONF-2013-025



ATLAS-CONF-2013-025

21 fb^{-1}@ 8 TeV

ATLAS-CONF-2013-35

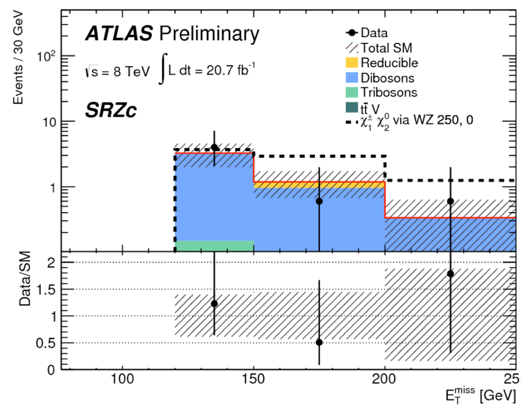
ATLAS Direct EWKino search (3lep)

- Sensitive to associated production of

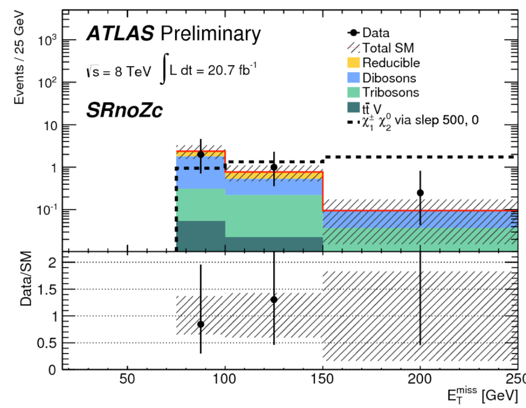
$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (l^+\nu\tilde{\chi}_1^0)(l^+l^-\tilde{\chi}_1^0)$$

- decay can proceed either via slepton or bosons (only W,Z considered in the simplified model)
- looking for 3-lep + E_T^{miss} final state
- Main background:
  - reducible (fakes) : tt, Wt, WW, Z/W+jet/γ
  - irreducible: di- and tri- boson, tt+W/Z

ATLAS-CONF-2013-035



ATLAS-CONF-2013-035



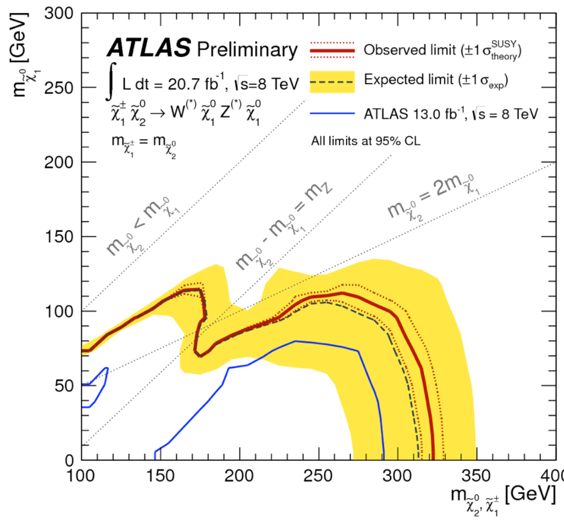
6 SR (targetting different neutralino decays):

3 Z-depleted (Z off-shell or slepton decay)

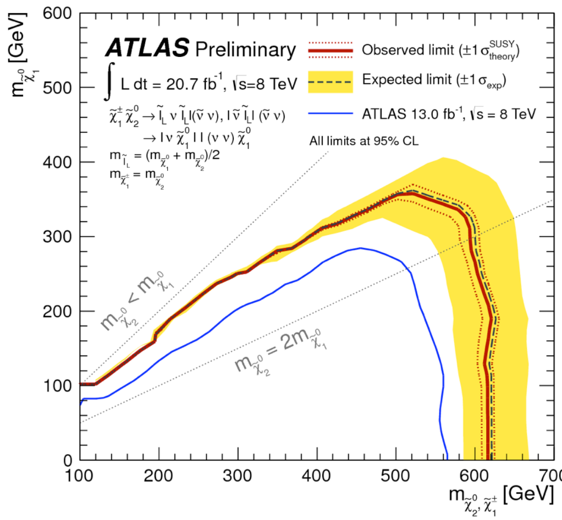
3 Z-enriched (Z on-shell decay)

- Selection based on
  - m(ll), b-veto, m_T, E_T^{miss},

ATLAS-CONF-2013-035



ATLAS-CONF-2013-035



12.8 fb^{-1}@ 8 TeV

ATLAS-CONF-2012-165

ATLAS Direct Sbottom search

- Sensitive to direct sbottom pair production

$$\tilde{b}_1\tilde{b}_1 \rightarrow (b\tilde{\chi}_1^0)(b\tilde{\chi}_1^0)$$

with different kinematics driven by:

$$\Delta m = m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0}$$

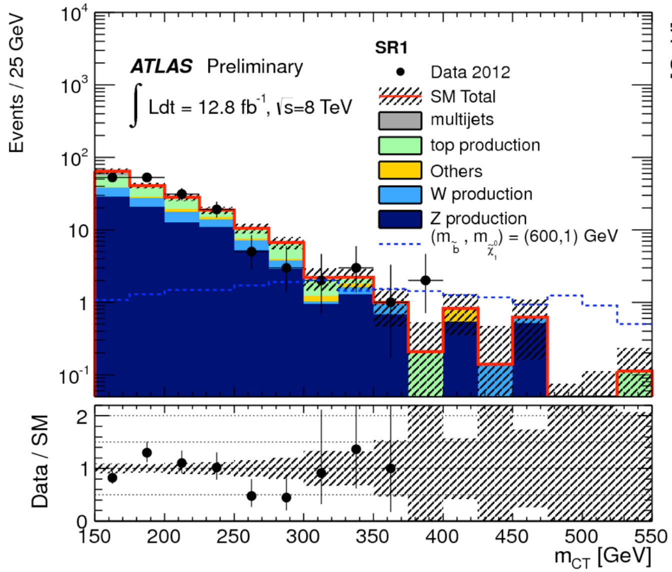
- Main backgrounds:
  - tt, W+HF, Z(→νν)+HF, QCD multijet
  - tt+W/Z, tt+bb

Selection based on lepton veto, E_T^{miss}, b-tagging, E_T^{miss}/m_{eff}, m_{CT}, H_T

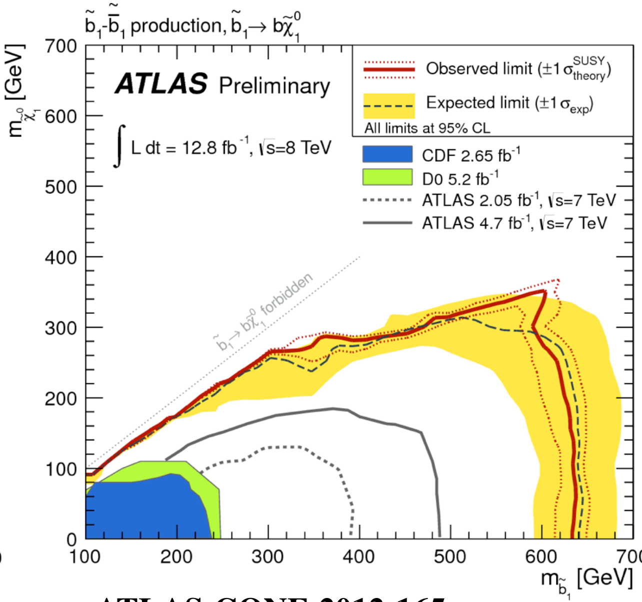
$$m_{CT}^2(v1,v2) = (E_T(v1)+E_T(v2))^2 - (\mathbf{p}_T(v1)-\mathbf{p}_T(v2))^2$$

m_{CT} in bounded from above by

$$M_{CT}^{MAX} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$



ATLAS-CONF-2012-165



ATLAS-CONF-2012-165

no excess observed →limits

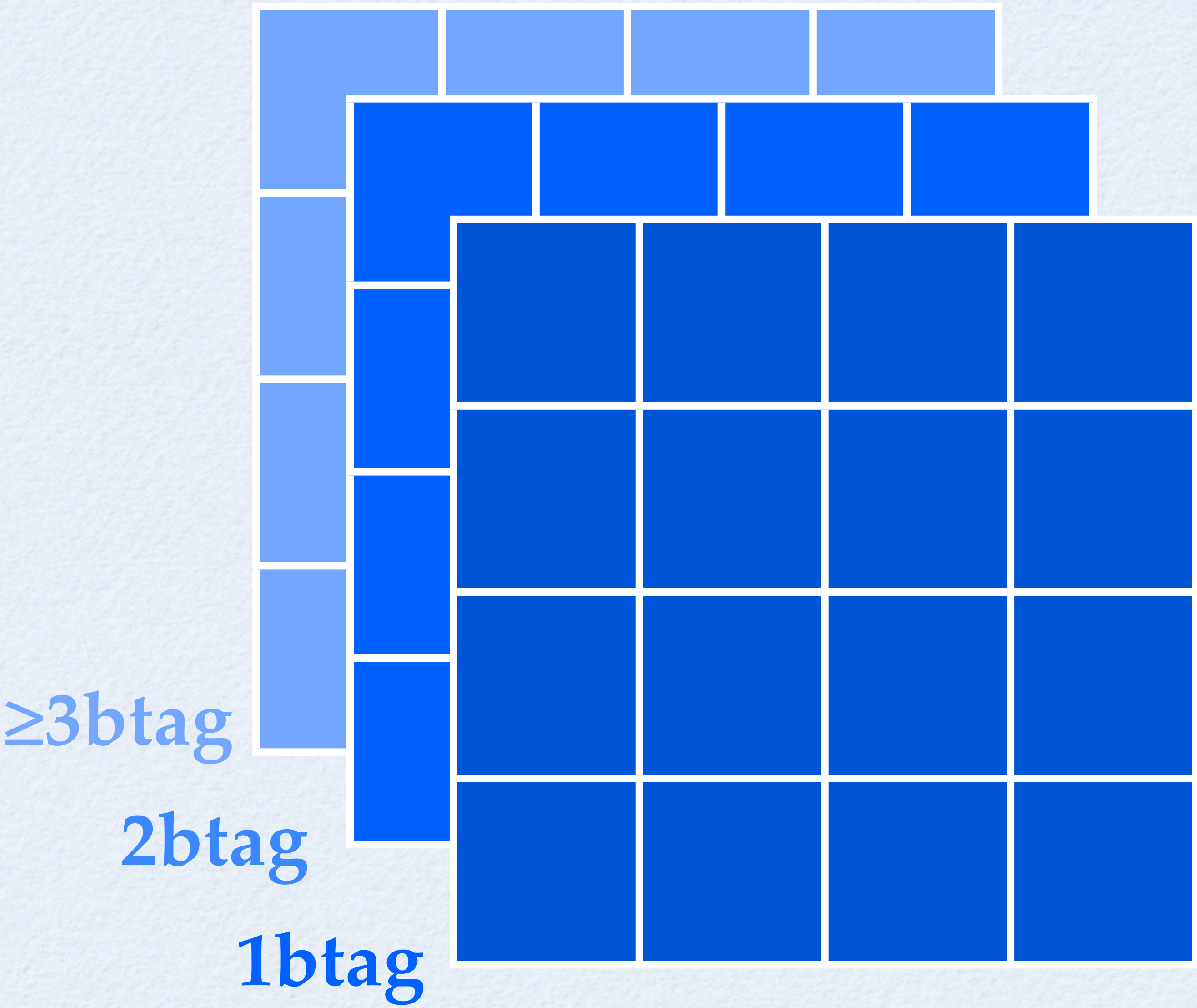
Simplified model scenario:

$m(\tilde{\chi}_1^0) < 150\ GeV$	$m(\tilde{b}_1) > 620\ GeV$
$m(\tilde{b}_1) \sim 550\ GeV$	$m(\tilde{\chi}_1^0) > 320\ GeV$
$m(\tilde{b}_1) < 300\ GeV$	$\Delta m(\tilde{b}_1, \tilde{\chi}_1^0) < 40\ GeV$

update to 21 fb^{-1} ongoing

Analysis Details
CMS

19 fb^{-1} MULTI(B)JET+MET SUS-12-024



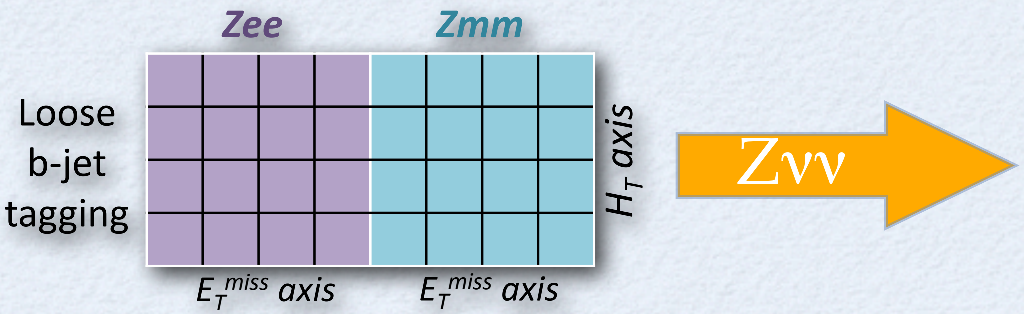
Kinematic plane binned in 4x4 regions in slices of btag multiplicity

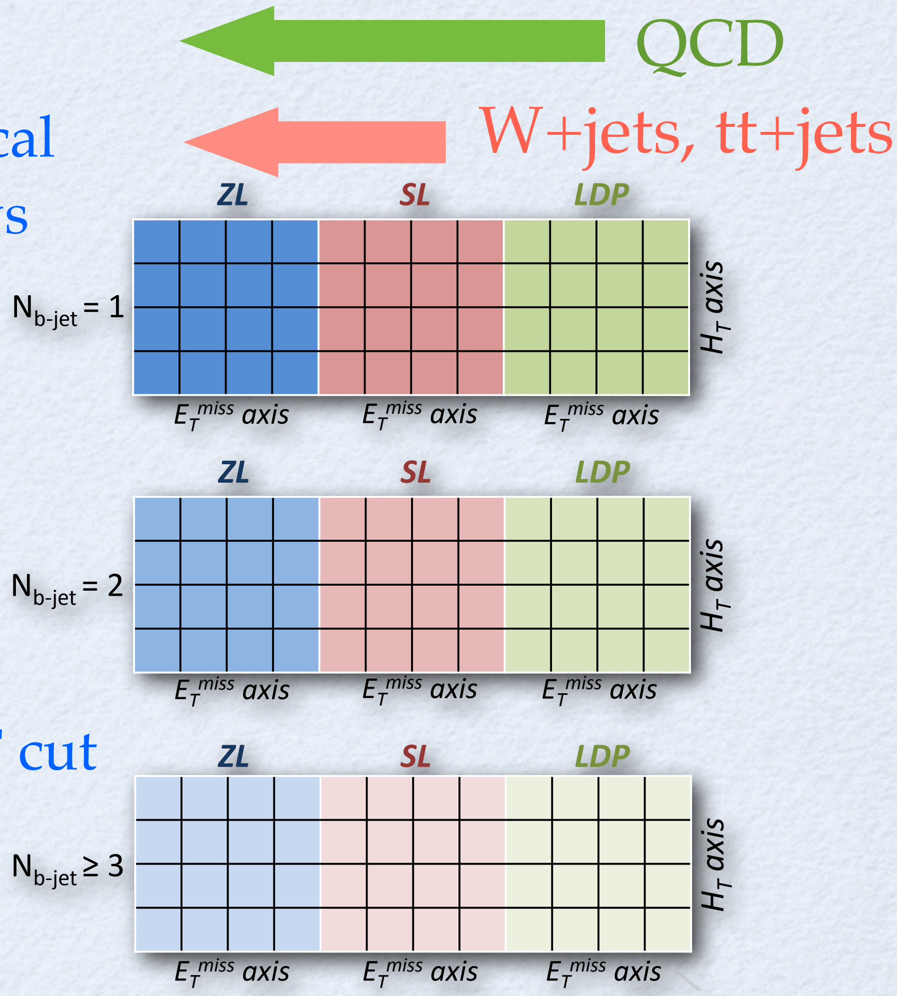
Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

19 fb^{-1} MULTI(B)JET+MET SUS-12-024

ZL = Zero Lepton; signal sample	***SL*** = Single Lepton; top & W+jets control sample	***LDP*** = low $\Delta\hat{\phi}_{min}$; QCD control sample	***Zee*** = $Z \to e^+e^-$; Z to $\nu\bar{\nu}$ control sample	***Zmm*** = $Z \to \mu^+\mu^-$; Z to $\nu\bar{\nu}$ control sample

Bkg predicted from data control samples x scal factors, bin by bin in 3D space (HT vs MET vs btag)





Signal contamination in SL reduced with mT cut and taken into account when not negligible

Other control samples defined signal free

19 fb^{-1} MULTI(B)JET+MET SUS-12-024

bin-by-bin scale factor (constrained to MC with sys error)

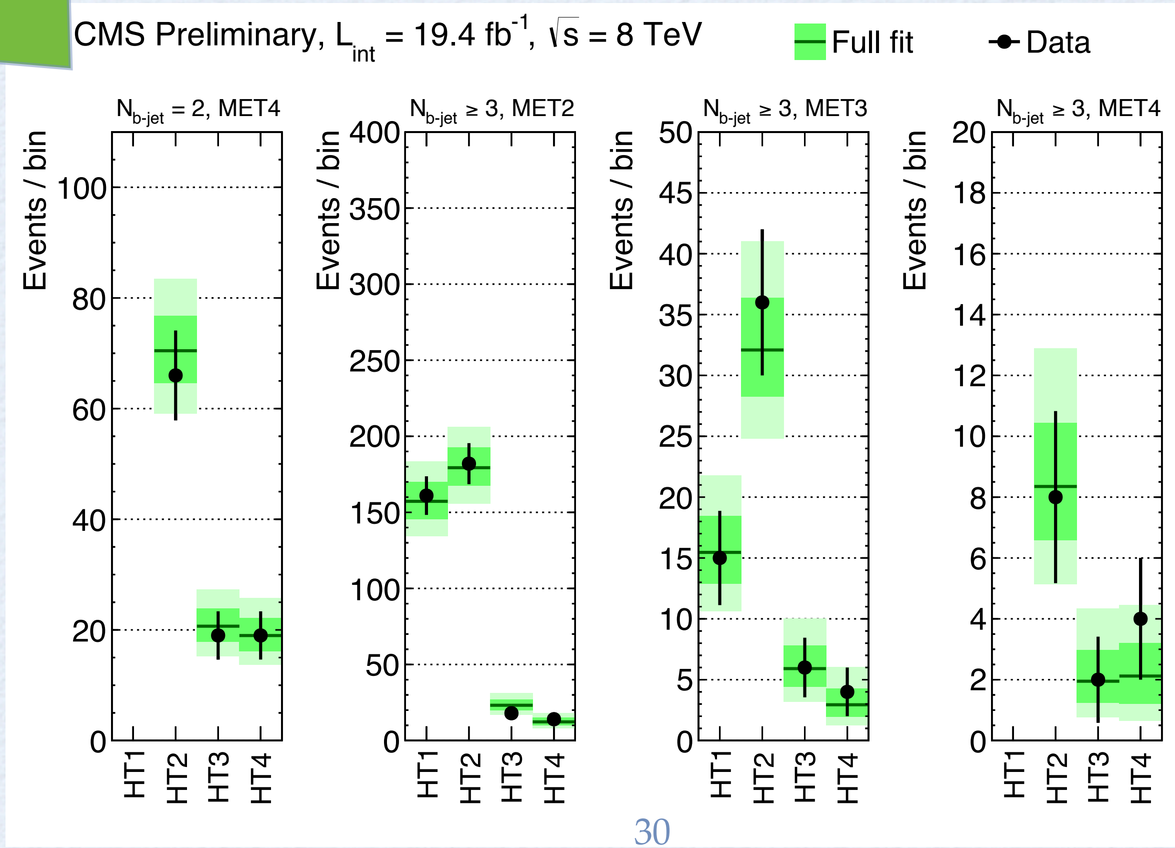
expected background in bin ijk

observed yield in control sample

$$\mu^{ttWj}_{ZL;i,j,k} = S^{ttWj}_{i,j,k} \cdot R^{ttWj}_{ZL/SL} \cdot \mu^{ttWj}_{SL;i,j,k},$$

overall normalization (unconstrained nuisance)

16 most sensitive bins shown



Data agree with prediction

No evidence for excess

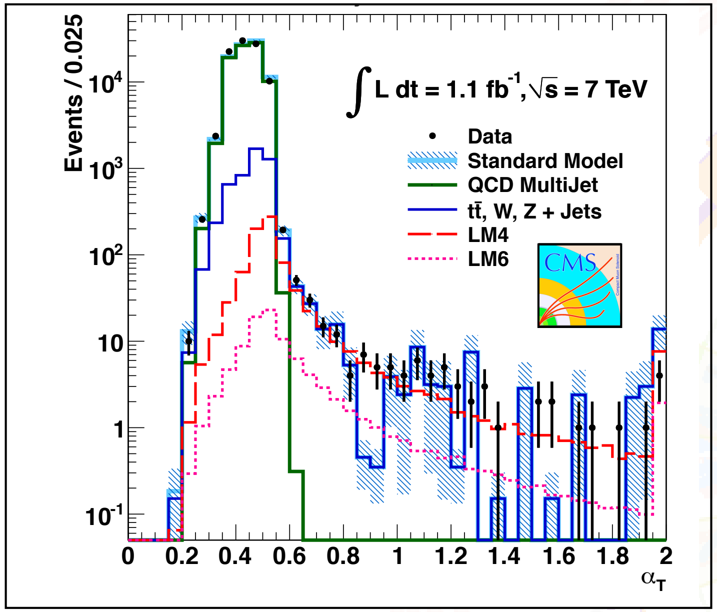
Other

α_T: Rejecting QCD

$$\alpha \equiv \frac{p_{T2}}{m_{jj}}.$$

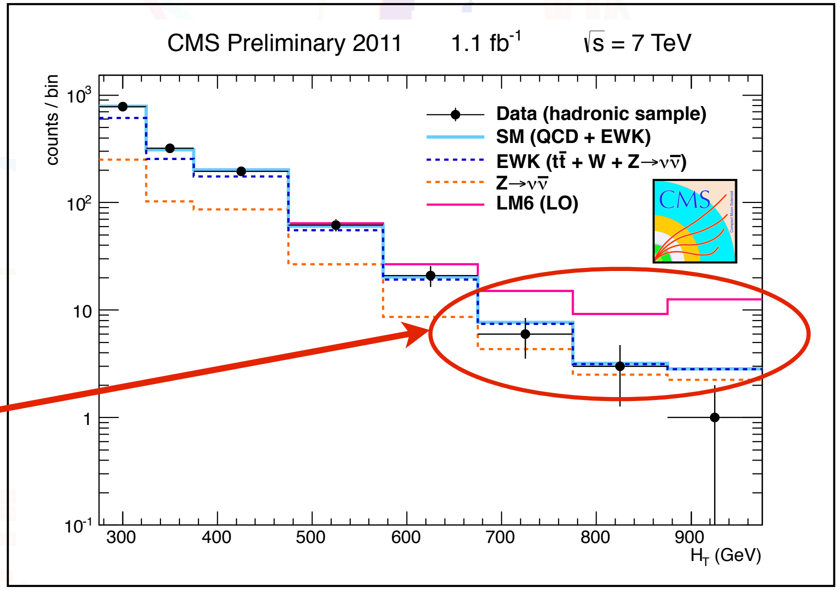
$$\alpha_{\mathrm{T}} = \frac{E_{\mathrm{T}}^{\mathrm{jet}_2}}{M_{\mathrm{T}}} = \frac{E_{\mathrm{T}}^{\mathrm{jet}_2}}{\sqrt{\left(\sum_{i=1}^{2} E_{\mathrm{T}}^{\mathrm{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{\mathrm{jet}_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{\mathrm{jet}_i}\right)^2}}$$

Randall & Tucker-Smith



- α_T = 0.5 for perfectly balanced dijet events
- α_T<0.5 for dijet + mismeasurements
- EW main bkg after α_T cut
- QCD events could leak to α_T>0.5 because of detector effects (rare)
- large fraction of signal events removed (efficiency vs purity)

- After α_T cut the signal looks similar to bkg in α_T
- another variable needs to be used to characterize the signal
- Back to the "classic" paradigm": signal as a tail on H_T used by CMS



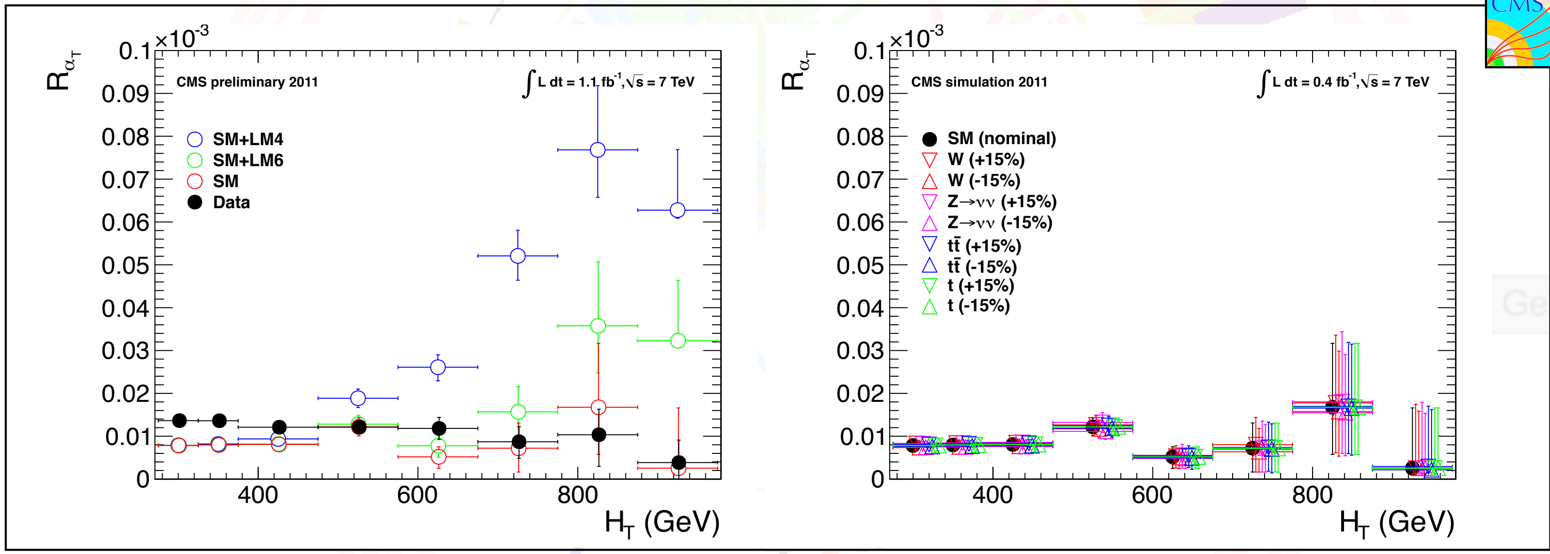
α_T: BKG Estimate

- EW bkg is estimated using the $R_{\alpha T}$ (*) ratio

$$R_{\alpha_T} = N^{\alpha_T > \theta} / N^{\alpha_T < \theta}$$

- This is computed scaling the p_T of the jets with the HT threshold, to event topology

- The ratio is found to be compatible with the flat hypothesis within the available data and SM MC statistics



- This is used to predict the bkg expected in each bin of HT. Then a fit to the HT shape is used

(*) Number of EW events with $\alpha T>\theta$ / number of QCD events with $\alpha T<\theta$

The Razor

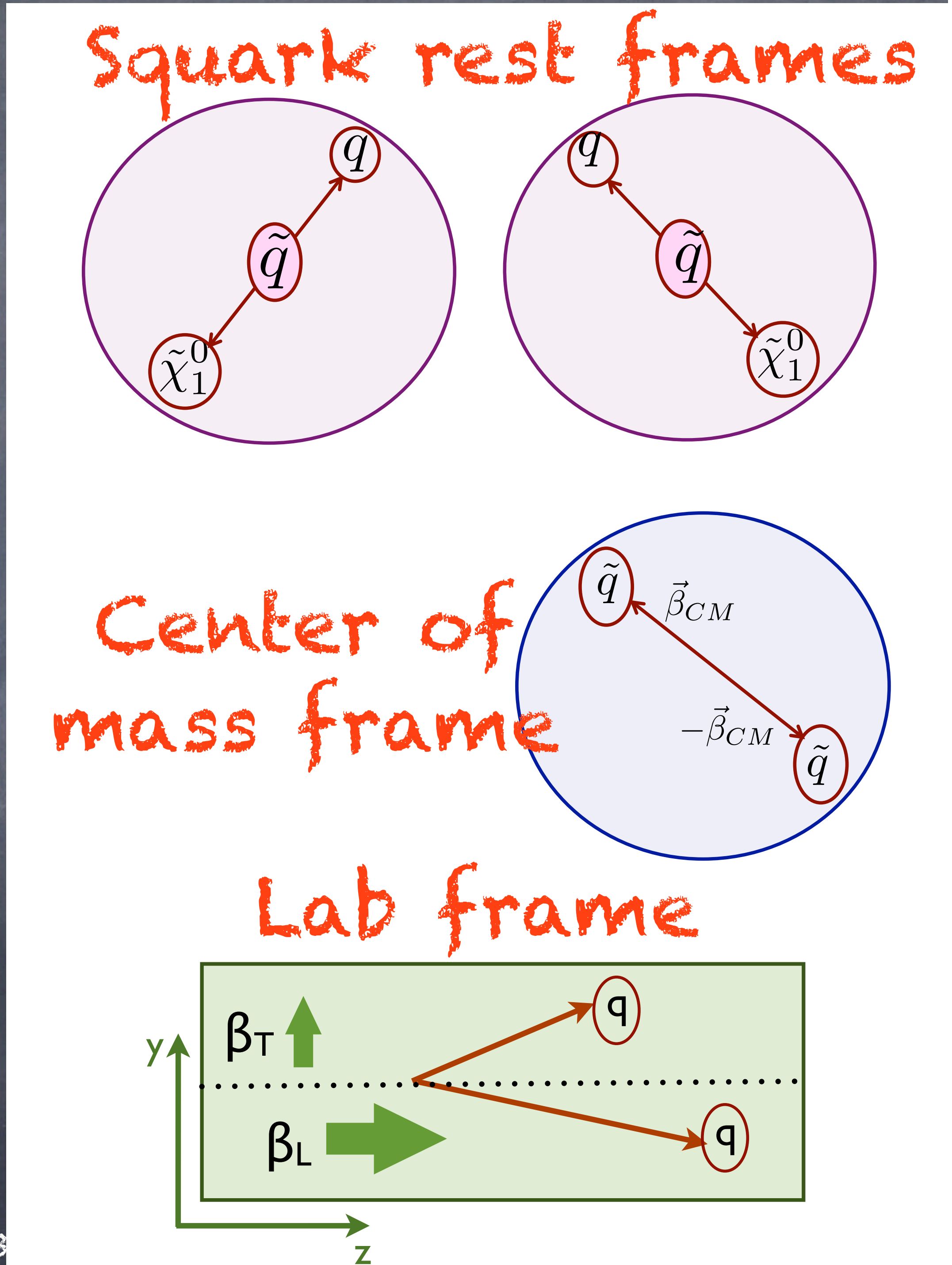
- The prototype process is squark-squark -> jj + 2 LSP

- If we could put the squarks in their rest frames, we would see two jest with same |p|

$$M_\Delta \equiv \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}} = 2M_{\tilde{\chi}}\gamma_\Delta\beta_\Delta$$

- We observe the jets in the lab frame, boosted by relative squark momentum and partons boost

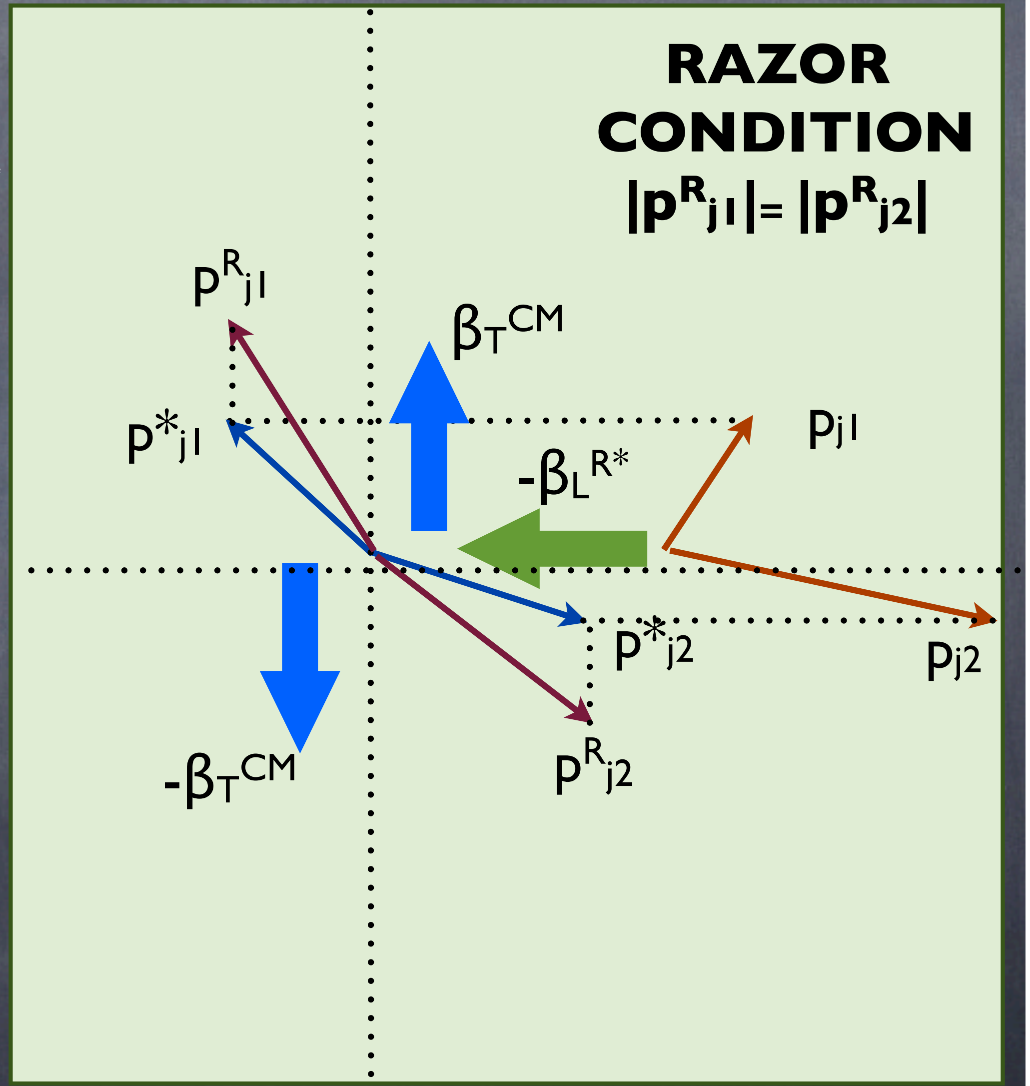
- We would like to undo the two boosts



The Razor

- In reality, the best we can do is to compensate the missing degrees of freedom with assumptions on the boost direction
  - The parton boost is forced to be longitudinal
  - The squark boost in the CM frame is assumed to be transverse
- We require that the two jets have the same momentum after the transformation, and we solve for the boost
- The transformed momentum defines the M_R variable

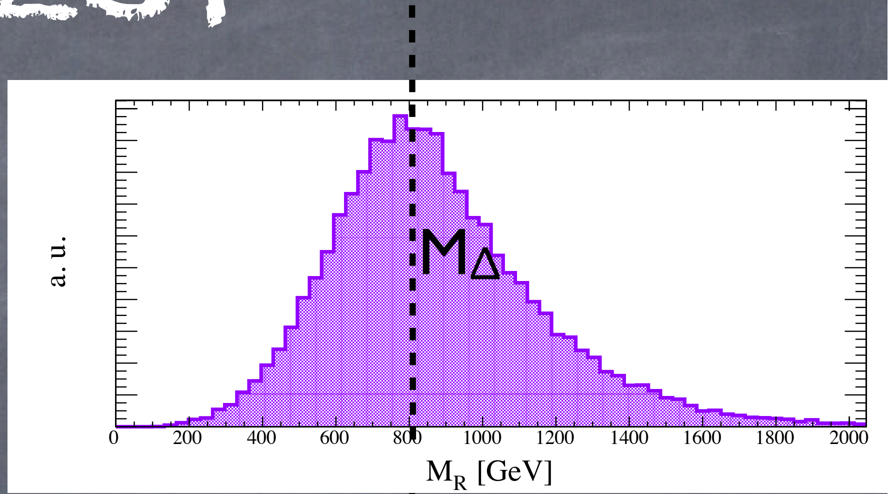
$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

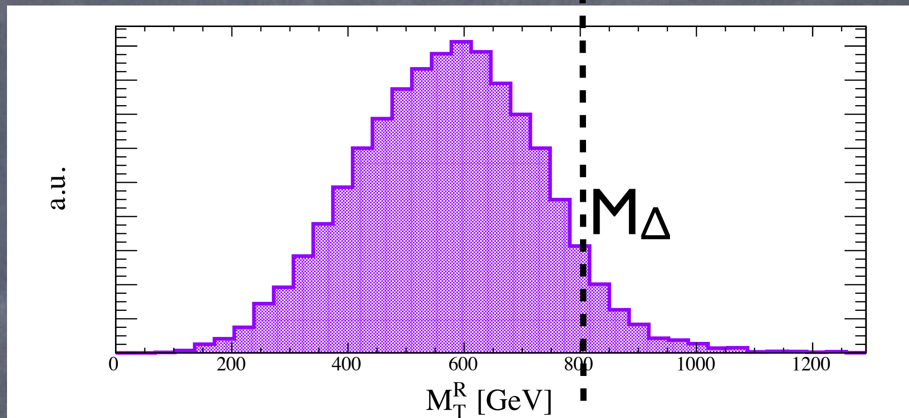


The Razor

- M_R is boost invariant, even if defined from 3D momenta
- No information on the MET is used
- The peak of the M_R distribution provides an estimate of M_Δ
- M_Δ could be also estimated as "edge" of M_T^R

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1}+p_T^{j2}) - \vec{E}_T^{miss}\cdot(\vec{p}_T^{\,j1}+\vec{p}_T^{\,j2})}{2}}$$

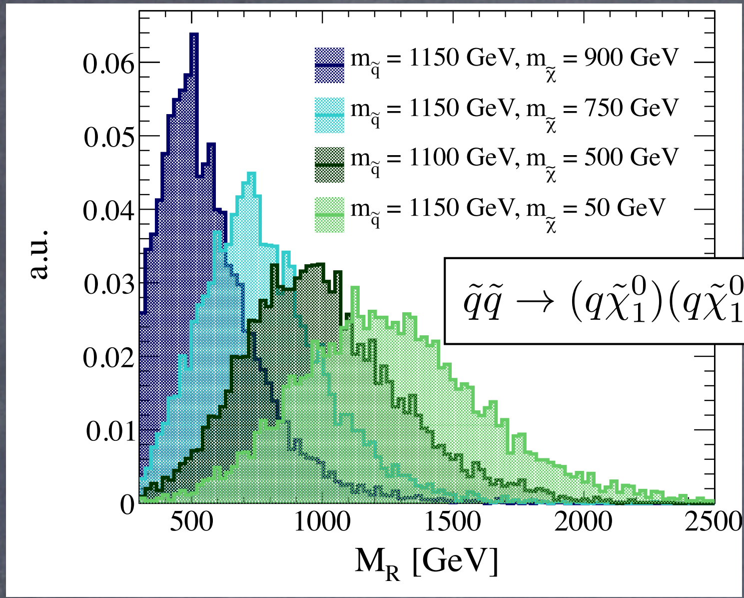


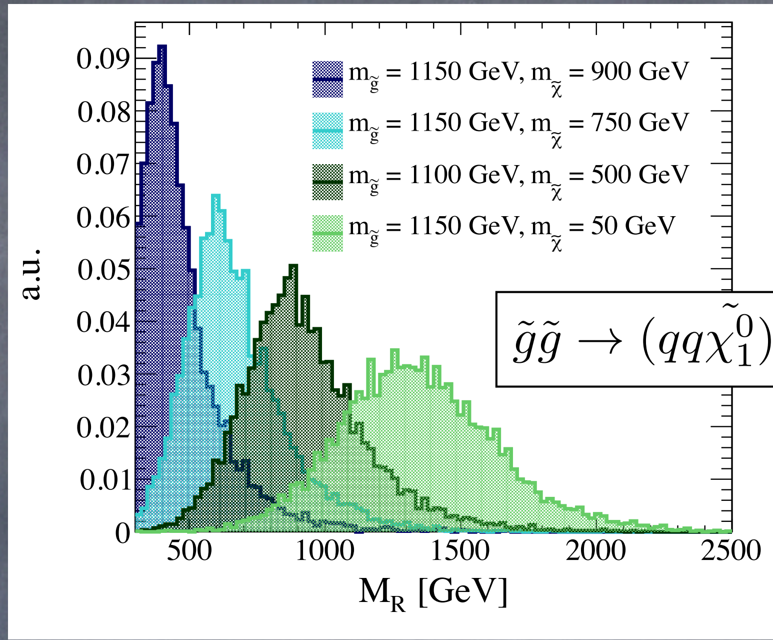


- M_T^R is defined using transverse quantities and it is MET-related
- The Razor (aka R) is defined as the ratio of the two variables

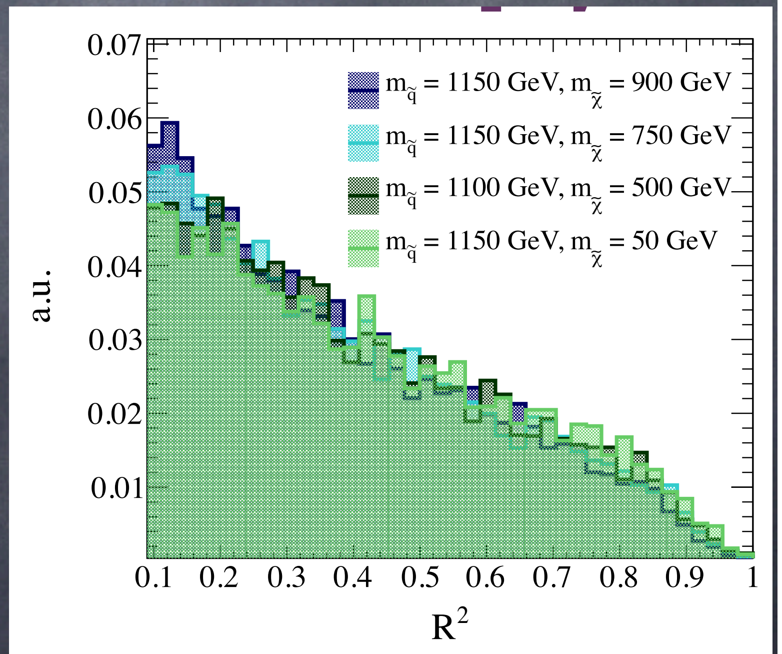
$$R \equiv \frac{M_T^R}{M_R}$$

SUSY Search As a Bump Hunting



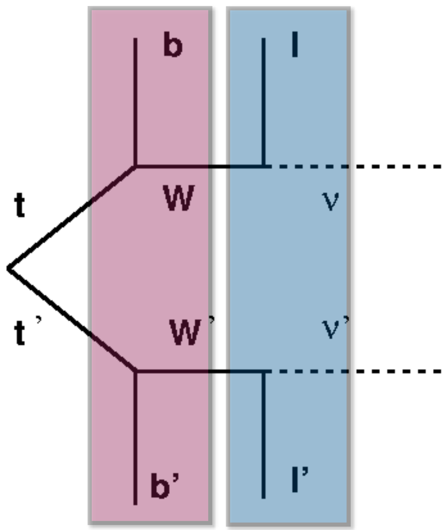


- Peaking signal at $M_R \sim M_\Delta$ (discovery and characterization)
- R^2 is determined by the topology, but not changes too much vs particle masses

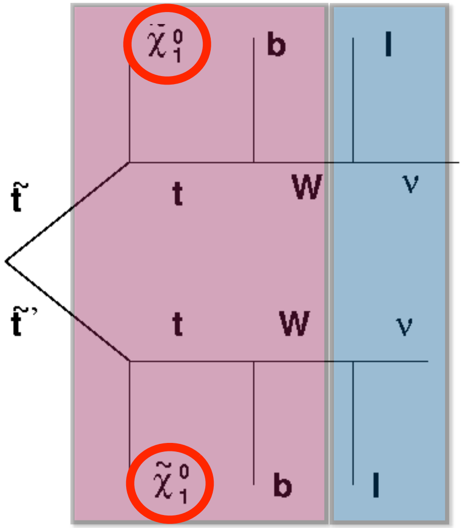


Cut & Count Approach

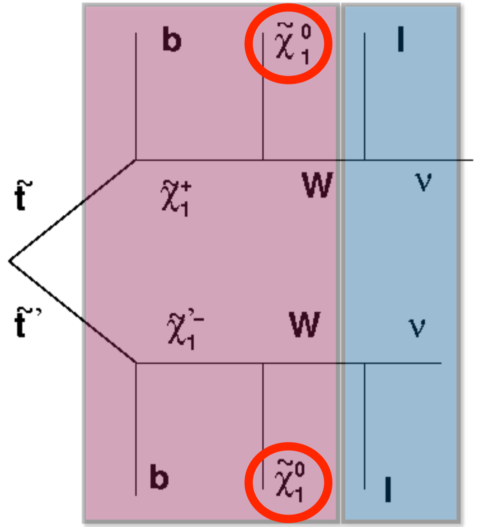
$t \rightarrow Wb$



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



$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$

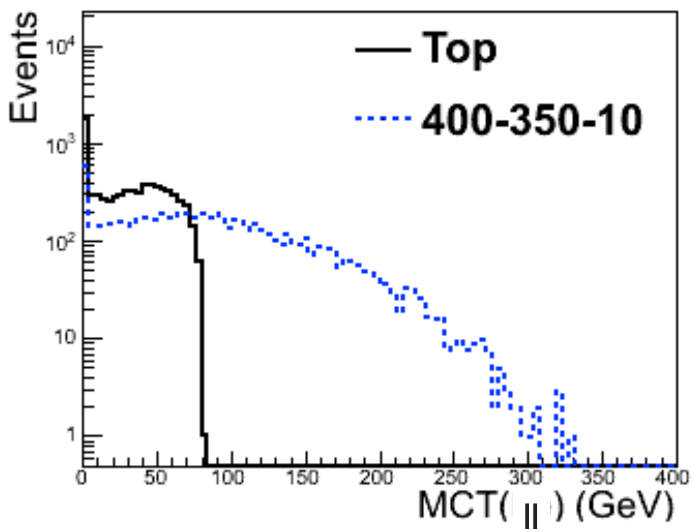


The contransverse mass (MCT) and stransverse mass (MT2) show end points at approximately:

$$M_{CT}^{MAX}(l_1, l_2) = \frac{m^2(W) - m^2(\nu)}{m(W)} = 80.4GeV$$

$$M_{CT}^{MAX}(b_1, b_2) = \frac{m^2(t) - m^2(W)}{m(t)} = 135.0GeV$$

In stop decay one has two invisible particles among the upstream particles and two among the downstream particles. Both classes of particles are summed up in MET



Exclusion Limit

❑ Exclusion limits : a new standard ATLAS/CMS procedure (>June 2012)

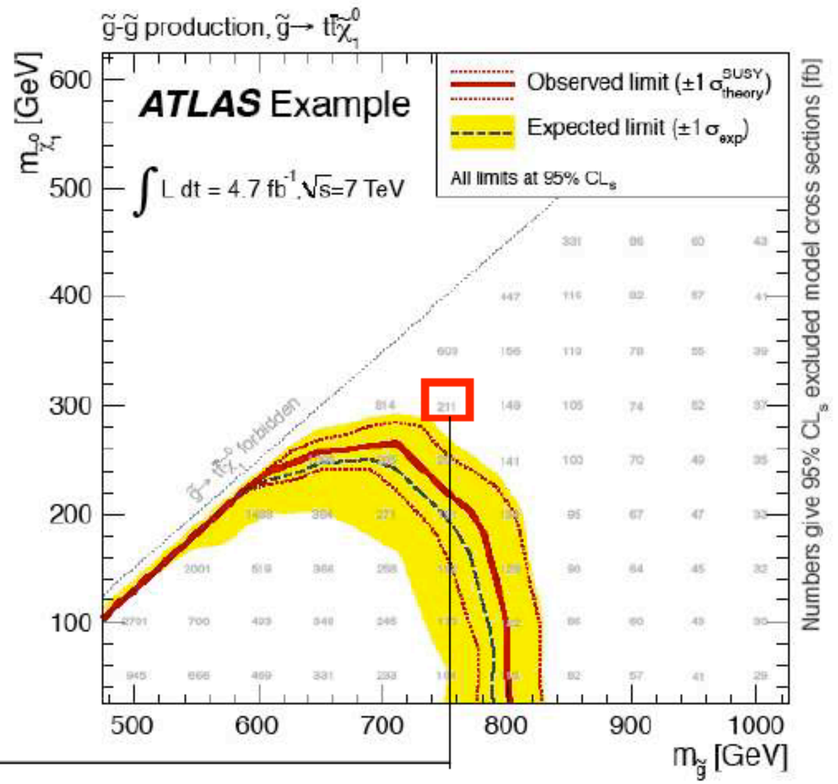
- Ease the life of theorist by separating the signal theoritical and experimental systematics

Expected limit:

- **Central value:** all uncertainties included in the fit as nuisance parameters, except theoretical signal uncertainties (PDF,scales)
- **±1σ band** : ±1σ results of the fit

Observed limit:

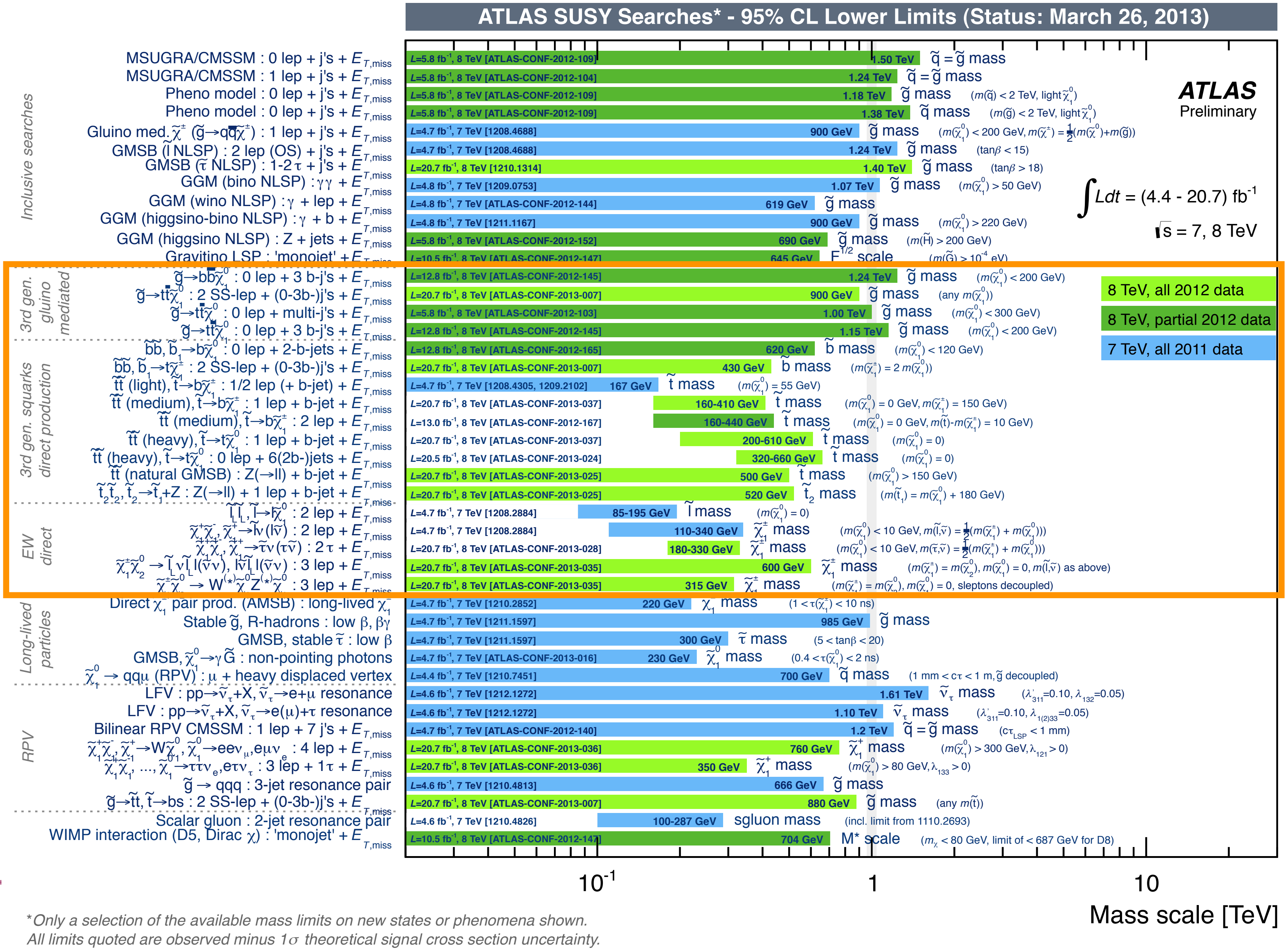
- **Central value**: Idem as for expected limit
- **±1σ band** : re-run and increase/decrease the signal cross section by the theoretical signal uncertainties (PDF, scales)



Excluded Model Cross section (SMS)

➔ Number quoted in paper correspond to observed -1 σ observed (conservative)

Summary ATLAS searches



Sparticle spectrum

Chiral supermultiplet

Names		Spin 0	Spin ½
Squarks, quarks (x 3 families)	Q $\bar{u}$ $\bar{d}$	$(\tilde{u}_L \quad \tilde{d}_L)$ $\tilde{u}_R^*$ $\tilde{d}_R^*$	$(u_L \quad d_L)$ u_R^T d_R^T
Sleptons, leptons (x 3 families)	L $\bar{e}$	$(\tilde{\nu} \quad \tilde{e}_L)$ $\tilde{e}_R^*$	$(\nu \quad e_L)$ e_R^T
Higgs, higgsinos	H_u H_d	$(H_u^+ \quad H_u^0)$ $(H_d^0 \quad H_d^-)$	$(\tilde{H}_u^+ \quad \tilde{H}_u^0)$ $(\tilde{H}_d^0 \quad \tilde{H}_d^-)$

Gauge supermultiplet

Names	Spin ½	Spin 1
Gluino, gluons	$\tilde{g}$	g
Winos, W bosons	$\tilde{W}^\pm \ \tilde{W}^0$	$W^\pm \ W^0$
Bino, B boson	$\tilde{B}^0$	B^0

NAMES	SPIN	GAUGE EIGENSTATES	MASS EIGENSTATES
Neutralinos	1/2	$\tilde{B}^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0$	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
Charginos	1/2	$\tilde{W}^\pm, \tilde{H}_u^+, \tilde{H}_d^-$	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$