Searches for Supersymmetry at ATLAS

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On behalf of the ATLAS Collaboration

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UNIVERSITÄT
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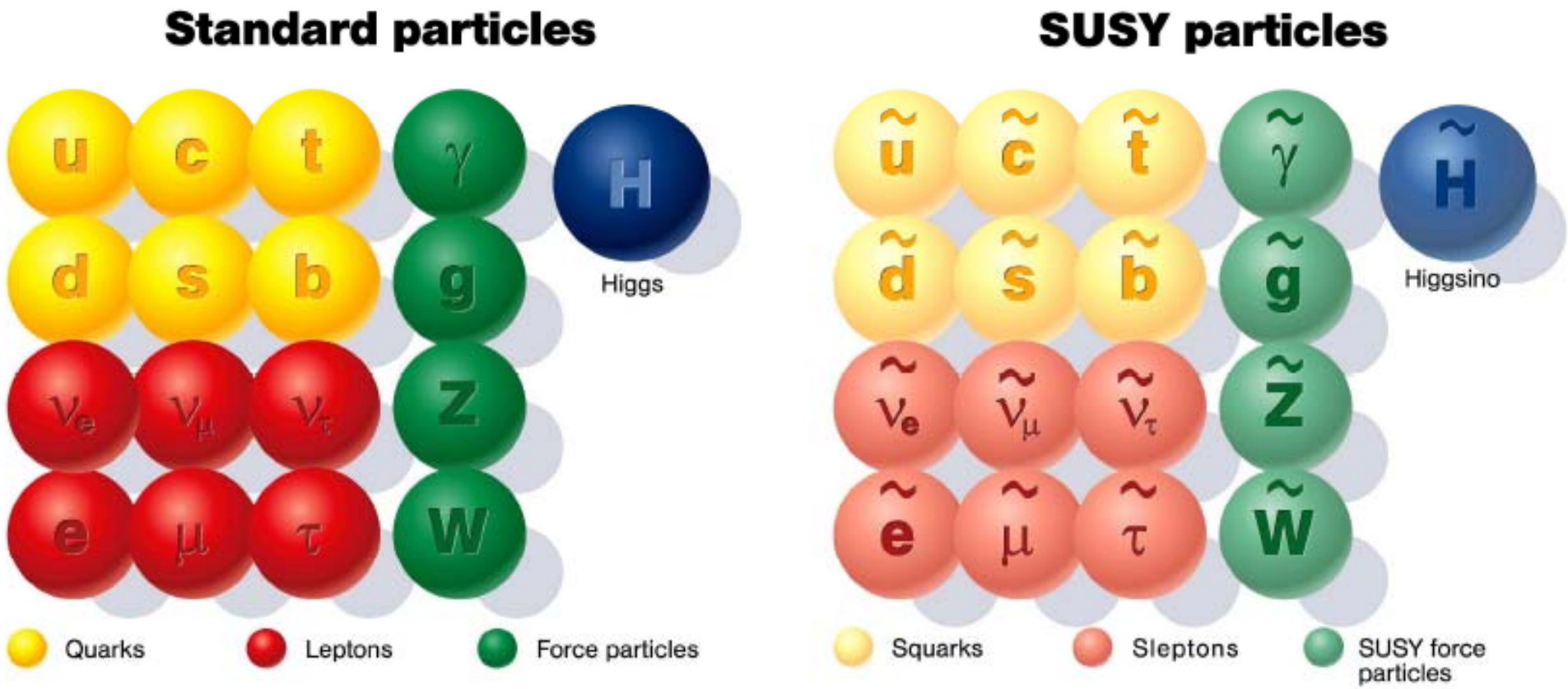
Outline

- SUSY phenomenology
- Strategies to search for SUSY
- Results based on sparticle production:
  - Strong production
  - Stop / sbottom production
  - Electroweak production
  - R-parity Violation
  - Summary plots
- Conclusions

SUSY Particles



(Phenomenological) MSSM

Parameter	Description
M_1	Bino mass
M_2	Wino mass
M_3	Gluino mass
$m_{\tilde{e}_L} = m_{\tilde{\mu}_L}$	1st / 2nd gen. L_L slepton
$m_{\tilde{\tau}_L}$	3rd gen. L_L slepton
$m_{\tilde{e}_R} = m_{\tilde{\mu}_R}$	1st / 2nd gen. E_R slepton
$m_{\tilde{\tau}_R}$	3rd gen. E_R slepton
$m_{\tilde{u}_L} = m_{\tilde{d}_L} = m_{\tilde{c}_L} = m_{\tilde{s}_L}$	1st / 2nd gen. Q_L squark
$m_{\tilde{t}_L} = m_{\tilde{b}_L}$	3rd gen. Q_L squark
$m_{\tilde{u}_R} = m_{\tilde{c}_R}$	1st / 2nd gen. U_R squark
$m_{\tilde{t}_R}$	3rd gen. U_R squark
$m_{\tilde{d}_R} = m_{\tilde{s}_R}$	1st / 2nd gen. D_R squark
$m_{\tilde{b}_R}$	3rd gen. D_R squark
A_t	Trilinear coupling t-quark
A_b	Trilinear coupling b-quark
A_τ	Trilinear coupling τ-lepton
m_{H_1}	u-type Higgs doublet mass
m_{H_2}	d-type Higgs doublet mass
$\tan\beta$	Ratio scalar doublet VEVs

e.g. Phys.Rev.D81:095012,2010

General structure of superpotential

$$\mathcal{W}_{gen} = \frac{1}{2} M_{ij} \Phi_i \Phi_j + \frac{1}{6} y_{ijk} \Phi_i \Phi_j \Phi_k$$

Structure of soft-SUSY breaking Lagrangian

$$\mathcal{L}_{soft}^{gen} = -\frac{1}{2}\left(\tilde{M}_{\lambda_a} \lambda_a \lambda_a + h.c.\right) - m_{ij}^2 \phi_i^* \phi_j - \left(\frac{1}{2} b_{ij} \phi_i \phi_j + \frac{1}{6} a_{ijk} \phi_i \phi_j \phi_k + h.c.\right)$$

SUSY Phenomenology

- SUSY theory includes > 100 parameters
- Additional sets of parameters for RPV or extended Higgs sector
- *R*-parity conserving signatures $R = (-1)^{3(B-L)+2S}$
  - Production of sparticles in pairs, decays to LSP
  - Mass of WIMP-LSP sets scale for minimal E_t^{miss}
- Signatures from prompt RPV
  - Enhanced lepton and/or jet multiplicities from LSP decays
  - More candidates for LSP
  - Resonances from single sparticle production / subsequent 2-body decay
- Long-lived particles
  - Displaced vertices due to small RPV-couplings
  - Mass-degeneracy
  - Hadronic states from heavy mediator sparticles (squarks)

RPV SUSY Parameters

R-Parity: $R = (-1)^{3(B-L)+2S}$

(Non-)conservation of *B* and *L*

Superpot. $W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k + \kappa_i L_i H_2$

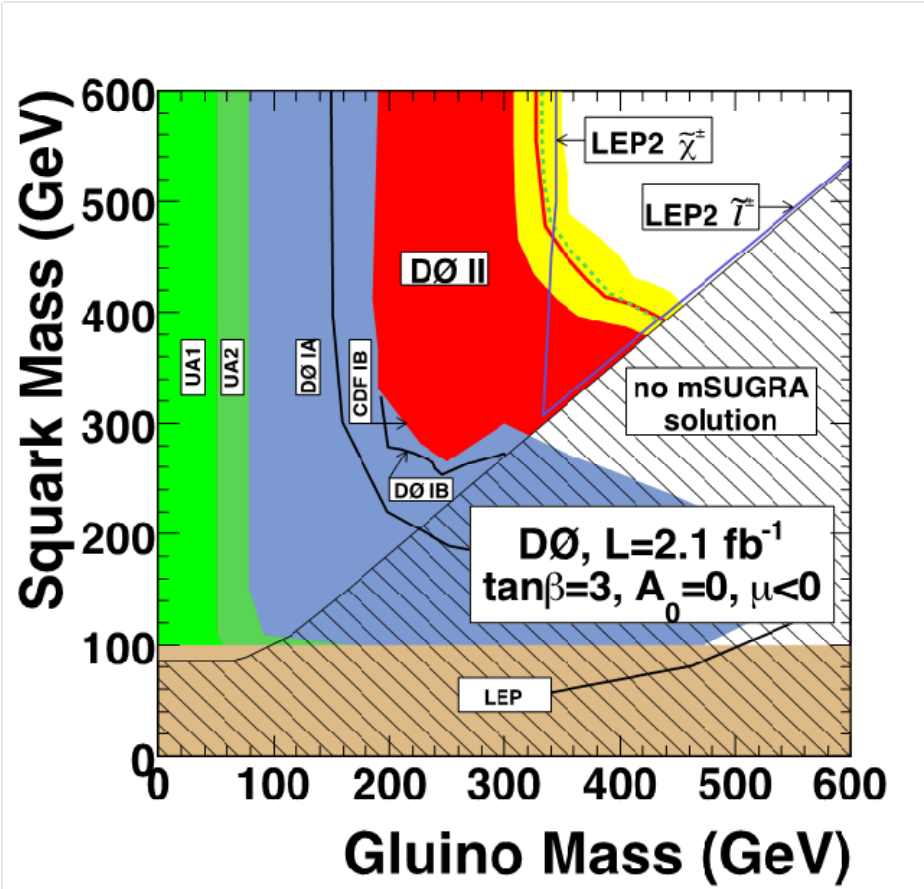
- Most constraints only assume one (or product of two) coupling(s)
  - Neutrino masses
  - Charged current universality
  - Proton decay, di-nucleon decay, neutron oscillation
  - Flavor violating decays
  - Collider limits
- Number of parameters
  - 9 λ_{ijk} ($\lambda_{ijk} = - \lambda_{jik}$)
  - 27 $\lambda`_{ijk}$
  - 9 $\lambda``_{ijk}$ ($\lambda``_{ijk} = - \lambda``_{ikj}$)
  - 3 dimensionful κ_i

Pre-LHC experimental constraints

- Low-energy constraints
  - $b \rightarrow s\,\gamma$
  - g_μ-2
- Astrophysical results
  - Cold Dark Matter
  - WIMP production
- High-energy colliders
  - LEP
  - Tevatron

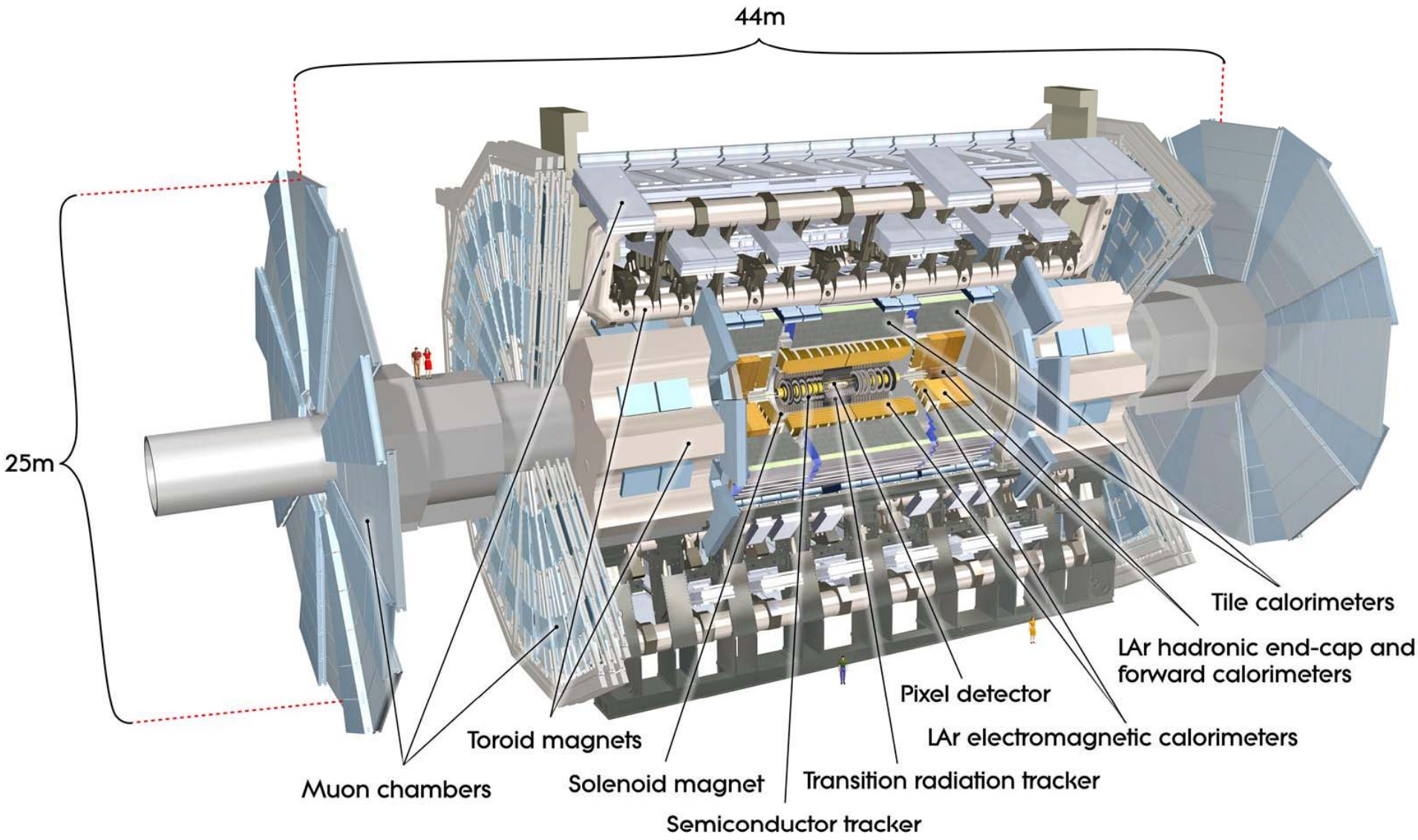
- Impact on SUSY parameter space
- See PDG

Jets + MET searches for squarks and gluinos at D0

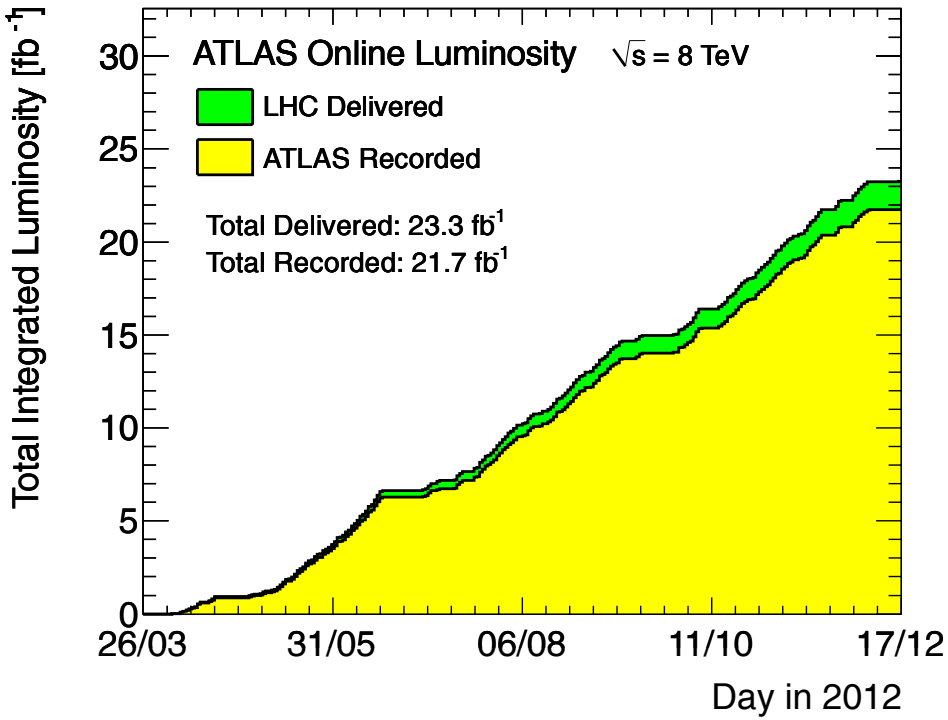


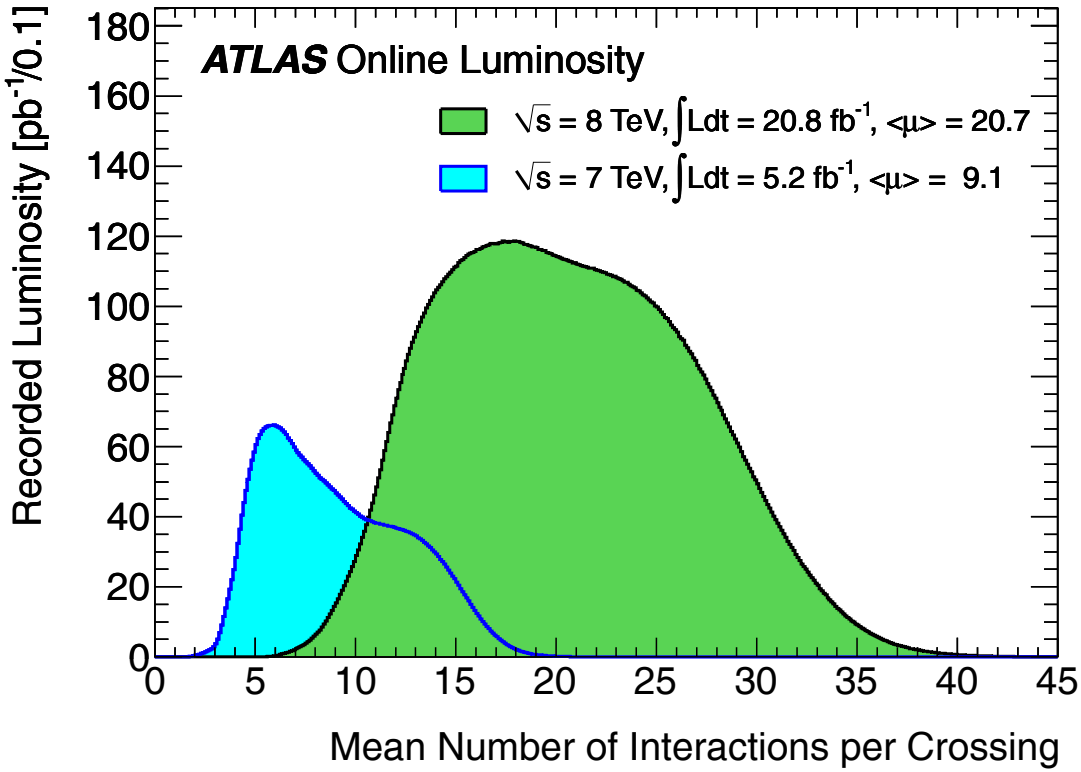
D0 0712.3805

ATLAS Detector



Luminosity and Pileup





- Luminosity recorded at 8 TeV in 2012
- Total efficiency (delivered → physics analysis): ~89%

- No significant impact on tracking, muons, electrons, photons expected
- Sizeable impact on jets, E_T^{miss} , tau reconstruction and trigger rates

Strategies to search for SUSY

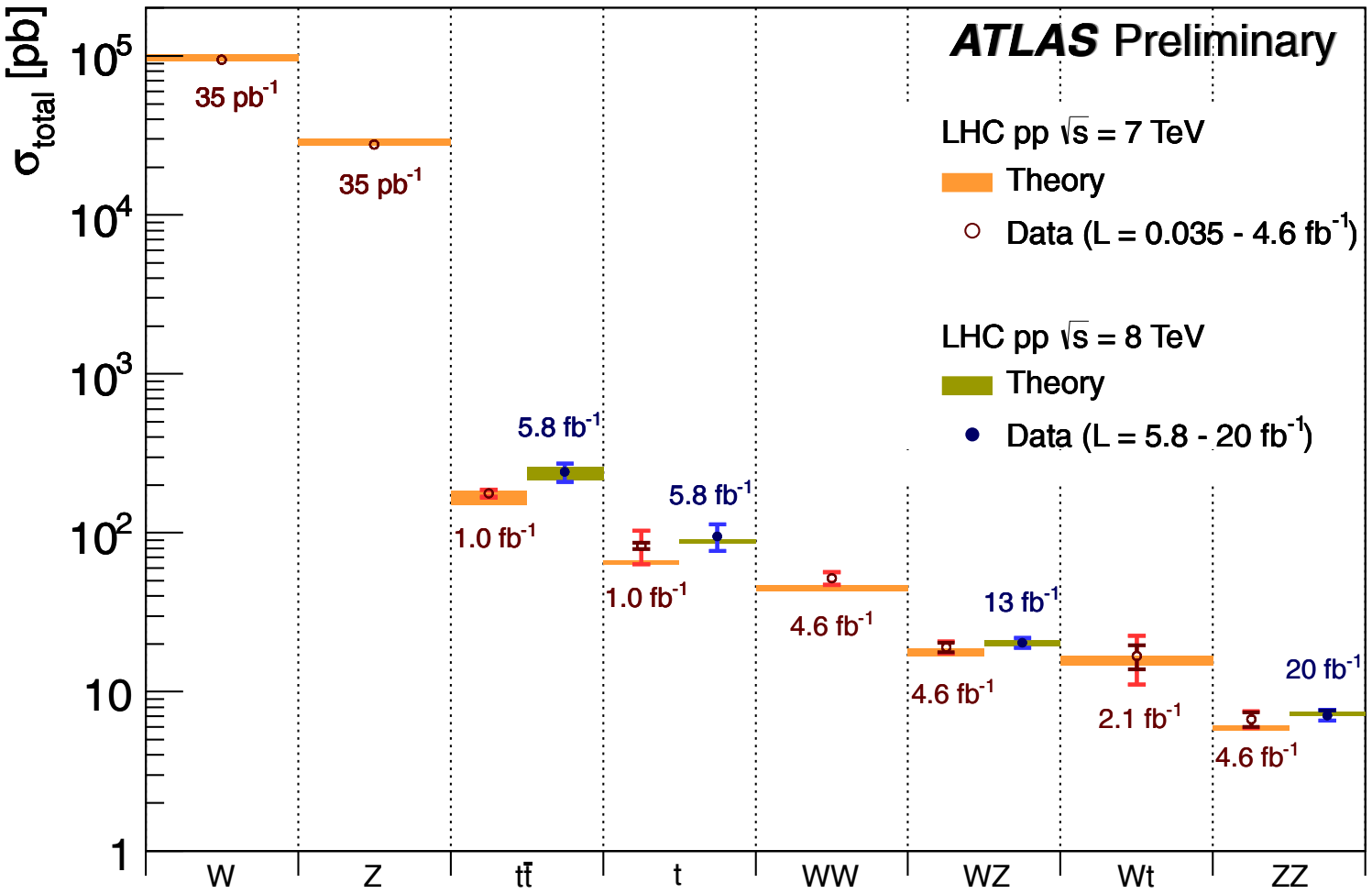
- **Inclusive searches**
  - Based on generic signatures and models
  - Coverage of large parameter space
- **Dedicated searches** for studies of more model-specific features
- Complex **sparticle production** and **decay chains**
  - Requirements on final state jets, leptons, taus, photons, E_t^{miss}
  - Optimization of Signal Regions
- Control of **reducible** and **irreducible backgrounds**
  - Data-driven methods
  - Normalization of MC in Control Regions
- Estimation of **systematic uncertainties**
- **Statistical analysis**
  - Combined binned profile likelihood fit using CL_s prescription for limits
  - Systematic uncertainties as nuisance parameters in fit, correlated among regions

SUSY Models

- High-energy models of SUSY-breaking
  - mSUGRA / CMSSM
  - GMSB / general Gauge Mediation
  - AMSB
- pMSSM
- Simplified models
  - Decoupling limit of most sparticles
  - Electroweak production
  - Exclusive pair-production of
    - Gluinos
    - Stops / sbottoms
    - Charginos / neutralinos
    - Sleptons …
  - Fixed (maximal) Branching Ratios

Constraints from Higgs mass around 125 GeV

SM Background Processes



top quark pair production at 7 TeV: combination of single-lepton, dilepton and all-hadronic channels, 8-TeV measurement from single-lepton channel

ZZ cross section at 7 TeV includes combination of several measurements, 8-TeV only uses on-shell Z boson decays

Dark-color (lighter-color) error bar for stat. uncertainly (full uncertainty)

Production processes and searches

Strong (gluino / squark) production

0 lepton + 2-6 jets + E_t^{miss} (ATLAS-CONF-2013-047)

0 lepton + 7-10 jets + E_t^{miss} (ATLAS-CONF-2013-054)

1-2 taus + jets + E_t^{miss} (ATLAS-CONF-2013-026)

2 SS leptons + 0-3 b-jets + E_t^{miss} (ATLAS-CONF-2013-007)

Based on full 2012 8 TeV data

Stop and/or sbottom production

Z + b-jet + jets + E_t^{miss} (ATLAS-CONF-2013-025)

2 leptons (+ jets) + E_t^{miss} (ATLAS-CONF-2013-048)

0 lepton + 2 b-jets + E_t^{miss} (ATLAS-CONF-2013-053)

0 lept. + 6(2 b-)jets + E_t^{miss} (ATLAS-CONF-2013-024)

1 lept. + (1 b-)jets + E_t^{miss} (ATLAS-CONF-2013-037)

Electroweak production

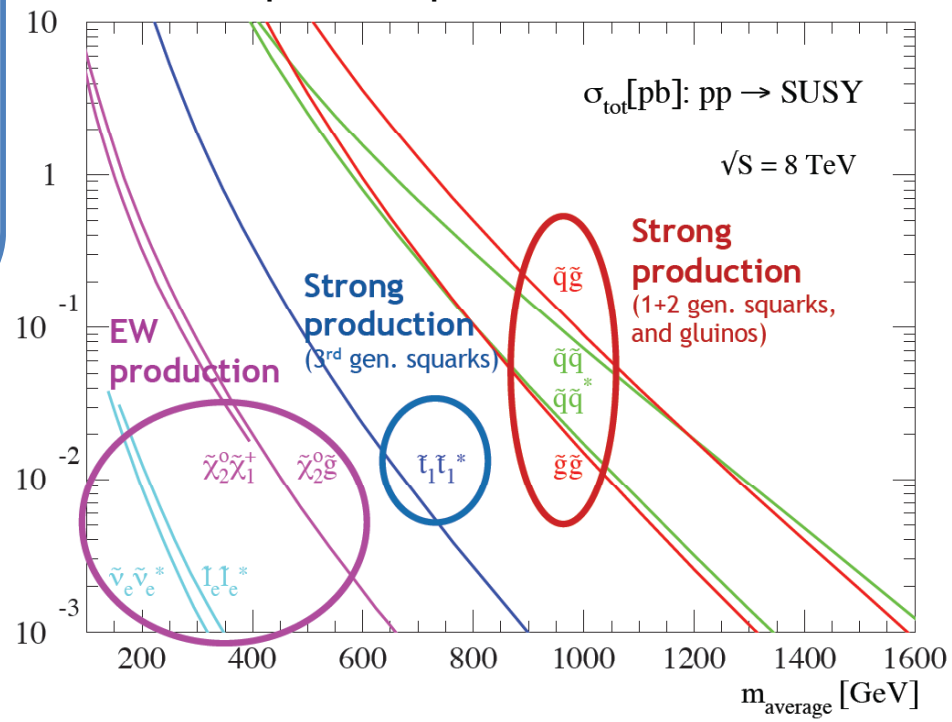
2 leptons + E_t^{miss} (ATLAS-CONF-2013-049)

2 taus + E_t^{miss} (ATLAS-CONF-2013-028)

3 leptons + E_t^{miss} (ATLAS-CONF-2013-035)

4 leptons + E_t^{miss} (ATLAS-CONF-2013-036)

Total cross-sections for sparticle production at 8 TeV



Recent results

- **Strong (gluino / squark) production**
  - 1 lepton+jets+ E_t^{miss} (ATLAS-CONF-2013-062)
    - 1-step, 2-step simplified models (with sleptons)
    - mSUGRA /CMSSM
    - minimal Universal Extra Dimension model

Based on full 2012 8 TeV data

- **Stop / sbottom production**
  - 0-1leptons+3b-jets+jets+ E_t^{miss} (ATLAS-CONF-2013-069)
    - Gluino decaying via sbottom-b, stop-top
    - mSUGRA / CMSSM

- **Long-lived sparticle production**
  - Stopped gluino R-hadrons (ATLAS-CONF-2013-057)
  - Long-lived sleptons (ATLAS-CONF-2013-058)
    - Stau in GMSB
    - Direct stau production
    - Electroweak production of charginos decaying to stau

0 leptons + 7-10 jets + Etmiss- Overview

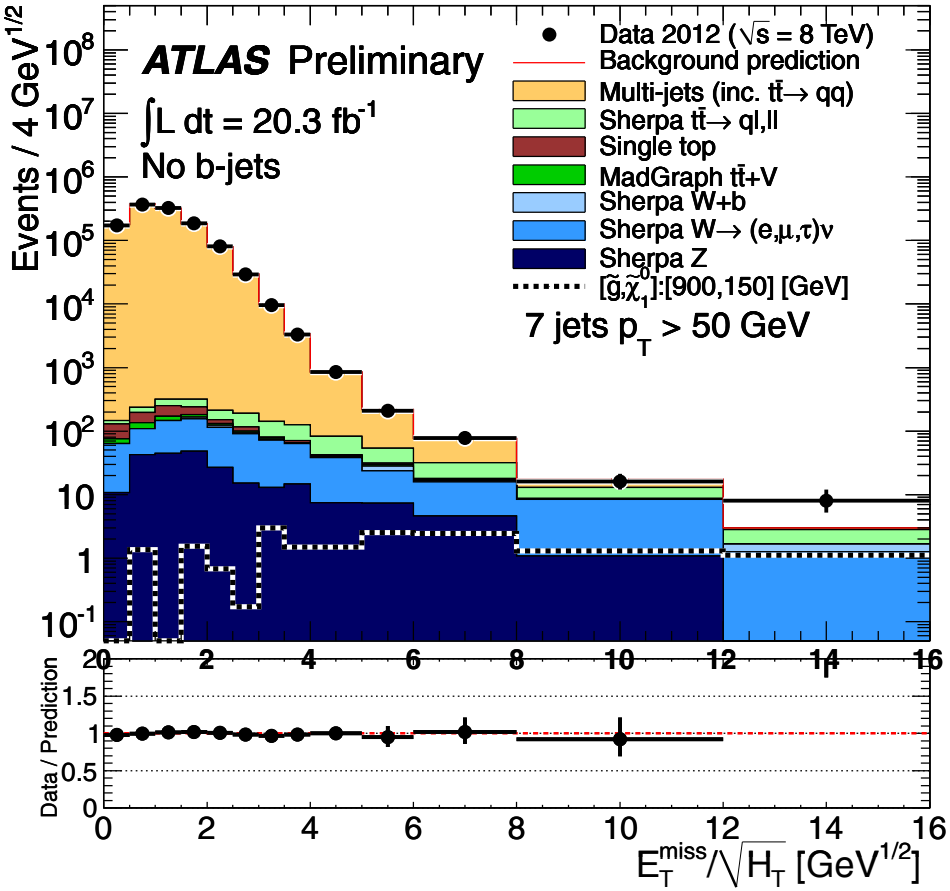
- Large jet multiplicities from various decays
- Selection of at least 7 – 10 jets
- Significant E_T^{miss}
- Multi-jet + flavour stream
  - Reconstruction with jet dist. parameter *R=0.4*
  - Selection of number of *b*-jets
- Multi-jet + M_J^{Σ} stream (complementary)
  - Re-clustering of *R=0.4* jets into large (*R=1.0*) composite jets
  - Sum of masses of composite jets as event variable
- Main backgrounds: Multi-jet, *t-tbar*, *W*+jets
  - Distribution of $E_t^{miss}/\sqrt{H_T}$ in CR / SR
  - E_t^{miss} resolution prop. to $\sqrt{H_T}$ (in events dominated by jet activity)

Main processes:

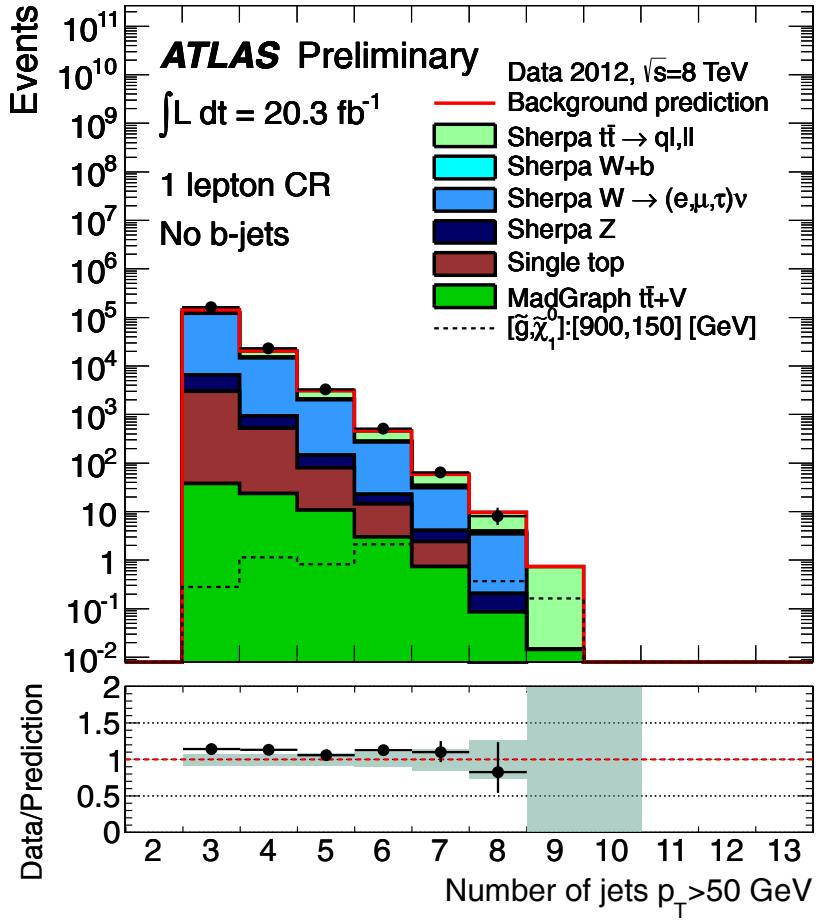
$$
\begin{aligned}
q + q' &\rightarrow \tilde{g}\tilde{g} \\
\tilde{g} &\rightarrow q + \tilde{q} \\
\tilde{g} &\rightarrow t + \bar{t} + \tilde{\chi}_1^0 \\
\tilde{q} &\rightarrow q + \tilde{\chi}_1^0 \\
\tilde{q} &\rightarrow q' + W + \tilde{\chi}_1^0
\end{aligned}
$$

$$M_J^{\Sigma} = \sum_j m_j^{R=1.0}$$

0 leptons + 7-10 jets + Etmiss- Backgrounds



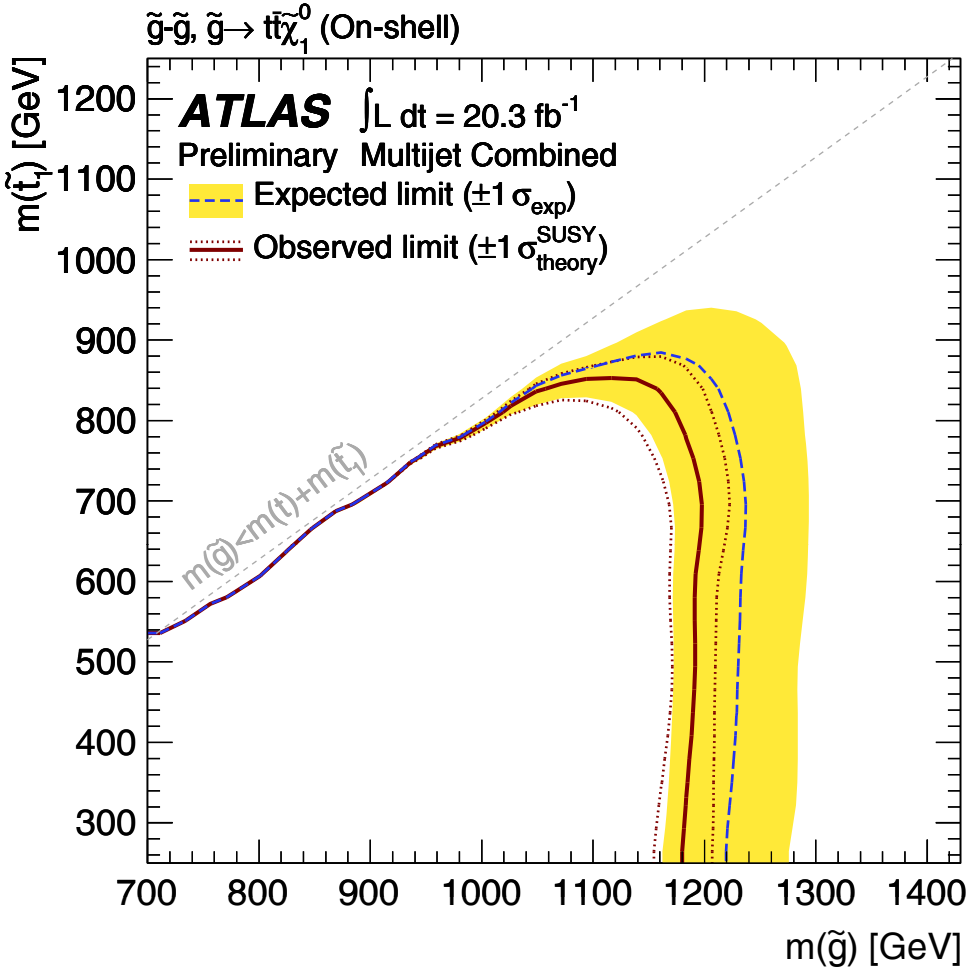
ATLAS-CONF-2013-054

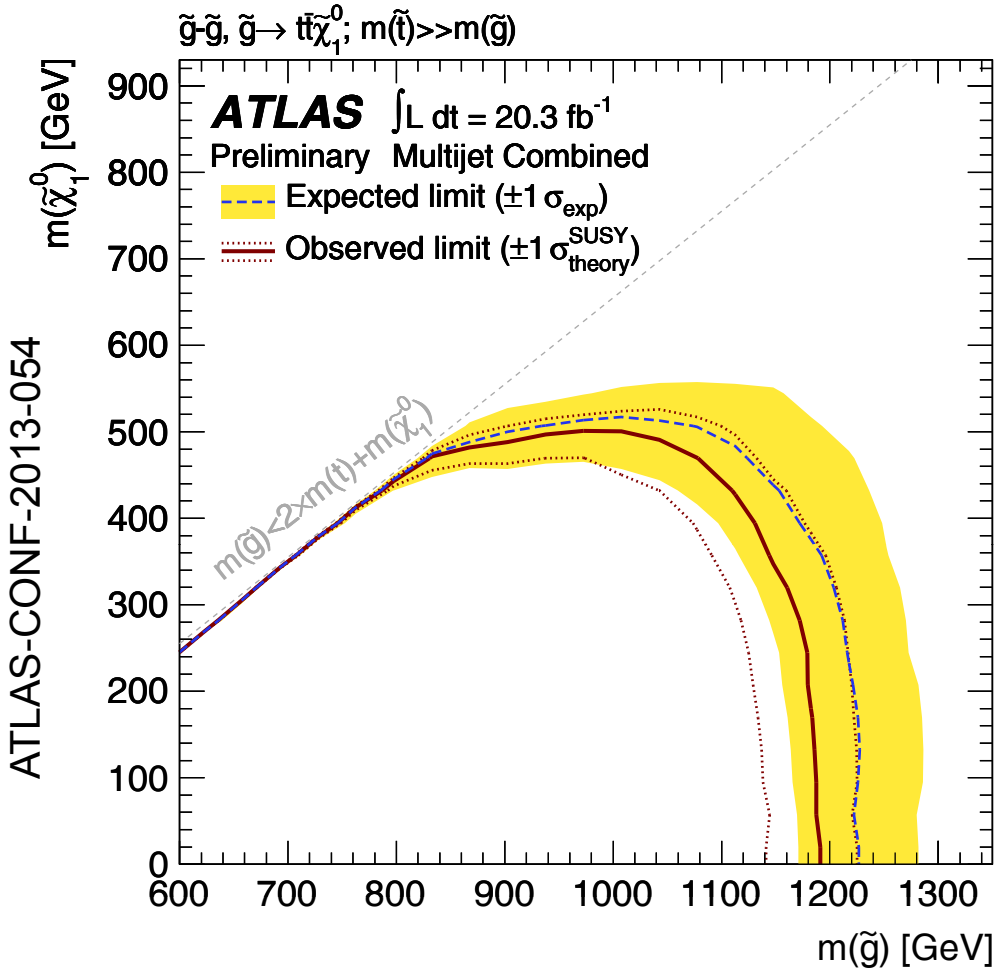


CR with exactly 7 jets, 0 *b*-jets
multi-jet prediction determined from $ME_T/\sqrt{H_T}$ template (based on exactly 6 jets)
normalized to data in region $ME_T/\sqrt{H_T} < 1.5\ \sqrt{GeV}$
after subtraction of "leptonic" backgrounds

1-lepton *ttbar* and *W*+jets CR, 0 *b*-jets
MC predictions before fitting to data.
Band in ratio plot: Exp. uncertainties on MC prediction and also MC stat. uncert.

0 leptons + 7-10 jets + Etmiss- Results

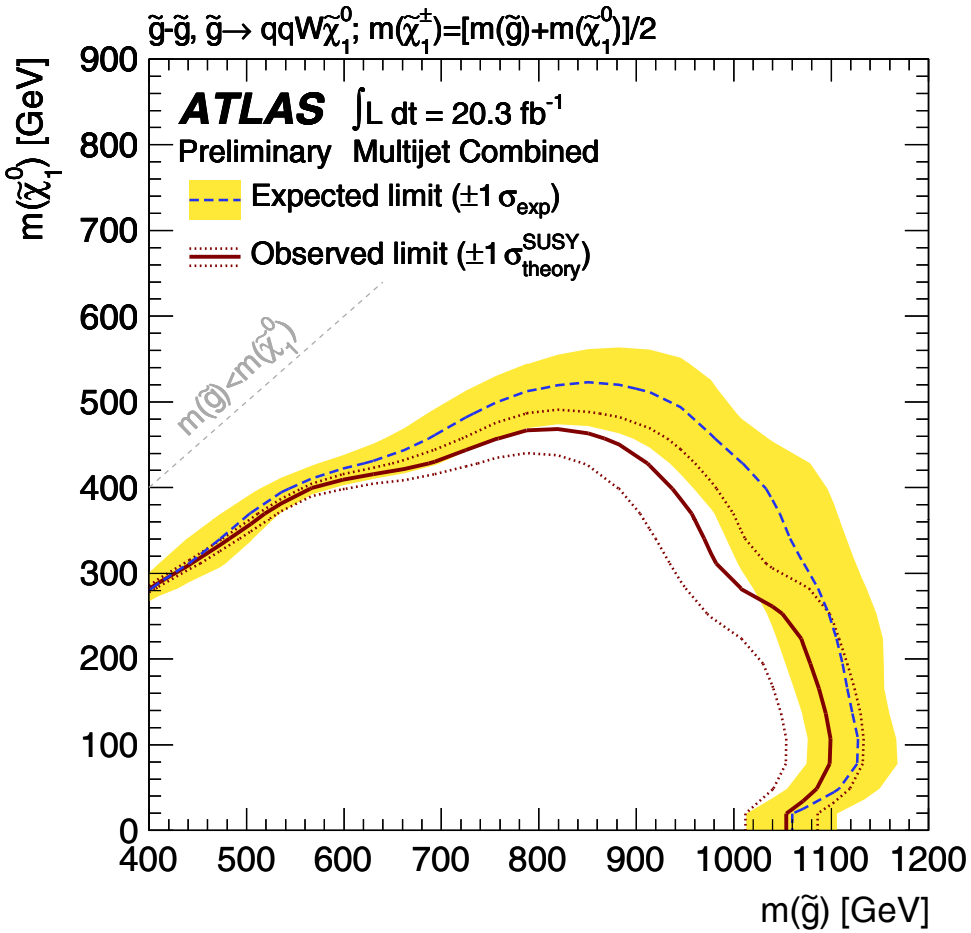




simplified gluino-stop (on-shell) model
gluino decays to stop and top
stop to top and LSP
m_{LSP}=60 GeV

simplified gluino-stop (off-shell) model

0 leptons + 7-10 jets + Etmiss- Results



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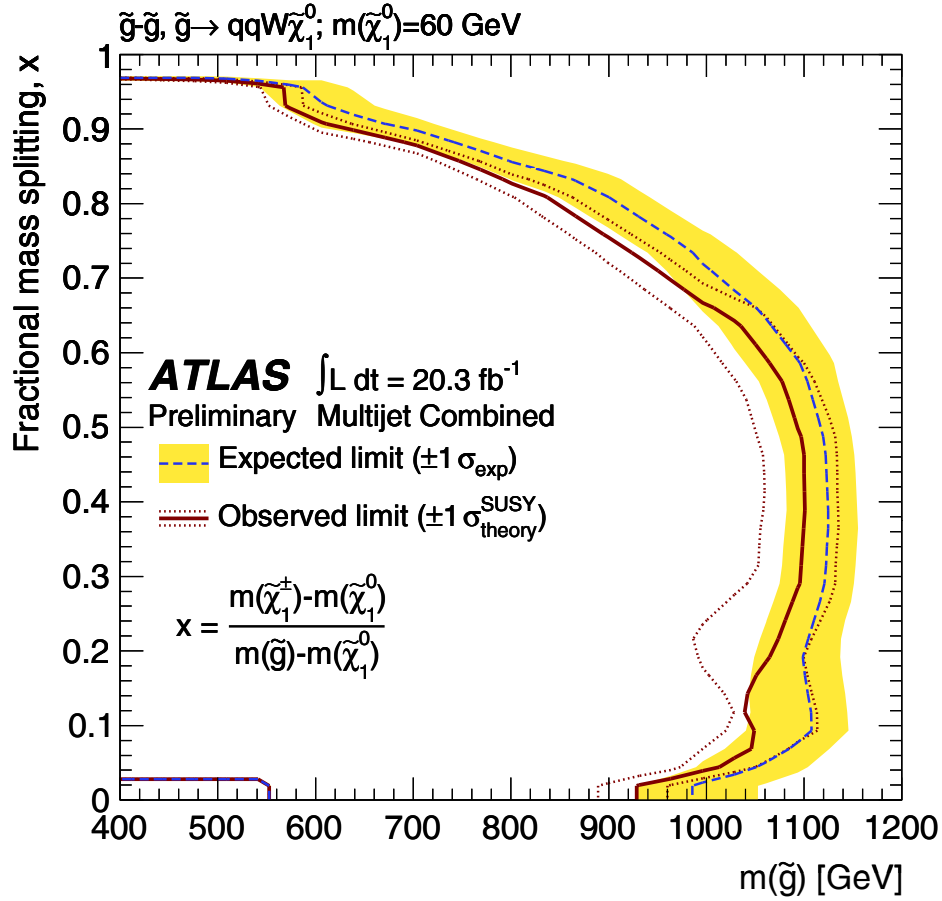


simplified gluino-squark (via chargino) model
C1 to *W* + *LSP*, sleptons decoupled
$x = (m_{chargino} - m_{LSP})/(m_{gluino} - m_{LSP})=1/2$
varying LSP mass

simplified gluino-squark (via chargino) model
varying $x = (m_{chargino} - m_{LSP})/(m_{gluino} - m_{LSP})$
LSP mass of 60 GeV

1 lepton + jets + Etmiss- Overview

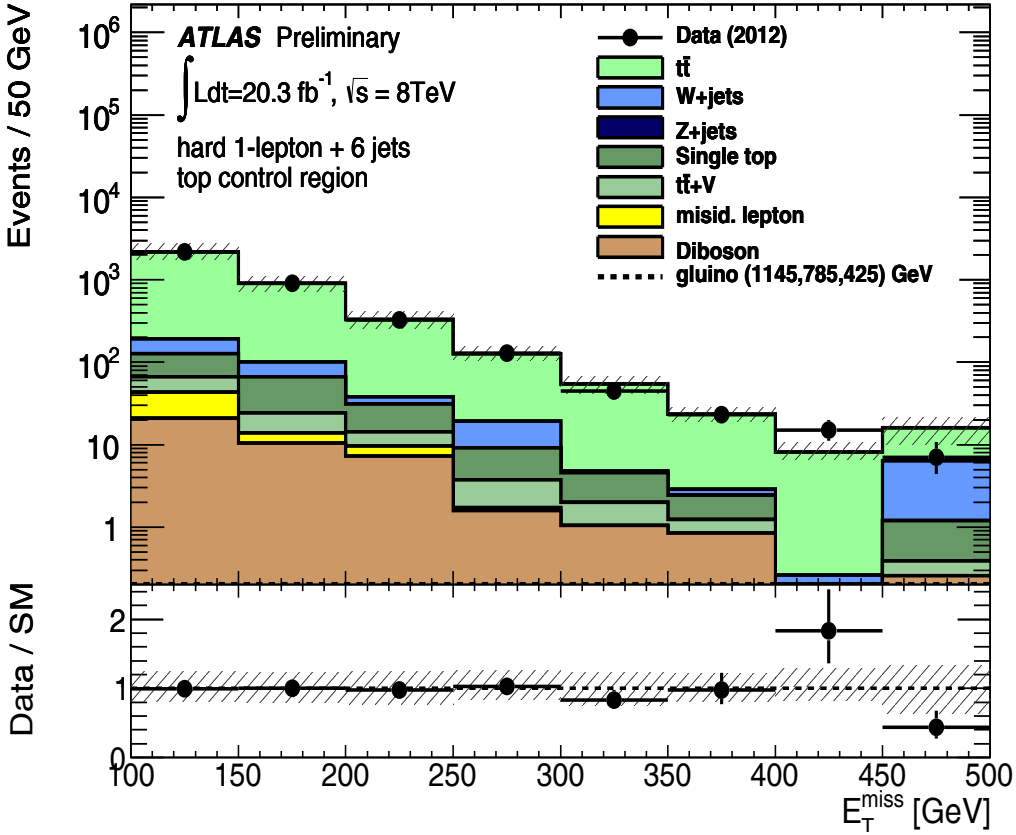
- 1 isolated electron or muon, significant E_t^{miss}
  - Soft-lepton channel (p_T < 25 GeV)
  - Hard-lepton channel (p_T > 25 GeV)
- Selection of at least 2 jets (add. b-jets)
- Main backgrounds: Multi-jet, *t-tbar*, *W*+jets
- Reduction of backgrounds:
  - Misidentified leptons (ΔR_{min})
  - Fake E_t^{miss} in events from multi-jets ($\Delta\varphi_{min}$)
  - Leptonic *W*-decays (m_T)
  - Overall scale of hard scattering proc.(m_{eff}^{inc}, $H_{T,2}$)
  - E_t^{miss} in soft single lepton + b-jets (m_{CT})
- Interpretations:
  - Simplified Models: 1-step, 2-step (with sleptons)
  - mSUGRA/CMSSM
  - minimal Universal Extra Dimension model

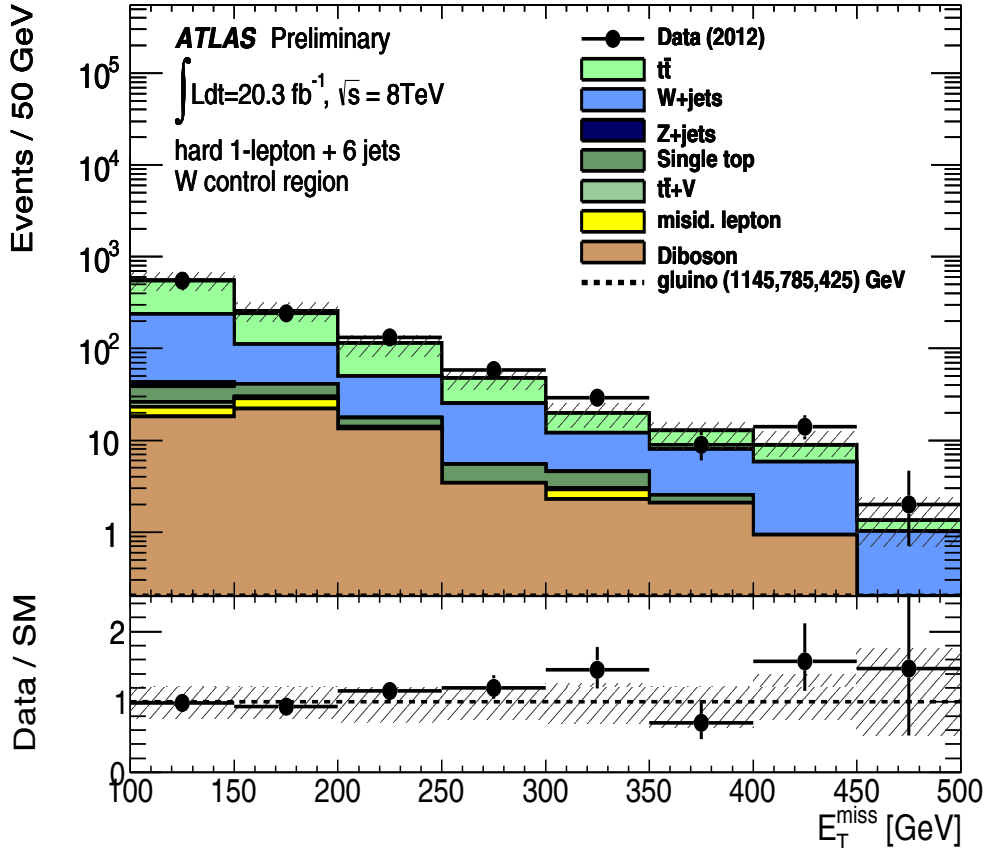
Main processes:

$$
\begin{aligned}
q + q' &\rightarrow \tilde{g} + \tilde{g} \\
\tilde{g} &\rightarrow q + \tilde{q} \\
q + q' &\rightarrow \tilde{q}_{(L)} + \tilde{q}_{(L)} \\
\tilde{q}_L &\rightarrow q' + W + \tilde{\chi}_1^0 \\
\tilde{q}_L &\rightarrow q' + l + \bar{l} + \tilde{\chi}_1^0 \\
q + q' &\rightarrow \tilde{t}_1 + \tilde{t}_1 \\
\tilde{t}_1 &\rightarrow b + \tilde{\chi}_1^{\pm} \rightarrow W^{(*)} \tilde{\chi}_1^0 b
\end{aligned}
$$

1 lepton + jets + Etmiss- Backgrounds

ATLAS-CONF-2013-062





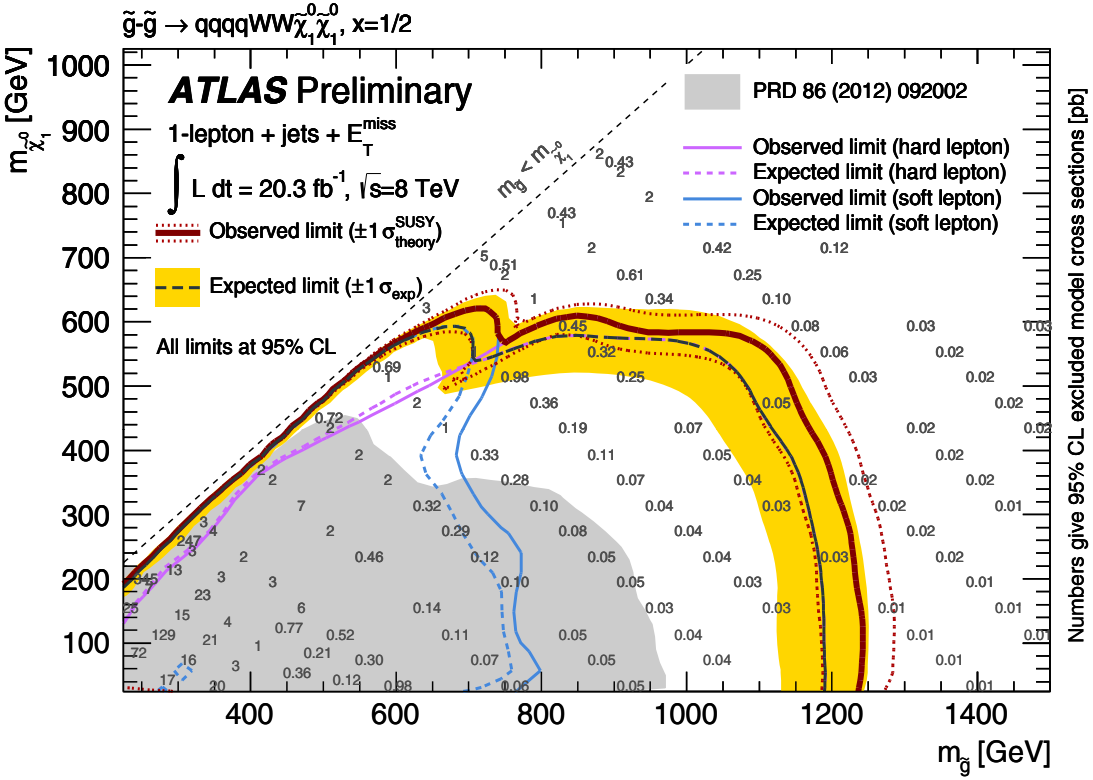
***t-tbar* (left) and *W+jets* (right) control regions**

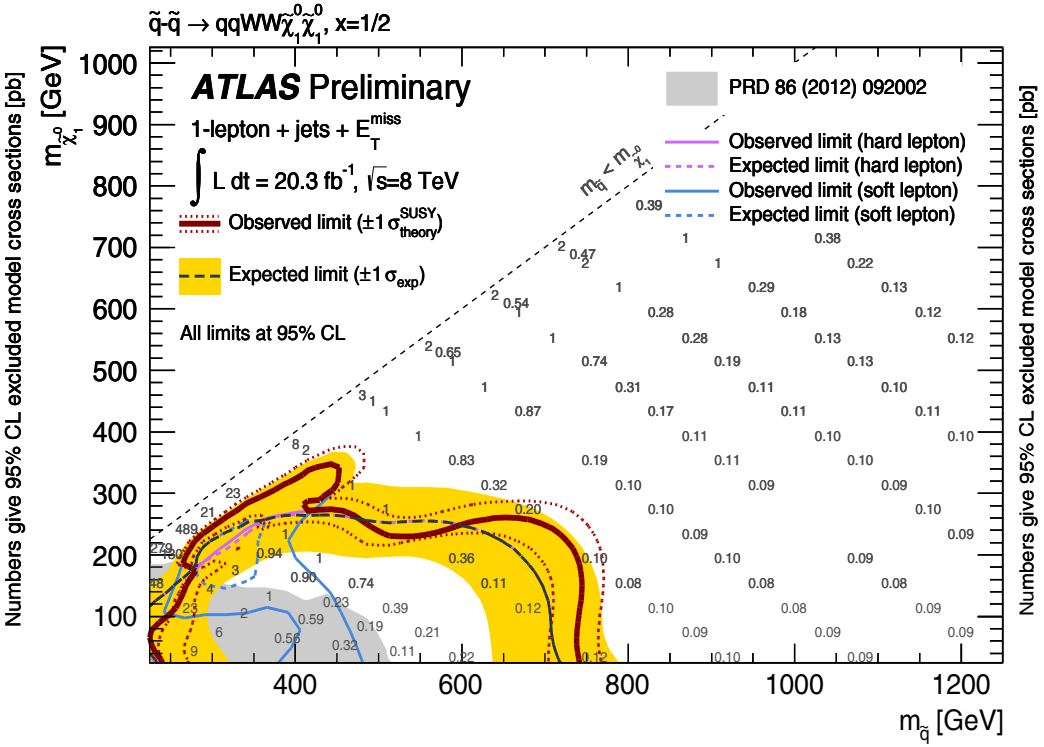
Hard single-electron channels

Before cut on E_t^{miss}

1 leptons + jets + Etmiss- Results

ATLAS-CONF-2013-062





Gluino simplified model
C1 to *W* + *LSP*, sleptons decoupled
chargino mass fixed at x=1/2,
where $x = (m_{chargino} - m_{LSP})/(m_{gluino} - m_{LSP})$
7 TeV data shown as grey area

1st / 2nd gen. squark simplified model
C1 to *W* + *LSP*, sleptons decoupled

Production processes and searches

Strong (gluino / squark) production

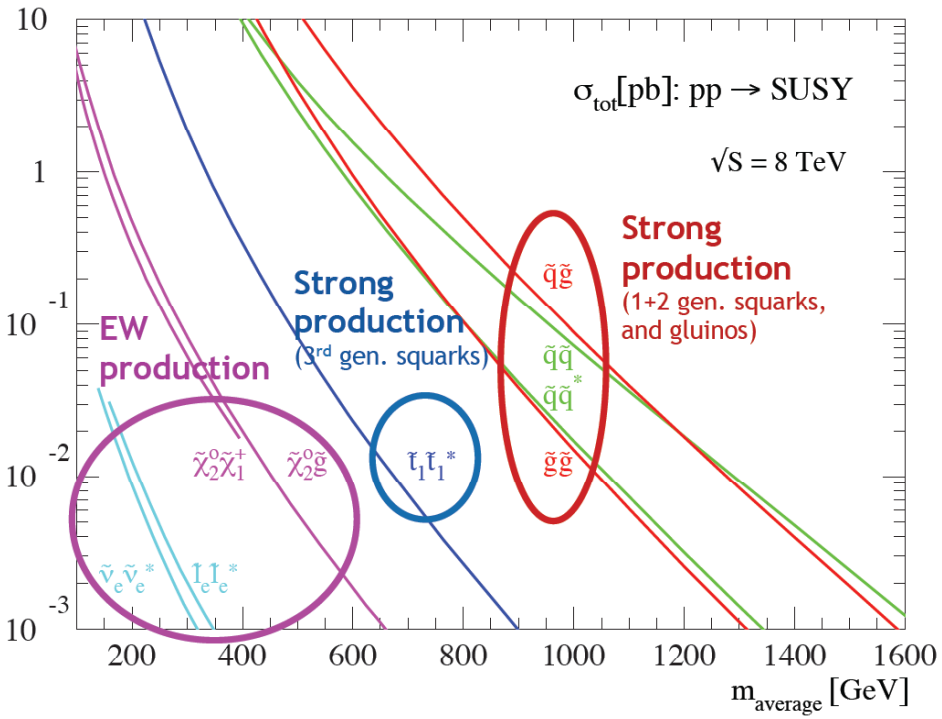
0 lepton + 2-6 jets + E_t^{miss} (ATLAS-CONF-2013-047)
0 lepton + 7-10 jets + E_t^{miss} (ATLAS-CONF-2013-054)
1-2 taus + jets + E_t^{miss} (ATLAS-CONF-2013-026)
2 SS leptons + 0-3 b-jets + E_t^{miss} (ATLAS-CONF-2013-007)

Based on full 2012 8 TeV data

Stop and/or sbottom production

Z + b-jet + jets + E_t^{miss} (ATLAS-CONF-2013-025)
2 leptons (+ jets) + E_t^{miss} (ATLAS-CONF-2013-048)
0 lepton + 2 b-jets + E_t^{miss} (ATLAS-CONF-2013-053)
0 lept. + 6(2 b-)jets + E_t^{miss} (ATLAS-CONF-2013-024)
1 lept. + (1 b-)jets + E_t^{miss} (ATLAS-CONF-2013-037)

Total cross-sections for sparticle production at 8 TeV

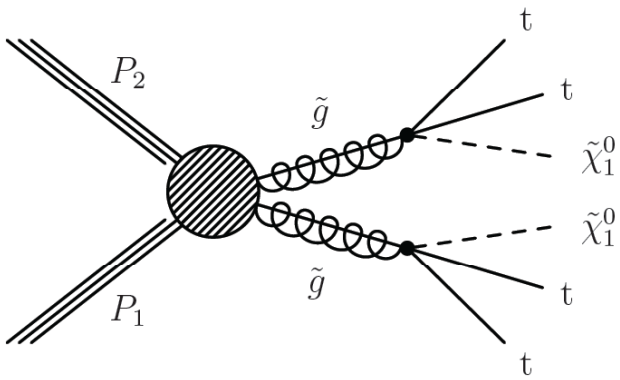


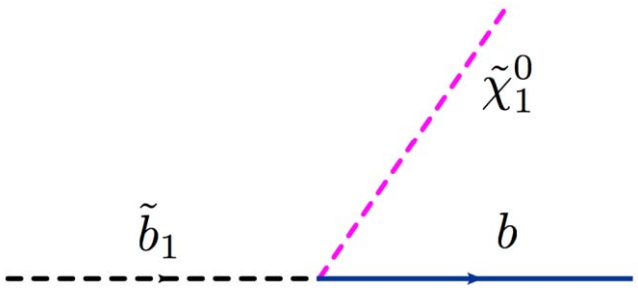
Electroweak production

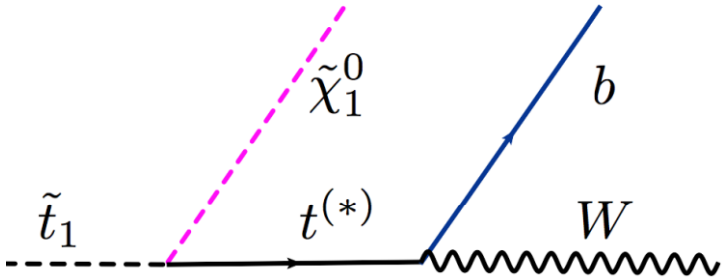
2 leptons + E_t^{miss} (ATLAS-CONF-2013-049)
2 taus + E_t^{miss} (ATLAS-CONF-2013-028)
3 leptons + E_t^{miss} (ATLAS-CONF-2013-035)
4 leptons + E_t^{miss} (ATLAS-CONF-2013-036)

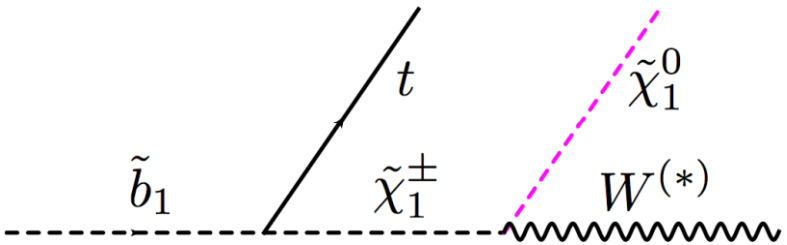
Stop- / sbottom processes

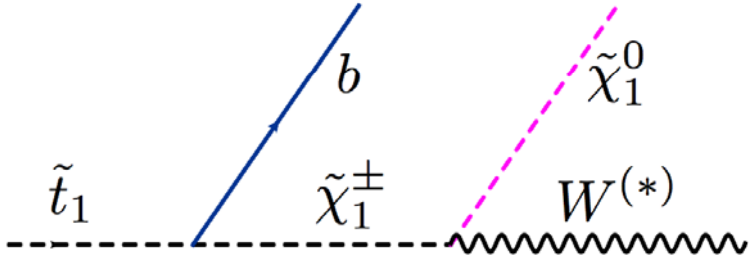
- **Naturalness** arguments for “light ” third generation squarks
- Pair-production of stops / sbottoms:
  - Gluino-mediated
  - Direct production
- Final state with high top / bottom multiplicities

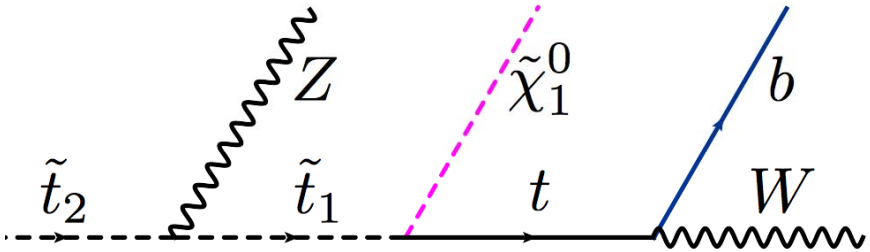












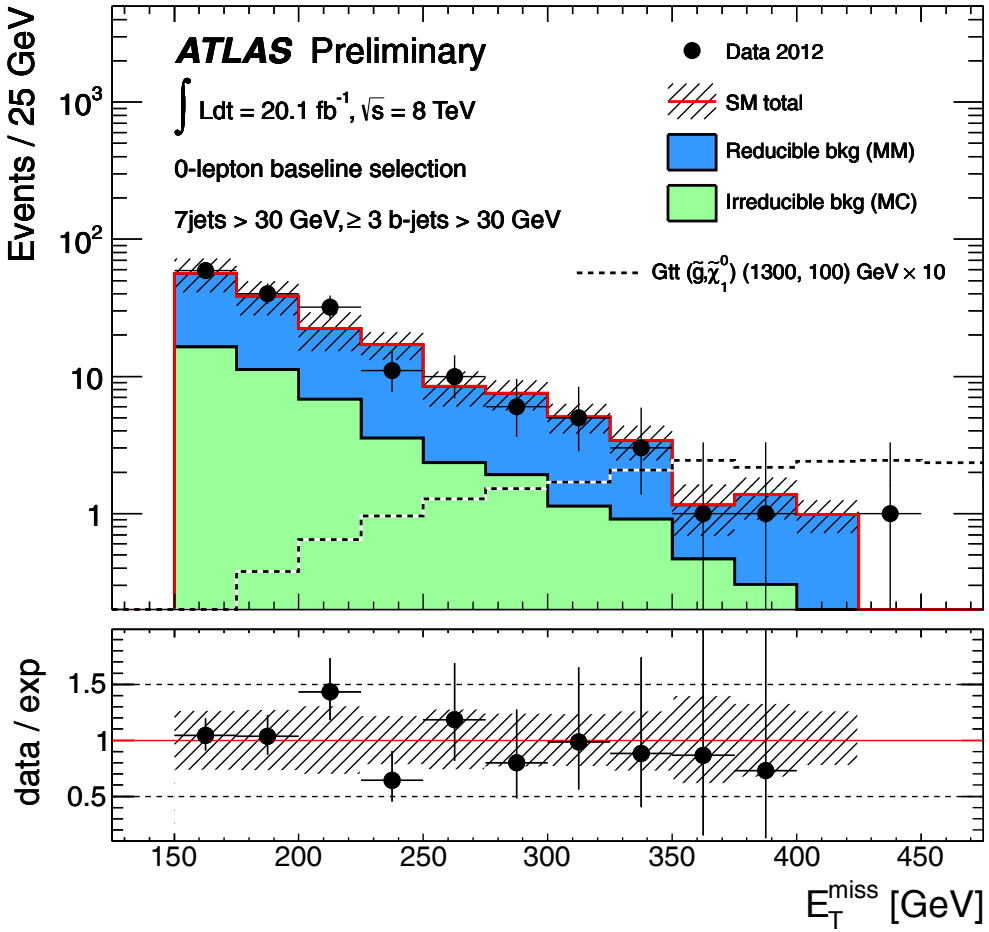
0-1 lepton + 3b-jets + jets + Etmiss- Overview

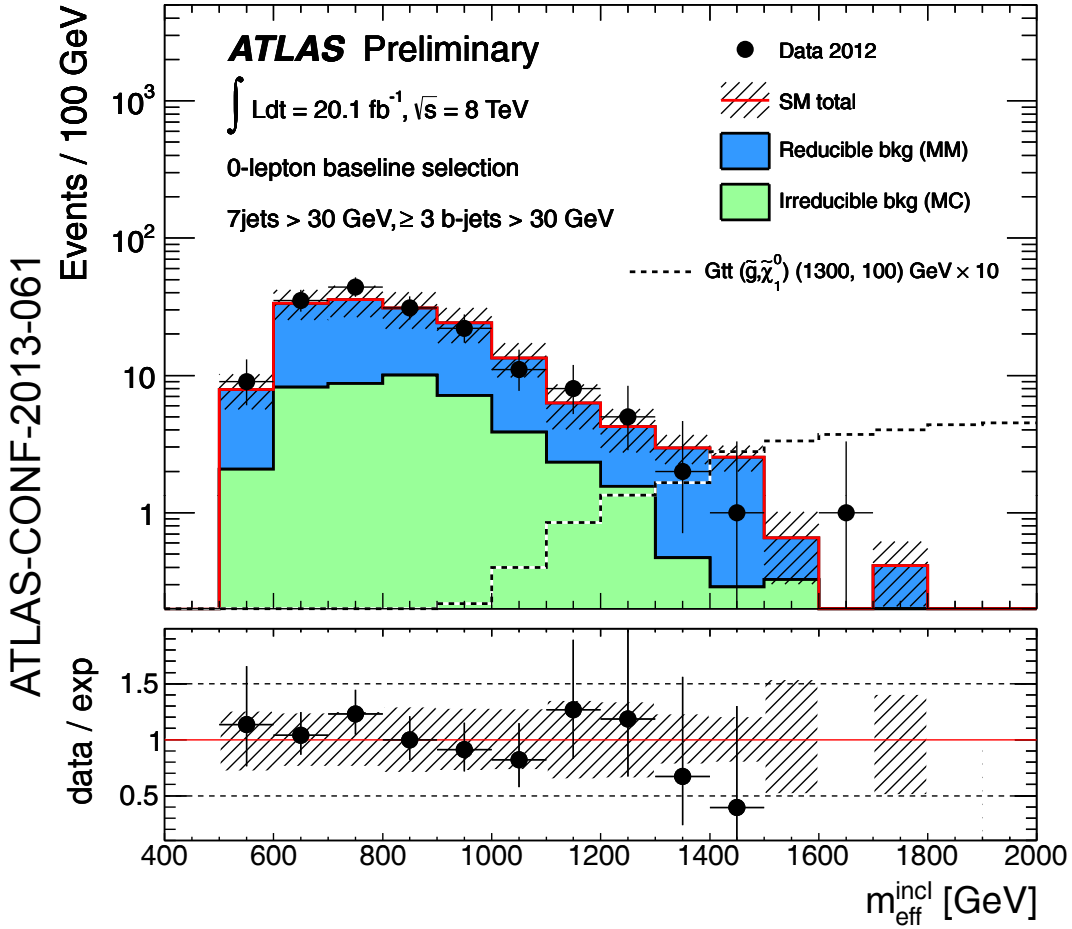
- Selection:
  - At least 3 *b*-jets
  - Up to 1 *e* or *μ*
  - At least 4 jets (non *b*-tagged)
- Main background: *t-tbar*
  - *Irreducible:* at least 3 real *b-jets*
  - *Reducible:* at least 1 *b-jet* misidentified
- Discrimination of backgrounds with variables
  - $E_t^{miss}/\sqrt{H_T}$, m_T , m_{eff}^{inc}, $\Delta\varphi_{min}^{4j}$
- Interpretation of results: Various mass hierarchies among gluinos, stops, sbottoms, neutralinos and charginos
  - Direct production of stops / sbottoms
  - Gluino-med. production (off-shell 3rd gen. squark)

Main processes:

$$
\begin{aligned}
q + q' &\rightarrow \tilde{g} + \tilde{g} \\
\tilde{g} &\rightarrow \tilde{b}_1 + b \\
\tilde{g} &\rightarrow \tilde{t}_1 + t \\
q + q' &\rightarrow \tilde{t}_1 + \tilde{t}_1 \\
q + q' &\rightarrow \tilde{b}_1 + \tilde{b}_1
\end{aligned}
$$

0-1 lepton + 3b-jets + jets + Etmiss- Backgrounds



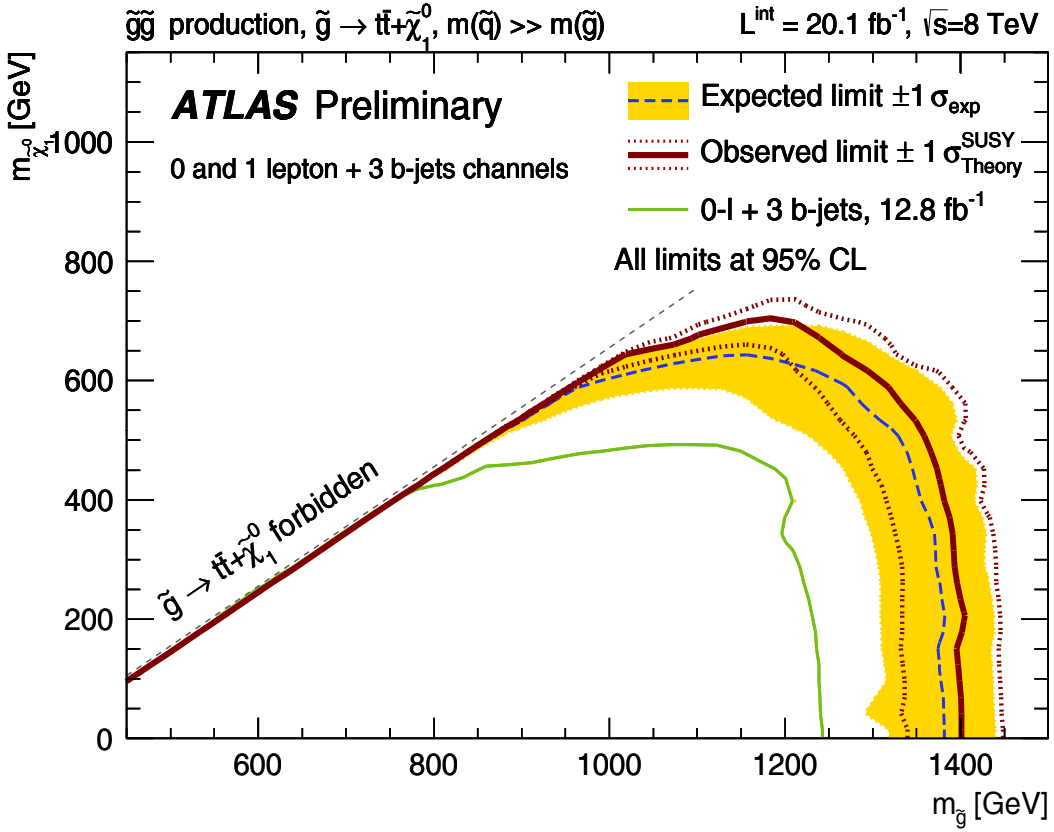


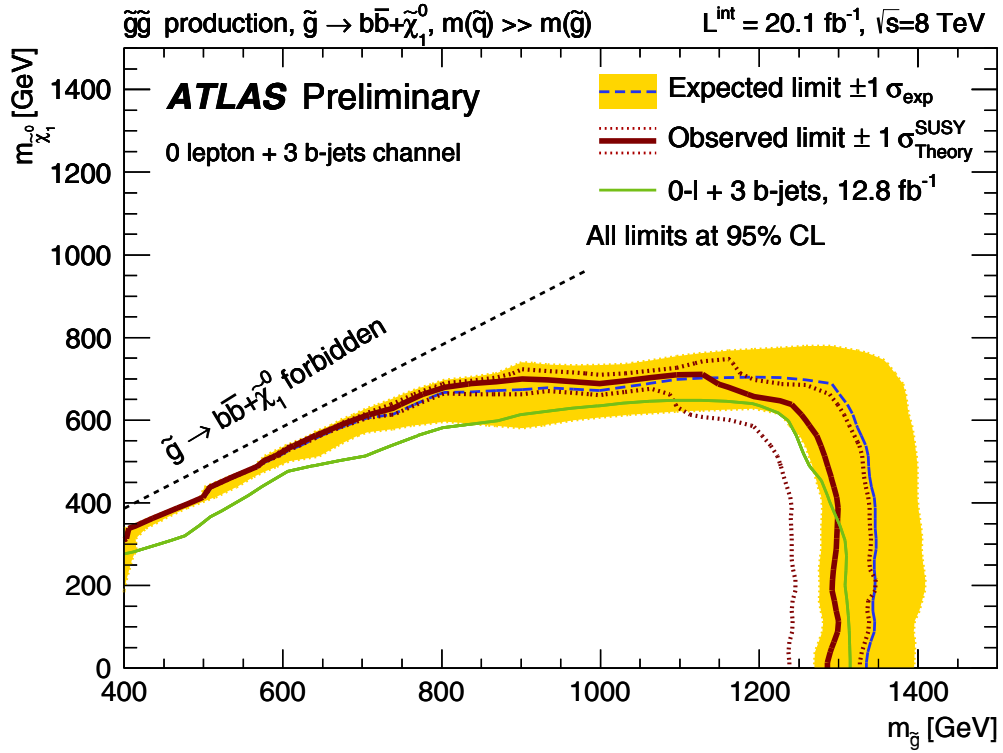
ATLAS-CONF-2013-061

Matrix method for reducible background
MC for irreducible background
0-lepton channel after requiring at least 7 jets with p_T > 30 GeV

0-1 lepton + 3b-jets + jets + Etmiss- Results

ATLAS-CONF-2013-061

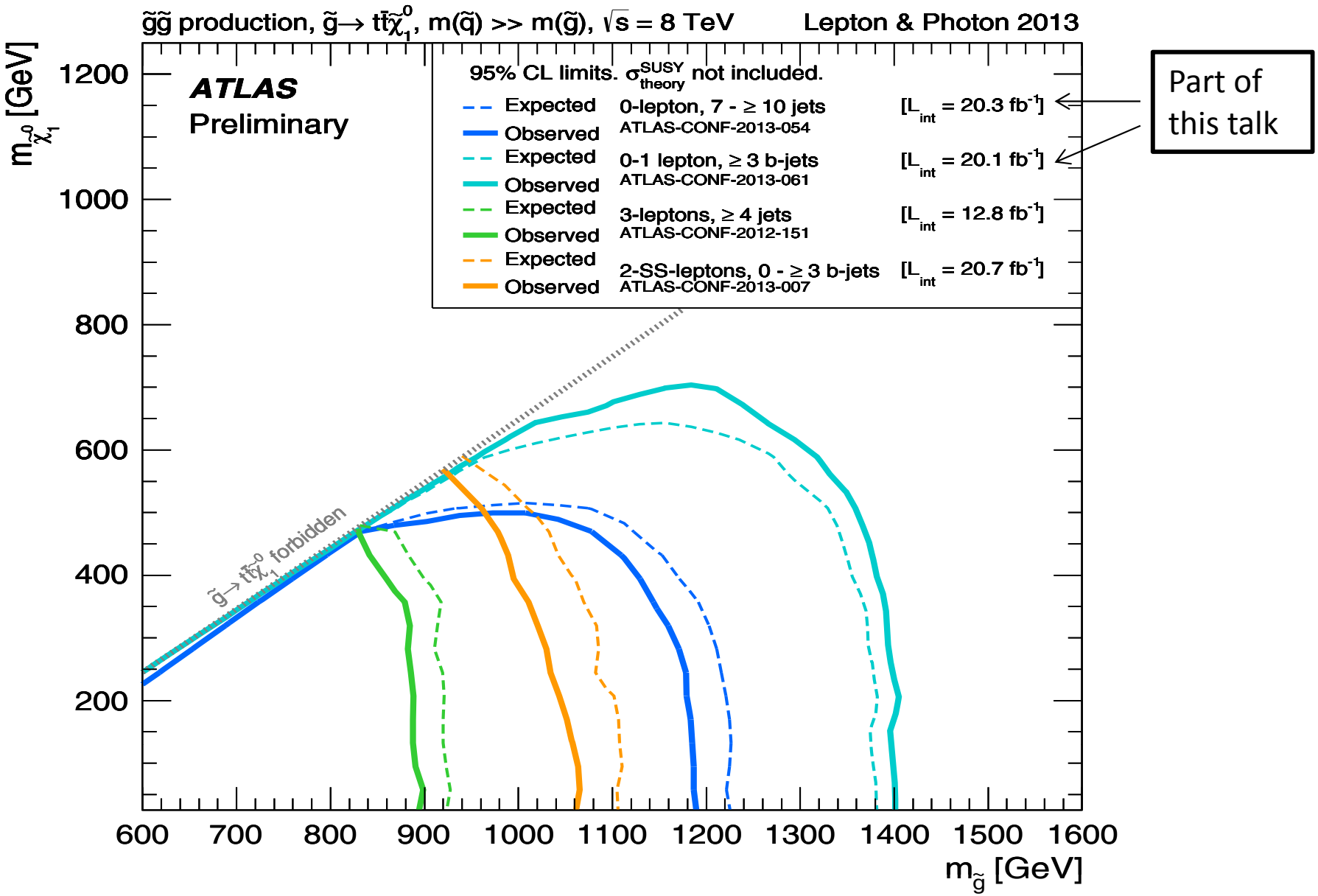




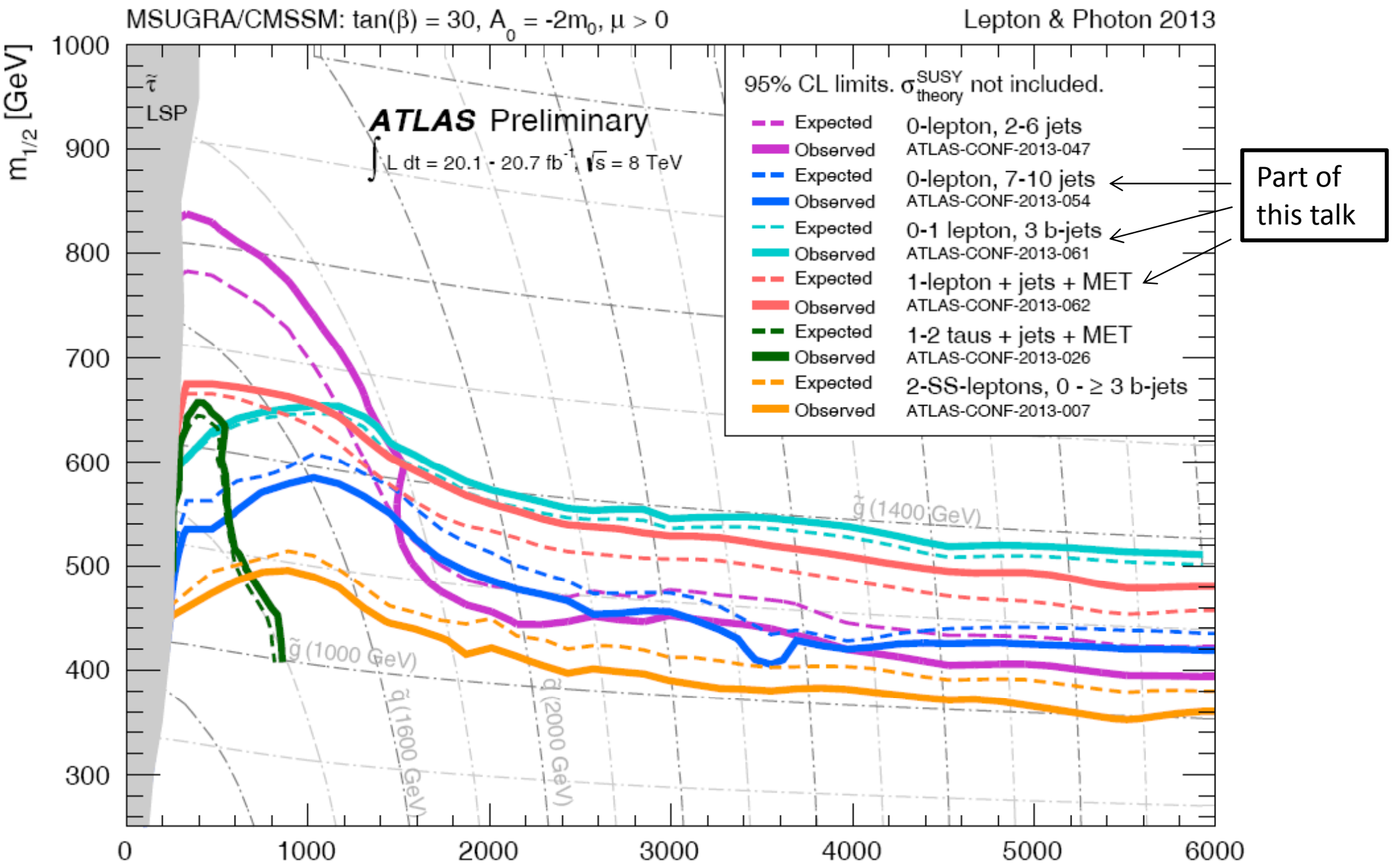
Gtt simplified model

Gbb simplified model

Summary of gluino-mediated stop results



mSUGRA/CMSSM summary plot



Part of this talk

2 leptons (+ jets) + Etmiss- Overview

- Direct pair-production of stop squarks
- Top decays:
  - 2 isolated leptons in final state
  - *b*-jets
- Significant E_t^{miss}
- Investigation also of 3-body decay mode
- Various assumptions on mass hierarchy between *C1* and *N1*
- Discrimination of backgrounds also with "stransverse" mass m_{T2}

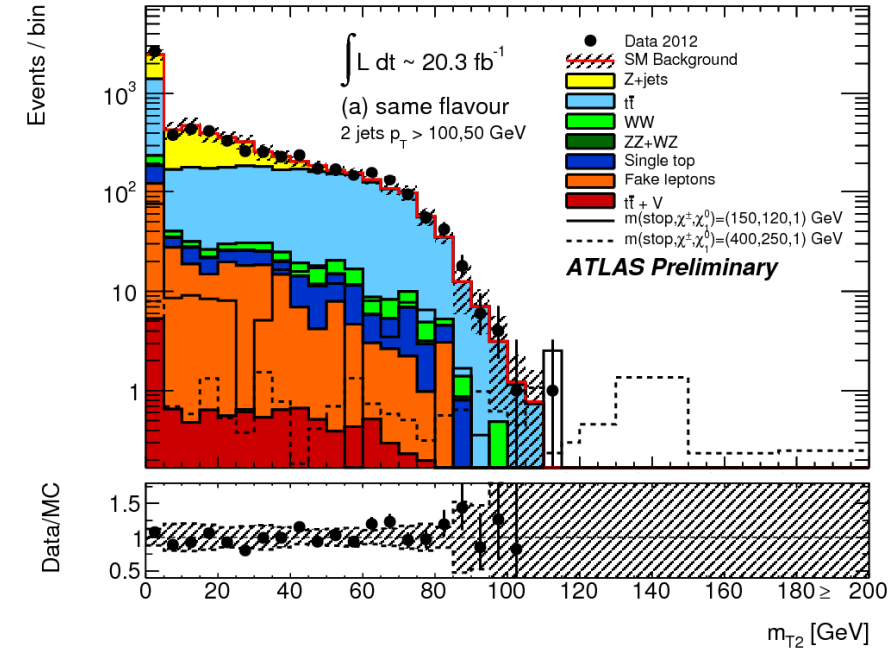
$$m_{\text{T2}}(\mathbf{p}_{\text{T}}^{\ell_1}, \mathbf{p}_{\text{T}}^{\ell_2}, \mathbf{p}_{\text{T}}^{\text{miss}}) = \min_{\mathbf{q}_{\text{T}}+\mathbf{r}_{\text{T}}=\mathbf{p}_{\text{T}}^{\text{miss}}} \left\{ \max[\, m_{\text{T}}(\mathbf{p}_{\text{T}}^{\ell_1}, \mathbf{q}_{\text{T}}), m_{\text{T}}(\mathbf{p}_{\text{T}}^{\ell_2},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

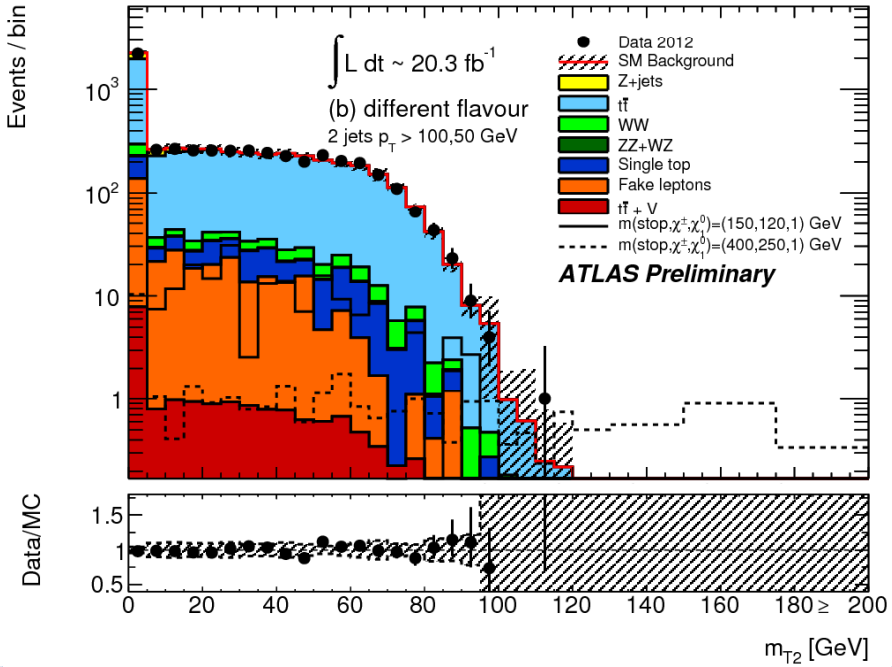
Main processes:

$$\begin{aligned} q + q' &\rightarrow \tilde{t}_1 + \tilde{t}_1 \\ \tilde{t}_1 &\rightarrow b + \tilde{\chi}_1^{\pm} \\ \tilde{t}_1 &\rightarrow b + \tilde{\chi}_1^{\pm} \rightarrow W^{(*)} + \tilde{\chi}_1^0 + b \end{aligned}$$

2 leptons (+ jets) + Etmiss- Backgrounds

ATLAS-CONF-2013-048



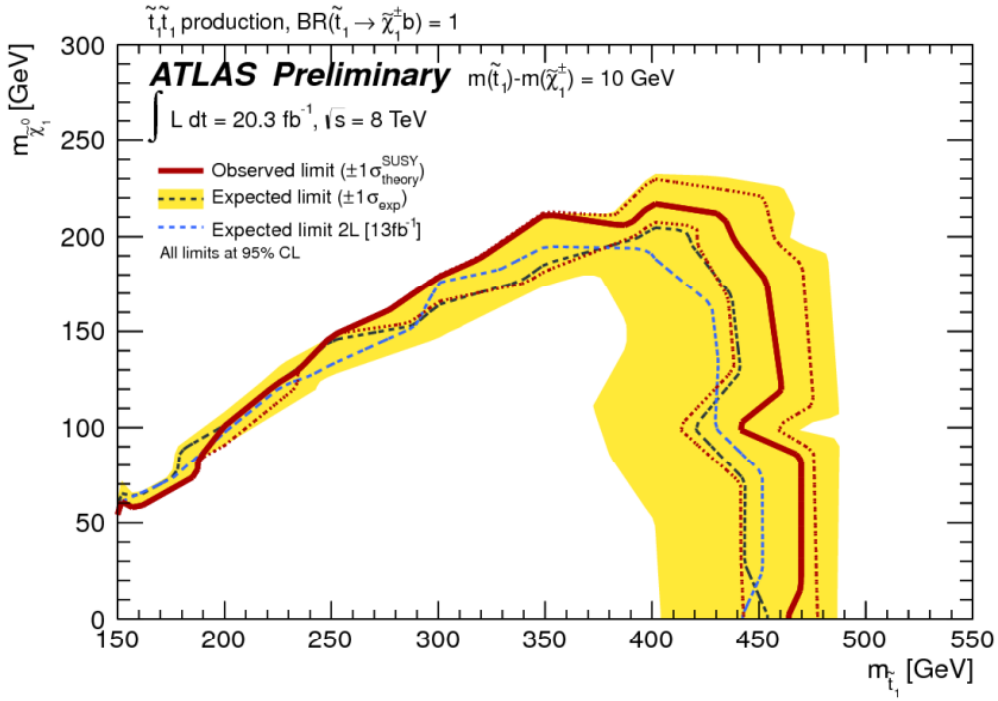


Same Flavor / Different Flavor events passing all **signal selections** requirements, **except of m_{T2} and M100**
"fake lepton" estimated from data
other backgrounds estimated from MC simulation with normalizations measured in CRs for ttbar and diboson backgrounds.

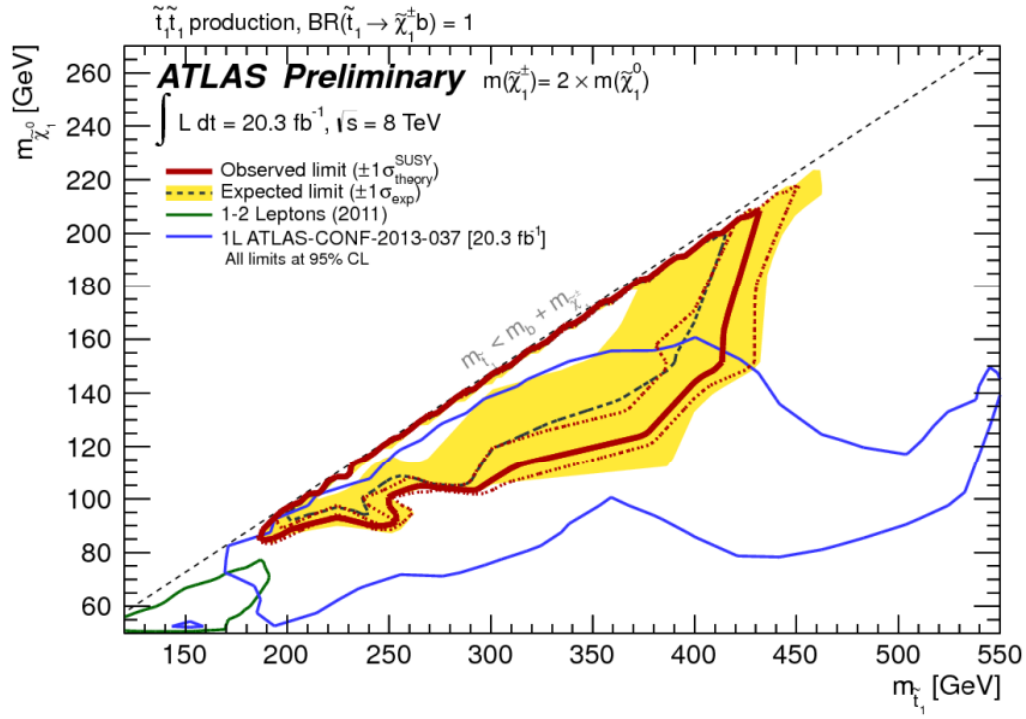
Signal models:
full line corresponds to *m(~t1)* = 150 GeV, *m(C1)* = 120 GeV and *m(N1)* = 1 GeV;

dashed line to *m(~t1)* = 400 GeV, *m(C1)* = 250 GeV and *m(N1)* = 1 GeV

2 leptons (+ jets) + Etmiss- Results



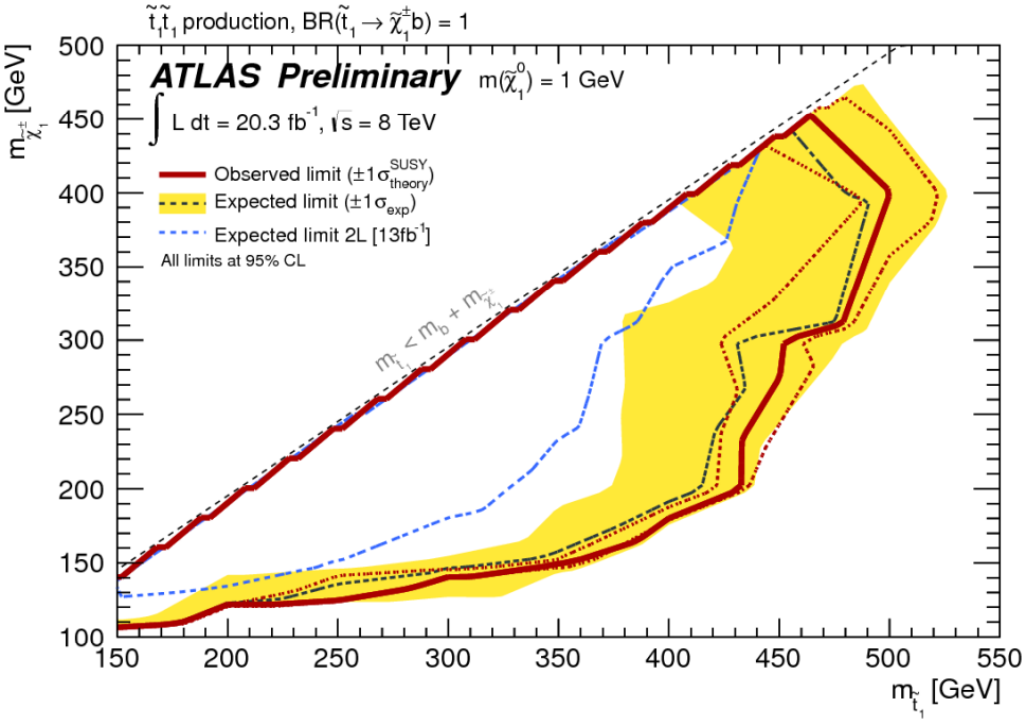
ATLAS-CONF-2013-048

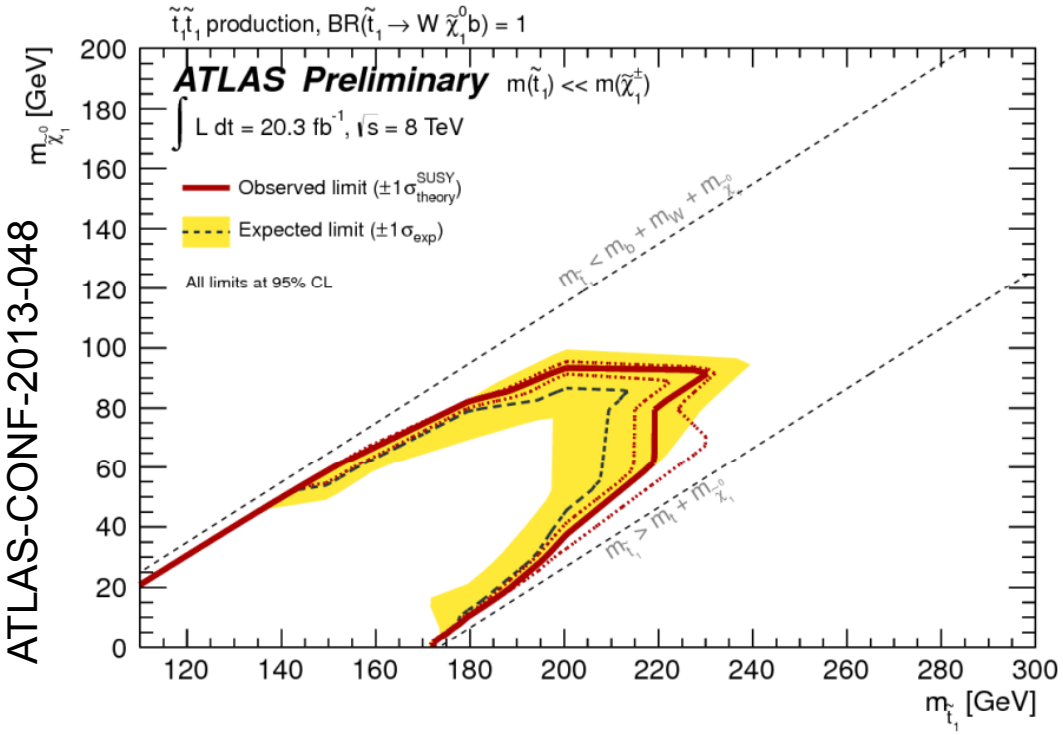


fixed *m(~t1)-m(C1)* = 10 GeV assuming *BR(~t1 → C1 b)* = 1

m(C1) = 2 m(N1) assuming *BR(~t1 → C1 b)* = 1

2 leptons (+ jets) + Etmiss- Results



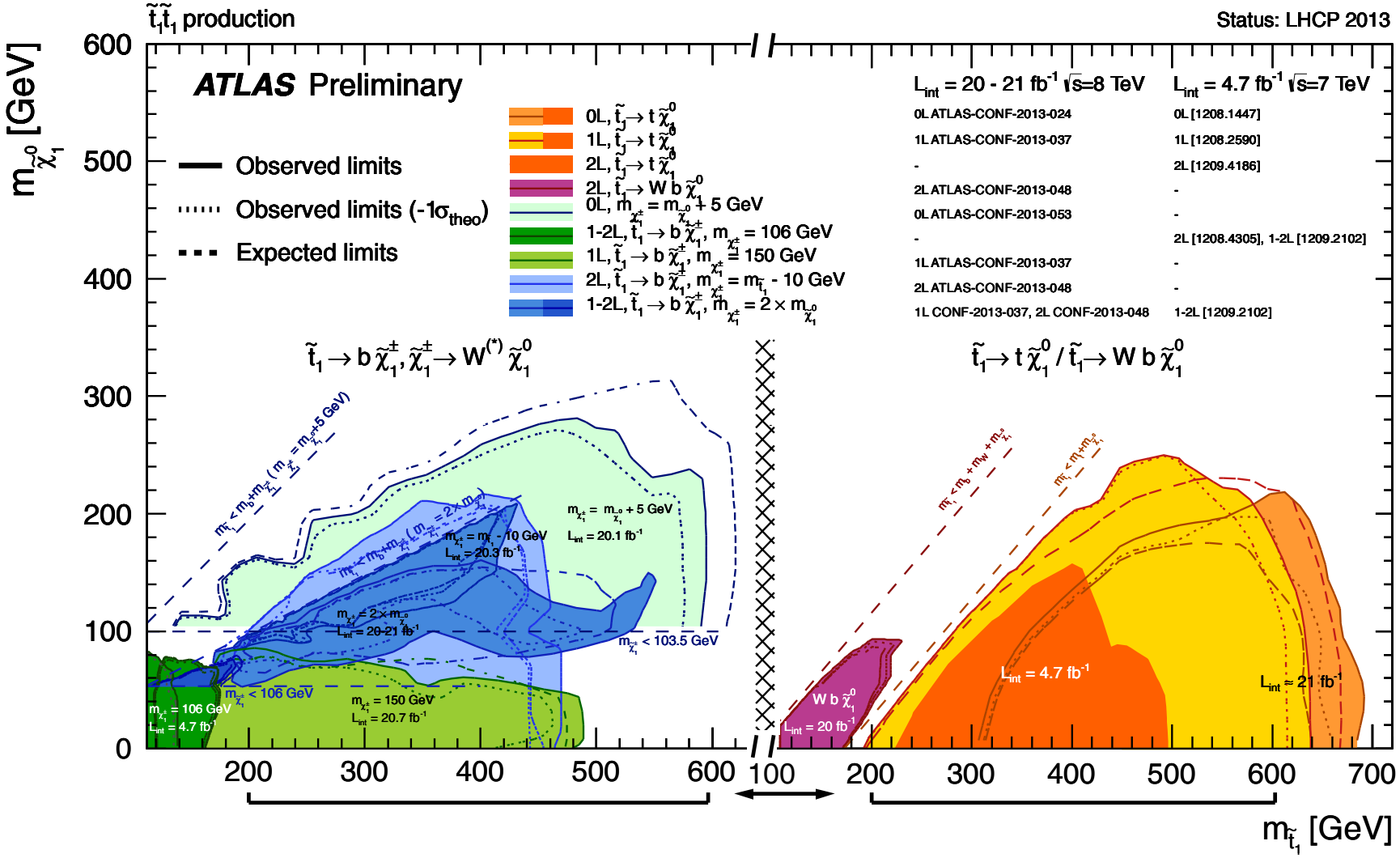


ATLAS-CONF-2013-048

neutralino with mass of 1 GeV
assuming *BR(~t1 → C1 b)* = 1

assuming *BR(~t1 → N1 W b)* = 1

Summary of stop-based results



Decay modes with 100% BR:

$\tilde{t}_1 \rightarrow t + \tilde{\chi}^0_1$ (7 TeV, 8 TeV, where the $\tilde{t}_1$ is mostly $\tilde{t}_R$),

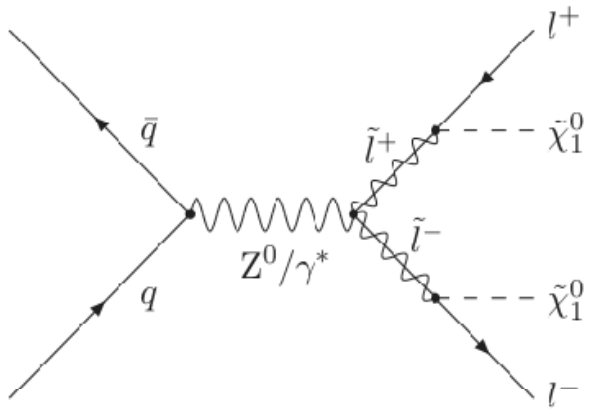
$\tilde{t}_1 \rightarrow W + b + \tilde{\chi}^0_1$ (3-body decay for $m(\tilde{t}_1) < m(t) + m(\tilde{\chi}^0_1)$, 8 TeV)

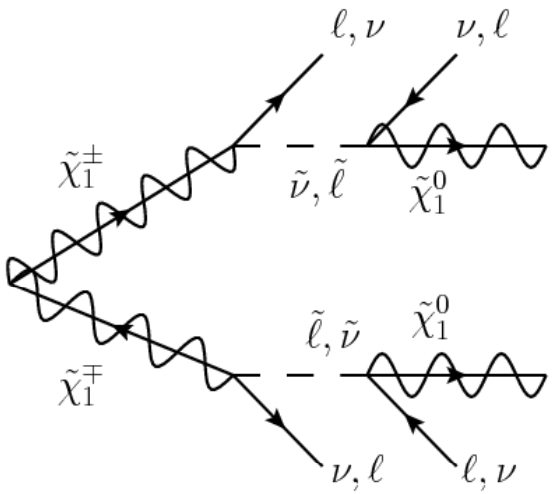
$\tilde{t}_1 \rightarrow b + \tilde{\chi}^{\pm}_1$, $\tilde{\chi}^{\pm}_1 \rightarrow W^{(*)} + \tilde{\chi}^0_1$ (several hypotheses on $\tilde{t}_1$, $\tilde{\chi}^{\pm}_1$, $\tilde{\chi}^0_1$ mass hierarchy)

Electroweak SUSY production

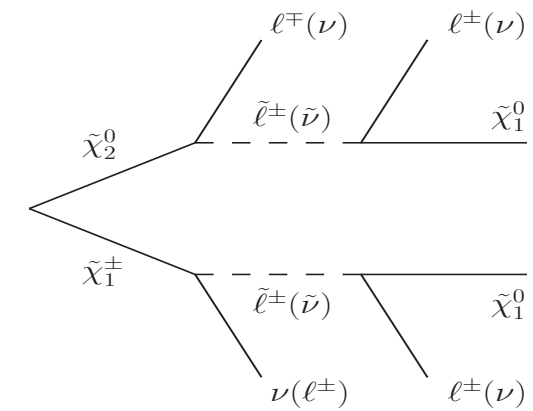
- Production of charginos, neutralinos or sleptons
- Searches for at least 2 light leptons or taus

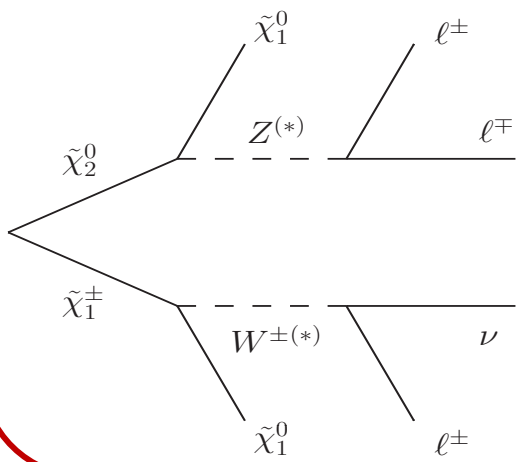
2 leptons (e/mu/tau)



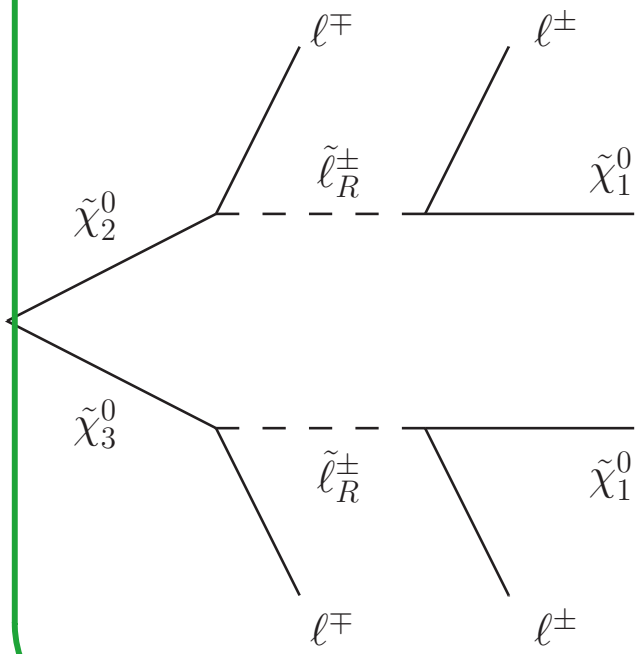


3 leptons





4 leptons



2 leptons + Etmiss [EW]- Overview

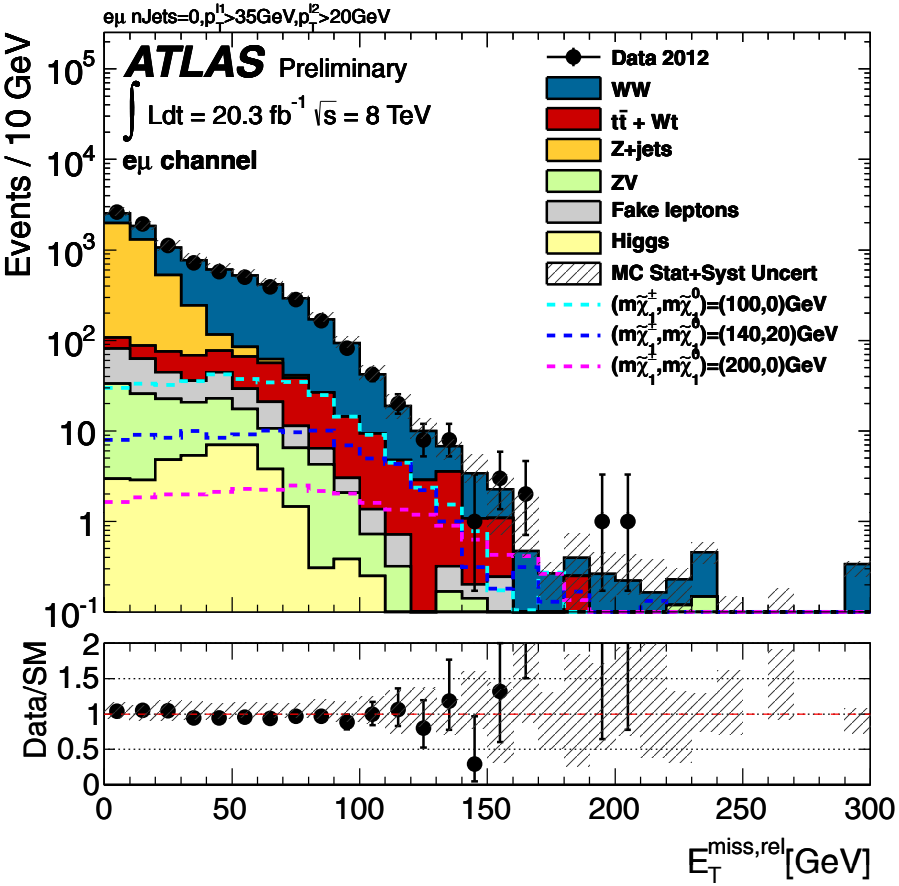
- Pair-production of charged sleptons or charginos
- 2 OS (SF or DF) leptons in final state
- Significant E_t^{miss}
- Smaller backgrounds for e-μ based signatures
- Discrimination of backgrounds with m_{T2} and $E_t^{\text{miss,rel}}$ variables
- Scenarios for interpretations:
  - Direct slepton
  - Chargino-to-slepton
  - Chargino-to-W
  - GMSB with charginos NLSP

Main decays:

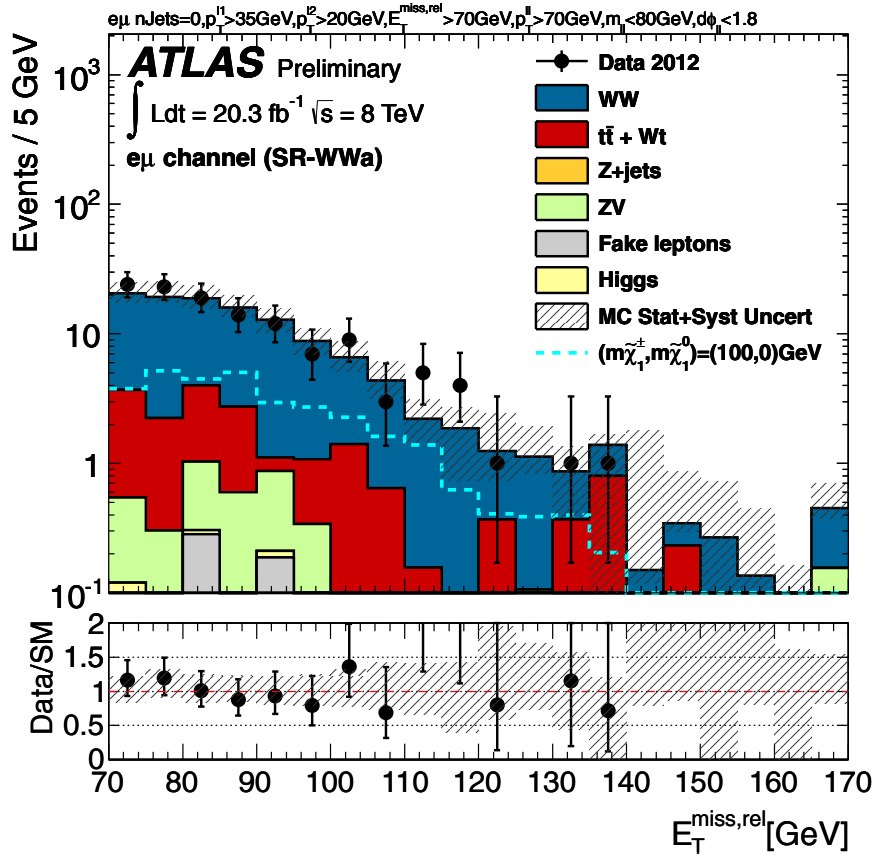
$$\tilde{l}^{\pm} \rightarrow l^{\pm}\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{l}^{\pm}\nu \ / \ l^{\pm}\tilde{\nu} \rightarrow l^{\pm}\nu\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{G}$$

$$E_{\text{T}}^{\text{miss,rel.}} = \begin{cases} E_{\text{T}}^{\text{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \\ E_{\text{T}}^{\text{miss}} \times \sin\Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \end{cases}$$

2 leptons + Etmiss [EW]- Backgrounds



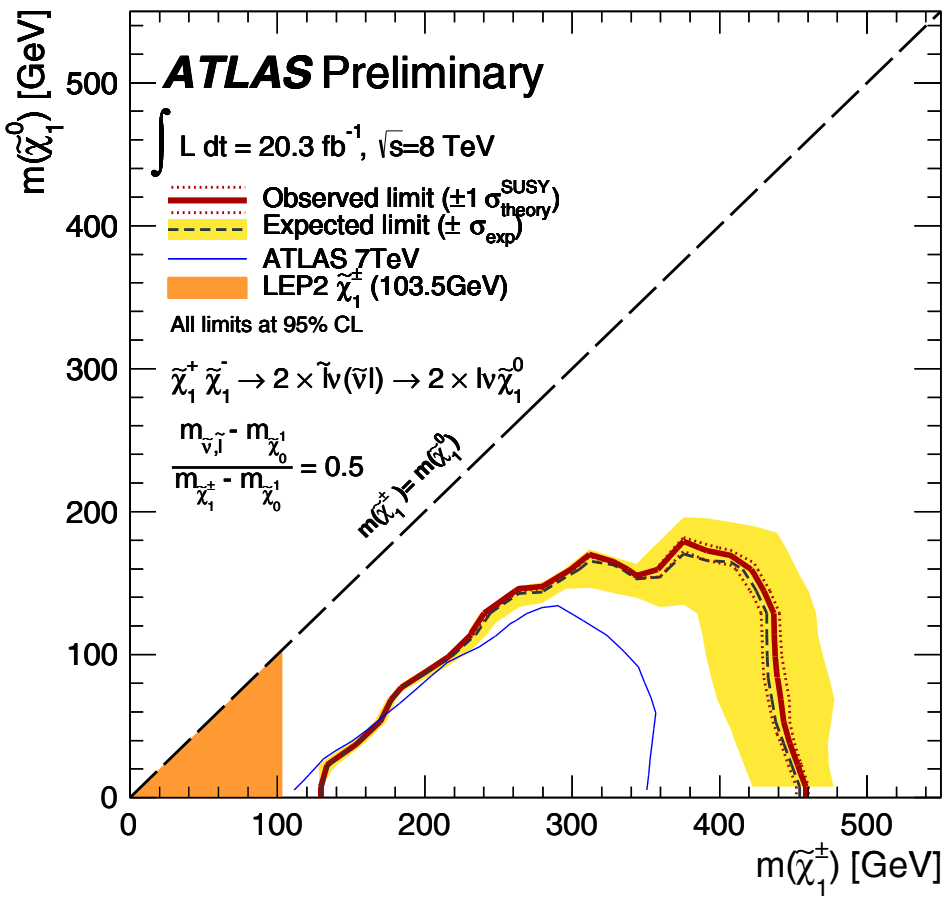
ATLAS-CONF-2013-049



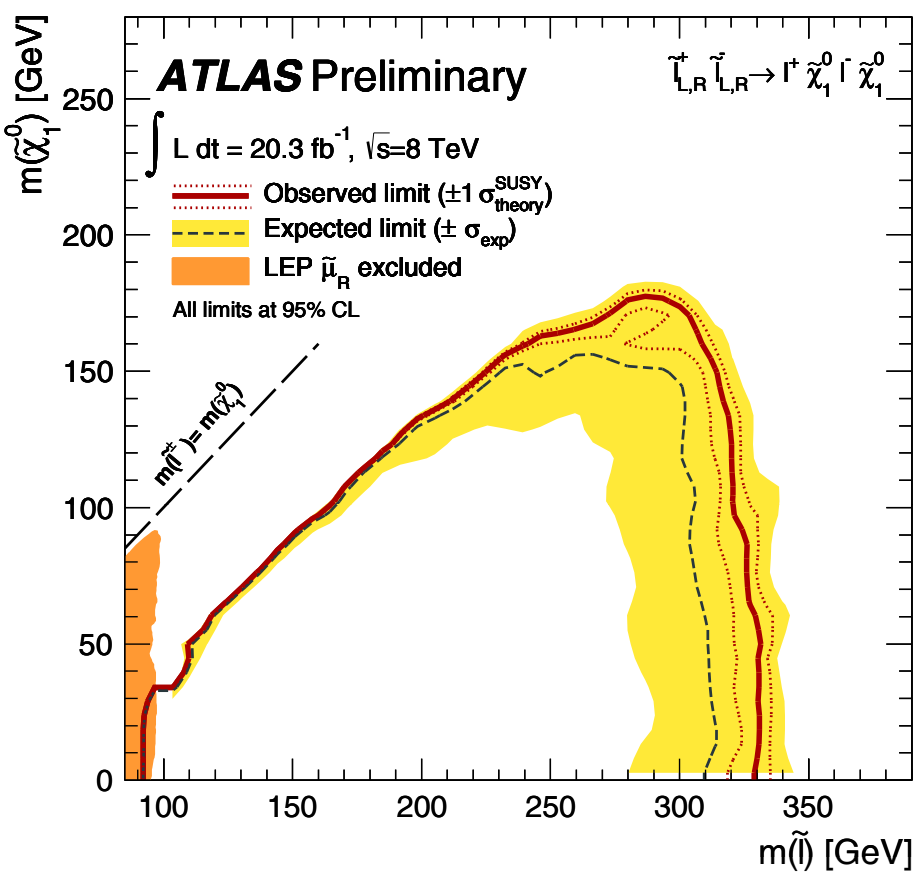
pT(l1) > 35 GeV and *pT(l2)* > 20 GeV
WW and *ttbar:* corrected with data-driven scale factors
hashed regions: total uncertainties on background estimates

SR-WWa
Effect of limited data events in CR included in systematic uncertainty.
ZV includes *WZ* and *ZZ* events

2 leptons + Etmiss [EW]- Results



ATLAS-CONF-2013-049

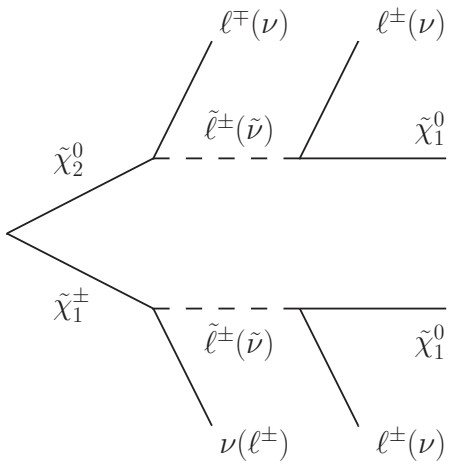


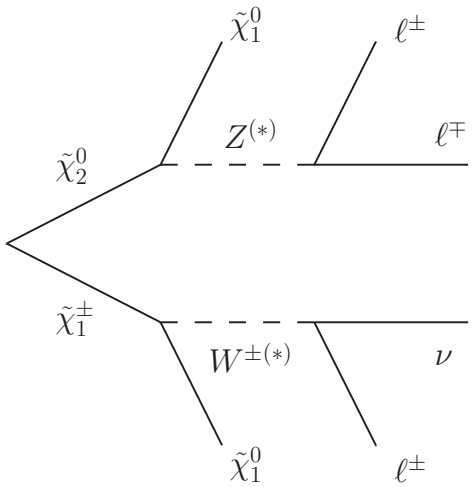
C1C1 pair production in simplified model with sleptons and sneutrinos with
m(slepton) = m(neutrino) = (m(C1)+m(N1))/2
LEP limit on mass of the chargino

C1C1 pair production in simplified model with sleptons and sneutrinos with
m(slepton) = m(neutrino) = (m(C1)+m(N1))/2
LEP limit on mass of the chargino

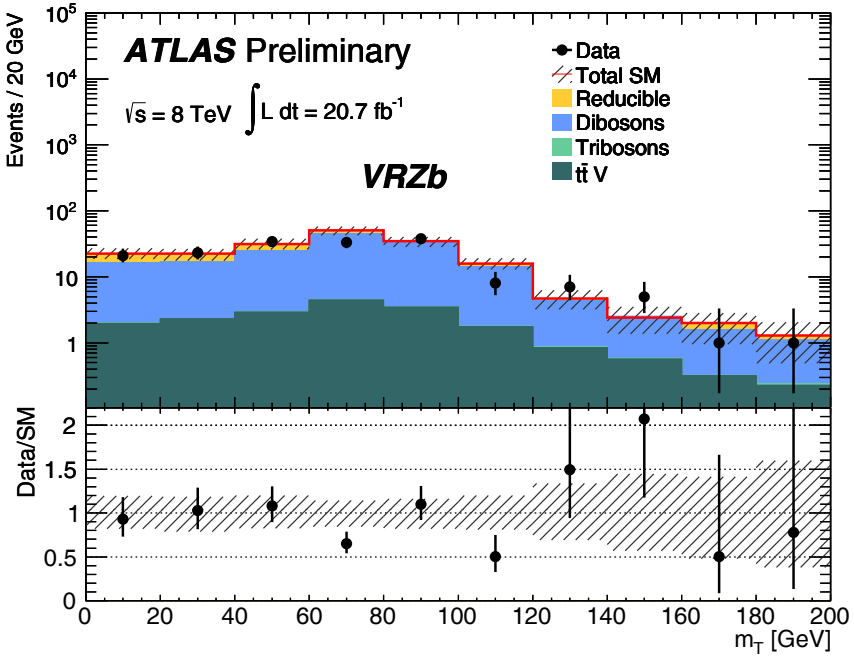
3 leptons + Etmiss - Overview

- Associate production of *N2-C1*
- *N2* and *C1* mainly wino, *N1* predominantly bino
- Masses of *N1,N2, C1*, sneutrinos and left-handed sleptons as free parameters
- Signal with 3 leptons including 1 OSSF lepton pair (no decays via Higgs bosons)
- Main backgrounds:
  - Reducible: t-tbar, Z+ jets (estimated with matrix methods)
  - Irred.: Diboson, triboson and ttbarWZ (MC samples)
- Discrimination of backgrounds with m_T, *b*-veto, partly *Z*-veto
- Simplified models for interpretations:
  - Light sleptons with equal masses
  - Heavy sleptons, signal decays via *W(*)/Z(*)*

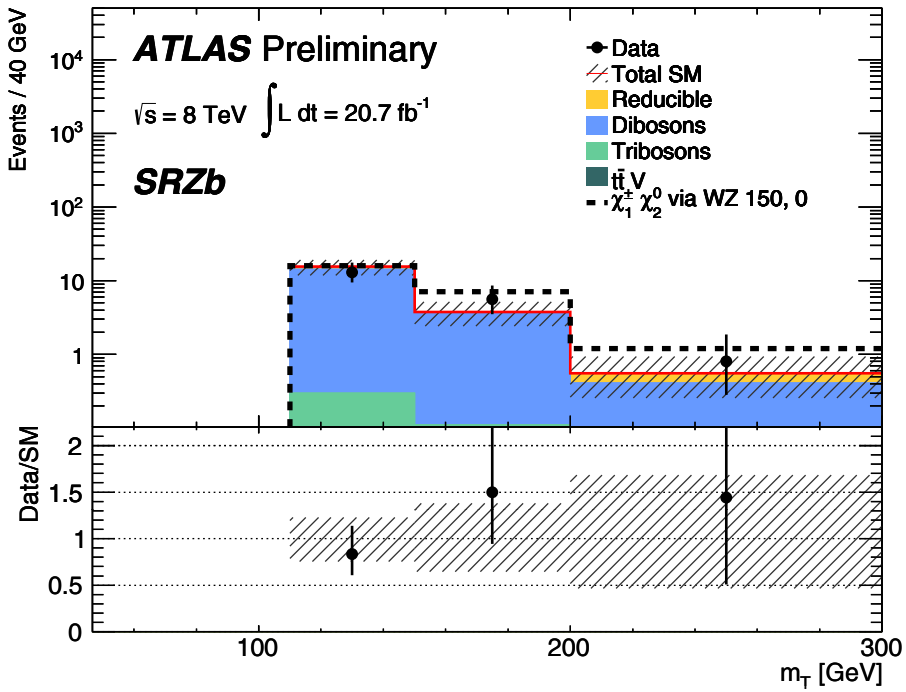




3 leptons + Etmiss - Backgrounds



ATLAS-CONF-2013-035



VRZb

uncertainty band includes statistical and systematic uncertainties on SM prediction

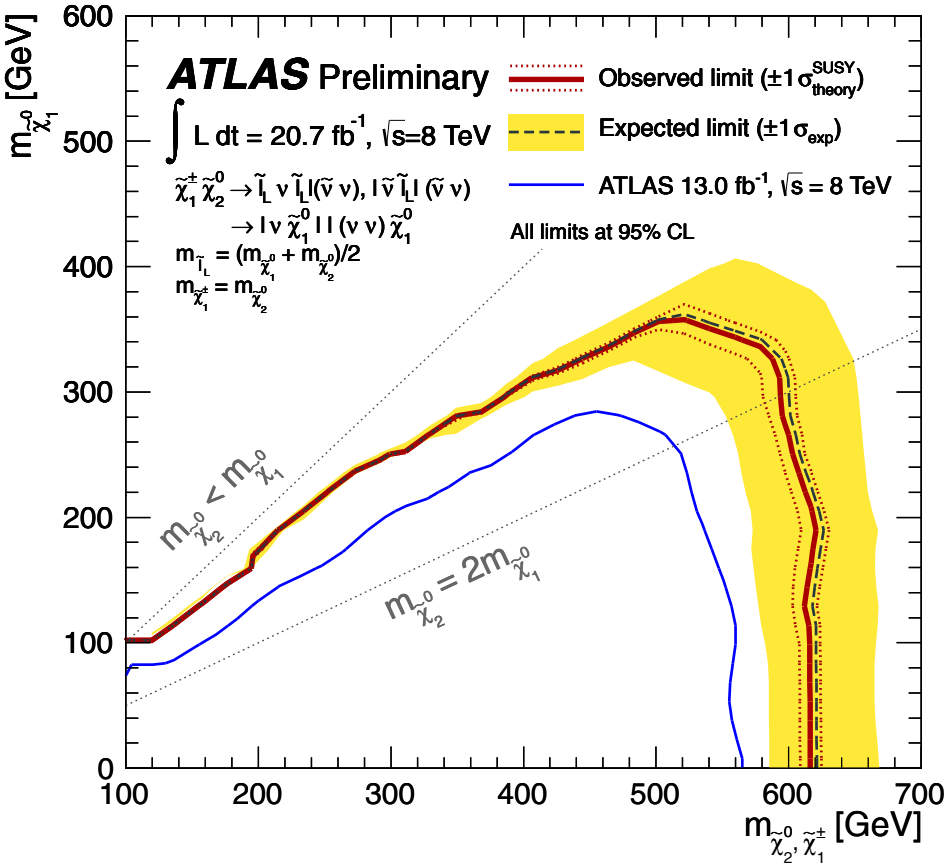
Selection	SRZb
m_{SFOS} [GeV]	81.2–101.2
E_T^{miss} [GeV]	75–120
m_T [GeV]	>110
p_T 3rd ℓ [GeV]	>10

SRZb

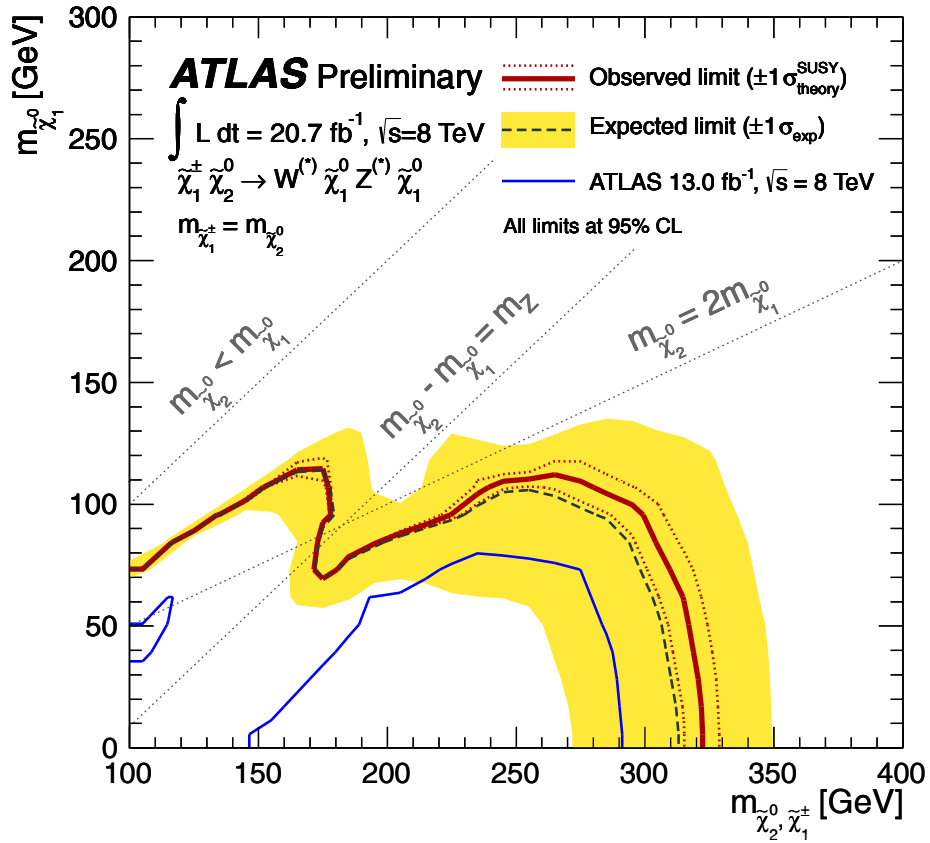
uncertainties on data points statistical only.

simplified model scenarios, where ``$\chi_1^{\pm}$ $\chi_2^0$ via slep x,y'' (``$\chi_1^{\pm}$ χ_2^0 via WZ x,y'') with decays via sleptons (via gauge bosons), and x is the χ_2^0 , $\chi_1^{\pm}$ mass and y is the χ_1^0 mass in GeV.

3 leptons + Etmiss - Results



ATLAS-CONF-2013-035



chargino and neutralino production in simplified model with **decay via sleptons**

chargino and neutralino production in simplified model with **decay via gauge bosons**

4 leptons + Etmiss - Overview

- Single coupling dominance λ_{121} or λ_{133}
- RPC pair production
- Prompt Neutralino-LSP decays -> Large lepton multiplicities
- NLSP: Wino-chargino or gluino
- Decoupling limit of other sparticles (masses at 4.5 TeV)
- Lambda > (0.3-1)*10^{-4} depending on masses
- Discrimination of backgrounds with m_{eff} , E_t^{miss}, veto on Z

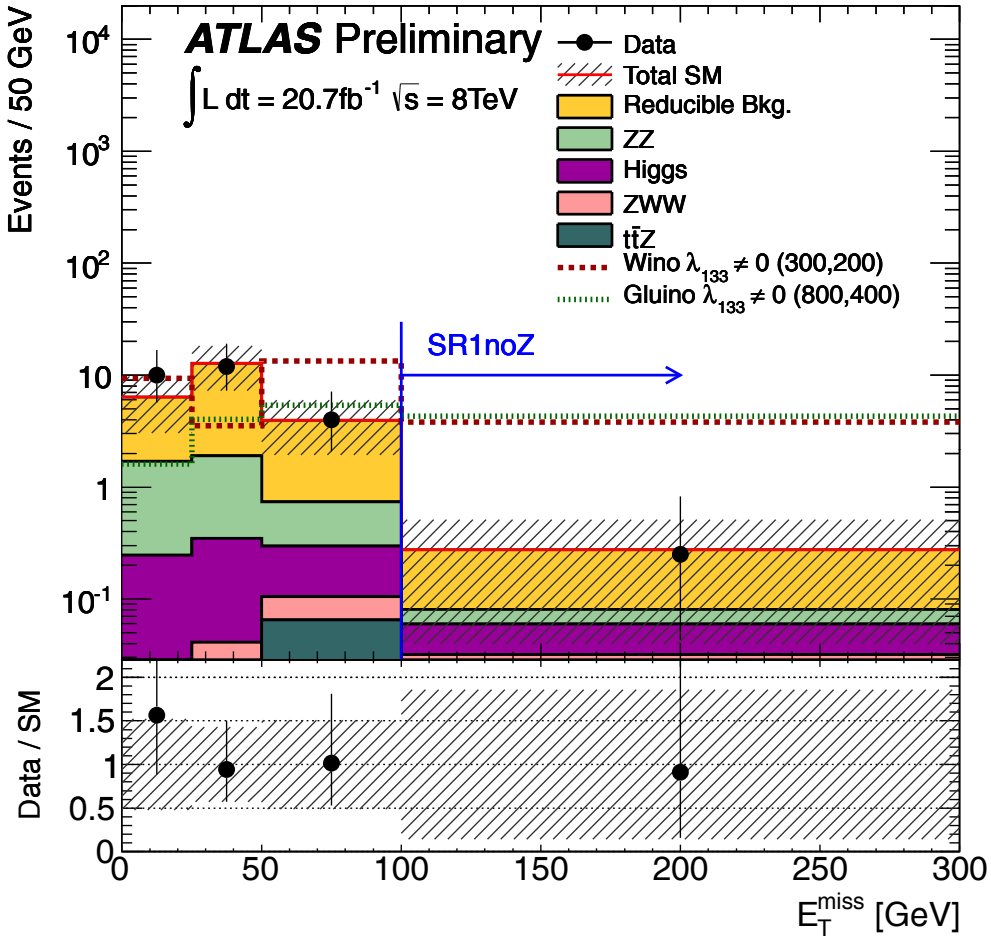
Wino-NLSP:

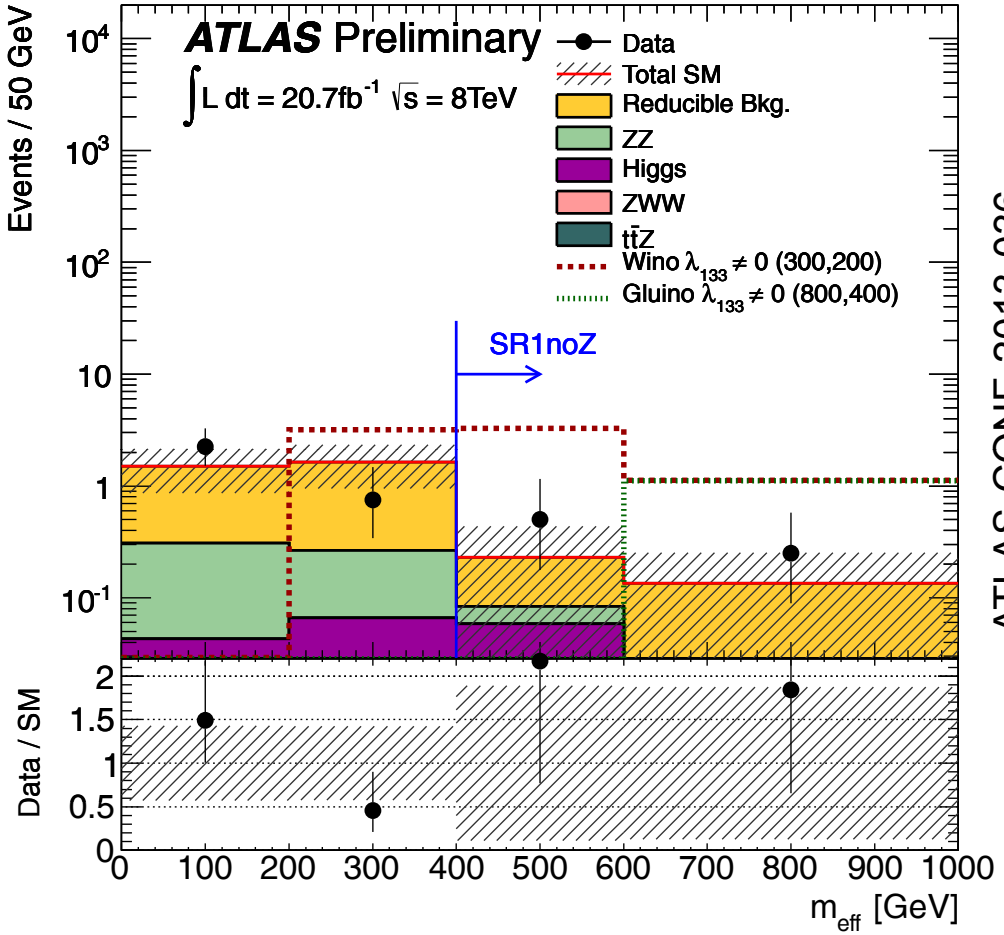
- $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production
- decay $\tilde{\chi}_1^\pm \to W^{\pm(*)}\tilde{\chi}_1^0$

Gluino-NLSP:

- $\tilde{g}\tilde{g}$ production
- decay $\tilde{g} \to q\bar{q}'\tilde{\chi}_1^0 \quad (q, q' \in u, d, s, c)$

4 leptons + Etmiss - Backgrounds

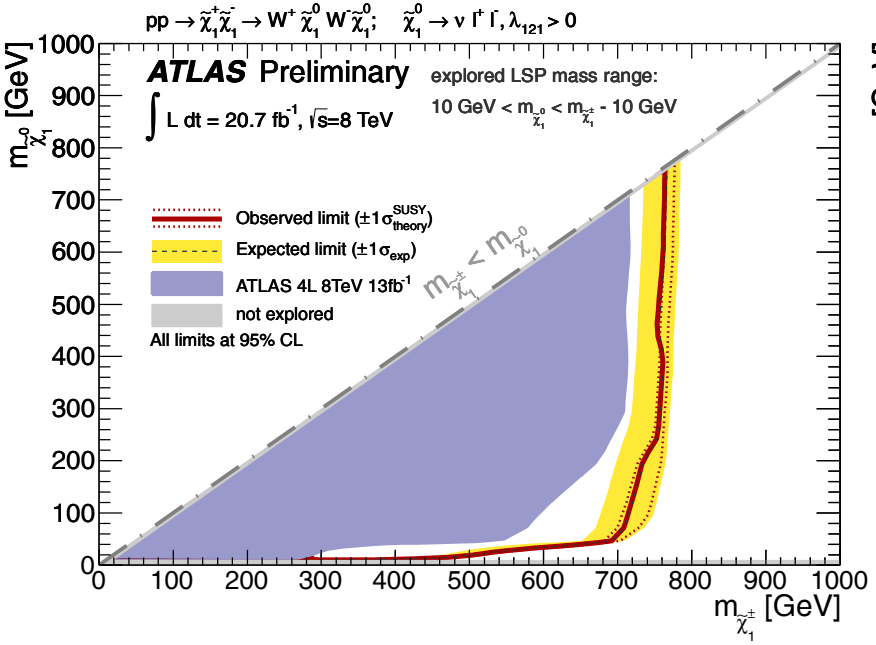


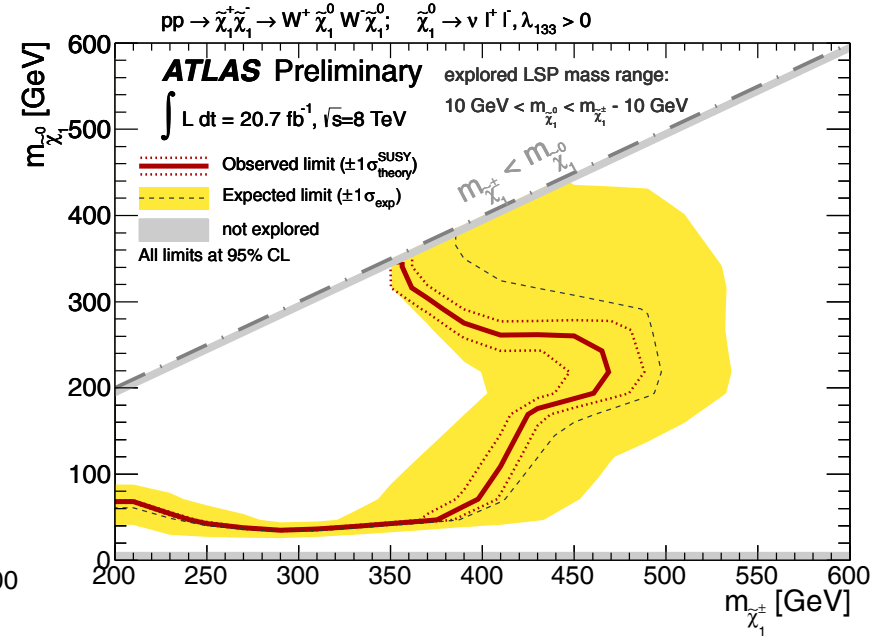


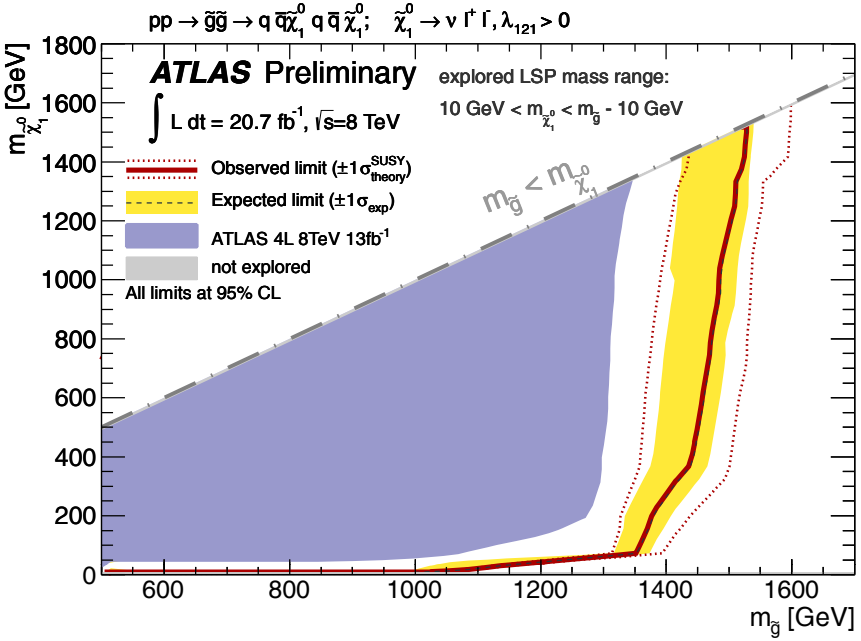
ATLAS-CONF-2013-036

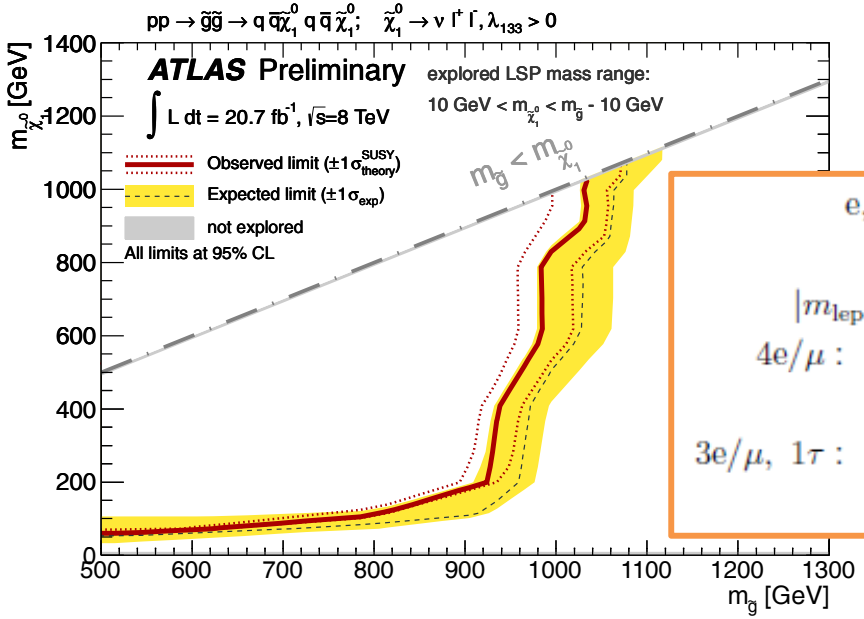
events with ***=3ℓ≥1τ* and a *Z veto***
uncertainty band includes statistical and systematic uncertainties.

4 leptons + Etmiss - Results









ATLAS-CONF-2013-036

e, μ	p_T	>	10 GeV
τ	p_T	>	20 GeV
$\lvert m_{\rm lep} - m_Z \rvert$		>	10 GeV
$4e/\mu$:	MET	>	75 GeV or
	$m_{\rm eff}$	>	600 GeV
$3e/\mu,\ 1\tau$:	MET	>	100 GeV or
	$m_{\rm eff}$	>	400 GeV

Recent results on Long-Lived Sparticles

- **Strong (gluino / squark) production**
  - 1 lepton+jets+ E_t^{miss} (ATLAS-CONF-2013-062)
    - 1-step, 2-step simplified models (with sleptons)
    - mSUGRA /CMSSM
    - minimal Universal Extra Dimension model

Based on full 2012 8 TeV data

- **Stop / sbottom production**
  - 0-1leptons+3b-jets+jets+ E_t^{miss} (ATLAS-CONF-2013-069)
    - Gluino decaying via sbottom-b, stop-top
    - mSUGRA / CMSSM

- **Long-lived sparticle production**
  - Stopped gluino R-hadrons (ATLAS-CONF-2013-057)
  - Long-lived sleptons (ATLAS-CONF-2013-058)
    - Stau in GMSB
    - Direct stau production
    - Electroweak production of charginos decaying to stau

Stopped gluinos - Overview

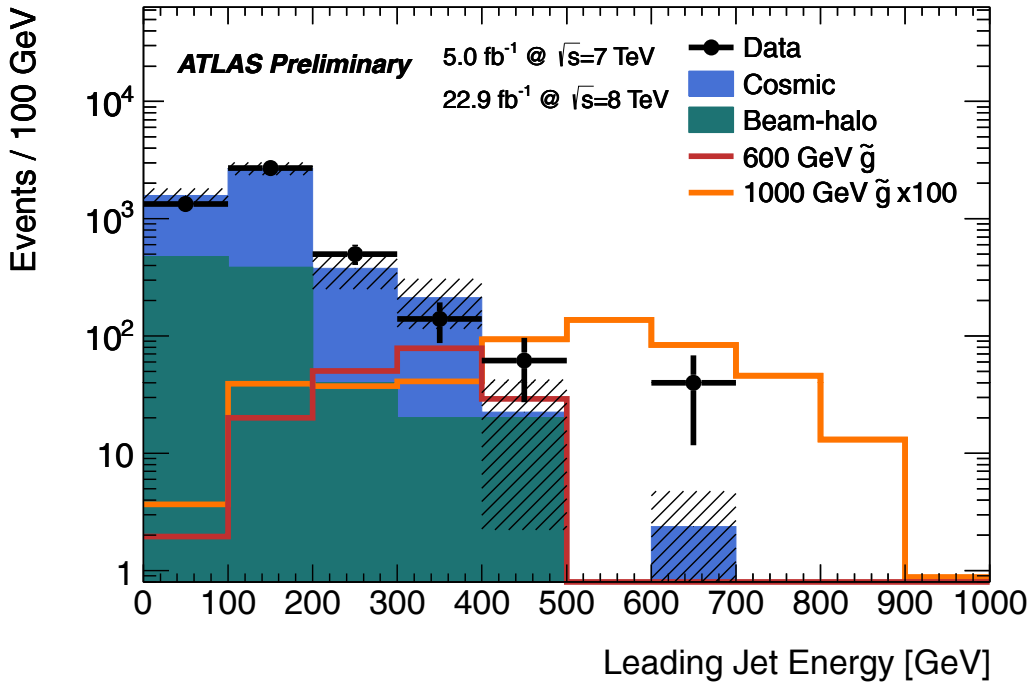
- Gluino *R*-hadrons stopped within ATLAS calorimeter due to ionization energy loss
- Split SUSY with suppressed gluino decays
- triggered in empty bunch crossings of LHC, elimination of collision background
- Backgrounds: cosmic ray events and beam-halo muon backgrounds
- Discrimination via jet shape and muon-system activity
- ***R*-hadron model:** Gluino as heavy, non-interacting spectator, surrounded by a cloud of interacting quarks
  - Hadronization into color-singlet *R*-hadrons
  - **Generic:** Many allowed stable states, also doubly charged R-hadrons
  - **Regge:** Only 1 electrically neutral baryonic state allowed
  - **Intermediate:** Charged baryons, more restriced than Generic model

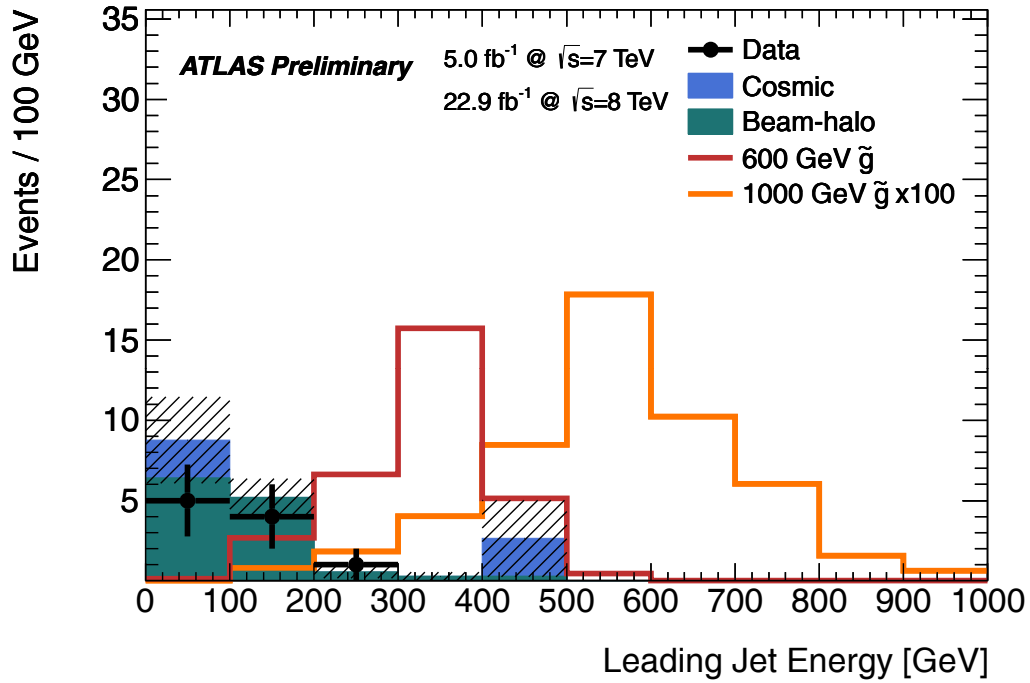
Main processes:

$$
\begin{aligned}
q + q' &\rightarrow \tilde{g} + \tilde{g} \\
\tilde{g} &\rightarrow g + \tilde{\chi}_1^0 \\
\tilde{g} &\rightarrow q + \bar{q} + \tilde{\chi}_1^0
\end{aligned}
$$

Stopped gluinos - Backgrounds

ATLAS-CONF-2013-057

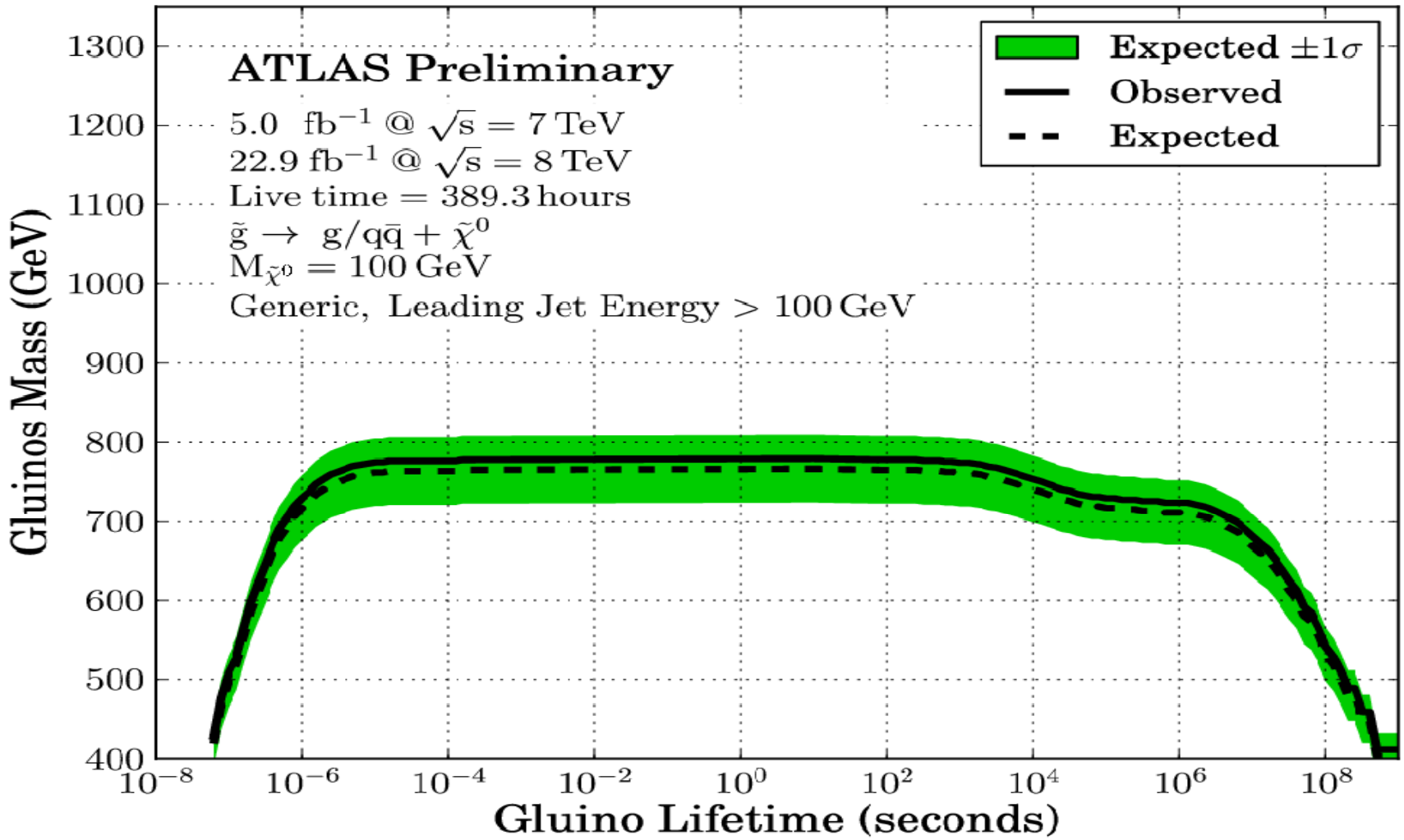




Leading jet energy for the **empty bunch signal triggers**

Signal region with **all selections** muon segment veto (no segments reconstructed in the muon system) excluding jet energy > 100 GeV

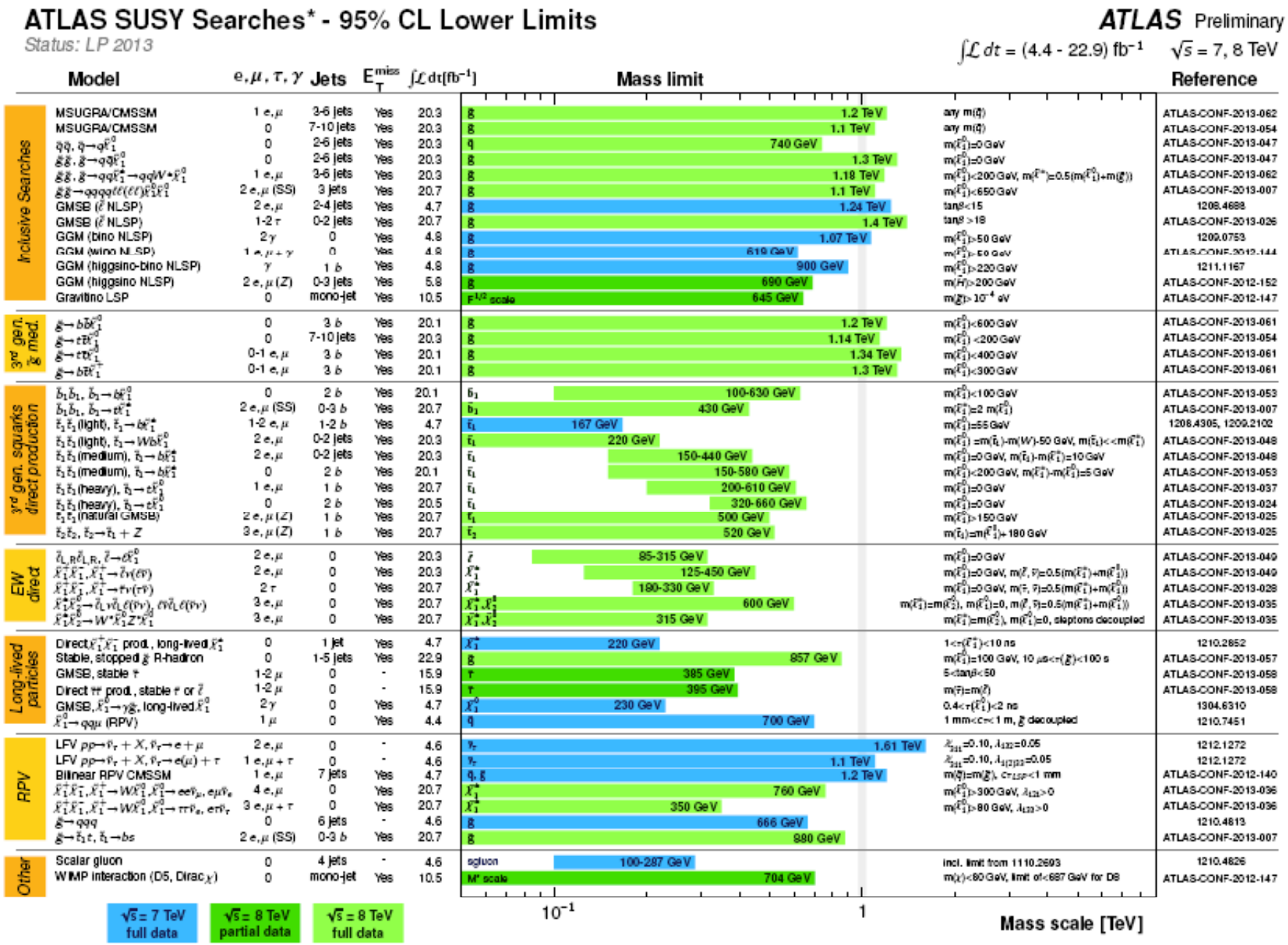
Stopped gluinos - Results



ATLAS-CONF-2013-057

(Bayesian) lower limits on **gluino mass versus gluino lifetime**
Leading jet energy > 100 GeV
800 GeV gluino in Generic R-hadron model

Summary plots



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Conclusions

- Large amount of results based on 2012 8 TeV data
- No evidence for SUSY found
- Several analyses to be finished, including combinations
- Search for Natural SUSY in large areas of parameter space

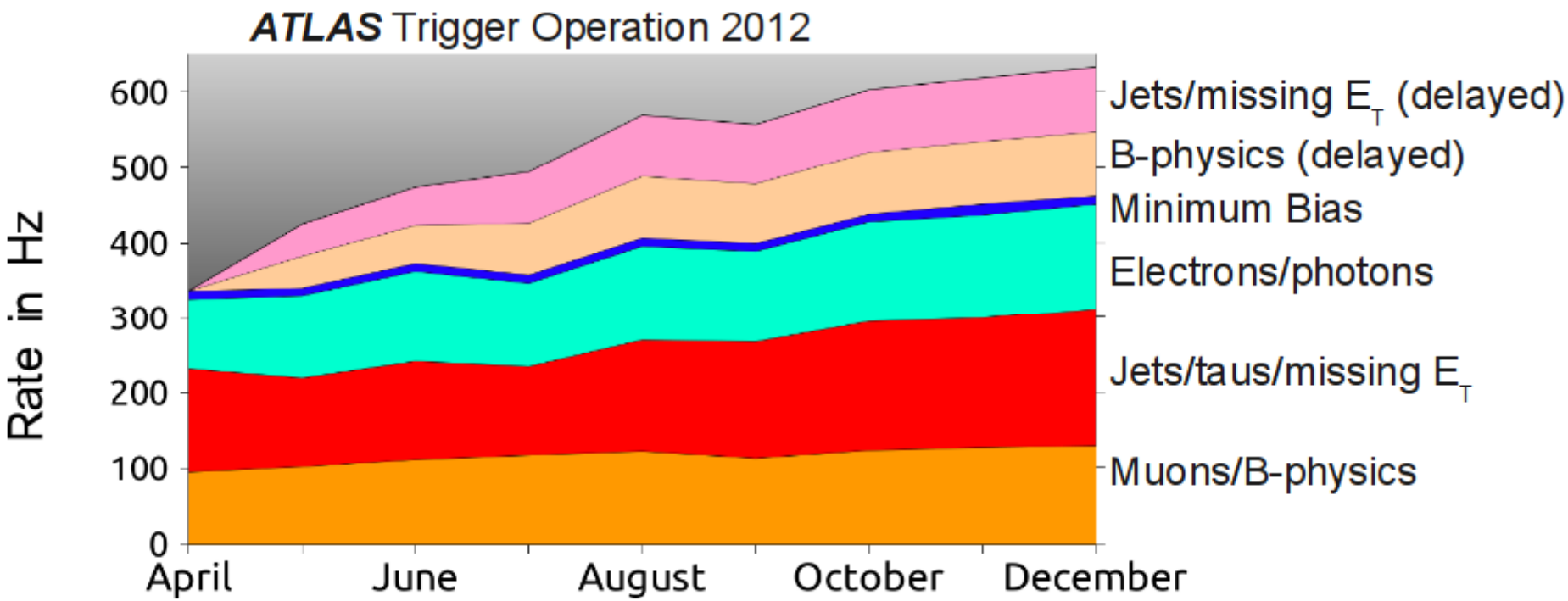
- Further R&D during LS1:
  - Improving MC generator predictions for SM backgrounds
  - Measurements in rare background channels
  - Extend techniques for soft, boosted or displaced objects

- Prospects for natural SUSY to be discussed with colleagues from various SUSY communities

Extra material

2012 Triggers

- Trigger menu:
  - Baseline designed for $L = 8 \varnothing 10^{33}\ cm^{-2}s^{-1}$
  - Mostly unchanged during 2012 run
- Average trigger rate during stable beam operation:



Systematic uncertainties

- Experimental
  - Luminosity
  - Jet Energy Scale
  - Jet Energy Resolution
  - Pileup
  - *B*-tagging
  - Lepton energy scale
  - Lepton efficiency
  - Trigger efficiency
- Theoretical
  - MC statistics
  - Factorization / renormalization scale
  - ISR / FSR uncertainty
  - Parton shower
  - PDF uncertainties

0 leptons + 7-10 jets + Etmiss- Results

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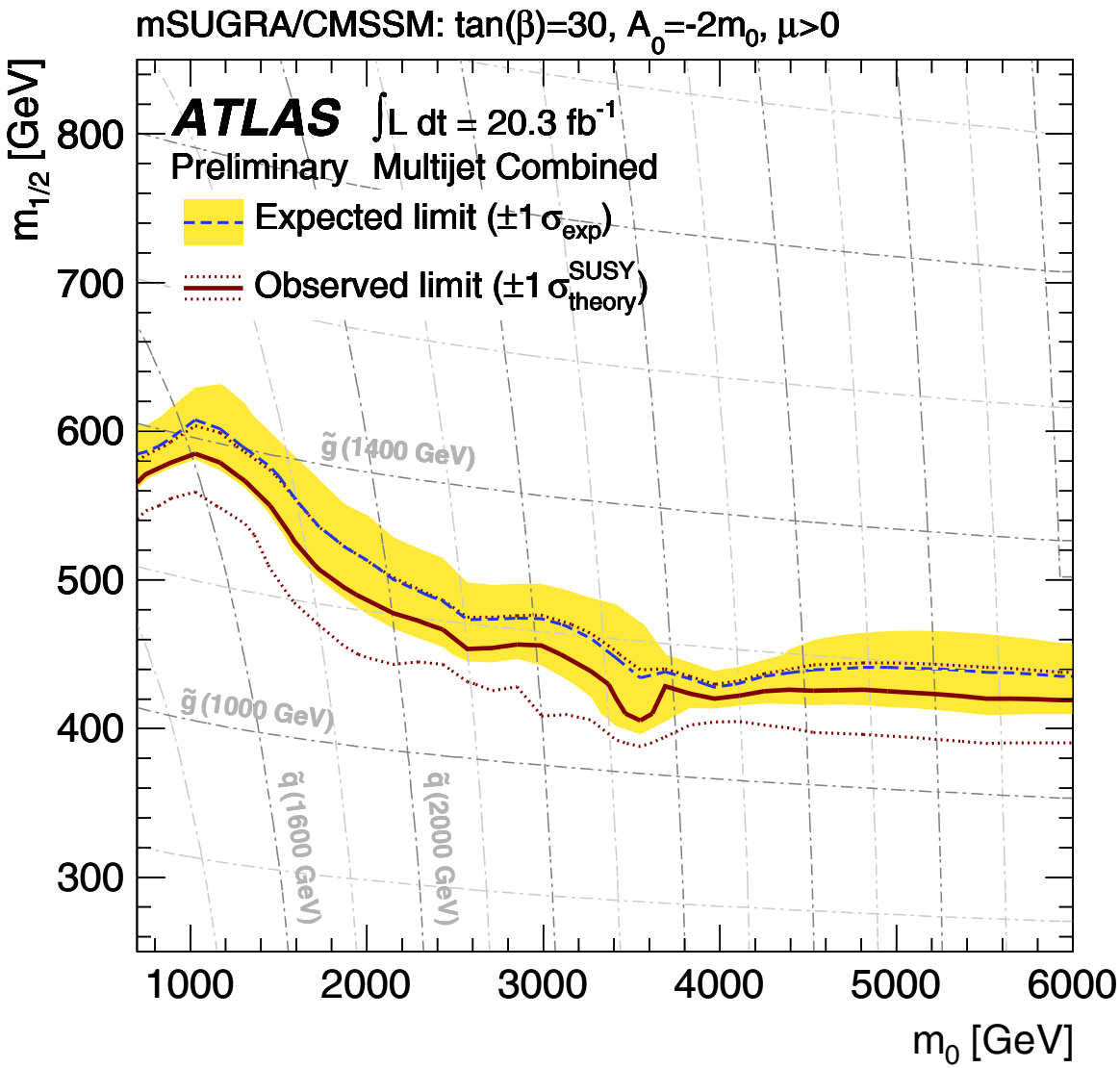

95% CL exclusion curve for the **mSUGRA/CMSSM model**, generated with parameters tan β = 30, A_0 = -2 m_0 and μ > 0 (Higgs-aware)

1 leptons + jets + Etmiss- Variables

$$\Delta R_{\mathrm{min}} = \min\left(\Delta R(j_1, \ell), \Delta R(j_2, \ell), ..., \Delta R(j_n, \ell)\right)$$

$$\Delta\phi_{\mathrm{min}} = \min\left(\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{jet,1}}), \Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{jet,2}})\right)$$

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\Delta\phi(\vec{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})))}$$

$$m_{\mathrm{eff}}^{\mathrm{inc}} = \sum_{i=1}^{\mathrm{N}_{\ell}} p_{\mathrm{T,i}}^{\ell} + \sum_{j=1}^{\mathrm{N}_{\mathrm{jet}}} p_{\mathrm{T,j}} + E_{\mathrm{T}}^{\mathrm{miss}}$$

$$m_{\mathrm{CT}}^2(b\text{-jet}_1, b\text{-jet}_2) = \left[E_{\mathrm{T}}(b\text{-jet}_1) + E_{\mathrm{T}}(b\text{-jet}_2)\right]^2 - \left[\boldsymbol{p}_{\mathrm{T}}(b\text{-jet}_1) - \boldsymbol{p}_{\mathrm{T}}(b\text{-jet}_2)\right]^2$$

4 leptons + Etmiss – LSP decays